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2nd **E**uropean Conference
on Plasma Diagnostics
18-21 April 2017, Bordeaux, France

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Incoherent and collective Thomson scattering for the determination of electron and ion properties in high density, low-temperature plasma

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First results have been obtained for a collective Thomson scattering (CTS) system, based on the fundamental mode of a seeded Nd:YAG laser, which is being developed for high density, low-temperature plasma. The small Debye length of the dense low temperature plasma enables application of this method at relatively short laser wavelength. The combination of this CTS system and existing incoherent Thomson scattering (TS) system will enable accurate determination of electron density (ne) and temperature (Te) as well as ion temperature (Ti) and plasma velocity of the near surface plasma. This development will shed new light on mechanisms involved during plasma-wall interaction as in the ITER divertor. An upgraded system allows to measure Ti at ne>$5{\cdot}10^{20}$ m^{-3} (1 eV<Te<50 eV), i.e. for the first time this state of the art technique can be deployed on industrial-type plasma devices. TS and CTS results be reported along with the prospects for CTS.

Keywords: medium, size tokamak, EUROfusion, roadmap, Diagnostics

Mix and Hydrodynamic Instability Experiments on National Ignition Facility

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In Inertial Confinement Fusion (ICF), an indirectly driven implosion begins with an acceleration phase when the hohlraum x-rays ablate the shell surface and the capsule starts to converge. At this stage, outer-shell non-uniformities grow due to the acceleration-phase Richtmyer-Meshkov (RM) and Rayleigh–Taylor (RT) instabilities. As the shell accelerates, these front-surface perturbations feed through the shell, seeding perturbations on the ablator-ice and ice-gas interfaces. During the deceleration phase, the inner surface of the shell is subject to RT instability.
Several new platforms have been developed to experimentally measure hydrodynamic instabilities in all phases of implosions on NIF. At the ablation front, instability growth of pre-imposed modulations was measured with face-on x-ray radiography platform in the linear regime using the Hydrodynamic Growth Radiography (HGR). In addition, modulation growth of 3-D "native roughness" modulations was measured in conditions similar to those in layered DT implosions.
A new experimental platform was developed to measure instability growth at the ablator-ice interface. 2-D modulations were laser-imposed at the inner surface of the plastic capsule for implosions with DT layers to probe stability of the ablator-ice interface using x-ray radiography with this new Layered Hydrodynamic Growth Radiography (LHGR) platform.
In the deceleration phase of implosions, an innovative method was developed to use the self-emission from the hot spot to "self-backlight" the shell in-flight. Capsules used argon dopant in the gas to enhance x-ray emission at the beginning of the deceleration phase that serves as a "backlighter" to image growing shell modulations. To stabilize instability growth, new "adiabat-shaping" techniques were developed at the ablation front using the HGR platform and applied in layered DT implosions. Experimental results from all these campaigns will be presented.
This work was performed under the auspices of the U.S. Department of Energy by LLNL under Contract DE-AC52-07NA27344.

Keywords: Hydrodynamic Instabilities, Inertial Confinement Fusion

Science with hot astrophysical plasmas

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In this contribution I will present some recent highlights and prospects for the study of hot astrophysical plasmas. Hot plasmas can be studied primarily through their X-ray emission and absorption. Most astrophysical objects, from solar system objects to the largest scale structures of the Universe, contain hot gas. In general we can distinguish collisionally ionised gas and photoionised gas. I will introduce several examples of both classes and show where the frontiers of this research in astrophysics can be found. I put this also in the context of the current and future generation of X-ray spectroscopy sattelites. The data coming from these missions challenge the models that we have for the calculation of the X-ray spectra.

Keywords: X, rays, astrophysics, plasma model

Diagnostics of Atmospheric Pressure Plasmas

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Non-equilibrium atmospheric pressure plasmas gained huge interest over the past decade due to their easy integration with other process technologies. However, numerous physical questions need to be addressed to reach a stable homogeneous atmospheric pressure non-equilibrium plasma: How can the instabilities of these atmospheric pressure plasmas be mastered? How is the coupling and coupling-out of particles, radiation and energy in these systems realized? How can the plasma chemistry and the gas flow self-consistently treated in modeling? How need classical diagnostic concepts to measure standard plasma parameters such as electron density or temperature to be adapted at atmospheric pressure to be reliable? In all of these questions, we are currently reaching the limits of the possibilities of experiment, theory and simulation. Therefore, this area remains a highly attractive topic for many years and an outstanding international challenge for theoretical and experimental plasma physics. In this contribution, the basic concepts and questions of the very hot topic of cold atmospheric pressure plasmas will be explained and illustrated and the diagnostic challenges discussed for some selected examples.

Keywords: plasma diagnostics, atmospheric pressure plasmas

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Development of an Optical Thomson Scattering Diagnostic for the NIF

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We report on the design and implementation of an optical Thomson scattering diagnostic for the National Ignition Facility (NIF) at Lawrence Livermore National Laboratory (LLNL), USA. This diagnostic will be used to access under-dense plasma conditions inside indirect inertial confinement fusion (ICF) hohlraums using a 5th harmonic (210 nm) optical probe laser. Other applications will include assessment of plasma conditions produced by direct-drive ICF capsules, and the assessment of the growth of laser plasma instabilities (LPI) around these targets.

Carrying out optical Thomson scattering measurements in the experimental environment produced during ICF experiments is challenging for a number of reasons. Hohlraum emit a intense, structured and broadband optical background which must be overcome by the scattered signal in order to make a clean measurement. They are also intense emitters of soft x-ray radiation, which have the potential to blank the optics used to collect the scattered signal. In this presentation we will present the optical design of this diagnostic and discuss the methods used to overcome these obstacles.

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

Keywords: Thomson Scattering, NIF, ICF

Properties and practical diagnostics of astrophysical plasmas

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X-ray spectroscopy of astrophysical plasmas holds the promise of huge potential scientific returns. The 0.1-10 X-ray bandpass includes transitions from the K-, L-, and M-shell of every cosmically abundant element and ion except H and He. With sufficient data, even at moderate (R $\sim$ 1000) resolution these transitions can even be separated into gas, molecular, and solid state phases. Diagnostics exist using line and continuum measurements at lower resolutions (R $\sim$ 100) that can determine the electron temperature, estimate the electron density or radiation field and reveal if the plasma is in equilibrium. Achieving these returns, however, requires accurate data for the underlying rates and transition wavelengths for ions, molecules and solid state materials. Uncertainties in the oscillator strengths and a paucity of laboratory wavelengths and collisional rates in the 50-150 Å bandpass have already limited the results that can be inferred. I will describe the atomic physics required for X-ray diagnostics used with existing X-ray missions and what will be required for future X-ray missions.

Keywords: X, ray, spectroscopy, astrophysics

Microprobes in Plasma Diagnostics

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The Debye length lambda$_D$, is a fundamental scale size in plasmas. Below this length, waves and other collective plasma effects do not occur, and objects with this dimension will minimally disturb the plasma. This is why detectors on satellites are highly successful, for example the Debye length in the auroral ionosphere is 0.1 meter or more. Two examples of phenomena on this scale are Langmuir waves and electron phase space holes; both have wavelengths as small as several lambda$_D$. Phase space holes are nonlinear structures, which have been observed at many locations within the ionosphere and earth's magnetosphere. With MEMS (Micro-Electro-Mechanical Systems) techniques it is possible to grow novel detectors on the scale of tens of microns to access the relevant regime in the laboratory. We have grown and used such probes to measure phase space holes and waves in the LAPD plasma. We also discuss the construction of a variety of other detectors that could measure magnetic fields, particle distribution functions, correlation functions, and field emitting beam probes. For instance, to measure the 3D distribution function, gridded electron analyzers must be smaller than an electron gyro radius, which can easily be of order of the Debye length. Tiny probes of necessity will measure very small voltages or currents, and ideally the probes should be grown with amplifiers adjacent to the probe surface. We report an amplifier scheme of this type, but with constructed amplifiers.
These probes could revolutionize the way we take measurements in plasmas. Toward this end, thousands of non-perturbative probes in a mesh network could make detailed measurements in a single experiment or an ensemble of experiments.

Keywords: plasma diagnostics, microprobes, micro probes, debye scale, debye

Optical Diagnostics for Dusty Plasmas

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Particle-containing (dusty) plasmas offer and require the development of sophisticated diagnostic techniques to measure particle size, particle density, particle motion and even particle charge. Different optical techniques in dusty plasmas will be reviewed for practical application. The determination of the three-dimensional trajectory of particle on the individual kinetic level can be achieved by stereoscopic cameras or holographic imaging techniques. Optical tomography reveals the spatially resolved particle density in dense dust systems. Further, Mie scattering allows to measure the size and size distribution of particles trapped in the plasma. Finally, in the infrared spectral regime the light-scattering properties of particles can reveal the charge state of the particles. The talk will discuss prospects and limitations of the individual diagnostics.

Keywords: dusty plasma, tomography, stereoscopy, holography

The Evolution of Millimeter-wave Diagnostics to Study Fusion Plasmas

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The evolution of millimeter-wave diagnostics is described together with a perspective on future development needs. The 1970s was the start of a ”golden era” for fusion research. A series of successful tokamaks (e.g. PLT, PDX, etc.) were constructed at Princeton Plasma Physics Laboratory leading to groundbreaking of the Toroidal Fusion Test Reactor (TFTR) in 1977. In parallel, the Joint European Torus (JET) was under design (1973) leading to a construction start at the Culham site in 1978 with first plasma in 1983. During this same period, development of millimeter-wave diagnostics across the globe grew rapidly - interferometry/polarimetry, electron cyclotron emission (ECE), millimeter-wave scattering were all being actively developed and deployed. Since that early period, diagnostic capability has continued to evolve. Examples include reflectometry (both for density profile and fluctuation measurements), correlation ECE for temperature fluctuations, ECE imaging for visualization, Doppler Backscattering (DBS) for local density turbulence and flow measurements, and cross-polarization scattering (CPS) for magnetic fluctuations. Now, as we approach the burning plasma era of fusion research epitomized by the ITER device, it becomes critically important to develop reliable systems that are fully compatible with such plasmas. Many existing fusion diagnostics will be significantly challenged - particularly optical diagnostics. For burning plasmas beyond ITER, the even harsher environment, decreased access, and the need for turn-key, reliable operation make measurements even more challenging. Millimeter-wave diagnostics are well-suited to a burning plasma environment. Large diameter, overmoded, corrugated waveguide can be utilized to transport radiation to and from the plasma allowing sensitive diagnostic hardware to be remotely located. It will be critically important to integrate multi-parameter capabilities into these measurement systems, so that they provide the essential information for control and understanding in future burning plasmas.

Keywords: millimeter, waves, diagnostics, burning fusion plasma, history

A suite of diagnostics to validate and optimize the prototype ITER neutral beam injector

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The ITER project requires additional heating provided by two neutral beam injectors using accelerated negative deuterium ions. As the beam requirements (1MeV particle energy, 40A accelerated current for one hour) have never been experimentally met, a test facility is under construction at Consorzio RFX, which hosts two experiments: SPIDER, full-size 100 kV ion source prototype, and MITICA, 1 MeV full-size ITER injector prototype.
Since diagnostics in ITER injectors will be mainly limited to thermocouples, due to neutron and gamma radiation and to limited access, it is crucial to get from more accessible experiments a wider knowledge of the key parameters of source plasma and beam, obtained using several complementary diagnostics assisted by modelling. The set of diagnostics in SPIDER and MITICA has been selected and designed with this goal.
The ion source parameters are measured by the combination of optical emission spectroscopy, assisted by collisional radiative model, thermocouples for heat load and electrostatic probes for electron density and temperature, together with cavity ring down spectroscopy for HÂŻ density and laser absorption spectroscopy for cesium density. These measurements over multiple lines-of-sight will provide the information on the spatial distribution of the parameters over the source extension. The beam profile uniformity and its divergence are studied with beam emission spectroscopy, complemented by visible tomography and neutron imaging, which are novel techniques, while an instrumented calorimeter based on custom mono-directional carbon fiber composite tiles observed by infrared cameras will measure the beam footprint on short pulses with highest spatial resolution. All heated components *will* be monitored with thermocouples: as these will likely be the only measurements available in ITER injectors, their capabilities will be investigated by comparison with other techniques. *SPIDER and MITICA* diagnostics will be described with a focus on *their rationale,* key solutions and most original and effective implementations.

Keywords: ITER, neutral beam, beam diagnostics

Overview of the Physics Diagnostics on EAST

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Tremendous progress of EAST diagnostics has been made for the new stage of the EAST project. Varieties of diagnostics have been employed to provide high quality experimental data for plasma control, operation of machine, and advanced physics research to accommodate requirements for the study on high performance steady-state operation in EAST and scientific understanding in support of CFETR and ITER.
In this paper we present an overview of newly developed or upgraded diagnostics, in particular for current density and pressure profile measurements which serve a foundation of tokamak researches. An 11 chord, double-pass, radially-viewing, far-infrared laser-based POlarimeter-INTerferometer (POINT) system has been routinely operated for fully diagnosing the plasma current and electron density profiles throughout the entire plasma discharge, over 100 seconds, with microsecond time response able to detect MHD events, for all heating schemes and all plasma conditions (including ITER relevant scenario development) since 2015. A 40-channel core (10 Hz) and a 10-channel edge (50Hz) Thomson scattering (TS) system for density and electron temperature is routinely operated. An X-ray crystal spectroscopy provides both ion and temperatures and plasma rotation velocity. A charge exchange recombination spectroscopy (CXRS) for the plasma ion temperature and toroidal rotation velocity for core and edge plasma with a high spatial resolution up to $\sim$ 5-7 mm has been well developed.

In addition, ECEI for turbulence and fluctuation research is also developed. FIDA is developed for fast ion behavior and responsible for the possible damage of the first wall during NBI heated plasma. An EUV spectrometers provides the measurement of tungsten spectra on EAST for ITER-like tungsten divertor physics study. Particular attention has also been devoted to the edge diagnostics (AC-BES; Li-BES; GPI; Reflectrometry) and diagnostics in measurement of fusion product (Gamma ray).
It has opened up a new stage of physics research on EAST.

Keywords: plasma diagnostics, EAST tokamak

Progress of inertial confinement fusion diagnostics technique based on shen guano III laser facility in China

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Shenguang III (SGIII) is the newly developed largest high power laser facility for inertial confinement fusion and other high energy density physics research in China. There are 48 beams on SGIII with an aperture of 400×400mm, and its total output was designed as about 180kJ/3ns of 0.351mm laser to the center of targets chamber.

After a long time developing, total 40 types (about 110 diagnostic equipments) have been completed in 2016. In this presentation, we will introduce the whole diagram of diagnosis system in SGIII laser facility, including optical system, X-ray system and nuclear reaction system. The technique system to measure the back scattered light, spectrum and flux of x-ray have been built up.The back scattered light technique, called full aperture back scattered system(FABS) and near back scattered imaging system(NBI), has been completed. This system are differ from the scattering plate technique in national ignition facility (NIF). The velocity interferometer system for any reflector (VISAR) has got the shock signal in SGIII experiment. Other diagnostics to characterize the behavior of shock, symmetry and trajectory of capsule implosion, fusion neutron yield and so on, have been achieved. The new design diagnostic technique, including x-ray streak camera (XSC), x-ray frame camera (XFC) and crystal spectrum (CS) with high resolution, will be introduced. The proposal of flat reaction X-ray detector (FXRD), which can measure the radiation flux with low expensive and flexible character, will be presented. The detector's panel of FXRD has been designed carefully to have a "flat" response function of X-ray from 0.1keV to 4keV.

Some shots of experiments have been conducted on SGIII laser to test diagnostics or performance of laser system. Some primary experiments on holhraum and indirectly driven implosion have been performed. The progress of diagnostics and experiments on SGIII laser facility will be introduced in this presentation.

Keywords: Shenguang III laser facility, diagnosis system, holhraum, implosion

Preparation of exploitation of medium-size tokamaks under European roadmap for the realization of fusion energy

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To implement the European fusion research programme, outlined in the "Roadmap to the realisation of fusion energy" and published in 2012 [1], a coordinated programme of the diagnostic upgrades to the European Medium-Size Tokamaks (MST) (AUG, MAST-U, TCV) has been identified. The focus is to enable the integrated exploitation of the MST and JET devices, both through the selection of the new diagnostics and the timely staging of their upgrades. A special, multi project Work Package has been established by the EUROfusion consortium to solve the associated challenges. The project selection and priorities come from a gap analysis based on the fusion roadmap as well as the MST timeline and programmatic needs. The particular importance of resolving the power exhaust solutions has resulted in MST wide EUROfusion investment in edge and divertor diagnosis projects. The gap analysis also identified the need for research and development contributing to the real time diagnosis of disruptions, conditions and control of runaway electron generation, improving and developing of ITER relevant fast ions diagnostics as well study of the physics of sheath effects. This work is further supported by the investigations which are better performed on the test stands and smaller machines for safety (runaway electron, sheath studies etc.) or monetary reasons. This paper discussed the scientific case made to identify the gaps in the diagnostics development, the implementation of the selected projects on the three MST and the first results.

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

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Keywords: medium, size tokamak, EUROfusion, roadmap, Diagnostics

Probing mechanisms in low-temperature reactive gas plasmas: towards improved models of industrial plasma etch processes

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Inductively-coupled radiofrequency plasmas in molecular, electronegative gases are widely used for plasma processing of surfaces, and in particular for the etching of thin films. Such plasma processes have allowed the information revolution since they are essential for the manufacture of CMOS integrated circuits. The complexity of these systems is such that they can only be described by multi-physics models which simultaneously describe a) the dynamics of charged particles and electric fields, b) the elastic and inelastic collisional pro- cesses between charged and neutral (molecular) species, and c) plasma-surface interactions. However, these models have not previously been rigorously tested against comprehensive quantitative measurements of transient particle densities over a wide range of parameter space. We have studed the Cl_2/O_2 system because of its industrial process relevance but also because methods exist to measure the density of most of the transient species present. A microwave hairpin resonator is used to measure the electron density, and (combined with laser photo-detachment) the negative ion density. Absolute Cl and O atom densities are determined by Two-photon Absorption Laser-Induced Fluorescence, combined with novel calibration schemes. A new ultra-low noise broadband UV-visible absorption bench allows measurement of the densities of ground state Cl_2 molecules, Cl_xO_y reaction products and vibrationally excited states of Cl_2 and O_2. These measurements were compared to a state of the art 2-dimensional hybrid fluid model, showing considerable discrepancies in both the absolute values and trends with gas pressure.The models can be improved significantly by paying attention to gas heating mechanisms, surface processes (atom recombination and ther- mal accommodation) and by improved cross-sections for processes including electron-impact dissociation of molecules and vibrational excitation.

Keywords: TALIF, ultraviolet absorption, plasma etching, inductively, coupled plasma

Diagnostics on collisionless shock experiments

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Collisionless shock is ubiquitous in space and astrophysical plasmas, such as Earth's bow shock and supernova remnant shocks. Collisionless shock is a shock wave generated in a collisionless plasma, in which Coulomb collisions are negligible. Whereas the shock-front thickness of collisional shock is of the order of Coulomb mean-free-path (mfp), that of collionless shock is much smaller than the mfp, and wave-particle interactions and collective effects of electric and magnetic fields play essential roles in the shock formation. Collisionless shock has been studied more than half century as one of the most important topics in space and astrophysics, because it is believed to be the source of cosmic rays and rich in plasma physics. In addition to local observations of space plasmas by spacecraft and global emission measurements of astrophysical plasmas, laboratory experiments can be an alternative approach to study the formation of collisionless shocks.
In this paper, an overview is given for the diagnostics on collisionless shock experiments using high-energy laser systems. Electrostatic shock [1] and Weibel-instability mediated shock in a self-generated magnetic field [2-4] are studied in laser-ablated counter-streaming plasmas using double-plane target. Optical diagnostics (interferometry, shadowgraphy, and visible self-emission) are used to observe global structures of plasmas and shocks. Collective Thomson scattering method is applied to clarify local plasma parameters, such as electron and ion temperatures, flow velocity, and electron density. Proton radiography, using both a short-pulse laser created protons and D-3He fusion produced protons, is employed to measure electromagnetic fields and filament structures in a plasma.

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Keywords: collisionless shock, collective Thomson scattering, proton radiography, Weibel, instability

Chemical kinetics in atmospheric pressure plasmas - a diagnostics challenge

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Atmospheric pressure plasmas are versatile and efficient sources for reactive species at ambient room temperature. The non-equilibrium chemical kinetics is initiated and determined by the electron dynamics. Due to the strongly collisional environment and associated short electron energy relaxation times the electron dynamics can be tailored using multi-frequency power coupling techniques, enabling separate control of key parameters like electron density and electron mean energy. Details of the chemical kinetics depend on the feedgas composition and desired application. Measurements and predictive simulations of key reactive species are equally challenging due to the strongly collisional environment and their multi-scale nature in space and time. The most promising approach is the exploitation of complementary advantages in direct measurements combined with specifically designed numerical simulations. The employed diagnostic techniques include picosecond laser spectroscopy (O, N, H measurements), synchrotron VUV spectroscopy (O, N measurements), UV & IR absorption spectroscopy (OH, O_3, CO_2, CO measurements) and nanosecond optical imaging spectroscopy (electron dynamics). The presentation will focus on examples of He-O_2-N_2-H_20 mixtures for bio-medical applications and He/Ar-CO_2 mixtures for CO_2 conversion into value-added chemicals.

Keywords: Optical diagnostics, laser spectroscopy, atmospheric pressure plasmas, low temperature plasmas, radio, frequency plasmas, chemical kinetics

Thermal high spectral resolution x-ray spectrometers

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Crystal and grating spectrometers have long dominated diagnostics for high resolution x-ray spectroscopy both on the ground and in space. However, there are limitations to these techniques that restrict their application in some circumstances: limited dynamic range, and limited efficiency, for example. An additional problem for x-ray astrophysics is spatial-spectral confusion since the instruments typically do not include a slit. Thermal x-ray spectroscopy is a relatively new technique that can produce precision measurements without some of the limitations of dispersive methods. Moderate spectral resolution, R=1000, small pixel count thermal spectrometers have flown multiple times on the XQC sounding rocket experiment to study the soft diffuse x-ray background, and on the Astro-H x-ray observatory. We have used similar spectrometers for over a decade at the Lawrence Livermore Electron Beam Ion Trap and the Linac Coherent Light Source for laboratory astrophysics. The next generation of thermal spectrometers will have significantly improved performance and much larger pixel counts. The XIFU instrument on Athena will have resolving powers of around 3000 across its bandpass from below 0.3 keV to above 10 keV, with over 4500 imaging elements. Here we will introduce thermal x-ray spectrometers, discuss where this technology is headed, and show how we use them to complement our dispersive spectrometers in laboratory experiments.

Keywords: x, ray, spectrometer, x, ray astrophysics

High speed imaging and spectroscopy of X-rays and particles with silicon detectors

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- Silicon detectors are widely used as high performance sensors for photons from 1 eV energy up to hundreds of keV and as particle detectors for tracking, imaging and spectroscopy. In the visible domain CCDs, CMOS imagers and SiPMs are spread over a wide range of scientific applications.

- Columnar scintillators are coupled to light detecting sensors (CCDs and SDDs) to expand the energy bandwidth to several hundred keV or SiPMs are coupled to scintillating materials in high energy physics experiments. In this case of indirect radiation detection the silicon sensors are used as light detectors.

- In a direct detection mode of ionizing radiation the impact of Silicon Drift Detectors (SDDs), pnCCDs and DePFET active pixel sensors on the measurement of energy (Fano limited), position (diffusion limited), intensity (dynamic range limited) and time (mobility limited) will be discussed to explore the optimum use of the sensors and the associated electronics.
- The use of silicon detectors for particles and photons as a powerful diagnostic tool will be highlighted and examples from recent experiments will be given:
- from astrophysics
- from synchrotron and X-ray Free Electron Laser science
- from material science
- from plasma science
- from TEM science

Keywords: X, ray imaging, Silicon radiation detectors, energy resolution, position resolution, time resolution, radiation hardness

In-vessel Diagnostics Development for ITER

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ITER (Nuclear Facility INB-174) will have over fifty diagnostic systems that will become operational in a coordinated way to support all stages of the ITER research plan. Systems mounted on the ITER vacuum vessel (VV), facing the plasma or the VV thermal shield are needed early and their development is advanced. These include electrical systems such as magnetic sensors commissioned with the plasma control system (PCS) from the first phase, bolometers for the second operation phase to monitor radiated power and a robust set of in-vessel electrical cabling that has been developed to support these and other client systems. In addition there are reflectometers for density profile and gap measurements as well as neutron diagnostics (micro-fission chambers, neutron activation system) and a dust monitor with dedicated transmission lines. For all systems, interfaces are near-final and the designs are entering manufacturing stage. Items developed to now include features to allow assembly to the VV (a nuclear pressure vessel), robust transmission feedthroughs and, for certain critical items, an in-vessel connection scheme that can allow replacement. For extended systems and larger components, challenges remain: compliance to the VV under load is harder to achieve and for waveguides, in addition, their design must allow very small distortion in-service despite the loads and industrial nature of their assembly process. One of the key loads, first faced in the development of W7-X diagnostics, is the stray ECH. It has been quantified for all these systems and a dedicated ECH sensor (bolometer) has been developed and will be deployed to allow confirmation of the loads in-service and protection functions to be implemented as needed. This talk will outline the key design features and design development steps of the in-vessel diagnostic set and summarize lessons learnt from this process for future fusion devices.

Keywords: ITER, diagnostics, radiation hardness

Diagnostic Developments to Measure Stellarator Optimisation in Wendelstein 7-X

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Wendelstein 7-X started its first plasma operation phase, OP1.1, in December 2015. Towards the end of the campaign more than 20 diagnostics were in operation, including Thomson scattering, electron cyclotron emission, dispersion interferometer, neutral gas manometers, X-ray imaging crystal spectrometer, spectroscopic diagnostics and camera systems with more than 30 cameras. The plasma performance was above expectation: $T_e \sim$10 keV, $T_i \sim 2$ keV, n_e $3 \cdot 10^{19}$ m^{-3}, and discharges up to 6 seconds. The electron-root confinement regime has been reproduced with steep gradients in the electron temperature and flat density profiles. The reduced electron heat transport is caused by the radial electric field profile with negative values ate the edge and positive in the core.

For the next phase, OP1.2, in 2017 an island divertor will be installed together with increased ECRH and NBI heating capacity. The aim is to increase the plasmas density approaching $n_e \sim 10^{20}$ m^{-3} to obtain better ion-electron equilibration $T_i = T_e$. For these studies, new diagnostic capabilities will be installed. A Charge Exchange Recombination System on the heating NBI source will be implemented for measuring T_i, n_i and E_r. The Thomson scattering system will be upgraded to the full profile with about 90 spatial points from a half profile with 10 points. Impurity studies will be enabled by new spectroscopy systems and a laser-blow-off system to study the direction of the impurity transport in optimized transport regimes. Radiation tomography from bolometry data and heat load measurements with IR cameras, endoscopes and a set of Langmuir probes aim at testing the first wall compatibility with optimized configurations. The fluctuation diagnostics will be expanded to study the core and edge transport in details. An overview of the expected plasma performance will be given together with a detailed overview of the new diagnostics enabling the exciting study of optimised stellarator performance in W7-X.

Keywords: Wendelstein, optimized stellarator, diagnostic overview, OP1.2

Development of Laser Megajoule and PETAL Diagnostics: present status

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The laser Megajoule (LMJ) facility, developed by the Commissariat à l'énergie atomique et aux énergies alternatives (CEA), is designed to provide the experimental capabilities to study High Energy Density Physics (HEDP). The LMJ is a keystone of the French Simulation Program, which combines improvement of physics models, high performance numerical simulation, and experimental validation. The 176 beams of the facility will deliver a total energy of 1.4 MJ of 0.35 μm (3ω) light and a maximum power of 400 TW. The PETAL project (PETawatt Aquitaine Laser), part of the CEA opening policy, consists in the addition of one short-pulse (500 fs to 10 ps) ultra-high-power, high-energy beam (a few kJ compressed energy) to the LMJ facility. PETAL is focalized into the LMJ target chamber and could be used alone or in combination with LMJ beams. Since the first experimental campaign conducted in 2014 with a mid-field Gated X-ray Imager (GXI) and two quadruplets (20 kJ at 351 nm) focused on target, the LMJ operational capability is growing up. The experiments performed, since this first experiment, were dedicated to radiative transport, implosion hydrodynamics and hydrodynamic instabilities in order to validate radiative hydrodynamics simulations and prepare ignition. New plasma diagnostics have been implemented, and LMJ will increase its capacities in the following years with the completion of other beams and the development of new diagnostics. PETAL, which is devoted to the academic research, will also extend the LMJ diagnostic capabilities; a first set of diagnostics, part of the the Equipex PETAL+ project funded by the French National Agency for Research (ANR), will measure hard X-ray and the particles (protons/ions/electrons) spectrum, and will also provide point projection proton-radiography capability. We propose to give an overview of the plasma diagnostics development status conducted at CEA for experimental purpose in the LMJ and PETAL facilities.

Keywords: Plasmas diagnostics, ICF, LMJ, PETAL

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Cavity-enhanced absorption spectroscopy to characterize atmospheric pressure plasma jets

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Atmospheric pressure plasma jets gain more and more interest as their technological applications increase in diverse fields such as material processing and plasma medicine, exploiting their high reactivity at low gas temperature. Hence, it is essential to diagnose the fluxes of the species generated by these plasma sources to identify relevant fundamental processes and to improve process efficiency. Especially, high precision measurements of reactive molecular precursors, free radicals and short lived species are of crucial importance. However, the detection of transient species in these type of plasmas poses a challenge for diagnostic techniques as the plasmas typically have small dimensions and high density gradients in space and time. We have overcome these limitations by using optical cavities to achieve effective absorption path lengths of up to 100 meters in mm sized plasma jets [1]. In this contribution, the latest results concerning the detection of species in plasma jets employing optical cavities in the near- and mid-infrared spectral range will be presented. Using cavity-enhanced absorption spectroscopy (CEAS), resulting in effective absorption path lengths of 10 meters, CH4 created in the dissociation process of the hexamethyldisiloxane (HMDSO) precursor in the deposition process of SiO2 thin films was detected. Furthermore, the detection of the highly reactive HO2 radical in a cold argon plasma jet used in plasma medicine will be presented where the method of optical feedback CEAS is employed to achieve absorption path lengths of up to 100 meters. The achieved detection levels indicate that CEAS-based spectrometers provide a new way of testing and improving our modelling of these complex plasma environments and will find broad application in future studies of the chemical network in the effluent of plasma jets.

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Keywords: cavity enhanced absorption spectroscopy, optical cavities, absorption spectroscopy

Frontiers in Tomography Reconstruction Methods for Tokamak Plasmas

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In thermonuclear plasmas, emission tomography relies on integrated measurements along lines of sight (LOS) to determine the two-dimensional (2-D) spatial distribution of the volume emission intensity. The technique can be applied to gamma-ray, neutron, total radiation, soft and hard X-ray emissions. The information provided by tomography can be therefore invaluable for assessing very delicate aspects of the discharges, ranging from the neutron emission to the behavior of the alpha particles and the distribution of total radiation. In all these cases, the measurements are line integral data obtained by arrays of collimated detectors looking through the plasma along different LOSs at different orientations. In order to compensate for the lack of experimental data, additional a priori information must be incorporated in the reconstruction method.

A number of valuable approaches have been developed for the tomographic reconstruction on JET. Most of them use an additional term in the objective function or an extrinsic regularization procedures enforcing preferential emissivity smoothness along magnetic flux surfaces. Several methods incorporate different statistical principles like minimum Fisher information or maximum likelihood. Alternative approaches based on an emissivity parametric model coupled with neural networks or a generalization of the known Abel inversion have been also proposed.

The problem of evaluating the errors associated with the reconstructed emissivity profile is very important for physical interpretation and for quantitative analysis. Recently a method for the numerical evaluation of the statistical properties of the uncertainties in reconstructions has been developed. Apart from the noisy data, the final reconstructed image quality also depends on the constraints imposed for the compensation of the limited measuring geometry. The occurrence of specific artefacts has been assessed in order to avoid wrong conclusions.

Keywords: Plasma diagnostics, Tomography, Reconstruction Uncertainties

Optical probing of strong electromagnetic pulses from petawatt laser-matter interactions

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Strong Electromagnetic pulses (EMP) can be produced by intense laser-matter interactions. EMP can be problematic in high-power laser facilities; it can affect electronic systems in target areas, possibly resulting in loss of recorded data such or even permanent damage to valuable equipment. However, EMP can also be used as a complementary diagnostic to give insight into charged particle dynamics. Here, we report on the first petawatt-regime optical EMP measurements. EMP is usually characterised with conductive probes; even with shielding, these are troubled by electrical noise pickup from EMP coupling to conductive cabling, hence it is challenging to obtain good signal-to-noise ratios. Furthermore, conductive probes locally perturb the fields being measured.

Using a fundamentally different probing mechanism can mitigate these issues, in our case the electro-optic Pockels effect in dielectric crystals. By using polarising optics in conjunction with ”probe” crystals, local electric fields can be mapped onto intensity changes on a continuous-wave laser. Using dielectric probes minimises local field disturbances, while optical techniques are advantageous for noise-reduction, as signal transport to the readout system can be via fibre-optic cables. This ensures high inherent electrical noise immunity, as the oscilloscopes and photodetectors recording data can be located in a Faraday Cage outside the target area.

Keywords: Electromagnetic Pulses, Electro optics, Laser plasmas, Optical diagnostics

Orbital Motion Theory for Cylindrical Emissive Probes

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The well-known Orbital-Motion Theory is for the first time used to model the thermionic emission from a cylindrical emitter to plasmas, considering Maxwellian for plasma electrons and ions while half-Maxwellian for emitted electrons. Taking advantage of three conserved quantities, distribution function f, transverse energy E, and angular momentum J, the stationary Vlasov-Poisson system is written as a single integro-differential equation. As long as collisions, plasma drift, particle trapping, transient effects, and magnetic fields are not significant, this equation describes self-consistently the probe characteristics, being valid for any parameter range. A numerical scheme, using a finite-element method and a Newton algorithm, is implemented to solve this equation. For given plasma parameters and probe properties, the model provides the radial structure of the electrostatic potential and the densities of all three species. Current-voltage characteristics are computed for a wide range of conditions. The operational regimes of emissive probes, including positive/negative probe bias, monotonic/non-monotonic potential, OML (orbital-motion-limited)/non-OML collection, and SCL (space-charge-limited)/non-SCL emission, are discussed and organized in a parametric plane of probe bias and emission level. Virtual cathode, i.e., non-monotonic potential, is found for both negative and positive probe bias. The probe can even float (zero net current) at a positive bias relative to the plasma. Applications and limitations of the model to plasma diagnostics experiments are discussed.

Keywords: emissive probe, orbital motion theory, space charge effects, virtual cathode

Absolutely calibrated Doppler coherence imaging flow measurements in the divertor of a tokamak

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Doppler coherence imaging spectroscopy (DCIS) is a relatively new technique for the observation of plasma bulk ion dynamics in magnetically confined plasma experiments. It is a passive optical diagnostic that measures 2D images of the line-integrated ion flow and temperature.
Since its invention, the DCIS has been constantly developed and tested in several magnetic confinement devices such as DIII-D [1], H-1NF [2], MAGPIE [3] and MAST [4]. DCIS has the advantage of a relatively simple hardware set-up with high entendue, providing: high flow sensitivity and an order of magnitude more data at higher signal-to-noise than traditional systems. However, absolute flow calibration has proven to be difficult for many impurity ion species present in the divertor of larger plasma experiments. This is due to lack of nearby calibration lines, ambient temperature changes of the diagnostic hardware as well as the difficulty to use a calibration light source in the image plane of the diagnostic's camera.

For this study, the DCIS was used to measure the ion dynamics in the divertor of ASDEX-Upgrade. A flexible diagnostic set-up was designed to directly calibrate each flow measurement immediately before and after an investigated plasma discharge, making absolutely calibrated flow measurements possible. They show a change of flow sign between the two divertor legs that is expected due to magnetic topology. Furthermore, they roughly confirm the position of zero flow that was determined in previous, non-absolutely calibrated DCIS measurements [4]. Measured flows of C-III, He-II and D-I and derived parallel flows along the magnetic field will be presented. In addition, a comparison is made with EMC3-Eirene flow simulations.

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Keywords: Doppler coherence imaging, coherence imaging, ASDEX, Upgrade

Dual HIBP - a multi-purpose diagnostics for electric potential and plasma fluctuations in the TJ-II stellarator

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Heavy Ion Beam Probing (HIBP) is a unique diagnostics for core plasma potential, it operates now in the T-10 tokamak and TJ-II stellarator. Fine focused (<1cm) and intense (150mA) Cs+ or Tl+ beams with energy up to 300keV, equipped by advanced control systems provide measurements in wide density interval $ne = (0.3–5)10^{19}$ m^{-3} in wide range of magnetic configurations in the Ohmic, ECR and NBI heated plasmas.
Multi-slits energy analyzers provide simultaneously the data on plasma potential j (by beam extra energy), plasma density (by beam current) and Bpol (by beam toroidal shift) in each of 5 poloidally shifted sample volumes. Thus Epol=(j1-j2)/x, x∼1 cm, and electrostatic turbulent particle flux GammaE×B(t)=Ep$ol(t)$/Bt is derived. Density oscillations cross-phase produces phase velocity of poloidal propagation of perturbation or plasma turbulence rotation and poloidal mode number m. Time evolution of radial profiles and/or local values of plasma parameters can be measured in a single shot at (-1<r/a<1).
Dual HIBP in TJ-II, consisting of two identical HIBPs located 1/4 torus apart, provides the study of toroidal correlations in core plasmas. High gain (10^7 V/A) preamplifiers with 300 kHz bandwidth allows us to study broadband turbulence. The recent application of the Dual HIBP to study Long-Range Correlations, Geodesic Acoustic Modes, Alfven Eigenmodes including chirping modes with frequencies up to 400 kHz will be presented in the paper.

Keywords: Heavy Ion Beam Probe, Turbulence, Long, range Correlation

Characterization of the relativistic laser-plasma interaction with optical diagnostics

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The interaction of short ultra-intense laser pulses with sub-micrometer thin targets is a current topic in plasma physics, that has been enabled by the latest improvements on the temporal contrast of the driving laser pulse at most of the major laser facilities worldwide. This development allows for the laser pulse to interact with an over-critical plasma, even for targets of very limited areal density. In such conditions, processes that have been theoretically and numerically predicted, like volumetric ion acceleration, can be studied. It is also of interest to study the interaction on the picosecond level as the best results so far have been obtained at sub-picosecond facilities rather than with ultrashort femtosecond lasers. In such a case, the interaction is influenced by the non-ideal laser pulse profile and some hydrodynamic effects occur, in particular during the rising slope of the pulse on the last 10's of picoseconds, which strongly conditions the interaction.
In this contribution we present results obtained using optical diagnostics used in interaction experiments conducted at the PHELIX facility. Short-laser pulses with an intensity of $(1.0\pm0.5)\cdot10^{20}$ W/cm^2 with an energy of 100 J have interacted with thin plastic foils in the range of 0.1 to 1 micrometer provided by the target laboratory of the Ludwig Maximilian University of Munich. The setup included time-resolved spectral diagnostics working at the laser frequency to characterize the light back reflected and transmitted through the target. For the back reflected light, spectral measurements show a strong Doppler shift of the back reflected spectrum, what is also confirmed by the FROG (frequency-resolved optical gating) analysis of the reflected pulse. In the transmitted direction, an innovative pump-probe arrangement coupled with spectral analysis with Fourier-transform spectral interferometry yields interesting insights on the propagation of short laser pulses in target at near critical plasma densities.

Keywords: relativistic laser, plasma interaction, interferometry, time, resolved diagnostics

X-ray spectroscopy diagnostics on supersonic astrophysically-relevant magnetized plasma flows

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Laboratory experiments employing the plasma produced by high power lasers can be scaled to astrophysical systems by matching dimensionless scaling parameters and thus providing the studies of astrophysical phenomena in controllable conditions. Particularly, laser produced supersonic jets are fully scalable to that one from young star objects, and the application of external magnetic field to plasma flows allows to investigate stable, large aspect ratio plasma jets. While the laser produced plasma expands from the target surface, it becomes overcooled, *i.e.* recombining one, and with non-stationary ionization state in the most of cases. Accordingly, to improve diagnostic methods applicable for such plasma is rather important task in laboratory astrophysics. Here X-ray spectroscopy method considering the relative intensities of spectral lines emitted by He-like and H-like F and O ions is developed and implemented to determine electron temperature Te and density Ne profiles of plasma jets along its propagation in vacuum, external magnetic field, plasma precursor, and in its interaction with solid obstacle. Particularly it is shown that Ne decreases monotonically in the case without B-field, but demonstrates an extended density profile when 20 T poloidal magnetic field is applied. While at target surface irradiated by 60 J 1 ns laser pulses the electron temperature peaks at 250-280 eV, at 3 mm distance it cools down to $\sim$ 20 eV. Then, due to the impact of B field providing the collimation of the jet, Te and Ne are measured to keep at almost constant values for a long distance along the jet. Laboratory experiments reveal that the shaping of narrow jets emerging from young stars can be explained by axial magnetic fields in which the stars are embedded.

Keywords: recombining plasma, supersonic plasma jets, magnetized plasma flows, x, ray spectroscopy diagnostics, laboratory astrophyiscs

Results and performances of X-ray imaging GEM cameras on FTU (1-D), KASTAR (2-D) and progresses of future experimental set up on W7-X and EAST facilities

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The triple Gas Electron Multiplier (GEM) is a good candidate for the observation of the plasma volume emitting X-rays photons in the energy band up to 30 keV. The GEM camera system can be simply installed outside the port of a fusion device and it's a micropattern proportional gas detector which consists of an ionization gap, where X-rays photon conversion occurs, three consecutive foils working as amplification stage and finally a dedicated printed circuit board. Its simple experimental setup can be made in different configurations with 1D or 2D imaging possibilities: perpendicular GEM camera allows a 1D emissivity profile reconstruction instead a tangential GEM camera allows a poloidal cross-section image. Moreover, they offer high sensitivity, noise free, optical flexibility (zooming and tilting, magnification 10x up to 30x), high contrast, high dynamic range (6 orders of magnitude) and good time resolution (submillisecond). In this work several experimental results already observed on FTU and KSTAR will be presented. The perpendicular installation on FTU allows a 1D radial profile with 128 lines of sight, while thanks to the 2D tangential view of the plasma, the reconstruction of the cross section has been done on KSTAR. Between them there are dynamic and precursors of sawtooth, effects of ELMs in the core and possible interplay between core and edge in ELMs (high m modes), effects of plasma rotation in the core, dynamic of injected impurities in the outer part of the plasma or also impurity accumulation and localized effects of additional heating. Installation of GEM systems is planned on W7-X and EAST also for their robustness and flexibility X-rays detection in presence of high radiative environments (neutrons and gammas). In future applications on the above mentioned fusion devices, another possibility under evaluation is to use standard tomographic methods using two orthogonal GEM camera systems.

Keywords: GEM, X, RAY IMAGING, SOFT, X, FTU, KSTAR, W7, X, EAST

Operating Diagnostics in JET with a Metal Wall and Different Fuel Mixtures in Preparation for the Next Step Devices

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The preparations for ITER and DEMO require still various developments in Tokamak diagnostic capability. Indeed the experience of operating metallic machines in conditions relevant to next step devices and in D-T is quite limited. In this respect, JET can provide unique information.

With regard to basic plasma measurements, the presence of heavy impurities has increased qualitatively the difficulty of active spectroscopy. Therefore, several improvements of CXR are being pursued. The effects of tungsten on the plasma performance have motivated the development of various spectroscopic systems. New upgrades of reflectometry, correlation and Doppler, and of the TAE system have proved that these techniques can characterize instabilities and turbulence in large machines.

The recent JET campaign in Hydrogen has allowed testing various measurements of the isotopic composition, which remains a delicate task in ITER. The coherence between the NPA, neutron diagnostics, edge spectroscopy and global particle balance provide a good basis to develop a strategy for the next step devices.

As far as fusion products are concerned, JET can deploy a consistent set of techniques to measure the neutron yield, neutron spectra and fast particles. Vertical and horizontal lines of sight are foreseen for neutron spectrometry, in order to separate the RF contribution. Various gamma ray spectrometers will provide unique input to various codes for discriminating the trapped and passing fast particles. The redistribution of the alphas and fast ions will be measured with the gamma ray cameras.

From a technological perspective, the planned D-T campaign will provide a unique opportunity to test ITER relevant technologies. Indeed the expected neutron flux at the first wall ($\sim 10^{16}$n/cm^2) is comparable to the one in ITER behind the blanket. A full calibration of the neutron diagnostics with a 14 MeV source is being finalised, after the recent successful calibration for the 2.45 MeV neutrons.

Keywords: JET diagnostics, Burning Plasma diagnostics, isotopic composition, fuel mixture, neutrons, gamma rays

Solid density x-ray spectroscopic at ultra-high laser intensities

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An ultra-intense laser (>10^{20} W/cm^2) solid interaction can lead to intense beams of relativistic electrons as these electrons propagate through a target they generate intense x-ray line and broadband emission through ionisation and excitation processes in the solid and via bremsstrahlung and other scattering processes. We present x-ray spectroscopic measurements and emphasise spectroscopic techniques are being use to give insight into the target and laser interaction physics.

Keywords: Petawatt, electron transport

Ohms law and the collision of magnetic flux ropes

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Department of Physics and Astronomy, UCLA Magnetic flux ropes are bundles of twisted magnetic fields and their associated current. They are common on the surface of the sun (and presumably all other stars) and are observed to have a large range of sizes and lifetimes. They can become unstable and resulting in coronal mass ejections that can travel to earth and indeed, have been observed by satellites. Single and multiple flux ropes have been reproducibly generated in the LArge plasma device (LAPD) at UCLA. Using a series of novel diagnostics the following key quantities, B,Vp,n,Te (**u** is the plasma flow and Vp the plasma potential) have been measured at more than 48,000 spatial locations and 7,000 time steps. The construction and deployment of the diagnostic probes and conditional averaging techniques will be presented. From these measurements along with the magnetic Helicity, and Qusai Seperatrix Layer (QSL) are derived from the data in three dimensions. Every term in Ohm's law is also evaluated across and along the local magnetic field and the plasma resistivity derived. Ohms law does not yield a physically meaningful resistivity and there is evidence that it is non-local. The Kubo AC conductivity, at the flux rope rotation frequency, is a 3X3 tensor and evaluated will be presented. This yields meaningful results for the global resistivity. The temporal variation of the helicity and helicity transport into the QSL is used to calculate the resistivity in the narrow reconnection region. The contribution to the power density, from the region in which reconnection occurs is compared to heating in the current channels.

Keywords: flux ropes: Ohms law : non, local Ohms law, Kubo resistivity, plasma diagnostics, labortaory experiment

Measurements of the temperature of tungsten micro-particles in Pilot-PSI plasmas from their thermal radiation

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The presence of micrometric metallic dust particles in future fusion power plants is an issue for reactor operation. In ITER, the amount of in-vessel tungsten and beryllium dust is restricted below predefined limits based on estimates of tritium retention and hydrogen production in case of accidental air or water ingress. While dedicated dust-plasma interaction models have been developed over the last few years, *in situ* dust diagnostics in fusion devices mainly consist of camera observations of the particles' trajectories, providing little to no information on the key parameters controlling dust heating and lifetime. In particular, dust temperature measurements constitute an invaluable input to validate theoretical models.
A spectroscopic method based on dust thermal radiation measurements is presented, allowing the dust temperature and size to be deduced. The measured thermal spectra are fitted against the theoretical gray-body law with a size- and temperature-dependent emissivity calculated from Mie theory. The fitting procedure provides both the values and their statistical errors.

This method has been applied to tungsten dust injection experiments through divertor-like plasmas in Pilot-PSI, complemented with direct trajectory recording. The radiation spectra of the micro-particles have been measured with a grating spectrometer in the visible range and recorded by a fast camera. The diagnostic system provides temperature measurements at a high repetition rate (5 kHz) and spatial resolution of 1.3 mm. Due to the large amount of detected particles per discharge, spatial dust temperature profiles have been measured.
Experimental results are presented for two types of Pilot-PSI discharges. In plasmas with 1.5 eV and $2.5*10^{20}$ m^{-3}, the tungsten particles were found to be heated up to their melting point. In more energetic plasmas, 2.5 eV and $4*10^{20}$ m^{-3}, temperatures above 5000 K were measured, along with additional line emission consistent with tungsten vaporization and ionization.

Keywords: metal dust, heat balance, edge and divertor plasmas, thermal radiation, pyrometry

Deuterium charge exchange recombination spectroscopy from the top of the pedestal to the scrape off layer in H-mode plasmas

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The recently commissioned 16 channel edge deuterium charge exchange recombination (CER) spectroscopy diagnostic on DIII-D is revealing differences in impurity and main-ion temperature and toroidal rotation from the top of the pedestal through the steep gradient region and into the scrape off layer. Fitting the D-alpha spectra provides apparent measurements of temperature, velocity, and density. To obtain the actual local deuterium temperature, toroidal rotation and density requires corrections for the atomic cross section distortion and line of sight smoothing. These corrections are significantly more complicated for deuterium than for impurity CER due to comparable emission between direct charge exchange and halo charge exchange. These challenges are overcome using a comprehensive collisional radiative model (implemented in the FIDASIM code) in an iterative loop to uncover the deuterium profiles that generate the measurements. Details of the diagnostic system, analysis procedure, and recent results showing significant differences between deuterium and impurity temperature and rotation in H-mode plasmas will be presented.

Work supported by the U.S. DOE under DE-FC02-04ER54698 and DE-AC02-09CH11466.

Keywords: CER, rotation, temperature

Study of the Imaging Plates response functions to X-rays

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Thanks to their high dynamic range and ability to withstand electromagnetic pulse, imaging plates (IP) were chosen to measure the absolute particle spectra inside the PETAL+ diagnostics. These phosphor films are commonly used in laser-plasma experiments and their sensitivities seem to be well known. However, still few data are available on the absolute IP response functions to ionizing particles.
Within the PETAL+ project, we performed an experimental campaign dedicated to improving our knowledge of IP response functions to photons [1], electrons [2,3] and protons [4]. In this contribution, we focus on low-energy photons, for which important discrepancies are found in the literature, e.g. [5,6]. We performed two calibration experiments to X-rays :

- in the [8-75] keV energy range using a 160 kV generator at CEA DAM DIF.
- in the [22-25] keV energy range using laser-induced K-shell X-rays at CELIA.

Finally, the response functions have been modeled in Monte-Carlo GEANT4 simulations in order to reproduce experimental data. Simulations enable extrapolation of the IP response functions to energies from 1 keV to several hundreds of MeV, covering the full energy range of photons, which will be produced with PETAL. Such response functions are thus of interest for soft and hard X-ray diagnostics as well as for laser-driven radiography, using PETAL or elsewhere.

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Keywords: Imaging Plates, X, rays, PETAL

Development of a multilayer mirror for a broad spectral band multiple monochromatic x-ray imager designed for implosion experiments

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In inertial confinement studies, quasi monochromatic images of an imploding doped microballoon provide local informations of plasma conditions. Common dopants are argon in the gas and titanium in the shell. So images in the spectral range 3 keV to 6 keV are needed. There is a specific diagnostic called MMI [1] available on the OMEGA laser facility for direct drive experiments. It includes a pinhole array with 800 pinholes 17 mm from target, a flat Bragg mirror and a framing camera.
This plasma diagnostic combines x-ray spectroscopy and x-ray imaging and provides quasi-monochromatic images at magnification 9. We propose a new multilayer mirror design which would make possible to increase the spectral bandwidth or decrease the angular acceptance of the diagnostic while keeping the same geometry. This new design consists in making a d spacing variation along the multilayer while fulfilling the Bragg law.
It is better not to have the front of a diagnostic too close to the target due to the harsh conditions in the center of the OMEGA, the LMJ or the NIF target chamber. So we have chosen to decrease the angular acceptance by increasing the distance of the front of the diagnostic to the target. This designed multilayered mirror has been made by Xenocs and characterized at the PTB. Design of this new mirror and qualification results will be presented.

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Keywords: multilayer mirror, X, ray spectroscopy, X, ray imaging

High Resolution Neutron Spectrometer for ITER - conceptual design

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The aim of neutron spectrometers is to measure the neutron energy distribution of the emitted fusion neutrons. This type of measurement can provide information on the thermal ion temperature, intensities of different neutron components due to plasma heating and distribution on fuel ions.
The High Resolution Neutron Spectrometer (HRNS) is a part of that ITER neutron diagnostics set, which will measure the time resolved neutron spectrum for both DD and DT plasmas, providing plasma parameters presented mainly as the fuel ion ratio, ion temperature. HRNS is a one channel collimator system able to perform neutron measurements providing line-integrated data, where the record signal is an integral over local plasma conditions along the instrument's line-of-sight (LOS).
The HRNS system is dedicated measurement to the 14-MeV neutron emission from ITER DT plasmas and also to the 2.45 MeV neutron emission. A suitable 2.45-MeV spectrometer is an important part of the HRNS system which provides important information during scenario developments and testing of the heating systems. In addition, due to the long pulses and good confinement properties of ITER, the tritium inventory in D plasmas will be high, and triton burn-up studies will provide good opportunity for testing and tuning all of ITER's 14-MeV neutron diagnostics [1].
This paper describes the conceptual design of a High Resolution Neutron Spectrometer (HRNS), its role in the set of the neutron diagnostics on ITER.
The work has been performed by a Consortium , Institute of Nuclear Physics, Polish Academy of Sciences, Kraków, Department of Physics and Astronomy, Uppsala University, ENEA C. R. Frascati Dipartimento FSN, Frascati, Istituto di Fisica del Plasma "P. Caldirola", Consiglio Nazionaledelle Ricerche, Milano in the frame of F4E grant no F4E- GRT-403.

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Keywords: ITER, neutrons, spectrometers

X-ray absorption radiography for high pressure shock wave studies

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The study of the matter in extreme condition is important in different research areas (equation of states, inertial confinement fusion, astrophysics, etc...). Multi-megabar pressures can be obtained in laboratory using laser-driven shocks. However, a detailed characterization of the shock wave is required. In this work, we performed an experiment at LULI laser facility to characterize shock propagation using time-resolved X-ray radiography. The target was made of a plastic cylinder with diameter of 500 μm and thickness of 250 μm on the laser side glued on a plastic layer of 20 μm thickness followed by 10 μm of Molybdenum and a thick layer of quartz. Molybdenum shielded the rear side of the target thereby protecting the streak cameras (VISAR and SOP measurements). The quartz layer allowed obtaining a direct measurement of the shock velocity with VISAR. Targets with a hemispherical interaction surface were also used. The hemisphere had diameter of 500 μm. The LULI2000 laser beam (E = 500 J, λ = 526 nm, τ = 2 ns) was used to launch a strong shock. X-ray radiography images of shock position at different times obtained using Vanadium Kα radiation (4.9 keV) by focusing the PICO2000 laser beam (E = 40 J, λ = 526 nm, τ = 3 ps) on Vanadium target were compared to hydrodynamic simulations performed with the code DUED coupled to a post-processor creating synthetic radiography images. This allowed to take into account important physical effects, like the finite source-size of the X-ray backlighting source, which are neglected if one simply compute the Abel inversion of experimental data to get the density maps related to shock propagation in the target. We show here how the synthetic radiography allows reproducing the shock dynamics and its characteristics in both flat and hemispherical targets.

Keywords: X, ray Absorbtion Radiography, shock waves, hydrodynamic simulations, Inertial Confinement Fusion

Characterization of radiofrequency-microwave electromagnetic-pulses (EMPs) generated in experiments relevant to inertial confinement fusion

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The generation of radiofrequency-microwave electromagnetic-pulses (EMPs) by laser-plasma interaction in regimes relevant for inertial confinement fusion is a very important topic of research. The EMPs are transient electromagnetic fields observed for pulse duration from nanosecond up to femtosecond laser regimes and can create electric fields up to the MV/m, distributed manly within the experimental vacuum chamber. They have bandwidths of several GHz, duration up to hundreds of nanoseconds, and in many cases produce saturation and even damage to the electronic equipment within and nearby the experimental chamber. It is of primary importance to improve knowledge on EMPs for dealing with these problems on present and future plants for inertial-confinement-fusion and laser-plasma acceleration (NIF, LMJ, PETAL, ELI, Apollon...). Moreover, EMPs can supply information on the related laser-plasma interaction and their characterization can become an effective diagnostic tool. Measurement of EMPs presents many difficulties with classical metallic probes, which heavily suffer of effects due to ionizing radiation generated from laser-plasma and give only access to the time derivative of the field. For this reason we proposed an innovative electro-optical way for the measurement of the EMP electric fields in nanosecond laser-plasma interaction by means of Pockels effect on crystals [1], which has been recently applied successfully to the petawatt regime on experiments with Vulcan picosecond laser [2]. In this work we will present results obtained by electro-optic measurements in experiments of nanosecond laser-plasma interaction at intensities of 1014-1015 W/cm2 for l = 1054 nm and we will compare them with those achieved by classical metallic probes. The study indicates that signals are related with the emission of charged particles from target and that anisotropic particle emission, X-ray photoionization and charge implantation on surfaces exposed to plasma can be important EMP contributions.(a)

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(a) This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

Keywords: Electromagnetic Pulses, EMP, laser plasma interaction, electro optic (Pockels) effect, field probes, inertial confinement fusion, laser plasma acceleration

Cluster size distributions for different nozzle geometries in noble gas jets

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Pulsed gas jets obtained importance as intense sources of VUV radiation with high harmonic generation (HHG) and also they serve as targets for electron acceleration using short laser pulses. Especially the cluster-containing jets can be effective in HHG. Recent works [1] showed that the nanoplasmas appearing during the interactions result in a spectral shift of the harmonics, thus allowing the estimation of the cluster sizes. Although they are attractive sources, the reproducibility of cluster experiments is often poor. Therefore we characterized different shapes and types of nozzles determining cluster sizes using Rayleigh scattering diagnostics and compared the results with the generally used scaling laws [2,3].
Monitoring the spatial distribution of the clusters were carried out by using a CCD camera, whereas cluster sizes could be estimated using a photomultiplier detection of the scattered radiation from a 0.53 mm radiation of a cw laser.

The spatial distribution measurements show that supersonic de Laval nozzles can provide flat-top density profiles close to the exit of the nozzles. Earlier simulations [4] showed that with nozzles of different contour parameters different density modulations can be observed in the jet center even for monomer gases. We showed experimentally in clustered gas that when using de Laval nozzle with exit diameter of there is no density drops in the jet center, whereas for the exit diameter of 1 mm an annular distribution will be formed after propagation.

The concluded cluster sizes show significant deviations as compared with the Hagena- [2] or the Dorchies-scaling [3], especially for Xe. The home-made subsonic nozzle supplement on a Parker valve [5] shows the largest deviation, giving steeper pressure dependence. In contrast to the Hagena-scaling the difference between Ar and Xe cannot be described by a simple multiplicative scaling factor. Comparison with the HHG data shows, that the results can only be well interpreted by a complete mapping of the spatial and temporal dependence of cluster distribution.

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Keywords: harmonics, clusters, nanoplasmas

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Bayesian comparison of the electrostatic and the electromagnetic models of collective Thomson scattering

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Minerva is a completely Bayesian data analysis framework used on Wendelstein 7-X. It has a block structure which allows decoupling between the data sources, forward models of the diagnostics, and the physics models implemented in this framework [1]. The block structure of Minerva facilitates the exchange of physics models underlying a particular diagnostic. We intend to exploit this unique feature and use the Minerva framework as a platform to compare the electrostatic and the electromagnetic models of collective Thomson scattering (CTS) in a magnetized plasma, since both the electrostatic and the electromagnetic model are currently used for CTS data interpretation on different fusion experiments but in similar plasma conditions. Within Minerva we can explicitly define all dependencies between a particular physics model and the observed data. Given the data, we will use Bayesian analysis to infer not just a single set of model parameter values, but the entire posterior probability distribution which quantifies all uncertainties in the inversion process. These uncertainties reflect the inability of a particular model to predict the data, and the Minerva framework allows controlled full exploration of the influence of all uncertainties [2]. Comparison of the two models within Minerva will lead to a better understanding of the limitations of the electrostatic model with respect to the fully electromagnetic model, but potentially also provide insight into the limitations of the fully electromagnetic model alone.

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Keywords: magnetized plasma, collective Thomson scattering, forward modelling, electrostatic approximation, electromagnetic treatment, Bayesian inference, graphical models, scientific analysis infrastructure, Wendelstein 7, X

Hot electrons study in the shock ignition regime

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Shock ignition (SI) [1] is a novel approach to inertial confinement fusion [2], based on the separation of the compression of a DT pellet by ns laser beams at $I < 10^{15}$ W/cm^2 and ignition phases with ps laser intensities I $\approx 10^{15}$-10^{16} W/cm^2. At laser intensities up to 10^{16} W/cm^2, laser interaction with the long scale plasma may lead to the generation of hot electrons (HE). The experiment aims at investigating of the generation of such HE and their role in the generation of the shock wave [3]. We used two beams of iodine laser: an auxiliary beam (1ω) (60 J, 1×10^{14} W/cm^2, and a main beam (wavelength $\lambda = 1315/438$ nm for $1\omega/3\omega$, respectively, pulse duration ≈ 0.3 ns, energy between 170 and 440 J focused to intensities up to $I = 2\times10^{16}$ W/cm^2). The auxiliary beam arrived on target up to 1.2 ns before the main one, simulating the long-scale pre-plasma typical of ICF. Main beam launches the strong shock. The analyses of the experiment show both the K_α spot size and the number of K_α photons are higher at 3ω in comparison to the ones at 1ω. To determine the energy of HE we first fit an exponential function to the experimental data to measure the penetration depth inside the target and then by looking to the ESTAR database we estimated the energy of HE which was in the range 50-60 keV. Afterwards we applied the semi-analytical Harrach-Kidder?s model to compare the experimental data with the analytical ones and to confirm the accuracy of H-K model. According to the H-K model the energy of HE is about 21.6 keV or 29 KeV, depending on the thickness of the Cu layer, which is in good agreements with the experimental.

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Keywords: CXRS, UF CXRS, plasma density fluctuation

Phenomenon of side-scattering during laser-plasma interactions

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In the context of laser-driven-particle acceleration, the interaction dynamics between an intense laser pulse, and near-critical plasma is relatively under-explored. For electron densities close to critical density (0.1nc-1nc), the laser energy absorbed by the plasma is expected to increase due to resonance conditions (laser freq. ≈ plasma freq.). Simulations show that this density region can be used for efficient electron and ion acceleration, laser contrast improvement and pulse shortening. Thus, in order to shed more light into this interaction region, an experiment was carried out at JETI40, IOQ Jena, Germany where Argon gas-jet was used to create near-critical plasma. The interaction region was imaged using a second-harmonic probe beam at 90deg to the propagation direction. As the intense laser pulse ($> 10^{17}$ W/cm^2) propagates from the outer-edges of the gas-jet towards its centre, the phenomena of side-scattering has been observed on one-side of the interaction region. The scattering-angle is found to decrease for increasing electron densities ranging from 0.01-0.25nc. Although such scattering has been previously observed, it has been incorrectly attributed to Raman-scattering[Matsuoka2010]. Here, the scattering process has been shown to result from the non-uniform density distribution of the gas-jet where, the scattering-angle is oriented along the direction of the resulting electron density distribution.

Keywords: side, scattering, Raman scattering, gradient, phase, matching

The impact of the fast ion fluxes and thermal plasma loads on the design of the ITER fast ion loss detector

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In ITER, the fusion reactions and the use of neutral beam and ion cyclotron heating systems will generate fast ions. These can be expelled from the core region to the plasma edge by various instabilities. Fast ion loss can adversely affect confinement and plasma heating and can lead to appreciable heat load on the plasma facing components. ITER currently does not have any diagnostic for fast ion loss measurements.
Fast ion loss detector (FILD) is one of the most widely used diagnostics for measuring fast ions in the plasma edge. A fraction of the incident fast ions are transmitted into a FILD where they encounter a scintillator. The interaction of fast ions with the scintillator provides measurements of their energy and the velocity pitch, $v_{||}/v_{total}$ with the time response up to the Alfvénic frequency. This allows extracting information about the underlying loss process. FILDs are installed in all major tokamaks. The Port Plugs and Diagnostics Integration Division at ITER Organization has recently initiated an effort to develop a reciprocating FILD in ITER.

The harsh environment in ITER - a nuclear installation - places a number of requirements on the FILD design, unprecedented in tokamaks with easier access and more tolerable conditions. During the measurement, a FILD will be exposed to thermal plasma and fast ion heat loads. In its resting position, a FILD will be permanently exposed to nuclear heating (∼<10 MW/m3), gammas and plasma radiation (∼<100 kW/m^2). The avoidance of j'B force due to Halo currents during unmitigated disruptions requires retraction of a FILD into the magnetic shadow of a port within ∼10ms. The mechanical design must be also extremely reliable and safe because of no possibility of any kind of repair.

This contribution will address the impact of the fast ion fluxes and thermal plasma loads on the design of the ITER FILD. ASCOT code simulations are employed to optimize the FILD location within the diagnostic port and to estimate the fast ion flux to the FILD head inserted into the ITER far SOL, taking into account the magnetic perturbations and the ion flux attenuation by the surrounding first wall panels. The simulations show that the FILD insertion depth ∼10 cm in front of the port is needed in order to collect an appreciable fraction of fast ions: a few percent for $v_{||}/v_{total}$ » 0.1 and effectively 100% for v||/vtotal = 1. The insertion depth of 10 cm is associated with relatively modest (∼10 MW/m^2) thermal plasma loads, estimated from the full three dimensional field line tracing simulations combined with the model for the time-averaged parallel ELM heat flux densities in the ITER far SOL [1]. The impact of individual mitigated and small natural Type-I ELMs on the FILD surface temperature is addressed as well. The distribution of the fast ion heat load on the ITER first wall (concentrated around/below the outboard mid-plane) obtained from the ASCOT simulations is presented.

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Keywords: ITER, diagnostics, fast ions, thermal analysis, FILD, MHD, alpha

Data analysis tools and coding activity in support of the FTU Collective Thomson Scattering diagnostic (P-5)

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The Collective Thomson Scattering is known to be a flexible technique for investigating the ion dynamics. Recently this diagnostic turned out to be suitable also for investigating other plasma characteristics. Particular regimes are presently under study in several fusion machines, where non-thermal signals, which may be associated with a newly explained low power threshold parametric decay process [1], often appear in the CTS spectra. A second attractive application of the CTS diagnostics, strictly correlated to the study of the thermal ion distribution function, consists in measurements of the plasma composition [2].
Recent advances in the data analysis activity and in the code coupling, finalized to help the interpretation and to deepen the comprehension of the above described phenomena, are presented. A renewed software has been implemented for the analysis of the CTS spectra measured during the last experimental campaigns of FTU and for the comparison with the MHD spectrograms and the plasma signals. The software also allows one to analyze data detected simultaneously with two radiometric systems that operate in parallel in FTU since the beginning of 2016 [3]. The Thermal Collective Scattering Code [4] is able either to predict and analyze thermal ion spectra as well as to infer the main plasma compositions starting from the CTS measurements. The wave and plasma parameters at the scattering volume can be estimated with a beam tracing code as GRAY [5], allowing one to calculate the expected thermal features in the CTS spectrograms.

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Keywords: CTS, diagnostic, coding

Development PETAL diagnostics: PETAPhys project

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The PETAPhys project provides a support to the qualification phase of the PETAL laser operation, before it will become available to academic experiments. It is complementary to the Equipex project PETAL+, which delivers the major diagnostic equipment. Within the PETAPhys project, we are developing two simple and robust diagnostics permitting both to characterize the focal spot of the PETAL beam and to measure the hard X-ray spectrum at each shot.
The first diagnostic consists in optical imaging of the PETAL beam focal spot in the spectral range of the second and third harmonic radiation emitted from the target. The diagnostic system is designed by using numerical simulations with a PIC code for evaluation of the harmonic emission intensity. The design concept is tested in an experiment performed at CELIA in the 10^{16}-10^{18} W/cm^2 intensity range.
The second diagnostic is a hard X-ray dosimeter consisting in a stack of imaging plates (IP) and filters placed inside a re-entrant tube. The spectrometer is designed with numerical simulations of PETAL interaction with a typical target, which is a 2 mm thick tungsten disc. The PIC simulations were provided the number, the angular and energy distribution of electrons. Then, a Monte-Carlo code has been used to infer the characteristics of photon source escaping from target and the physical signal inferred by the IP.
The PETAPHYS diagnostics are expected to be ready for the first PETAL experimental campaign.

Keywords: PETAL, focal spot, harmonic generation, 2w imaging, 3w imaging, Particle, in, cell simulations, Monte, Carlo simulations, X, ray spectrometer, Bremsstrahlung

Upgrade of Thomson scattering system for Wendelstein 7-X

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The Wendelstein 7-X Thomson scattering system is a standard diagnostic for electron temperature and density profiles. The system is a classical Nd:YAG setup covering a full profile with two lens systems. The scattered light is guided with fiber bundles to filter polychromators. Two volumes are analyzed with one polychromator by using a delay line. The output signals are recorded with 14bit, 1GSPS digitizers. Temperatures and densities are recovered with Bayesian analysis.

In the first operational phase that took place last year one lens system covering the outboard profile half was used. Ten scattering volumes with lengths from 22mm in the center to 36mm at the edge were observed. All polychromators were equipped with five filters for measuring temperatures between 10eV and 8keV. One laser with pulse energy of up to 2J and 10Hz repetition rate was employed. The diagnostic provided data consistent with other temperature and density diagnostics and was used e.g. for confinement studies.

The system will be upgraded for the second operational phase that will start in July 2017. Six volumes will be added to the outboard side, volume lengths for this half will not be changed. The inboard side will be covered with 75 channels with lengths from 20mm in the center to 7mm at the edge, where large gradients are expected. Three additional lasers will be available, which can be used to increase the time resolution or the pulse energy. The polychromators will be upgraded with a more suitable choice of filters for different regions. In the center 6th spectral channel will be introduced for temperatures above 10keV. Further considered questions include improvement of the signal to noise ratio by introducing a polarizer and filtering out impurity lines, and calibration procedures. The upgrade will allow measurements e.g. of Shafranov shift and possible high gradient regions.

Keywords: Thomson scattering, W7, X, Wendelstein, electron temperature, electron density

The new Imaging Motional Stark Effect diagnostic at ASDEX Upgrade

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Motional Stark Effect (MSE) diagnostics are important for providing information on the safety factor in fusion plasmas. Imaging MSE (IMSE) systems utilize the Stark-split D-alpha light emitted by injected neutral particles and lead this light through a series of birefringent plates. This is imaged onto a CCD, forming an interference pattern. While conventional MSE systems filter out the π- or σ-lines of the Stark spectrum, IMSE diagnostics utilize all the lines increasing the signal to noise ratio and eliminating the need for narrow-band filters. Furthermore, IMSE is not disturbed by polarized broadband background light and provides a 2-D image of polarisation angle, significantly increasing the quality of the equilibrium reconstruction compared to 1D MSE systems.

The new ASDEX-Upgrade IMSE has a wider field of view, imaging from the outer separatrix to 10 cm on the high field side. The optics are designed for low Faraday rotation, which is monitored, together with possible drifts, using in-vessel polarized light sources. For the 2016 campaign a prototype "back-end", the lenses and crystals which create the interference pattern, was mounted to the new optical relay system. It was possible to resolve polarization changes of 0.05○ at a time resolution of 5.6 ms, enabling the study of current redistribution during sawteeth. The prototype back-end will be replaced by a fully optimized system at the start of the 2017 campaign. The new design features larger birefringent plates yielding a larger étendue, higher stability and improved calibration possibilities.

Details of the new IMSE diagnostic at ASDEX Upgrade will be presented, together with a comparison with the conventional MSE system and the benefit of the IMSE data for the reconstruction of magnetic equilibria. Furthermore, a calibration method using specially designed forward and reversed magnetic field discharges will be introduced, as well as results from discharges with modified q-profiles.

Keywords: MSE, ASDEX Upgrade, current measurement, tokamak

3D simulations of Photonis®P510/PSU streak tube

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Streak cameras are one of the fastest available instruments enabling high speed photonic phenomena to be observed by direct imaging. Streak cameras are routinely operated for experiments on laser facilities. Such opto-electronic instruments offer one-dimensional time-resolved imaging from the IR through X-rays. Fusion diagnostic community requires optical recording instruments with precise time resolution covering a dynamic range of many orders of magnitude. A key component of a streak camera is the streak tube. In order to meet requirements for fusion diagnostics, the CEA has recently embarked on the improvement of streak tubes performances. A program which partly relies on a numerical simulation approach has been initiated. First steps of this program are devoted to the PHOTONIS®P510/PSU streak tube. We address here the 3D simulations of this tube in static regime using the Tracking software package from Computer Simulation Technology®(CST).

Keywords: Streak tube, high speed photonic imaging, CST simulations

Current profile measured by the motional Stark effect polarimeter in the HL-2A tokamak

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The safety factor and current density profiles play a very important role in understanding magnetohydrodynamics and micro-instability. Motional Stark effect (MSE) is one of the most powerful tools to measure the current density. A 4-channel MSE polarimeter based on dual photo-elastic modulators (PEMs) has been developed in the HL-2A tokamak.

For each channel, 6 1-millimeter silicon fibers are applied. And off-the-shelf avalanche photodiode detectors with frequency band of 250 kHz are adapted due to its quantum efficiency up to ∼83% at 660 nm. The beam emission spectra are filtered by a monochrometer; and the filter is controlled by an absolutely calibrated rotator, which can change the tilting angle of the filter with velocity of 720 degree/s, corresponding to the wavelength change of 288 nm/s with the filter. The rapid angle change of the monochrometer enables the wavelength to be swept during the discharge. The accuracy of the MSE can be up to ±0.15° in the calibration experiments.

On HL-2A, the motional Stark effect is rather weak [1]. During the pilot experiment, the pitch angles of magnetic field are obtained for 3 spatial channels covering 10 cm along the major radius with time resolution of 5 ms. The profiles of current density and safety factor are obtained by the Current Profile Fitting (CPF) code, as shown in Figure 1. The q profile is monotonic, and the minimum q value is around 0.7. And the position of the q=1 surface consists with the sawtooth inversion radius measured by ECE.

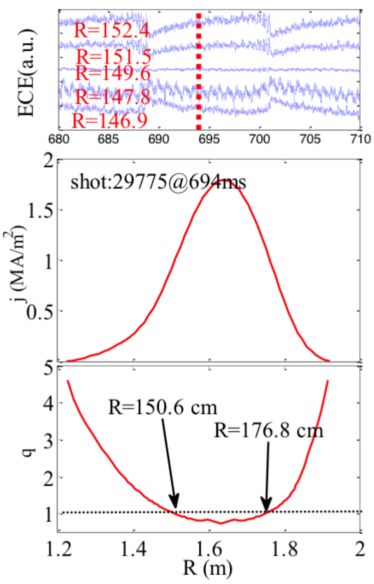

Figure 1: Sawtooth inversion measured by ECE (a);the reconstructed plasma current (b) and safety factor (c).

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Keywords: current profile, Motional Stark effect

Development of Vacuum Ultraviolet Spectroscopy System on J-TEXT

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A Vacuum Ultraviolet (VUV) spectroscopy system has been constructed on J-TEXT tokamak in order to study the transport of the light impurities including carbon and oxygen in edge region with the effect of RMP or ECRH. Its wavelength range is 30nm-300nm. As the limiter and the tiles on the vacuum wall are both made of silicon-carbide coated graphite, lines for the intrinsic impurities in J-TEXT (C, O, Si, and so on) are abundant in this range. The normal incidence monochromator with concave grating with the focal length of 1 meter is chosen for light dispersion. For the profile measurement, a 1024*1024 CCD is chosen as the detector. The size of the CCD is 13.3*13.3 mm^2 (13*13 μm^2/pixel). The time resolution reaches 6ms (Full Vertical Binning mode) and is near 40ms for 20 vertical groups' setup.The ability of spatial resolution is achieved by using a horizontally adjustable slit equipped in the monochromator. The design and preliminary results of the system will be presented at this conference.

Keywords: Vacuum Ultraviolet, Impurity, Spectroscopy

Effect of plasma position and profile on the measurement accuracy of ITER neutron activation system

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One of the main purposes of the neutron activation system (NAS) is to evaluate total neutron production rate from all over the plasma, regardless of the position or the profile of the neutron source. Therefore it is normal practice to minimize material and its density variation across the field of view between the plasma and the irradiation end. Due to the harsh radiation and thermal environment of the ITER in-vessel, however, the measurement from ITER NAS cannot avoid strong influence from in-vessel materials such as the diagnostic first wall, blanket modules, and divertor cassettes, those are located near the irradiation ends. In order to assure the reliability of the measurement in such environment, special cutouts in the diagnostic first wall were introduced near the irradiation end structures located in the port plugs. The effect of the position and profile of the neutron source in the plasma were evaluated for these irradiation locations, as well as the ones under the divertor cassettes and between blanket modules, by the Monte-Carlo neutron transport calculation. Calculation results show that measurements at the upper port location can provide highly accurate results even without a position or profile correction from other diagnostics, when the vertical plasma deviation can be well compensated with the measurements at the irradiation location under the divertor cassettes.

Keywords: ITER, neutron diagnostics, neutron activation system

2-D imaging characterization and spectral sensitivity of an X-ray GEMPIX detector on ECLIPSE laser facility

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GEMpix is an X-ray a gas detector based on a triple Gas Electron Multiplier (GEM) with a front-end electronic based on four medipix chips, with 512 x 512 squared pixels, 55 micron wide. It can work in a range of X-ray fluence of 6 orders of magnitude, arriving to the detection of a single photon. In addition medipix electronics allows working in Time over Threshold (ToT) mode: each pixel registers digital counts proportional to the total charge released in the gas and this is useful for studying x-ray emissivity of laser produced plasma, whose time scale, nanosecond or lower, is much shorter of the time resolution of the detector. GEMpix 2-D imaging properties have been studied at the Eclipse laser facility (CELIA, Bordeaux, France), with different targets, by means of Uttner masks. Spatial resolution depends on the intrinsic gain, ranging from one to tens of pixels, and Modulation Transfer Functions have been calculated in different conditions. In addition imaging capabilities have been proven by means of shadowgraphies of different plastic object placed in front of the detector. GEMpix sensitivity to the X-ray spectrum has been investigated, thanks to a mask with 4 different absorbers. We generated different X-ray spectra firing the ultrafast (40 fs) laser on various targets: Fe, Cu, Ag, W, plastic. For each one a scan in the discrimination threshold of the detector has been performed, cutting progressively the pulse amplitude spectrum generated in each pixels. These scans show a different shape each other, confirming the capability of the detector to discriminate different X-ray spectra. Imaging capabilities, high adjustable dynamic range, spectral sensitivity and immunity to Electromagnetic Pulse disturbances, at least at this level of power (1013 W) make this detector a good candidate as diagnostic for laser produced plasma, to be checked at higher power.

Keywords: GEM, GEMpix, X, ray imaging, laser plasma, X, ray spectrum, Eclipse

Measuring issues in the GEM detector system for fusion plasma imaging

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The measurement system based on GEM - Gas Electron Multiplier detector is developed for X-ray diagnostics of magnetic confinement tokamak plasmas. The multi-channel setup is designed for estimation of the energy and the position distribution of an X-ray source. The main measuring issue is the charge cluster identification by its value and position estimation. The fast and accurate mode of the serial data acquisition is applied for the dynamic plasma diagnostics. The samples of the ADC - Analog-to-Digital Converter which are triggered by the detector current are acquired independently for the measurement channels. The FPGA - Field-Programmable Gate Array based system performs the basic functions of data processing: data receiving, signals selection, charge estimation and memory operation. High flux radiation cause the problem of coinciding signals for cluster charge identification. The amplifier with shaper determines time characteristics and limits the pulses frequency. The essential assumption is that ADC overlapping signals can be reconstructed if primary GEM pulses do not coincide. The ending tail of the signal can be restored for the given electronics characteristics. The proposed algorithm can be apply iteratively for series of superimposed pulses. Separation of coincided signals was introduced and verified for simulation experiments. On line separation of overlapped signals was implemented applying the FPGA technology with relatively simple firmware procedure. Representative results for reconstruction of coinciding signals are demonstrated. Radiation source properties are presented by the histograms for selected range of position, time intervals and cluster charge values corresponding to the energy spectra.

Keywords: GEM, Pixelated detectors, X, ray detectors, Charge cluster, Plasma diagnostics

Overview of Active Beam Spectroscopy developments for ITER

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Active Beam Spectroscopy diagnostics on ITER measure spectra of light emitted due to plasma interaction with the beams of neutral hydrogen isotopes injected into the plasma. They fall in roughly 3 groups:

- Charge Exchange Recombination Spectroscopy (CXRS), analyses line emission of plasma ions that receive electrons from the neutral beam atoms. The intensity, Doppler width and Doppler shift reveal information on the plasma ion density (typically an impurity), the ion temperature and the bulk ion velocity, respectively.
- Motional Stark Effect (MSE), analyses Stark split line emission of the beam atoms itself due to collision with the background plasma. The Stark split is a result of the Lorentz electric field experienced by the beam atoms due to their motion across the magnetic field. Both the polarization of and the wavelength separation of the emission lines reveal information about the local magnetic field that provides powerful constraints to the plasma equilibrium reconstruction.
- Beam Emission Spectroscopy fluctuations (BES), provides a fast (several 100 kHz bandwidth) measurement of the (filtered) intensity of the above mentioned MSE emission. The intensity fluctuations are proportional to electron density fluctuations due to turbulence and MHD modes.

On ITER, active beam spectroscopy is faced with several challenges that are less present in current day devices: dominating background emission, partly due to reflection on the metallic walls and potentially polarized, low signal due to strong neutral beam attenuation, deposition of coatings on first mirrors, compliance with nuclear regulations and remote handling, limited access for in-vessel calibration et cetera. Presented in this contribution are an overview of the main challenges and the current status in research, development and design of the ITER active beam spectroscopy systems.

The views and opinions expressed herein do not necessarily reflect those of the ITER Organization.

Keywords: ITER, Fusion, Plasma, Charge Exchange Recombination Spectroscopy, CXRS, Motional Stark Effect, MSE, Beam Emission Spectroscopy, BES, Active Beam Spectroscopy

Measurements of Canonical Helicity within Two Interacting Flux Ropes

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Magnetic helicity has become a useful tool in the exploration of astrophysical plasmas. Its conservation in the magneto hydrodynamic limit (and even some fluid approaches) constrains the global behavior of large plasma structures. One such astrophysical structure is a magnetic flux rope: a rope-like, current-carrying plasma embedded in an external magnetic field. Bundles of these ropes are commonly observed extending from the solar surface, forming an arched loop, and can be found in the near-earth environment. In this well-diagnosed experiment (three-dimensional measurements of ne, Te, Vp, B, J, E, v), two magnetic flux ropes were generated in the Large Plasma Device at UCLA. These ropes were driven kink-unstable, commencing complex motion. As they interact, helicity conservation is examined in regions of reconnection. The changes in helicity can be visualized as 1) the transport of helicity and 2) the dissipation of the helicity. As the ropes move and the topology of the field lines diverge, a quasi-separatrix layer (QSL) is formed. The initiation of the QSL corresponds to an absolute peak in magnetic helicity within the entire experimental volume; and, as the QSL forms, magnetic helicity is dissipated within this region. At the same time, while helicity is being dissipated inside the QSL, an influx of canonical helicity moves into the region such that temporal derivative of magnetic helicity is zero.

Keywords: Magnetic Reconnection, Flux Rope, Magnetic Helicity, Vorticity, Canonical Helicity, LAPD, Experiment

Development and Commissioning of the Hybrid Pulse-Burst Laser System for NSTX-U

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Fusion performance in tokamaks has been shown to be dictated by the edge pedestal. Understanding and controlling the dynamics of the edge pedestal, which is a major component of the NSTX-U research program, are important for the operation of fusion devices. To achieve this goal, we are developing a pulse burst laser system (PBLS). This system comprises optical elements from a Quantel flashlamp-pumped Nd:YAG laser coupled with a specially engineered power supply system designed and fabricated at Physical Science Lab (PSL) at the University of Wisconsin. The system builds on previous development done on MST [1]. The PBLS base repetition rate of 30 Hz has been selected in order to mesh with the two existing lasers, resulting in a 90-Hz combined base operation. The base mode can be interrupted and bursting initiated on demand. Up to 50 pulses can be delivered in a fast burst (FB) at 10 kHz over 5 ms, or in a slow burst (SB) at 1 kHz over 50 ms. The laser optical chain included a birefringence compensated oscillator followed by two amplifiers. A 12-mm diameter beam with a 0.5 mrad divergence is expected with pulse energy of 1.5 J at 1064 nm and duration of 10 ns. In this paper, we will describe in detailed the system and provide a status update on the installation and commissioning on NSTX-U. This work is supported by the DoE Early Career Research Program.

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Keywords: Thomson Scattering, Laser system

Monochromatic high resolution X-ray imaging of plasma-laser produced using Fresnel zone plate

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Monochromatic X-ray imaging at micron scale is a convenient tool for studying the dense plasma produced by laser facilities. We use a microscope made of a gold transmission Fresnel Phase Zone plate (FPZP) which has high spatial resolution capability (1-5 μm) and high efficiency [1]. We explore different zone plates optimized at different photon energies. We present experimental imaging studies of plasma X-ray sources with FPZP's. We show the interest to combine FPZP with a multilayer mirror (ML) which selects a narrow bandwidth. This device allows to choose the imaging wavelength by modifying the focal length and the angle of ML.

We compare the performances of two gold FPZPs with and without central beam stopper. These lenses have a focal length of 250 mm for 1.835 keV. A complete characterization of ML and FPZP were made at the synchrotron radiation facilities: Physikalisch Technische Bundesanstalt (PTB) laboratory [2] and SOLEIL metrology beamline [3]. Spatial resolution close to the theoretical value of the FPZP is achieved. We explain the difference between experimental results obtained with monochromatic and quasi-chromatic X-ray plasma sources. References

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Keywords: Fresnel zone plate, X, ray imaging, monochromatic

Multiple-image Kirkpatrick-Baez microscopes for hydrodynamic experiments on SGIILaser facility

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High spatial resolution time-resolved multiple-image Kirkpatrick–Baez(KB) microscopes were developed for the ICF related hydrodynamic experiments on ShenguangII(SGII) laser facility. A framed, 4-image KB x-ray microscope, with 3 selectable spectral windows (1-2keV, 4.75keV, 8keV) based on multilayer mirror elements, has been built and used in laser ablative hydrodynamic-stability experiments. And, another framed, 8-image KB x-ray microscope has been developed and used in laser-imploded spheric shell diagnostics. The details of Rayleigh-Taylor instability pattern and the hot spot region can be studied with these high spatial resolution imaging systems.

Keywords: Kirkpatrick–Baez, x, ray, Rayleigh, Taylor instability, ICF

Non-equilibrium solid-to-plasma transition dynamics using XANES diagnostic

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The advent of femtosecond lasers has shed new light on non-equilibrium high energy density physics. The ultrafast energy absorption by electrons and the finite rate of their energy transfer to the lattice creates non-equilibrium states of matter, triggering a new class of non-thermal processes from the ambient solid up to extreme conditions of temperature and pressure, referred as the warm dense matter regime. The dynamical interplay between electron and atomic structures is the key issue that drives the ultrafast phase transitions dynamics. Bond weakening or bond hardening are predicted, but strongly depends on the material considered. Many studies have been conducted but this physics is still poorly understood. The experimental tools used up-to-now have provided an incomplete insight. Pure optical techniques measure only indirectly atomic motion through changes in the dielectric function whereas x-ray or electron diffraction only probes the average long-range order. This review is dedicated to recent developments in time-resolved x-ray absorption near-edge spectroscopy, which is expected to give a more complete picture by probing simultaneously the modifications of the near-continuum electron and local atomic structures. Results are reported for three different types of metals (simple, transition and noble metals) in which a confrontation has been carried out between measurements and ab initio simulations.

Keywords: Warm dense matter, Non, equilibrium physics, X, ray Absorption Diagnostic

Detector concept and calibration for the charged particle detectors of the PETAL laser and first test of the SEPAGE diagnostic

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The LMJ laser beams produce nanosecond pulses to heat targets at extremely high temperature and generate strong shocks. PETAL is a picosecond - sub-picosecond pulse laser, which will be used either directly on the primary LMJ target or to generate secondary sources of particles such as high-energy photons, electrons, protons or ions. These particles can be used as probes of the LMJ primary targets or to study the mechanisms of laser acceleration of particles at high power and energy.
The PETAL+ project is aiming at designing and building the first diagnostics to characterize the source of particles. This contribution will present one of them, a diagnostic comprising two Thomson parabolas and a proton radiography for the primary LMJ targets (SEPAGE). The diagnostics for these particles have been designed to cover the detection range from 0.1 to 100 - 200 MeV (electron & proton energy), with the scaling factor Z2/A for ions of mass number A and charge Z.

To prepare the experimental program to be performed with SEPAGE, we have performed experiments to study passive detectors based on Imaging Plates with or without additional layers of high-Z materials in front or behind, with electrons between 5 & 140 MeV and protons from 1 to 200 MeV. Our data have been analysed with the help of a dedicated GEANT4 simulation for the interaction of the particles with these detectors.

In this presentation we will give the final results of this study of passive detectors. Along with those, results of a first test of a demonstrator of one of Thomson parabolas to be installed in the PETAL+/SEPAGE diagnostic will be presented. A possible design of the detectors combining Imaging Plates and high-Z metal shielding will be proposed to optimize the signal to background ratio.

Keywords: Imaging Plates, Thomson parabola, Charged particle diagnostics

Proton probing of coil targets driven by ns or ps laser pulses

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Fast proton probing of laser-driven ps-timescale electric- and magnetic-fields combined with the imaging by a stack of Radio-Chromic Films (RCF) gave first imprints of field dynamics in coil-targets driven by ns and also ps laser pulses. Coil-targets comprise a mm-size coil-part linked to a driver-laser interaction zone. In a single shot proton deflectometry based on Targent Normal Sheath Acceleration (TNSA) can resolve spatially the whole coil-part during an adjustable window of some hundred ps according to the proton time of flight and generation time. Our experiments regarding the influence of coil materials, laser parameters and the coil's geometry aim the use of laser-driven fields as well characterized tool.

Experiments at LULI2000 [Santos et al. NJP 17, 083051 (2015)] dealt with ns-pulses driving quasi-static magnetic fields in the range of kT, over nanosecond time-scale and sub-mm spatial-scale. The open geometry of this novel platform is adapted for the magnetization of secondary samples, paving the ground for many applications in magnetized high-energy-density matter.

An experiment at PHELIX aimed at imposing electromagnetic discharges through coil targets under intense ps laser interaction. The discharges were used to focus up to 15 MeV TNSA protons propagating along the coil's symmetry axis. Measured discharges are of the order of 10 ps. Therefore the platform works as an energy-selection system as the very fast discharge affects only a small energy range of the whole TNSA proton energy spectrum. Change of the proton's phase space is simply controlled by the delay between two laser pulses – driving respectively the coil-target discharge and the TNSA foil – and the time-of-flight between the foil and the coil.
With regard to proton-deflectometry, advantages – like the determination of absolute proton numbers on RCF – as well as disadvantages – like the integrative character of the measurement – will be discussed thoroughly.

Keywords: proton, deflectometry, probing, ultra, fast, dynamic, magnetic, electric, fiels, imaging, RCF, coil, coil, target, TNSA, quasi, static, intense, laser, interaction, discharge, high, energy, density, ns, ps, pulses, pulse

Investigation of linearity of the ITER outer-vessel steady-state magnetic field sensors at high temperature

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Three vacuum vessel sectors in ITER will be instrumented by the outer-vessel steady-state magnetic field sensors. Each sensor unit features a pair of metallic Hall sensors with a sensing layer made of bismuth. A characteristic feature of the bismuth Hall sensors is an approximately inversely quadratic dependence of the sensor sensitivity on temperature and non-linear dependence of the sensitivity on the magnetic field. The simultaneous influence of temperature (RT -180°C) and magnetic field on sensor sensitivity was tested at first at low magnetic field up to 0.7 T. Conclusion concerning the sensors calibration procedure will be presented.

Keywords: Hall sensor, bismuth, magnetic field, calibration

Visible spectro-tomography: from low temperature laboratory plasmas to the WEST tokamak

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With regard to proton-deflectometry, advantages – like the determination of absolute proton numbers on RCF – as well as disadvantages – like the integrative character of the measurement – will be discussed thoroughly.

Keywords: proton, deflectometry, probing, ultra, fast, dynamic, magnetic, electric, fiels, imaging, RCF, coil, coil, target, TNSA, quasi, static, intense, laser, interaction, discharge, high, energy, density, ns, ps, pulses, pulse

Conceptual design of a scintillator based Imaging Heavy Ion Beam Probe for the ASDEX Upgrade tokamak

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A conceptual design of a new diagnostic for the simultaneous space and time resolved measurement of plasma density, potential and poloidal magnetic field fluctuations at ASDEX Upgrade is proposed. The diagnostic combines the detection techniques of standard heavy ion beam probes (HIBP) [1] and scintillator based fast ion loss detectors (FILD) [2], making use of an atomic beam to probe plasma parameters with high spatio-temporal resolution. This new approach takes advantage of using a neutral probe beam and a scintillator plate as detection system. The combination of these two techniques makes the diagnostic more compact than standard HIBP facilitating its integration in the machine. Simulations using an orbit following code have been carried out to investigate the viability of the proposed detection method based on the displacement of the beam strike-line on the scintillator plate. Relative plasma potential fluctuations from 10% to 100% in the potential well induce localized displacements in the strike line in the range of 0.1-1.0 mm, while poloidal magnetic field fluctuations such as those arising from edge currents produce displacements in the order of mm. The use of a scintillator screen provides virtually infinite spatial resolution together with a temporal resolution up to the MHz range, needed for the identification of internal fluctuations.

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Keywords: Heavy Ion Beam Probe, Scintillator

D+D fusion reactions in high intensity laser-plasma interactions

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We recently studied D+D fusion reactions in CELIA/ECLIPSE laser facility. These reactions were triggered by focusing the ECLIPSE laser (up to 100 mJ on target, pulse duration of 40 fs and focal spot of 10 μm FWHM) on a solid C_2D_4 target. By detecting the 2.5 MeV neutrons, produced in the D+D fusion reaction, using C_6D_6 sintillators in a time-of-flight experimental set-up, we measured a rate of a few hundred fusions per shot. At the same time, we detected also energetic ions (up to a few 100 keV) using time-of-flight diamond detectors. The experimental set-up will be presented and the results discussed, comparing them with dedicated simulations.

Keywords: Inertial Confinement Fusion, Proton Laser, plasma acceleration

Development and calibration of Phase Contrast Imaging on HL-2A Tokamak

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In this article we present the development of a phase contrast imaging (PCI) system on HL-2A tokamak, together with the intensity calibration of the diagnostic. This system is developed to diagnose tangentially integrated density fluctuations by measuring the phase shift of a CO2 laser beam with a wavelength of 10.6 μm when the laser beam passes through plasma. It can diagnose plasma density fluctuation with the maximum wavenumber of 15 cm^{-1}, a wavenumber resolution of 2 cm^{-1} and a temporal resolution of 0.2 μs. Phase scintillation effect is carefully discussed to calibrate high wavenumber response and audio- frequency wave is used to calibrate the signal intensity. Diffraction effect on guassian field by the diagnostic window is also discussed to explain the detected signal.

Keywords: PCI, phase shift, density fluctuations

Runaway Electron Imaging Spectrometry (REIS) at the Frascati Tokamak Upgrade (FTU)

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A portable Runaway Electron (RE) Imaging and Spectroscopy System (REIS) has been developed at the FTU for the measurement of synchrotron radiation spectra from runaway electrons in tokamaks.
The camera is provided with a wide-angle optical system to collect RE synchrotron radiation from different portions of the plasma, two diametrically opposite poloidal cross sections corresponding respectively to the RE backward and forward emission. Part of the collected radiation is optically transmitted to two visible (Ocean Optics HR2000+) and one infrared (Ocean Optics NirQuest 256 High Resolution Near-Infrared) spectrometers through an incoherent bundle of fibres, with a spectral range that spans from 300 nm to 2000 nm.
The Toshiba CCD color micro head camera captures the RE synchrotron radiation with a rate of 35 frames per second. The entire system is supervised and managed through a dedicated LabVIEW program that synchronizes, through an external time trigger, and acquires the data of the three spectrometers every 25ms (configurable down to 10ms). The paper gives an overview of REIS and its acquisition system and presents measurements performed in FTU runaway discharges.

Keywords: Runaway Electron, Imaging, Spectrometry, REIS, Frascati Tokamak Upgrade, FTU

Rogowski Coils - an old technology delivers new insights into laser driven plasma acceleration

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Since Rogowski coils have been used to diagnose high energetic electron beams in the middle of the last century, such measurements were spatially restricted to a single point on the beam axis.

In order to introduce spatially resolved measurements of the plasma density in the axial and radial direction of a plasma accelerated by a laser, a novel concept is proposed in this poster. We suggest the usage of nested arrays of Rogowski coils to measure the current contributions parallel and normal to the laser beam with a spatial resolution in the mm range. The principle of the experimental setup will be shown in 3-D CAD models. Additionally, first numerical simulations of the field gradients, which are to be expected within the coils, are presented. The electron density profile within the plasma channel was obtained by particle-in-cell (PIC) code simulations. From these results the currents as well as the field gradients were calculated. The inner coils are tilted 90 degrees with respect to the capillary axis while the outer ones will be coaxial to the plasma channel. This plasma diagnostics method is simple and robust and it is a passive measurement technique, which does not disturb the plasma itself. As such coils rely on a Biot-Savart inductivity, they allow to distinguish the contributions of the parallel and perpendicular currents. Rogowski coils do not have a ferromagnetic core. Hence, non-linear effects resulting from such a core are to be neglected, which increases the reliability of the obtained data. They also allow the diagnosis of transient signals that carry high currents (up to several hundred kA).

Keywords: Magnetics, Plasma diagnostics, Laser acceleration

Optical Analyzer Development for Laser MegaJoules

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The Laser Mega Joule (LMJ) facility is using several diagnostics for analyzing and imaging the target in the scope of VUVs, X-Rays, Gammas and Neutrons. Most of these diagnostics are using Diagnostics Insertion Systems (SID) designed and manufactured by CNIM and Bertin Technologies (BT). Time resolution of the target emissions leads to use fast electrical devices (sensors and fast oscilloscopes) as well as ultra-fast cameras.
Bertin Technologies is responsible to integrate the nine first plasma diagnostic analyzers. They comprised 1-D High Voltage streak cameras and 2-D gated detectors (MCP), coupled to CCD read-out systems and embedded control electronic modules designed by BT. They are packaged inside an hermetically sealed chamber surrounded by a W shielding, operating in a harsh environment induced by fluxes of neutrons, X-rays and gammas. The sensors needs generating high voltages of several kV presenting a stability and an accuracy of 0,01% and fast high voltage ramps (2ns) with very low jitter (6ps). Role of BT Based on the CEA conceptual design, Bertin Technologies is involved in the whole life cycle: preliminary final design, manufacturing, qualification, installation

Keywords: Diagnostics, LMJ, Optics, X rays, Diagnostics Plasma, Electronics, Neutrons, Gamma

Characteristics of a High Enthalpy Plasma Flow for Testing Plasma Facing Materials

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A high enthalpy plasma facility capable of producing 400 kW of power was constructed at Chonbuk National University (CBNU) in Korea. Thermal plasma with high enthalpy produced at this facility can provide a suitable environment for assessing PFMs for use in fusion reactors. Enhanced segmented arc plasma torches are used as the plasma sources, allowing it to produce enthalpies greater than 10 MJ/kg. Diagnostic systems include intrusive diagnostics such as an enthalpy probe, a heat flux probe, and a wedge probe and non-intrusive diagnostics such as a pyrometer, a fast camera, an optical emission spectroscopy, and a laser Thomson scattering. We investigated the characteristics of the plasma flow with gas flow rates from 10 to 16 g/sec, input currents from 140 to 350 A, and chamber pressure set to 40 mbar. It is shown that this flow produces particle flux greater than 1024/(m2sec) and heat flux greater than 10 MW/m2, that are relevant for testing PFM under fusion reactor conditions.

Keywords: High enthalpy plasma, Plasma facing material, Fusion reactor

Diagnostic for ultra-intense laser plasma experiments based on frequency resolved optical gating

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Laser pulses of the highest intensities interact with sub-micrometer targets in conditions where hole boring and relativistic effects play a predominant role. In particular, these effects imprint a strong signature of the light being either transmitted or reflected by such targets. To fully understand the dynamics of the interaction, it is desirable to spectrally and temporally resolve the resulting pulses. In this contribution, we report on the development of a time-resolved diagnostic setup for high intensity laser plasma experiments at the petawatt-class laser facility PHELIX. The diagnostics are integrated in the target area to measure both back-reflected and transmitted parts of the laser pulse. For this purpose, we use two specifically designed single-shot second-harmonic frequency-resolved optical gating (SHG-FROG) systems. The requirements for the diagnostics are set by the conditions of typical experiments, where the spectral bandwidth of back-reflected pulses is broadened to 30 nm and above. The FROG achieves a spectral resolution in the sub-nanometer range and the temporal window of 10 ps is sufficient to characterize pulse durations up to 2 ps (FWHM), with a temporal resolution of 20-50 fs, depending on the system. The setup for characterizing the back-reflected pulses is permanently installed at the PHELIX target area, whereas the diagnostic for transmitted pulses can be optionally set up. Both FROGs have been characterized off-line prior to installation and commissioning. They yield a full characterization in phase and amplitude of the light pulses and therefore can be used to study effects like laser-hole boring or relativistic self phase modulation, which are important features of laser-driven particle acceleration experiments.

Keywords: FROG, frequency resolved optical gating, laser plasma

Coherence Imaging of Flows in the ITER Tokamak Boundary

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Spectro-polarimetric "coherence imaging" (CI) systems have opened new and better ways to study the spatial and dynamical behaviour of plasma properties including electric current distribution and the velocity distribution function of radiating species from the plasma edge to the core.
Spatial-heterodyne polarization-interferometers can be used to analyse the spectral or polarimetric properties of relatively narrow-band spectral scenes (transmitted by an optical interference pre-filter) such as Doppler broadened emission lines or polarized multiplets. The physical parameters determining the emission spectral properties are recovered from the interferometric phase and amplitude images at one or more appropriately chosen optical path length delays.

An optical coherence imaging system is presently being designed for impurity transport and physics studies on ITER. The wide variation in magnetic field strength and pitch angle (assumed known) across the field of view generates additional Zeeman-polarization-weighting information that can improve the reliability of tomographic reconstructions and offer some discrimination against bright reflection contamination.

We describe a Stokes-Doppler coherence-imaging system to map the full Stokes vector of Zeeman-split impurity lines in the ITER boundary and divertor. Polarization filtering by a front-end polarimeter modifies the spectrum received by the interferometer. For appropriate choice of the interferometric delay (comparable to the optical coherence length of the multiplet) these changes are registered, along with the Doppler information, as modulations in the interferometric fringe contrast and phase.

Because of its much shorter coherence length, the interferometer is insensitive to polarized broadband radiation falling within the pre-filter optical passband. Moreover, because light that is diffusely scattered from rough surfaces such as divertor tiles becomes depolarized, coherence imaging of the polarized fraction only offers the prospect of suppressing this contaminating component and providing additional information for the Doppler tomography of plasma edge and divertor flows.

Keywords: Coherence imaging, polarization spectroscopy, ITER diagnostics

Track-discrimination technique in CR39 detectors for low-yield reaction experiments

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There is a great interest in the study of p-11B aneutronic nuclear fusion reactions, both for energy production and for determination of fusion cross sections at low energies [1-5]. Because of the small cross sections at these energies the number of expected reactions is low.
In this context we performed experiments at CELIA in which energetic protons, accelerated by the laser ECLIPSE, were directed toward a solid Boron target. CR39 SSNTD were used to detect the alpha particles produced. Because of the low expected yield, it is difficult to discriminate the tracks due to true fusion products from those due to natural background in the CR39.

On this purpose we developed a methodology of particle recognition according to their direction with respect to the detector normal, able to determine the position of their source. We applied this to the specific experiment geometry, so to select from all the tracks those due to particles coming from the region of interaction between accelerated protons and solid boron target.

This technique can be of great help on the analysis of SSNTD in experiments with low yield reactions.

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014–2018 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

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Keywords: CR39, particle discrimination, low yield reaction, p, 11B, aneutronic

Plasma radiation measurement in gas impurity injection experiment in KSTAR using infrared imaging video bolometer (IRVB)

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Accurate measurement of plasma radiation is important for particle and energy transport study in fusion plasmas. With a wide tangential field of view and flat sensitivity, infrared imaging video bolometers (IRVB) have been used for radiation power measurement in several fusion devices. An IRVB is equipped with a metal foil that absorbs plasma radiation and the IR radiation emitted from the foil is measured by an IR CCD camera. Two-dimensional (2-D) radiation profiles can be obtained by solving the heat diffusion equation of the foil. However, the raw data of IRVB is the sum of local radiation power density along the line of sight. Therefore, tomographic reconstruction for eliminating line-integration effect is necessary to obtain accurate 2-D cross-sectional radiation profiles. In this study, tangential reconstruction algorithm for KSTAR IRVB was developed using the Phillips-Tikhonov (P-T) method. Reconstruction tests with various synthetic images (phantom) were carried out for validation of the tangential reconstruction. The test results are in good agreement with the original images including typical D-shaped ELMy KSTAR plasmas. In 2016 KSTAR campaign, impurity transport experiments with injected argon and krypton gases were carried out. Radiation increment by impurity injection was successfully measured by the IRVB. Using tangential reconstruction, time evolution of 2-D radiation profiles during impurity injection was analyzed. Total radiation power calculation from the reconstructed images shows that significant amount of plasma energy is dissipated by radiation. In addition, argon transport experiment during edge localized mode (ELM) mitigation was analyzed. The behavior of argon radiation profiles with and without ELM was studied using the IRVB tomography.

Keywords: tokamak, radiation, bolometer, tomography, KSTAR

Evaluation of the DD/DT neutrons ration by the use of neutron flux monitor measurement

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Precise measurement of fusion power and total neutron yield in fusion plasma depends on accurate measurements of the number of neutrons being produced from both DD and DT reactions. In case of pure DD plasma and/or trace tritium fusion experiments the uncertainty of fusion power measurement can significantly rise due to different sensitivities of neutron flux monitor to 2.5 and 14 MeV neutrons. Direct independent DD and DT neutron flux measurements can be realized using neutron spectrometry or neutron activation system. Both methods are based on the fact that neutron detectors have different response function for DD and DT neutrons. Generally neutron spectrometer has pure time resolution while neutron activation systems are usually used without temporal resolution at all. Typical time resolution of neutron flux monitor measurements on the present fusion machines is in the range 0.1÷5.0 ms. Neutron flux monitor which consist of two neutron detectors with different sensitivities and response functions could provide rapid information about DD/DT neutrons ratio. The use of combination of U-235 and U-238 fission chambers has been studied for the proposed method. Experiments were performed with DD and DT neutron generators which are able operate simultaneously. The range of neutrons ratio and expected uncertainty was investigated. Possible application for ITER neutron diagnostic is discussed and requirements for implementation are evaluated.

Keywords: DD DT neutrons, diagnostic, neutron flux monitor

High energy density generation by laser irradiation of micro-pillar arrays

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Nano- and micro-structured targets have recently emerged as promising techniques for increasing the conversion efficiency of laser energy into hot electrons.
We report on high-resolution x-ray spectroscopy of laser irradiated micro-pillar arrays. We measured evidences of the generation of high energy density conditions in the micro-pillar arrays.
State-of-the-art particle-in-cell simulations reveal that this remarkable result stems from the greatly increased absorption of the laser pulse into energetic electrons. The micro-pillars indeed behave as a near-solid hollow material, in the interstices of which the laser is able to penetrate to large depths. The resulting specific geometry of the laser-pillar interaction leads to an efficient, direct electric-field acceleration of the electrons (instead of the ponderomotive acceleration that usually prevails in the laser-foil interaction). The pillar array then rapidly fills up with a dense cloud of energetic electrons, which subsequently volumetrically heat the micro-pillar array before it has time to hydrodynamically expand.

Keywords: micro, pillar, micro, wire, laser, x, ray, spectroscopy, HED

Turbulence measurements in the Scrape-Off-Layer of Wendelstein 7-X

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Keywords: micro, pillar, micro, wire, laser, x, ray, spectroscopy, HED

Laboratory-based validation of the baseline sensors of the ITER DRGA

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The ITER Diagnostic Residual Gas Analyzer (DRGA) comprises a set of radiation-resistant total and partial pressure sensors, a sampling pipe robust enough to meet containment requirements for an ITER primary-vacuum extension, yet compatible with a ∼1s response time requirement [1], and electronics sufficiently separated from the sensors to comply with ionizing radiation (n, g) exposure limits. A series of laboratory-based studies were carried out to validate performance of the baseline set of sensors. These demonstrated that the Penning-optical gas analyzer (Penning-OGA), part of the sensor suite, will detect He concentration (in D2) down to 0.5 mol%, (the concentration of fusion-produced He expected in ITER's D-T phase). Concurrently, the studies validated the operation of the Penning-OGA while attached to an inter-stage port (i.e., between rotor stages) of the differentially-pumped, sampling chamber's turbo-molecular pump, a unique (to ITER) implementation. This allows the OGA's Penning-type plasma light-source to operate at pressures above the DRGA sampling chamber, improving light emission, while maintaining the DRGA's quadrupole mass spectrometers (QMS) at their lower operational pressure. It was further demonstrated, using H2 as a proxy for T2, that H2 concentration in D2 could be detected down to the 1 mol% level, also sufficient for ITER D-T. The sensitivity of the present, baseline QMS model to low magnetic fields (∼<50-Gauss, the design value for the sensor's primary, soft-iron shield for a ∼1-2kG tokamak fringing field) was explored. Although such low fields do not prevent QMS operation, they impact the accuracy of the measurement. For the present, baseline QMS, the impact of such low fields on the measured mass spectra was consistent with the literature and correctable using high permeability metal foils as a secondary shield. Unexpected, a recently-commercialized ion trap-based mass spectrometer, also in the baseline sensor set, was more sensitive to low fields than the QMS.

Keywords: ITER, Fusion energy, Residual gas analysis, Plasma diagnostic, Penning discharge optical spectroscopy, helium exhaust, isotopic ratios

Improvement of the Dispersion Interferometer at the Stellarator Wendelstein 7-X

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A single channel dispersion interferometer (DI) was operated successfully at the stellarator Wendelstein 7-X (W7-X) for electron density measurements during the first operation campaign (OP1.1) in 2016.

The interferometer is based on a 20W CO2 laser. Its second harmonic is generated by a AgGaSe2 frequency doubling crystal. Both beams pass the plasma vessel twice being reflected by a corner cube reflector (CCR). A separate reference path is not required. After doubling the frequency of the residual 10.6 ?m beam by a second AgGaSe2 crystal, the phase shift of the 5.3 μm signals is detected. The phase measurement uses a heterodyne modulation scheme applying a photoelastic ZnSe modulator (PEM) at a modulation frequency of 50 kHz which also determines the temporal resolution. The interference signals are evaluated by means of a Field Programmable Gate Array (FPGA) which provides data in real time.

The interferometer is dedicated for density control of W7-X in the next experimental campaigns and also serves as protection interlock for the heating systems. A particular change is the use of the interferometer in 30 min. discharges. Therefore improvements are implemented to enhance the long term stability of the phase signal and to improve the FPGA data evaluation routine to allow for a larger dynamical range of the density signal. Also the time resolution - during OP1.1 restricted to 1 ms - will be improved.

Long term drifts resulting from the long path-length and thermal movements of the components will be compensated by a feedback controlled laser beam steering system. Additional water cooling is applied to components of the optical set-up. Especially the temperature of the frequency doubling crystals must be kept constant to provide a constant initial phase of the interferometer signal. A wedged ZnSe plate on a motorized stage is included for phase compensation.

Keywords: Interferometer, Electron Density, Stellarator

Experimental development of isoelectronic line ratios in soft X-ray absorption spectra as a temperature diagnostic on Sandia's Z machine

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Iso-electronic lines (different element, same charge state) provide an intriguing complement to standard iso-element line ratios (same element, different charge state) for diagnosing temperatures of high-energy-density plasmas. The principle advantage is that ions of the same charge state will have a similar response to electromagnetic fields, potentially reducing measurement error as compared to the iso-element case. To date, iso-electronic line ratios have been primarily examined in emission. We examine the feasibility of this technique as a diagnostic in absorption by experimentally measuring transmission spectra through a 0.4 μm Mg-NaF foil, tamped with parylene (CH), on the Z facility at Sandia. A dynamic hohlraum target was used to simultaneously heat and backlight the foil, with measurements taken in the 7-16 Å range. The foil was found to be at a temperature of 63 $\pm$4 eV from isoelectronic line ratios and 58 $\pm$ 6 eV using the isoelement line ratios.

Keywords: radiation, spectroscopy, pulsed, power, x, ray

Accuracy of amplitude and fringe contrast retrieval in case of non-homogeneous probing beam intensity distribution using complex interferometry

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Classical interferometry became widely used method of active optical diagnostics. Its more advanced version, allowing reconstruction of three sets of data from just one complex interferogram was developed in the past and became known as complex interferometry. Along with the phase shift, which can be retrieved using classical interferometry, also the amplitude modifications of the probing beam as well as the contrast of the interference fringes can be retrieved using the complex interferometry approach.

In order to compensate for errors in the reconstruction due to imperfections in the diagnostic beam intensity structure as well as a non-ideal optical setup of the interferometer itself (including the quality of its optical components), a reference interferogram can be used. This method for analysis of interferograms has been successfully implemented, verified and used in analysis of experimental data.

In majority of interferometer setups (especially in the case of the ones employing the wavefront division) the probe and the reference part of the diagnostic beam would feature different intensity distributions over their respective cross sections. This introduces additional error into the reconstruction of the amplitude and the fringe contrast, which cannot be resolved using the reference interferogram only. Assuming a sufficient stability of the whole diagnostic system two additional separately recorded images of the intensity distribution of the probe and the reference part of the diagnostic beam can be put to a good use in removing the detrimental influence of the non-ideal quality of the diagnostic beam on the amplitude and the fringe contrast reconstruction.

In this poster, efficiency of this approach is verified using computer generated complex interferograms and its three counterparts containing arbitrary artificially introduced intensity variations in the probe and the reference part of the diagnostic beam. These sets of data are subsequently analyzed and the errors of the reconstruction are evaluated.

Keywords: plasma density, complex interferometry

Design of geometric phase measurement in EAST Tokamak

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The aim of this report is to propose the optimum scheme for geometric phase measurement in EAST Tokamak. On the one hand, the experimental observation of geometric phase in plasma systems is an essential verification of the geometric phase theory by a new experimental technique. On the other hand, the measurement of geometric phase confirms geometric effect as a new system error in the existing diagnostics. The geometric phase in Faraday rotation angle for linearly polarized electromagnetic waves propagating in non-uniform magnetized plasmas is a good candidate for the first identification of geometric phase in plasma. [1]

In this report, the theoretical values of geometric phase for the probe beams of EAST Polarimeter-Interferometer (POINT) system are calculated by path integration in parameter space. Several schemes are proposed for the measurement of the geometric phase in POINT system by amplifying the geometric phase and enhancing the diagnostic resolution. To reach the conditions of the designed scheme for geometric phase measurement, the feasibility of replacing individual retro reflectors (RRs) with retro reflector array (RRA) in POINT system is verified experimentally. Corresponding results are beneficial for geometric phase measurement in EAST Tokamak. [2]

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Keywords: geometric phase measurement, polarimeter interferometer system, EAST Tokamak

Study of the HD-V2 radiochromic films response to protons

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Radiochromic films (RCF) are regularly used in plasma physics experiments, especially to detect protons. These films are composed of a radiosensitive layer deposited on a polyester base. Under irradiation, this active layer darkens, and the optic density of the film is related to the deposited energy. As HD-V2 films do not have a protective layer in front of the active one, they are well adapted to low energy protons. The 4MV Van de Graaff accelerator of CEA-DIF was used to study the response of HD-V2 films to protons. RCF were irradiated with mono-energetic protons between about 0.5 MeV and 3.3 MeV. The relation between optic density and proton fluence was then determined for each incident energy. The experimental setup and results will be presented. The possibility of determining a proton spectrum with a RCF stack will then be discussed. This work takes place within the EQUIPEX PETAL+ funded through the PIA by the french National Agency for Research (ANR) coordinated by the University of Bordeaux.

Keywords: radiochromic film, protons

Development of an inverse Compton short pulse hard X-Ray source for the characterization of plasma diagnostics in the 10-90 keV range on the ELSA accelerator

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An Inverse Compton Source (ICS) is under development on the ELSA Linac of CEA to produce 30ps X-ray pulses in the 10-90 keV range. The goal is to provide photons for the characterization of diagnostics for the Laser MegaJoule. The advantages of such a source lie in its tunability, its flexibility in implementing various characterization experiments and its accessibility. An upgrade of the ELSA accelerator was done in 2016. Electron energy could be raised from 19 to 34 MeV, and first Compton X-ray photons at 33 keV were observed with 30 MeV electrons. In the course of this upgrade, a new optical system was developed to multiply the number of visible photons involved in the inverse Compton scattering process, allowing a multiplication of X photons by a factor of 8. Results of the first experimental tests of this system, along with first images of the 33 keV X-ray photons beam, are presented.

Keywords: Compton, X, ray source, electrons, photons

Diffusion and screening effects on atomic collisions in Lorentzian turbulent plasmas

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The influence of diffusion and plasma screening on the electron-ion collision is investigated in Lorentzian turbulent plasmas. The second-order eikonal analysis and the effective interaction potential including the Lorentzian far-field term are employed to obtain the eikonal scattering phase shift and the eikonal collision cross section as functions of the diffusion coefficient, impact parameter, collision energy, Debye length and spectral index of the astrophysical Lorentzian plasma. It is shown that the non-thermal effect suppresses the eikonal scattering phase shift. However, it enhances the eikonal collision cross section in astrophysical non-thermal turbulent plasmas. The effect of non-thermal turbulence on the eikonal atomic collision cross section is weakened with increasing collision energy.

Keywords: Diffusion, Screening, Atomic collision, Turbulent plasmas

Spectroscopic diagnostics for negative ion source test facility at ASIPP

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In order to support the development of the negative ion based neutral beam injection system for next generation fusion experimental reactor, a negative ion source test facility with radio frequency source is being built at Institute of Plasma Physics, Chinese Academy of Sciences (ASIPP). A full set of spectroscopic diagnostics was designed to meet the requirement of operation performance optimization. This paper describes the design of optical emission spectroscopy of the plasma source and negative ion absorption spectroscopy. Ion formation and recombination processes are accompanied by radiation of different characteristic spectral lines, the Balmer series and Cs line at 852.1nm. By measuring the intensity of spectral lines, the key parameters, such as temperature and density of electron and cesium quantity, will be estimated. Absorption spectroscopy, with a cavity ring-down technique, will provide a direct measure of the negative ion density. These diagnostics will provide strong support for the coupling of RF power and improvement of negative ion density.

Keywords: spectroscopic diagnostics ; negative ion ; absorption spectroscopy

New Thomson scattering diagnostic for measurement of electron distribution function in the gas dynamic trap plasma

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New heating regimes of the gas dynamic trap magnetic mirror demonstrate electron temperatures of 1 keV making an upgrade of the Thomson scattering diagnostic a mission-critical task. New Thomson scattering diagnostic uses a pulsed 10 Hz 1064 nm Nd:YAG laser. The input laser beamline is provided with an automated control of alignment by means of a red laser, a five-diode detector and motorized mirrors. Collecting optics is a low-aberration achromatic six-element lens. It receives 90° scattered radiation and forms images of observation points along the plasma diameter of 31 cm onto eleven fiber-optical bundles. All the components of the registration system are assembled inside a shielded temperature-controlled diagnostic cabinet. Each optical signal from the corresponding spatial point inside the plasma is processed by a spectrometer dispersing light by the set of six narrowband interference filters. Comparing to the classical layout, there are several improvements introduced in our instrument's design. We use new HAMAMATSU avalanche photodiodes having a bigger quantum efficiency in the near-infrared wavelength region of up to 1000 nm. Every spectrometer has an "electronics box" onboard comprising of six sensor modules and signal processing and recording facilities. To manage a possible condition of acquisition of relatively small scattering pulse on top of a massive light background, the detection module electronics splits a low-frequency and a high-frequency band. Background pedestal is in the LF-band signal, which is amplified and digitized directly. The HF-band processing unit employs a fast switched capacitor array DRS4, which records a signal shape. This signal is digitized offline by a relatively slow ADC but then having a respectable amplitude dynamic range of 10.5÷11 bit. Our method allows *inter alia* for a significant reduction of the per-channel cost of fast multichannel hi-res detection systems like the one for a laser Thomson scattering diagnostic.

Keywords: Thomson scattering, laser aided diagnostic, open magnetic trap

A compact, smart Langmuir Probe control module for MAST-Upgrade

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A new control module for the MAST-Upgrade Langmuir Probe system has been developed. It is based on a Xilinx Zynq FPGA, which allows for excellent configurability and ease of retrieving data. The module is capable of arbitrary bias voltage waveform generation, and digitises current and voltage readings from 16 probes. The probes are measured one at a time in a time multiplexed fashion, with the multiplexing sequence completely configurable. In addition, simultaneous digitisation of the floating potential of all unbiased probes is possible. A suite of these modules, each coupled with a high voltage amplifier, enables biassing and digitisation of 640 Langmuir Probes in the MAST-Upgrade Super-X divertor.

The system has been successfully tested on the York Linear Plasma Device and on the COMPASS tokamak. It will be installed on MAST-Upgrade ready for operations in 2017.

Keywords: Langmuir Probes, FPGA, MAST, Upgrade

On some design aspects of the development of GEM Based Detectors for Plasma Diagnostics

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The proposed work refers to the development of gaseous detectors for application at tokamak plasma radiation monitoring. Soft X-ray radiation (0.1-20 keV) measurement of magnetic fusion plasmas is a standard way of accessing valuable information on particle transport and magnetic configuration. To develop the photon conversion and signal processing part of the proposed monitoring system many physical, technical and technological aspects are needed to be taken into consideration in the design and manufacture.
The paper presents the results of simulations performed to optimize the operating parameters of Gas Electron Multiplier (GEM) based soft X-ray radiation detecting system which is under development by our group. Detector is devoted to study X-ray emission of plasma radiation with focusing on tungsten emission lines energy region. This information is especially crucial for future ITER-like machines - e.g. WEST project. Presented simulations were done using the Garfield++ software - a toolkit for the detailed simulation of particle detectors that use gas and semi-conductors as sensitive medium. The calculations were performed in order to select the appropriate supply voltage values for the detector elements in such a way to ensure the best performance of the developed detector. Particular attention was paid to parameters such as the electron gain of electrons, electrons transmission efficiency in the detector and the time of the signal formation. The preliminary results of laboratory tests will be also presented.
This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement number 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

Keywords: GEM detector, soft X, ray detector

Progress on Radiation Hardness Assurance for Electronics of Diagnostic Systems in ITER

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The ITER diagnostics systems will provide accurate measurements of the plasma behaviour and performance. Measurements will be used for different operational roles ranging from real time machine protection to physics understanding. Most of these systems will have sensors (e.g. cameras, detectors) and signal conditioning electronic components (e.g. preamplifiers, ADCs) located in the Tokamak building and in particular in the port-cell area. These components will be exposed to gamma and neutron fluxes from the plasma, from the activated water circulating in the pipes of the water cooling system and from the cask transporting activated components during maintenance operation.

A dedicated workshop on diagnostic electronics exposed to radiation has been held in 2016. The aim of the workshop was to review the radiation conditions in ITER, their effects and consequences on electronics with an emphasis on operational aspects through return of experience, mitigation strategy (relocation, shielding, redundancy, software solutions, radiation tests, rad-hard component design). One of the important goals of the workshop was to elaborate a common work plan for component tests and design to be implemented by the different participants and coordinated by the ITER Organization. First results of radiation tests on signal conditioning electronics have been presented as well as statistical analysis of radiation effects on cameras exposed to plasma radiation. This paper is addressing the outcome of this workshop in the perspective of the incoming ITER nuclear radiation compatibility handbook. The paper will also give an update on the follow up of the actions from the workshop, in particular on the component classification, on the radiation test plan elaboration for system qualification, and on local shielding design for components in port-cells.

Keywords: ITER, diagnostics, electronics, radiation hardness

Electromagnetic diagnostics of ECR-Ion Sources plasmas: optical and X-ray imaging and spectroscopy

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Magnetoplasmas in ECR-Ion Sources are excited via Electron Cyclotron Resonance from gaseous elements or vapors by microwaves in the range 2.45-28 GHz. A B-minimum, MHD-stable configuration is used for trapping the plasma. The values of plasma density, temperature and confinement times are typically $n_e = 10^{12} - 10^{14}$ cm^{-3}, $T_e > 0.1 - 100$ keV, $t_c = 0.001 - 1$ sec. At INFN-LNS several diagnostics tools have been developed for probing the electromagnetic emission of such plasmas, in the optical/X-ray domain. Fast SDD detectors with high energy resolution of 125 eV at 5.9 keV have been used for the characterization of plasma emission at 2$

Keywords: Plasma diagnostics, Optical imaging, X, ray imaging, Optical emission spectroscopy

SXR measurement and W transport survey using GEM tomographic system on WEST

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Heavy impurities like tungsten (W) could degrade plasma core performances and cause radiative collapses, it is thus necessary to develop new Soft X-ray (SXR) diagnostics to be able to monitor the impurity distribution in harsh fusion environments like ITER. A gaseous detector with energy discrimination would be a very good candidate for this purpose. The design and implementation of a new SXR diagnostic developed for the WEST project, based on a triple Gas Electron Multiplier (GEM) detector is presented. This detector, tested on ASDEX-Upgrade before the WEST installation and the first experimental campaign in 2017, works in photon counting mode and presents energy discrimination capabilities. The SXR system is composed of two 1D cameras (vertical and horizontal views respectively), located in the same poloidal cross-section to allow for tomographic reconstruction. An array consists of up to 128 detectors in front of a beryllium pinhole inserted at about 60 cm depth inside a cooled thimble in order to retrieve a wide plasma view. Acquisition of low energy spectrum is insured by a helium buffer installed between the pinhole and the detector. Complementary cooling systems (water and alcohol) are used to maintain a constant temperature (25°C) inside the thimble. Finally a real-time automatic extraction system has been developed to protect the diagnostic during baking phases or any overheating unwanted events.
Preliminary simulations of plasma emissivity and W distribution have been performed for WEST using a recently developed synthetic diagnostic coupled to a tomographic algorithm based on the minimum Fisher information (MFI) inversion method. Comparison with first GEM acquisition are performed as well as estimation of transport effect on local ionization equilibrium and cooling factor depending on the choice of range of energy used for the tomographic inversion.

Keywords: tomamak, Soft X, ray, GEM detector

On a Gas Electron Multiplier based synthetic diagnostic for soft x-ray tomography on WEST with focus on impurity transport studies

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The first experimental campaign of WEST will start in 2017 with the plan of testing ITER divertor components in long pulse operation. Unfortunately, radiation cooling due to heavy impurities like tungsten (W) - in particular in the soft x-ray (SXR) range [0.1 keV; 20 keV] by Bremsstrahlung, radiative recombination and line emission - can be detrimental for plasma core performances and sometimes even leads to disruption.

The SXR diagnostic of WEST [1] will be composed of two new detectors based on a Gas Electron Multiplier (GEM) technology which has been recently tested on ASDEX-Upgrade [2]. The WEST SXR cameras will be used for impurity transport studies by performing 2D tomographic reconstructions with spectral resolution in tunable energy bands. Indeed the GEM detectors will work in photon counting-mode in contrast with conventional semiconductor diodes working in current mode. Such gaseous detectors offer better intrinsec robustness to ageing in harsh environments like ITER.

In this paper, we present the capabilities of this diagnostic for retrieving SXR emissivity of the plasma and for monitoring W concentration, thanks to a synthetic diagnostic recently developed in [3] and coupled with a tomography algorithm based on the minimum Fisher information (MFI) inversion method [4]. The synthetic diagnostic includes the plasma emission (ADAS) from a given scenario, photoionization in the detection gas mixture, transport of the resulting electron cloud in the gas and electron avalanches through GEM foils thanks to Magboltz [5]. Preliminary analysis of the first WEST campaign are also presented.

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Keywords: Tokamaks, Soft X Rays, Diagnostics, Gas Electron Multiplier

THz Multi line-of-sight polarimeter for fusion reactors

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In nuclear fusion research, polarimetry is a well established technique to measure fundamental plasma parameters, such as the electronic density and the poloidal field. By measuring the Faraday rotation angle, the path integral of these two quantities can be obtained. When coupled with the line integrated density measurement along the same chord coming from an interferometer, the plasma current density can be obtained. In this paper we present the first preliminary study of a new polarimetry diagnostic system. The device foresees multiple lines of sight, so that the evaluation of the aforementioned parameters can be performed at different chords along the poloidal plane, parallel to the equatorial direction, in a single acquisition cycle. Considering the typical plasma conditions of the actual magnetic confinement machines, we need to employ sources in the range of the low (<3) THz to have appreciable rotation angles. As source the diagnostic foresees the use of Quantum Cascade Lasers (QCL) which represents a very promising solution, given their ability to operate at the expected frequency of 1.6 THz at cryogenic temperatures. Since the power of the probe beam is in the order of microwatts, a cryo-detector, such as superconducting bolometer (HEB) or kinetic inductance detector (KID) is required. This opens the field for a very compact modular machine, composed by a single cryogenic cooler encasing source, detector and the optical section. The conceptual study has been performed taking into account the performances, reliability and adaptability to multiple machines, and enriched with estimates of the Faraday rotation at different conditions, using as base data coming from the ASDEX Upgrade tokamak located at IPP in Garching.

Keywords: polarimetry, terahertz, diagnostics

Diagnostics for laser-driven neutron sources

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Neutrons generated using intense laser driven ion beams have recently received a great deal of attention. Intense lasers can produce 10s of MeV protons in a small divergence cone via the so-called Target Normal Sheath Acceleration (TNSA) mechanism, which are highly efficient in producing fast neutrons via fusion reaction with low mass atomic nuclei. Employing neutron converters in a close proximity to the laser driven ion source, a beamed neutron flux can be obtained which is highly suitable for imaging application. While fast neutrons are also useful in many applications, such as fast neutron therapy [1], material testing in fission and fusion reactor research [2], a laser driven short neutron bursts can be moderated down to thermal and epithermal region for other types of applications, such as imaging [3], nuclear resonance spectroscopy [4], Boron neutron capture therapy [5] etc. Characterisation of the intense laser driven fast and slow neutrons, produced in a recent experimental campaign at Rutherford Appleton laboratory employing 100 TW Vulcan laser, will be presented, which was carried out using a full suit of neutron diagnostics. While the fast neutron flux was measured by means of absolutely calibrated fast plastic scintillators [6] and CR39 sheet detectors, spectra of moderated neutrons were obtained in a time-of-flight arrangement employing multiple He-3 proportional counters. The spectral distribution of the moderated neutrons was also measured by means of neutron capture reaction in boron nitride sheets, backed by solid state track detectors such as CR39 and LR films [7].

Keywords: Laser driven neutrons, diagnostics, scintillators, moderation

Runaway Electron diagnostic development and performance at the COMPASS tokamak

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Control and/or mitigation of Runaway Electrons (RE) present one of the key tasks for experimental work on present tokamaks in support of the ITER programme. In this respect, the COMPASS tokamak dedicates an important part of its capacity to the RE experiments. As a part of this experimental programme, novel diagnostic systems and/or specific procedures for data processing have had to be introduced in order to measure, analyse and interpret behaviour of RE in the facility. This contribution reviews experience and results achieved with regard to this effort in the COMPASS tokamak. The referenced diagnostic tools include a NaI(Tl) scintillation detector with photomultiplier for hard X-ray (HXR) measurements, a ZnS(Ag) scintillation detector embedded in a plastic matrix (EJ-410) with photomultiplier for combined HXR and neutron emission measurements, and two 3He proportional counters for the neutron emission diagnostics. Furthermore, the COMPASS tokamak has been used as a test bed for development of a new in-vessel three channel Cherenkov detector for a direct observation of fast electron losses, as well as for an assessment of a silicon matrix detector (MediPix) as a new prospective HXR and neutron diagnostics with spatial resolution. Hard radiation data are complemented by data from plasma imaging with fast cameras in both visible and infrared spectral ranges; RE synchrotron radiation was observed and analysed in the latter range. A new approach for measurements of the Electron Cyclotron Emission (ECE) in vertical direction (ie along the constant toroidal magnetic field) which should be better suited for the highly non-thermal electron distribution is also presented. Among the basic diagnostic systems of the COMPASS tokamak, the role of its rich set of magnetic field sensors with poloidal and toroidal resolution and fast data acquisition for the RE relevant studies will be presented.

Keywords: Runaway Electrons, hard X, rays, neutrons, ECE, fast cameras

Secondary electron emission in DC operation of the retarding field analyzer

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The DC operation of a retarding field analyzer (RFA) has been proposed for the direct instantaneous measurements of the ion temperature in the plasma scrape-off-layer [1]. The method is based on the relation for the RFA current-voltage (I-V) characteristic resulting from a common RFA model of a shifted Maxwellian distribution of the analyzed ions and the measurements of two points on the exponentially decaying region of the I-V characteristic with two differently DC biased RFA electrodes. It was mentioned that the secondary electron emission from the RFA electrodes could be a serious problem for the correct application of the method. From the measurements on the tokamak ISTTOK in Ref.1, the secondary electron emission yield for ions was estimated as g $\sim$ 0.2, giving a $\sim$10% contribution to the results of ion temperature measurements. However, in the followed investigations it was observed that the secondary electron emission yield could be up to g $\sim$ 0.6 (depending particularly on the discharge conditions), and, therefore, should be included into analysis. In this contribution, the limitations of the method due to secondary electrons are considered by analyzing in detail the RFA operation with the secondary electron emission from the RFA electrodes. The results of the analysis are illustrated and supported by the experimental data from the tokamak ISTTOK.

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Keywords: plasma, ion temperature, retarding field analyzer

Improvement of density resolution in short-pulse hard x-ray radiographic imaging using detector stacks

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We demonstrate that stacking several imaging plates (IPs) constitutes an easy method to increase hard x-ray detection efficiency. Used to record x-ray radiographic images produced by an intense-laser driven hard x-ray backlighter source, the IP stacks resulted in a significant improvement of the radiograph density resolution. We attribute this to the higher quantum efficiency of the combined detectors, leading to a reduced photon noise. Electron-photon transport simulations of the interaction processes in the detectorreproduce the observed contrast improvement. Increasing the detection efficiency to enhance radiographicimaging capabilities is equally effective as increasing the x-ray source yield, e.g., by a larger drive laser energy.

Keywords: x, ray radiography, density resolution, imaging plate

Two-Wavelength LIDAR Thomson Scattering for ITER Core Plasma

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Our proposal for a LIDAR Thomson scattering system to measure T_e and n_e profiles in the ITER core plasma1, is based on experience with the LIDAR system on JET, which is still operational after 30 years. The design uses technology and complies with the measurement requirements given by ITER. In addition, it offers the following advantages over the conventional imaging approach currently being adopted by ITER: 1) No gas fill of the vessel required for absolute calibration. 2) Easier alignment. 3) Measurements over almost the complete plasma diameter. 4) Two mirrors only front optics.
For a given laser wavelength the dynamic range of the Te-measurements is mainly limited by the collection optics' transmission roll-off in the blue and the range of spectral sensitivity of the required fast photomultipliers. With the proposed Ti:Sapphire laser, measurements of the envisaged maximum temperature of 40 keV are marginally possible.

Here we present encouraging simulation results on the use of other laser systems and on the use of two lasers with different wavelength. Alternating two wavelengths was proposed already in 19972 as a method for calibrating the transmission of the collection system. In the present analysis, the two laser pulses are injected simultaneously. We find that the use Nd:YAG lasers operated at fundamental and second harmonic, respectively, yields excellent results and preserves the spectral calibration feature [1-3].

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Keywords: ITER, Core, Thomson Scattering, LIDAR

Electromagnetic modelling and 3D PIC simulations of the pulse-dilation system for prototyping next-generation streak cameras with 1 - 2ps temporal resolution and $>$ 100 dynamic range

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Future experimental requirements for the Orion laser facility at the AWE include measurements of materials properties in new, highly transient regimes, and streak cameras are a critical source of these data. Although existing streak cameras have good temporal resolution, there is a vital need to improve their very low dynamic range (∼5) encountered at <5ps timescales for short-pulse laser-plasma measurements. To this end, a recently verified technology, called Pulse-Dilation, is now being incorporated into a next-generation streak camera, the Pulse-Dilation Streak Camera (PDISC). There are two key advantages of this technique over the existing streak camera method. These are the much larger photocathode area than the standard slit size, reducing the photocathode current density, and the absence of the photoelectron cross-over point, which can be a significant source of space charge induced distortions. We present the modelling and simulations of the PDISC operation using a 3D Particle-In-Cell (PIC) code called Computer Simulation Technology (CST) Particle Studio. PIC simulations enable quantitative assessment of the effects of space charge induced distortions on the PDISC dynamic range. Simulation results have now indicated that short-pulse laser-driven spectroscopy/streaked imaging of 1 - 2ps temporal resolution with a dynamic range of >100 is viable using the PDISC. Future plans for building the prototype PDISC and proof-of-concept experiments at the Orion laser facility will be discussed

Keywords: Laser, streak camera, pulse, dilation

Femtosecond dynamics of energetic electrons in high intensity laser-matter interactions

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Highly energetic electrons are generated at the early phases of the interaction of short-pulse high-intensity lasers with solid targets. These escaping particles are identified as the essential core of picosecond-scale phenomena such as laser-based acceleration, surface manipulation, generation of intense magnetic fields and electromagnetic pulses. Increasing the number of the escaping electrons facilitate the late time processes in all cases. Up to now only indirect evidences of these important forerunners have been recorded, thus no detailed study of the governing mechanisms was possible. Here we report, for the first time, direct time-dependent measurements of energetic electrons ejected from solid targets by the interaction with a short-pulse high-intensity laser. We measured electron bunches up to 7 nanocoulombs charge, picosecond duration and 12 megaelectronvolts energy. Our 'snapshots' capture their evolution with an unprecedented temporal resolution, demonstrat- ing a significant boost in charge and energy of escaping electrons when increasing the geometrical target curvature. These results pave the way toward significant improvement in laser acceleration of ions using shaped targets allowing the future development of small scale laser-ion accelerators.

Keywords: electron dynamics, laser, matter interaction, femtosecond diagnostics

Development of a Cherenkov-type diagnostic system to study runaway electrons within the COMPASS tokamak

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Direct measurements of fast electrons, which are produced in high-temperature plasma and escape from tokamak-type facilities, are of particular interest for ITER and future fusion devices, where runaway electrons can significantly damage first wall components. Therefore, runaway control and mitigation based on credible measuring methods must be developed already on present devices. A team of the National Centre for Nuclear Research (NCBJ), Poland, developed special probes equipped with Cherenkov-type detectors for measurements of fast electrons in in the edge plasma of tokamaks. These detectors have high spatial and temporal resolution.

Studies of fast runaway electrons were intensively carried out at the COMPASS tokamak at the Institute of Plasma Physics (IPP) in Prague during experimental campaigns in 2014-2015. The paper presents the most important experimental results of the recent fast electron-beams studies performed there. In order to investigate an electron-beam energy distribution a three-channel probe equipped with the Cherenkov-type detectors sensitive to different electron energies has been constructed. The measurements performed by means of these detectors showed that the first fast electron peak appears usually in the current ramp-up phase, even before the hard x-rays (HXR) pulse. Some electron signals can be observed also during subsequent HXR emissions. However, the most distinct electron peaks in all energy channels appear mainly during the plasma disruption. A correlation of Cherenkov signals with the MHD activity was also studied and will be discussed.

Keywords: runaway electrons, tokamak diagnostics, Cherenkov, type detectors

SPECTIX X-ray spectrometer at PETAL: design, calibration and preliminary tests at LULI 2000

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This presentation will describe the design, calibration and early tests at LULI 2000 of the transmission crystal X-ray spectrometer SPECTIX (Spectromètre PETAL à Cristaux en Transmission X) built for the LMJ/PETAL laser facility. Its goal is to characterize the interaction of the PETAL laser with a target by detection of hard x-ray photons from the Ka lines of different target materials or tracers within these targets. The construction of the spectrometer allows montage of two cylindrically bent crystals in parallel, which leads to broadening of the spectral range (7 to 100 keV) and flexibility in determination of the desired measurement range or sensitivity. Detection is done with passive detectors: imaging plates. Shielding has been dimensioned in order to protect detection against parasitic x-rays produced by PETAL shots. It includes magnets to remove electrons entering this spectrometer, tungsten frontal shielding with 20mm thickness and lead side shielding with 6 mm thickness. This x-ray spectrometer has been built and tested in an experimental campain at LULI 2000. It is presently in the commissioning process for use in the LMJ laser facility and will be used in a few months in the first PETAL experimental campaign open to the academic community.
This work for development of diagnostics takes place within the EQUIPEX PETAL+ funded through the PIA by the french National Agency for Research (ANR) coordinated by the University of Bordeaux.

Keywords: PETAL, LMJ, spectrometer, crystal, LULI 2000

Experimental investigation of an expanding supersonic plasma jet by quadrupole mass spectrometry

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The controlled growth of nanostructured thin films represents a challenging field of research which is related to many different applications of great scientific relevance. The properties of many materials can be greatly enhanced by optimizing the nanoscale assembly processes: by modelling the nanoparticles which create and assemble a film it is possible to achieve very promising results, although it requires a bottom-up approach capable of tailoring the properties with a high level of control or a complex set-up. Plasma-based synthesis processes have been widely developed and applied for an increasing number of technologies leading to important achievements and many industrial-scale applications, in particular in the field of nanoscience.Combining a reactive plasma with a supersonic jet we developed a novel approach for thin film deposition: Plasma Assisted Supersonic Jet Deposition [1]. An argon-oxygen inductively coupled plasma offers a reactive environment where a titanium metalorganic precursor (titanium isopropoxide) is dissociated and oxidized. The gas is then left to expand from a small orifice into a lower pressure vacuum vessel forming a supersonic jet, where the TiO2 nanoparticles are assembled and accelerated onto a substrate by the gas carrier mixture. This deposition technique has proved useful for the deposition of nanostructured thin film having a desired morphology at competitive deposition rates. Little is know about the free gas expansion at the fluid regime considered in this work (transitional regime) or about the plasma component extracted by the jet. We performed a deep characterization of the supersonic plasma jet using a quadrupole mass spectrometer to sample the gas from the jet at different position along its axis of symmetry and its radial coordinate. The detection of neutral species, radicals, ions and ion energy distribution functions has led to an understanding of the expanding plasma properties and its composition.

Keywords: nanostructures, plasma, supersonic, films

Characterization of a compact LaBr3 detector with Silicon photomultipliers at high 14 MeV neutron fluxes

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The Gamma Camera installed at JET consists of a vertical and a horizontal camera made of 9 and 10 collimated lines of sight, respectively. Measurements along this multiple set of channels allow the tomographic reconstruction of the gamma emission source in the plasma. In particular, in Deuterium-Tritium thermonuclear plasmas (DT), the detection of the 4.44 MeV gamma-rays emitted by 9Be(α,nγ)12C reactions plays a key role in the study of the alpha particle confinement. The new detectors will be installed in 2017 enabling gamma-ray spectroscopy in the forthcoming high power plasma campaigns with and without tritium. The upgrade aims to improve the spectroscopic capabilities allowing gamma-ray measurements at MHz counting rate with enhanced energy resolution in a harsh neutron-gamma mix environment. In order to meet these requirements together with important limitations given by the detector available space, the project team has developed a compact gamma-ray spectrometer based on a Silicon Photo-Multiplier (SiPM) coupled to a LaBr3(Ce) scintillator crystal. Silicon Photo-Multipliers represent a good alternative to standard photomultiplier tubes due to their insensitivity to magnetic fields, high internal gain and extremely compact size. In this work we present the response of the LaBr3(Ce) crystal to 14 MeV neutron irradiation measured at the Frascati Neutron Generator (FNG) including a comparison with the results from MCNP simulations. The neutron resistance of the SiPM has been also assessed after a neutron irradiation up to about 10^10 n/cm2. The SiPM showed a significant increase of dark current and a change in the current-voltage characteristic curve, but without changes in the recorded pulse height spectrum. A partially self-recovering process of the SiPM has also been observed leading to a decrease of dark current and I-V curve after few weeks. Based on these results we can extrapolate that the developed prototype can sustain neutron fluxes corresponding to approximately 100 record DT JET plasma discharges.

Keywords: Gamma ray spectroscopy, nuclear diagnostic, Gamma ray diagnostic, plasma diagnostic

Spectroscopic analysis of plasmas created in high contrast relativistic laser-matter interaction

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In this work we present an experimental evidence of a highly ionized plasma state with a solid electron density obtained due to interaction of the high contrast 50 fs relativistic laser pulse with Ti-foils. Intensity of the second harmonic (400nm) Ti-sapphire laser pulse onto the target reached 10^{19} Wcm^{-2}. Complex diagnostic set-up was used for measuring a characteristic plasma radiation, a bremsstrahlung radiation provides by suprathermal electrons and an energy distribution of energetic electrons escaped the target.
Analysis of the intercombination (1s2 -1s 2p 3P1) and the resonance (1s2 -1s 2p 1P1) transitions in Ti^{+20} as well as radiation transitions from double excited states in Ti^{+19} (1s2 2l -1s 2l2l'; l, l'=s, p) shows that the radiation is coming from the solid density plasma with the bulk electron temperature of 1.5-2 keV. Low intensity of the Lya (1s-2p) transition in Ti^{+21} speaks for the transient character of the charge state formation, where a characteristic K-shell ionization time is far above the laser pulse duration. Measurements of the suprathermal electron temperature using bremsstrahlung radiation give a rather moderate value of 10-15 keV. Electron spectrometer registered a very small fraction of the "run-away" electrons with energies up to 200-400 keV. By using of layered targets it was found out, that the depth of the hot plasma region is less than 200nm.

PIC simulations confirm that at the high contrast laser-matter interaction, the laser energy is stored mostly in electrons with energies below 10 keV. By propagation in matter, these electrons are stopped in a very thin layer of hundreds of nm. High energy density stored in a small target volume leads to creation of keV hot plasma of solid density diagnosed in the experiment.

Keywords: laser matter interaction, X-ray spectroscopy

Integration of an Electron Cyclotron Imaging diagnostic in WEST tokamak

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Direct 2-D visualization of plasma dynamics via microwave imaging are extremely effective in research of magnetic fusion plasmas. Electron Cyclotron Emission imaging (ECEI) diagnostic, first developed in the 90's, images the temperature fluctuations induced by magnetohydrodynamic instabilities or turbulence [1].
An ECEI system has been developed through French Korean collaboration for the WEST tokamak [2]. WEST (Tungsten (W) Environment (E) Steady-state (S) Tokamak (T)) is an upgrade of the Tore Supra tokamak and the goal is to test critical components for ITER during long pulses.
While the WEST ECEI system is based on the same principles, new approach has been developed to implement the ECEI optics in WEST. Existing ECEI diagnostics are in straight view of the plasma and use composite lens outside the vacuum vessel. In WEST, the only port where ECEI could be implemented is lim5 m away from the plasma edge with a tangential view. A large front-end optics must withstand the plasma radiation heating during long discharges. Two metallic mirrors (0.56 m height x 0.18 m width) are installed at 2 meters from the plasma edge to focus and to redirect the microwave beam.
A compact optical housing is constructed to fit in a limited space [1,2].

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Keywords: Fusion plasma diagnostic, microwave radiometry, ECEI

Design and optimization of the electrostatic input module for the Tokamak ISTTOK HIBD cylindrical energy analyzer

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The Heavy Ion Beam Diagnostic in ISTTOK (a = 0.085 m, R = 0.46 m) is based on the injection of a singly ionized primary beam (Xe+, Cs+) of energy 20-25 KeV and on the collection of all doubly ionized ions emerging from the primary beam due to the impact ionization with the plasma electrons. In the present configuration, three local plasma parameters can be retrieved: *ne, Te, and Bp.* A new detection system is being design in order to determine the plasma potential (*Vp)* profile via the secondary ions energy measurements. To that end an improved 90° cylindrical electrostatic analyzer (CEA) has been designed and optimized to measure the energy of the secondary ions. This paper reports on the design optimization of the first stage of the new detection arrangement to guide and shape 4 secondary beams into the entrance of the CEA. It is composed of a set of four electrostatic cylindrical plates followed by a set of steering plates (Y-direction) and a multiple aperture Einzel-like electrostatic lens, consisting of four parallel vertical plates with four slits. Additional strips of electrodes are integrated along the sides of every aperture for allowing beam shaping and alignment in horizontal Z-direction.
The beam dimension of 8 mm × 2.5 mm was obtained without any overlapping between the four beams from different slits and without any loss of current at the CEA entrance slit. Changing beam energy by 200V from 20KeV, shows a vertical shift of 1mm which can be recovered by changing the voltage on the parallel plate arrangement by 40V. The flexibility and tolerance of the optic system was tested successfully for the expected angular uncertainty of the beam by +/-0.5° at the entrance and with expected energy spread of the beam corresponding to different plasma positions inside tokamak.

Keywords: Heavy ion beam diagnostics, electrostatic energy analyser, Ion optics, Beam focusing

Multi-detector HXR spectrometry system for runaway electron studies

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Multi-detector system for runaway electron diagnostics has been developed in the Ioffe Institute. The system is based on use of scintillation gamma-ray spectrometers for measurements of hard X-radiation (HXR) generated during interaction of relativistic electrons with plasma components and materials of tokamak chamber. The system was tested in experiments at the Tuman-3M tokamak (R = 0.53 m, a = 0.22 m, Ip <180 kA). It includes two spectrometers with LaBr3(Ce) detectors observing the poloidal limiter of the tokamak chamber with different lines of sight: electron beam comes into the limiter in the direction of the first detector; the second detector observes the same area of the limiter from the opposite side. Fast transient digitizer AMBPEX5/ADM214x400M/2 developed by "Instrumental Systems Ltd." company was enabled to record the LaBr3(Ce) detector signals. The digitizer provides measurements with 200-500 MHz sampling rate for each of two available channels. During the experiments signals were recorded into the PC memory and processed in off-line mode. LaBr3(Ce) detectors with Ø76×76 and Ø25×76 mm crystals enabled in the experiments are proposed to be used in the gamma-ray spectrometer systems at the ITER tokamak. The third detector with NaI(Tl) crystal having quasitangential line of sight the tokamak plasma is designed to measure the hard X-rays generated in the plasma and in the inner wall of the tokamak chamber. Reconstruction of the runaway electron energy distributions from the measured HXR spectra was carried out with use of the DeGaSum code [1, 2] developed in the Ioffe Institute. The spectrometers demonstrated stable operation at the counting rate up to 10 MHz. The analysis of the LaBr3(Ce) spectrometer performances and obtained runaway electron distribution functions is presented in the report.

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Keywords: tokamak, runaway electrons, HXR spectrometry, gamma spectrometer, LaBr3(Ce) detector, physics of plasma

Absolute calibration of image plate detector for electron energies less than 2.25 MeV

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Imaging plates (IPs) are often used to detect electrons in a wide variety of laser plasma experiments. Typical diagnostics include magnetic spectrometers, electron radiography and gamma-ray detectors. The energies of these electrons range from 100s of keV to a few GeV. Several calibration results have been published for the range of electron energies from 5 MeV to up to a GeV energy. However, there are no published data based on direct calibrations for the lower energy range from 100s of keV to a few MeV. This range is critical because the sensitivity of the IPs changes by an order of magnitude within a narrow energy band of 200 keV as the electrons transition from being completely absorbed to being minimally ionizing within the sensitive layer of the detector. This range of energies is useful in absolutely calibrating filter stack gamma-ray detectors and electron spectrometers for long pulse (ns) laser matter interaction experiments.
In this presentation, we describe the electron calibration of two different kinds of IPs (BAS- MS and BAS-SR manufactured by Fuji Film) in the range of kinetic energies from 0.15 to 2.25 MeV. The calibration was performed using a 90 Sr source [1]. Calibration results indicate that MS is 5-6 times more sensitive than SR. In addition, we also measured the fading response for MS and SR in the time range from 12 minutes to 18 hours. Calibration results are also compared to Monte Carlo simulations of energy deposited by the electrons in the sensitive layer of the IPs.

Keywords: Image plate detector, Electron spectrometer, Gamma ray spectrometer, Plasma diagnostic

Synthetic neutron diagnostics (KN3/TOFOR) in JET based on AFSI-ASCOT simulations

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The ASCOT Fusion Source Integrator (AFSI) has been used to calculate neutron production rates and spectra corresponding to the JET 19-channel neutron camera (KN3) and the time-of-flight spectrometer (TOFOR) as ideal diagnostics, without detector-related effects. AFSI calculates fusion product distributions in 4D, based on Monte Carlo integration from arbitrary reactant distribution functions. The distribution functions were calculated by the ASCOT Monte Carlo particle orbit following code for thermal, NBI and ICRH particle reactions. Fusion cross-sections were defined based on Bosch-Hale model and both DD and DT reactions have been included.
Neutrons generated by AFSI-ASCOT simulations have already been applied as a neutron source of the Serpent neutron transport code in ITER studies. Additionally, AFSI has been selected to be a main tool as the fusion product generator in the complete analysis calculation chain: ASCOT - AFSI - SERPENT (neutron and gamma transport Monte Carlo code) – APROS (system and power plant modelling code), which encompasses the plasma as an energy source, heat deposition in plant structures as well as cooling and balance-of-plant in DEMO applications and other reactor relevant analyses.
This conference paper presents the first results and validation of the AFSI DD fusion model for different auxiliary heating scenarios (NBI, ICRH) with very different fast particle distribution functions. Both calculated quantities (production rates and spectra) have been compared with experimental data from KN3 and TOFOR and no qualitative differences have been observed. In future work, AFSI will be expanded for synthetic gamma diagnostics and additionally, AFSI will be used as part of the neutron transport calculation chain to model real diagnostics instead of ideal synthetic diagnostics for quantitative benchmarking.

Keywords: synthetic diagnostics, fusion neutrons, JET

First results of a compact advanced extreme ultraviolet spectrometer to measure spatio-temporally varying tungsten spectra in fusion plasmas

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High-Z impurity transport including tungsten (W) has become a critical research issue in tokamak plasmas due to the employment of W for ITER divertor. Charge states of W 27+ to 45+, that can exist mostly in the core region of a typical fusion plasma [1], emit radiations near the wavelength of a few nm in EUV range. We have recently developed for KSTAR a compact advanced imaging extreme ultraviolet (EUV) spectrometer (CAES). It is based on a diffraction grating working in the 1?7 nm EUV range to measure spatio-temporally varying line emissions from tungsten. The main feature of this system is a set of two perpendicularly-crossed slits inside a chamber operating as a pinhole which enables it to obtain spatial distribution of line emissions. The back-illuminated charge-coupled device (BI-CCD) is used as a detector which has 2048 x 512 active pixels with each dimension of 13.5 x 13.5 ?m2 and a gold-coated laminar-type diffraction grating was used. The entire setup of the system installed in KSTAR is 4 m away from a typical magnetic axis of the KSTAR plasma. The possible vertical imaging area of the KSTAR plasma is roughly 18 cm at the centre of the plasma. Space-resolved W spectra showing the already known W27+-W39+ quasi-continuum [2] were successfully observed during the 2016 KSTAR campaign after injection of 12 ?m W powder using a metal impurity injection system [3]. Another spectrometer system identical with the one on KSTAR will be installed in WEST tokamak to compare the experimental data from both tokamaks.

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Keywords: Hydrodynamic Instabilities, Inertial Confinement Fusion

Motional Stark effect imaging on DIII-D

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The motional Stark effect (MSE) is a widely used spectroscopic technique for constraining the toroidal current profile in tokamaks and stellarators. The diagnostic observes Doppler shifted, Balmer-alpha emission from neutral beam atoms experiencing a motional electric field E=vxB. This electric field splits the emission into pi and sigma components, polarised parallel and perpendicular to the electric field respectively. Measurement of the polarisation orientation therefore determines the 'pitch' of the magnetic field.
Conventional MSE systems use narrowband filters to isolate a sigma or pi component for polarisation analysis. However, as the Doppler shift varies across the field of view of the beam, an individual filter is required for each radial viewing position, limiting the diagnostic to 10's of channels in the midplane. A more recently developed technique instead uses birefringent crystals to establish a sinusoidal spectral filter. Camera imaging of the entire neutral beam emission is possible the technique as it doesn't require precise tracking of the Doppler shift across the field of view. The increased resolution and 2D nature of imaging MSE have opened new opportunities for directly measuring the toroidal current profile, and for examining instabilities and edge pedestal structures.

An imaging MSE system was installed on the DIII-D tokamak for several weeks in 2016, with results showing good agreement with existing diagnostics. We discuss the operating principles, calibration and results of this imaging MSE system. The system employs a temporally modulated ferro-electric liquid crystal, as shown in Figure1, to provide high spatial resolution imaging. An example of the polarisation angle measured with the diagnostic, compared with a conventional MSE constrained EFIT, is seen in Figure2. An image of the vertical component of the magnetic field can be obtained from the polarisation angle which in turn can be integrated to determine the poloidal flux surfaces, shown in Figure3.

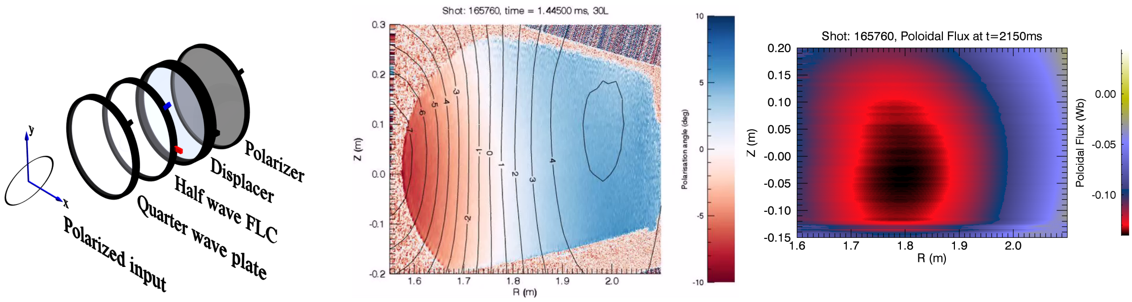

Figure 1: *Fig. 1 (left), Fig. 2 (center), Fig. 3 (right)*

Keywords: Imaging Motional Stark Effect, DIII, D

A new interferometric/polarimetric setup for plasma density measurements in compact microwave-based Ion Sources

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A K-band (18.5-26.5 GHz) microwave interferometry/polarimetry setup, based on the Frequency-Modulated Continuous-Wave (FMCW) method, has been developed at INFN-LNS under the VESPRI project. The interferometer has been proven to provide reliable measurements of the plasma density even in the extreme unfavorable conditions$\lambda_p \simeq L_p \simeq L_c$, being λ_p, L_p and L_c the probing signal wavelength, the plasma dimension and the plasma chamber length respectively. The VESPRI setup has been therefore upgraded with a rotating polarimetric system based on waveguide OMTs (OrthoModeTransducers) for the measurement of the magnetoplasma-induced Faraday rotation. An analysis method has been developed on purpose in order to discriminate the polarization plane rotation due to the plasma only, excluding the effects of the cavity resonator which represents the primary error source on phase angle measurement.The developed diagnostics method will be a powerful tool for probing in a non-intrusive way very compact devices, such as plasma based Electron Cyclotron Resonance Ion Sources and, more generally, compact magnetic traps containing microwave-generated plasmas.

Keywords: Plasma diagnostics, interferometry, spectroscopy and imaging, Polarimeters

High Resolution Spectrometer - Polychromator for the ITER CXRS Diagnostic System

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A tri-band high resolution spectrometer - polychromator, which was designed for performing diagnostics on the ITER facility using the charge-exchange recombination spectroscopy (CXRS), is described. The CXRS allows measurements of such plasma parameters as the ion temperature, the velocity of the toroidal and poloidal plasma rotation, and the concentration of light impurities. The spectrometer - polychromator is based on three transmission holographic diffraction gratings and is designed to operate simultaneously in three spectral ranges: 468±6 nm, 529±6 nm and 656±8 nm. The results of measuring the main performance parameters of the transmission holographic diffraction gratings and the spectrometer - polychromator as a whole are presented. It was established that the characteristics of the developed spectrometer - polychromator satisfy the requirements for the spectroscopic equipment for the ITER CXRS diagnostic system.

Keywords: Spectrometer, Polychromator, charge, exchange recombination spectroscopy, holographic diffraction grating

Tests of a CO2 and Quantum Cascade Laser Based Two-Color Interferometer and Polarimeter for ITER Density Measurements

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A full-scale 120 m path length ITER toroidal interferometer and polarimeter (TIP) prototype, including an active feedback alignment system, has been constructed and undergone initial testing at General Atomics. In the TIP prototype, two-color interferometry is carried out at 10.59 μm and 5.22μm using a CO2 and Quantum Cascade Laser (QCL) respectively while a separate polarimetry measurement of the plasma induced Faraday effect, utilizing the rotating wave technique, is made at 10.59μm. The polarimeter system uses co-linear right and left-hand circularly polarized beams upshifted by 40 and 44 MHz acousto-optic cells respectively, to generate the necessary beat signal for heterodyne phase detection, while interferometry measurements are carried out at both 40 and 44 MHz for the CO2 laser and 40 MHz for the QCL. The high-resolution phase information is obtained using an all-digital FPGA based phase demodulation scheme and precision clock source. This TIP prototype is equipped with a piezo tip/tilt stage active feedback alignment system responsible for minimizing noise in the measurement and keeping the TIP diagnostic aligned indefinitely on its 120 meter beam path including as the ITER vessel is brought from ambient to operating temperatures. The prototype beam path incorporates translation stages to simulate ITER motion through a bake cycle as well as other sources of motion or misalignment. Even in the presence of significant motion, the TIP prototype is able to meet ITER's density measurement requirements over 1000 s shot durations with demonstrated phase resolution of 0.06 Deg. and 1.5 Deg. for the polarimeter and vibration compensated interferometer respectively. TIP vibration compensated interferometer measurements of a plasma have also been made in a pulsed radio frequency (RF) device and show a line-integrated density resolution of δnL=3.5x1017 m^{-2}. Preparations are currently underway for TIP tests on the DIII-D tokamak at General Atomics. **Keywords:** interferometer, polarimeter, laser, ITER, tokamak, density measurement

Synthetic NPA diagnostic for energetic particles in JET plasmas

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Neutral particle analysis (NPA) is one of the few methods for diagnosing fast ions inside a plasma by measuring neutral atom fluxes emitted due to charge exchange reactions. The JET tokamak features two NPA diagnostics, measuring neutral fluxes from hydrogen, deuterium, tritium and helium species at energies ranging from 5 keV to 1 MeV. A synthetic NPA diagnostic for the JET neutral particle analyzers has been developed and used to interpret these measurements to diagnose energetic particles in various JET plasmas.

The synthetic NPA diagnostic performs a Monte Carlo calculation of the neutral atom fluxes in a realistic geometry. The 4D fast ion distributions, representing NBI or ICRH accelerated ions, were simulated using the Monte Carlo orbit-following code ASCOT. Neutral atom density profiles were calculated using the FRANTIC neutral code in the JINTRAC modelling suite. Additionally, for rapid analysis, a scan of neutral profiles was precalculated with FRANTIC for a range of typical plasma parameters. These were taken from the JETPEAK database, which includes a comprehensive set of data from the flat-top phases of nearly all discharges in the recent hydrogen campaign.

The synthetic diagnostic was applied to various JET plasmas, including the recent hydrogen campaign where different hydrogen/deuterium mixtures and NBI configurations were used. The simulated neutral fluxes from the fast ion distributions were found to agree with the measured fluxes, reproducing the slowing-down for different beam isotopes and energies and quantitatively estimating the fraction of hydrogen and deuterium fast ions.

Keywords: NPA, fast ions, JET

X-ray and Extreme UV Spectroscopy During the DIII-D Tungsten Divertor Campaign

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Two toroidal rings of tungsten-coated tile inserts were installed in the DIII-D lower divertor and a range of L- and H-mode plasma discharges were compared during a dedicated two-week run campaign. A high-resolution (1340 spectral channels), variable-ruling grating X-ray and Extreme Ultraviolet Spectrometer (XEUS) was installed to measure tungsten emission in the core of the plasma. The XEUS spectral range extends from 10 to 70 Å and measures multiple groups of tungsten emission lines. At DIII-D core plasma temperatures of 2-4 keV, several emission lines from W27+ through W45+ were identified. Tungsten density evolution and profiles are derived from experimental data using the STRAHL radial transport code. STRAHL uses tungsten emission from XEUS and a SPRED spectrometer (100 - 300 Å), soft X-ray, and bolometer signals to calculate the tungsten density profiles. These results are used to understand the differences in tungsten accumulation between different advanced tokamak scenarios on DIII-D.

Keywords: tokamak, tungsten, transport, spectroscopy

Multi-spectral imaging of tokamak edge and divertor plasmas

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Future large-scale tokamak reactors will require large fractions of the 10^9 W fusion power to be radiated away, in order to achieve a plasma state in which the energy and particle fluxes are largely decoupled from the machine walls ("plasma detachment"). This requires careful tailoring of the 2D distributions of radiation from various impurities, and thereby of the main plasma parameters. It is known that detachment scenarios may exhibit unstable dynamic behaviour, and that they are sensitive to external disturbances and naturally occurring plasma instabilities. Fast visible imaging provides detailed *qualitative* information about the detachment process. This paper presents the development of the Multi-spectrally Acquiring Narrowband Time-resolved Imaging System (MANTIS), which aims to provide high-resolution 2D profiles of the main plasma parameters in the whole divertor region at once. This much-needed information will be used for detailed studies into the physics and chemistry of detachment, and opens the door to new active feedback-control strategies. The optical design of MANTIS is based on that of the Motional Stark Effect diagnostic developed at MIT for the Alcator C-mod tokamak. An optical cavity consisting of concave spherical mirrors, relay lenses, and dielectric interference filters, re-images the object up to 10 times in a way that naturally cancels astigmatism and coma, leaving spherical aberration as the resolution-limiting aberration. The dielectric interference filters pass a narrow wavelength band around a chosen spectral line and act as a mirror for the rest of the visible spectrum. The passed light is imaged onto a camera sensor, while the reflected light continues towards the next channel. This contribution presents the results of optical image quality tests, of the first multi-spectral imaging results of detachment experiments in the TCV tokamak, and outlines the hard- and software of the final system.

Keywords: imaging, spectroscopy, divertor, scrape, off layer, detachment, tokamak, power exhaust

Progress in diagnostics of the COMPASS tokamak

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The COMPASS tokamak at IPP Prague is a small-size device with an ITER-relevant plasma geometry and operating in both the Ohmic as well as neutral beam assisted H-modes since 2012. A basic set of diagnostics installed at the beginning of the COMPASS operation has been gradually broadened in type of diagnostics, extended in number of detectors and collected channels and improved by an increased data acquisition speed. In recent years, a significant progress in diagnostic development has been motivated by the improved COMPASS plasma performance and broadening of its scientific programme (H-mode and pedestal studies, magnetic perturbations, runaway electron control and mitigation, plasma-surface interaction and corresponding heat fluxes, edge localized mode observations, disruptions, etc.). In this contribution, we describe major upgrades of a broad spectrum of the COMPASS diagnostics and discuss their potential for physical studies. In particular, among optical tools, an upgraded high-resolution edge Thomson scattering diagnostic for pedestal studies and a set of new visible light (observation of edge plasma modes) and infrared (plasma-surface interaction investigations) cameras will be introduced. Scrape-off layer plasma diagnostics will be represented by a new divertor set of Langmuir and ball-pen probe arrays and newly constructed probe heads for reciprocating manipulators. Particle diagnostics will be covered by a neutral particle analyzer, an atomic beam probe on a lithium diagnostic beam, Cherenkov detectors (for a direct detection of runaway electrons) and two different kinds of neutron detectors. We will also show new modifications of the two-band microwave reflectometer for fast edge density profile measurements.

Keywords: tokamak, Thomson scattering, cameras, probes, diagnostic beam, neutral particle analyzer, neutron detector, Cherenkov detector, magnetic diagnostics

Advanced neutral gas diagnostics for magnetic confinement devices

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The neutral gas measurement in a magnetic confinement device is an important diagnostic task. The standard method is to use manometers of the ASDEX type for the in–vessel measurements and Penning gauges in the pumping ducts further away. The first ones make use of the strong intrinsic magnetic field of 2-3T, while the Penning gauges in the pumping ducts are mounted at locations with about 10 mT.
For the first operational phase of the Wendelstein 7- X (W7-X) stellarator we had installed 5 in-vessel manometers of the ASDEX type, one per stellarator module. Additional to the Penning gauges in the pumping ducts we installed a Penning gauge with optical observation to study the partial pressures of the constituents of the neutral gas. The magnetic field at the end of the port was about 100mT. We will show some of the results of this Penning Gauge and the ASDEX manometers in the first operational phase of W7-X.

We found out that the cathode wires of the ASDEX manometers can be deformed by the strong Lorentz forces. Therefore, we have recently started to develop a manometer with a LaB6 electron source that requires less current. Due to the lower j X B force and the higher structural strength, the cathode is expected to be much more stable in a strong magnetic field. We will show the first results of a prototype manometer tested in a 3T magnet.
The Penning gauge with optical observation at the end of the port had the drawback of runtime effects compared to the in-vessel manometers of the ASDEX type. We developed a miniaturized Penning cell which can use the intrinsic magnetic field in the plasma vessel. We will show the results from the laboratory and the experimental set-up for the next operational phase of W7-X.

Keywords: pressure gauges, strong magnetic fields

Development of an optical Thomson scattering system for the Orion laser

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Thomson scattering in the optical-wavelength regime can be used to provide temporally- and spectrally-resolved information on under-dense, high temperature plasmas. Specifically, scattering from the high-frequency collective excitations of the electrons (plasma/Langmuir waves) can be used to constrain the temperature and number density of the electrons based on the width, amplitude and location of resonances in the scattered spectrum. Similarly, the width and amplitude of the low-frequency ionic excitations (acoustic waves) spectral features provide estimates of the ion and electron temperature ratio as well as the mean ionisation state of the plasma. Furthermore, the scattered light can be spectrally dispersed and streaked simultaneously allowing the time evolution of the plasma conditions to be studied.

In this presentation we discuss the development of an optical Thomson scattering diagnostic for the Orion laser system. A 3ω probe beam will be used and the light scattered by the volume of plasma under study will be collected using a reflective telescope system. Light from the ion and electron features can be split into two spectrometers, one covering the narrow bandwidth of the acoustic waves with high resolution and a second spectrometer to cover the broader wavelength range of the plasma waves. Time resolved data can then be obtained by relaying the spectrally resolved signal onto an optical streak camera.

Keywords: Thomson scattering, optical diagnostics, laser plasma

Pinhole camera as a tool for imaging of fast neutrons from the PF-24 plasma focus device at IFJ PAN

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A fast-neutron pinhole camera was designed and constructed at the Institute of Nuclear Physics of the Polish Academy of Sciences (IFJ PAN), Poland. This diagnostic tool is dedicated to the investigations of spatial and temporal distributions of neutrons from DD fusion reactions in the PF-24 plasma focus device.The detection system of the camera consists of BCF-12 small-area (5 mm x 5 mm) plastic scintillation detectors, located at the image plane, which are coupled via 25 meters long optical fibres to Hamamatsu H3164-10 photomultiplier tubes (PMTs). In order to reduce an inherent gamma-ray background, in front of the detectors and around the detectors a cone-shaped bismuth shield and a 40 mm thick lead shield were applied, respectively. The 420 mm long cylindrical copper collimator with an effective aperture of 1.7 mm ensures a high-quality neutron collimation while a cylindrical polyethylene tube, that surrounds the collimator, guarantees a proper shielding against the neutrons not propagating through the pinhole. This work presents first results obtained with the detection system in the mixed radiation fields (hard X-ray and neutron) of the PF-24 plasma focus device. The dynamics of the PF-24 neutron source in single discharges was reconstructed based on the signals from the four scintillator-PMT channels recorded with a digital oscilloscope.

Keywords: plasma focus device, pinhol camera, scintillation detectors, neutrons

Experimental test of the reconstruction method of the Laser-driven Ion-beam Trace Probe

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The Laser-driven Ion-beam Trace Probe (LITP), a new method to diagnose the poloidal magnetic field and radial electric field of tokamak plasmas, was first proposed in 2014 [1, 2], and the two-dimensional reconstruction theory of LITP was proposed in 2016 [3].
There are three parts of the LITP system: the laser-driven ion accelerator, the ion detector, and the reconstruction method. To validate the basic principle of LITP, a simplified test system was setup in the PKU Plasma Test (PPT) device [4]: a penning ion source is used instead of the laser-driven ion accelerator, and a scintillator-CCD system to simulate the ion detector. Adjustable ion energies and pitch angles of the penning source could simulate the wide energy spread and large angular distributions of the laser-driven ion beam. Scintillator-CCD system is used to detected ions which produce high space resolution. The reconstruction code has been upgraded according to the experimental parameters. In this paper, some preliminary experiment results will be reported. The accuracy of reconstructed q-profile, and the feasibility of LITP in the torus device will also be discussed.

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Keywords: LITP, plasma diagnostics, q profile, poloidal magnetic field

Application of two-photon-absorption laser induced fluorescence (TALIF) to study hydrogen isotope atomic surface loss coefficients on tungsten

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Plasma surface interaction (PSI) is considered to be one of the key scientific gap in realization of nuclear fusion. Interaction between hydrogen isotope and surface materials such as tungsten is of particular importance. The hydrogen isotope atomic surface loss coefficient (γ) is a key point in PSI studies. It can give information on hydrogen isotope inventory in the walls and is an important input for modeling. The aim of this project is to determine atomic hydrogen and deuterium (H/D) surface loss coefficient on tungsten (W) and tungsten nitride (WN) sample in a low-pressure radio-frequency inductively coupled plasma (ICP) by using two-photon-absorption laser induced fluorescence (TALIF) technique.

TALIF offers the possibility to determine relative and absolute density (with calibration) of atoms and also can give information about atomic temperature. It can probe ground state of hydrogen atom by absorbing two photons produced by commercially available lasers. In this project a10 cm diameter sample is introduced inside the ICP plasma chamber and pulsed plasma is used. Atoms are created during discharge and then laser pulse is applied to post-discharge to excite remained atoms. Decay of the atomic density in the post-discharge is correlated to the surface loss coefficient which can be deduced from the measurements. During plasma discharge atomic temperature (Ta) was increased, and then Ta will cool down during post-discharge. Since higher Ta lead to a wider Doppler broadening. For each delay, the laser wavelength is scanned over the line absorption profile to get the atomic density. Meanwhile, the time evolution of the atomic temperature is obtained. From the measurements, the surface loss coefficient on tungsten (W) for hydrogen atom (γH) is on the order of 10-2 in the early post discharge. The TALIF measurements also shows very high atomic temperature in the plasma and very fast cooling in the afterglow.

Keywords: laser induced fluorescence, surface loss coefficient

Development of the gas-puffing and supersonic molecular beam imaging diagnostic on HL-2A tokamak

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A new ultra-fast gas-puff imaging (GPI) diagnostic system has been developed on HL-2A tokamak to study plasma turbulence and the transport dynamics of Supersonic Molecular Beam Injection (SMBI) fueling at edge. A specially designed telescope and an ultra-high speed camera are used to observe and photograph the emission from the neutral gas cloud, typically helium or deuterium. The brightness and contrast of the two-dimensional (2D) radial vs poloidal frames reveal the structure of the turbulence or the interaction between the supersonic molecular beam and plasma. Neutral helium or deuterium gas is puffed into the plasma via a rectangular multi-capillary nozzle or the SMBI nozzle to generate gas cloud in different specially designed shapes. The diagnostics was put into service during the latest campaign under various discharge modes, including ohmic, L-mode and H-mode. Some initial engineering and experimental results will be presented and analyzed.

Keywords: tokamak, HL2A, GPI, SMBI, turbulence

Adjustable Kirckpatrick-Baez microscope as a diagnostic for laser-driven x-ray sources

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Kirckpatrick-Baez (KB) x-ray microscope systems [1] are used by different scientific communities, for imaging and focusing X ray radiation. Such devices can reach high spatial resolution, which make their use preferable for high accuracy measurements [2].
Here we present preliminary results in focusing laser-driven betatron radiation up to few tens of micrometers by using an adjustable KB microscope in the context of a CLPU experimental campaign whose goal is to use an ultrafast X-ray source to probe Warm Dense Matter.

The KB microscope has been developed at CLPU, in collaboration with University of Alberta. It is characterised by a relatively small size (21cm×31cm×27cm) and permits remote control and modification of both, the focal length and the grazing incidence angle. The current design is optimized for use at photon energies of around 1500 eV but can easily be modified for other x-ray energies.

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Keywords: x, ray, Kirckpatrick, Baez, microscope, imaging, spectroscopy, focusing, mirror, CLPU

First set of gated x-ray imaging diagnostics for the Laser Megajoule facility

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The Laser Megajoule facility started to operate in the early 2014 with one bundle consisting of two quadruplets (20 kJ at 351 nm) focused on target for the first experimental campaign. We present here the first set of gated x-ray imaging (GXI) diagnostics implemented on LMJ since mid-2014. This set consists of two imaging diagnostics with spatial, temporal, and broadband spectral resolution. These diagnostics will give basic measurements, during the entire life of the facility, such as position, structure, and balance of beams, but they will also be used to characterize gas filled target implosion symmetry and timing, to study x-ray radiography and hydrodynamic instabilities. The design requires a vulnerability approach, because components will operate in a harsh environment induced by neutron fluxes, gamma rays, debris, and shrapnel. Grazing incidence x-ray microscopes are fielded as far as possible away from the target to minimize potential damage and signal noise due to these sources. These imaging diagnostics incorporate microscopes with large source-to-optic distance and large size gated microchannel plate detectors. Microscopes include optics with grazing incidence mirrors, pinholes, and refractive lenses. Spatial, temporal, and spectral performances have been measured on x-ray tubes and UV lasers at CEA-DIF and at Physikalisch-Technische Bundesanstalt BESSY II synchrotron prior to be set on LMJ. First experiments on LMJ are presented here including results using the very recently commissioned second bundle.

Keywords: Plasma diagnostics, LMJ, optics, X-ray imagery

The DMX X-ray broad-band spectrometer for LMJ

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A primordial diagnostic for indirect-drive physics is an absolutely calibrated time-resolved spectrometer for absolutely calibrated measurement of the photon flux in the photon energy range from 0.05 keV to 6 keV, and up to 20 keV. LMJ-DMX has been especially developed to match the constraints of the Laser MegaJoule facility. DMX-LMJ is composed of a set of four diagnostics: firstly, a time resolved broad-band X-ray spectrometer, equivalent to DANTE at LLNL, made of 20 measurement channels (covering the 50 eV - 20 keV range) combining mirror, filters, specially designed flat X-ray diodes and high bandwidth scopes (time resolution of 100 ps), secondly, a time resolved soft X-ray spectrometer (100 eV - 1500 eV) with gratings and streak camera (time resolution of about 50 ps), thirdly, a time integrated X-ray Laser Entrance Hole imaging with pinhole and CID camera and fourthly a time resolved X-ray power measurement spectrally integrated. DMX-LMJ is now operating since winter 2015. Experimental set-up and first results are presented.

Keywords: Plasma diagnostics, ICF, LMJ, PETAL, X, ray spectrometer, temperature

Monochromators unfolded on x-ray generators to perform absolute calibration of Laser MégaJoule X-ray cameras over the 0.1-10 keV spectral range

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In the context of inertial Confinement Fusion (ICF) accurately calibrated and characterized x-ray diagnostics are a key requirement to correctly interpret experimental results. In the field of x-ray imaging diagnostics a wide variety of imaging sensors is currently used such as x-ray streak cameras, framing ones, CCD, hybrid CMOS sensors. To calibrate all these kinds of detectors, a laboratory is equipped by two x-ray generators to cover the 0.1-10 keV spectral region. To avoid bremsstrahlung emission not completely vanished by filtering a great effort is carried on since two years to develop x-ray monochromators. Both monochromators are combined with a new kind of vacuum manipulator which enables the simultaneous boarding of two detectors: a silicon drift detector to record the x-ray intensity of the monochromatic spectrum and the x-ray camera to be calibrated. Their first application consisted in calibrating an x-ray CCD in terms of quantum efficiency (QE). In this paper we present therefore both monochromators we developed and our calibration system. At last the QE results of the CCD are presented and compared to the manufacturer's model.

Keywords: Monochromator, x, ray calibration, x, ray camera

Thomson scattering system for high resolution measurements of electron temperature, density and drift velocity in the plasma pedestal of the ASDEX Upgrade tokamak

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A new Thomson scattering (TS) diagnostic system has been developed and installed in the ASDEX Upgrade tokamak for the study of fast electron dynamics in plasma pedestal. The diagnostic is being prepared for measurements in the 2017 campaign. A pedestal region is probed by 14 laser beams providing 2D measurements in a 30*30 mm^2 poloidal plasma cross section located at the low field side of the tokamak mid plane. The probing beams circulate in a multi-pass intra-cavity laser probing system delivering a high pulse probing energy in the plasma at a high repetition rate. The multi-pass spherical mirrors of the system are installed inside the tokamak vessel.

Scattered light from the probing region is collected along the toroidal direction by a light collection system installed in the tokamak vessel as well. Collected light is transmitted to a grating spectrometer with the use of two optically coupled fiber bundles. Spectra of scattered and plasma background light are intensified and measured by two fast CMOS cameras.

The radial and vertical resolutions of temperature and density measurements are ∼1 mm and 4 mm correspondingly. The high laser probing energy and the large etendue of collection optics enable to measure deviations of TS spectra caused by toroidal plasma current in the pedestal region with a vertical resolution of 30 mm. The repetition rate of the TS measurements is up to 10 kHz during 9 ms laser bursts. The system provides generation of up to 4 bursts along the plasma discharge with minimal time intervals between consecutive bursts of 0.5 s.

The paper describes details of the design, installation and measured parameters of the diagnostic system and discusses its performance in coming plasma experiments.

Keywords: Tokamak, ASDEX Upgrade, Thomson scattering, plasma pedestal

An Absolute Calibration Method for Doppler Coherence Imaging

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Doppler Coherence Imaging Spectroscopy (CIS) is maturing as a diagnostic method for measuring 2D ion velocity profiles in a variety of plasma environments. These measurements are being used in tokamaks to diagnose ion flow behavior in the divertor and scrape-off-layer (SOL) where velocities are measured up to 30 km/s (Doppler shifts $<$ 0.5 Å). To remove systematic offsets, CIS requires an excellent zero-velocity reference. Plasma fiducials can be used, however this method requires significant assumptions about plasma behavior and can restrict the available camera views. A spectral lamp can also be used as a reference by measuring the interferometric phase shift between the spectral lamp's known spectral output and the plasma's Doppler shifted emission. The difficulty with this approach is that the interferometer's inherent non-linearity introduces large extrapolation errors if the wavelength of the spectral lamp is not very close to that of the plasma. This error can be on the order of the measurement signal; an extrapolation distance of 30 Å results in a velocity error of 20 km/s. This problem has been solved through the development of a synthetic diagnostic that generates artificial interferograms based on the qualities of the birefringent crystal and the viewing optics. This allows the system non-linearity to be quantified and accounted for. However, careful crystal characterization and the elimination of environmental effects including ambient temperature, system vibration, stress-induced birefringence, and non-ideal optical coupling is required. Benchmarking this approach with Cu, Eu, Ti, Zn and Cd spectral lamps demonstrated an absolute accuracy on the order of 2 km/s over a 50 Å extrapolation distance. Implemented on the DIII-D tokamak's two CIS systems, the technique has resulted in greater measurement accuracy and a more flexible system able to measure absolutely calibrated velocities of multiple ion species.
Work supported by the US DOE under DE-AC52-07NA273441, DE-FC02-04ER546981.

Keywords: Coherence Imaging, DIII, D, Velocity, Spectroscopy

Measurements of density fluctuations in magnetic confined plasmas using Doppler backscattering technique

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Magnetic confinement fusion, which is one of two major branches of fusion energy research, has experienced major progress during the last decades. However, performances of present magnetic confinement machines, such as tokamaks, are limited by the development of micro-turbulence that generates most of the radial transport of heat and particles. The prediction and the control of energy confinement, and therefore of performances of such machines are thus important issues. A key element in the effort for understanding of turbulent transport is the confrontation between precise measurements and theoretical predictions.
A complete characterization of turbulence requires highly detailed measurements of fluctuations in the core of hot magnetized plasmas, where probes and cameras are not usable. Microwave scattering systems which combine advantages of both reflectometry and scattering techniques appear as a powerful technique for such purpose. As for reflectometry, the presence of a cut-off layer in the plasma brings a good spatial localization of the measurements. In addition, the scattering condition of probing waves scattered by the plasma fluctuations allows for spatial scale selectivity.

In particular, Doppler backscattering technique is based on the detection of the field backscattered on density fluctuations in the vicinity of the cut-off layer. In such system, the probing wave is launched in oblique incidence with respect to the normal of iso-index surfaces thereby only the back-scattered signal is detected by the emitter antenna, which also serves as a receptor. The fluctuations whose wave-number matches the Bragg rule are selected exclusively. This technique gives access to both spatial scales and dynamic of density fluctuations. Three " state of the art " systems have been installed on the French tokamak Tore Supra during several years, providing a complete characterization of density fluctuations including the repartition of energy fluctuation over the different spatial scales as well as the fine dynamics of fluctuations and turbulence generated flows.

The restart of the Tore Supra Tokamak is planned for April 2017, after a large modification of its magnetic configuration, under the new name of WEST. In addition to the updated Doppler systems, a new system, based on the detection of field backscattering in vicinity of the Upper Hybrid Resonance (UHRS) (instead of using the cut-off) will be installed on WEST. Such system should allow the measurement of smaller scale turbulence as compared to the Doppler system.
In this contribution, descriptions of both Doppler and Upper Hybrid Resonance Scattering techniques as well as main results obtained in Tore Supra using Doppler backscattering system will be presented.

Keywords: turbulence, micro, wave, dynamics

Conceptual design of a dispersion interferometer polarimeter for ITER

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To achieve improved availability, ITER will operate with two main diagnostics for line-averaged density measurement. The newly designed Density Interferometer Polarimeter (DIP) will work in parallel with the 5-chord Toroidal Interferometer Polarimeter (TIP), designed by the US-DA. The DIP is a dispersion interferometer which will have 2 chords – one radial and one tangential – entering the vacuum vessel through the Equatorial Port Plug #08 with corner-cube retroreflectors (CCR) located in Equatorial Port Plug #03 and the blanket first-wall.
The tangential chord will also operate as a polarimeter. CO2 lasers are foreseen with wavelengths around 10 μm. The choice of wavelength is a balance between the risks linked to first mirror reflectivity degradation (for 1 μm), to the beam refraction and sensitivity to fringe jumps (for 100 μm). The required time resolution of 10 kHz is achieved using Photoelastic Modulators (PEMs) with the option of reaching the MHz range using Acousto-Optic Modulators. Both the DIP and the TIP each meet or exceed the requirements for Basic Control of the plasma and can be monitored and selected as needed by the Plasma Control System during operation.

The DIP radial chord will be available for ITER first plasma using a temporary in-vessel CCR mounted on the vacuum vessel inner wall. For the subsequent plasma phases, this CCR will be replaced by one embedded in the blanket first wall. The tangential chord will be available after First Plasma and its retro-reflector will be much better protected deep inside an equatorial port plug. Beam alignment will be achieved using detectors and piezo-actuators located in the Port Cell. Window materials have been selected for the double vacuum windows (BaF2) and for the secondary zoning windows (ZnSe).
The DIP design will be assessed at a conceptual design review before proceeding to the preliminary detailed design phase.

Keywords: dispersion interferometer polarimeter ITER

Enhancements of JET Diagnostic Capabilities in Preparation for DT Scientific Campaigns

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In order to complete the exploitation of the JET ITER-like Wall and to take full benefit from deuterium-tritium experiments on JET, a set of diagnostic system refurbishments or upgrades is in different stages of development. These diagnostic enhancements focus mainly on neutron, gamma, fast ions, instabilities and operations support. This effort intends to provide better spatial, temporal and energy resolution while increasing measurement coverage. Guaranteeing diagnostic reliability and consistency during the expected DT conditions is also a critical objective of the work and systems being implemented. Also previously non existing capabilities, such as Doppler Reflectometry, are now available for scientific exploitation. Furthermore initial experimental results have been obtained by a new set of Vertical Neutron Spectrometers and with the refurbished Toroidal Alfvén Eigenmode diagnostic system. An overview of status and scope of the ongoing projects is presented.

Keywords: Nuclear Fusion, Diagnostics

Status of neutron emission spectroscopy diagnostics at the EAST tokamak

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The measurement of DD fusion neutrons is one of important diagnostics of high temperature plasma in EAST. Compact neutron spectrometers, based on liquid scintillators, a stilbene crystal detector and a scCVD diamond detector with 5 μm of LiF layer, have been developed. New digital pulse shape discrimination techniques, including the moment analysis (MA) and digital delay-line-shape (DDLS) method, are presented and a count rate of about 45 kHz has been achieved with good neutron/gamma discrimination performances. The well-characterized spectrometers have been employed for fusion plasma diagnostics, and plasma ion temperature values were deduced from the measured neutron spectra in DD discharges with lower hybrid wave injection and ion cyclotron resonance heating.
The prototype neutron time-of-flight enhanced diagnostics (TOFED) spectrometer has been developed for deuterium plasma operation in EAST in order to provide the essential information on ion temperature, fuel ion composition and the neutron yield rate of the plasma related to fusion power and also understand the behavior of fast ions of external auxiliary power. The TOFED design, where the ring of second plastic scintillators (S2) is split into two spherical zones, is shown to enhance the discrimination capability and will provide fusion neutron spectra with reduced admixture of multiple scattering events, which is essential for increasing the sensitivity to weak components in the neutron emission. The prototype TOFED spectrometer consists of 32 S2 plastic scintillators and a five-layered detector (S1) assembly coupled to photomultiplier tubes. A new fully digital data acquisition system with on-board CFD timing function has been adopted and can provide a time resolution <500 ps, compatible with high count rate capability up to about 1 MHz/channel of the prototype TOFED spectrometer. TOFED is expected to have high energy resolution of 6.6% for deuterium-deuterium neutrons. On the other hand, the preliminary implications of measuring the neutron emission on EAST together with the experimental challenges are presented, and limitation of this system and ways of further improvement are suggested.

Keywords: neutron Emission spectroscopy, time, of, flight, compact spectrometer, ion temperature, EAST