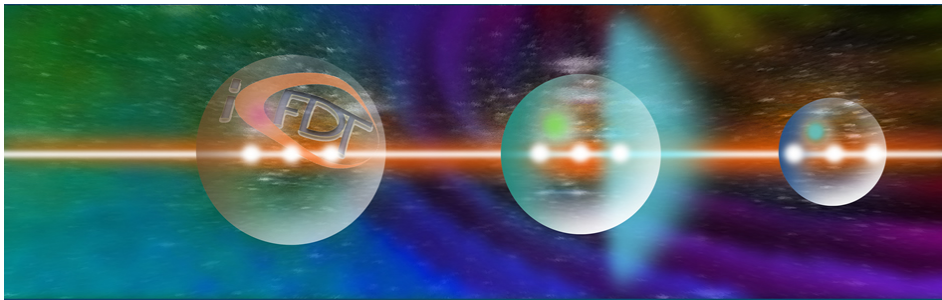


# **ICFDT5 - 5th International Conference on Frontier in Diagnostic Technologies**

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## **Book of Abstracts**



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## POSTER SESSION / 0

**SNIP-based algorithm for gamma-ray spectrum analysis****Author:** Maciej Linczuk<sup>1</sup>**Co-author:** Izabella Zychor<sup>2</sup><sup>1</sup> *Warsaw University of Technology, Institute of Electronics Systems*<sup>2</sup> *National Centre for Nuclear Research, Poland***Corresponding Author:** mlinczuk@elka.pw.edu.pl

Scintillators are commonly used in many gamma-ray experiments because they are characterized by a good energy resolution and a rather high detection efficiency for a few MeV gamma-rays. Gamma-ray peaks, especially full energy, single escape and double escape peaks registered in scintillators, are relatively broad and observed on a high non-linear background. Any software dealing with the analysis of gamma-ray spectrum has to find peaks and estimate the following peak shape parameters: position, height, width, and a number of counts.

The presented software was prepared for analysis of gamma-ray spectra registered in scintillators. Peak finding is based on the Sensitive Nonlinear Iterative Peak (SNIP) algorithm and peak analysis - on CERN ROOT libraries. An estimation process is automated with a limited number of input values.

A sum of Gaussian and linear function is used to approximate peaks. Because such a function is nonlinear, an iterative method to find peak shape parameters has to be applied. As a result of a computation process, a mean value and a variance of the Gaussian function that corresponds to a location and a peak width are determined. In addition, measures of goodness of fit are computed, i.e. the number of degrees of freedom and results of  $\chi^2$  tests. Results of estimation are presented graphically and saved to a text file. The software was written in C++ language.

Gamma-ray spectra measured with scintillators were used to demonstrate properties of the prepared software.

This scientific work was partly supported by Polish Ministry of Science and Higher Education within the framework of the scientific financial resources in the years 2015-2018 allocated for the realization of the international co-financed project.

**Astrophysics / 2****X-ray diagnostics and technologies for High Energy Astrophysics****Author:** Yuri Evangelista<sup>1</sup><sup>1</sup> *ROMA2***Corresponding Author:** yuri.evangelista@roma2.infn.it

High energy radiation from celestial objects is one of the most powerful diagnostic tools to access and understand the mechanisms underlying the most energetic and violent phenomena in our Universe. The X-ray range (0.5-20 keV) is particularly suitable for this investigation thanks to a mature detector and optics technology. Spectral, timing and polarimetric radiation signatures at these energies offer a direct access to plasma in environments hosting extreme conditions of gravity, density or magnetic field.

The need for high sensitivity spectroscopic, timing and polarimetric experiments has inspired in the last years intensive R&D programs focused on the development of innovative imaging photoelectric polarimeters and fast, pixelated and large-area Silicon Drift Detectors (SDDs). These activities, carried out by the Italian National Institutes for Astrophysics (INAF) and Nuclear Physics (INFN),

has led to the design, production and test of several space instruments on upcoming or future space missions.

In this paper I will report about the most recent developments in the field, highlighting their innovative and multi-disciplinary aspects.

### Data Mining / 3

## A Model Falsification Approach to Learning in Non-Stationary Environments for Experimental Design

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The application of machine learning and advanced statistical tools to complex physics experiments becomes very problematic, when the i.i.d. (independent and identical distribution) hypothesis is not verified, due the varying conditions of the systems to be studied. In particular, new experiments have to be executed in unexplored regions of the operational space. As a consequence, the input quantities used to train and test the performance of the tools are not necessarily sampled by the same probability distribution as in the final applications. In the present study, a new data driven methodology is proposed to guide planning of experiments and to explore the operational space. The approach is based on Symbolic Regression via Genetic Programming to the available data, which allows identifying a set of candidate models. The confidence intervals for the predictions of such models permit to find the best region of the parameter space for their falsification, where the next set of experiments can be more profitably carried out. The procedure is repeated until convergence on a satisfactory model. Extensive numerical tests and applications to the scaling laws in Tokamaks prove the viability of the proposed approach.

### Industrial Plasmas / 4

## Plasma characterization in Hall thrusters by Langmuir probes

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Hall thruster (HT) technology is a mature propulsive option for orbit-raising and station-keeping of satellites, benefiting from both widespread R&D activities and heritage of in-space applications. A typical Hall thruster assembly essentially consists of an acceleration channel, often made of ceramic material, a magnetic circuit and two electrodes, i.e. the anode and the cathode. The magnetic field configuration of the thruster has a significant role in the acceleration process and, at the same time, on the wear of the thruster surfaces due to the ion bombardment. The aim of the present research activity was to study different, non-standard magnetic field configurations of a 5 kW HT, looking for an optimal compromise between the reduction of thruster erosion and its performance. The prototype tested was a flexible thruster mock-up based on SITAEL HT5k. The mock-up thruster was

equipped with four arrays of flat tungsten probes, installed in the inner and outer channel walls to characterize the near-wall plasma properties at the channel exit. Furthermore, in order to obtain a complete characterization of the plasma behaviour inside the thruster, a triple Langmuir probe was used. The triple Langmuir probe was mounted on an articulated arm that rapidly inserted the probe inside the thruster channel, giving a clear picture of the relevant plasma properties along the channel centreline, from the near plume to the near-anode region. For each operating condition of the thruster, measurements were performed with different arrangements of the triple probe electrodes and with different applied potential differences between the electrodes. In order to analyse the data gathered by the triple probe, a Bayesian integrated data analysis was used. This method made it possible to combine measurements from different probe configurations and to improve the quality of the inferred plasma parameters. Non-uniformities of the plasma sensed by the probe electrodes were taken into account within the physical model considered to make the analysis. In order to model the interaction of the electrodes with the plasma, a parametrization of the Laframboise sheath solution was used. The performed experimental investigation, coupled with a reduced order model of the thruster plasma discharge, allowed reconstructing the profiles of the plasma properties along the discharge channel and near the thruster walls. The developed diagnostic system, together with the integrated data analysis, proved to be an effective tool to characterize the plasma flow in Hall thrusters.

## POSTER SESSION / 5

### Plume Characterization of a High Current LaB6 Hollow Cathode

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Lanthanum hexaboride hollow cathodes have been the prime choice for high power Hall thruster applications, under development for the next generation of manned and robotic interplanetary missions. In this scenario, SITAEL is actively developing high current hollow cathodes capable of providing discharge current in the range 10-100 A to be coupled with high power Hall thrusters.

Despite the application of hollow cathodes on flight and laboratory model Hall thrusters, many unsolved questions still remain. In particular, topics related to onset of instabilities, due to plume mode or ion acoustic turbulence, are still unclear, while it is known that they can affect the overall performance of the cathode and thruster unit.

This research focuses on the experimental investigation of the plume exiting the cathode by means of measurements of main plasma parameters, at different operative conditions and geometry.

The cathode subjected to the study, named HC60, can provide discharge current in the range 30-80 A, and it has been coupled with SITAEL HT20k, a 20 kW power Hall thruster. The cathode is made of a LaB6 cylindrical emitter in a refractory metal tube; it hosts heaters to warm up the cathode prior to ignition, and it is surrounded by an electrode named keeper, acting also as protective element.

The experimental campaign has been performed using triple Langmuir probes as plasma diagnostic system. The probes were mounted on scanning mechanisms capable of measuring the parameters of the plume at various radial and axial distances from the keeper exit. The HC60 was mounted in stand-alone configuration with a cylindrical anode to simulate the thruster unit environment, and it was placed in a vacuum facility suitable for cathode testing.

The analysis on the probes measurements and the resulting plasma parameters are presented. General trends of electron temperature, plasma potential and plasma density are evaluated in terms of discharge current, mass flow rate and orifice geometry. The results highlight stable operative conditions of the cathode in the current range required by the thruster.

## POSTER SESSION / 6

## Ultrafast diagnostic for ultrashort laser pulse, applied to the VUL-CAN and FLAME laser systems

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The complete characterization of the laser pulse parameters was made using a new algorithmic method: GRenouille/FrOG (GROG), based on the 1D Conjugate Gradient Minimization Method. The purpose is, analyzing experimental FROG/GRENOUILLE traces, to accurately retrieve intensity and phase both in the temporal and spectral domain so as to completely characterize an Ultra Short High Power laser pulse. This algorithm shows important features in the reconstruction of many different pulse classes. The employment of this algorithm also permits the inclusion of material response function present in the FROG/GRENOUILLE set-up.

The GRENOUILLE traces of FLAME Probe line pulses (60 mJ, 70 fs, 10 Hz) were acquired in the FLAME Front End Area (FFEA) at the Laboratori Nazionali di Frascati (LNF), Istituto Nazionale di Fisica Nucleare (INFN).

A FROG diagnostic is being developed in Central Laser Facility in RAL able to characterize the 100J, 1.4ps, 2nm @1053.5 nm laser pulses in Target Area West (TAW).

## Data Mining / 7

## Causality detection methods for time series analysis

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Coupling and synchronization are common phenomena that occur in nature, e.g. in biological, physiological and environmental systems, as well as in physics and engineered systems. Depending on the coupling strength, the systems may undergo phase synchronization, generalized synchronization, lag synchronization and complete synchronization [1]. Lag or intermittent lag synchronization, where the difference between the output of one system and the time-delayed output of a second system are asymptotically bounded, is the typical case of the fusion plasma instability control by pace-making techniques [2-3]. The major issue, in determining the efficiency of the pacing techniques, resides in the periodic or quasiperiodic nature of the plasma instabilities occurrence. After the perturbation induced by the control systems, if enough time is allowed to pass, the instabilities are bound to reoccur. Therefore, it is crucial to determine an appropriate interval over which the pacing techniques can have a real influence and an effective triggering capability.

Several independent classes of statistical indicators developed to address this issue are presented.

The transfer entropy [4] is a powerful tool for measuring the causation between dynamical events. The amount of information exchanged between two systems depends not only the magnitude but also the direction of the cause-effect relation. Recurrence plots (RP) is an advanced technique of nonlinear data analysis, revealing all the times when the phase space trajectory of the dynamical system visits roughly the same area in the phase space [5]. RP refinement, called joint recurrence plots (JRPs), can be used to relate the behavior of one signal with the one of another. Convergent cross mapping (CCM) [6], tests for causation by measuring the extent to which the historical record of one time series Y values can reliably estimate states of another time series X. CCM searches for the signature of X in Y's time series by detecting whether there is a correspondence between the "library" of points, in the attractor manifold built from Y, and points in the X manifold. The two manifolds are constructed from lagged coordinates of the two time-series. The Weighted Cross Visibility Graph (WCVG) method [7] starts from the idea of mapping the coupled time series into a complex network [8] and evaluates its structural complexity by mean of the Shannon entropy of the modified adjacency matrix (constructed by weighting the connections with the metric distance between two connected values in the time series).

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## POSTER SESSION / 8

### Gamma-ray Imaging of Fusion Plasmas

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Gamma-ray diagnostics are some of the most important tools for the fast-ion studies in fusion devices. Intense gamma-ray emission is produced when fast ions (fusion products, ICRF driven ions and NBI-injected ions) react either with plasma fuel ions or with the plasma impurities such as beryllium and carbon [1]. On JET, the gamma-ray emission measurements are routinely used to interpret different fast ion physics effects arising during ICRF and NBI heating. Spatial profiles of the gamma-ray emission in the energy range  $E_\gamma > 1$  MeV are tomographically reconstructed on JET by using the gamma-ray cameras [2], which comprise two fan shaped multi-collimator cameras, with 10 channels in the horizontal camera and 9 channels in the vertical camera. The 2-D slice determined by the 19 lines of sights (LOS) is in the poloidal plane and has a thickness of approximately 75 mm. Integrated gamma-ray measurements along the 19 LOSs are used as input signals to determine the two-dimensional (2-D) spatial distribution of the gamma emission intensity.

Due to the availability of only a limited number views and to the coarse sampling of the LOS, the measurements themselves do not identify a unique solution and therefore the tomographic inversion is a limited data set problem. Therefore, appropriate algorithms, able to work with the specific constraints and allowing effective tomography from the available limited data, have been developed. The method developed by Ingesson et al. [3] is based on a series expansion of the reconstructed image, with a grid of pyramid local basis functions. The solution is found by a constrained optimization, which uses anisotropic smoothness on flux surfaces as objective function (a priori physical information about the expected emission profile) and measurements as constraints. The approach based on the Maximum Likelihood (ML) method [4] finds the estimate of the emissivity distribution

that is most consistent with the measured tomographic projections in the sense of maximizing the likelihood (conditional probability of the data given the parameters). The regularization procedure assumes smoothness along magnetic profiles. Recently an algorithm based on a generalization of the known Abel inversion and taking into account the non-circular shape of the plasma flux surfaces has been proposed [5]. Methods, based on the Fisher information and already successfully applied for JET neutron tomography [5], may represent also a valuable solution.

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## Diagnostics for fusion reactors / 9

### Electron Density Measurement of PROTO-SPHERA Plasma by Second Harmonic Interferometer

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The PROTO-SPHERA (PS) [1] experiment at Frascati ENEA Research Centre produce a Spherical Torus (ST) around a Plasma Centerpost (PC). The PC is an arc discharge driven by DC voltage between two annular electrodes.

This alternative and stable magnetic configuration is obtained without the internal toroidal coils and without the central ohmic transformer of a traditional tokamak. In fact, the PC, opportunely shaped by the PF Coils internal to the vessel, together with additional external poloidal field coils, forms the torus and is able to sustain its current through magnetic reconnections; moreover the torus is limited by two ordinary X-points with zero poloidal field, as in a double null divertor tokamak.

After resolving many issues, the device was capable to routinely operate with a 10 kA stable longitudinal current in the PC, and 5 kA in the Torus for 0.5 seconds. In order to measure the electron density inside PS, we selected a common-path Second Harmonic Interferometer (SHI) that fits well with the expected density range and construction constraints of the chamber. The SHI [2], developed by Pisa group and installed in several plasma devices along many years is insensitive-to-vibrations device, that has allowed an easy installation on the machine, thanks to a compact modular design.

In this work, we present the electron density measurements for different gases

(Ar and H) in various operating conditions and its correlation with other diagnostics.

In comparable plasma configurations, by using two filling gases,

the maximum line-averaged electron density through the machine midplane of PS was measured as  $4 \cdot 10^{20} \text{ m}^{-3}$  for Argon and as  $1.5 \cdot 10^{20} \text{ m}^{-3}$  for Hydrogen.

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## POSTER SESSION / 10

## Absolute calibration of Fujifilm BAS-TR image plate response to high energy protons in the range 10-40 MeV

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Imaging Plates (IPs), relying on photo-stimulated luminescence (PSL) are amongst the most popular and reliable detectors for laser driven particle acceleration experiments. IPs are composed of an active layer on top of a magnetic base [1]. The Fujifilm BAS-SR and BAS-MS brands of imaging plate also have a protective layer over the active layer, however the BAS-TR, which this presentation will focus on, does not. The active layer is usually composed of europium doped barium fluoride phosphor, BaFBr0.85I0.15:Eu2+. When ionizing radiation is incident on the active layer, the above molecule is promoted to an excited, metastable state which can persist for several hours. The state can decay either via spontaneous emission or by stimulated emission when irradiated by light at an appropriate wavelength. Image plate scanners use red laser radiation to stimulate the emission of a 400nm photon, which is then detected and recorded in the scanner as a pixel value. This pixel value can be converted, using a formula provided by Fujifilm [2], to a parameter known as the PSL value. The PSL value at any point is related to the type of ionising radiation, as well as the energy and number of particles incident at that point. The response of protons to this brand of IP has been previously calibrated up to 20 MeV in laser driven acceleration experiments [3], and from 80-200 MeV using a conventional linear accelerator [4].

In this experiment, the response of Fujifilm BAS-TR image plates to high energy laser accelerated protons up to 40 MeV has been determined. These were calibrated using a Thomson parabola spectrometer and CR-39 solid state detector to determine absolute proton number in specific energy ranges determined through the use of iron or copper filters placed in front of the CR-39. This calibration fills the gap in the literature which has existed for energies between 20 and 80 MeV and is in agreement with the previous works. Proton spectra were taken from the Thomson parabola spectrometer to compare the new calibration with a previous one. The two spectra were found to be in good agreement, confirming the validity of the technique.

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## POSTER SESSION / 11

## Investigation of Near-Frequency Spectral Features by 140 GHz Wave Probing Using a Smart Scattering Setup

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A certain number of plasma parameters can be diagnosed with a technique implemented in the last decades in several tokamak devices, which exploits the detection of emissions due to Collective Thomson Scattering (CTS) of a probe radiation by plasma ion populations. Since the beginning, this diagnostic was mainly developed to locally measure the spectral power density which gives information either on the plasma bulk or on the fast ion dynamics by temporally resolved measurements. Also in ITER, a CTS system for fast ion detection, exploiting a 60 GHz probe beam, will be integrated for measurements of the velocity distributions of confined fast alpha particles.

The possibility of using the same CTS setup, designed for measuring ion dynamics, to investigate also the occurrence of non-linear phenomena such as Parametric Decay Instabilities (PDIs) was demonstrated [1]. In particular, low-power thresholds of PDIs, as described by newly developed theoretical models [2], recently started to raise interest in the scientific community. The reason lies in the fact that emissions expected to be due to such processes could be detected with the microwave diagnostics of different devices with ECRH during standard CTS measurements and that, according to predictions, they have power thresholds of the same order of magnitude of the typical electron cyclotron power applied for heating and current drive in fusion plasmas.

The CTS diagnostic installed on the FTU tokamak, operating at 140 GHz, has been upgraded during the last years [3]. The aim for such renovation is to allow observing both CTS thermal spectra (due to the well known mechanism of a probe wave scattering off electron density fluctuations, governed by the collective behavior of particles) and PDI signals in the FTU scenarios, and investigate their possible effects on the injected gyrotron beam, which should be described by non-linear processes. The present status of this activity and the most recent improvements in the CTS diagnostic of FTU are described in this work.

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## Data Mining / 12

# Statistical learning theory for scientific applications: an overview

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The statistical learning theory allows the estimation of functional dependency from a given collection of data. It includes discriminant analysis, regression analysis and the density estimation problem. It

is used to obtain data-driven models to relate heterogeneous quantities with the aim of making predictions. In science, statistical learning is an essential theory to find relationships among quantities whose formulation cannot be deduced from first principles. This talk summarizes the use of statistical learning methods in scientific problems: from unsupervised techniques to supervised techniques, from simple predictions to probabilistic predictions, from non-parametric estimations to parametric estimations, from real-time needs to off-line needs and from standard datasets of information to privileged datasets of information. Concepts and examples will be given.

#### Special session: Advanced techniques of acceleration / 13

### Laser diagnostics for particle acceleration experiments

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In the last years the power of the laser increases dramatically reaching Petawatt level. This unique high power is achieved mainly by decreasing the pulse duration down to tens of femtosecond. The characterization of this laser pulses requires special techniques, creating a research field on it's on. In addition to that, the high power increases the difficulty of fully characterize this laser system. This problem could be divided in different fields: short pulse characterization, contrast, beam characterization and beam sampling. Each of these fields are related to a particular parameter and/or problem.

All these fields will be discussed in the talk, within benefit and/or limitation of the different techniques and the different issue in setting up the diagnostic for a high power laser beam, focusing the emphasis on the laser parameters crucial for the electron acceleration experiments, like pointing stability and pulse front tilt.

Finally, a brief introduction of the new short pulse beamline in construction at the Vulcan facility, aiming to delivery 20J in 30fs for betatron imaging, will be presented, with the plan for the short pulse diagnostics.

#### POSTER SESSION / 14

### Absolute Calibration of Thomson Parabola-Micro Channel Plate (MCP) for multi-MeV laser driven carbon ions

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Laser driven ions have gained significant attention due some of their unique properties making them a potential source of high energy radiation for a range of applications including particle therapy.

Current facilities produce particles up to ~100 MeV with an ultra-short duration (~1ps at the source)<sup>1</sup>. Some of these facilities, typically the ones based on Ti:Sapphire, ultra-short pulse lasers, have a high repetition rate which makes the use of some diagnostics the limiting factor for data collection during experiments. Future facilities such as the Extreme Light Infrastructure will operate at 1 shot per minute or less<sup>2</sup>. The Thomson Parabola Spectrometer (TPS) is a widely used diagnostic for determining the maximum energy and the spectrum of each species generated in the interaction. Image Plates (IP) are typically used as the detector in TPSs since they are well calibrated for high energy particles<sup>3,4</sup> and are easy to set up. However, IPs are slow to process and typically require breaking the vacuum of the interaction chamber in order to do so.

These disadvantages can be overcome by using MicroChannel Plates (MCPs) which act as an electron multiplier to incident ionizing radiation. The electrons are accelerated by a potential difference towards a phosphor screen which fluoresces and an image is collected onto a CCD. This allows for an on-shot ion energy diagnostic, when used with a TPS, which can be collected remotely and can be used again instantly thus not limiting the frequency of laser shots.

The particle spectrum is an important measurement as spectral features can indicate the acceleration process occurring and particle numbers are important, e.g. when looking to use the ion beams for radiobiological purposes. Thus, it is important to calibrate the detector in absolute terms, and we present here a calibration procedure for high energy Carbon ions. The MCP calibration was done for C<sup>6+</sup>, the dominant species generated in the interaction, up to 21MeV/u (252MeV) using the Gemini laser at RAL (U.K.), focused at an intensity of ~5x10<sup>20</sup>W/cm<sup>2</sup> onto a 15nm amorphous carbon target. The calibration, which can be extended to higher energies by using a fit to the calibration data, was obtained by using slotted CR-39 so that the pixel value from the detector can be directly compared to the absolute number of particles counted on the CR-39 at a number of different energies. A calibration can then be built up by measuring the response of the MCP to these ions of varying energy. Previous calibrations have been done at much lower energies<sup>5,6</sup> thus our work extends significantly these previous efforts.

This calibration is of particular importance in the perspective of developing diagnostic approaches capable of performing at high repetition rate on the next generation of lasers where high energy ions will be readily generated and a reliable online measurement of their spectra will be required.

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#### Fast events - Inertial Confinement / 15

### Characterization of intense electromagnetic fields in the radiofrequency-microwave regime generated by powerful laser-matter interaction

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The measurement of intense electromagnetic fields in the radiofrequency-microwave regime in experiments of laser interaction with matter is a hot topic both in laser-plasma particle-acceleration context and in inertial-confinement-fusion one. Fields up to MV/m intensity are generated in powerful interactions, but their characterization is a very delicate and complex issue, especially when using classical conductive probes. In this work we describe the measurements of these fields by means of electro-optic methods based on Pockels effect, capable to give accurate field characterization in very harsh environments for laser intensities up to the petawatt range. We describe also the techniques used in some experiments with high-intensity and high-energy lasers to achieve suitable field measurements also by means of classical conductive probes (a).

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## POSTER SESSION / 16

### Sensitivity improvement by optically-absorbent plastics of electro-optical probes for high-intensity electromagnetic-fields generated by laser-matter interaction

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Radiofrequency-microwave electromagnetic pulses (EMPs) of high intensity generated by powerful pulsed laser-matter interaction are a very hot topic of research. They are often detrimental for active diagnostics placed around the interaction region, but could be used for diagnostic purposes or for application to studies on materials and devices in these extreme conditions. This is a common and important issue in facilities for Inertial Confinement Fusion and Laser-Plasma Acceleration using solid-state near-infrared lasers of high energy and intensity. The reliable measurement of these intense fields by classical conductive probes is a well-known hard task because of the high level of electromagnetic background noise affecting the measurement setups. Fully electro-optical probes proved to be a very interesting solution to this problem even at petawatt laser pulse regimes, leading to the accurate measurement of fields up to hundreds of kV/m. A CW laser is commonly used to monitor the properties of the dielectric permittivity tensor of a crystal; because of Pockels effect, it changes according to an externally-applied electromagnetic field. In some experiments we found

that part of the diffused main laser-pulse may occasionally be coupled to the optical path of the probing CW laser within the crystal. Due to the high intensity of the main pulse, we found experimentally that even slight couplings may lead to important reductions of the measurement field sensitivity on the first nanoseconds. A solution to this problem could be the use of thick plastic shields for the crystal, highly absorbing for the main laser wavelength, but at the same time highly transparent to the wide radiofrequency-microwave range of the EMP fields to be measured. For this reason we performed two experimental campaigns for the electromagnetic absorption characterization of several plastic materials in both the two frequency ranges. A spectrophotometer operating in the visible and near-infrared spectral interval was used for the characterization of the optical absorption and a Dual TEM Cell for the radiofrequency-microwave transmission. Results of experimental measurements for several materials will be described and discussed for the effective improvement of the EMP electro-optical probe sensitivity (a)

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## POSTER SESSION / 17

### Irradiation and dosimetry arrangement for a radiobiological experiment employing laser-accelerated protons

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Due to the phenomenon of the Bragg Peak, the use of charged particle beams in cancer treatment allows for precise energy deposition in a tumour, whilst largely reducing the dose deposited to the surrounding healthy tissue in comparison with treatment from traditional photon radiotherapy. However, the residual dose that is deposited to the surrounding area is non-negligible and may result in cell death or sub-lethal cell damage, although the full extent of this biological impact is uncertain. Additionally, the role of the particle dose rate on these effects is unknown, and motivates radiobiology experiments with particle beams accelerated through innovative, laser-driven processes enabling the delivery of ultrashort bursts protons at extremely high dose rates, in excess of  $10^9$  Gy/s. These studies are also of relevance in view of the proposed use of laser-driven ions as an alternative to RF accelerators for future radiotherapy.

In light of the peculiar properties of laser-driven ion beams (high-flux, divergence, short pulse duration, broadband spectrum), carrying out radiobiology experiments with laser-accelerated ions, as well as characterizing the dose delivered to the samples, requires bespoke solutions which differ significantly from the arrangements typically employed on conventional accelerators or microbeams. We report on the dosimetric and irradiation arrangement employed in an experiment carried out in the LULI2000 facility (pico2000 beamline), where a laser-driven proton was used to irradiate human cell line samples (HUVEC cells and AGO1522 fibroblasts). A series of biological assays were carried out in the LULI2000 laser facility using the pico2000 beamline; clonogenic, senescence and FOCI assays. The laser beamline delivered 80J in  $\sim 1$  ps pulses at 1 w at a repetition rate of approximately 1 shot every 90 minutes. The proton beam accelerated from a foil was dispersed by a magnetic system and used to irradiate the cells through a transmission window located on an insertion tube. Dosimetry was carried out through the use of high sensitivity EBT-3 Gafchromic films (customized so the protective top layer was removed), and CR-39. These dosimeters were placed immediately after the

film substrate where upon the cells were deposited in order to monitor the dose deposition of the sample on a shot to shot basis.

## POSTER SESSION / 18

### Optical diagnostics applied on Proto-Sphera plasmas

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Proto-Sphera is an innovative plasma confinement concept based on the formation of a toroidal plasma around an axial screw pinch which provides the toroidal magnetic field. Optical emission (OE) from the Proto-Sphera device is detected by a compact spectrometer array covering the range 235-790 nm with the resolution from 0.09 nm in UV to 0.14 nm in IR. Plasmas formed in both Argon and Hydrogen gases are studied. The spectra are registered each 5 ms in order to study the time evolution of different species in the plasma that include H I, O I, Cu I and Cu II coming from the cathode erosion, C I present due to the wall erosion, and Ar I to Ar III in case of the discharge in argon environment. Simultaneously, the transmitted intensity of a collimated He-Ne laser beam, crossing the chamber towards the detection system, is also monitored. The optical system is equipped with a variable focusing in order to collect the signal mainly from the reactor's center ( $R = 0$ ) or at distances from the center up to the plasma edge ( $R \approx -30$  cm). In presence of the plasma, which is almost spherical around the reactor's center, the detected He-Ne line intensity increases, likely because of the radial distribution of the electron density, having a peak at the center, as confirmed by the spatially resolved OE spectroscopy. From the latter data, in case of H environment the central plasma column seems to be almost fully ionized after about 30 ms from the discharge ignition and has a rapid drop of the electron density beyond 10 cm from the center. Basing on the ionic to atomic line intensity ratios, the central plasma temperature is maximum shortly before turning off the discharge while the electron density in hydrogen decreases due to the plasma expansion, differently from the more compact Ar plasma. With the aim to reach the absolute values of the plasma parameters, the acquired temporally and spatially resolved spectroscopic data will be exploited to simulate the plasma (de)focusing effect and as an input for the interferometric measurements that presently considers an uniform electron density across the observation path and thus supplies only the average value.

## Fast events - Inertial Confinement / 19

### Spectral characterization by CVD diamond detectors of energetic protons from high-repetition rate laser for aneutronic nuclear fusion experiments

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The use of high-power femtosecond lasers to accelerate particles through the Target Normal Sheath Acceleration (TNSA) process is one of the most active fields of research of the last years. Protons have been produced in facilities worldwide, with energies up to tens of MeVs. For some applications the main requirement is to maximize the particle flux in a specific energy range. For aneutronic p+11B fusion reaction, the most suitable proton energies are of the order of a few hundreds of keVs, corresponding to resonances in the fusion reaction cross-section. Prominent candidates to give reliable results in terms of time-of-flight diagnostics of the accelerated protons in this range of energies are the Chemical Vapor Deposition (CVD) monocrystalline diamonds detectors we developed, which are also specifically designed to operate in harsh environments where large ElectroMagnetic Pulses (EMPs) are generated during laser-target interaction.

In this work we describe the results of experiments performed at the femtosecond ECLIPSE laser facility at CELIA in Bordeaux. We irradiated targets constituted by aluminum foils of various thicknesses and, by means of the diamond detectors, we characterized the accelerated protons with energies in the range of interest for p+11B nuclear fusion. The 1 Hz high repetition rate used for the ECLIPSE laser allowed the collection of a large number of similar shots, giving therefore a large statistics to accurately characterize the energy spectrum of the laser-plasma accelerated protons. The laser repetitiveness at a relatively small intensity permits to improve the signal to noise ratio of the detection of the products of low cross-section reactions, as the p+11B fusion reaction, by their collection over a large number of similar shots.

## POSTER SESSION / 21

### TOF diagnosis of laser accelerated high-energy protons using diamond detector

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Significant challenges in the detection of laser-accelerated ions result from the high flux ( $10^{10}$ - $10^{12}$  ions/pulse) and the short bunch duration (0.1 - 1 ns near the source), which are intrinsic to laser-driven sources. While the progress towards the stringent requirements of such applications (higher energies, repeatable generation, mono-chromaticity) will be facilitated by the on-going development of next generation laser drivers and target technology, present limitations in the ability to fully characterize the beams on a shot-by-shot, real time basis also need to be overcome in order to provide optimized and controllable beams for applications.

The use of a real time diagnosis based on Time of Flight (TOF) technique coupled with diamond detectors for full characterization of high-energy laser-driven proton beams will be reported in the present contribution. The TOF detection system will be used as the main diagnostics to monitor on a shot-by-shot basis the main ion beam features up to a repetition rate of 10 Hz, and to optimize ion beam transport and selection tuning in real-time the particle beam transport optics along the unique user beam line ELIMAIA (ELI Multidisciplinary Applications of laser-Ion Acceleration), which will be installed at the ELI- Beamlines facility in Prague (Czech Republic) within 2018.

Real time diagnosis of the main beam parameters for high-energy protons generated by the VULCAN-PW laser system at RAL (UK) has been performed using the on line diagnostics based on the TOF technique and on the use of diamond detectors. Results on the characterization of a proton source generated from the interaction of the PW- class laser and a solid hydrogen ribbon will be also discussed

High yield proton energy spectra were measured for energies exceeding 50 MeV in both directions (forward and backward with respect to the incoming laser beam). The result shows that, employing diamond detectors, the TOF method is a robust real-time diagnostics offering the possibility to monitor on a shot-by-shot basis the main beam parameters MeV level and this diagnostic approach is particularly attractive for the characterization of sources of single species ion beams, e.g. as emerging from cryogenic hydrogen target experiments.

## POSTER SESSION / 22

### Colour centres in lithium fluoride crystals for Bragg-curve imaging of low-energy proton beams by fluorescence microscopy

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Recently, novel solid-state radiation detectors, based on the photoluminescence of stable point defects in lithium fluoride (LiF) crystals, have been used for advanced diagnostics of the segment up to 27 MeV of the TOP-IMPLART proton linear accelerator for protontherapy applications, under development at ENEA C.R. Frascati.

Due to the peculiar particle-matter interactions, in the LiF crystals low-energy proton beams generate a spatial distribution of aggregate F2 and F3+ color centers, whose efficient red-green photoluminescence is emitted in the visible spectral range. It was found that their visible emission is proportional to the proton fluence. After irradiation, the stored latent information was acquired as an optical PL image by a fluorescence microscope under blue-light excitation and the signal intensity resulted to be locally proportional to the energy deposited by low-energy protons in a wide interval of dose.

By mounting the LiF crystals in two different irradiation geometries, the wide PL dynamic range, combined with the high intrinsic spatial resolution, allowed obtaining two-dimensional (2D) images of both the beam transverse intensity distribution and of the overall Bragg curves, each one in a single exposure, directly performed in air.

The versatility offered by the optical fluorescence microscope allows acquiring well resolved energy depth profiles in different portions of the beam, in order to clearly identify the Bragg peak positions and their intensity ratios: the estimation of the proton beam energy components was derived on the basis of the free Montecarlo simulation software SRIM (the Stopping and Range of Ions in Matter)

for different operating conditions of the accelerator and successfully compared with its dynamical behavior.

In the case of mono-energetic proton beams, the full Bragg curves were reconstructed by taking into account finite proton energy bandwidth and saturation of defects concentration.

Taking into account that these passive LiF detectors are easy to handle, as insensitive to ambient light and no development process is needed, the results are encouraging for a full three-dimensional (3D) reconstruction of the energy deposited by proton beams in matter.

## Diagnostics for fusion reactors / 23

### Progress in Development of ITER Diagnostic Infrastructure

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Integration of diagnostics in the ITER complex is a very important task that requires interfaces with other systems, like vacuum vessel, port plugs, buildings, vacuum systems and remote maintenance. The latter is particularly important as many diagnostics will have to be handled remotely during installation/removal, in order to carry out refurbishment, environmental and functional tests in the Hot Cell Facility outside the tokamak. Another very important design driver for diagnostics is occupational safety and occupational radiation exposure for workers who will have to perform hands-on maintenance operations. Finally, various parts of ITER diagnostic systems will experience different load conditions, arising from electromagnetic events (during disruption), thermal and neutronic heating, and seismic events. At the same time, it is imperative to ensure that diagnostics will be able to fulfil their measurement roles during operation of ITER.

The current status of the diagnostic infrastructure development, as well as the integration activities, will be presented.

#### Summary:

The current status of the ITER diagnostic infrastructure development, as well as the integration activities, will be presented.

## POSTER SESSION / 24

### Characterization of a X-Ray source for contact-microscopy applications obtained from laser-produced plasma

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A promising field of application of the X-ray radiation generated by intense laser-matter interaction is the contact-microscopy of biological samples. In order to optimize the yield on the desired spectral window, it is fundamental to have accurate characterization of this emitted radiation. To this purpose, an experimental campaign is underway with the three-nanosecond phosphate Nd:glass laser at the ABC laboratory in ENEA. The plasma was generated by irradiating solid targets with energy up to 30J, and intensity on target  $I \approx 10^{13} \text{ W cm}^{-2}$ . A transmission grating provided low-resolution spectra of a wide spectral range (5-50 Å). This covered also the so-called "water window" region, namely the spectral region between oxygen and carbon K-absorption edges (23 to 44 Å) where the absorption of carbon is ten times that of oxygen, and for this reason is of high interest for the contact-microscopy application. The X-ray yield in this spectral region was also monitored by a PIN diode filtered with 0.5 μm vanadium foil and coupled with a grazing-incidence copper mirror. A spherically-bended mica crystal was used to obtain high resolution spectra of the region going from 5.1 to 5.7 Å. This narrow spectral range was analyzed for determining density and temperature of the produced plasma through the identification of different lines and of their intensity. In addition to the aforementioned diagnostics, several Imaging Plates detectors were placed inside the experimental chamber and equipped with different filtering masks, in order to have an additional estimation of the plasma temperature.

## POSTER SESSION / 25

### Latency and throughput of online processing in Soft X-Ray GEM based measurement system

**Author:** Paweł Linczuk<sup>1</sup>

**Co-authors:** Andrzej Wojeński<sup>2</sup>; Ewa Kowalska-Strzęciwilk<sup>3</sup>; Grzegorz Kasprówicz<sup>2</sup>; Karol Malinowski<sup>1</sup>; Krzysztof Poźniak<sup>2</sup>; Maryna Chernyshova<sup>1</sup>; Michał Gąska<sup>2</sup>; Piotr Kolański<sup>2</sup>; Rafał Krawczyk<sup>2</sup>; Tomasz Czarski<sup>1</sup>; Wojciech Zabołotny<sup>2</sup>

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Plasma magnetic confinement with tokamak device usage is a complex phenomenon. To understand it clearly, various diagnostics must be used. One of them is plasma impurities monitoring, which can be done with measurement of their soft X-ray radiation. Our system implements such functionality [1].

Done from scratch with Gas Electron Multiplier (GEM) based detector, analog and digital (with use of FPGA) electronics and connection to server-grade PC (based on Xilinx DMA driver) it holds complete execution environment for low latency and high-performance calculations. The systems consist of analog modules, analog-to-digital converters, FPGA-based modules capable of fast acquisition and pre-processing of the data and PC with dual socket CPU motherboard.

It is the upgrade of the former system presented earlier in [2] for offline (prior to pending plasma shot) calculations done in MATLAB environment. Current version, with improved latency of computations, was implemented with performance in mind and can provide online output. It consists of upgraded PCIe communication, software environment preparation for low latency processing, data dispatching sub-system and optimized C/C++ based implementation of algorithms used for computations.

The throughput of the hardware acquisition part of the system was tested earlier in [3]. That work included the data path up to the storage in the PC memory. Such a solution, along with the new software processing, provides good low-latency processing capabilities. Present work will show performance study of whole processing pipeline - throughput and latency for raw-data acquisition and global trigger (a single channel triggers data acquisition from all the channels). Latency will be measured between an acquisition start of the GEM detector and spectral histogram output at the end of computational part along with the storage.

Our work would present results of the tests, which were done with measurements of radiation generated by X-ray tube with different flux levels. Discussion about the system usage in real case scenario with tokamak device will be presented.

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#### Data Mining / 26

### Determining the causality horizon in synchronization experiments

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Synchronization can be defined as the coordination of events to operate a system in harmony. It is important in the operation of manmade systems and in the investigation of natural events. In the last decade or so, synchronization of multiple interacting dynamical systems has become a lively field of study for control. In Magnetic Confinement Nuclear Fusion, various pacing concepts have been recently proposed to control various instabilities, such as sawteeth and ELMs. Some of the main difficulties of these experiments is the quantification of the synchronization efficiency and its role in the understanding of the main physical mechanisms involved. In this paper, various classes of independent of statistical indicators are introduced to address these issues. In metallic Tokamaks, one of the most recent applications of ICRH heating on JET is sawtooth control by ICRH modulation, for avoiding triggering dangerous NTM and counteracting impurity accumulation. Various forms of ELM pacing have also been tried to influence their behaviour using external perturbations and the one studied in this paper, injection of pellets, seems the most promising in the perspective of future devices. In the application to JET experiments with the ILW, the proposed indicators provide sound and coherent estimates of the efficiency of the synchronisation scheme investigated. They also confirm the interpretation that the fast ions play a fundamental role in the stabilization of the sawteeth, in both L and H mode.

## Data Mining / 27

## Adaptive Learning for Disruption Prediction

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Accurate prediction of catastrophic events is becoming an important area of investigation in many research fields. In Tokamaks, detecting disruptions with sufficient anticipation time is a prerequisite to undertaking any remedial strategy, either for mitigation or for avoidance. Traditional predictors based on machine learning techniques can be very performing, if properly optimised, but tend to age very quickly. Such a weakness is a consequence of the i.i.d. (independent and identically distributed) assumption on which they are based, which means that the input data are independent and are sampled from exactly the same probability distribution for the training set, the test set and the final actual discharges. These hypotheses are certainly not verified in practice, since nowadays the experimental programmes of fusion devices evolve quite rapidly and metallic machines are very sensitive to small changes in the plasma conditions. This paper describes various adaptive training strategies that have been developed to preserve the performance of disruption predictors in non-stationary conditions. The proposed techniques are based on new ensembles of classifiers, belonging to the CART (Classification and Regression Trees) family. The improvements in performance are remarkable and the final predictors satisfy the requirements of the next generation of experimental devices.

## Imaging / 28

## X-ray phase contrast imaging applied to laser driven shocks

**Authors:** Francesco Barbato<sup>1</sup>; Luca Antonelli<sup>2</sup>**Co-authors:** Angelo Schiavi Schiavi <sup>3</sup>; Bernhard Zielbauer <sup>4</sup>; Christian Brabetz <sup>4</sup>; Dimitri Batani <sup>5</sup>; Donald Mancelli <sup>6</sup>; Ghassan Zeraoui <sup>7</sup>; Guillaume Boutoux <sup>8</sup>; Luca Volpe <sup>7</sup>; Nigel Woolsey <sup>2</sup>; Philip Bradford <sup>2</sup>; Stefano Atzeni <sup>9</sup>; Trela Jocelain <sup>6</sup>; Vincent Bagnoud <sup>4</sup><sup>1</sup> *EMPA*<sup>2</sup> *University of York*<sup>3</sup> *SBAI Department, Sapienza University of Rome*<sup>4</sup> *GSI*<sup>5</sup> *INFN*<sup>6</sup> *University of Bordeaux*<sup>7</sup> *CLPU, University of Salamanca*<sup>8</sup> *CEA*<sup>9</sup> *Università di Roma "La Sapienza" and CNISM***Corresponding Author:** luca.antonelli@york.ac.uk

X-ray phase contrast imaging (XPCI) is an imaging technique based on the phase-shift of an X-ray photon induced by the refractive index. In particular, the phase-shift is related to the real part of X-ray phase contrast imaging (XPCI) is an imaging technique based on the phase\_shift of an X-ray

photon induced by the refractive index. In particular, the phase-shift is related to the real part of the refractive index, while the imaginary part is related to the absorption. A coherent X-ray source such as a synchrotron or X-ray free electron laser are the best choice for XPCI, however, it is possible to use broadband incoherent X-ray sources by limiting the source size and careful positioning of the experiment and detector. The interaction of high power laser with matter produces X-rays according to the intensity, energy and pulse duration. These sources can be used for XPCI. In this work we present the characterization and the application of XPCI using a laser-produced bremsstrahlung source to a shock. The X-ray source was created by irradiating a 5  $\mu\text{m}$  diameter tungsten wire with a Nd:Glass laser pulse 0.5 ps long and energy of 25 J in first harmonic. This produces a strong bremsstrahlung radiation. We applied this source to XPCI static objects and a laser-driven shock-wave in a plastic target. In both cases the XPCI clearly indicates the presence of density interfaces with 5  $\mu\text{m}$  spatial resolution. This proof-of-principle experiment shows how this technique can be a powerful tool for the study of warm and hot dense matter on large scale high-energy-density facilities.

therrefractive index, while the imaginary part is related to the absorption. A coherent X-ray source such as a synchrotron or X-ray free electron laser are the best choice for XPCI, however, it is possible to use broadband incoherent X-ray sources by limiting the source size and careful positioning of the experiment and detector. The interaction of high power laser with matter produces X-rays according to the intensity, energy and pulse duration. These sources can be used for XPCI. In this work we present the characterization and the application of XPCI using a laser-produced bremsstrahlung source to a shock. The X-ray source was created by irradiating a 5  $\mu\text{m}$  diameter tungsten wire with a Nd:Glass laser pulse 0.5 ps long and energy of 25 J in first harmonic. This produces a strong bremsstrahlung radiation. We applied this source to XPCI static objects and a laser-driven shock-wave in a plastic target. In both cases the XPCI clearly indicates the presence of density interfaces with 5  $\mu\text{m}$  spatial resolution. This proof-of-principle experiment shows how this technique can be a powerful tool for the study of warm and hot dense matter on large scale high-energy-density facilities.

**Special session: Advanced techniques of acceleration / 29**

## Temperature analysis in the shock waves regime for gas-filled plasma capillaries in plasma-based accelerators

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Plasma confinement represents a crucial point for plasma-based accelerators. For this reason, since each plasma parameter, such as the degree of ionization, the plasma temperature and the electron density, can affect the electron beam parameters, an accurate measurement of the plasma properties must be performed. In this paper, we introduce a novel method to detect the plasma temperature inside gas-filled capillaries in use at the SPARC\LAB test facility. The proposed method is based on the shock waves produced at the ends of the capillary during the gas discharge and the subsequent plasma formation inside it. By measuring the supersonic speed of the plasma outflow, the temperature is obtained both outside and inside the capillary. A plasma temperature between 0.3 and 2 eV has been measured, depending on the geometric properties and the operating conditions of the capillary.

## Optimisation of the input polarisation angle on lines of sights of a polarimetry system for a fusion reactor

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The study is dedicated to the evaluation of the effects of the input polarisation angle with the respect to the toroidal magnetic field on the values of the Faraday Rotation, Cotton-Mouton phase shift angle (and then ellipticity). The need of this evaluation is connected to the optimisation of the polarimetry quantities in view of having a complete information related to magnetic fields, plasma density and electron temperature. A polarimeter with four vertical as well as four horizontal lines of sights at various angle with respect to the equatorial axis is considered. The equilibrium used is a circular analytic model which considers a tokamak in the slab approximation. The plasma parameters considered are  $B_t=5T$  (toroidal magnetic field),  $I_p=10MA$  (plasma current), plasma density  $n_e=10^{20}m^{-3}$ ,  $R=9m$  (major radius),  $R/a=3.5$  (aspect ratio). The scenarios considered are H-mode baseline and optimised shear with slightly reversed shear current profile. The input polarisation angle is varied between  $0^\circ$  and  $45^\circ$ . It is found that the polarimetry signals of horizontal lines of sights are very sensible to the polarisation input angle leading to the strengthening the possibility of measuring the plasma density and electron temperature in these lines.

Imaging / 31

## X-ray K-edge imaging with photon counting detectors and polychromatic sources

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X-ray K-edge Subtraction (KES) Imaging is a procedure based on the acquisition of two images at different energies, one below and one above the K-edge of an element contained in a detail to detect. The technique allows highlighting the detail suppressing the background.

Most recent Photon Counting X-ray Detectors (PCXD) have advanced spectral features, including multiple thresholds and multiple counters, allowing performing "color" imaging even when using polychromatic sources. With this kind of devices it is possible to perform the KES employing common X-ray tubes and collecting the two images in a single shot. This eliminates the risk of misregistration due to motion of the sample making them appealing for medical applications.

On the other hand, the quality of the KES imaging, performed using PCXD, depends on the performance of the detector and it is influenced by the choice of various additional parameters including the shape of the radiation spectrum, the thresholds etc.

In this speech, I will point out the effect of the different parameters on the global quality of the KES imaging. I will show some applications of this technique describing in particular the experimental results obtained by KEST (K-Edge Spectral Tomography), a project supported by the Istituto Nazionale di Fisica Nucleare (INFN), that employ a Pixirad-PIXIE-III "color" imaging detector.

POSTER SESSION / 32

## Low Temperature Kinetic Model of Collective Thomson Scattering and its relevance to the measurements of ion features in fusion reactors

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The low temperature kinetic model was introduced in the context of interpretation of Collective Thomson Scattering measurements. The key hypothesis of the model is related to the physical assumption that in the context of unmagnetised plasma the phase velocity of the plasma fluctuations which scatter the incident beam is higher than the thermal velocity of the electrons. The physics scheme considered is that in practice the electrons scatter the incident light and the ion feature emerges from the influence of the ion dynamics on the fluctuation of the electron density. In magnetised plasmas [1,2,3] this assumption is specialised in separating the parallel from the perpendicular (to the toroidal magnetic field) dynamics ( $v_{||el}$  is the parallel electron velocity;  $v_{||phase}$  is the parallel phase velocity of the fluctuation;  $K_{\perp}$  is the component of the scattering K-vector= $K_i - K_s$ ,  $K_{i,s}$ =wave vectors of incident and scattered waves, perpendicular to the magnetic field;  $\rho_{\perp}$  is the perpendicular electron Larmor radius): (i)  $v_{||el} / v_{||phase} \ll 1$ , and (ii)  $K_{\perp} * \rho_{\perp} \ll 1$ . It is possible that in geometries where the angle between the scattering plane, defined by the incident and scattered light K-vectors, and the toroidal magnetic field is close to the 90deg: in this case  $v_{||el} / v_{||phase} > 1$  and the approximation (i) is not precisely verified. The paper develops the analysis of the validity of the assumptions of the Collective Scattering models elaborated so far in geometries and plasma parameters relevant for fusion reactors, like ITER and DEMO considering possible alternative approximations and comparing them with the rigorous solutions of the Thomson scattering theory.

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### Satellite Meeting on Metamaterials / 33

## METAMATERIAL DEVICES BASED ON NANO GAP HYBRID LC MICROCAVITIES

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### METAMATERIAL DEVICES BASED ON NANO GAP HYBRID LC MICROCAVITIES

Metamaterials based on split-ring resonators have been the subject of intense research efforts in the last two decades. Initially conceived to manipulate the magnetic response of solids [1], metallic metasurfaces have found applications in sensing [2] as well as in flat optics [3]. Among other features, the metallic split ring resonators present a remarkable sub-wavelength 3D confinement of the electric field which has been exploited in a variety of applications including the ultra-strong light

matter coupling regime but also to improve the performances of active Terahertz metamaterial devices .

Recently, we reported on experiments with a complementary superconducting niobium (Nb) cavity showing a fully switchable behavior as a function of the temperature with a quality factor  $Q=54$  coupling at THz frequencies [4].

We are now investigating another functionality of a THz metasurface integrating a nanodetector, consisting of a ultra small superconducting hot electron bolometer (HEB), into a narrow band subwavelength LC split ring resonator (SRR), realizing an active metamaterial device adding the detection capability of the incident input power coupled to metasurface. In this work, we will report our latest achievements in the field of metamaterial based devices showing our results obtained with nanogap hybrid LC microcavities

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#### Summary:

In this work we will report our latest achievements in the field of metamaterial-based devices: we will show our results obtained with nanogap hybrid LC microcavities.

#### POSTER SESSION / 34

### Approximate solutions of polarization state evolution in tokamak plasma polarimetry and their precision

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Polarimetry measurement results are used in tokamak plasma equilibrium codes as a constraint, decreasing the measurement uncertainty in determination plasma current, safety factor and density profile. In numerical codes, instead of solving rigorous equation of polarimetric state evolution, approximate analytical expression could be used to increase computing efficiency. In this paper is analysed the precision of three different models compared with exact solution of evolution equation for angular variables ( $\psi, \delta$ ). Calculations are made for circular plasma model, with a wide variety of plasma conditions, representative for the JET operating domain. The limits of applicability of these approximations, due to the accuracy of the Faraday rotation and Cotton-Mouton angle value approximation, are estimated. The obtained results define the limits of applicability of the proposed methods in equilibrium codes for plasma in configuration considered in the paper.

#### POSTER SESSION / 35

### A new approach to calorimetry in space based experiments for high-energy cosmic rays

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Unambiguous measurements of the energy spectra and of the composition of cosmic rays up to the knee region, around 1 PeV, could provide important clues on their origin, acceleration mechanism, propagation, and composition. A space experiment dedicated to measurements in this energy region has to achieve a balance between the requirements of lightness and compactness, with that of a large acceptance to cope with the low particle rates.

CaloCube is a four-years R&D project, approved and financed by INFN in 2014 aiming to optimize the design of a space-borne calorimeter. The large acceptance needed is obtained by maximizing the number of entrance windows, while thanks to its homogeneity and high segmentation this new detector allows achieving an excellent energy resolution and an enhanced separation power between hadrons and electrons.

In order to optimize detector performances with respect to the total mass of the apparatus, comparative studies on different scintillating materials, different sizes of crystals and different spacings among them have been performed making use of MonteCarlo simulations. In parallel to simulations studies, several prototypes instrumented with CsI(Tl) cubic crystals have been constructed and tested with particle beams. An overview of the results obtained so far will be presented and the perspectives for future space experiments will be discussed.

In addition, we will present the TIC (Tracker-In-Calorimeter) project, the natural development of CaloCube, financed by the INFN for 2018. The basic idea is to study the feasibility of including several silicon layers at different depths in the calorimeter in order to reconstruct the particle direction. Respect to the traditional approach of using a tracker with a passive material in front of the calorimeter, the TIC solution can save a significant amount of mass budget in a space satellite experiment, that can be therefore exploited to improve the acceptance and the resolution of the calorimeter. The studies realized so far making use of MonteCarlo simulations will be presented.

**Fast particles / 36**

## New MPGD applications

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Born in the late 90's, Micro-Pattern Gaseous Detectors (MPGD) have opened the way for the construction of detectors whose performance surpasses that of the previous generations in terms of spatial resolution, high-rate capability and increased radiation hardness. Micro-Mesh Gaseous Structure (Micromegas) and the Gas Electron Multiplier (GEM), the mostly used MPGD-type, are mature technologies exploited in a variety of experiments at high energy physics. Thanks to their excellent performance and their modularity several application beyond HEP profited from their introduction such as medical imaging, dosimetry and beam diagnostics for high energy beams and for nuclear reactors. Among all the new developments, performance of GEM-based detectors for soft X-ray and fast/thermal neutron detection linked to fusion experiments and spallation neutron sources will be treated in detail underlining the new capabilities of these devices over state of the art.

**DTT (Divertor Test Tokamak) / 37**

## Kinetic complexity in divertor region: Insights from particle-in-cell simulations

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The coupled dynamics and kinetics between gas and plasma in the divertor region is studied by means of a one-dimensional Particle in Cell-Direct Simulation Monte Carlo (PIC-DSMC) model.

In particular, the collision-induced vibrational excitation/relaxation of H<sub>2</sub> molecules and particle-surface interaction (vibrational relaxation and recombinative desorption) have been considered in detail to assess the importance of plasma volumetric recombination by molecular assisted reaction (MAR).

Spatially resolved results show that MAR processes are effective very close to the divertor plate in a region closer than 1.5 mm from the divertor plate. For farther regions the atom ionization, produced by MAR, starts to make molecular assisted recombination an ineffective reaction.

**Special session: Advanced techniques of acceleration / 38**

## Emittance measurement through betatron radiation in laser-plasma accelerators

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A technique to measure the transverse phase space and the rms emittance of plasma accelerated electron beams is described. First tests have been performed at the SPARC-LAB test facility through the interaction of the ultra-short ultra-intense Ti:Sa laser FLAME with a He gas-jet target. The proposed technique seems to be promising for the detection of ultra-low (sub-micrometric) emittances of high-quality plasma accelerated electron beams.

**Satellite Meeting on Metamaterials / 39**

## THz metamaterials meet accelerators

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We propose to use building blocks of THz metamaterials and THz plasmonics for advanced accelerators. Metamaterial building blocks and plasmonic structures allow for a precise control of the electromagnetic near-field distribution in a volume that is defined by the geometry of the structure. THz radiation with wavelengths on the order of a hundred micron is well matched to the transverse and longitudinal size of typical electron bunches in advanced accelerators. Moreover, today's pulsed THz sources provide field strengths up to hundreds of MV/m and thus become competitive

with standard microwave sources. And when combined with structures featuring high values of either electric or magnetic field enhancement, the maximum field strength can even be a hundred to a thousand times higher.

After a general discussion of the properties and possibilities offered by THz metamaterial and THz plasmonic structures we present two examples in more detail. A new concept and experimental results for an electron streaking detector with a femto- to sub-femtosecond resolution and a THz driven plasmon undulator. The ultrafast streaking device is based on a split ring resonator which is loaded by a single cycle THz pulse. The electron bunch passing through the resonator's gap experiences a transverse momentum transfer which sign and magnitude depend on the longitudinal bunch position. Thus, the longitudinal bunch density is mapped onto the transverse axis and can be easily measured with a spatially resolved electron detector. The THz driven undulator is composed of two graphene coated dielectric gratings separated by a vacuum gap. The plasmonic fields force the electron bunch on an oscillatory motion which in turn causes the bunch to radiate.

## POSTER SESSION / 40

### THz driven surface plasmon undulator

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In a free-electron laser a beam of relativistic electrons is moving in vacuum through a magnetic undulator producing electromagnetic radiation with high brightness and narrow bandwidth. In order to build a table-top source one has to reduce the undulator periodicity. One approach for realizing such mini-undulator is by laser micromachining permanent magnets or by electroplating a magnetic material onto silicon. Another approach is to use the periodic electromagnetic field of surface plasmon polaritons and our approach is derived from this proposal.

Here, we propose a THz driven undulator which is composed of two graphene coated dielectric gratings separated by a vacuum gap. The periodic plasmonic fields force the electron bunch on an oscillatory motion which in turn causes the bunch to radiate. First, we characterize the graphene plasmons excited by the incident THz pulse. The resulting electromagnetic field distribution is subsequently used to calculate the trajectory of a single electron or of a bunch of electrons. The trajectories are further used to calculate the radiation emitted by the electrons. The emitted radiation is analyzed for different accelerator and undulator parameters.

## Fast particles / 41

### Diagnostic of fast-ion energy spectra and densities in magnetized plasmas

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The measurement of the energy spectra and densities of alpha-particles and other fast ions are part of the ITER measurement requirements, highlighting the importance of energy-resolved energetic-particle diagnostic for the mission of ITER. However, it has been found in recent years that the velocity-space interrogation regions of the foreseen energetic-particle diagnostics do not allow these measurements directly. We will demonstrate this for gamma-ray spectroscopy, collective Thomson scattering, neutron emission spectroscopy and fast-ion D-alpha spectroscopy by invoking just energy and momentum conservation. The consequences of these conservation laws highlight analogies and differences between the velocity-space sensitivities of the diagnostics. Nevertheless, alpha-particle energy spectra and densities can be inferred at ITER for energies larger than 1.7 MeV through integrated data analysis of CTS and GRS by velocity-space tomography. Further, assuming isotropy their energy spectra can also be inferred by 1D inversion of spectral single-detector measurements, allowing the recovery of alpha-particle energy spectra and densities down to about 300 keV by CTS. Examples of these inversion formalisms will be given.

**Imaging / 42**

## The latest advances in optoacoustic diagnostic imaging of cancer and image-guided interventions

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This lecture will discuss recent advances in the development and clinical translation of two-dimensional and three-dimensional laser optoacoustic ultrasonic imaging systems with applications in detection of cancer, guiding surgery and monitoring therapeutic interventions. Specific examples will include in vivo molecular and functional images in small animals and the most recent breakthroughs in diagnostic imaging of breast cancer. These systems utilize the most compelling properties of light (high tissue contrast based on spectroscopic capability and molecular specificity) and sound (high spatial resolution enabled by well-defined propagation of ultrasonic waves without scattering). The detection and tomographic projection of the optically generated acoustic signals enable imaging in the depth of tissue with high optical contrast and high ultrasonic resolution, a feature not attainable by either optical or acoustic technologies applied separately. We also present the design features and technical parameters of the optoacoustic imaging systems combined with ultrasound that can uniquely provide coregistered anatomical and functional molecular imaging of live biological tissues, which represents the most comprehensive information for medical diagnostics. A special attention will be given to the application of Laser Optoacoustic Ultrasonic Imaging Systems in diagnostic imaging of breast cancer. Finally, we will present our vision of the future medical imaging modalities based on a combination of light and sound and their clinical applications in diagnostics and image-guided therapy and surgery.

**Spectroscopy / 43**

## Nanoparticle Enhanced Laser Induced Breakdown for chemical analysis of trace elements

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In 2013 we proposed the Nanoparticle Enhanced Laser Induced Breakdown Spectroscopy (NELIBS) [1] for enhancing the LIBS performances in terms of signal enhancement in several applications, spacing from metal sample analysis to biological samples [2].

After a few years several groups around the world have applied NELIBS in different applications. Although the promising results presented by several authors, the basic concepts of the laser matter interaction when NPs are deposited on the sample are still receiving poor consideration leading to misunderstand the real advantages and the limitation of this powerful technique [3].

In this view this lecture is aimed to discuss the basic aspects of NPs supported laser ablation and a general overview of the future perspectives and applications of NELIBS.

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**Spectroscopy / 44**

## Laser Induced Fluorescence in a collisional environment: a molecular probe for rapidly changing media

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Laser Induced Fluorescence (LIF) is nowadays a well established and widely used technique in gas discharges research, and one might wonder if there is really anything left to understand and investigate about it. The answer is yes, of course. The need for further deepening of the knowledge about LIF basically comes from its application to atmospheric pressure discharges, that is to highly collisional conditions. LIF, intended as a way to measure the concentration of transient species M, is in principle an absorption technique with a different observable, the fluorescence from an electronically excited state  $M_{\text{prepared by absorption of resonant laser light}}$ . In a molecular case, M can be a single ro-vibronic state. Collision energy transfers (CET) processes involving  $M^*$  and the background molecules have an heavy influence on the fluorescence outcome. This is generally considered as a shortcoming, since the quantitative use of LIF for the characterization of the transient specie M requires a detailed

knowledge of the collision frequencies. Reversing the point of view, this knowledge allows to use the laser prepared electronic state M as a transient quantum sensor for the medium composition, that can be used in hostile environments characterized by rapid changes (sub- $\mu$ s scale) of temperature, pressure and gas composition. This is possible since the CET processes with the background molecules redistribute the energy initially deposited in a single rovibronic state [1, 2], and thanks to the quantum nature of the molecular interaction that makes the CET processes depend strongly on the collisional partner. In this paper we shall present the general aspects of LIF in a collisional environment, introduce the idea of CET-LIF [3], and describe its application to the measurement of CO<sub>2</sub> dissociation in a nanosecond repetitively pulsed (NRP) spark discharge, using OH(A) state as the molecular sensor [4]. In parallel with the applications, we shall describe our work on the quantitative characterization of the CET processes in equilibrium [2] and non-equilibrium (work in progress) conditions.

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### Satellite Meeting on Metamaterials / 45

## Frontier Applications of Metamaterials to Magnetic Confinement Fusion

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The heating, current drive and diagnosis of magnetized plasmas relies heavily on the injection and emission of electromagnetic waves. The requirements for beam steering and focusing are stringent and, often, unique. As an example, perfect focusing of Electron Cyclotron Emission requires that higher frequencies be focused at larger distances from the receiver. This implies the need for a dramatic, “reverse” chromatic aberration, opposite to the behavior exhibited by conventional focusing elements. Starting from this example, I will show that the optical properties of metamaterials can be tailored to the focusing and steering needs of plasma heating, current drive and diagnostics. In addition, metamaterials for passive diagnostics in the microwave range can be easily and cost-effectively manufactured by ink-jet printing on plastic substrates. The ink in question is a liquid suspension of silver nanoparticles. With different designs and materials, this approach is easily generalized to high-power heating, current drive and active diagnostics.

### Special session: Advanced techniques of acceleration / 46

## The PolariX TDS: A novel X-band Transverse Deflection Structure with variable polarization

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A collaboration between DESY, PSI and CERN has been established to develop and build an advanced modular X-band transverse deflection structure (TDS) system with the new feature of providing variable polarization of the deflecting force. The design of this Polarizable X-band (PolariX) TDS requires a very high manufacturing precision to guarantee highest azimuthal symmetry of the structure to avoid the deterioration of the polarization of the streaking field. Therefore, the high-precision tuning-free production process developed at PSI for the C-band and X-band accelerating structures will be used for the manufacturing. We summarize in this paper the status of the project and its technical parameters including a list of applications foreseen at PSI and DESY.

## POSTER SESSION / 47

### A new Data Handling of the IR Spectra of Electrolytic Solutions and Similarities with Thermonuclear Plasmas

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Classical theories of electrolytes are based on the picture of a fully ionised gas [1] because it is assumed that, during the solution, salts are completely dissociated in ions. This makes the theoretical problem of the electrolytic solutions equivalent to the problem of a fully ionised gas.

We studied the water molecule organization in chlorides salts by using the methods of the classical Infra-Red spectroscopy [2]. The existence of an isosbestic point (i.e. equal absorption point) allows us to perform an innovative analysis on the long-range restructuring of water on increasing concentration of the solute. Isosbestic points are commonly met when spectra are taken on a system where a transformation is in progress upon changing a parameter and represents the equilibrium point between two populations of molecules differing from their degree of reciprocal correlation. We defined a deformation parameter which shows that the spatial organization of the solution occurs in three different phases depending on the solute density: a low concentration phase, where the solutes are accommodated without important distortion of the pure water matrix; an intermediate phase showing a cooperative behavior among molecules; and a third, where the deformation reaches its maximum value because any further increase of the ions in solution is prevented by the recombination.

A simple mathematical treatment of the data shows the emergence of a self-similar behaviour in concentrated solutions of strong electrolytes. Actually, a log-log linearity is observed showing that the deformation of the OH vibration band increases by the same amount per unit of solute, freely both from the total quantity of ions present in the solution and from the ion type. In other words, beyond certain concentrations (whose exact value depends on the ion nature), the restructuring of the water-water interactions shows similar patterns at increasingly changing scales. This observation implies a collective property of a system and cannot be anyhow related to the behaviour of independent molecules.

We propose that a similar model can be applied to thermonuclear plasma after a suitable choice of the deformation parameter. It can be expected that, beyond a certain density limit, collective (and possibly coherent) behaviour of the plasma have to be taken into account and that the plasma-wall interactions can be correctly described only keeping into account the collective behaviours.

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## Fast particles / 48

### Detector challenges at (low energy) Free Electron Lasers

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Free electron lasers (FEL) and 3rd/4th-generation storage rings operating in the (soft) X-ray regime offer a unique combination of properties such as extreme brightness, ultra-short pulse duration as well as temporal and lateral coherence. These properties are anticipated and are actually being proven to provide new scientific opportunities for time resolved structural studies. This enables for instance a new class of single shot coherent diffraction X-ray imaging from a huge variety of samples. However, these photon sources impose demanding constraints on both, beam diagnostics and imaging detectors, as the high peak brilliance of the generated beams implies that many photons may arrive simultaneously on the same detector area thus compelling for charge integration schemes while at the same time single-photon resolution in weakly illuminated areas is required. Such applications calls for detectors and associated readout electronics able to acquire and process up to Giga byte of data in a time comparable to the FEL repetition rate, which usually is in the range of 10-120 frames/second.

Additional detector challenges are imposed, when soft x-rays are utilized since here window-less and in-vacuum sensors are compulsory.

By means of some selected applications at storage rings and FELs the associated detector challenges will be discussed and some examples of specific detector developments and beam diagnostics will be presented.

## Fast particles / 49

### PIX-based detectors

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The Medipix collaboration has developed during last years few chips able to readout silicon sensors with high space resolution (50x50 microns). Medipix, Timepix and Timepix3 are the best and the most used. Recently some other detectors have been coupled to this ASICs like GEMs and Diamonds. A review of these new pix-based detectors will be presented with their performances and applications. In particular their use as beam monitors in medical application, accelerator and plasma physics will be discussed.

## Diagnostics for fusion reactors / 50

### Design and development of the ITER Plasma Position Reflectometry system

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The ITER Plasma Position Reflectometry (PPR) diagnostic is planned to be used to measure the plasma edge density profile at or near four pre-defined locations distributed both poloidally and toroidally in the ITER vacuum vessel. The measured density profile will then be provided in real-time to the Plasma Control System, which will use it to derive a supplementary contribution to

the magnetic measurements by tracking the position of the magnetic separatrix (or any other pre-defined density layer), whose movement, for known regimes of operation, can signal the approach of the plasma to the first-wall. During long discharges, the information from the PPR can also be used to correct any potential drifts of the magnetic measurements. Also, as already demonstrated in ASDEX Upgrade, the PPR can be used for plasma control purposes independently of the magnetic diagnostics. The system consists of five O-mode FM-CW reflectometers covering the edge plasma up to  $7 \times 10^{19} \text{ m}^{-3}$ . Overall, each reflectometer consists of three major sub-systems: (i) the front-ends, located both in-vessel and in port-plugs; (ii) the ex-vessel waveguides, which include the secondary confinement barriers located in the transitions between the traversed zones; and (iii) the back-end microwave electronics and digital sub-systems. The front-ends consist of the antennas and transmission lines up to the double vacuum windows, which are part of the first confinement barrier and define the interface with the ex-vessel part of the systems. The ex-vessel waveguides route the microwave signals between the tokamak and the diagnostic areas, where the back-ends are located. The design of the PPR system is about to enter the preliminary engineering design phase, which will last until the preliminary design review. In this talk, we present the current design status of the PPR system as well as the development work performed so far, including the design optimisation of critical components and the manufacturing and testing of prototypes for design evaluation and risk mitigation.

#### Summary:

The design of the PPR system is about to enter the preliminary engineering design phase, which will last until the preliminary design review. In this talk, we present the current design status of the PPR system as well as the development work performed so far, including the design optimisation of critical components and the manufacturing and testing of prototypes for design evaluation and risk mitigation.

#### Diagnostics for fusion reactors / 51

### Modelling Reflectometry Diagnostics: Finite-Difference Time-Domain Simulation of Reflectometry in Fusion Plasmas

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Reflectometry simulations are particularly important since they permit to assess the measuring capabilities of existing experimental systems and to predict the performance of future ones. We present a brief overview of reflectometry together with a short introduction to the Finite Difference Time Domain (FDTD) method for the simulation of reflectometry. The goal is to prepare the listener for the presentation of the family of REFMUL\* codes, which incorporate new numerical solutions such as new kernels and source techniques. Their use allows to set up synthetic diagnostics that not only consider the wave propagation in a given plasma but also take into account the system's location within the vacuum vessel, together with a characterization of its access to the plasma (waveguides and antennas). The synthetic diagnostic is complemented with the signal processing techniques necessary to process the measured reflectometry data. We illustrate the use of synthetic diagnostics in the assessment of the Plasma Position Reflectometers of ITER and DEMO.

#### Summary:

Synthetic reflectometry diagnostics implemented using the FDTD method permit to assess the measuring capabilities of existing experimental systems and to predict the performance of future ones such as the Plasma Position Reflectometers of ITER and DEMO.

**Fast events - Inertial Confinement / 52**

## Ultra-intense X-rays in PW laser plasma - generation, transport and application to study radiation dominated and warm dense matter

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In experiments with pico- and femtosecond optical laser pulses of relativistic intensities exceeding 1021 W/cm<sup>2</sup> the laser energy is efficiently converted to X-ray radiation, which is emitted by hot electron component in collisionless processes. In turn, the intense X-ray radiation effectively ionizes the matter inside out, providing a large population of exotic states called hollow ions, and opens the way to study the matter in Radiation Dominated Regime. As well, together with fast electron flow, the radiation heats up the vicinity of the focal spot and deep-lying layers of the target to Warm Dense Matter states.

In this context, the following recent experimental studies on intense X-ray generation and consecutive phenomena in relativistic laser plasma of solid targets are overviewed:

- Non-linear growth of X-ray yield while optical field intensity ranges from 1e19 to 1e22 W/cm<sup>2</sup>, and spectroscopy studies on X-ray emission from deeply-charged high-Z ions;
- Observation of KK-hollow and high-n-hollow atoms, and the matter in Radiation Dominated Kinetics Regime in picoseconds PW laser plasma;
- Transport of laser-generated X-rays through inner-lying target layers, and WDM temperature measurements by means of X-ray absorption spectroscopy.

**POSTER SESSION / 53**

## Calibration of Polarimetric Thomson scattering by depolarization measurements of Raman scattering on Nitrogen

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The absolute calibration in Thomson Scattering (TS) systems is done usually by measuring the scattered light by a gas like Nitrogen or Hydrogen at a given pressure[1,2]. The Raman lines of Nitrogen or Hydrogen are used to avoid the stray light at the laser wavelength. Since the measured signal can be accurately calculated knowing the cross section from this signal the spatial emission profile of the laser is deduced. The same concept is used in the Polarimetric Thomson Scattering where the depolarization of scattered light is measured to deduce the temperature of plasma. In this case the depolarization of Raman light can be measured and since this is precisely known the calibration can be deduced. This paper describes the project of the calibration of the Polarimetric Thomson Scattering system on FTU. Preliminary Raman depolarization measurements are done in laboratory to determine the level of the signal available, using a prototype polarimeter. These measurements

can be helpful also in characterising the polarimeter to be used in the Raman calibrations measurements of on the TS system on FTU[3]. The results of Raman depolarisation measurements and the deduced figures of the polarimeter are reported Therefore the project of the Raman depolarization measurements on FTU TS is described: the lay-out of the calibration system ( which includes the polarimeter characterised in laboratory) is detailed and the evaluation of the signal to be detected, Finally the evaluation in high temperature scenarios of FTU of the depolarisation in the Thomson scattering is discussed and the signal to be detected is calculated.

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## POSTER SESSION / 54

### The development of a diamond detector based Bonner sphere spectrometer for neutron field characterization in the EAST tokamak

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A time-of-flight enhanced diagnostic (TOFED) neutron spectrometer has been developed as a neutron emission spectroscopy for plasma physics study in the Experimental Advanced Superconducting Tokamak (EAST). The TOFED was previously installed in a shield positioned inside the EAST experimental hall, but could not work well because of high  $\gamma$ -ray background. A new neutron diagnostic house was built outside the experimental hall based on 1.5 m thick concrete wall as shielding, and could fulfill the requirements for the TOFED normal operations. However, it is still significant to interpret the source of the  $\gamma$ -ray background in the previous shielding, and estimate the neutron dose level in the new diagnostic house for the normal work of staff during the discharge of EAST. These rely on the neutron spectrum information covering entire energy range in these places. The characterization of the neutron fields outside and inside of the EAST experimental hall can benchmark the Monte Carlo model of EAST for other neutron related research. The Bonner sphere spectrometer (BSS) was chosen to measure the neutron field with energy up to 2.5 MeV for EAST operated in DD plasmas.

A set of <sup>3</sup>He gas counter based BSS, consisting of 10 spheres, has been successfully applied to the neutron field measurement. More central counters are needed to speed up the experiment by carrying out the measurement at different positions at the same time. Considering the high price of <sup>3</sup>He counters and the saturation problems occurring in EAST and the potential application to ITER and CFETR for the BSS based on usual active sensors like <sup>3</sup>He counters, the single crystal diamond detector coated with a <sup>6</sup>LiF converter was chosen because of its simple geometry and high radiation resistance. The BSS based on diamond detectors can characterize the high intense indoor neutron fields when employing NBI. An air gap of several mm between the diamond and converter was designed to improve its applicability in high  $\gamma$ -ray backgrounds. A high speed digitizer was used to

record the diamond detector pulses, and a pulse shape analysis was implemented to discriminate signals from backgrounds to further enhance the applicability of the BSS in harsh environment. The response function was established by MCNPX code in the energy up to 20 MeV. The successful derivation of a neutron spectrum at EAST verified the good performance of the new BSS on the measurement of high intense neutron fields when employing NBI.

## POSTER SESSION / 55

### Soft x-ray and gamma detectors based on Timepix chips for Laser Produced Plasmas

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The x-rays and gammas diagnostic on Laser Produced Plasmas (LPPs) is a challenging task. In both cases the photons emission comes in burst that last from few tens of ps to few ns, depending on the power and the laser pulse time width. A measurement of the photon flux cannot be performed using traditional diagnostics systems. In this work we propose the innovative usage of two detectors: the GEMpix [1] for soft x-rays and the Silicon Timepix3 [2] for gammas. The GEMpix is a proportional gas detector based on 3 consecutive Gas Electron Multiplier (GEM) foils with a front-end electronic based on four Timepix [3] chips, with 512 x 512 squared pixels each 55  $\mu$ m wide. It allows a 6 orders of magnitude range on the photons flux. It gives the possibility to work on Time over Threshold (ToT) mode where each pixel provides a digital measure of the released charge in the gas mixture. In addition, the charge can be amplified through the GEM foils with 4 order of magnitude spanning gain offering, in this way, a big dynamic range. Some results obtained on the Eclipse laser facility (CELIA, Bordeaux, France) will be presented [4]. In some LLPs experiments, also a high energy gamma photons flux is expected and its measure is often mandatory for the characterization of the plasma physics. To this end, we have used the new Timepix3 Silicon chip. It is constituted by 256 x 256 pixels bump-bonded on a 300  $\mu$ m thick Silicon layer. As a result of the gammas interaction, some characteristic tracks are detected as a main consequence of the Compton interaction. It is possible to define some morphological parameters as: cluster size, total charge, roundness, linearity and so on. The detector response can be characterized using some gammas and electron sources with different energies. After its laboratory calibration, this detector has been mounted on the VEGA laser facility (Salamanca, Spain) during an experiment aimed to produce photo-neutrons. The use of a 2D detector allows a clusterization procedure that gives, as a final result, the possibility to discriminate between different energy bands. In the present work the very first results are presented.

## Satellite Meeting on Metamaterials / 56

### Application of Phononic crystals and Acoustic Metamaterials to the detection and imaging of nonlinear defects

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Phononic crystals (PCs) and acoustic metamaterials (AMMs) are artificially structured composite materials that enable manipulation of the dispersive properties of elastic waves, exploiting Bragg scattering or the presence of localized resonances. Generally, they are periodic distributions of cavities or inclusions (scatterers) embedded in a matrix. Among their unique vibrational characteristics, we recall effects such as frequency band gaps, negative refraction, wave filtering/focusing, acoustic cloaking, subwavelength sensing, etc. In particular, their ability to act as stop-band filters (opening bandgap in the frequency domain) and focus selected frequency bands make them potentially interesting for applications in nonlinear acoustics and structural health monitoring.

Nonlinear nondestructive techniques that exploit nonlinear signatures to detect and locate damage often encounter limitations linked to the weakness of nonlinear components of the signal, which can fall below the noise level, making it difficult to detect and estimate them. Here, we apply PCs and AMMs to Nonlinear Time Reversal (TR-NEWS) with specific designs that demonstrate the possibility of greatly enhancing the sensitivity of this nonlinear imaging technique. Moreover, we demonstrate that, combining the properties of higher order harmonic generation by nonlinear elastic materials and of suppression of selected frequencies by AMMs, it is possible to realize systems that can realize unidirectional nonreciprocal wave propagation, i.e. so-called “acoustic diodes”.

**POSTER SESSION / 57**

## **Application of Miniaturized sensors to Unmanned Aerial Vehicles, a new pathway for the survey of critical areas**

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During the latest decades, an increasing of threats associated to CBRN events took place. For what regards break-out of chemical and radiological compounds, several episodes have occurred, such as unwanted industrial leakage, intentional use of chemical weapons by non-state actors or smuggling of nuclear material, that, by materializing a global threat, have conducted to casualties the actors involved, inter alia fire brigades and military first responders. Concerning the equipment provided to these operators, huge progresses have been done in portable detectors, now able to employ numerous different working principles and technologies. Nonetheless, especially during the survey phase after a CBRN release, the operators enter in a potentially contaminated area without knowing type and amount of the contamination, running the risk of losses during the reconnaissance.

On the other hand, nowadays we are witnessing a worldwide spread development of Unmanned Aerial Vehicles (UAV), with countless uses in different fields. They have founded fruitful implementation across civil and military ground in aerial photography, express shipping, gathering information during disaster management, thermal sensor drones for search and rescue operations, geographic mapping of inaccessible locations, severe weather forecasting.

What if we could send one or more of these flying platforms equipped with CBRN sensors, geolocalized and able to collect samples and to detect in real time a contamination. Subsequently, once the CBRN incident occurrence is confirmed, after the analysis of collected samples is likely to determine the chemical compound or the radiation emitter involved and the level of contamination. If

all this is made feasible, we will be able to minimize or completely avoid the exposure of personnel, moreover it will be determined the exact position of the hotspot and better supported the choice of personal protective equipment to be used to enter in the hazard area. Finally, time will be saved by an early UAV survey, while waiting to obtain the safety permissions for entry in the area.

To sum up, in this paper will be examined different possible applications of sensors for detection and identification of CBRN materials, miniaturized with the aim to be applied to a flying platform in the way to lower the exposure of personnel, civil defense or military personnel, with drastic reduction of casualties and time loss.

## POSTER SESSION / 58

### The Project TELEMACO: Detection, Identification and Concentration measurement of Hazardous Chemical Agents

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Nowadays, the monitoring of air in the environment is crucial to prevent chemical poisoning and disease onsets. Among the several techniques used to monitor the environment, the DIAL method has a very interesting approach. It is a remote technique able to give linear, areal or volumetric information. The range can be very large (until than 2 km) and the response is fast. Contrariwise, the classical DIAL approach is limited to the measurement of only one chemical and it is affected by the influence of other chemicals, which makes the sensitivity and specificity of the method low. In this work, the authors describe the project TELEMACO, which was born to develop a multiwavelength-based DIAL demonstrator able to perform the measurement of several hazardous chemicals in the environment in the same time and to increase the accuracy of the technique decreasing the false alarm. TELEMACO able to scan 66 wavelength lines and, at the moment, it can identify and measure the concentration of 24 chemicals enclose into database. However, the database can be extended with new chemicals compound. The experimental apparatus is thoroughly described as well as its functioning. Then, the most relevant tests performed to validate the functioning of TELEMACO are shown and discussed. The potentialities and the limits of this promising technology are analysed, highlighting its future developments.

## POSTER SESSION / 59

### An UV-LIF system to detect, identify and measure the concentration of biological agents in HVAC

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Bacteria, viruses and fungi may proliferate in heating, ventilating, and air-conditioning (HVAC) systems, representing a serious concern in healthcare settings, due to the occurrence of nosocomial

infections in vulnerable patients. Detection and classification of biological agents are not easy, especially at an early stage of contamination and when more than one species are aerodispersed. Our research aims at demonstrating the capability of UltraViolet Laser-Induced Fluorescence (UV-LIF) technique in monitoring the level of biological contamination in the HVAC system of healthcare settings exploiting ubiquitous endogenous fluorophores. The incident radiation is a second harmonic Nd:YAG laser emitting at 355 nm. A spectrometer collects the fluorescence spectra that are subsequently analysed in order to achieve information about the classification and the concentration of each agent in the sample.

The benefits of the UV-LIF combined with data analysis techniques concern the speed of the analysis, the limited costs for the equipment, and the possibility to analyse the airflow without the need for sampling. The application of this method to the monitoring of HVAC systems in healthcare settings could allow a fast and targeted response in the event of a contamination, decreasing the risks related to nosocomial infections and reducing the costs for the maintenance of the system.

In this work, the experimental setup and the capability of the classification and measurement techniques will be discussed. First measurements are used to test the possibility to classify the different biological agents of a mixture sample by Principal Component Analysis and Least Square Minimisation Method, both based on the application of classification algorithms to the spectra measured.

## POSTER SESSION / 60

### Thin and ultrathin conducting MoO<sub>3</sub> films on copper: a new route for improved RF devices.

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One of the main goals of the next generation of accelerators is to use cavities with higher RF fields, reducing significantly the length of particle accelerators. In order to accomplish these objectives is necessary to reduce the overheating effects due to the RF and to the electrical breakdown that induce damages on the surface of any RF device. In order to accomplish these objectives is necessary to reduce the overheating effects due to the RF and to the electrical breakdown that induce damages on the surface of any RF device. One of the possible solutions is to cover the inner metallic surface of a RF device with harder materials like a transition metal (TM) oxides [1,2].

In particular we describe the properties of molybdenum trioxide thin films deposited on a thick metallic copper substrate manufactured with a low roughness. Actually, a thin layer of molybdenum trioxide, a hard transparent insulator deposited on copper tends to be conductive, while its work function remains almost constant and higher than the original copper surface[3,4,5]. We developed and built a dedicated evaporation setup to growth by vacuum sublimation molybdenum trioxide films on copper and we measured both the conductivity and work function. Morphological characterizations and spectroscopic experiments have been performed to support the interpretation of the conductive behavior of thin layers of molybdenum oxides on copper.

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## Diagnostics for fusion reactors / 61

### High availability control and data acquisition for fusion experiments

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Near steady-state operation of plasmas in fusion machines controlled by systems with high acquisition channel density require much reduced downtime (High Availability or HA). To achieve adequate HA for scalable, high performance systems, various techniques can be applied:

- Serviceability - remote hardware management, modules hot-swap, modularity, firmware update support;
- Fault detection and mitigation;
- Redundancy - sensor level, system level, software/firmware level, scalable redundancy schemes (1 + 1 up to N + M);
- Resilience to errors, EM fields and neutrons;
- Transposition of sensitive hardware from hazardous radiation locations;
- Time-stamping (absolute time applicable standards: IEEE-1588, White Rabbit and IRIG), synchronization and real-time event management embedded on the acquisition hardware;
- Choice of instrumentation standards, based on Modularity, Expandability, Hardware Management capability, embedded HA schemes, data processing/transfer capability;
- Software - “universal” common device driver layer supporting the above mechanisms/methods; high performance and Computational power techniques to process real-time complex algorithms (e.g. in GPU, FPGA); centralized hardware management including firmware updating methods.

An overview of the application of these techniques in prototypes of systems targeting current and future fusion experiments will be presented, including the hardware, gate-ware and software development details.

## Imaging / 62

### Imaging the invisible parts of the Earth - ESA's Swarm mission probing the core, the magnetosphere, and nearly everything in-between

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ESA's magnetic field and geospace explorer constellation mission Swarm was launched in November 2013 and has ever since delivered on all its promises. In particular, the mission has offered new ways of mapping the rapid dynamics of Earth's outer core, the crystalline mantle, and the magnetisation of the rocks in the lithosphere. Concerning magnetic fields external to the Earth, the mission has

detected strong dynamics in the ionospheric plasma and magnetic field even during geomagnetically extremely quiet periods, with due implications on the understanding of magnetosphere-ionosphere-thermosphere coupling. Last but not least, the mission is also routinely measuring the space weather effect of weather phenomena occurring in the lower atmosphere, and lower/upper atmosphere coupling imaging techniques are gradually becoming more central to the mission exploitation activities. This contribution aims at describing the major discoveries enabled by Swarm since launch nearly five years ago.

## POSTER SESSION / 63

### Calibration of a Cherenkov diagnostic to study runaway electrons dynamics

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Studies of runaway electrons in tokamaks are essential to improve prediction and control of plasma disruptions, for a reliable application on nuclear fusion [1]. The potential damage of such a localised beam of highly-energetic particles striking the vessel wall is substantial, particularly in view of future large tokamaks, such as ITER, since the runaway generation rate increases exponentially with the plasma current. This damage must be avoided or reduced using mitigation techniques [2] to make stable and reliable ITER operation. In addition, measurements of runaway electrons produced in the plasma core and escaping from it are of interest to study processes occurring inside the plasma itself. A Cherenkov diagnostic detector was installed on FTU and its performances have been investigated [3]. In this work a laboratory characterization of the Cherenkov probe is presented. The contribution of visible light and X-rays up to 85 keV was explored confirming that soft and hard X-rays do not affect the measurement of the probe (by 1%). A first calibration of the Cherenkov probe with an intense electron beam of 2.3 MeV and at high fluxes (1012 e<sup>-</sup>, much higher than the 104 e<sup>-</sup> of the radioactive sources) was done at ENEA's Microtron source facility [4]. The characterization was performed together with a spectrometric analysis, which gave a deeper insight of the phenomena occurring inside the detectors. The results show an ionization spectrum, confirming the suspects that the signals observed during plasma discharges are due mainly to luminescence. Nevertheless the validity of the Cherenkov probes as diagnostic tool is not compromised, considering the good correlation with plasma instabilities and runaway electrons production measured by different diagnostics. Moreover, the direct detection of runaway electrons with high time resolution showed interesting features not present in other diagnostics. This configures the Cherenkov as a very promising diagnostic for real time control and monitoring of runaway electron beams for future machines. Thanks to this calibration, bunches of runaway electrons have been estimated in 8x10<sup>7</sup> e<sup>-</sup> of about 2.3 MeV, corresponding to a signal of 2 V in FTU.

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## Satellite Meeting on Metamaterials / 64

**Metamaterials: a new dimension in electromagnetism****Author:** John Pendry<sup>1</sup><sup>1</sup> *Imperial College London*

Building any device requires the use of materials and in electromagnetism it is often the case that nature does not provide what we need. Hence the concept of a metamaterial which adds the engineering subwavelength structure within a material to the choice of chemical composition. In this way entirely novel properties have been realised most prominent of which have been metamaterials with a negative refractive index. I shall outline the development of the field with some examples of applications and the more recent applications to commercial products.

## Imaging / 65

**Space for Sustainable Development****Author:** pierre-philippe mathieu<sup>1</sup><sup>1</sup> *ESA*

The view from space has forever changed our vision on our home planet, revealing its beauty while pointing at the same time to its inherent fragility. This new perspective from above contributed to the emergence of the concept of Sustainable Development (SD), by convincing many of the need to (better) manage our (rapidly depleting) resources in a sustainable manner that would “meet the needs of the present without compromising the ability of future generations to meet their own needs”.

Over the last decades, the principles of SD were progressively adopted by world leaders on the occasion of a series of Earth Summits. One of the key challenges to implement SD however lies in one's ability to measure it. As stated by Lord Kelvin, “if you cannot measure it, you cannot improve it”. The challenge is further compounded by the inherent global nature of the problem, which calls for global data sets.

Earth Observation (EO) satellites can play a key role to meet this challenge, as they uniquely placed to monitor the state of our environment, in a global and consistent manner, ensuring sufficient resolution to capture the footprint of man-made activities.

The world of EO is rapidly changing driven by very fast advances in sensor and digital technologies. The speed of change has no historical precedent. Recent decades have witnessed extraordinary developments in ICT, including the Internet and cloud computing, and technologies such as Artificial Intelligence (AI), leading to radically new ways to collect, distribute and analyze data about our planet. This digital revolution is also accompanied by a sensing revolution providing an unprecedented amount of data on the state of our planet and its changes.

Europe is leading this sensing revolution in space through the EO missions of the European Space Agency (ESA), a new generation of meteo missions for Eumetsat, and especially the Copernicus initiative led by the European Union (EU). The latter is centered around the development of a family of Sentinel missions by ESA for the EU so as to enable global monitoring of our planet on an operational and sustained basis over the coming decades. In addition, a new trend, referred to as “New Space” in the US or “Space 4.0” in Europe, is now rapidly emerging through the increasing commoditization and commercialization of space. In particular, with the rapidly dropping costs of small sat building, launching and data processing, new EO actors including startups and ICT giants, in particular across the Atlantic, are now massively entering the space business, resulting in new constellations of small-sats delivering a new class of data on our planet with high spatial resolution and increased temporal frequency.

These new global data sets derived from space lead to a far more comprehensive picture of our planet, thereby enabling the monitoring of SD progress. In this context, this talk will briefly present some elements of the ESA EO programmes and missions, and their evolution, highlighting their related scientific and societal applications, in particular regarding how space can help in supporting SD.

**DTT (Divertor Test Tokamak) / 66****Diagnostics for DTT in view of DEMO****Author:** marco valisa<sup>1</sup>**Co-authors:** Marco Tardocchi <sup>2</sup>; Onofrio Tudisco <sup>3</sup>; Paolo Innocente <sup>1</sup><sup>1</sup> *Consorzio RFX*<sup>2</sup> *Istituto di Fisica del Plasma "Piero Caldirola", CNR*<sup>3</sup> *ENEA*

The main mission of the Divertor Test Tokamak (DTT) is to explore viable solutions to the power exhaust issues in a fusion reactor. The ultimate goal will be to qualify and control in various divertor configurations DEMO relevant heat flux densities to the wall while preserving the integrity of both the plasma facing components and the plasma performance. Experiments will involve tailored magnetic topologies, highly radiative regimes and advanced materials.

In this contribution, we describe the package of diagnostic systems that will be deployed to allow DTT accomplishing its tasks. Diagnostics and feedback control are particularly functional to the need of maintaining the plasma close to equilibrium in situations prone to instabilities where the plasma wall interaction is optimized. Focusing on the divertor diagnostics, a particular effort will consist in obtaining space resolved measurements of density, temperature, impurity densities and ionization front that can be compared with the 2D results of model simulations. This will be possible using mainly optical diagnostics based on filtered cameras and spectrometers deployed in imaging mode, complemented by local measurements obtained by a space resolved Thomson scattering, Langmuir probes and gas puffing imaging systems. Diagnostics of the main plasma will assure a full qualification of the core and of the pedestal in terms of thermal contents, equilibrium, fast particles densities, impurities, reactivity levels and turbulence.

Strongly oriented to the exploration of control methods suitable for DEMO, DTT will also address the study of control systems based on physics and engineering models, which in DEMO are expected to take over the role of the diagnostics deemed to be incompatible with the harsh environment of a fusion reactor.

**Diagnostics for fusion reactors / 67****Diagnostic design for a Nuclear Fusion Device****Author:** Michael WALSH<sup>1</sup><sup>1</sup> *ITER ORGANIZATION*

In southern France, 7 partners comprising of 35 nations are collaborating to build the world's largest tokamak.

This is a magnetic fusion device called ITER that has been designed to prove the feasibility of fusion. This project is now well advanced in its construction. This includes the buildings, the major components and the independent systems. Amongst these are the diagnostic systems.

Diagnostic techniques have been successfully developed through many generations of tokamaks and other devices, and realization of the measurement requirements in ITER needs to draw on this knowledge and push the boundaries to advance the designs to handle the new challenges. These involve long pulses, high neutron rates and activation, significant engineering, high heat fluxes and plasma facing mirrors to name a few. To address these challenges, a rigorous system engineering approach with detailed requirements flow-down from the top level Project Requirements to System requirements and beyond is followed. These requirements really define all the needs of the different projects. One very important aspect of these requirements is the measurement requirements. These define what each system will measure. This can be the spatial resolution to the time resolution to the measured quantity error.

While each diagnostic provides its own challenges, integration of the systems in to a coherent working arrangement is a major challenge. This is because of the demands on space, overall cost and the need to solve various technical issues. Very often, the diagnostics are very closely integrated

with each other and the other surrounding systems necessitating the need for tight management of interfaces. Adding to this is the fact that ITER is the first Nuclear Tokamak facility, means that the engineering is pushing the boundaries in many dimensions. This extends from welding attachments of components to the vacuum vessel to maintaining the performance of the first mirrors that are so important for several measurements.

Several strong teams across the partners have been working on the diagnostics and the engineering developments, and currently the diagnostic systems are in various stages of development from fully manufactured to some still in early design. This paper will discuss the current status and challenges of the diagnostic systems. An assessment of the different risks that may impact the performance of these systems will be outlined.

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

## Imaging / 68

### Novel contrasts and technologies in diagnostic neuroimaging

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Single modality neuroimaging has been a cornerstone of clinical as well as research applications in Neurology and Psychiatry (e.g. Alzheimer's Disease, Parkinson's Disease, Ataxias, Progressive Supranuclear Palsy just to name a few) as well as in a wide range of other diseases with neurological implications like Primary open angle Glaucoma, Obesity, Diabetes, Acquired Immunodeficiency Syndrome (AIDS) and Cancer just to name a few. The insights gained by standard modalities like e.g. structural (T1-weighted) Magnetic Resonance Imaging (MRI), Fluid-attenuated Inversion Recovery (FLAIR) (MRI), Electroencephalography (EEG), Computed Tomography (CT), fludeoxyglucose (FDG) positron emission tomography (PET) are by now crucial in correct diagnosis, disease staging, and tailoring of therapeutic strategies in clinical practice as well as in facilitating clinical trial. Still, more recent technological developments have the potential to empower diagnosis as well as clinical trials with 1) a number of novel imaging modalities which provide access to metabolic, functional, and microstructural information within clinically reasonable scanner times and 2) novel processing strategies and data integration algorithms which allow the formulation of multi-mechanisms hypotheses about the genesis, current stage and future evolution of brain disease. In this context, we will discuss recent developments in Magnetoencephalography (MEG)-based brain connectivity estimation, the advent and impact of combined PET-MRI machines on diagnostic accuracy and feasibility of multimodal imaging, the possibility of employed ultra-fast, ultra-high field MRI to estimate potentially novel biomarkers like the elasticity of the brain parenchyma and brain vascular tissue, and the use of advanced models for the diffusion weighted MRI signal in the brain in order to obtain both sensitive and specific white matter microstructural information. In addition, during the last three years a particular class of machine learning methods one particular class of methods known as deep neural networks (DNN) has provided disruptive innovation in a number of fields, including medical applications in general and decision support in complex problems based on multimodal data in particular. We will show how deep learning can be successfully applied to diagnostic problems in medical application with success rates which equal (and often exceed) those achieved by medical experts, as well as to related problems like radiation oncology treatment planning.

## DTT (Divertor Test Tokamak) / 71

### Talk Prize Best Poster

## Special session: Advanced techniques of acceleration / 72

## **Plasma based devices for acceleration, transport and diagnostics of high brightness electron beams**

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In recent years, the need for much higher field strength acceleration and focusing in high energy electron beams has yielded a push towards developing new devices and instruments based on plasmas. We review the most compelling of these new scenarios: plasma wakefield acceleration up to TeV/m; unprecedented strong focusing lenses; and ultra-high strength undulators. As these physical systems operated at very short length and time scales, we discuss the beam-plasma diagnostic challenges and opportunities at the sub-micron and sub-femtosecond level.

**Imaging / 73**

## **Advance in image analysis for biomedical applications**

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