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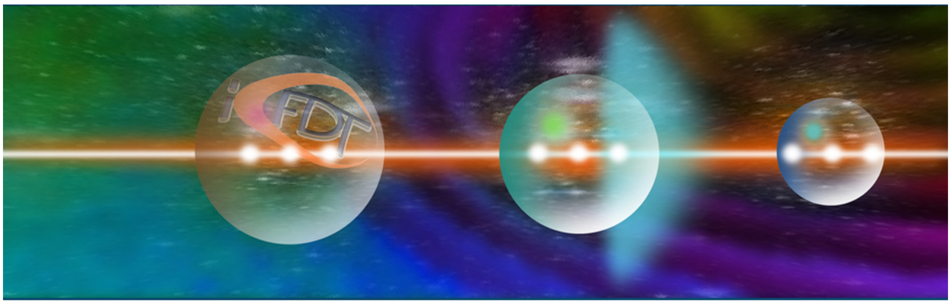

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Book of Abstracts

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"Clinical data in sepsis management –AI and clinical decision support systems at the Neonatal Intensive Care Units (NICU) in hospitals."

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In medicine, evidence forms the cornerstone of its paradigm, primarily derived from data. Across the system of healthcare, these data sources have greatly grown with each passing decade. They encompass a wide range of inputs including clinical trials, hospital information systems, medical equipment, as well as sensors and innovative tools. Consequently, the processing of medical data has become increasingly demanding and time-sensitive for analysis and conclusion. In adherence to the principles of evidence-based medicine, hospitals, and healthcare institutions necessitate efficient management, analysis, and interoperability of data across multiple systems.
Data analytics models and artificial intelligence are poised to become integral components of hospitals, ensuring the fulfillment of the mentioned imperatives. One example of this integration is found in clinical decision support systems (CDSS), which facilitate the real-time data analysis of both retrospective and contemporaneous data for inference, trend prediction, monitoring dynamic changes, and generating insights. Timely access to such information enables optimal physician workload management, minimizes error risks, and enhances the planning of diagnostic and therapeutic journeys for patients.
A spectrum of clinical decision support system models exists, leveraging data repositories, inference engines, and communication systems, and depending on machine learning or statistical pattern recognition. Categorized into model-driven, data-driven, knowledge-driven, and document-driven approaches, these models find application across various domains, yielding diverse outputs, thus propelling medicine into the era of real-time evidence. The foundation of this analysis lies in the authors' experiential insights gained through the implementation of a doctoral thesis within the realm of artificial intelligence (AI) applied to medicine, specifically focusing on the prediction of early neonatal sepsis (EOS).

Keywords: real-time data, clinical decision support system, neonatal sepsis, data management, clinical decisions

Spectroscopy / 11

Radiation-induced photoluminescent colour centres in lithium fluoride films for the detection of monochromatic hard X-rays

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Pure and doped lithium fluoride (LiF) crystals and thin films are extensively investigated as imaging detectors of ionizing radiations (X-rays, ⊠-rays, protons, neutrons, electrons, etc.), based on the optical reading of visible photoluminescence (PL) emitted by stable radiation-induced F2 and F3+ colour centres (CCs) [1]. These aggregate CCs (two electrons bound to two and three close anionic vacancies, respectively) possess almost overlapped absorption bands peaked at 444 and 448 nm, respectively. Under optical excitation in the blue spectral region, they simultaneously emit broad PL bands peaked at 678 and 541 nm, respectively, which can be read in non-destructive way by using fluorescence microscopy. The growing interest in these passive radiation detectors is due to their promising properties such as high intrinsic spatial resolution over a large field of view, wide dynamic range and simplicity of use, as they are insensitive to ambient light and do not require development or chemical processing.
Optically-transparent polycrystalline LiF films (thicknesses of 0.5, 1.1 and 1.8 μm) were grown by thermal evaporation on Suprasil®, glass and Si(100) substrates at ENEA C.R. Frascati. They were irradiated at several doses with monochromatic X-ray beams of energy 7 and 12 keV at the METROLOGIE beamline of the SOLEIL synchrotron at Saint Aubin (France). After irradiation, their PL response, carefully investigated by using a fluorescence microscope, showed a linear behaviour as a function of the irradiation dose. This linear dose-response function [2] is a highly desiderable features for a quantitative analysis of the fluorescence images obtained in edge-enhancement imaging experiments, performed by interposing an Au mesh, 400 lpi, at a distance of 15 mm from the samples, which allowed estimating a spatial resolution of (0.38 ± 0.05) μm.

Acknowledgments
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[2] M.A. Vincenti et al., Opt. Mater. 119 (2021) 111376.

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Direct detection of particle radiation with perovskite sensors

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In the past decade, organometal halide perovskites (OMHP) semiconductors have been studied as sensors for ionization radiation and X-ray detectors, beside the well known success as photovoltaic devices. Properties such as simple single crystal growth from low-cost solution processes, high stopping power, defect-tolerance, large mobility-lifetime product and tunable bandgap make OMHP very promising materials for novel detectors.
In the first part of the talk an overview of usage of perovskite for radiation detection of charge particles (⊠ and ⊠ particles) and electromagnetic radiation (X-rays and ⊠-rays) will be presented.
In the second part, the results of PEROV INFN project [1] will be shown: OHMP based single crystal devices have been developed and tested with electrons from the Beam Test Facility at INFN Frascati National Laboratories, close to the minimum ionizing energy deposition. The crystal sensor can reach the single particle sensitivity with a bias voltage as low as 5 V. It also shows a good linearity of the response as a function of the number of electrons with a dynamic range of approximately 104.
Efforts towards the application of OMHP sensors as X-ray detectors will also be also discussed.

[1] Testa et al, Direct detection of minimum ionizing charged particles
in perovskite single crystal detector with single particle
sensitivity, accepted by Nanoscale, https://doi.org/10.1039/D4NR01556H (2024)

Imaging / 13

Advanced X-ray imaging for intraoperative imaging and national security

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The Advanced X-Ray Imaging (AXIm) group at University College London has developed technology that enables x-ray phase contrast imaging (XPCI) to be performed with conventional x-ray sources. The group is now engaging with industrial collaborators to seek translation of the developed technology.
The most advanced applications, which have reached the pre-commercial prototype stage, are intraoperative imaging for real-time use during surgery procedures and detection of threat materials in security scans. In the former area, the technology has been piloted for breast conserving surgery and proof-of-concept data have been collected in oesophageal interventions. The latest developments show that microscopic implementations of the technique are also viable, allowing to scan biopsies with sub-cellular resolution. In security, the technique showed exceptional capabilities for detection of concealed explosives when combined with machine learning.
This talk with present the stare-of-the-art in both areas, show key results and discuss future perspectives.

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Merging Data-Driven and Physics Knowledge for Improved Diagnostics, Interpretation, and Modelling by Physics-Informed Neural Networks

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In many scientific and engineering endeavours, the diagnostic of several quantities is complex, indirect, and rely on several simplifying assumptions that are not always exact. Especially in these cases, the integration of measurements with physical knowledge is the most performant way to obtain accurate and reliable results. Despite this, the fusion of partial differential equations (PDEs) and experimental measurements remains a challenging task, often leading to disparate approaches that fail to leverage the complementary strengths of both worlds. Another typical limitation is that when PDE parameters are not known (uncomplete physics), several numerical simulations must be performed, making the modelling complex and time consuming.
Recently, a new artificial intelligence technology, known as Physics-Informed Neural Network (PINN), has been developed to overcome these limitations. PINNs are neural networks that are trained by minimising a loss function that takes into account both data and physical equations, allowing for an easy and flexible integration of physics a priori knowledge with data. They showed a great potential in various fields of science and applications, such as numerical simulations, inverse problems, data integration, etc. Moreover, they can work also with uncomplete physics, allowing for improved physics-constrained data-guided modelling.
This work investigates the possibility of using Physics Informed Neural Networks (PINN) for solving two main classes of problems: data-driven solution and data-driven discovery of PDEs. Moreover, the approach is extended to other fundamental tasks in physics and engineering, such as the solution of very ill-posed inversion problems and causality detection. Applications to both time series and cross-sectional data are covered.
In addition, so systematic use of synthetic data to corroborate the potential of PINNs, real-life examples from the field of thermonuclear tokamaks are presented, including the solution of inversion problems (tomography, magnetic equilibrium reconstruction) and the investigation of the plasma dynamics in the presence of various instabilities (ELMs, sawteeth, disruptions). The obtained results confirm that the synergy of experimental data and theory, inherent in the PINN approach, constitutes a very significant competitive advantage, allowing the technology to outperform the main alternatives reported in the literature.

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Advances in Maximum Likelihood Tomography Applied to Bolometry for the Investigation and Control of the Total Radiation Emission in Tokamaks

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The measurement of the radiation emitted by tokamak plasmas is essential for both control and the investigation of the physics. Radiation represents an energy loss, and its quantification is therefore crucial for power balance assessments. Localized plasma cooling can lead to anomalies in electron temperature, such as hollowness in the core or cooling of the edge, thereby causing instability and, eventually, disruptions. On the other hand, different highly radiative scenarios are being studied to reduce the thermal load on the plasma facing components. Consequently, many experiments are conducted in different machines for the control of the detachment and X point radiating regimes Therefore, understanding whether the plasma is emitting an acceptable level of radiation in any region of the cross section is indispensable.
The total radiation is measured with specific detectors called bolometers along defined lines of sight. The local emission from these integrated measurements is obtained with sophisticated tomographic algorithms, which are required to solve very ill-posed inversion problems. The maximum likelihood tomography is one of the most advanced techniques applied to the bolometric tomography in tokamaks. In this work the latest developments of the maximum likelihood algorithm are presented.
The accuracy and flexibility of the method are improved by substituting the traditional regularization techniques with suitable filtering. An adaptive procedure autonomously adjust the parameters to the radiation patterns, improving the capability of the technique to discover new physics. In addition the algorithms have been standardised and run systematically on large databases without the need for human intervention. Furthermore, the error estimation provided by the maximum likelihood is improved and validated with systematic Monte Carlo simulations. Last but not least, a matrix formulation of the problem allows reducing the computational times of orders of magnitude, making the approach suitable for real-time applications and opening new perspective to feedback control of the emitted radiation.
The performances of the new algorithms are compared with those of other methods reported in the literature with both synthetic and experimental data. The potential of the new algorithms is demonstrated with its application to the data of JET with a metallic wall, reconstructing the evolution of the emitted radiation in phenomena such as MARFE, temperature hollowness, detachment and disruptions

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The Integration of Diagnostics in DTT at the Conceptual Design Stage: Technological and Instrumental Challenges

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The main goal of the Divertor Test Tokamak (DTT) facility is the investigation of viable particle and power exhaust solutions for fusion reactors [1,2]. Performances, integration of edge and core and flexibility of the configuration are the guidelines of the DTT project, in order to test various power exhaust strategies for reactor relevant confined plasmas in a compact device. In this context, the integration of a complex and comprehensive set of diagnostics has to face the challenges imposed by advanced performance plasmas, a harsh environment and severe topological constraints. Once identified the scientific and functional requirements of each system, the design and implementation of the diagnostics have also to address several interface issues, including remote handling compatibility and stray electron cyclotron radiation, and severe levels of neutron and gammas radiation, particularly dangerous for optical components and electronics. In addition, the high degree of integration between the various systems and subsystems, required in a compact device, impose the adoption of strict methodologies of functional analysis, to guarantee a proper trade-off between the sometimes conflicting needs of machine protection, plasma control and physics programme.

Industrial and Cold Plasmas / 18

LIBS Application on JET and prospects for ITER

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In JET and future fusion reactors, thick co-deposited layers will be formed on their inner walls during extended plasma operations. Experiments in present-day fusion devices indicate these layers to consist of eroded plasma facing materials, various impurities in the edge parts of the fusion plasma, and actual plasma fuel species deuterium and tritium. Monitoring the inventory of the radioactive tritium in the reactor vacuum vessel is a particularly critical safety issue. LIBS is one of the few techniques available for monitoring the tritium content and the composition of co-deposited layers during fusion reactor operations and maintenance breaks. Feasibility of a LIBS-based tritium monitoring diagnostics developed at ENEA for fusion reactors is presently being investigated at the JET tokamak in the UK.

At VTT, together with the European collaborators, we have actively participated in the JET project and developed methods to assess the amount of deuterium and tritium in plasma facing components removed from JET and other fusion devices. Our LIBS system is capable of handling all kinds of materials, including the toxic beryllium which has been used as a wall material at JET. Different quantification approaches such as calibration-free LIBS have been successfully tested and reported in laboratory conditions. Test measurements have been performed at VTT using the LIBS enclosure developed at ENEA. Both pure metallic samples and JET limiter and divertor samples have been characterized. Final setup of the LIBS system has now been commissioned at JET including the high resolution Littrow spectrometer and the photomultipliers. Presently the LIBS enclosure is being mounted on to the MASCOT telemanipulator robot which is a two-armed machine with back-drivable actuators and a large dexterous workspace. Each arm can operate within the full 6 degrees of freedom. The MASCOT manipulator is remotely operated from the control room. The LIBS experiment will be performed at JET in August 2024 and aim is to analyse ~960 locations on the main wall and the divertor.

Finally, prospects for ITER will be discussed.

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Diagnostic Systems in the Muon g-2 Experiment at Fermilab

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The muon anomalous magnetic moment, $a_\mu = \frac{g-2}{2}$, is a low-energy observable which can be both measured and computed to high precision, making it a sensitive test of the Standard Model and a probe for new physics. This anomaly was measured with a precision of 0.20 parts per million (ppm) by the Fermilab's E989 experiment. The final goal of the E989 experiment is to reach a precision of 0.14 ppm. The experiment is based on the measurement of the muon spin anomalous precession frequency, ω_a, based on the arrival time distribution of high-energy decay positrons observed by 24 electromagnetic calorimeters, placed around the inner circumference of a 14 m diameter storage ring, and on the precise knowledge of the storage ring magnetic field and of the beam time and space distribution.

To achieve this level of precision is needed a very specific control on the systematics, and this is achieved through several diagnostic devices, at accelerator level to monitor the quality of the injected beam (e.g. to ensure it's at the correct momentum value), and and at detector level to monitor both

the magnetic field and the calorimeters gain. In this talk I will present the devices and techniques used by the E989 experiment.

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Diagnostics and control on FCC

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The Future Circular Collider (FCC) project aims to construct the next-generation accelerator of the CERN complex. The primary objective is to build a 90 km electron-positron collider (FCCee), designed to operate at beam energies ranging from 45.6 to 182.5 GeV. The immense scale of this machine and the unprecedented properties of its beams present significant challenges for beam diagnostics. This talk provides an overview of the diagnostic options currently under investigation for FCCee, focusing on dedicated R&D activities aimed at developing novel instrumentation. The Heterodyne Near Field Speckle (HNFS) technique is presented as a non-invasive solution to assess the transverse beam distribution from the coherence properties of the synchrotron radiation spontaneously emitted by the particles. Successfully tested at the ALBA synchrotron, this technique may push the boundaries of current technology in the field of transverse beam diagnostics, with potential applications in existing accelerator facilities.

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Introduction to experiments on plasma acceleration

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Plasma acceleration is a novel technique for a large variety of applications, including radiation sources of new generation. X-ray sources based on betatron radiation from plasma accelerators hold promise as compact, innovative and highly accessible solutions for radiation users. The key feature that makes these sources unique, lies in the shortness of the pulses delivered, falling in the femtosecond range and paving the way for ultrafast photon science in the X-ray range.
In this work, single-shot temporal characterization of the betatron radiation pulses emitted by fs-long, 100's MeV electron bunches undergoing acceleration and propagating through a plasma wiggler is shown in the soft X-ray domain. The retrieved pulse lengths agree with independent measurements performed in the THz spectral range and with theoretical predictions.

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DTT interferometer and polarimeter systems

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Interferometric and polarimetric diagnostics are traditionally exploited in plasma experiments, and, in particular, in magnetically confined fusion experiments, to determine plasma electron density and to give valuable information on the internal magnetic fields, respectively [1]. These information enter into the evaluation of the plasma magnetic equilibrium and in particular into the real-time estimation of the q profile to allow feedback configuration control. Interferometers and polarimeters are often combined together to form a single diagnostics, i.e. an interferometer/polarimeter, to allow for simultaneous measurements of plasma electron density and magnetic fields [2].

This work presents a description of the interferometric and polarimetric systems for the Divertor Tokamak Test facility, a new tokamak experiment under construction in Frascati, Italy [3]. Three systems are expected to be implemented in the DTT experiment: a two channel infrared tangential disperion interferometer; a multi-chord far-infrared poloidal interferometer/polarimeter; and a scanning infrared dispersion interferometer for the divertor. In particular, the status of the art of the development of the three systems will be presented as well as an estimate of the expected signals for the three diagnostics.

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Cultural Heritage / 25

Prototype tests of integrated systems CRM-FBG sensors for civil structural health monitoring

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Preserving the integrity of the built heritage by detecting degradation, as well as monitoring the behavior of civil structures in response to vibrations or seismic phenomena is a challenge that is addressed by proposing different approaches and lines of research.
CRM (Composite Reinforced Mortar) with embedded FBG (Fibre Bragg Grating) sensors was tested

in order to guarantee long-term effectiveness end of reinforcement as well as continuous monitoring. Indeed, to measure mechanical parameters for Structural Health Monitoring (SHM) of civil engineering structures, fiber optic sensors based on FBG technology are widely used. These FBG sensors are made in the core of the optical fiber, as a short segment of fiber in which a diffraction grating is produced and are particularly suitable for permanent monitoring applications in civil structures, being able to specifically exploit some unparalleled characteristics of FBG sensors: resistance to atmospheric agents, low invasiveness of both the sensors and the wiring.
A project involving an experimental working group between the DICITA (Department of Civil, Computer and Aeronautical Engineering) of Roma Tre University and the FOS (Fiber Optic Sensors) ENEA laboratory produced prototypes of structural reinforcement. This work presents scientific validation, through laboratory tests consisting of pull-out tests on glass fiber reinforced polymer (GFRP) connector bar samples equipped with FBG sensors housed in optical fibers incorporating FBG sensors. The results underlined the reliability of the proposed CRM-FBG integrated system for combined strengthening and structural health monitoring purposes.

Keywords: Fiber Bragg Grating sensor, Structural Health Monitoring, Optical sensory systems, Data processing methods, Digital Image Correlation.

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Environmental Application and Medical Diagnostics / 26

Advanced use of autoencoders (AE) on experimental signals preprocessing: a lidar application

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An autoencoder (AE) is an unsupervised artificial neural network used to learn data patterns. By compressing data, an input signal is encoded into latent space variables and then decoded to reconstruct the input from these variables. This compression process, a form of dimensionality reduction, retains only the intrinsic characteristics of the signal, excluding non-descriptive elements. This approach is crucial for experimental signal preprocessing, particularly in the denoising phase and database anomaly detection, especially in applications where the use of filters may compromise the visibility of signal anomalies or where it is not possible to collect more signals for statistical comparison. Autoencoders are particularly valuable in these cases because, once the network is trained, they can be used for real-time applications. Additionally, as an unsupervised approach, they are not prone to overfitting even if the database contains anomalous signals.
In this work, we present the application of autoencoders in lidar environmental contexts to address the challenge of denoising signals affected by high electromagnetic periodic noise. Additionally, we demonstrate a more common anomaly detection application of autoencoders in database processing.

Spectroscopy / 27

Quantum spectroscopy approach for novel diagnostics

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Quantum Sensing is a rapidly growing branch of research within the area of quantum science and technology offering key resources, beyond classical ones, with clear potential for commercialisation of novel (quantum) sensors. Their physical implementation can vary and each approach has specific advantages/limitations and varying levels of TRL for different applications.
The activity of our lab is focused on the exploitation of quantum resources offered by photons to boost the performance of novel quantum sensors, drawing an innovative programme of challenging applications. We are building on the idea of the Quantum Ghost Spectroscopy (QGS), i.e. the counterpart in the frequency domain of Quantum Ghost Imaging (QGI), and we are addressing challenges in basic research, targeting novel applications. Ghost imaging (GI) is a sophisticated method to image an object without analysing the light that passed through it.
The framework of QGI extends such possibility to the quantum domain usually through the use of spatial quantum correlations of pairs of photons generated via Spontaneous Parametric Down Conversion (SPDC). However, focusing on spatial correlations only is quite restrictive, as such correlations can be in the spectral or polarization domain as well. In fact, each photon is in a superposition of several possible modes (spatial, frequency or polarization), all of which arrive on the object, and are then measured by a mode-insensitive bucket detector. Due to the correlations intrinsic to the pair-production process, the analysis of one of the correlated photons provides information on what has occurred to its twin [Fig.1]. Therefore, if the SPDC source generates pairs of photons in a nondegenerate configuration, i.e. belonging to different wavelength ranges (the first in the VIS and the second in the IR range), it could be possible to link IR and VIS components of the emission in such a way that spectral information in the former range can be assessed by looking only at the latter. This means that the requirements for accurate measurements are shifted from the IR to the VIS domain, for which much more solid, reliable and cost-effective solutions are available. Hence, the time-frequency domain reveals a huge potential for several applications and frequency correlations represent a versatile tool that can be exploited to enable the spectral analysis of objects where a direct measurement would not be feasible.
This approach has been employed by the HADES project [1] for the detection of several possible harmful threats showing optical properties in the NIR spectral regions. The obtained results and the future developments of our work will be presented and discussed.

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Imaging / **29**

Graphene growth from commercial Kapton by direct laser scribing studied by confocal micro-Raman spectroscopy, laser confocal and atomic force microscopies.

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Laser-induced graphene (LIG) is prepared by single step laser writing processes on many carbonaceous material [1]. By Raman spectroscopy it is observed that the laser scribing on a polymeric material with hexagonal structure, such as polyimmide (Kapton), induces a breaking of C-O, C=O

and C-N bonds, with consequent rearrengement of carbon atoms to form a graphene structure. Depending on the laser wavelength (IR or UV) the pristine bonds are broken by pyrolisis or by photolysis process. Anyway, due to the short conversion time, it is necessary to carefully choose the laser writing parameters to obtain the appearence of 2D band which indicates that the black material on the Kapton surface is really graphene.
In this work, we performed different scribing tests irradiating a commercial Kapton tape with nanosecond UV and CO2 lasers by changing writing speed and laser power to systematically investigate the light-material interactions in LIG fabrication processes and to optimize the experimental parameters. Graphene straight lines (Fig.1) and squares were produced and characterised by confocal micro-Raman spectroscopy, laser confocal and atomic force microscopies gaining a deep insight on transient formation process of LIG and helping the identification of critical parameters that govern this process. The present study investigates the effects of the laser processing parameters on the LIG quality, with consequent process optimization confirming that LIG is a low-cost straightforward method to directly fabricate graphene sheets on a carbon-rich substrate that will have a growing importance in a near future.

Figure 1. (a) Bright field optical images of lines scribed with UV nanosecond laser at a scanning speed of 5 mm/s and increasing power from line 1 to 3. (b) Raman spectra acquired from lines 1 (light blue), 2 (blue) and 3 (green).

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Environmental Application and Medical Diagnostics / 30

Laser based D2O sensing technique for nuclear and biomedical applications

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To efficiently control and monitor the usage of D2O is of paramount importance in many research domains. In the biomedical field, D2O detection is essential for metabolic studies and tracing water in biological tissues, providing new tools for medical and clinical research. In the nuclear sector, monitoring D2O is crucial for controlling fission processes since it is used both as coolant and moderator for ensuring the safety of nuclear plants. For this, the development of advance sensors is crucial. In this work we present a new, fast and reliable method for the assessment of D2O in water, down to a few percentage. The method makes use of a Quantum Cascade Laser (QCL) photoacoustic system developed in our laboratory. The reported results demonstrate the potential of this technique to provide accurate and reliable data. Additionally, this technique is promising for environmental monitoring, enabling the detection of pollutants and tracing the water cycle in various ecosystems.

Environmental Application and Medical Diagnostics / 31

Diagnostic Technologies for an Innovative Approach to Tumor Detection via Blood Plasma Measurements

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In the frame of the research of new, non-invasive, and reliable diagnostic methods for the detection of tumor pathology, a systematic feasibility study was performed at Linköping University, Sweden, based on an electronic nose (e-nose) approach, which provided a very high percentage of agreement with the clinical diagnosis. The device consists of 32 metal-oxide chemical sensors configured in four banks including eight sensors each, operating at different temperatures. Data were collected at a sampling rate of 10 Hz for 600 s by measuring volatile organic compounds emitted from blood plasma samples of 1 ml volume. Using a 5-fold cross validation, we demonstrated that our e-nose detected ovarian cancer with a sensitivity of approximately 98%, specificity of 85%, and overall accuracy of 95% [1]. The study was conducted on 87 ovarian cancer samples from patients with diagnoses ranging from borderline to stage IV together with 26 healthy samples used as negative control group. We are now in the process of conducting a larger study, including other types of cancer and analytical techniques [2]. To achieve this goal, a parallel study based on laser sensors is starting at the ENEA Research Centre in Frascati, Italy, the experimental program emerging in collaboration with Linkoping University, VOC Diagnostics AB, University of South Florida, and University of Texas at Dallas [3]. The central step of the proposed diagnostic procedure is a machine learning/artificial intelligence-based processing of sensor data. The ultimate goal of the cooperation will be to realize a hybrid sensor platform for early cancer detection, which will allow the translation of basic research findings into clinically useful diagnostic tools. Here, we present the preliminary results of our study.

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Diagnostic for High Energy Physics and Plasma Acceleration / **32**

The EuPRAXIA project

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Plasma acceleration is paving the way for new compact accelerators aiming at reducing the scale of the facilities needed by free electron laser (FEL) or high energy physics by employing accelerating gradients much larger than conventional RF structures. The EuPRAXIA Design Study (1) is dedicated to realizing a distributed FEL facility powered by plasma acceleration in the European framework (it is included in the ESFRI roadmap).

As part of the EuPRAXIA project, Frascati National Laboratories propose hosting a cutting-edge facility named EuPRAXIA@SPARC_LAB (2), tailored to meet these specific requirements with a unique combination of a high-brightness X-band RF linac driving a plasma-accelerator-based FEL. We plan to realize a FEL in the XUV (3-15 nm) and we are studying the possibility to have a second beamline beamlines in the VUV (50-150 nm). We are preparing a Technical Design Report, while the building is in the executive drawing phase.

We plan to have dedicated diagnostics for the high quality electron beam, plasma interaction and FEL light: while most of the diagnostics will be well established (to have a reliable user machine), some unique properties of the machine will require innovative solutions.

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Diagnostic for Fusion Machines / 33

Identification and Analysis of New Tungsten X-ray Spectra on EAST based on a medium-energy electron beam ion trap

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New X-ray spectra of tungsten have been observed using the X-ray Crystal Spectrometer (XCS) on the Experimental Advanced Superconducting Tokamak (EAST). The wavelength of these new x-ray spectra ranges from 3.895 Å to 3.986 Å. It is tentatively determined that the unidentified spectra measured by X-ray crystal spectrometer in EAST are emitted from W43+, W44+ and W45+ [1]. However, there is no sufficient evidence for the identification of these lines. To validate the spectral lines, this study adopted the Flexible Atomic Code (FAC) to calculate the atomic parameters such as the energy level, transition energy, spontaneous emission transition probability, and the electron collisional excitation cross section of W43+-W45+ ions. The simulated results were further validated using the Medium-Energy Electron Beam Ion Trap (EBIT) spectroscopy research platform, which can provide an electron beam currents reaching 20 mA and electron energies ranging from 80 eV to 30 keV [2]. The results are in reasonable agreement with the available experimental and theoretical data. These newly identified spectral lines are validated and crucial for measuring ion and electron temperatures, high-Z impurities, and rotation velocities in current tokamaks and future fusion experimental reactors.

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Diagnostic for High Energy Physics and Plasma Acceleration / 34

Mechanical strength investigations of the APPLE-X undulator using Fiber Bragg Grating strain measurements

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The SPARC_LAB facility at the INFN laboratory in Frascati is being upgraded to accommodate a new user facility as part of the SABINA (Source of Advanced Beam Imaging for Novel Applications) project. The SPARC laboratory was set up to investigate the feasibility of an ultra-brilliant photoinjector and to perform FEL experiments. Over the years, upgrades, additional beamlines, and experiments have been added. One of the latest upgrades, to be completed in 2024, will include improvements to the main infrastructure, laser and radiofrequency systems, and the implementation of a new electron beam line for SABINA.
The beamline dedicated to SABINA will be equipped with three APPLE-X undulators acting as amplifiers to deliver IR/THz radiation with photon pulses in the ps range, with energy of tens of µJ, and with the possibility of choosing between linear, circular, or elliptical polarisation. The APPLE-X, designed and built by KYMA S.p.a., guarantees the possibility to vary the gap amplitude between the magnet's arrays and their relative phase. The entire system, from the mechanics to the kinematic subsystems, has been designed from scratch, and a structural analysis has been carried out to evaluate the production.
The undulators were delivered to Frascati in 2023 and, in collaboration with ENEA, a further investigation campaign was launched on the mechanical parts in the vicinity of the permanent magnets, using strain measurements based on optical methods.
Fiber Bragg Grating sensors proved to be perfectly suitable to the requirements of these tests, mainly because of their immunity to electromagnetic noise. They consist of a phase grating inscribed in the core of a single-mode fiber, whose Bragg-diffracted light propagates back along the fiber. If bonded to the mechanical structure, they can be used as strain sensors. Indeed, any deformation of the monitored mechanical parts causes a deformation of the grating with a consequent change of its pitch and a related variation of the Bragg-diffracted wavelength. By following the variations in the scattered spectrum, it is possible to perform strain measurements. One µstrain resolution is within the reach of the current technology.
Using multiple FBGs applied at selected locations on the undulator, several measurements were made by following the different possible kinematics, such as opening and closing the gap between the magnetic arrays or changing the phase, but also by studying the quiescent response as a function of the ambient temperature.
The results of these tests show that there is a clear deformation of the structure related to the temperature changes and magnetic forces, but the magnitude of this deformation is well within the tolerances required for the functionality of the undulator since they are compatible or lower with respect to the one calculated with the finite elements methods. The tests, therefore, confirm the reliability of the mechanical structure.

Fusion Products / 35

Nuclear Spectroscopy on Fusion Reactors

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Historically, nuclear measurements have played a primary role in nuclear fusion experiments, such as those conducted on tokamaks. The notable example is given by the measurement of the neutron counts which provides the direct estimation of the fusion power. This is an essential parameter to know, in particular for the forthcoming DT fusion reactors.
The advent of neutron and gamma ray spectroscopy, which is the measurement of their energy spectra along collimated lines of sight, opened up to new diagnostic opportunities allowing to assess the fuel ions distribution functions and the effectiveness of the external heating systems. In this contest, the recent DT experimental campaigns of the Joint European Torus provided a unique opportunity to evaluate the performance of the nuclear diagnostics suite which has been recently upgraded within the EUROfusion Enhancement program.
This talk will present the state of the art of nuclear spectroscopy diagnostics and their exploitation on DT fusion reactors, drawing on the experience gained from JET. Examples of instruments developed for ITER and SPARC will be presented. Additionally, an alternative method for assessing the fusion power based on the spectroscopy measurement of the 17 MeV gamma rays emitted by the weak (≈10-5) DT reaction channel will also be discussed.

Diagnostic for Density and Temperature / 36

Overview of the studies towards a Plasma Position Reflectometry System for Divertor Test Tokamak (DTT)

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Plasma Position Reflectometry (PPR) is taking an important role in next generation fusion machines, such as DEMO, as a diagnostic to monitor the position and shape of the plasma, complementing magnetic diagnostics. The Divertor Test Tokamak Facility (DTT) presents itself as the perfect machine to implement, develop and test PPR systems, contributing in this way to the gain of a knowledge database in position reflectometry needed for DEMO. Important assessment work is being done to

evaluate the performance of a tentative PPR system in DTT. Part of these efforts is integrated in the EUROfusion Enabling Research Project (ENR-TEC.01.IST), These efforts involve the design of two- and three-dimensional synthetic diagnostics for the Low (LFS) and High Field Sides (HFS), using Finite-Difference Time-Domain codes capable of simulate the propagation in the plasma but also to describe the system location in the vacuum vessel and characterize its access to the plasma (waveguides and antennas) [1,2]. This simulation exercise works in parallel with the design of antennas for the LFS and HFS. Their integration in the synthetic diagnostics is done through the use of a CAD conversion pipeline [3]. An overview of the progress achieved together with future work planned is offered in the present work together with an analysis of the accuracy on the localization of the separatrix at different positions around the vessel.

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Diagnostic for Fusion Machines / 38

Design of Microwave Reflectometry for Helimak

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Helimak is a plasma experimental device with a helical magnetic field and a toroidal vacuum vessel. The structure of Helimak is similar to that of a tokamak, which make it possible to simulate a tokamak-like in-vessel environment. Low operating costs make it a validation platform for wall conditioning technology of fusion devices.
Microwave reflectometry is a widely used plasma density diagnostic on tokamaks. To obtain the plasma parameters of Helimak, microwave reflectometry was proposed to measure the plasma density distribution to supplement the measurement of the Langmuir probe. According to simulated distribution of plasma density and magnetic field, the characteristic frequency distribution of Helimak plasma is shown in Figure 1. The left-hand cutoff frequency (fL) of extra-ordinary mode (X-mode) is too low, and the cutoff frequency distribution of ordinary mode (O-mode) is too flat. The right-hand cutoff frequency (fR) of X-mode is chosen as probing frequency, which is from 2GHz to 4.5GHz. For Helimak, we are interested in its density distribution near the wall of the vacuum vessel. In order to reduce the difficulty of system construction, the frequency span should be avoided to be too large, so the working frequency band of the microwave reflectometry is determined to be 1.7~3.7 GHz.
The microwave reflectometry is divided into two subsystems, responsible for signal generation and reception at 1.7-2.6 GHz and 2.6-3.7 GHz respectively. The microwave reflectometry uses a Frequency Modulated Continuous Wave (FMCW) transmitter and a superheterodyne receiver. The core of the transmitter is a voltage controlled oscillator controlled by an arbitrary waveform generator. The generated signal is transmitted after single-sideband modulation and power amplification. In the receiver, the received signal is mixed with the reference signal and demodulated by the IQ detector to finally obtain the analytical signal.
Currently, the system design and circuit construction work has been completed. The system bench test is currently underway, and it will soon be installed on Helimak for experimental testing.

Diagnostic for Fusion Machines / 39

First measurements for the ITER-like CXRS-edge diagnostic on EAST

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Charge eXchange Recombination Spectroscopy (CXRS) diagnostic is widely deployed in fusion experimental devices as an effective method for the local measurement of key parameters such as plasma temperature, rotation velocity and impurity density. Designated to fulfill the requirements for International Thermonuclear Experimental Reactor (ITER) CXRS diagnostic measurements, the RF-DA has developed the High-Etendue Spectrometer (HES)[1]. The HES is based on three large-size transmission holographic diffraction gratings that operate simultaneously in three spectral wavelength ranges to measure Helium, Carbon and Beam emission spectra. As the heating methods, divertor configuration and operation scenario adopted for EAST are similar to those of ITER. The prototype HES was first applied on EAST, and coupled to the EAST CXRS fiber bundles for initial testing. The neon lamp is used to perform the wavelength calibration for the green channel, while the red channel is calibrated with both neon lamp and hydrogen-deuterium standard light sources. The actual linear dispersion is 0.0073nm/pixel for the green channel and 0.0082nm/pixel for the red channel. The carbon spectra and beam emission spectra are measured at EAST by HES, and the calculated plasma parameters are compared with the original reflectance spectrometer measurements and XCS measurements, respectively. Due to the higher etendue, the intensities of the spectral signals measured by HES are several times greater than those of the original spectrometer.

Diagnostic for Fusion Machines / 40

A novel terahertz line array detection scheme of solid-source interferometer system on EAST

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Abstract—A vertical single channel 0.65THz solid-source interferometer (SSI) has been established on Experimental Advanced Superconducting Tokamak (EAST) for real-time electron density measurement and feedback. A novel terahertz line array detection scheme is proposed to improve the spatial resolution of the SSI. By employing high-power solid-state diode sources and an AlGaN/GaN line array high electron mobility transistors (HEMT) detector with high integration and good sensitivity, five channels will be added to obtain more spatial information of plasma. The line array HEMT detector is installed on the SSI system and the line-integrated density signals of three channels are obtained in the initial commissioning operation. The density measurement is implemented with IF 0.85 MHz, in a plasma with Ip = 400 kA and PECRH = 1.1 MW on EAST. The line array detector also detects the density frequency disturbance during the plasma discharge, which shows a good ability to study small-scale spatial MHD phenomena. Further engineering commissioning and subsequent data processing algorithms are still expected to optimize the measurement results of the line array detection scheme.

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Semiconductor-based proton spectrometer for laser-driven sources applications

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Laser-driven particle acceleration relies on the interaction between ultraintense (I>1018 W/cm2) laser pulses and matter. A plasma is formed due to the ionization of the target, and electrons are heated until they escape from the interaction region, giving rise to a strong charge separation. This electric field is thus responsible for protons and heavier ions accelerated forward [1].
This phenomenon has gained increasing interest in recent years as it could allow the building of compact and versatile ion sources, with many potential applications in scientific and technological contexts [2]. Among them, Laser-driven Particle Induced X-ray Emission (PIXE) [3] can be exploited for elemental and stratigraphic analysis of samples. As a non-destructive technique, it can be used in the study of artworks and the preservation of cultural heritage.
To this aim, an accurate, quantitative characterization of beam properties is of fundamental importance. In particular, the adopted instruments should provide real-time measurements, and discriminate the different types of radiation. The standard employed devices are Thomson parabola (TP) coupled with an MCP and a CCD camera, and Time-of-Fligth (ToF) spectrometers [4]. Despite their efficacy in addressing the problem, they present some limitations, e.g. TP shows high sensitivity to photons and high voltage supply fluctuations that degrade calibration and resolution, while ToF requires complex deconvolution procedures due to the superposition of signals from different particles.
Here, we present the design of a spectrometer [5] based on silicon photodiodes. The device comprises a dipole magnet to deflect the ions along different trajectories according to their energies. We exploit a finely-shaped differential filter to cut the unwanted heavy ions contribution, and photodiodes to record proton signals. The magnetic field of the dipole can quickly be tuned, so that on subsequent shots one can use it to measure the proton spectrum, or just to remove electrons, leaving the proton beam practically unperturbed and available for its use. This feature is of particular interest for laser-driven PIXE, providing online proton spectra with absolute calibration and enabling sample irradiation without changing the experimental setup.
The spectrometer was experimentally characterized and analytically modelled. Monte Carlo simulations are used to validate the model and calibrate the system, and the first measurements of laser-driven proton spectra were carried out at Centro de Làseres Pulsados (VEGA-3).

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Liquid layers in imaging systems for fusion applications: materials, advantages and limits.

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Imaging optics for plasma diagnostics in fusion experiments are challenging systems, since they have to face extreme heat and radiation fluxes. These problems can be partially addressed by means of reflective systems, which are easier to cool and less sensitive to radiation damage. On the other hand, reflective systems tend to be bulkier because on their intrinsic folding, and less suited for covering high fields of view with a sufficient aperture.
A different approach is explored here, exploring the possibility to use liquid layers in refractive optical groups for cooling, radiation shielding and aberration correction (in particular, for chromatism correction). The choice of different organic material is discussed, taking into account their refractive and dispersion indexes, their transmission spectrum as well as their chemical and thermal characteristics. Simple optical systems are shown and discussed by means of ray-tracing and fluid simulations, identifying advantages and limits of this approach.

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First observation of full radial profile of Zeff using high-performance visible spectrometer in EAST tokamak

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The effective ion charge, Zeff, is a key parameter in magnetic confinement fusion plasma, quantifying the average ionization state of impurities and is critical for assessing plasma impurity level and radial impurity distribution. In ITER tokamak, the expected Zeff is around 1.8, with permissible variations limited to ±0.2. The visible bremsstrahlung measurement is a useful tool for measuring Zeff and therefore is widely used in many tokamak devices, including EAST [1], DIII-D [2], ASDEX Upgrade [3]. Due to a poor plasma accessibility with large distance between plasma and port for the machine with superconducting coils, e.g. EAST tokamak, it is difficult to observe the full radial profile of visible bremsstrahlung based on conventional ex-vessel optics. Very recently, in EAST, based on the endoscopic optic design a space-resolved visible spectrometer working at 370-850 nm has been newly developed to observe full radial profile of line emissions from lowly charged impurity ions and visible bremsstrahlung continua. The visible spectrometer system consists of a vertically aligned 60-channel fiber-optic array, three diffraction gratings with groove densities of 300, 1200, and 2400 grooves/mm respectively, and a CMOS detector (Andor Marana 4.2B). Wavelength calibration is performed using the neon and xenon lamps, as well as the well-known spectral lines from plasma. Meanwhile, absolute intensity calibration is performed using an integrating sphere standard light source. Precise wavelength and absolute intensity calibration enables an accurate determination of bremsstrahlung intensity across all channels. Local bremsstrahlung emissivity profile is then derived from the space-resolved measurement of these chord-integrated bremsstrahlung intensity by Abel inversion methods based on the EFIT magnetic equilibrium calculation and measurement of electron density and electron temperature profiles. Relationship between Zeff and the local bremsstrahlung emissivity is established by incorporating the Gaunt factor into classical radiation theory and simplifying the expression based on the typical parameters observed in EAST. In this work, the entrance slit with 50 μm width, a grating with 300 grooves/mm, cycle time of 100 ms/frame is set respectively for the observation. And the bremsstrahlung at central wavelength of 523 nm with a bandwidth of 0.2 nm is selected for the calculation of Zeff profiles. The experiment was performed with the

upper single null (USN) divertor configuration. The auxiliary heating scheme was a 0.6MW Electron Cyclotron Resonance Heating. As a result, the full radial profile of Zeff is obtained in EAST plasma for the first time. The achievement of full radial profile of Zeff is essential not only for impurity level assessment, impurity control, plasma scenario development but also for the in-situ absolute intensity calibration of existing EUV spectrometers [4-5].

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Diagnostic for Density and Temperature / **44**

Fast Wave Interferometer/Reflectometer for Ion Measurements on DIII-D and Prospects for Magnetic Confinement Fusion Reactors

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The index of refraction of a plasma in a magnetic field is described by the ion density n_i, with i=D (deuterium) or H (hydrogen), in the frequency range of the fast wave. Hence, interferometry and reflectometry using the fast wave as a probe wave can provide the ion mass density m_i n_i [1,2] and the isotope ratio n_D/(n_D+n_H) [3], respectively. The frequency range of the fast wave for these diagnostics on present magnetic confinement fusion devices is about 10-100 MHz.
The ion mass density and the isotope ratio are important parameters for burning plasma control in future magnetic confinement fusion reactors. Fast wave interferometry/reflectometry (FWI/R) is a reactor-relevant diagnostic as it is inherently immune to many of the issues plaguing more traditional interferometric measurements. In contrast to a laser interferometer, a FWI/R does not require in-vessel optics that risk degradation from optical fouling and neutron darkening nor does it require real-time alignment control or precise beam alignment. In-vessel FWI/R components (antennas and waveguides) are unlikely to deteriorate via erosion and impurity depositions or by neutrons and gamma rays. FWI does not require precise alignment since the broad, emitted radiation pattern is easily coupled onto the receiver antenna even if antennas are displaced by thermal expansion and vibration. Therefore, FWI/R is a potentially robust and low-maintenance diagnostic for fueling control in future reactors.
FWI/R was first demonstrated on DIII-D [1-3] and has been further tested using several different antenna configurations [4,5]. Bremsstrahlung spectroscopy is used to compute Z_eff and when combined with the CO2 laser interferometer, can produce an estimate of the line averaged ion density, n_i. Z_eff can also be used with the FWI via Σ m_i n_i (i=H,Carbon) to derived the line-averaged ion density and compare the accuracy and efficacy of the two techniques. Following comparisons on DIII-D, the ion density by the radial FWI was consistent to within approximately 15% of the value measured by the CO2 laser interferometer. Additionally, it was demonstrated on DIII-D that the several MHz bandwidth of FWI allowed probing of fluctuations of the magnetic field or the ion mass density directly from observation of core-MHD in the FWI spectrum. Evaluation of the isotope ratio by FWR was also conducted in a deuterium-and-hydrogen plasma in DIII-D. This versatile feature is valuable since the number of diagnostics on the reactor will be limited due to the harsh environment.
This material is based upon work supported by General Atomics corporate funding.

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Spectroscopy / 45

Hydrogen Detection from Distance

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Hydrogen Detection from Distance

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Green hydrogen is regarded as an important carrier of clean energy for the upcoming decades. Gas leakage from infrastructures like pipelines and storages is discussed with regard to the effects of H2 emissions on atmospheric chemistry as well as general safety issues. While accumulations in buildings can be detected with standard gas sensors, coverage of larger areas is an important issue. To address this need for a standoff sensing technology, we adapted a chlorine gas sensor based on spontaneous Raman scattering. In the present work, the development steps from the model to the retrieval of experimental spectra are described. Eventually, the system was modified to a UV Raman LIDAR for the detection of low percentages of hydrogen in air (1-10%) at distances of 20-100 m. Finally, potential applications and scientific challenges such as the suppression of interfering topographic background signals are discussed.

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Preliminary Results and Analysis of a Tangential TV Thomson Scattering Diagnostic System on EAST

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High spatial resolution edge Thomson scattering diagnostic is important for fusion research. The electron temperature and density profiles of plasma are basic parameters in the study of Tokamak plasma physics, so the development of high spatiotemporal resolution edge Thomson scattering diagnostic has been carried out in many major tokamak devices, such as DIII-D[1], JT-60U[2], JET[3], EAST[4], ITER[5]. However, because of the optical coating and detection efficiency, it is difficult to

further improve the spatial resolution of the traditional Thomson scattering diagnostic based on the filter splitting technology. TVTS might be a good solution.
Recently, we completed the development of a tangential TVTS (Television Thomson scattering) system in EAST. We developed a high-power, high-frequency 532nm laser as a diagnostic laser source. The laser can generate a 3.5J laser pulse at a frequency of 10Hz. The laser can work continuously for more than 1000 seconds with an energy deviation of less than 5%. For this laser wavelength, we adopted a transmission grating spectrometer design scheme, the average transmittance of 100nm around the central wavelength (532nm) is more than 50%. At the same time, we adopt double MCP coupled ICCD technology, so that the detection efficiency of the system can reach 3000 counts/photon. The TVTS system's light path, which follows a tangential optical path, primarily covers the plasma region from $\rho = 0.85$ to 1.1, the spatial resolution of the system is about 3mm, and the measurable electron temperature range is 50eV-2keV, with the accuracy expected to about 10%. This system has been applied on EAST. Based on relative calibration, reliable 6-point edge measurement data have been obtained. The data are compared with the measurement results of the filter Thomson scattering diagnostic system, which proves that the temperature measurement has high reliability. In the next phase, we will continue to complete the density calibration study.

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Diagnostic for Fusion Machines / 47

Intercomparison of High Electron Temperature Measured by TS and ECE on EAST

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High electron temperature(Te) is an important parameter for future fusion reactors. Among the most common techniques used to evaluate Te are incoherent Thomson scattering (TS) and electron cyclotron emission (ECE). Due to the different diagnostic application conditions brought by different measurement principles and certain limitations of technology, it is difficult to maintain absolute consistency between the two diagnostic results in terms of temperature measurement, especially under high electronic temperature conditions, this difference is particularly obvious. To address this discrepancy, related research is being conducted on major devices such as ITER and JET to explore the influencing factors. This issue is also a significant topic for the International Tokamak Physics Activity (ITPA).
Recently, related work has also been carried out on EAST. We compared the temperature measurement results of TS and ECE at high electron temperatures, trying to identify the applicable conditions for diagnostics and technical deficiencies such as calibration. In addition, we try to obtain a high electron temperature through different discharge conditions, and based on this, we compare the different results of the two diagnostics, trying to understand the influence of different heating conditions and wall conditions on the diagnostic measurements.
In these experiments, under conditions dominated by electron cyclotron (EC) heating, different combinations of heating methods, as well as variations in power and current, were applied. The exper-

imental results revealed discrepancies between the two measurements under different wall conditions. Under Li-wall conditions, the electron temperatures measured by TS were significantly higher than those measured by ECE. In contrast, under B-wall conditions, the measurement differences between the two were not significant. Additionally, in the presence of ion cyclotron (IC) heating, the electron temperatures measured by TS were consistently higher than those measured by ECE. The influence of fast ions on the electron distribution function could be considered in this context.
These research will not only improve the accuracy of temperature measurement systems but also help explore the conditions for achieving high electron temperatures in modern fusion machines.

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Evaluation of the viewing factors of tokamak bolometric diagnostics using ray tracing for the improvement of tomographic reconstructions

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Nuclear fusion offers the potential for an almost limitless and clean energy source. Achieving controlled fusion necessitates the confinement of hot plasmas within devices called tokamaks, which use magnetic fields for this purpose. Accurate measurement of total radiation and impurities in these plasmas is crucial for optimizing performance and ensuring safety.
Bolometers, which provide line-integrated measurements, are key diagnostics for measuring radiation. Tomography is essential in these measurements as it converts line integrals into spatially resolved emissivity, a process complicated by its inherently ill-posed nature. Traditional tomographic methods often approximate lines of sight as exact lines; however, these lines broaden due to the geometry of the collection system and the finite dimensions of the detectors, significantly affecting the accuracy of reconstructions. Enhancing the quality of these reconstructions requires a precise understanding of the viewing geometry.
This work presents a comprehensive methodology for calculating and validating viewing factors using ray-tracing simulations. This approach evaluates viewing factors and étendue by considering the detailed geometry of the machine and detectors.
This method can handle complex aperture and collimator geometries and its applicability and effectiveness are demonstrated for the diagnostics of various European tokamaks.

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Experience on the interferometry and polarimetry for fusion reactors

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After more than half a century of mostly academic research on nuclear fusion, we are now at a phase to start building industrial size machine to operate with reactor-mode. However, to control and operate such complex machines, robust and reliable diagnostics are essential.
Reactor- grade diagnostics systems requirements translate in the ability to operate in an incredibly challenging environment and that is matched only to a certain extent in some of past or existing fusion devices around the world.
Some conditions will be new such as strong electro-dynamic forces due to high (10 Tesla) magnetic fields, neutron fluence(for the lifetime of the machine) five to seven order of magnitude larger than any past or existing plasma experiment, extremely limited access to the machine for viewing ports, plasma duration measured in hours and days and, most notably, very low or zero access to most of the parts of diagnostics. With that in mind one must develop a system with enough redundancy and robustness to survive these extreme conditions for many years to come.
None of the diagnostics existing today would translate directly to a reactor design but we can use the experience accumulated over 70 years in developing and operating diagnostics systems for a fusion reactor.
This presentation will focus on key aspects, requirements, and strategy in designing future reactor grade nuclear diagnostics, with focus on the interferometry and polarimetry based on experience accumulated on various machines (JET being the primary example with more than 40 years of operation).

Acknowledgments
JET, which was previously a European facility, is now a UK facility collectively used by all European fusion laboratories under the EUROfusion consortium. It is operated by the United Kingdom Atomic Energy Authority, supported by DESNZ and its European partners. This work, which has been carried out within the framework of the Contract for the Operation of the JET Facilities up to 31 October 2021, has been funded by the Euratom Research and Training Programme. Since 31 October 2021, UKAEA has continued to work with the EUROfusion Consortium as an Associated Partner of Max-Plank-Gesellschaft zur Förderung der Wissenschaft e.V represented by Max-Plank-Institut fur Plasmaphysik ("IPP") pursuant to Article 9.1 of the EUROfusion Grant Agreement for Project No 101052200. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

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Review of the Ignition campaign on the National Ignition facility

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Fusion energy has been the driven force in the High Energy Density (HED) community for more than fifty years but especially since the start of the National Ignition Campaign in 2009 on the National Ignition facility (LLNL, USA). The National Ignition Campaign, though a marvel in term of laser technology and data quality in this challenging regime, has failed to achieve ignition. This failure has shed lights on gaps of our understanding of fundamental plasma properties such as thermal transport or emissivity. Following these initial difficulties, evolution of the design (higher adiabat, new ablator, new hohlraum conditions) has led to significant improvement in implosion performance over the years and finally to ignition (Q=1.5) in December of 2022. I will go over these evolutions and why they led to the recent successes obtained on the NIF.

Diagnostic for High Energy Physics and Plasma Acceleration / 51

Advanced Diagnostics for Novel Ceramic Plasma Discharge Capillaries

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Spectroscopic and microscopic techniques adopted for the characterization of ceramic plasma discharge capillaries, designed for high repetition rate plasma-based particle accelerators

Cultural Heritage / 52

Comprehensive scanning system utilizing multiple sensors covering X-ray to infrared range, dedicated to the analysis of paintings

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Innovative technologies play a crucial role in the protection and conservation of cultural heritage against anthropogenic risks and climate change. In particular, multi-analytical approach offers comprehensive surveillance capabilities, identifying potential threats and damages [1]. In this sense, a multi-sensor scanning system able to acquire spectroscopic images using different techniques (X-Ray Fluorescence, UV-induced fluorescence, fiber optical reflectance and reflection FT-IR spectroscopies) was realized to analyze paintings [2]. The acquiring system is mounted on a 3-axis scanner, remotely controlled, equipped with a laser sensor to control the working distance. The high precision and reproducibility of the positioning system gives the possibility of acquiring data with the different techniques in the same points. The acquired data can be recombined giving rise to hyperspectral images of paintings containing all the different information.
The scanner was developed thank to the ARTEMISIA project, financed by Lazio Innova in the "DTC Excellence Centre for Cultural Heritage"contest and applied in the CHANGES project, Spoke 7 "Protection and conservation of cultural Heritage against climate changes, natural and anthropic risks", financed by the European Union-NextGenerationEU [3].

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SINBAD-IR beamline at DAFNE-Light: applications and developments of FT-IR spectroscopy in the field of Cultural Heritage

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The SINBAD-IR beamline at the INFN-Frascati National Laboratories, uses the synchrotron radiation produced by the DAΦNE electron ring, and conventional IR sources, for spectroscopy and imaging experiments targeting materials'characterization across the infrared spectral range, from THz to NIR [1].
In the Cultural Heritage field, FT-IR spectroscopy is often used to study the spectral response of materials, including the characterization of paintings, the evaluation of the effectiveness of cleaning treatments, and the assessment of artworks'conservation states [2,3]
The high precision and accuracy of IR spectroscopy, combined with its non-destructive nature and the possibility of working on very small samples makes it the ideal technique for the chemical and mineralogical characterization of materials constituting artworks. Some of the applications carried out at the synchrotron radiation laboratory on Cultural Heritage materials, highlighting the advantages of the technique and future developments [4] will be reported.

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Diagnostic Capabilities at Wendelstein 7-X Stellarator

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Wendelstein 7-X (W7-X) is the largest and most advanced superconducting stellarator currently in operation. The primary objective is to demonstrate the ability to maintain a steady-state plasma with fusion-relevant plasma parameters and thus proving that the stellarator is a viable fusion power plant concept. In the most recent test campaign, the new and fully water-cooled divertor was tested with a heating power of up to 7 MW and a long-pulse operation of up to 8 minutes with 1.3 GJ of injected energy was achieved.

While electron temperatures of up to 5 keV and densities of 2.4×10^{20} m^{-3} are found in the centre of the plasma, these drop to a few 10 eV and 10^{19} m^{-3} at the plasma edge. Consequently, a number of different plasma physical effects must be exploited to determine important plasma parameters, profiles, flows or turbulence phenomena. Diagnostics inside the plasma vessel are subject to harsh boundary conditions, including thermal loads in the divertor of up to 10 MW/m^2 as well as plasma and microwave scattering radiation of up to 100 kW/m^2 each. They must therefore be adequately protected and thermally connected to the cooling structures. Another challenge, especially for the safety-relevant diagnostics such as the IR cameras for monitoring the divertor surface temperature, is the long-term operation of up to 30 minutes and the handling of large amounts of data. In addition, the complex 3D magnetic field structure and additional asymmetries of the plasma require extensive mapping techniques for comparisons at different toroidal positions and for different diagnostics.

The presentation will give an overview of the development and application of some diagnostics in relation to the aforementioned requirements.

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Cultural Heritage / 55

Motion Magnification of videos for the diagnostics of buildings' state of damage

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The assessment of the state of damage of modern or ancient buildings is extremely important in the engineering practice. Today, the focus is on the use of non-destructive methods, among which video-based diagnostics may play a major role because of many advantages with respect to contact and traditional methods, especially in the application to Cultural Heritage assets. An emergent methodology within this field is the motion magnification (MM) of recorded video footages. MM technique is based on algorithms able to magnify the movements of objects in a video by amplifying the acquired pixels signals, while keeping the objects topology. As a result, tiny movements of objects present in the video, invisible to the naked eye, are magnified becoming clearly visible. Besides, they can be processed for a quantitative analysis of objects dynamics. Importantly, the magnification can be operated in a selected range of frequencies. In addition to traditional quantitative methods (e.g. in the frequency domain) innovative methods can be applied to magnified videos, along to simple qualitative visual methods. Here we intend to show some of them.

Diagnostic for Inertial Confinement / 56

Novel “Octopus”diagnostics for the investigation of side stimulated Raman scattering at ICF laser intensities

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One of the main concerns of Inertial Confinement Fusion (ICF) is the impact of laser parametric instabilities growing during the interaction of the laser pulse (~10^14-10^15 W/cm2) with the long-scale plasma corona; the issue is even more serious in the Shock Ignition scheme, where the intensity of the laser spike (~10^16 W/cm2) is an order of magnitude higher than the intensity needed in the classical direct-drive scheme. Among laser-plasma instabilities, Stimulated Raman Scattering is particularly dangerous for ICF performance and above all in Shock Igntion regime, because it results in the generation of large fluxes of suprathermal hot electrons, that can preheat the cold fuel, and because it scatters a significant amount of energy increasing the energy requirements for the laser driver.

In this context, in the last 30 years a large effort was devoted to the investigation of Backward Stimulated Raman Scattering (BSRS), where Raman light is scattered in the laser beam backscattering direction by a forward travelling electron plasma wave. However, recent experiments at NIF and Omega laser facilities revealed the importance of side-SRS (SSRS) instability, where SRS light is scattered in a direction perpendicular to the density gradient, and the scattered light is successively refracted to lower densities, finally exiting the plasma at large angles. These experiments also suggest that in ICF conditions SSRS can even prevail on BSRS. SSRS is hystorically the less understood parametric instability, which depends also on the experimental difficulty to detect and quantify SRS light scattered in the full solid angle.

Here, we describe the “Octopus”multi-fiber diagnostics which has been designed at INO-CNR and successfully used in a recent experiment at PALS laser for the angularly and spectrally resolved investigation of SSRS at Shock Ignition laser intensities. The Octopus diagnostics allowed a clear detection of SSRS, and permitted to reveal its dependence on the polar and azimuthal angle of detection, and the different scaling on laser-plasma interaction conditions with respect to the Backward SRS.

Diagnostic for High Energy Physics and Plasma Acceleration / 57

Diagnostics for plasma acceleration and secondary radiation sources for EuPRAXIA Advanced Photon Source (EuAPS) at FLAME laser facility

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The EuPRAXIA Advanced Photon Source (EuAPS) will be the first user-oriented radiation source based on betatron radiation, and it is currently under development at Laboratori Nazionali di Frascati - INFN at the FLAME laser facility.

Betatron radiation is emitted due to the betatron oscillations of electrons in a plasma during the

Laser WakeField Acceleration (LWFA) process. An intense laser beam (10^{19} W/cm^2) is focused on a supersonic gas jet, simultaneously creating a plasma, injecting, and accelerating electrons, which then emit radiation.

A precise characterization of the plasma density, as well as the electron and radiation spectra, is required to optimize the source. Preliminary measurements of these parameters have been conducted using a Mach-Zehnder interferometer, a magnetic dipole and a CCD-X camera.

Diagnostic for Fusion Machines / 58

Extreme Ultraviolet Spectrometers for fast observation of high-Z impurity line emissions and their density radial profiles in Experimental Advanced Superconducting Tokamak

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The plasma-facing components (PFC) in EAST tokamak are primarily composed of metallic materials, including tungsten divertor and limiter, titanium-zirconium-molybdenum (TZM) alloy first wall, copper antennas, and various components made of iron alloys. Consequently, multiple high-Z impurity species including Fe, Cu, Mo, W, will exist in EAST plasma due to inevitably plasma-wall interaction (PWI). Plasma performance could then be degraded by serious radiation power loss contributed by those high-Z impurity ions once they transport into plasma core region. In order to monitor impurity components and their evolution, observe high-Z impurity density distribution and study the impact the high-Z impurity behavior on plasma performance, several sets of extreme ultraviolet spectrometers have been newly developed including four fast-time-response extreme ultraviolet spectrometers with a temporal resolution of 5 ms/frame working at 5-520 Å [1, 2], two pairs of space-resolved spectrometers with a large viewing range working at 30–520 Å [3], another two pairs with high temporal resolution working at 5–138 Å [4, 5]. The grazing-incidence flat-field imaging optics are designed for all the EUV spectrometers. An entrance slit of 30 μm width is installed on the fast-time-response spectrometer, and the space-resolved spectrometer is equipped with an entrance slit of 100 μm and a space-resolved slit of 1 mm width. The laminar-type concave holographic grating with varied-line-spacing groove of 2400 and 1200 grooves/mm is equipped for spectrometer working at shorter or longer wavelength range, respectively. Two CMOS detectors with fast readout rate are installed in two pairs space-resolved EUV spectrometer enable a high temporal resolution of 15ms/frame. While CCD detectors are installed for other six EUV spectrometers. During EAST experiment, four fast-time-response EUV spectrometers operated at the wavelength ranges of 5-50 Å, 40-180 Å, 160-386 Å, and 245-500 Å, respectively, allowing simultaneous observation of low and high charge states ions of high-Z impurities. Additionally, the space-resolved EUV spectrometers operating at 40-70 Å to measure the radial profile of the tungsten line emissions. The wavelength and absolute intensity calibration has been performed precisely. As a result, the spectra lines from C2+-C5+, O2+-O7+, Ne+-Ne9+, Si4+-Si11+, Ar9+-Ar15+, Al3+-Al12+, Fe4+-Fe23+, Cu9+-Cu26+, Mo4+-Mo31+, W4+-W46+ ions has been identified for the first time in EAST based on the fast-time-response EUV spectrometers [6-8], and the density profile of Fe22+, Mo30+-Mo31+, W43+-W45+ has been measured by space-resolved EUV spectrometers [9]. The tungsten behavior during plasma disruption and sawtooth crash has been studied utilizing the fast-time space-resolved spectrometers. The high-performance EUV spectrometers and the measurement of high-Z impurity profiles have become the powerful tools for studying the transport process of high-Z impurities and their impact on plasma performance.

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Diagnostic for Fusion Machines / 59

New diagnostic capabilities of DIII-D

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Comprehensive and accurate physics parameter measurements with appropriate spatial and temporal resolution are vital for controlling plasma shape, equilibrium profiles, and maintaining magnetohydrodynamic (MHD) stability. Additionally, these measurements are key to validating theoretical models and achieving a predictive understanding of plasma behavior for fusion pilot plant (FPP) plasma control.
The DIII-D tokamak is recognized as one of the best-diagnosed magnetic fusion experiments. The diagnostic systems at DIII-D support various aspects of fusion research, including basic tokamak control, transport studies, stability analysis, boundary studies, heating and current drive research. The diagnostic set on DIII-D is the result of collaborations with over 130 institutions, including universities, national laboratories, and industry. In addition, DIII-D provides a flexible environment that supports further development and implementation of new and innovative diagnostics.
This paper briefly describes several new diagnostic capabilities recently added to DIII-D: Doppler-free saturation spectroscopy (DFSS) to directly measure RF fields, a textured tile to estimate the contribution of charge exchange neutrals on the first wall erosion and deposition, an upgrade of the Doppler-back scattering (DBS) system to measure fluctuations associated with Helicon waves, thermal Helium Beam diagnostic for profiles near Helicon antenna, a new 2D divertor Thomson scattering (DTS-2D) system enabling imaging in lower divertor for a variety of shapes, additional hydrogenic Lyman alpha measurements to diagnose neutrals (LLAMA and ALPACA), an additional toroidally displaced chord added to the radial interferometer polarimeter to measure toroidal mode number of high-n fluctuations (TRIP), charge exchange neutral spectroscopy (CENS) diagnostic to measure the atomic neutral energy distribution inside the confined plasma, a fiber-optic bolometer (FOB) utilizing phase shift caused by thermal expansion of micro-silicon pillar, and a pellet sizer which measures the size of fired pellets in-situ.
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Design of Gas Electron Multiplier detector as a compact neutron spectrometer to fusion devices

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Measuring fusion neutron spectra can give important information on ion fuel ratio and ion temperature, which are the goals of the High-Resolution Neutron Spectrometry (HRNS) on ITER [1]. This role is foreseen to be fulfilled by the HRNS system, comprising a set of different neutron spectrometric technique with distinct operation range: Time-of-Flight (ToF), diamond detectors and thin-proton recoil (TPR) with dE-E silicon detectors [1]. The concept of performing TPR neutron spectroscopy with a gas electron multiplier (GEM) detector coupled with a polyethylene converter, so-called NS-GEM, has recently been proposed in [2].
Based on the simulation results, the concept of the NS-GEM spectrometer was developed, and a detailed detector design was prepared, starting with a standard 3-stage GEM detector. A detector model for GEANT4 simulation was built and extensive Monte Carlo simulations with appropriately large statistics were performed. The simulation results allowed us to evaluate the energy resolution of our demonstration detector, considering the following issues: recoil proton generation efficiency, recoil proton scattering in the converter and detector, proton energy losses in the converter and detector. By taking these effects into account, we can generate dE/dx calibration curves as a function of the initial energy of the recoil protons.
The simulation results clearly show that the converter thickness is a critical parameter affecting the neutron energy resolution. The thickness of the converter should be kept below 0.5 mm and preferably around 0.1 mm, although a thinner converter means lower recoil proton production efficiency.
In parallel with modeling the detector response, work on the detector design was carried out. The NS-GEM detector together with the electronic readout system and the detector polarization system were transported to the Institute of Nuclear Physics and assembled in the IGN-14 generator. The detector and collimator were aligned and positioned in front of the tritium target. Based on this experimental set-up the preliminary measurements were carried out.
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Diagnostic for Fusion Machines / 61

Update of mid-plane reflectometer system and the design of divertor reflectometer on the EAST tokamak

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The EAST tokamak is a full superconducting toroidal device with a major radius of $1.85\ m$ and a minor radius of $0.45\ m$. The typical density range of the plasma is below $8 \times 10^{19}\ m^{-3}$, and the magnetic field at the magnetic axis can be vary from $0 - 3\ T$. On EAST, the frequency modulated continuous wave (FMCW) reflectometer systems for density profile measurements have been continuously developing since 2012, and are composed with Q-band ($33 - 50\ GHz$), V-band ($50 - 75\ GHz$) and W-band ($75 - 110\ GHz$) reflectometers. The polarization of these reflectometer systems is X-mode. The arrangement of the antennas is bistatic, i.e., using the separate antenna to lunch and receive microwaves. The probing wave is launched into the plasma on the mid-plane

from the low field side (LFS) of the plasma. Recently, a quasi-optical (QO) combiner/de-combiner by using frequency selective surfaces (FSSs) has been built to combine the three bands so that these waves ($33 - 110\ GHz$) can be transmitted to the antenna by using one single oversized waveguide. Two double-ridged horns are used for launcher and receiver. The received waves are decoupled by using a QO decombiner, the same with the combiner. In EAST experiments, the density pedestal evolution shows a well correlation with the edge localized modes (ELMs) in with the application of the updated reflectometers.
Equipped with tungsten divertor and full-metal first wall, the EAST is a good platform to study the SOL/divertor tungsten transport, which is one of the ITER priority issues. Divertor reflectometer could provide the necessary density information. In the design, the transmitting and receiving antennas will be installed in the upper divertor plate toward the leg in the LFS. According to the density distribution around the divertor leg from SOLPS simulation ($B_t \sim 2.4\ T$), the characteristic frequency distribution is calculated. In order to avoid the impact of large wave-guide size on the structure of the divertor component, and considering the flat distribution of the O-mode, the right-hand cutoff frequency of X-mode is chosen as probing frequency. The wider frequency range is chosen for the consideration of measurement of zero point in the lower field ($B_t \sim 1.8\ T$). The divertor reflectometer is divided into two subsystems, responsible for FMCW signal generation and reception at $50 - 75\ GHz$ and $75 - 110\ GHz$ respectively. The well-developed superheterodyne circuit construction of mid-plane reflectometer could be utilized on this system. However, the long and complex waveguide is an important component in the system, currently the construction of transmitting line is to be tested in the simulation.

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A space-resolved visible spectroscopic platform based on compact endoscopic optics for full radial profile measurement of impurity line emissions in EAST tokamak

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Upper and lower graphite divertors in Experimental Advanced Superconducting Tokamak (EAST tokamak) were replaced by tungsten divertors in 2014 and 2021, respectively. And boronization was performed in EAST to improve plasma performance in long pulse discharges and accumulate experiences for ITER operation with tungsten wall. Therefore, studies on the behavior of tungsten and boron and other impurity particles in plasma especially in edge region are then crucially important. For the purpose, a space-resolved visible spectroscopic platform working at 320-800nm has been newly developed on EAST tokamak. The platform is built based on a compact endoscopic optics design, which enables two spectrometer systems covering advanced viewing ranges, i.e. vertical and toroidal (2D) space-resolved observation of tungsten and boron source on upper edge/divertor region, and investigation of the impurity line emissions profiles covering the whole poloidal cross section of EAST (1D) by equipping with fiber bundles of 11×10 planar and 60 vertical array, respectively. Especially full radial profile observation of M1 forbidden transition from tungsten ions of W8+-W12+ and W26+-W28+ will be also attempted with the 1D system. Combining with W24+-W28+ ions observation by EUV spectroscopic system , simultaneous observation of tungsten source, weakly- and highly-ionized tungsten ions will enable an experimental study on tungsten edge-core coupling transport study. Additionally, the profile of edge impurity flow and full radial profile of effective Z, Zeff, could also be inferred from this platform. Layout of the platform, design of the endoscopic optics, R&D of the quartz window and shutter and arrangement of spectrometer and detector, as well as the preliminary results, will be presented in this paper.

Diagnostic for Fusion Machines / 63

Mechanical Design of the new Bolometric and Soft-X ray diagnostics for DTT

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In the European roadmap towards nuclear fusion, the new Italian project DTT (Divertor Tokamak Test) [1], currently under construction at the ENEA Frascati Research Centre, aims at exploring alternative solutions for the divertor and optimizing the divertor configuration foreseen for DEMO.
A dedicated set of diagnostics are planned to measure the radiated power by integrated emission detection and to monitor plasma processes by means of Soft-X emission measures. The measurement of the total radiated power will rely on commercial metal resistor bolometers [2], while for the SXR range of energies a new technology based on custom Chemical Vapor Deposition diamonds (CVD) will be adopted [3].
This work focuses on the mechanical layout design of these integrated diagnostics, respecting geometrical and functional constrains of DTT and minimizing the diagnostics encumbrance inside the access pipe. An integrated and compact solution, allowing flexible positioning and easy maintenance of the two systems has been pursued, with a structural layout based on a modular approach. The detectors of the two diagnostics are mounted on a common frame, with adjustable mounts for an independent fine-tuning of their alignment.
The high heat load from the plasma is coped with by means of a custom designed active water-cooling system, to protect the sensors while ensuring stable and reliable operations.
To allow a good physical exploitation of the collected data, i.e. with tomographic reconstructions, the lines of sight of both systems must be properly arranged on the poloidal section of the plasma. The proposed mechanical design foresees a customized chassis for each of the four poloidal ports of the DTT vacuum vessel, assuring a suitable coverage of the plasma's poloidal section.

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Diagnostic for Inertial Confinement / 64

Advanced diagnostic methodologies for laser-generated electromagnetic fields in experiments of Inertial Confinement Fusion

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The interaction of high-power laser pulses with matter produces electromagnetic radiation with a broad frequency spectrum, ranging from the MHz up to the THz range [1,2]. These pulsed fields (known as Electromagnetic Pulses: EMPs) can reach intensities of the MV/m order at meter distance from the interaction point and are, therefore, often considered as a hazard in laser-plasma experiments, due to their capability of potentially damaging the surrounding electronic devices. However, recent research shows that these fields, if controlled with ad-hoc techniques, can be exploited for promising applications, including high-intensity magnetic fields for inertial confinement fusion schemes [3], the transport and acceleration of particle beams [4] and the controlled generation of transient high-intensity electric fields over large-volumes [5]. Thus, the comprehension of their origin and the development of diagnostic techniques and devices, is crucial for mitigating unwanted EMPs and use them, on the other hand, for applications. We present here the state-of-the-art of diagnostics techniques for characterizing the transient electromagnetic emission, in the spectral range of MHz-GHz, generated by laser-matter interactions, addressing challenges and technological aspects. In this frequency range, due to the typical intensities and time duration of laser-driven EMPs, conductive probes are most commonly used for field probing, although they are intrinsically much affected by background noise, due to ionizing radiation. Innovative electro-optical probing techniques promise instead more robustness; we will highlight their features, their limitations and the challenges of their implementation during experiments.

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Diagnostic for High Energy Physics and Plasma Acceleration / 65

Spectroscopic Methods for Density and Temperature Diagnosis in Plasma Capillary Tube

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Laser plasma accelerators (LPAs) represent a cutting-edge technique designed to achieve high accelerating gradients on the GV/m scale [1,2,3]. These advanced systems are gaining traction in particle physics due to their potential to surpass the limitations of traditional accelerator structures. Their

appeal lies in the compact design of plasma-based accelerators (PBAs), utilizing small-scale plasma modules ranging from millimeters to centimeters.
In this context, we present experimental findings from testing a plasma capillary tube designed specifically for PBAs. Here, hydrogen gas is ionized using a high-voltage electrical discharge (HVDC). A key challenge in this approach is the precise monitoring and characterization of the plasma, which is essential for synchronization with the accelerated beam generated by intense laser pulses (LWFA) or energetic electron beams (PWFA). This characterization requires understanding the distribution of neutral gas within the capillary, the dynamic behavior of the plasma, and its stability and uniformity.
To tackle these challenges, our study employs spectroscopic methods to investigate the electron density and temperature of the plasma generated within a plasma capillary tube [4]. We investigate the temporal evolution of electron density using Stark broadening profiles [5,6,7,8] and analyze line profiles of various ionic species, specifically assessing the intensity of lines from successive ionization stages of oxygen to understand variations in electron temperature and determine the overall plasma characteristics [9]. These efforts significantly advance our understanding of plasma dynamics, crucial for optimizing PBA technologies.
The proven efforts and techniques have been developed within the EuPRAXIA (European Plasma Research Accelerator with eXcellence In Applications) framework at INFN–LNF (Istituto Nazionale di Fisica Nucleare –Laboratori Nazionali di Frascati) [10].

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Diagnostic for Fusion Machines / 66

Evaluation of expected UV/SX and neutron induced current in thin diamond detectors from plasma in a tokamak environment

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Thin diamond detectors have proven to be excellent diagnostic tools for plasma diagnostic in a tokamak machine for the detection of soft X (SX) and UV radiation [1]. Furthermore, thanks to the excellent physical properties of diamond, i.e. wide band-gap, fast response time and radiation hardness, diamond detectors are among the alternative diagnostic tools in the next generation fusion machines that will be producing huge neutron and gamma fluxes. Therefore, it is important to know as better as possible how diamond detectors operate under intense neutrons and photons radiation.
Thin diamond detectors (<15 µm thickness), developed at Tor Vergata University of Rome, allow for effective detection of incident UV and SX radiation while ensuring excellent radiation hardness [2]. For UV/SX diagnostics, it is crucial to optimize the photon signals and minimize neutron noise as

much as possible.
The aim of this work was to evaluate the attended induced signal in such thin diamond detectors from both photons and neutrons. In order to achieve that, Monte Carlo simulations were performed to evaluate the current induced by a neutron spectrum expected by a D-T fusion tokamak machine. Results were compared and validated through an experimental campaign that utilized a 14 MeV neutron spectrum.
In order to compare the current values obtained from the neutrons with that from UV/SX radiation, radiative power provided by the plasma was estimated as a function of the plasma radius and energy of the photons, based on physical input parameters such as light and heavy impurities, temperature and plasma geometry. Once the radiative power was obtained, the expected current value from UV/SX spectral range was extrapolated using the responsivity curves of thin diamond detectors, which where both calculated and experimentally measured.
This work aims at developing a signal prediction tool based on fusion plasma conditions, to provide precise design and optimization guidelines for the diamond detector unit and its electronics in view of their planned extensive application as detectors for tomography diagnostics, replacing the standard Si or CdTe photodiodes used so far.

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Diagnostic for Fusion Machines / 67

Development of CVD diamond-based photodiodes for UV and SX-rays detection

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The well-known physical properties of Chemical Vapor Deposition (CVD) diamonds have made them highly attractive for use as detectors in harsh environments characterized by high irradiation levels, such as those found in fusion machines [1]. Notably, their good radiation hardness, visible wavelength blindness, high carriers'mobility, and high signal-to-noise ratio make diamond a promising alternative to the employment of conventional silicon diodes for plasma diagnostics.
In recent years, the Department of Industrial Engineering of "Tor Vergata"University of Rome has conducted extensive research on the development of photodiodes based on high-purity thin diamond layers (5-50 μm of thickness) for the detection of UV and Soft X-rays. Their application within tokamaks such as FTU [2] and JET [3] has yielded outstanding results in terms of performance and reliability, paving the way for the design of more comprehensive tomographic systems based on these devices.
The study focused on two main detector layouts: the "layered layout", which allows the detection of photons with energies ranging from 20 eV to 2-3 keV, and the "LAT layout", which permits the detection of photons of higher energies [4]. Tomographic systems based on these devices are currently being designed for two fusion machines under construction, the Divertor Tokamak Test (DTT) in Italy [5] and SPARC in US. These systems involve ~10^2 detectors arranged along specific lines-of-sight to fully cover the poloidal cross section of the plasma. Consequently, a multichannel amplifier

was specifically developed to minimize electronic noise from the environment, and tests were conducted on a first compact prototype.

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Diagnostic for Astrophysics and Space / 69

The X-ray calibration facility for the characterization of Gas pixel Detectors

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The X-ray Calibration Facility (XCF) at the University and INFN of Torino is dedicated to the calibration and characterization of X-ray detectors, sensible to position, energy and polarization.
The facility is focused on the study of the Gas Pixel Detectors [1] for x-rays polarimetry of astrophysical sources, developed at INFN-Pisa. Such detectors are the core of the detector units of the IXPE (Imaging X-ray Polarimetry Explorer) mission, that was launched by NASA on December 2021 and is currently taking data. Upgrades of the GPD are under study for future x-ray polarimetry missions.
The XCF facility hosts two X-ray tubes spanning energy ranges from 2 to 8 keV, providing two distinct beams, one of which is polarized via Bragg's diffraction. A positioning system allows to move the detector to be tested under the polarized or unpolarized beams.
Although conceived to qualify GPDs, XCF can support R&D programs for innovative position-energy and polarization-sensitive X-ray detectors. In this contribution the Gas pixel Detector and the XCF facility are described.

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Environmental Application and Medical Diagnostics / 70

Monte Carlo simulation of the ISOLPHARM gamma camera for Ag-111 imaging

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One consolidated technique for the treatment of cancer is Targeted Radionuclide Therapy (TRT). With this technique, radionuclides are attached to a specific drug that is able to bring them to the target tumor site [1]. The ISOLPHARM project is currently developing a radiopharmaceutical for TRT based on Ag-111, an innovative radionuclide [2] [3]. Ag-111 has a half-life of 7.45 days and decays emitting both electrons and gamma-rays (mainly with energy of 342 keV). The emission of gamma-rays allows the Ag-111 nuclei to be visualized through the use of a gamma camera.
In this contribution, we describe the Monte Carlo simulation built to optimize the parameters of this imaging device (see Figure 1). The software used for this aim is the Geant4 toolkit, which is able to simulate the interaction between particles and matter [4].

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Initial Design of a Real-Time and Intershot Bolometric Data Exploitation Strategy for DTT

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One of the milestones to be achieved in the design of the bolometric diagnostics for the new Italian Divertor Tokamak Test (DTT) project [1] is the estimation of the radiated power for the start of the operation, i.e the so called Phase 1. Such an achievement has several implications, ranging from the scientific analysis and planning of the discharges between shots to the feedback protection of the machine. Indeed, real-time (RT) feedback control of the radiation pattern for prevention is both a delicate and important matter, for example in terms of mitigating and avoiding disruptions [2]. Therefore, a wise approach would be to monitor not only the total radiated power, but also that radiated from different regions of the device [3]. This contribution then focuses on showing the design of the main strategy regarding the estimation of the plasma radiation in two different steps: for RT control and for inter-shot analysis. The first approach (RT) is based on the estimation of the radiated power inside the first wall using specific lines of sight (LoS). Such estimates have been compared with those obtained from slower tomographic reconstructions of synthetic emissivity profiles (phantoms). Furthermore, a first design of the Region Of Interest (ROI) for a fast implementation of an already established macro-estimation of the radiated power in different locations of the main chamber is provided and the overall method is adapted for DTT. Finally, considering the actual planning of the DTT pulses, the second step of the design concerns the inter-shot data exploitation. Since tomographic reconstructions will most likely be available during an inter-shot basis, in combination with the knowledge of the geometry and the contribution of each voxel, and by considering the main outputs of the RT estimators in different regions of the device, it is planned to provide a more accurate estimate of the radiated power from different locations of the device for a better design and tuning of the discharges.

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AI in Support of Diagnostics and Inverse Problems / 72

A Physics-Informed Deep Learning Model for Data-Unsupervised Extraction of Information in the Spectroscopy Field

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Spectroscopic analyses are between the most used methodologies to investigate any state of matter. In fact, from the analysis of the electromagnetic spectra it is possible to extract several quantities that are characteristics of the analysed medium. Therefore, the spectrum must usually be analysed and computed by some specific algorithms, such as pre-processing and calibration tools, to extract the various pieces of information of interests. Such algorithms are usually developed by using a sort of supervised approach, where some ad hoc controlled experiments are performed to finely tune the algorithms to achieve the highest performances. However, such supervised approaches are sometimes prohibitive or not economical, limiting the diagnostic potentialities to only qualitative results or not accurate quantitative measurements. Therefore, new methodologies based on not supervised approaches, which do not require controlled experiments and labelled data, would help in improving the diagnostic potentialities and performances in these fields and applications.
This study introduces an innovative unsupervised physics-informed deep learning methodology for data preprocessing, calibration and information extraction directly from raw measurements. Unlike traditional supervised approaches, this methodology automates data processing without relying on controlled experiments, but processing the data according with physics theoretical models, a relevant aspect if we consider that controlled experiments are not always possible.
In this work, the potentialities of this new approach are investigated by a series of synthetic cases and some experimental tests. The analyses clearly demonstrate the huge potentialities of the physics-informed deep learning model, allowing for preprocessing and calibration performances comparable with supervised models.
Obtaining such great performances without the need of controlled experiments and labelled data opens to the possibility to improve pre and post processing of diagnostics even in applications where standard calibration approaches are not affordable. Moreover, even if the model has been particularized for spectroscopic applications, it is worth it to highlight that the methodology is fully general and can be easily transferred to any other field.

Keywords: Physics-Informed Neural Network, Deep Learning Model, PINN, Spectroscopy, Unsupervised Information Extraction

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Streak camera diagnostic for high-power laser-matter interactions

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The use of streak cameras in inertial confinement fusion (ICF) and generally in laser-matter interaction experiments dates back to the 1960s. Nowadays such instruments can provide accurate time-resolved information about the evolution of laser-generated of plasma plumes.
Converting the streaked image in quantitative data about plasma parameters, such as plasma density and temperature, requires an accurate modeling of the plasma emissivity and of the efficiency of the instrument, which in general depends on the wavelength of the collected radiation.
In this contribution the development of a synthetic streak camera for the FLASH code, at the moment widely used in the community, will be discussed, with the aim of reproducing experimental streaked images starting from simulation data. The modeling will be developed both for visible and x-ray streak cameras, as the one for example in [1]. The first part of this work is dedicated to the study of the radiative mechanisms responsible for the leading components in plasma emissivity and absorption for appropriate wavelength ranges. These results will then be coupled with the known technical parameters of the diagnostics.
One of the final results of this work will be the time-resolved sampling of the ion speed of sound to estimate the plasma temperature locally in time. The long-term development of this tool can potentially lead to the capability of streamlining the interpretation of the raw data from the instrument and be of use in experiments across the field.

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Cultural Heritage / 74

Damage diagnostic method by artificial intelligence analysis of shaking table data of a typical Italian building prototype

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A damage diagnostic method based on the use of artificial intelligence (AI) was pointed out for the analysis of displacement data recorded in shaking table tests of a prototype representing a typical Central Italy historic masonry building. The displacements were measured by the use of a 3D motion capture system capable of tracking the motion of passive optical markers located at several positions on the tested building.
In particular, machine learning was used to provide an estimation of the state of damage of the tested prototype. The state of damage was initially estimated by calculating a widely accepted Damage Index (DI) based on the first mode frequency decay of the building calculated by conventional Frequency Response Function (FRF) for modal analysis of the markers displacements data.

More specifically, a damage index prediction method based on Convolutional Variational Auto-Encoder (CVAE), an important generative model in unsupervised deep learning, was applied to the recorded displacement data, after proper partitioning. Regression techniques were then applied to the CVAE latent encoding space generated from the time sequences of the 3D motion markers to predict the DI values. Coefficient of determination (R2) and Relative Percent Deviation (RPD) were considered to assess the quality of the obtained regressions. The results showed that the methods provided by machine learning are very promising in their potentialities of assessing the structural damage in typical historic masonry buildings.

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New insights on the D(T,5He)γ reaction and prospects for D-T fusion power measurements on ITER

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Besides the well known emission of a 14 MeV neutron and a 3.5 MeV alpha particle, the D-T fusion reaction may also evolve with a secondary branch in which a 17 MeV gamma-ray is emitted together with a 5He nucleus. The physical properties of this secondary branch, though, were poorly known because of its very low probability to occur of about 10-5.
The second and third D-T experimental campaigns at the Joint European Torus allowed to investigate this radiative branch for the first time in a magnetic confined plasma, revealing unpredicted informations about its energetic distribution and occurrence rate with unparalleled accuracy [1-2]. For this purpose, a single line-of-sight LaBr3-based gamma-ray spectrometer was employed and an absolute counting of these fusion gamma-rays was performed.
These accurate determinations pave the way for a direct and neutron-independent measurement of the fusion power in magnetic confinement fusion reactors, based on the absolute counting of D-T gamma-rays.
In particular, the development of a gamma-ray spectrometer for fusion-power measurements is currently under investigation for ITER, promising to provide measurements with 1 s time resolution and less than 10% uncertainty for fusion powers in the [3 MW –500 MW] range.

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Exploitation of neutron spectroscopy measurements for assessment of DT fusion power without in-vessel calibration

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Neutron measurements are of crucial importance for nowadays nuclear fusion plasma experiments, even more for the forthcoming DT fusion reactors. In particular, neutron diagnostics are a key tool for measuring the fusion power which is a primary parameter to evaluate the fusion performance. Historically, fusion power measurements are based on counting the neutrons with fission chambers or activation foils and translate the counts in total neutron produced by the extended source which is the plasma. This is supported by intense neutron transport simulations benchmarked by extensive in-vessel calibration campaigns.
In this work an alternative method for assessing the fusion power without the need of an in-vessel calibration will be presented. It is based on the neutron spectroscopy measurements with single crystal diamond detectors along collimated lines of sight. Beyond their use as 14 MeV neutron spectrometer, in the last two JET deuterium-tritium (DT) experimental campaigns, diamonds have been exploited as DT neutron yield monitor. Results from the JET DT campaigns will be described, together with a comparison with the Magnetic Proton Recoil (MPR) data.

Imaging / 77

Investigating Complex Structures Through Advanced Correlative Microscopy Techniques

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The long journey of correlative microscopy (CM) began in 1945 when Keith Porter conducted pioneering studies demonstrating that specific details within specimens could be observed and characterized using both light microscopy (LM) and electron microscopy (EM) with proper sample preparation. Subsequent comparative attempts followed, thanks to contributions from McDonald, Pease, Hayes, and Geissenger, culminating in the development of detailed and robust protocols leading to correlative light and electron microscopy (CLEM) by 1980. Since then, CLEM has matured significantly, benefitting from technological advancements in both LM and EM fields, including super-resolution techniques overcoming the Abbe limit and the introduction of EM tomography enabling three-dimensional structure surveys with nanometric resolution. The innovative approach brought by CLEM has delineated the fundamental principles of modern CM, representing a game-changing element in scientific research. The increasing complexity of scientific questions necessitates a holistic, multimodal, and multiscale approach, from macrostructures down to the atomic level, across multiple characterization tools. This talk elucidates the pivotal role of CM, as a key enabling technology,

for the development of new investigation workflows and protocols, exploring its versatility in addressing advanced scientific problems and revealing hidden details across multiple length scales and modalities within specimens. The application of CM workflows based on both non-destructive and destructive characterization techniques in some of today's cutting-edge scientific research fields will be described, including electronics and semiconductors, aerospace, biodegradation of recalcitrant materials, geosciences, and cultural heritage.

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Current Status of Diagnostic Integration in Port Plugs for DTT

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The Divertor Tokamak Test (DTT), currently under construction at ENEA in Frascati, represents a crucial step in the development of magnetic confinement nuclear fusion [1]. DTT is a fully superconducting, high magnetic field tokamak, designed to significantly contribute to the integrated study of various divertor configurations. The diagnostic equipment includes advanced diagnostic systems for machine protection and plasma control, as well as for scientific exploitation.
Integrating diagnostics into the machine's ports presents significant complexities. The compact dimensions of the DTT, the huge heating system, the active cooling of the machine components, and the intense remote handling activity required, further complicate the optimization of allocation activities. The implementation of the DTT diagnostics is planned according to the needs of the different operational phases of the machine.
This work focuses on the integration of front-ends into the port-plugs structure supporting the diagnostics, the design of which should be optimized in compliance with foreseen remote handling

activities. The focus is primarily on the equatorial ports (3). Indeed, the equatorial ports are particularly crowded, as they offer the best view to observe both plasma core and divertor targets. The equatorial ports considered are those in sectors 1, 3, 5, 8, 9, 10, 15, and 17 as, of the 18 machine sectors, they are not allocated to heating systems. In 2023, the diagnostic project leaders carried out a thorough analysis and resolution of the interface issues, supported by close diagnostic coordination. This effort has been performed in compliance with the requirements of the involved DTT-WBS interfacing teams and has been fully implemented in the CAD machine design model.
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Diagnostic for Fusion Machines / 79

Conceptual design of collective Thomson scattering system for burning plasma experimental superconducting tokamak

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The Collective Thomson Scattering (CTS) diagnostic will be a primary diagnostic for measuring the dynamics of the confined fusion born alpha particles for burning plasma experimental superconducting tokamak (BEST), and will be the only diagnostic for measuring D/T ratio. The proposed CTS diagnostic system for BEST provides the unique capability of measuring the temporally and spatially resolved velocity distribution of the confined fast ions and fusion alpha particles in a burning plasma. The present paper describes the conceptual design of the BEST fast ion CTS diagnostic. The probe beam of the CTS diagnostic comes from a 60GHz 1MW gyrotron operated in ~1Hz modulation sequence. In addition, the CTS system has a receiver unit, which consists of five channels. Both the launch antenna and receiver unit are installed in an equatorial port plug. In order to prevent neutron damage to moveable parts, the geometry of the probes and receivers is fixed.

Diagnostic for Fusion Machines / 80

Exploitation of a 2D triple GEM detector at the MASTU spherical tokamak

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Within the scope of magnetic confinement fusion experiments, a Gas Electron Multiplier (GEM)-based detector was employed during the 2023 experimental campaigns at the MASTU (Mega Amp Spherical Tokamak) spherical tokamak to investigate the Soft X-Ray (SXR) radiation (0.1-20 keV) emanating from the plasma. GEM detectors are promising candidates as SXR diagnostics on the next generation on fusion devices for two main reasons: their resilience in the high neutron flux environments that will characterize the next generation of fusion devices, and their ability to combine spectroscopic capabilities with sub-millisecond time resolution imaging. As a result, the adoption of GEM-based detectors has surged in recent years, with numerous installations on tokamaks like FTU, KSTAR, EAST, and WEST, both as 1D array or 2D matrices.
The GEM detector featured in this study is positioned in front of a beryllium window that serves as a low-energy filter, employing a pinhole geometry outside the vacuum chamber. Its operation relies on the photoelectric effect, initiated by the interaction between the SXR and a gas mixture of ArCO2, followed by electron multiplication. The detector consists of an aluminized Mylar cathode,

succeeded by three GEM foils, and includes a 2D readout anode made of a 16x16 matrix of 6mm² square pads. It incorporates custom GEMINI ASICs for signal readout, enabling photon-counting techniques with Time over Threshold (ToT) analyses on each detector channel, achieving a total maximum rate of 256 MHz.
Preliminary findings from the 2023 campaign demonstrate the effectiveness of the GEM detector in identifying Magnetohydrodynamic (MHD) instabilities, with spatial and temporal resolution aligning well with existing SXR camera data. The detector's spectroscopy capabilities have proven capable of providing insights into the energies of particles during magnetic reconnection events, with more experiments planned on this topic. Additionally, the GEM detector has been able to estimate the electron temperature for Ohmic shots, with future potential to obtain local electron temperatures.These results highlight the potential of the GEM-based diagnostic system in advancing tokamak research, enabling comprehensive plasma characterization and control.
The diagnostic is currently installed on MASTU for the ongoing campaign, with a particular focus on supporting studies of accelerated particles and on the development of energy-resolved tomographic inversion.

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Numerical studies and design of the DTT HFS Plasma Position Reflectometer

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The Divertor Tokamak Test (DTT) facility [1] will feature a poloidally distributed O-mode plasma position microwave reflectometry (PPR) system, crucial for future reactors, where in- vessel magnetic sensors for position control will be limited by high neutron flux and long pulse durations. The DTT PPR system will have a number of Lines of Sight (LOS) at the Low Field Side equatorial and oblique ports, the top vertical port, and the High Field Side (HFS) region. This contribute focuses on the HFS subsystem design, which requires bistatic hog-horn antennas and waveguide routing behind the first wall through the top vertical port, due to the limited available space. The layout uses pairs of single oversized waveguides and optimized antennas [2] for each LOS, covering the 18–110 GHz range. Extensive FEM simulations (via COMSOL Multiphysics and CST) on the waveguides, together with simulations on the system's coupling with the plasma, realized through the FDTD full-wave 3D code REFMUL3, guided the design process. In particular, FEM simulations allowed to minimize mode conversion in curved waveguides by opting for hyperbolic bends over constant curvature ones, while the REFMUL3 simulations provided insights into how the installation of a reflectometer in a reactor relevant machine could affect the measurement accuracy. Additionally, the integration of waveguides and antennas led to a proposed modification of the first wall design, replacing a cooling pipe with a copper thermal bridge (structural analyses are ongoing). Despite some challenges, particularly with mode conversion, this work marks significant progress towards the implementation of a PPR in this complex environment.

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A Near Infra-Red dispersion interferometer for ST40 and future fusion reactors

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Dispersion interferometers are gaining in popularity for the measurement of line-integrated electron density in magnetically confined (MC) plasmas. Systems have been developed for use on several MC devices around the world, mostly using a CO2 laser to produce the fundamental wavelength and frequency doubling crystals such as OPGaAs, AgGaSe2 or ZnGeP2 to generate the second harmonic. Systems working at the 10.6m wavelength of the CO2 laser suffer two major disadvantages: the poor efficiency of doubling crystals at this wavelength and the presence of ro-vibrational resonances in the molecular gases present in air (O2, N2, CO2 and H2O) around the second harmonic wavelength (~5m). The use of a shorter wavelength does improve the doubling efficiency; however the signal level is proportionately reduced with the wavelength. This paper discusses a dispersion interferometer using a near infra-red laser and will show results of a working system achieving high signal to noise performance.

Environmental Application and Medical Diagnostics / 83

In silico medicine: predictive biomechanics for future diagnoses and therapies

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Precision medicine aims to provide highly personalized responses to clinical needs. To achieve this goal, doctors need to have more patient-specific information for diagnosis and a better understanding of the effects of the therapies. Hence, there is the urgent demand of new diagnostic and prediction tools. In silico models can be powerful tools to achieve these goals, but they still have limited capabilities in replicating the integrated and multi-factorial mechanisms underlying the functioning of physiological systems. This lecture will introduce chemo-mechano-biological in silico tools developed by our group to address some of the unique challenges arising in this context for cardiovascular biomechanics. A better understanding of mechanisms driving pathological progression or regression is gained, leading to improved treatment and prevention strategies for cardiovascular diseases.

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Soft X-ray tomography for monitoring fusion plasma dynamics

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In fusion devices, the local soft X-ray (SXR) plasma emissivity is rich in information about electron temperature and density, magnetohydrodynamic (MHD) activity and concentration of impurities that can be inferred with the help of dedicated tomographic inversion and synthetic diagnostic tools [1, 2]. Nevertheless, estimating the local plasma emissivity from a sparse set of noisy line-integrated measurements is a mathematically ill-posed reconstruction problem, that requires an adequate regularization procedure [1]. In this contribution, we introduce some tools aiming at validating and speeding up the X-ray tomographic inversions. The traditional approach based on Tikhonov regularization, including magnetic equilibrium constraint and parameter optimization, is presented. The advantages and drawbacks of substituting it with neural networks for fast inversions are investigated. Finally, the perspectives for plasma profiles reconstruction and validation are discussed.

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Cultural Heritage / 85

Use of the electromagnetic radiation for cultural Heritage

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Electromagnetic Radiation, in a wide range of frequencies, from microwaves to X-rays, is a useful tool for non-destructive analysis of Cultural Heritage. In this tutorial the main principles of the interaction between radiation and matter, and their application in the field of cultural Heritage will be presented. Starting from X-ray radiography, X-ray fluorescence, to Lased Induced Breakdown Spectroscopy, UV fluorescence, Laser induced Fluorescence, Optical Coherent Tomography, RGB Imaging Topological Radar, Multispectral and Hyperspectral IR reflectometry, Optical and Raman Spectroscopy, up to THz imaging and spectroscopy, the main features and limits of each technique will be presented, to offer the public an overview of the possibilities of these technologies in the field of cultural heritage.

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Triton burn up detection study for the Divertor Tokamak Test facility

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The measurement of 14 MeV neutrons present in a deuterium-deuterium plasma is an important parameter for the estimation of the triton burn up component in a tokamak. The deuterium-deuterium reaction has two equally possible branching ratios, one of which leads to the presence of tritons in the plasma. A fraction of these can cause a deuterium-tritium reaction, producing 14 MeV neutrons that constitute up to a few percent of the total neutron yield and provide information on the confinement of the tritons.

During the initial operation phases of the Divertor Tokamak Test facility, time-resolved triton burn up measurements will be carried out by means of a dedicated set of detectors distributed around the machine in the Torus Hall. Candidate detectors are a liquid scintillator (EJ301 type, 1.5 cm diameter and 1 cm thickness) and two 10-pixel single-crystal diamond matrices (4.5 mm $\times$ 4.5 mm $\times$ 200 μm and 4.5 mm $\times$ 4.5 mm $\times$ 50 μm respectively). Such set of detectors has been selected in order to cover the entire range of the total DTT neutron yield for various power scenarios, with the scintillator working for a neutron yield up to 10^{14} n/s, the thicker sCD working between 10^{14} - 10^{16} n/s and the thinner sCD between 10^{16} - 10^{17} n/s.

The three detectors are all sensitive not only to 14 MeV neutrons but also to lower energy neutrons and gamma-rays. Even though these unwanted signals can be rejected during data processing by setting appropriate energy thresholds in the spectra and using pulse-shape discrimination analysis, the presence of gamma-rays and the high flux of the predominant 2.45 MeV neutrons (produced by deuterium-deuterium fusion) limit the range of operation of the detectors due to pulse pile-up and to the load they produce on the scintillator photomultiplier, the front-end and the back-end electronics.

A method to improve the triton burn up measurement statistics is to use appropriate shielding materials in front of the detectors to reduce the gamma-ray and lower-energy neutron component while maintaining as much as possible the flux and energy spectrum of the 14 MeV neutrons. A study of candidate materials of different atomic number, in various thicknesses and geometry configurations is carried out by means of MCNP simulations in order to assess the feasibility of such an approach for improved triton burn up measurements.

The present work provides firstly an overview of the proposed triton burn up detectors at the Divertor Tokamak Test facility and then presents the results of the MCNP simulations to evaluate the potential extension of their operating range by the addition of dedicated shielding units that improve the ratio of 14 MeV/2.45 MeV neutrons at the measurement position.

Industrial and Cold Plasmas / 87

Recent advances and future perspectives in LIBS for industry and environment

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Laser-induced plasmas are versatile physical systems with applications in a wide range of fields, spanning from materials and biomedical sciences to environmental and food safety to extraterrestrial planet exploration, and more. Making the most of this broad set of applications requires a detailed knowledge of the plasma parameters and elementary processes responsible for the generation and time evolution of the plasma itself.

Laser-Induced Breakdown Spectroscopy (LIBS) is a powerful means to this end, providing both fundamental insight into laser-induced plasmas and a practical approach to obtain qualitative and quantitative elemental analysis of a vast variety of samples.

This tutorial talk will cover the fundamentals of LIBS, from both the theoretical and the practical point of view, as well as review various experimental approaches to tailor the technique and maximize its analytical performance.

These aspects will be discussed within the frame of two of the most promising and mature fields of application of LIBS as an analytical technique, i.e., industrial monitoring and environmental sciences, and particular emphasis will be given to an overview of key advances in areas of strategic importance such as pharmacology, mining, metallurgy, and waste recovery and recycling.

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Standardizing High Electron Temperature Measurement Comparisons: A Method for Cross-Diagnostic and Cross-Machine Analysis

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It is well-known that in tokamaks, measuring electron temperatures in the plasma core can become problematic when certain values are reached, typically exceeding 6-8 keV [1]. Discrepancies often arise between the values provided by different diagnostics, such as Thomson Scattering and Electron Cyclotron Emission (ECE), which are expected to agree. Accurate and reliable determination of electron temperature, especially in high-temperature scenarios, is crucial for the development of future reactors like ITER and Demo (with ITER's core plasma expected to have an electron temperature of about 25 keV at the center) [2], as well as for the Chinese Fusion Engineering Test Reactor (CFETR) [3], where conditions in which discrepancies in electron temperature measurements are most pronounced. Resolving this diagnostic issue is crucial for understanding important aspects of plasma physics in the core and beyond [4]. Recently, further studies on this topic have yielded substantial results and clarified several aspects. Current research focuses on the possible causes of the local non-Maxwellian shape of the electron energy distribution function, which is at the root of these discrepancies [1,4]. Ongoing research by various groups working on magnetic confinement machines worldwide aims to address this long-standing issue within the framework of an ITPA initiative.
This paper proposes a method to compare data collected from different machines using a code (currently under development) based on the previous one employed for the analysis of JET data [1]. The goal is to facilitate comparisons under consistent conditions, irrespective of machine-specific factors such as dimensions, fields, and equilibrium coordinates. The code addresses several critical aspects, including the positions of measurements (i.e., the plasma position relative to the diagnostics' lines of sight), the involved volumes, and other controls to ensure uniformity of results during multi-shot analyses. These controls encompass acquisition rate/resampling, data interpolation, and equilibrium reconstruction codes.

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Diagnostic for Density and Temperature / 89

Measurements of electron temperature in Tokamak Fusion Power Plants

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The measurement of electron temperature (Te) is done in tokamak plasmas mainly by Electron Cyclotron Emission(ECE) and using the Thomson scattered laser radiation(TS).
Recently these measurements were reviewed in the JET (Joint European Torus) DTE2 (second deuterium-tritium campaign) and differences Te_ECE –Te_TS were detected in particular at high electron temperature (Te>6KeV)[1]. Previously these differences were detected in JET, TFTR, FTU tokamaks[2]. The differences can be connected to the physics of ECE and TS and to the intrinsic non-maxwellian nature of the electron velocity distribution function (EVDF) of tokamak plasmas. In practice the strong sensitivity of ECE radiation emission to the deviation from maxwellian of EVDF has been identified as a possible cause of these differences .
The need of measuring the deviation of the EVDF from the maxwellian emerges from a large dataset on various machines . In tokamak fusion reactors ITER, CFETR and DEMO the evaluated bulk plasma electron temperature is higher than 10keV and the EVDF could exhibit a deviation from the maxwellian. The paper presents i) a review on the experimental evidences supporting the physics involved in understanding the differences between the Te_ECE and Te_TS, ii) how such deviations from the maxwellian EVDF can be evaluated and possibly measured in the context of fusion reactors, iii) the minimum set of diagnostics dedicated to the measurement of electron temperature in fusion reactors.

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Diagnostic for Density and Temperature / 90

Fast particle effects on polarimetry in JET Deuterium-Tritium (DTE2) high performance scenarios

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The Polarimetry measurements, i.e. Faraday Rotation(FR) and Cotton-Mouton Phase Shift (CM), are useful as constraint for the determination of the plasma equilibrium and for the measurement of the plasma density, respectively [1,2]. The modelling tool for polarimetry, tested on JET data, is the Stokes model [3], where FR and CM are calculated using the spatial profile of the components Br

and Bz (both perpendicular components in the poloidal plane) of the plasma magnetic field(B) determined by the equilibrium. In the 2nd Deuterium-Tritium Campaign (DTE2) discharges, the Fast Particle Pressure (FPP) can be significant at plasma centre: in the pulse# 99643 the TRANSP evaluation gives the FPP at the level of 30% of the thermal DT pressure at plasma centre(at time=49.8s). The FR measurement (in channel #3), in the same discharge #99643, follows in time the periodically varying ICRH (Ion Cyclotron Resonance Heating), the measured neutron flux and the fusion energy production. This means that the structure of the magnetic field internal to the plasma can be significantly influenced by FPP. Then, in general EFIT computations must include FPP from NBI (neutral beam injection) and also ICRH. In fact, in the 2nd Deuterium-Tritium Campaign (DTE2) a new feature emerged in the polarimetry measurements: the need to include the fast particle effects on equilibrium for evaluating the FR, in particular for the line of sight intersecting the plasma center. This effect appears also in the DTE2 record fusion energy pulse #99971 and in the 'afterglow' scenario (pulse #99946). This procedure is essential for the evaluation of FR in the line of sight passing through the plasma magnetic centre (i.e. the polarimetry channel# 3) while the other channels are not sensible to the effects of FPP. The CM evaluation seems far less sensible to the FPP effects.
see the author list of 'Overview of T and D-T results JET with ITER-like wall'by C Maggi et al. to be published in Nuclear Fusion Special Issue for IAEA FEC23 London 19-21 oct.2023.
(**) See the author list of âProgress on an exhaust solution for a reactor using EUROfusion multi-machines capabilitiesâ by E. Joffrin et al. to be published in Nuclear Fusion Special Issue: Overview and Summary Papers from the 29th Fusion Energy Conference (London, UK, 16-21 October 2023).
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ECE diagnostics for NTM detection and tracking in fusion reactors

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Magneto-hydrodynamics instabilities (MHD) like Magnetic Islands can appear in the plasma of magnetically confined fusion reactors because of (neo-classical) tearing modes (NTM). NTMs perturb the magnetic equilibrium configuration creating shortcuts for the heat and particle radial transport, hence affecting the confinement, reducing the plasma internal pressure and in turns reducing the nuclear D-T reactions rate. In tokamaks, large magnetic Islands are responsible also of abrupt termination of the plasma discharge, a harmful event which produces strong electromagnetic loads on the metallic structure of the device and heat loads on the plasma facing components.
Control of magnetic Islands can be achieved by accurate injection of heating power inside the magnetic Islands, and injection of MW power at the Electron Cyclotron frequencies (ECH/CD) is usually preferred because of its capability to inject power within a reduced and well localized plasma volumes. However, the ECH/CD deposition volume must be controlled in real-time to guarantee the maximum possible efficiency for earlier suppression of the magnetic Island.
The present contribution will provide a short overview of the different control schemes, with the relative diagnostic set-up, developed in Tokamak experiments to steer the ECH/CD deposition and will focus on the Electron Cyclotron Emission (ECE) diagnostics.
Microwave diagnostics are promising candidates for control application thanks to the high robustness and reliability of their Plasma Facing Components in the harsh environment of a fusion reactor. ECE diagnostics is a promising candidate for NTM control applications as, in a suitable lay-out, they

can exploit the dual properties of absorption/emission of EC waves working at the same frequencies for the ECH/CD actuator (gyrotrons) and the detection system. This implies that localization of the Island on a ECE diagnostics properly designed will need no further calculations to steer the high-power launchers. However, different technological issues should be taken into account to design such diagnostics for a fusion reactor: protection from stray radiation coming from the plasma back-reflected ECH/CD power; high plasma temperature effects as the doppler shifted higher harmonic emission; capability of providing the Island position with adequate resolution and need of minimizing the complexity of the components facing the plasma. Present contribution will address such problems taking as reference environment an EU-DEMO like reactor.

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Research on Wavelength Calibration and Data Processing Algorithms of extreme ultraviolet (EUV) Spectrum

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High-Z materials are used as plasma facing components due to excellent material properties in fusion devices. However, impurities are inevitably induced in plasma discharge by plasma-wall interactions. The presence of these impurities can lead to increased energy loss and degradation of plasma confinement. Therefore, the study of impurity behavior based on impurity spectral diagnosis is of crucial importance in fusion research. At present, the newly developed four fast-time-response Extreme Ultraviolet (EUV) Spectrometers on EAST have been operating [1-3]. Capability of accurate wavelength measurement is requirement for line identification of EUV spectra from high-Z impurity especially tungsten. In this work, an integrated impurity data analysis and wavelength calibration method is developed based on the complete impurity spectra database established on EAST [4, 5]. This approach incorporates algorithms for direct peak detection, Gaussian peak fitting, and Lorentzian peak fitting, replacing traditional manual methods to enhance efficiency. Integration of sub-pixel interpolation has improved peak detection accuracy. In addition, the methodology uses a model trained from the impurity spectral database with linear regression to predict the peaks corresponding to strong spectral lines, followed by wavelength calibration using polynomial approximation, polynomial fitting, and piecewise polynomial approximation methods for theoretical calculation values, cubic polynomial fitting values, and algorithm reference values. The results of the wavelength calibration are evaluated using Density-Based Spatial Clustering of Applications with Noise (DBSCAN) and pixel point uncertainty, with cross-validation between the three types of wavelength values for iteration. As shown in Fig. 1, the absolute value of the wavelength uncertainty is within 0.03 Å. After determining the wavelength calibration results based on strong spectral lines, the spectral drift correction for weaker spectral lines is performed using the Particle Swarm Optimization (PSO) algorithm, and the aforementioned evaluation and iteration process is repeated. This work has not only significantly enhanced the efficiency and accuracy of data analysis but also markedly reduced reliance on manual operations, offering a practical and viable solution for automating and enhancing the intelligence of data processing.

Diagnostic for Fusion Machines / 93

Research on Frequency Feedback Control Method of Laser-aided

Interferometer Based on Incremental Neural Network PID Algorithm

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Plasma electron density, as one of the core parameters of plasma characteristics, accurate and reliable measurement and real-time feedback control are indispensable foundations for ensuring stable operation of plasma and in-depth physical study. Specifically, online monitoring of electron density is an indispensable diagnostic method for every tokamak device. A Polarimeter/Interferometer (POINT）
is established based on the three-wave method, with its light source consisting of three optical pumping lasers. Stable intermediate frequency (IF) must be ensured between any two of these lasers to obtain low-noise phase information. An high-speed real-time IF stabilization system is specifically designed for POINT on EAST to address the issue of IF instability in electron density measurement. The system innovatively adopts active frequency stabilization technology based on neural networks, breaking through the limitations of traditional passive frequency stabilization, such as constant temperature control, vibration isolation[1]. By accurately monitoring frequency offset and adjusting the laser cavity length in real time, it can achieve fast and high precision frequency stabilization. Of particular note is that we have for the first time combined a back propagation (BP) neural network algorithm that combines incremental proportional integral derivative (PID) with the high-performance ZYNQ-7020 development board. This algorithm has been applied to POINT system on EAST. Compared to traditional digital PID, incremental PID enhances stability and anti-interference, and reduces the impact of the control variable on the PZT controller. The control variables output by the three-layer (4 input -5 hidden -3 output) structure of the neural network model[2] effectively eliminate a large number of overshoot phenomena that can cause damage to the PZT adjustment mechanism using a single incremental digital PID algorithm[3]. The AD/DA acquisition board connected to the PL side of ZYNQ performs fast Fourier transform on the collected laser IF signals, obtains the imaginary and real parts, and then calculates the effective IF frequency point. According to the Nyquist sampling theorem, the sampling frequency should be at least twice the original frequency[4]. To better apply it in engineering, a sampling frequency of 5~10 times the original frequency (approximately 4~8 MHz) is used. Then the amplitudes of each frequency point are compared to get the frequency point with the maximum amplitude. Then the current frequency value will be calculated according to the formula. GP interface is employed to complete communication between PL side and PS side of ZYNQ via Verilog HDL[5]. The BP neural network incremental PID algorithm, due to its large computational scale, puts the neural network algorithm model suitable for the dual-laser into the PS side for computation, and then the PZT controller obtains control rate after computation. Overall, through extensive statistics on algorithm completion time, the average calculation time for a single control rate can be better than 0.03 microseconds which can meet the control requirements. This innovative application utilizes ZYNQ-7020 platform as the hardware carrier and adopts the BP neural network as the algorithm for controlling variable output. When applied to the dual-laser IF stabilization system, it will enable the POINT diagnostic system to meet the requirements for long-term stable electron density measurement on EAST. The design and implementation of this system will provide design references for the IF stabilization of lasers in future Tokamak devices.

Diagnostic for Density and Temperature / 94

Compact, Reconfigurable Millimeter-Wave Back-End for Next-Generation Fusion Reactors

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Diagnosing plasma parameters in next-generation fusion reactors like DEMO [1] poses a challenge due to limited in-vessel access and harsh environments. Millimeter-wave diagnostics offer a robust solution to measure electron density, but achieving comprehensive plasma coverage, essential for plasma position and shape control [2], requires large number of probing channels with wide frequency bandwidths and compact back-ends [3]. We present a redesigned compact, fast frequency-sweeping millimeter-wave back-end overcoming limitations of a previous prototype. The back-end utilizes commercially available Monolithic Microwave Integrated Circuits (MMICs) to achieve a base frequency range of 10-20 GHz. External frequency multipliers extend this range to ultra-wideband coverage up to 160 GHz, enabling detailed plasma characterization. Driven by component obsolescence, the back-end underwent a complete PCB redesign, incorporating key improvements: (1) a programmable function generator for variable tuned oscillator (VTO) sweeping, enhancing control and flexibility; (2) a novel frequency translator scheme based on a vectorial modulator, potentially improving system efficiency, flexibility and cost; and (3) a new programmable PLL for the in-phase/quadrature (I/Q) reference signal, enabling precise signal generation. This work details the new back-end design and its subsequent performance evaluation. This work has been carried out under EUROfusion Enabling Research Project (ENR-TEC.01.IST).

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Imaging / **95**

Inverse Compton Scattering X-ray Sources for Diagnostics

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The Southern European Thomson Back-Scattering (TBS) source for Applied Research (STAR) is a cutting-edge high-energy photon facility situated on the campus of the University of Calabria (UniCal). Recognized as a national Research Infrastructure within the Italian Research Infrastructure Plan (PNIR) 2021-2027, STAR represents a significant milestone in integrating large-scale scientific facilities within a university setting.
The STAR infrastructure is equipped with two advanced beamlines:
• Low Energy (LE) Line: Capable of operating at a maximum energy of 65 MeV, this line powers an Inverse Compton Scattering (ICS) source that generates photons with energies up to 70 keV.
• High Energy (HE) Line: Operating up to 150 MeV, this line drives an ICS source capable of producing photons with energies up to 350 keV.
Completed in December 2023, the installation of STAR involved over a decade of meticulous planning, funding acquisition, design, development, and realization. This presentation will delve into the comprehensive journey of STAR, from its initial proposal to its current operational status, highlighting the collaborative efforts that brought this vision to fruition.
The STAR infrastructure includes state-of-the-art experimental stations and service laboratories, facilitating a wide array of research and diagnostic applications:
• X-ray Source and Beamlines: Featuring components such as lasers, electronics and control systems, radiofrequency systems, and advanced data storage and processing units.
• Service Laboratories: Including the Biological Sample Preparation Lab, Material Preparation Lab,

Material Characterization Lab, Physical Prototyping Lab, Advanced Spectroscopy and Microscopy Lab, and the Modeling Simulation and Visualization Lab.
The integration of STAR within a university environment underscores a significant shift in how large-scale research infrastructures can coexist and thrive within academic settings traditionally focused on distributed research efforts. This talk will explore the transformative impact of STAR on UniCal, providing insights into the unique challenges and opportunities encountered in bridging the gap between large-scale project execution and university-led research.
By presenting the capabilities and future potential of STAR's experimental stations, this communication aims to illustrate how advanced ICS X-ray sources can upgrade and empower diagnostic technologies, paving the way for groundbreaking research and applications across various scientific domains.

Diagnostic for Density and Temperature / 96

Thomson Scattering for the DIII-D Tokamak Divertor

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Thomson scattering has been utilized as a diagnostic technique for measuring electron temperatures and densities in DIII-D divertor regions since 1995. Together with a range of other divertor-focused diagnostics, Divertor Thomson Scattering system (DTS) has advanced knowledge of divertor detachment, surface material erosion yield and heat fluxes, and enabled validation of boundary codes. Recently, DTS has been expanded to include the lower divertor floor region used in high-triangularity plasmas, through eight, rapidly-selectable laser beam paths within a single poloidal plane. The system can redirect a ~1J Nd:YAG 10 ns laser pulse, via an ex-vessel fast-steering mirror, to a new beam path within 20 ms, continuously scanning through all eight positions each 160ms period during a plasma shot. In-vessel optical components mounted underneath the vessel tiles complete the beam redirection. Up to twelve measurement locations are available at each laser beam position by dynamically refocusing the ex-vessel collection fiber array using a high-speed linear stage. A fixed, in-vessel mirror with a centered hole allows the laser to pass through, retaining current measurement locations above the nearby divertor shelf. Initial results from this new system capability (named DTS-2D) provide a two-dimensional map of electron temperature without needing the previous technique of sweeping a diverted plasma across a single laser beam position.

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Diagnostic for Inertial Confinement / 97

Novel techniques of imaging interferometry analysis to study gas and plasma density for laser-plasma experiments

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Laser-plasma based experiments is always more demanding about the plasma characteristics which need to be generated during the interaction. This is valid for laser-plasma acceleration as well as for inertial confinement fusion experiments. Most of these experiments are moving toward high repetition rate operation regimes, making even more demanding the requests on the plasma sources and the diagnostics to be implemented.
Interferometry is one of the most used methods to characterize these sources, since it allows for non-intercepting, single-shot measurements either of the neutral gas density or the plasma one. The design of the interferometric setup is non-trivial and needs to be shaped on the actual conditions of the experiment. Similarly, the analysis of the raw data is a complex task, prone to many sources of error and dependent on the manual inputs.
In this presentation, we will present the techniques we are investigating for the measurement of the gas and plasma density. We will show the methods, the progress and the problems we encountered in the development of novel routines of analysis based on machine learning and on the simultaneous analysis of both interferograms and shadowgrams. Details on the architectures of these routines and the methods to collect data used to train and test them will be also presented. The study is ongoing and preliminary results with synthetic data will be also presented. The goal is to set up a fast and operator independent diagnostic for the feedback of plasma sources toward high repetition rate experiments.

Diagnostic for Fusion Machines / **98**

Diagnostics for Wall Conditioning Studies of Magnetically Confined Plasmas on the TOMAS Device

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The TOMAS device, located at the Forschungszentrum Jülich (Germany), is dedicated to studies of wall conditioning, plasma production, and plasma-wall interaction, providing a versatile experimental environment that supports activities related to superconducting fusion devices such as W7-X, JT-60SA, and ITER.

TOMAS is a fully metallic plasma device with a major radius of 0.78 m and a minor radius of 0.26 m. The vessel's volume is approximately 1.1 m^3, and its inner surface area is around 8.5 m^2, which can be baked to an average temperature of up to 80℃. The system features 16 toroidal magnetic field coils that provide a magnetic field on axis of up to 125 mT. The device includes a Glow Discharge system (9 kW), an Electron Cyclotron Resonance Heating system (2.45 GHz, 0.6 –6 kW), and an Ion Cyclotron Range-of-Frequency system (10-50 MHz, up to 6 kW), producing plasmas with densities and temperatures ranging from 10^{13} to 10^{17} m^{-3} and 5 to 150 eV, respectively.

TOMAS is equipped with several diagnostics, including Langmuir probes, a Time-of-Flight Neutral Particle Analyzer (ToF NPA), a Residual Field Energy Analyzer (RFEA), a Microwave Interferometer, Optical Emission Spectroscopy, Quadrupole Mass Spectrometers, and video diagnostics, along with various pressure gauges. For plasma-wall interaction studies, a specially built sample load-lock system is used to expose material samples, allowing free orientation and a temperature range of up to 600℃.

This paper provides an overview of the current diagnostic capabilities of TOMAS, as well as planned upgrades. The novel aspects include the installation of an in-situ laser-induced desorption quadrupole mass spectrometry (LID-QMS) system, the extension of NPA data to deuterium, and a comparison of local density measurements from the Langmuir probes with line integrated measurements from the microwave interferometer.

Overall, TOMAS is a highly flexible device, capable of operating under a broad range of conditions without time limits regarding availability and access to the experiment.

Diagnostic for Fusion Machines / 99

Diagnostic Challenges for European DEMO: A Case Study in Optical Diagnostics

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Future fusion reactors will differ significantly in many ways from the current fusion devices. The main goal of the current experiments is to measure as much information as possible about the state and temporal evolution of the plasma, in parallel performing technology tests. In future reactors, diagnostics will only serve plasma control functions[1]. In a commercial power plant, the number of utilized diagnostics should be minimized, as they would add significant costs not only to the construction but also to the maintenance. Additionally, due to the maximum surface area required for tritium breeding blankets, diagnostics must be confined to the smallest possible space. Therefore, in the early design phase of future fusion power plants, it must be decided which actuators should be controlled by which diagnostic signals. Diagnostics must operate with high reliability under much harsher conditions than those of ITER. The DEMO environment demands new design solutions from almost all diagnostics, while we have little experimental data on the behavior of materials under the expected doses.

The challenges can be illustrated through the example of the development of optical diagnostics. In DEMO, three imaging optical diagnostics are foreseen[2]: the divertor monitoring diagnostics, the pellet monitoring diagnostics and the limiter monitoring diagnostics. The divertor monitoring system will be responsible for the detachment control, which is crucial for safe operation. As the plasma diagnostics capabilities will be very limited, the acquired data must be used to gain the maximum information. In addition to the detection of the loss of detachment, the divertor monitoring diagnostic is required to measure the inner and outer divertor vertical target temperatures; the local Tungsten erosion on the inner and outer divertor vertical targets; detect ELMs; detect MARFEs; and if possible, measure the plasma temperature near the divertor targets[2].

The optical diagnostics will be installed in the equatorial ports of DEMO. The extremely harsh environment and high reliability requirements demand unique optical and opto-mechanical solutions. The protection of the first mirror can only be achieved with Helium filled duct, which is integrated with the opto-mechanics. The main DEMO-specific requirements and the selected engineering solution are also introduced.

Keywords: EU-DEMO; Diagnostics; Spectroscopy

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Industrial and Cold Plasmas / 100

Simulating Fission Fragments for Advanced Energy Applications

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This study explores the possibility of using a neutron source that fissions a fissile thin layer, this last is used to cover a tank full of light gas. It's possible to exploit the released energy of the reaction and from the same fission products for various applications (e.g. spatial propulsion, hybrid reactors etc.) not argued in this work.
A dedicated Monte Carlo model simulating fission events in a U235 target layer is presented. The model characterizes each event by a set of key parameters of the produced fission fragments, specifically focused on their energy distribution. These generated parameters are compared with established nuclear transport codes to ensure consistency. The model demonstrates its accuracy by reproducing experimental distributions of critical parameters involved in the fission process.
An initial analysis of the behavior of FFs in a physical structure is addressed. This structure, designed as a thin slab containing a support structure and a light gas, represents a practical step toward designing a containment tank for energy collection. The analysis also investigates here the interaction of fission fragments with the different materials and their energy deposition patterns. This work then lays the groundwork for further investigation into the use of fission fragments for energy transfer applications, potentially contributing to the development of innovative propulsion systems.

Imaging / 101

Gas Puff Imaging at the Tokamak à Configuration Variable (TCV)

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We present the design of the suite of Gas Puff Imaging (GPI) diagnostic systems on the Tokamak à Configuration Variable (TCV). These systems enable the study of Scrape-Off-Layer (SOL) turbulence in the tokamak, specifically focusing on the phenomenon of blobs. For the first time at TCV, we now have the capability to simultaneously collect poloidal 2D images of turbulence at several locations: the outboard midplane, around the magnetic X-point, in both the High-Field Side (HFS) and Low-Field Side (LFS) SOL, and in the divertor region. We characterize the innovative gas injection control systems for deuterium and helium, which have now become the default standard for all gas injections

at TCV. This suite of diagnostics has driven several successful studies and the development of AI tools for the analysis of turbulence. These first results will be presented.

Cultural Heritage / 102

Gamma radiation in Cultural Heritage preservation: research activities at the Calliope gamma irradiation facility (ENEA Casaccia R.C., Rome, Italy)

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Ionizing radiation has been used globally for decades across various fields, including industry, medicine, food, agriculture, and environmental science, as well as in space and nuclear applications. One notable use is in Cultural Heritage (CH) preservation, where gamma rays, X-rays and electrons can be successfully used to disinfect and disinfest historical materials (e.g., paper, parchment, wood, stone) from harmful organisms like insects, fungi, bacteria, and molds.
Radiation treatment offers significant advantages over traditional preservation techniques: it leaves no toxic chemicals or residues, avoids temperature increases, and effectively eliminates harmful microorganisms, including fungal spores. Specifically, gamma radiation also provides the possibility to process a large number of objects in a short time [1]. Despite these benefits, some CH professionals remain resistant to ionizing radiation due to concerns about potential physical-chemical modifications (secondary effects) of the materials.

To address these concerns, extensive research has been conducted at the Calliope ^{60}Co gamma irradiation facility (ENEA Casaccia R.C., Rome, Italy [2]). Studies using techniques such as infrared spectroscopy, Electron Spin Resonance spectroscopy, colorimetric analysis and polymerization degree evaluation have been performed with the aim of optimizing irradiation parameters (e.g., absorbed dose, dose rate) to minimize unwanted secondary effects [3-7] while ensuring effective disinfection of cellulose-based substrates.

Ongoing research includes studying radiation-induced modifications over time and comparing the changes induced by different radiation sources on paper samples. Preliminary results from the PERGAMO Project, funded by the Centre of Excellence of the Cultural Technological District of Lazio Region, will be presented as an example of the first application of gamma radiation for preservation purposes in Italy.

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Cultural Heritage / 103

Advanced diagnostic techniques for reading the carbonised Herculaneum papyri

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The discovery of hundreds of carbonised papyri in the 18th century in the Villa dei Papiri at Herculaneum opened new insights into the knowledge of ancient philosophy and, at the same time, an important and global technical challenge in unrolling and reading them. The rolls underwent several chemical and mechanical treatments aimed at their unrolling, often compromising their preservation. With the invention of the Piaggio machine, most of them (around 1700) were mechanically unrolled and musealised [1], enabling the textual reading. From the conservative point of view, the volcanic surge that poured over Herculaneum during the eruption of Mount Vesuvius in 79 AD allowed the preservation by carbonisation of numerous organic artefacts such as the papyri, even though they are extremely fragile [2]. For the importance of these manuscripts and their critical conditions, non-invasive and non-destructive advanced imaging techniques were applied for the study of both texts and materials, within the context of the ERC Advanced Grant 885222-GreekSchools [3]. In this paper, an overview of the outcomes of the on-going project are presented by showing the adopted multi-technique experimental approach along a wide spectral range. Technical photography [4], infrared digital microscopy, hyperspectral imaging [5] and optical coherence tomography [6] were applied to the analysis of several papyrus fragments, nowadays preserved at the Officina dei Papiri Ercolanesi of the National Library "Vittorio Emanuele III"of Naples. The results were excellent as far as textual reading is concerned (Fig.1), especially in the case of very dark samples, thanks to the recovering of text in several damaged parts due to post elaboration, such as e.g. principal component analysis of the hyperspectral cubes.

Cultural Heritage / 104

Motion Magnification of videos for the diagnostics of buildings' state of damage

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The assessment of the state of damage of modern or ancient buildings is extremely important in the engineering practice. Today, the focus is on the use of non-destructive methods, among which video-based diagnostics may play a major role because of many advantages with respect to contact and traditional methods, especially in the application to Cultural Heritage assets. An emergent methodology within this field is the motion magnification (MM) of recorded video footages. MM technique is based on algorithms able to magnify the movements of objects in a video by amplifying the acquired pixels signals, while keeping the objects topology. As a result, tiny movements of objects present in the video, invisible to the naked eye, are magnified becoming clearly visible. Besides, they can be processed for a quantitative analysis of objects dynamics. Importantly, the magnification can be operated in a selected range of frequencies. In addition to traditional quantitative methods (e.g. in the frequency domain) innovative methods can be applied to magnified videos, along to simple qualitative visual methods. Here we intend to show some of them.

Environmental Application and Medical Diagnostics / 105

The combination of HotSpot code and MATLAB to simulate radiological dispersions and evaluate solutions to protect the population

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We are surrounded by emergencies; the past and new threats push researchers to find innovative solutions to increase the safety of the population and the security of the environment. In this paper, the authors will use the HotSpot ~ Health Physics Codes for the PC to simulate two different scenarios'(and several case studies related). The first scenario is constituted by simulations of accidental dispersions of radiological substances in atmospheres (Cs-137, I-131, Co-60, and Sr-90), and the second scenario is constituted by simulations of different fallout due to an Improvised Nuclear Device (IND). The two worst-case scenarios will be used to furnish the boundary conditions to simulate a shielding apparatus (like a bunker) to protect the population; the MATLAB code will be used by the authors to implement this second part of the research. The paper aims to demonstrate that combining open codes, like HotSpot and MATLAB, can be a low-cost solution to support the experts in the prediction and prevention phases of a radiological event.

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ANALYSIS OF THE METHODS FOR HUMAN-INDUCED EVENTS RISK EVALUATION FOR CRITICAL INFRASTRUCTURES LIKE ENERGY PRODUCTION PLANTS BASED ON NUCLEAR REACTIONS

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As the world seeks sustainable and low-carbon energy sources, nuclear fusion has emerged as a promising solution with its potential to generate vast amounts of clean energy as well as nuclear fission is considered by many countries that closed the nuclear fission programs many years ago like Italy. This study analyses the methods for risk evaluation of fusion and fission plants (approached like critical infrastructures for energy production) to deliberate sabotage, cyberattacks, insider threats, and other forms of malicious interference and the principal methods to evaluate the related probabilities that certain events can happen. Drawing insights from existing literature, expert opinions, and case studies from related critical infrastructures, this work aims to raise awareness about the importance of integrating robust security measures into the design, operation, and regulation of those plants. By identifying the methodologies for risk evaluation and proposing proactive strategies to mitigate risks, this research contributes to the development of a resilient and secure energy infrastructure for the future.

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Reconfigurable Architecture of Real-Time Data Processing for Laser-aided Electron Density Diagnostics on EAST Tokamak

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This paper presents a reconfigurable architecture designed for real-time data processing in tokamak diagnostics. Through the deployment and application on various laser-aided electron density diagnostics, including the HCN interferometer, POINT, solid-state source interferometer, and carbon dioxide dispersion interferometer, the architecture has been validated to meet the real-time data processing requirements of the diagnostic system on the EAST Tokamak.

A reconfigurable framework is a type of computing architecture that can adapt its hardware and software configurations to optimize performance for specific measurement tasks. In the realm of laser-aided density diagnostics on tokamaks, the data processing system is an indispensable part. Currently, different self-developed data processing systems are used in laser-aided density diagnostics on various tokamak devices, and some of these systems, after many years of use, face the risk of being unmaintainable and irreparable. Utilizing a reconfigurable architecture, not only can standard data acquisition (DAQ) and processing equipment be formed on the EAST to help rapidly build the diagnostic systems, but it can also provide a real-time data processing workflow and framework for other existing devices and future devices, offering effective reference for the design of the final data processing system.

A reconfigurable architecture mainly consists of three parts: the first is its main hardware platform, which serves as the carrier of algorithms and measurement data; the second is the algorithm component, which exists in the form of firmware cores and determines the boundaries of the modules through interfaces and functional divisions; the third is the software system, used for processing non-real-time data and relatively simple command data transmission. For the specific application of real-time data processing system for diagnostics, some key components need to be introduced detailly.

• FPGA-based development board
According to the different measurement principles, each diagnostic will have different data processing methods. Even for different laser-aided interferometers, different light sources, optical path designs, and detectors will also lead to different processing methods. Therefore, field-programmable devices must be present in the real-time data processing system to accommodate different parameters and different data processing methods. The main board's function is to provide field-programmable devices and their supporting chips, meeting the needs for algorithm carriers, low-ripple power supply, data buffering, and the ability to provide highly stable clock signals. As a versatile field-programmable device, the FPGA features high speed, multi-channel capabilities, and full digitalization, making it well-suited for subsequent data processing in coordination with front-end signals.

• FMC boards and interfaces
After the detector signal is output, it needs signal conditioning, followed by analog-to-digital conversion (ADC) before being sent to the FPGA. The ADC and its supporting circuitry are designed and implemented through FMC (FPGA Mezzanine Card) boards. Different FMC boards can be designed to meet various applications, enabling rapid system setup.

• Firmware cores
The firmware cores are the most important component for implementing data processing algorithms. By hardware-accelerating the phase information calculation algorithm, fringe jump counting algorithm, and other general-purpose cores such as general digital signal processing, frequency stabilization, and triggering modules, this real-time processing diagnostic framework can ultimately realize the processing workflow and hardware structure from raw signals to density information.

By testing the mainboard and existing FMC boards in the laboratory, we have obtained electronic results that meet the experimental requirements. Through installation and application on the HCN interferometer, POINT, solid-state frequency-doubling interferometer, and carbon dioxide dispersion interferometer, the reconfigurable architecture has been validated and can meet the real-time data processing requirements of the diagnostic system on the EAST Tokamak.

Cultural Heritage / 108

Synchrotron radiation for cultural heritage

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In recent years, the development of synchrotron radiation (SR) sources has resulted in the creation of beamlines tailored for studying cultural heritage materials. These beamlines often require specialized setups, specific spatial resolutions, and precise detection limits. In cultural heritage research, integrated approaches that combine multiple techniques are often essential. Some beamlines at large facilities enable various types of measurements to be taken at the same analysis point, supplementing preliminary data typically obtained through conventional laboratory or portable in situ methods. This presentation will review the past decade of synchrotron applications in cultural heritage studies, discussing the challenges and advancements in methods and techniques. The potential of synchrotron techniques will be illustrated through different case studies, for instance on a particular type of painted ceramics, demonstrating how a combination of SR-based methods can address diverse research questions.

Diagnostic for Astrophysics and Space / 109

Characterization of laser-produced strongly coupled plasma with density and temperature relevant to solar photosphere

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We report a study of laboratory plasmas with density (n_e) and temperature (T_e) close to those of solar chromosphere and photosphere. The dense plasmas produced in supercritical fluids [Nature Commun. 12, 4630 (2021)] by ns laser pulse show blackbody emission spectra, which gives $T_e \sim 1$ eV. The Saha equation modified by ionization potential depression gives n_e 10^{21} cm^{-3}, implying that the ions and electrons are strongly coupled with the Coulomb coupling parameter larger than unity [Plasma Phys. Control. Fusion 64, 095010 (2022)]. Our study paves a way to investigate the physics of strongly coupled plasmas and help understand the dynamics events in solar surface and atmosphere. * The work is supported by the National Research Foundation of Korea under grant No. RS-2024-00349684.

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A Machine Learning-Based Technique to Assess DT Fusion Power at ITER with Gamma Ray Spectroscopy

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Besides the primary emission of a 14MeV neutron, the fusion reaction of Deuterium and Tritium may instead lead to the emission of a 17MeV gamma-ray, with a $2.4 \cdot 10^{-5}$ probability [1]. A novel approach for measuring the fusion power at ITER has been suggested based on the absolute measurement of these gamma-rays, using the plasma's gamma ray emission detected by ITER's Radial Gamma Ray Spectrometer (RGRS) [2].

This project has aimed to reduce the systematic uncertainty in the approach of [2], developing a machine learning-based technique that also integrates the magnetic equilibrium as a further source of information. The proposed algorithm works by reconstructing the fusion gamma-rays emissivity profile. The observed magnetic equilibrium and RGRS measurement values are used to constrain the possible emissivity profiles. Applying Principal Component Analysis (PCA) to a set of simulated profiles [3] from the IMAS database [4] allows the estimation of one specific profile and one specific fusion power.

Testing the algorithm by repeated 5-fold cross-validation on a dataset of 75 scenarios from the IMAS database, the average deviation of the estimated fusion power from the reference is 0.33%. The relative error has a standard deviation of 0.97%: promising results for this first, simple machine learning approach.

Industrial and Cold Plasmas / 111

Chemical characterization of different fusion-relevant metallic coatings by using Laser-Induced Breakdown Spectroscopy (LIBS) in view of LIBS application in JET and ITER

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In this work we report on the chemical characterization of metallic tiles of interest for nuclear fusion technology by using the Laser-Induced Breakdown Spectroscopy (LIBS) technique. The LIBS system used was designed to be compact and light, equipped with a sub-ns laser and suitable to be mounted on the Joint-European-Torus (JET) robotic arm. The coatings, composed of tungsten (W), Molybdenum enriched with deuterium (D) or directly retrieved from the WEST and JET tokamaks after their experimental campaigns with fusion plasma, are or simulate plasma-facing components (PFCs) of the present and next generation fusion devices contaminated with nuclear fuel (here representd by D only) in the divertor area of the vacuum vessel. The application of the LIBS technique is proposed as a diagnostics tool for a rapid chemical characterization suitable for the International Thermo-nuclear Reactor (ITER), whose PFCs will be made of W. The sub-ns LIBS technique allowed for the detection of D at low concentrations, with a single laser shot and an average ablation rate of about 100-150 nm. The depht profiling technique, consisting of delivering multiple laser shots on the same point of the sample and record the evolution of the LIBS spectral signal, allowed to investigate the erosion and re-deposition of different materials on the samples surface. The obtained results demonstrate that LIBS is an eligible diagnostic tool to characterize PFCs in JET after its last experimental campaign, with high sensitivity and accuracy, being minimally destructive on the samples and without PFCs manipulation or removal from its original position and pave the way for similar applications in ITER.

Cultural Heritage / 112

C14 Dating, paleoclimatic and paleofood research using stable isotopes Carbon and Nitrogen

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At present the advent of ultrahigh precision measurements (<0.3% of relative uncertainty) in ^14^C relative abundances has drastically improved the quality of produced data. Such performance improvement projects its benefits (high sensitivity) over chronological data and/or sequences sometime highlighting the necessity to review usually applied assumptions for dating due to first order like approximations.
It is the case, for example, of the so called dead carbon dietary effect where the possible dietary input of sea grown organisms may lead to age overestimation implying sensitive biases (i.e. ageing) for analyzed sequences. This issue is usually tackled by measuring stable isotope ratios that usually preserve info on the sample life.
Ultrahigh precision measurements also affect chronological measurements indirectly, it is the case of the calibration dataset (calibration curve) which drastically improve its definition by take advantages from increased measurement precision and the development of single year calibration curves with respect to 5 year averaged curves.
This contribution aims to discuss the role of high precision measurements by discussing some practical applications at CIRCE lab and pros/cons of applied correction models.

Fusion Products / 113

The SPARC Formula for DT Tokamak Neutron Diagnostics

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A deuterium-tritium (DT) fuel mix has been commonly proposed for the first generation fusion power plants. Majority of the DT reaction energy is carried away by the 14 MeV DT neutrons; thereby, monitoring of the fusion power (Pfus) and control of the plasma burn can be accurately done through the neutron diagnostics. Quite a limited experience exists in the integrated neutron diagnostics for DT tokamaks, from the concluded (JET, TFTR) or upcoming (ITER) projects. The SPARC tokamak presents a robust, economic, and future proof solution to this, with its four neutron diagnostics subsystems optimized in terms of physics performance and rapid engineering deliverability. SPARC has a fleet of flux monitors of ionization chamber and proportional counter types, two independent neutron activation systems, a spectrometric neutron camera for plasma profile monitoring, and a high-resolution magnetic proton recoil spectrometer for the plasma core. These systems ensure redundancies of sensors and methods, are designed to fetch high accuracy (σ<10%) of Pfus, cover a wide dynamic range (>8 orders of magnitude, <5.E19 n/s), and provide high resolutions of time (10 ms), space (~7 cm), and energy (<2% at 14 MeV). The design calculations are assisted by sophisticated neutronics simulations using Monte-Carlo and deterministic methods, and heavily detailed facility geometry descriptions. At the same time, extensive prototyping activities at CFS and the collaborating neutron generator sites (MIT and FNG) are supporting the sensor development. A minimum viable yet rigorous, in-situ calibration methodology has been developed employing strong sources of fast neutrons. Finally, a preliminary assembly and commissioning plan has been developed, fitting into the tight schedule of the SPARC project, aiming for its first plasma and fusion breakeven (Q>1) in 2026.

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For a list of co-authors, see the author list of the article "P. Raj et al, Rev of Sc Instr. 2024, Proceedings of the HTPD 2024 conference".

Diagnostic for Fusion Machines / 114

Graphical User interface for the MHD mode analysis on JET

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The analysis of the MHD modes present in a tokamak plasma is fundamental for experiment successes. MHD modes can degrade plasma performance but can also be used as indicator for the reconstruction of the current profile [1]. It is essential that the information about MHD modes were available before programming a subsequent plasma discharge.
A graphical user interface can speed up the MHD mode analysis so it can be carried between discharges, and, even though, it cannot be done by not expert people, it allows a fast check of the relevant information. A fast graphics library was needed, and the choice fell to "pyqtgraph"[2].
Two GUI have been written, one devoted to the analysis of the MHD signal from a toroidal array of

coils that can give information on their toroidal mode number, amplitude and frequency, the other for the cross correlation with a fast electron temperature signal that can give information on the main localization of these modes. Localization of the mode can be also obtained just from magnetic signal and plasma rotation as the rotation frequency is related to the plasma rotation.

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Diagnostic for High Energy Physics and Plasma Acceleration / 115

Precision measurements in gravitational wave detectors

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The detection of gravitational waves requires the ability to measure extremely small effects, specifically variations in the length of the interferometer arms that are 1000 times smaller than the size of a proton.
Central to the success of detectors such as Virgo and LIGO are advanced optical technologies that enable unprecedented sensitivity and precision in the control of the interferometer working point.
In this talk, some of the typical issues of these systems will be described, with a focus on adaptive optics systems which are essential in detecting and compensating optical aberrations in the interferometer core optics.
The concepts behind the system that monitors and actively corrects aberrations in current and future detectors will be reported.

Diagnostic for Density and Temperature / 116

ITER Density Interferometer Polarimeter: design update and synthetic diagnostic development

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A phase-modulated dispersion interferometer combined with a polarimeter is currently being designed in ITER. This diagnostic, called DIP (Density Interferometer Polarimeter), aims at performing reliable electron density (ne) measurements with a time resolution of 1 ms and an accuracy of 10% during ramp up/down phases, and 2% during flat-top, serving as a complementary system for ITER's main ne diagnostic, the TIP (Toroidal Interferometer/Polarimeter) [1]. ITER's DIP is based on a CO_2 laser (λ = 9.6 μm). It is inherently insensitive to mechanical vibrations and, thanks to the combined polarimeter, can correct fringe jump errors [2]. Phase-modulation is performed using a photo-elastic modulator (PEM) [3].
This work presents recent updates on the system design and synthetic diagnostic development. In particular, a model that takes into account the variations of air [4] and ZnSe optical windows [5]

refractive index due to environmental parameters (temperature, pressure and humidity), eventually affecting phase measurements, is here described.

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

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Industrial and Cold Plasmas / 117

Compact Ion Beam System for Fusion Demonstration

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We demonstrate a compact ion beam device capable of accelerating H+ and D+ ions up to 75 keV energy, onto a solid target, with sufficient beam current to study fusion reactions. The ion beam system uses a microwave driven plasma source to generate ions that are accelerated to high energy with a direct current (DC) acceleration structure. The plasma source is driven by pulsed microwaves from a solid-state radiofrequency (RF) amplifier, which is impedance matched to the plasma source chamber at the S-band frequency in the range of 2.4–2.5 GHz. The plasma chamber is held at high positive DC potential and is isolated from the impedance matching structure (at ground potential) by a dielectric-filled gap. To facilitate the use of high-energy-particle detectors near the target, the plasma chamber is biased to a high positive voltage, while the target remains grounded. A target loaded with deuterium is used to study D-D fusion and a B4C or LaB6 target is used to study p-11B fusion. Detectors include solid-state charged particle detector and a scintillation fast neutron detector. The complete ion beam system can fit on a laboratory table and is a useful tool for teaching undergraduate and graduate students about the physics of fusion.

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ICAERUS project: olive trees health assessment through deep learning technique on multispectral drone camera

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In recent years, olive trees have been increasingly threatened by "Olive Quick Decline Syndrome" (OQDS), a disease caused by the harmful bacterium *Xylella fastidiosa.* This disease poses a significant challenge in Europe, especially in Italy, where olive oil production plays a major economic role. The

syndrome harms the plant by thinning the xylem tissue, which disrupts the flow of water inside the plant. This reduction in the plant's vascular system causes leaf necrosis along the margins or tips, often followed by chlorosis and, in many cases, premature leaf drop. The symptoms usually begin in isolated sections of the foliage but gradually spread until the entire canopy is affected. Early detection of *Xylella fastidiosa* is, therefore, essential to protect local plant life and hopefully prevent the disease from spreading to other plants.

To assess and quantify a plant's health status, the NDVI (Normalized Difference Vegetation Index) is widely used as a metric. This index is calculated based on the correlation between two spectral bands (red and near-infrared) acquired through a multispectral camera. Recent advancements in technology have made it possible to develop commercially available mobile platforms equipped with multispectral camera systems, ideal for large-scale data acquisition. By utilizing data captured by drone-mounted multispectral cameras, we propose a deep learning approach to identify and classify olive trees in rural landscapes, enabling the assessment of individual plants' health status. Specifically, data was captured using both RGB and multispectral cameras during drone flights over olive tree fields. Once individual trees were identified, the NDVI index was calculated and combined with deep learning techniques to determine each olive tree's health status in a single step.