International Conference on Diagnostics For Fusion Reactors: the Burning Plasma Era (ICFRD2025)

INTERNATIONAL CENTER PIERO CALDIROLA

ICPC

Report of Contributions

Contribution ID: **1** Type: **Invited Oral**

Assessment of the gas detector-based SXR diagnostics performance as a plasma radiation device at WEST

Monday 1 September 2025 10:00 (30 minutes)

The proposed contribution concerns the development of gas detectors for use in the future reactors. Measurement of soft X-ray (SXR) radiation of magnetic plasmas is a standard method of obtaining valuable information on particle transport and magnetic configuration. Recent consideration of a gas detector for future fusion reactors extends its potential use as part of the plasma control structure, which places a significant burden on the development of such a system for such a demanding application. The development of the photon conversion and signal processing components of the proposed monitoring system necessitates the consideration of numerous physical, technical and technological aspects during the design and manufacturing stages.
The contribution will present the advances of development of a Gas Electron Multiplier (GEM)-based SXR detection system at its exploitation results obtained at WEST tokamak. The examination of the plasma radiation emission patterns across the WEST experimental campaigns, utilizing a GEM detector, will also be presented. The presentation will also include a comparison and correspondence of the obtained results from the last campaigns at WEST with the GEM detector to the related plasma data, as well as the results of the plasma radiation simulations towards the commissioning of the diagnostics. The simulations of plasma radiationfor WEST discharges will be based on the coronal equilibrium model, whilst GEANT4 will be utilized for simulations of the plasma radiation interaction with the detector materials. These numerical results will then be compared with the experimental data that has been taken.
The presentation will provide an overview of the status and outcomes of the research and development phase, in conjunction with the experimental findings derived from the campaigns at WEST tokamak.

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Track Classification: Overview of existing and future machines

Contribution ID: **2** Type: **Invited Oral**

Avoiding the Collapse of the Tokamak Configuration: an AI based Control Strategy for Reactor Grade Devices

Thursday 4 September 2025 09:00 (30 minutes)

Disruptions are one of the major problems for the control of thermonuclear plasmas. The fast termination of the discharge can indeed induce huge heat loads on the plasma-facing components and high electromechanical forces on the structures of the devices. In the commercial reactors, disruptions will have to be completely avoided as much as possible, since even a single disruption could compromise their integrity.

In present Tokamaks, disruptions are unavoidable. Their occurrence is particularly likely in the baseline at low safety factors (around q95=3), the reference scenario in ITER. On DIII-D, the disruptivity at this safety factor is around 60%. On JET, in some high current low q95 campaigns, the disruptivity rate also reached 60%, even for a low radiated fraction. The next generation of devices will have to operate with radiation above 90% of the input plus alpha particle power, and with fully detached divertors, conditions that have been proven experimentally to increase significantly the disruptivity rate.

This contribution reports the deployment of new AI based analysis methods on thousands of JET discharges. The investigated regimes cover the isotopic compositions from hydrogen to full tritium and include the last major D-T campaigns. A new approach to proximity detection permits to determine both the probability of and the time interval remaining before an incoming disruption. The developed techniques combine physics and data-driven methodology, implement adaptive and from scratch learning, and real real-time compatible. The proposed control logic results in no missed alarms, 65% of avoided and prevented disruptions and almost no false alarms or wrong actions. Consequently, the obtained results indicate that physics-based prediction and feedback schemes can be developed, to deploy realistic strategies of disruption avoidance and prevention, meeting the requirements of the next generation of devices.

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Track Classification: AI and real time diagnostics

Contribution ID: **3** Type: **Invited Oral**

A Neural Network Approach to Integrated Data Analysis: an Application to Multi-Diagnostic Equilibrium Reconstruction

Thursday 4 September 2025 09:30 (30 minutes)

Integrated data analysis is essential for the full exploitation of diagnostic measurements. In the past various approaches were investigated but the main techniques utilised were based on Bayesian statistics. Physics-Informed Neural Networks (PINNs) are an alternative worth addressing. Indeed PINNs constitute a new branch of artificial intelligence that gives the possibility of integrating data-driven methodology and physics equations in a very efficient way. They offer several benefits over traditional methods, such as their capability of handling incomplete physics equations, of coping with noisy data, and of operating mesh-independently. The subject of the present work consists of assessing the potential a Physics-Informed Neural Network (PINN) algorithm for reconstructing the plasma equilibrium using a multi-diagnostic approach, which includes magnetics, kinetic pressure, and interferometer-polarimeter data. This constitutes a quite severe benchmark for any strategy of integrated data analysis. Indeed in a tokamak the equilibrium reconstruction is a severely ill-posed problem. To achieve reasonably accurate results, it is therefore essential to constrain the algorithms with multiple diagnostic data. Among these, the interferometer-polarimetric measurements are some of the most valuable, as this diagnostic is one of the few that can provide information about the internal fields, even if in a line-integrated form. However, the propagation of an electromagnetic wave in a magnetised plasma requires the quantification of significant non-linear effects, which render the integration of this information into the reconstruction process anything but straightforward. Unfortunately, the linearisations and approximations implemented in the past limited the quality of the reconstructions, particularly at high fields and currents. On the contrary, the developed PINN algorithm implements a complete hot plasma model that accounts for these nonlinearities and also thermal effects, both relativistic and non-relativistic. A systematic series of tests with synthetic data demonstrates that the hot plasma model provides results consistently more accurate than those obtained with the cold-plasma approximation or linearization of the polarimetric measurements. The models derived with the PINNs have been also tested with JET data collected high current campaigns, confirming the quality of the obtained reconstructions in all the investigated experimental conditions.

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Track Classification: AI and real time diagnostics

Contribution ID: **4** Type: **Short Contributed Oral**

Convolutional Neural Network Algorithm for Automated Processing of $LaCl_3$ Scintillator Waveforms Incorporating Pulse Shape Discrimination and Pile-up Recovery

Thursday 4 September 2025 10:30 (15 minutes)

Neutron Emission Spectroscopy is a key diagnostic technique in nuclear fusion research, enabling the characterization of fuel ion populations in fusion plasmas. The state-of-the-art instrumentation for neutron spectroscopy in deuterium plasmas relies on the time-of-flight (TOF) technique [1].
However, despite its performance, it necessitates the deployment of large-scale systems. Recent investigations on compact alternatives have focused on chlorine-based scintillators, which exploit the 35Cl(n,p)35S nuclear reaction to produce a Gaussian-shaped response in the neutron energy spectrum. Among the promising candidates, CLYC scintillators [2, 3] offer good energy resolution but are constrained by limited count rate capabilities (tens of kHz). Alternatively, $LaCl_3$:Ce scintillators uses the same nuclear reaction, but combine similar energy resolution with faster scintillation decay times (<1 µs), supporting higher count rates. However, $LaCl_3$:Ce presents significant challenges in particle discrimination, and traditional pulse shape discrimination (PSD) methods offer limited separation performance.
To address these limitations, an advanced particle identification algorithm based on Fast Fourier Transform (FFT) analysis was introduced in [4], enhancing discrimination accuracy. Nonetheless, this method (like conventional PSD techniques) relies on user-defined selection regions in the PSD vs. energy space, introducing operator-dependent variability. This limitation may pose a significant challenge to real-time implementation on FPGAs. To overcome this possible challenge in view of real-time applications, an alternative discrimination algorithm based on convolutional neural networks (CNNs) is under development. This algorithm enables the classification of α, γ, and neutron-induced events, as well as the recovery of pile-up pulses, in an automatic and operator-independent way. The pile-up recovery is particularly relevant during transient plasma phenomena that produce bursts of neutrons, potentially resulting in a high incidence of pile-up events. The algorithm was optimized for fast neutron detection characterized by α and γ background. Particular attention has been paid to facilitate potential future implementation on FPGA by employing algorithms compatible with hardware realization.
The neural network models have been trained and tested using experimental datasets from multiple sources: the intrinsic radioactivity of the $LaCl_3$ crystal, γ-ray calibration sources, and neutron measurements conducted at the Physikalisch-Technische Bundesanstalt Ion Accelerator Facility (PIAF) [5] and the Neutron Irradiation Laboratory for Electronics (NILE) [6]. At these facilities, neutron measurements across different energies (from 2 to 5 MeV range and 14.8 MeV) were obtained using various beam-target combinations, including proton and deuteron beams with Ti(T) and D_2-gas targets, and at different detection angles.

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Track Classification: AI and real time diagnostics

Contribution ID: **5** Type: **Short Contributed Oral**

Gamma-ray spectrometry of fusion plasmas: new approaches

Tuesday 2 September 2025 12:00 (15 minutes)

The report is devoted to the development of gamma-ray spectrometry methods of energetic particle diagnostics, both in terms of hardware and analysis of experimental data. Measurements in the conditions of a thermonuclear experiment, i.e. in the presence of a stray magnetic field of the tokamak, high neutron and gamma background, hardly allow the use of serial laboratory equipment and require utilization of advanced methods of radiation registration, digital signal processing and algorithms for the analysis of experimental data [1]. The use of traditional scintillation spectrometers with PMTs is complicated by the presence of a variable magnetic field, a wide energy range of the measured radiation and a wide range of radiation fluxes entering the detector. All these factors affect the stability and linearity of the amplification tract of the spectrometer. A possible solution to this problem is the use of digital gain correction systems (LED illumination of the PMT) and advanced methods of digital signal processing. The development of semiconductor photodetectors (SiPM) offers the possibility of solving the problem of detector sensitivity to magnetic fields. However, the problems of gain linearity and radiation resistance of the devices remain. Detectors based on modern SiPMs demonstrate high count rates of up to 106 1/s while maintaining gain stability and energy resolution. The problem of radiation resistance of light detectors can be solved by modern methods of light transmission through liquid light guides over considerable distances with acceptable losses.
Semiconductor detectors such as HPGe have proven to be highly effective in providing information on the energy distribution of fast ions in JET experiments due to their high energy resolution. Using them in next-generation facilities like ITER and BEST requires solving the problem of correctly estimating measurement dead time using new digital signal processing methods. The most important requirement for the effective use of gamma-ray spectrometers in plasma measurements is the preliminary study of their characteristics at charged particle accelerators. The results of test measurements of detectors of different types, such as LaBr3 scintillation detectors with both conventional PMT and SiPM, as well as semiconductor HPGe spectrometers, on the cyclotron ion beam and in experiments on the Globus-M2 tokamak, are presented. New approaches to reconstructing energy ion, and electron distributions from measured photon emission are also discussed.
The study was supported by the RSF research project № 21-72-20007-P.

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Track Classification: Energetic Particle Diagnostics

Contribution ID: **6** Type: **Short Contributed Oral**

Real Time Compatible Tomographic Algorithms for the Control of Burning Plasma Tokamaks

Thursday 4 September 2025 11:45 (15 minutes)

In tokamaks the interpretation of many diagnostic signals requires some form of inversion, because the measurements are taken from outside the plasma but what is desired is local internal information. Some examples are the magnetic equilibrium from coils and polarimetry, video cameras and the unfolding of various neutron and gamma detectors. A specific set of diagnostics are also needed to reconstructed internal distributed quantities from line integrals measurements. The techniques to tackle this task are quite sophisticated tomographic algorithms, which have been applied to the measurements of neutrons, gamma rays, SXRs, and bolometric sensors. Unfortunately, these tomographic inversion tasks are typically very ill-conditioned problems. Consequently, to obtain local information, sophisticated inversion algorithms have to be deployed and their computational times, of the order of minutes, are not compatible with real time applications.
This contribution presents a new evolution of the Maximum Likelihood tomography explicitly conceived for feedback applications. It does not require the magnetic topology as input, because the regularisation is achieved by a convolution with Gaussian filters. Its computational times are of the order of ms and its accuracy is acceptable for most applications. The method has been particularised for the bolometric tomography, which presents the most challenging tomographic inversion problems, given the complexity of the radiation patterns to be reconstructed in reactor relevant scenarios (detachment, X-point radiator, MARFEs etc.). The quality of the approach is demonstrated by a battery of numerical tests and application to JET bolometric measurements collected in various high power discharges, including the last DT campaigns.

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Track Classification: AI and real time diagnostics

Contribution ID: **7** Type: **Invited Oral**

Design and development of gamma-ray diagnostics for next generation tokamak of burning plasma (Remote)

Tuesday 2 September 2025 11:00 (30 minutes)

Gamma-ray diagnostics play a crucial role in the study of high-energy particle behavior and nuclear processes in tokamak plasmas. Information on the alpha particles produced in fusion is of paramount importance for burning plasma device, such as ITER [1-2]. The fusion rate can be determined by measuring the fluxes of 17-MeV gamma quanta born in D-T fusion reactions, and the fusion product can be obtained by measuring and analyzing gamma-ray lines that are characteristic of nuclear reactions between alpha particles and plasma impurities.
A new facility, the Burning plasma Experimental Superconducting Tokamak (BEST), is being constructed in China. Gamma-ray diagnostics, consisting of the radial gamma-ray camera (GRC) with 7 line-of-sights, the vertical GRC with 4 line-of-sights and radial gamma-ray spectrometer with 3 line-of-sights, have been designed to provide measurement of alpha particles and runaway electrons for BEST tokamak. In this report, the preliminary design of gamma-ray diagnostics for BEST tokamak will be presented for the first time, including the system configuration, the design of detectors, magnetic shielding, neutron filters and data acquisition system and so on. The technical challenge to measure the gamma-ray lines on BEST tokamak with a high magnetic field and strong neutron flux background will be discussed. Two types of new detectors have been designed and fabricated to against from strong stray magnetic field. One is LaBr3(Ce) crystal coupled with SiPM, and another one is LaBr3(Ce) coupled with liquid light guide and PMT. The prototypes detectors have been developed and validated on EAST tokamak for their performance evaluation. Moreover, the design and development of synthetic gamma-ray diagnostic in IMAS infrastructure [3] will be introduced, which is mainly used to optimize the diagnostic performance, as well as to support the gamma-ray spectrum deconvolution and reconstruction of alpha particles distribution function.

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Track Classification: Energetic Particle Diagnostics

Contribution ID: **8** Type: **Short Contributed Oral**

Development of gamma-ray detectors in high stray magnetic field for burning plasma tokamak (Remote)

Tuesday 2 September 2025 11:30 (15 minutes)

Measurement of alpha-particles and other fast ions which are born in nuclear reactions is of great importance to optimize the heating schemes for ITER and future fusion reactors. Gamma-ray spectrometers have been extensively used on tokamaks for studying the behavior of fast ions including fusion alpha-particles, and runaway electrons.
Gamma-ray diagnostics of Burning plasma Experimental Superconducting Tokamak (BEST) have been designed. However, the magnetic field is up to 1000 Gauss around the vertical gamma-ray detectors. And conventional photomultiplier (PMT) can't be used in such strong stray magnetic fields. Two new gamma-ray detectors have been developed: (1) LaBr3(Ce) scintillator integrated with a silicon photomultiplier (SiPM) which is insensitive to the magnetic field; (2) small-size LaBr3(Ce) crystal equipped with a liquid light guide (LLG) and Photomultiplier (PMT) for remote gamma-ray detection. The prototypes of the detectors have been fabricated and installed on EAST to validate their performance. The data acquisition system (DAQ) is fulfilled with a 14 bit and 400 MS/s digitizer and a PC. The DeGaSum code with advanced algorithms [1-2] is implemented to digitize and process signal pluses.
A good stability at high counting rates up to 106 /s is achieved with the SiPM-LaBr3 detector, which is very important in high performance plasma discharges. A good energy resolution is obtained of 4% at 662 keV. The counting rate can be up to 107 /s for the LLG-PMT-LaBr3 detector, and the energy resolution degrades not too much with an additional light guide, which shows a promising application in remote gamma-ray detection. With the scintillators and DAQ, bremsstrahlung from runaway electrons and gamma-rays were observed in EAST plasma discharges, and the detailed analysis is ongoing.

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Track Classification: Energetic Particle Diagnostics

Contribution ID: **9** Type: **Short Contributed Oral**

Towards large database analysis for reactors relevant studies on the high electron temperature measurement discrepancy

Thursday 4 September 2025 16:00 (15 minutes)

In tokamaks, measuring core electron temperatures becomes challenging at high values (typically >6–7 keV), where discrepancies often arise between diagnostics such as Thomson Scattering and ECE. Yet, accurate temperature measurements are critical for future reactors like ITER, CFETR or DEMO, where core Te is expected to be over 25 keV [1,2,3]. These discrepancies, evident in such high-Te scenarios, highlight not only a diagnostic issue but also an opportunity to deepen our understanding of core plasma physics, and recent studies have provided further insights, yielding more substantial results and clarifying additional aspects [4,5,6].

At the same time, the scientific community requires a larger experimental database to strengthen hypotheses developed in recent years. Data at relevant temperatures are becoming increasingly available as tokamak advancements progress toward reactor-scale conditions. Higher injected power (NBI, ECRH, CRH), longer plasma discharges, and improved diagnostics now enable the construction of an extensive database—more comprehensive than ever before—to investigate the discrepancy systematically using a standardized procedure [7].

To achieve this goal, the entire JET-DTE3 dataset is being analysed, with careful selection of relevant shots. Corrupted shots are excluded, and only discharges with consistent ECE and HRTS measurements are considered (Figure 1).

This contribution aims to provide some preliminary results obtained from the larger database, in the framework of the ITPA activity (ITPA JEX#17 on 'High Te measurements') born to compare data collected in different machines around the world, trying to find a full explanation of the discrepancy.

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Track Classification: Fusion Technologies

Contribution ID: **10** Type: **Invited Oral**

A Volumetric Neutron Source (VNS) for the nuclear qualification of invessel components: design and role in the EU roadmap

Friday 5 September 2025 09:00 (30 minutes)

According to the recently released Research Plan ([1] and references therein), ITER operation is currently foreseen to start in 2034, with the long-duration high neutron fluence discharges for the qualification of Test Blanket Modules (TBM) being scheduled for the latest stage of the machine operation (DT-2) –making it potentially susceptible to additional delays. While the role of ITER to investigate the physics of burning plasmas and their control and operation remains fundamental, the long wait time between today and the availability of its results offers the opportunity for another nuclear machine to be built and operated in parallel. Its role shall be complementary to ITER in producing the knowledge for the construction and operation of a Fusion Power Plant (FPP), i.e. it must be focused on the technology qualification. In this context, a Volumetric Neutron Source (VNS) is proposed. In its current configuration [2], VNS is a medium-size, large aspect ratio tokamak (⊠ = 2.67 m, ⊠ = 4.25) with a limited fusion power (⊠⊠⊠ < 40 MW) but reactor-relevant peak neutron wall load on the outer midplane (NWL ≃0.5 MW/m2), where testing ports are located. Fusion is mainly obtained via beamtarget reactions, following the experience of the recent D-T campaigns in JET [3]. This approach allows the machine size to be kept small and, most importantly, an operation with low tritium consumption - since VNS must rely on external tritium supply. The aim of this device is to test in-vessel components like breeding blanket modules under 14 MeV neutron irradiation levels, and operational conditions in general (e.g. heat loads and magnetic field strength), very close to a reactor environment. The reference plasma scenario has been conceived as fully noninductive (by means of NBCD and ECCD). This aspect is relevant both for allowing the thermal equilibration of breeding blanket modules, which is an essential condition for testing, but also to achieve significative neutron fluences (i.e. tens of dpa) in few full-power years. In these conditions, VNS will allow the achievement of TRL level of 7, or even 8, for these fundamental components [4]. In this contribution, a detailed description of current VNS design and its physics basis are illustrated, and criticalities are highlighted. Plus, its potential role in the new Europan Roadmap is discussed. Strategically, parallel operation of VNS and ITER would allow the achievement of all the necessary technology, physics and operation knowledge to build and operate an FPP, significantly reducing the need for qualification phases on the reactor itself [5].

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Track Classification: Overview of existing and future machines

Contribution ID: **11** Type: **Short Contributed Oral**

Progress in EAST Neutral Particle Analyzer: INPA and E//B NPA Development for the BEST

A high-performance imaging neutral particle analyzer (INPA) has been developed and installed on the Experimental Advanced Superconducting Tokamak (EAST). Using carbon foils to ionize charge-exchanged neutral particles and scintillator screens to resolve their energy and radial profiles, the INPA's capabilities have been significantly enhanced through multiple upgrades. It functions in both active and passive modes; notably, passive mode signals are also inversely proportional to electron density. Key findings include: the INPA signal's proportionality to neutron yield at constant electron density, successful recording of fast ion redistribution during sawtooth crashes, the distribution of hydrogen fast ion pitch angles accelerated via ICRH up to 100 keV in energy, and observation of an increasing radial gradient in fast ion density during internal transport barrier (ITB) formation—often concurrent with fishbone instability. The model developed based on FIDASIM code has successfully explained the relevant experimental results of INPA data from EAST. Furthermore, an E//B NPA diagnostic has recently been designed for EAST. It is essential for investigating the synergy effect between NBI and ICRH. This diagnostic will also be utilized on BEST, which will be used to monitor Deuterium-Tritium (D-T) burn rates relevant to future fusion reactors.

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Track Classification: withdrawn

Contribution ID: **12** Type: **Invited Oral**

Validation of a Bayesian method for current tomography at WEST

Monday 1 September 2025 15:30 (30 minutes)

We present a validation study of a Bayesian integrated data analysis (IDA) approach for current tomography, applied to the WEST tokamak using only external magnetic diagnostics. The methodology was originally developed for DEMO but is here adapted to real data, addressing challenges such as noise, currents in structural elements, and iron core effects [1].

A Gaussian prior distribution was constructed for the plasma current density, using the raw second moment from a series of reference equilibria obtained from WEST. The iron core was explicitly modeled using a Gaussian process prior, by segmenting it into six regions, with correlations between segments described by a squared exponential (SE) kernel. No fixed currents were assigned to the iron core; instead, the most probable distribution of core-induced currents was inferred self-consistently from the diagnostic measurements and the prior.

Validation was performed over multiple WEST discharges, focusing on plasma parameters such as the current centroid, total current, and X-point position. As standard WEST reconstructions using the NICE code can suffer from systematic errors [2], the VacTH code was used as an independent reference for the X-point location [3]. Weakly informed priors were used to increase the influence of the diagnostic measurements, identifying systematic discrepancies between our results and those from NICE. A global shift and scaling of the WEST tomograms were then applied to minimize discrepancies for estimates of the current centroid and total current.

The corrected Bayesian reconstructions showed better agreement with VacTH-derived X-point positions compared to the original WEST reconstructions (NICE), confirming the capability of the method to improve plasma boundary determination using external magnetic signals only. This work provides a stepping stone towards integrated plasma reconstruction including additional diagnostics.

J. De Rycke acknowledges the Research Foundation - Flanders (FWO) via PhD grant 1SH6424N
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Track Classification: Energetic Particle Diagnostics

Contribution ID: **13** Type: **Short Contributed Oral**

Investigating Bremsstrahlung Spectral Features Using Multiple Lines of Sight in Runaway Electron Scenarios at JET

Monday 1 September 2025 16:45 (15 minutes)

Runaway Electrons (RE) are one of the main particle populations in tokamaks that must be carefully controlled and understood. Future devices will need to operate either without disruptions or with reliable mitigation strategies. Disruptions are characterised by abrupt losses of plasma confinement, during which strong electric fields can be generated. These fields may accelerate electrons into the "runaway" regime, where collisional friction is no longer sufficient to slow them down. REs can impact the tokamak wall, potentially causing severe damage.

These phenomena can be indirectly detected through gamma-ray diagnostics. In particular, REs interacting with plasma ions emit intense Bremsstrahlung (Bs) radiation in the Hard X-Ray (HXR) energy range from some keV to several MeV. At JET, Bs emission has been observed during dedicated experiments using various gamma-ray diagnostics, including the Gamma Camera and both tangential and vertical gamma-ray spectrometers, based on the Lanthanum Bromide scintillator. Through these measurements, information on the RE energy distribution and RE emissivity profile can be obtained.

In this study, we analyse the spectral features of Bs emission when different Lines of Sight (LoSs) in RE experiments are employed. Previous studies typically assumed a strongly co-passing RE distribution, with negligible population at pitch angles different from zero. Based on theoretical considerations, we show that the slope of the HXR spectrum can vary when comparing measurements along different LoSs and if the particles are not only strongly co-passing. This effect may help explain experimental observations at JET, where different Bs spectral slopes are measured using gamma-ray spectrometers with different observation angles relative to the magnetic field.

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Track Classification: Energetic Particle Diagnostics

Contribution ID: **14** Type: **Short Contributed Oral**

First evaluation of gamma-ray emission from alpha-boron reactions in the ITER tokamak with a tungsten wall

Wednesday 3 September 2025 11:45 (15 minutes)

Obtaining experimental information on the properties of alpha particles, such as their energies and spatial profile, is quite challenging. One of the methods currently planned for the ITER tokamak is *gamma-ray spectroscopy*.

Until 2023, alpha particle measurements via gamma-ray spectroscopy relied on nuclear reactions between alpha particles and ^{9}Be impurities. However, since ITER will feature a fully tungsten first wall conditioned with natural boron instead of a ^{9}Be wall, new approaches are needed.
Boron will be injected to condition the wall and support plasma operations, but no experiment has yet studied boron-based reactions to derive alpha particles information in tokamaks.

This work makes a first contribution to this problem by computing the alpha-boron gamma-ray emission expected at ITER including a first
calculation of the background.
The calculation focuses on the RGRS (Radial Gamma Ray Spectrometer) diagnostic, which consists of three gamma-ray spectrometers observing the plasma through three co-planar, collimated and radial lines of sight.
The numerical evaluations performed in this work are based on simulations of ITER plasma scenarios stored in the IMAS database.
Starting from the density, emission and temperature profiles of the particles in a DT plasma discharge, quantities of interest were derived to predict the signal expected from the ^{10}B(α, $p\,\gamma$)^{13}C reaction. From these data, it was possible to implement scenarios with different fuel composition (D^{3}He) and different thermal equilibrium (supra-thermal scenarios) to study the alpha particle measurement capability of RGRS under a range of conditions.

In order to assess the RGRS performance in a DT/D^{3}He plasma scenario, specific Monte Carlo simulations were conducted. These took into account the geometrical and structural aspects of the tokamak and the diagnostics under consideration, together with the expected amount of neutron and photon fluxes.

First calculation results of the radiation background expected at the detector position were also included in the model. We find that gamma-ray measurements are possible with a time resolution of the order of the alpha particle slowing down time for most of the detectors. We also identify the radiation background at the detector as the main
factor that determines the feasibility of the measurements.

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Track Classification: Energetic Particle Diagnostics

Contribution ID: **15** Type: **Short Contributed Oral**

Machine Learning prediction of bolometric signals from AXUV diode measurements for fast plasma events in tokamak devices

The measurement of the total radiative power emitted by the plasma is a key aspect of diagnostics in tokamak fusion reactors, as this quantity represents the energy lost through electromagnetic radiation and is crucial for managing the energy balance. For these measurements, bolometric diagnostics are widely used in fusion experiments due to their precision, reliability, and ease of calibration. These detectors work by converting incident radiation into heat, causing a temperature increase in a thin absorber (typically a gold foil), which induces a change of the electrical resistance in a Wheatstone bridge. However, their time resolution is limited to a few milliseconds, while many plasma events occur on much shorter timescales. To address this, AXUV diodes, p-n junction photodetectors sensitive to visible light, UV, and soft X-rays, are also employed. Their high temporal resolution enables the detection of fast plasma phenomena such as instabilities and confinement losses. The disadvantages are that it has not been possible so far to implement an absolute in-situ calibration of this type of detectors and to extend their spectral response to the visible range..

In this work, a machine learning-based approach is proposed to predict bolometric measurements from AXUV diode signals, effectively enabling the reconstruction of plasma emissivity with high temporal resolution. Neural networks have been trained to learn the mapping between diode measurements and the corresponding output of the bolometric system. This data-driven model exploits the complementary nature of the two diagnostics systems, capturing the underlying correlations despite their differing spectral sensitivities.

Particular attention is devoted to autoencoder type neural networks, which are able to learn a compressed and meaningful features from the high-dimensional diode signals. Once trained, the model can provide synthetic bolometric signals at high temporal resolution, allowing the study of radiative behaviour during fast transient events that are otherwise inaccessible with conventional bolometric diagnostics.

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Track Classification: withdrawn

Contribution ID: **16** Type: **Short Contributed Oral**

Orbit-space sensitivity for neutron and gamma-ray detectors in tokamaks

Monday 1 September 2025 16:30 (15 minutes)

Neutron and gamma-ray diagnostics will play a fundamental role in fast-ion detection in burning fusion plasmas. As the fast ion undergoes a fusion reaction, the generated neutron or gamma-ray will carry away some of its energy, which can be detected. In the context of axisymmetric machines with high aspect ratio, it is possible to represent the fast-ion phase space in the reduced three-dimensional orbit space, combining position and velocity. In this work, we show the link between position space and fast-ion orbit space for two different choices of coordinates, i.e. the energy, maximum major radius and pitch at maximum major radius (E,R_m,p_m) and the energy, magnetic moment and toroidal canonical angular momentum (E,μ,P_ϕ). We do so by calculating the sensitivity of hypothetical diagnostics in the magnetic equilibrium of ITER for a set of different line-of-sight geometries. This information is encoded in the so-called orbit-space weight functions.

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Presenter: VALENTINI, Andrea

Track Classification: Energetic Particle Diagnostics

Contribution ID: **17** Type: **Short Contributed Oral**

Envisioning a Microwave-Dominant Diagnostic Suite for Fusion Reactors

Thursday 4 September 2025 12:00 (15 minutes)

Microwave diagnostics present the opportunity for multiplexed plasma control measurements, enabling a minimal plasma-facing footprint and a consolidated measurement suite, though uncommon or new approaches might be necessary for these technologies. The limited set of plasma control and machine monitoring diagnostics expected on future pilot and commercial DT fusion machines will face extreme constraints unlike those found on any currently operating device. Detection of long wavelengths, such as RF, mm-wave, and even THz, offer unique advantages in enabling robust signal capture and relay systems.

High neutron/gamma flux can be a significant source of noise, material damage, and thermal loads that will be detrimental or destructive to most current diagnostic systems. Requisite steady-state operation makes suppression of signal drift and calibration difficult or impossible while erosion and redeposition of plasma-facing components becomes significant. It is estimated that over 90% of the plasma facing surface needs to be used for neutron capture and tritium breeding to ensure an economical plant design. Current future detector designs are unlikely to survive the nuclear environment near the vacuum chamber so must be placed behind shielding several meters away from the first wall. Usage of optical and electronic relay components will be minimal or nonexistent due to their degradation in such proximity to the plasma. High radiation fluxes have been observed to cause debilitating embrittlement and transmutation, and opportunities to repair or replace these components will be rare.

The need for relay optics can be eliminated by using metallic antennas and waveguides, which can be used to capture and transmit signals up to about 2 THz. Fusion experiments around the world have employed antennas and transmission lines for microwave diagnostics for decades, and experience shows that these solutions are robust and long-lasting. Conventional microwave techniques have demonstrated reliable measurements of the plasma such as electron temperature, electron density, and energetic ion population, all crucial plasma measurements in any commercial device. Emerging techniques are also showing promise for extracting plasma shape, plasma position, and D/T ratio. This talk will discuss critical considerations and some recent developments for microwave-based commercial fusion diagnostics.

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Track Classification: AI and real time diagnostics

Contribution ID: **18** Type: **Invited Oral**

High Resolution Neutron Spectrometer system for ITER

Monday 1 September 2025 15:00 (30 minutes)

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The ITER project is intended to generate (and sustain for several hundred seconds) thermonuclear fusion reactions based on either deuterium-deuterium (DD) or deuterium-tritium (DT) fusion reactions in plasma, producing neutrons of 2.45 and 14.1 MeV, respectively. Several neutron measurement systems will be installed on ITER to collect information on the neutron emission from the plasma and to derive a number of plasma parameters.
The High Resolution Neutron Spectrometer (HRNS) is part of that ITER neutron diagnostics set. Such system can measure the time-resolved neutron spectrum for both DD and DT plasmas, providing plasma parameters, such as fusion power, power density, ion temperature, fast ion energy and their spatial distribution in the plasma core.
In particular, for ITER, the HRNS must determine the ratio of fuel ions (tritium to deuterium: nt/nd) in the plasma core (r/a <0.3). This quantity is crucial for protecting the machine and controlling the burning fusion plasma. Reliable measurements of this quantity are essential for ITER to meet the nt/nd requirements for the fusion power range from 0.5 to 500 MW and the nt/nd parameter range: 0.01 < nt/nd < 10. These requirements cannot be met by a single spectrometric technique, therefore, the following neutron spectrometers have been proposed: Thin Proton Recoil (TPR), Diamond Neutron Detectors, Backscatter Time-of-Flight (bToF) and Forward Time-of-Flight (fToF).
This presentation summarizes the current status and future perspectives of the system (HRNS) in ITER, including its geometry, positioning in Equatorial Port #1 (EQ#1) and collimation of the neutron beam. In its current positioning, HRNS has a single-channel collimator system perpendicular to the plasma, capable of performing neutron measurements, providing integrated data over the instrument's field of view. The recorded signal is an integral of the local plasma conditions. The most fundamental aspect is the information contained in the neutron emission intensity. Hence, both the line of sight (LOS) and the size of the first wall aperture play an important role in this measurement, as they determine the neutron flux registered by the spectrometer. This undoubtedly affects the quality of the measured spectrum and, in turn, the issues related to the information contained in the neutron spectrum due to the measurement requirements of ITER.
The presentation will also include the results of neutron transport calculations and issues related to radiation safety, as well as some design problems of the HRNS system. Additionally, a new concept will be presented related to the use of Gas Electron Multiplier (GEM) detector to measure the neutron spectrum.
Finally, we would like to stress that the one of the objectives of this work is to show the process of developing methods for measuring the spectrum of fast neutrons over a wide range of energies and fluxes. This effort is the result of long-term cooperation between institutions in Poland, Sweden,

and Italy involved in the ITER project.

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

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Track Classification: Energetic Particle Diagnostics

Contribution ID: **19** Type: **Short Contributed Oral**

Feasibility study of a vertical neutron profile monitor and radial compact spectrometer for JT-60SA

Tuesday 2 September 2025 11:45 (15 minutes)

As part of the EUROfusion Enhancements Activities for JT-60SA, a feasibility study was launched for a Vertical Neutron Camera (VNC) and a Compact Neutron Spectrometer (CNS) to complement the current Neutron Diagnostics (NDs) already present. This paper describes the conceptual design of a VNC and a CNS that satisfy the rather severe engineering constraints determining the measurement specifications. Space allocation for the neutron and γ-rays shielding, port access and free views of the plasma severely limited the diagnostic design. As a result of this study, a high resolution neutron spectrometer based on the time of flight technique was not considered feasible due to engineering constraints.

The main scientific rationale of these NDs is to clearly distinguish neutron generation mechanism (thermal-thermal and beam-thermal) and to contribute to the characterization of fast ions and their interactions with MHD instabilities with the ultimate goal to extrapolate the performance of JT-60SA to ITER. The presence of both positive and negative neutral beam injectors with 85 and 500 keV energy respectively will produce two different fast ions populations with different pitch angle driving different energetic particle modes, BAEs, TAEs, GAEs and CAEs. In particular, the role of confinement and loss of fast ions, including

ELMs and RMPs, has a strong impact on current drive efficiency. Finally, these additional NDs will allow studies of triton burn-up especially important for validating fast particle transport models and testing predictions of MHD stability and anomalous losses which is of

direct relevance to future reactors (e.g. ITER and DEMO) due to the 1 MeV T having a Larmor radius similar to that of 3.5 MeV α-particles.

A feasibility study shows that the VNC looks at the plasma through a vertical port and a 60 mm gap in the divertor intersecting the plasma core region from a pocket in the floor underneath the cryostat. The gap in the divertor limits the view in the radial direction constraining the number of lines of sight to less than 8. A collimator of 1.5 m length and 3

mm diameter results in count rates ranging from 2 × 103 to 1 × 106 s−1 for scenarios S2 and S5 (lowest and highest NBI power) respectively based on typical liquid scintillator detectors. Alternative detectors are also under consideration including organic glass scintillator and LaCl3(Ce) crystals both with neutron/γ-rays pulse shape discrimination capabilities. In the latter, neutron detection occurs via a nuclear reaction resulting in a peak in its energy spectrum enabling neutron spectroscopy. The LaCl3(Ce) based detector is also considered for the CNS which has a tangential view of the plasma equatorial plane and is located inside

a borated polythelene/lead shielding of 95 cm length and 3 cm diameter resulting in a count rate in the range 1 - 10 ×103 cps for scenario S5. Neutron emissivities and spectra for the relevant scenarios have been calculated using the TRANSP/NUBEAM and DRESS codes.

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Track Classification: Energetic Particle Diagnostics

Contribution ID: **20** Type: **Invited Oral**

Probing wave-particle interactions with scintillator based fast-ion loss detectors: from present experiments to burning plasmas

Tuesday 2 September 2025 15:00 (30 minutes)

In magnetically confined fusion plasmas, effective confinement of fast ions—produced by external heating systems and fusion reactions—is essential to ensure efficient plasma heating, current drive, and machine protection. To optimize fast-ion confinement, it is crucial to develop a comprehensive understanding of their interaction with plasma instabilities.

In this context, scintillator-based fast-ion loss detectors (FILDs) have proven to be a powerful diagnostic tool. FILDs provide direct measurements of the gyroradius and pitch angle of escaping fast ions, with high temporal resolution (up to the MHz range), enabling detailed studies of wave–particle interactions and the physical mechanisms driving fast-ion transport.

This contribution will present an overview of the measurement principles and design considerations of FILD diagnostics, as well as highlight key physics results obtained in devices such as ASDEX Upgrade, MAST Upgrade, and TCV. The prospects for FILD applications in future burning plasma experiments will be discussed.

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Presenter: GALDON-QUIROGA, Joaquin (University of Seville)

Track Classification: Energetic Particle Diagnostics

Contribution ID: **21** Type: **Short Contributed Oral**

Runaway Electron Synchrotron Radiation Measurements in WEST

Thursday 4 September 2025 15:45 (15 minutes)

Runaway electrons (RE) pose significant challenges to plasma-facing components in large tokamaks due to their high energy, which can damage materials and limit plasma operations. Therefore, understanding and controlling RE is a critical area of research, particularly for devices like ITER, where runaway events could have severe consequences. In order to address these challenges, the behaviour of RE is being studied in present-day tokamaks using advanced diagnostic tools such as the Runaway Electron Imaging and Spectroscopy System (REIS) [1]. In this work, measurements of synchrotron radiation emitted by RE in the WEST (Tungsten Environment in Steady State Tokamak) [2] tokamak are presented. Up to 400 milliseconds RE beam have been achieved in post-disruption mode. A method based on the comparison between experimental and simulated data has been adopted to infer the RE number, pitch angle, energy and radial profile. The experimental data are synchrotron spectra collected by REIS in the range 520-4000 nm and images obtained by visible and infrared cameras. The simulations are carried out bymeans of the synthetic synchrotron radiation diagnostic tool SOFT (Synchrotron-detecting Orbit Following Toolkit) [3]. The results provide information on the dynamics of RE in pre- and post-
disruption phases in WEST discharges from recent experimental campaigns (2023-2025).

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Track Classification: Fusion Technologies

Contribution ID: **22** Type: **Invited Oral**

Advanced instruments for fusion gamma-rays and alpha-particles monitoring of reactor plasmas

Monday 1 September 2025 11:00 (30 minutes)

Advanced instruments for fusion gamma-rays and alpha-particles monitoring of reactor plasmas
V.G. Kiptily on behalf of JET contributors*and the EUROfusion Tokamak Exploitation TeamUKAEA, Culham Campus, Abingdon, Oxfordshire, OX14 3DB, United Kingdom*
In fusion reactors with magnetic confinement the burning plasma control is strictly needed, i.e. the deuterium–tritium fuel ratio and temperature are among important parameters. Also, since the 3.5-MeV α-particles are a primary source of the plasma self-heating, they should be under continuous monitoring. However, a significant level of neutron and γ-ray fluxes requires to reduce the physical access to the plant that means some conventional diagnostics for the fusion plasma control will be unfeasible. Among the restricted set of instruments, which are available for the burning reactors, neutrons and γ-ray measurements will be demanded as the detectors can be placed far away from the plasma without a direct access to the vacuum vessel.
The recent full-scale D-T experiments (DTE2 and DTE3 campaigns in 2021 and 2023 accordingly) on JET a valuable experience of direct measurements of α-particles and fusion γ-rays has been obtained. These experiments confirm that a substantial development of dedicated instruments and methods are needed for the burning plasma reactor exploitation. Furthermore, understanding of a diagnostic-friendly reactor design is crystalised out.
*In the talk the advanced burning plasma diagnostic instruments as well as their applications in reactors are presented. Using experience of γ-ray measurements in DTE2/3, a high-performance fusion γ-ray spectrometer, FUGAS, is under development for monitoring of the DT-fusion rate, plasma core temperature and fuel-ratio as well as the confined α-particles [1,2]. Alpha-particle measurements required a special diagnostic development. The confined α-particle measurements in DTE2/3 were based on detection of γ-rays from the beryllium nuclear reaction. For the non-beryllium fusion reactors alternative α-particle reactions are proposed, e.g. with boron [3]. The α-particle losses in JET were measured with an array of Faraday cups and the scintillator probe known as FILD. Considering the diagnostic benefits of these devices, an advanced concepts of the α-particle loss detector, SFILD and FILCA, are developed. These detectors could be used for α-particle loss measurements in the pre-burning phase of the reactor exploitation to optimise plasma scenarios. In the burning plasma phase, a remote technique of the α-particle loss monitoring, i.e. GRAM [4], with advanced γ-ray spectrometer FUGAS is proposed.*See the author list of C.F. Maggi et al 2024 Nucl. Fusion 64 112012
** See the author list of E. Joffrin et al 2024 Nucl. Fusion 64 112019
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Track Classification: Energetic Particle Diagnostics

Contribution ID: **23** Type: **Invited Oral**

Phase-space tomography for fast-ion diagnostics in burning plasmas

Monday 1 September 2025 12:00 (30 minutes)

With the era of burning fusion plasmas approaching, the importance of a thorough understanding of fast-ion physics has never been greater [1]. Burning plasmas are characterised by being predominantly self-heated through the transfer of energy from the fast alpha particles born in fusion reactions to the bulk plasma via collisions. Thus, fast ions will form an integral part of future burning fusion reactor plasmas. Furthermore, fast ions have been found to drive instabilities in the plasma, thus deteriorating mainly their own confinement [2,3]. On the other hand, they are also thought to generate zonal flows, which reduce turbulent transport, and thereby improve the plasma confinement [4]. Measurements of fast-ion distribution functions are essential to enhance the knowledge basis on their role in fusion plasmas. However, reconstructions of fast-ion distribution functions from diagnostic data can only be achieved by solving an ill-posed inverse problem. In this talk, we will give an overview of the efforts made to date in reconstructing the fast-ion distribution function in tokamaks, both in velocity space parametrised locally in (R,z), and in the global orbit space. In addition to this, we will discuss the possibility to determine the distribution function of lost energetic particles by inversion of scintillator-based loss detector measurements. In the process, we will examine the role previous and currents efforts can play in future burning plasmas, including which types of physical constraints and theoretical models are available to serve as prior information in such scenarios.

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Track Classification: Energetic Particle Diagnostics

Contribution ID: **24** Type: **Short Contributed Oral**

In Vessel Calibration Strategy for ITER Divertor Neutron Flux Monitor

Thursday 4 September 2025 15:00 (15 minutes)

Neutron diagnostics play a crucial role in fusion reactors by providing essential data for plasma control, machine protection, and nuclear safety. In ITER, neutron diagnostics are exposed to a wide spectrum of neutron energies, ranging from thermal to fast neutrons, and operate across a broad neutron flux range (10^6 to 10^{14} n.cm^{-2}s^{-1}). These detectors are critical for quantifying fusion plasma parameters, including neutron emissivity, D-T ion fueling ratio, total neutron yield, and fusion power.
Achieving high operational accuracy requires in-situ calibration using neutron generators with 2.45 MeV and 14.1 MeV neutron energies, as in DD and DT plasmas. The purpose of in-vessel calibration is to accurately determine detector calibration coefficients, particularly for the most sensitive detectors like the Divertor Neutron Flux Monitors (DNFM). This process involves linking experimental counts to physical plasma parameters while considering coefficients accounting for the plasma neutron source profile, machine integration, and detector response.
However, full in-situ calibration is challenging due to the size of the ITER tokamak, the limited yield of the neutron generator and the low sensitivity of systems designed for high-fusion power operation. Therefore, a comprehensive calibration strategy that incorporates high-detail neutronic simulations is necessary to minimize uncertainties and improve cross-calibration accuracy. This strategy includes sensitivity studies to address the effect of uncertainties in the geometrical factors of the tokamak environment and in the material nuclear properties. Then, by determining the corrective coefficients of the detector response, sensor readings are adjusted for geometric and background effects. These coefficients will be derived from a dedicated characterization experiment. But DNFM characterization is not straightforward, due to the detectors' location outside the Vacuum Vessel. Indeed, the moderated neutron spectrum is complex to reproduce in the laboratory, which prevent characterization in the same operational field. This requires a thorough understanding of the sensor response, from neutron interaction to signal formation, considering all relevant parameters, such as filling gas pressure and fissile deposit layer thickness, while also addressing operational constraints like magnetic fields, electromagnetic noise, and temperature.
This study focuses on different phases of the in-vessel calibration strategy, detailing the DNFM unit design, assessment of the impact of the tokamak environment and surrounding materials, characterization objectives, modeling scheme using GEANT4 Monte-Carlo code for fission fragment transport, and recommendations for experimental procedure.

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

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Presenter: POTIRON, Quentin

Track Classification: Fusion Technologies

Contribution ID: **25** Type: **Short Contributed Oral**

Design and optimization of the Radial Gamma Ray Spectrometer system for ITER

Tuesday 2 September 2025 12:15 (15 minutes)

A set of gamma-ray spectrometers has been designed for ITER as part of the Radial Gamma Ray Spectrometer (RGRS) project. The aim of this project is to design a system, integrated with the ITER Radial Neutron Camera, capable of measuring gamma rays emitted from the plasma with high energy resolution and at high counting rates (exceeding 500 kHz).
The RGRS will operate during the ITER DT phase and will measure gamma rays emitted from:

1. reactions between fast ions (i.e., fusion-born α particles) and light impurities (e.g., ^{10}B),
2. bremsstrahlung emission generated by runaway electrons during disruptions, and
3. the fusion reaction T(D, γ) ^{5}He, which can provide a neutron-independent measurement of the fusion power.

The RGRS detectors are arranged along four lines of sight, each equipped with a large $LaBr_3$ scintillator crystal and a LiH neutron attenuator. Due to the high neutron flux and strong magnetic field, the entire RGRS configuration module is filled with SWX-277Z-5 Kretekast and each $LaBr_3$ detector is housed in a magnetic shielding composed of layers of Hiperco 50A and Mu-metal.
In this contribution, I will describe the main challenges encountered during the RGRS design and the adopted solutions —from detector arrangement to shielding optimization. Finally, I will summarize the RGRS capabilities in measuring the alpha particle profile and assessing the fusion power.

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Track Classification: Energetic Particle Diagnostics

Contribution ID: **26** Type: **Short Contributed Oral**

Study of in-vacuum discharges with X-rays at the High Voltage Padova Test Facility

Wednesday 3 September 2025 16:15 (15 minutes)

The Neutral Beam Test Facility in Padova, Italy, is the site where the development of the Neutral Beam Injector (NBI) for the ITER tokamak is being carried out. In this context, the Megavolt ITER Injector and Concept Advancement (MITICA), which is the full-scale prototype of the NBI, is in the installation and commissioning phase. The system aims at producing neutrals of 1 MeV energy to be injected in the plasma, through acceleration and neutralization of a negative ion beam. A multi-grid multi-aperture system is designed for the accelerator part, and high voltage holding in vacuum over long distances is one of the critical aspects for the prototype to be functional. Operations can be interrupted by in-vacuum discharges and breakdowns, which can also damage the system. The phenomenology of these occurrences is studied at the High Voltage Padova Test Facility (HVPTF), which hosts a cylindrical vacuum vessel containing two electrodes that can be set at voltage differences up to 800kVDC. During operations, current and voltage are monitored for the two independent power supplies, together with the pressure inside the chamber. Moreover, different lines of sight allow for other observations during the experimental campaigns. The dynamics of the discharges have been observed with different cameras in the visible, UV and IR spectrum ranges. In the latest years, X-ray emissions from the vacuum chamber have been observed and studied as well, first with inorganic scintillators and then also with Gaseous Electron Multiplier (GEM) detectors. A strong correlation has been found between the current signal at the power supplies and the X-ray signal at the detectors, suggesting that the study of this radiation can be helpful in the characterization of the discharges and the development of a mean to mitigate and prevent breakdown occurrences. This paper presents a brief summary of the observations that have been made regarding the X-ray time dynamics on the basis of the GEM detector data, together with the initial development of a multi-environment simulation code aiming at reproducing the main aspects of the observed experimental results.

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Track Classification: Fusion Technologies

Contribution ID: **27** Type: **Short Contributed Oral**

Development of fast and scalable hybrid profile reflectometry for real-time plasma control

On the pathway to delivering net-energy power plants, microwave diagnostics offer a promising solution for real-time control of several parameters related to electron temperature and density profiles, as well as magnetic-field pitch angle. Microwave diagnostics are promising because the wavelength range is at a sweet spot between a few millimetres and a few centimetres, providing excellent robustness and potential for cm to sub-cm precision; and their measurement speed is compatible with real-time control.

One critical application foreseen via microwave reflectometry is the real-time control of plasma position and shape. As an example, the implementation foreseen for DEMO[1] encompasses two poloidal arrays of 16 lines-of-sight each, with a similar approach being assessed for STEP. Some challenges in developing such systems include the real-time frequency calibration of frequency-swept oscillators, the challenge with out-of-the-midplane lines-of-sight where cut-off layer curvature can potentially play a role, the cooling of the front plasma-facing elements, the space available for testing multi line-of-sight prototypes in operating experiments, the complexity and associated prototyping cost for a large number of reflectometers, and the reliable evaluation of the accuracy and precision that will be achieved.

A multi-line-of-sight prototype is being developed for deployment on MAST-U, starting with a single line-of-sight at the midplane, to mitigate some of the aforementioned challenges and also likely uncover unforeseen obstacles in real-time operation. The implementation on MAST-U at first minimizes the use of waveguides and plasma-facing components, as these challenges should be tackled on a harsher environment. The focus is rather on developing scalable solutions for the backend electronics, which encompasses deploying the fastest cost-effective ADC/DACs and host FPGAs, as well as modular surface-mount drop-in RF components for rapid prototyping and reduced footprint and overall overhead. Because of the reduced cost and footprint, high signal generation flexibility and high speed that these systems provide, they will also enable us to explore a combination of multiple operational modes. The first candidate to be tested is the use of short pulse reflectometry to constrain the initialization of profile reconstruction from FMCW (Frequency-Modulated Continuous Wave) measurements, be it from X-mode first-fringe detection and/or O-mode estimated non-probed density profile.

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Track Classification: withdrawn

Contribution ID: **28** Type: **Short Contributed Oral**

Radiation-Hardened Hall Sensors: From ITER Deployment to DEMO Readiness

Friday 5 September 2025 10:00 (15 minutes)

Hall sensors based on antimony-sensitive layers are being deployed on ITER within the Outer Vessel Steady-State magnetic field Sensors (OVSS) system and are also considered for the future European DEMOnstration fusion power reactor (EU-DEMO). Their primary role is to support the determination of key tokamak plasma parameters such as plasma position, shape, and plasma current. Ensuring long-term stability and robustness under high radiation loads—expected to be significantly higher on EU-DEMO—is a critical design challenge.
This contribution presents a new generation of antimony-based Hall sensors housed in alumina substrates metallized using Thick Printed Copper (TPC) technology. The integration of TiW diffusion barriers has proven effective in suppressing copper contamination of the antimony layer, significantly improving high-temperature stability. A summary of sensor design, parameters, and laboratory testing results will be provided.
In addition, we present the design and initial results of a high-fluence neutron irradiation experiment carried out at the LVR-15 (10 MW) research fission reactor. Eight Hall sensors with varying design features are being exposed in the reactor core, targeting radiation damage levels up to 0.5 dpa. Unlike earlier non-instrumented tests, this experiment allows real-time monitoring of sensor sensitivity, input/output resistance, and temperature during irradiation. The experimental setup required the development of a compact magnetic field source (several tens of mT) operational within the reactor's active zone, as well as robust control and safety systems adapted to strong radiation heating and space constraints.
Initial data from the first irradiation cycle—ongoing at the time of the conference—will be presented alongside key technological challenges and lessons learned from the experiment design and execution.

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Track Classification: Fusion Technologies

Contribution ID: **29** Type: **Short Contributed Oral**

Development of high-density channel SXR FPGA-GEM-system for tokamak plasma diagnostics

Thursday 4 September 2025 12:15 (15 minutes)

Abstract:
Soft X-ray (SXR) diagnostics are widely used in fusion research to investigate plasma behavior and provide data for detailed studies, particularly, in the context of magnetohydrodynamic (MHD) activities or impurities transport. The outputs can be used for monitoring the plasma stability, such as by tracking impurities during the discharges and their accumulation in the plasma core. Such measurements are especially relevant for next generation devices like ITER, where impurity control, such as tungsten, is critical for sustaining high performance plasma operation. Gas Electron Multiplier (GEM) detectors are considered promising candidates for diagnostic applications in advanced and future tokamaks due to their high tolerance to neutron radiation. The GEM detector consists of a gas filled amplification region and one or more perforated GEM foils, which are biased with high voltage to enable electron multiplication. When soft X-ray photons interact with the gas, they produce primary electrons that are subsequently amplified through successive stages in the GEM foils. The resulting electron charge is collected at the readout anode, typically implemented as a printed circuit board (PCB), which enables spatially resolved signal detection.
This work focuses on a new generation of SXR diagnostics based on GEM detectors integrated with a modern FPGA-based data acquisition infrastructure. The presented solution represents the third generation of SXR detection systems developed by our team. Earlier versions have been successfully deployed on the JET tokamak (UK, operated by CCFE) and the WEST tokamak (France, operated by CEA). These include a hardware histogramming system (1st generation) and a hybrid streaming system (2nd generation). The current design differs significantly form its predecessors, primarily due to the highly complex readout architecture of the GEM detector. It incorporates approximately 34,000 pixels, organized into around 3000 readout channels using an advanced XYUV coordinate mapping scheme. Due to foreseen particle flux at a level of ~2MHz/channel, the data acquisition requires high-performance electronics and dense signal connections in relation to a budget-optimized way of constructing the diagnostic. This work emphasizes a highly standardized system design, leveraging Customer-Off-The-Shelf (COTS) components, wherever feasible, and custom development of the most essential elements of the electronics. The architecture is based on multiple FPGA units, each capable of handling up to 256 signal processing channels. A key feature of the proposed system is its ability to acquire raw analogue signals directly from the GEM detector and process them though several stages, improving the quality of the output data. This processing is split between real-time FPGA-based preprocessing and post-acquisition analysis on an HPC cluster. The resulting data is high time resolution energy and topology spectra tailored user defined configurations.
The system is still under active development. In this work we present the most recent results, with a particular focus on the construction strategy and early performance validation.
Acknowledgements
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Track Classification: AI and real time diagnostics

Contribution ID: **30** Type: **Short Contributed Oral**

Latest progress in the design of the hard X-ray monitors for runaway electron detection in SPARC

Wednesday 3 September 2025 11:00 (15 minutes)

As tokamak devices prepare to enter the burning plasmas era, as for example with the SPARC [1] experiment, one of the few remaining challenges is represented by runaway electrons (RE). Due to the plasma parameters necessary to create a burning plasma, REs can potentially reach tens of MeV of energy and carry multi-MA of current. Models of the interaction of REs with SPARC first wall [2] show that the dissipation of RE power could produce severe damage to the device. Thus SPARC will be equipped with a set of diagnostics for start-up RE detection, which will inform the plasma control system to interrupt an experiment before a RE beam could gain excessive energy. Among these diagnostics, the hard X-ray (HXR) monitors will detect bremsstrahlung radiation in excess of 100 keV, emitted by REs interacting with the bulk of the plasma or more likely with the plasma facing components.
In this contribution, we present the latest design of the HXR diagnostics, which will be two cylindrical 1.5 inch diameter x 1.5 inch height LaBr3 inorganic scintillators, coupled with PMTs. The two monitors will be located in two tangential penetrations in the tokamak hall wall, with a wide field to observe co- and counter current RE beams. The characterization of a prototype unit has been conducted [3], returning an estimate for its energy resolution, total efficiency, and dynamic range. We then discuss the strategy for implementing a digital acquisition chain capable of performing simultaneous measurements in spectroscopic and current modes. Due to their position, the detectors will operate in an unprecedented harsh environment, with high neutron fluxes (expected to reach few 10^{10} n/cm2/s) and high residual magnetic fields (~100 G) from the poloidal field coils. A neutron attenuator made of high density polyethylene (HDPE) has been designed using neutronics simulations, such as OpenMC [4] and FISPACT [5], to mitigate both the prompt neutron-induced and the delayed activation-induced backgrounds on the detector. Finally, we conclude presenting our strategy to minimize and correct the effect of the external magnetic fields by a combination of magnetic shielding and an LED-based monitor for the detector gain.

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2A. Freyer et al., APS-DPP 2024, "Implementation of a runaway electron module in HEAT"
3E. Panontin et al. Rev. Sci. Instrum. 95 (2024); doi: 10.1063/5.0219549
4P. Romano et al., Ann. Nucl. Energy 82 (2015), doi: 10.1016/j.anucene.2014.07.048
5J-Ch. Sublet et al., Nuclear Data Sheets 139 (2017) 77-137 doi: 10.1016/j.nds.2017.01.002

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Track Classification: Energetic Particle Diagnostics

Contribution ID: **31** Type: **Short Contributed Oral**

Laser-Based Photomultiplier Gain Monitoring for the ITER Radial Neutron Camera

Friday 5 September 2025 09:45 (15 minutes)

The ITER Radial Neutron Camera (RNC) is a key diagnostic system designed to provide time resolved measurements of the neutron source profile through the application of reconstruction techniques to the line-integrated neutron fluxes. It is composed of two subsystems, the In-Port RNC and Ex-Port RNC located, respectively, inside and outside the Plug of Equatorial Port #01. The Ex-Port RNC features 16 Lines of Sight (LoS) along which the neutron flux is measured by a set of 3 detectors, two of which are scintillators (EJ-276G plasΘc and 4He gas) coupled to photomulΘplier tubes (PMTs). PMTs suffer gain variations (due to change of the incoming neutron flux, temperature drifts and PMT aging) that need to be monitored and corrected via software reconstruction. This is done using a light source of well-known characteristics (amplitude, shape, duration), typically LED signals. In the RNC the light source is foreseen to be coupled to the PMTs through optical fibers. This work presents the design of a novel system of PMT gain monitoring using a 520 nm LASER diode as replacement of the traditional LED-based system that is not suitable in the ITER environment due to the insufficient power, given the expected radiation-induced reduction of the optical fiber transmission
throughout the ITER lifetime. An overall description of the LASER system is provided including layout, positioning, optical components, fibers, detectors and PMTs. The LASER can generate customizable pulses to be routed through radiation-hard optical fibers to the detectors. Experimental tests run with PMTs coupled to the scintillators enabled us to determine the optimal set-up of the LASER pulses in terms of LASER current, pulse shape and width. The LASER is found to produce stable and tunable signals suitable for PMT monitoring, achieving LASER pulse height resolutions as low as 2.4%.
The use of a single LASER diode for monitoring the whole set of 32 RNC PMTs simplifies the system architecture and improves maintainability in the ITER's remote and radiation-intensive environment.

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Track Classification: Fusion Technologies

Contribution ID: **32** Type: **Short Contributed Oral**

Status of the high-resolution magnetic proton recoil neutron spectrometer for SPARC burning plasma diagnosis

Wednesday 3 September 2025 11:15 (15 minutes)

This contribution presents the status of the magnetic proton recoil (MPR) neutron spectrometer being developed for SPARC, a high-field tokamak under construction in Devens, MA, USA expected to achieve burning plasma conditions and produce up to 140 MW of DT fusion power. This high-resolution neutron spectrometer will enable critical measurements core plasma performance, including ion temperature, fuel ion ratio, nonthermal fusion due to radio frequency and alpha heating, and an independent measure of the total fusion power. The MPR views the plasma core along a radial midplane line of sight defined by a 3 cm diameter collimator through the tokamak hall wall, and constitutes the central line of sight of the poloidal neutron camera. Collimated neutrons are incident on a thin polyethylene conversion target, located 16 m from the plasma, where they scatter elastically on protons. A target swapping mechanism is planned to enable shot-to-shot selection of conversion target geometry, giving flexibility to tailor the sensitivity-resolution trade off to meet a variety of experimental conditions and goals. Forward scattered protons receive up to the full neutron energy and are selected by an aperture to enter an ion optical beamline consisting of 3 electromagnets which focus and disperse protons according to their momentum. Thanks to its electromagnetic design, the spectrometer can be tuned to observe the neutron spectrum from 1-20 MeV, with an energy bite of ±25% of the chosen central energy. The beamline has been optimized to correct nonlinear ion optical aberrations, achieving an ion optical energy resolution dE/E < 1% over much of the energy bite. The magnets are currently being manufactured by Buckley Systems, and the mechanical design gives excellent agreement to the idealized ion optical calculations. The focal plane of the beamline is tiled with plastic scintillators whose dimensions are optimized to maximize the signal-to-background ratio. We present calculations of the instrument response function and quantify the performance of the spectrometer's operating modes in terms of energy resolution, sensitivity, and signal to background ratio.

This work is supported by Commonwealth Fusion Systems.

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Presenter: MACKIE, Shon

Track Classification: Energetic Particle Diagnostics

Contribution ID: **33** Type: **Short Contributed Oral**

NEFERTARI project: a network of Research Infrastructures for Magnetic Confinement Fusion Research

Wednesday 3 September 2025 15:30 (15 minutes)

In the framework of the Italian National Recovery and Resilience Plan (NRRP), funded by the European Union NextGenerationEU plan, a project named "New Equipment for Fusion Experimental Research and Technological Advancements with the RFX Infrastructure"(NEFERTARI) has been awarded of funding by the Italian Ministry of University and Research (MUR), with the main aim of strengthening the research infrastructures and more specifically in fusion energy field.
The scientific and technological objectives of the project are mainly the enhancement of a large set of diagnostic systems and experimental technological plants for the RFX-mod2 fusion experiment, based in Padova (Italy), capable of operating both in Reversed Field Pinch and Tokamak configuration, and the reinforcement of a network of laboratories (located in different sites, Bari, Milano, Napoli) featuring specific competences on plasma wall interaction with the BiGym linear device, diagnostics for imaging of soft X-rays and neutrons, optical plasma diagnostics, High Voltage insulation, Remote Handling Systems.
The project is shared among 3 public research institutions (CNR, University of Napoli, University of Padova), with contribution as third party of Consorzio RFX, and involves a team of 40 Full Time Equivalent per year, a total budget of 18M€, with a planned duration of 3 years (2022-2025).
This paper will present an overview of the project, with an update of the scientific and technical achievements in each main topic of the work breakdown structure. In particular, evidence of the effective synergy between public research and private implementation will be given, with the description of the status of the main procurement contracts from design to commissioning phase.
Moreover, prospects for the exploitation of this spread Research Infrastructure for the forthcoming years, after the completion of the NEFERTARI project, will be reported, with highlights on the expected contribution for the development of technological and scientific competencies necessary both to study the RFP as an alternative to the Tokamak and Stellarator for the future fusion reactor and to contribute to the study of Tokamak physics in support of DTT and ITER.
Finally, a specific mention will be given to the training opportunities offered to younger generations in preparation of forthcoming fusion experiments, with possibility of proposing and conducting experiments, optimizing diagnostics and data analysis tools, testing simulation models, new theories and technical innovative solutions.

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Track Classification: Fusion Technologies

Contribution ID: **34** Type: **Short Contributed Oral**

Measuring Ion Dynamics in the Core of European DEMO: A Design Space Exploration for Collective Thomson Scattering

Friday 5 September 2025 09:30 (15 minutes)

Accurate measurement of core ion dynamics is essential for understanding and controlling plasma behaviour in reactor-scale devices. We present recent progress in optimising a Collective Thomson Scattering (CTS) system for the European DEMO, with a focus on maximising diagnostic sensitivity to toroidal plasma rotation, ion temperature, and fusion-born alpha particle density. Building on findings from previous studies Rasmussen et al. (2024), Korsholm et al. (2024), we explore the impact of the scattering geometry, probe frequency, and receiver configuration on measurement performance, supported by synthetic diagnostic studies based on the recent DEMO low-aspect ratio (LAR) scenario. Our results indicate that achieving reliable core measurements will likely require probe frequencies slightly below the previously assumed 60 GHz, due to the reduced magnetic field in DEMO LAR. We highlight other key trade-offs and design considerations for achieving accurate, core-localised ion measurements in the challenging DEMO environment.

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Track Classification: Fusion Technologies

Contribution ID: **35** Type: **Invited Oral**

The potential of collective Thomson scattering measurements in burning-plasma devices

Monday 1 September 2025 11:30 (30 minutes)

As we approach the era of burning fusion plasma experiments, the ability to monitor and control the conditions in the plasma core becomes increasingly important. The versatility and reactor relevance of collective Thomson scattering (CTS) makes it an attractive option for diagnosing thermal and energetic confined ions in the core of burning plasmas. Here we review ongoing work related to the diagnostic design and measurement potential of CTS at ITER, DEMO, SPARC, and STEP. At ITER, CTS will measure fusion-born alpha particles in 7 spatial locations, for energies from their birth energy to thermalization, and the diagnostic design is now approaching the manufacturing stage. A 2-view CTS diagnostic design for EU DEMO in the new low aspect ratio configuration is being developed for measurements of core toroidal rotation, ion temperature, alpha density, and D/T fuel-ion ratio. At SPARC, CTS measurements can additionally help to monitor the core content of He-3, used as a minority species for ion heating. In contrast to these cases, which would all operate below the fundamental electron cyclotron resonance frequency throughout the plasma, initial studies for STEP suggest challenging conditions for microwave-based CTS on this device, although these might be overcome using a THz-range vertical forward-scattering setup. We also briefly comment on possibilities for CTS at additional devices including JT60-SA, the largest non-burning plasma experiment, and discuss ongoing efforts to enable rapid inference of CTS-relevant plasma parameters for reactor control purposes using machine learning.

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Presenter: RASMUSSEN, Jesper (Technical University of Denmark)

Track Classification: Energetic Particle Diagnostics

Contribution ID: **36** Type: **Short Contributed Oral**

MCNP-based characterization of the High-Energy Background in gamma ray spectrometers for fusion power measurements in DT plasmas

Wednesday 3 September 2025 12:15 (15 minutes)

Accurate measurement of fusion power in tokamaks is vital for operational control, licensing, and scientific research. Conventionally, this is achieved by detecting neutrons produced in the $T(D,n)^4He$ reaction. A novel alternative, gamma-ray spectroscopy of the $T(D,\gamma)^5He$ reaction, has recently been demonstrated at JET [1,2]. Unlike neutron diagnostics, which require detailed knowledge of plasma distribution and the computation of adjoint flux via an MCNP reactor model, gamma-ray diagnostics demand only knowledge of the plasma volume along the detector's line of sight, thereby simplifying and accelerating the calibration procedure.
Despite its advantages, this gamma-ray technique introduces several complexities, such as the need to design an effective neutron attenuator, necessitated by the $T(D,\gamma)^5He$ reaction's low branching ratio of $2.4\cdot10^{-5}$ relative to $T(D,n)^4He$, and the challenge of understanding the origin of high-energy gamma background.
To investigate the source of background in the 15–20 MeV energy range, beam-on-target experiments were performed at FNG, supplemented by MCNP simulations. Results identified steel and copper near the target as the dominant contributors to high-energy background, consistent with findings reported in literature [3].
Further analyses were carried out in the context of the JET tokamak, by developing an MCNP model aimed at the characterization of the high energy gamma background of the 3×6 $LaBr_3$ gamma-ray detector used during JET campaigns.
Due to the low probability of gamma reactions in the high energy region, variance reduction techniques, such as Weight Windows, DXtran, and F5 tallies, were employed to improve simulation efficiency. Analyses of these methods, as well as a comparison between nuclear libraries, will be presented. Final validation of simulation outcomes will be performed against experimental results, and the role of gamma-ray diagnostics in future fusion devices, including ITER, DEMO, BEST, and SPARC, will be evaluated.

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2 Dal Molin A et al. "Measurement of the Gamma-Ray-to-Neutron Branching Ratio for the Deuterium-Tritium Reaction in Magnetic Confinement Fusion Plasmas."Phys Rev Lett. 30 July 2024;133(5):055102.
[3] Parker, C. E. (2016). "The $^3H(d,\gamma)$ Reaction and the $^3H(d,\gamma)/ {}^3H(d,n)$ Branching Ratio for Ec.m. ≤ 300 keV"[Doctoral dissertation, Ohio University]

Author: COLOMBI, Stefano

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Presenter: COLOMBI, Stefano

Track Classification: Fusion Technologies

Contribution ID: **37** Type: **Invited Oral**

The Role of KSTAR in Burning Plasma Research as an Innovative Control Test Bed

Tuesday 2 September 2025 10:00 (30 minutes)

As the global fusion research community moves toward realizing a fusion reactor, the need for robust control strategies is increasing. Furthermore, smaller fusion reactors than ITER are being proposed to accelerate the demonstration of burning conditions. These reactors will require next-generation scenarios and sophisticated control techniques to efficiently confine plasma at high pressure. They will also require diagnostics and actuators.

The Korea Superconducting Tokamak Advanced Research (KSTAR) project is developing and validating innovative control methods for next-generation fusion reactors. With its superconducting magnets, stable NBI heating system, and tungsten monoblock diverters, KSTAR enables long-pulse, high-performance plasma discharges under conditions relevant to reactors.

This presentation will highlight KSTAR's recent achievements and its strategic role in addressing key challenges in burning plasma research. Strategies to mitigate plasma performance degradation through impurity control in a tungsten environment, suppression of edge-localized modes (ELMs), and plasma disruption using three-dimensional magnetic perturbation have been tested. The development of a plasma control system relevant to ITER is in progress. These upgrade plans include synthetic diagnostics, Bayesian analysis techniques, and a variety of actuators. KSTAR's flexible control architecture and integrated diagnostics suite make it ideal for testing AI-enabled feedback systems and control algorithms, which will be essential for future devices, such as ITER and DEMO. These capabilities enable KSTAR to serve as a national research facility and a global collaborative platform for advancing the physics and control of burning plasmas.

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Presenter: NAM, Yongun (Korea Institute of Fusion Energy)

Track Classification: Overview of existing and future machines

Contribution ID: **38** Type: **Short Contributed Oral**

Neutron diagnostics for RFX-mod2

Wednesday 3 September 2025 15:45 (15 minutes)

As fusion research advances toward the burning plasma era, the role of neutron diagnostics becomes increasingly central, not only as a tool for assessing fusion performance, but also for probing fast ion behavior, confinement properties, and plasma heating. In this context, RFX-mod2, a major upgrade of the RFX-mod reversed-field pinch experiment, is being equipped with a new suite of neutron diagnostics aimed at expanding its capabilities for studying energetic particle physics and fusion neutron production. This contribution presents the development of fast 2.5 MeV neutron detectors designed to operate in the challenging conditions of RFX-mod2, where compactness, insensitivity to magnetic fields, and high temporal resolution are essential. The system is based on organic scintillators coupled with silicon photomultipliers to achieve a high counting rate and effective discrimination between neutrons and gammas, enabling time-resolved studies of neutron emission even in short or rapidly evolving plasma phenomena, such as magnetic reconnections.

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Presenter: DAL MOLIN, Andrea

Track Classification: Fusion Technologies

Contribution ID: **39** Type: **Short Contributed Oral**

Irradiation and characterization of a single hodoscope channel for the SPARC magnetic proton recoil neutron spectrometer with different radioactive sources

Wednesday 3 September 2025 11:30 (15 minutes)

The SPARC tokamak aims to demonstrate a net fusion power gain in tokamaks for the first time (Qfus>1)1. A neutron spectrometer based on the magnetic proton recoil technique 2 is being built to measure neutrons with energy between 1 and 20 MeV emitted by fusion reactions. It will infer the total fusion power emitted by the machine, corroborating the demonstration of Qfus>1 through the primary Pfus measurement from other neutron diagnostics [3]. This diagnostic will also provide useful information on ion temperature, D/T ratio, and non/thermal fusion neutrons.
The SPARC NSPC is based on the generation of recoil protons via elastic scattering of collimated neutrons on a foil target and their dispersion via a set of magnets [4][5]. The recoil protons are momentum analysed by the magnets and dispersed onto a hodoscope consisting of an array of ~40 detectors made by a plastic scintillator rod of EJ276D coupled to photomultiplier tubes [6]. The hodoscope is made of three groups of channels whose dimensions are optimized based on the ion optics and the energy of protons.
This work presents the characterization of a single central hodoscope channel using two EJ276D scintillator rods, with dimensions (8×5×100) mm³ and (9×3.6×90) mm³, respectively. Each was optically coupled to a PMT through a silicone rubber interface and in some cases via a light guide.
The detectors were tested using alpha, neutrons, proton and gamma-ray sources. The first rod was characterized at the Massachusetts Institute of Technology. . The second one was evaluated at ISTP-CNR in Milan, and preliminary results from measurements at the Legnaro National Laboratories (LNL) are also included.
Preliminary results demonstrate the pulse shape discrimination capabilities between gammas and neutrons of the scintillation rods and their performance in detecting protons, confirming the suitability of the scintillator-PMT configuration for high-resolution neutron spectroscopy in SPARC.

This work is supported by Commonwealth Fusion Systems and ENI SpA.

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[6] M. Dalla Rosa et al., Rev. Sci. Instrum. 95, 083508 (2024)

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Presenter: DALLA ROSA, Marco (Università di Milano Bicocca)

Track Classification: Energetic Particle Diagnostics

Contribution ID: **40** Type: **Short Contributed Oral**

Absolute measurements of 14 MeV neutrons with diamond detectors

Thursday 4 September 2025 15:30 (15 minutes)

Neutron measurements are of crucial importance for the forthcoming DT fusion reactors as they allow to measure the fusion power, which is a primary parameter to evaluate the fusion performance.
The standard method for fusion power measurement is based on counting neutrons with fission chambers cross-calibrated with activation foils. This method requires complex Monte Carlo simulations benchmarked with in-vessel calibration measurements. The capacity of performing absolute neutron measurements allows to overcome these necessities.
In this work a diamond detector is studied to obtain absolute measurements of 14 MeV neutrons produced by the DT reactions. The detector was studied first at the Frascati Neutron Generator (FNG) in Frascati, Italy, where the absolute neutron flux is well known, in order to obtain the detector efficiency. The measurements were then repeated at the Neutron Irradiation Laboratory for Electronics (NILE) facility at the Rutherford Appleton Laboratory (RAL) in the UK to verify the efficiency obtained previously. The measurements of the neutron flux are taken simultaneously with several activation foils and a metrology calibrated diamond detector in order to confirm the results.

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Presenter: TEDOLDI, Letizia Giulietta

Track Classification: Fusion Technologies

Contribution ID: **41** Type: **Invited Oral**

Development of a Detachment Control Diagnostic for EU-DEMO

Wednesday 3 September 2025 09:00 (30 minutes)

Future fusion reactors will differ significantly from current fusion devices, particularly in that diagnostics will serve exclusively plasma control functions 1. These diagnostics must operate with high reliability under conditions far harsher than those found, for example, in ITER. The DEMO environment demands novel design solutions for nearly all diagnostics, even though experimental data on material behavior under the expected radiation doses remains limited.
The challenges can be illustrated through the example of the development of an optical divertor monitoring diagnostic system, which includes the detachment control 2. The diagnostic capabilities are developed to meet the requirements of the plasma control system 1. A key question for the conceptual design of the detachment control branch is whether a relatively simple signal can be identified that reliably indicates the detachment. Based on previous JET experimental results [3] the ratios of various Hydrogen and Helium emission lines in the visible spectrum were identified as possible candidates based on SOLPS-ITER simulations [4].
Optical diagnostics are planned for installation in the equatorial ports of DEMO. The extremely harsh environment and high reliability requirements necessitate specialized optical and opto-mechanical solutions. The first mirrors are exposed to continuous impurity fluxes from the plasma, leading to erosion and deposition on the mirror surface. Deuterium-filled ducts, for example, can mitigate damage from high-energy charge-exchange neutrals, and a novel opto-mechanical design has been proposed [5] to enhance the lifetime and optical performance of the first mirror. For the first time, ERO2.0 simulations - including the release and transport of sputtered iron particles from the duct walls - have been performed in a realistic diagnostic geometry to predict erosion and deposition on the first mirror. The presented methodology can be generalized and transferred to other optical diagnostics in DEMO or similar fusion power plants.

Keywords: EU-DEMO; Diagnostics; Spectroscopy, Detachment

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Presenter: DUNAI, Daniel (HUN-REN Centre for Energy Research, Budapest, Hungary)

Track Classification: Edge, divertor and PWI diagnostics

Contribution ID: **42** Type: **Invited Oral**

JT-60SA diagnostcis advances system: VUV Divertor Spectrometer

Wednesday 3 September 2025 10:00 (30 minutes)

This work presents the Vacuum Ultraviolet Spectrometer (VUV) designed to monitor the divertor region of JT-60SA which is starting its activity in support of the exploitation of ITER and by complementing it in resolving key physics and engineering issues for DEMO. The aim of the spectrometer is to characterize the contribution of impurities to the radiation emitted in the divertor region in different scenarios and to study the divertor physics including the plasma detachment. Positioned on an upper port with a vertical line of sight aiming at the divertor, the spectrometer is based on the double SPRED (survey, poor resolution, extended domain) spectrometer originally employed on Textor. It has been refurbished with two new toroidal gratings specially designed to compensate the aberration, to allow 1D imaging detection and to maximize the spectral resolution. The instrument covers a wavelength range from 10 nm to 125 nm separated in two ranges of 10-48 nm and 44-125 nm, with an overlapping region to perform the cross calibration. These two ranges are measured simultaneously using the two separate channels, enabling the instrument to resolve the emission across the entire range. Wavelength resolution in the two ranges is 0.08 nm and 0.14 nm respectively, with a 50 μm wide entrance slit for each. Given the extended length of the JT-60SA port ducts, the system is equipped with a custom-designed optical relays comprising golden-coated toroidal mirrors with possibility of remote control of the alignment. These mirrors focus the plasma emission at the divertor onto the two slits. Subsequently, the emitted light is dispersed by the gratings and measured by two high sensitivity CCD detectors. Integration on the machine required analysis of the compatibility with the magnetic environment as well as the thermal conditions, especially of the components that protrude into the duct.

Author: BELPANE, Andrea (Consorzio RFX)

Presenter: BELPANE, Andrea (Consorzio RFX)

Track Classification: AI and real time diagnostics

Contribution ID: **43** Type: **Short Contributed Oral**

Preliminary considerations on the use of LiH as a neutron attenuator for gamma-ray diagnostics

Wednesday 3 September 2025 12:30 (15 minutes)

Lithium hydride (LiH) is widely used as a neutron attenuator in gamma-ray diagnostics for fusion reactors. These include diagnostics on past machines (e.g., JET) as well as future devices, such as the ITER Neutral Particle Analyser and Radial Gamma-Ray Spectrometer. Despite its utility, LiH remains a hazardous material: it reacts violently with water, including air moisture, producing lithium hydroxide and hydrogen, which is highly flammable, and thermally decomposes at elevated temperatures even under inert atmospheres. In the case of a fire scenario, this decomposition can generate substantial pressure inside the attenuator, and if the containment fails, the released hydrogen could ignite, potentially causing an explosion. In this work, we present experimental results on the internal pressure evolution of a LiH attenuator as it is heated, which, although initial, provide guidance for safety considerations.

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Presenter: SCIOSCIOLI, Federico (Università degli Studi di Milano Bicocca)

Track Classification: Fusion Technologies

Contribution ID: **44** Type: **Invited Oral**

AI-based profile control with RTCAKENN on DIII-D: Toward robust operation under diagnostic degradation and failure for FPP

Thursday 4 September 2025 10:00 (30 minutes)

In future fusion power plants, full diagnostic coverage may not always be available due to radiation damage, access limitations, or cost constraints. To explore profile control under such conditions, we tested a real-time control scheme on DIII-D that is robust against the loss of primary kinetic diagnostics. The system uses RTCAKENN[1], a neural network trained to infer seven kinetic profiles—including density, temperature, and rotation—based only on real-time-compatible inputs. In experiments, we evaluated its performance by selectively removing inputs from diagnostics such as Thomson scattering or charge exchange. Even with missing data, RTCAKENN continued to provide profile estimates with sub-5 ms latency and promising agreement with available measurements. These inferred profiles were used by a model predictive controller to adjust actuators like neutral beam injection and gas fueling. This approach may offer a practical solution for profile control in reactor environments where some diagnostics are unavailable or degraded.

This work was supported by the National Research Foundation of Korea (NRF), funded by the Korean government (Ministry of Science and ICT) under RS-2023-00255492. It was also supported by the U.S. Department of Energy (DOE), Office of Science, Office of Fusion Energy Sciences, through the DIII-D National Fusion Facility under Award DE-FC02-04ER54698, and under Awards DE-SC0015480 and DE-AC02-09CH11466.

References:

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Presenter: SHOUSHA, Ricardo (Princeton Plasma Physics Laboratory)

Track Classification: AI and real time diagnostics

Contribution ID: **45** Type: **Short Contributed Oral**

Design and Optimization studies of a Diamond-based High-resolution Neutron Spectroscopic Camera for SPARC.

Wednesday 3 September 2025 15:00 (15 minutes)

SPARC is a compact, high-field Deuterium-Tritium (DT) tokamak currently under construction by Commonwealth Fusion Systems (CFS). The device aims to achieve net fusion energy, targeting a plasma gain (QP) greater than 5 and producing up to 140 MW of fusion power (PFUS). It will feature a poloidal neutron camera (NCAM) designed to provide energy, time, and space-resolved measurements of neutron emission. The system consists of multiple detectors located at the endpoints of collimated lines of sight (LOS). For high-power DT operations, the NCAM adopts Chemical Vapor Deposition diamond detectors as its baseline technology, selected for their radiation hardness, ~1% intrinsic energy resolution at 14 MeV, high count-rate capability (up to 1 MHz), and compact size (~10 mm^3).
This work focuses on optimizing the layout of the NCAM diamond detectors to support ion temperature profile reconstruction over a broad range of neutron fluxes expected during DT plasmas. Specifically, it investigates the optimal number and size of diamond pixels at the LOS endpoints to support both inter-shot analysis and potential real-time applications. Synthetic data and an inversion algorithm are developed and applied to the reference SPARC plasma scenario. To assess the reconstruction capability of different NCAM configurations with the developed algorithm, the reference scenario is perturbed using heuristic variations, designed to test robustness against plasma shape and position changes, as well as Poisson noise.
The results demonstrate that multiple design configurations satisfy the required time and energy resolution for ion temperature profile reconstruction, specifically, a time resolution below 100 ms and an Ion Temperature profile accuracy better than 10%. A minimum viable setup for DT operations is identified, capable of supporting both early-phase experiments (1 MW < Pfus < 20 MW) and later high-power campaigns (Pfus < 140 MW).
This work was supported by Commonwealth Fusion Systems and ENI SpA.

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Presenter: CELORA, Agostino (University of Milan-Bicocca)

Track Classification: Energetic Particle Diagnostics

Contribution ID: **46** Type: **Short Contributed Oral**

The GEM soft x-ray diagnostics on RFX-mod2

Wednesday 3 September 2025 16:00 (15 minutes)

A novel soft X-ray (SXR) diagnostics system employing Gas Electron Multiplier (GEM) technology is under development for the RFX-mod2 device, the upgraded reversed field pinch (RFP) experiment aimed at advancing magnetic confinement fusion research. The GEM-based system is designed to provide energy-resolved, high-temporal-resolution measurements of SXR emissivity, enabling detailed studies of core MHD activity, impurity transport, and thermal structures in high-performance plasma scenarios.

Compared to conventional SXR detectors, GEM detectors offer coarse energy discrimination, imaging capability, radiation hardness and MHz counting rate capability —features that are particularly advantageous in the harsh environment of fusion devices. The system architecture includes two GEMs with segmented anode installed in pin-hole configuration on two vertical lines of sight to capture the poloidal cross-section of the plasma. Integration with synthetic diagnostics and modeling tools will further support interpretation and validation.

This contribution will outline the diagnostic concept, key design choices, integration strategy within the RFX-mod2 vessel, based on the experience gained from the installation of a similar diagnostic on the MAST-U tokamak. The GEM-SXR system is expected to play a critical role in characterizing MHD dynamics and impurity behavior, and more broadly in supporting the development of advanced confinement regimes in the RFP configuration.

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Presenter: Dr PUTIGNANO, Oscar (ISTP-CNR)

Track Classification: Fusion Technologies

Contribution ID: **47** Type: **Invited Oral**

Overview of Diagnostic design for burning plasma experimental superconducting tokamak

Monday 1 September 2025 09:30 (30 minutes)

This talk presents the progress in the design of the diagnostic system for the burning plasma experimental superconducting tokamak. Different from present diagnostics, new requirements and challenges arising from burning plasma for diagnostics have been investigated first. These specifications facilitate establishing criteria for measurement identification and technique selection. A comprehensive workflow is then outlined to clarify the design steps. Given the harsh environment and limited port resources, a compact and robust diagnostic system is envisioned. The measurements for nuclear safety and machine protection, plasma operation control, and fusion physics understanding are proposed, and 28 candidate systems and techniques are selected for burning plama experimental superconducting device. Key R&D challenges, such as the high neutron radiation environment and advanced diagnostic port integration, are identified. Additionally, the development of new diagnostic techniques and synthetic diagnostics is discussed. Finally, the talk concludes by outlining future wok.

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Presenter: LIU, Haiqing (ASIPP)

Track Classification: Overview of existing and future machines

Contribution ID: **48** Type: **Invited Oral**

Advancing Diagnostics for Spherical Tokamaks: Developments at Tokamak Energy

Tuesday 2 September 2025 09:30 (30 minutes)

J. Flanagan, S. Abouelazayem, O. Asunta, H. Bohlin, P. F. Buxton, T. Brewer, C. Colgan, A. Dnestrovskii, M. Fontana, M Gemmell, J Hakosalo, F. Janky, M. Iliasova, D. Kos, H.F. Lowe, M.P. Gryaznevich, L. Martinelli, S.A.M. McNamara, G. Naylor, M. Romanelli, V. Nemytov, A Prokopyszyn, M. Sertoli, J. Sinha, S Sridhar, J. Varje, H.V. Willett, P. Thomas, Y. Takase, A. Rengle, T. O'Gorman, B. Vincent(1), J. Wood and the ST40 team.

Tokamak Energy Ltd., 173 Brook Drive, Milton Park, Oxfordshire, OX14 4SD, United Kingdom

(1) ICTEAM, UCLouvain, Louvain-la-Neuve, Belgium

Tokamak Energy (TE) is advancing diagnostic technologies to support its mission of delivering commercial fusion energy through compact spherical tokamaks, guided by strong public-private partnerships. This presentation will outline recent and ongoing diagnostics development across several programmes, with a focus on ST40—the highest field spherical tokamak in the world.

ST40, which has demonstrated ion temperatures above 100 million degrees Kelvin 1, is currently running a campaign to evaluate confinement scaling at higher fields and maximise the fusion triple product. Lithium granule injection is also being trialled to assess its impact on performance and impurity control. The campaign is supported by a suite of advanced diagnostics, including Thomson Scattering, sub-mm interferometry, soft X-ray and bolometer cameras, neutron cameras, spectrometers and diamond detectors, Langmuir probes, visible-UV and X-ray spectrometry, and infrared imaging 2.

The next phase of ST40 is defined by the LEAPS programme –a $52 million collaboration with the US Department of Energy (DOE) and the UK Department for Energy Security and Net Zero (DESNZ). This upgrade will involve a lithium evaporative coating of the wall combined with the lithium granule injection, building on foundational work by the Princeton Plasma Physics Laboratory (PPPL) and the Oak Ridge National Laboratory (ORNL), and will position ST40 as a key testbed for addressing plasma-wall interaction challenges in future fusion devices. To optimise measurement capabilities, the ST40 diagnostic suite will be further upgraded and enhanced with the addition of several new diagnostics.

In parallel, TE is contributing to the U.S. DOE Milestone-Based Fusion Development Program. The Milestones include a pre-conceptual design of a pilot plant, with a minimum viable diagnostic set, and a technology development roadmap addressing long-pulse operation, environmental resilience, and supply chain readiness.

TE additionally plays a key role in accelerating innovation in diagnostics for future fusion devices and fusion supply chain development through in-house research and development activities, and by supporting large scale initiatives: experts from TE are technical advisors to 13 organisations developing sensors for extreme fusion conditions as part of UKAEA's Fusion Industry Programme.
These developments are central to TE's mission of enabling high-performance, reactor-relevant plasma operation in compact devices. They support current experimental goals and lay the foundation for scalable diagnostics in future pilot plants and commercial fusion systems.
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Author: Dr FLANAGAN, Joanne (Tokamak Energy)

Presenter: Dr FLANAGAN, Joanne (Tokamak Energy)

Track Classification: Overview of existing and future machines

Contribution ID: **49** Type: **Invited Oral**

Overview of plasma real-time control at TCV

Thursday 4 September 2025 11:15 (30 minutes)

Real-time plasma control systems are at the heart of operation of modern tokamaks. The contribution focuses on plasma real-time control experimental activities recently performed on the TCV Tokamak of the Swiss Plasma Center, EPFL. State of the heart TCV real-time Plasma Control System (PCS) developments will be presented alongside domestic and international plasma real-time control experiments and associated results ranging from classical magnetic control, model based density control, multi task integrated control and machine learning based control. Insights on ITER control related activities will be presented too.

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Presenter: GALPERTI, Cristian (Swiss Plasma Center, EPFL)

Track Classification: AI and real time diagnostics

Contribution ID: **50** Type: **Invited Oral**

Micro-Electromechanical Systems (MEMS) for extreme fusion environments

Wednesday 3 September 2025 09:30 (30 minutes)

This invited presentation highlights recent advances in developing Micro-Electromechanical Systems (MEMS) for the extreme environments of fusion reactors. There is a critical technological need for diagnosing wall conditions with high spatial and temporal accuracy within a Fusion Pilot Plant (FPP). MEMS encompass a wide range of micron-scale devices that seamlessly integrate mechanical and electrical components for high-sensitivity measurements and actuation. Collaborating with other leading institutions, Sandia National Laboratories is developing embedded, radiation-hardened MEMS sensors for in-situ monitoring of tungsten (W) armor erosion of plasma-facing components (PFC). The principal designs are MEMS devices embedded between the W armor and bulk tile material, such that an array of MEMS would provide local, in-situ, real-time thickness measurements as the armor erodes from the plasma-facing side. Two routes are explored: an ultrasonic MEMS device that propagates an acoustic wave (100kHz-10MHz) through the W via a high-temperature piezoelectric, and an optical interferometer that infers thickness via the resonant frequency of the W armor without the need for active electronics. First generation ultrasonic MEMS made of lithium niobate (LiNbO3) and aluminum nitride (AlN) have been fabricated and tested at Sandia. Frequency-domain thickness measurements of 6mm W samples have been demonstrated, with signal response matching that predicted by COMSOL modeling. First fabrication of silicon photonic crystals for optical MEMS has been conducted at Stanford University. Initial results show that the photonic crystals meet the criteria for a 'zero-length sensor'required to accurately measure the W resonant frequency, which is proportional to armor thickness. Fabrication processes are tailored to control the optical cavity dimensions within the photonic crystal to improve performance, enabling monolithic silicon sensors that are expected to withstand the extreme radiation environment.
Additionally, Sandia has fabricated a new generation of MEMS charge-exchange (CX) sensors with remotely activated shutters. These are palladium metal insulator semiconductor (Pd-MIS) sensors which provide a compact way to perform local CX neutral flux measurements. Next-generation sensors have been fabricated with variable gold overlayer thicknesses to provide coarse energy resolution. Actuating silicon MEMS shutters with displacements of 30μm at 2.8kHz were successfully demonstrated, and will incorporate a 10μm electroplated gold coating to extend sensor lifetime. These MEMS development efforts support an ongoing project with Oak Ridge National Laboratory to develop in-situ W PFC repair methods using additive manufacturing (AM) and remote handling technologies. Preparations are underway for real-time MEMS thickness measurements during an in-situ W deposition procedure using the AM test stand at Oak Ridge. Integration and testing at operating tokamak facilities is also envisioned. Through these collaborative efforts, MEMS technologies will be validated for use in future FPPs, providing spatially and temporally resolved diagnostic data that will enable operational efficiency, acceptable component lifetime, and successful fusion energy generation.

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Presenter: COBURN, Jonathan (Sandia National Laboratories)

Track Classification: Edge, divertor and PWI diagnostics

Contribution ID: **51** Type: **Short Contributed Oral**

Single crystal diamond detectors for nuclear spectroscopy measurements on DT plasmas at JET

Thursday 4 September 2025 15:15 (15 minutes)

In the last decade, single crystal diamond detectors have been extensively used at JET for neutron spectroscopy measurements along collimated lines of sight. Although diamonds can measure 2.5 MeV neutrons, their use is optimized for 14 MeV neutrons. This is due to the exploitation of the 12C(n-⍰)9Be nuclear reaction channel which results in a well-defined gaussian peak in the recorded energy spectrum. 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. Furthermore, they can spectrally separate 2.5 MeV and 14 MeV neutrons providing a challenging DT fusion power measurement in trace tritium plasmas, when the neutron contribution due to deuterium-deuterium fusion reactions is important.

Diamonds have been cross-calibrated with the standard neutron yield diagnostics at JET and demonstrated to be reliable over the whole DT campaigns. Results from the JET DT campaigns will be described.

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Presenter: RIGAMONTI, Davide

Track Classification: Fusion Technologies

Contribution ID: **52** Type: **Short Contributed Oral**

Design and characterization of a deuterated-xylene spectrometer for the SPARC neutron camera

Wednesday 3 September 2025 15:15 (15 minutes)

SPARC is a compact, high field tokamak now under construction in Devens, MA by Commonwealth Fusion Systems. It is predicted to robustly enter the burning plasma regime, $Q_p > 5$, producing at most 140 MW of DT fusion power. A poloidal neutron camera is being designed for the machine to resolve its neutron emission in time, space, and energy. Neutron cameras have been fielded on a variety other magnetic confinement fusion devices (JET, TFTR, LHD, MAST-U), many of which have employed liquid scintillators as detectors. The SPARC neutron camera will be the first to operate with energy-resolved detector units, enabling more accurate emissivity reconstructions and measurement of the ion temperature profile. While liquid scintillators provide many advantages such as low cost, high sensitiviy, and good neutron/gamma discrimination, performing spectrometry can be difficult because of the poor coupling between incident neutron energy and measured pulse height. Modern deuterium-based scintillators have been shown to offer superior spectrometric performance because of the anisotropic nature of neutron scattering on deuterium[1]. For DD and low power DT operation, a deuterated-xylene based liquid organic scintillator detector is under development at MIT for use on SPARC. In this work we discuss the design of the detector, as well as the semi-empirical response matrix generation methodology used to model the detector response. Specifically, the efficacy of an LED pulser for characterizing the detector's intrinsic resolution is evaluated using a custom pulser unit and prototype detector. Measurements and spectrum unfoldings of DD and DT beam-target neutron generator emissions are made to explore the prototype's spectrometric performance.

[1]C. C. Lawrence et al. "Comparison of spectrum-unfolding performance of (EJ315) and (EJ309) liquid scintillators on measured 252Cf pulse-height spectra" NIM A **729** (2013)

This work is supported by Commonwealth Fusion Systems.

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Presenter: BALL, John (MIT Plasma Science and Fusion Center)

Track Classification: Energetic Particle Diagnostics

Contribution ID: **53** Type: **Invited Oral**

Overview of Fusion Neutron Measurements During Recent JET deuterium-tritium campaign

Tuesday 2 September 2025 09:00 (30 minutes)

JET, the Joint European Torus, has recently set new fusion records in two successive tritium campaigns in 2021 and 2023. An integral fusion neutron budget of 7.4e20 neutrons was carefully exploited, in the final campaign (DTE3) of JET's historic mission, to maximise on the scientific impact of a series of campaigns exploring heating, fuelling, plasma control, disruption mitigation and tritium retention studies. A constant through these scientific campaigns was the need to have reliable neutron and gamma diagnostics, amongst others, monitoring the behaviour of the plasma and quantifying critical output parameters such as the neutron yield,
fusion power, plasma ion temperature, fuel ion ratio etc.
This work aims to outline the methodology followed in deriving neutron yields on the JET reactor during the record DT/DD campaigns and to highlight the associated uncertainties in the derived data. To correctly deduce neutron yields from sets of discrete measurements, extensive data validation and modelling work needs to be carried out. Monte Carlo simulations, from a new high-fidelity radiation transport model of the JET machine, will be discussed along with plasma
neutron distributions, their source (birth) location, the scattering effects inside the vessel and the phenomena of neutron multiplication inside the machine via (n,2n) nuclear reactions.
Indeed, it has been found that since the introduction of the beryllium wall on JET, the degree of neutron multiplication reactions has increased considerably and now makes up approximately 20% of all neutrons during DT operations. The production, location and impact of these additional neutrons will be explained and their effects on fusion diagnostics and fusion power calibrations expanded upon.

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Co-authors: Dr CONROY, S (University of Uppsala); KIPTILY, Vasily (UKAEA Fusion)

Presenter: Dr GHANI, zamir (UKAEA)

Track Classification: Overview of existing and future machines

Contribution ID: **54** Type: **Short Contributed Oral**

Assessment of DT fusion power at ITER with gamma-ray spectroscopy and machine learning techniques

Wednesday 3 September 2025 12:00 (15 minutes)

Real-time measurement of the fusion power released from Deuterium-Tritium (DT) plasmas remains one of the the most challenging technical aspects of magnetic confinement fusion.

Recently, during the second DT campaign at JET, a novel method was developed to measure fusion power with gamma-ray spectrometers detecting gamma-rays released by the secondary, radiative branch of the DT fusion reaction. Expanding on this previous work, a machine learning algorithm was developed to estimate DT fusion power at ITER by use of the Radial Gamma-Ray Spectrometer (RGRS) measurements, as well as the magnetic equilibrium as an additional source of information.

The algorithm was trained and tested on a set of 75 simulations of ITER DT plasma scenarios. By testing the algorithm by repeated 5-fold cross-validation, the average deviation of the estimated fusion power from the reference was found to be 0.32\%, while the relative error had a standard deviation of 0.97%. When statistical fluctuations were included in the analysis, the lowest measurable fusion power resulted to be around 30 MW, making the RGRS suitable for the fusion power measurement requirements at ITER.

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Presenter: MARCER, Giulia (University of Milano-Bicocca)

Track Classification: Fusion Technologies

Contribution ID: **55** Type: **Short Contributed Oral**

Digital Readout of Diamond Detectors for Fast Neutron Spectroscopy: Performance and Perspectives for Fusion Diagnostics

Thursday 4 September 2025 17:00 (15 minutes)

Diamond detectors are increasingly adopted for fast neutron measurements thanks to their excellent timing resolution, radiation hardness, and low noise. In a dedicated measurement campaign at the ISIS spallation source, we implemented a full digital acquisition chain based on a 500 μm thick single-crystal diamond detector, broadband preamplification, and the CAEN DT5751 digitizer (10-bit, 1–2 GS/s). The system acquired synchronized waveforms from the neutron beam and accelerator trigger, enabling nanosecond-precision time-of-flight (ToF) analysis.
Each recorded event was processed to extract both ToF and pulse integral, generating biparametric ToF–energy spectra that revealed distinct neutron interaction channels, including elastic scattering and inelastic (n,α) and (n,3α) reactions on carbon. The setup resolved the dual-bunch beam structure of ISIS and discriminated prompt gamma flashes from neutron signals via energy thresholding.
The acquisition chain, fully digital and compact, demonstrated the capability to characterize fast neutron beams with high accuracy, without relying on analog shaping or external timing modules.
Building on this approach, CAEN has developed new instrumentation—such as the DT2751 digitizer with 16 channels at 1 GS/s sampling , 14-bit and an open FPGA architecture—which allows implementation of advanced real-time processing algorithms. These new tools are fully compatible with the measurement technique demonstrated in this work and offer enhanced flexibility and performance. In particular, they open the way to apply waveform-based ToF–energy spectroscopy with diamond detectors to neutron diagnostics in fusion plasmas, where high timing resolution and compact form factors are essential.

Author: VENTURINI, Yuri (CAEN SpA)

Co-authors: ABBA, Andrea (Nuclear Instruments SRL); TINTORI, Carlo

Presenter: VENTURINI, Yuri (CAEN SpA)

Track Classification: Sponsors

Contribution ID: **56** Type: **Short Contributed Oral**

Accelerating the Design of Readout Systems for New Physics Experiments Using Visual Programming

Thursday 4 September 2025 17:15 (15 minutes)

In the field of contemporary trigger and data acquisition (DAQ) systems, the utilization of programmable logic devices highlights the benefits of adaptable, reusable mixed-signal platforms, commonly referred to as open FPGA boards. These platforms support the direct incorporation of application-specific processing routines into firmware, making them highly attractive for a wide array of use cases. Nonetheless, traditional hardware description languages such as VHDL or Verilog often pose a significant barrier to entry for designing custom logic and readout solutions. We introduce an intuitive visual programming environment equipped with a library of IP cores specifically designed for nuclear physics workflows. This environment enables users to construct trigger schemes by linking functional blocks. Sci-Compiler includes virtual modules like scalers, counters, TDCs, energy computation blocks, and Pulse Shape Discrimination units. By simplifying algorithm integration, Sci-Compiler automatically builds all necessary firmware elements and supporting libraries required for the end-to-end acquisition pipeline—from sensor output to data archiving. This shifts the focus toward application-level development and removes the necessity for deep FPGA design expertise. The ecosystem supports a variety of open FPGA boards—with or without onboard ADCs—ranging from single-channel setups to 128-channel systems and sampling capabilities up to 5 GSPS.
Index Terms—Spectroscopy, Digital Signal Processing, FPGA, parallel computing

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Presenter: ABBA, Andrea (Nuclear Instruments SRL)

Track Classification: Sponsors

Contribution ID: **57** Type: **Short Contributed Oral**

Eni and the Future of Energy: Advancing Fusion for a Sustainable Tomorrow

Thursday 4 September 2025 16:45 (15 minutes)

Fusion energy represents a transformative opportunity for the global energy sector, offering a safe, zero-carbon, and virtually limitless source of power. Recent scientific and technological advances have accelerated its path toward industrialization, with over 150 fusion projects active worldwide. Eni is at the forefront of this transition, supporting fusion development through technological, industrial, and business initiatives. Key efforts include strategic partnerships with Commonwealth Fusion Systems (CFS), ENEA (DTT project), UKAEA (H3AT Tritium Loop Facility), and collaborations with universities and research centers. Eni also promotes education and research through dedicated programs and provides advanced computational resources via its Green Data Center. These initiatives position Eni as a leader in enabling fusion energy as a cornerstone of the future energy mix.

Author: GALLO, Erik (ENI S.p.A Technology)

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Presenter: VANELLONE, Silvia (Eni S.p.A)

Track Classification: Sponsors

Contribution ID: **58** Type: **Invited Oral**

Burning Plasma Measurements - a vision for the future

Monday 1 September 2025 09:00 (30 minutes)

Presenter: WALSH, Michael (ITER ORGANIZATION)

Track Classification: Overview of existing and future machines

Contribution ID: **59** Type: **not specified**

Registration

Monday 1 September 2025 08:15 (30 minutes)

Contribution ID: **60** Type: **not specified**

Welcome and Opening by Giuseppe Gorini (UNIMIB), Olga De Pascale (CNR-ISTP) and Francesco P. Orsitto (ENEA)

Monday 1 September 2025 08:45 (15 minutes)

Authors: GORINI, Giuseppe (Universita' degli Studi di Milano-Bicocca); Dr DE PASCALE, Olga (Institute for Plasma Science and Technology - CNR)

Contribution ID: **61** Type: **not specified**

Summary

Friday 5 September 2025 11:00 (30 minutes)

Contribution ID: **62** Type: **not specified**

Awards - Closure

Friday 5 September 2025 11:30 (30 minutes)

Contribution ID: **63** Type: **not specified**

Development of Radiation-Hardened Millimeter-Wave Diagnostics for D-T Fusion Reactors (Remote)

Wednesday 3 September 2025 17:00 (30 minutes)

Presenter: ZHU, Yilun (University of California, Davis)

Track Classification: Fusion Technologies

Contribution ID: **64** Type: **Short Contributed Oral**

High Temperature Operation of a SiC Fast Neutron Detector

Wednesday 3 September 2025 17:30 (15 minutes)

Author: KUSHORO, Matteo Hakeem (Istituto Nazionale di Fisica Nucleare)

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Presenter: KUSHORO, Matteo Hakeem (Istituto Nazionale di Fisica Nucleare)

Contribution ID: **65** Type: **not specified**

Satellite Meeting - Discussion on Neutron Calibration

Thursday 4 September 2025 14:00 (1 hour)