EUROfusion

PSD Project Board 27 October 2025

Enhancement and Commissioning of JT-60SA (WPSA) Status summary of 2025

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JT-60SA Advanced Superconducting Tokamak
BA-Satellite Tokamak Program

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Background

- JT-60SA tokamak through Machine Enhancements 1 for the whole year
- (Remote) data access unavailable until September 2025
- JT-60SA data server and analysis cluster transferred to IFERC network as one of the actions taken after the OP1 experience

Scope=>

OP1: first plasma

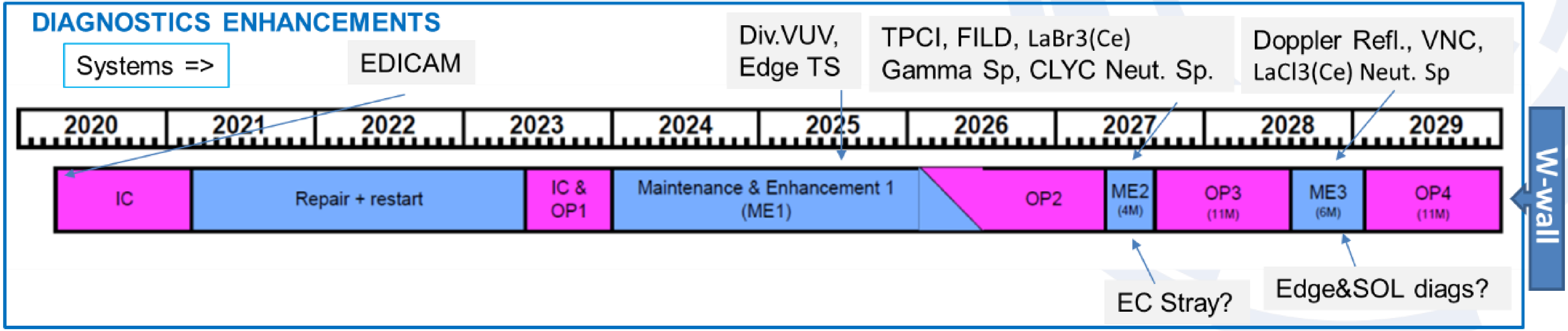
EC assisted breakdown at low $E_{//}$
Plasma control with SC coils
Disruption characterization

OP2: high Ip operation

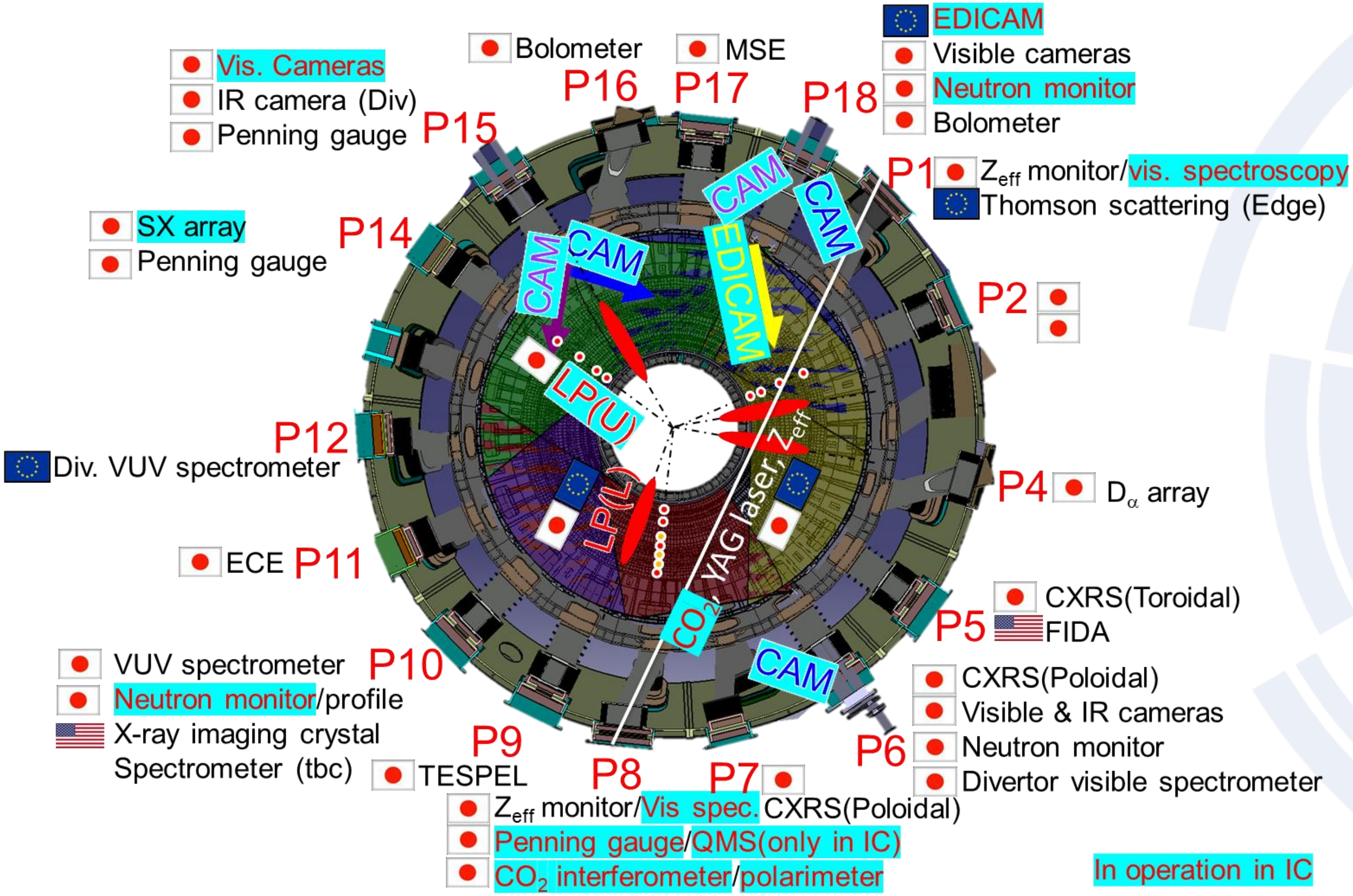
Extension of the operation domain (high Ip, H mode, Beta, collisionality, ...)
Disruptions and Runaway control, Error field
Heat transport L mode with dominant Electron heating
Shine through, Fast ion losses, LH transition, ELMs,
SOL scaling at high IP, Divertor characterization

OP3: H mode development

ITER relevant H-mode and high beta scenarios
High Beta non-inductive steady-state scenarios
NTM, RWM, ST control
Heat transport L mode with dominant Electron heating
Fast ions and turbulence, Alpha particles in D-3He plasma
ELMs regimes, W screening, Seeding



Enhancements in ME1



- Input power upgrade:
  - EC: 1.5 MW → 3 MW (steerable 82, 110, 138 GHz)
  - NB: 0 MW → 16 MW(H) / 23.5 MW(D): 10 MW of 500 keV negative-ion NBI
- Lower divertor
- Several plasma control coils
  - Error Field Correction coil (EFCC),
  - Resistive Wall Mode coil (RWMC),
  - Fast Plasma Position Control Coils (FPPCC)
- ~20 Upgraded Diagnostics
- 2 Massive gas injection for disruption mitigation
- Stabilizing plate : CuCrZr heat sink + Carbon tiles

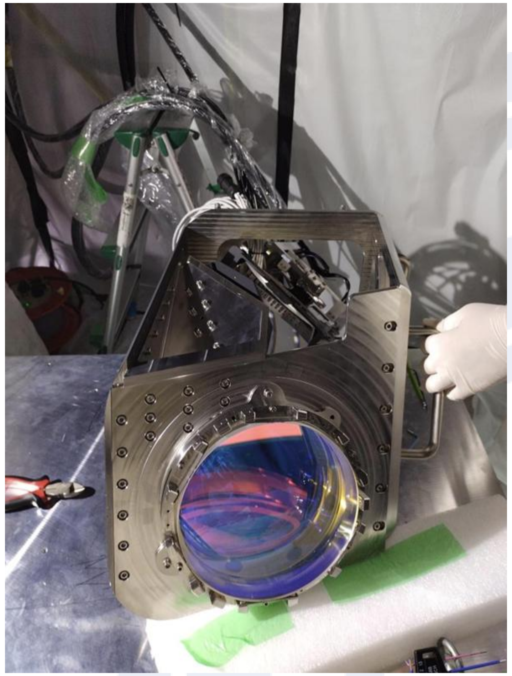
2025 objectives (as for PB in April)

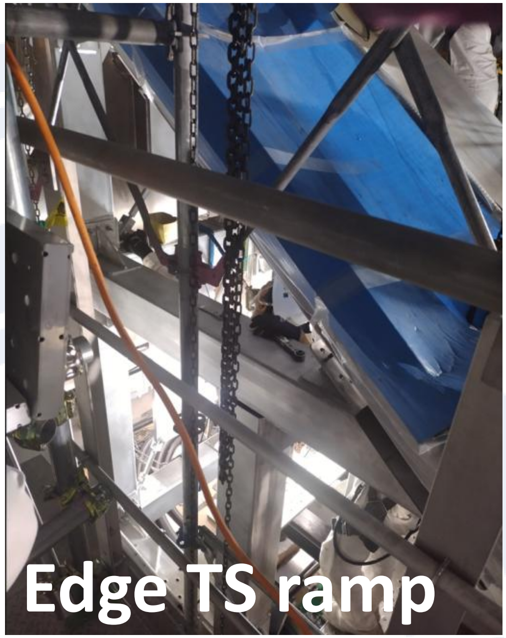
- Prepare and assist machine integration of the EU-led diagnostic systems (OP, ENH) in 2025/26
- Prepare commissioning and first operation of the EU-led diagnostic systems for "delivering" to the scientific community (Experiment Team) (OP) in 2026/2027
- Prepare and verify a suite of tools and codes for the Scientific Exploitation, including operation-oriented tools, synthetic diagnostics, simulation workflows (CM) preparing the subsequent validation on data or benchmarking with/in WPTE
- Support new users in data analysis, leveraging experience gained during commissioning
- Support training for control room tools
- Develop feasibility, design, assist procurement of new subsystems according with the JT-60SA scientific plan (ENH), in particular concerning diagnostics for plasma edge and plasma-wall interaction

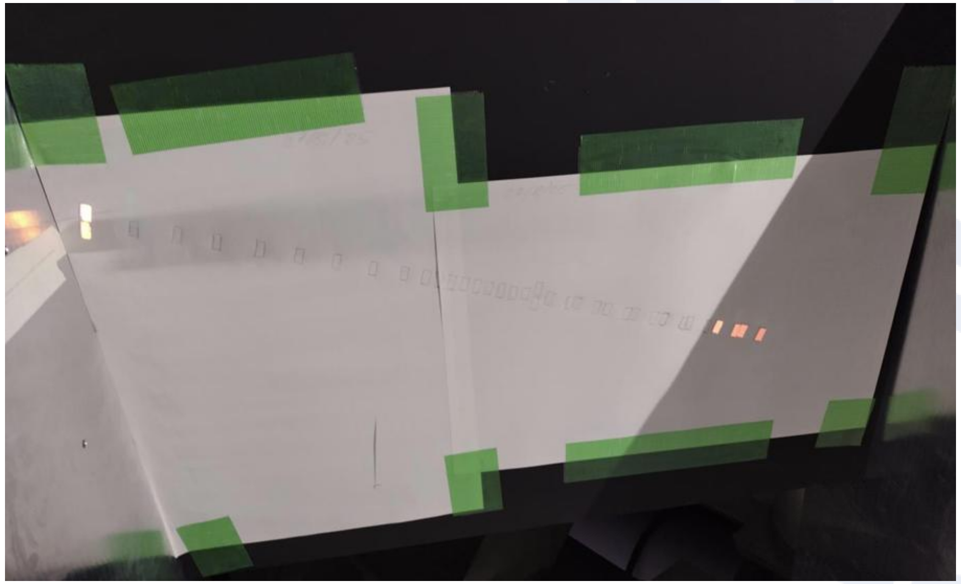
- Establish a plan for the EU contribution to the transition to W divertor and wall. This might include several lines of work and collection of information of activities performed in other EuroFusion WPs, taking into account the scientific priorities for the C phase and for the W phase and W-related preparation experiments in the C phase of JT-60SA (JT-60SA Experiment Team)
- o Core and impurity transport (WPTE)
- o Modeling of heat load on PFCs (WPTE)
- o Modeling for PFCs shape optimization (WPPWIE)
- o Test of PFCs (WPPWIE)
- o Development and qualification of PFCs (WPDIV)
- o Diagnostics upgrade for W monitoring, wall and divertor protection
- o Upgrade of the heating systems
- o Upgrade of the protection system
- o Review of the wall cleaning systems and procedures
- o Review of the gas injection system

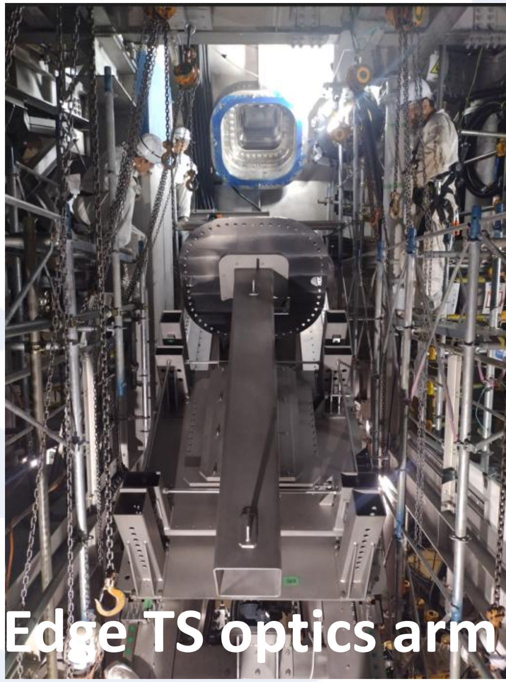
Machine integration and commissioning of the EU-LED systems: Edge Thomson Scattering

- Edge Thomson Scattering: laser source, polychromators with detectors successfully installed previously in 2024
- External mechanical structure installed and aligned in summer 2025
- Minor adjustments of the mechanics completed
- Movements of the translation stages of the fiber bundles were tested under the load of all the fiber
- Alignment test of the fiber bundles completed
- …
- Last phase of the installation (in-vessel optics) in March 2026



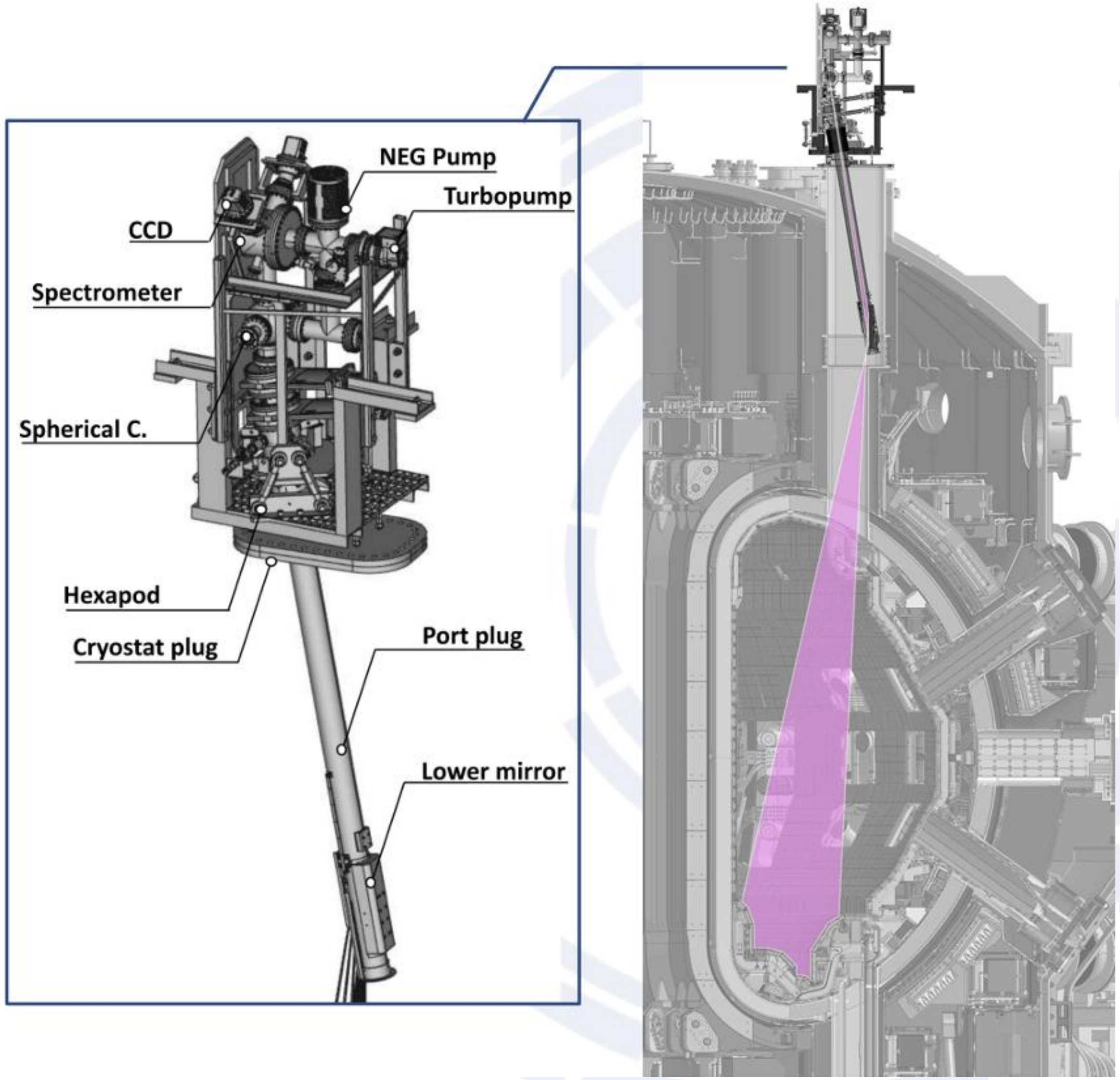






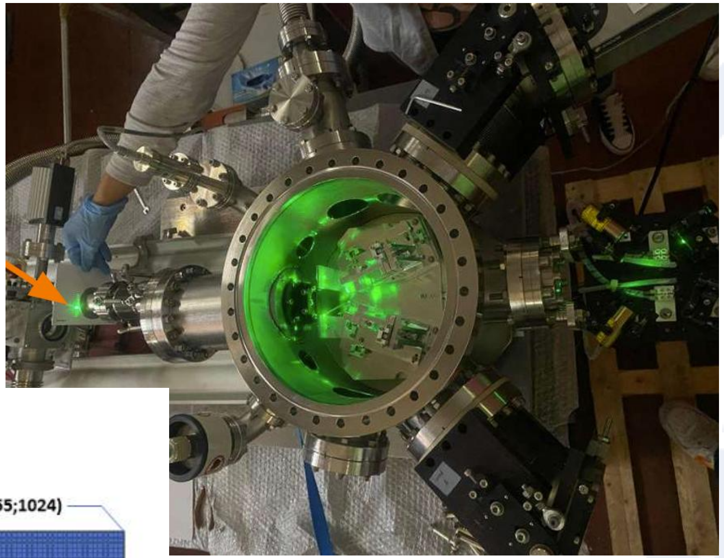
Machine integration and commissioning of the EU-LED systems: divertor VUV

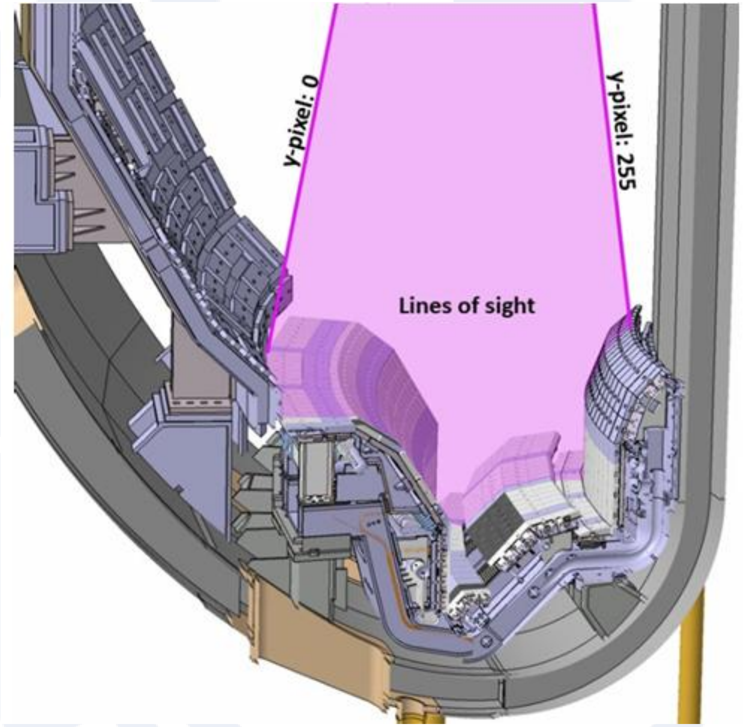
- Mechanical structure acceptance test passed at ICSI (Romania) in September 2025.
- Mechanical structure and vacuum chamber for vacuum test transferred in ENEA Frascati for last step of the acceptance.
- Accident to one CCD detector due to a malfunctioning vacuum pump. Substitution being organized, not impacting the schedule.

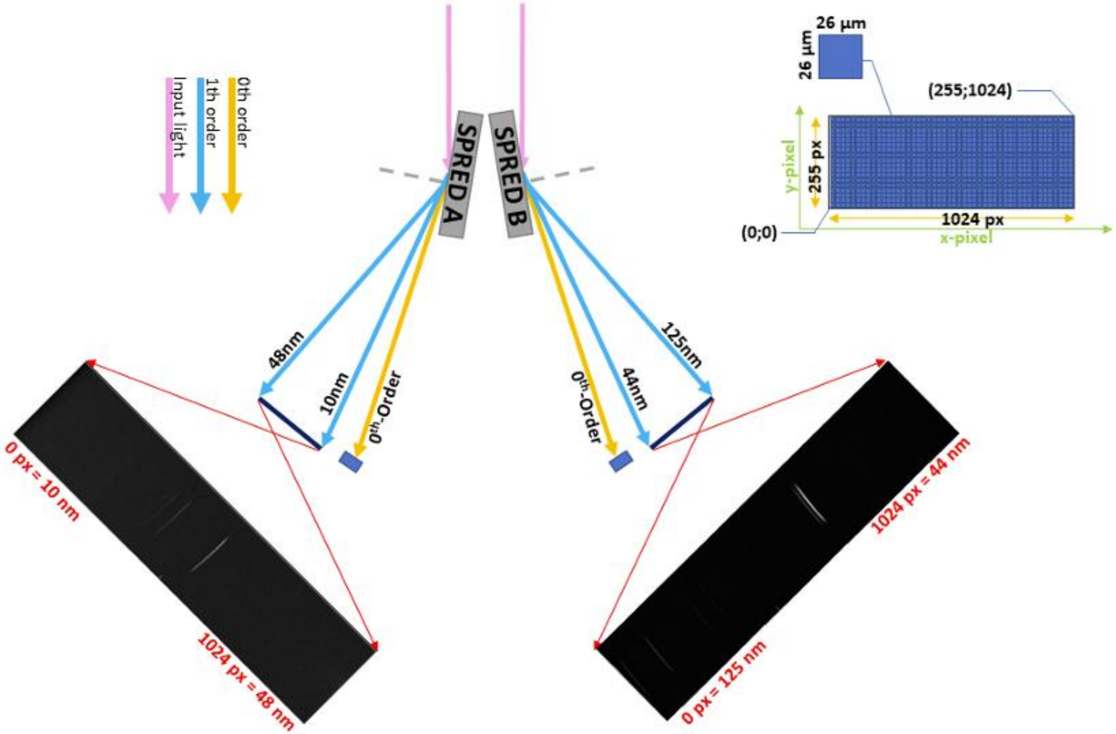


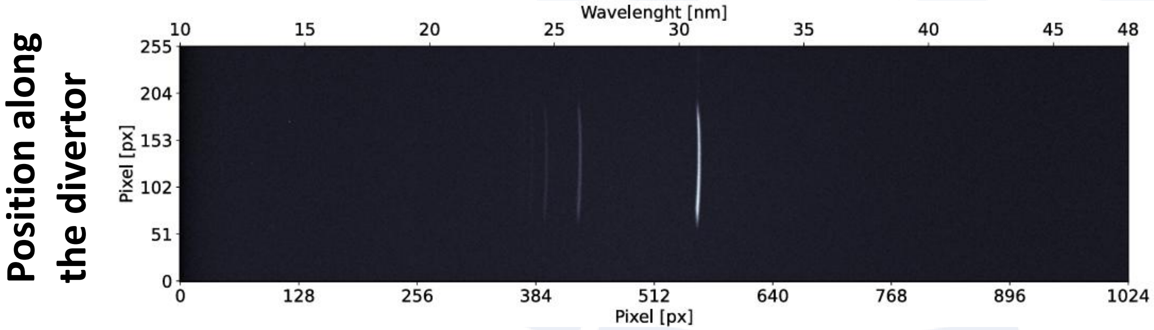
Machine integration and commissioning of the EU-LED systems: divertor VUV

- Spectrometer acceptance test completed in ENEA Frascati in May 2025.
  - Optical alignment
  - Spectral calibration
  - Imaging capabilities (100mm resolution)



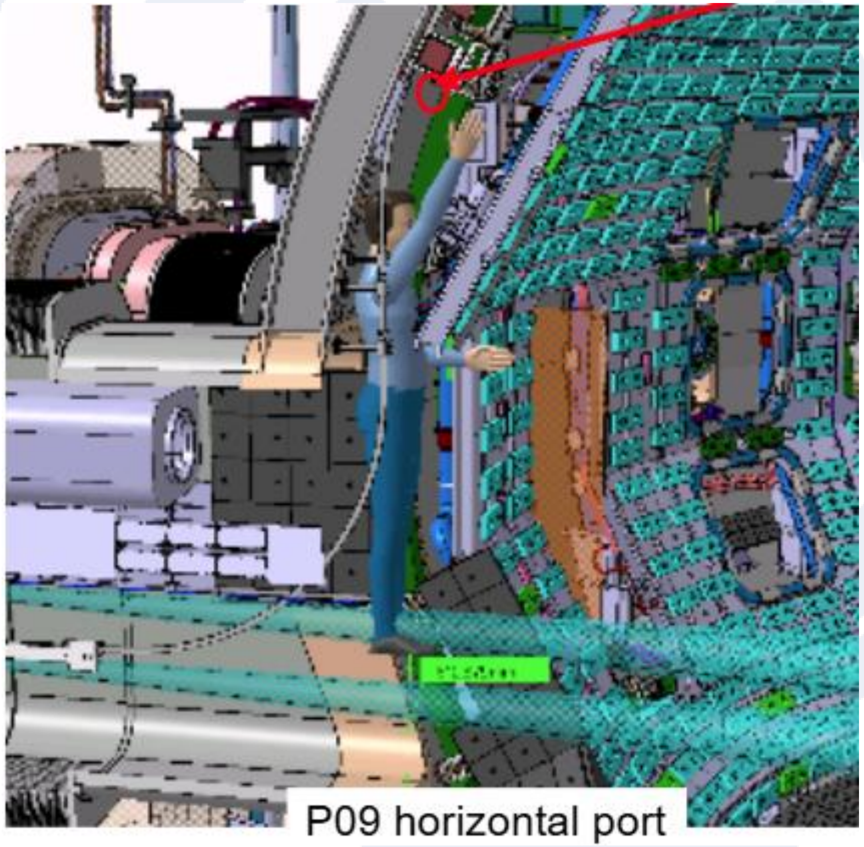






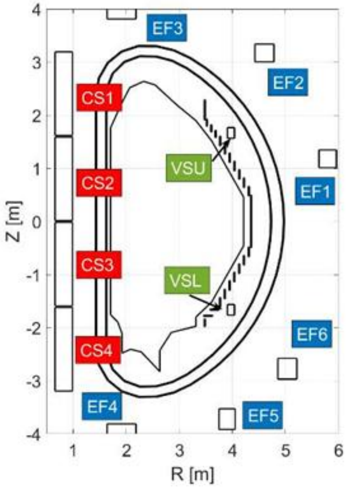
Machine integration and commissioning of the EU-LED systems

- MGI: After delivery in 2024, modifications on site (F4E) due to failure of part of the acceptance test (in particular: pressure test and He leak test)
- After refurbishment, pre-baking pressure test and He leak test passed. Baking on going, then repetition of the test. If ok, installation in vessel next Dec-Jan, completion of the integration (QST) by March 2026
- Scientific support for the commissioning phase planned for 26-27 (WPSA)
- Divertor cryopumps: Delivered in 2024, now under installation
- EDICAM: operational, software upgrade planned for November 2025.
- For all systems: installation procedure, calibration and commissioning plans are part of the delivery process



Operation-oriented tools: pulse design simulator

- PDS has the goal to offer a practical tool for the scientists and operators to prepare plasma scenario within the technical limits of the device.
- Based on the fast kinetic code METIS coupled with the free boundary code and controllers adapted for the different phases of the discharges
- The magnetic controllers are relying on simple linearized models describing the dynamic behaviour of the plasma, the active control circuits, and the currents flowing in the surrounding conductive structures.



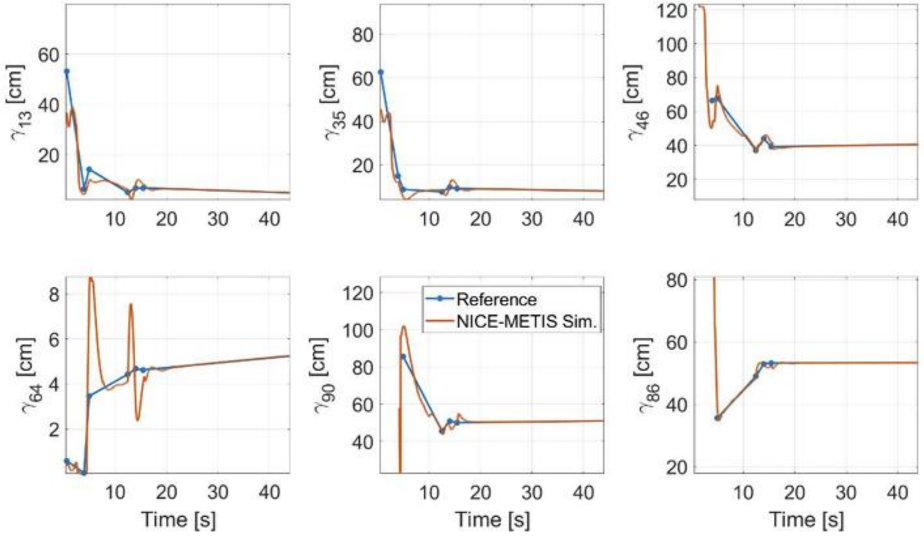
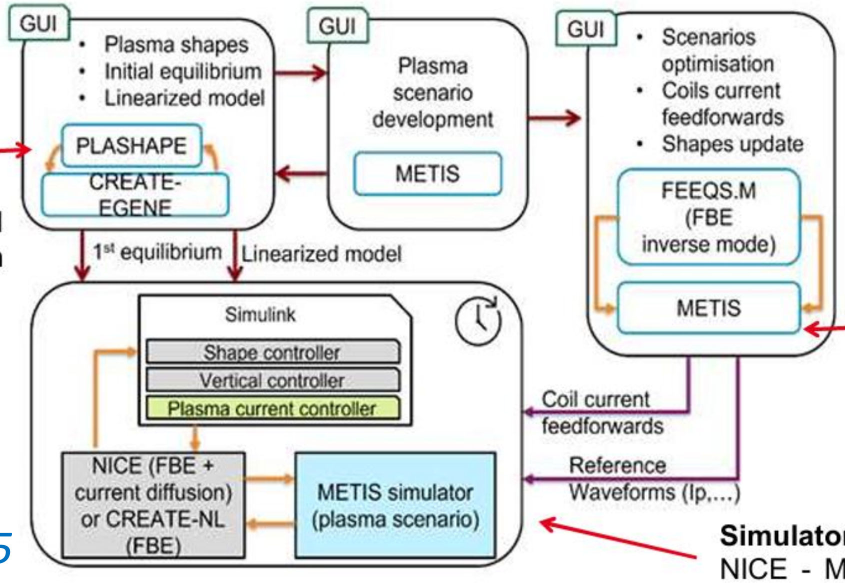


Figure 5 -Controlled gaps during NICE-METIS simulation for the 4.6MA scenario

The simulator is built on the coupling of three main components:

1. The plasma kinetic simulation from METIS [1]
2. A free boundary equilibrium (FBE) code CREATE_NL[2] or NICE [3] (used in "direct mode")
3. The Simulink© controllers.

Shape sequence and scenario description EGENE and METIS

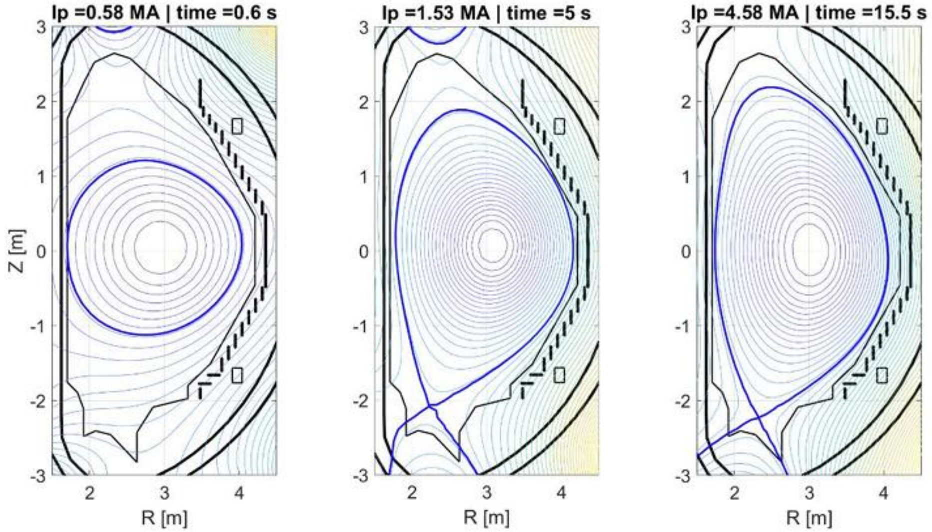


Coil current and forces tested using the free boundary equilibrium code FEEQS [4] in inverse mode

Simulator: coupling NICE - METIS; NICE - controlers

Figure 1: Pulse simulator structure

Joffrin, IAEA-FEC 2025

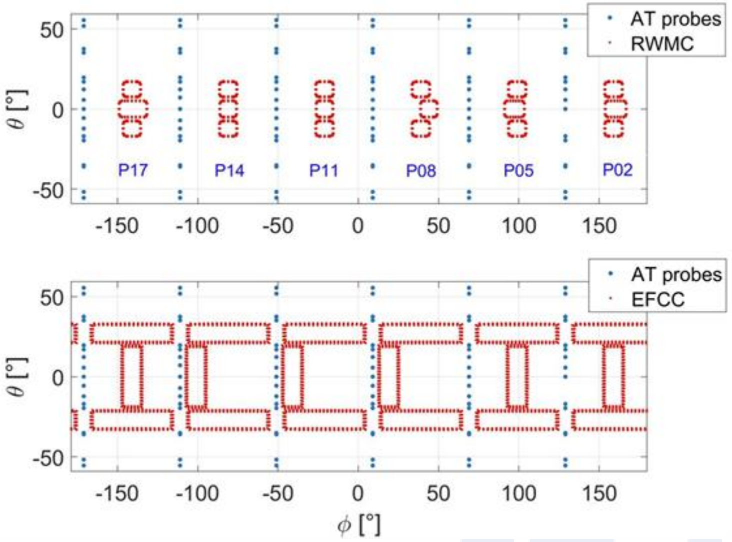


Gap control and relevant plasma shapes during NICE-METIS simulations for the 4.6 MA scenario

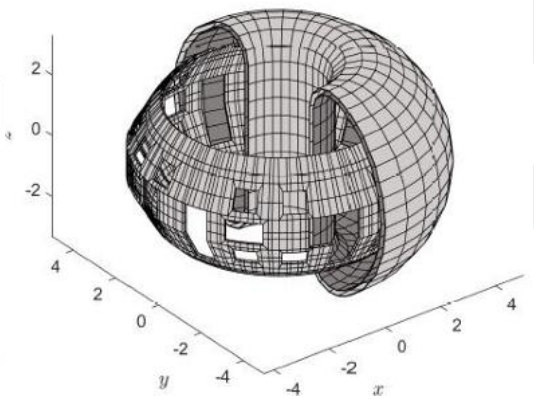
Operation-oriented tools: feedback control model for RWM control coils

Set of non-axisymmetric coils and magnetic sensors

- 6x3 Error Field Control Coils (EFCC), outer side of Stabilizing Plate (SP)
- 6x3 Resistive Wall Mode Coils (RWMC), inner side of SP
- 18x6 bi-axial sensors (108 $B\theta$, 108 Br) for RWM control *



Model of passive structures and coils: Axisymmetric VV and 3D SP (double wall) with holes

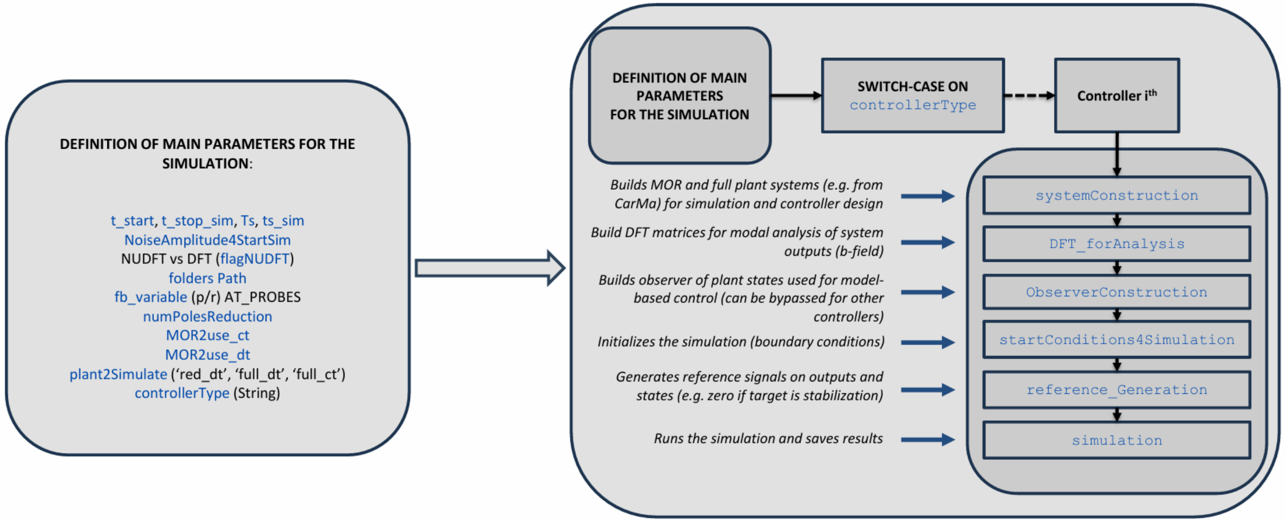


- Application of Error Field Correction Coils (EFCC) in the JT-60SA tokamak. Modeling of the plasma response to resonan magnetic perturbations and assessment of their impact on core and pedestal regions with comparison of the mode locking thresholds.
- EFCC system can effectively mitigate error fields and control plasma instabilities.
- Development of a dynamic simulation tool to predict reference EFCC currents and model the actual load currents to optimize EFCC operations for error field correction.

L. Pigatto et al.
Fusion Engineering and Design 222 (2026) 115489

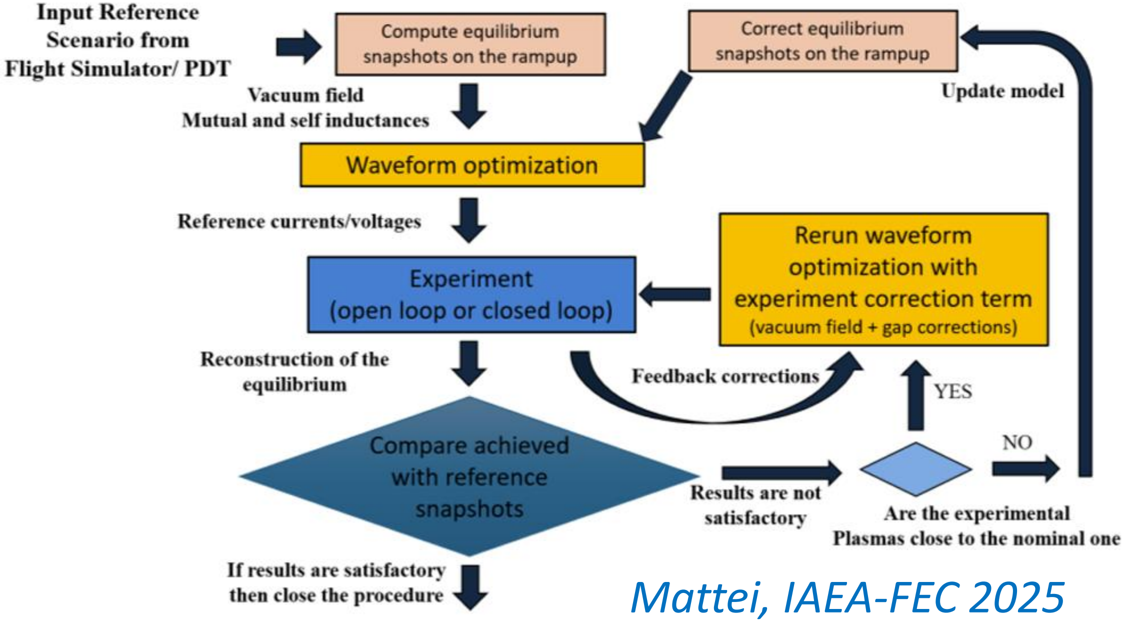
- Application to pressure-driven instability in high performance scenario

Modular code for time simulation of RWM control

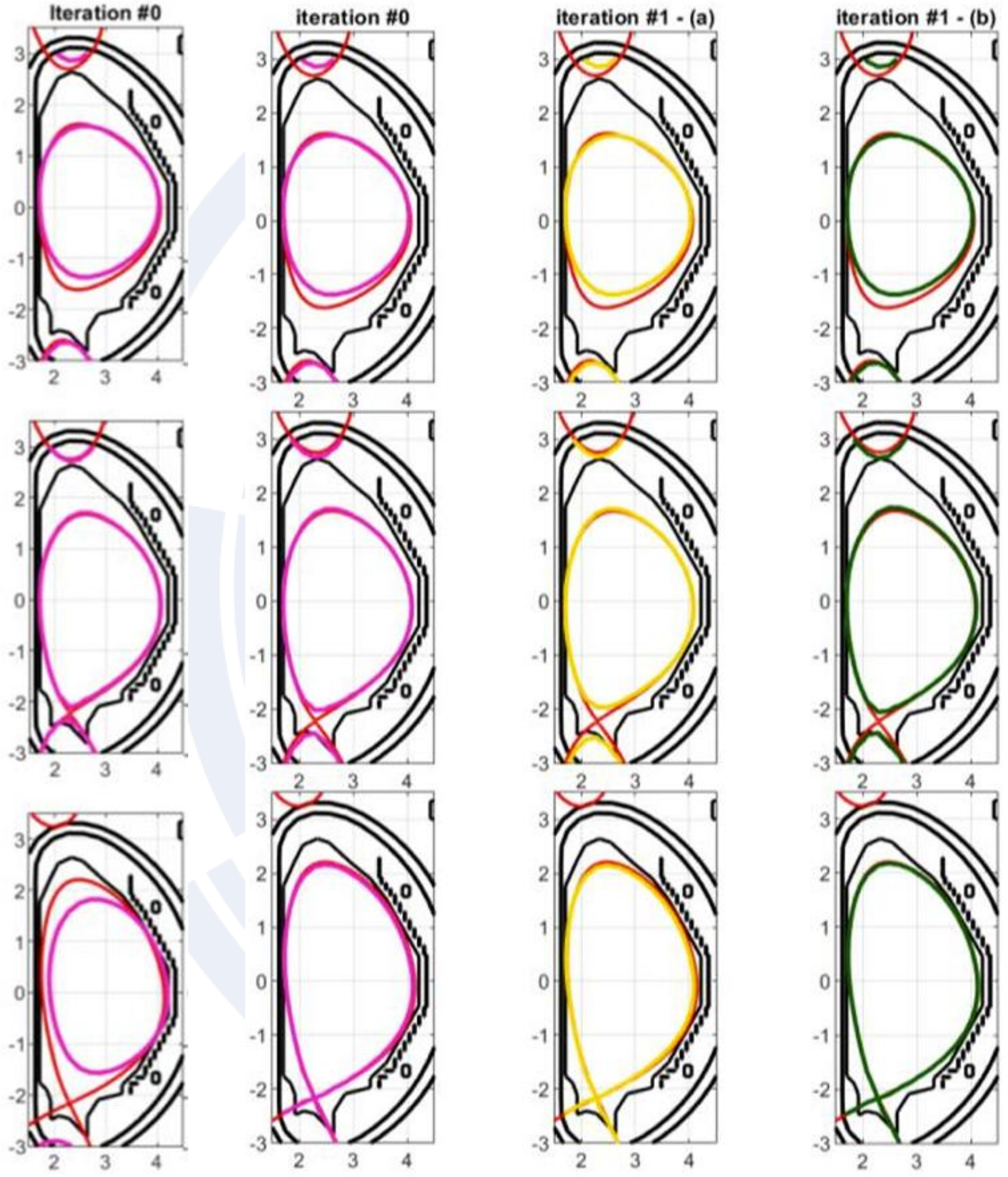


Operation-oriented tools: tools for breakdown and ramp-up optimizations

- The success of a ramp-up is strongly dependent on magnetic control, and in particular on the design of current and voltage waveforms.
- Model based intra-shot optimization tool based on iterative learning control.
- After a first model-based design obtained with classical tools, the scenario is corrected step by step solving a linearly constrained quadratic optimization problem which makes use of the results of previous experiments.
- Proved to be useful for the magnetic design of plasma initiation and early ramp-up scenarios, now extended to the full ramp-up
- The algorithm was modified to account for the beneficial contribution of closed loop control



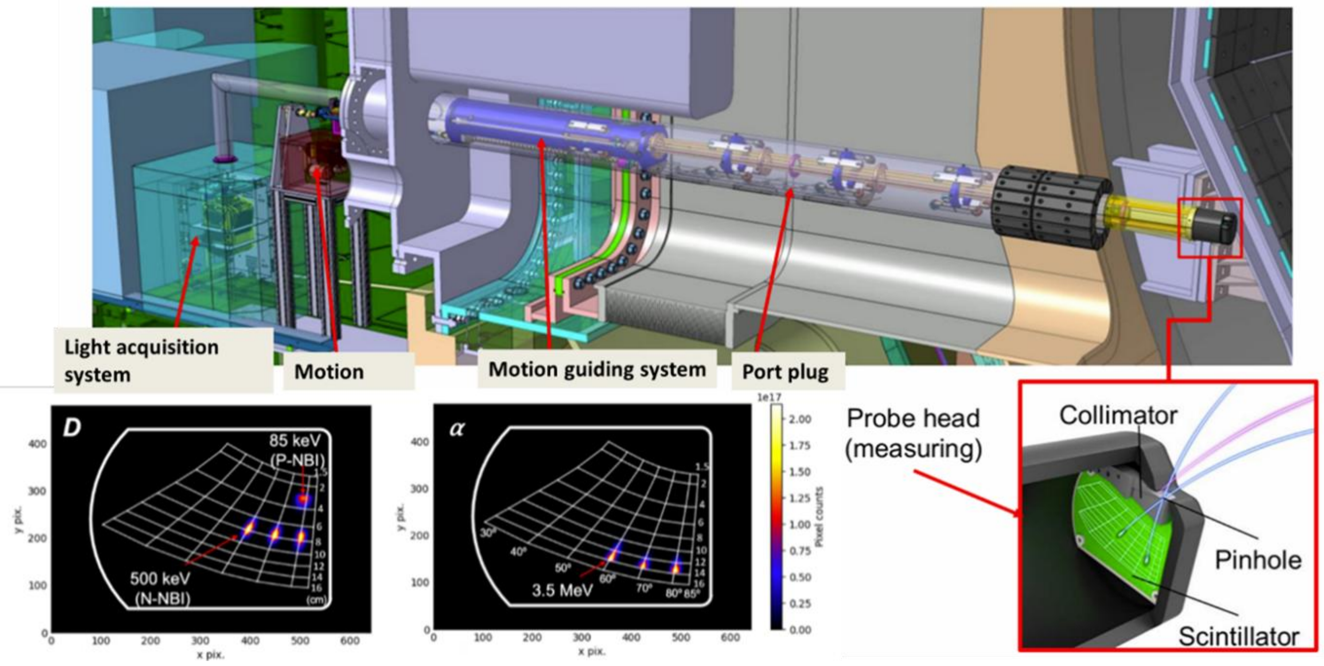
Mattei, IAEA-FEC 2025



Status at September 2025

- Development ongoing for
  - Doppler Reflectometry (CIEMAT: E. de la Luna, D. Carralero, T. [...]era José Martinez
  - Fast Ion Loss Detector (J. Ayllon Guerola and FILD team, Univ of Seville)
  - Gamma rays spectrometer (M. Nocente and GRS team, UNIMIB, ISTP-CNR, UKAEA)
  - Neutron spectrometer and Vertical Neutron Camera (M. Cecconello, J. Eriksson, A. Hjalmarsson (Uppsala) L.Swiderski, (NCBJ), D. Rigamonti (ISTP-CNR)
  - [TPCI S. Coda and K. Tanaka – Installation started]
- Under consideration
  - RE monitor (D.Marocco, B.Esposito ENEA)
  - Activation foils (Katarzyna Mikszuta-Michalik, IFPiLM)
  - EC stray radiation (H. Oosterbeek, J. Zimmermann IPP Greifswald, S. Garavaglia, A.Bruschi, F. Fanale ISTP-CNR)
- New diagnostics proposals being considered for feasibility

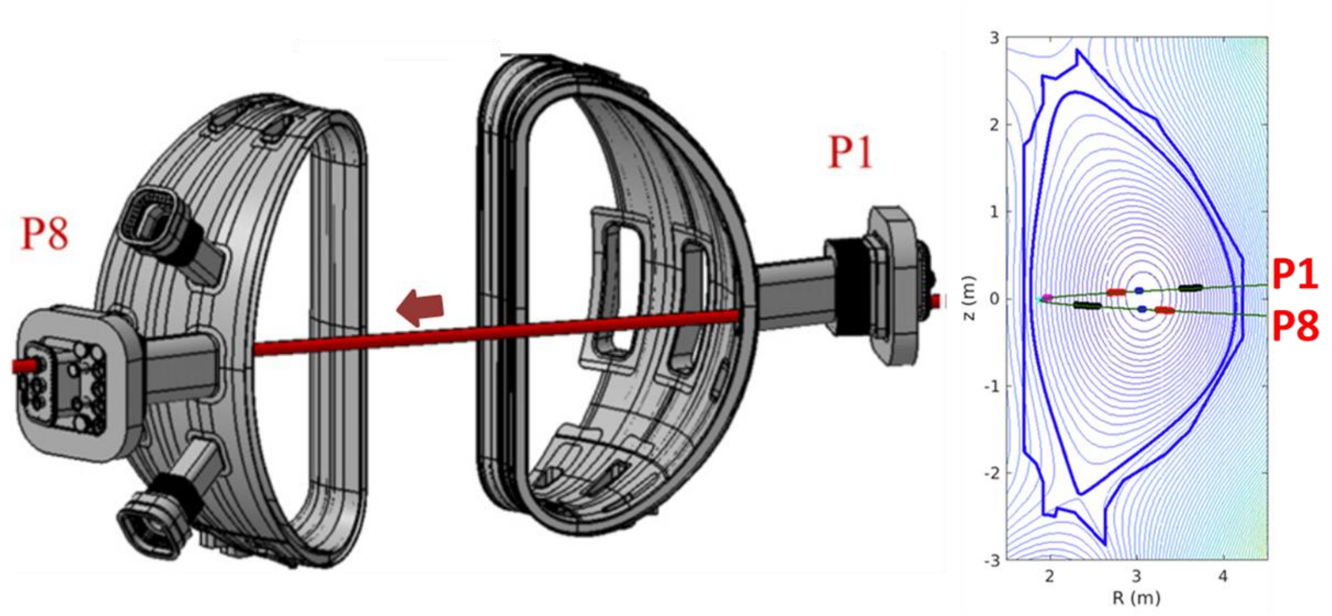
Fast-ion Loss Detector (FILD)



- measures unconfined fast ions escaping from the plasma (~toroidal magnetic asymmetry) using a detector head mounted on a reciprocating arm.
- FILD collects, collimates and disperses, exploiting the local magnetic field of the tokamak, the escaping ions onto a scintillator plate [5].
- The impinging position of the ions on the plate depends on their energy and pitch-angle ratio v_{perp}/v_{tot} =>information on their velocity-space
- optimized for the 500 keV injected by the N-NBI (measured with a resolution of <20 keV, <1º, < 1µs) but also detects the energy of P-NBI (85 keV) and 3.5 MeV fusion born alpha particles with no significant signal overlap observed [6].

Status: Fully designed except shielding, procurement on going (Inst. ME2)

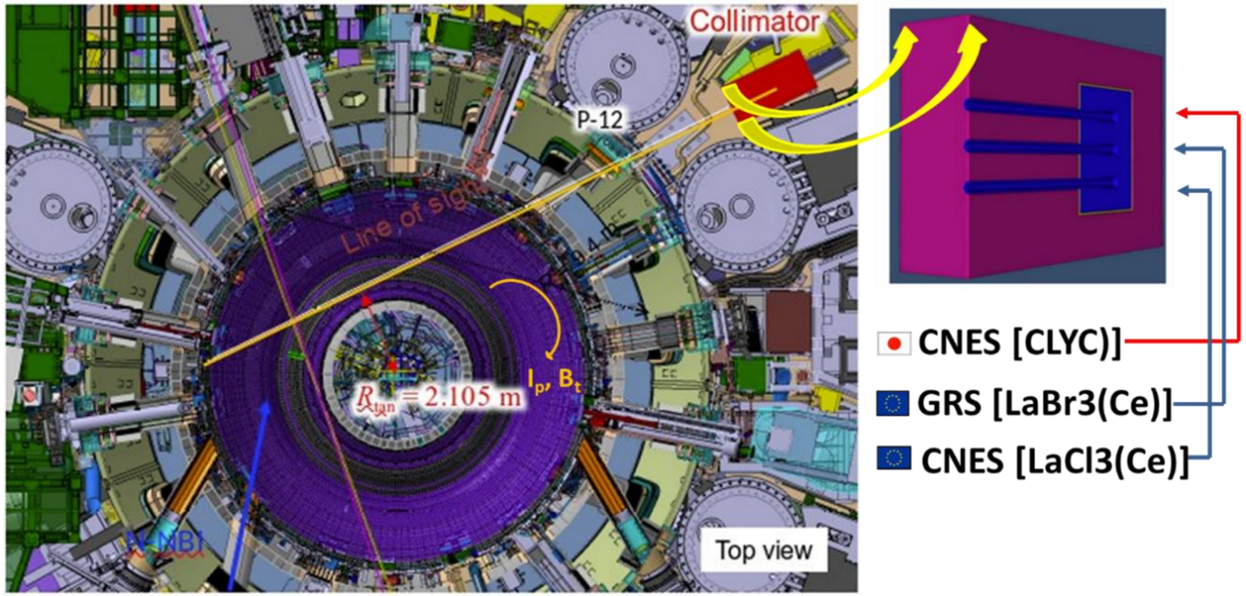
Tangential Phase-Contrast Imaging (TPCI)



- internal-reference laser-based interferometer that measures line-integrated density fluctuations
- tangential configuration with the laser beam having a quadruple pass across the plasma minor radius
- longitudinal localization by exploiting the twisting of the measured density fluctuations wave vector perpendicular to beam propagation and the local magnetic field
- radial localization of <0.1 of the minor radius in the core and high field side pedestal and ~0.35 elsewhere.
- sensitivity $\delta n/n \sim 10^{-5}$ [2].
- accessible wave-number range, $0.06 < k\rho_i < 12$ => ITG, TEM and marginally ETG

Status: partial ex-vessel installation started, procurement ongoing (Inst. ME2)

Neutron and Gamma deagnostics



Compact Neutron Energy Spectrometer (CNES)

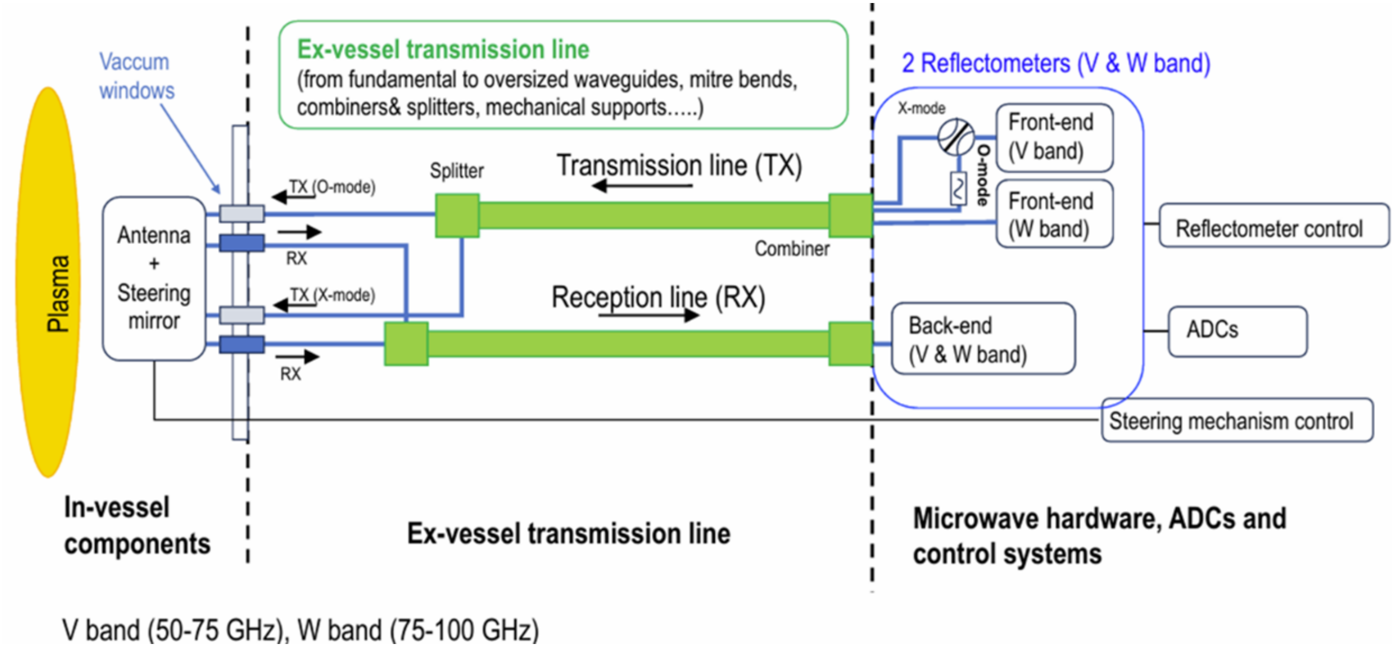
- based on $LaCl_3$ which has a fast scintillation decay time of 28 ns and is suitable for the high neutron rate (>100 kHz) expected in JT-60SA [8].
- Good neutron/gamma discrimination capability achievable applying a FFT based algorithm for pulse shape analysis [9]
- **Gamma Ray Spectrometer (GRS)**
- based on a 3''x6'' $LaBr_3$ detector [11] to measure runaway electrons bremsstrahlung emission in the MeV range,
- 5.5 MeV γ emission by the reaction of 500 keV fast protons provided by NNBI through the $p(d,\gamma)^3He$
- 16.4 MeV γ emission by the reaction of 500 keV deuteron with ^3He added to the plasma producing α particles through $^3He\ (D, \gamma)\ ^5Li \rightarrow\ ^4He+p$.
- α slowing down can be investigated via the γ emission produced for reactions with impurities such $^9Be(\alpha,n\gamma)^{12}C$ or $^{10}B(a,p\gamma)^{13}C$.

Vertical Neutron Camera (VNC)

- under consideration with access from the lower side of JT-60SA [7]. Aiming to detect changes in the neutron emission profiles related the redistribution of fast ions.

Status: Design ongoing, GRS planned for ME2, CNS for ME3

Doppler Reflectometry (DR)



- amplitude of local density fluctuations through the Bragg back-scattering of a probing oblique-propagating microwave beam at the density cut-off layer
- The incidence angle of the probing beam at the cut-off layer and its frequency determines the perpendicular wavenumber k⊥ of the detectable fluctuations [3]
- radial scan ($0.4<\rho<1$) realized changing the frequency of the incident wave
- velocity of the fluctuations perpendicular to the magnetic field can be measured by the frequency (Doppler) shift of the scattered wave.
- estimation of the phase velocity of the fluctuations => profiles of the radial electric field and of its radial shear
- spectrum of k⊥ obtained scanning the incidence angle [4]
- accessible range of wavenumber spectrum is $0.3<k_\perp\rho_i<5$, (ITG and TEM) physics,
- Resolution of $\Delta r \sim 1$cm, ~1ms for fluctuations flow velocity and ~1μs for amplitude fluctuations, spectral resolution of $\Delta k_\perp \sim 1 cm^{-1}$.

Status: detailed design started, planned for ME3

Proposals for Edge & SOL diagnostics (WPSA call in 2025)

- Accepted proposals
  - High-resolution visible overview camera with real-time and multispectral capabilities
  - MANTIS multispectral visible imaging
  - RE monitor
  - SOL-Pedestal Imaging Vacuum-Ultraviolet spectrometer
  - Thermal Helium Beam
  - EU-DEMO like real-time detachment control diagnostics for JT-60SA
  - Neutral Gas Analyser
  - Quartz Crystal Microbalances
  - Directional Electron Probe
  - Enhancement of the fast charge exchange spectroscopy
  - Collective Thomson Scattering

- Presently not supported proposals (for various reasons!)
- Deuterium beam emission spectroscopy (only basic support for further clarification assigned)
- Alkali beam emission spectroscopy
- Gas Puffing Imaging of turbulent structures
- Divertor Thomson Scattering

Objective of the new studies

- Feasibility study of the proposed diagnostic system (or upgrade of the already existing one)
  1. Specification/verification of the scientific outcome (measurement performance)
  2. Conceptual design (including selection of detector type, preliminary analysis, space reservation and main components definition).
  3. Preliminary layout in the JT-60SA environment
  4. Draft implementation plan (sequence of the activities to be accomplished)
  5. Draft evaluation of the costs (HRs, HW, other)
  6. Draft timeline
  7. Reliability for the transition to W (W traces experiments before transition, modifications afterwards,…)

- This phase is expected to be concluded in 2025 – Final report expected in December (January 2026)
- Deliverable: Feasibility report including the items in the previous list

Training and Synthetic Diagnostics and others

- Training opportunities
  - Pulse design simulator: training material being prepared, aiming to an user course in before mid 2026
  - High Energy Particles workflow (ready)
  - MHD stability workflow (ready)

- Synthetic diagnostics finalized or being completed
  - Edge Thomson Scattering
  - Div. VUV
  - FILD
  - TPCI
  - ECE and ECRH deposition tools

- Remote access re-established in September through IFERC network, not full access granted however
  - Raw data generally not accessible
  - Control PCs of diagnostics not accessible

Backup

2025 Grant milestones

GA Milestone No.	GA Milestone Title	Due Date [mm/yyyy]
SA.M.05	Participation to the development of scenario at high plasma current in H mode(1)	Dec. 2025 *

2025 Grant deliverables

GA Deliverable No.	GA Deliverable Title	Due Date [mm/yyyy]
SA.D.05	Delivery and final tests of EU-REC completed(2)	June 2024 *
SA.D.06	Installation of the EU systems before the OP2 campaign(3)	Dec. 2024
SA.D.07	Report on participation to the OP.2 campaign. Results and return of experience(1)	Dec. 2025 *
SA.D.10	Delivery of EU procurements (TBD) for the OP3 campaign completed(4)	Dec. 2025

(*)Milestones/Deliverables dependent on external conditions to which the workpackage is constrained, see Risk Table (WPR-04)

(1) To be cancelled in the next GA Amendment: The participation to scientific campaigns is moved to under WPTE.

(2) Expected delivery date is June 2025. Scope of this deliverable has been redefined. It includes:

- test of remote connection from an EU site with interaction with local systems (e.g. software maintenance of a passive diagnostics)
- test of the tools for data access and remote participation after the upgrade being performed within the JT-60SA project

(3) Installation of the EU lead systems (except Pellet Launching System) before the OP2 campaign will be performed, but the installation date is delayed according with the timeline of JT-60SA, therefore expected delivery date is December 2025.

(4) Installation of the EU lead systems for OP3 campaign is delayed according with the timeline of JT-60SA. Start of the OP3 campaign is presently foreseen in second half of 2027

Grant Agreement Milestones

Table 6-1: Grant Agreement Milestones

GA Milestone No.	GA Milestone Title	Due Date [mm/yyyy]
SA.M.01	Participation in the Integrated Commissioning before plasma operations	June 2021 √
SA.M.02	Start of the EU-REC project	Apr. 2022 √
SA.M.03	Decision on plan and resources of EU enhancements for BA Phase II – 2025-2029	June 2023 √
SA.M.04	Call to start EU enhancement programme for 2025-2029	Sept.2023 √ (1)
SA.M.05	Start of the new EU enhancement projects (TBD)	Nov. 2023 √ (2)
SA.M.06	Participation to the development of scenario at high plasma current in H-mode**	Dec. 2025*

- (*)Milestones dependent on external conditions to which the workpackage is constrained, see Risk Table (WPR-04)
- (**) To be cancelled in the next GA Amendment: The campaign participation is moved to under WPTE. Therefore this GM, closely connected to the operation of JT-60SA, shall be cancelled here. Since the operation will not happen before 2026 it is proposed to include this line in the extension of the GA under WPTE for 2026.

(1) Milestone completed in March 2024

(2) Milestone partially completed in July 2024. One system under the enhancement program (Neutron spectroscopy) required more preparation time. The call for the implementation of a second enhancement (EC stray radiation detection system) did not receive offers for implementation. Gamma rays, Doppler reflectometry, Fast Ion Losses Detection, Tangential Phase Contrast Imaging diagnostics proceed as planned (with minor delays not impacting the JT-60SA time plan)

Grant Agreement Deliverables

Table 6-2: Grant Agreement Deliverables

GA Deliverable No.	GA Deliverable Title	Due Date [mm/yyyy]
SA.D.01	Appointment of Experiment Leader from EU (after call issued end 2020)	Apr. 2021 √
SA.D.02	Report on the first phase of the Integrated Commissioning (before plasma operations). Results and return of experience, mainly for DTT	Dec. 2021 √
SA.D.03	Report on the initial organisation of the JT-60SA scientific exploitation	Dec. 2021 √
SA.D.04	Documented plan of EU enhancement programme for BA Phase II– 2025-2029	Dec. 2022 √
SA.D.05	Delivery and final tests of EU-REC completed	Jun. 2024 (1)
SA.D.06	Installation of the EU systems before the OP2 campaign.	Dec. 2024 (2)
SA.D.07	Report on participation to the OP.2 campaign. Results and return of experience	Dec 2025 (3)
SA.D.08	Final Report on the Integrated Commissioning (including plasma operations)	Dec. 2023√
SA.D.10	Delivery of EU procurements (TBD) for the OP3 campaign completed.	Dec. 2025* (4)

(*)Deliverables dependent on external conditions to which the workpackage is constrained, see Risk Table (WPR-04)

(1) Expected delivery date is June 2025. Scope of this deliverable has been redefined. It includes:

- test of remote connection from an EU site with interaction with local systems (e.g. software maintenance of a passive diagnostics)
- test of the tools for data access and remote participation after the upgrade being performed within the JT-60SA project

(2) Installation of the EU lead systems (except Pellet Launching System) before the OP2 campaign will be performed, but the installation date is delayed according with the timeline of JT-60SA, therefore expected delivery date is December 2025.

(3) This deliverable is dependent on external conditions to which the workpackage is constrained. OP2 campaign is delayed to 2026-27. Therefore it is proposed to be cancelled in the next GA Amendment: The campaign participation and all related work is moved to under WPTE. Therefore this GD, closely connected to the operation of JT-60SA, shall be cancelled here. Since the operation will not happen before 2026 it is proposed to include this line in the extension of the GA under WPTE for 2026.

(4) This deliverable is dependent on external conditions to which the workpackage is constrained. Start of the OP3 campaign is postponed to 2027.