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OVERVIEW OF THE EUROPEAN CONTRIBUTION TO THE DIAGNOSTIC EQUIPMENT OF JT-60SA FOR THE NEXT OPERATIONAL PHASE

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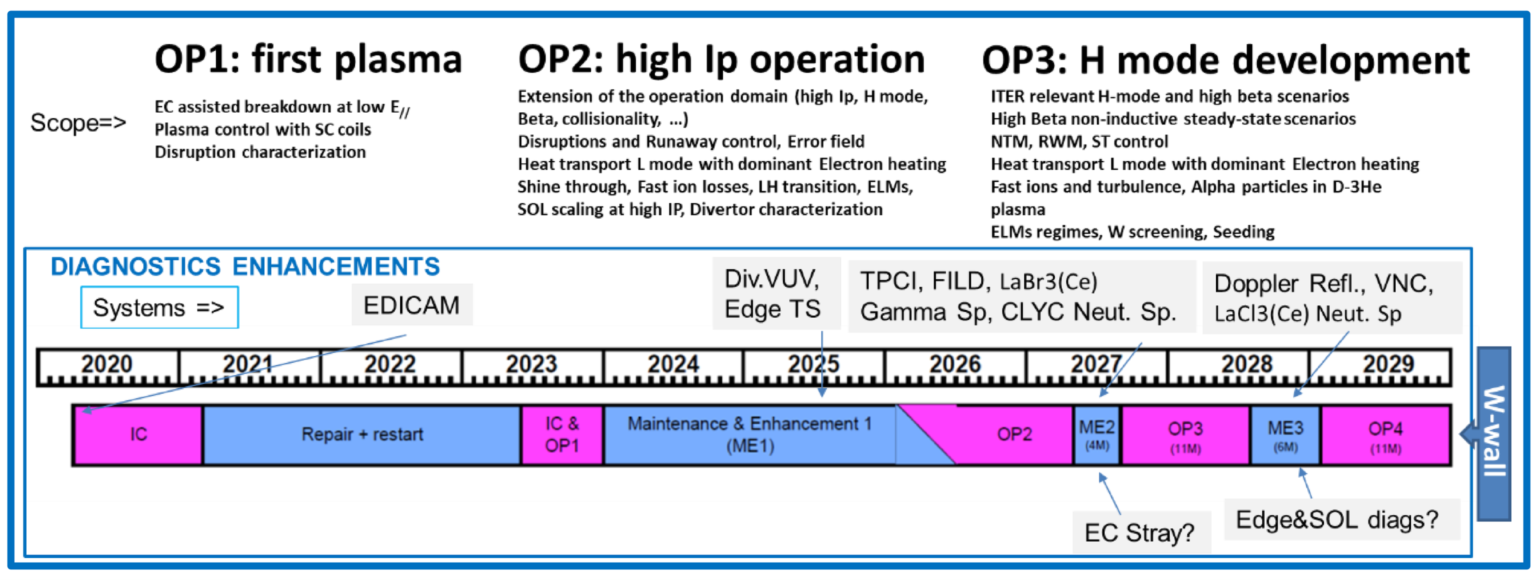
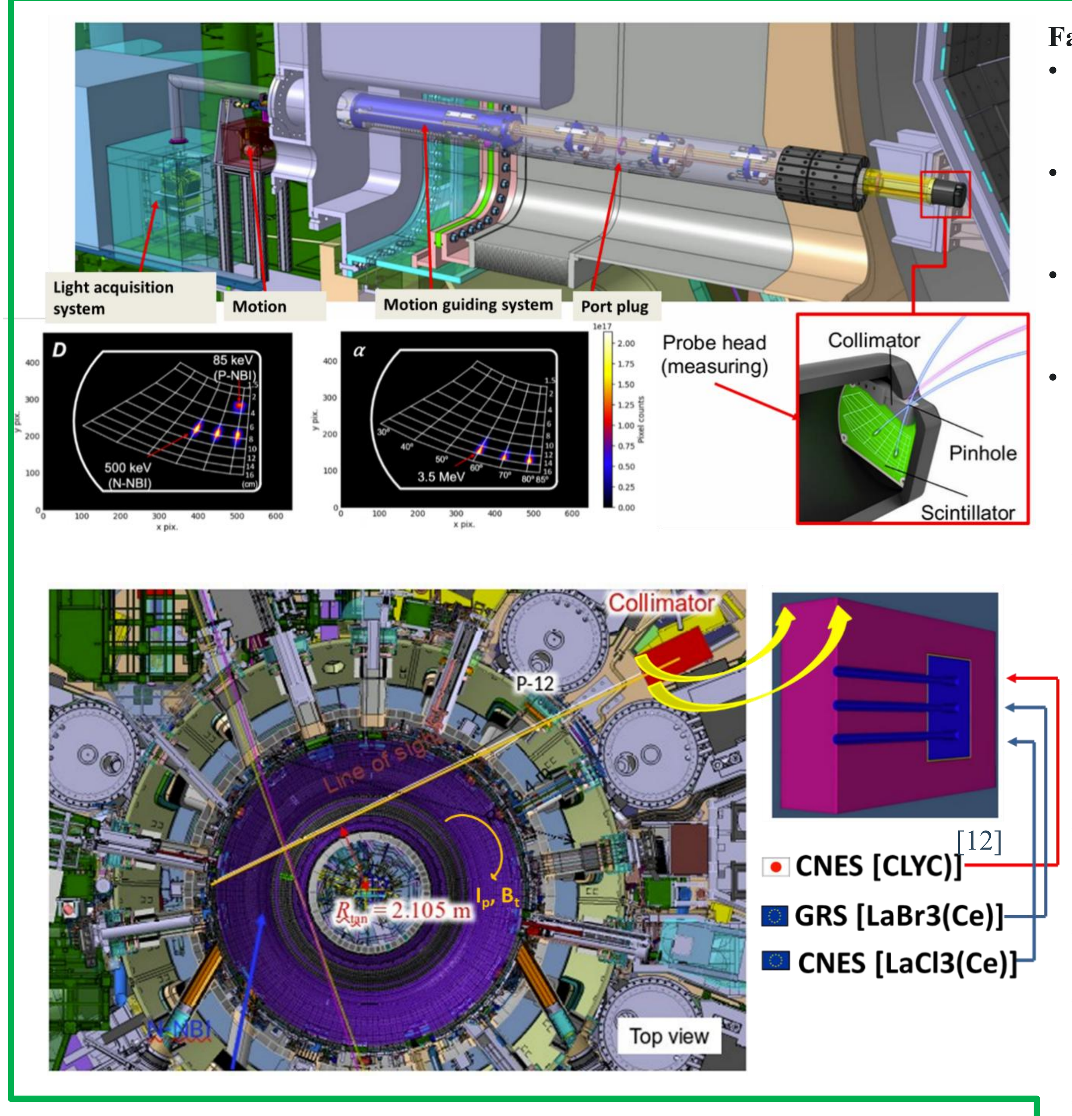
- JT-60SA is the highly shaped, largest superconducting tokamak in operation with unprecedented combination of features [1] in terms of plasma volume and current, additional heating including 3-frequency ECRF, 85 kV PNBI and 500 kV NNBI, and 100s pulse duration
- The main scientific purpose of JT-60SA is complementing ITER in the preparation of the operation of a DEMOnstration fusion reactor, in particular investigating the conditions for a controllable high beta steady-state regime able to optimize the fusion gain.
- In order to accomplish this task, a sequence of operation and machine enhancement periods in the next few years are planned to reach the target performance of the machine before a transition to a full tungsten wall.
- EUROfusion and Fusion for Energy are jointly contributing to the enhancement plan of JT-60SA, in particular, for what concerns the present contribution, to provide JT-60SA with state-of-art diagnostics in support of its scientific and technical objectives.
- This paper reports the status of the projects being implemented in view of the next scientific campaigns or under consideration through the various stages from feasibility to detailed design.



FAST PARTICLES



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].

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]

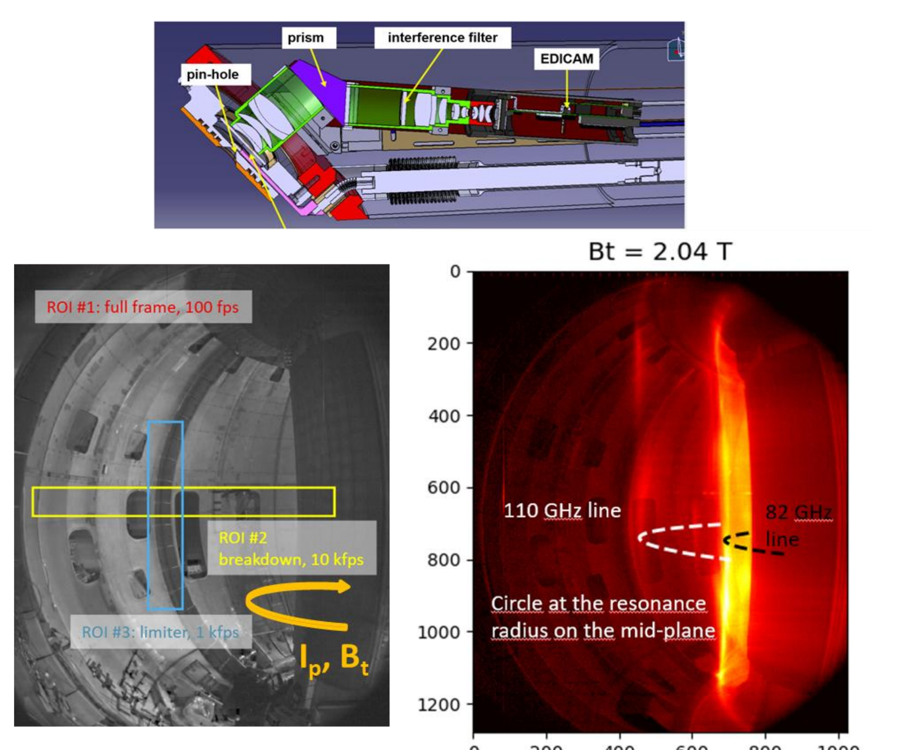
Gamma Ray Spectrometer (GRS)

- 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.

PLASMA OPERATION



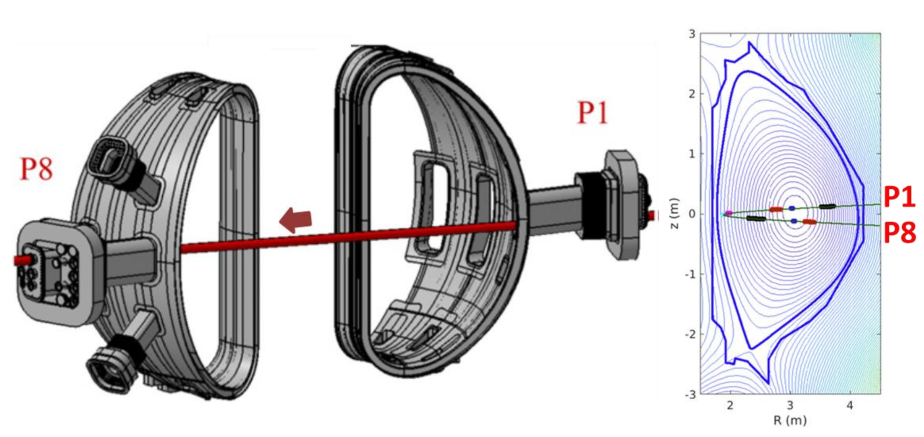
EDICAM

- wide-angle, 1280x1024 pixel C-MOS sensor video diagnostics sensitive to the visible spectrum with intelligent event detection capabilities
- non-destructive read-out capabilities and possibility of definition of regions of interest of reduced size. => simultaneous acquisition of fast-framing small regions (up to 20 kHz) and low framing (50-400Hz) full resolution images [17, 18].

EC Stray

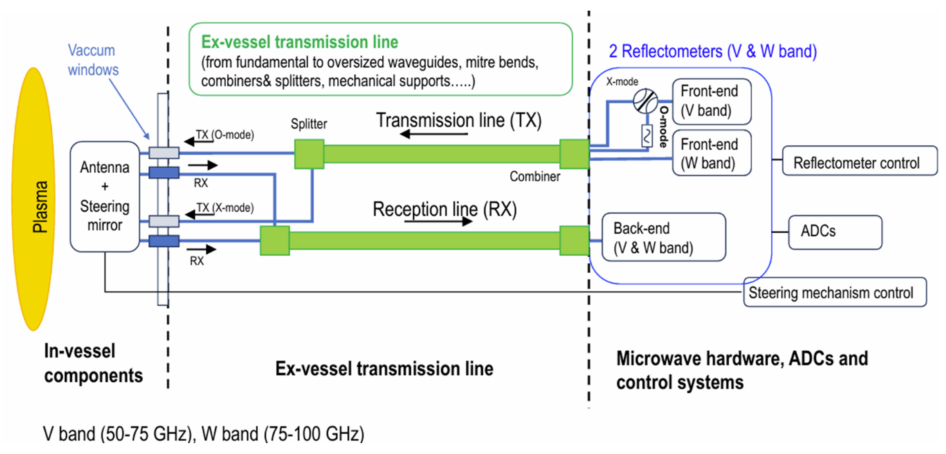
- radiation detector under development [19, 20] to assist the optimization of the ECRF operations, also in view of the increasing of the installed power and of the transition to the tungsten divertor and first wall.

TRANSPORT AND CONFINEMENT



Tangential Phase-Contrast Imaging (TPCI)

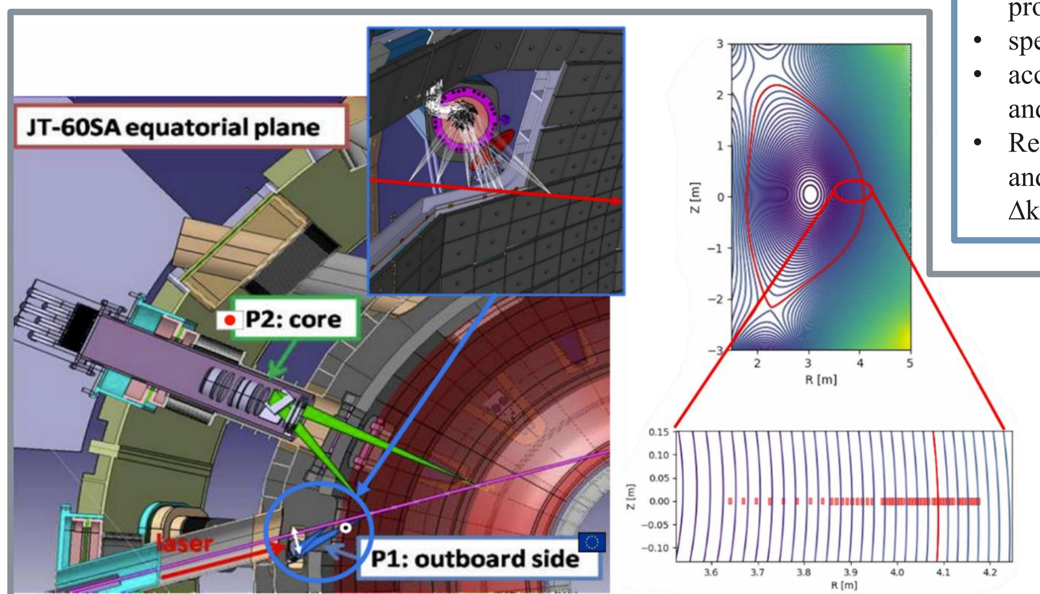
- internal-reference laser-based interferometer that measures line-integrated density fluctuations
- tangential configuration with the laser beam having a quadruple pass across the plasma minor radius
- longitudinal localization by exploiting the twisting of the measured density fluctuations wave vector 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



Doppler Reflectometry (DR)

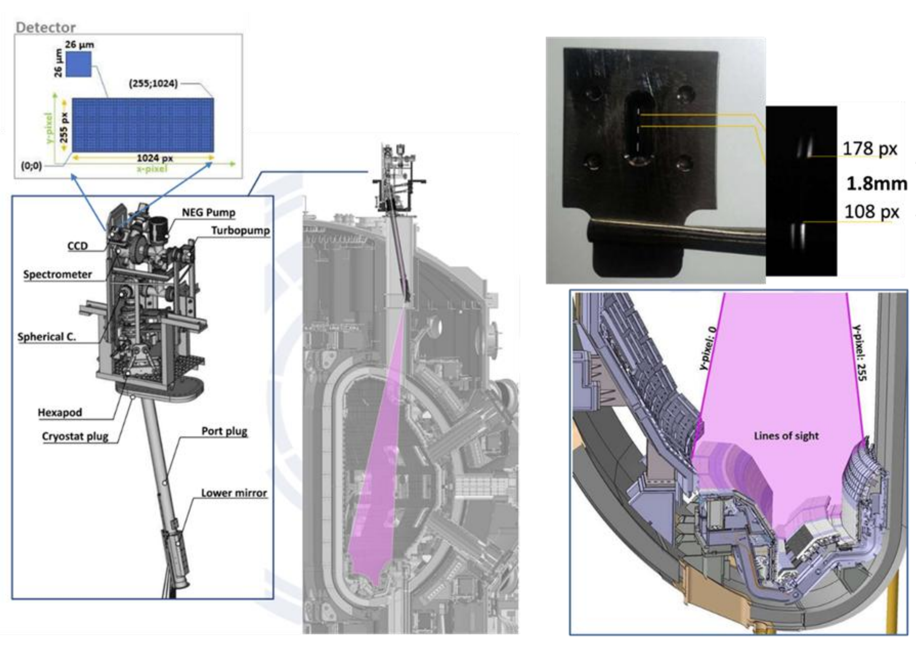
- amplitude of local density fluctuations through the Bragg back-scattering of a probing oblique-propagating microwave beam at the density cut-off layer
- The incidence angle of the probing beam at the cut-off layer and its frequency determines the perpendicular wavenumber k⊥ of the detectable fluctuations [3]
- radial scan (0.4<ρ<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 Δr~1cm, ~1ms for fluctuations flow velocity and ~1μs for amplitude fluctuations, spectral resolution of $\Delta k_\perp \sim 1cm^{-1}$.

PEDESTAL AND PLASMA WALL INTERACTION



Edge Thomson Scattering (ETS)

- measures electron temperature and density at 100 Hz rate with a dynamic range of 0.01-10keV at 50 radial positions in the low field side outer plasma region, R=3.7-4.17m [13]
- Light of a 1064 nm Nd:YAG diode-pumped laser scattered by the plasma electrons collected from another port, imaged into fiber bundles by a collection optics and spectrally analyzed using polychromators.
- Intensity ~ plasma density,
- Doppler broadening of the frequency ~plasma temperature.
- The spatial resolution from 25 to 5.5mm core to edge
- detailed studies of the pedestal region where the density and temperature gradients increases and across the separatrix.
- At the most unfavourable limit of the expected density ($1x10^{19}m^{-3}$) the relative measurement errors are always <12% for T_e and <6% for n_e but significantly decrease (<4% and <2% respectively) for R<4.10m where the density is higher [14].



Vacuum UltraViolet Divertor (DivVUV)

- spectroscopy system aiming to track intrinsic and extrinsic impurity species [15]
- two wavelength ranges 10-48nm and 44-125nm with resolution respectively of 0.08nm and 0.14nm.
- signals from D, He and C, N, Ne, Ar, Cr, Fe, Ni impurities.

- The core of the spectrometer are two toroidal gratings fed by two pairs of mirrors (lower pair: cylindrical; upper pair: toroidal) which redirect the light emitted from the divertor region towards the pair of 225x1024 pixel detector of the CCD cameras optimized for the VUV range [16].
- 1-D imaging capability with spectra preserving information about the spatial distribution of the sources with enough resolution to distinguish the emission from the X point, inner and outer strike points on the divertor.
- When the spectrometers are operated in imaging mode, in the plane of the CCD detector one axis represents the wavelength and the second the position.
- For low signals or high acquisition rate the spectrometers can be used in binning mode adding up all the spectra on a single detector line (time resolution of ~0.5 kHz suitable for detachment studies)

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