Planning for future diagnostics enhancements

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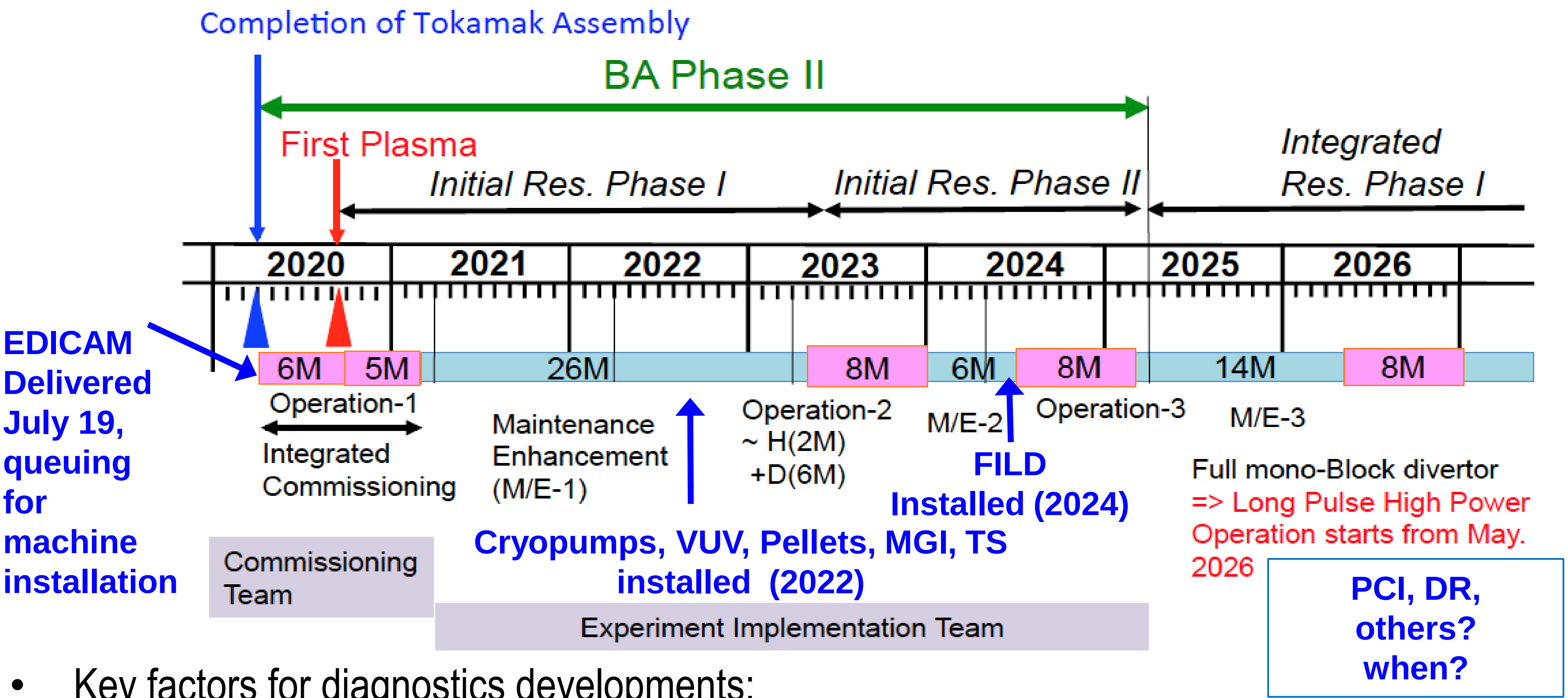
JT-60SA timeline



- Key factors for diagnostics developments:
  - Machine capabilities (plasma current, additional power, pulse duration,…) and scientific objectives focused in the various campaigns according with EU strategic priorities
  - Transition C-W (~2029 in the present schedule, but planning revisions ongoing)
  - ITER research plan and needs
  - Overall support for diagnostics enhancements and enhancements in general (funding, know-how availability etc.); but also for diagnostics operation and scientific exploitation
- New proposals to be addressed through the Experiment Team (after the end of the IC)
- Time scale for a new diagnostics ~ 3-5 years

More on completed diagnostics studies:
https://users.euro-fusion.org/iterphysicswiki/index.php/Annual_reports_for_EUROfusion

Planned diagnostics in JT-60SA

Section	Port	Use	Comments
P-1	Horizontal	CO2 Laser interferometer (tangential) CO2 Laser polarimeter (tangential) YAG laser Thomson scattering Zeff monitor (visible spectrometer)	CCR CCR Laser injection
	L-Oblique	YAG laser Thomson scattering (edge)	Optics
P-2	Horizontal	YAG laser Thomson scattering (core) CXRS (toroidal, BG)	Optics
P-4	L-Oblique	D_α emission monitor	
P-5	Horizontal	CXRS (toroidal)	
P-6	Upper	Visible spectrometer for divertor	
	Horizontal	Neutron monitor Infrared TV camera (main) CXRS (poloidal, BG) Visible TV camera (+ light guide)	co, endoscope co, endoscope
	Lower	Visible spectrometer for divertor	
P-7	Horizontal	CXRS (poloidal)	
P-8	Horizontal	CO2 Laser interferometer (tangential) CO2 Laser polarimeter (tangential) YAG laser Thomson scattering Zeff monitor (visible spectrometer) Penning spectroscopy	Laser injection Laser injection Beam dump
P-9	Horizontal	TESPEL	
P-10	Horizontal	Neutron monitor VUV Spectrometer Crystal spectrometer	
P-11	Horizontal	Electron cyclotron emission diagnostics	
P-12	Upper	VUV spectrometer for divertor	
P-14	Upper U-oblique Horizontal	Soft X-ray detector array Soft X-ray detector array Soft X-ray detector array	 Modified chord

T_e meas in FPO

Section	Port	Use	Comments
P-15	Horizontal	Visible TV cameras (+ two light guide)	Two sets (co, ctr)
P-16	Lower	Bolometer	
P-17	Horizontal	Motional Stark Effect polarimeter	
P-18	Upper	Bolometer	
	Horizontal	Neutron monitor Visible TV camera (+ light guide) Bolometer EDICAM (+ light guide)	 ctr co
P-3,4,9,15		Langmuir probes on lower divertor	

Magnetic measurements

Type	Measurement	Number	Channel	Purpose
Magnetic probe for Plasma control	Poloidal magnetic field	90 (45(pol) x 2(tor)) (1) in FPO	90	Equilibrium reconstruction and plasma control. Low frequency MHD mode.
Magnetic probe for RWM control	Poloidal and radial magnetic field	108 (18(pol) x 6(tor))	216 (biaxial)	RWM control
Magnetic probe for MHD	Poloidal magnetic perturbation	72 (32(pol) x 2(tor) + 8)	72	MHD mode measurement
Rogowski loop	Plasma current	3 sets	7	One loop around the vacuum vessel
Oneturn loop	Poloidal flux	24	24	Equilibrium reconstruction and plasma control
Diamagnetic loop	Diamagnetic flux	4 sets	8	Plasma stored energy
Saddle coil	Radial magnetic field	36 (18x2)	36	Rotation and non rotating MHD
Halo current	21(TBD)	21(TBD)	21(TBD)	
Total			438	

- In red: available for IC-FPO
- In black: available for PO-2, PO-3
- Port allocation *in some extent* to be completed ***(t.b.c)***
- *Fast Ion Loss Detector (P-15 eq. below midplane)*
- *Phase Contrast Imaging (P-1/P-8 eq.)*
- *Doppler Reflectometer (P-18 eq.)*

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

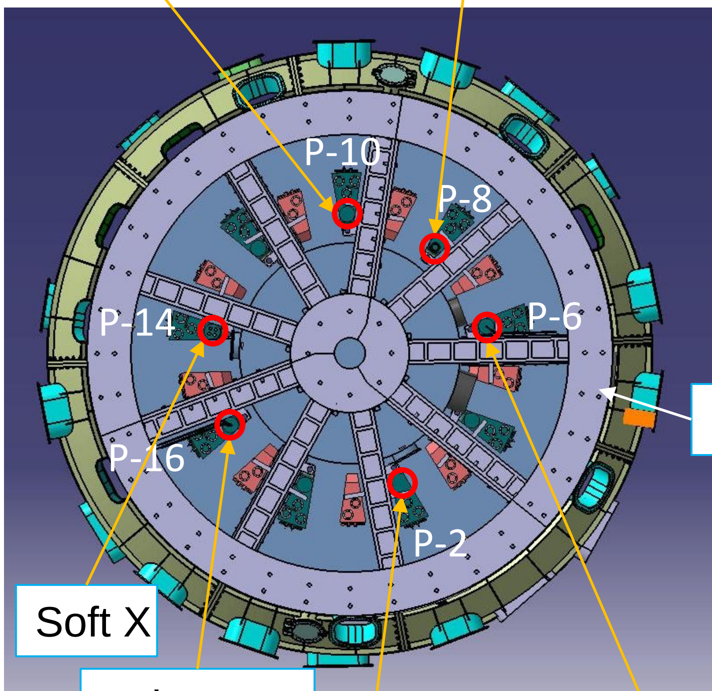
N. Oyama & PID 4.0

Port allocation

Lower diagnostics ports

Reciprocating material probe (TBD)

CO2 Laser interferometer
/polarimeter, neutral pressu



Soft X

Bolometer

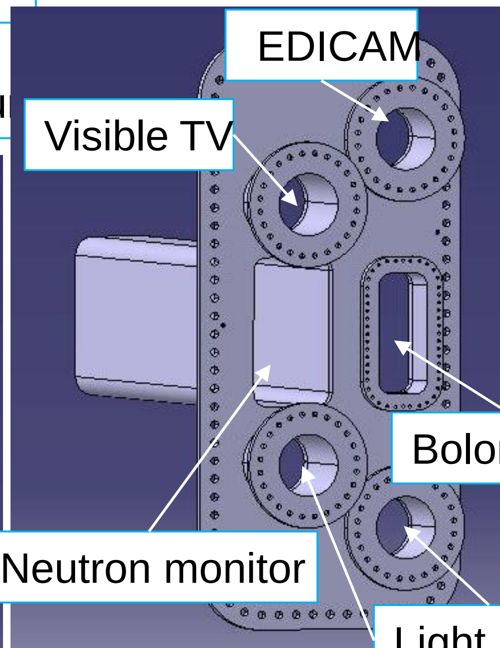
Visible spectrometer for divertor

Divertor Thomson (TBD)

Diagnostics Flange (P-18)

EDICAM

Visible TV



Bolometer

Neutron monitor

Light
guide

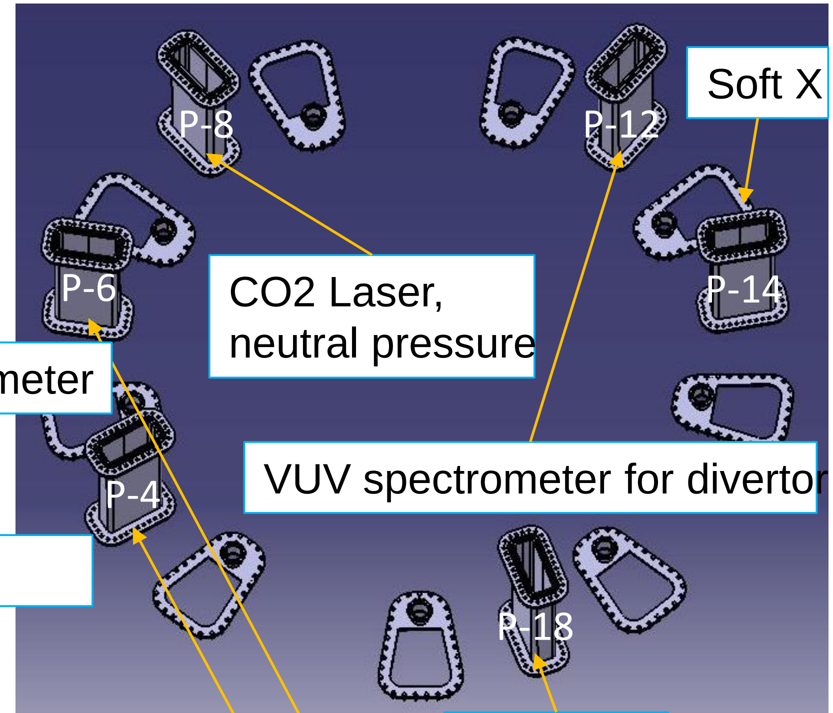
Reflectometer(TBD)

LiBp(TBD)

Infrared TV for divertor (TBD)

Upper diagnostics ports

Soft X



CO2 Laser,
neutral pressure

VUV spectrometer for divertor

Bolometer

Visible spectrometer for divertor

Neutral particle analyzer
Neutron emission profile monitor

Advanced Superconducting Tokamak
BA-Satellite Tokamak Program

N. Oyama & PID 4.0

To which direction new diagnostic proposals should aim?

ITER expression of interest From I/O (T.Luce, R.Pitts)

Topic	IO Need	JT-60SA Data
Plasma Startup	2023	2020
Alignment of B and First Wall	2023 or 2025	2021, 2025
EC Wall Conditioning	2027	2021, 2023
Hydrogen H mode	2027	2023
Vertical Position Control	2027	2023, 2027
Prototype Magnetics	2023	2021, 2028
NB Shinethrough	2023 or 2029	2023, 2025
Third Harmonic EC Heating	2027	2023, 2027
IMAS use	2023	2021
Protocol for Error Field Correction	2027	2023, 2027
Commissioning of Magnets	2023	2021, 2023
Cryoplant Commissioning	2020	2020
Integrated Commissioning	2023	2020
Vacuum Prep/Wall Conditioning	2023	2020
Simulation Code Validation	2023	2021, 2023
SPI or Alternate DMS Tests	2022 or 2027	?

- Specific areas of interest to ITER for first JT-60SA campaigns
  - First wall alignment, start-up, conditioning
  - Disruption loads and mitigation
  - H-modes, ELM control, plasma magnetic control, NBI shine-through

EU Scientific Priorities

1. Development and investigation of high performance **scenarios compatible with future W-PFCs.**
2. Avoidance and mitigation of **disruptions and runaways**,
3. **Fast ion physics**,
4. Development and validation of high level **real-time control strategies.**

- ECH (assisted plasma iniziation, Wall conditioning, 3rd Harmonics ECH for H mode)
- Disruptions
- Heat flux measurements on PFCs

Required R&D in existing fusion facilities to support the ITER Research Plan (see: ITER IDM ITER_D_XAKZLX)

System/ Issue	Required R&D	Category 1=major 2=medium 3=optimization	Required experimental facilities	Comment	Phase when system required/ Most impacted Phase
Radiant Tolerant Detectors	Demonstrate of compact long life detectors for x-ray and VUV	2	x-ray sources combined with neutron and gamma ray sources	Extend the operating capability and availability of these systems	PFPO-2 (2032)
Neutron Detector development	Compact solid state long life radiation tolerant neutron detector development for in port and in-vessel e.g. advanced self powered neutron detectors	2	neutron laboratory	Extend the operating capability and availability of these systems	PFPO-2 (2032)
Polarimetric Thomson Scattering	Demonstration of a working Polarimetric Thomson Scattering on a high temperature device.	2	High temperature plasma device >10keV	Extend the dynamic range in temperature of a classic Thomson scattering system	PFPO-2 (2032)
X-ray optics	Develop x-ray reflection systems to allow extended spatial coverage and reduce neutron transmission.	2	X-ray optics laboratory and access to a facility to test the components	Extend the spatial coverage and detector lifetime	PFPO-2 (2032)
Two Wavelength Thomson scattering	Demonstration of a working 2-wavelength Thomson Scattering system on a high temperature device.	2	Experience in Thomson scattering as well as appropriate facilities such as high electron temperature device and suitable experts	Extend the dynamic range in temperature of a classic Thomson scattering system and enable an auto-calibration procedure	PFPO-1 (2028)

Diagnostics for disruption studies

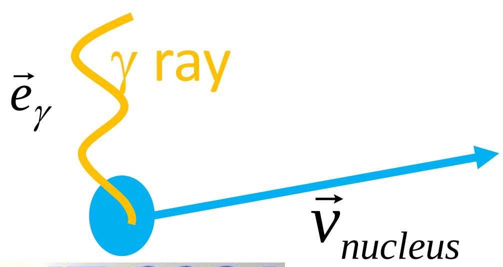
- Assessment performed in 2015(?) by G Pautasso (IPP-Garching), P de Vries (ITER IO) , F P Orsitto (ENEA Frascati) https://users.jt60sa.org/?uid=26K4CU

Diagnostics for disruption studies		
category	**measurement**	**comment**
Mechanical loads	toroidal vessel current	4 sectors 90° apart
Mechanical loads	halo current (shunts or Rogowski)	4 sectors 90° apart
Mechanical loads	strain-gauges and position sensors	
Magnetics	arrays of poloidal magnetic coils and localized flux measurements for equilibrium reconstruction (1kHz)	4 sectors 90° apart
Magnetics	MHD (100kHz)	
Magnetics	Saddle coils for locked mode	4 sectors 90° apart
Thermal loads	thermography cameras (wall and divertor)	
Radiation	Fast AXUV diode arrays for tomographic reconstruction	
Radiation	Fast CCD camera with selective filters for ionization stages	
Radiation	Foil-bolometer cameras for radiated power fraction	at least 2 sectors
Radiation	fast spectrometer	
runaway electrons	Hard-X ray cameras	
runaway electrons	IR/Visible cameras with counter tangential view for synchrotron radiation	
density	interferometer/polarimeter chords able to measure fast variation of electron density	

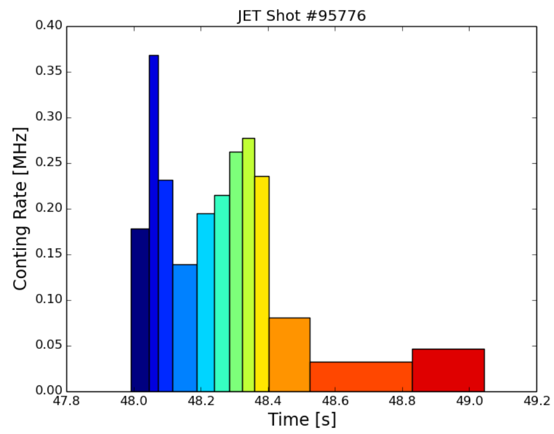
Gamma measurements

- γ-rays are produced by nuclear reactions between fast ions and impurities
- They can be produced in fusion reactions (I step reaction)
  - $d + p \rightarrow {}^{3}He + \gamma$ (5.5 MeV)
- or result from the de-excitation of a nucleus (II step reaction)
  - $\alpha + {}^{9}Be \rightarrow {}^{12}C^{*} + n$,
  - ${}^{12}C^{*} \rightarrow {}^{12}C + \gamma$ (4.44 MeV)

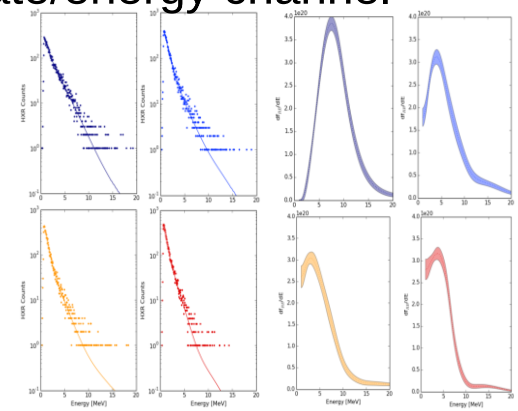
- Diagnostic information of increasing detail:
  - Reaction assessment (peak energy identification)
  - Temperature of fast ions (spectroscopy),
  - Effect of MHD instabilities (count rate)
  - Spatial distribution of the fast ions (multiple lines of sight)
- Measurements of the bremsstrahlung radiation spectrum in the MeV range also give information on the RE distribution function



Counting rate

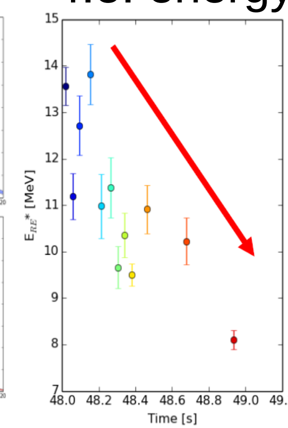


γ-Rate/energy channel



γ-spectrum

r.e. energy



Gamma measurements /2

Possible useful reactions for proton & deuteron studies (500 KeV NBI) have been identified

- Sector P4, upper:
  - NPA, neutron and γ-ray profile monitors
  - An efficient γ-ray spectrometer (MeV gammas) could be installed behind of NPA, as in ITER
- Sector P8, horizontal:
  - NPA
  - An efficient γ-ray spectrometer (MeV gammas) could be installed behind of NPA, as in ITER
- Sector P10, horizontal:
  - neutron and γ-ray profile monitors

- In the neutron profile monitor the γ-ray detectors could be setup (1) with independent collimators (a favourable option); (2) on slider in front of neutron detectors as on JET (a restricted use of the diagnostics)
- Behind NPA a large volume (high efficiency) γ-ray detectors could be useful
- On JET, we use $LaBr_3$ and $CeBr_3$ fast scintillators that provide high energy/time resolution at several MHz count rate
- $CeBr_3$-detector could be a favourable option for JT60SA

(Existed diagnostics, Table D-6 on pp.148-150, are in blue; proposed – in red)

Developed for the JET *Gamma-ray Camera Upgrade* project

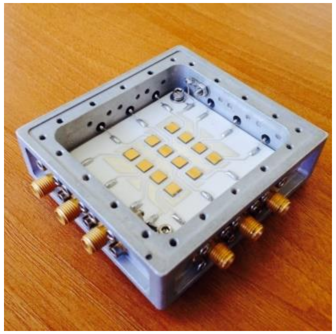
- Fast (≈ 200 ns FWHM)
- Compact (1”x1”)
- Insensitive to magnetic fields
- Can be placed in an already existing neutron camera

M. Nocente et al. UNIMIB, M.Tardocchi, E.Perelli-Cippo et al. ISTP-CNR, V. Kiptily CCFE

Compact neutron spectrometers

- Main application of neutron spectrometry at JT-60SA:
  - studies of the deuterium population (eg. D-NBI, thermal/non-th. neutron fraction)
  - Valuable (even though more limited wrt ToF sp.) information on the neutron spectrum can also be gained with relatively inexpensive compact spectrometers, at least as exploratory instruments for the initial phases.

VNS matrix at JET



JET standalone oblique diamond detector

- Development of a matrix of synthetic ***diamond detectors*** at JET (VNS project) as well as standalone detectors
  - **Main application at JT60-SA:** integration in the ***neutron camera***
- ***Liquid scintillator detectors***
  - *more limited energy resolution w.r.t. diamonds but*
  - ***higher sensitivity*** *for applications at* ***low neutron yields***
- ***New concept detectors (CLYC-7)***
  - *Very new technology. Higher sensitivity than liquids and* ***improved neutron/gamma-ray discrimination****. Good for* ***low neutron yields****. Soon to be tested at EAST.*

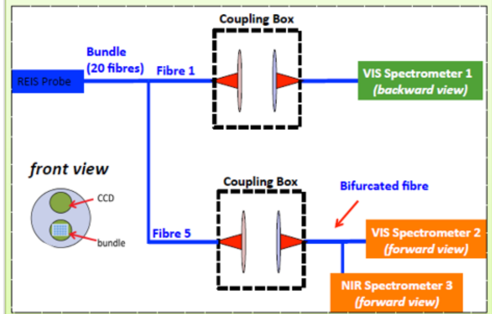
Runaway Electron Imaging and Spectrometry System

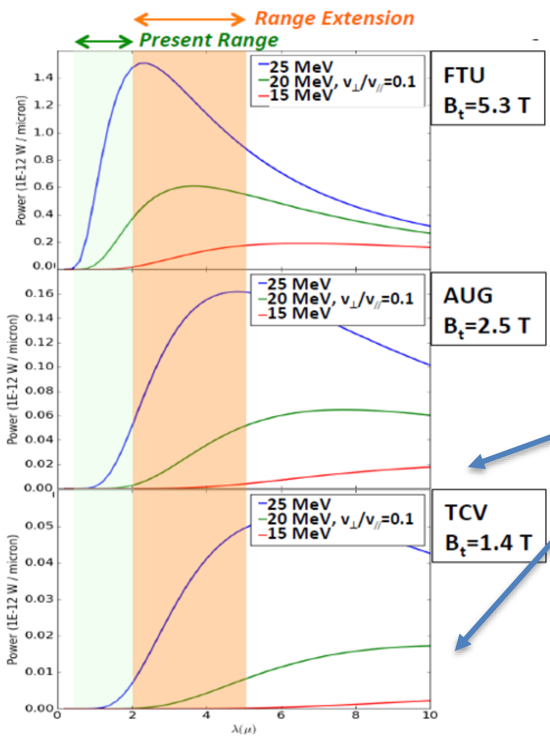
B.Esposito, F.Causa et al.

- Runaway Electron Imaging and Spectrometry System (REIS) was developed to measure synchrotron radiation spectra from in-flight, confined runaway electrons in tokamaks.
- The REIS is a wide-angle optical system collecting simultaneously visible and infrared emission spectra using an incoherent bundle of fibers, in a spectral range (VIS+NIR) that spans from 500 nm to 2500 nm, and visible images using a CCD color microcamera at a rate of 25 frames/s.

Wide-angle lens coupled to CCD camera (**Imaging**) and to visible (VIS) and near-infrared (NIR) spectrometers through an incoherent bundle of fibres (**Spectrometry**)

→ Measurement of synchrotron radiation (***RE Forward*** *and* ***Backward*** views)

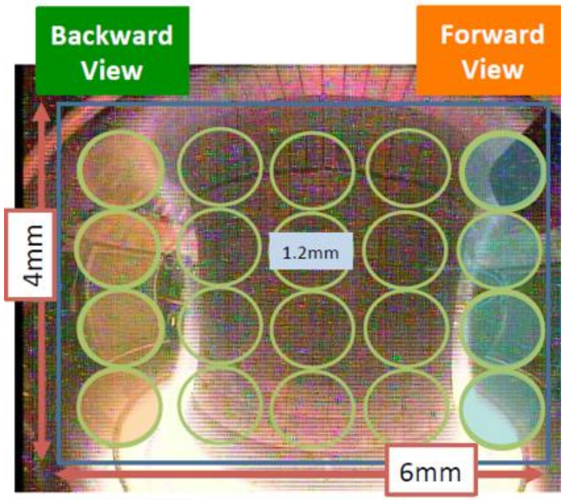


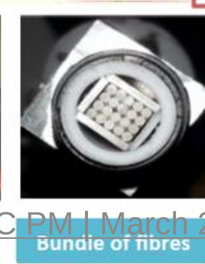


- The emission spectra depends on electron energy, pitch angle, and magnetic field intensity. total synchrotron power

$$P = \frac{e^4}{6\pi\epsilon_0 m_e^2 c} p_\perp^2 B^2 \propto p_\perp^2 B^2 \propto p^2 B^3$$

- Extension of the spectrum to 5000 nm is feasible (relevant for JT-60SA)
- The REIS is a portable system developed for use in medium size tokamaks
- Physics Mission: obtain information on RE energy distribution function





Diagnostics for ECRF stray detection

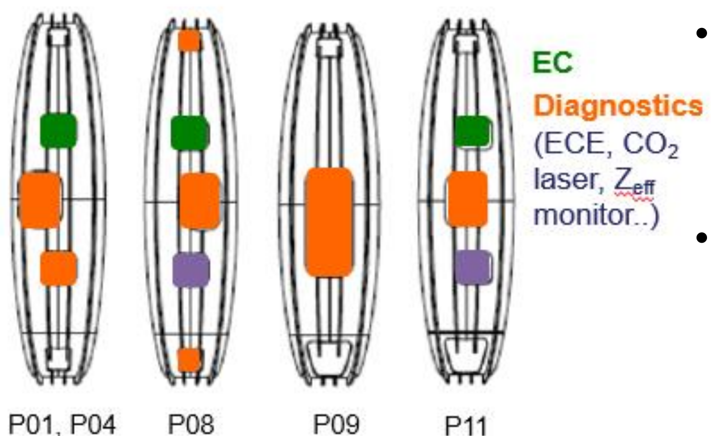
A.Moro, C.Sozzi, L.Figini

Residual cross polarized fraction (5%) at 5 keV plasma temperature

(kW/m² per 1MW injected beam)	peak incident power density (scen 2)		estimated peak absorbed power density on CFC (scen 2)		peak incident power density (scen 4)		estimated peak absorbed power density on CFC (scen 4)		duration
poloidal angle	1st bounce	2nd bounce	1st bounce	2nd bounce	1st bounce	2nd bounce	1st bounce	2nd bounce	
0	508.50	18.68	45.26	1.66	1017.00	99.60	90.51	8.86	pulse length
-20	375.00	10.75	33.38	0.96	70.50	6.06	6.27	0.54	
-35.5	334.50	41.40	29.77	3.68	61.33	13.41	5.46	1.19	

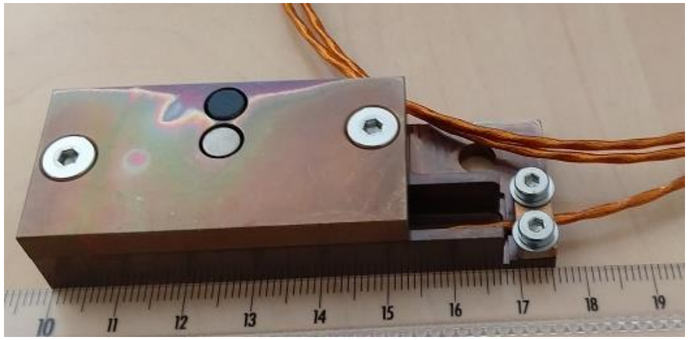
Low absorption scenario at low plasma temperature (50 eV)

(kW/m² per 1MW injected beam)	peak incident power density (scen 2)		estimated peak absorbed power density on CFC (scen 2)		peak incident power density (scen 4)		estimated peak absorbed power density on CFC (scen 4)		duration
poloidal angle	1st bounce	2nd bounce	1st bounce	2nd bounce	1st bounce	2nd bounce	1st bounce	2nd bounce	
0	6780.00	16.60	603.42	1.48	16950.00	1660.00	1508.55	147.74	1-1000 ms
-20	3000.00	8.60	267.00	0.77	9000.00	180.60	801.00	16.07	
-35.5	669.00	0.28	59.54	0.02	3345.00	276.00	297.71	24.56	



Risky areas

- Sensor to monitor ECH stray radiation level in vessel (being developed for ITER)
- 2 bolometers (ECH absorbing/reflecting) connected to a differential thermocouple
- Connected to standard twisted copper pair
- Facing plasma

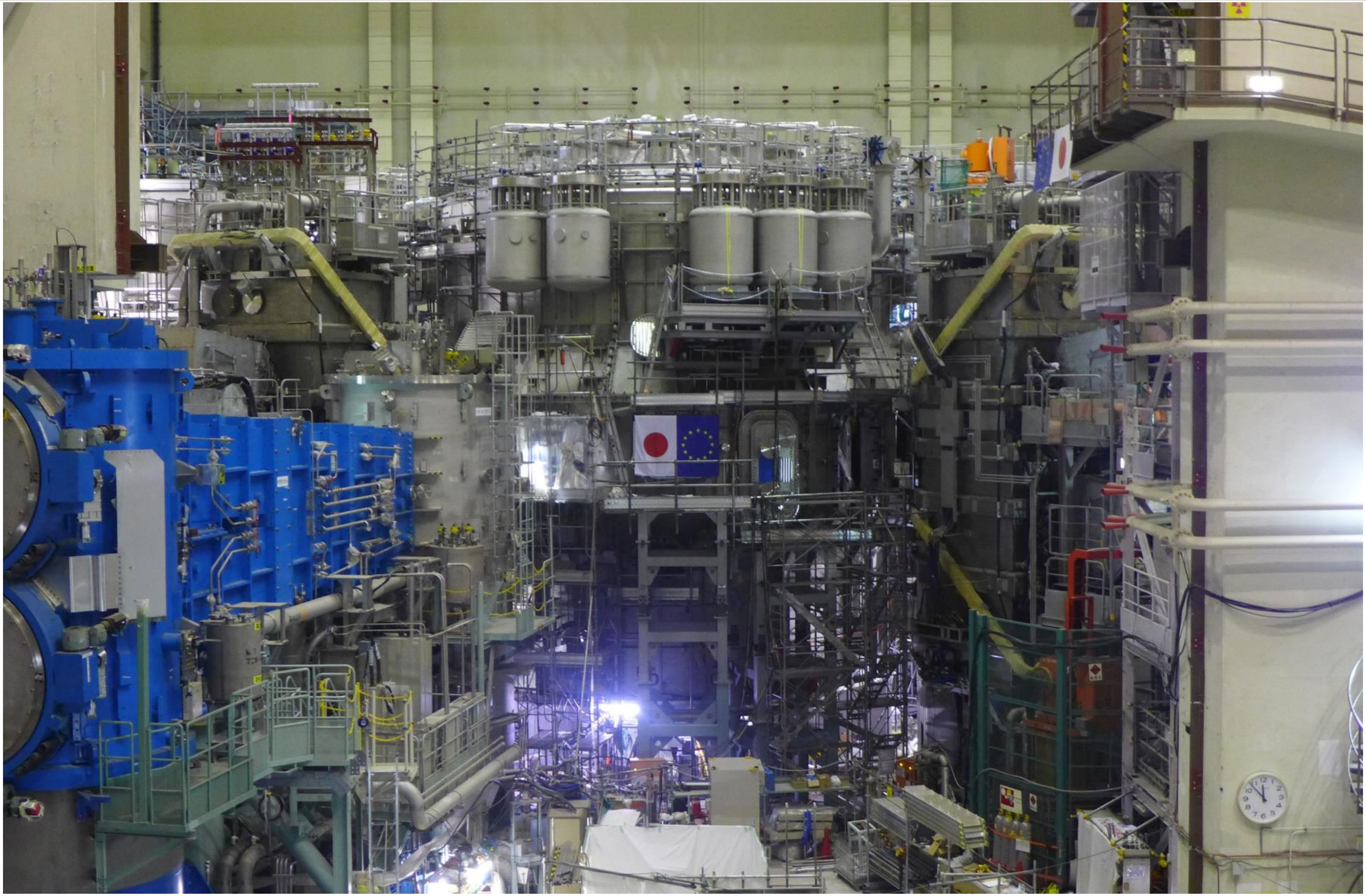


- Time response:100-300ms
- accuracy100kW/m²

Final remarks

- Diagnostics are an effective way to contribute to the JT-60SA scientific programme. Summary of EU diagnostics proposals
  - 3 feasibility completed and frozen (BES-Li, BES-D, Polarimetry)
  - 1 delivered and installed (EDICAM)
  - 3 live projects (Edge-TS, Divertor VUV, FILD)
  - 2 running feasibility (PCI, DR)
  - 2 idling feasibility (HFS-TS, ECH Stray)
  - More being considered (γ-camera, compact n-spectrometer, REIS)
- Limited room for new diagnostics => need to focus new proposals wrt the research plan and its adaptations,
  - through the ROs (until in charge, ~2020) and
  - through the experiment implementation team (~ 2021)
- The capabilities of some of the already planned diagnostics are not fully clear and they should go through the process of approval of the respective specifications.
- A sequence of design reviews is being planned for the next months for which the EU expertize will be involved.

JT-60SA Assembly completed in March 2020!



Enhancement Projects updates, planning, organisation, discussion

speaker	WG-E1: matter injection and control	status - 2020 objective
Peter Lang	Pellet	Detailed design-Manufacturing
Mathias Dibon	MGI	Detailed design-Manufacturing
Christian Day	Divertor Cryopumps	Detailed design-Manufacturing
Rudi Neu	W-PFC	Project plan and PFC samples test
Sam Davis	F4E plans on Enhancements	
all	Discussion	
	WG-E2: diagnostics*	
Roberto Pasqualotto	Thomson Scattering	Optics/Mechanics/Laser procurement
Marco Valisa	VUV divertor spectroscopy	Spectrometer assembly and test
Manolo Garcia-Munoz/Juan Ayllon	Fast Ions losses Diagnostics	Design finalization and start of manufacturing and test
Stefano Coda	Phase Contrast Imaging	Design
Daniel Carralero	Doppler Reflectometry	Feasibility
C. Sozzi	Possible further activities on diagnostics	Radiation diagnostics preliminary study
all	Discussion	
Tamas Szepesi	EDICAM – being installed (Operational phase being discussed in WG O3)	Commissioning and plasma operation

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