EUROfusion

Diagnostics for the JT-60SA Integrated Commissioning. A collection of information

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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.)*
- *+FIDA (USA), +XICS (USA), + TESPEL*

N. Oyama & PID 4.0

Diagnostics at Integrated Commissioning

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

Yoshida, PTM

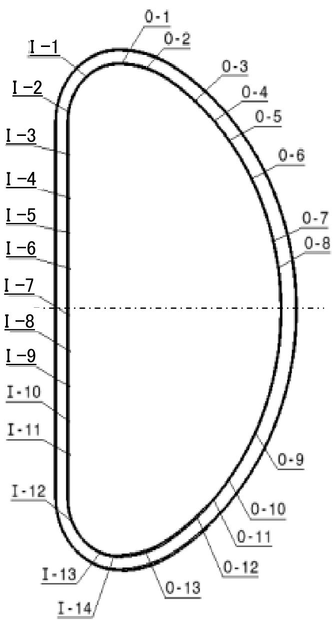
Magnetic sensors

- Flux loops: 27
- Magnetic probes: 17
- Rogowski coil: 2
- Diamagnetic loop: 1
- AT probe: 8

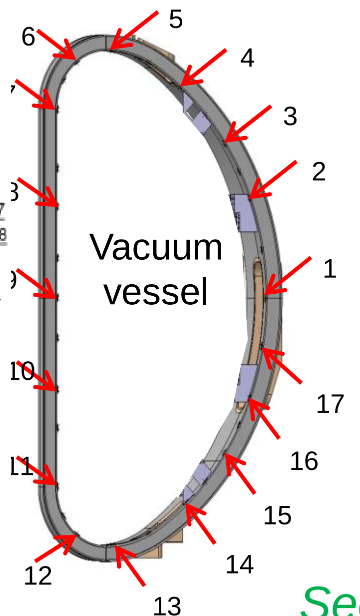
List of diagnostics and their location

Diagnostics	Section	Port/Location
CO_2 Laser interferometer (tangential), Visible spectroscopy (tangential)	P1 and P8	Horizontal
Soft X-ray detector arrays	P14	Horizontal
Visible TV cameras (+ two light guide)	P15	Horizontal
EDICAM	P18	Horizontal
Langmuir probes	P2, P8 and P14	upper divertor

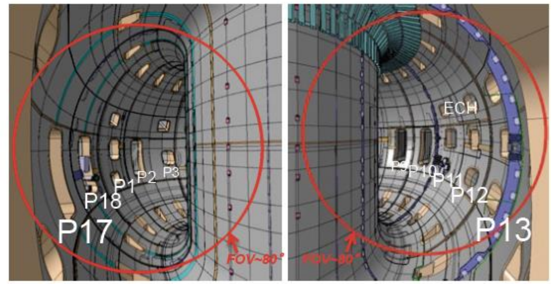
Flux loops



Magnetic probes

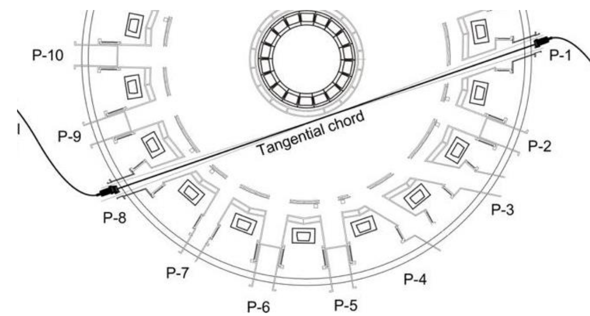


Visible camera

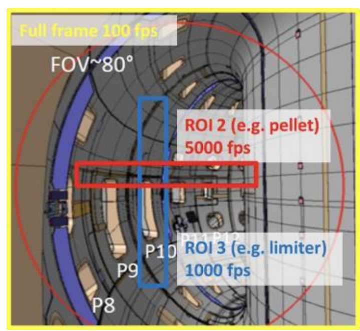


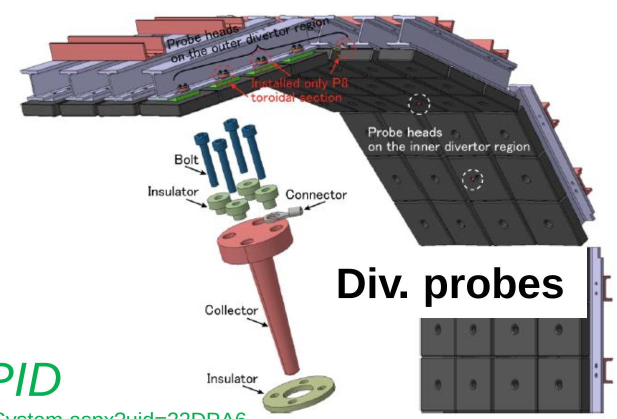
Co-direction viewing Ctr-direction viewing

CO2, Visible spectrometer



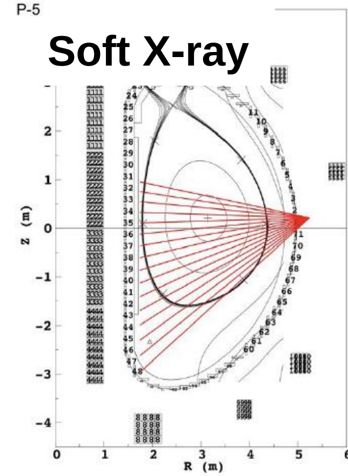
EDICAM





Div. probes

Soft X-ray



See more details in PID

https://users.jt60sa.org/IDM/Pages/DocumentSystem.aspx?uid=22DPA6

Magnetics

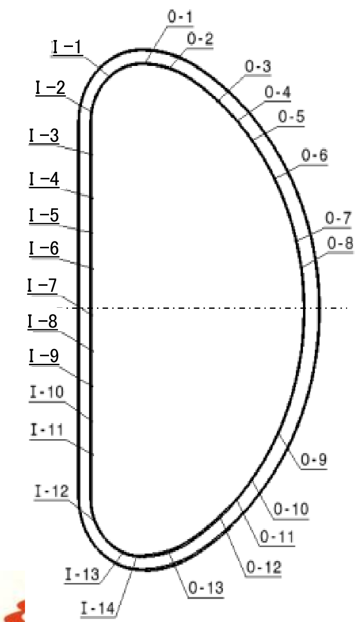
Magnetic sensors

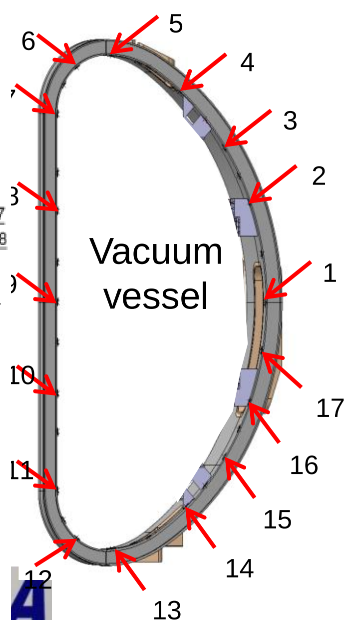
- Flux loops: 27
- Magnetic probes: 17
- Rogowski coil: 2
- Diamagnetic loop: 1
- AT probe: 8

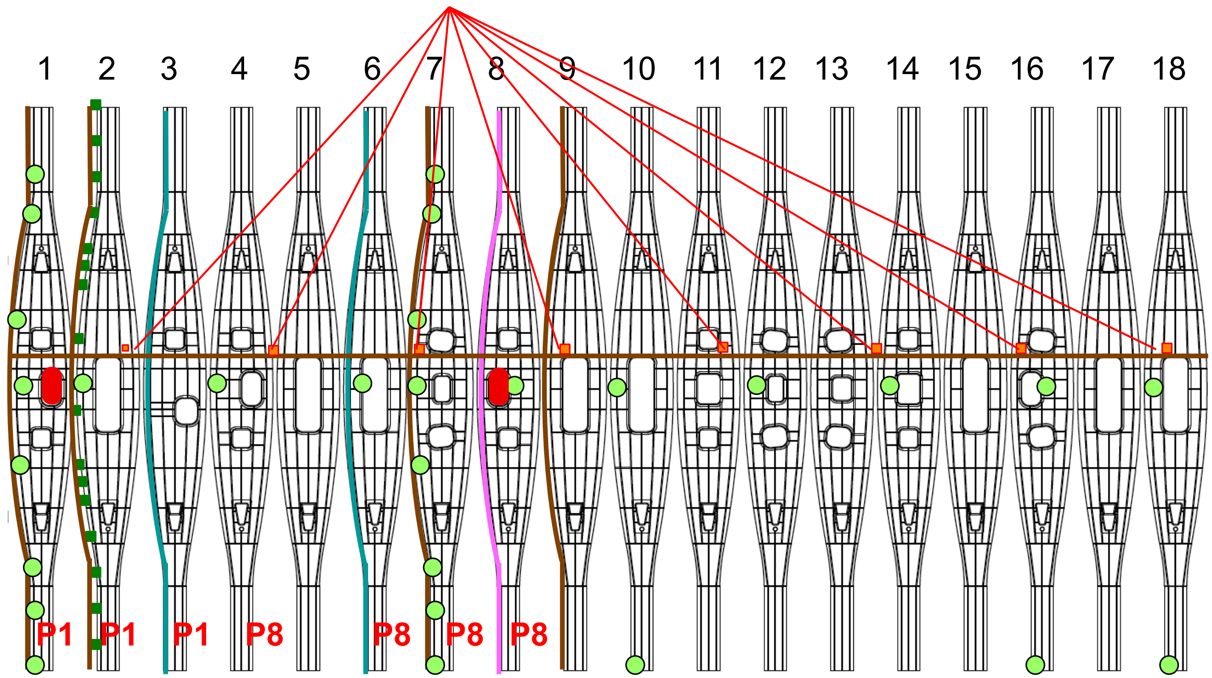
Type		Number	Location	Purpose
Magnetic sensors	One-turn loop	27	Poloidally distributed	Poloidal magnetic field
	TC (Tangential Coil) probe	17	P02	Plasma current
	Rogowski coil	2	P03, P06	Poloidal flux
	Diamagnetic loop	1	P08	Plasma stored energy
	AT probe	8	P01, P04, P07, P10, P13, P16	Magnetic fluctuation

Magnetic probe (Mirnov coil) (<1MHz sample)

Flux loops **Magnetic probes**



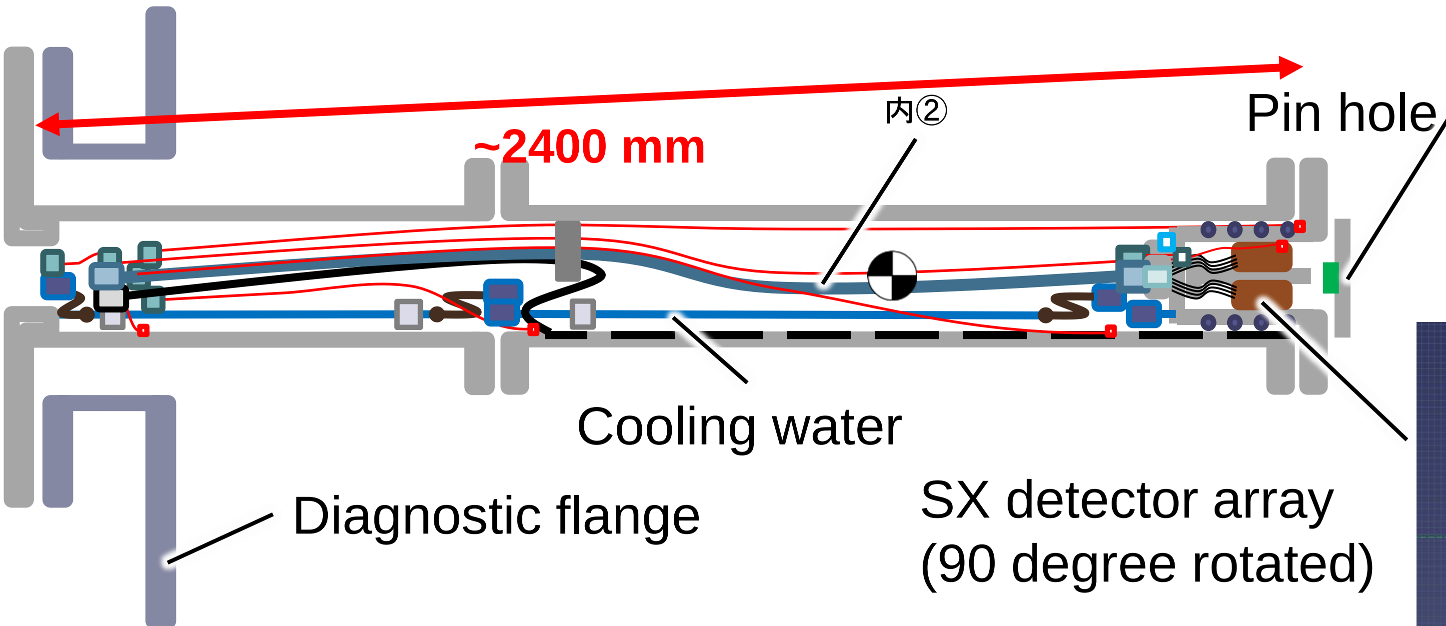


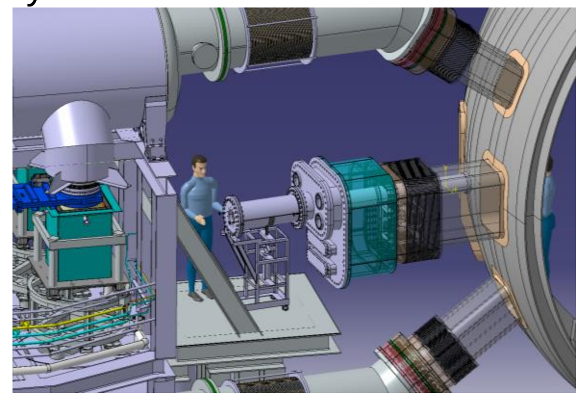


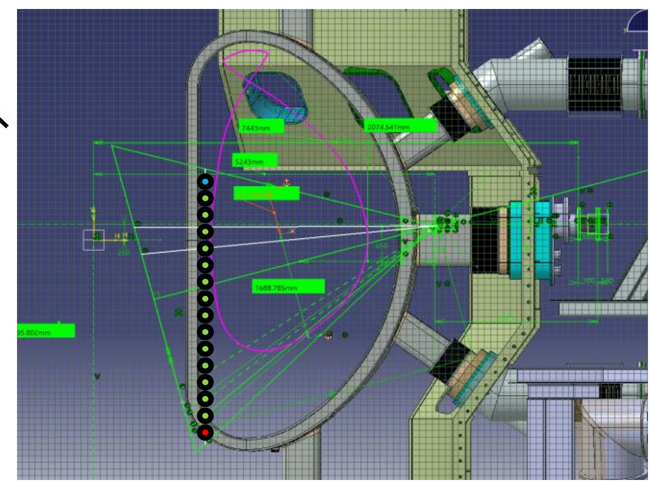
Advanced Superconducting Tokamak
BA-Satellite Tokamak Program

Soft X-ray detector array

- The purpose of this system is to observe the last closed flux surface (LCFS), the magnetic axis and the electron temperature profile by measuring the intensities of soft X-ray emission through a pinhole.
- The system consists of two detectors.
- Each detector has an Absolute X-ray a pre-amplifier and thin beryllium films. The detectors are put on the end of a port plug and the port plug is inserted at the P14 horizon port. Both detectors have a similar measuring range set at a poloidal angle of ~15 degrees downwards which allows to measure the lower half of the plasma
- Since Be films work as band pass filters, the electron temperature can be evaluated by the ratio of the intensities from two detectors with different film thickness.







- Because of limited work space near cryostat, separated port-plug should be used.
- Water cooling is required to remove heat load during baking.

Soft-X emissivity

SXR emissivity

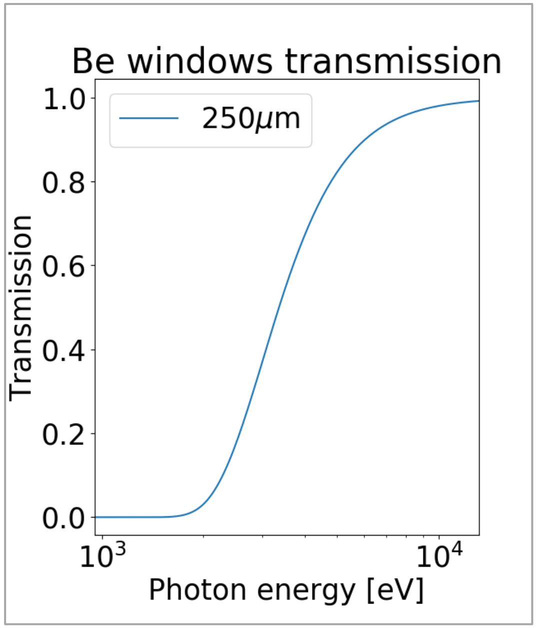
- **Predominant Bremsstrahlung emission (i.e. low impurity)**

$$\epsilon \sim n_e^2 \sqrt{T_e}\, Z_{eff}$$

- **Predominant line emission (i.e. impurity accumulation)**

$$\epsilon \sim n_e \left[n_I + \sum_s n_s \right]$$

I = main plasma ions
s = impurities

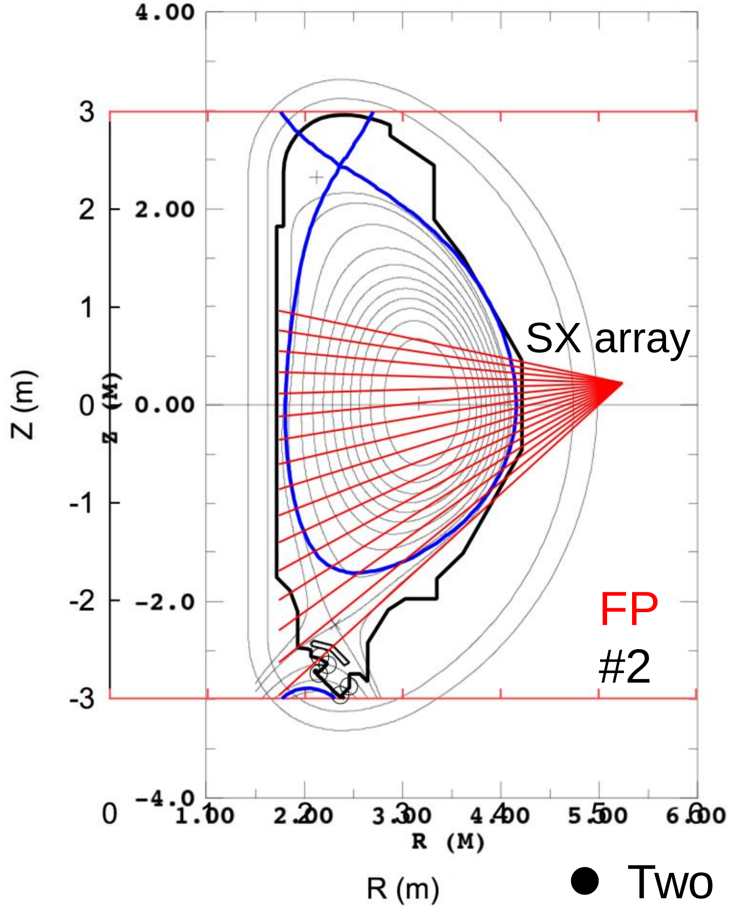


- **Emissivity along a line of sight:**

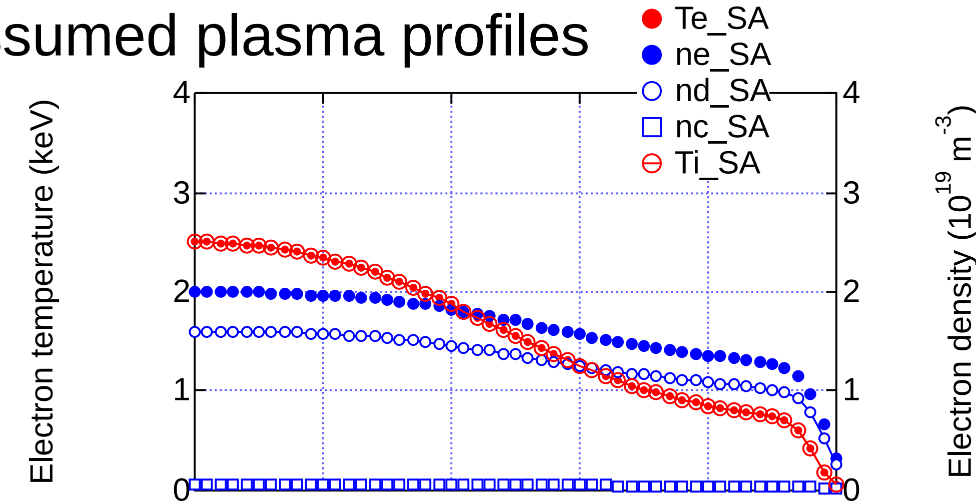
$$I = \int_{LOS} \epsilon(s)ds.$$

Evaluation of $T_e(r)$ using SX signals

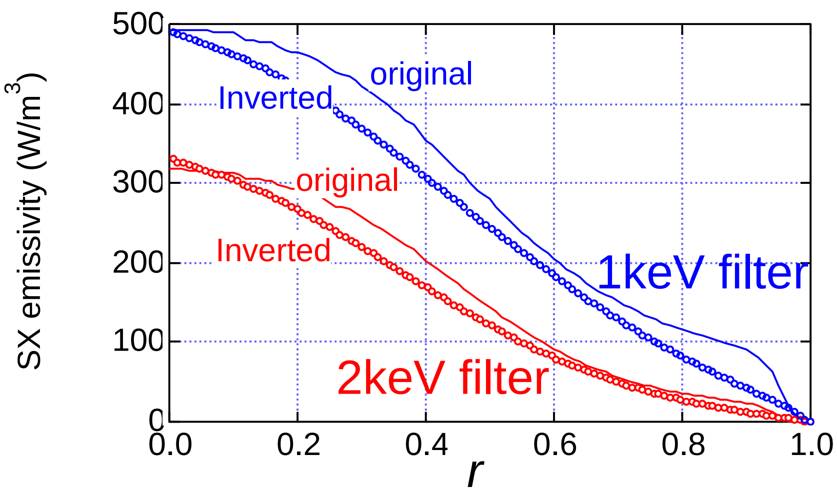
Soft X-ray photodiode detector
AXUV array 2x
16ch at a poloidal cross section
(1MHz sample)



Assumed plasma profiles

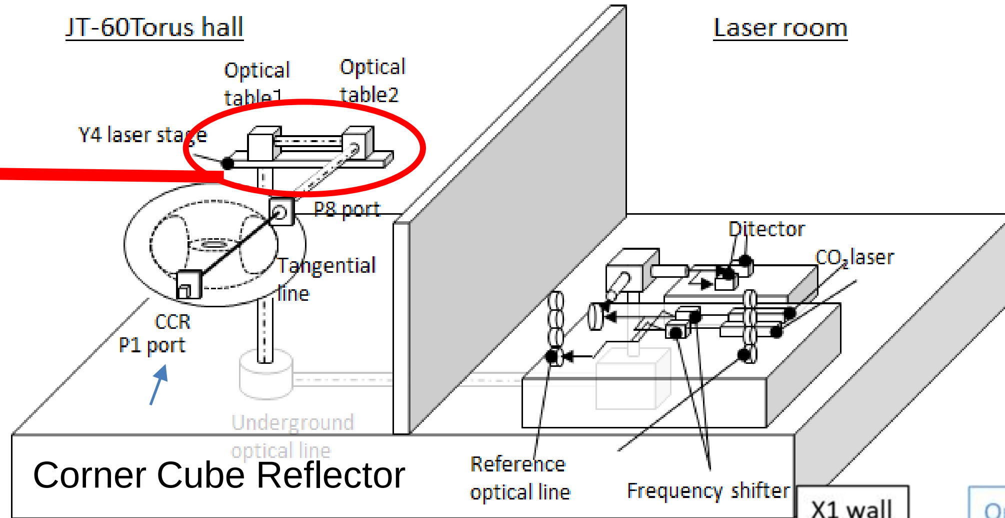


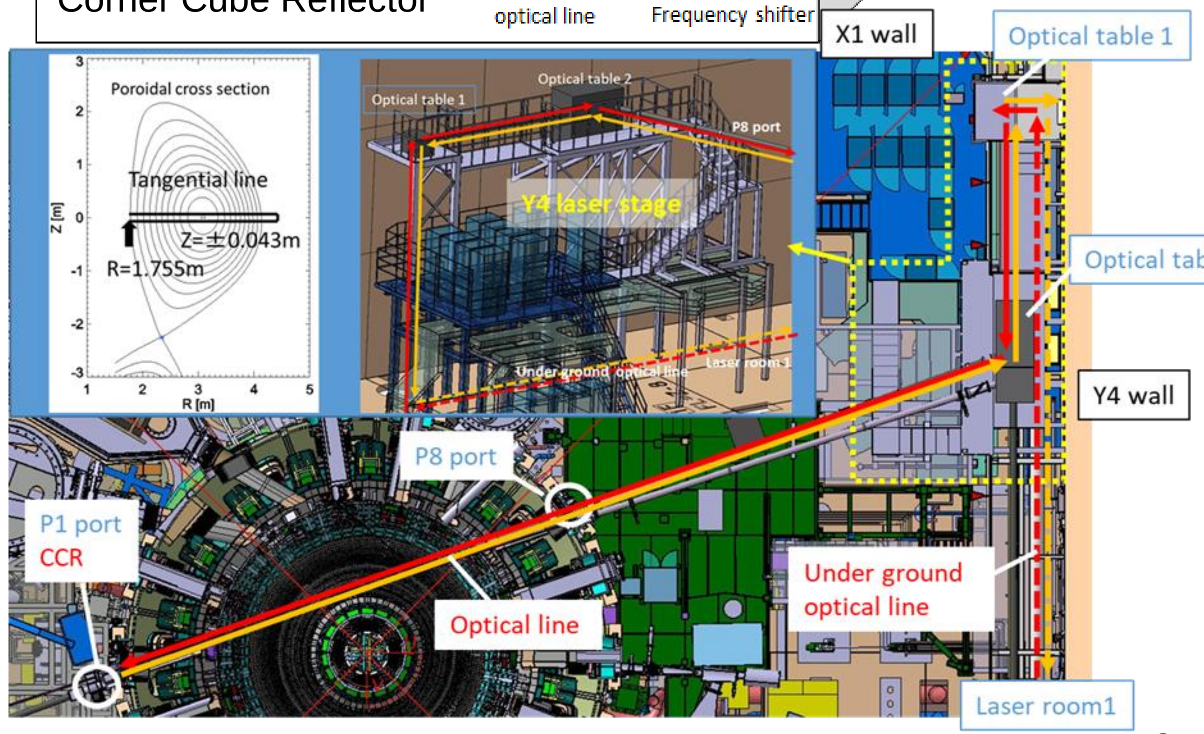
Abel inverted SX emissivity



- Two SX detector arrays having different filter will be installed.
- Using Abel inverted SX emissivity, T_e profile can be evaluated.

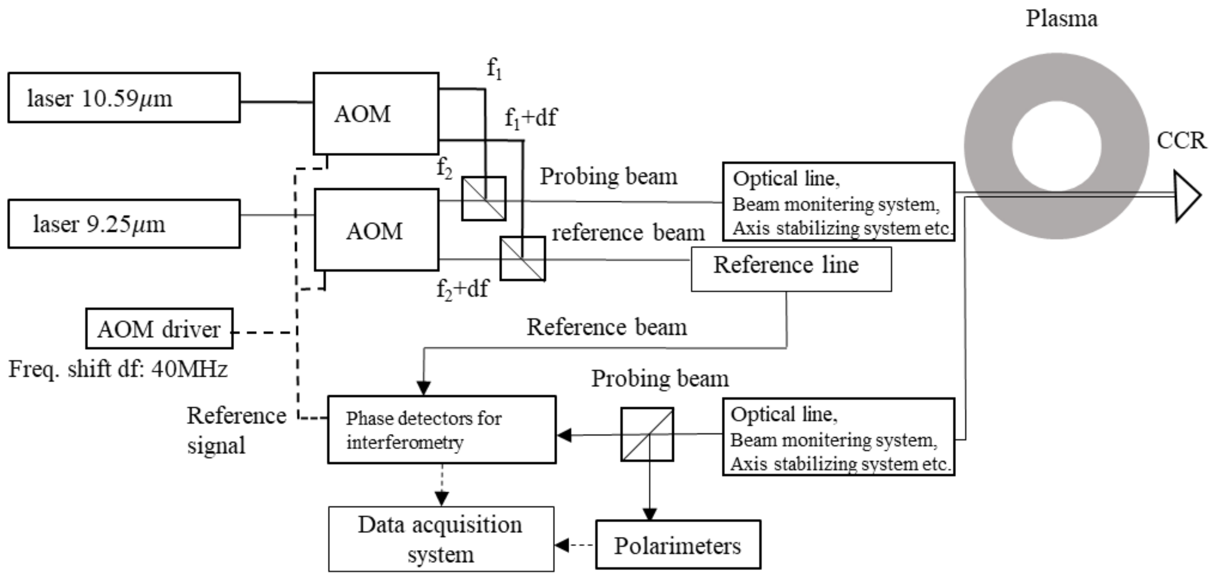
2-colour CO_2 laser interferometer





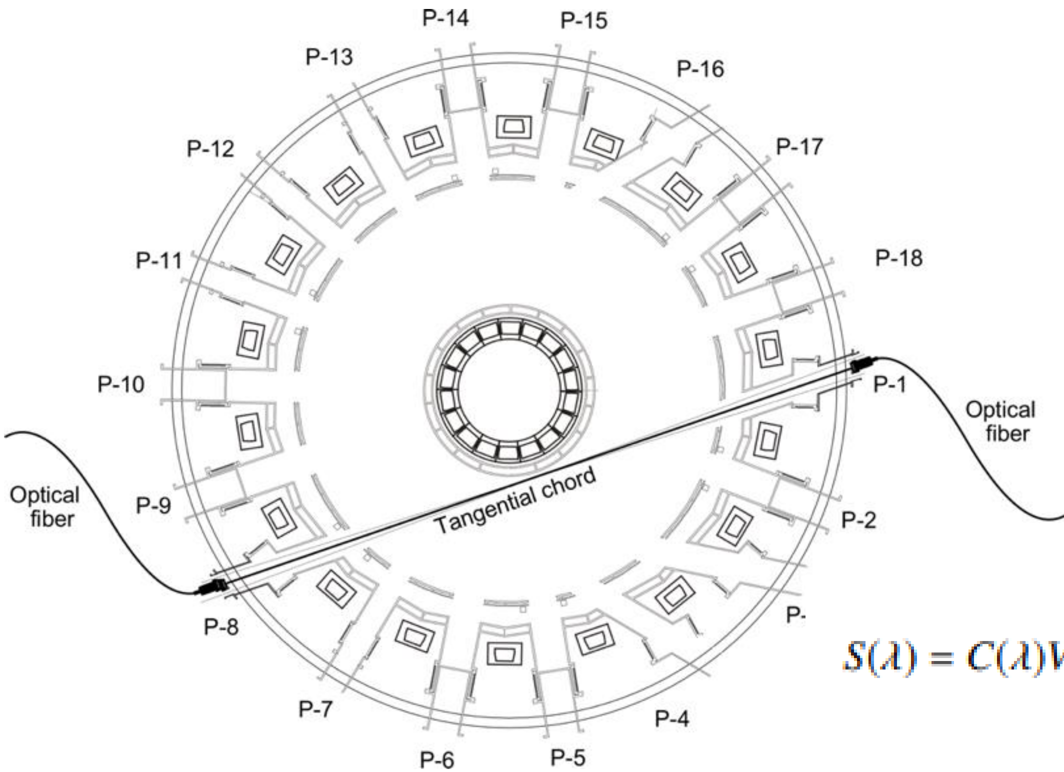
temporal resolution	5 μs (offline data) and 1 ms (for realtime feedback)
density resolution	~2x10^{19} m^{-2} (5 μs) and ~0.5x10^{19} m^{-2} (1 ms)
Channels	1 (tangential, P8-P1)

2-colour CO_2 laser interferometer



- two color interferometer with two different wavelengths of CO_2 laser to compensate the effects of vibration and displacement of optical components.
- The polarimeter provides reliable density data without errors like "fringe jump" (Faraday rotation angle $\sim\lambda^2\int n_e B_{t//} dl$)

Visible spectroscopy



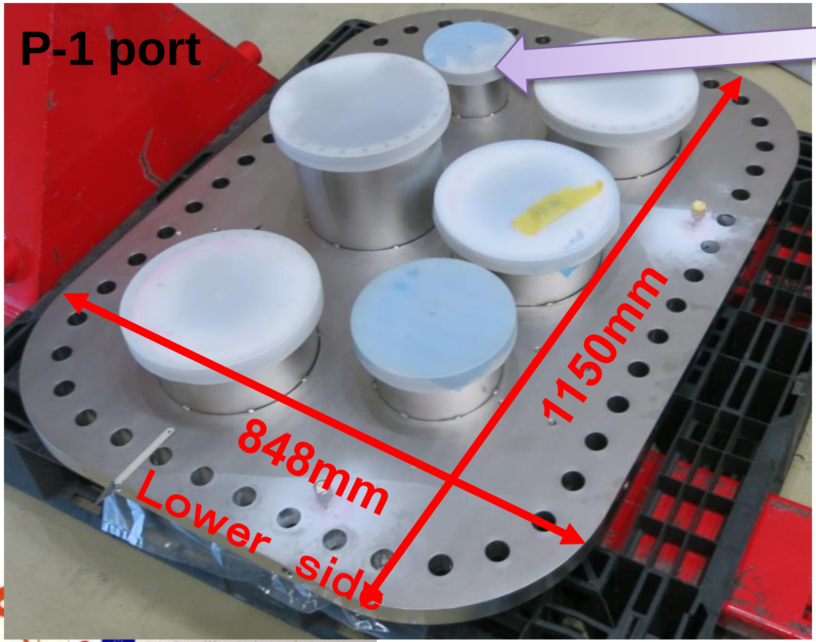
- The purpose of this system is to measure the intensities of
  - H_α emission,
  - Bremsstrahlung emission (Z_{eff})
  - and other spectral lines.
- The viewing chord is tangential between the P1 horizontal port and the P8 horizontal port

$$S(\lambda) = C(\lambda)V(\lambda) = C(\lambda)\int g_{ff}(Z_{eff}, T_e, \lambda)\frac{n_e^2 Z_{eff}}{\sqrt{k_b T_e}}\exp\left(\frac{hc}{\lambda k_b T_e}\right)\frac{1}{\lambda^2}dl$$

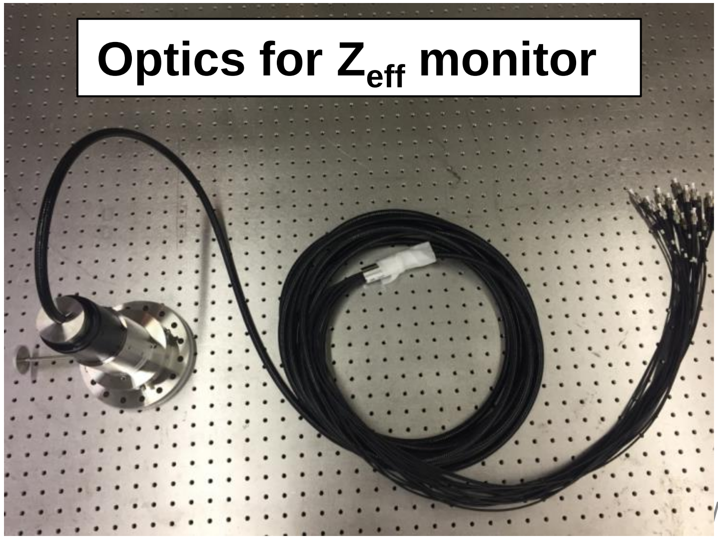
- The layout of the optics allows to calibrate the sensitivity of the whole spectroscopic system including the vacuum window without in-vessel work:
- a standard light source just outside the vacuum window can be used to calibrate the sensitivity of the other optical system through the two vacuum windows.
- In addition, simultaneous measurement from the two ports enables to improve the accuracy through comparison and provide redundancy

Z_{eff} monitor (visible spectrometer)

- Emission from the plasma through the optics system is transmitted to the diagnostic room.
- In the diagnostics room, photomultipliers detect and filter the emitted light filtered with interference filters with a bandpass width of 1 nm and a transmittance peak wavelengths of
  - 656.1 nm (H_α),
  - 523.2 nm (Bremsstrahlung)
  - and 657.8 nm (C II, for example)
- time resolution of 50 ms.
- Some of the optical fibers are connected to a spectrometer with a spectral band ranging from 400 nm to 800 nm with a time resolution of 300 ms (back-illuminated CCD camera)



Z_{eff} monitor

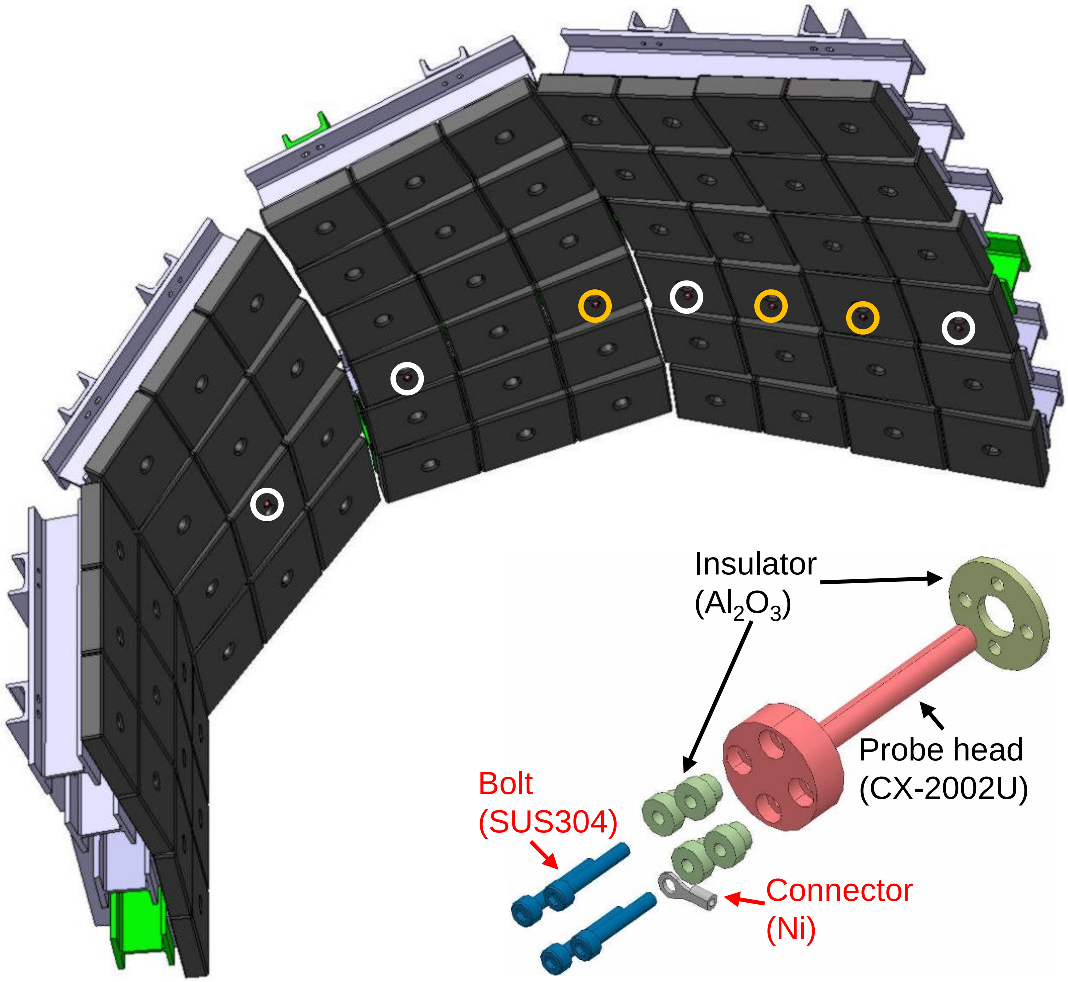


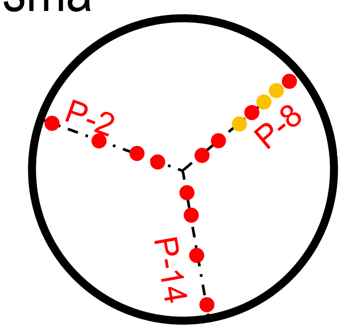
- Two tangential views
- Fibers are connected to
  - BPF+PMT for Z_{eff}
  - BPF+PMT for Hα
  - Visible spectrometer

18 fibers

Langmuir probes

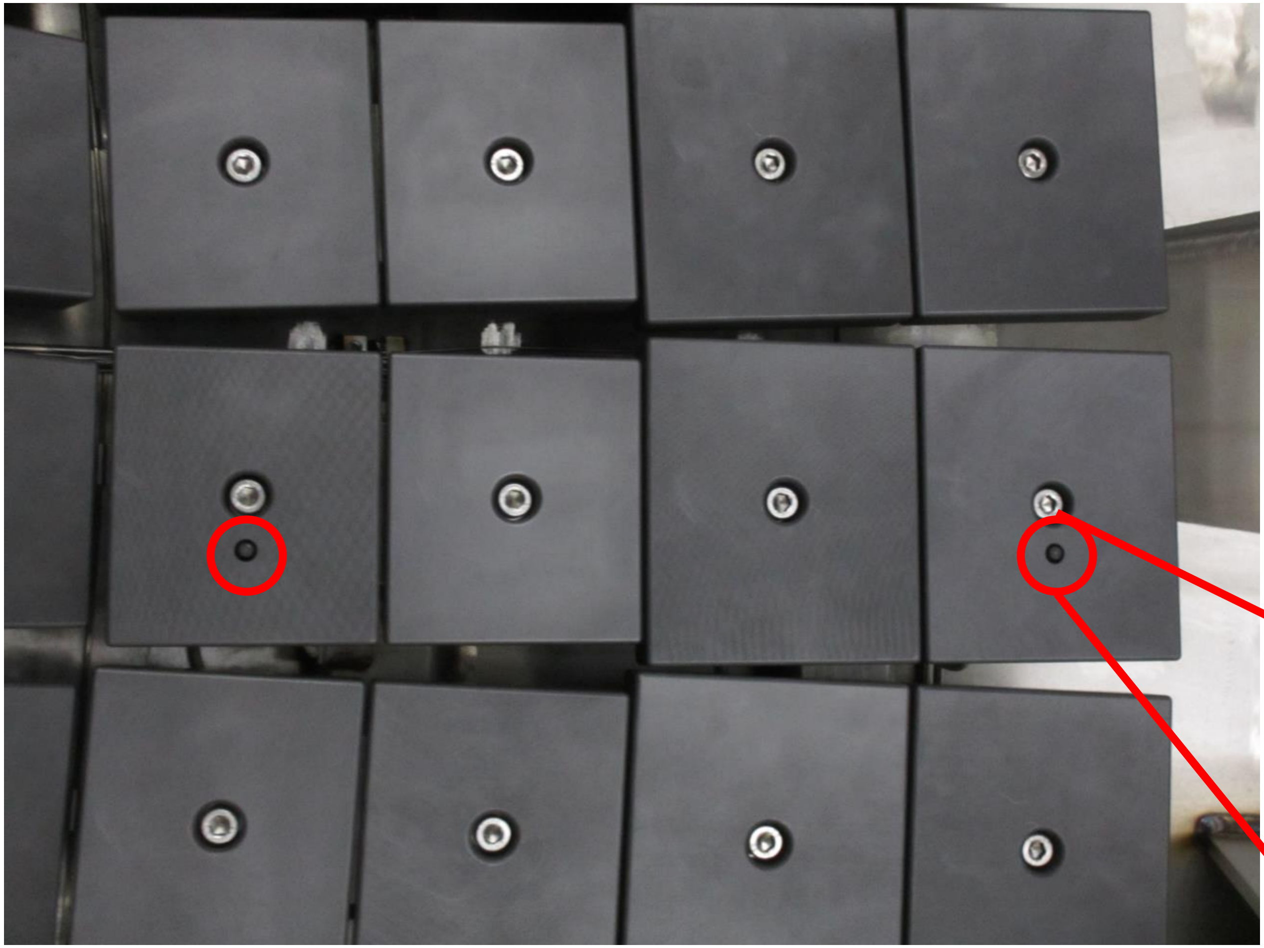
- The primary purpose of the Langmuir probes is the detection of the divertor legs and their sweeping.
- => comparison with Plasma Control System (PCS) and equilibrium solver
- Four Langmuir probe heads (two is the inner divertor region and two the outer divertor region) are installed at the P2, P8 and P14 toroidal sections of the upper divertor.
- Additional three heads are installed around the outer divertor region at the P8 toroidal section to evaluate the position of the divertor legs for various plasma configurations.

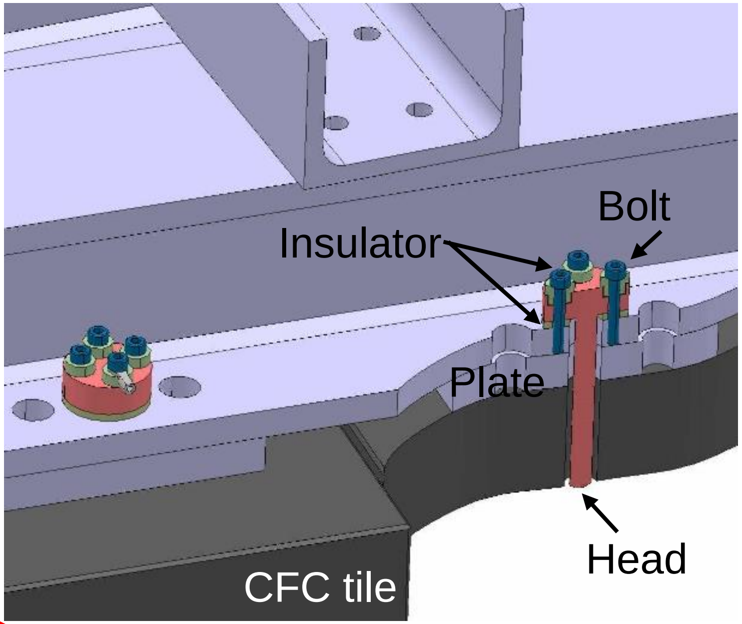


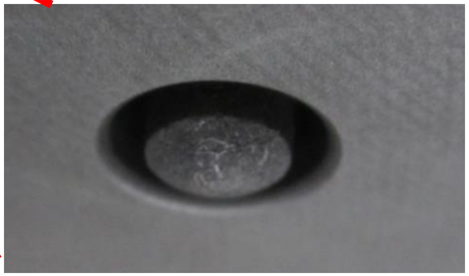


Langmuir probe on upper divertor

Outer target at P2 section



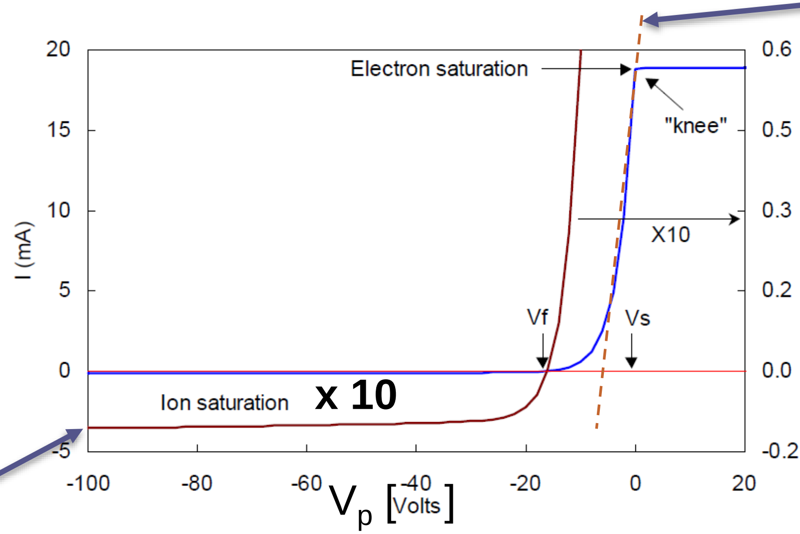




Divertor probes

- Evaluation of electron temperatures (T_e), electron densities (n_e) and floating potential (V_f) can be evaluated by sweeping the applied voltage.

Slope: T_e



$I_{es}\propto n_e$ once T_e known

$I_{es}=n_e(KT_e/2m_e)A$

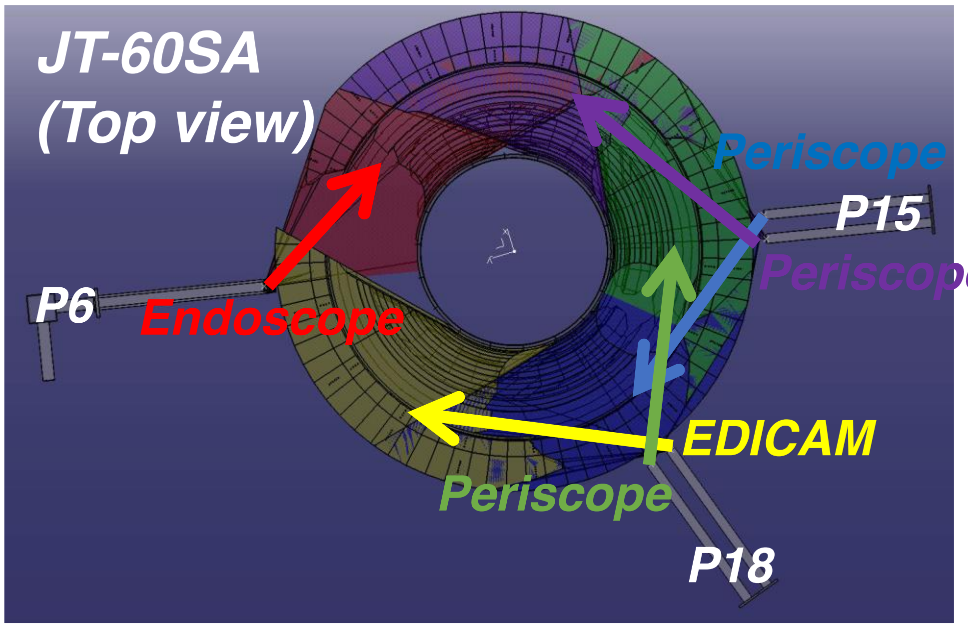
$I_e = I_{es} \exp[e(V_p - V_s) / KT_e)]$,

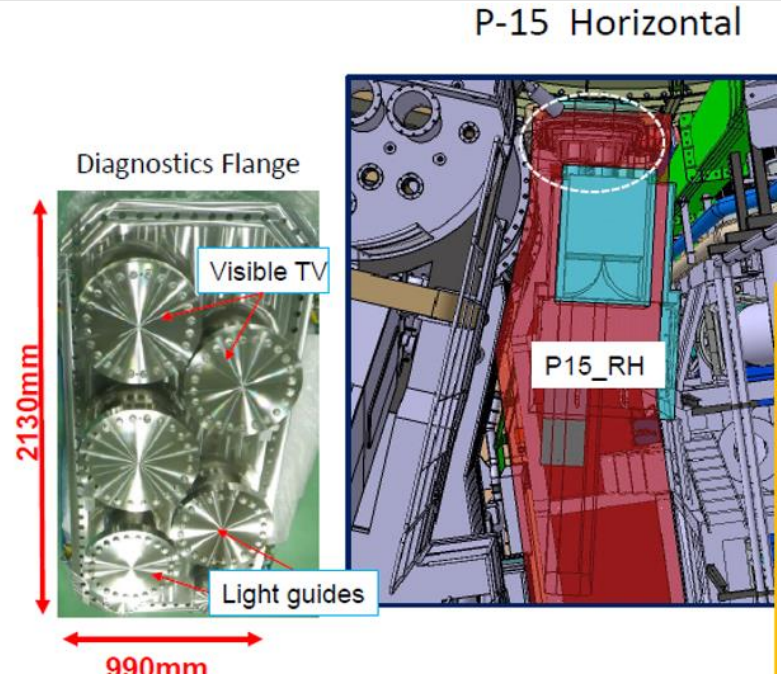
V_f=fluctuating potential
V_s=plasma potential
V_p=probe potential

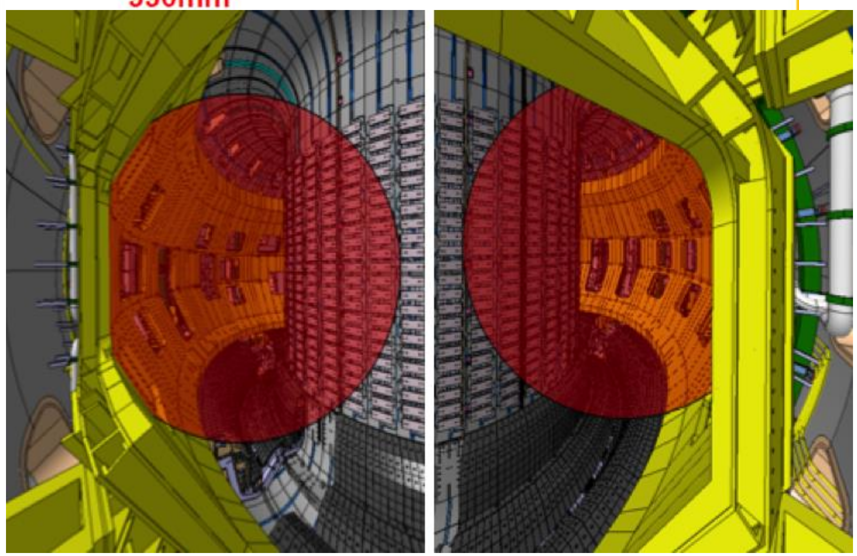
Location and number of probes	**P2 and P14: 2 in inner divertor region and 2 in outer divertor region** **P8: 2 in inner divertor region and 5 in outer divertor region**
Time resolution	Ion saturation current mode (I_{is}): 50 ms Voltage sweep mode (T_e, n_e and V_f): 1 ms

Visible cameras

- For IC, only two sets of visible TV camera systems will be available and installed in the P15 horizontal port.
- tangential co- or counter-view
- For investigations inside the vacuum vessel without plasma, two addional dedicated port plugs for light source are available at P15.



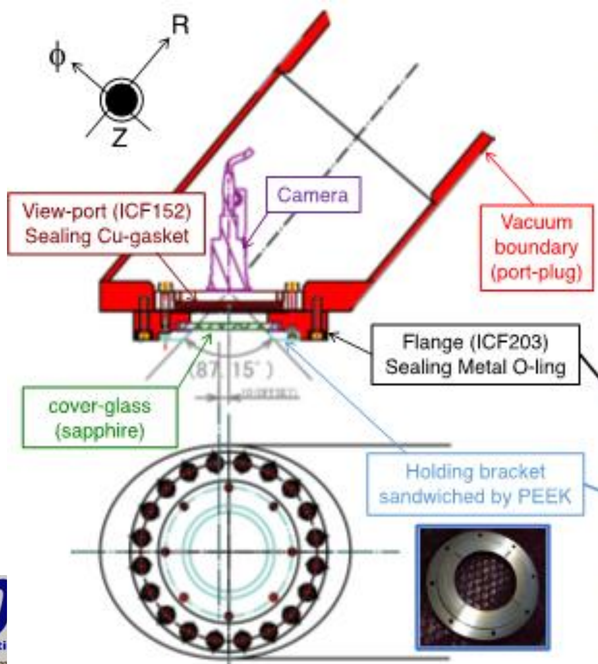


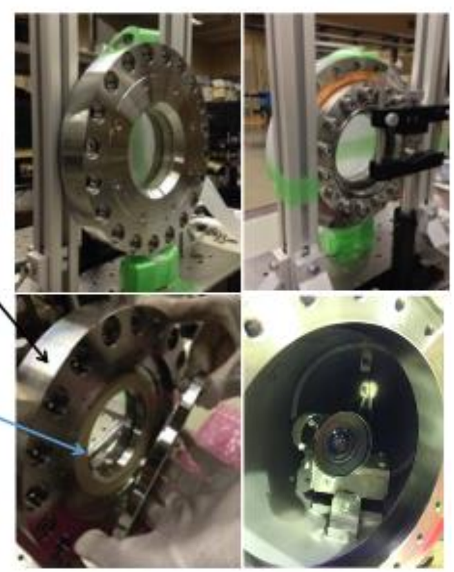


FoV of the P15 Visible TV diagnostics. Left figure is the tangential co-viewing, while right figure is the tangential counter-viewing

Visible cameras

	Periscope	Endoscope
Camera type [Resolution]	Analog colour (NTSC) [768(H)×494(V)]	Digital colour (GigE) [1920(H)×1080(V)]
Field-of-view	~80°	
Depth-of-field	3-8 m	
Viewing direction	tilted by +/- 40° to port plug axis	
Temporal resolution	30 Hz	37Hz
Spatial resolution	4~5 cm	1~2 cm
Wavelength range	520 – 720 nm	
Mechanical protection	Double windows having sapphire (6mm thickness) for cover glass	Steel cover plate with pin-hole (entrance pupil) and shutter
Heat load tolerance	max. 25 kW/m^2 for 100 s, inertia cooling	max. 55 kW/m^2 for 100 s, water cooling for pin-hole
Vacuum flange	f450 mm, flat surface	f500 mm, flat surface





- A “periscope” system is used for P15 (co- and counter-views) in which the visible TV camera (analog color CCD) is located at the end of the port-plug having double window without shutter and cooling, viewing the plasma directly.

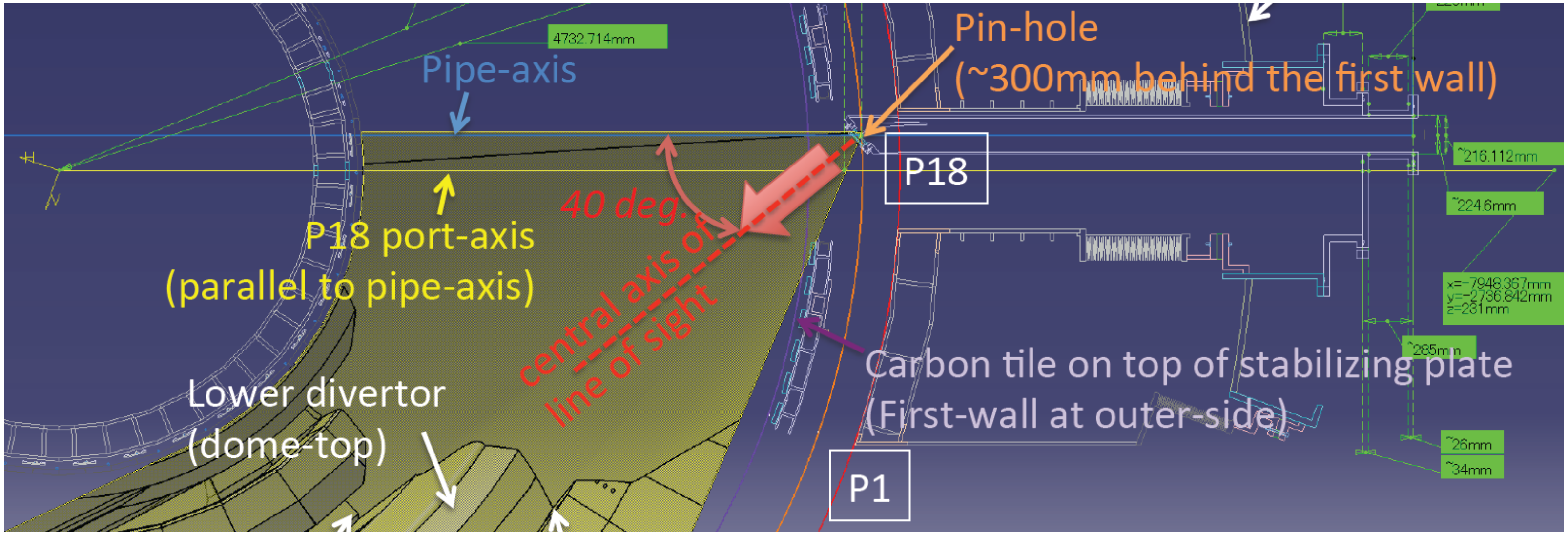
  Extended separation between CCD-head and its controller by a long camera cable (Resilient to e.m. noise)

  No tolerance for neutron load

Single channel wide-angle fast video diagnostics

Features

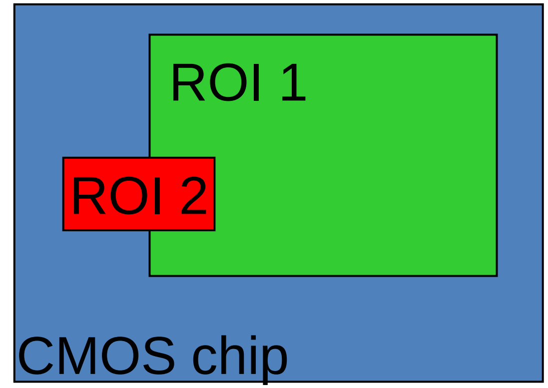
- Field-of-view: 80° (wide-angle)
- Tangential view
- Temporal resolution: 100 Hz
  → max. 400 Hz full frame, up to 20 kHz for ROIs
- Spatial resolution: better than 13 mm (over 3-8 m distance)



Advanced EDICAM camera control: multiple ROIs, non-destructive readout

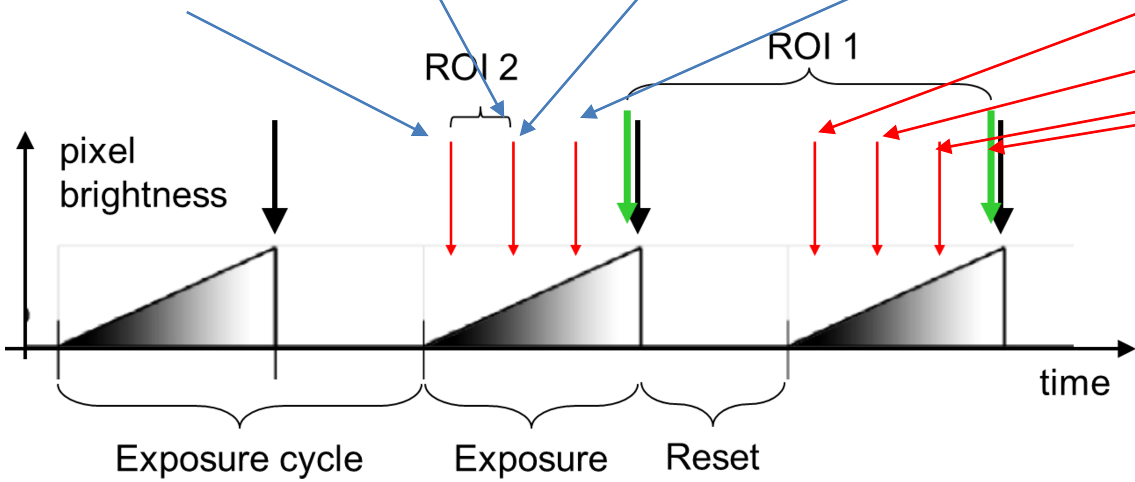
Define several regions to be observed (max. 6)

- different size and position
- independent timing
- **NDR = sensor content is not erased**



Stationary objects

Moving objects



Plasma size and position
Safety-related issues
Breakdown studies
Other fast measurements

Tomography reconstruction being investigated

EDICAM set-up for the first campaign

Set-up

Wide-angle view: ca. 1/5 of torus

- ROI 1: full frame overview

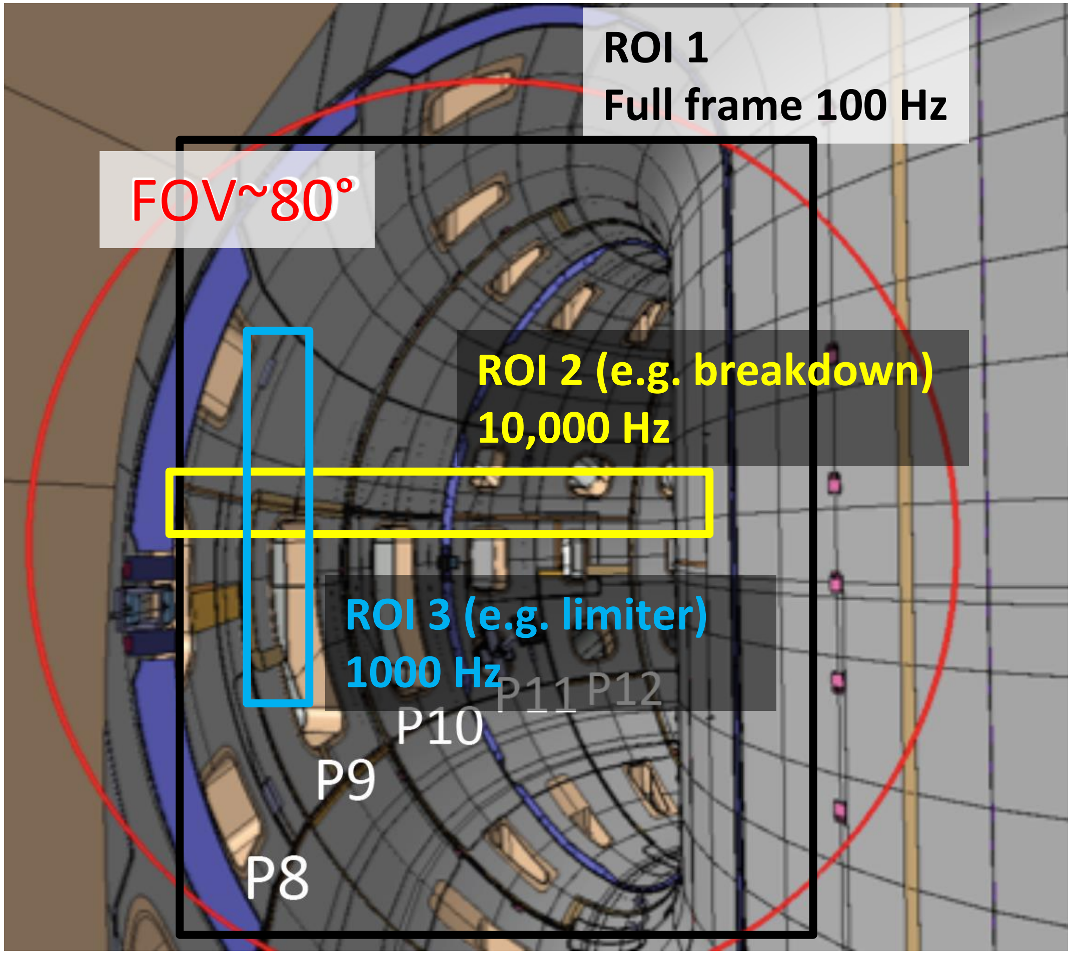
  → 1280x1024 @ 100 Hz

- ROI 2, 3, …

  → fast observations

- Aim: make calibration image with illuminated torus

→ refine ROIs using real image



NB sector numbers wrong in the figure : P1-P5 inside FOV

Final remarks

- Rather “essential” set of measurements. They should anyway be sufficient for the IC objectives (unless of…)
- Reasonable to expect a lot of work for debugging, understanding, calibration
- Most of the measurements are “coupled”: no final answer until all the pieces are in place

- No informative material on
  - Optical penning gauge / ion gauge / baratron
  - Neutral gas analyzer (Quadruple Mass Analyser)

- To be complemented with
  - RT capabilities
  - data access software, name of signals etc
  - Data analysis tools

- Main sources: PID 4.2, TCM and RCM presentations, Plasma Team meeting