Recent progress in JT-60U experiments and Plasma diagnostics plan in JT-60SA tokamak

Presented by

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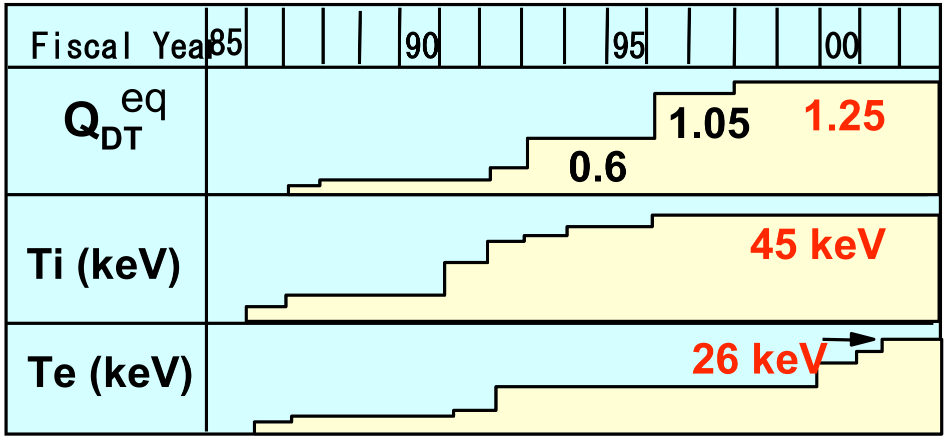
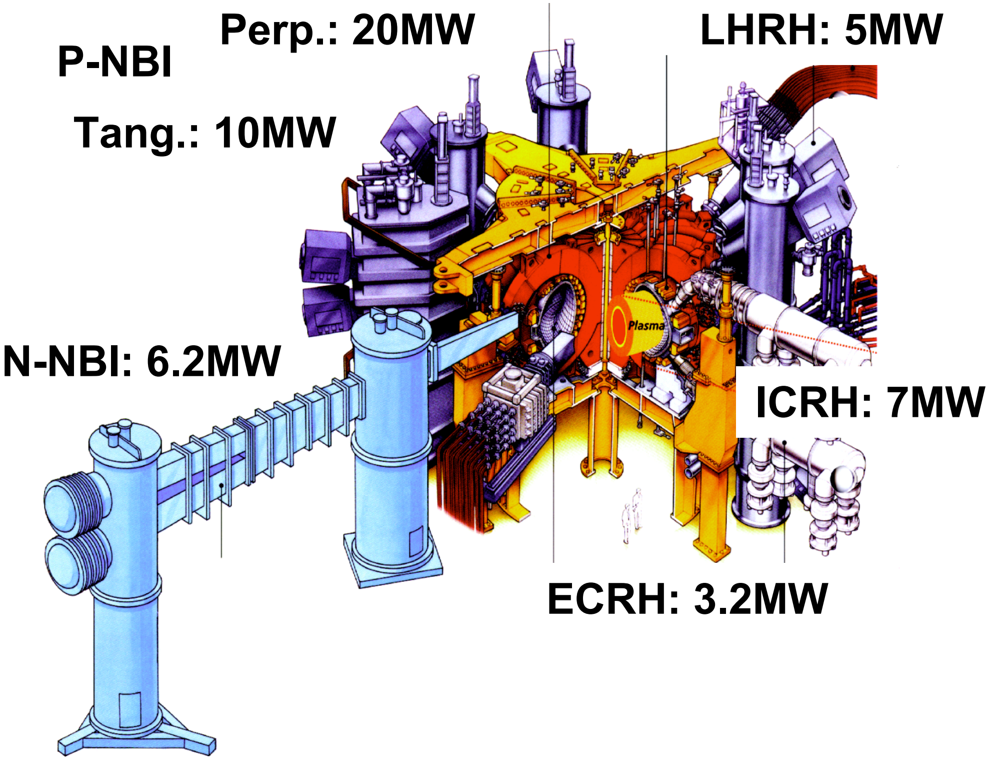
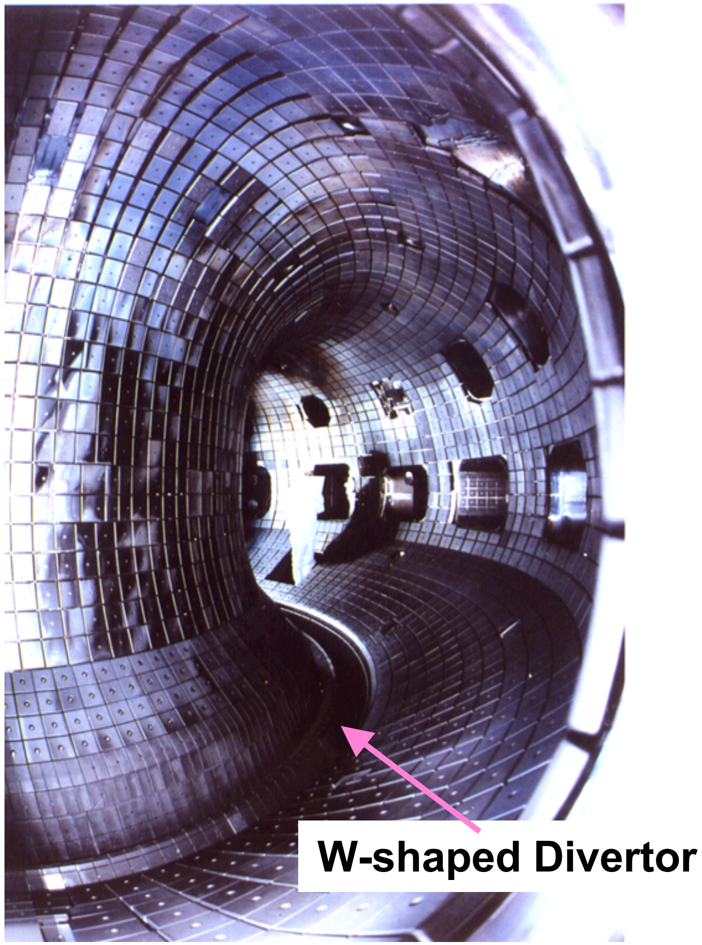
Outline of JT-60U

JT-60U



I_p < 3 MA, B_T < 4 T
R = 3-3.5 m, a = 0.6-1.0

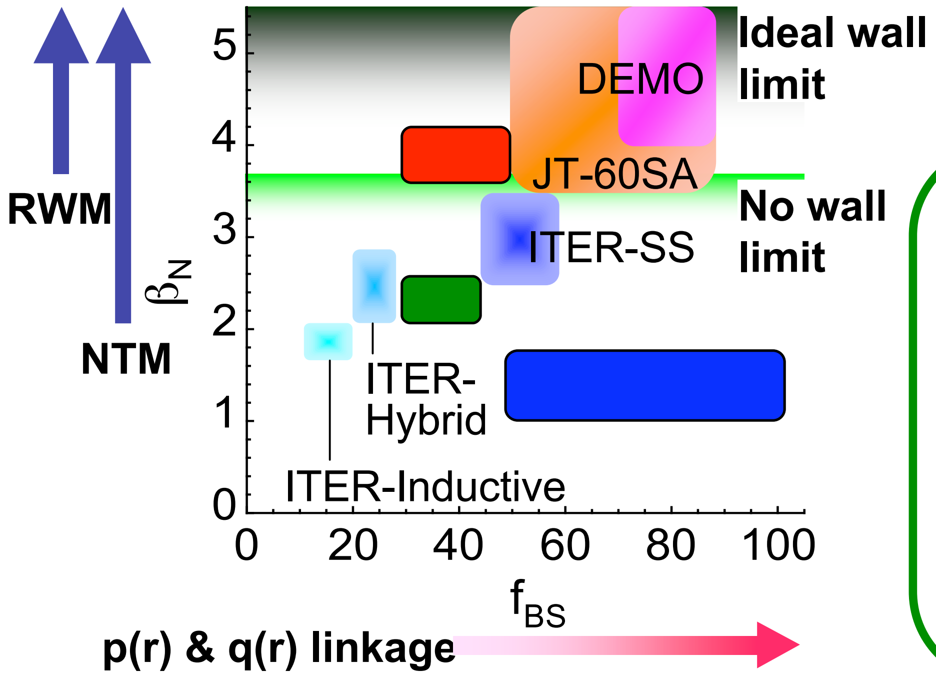


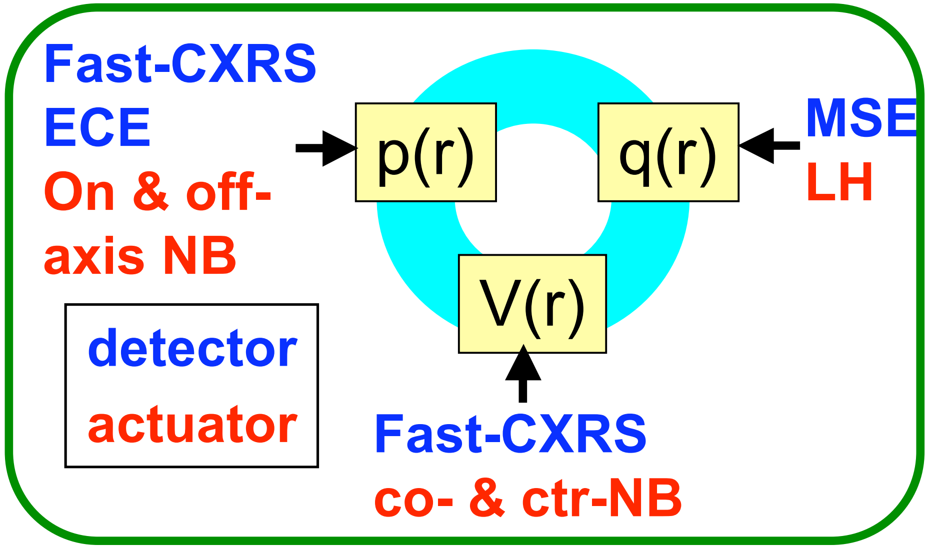


In-Vessel View

AT reserch in JT-60 toward DEMO

JT-60U





Objectives of JT-60 experiments during 2007-2008

JT-60U

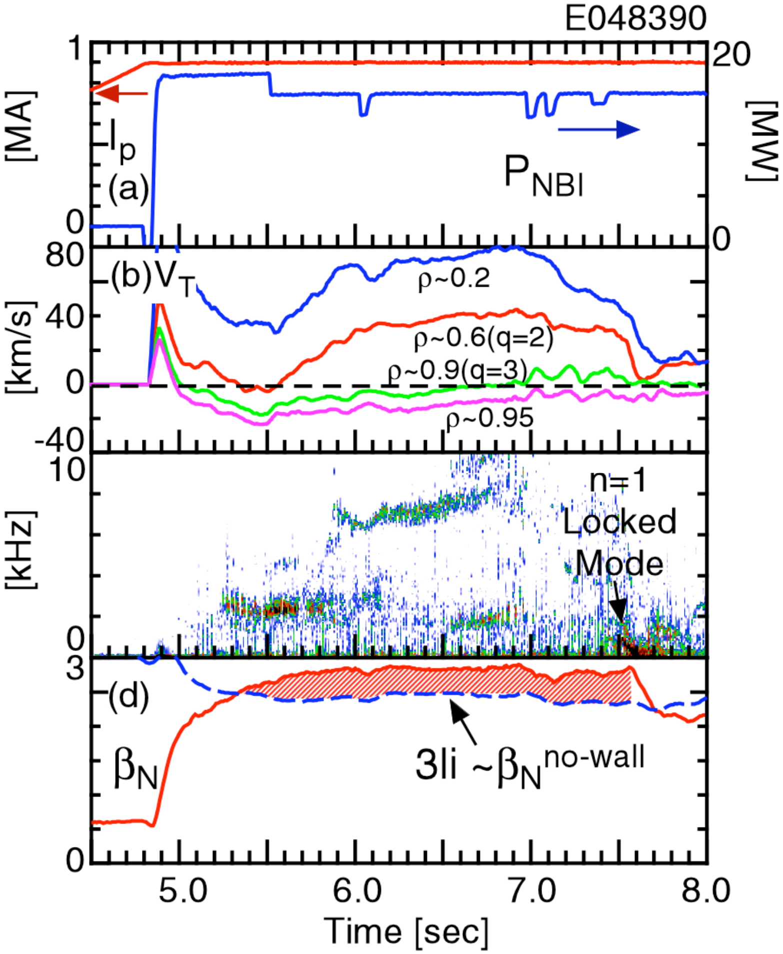
- Extension of operation regime based on steady-state high beta research using modified heating system and optimized control system towards DEMO, ITER and JT-60SA.
- Development of real-time control scheme for burning plasma control and establishment of physics bases for accurate predictions of a plasma performance using newly installed diagnostics.
- Physics R&D for JT-60SA design.

- Targets
  - Achievement of long sustainment of high integrated performance β_N=2.5-3, HH$\geq$1, $f_{BS}\geq$0.4, $\tau_{duration}$=25-30 s (~$\tau_{NB\text{-}inj.}$)
  - Achievement of long sustainment of high beta exceeding no-wall ideal MHD limit β_N=3-3.5 (>$\beta_N^{no\text{-}wall}$), $\tau_{duration}$=5-8 s (~τ_R)
  - Achievement of long sustainment of high radiation fraction $f_{rad}\geq$0.8, HH$\geq$0.9, $n_e/n_{GW}\geq$0.7, $\tau_{duration}$=15-25 s (~τ_{wall})

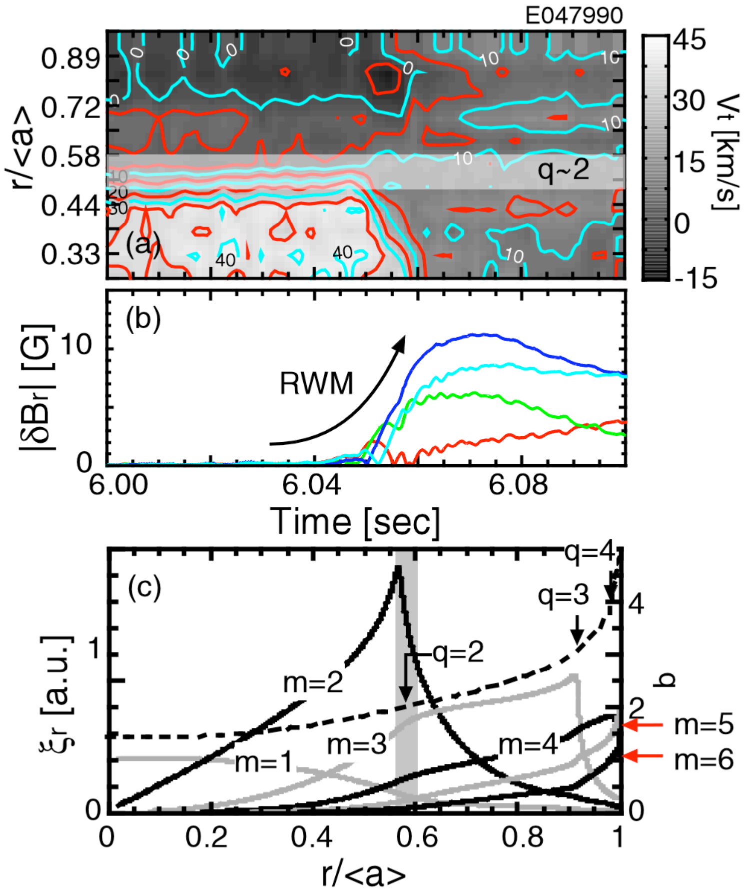
The dynamics and stability of the resistive wall mode (RWM) are investigated in the JT-60U high-β plasmas.

JT-60U

* β_N ~ 2.8 sustained for 2 s above the ideal no-wall β-limit (= 2.4)



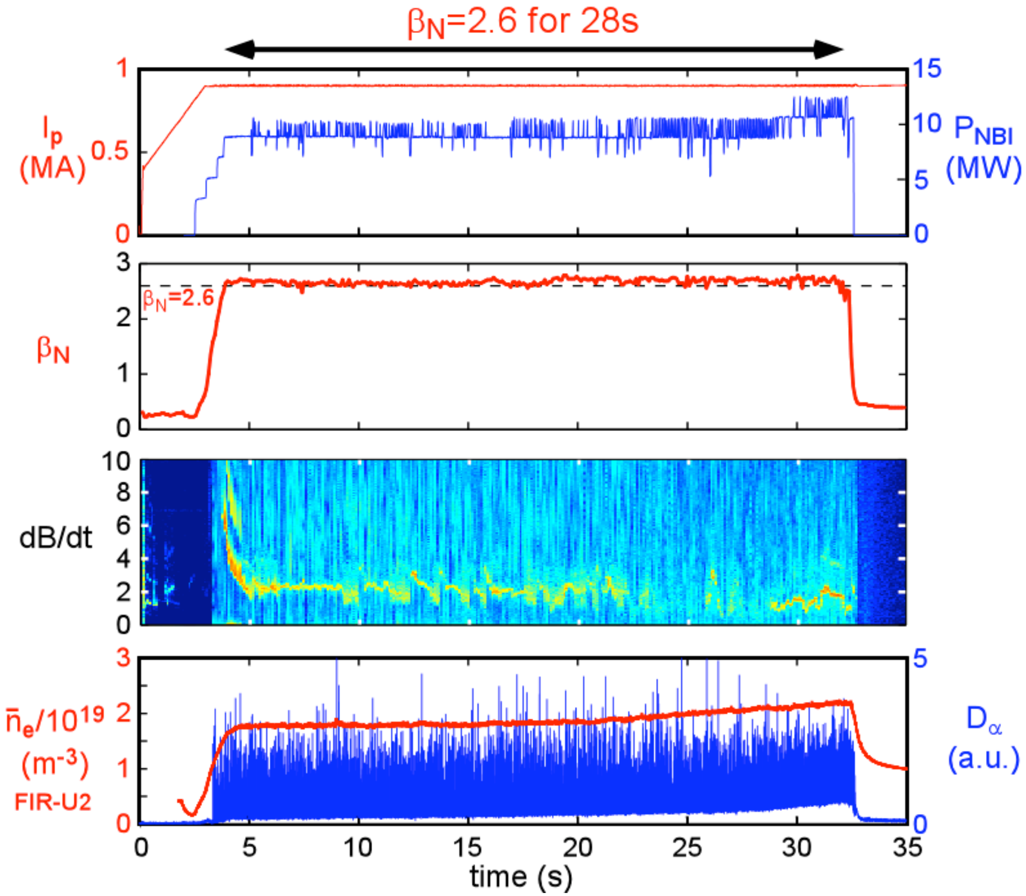
* Braking of the plasma rotation inside q = 2 surface observed



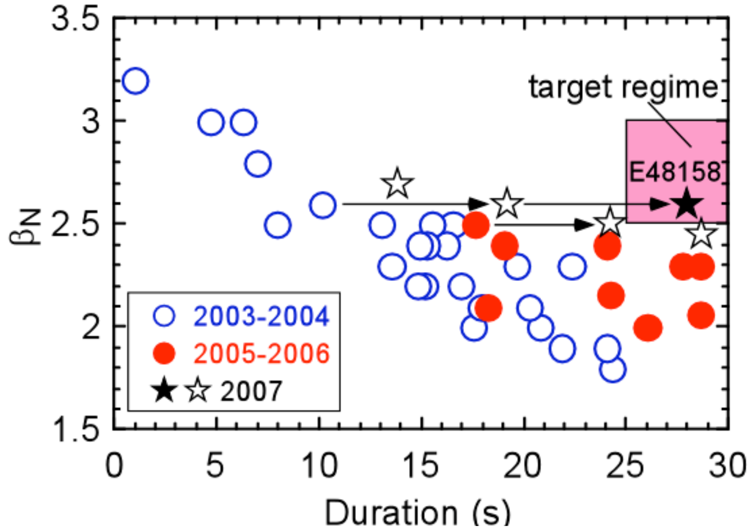
High integrated performance with long pulse length

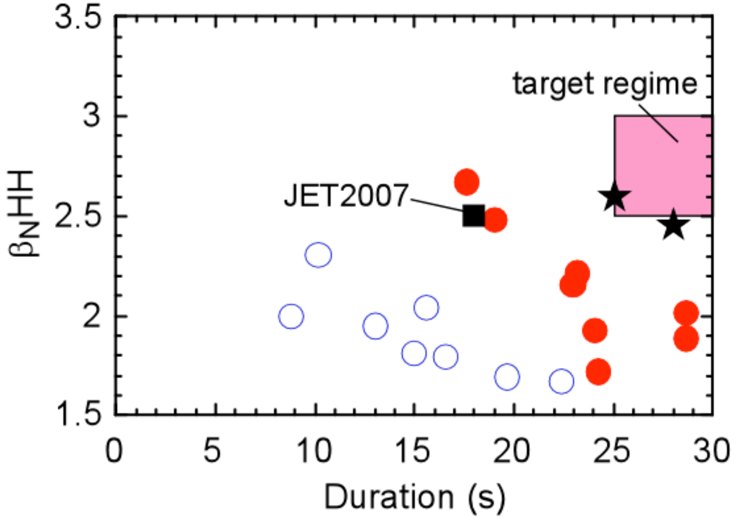
JT-60U

E48158 was satisfy following condition. “To sustain high integrated performance plasma for 25-30s, whose parameters are β_N>2.5, H_H≥1 and f_{BS}≥0.4”



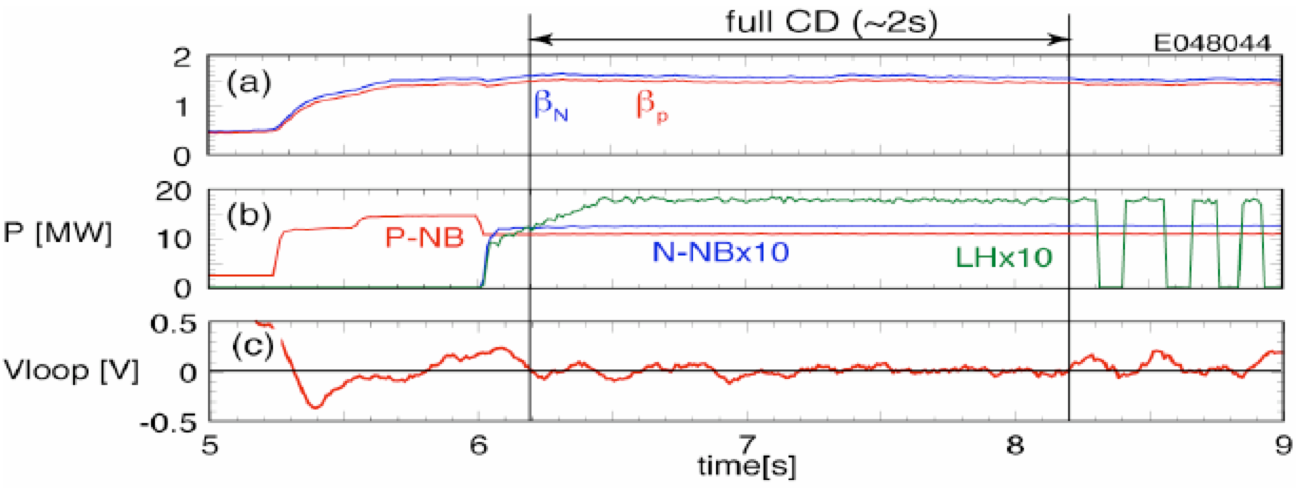
A series of 3 sequential long-pulse discharges and 7 hours GDC were effective to reduce recycling.

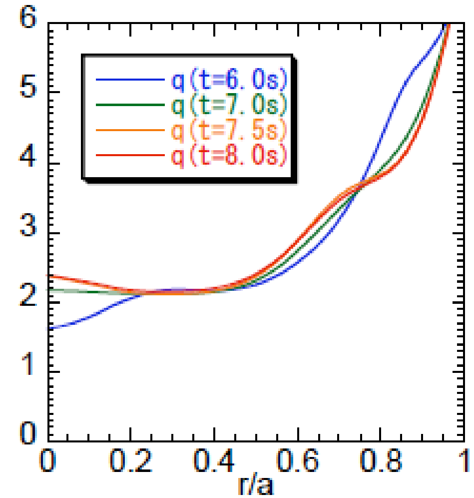




Fully non-inductive having relaxed current profile with high f_{BS} (= 0.5)

JT-60U

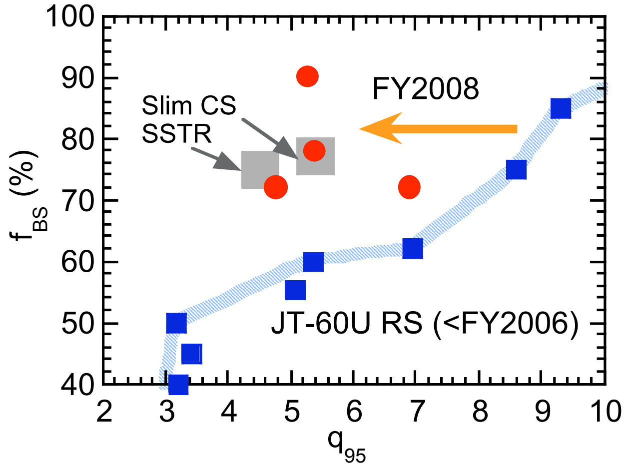




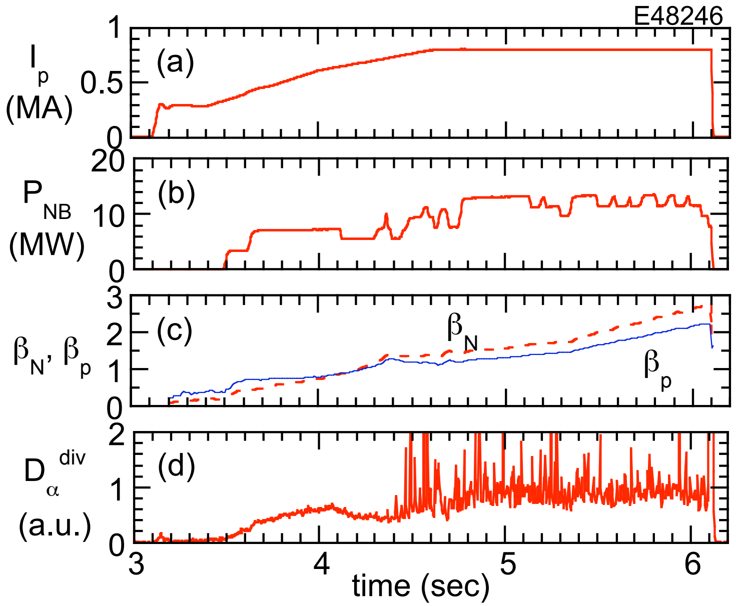
- Full CD condition was obtained in the high βp plasma, assisted by N-NB (320keV, ~ 1.2MW) and LHCD (~ 1.8MW) in E48044 (Ip=0.8MA, Bt(0)=2.3T, q_{95}=5.8).
- Current drive fraction (ACCOME code)
  - **Bootstrap current ; 50%**
  - **LHCD; 26%**
  - **N-NB CD ;24%**
- Weak shear regime at q_{min}=2.1(>2) and q(0)=2.4.
- No MHD activity was observed (1/1, 3/2, 2/1 mode-free q profile).

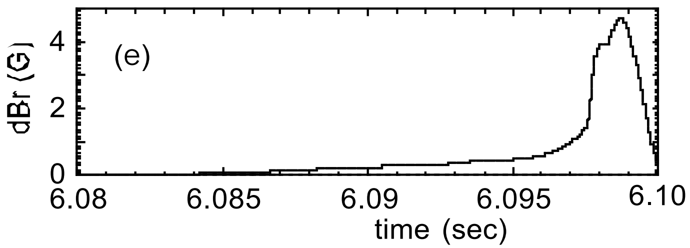
Reversed shear plasmas with high f_{BS} were extended to the low q_{95} (~ 5) and high β_N regime

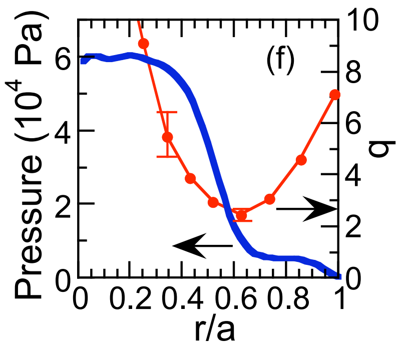
JT-60U

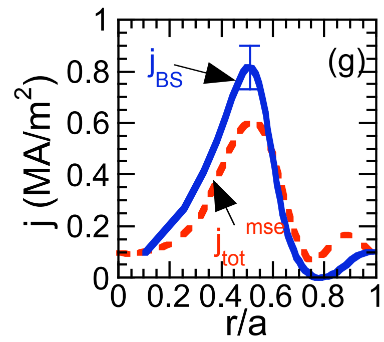


- By utilizing large volume configuration close to the conductive wall for wall stabilization (d/a ~ 1.2), beta limit is significantly improved.
- As a result, β_N ~ 2.7 and β_p was achieved in RS plasma with q_{min} ~ 2.4.









Tungsten accumulation found to be a strong function of the plasma rotation speed.

JT-60U

There are strong arguments on the choice of Tungsten as the first wall materials in ITER.

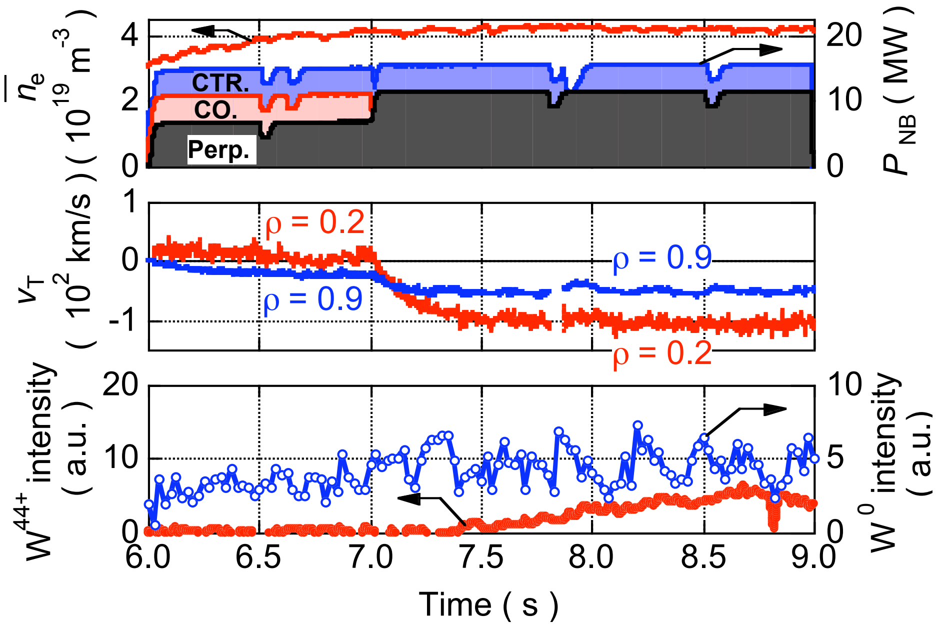
Merit (compared with CFC)

- Small amount of tritium retention.
- Small sputtering yield.

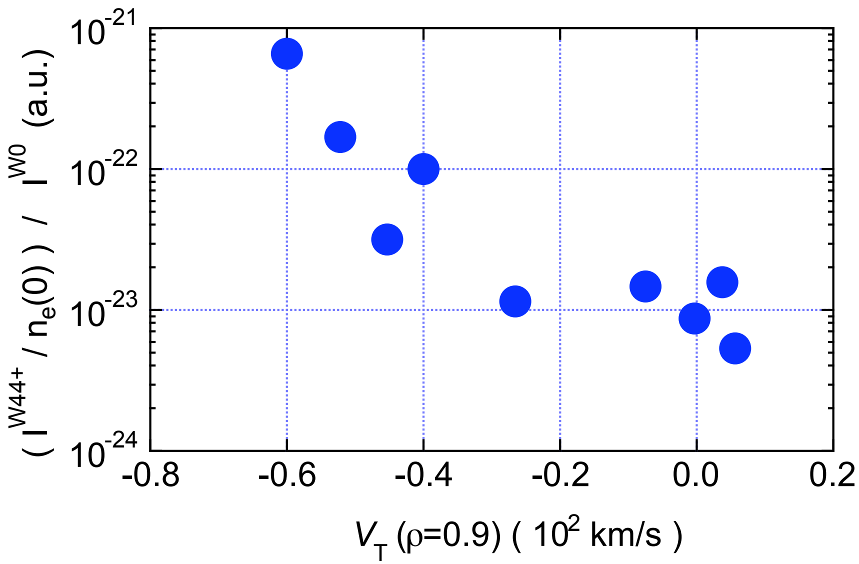
Demerit

- Strong radiator in high Te plasmas.
- Small amount of W allowed.

Plasma rotation changed when the outer strike point is on the W coated tiles. (~5 % of toroidal coverage).



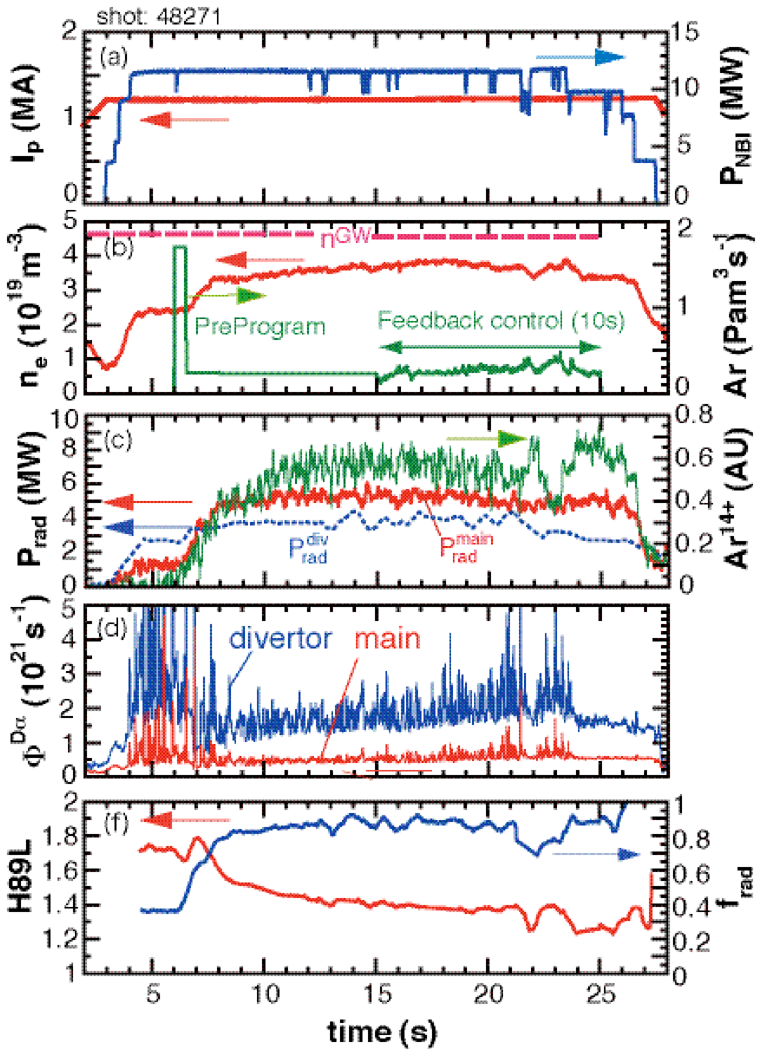
Tungsten accumulation rapidly increases with VT in counter Ip direction.



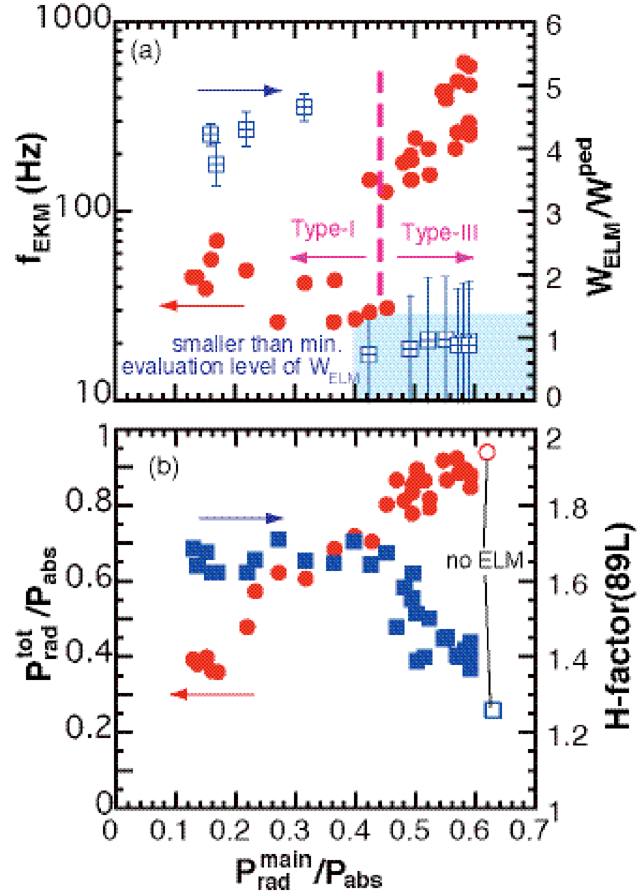
Long-sustainement of good energy confinement plasma with low ELM energy loss due to large radiation fraction by Ar seeding.

JT-60U

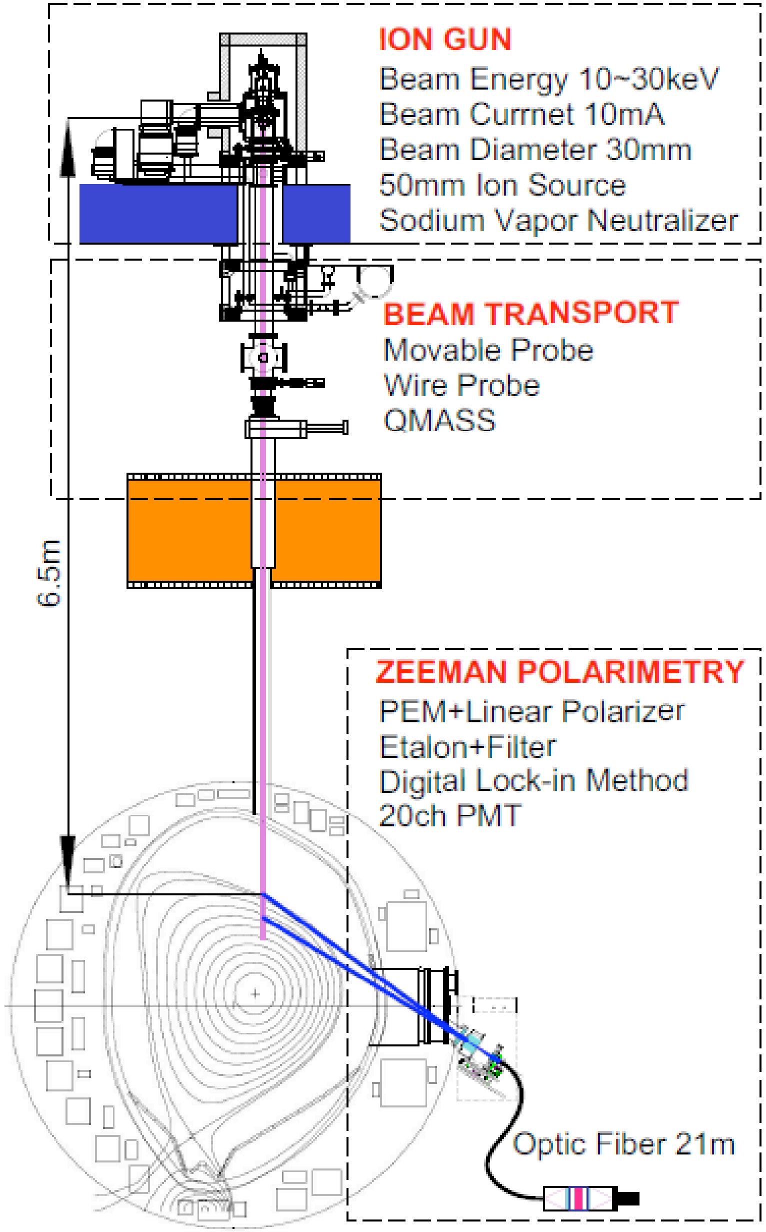
- Large frad (= 0.82-0.9), high n_e/n_{GW} = 0.74-0.8 and relatively good H_{89L}(= 1.37-1.45) was sustained for 16s.

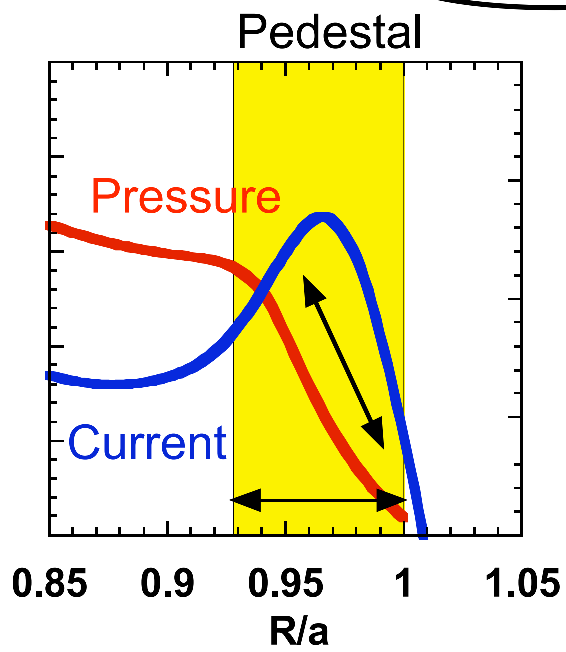


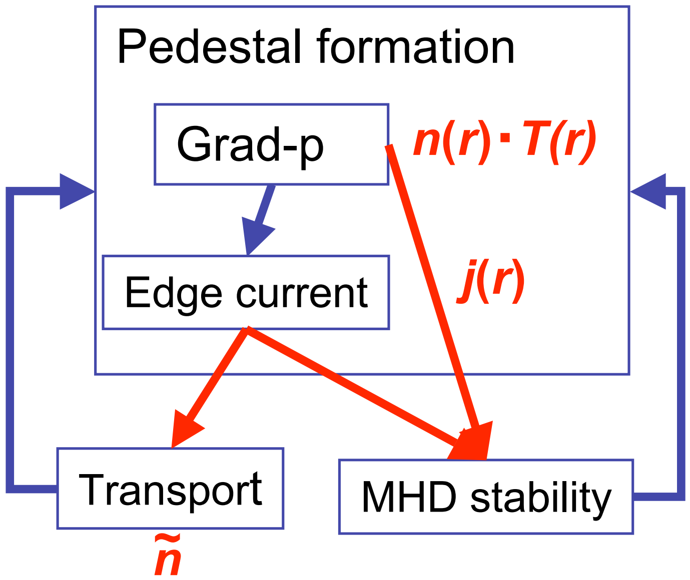
Low ELM energy loss (W^{ELM}/W_{ped}<1.7%)



Lithium Beam Probe is being developped for JT-60U

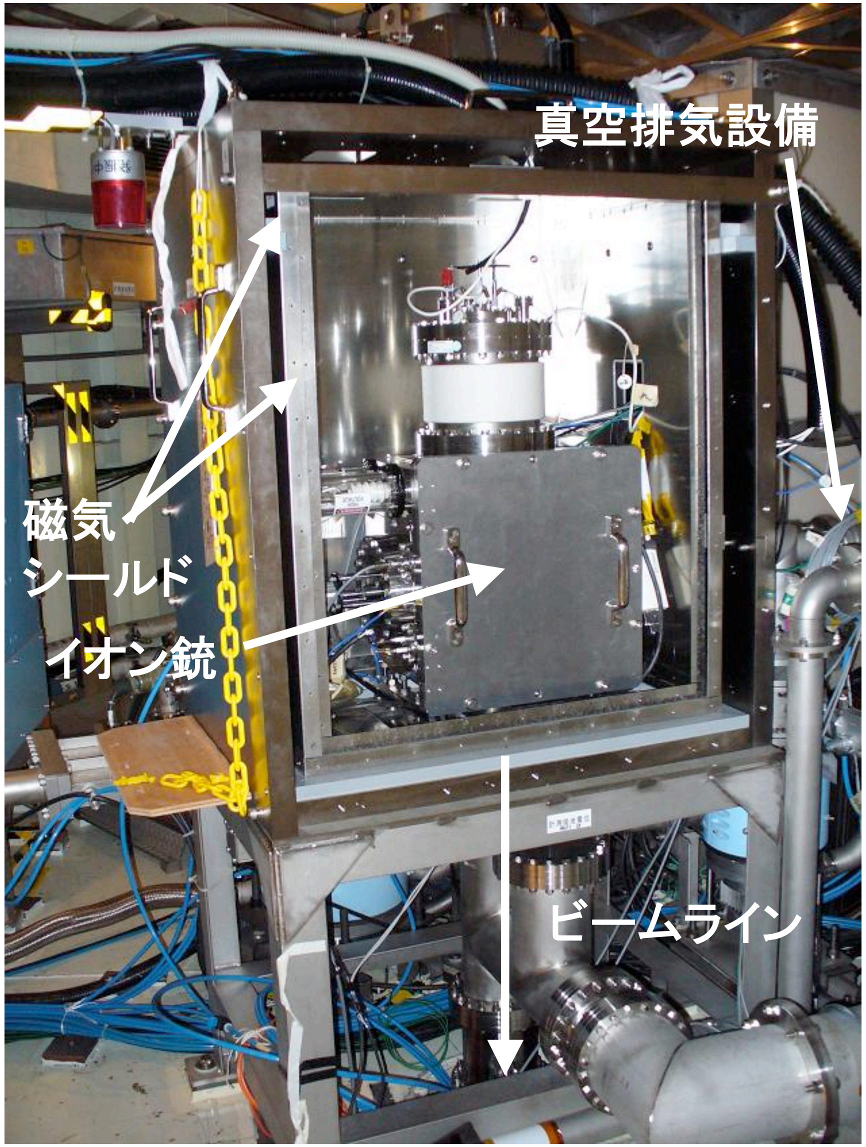


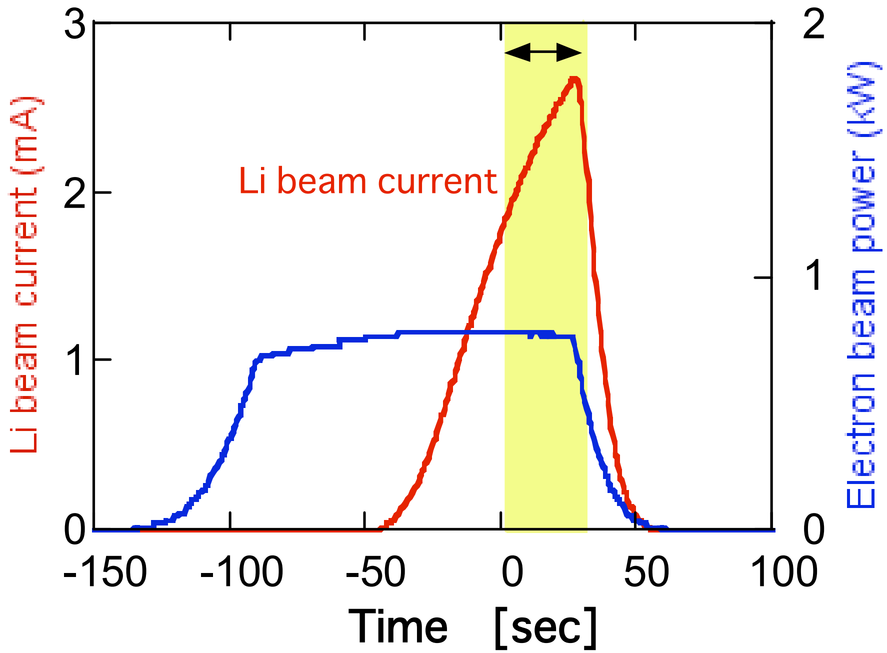




Li beam gun installed in JT-60

JT-60U

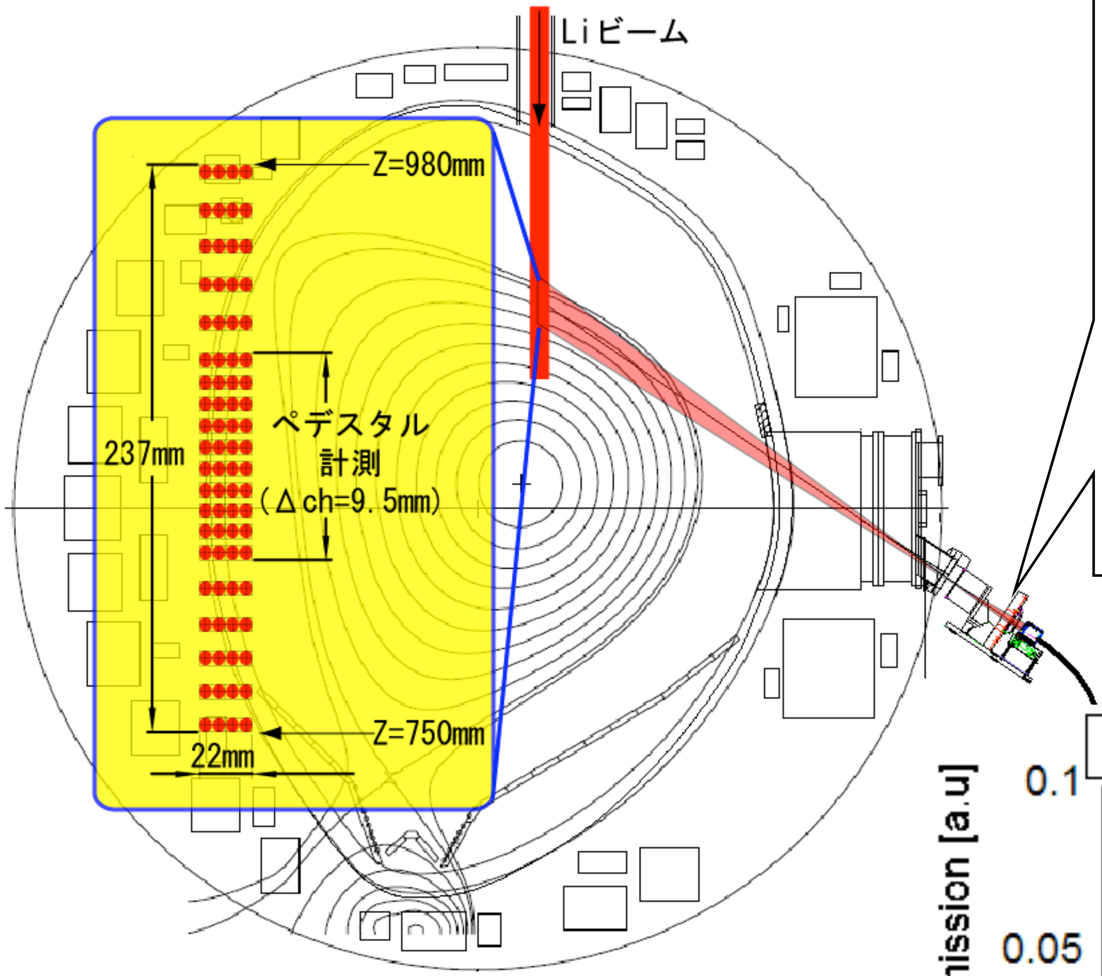


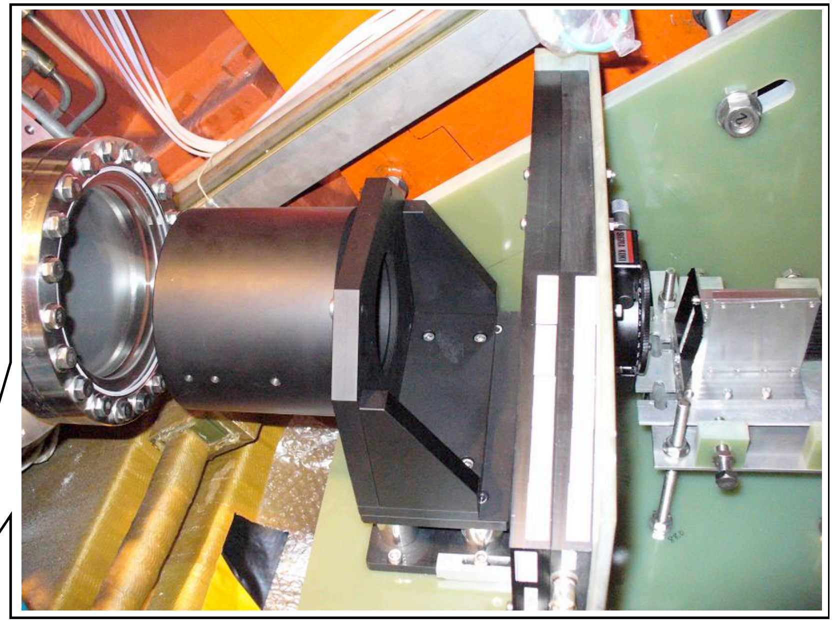


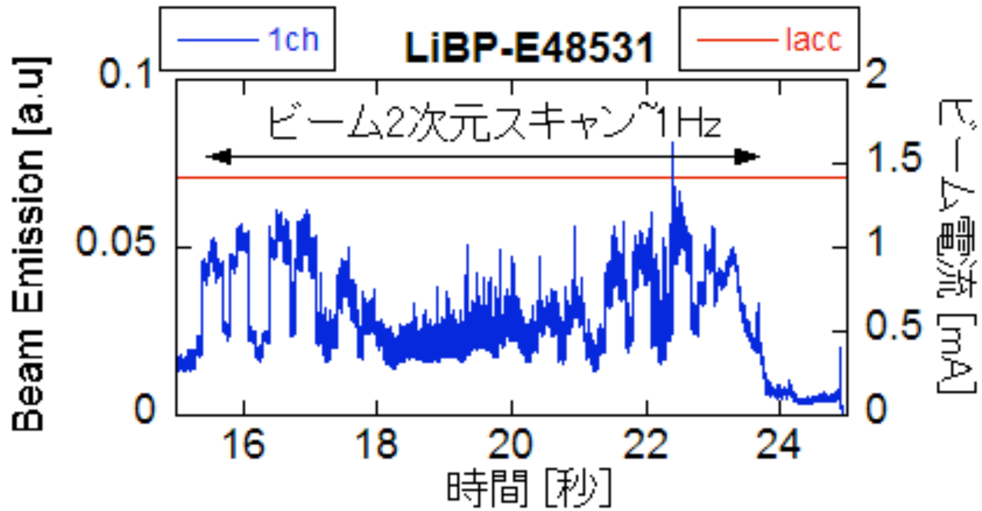
- Magnetic shield 300G -> 0.1G

Li BP is now ready for the plasma density measurement

JT-60U





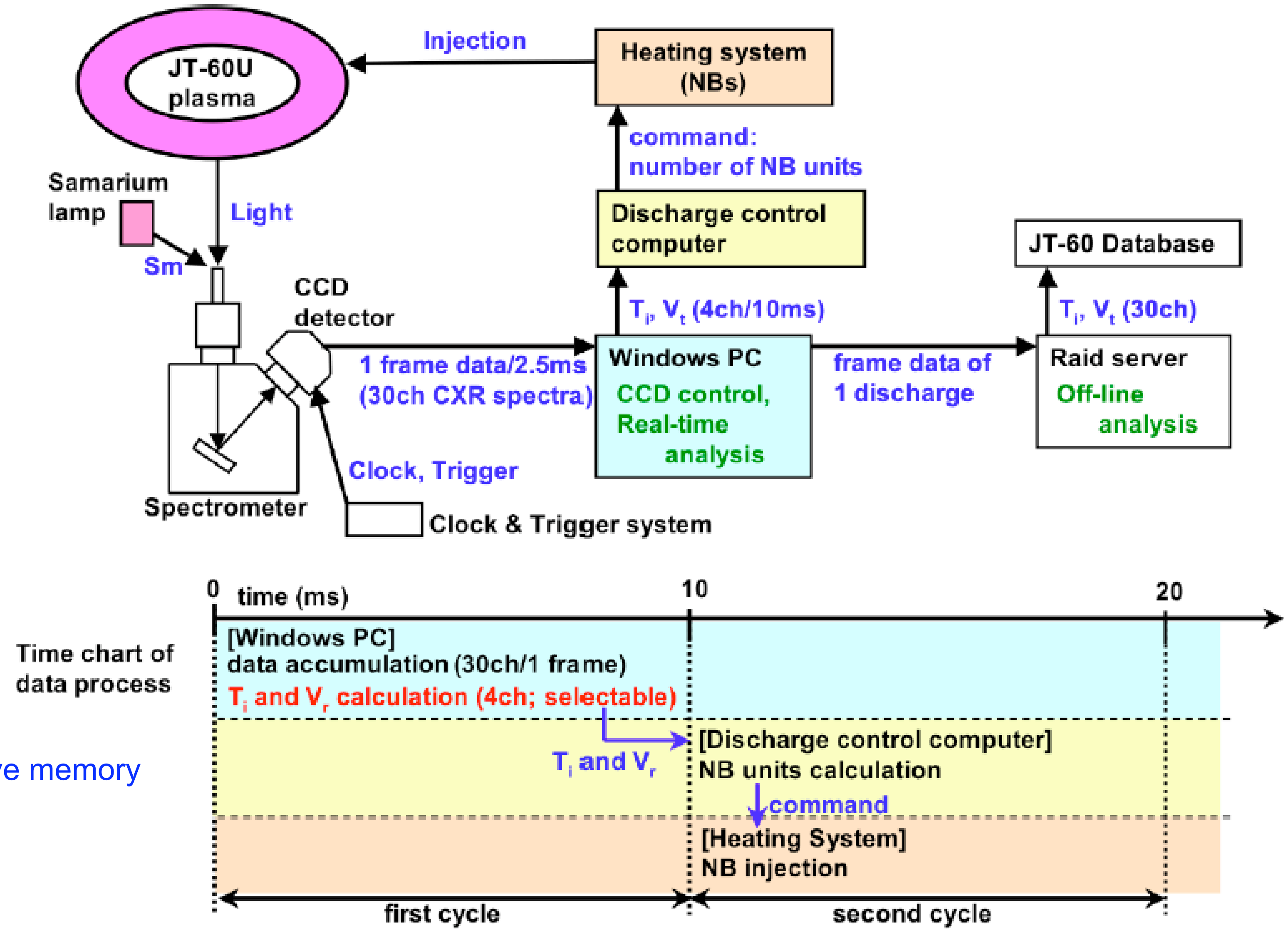


- Data Acquisition

20ch、1MHz sampling

Real time control using fast CXRS

JT-60U

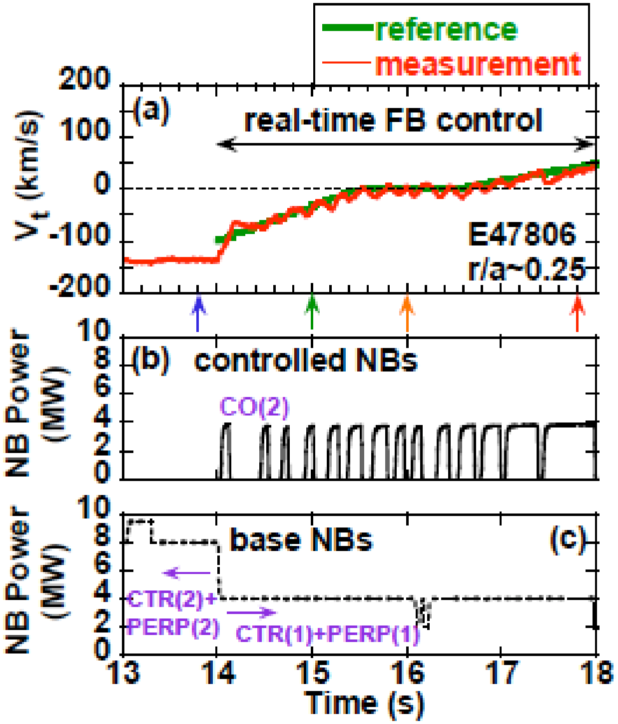


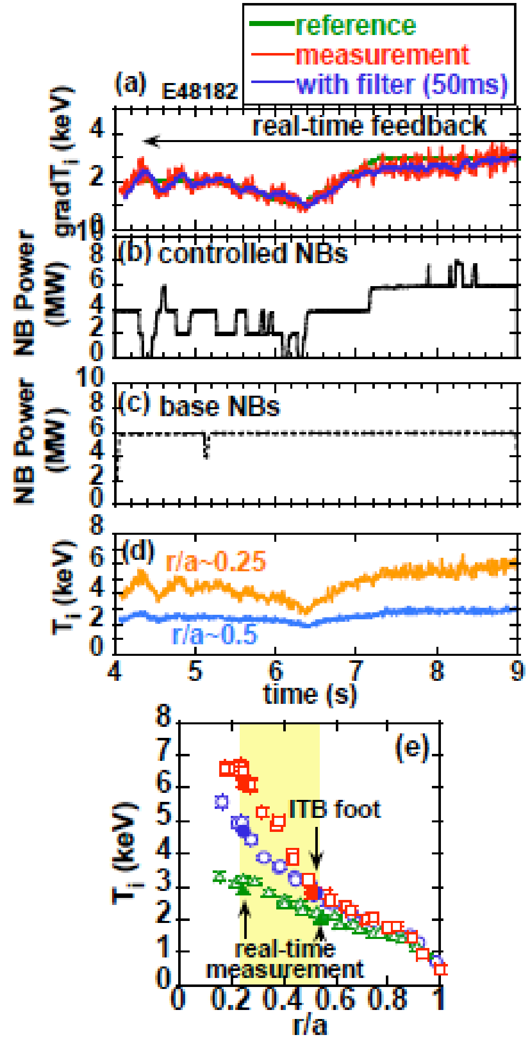
Reflective memory

Vϕ and grad p control in JT-60U

JT-60U

- *M. Yoshida et al, submitted to Fusion Engineering and Design (2008)*





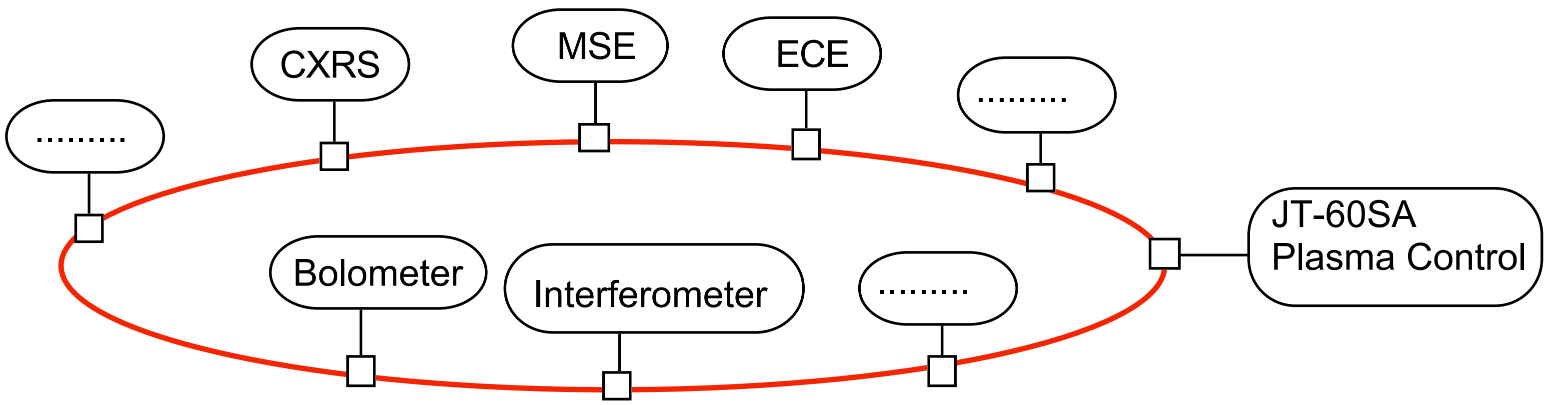
Simultaneous plasma control in JT-60SA

The current density profile j(r) is strongly linked with the plasma pressure profile p(r) in high f_{BS} *plasmas.*

In order to achieve high β_N *plasmas above the no wall limit in steady state, the NTM modes and RMW must be suppressed by the real time control of the plasma profiles, such j(r), p(r) and* V_ϕ*, simultaneously.*

In addition to the main plasma parameters, the detached divertor must be sustained and controlled in the divertor plasma.

- Reflective memory loop for real time control

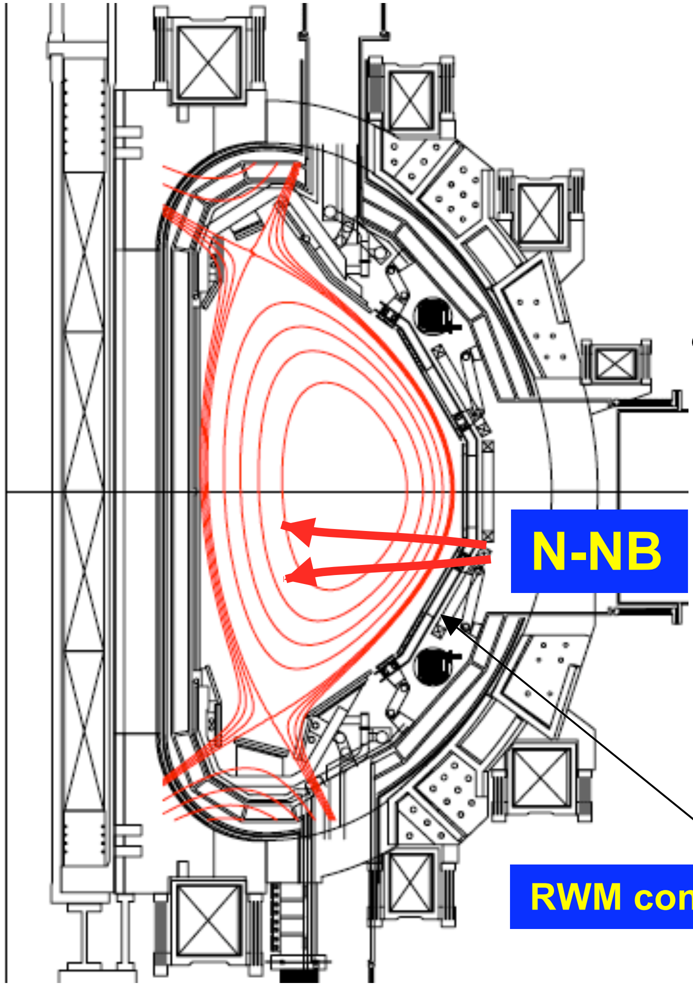


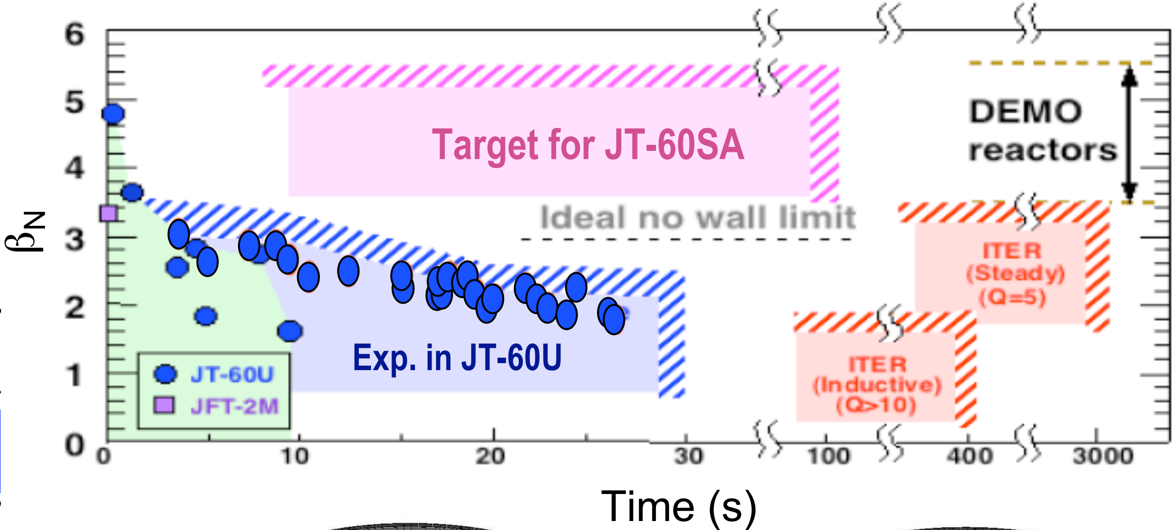
Each diagnostic system provides the processed plasma parameters in real time to this loop, which is refleshed in time scale of the plasma control.

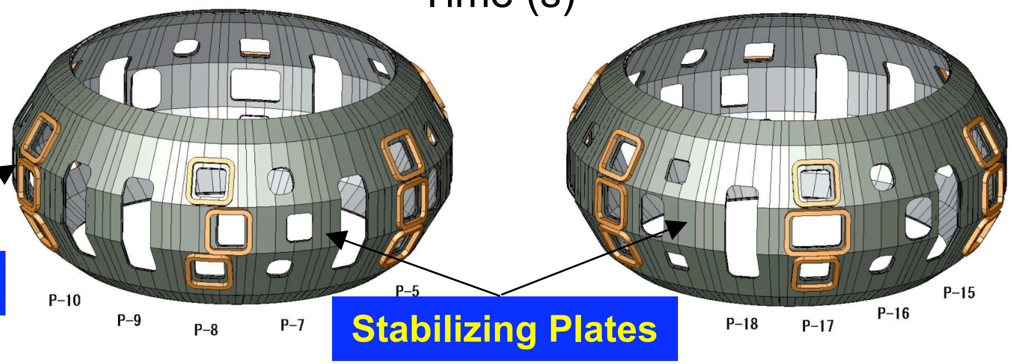
Plasma diagnostics plan in JT-60SA tokamak

Mission of JT-60SA is to support and supplement ITER toward DEMO.

JT-60 SA is a combined program of ITER Satellite Tokamak Program of JA-EU and Japanese National Program







Sharing of construction of JT-60SA

Superconducting Magnets
- Poloidal field coils (CS & EF)
- Toroidal field coils

Cryostat

Cryogenic System

Power Supply

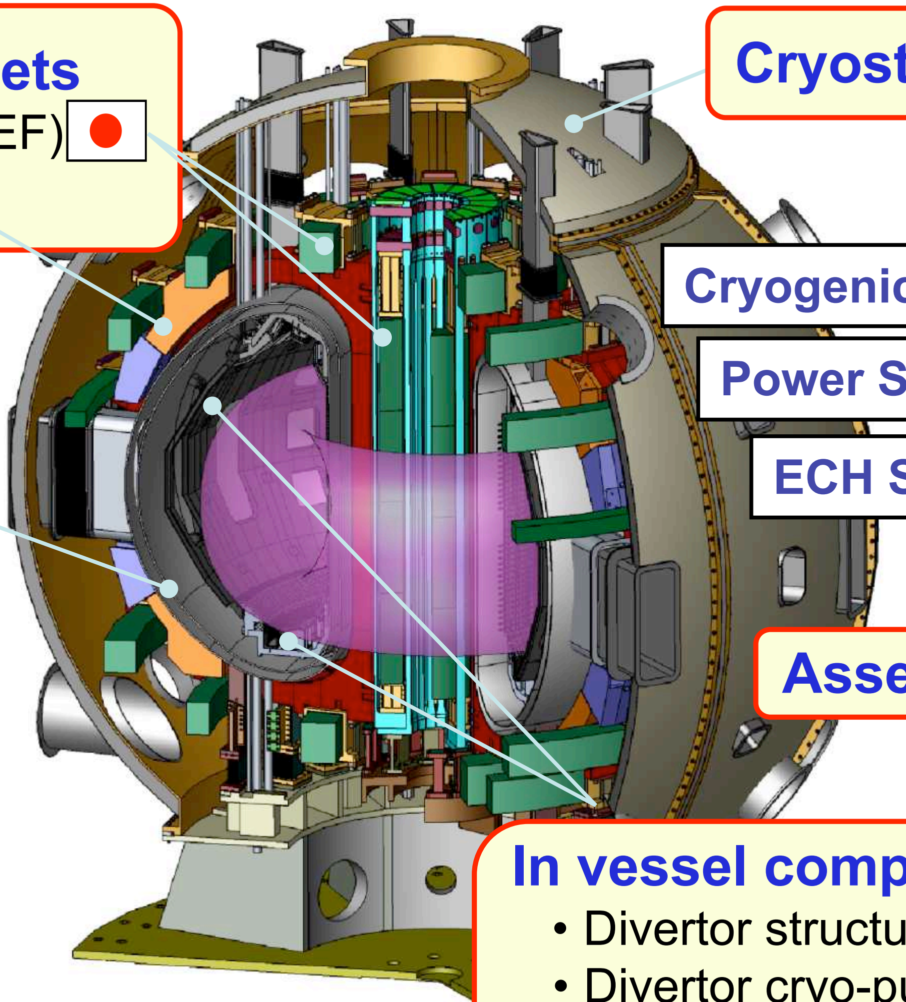
ECH System

Vacuum Vessel

NBI system

Diagnostics

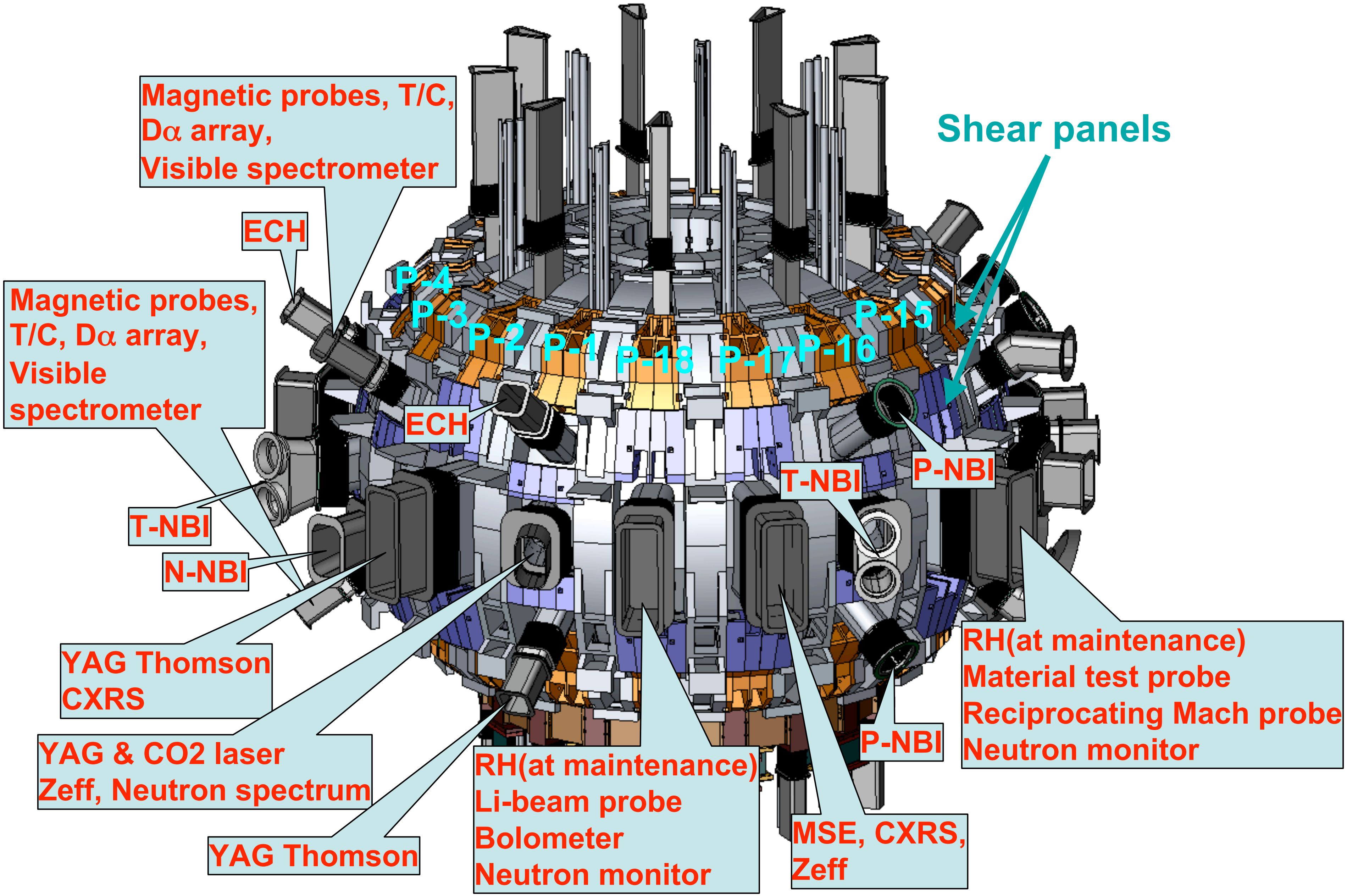
Assembly



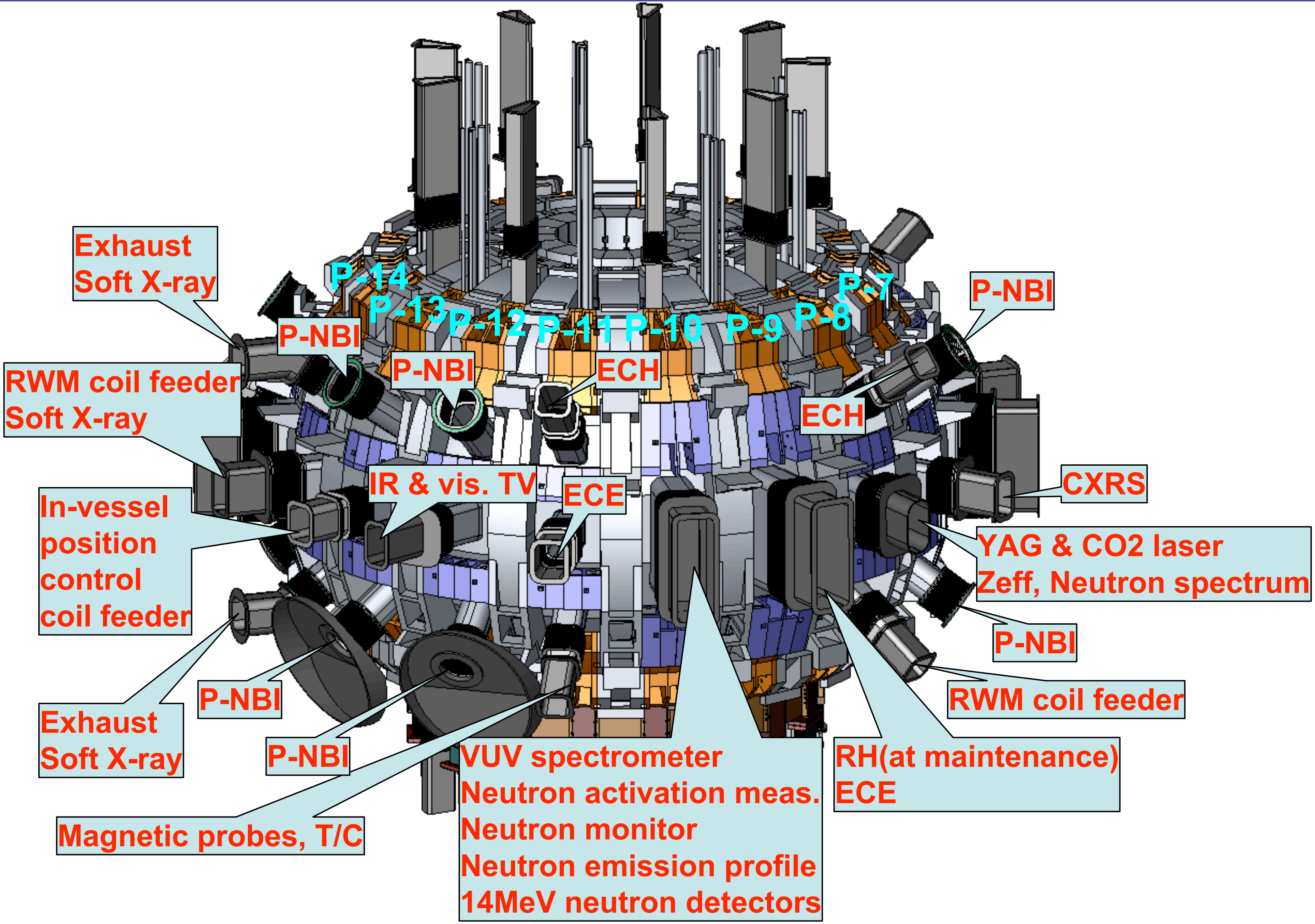
In vessel components
- Divertor structures
- Divertor cryo-pumps
- First walls
- In vessel coils

Remote Handling System

Outline of Port Allocation(P-4, P-3, ---, P-16, P-15)



Outline of Port Allocation(P-14, P-13, ---, P-8, P-7)



Specification of the diagnostic systems (SA-CDR Appendix)

• For Machine Protection and Operation

System	Specification
Neutron monitor	Total DD neutron emission rate measurement. Sets of 235U and 238U fission chambers will be installed at two or three toroidal positions and one micro fission chamber (235U) will be installed inside a horizontal ports.
Neutron activation measurement	Calibration measurement for the neutron monitor. The main components of the present system in JT-60U are reused. (Ge detector for gamma ray).
Visible TV	Plasma and First wall are monitored with visible light images. This system consists of the endoscope, visible camera and image processing hardware.
Dα emission monitor	Particle recycling measurement. The main components of the present system in JT-60U are reused except for the objective optics. 32 ch (8 ch for the lower divertor, 8ch for the upper divertor, 8ch for the lower baffle and 8ch for the
Divertor Langmuir probe	Divertor plasma parameters (Te, ne, potential etc.) measurement. Two sets of ~ 24ch arrays are expected both for the lower and upper divertor plates, including dome. Additional channels to cover the baffles and first walls are planned.
Infrared TV camera (diertor)	Profiles of temperature and heat flux density on the divertor are measured. IR images of targets in the lower and upper divertor are transferred via IR endoscopes and then monitored by IR cameras.

• For Fundamental Parameter Measurement

System	Specification
YAG laser Thomson scattering system	Te and ne profile measurement. This new system consists of the tangential injection of YAG laser beam and three detection optics (edge, core and inside). The repetition frequency of YAG laser is 50Hz. The inside and edge optics are deferred to the operational phase.
CO2 laser interferometer / polarimeter (tangential)	Line density (tangential chord) measurement. The specifications will be similar to those of the present system (e.g., resolution with 1 ms sampling is ~0.5×10^{19} m^{-2}, the resolution with 5ms sampling is ~2×10^{19} m^{-2}.
CO2 laser interferometer / polarimeter (vertical) *	Line density (vertical chord) measurement. The specifications will be similar to those of the tangential system. This system is deferred to the operational phase.
ECE diagnostics (Fourier transform spectrometer, Grating polychoromator, Heterodyne radiometer)	Te profile measurement. Time resolutions are as follows, FTS: 25ms & typically ~20ch depending upon Bt & configuration, GP: 20 μs & 40ch, HR: 20 μs & 24ch (+24ch capability) , respectively.
Charge exchange recombination spectroscopy	Ti and the plasma rotation profile measurement. This system consists of the toroidal system (~18ch) and the poloidal system for the core plasma (~18ch) and the poloidal system for the edge plasma (~8ch). The spatial resolution of 3 ~ 6 cm and the time resolution of up to 2.5 ms are expected.
Z_{eff} monitor (visible bremsstrahlung emission)	Zeff profile measurement. Number of the tangentially viewing chords is 14 ch, time resolution 1 ms.
VUV spectrometer	Spectrum measurement of VUV light from the main plasmas. Measurable wavelength is from 0.5 to 40 nm with 20ms time resolution.
Motional Stark effect polarimeter	Plasma current density profile measurement. Spatial resolution ~10cm. Time resolution ~10ms.
Bolometer (main, divertor)	Plasma radiation profile measurement. In addition to the resistive bolometer arrays, the imaging video bolometer (IRVB) systems, which is underdeveloped

* Defered to the operational phase.

• For Physics Understanding

System	Specification
Soft X-ray detector array	MHD fluctuation measurement. Four detector arrays provide 80 chords, which are used to reconstruct emissivity profiles of soft X-ray from the main plasmas.
Neutron emission profile monitor *	Measurement of DD neutron emission profile in the core plasma. The main components of the present system in JT-60U are reused.
14 MeV neutron detectors *	DT neutron measurement. The main components of the present system in JT-60U are reused. This system is deferred to the operational phase.
Neutron spectrometers *	Energy spectrum of DD neutron measurement. The main components of the present system in JT-60U (time resolution ~0.1s) are reused.
Infrared TV camera (first wall) *	First wall are monitored with IR light images. This system consists of IR endoscopes, IR cameras and image processing hardware.
Li-beam probe *	Measurement of current density and ne in the edge plasma. The system consists of the Li-Beam injector and the detection optics. This system is underdeveloped in JT-60U and reused in JT-60SA.
Reflectometer *	Plasma density fluctuation measurement. The main components of the present system in JT-60U are reused. O mode, 3ch (34GHz, 36 GH, 48GHz)
Reciprocating Mach probe *	SOL plasma parameters (Te, ne, potential etc.) measurement. The basic design is similar to the present system in JT-60U are reused. This system is delayed to the operational phase.
Visible spectrometer for the divertor	Multi-channel spectrometer of visible light from the divertor plasmas. Low wavelength resolution spectrometer (instrumental width 0.05nm, 16ch), High wavelength-resolution spectrometer (instrumental width 0.006 nm, 16ch) and Survey spectrometer (wavelength band 500 nm, 100ch) are equipped.
VUV spectrometer for the divertor *	Spectrum measurement of VUV light from the divertor plasmas. The main components of the present system in JT-60U are reused. Measurable wavelength is from 2.5 to 130 nm with 20ms time resolution.
Neutral gas pressure gauge (Penning gauge, Fast response ionization gauge)	Several sets of penning gauges (for pumping regions and main chamber region) and fast response ionization gauges (for the upper and the lower divertor regions).

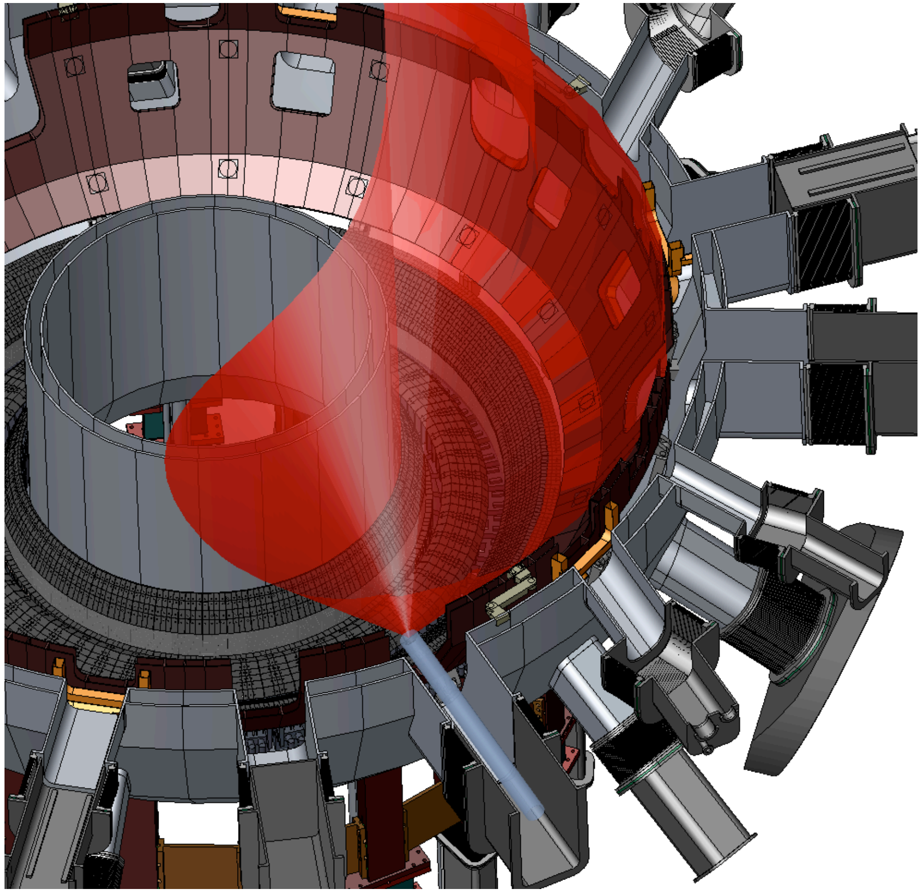
* Defered to the operational phase.

Wide angle IR/Visible periscope

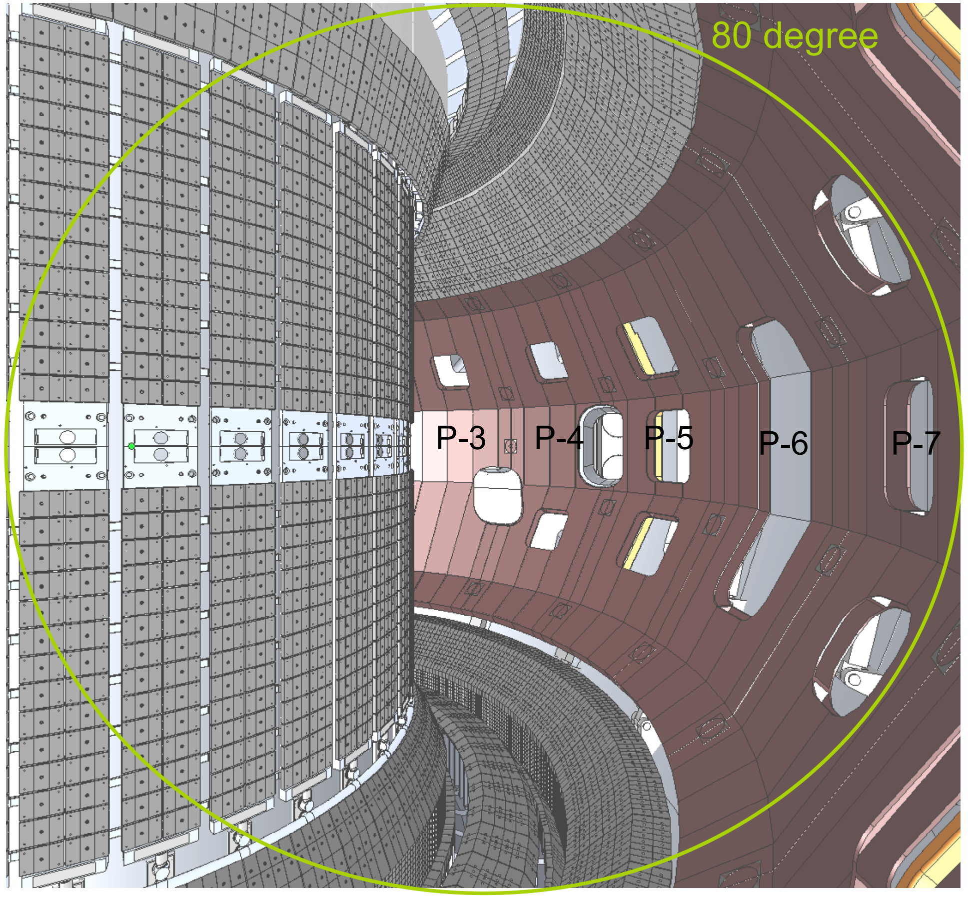
Visible TV camera (Plasma and First wall)

JT-60SA

Bird eye view



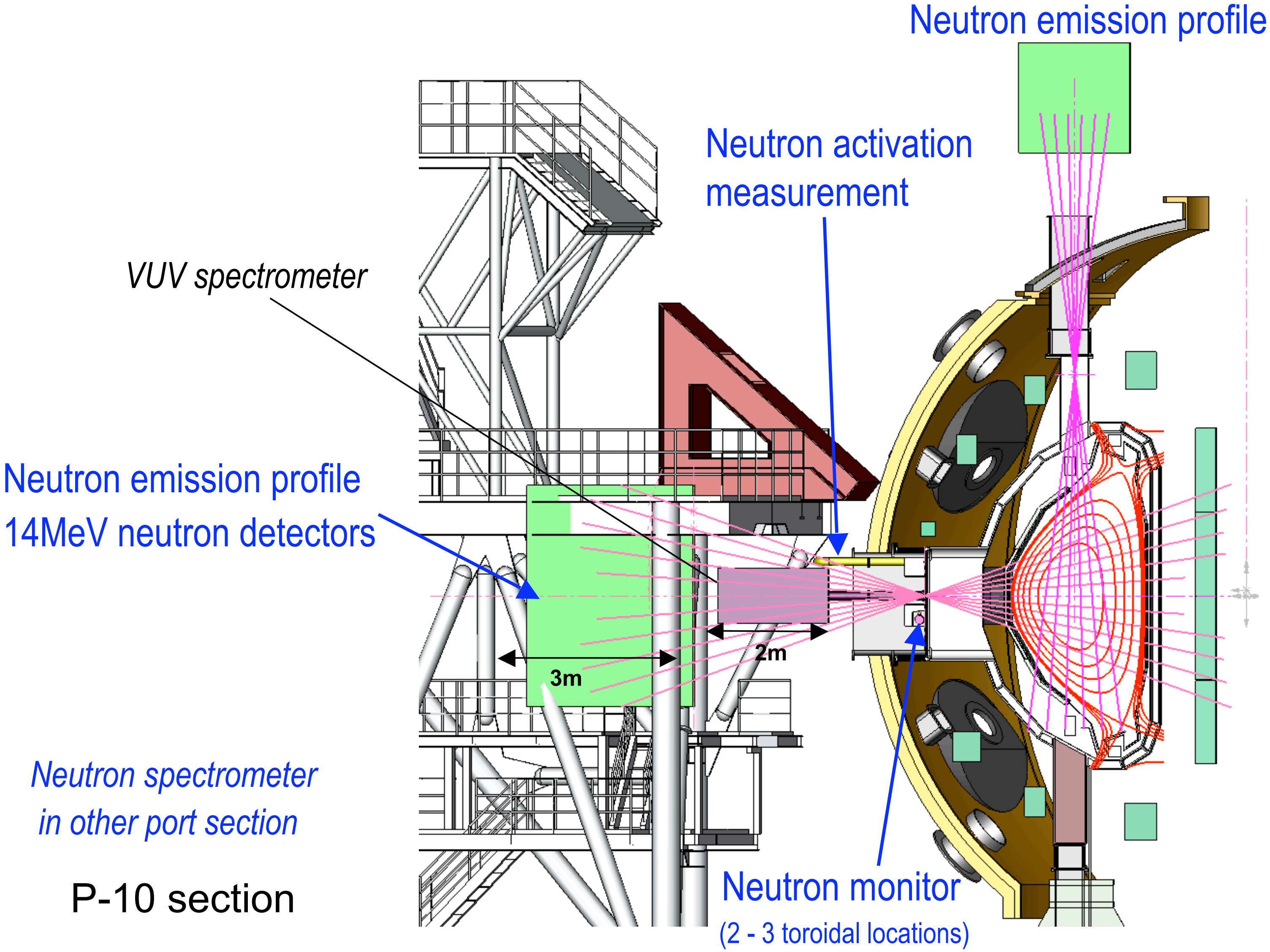
Inside vessel



Neutron measurements

Neutron monitor, Neutron activation measurement

Neutron emission profile monitor, 14MeV neutron detectors, Neutron spectrometer

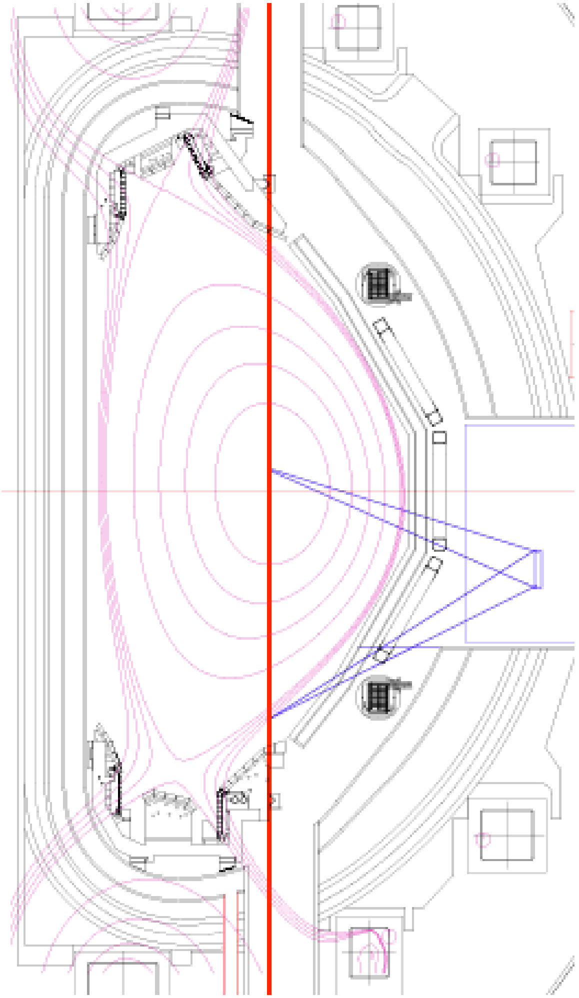


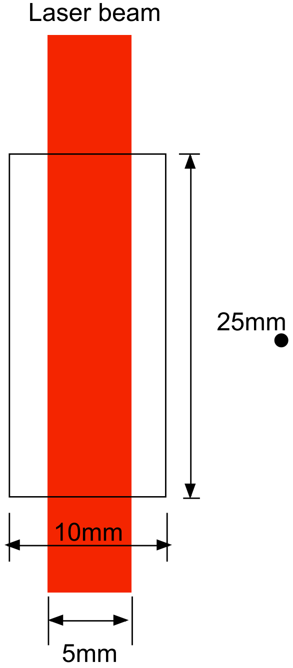
Neutron spectrometer in other port section

P-10 section

Enhancement of the spatial resolution from JT-60U and capabilities to measure Te = 30 keV is required.

YAG laser Thomson scattering





Good spatial resolution is required for ne, Te and Ti measurement on the ITB (Δ /a ~ 0.1) in the strong reversed shear plasmas and on the edge transport barriers (Δ /a ~ 0.05) in H-mode plasmas.

- A large enhancement of the spatial resolution of YAG laser Thomson scattering from JT-60U is required for ne and Te profile measurement.

- The enhanced electron enhanced heating capabilities (P_{NNB} = 10 MW, P_{ECH} = 7 MW), requires the YAG Thomson scattering system capabilities to measure T_e = 30 keV.

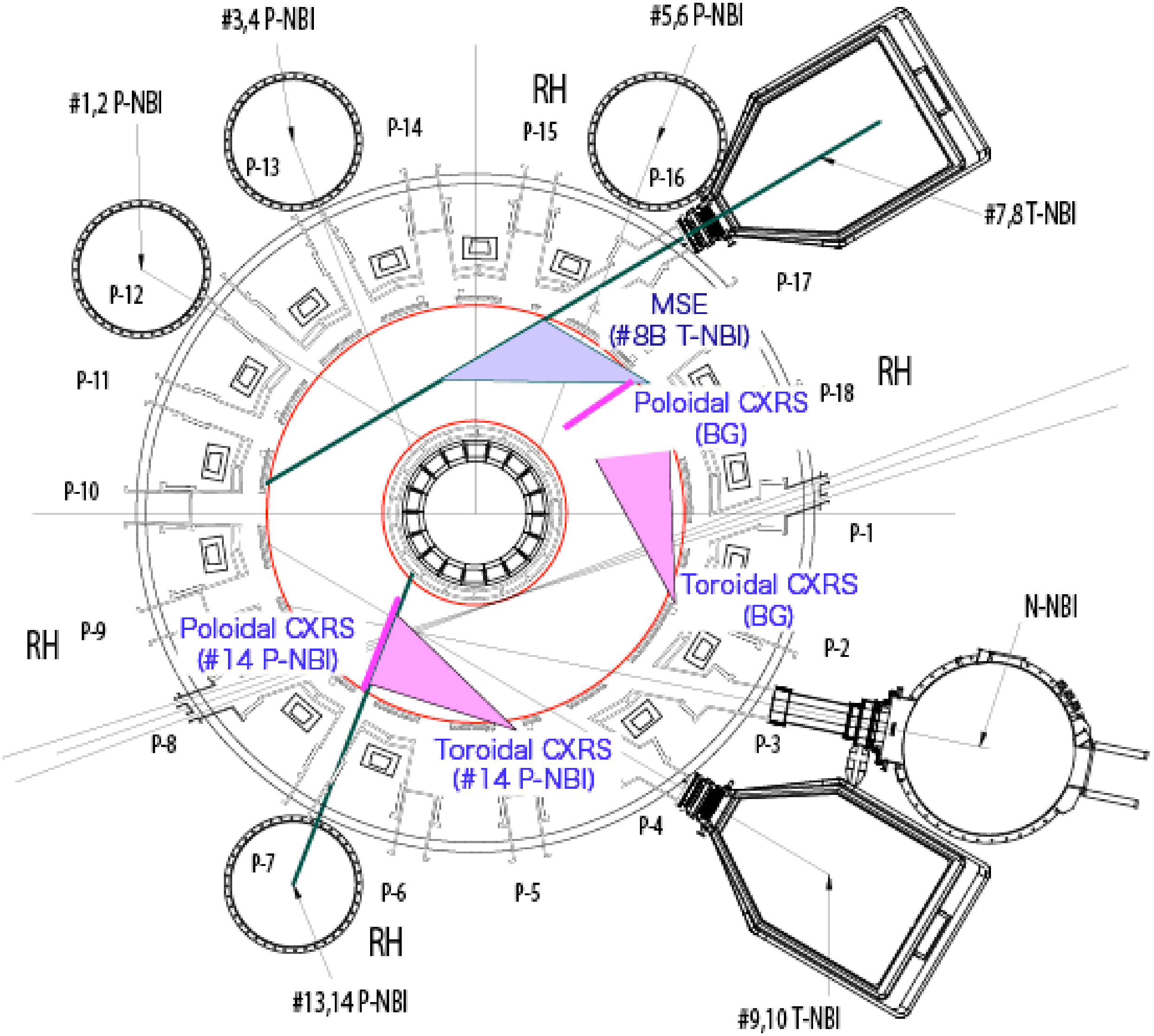
P-5&P-2 Toroidal field of view, P-8&P-17 Poloidal field of view

Toroidal & Poloidal CXRS (charge exchange recombination spectroscopy)

P-17 Tangential field of view

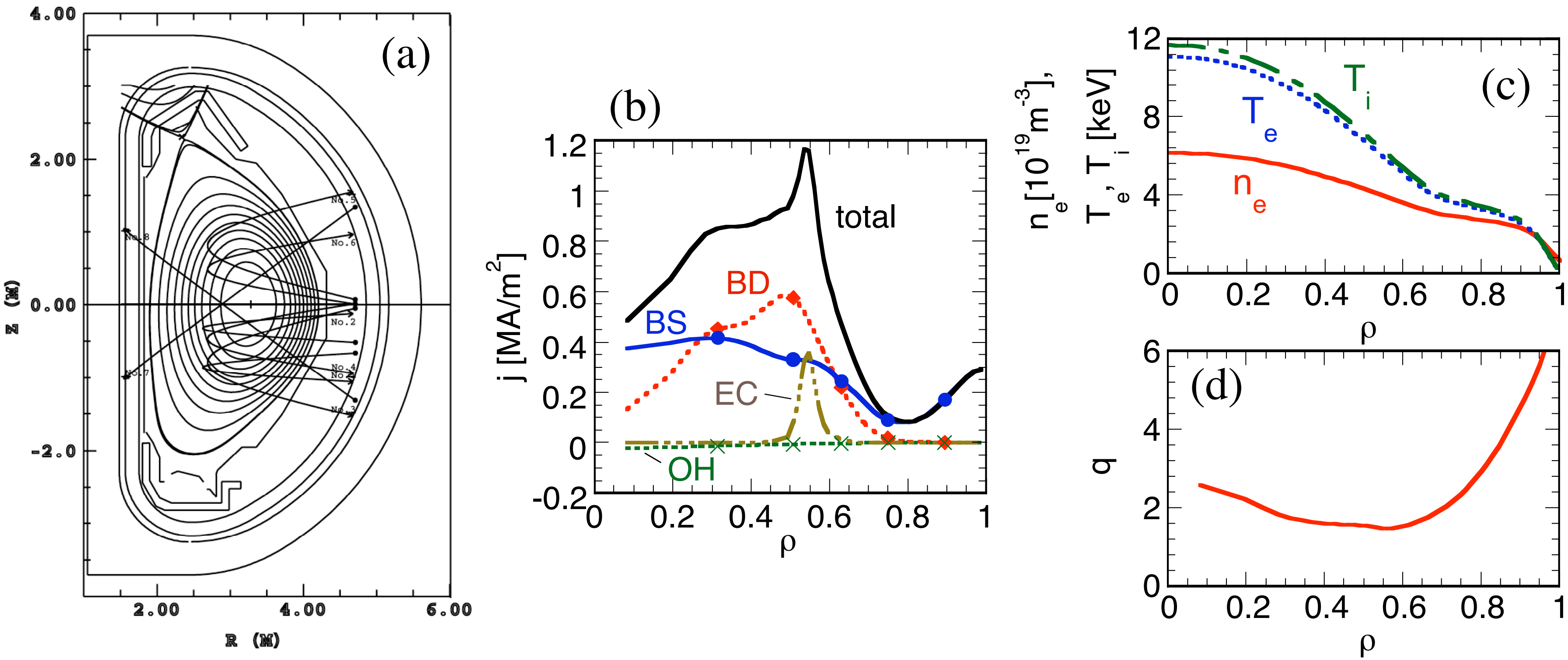
MSE (MSEortional Stark effect polarimeter)

JT-60SA



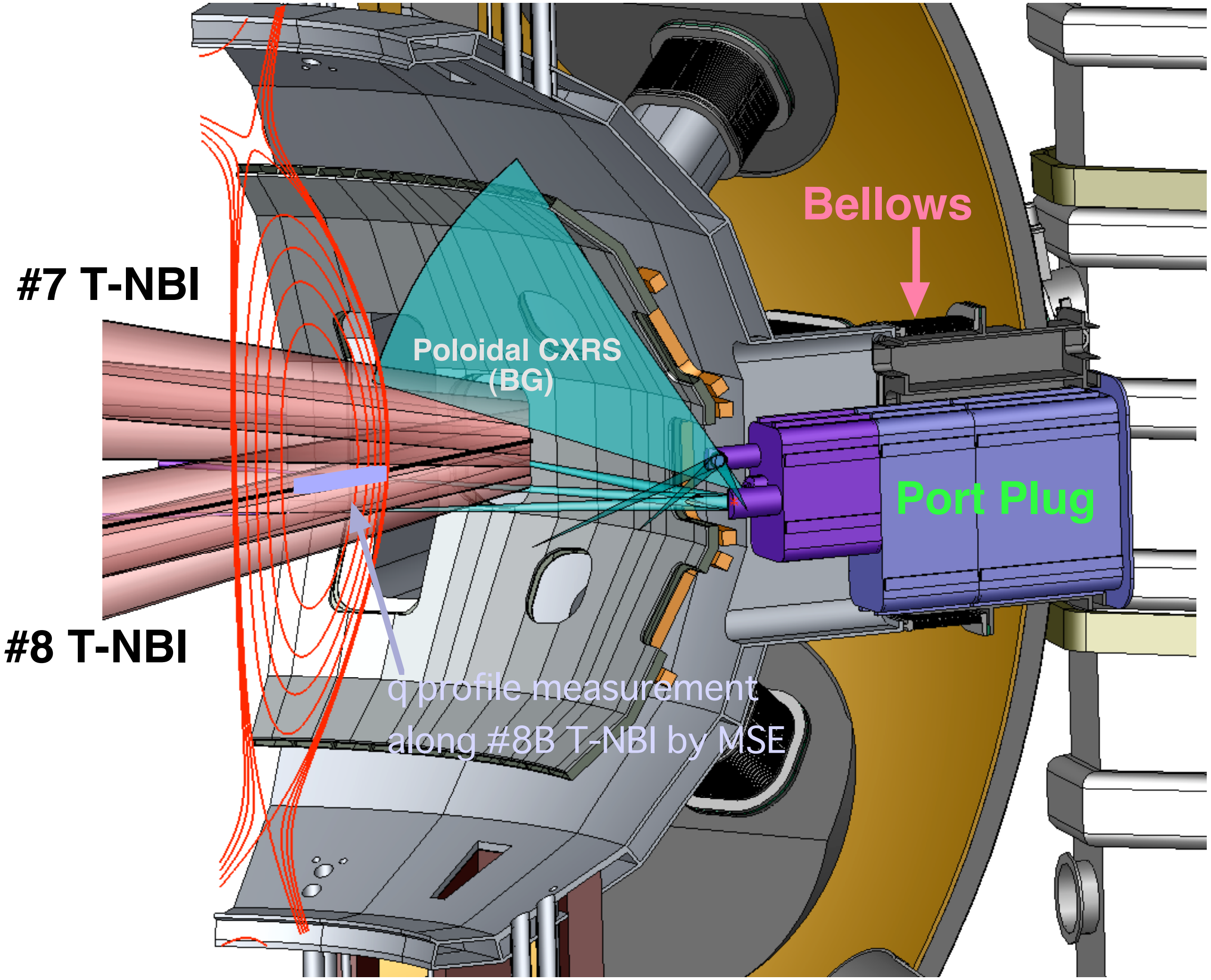
Plasma current profile measurement by MSE

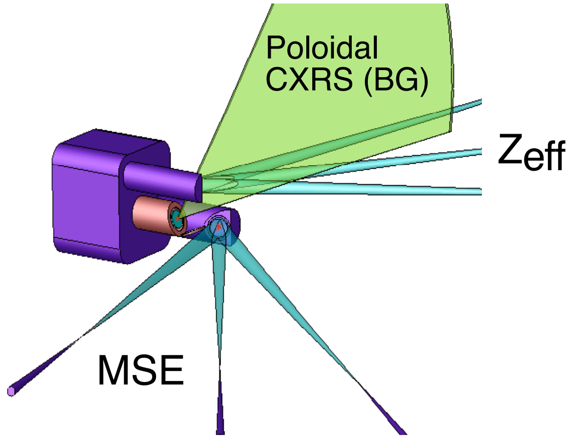
- ECH has very localized absorption and current drive profile in the middle of the plasma.
- A spatial resolution of d/a ~ 0.03 is required in MSE measurement. (Improvement in spatial resolution by a factor of 1.5 from JT-60U)



A full CD plasma scenario, produced by ACCOME code in the conditions with I_p = 3 MA (B_t = 2.27 T, q_{95} = 5.6, b_N = 3.6, b = 4.2%,. f_{BS} = 0.55) for H_{H98y2} =1.33 with total heating power of 41 MW.

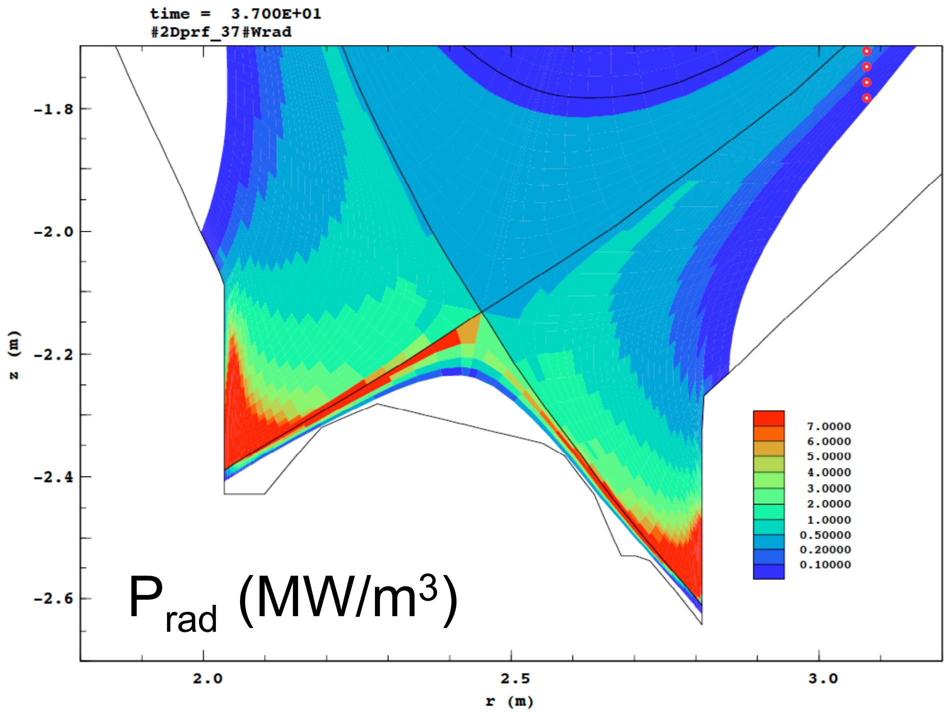
The objective optics of MSE, Z_{eff} and CXRS are encolsed in a port plug and inserted in P-17 horizontal port section





Observation of detached divertor

- Detached divertor associated with strong flow in SOL is the key physics issue for the heat and particle control for steady state operation.
- The peak heat flux density must be suppressed below 15 MW/m^2 by the enhanced radiation power near the strike point of separatrix under the full heating power of 41 MW in JT-60SA.



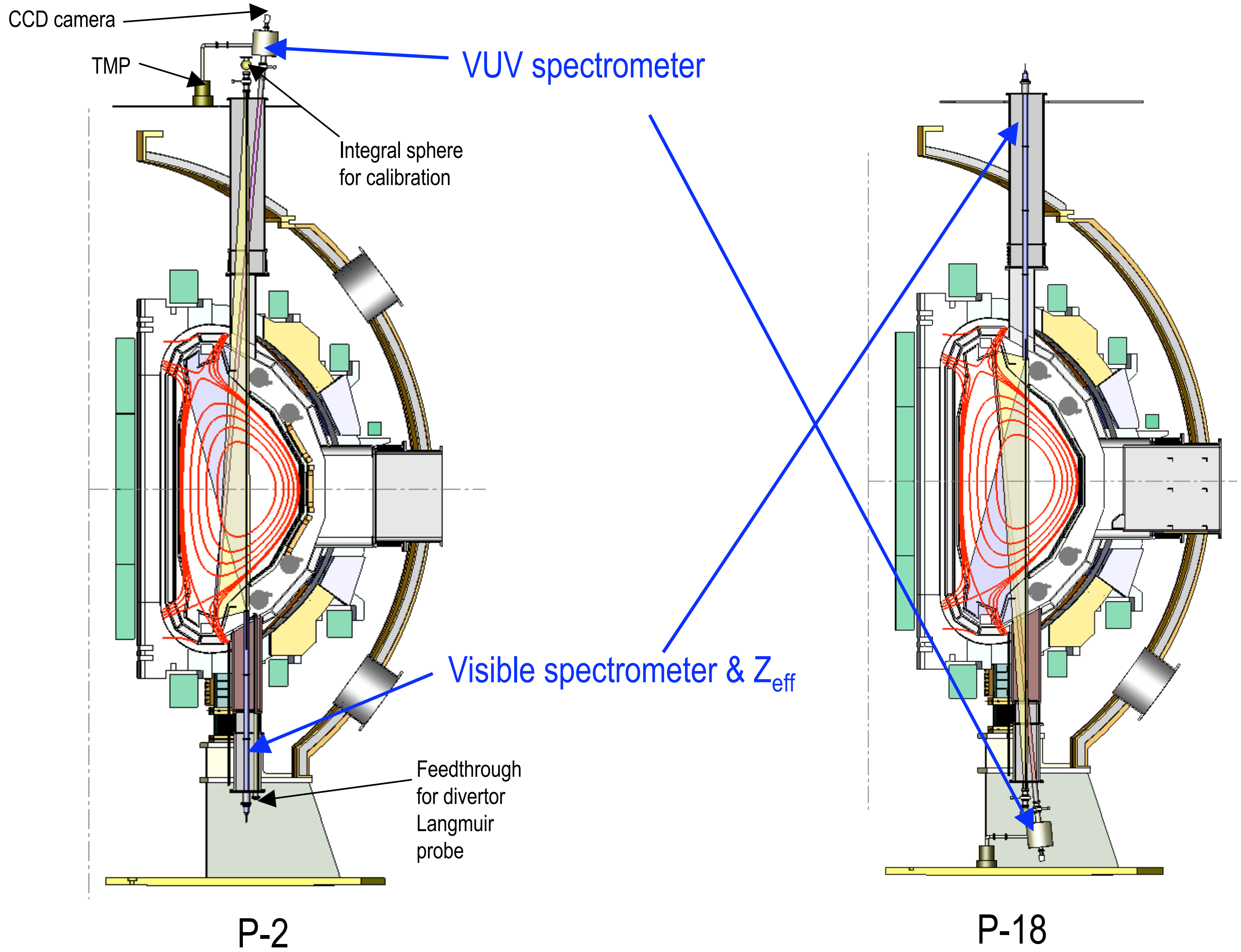
Simulation with the plasma fluid code (SOLDOR) and the neutral Monte-Carlo code.

- Dα ,
- Divertor visible
- Divertor VUV
- Bolometer
- Divertor IR camera
- Langmuir probes
- YAG laser Thomson scattering

Divertor optical diagnostics

Visible & VUV spectrometers for divertor, Z_{eff} monitor

• Upper divertor viewed from the lower port: Lower divertor viewed from the upper port:



Status of JT-60SA dagnostics

- Specification of JT-60SA diagnostic system is defined in SA-CDR appendix.
- Port allocation to the diagnostic systems is under consideration.
- Preliminary design study using CAD is in progress.
  - Field of view design.
  - Arrangement of multiple diagnostics in port plugs.
  - Design change request to in-vessel component, VV and etc.
- Schedule

Fiscal Year	07	08	09	10	11	12	13	14
Design study usign CAD								
Conceptual design								
Detailed design								
R&D (Port Plug,Shutter,etc)								
Fabrication and Installtion								
Test and Comissioning								