EUROfusion

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

ENEA
AGENZIA NAZIONALE PER LE NUOVE TECNOLOGIE, L'ENERGIA E LO SVILUPPO ECONOMICO SOSTENIBILE

The scientific programme of JT-60SA tokamak

Francesco Paolo Orsitto

Colloquium at Columbia University
17 april 2015

Associazione Euratom-ENEA sulla Fusione

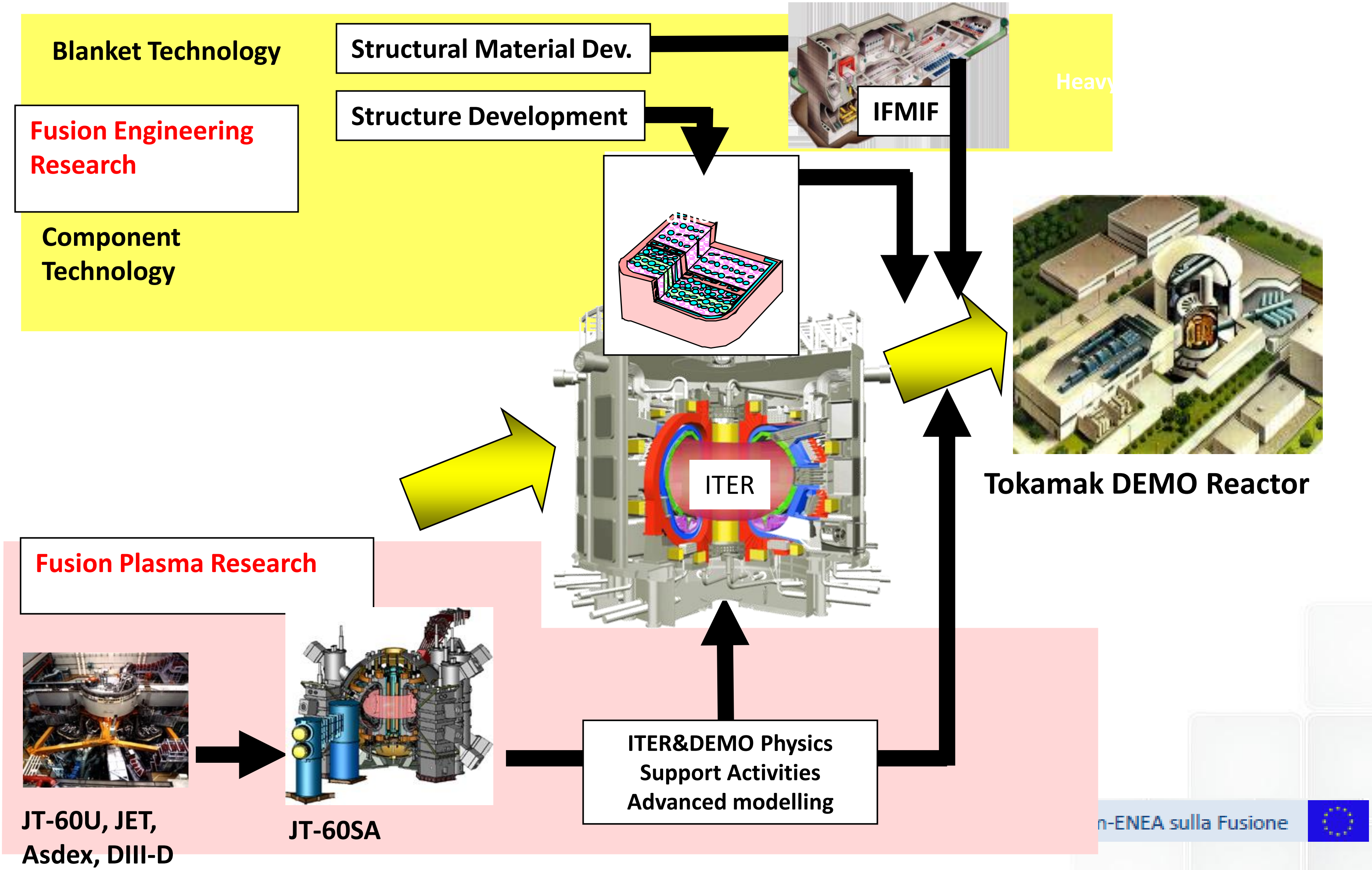
Outline

- The Broader Approach agreement for Fusion energy research
- The JT-60SA tokamak device
- JT-60SA scientific objectives and Research Plan
- Conclusions.

sources: - *Public Broader Approach web site:* http://www.ba-fusion.org
- *Public JT-60SA web site:* http://www.jt60sa.org/b/index.htm
- *S. Ishida et al., Fus. Eng. Des.* ***85*** *(2010) 2070*
- *Y. Kamada et al., Nucl. Fus.* ***51*** *(2011) 073011*
- *Y. Kamada et al., Nucl. Fus.* ***53*** *(2013) 104010*
- *JT-60SA Research Plan, v3.2(Feb. 2015)* [http://www.jt60sa.org/pdfs/JT-60SA_Res_Plan.pdf]

THE BROADER APPROACH AGREEMENT FOR FUSION ENERGY RESEARCH AND JT-60 SA TOKAMAK

From present-day tokamaks to DEMO

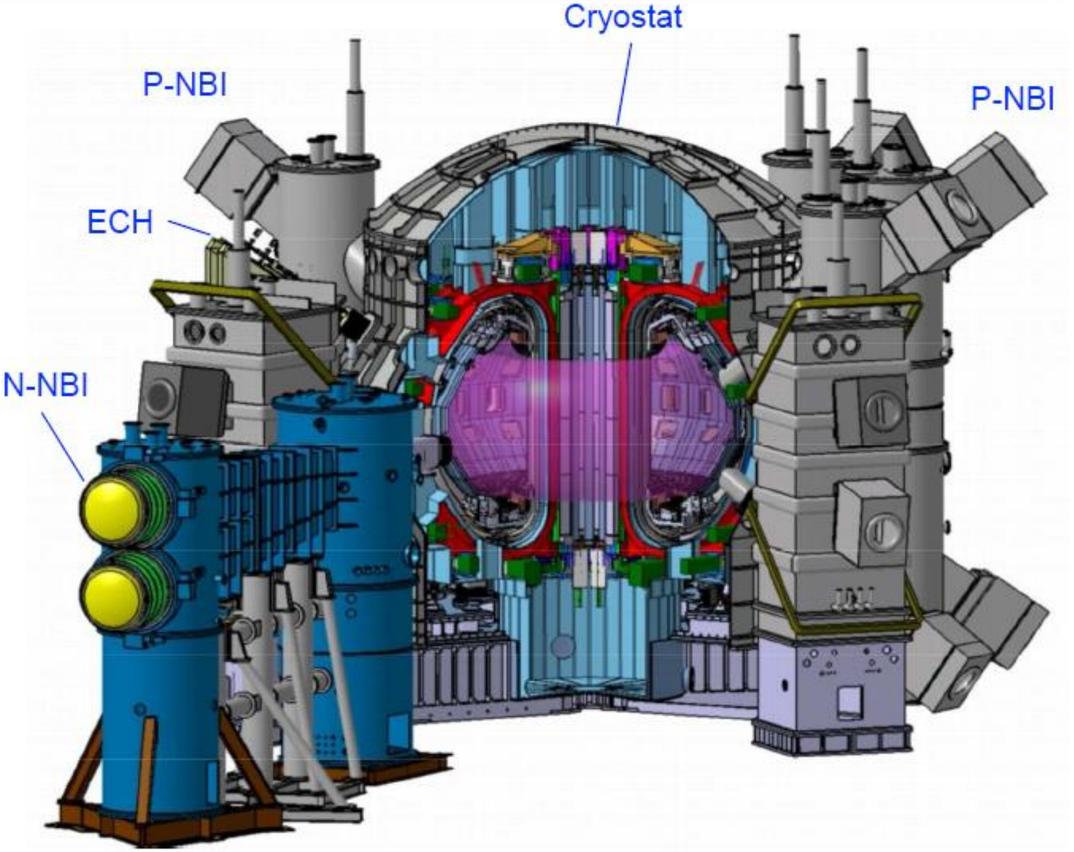


The JT-60SA tokamak

Mission of the JT-60SA project is to contribute to the early realization of fusion energy by its exploitation to support the exploitation of ITER and research towards DEMO, by addressing key physics issues for ITER and DEMO.

Basic machine parameters

Plasma Current	5.5 MA
Toroidal Field, B_t	2.25 T
Major Radius, R_p	2.96
Minor Radius, a	1.18
Elongation, κ_X	1.95
Triangularity, δ_X	0.53
Aspect Ratio, A	2.5
Shape Parameter, S	6.7
Safety Factor, q_{95}	~3
Flattop Duration	100 s
Heating & CD Power	41 MW
N-NBI P-NBI ECRF	10 MW 24 MW 7 MW
Divertor wall load	15 MW/m^2



S. Ishida, 2011

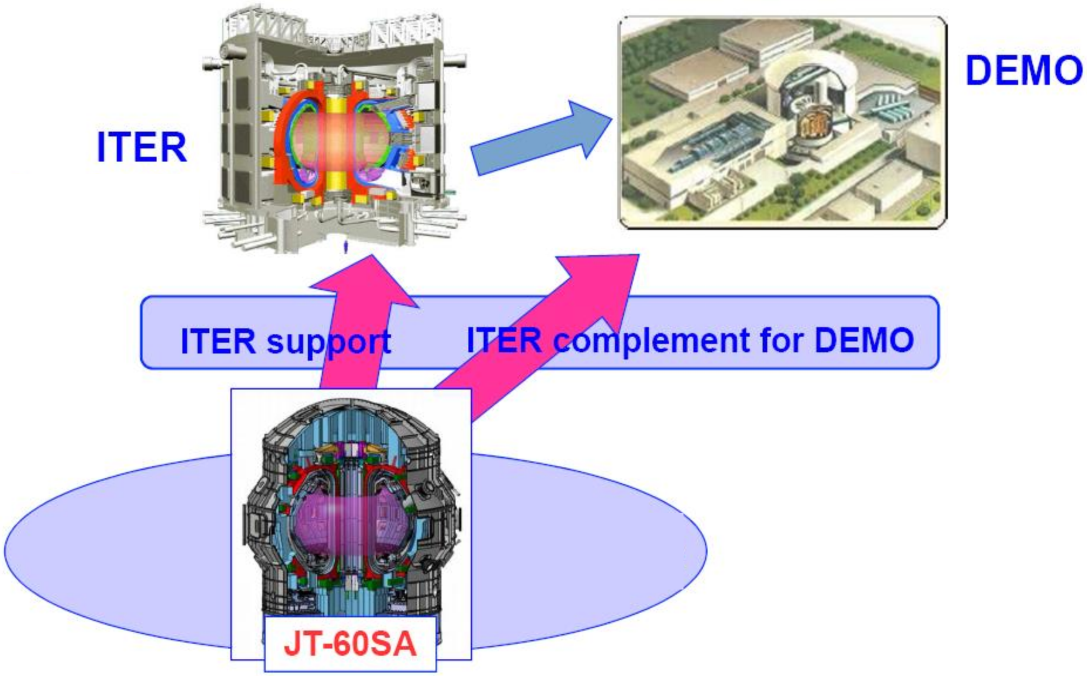
The JT-60SA scientific objectives

- Contribute to early realization of fusion energy by:
  - **supporting** the exploitation of ITER
  - **complementing** ITER in resolving key issues for DEMO

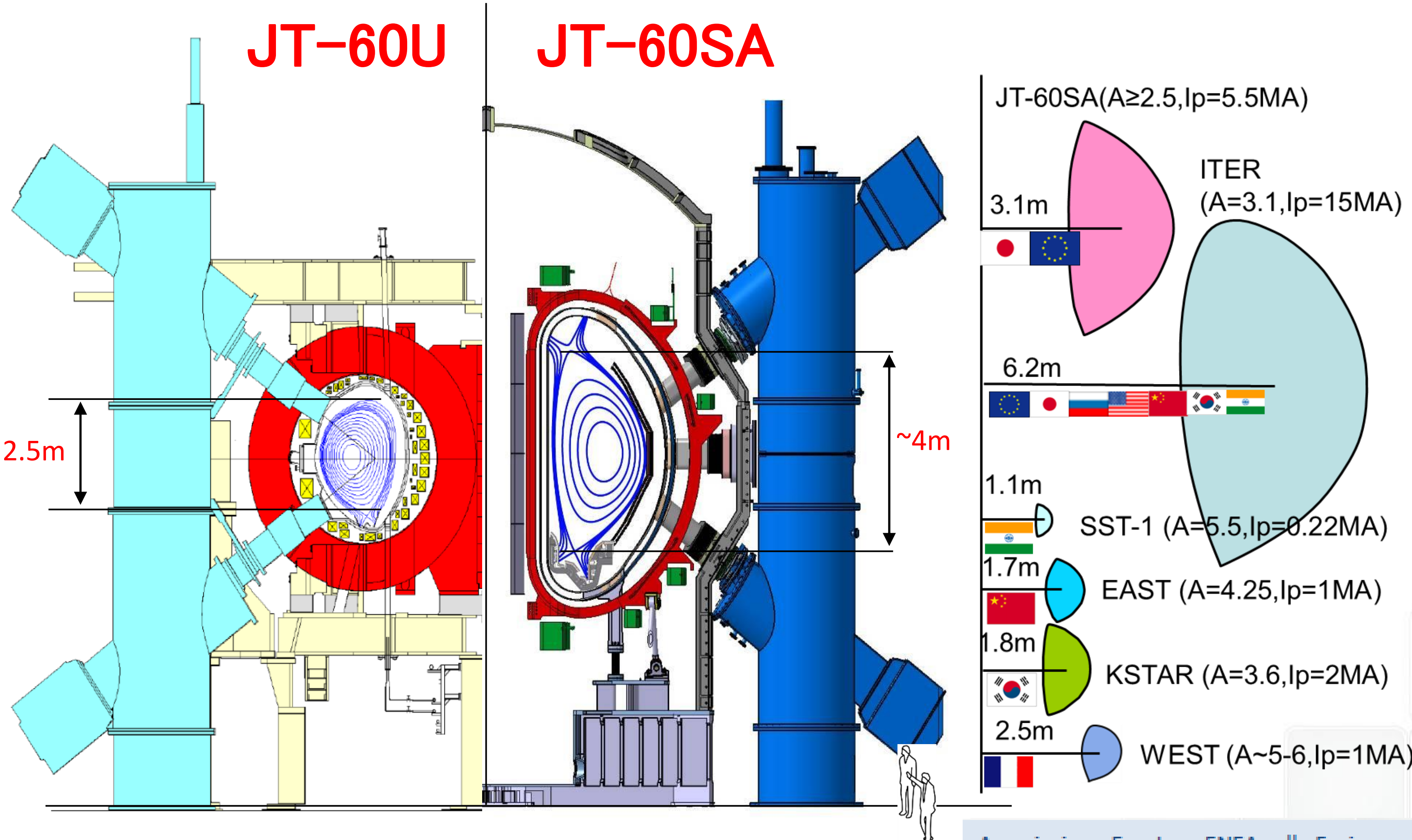
- The most important goal of JT-60SA is:
  - to **decide** the practically acceptable DEMO plasma design
  - including practical and reliable **plasma control** schemes

- A spectrum of **DEMO** design options will be considered, e.g., a compact **steady-state** reactor *

** Slim-CS design (R=5.5 m, β_N=4.3)*
K. Tobita et al.,
*Nucl. Fusion **49** (2009) 075029*



The Load Assembly



Volume SA = 2*Volume JT60U

Heating and CD Systems

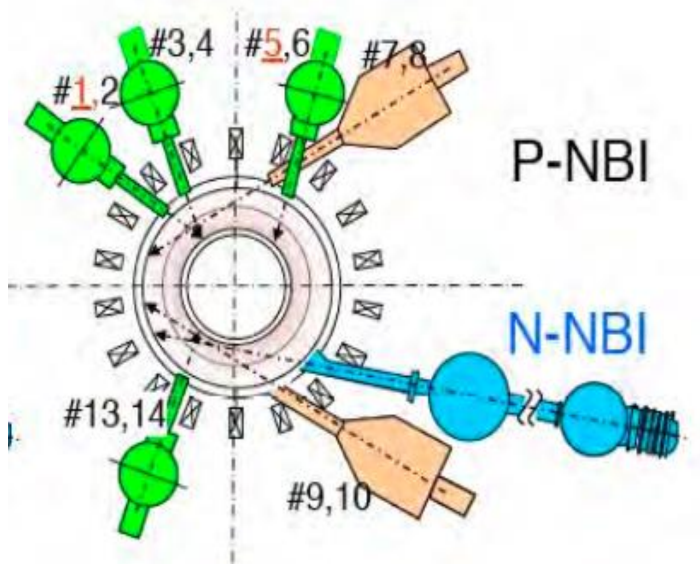
Variety of heating/current-drive/ momentum-input combinations

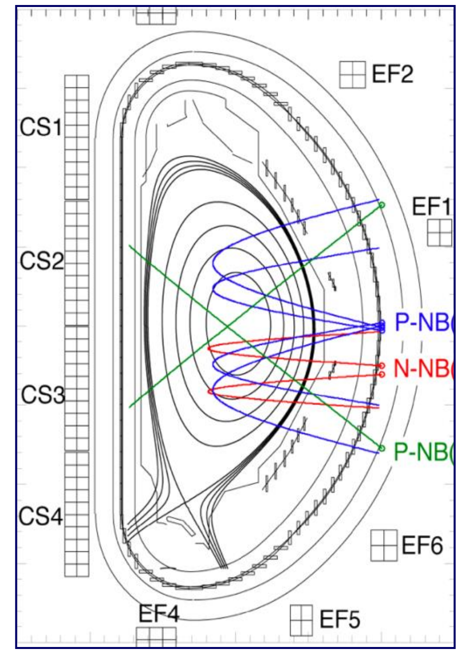
NB: 34MWx100s

Positive-ion-source NB
85keV

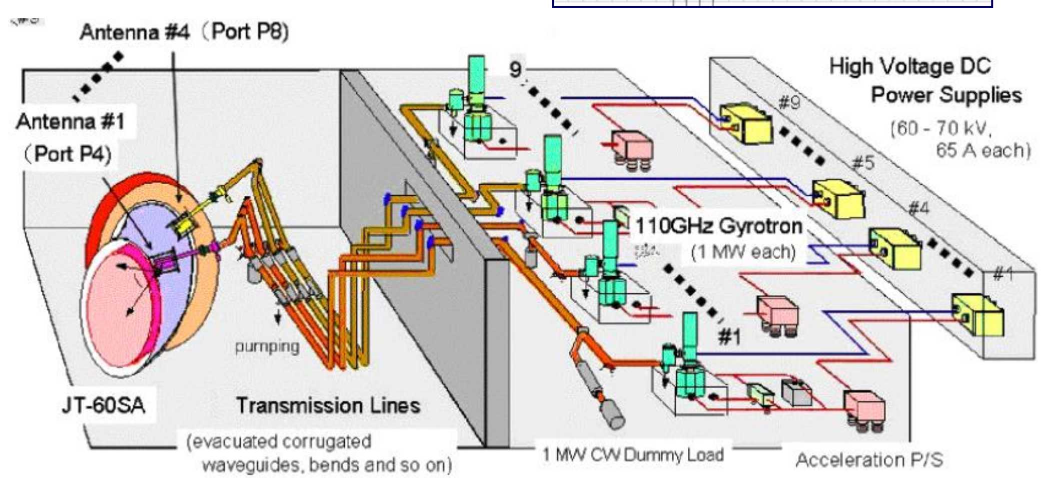
COx2u, 4MW
CTRx2u, 4MW
Perpx8u, 16MW

Negative-ion-source NB
500keV, 10MW
Off-axis for NBCD

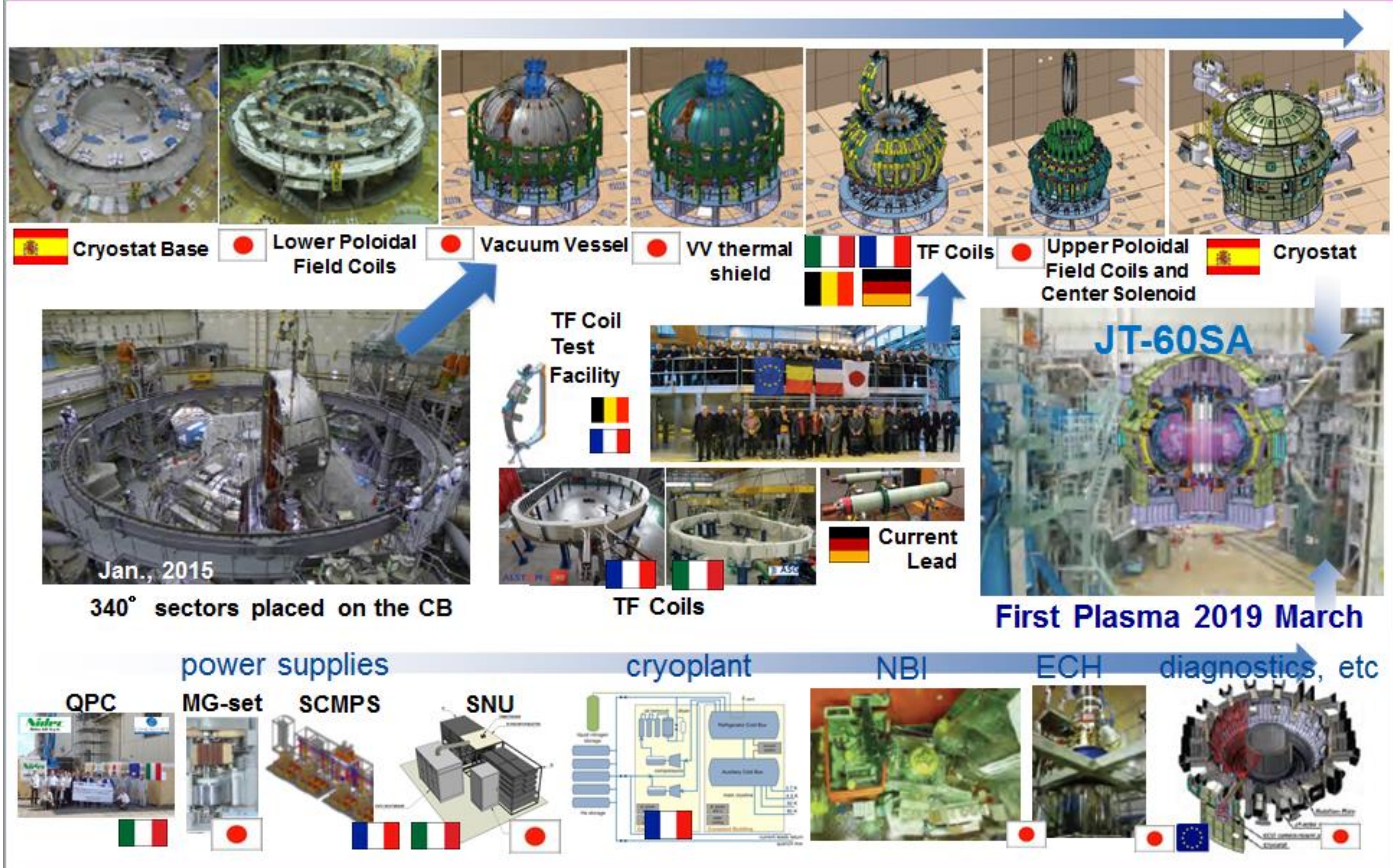




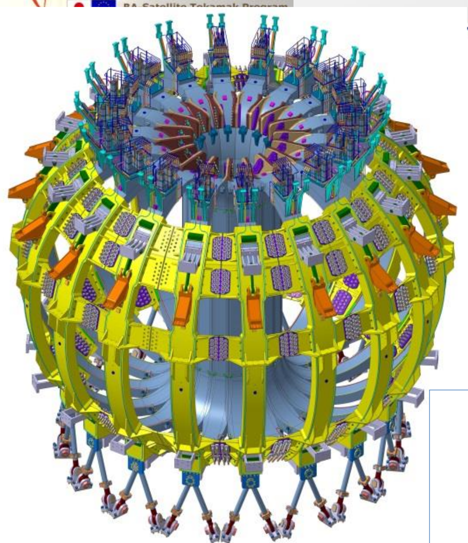
ECRF: 110 + 138GHz, 7MW x 100s
9 double-frequency gyrotrons,
4 Launchers with movable mirrors



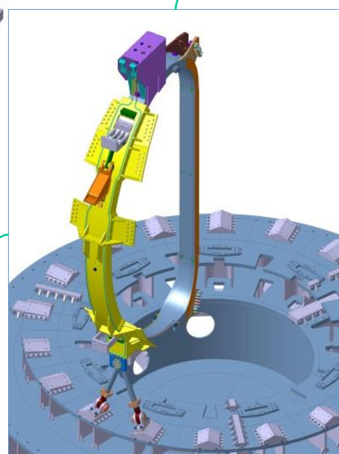
JT-60SA Manufacture and Assembly going on schedule



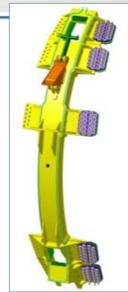
TF Coil manufacture



TF Magnet Manufacture

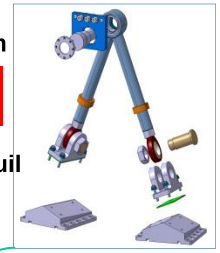


CEA (SDMS)
Isère



Outer Intercoil Structure

CEA Alsyom
Argenteuil



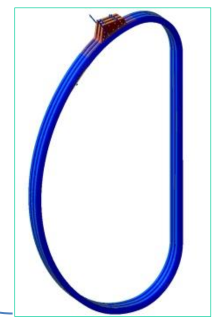
Gravity Support

F4E (Furukawa)
Strand
Nikko

ENEA (ICAS)
Conductor
Frascati

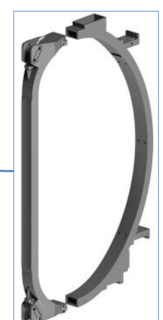
ENEA (ASG)
Genoa

CEA (Alstom)
Belfort



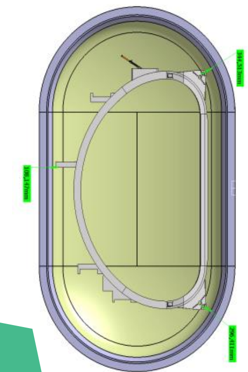
TF Winding Pack

ENEA (Walter Tosto)
Chieti



Casing

CEA (Saclay)
SCK/CEN (ALM)

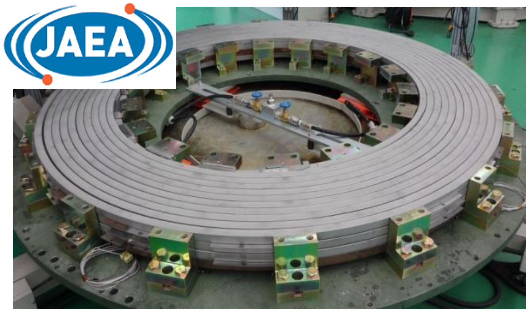


HV Tests
Leak Tests
Flow, Pressure Drop
Dimensional Stability during and after cooldown
Resistance, Joints
T_{margin}, Quench tests

18+1 TF coils and structures to be manufactured and fully cold tested at 4.5K

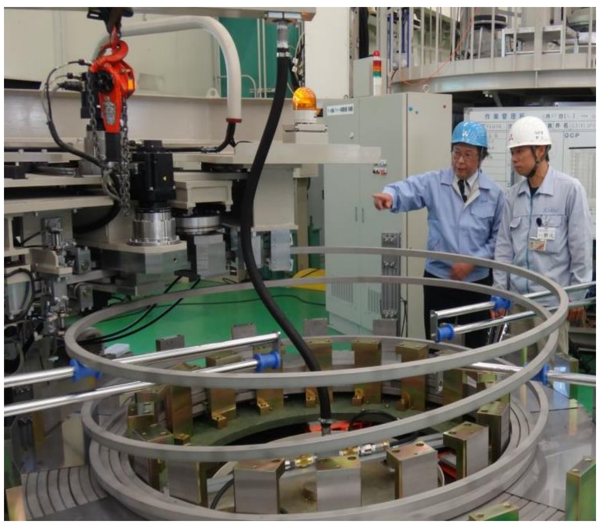
Central Solenoid

- The CS consists of a vertical stack of four independent winding pack modules.
- The CS pre-load structure, which consists of a set of tie plates located outside and inside the coil stack, provides axial pressure on the stack.
- Winding of the first quad-pancake (CS1QP)

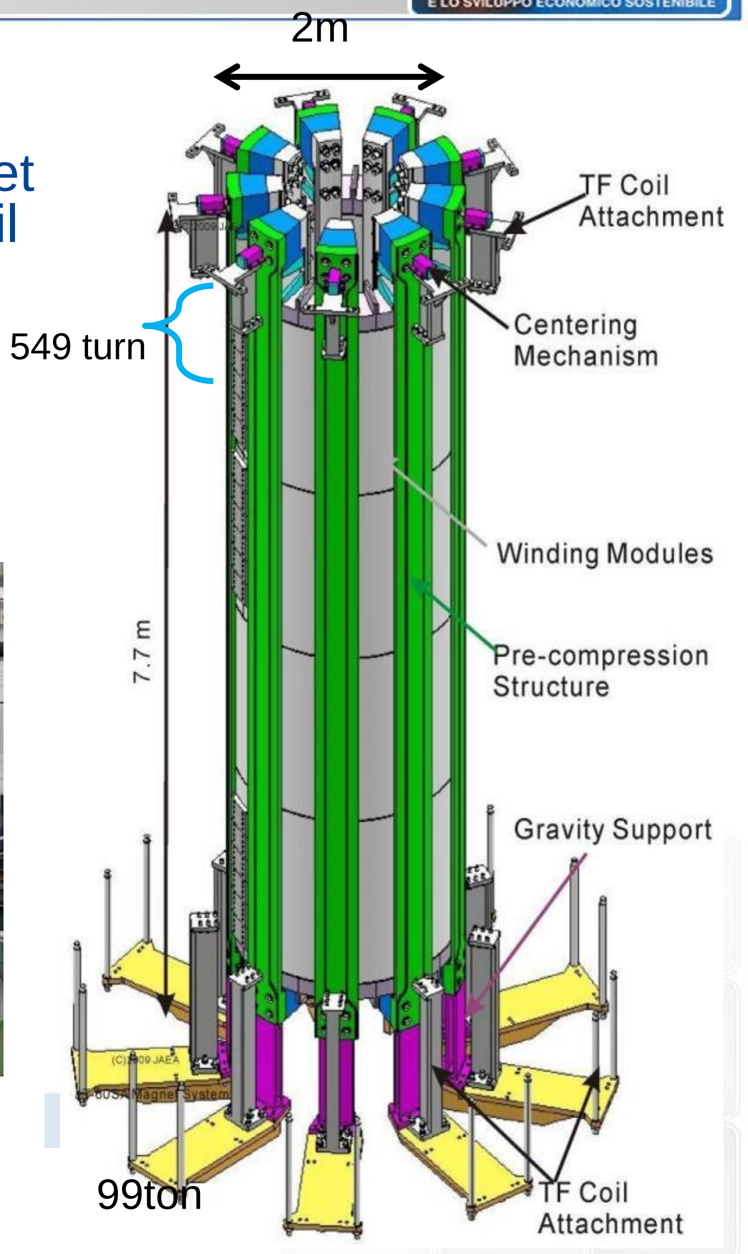


CS1QP

Nb_3Sn conductor



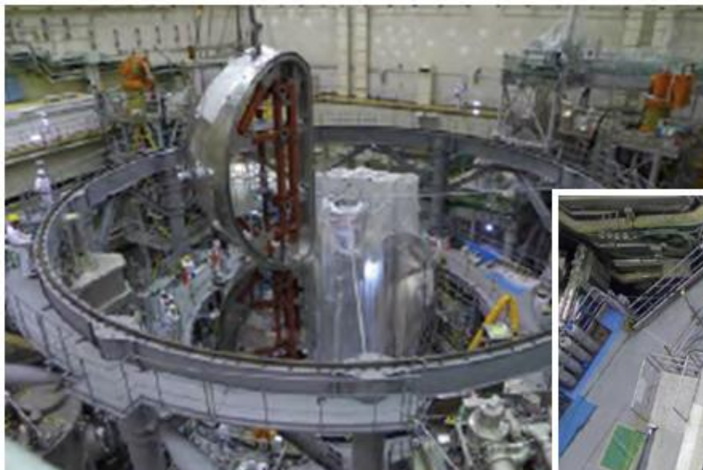
Manufacturing of CS1 module; under 2nd OP winding



Vacuum vessel

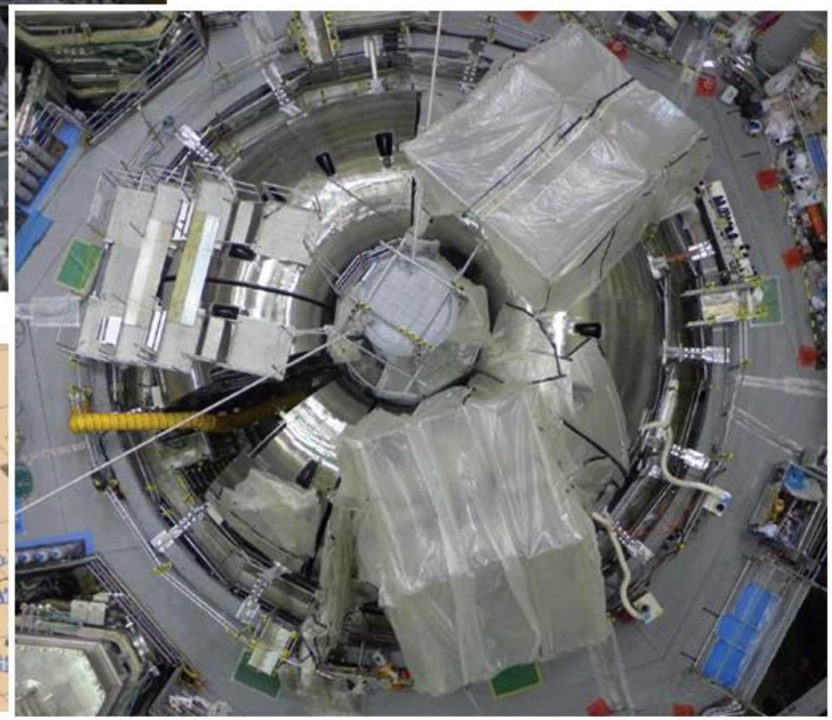
Completion of the initial assembly of the vacuum vessel

Vacuum Vessel Assembly



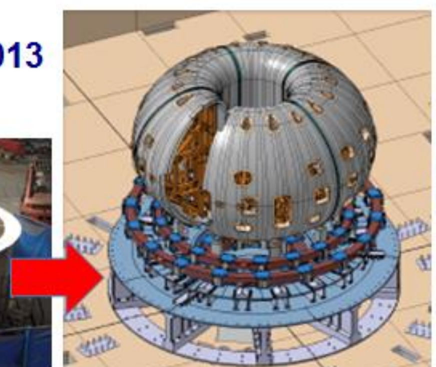
340-degree placed on the Cryostat Base (26 Jan. , 2015)

Vacuum Vessel 10-sectors completed



Cryostat Base installed in Jan. 2013

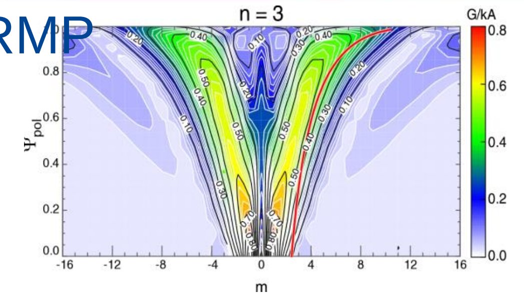
12m, 260t



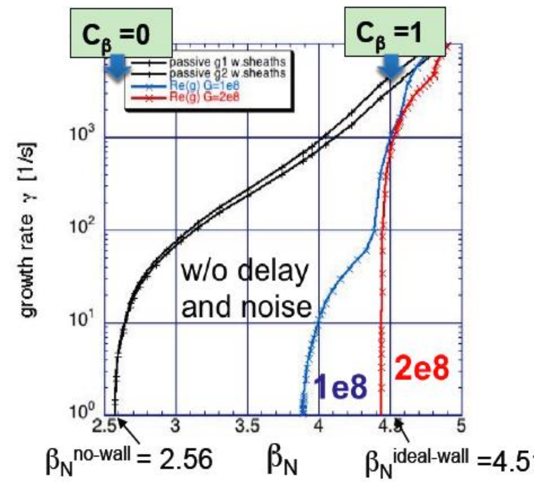
Key tools for MHD stability control

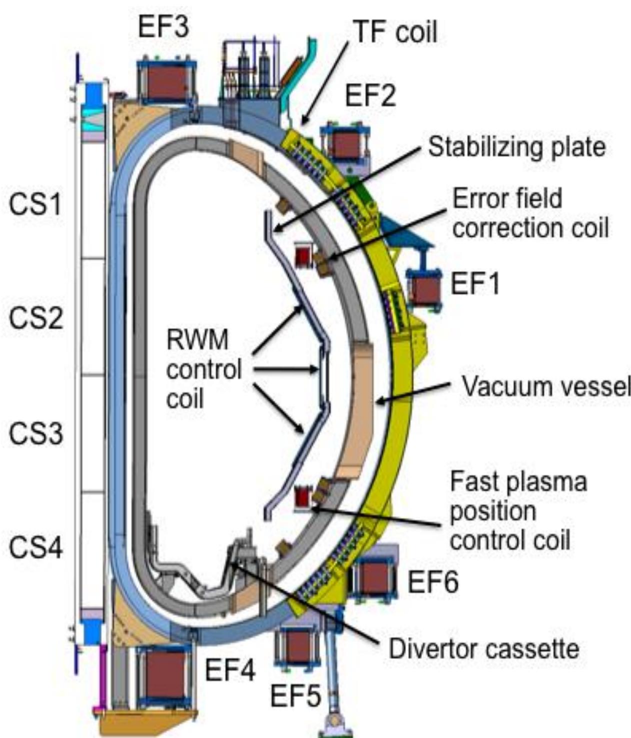
- Stabilizing Wall (conductor sheath: 1 mm)
- Fast Plasma Position Control coil
- Error Field Correction (EFC) coil) ;
  also for ELM control by RMP:18 coils 30 kAT, ~9 G
- RWM Control coil: 18 coils. on the plasma side.
  + ECCD (NTM), rotation control

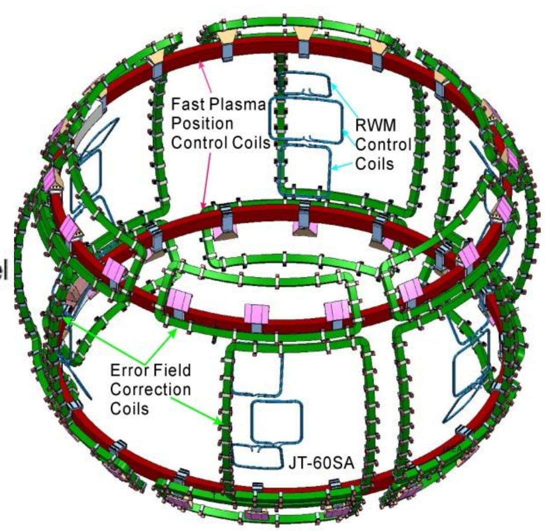
RMP



RWM control

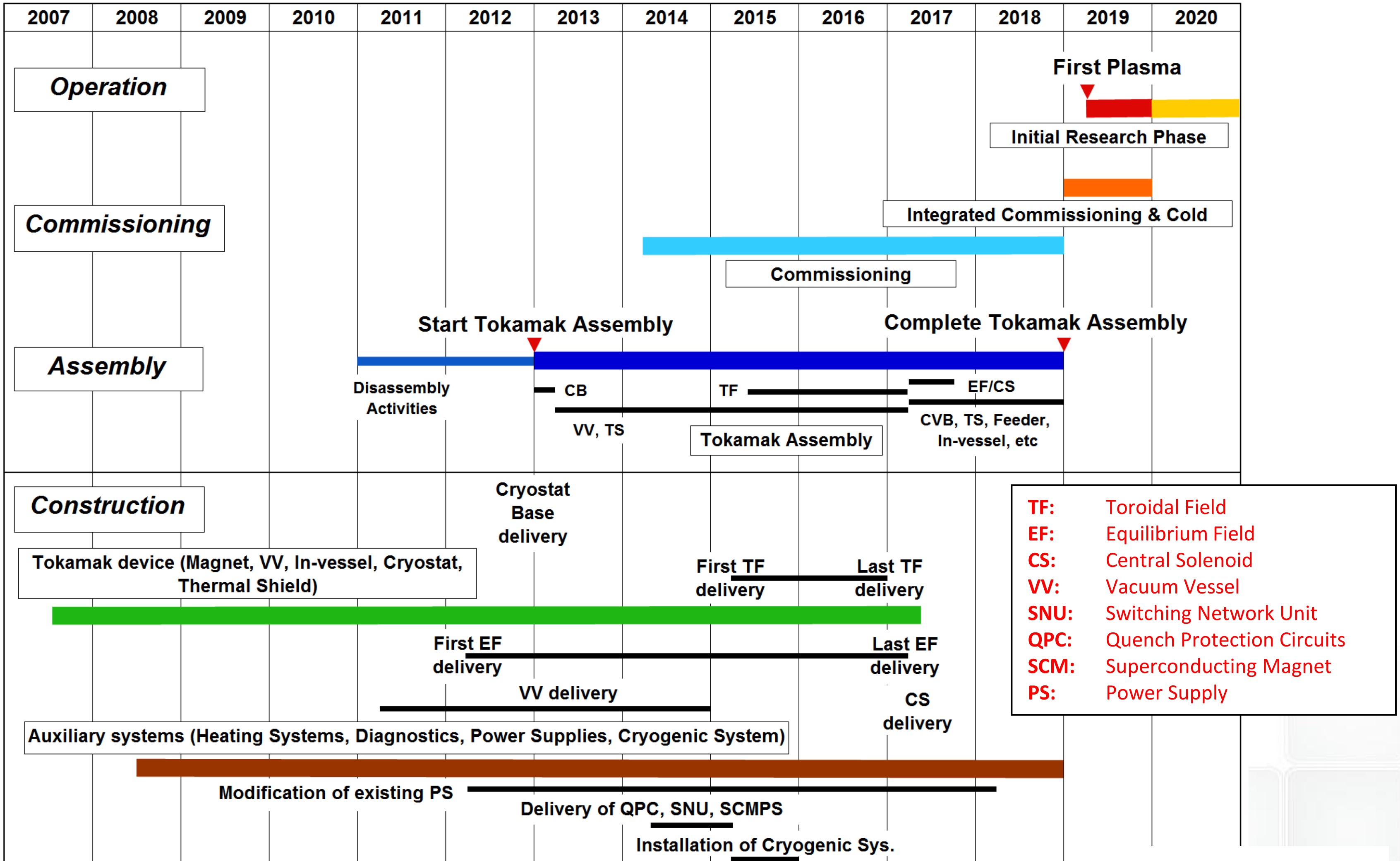






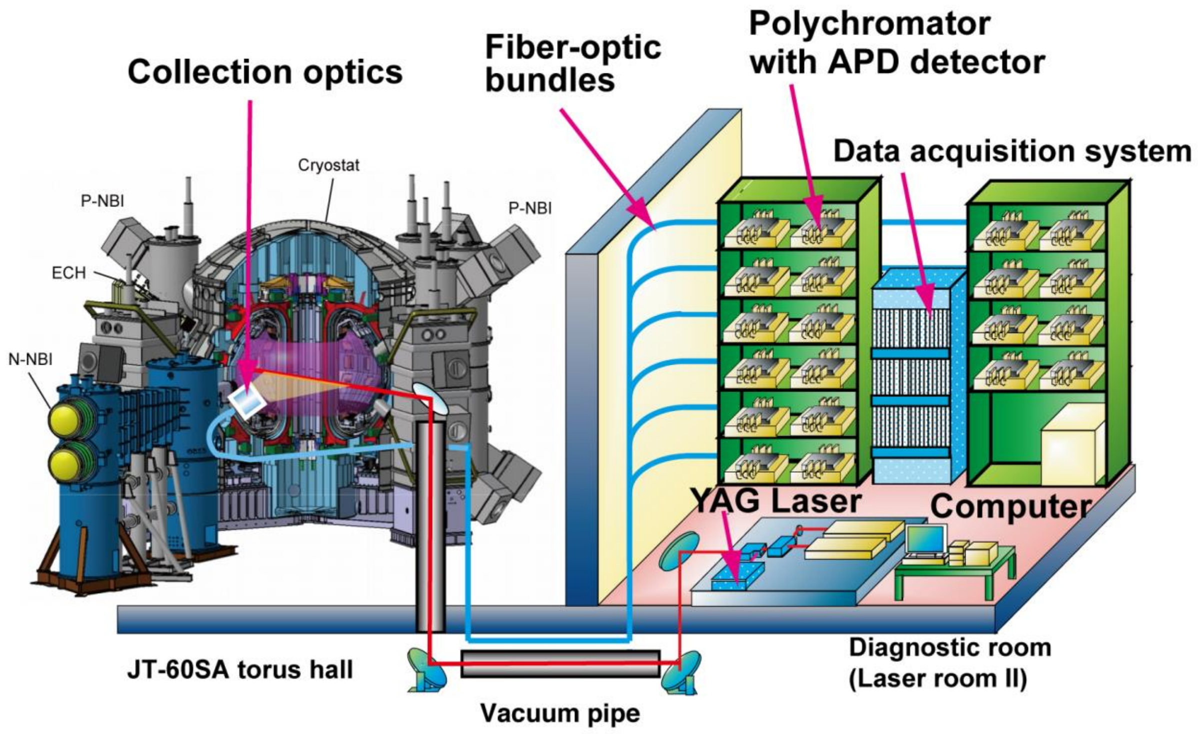
Stable up to **β_N = 4.1 (C_β =0.8) even with effects of conductor sheath, noise (2 Gauss), and latency (150 μs).**

The JT-60SA project schedule



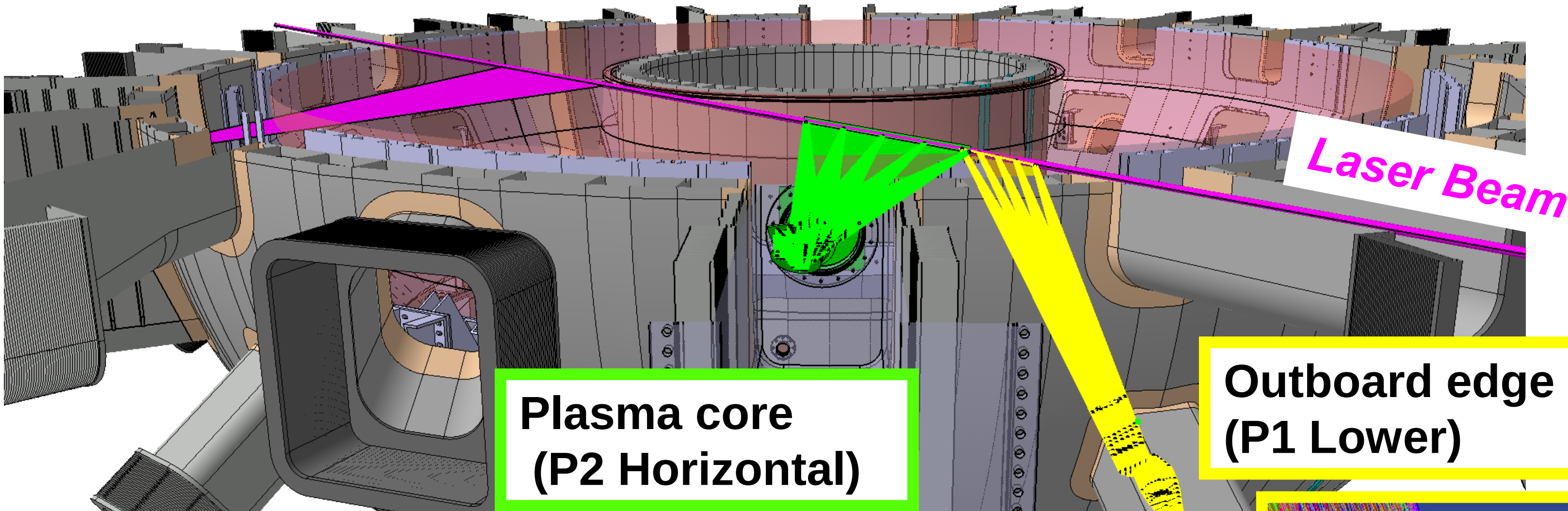
S. Ishida, 2012

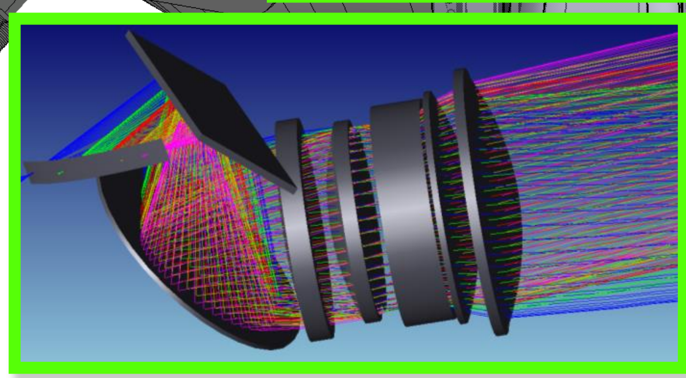
Thomson scattering on JT-60SA : rare capability to measure the Temperature and density profile along the entire diameter

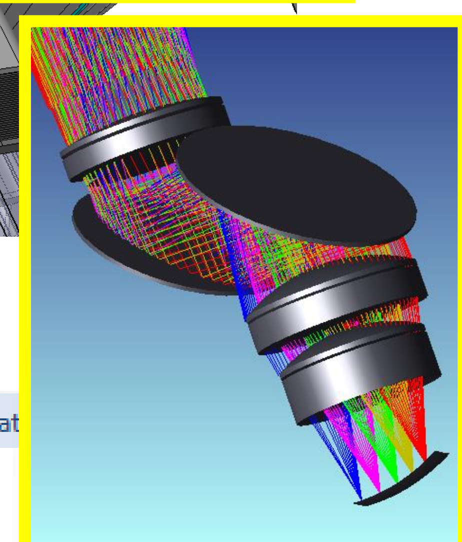


Concept design of the optics for the core and outboard edge measurement of the YAG laser Thomson scattering diagnostic has been performed.

The YAG laser Thomson scattering diagnostic measures the JT-60SA plasma from the outboard edge to the inboard edge.





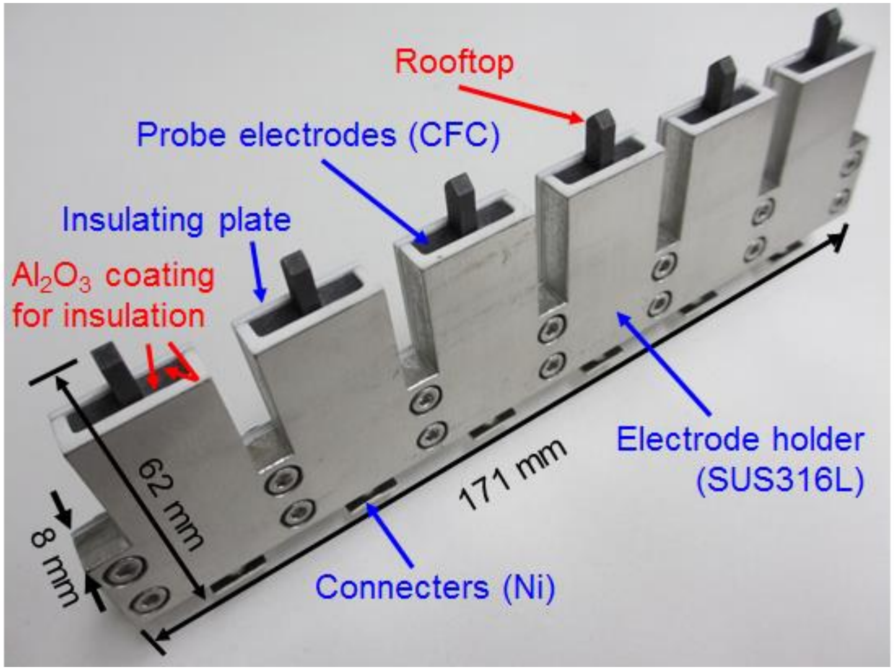


- **The spatial resolution will be 20 - 30 mm for the core and ~5 mm for the edges in minor radius.**

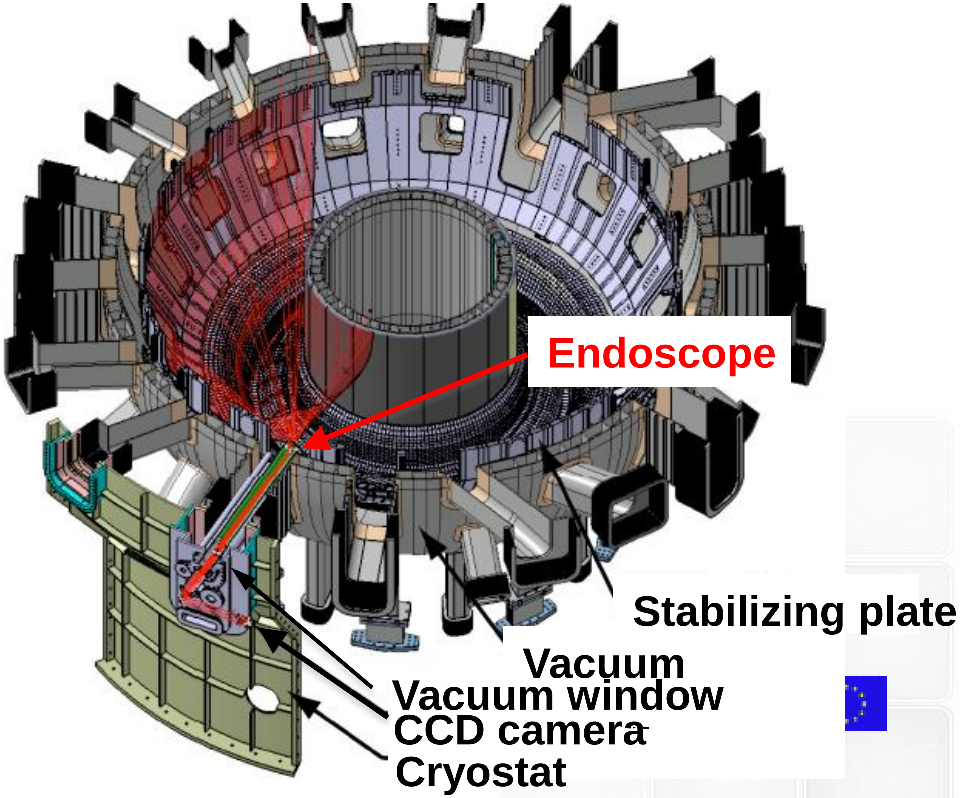
Development of Diagnostics

Divertor Langmuir probe arrays have been manufactured.

They withstand the high heat loads.
(10 MW/m^2 for 5 s, 1 MW/m^2 for 100s).



A IR/visible camera system has been designed to observe the divertor, inner wall, outer stabilizing plates, and counter faces for the tangential NB lines with a wide viewing angle.
(106° vertically, 53° horizontally)



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JT-60SA Advanced Superconducting Tokamak

BA-Satellite Tokamak Program

Motional Stark Effect systems

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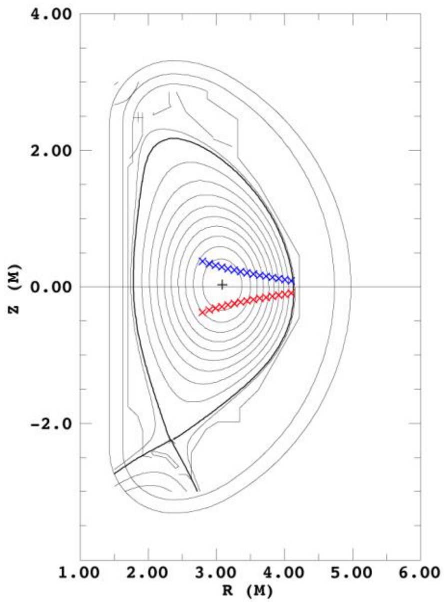

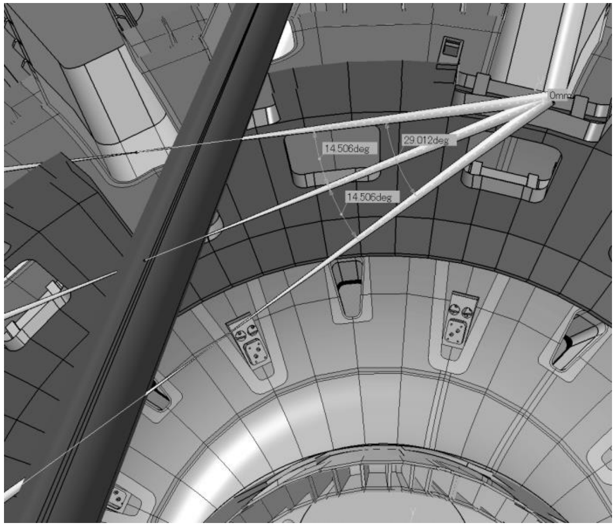

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JT-60SA SCIENTIFIC OBJECTIVES AND RESEARCH PLAN

JT-60SA Research Plan evolving by EU and JA

“Research items and Strategy for JT-60SA” to solve critical issues for ITER and DEMO

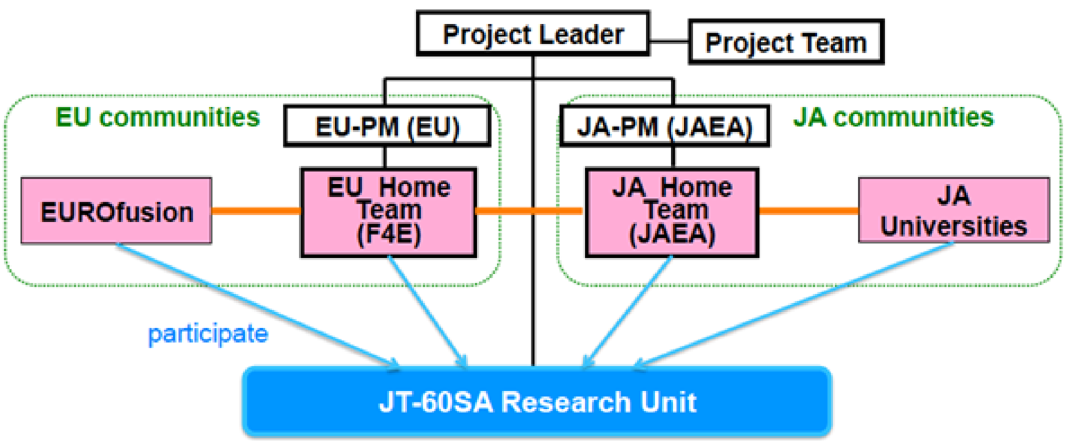
JT-60SA Research Plan updated to Ver.3.2 in 2015, Feb.

Co-Authors: 365 persons
JAPAN:157(83 JAEA,74 from 15 UNIV.)
EU: 203 (12 Countries, 26 Institutions)

=> Encourage collaborative studies
Optimize hard wares
Growing towards the first plasma

Expected experiment participants: JA: 250-300, EU: 200-250


BA_D_24C8WK
16 February 2015
JT-60SA Research Plan
= Research Objectives and Strategy =
Version 3.2
2015, February
JT-60SA Research Unit



Coordinators: M. Yoshida (JA), G. Giruzzi (EU)

3rd. Research Coordination Meeting
(Naka, May.,2014)

The JT-60SA phased operation plan

- JT-60SA will be upgraded according to a phased operation plan
- The exploitation will start with the initial research phase:
  - H operation for commissioning with the plasma
  - D operation for identification of the issues in preparation to full performance

<table>
<tr><th></th><th>Phase</th><th>Expected Duration</th><th></th><th>Annual Neutron Limit</th><th>Remote Handling</th><th>Divertor</th><th>P-NB</th><th>N-NB</th><th>ECRF</th><th>Max Power</th><th>Power x Time</th></tr>
<tr><td rowspan="2">Initial Research Phase</td><td>phase I</td><td>1-2 y</td><td>H</td><td>-</td><td rowspan="3">R&D</td><td rowspan="2">LSN partial monoblock</td><td>10MW</td><td rowspan="5">10MW</td><td rowspan="2">1.5MW x100s + 1.5MW x5s</td><td>23MW</td><td rowspan="4">NB: 20MW x 100s
30MW x 60s
duty = 1/30

ECRF: 100s</td></tr>
<tr><td>phase II</td><td>2-3y</td><td>D</td><td>4E19</td><td rowspan="3">Perp. 13MW

Tang. 7MW</td><td>33MW</td></tr>
<tr><td rowspan="2">Integrated Research Phase</td><td>phase I</td><td>2-3y</td><td>D</td><td>4E20</td><td rowspan="2">LSN full-monoblock</td><td rowspan="3">7MW</td><td rowspan="2">37MW</td></tr>
<tr><td>phase II</td><td>>2y</td><td>D</td><td>1E21</td><td rowspan="2">Use</td></tr>
<tr><td>Extended Research Phase</td><td></td><td>>5y</td><td>D</td><td>1.5E21</td><td>DN</td><td>24MW</td><td>41MW</td><td>41MW x 100s</td></tr>
</table>

Structure of the JT-60SA Research Plan

Ch.1	Introduction
Ch.2	Research Strategy of JT-60SA
Ch.3	Operation Regime Development
Ch.4	MHD Stability and Control
Ch.5	Transport and Confinement
Ch.6	High Energy Particle Behaviour
Ch.7	Pedestal and Edge Characteristics
Ch.8	Divertor, SOL and PMI
Ch.9	Fusion Engineering
Ch.10	Theoretical models and simulation codes

ITPA Groups (International Tokamak Physics Activity)
Integrated Operation Scenarios
MHD Stability
Transport and Confinement
Energetic Particles
Edge Pedestal
Divertor and SOL
Diagnostics

APPENDIX

A: Heating and Current Drive Systems

B: Divertor Power Handling and Particle Control Systems → Ch.8

C: Stability Control Systems → Ch.4

D: Plasma Diagnostics Systems

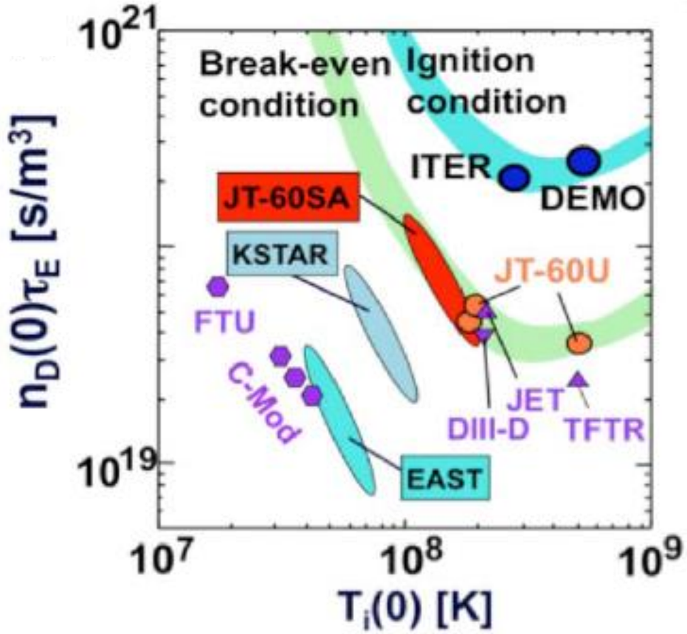
E: Magnetic field ripple → Ch.6

F: Operational scenarios → Ch.3

G: Design guidelines for additional components → Ch.9

JT-60SA for ITER

- **supporting** the exploitation of ITER :
  - demonstrate <u>integrated performance</u> of ITER scenarios, with similar control techniques
  - optimise MHD <u>control schemes</u>
  - develop <u>disruption</u> prediction and avoidance
  - perform <u>burn simulation</u> experiments
  - study <u>Alfvén eigenmodes</u> at β_{fast} ~ 0.2-1%, $V_{fast}/V_{alfvén}$ ~ 1.5-2 for a wide range of q profiles
  - study <u>pedestal</u> structure and <u>ELM</u> properties in a wide range of collisionality



Basic idea of steady state reactor

The idea of working at high β_N allows for a device with lower current and dimensions since Pfus~$(\beta_N)^2$ *Volume* Ip^2.*Bt^2.R*k

Minimizes the heating and current drive needs , since it allows higher values of beta poloidal and self-generated plasma current (bootstrap current) .
In fact the fraction of bootstrap current scales as :

$$f_B = \frac{I_b}{Ip} \approx \frac{1}{3} A^{-1/2} \beta_p$$

$$\beta_p \propto \beta_N / \beta_T$$

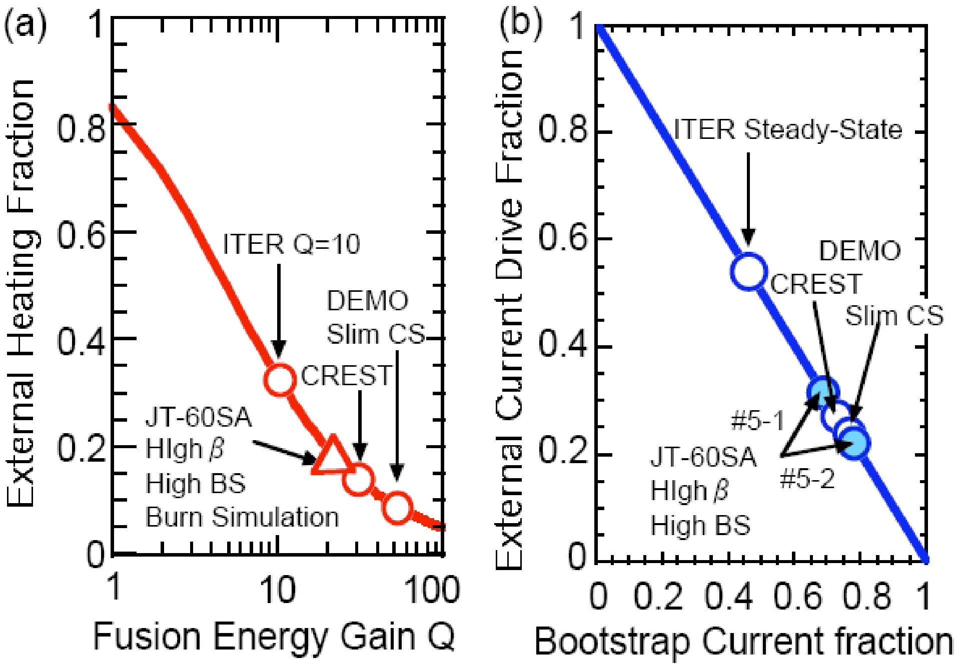
→ High βp, low A
And high βN

Where ε =a/R=minor radius/major radius=1/A, and q95 is the edge safety factor.

High bootstrap fraction implies
working at high q95≈4-5,
low inverse aspect ratio =1/4-1/3.5, and $\beta_N \geq 3$.

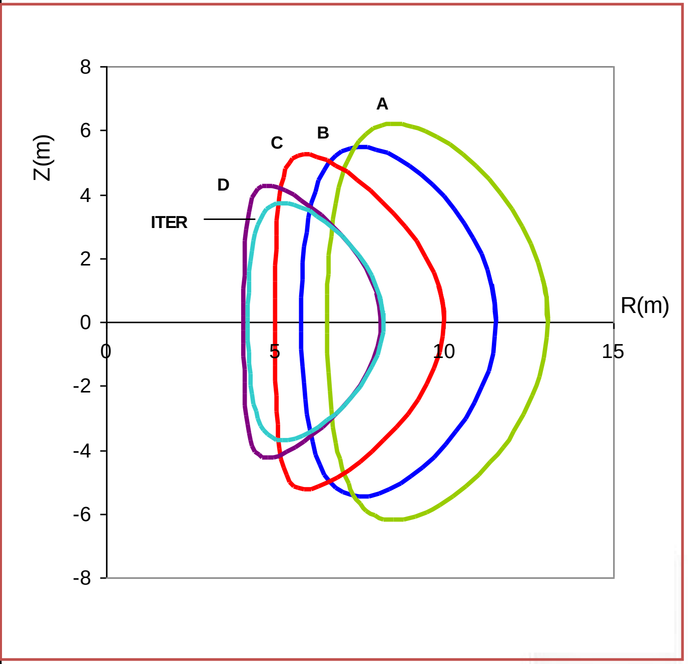
JT-60SA for DEMO (STEADY STATE)

- **resolving** key physics issues for DEMO :
  - understand self-regulating plasma systems
  - demonstrate steady-state sustainment of the required integrated plasma performance
  - extend operational boundaries: high β_N, bootstrap and Greenwald fractions, I_p ramp-up with minimum use of CS coil, ITBs, divertor radiation, etc.
  - **develop plasma control schemes with minimum actuator power and simplified diagnostics**



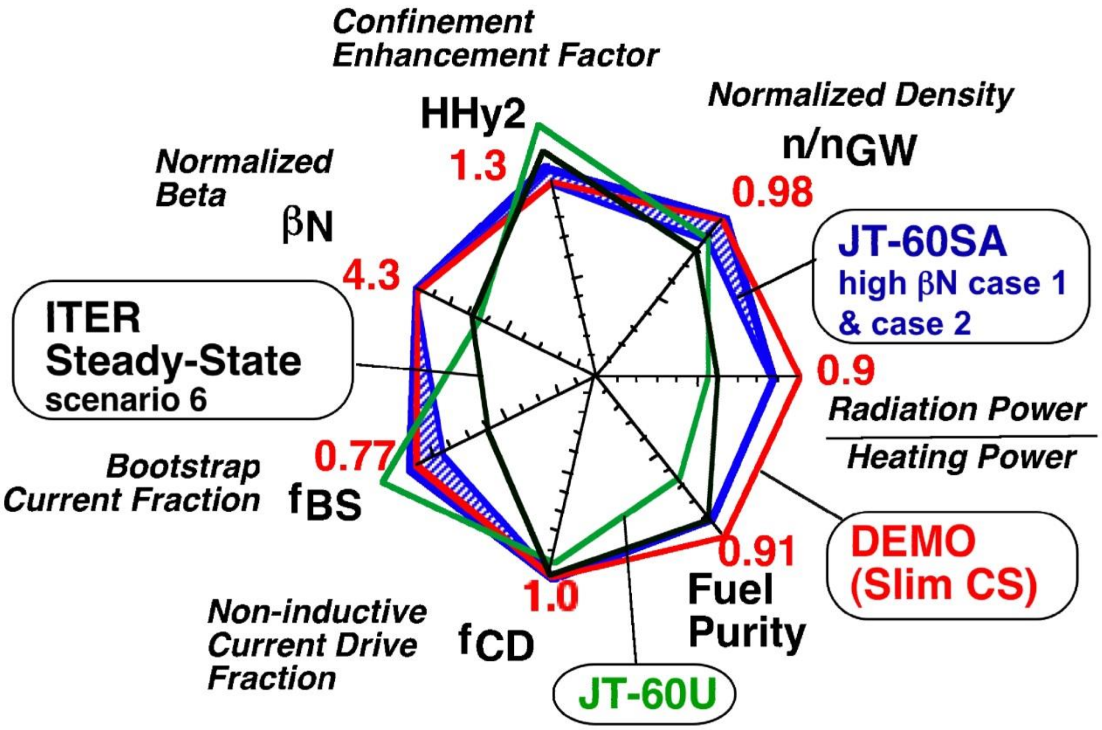
EXAMPLES OF SS MODELS

	ARIES RS	PPCS C	SLIM CS	ITER SS
R(m)	5,5	7,5	5,5	6,2
a(m)	1,375	2,5	2,1	2
Aspect ratio R/a	4	3	2,6	3,1
B(T) on axis	8	6	6	5,3
I(MA)	11,3	20	16,7	9
βN	4,8	4	4,3	2,9
fB	0,88	0,63	0,75	0,46
n/nG	1	1,5	1	0,78
HH(IPBy2)	1,15	1,3	1,3	1,6
Q	27	30	29,5	5
k elongation	1,9	1,9	2	1,8
δ triangularity	0,5	0,47	0,35	0,4
Fusion Power(GW)	2,17	3,41	2,95	0,36
Heating Power(MW)	80	112	100	70



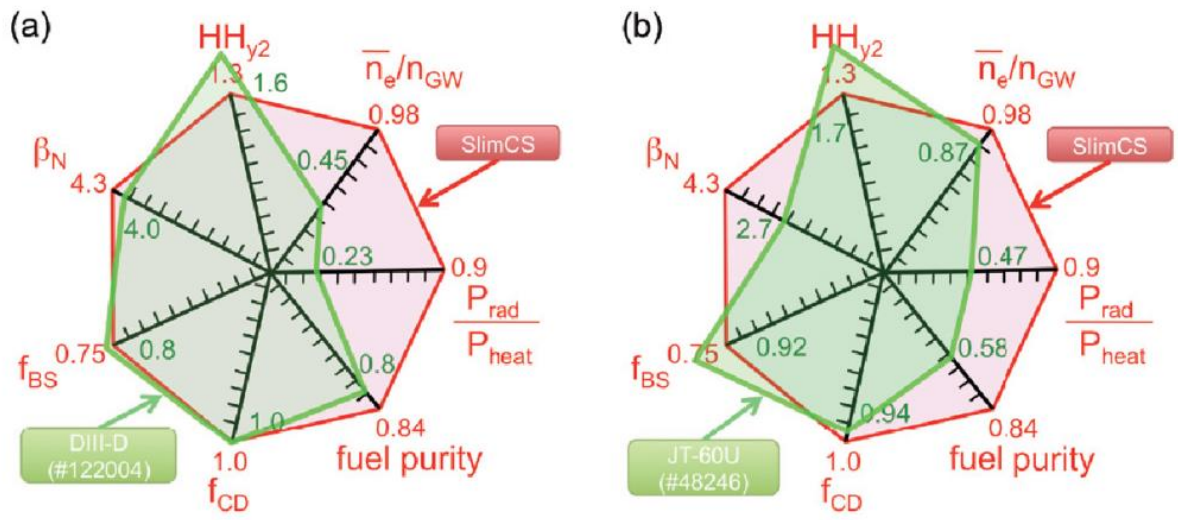
EU PPCS Models

Dimensionless parameters values comparison



JT-60SA is planning experiments to Cover most of the dimensionless Operation space for DEMO Steady state Extending definitely the JT-60U domain

Achieved performances on DIIID and JT-60U in transient conditions



Integrated performances achieved in transient conditions .
Comparison Of design values of SlimCS (red contour)
and a) DIII-D discharge (#122004) and b) JT-60U discharge (#48246)

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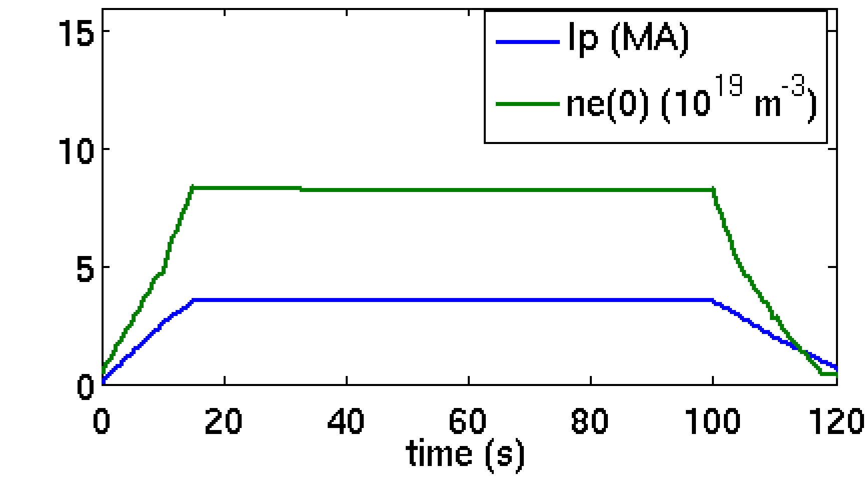
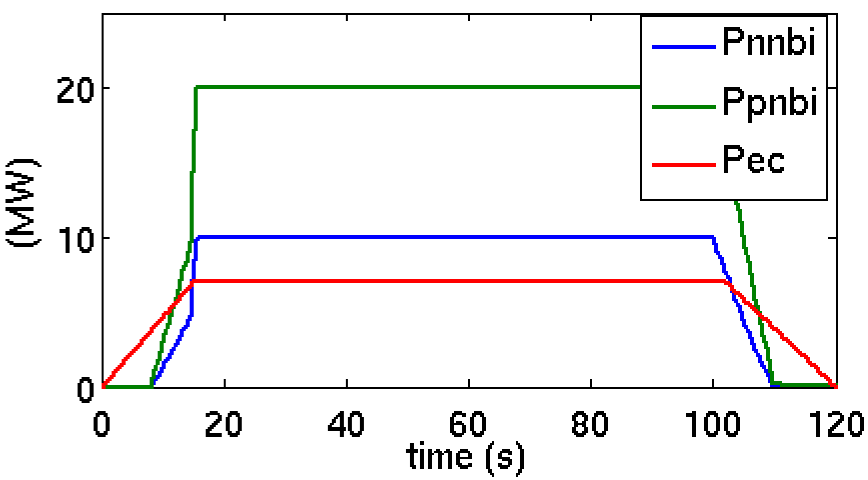
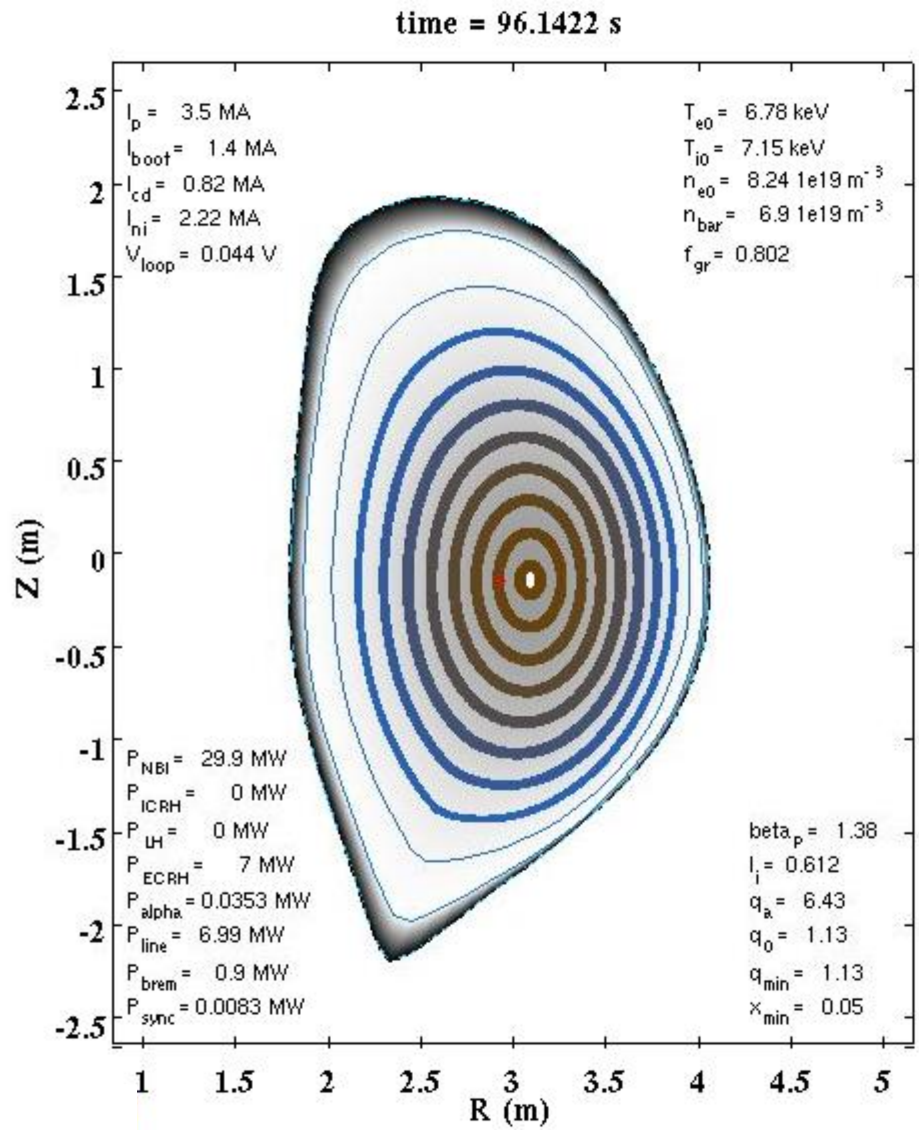
Operation Scenarios

	#1	#2	#3	#4-1	#4-2	#5-1	#5-2	#6
	Full Current Inductive DN, 41MW	Full Current Inductive SN, 41MW	Full Current Inductive SN, 30MW High dens.	ITER like Inductive SN, 34MW	Advanced Inductive (hybrid) SN, 34MW	High β_N full-CD 37MW	High f_G full-CD 30MW	High β_N 300s 13MW
Plasma current (MA)	5.5	5.5	5.5	4.6	3.5	2.3	2.1	2.0
Toroidal field (T)	2.25	2.25	2.25	2.28	2.28	1.71	1.62	1.41
q_{95}	~3	~3	~3	~3	~4.4	~5.8	~6	~4
R/*a* (m)	2.96 /1.18	2.96 / 1.18	2.96 / 1.18	2.93 / 1.14	2.93 / 1.14	2.97 / 1.11	2.97 / 1.11	2.97 / 1.11
Elongation / Triangul.	1.95 /0.53	1.87 /0.50	1.86 /0.50	1.81 /0.41	1.80 /0.41	1.90 /0.47	1.91 /0.45	1.91 /0.51
Normalised beta, β_N	3.1	3.1	2.6	2.8	3.0	4.3	4.3	3.0
Line-av. Density ($10^{19}m^{-3}$)	6.3	6.3	10.	9.1	6.9	5.0	5.3	2.0
Greenwald fract. f_G	0.5	0.5	0.8	0.8	0.8	0.85	1.0	0.39
P_{add} (MW) $P_{NNB}/P_{PNB}/P_{EC}$ (MW)	41 10/24/7	41 10/24/7	30 10/20/0	34 10/24/0	37 10/20/7	37 10/20/7	30 6/17/7	13.2 3.2/6/4
Thermal conf. time (s)	0.54	0.54	0.68	0.52	0.36	0.23	0.25	0.3
$H_{H98\,(v.2)}$	1.3	1.3	1.1	1.1	1.2	1.3	1.38	1.3
V_{loop} (V)	0.06	0.06	0.15	0.12	0.07	0	0	0.02
Neutron pr. rate (n/s)	$1.3\ 10^{17}$	$1.3\ 10^{17}$	$7.0\ 10^{16}$	$6.7\ 10^{16}$	$5.4\ 10^{16}$	$4.5\ 10^{16}$	$2.9\ 10^{16}$	$1.2\ 10^{16}$

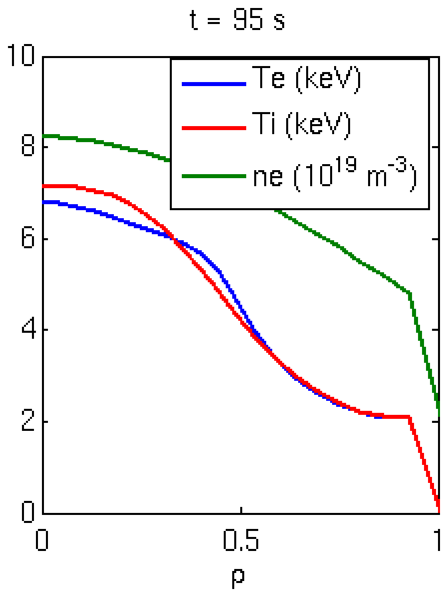
METIS simulation of JT-60SA Scenario 4-2 (hybrid, 3.5 MA) /1

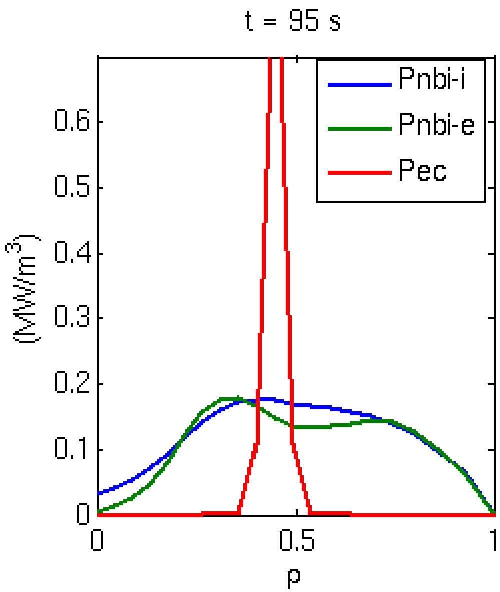


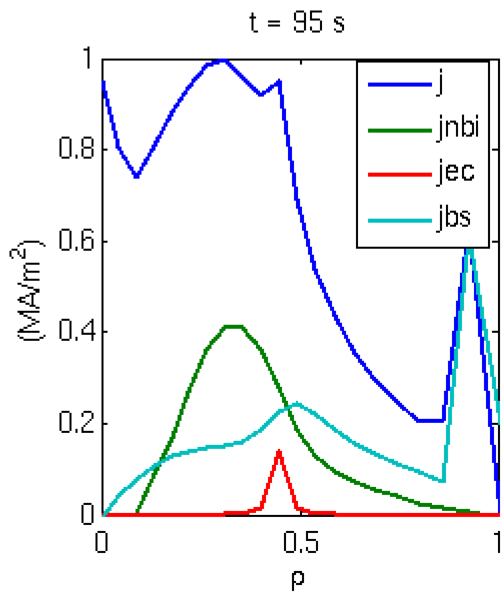


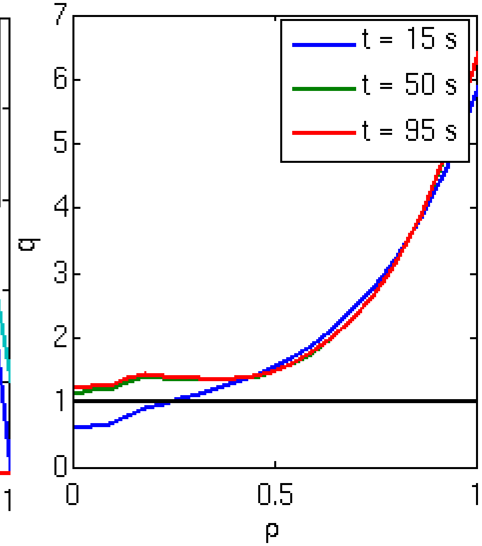


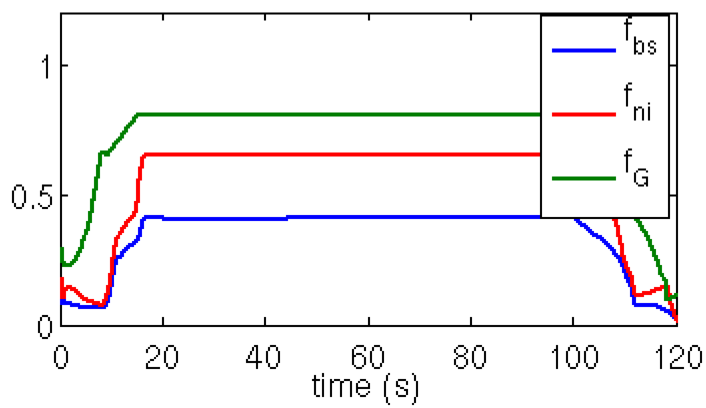
METIS simulation of JT-60SA Scenario 4-2 (hybrid, 3.5 MA) /2

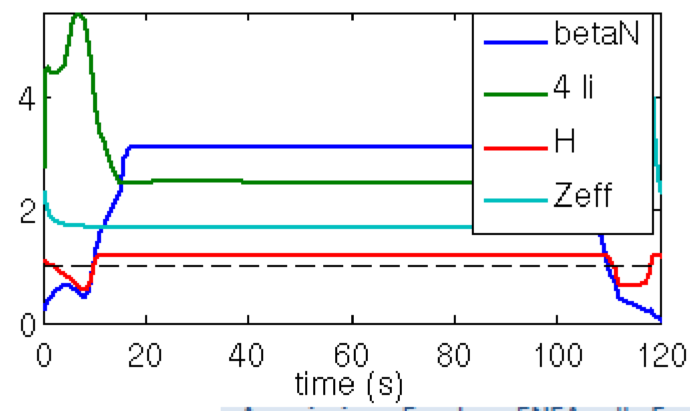




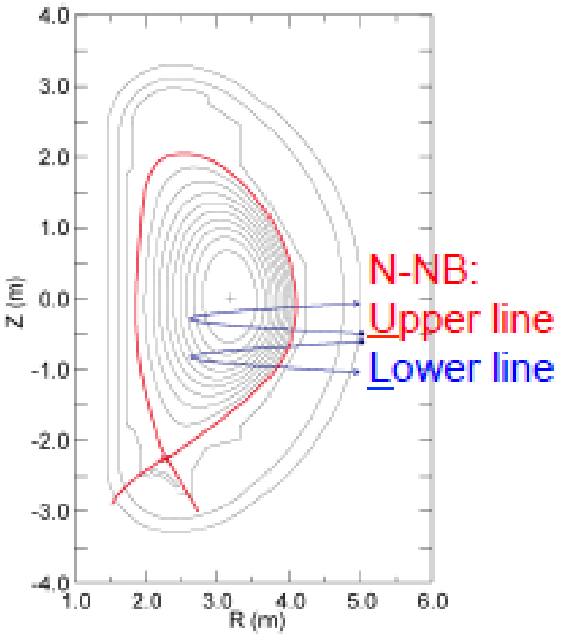




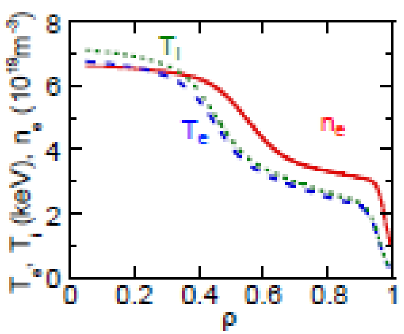


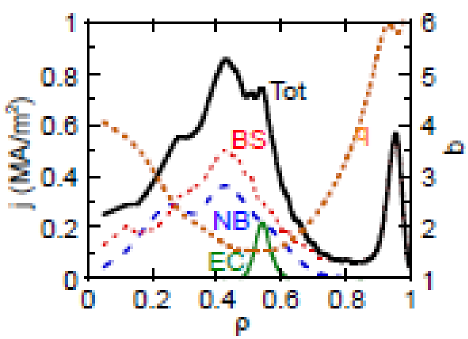


Two N-NBI as CD tools for current profile control (S.IDE)



- N-NB is the strongest current driver on JT-60SA and has two beam lines (Upper and Lower).
  - (almost) On- and Off-axis deposition.
  - $P \le 5$ MW, $E_B \le 0.5$MeV / beam line.
  - can be used for modification of current profile
- TOPICS simulation to examine how much change can be expected
  - temperature and equilibrium solved
  - n_e profile is fixed





Scenario #5-1
I_p/B_t=2.3MA/1.7T, q_{95}=5.8, f_{GW}=0.85,
P_{in}=37MW f_{BS}=0.68, β_N=4.3, H_H=1.3

Ch. 3: Operation regime development. Experimental phases

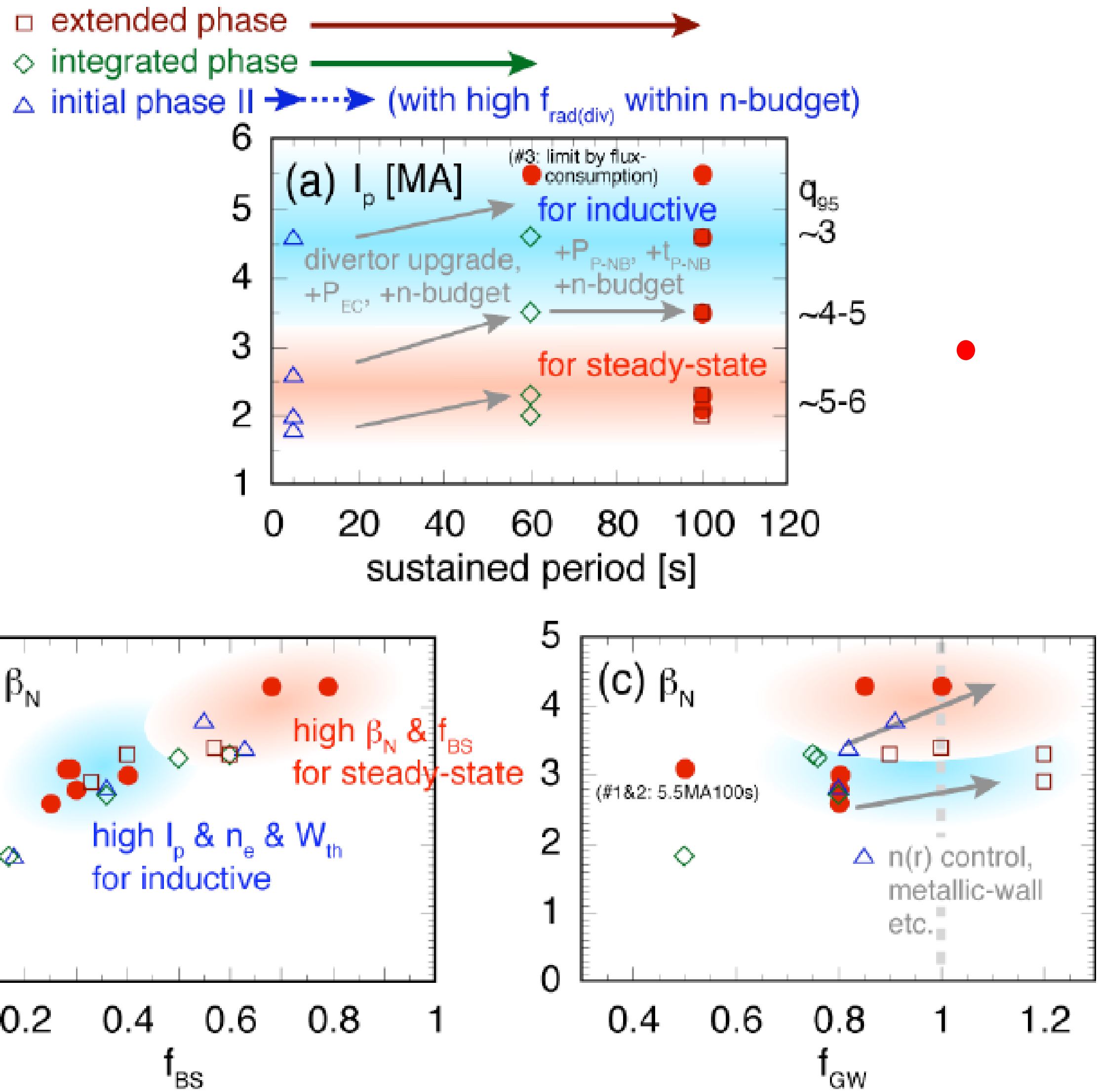


Table 3-4 Experimental program for operation scenario development

research issues	initial phase I	initial phase II	integ. phase I	integ. phase II	extended phase
controllability of plasma position and shape up to full current operation	■	◧			
safe shut down at heavy collapse, disruption and quench of SC magnets	■	■	■		
reliable plasma startup	■	◧			
volt-second consumption	■	◧			
wall conditioning in SC device	■	◧			
real-time function of actuators in open-loop	◧	◧			
validation of diagnostic data	■	◧			
introduction of real-time diagnostics	◧	■			
H-mode threshold power in hydrogen plasma	◧				
ELM mitigation using magnetic perturbation	■	■	■		
advanced real-time control		■	■	■	■
demonstration of ITER standard operation scenario		◧			
ITER hybrid operation scenario		■	■	■	■
ITER steady-state operation scenario		■	■	■	■
quantification of plasma response to actuators		■	■		
experimental simulation of burn control for ITER DT expeiment and DEMO		■	■	■	
radiated divertor study		■	■	■	
accomplishment of a main mission goal				■	■
demonstration of DEMO scenario				■	■

MHD control at high βN

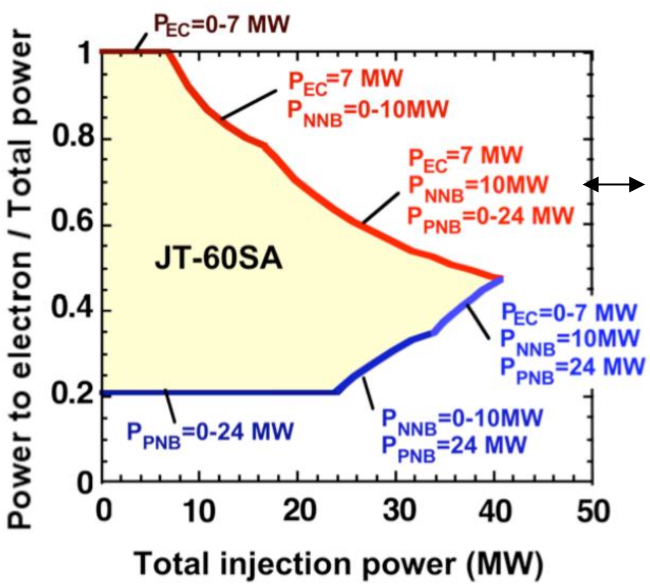
Central to the mission of JT-60SA device

- MHD stability at high βN: by RWM coils, rotation indiced by combination of NBI and NTM stabilization by ECCD
- Interaction of fast particles with Alfven eigenmodes(AE) to study the effects of AE on confinement of fast particles
- Disruption mitigation by hardware (fast walve , killer pellet) or neural network training .

The study of the stability of high βN scenarios to get $\beta N > 4$ implies the use of all the tools Available : plasma rotation, RWM coils , NTM stabilization(by ECCD)

Transport and confinement

- Transport studies in **dominant electron heating** conditions *(P_e/P_{tot} ~ 0.2-1)*
- Transport studies at high β with large **torque variations**
- Transport studies at ITER-relevant values of ν^*, ρ_p^*, β
- Study of **H-mode threshold** in H and He before ITER operation
- Impact of a **Test Blanket Module** on plasma profiles before ITER
- Transport studies with **modulated** heat, particle and torque sources
- **Turbulence** studies in ITER-relevant regimes, with complete diagnostic set



Domain of JT-60SA Dimensionless parameters

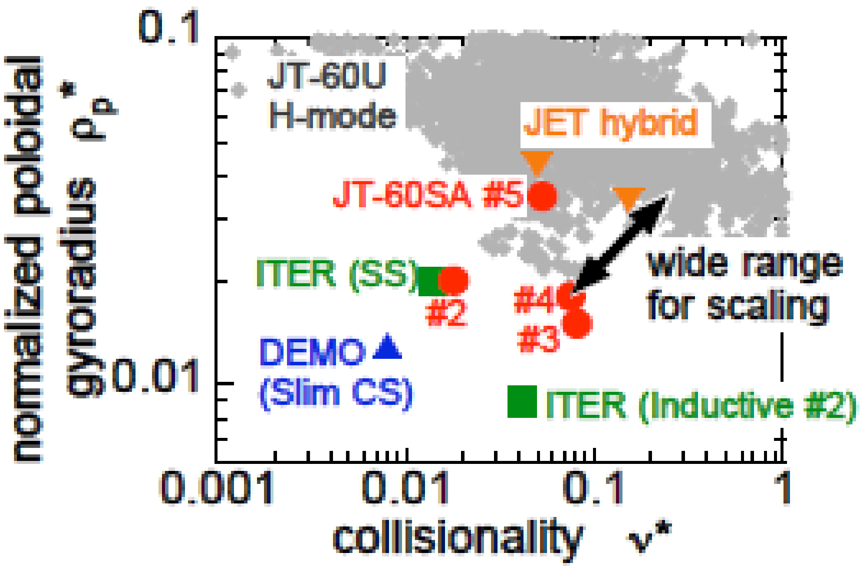


Fig.5-4 Non-dimensional plasma parameter regimes of JT-60SA. Transport experiment can be performed at ITER-relevant normalized collisionality (ν^*), poloidal larmor radius (ρ_p^*). Cloud indicates the regimes in JT-60U. Inverted triangles are data in JET hybrid plasmas.

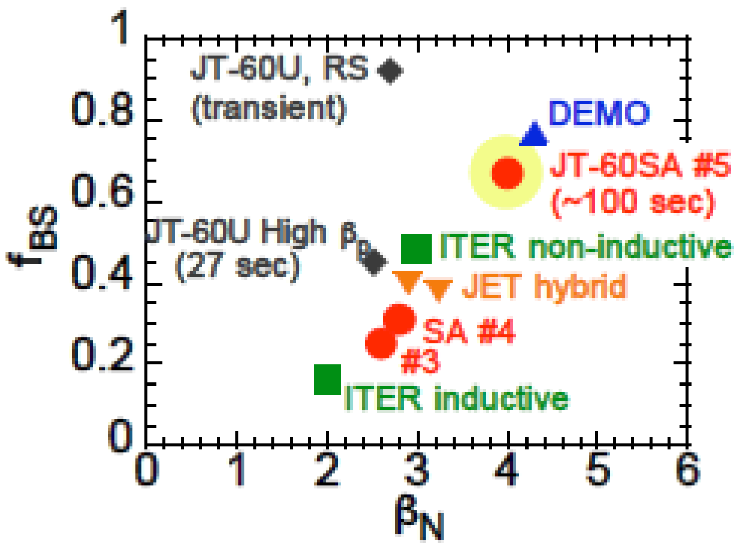


Fig.5-1 The bootstrap current fraction (f_{BS}) against the normalized beta (β_N). Linkage between plasma pressure, rotation and current profiles in highly self-organized plasmas is clarified taking advantage of high β_N and high f_{BS}. (DEMO [1], JT-60U [2, 3], JET [5]).

Transport key points

Study turbulence and transport in plasmas
With Dominant electron heating in presence of substantial population of
Fast particles

Confinement and transport scaling versus various combination of heatings

Confinement versus the shaping and the related changes in pedestal structure

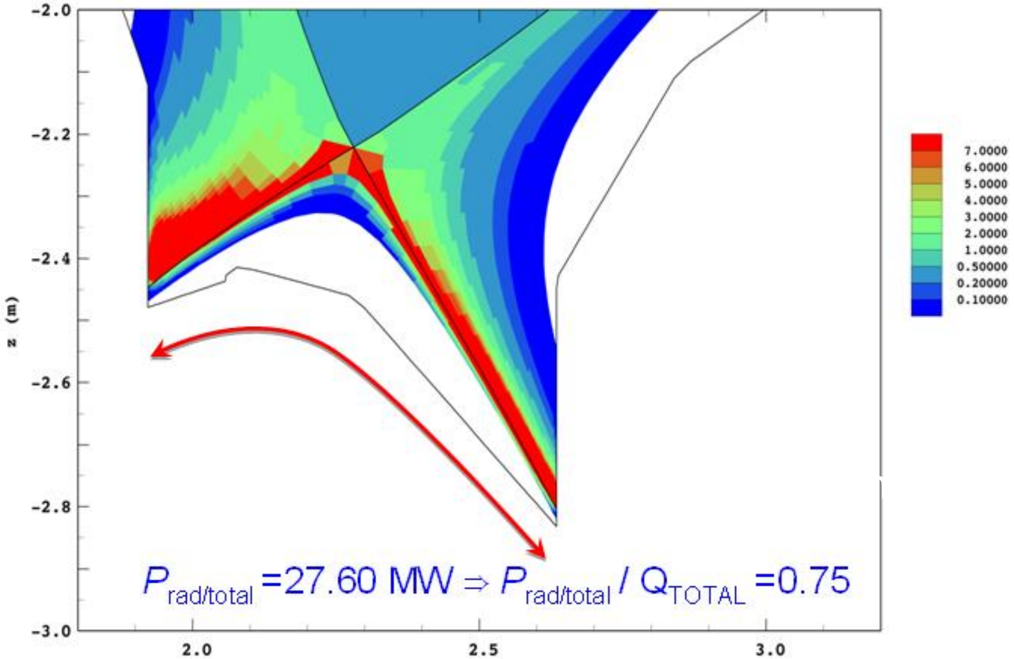
Plasma response and control at high beta normalized , where the control margins
Are low (the current generated by CD systems is less than 30%) like in DEMO

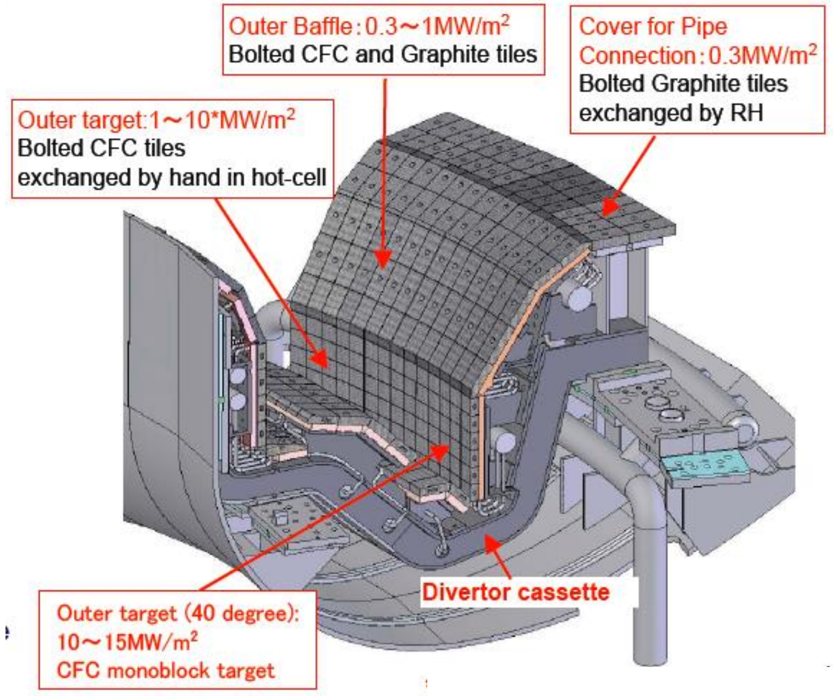
Confinement a high greenwald fraction

IMPORTANT : Diagnostics of turbulence (reflectometry , phase contract imaging ,
coherent Thomson scattering) and rotation (CXRS, spectroscopy)

Divertor, SOL and plasma-material interaction

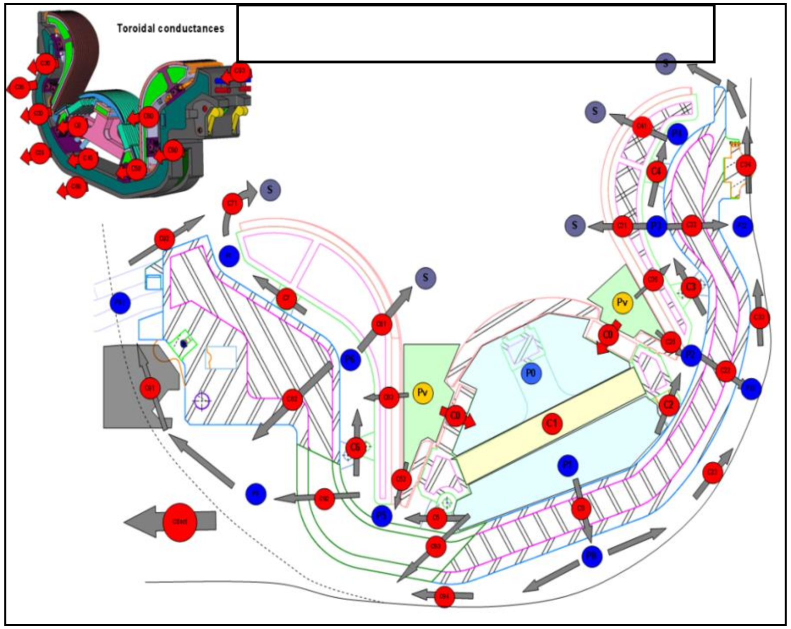
- Divertor evolution from bolted **C tiles** to full **monoblock** to **metallic (W)**
- Controlled **detached** and **highly radiative** divertor studies
- **Particle** and power balance studies for low-T (40°), saturated wall
- Dust, co-deposit, **material migration** studies, post-mortem tile analysis
- **Material probes** to study erosion, melting, blistering, deposition, retention
- **Wall conditioning** with toroidal field by EC waves

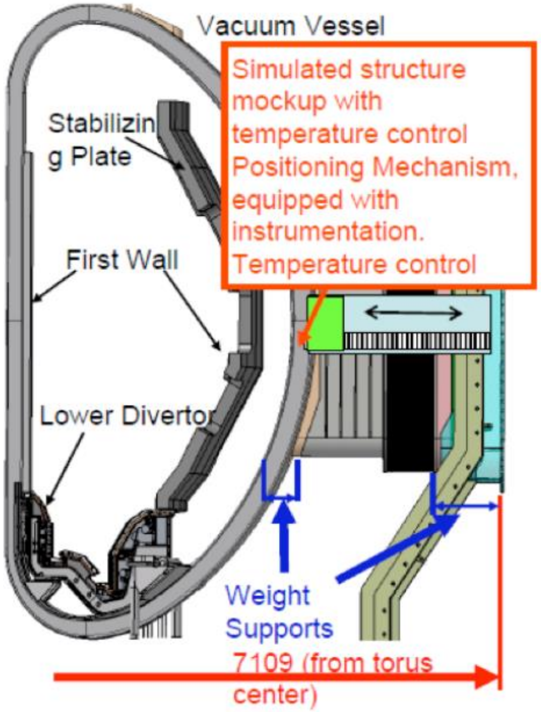




Fusion engineering

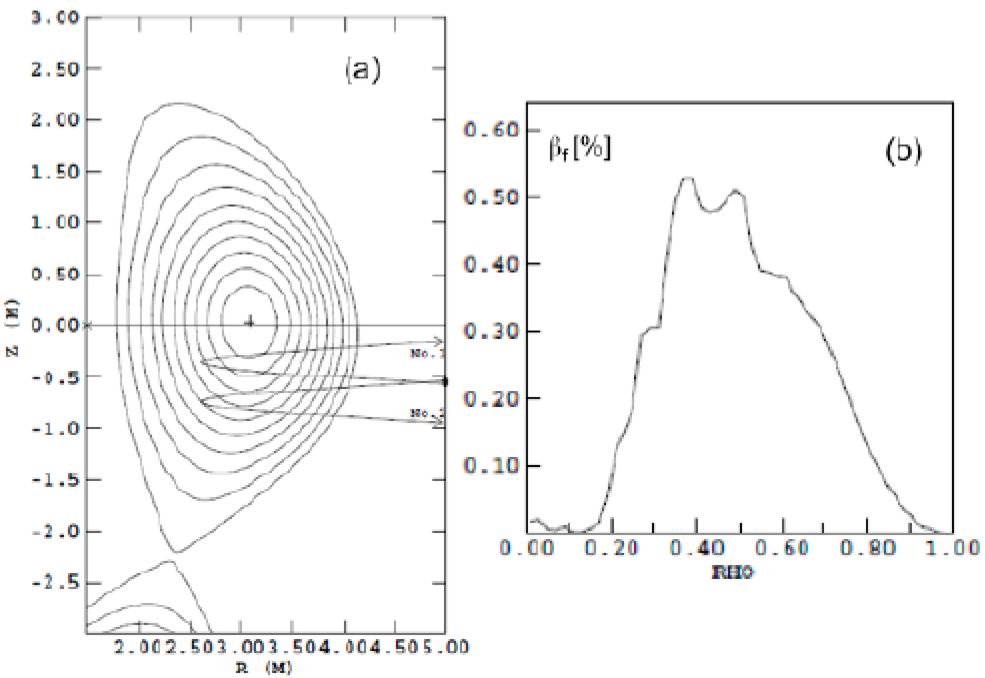
- Use of JT-60SA as **test-bed** for ITER, DEMO or fusion reactor components
- Mockup test of **measurement** equipments (controlled position,temperature)
- Mockup test of **blanket** structure and neutronic performance, divertor targets
- Test of **dust** monitoring and removal methods
- Test of new plasma facing **materials** (e.g., tungsten alloys)
- Test of **pumping** and fuelling systems

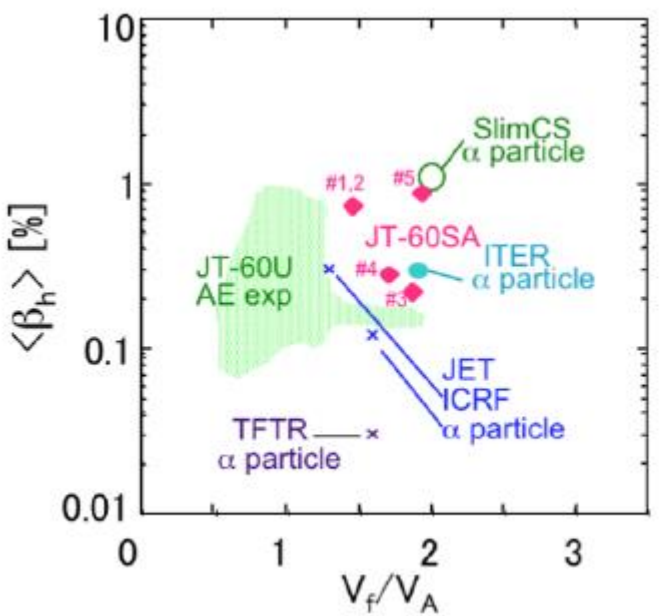




Ch. 6: High energy particle behaviour

- High-energy ions are produced by **500 keV N-NBI**
- Main focus of chapter is now :
  - off-axis NNBI current drive (fast ion transport and instabilities)
  - high-β_N scenarios and role of energetic particles in it
- Need for measuring high-frequency instabilites (CAEs, GAEs ~1MHz)
- Need for runaway diagnostics





Fast ion parameters

Table 6-1 Fast-ion parameters in contemporary experiments compared with projected JT-60SA and ITER values. Data in 2nd to 5th columns data is cited from "Progress in the ITER Physics Basis, Chapter 5: Physics of energetic ions", Nucl. Fusion 47, S264 (2007)

Tokamak	TFTR	JET	JET	JT-60U	ITER	Slim CS	JT-60SA Scen#1-#5-1
Fast ion	Alpha	Alpha	Alpha	Deuterium	Alpha	Alpha	Deuterium
Source	Fusion	Fusion	ICRF tail	Co NBI	Fusion	Fusion	Co NBI
τ_S [s]	0.5	1.0	0.4	0.085	0.8	~2	0.5 - 1.6
n_f _max / $n_e(0)$ [%][(a)]	0.3	0.44	1.5	2	0.85		0.35 - 2.2
β_f _max [%][(a)]	0.26	0.7	3	0.6	1.2		0.54 – 2.3
$<\beta_f>$ [%]	0.03	0.12	0.3	0.15	0.3	~1.2	0.2 – 0.9
β_f _max / $<\beta_f>$	8.7	5.8	10	4	4		2.5 – 3.2
max | $R\nabla\beta_f$ | [%]	2.0	3.5	5	6	3.8		5.2 – 65
v_f_max / v_A	1.6	1.6	1.3	1.9	1.9	~2	1.0 – 1.26

[(a)] Except for JT-60SA, "max" means the value at the plasma center.

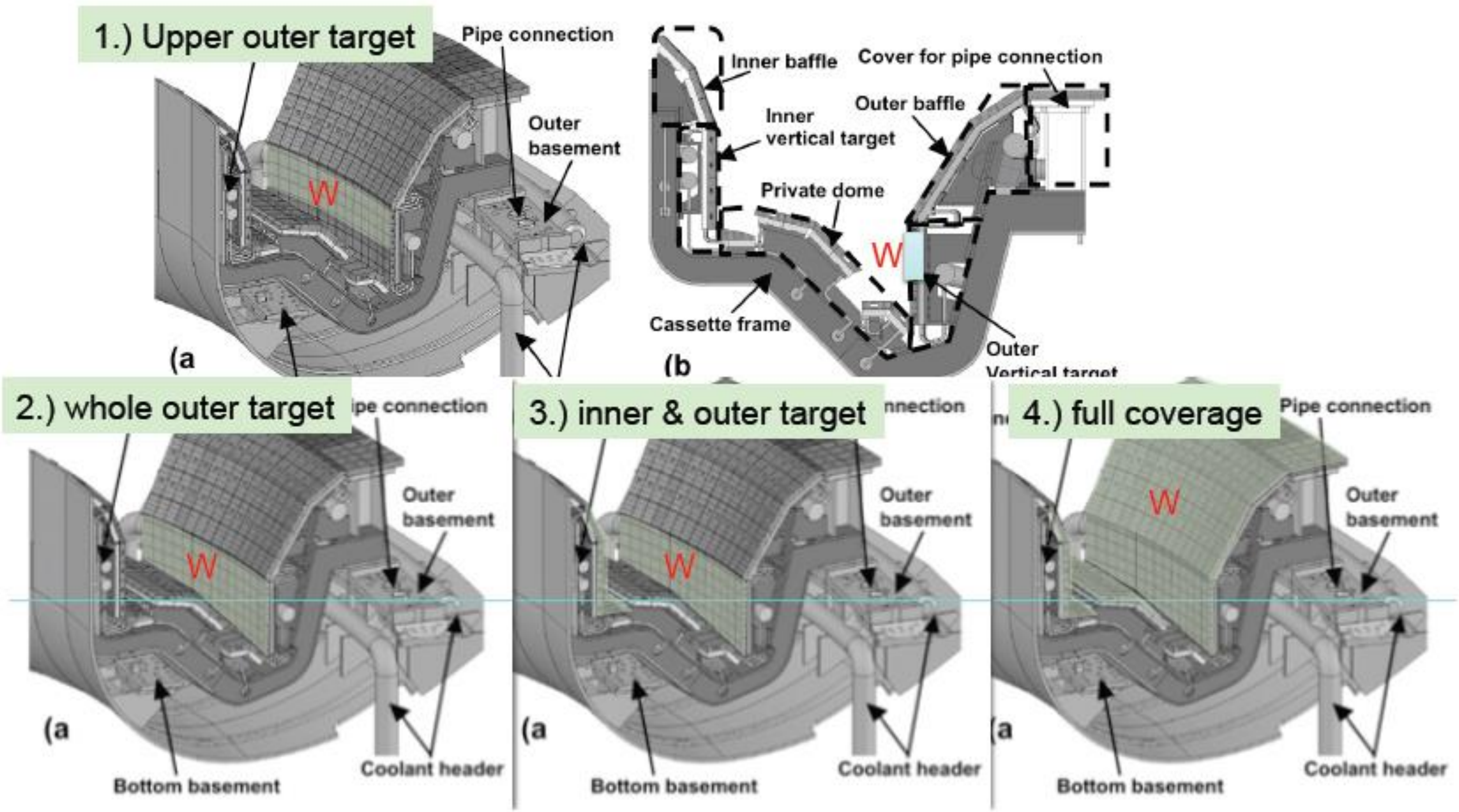
Associazione Euratom-ENEA sulla Fusione

Ch. 7: Pedestal and edge

- **Small or no ELM regimes**: include research on **QH** mode and type III ELMs
- **Active ELM control**:
  - Scenario integration with active ELM suppression
  - Active ELM suppression at low plasma rotation
  - Pellet ELM pacing studies
  - Synergy of mitigation techniques
- **L-H mode threshold**:
  - L-H transition studies at low ν^*/high density with NNBI
  - study H-mode quality at low input power above the L-H transition and at low plasma rotation
  - L-H transition studies in current ramps (likely scenario in ITER)
- **Edge pedestal characteristics:**
  - pedestal scaling with β_p
  - test of edge stability models (including High Field Side measurements)
  - recommendations on diagnostics

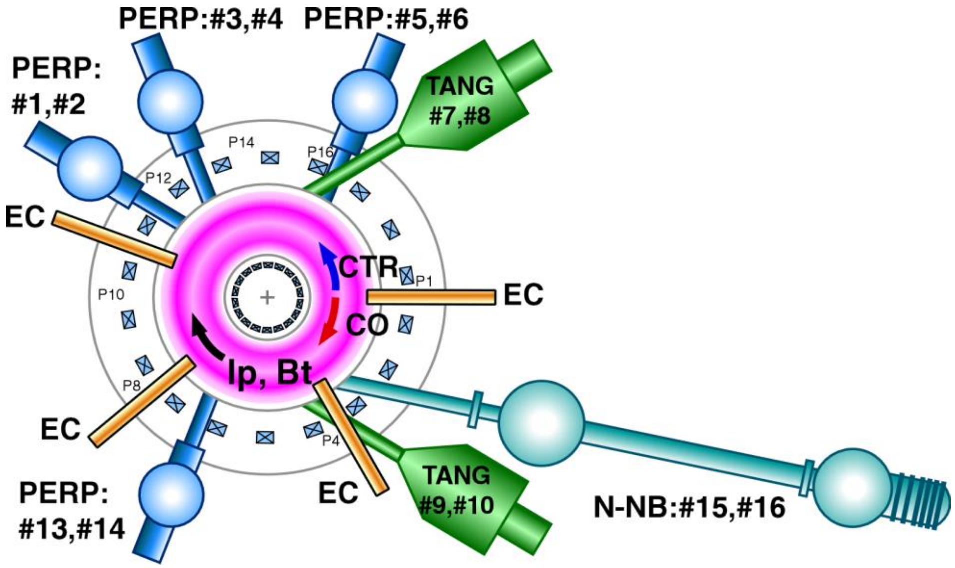
Ch. 8: Divertor W coverage (OPTIONS & IDEAS)

- Phased increase of coverage:



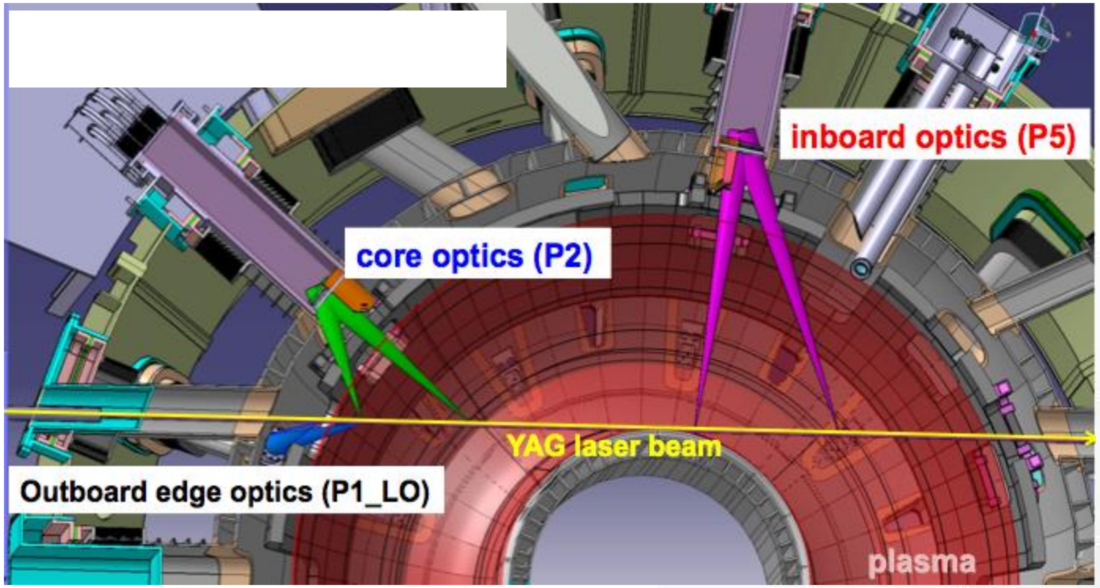
App. A: Heating and CD

- **NBI:**
  - clarify P/N-NBI CD capabilities, power modulation and active cooling specifications
  - clarify operational boundaries in the various scenarios
- **ECRF:**
  - Current drive capabilities in the various scenarios documented
  - relevance of the wave frequency in the various scenarios documented
  - Launcher design reviewed



App. D: Plasma Diagnostics systems

- comparison with the planned set of ITER diagnostics
- assessment of essential diagnostics for scenario development
- diagnostics for Real Time Control
- DEMO-relevant diagnostics (simple, robust, easy maintenance…)
- critical points identified:
  - fast ion diagnostics
  - ensemble of q-profile diagnostics
  - Thomson scattering optics
  - real time diagnostics

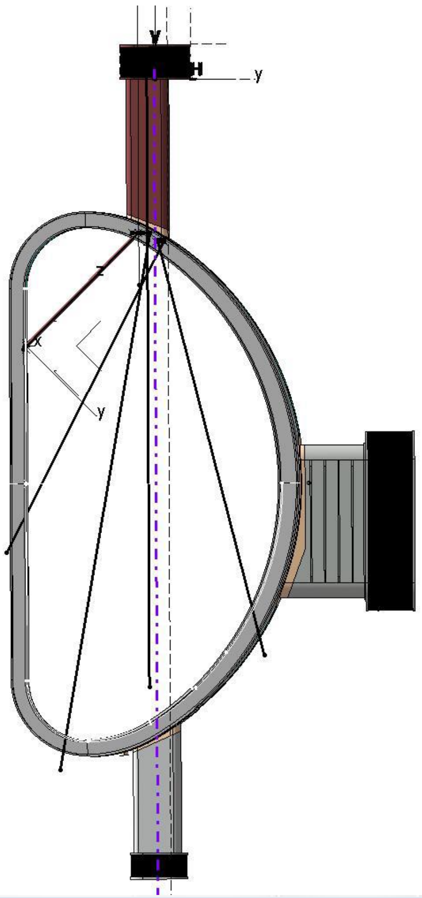


Joint EU-JA proposal for a conceptual study of a polarimeter

Provide Faraday rotation angle measurements in real-time during plasma for the ENTIRE length with a time resolution in the range of 1 to 10ms.

Provide fringe-jumps free density measurements via Cotton-Mouton measurement for at least one vertical channel in the view to be used as a backup for electron plasma density as provided by the interferometer.

Proposed wavelength is 195µm as at 118µm laser(ITER equivalent) the Faraday Angle range is very small (<10deg)



CONCLUSIONS

JT-60SA research programme has definitely challenging objectives

And

JT-60SA is a key device on the way to realize a fusion reactor