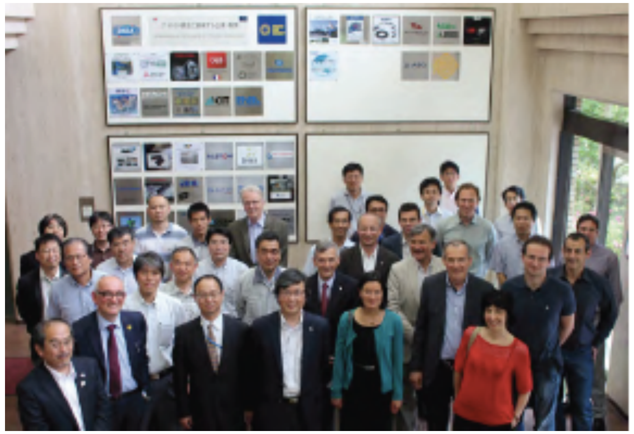
for 2014 FESAC Strategic Planning
Panel Meeting, 8th July, 2014

The JT-60SA Research Regimes for ITER and DEMO



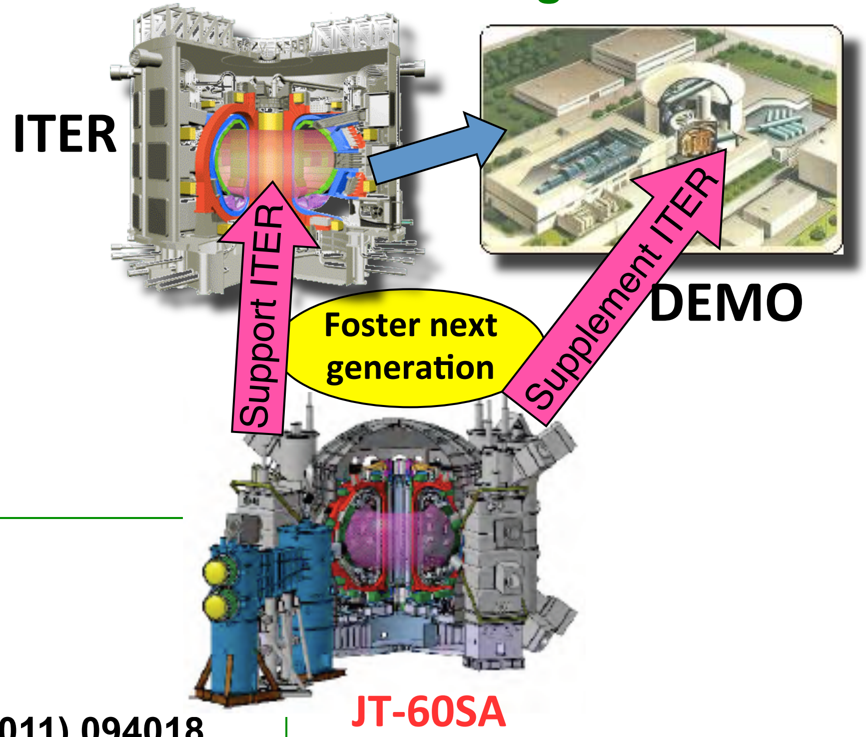
Y. Kamada (JAEA) and the JT-60SA Team

JT-60SA (JT-60 Super Advanced) Project

The 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.

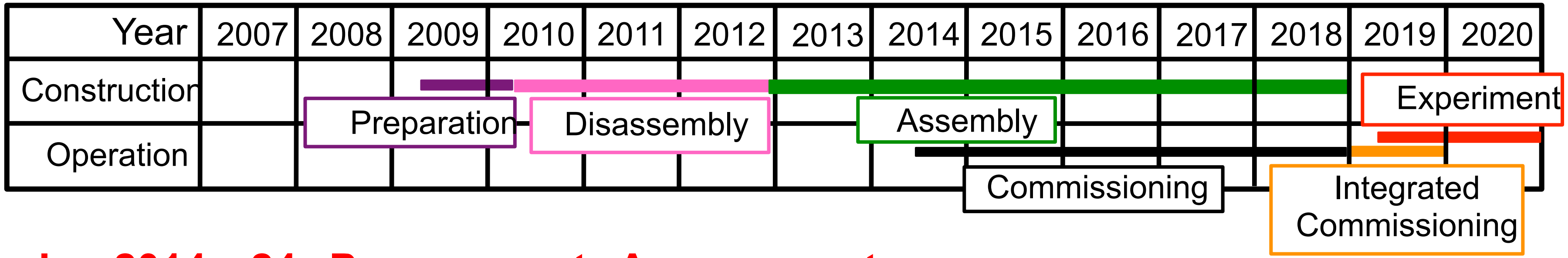
- support ITER
  using break-even-equivalent class high-temperature deuterium plasmas lasting for a duration (typically 100 s) for optimization of ITER operation scenarios.
- supplement ITER toward DEMO
  with long sustainment (~100 s) of high pressure plasmas necessary in DEMO for establishment of DEMO operation scenarios.

JT-60SA contributes to
'Success of ITER',
'Decision of DEMO design'
' Foster the next generation'

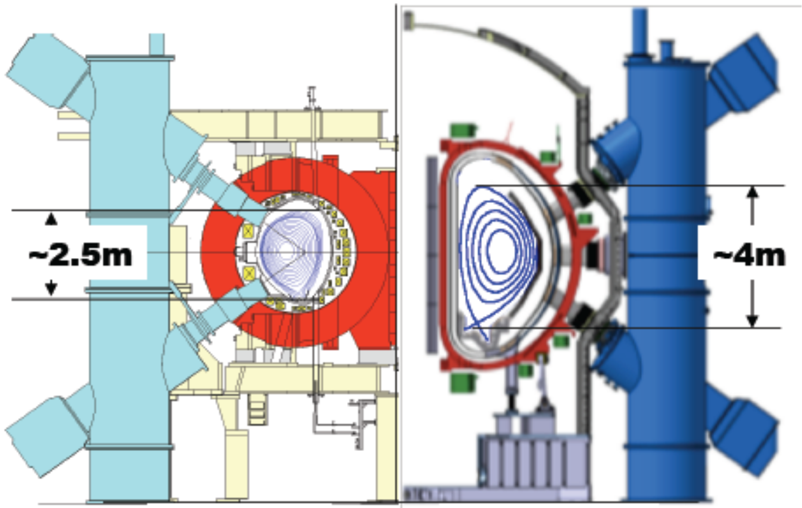


JT-60SA HP: http://www.jt60sa.org/b/index.htm
JT-60SA Research Plan:
http://www.jt60sa.org/b/index_nav_3.htm?n3/operation.htm
References:
S. Ishida, P. Barabaschi, Y. Kamada, et al., Nucl. Fusion 51 (2011) 094018
Y. Kamada, P. Barabaschi, S. Ishida, et al., Nucl. Fusion 53 (2013) 104010

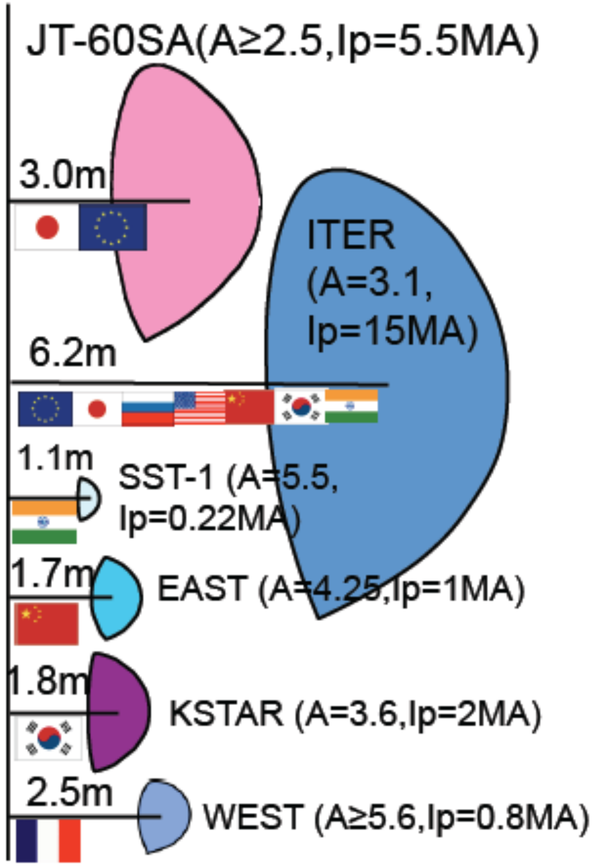
JT-60SA: First Plasma in Mar. 2019



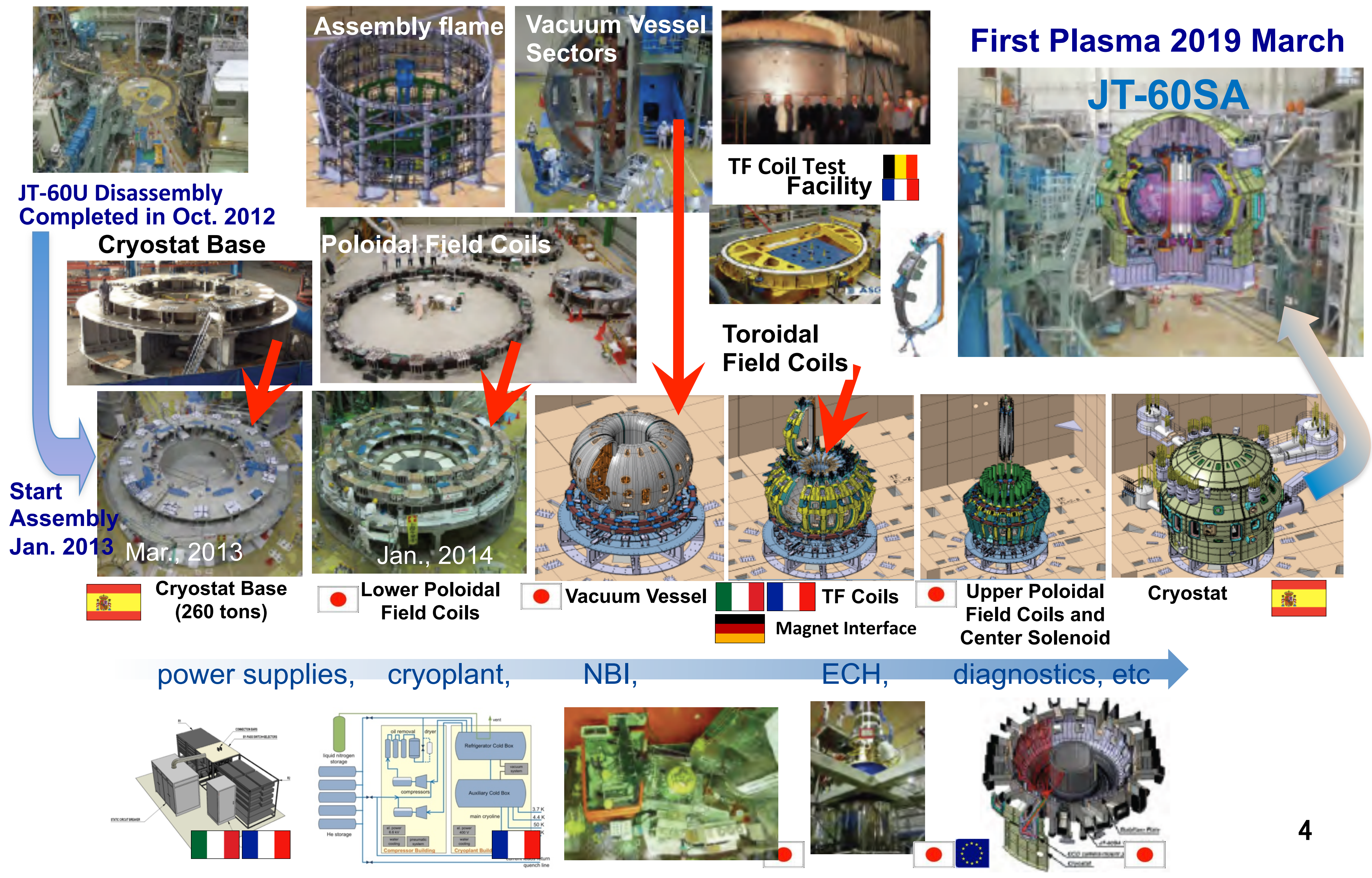
By Jun.2014, 24 Procurement Arrangements have been concluded:
(JA: 13PAs, EU: 11PAs) = 87% of the total cost of BA Satellite Tokamak Program.



JT-60U JT-60SA



JT-60SA Manufacture in EU& JA, and Assembly going on schedule

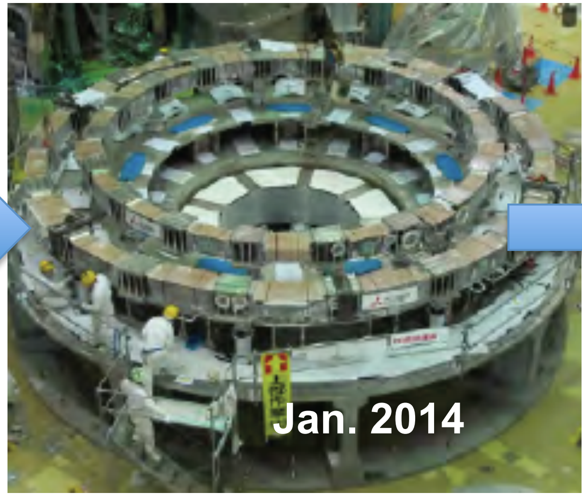


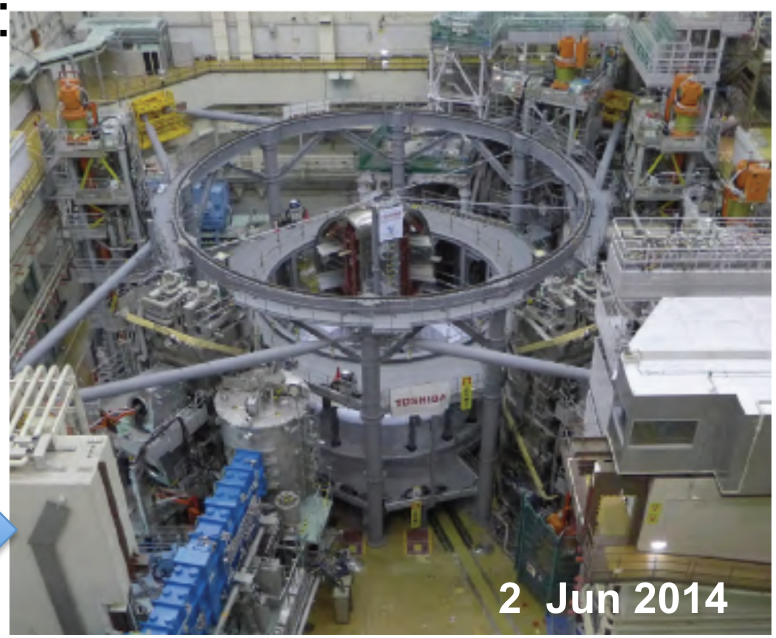
JT-60SA Torus Assembly Started

Temporary installation of EF4,5 & 6 on CB:
⇒Assembly Frame set up
⇒VV assembly starts in May 2014

Cryostst Base

Lower 3 EF Coils





Vacuum Vessel

360deg. (40deg. X 7 + 30deg.x2 + 20deg) has been completed

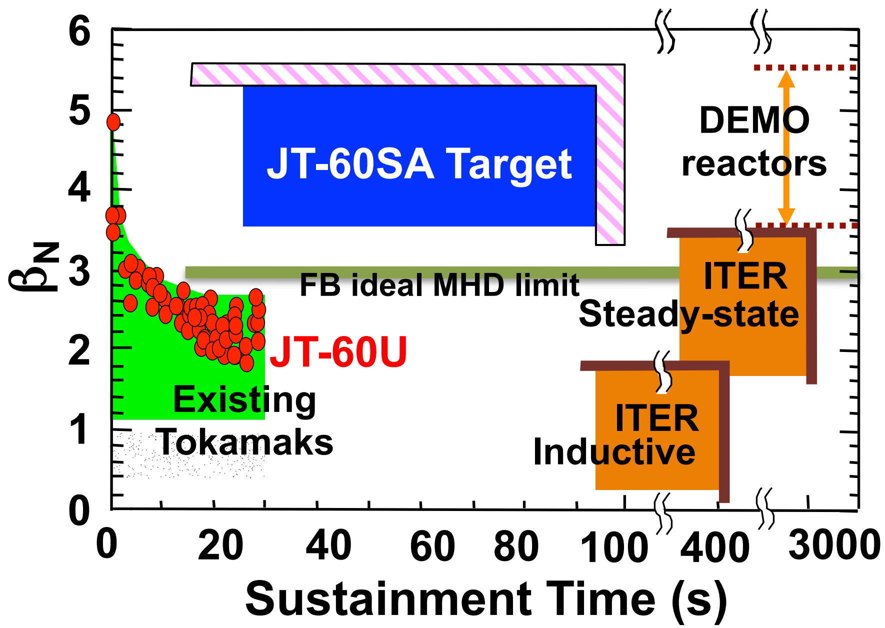
JT-60SA: Highly Shaped Large Superconducting Tokamak

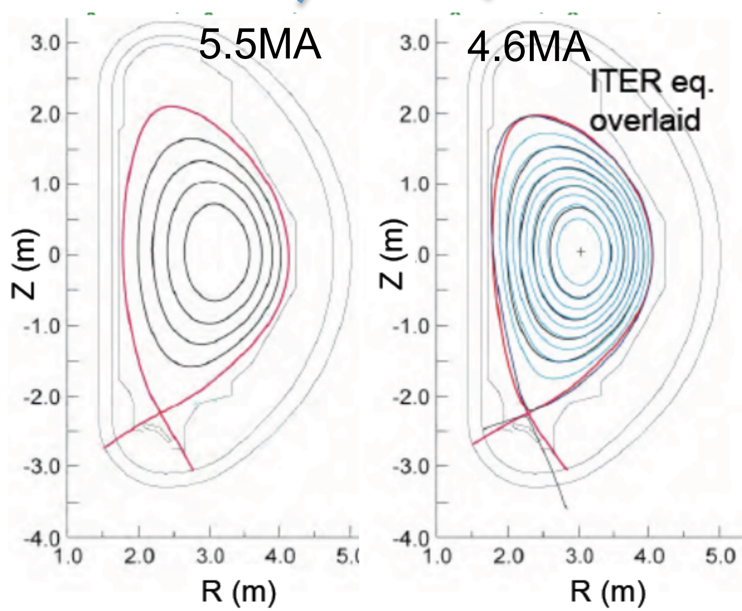
JT-60SA: highly shaped ($S=q_{95}I_p/(aB_t)$ ~7, A~2.5) large superconducting tokamak confining deuterium plasmas (Ip-max=5.5 MA) lasting for a duration (typically 100s) longer than the timescales characterizing the key plasma processes such as current diffusion time, with high heating power 41MW.

Utilizing the ITER- and DEMO-relevant plasma regimes and DEMO-equivalent plasma shapes, JT-60SA contributes to all the main issues of ITER and DEMO.

representative scenarios

	#2 Full Ip 41MW	#4-1 ITER-like Shape 34MW	#4-2 Advanced inductive 37MW	#5-1 High βN Full CD 37MW
I_p (MA)	5.5	4.6	3.5	2.3
B_T (T)	2.25	2.28	2.28	1.72
R_p (m)	2.96	2.93	2.93	2.97
A	2.5	2.6	2.6	2.7
κ95	1.72	1.7	1.72	1.83
δ95	0.4	0.33	0.34	0.42
q95	3.0	3.2	4.4	5.8
Pin (MW)	41	34	37	37
β_N	3.1	2.8	3.0	4.3
fBS	0.28	0.3	0.4	0.68



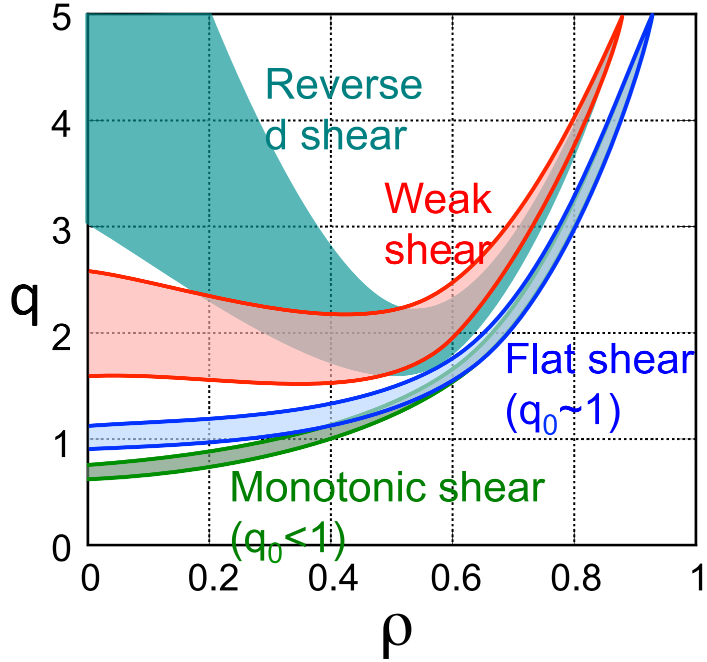


JT-60SA Research Regime for DEMO

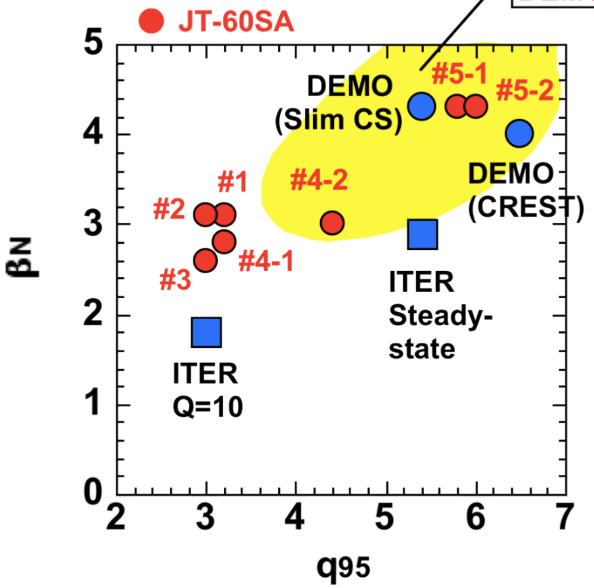
'Simultaneous & steady-state sustainment of the key performances required for DEMO' (= highly self regulating) <u>has never been achieved</u> => the goal of JT-60SA.

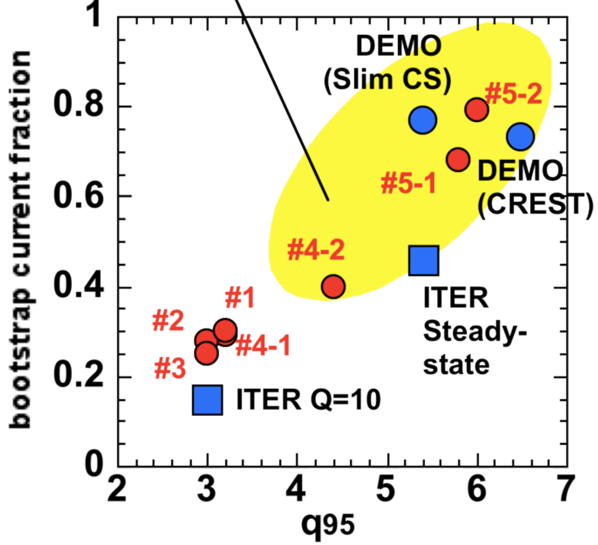
JT-60SA should decide the practically acceptable DEMO parameters, and develop & demonstrate a practical set of DEMO plasma controls.

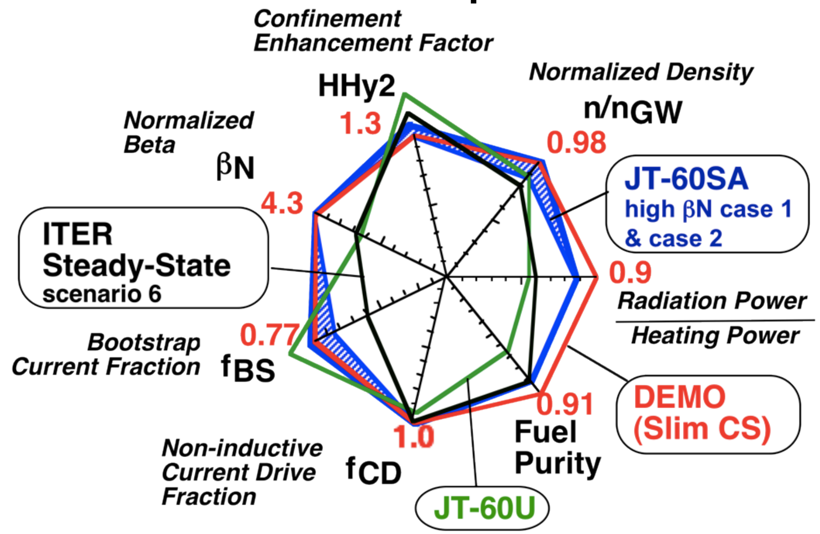
We treat 'the DEMO regime' as a spectrum.



JT-60SA regime for DEMO -assessment







JT-60SA is a flexible 'Test Stand' for ITER

H-mode operations towards Q=10 (H, He, D)

- L-H transition, Pedestal Structure
- H-mode confinement (incl. compatibility with radiative divertor, RMP, etc.)
- Local Ripple & TBM Test

ELM mitigation (RMP, pellet, …)

Disruption avoidance & mitigation (Intensive Gas, impurity pellet)

Divertor Heat Load reduction

Integrated Operation scenario optimization with superconducting PF coils.
(operation scenarios, plasma actuators, diagnostics …)

High Energy particle physics using 10MW 500keV N-NB for ITER a-heatin

- NB Current Drive studies (incl. off-axis NBCD),
- AE mode stability & effects on fast-ion transport,
- Interactions between high energy ions and MHD instabilities

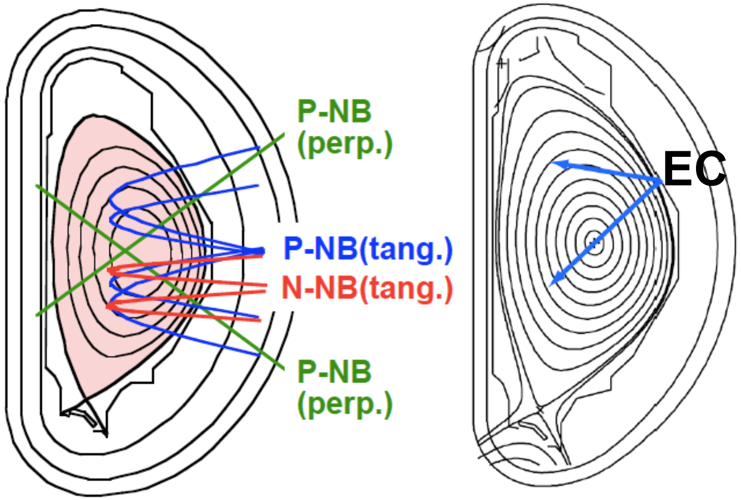
41MW×100s high power heating with variety

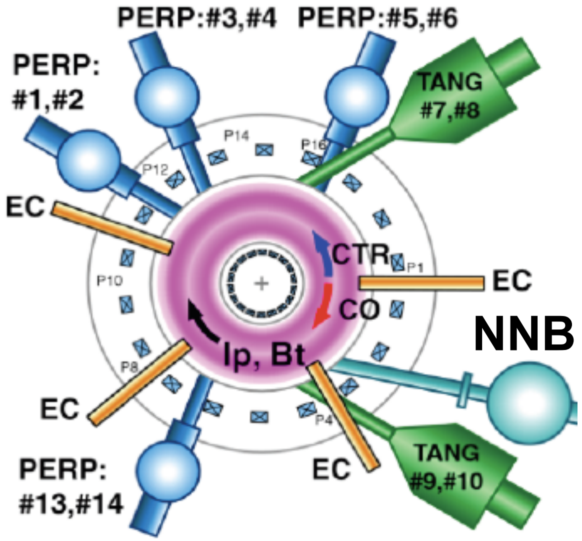
Variety of heating/current-drive/momentum-input combinations

NB: 34MW×100s

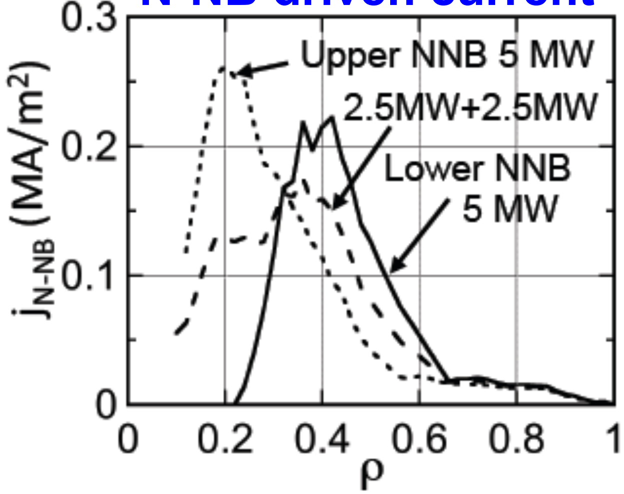
Positive-ion-source NB (85keV), 12units × 2MW=24MW,
CO:2u, CTR:2u, Perp:8u

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

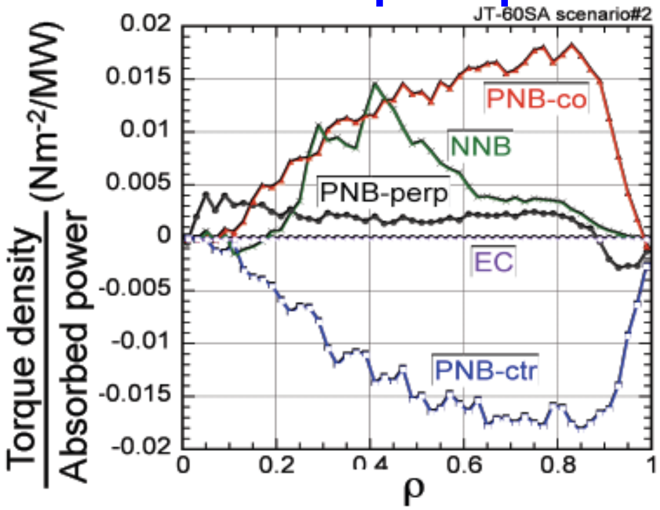




N-NB driven current



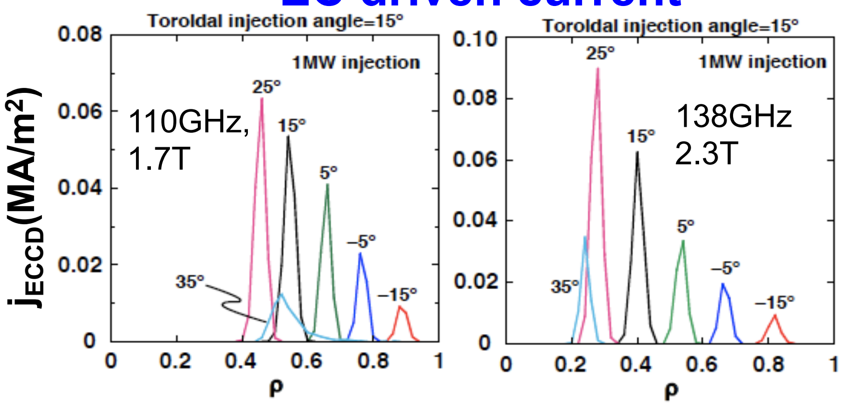
Torque input



ECRF: 7MW×100s

110GHz+138GHz,
9 Gyrotrons,
4 Launchers
with movable mirror
>5kHz modulation

EC driven current

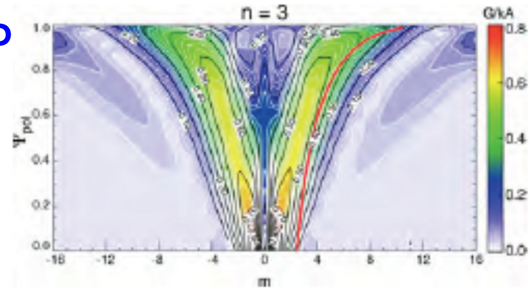


MHD stability control

- **Stabilizing Wall**
- **Fast Plasma Position Control coil**
- **Error Field Correction (EFC) coil)**
  (=>RMP, 18 coils 30 kAT, ~9 G~$4\times10^{-4}B_T$
- **RWM Control coil: 18 coils. on the plasma side.**

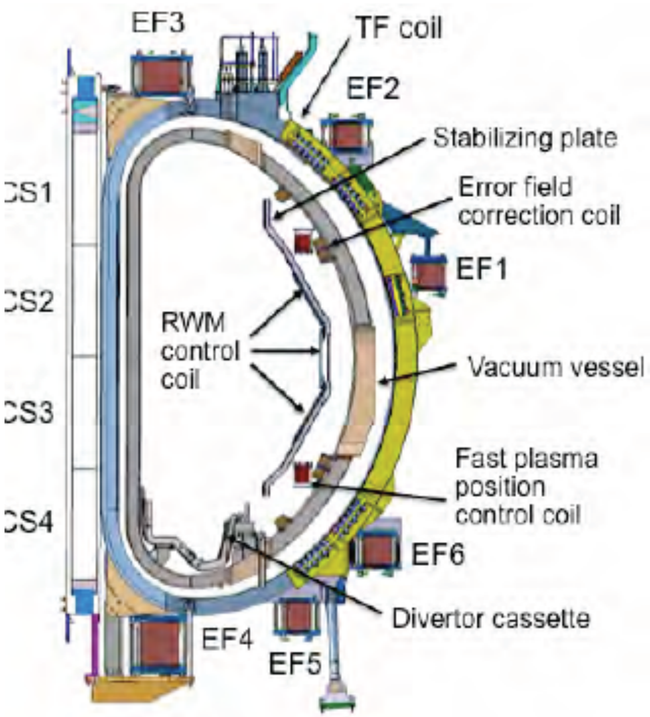
+ ECCD (NTM), rotation control

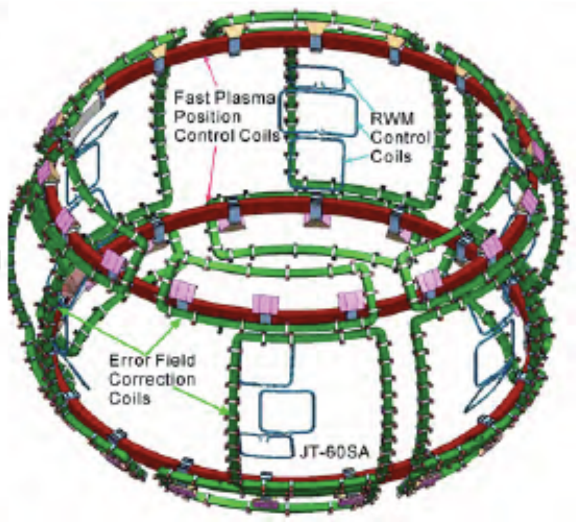
RMP

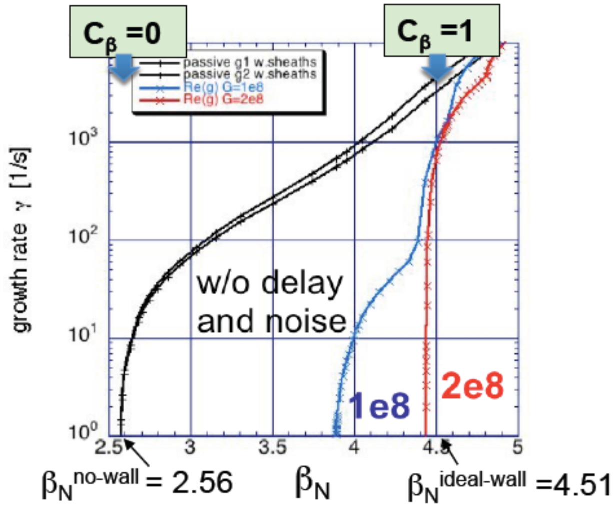


RWM control

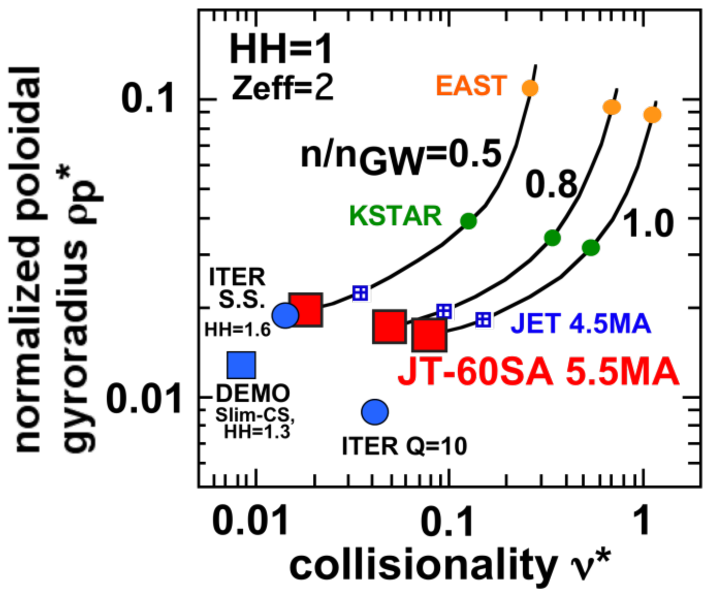
β_N = 4.1 (C_β =0.8) with effects of conductor sheath, noise (2G), and latency (150 ms).



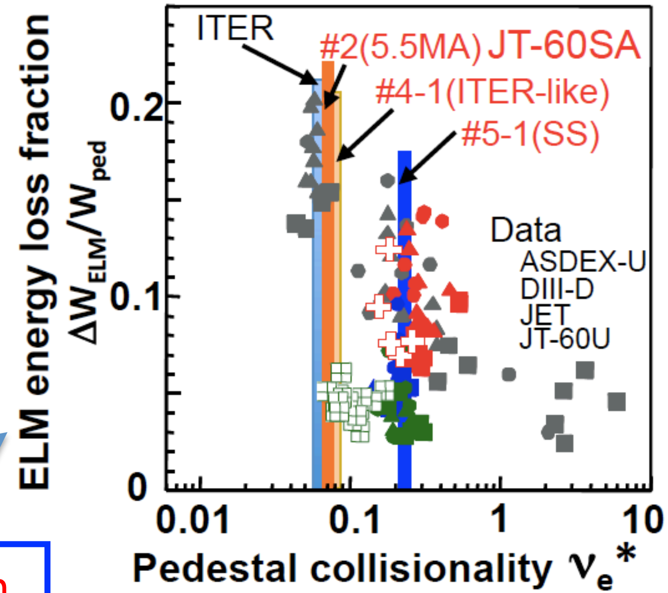




JT-60SA allows study on self regulating plasma control with ITER & DEMO-relevant non-dimensional parameters

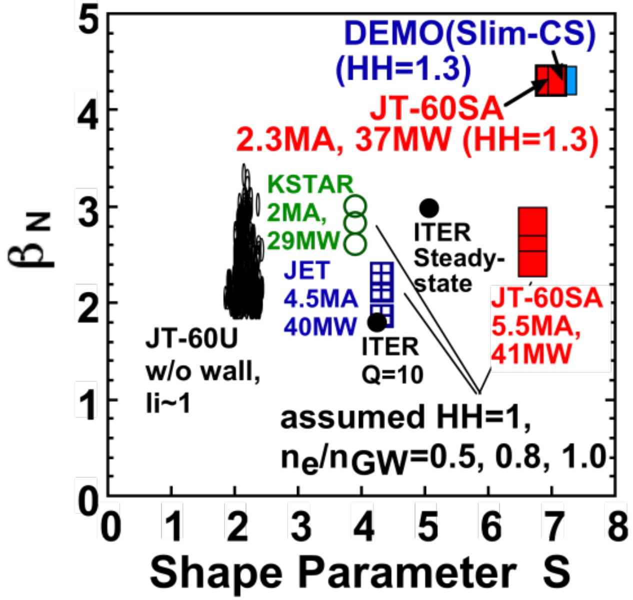


Collisionality,
Gyroradius,



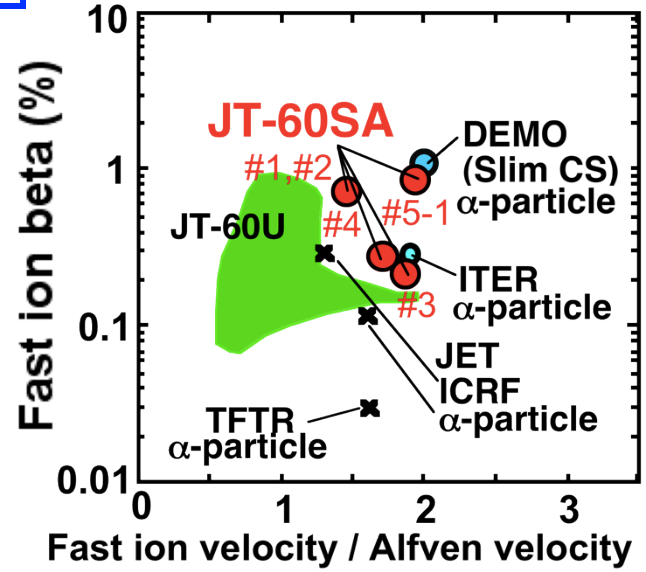
Pedestal
Collisionality

Mutual Interaction



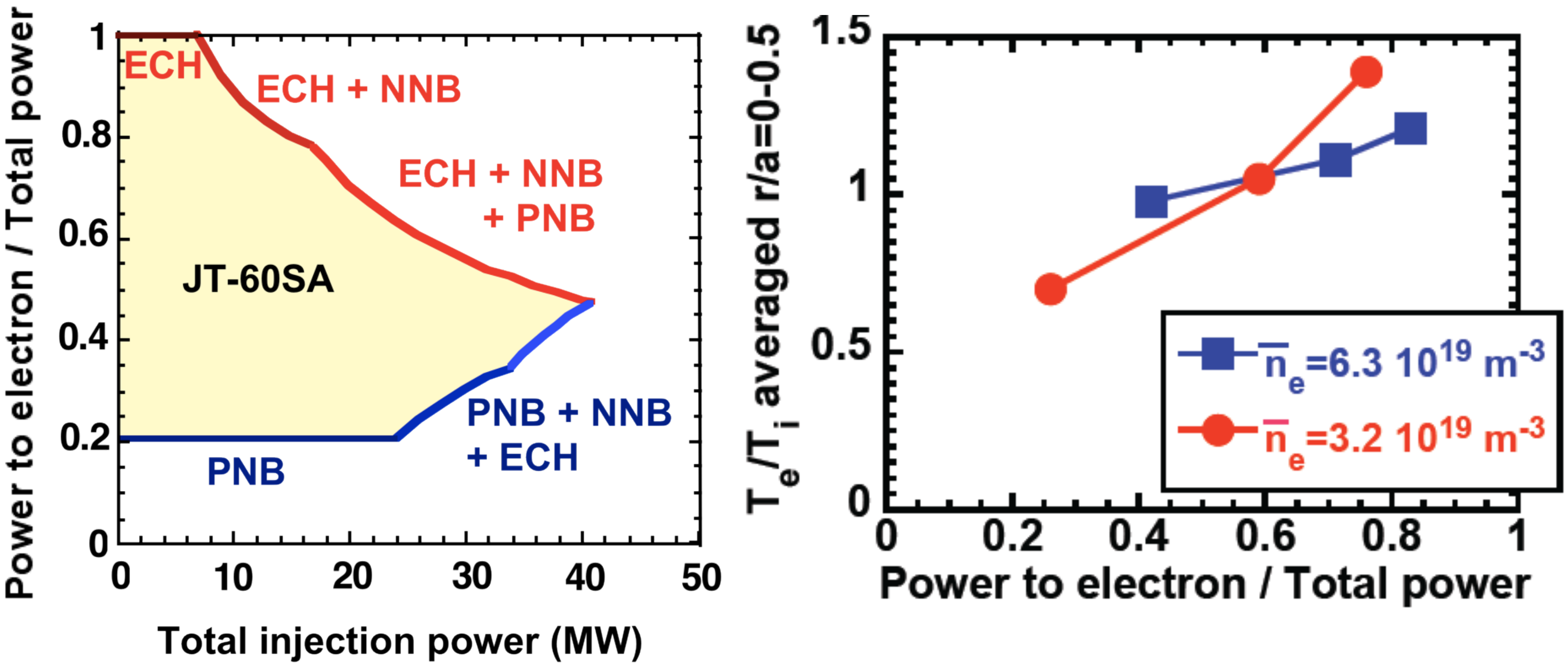
Beta,
Plasma shape,

First ion beta,
Fast ion speed,



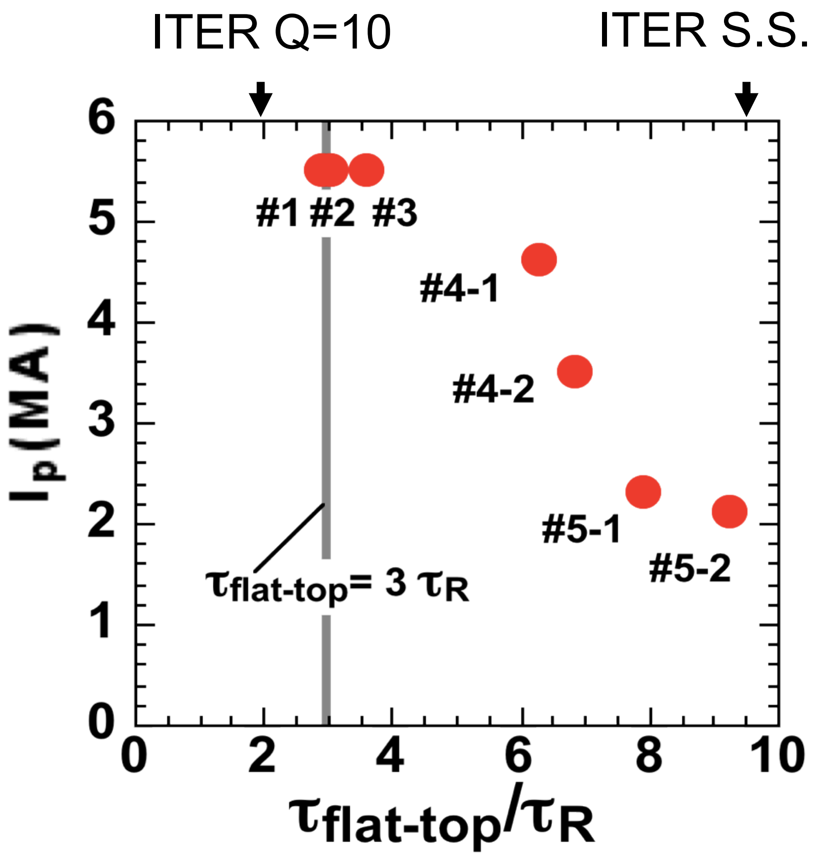
ITER- & DEMO- relevant heating condition

JT-60SA allows
* dominant electron heating,
  (+ scan of electron heating fraction)
* high power with low central fueling
• high power with low external torque (+ rotation scan)

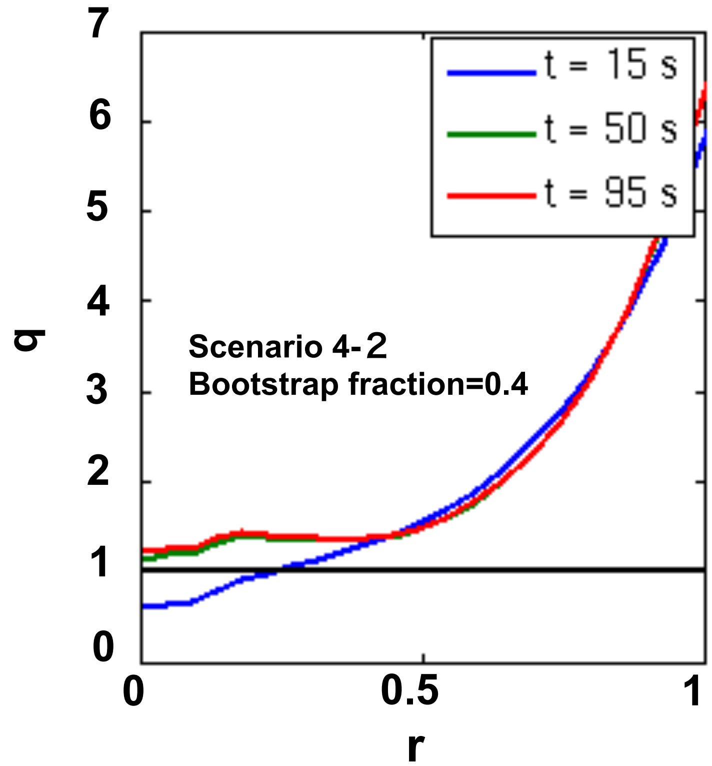


Sufficiently long sustainment time for ITER- & DEMO

For all the representative scenarios:
$t_{flat\text{-}top}$(100s) > 3 x current diffusion time t_R



Advanced inductive scenario (#4-2):
q(r) reaches steady-state before
t=50s with q(0)>1.



Fuel & Impurity Particle Control for ITER & DEMO

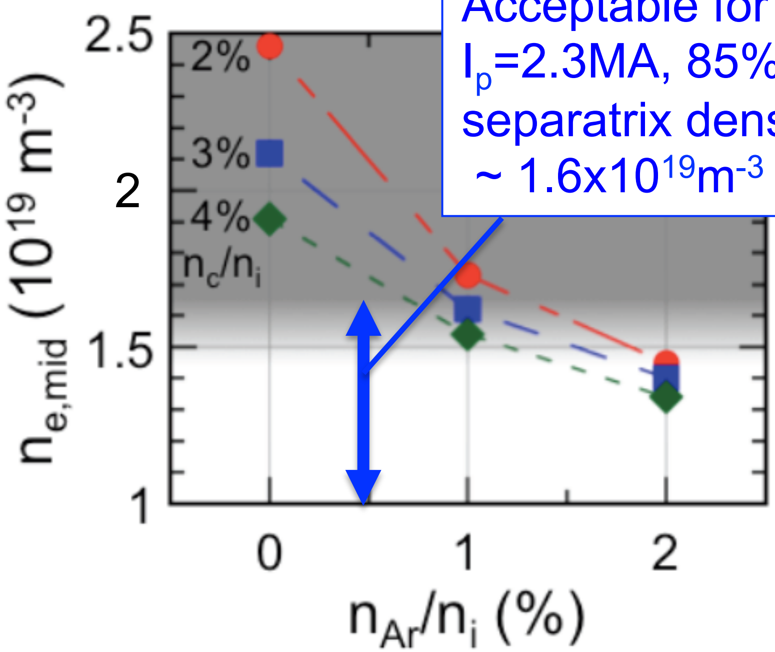
Compatibility of the radiative divertor with impurity seeding and sufficiently high fuel purity in the core plasma should be demonstrated.

SOL/divertor simulation code suite SONIC

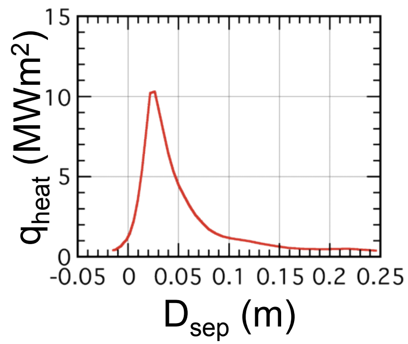
Divertor heat flux can be managed by controlling Ar gas puffing.

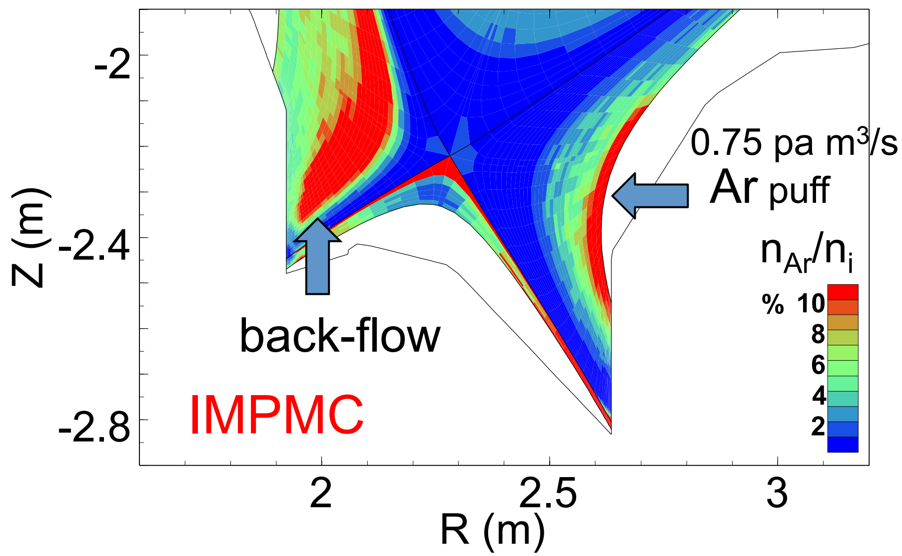
The separatrix density necessary to maintain the peak heat flux onto the outer divertor target <~10MW/m^2

Acceptable for #5-1: I_p=2.3MA, 85% n_{GW} , separatrix density ~ 1.6x10^{19}m^{-3}



Detailed simulation by IMPMC illustrates dynamics of impurity: Origin (puff and back-flow) and distribution of Ar illustrated.



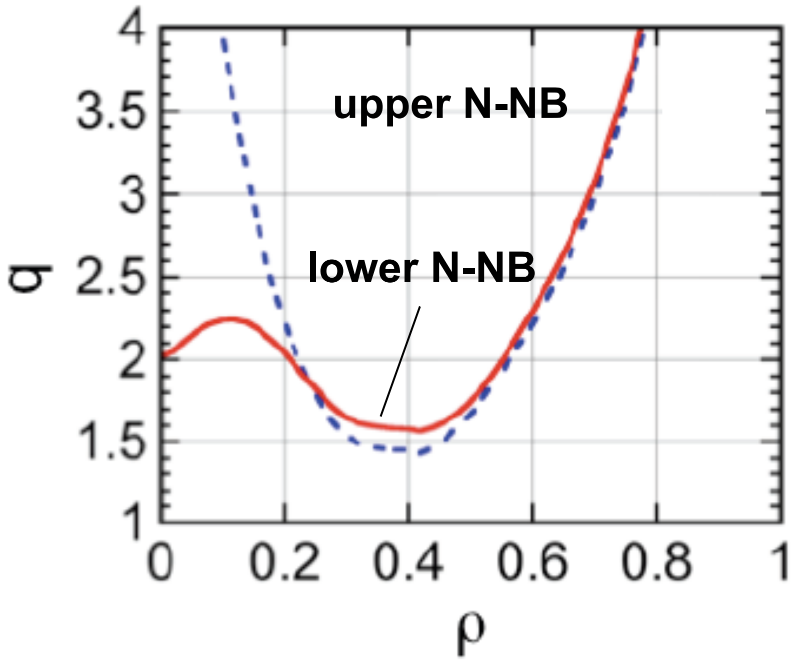


Profile controllability for high-β_N & high-bootstrap plasmas

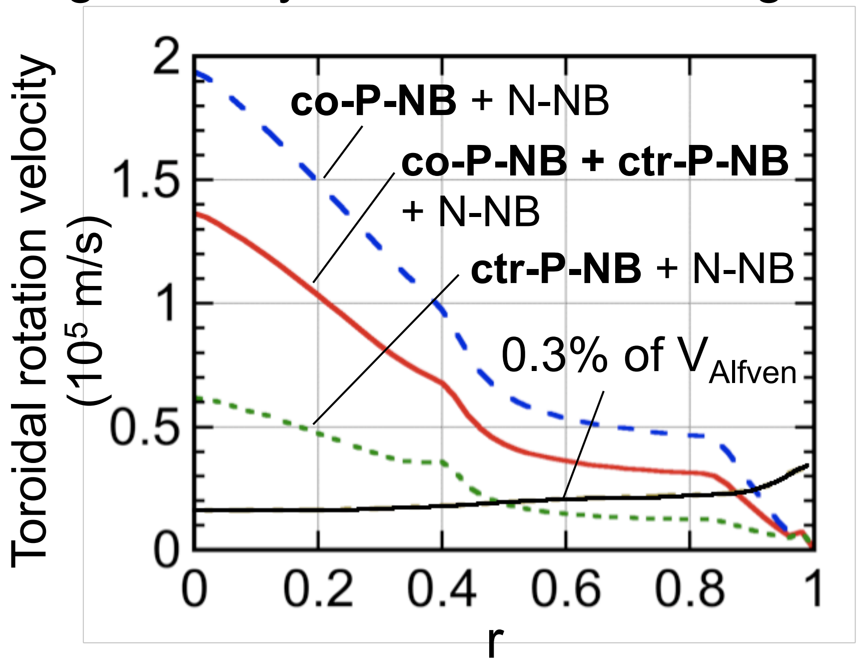
1.5D transport code TOPICS (with the CDBM transport model) + F3D-OFMC

➔ Self consistent simulation for Scenario 5-1(I_p=2.3MA with ITB)

By changing from the upper N-NB to the lower N-NB
=> qmin increases above 1.5.

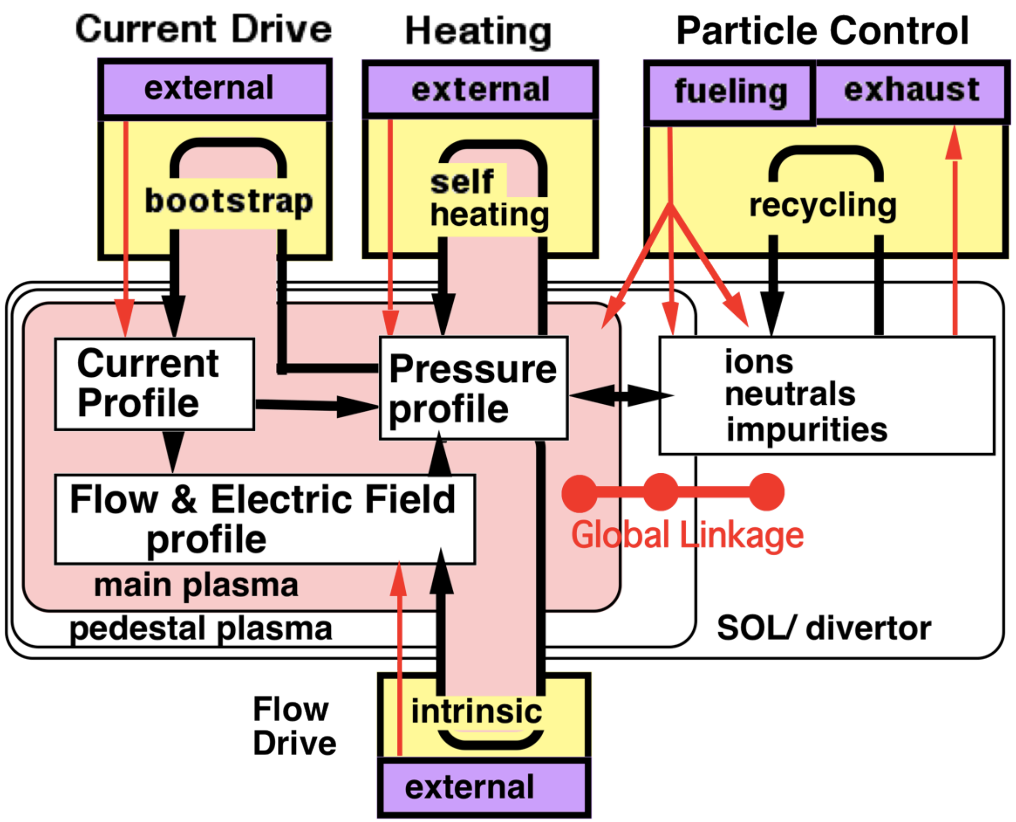


By changing combinations of tangential P-NBs (co, counter, and balanced) with N-NB, the toroidal rotation profile is changed significantly. ⇔ RWM-stabilizing rotation

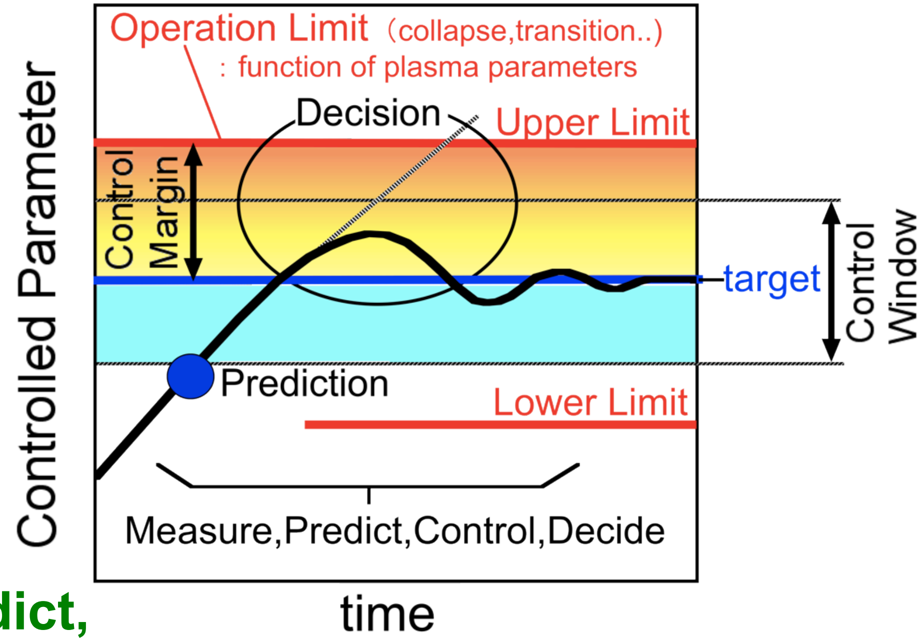


Integrated Control Scenario Development

Understanding & Control of the highly self-regulating combined plasma system for DEMO



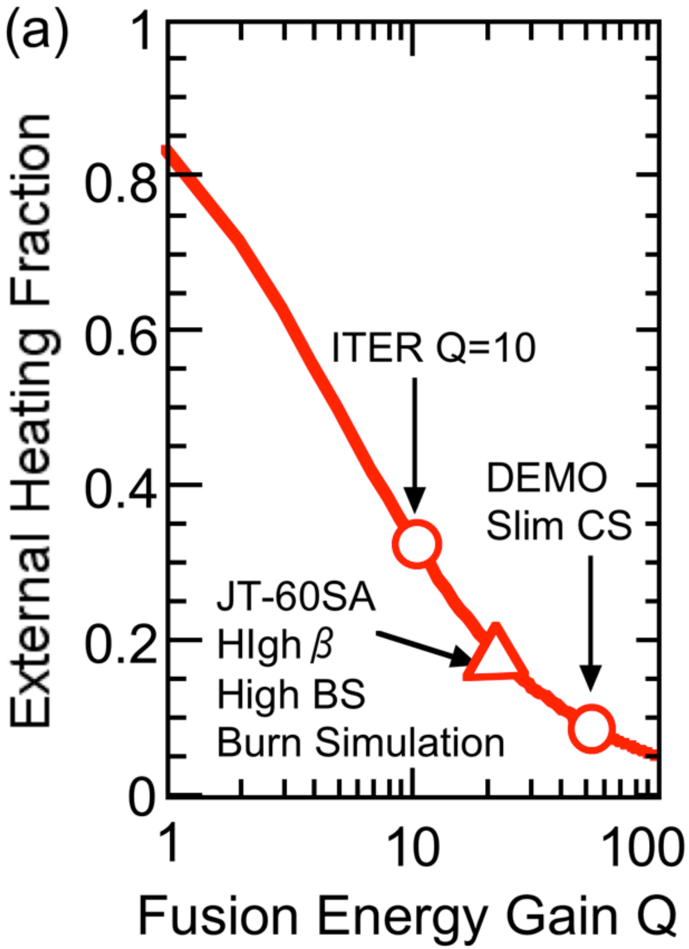
Determine the minimum suitable set of actuators & logic.

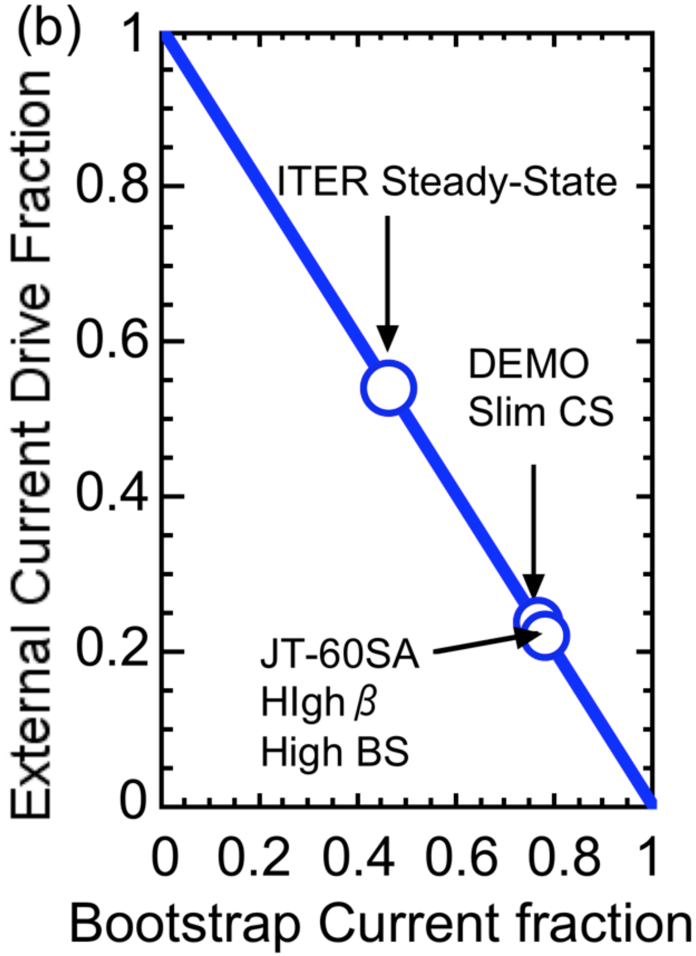


Measure, Predict, Control, Decide

Integration of achievements in JT-60SA high-β steady-state plasmas and in ITER burning plasmas

ITER + JT-60SA + Prediction Codes => DEMO





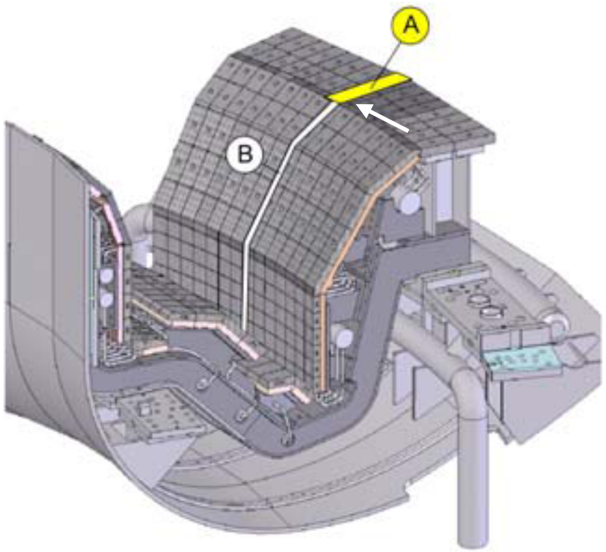
Fusion Engineering R&D

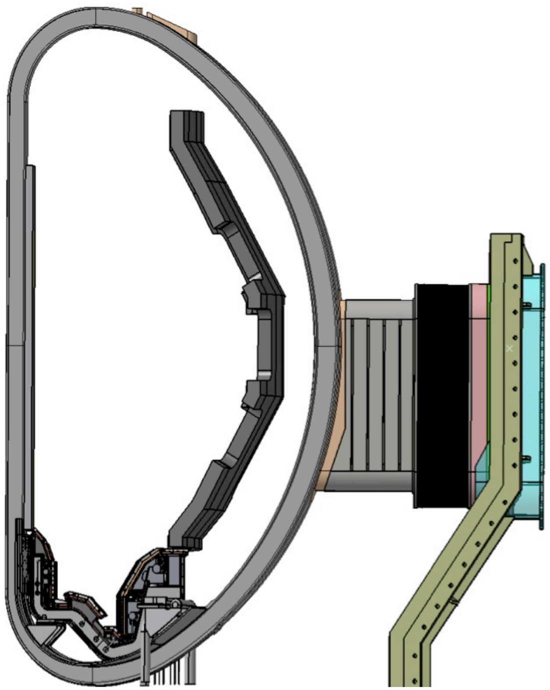
Large Ports can be used for Blanket R&D

Replaceable divertor and in-vessel structure
can be used for Plasma facing components R&D.

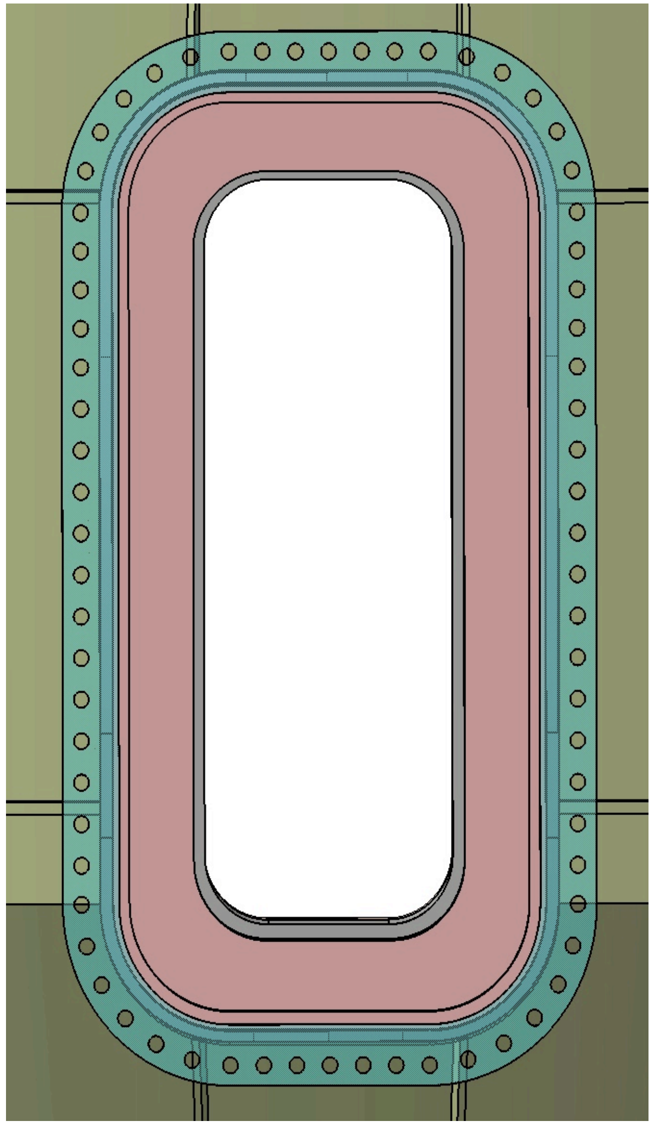
Particle Controllability / Pumping

Plasma / material interaction using
‘material probe’.





Allowable dimension
W660 X H1830



Research phases and status of key components

- **JT-60SA is planned to be upgraded according to the phased equipment plan.**
  - Divertor, ECRF, P-NB, Remote Handling

	Phase	Expected Duration		Annual Neutron Limit	Remote Handling	Divertor	P-NB 85keV	N-NB 500keV	ECRF 110 GHz & 138GHz	Max Power	Power x Time
Initial Research Phase	phase I	1-2y	H	-	R&D	LSN partial-monoblock Carbon Div.Pumping	10MW	10MW	1.5MW x100s + 1.5MW x5s	23MW	NB: 20MW x 100s 30MW x 60s duty = 1/30 ECRF: 100s
	phase II	2-3y	D	4E19			Perp. 13MW Tang. 7MW			33MW	
Integrated Research Phase	phase I	2-3y	D	4E20		LSN full-monoblock Carbon Div. Pumping			7MW	37MW	
	phase II	>2y	D	1E21	Use						
Extended Research Phase		>5y	D	1.5E21		DN full-monoblock Metal or Carbon Advanced Structure	24MW			41MW	41MW x 100s

Extended Research Phase:
Installation of the metallic divertor targets and first wall together with an advanced shape divertor will be conducted based on progress of the research in the world tokamaks including ITER.

Integrated Research Phase:
The divertor target & the first wall is now considered to be carbon before achievement of the JT-60SA's main mission of the high-β steady-state.
However, possibility of replacement to metallic materials will be discussed based on the results in JET & ASDEX-U.

Summary

The JT-60SA device has been designed as a highly shaped large superconducting tokamak with variety of plasma control capabilities in order to satisfy the central research needs for ITER and DEMO.

- **Manufacture of tokamak components is in progress on schedule by JA & the EU.**
- **JT-60SA Torus assembly started in Jan.2013.**
- **JT-60SA Research Plan Ver. 3.1 was documented by >300 EU & JA researchers in Dec. 2013**

In the ITER- and DEMO-relevant plasma parameter regimes, heating conditions, pulse duration, etc., JT-60SA quantifies the operation limits, plasma responses and operational margins in terms of MHD stability, plasma transport, high energy particle behaviors, pedestal structures, SOL & divertor characteristics, and Fusion Engineering. The project provides 'simultaneous & steady-state sustainment of the key performances required for DEMO' with integrated control scenario development.