Experiment team

JT-60SA Experiment Team Leaders
J. Garcia, M. Yoshida, H. Urano

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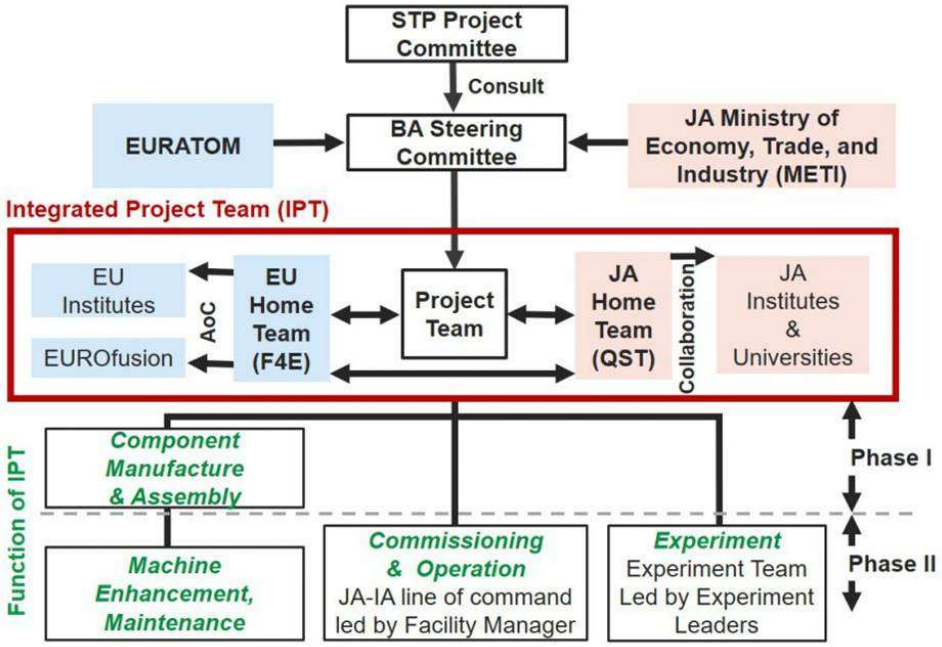
Global structure of the JT-60SA project



https://www.jt60sa.org/wp/

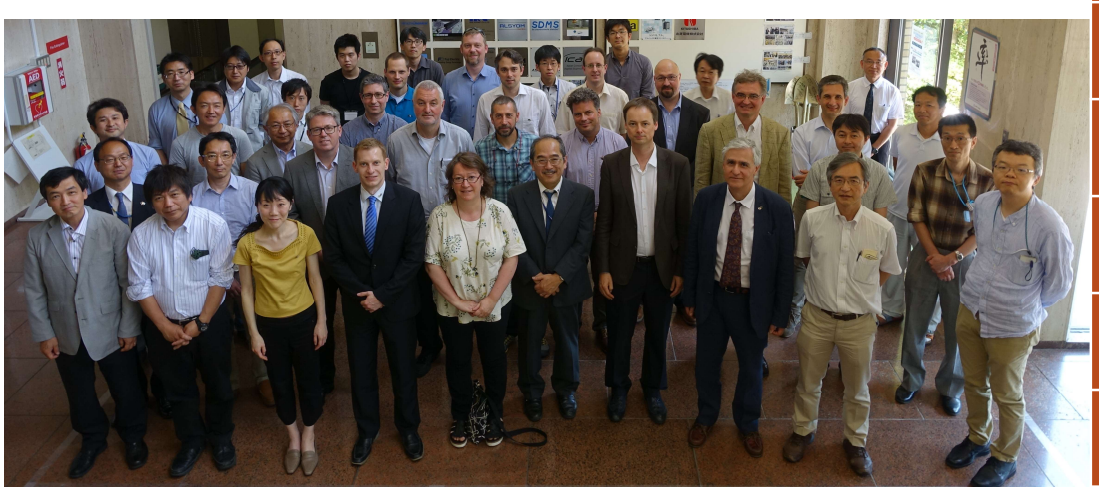
Acknowledgement: Great Leadership in Research Unit

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

Thank you very much for constructing Research Plan, research activities, and relationship between EU and JA.

Organizers/keypersons

Gerardo Giruzzi, Darren McDonald, Carlo Sozzi, Yutaka Kamada



	Technical Responsible officers
Operation Regime Development	Takahiro Suzuki, Emmanuel Joffrin
MHD Stability and Control	Go Matsunaga, Tommaso Bolzonella
Transport and Confinement	Maiko Yoshida, Michele Romanelli
High Energy Particle Behavior	Kouji Shinohara, Philipp Lauber
Pedestal and Edge Physics	Hajime Urano, Elena de la Luna
Divertor, SOL and PWI	Tomohide Nakano, Marco Wischmeier
Fusion Engineering	Shinji Sakurai, Christian Day
Theoretical models and simulation codes	Nobuhiko Hayashi, Jeronimo Garcia

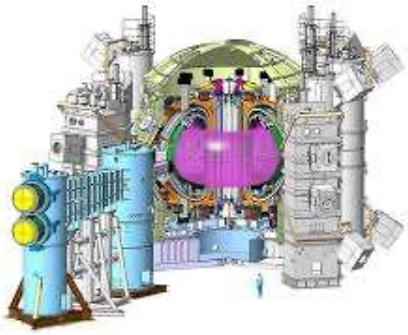
Research plan

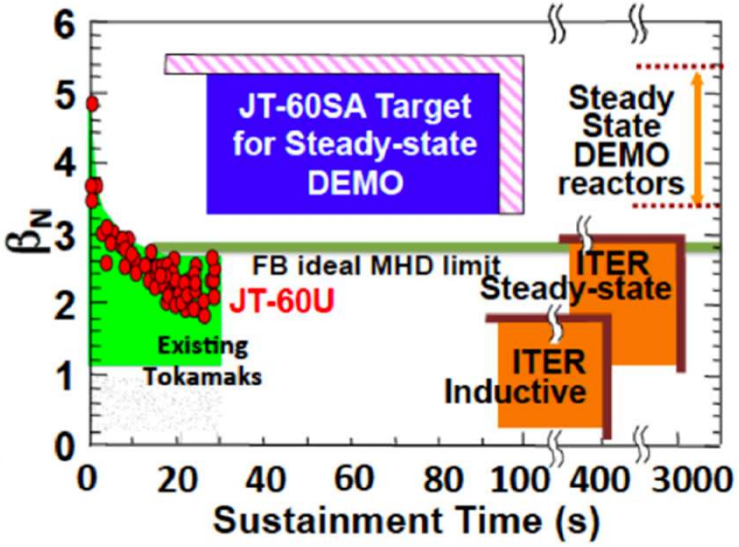
- JT-60SA research plan is a key pillar to understand our scientific objectives https://www.jt60sa.org/pdfs/JT-60SA_Res_Plan.pdf

JT-60SA Project for ITER and DEMO

JT-60SA:

- Large superconducting: R_P~3.0 m, a_P~1.2 m
- High plasma current: I_P/B_T=5.5 MA/2.3 T
- High power and long pulse: 41 MW × 100 s
- Highly shaped: $S=q_{95}I_P/(a_PB_T)$ ~7, A~2.7, κ_x ~1.9, δ_x ~0.5





Mission:

- Contribute to the early realization of fusion energy by addressing key physics issues for ITER and DEMO
- Aim at fully non-inductive steady-state high β_N operations above the no-wall ideal MHD stability limits, for long time (~3-4τ_R)

Scenario development

Target plasmas

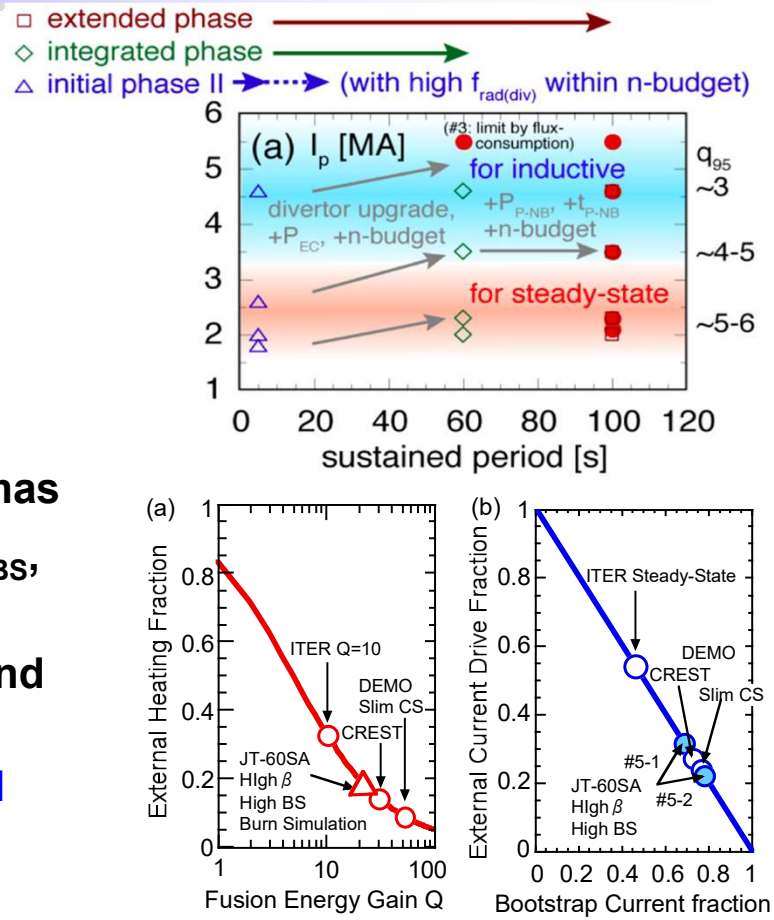
- ITER standard (q_{95}~3)
- ITER advanced-inductive (q_{95}~4-5)
- DEMO steady-state with 2-3 times of τ_R (q_{95}~5-6)

Evaluate DEMO design and ITER regime

- Scenario development for the three target plasmas
- Accessible integrated best performance of β_N, f_{BS}, H_{98y2}, f_{GW}, …
- Plasma control study in highly self-regulating and burning plasma conditions

⇒ **Suggest ITER operation scenarios and control schemes**

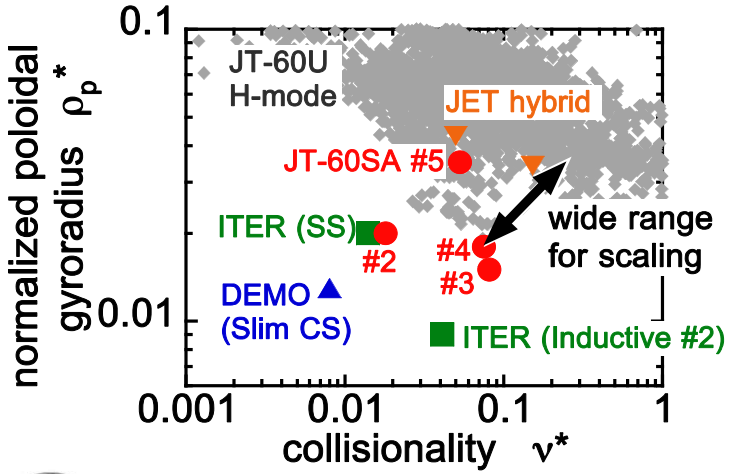
⇒ **Give DEMO concept designs**

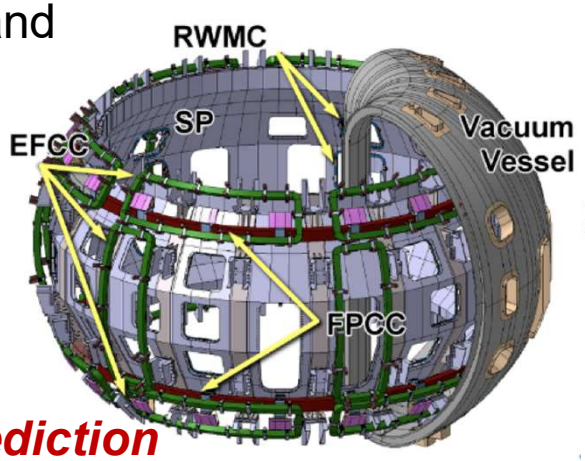


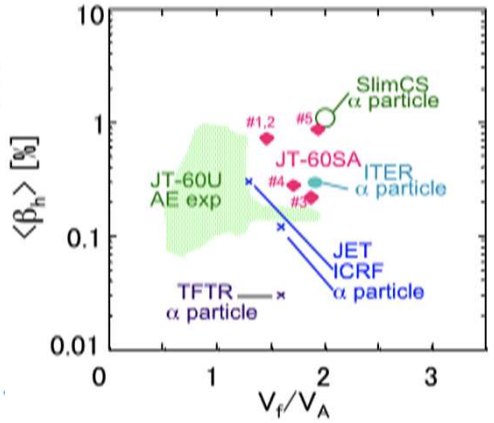
Physics and Control Studies in ITER, DEMO-relevant regimes

- **Core-edge transport and confinement studies in ITER and DEMO regimes**
  - Small ρ^*, low ν^*, high β, strong e-heating
  - ITER and DEMO like shapes
- **MHD mode control by various actuators**
  - NTM control by ECCD, kinetic profile
  - RWM control by stabilizing plate and coils, EP and rotation effects
- **AE mode and EP mode studies in ITER and DEMO regimes**
  - Fast ions produced by NNB of 500 keV at I_p=5.5 MA,

Develop models for ITER/DEMO prediction



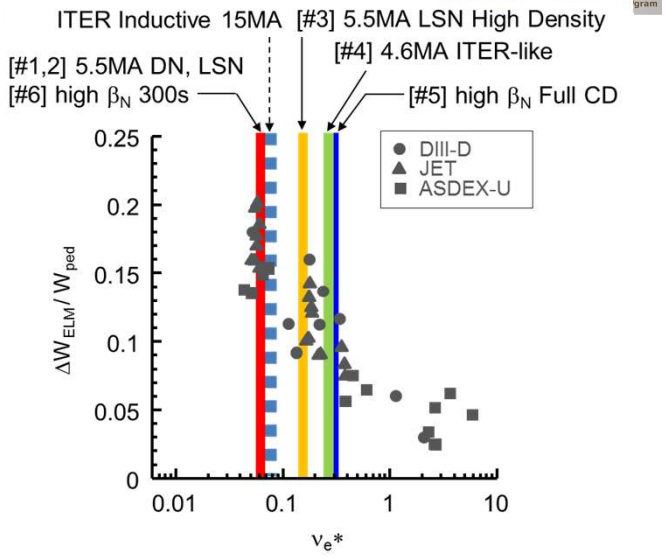


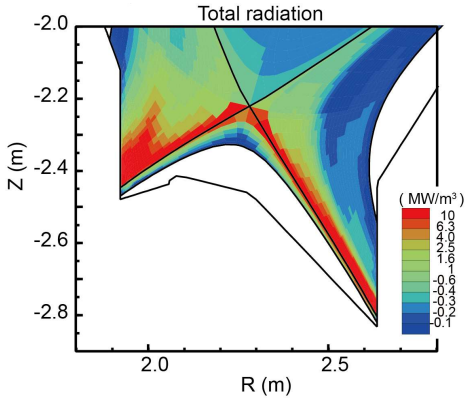


Risk mitigations at high performance plasmas

- **ELM mitigation and suppression**
  - at high I_P and low ν^* by RMP, pellets, shape
  - QH-mode development at low ν^* and low torque
- **Disruption mitigation and avoidance**
  - in high I_P and W_{sto} plasmas
  - Runaway electron study
  - Operation below MHD stability limit
- **Heat and particle handling**
  - Radiative divertor with impurity seeding at high power and long pulse
  - Detached divertor sustainment in V-shaped divertor (C-wall => W-wall)

Establish risk mitigation schemes in JT-60SA well before ITER





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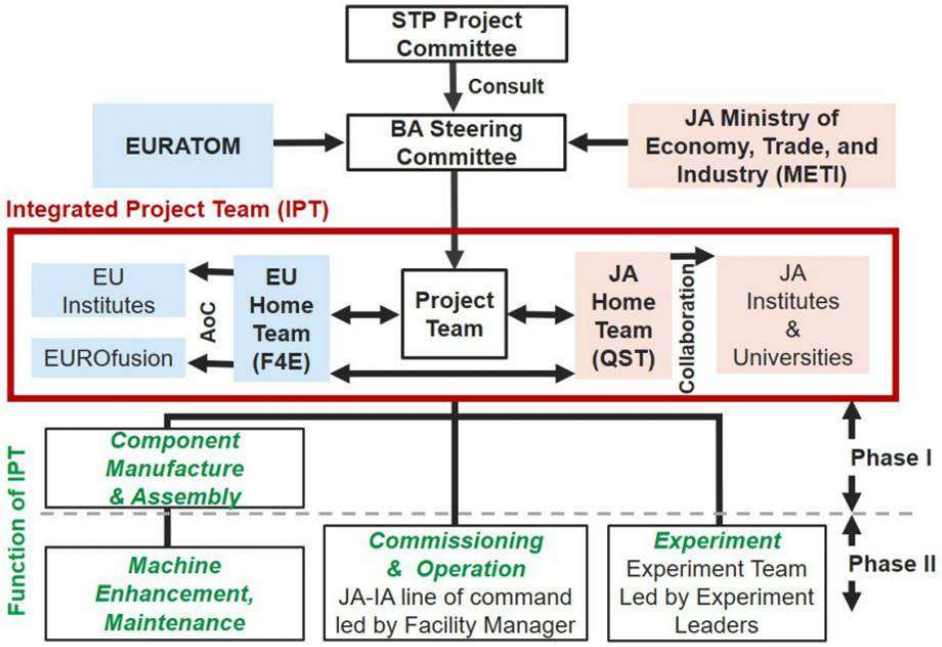

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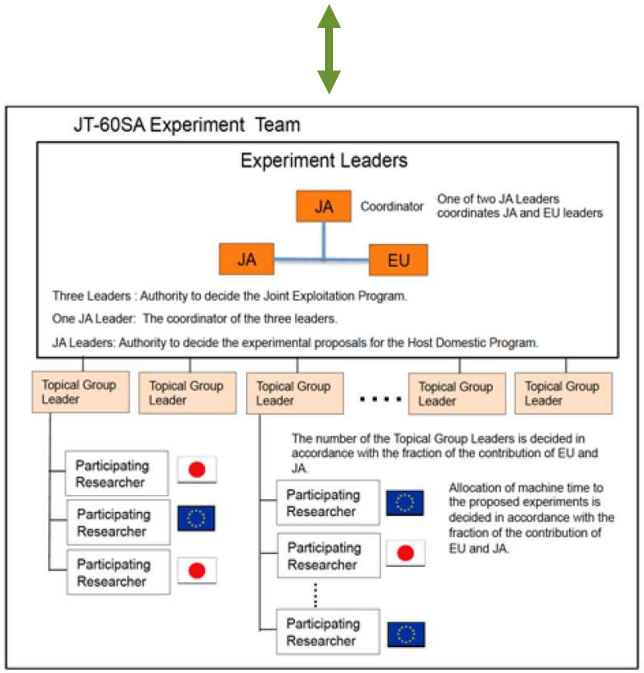
JT-60SA Experiment Team

JT-60SA Project leader and EU and JA Project Managers

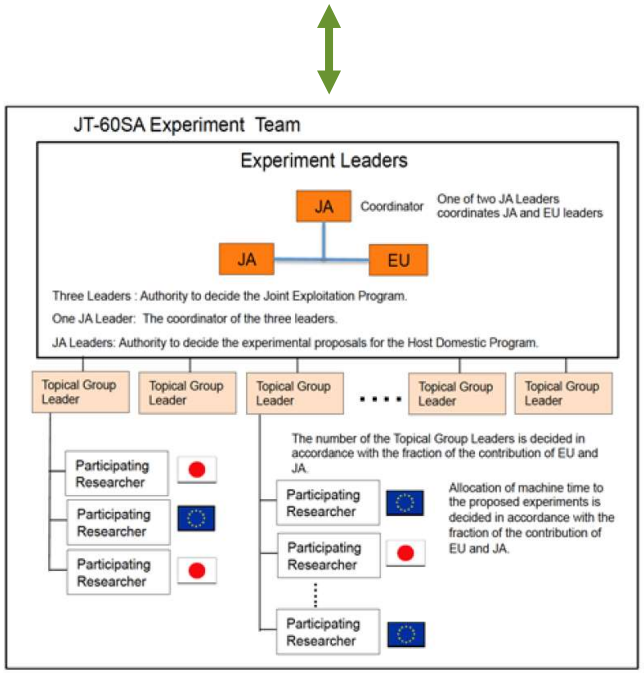


https://www.jt60sa.org/wp/

- The JT-60SA Experiment Team is the unified Experiment Implementation Structure for the JT-60SA experiment
- 3 Experiment Leaders
  - Maiko Yoshida
  - Hajime Urano
  - Jeronimo Garcia

JT-60SA Experiment Team: experiment leaders

JT-60SA Project leader and EU and JA Project Managers



- **Experiment Team Leaders are responsible for:**

- Jointly develop the Annual Experiment Programme and submit it with the Annual Experiment Report to the Project Managers (PMs) and to the Project Leader (PL)
- Jointly assessing, prioritizing, and allocating machine time to experimental proposals
- Jointly direct and supervise the Experiment Team in the implementation of the Annual Experiment Programme
- Jointly coordinate and validate the publications related to the Experimental Team activity.
- Jointly receive, assess and make proposals for machine enhancement from the experiment team
- Jointly contribute to the evaluation of the machine enhancement proposals from the PMs, in view of executing the Experiment Programme.

JT-60SA Experiment Plan Has Been Entrusted

Experiment Leaders

- **Operation Regime Development** — Takuma Wakatsuki (QST, Japan)
- **MHD Stability and Control** — Gianluca Pucella (ENEA, Italy)
- **Transport and Confinement** — Luca Garzotti (UKAEA, UK)
- **High Energy Particle Behavior** — Yevgen Kazakov (LPP-ERM/KMS, Belgium)
- **Pedestal and Edge Physics** — Nobuyuki Aiba (QST, Japan)
- **Divertor, Scrape Off Layer and Plasma-Material Interaction** — Tomohide Nakano (QST, Japan)

- **Topical group Leaders are responsible for**:
  - coordinate the scientific discussion of experiment proposals and the execution of the experiments assigned to the Topical Group
  - the Experiment Coordinator is assigned by the Topical Group Leader of the topic or by the Experiment Leaders when it is across multiple topics
  - the Topical Leader also summarizes the results and reports to the Experiment Leaders.

Technical Responsible officers
Takahiro Suzuki, Emmanuel Joffrin
Go Matsunaga, Tommaso Bolzonella
Maiko Yoshida, Michele Romanelli
Kouji Shinohara, Philipp Lauber
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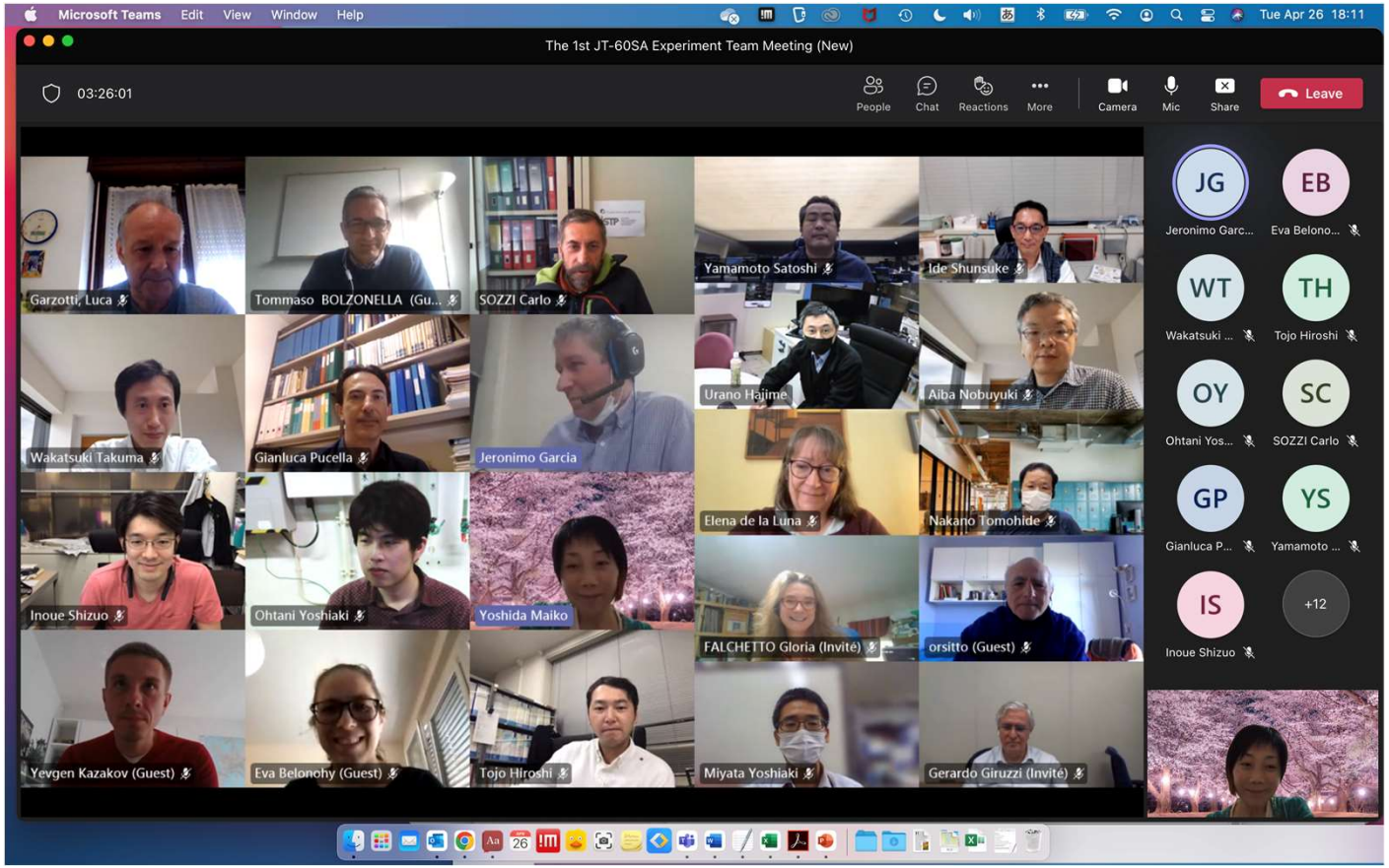
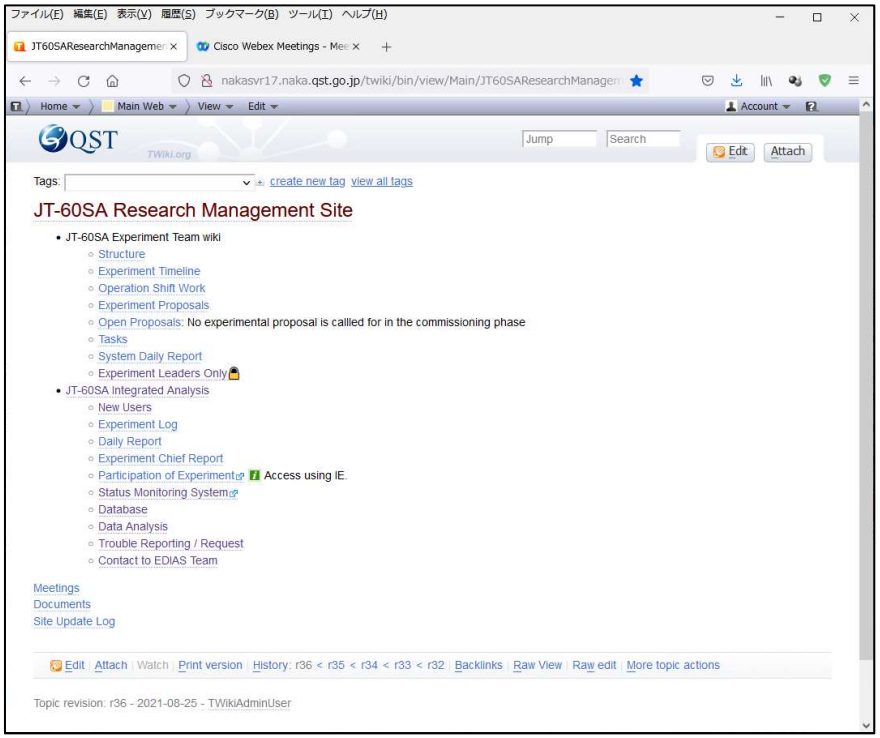
A joint team: First Experiment Team Coordination meeting



First steps: providing tools for management onsite and offsite



- Environment of participation to experiment and data analysis is being developed for as equivalent access as possible between on-premise and remotely
  - HMI: control and monitor for whole JT-60SA operation
  - Data Analysis and DB Access Infrastructure
  - eDAS: basic analysis software
  - Data Access Library: further advanced analysis
  - Remote Access: RCA and RDA
  - JT-60SA RMS: information sharing among participants
  - JT-60SA Pinboard: effective publication management
- Secondary processed data using several experiment data are also acquired to DB. Development of data validation system and compatibility to IMAS are being considered.

Control Room Structure

Plasma Operation Chief: Execute plasma operation requested by **Exp proposers**. Optimize discharge conditions and shot plan in the day considering subsystem status.

Plasma Operator: Program discharge conditions in Human Machine Interface (HMI) according to Plasma Operation Chief.

Experiment proposers: Design the plasma and shot plan and analyze data, request the shot to Plasma Operation Chief / Plasma Operator.

Specific working groups

- **Several topics have implications in the Experiment team and operational aspects**
- **Several working groups are being proposed/discussed:**

- **Working group: Real time control (creation, development) led by the Operation Regime Development TGL with participants from the integrated commissioning team (including F4E).**
- **Working group: Disruption avoidance techniques and disruption database led by MHD Stability and Control TGL with participants from the integrated commissioning team (including F4E).**
- **Working group: Integrated Data Management (Integrated data coherence, data validation chain and software management) under preparation. A meeting will be organized soon.**
- **Working group: Diagnostics (status, requests) under discussion. (the diagnostics are subsystems handled by QST)**

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Machine Enhancement - Step by Step -

JT-60SA

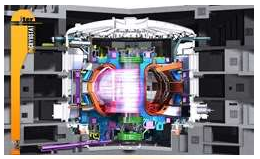
	Phase	Expected operation schedule		Annual Neutron Limit	Remote Handling	Lower Divertor (wall material)	P-NB Perp.	P-NB Tang.	N-NB	NB Energy Limit	ECRF 110 GHz & 138 GHz	Max Power
Initial Research Phase	phase I	2020-2023	H	-	R&D	-	0	0	0	0	1.5MWx5s	1.5MW
		2025		(N2)		Carbon Div. Pumping (Carbon)	3MW	3MW	10MW	23MW x 14s duty = 1/30	1.5MWx100s + 1.5MWx5s	19MW
	phase II	2025	D	3.2E19			6.5MW	7MW				26.5MW*
		2026		(N2)								
	phase III	2027					13MW					33MW*
Integrated Research Phase	phase I	2029 - 2032	D	4E20 (water)		Actively cooled Carbon Div.Pumping (10MW/m2 ss, 15MW/m2x5s) (Carbon)				20MW x 100s 30MW x 60s duty = 1/30	7MW x 100s	37MW
	phase II	2033 -	D	1E21 (water)	Use	Actively cooled Tungsten Div.Pumping (Tungsten)						
Extended Research Phase		>5y	D	1.5E21 (Boron)		Actively cooled Tungsten Advanced Structure (U. Div. to be considered) (Tungsten)	16MW	8MW		34MW x 100s		41MW

(filler in the VV double wall)

Upper Open Carbon Divertor (very limited heat handling capability) is always ready

*Real Injection: ~ 26MW x 2-3 sec limited by divertor cooling

ITER

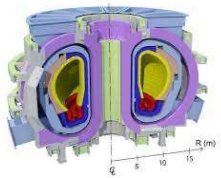


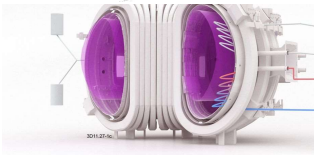
PFPO-1

PFPO-2

FPO-1

DEMOs





Machine Enhancements decision flow

QST or EU institutes

Diagnostic collaboration under a framework between institutes

Other ITER parties (US, CN, KO, ITER, etc.)
- Propose diagnostics & experiment with QST or EU
- Persons in charge join in Experiment Team

Additional flow for other ITER parties

Express to participate in BA Activities

Project Leaders and Project Managers judge the participation (at BASC)

Approval

Proposer prepares following materials
- Research needs and impact in JT-60SA program
- Design and feasibility studies of the diagnostics
- Available resources (budget and persons) by QST/EUROfusion/F4E/others

Propose

Experiment Team + other experts if necessary discuss the proposal from scientific viewpoint
Review of research needs, impact of the diagnostics in dedicated meetings
- ✓ Set the priority and plan the new diagnostic installation period
- Comparison with other diagnostics if conflicting

Experiment Leaders prepare an executive summary for enhancement request

Project Leaders and Project Managers judge the machine enhancement plan
- ✓ Design Review Meeting by JA and EU Home Teams and Project Team
- ✓ Procurement Arrangement between JA and EU Home Teams (Cost reallocation)

Approval

Manufacture starts under the Home Teams' or the QST experiment group control.

Flow for JA or EU

Machine Enhancements decision flow

- A prioritization of ME will be done by the EL+TGL before August
- Specific meetings are being organized in order to have a well informed opinion
- Prioritization will be done taking into account the scientific priorities for the initial experimental phase of the machine
- Prioritization will include ME proposed by USA

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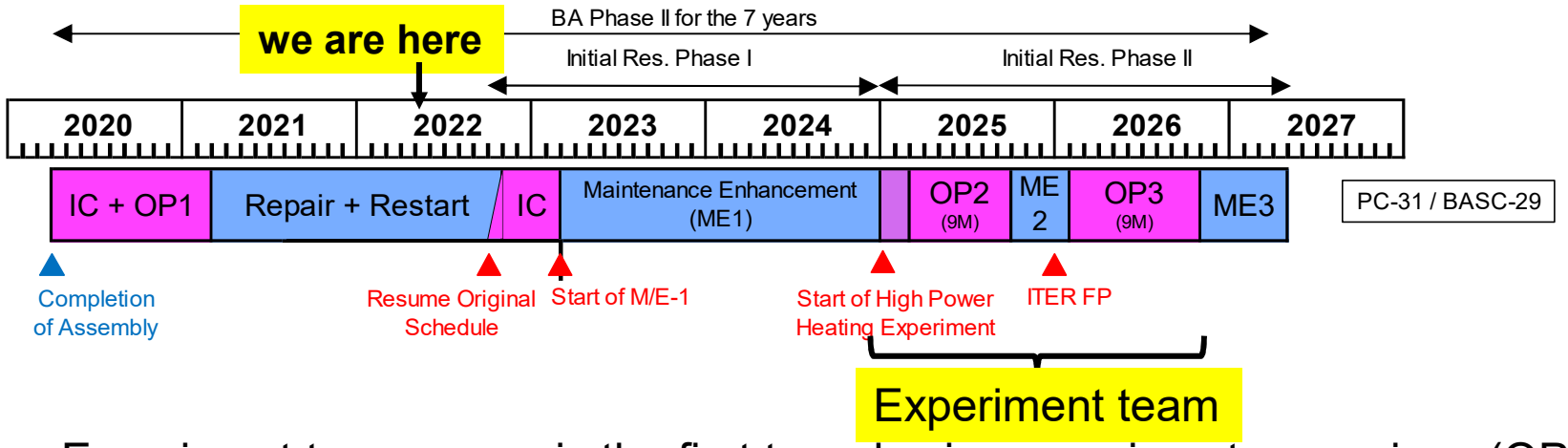
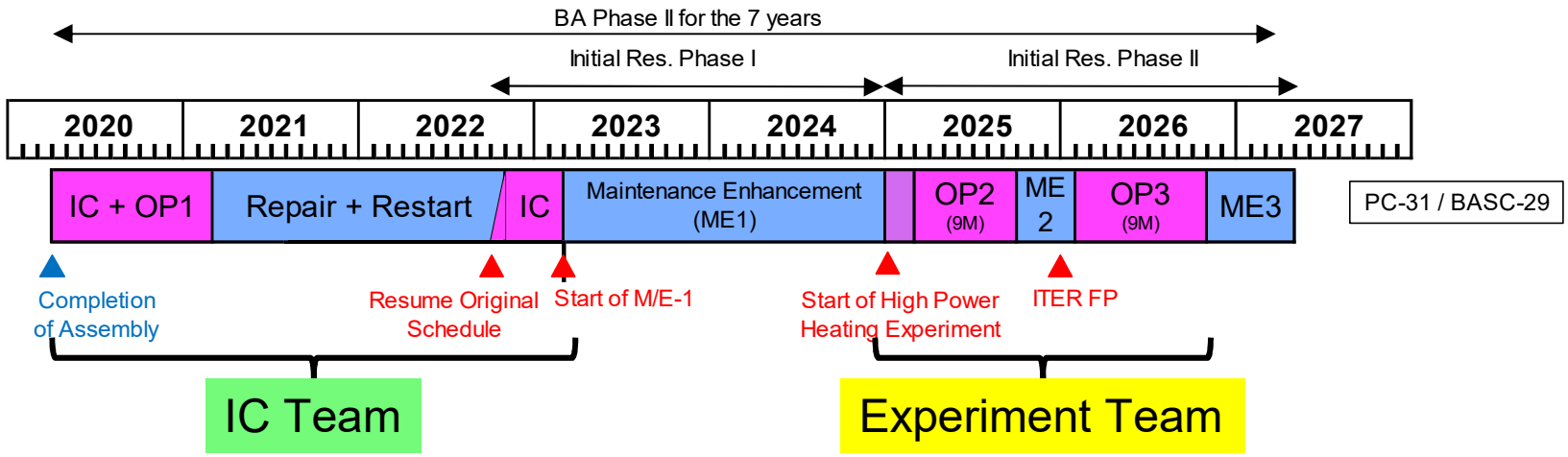
Timeline for JT-60SA Project



- Experiment team scope is the first two physics experiment campaigns (OP2 and OP3)
- To conduct experiments in OP2 and OP3 successfully EL+TGL:
  - ✓ Monitor the Integrated Commissioning and assess the results
  - ✓ Design the experiment plan and prepare the experiments
  - ✓ Consider the positions of OP2 and OP3 in the long-term project, ITER, DEMO
  - ✓ Propose the machine enhancement in ME2

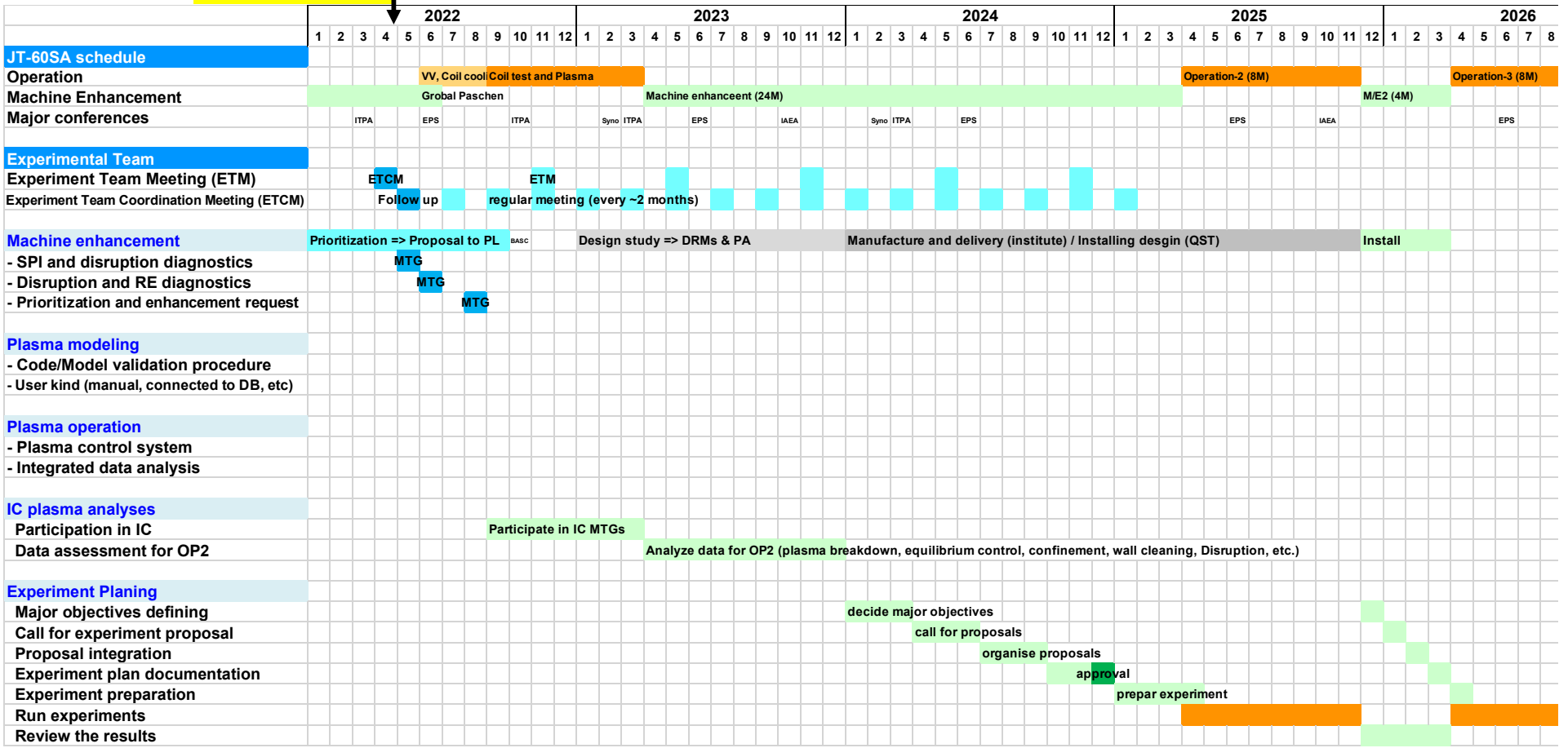
Experiment Team in Integrated Commissioning



- The Integrated Commissioning (IC) is conducted by the IC team.
  - ✓ Coil test, wall conditioning test, first plasma and control test
- Experiment Team (now EL+TGLs) will follow the progress of IC in order to start OP2 properly.
  - ✓ Data will be available after the commissioning and the analysis will be coordinated by the ET

Timeline for Experiment Team

we are here



Timeline for Experiment Team

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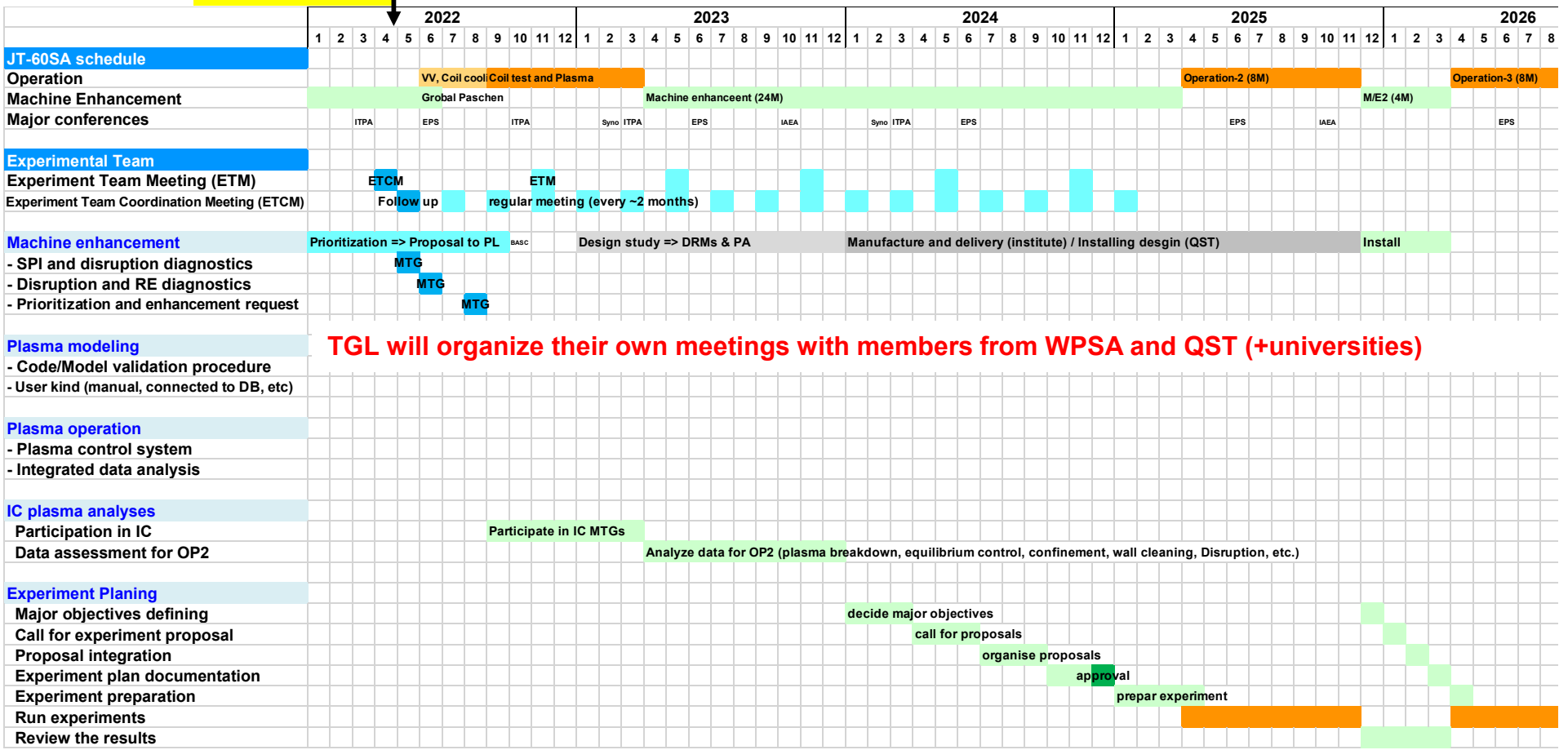

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The role of the Experiment Team

- The Experiment team is formed now by EL+TGL
- Still long way for real experiments,
- Call for experiment proposals is expected to happen after successful IC
- Whole experiment team formation still far
- but many things to do in the meantime for which the experiments team structure can be helpful
  - Reinforce collaborative work
  - Improve joint leadership
  - Exchange of new ideas towards the initial operation phase
  - Drive JA-EU sides towards a common goal
  - Define initial topics for the initial experiment phases
  - Coordinate joint modelling
  - Solve misunderstanding issues
- Interaction with WPSA is essential

Experiment team: Beyond the research plan

- JT-60SA research plan is a key pillar to understand our scientific objectives https://www.jt60sa.org/pdfs/JT-60SA_Res_Plan.pdf
- But it is not necessarily written in stone:
  - New proposals are welcome
  - Experience from other tokamaks is important but we should go beyond
- Research plan is giving generic scientific objectives, mainly focus on key goals
- Need to define the main scientific topics for the initial campaigns, coherent with
  - Required Machine Enhancements
  - Analysis and simulation codes available

Beyond the research plan: Exploratory ideas

- Is central heating in JT-60SA enough at high density?
- Would more ECRH be required?
- Is ICRH a possibility for JT-60SA? What would be its impact?
- Can experiments be proposed in European tokamaks to address JT-60SA physics?
- Is the strong electron heating a problem for confinement in JT-60SA?
- Is it needed a full assessment of transport & confinement in L-mode plasmas?

Contents

Conclusions

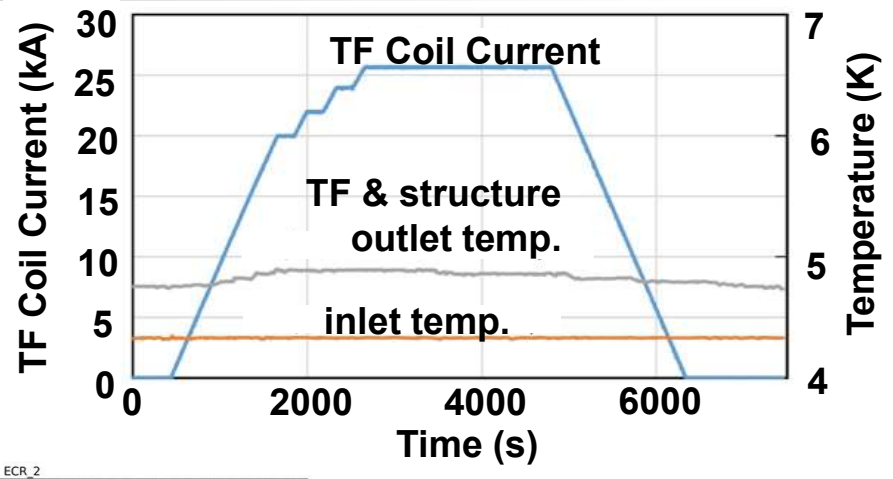
- The experiment team structure has been stablished in 2022.
- EL+TGL are already appointed
- The call for participation will be launched once the IC is successfully done
- In the meantime the ET will be useful for:
  - Discussing and deciding ME
  - Coordinate and favour joint activities
  - Propose new ideas
  - Improve link with the operator

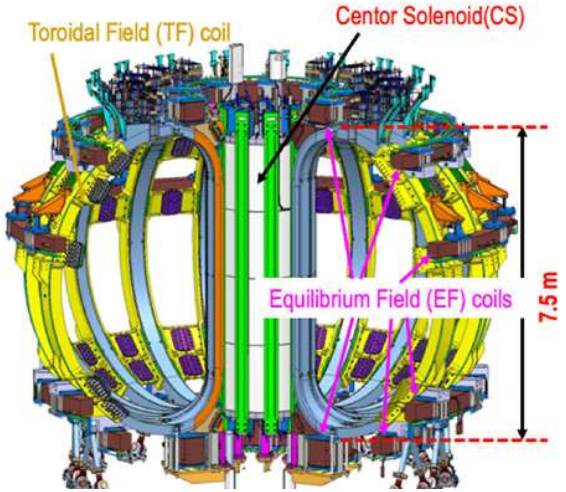
- Focus on the preparation for initial phases of the machine in coordination with the ME requirements and models available
- A first step is to map current scientific activities within WPSA and QST to the TG in order to favour joint discussions by calling for joint meetings

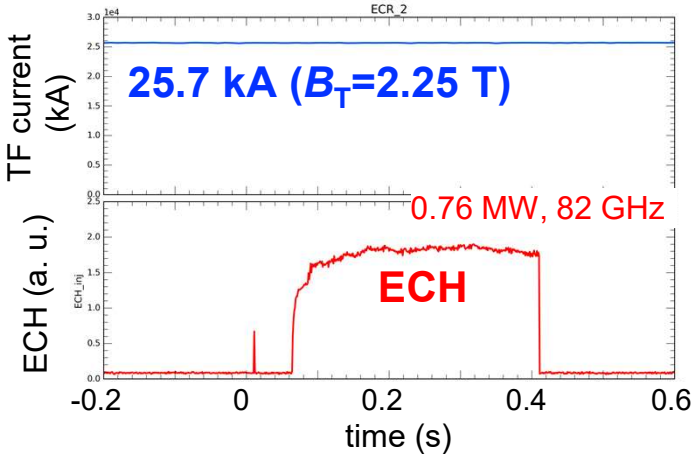
Back-up

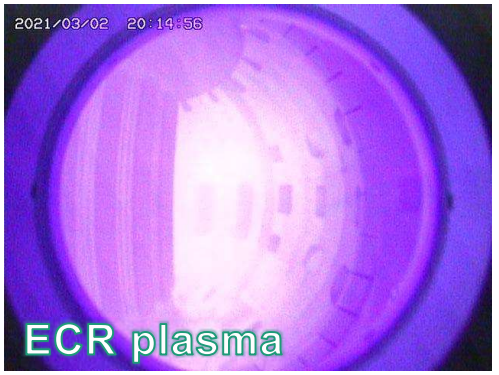
Status of Integrated Commissioning

- TF coil current reached 25.7 kA (100%)
- ECR plasma was obtained.
- PF coil current achieved 5 kA (25%)
  - But EF1 incident....☹
  - Ongoing coil repairing and insulation enhancement







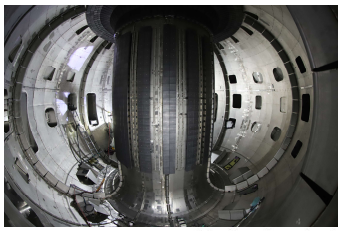


Diagnostics at Integrated Commissioning

List of diagnostics

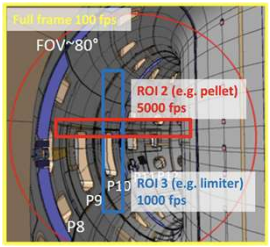
Diagnostics	Section	Port/Location
CO_2 Laser interferometer (tangential), Visible spectroscopy (tangential)	P1 and P8	Horizontal
Soft X-ray detector arrays	P14	Horizontal
Visible TV cameras (+ two light guide)	P15	Horizontal
EDICAM	P18	Horizontal
Langmuir probes	P2, P8 and P14	upper divertor

Visible camera

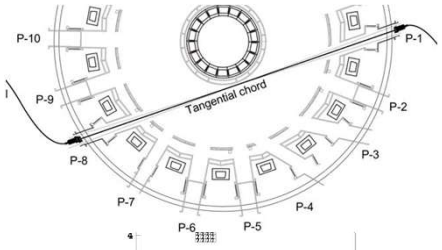


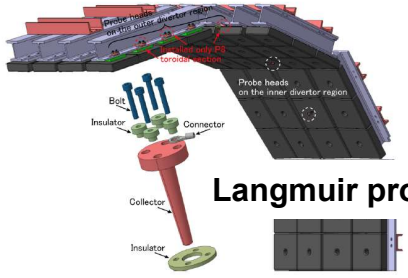
Co-direction viewing Ctr-direction viewing

EDICAM

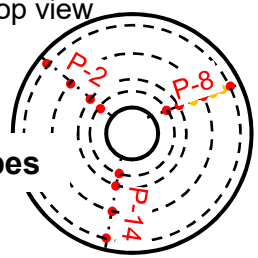


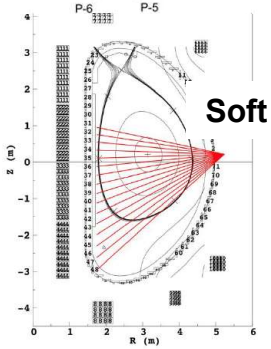
CO2, Visible spectrometer





Langmuir probes



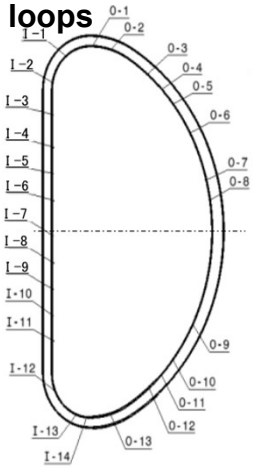


Soft X-ray

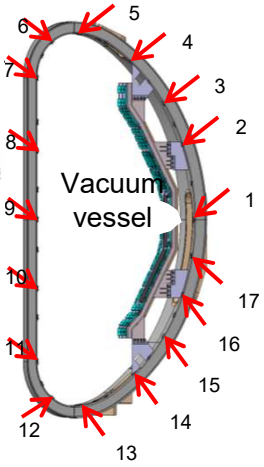
Magnetic sensors

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

Flux loops



Magnetic probes

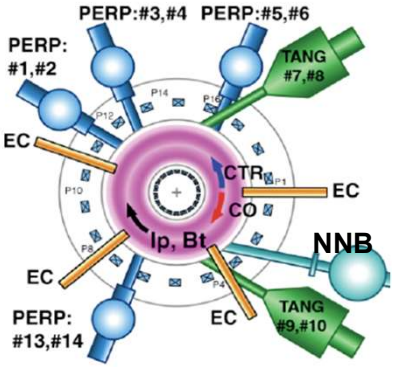


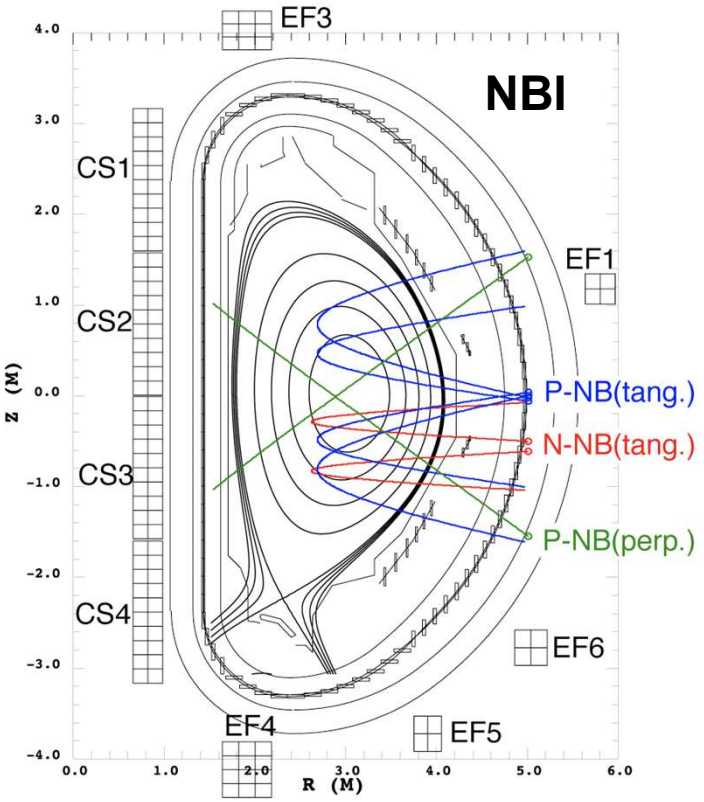
Neutral Beam Injection

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

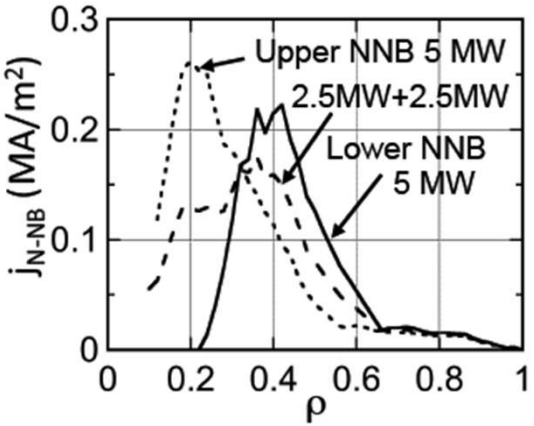
Positive-ion-source NB
85 keV, 24 MW
CO:2u, CTR:2u, PERP:8u

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

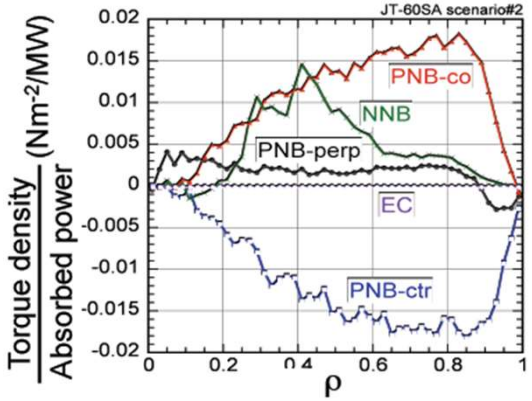




N-NB driven current



Torque input

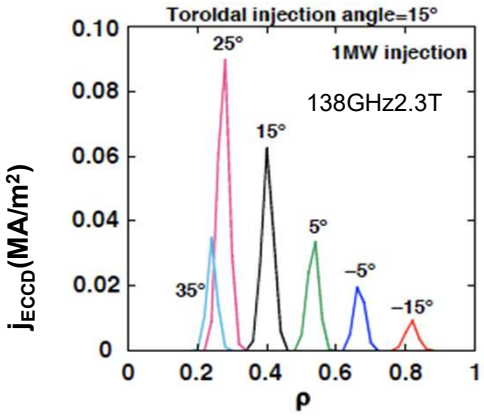


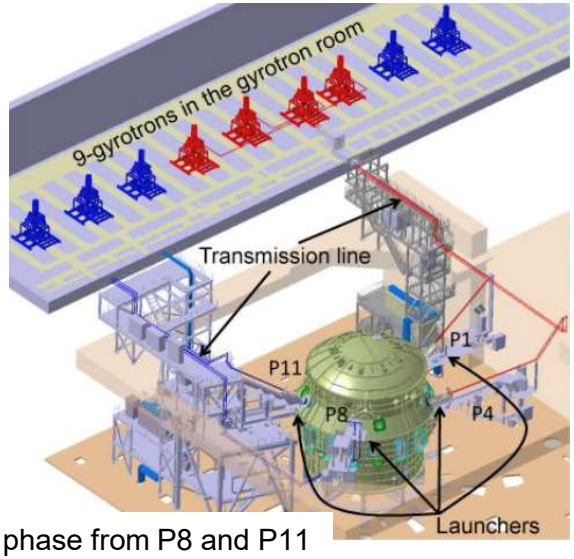
Electron Cyclotron Range of Frequency

	Initial research phase		Integrated research phase
Frequency	110 GHz	82/110/138 GHz	82/110/138 GHz
Max. Power into Plasma	~ 1.5 MW	~ 1.5 MW	7 MW
Max. Pulse Duration	5s	100 s (110/138 GHz) 1 s (82 GHz)	100 s (110/138 GHz) 1 s (82 GHz)

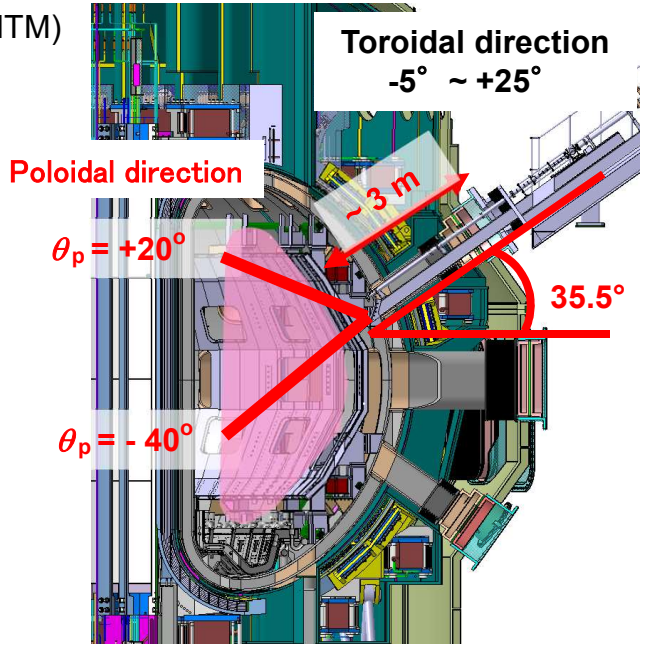
> 5 kHz modulation available (NTM)

EC current drive





Initial phase from P8 and P11



Fueling and Pumping

- Gas puff
  - ✓ 10 Injection lines, 31 Pam^3/s for each (D)
  - ✓ H, D, Impurities (He, N_2, Ne, Ar, Kr, Xe, CD_4, etc.)
- Pellet Launching System
- Massive Gas Injection

See plasma control session tomorrow.

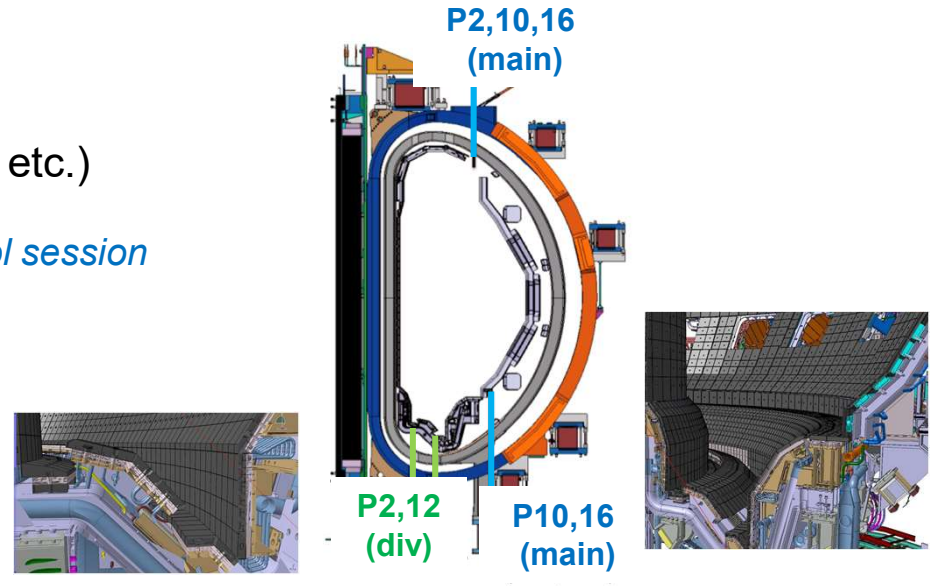
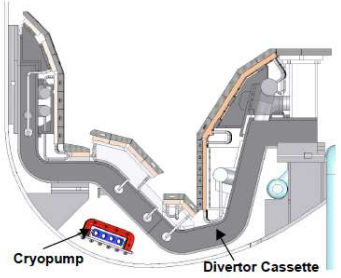


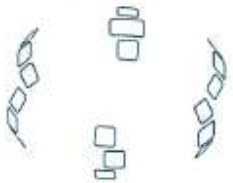
Table B-2 Specifications of particle fueling and pumping systems and results of SONIC simulation

System	JT-60U (D/s)	JT-60SA (D/s)	SONIC Simulation	
			Scenario #2	Scenario #5-1
Gas puff	1.8 x10^{23} (300 Pa m^3/s)	1.8 x10^{23} (300 Pa m^3/s) Future upgrade: + 0.5x10^{23} (90 Pa m^3/s)	1.5 x10^{22}	2.5 x10^{21}
pellet	1.0 x10^{22}	3.0 x10^{22} (3 sources)		
NB	2.0 x10^{21}	2.0 x10^{21}	2.6 x10^{21}	2.6 x10^{21}
N-NB	5.0 x10^{20}	5.0 x10^{20}		
Gas jet	Used	No request		
Divertor pumping	28 m^3/s (effective)	0-100 m^3/s	1.6 x10^{22} at 50 m^3/s	4.4 x10^{21} at 30 m^3/s

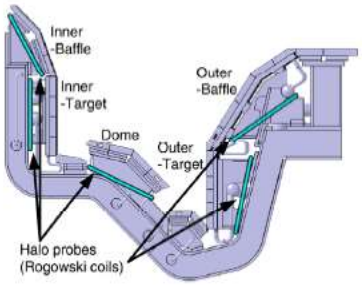
- Pumping with cryopump
  - ✓ 10 steps pumping speed between 0-100 m^3/s
  - ✓ Compatible to MGI



In-Vessel Coils and Stabilization Plates

Name	Purpose	Specification	Figure
FPPC Fast Plasma Position control Coil	fast position (vertical & horizontal) control	Number: 2 (Upper & Lower) Max current:120 kAT Location: Behind SPs	
EFCC Error Field Correction Coil	error fields (n≠ 0) correction and resonant magnetic field perturbation	Number: 18 (Tor 6 x Pol 3) Max current: 45 kAT Location: Behind SPs	
RWMC Resistive Wall Mode control Coil	RWM feedback control	Number: 18 (Tor 6 x Pol 3) Max current: 2.2 kAT Location: In front of SPs	
SP Stabilizing Plate	passive stabilization of VDE and RWM	Wall time constant: ~40ms	

See control session tomorrow.



Diagnostics

- **Integrated Commissioning**
  - ➢ **Machine protection**
    - Visible camera, EDICAM
  - ➢ **Plasma profiles**
    - Soft X-ray
  - ➢ **Impurities**
    - Visible sepc.,
  - ➢ **Radiation and others**
    - CO2 laser (*nl*), Upper divertor probes, Neutral pressure, magnetic sensors

- **Initial Research Phase-I/II**
  - ➢ **Machine protection, Licensing**
    - Visible/IRTV camera, EDICAM, Neutron monitor
  - ➢ **Plasma profiles**
    - YAG Thomson (T_e, n_e), ECE (T_e), CXRS (T_i, V_ϕ, V_θ, n_c), MSE (j_r), XICS (T_e, T_i, V_ϕ)
  - ➢ **Impurities**
    - Visible sepc.(Zeff), VUV spec., D_a/H_a, TESPEL
  - ➢ **Radiation and others**
    - Bolometer, CO2 laser (*nl*), Soft X-ray, Divertor probes, Neutral pressure, magnetic sensors,
  - ➢ **High energetic particle measurements**
    - FIDA, (FIELD for OP3)