RT15 priorities in 2027

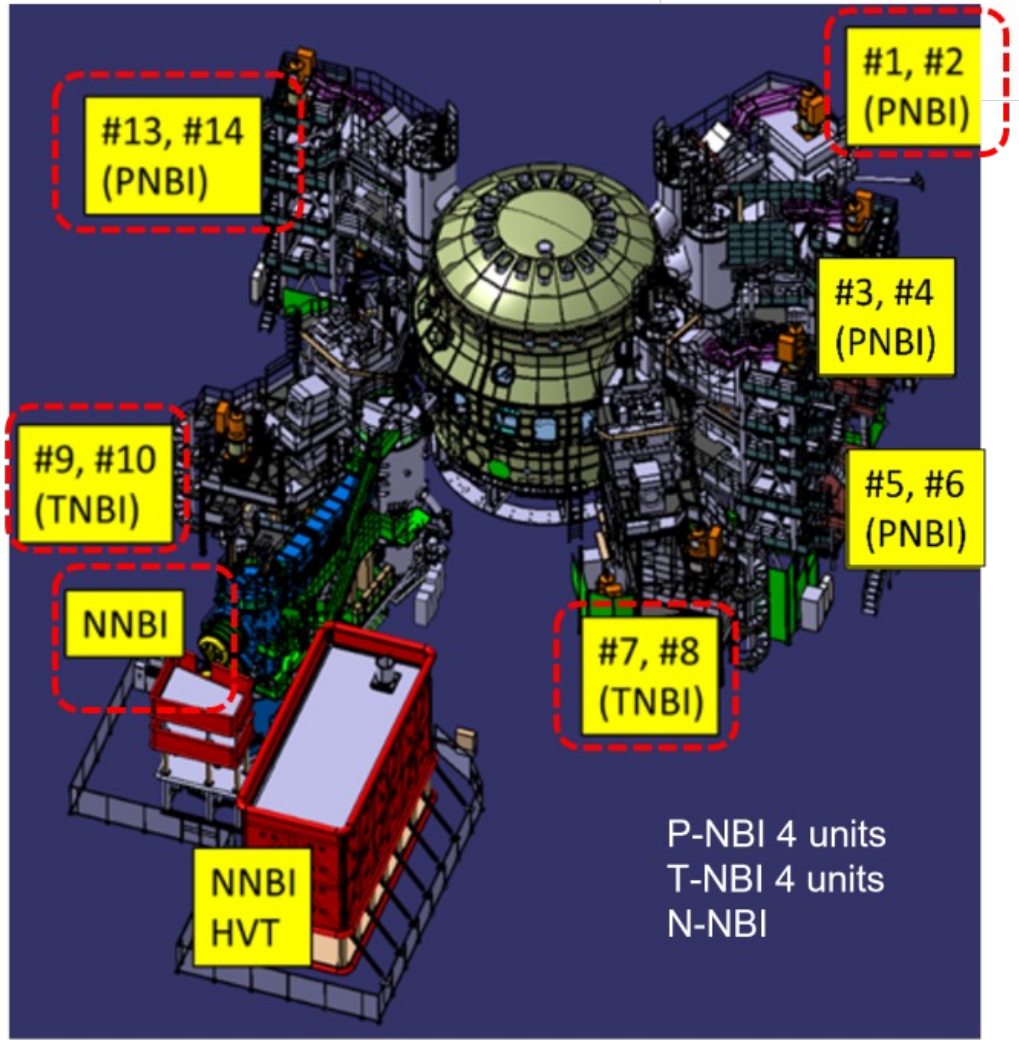
JT-60SA TG ‘High-Energy Particle Behaviour’

Yevgen Kazakov

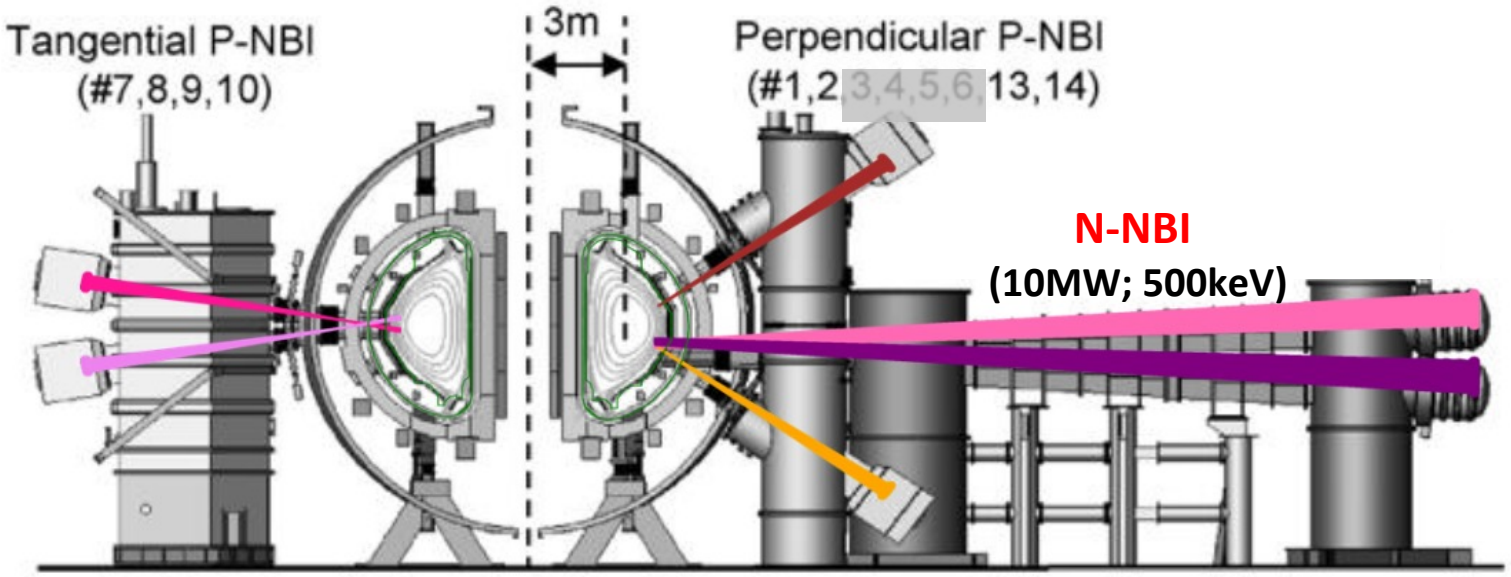
JT-60SA EU Experiment Leader
WPTE Deputy Task Force Leader

** Laboratory for Plasma Physics, LPP-ERM/KMS, Brussels, Belgium*

WPTE General Planning Meeting
Monday, 9 November 2026



Plasma heating systems in OP2 (NBI)

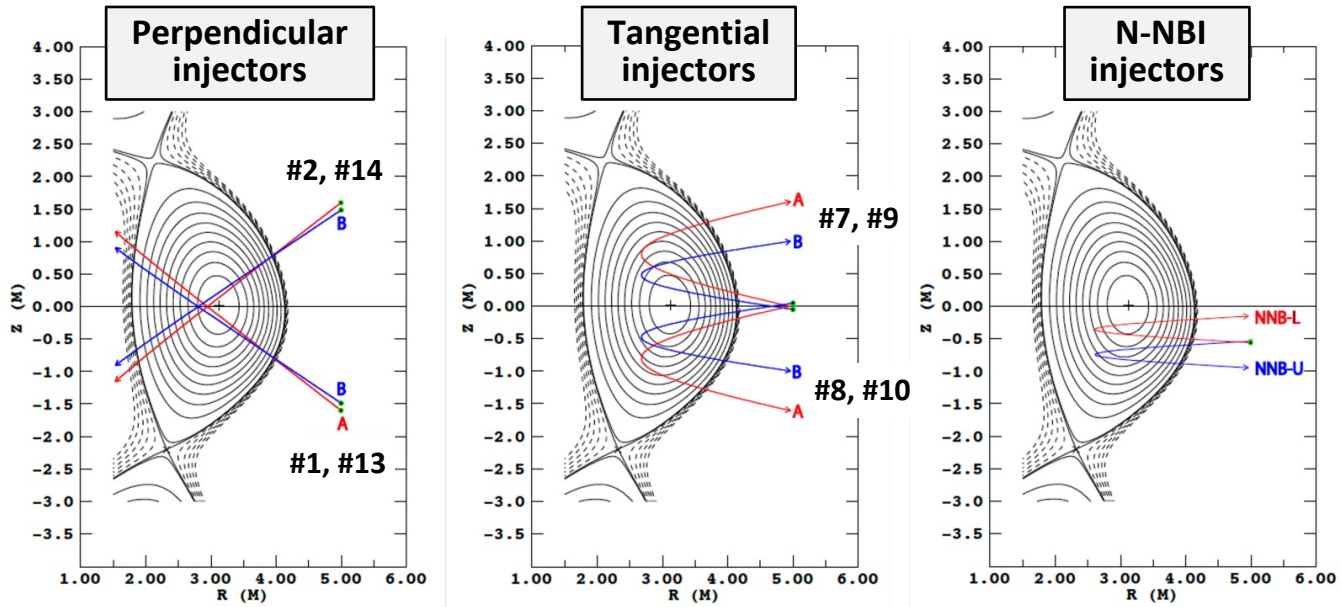


- **NBI in JT-60SA**: can operate with both hydrogen and deuterium beams
- **P-NBI in OP2**: 85keV, 13.5MW (D) vs. 6MW (H)
  [Units #1, #2, #7-#10, #13, #14; per unit: 1.6-1.7MW in D; 0.75MW in H]
- **N-NBI: up to 500keV, 10MW** (flexible: H or D)

Plasma heating systems in OP2 (NBI)

Deuterium: positive NBI (85keV) and negative NBI (500keV)

Injector	#1	#2	#13	#14		#7	#8	#9	#10		N-NB(U)	N-NB(L)
	Perpendicular injectors (P-NBI)					Tangential injectors (P-NBI)					Negative NBI	
						(counter-I_p)	(counter-I_p)	(co-I_p)	(co-I_p)			
Power	1.6MW	1.6MW	1.6MW	1.6MW		1.7MW	1.7MW	1.7MW	1.7MW		5MW	5MW
Diagnostics				CXRS, FIDA			MSE		Twin to #8			



Selected TG-EP experiments for OP2

OP2 experiment	EC	Co-EC
M02: Shinethrough studies in support of ITER	S. Sumida (QST)	**P. Vincenzi (RFX)**
M07: Neutron validation and beam ion confinement studies	**R. Coelho (IST)**	S. Sumida (QST)
M08: Physics of fast-ion-driven instabilities and their impact on the plasma	**S. Mazzi (CEA)**	A. Ishizawa (Kyoto Univ.)

Cycle #1 (H plasma)	Cycle #2 (H-D plasma)	Cycle #3 (D plasma)	Cycle #4 (D plasma)
2	0 [Piggyback during M07]	1	N-NBI (D): dedicated pulses N-NBI (H): 0

Cycle #1 (H plasma)	Cycle #2 (H-D plasma)	Cycle #3 (D plasma)	Cycle #4 (D plasma)
0	2	0	N-NBI (D): dedicated pulses N-NBI (H): 0

Cycle #1 (H plasma)	Cycle #2 (H-D plasma)	Cycle #3 (D plasma)	Cycle #4 (D plasma)
0	0	1	N-NBI (D): dedicated pulses N-NBI (H): 0

RT15 – M02 ‘Shinethrough studies in support of ITER’

M02: Shine through studies in support of ITER
Experiment Coordinator: S. Sumida (QST, Japan)
Co-EC: P. Vincenzi (RFX, EU)

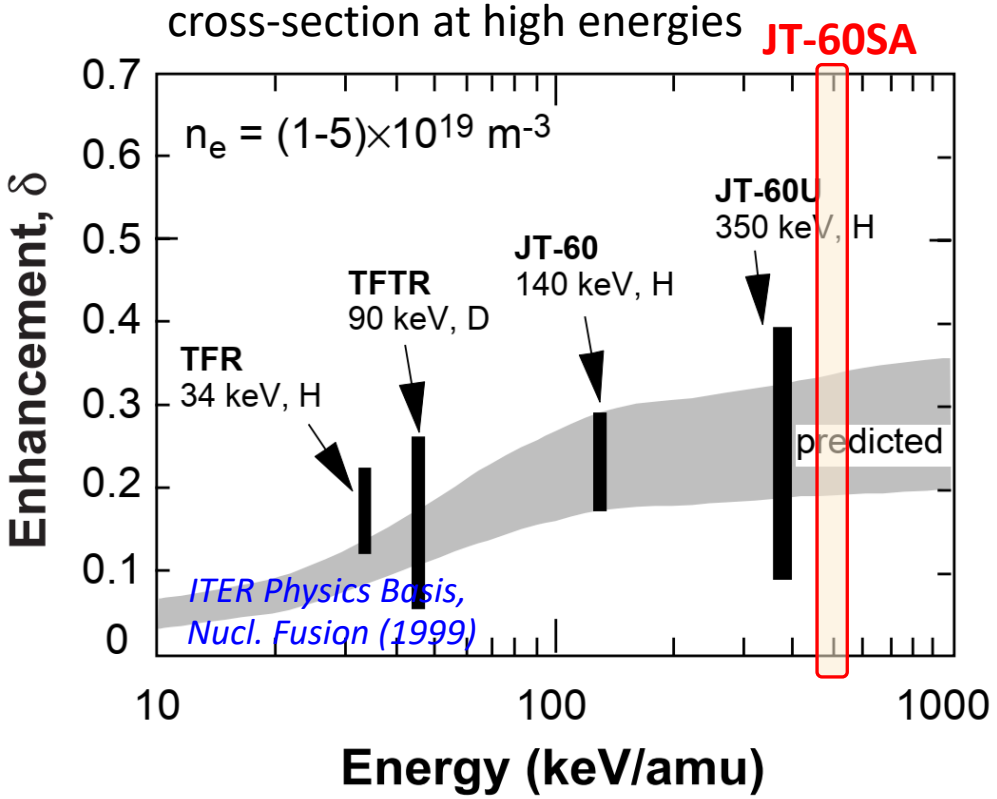
Deliverables	
M02-D1	Validate NBI shinethrough and the NBI ionization cross-section as a function of E_{NBI}
M02-D2	Characterize NBI shinethrough for the ITER-relevant configuration (hydrogen N-NBI into a deuterium plasma)
M02-D3	Assess the impact of intrinsic (carbon) and extrinsic (Ne/Ar) impurities
M02-D4	Validate shinethrough in high-power plasmas (e.g., H-mode) to support subsequent OP2 experiments
Extended goals	
M02-E1	Initial validation of the NBCD neoclassical model
M02-E2	Compare shinethrough for hydrogen and deuterium N-NBI

Session distribution in OP2

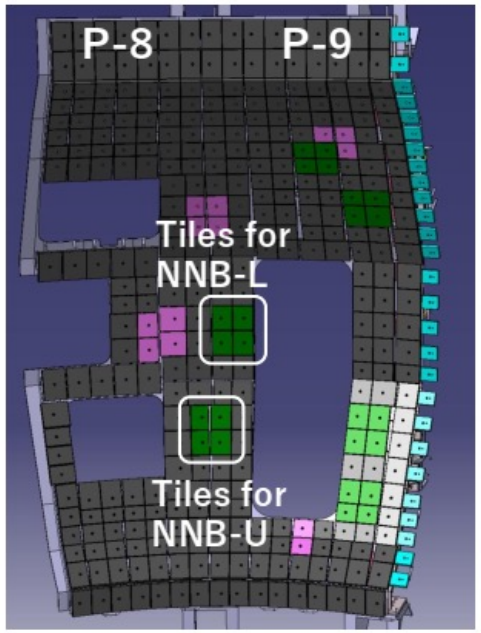
Cycle #1	Cycle #2	Cycle #3	Cycle #4
2	0 (piggyback, M07)	1	N-NBI (D): dedicated pulses N-NBI (H): 0

RT15 – M02 ‘Shinethrough studies in support of ITER’

Uncertainty in the NBI ionization cross-section at high energies

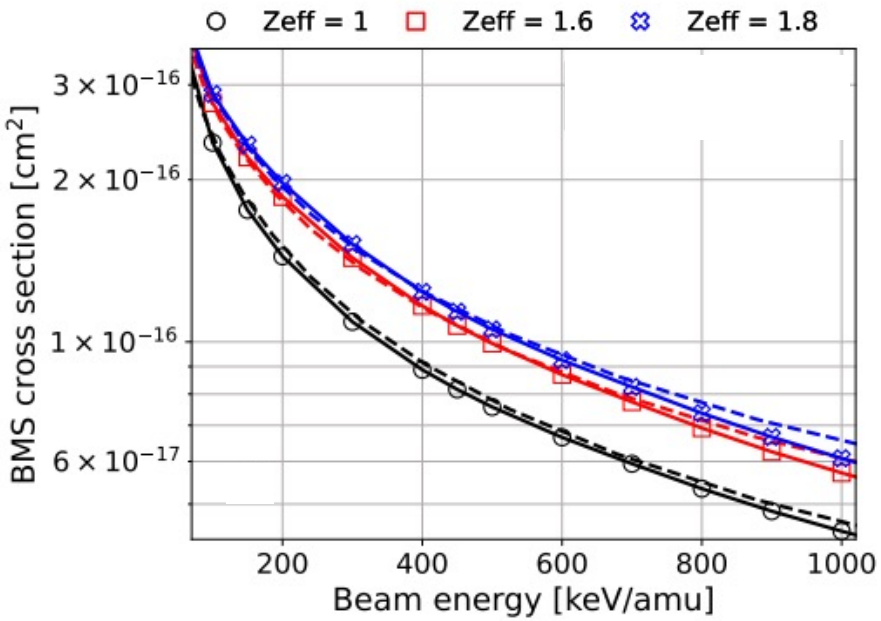


JT-60SA: calorimeters installed for shinethrough measurements



Experiment Coordinator on JT-60SA:
S. Sumida (QST)

NBI ionization cross-section dependence on the impurity level



Source: *R. Coelho and S. Sumida*

- Uncertainties in the NBI ionization cross-section at high beam energies, E_{NBI} > 300keV
- **Dedicated experiments on JT-60SA in support of ITER** (including D plasma with Hydrogen N-NBI)

RT15 – M02 ‘Shinethrough studies in support of ITER’

Priorities for 2027:

- M02 experiment preparation: assistance with the dedicated L-mode scenario preparation (e.g., AE stability analysis vs. E_{NBI} and n_e; impurity sensitivity analysis)
- Validate $\sigma_{ioniz.} = \sigma_{ioniz.}(E_{NBI})$ in dedicated L-mode experiments
- Validate $\sigma_{ioniz.} = \sigma_{ioniz.}(E_{NBI})$ in high-power H-mode experiments (piggyback)
- Compare experimental results with existing analytical formulas; improve analytical parametrizations for $\sigma_{ioniz.}$
- Assess the impact of impurities on $\sigma_{ioniz.}$ (input from impurity meas. experts welcome)
- Assess the sensitivity of shinethrough analysis results to input uncertainties (density profile, Zeff, etc.)

RT15 – M07 ‘Neutron validation and beam ion confinement studies’

M07: Neutron validation and beam ion confinement studies

Experiment Coordinator: R. Coelho (IST-Lisbon, EU)
Co-EC: S. Sumida (QST, Japan)

Deliverables	
M07-D1	Study neutron rate and emission for individual and group of P-NBI and N-NBI injectors
M07-D2	Benchmark measured neutron rate with NBI modelling
M07-D3	Evaluate beam ion confinement from neutron diagnostics
M07-D4	Develop accurate NBI modelling tool for intra-pulse neutron analysis
Extended goals	
M07-E1	Study of the D-D knock-on tail formation
M07-E2	Initial study of triton burn-up

Session distribution in OP2

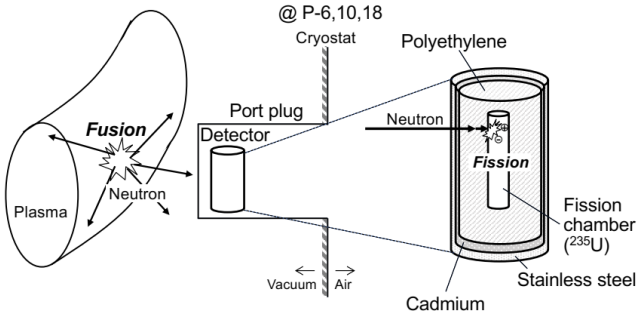
Cycle #1	Cycle #2	Cycle #3	Cycle #4
0	2	0	N-NBI (D): dedicated pulses N-NBI (H): 0

RT15 – M07 ‘Neutron validation and beam ion confinement studies’

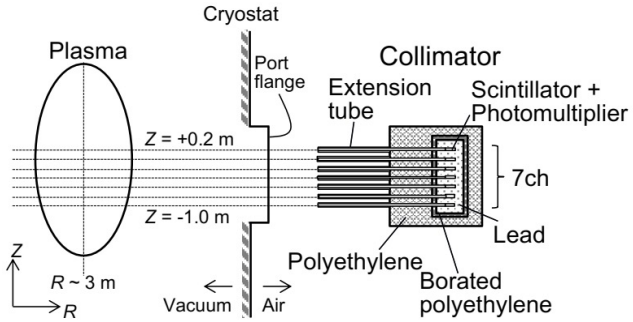
- JT-60SA OP2 campaign includes H, **H-D and D plasma operations**

- **Neutron measurements in OP2**
  - NBI modelling validation
  - **Fast-ion confinement studies**

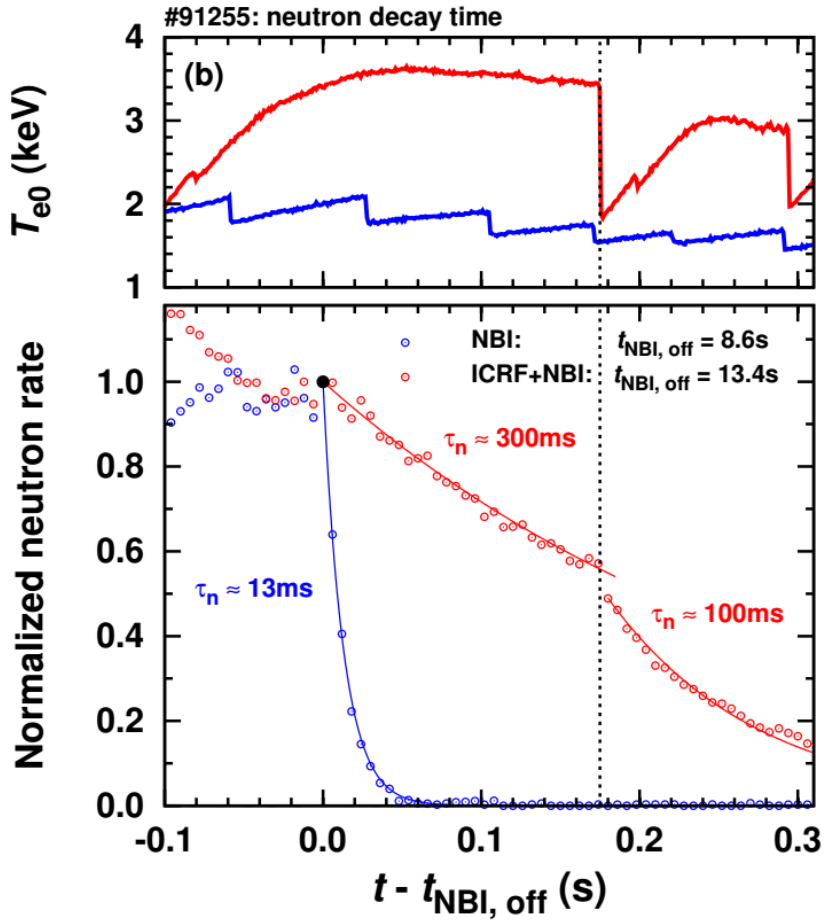
Neutron flux monitor



Neutron emission profile monitor



Source: S. Sumida (QST)



JET example:

Y. Kazakov et al., *Nucl. Fusion* **60**, 112013 (2020)

RT15 – M07 ‘Neutron validation and beam ion confinement studies’

Priorities for 2027:

- Preparatory modelling work
  - ASCOT benchmarking (EU groups)
  - ASCOT-OFMC benchmarking: neutron rate, power deposition (p_e, p_i), fast-ion losses
  - Development of intra-pulse neutron analysis tool(s)
- M07 experiment preparation
  - Main phase optimisation (e.g., NBI source grouping)
  - Optimize ‘afterglow’ phase for fast-ion confinement studies
- Compare neutron emission profile monitor data with NBI modelling
- Compare fast-ion confinement time with NBI modelling
- Develop technique to infer core H/(H+D) from neutron measurements during H-D changeover
- Study the impact of EFCC on neutron rate (piggyback analysis of M03 experiments with NBI)

RT15 – M08 ‘Physics of fast-ion-driven instabilities and their impact on the plasma’

M08: Physics of fast-ion-driven instabilities and their impact on the plasma

Experiment Coordinator: S. Mazzi (CEA, EU)
Co-EC: A. Ishizawa (Kyoto University Japan)

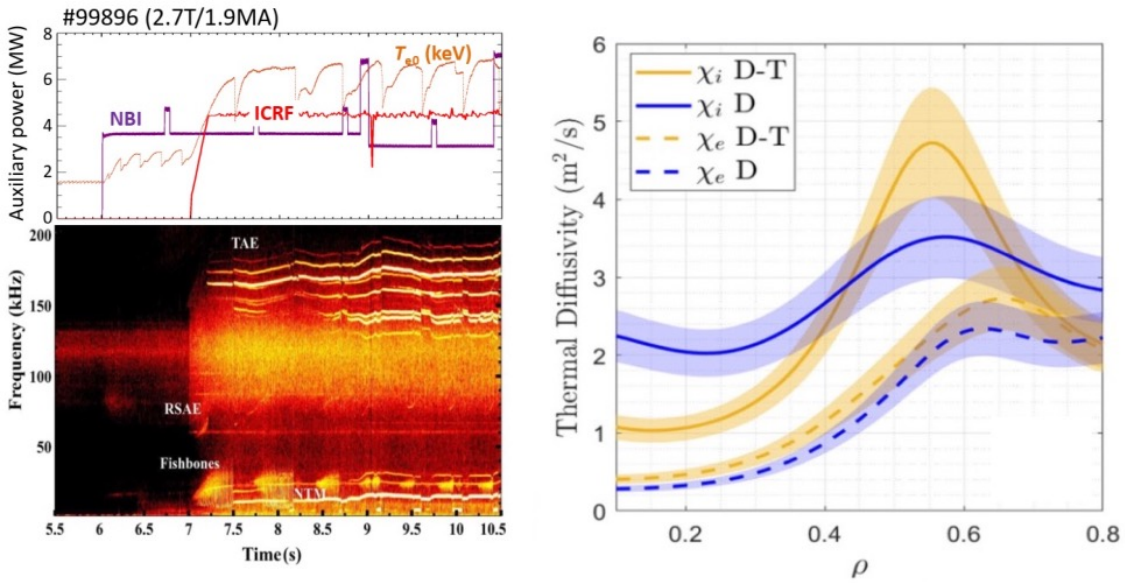
Deliverables	
M08-D1	Characterise fast-ion-driven instabilities in L-mode and H-mode plasmas
M08-D2	Initial study of the impact of FI-driven instabilities on fast ions
M08-D3	Initial study of the impact of FI-driven instabilities on thermal plasma confinement
M08-D4	Develop mode characterisation and MHD spectroscopy
Extended goals	
M08-E1	Study RSAEs (including high-frequency RSAEs) using ECRH/ECCD
M08-E2	Study impact of sawteeth and sawtooth-driven instabilities on fast ions

Session distribution in OP2

Cycle #1	Cycle #2	Cycle #3	Cycle #4
0	0	1	N-NBI (D): dedicated pulses N-NBI (H): 0

RT15 – M08 ‘Physics of fast-ion-driven instabilities and their impact on the plasma’

Recent tokamak observations show that thermal plasma confinement can be **improved** in the presence of FI-driven instabilities



J. Garcia, Y. Kazakov et al., *Nature Comm.* (2024)

- Source of highly-energetic ions
  - JET: dedicated ICRF schemes [Y. Kazakov et al., PoP (2021)]
  - JT-60SA: high-energy N-NBI system
- A range of fast-ion-driven instabilities is expected to be destabilized by N-NBI ions on JT-60SA
  [P. Adulsiriswad et al., NF (2023); R. Coelho et al., Frontiers in Physics (2023)]
- **JT-60SA:** additional actuators available (e.g., ECRF/ECCD)
- **JT-60SA:** new insights expected under reactor-relevant conditions (e.g. high-beta)

See also:

Y.-S. Na et al., *Nature Reviews Physics* (2025);
X.D. Du et al., *Phys. Rev. Lett.* (2025); J. Ruiz Ruiz et al., *Phys. Rev. Lett.* (2025);
A. Di Siena et al., *Nucl. Fusion* (2025); S. Mazzi et al., *Nature Physics* (2022)

RT15 – M08 ‘Physics of fast-ion-driven instabilities and their impact on the plasma’

Priorities for 2027:

- Preparatory modelling work, in particular, in support of shinethrough, neutron validation and main scenario experiments: AE stability and sensitivity analysis (e.g., *q*-profile; NBI energy; hydrogen vs. deuterium NBI); assessment of available actuators (e.g., ECRH/ECCD in OP2), …
- Develop methods for mode characterisation and MHD spectroscopy
- Characterise impact of fast-ion-driven instabilities on fast ions
- Initial characterization of fast-ion-driven instabilities on thermal plasma confinement (transport analysis and gyrokinetic modelling)
- Initial characterization of the impact of sawteeth on fast ions
- Preparation of the dedicated M08 session and possible additional pulses with N-NBI(D)

RT15 – WSA ‘Support for future JT-60SA operations and W-PFC transition’

Deliverables	
WSA-D1	Model EP scenarios for OP3 and OP4 to optimise the use of available EP actuators and diagnostic measurements
WSA-D2	Explore possible long-term enhancements for EP actuators and diagnostics for future W-PFC operations in JT-60SA

Priorities for 2027:

- Preparation and modelling of EP scenarios for OP3 and OP4 campaigns

  (e.g., alpha-particle, FILD and FI/RMP experiments)
- Explore possible long-term enhancements for EP actuators and diagnostics in JT-60SA

RT15 – Summary

OP2 experiment	EC	Co-EC
M02: Shinethrough studies in support of ITER	S. Sumida (QST)	**P. Vincenzi (RFX)**
M07: Neutron validation and beam ion confinement studies	**R. Coelho (IST)**	S. Sumida (QST)
M08: Physics of fast-ion-driven instabilities and their impact on the plasma	**S. Mazzi (CEA)**	A. Ishizawa (Kyoto Univ.)

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Cycle #1 (H plasma)	Cycle #2 (H-D plasma)	Cycle #3 (D plasma)	Cycle #4 (D plasma)
0	2	0	N-NBI (D): dedicated pulses N-NBI (H): 0

Cycle #1 (H plasma)	Cycle #2 (H-D plasma)	Cycle #3 (D plasma)	Cycle #4 (D plasma)
0	0	1	N-NBI (D): dedicated pulses N-NBI (H): 0

Data analysis and interpretation: neutron measurements; magnetics; impurity analysis; CO2 laser interferometer; ECE; SXR; MSE; FIDA; …

Modelling: NBI ionization; NBI slowing-down and losses; neutron rate and spatial profile; AE stability and sensitivity analysis; MHD spectroscopy; interaction of MHD and fast ions; impact of sawteeth on fast ions; core gyrokinetic modelling; intra-pulse modelling tools; alpha-particle modelling; fast-ion modelling in the presence of 3D fields; NBCD; equilibrium modification in the presence of fast ions; …