RESULTS OF ELECTRON CYCLOTRON HEATING AND CURRENT DRIVE SYSTEM OPERATION IN THE INTEGRATED COMMISSIONING PHASE ON JT-60SA

H. Yamazaki, M. Terakado, M. Sawahata, S. Hiranai, F. Sato, N. Toida, J. Hinata, T. Ishii, K. Asakura, H. Sugiyama, K. Ishita, T. Shinya, R. Ikeda, T. Kobayashi and K. Kajiwara

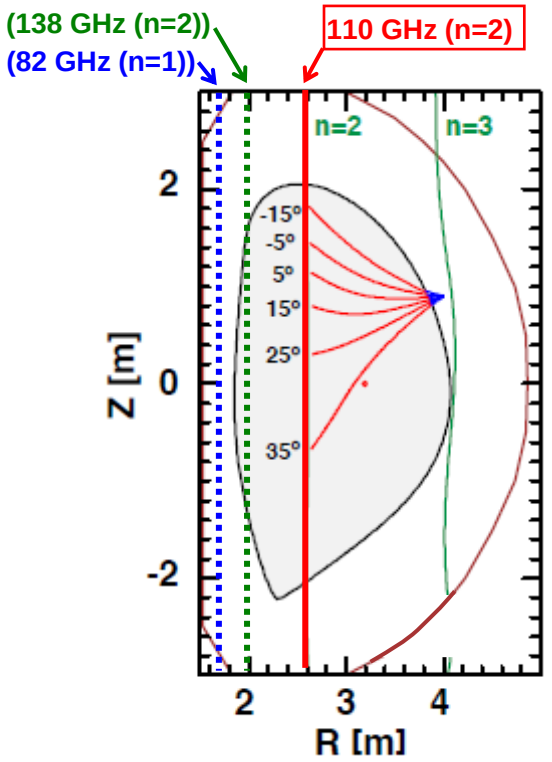
National Institutes for Quantum Science and Technology (QST)

QSTフュージョンエネルギーワークショップ 2025/9/4-26

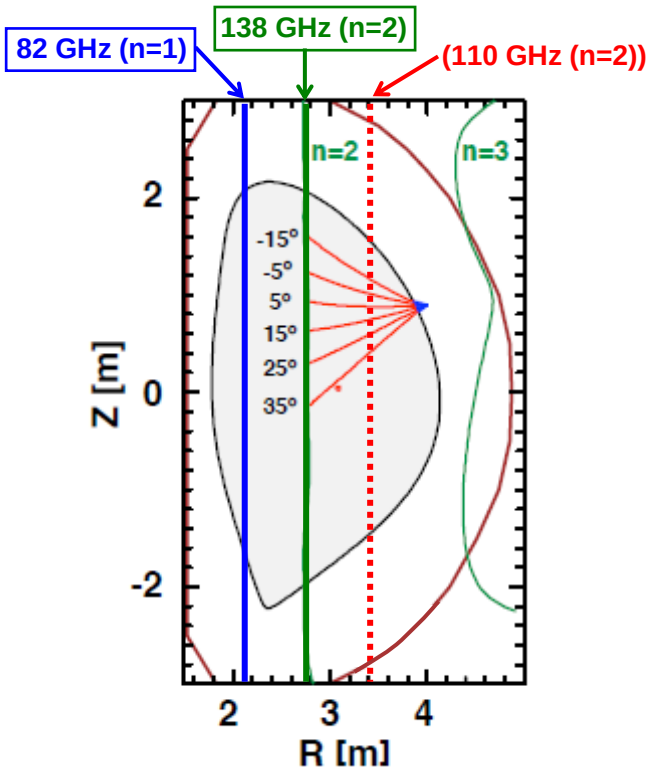
Introduction

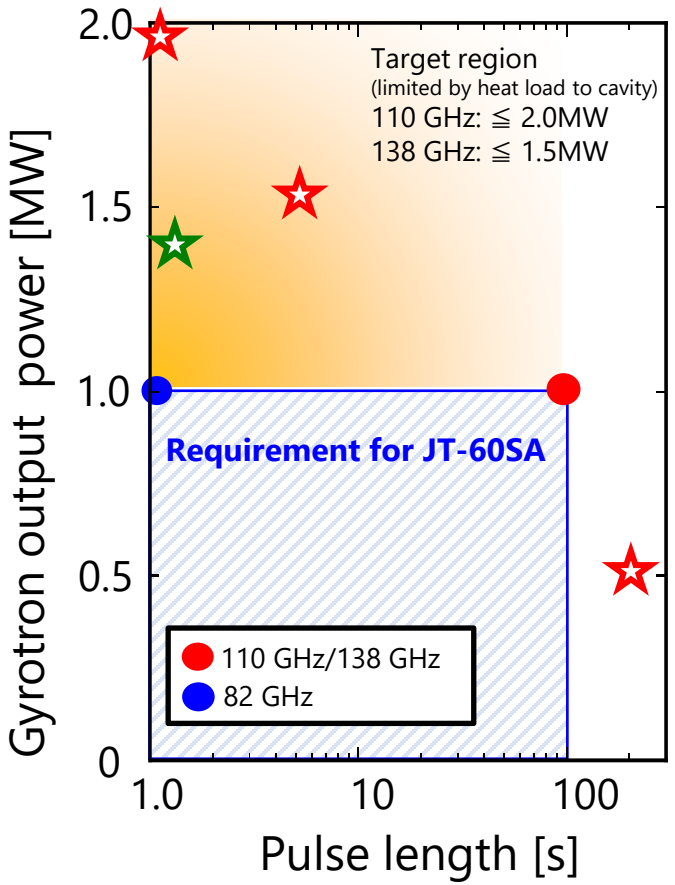
- Multi-frequency ECRH system has constructed & operated on JT-60SA

Scenario5
B_t = 1.7 T, 110 GHz



Scenario2
B_t = 2.25 T, 82/138 GHz

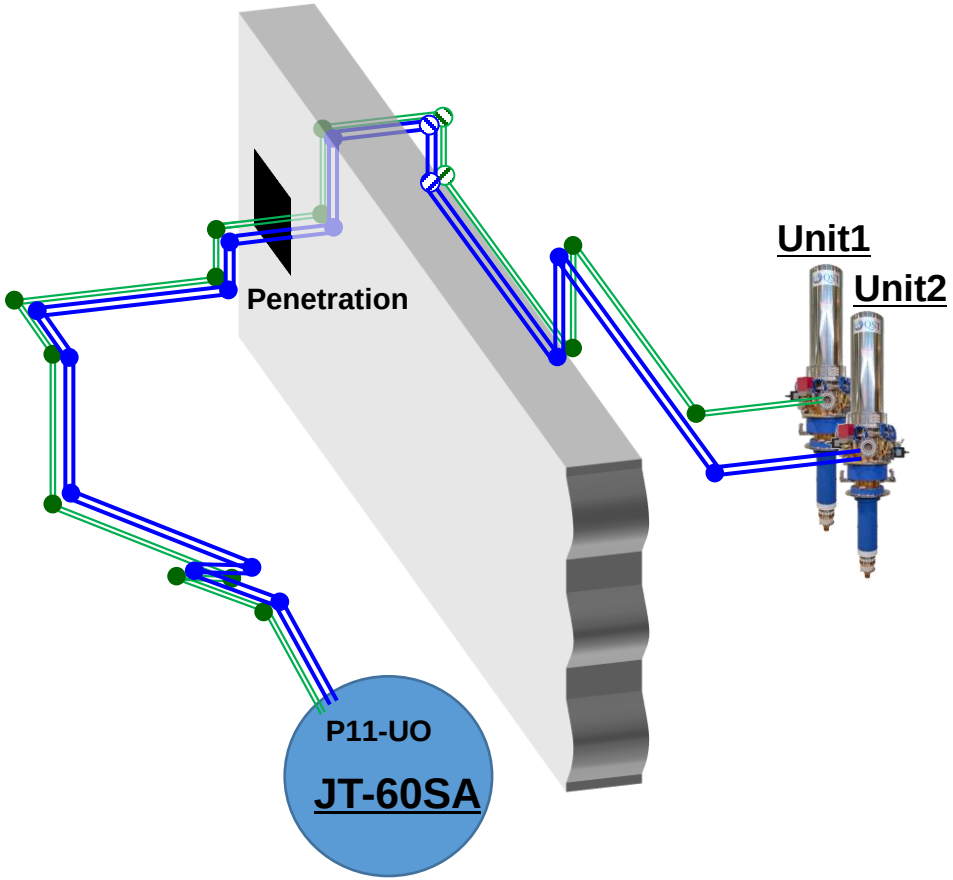




The multi-frequency gyrotron expands experimental flexibility

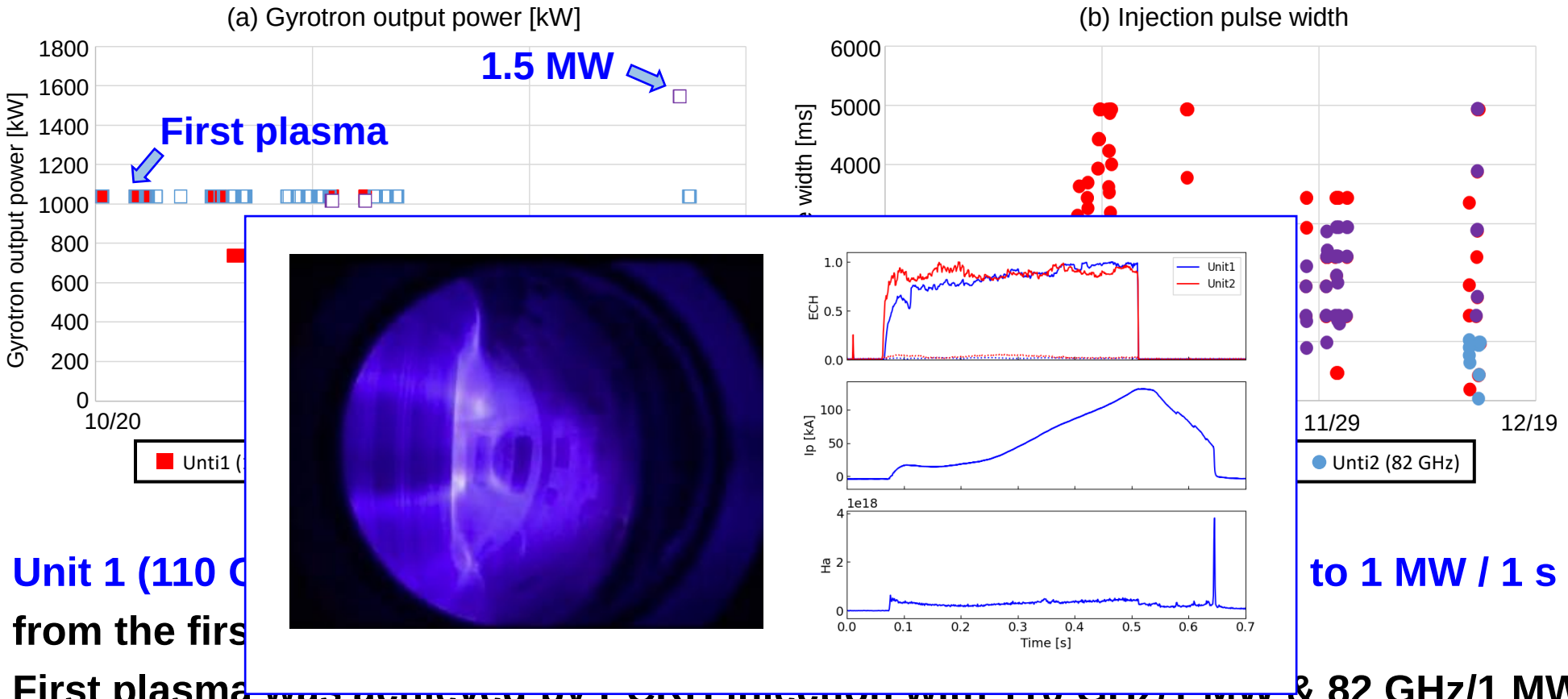
Transmission line installation and commissioning

- Two ECRH systems for the integrated commissioning phase



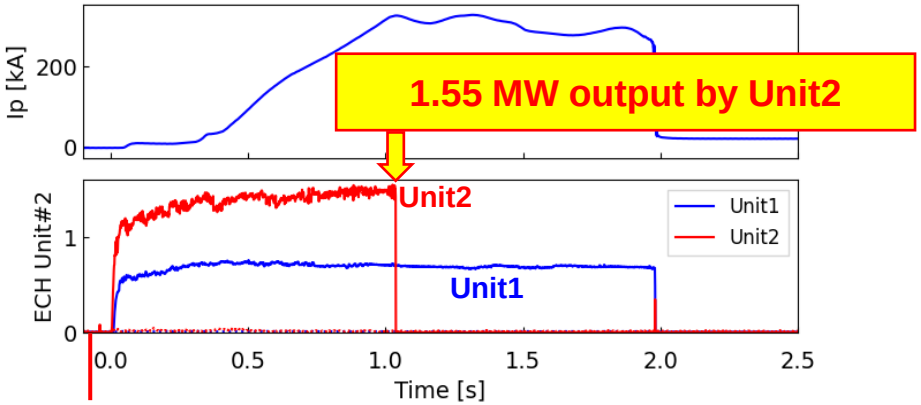
		JT-60U components	Multi-frequency
		Unit#1	Unit#2
Gyrotron	Frequency	110 GHz	82/110/138 GHz
	Output power	1 MW	1 MW
	Pulse duration	5s	110/138 GHz: 5 s 82 GHz: 1s
Transmission line	WG	φ 31.75 mm	φ 60.3 mm
	Total length	95 m	105 m
	No. of MBs	15	15
	Transmission efficiency (calc.)	66% (74%)	79%/85%/84% (80%/83%/83%)

Operation summary during the plasma experiments

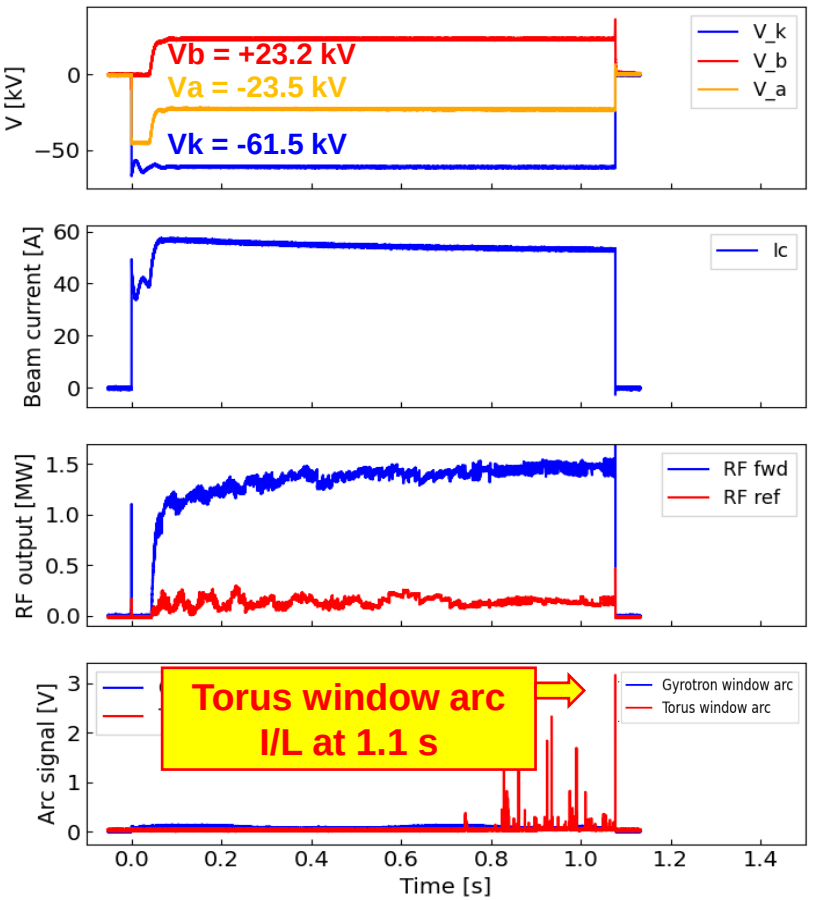


- Unit 1 (110 G … to 1 MW / 1 s from the firs…
- First plasma was achieved by ECRH injection with 110 GHz/1 MW & 82 GHz/1 MW
- 1.5 MW / ~1 s injection was also achieved.

Demonstration of 1.5 MW operation by single gyrotron



Unit2 Gyrotron waveform



Electron beam power: 84.7 kV x 53.1 A = 4498 kW
Output power (calorimetry measured): 1550 kW
Oscillation efficiency: 34.5%

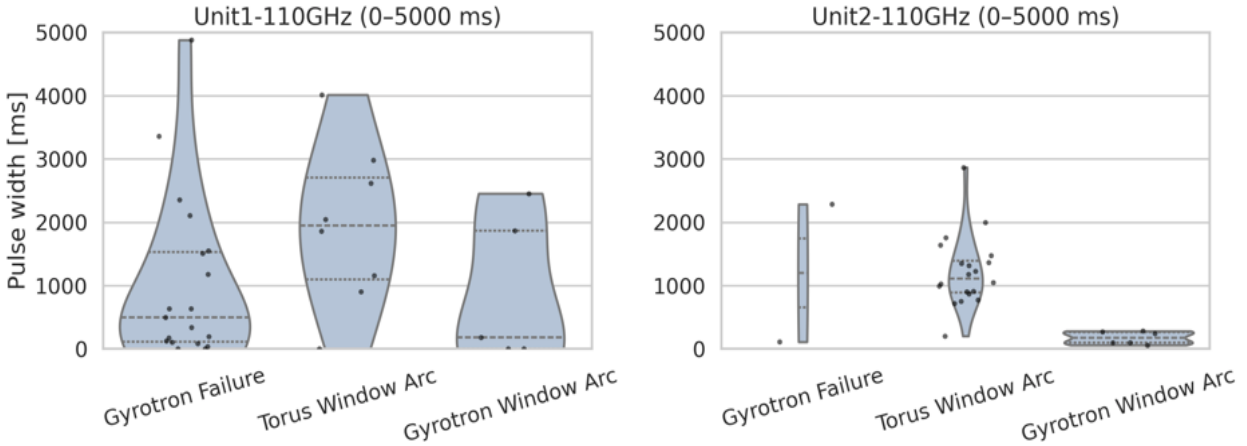
- Successfully achieved ~1 s of injection before stopping due to the arc signal interlock at the Torus window.
- The surface temperature of the waveguide in the MB closest to the launcher increased by 1.1 degrees, equivalent to a heat load of 16.7 kW/m²
- This heat load is lower than the maximum heat load considered in the TL design, suggesting the potential for future high-power operation with 1.5 MW

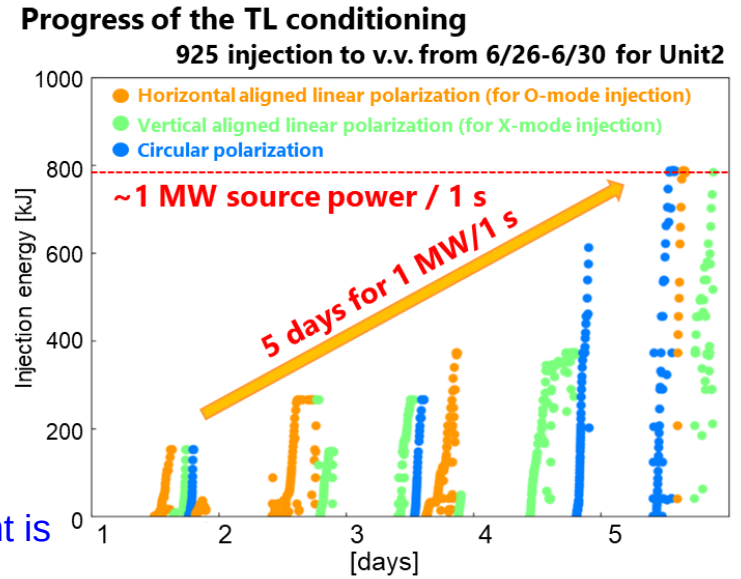
Operation reliability: 90%

Unit1		Number of pulses	Failed	Success [%]
Plasma experiment sequence		**340**	**34**	**90.0%**
110 GHz	＜1 s incl. wall cleaning	178	19	89.3%
	≧1 s	162	15	90.7%

Unit2		Number of pulses	Failed	Success [%]
Plasma experiment sequence		**350**	**34**	**90.3%**
82 GHz	＜1 s incl. wall cleaning	235	6	97.4%
110 GHz	＜1 s incl. wall cleaning	58	15	74.1%
	≧1 s width	57	13	77.2%
138 GHz		0	0	0.0%

Causes of Pulse Failure and Pulse Width



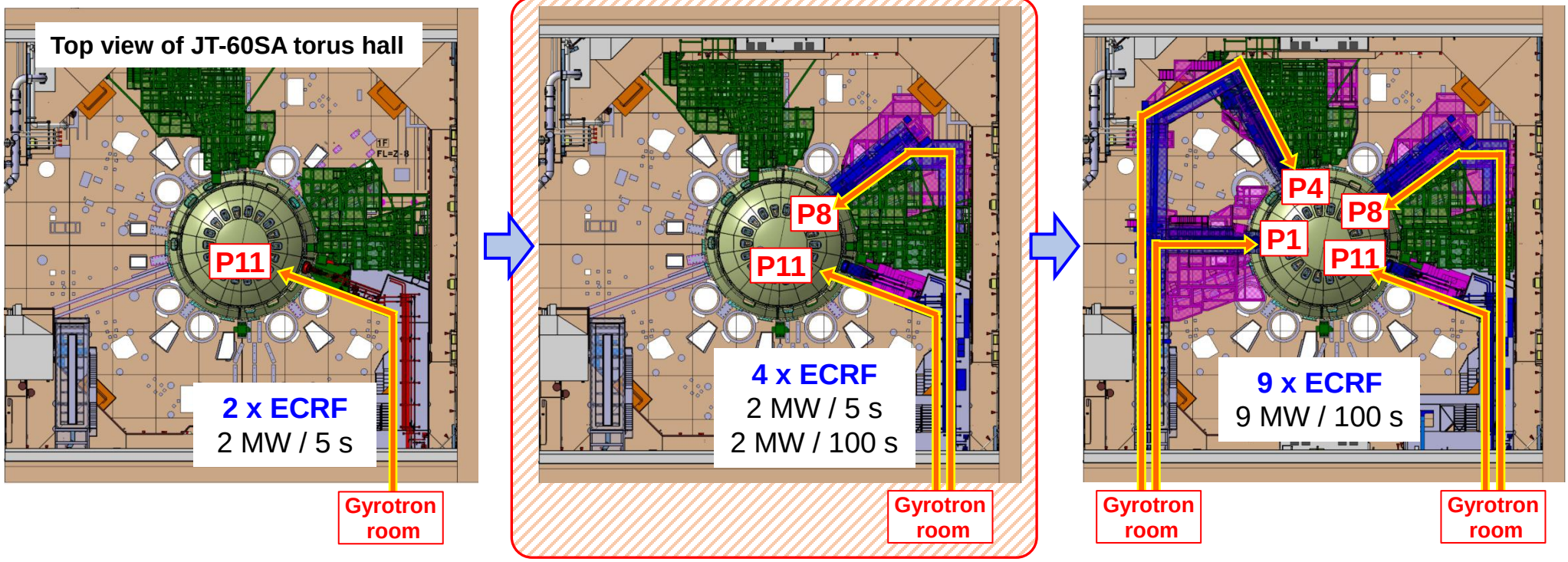


- The median time of shots halted due to Torus window arc is 2 s and 1.1 s
- A conditioning operation of up to 1 MW/1 s prior to the plasma experiment is useful for suppressing Torus window arc occurring within 1 s.
- Other factors are "uncertain events" that are independent of the conditioning results.
- Note that for Unit 1, the cause is considered to be mode deviation resulting from a reduction in beam current (as discussed in the poster).

(Phased construction of JT-60SA ECRH system)

- Multi-frequency (82/110/138 GHz) ECRH system will be upgraded in three phase:
  2 Units (I.C. phase) → 4 Units (init.R.P.) → 9 Units (integrated research phase)
- Transmission line (TL) development for initial research phase (4 units) is necessary.
- Demonstration of the TL has been conducted in the integrated commissioning phase

Integrated Commissioning Phase | **Initial Research Phase** | Integrated Research Phase



(Design of TL layout achieving target transmission efficiency)

☐ Determined transmission line layout for initial research phase

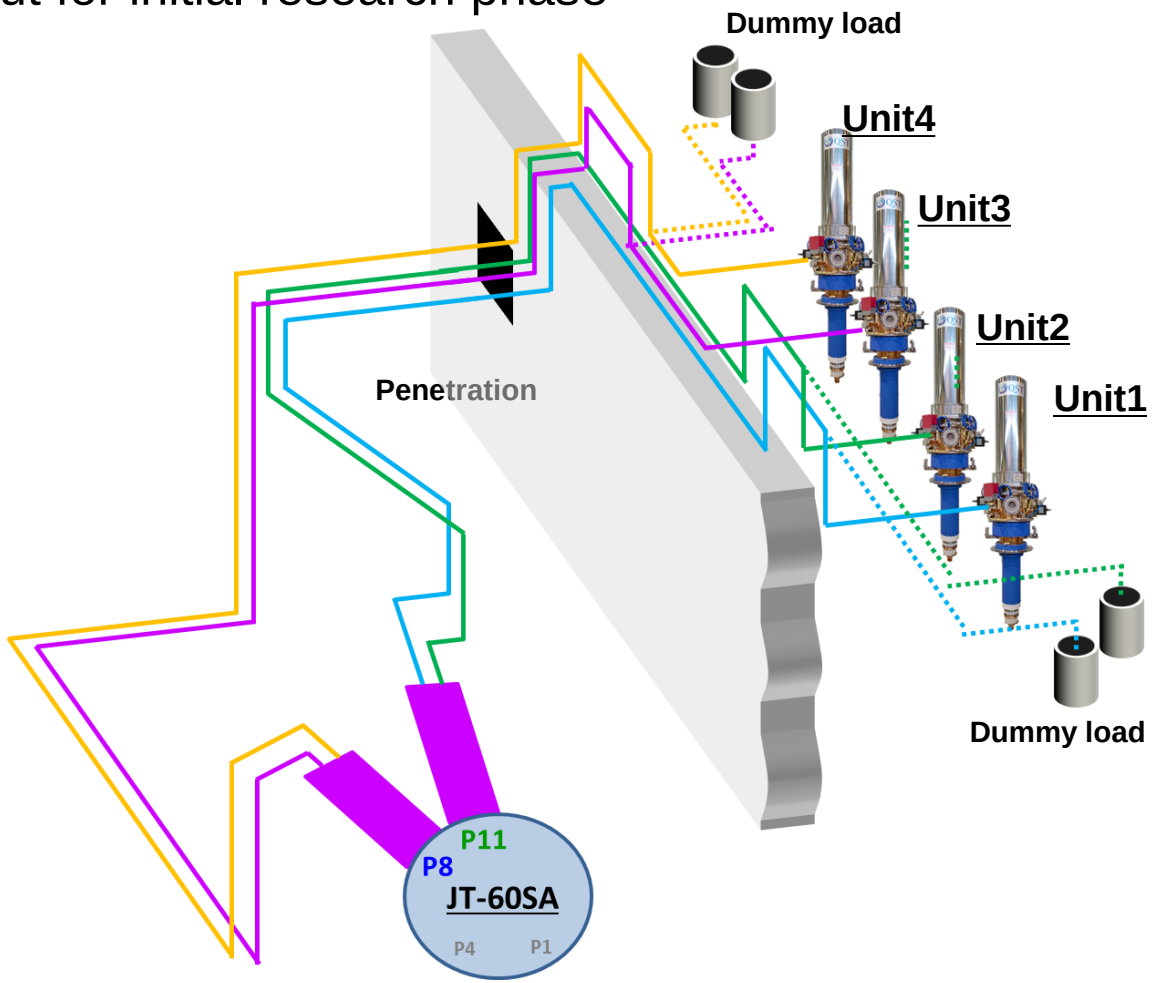
Unit1/Unit2: Transmission efficiency >85%

- total length of ~60 m
- 9 miter-bends including polarizers
- Connected on **P11-UO** launcher

Unit3/Unit4: Transmission efficiency >80%

- Total length of ~115 m
- 10 miter-bends including polarizers
- Connected to **P8-UO** launcher

		loss	Transmission efficiency	Target
P11 Unit1/2	82 GHz	10%	90%	85%
	110 GHz	9%	91%	
	138 GHz	9%	91%	
P8 Unit3/4	82 GHz	13%	87%	80%
	110 GHz	12%	88%	
	138 GHz	13%	87%	



Design target of 3 MW (75% efficiency x 4 units) of tokamak injection power can be achievable

summary

ECRF system installation

- High transmission efficiencies of 80/82/84% at 3 operating frequencies of 82/110/138 GHz were achieved by large-diameter corrugated waveguide.

Results of RF operation

- The ECRF was used in almost all plasma experiments (including ECWC), with an average reliability of 90%.
- Units 1 (110 GHz) and 2 (82 GHz/110 GHz) were successfully injected with up to 1 MW/1 s from the first day of the experiment, contributing to the achievement of first plasma.
- Conditioning before the plasma experiment was helpful in preventing injection failures due to Torus window arc event.

Layout design for next initial research phase TLs

- We designed the 4 units of ECRH systems for the next phase and target transmission efficiency (>85%) is expected to be achieved.