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Development of 1MW-CW Gyrotron for ITER

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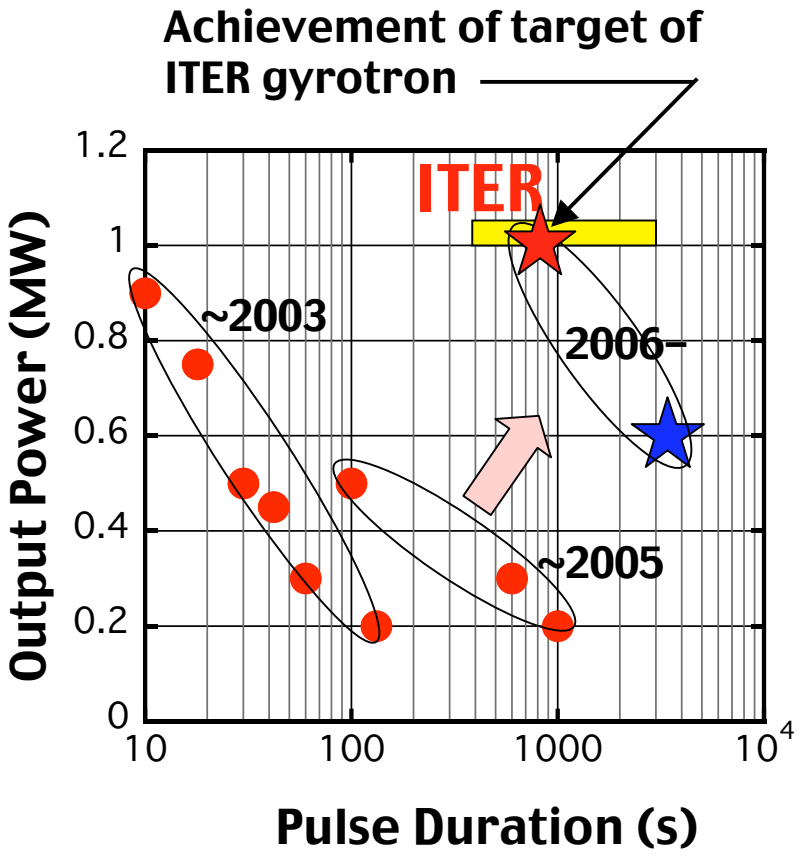
Status of 170GHz gyrotron performance

- **1hour/0.6MW**
  Demonstration of steady state operation

- **1.0MW/800s/55%**
  Satisfied basic requirement of ITER gyrotron (1.0MW/500s/50%)

Burning of plasma in ITER (>400s)



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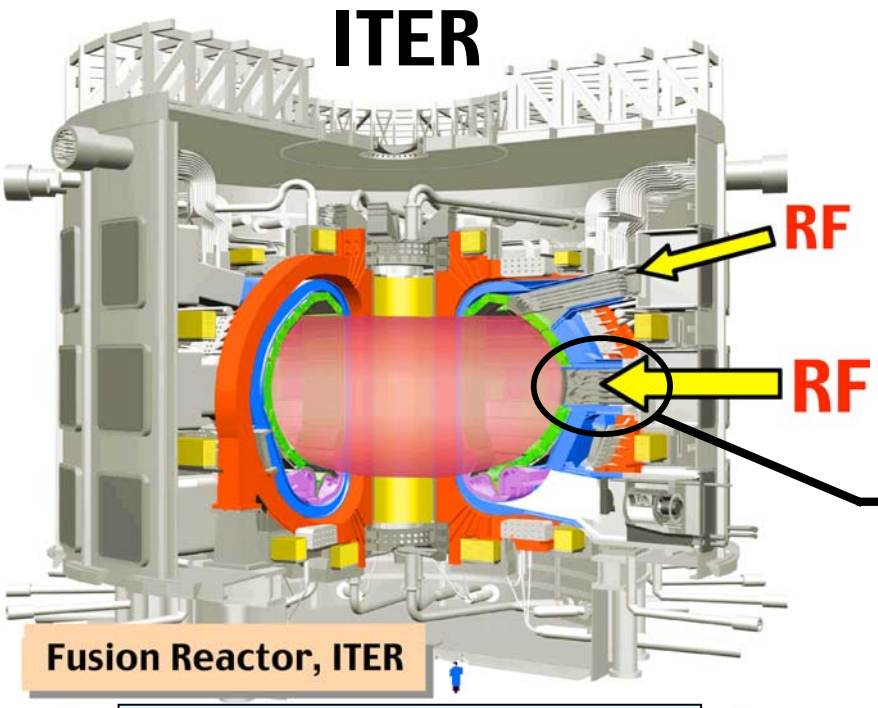
ECH system in ITER



Plasma radius	: 6.2m
Q value	: 10~
Burn time	: 400~500s
Fusion power	: 500MW

In ITER, 170GHz 24MW Electron Cyclotron Wave system is planned for plasma heating
/Current drive
/ Instability suppression.

Japan:
⇨ Equatorial launcher & 8-Gyrotrons

Most Important Technical Issue
⇨ Establishment of reliable & high power & CW Gyrotron

Final Target of ITER Gyrotron:

Demonstration of 170GHz,1MW, 500s, 50% efficiency

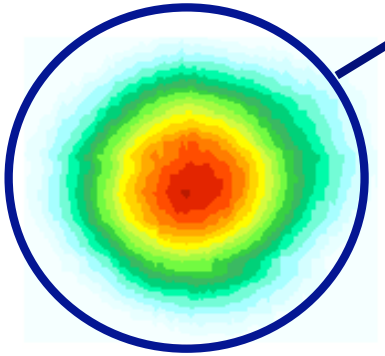
Gyrotron Technology

Artificial diamond window

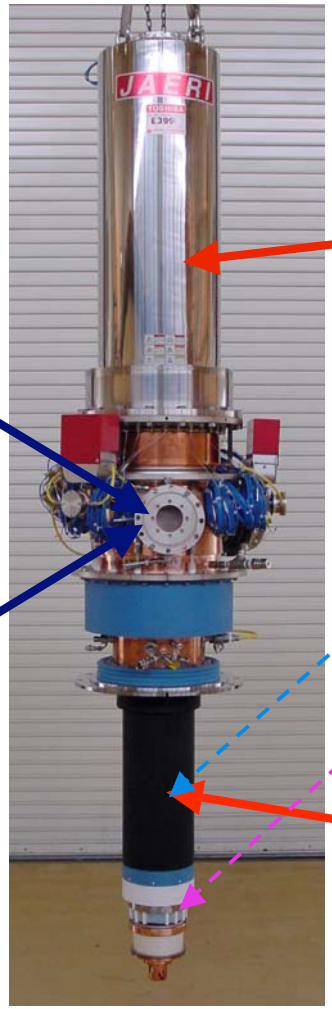
Long pulse operation

Low loss tangent

High thermal conductivity



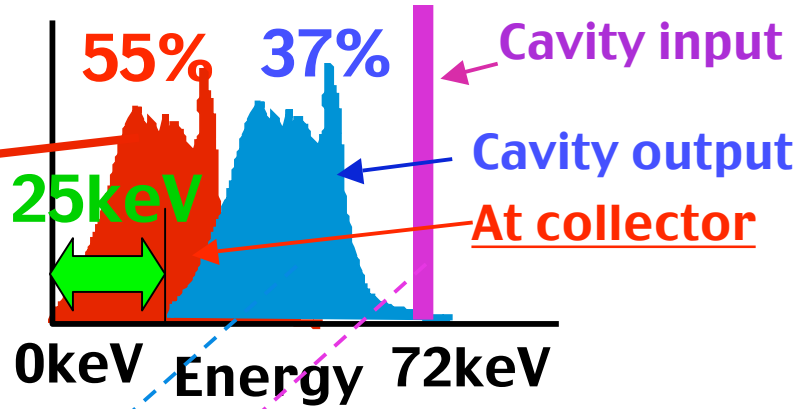
Output RF at window



ITER gyrotron

Energy recovery

Distribution function of e-beam

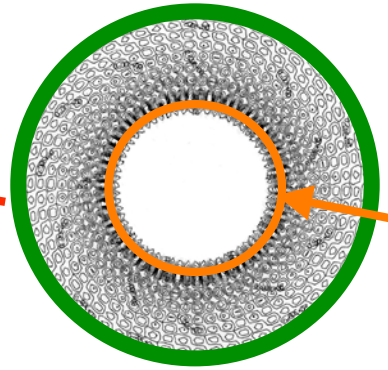


High power cavity

Higher oscillation mode

170GHz/1MW

(TE31,8)



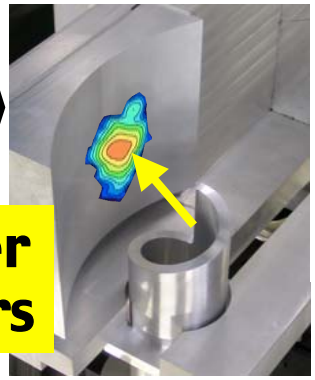
Field pattern at cavity (oscillation)

Major Improvements of the Gyrotron

② Optimization of launcher & mirrors

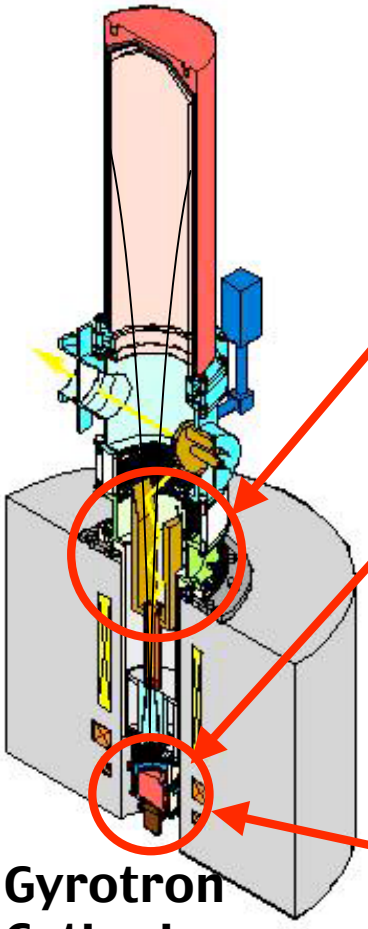
For high efficiency & reduction of stray RF

Oscillation mode : TE31,8 (Cavity)



Launcher & mirrors

Output : Gaussian beam

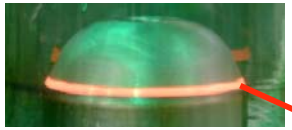


Gyrotron Cathode

① Electron beam quality

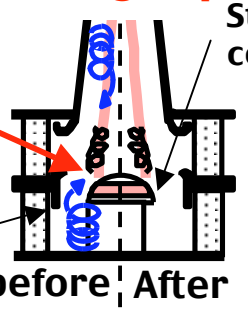
For high oscillation efficiency

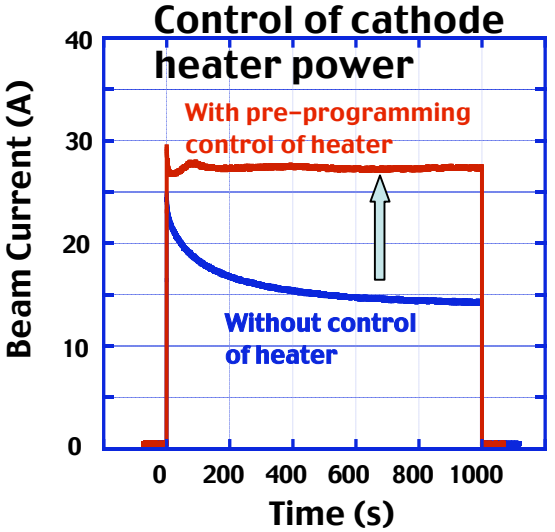
High quality beam



MIG & Emitter

unwanted electrons





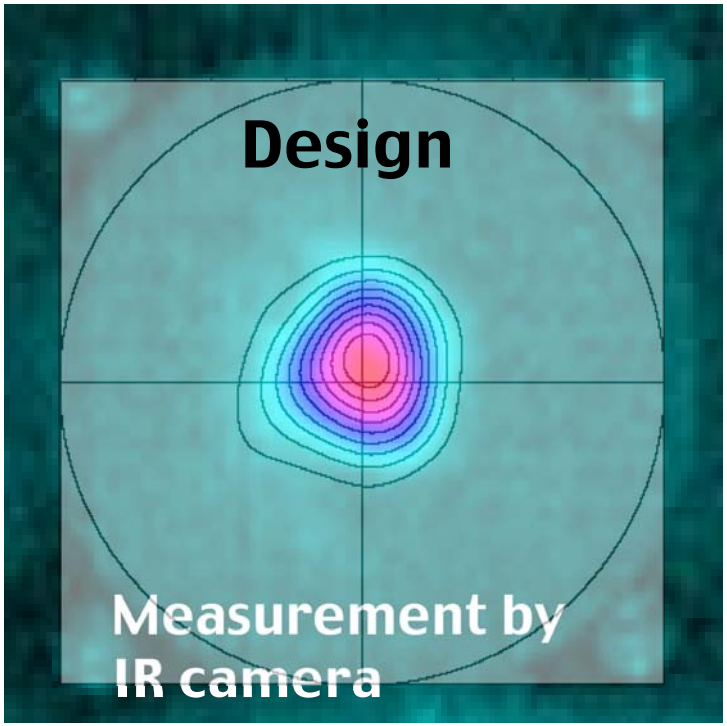
③ Beam current control

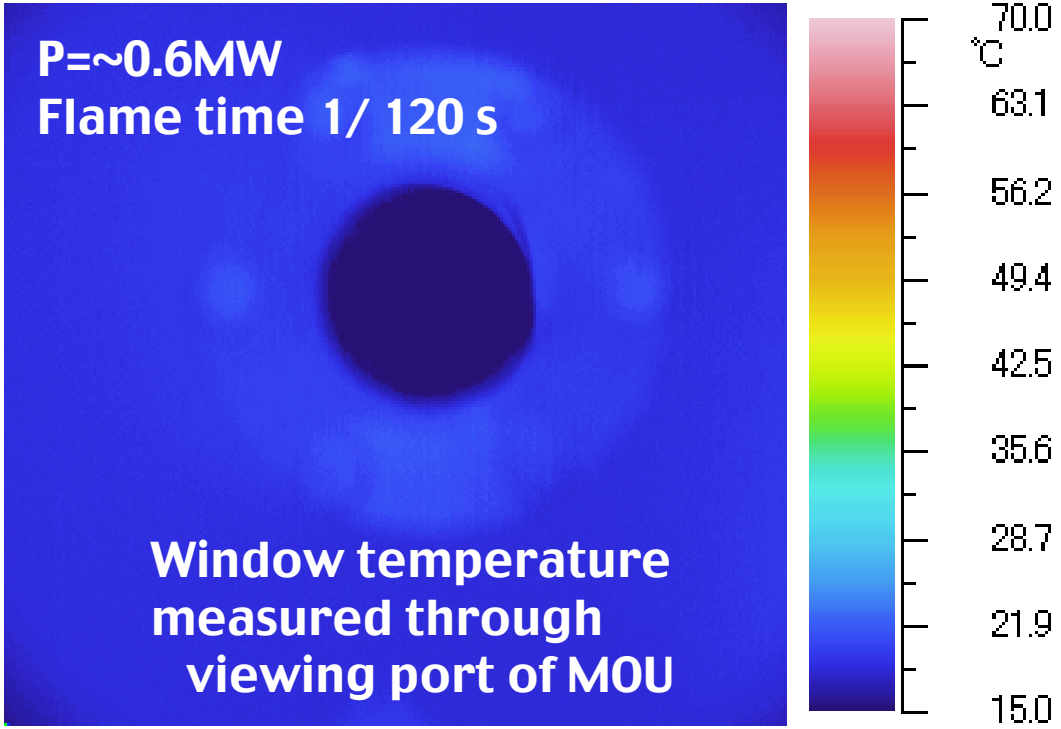
For Stable oscillation

Experimental Result of 170GHz Gyrotron

RF Profile at the Window

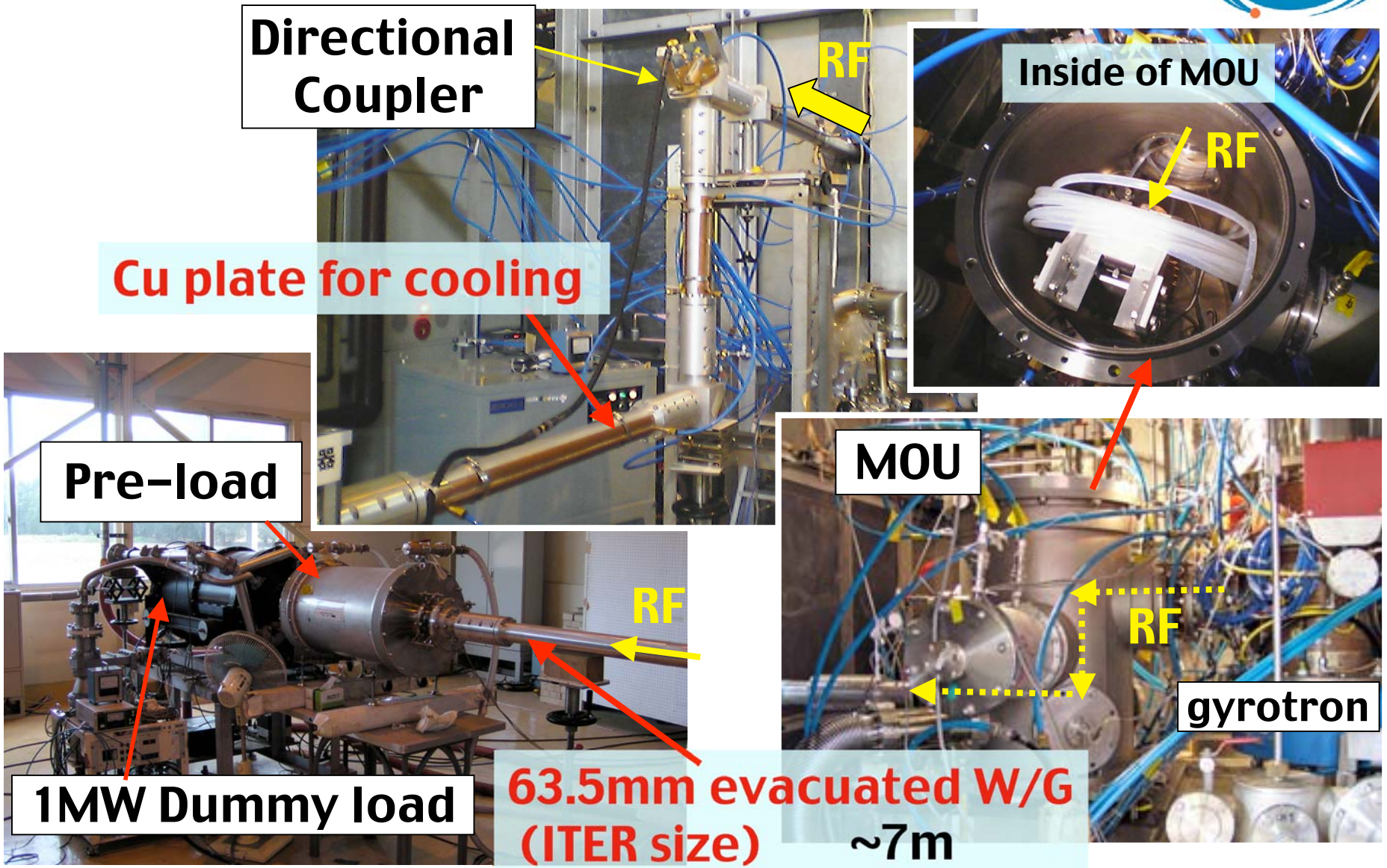
Measured RF output profile agreed well with the design.



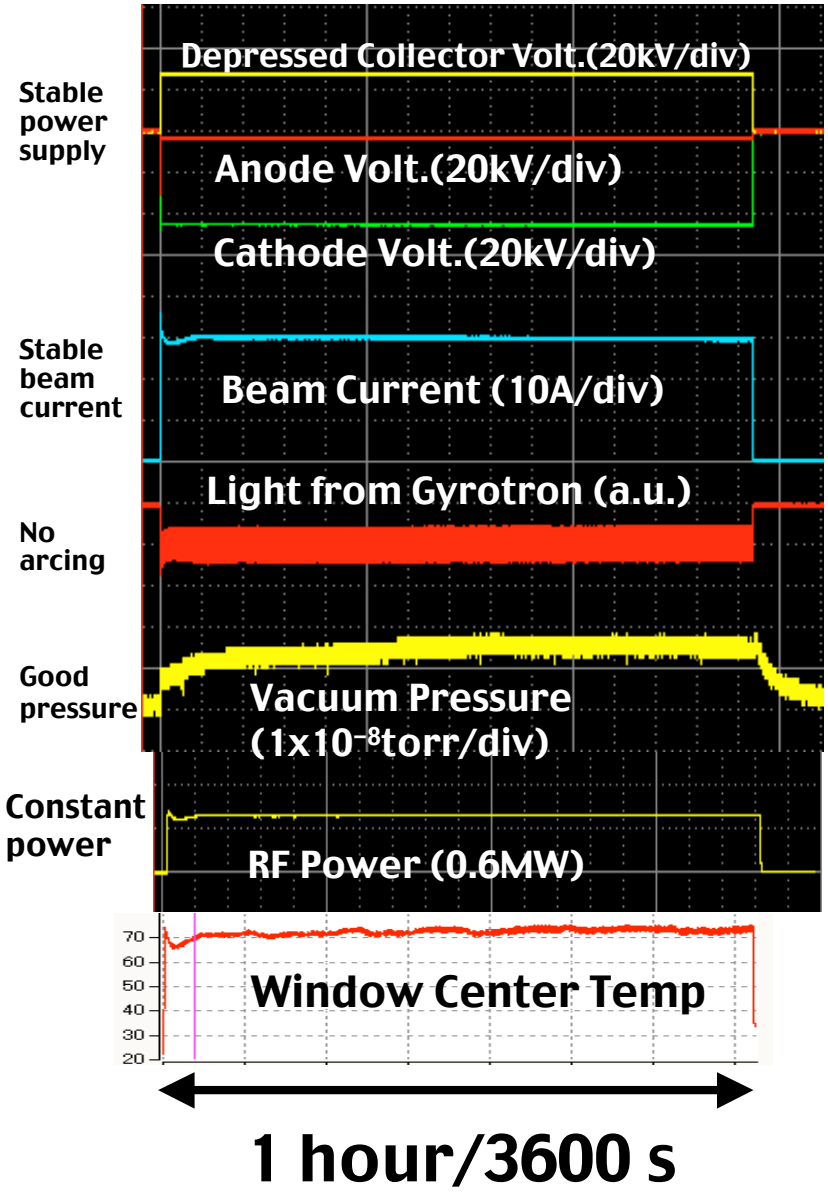


Measured stray radiation was reduced to ~2% of output power by optimization of the launcher & mirrors.

RF Transmission Line for Long Pulse Experiment



Stable One Hour Operation



● Steady State Operation

0.6 MW/1hour (steady state operation) was achieved

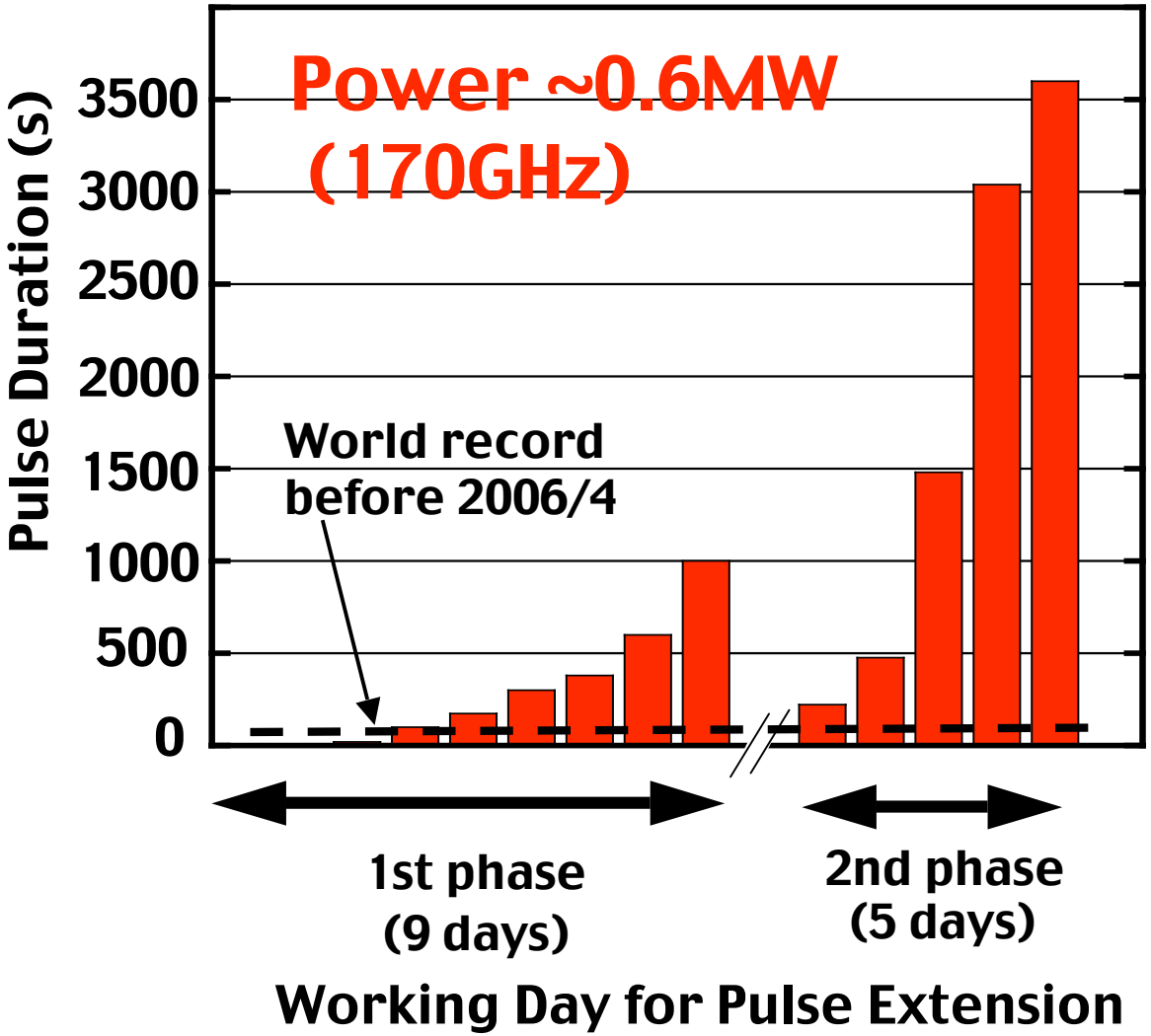
Output Energy =2.1GJ

Stable oscillation
No arcing and good vacuum
10^{-5} Pa during operation

● **No problem of cooling capacity because of low stray radiation**

Clear prospect for application to the ITER ECH system

Aging History up to 3600s Oscillation



High depressed collector voltage ~28kV & Low stray radiation

Outgas inside the gyrotron was low level.

It was possible to extend the pulse duration rapidly.

0.8s ⇨ 3600s : Short aging time within 2 weeks

Try to High Efficiency Operation

0.6MW/1hr operation

Soft self-excitation region (Low Efficiency)

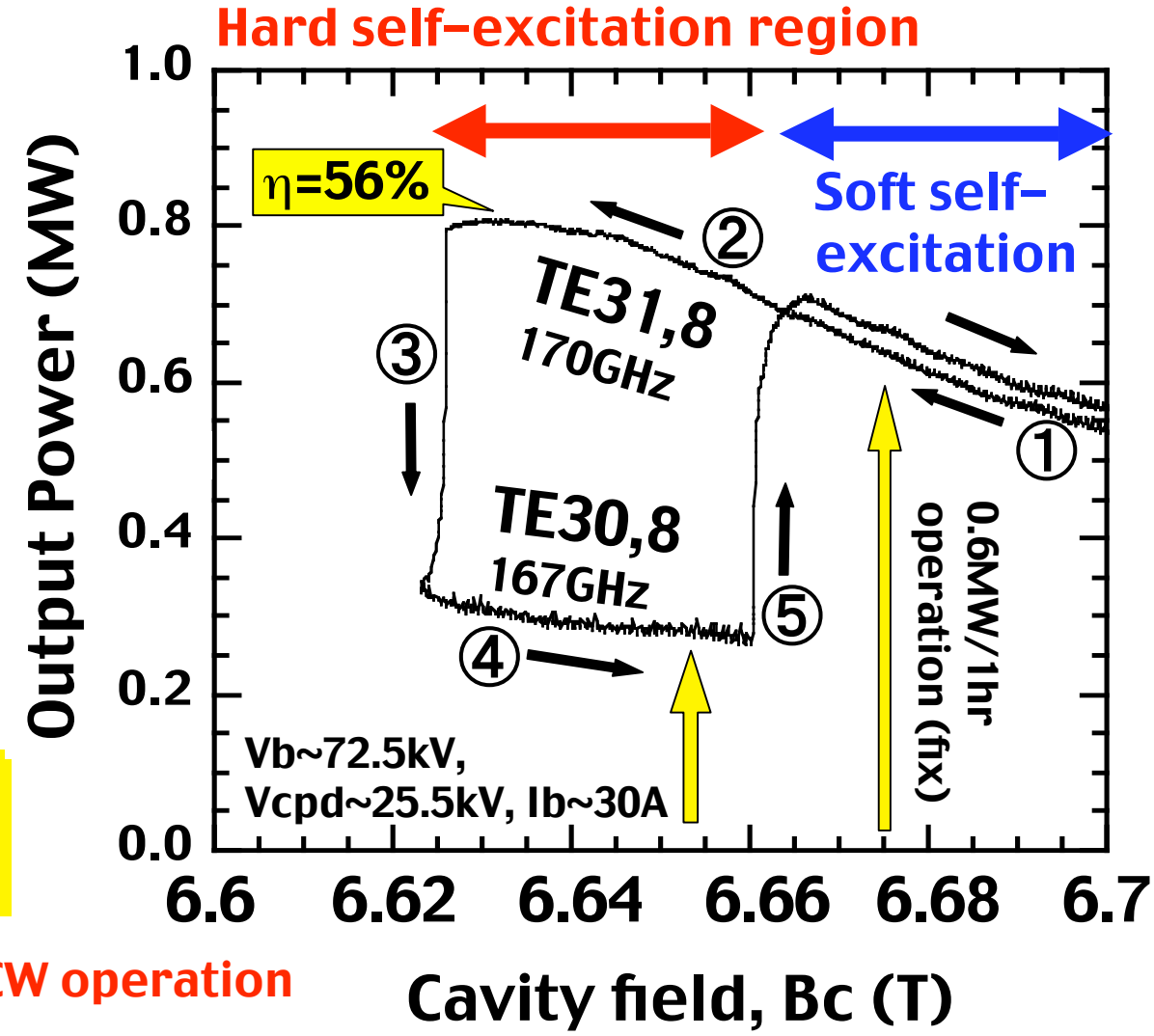
By decreasing Bc with keeping oscillation

Hard self-excitation region (High Efficiency)

In hard self-excitation region, TE31,8 can't excite directly.

Clear hysteresis effect on B_c scan

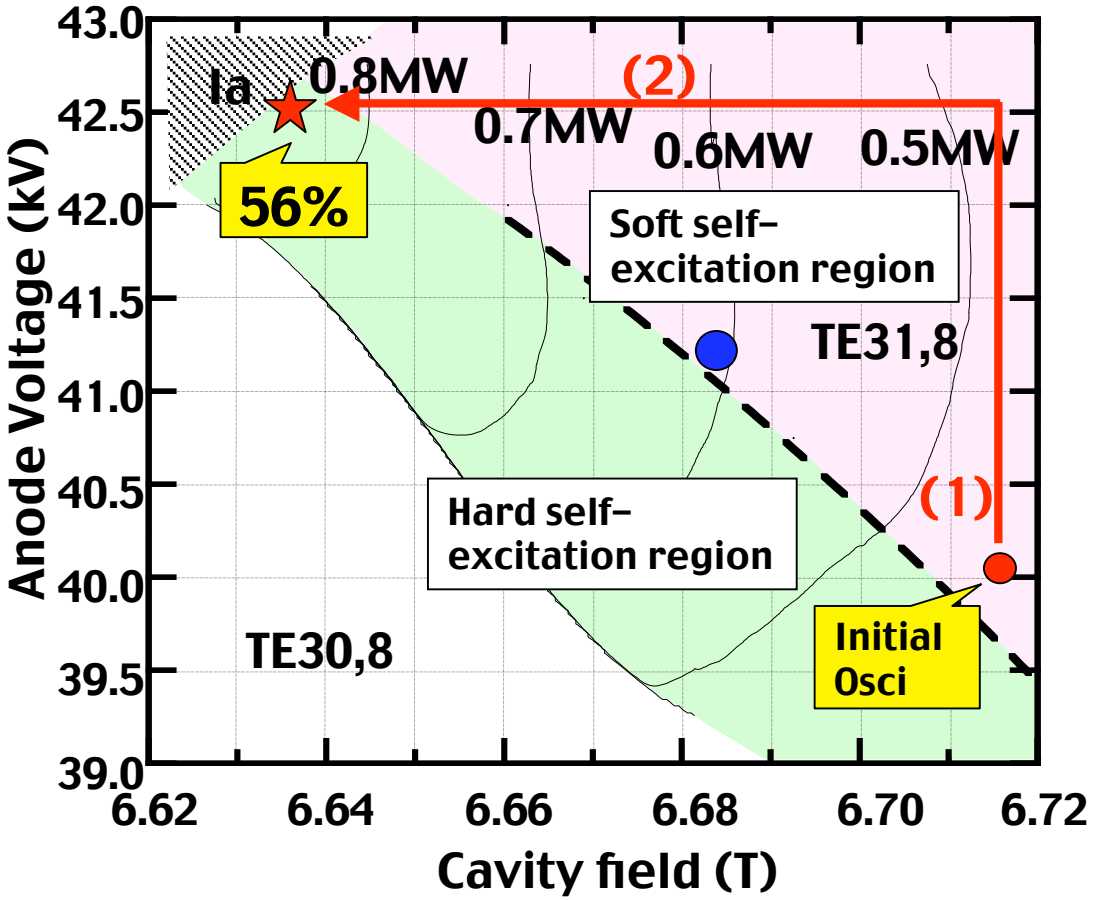
Reverse rotational modes (TE-28,9,TE-27,9) were not observed

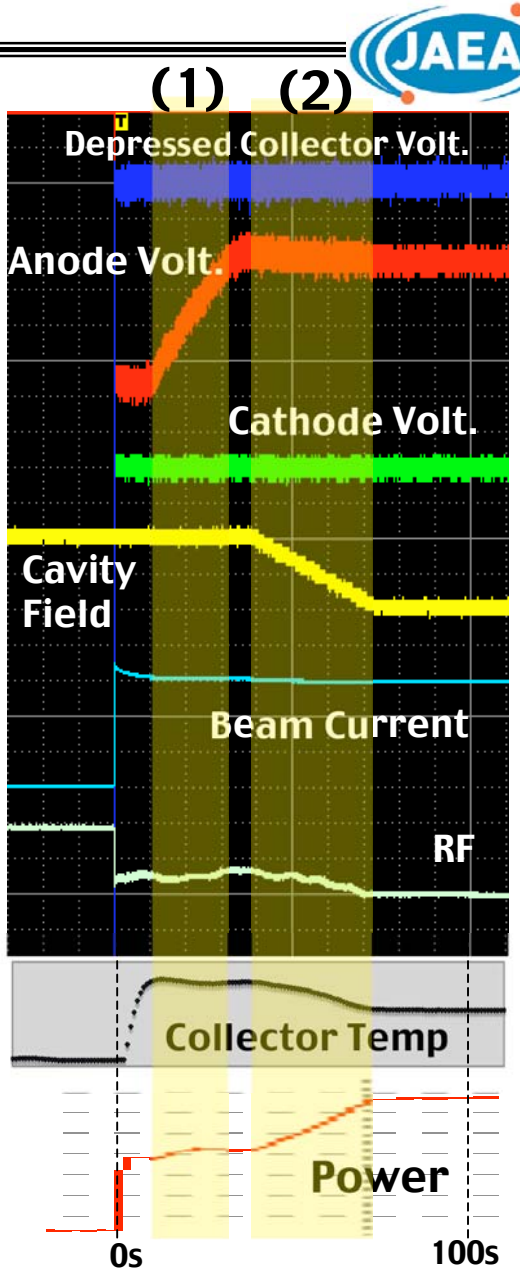


First demo by Bc scan with CW operation

Scenario for High Efficiency Operation

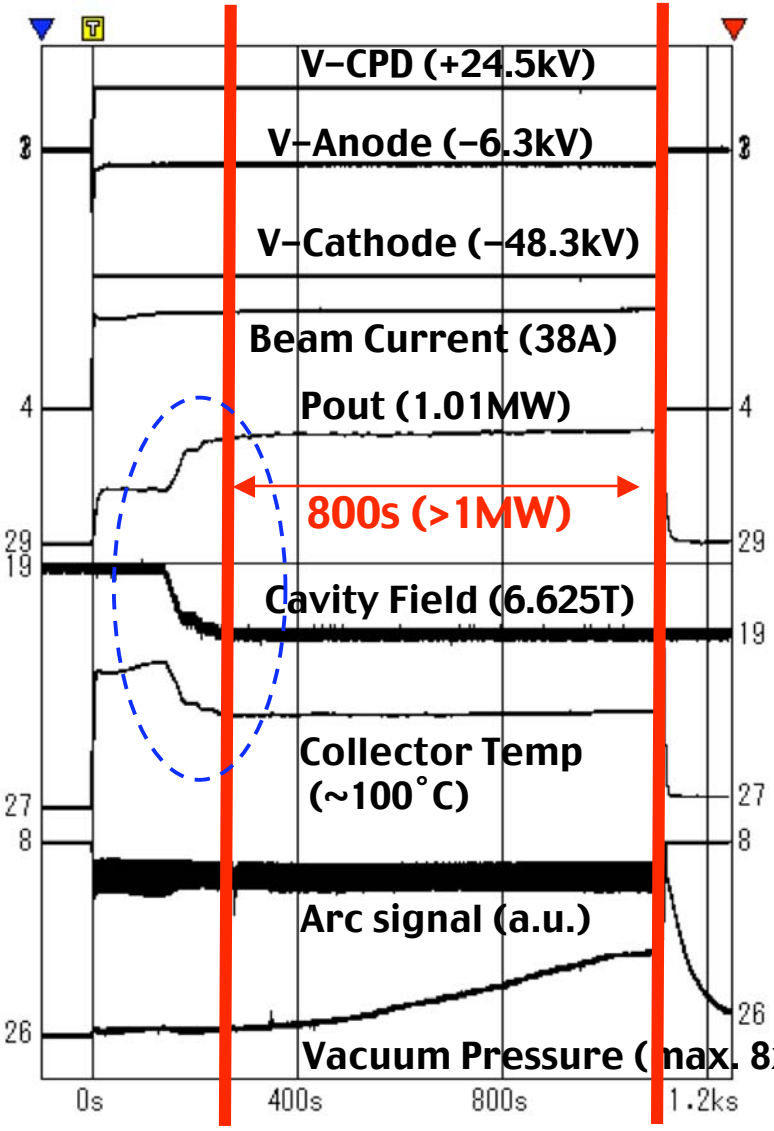
(1) Increase of anode voltage (α)
(2) Decrease of cavity field





It is proved accessibility to maximum theoretical efficiency by active control.

1MW/800s/55% operation



Ib~30A (0.8MW)

⇓ Increase of beam current

Ib~38A(1MW)

1MW/800s/55% attained with triode operation.

The development mission of ITER (1MW, 500s, 50%) was attained.

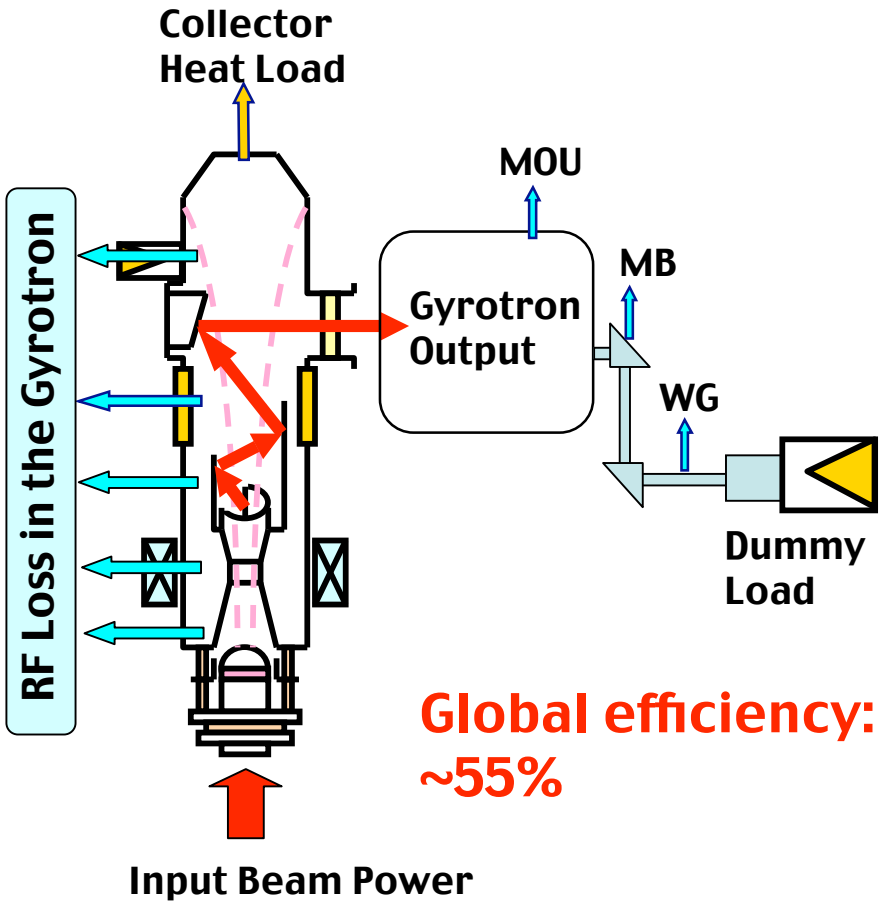
Power Balance of 1MW Operation

Input Beam Power		**1853.7** 48.4kVx38.3A
Total measured power		**1853.5**
	Generated RF power at cavity (A + B)	1111.5
	Collector heat load	742

RF Loss in the Gyrotron (A)		**87.2**
	relief windows	8.7
	DC Break ceramic insulator	15.2
	Mirrors (1st~3rd)	5.9
	Launcher & Jacket	15.3
	Beam tunnel	2.6
	Gyrotron body & 4th mirror	5
	Cavity	34.5

Gyrotron Output (B)		**1024.3**
	Dummy Load	968
	Miter Bends	2.7
	Waveguide	8
	MOU	45.6

(unit : kW)



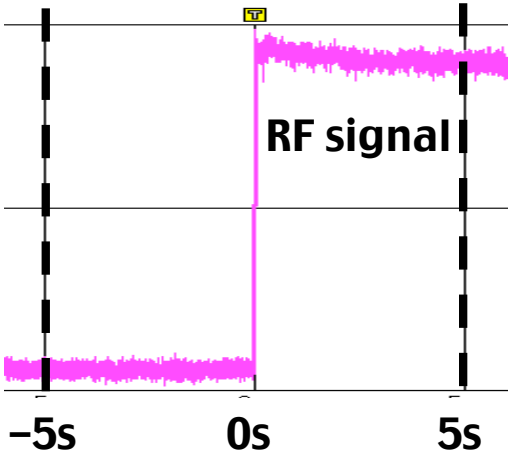
Global efficiency: ~55%

Input power and generated RF power and collector heat load are balanced.

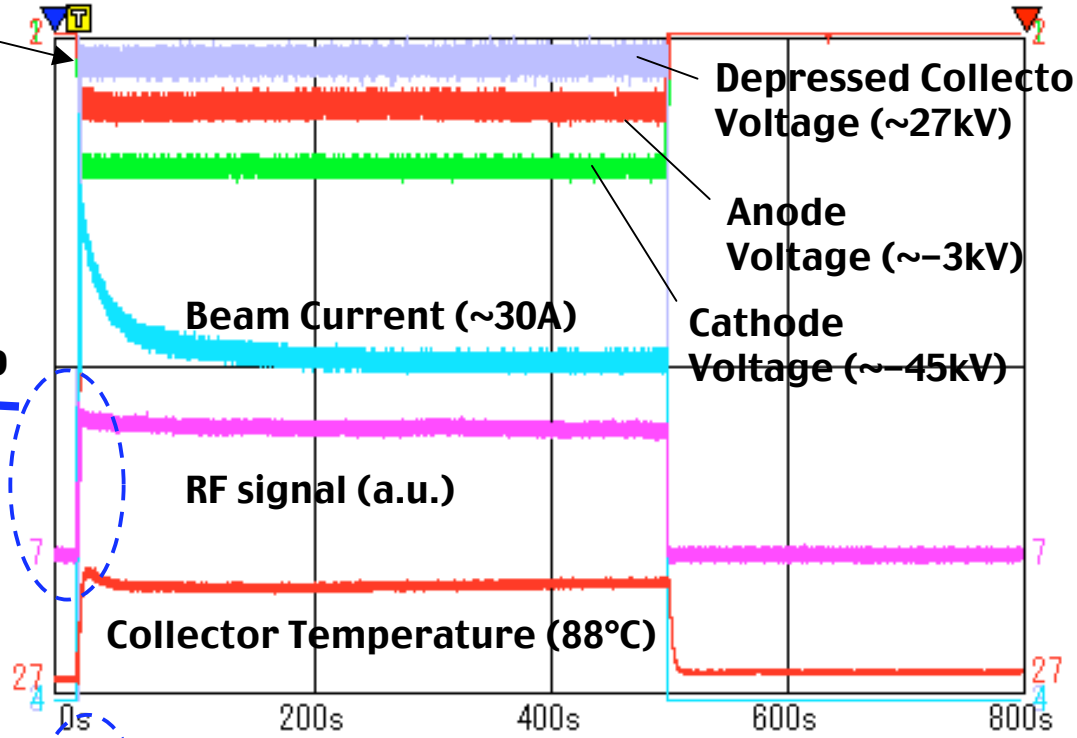
Quick Start of ~800kW operation

Initial current ~38A

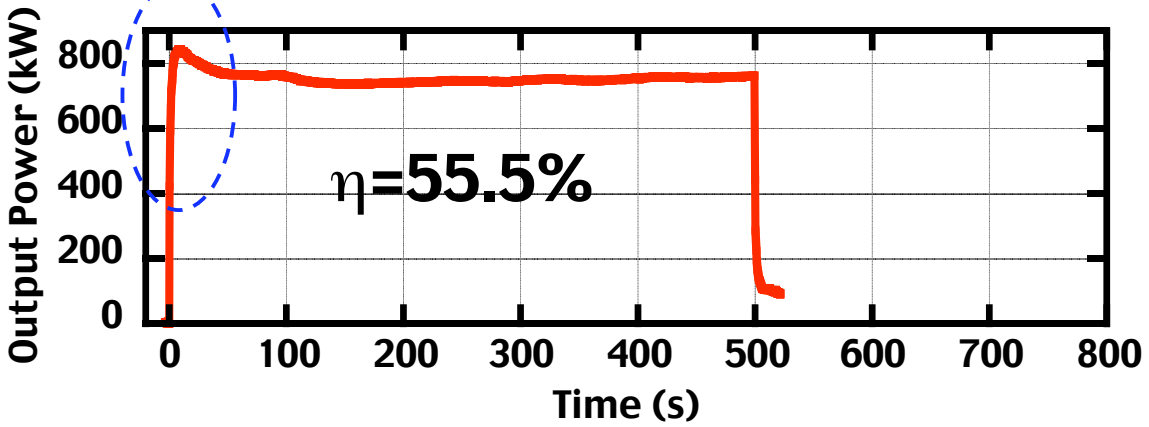
~800kW
within 100ms



Zoom up

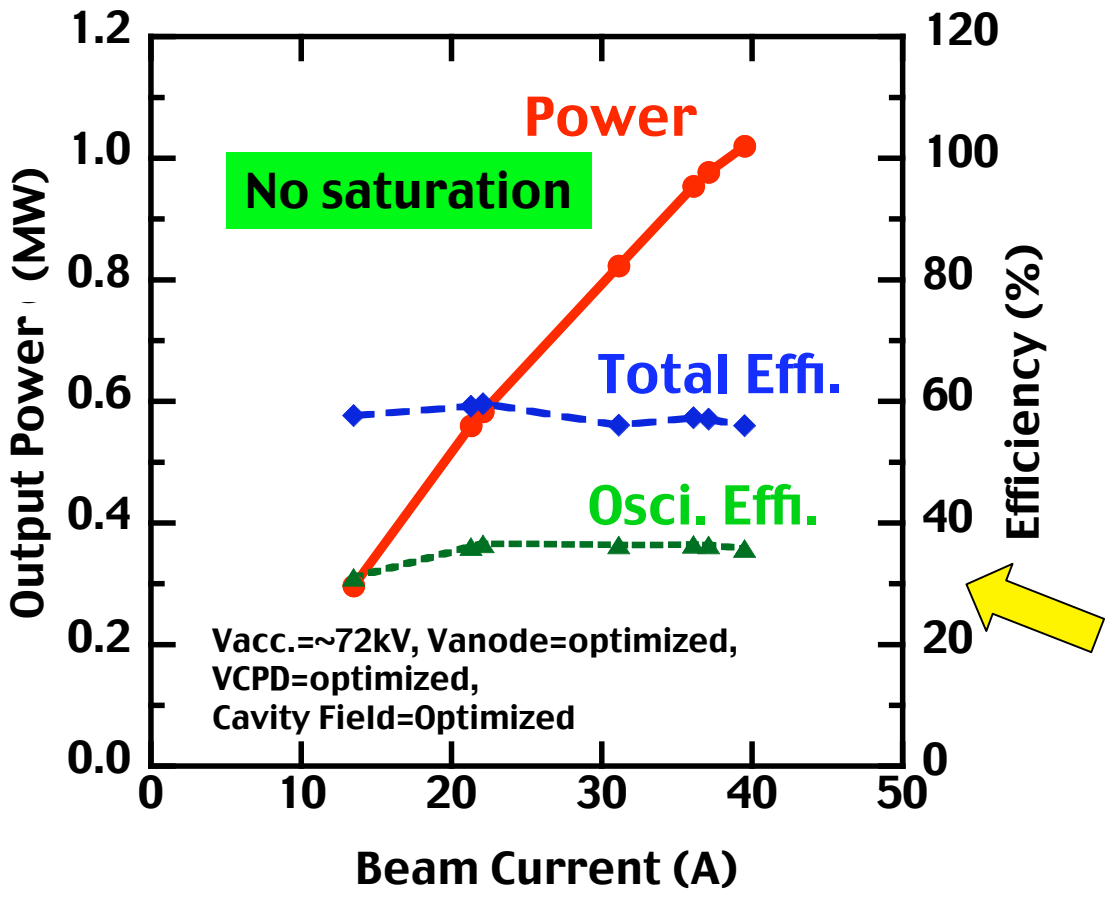


Bc: fixed
Anode Voltage:
-4→ -3kV after 100ms



Oscillation characteristics in Hard self-excitation region

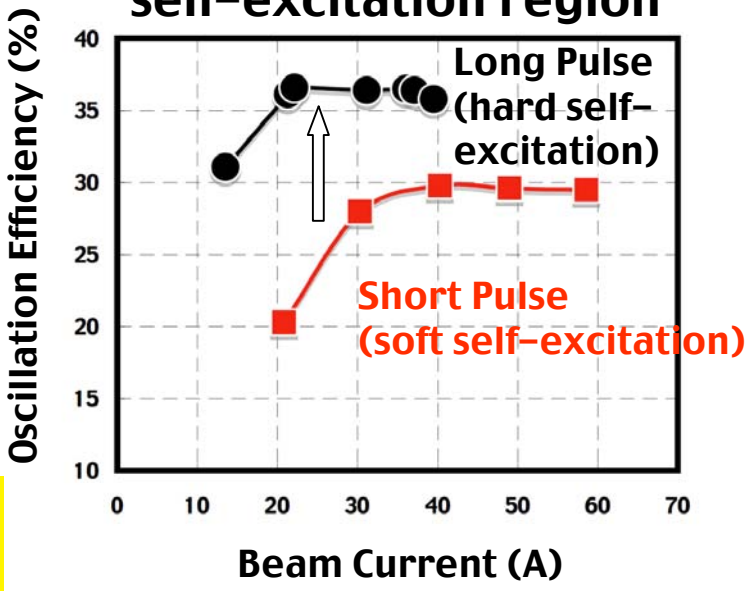
Long pulse operation (>300s)



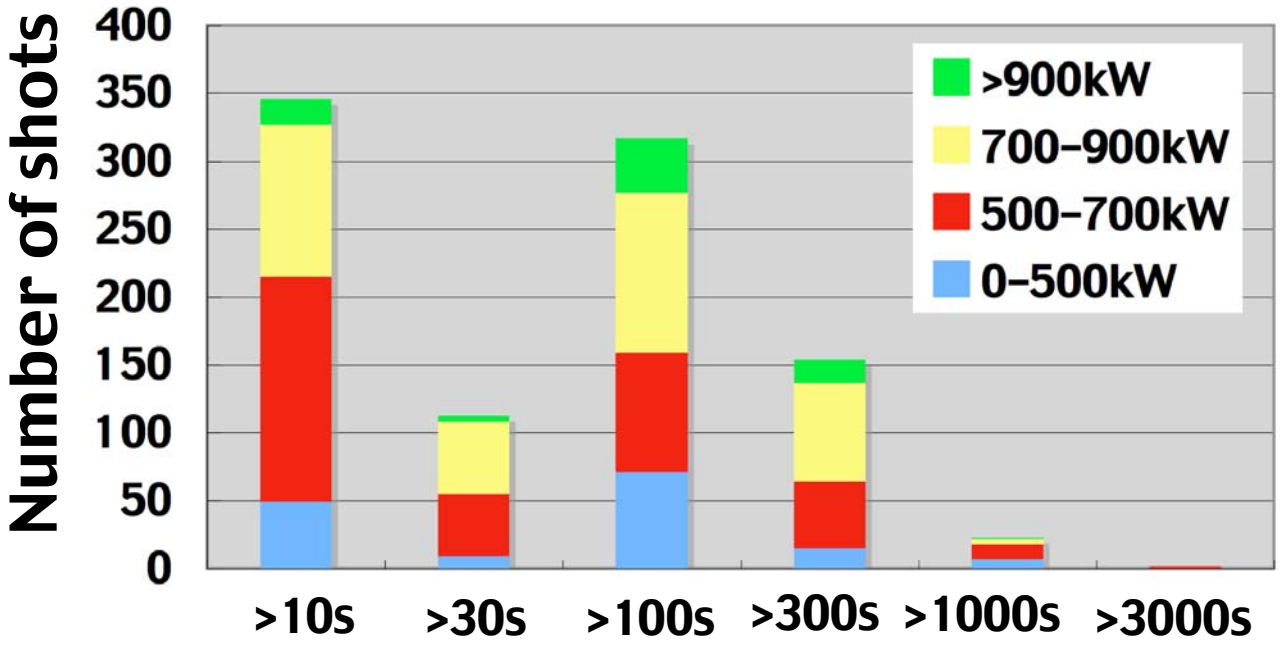
This result indicates that advanced operation scenario is available for each beam current.

Efficiency on hard self-excitation region is significantly improved in comparison with soft self-excitation region.

Comparison hard & soft self-excitation region



Total Shot Number



Operation:
Apr., 2006
~ Jan. 2008

Total Energy:
~144GJ

Number of Shots >1MW
: ~20 shots

Total Shots Number > 10s : ~ 1000 shots
No damage & No problem of oscillation

Demonstration of higher reliability

Summary

In development of 170GHz ITER gyrotron

- **1.0MW/800s/55%**
  Oscillation in hard self-excitation region by active parameter control

Basic objective for ITER gyrotron was attained with triode operation.

- **1hour/0.6MW**
  stable steady state operation.