A High-Power Gyrotron and high-power mm wave technology for Fusion Reactor

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Japan Atomic Energy Agency (JAEA)

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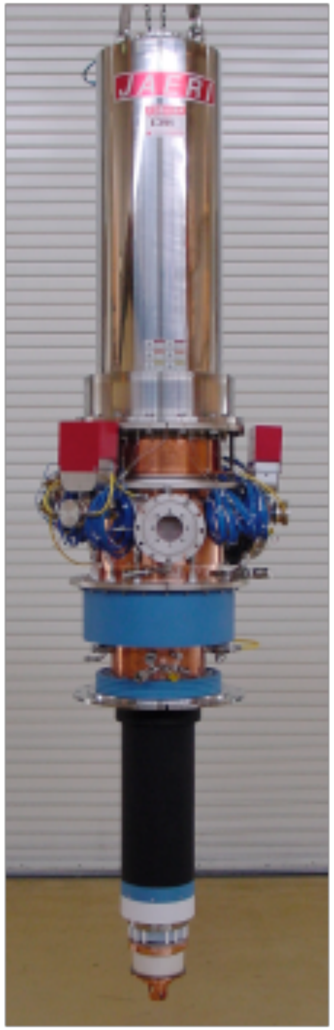


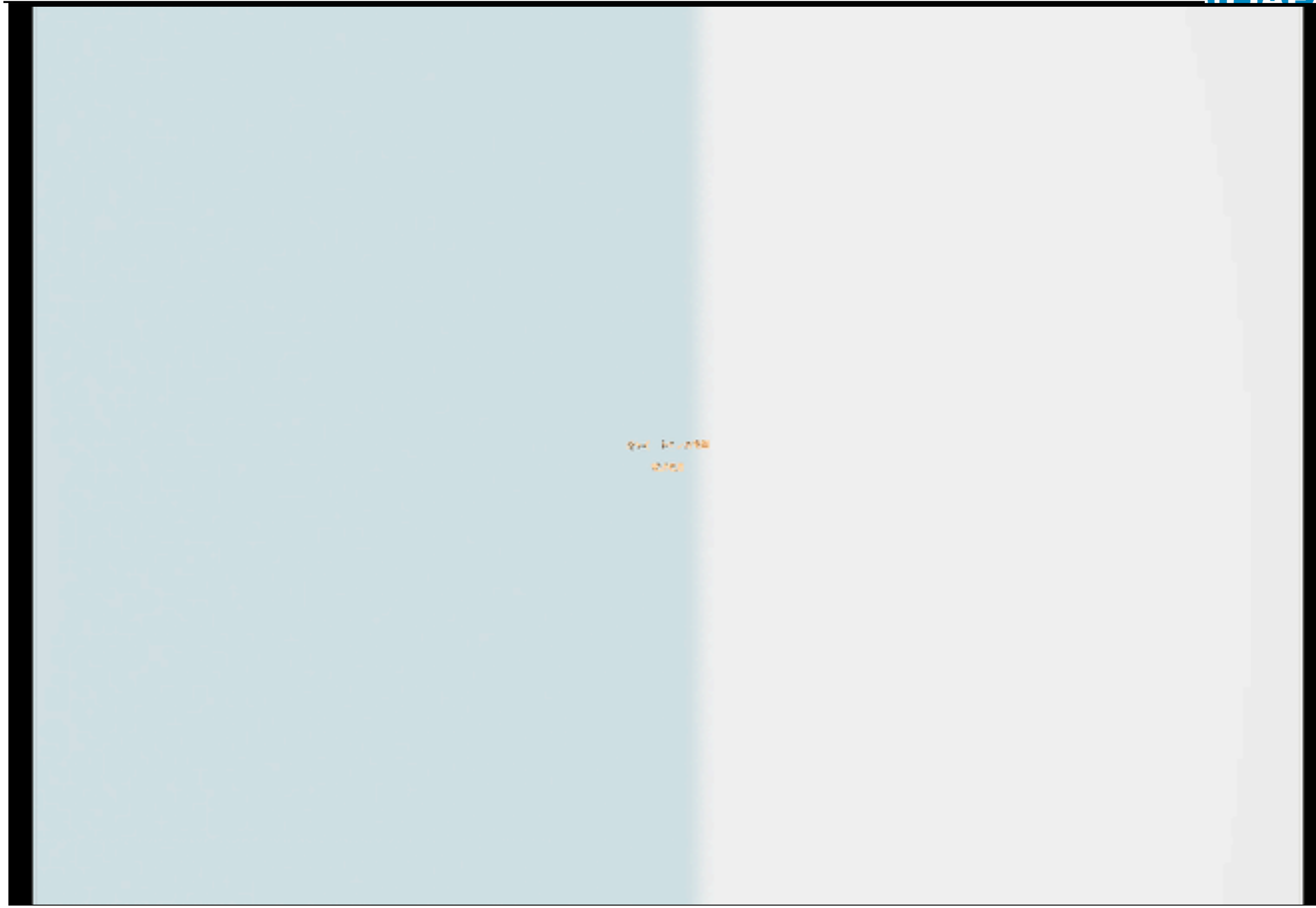
ITER Gyrotron

(1) Results of 170 GHz Gyrotron for ITER
(Working since 2006)

(2) Other Topics
- High order mode gyrotron (TE31,12)
- ITER Launcher and Transmission line
- EC system on JT-60U
- New magnet

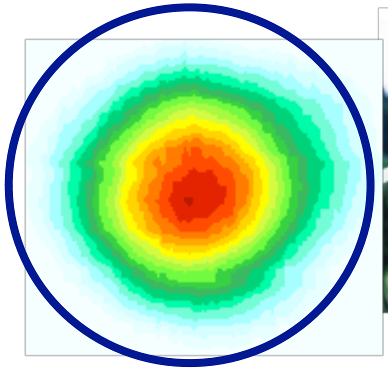
Development of EC technology will contribute to all kind of magnet confinement fusion devices including DEMO reactor.

Gyrotron and EC system



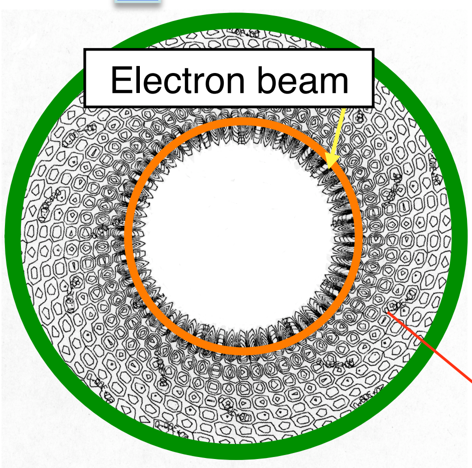
Features of 170GHz 1MW Gyrotron for ITER

Objective:
1MW, 500s, 50 %,
5kHz modulation,
High reliability

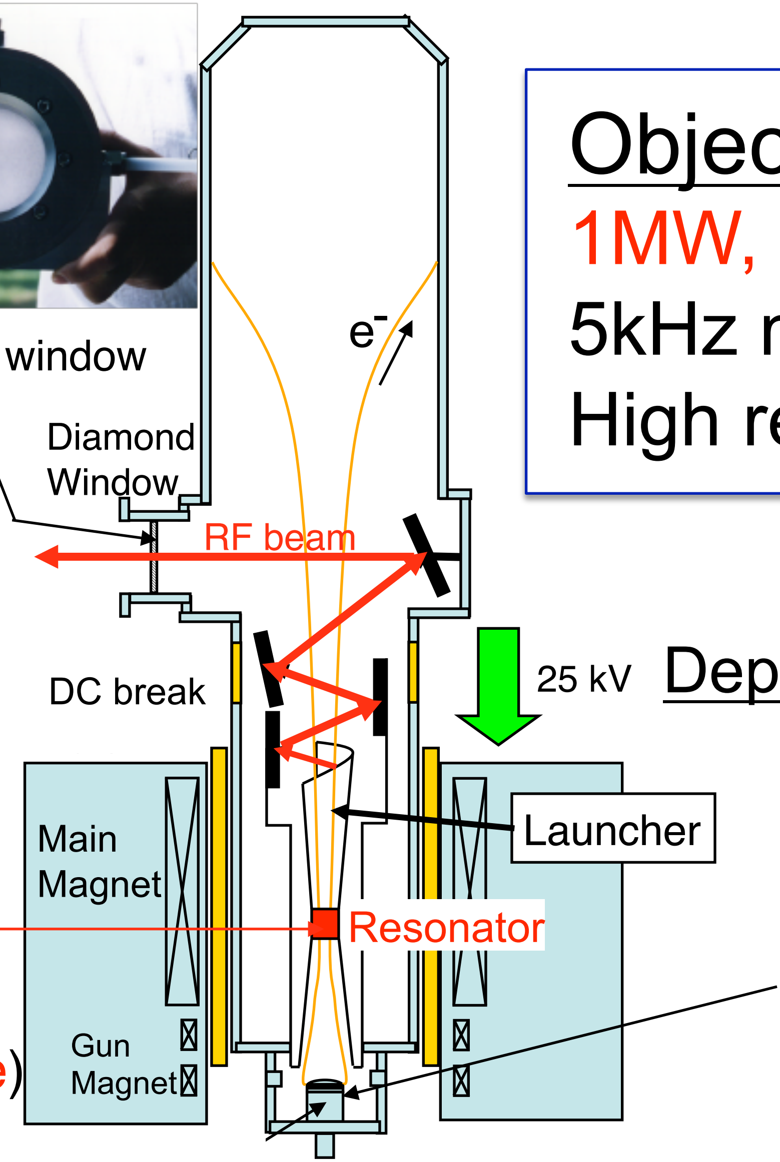


(c) Output window

~98%

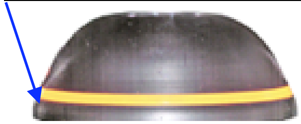


(b) Field pattern in the Resonator (TE31,8 mode)



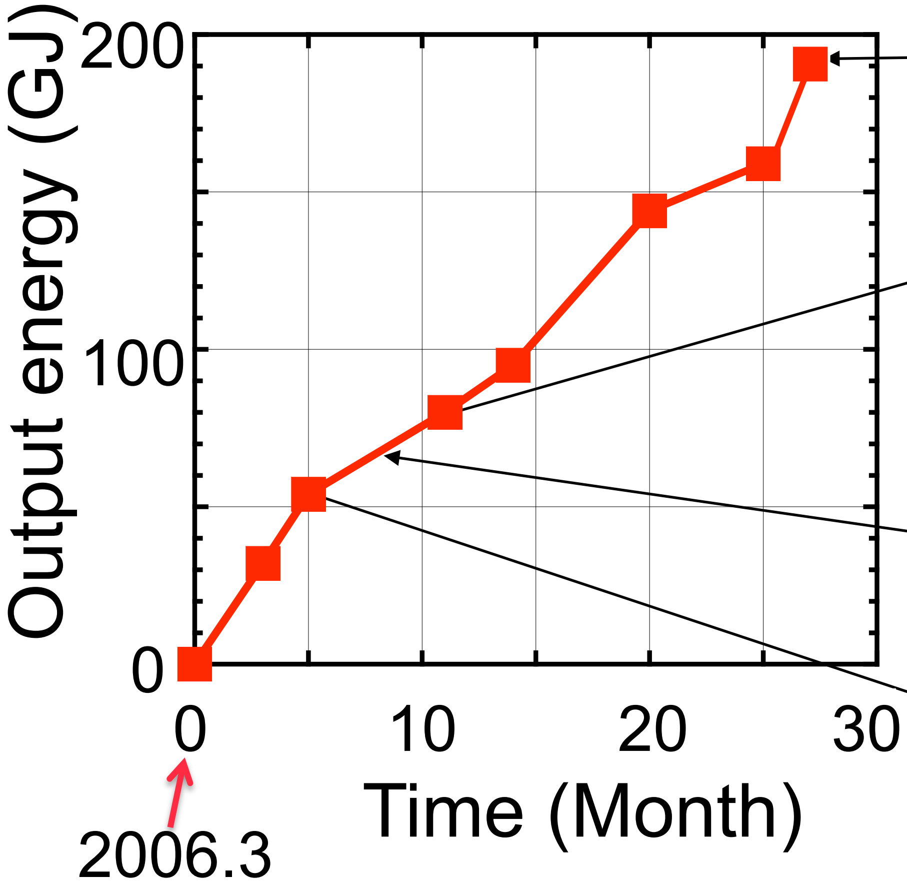
Depressed Collector

Electron Emitter



(a) Electron gun (Triode Type)

Status of ITER Gyrotron (I-J5M2)

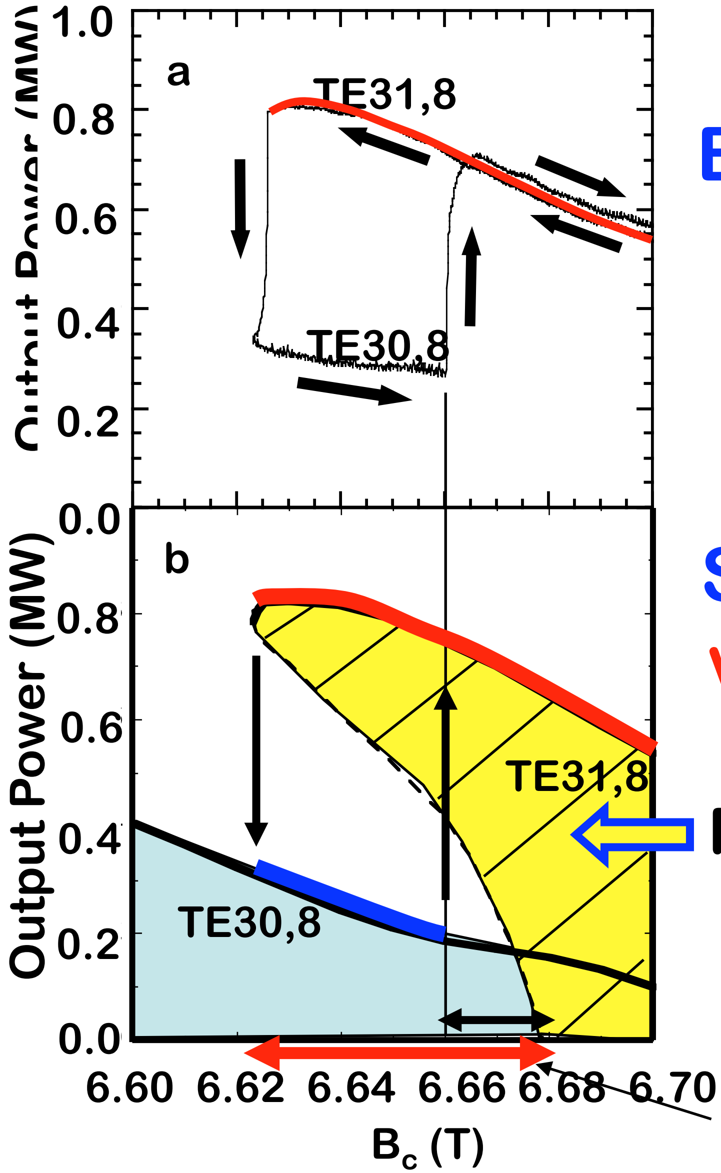


- 0.8MW/1hr/57%
- Demonstration of ITER criteria (1MW/800s/55%)
- Demonstration of 56% in hard excitation region
- 1 hr operation at 170GHz (0.6MW/1hr/45%)

Output energy of ~200GJ was attained with >2 years operation.

Stable Oscillation in Hard Excitation

Experiment vs. Simulation (Single mode analysis)



Experiment

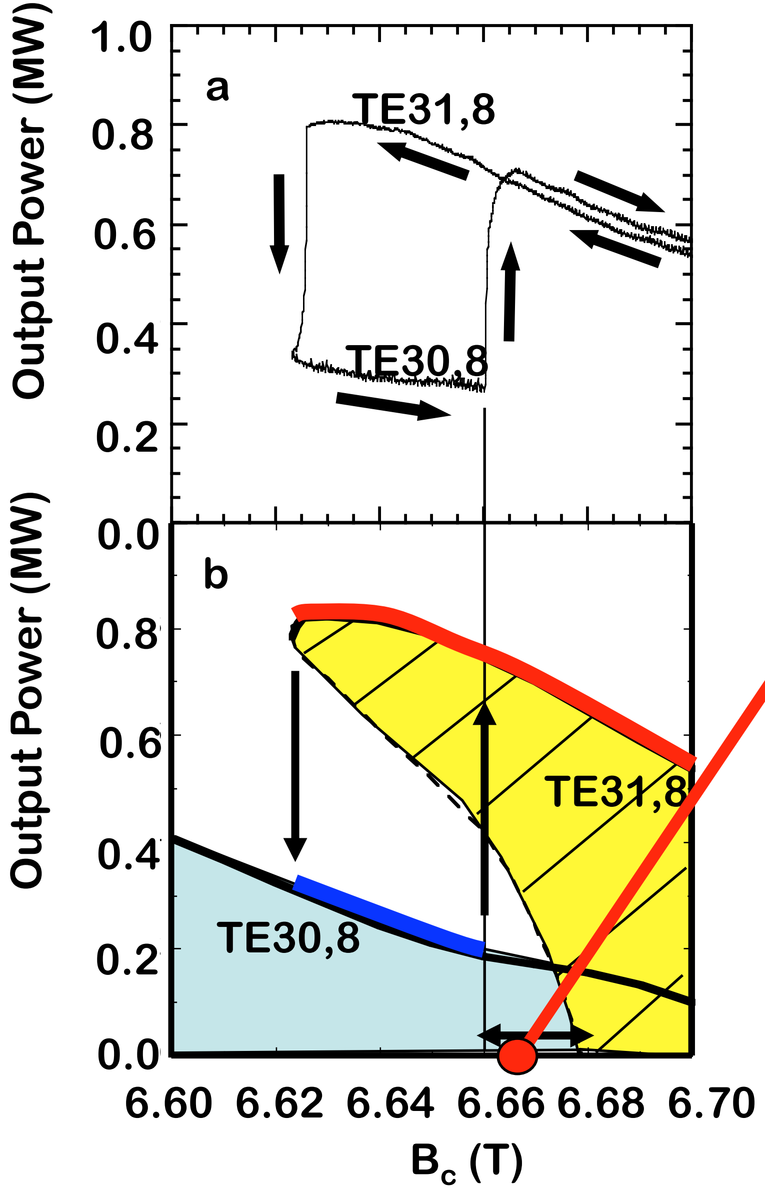
Simulation (Single mode)

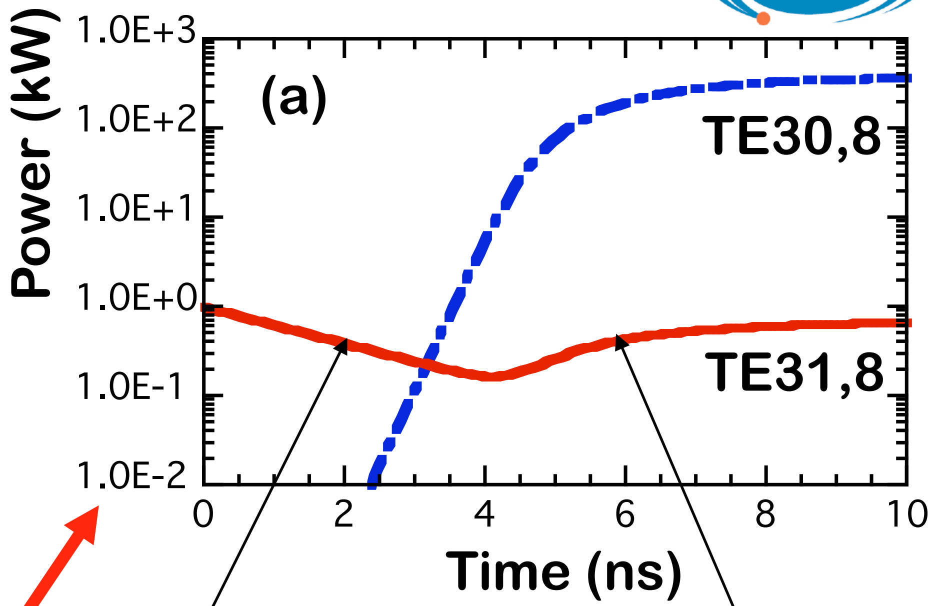
Very good agreement

Positive growth rate (TE31,8)

Hard excitation region

Nonlinear Excitation (Two-modes simulation)

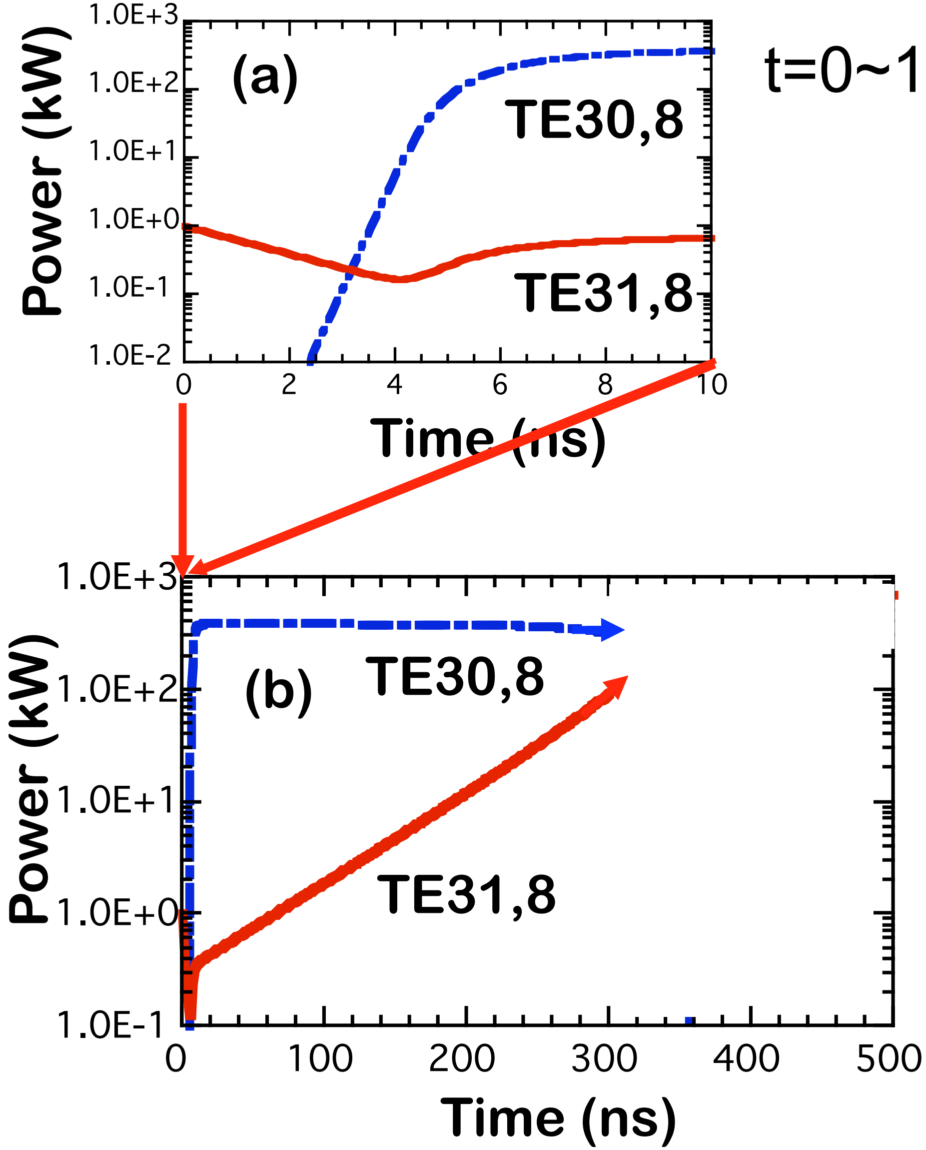




TE31,8 damps

When TE30,8 exist,
TE31,8 can grow.

Nonlinear Excitation

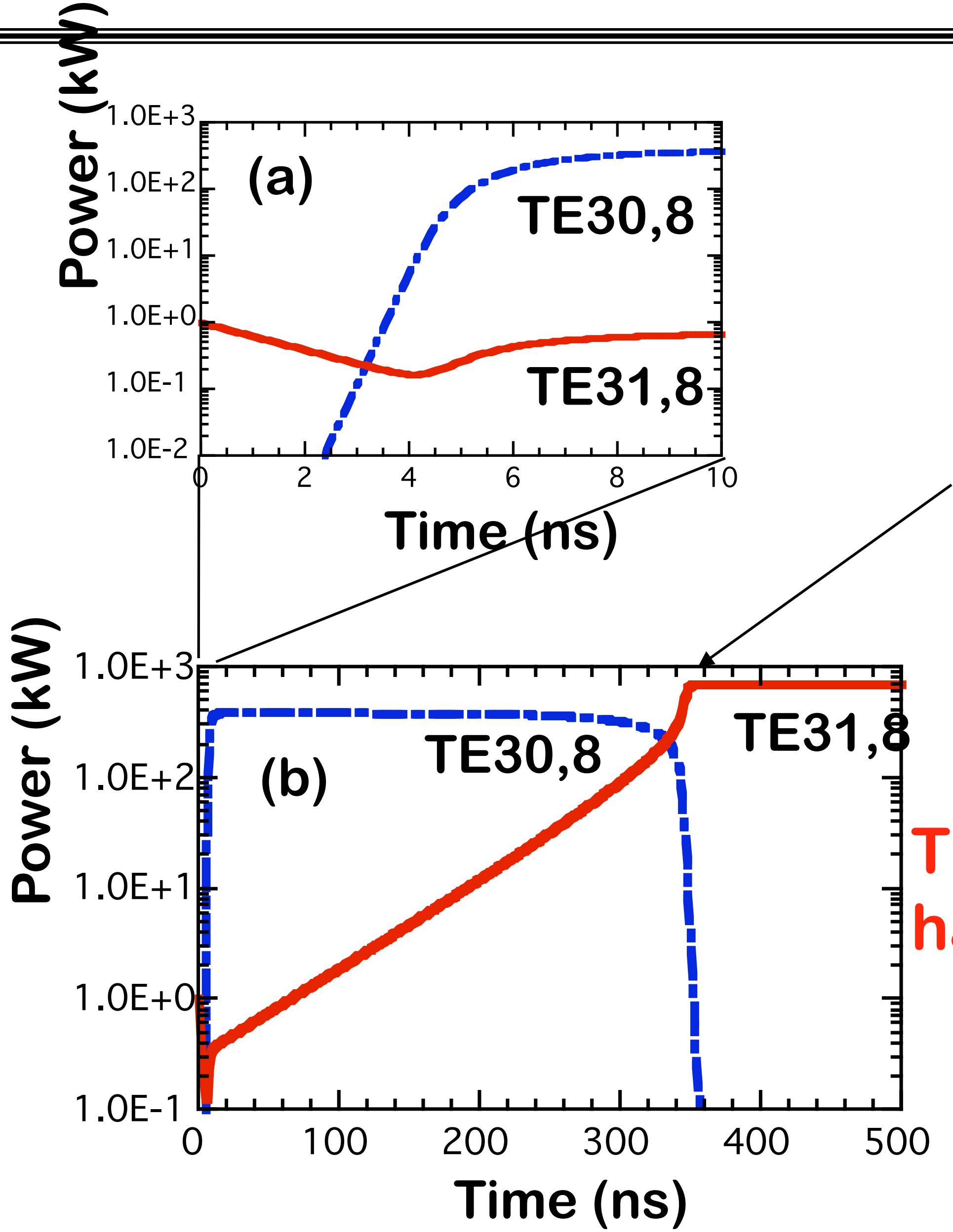


t=0~10ns

t=0~500ns

TE31,8 grows as a parasitic mode of TE30,8.

Nonlinear Excitation



TE31,8 suppress TE30,8.

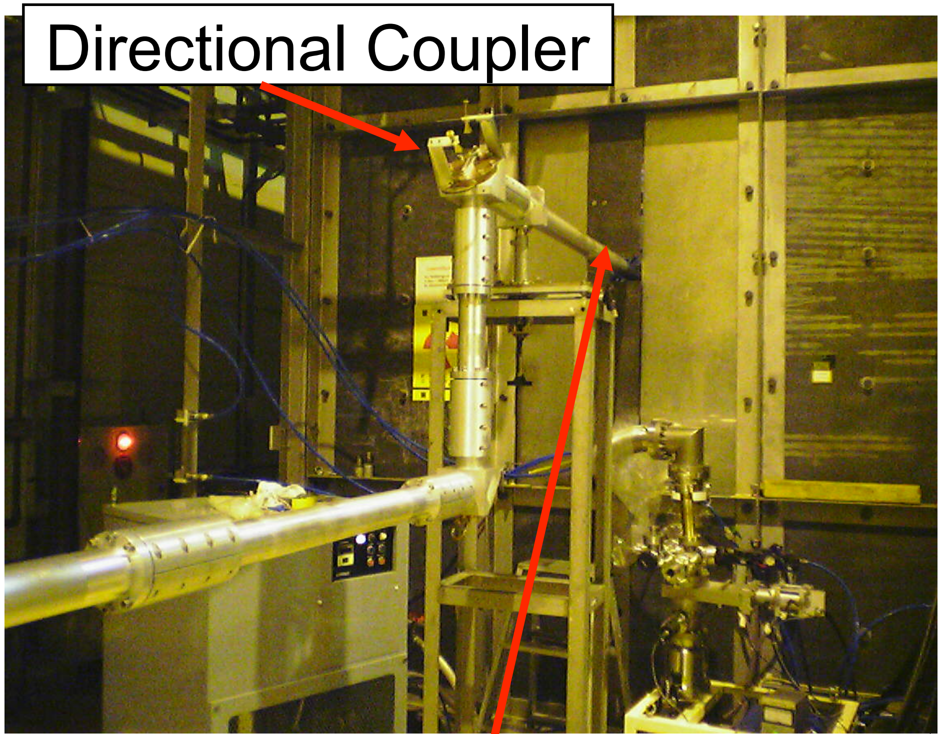
Single mode oscillation of TE31,8 is attained.

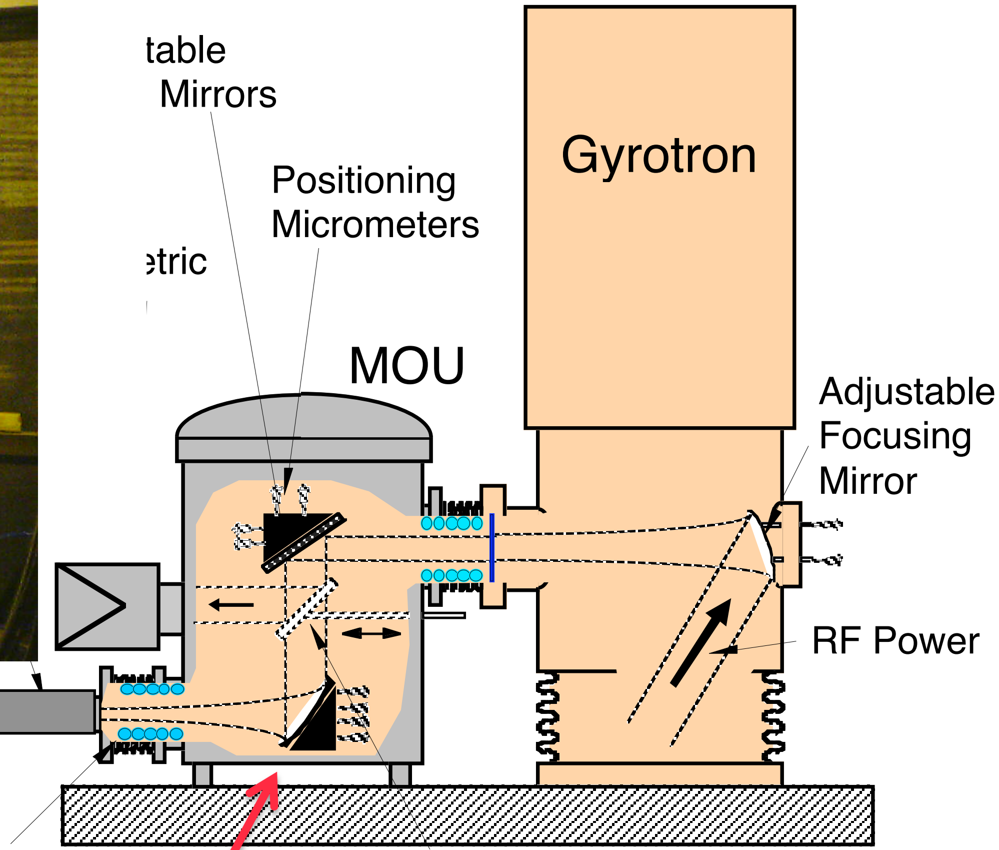
TE31,8 mode is robust in the hard excitation region.

High Efficiency, stable operation is available.

Transmission line for Gyrotron test

Directional Coupler



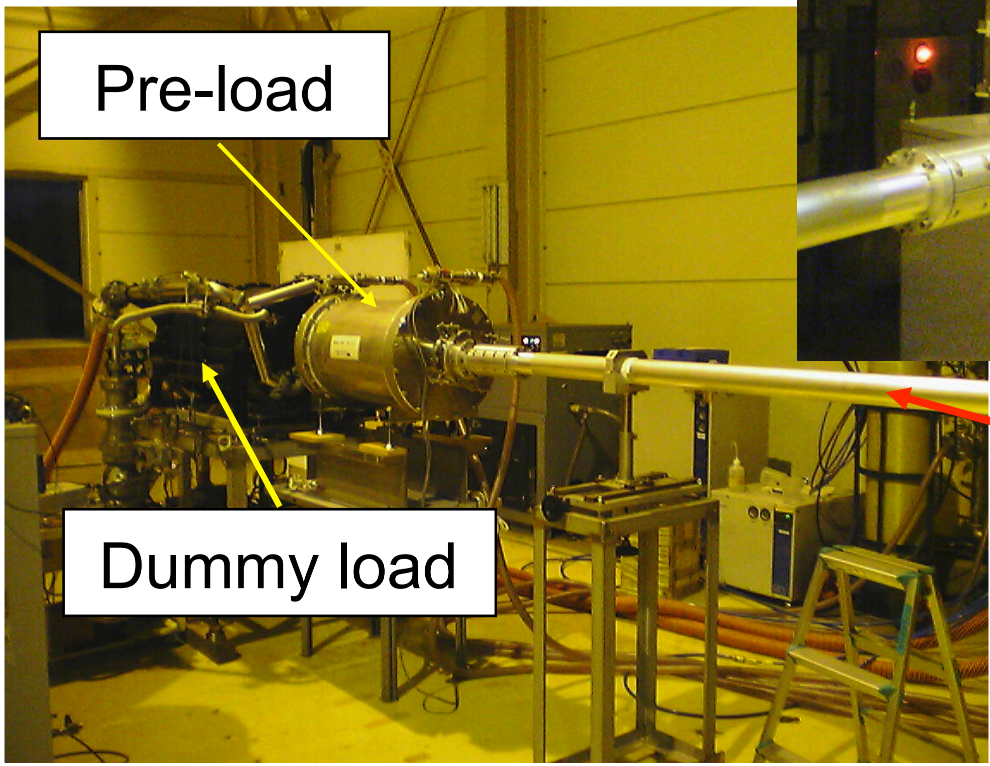


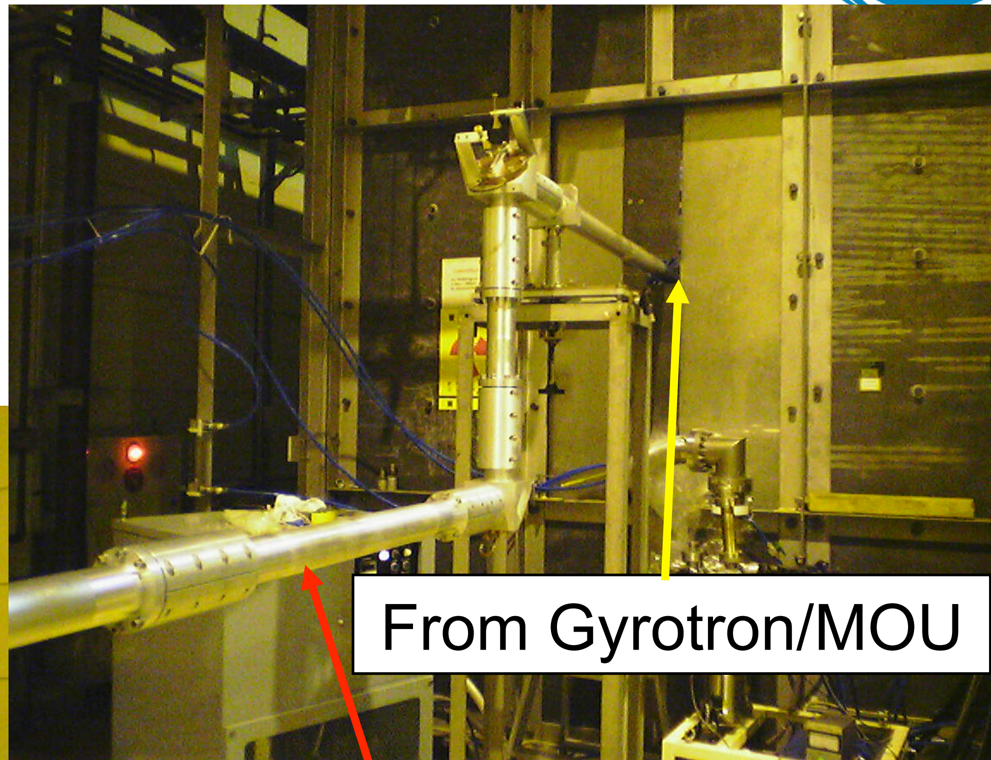
Corrugated W/G

63.5mm (evacuated)

Matching Optics Unit (MOU)

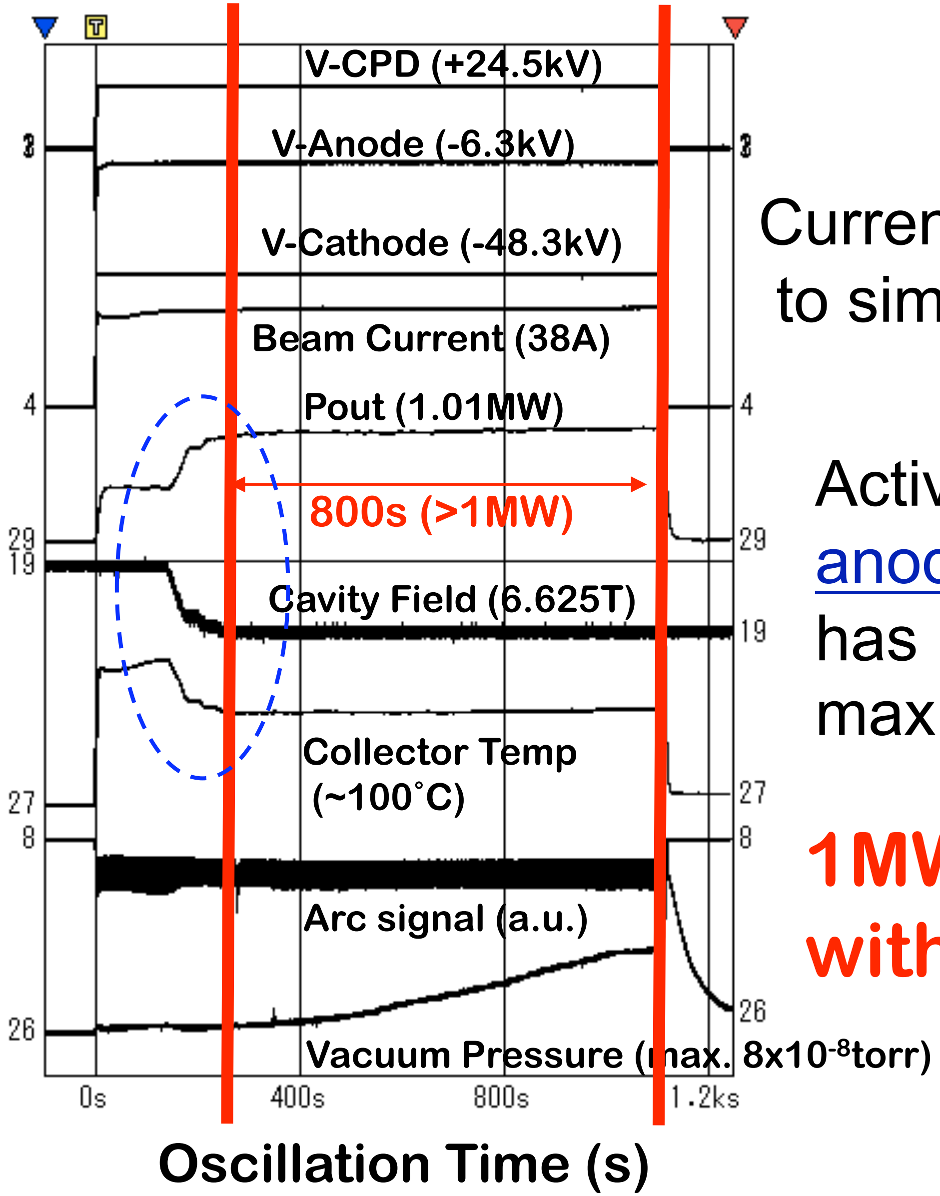
Transmission line and Dummy load





63.5mm evacuated W/G
(ITER size)

1MW/800s/55% operation



Current was kept I_c<40A,
to simulate the ITER power supply.

Active control of Cavity field, anode voltage, heater power has been performed to access maximum point at hard excitation.

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

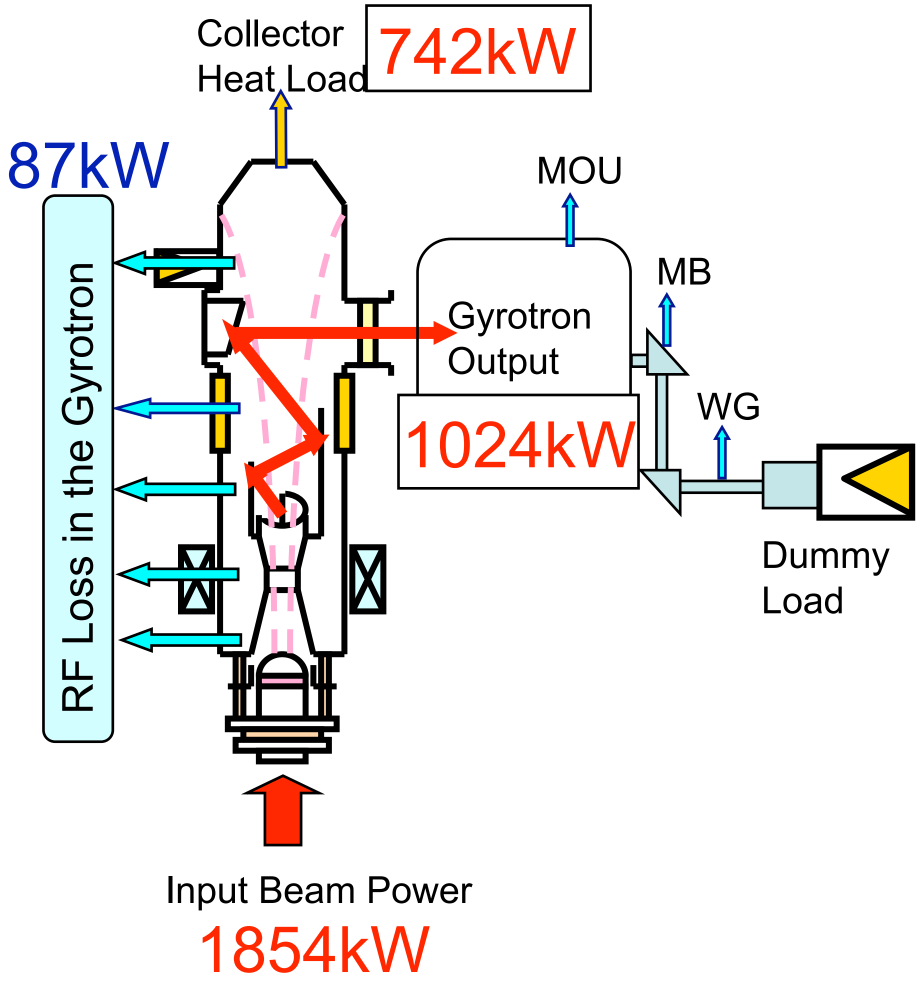
Power Balance at 1MW Operation

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
	Ceramic insulator for CPD	15.2
	Mirrors (1st~3rd)	5.9
	Launcher	15.3
	Beam tunnel	2.6
	Gyrotron body & 4th mirror	5
	Cavity	34.5

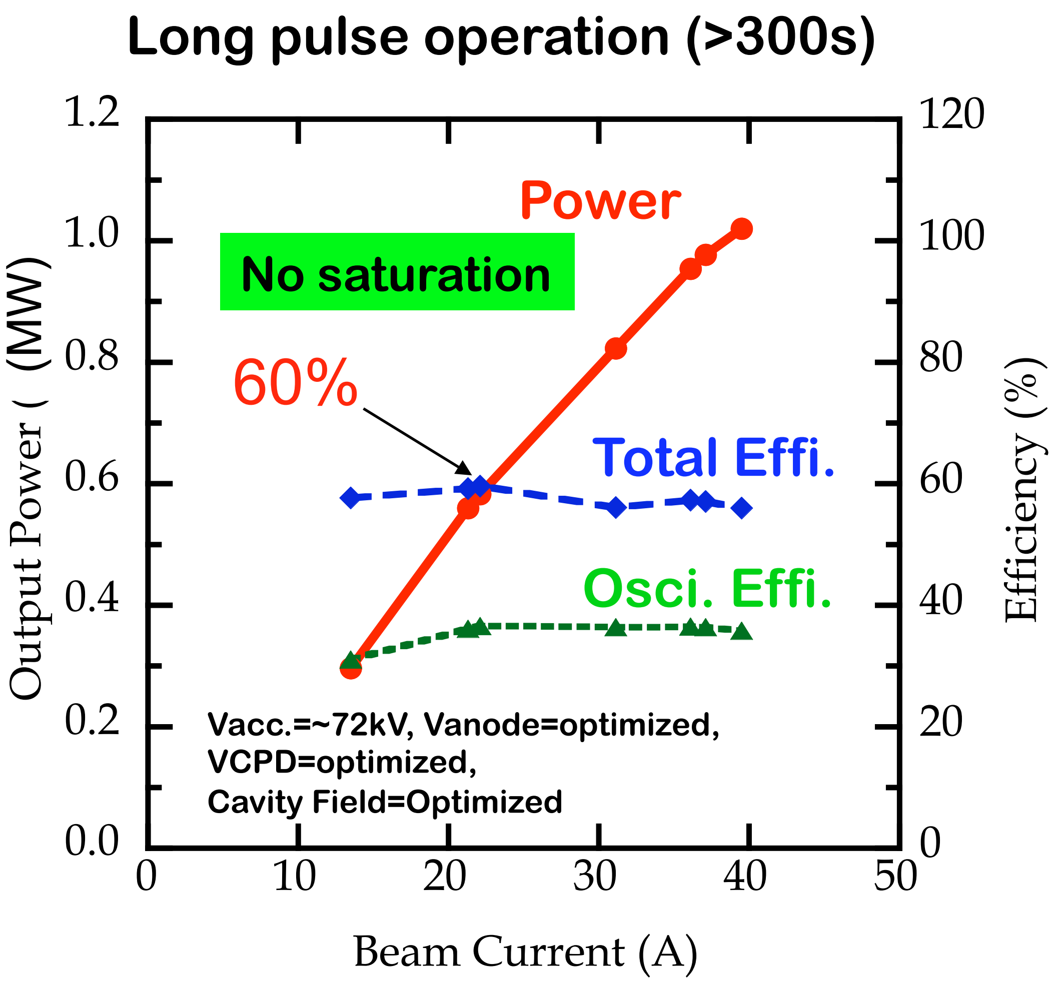
Gyrotron Output (B)		**1024.3**
	Dummy Load	968
	Miter Bends	2.7
	Waveguide	8
	MOU	45.6

(unit : kW)

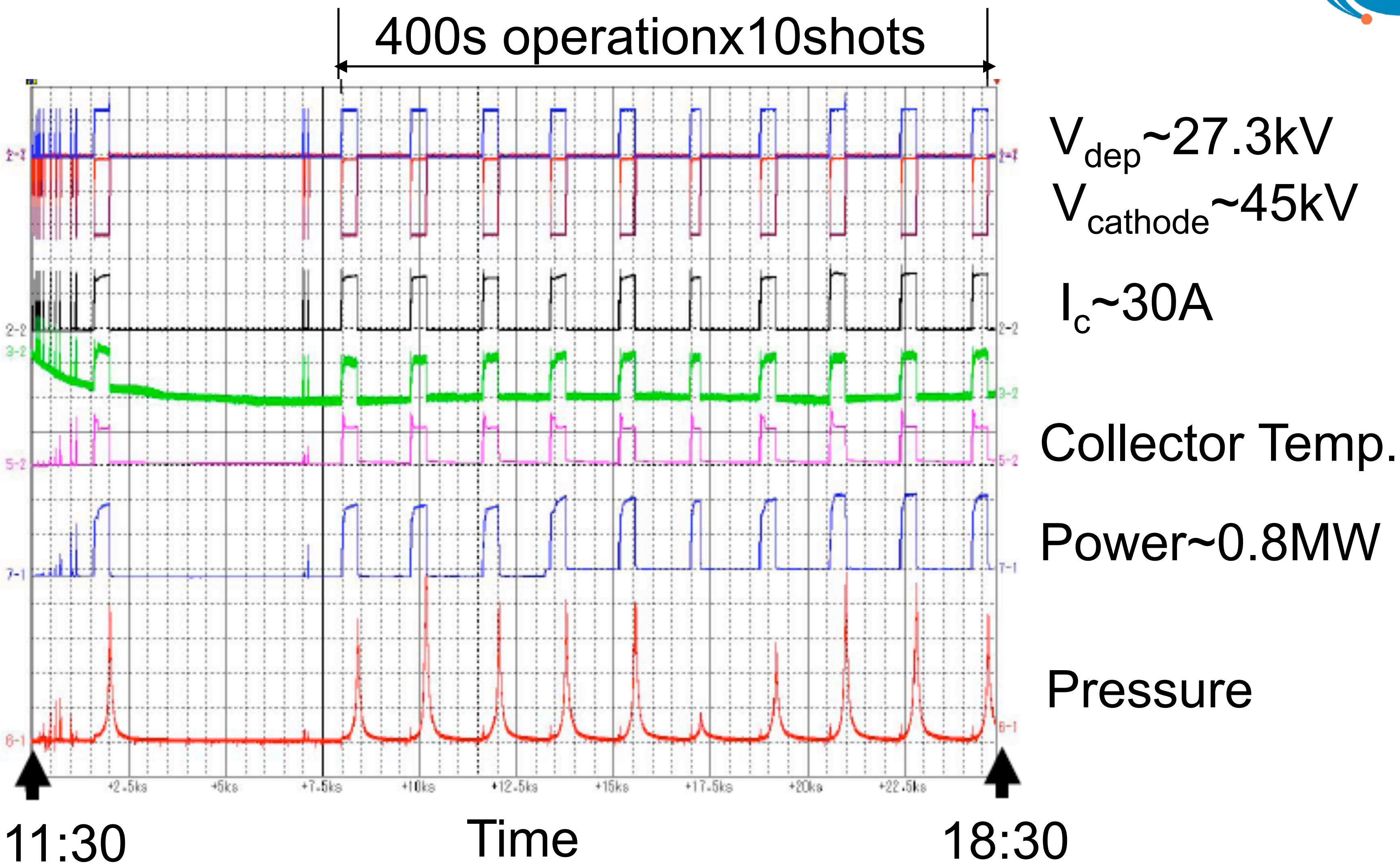


Output power, Efficiency v.s. Beam Current

Hard excitation region

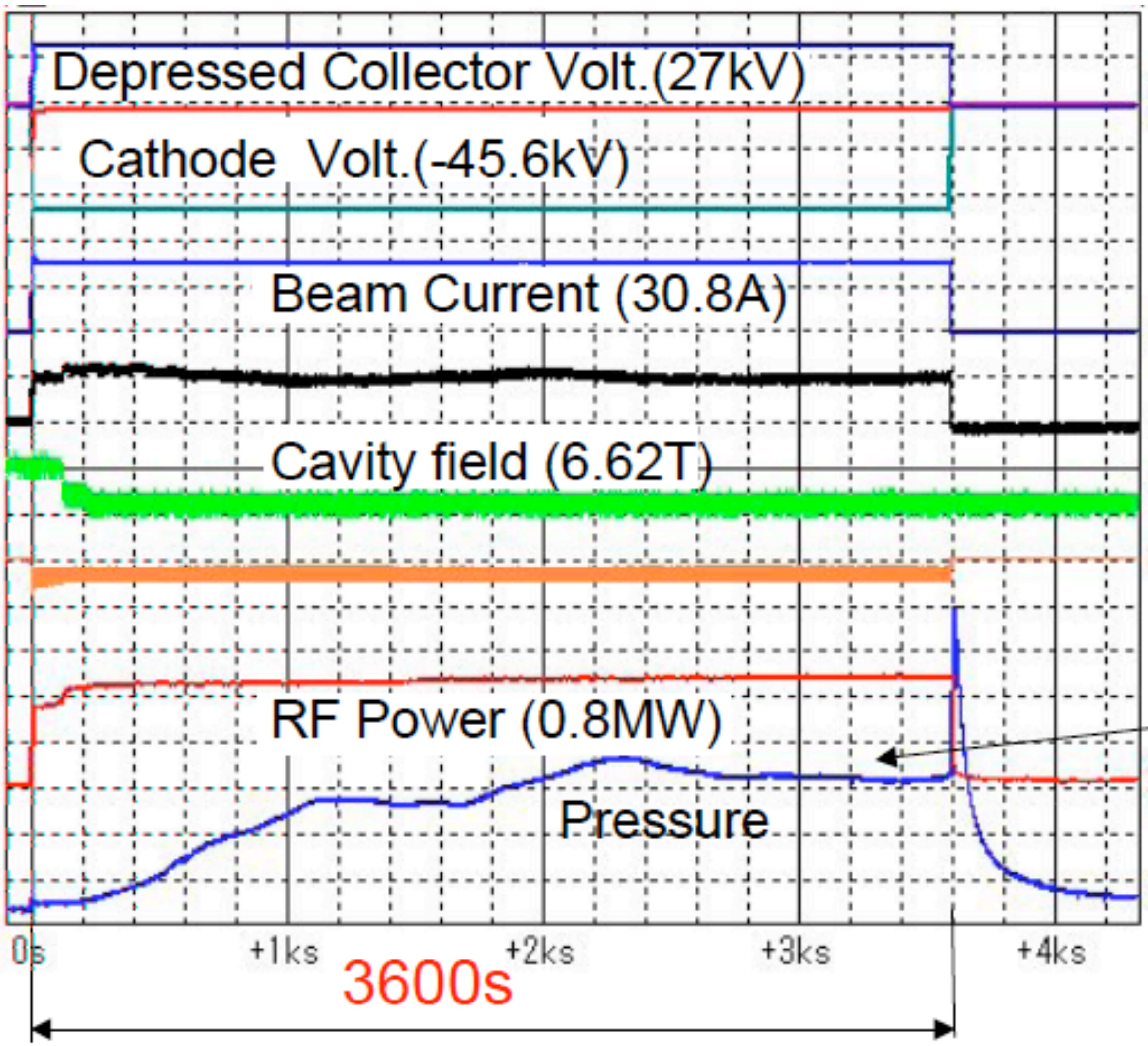


Repetitive Operation (0.8MW/400s/~56%, every 30min)



Stable operation. No conditioning between shots.

Demonstration of 1hr operation at 0.8MW



Power : 0.8 MW
Pulse : 1hr
Eff. : 57 %

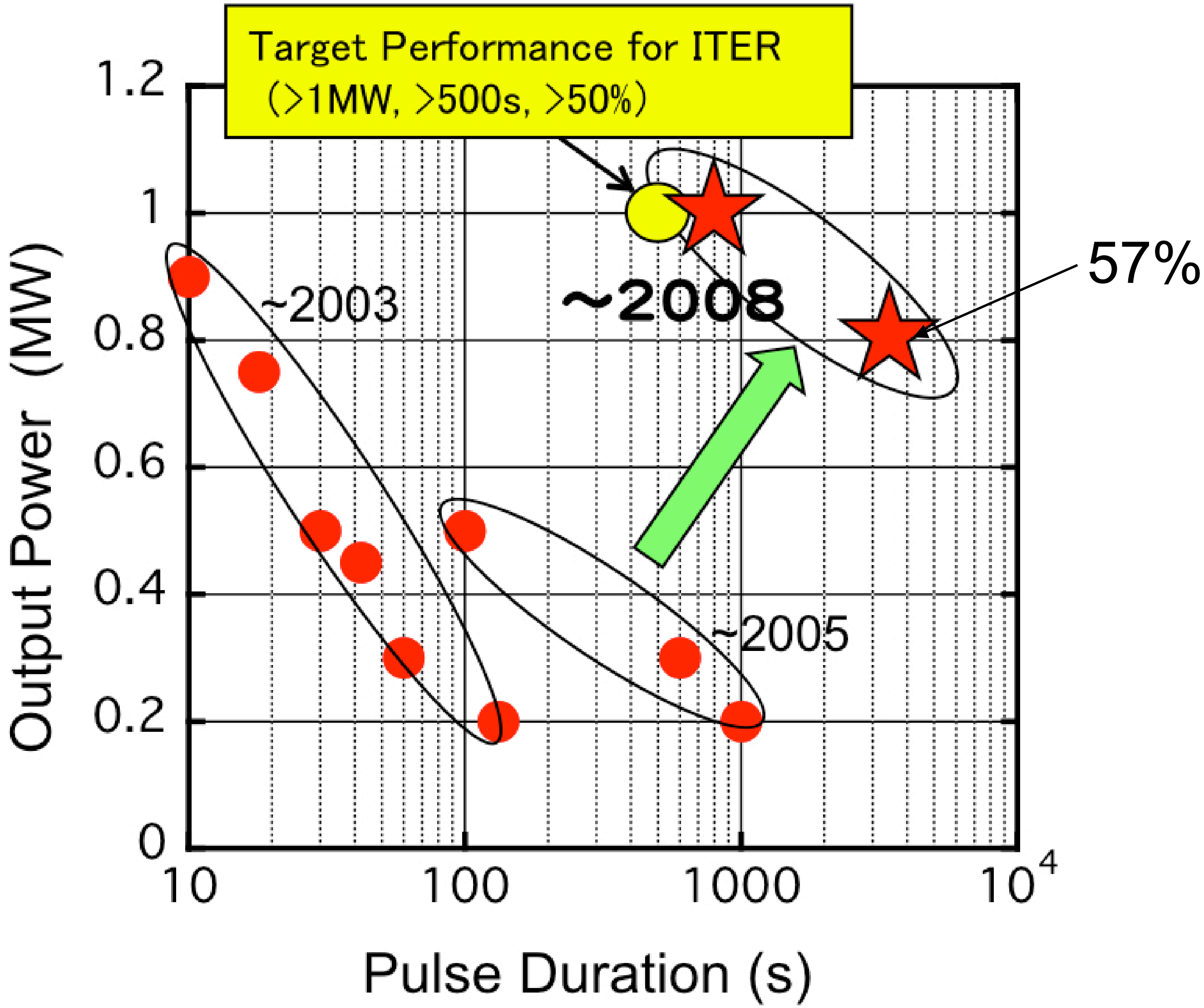
Cooling water for
Input : 42 deg.C

p~1.5x10^{-7}torr

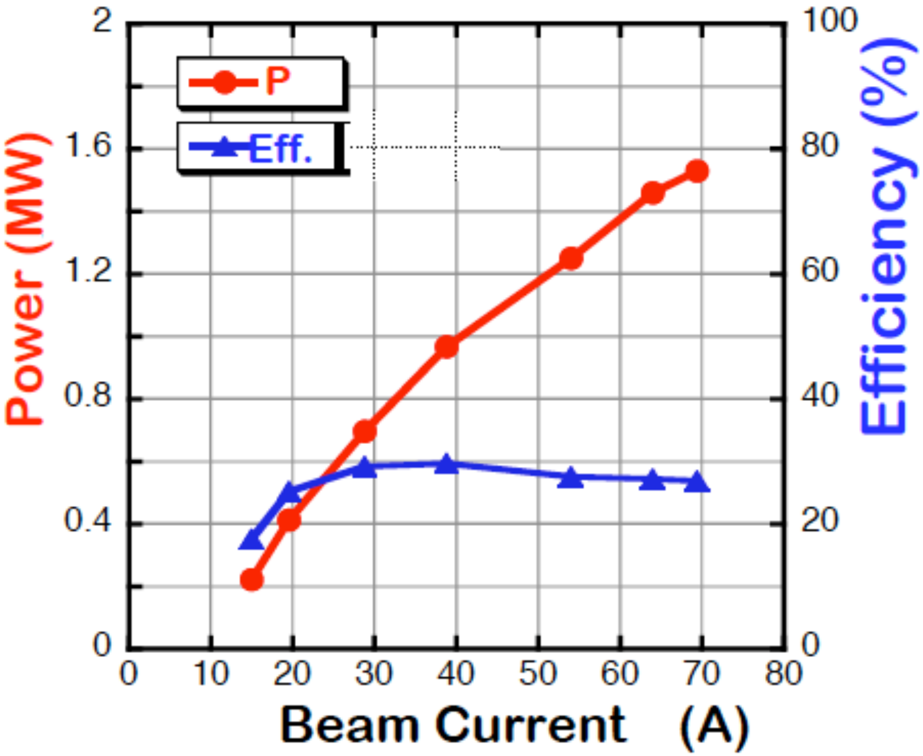
(June 11, '08)

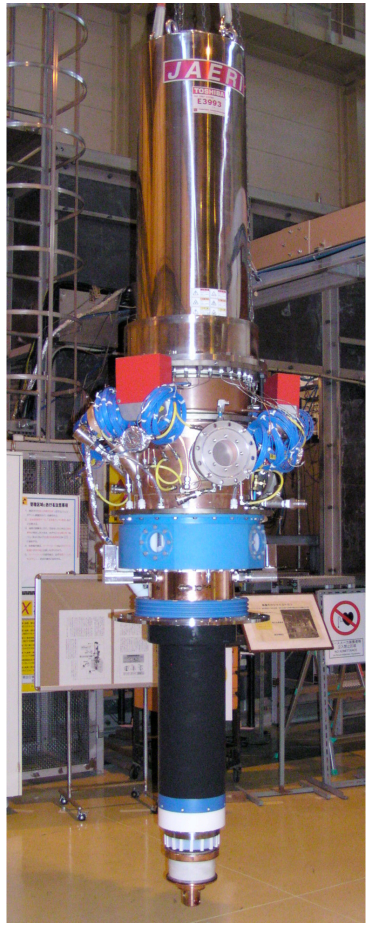
Stable 1hr operation at 0.8MW at 57%

Progress of gyrotron development in JAEA



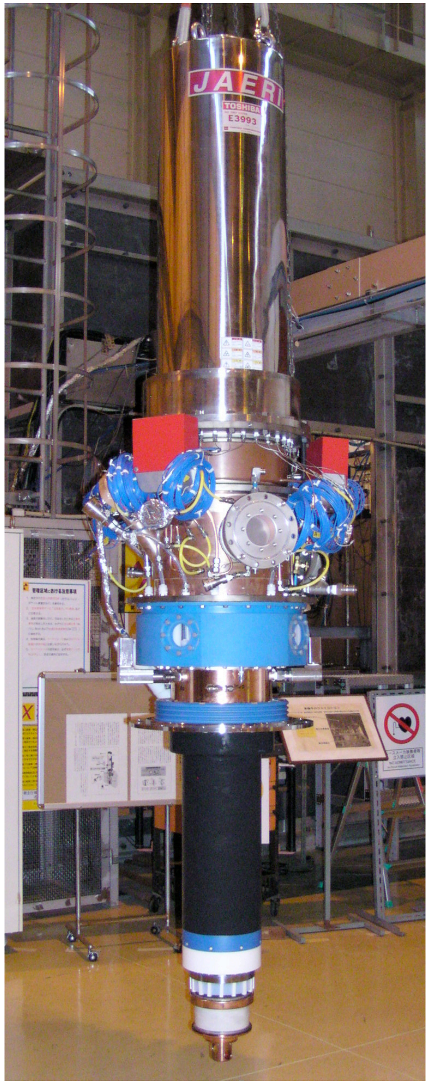
Results of $TE_{31,12}$ oscillation (170GHz)





1.56MW stable oscillation was achieved with cylindrical cavity. (w/o CPD)

Long Pulse Gyrotron ($TE_{31,12}$ oscillation)



Objective: Study of Oscillation stability
at 1.5 MW relevant-cylindrical mode
(does not mean a power increase for ITER)

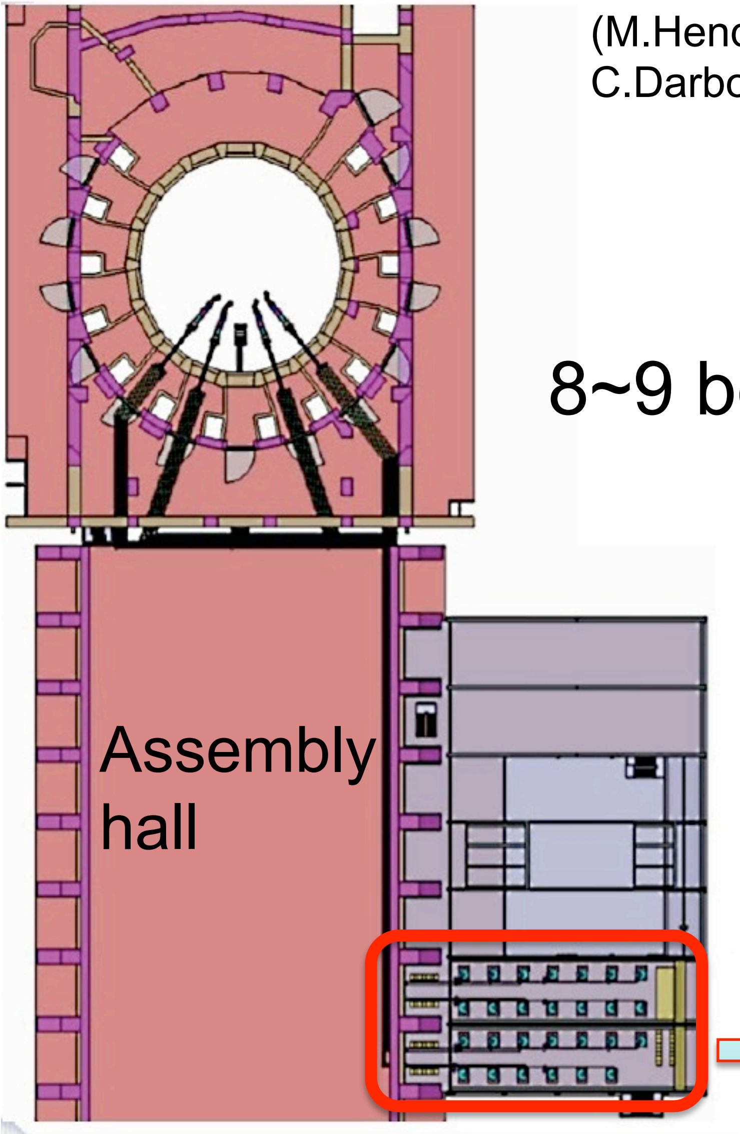
Freq. : 170 GHz
Osci. Mode : $TE_{31,12}$
(1.25kW/cm^2 @1MW osci.)
Output : Gaussian like beam

Collector, Electron Gun, Window, etc.
: Same with $TE_{31,8}$ gyrotron

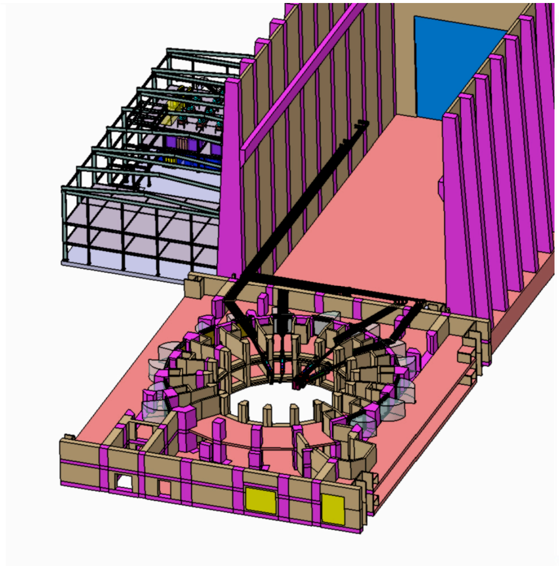
Experiment start from April 2009.

Layout of EC system of ITER

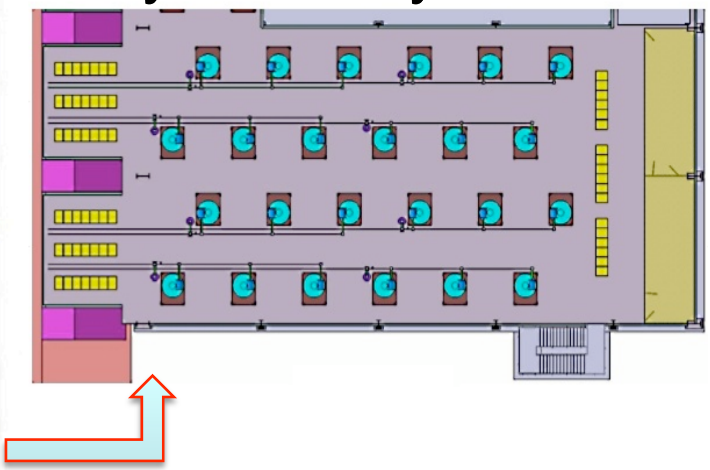
(M.Henderson, C.Darbos, ITER/IO)

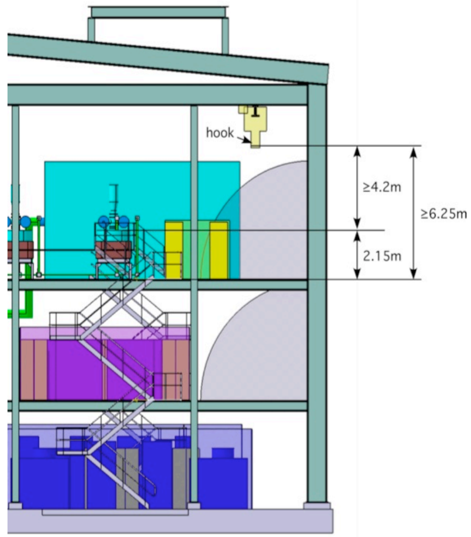


8~9 bends



Gyrotron layout

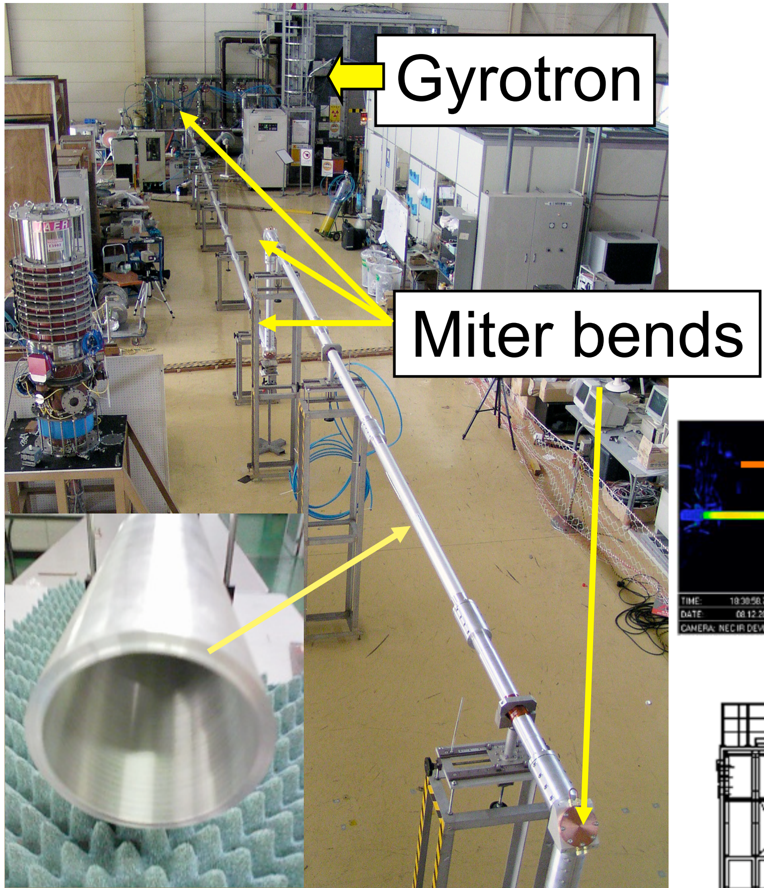




RF building

EC H&CD (Transmission Line, Launcher)

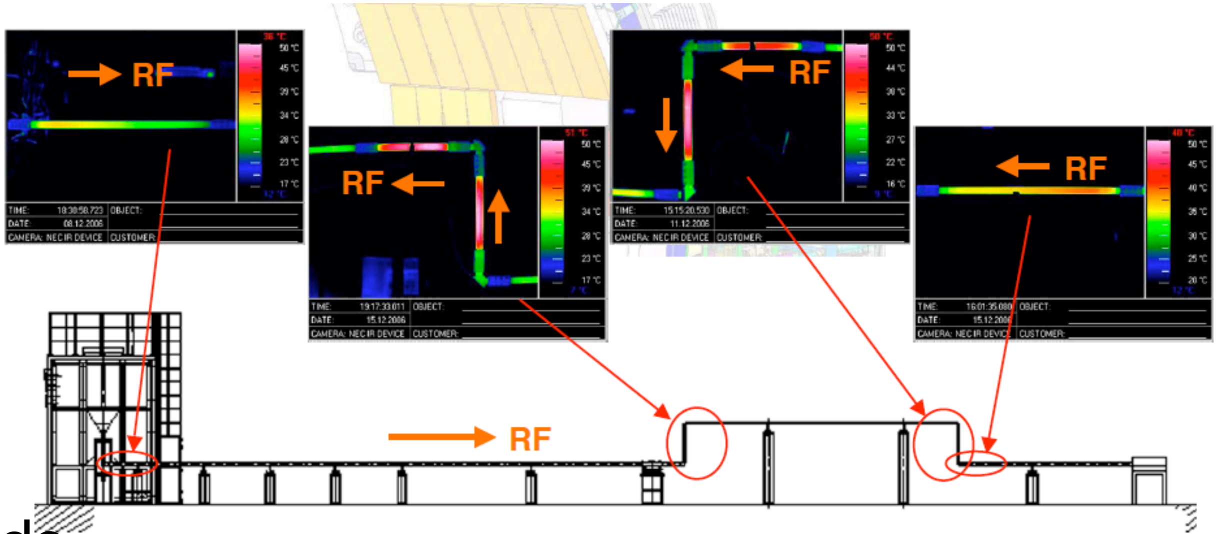
JADA Test stand



40m Waveguide +7 bends

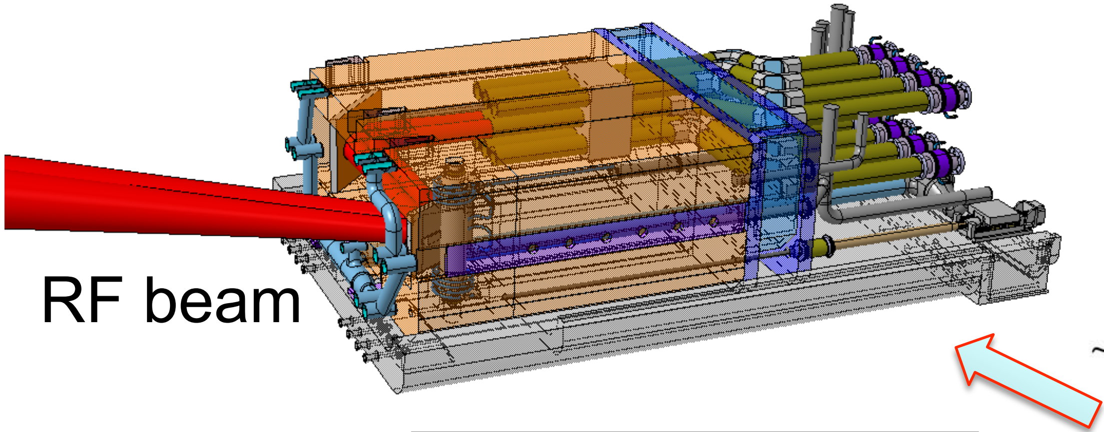
96 % transmission

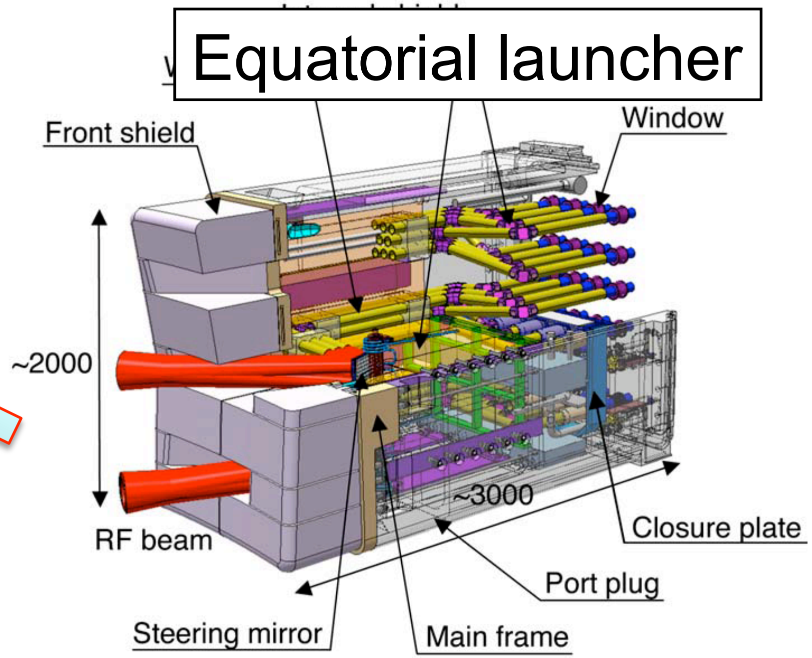
Gyrotron power is utilized
for the developments of
Transmission line,
EC components,
ITER Launcher.

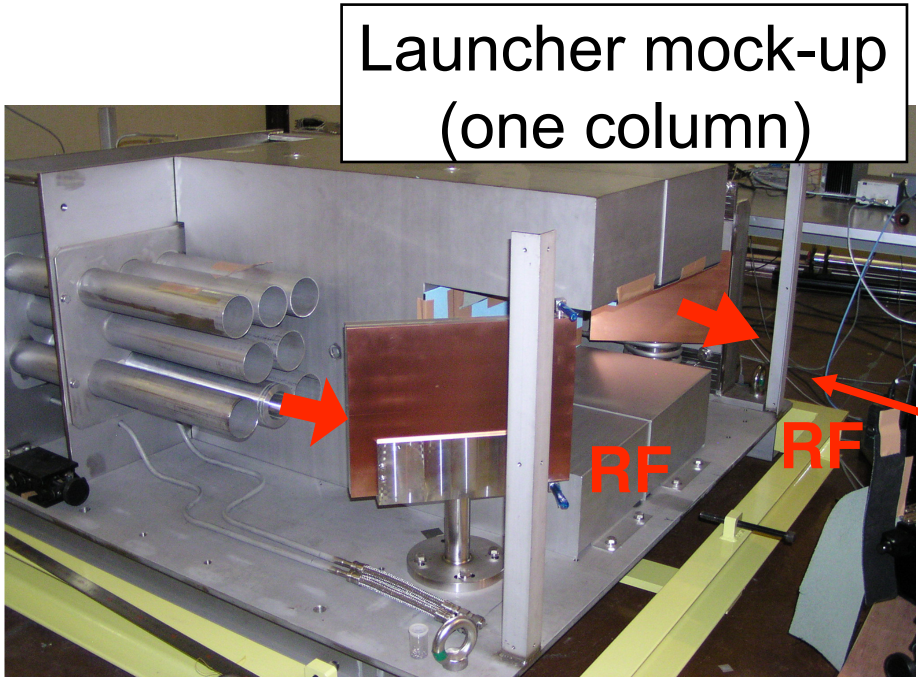


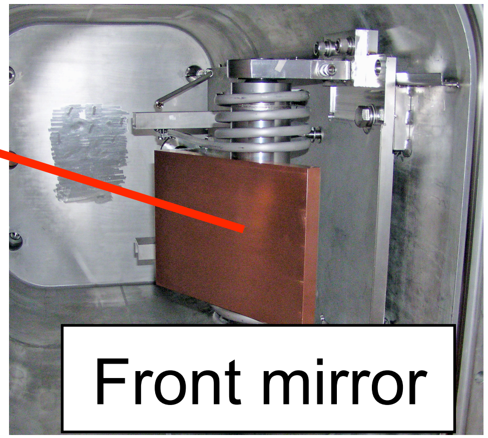
Power deposition around bends

Gyrotron power is used for Launcher development





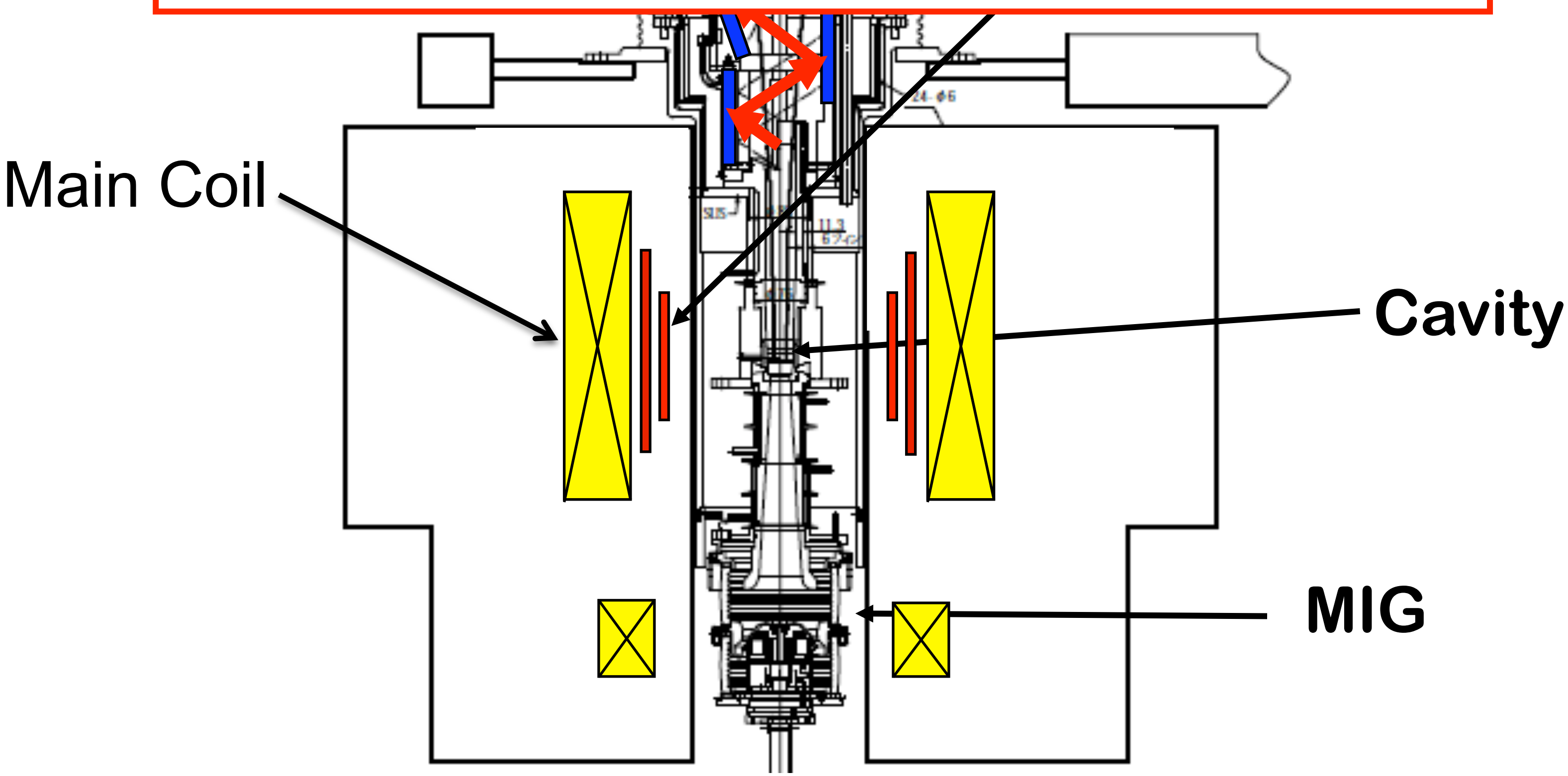




SCM for JAEA Test stand

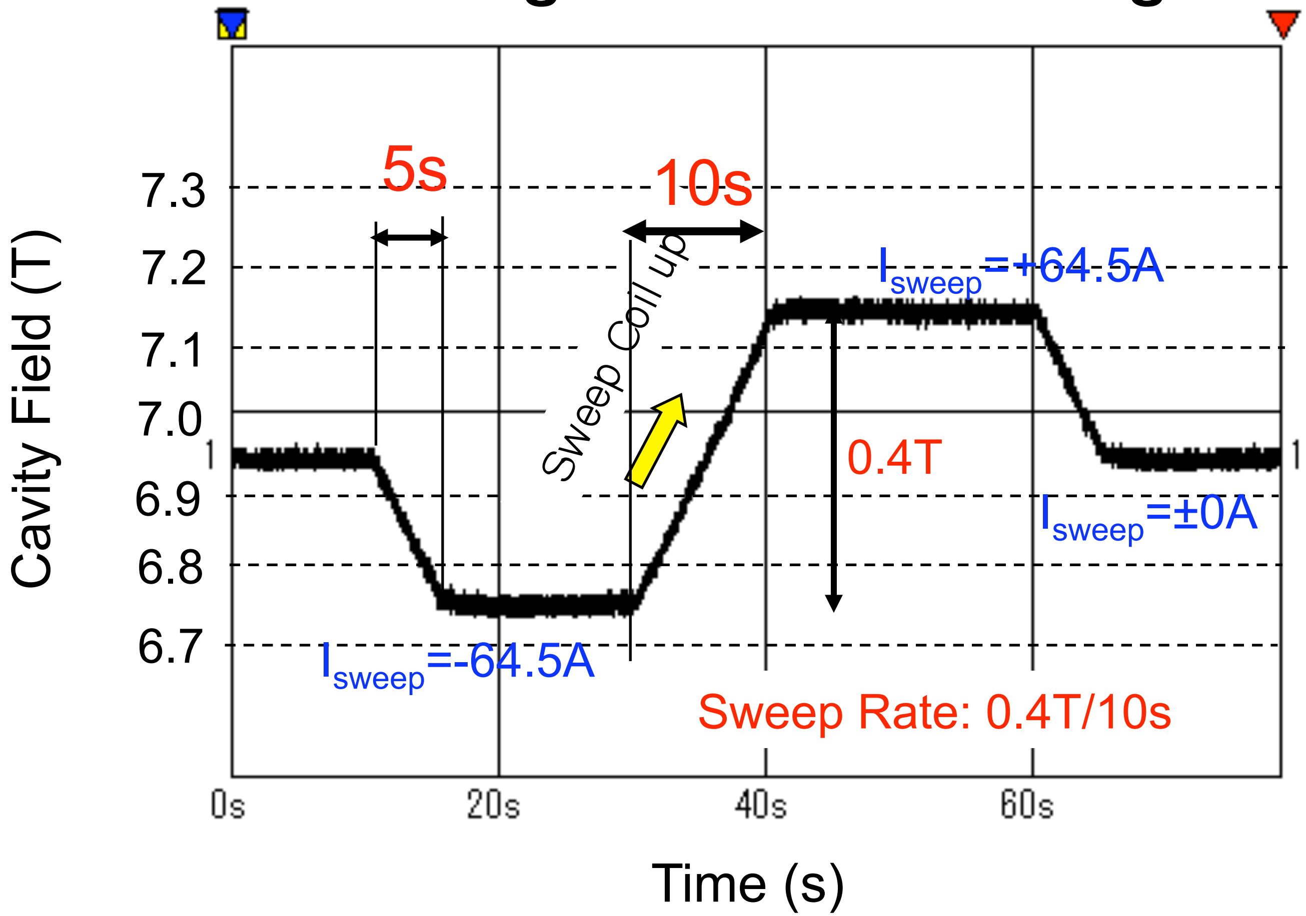
SC Magnet for fast frequency tuning

7T magnet with sweeping coil
Bore diameter: 240mm
Sweeping range: -0.2T~0.2T
Sweeping Speed: 0.2T/5sec (1GHz/1sec)
Liq. He free, conventional power supply



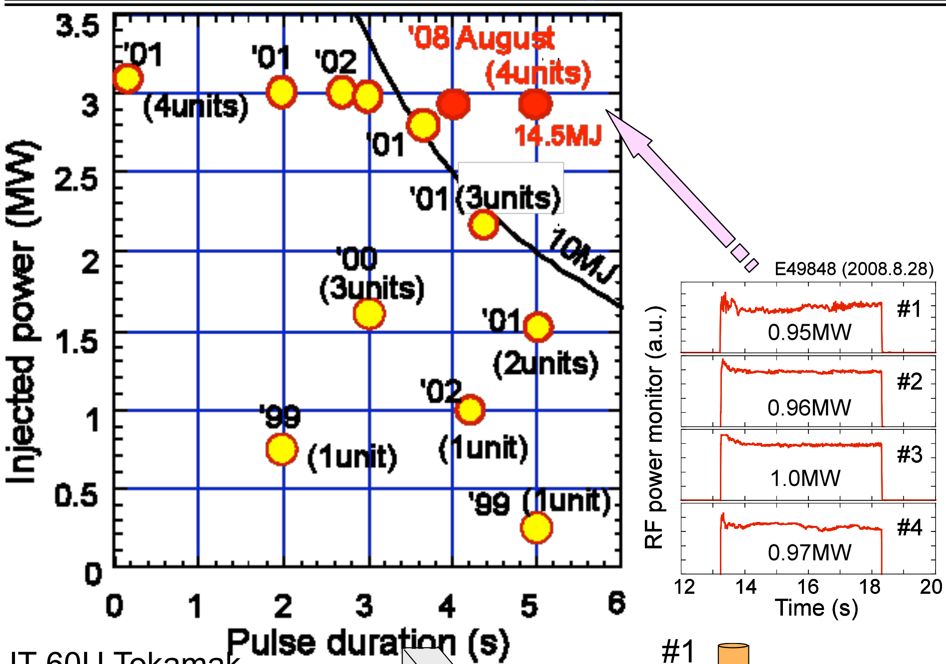
Experimental Data

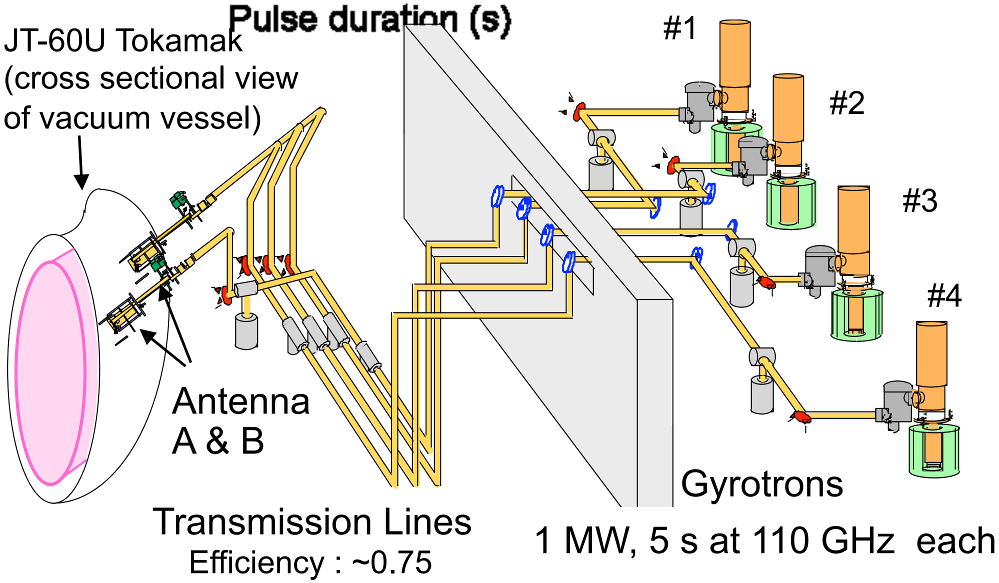
Fast magnetic field scanning



Quick frequency (oscillation mode) control is possible with a combination of beam voltage control

High power and long pulse on JT-60U (110GHz system)





Construction : 1998
Full operation : 2001

4 high power gyrotrons
4 transmission lines (HE11 mode)
2 antennas (launchers)

2.9 MW x 5.0 s plasma injection

1.5MW x 1.0s gyrotron operation

Conclusion

- 1.0MW/800s/55%
  Demonstrated ITER basic requirement
  (ITER:1.0MW/500s/50%)
- 0.8MW/1hour/57%
- Output Energy of ~200GJ (under working)
- High Order mode gyrotron will be tested from 2009.4.
- Development of Transmission line and launcher

EC technology will be inevitable for all kind of magnet confinement fusion devices including DEMO reactor.