Technology of Heating and Current Drive in ITER

Y.Shimomura
ITER Joint Central Team

Burning Plasma Science Workshop
Burning Plasma Science Experiment Concepts and Technologies
May 1-3, 2001
General Atomics, San Diego, USA

Heating and Current Drive System

EC 170 GHz, 20 MW (+ 20 MW)

Horizontal port: 20 MW / port

Heating and Current drive

Toroidally steerable mirror

Upper port: 7 MW/port x 3

Localized current drive to stabilize NTM

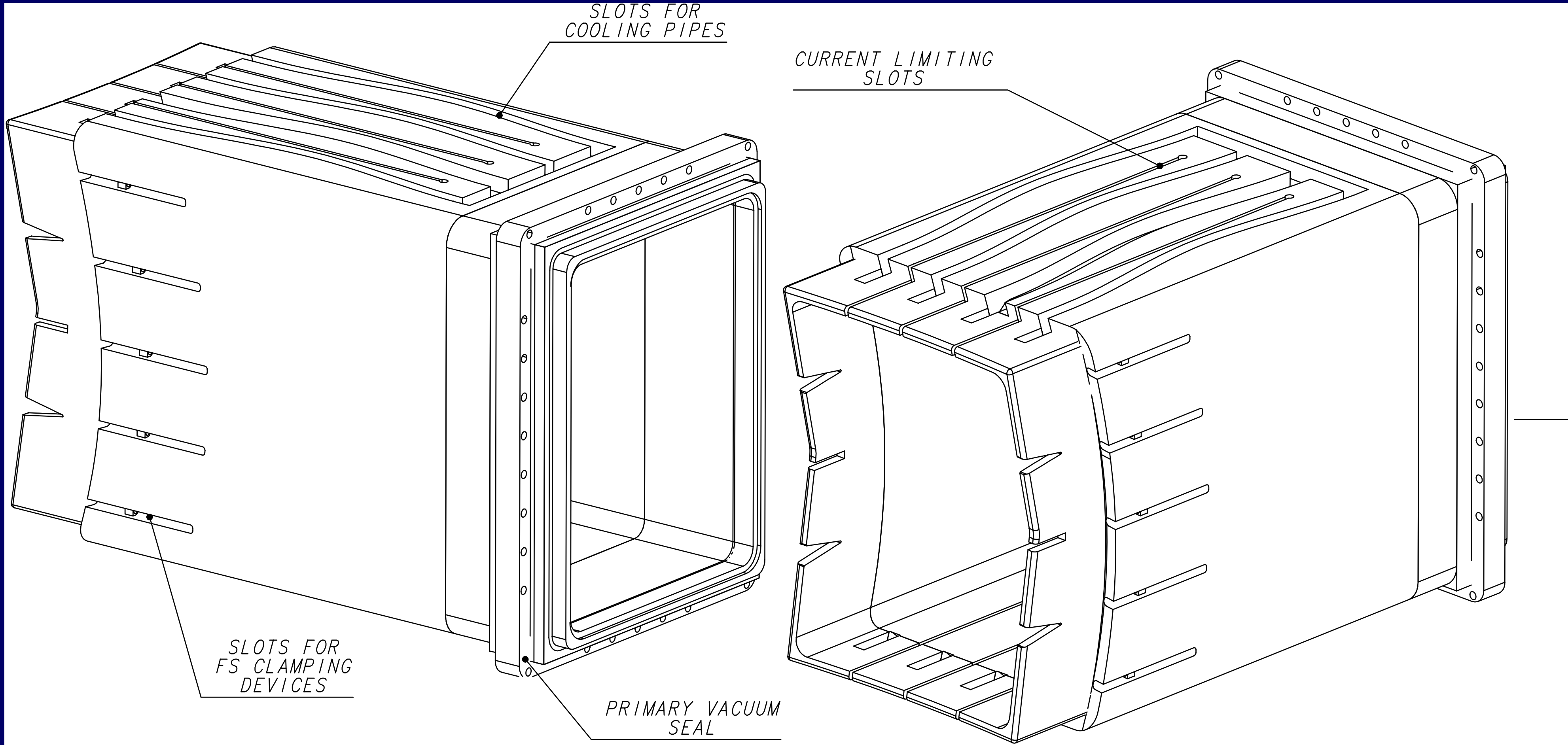
Poloidally steerable mirror

ICRF 40 – 56 MHz, 20 MW (+20 MW)

LH 5GHz, 0 MW (+40 MW)

NB 1 MeV 33 MW / 2 ports (+17 MW)

R_{tan} = 5.3 m, Zaxis = (-42) – (+15) cm (Plasma axis –32 cm)



**Front and Back of RF Assembly Common Support Structure,
Including Port Flange and Closure Plate (1.8 x 2.2 m)**

Table 2.5.4.1-1 Ion Cyclotron resonances

Resonance	(MHz)	Comments
$2\Omega_T=\Omega_{3He}$	53	Second harmonic + minority heating.
Ω_D	40	Minority heating. Strong competition of Be and α-particles
FWCD	56	On axis current drive
Ω_{3He}	45	Minority ion current drive at sawtooth inversion radius (outboard)

Table 2.5.4.2-1 Summary of Array Parameters (at R' = 4 Ω/m and f = 55 MHz)

Parameter	*Value*	*Parameter*	*Value*
Strap length (m)	0.3	MTL Voltage (kV)	12.25
Characteristic impedance (Ω)	~35.0	Max voltage in tuner (kV)	32.1& 40.0
Input power (MW)	2.5	Max E-field in strap (V/mm)	1.3
Input voltage (kV)	5.5	Power transfer efficiency (%)	~95
Max. strap voltage (kV)	27	Max. strap current (kA)	1.30

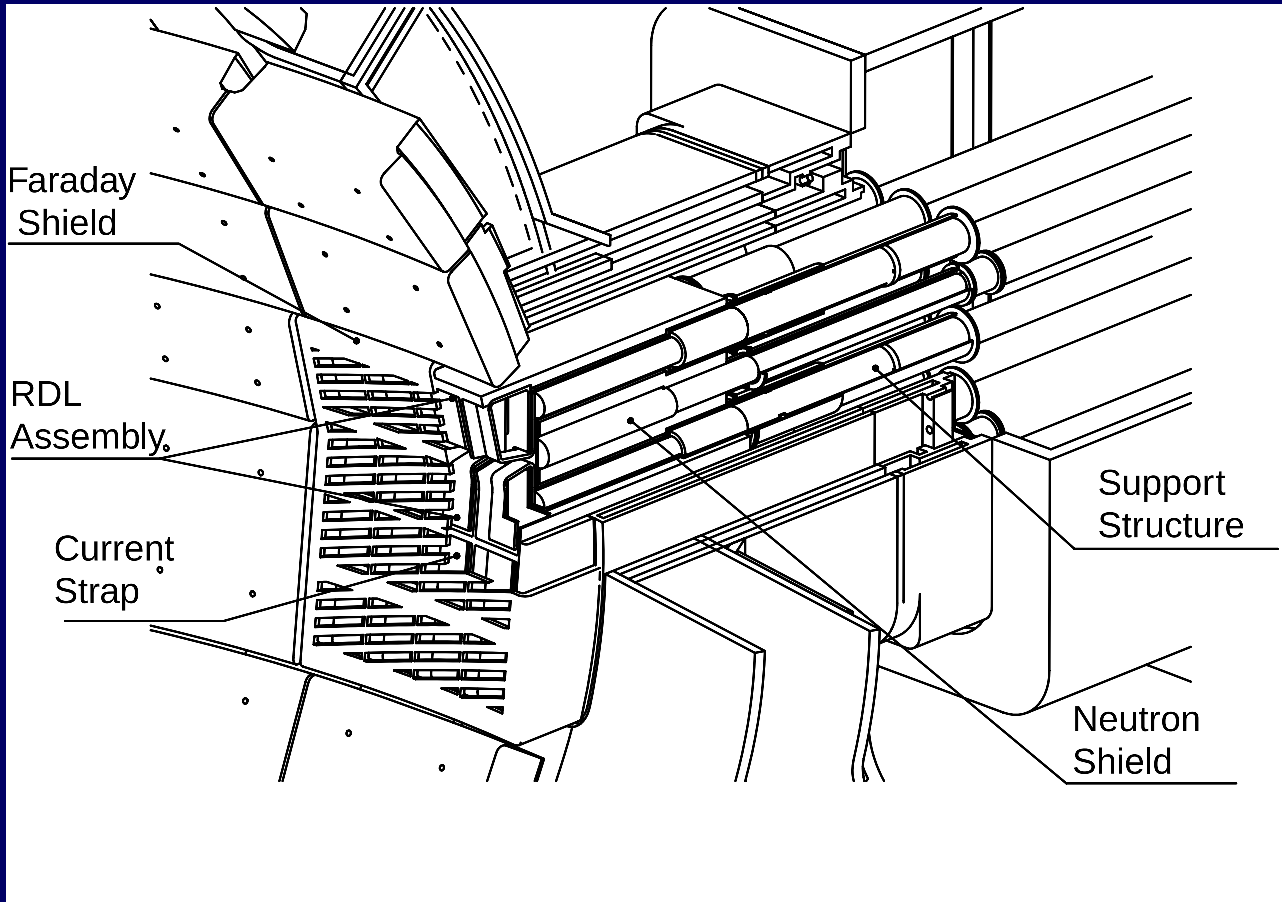
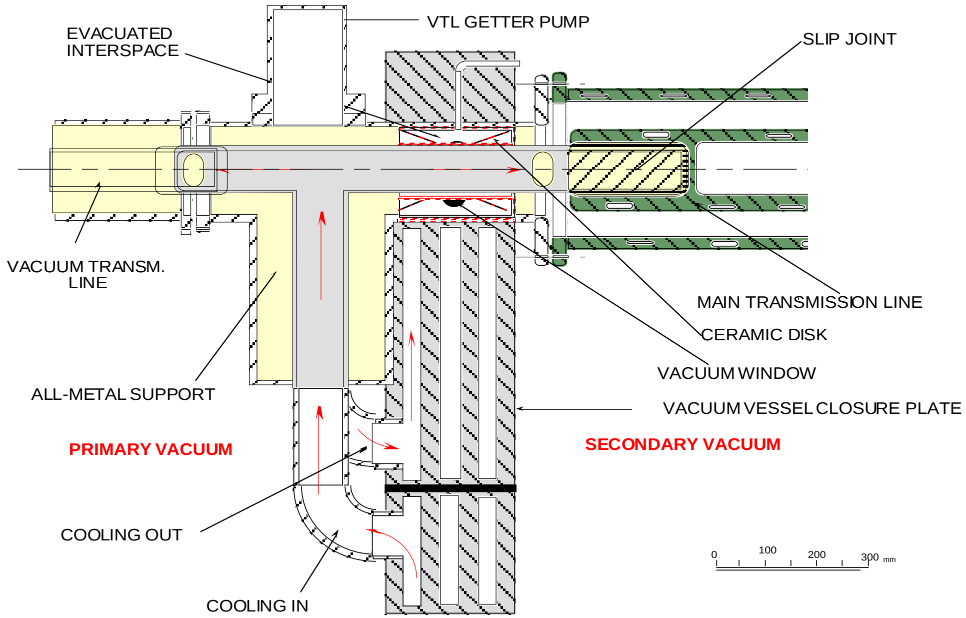


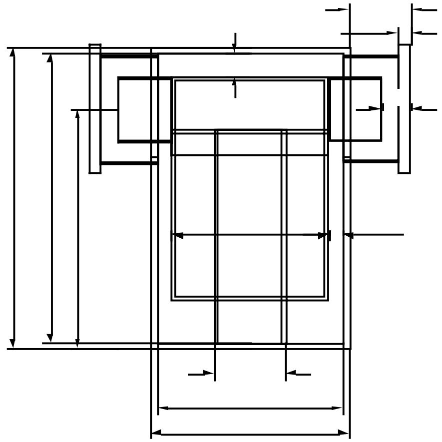
Figure 2.5.4-2 View of the IC Array Seen From the Plasma

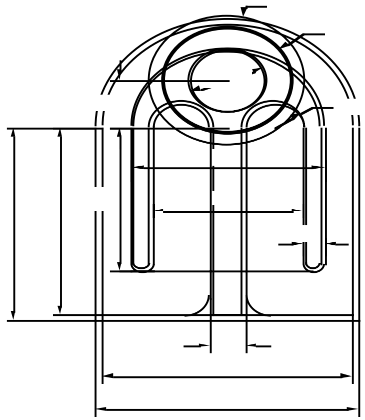
ICRF

All metal Vacuum Transmission Line Support

- Avoid dielectric material
- Cool through the inductive shunt







Prototype of Vacuum Transmission Line with All Metal Supports

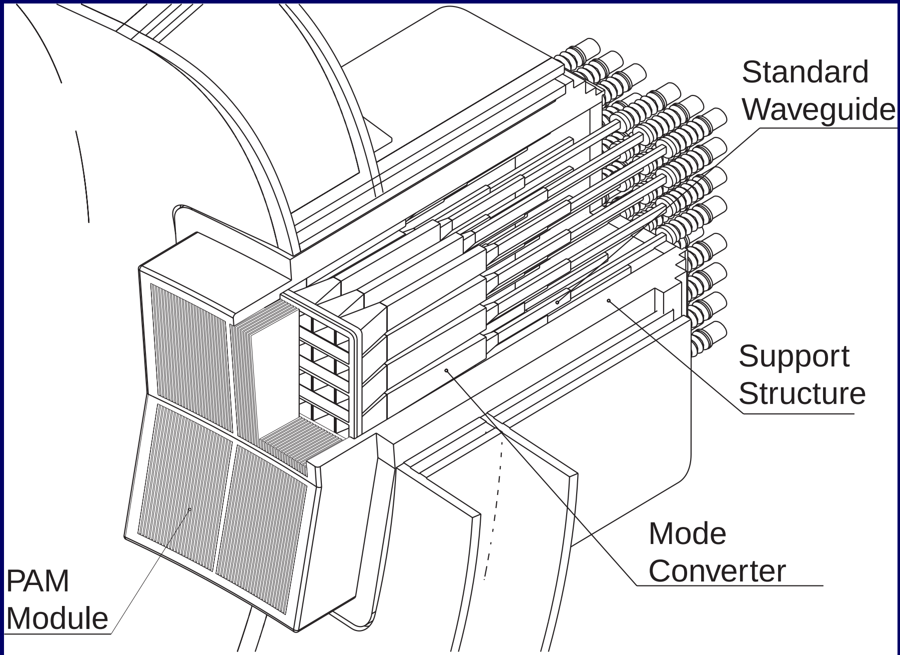
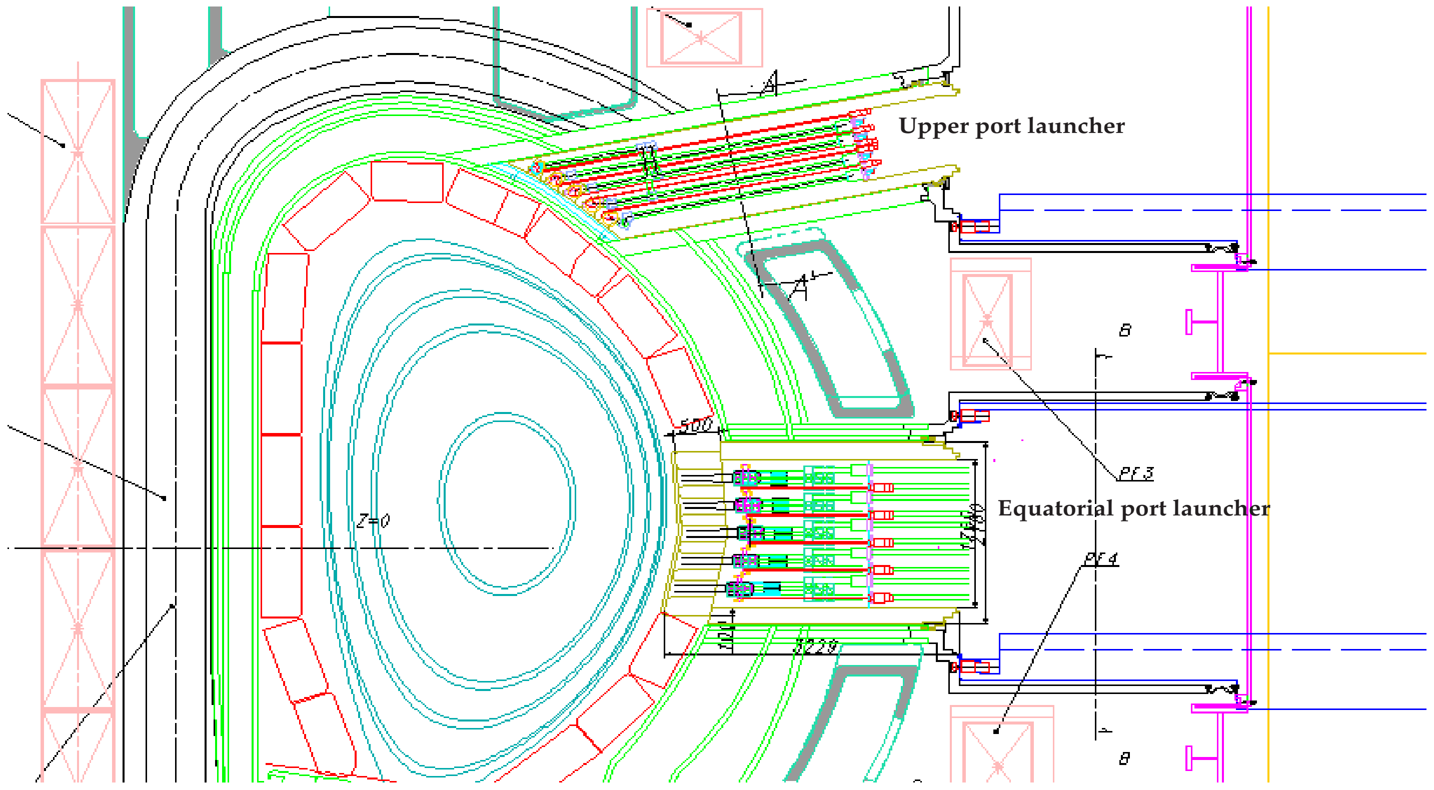


Figure 2.5.5-1 LH Launcher

Parameter	Value
Number of active wave-guides	24
Number of passive wave-guides	25
Cross section of active wave-guide (mm^2)	9.25 x 171
Mechanical length (mm)	900
Fundamental transmission mode	TE_{30}
Mechanical length (mm)	925 to 1050
Phasing among active wave-guides	$3\ \pi\ /\ 2$
Typical n// value	1.9-2.1
Max electric field in nominal power (22%) plasma reflection (kV/cm)	3.2

Table 2.5.5.2-1 Mechanical Dimensions of Multi-junction Stack

Electron Cyclotron System



Overview of EC-launcher

Upper launcher : poloidal steering = - 60 ~ -70°

toroidal angle = 24°

Equatorial launcher: toroidal steering = 20 - 45°

Equatorial port : standardized port plug for IC/EC/LH

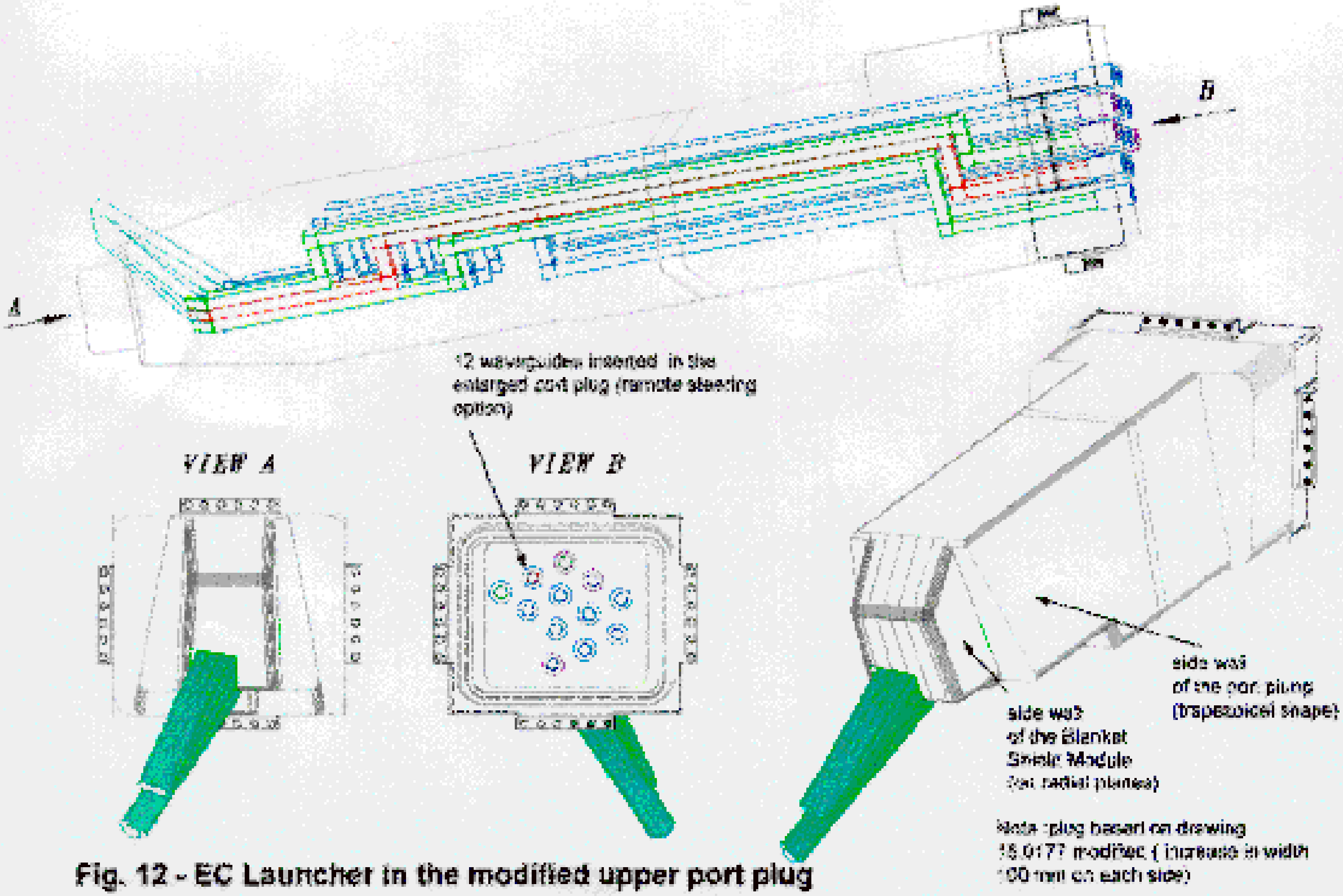
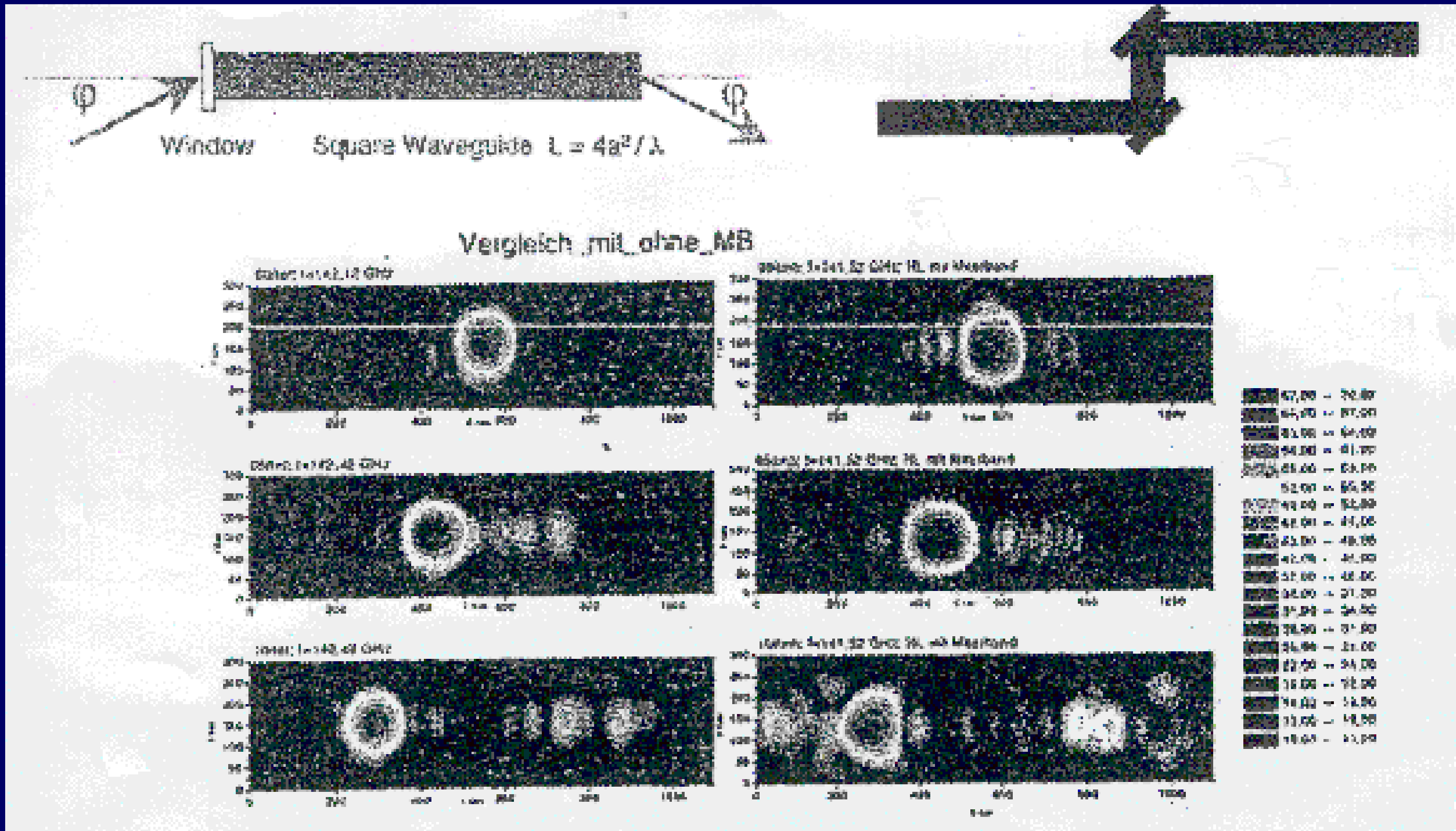


Fig. 12 - EC Launcher in the modified upper port plug

ECRH/ECCD for ITER:

ITER-task: Remote steering antenna for ECRH/ECCD



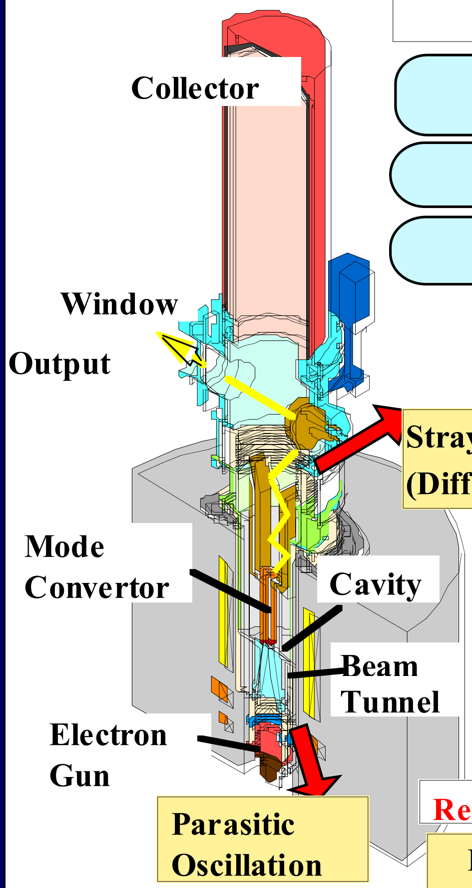
Far-field measurements, distance ca. 1700 mm
Scan angles 0˚, 5˚, 10˚

F = 142,42 GHz; (141,52 GHz with Mitrebends)
Length = 6720 mm; (6700 mm mit Miterbends)

•Collaboration with IAP Nizhny Novgorod and CRPP Lausanne

ITER Gyrotron Development

Major issues: 1) Cavity heat load, 2) Window heat load
3) Collector heat load, 4) Low efficiency



Stray RF (Diffraction)

Recent Research

- Reduction of diffraction loss by optimization of mode convertor design (~10% -> 5%)

Recent Research

Reduction of Parasitic Oscillation by RFabsorber in the beam tunnel. (SiC)

Achievement (1999):
170GHz, 0.5MW x 8sec, 32 %
110GHz, 1 MW x 2sec, 36%

Suppression of undesired mode
170GHz,1MW,57% 1s
(0.9 MW/9 s/43 % March 2001)

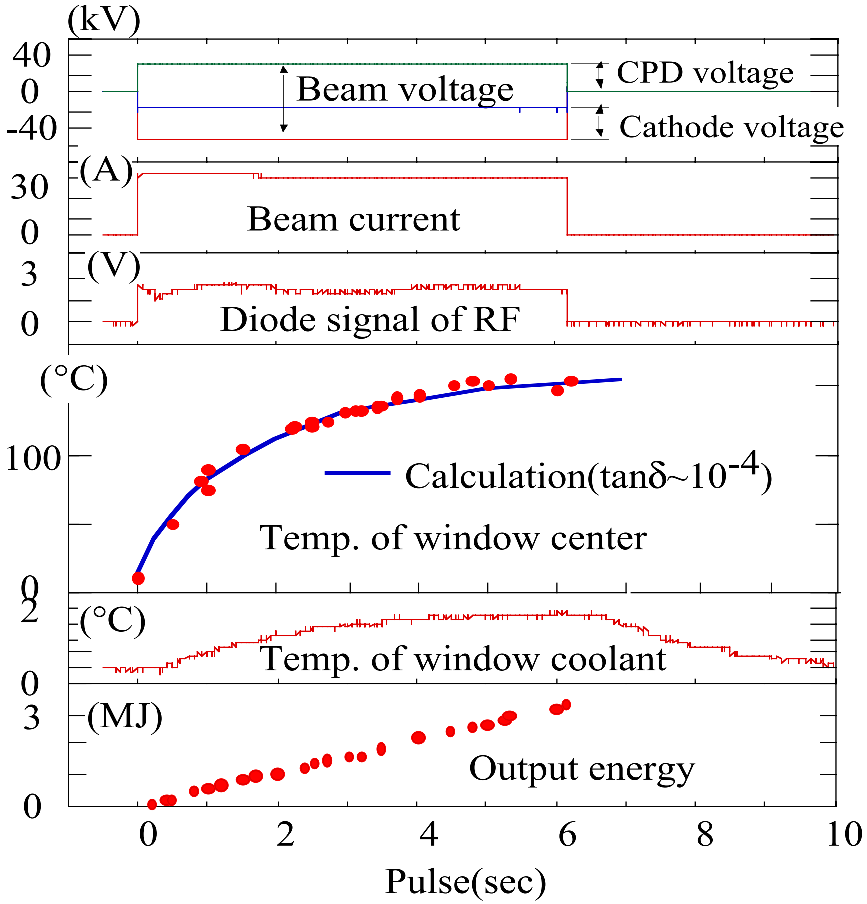
Limit;
Undesired mode
- Parasitic Osc.
- Diffraction

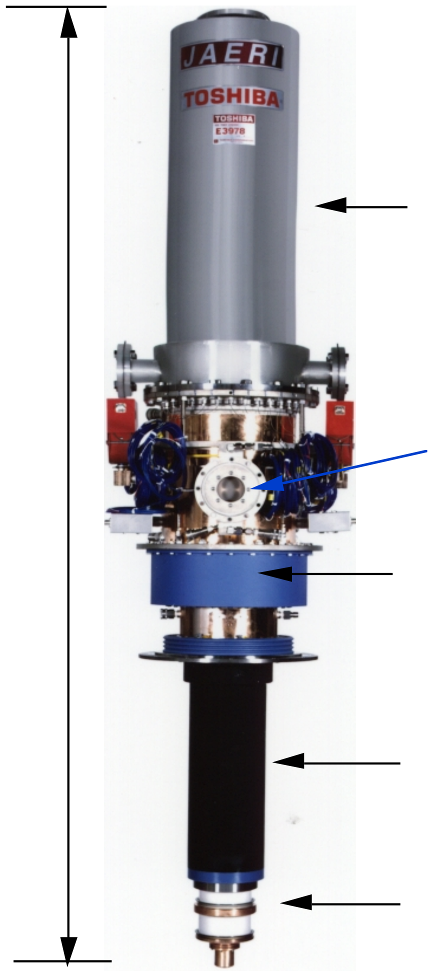
- Heating tube
- Reduce efficiency

Test from April 2001
Strengthen
- Cooling capability (SiC brazed to M.)
- Insulator against heat load ($Al_2O_3 \rightarrow Si_3N_4$)

ITER TargetÅF
170GHz, 1MW, >50%
>10s (CW in principle)

170 GHz long pulse gyroton



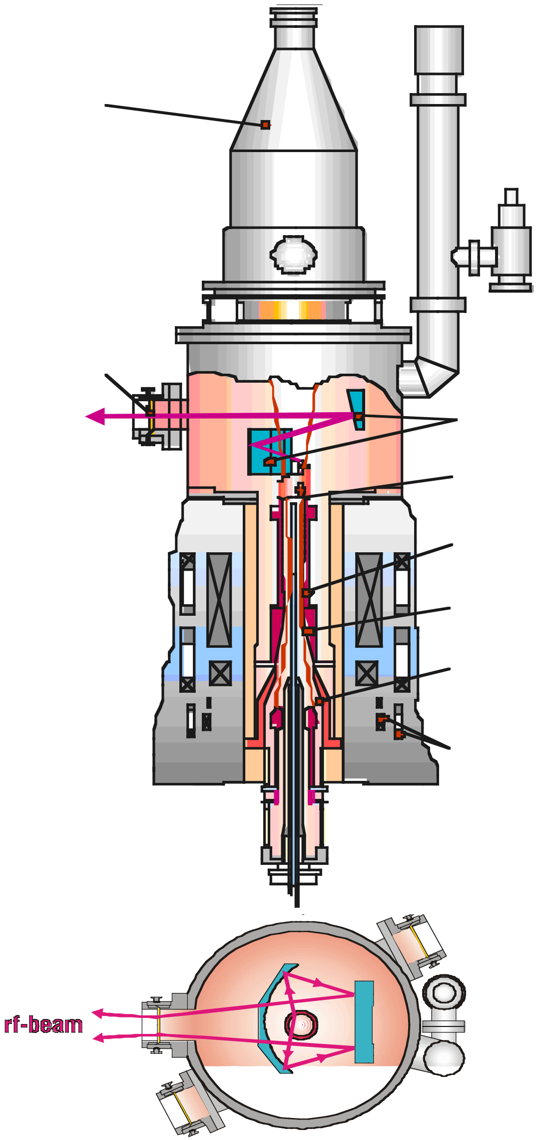


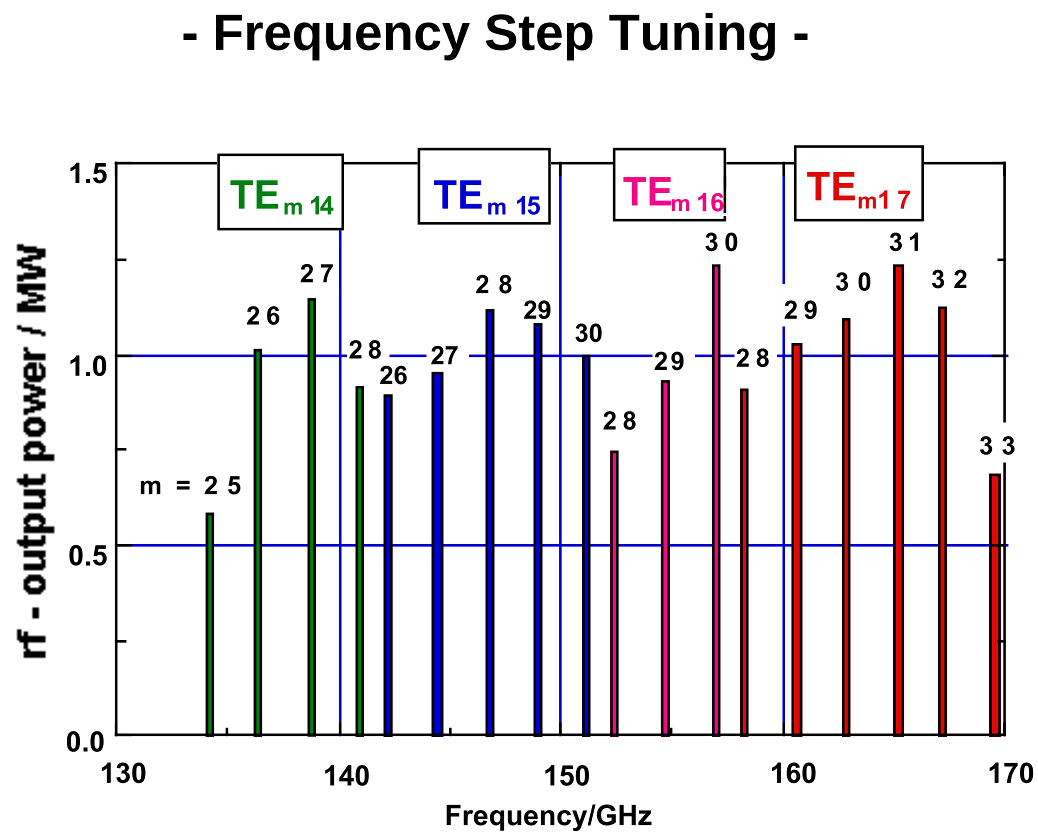
Achieved in 1999: 170 GHz, 0.5 MW- 8s, Now commercially available with maintenance free SC magnet system

Six same type gyrotrons (168 GHz) in LHD from 2000

(Achieved in April 2001: 140 GHz, 0.8 MW-45 s, 0.45 MW-180 s)

165GHz Coaxial Cavity Gyrotron (left) and Frequency Tuning (right)





Operating Parameters : $I_b \cong 50$ **A;** U_c**,** B_{cav} **and** R_b **adjusted individually.** U_c**,** B_{cav} **and** R_b **optimized for maximum rf-output power at** $TE_{31,17}$ **,** $TE_{32,17}$ **,** $TE_{30,16}$ **,** $TE_{28,15}$ **,** $TE_{27,14}$ **.**

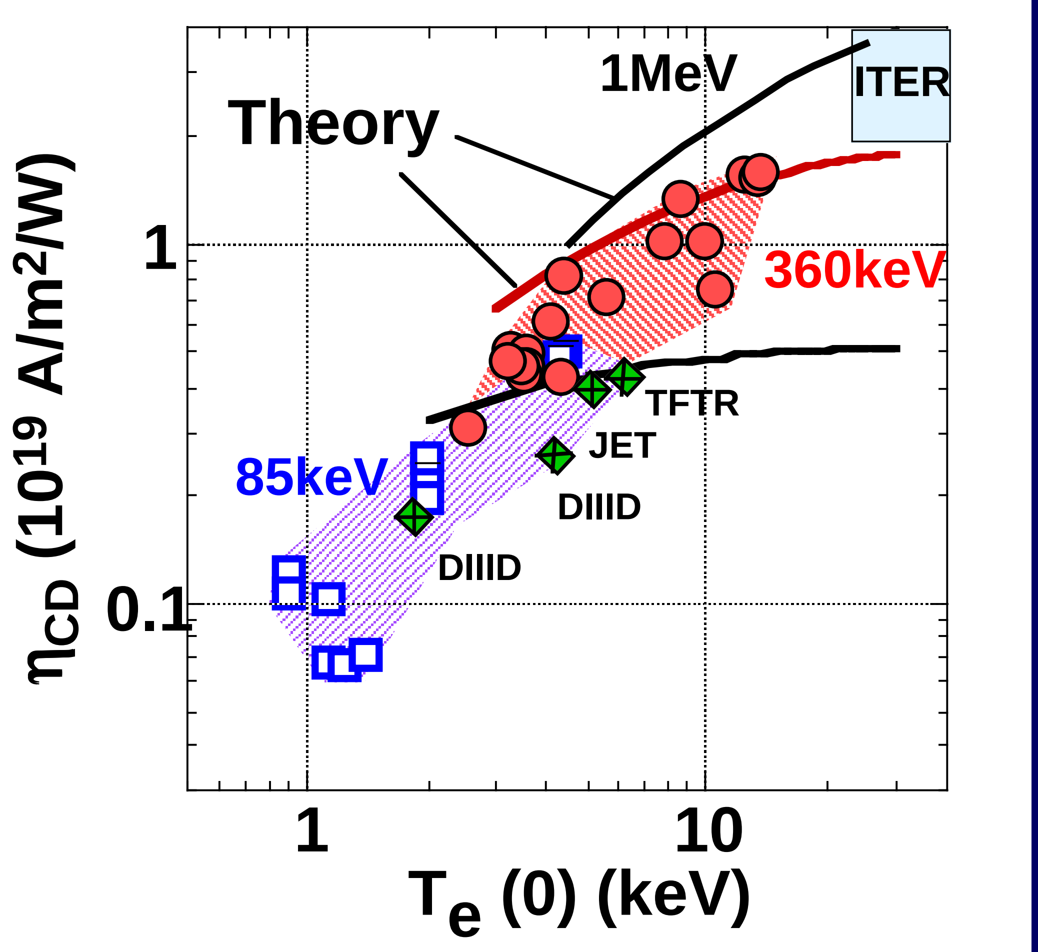
Achieved : 1.2 MW, 0.015, 50 % efficiency, frequency tuning, 2.2 MW/1ms

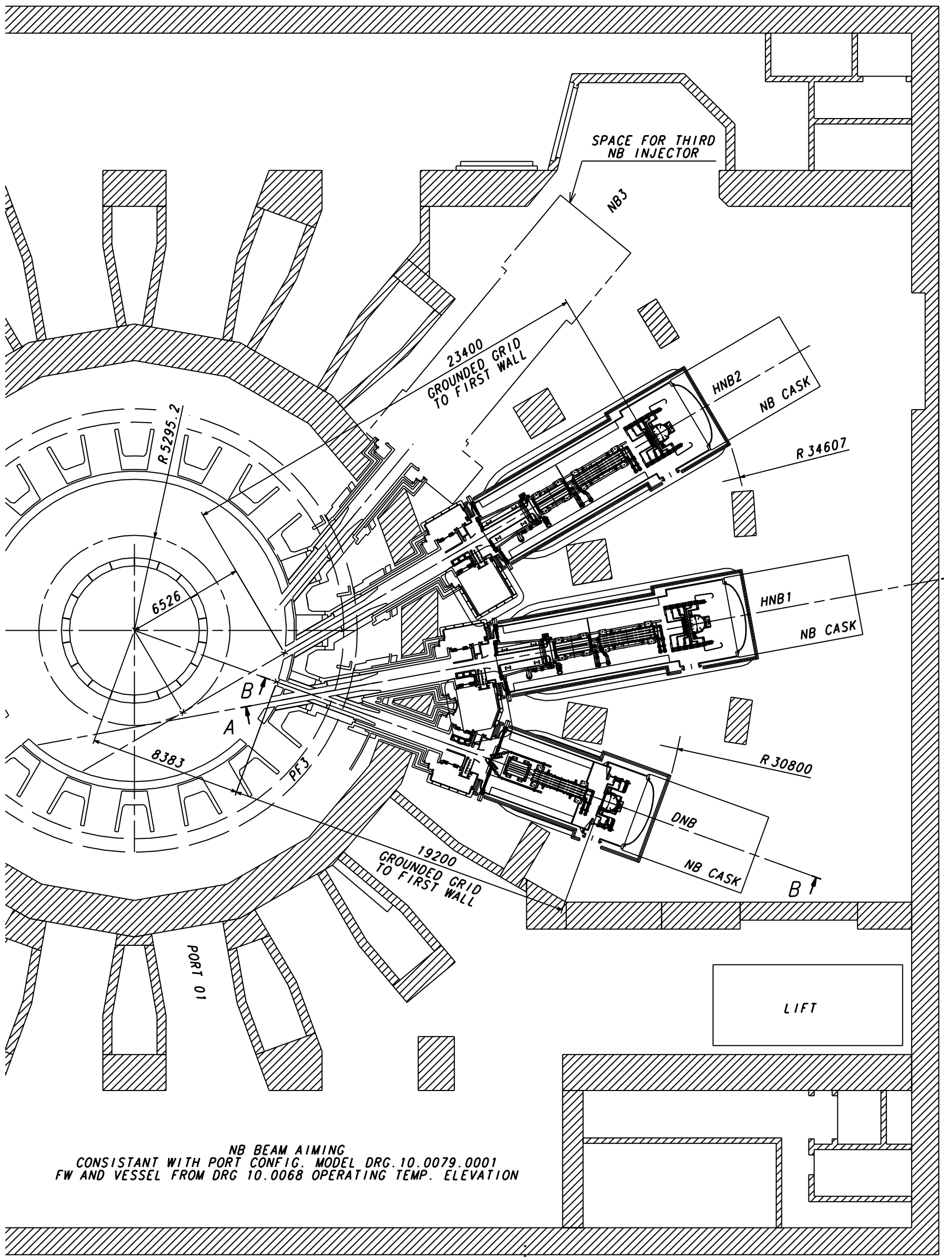
Target : 1.5 MW, 0.15 s at 165 GHz

Current Drive Efficiency of Neutral Beam

N-NB : 360keV

η_{CD-NB}=1.55x10^{19}A/m^2/W





N 53 GR 389 00-11-16 W 0.1

NB System Layout. Plan View

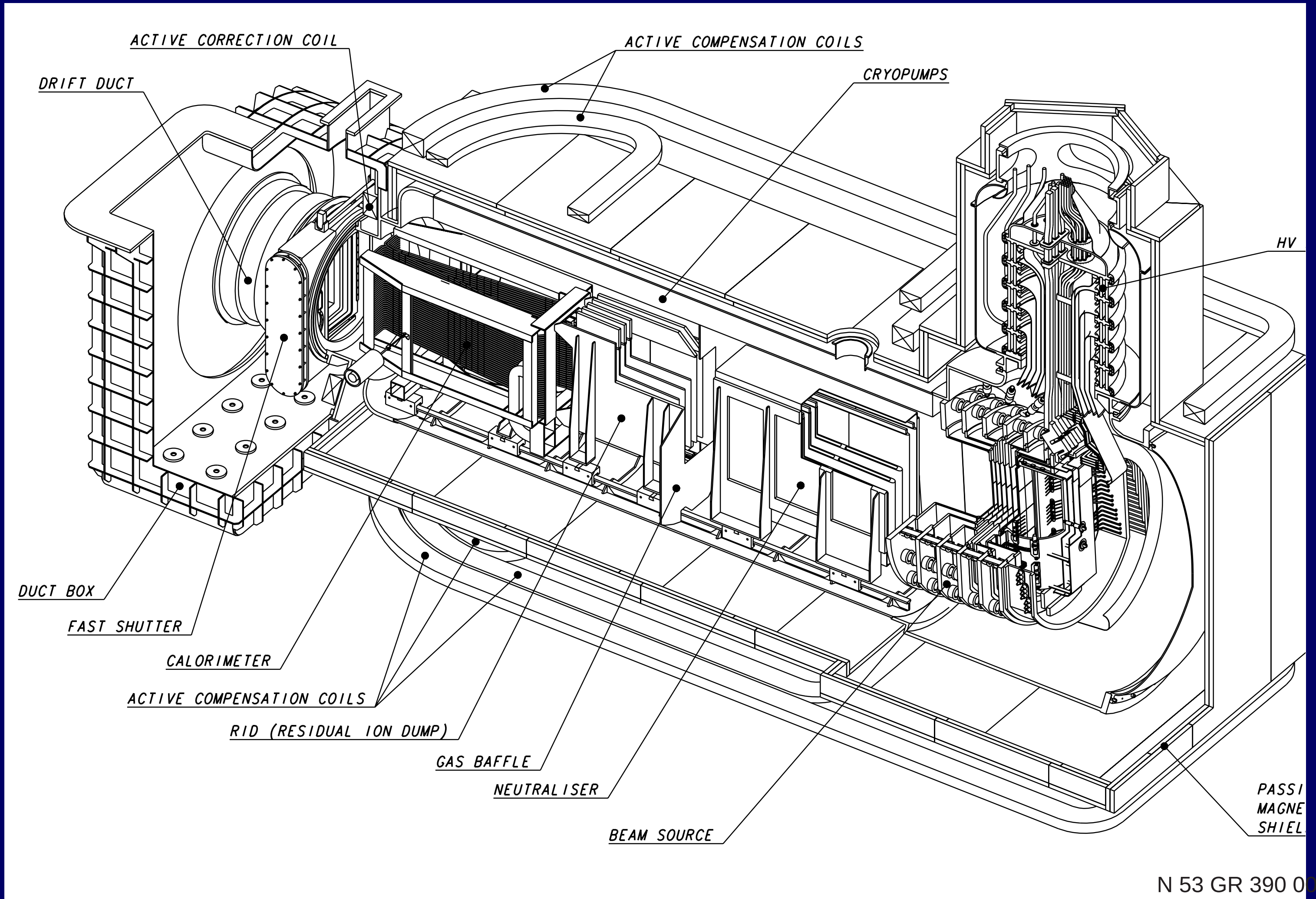
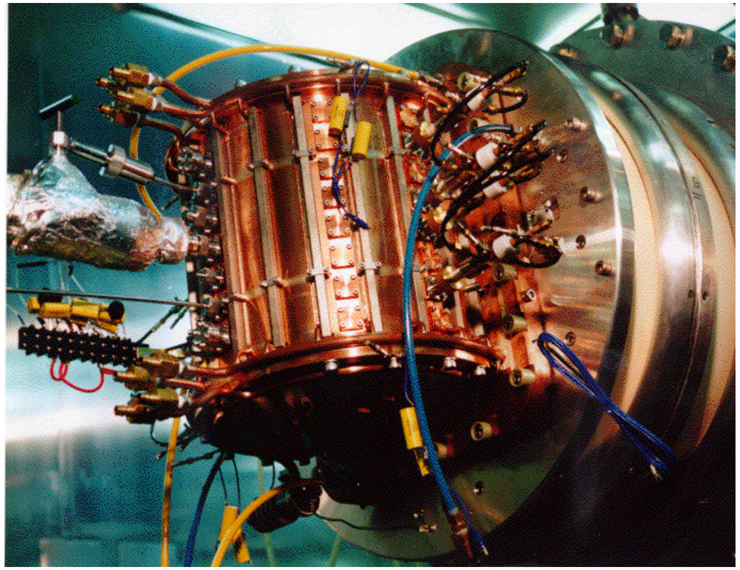
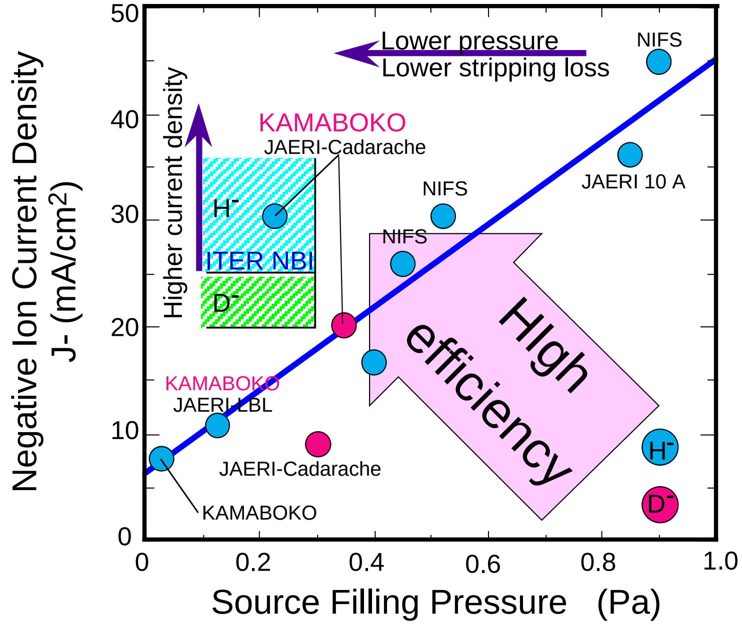


Figure 2.5.1-3 Neutral Beam Injector, Isometric View

Ion Source Development





20 mA / cm² **1000 s (H^-, H^-/D^-)**

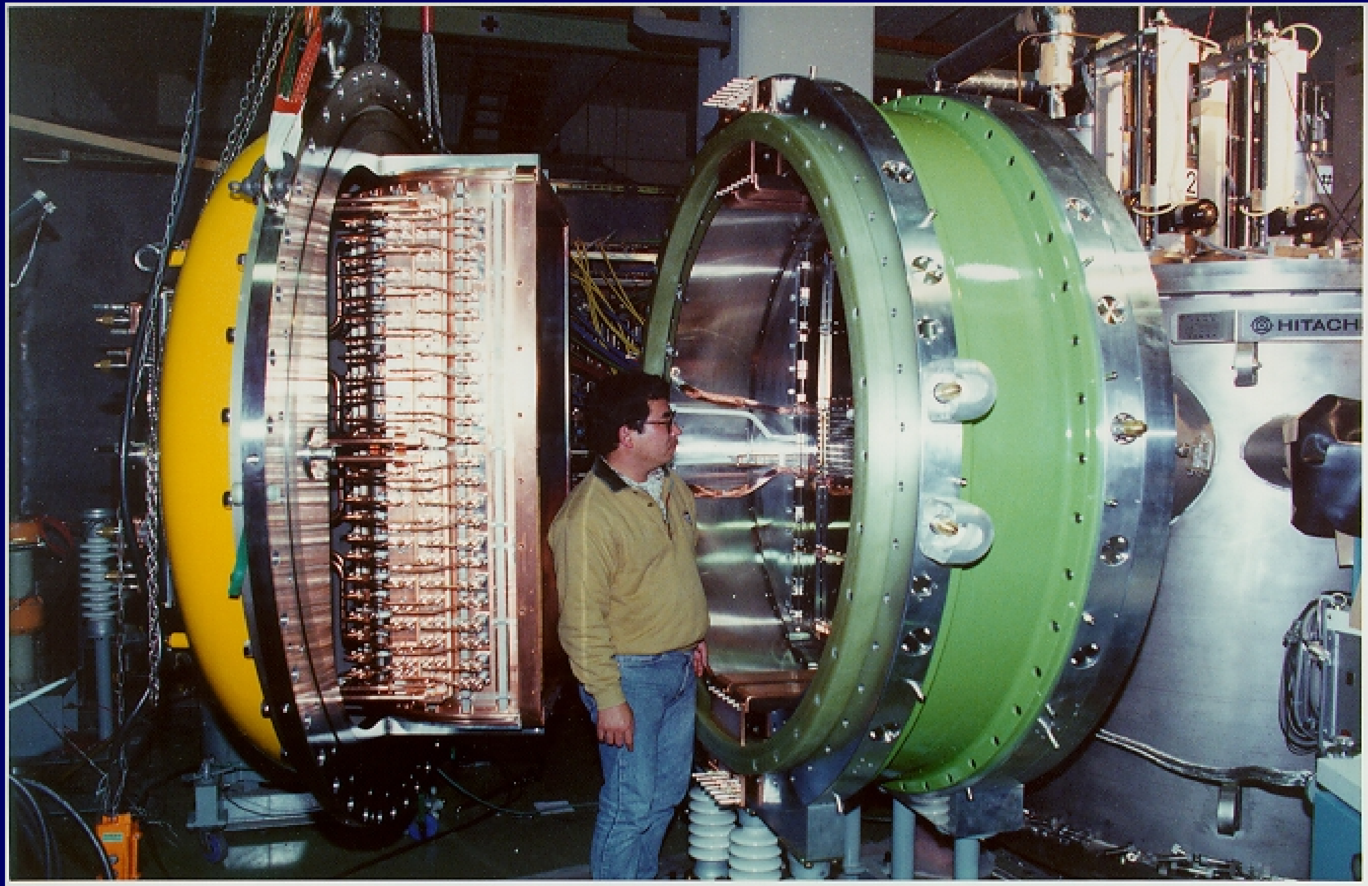
8 mA / cm² **One week**

The target current density is obtained and long life of Cs effect is demonstrated.

Neutralizer

60 % is achieved with gas which gives 16.7 MW /beam

Plasma neutralizer may increase to 20 MW/beam



JT-60U Ion Source

1.2m x 0.64 m, 5.2 MW/350 kV/15 A(D^0)/2s

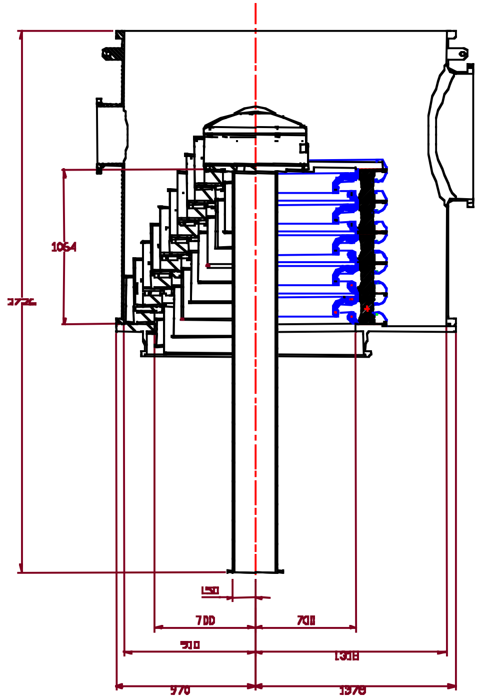
(ITER 1.17 m x 0.9 m, 16 MW/1MeV/16 A(D^0)/3600 s)

The large current of negative ion beam is demonstrated.

High voltage bushing

I: One ring is fabricated and will be tested (5 rings in ITER)

II: 90% size, 900 kV/1000 s is achieved



A 1 MV Ceramic SINGAP Bushing - Prototype for ITER NBI. Left: original epoxy bushing with present 9 stage, Right: section of prototype insulator/screen assembly.

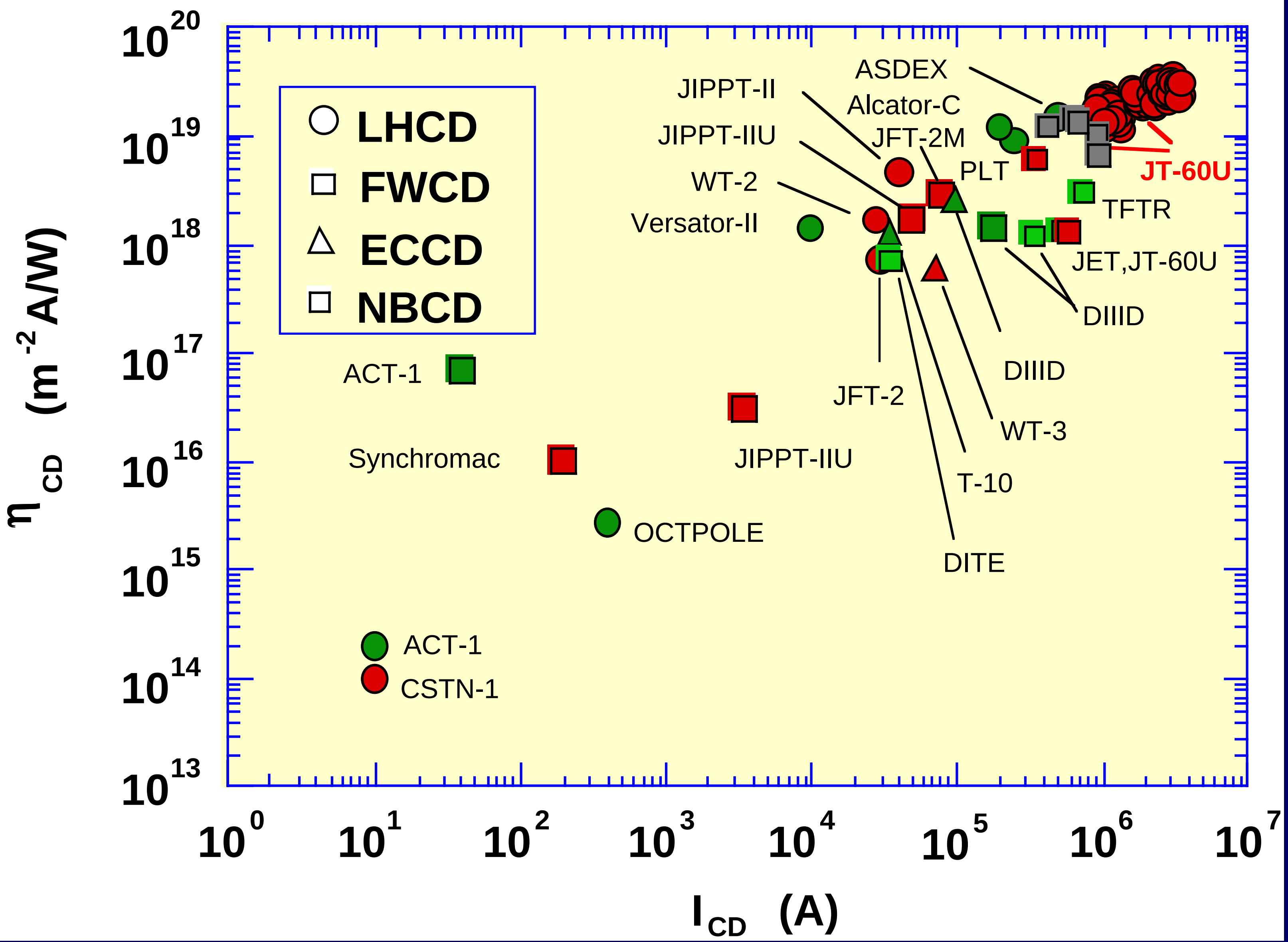
Test facility for the mockup bushing, located between two SF_6 tanks

High energy beam

0.9 MeV/180mAH$^-$, 1 MeV/25 m AH$^-$, 0.4 MeV / 14 AD$^-$

3-5 m rad is achieved at ~0.7MeV

Non-Inductive Current Drive

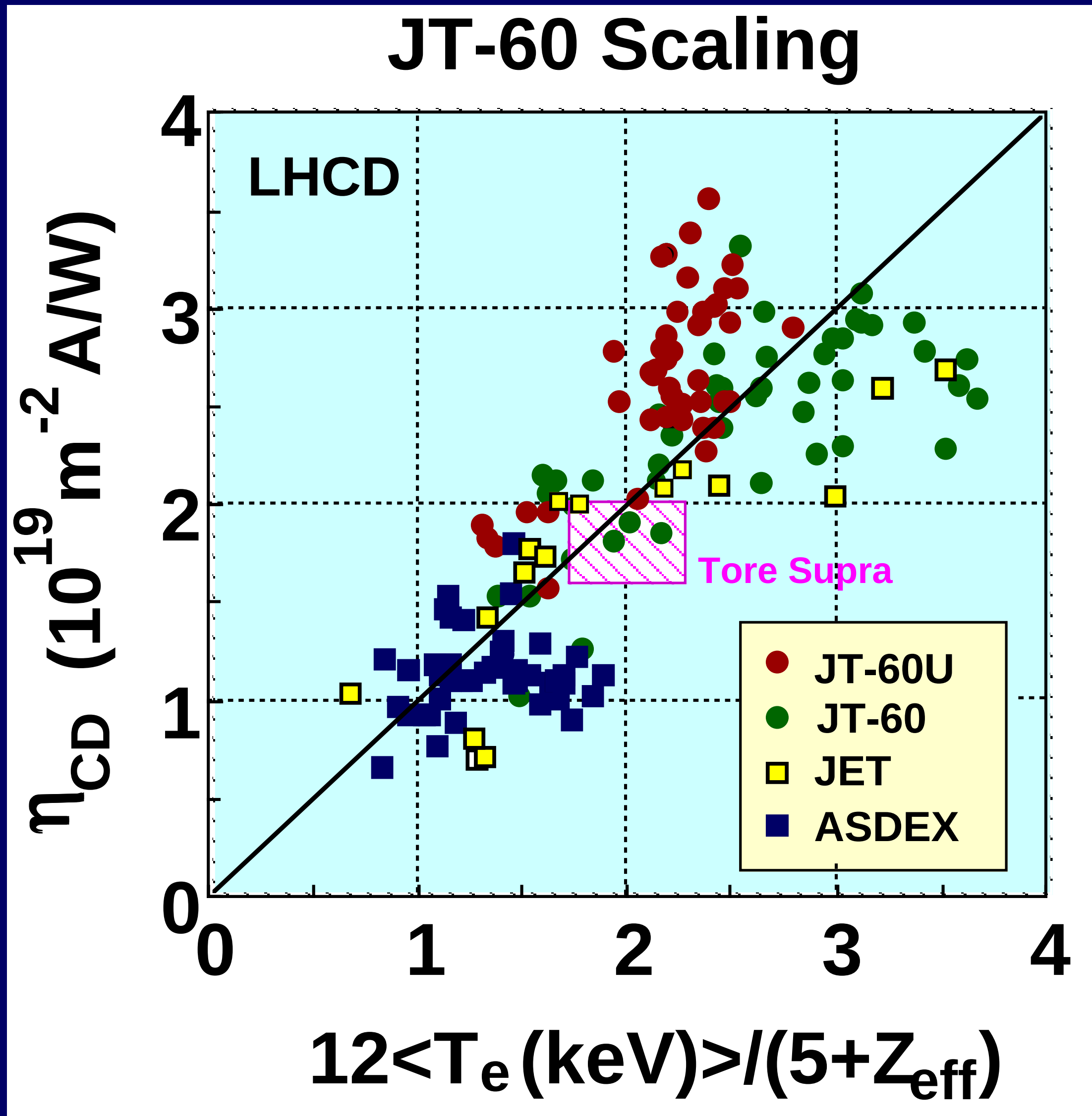


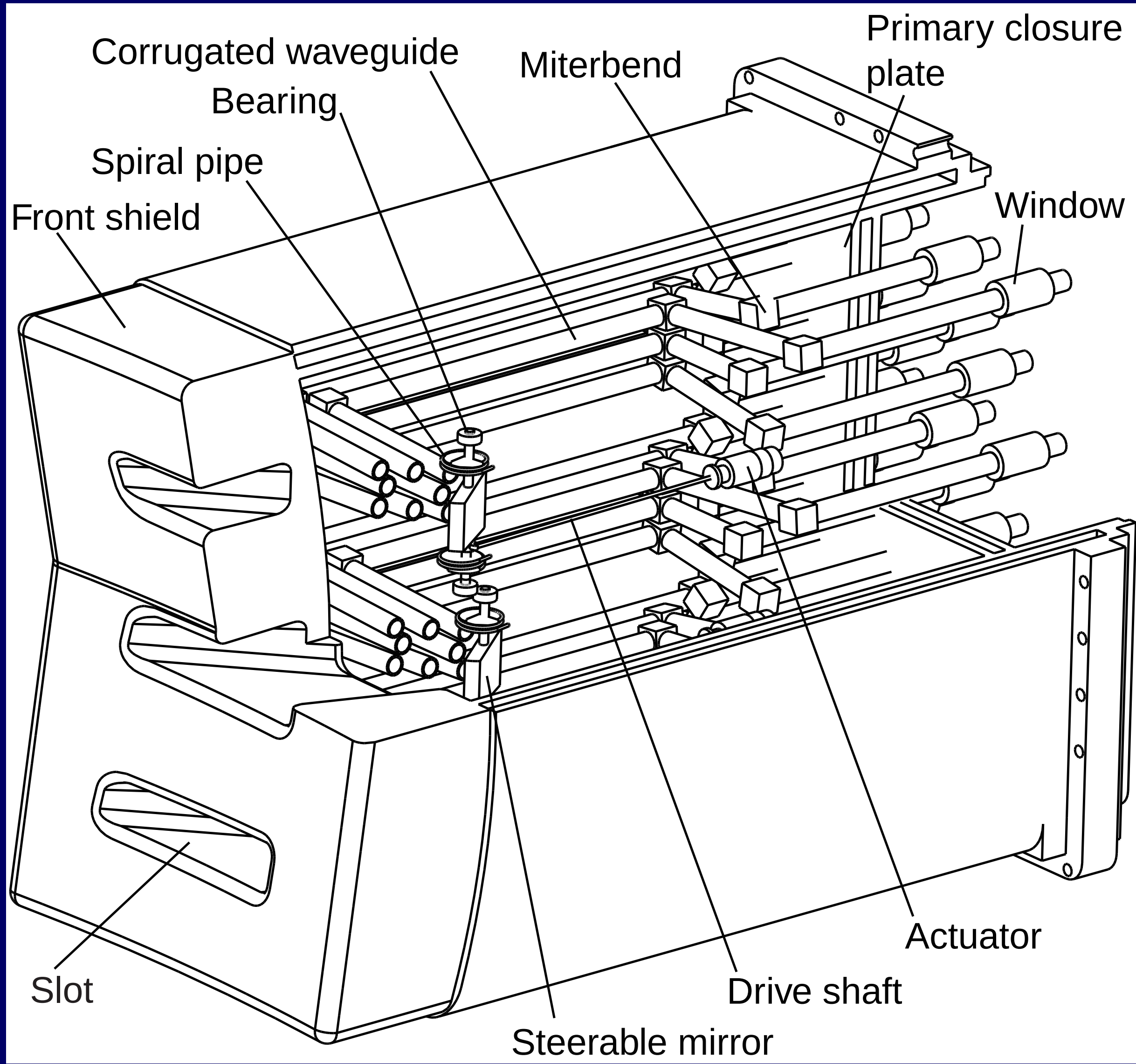
Conclusion

R&D is confirming applicability of each system to ITER.

(R&D of Heating and Current Drive System will be continued.)

Current Drive Efficiency of Lower Hybrid wave





Equatorial EC Launcher

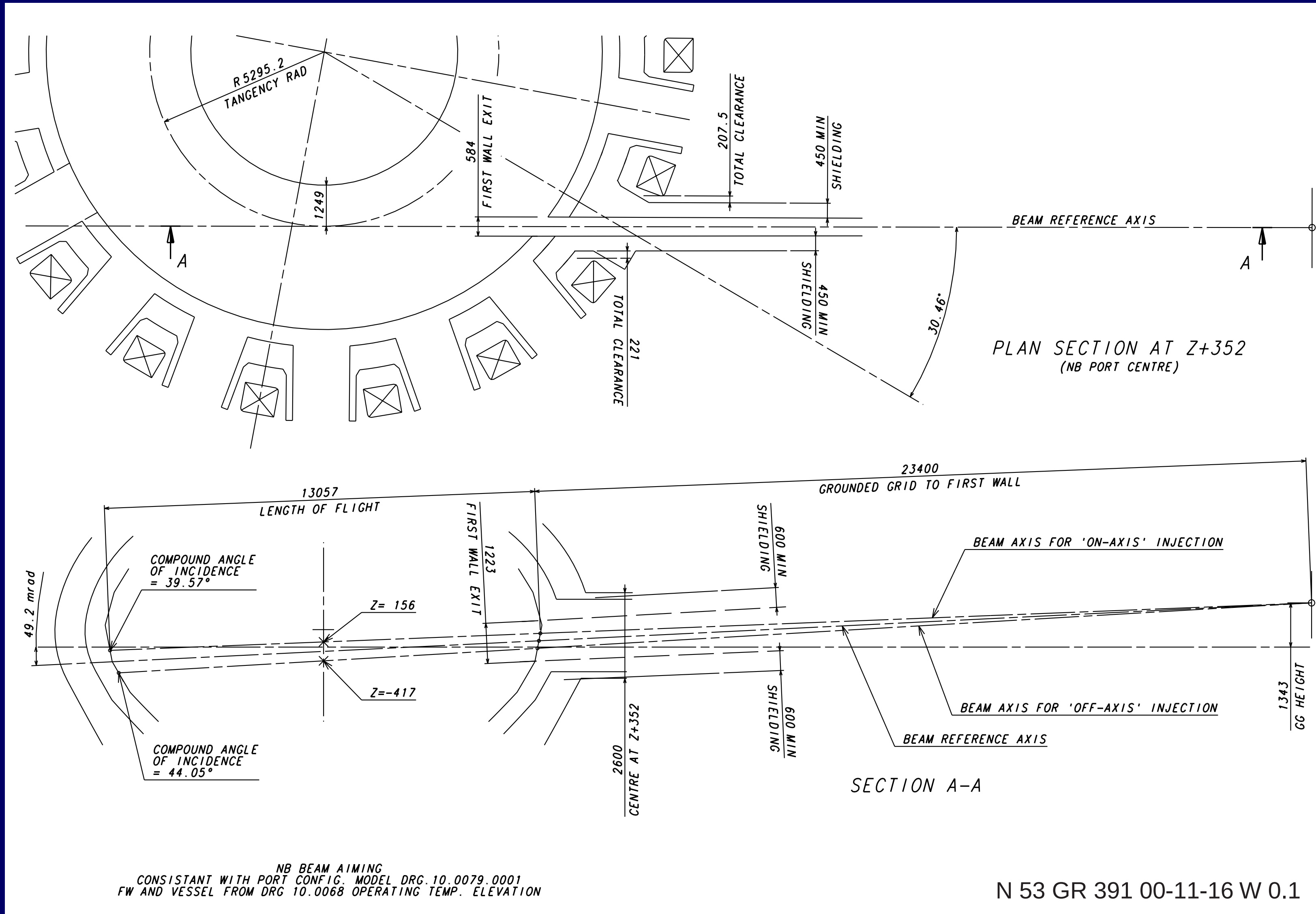


Figure 2.5.1-1 Tokamak and H&CD Neutral Beam Geometry