Plasma Current Start-up by ECH on LATE

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○ The LATE(Low Aspect ratio Torus Experiment) Device

・ Steady state (～1 s) plasma with 2.45 GHz, 5 kW RF

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○ New ECH system at 5 GHz

○ Summary

LATE (Low Aspect ratio Torus Experiment)

Objectives

Basic study in plasma production, heating and current drive in ST plasma with the microwave power in the electron cyclotron range of frequency.

* Start-up and Formation of ST Plasma by ECH/ECCD without Ohmic Heating.

* Electron Bernstein Wave (EBW) Heating and Current Drive in Overdense ST Plasma.

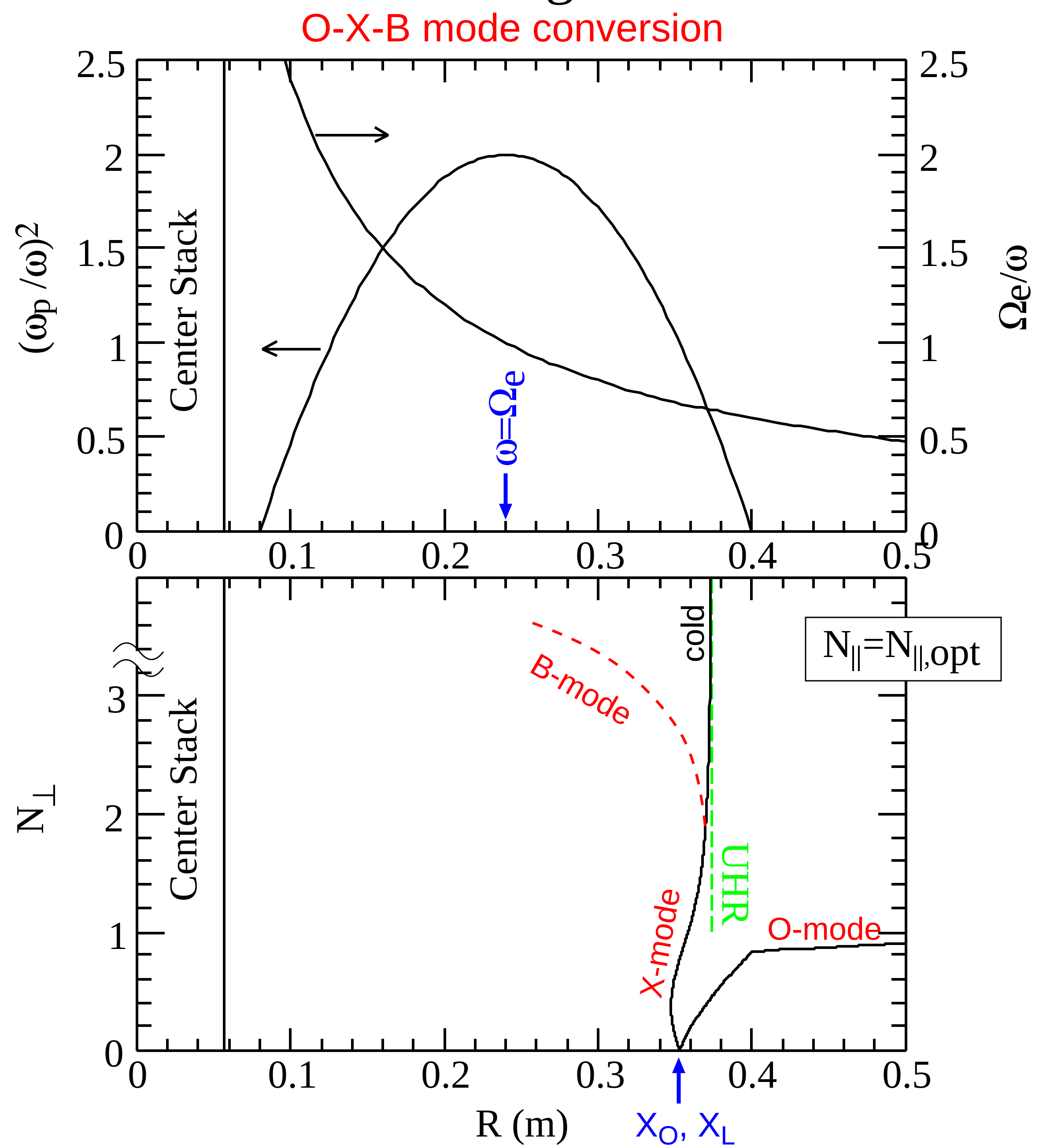
Scenario for Start-up and Formation of ST Plasma by ECH

1. Initiation of discharge near the EC resonance layer.
2. Application of a external vertical magnetic field.
   --> Initial current generation and formation of closed flux surfaces.
3. Improved particle confinement due to formation of closed flux surfaces.
   --> Production of overdense plasma.
   Mode conversion to EBW
   * O --> X --> B
   * X --> B
   --> EBW heating and current drive (without density limit).

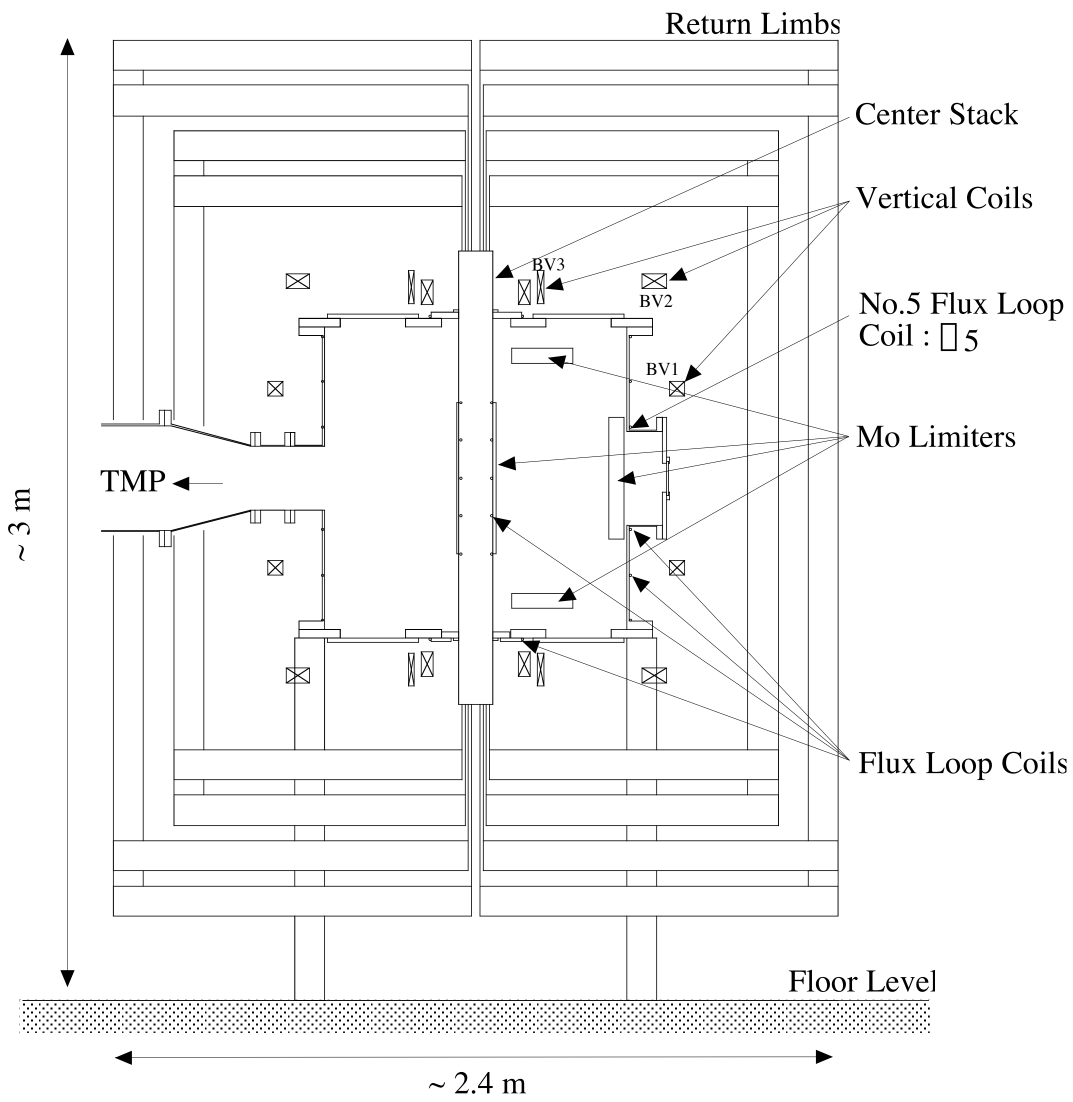
   ==>> "ECH Spherical Tokamak"

4. High beta plasma production with additional heating such as NBI.

EBW Heating Scenario



LATE (Low Aspect ratio Torus Experiment) : Side View



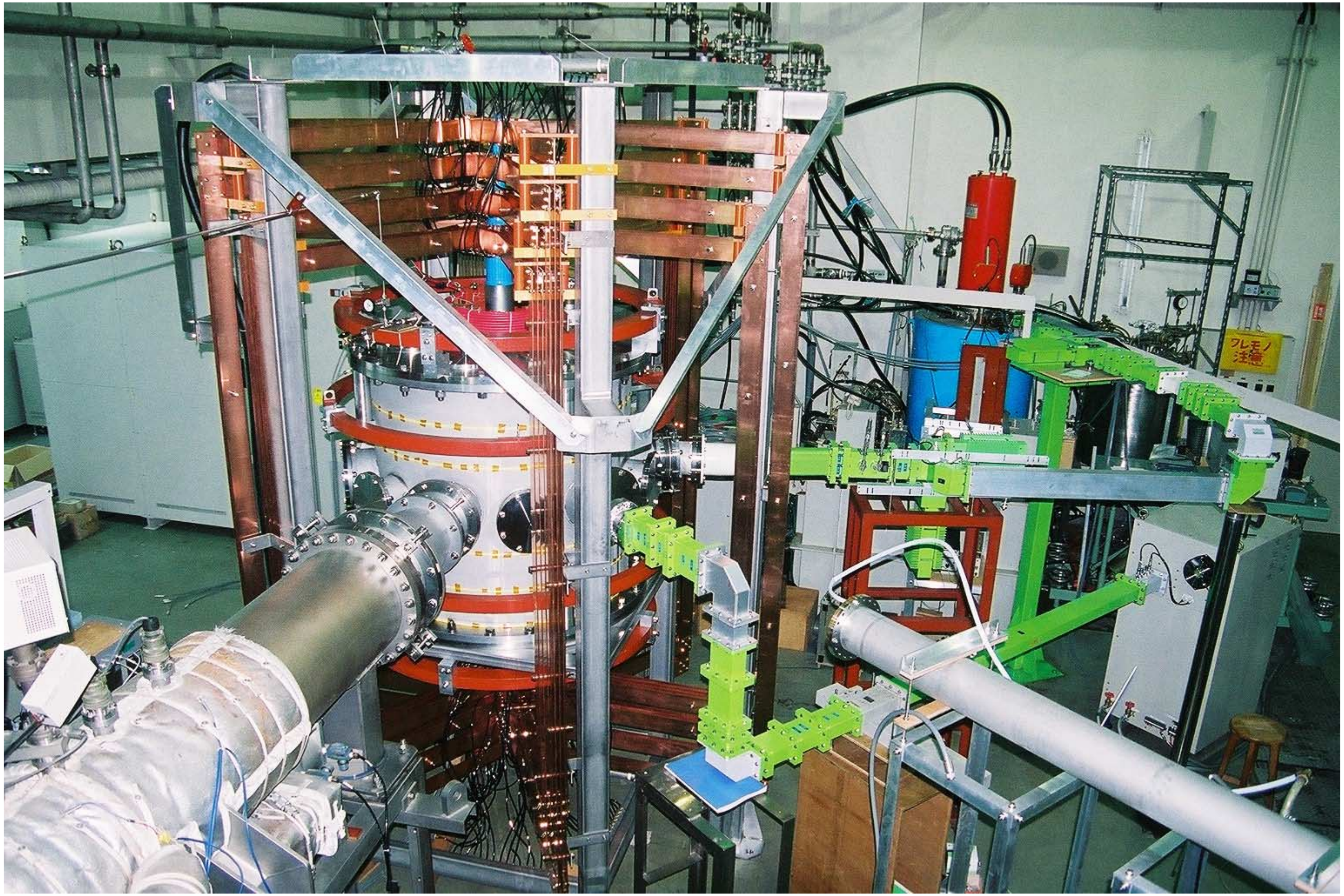
<u>Vacuum Vessel</u> : □100 cm x 100 cm

<u>Center Stack</u> : O.D.= □11.4 cm
60 kAT (Steady State)
875 G @ R = 13.7 cm
714 G @ R = 16.8 cm
180 kAT (0.1 s)
1786 G @ R = 20.2 cm

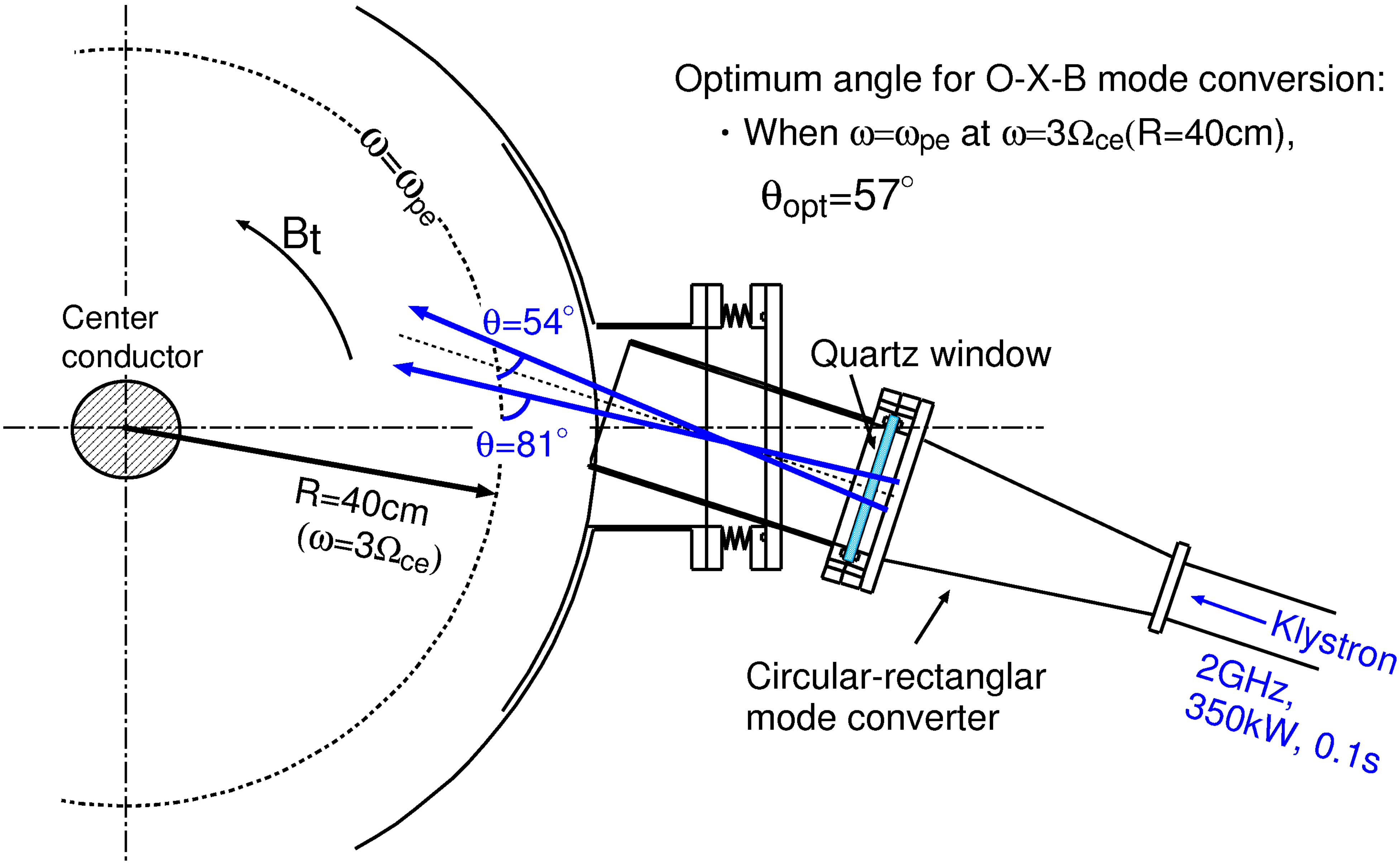
<u>Vertical Coils</u>
(BV-1) : 6.0 kAT (Steady State)
(BV-2) : 4.0 kAT (Steady State)
(BV-3) : 8.2 kAT (Steady State)
45.7 G @ (R, z) = (20 cm, 0 cm)

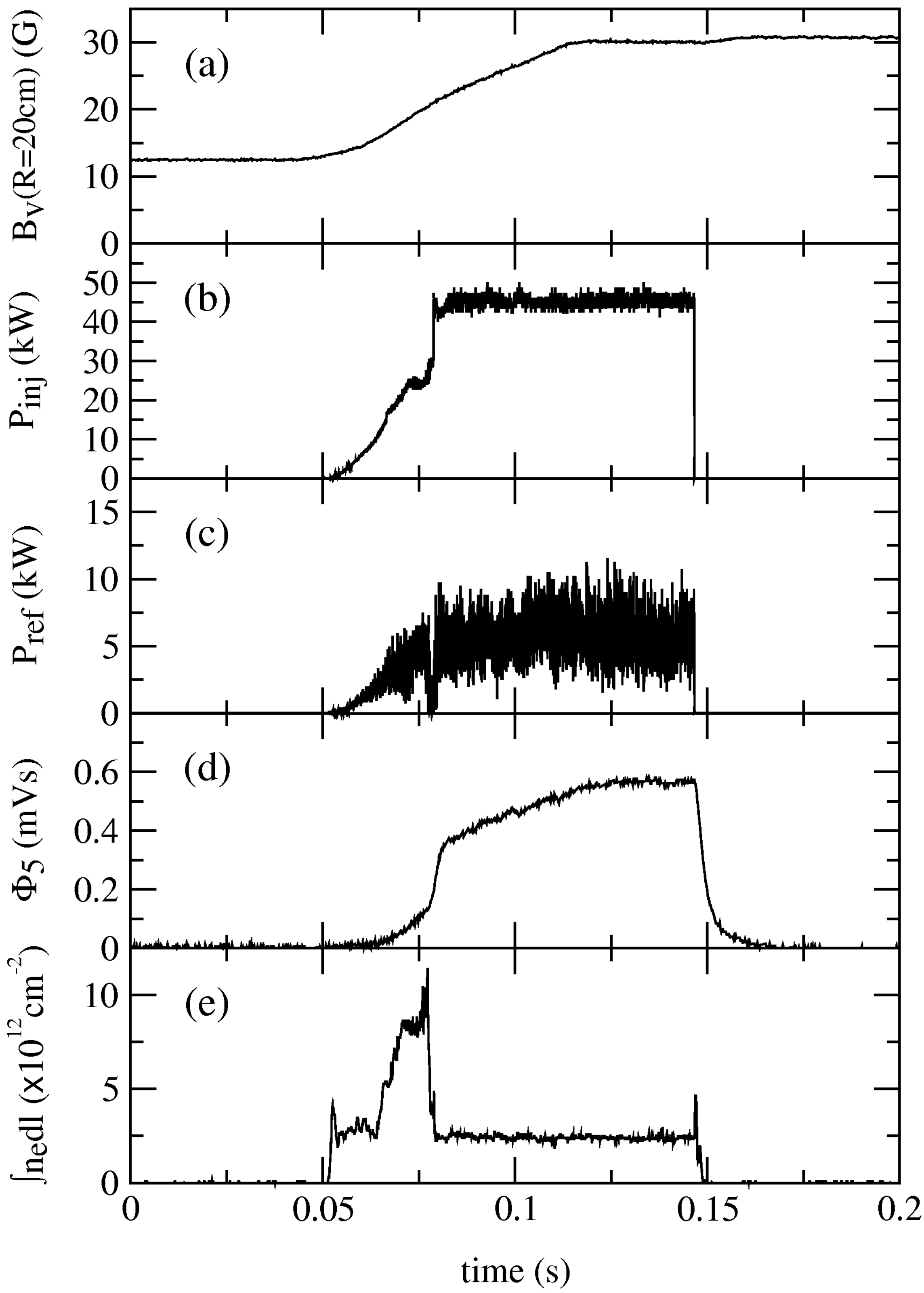
<u>RF Source</u>
2.45 GHz, 5 kW, CW (Magnetron)
2.0 GHz, 350 kW, 0.1 s (Klystron)
5.0 GHz, ~200 kW, 0.1 s (Klystron)

LATE (Low Aspect ratio Torus Experiment) at Kyoto Univ.



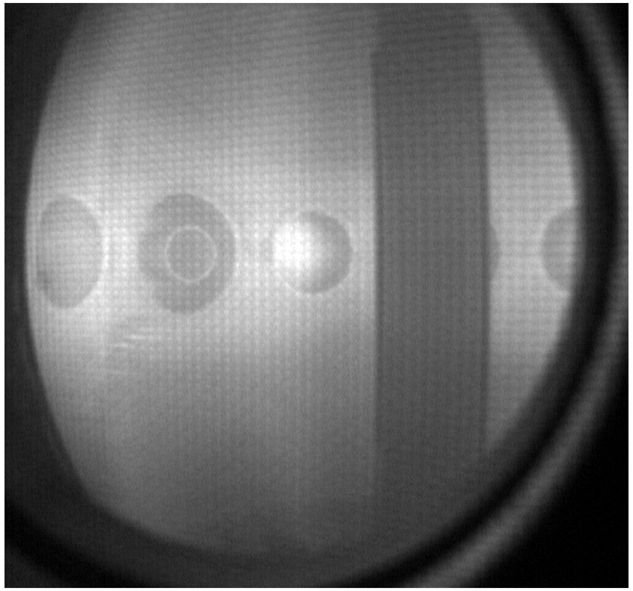
O-mode injection from outbord side



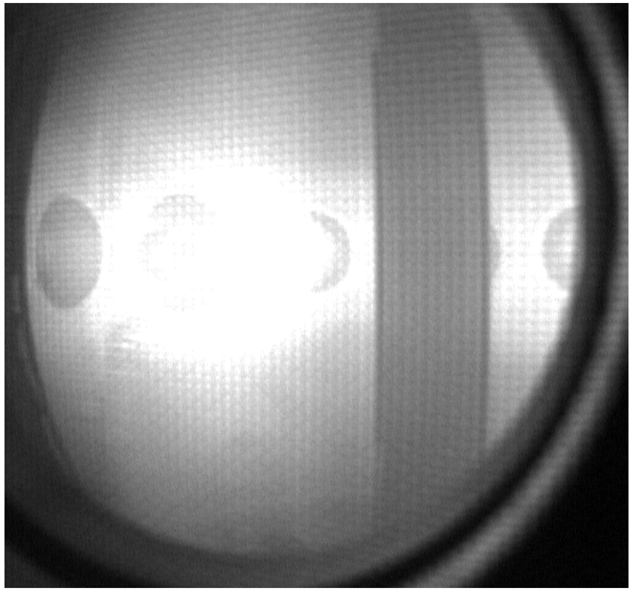


(a)
(b)
(c)
(d)
(e)
B_V(R=20cm) (G)
P_inj (kW)
P_ref (kW)
Φ5 (mVs)
∫nedl (x10^12cm^-2)
0
10
20
30
40
50
15
5
0.2
0.4
0.6
0.05
0.1
0.15
time (s)

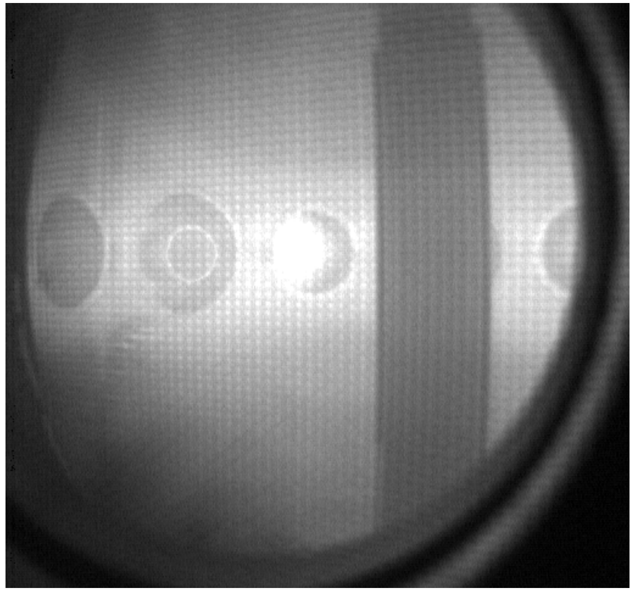
CCD images



t = 4 ms



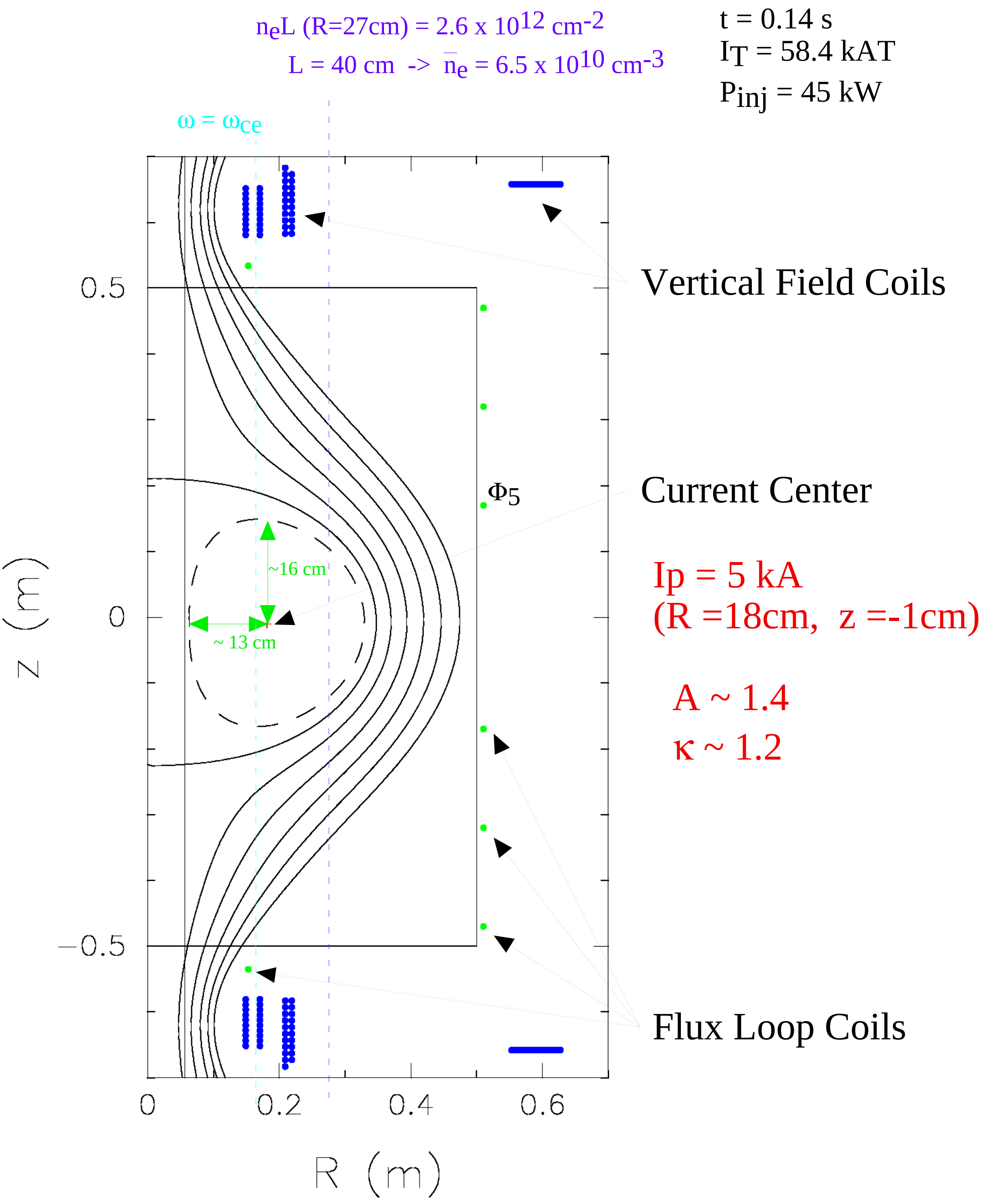
t = 12 ms



t = 60 ms

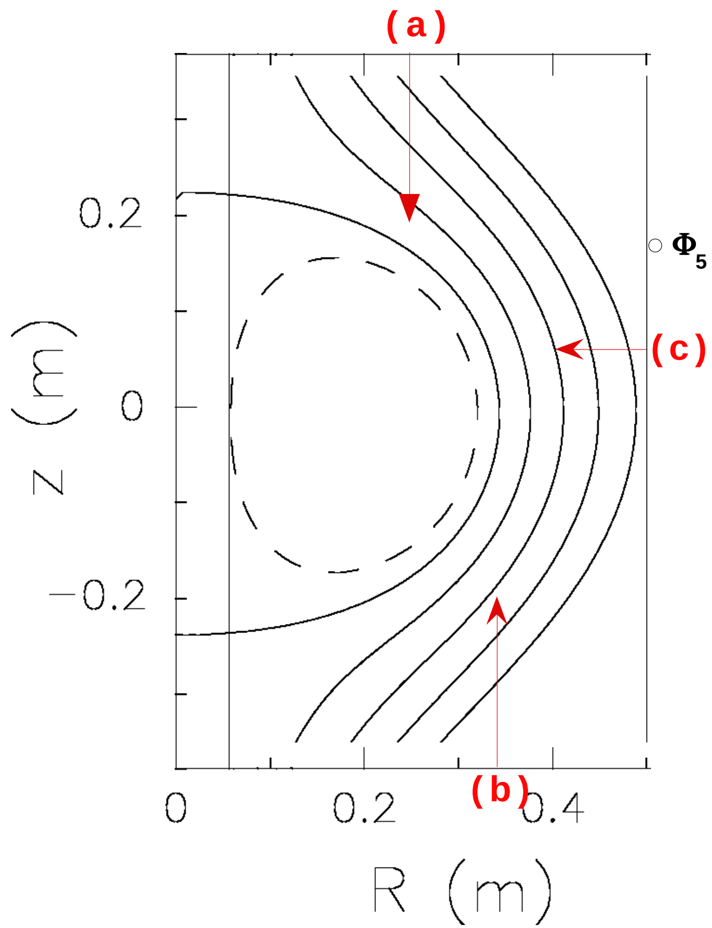
(After RF injection start)

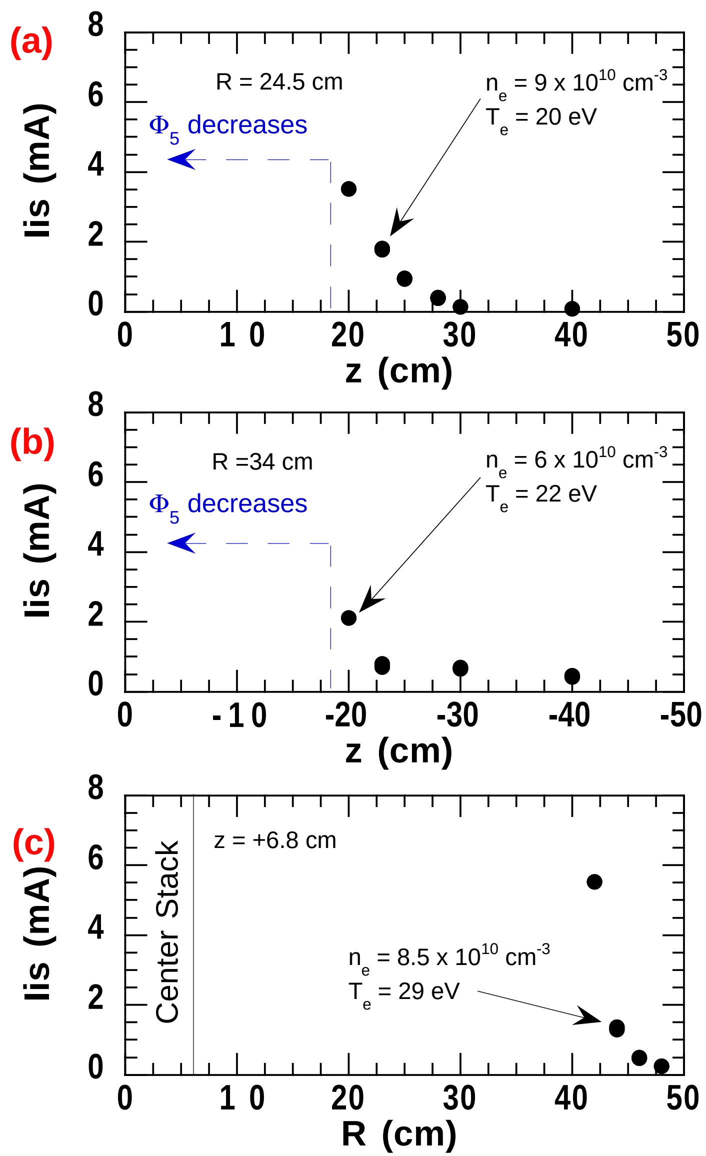
Poloidal Flux



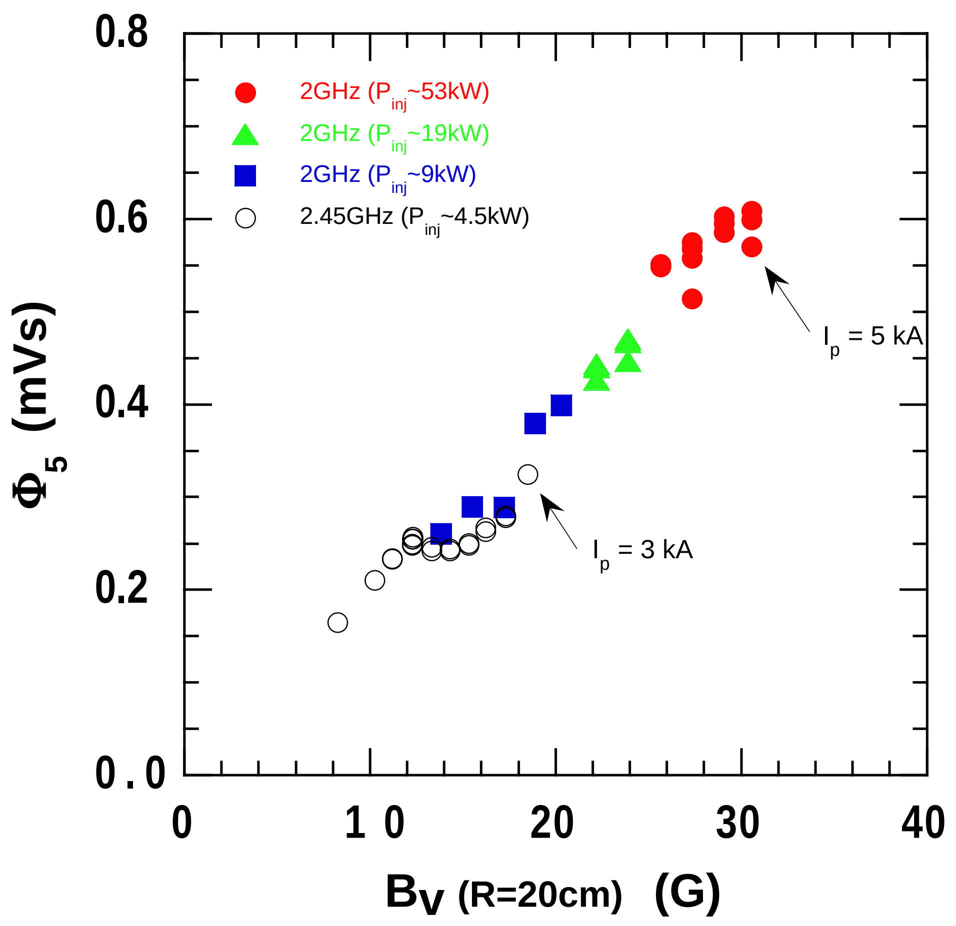
I_{is} profile vs Poloidal Flux

I_T = 58.4 kAT
P_{inj} ~ 16 kW
I_p = 4.5 kA
$R_{limiter}$ = 46 cm

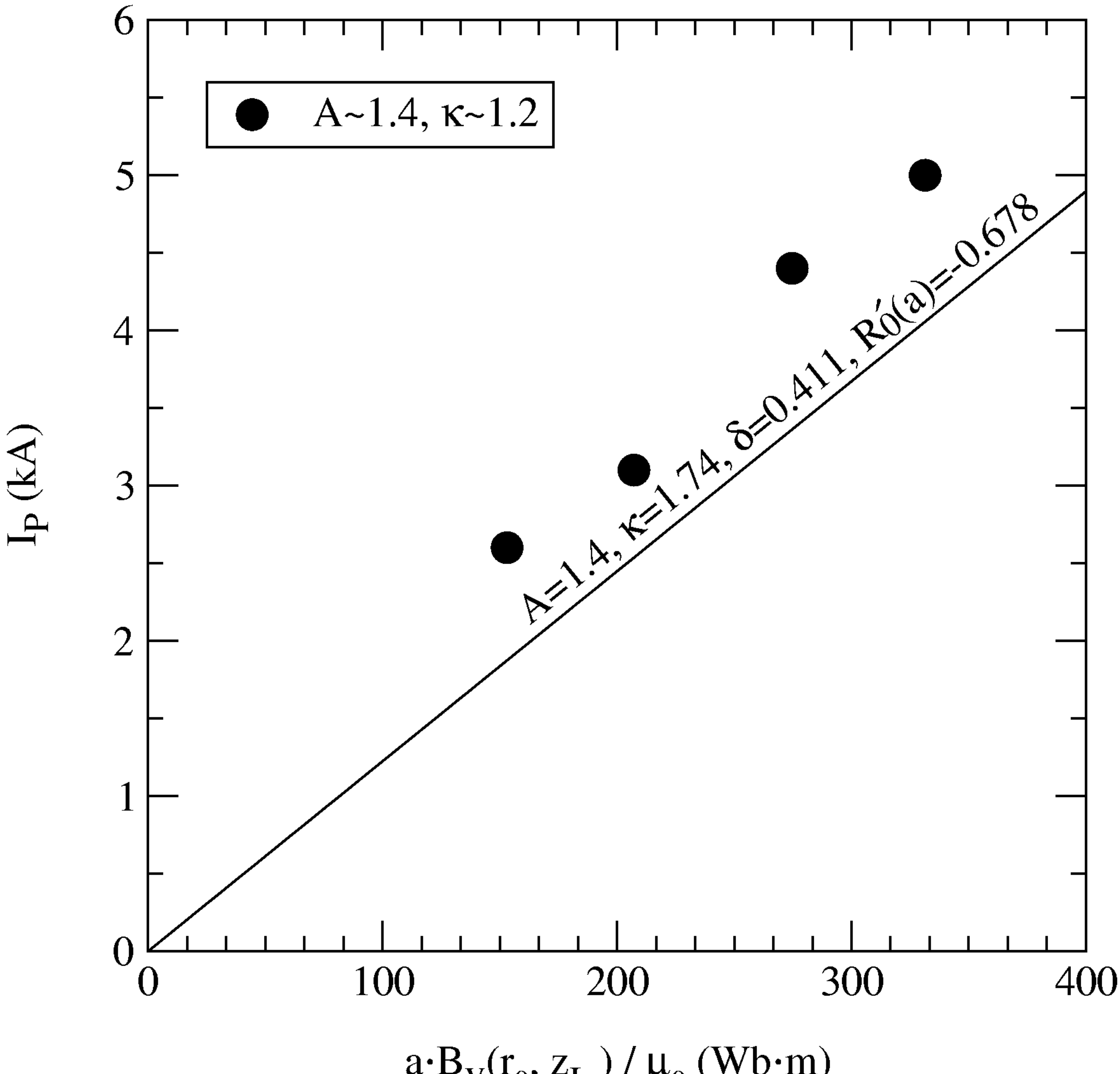




Flux Change in the No.5 Loop Coil vs. Bv



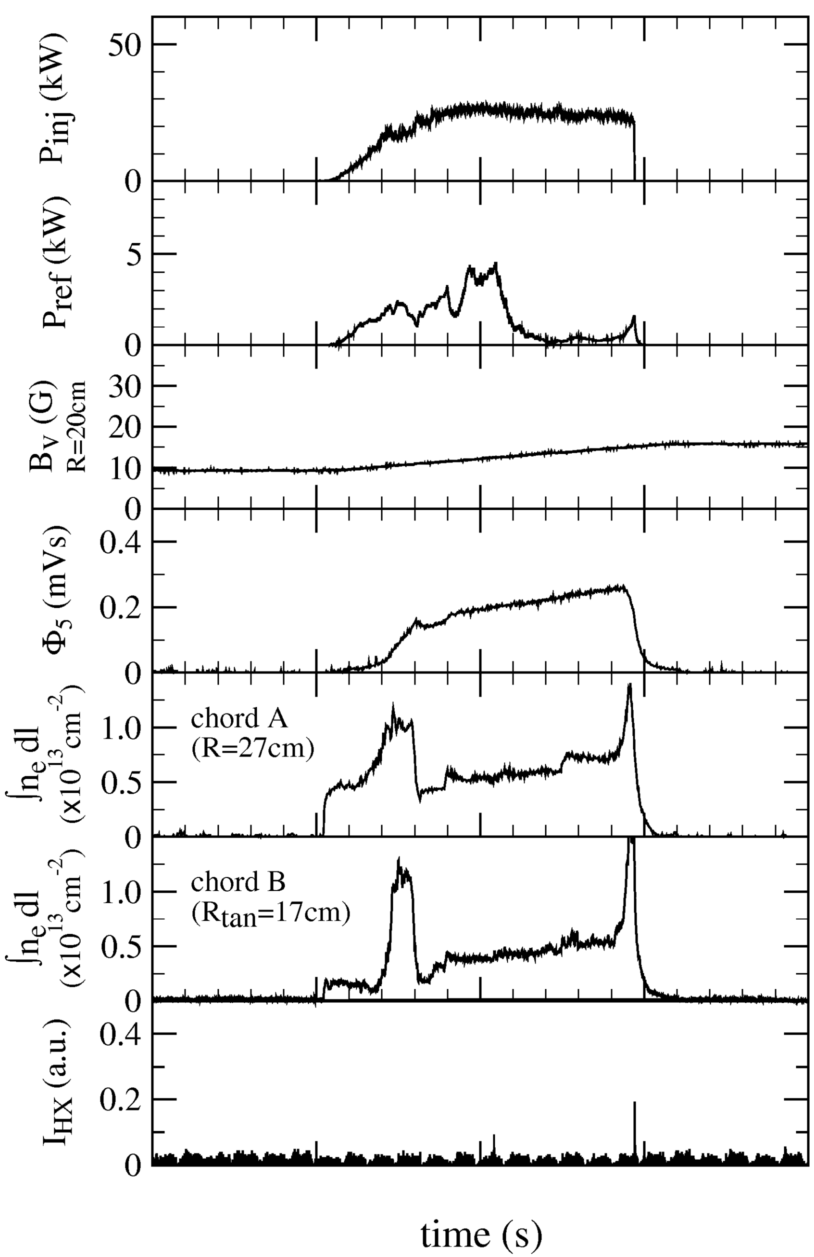
I_P vs. B_V



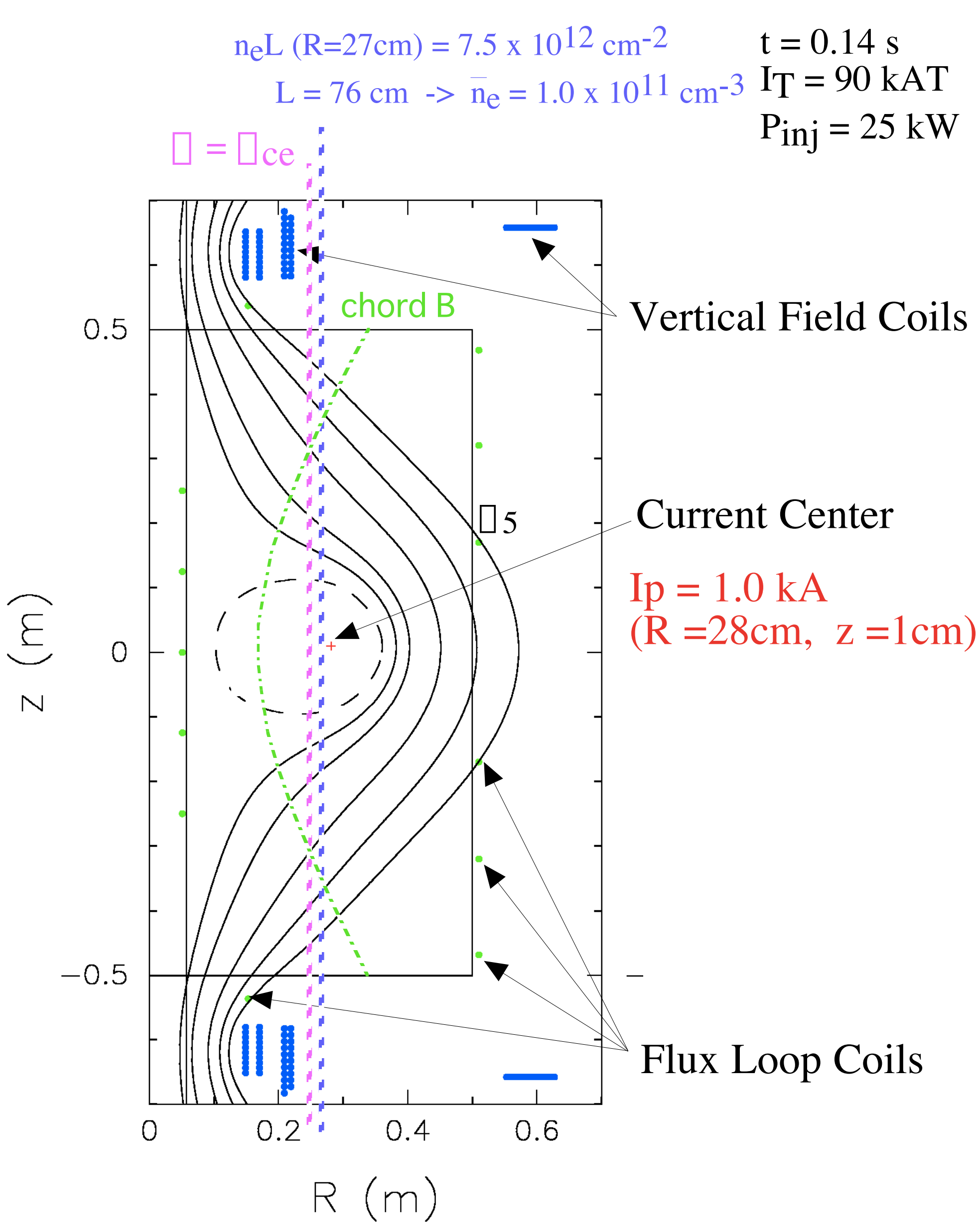
[Ref.] G. O. Ludwig and M. C. R. Andrade [Phys. Plasmas **5**, 2274 (1998)]

Time traces of a discharge

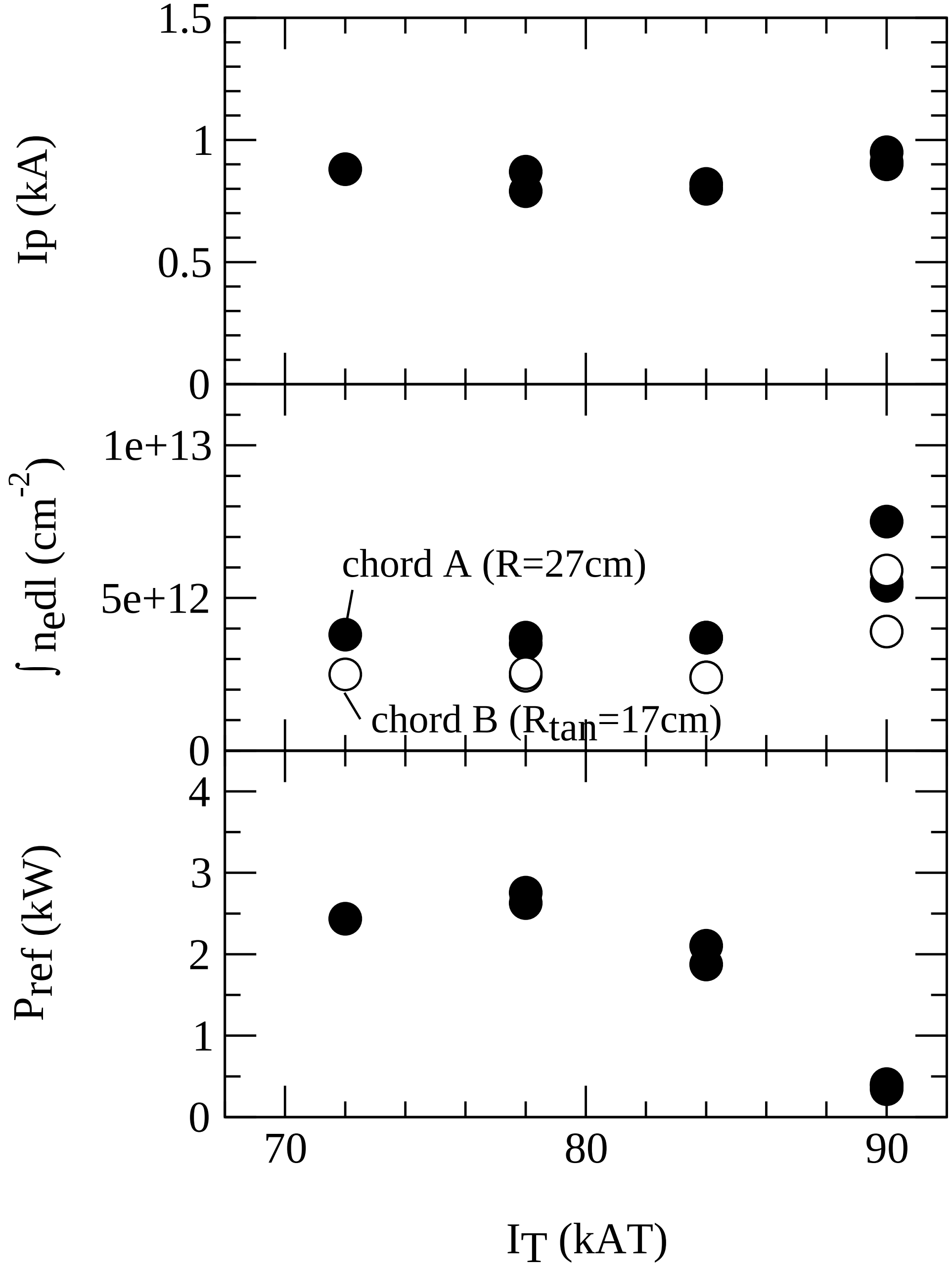
I_T = 90 kAT , $p_0(H2)$~8x10^{-3}Pa



Poloidal Flux



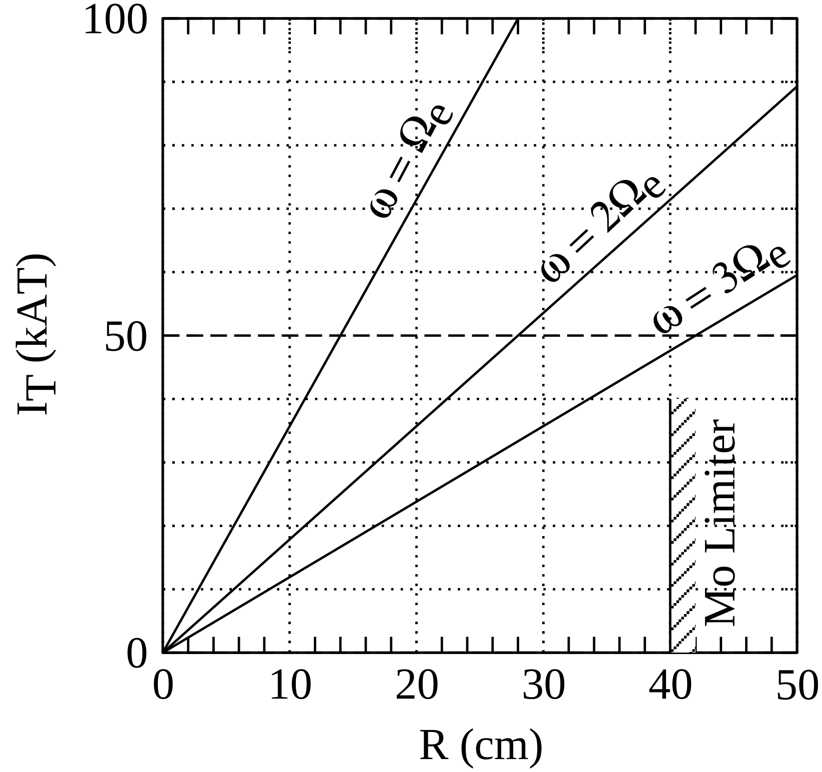
Dependence on B_T



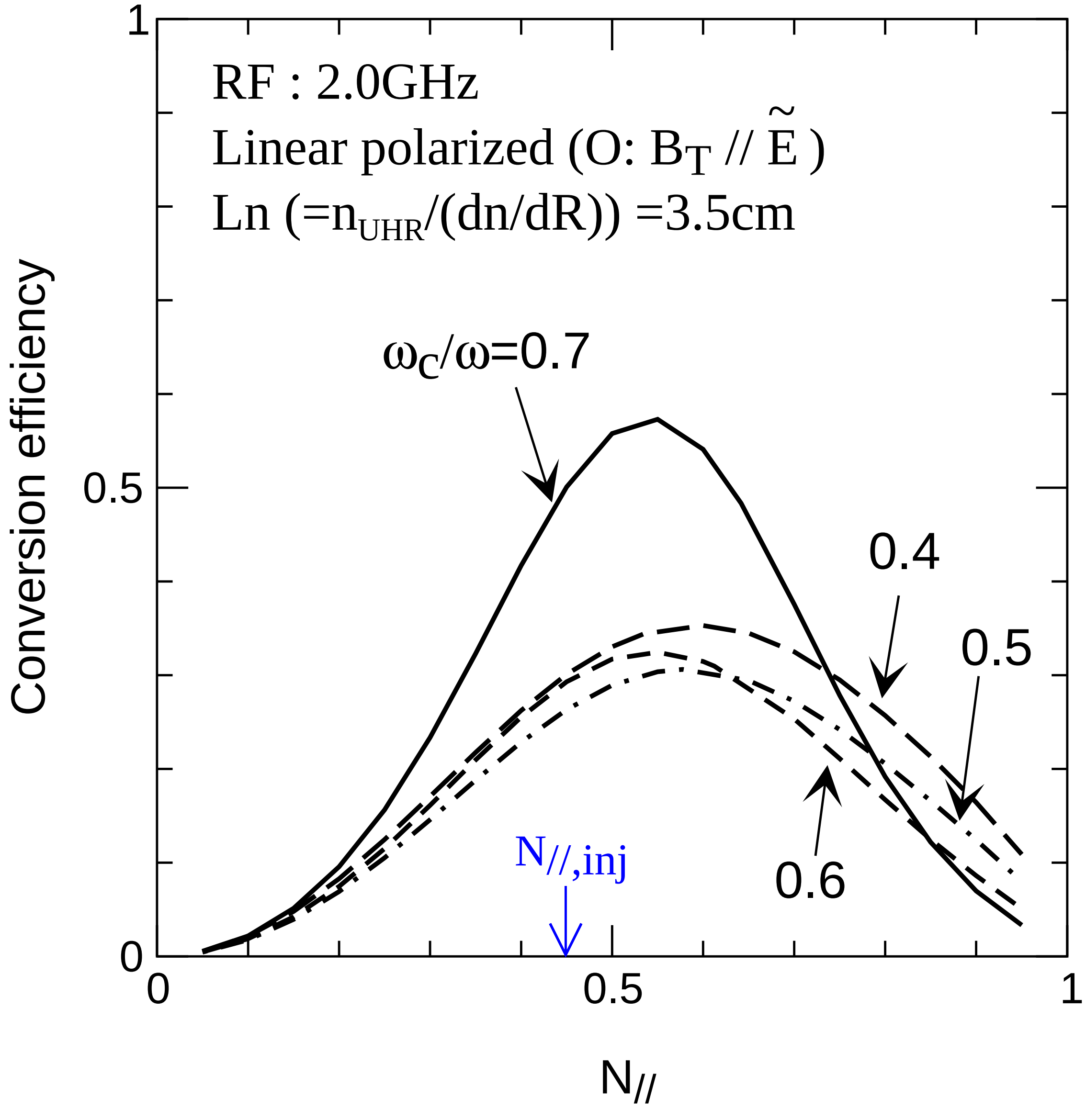
P_{inj}=25kW

$p_0(H_2)$ ~ 8x10^{-3}Pa

Bv(R=20cm)=10→15G



mode conversion efficiency



5 GHz ECH Experiment

* 5 GHz, ~ 200 kW, 0.1 s (klystron)

* $B_T(R = 20\ cm \sim R_{ECR}) = 1.8\ kG$ @ $I_T = 180\ kA$

--> better confinement

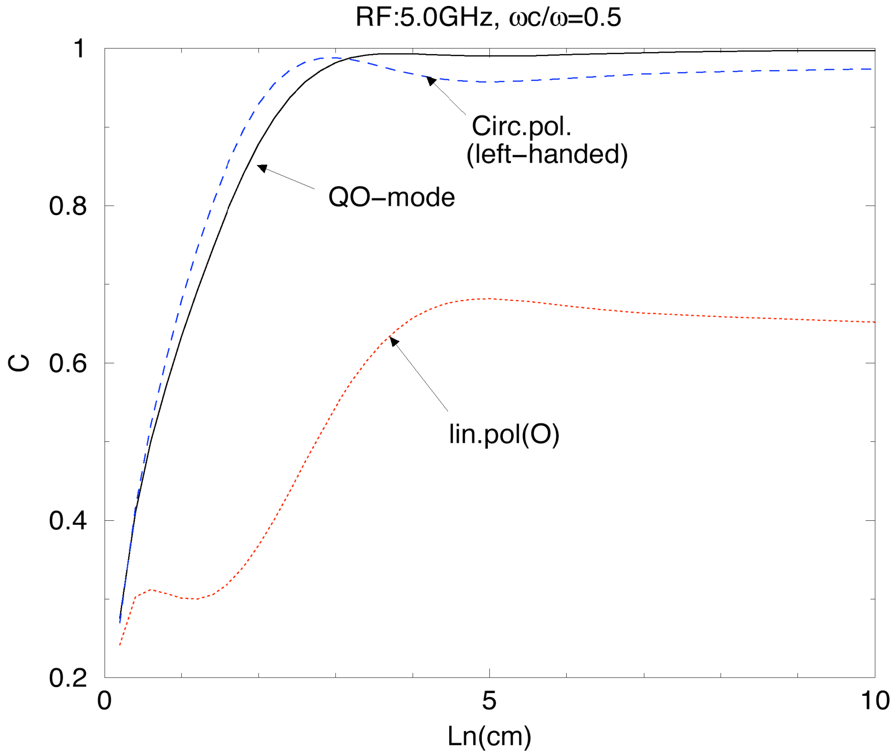
* cutoff density = $3.1 \times 10^{11}\ cm^{-3}$

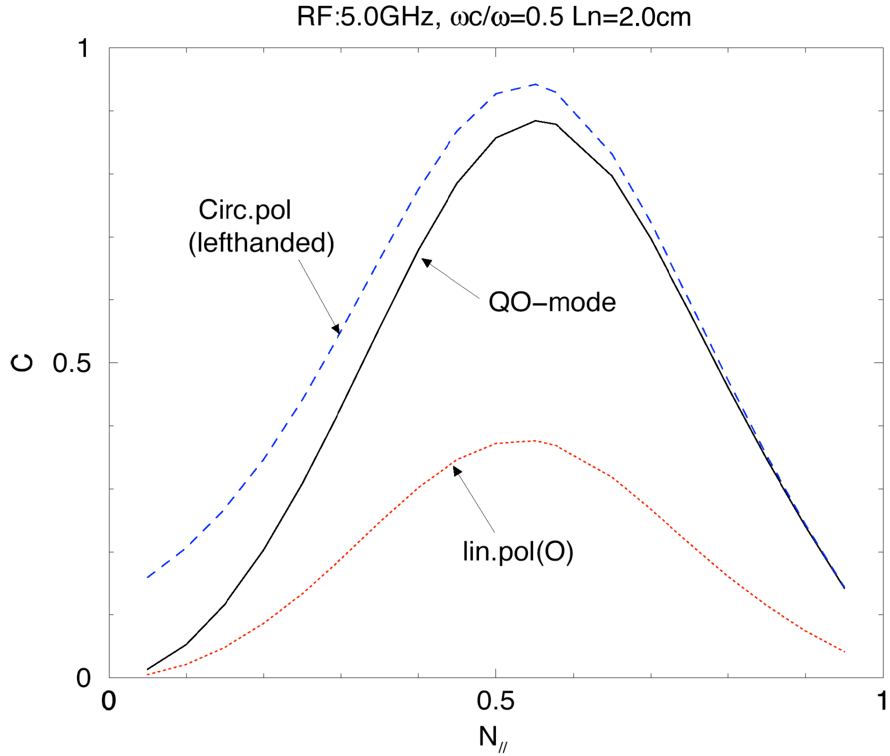
--> higher density

* OXB scheme : control of polarization

--> better mode conversion efficiency

Conversion Efficiency at 5 GHz





Summary

* By injecting the RF power (2 GHz, 45 kW, 0.1 s) and increasing the vertical field during the discharge, Ip is produced and ramped up to 5 kA.
* Formation of closed flux surfaces: The outer most flux surface has
  A ~ 1.4, □ ~ 1.2.
* Production of overdense plasma : $\bar{n}_e \sim$ 6.5 x 10^{10} cm^{-3} > n_c,
  --> suggesting EBW heating
* The maximum plasma current increases with the injected microwave power, and is linearly proportional to the applied vertical field strength.
  The relation is roughly consistent with the simple ST equilibrium model.
* At high power injection, RF power may be absorbed at plasma periphery before reaching the plasma center. --> Density profile control at the outside of the outermost flux surface is necessary.
* At higher B_T (I_T = 90 kAT), reflection is reduced and higher density is obtained :
  $\bar{n}_e \sim$ 1 x 10^{11} cm^{-3} --> suggesting that conversion efficiency increases.
* New ECH system is under construction.