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Stellarator/Helical System
Concept Improvement
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Recent CHS Experiments and Future Plan

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   - ITB formation of ECH plasma (HIBP)
   - profile bifurcation of potential (HIBP)
   - spontaneous plasma rotation (CXS)
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   - improved capabilities in heating and diagnostics
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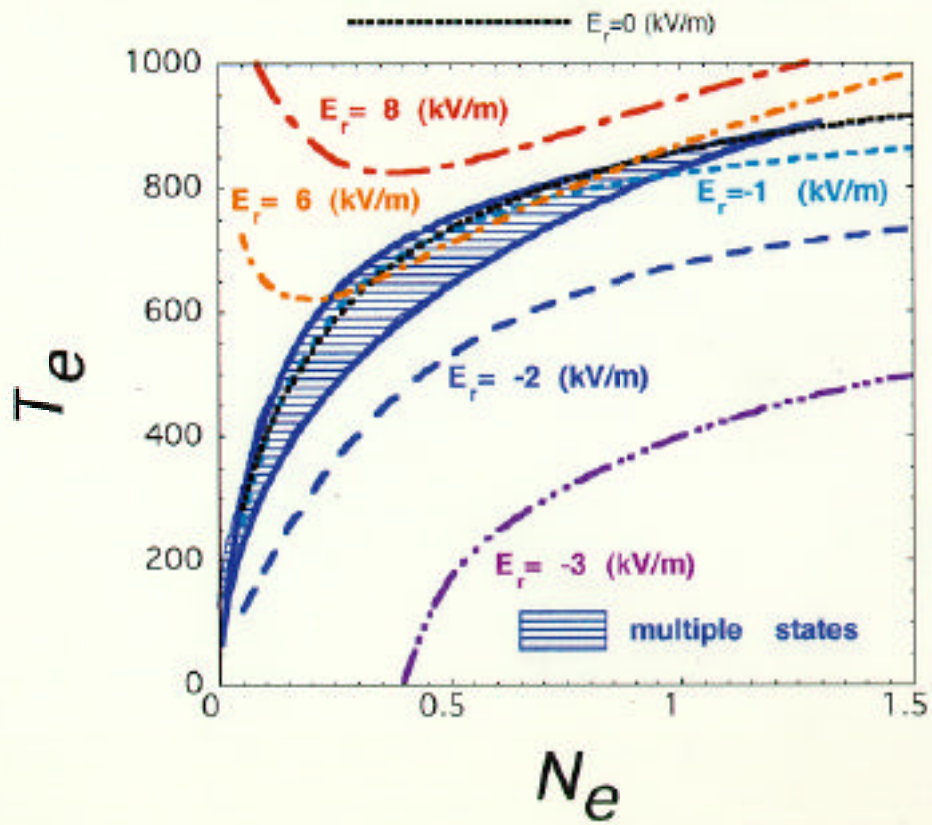
Introduction

Requisites for Helical System:

1) Confinement Improvement
   - E_r shear : bifurcation of potential
     : spontaneous plasma rotation
2) High-β Stability
   - 2nd stability at moderately inward shifted R_{ax}
   - more stable than Mercier prediction
3) Good Confinement of High Energy Particle
   - near-omnigenous configuration
4) Divertor
   - diagnostics with sheet beam probing

Multiple Steady States in Neoclassical Theory

Er-Phase Diagram



Assumption

$\varepsilon_h = 0.023 \qquad \varepsilon_t = 0.16$

$Z_{eff} = 2 \qquad T_i = 350\ \text{eV}$

$$\frac{\partial \log T(\rho)}{\partial \rho} = -0.6$$

$$\frac{\partial \log n_e(\rho)}{\partial \rho} = -0.5$$

The parameters correspond to $\rho \sim 0.3$ in CHS.

Electric Pulsation in a Toroidal Plasma

The oscillation is sustained as long as ECH is applied.

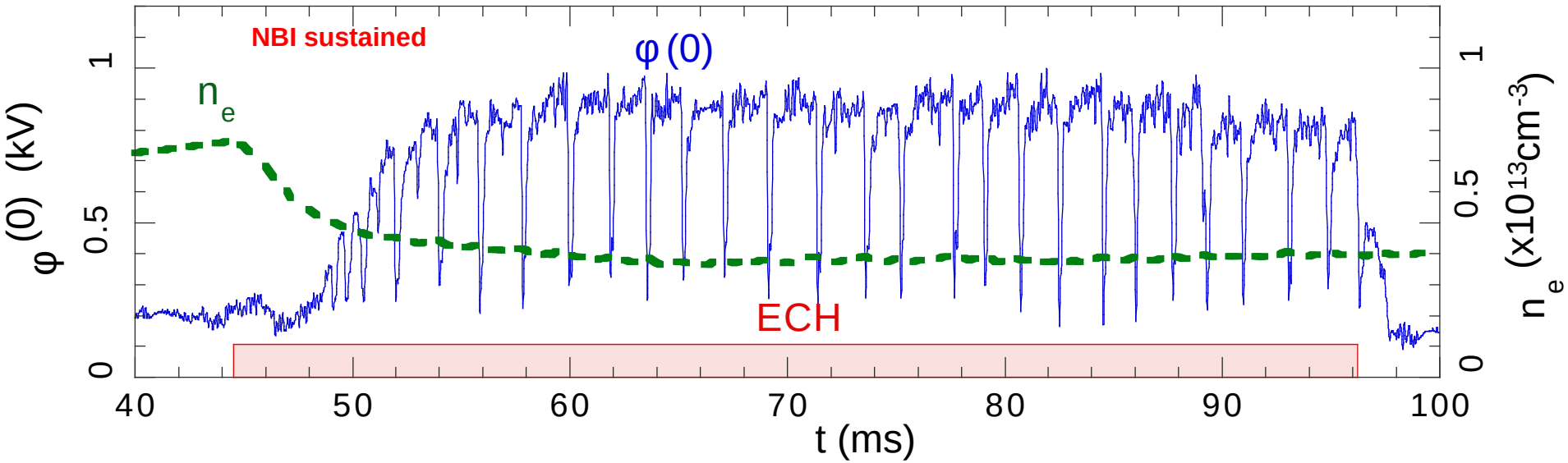
B_t=0.88T R_{ax}=0.921m

n_e~ 3x10^{12}cm^{-3} $T_e(0)$~ 1 keV

In every ~ 2ms pulse depth ~ 600V

β ~ 0.2 % No special MHD activity

~5 % of internal energy is lost from plasma, being accompanied with each crash.

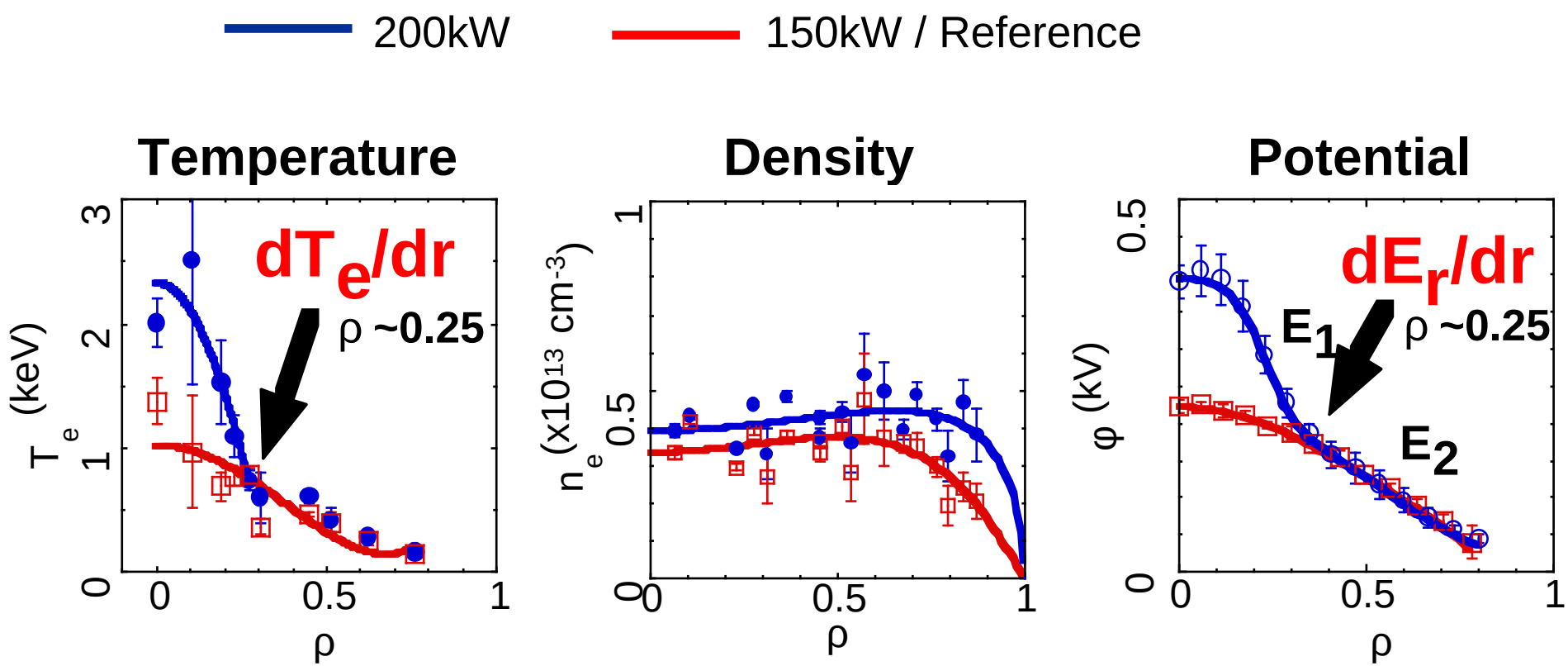


A. Fujisawa et al., Phys. Rev. Lett. **81** 2256(1998).

Internal Transport Barrier in ECH Plasma

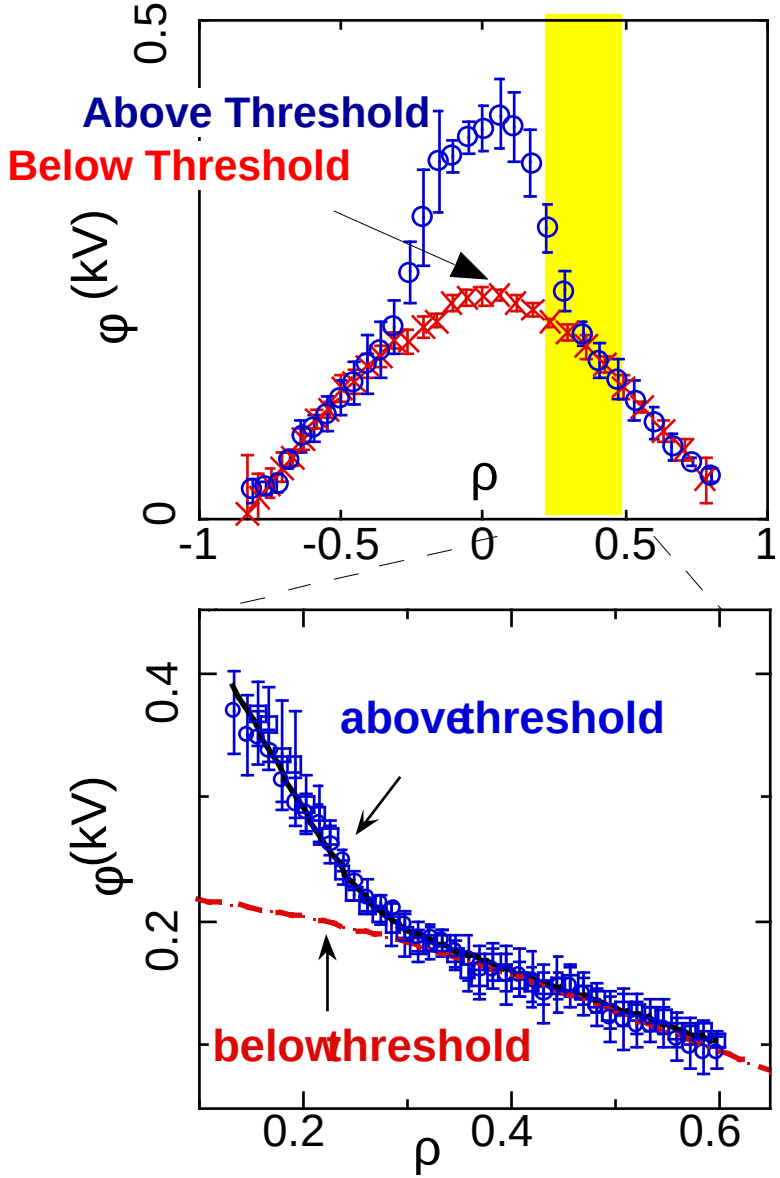
T_e (0) ~ 2keV for 200kW ECH input power.

Line average density $\langle n_e \rangle \sim 4\times10^{12} cm^{-3}$.



An internal transport barrier for electron is suggested in ECH plasmas.

Fine Structure of Potential in Interface Domain



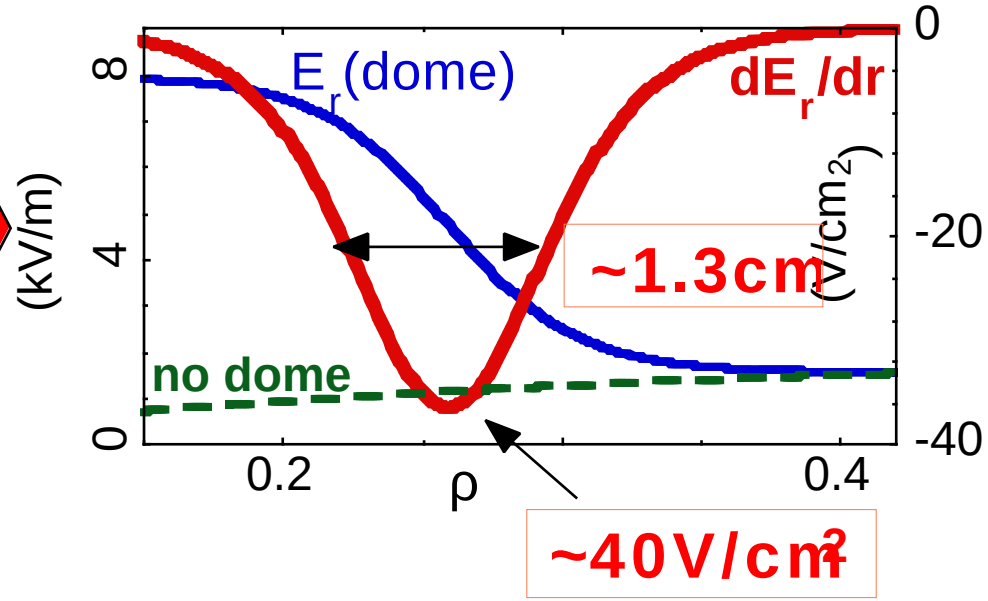
- **Power Threshold for a Dome**

  ~150-170kW for n_e ~ 3-4x10^{12}cm^{-3}

- **Precise Measurements of Interface**

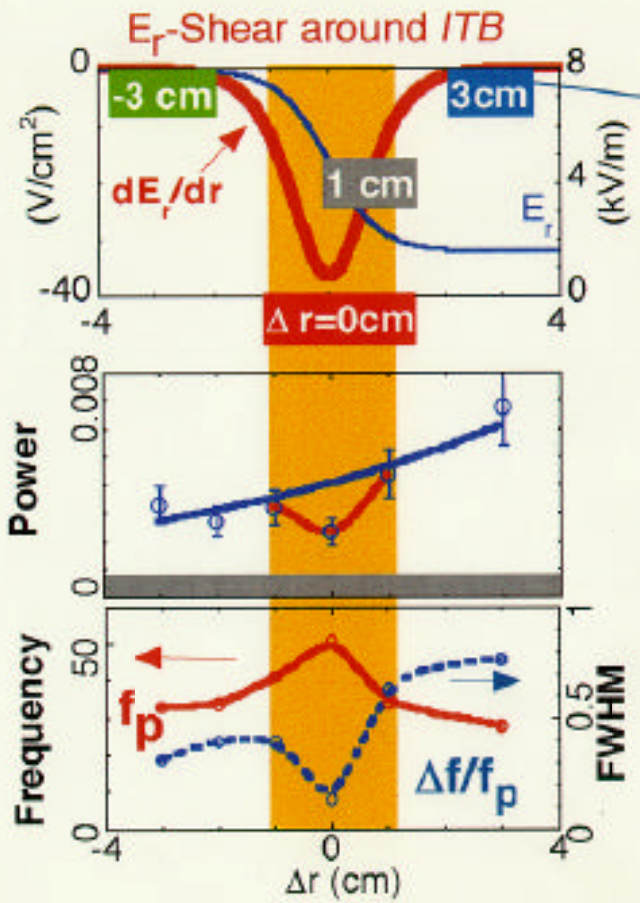
  Er can be divided into two phases

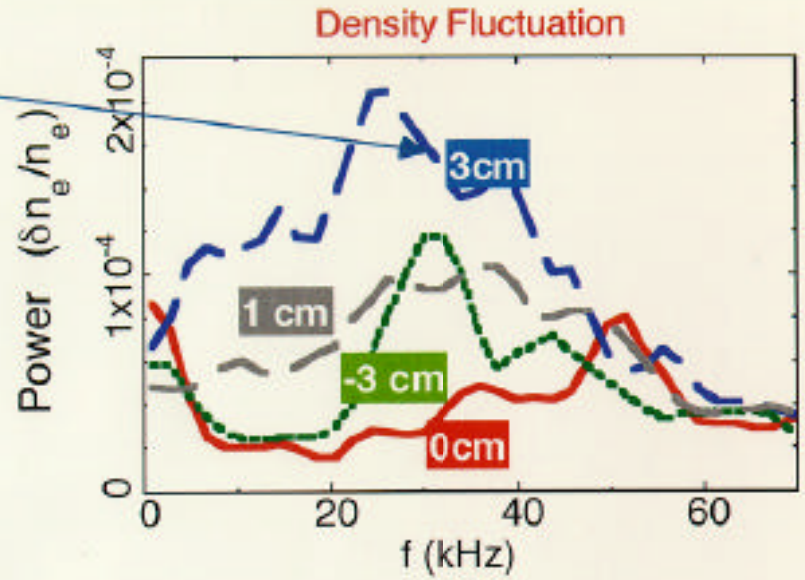
$$E_r(r) = A^* \, \mathrm{Tanh}[(\rho-\rho_0)/\alpha] + B$$



How is the fluctuation around the E_r-shear maximum ?

Fluctuation Suppression around *ITB*





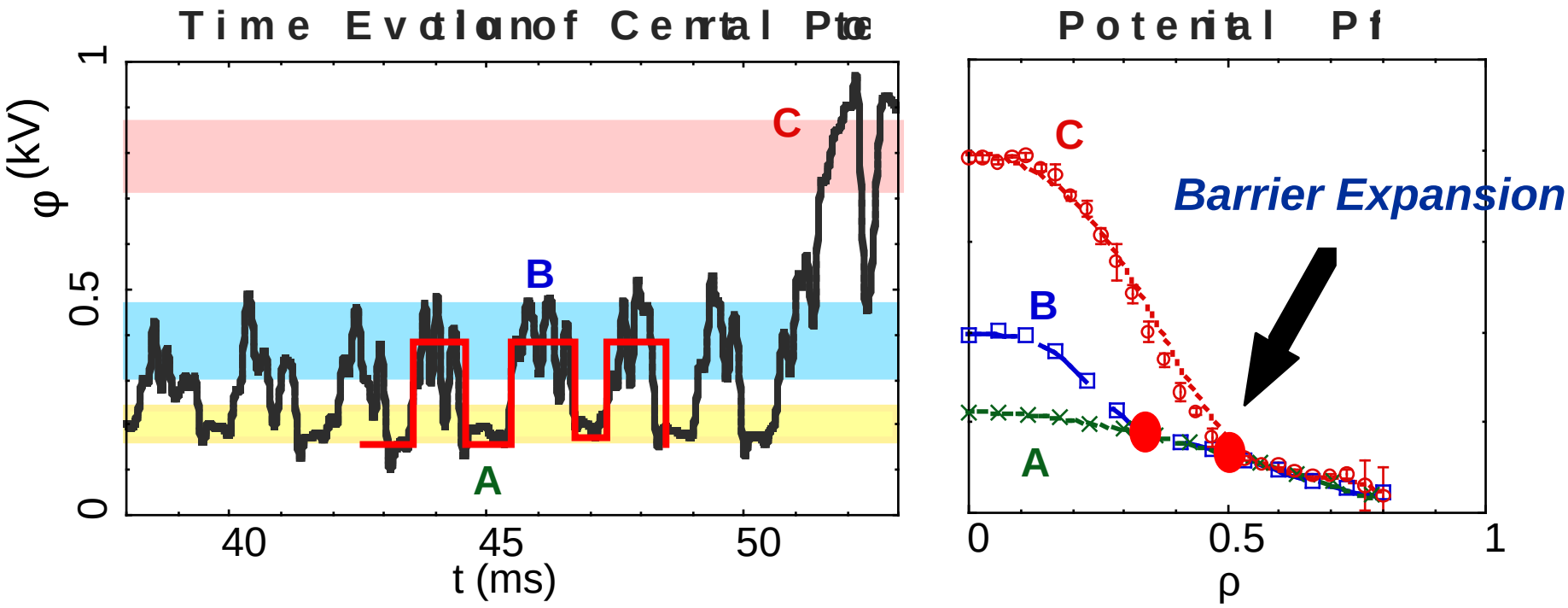
- At *Barrier* Point $dE_r/dr \sim 40 V/cm^2$
- Fluctuation power is reduced by ~50%.
- Lower f-wave are more suppressed.

Suppression of fluctuation leads to high $T_e \sim 2$ keV.

Bifurcation Nature in ECH Plasmas

- Bifurcation Nature in Time & Discontinuity of Potential Profile - D-Plasma

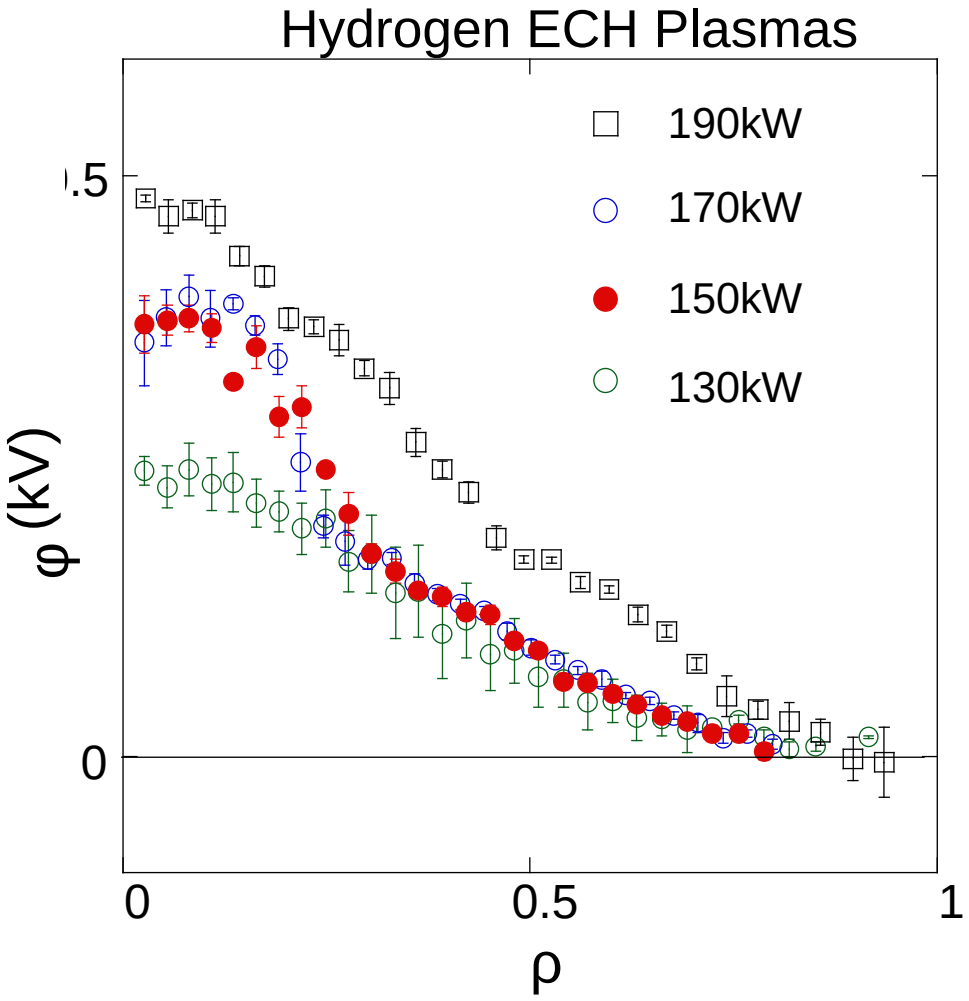
Near the ECH power threshold ~ 150kW n_e= ~ $4\times10^{12}cm^{-3}$



Successive spontaneous transitions (ELM-like behavior) are observed.

High T_e- regime could become wider with barrier expansion.

ECH Power Dependence of Potential Profiles



Profile bifurcation is also seen in ECH power scan.

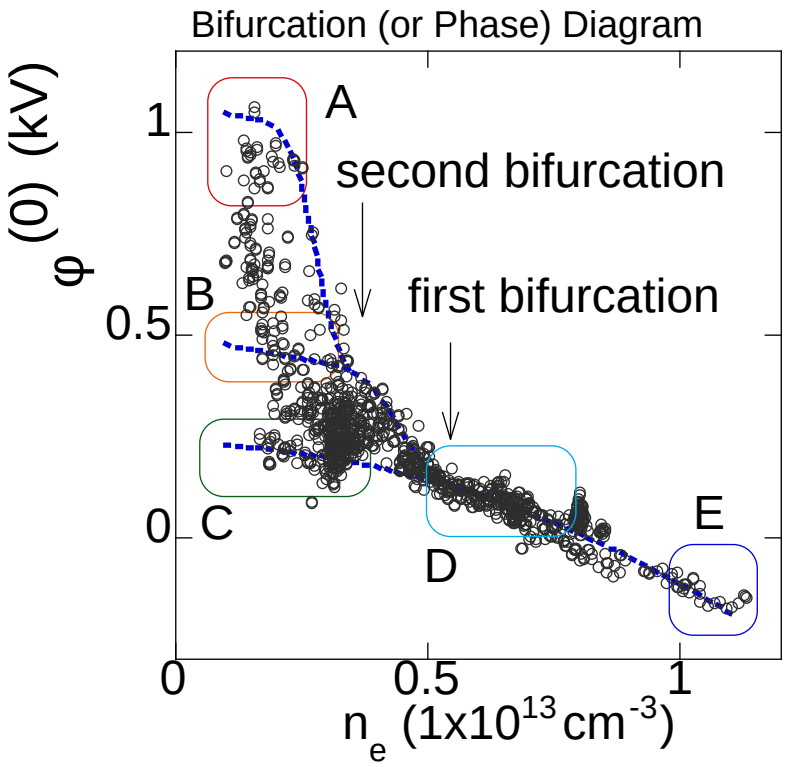
- As power increases,
central potential increases to form a dome
finally the dome disappears

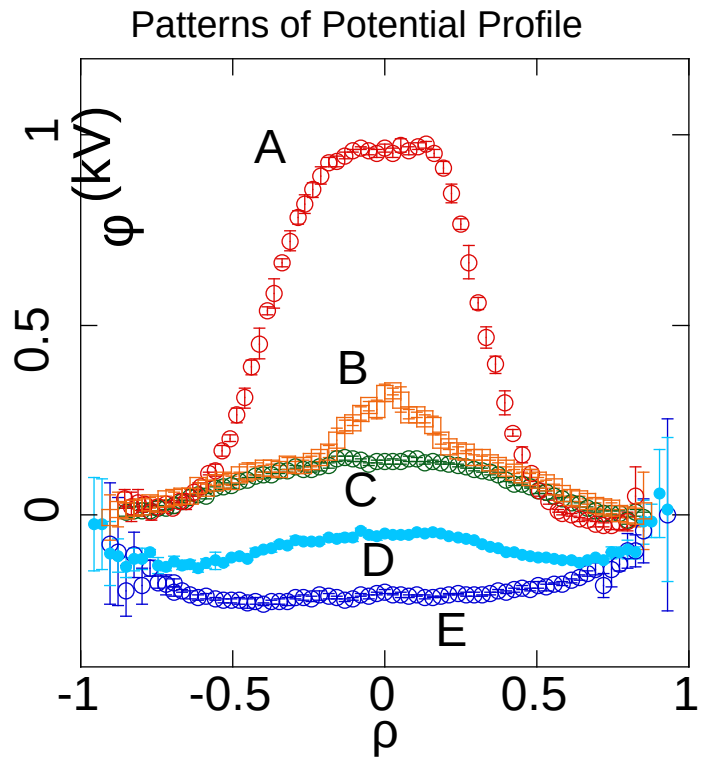
- Power Threshold for a dome
~ 150kW

Bifurcation Diagram of Er in ECR-Heated CHS Plasma

P_{ECH}=100kW

25 profiles x 35 shots ~ 800 points data

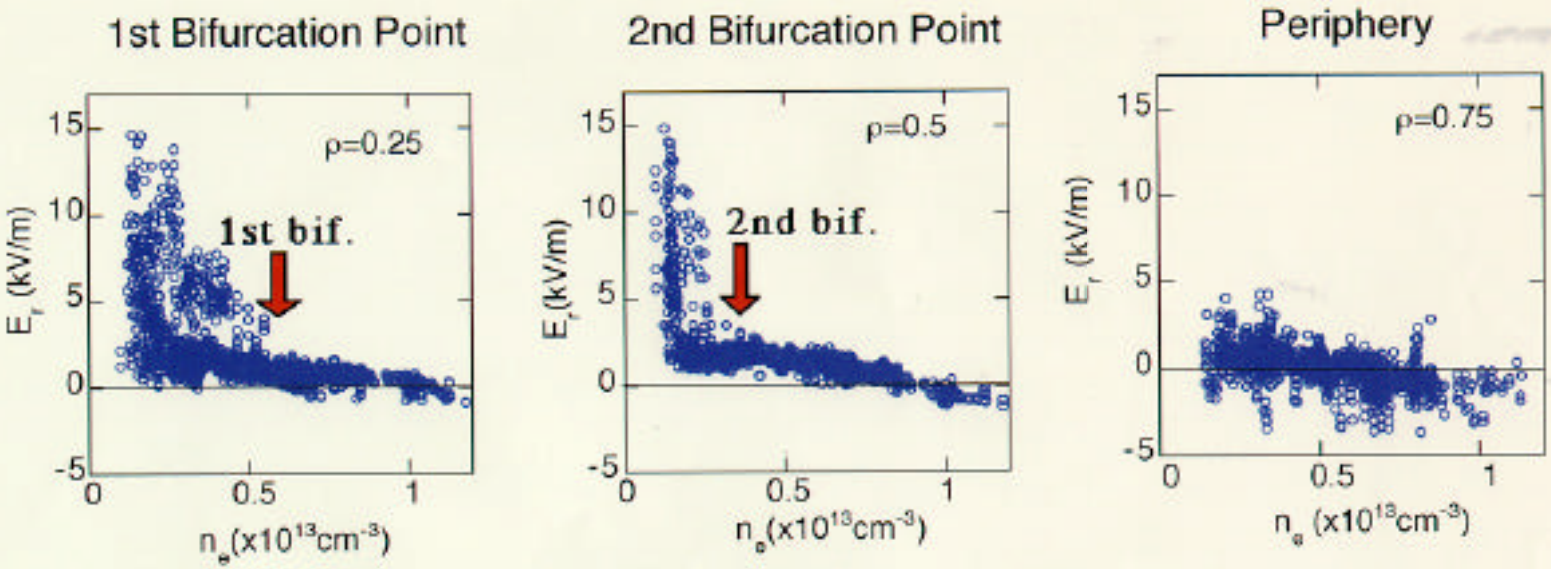




Three branches in low density

Classification of potential profile is possible using the bifurcation diagram.

Bifurcation Diagram of Er in ECR-Heated CHS Plasma



E_r in periphery shows continous change with density.

Structural bifurcation in potential profile is based on the bifurcations of E_r at two different radii.

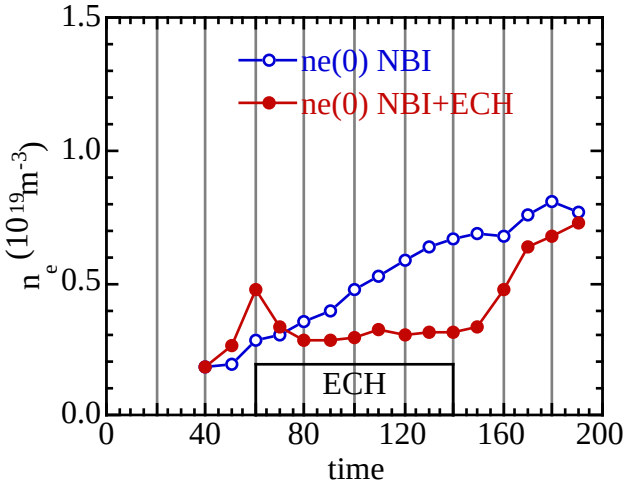
Spontaneous toroidal rotation in CHS

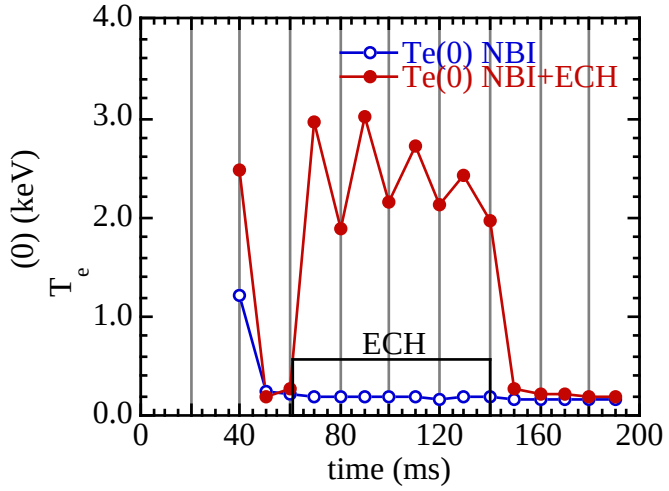
Bt = 0.88T

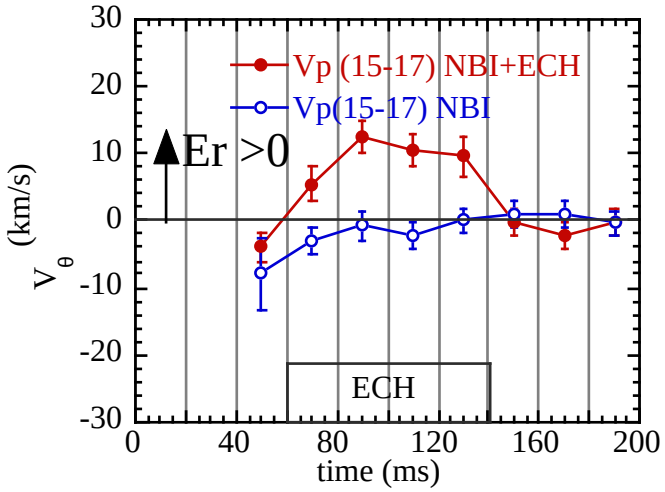
Rax = 0.92m

Pnbi = 0.7MW

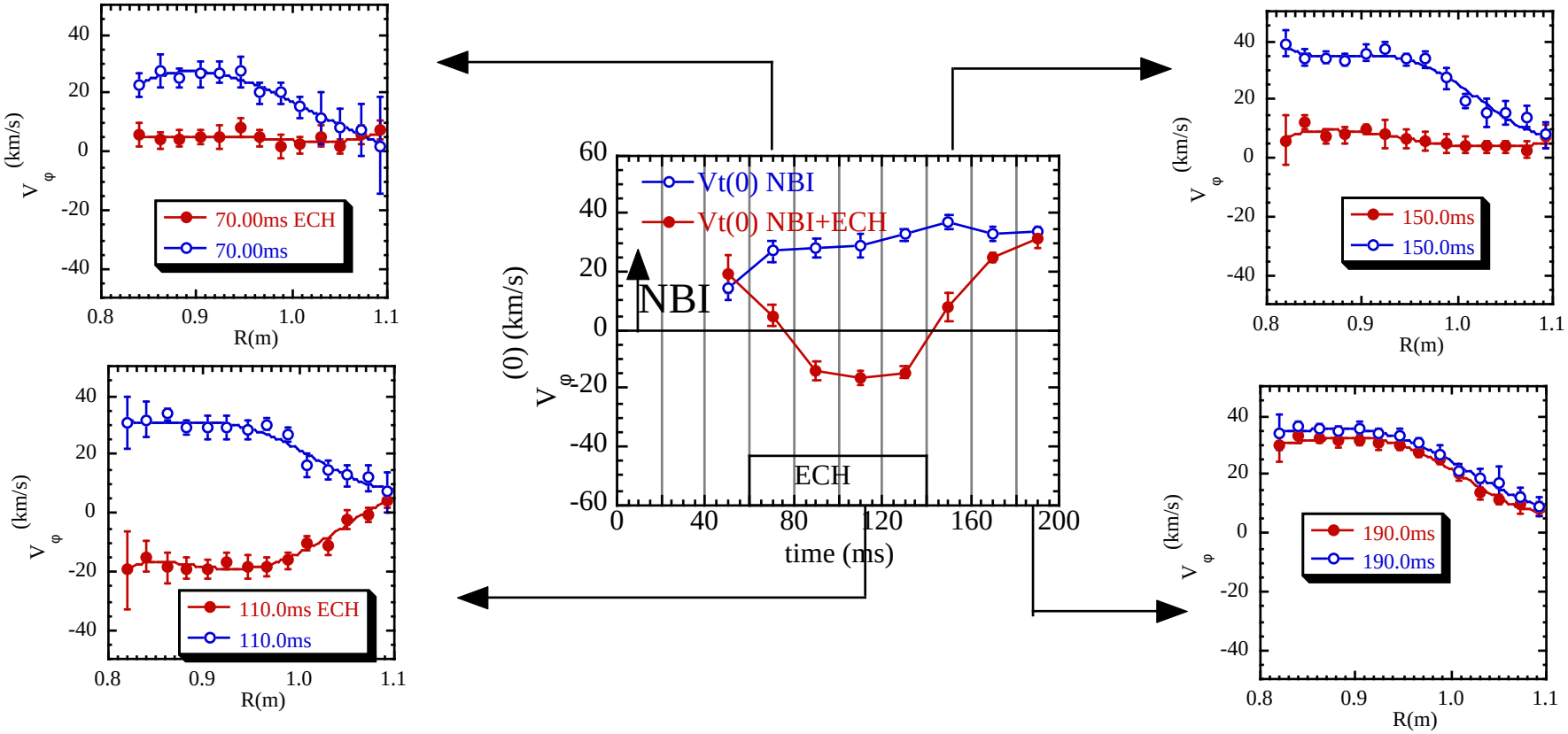
Pech= 0.12MW



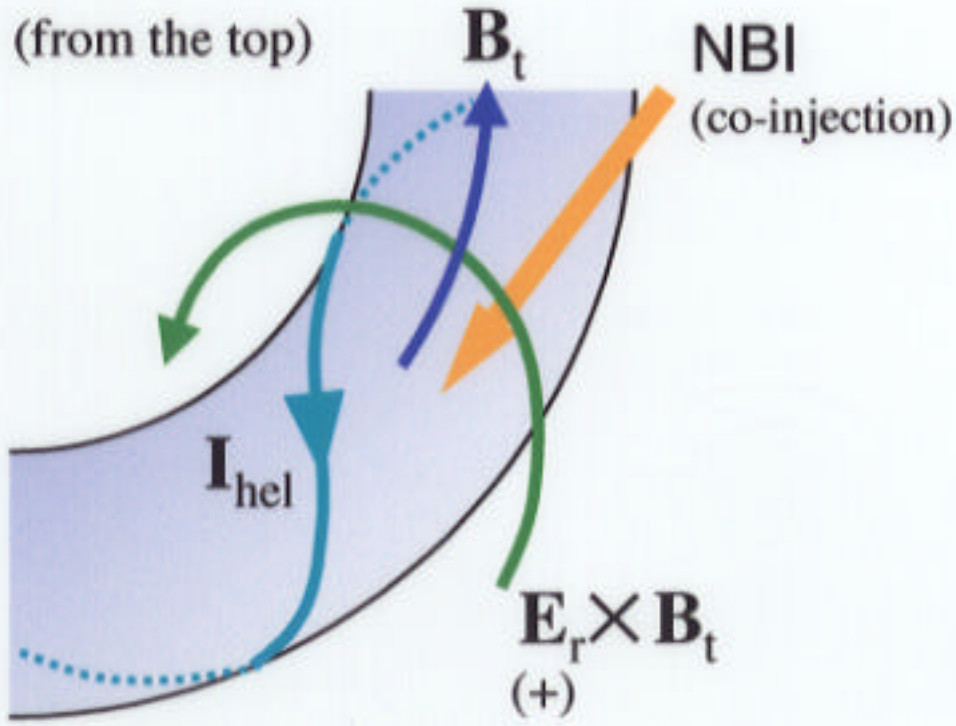




Spontaneous toroidal rotation in CHS

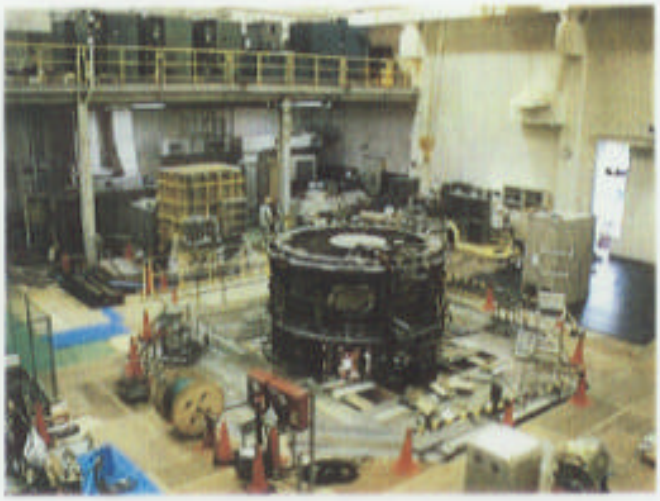


Spontaneous Plasma Rotation



- Direction is anti-parallel to co-injected NBI due to positive $\mathbf{E}_r$.
- Spontaneous plasma rotation should play an important role in confinement improvement.

CHS in New Torus Hall



Area of Torus Hall:
30m×30m
with additional 2nd floor

Power Supply:

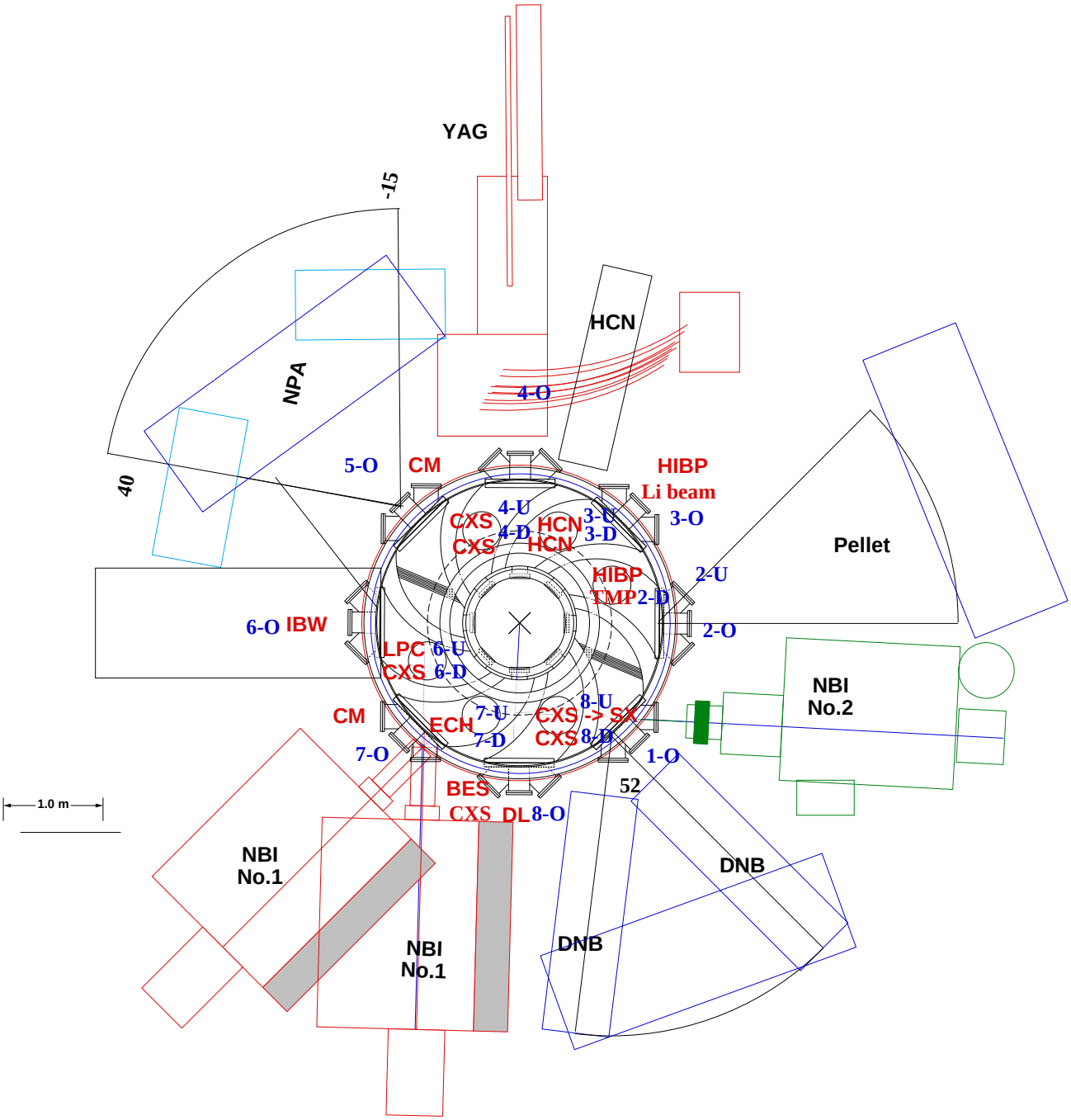
1) HF/OVF:	15kA/4800V
2) TVF:	15kA/4800V
3) SF:	8kA/2400V
4) IVF:	3.6kA/2400V
5) MVC:	5kA/2000V
6) IVC:	5kA/2000V

Water Cooling System:
2.7MW cw

New Features of CHS Experiment

- 2 beamlines are in the co-direction
  ---> increase in
  1) deposited power (high β experiment)
  2) toroidal rotation (rotation shear)
  3) beam fueling to the plasma core (high T_i-mode)
- HIBP in extended operation range (B_t)
  ---> bifurcation phenomena at extended plasma parameters (T_e, n_e)
- 2-D scanning capability of DNB, ice pellet injector
  ---> flexibility in T_i and rotation measurement for ECH plasma
  ---> high field side pellet fueling for confinement improvement
- divertor diagnostics with sheet beam probing

- experiment will start in Jan. of next year.


YAG
-15
HCN
NPA
4-O
5-O
CM
HIBP
Li beam
40
4-U
CXS
4-D
HCN
3-U
3-D
3-O
Pellet
HIBP
TMP
2-D
2-U
6-O
IBW
2-O
LPC
CXS
6-U
6-D
NBI
No.2
CM
ECH
7-U
7-D
CXS -> SX
CXS
8-U
8-D
7-O
1-O
52
BES
CXS
DL
8-O
1.0 m
NBI
No.1
DNB
NBI
No.1
DNB

Summary

1) Multiple steady state of helical plasma equilibrium manifests itself in ITB of electron temperature profile. High T_e is realized due to the fluctuation suppression at the interface domain.
   Data are obtained showing profile bifurcation.
2) Spontaneous plasma rotation, of which toroidal direction gets opposite to NBI, is observed by applying ECH to low density NBI plasma. $E_r \times B_t$ poloidal rotation induced drives the plasma in the direction of const. B.
3) CHS is to be operated to do experiments on confinement improvement, of which experimental subjects are complementary to LHD, until CHS-qa operation (when?).