I-12

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Topological Changes in Magnetic Flux Surfaces during IDB-SDC Discharge in LHD

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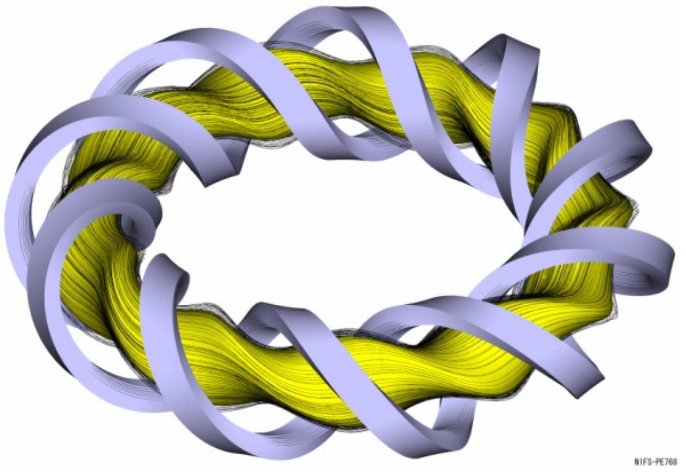
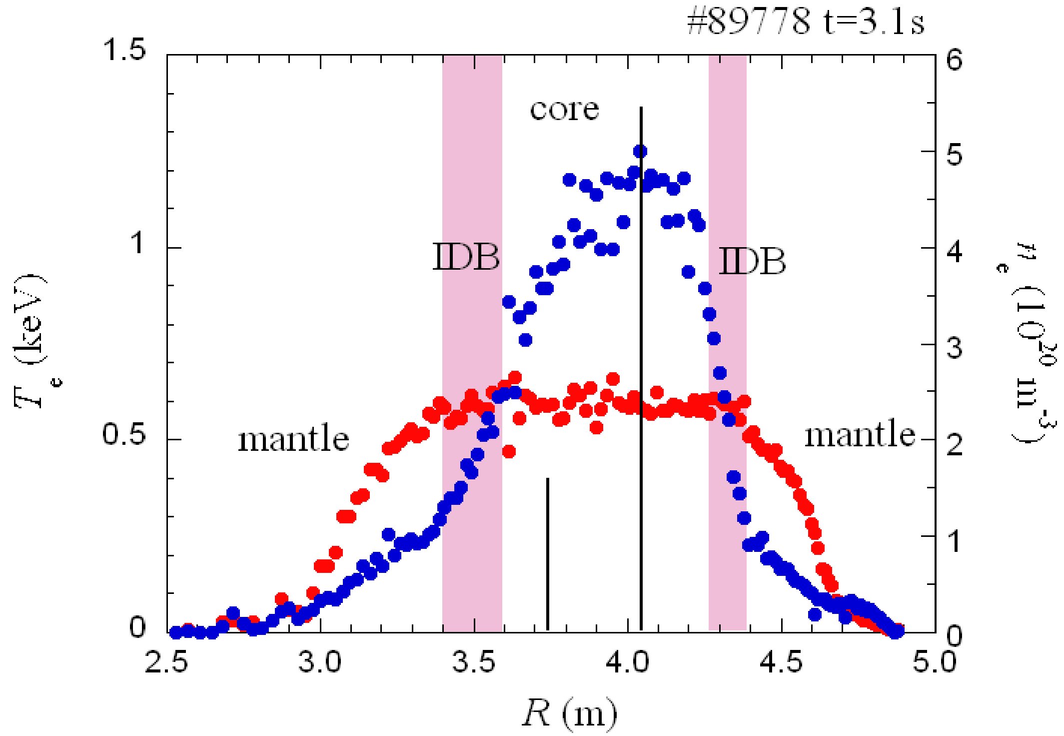
Contents

1) Motivation and background
2) Introduction to IDB-SDC discharge
3) Experimental numerical setup
4) Results
5) Summary



Motivation and background



SuperDense Core plasma with Internal Diffusion Barrier
(**IDB-SDC** plasma)

- * $n_e(0) \sim 1\times10^{21}$ m^{-3}
- * $Te(0) \sim 0.4$ keV
- * $P(0) \sim 140$kPa
- * $W_{dia} \sim 1$MJ
- * $\beta(0) \sim 4.7\%$
- *$n\tau T \sim 4.4 \times 10^{19}$ keVsm^{-3}

high pressure core region ==> - large Shafranov shift
steep gradient at IDB ==> - spontaneous current , e.g. bootstrap
- destabilization

on the other hand….

low pressure and low-gradient mantle

what happened to magnetic topology ?

Introduction to IDB-SDC plasma

Scenario to achieve IDB-SDC plasma

Edge plasma control with divertor and wall conditioning

- impurity control
- recycling control (profile control)

Central fuelling by pellet injection

low n_0
low edge n_e
high edge T_e
high T_e at pedestal

→ superdense core

IDB-SDC discharges with highly dense core and low mantle plasmas

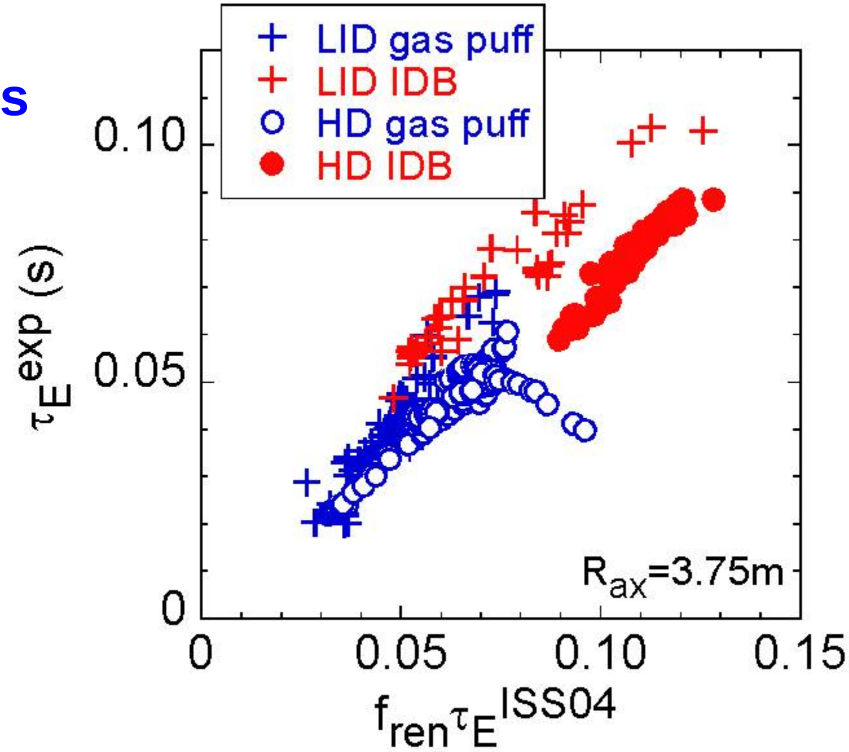
- reduce radiation loss in edge region
  ==> evade radiation collapse
- realize deep fuelling
- realize central deposition of heating power
- bring about steep T_e gradient

↓

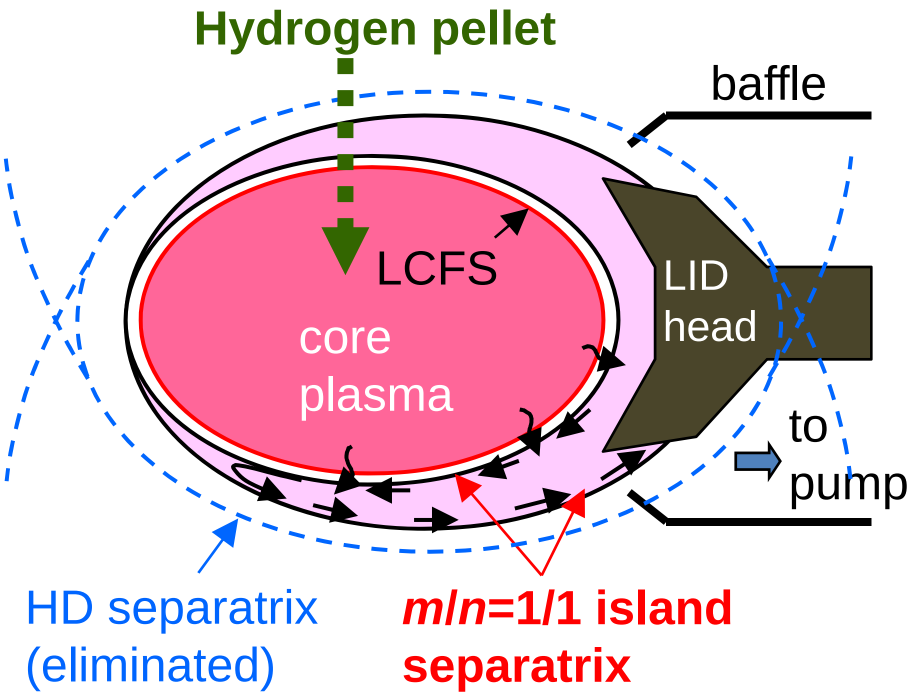
confinement improvement

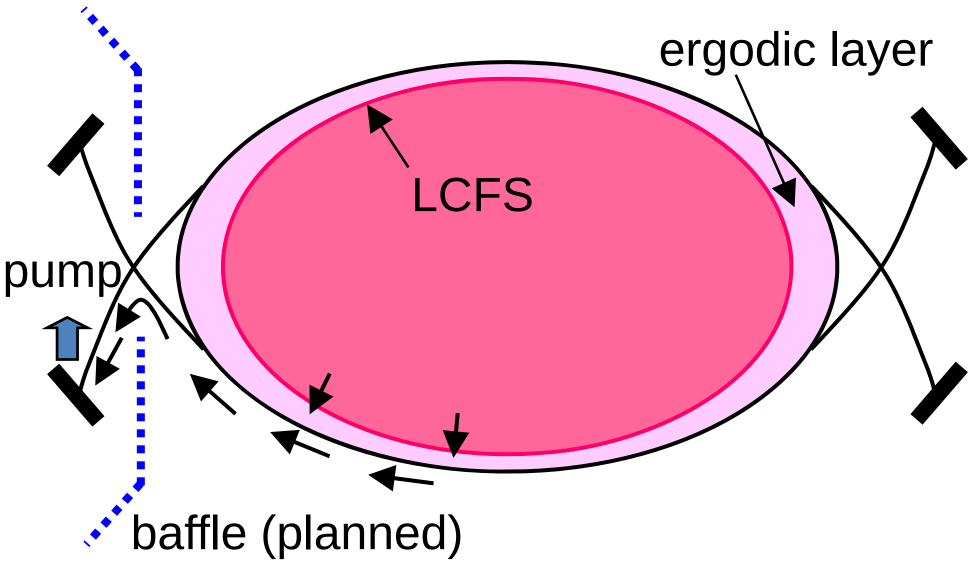
keeping positive n_e dependence

$$\tau_E^{ISS04} = 0.134 a^{2.28} R^{0.64} P^{-0.61} \bar{n}_e^{0.54} B^{0.84} \iota_{2/3}^{0.41}$$



Two divertor concepts in LHD





Local Island Divertor (LID)

* utilize *m*/*n*=1/1 island

* insert a divertor head **locally**

==> recycling region is localized

==> full closed configuration available

* no ergodic layer.

Helical Divertor (HD)

* Intrinsic double-null type divertor

* with thick ergodic layer

* long legs.

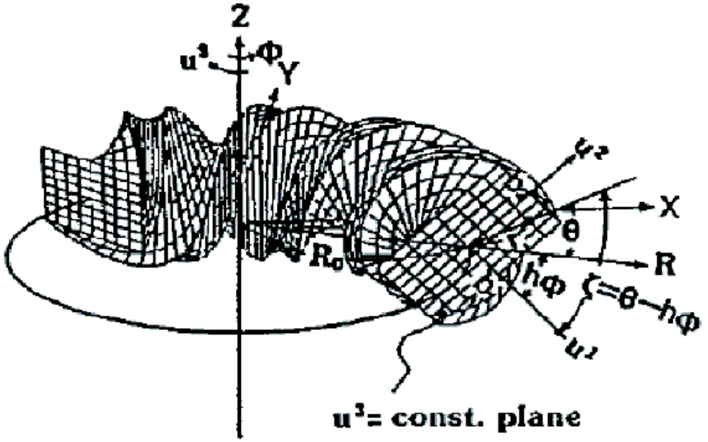
* short field lines (2-3m in LHD)

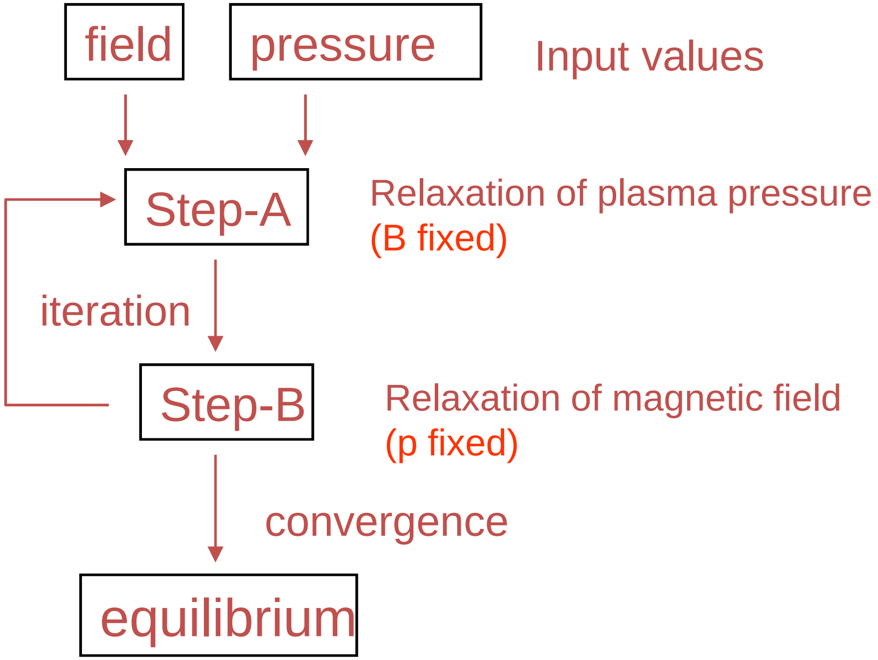
* nonaxisymmetric

HINT2 code

3D MHD equilibrium calculation code without assumption of nested flux surfaces

- relaxation method (initial value problem)
- Eulerian coordinate(rotating helical coordinate





field

pressure

Input values

Step-A

Relaxation of plasma pressure
(B fixed)

$$p^{i+1} = \bar{p} = \frac{\displaystyle\int_{-L_{\rm in}}^{L_{\rm in}} \mathcal{F} p^i \frac{dl}{B}}{\displaystyle\int_{-L_{\rm in}}^{L_{\rm in}} \frac{dl}{B}}, \quad \mathcal{F} = \begin{cases} 1 & : \ \text{for } L_C \ge L_{\rm in} \\ 0 & : \ \text{for } L_C < L_{\rm in} \end{cases}$$

iteration

Step-B

Relaxation of magnetic field
(p fixed)

$$\frac{\partial \mathbf{v}}{\partial t} = -f_C[\nabla p - (\mathbf{j} - \mathbf{j}_0) \times \mathbf{B}]$$

$$\frac{\partial \mathbf{B}}{\partial t} = \nabla \times [\mathbf{v} \times \mathbf{B} - \eta(\mathbf{j} - \mathbf{j}_0 - \mathbf{j}_{\rm net})]$$

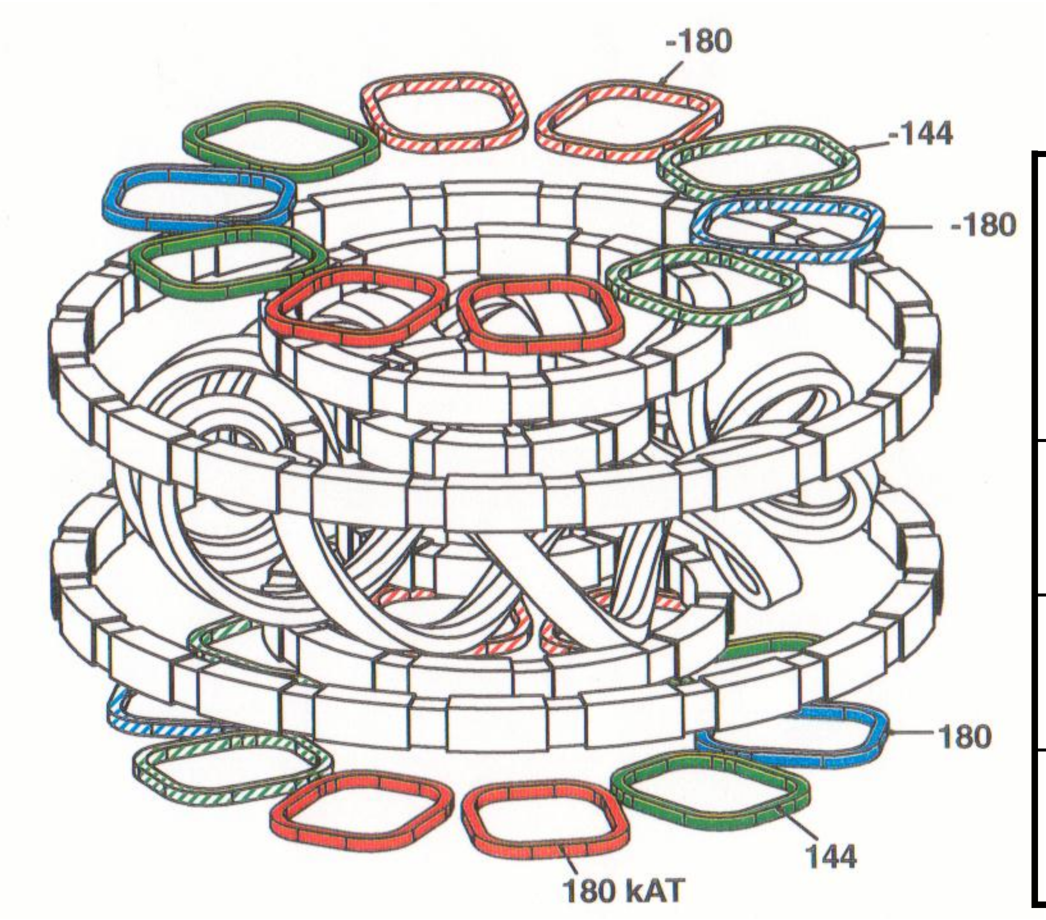
$$\mathbf{j} = \nabla \times \mathbf{B}$$

$$f_C = \begin{cases} 1 & : \ (B \le B_C) \\ (B_C/B)^2 & : \ (B > B_C) \end{cases}$$

convergence

equilibrium

Perturbation coils



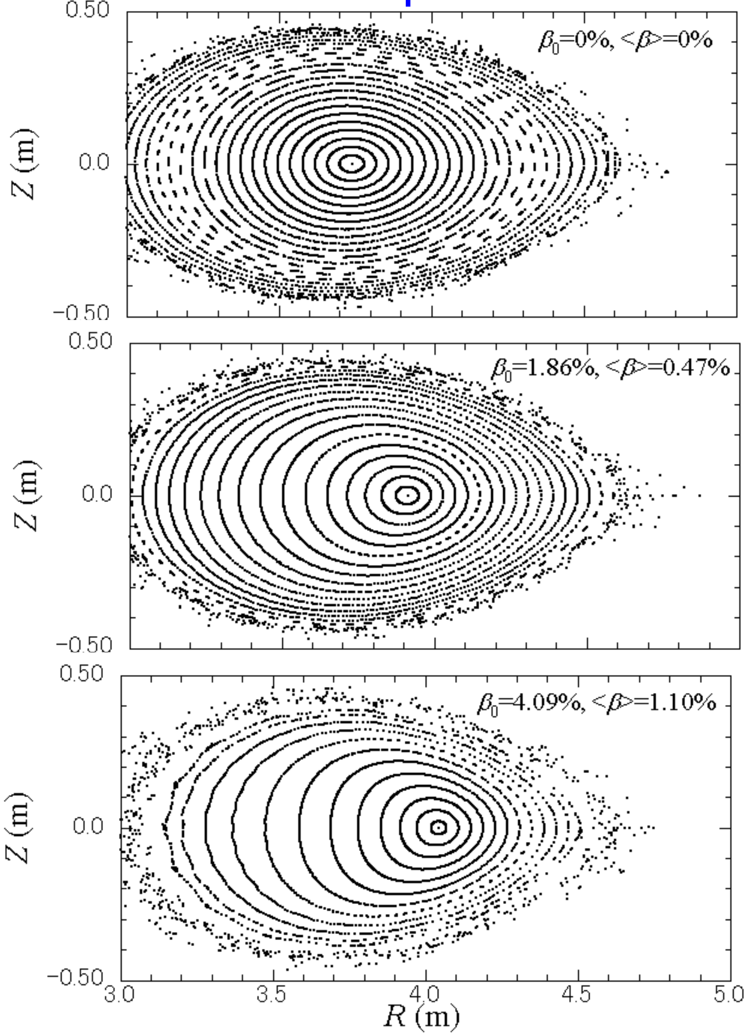
10 pairs of normal conductor coils

DC power supplies

	Steady state operation		Pulse operation	
	Current (kA)	Voltage (V)	Current (kA)	Voltage (V)
1	**1.92**	**240**	**3.84**	**350**
2	**1.92**	**460**	**3.84**	**680**
3	**1.92**	**460**	**3.84**	**680**

As β_0 increases .... (1)

b/B_T=0%

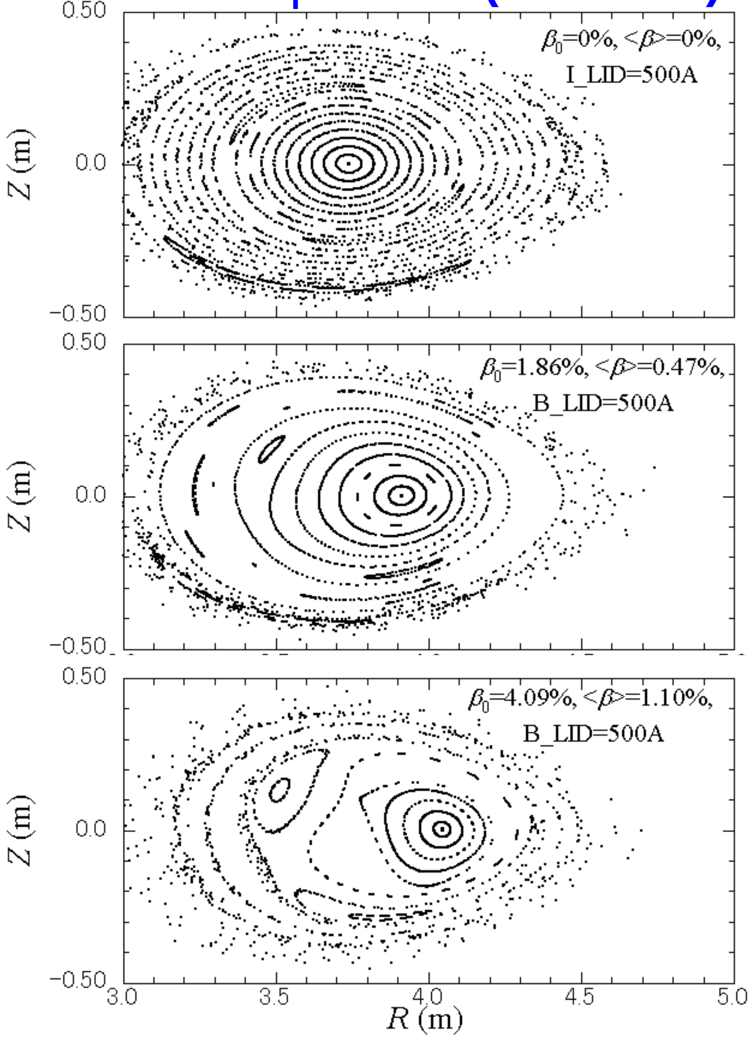


β_0=0%

β_0=1.86%

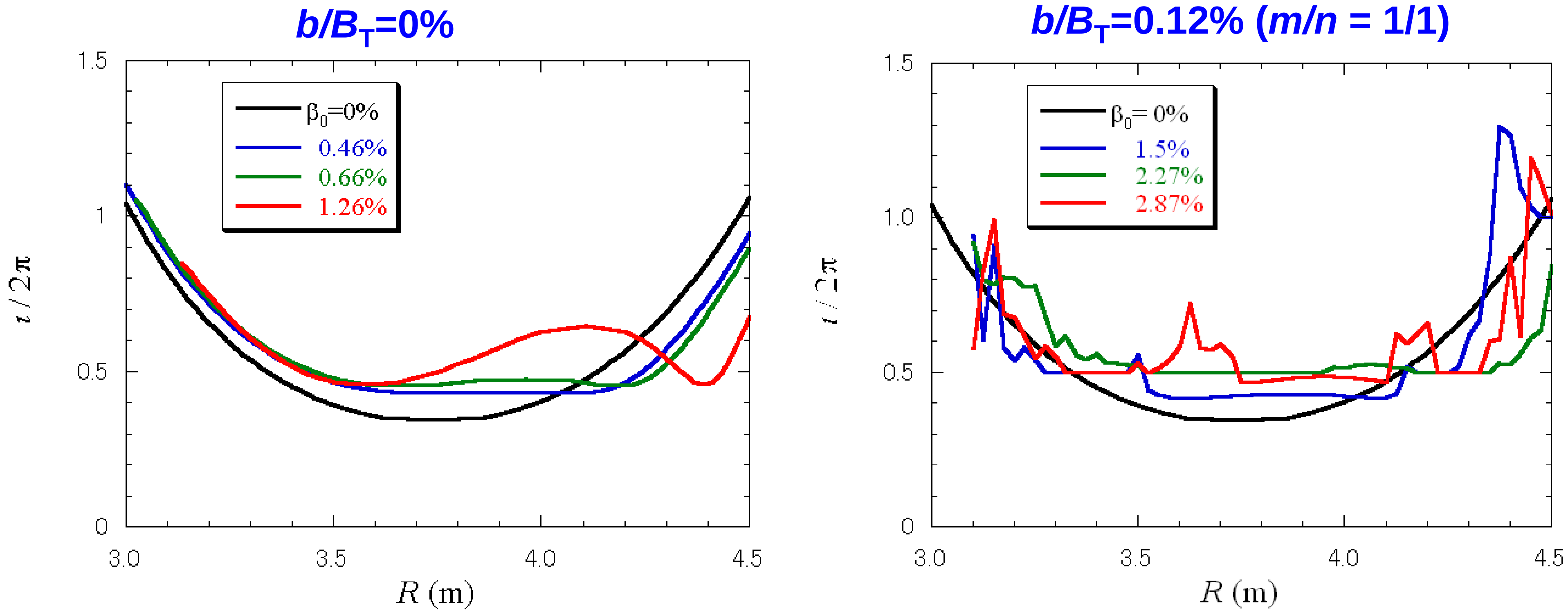
β_0=4.09%

b/B_T=0.02% (*m*/*n* = 1/1)



Flux surfaces are sensitive to external perturbation, especially in high beta regime.

As β_0 increases .... (2)



b/B_T=0%

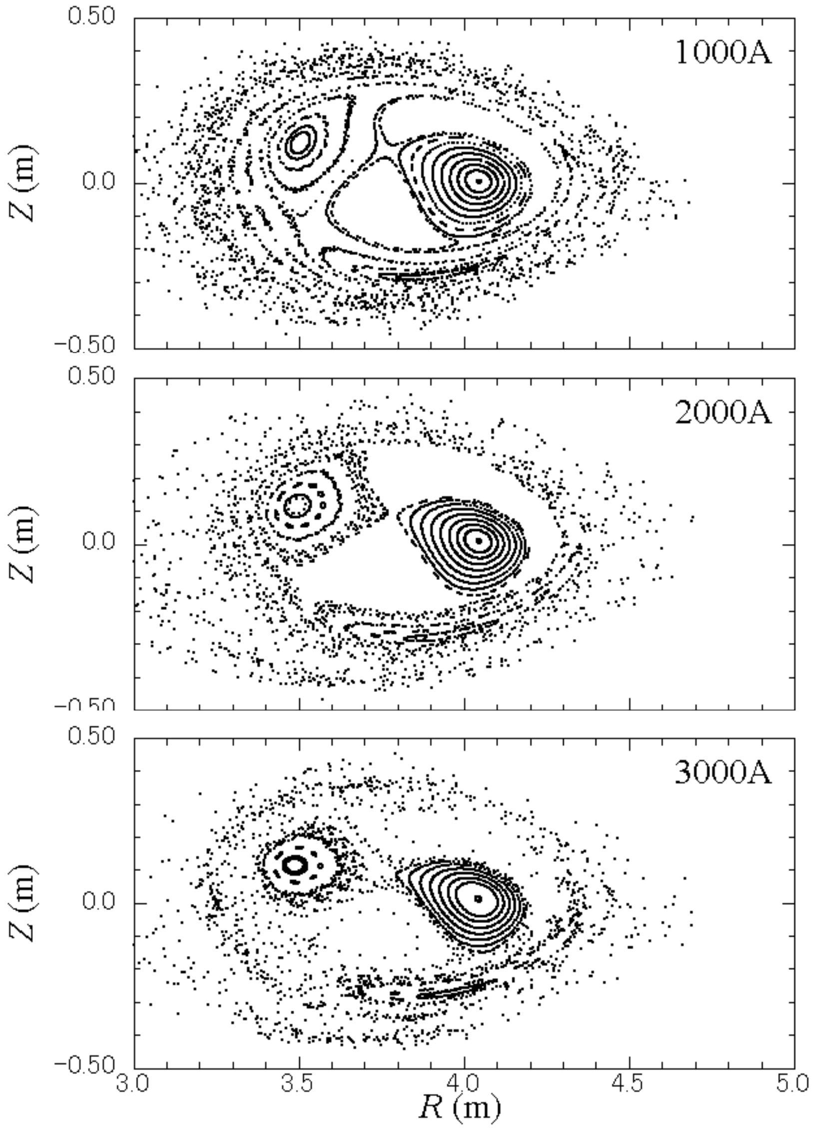
b/B_T=0.12% (m/n = 1/1)

- rotational transform increases with increase in beta
- shear near the center becomes low

Especially with perturbation, m/n=2/1 region spreads

==> wide 2/I island grows at the core region.

As b/B_T increases ....



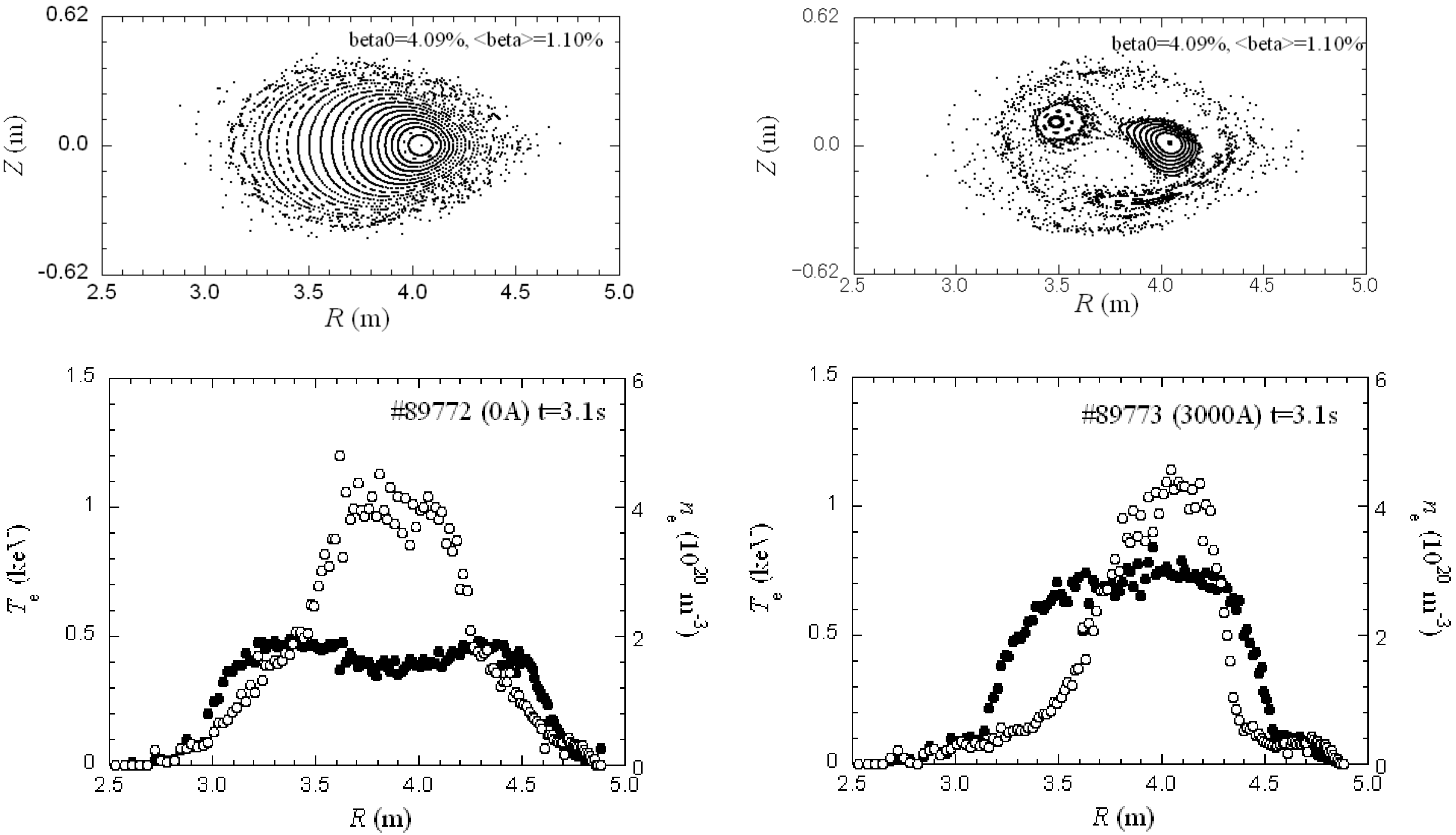
b/B_T=0.04% (m/n = 1/1)

b/B_T=0.08% (m/n = 1/1)

b/B_T=0.12% (m/n = 1/1)

Even a small perturbation, magnetic surfaces are modified or ergodized.

Experiment



n_e profile reflects magnetic structure, but Te does not follow it

Kolmogorov length L_K

$$d(l) = d_0 \exp\left(\frac{l}{L_K}\right)$$

d : circumference

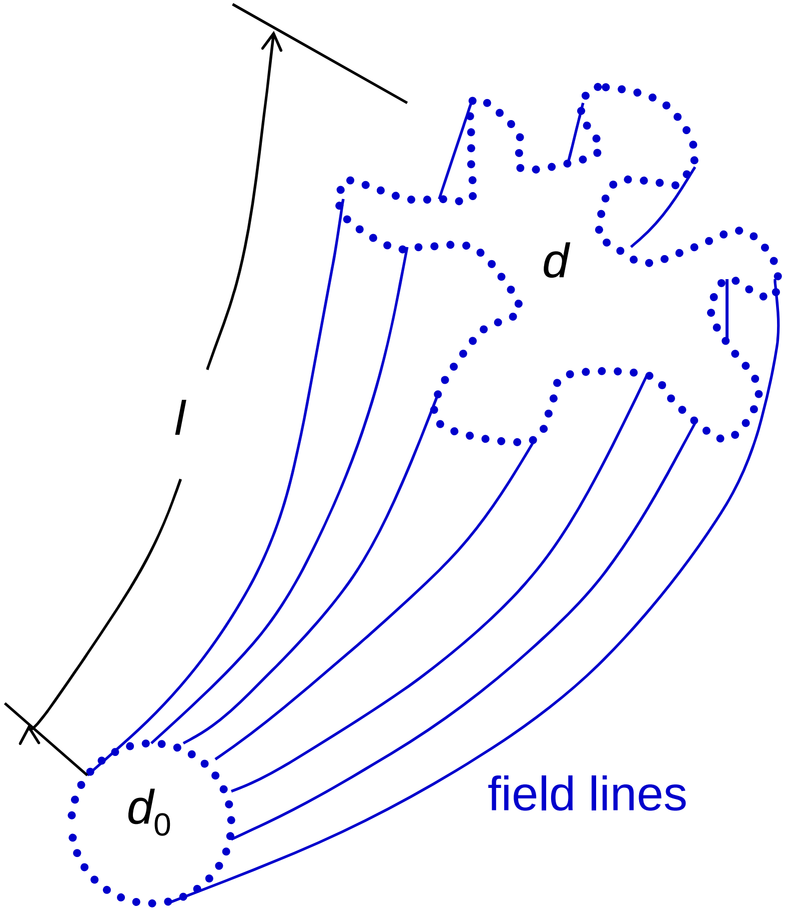
d_0 : initial value of circumference

l : length of flux tube

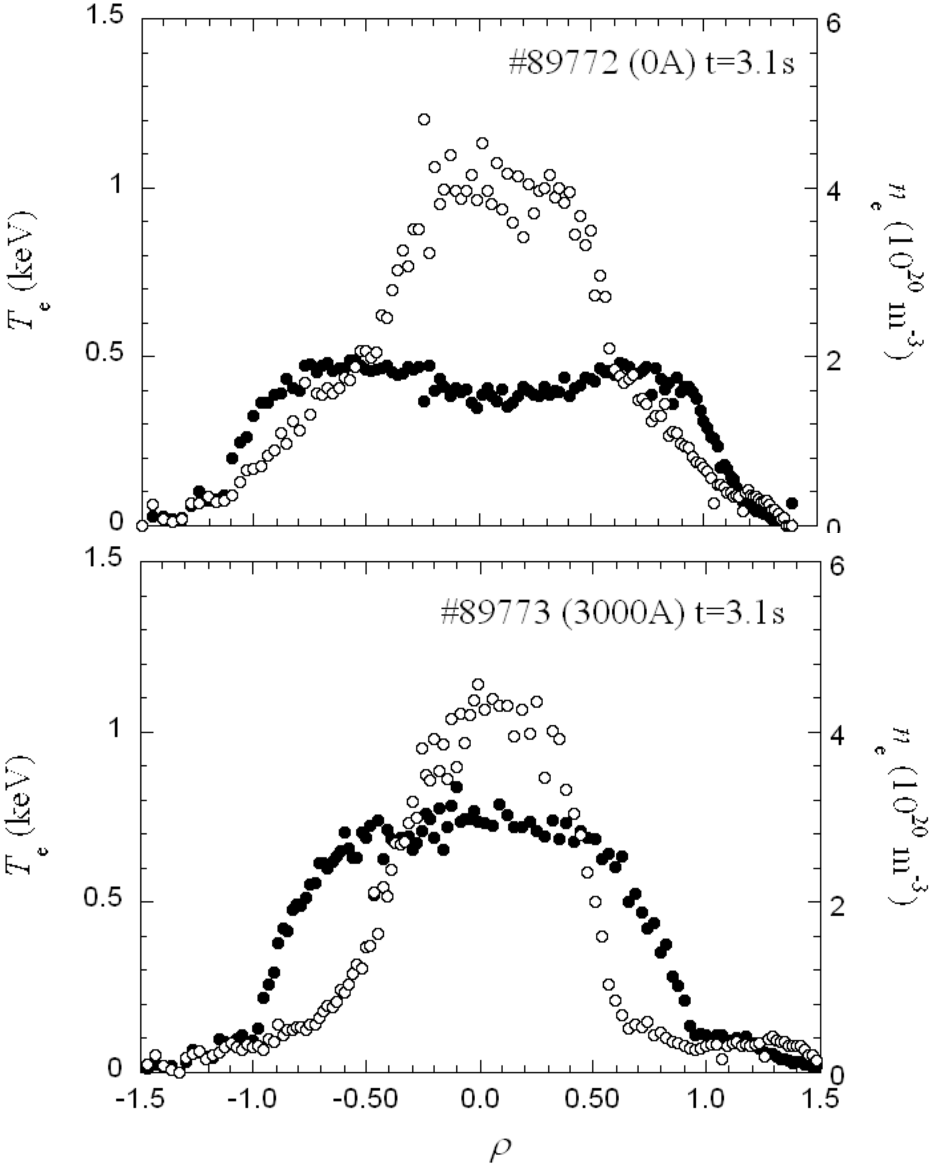
L_K : Kolmogorov length

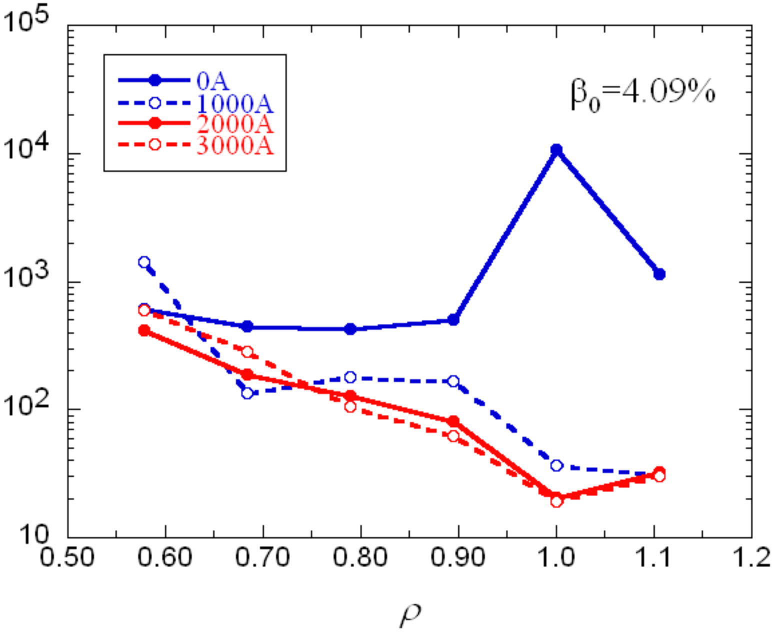
(e-folding length of

exponential increase of circumference)



Relation between L_k and profiles

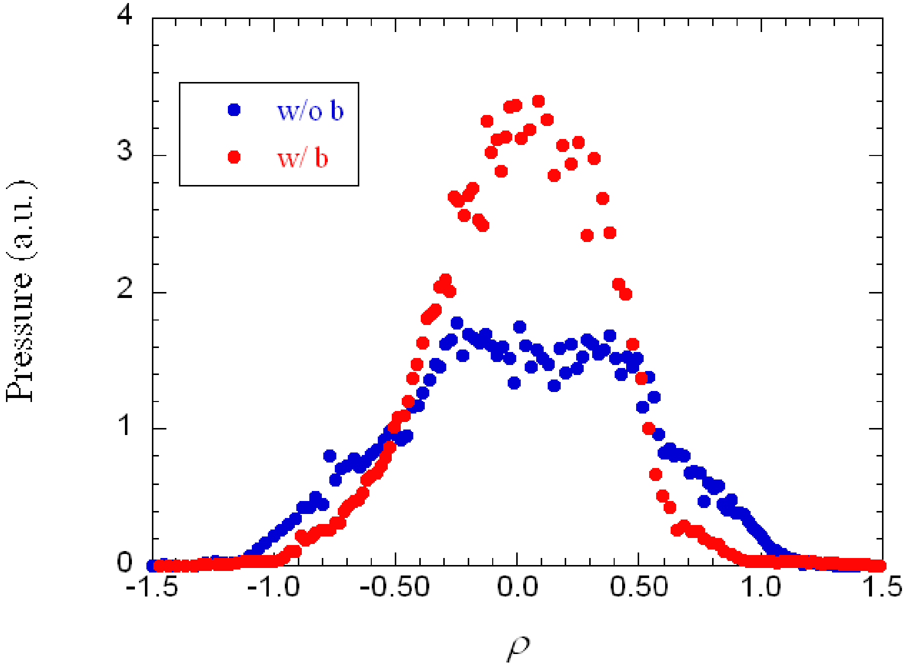


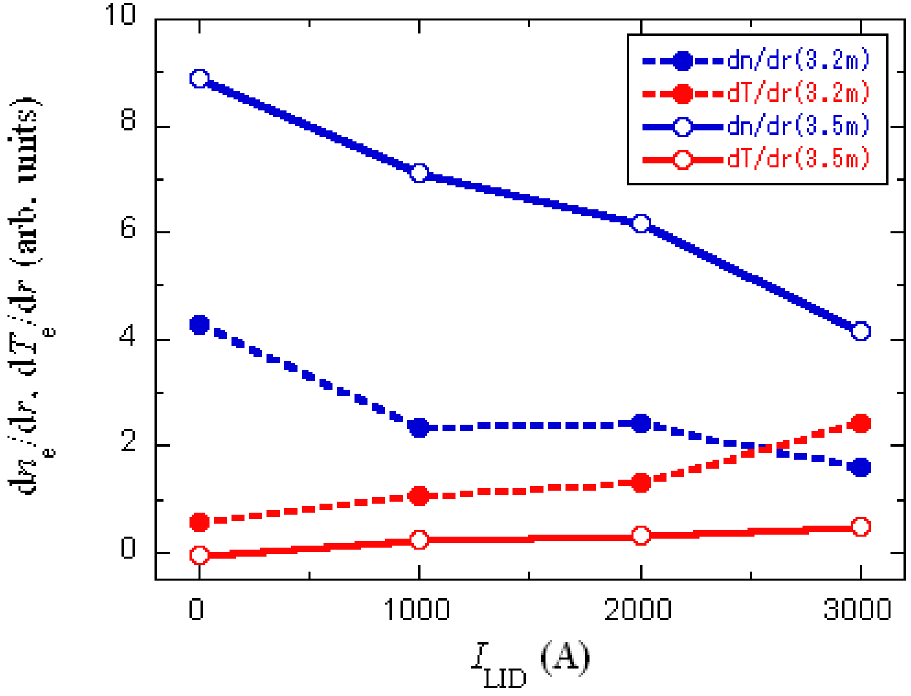


- L_k rapidly decreases when b is applied, especially in edge region

- Region where ne is flat corresponds to L_k profile

Erogodization produces higher P_0





- higher P_0 is obtained with applying the perturbation
- gradient of n_e is well correlated with magnitude of perturbation
- higher P_0 is due to the increase of T_e
  - ==> because of the reduction of the edge density
  - ==> deep penetration of heating power

Summary

Effect of the high pressure core plasma on magnetic topology is numerically and experimentally investigated.

-Magnetic flux surfaces are strongly affected by the high pressure core plasma.

- Even a small perturbation, it enlarges magnetic islands and enhances the ergodization

- Particle transport seems to follow the magnetic structure, on the other hand, energy transport does not follow.

- Edge ergodization contributes the reduction of edge ne, which leads to the higher central pressure.

  ==> edge ergodization can control the core plasma performance.