第10回若手科学者によるプラズマ研究会「ITERに向けたプラズマ科学の新展開」
平成18年3月14日(水)-16(金) 於 日本原子力研究開発機構那珂核融合研究所

LHDにおける外部摂動磁場印加時の周辺MHDモード特性

Effects of Externally Produced Static Magnetic Island on Edge MHD Modes in the Large Helical Device

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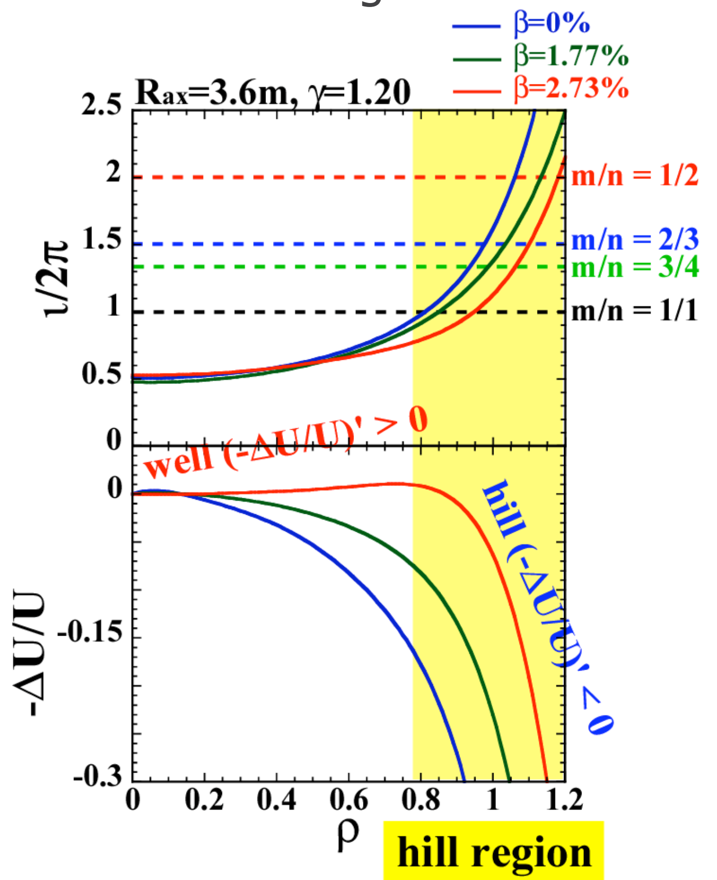
Outline

1. **Motivation**
2. **Experimental results**
   - Typical L-H transition plasma discharge in LHD
   - Effect of LID magnetic coil current on edge MHD modes
   - Radial structures of edge MHD mode measured by SX array detectors
   - Observation of ELM like oscillations
3. **Summary**

Motivation

- **In high beta and L-H transition plasmas, edge MHD modes are excited by the rise of edge pressure gradient.**
  K. Toi et al., Phys. Plasmas 12 (2005)020701.
  F. Watanabe et al., Plasma Physics and Controlled Fusion, 48 (2006)A210.
- **Edge MHD modes in LHD plasma ;**
  ☆ The rational surfaces exist near the last closed flux surface.
  ⇒ These mode number are m/n = 1/1, 3/4, 2/3, 1/2 etc..
  ⇒ This region is always in magnetic hill.
  ☆ These edge MHD modes sometimes interrupt the increase in the stored energy.
  ☆ These edge MHD modes sometimes induced ELM like oscillations.

LHD configuration



- **It is important to clarify the characteristics of edge MHD modes and their impact on plasma confinement in LHD.**
  ⇒ **internal structure**, growth rate and saturation level

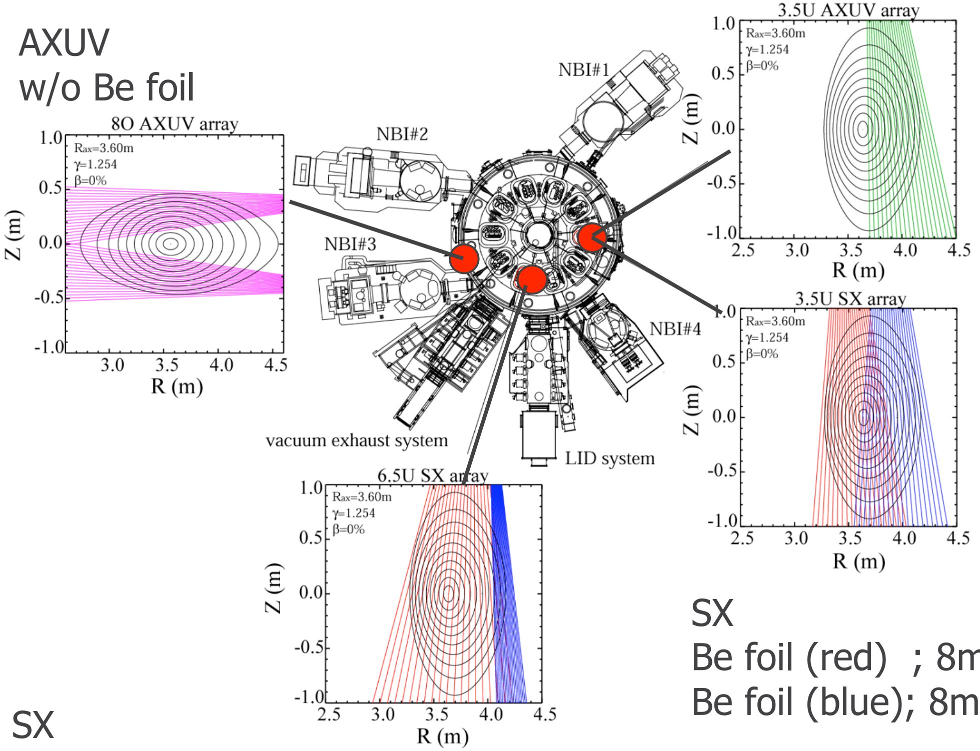
Soft-X ray (SX) and Ultra Soft-X ray (AXUV) array systems in LHD

SX array (20ch x 4sets) and AXUV array (20ch x 3sets)

❖ We have used Soft X-ray detector arrays in order to measure the radial structure of edge MHD modes and the stability of edge region.

AXUV
w/o Be foil

AXUV
w/o Be foil



SX
Be foil (red) ; 8mm
Be foil (blue); 8mm

SX
Be foil (red) ; 15mm
Be foil (blue); 8mm

❖ The SX emission of a plasma
⇒ The continuous Bremsstrahlung spectrum

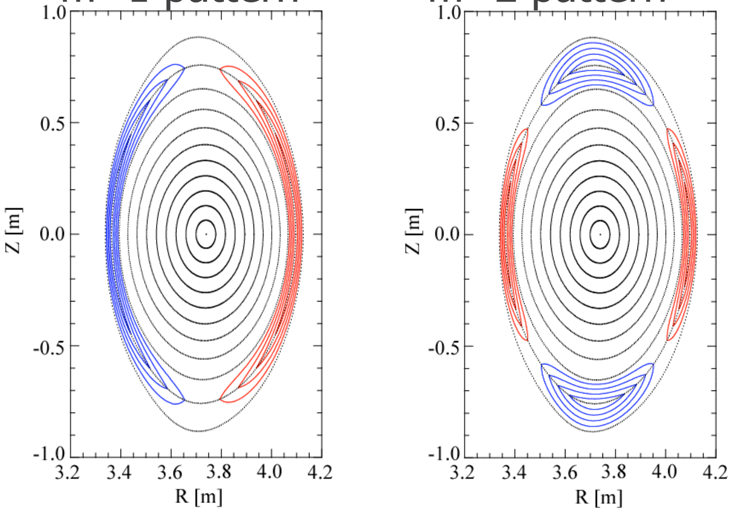
$$I_{sx} \propto n_e^2 \zeta \sqrt{T_e} \exp\left(\frac{-E_c}{T_e}\right)$$

15mm; E_c=1.09keV
8mm; E_c=1.34keV

Edge MHD modes

m=1 pattern

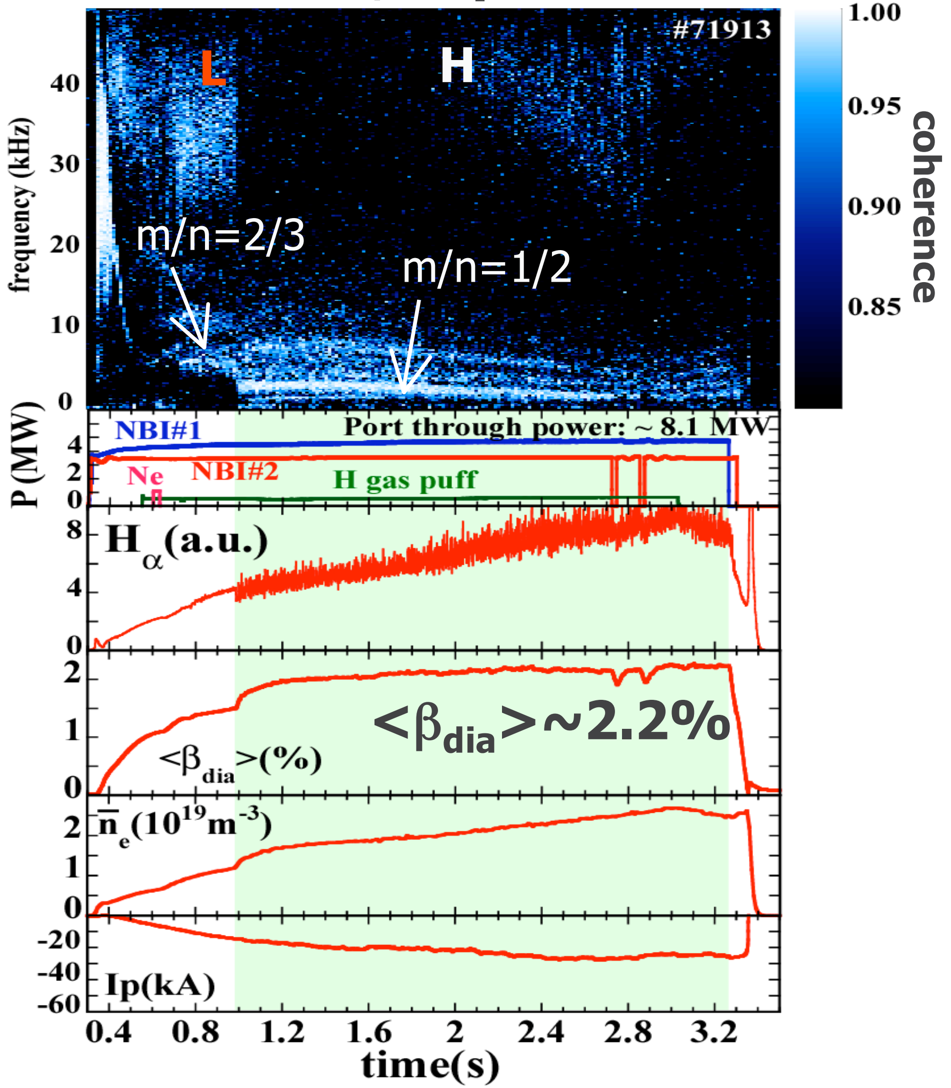
m=2 pattern



Typical L-H transition plasma in LHD

Bt=-0.9T,Rax=3.6m,γ=1.20,Bq=100%

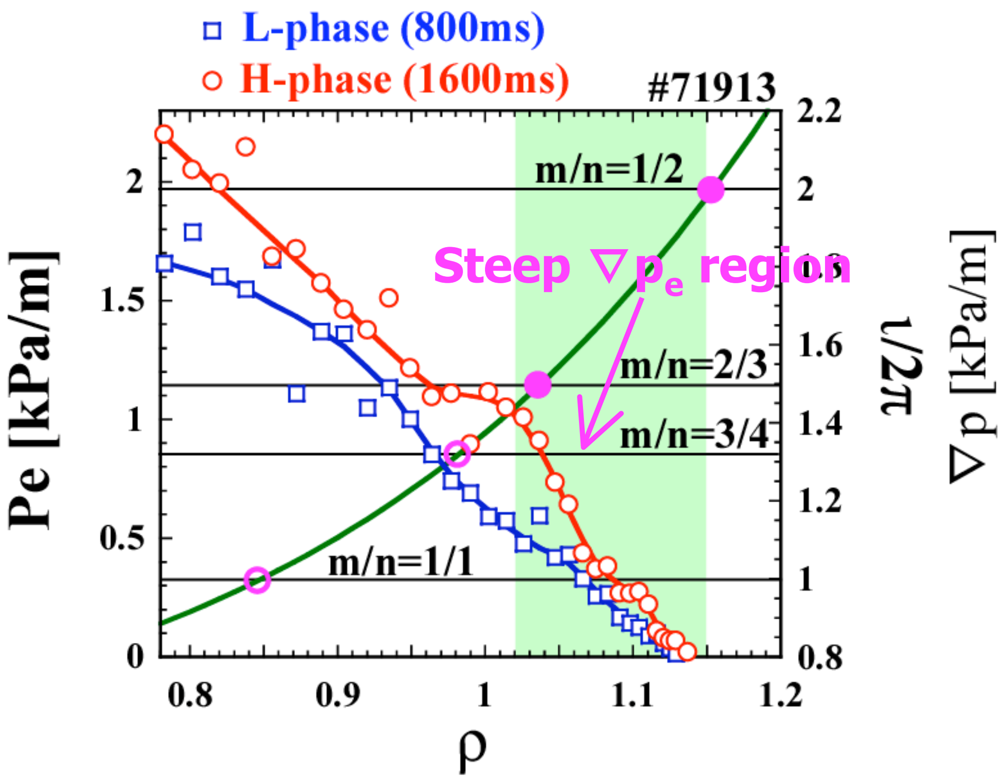
t>0.98s ; H-phase

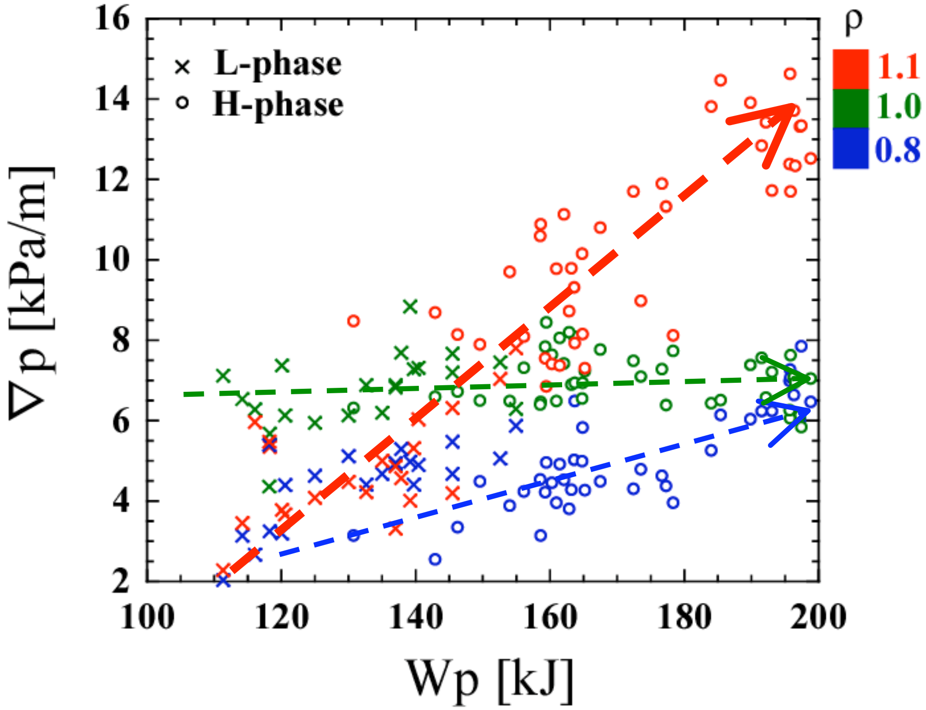


- Typical example of NBI heated plasma with L-H transition.
- Diamagnetic beta value ($<\beta_{dia}>$) is increased by ~30 % across the L-H transition.
- After the L-H transition, the beta value is rapidly saturated in the H-phase
- Edge MHD modes with m/n=1/2 mode structure is clearly enhanced after just a L-H transition.
- These modes observed by the magnetic probes and SX arrays.

Steep pressure gradient in edge plasma region

Rax=3.6m,γ=1.20,Bq=100%   0.9 T < |Bt| <1.0 T



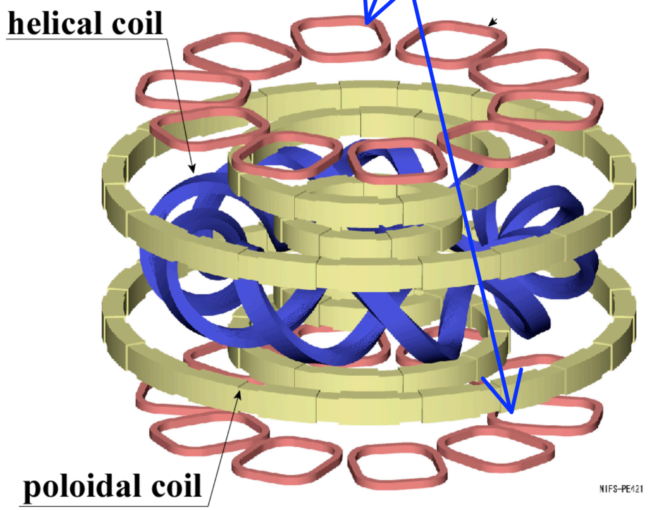


- Edge pressure gradient at very edge (ρ ~ 1.1) has increased rapidly with the increase of beta value (∝ stored energy; W_p) by the L-H transition.

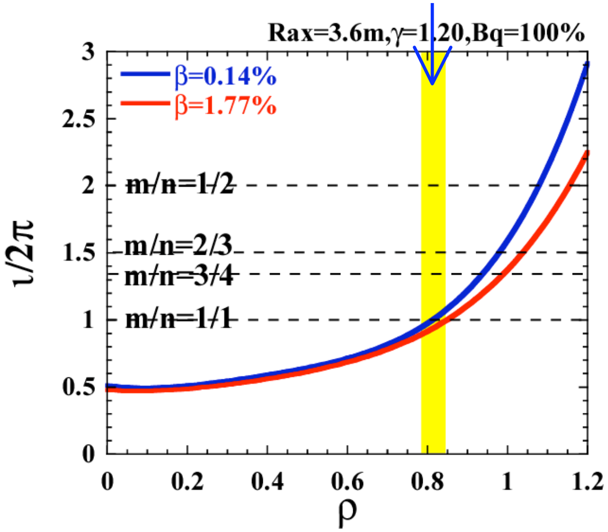
⇒ **The edge MHD modes are strongly destabilized in this steep pressure gradient.**

LID coil system in LHD

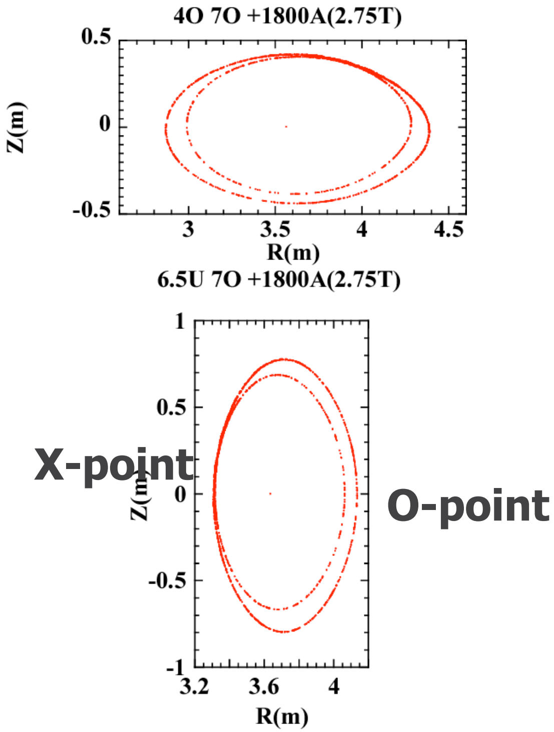
LID coil ; Local island divertor coil



ι/2π=1 surface



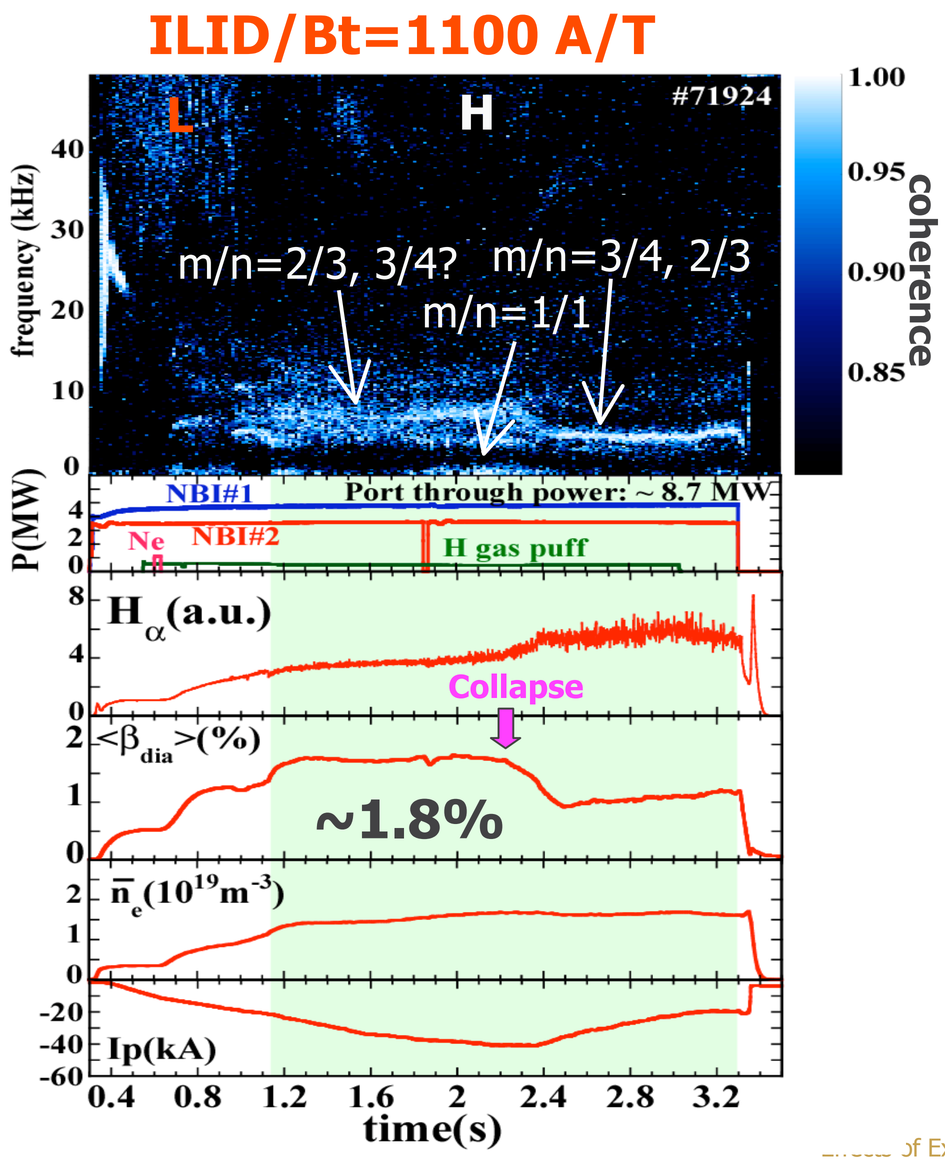
m/n=1/1 static island



- The LID coil system can apply the perturbation magnetic field to magnetic surface of LHD.
- The m/n=1/1 static island can be produced in $\iota/2\pi=1$ surface near the edge plasma region.

⇒ We can investigate the effect of the static island on edge MHD modes.

Effect of externally produced static island in L-H transition plasma



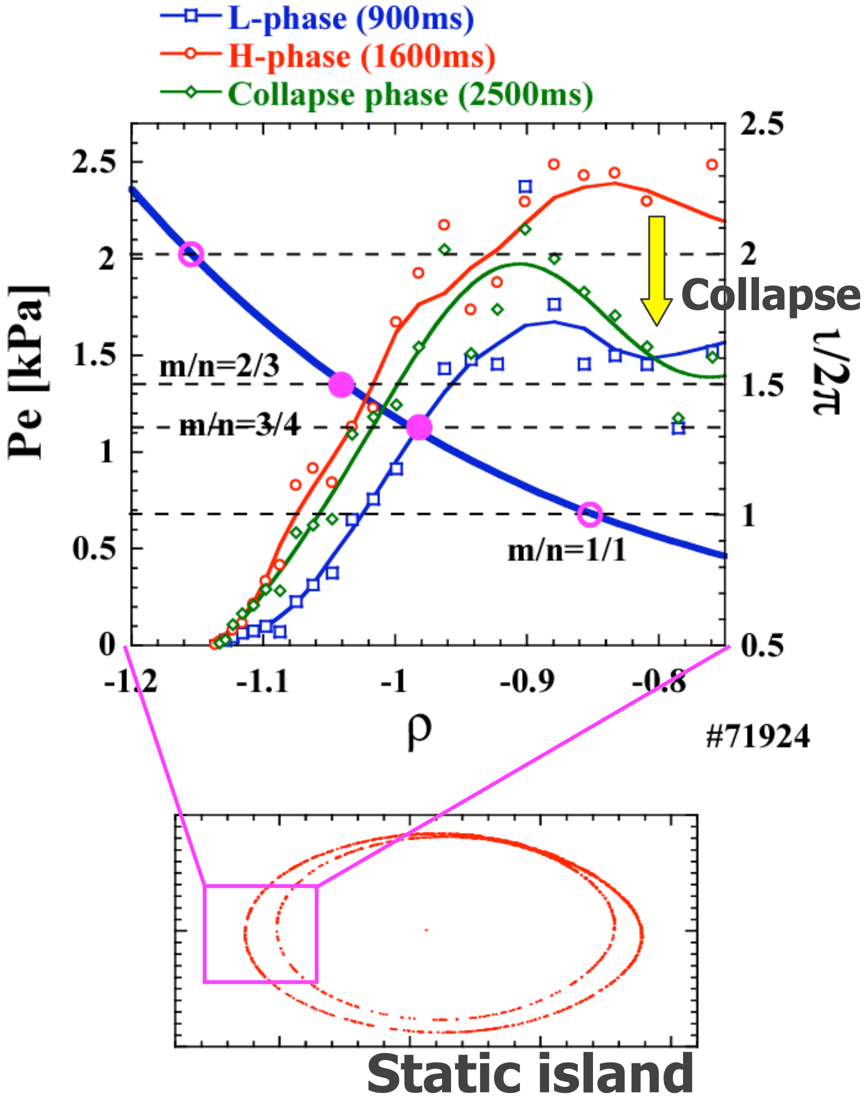
- L-H transition takes place at t~1.12 [s].
- $<\beta_{dia}>$ value is increased by ~30 % across the L-H transition.

  ⇒ Rate of increase of the $<\beta_{dia}>$ value is equal to the typical L-H transition.
- Plasma performance is deteriorated by the effect of externally produced static island. Maximum $<\beta_{dia}>$ is approximately 1.8% in this discharge.
- m/n=2/3 and 3/4 modes in the H-phase are predominant.

  ⇒ m/n=1/2 mode located in very edge region is not observed.
- Collapse phenomenon is observed at t~2.2 [s]

  ⇒ A decrease in the line averaged electron density is not seen.

Edge pressure profile near the O-point side of m/n=1/1 static island



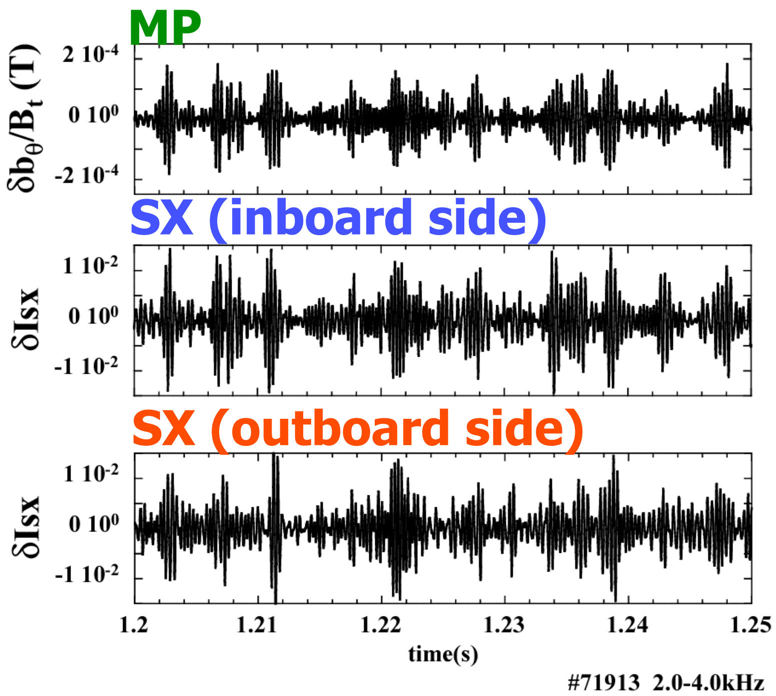
- The steep pressure gradient at the plasma edge is strongly enhanced after the L-H transition regardless of the static island.
- The steep pressure gradient is maintained even after the collapse of core plasma caused by expanding magnetic island.

  ⇒ Therefore, it keeps exciting these edge MHD modes (m/n=2/3,3/4).

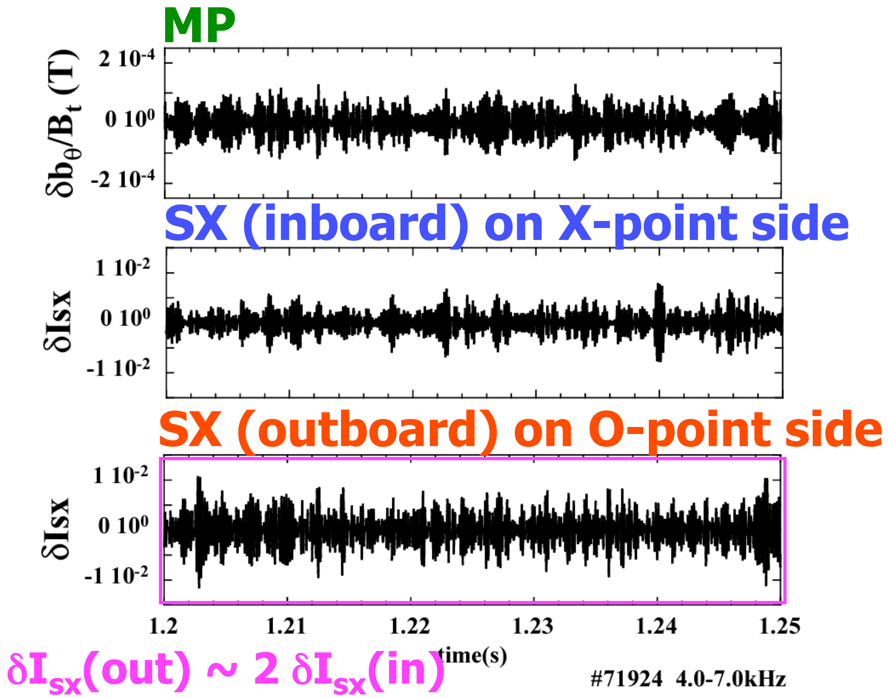
Magnetic fluctuation and SX fluctuation amplitude of edge MHD mode in H-phase

Bt=-0.9T,Rax=3.6m,γ=1.20,Bq=100%

ILID/Bt=0 A (w/o static island)
m/n=1/2 mode fluctuation in H-phase



ILID/Bt=1100 A (w/ static island)
m/n=2/3,3/4 mode fluctuation in H-phase

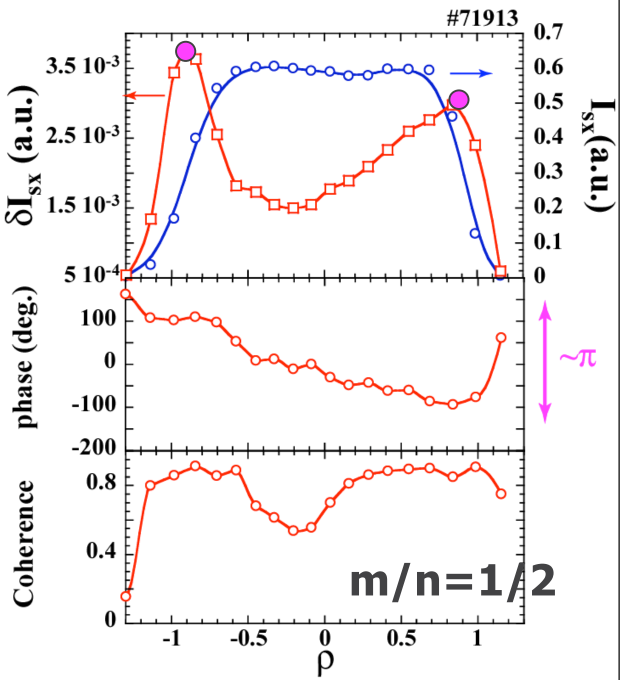


- The strongly intermittent characteristics of edge MHD modes are diminished due to the externally applied perturbation field.
- The SX fluctuation amplitude near the O-point side of m/n=1/1 static island is approximately twice larger than that near the X-point side.

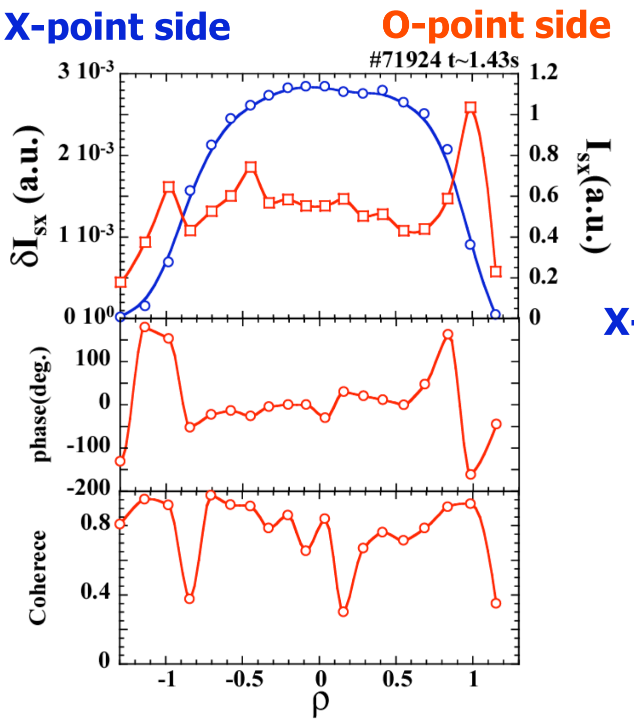
Radial structures of edge MHD modes by SX fluctuation measurement (m/n=2/3,3/4)

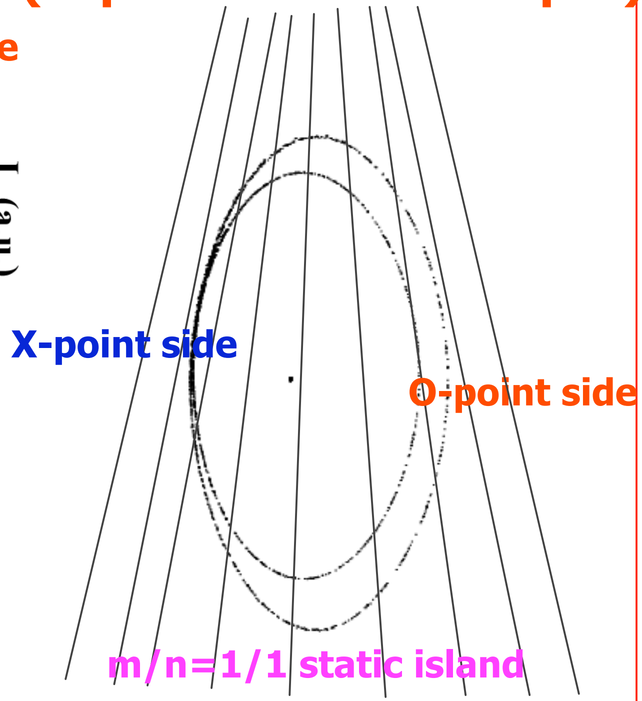
Bt=-0.9T,Rax=3.6m,γ=1.20,Bq=100%

ILID/Bt=0 [A/T] (H-phase)



ILID/Bt=1100 [A/T] (H-phase before collapse)



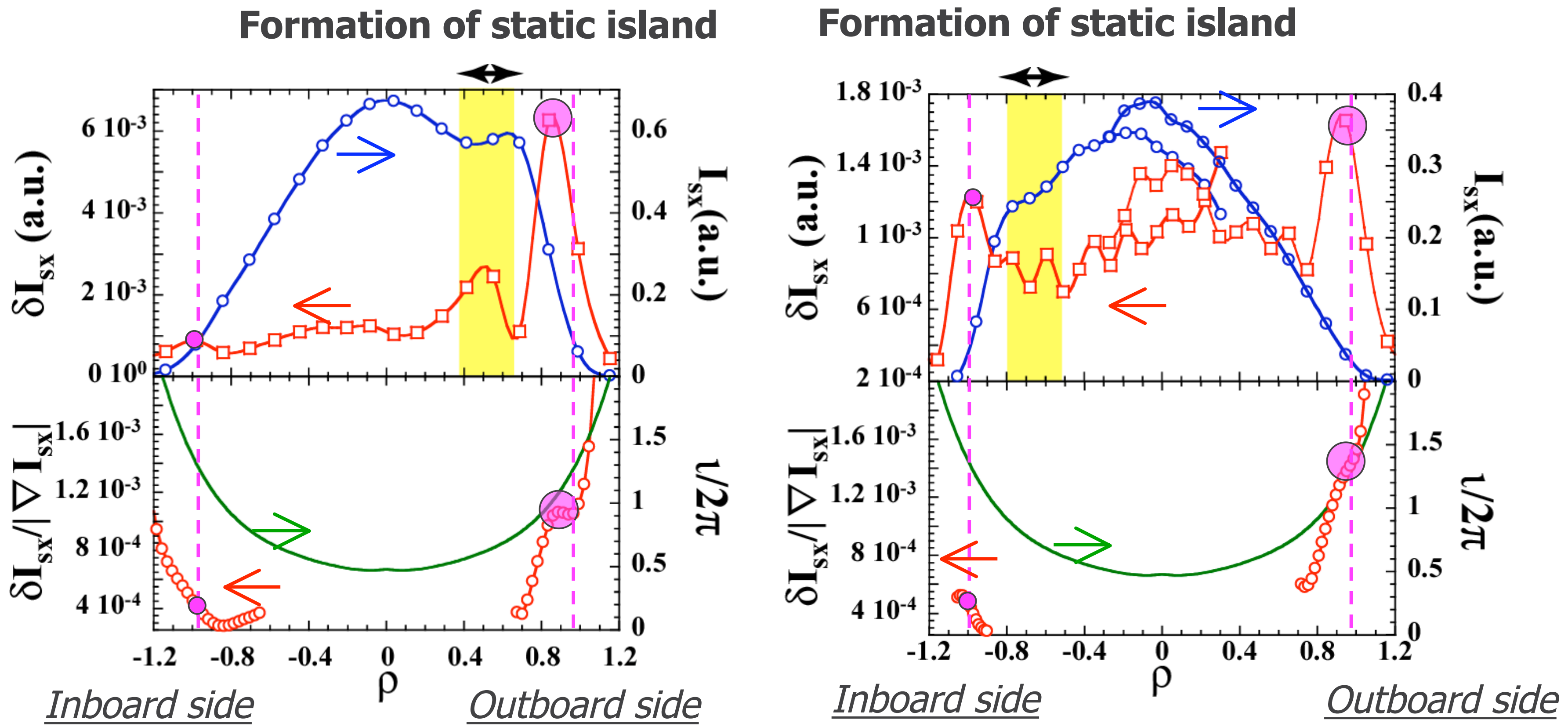


- Edge MHD modes in LHD usually show the feature of ideal / resistive interchange mode. In such a case, the mode amplitude of plasma edge is equal to both sides, or the fluctuation of inboard side is larger than that of outboard side.
- In the case with expanded the static island, the edge mode amplitude on O-point side is larger than that on X-point side.

Radial structures of edge MHD mode (m/n=3/4) observed in different poloidal cross section

- H-phase after collapse of core plasma -

- - - - m/n=3/4 surface



- The fluctuation amplitude on O-point side of static island is significantly large compared with the fluctuation amplitude on X-point side. (left-hand figures)

- It should be noted that this amplitude is appreciably larger than the fluctuation of X-point side (outboard side). (right-hand figures) ⇒ **ballooning character ?**

Summary

- **In LHD, we can investigate the effect of edge MHD modes by generating the static magnetic island.**

  ⇒ Especially, it is important to study the stabilization of edge MHD modes and characteristics of edge MHD modes in edge plasmas having high pressure gradient.

- **Effect of externally produced static island on edge MHD modes**

  ・The large coil current is usually deteriorated of the plasma performance. However, L-H transition is observed.

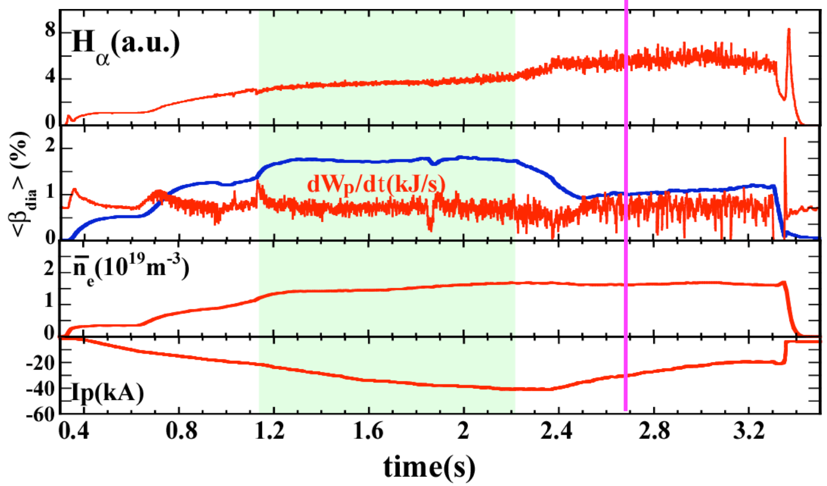
  ・In the H-phase, the total magnetic fluctuation amplitudes of edge MHD modes decrease compared with no static island case.

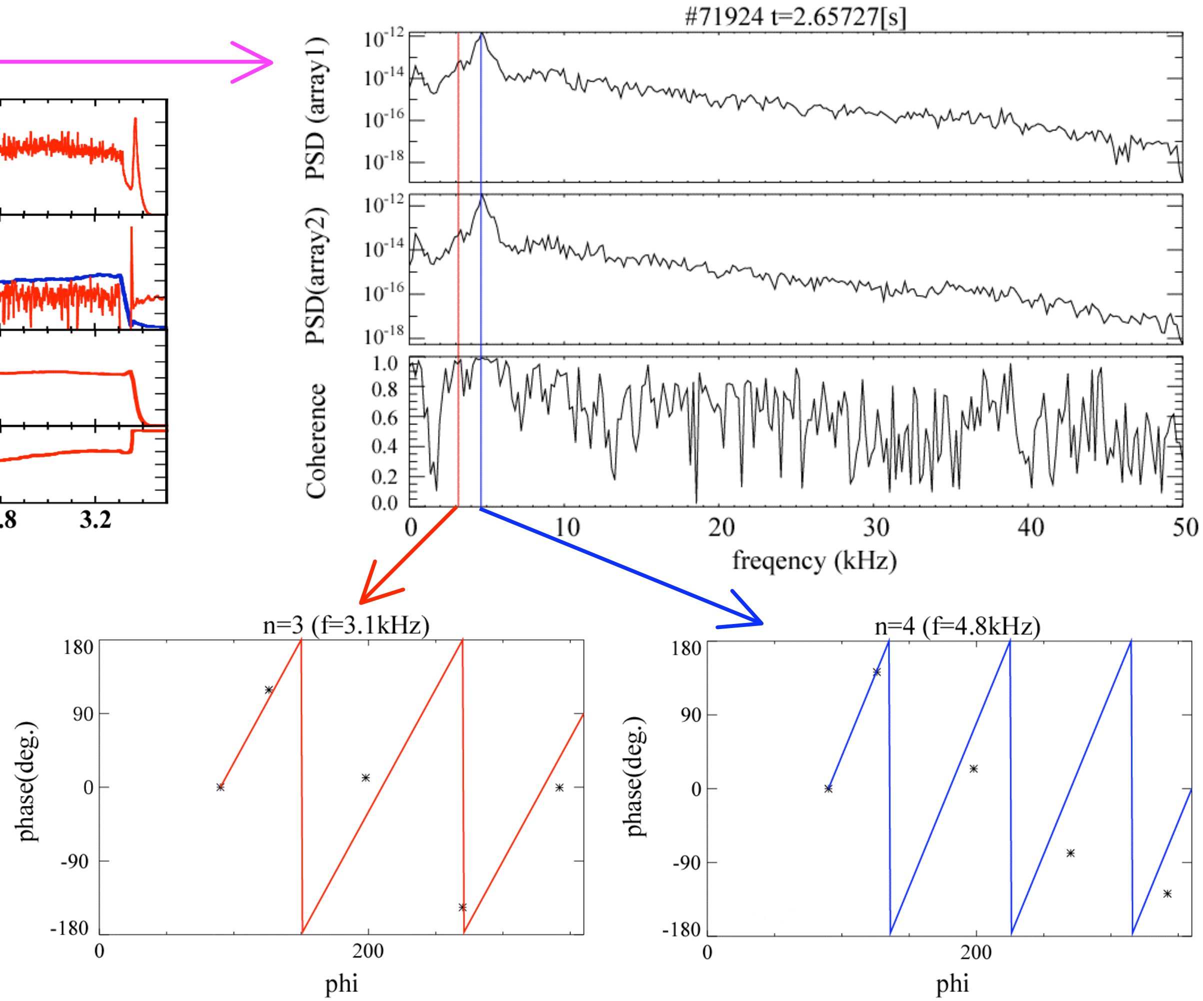
  ・However, the fluctuation amplitude of edge MHD modes on outboard side is obviously larger than that on inboard side.

  ⇒ **This effect has a possibility of ballooning character.**

MHD mode analysis

Collapse phase after the L-H transition





- The m/n=2/3 mode exists slightly after collapse of core plasma.

  ⇒However, the fluctuation amplitude of m/n=3/4 mode is predominant.

It is difficult to decide mode number completely.

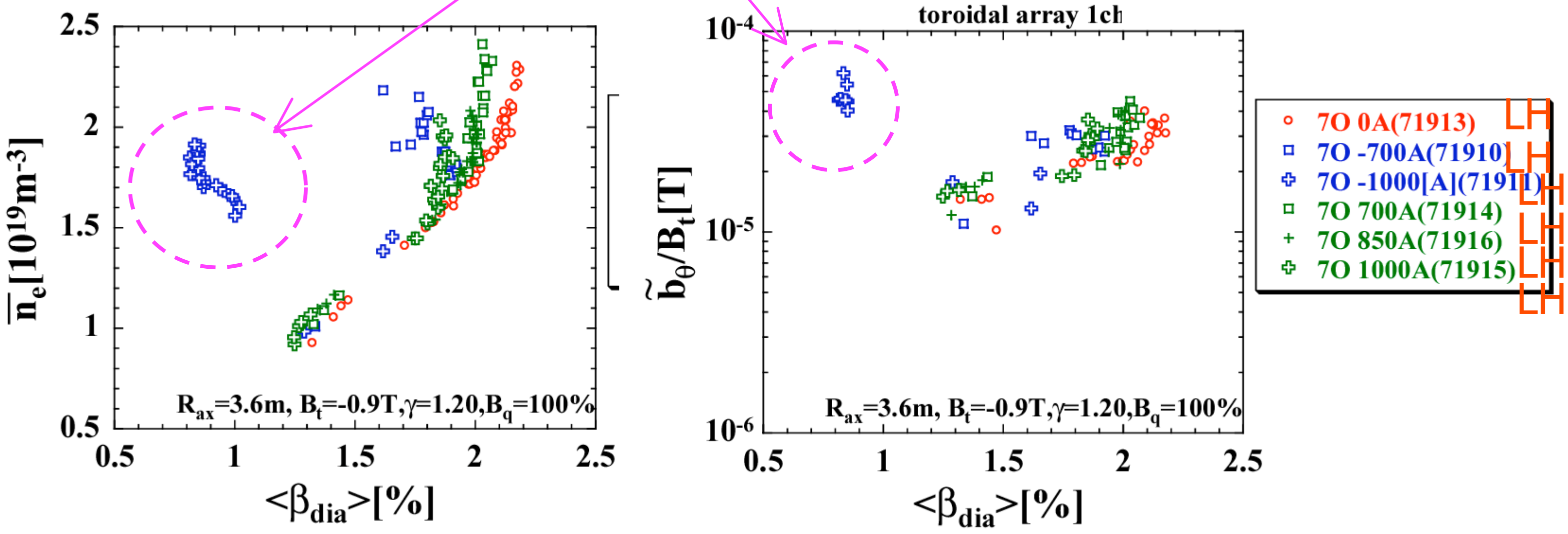
⇒ External control might influence at mode structure.

Effect of LID magnetic coil current and polarity

- diamagnetic beta vs electron density and magnetic fluctuation of edge MHD mode-

Bt=-0.9T,Rax=3.6m,γ=1.20,Bq=100%

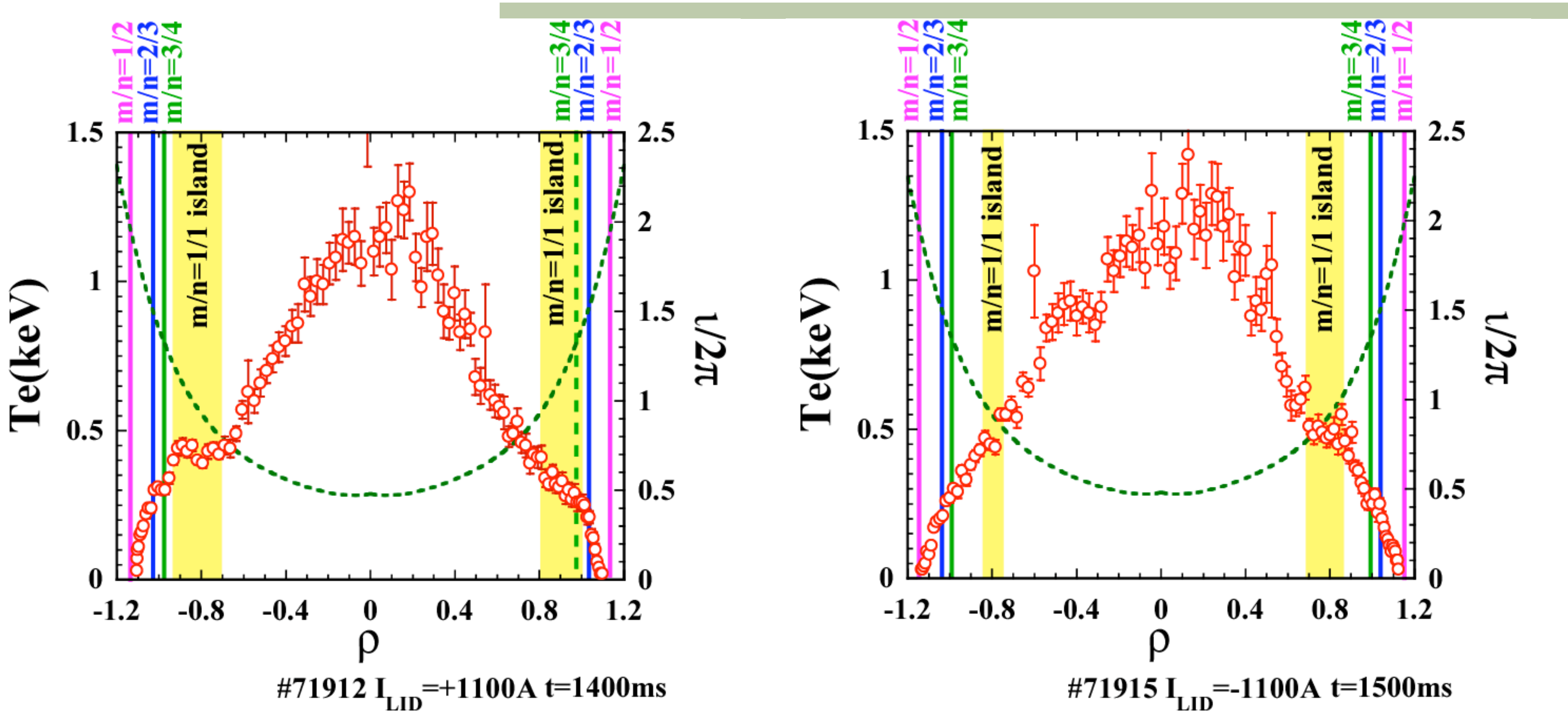
Big magnetic island is observed in this region.
(Collapse of core plasma T_{e_core} ↓)



- Edge pressure gradients keep maintaining a steep state.

  ⇒ The fluctuation amplitude of edge MHD modes often increase as compared with one before collapse of core plasma.

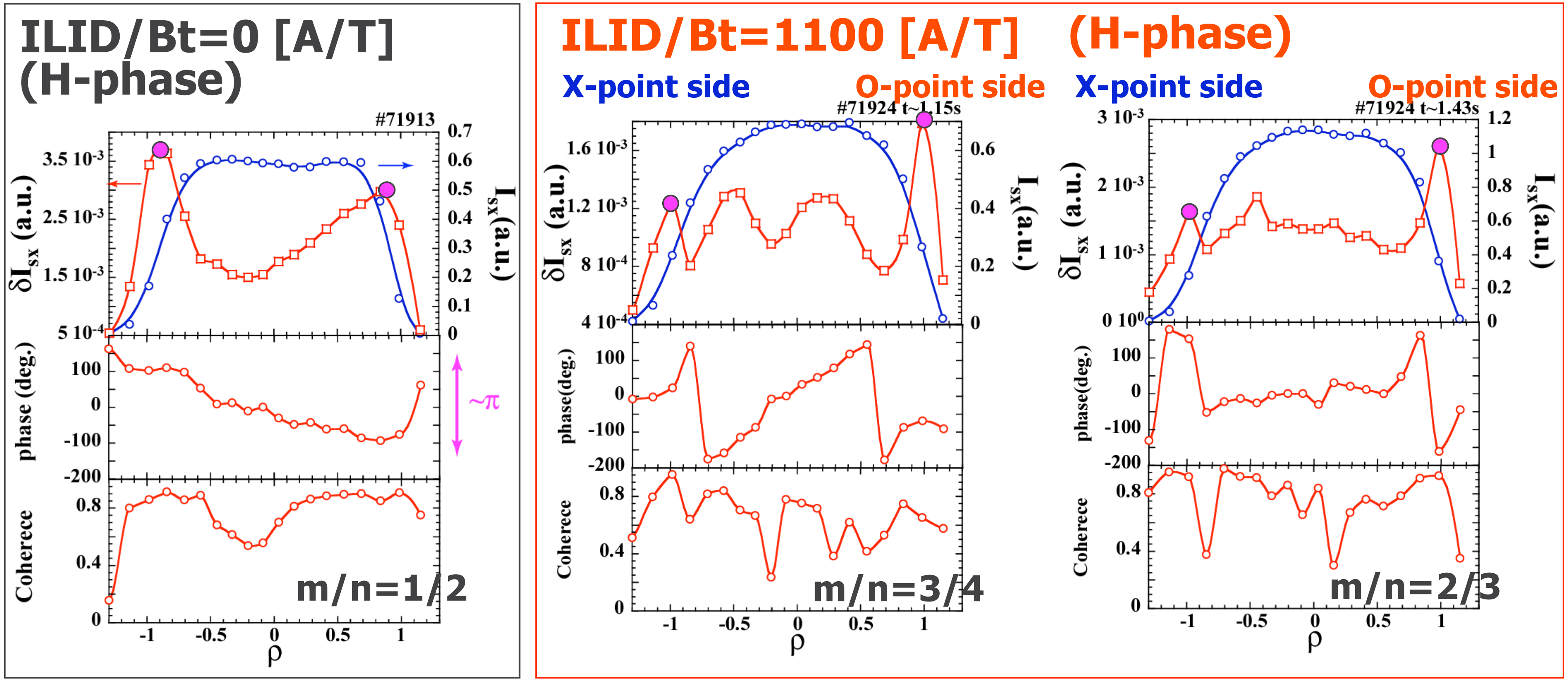
m/n=1/1 static island and MHD modes in peripheral plasma region



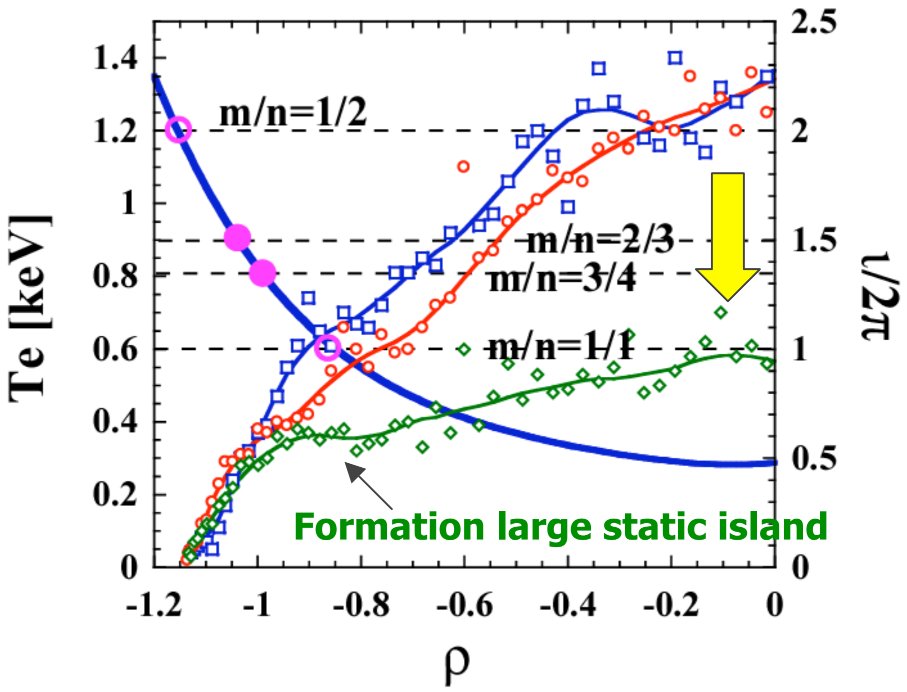
- In LHD configuration, the m/n=1/1 static island can be produced by island control coils.
- Many rational surfaces (m/n=3/4,2/3,1/2 etc.) exist outside of m/n=1/1 island.
  ⇒ Control edge plasma, stabilization and destabilization of edge MHD modes

Radial structures of edge MHD modes by SX fluctuation measurement (m/n=2/3,3/4)

Bt=-0.9T,Rax=3.6m,γ=1.20,Bq=100%,ILID/Bt=1100A



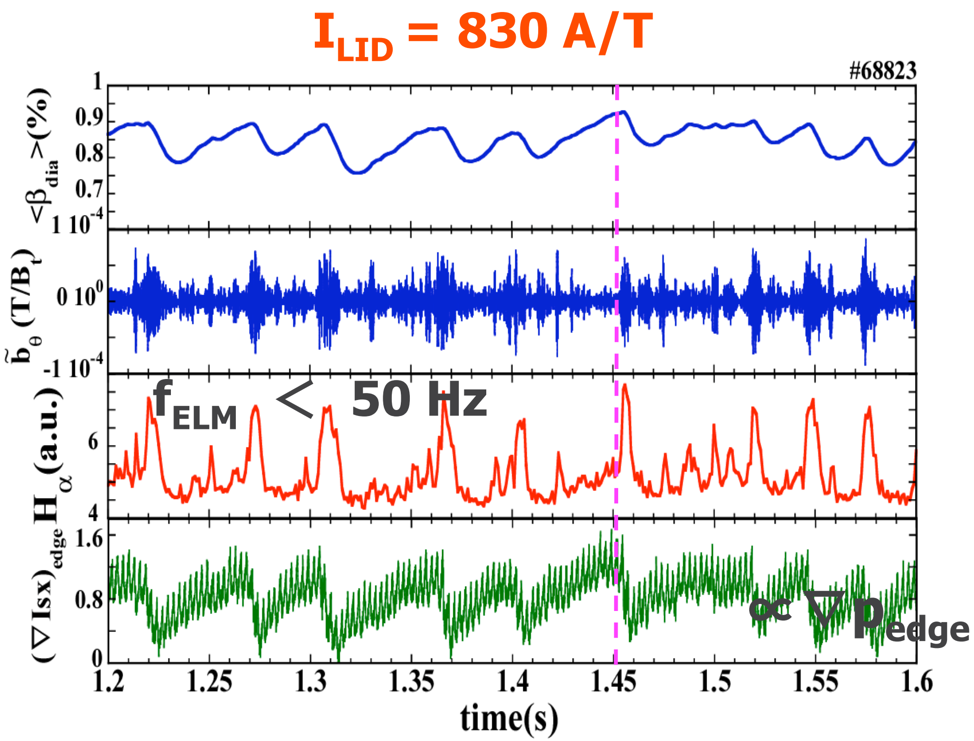
- The steep pressure gradient at the plasma edge is strongly enhanced.
- In this particular case, the edge SX fluctuation amplitudes on O-point side of static island are remarkable.

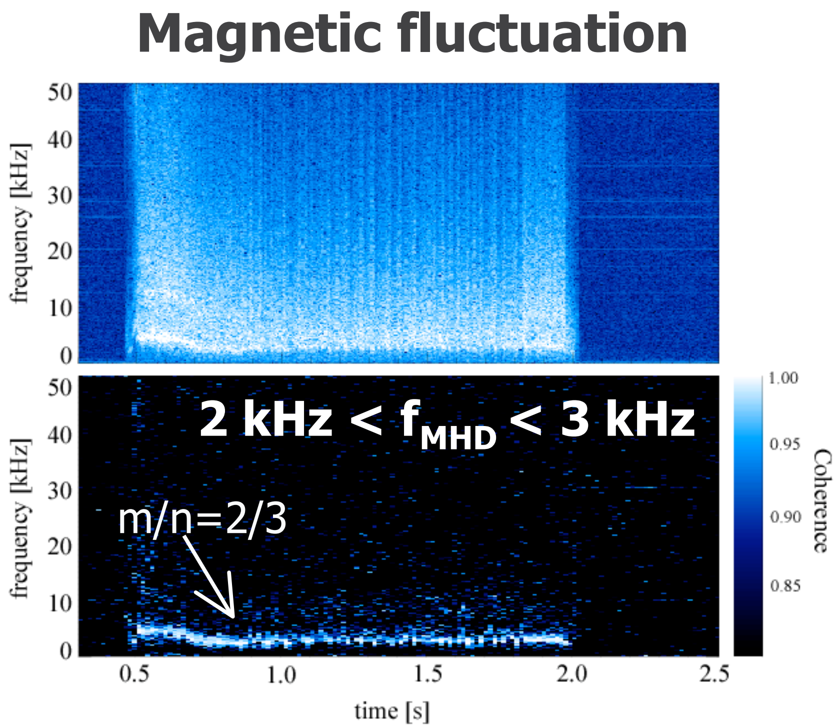


Te [keV]
ι/2π
ρ
m/n=1/2
m/n=2/3
m/n=3/4
m/n=1/1
Formation large static island

Observation of ELM like oscillation in L-mode plasma

Bt=-0.9T,Rax=3.6m,γ=1.18,Bq=100%



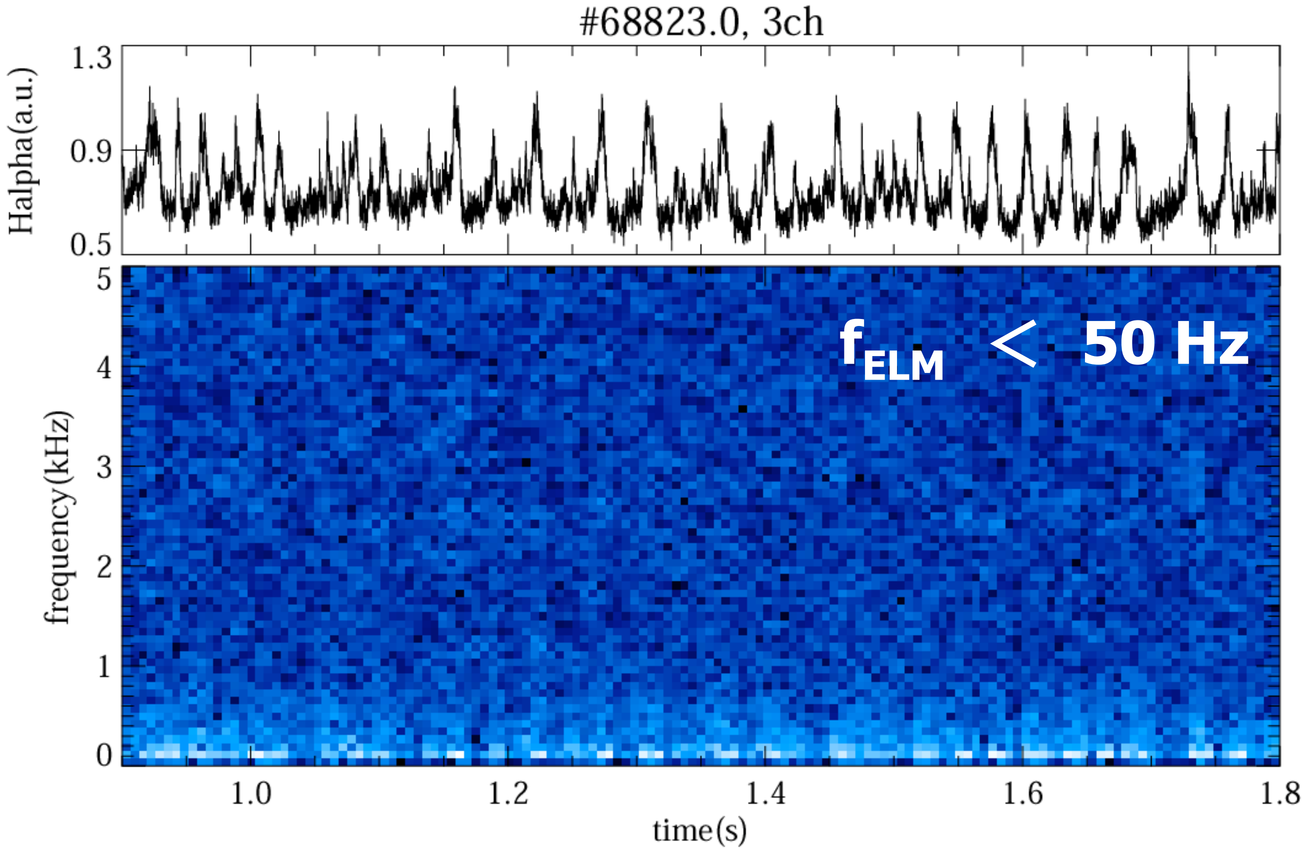


- ELM like oscillations are observed in the magnetic configuration having a high aspect ratio.

  ⇒ It resembles ELMs observed with Tokamak plasmas due to the control of edge plasma.

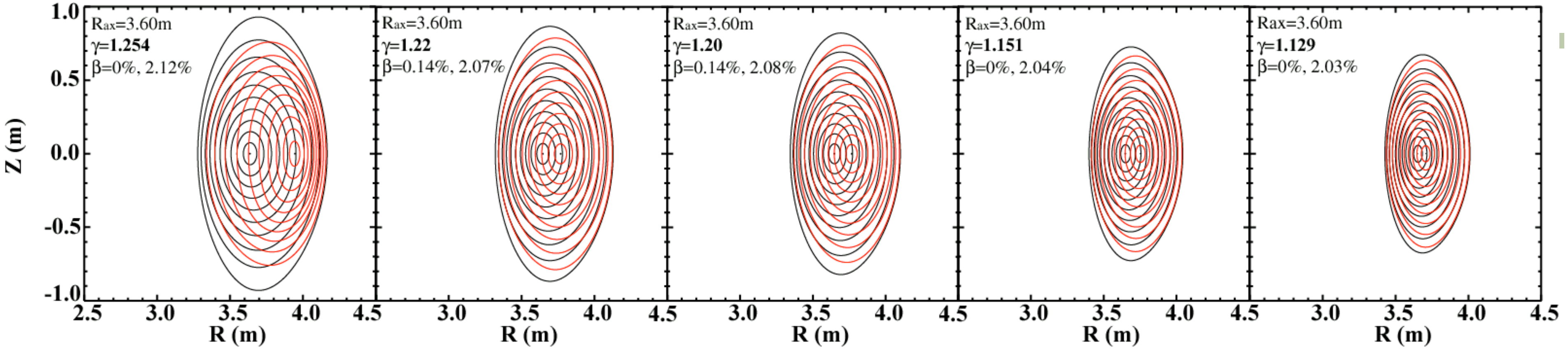
ELM like oscillation by Hα fluctuation signal

Bt=-0.9T,Rax=3.6m,γ=1.18,Bq=100%



- The frequency of ELM like oscillation is smaller than 50 Hz.
- The strong correlation with the fluctuation amplitude of edge MHD modes is not seen in the Ha signal.

Variation of Magnetic Configurations of LHD by the Change of γ



Aspect Ratio → **Large**

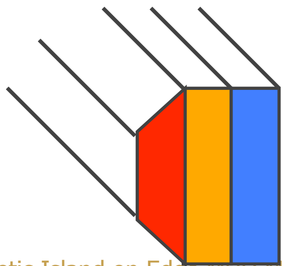
γ value → **Small**

coil pitch parameter

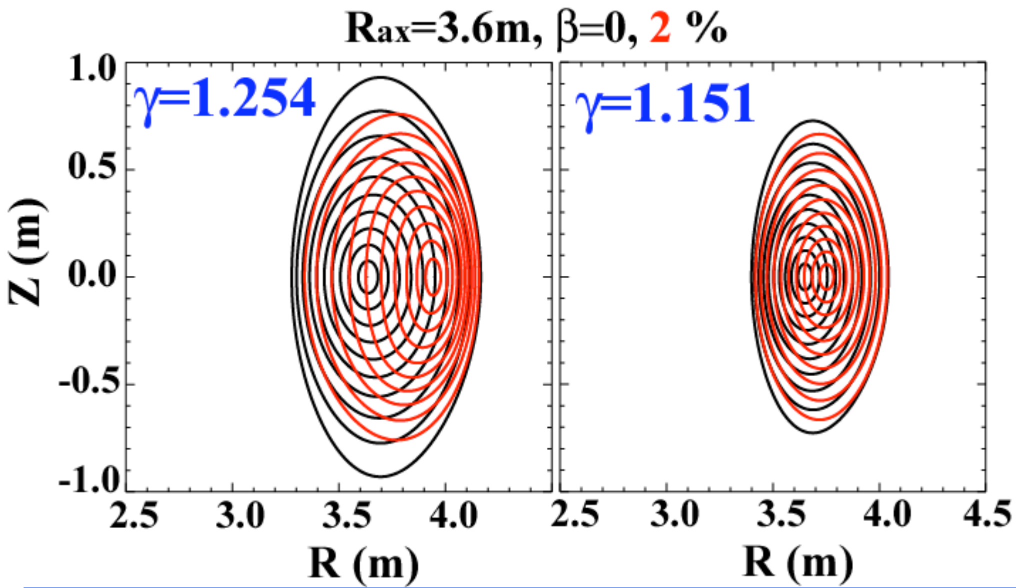
$$\gamma = \frac{M}{L} \cdot \frac{a_c}{R}$$

This parameter can be changed by changing the ratio of currents in three layers of helical coils on LHD.

M ; pitch number of the helical magnetic field (10)
L ; helical pole number (2)
a_c ; minor radius of coil (0.897~1.053m)
R ; major radius of coil (3.9m)

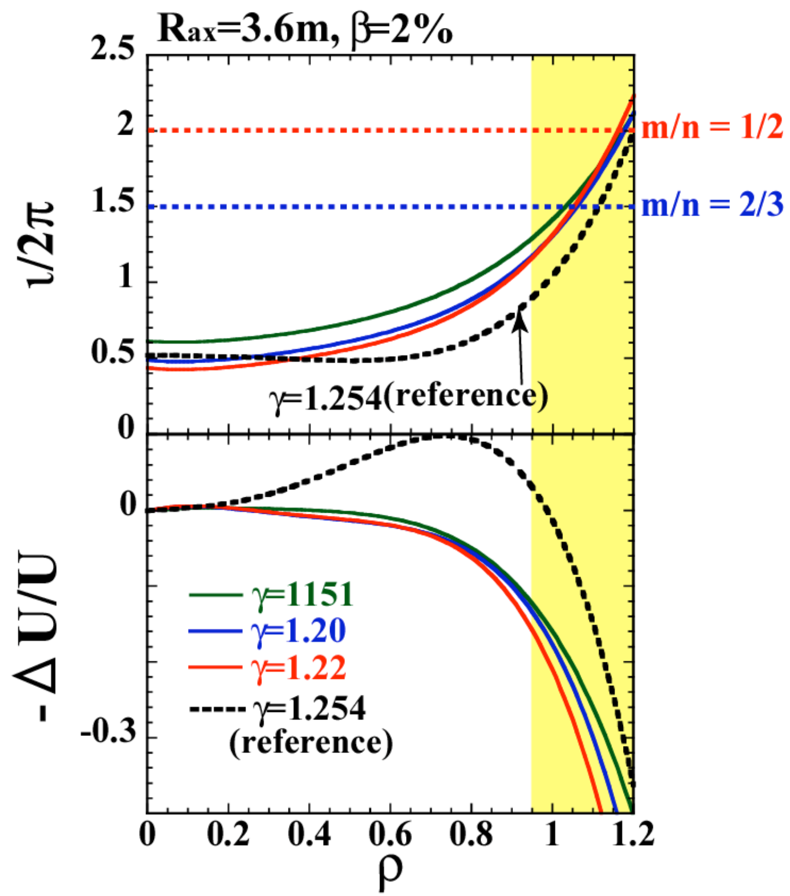


Modification of LHD Magnetic Configurations by the Change of γ



γ ; **helical coil pitch parameter.** $\gamma = \frac{M}{L} \cdot \frac{a_c}{R}$

a_c ; minor radius of coil (0.897~1.053m)



- In a typical LHD configuration with γ = 1.254, large Shafranov shift is induced with increased. → **This leads to worse NBI deposition**
- In the configuration with large aspect ratio (γ < 1.254), **strong magnetic hill configuration extends toward the plasma core region**.
- **We need a configuration with low Shafranov shift and MHD stability.**