第10回若手科学者によるプラズマ研究会「ITEPに向けたプラズマ科学の新展開」
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CHSにおけるETBプラズマの三次元構造および揺動特性の研究

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Outline

- Motivation
- Experimental setups
  - Experimental device (Compact Helical System) and arrangement of LP
  - Experimental condition and magnetic configuration
- Experimental results
  - 3-dimensional measurements of ETB
    - Time evolution of the L-H transition
    - ETB structure
    - Fluctuation characteristics
- Summary

Motivation

- On study of magnetic confinement fusion, the spontaneous transition from low to high confinement state (**L–H transition**) is an interesting phenomenon. The H–mode with the edge transport barrier (ETB) is observed in many tokamak devices, and is a standard operation mode of ITER.

- On the other hand, the L–H transition is observed in **helical devices** such as CHS and Wendelstein7–AS, Heliotron J and LHD.

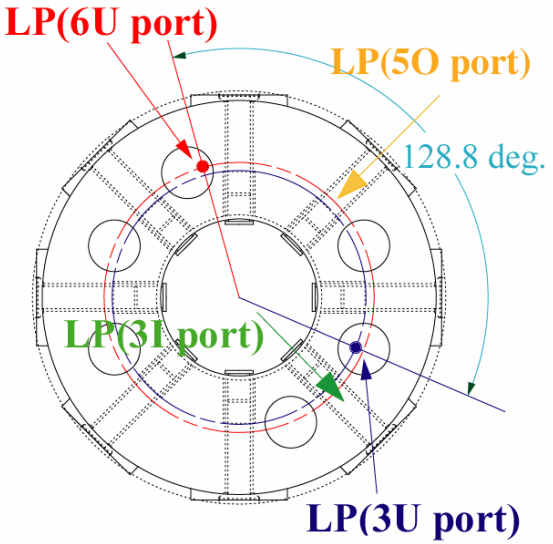
- The study of the L–H transition has progressed theoretically and experimentally. However, understanding of the L–H transition is still in the preliminary level in helical plasma.

- Moreover, helical plasma has **three dimensional magnetic configuration** which is often deformed by **magnetic islands** or **field stochasticity**

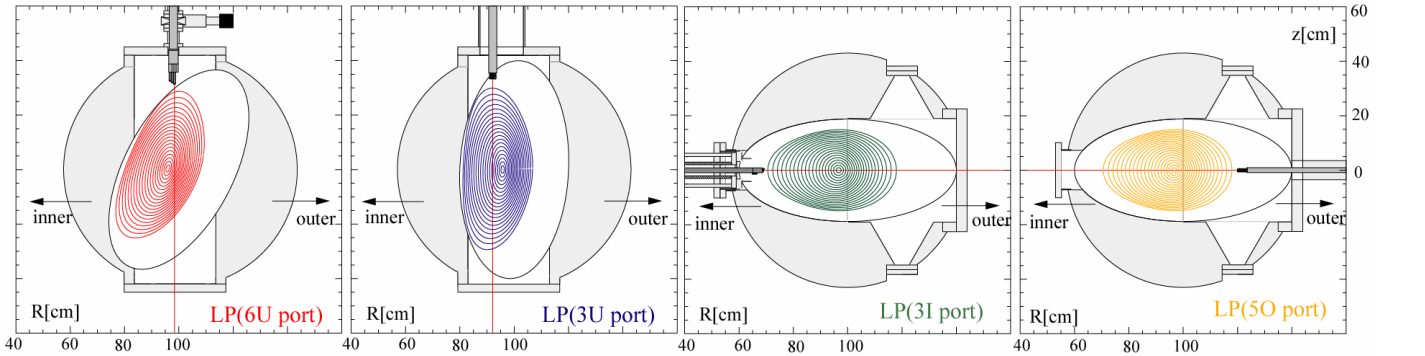
On the helical device (CHS), the **3-dimensional ETB structure** and the **fluctuation characteristics** measured by the **triple-typed Langmuir probes** installed on the different toroidal sections were studied.

Experimental setups
1. Experimental device and Arrangement of LP

- Compact Helical System (CHS)
  - Helical device
  - Heliotron/torsatron configuration
  - Major radius: R ~ 0.9–1.0 m
  - Minor radius: $\langle a \rangle$ ~ 0.2 m
- Triple-typed Langmuir probe (LP)
  - **Simultaneous measurements of electron temperature (T_e), electron density (n_e), space potential (V_s) and their fluctuations**
  - Move shot by shot from ρ ~ 0.94 to ρ ~ 1.1
  - Time resolution: 1 μs
  - Spatial resolution: poloidal ~6 mm, radial ~2 mm



CHS top view

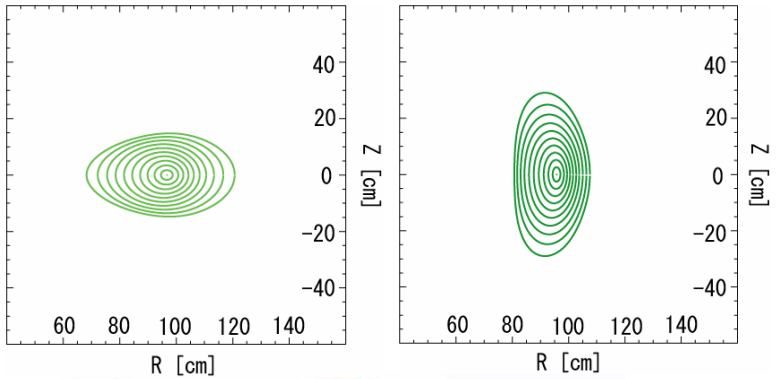


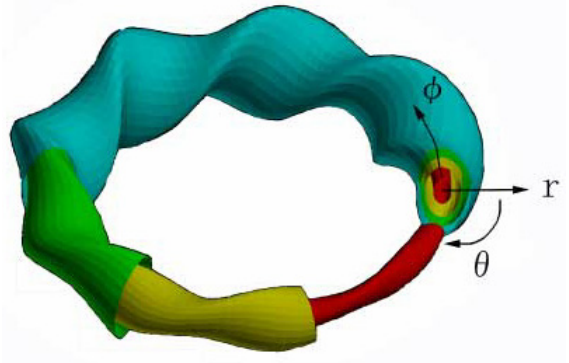
Upper location | Upper location | Inboard location | Outboard location

Vertically elongated section | Horizontally elongated section

Experimental setups
2. Experimental condition and magnetic configuration

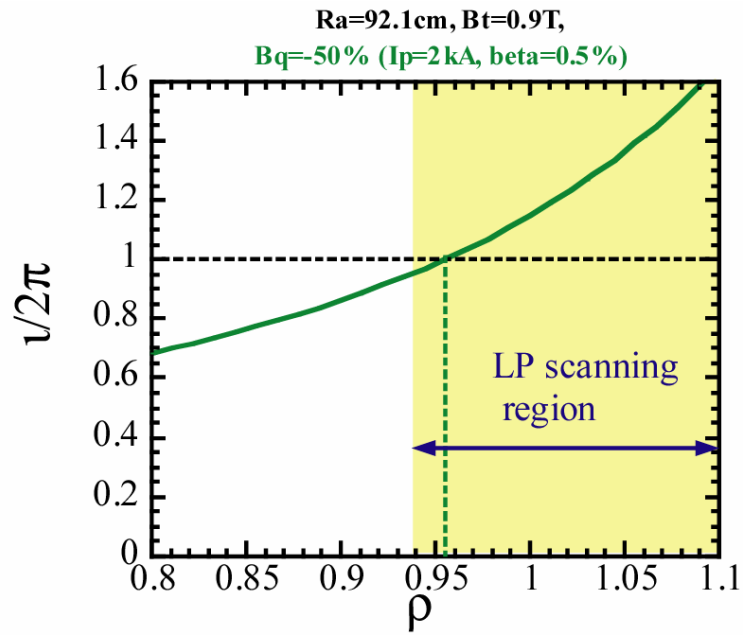
- Experimental condition
  - Gas: Hydrogen
  - Position of magnetic axis: R_{ax} = 92.1 cm
  - Toroidal magnetic field: B_t = 0.9 T
  - NBIs (co-injections) absorption power: P_{abs} ~ 800 kW
  - Quadrupole field: B_q = −50% (standard)





CHS plasma has m=8 periods in toroidal direction.

- Rotational transform



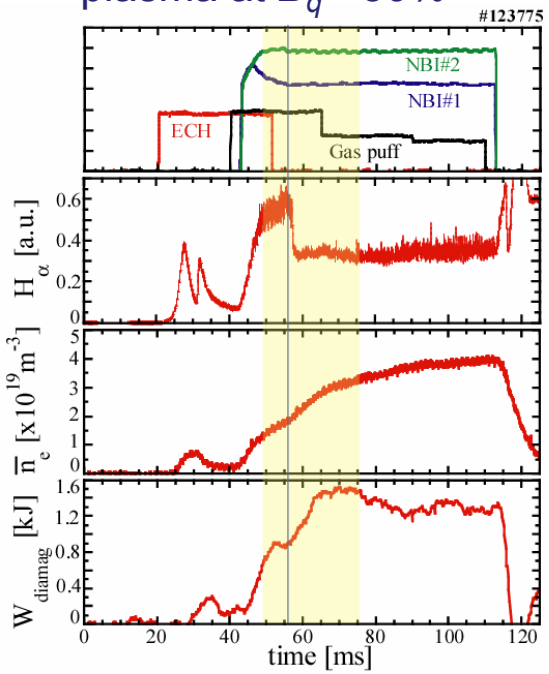
Rotational transform increases toward edge.

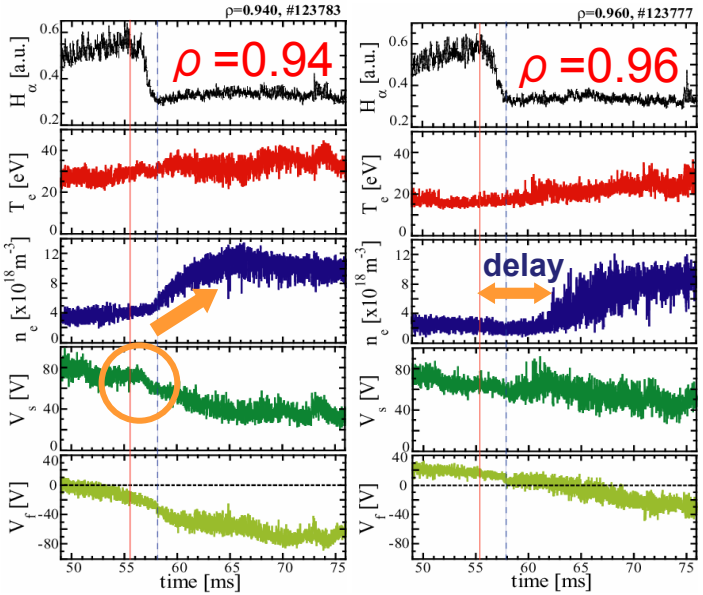
Time evolution of H_α, T_e, n_e, V_s and V_f at two upper locations (6U and 3U port) at B_q=-50%

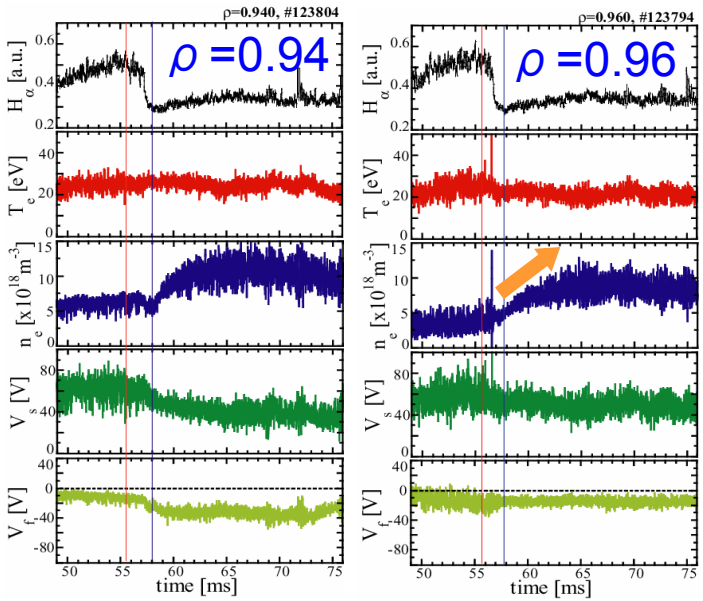
upper location

6U port

Typical discharge of ETB plasma at B_q=-50%







upper location

3U port

Toroidally separated for 130 degree from 6U port

At ρ = 0.94, V_s starts to decrease and at the same time n_e starts to increase. T_e remains unchanged across the transition.

The improvement of the **particle confinement** mainly occurs.

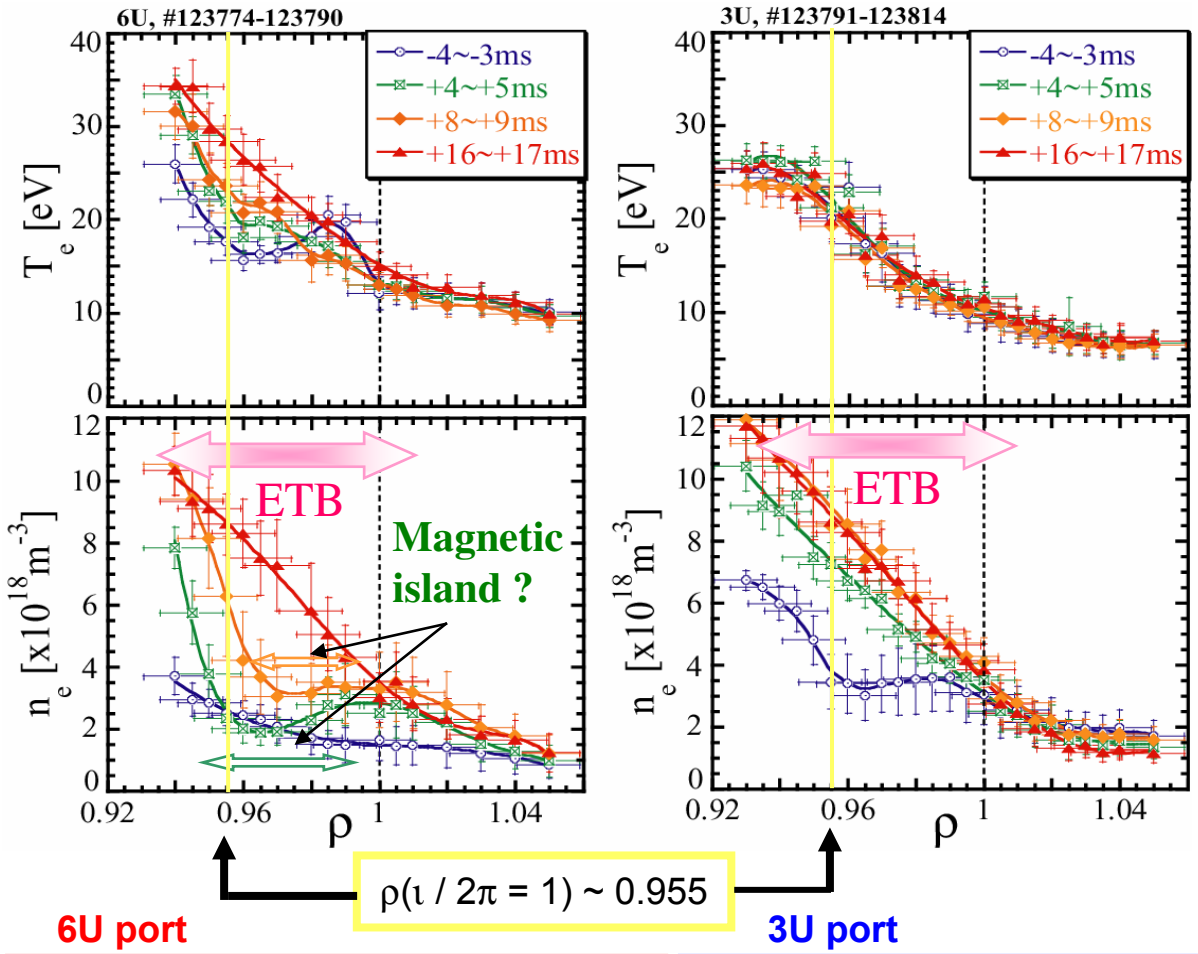
At ρ = 0.96 of 6U port, the increase of n_e delayed from the drop of H_α emission.

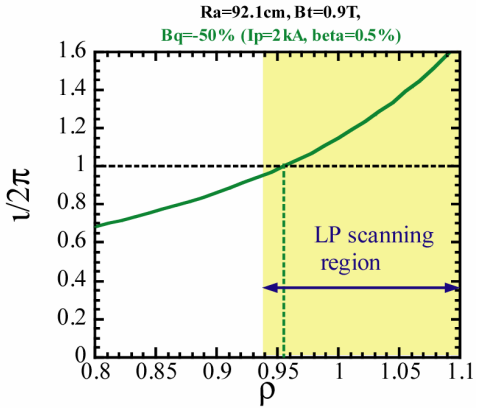
At ρ = 0.96 of 3U port, n_e starts to increase at the drop of H_α emission.

Comparison of time evolutions of two upper location (6U and 3U port) at B_q=-50%

6U port

3U port





- This peculiar edge structure may link to the presence of the magnetic island at $\iota/2\pi = 1$.
- The growth of ETB in n_e and T_e profiles may be locally blocked by a non-rotating magnetic island for error fields at the 6U port.

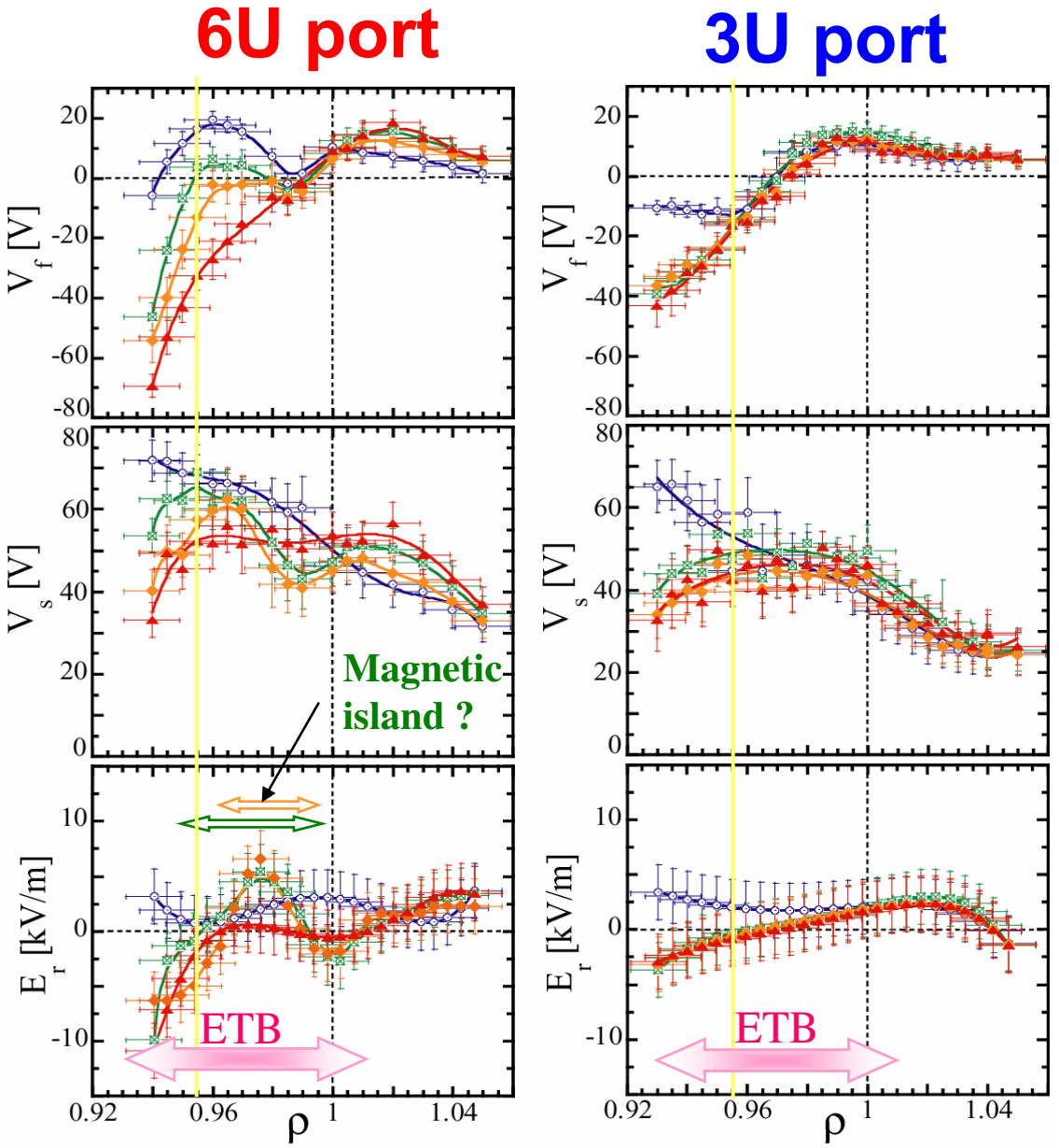
6U port

T_e: slightly deformed profile
n_e: peculiar concave structure

3U port

T_e: unchanged
n_e: Smoothly evolve and have steep gradient

Comparison of time evolutions of radial profiles of V_f, V_s and E_r at B_q=-50%



ρ(ι / 2π = 1) ~ 0.955

3U port

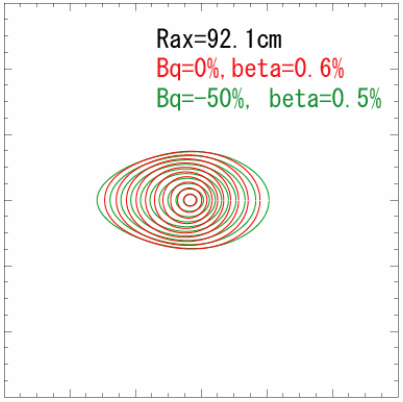
E_r changes from positive to negative with **monotonic shape**

6U port

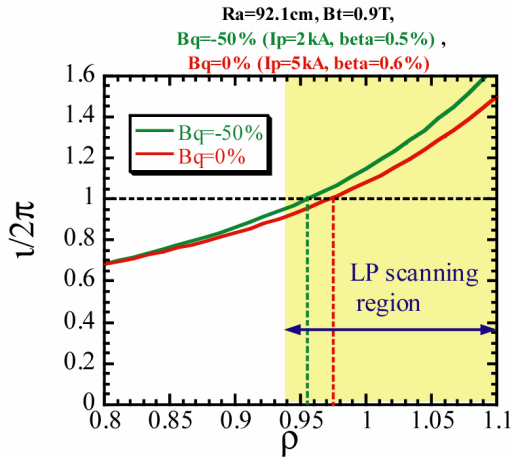
E_r changes to **wavy shaped** profile with **a hump**

Effect of the magnetic island at $\iota/2\pi = 1$?

Typical discharge of ETB plasma at B_q= 0%

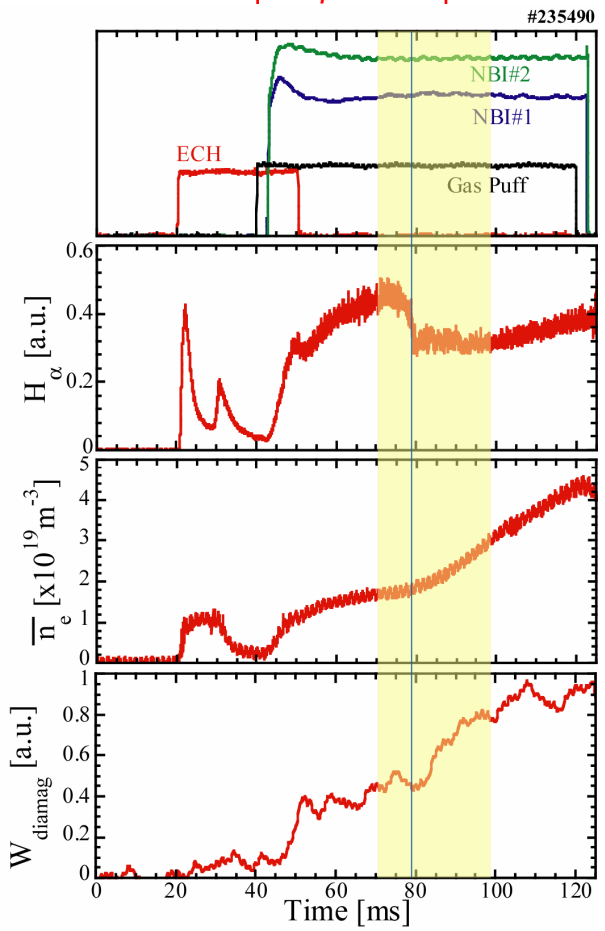


The configuration of B_q=0% is slightly smaller than that of B_q=-50% in horizontal direction.

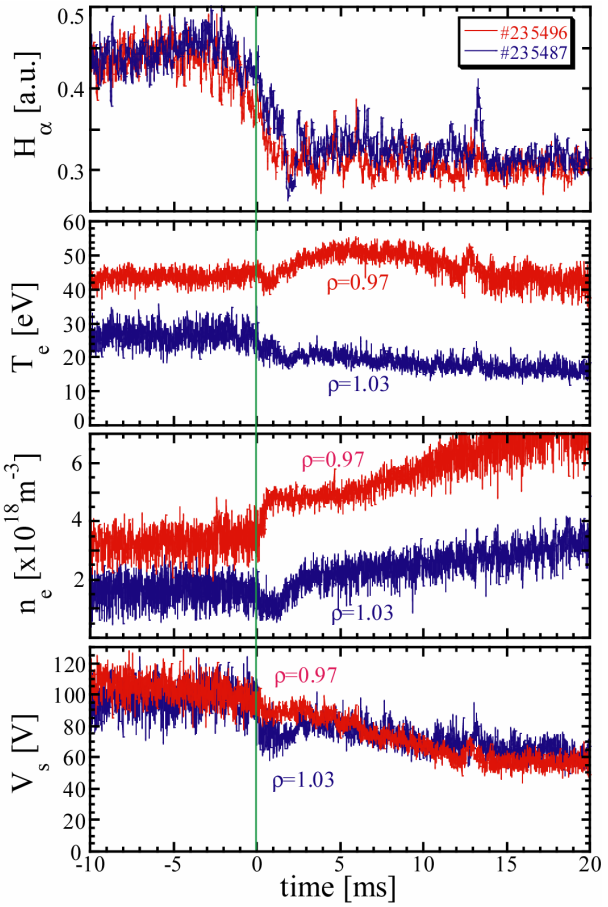


The rotational transform is slightly different in the edge region.

B_q=0%

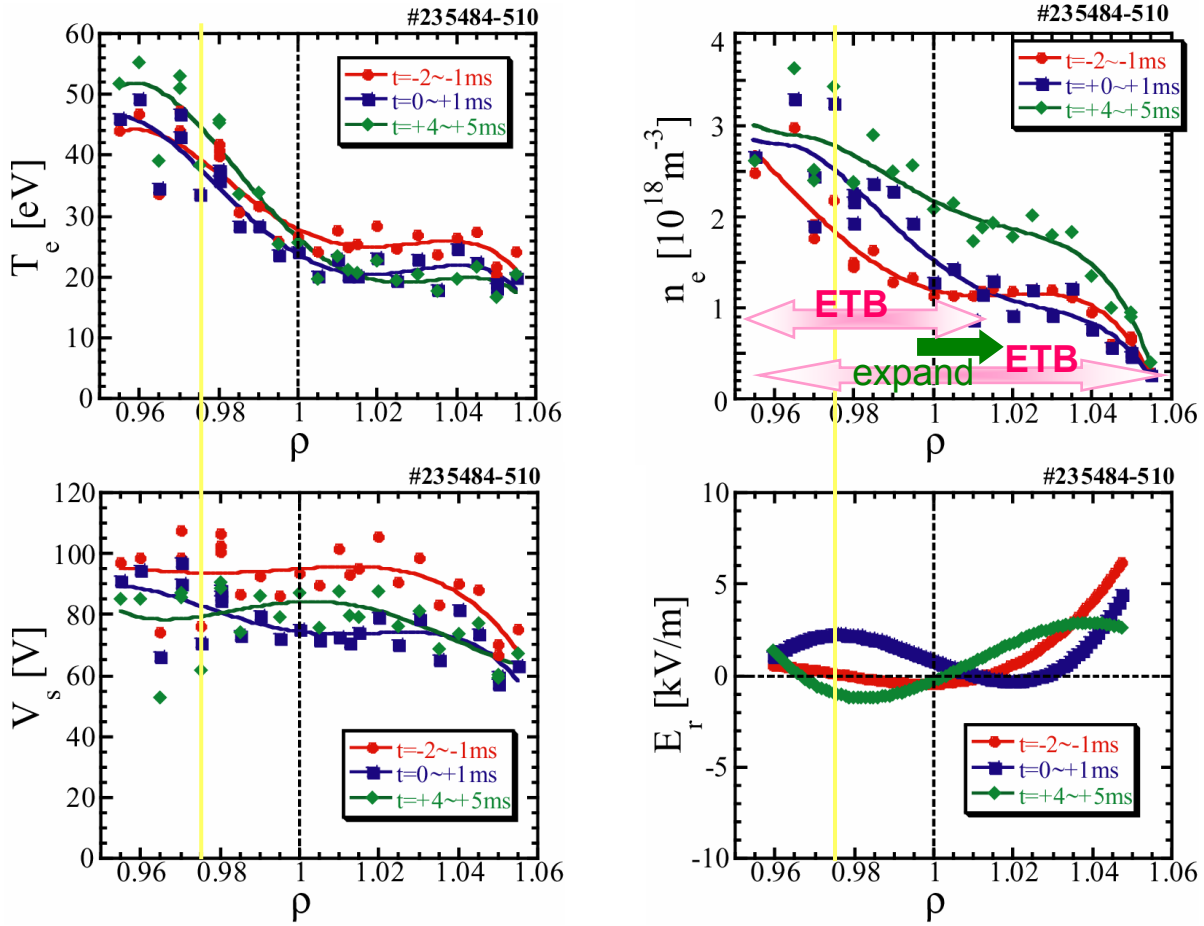


Time evolutions at 6U port



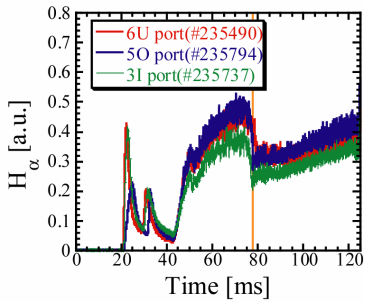
At this configuration, we compared the measurements at the outboard and inboard location as well as the upper location.

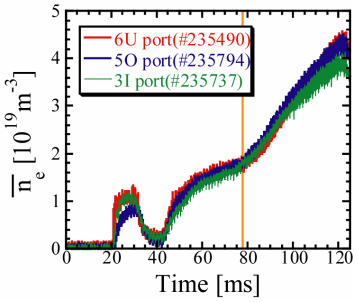
The radial profiles of T_e, n_e, V_s and E_r in edge region at the upper location (6U port) at B_q=0%

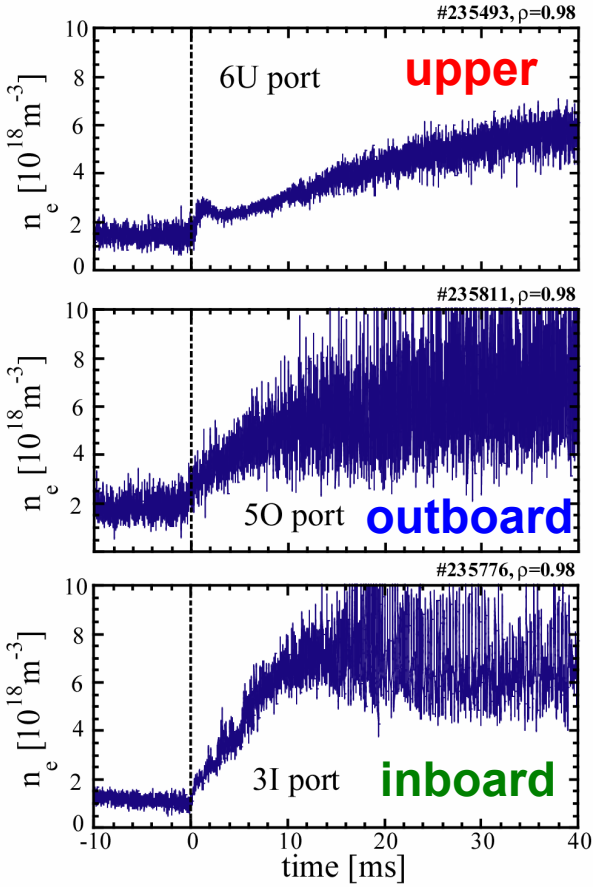


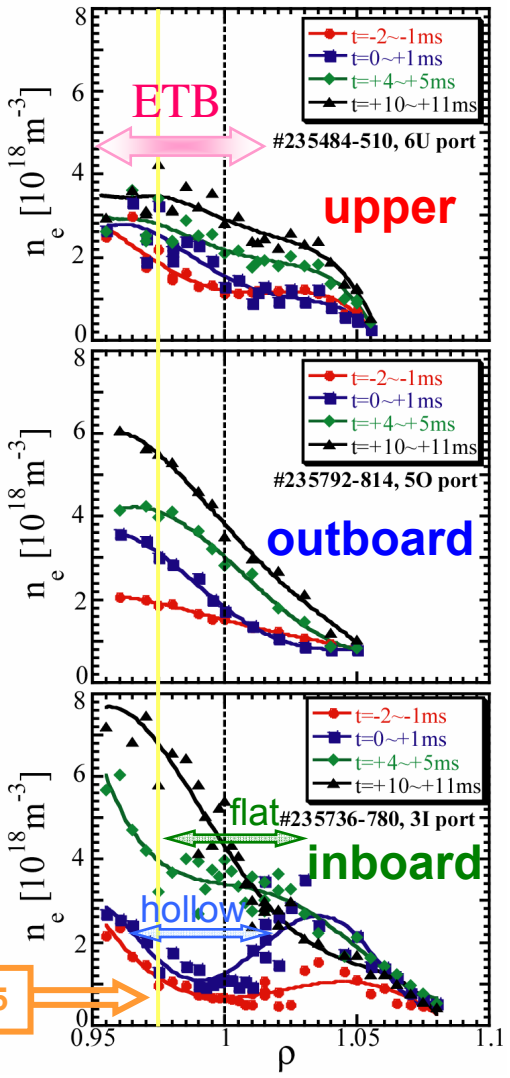
- It is seen that the ETB was formed at around ρ ~ 0.95–1.01 just after the transition (t=+0~1ms).
- Within 5ms after the transition, the ETB layer seems to expand outward.
- E_r profile dose not evolves without simply change from positive to negative.

Comparison of time evolutions of n_e at the upper (6U), the outboard (5O) and the inboard (3I) location









➢The time evolution of n_e across the transition at different toroidal sections shows the characteristic behavior.

ρ (ι / 2π = 1) ~ 0.975

➢At Inboard location, hollow or flat structure was observed just after the transition in $0.97 < \rho < 1.02$.
➢It is speculated that a static m/n = 1/1 **magnetic island** at ι/ 2π = 1 would bring about the hollow or flat structure.

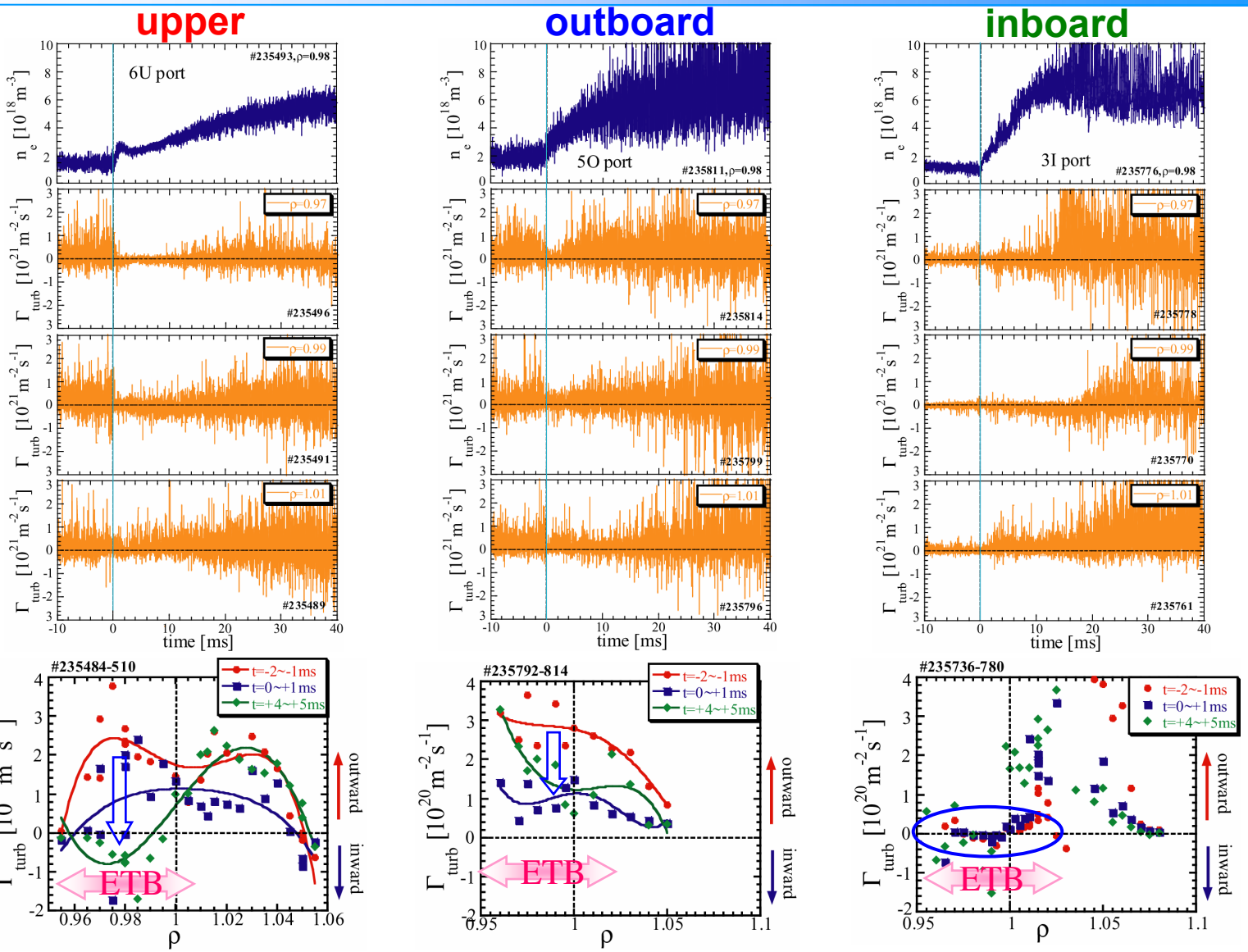
Time evolutions and radial profiles of turbulent particle flux

$$\Gamma_{turb} = \frac{\langle \tilde{n}_e \tilde{E}_\theta \rangle}{B_t}$$

$\rho = 0.97$

$\rho = 0.99$

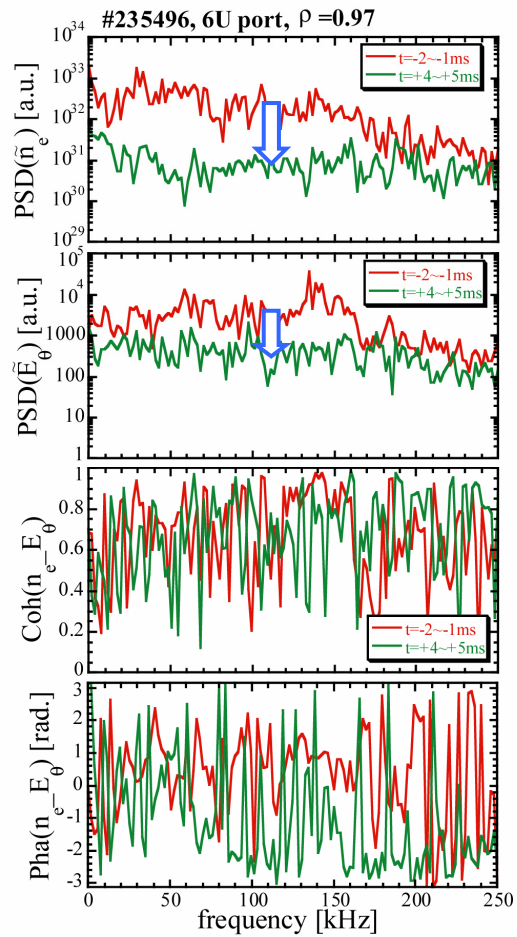
$\rho = 1.01$



The reduction of the turbulent particle flux was observed across the L–H transition.

Frequency spectra and radial profiles of fluctuations of n_e and E_θ at 6U port

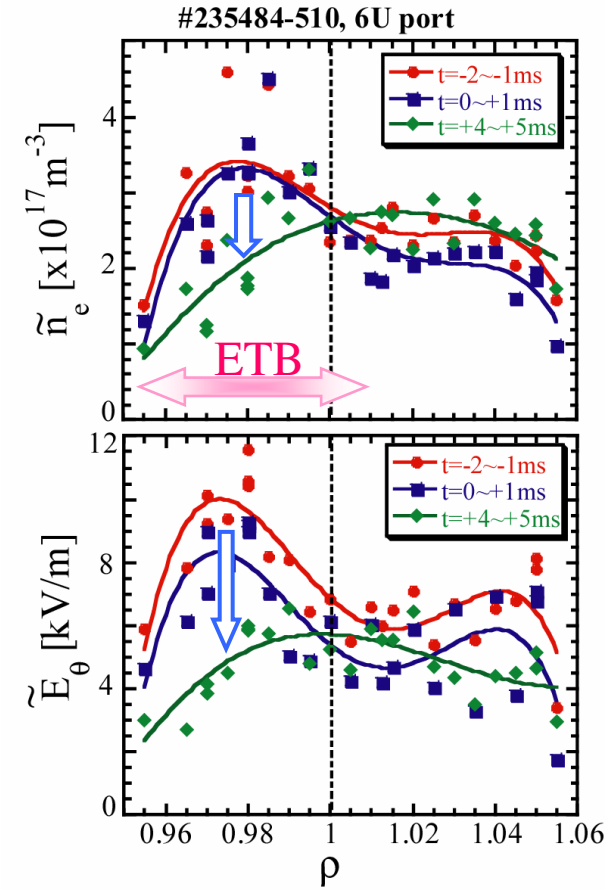
$$\Gamma_{turb} = \frac{2}{B_\phi}\int_0^\infty Coh(\tilde{n}_e \_ \tilde{E}_\theta)\bullet\cos\left\{Pha(\tilde{n}_e \_ \tilde{E}_\theta)\right\}\bullet\left[P(\tilde{n}_e)P(\tilde{E}_\theta)\right]^{1/2} df$$



$\rho = 0.97$

t=-2~-1ms
Before the transition

t=+4~+5ms
After the transition



The reduction of the turbulent particle flux is mainly due to **the reduction of fluctuations of n_e and E_θ**

Summary

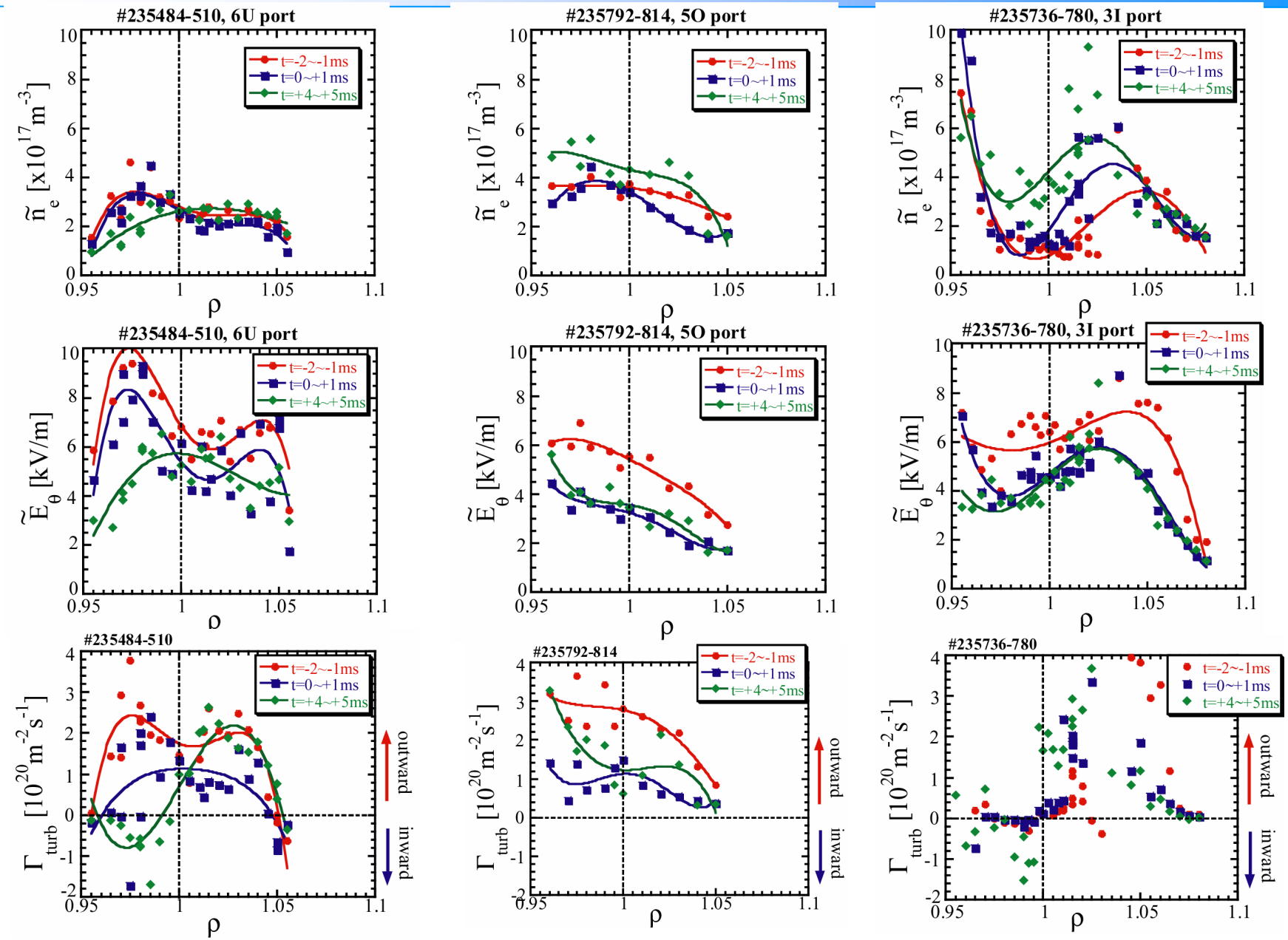
The measurements by triple-typed Langmuir probes installed at the different toroidal sections were done in ETB plasmas in CHS.

- Time evolution of L–H transition
  - **The improvement of the particle confinement** mainly occurs.
  - **The time evolution of n_e** across the transition at different toroidal section shows **the characteristic behavior**.
- ETB structure
  - At the upper location (6U port), hollow structure in n_e was observed just after the transition, however, at the other upper location (3U port), there was no hollow structure.
  - E_r changes to wavy shaped profile with a hump at 6U port.←**effect of magnetic island**?
  - Within 5ms after the transition, the **ETB layer seems to expand outward**.
  - At the inboard location (3I port), hollow structure was observed just after the transition, however, at the other upper port (6U and 5O port), there was no hollow structure.

    → It is speculated that the static m/n = 1/1 **magnetic island** would bring about the hollow and flat structure.
- Fluctuation characteristic
  - **The reduction of the turbulent particle flux** was observed across the L–H transition.
  - The reduction of the turbulent particle flux is mainly due to **the reduction of fluctuations of n_e and E_θ**.

The following is appendix

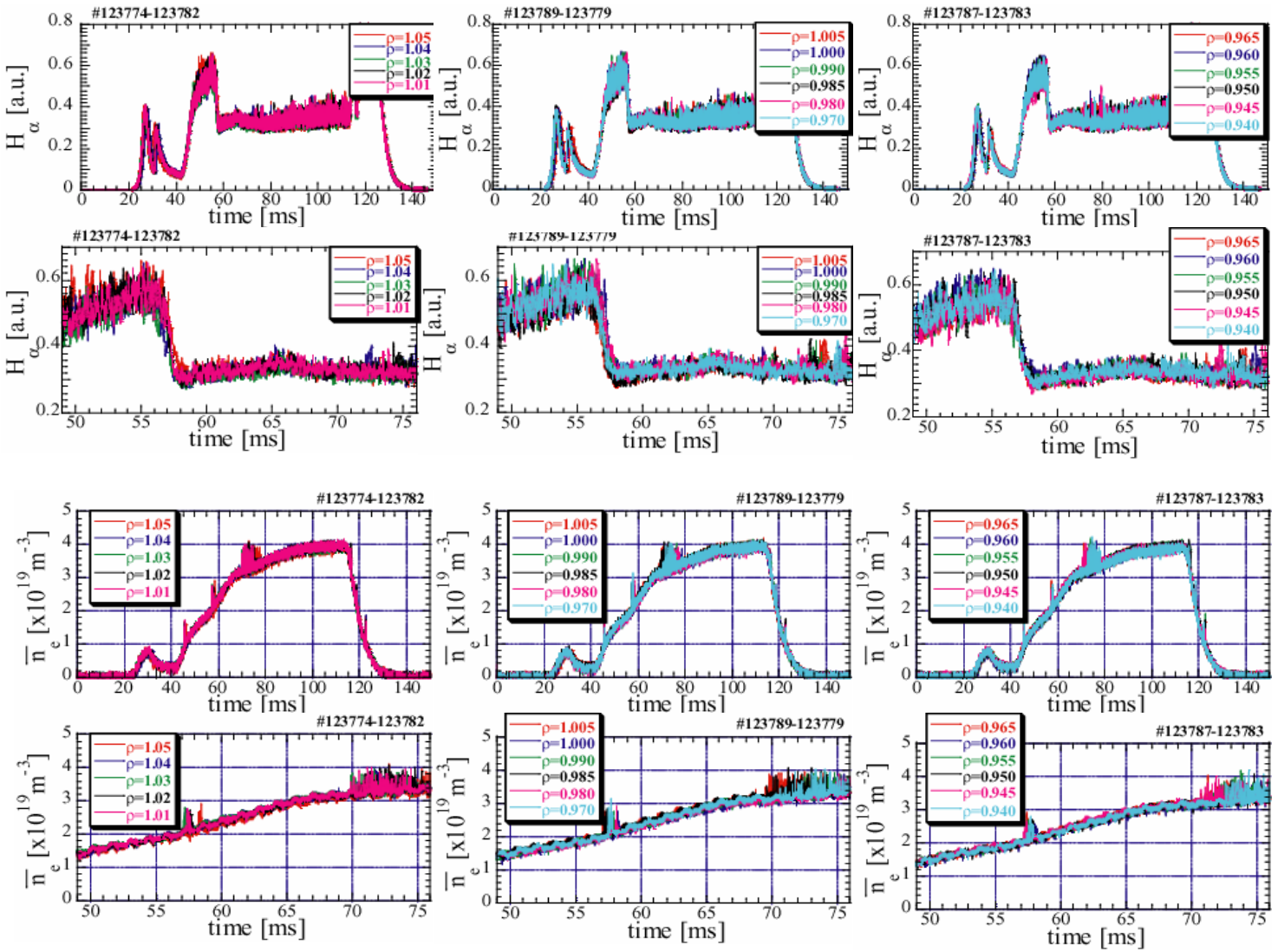
Radial profiles of turbulent particle flux and fluctuations of n_e and E_θ



Confirmation of reproducibility of ETB plasma

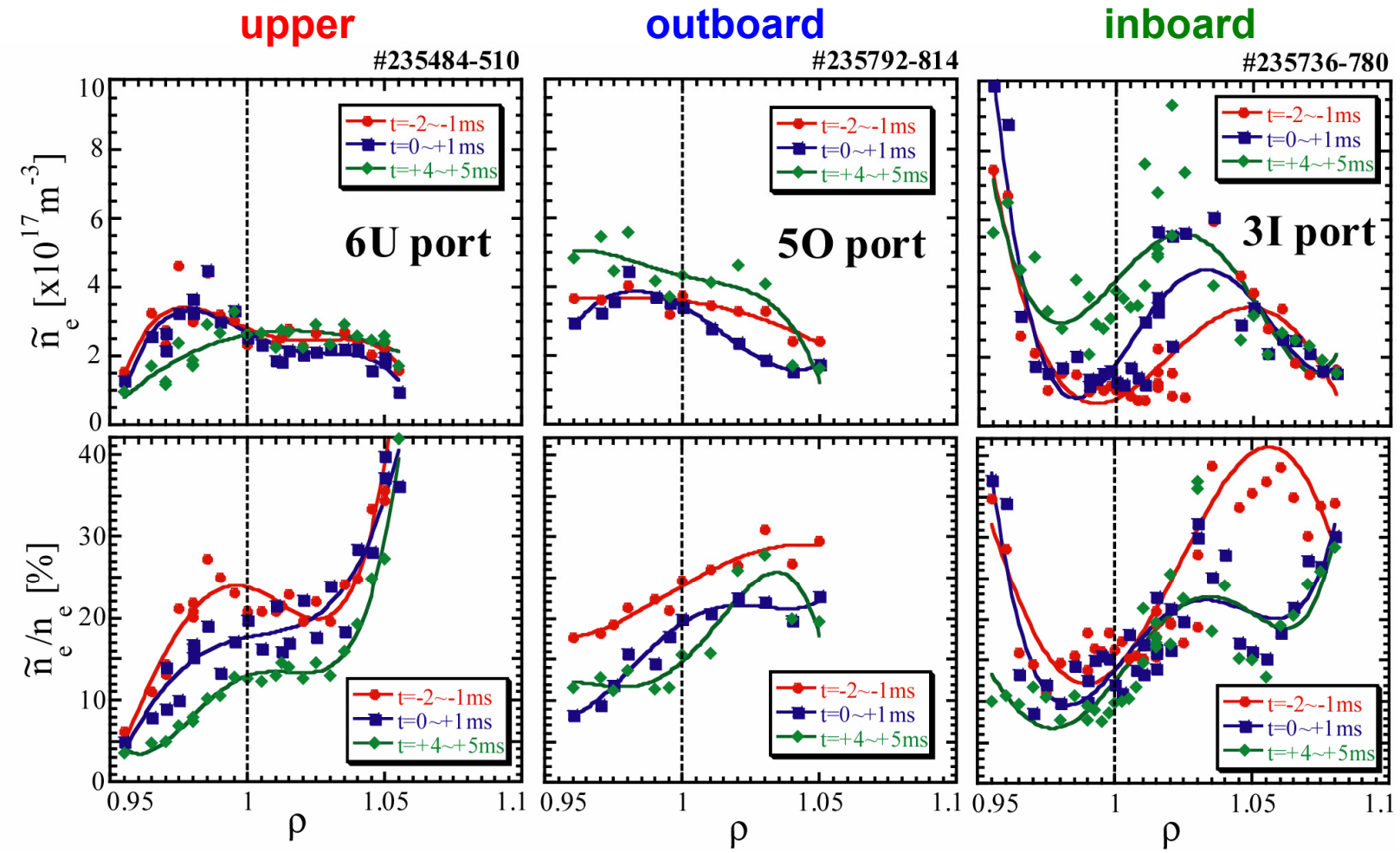
Hα emission

Line average electron density



- This time evolutions of Ha, ne show that 17 ETB shots have good reproducibility.

Radial profiles of fluctuation and normalized fluctuation of n_e at the upper (6U), the outboard (5O) and the inboard (3I) location



- Fluctuation of n_e decreased in the region of $0.95 < \rho < 1.0$ at the upper location.
- Normalized Fluctuation of n_e decreased.
- At the inboard location, the radial profiles of fluctuation of n_e has characteristic shape.