P8-13

Measurement of 3-D Mode Structure of the Edge Harmonic Oscillations in CHS using Beam Emission Spectroscopy

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Introduction

How can we measure the 3-D spatial structure (radial locality and poloidal/toroidal mode number) of the fluctuation in the plasma parameters?

... For the magnetohydrodynamic (MHD) oscillation in magnetically-confined torus plasmas, we might estimate its locality from the mode number measured using the magnetic probes and the position of rational surface with corresponding rotational transform.

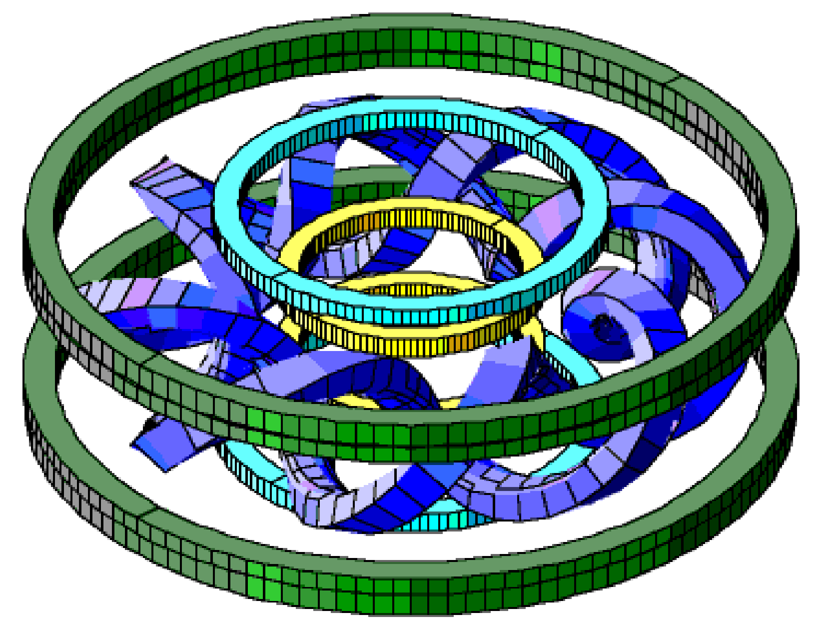
⇔ However, accurate locality of fluctuations can be obtained only by using the local diagnostics methods of fluctuations.

3-D spatial structure of fluctuations in CHS is investigated using the beam emission spectroscopy (BES) as the diagnostic method of the local density fluctuations and the magnetic probe array.

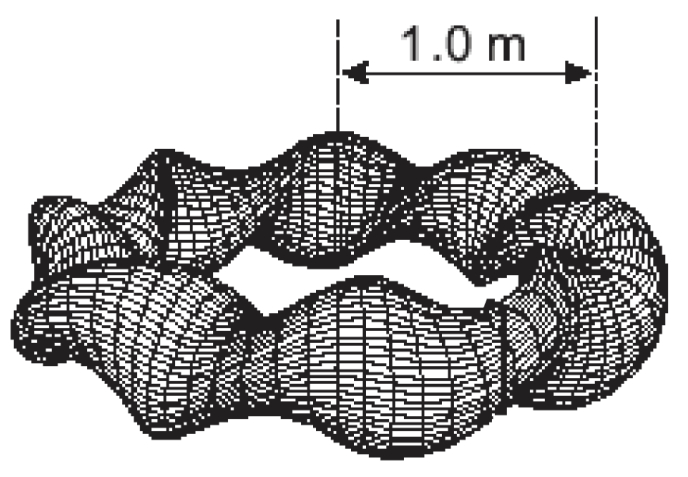
Target of the measurement in the present study
... Edge harmonic oscillations (EHO)
in the compact helical system (CHS).

Compact Helical System (CHS) @ NIFS

Configuration of coils



Shape of the plasma



- Parameter of CHS
  - Multi polarity: l=2
  - Toroidal periods: m=8
  - Major radius:1.0m
  - Minor radius:0.2m
  - $n_e \sim 10^{13} cm^{-3}$
  - $T_e \sim 1keV$
  - R_{ax}: 92.1 cm, B_{ax}: 0.95 T (standard configuration)
- Heating
  - ECH, ICRF, NBI × 2
- Probe beam for BES: NBI#2
  - Acceleration voltage: 25～32keV
  - Hydrogen atom beam
  - Positive ion source

BES system in CHS

- Emissions from the collisionally excited neutral beam atoms (“**beam emission**") are detected.
- The **sightlines** are
  - **tangent to the local magnetic field** to have a good spatial resolution.
  - **parallel to the beam line** to yield large Doppler shift of the beam emission.
- Hydrogen plasma, hydrogen atom beam

  →Beam emission: Doppler-shifted H_α

$$I \approx \frac{A_{32}}{A_{32}+A_{31}} \cdot h\nu \cdot \Delta V \cdot \Delta\Omega / 4\pi$$

$$\cdot(\underline{n_e \cdot n_{beam} \cdot <\sigma_e v>} + \underline{n_i \cdot n_{beam} \cdot <\sigma_i v>})$$

$$= \boxed{n_e} \cdot n_{beam} \cdot v_{beam} \cdot (\underline{<\sigma_e v>/v_{beam}} + \underline{\sigma_i})$$

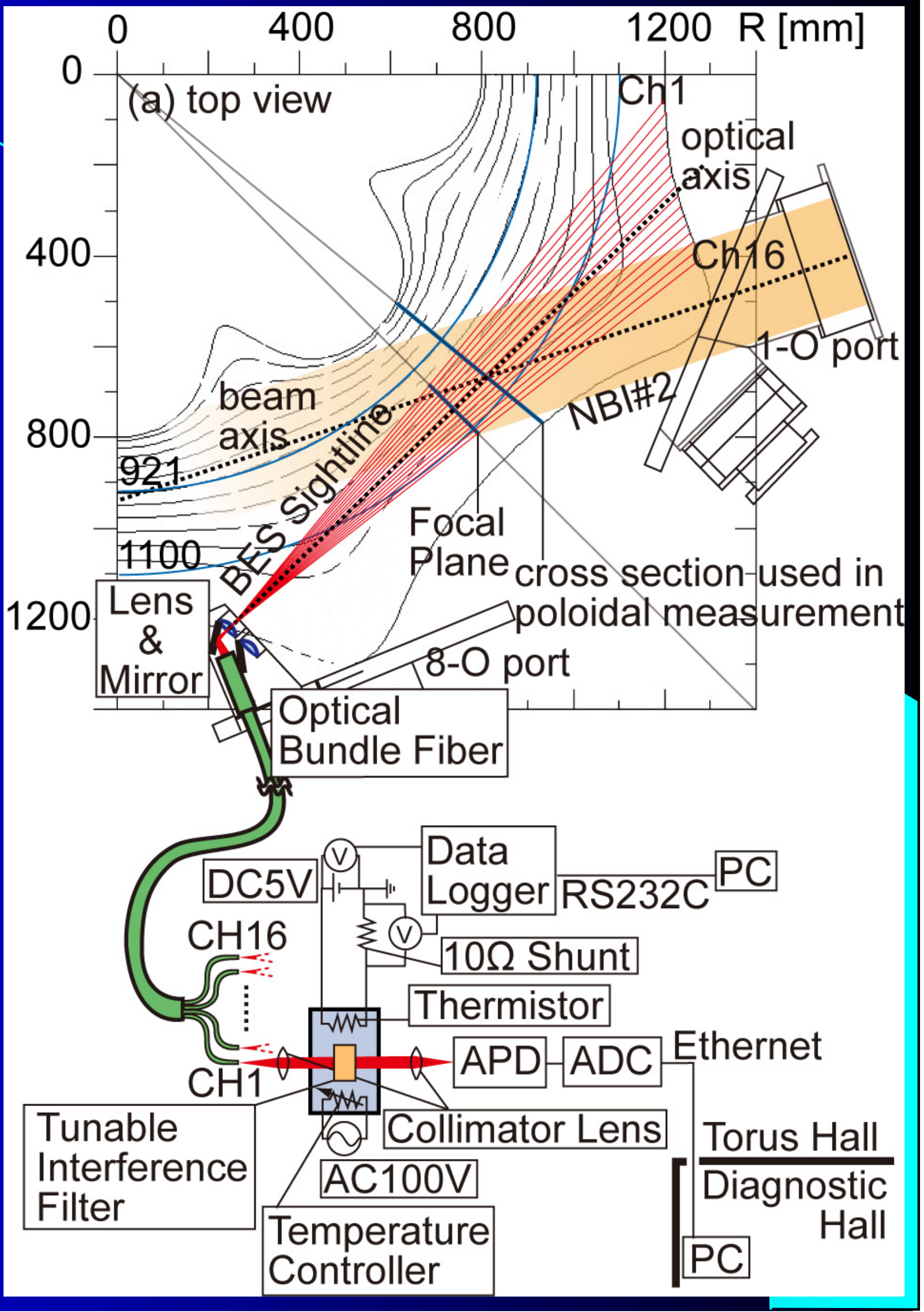
e-H^0 collision **H$^+$-H^0 collision**

- Density fluctuations:

$$\frac{\tilde{I}}{I} = F\left(\boxed{\frac{\tilde{n}_e}{n_e}, \frac{\tilde{n}_i}{n_i}, \frac{\tilde{n}_{beam}}{\underline{n_{beam}}}}, <\sigma_e v>(T_e, \tilde{T}_e)\right)$$

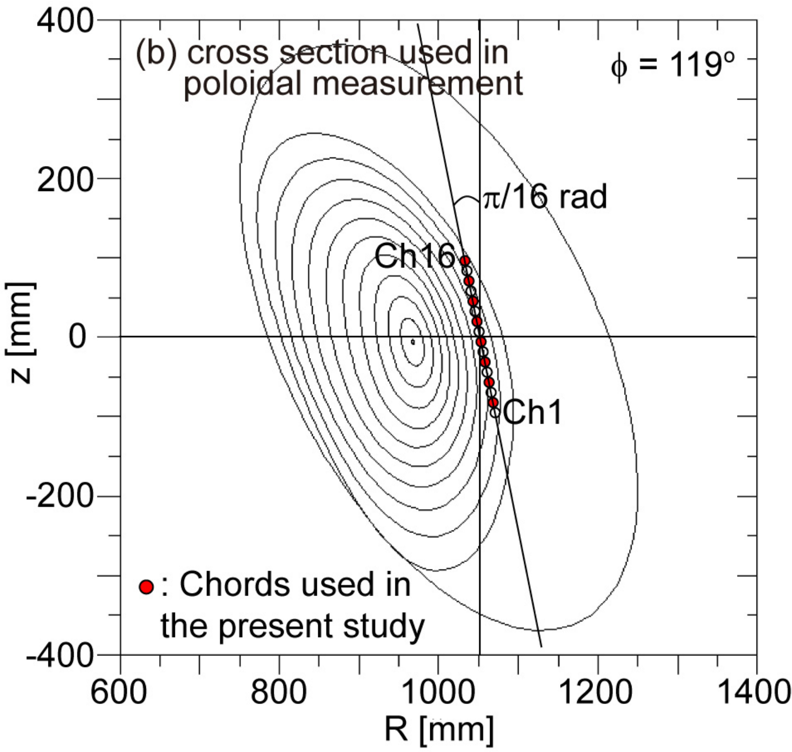
Removed by data processing

$$\boxed{\frac{\tilde{I}}{I} = \frac{\tilde{n}}{n}(e,i)}$$



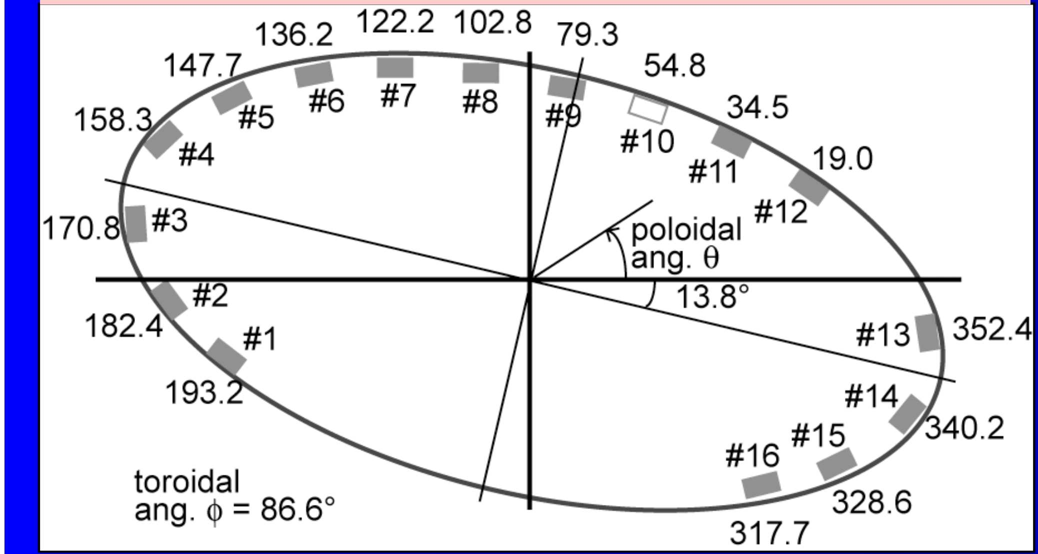
- **Detection system**
  - optical band-pass tunable interderence filters ($\Delta\lambda$ = 1.0 nm in FWHM)
  - APD detectors with a 100 kHz low-pass filter
  - Isolation digitizers with the sampling rate of 1 MHz

- **Arrangement of the fibers**
  - **Radial** (spatial pitch Δx = 1.1 cm -> Nyquist wavenumber $k_N = \pi/\Delta x$ = 2.86 rad cm^{-1})
  - **Poloidal** (Δx = 2.6 cm k_N = 1.21 rad cm^{-1})



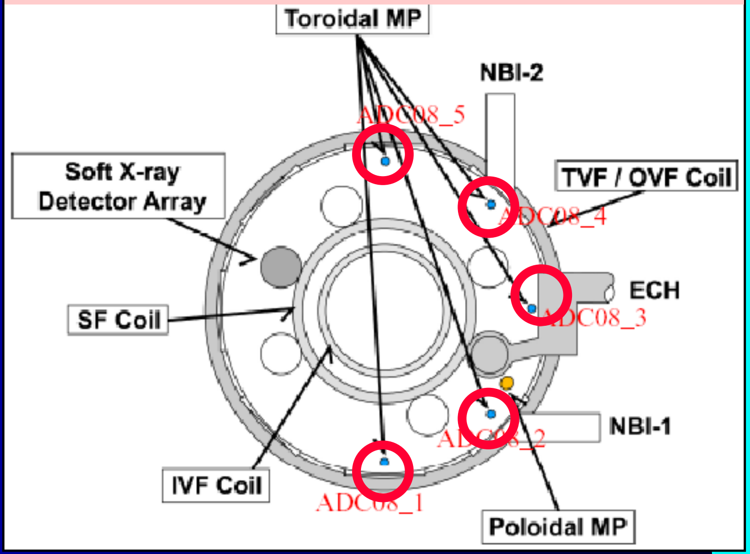
Magnetic Probes (MP)

MP poloidal array



16 probes covering $\Delta\theta$ = 235.5°.

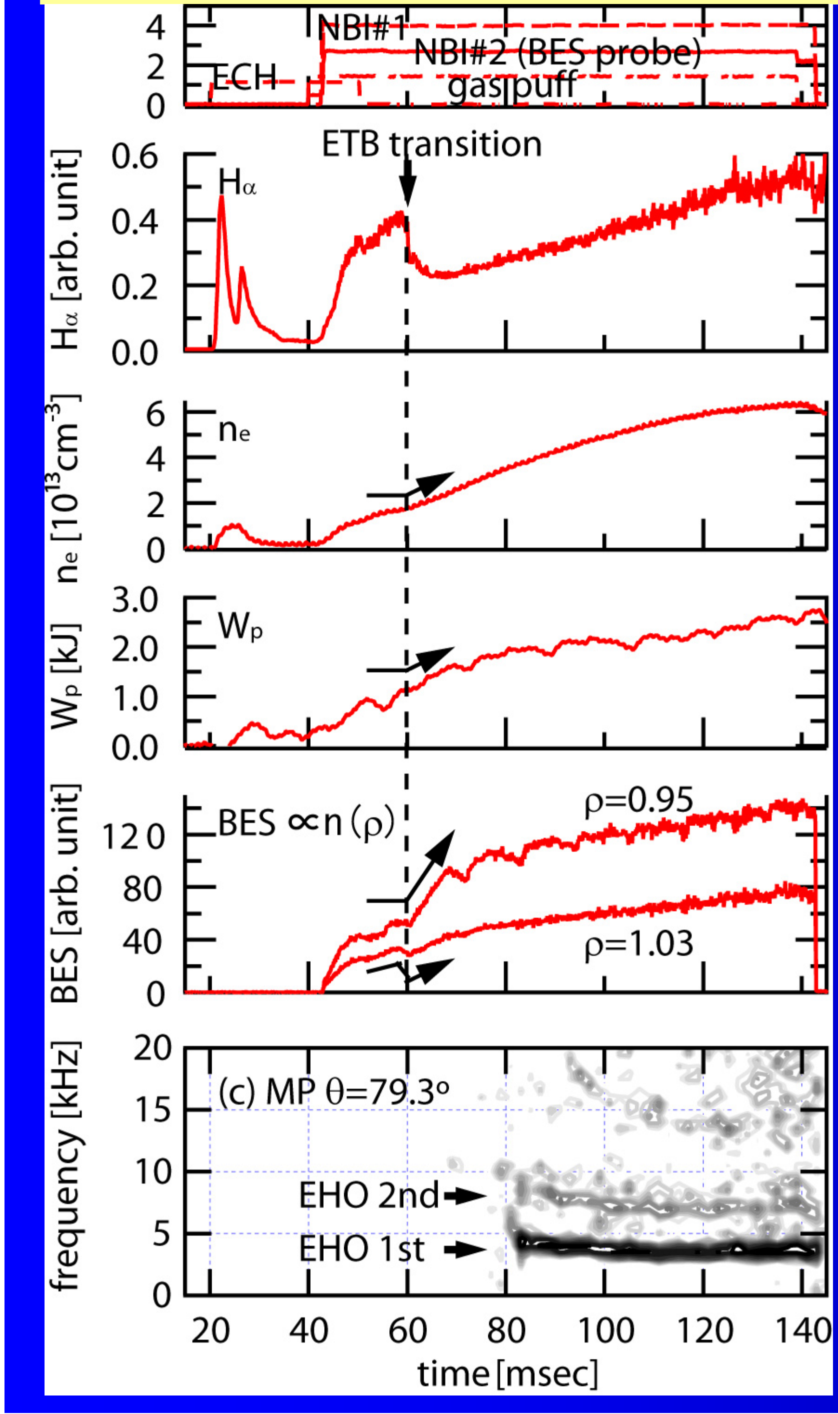
MP toroidal array



5 probes covering $\Delta\phi = \pi$ rad.

EHO in the ETB discharges in CHS

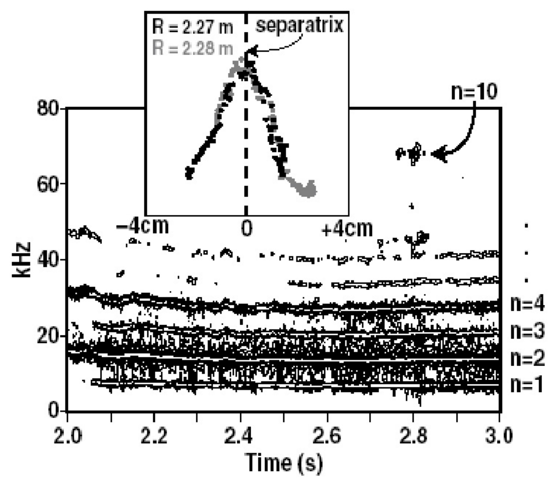
Waveform of the ETB discharge in CHS



- **Condition for ETB formation**
  - **- Heated by two NBIs, co-injection**
  - **- Threshold in heating power**
- **Evidence of ETB formation**
  - **- H_α ↓, n_e ↑, ∇n_{edge} ↑, W_p ↑**
- **For the heating power much above the ETB transition, coherent fluctuation (*f* ~ 3.5 kHz and the 2 *f* ~ 7.0 kHz) appears in the latter half of the discharge.**

⇒ similar to the edge harmonic oscillations (EHO) in tokamaks.

Cf. EHO in DIII-D

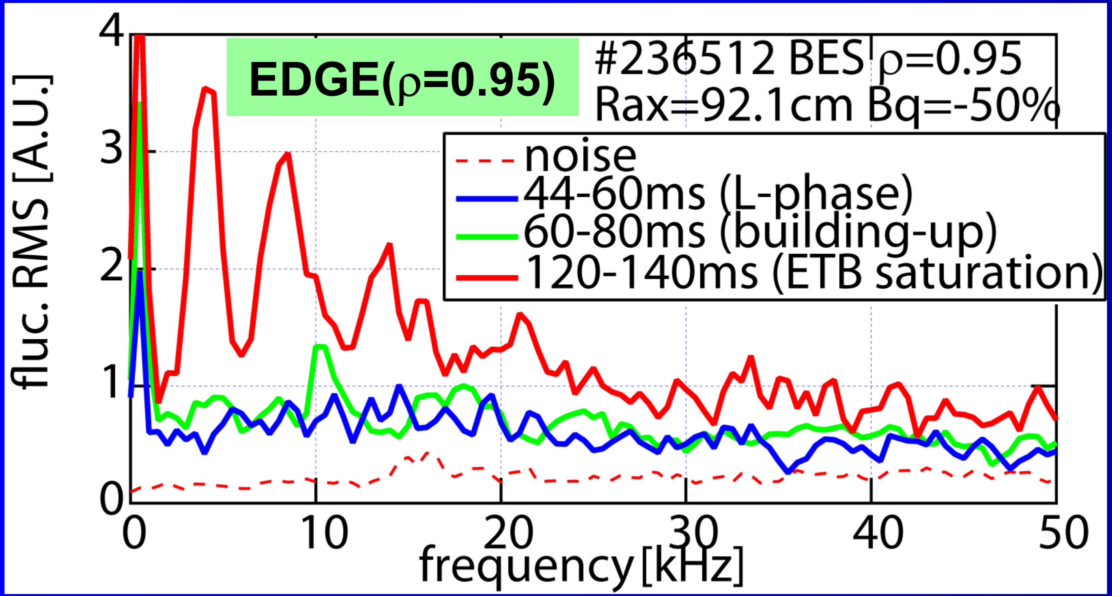


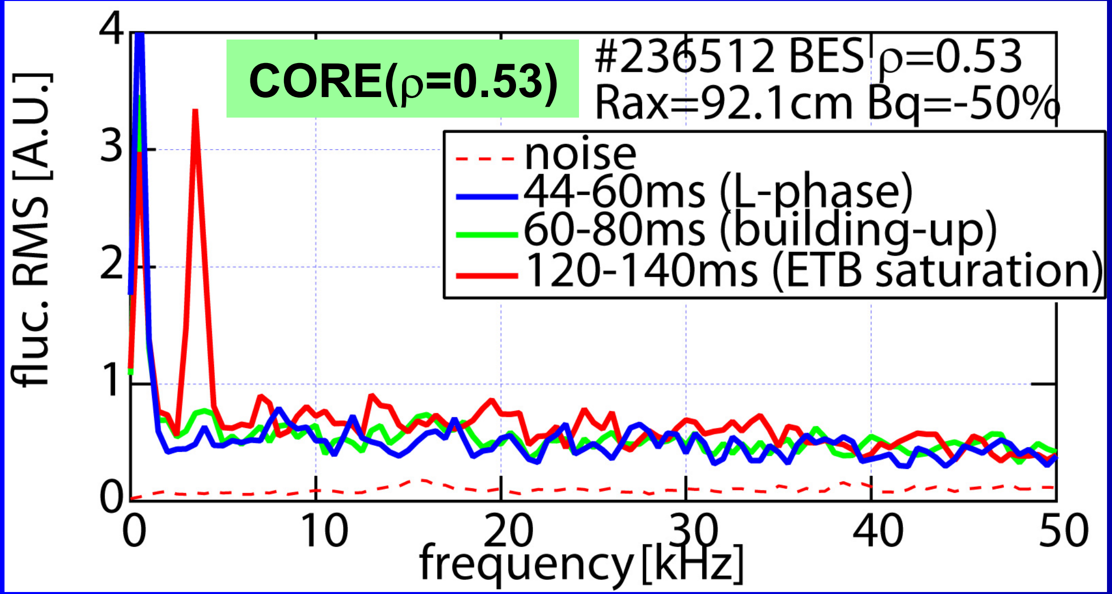
(C. M. Greenfield *et al.*, PRL 86 (2001) 4544)

- **-MHD mode observed in the quiescent H-mode discharges in tokamaks.**
- **-Having several harmonic components.**
- **-Localized at the edge.**
- **-Enhances particle transport through the boundary instead of the edge localized modes.**

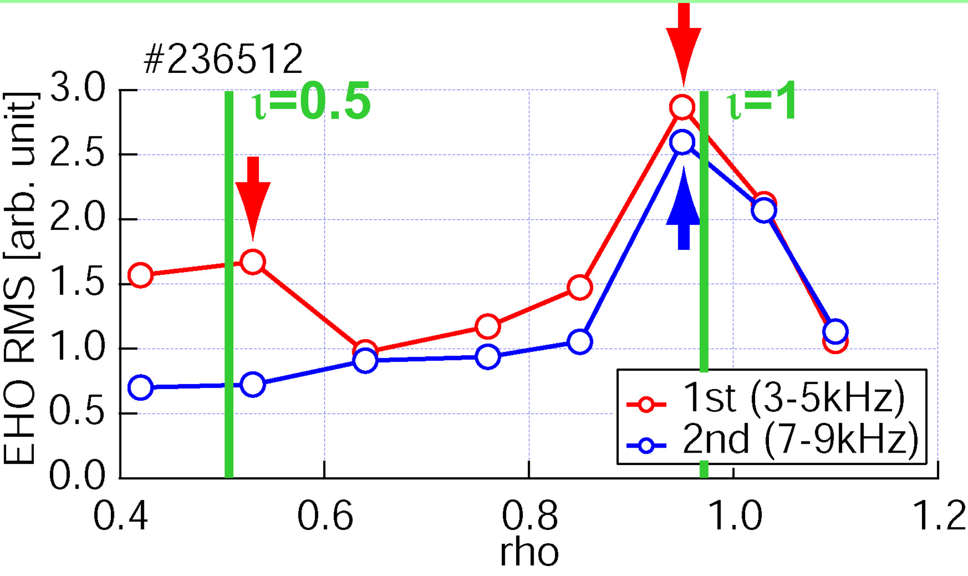
EHO observed in the BES signal

Power spectra of the density fluctuations measured using BES





Radial profile of the RMS value of density fluctuation



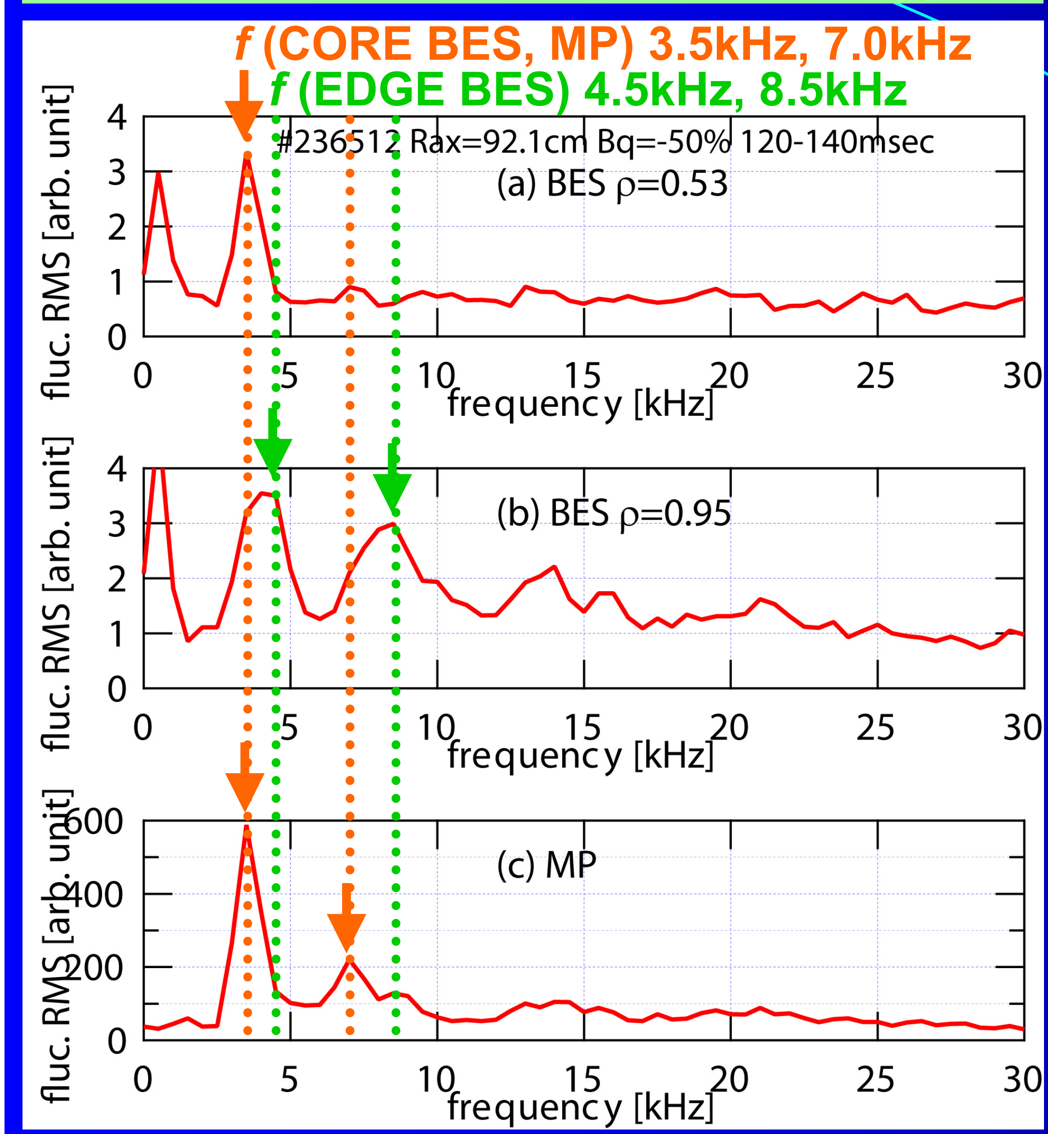
- Coherent modes appears in the ETB saturation phase.
  - 1st mode... both CORE (ρ~0.5, ι=0.5) and EDGE (ρ~0.95, ι=1).
  - 2nd mode... EDGE.

We call this mode with harmonics in CHS “EHO”.

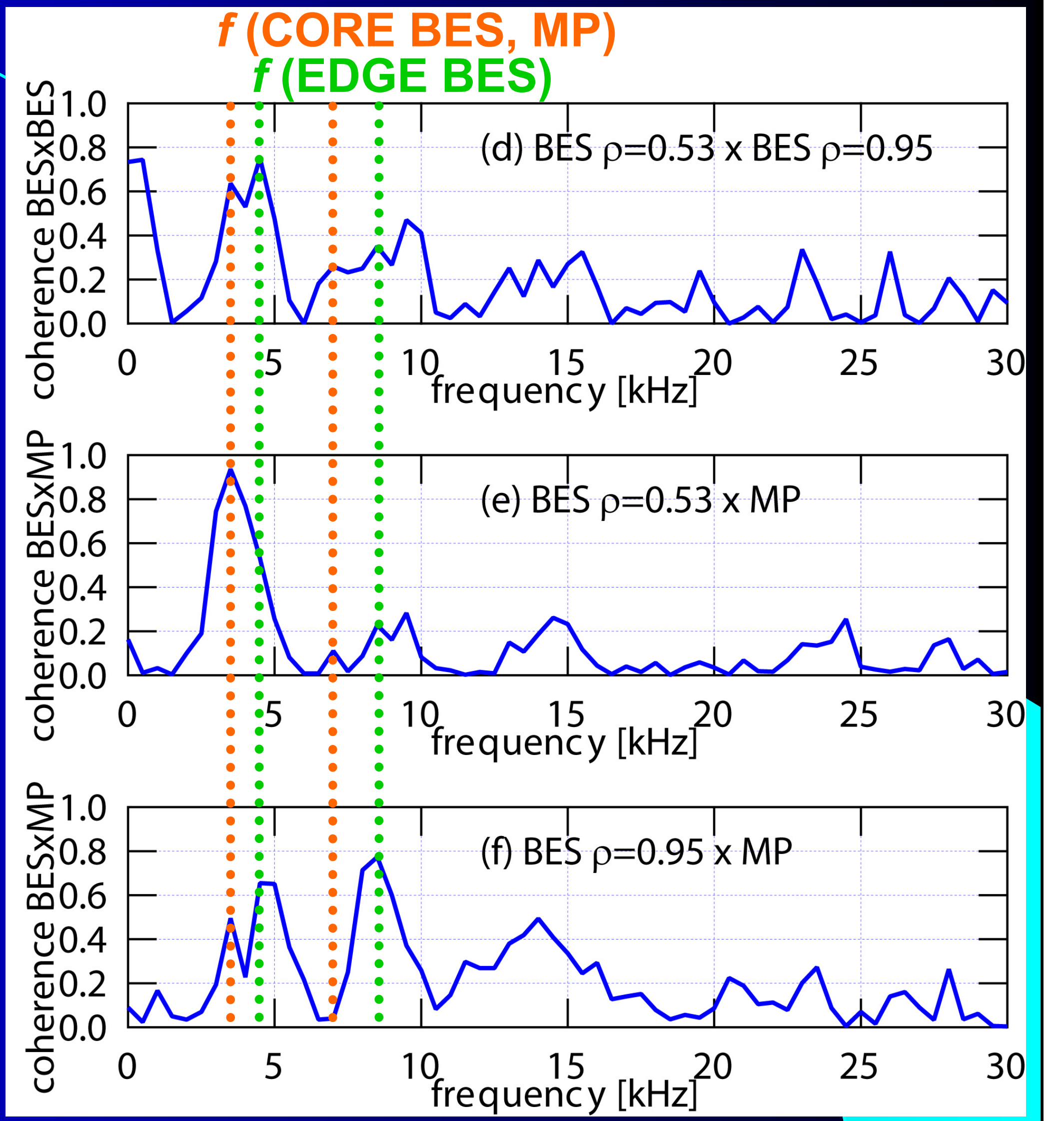
Are 1st mode in CORE and EDGE identical?

CORE-EDGE EHO frequencies comparison

Power spectra



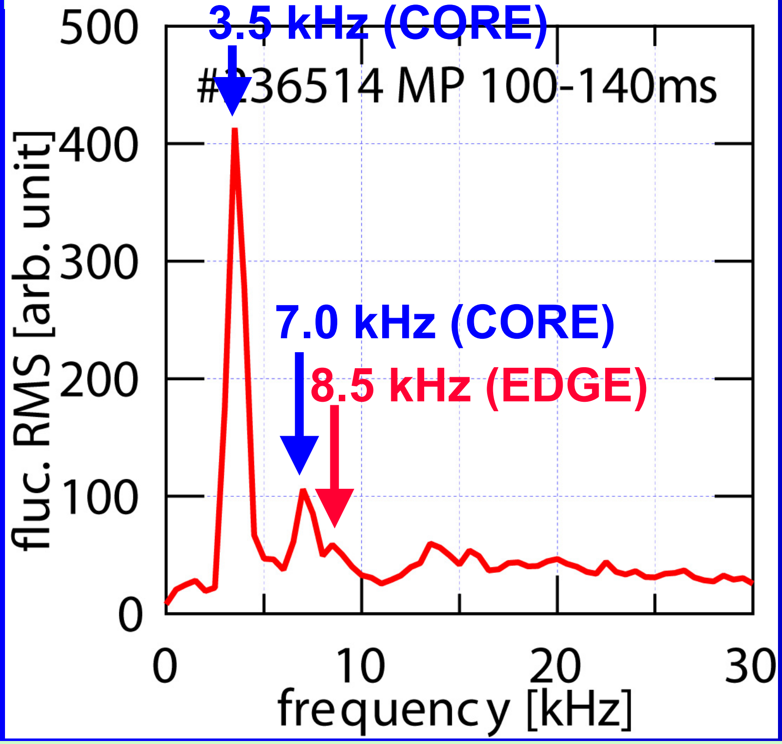
Cross coherence



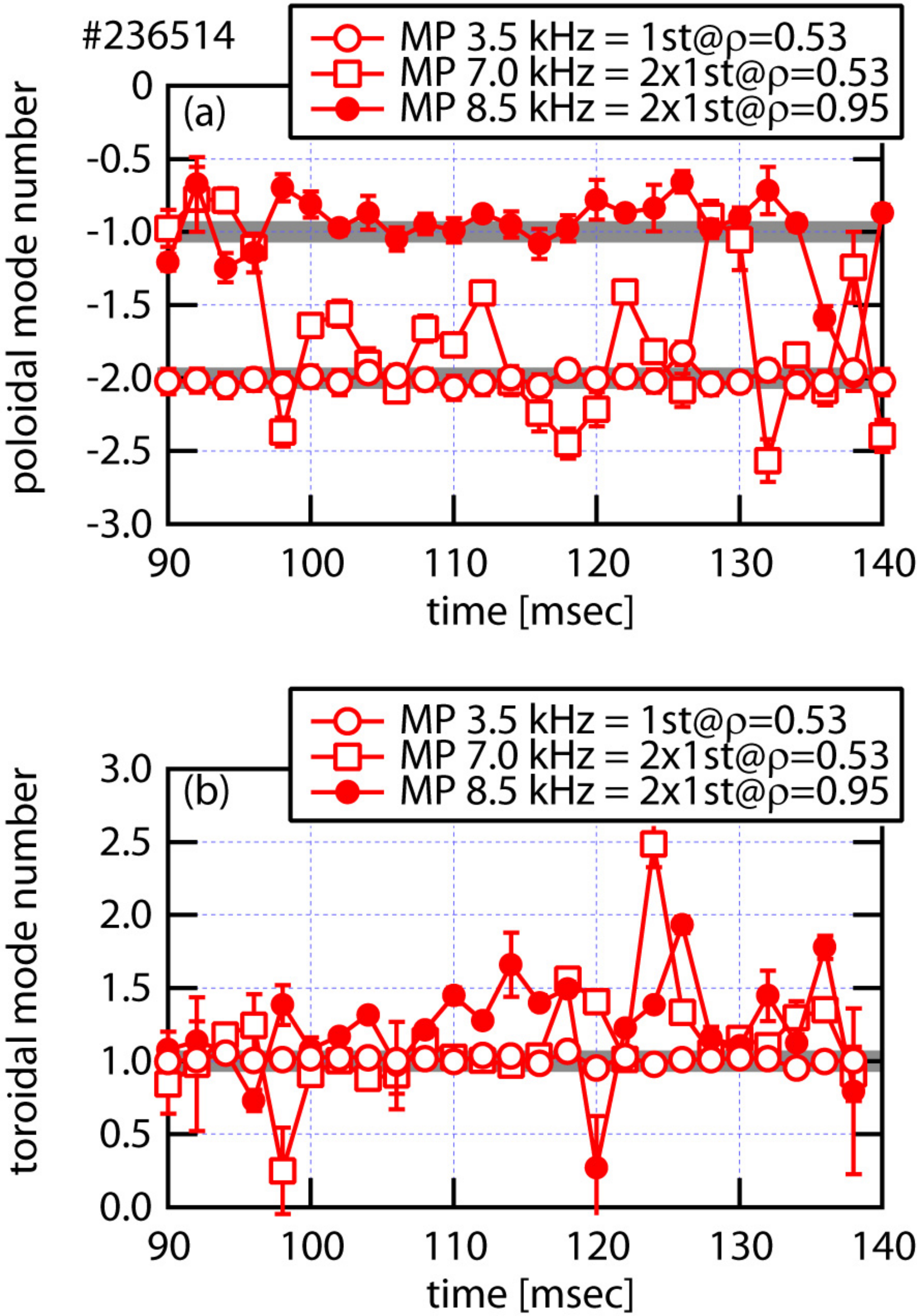
- EHO frequencies in the CORE and EDGE BES differ by a very small amount. *f* (EDGE BES) ≠ *f* (MP), 2*f* (EDGE BES) ≠ 2*f* (MP) -> Two pairs of EHOs.
- *f* (CORE BES) = *f* (MP), EHOs in CORE BES and MP correlate strongly.
- EHOs in CORE and EDGE BES correlate moderately each other.

Mode analysis of the EHOs (1) - MP -

MP power spectrum



Temporal evolution of mode number



poloidal/toroidal mode number m/n

- **3.5 kHz, 7.0 kHz (CORE)**

-> m/n=-2/1

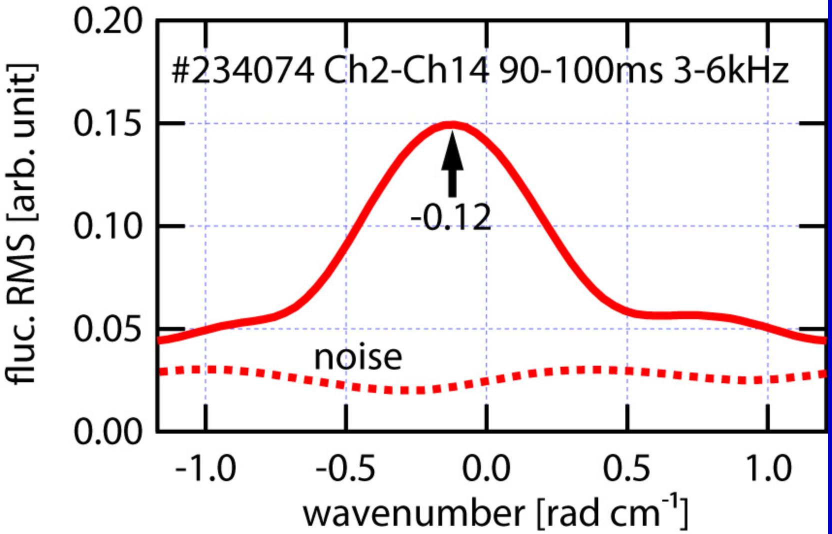
- **8.5 kHz (EDGE)**

-> m/n=-1/1

4.0 kHz peak (1st frequency of the edge mode) is difficult to find in MP spectrum.
-> Trial for the measurement of poloidal wavenumber of the edge mode using BES.

Mode analysis of the EHOs (2) - BES -

Wavenumber spectrum of the 1st component of the edge mode measured using BES



k_θ = 0.12 rad cm^{-1}.
-> the poloidal mode number m = -1.
[$m = k_\theta(\Delta l/\Delta\theta)$, where
Δl (= 15.6 cm) : length covered by the BES chords
$\Delta\theta$ (=1.5 rad) : poloidal angle covered by the BES chords]

- Harmonics of *f* (CORE)

-> m/n=-2/1, related to ι=0.5 rational surface at ρ~0.5.

- Harmonics of *f* (EDGE)

-> m/n=-1/1, related to ι=1 rational surface at ρ~0.95.

... Mode numbers, rotational transform, and locality are consistent.

Problems to be solved in the future

- Why were the magnetic probes less sensitive to the edge mode?
- It seems to be peculiar that 1st and 2nd harmonic component have same mode number.
  (-2/1 for the core mode while -1/1 for the edge mode)
  -> The phase velocity of the 2nd mode is twice larger than that of the 1st mode.

Summary

- The coherent fluctuation which has the fundamental (*f* = 3.5 kHz) and 2nd harmonic frequencies was observed. It is considerably similar to the edge harmonic oscillation (EHO) observed in tokamaks.

- BES measurement has revealed that EHO in CHS consists of two pairs of harmonic components. One locates in EDGE region near ι = 1 rational surface, the another locates in CORE region near ι = 0.5 rational surface. Mode number of each mode obtained using MP and BES is consistent to the locality and corresponding rotational transform.

NOTE! MP was sensitive to the CORE mode in our case.

-> Without local measurement such as BES, we could not distinguish CORE mode and EDGE mode.

We can conclude that the local fluctuation measurement plays a significant role to investigate the characteristics of the fluctuations.