平成26年3月5日（水）13:00 - 7日（金）
第17回若手科学者によるプラズマ研究会

# ヘリオトロンJにおける 高速イオン励起不安定性の挙動とそれに伴う構造形成

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# Introduction (1/2)

- Physical mechanism and loss of fast ions have been main targets in study of energetic particle driven instabilities.
  [e.g. W.W. Heidbrink *et al*, PoP (2008)]

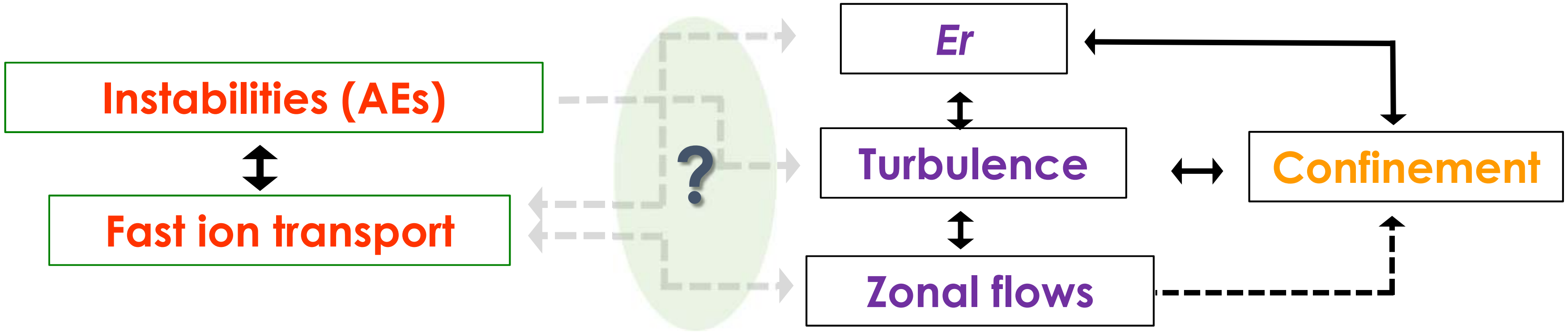
- Energetic particle induced geodesic acoustic modes(EGAM) were discovered in several machines (JET, DIII-D, LHD etc.).

- Moreover, several studies indicate the energetic particle driven instabilities may
  - change *Er* profile by fast ion transport [K. L. Wong, Nucl. Fusion (2004)]
    → <u>ITB formation ?</u>
  - excite zonal flows. [L.Chen&F.Zonca, PRL (2011)]
    → <u>turbulence suppression ?</u>

- The framework of the studies is being expanded widely and deeply.

# *Introduction* (2/2)

- Can the instabilities and fast ion transport have influences on confinement properties ?



**Instabilities (AEs)**

**Fast ion transport**

**?**

***Er***

**Turbulence**

**Zonal flows**

**Confinement**

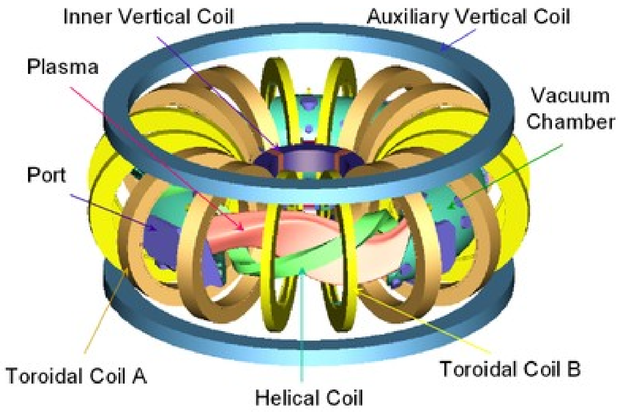
- However, clear experimental observation relating to these influences of AEs are not so many…

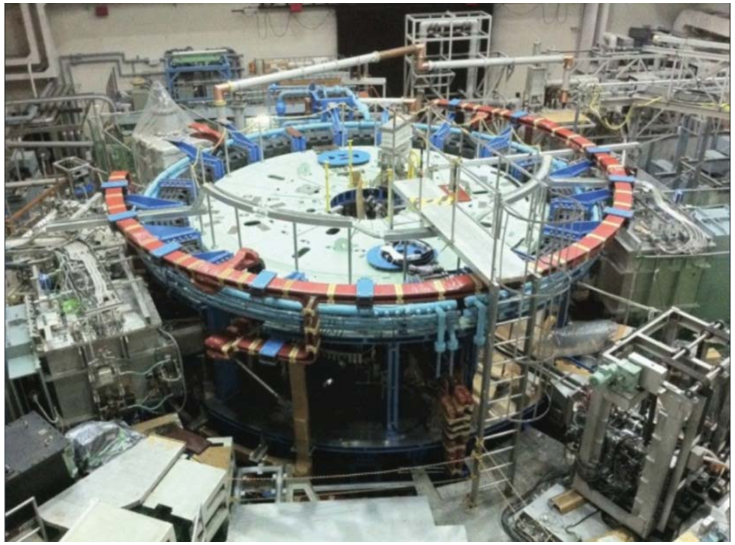
In Heliotron J, phenomena relating to the influences,
1. Influence of AE on turbulence
2. Structural change of *Er* synchronized with AE burst

were observed.

### Experimental Set Up

# Heliotron J device





- ◆ Major Radius : R=1.2 m
- ◆ Plasma Minor Radius : a=0.1-0.2 m

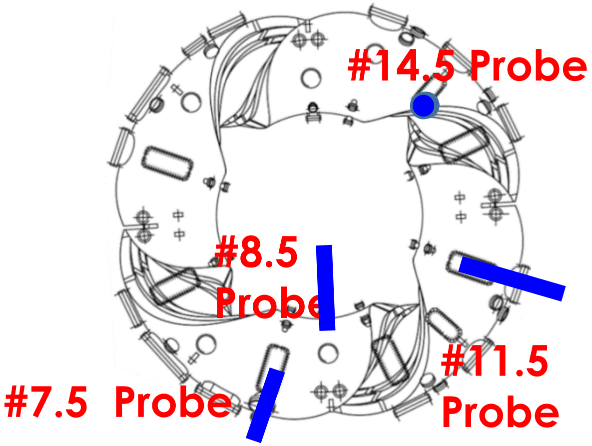
- ◆ Magnetic Field : B≦1.5 T
- ◆ Vacuum iota : 0.3-0.8
  with low magnetic shear, (Δι/ι < 0.04)

- ◆ Coil system :
  One helical coil (l/m=1/4)
  Two sets of toroidal coils(TA and TB)
  Three pairs of vertical field coils
  (main V., AV,IV)

- ◆ Heating System:
  ECH 70GHz 0.4MW
  NBI 30kV 0.7MW x 2(Co&Ctr.)
  ICRF (16-24MHz, 0.4MWx2)

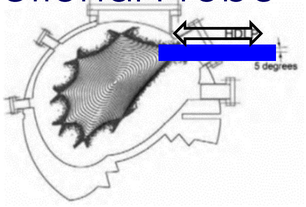
*Experimental Set Up*

# *Probe systems in Heliotron J*



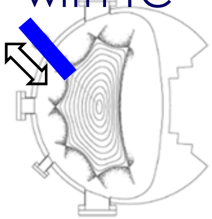
#7.5 X-point

Directional Probe



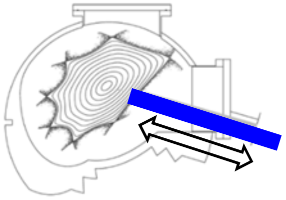
#8.5 X-point

LP with TC



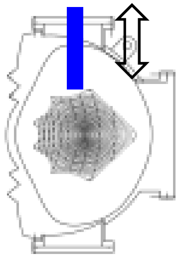
#11.5 O-point

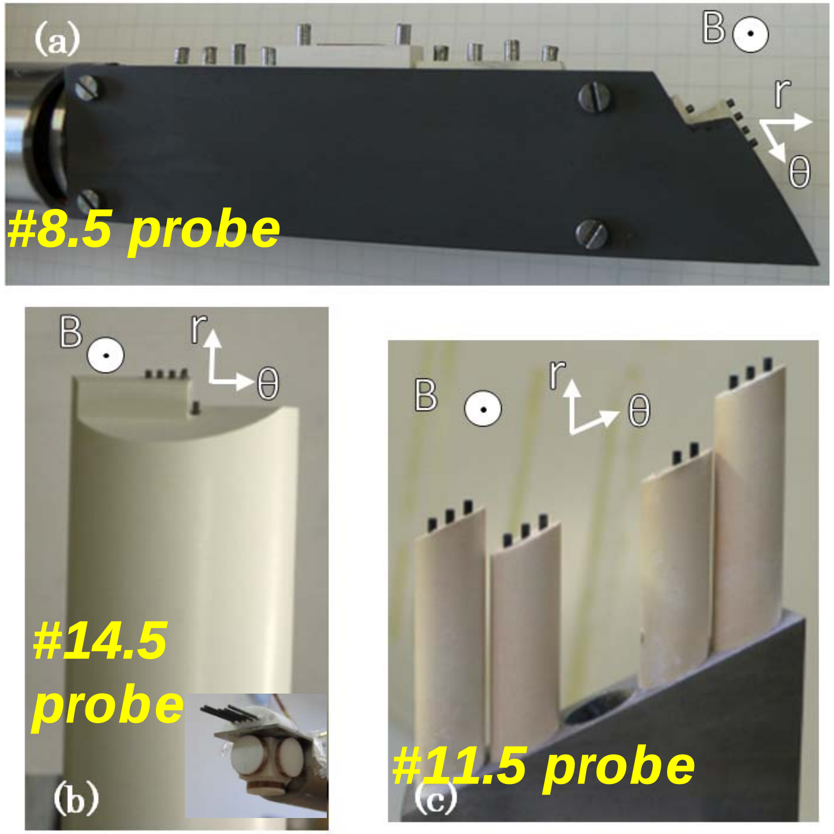
Multi-channel Probe



#14.5 O-point

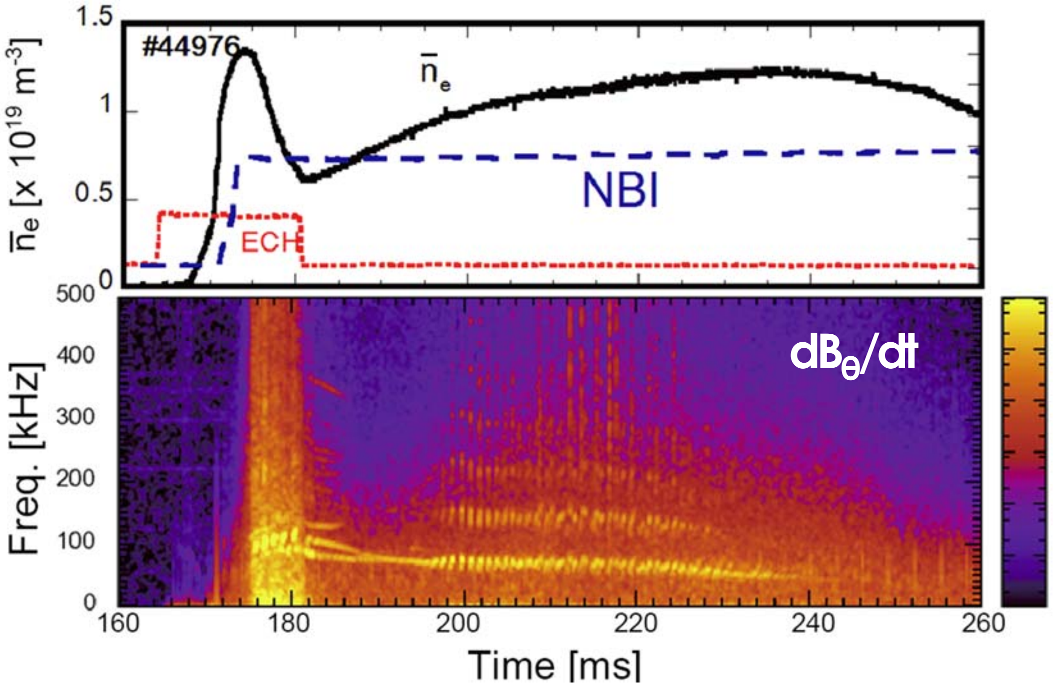
LP with MP





Probe head structures at (a)#8.5, (b)14.5 and (c)11.5 sections.

# *Alfven Eigenmodes observed in NBI plasma*



- ✓ $\bar{n}_e \sim 1 \times 10^{19} m^{-3}$
- ✓ NBI heating plasma

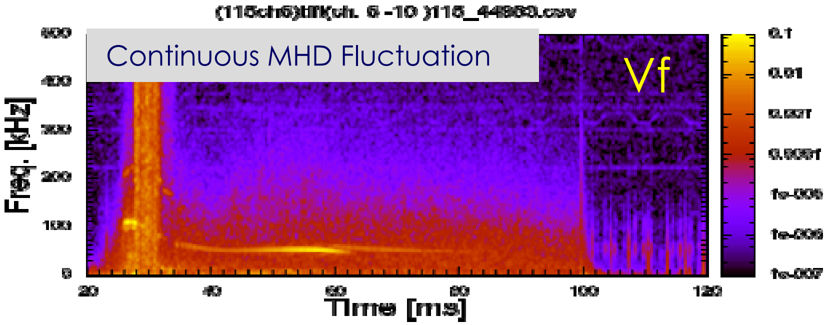
➢The MHD fluctuation with higher harmonics was observed in the frequency range of 60-80kHz.

➢m/n=1/1

➢rotating in ion diamagnetic direction.

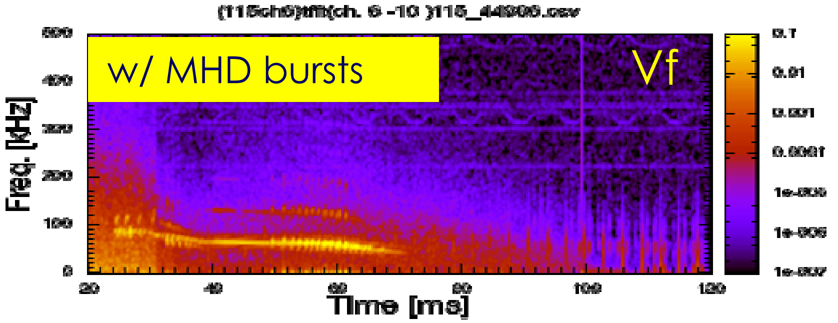
➢The candidates of the AE are EPM or GAE.

# *Two kinds of couplings were observed in bicoherence analysis results*



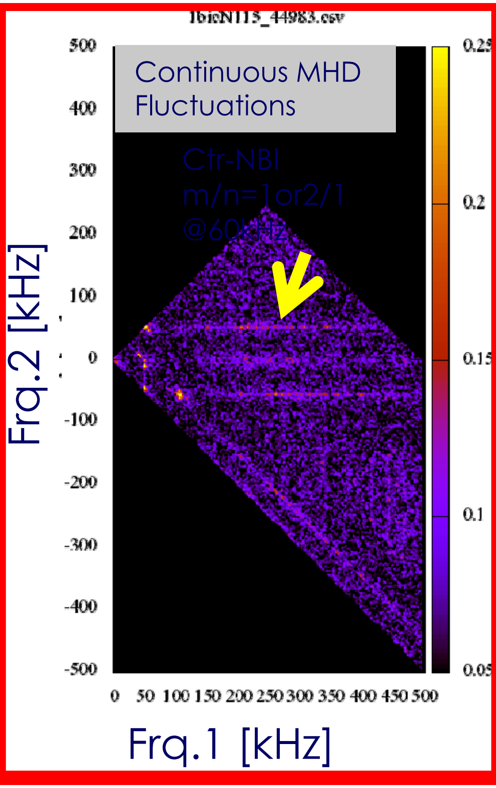
Continuous MHD Fluctuation

Vf



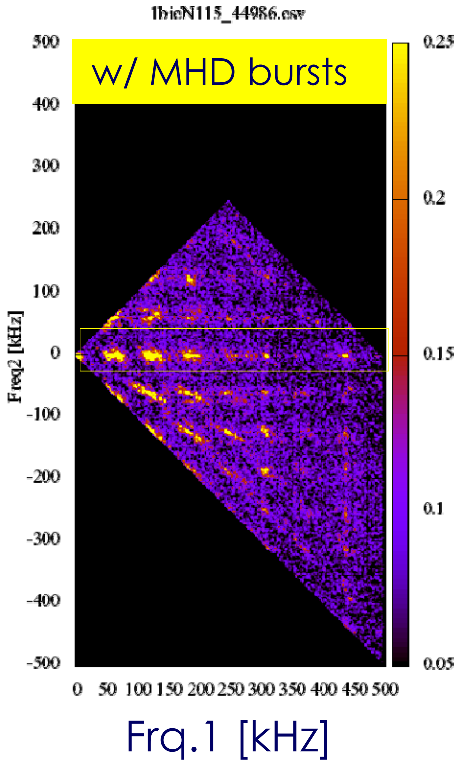
w/ MHD bursts

Vf



Continuous MHD Fluctuations

Ctr-NBI
m/n=1or2/1
@60kHz



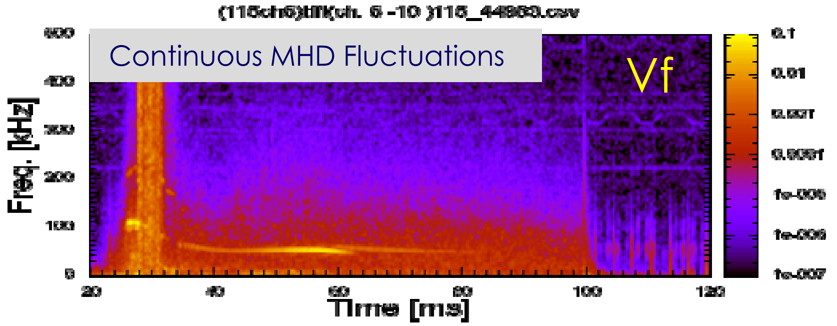
w/ MHD bursts

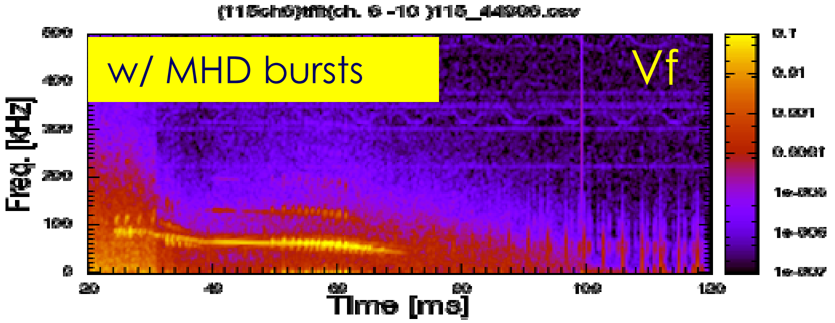
**Type 1**. Continuous MHD Flutuation
→ Coupling with broad-band turbulence

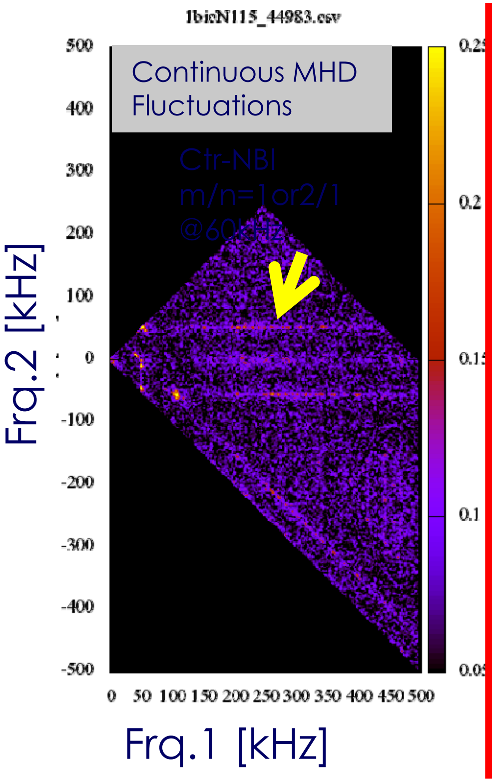
Particle flux modulation was observed!

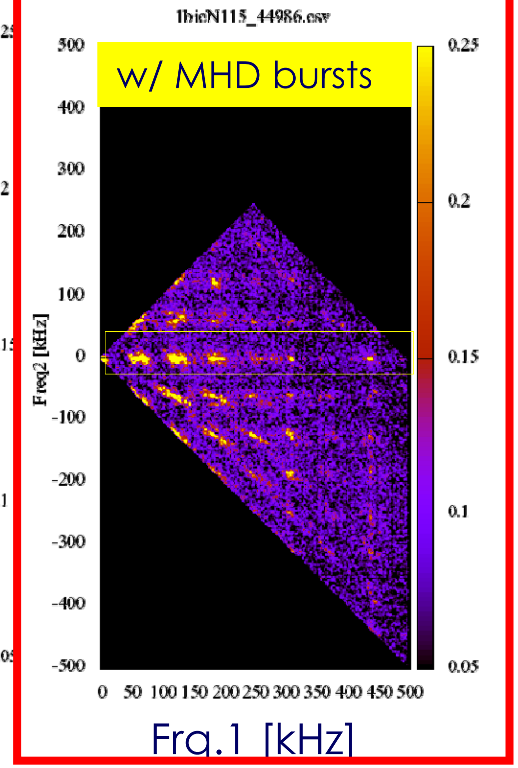
Type 2. MHD burst
→ Coupling in low frequency range (~ 1 kHz).

# Two kinds of couplings were observed in bicoherence analysis results





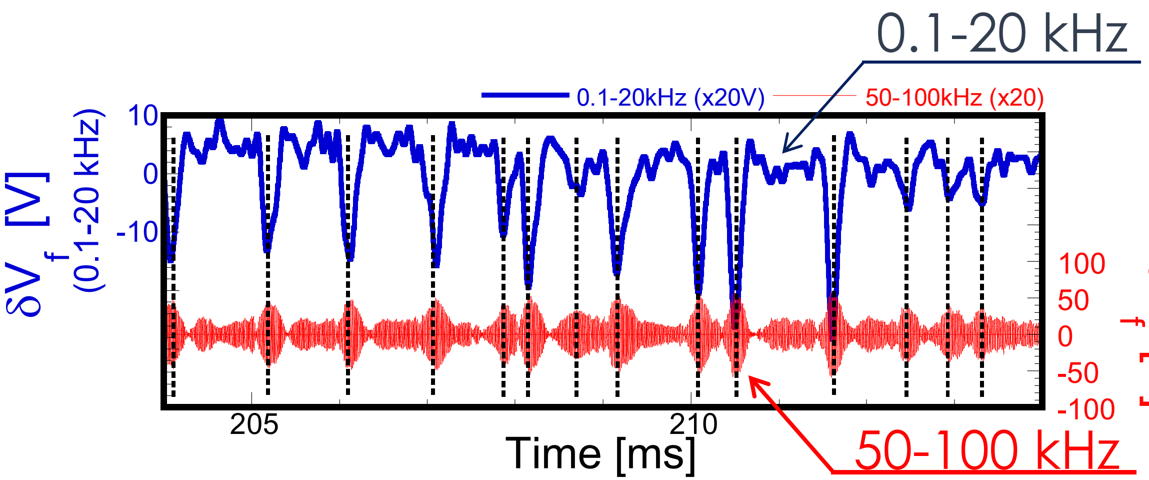


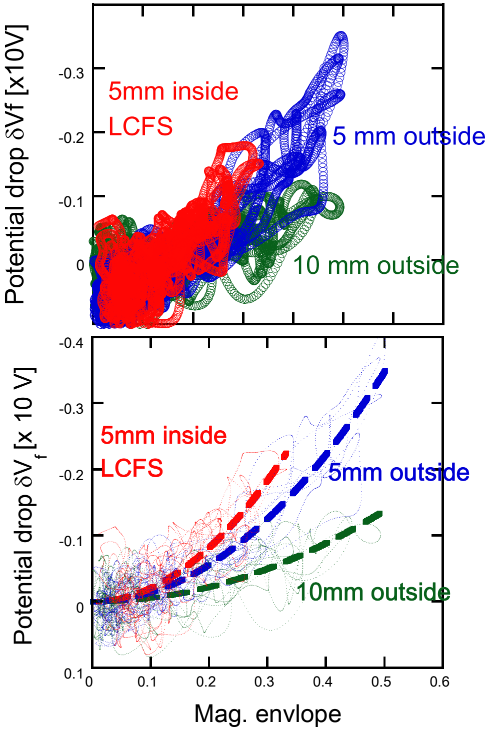


Type 1. Continuous MHD Flutuation
→ Coupling with broad-band turbulence

**Type 2**. MHD burst
→ Coupling in low frequency range (~ 1 kHz).

# *Low frequency potential responses synchronized with MHD bursts*

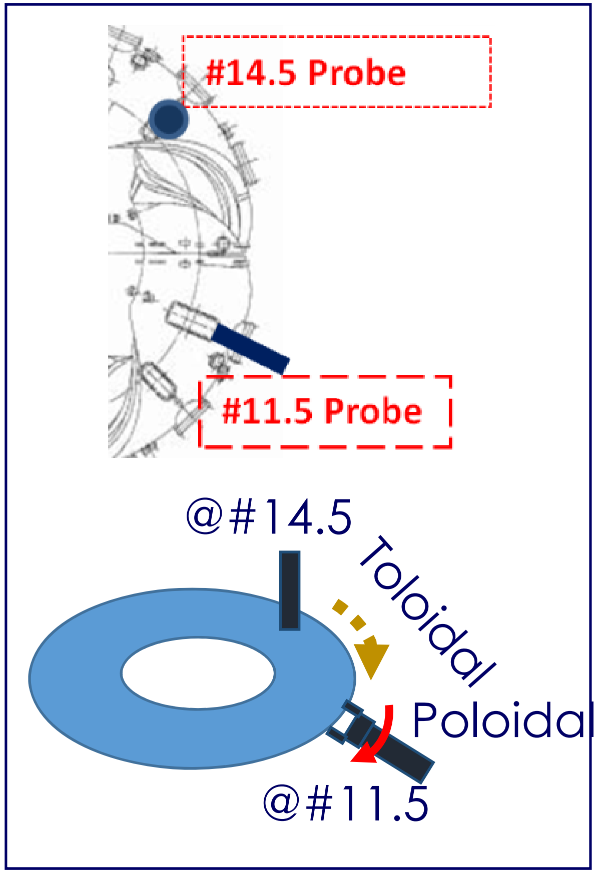




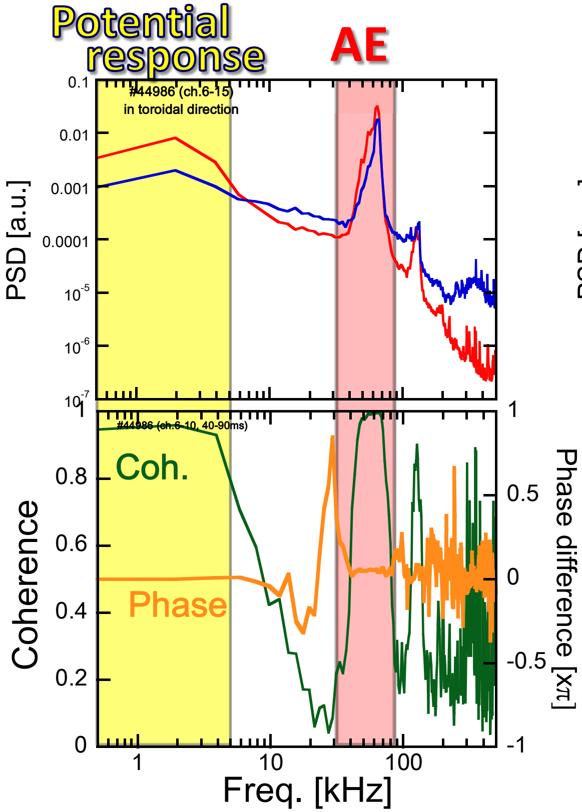
- ✓ Potential responses synchronized with the MHD burst were observed. →corresponds to the coupling in low frequency range in bicoherence analysis
- ✓ Potential response is clearly proportional to the amplitude of burst.

**What structure does the potential response have?**

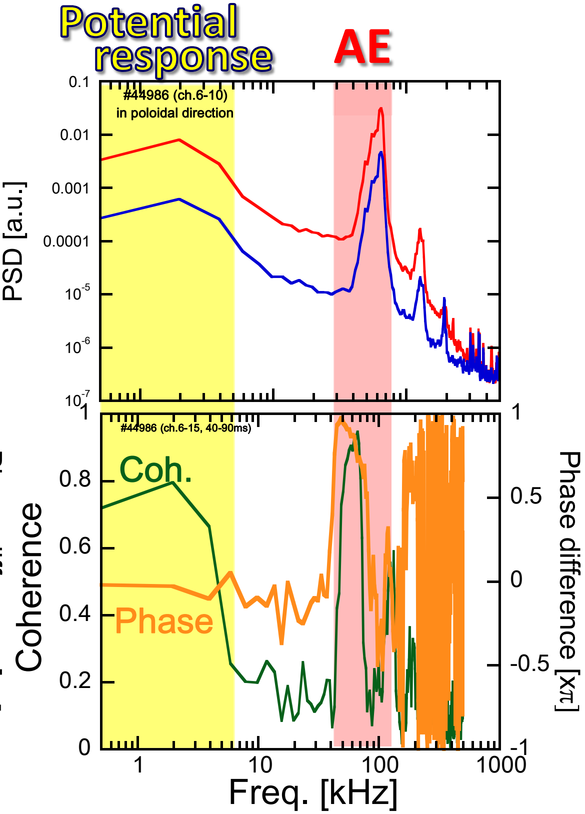
# *Symmetric potential response in toroidal/poloidal directions*



**- In toroidal direction**

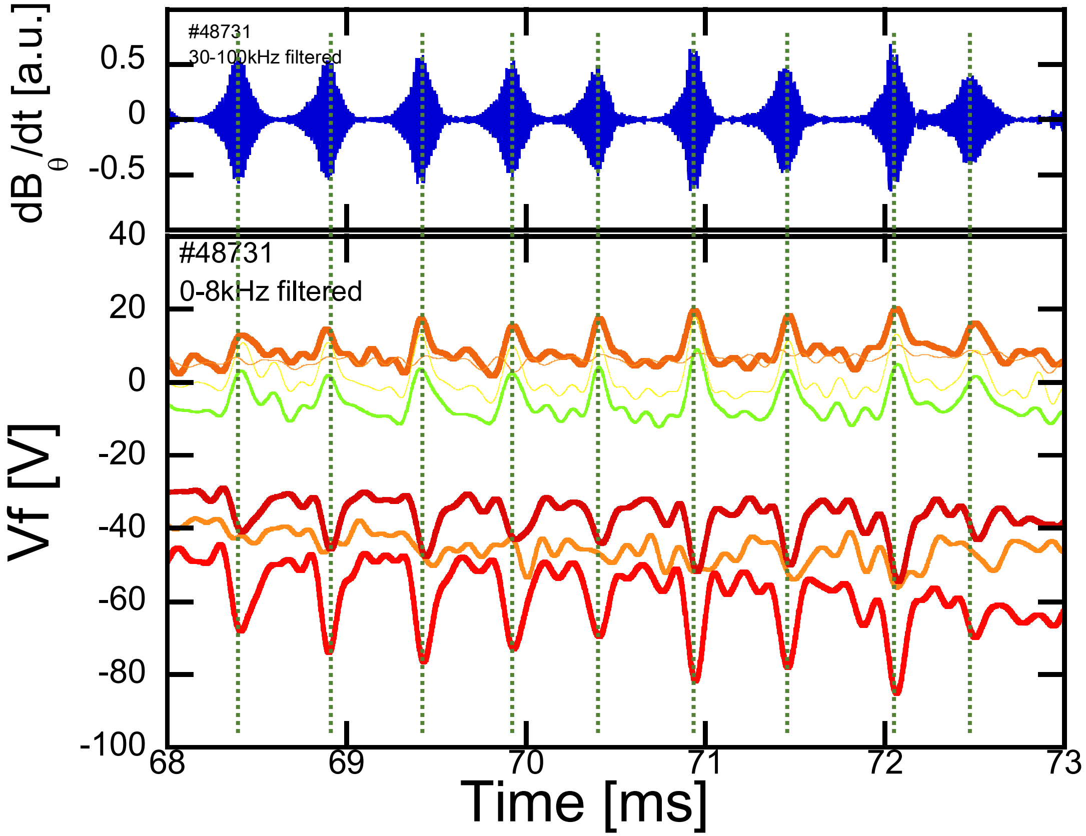


**- In poloidal direction**



- High coherence and no phase difference is observed in low frequency range in Toroidal/Poloidal directions.
- The responses are symmetrical change in torus.
- can not be attributed to the influx of fast ions to the probe tips.

# *Radial Responses of Potential*

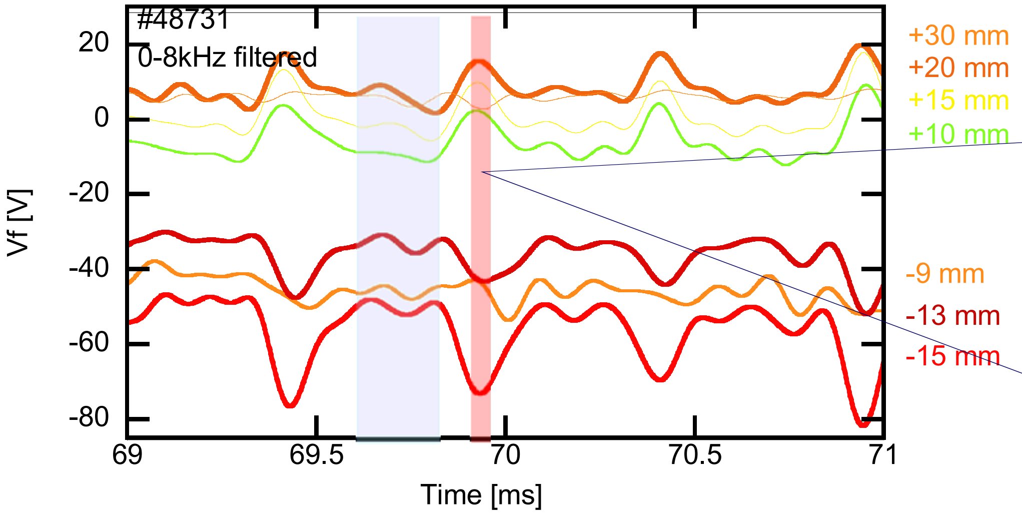


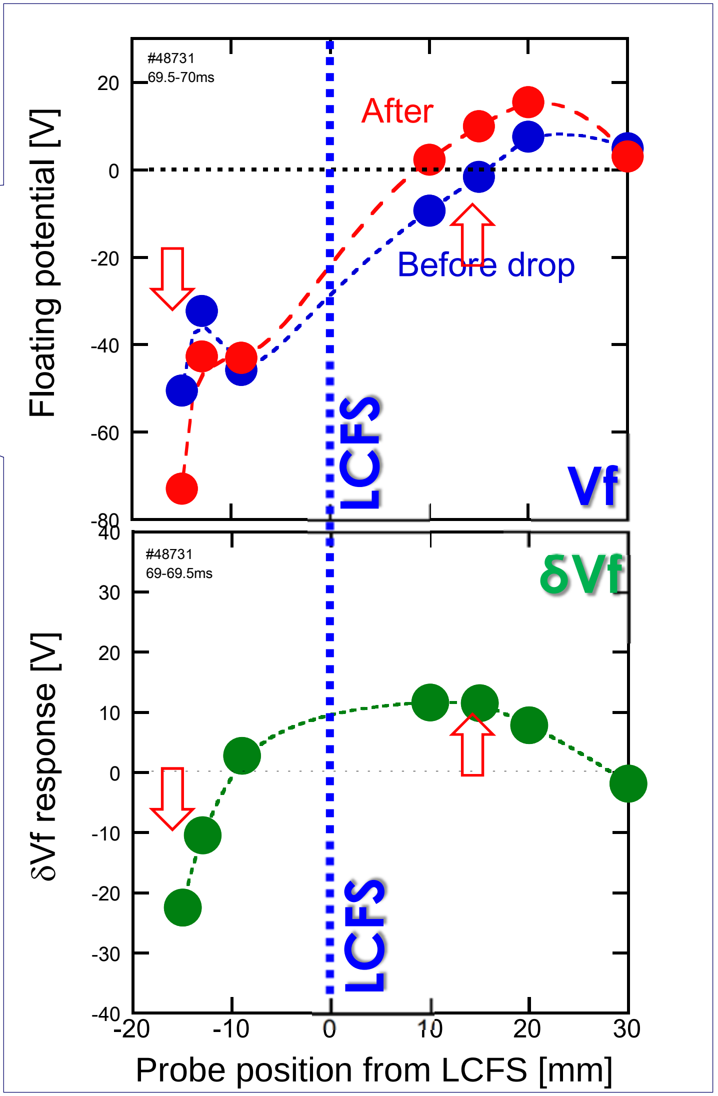
Radial array probe was used

- ➢ **Inside LCFS**
**→Potential drops**
- ➢ **Outside LCFS**
**→Potential rises**
were observed.

Time delay was not observed in radial direction.

# Typical potential profile change

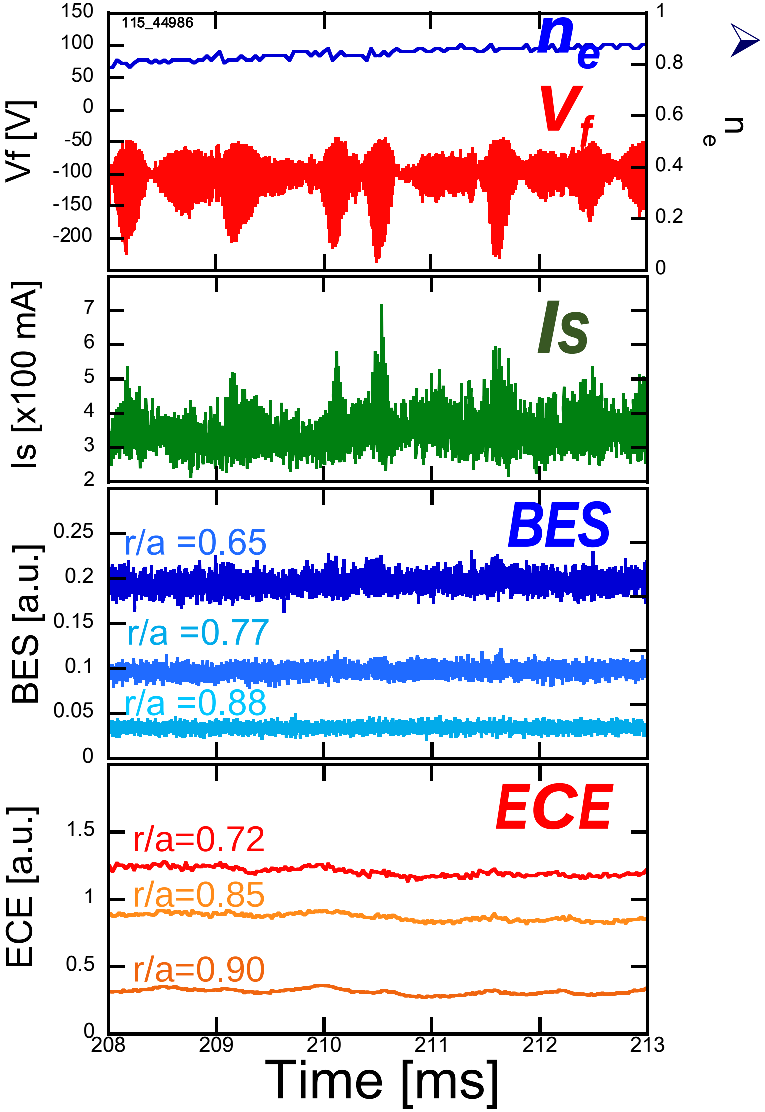




- Potential profile changes were synchronized with MHD bursts.

→ *Er* is modified by MHD burst!!

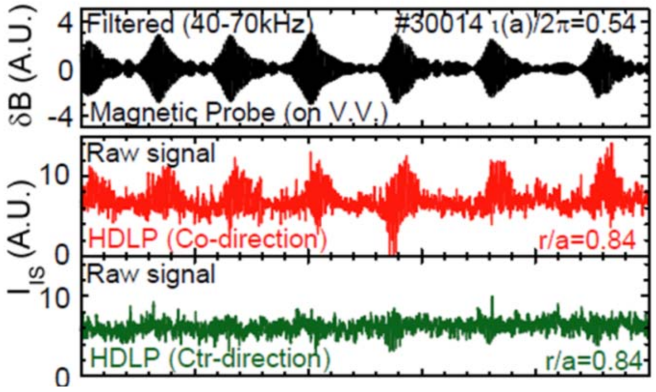
# *What causes the response of $E_r$ ?*



- No clear responses in ECE/BES signals → Profile change of $n_e/T_e$ can not explain the $E_r$ change.

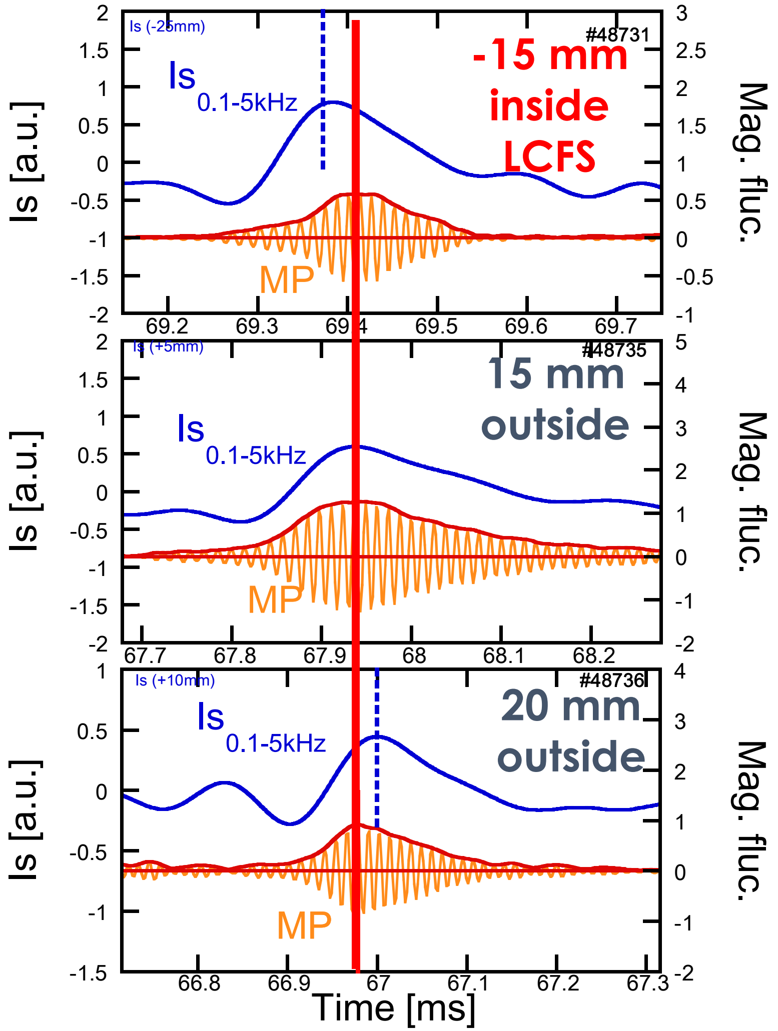
*Fast ion loss detected by directional probe in Heliotron J.*

*(S. Kobayashi et al, EPS proceedings 2010)*



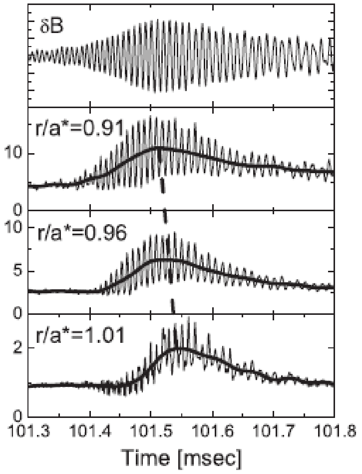
→ Fast ion responses are detected on $I_s$ signals.

# *Radial transport of fast ions*



Fat ion transport observed in CHS

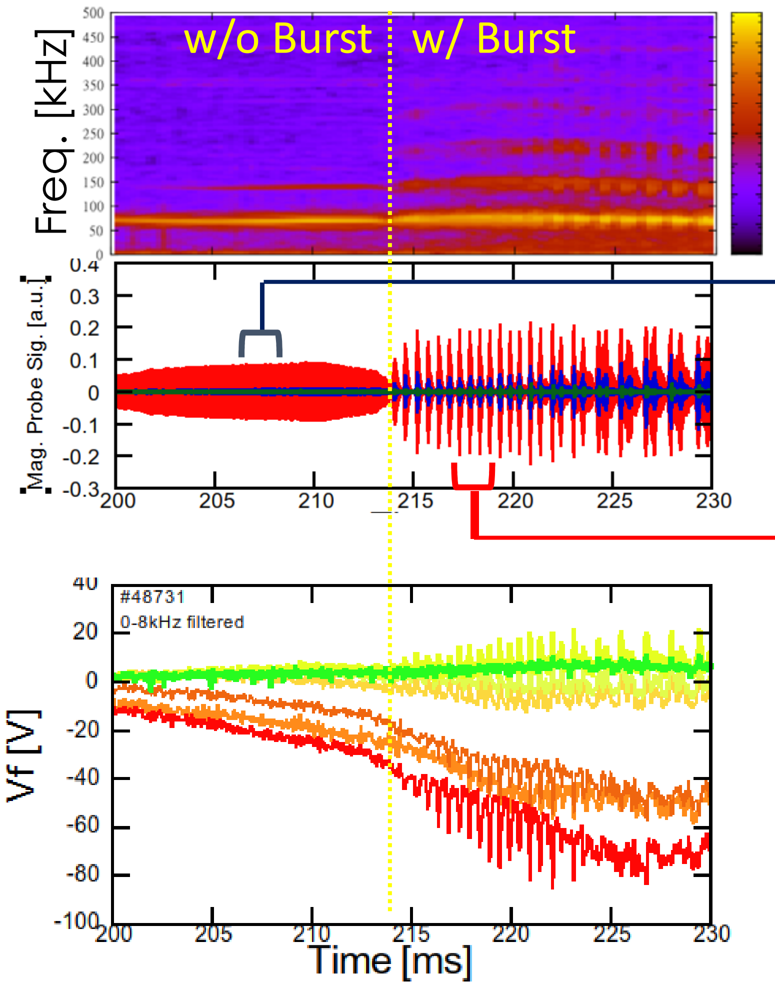
K.Nagaoka, PRL, (2006)

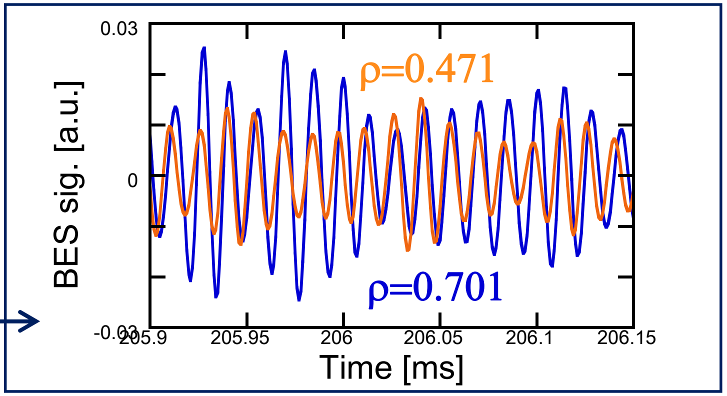


- ➢ The delay of the slow *Is* responses → Fast ions are transported in radial direction.

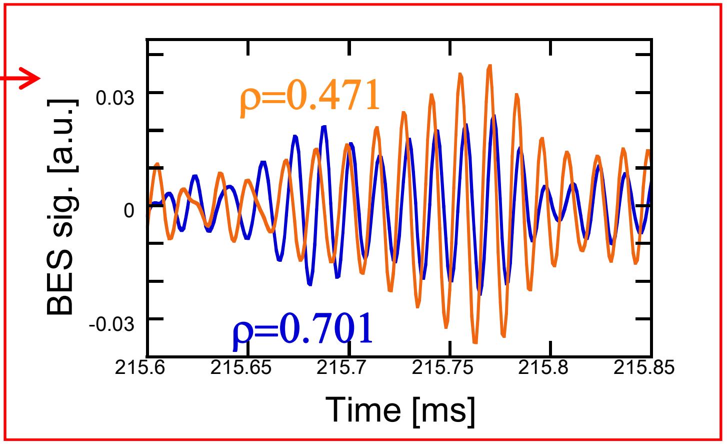
  *Strong candidate*
  *to explain Er response !*

# *Internal fluctuation measurement using BES*





Phase difference is constant



Phase difference is developing **in each burst**

→ Internal structure is changing in each burst!

# Technique to evaluate instantaneous phase difference using Hilbert transform

*It is difficult to improve temporal resolution of Fourier transform……*

If fluctuation can be expressed as
single frequency fluctuation like $z(t) = r(t)\cdot\exp(2\pi i\cdot f(t)\cdot t)$

1. Analytic function can be generated by Hilbert transform.

$Z(t) = r(t)\cdot\exp(i\theta(t))$

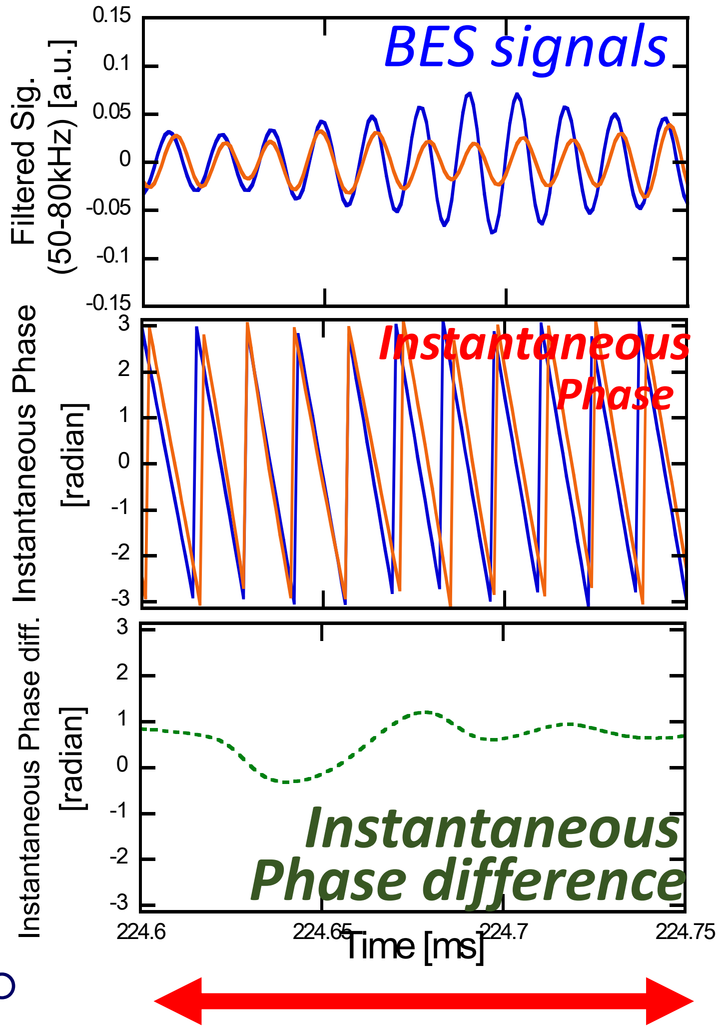
| | |
|---|---|
| Instantaneous amplitude | $r(t)$ |
| Instantaneous phase | $\theta(t)$ |

2. **Instantaneous phase difference** can be evaluated by multiplying $Z_1(t)$ and $Z_2(t)$.

$$Z_1^*(t)\cdot Z_2(t) = |Z_1^*(t)|\cdot|Z_2(t)|\exp(i\,\underline{\varphi(t)})$$

phase difference
$(\varphi(t) = \theta_1(t) - \theta_2(t))$

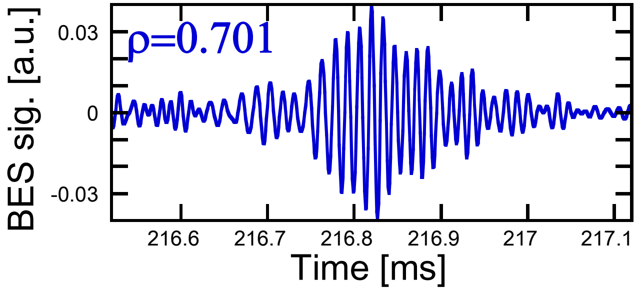
3. **Conditional Average technique** was applied to obtain averaged time development of burst amplitude and the phase difference

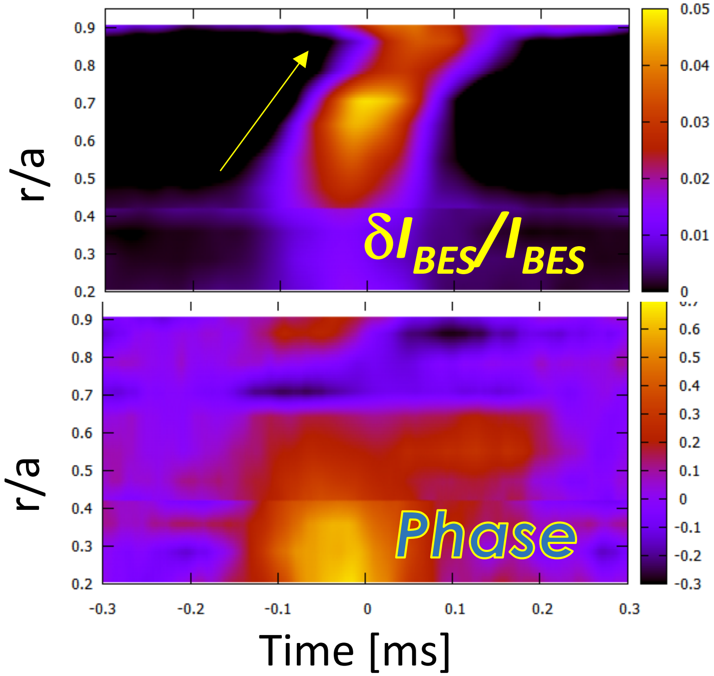


**0.15 ms !**

# *Distortion of mode structure on each MHD burst*

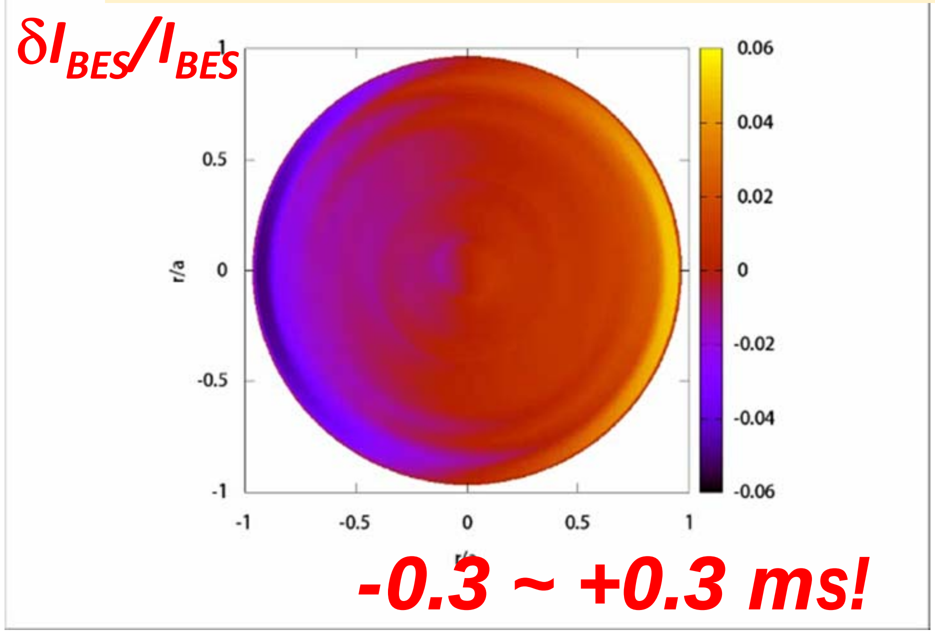
- Temporal development of the mode structure





Profiles of the amplitude and phase difference are developing in each burst.

$$\phi(r, \theta, t) = A(r, t) \exp(im\theta - \omega t + \delta(r,t))$$

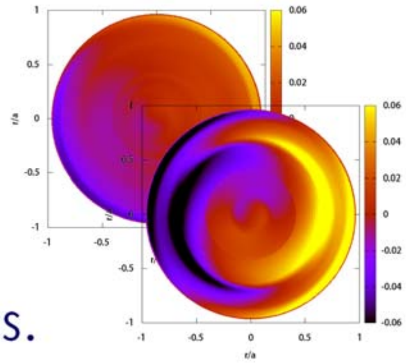


***-0.3 ~ +0.3 ms!***

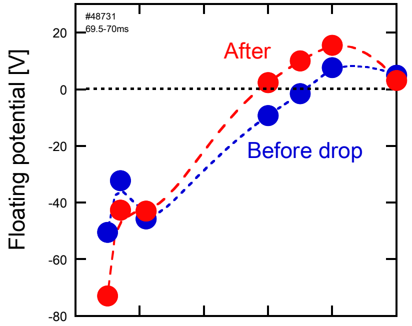
→ The structural change of the mode may relate to the distortion of fast ion distribution in real/velocity space.

# Summary

✓**Energetic particle driven MHD bursts** were investigated in Heliotron J.



✓**Distortion of the mode structure** was observed in each burst using BES diagnostics.



✓**Radial transport of fast ions** around LCFS was found on probe ( *Is* ) signal.

✓***Er* is responding to each MHD burst** around LCFS.

- These results suggest that **AEs can affect *$E_r$*,** which may have influences on confinement properties.