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Effect of energetic-particle induced n=0 instabilities to bulk-ions on LHD

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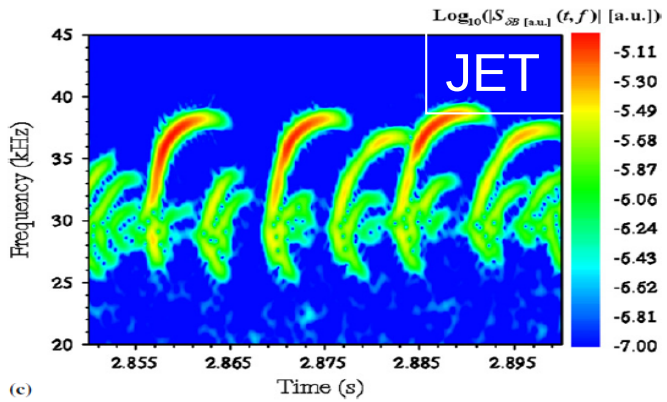
Background & Motivation

- Zonal Flow(ZF) and Geodesic Acostic Mode(GAM) get much attention recently, since it could be a knob to regulate turbulence in plasmas and to reduce anomalous transport.
- Energetic-particle(EP) induced GAMs are observed in several toroidal devices, such as JET, DIIID and LHD. Effect of GAMs on the energetic particle behaviors needs to be investigated.
- Recently, an influence of EP induced GAM was observed on LHD.

  ⇒ The influence of EP induced GAMs on bulk ions as well as on energetic particles needs to be investigated.

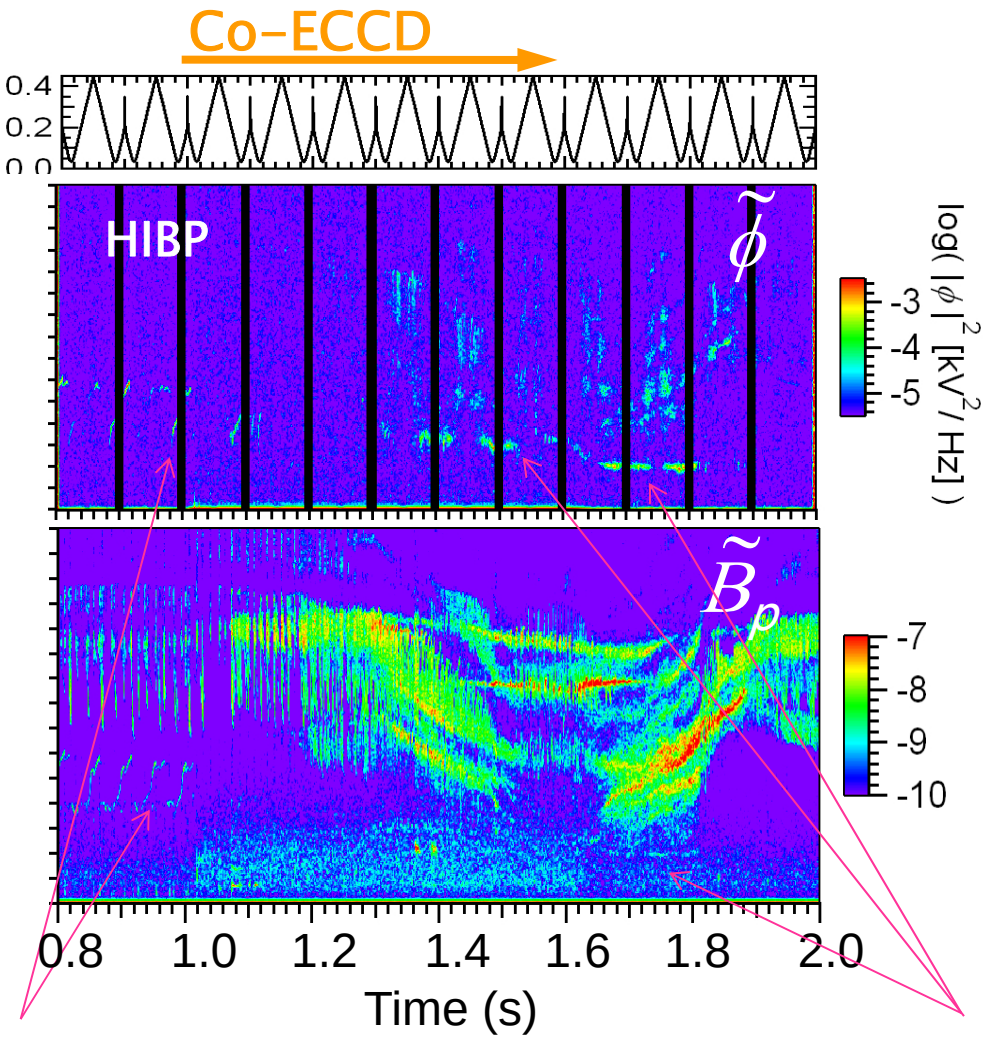
Energetic particle induced GAM (n=0 modes) on various toroidal devices.

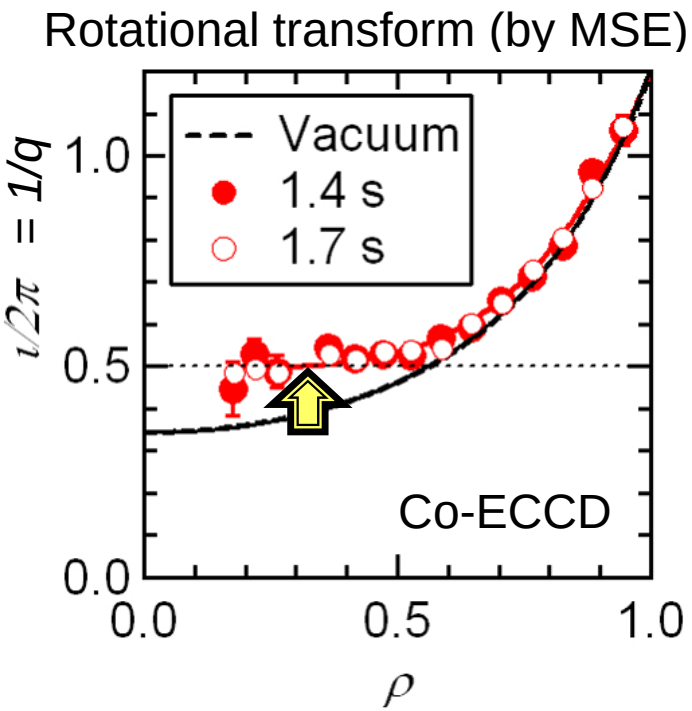
- JET: Global GAM
  - H.L.Berk, et.al., Nucl. Fusion **46**, S888
  - C.J.Boswell, et.al., Phys. Lett. A , **358**, 154
- DIIID: Energetic-particle-induced GAM (EGAM)
  - R.Nazikian, PRL 101, 185002
  - G.Y.Fu, PRL 101, 185002
- LHD:
  - K.Toi: 22nd IAEA-FEC, EX P8-4
  - T.Ido : 23rd IAEA-FEC



Energetic particle induced GAM on LHD

T.Ido, et.al.,



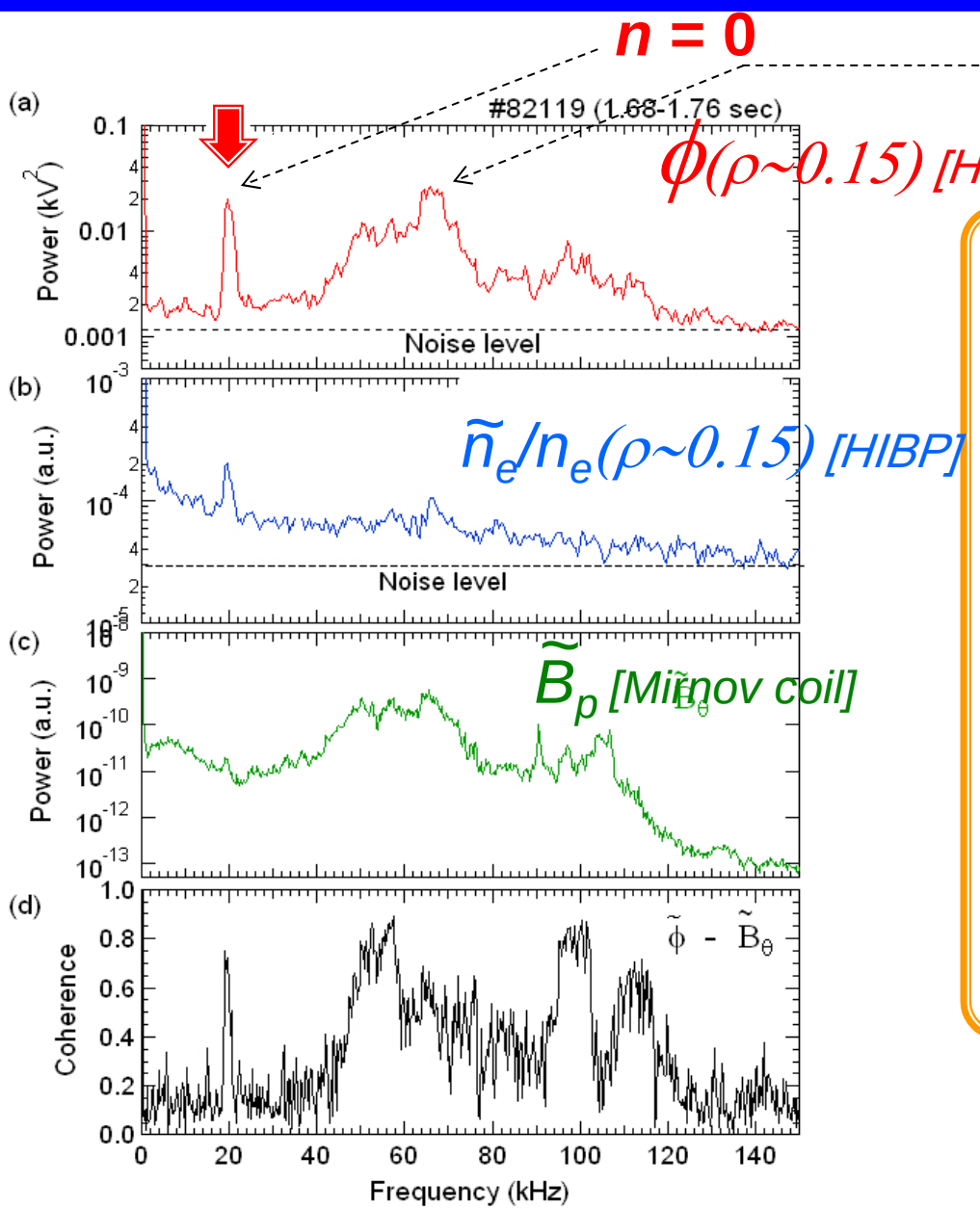


Upward-shift of the frequency in monotonic shear plasmas.

Constant at the GAM frequency in reversed shear plasmas.

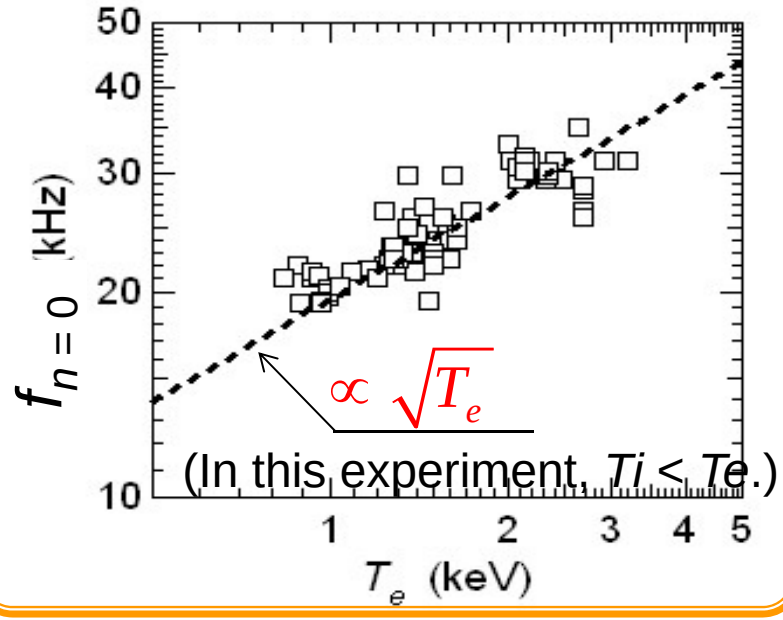
$\tilde{\phi}$, $\tilde{n}_e$, and $\tilde{B}_p$ associated with EP induced modes

T.Ido, et.al.



GAM frequency

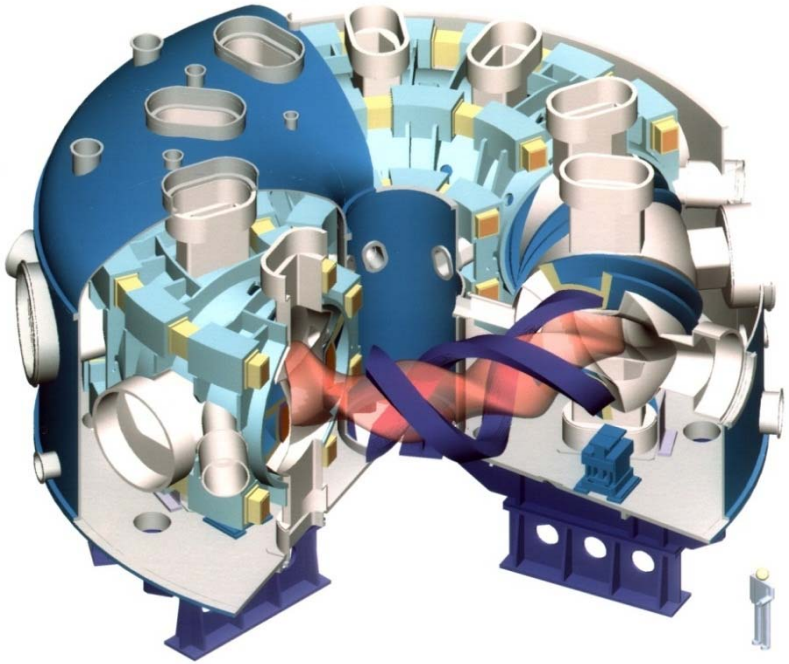
$$f_{GAM} = \frac{1}{2\pi R_0}\sqrt{\frac{T_e + \frac{7}{4}T_i}{M_i}}G$$



These modes(n=0, 1) are not observed in plasmas without tangential NBI.

Experimental results

Large Helical Device (LHD)

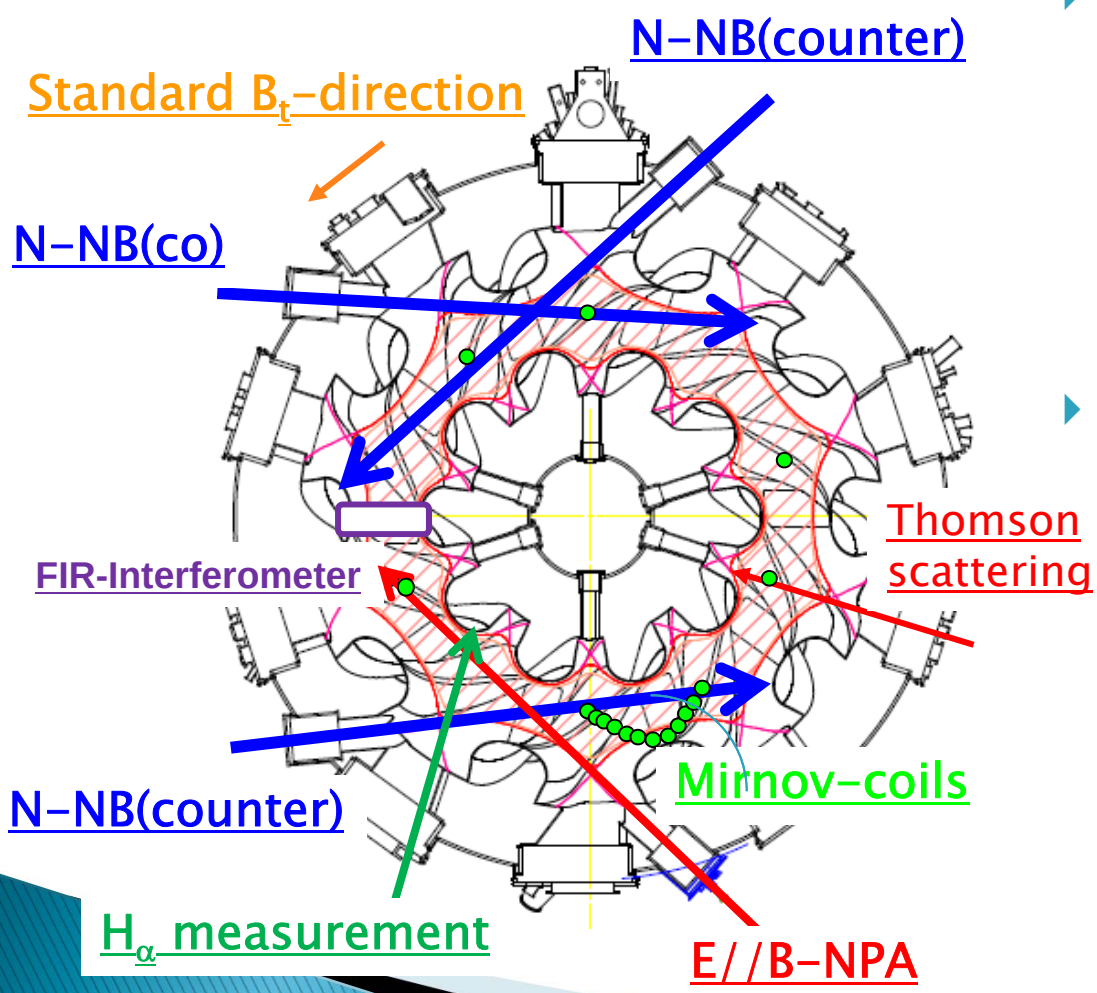


Heliotron configuration of
l=2/m=10 field period
All superconducting coil system

Plasma major radius	3.42-4.1 m
Plasma minor radius	0.6 m
Plasma volume	30 m^3
Toroidal field strength	0.4~2.9 T

- The confining magnetic fields are externally applied on LHD. Thus, it is free from disruptions.
- Combining this feature with the high-energy N-NBI and high-power gyrotrons, **LHD could be a good plat home of exploring high-energy particle physics.**

Experimental Apparatus

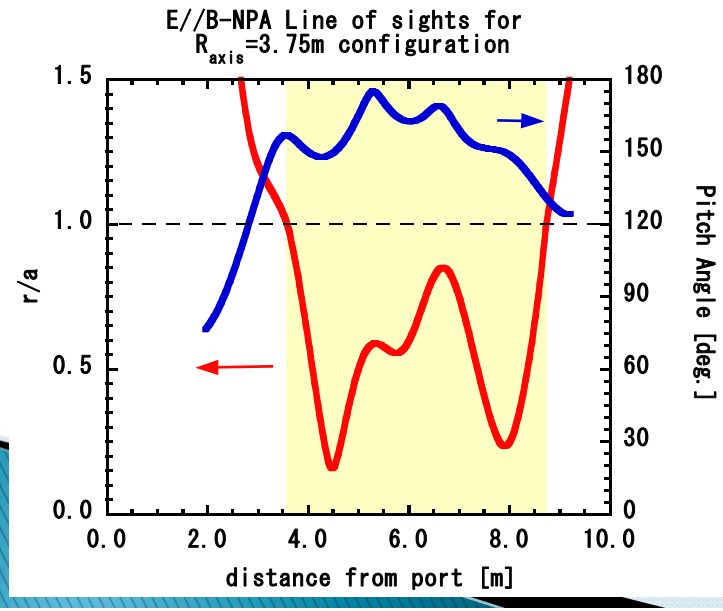


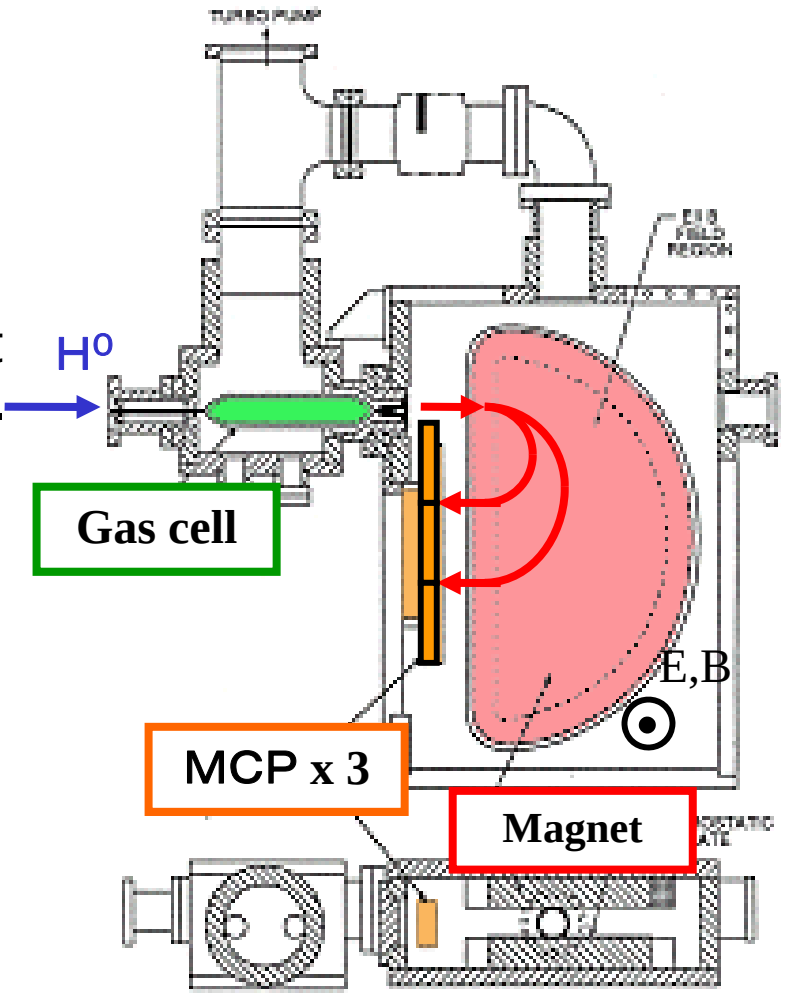
- Heating Facility:
  - N-NBI:180keV/5MW x3
  - P-NBI: 40keV/6MW x2
  - ECH: 77GHz/1MW x3
    84GHz/0.3MW
    168GHz/
- Diagnostics:
  - Tangential E//B-NPA.
    - ✓ Measurement of high energy ions and bulk ions.
  - Mirnov-coils:
    - Toroidal x6ch, Helical x13ch
  - E//B-NPA

E//B-NPA on LHD

Thanks to the collaboration with PPPL

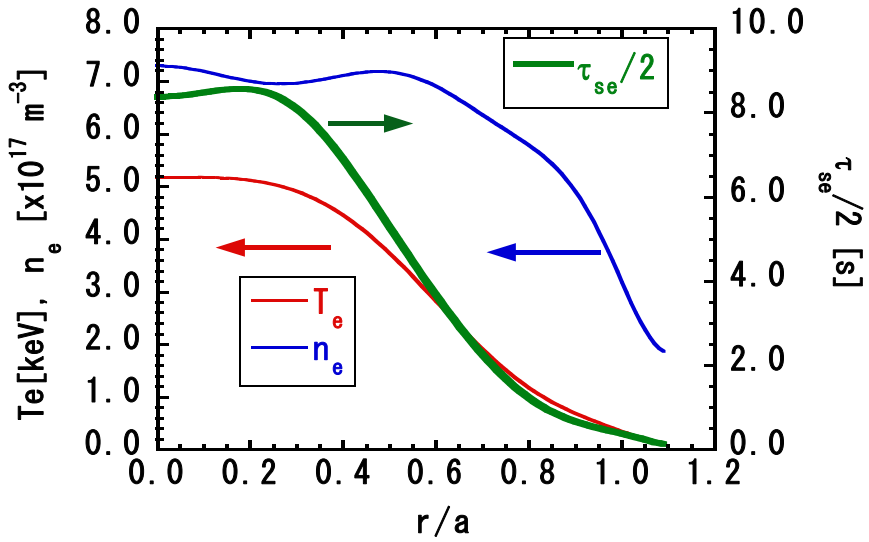
- Passive measurement.
- Measureable energy range is 0.5 – 200 [keV] for Hydrogen.
- Time resolution of up to 0.25ms is possible by counting mode, and ~5μs is possible to current mode.
- Installed at tangential port and its sight line locates 10cm below the mid-plane. Thus, inner most observable location is limited to r/a =0.16

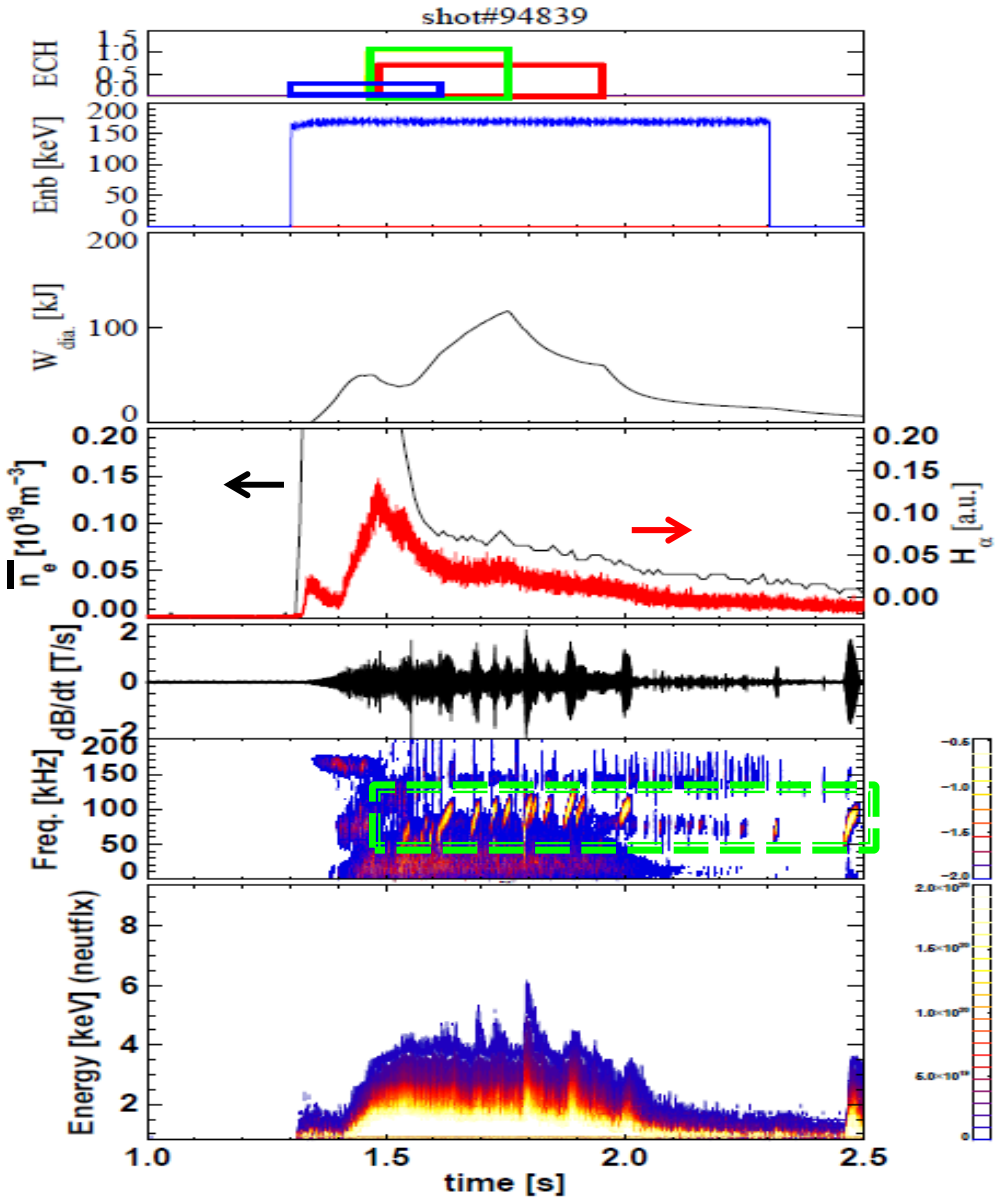




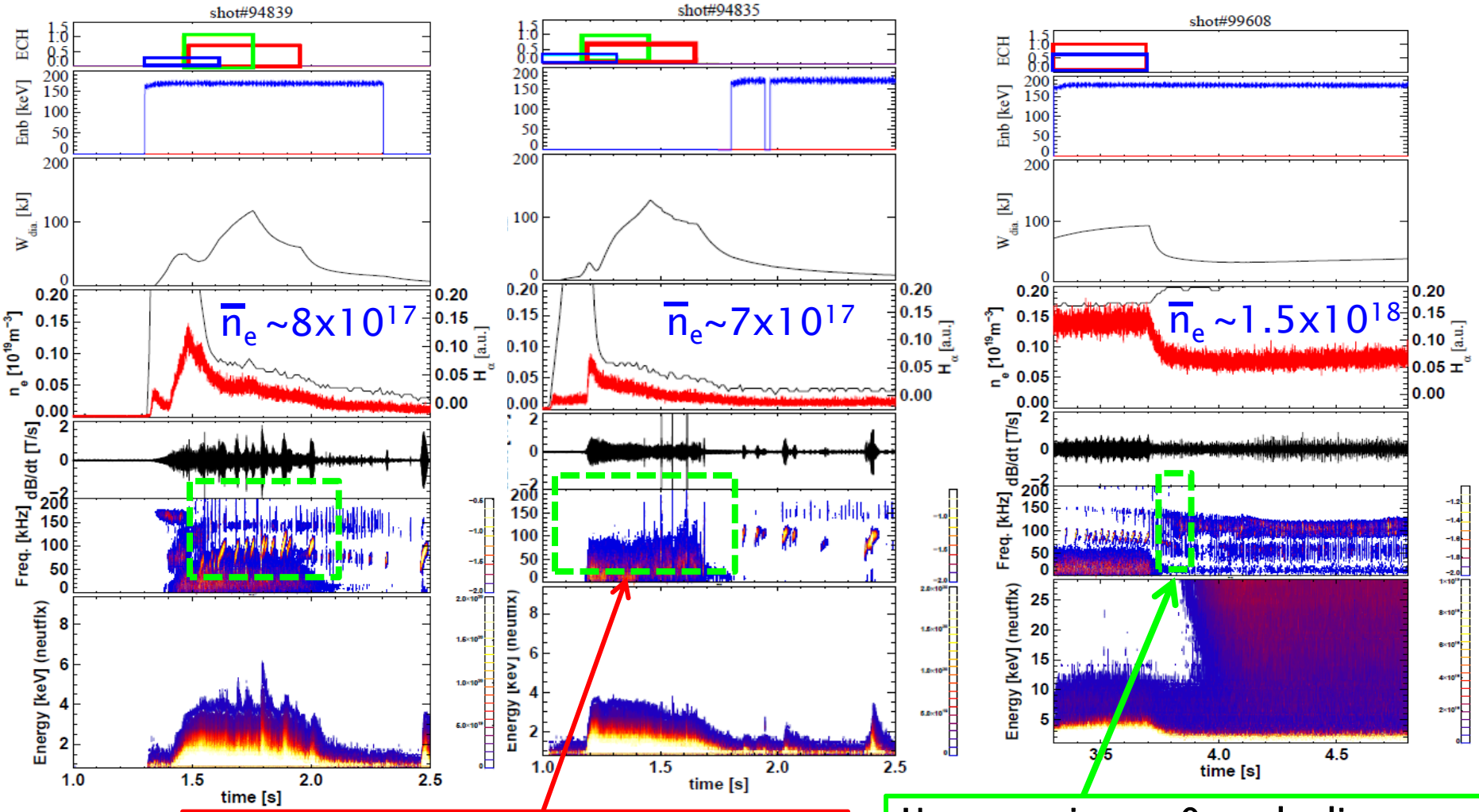
Up-sweeping n=0 modes associated with neutral flux increase were observed for low density LHD plasmas.

- The typical initial frequencies are 50 -70kHz and their frequencies chirp-up during their mode activity activities.
- No significant increase of Hα-signals were observed.
- Typical estimated slowing-down time is ~8[s] at the core.





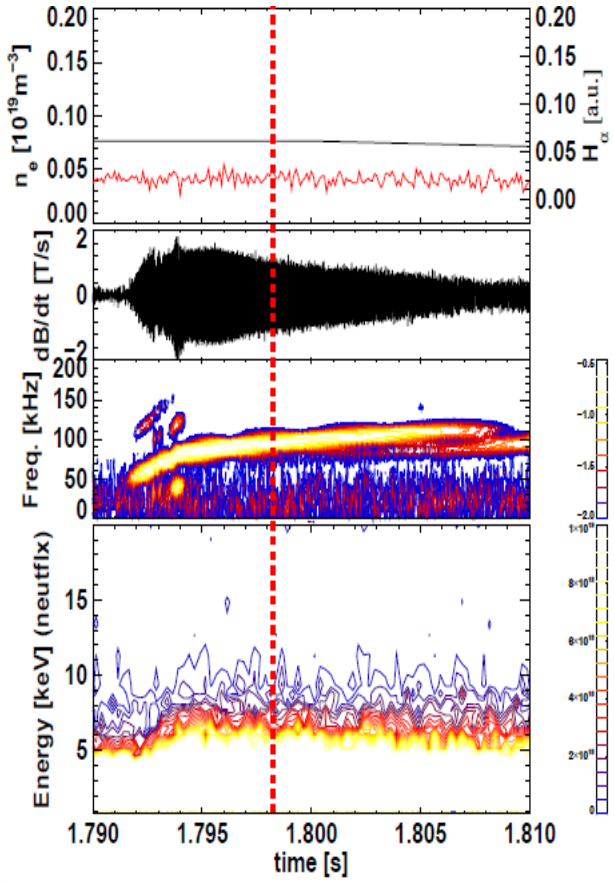
Both energetic-ions produced by NBI and energetic electron components with intensive ECRH seems to be necessary to excite these n=0 mode.

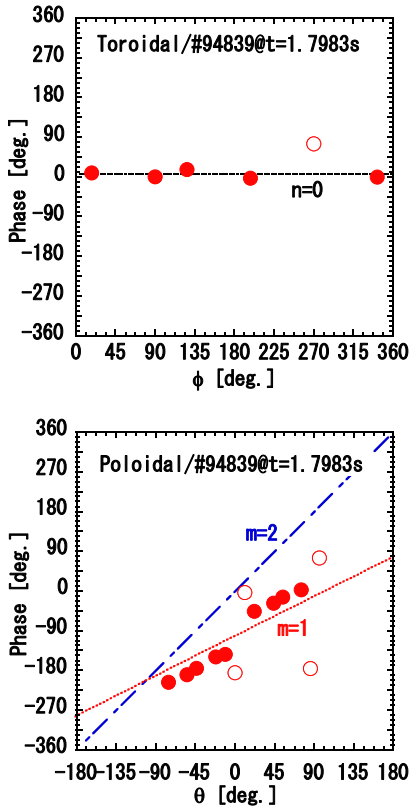


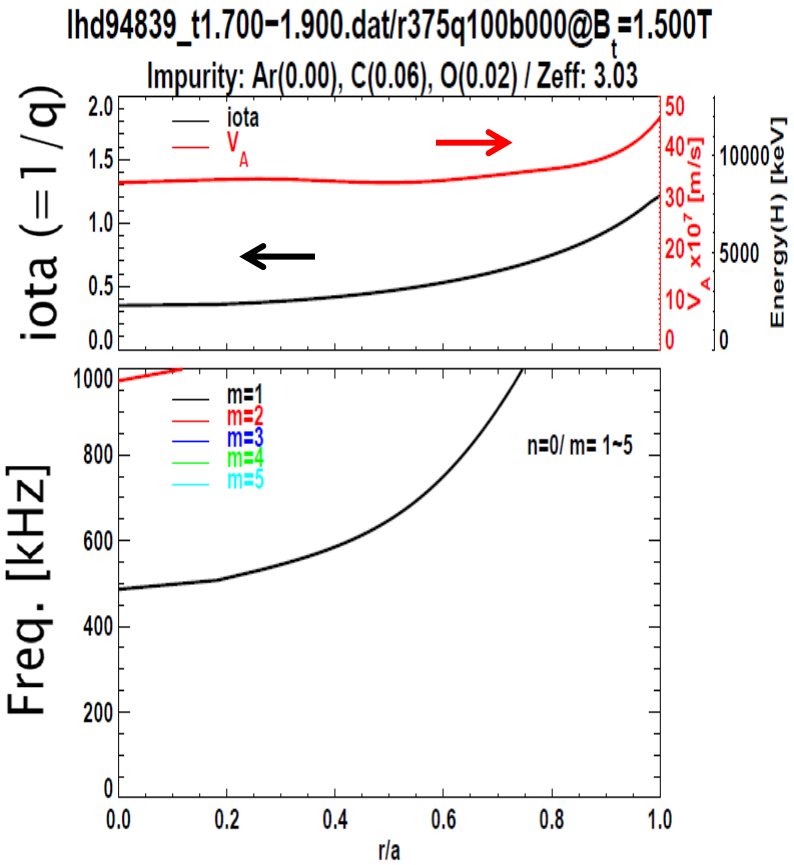
Up-sweeping n=0 mode
NOT observed during ECH-only phase

Up-sweeping n=0 mode disappears quickly after ECH turn-off.

The toroidal mode number is n=0, and the dominant poloidal mode number is m=1.

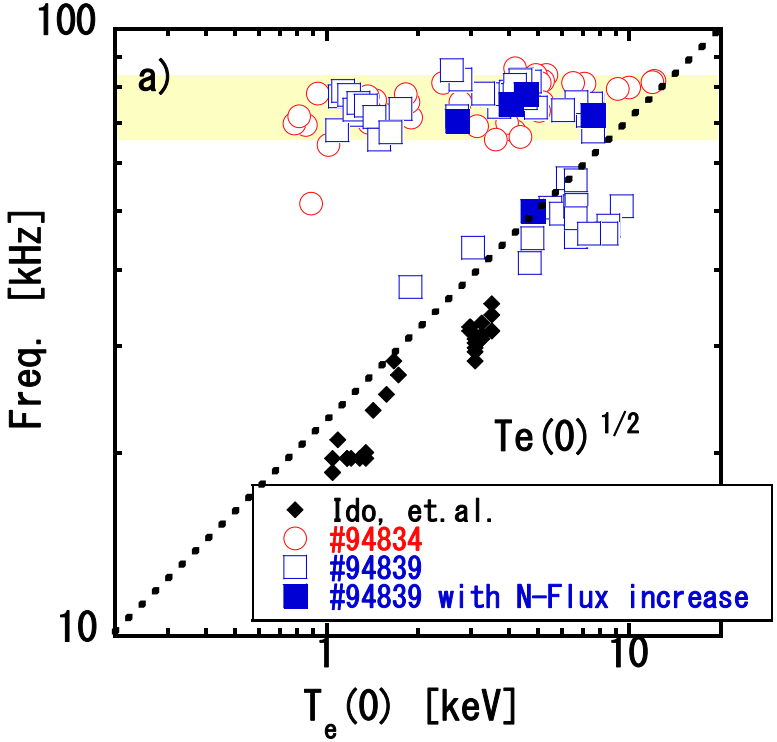


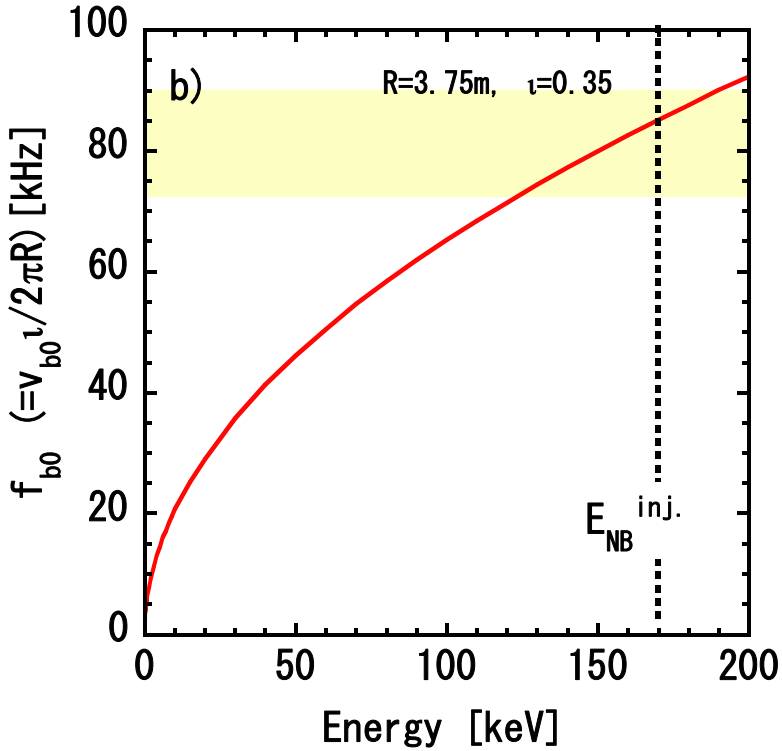




The initial frequency of the mode is much smaller than expected n=0 GAE frequencies (f>500kHz).

The observed n=0 mode can be classified into two categories.

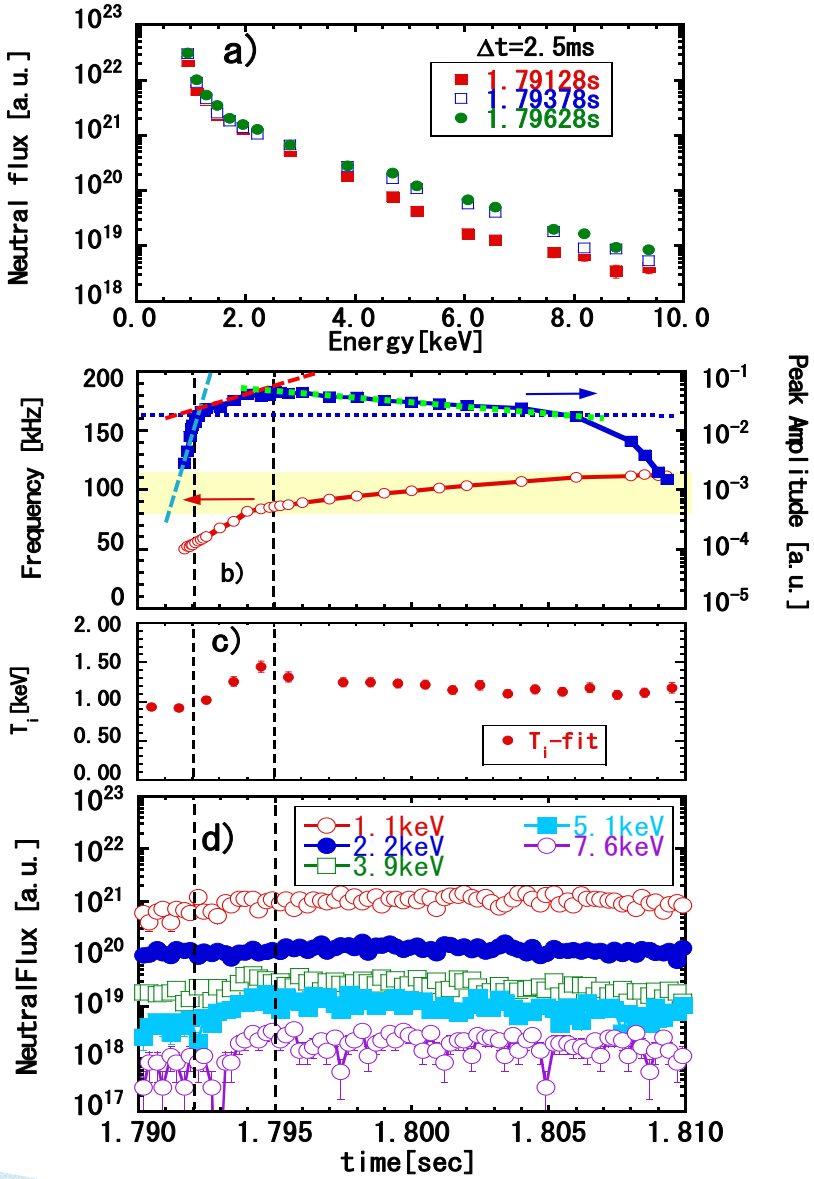




- One has the Te $^{0.5}$-dependence of its mode frequency. This mode can be considered to be similar to the energetic particle induced GAM on LHD.
- The other mode has weak dependence of its mode frequency on Te. The mode frequency is larger than the usual GAM mode and is close to the orbital frequency of the NB produced energetic particles.
- Neutral flux increase was observed for both cases.

Temporal behavior of the mode and neutral flux indicates either anomalous heating or radial transport of bulk ions by the mode activity.

- The mode grows very quickly at its initial phase (γ_{eff}=~4.6x10^3[s^{-1}]).
- The ion temperature starts to increase when the mode amplitude reaches a certain value (~2x10^{-2} [a.u.]), and the effective growth rate of the mode decreases (γ_{eff}=~2.3x10^2 [s^{-1}]), simultaneously.
- When the mode frequency reaches to a certain frequency close to the orbital frequency of the energetic particle produced by the NB, the mode amplitude starts to decrease gradually (γ_{eff}=~ −69 [s^{-1}]) .



SUMMARY

- At low density intensive EC heated LHD plasmas, energetic particle induced n=0/m=1 modes being associated with the flux increase of low energy neutrals are observed.

- The modes can be categorized into two type.
  - The one has $Te^{0.5}$ dependence of its frequency and is considered as energetic particle induced GAM.
  - The other has weak Te dependence of its frequency. The frequency is almost constant at around the orbital frequency of the NB-produced fast-ions.

- For both modes, the neutral flux increase was observed at the energy ranges close to the bulk ions.

- The temporal behavior of the mode and the neutral flux indicates an anomalous heating or radial transport of bulk ions by the n=0 mode.