27-2-4

The Joint Meeting of
5th IAEA Technical Meeting on ST
16th International Workshop on ST
2011 US-Japan Workshop on ST plasma
September 27-30, 2011, NIFS

# Characteristics of bulk and fast electrons observed in the LATE plasmas with externally applied radial magnetic perturbations

F. Watanabe, M. Uchida, H. Tanaka and T. Maekawa
Graduate School of Energy Science, Kyoto University

# Motivation

◆ In toroidal confined fusion plasmas, particle and energy transport caused by **externally applied magnetic perturbation (MP) fields** and/or therefore stochastic fields is very important for controlling the plasma performance and MHD instabilities.

## Control of edge bulk plasma

- **ELM suppression and mitigation** were successfully done by application of magnetic perturbation fileds in **DIII-D (n=3)**[T. Evans et al., PRL 92, 235003(2004)], **JET (n=1)**[Y. Liang et al., PRL 98, 265004(2007)] and **ASDEX-U (n=2)** [W. Suttrop et al., PRL 106, 225004(2011)].
- Many other tokamaks such as **NSTX** and **MAST**, and helical device such as **LHD** have also been investigated.

→ The major difference is the MP spectra, which includes not only the mode number but also **the ratio of the resonant to the non-resonant components**.

⇓

*It is important to clarify the effects among these qualitatively different RMPs.*

# Motivation (cnt'd)

## Control of runaway electron

- **Losses of runaway electrons** in ergodized plasmas were investigated by applying perturbation fields in **TEXTOR (n=1, 2)**[K.H. Finken et al., NF 47, 91 (2007), M. Lehnen et al., PRL 100,255003 (2008)] and **JFT-2M (n=2)**[H. Kawashima et al., JPFR 70, 868(1994)].
  → Loss of runaway electron is smaller than that of thermal electrons, because the large shift of the drift surface from the magnetic surface causes a significant reduction in transport with RMPs.

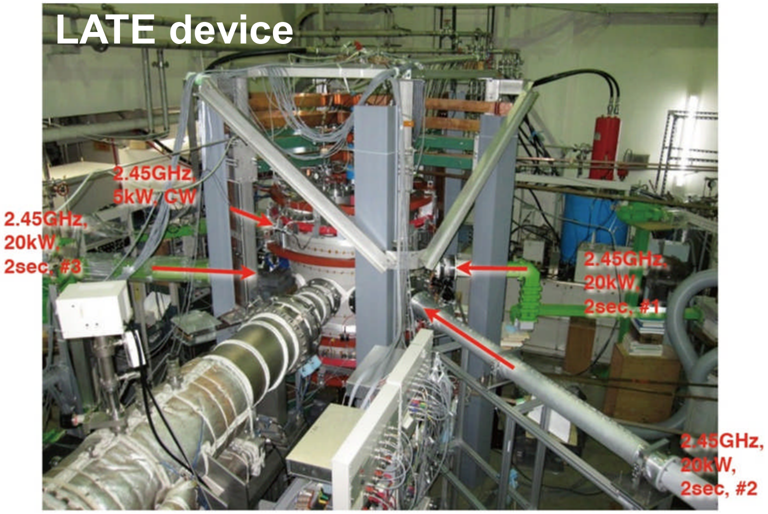
## Control of fast electrons and alpha particle

- **"Passing" and "trapped" high-energy electrons (fast electrons)** play an important role in the ECH/ECCD plasma performance.
- **Alpha particle** confinement is very important for future burning plasmas such as **ITER**.

⇩

***Experimental understanding of these characteristics with RMPs and non-RMPs has not been clarified so far.***

# Low Aspect Torus Experiment (LATE) device




**Device Parameters**

Vacuum vessel: diameter = height = 1m

Center post: diameter = 0.114m

Toroidal field coils :

Bt = 0.048T (R=0.25m), 10sec.

Bt = 0.115T (R=0.25m), 0.3sec.

Vertical field coils : 3sets (32kAT, 12kAT, 16kAT)

Vertical position control coil: 1set

Microwaves :

2.45GHz (5kWx1 CW, 20kWx3 2sec.)

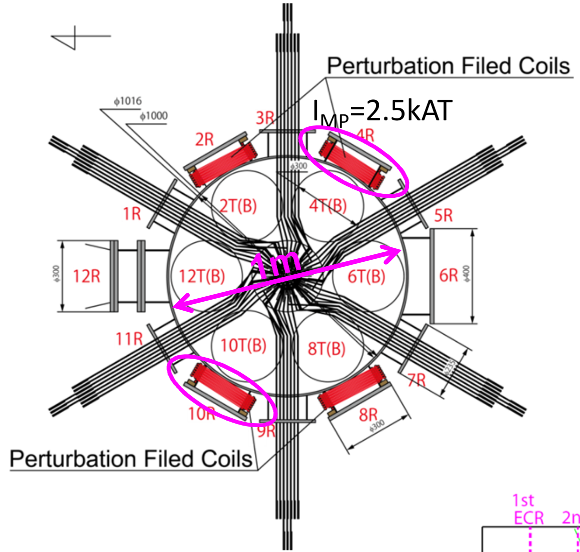
**Non-inductive plasma current start-up and ramp-up solely by electron cyclotron heating and current drive (ECH/ECCD)** have been studied on the LATE device.

[T. Yoshinaga *et al.* PRL (2006), M. Uchida et al. PRL (2010)]

→ *The formation of closed magnetic field surface is produced by* ***a current carrying high-energy electron tail.***

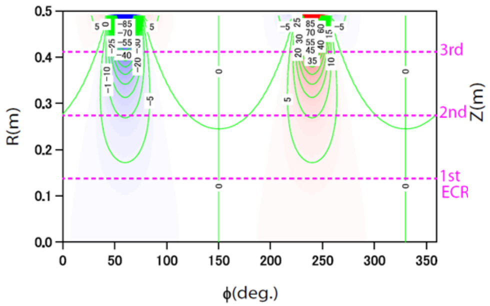
- **We can focus on studying effects of an externally applied MP field on fast electrons in the LATE device.**

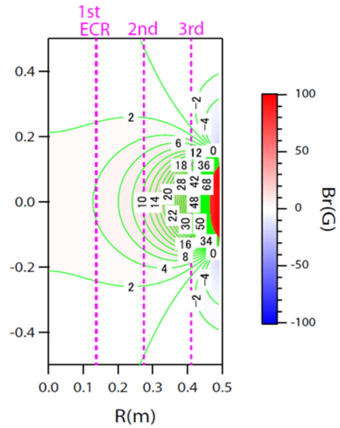
# Radial magnetic perturbation coils



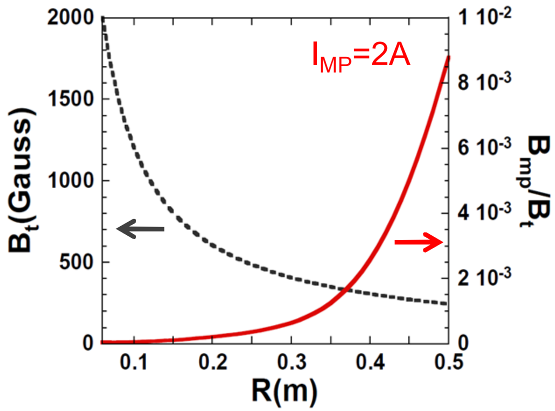

- Magnetic perturbation coil system is composed of four coils installed to surround horizontal port sections outside the vacuum vessel.
- Coil winding number has **25 turns**.
- Bipolar power supply; **±100A/±60V** （DC~1kHz）

n=1



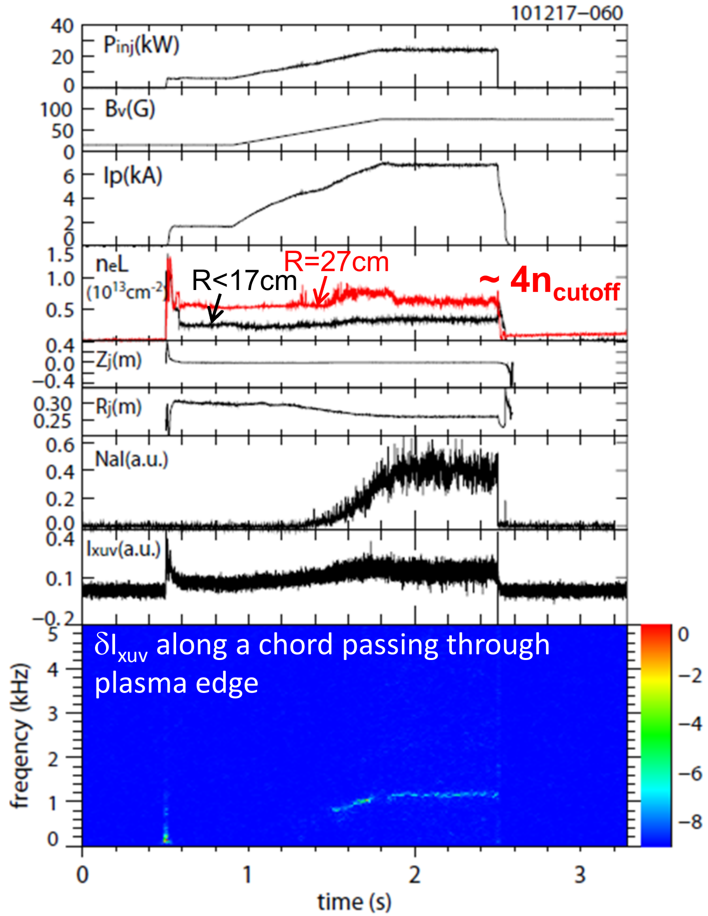




$10^{-4} < \delta b_r(I_{MP}=2A)/B_t < 10^{-2}$




(The fig. is values on the horizontal plane)

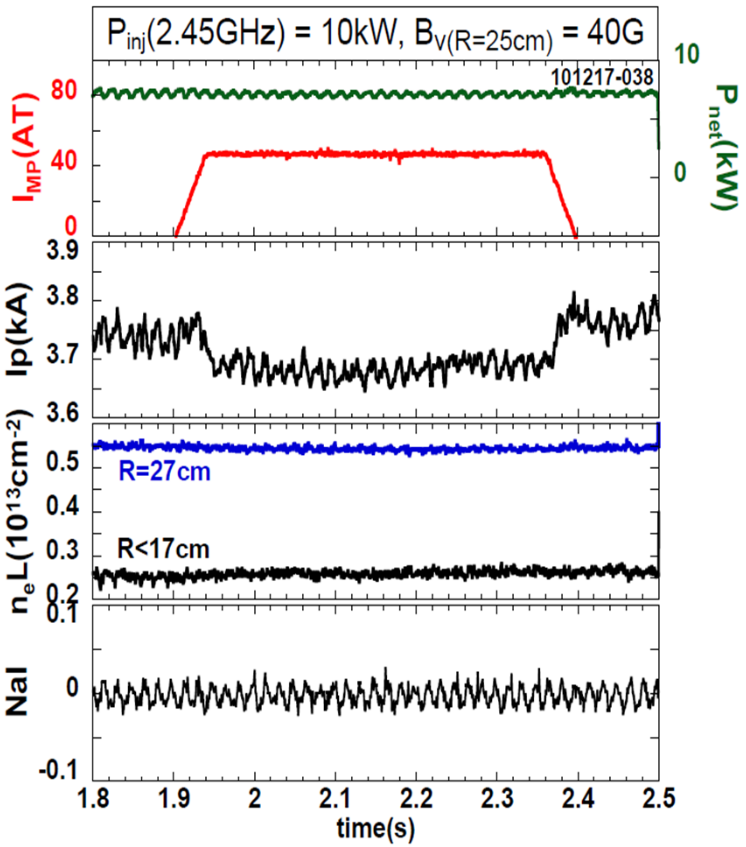
# Typical plasma discharge in the LATE device




- Magnetic conditions at R=25cm:
  $B_t$=480G, **$B_v$=15→80G**
- $R_{ECR}$=13.5cm
- $P_{inj}$(2.45GHz)=8→29kW
- Gas puff : $H_2$

- An example of long pulse discharge (t=2s)
- Plasma current is increased with ramp-up of the vertical field and RF input power.
- A hard X-ray emission measured by a NaI scintillator which mainly results from fast electrons hitting the center post component is rapidly increased in the range of Ip > 4kA.
  → Coherent fluctuation is observed by $\delta I_{XUV}$ signals.

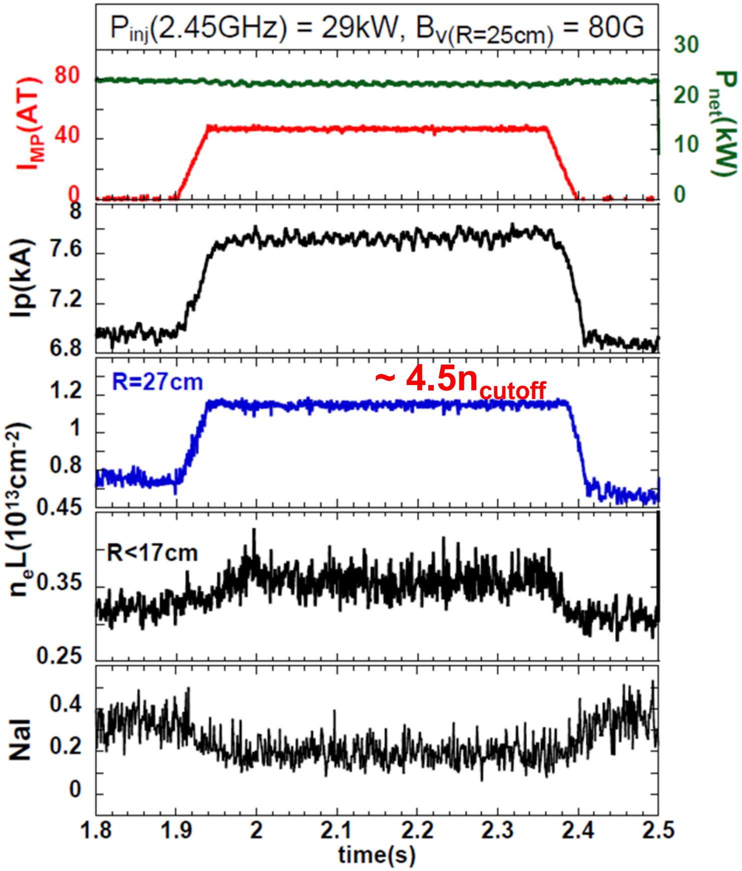
# Loss of fast electrons is observed in the low vertical field discharge with applied a weak n=1 MP




- Magnetic conditions at R=25cm: $B_t$=480G, **$B_v$=40G**
- $R_{ECR}$=13.5cm
- $P_{inj}$(2.45GHz)=10kW
- Gas puff : $H_2$

- **Plasma current is slightly decreased in the applied n=1 MP phase.**
- Line averaged electron density ($n_eL$) does not change.
- A hard X-ray(HX) emission measured by a NaI scintillator which results from fast electrons hitting the center post component cannot be observed in the range of $B_v$ = 40G.
  → Energy of the fast electrons is still relatively low.

# Increment of plasma current is observed in the middle vertical field discharge with applied a weak n=1 MP




- Magnetic conditions at R=25cm: $B_t$=480G, **$B_v$=80G**
- $R_{ECR}$=13.5cm
- $P_{inj}$(2.45GHz)=29kW
- Gas puff : $H_2$

**Effects on fast electrons in the applied n=1 MP field phase**

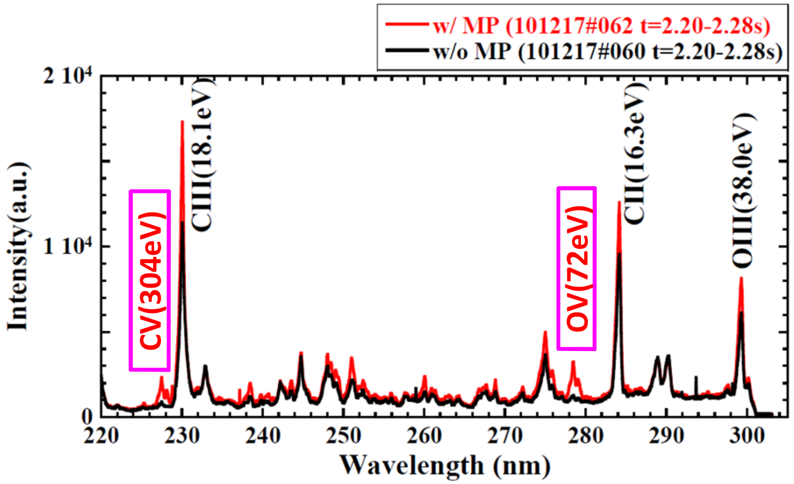
- ***14%*** **increase in plasma current**
- Decrease in HX emission

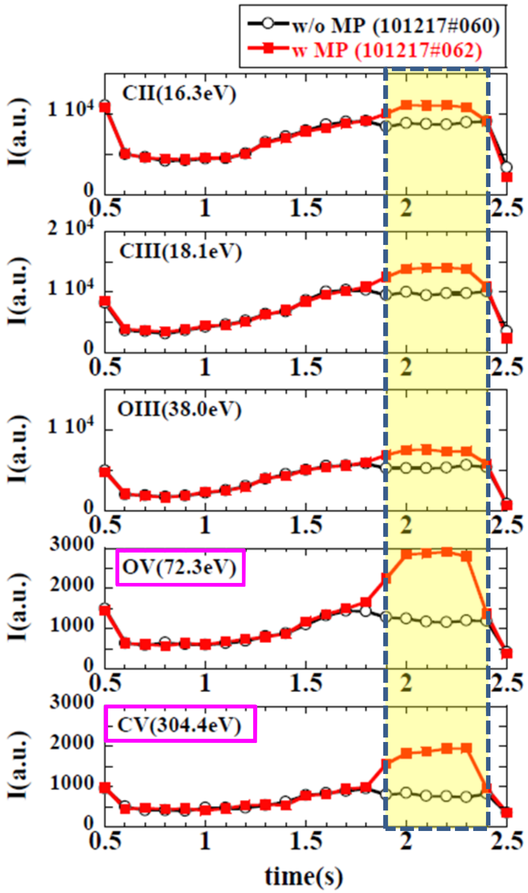
**Effect on bulk electrons**

- ***90%*** **increase in line averaged electron density (mainly R=27cm)**

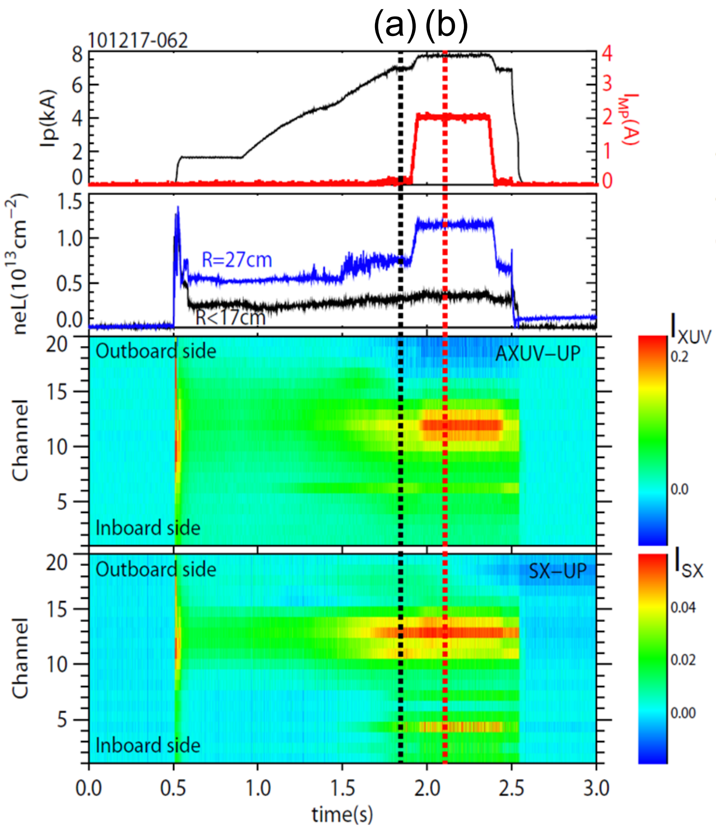
# Impurity line radiation suggests increase in bulk electron temperature

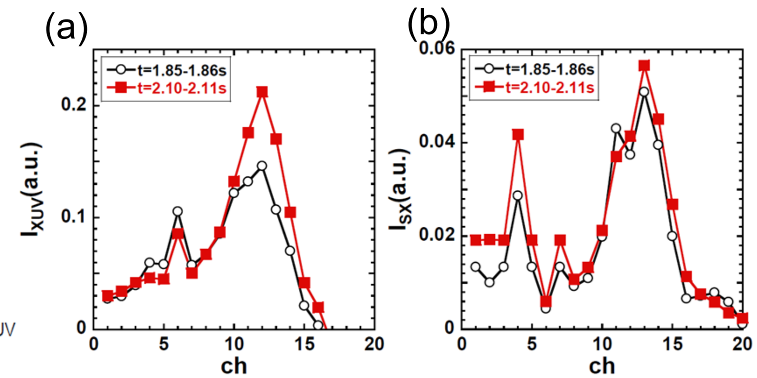
- Impurity line radiation such as **OV** and **CV** having high excitation energies measured by a visible spectroscopy is significantly enhanced.



# XUV and SX intensity profiles

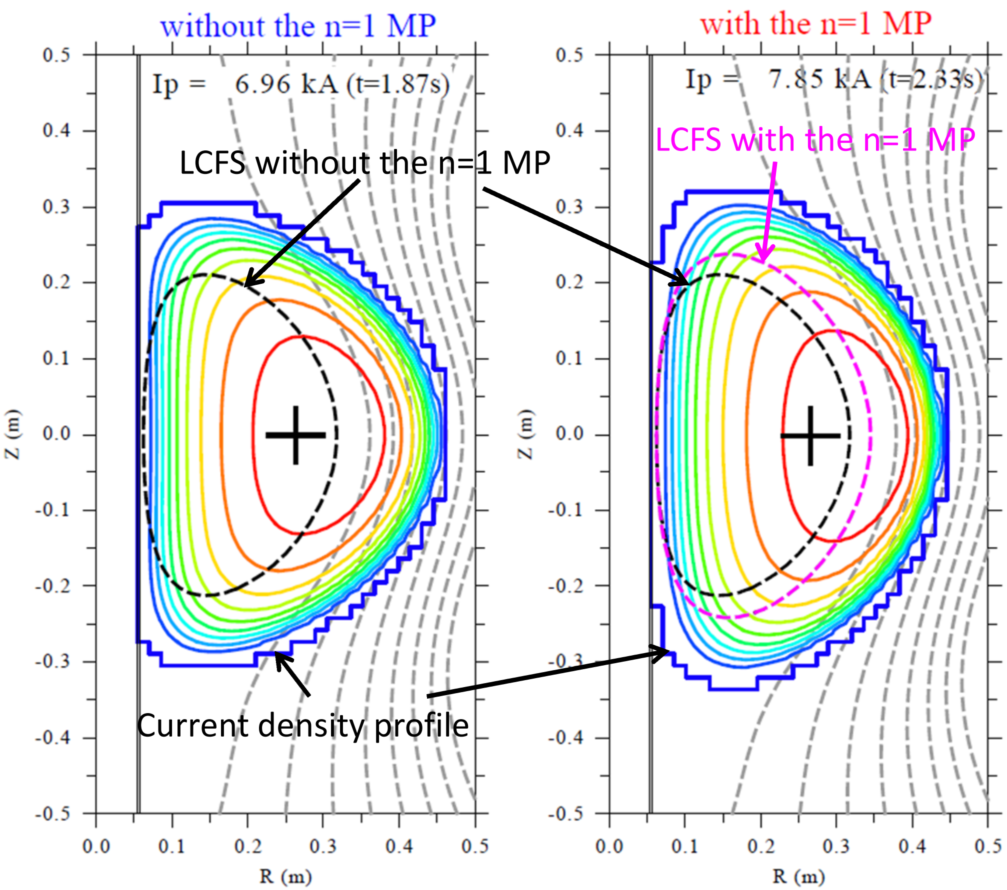



- XUV intensity in plasma core region is increased with the MP field.

→ This is consistent with increase in $n_eL$(R=27cm).

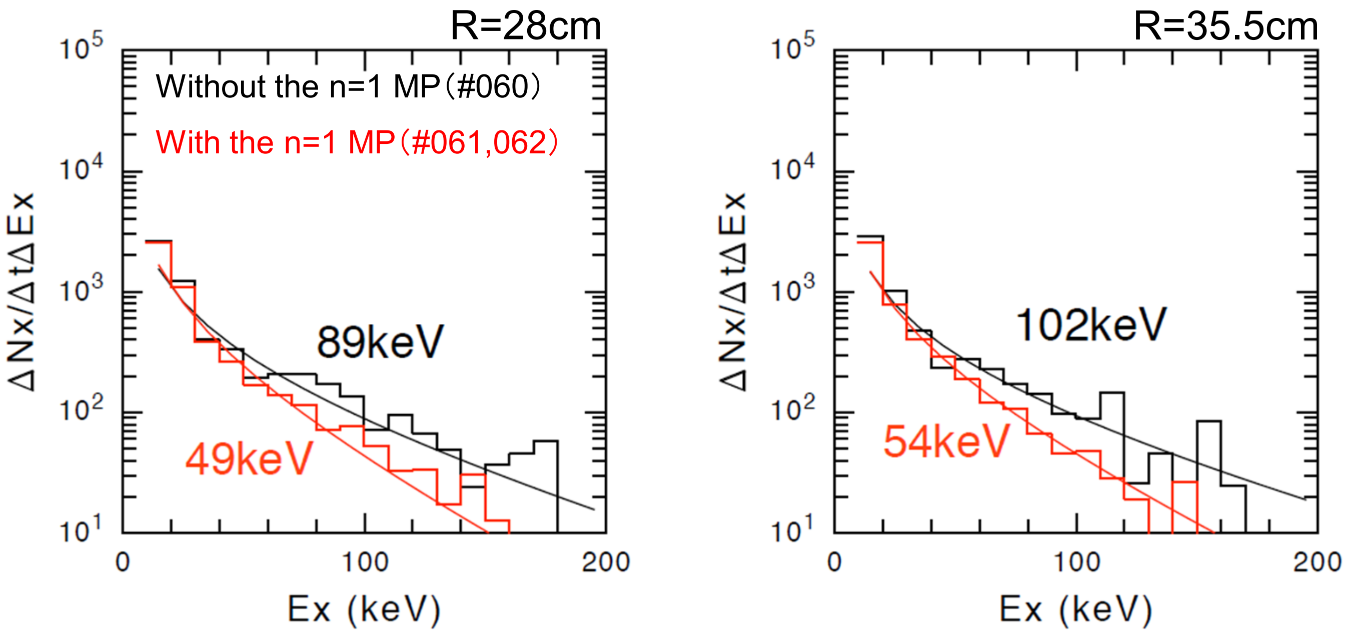
# Current density profile and last closed flux surface estimated by a magnetic analysis




- Expanding of magnetic surface is seen.
- Current density profile in the LFS is mainly modified by the applied n=1 MP field.

# Hard X-ray spectra analysis measured by PHA system

- This suggests that the application of the n = 1 MP field may induce the loss of high-energy trapped electrons located on the LFS and prevent the production of high-energy trapped electrons by ECH.

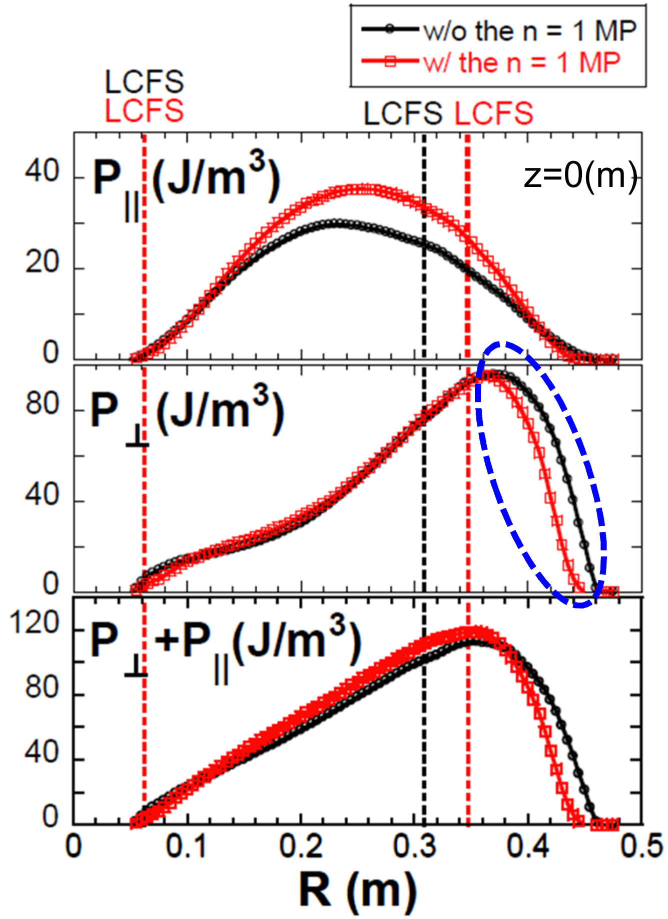



2.45GHz, 2sec, $I_{tc}$=1kA, Bv=15 -> 80G

G21~G23 : t=2.0~2.3sec (sys3のみG21+G23)

ΔEx=10keV

# Radial pressure profiles estimated by a magnetic analysis method with/without the n=1 MP




$P_\perp$ and $P_{||}$ indicate the pressures of parallel and perpendicular components to the toroidal magnetic field, respectively.

- The $P_\perp$ profile outside the LCFS on the LFS with the n=1 MP is clearly reduced compared with the parallel one.

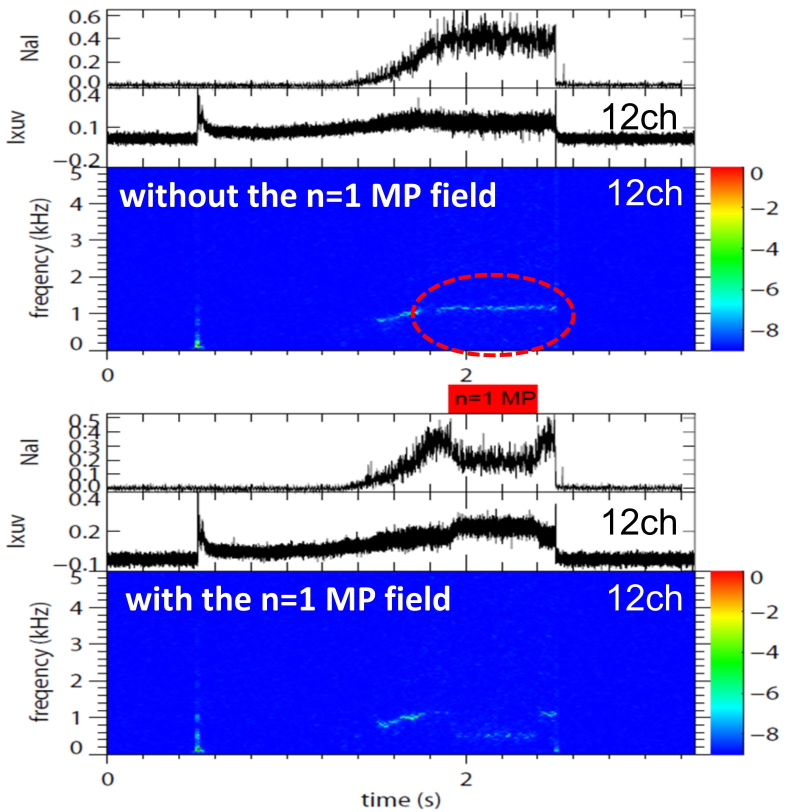
→ The applied n = 1 MP field leads to the enhanced loss of the trapped electrons rather than the passing electrons.

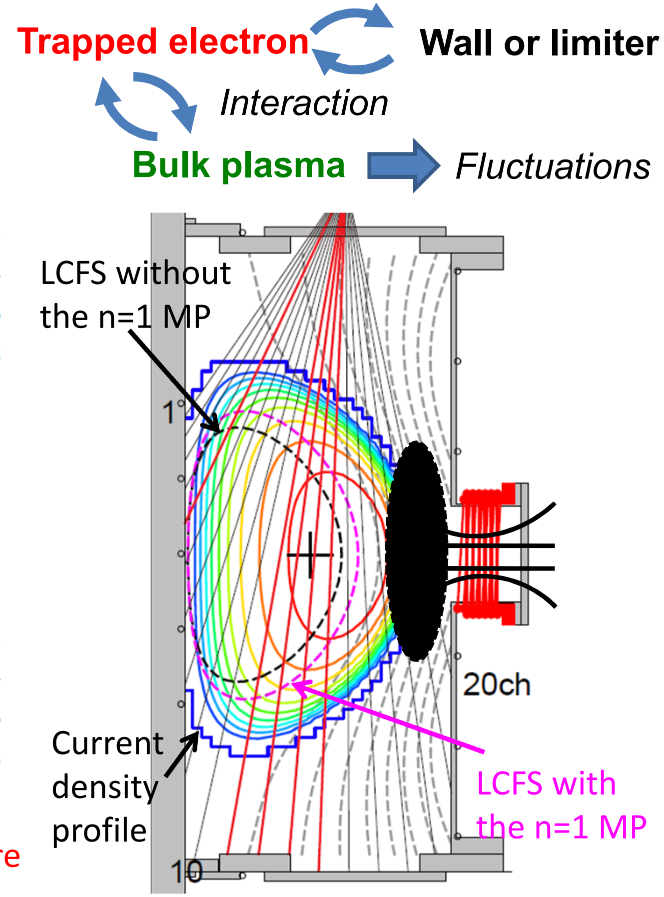
- The $P_{||}$ inside the LCFS increases.

→ Speculations;

  - trapped electrons kick in the core region
  - improvement of heating efficiency in the core region

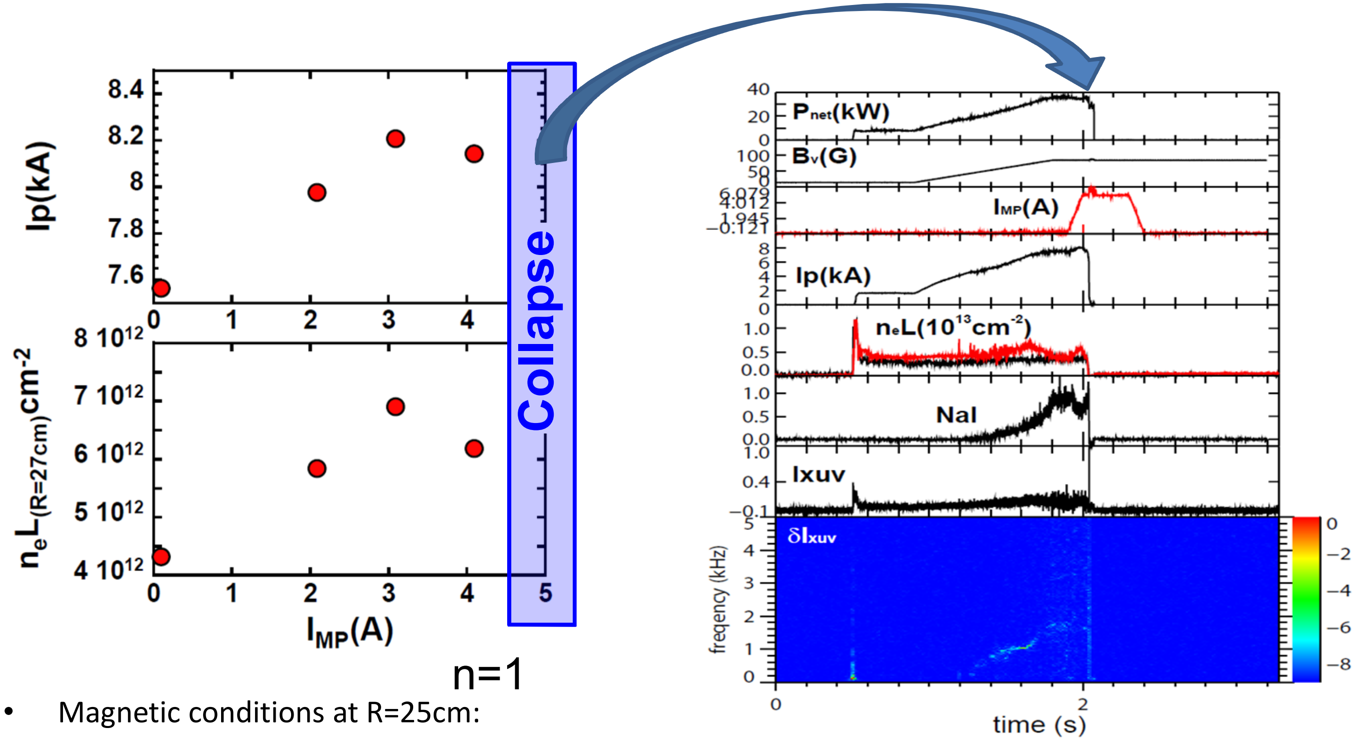
# Coherent fluctuations in the XUV signals ($\delta I_{XUV}$) are decreased with the applied n=1 MP field




- XUV fluctuations in mainly low field side are decreased (red lines in right figure).

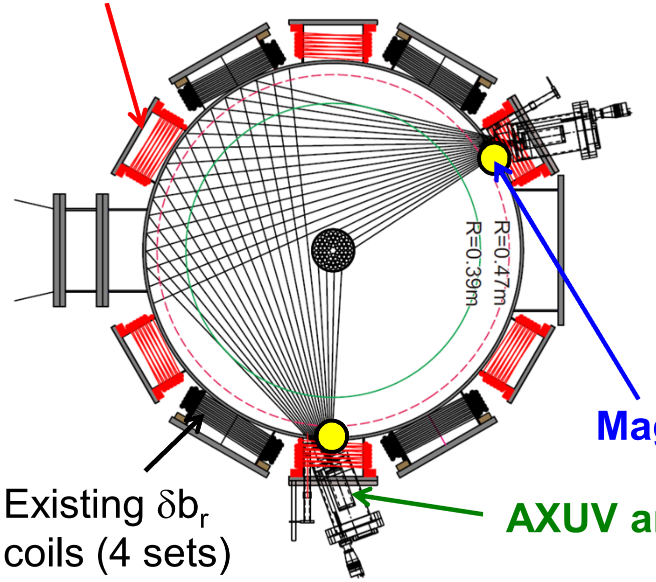
# Plasma performance is sensitive to magnetic perturbation in high Ip regime




- Magnetic conditions at R=25cm: $B_t$=480G, **$B_v$=90G**
- $R_{ECR}$=13.5cm
- $P_{inj}$(2.45GHz)=38kW
- Gas puff : $H_2$

- It is difficult to optimize plasma performance in the magnetic perturbation coil system.

# New experiment is now in progress




- In order to investigate different coil configurations and optimize the plasma performance, a new coils on the LFS were installed.
- In addition, AXUV array and magnetic probe array were installed.

| | Existing coils | New coils |
|---|---|---|
| Coil winding number | 25 | **13** |
| Coil diameter | ~254mm | **~184mm** |
| Toroidal mode number | n=1 and 2 | **n=1-3** |

# Summary

- **Effects of an externally applied MP field on fast electrons and bulk electorns** have been investigated in ECH/ECCD plasmas on the LATE device.
- **The applied n = 1 MP field have positive effects on an ECH/ECCD plasma in the high plasma current regime.**
  → Increases in Ip, $n_eL$ and $T_e$
  → Expanding of the LCFS (estimation by a magnetic analysis)
  → Reduction of HX emission outside the LCFS
  → $P_\perp$ outside the LCFS on the LFS is reduced, but $P_{||}$ inside the LCFS increases (estimation by a magnetic analysis)
  → Coherent XUV fluctuations in mainly low field side are decreased
- **These results suggest a possibility of selective controlling the pitch angle of fast electrons by the application of the MP field.**

✓ **Further experiments are just in progress following new coils and enhanced measurement systems (AXUV and magnetic probe).**