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Interactions between MHD events in the JT-60U high-β plasmas

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Introduction

Toward fusion reactor, MHD controls in the high-β_N must be established. In current devices, following methods are being studied as promising MHD controls :

- RWM
  - stabilizing by plasma rotation →NB, Coils
  - stabilizing by feedback coils →Coils
  - stability sensing by active MHD spectroscopy (RFA) →Coils
- ELM
  - pacing by pellet injection →Pellet
  - mitigation/suppression by RMP →Coils
  - grassy-ELM/QH-mode
- NTM
  - stabilizing by ECCD/ECH →ECH
  - avoidance by profile control

Introduction

Usually, these MHD controls need external actuators:

coils, pellet and heating system.

However, some of these are hardly installed in reactors.

MHD control w/o actuators can be very preferable for reactors.

In the JT-60U high-β_N plasmas, interesting MHD interactions, suggesting that useful idea for MHD control, are observed.

Outline of this talk

We focus on the following issues:

Energetic particle driven wall mode (EWM)

- Current interpretation

EWM-triggered ELM

- Interaction between EWM and ELM

ELM-Impacted RWM

- Interaction between ELM and RWM

~ Energetic particle driven wall mode ~

n=1 busting mode was observed in wall-stabilized high-β_N region

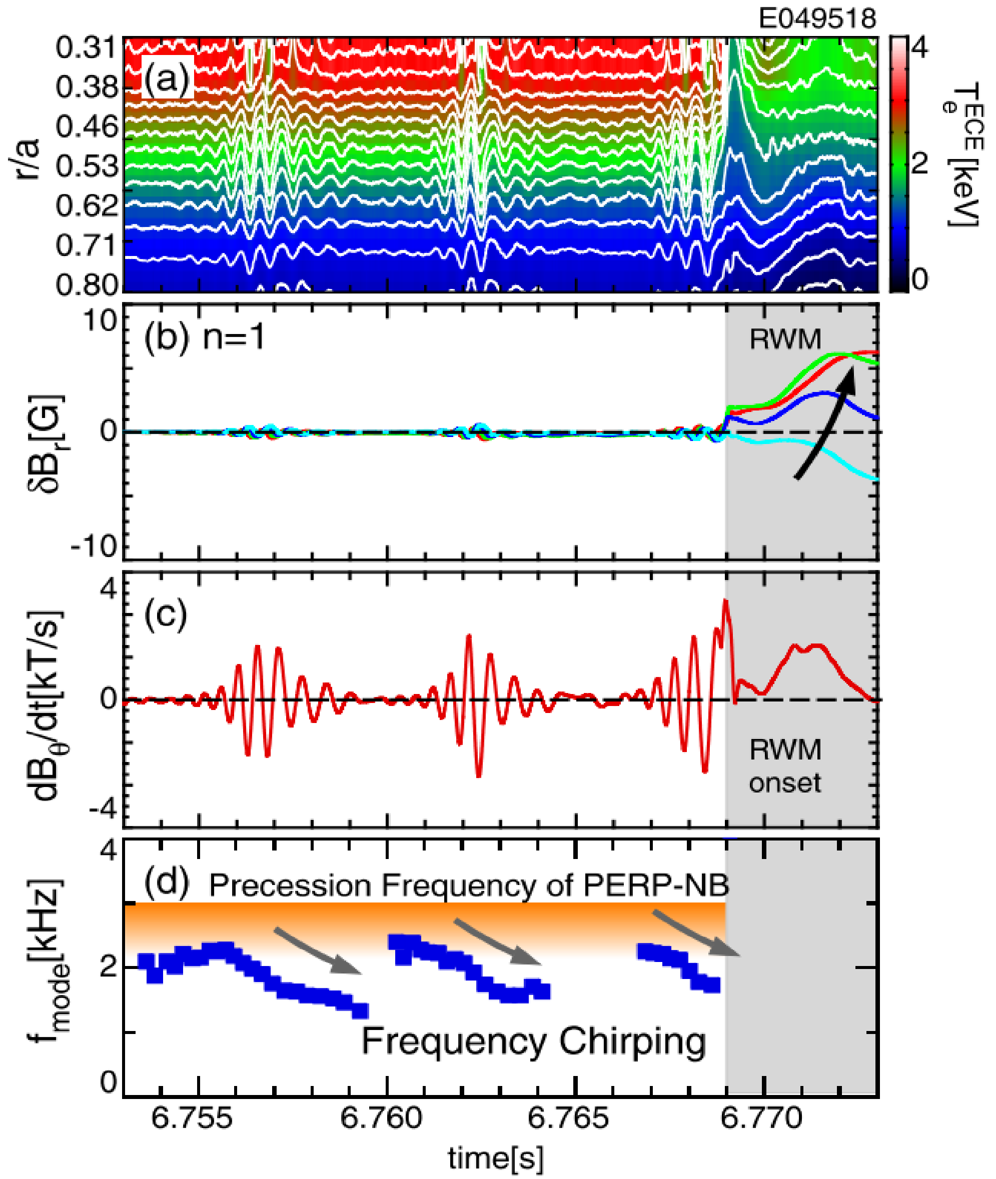
In JT-60U n=1 fishbone-like mode was newly observed.

G. Matsunaga et al., IAEA 2009, EX5-2
G. Matsunaga et al., PRL103, 045001 (2009)

- The mode can often trigger the RWM.
- The mode was mainly observed in the wall-stabilized high-β_N region, $\beta_N > \beta_N^{\text{no-wall}}$.
- The mode frequency is close to the precession frequency of the trapped fast ions from PERP-NB with ~85keV.

→Energetic particle driven mode

The mode was named as
"**Energetic particle driven wall mode (EWM)**"



~ Energetic particle driven wall mode ~

Possible candidates of EWM origin

On the basis of the m/n=1/1 fishbone analogy, EWM is considered to be originated as MHD mode driven by EP.

At present, possible candidates are

- **Ideal kink-ballooning mode (IKBM)**
- **Resistive wall mode (RWM)**

Because both modes are thought to be marginal in the wall-stabilized high-β_N region.

$$\omega^2 K + \underbrace{\delta W_{\mathrm{MHD}}}_{\text{MHD}} + \underbrace{\delta W_{\mathrm{k}}^{\mathrm{fast}}}_{\text{Kinetic contribution of fast ions}} = 0$$

$\delta W_{\mathrm{MHD}} > 0$: Marginally Stable

$\delta W_{\mathrm{MHD}} + \delta W_{\mathrm{k}}^{\mathrm{fast}} < 0$:Unstable

- $0<C_\beta<1$
  RWM : marginally stable by plasma rotation
  IKBM : marginally stable by ideal wall

$$\omega^2 K + \delta W_{\mathrm{RW}} + \delta W_{\mathrm{k}}^{\mathrm{fast}} = 0$$

EWM unstable

Cubic equation:

- **Positive and Negative IKBM roots**
- **RWM**

~ Energetic particle driven wall mode ~

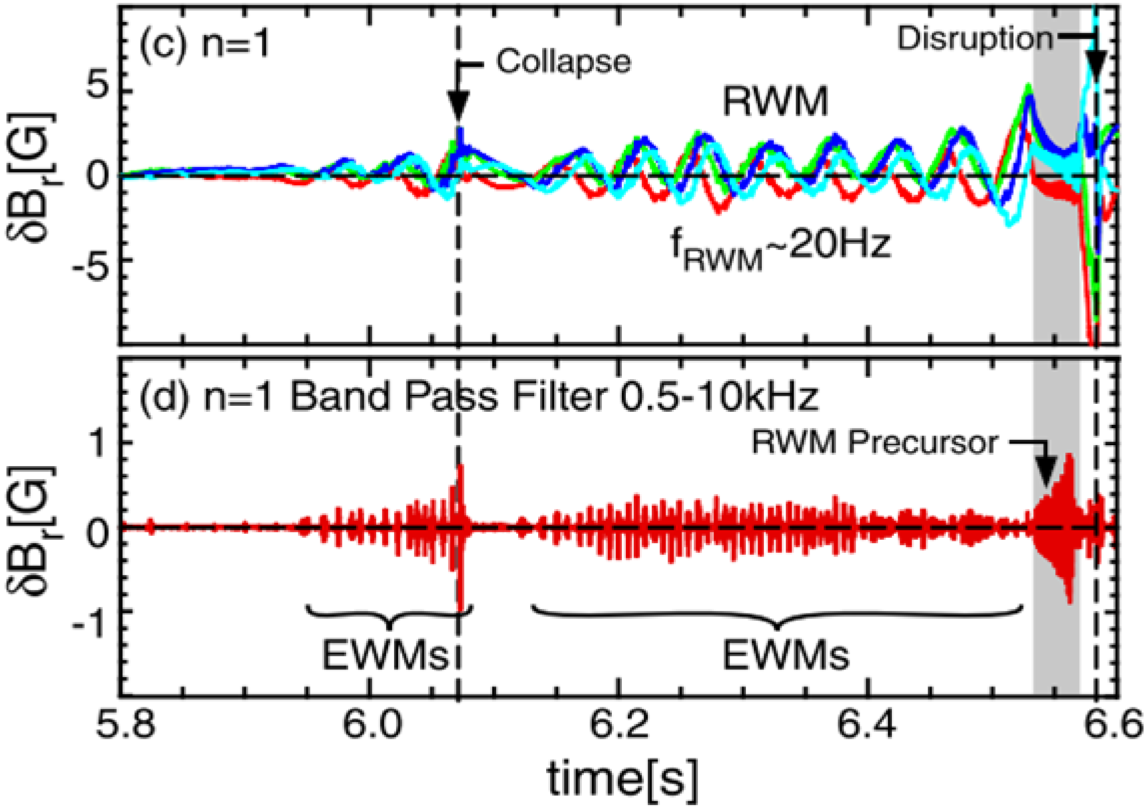
Simultaneous observation of RWM and EWM

In high-β_N discharge with large plasma rotation, a slowly oscillating mode was observed with EWMs.

- mode frequency : ~20Hz
- mode structure : global by Ti(r,t)

From the results,
the observed mode is thought to be RWM that has a marginal stability by large rotation.

Simultaneous observation of EWM and RWM suggests that EWM is not identical to RWM.



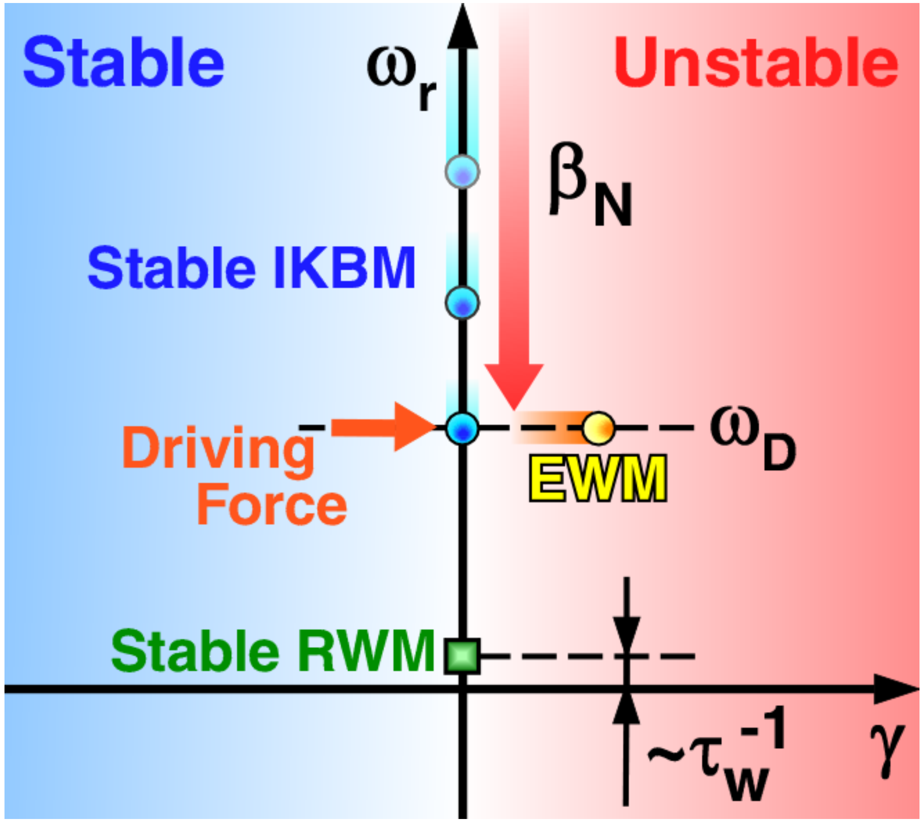
~ Energetic particle driven wall mode ~

Possible interpretation of EWM

MARG2D analysis:
IKBM is stabilized by ideal-wall,
IKBM real frequency is ~3kHz.

Our interpretation:
- Trapped fast ions can act as driving force at precession frequency ω_D.
- Real frequency of stable IKBM ω_{IKBM} is decreasing as β_N increasing.
- When $\omega_{IKBM} \sim \omega_D$, IKBM can be driven by EP as EWM.

From these results and analyses, EWM is thought to be **IKBM driven by trapped fast ions.**

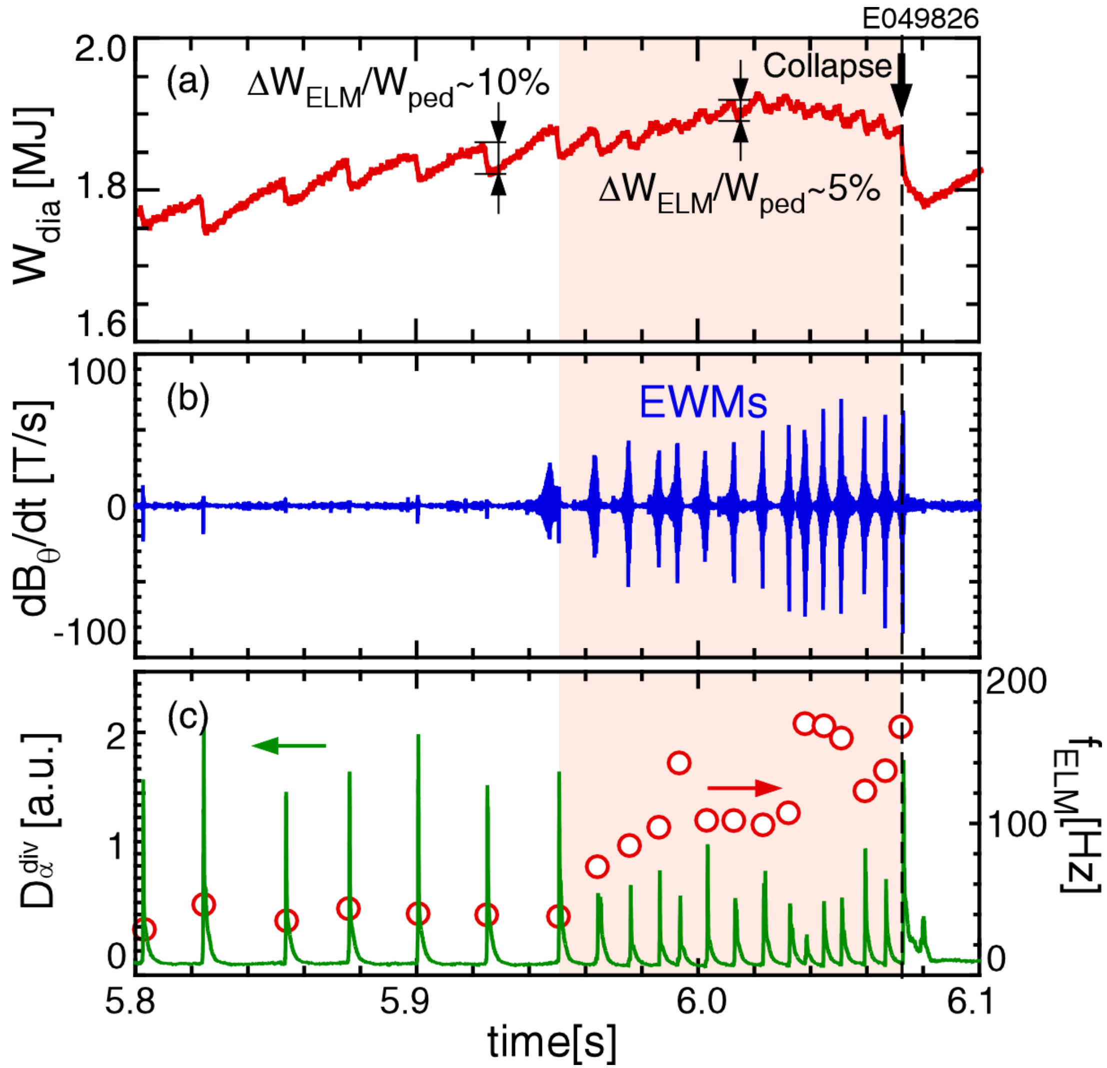


EWM should be avoided because EWM can trigger RWM.
However, EWM can affect other MHD events, and it is useful for MHD control.

~ EWM-triggered ELM ~

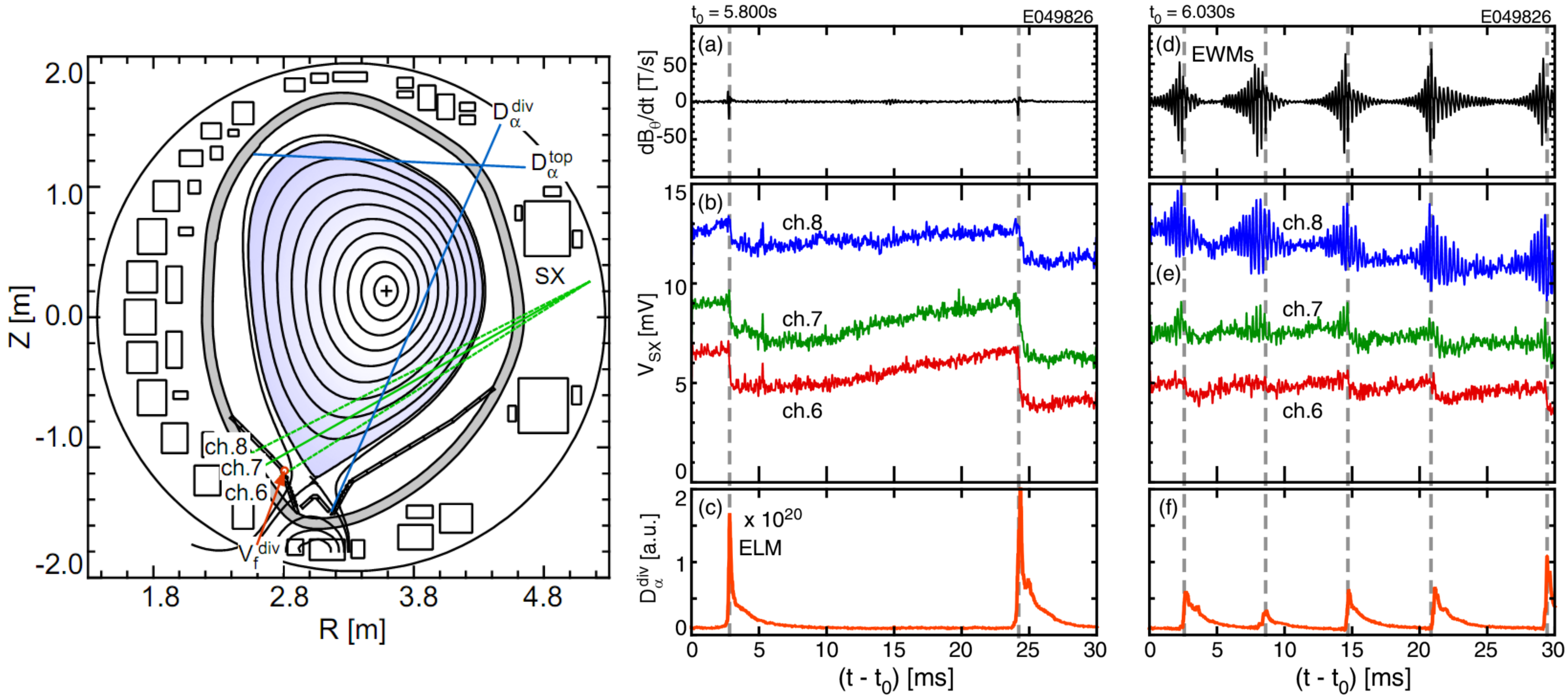
Observation of ELM mitigation during EWM phase

- Establishment of ELM control is one of urgent issues for ITER and reactors because heat load of ELM is crucial for diverter.
    - RMP/Pellet pacing
    - Grassy-ELM/QH-mode
- In the JT-60U high- β_N plasmas, ELM mitigation was observed during EWM phase.
- ELM frequency became ~3 times higher 40 to ~100Hz.
- Energy drop $\Delta W_{ELM}/W_{ped}$ of ~10% decreased ~5%.



~ EWM-triggered ELM ~

ELM can be triggered by EWM



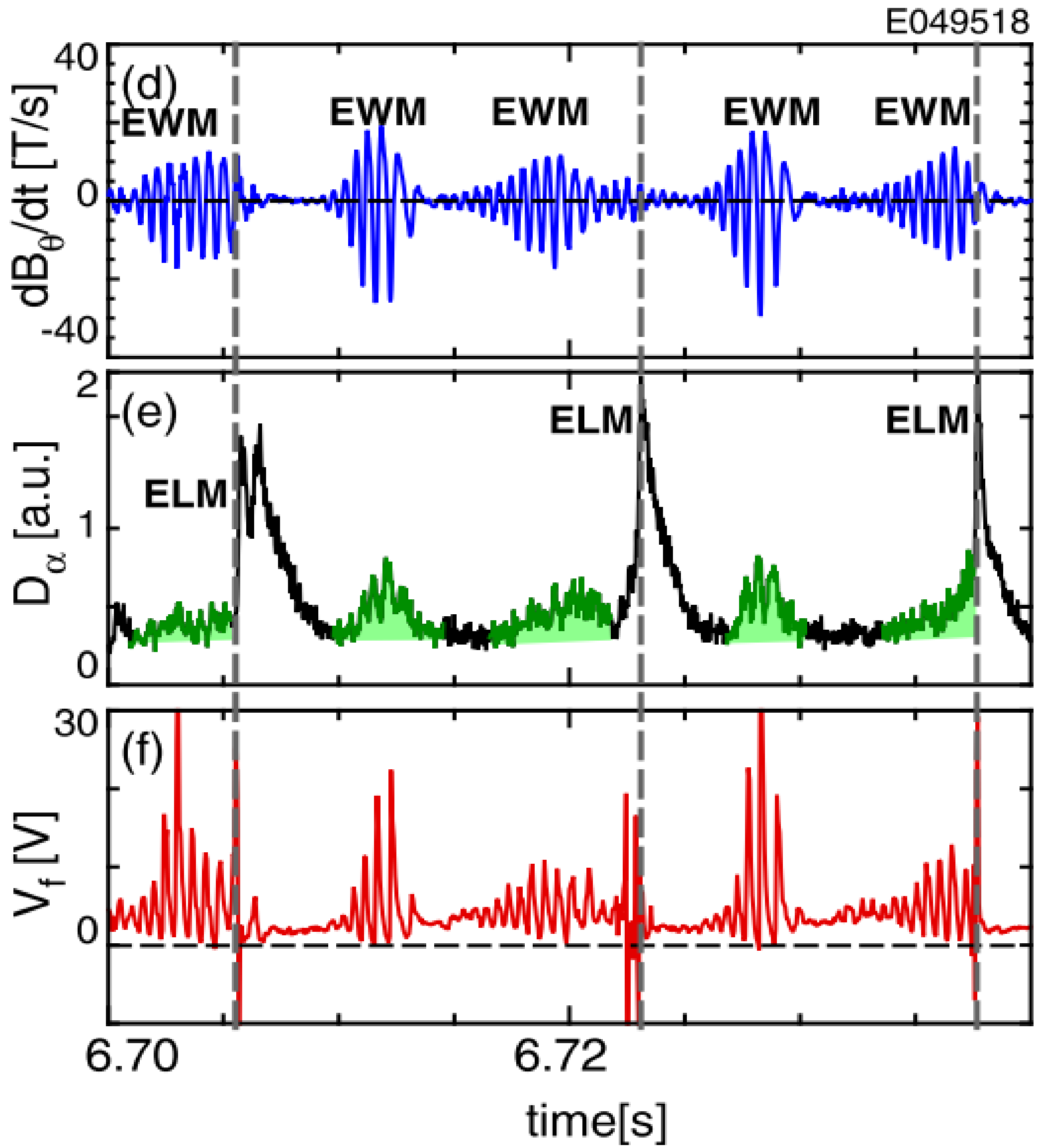
- Local measurements also show the "ELM mitigation".
  - Energy drops became smaller
  - ELM frequency became higher

During the EWM phase, ELMs were synchronized with the EWM

~ EWM-triggered ELM ~

EWM can enhance ion transport (loss) to the edge region

- Floating potential measured by Langmuir probe at the diverter shows positive spikes synchronized with EWM amplitude.
  → Ion loss occurs by EWM
- EWM is thought to be driven by fast ion.
  → Fast ion loss (resonantly)?
- Ion loss to the wall is though to enhance recycling at SOL region.



~ EWM-triggered ELM ~

Observation of ELM mitigation during EWM phase

Possible mechanisms :
i) EWM affects MHD stability at edge?
ii) Fast ion transport might affect edge current ?
iii) Fast ion transport provides additional pressure to pedestal in low field side?

1. EWM induce fast ion transport to pedestal region.

↓

2. Total pedestal pressure increase.

$$p_{ped} = p_{bulk} + p_{fast}^{loss}$$

↓

3. When total pedestal pressure gradient reaches its critical value, ELM occurs and pedestal is destroyed.

Peeling ballooning mode

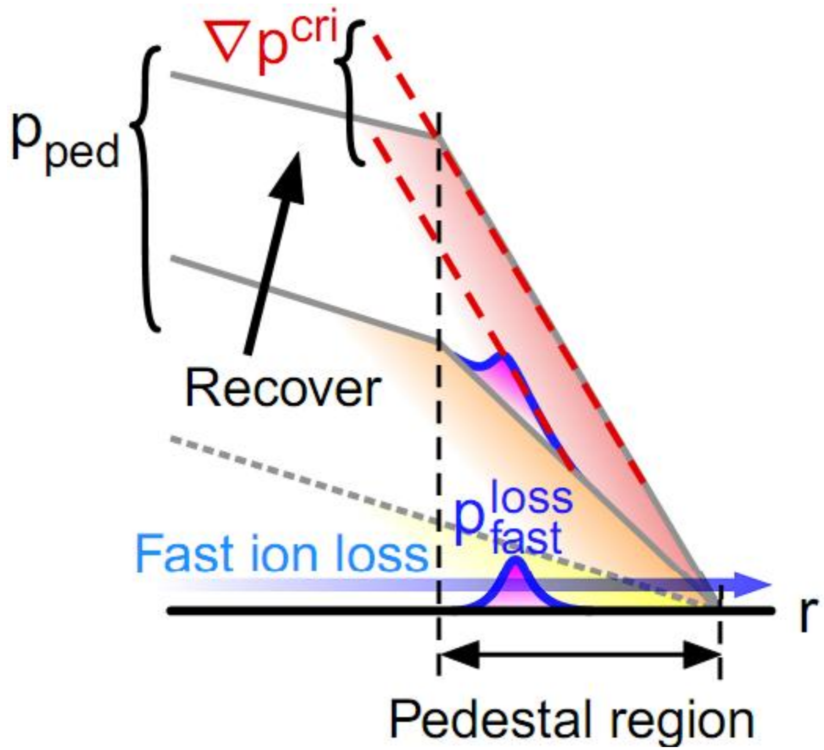
$$\nabla p_{ped} \geqq \nabla p^{cri}$$

w/o EWM :

$$\nabla p_{bulk} \geqq \nabla p^{cri}$$

w/ EWM :

$$\nabla (p_{bulk} + p_{fast}^{loss}) \geqq \nabla p^{cri}$$



Understanding of this phenomenon is still open.
Since EWM-triggered ELM is interesting for ELM mitigation, further analyses are required.

~ ELM-impacted RWM ~

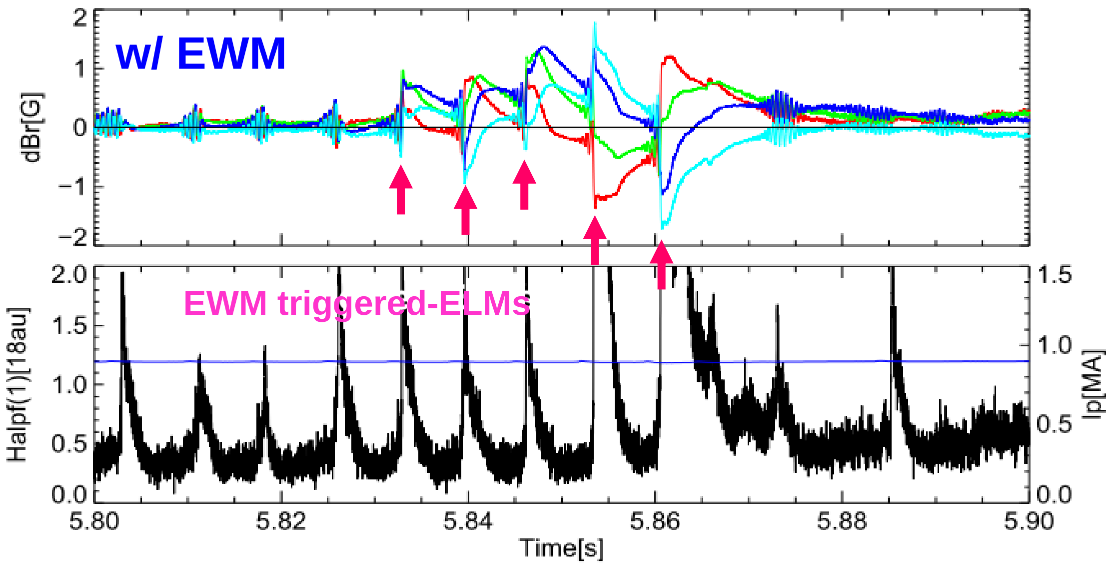
Marginal RWM can be diagnosed by external magnetic field perturbation via resonant field amplification (RFA) effect.
DIII-D, NSTX and JET
H. Reimerdes et al., PRL93, 132002(2004)

- On JT-60U, it was observed that n=1 distortion was excited by EWM triggered-ELM.
  ※ELM triggered RWM was reported in DIII-D.
  M. Okabayashi et al., NF 49, 12503 (2009)

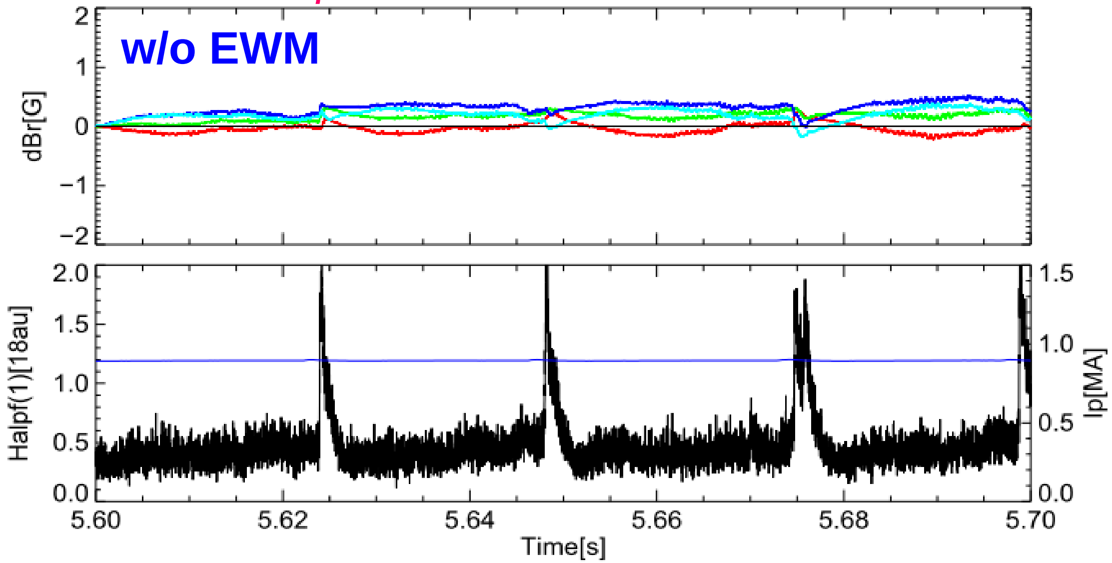
- The phenomena were observed in the wall-stabilized high-β_N region.

- Excited distortion decayed within ~10ms.

β_N~2.8 (C_β~0.6)



β_N~2.5 (C_β~0.3)



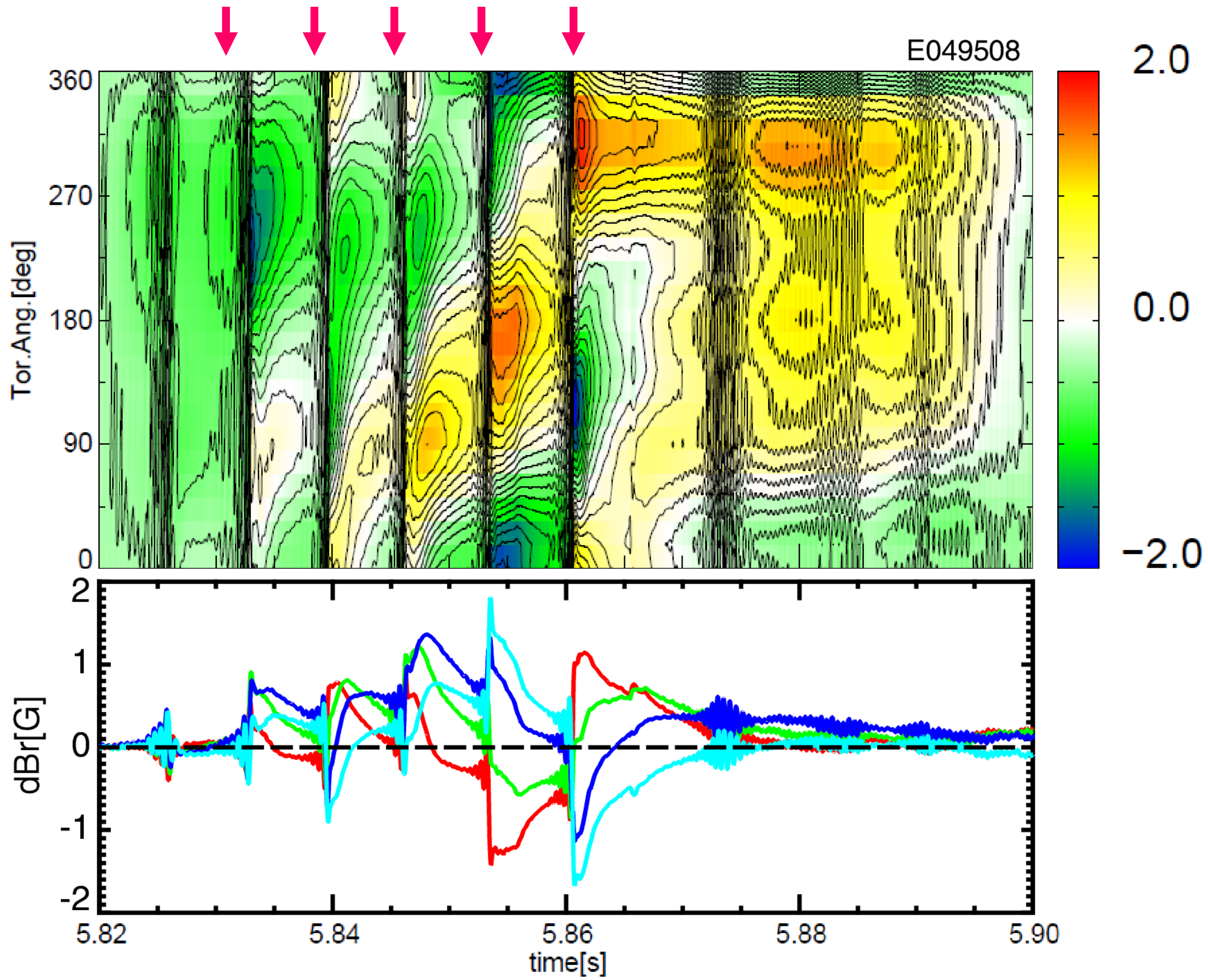
~ ELM-impacted RWM ~

Impacted response looks like RWM

- Excited distortion has an n=1 toroidal mode structure.
- The structure was toroidally rotating with ~30Hz.

  → $\sim\tau_w^{-1}$

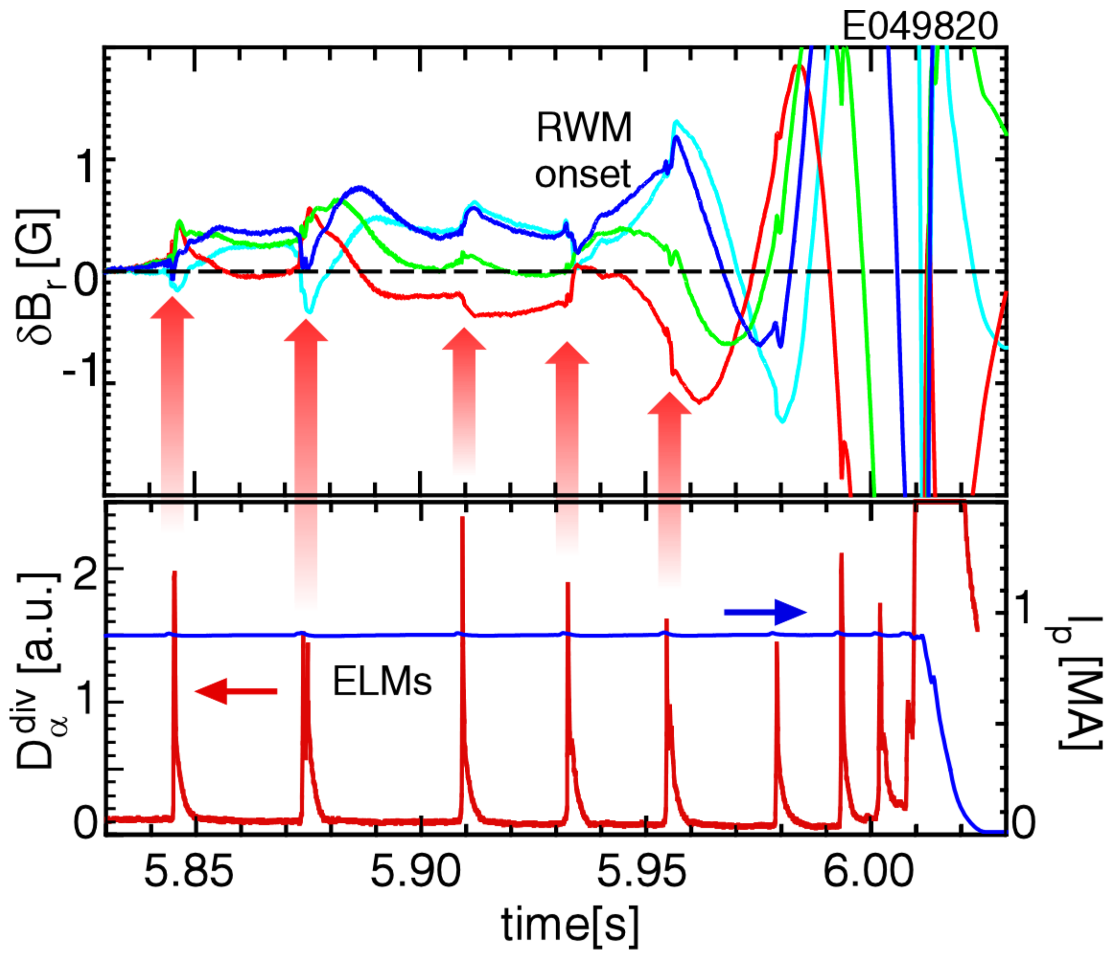
- It is considered that the marginal-RWM is excited by EWM-triggered ELM.
- These responses look like impulse - response.
- Damping rates can be estimated by these waveforms. → future work



~ ELM-impacted RWM ~

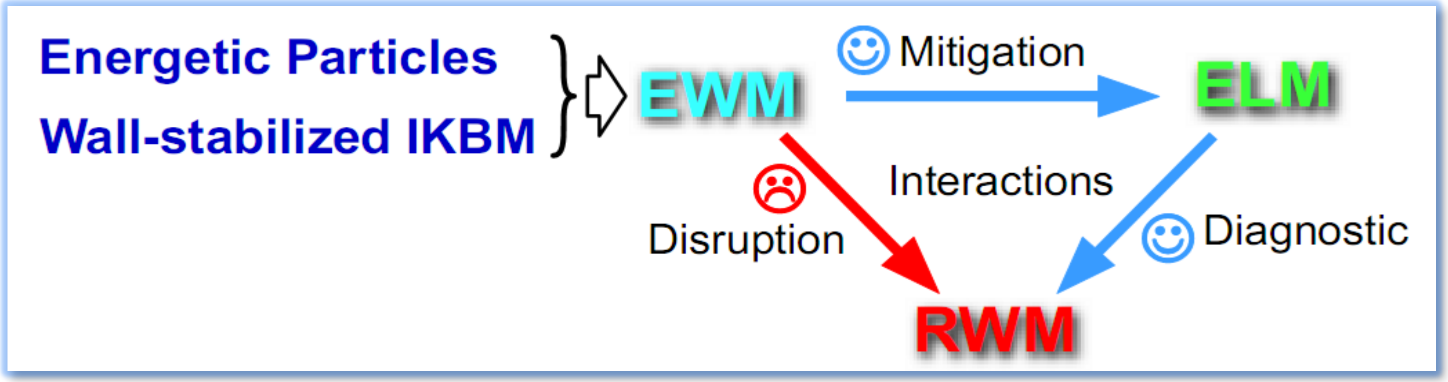
ELM-impacted RWM was observed without EWM

- Similar phenomenon was observed without EWM.
- This phenomenon was usually observed in the high-β_N discharge with larger rotation.
- In this discharge, finally, RWM became unstable.
- However, it is not clear which mode, EWM or ELM, is essential to excite marginal RWM.



Summary

Introduced interactions seem to be useful for MHD control without any actuators:



~ EWM-triggered ELM ~

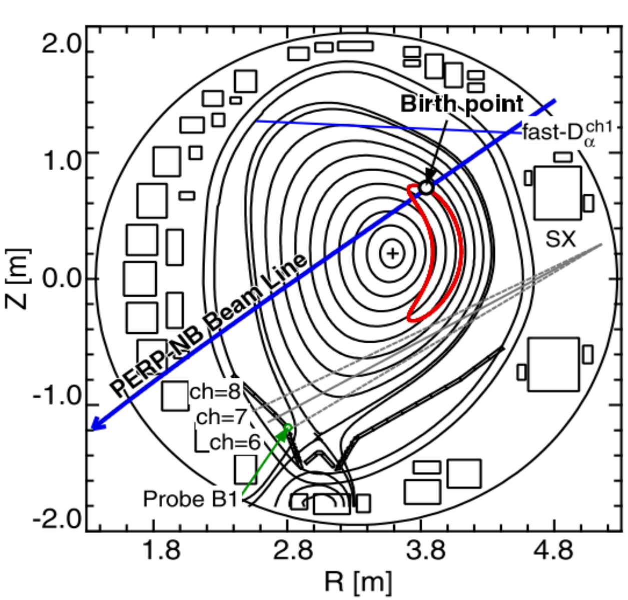
ELM-mitigation by EWM is possible?
even if it is not externally controlled.

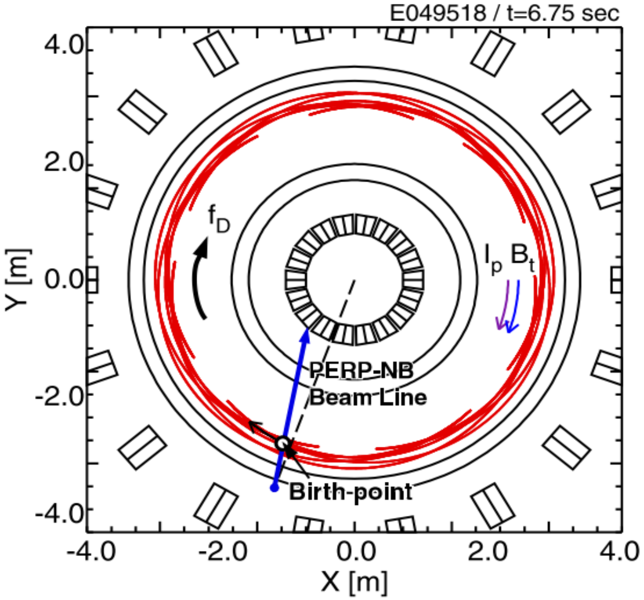
~ ELM-impacted RWM ~

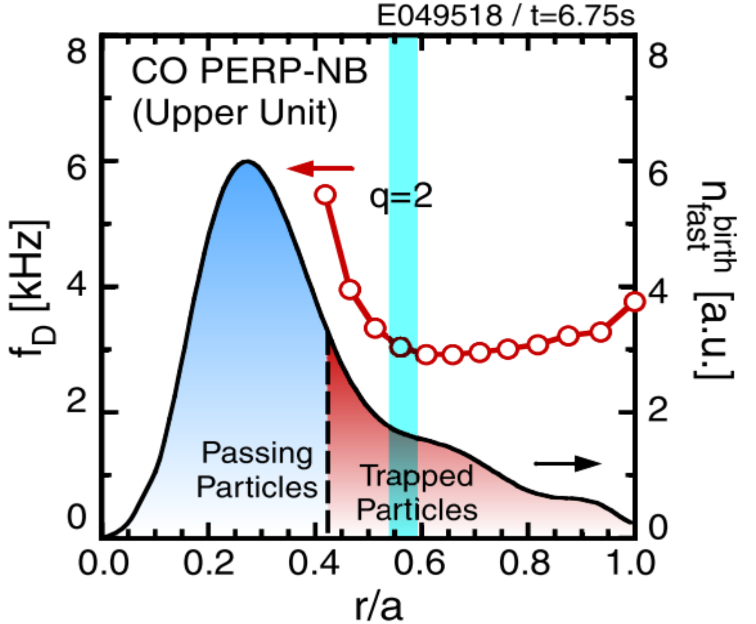
Marginal RWM can be diagnosed by ELM impact without any coils.

Although physics to be clarified still remain, these ideas are interesting for MHD control in DEMO and reactors.

Precession motion of trapped energetic particle







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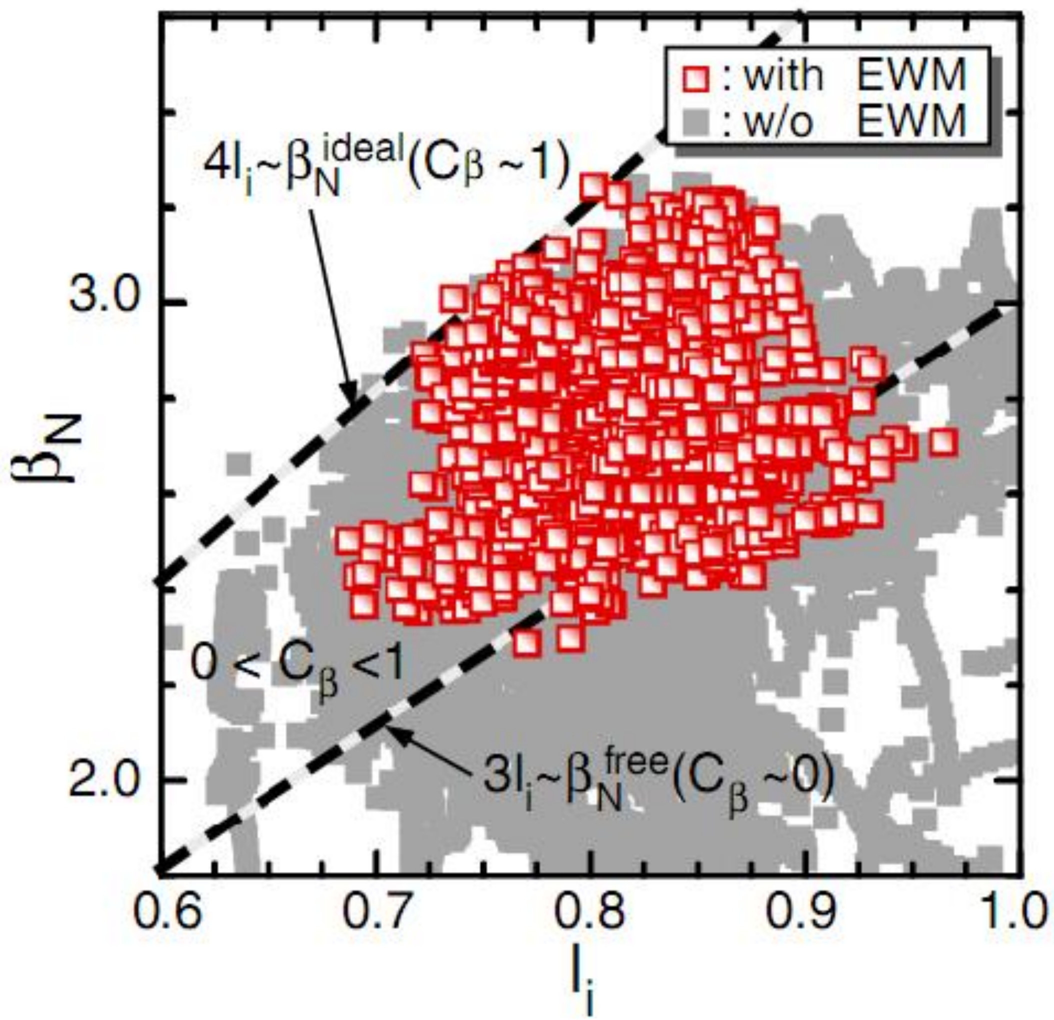
EWMs were mainly observed in the wall-stabilized high-β_N region



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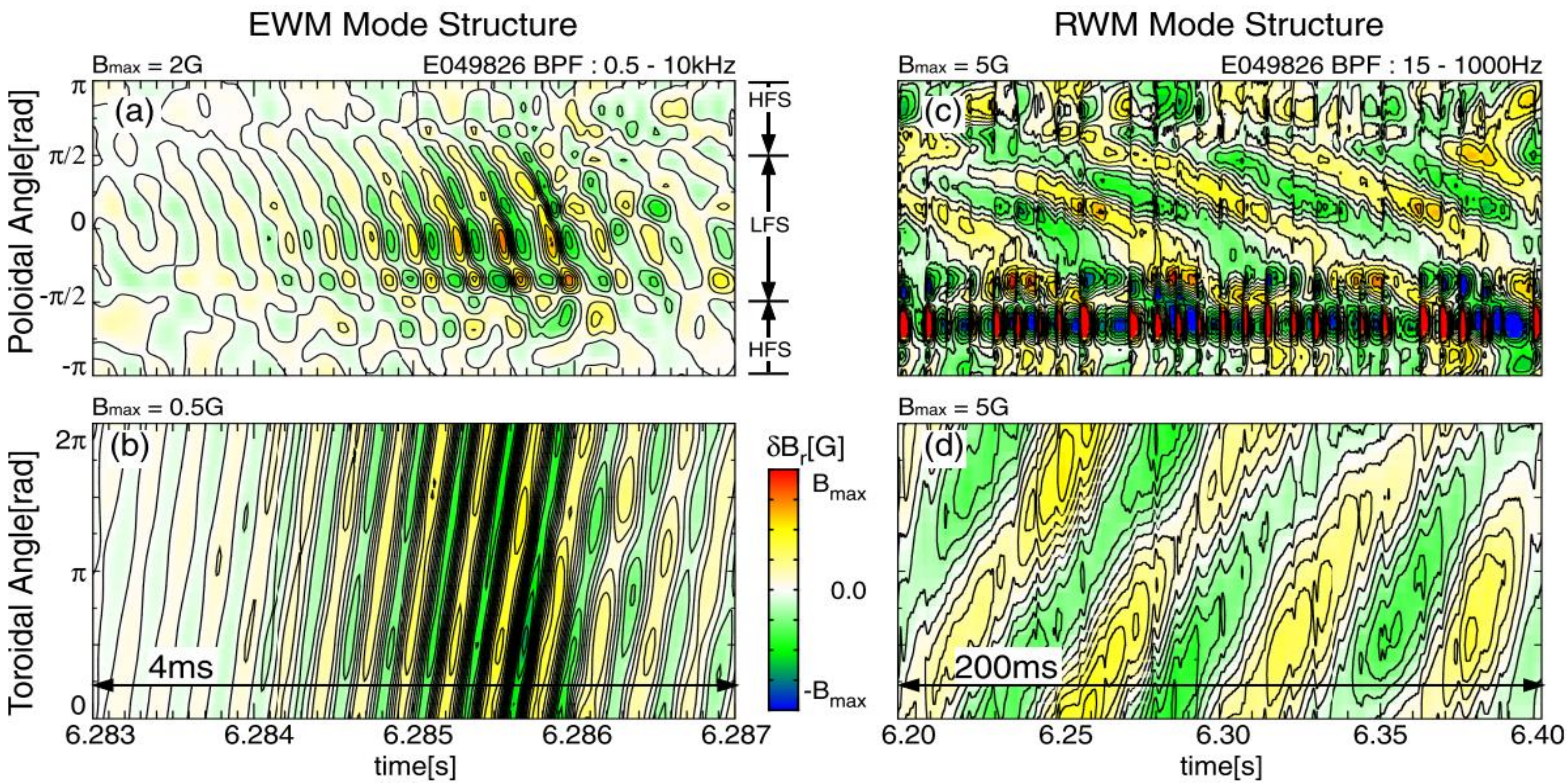
Comparison between EWM and RWM



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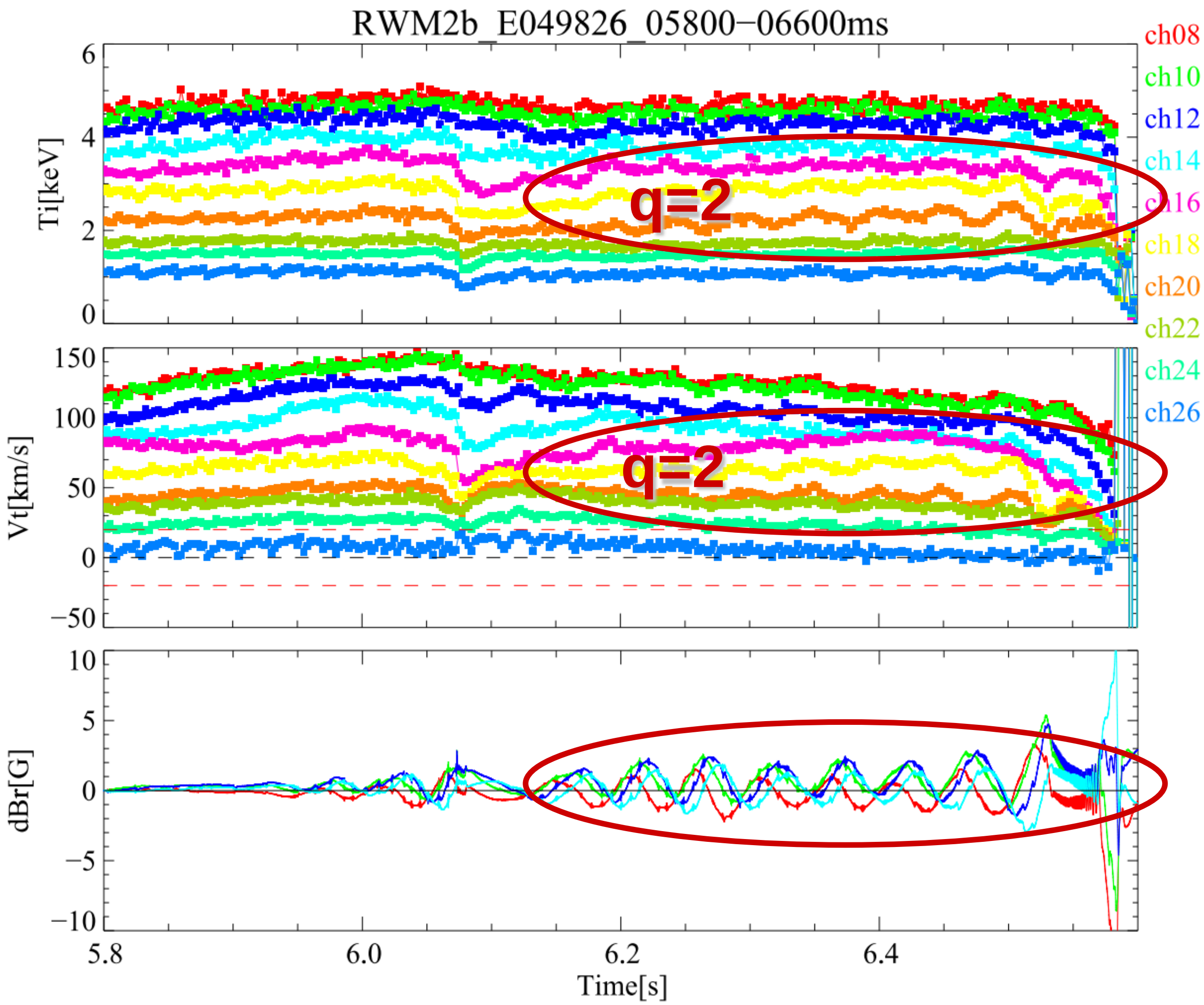
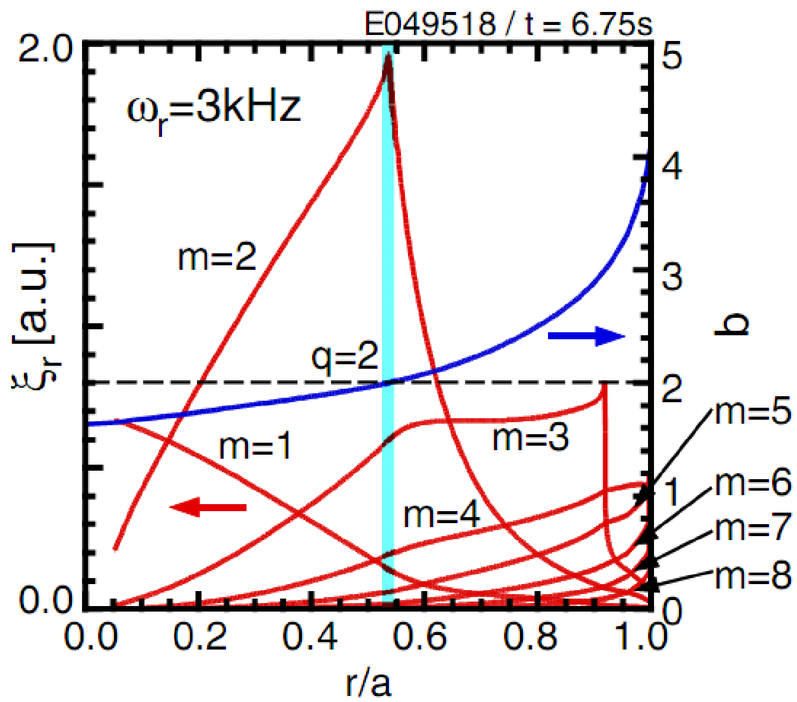
Simultaneous observation between EWM and RWM





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