# Toroidal phase dependency of ELM-driven RWM

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# Outline

- **ELM-driven RWM**
  - ***Background***

  ***Big ELM-induced n=1 mode amplitudes alone may not be a sufficient condition to drive RWM.***

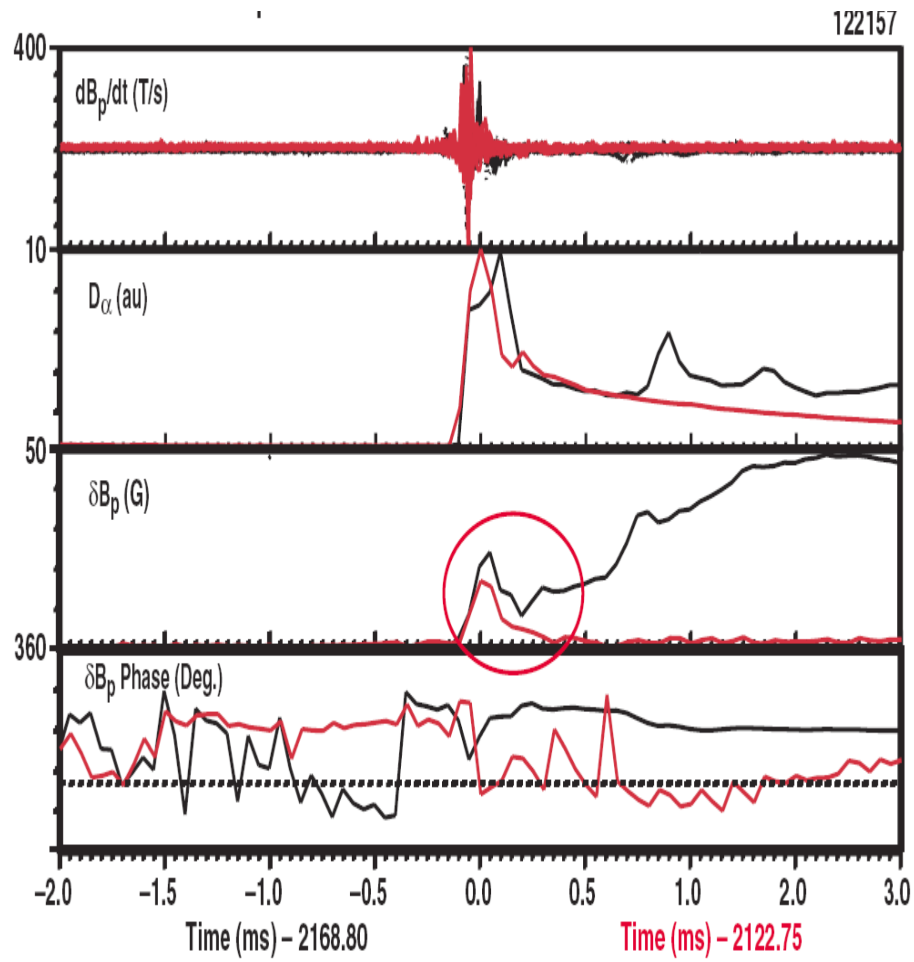
- **Experiments**
  - ***Phase dependency of externally stimulated n=1 pulses***

  ***'Stronger' plasma response occurs at a certain toroidal location than at any other toroidal location.***

  - ***Phase dependency of ELM-driven RWM***
  - ***Impacts of ELM-driven toroidal mode spectra***
- **Caveats**
- **Conclusion**

# Rotationally stabilized plasmas do not guarantee RWM-free operation.

- **Rotational stabilization might not be robust, in that any non-axisymmetric disturbance could trigger RWM.**
  - ***Is ITER safe against RWM if the rotation is well above the rotational threshold?***
  - ***Maybe not, because a zero frequency MHD activity (e.g. ELMs) may trigger RWM even in rotationally stabilized plasmas[1].***
- **According to a zero-dimensional model[2], a disturbance threshold exists in order to explain certain ELM-driven RWMs.**

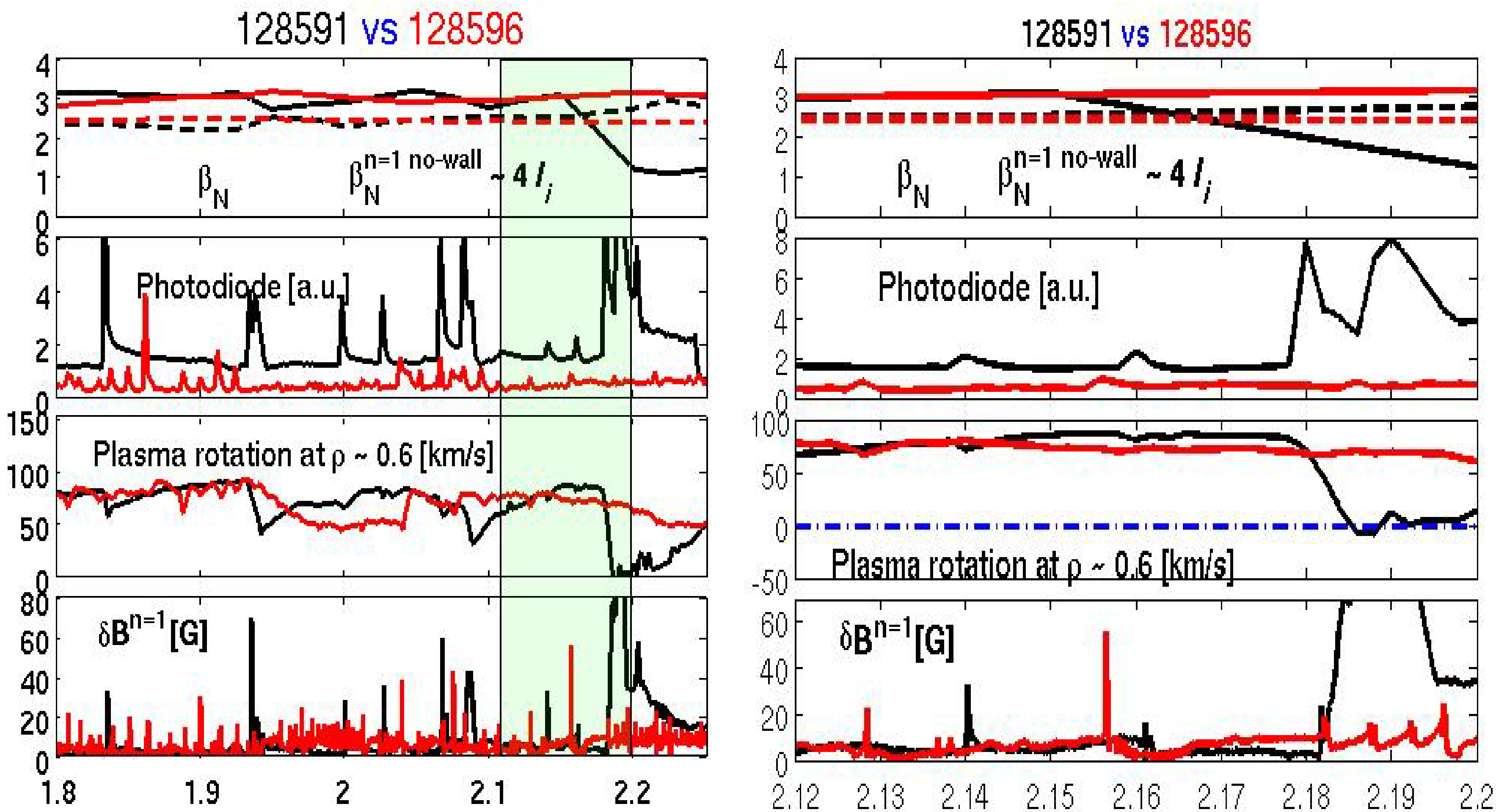



***[From Strait et al, APS-DPP (2005)]***

[1]. *Garofalo et al., NF (2007)*

[2]. *Strait, IT-4 Mtg in DIII-D (2007)*

# In ELM-driven RWM, big *n*=1 mode amplitudes alone may not be a sufficient condition to lead to RWM.




**The interaction of the ELM-driven *n* = 1 mode with weakly damped stable RWM needs to be understood in high torque plasmas.**

# The plasma responses during a toroidal sweep of *n*=1 pulse would reveal any toroidal phase dependency.

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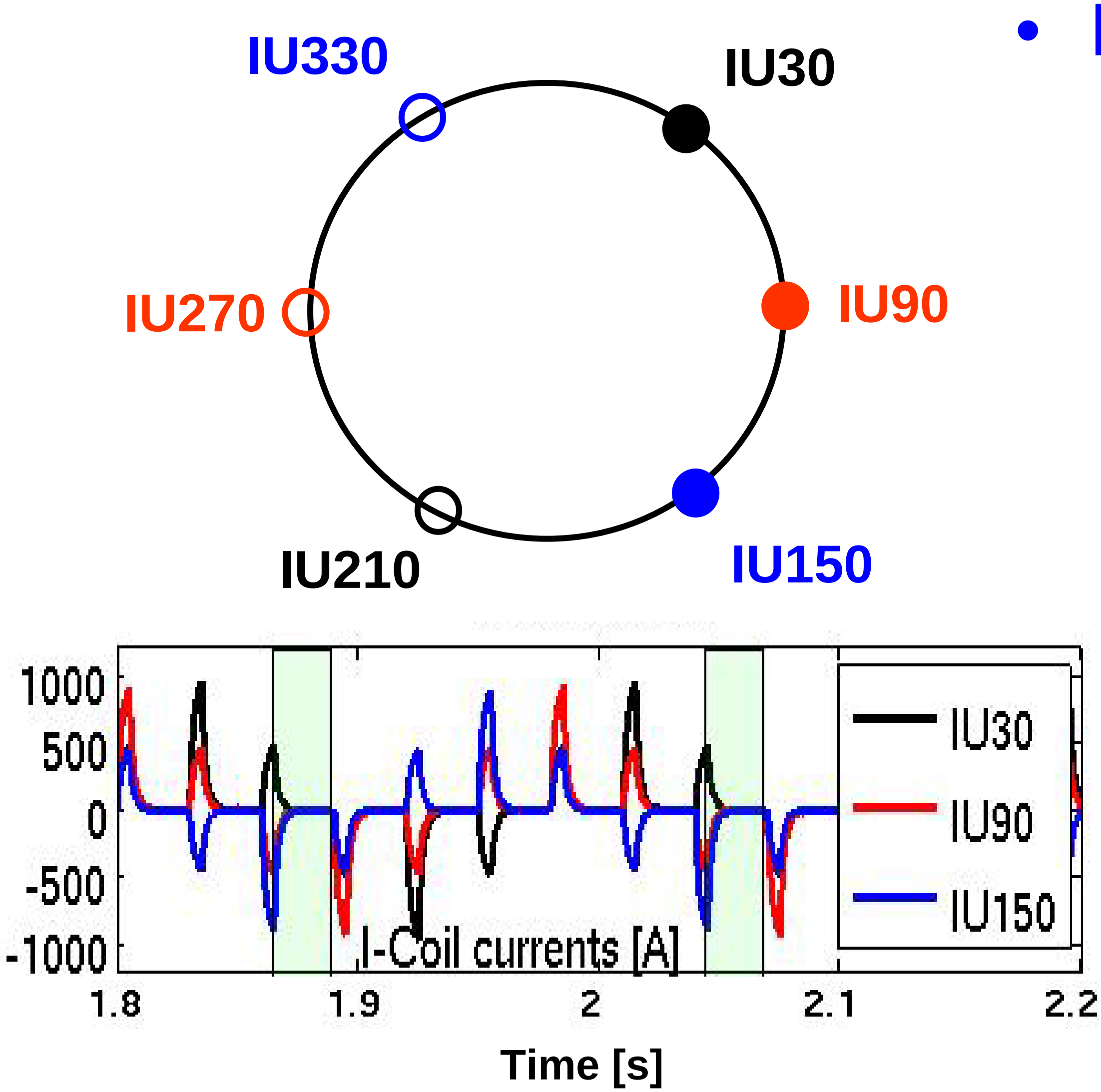
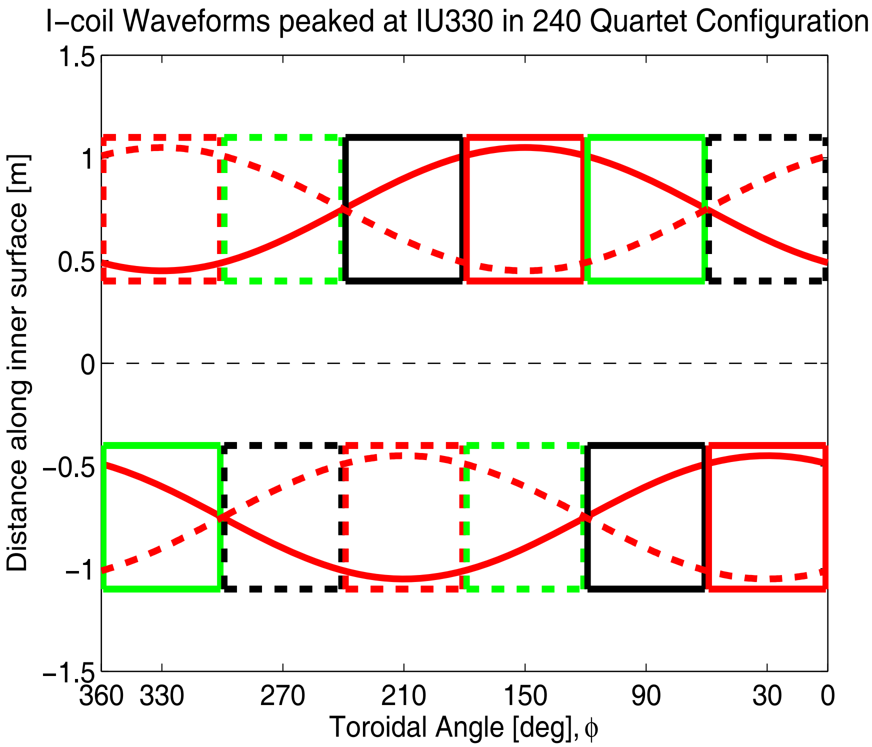
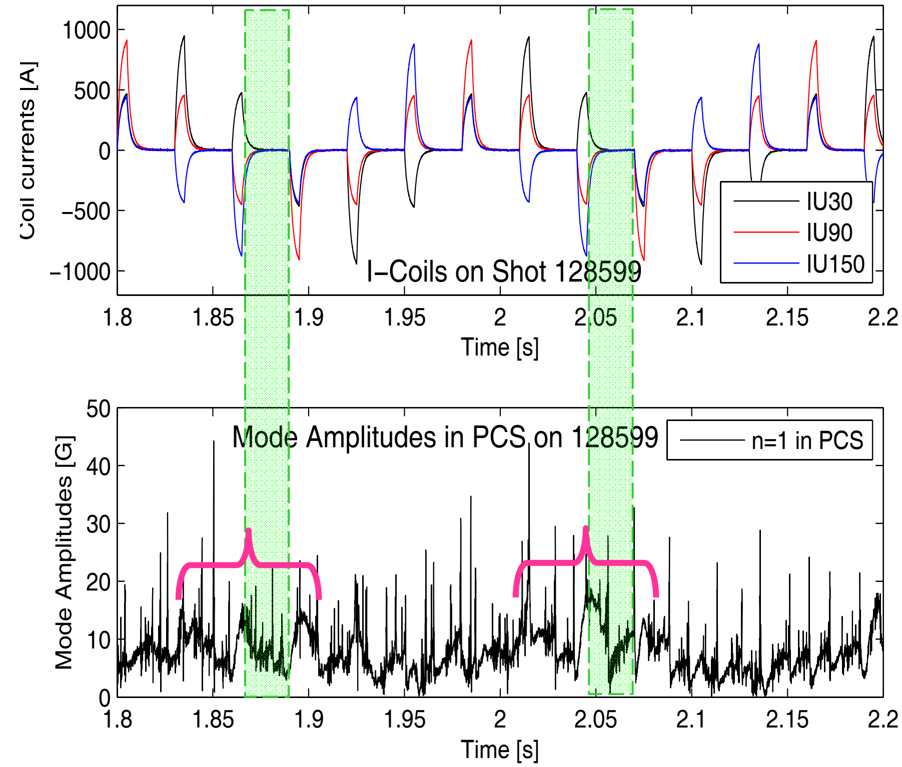



- **Hypothesis**
  - *ELM-driven RWM might be due to stronger plasma response at a certain toroidal location than in any other location.*
  - *If so, the toroidal sweep of n=1 pulse may reveal the toroidal angle dependency of ELM-driven RWM.*
  - ***Criteria:***
    - **higher amplitude**
    - **slower damping**

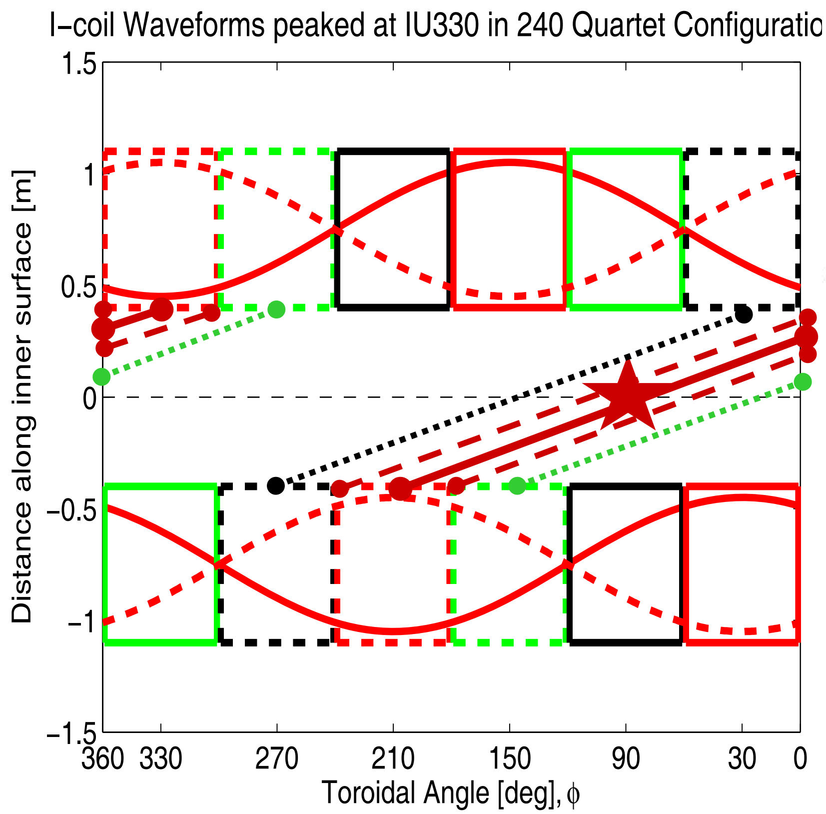
# Overall, stronger plasma responses are observed at half of the machine angle than at the other half.

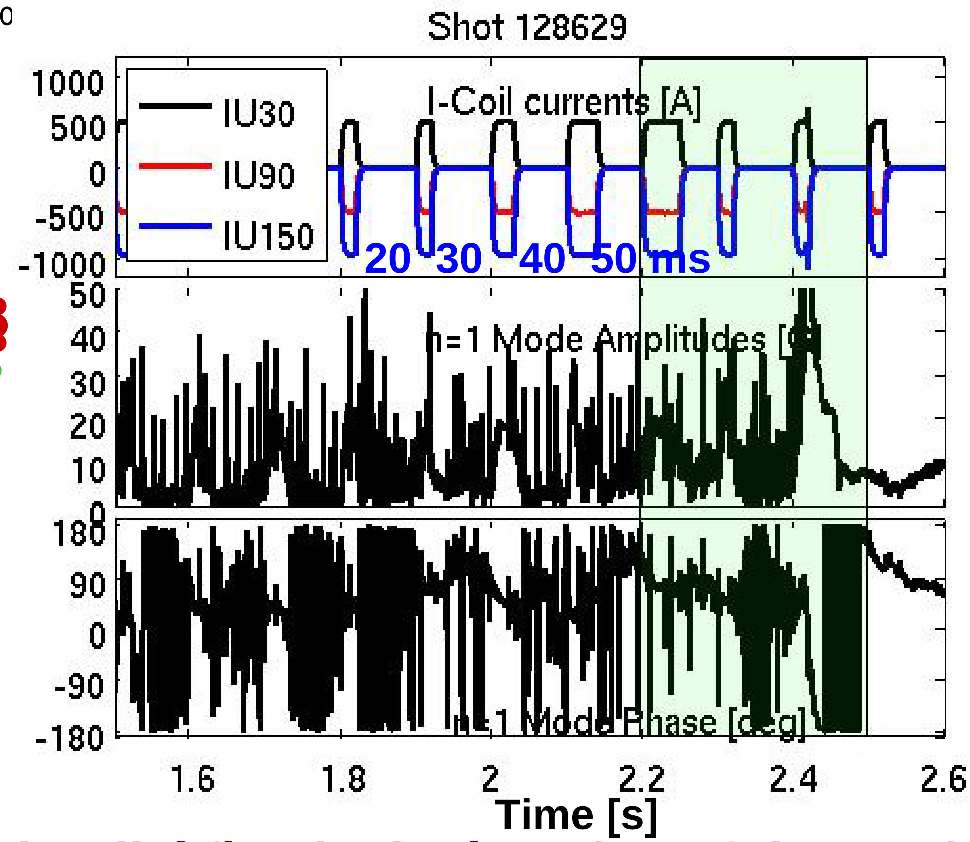



- **Arguably, the strongest plasma response was observed when IU330 was peaked.**

# ELM-driven *n*=1 field may trigger RWM more readily near 90 degree than at any other toroidal angle.

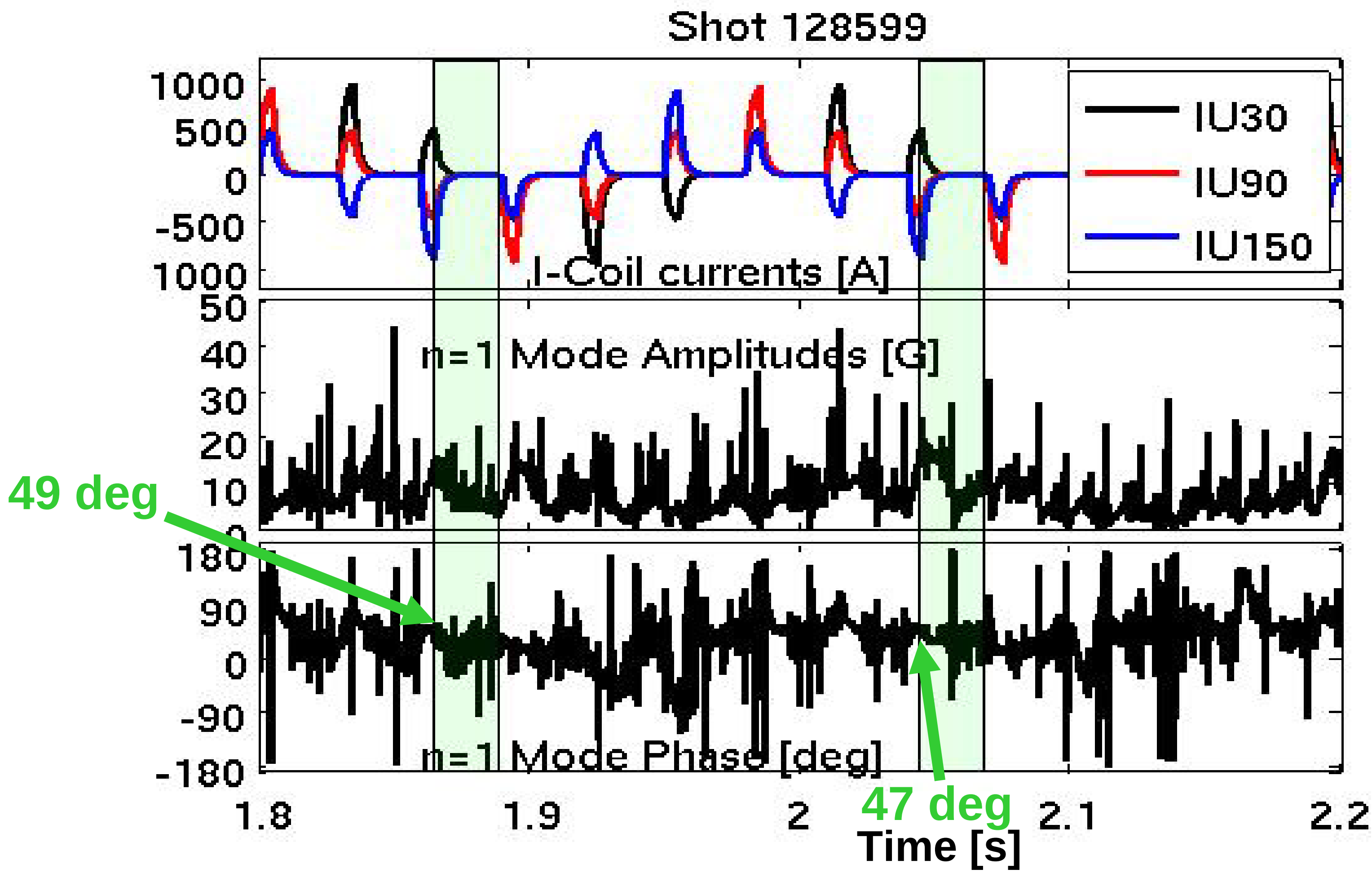



- Assuming that a peaked outward radial flux is the location of the mode, the preferred toroidal angle for ELM-driven RWM can be expected to show similar plasma response.

- Pulse durations may not change RFA, nor damping rate.

# Plasma response to each pulse would result from all the *n* =1 fields, as well as the applied field.




**Although the applied field is configured at 90 degree, the observed phase was toroidally shifted to ~ 50 degree.**

# A preferred toroidal angle would reside in a quadrant of the machine angle, showing a tendency to induce ELM-driven RWM.

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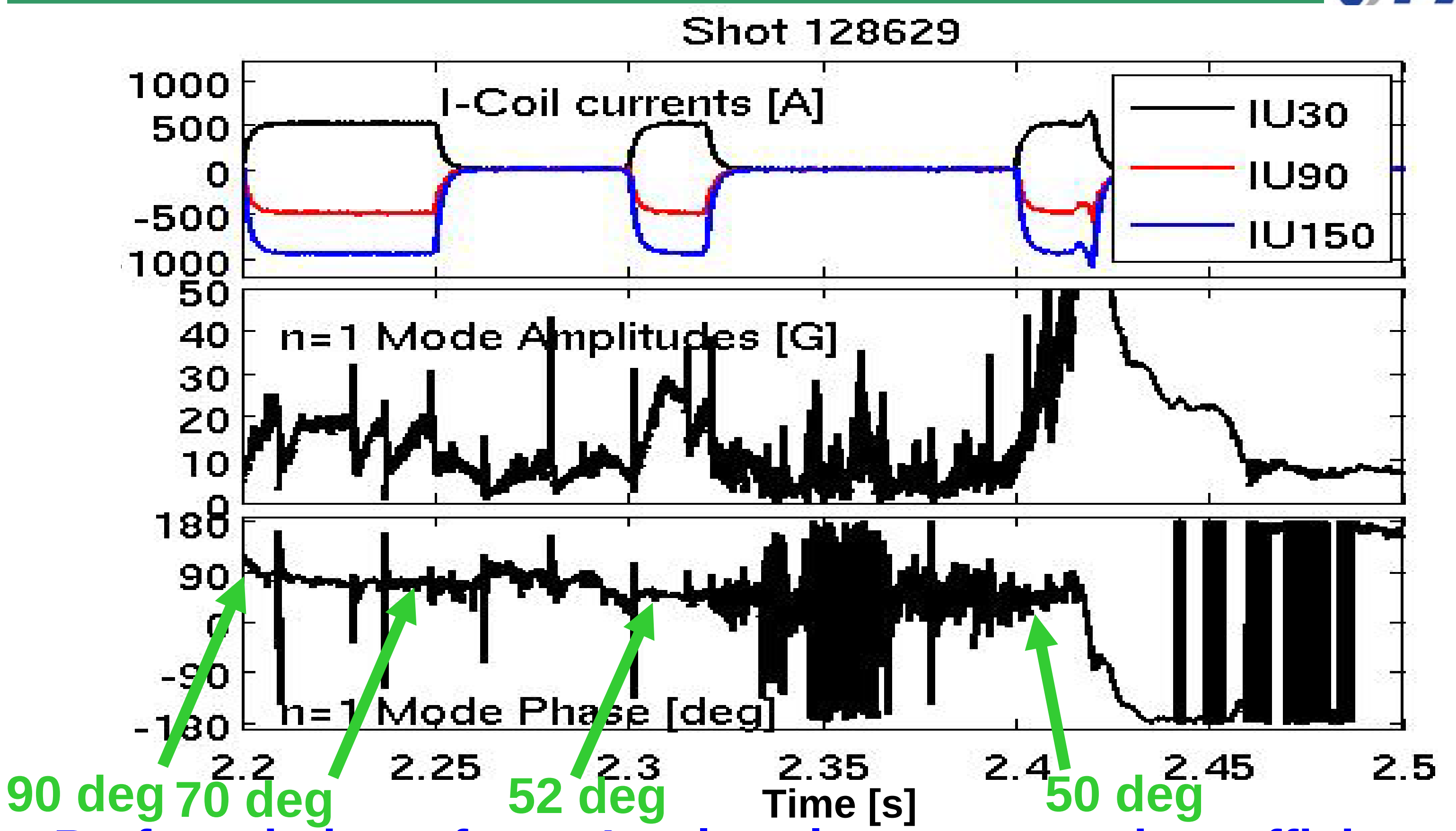
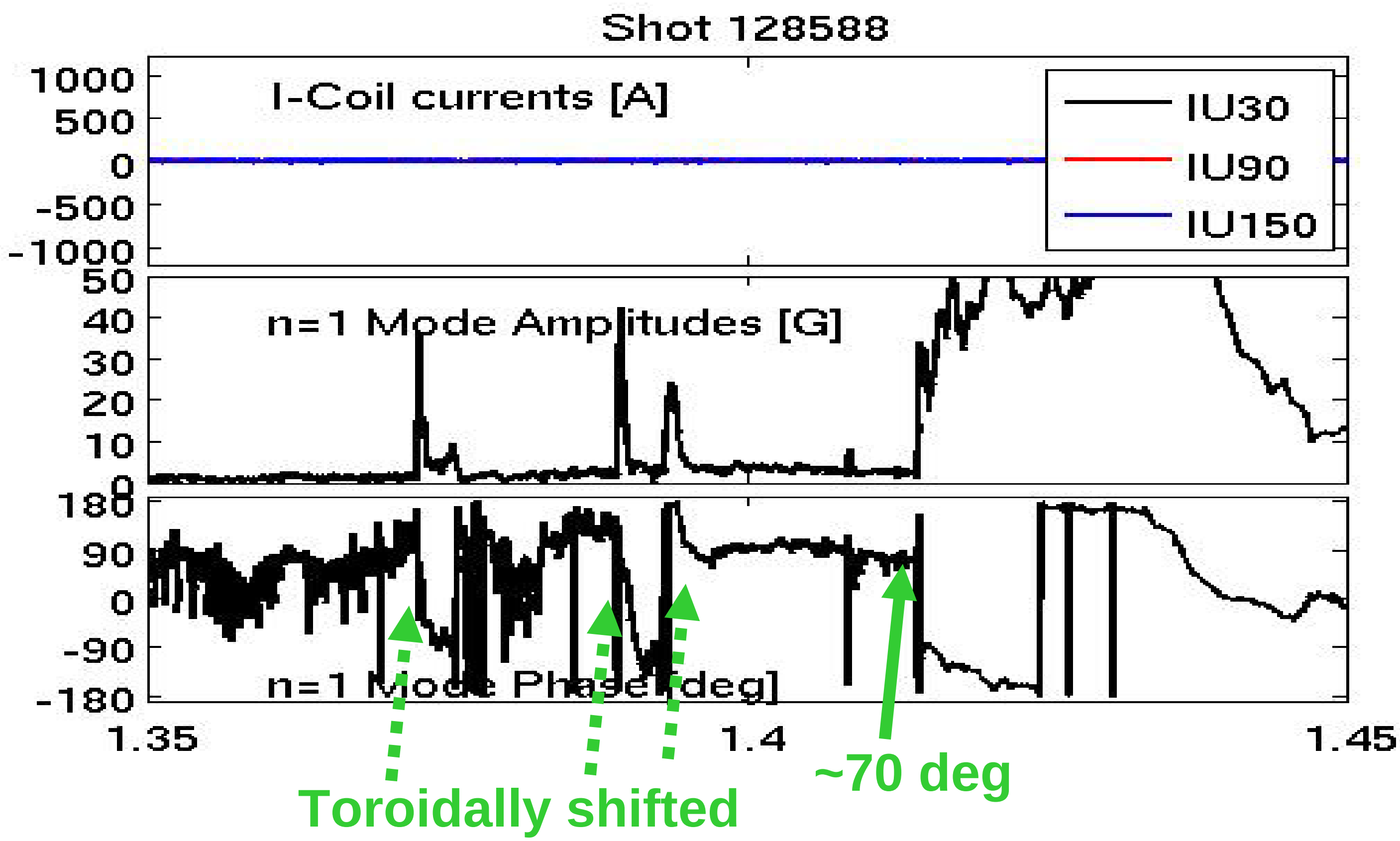


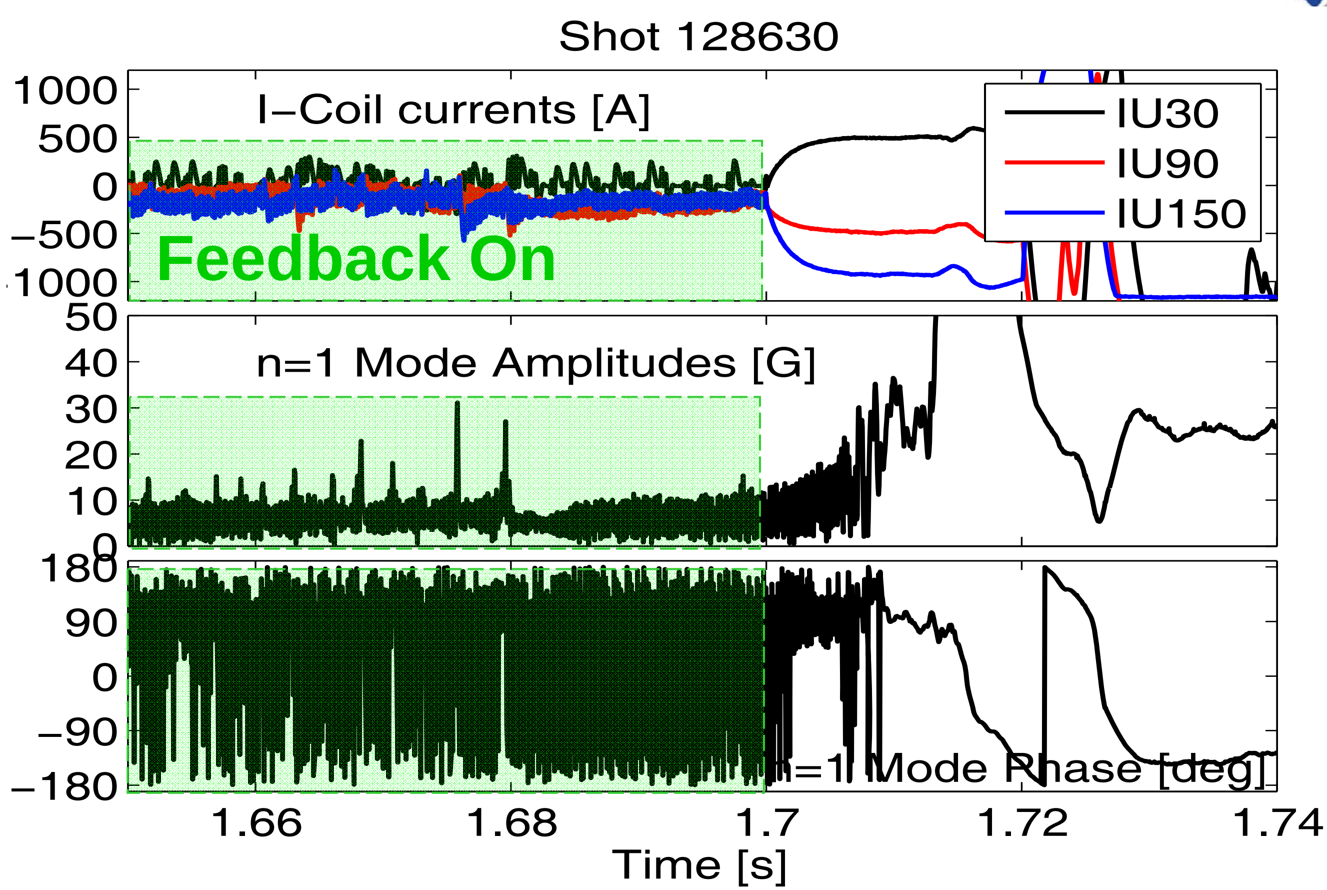

- **Preferred phase for *n*=1 pulse alone may not be sufficient to result in RWM, either.**
- **Then, combination of amplitude and phase (e.g. near-static but slowly rotating) OR something else (e.g. non-rigidity, evolving damping process) ?**

# The plasma response of ELM-driven *n*=1 mode is similar to that of the externally stimulated *n*=1 pulse.



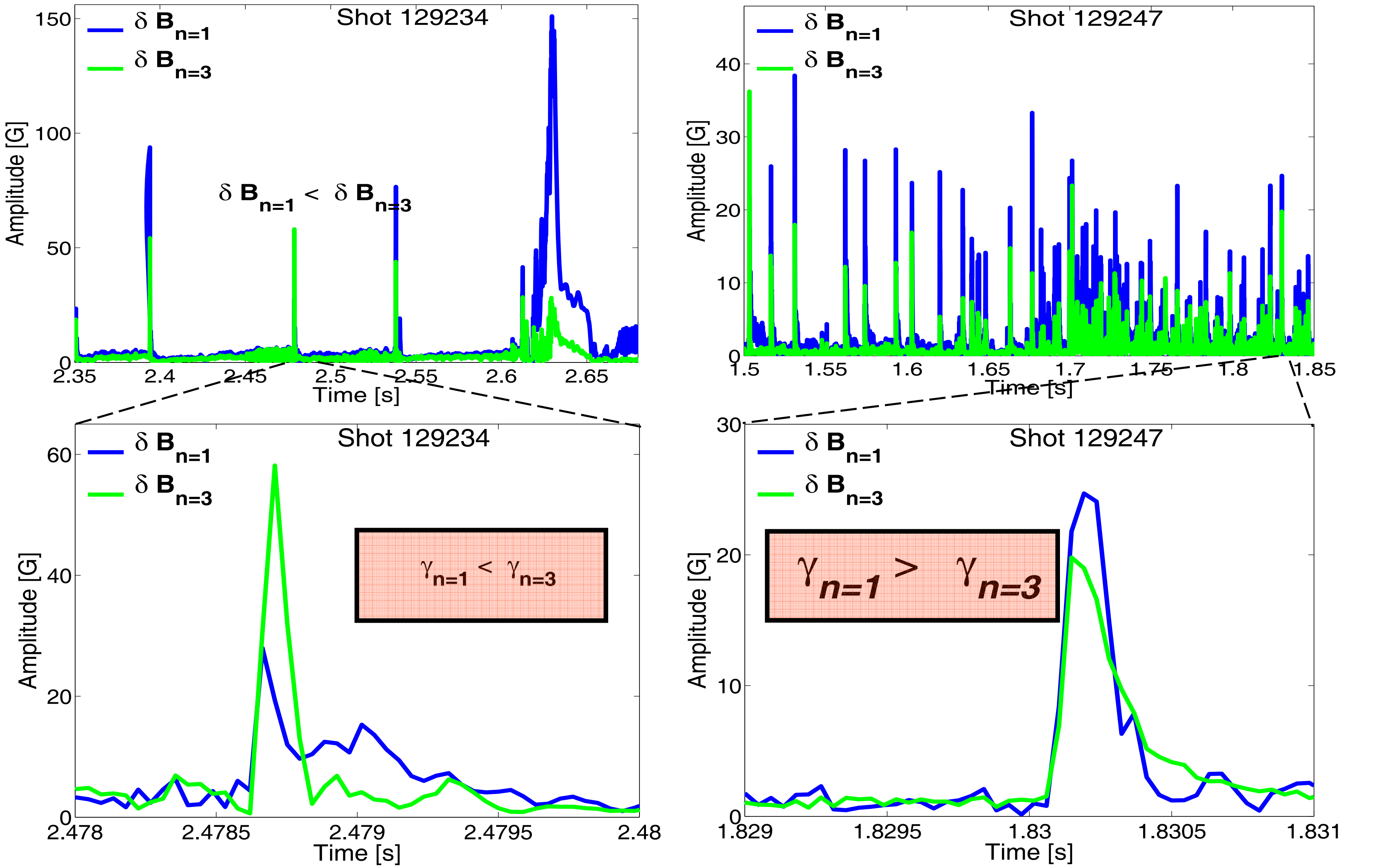

**While the ELM-driven *n* = 1 mode is usually accompanied by toroidal phase shifts, the measured phase of ELM-driven RWM shows a tendency to reside in a quadrant of the machine angle.**

# Active feedback control prevents the ELM-driven n=1 field from interacting with weakly damped stable RWM.




**Without active feedback, the RFA occurs first, leading to RWM.**

# ELM-driven toroidal mode spectra show that significant *n* > 1 components are present, as well as *n*=1 fields.



# Caveats

- **Externally stimulated n=1 pulses cannot reproduce the same toroidal mode spectra as ELM drives.**
  - ***L/R time of externally driven n=1 current vs natural ELM***
  - ***Typically, the multiple low-n modes, including n=1 mode, are almost always observed, when ELMs occur in high beta plasmas.***
- **Any intrinsic or externally overdriven/underdriven non-axisymmetric fields can pose a potential threat to interact with weakly damped stable RWM, being amplified and causing unstable RWM.**
  - ***With active feedback on, the damping rates of the n=1 fields can be reduced down to sub-milliseconds.***
- **Impacts of ELM-driven toroidal mode spectra on error fields, toroidal rotation, and multiple RWM need to be assessed.**

# Conclusions

- **Even in high rotation plasmas, any non-axisymmetric disturbance could trigger RWM, which might be due to the interaction of the disturbance with weakly damped stable RWM.**
- **In ELM-driven RWM,**

  ***big n=1 mode amplitudes alone may not be a sufficient condition to lead to RWM.***
- **ELM-driven RWM shows a toroidal phase dependency, where the interaction of non-axisymmetric mode with wall stabilized mode appears to readily occur.**
- **Active feedback control prevents the ELM-driven n=1 field from interacting with weakly damped stable RWM.**