Issues of RWM stabilization at low rotation in DIIID and JT60U

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JAEA

PPPL PRINCETON PLASMA PHYSICS LABORATORY

332-08/MO/rs

RWM at low rotation plasmas

- DIII-D /JT60U demonstrated the existence of RWM stable regime in low rotation in IAEA FEC 2006

  - Challenge to theoretical understanding;
    Concept of a critical rotation

- Assessment of RWM stability near critical rotation has been explored (IAEA FEC 2008):

  - DIII-D - ECCD-NTM suppression (IAEA 2008 EX-P9-5)

  - JT60U - Scanning rotation by NBI combination (IAEA 2008 - EX_5-2)

Recent Results (IAEA 2008)

- **Mode at low rotation at the beta collapse**

  (DIII-D) non-rotating mode is likely NTM
  (JT60U) RWM (External kink)without magnetic island

- **Energetic particles destabilize the RWM**

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  (JT60U) Energetic particle wall mode (EWM)

--> Common Observations and Differences

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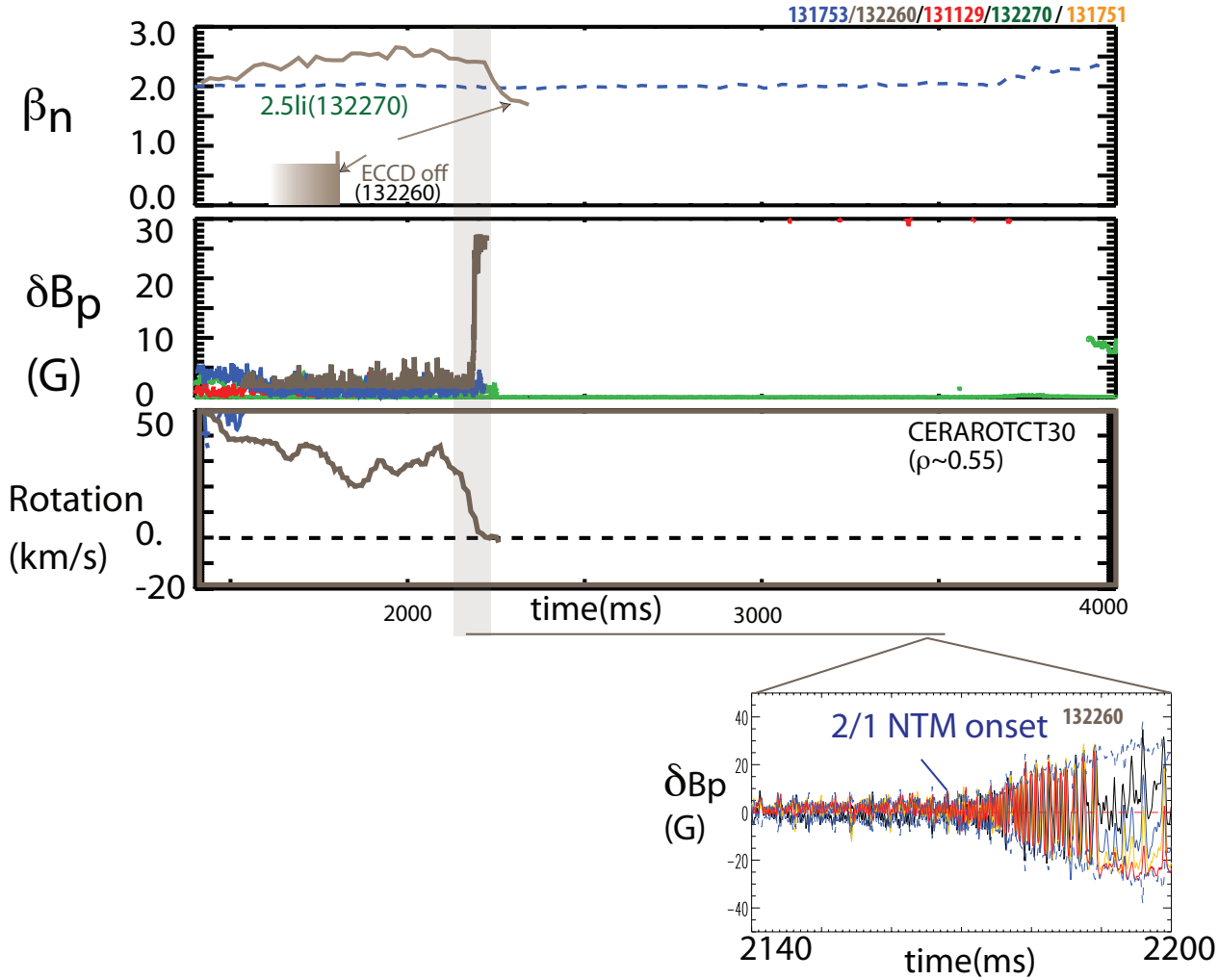
Recent ECCD-NTM Suppression Experiment is Useful to Identify n=1 Global MHD above No-wall Limit



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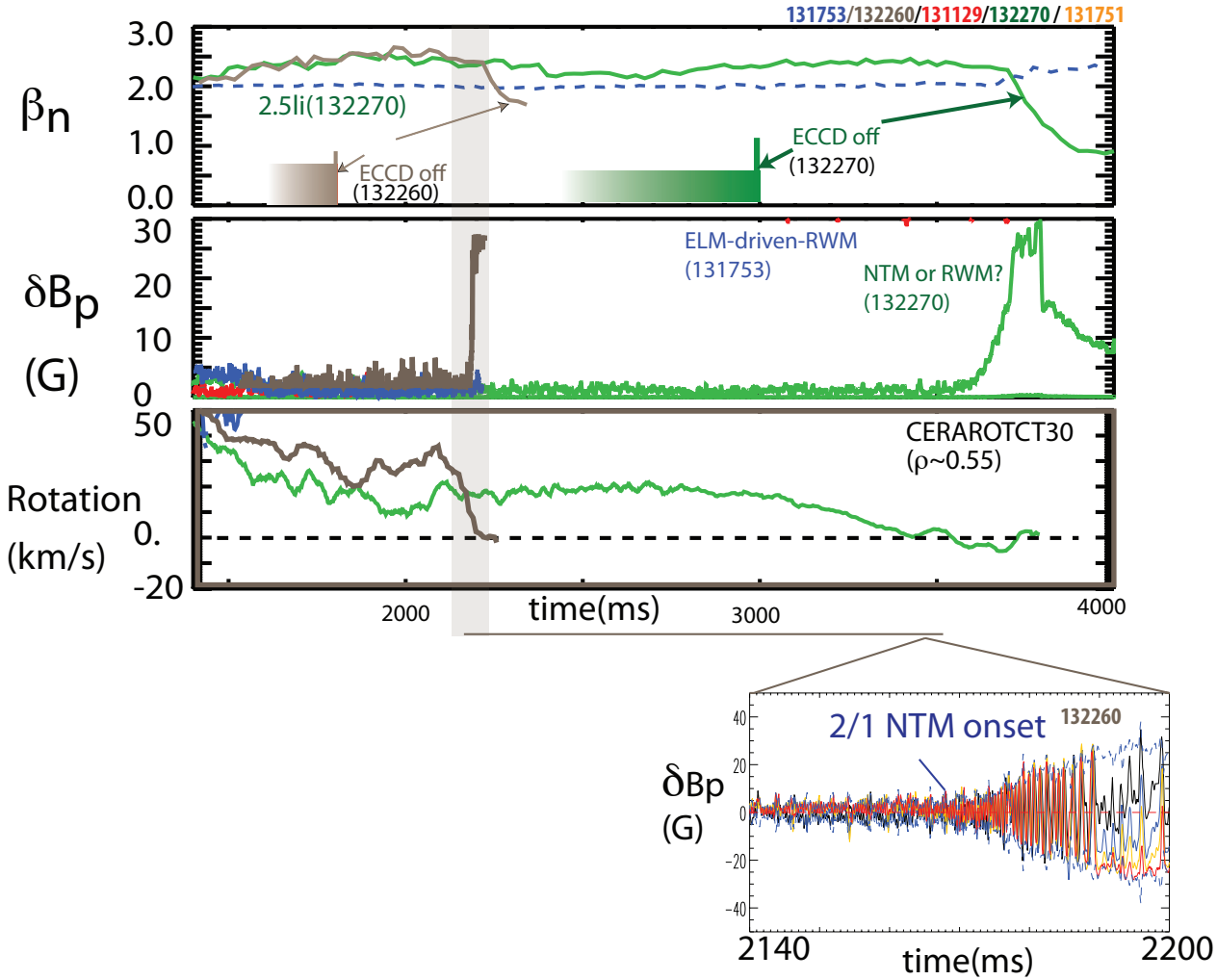

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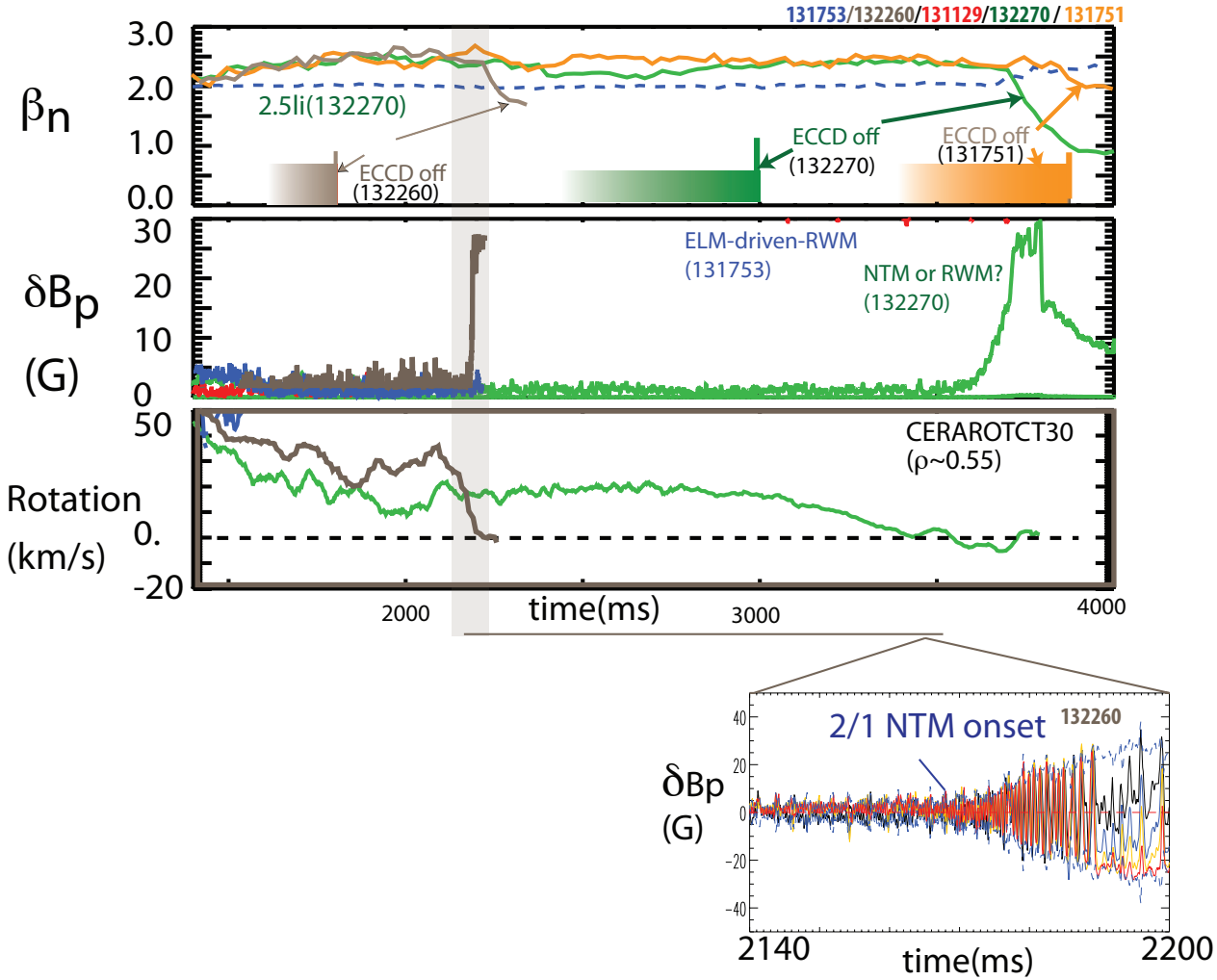

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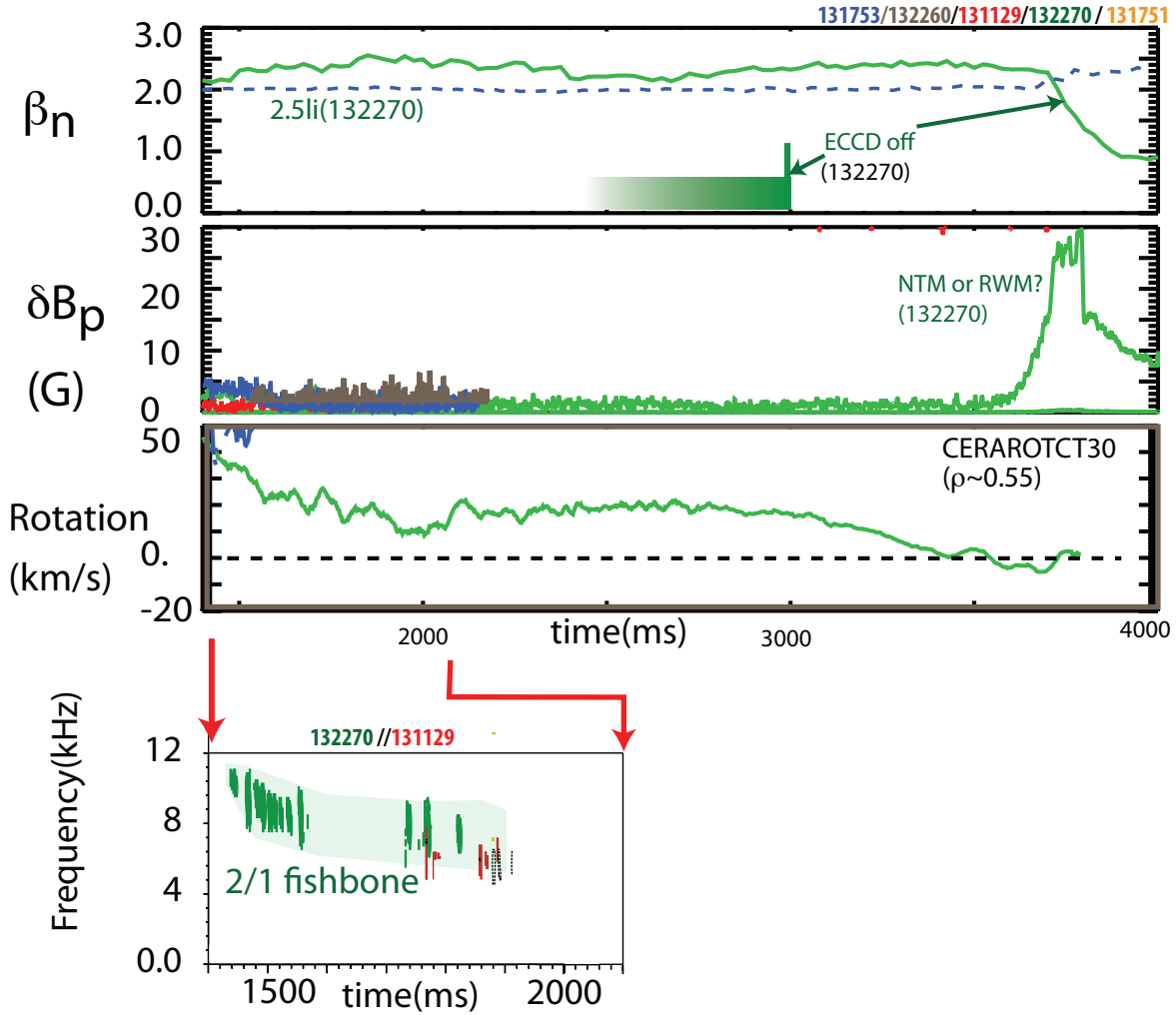

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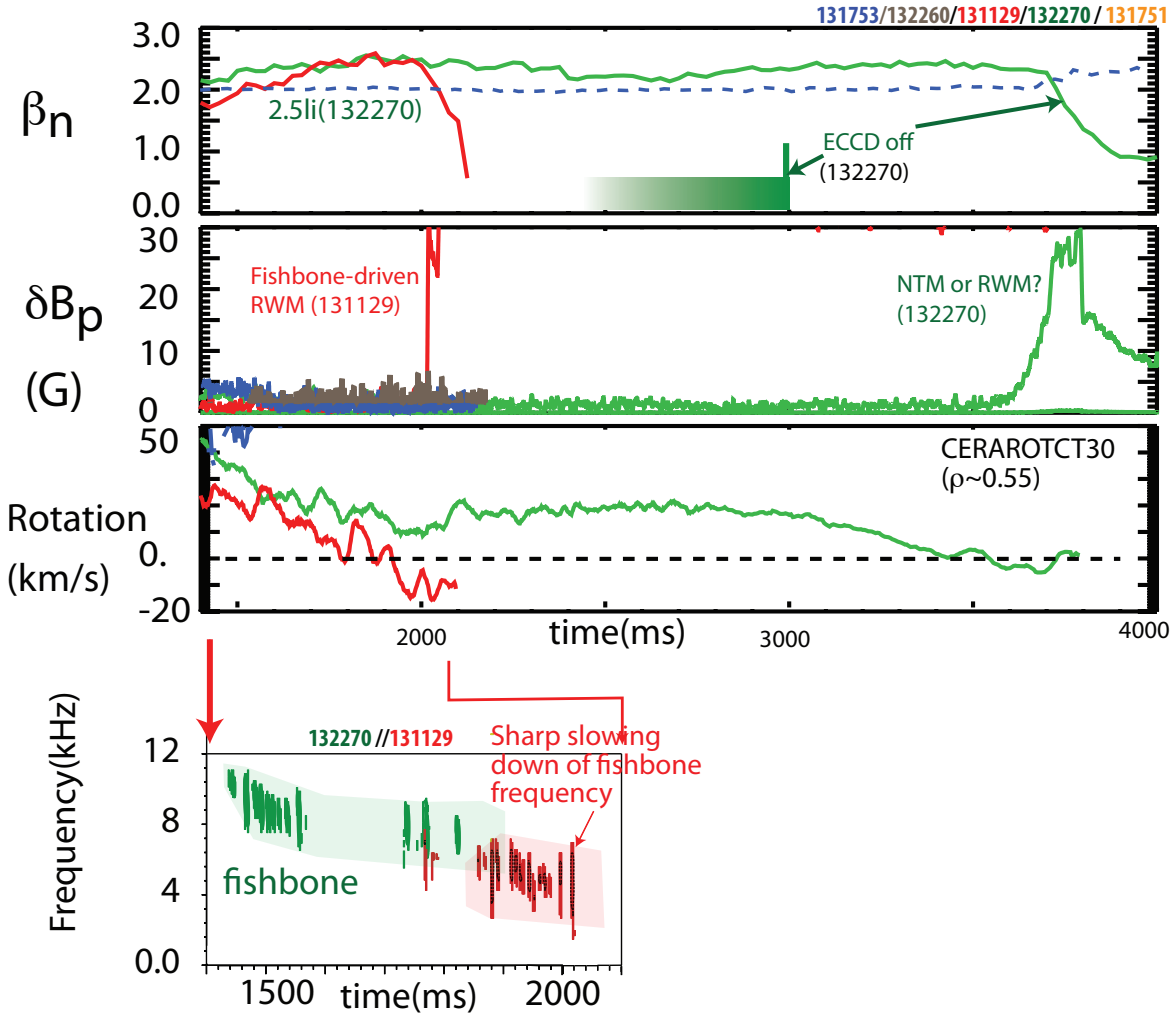

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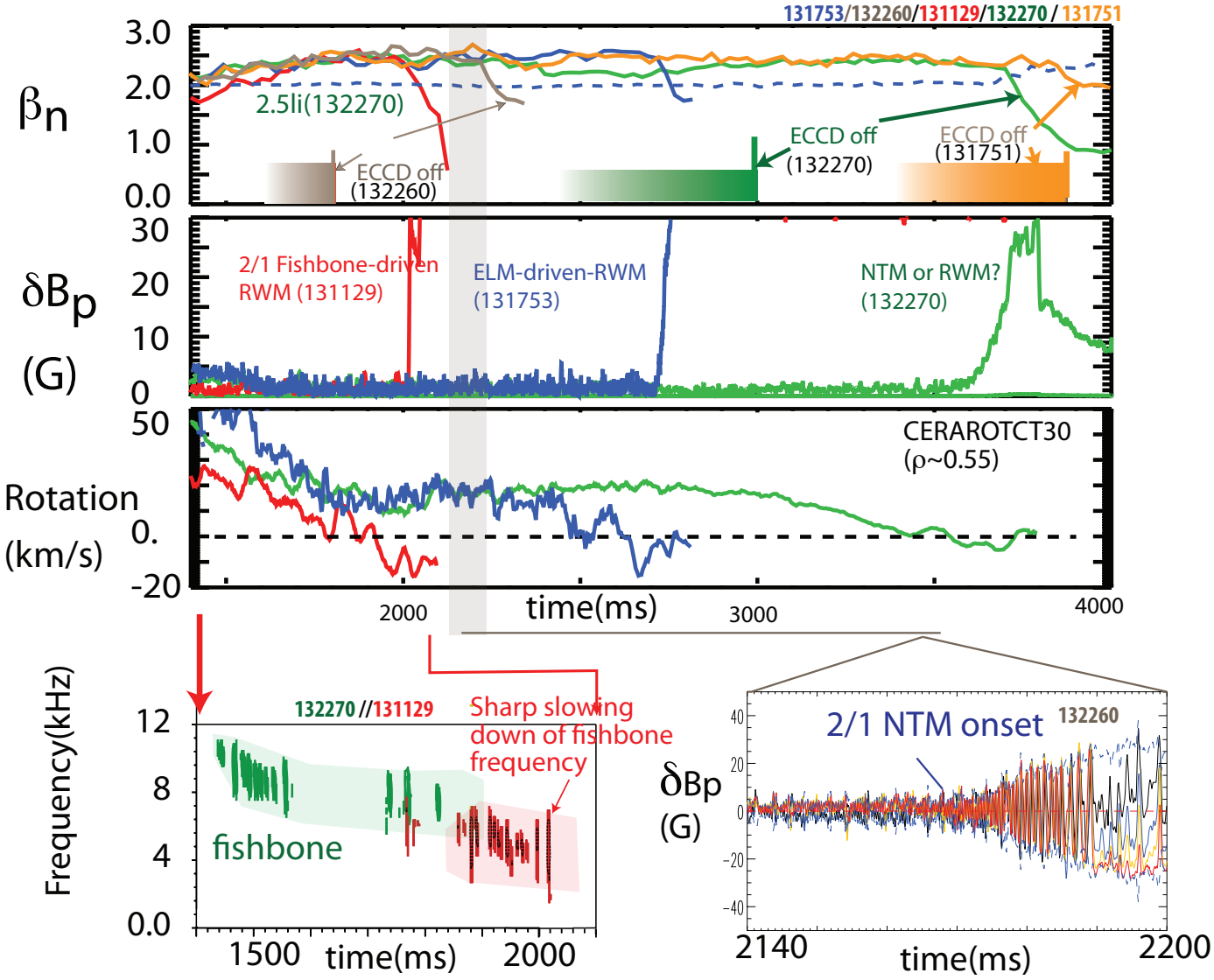

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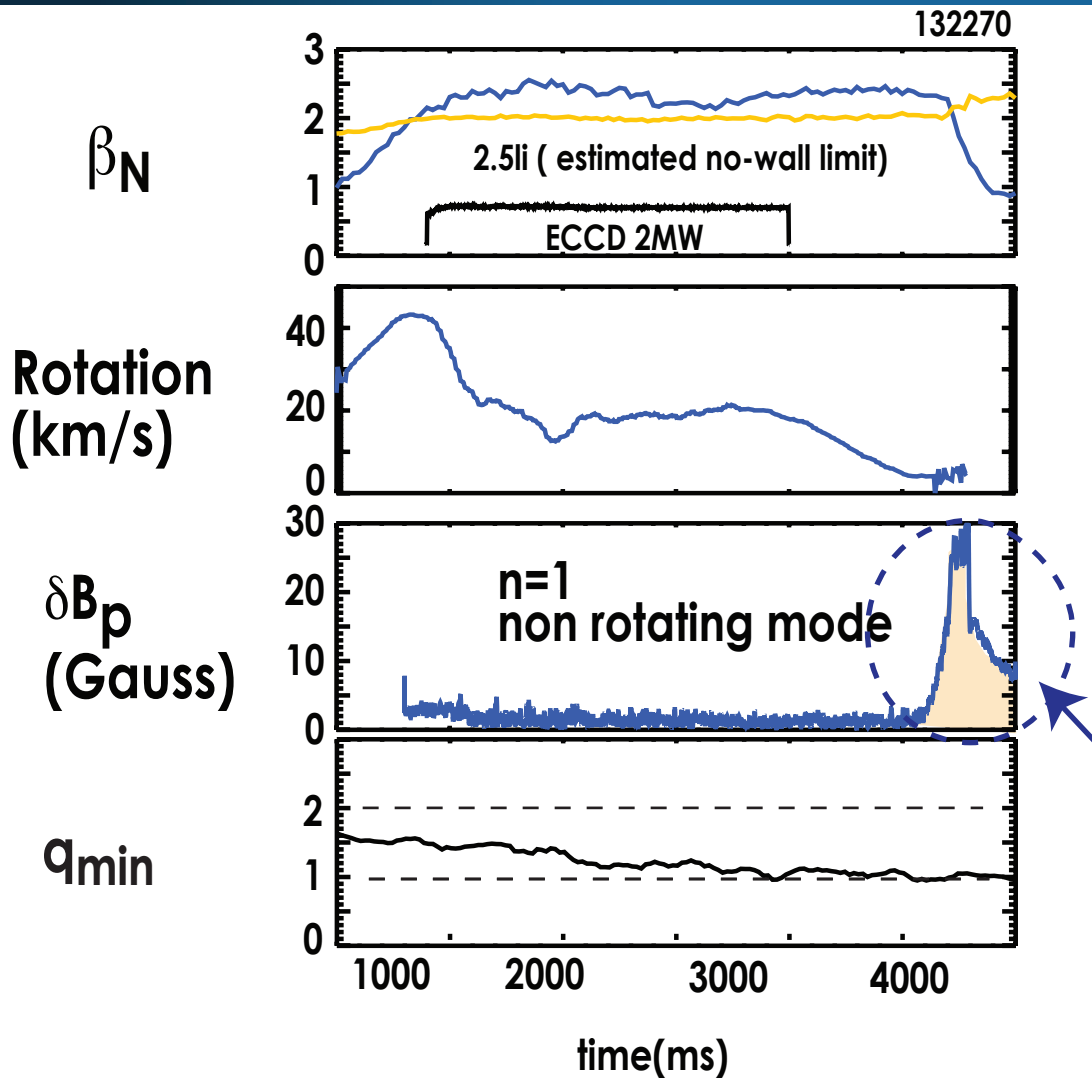
Long Duration RWM/NTM Free Operation at $\beta_N > \beta_{N.no\text{-}wall}$ Routinely Achievable with ECCD NTM Suppression at Low Rotation



- Possible NTM excitation at $\beta \sim \beta_{N.no\text{-}wall}$ complicates RWM

A question arises:
Is this non-rotating mode a NTM or RWM?

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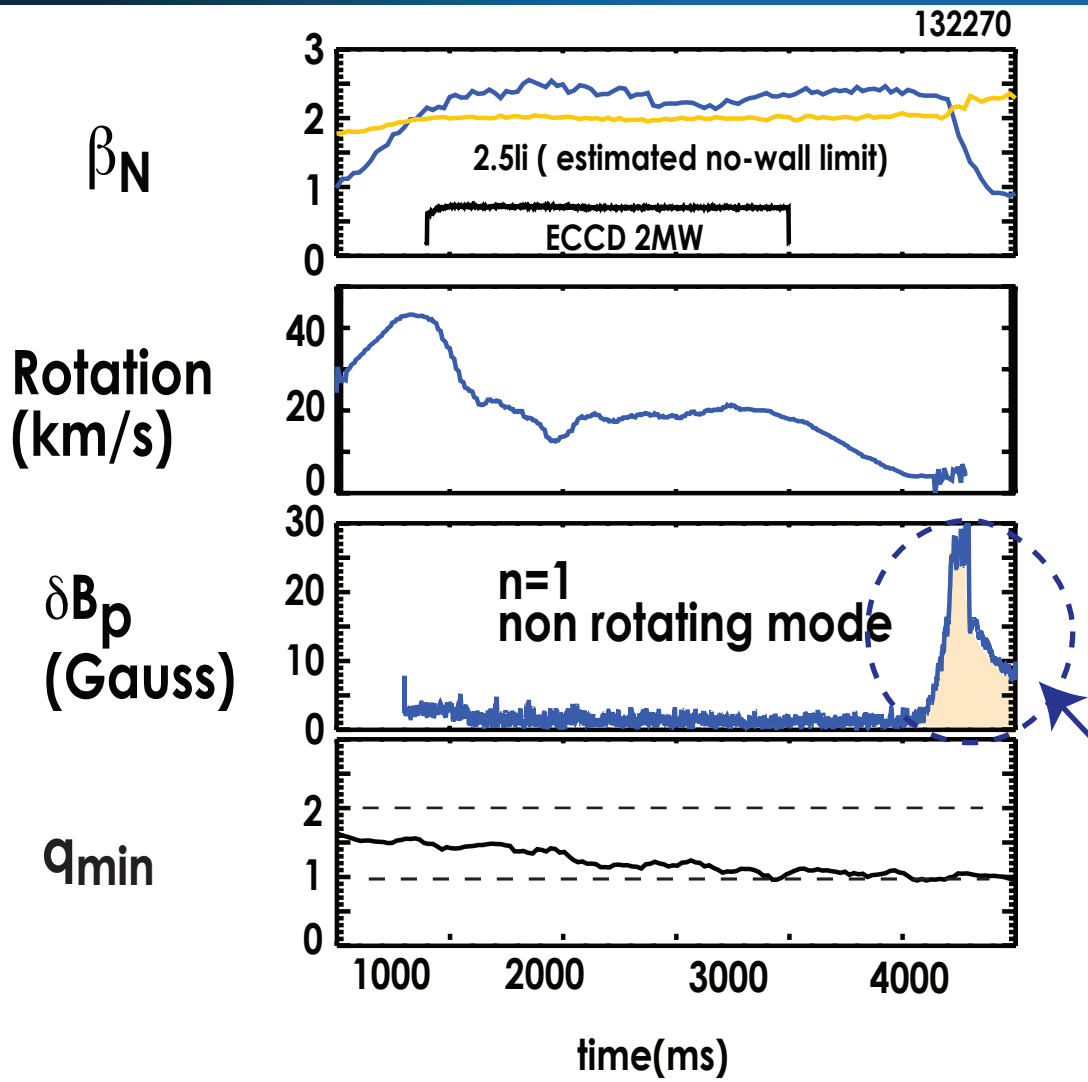


- **NTM excitation at $\beta \sim \beta_{N.no\text{-}wall}$ complicates RWM**

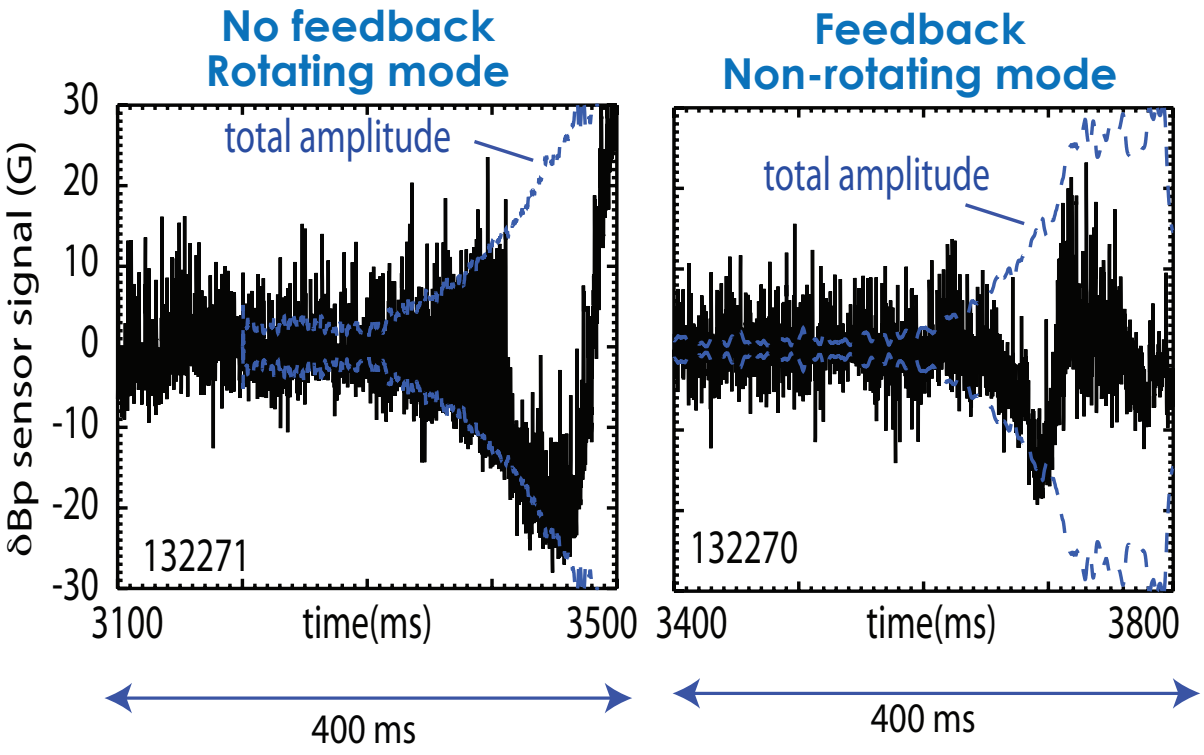
– NTM threshold was observed to depend on plasma rotation in DIII-D [R. Buttery, et al., Phys. Plasmas 15, 056115 (2008).]

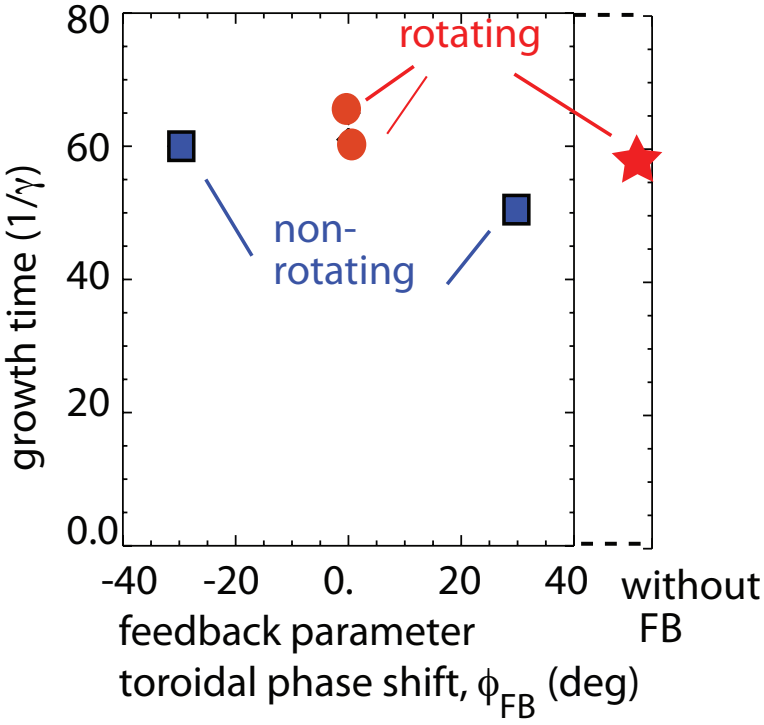
– Possible NTM excitation without seed magnetic island [D. Brennan et al.., Phys. Plasmas 9, 2998 (2002).]

A question arises:
Is this non-rotating mode a NTM or RWM?

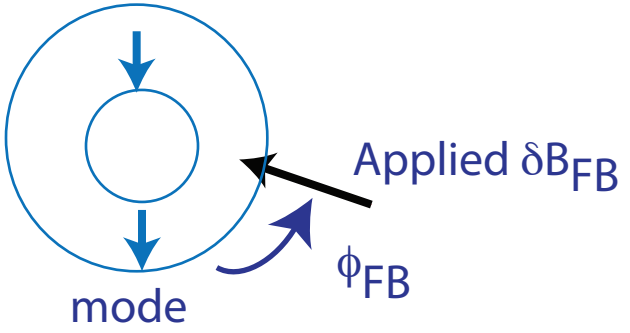
Insensitivity to Feedback Suggests N=1 Non-rotating Mode is NTM

- No Obvious Preference was Observed to Feedback Being on or off, Feedback Phase Shift

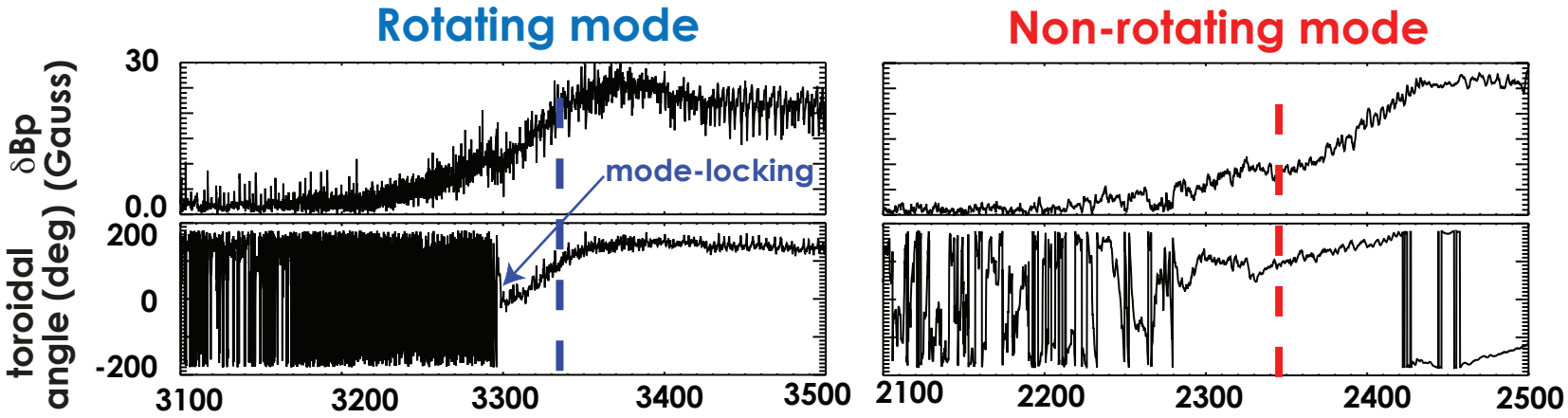




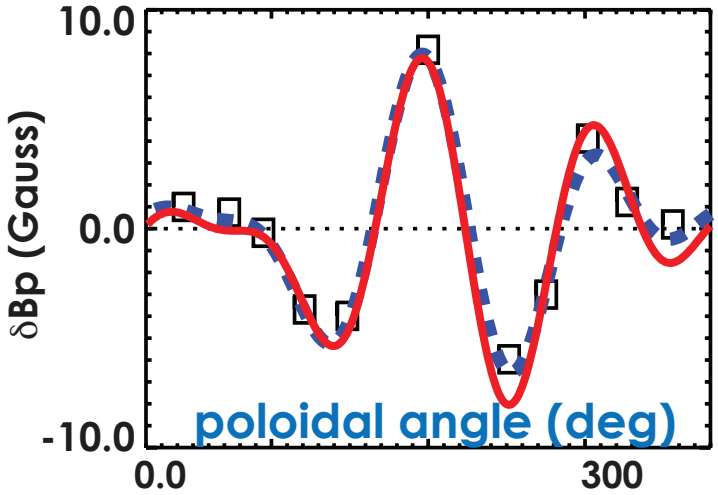
- ECCD was turned off at t=3000 ms

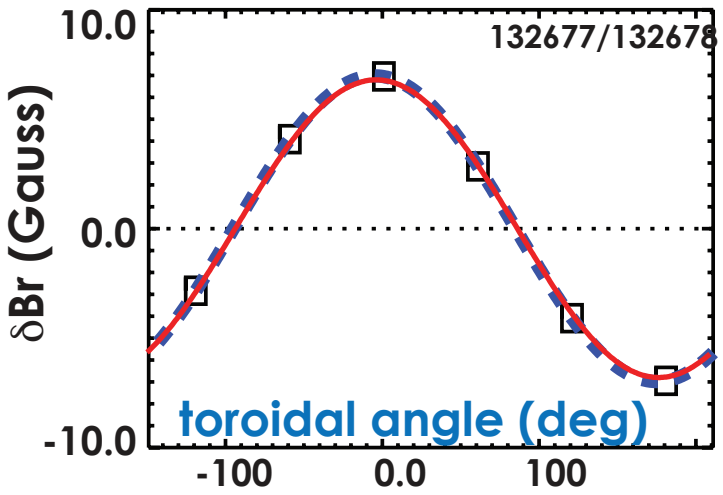


Sometimes Mode Rotates, However, Mode Structure of Rotating / Non-rotating Modes are Identical



Blue: rotating (after locking) / Red: non-rotating

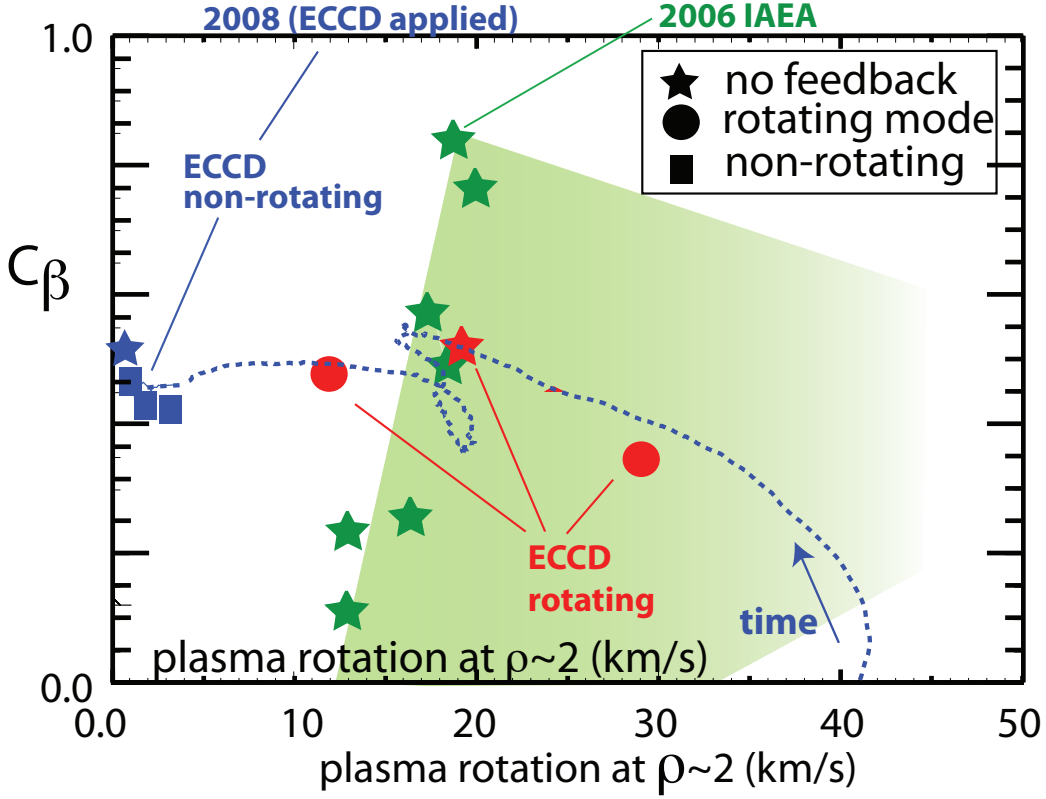


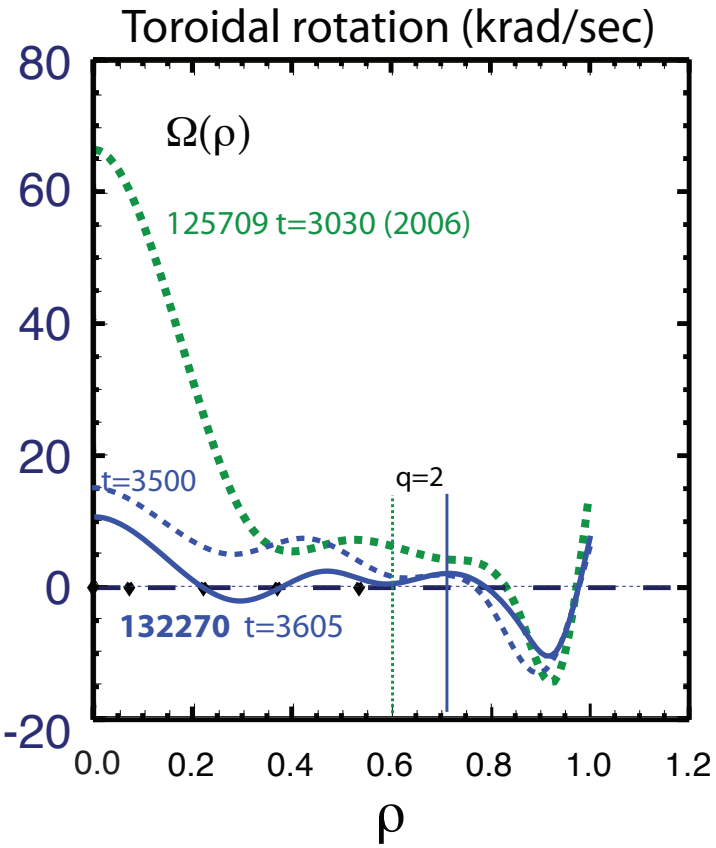


* magnitude of 132278 was normalized (by x 2.2)

Plasma Rotation below the Previously-Reported Rotation Threshold was Achieved with Pre-emptive ECCD-NTM Suppression

- Plasma rotation profile: ~ zero except near the edge
- Rotation at onset: below previously reported (Garofalo, IAEA FEC in 2006)
- Possible existence of RWM suppression mechanisms even when the plasma rotation is totally absent

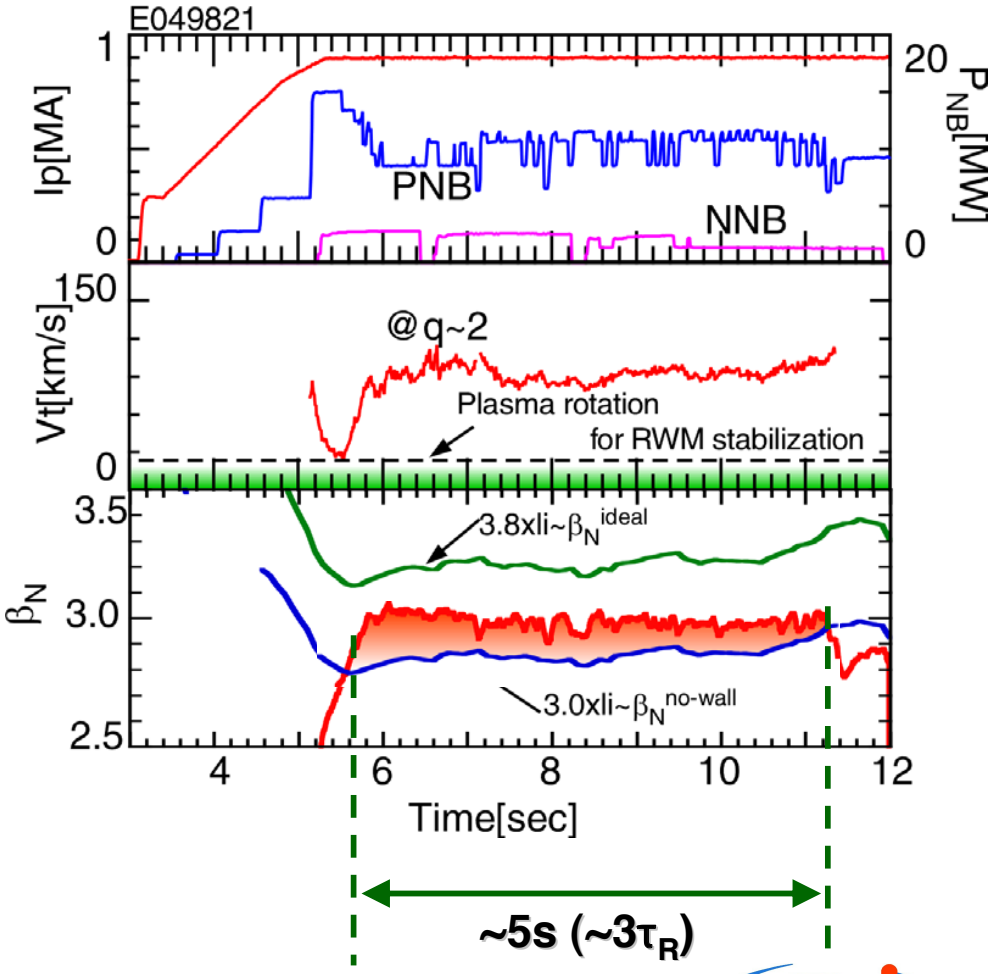




On the best discharge, the high-β_N was sustained for ~5s

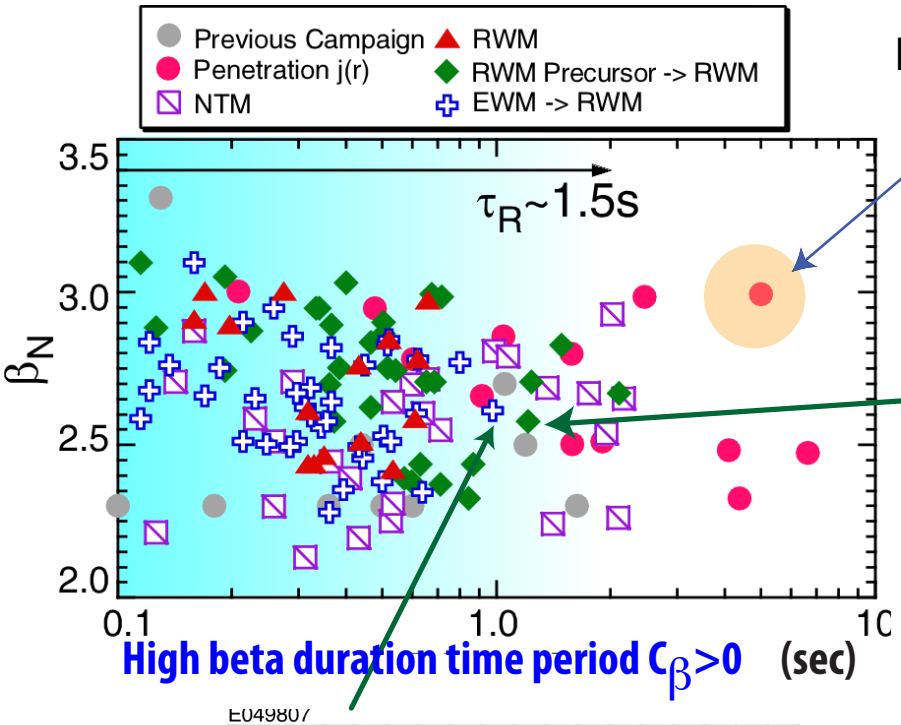
On the best discharge,

- β_N~3.0 (C_β~0.4) was sustained by plasma rotation > V_t^{cri}.
- Sustained duration is ~5s, which is ~3 time longer than τ_R.
- Time duration is determined by the increase of $\beta_N^{no\text{-}wall}$ due to gradual j(r) penetration.
- According to ACCOME, f_{CD}≥80% and f_{BS}~50% were also achieved.

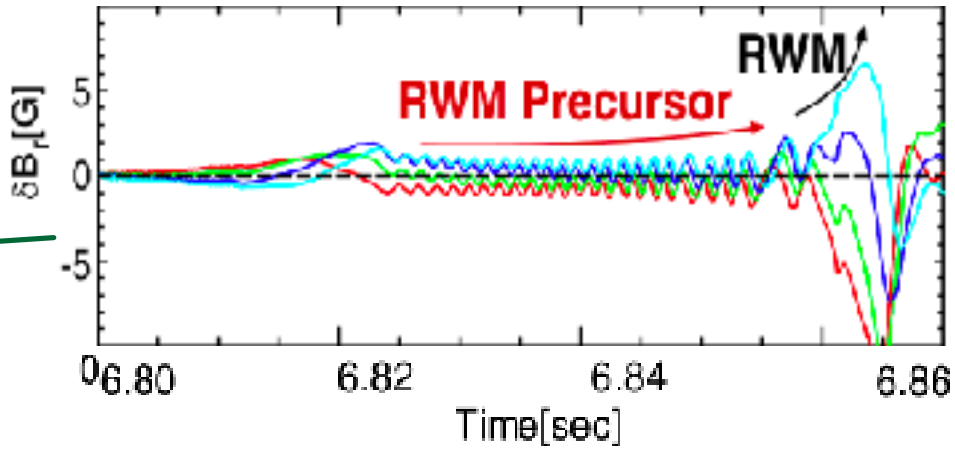


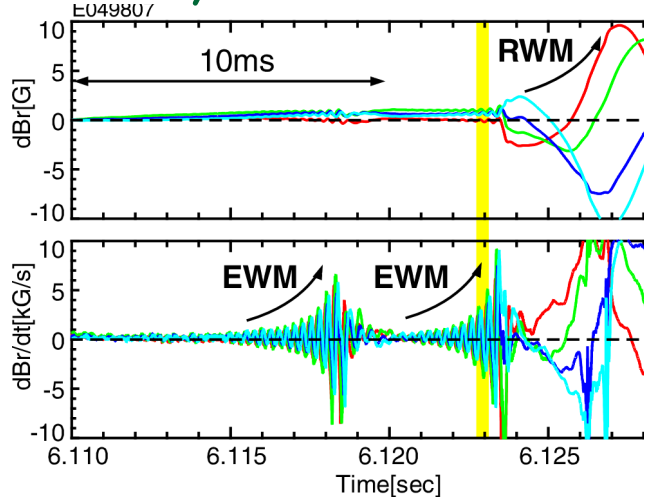
Dr. Matsunaga: from IAEA FEC 2008 EXP/5_2
"Dynamics and Stability of Resistive Wall Mode in the JT-60U High-βPlasmas"

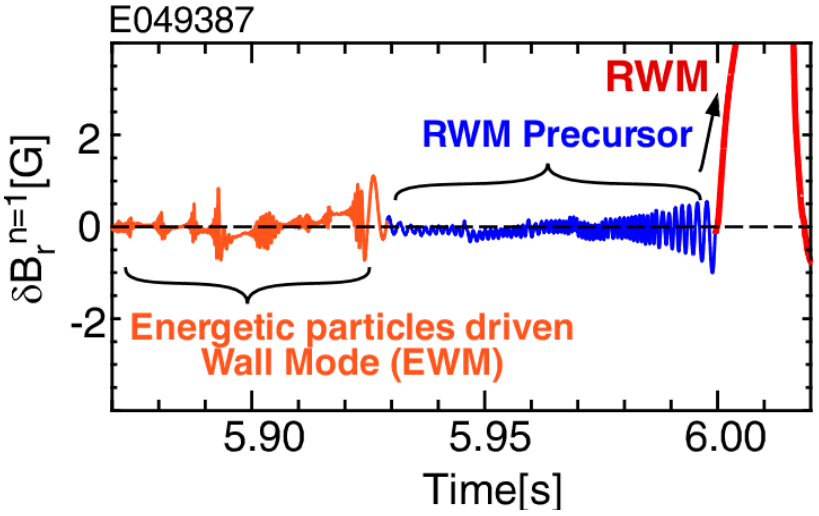
High Betan above No-wall Limit is not Automatically Guaranteed (G. Matsunaga IAEA FEC 2008 EXP_5_2)



Long Duration high betan above no-wall limit







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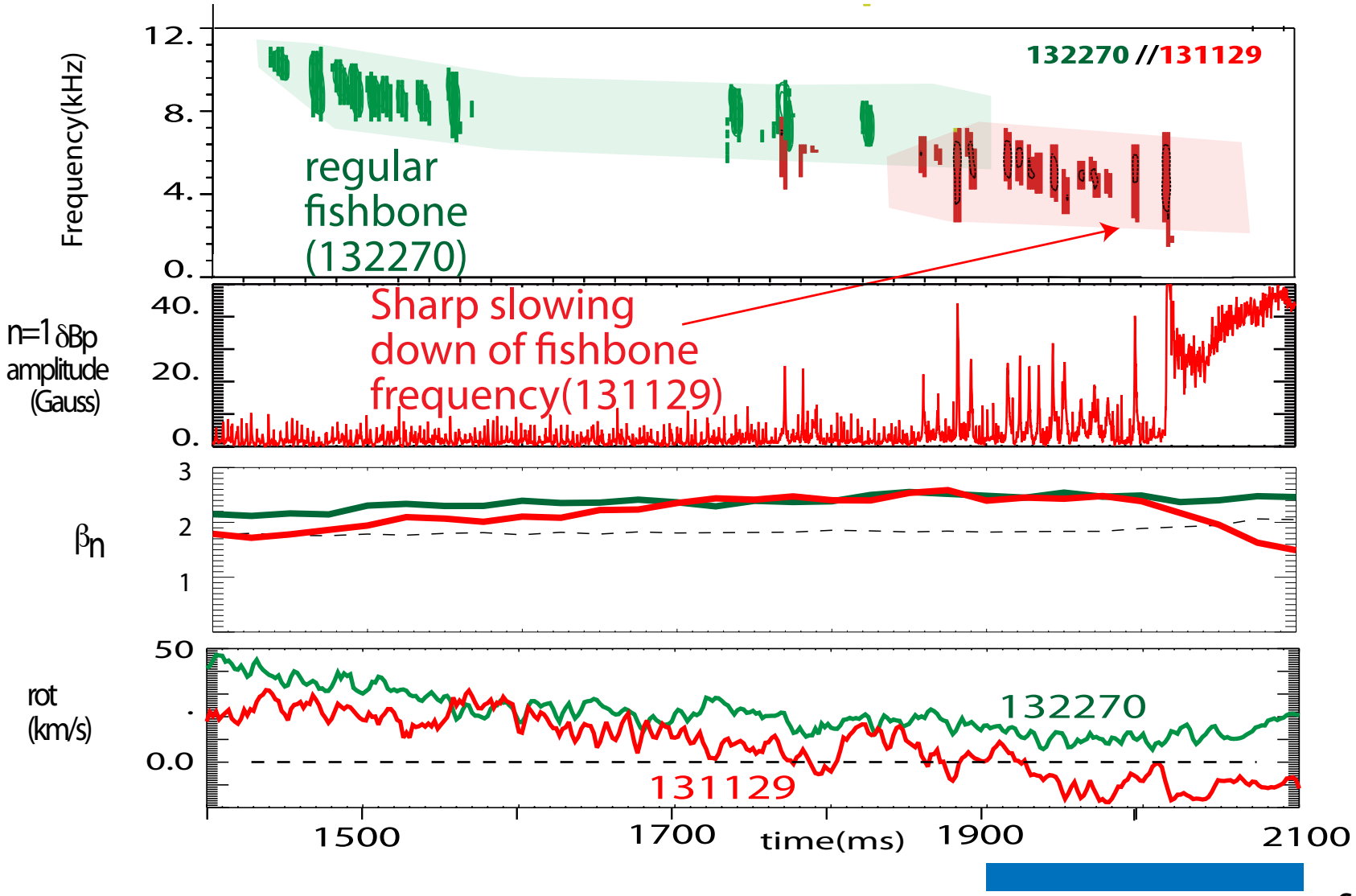
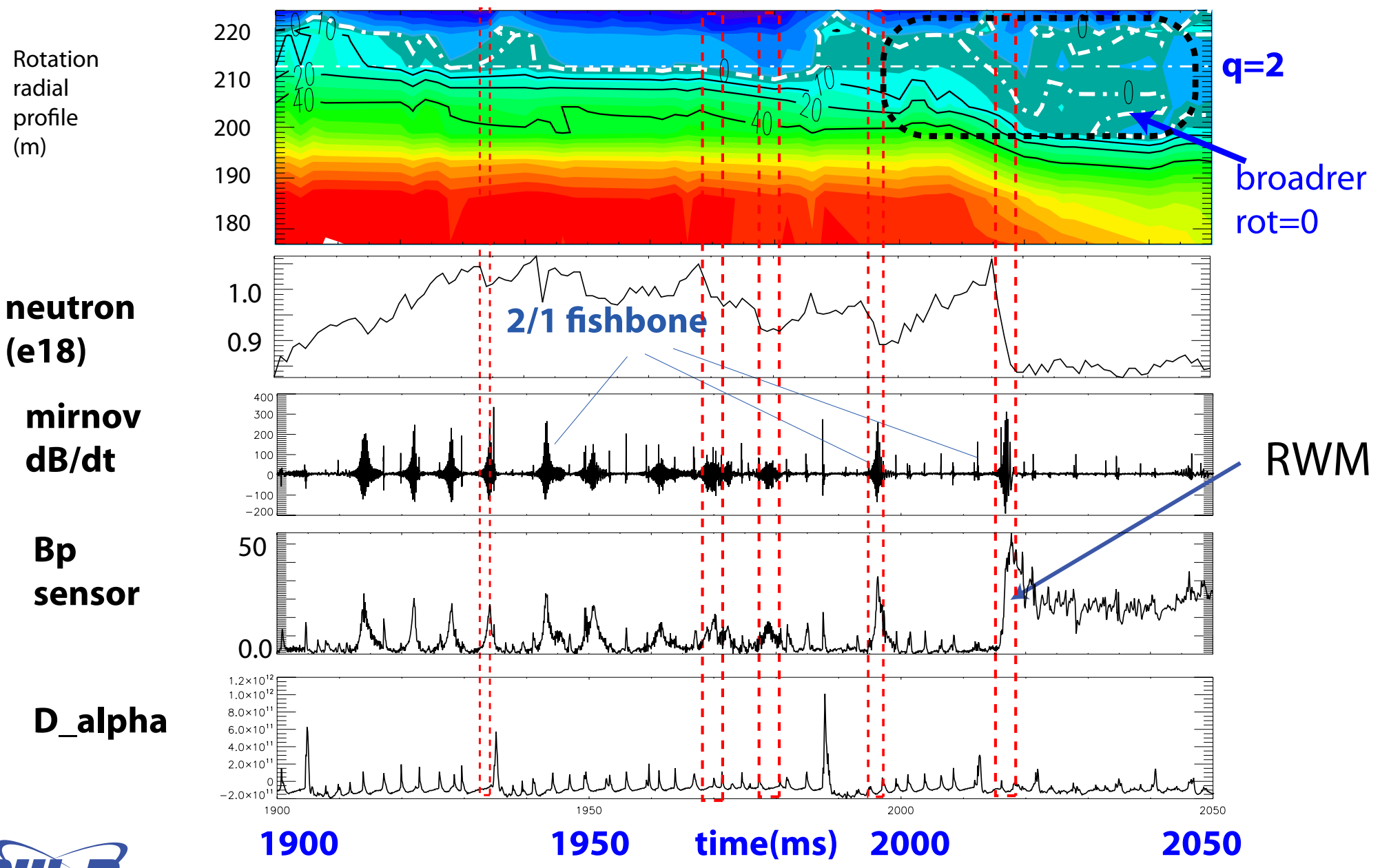
--> Common Observations and Differences

2/1 Fishbone at Near-zero Rotation Triggers RWM (~ 50 Gauss) Leading to beta-collapse



next figure

Increase of near-zero rotation domain near q=2 leads to onset of RWM



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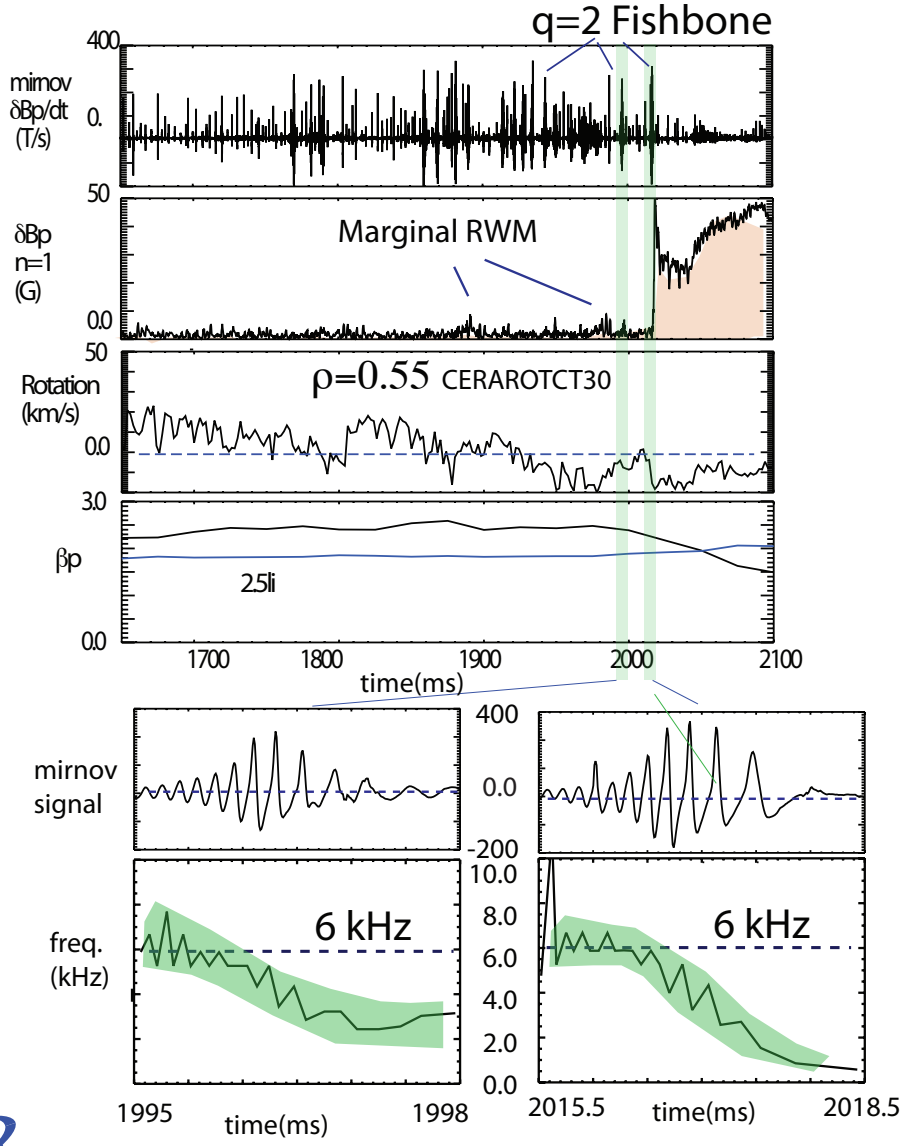
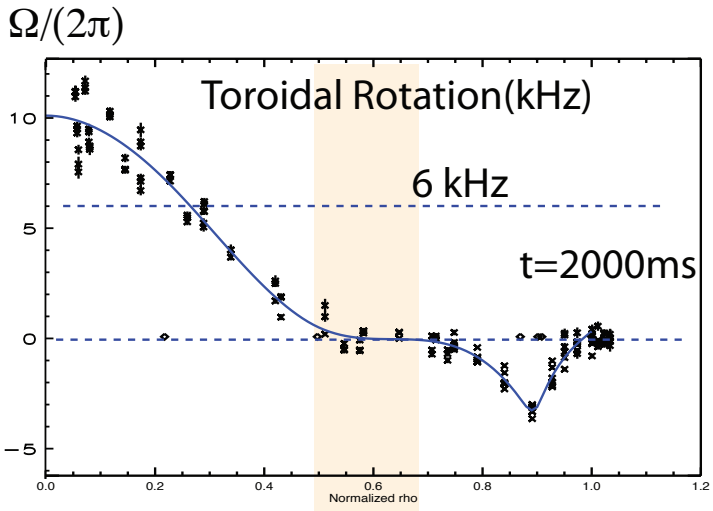
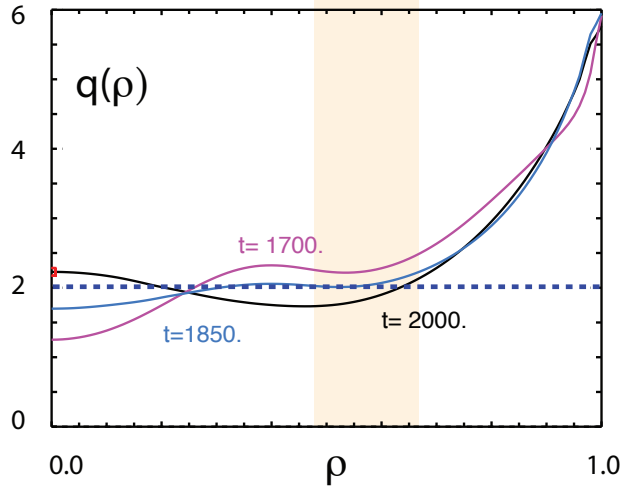
High βn Discharges with Low Rotation Profile Excites q=2 Fishbone-driven RWM







- Precession frequency ~ 2 kHz

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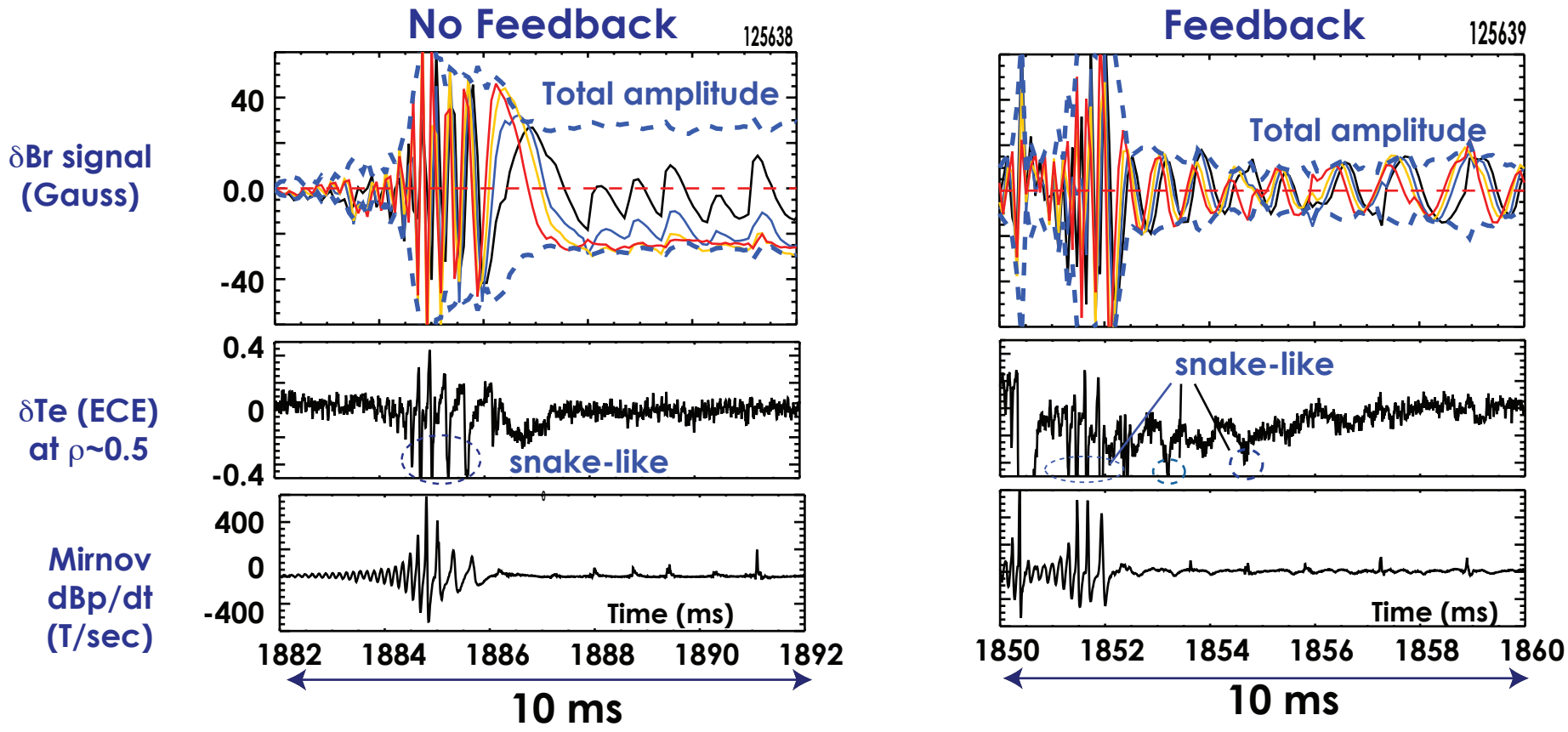
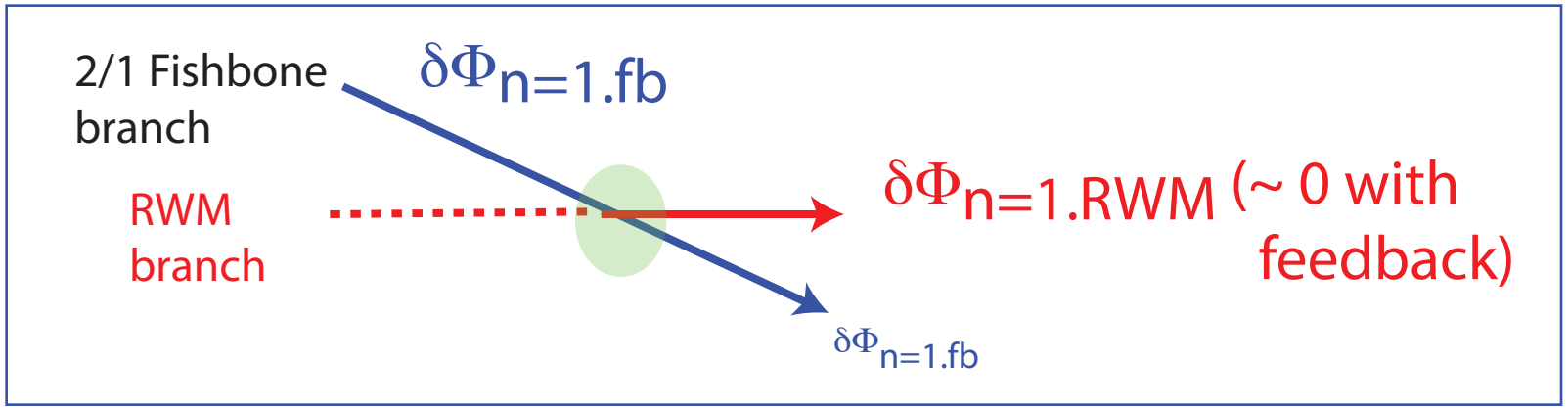
Feedback Suppresses the Magnitude of RWM $\delta\Phi_{n=1.RWM}$ comparable to the original 2/1 fishbone $\delta\Phi_{n=1.fb}$





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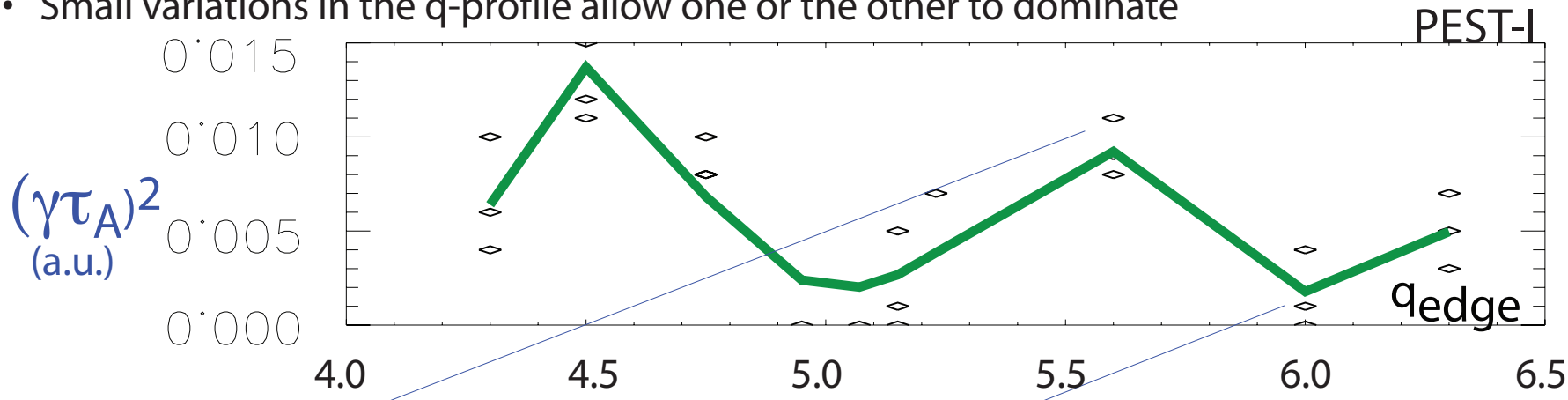
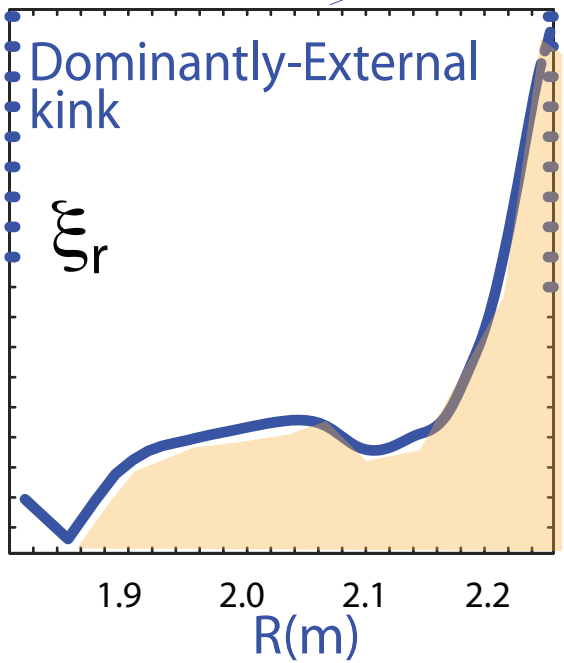
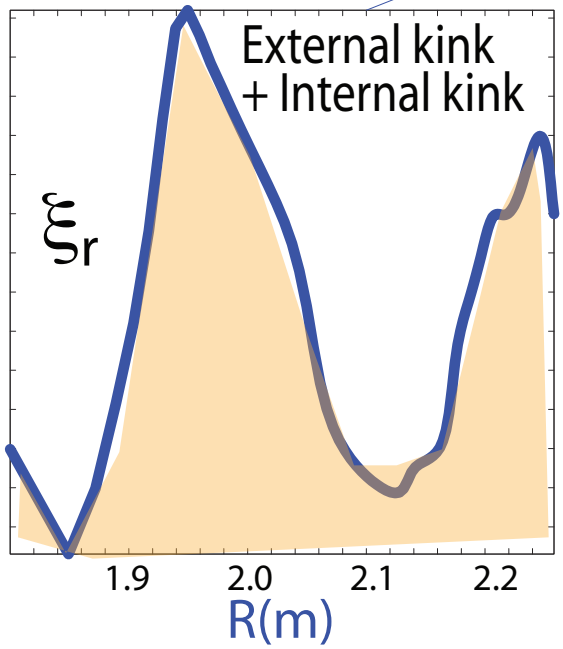
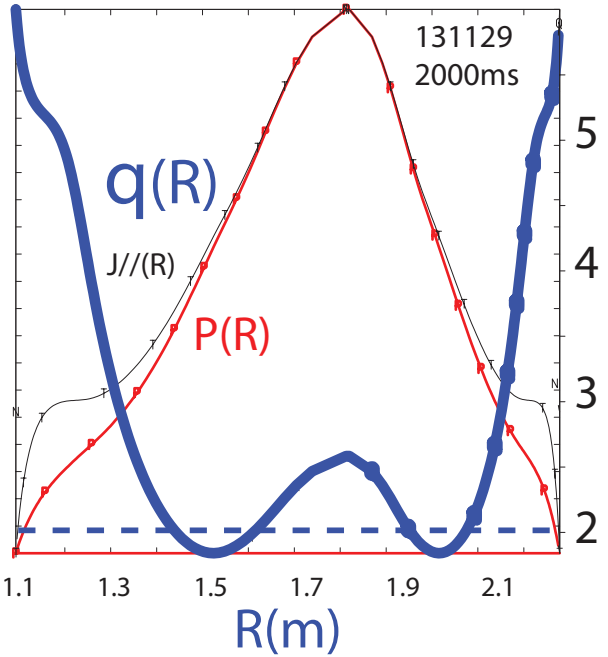
The external (RWM) and internal (Fishbone) modes are both close to marginal stability. Full analysis is needed

- Small variations in the q-profile allow one or the other to dominate







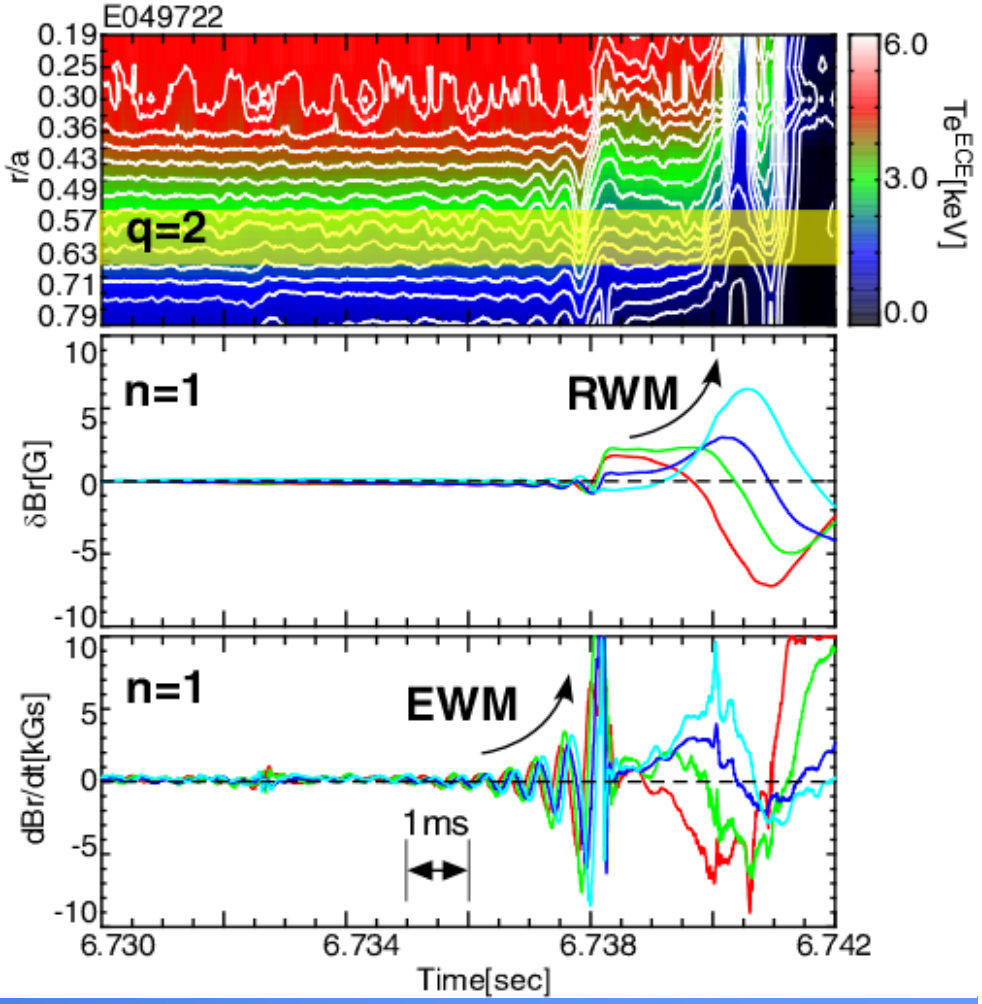


EWM was observed in the wall-stabilized high-β_N region

At IAEA FEC in Geneva, we have introduced
Energetic particle driven Wall Mode (EWM) .

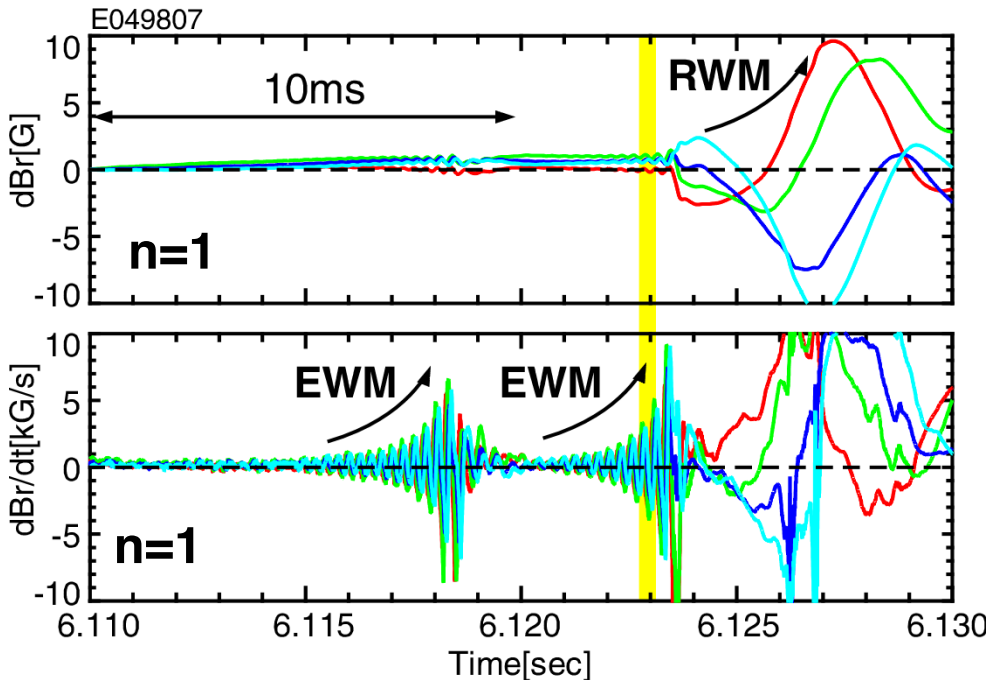
It is concluded that EWM is a high frequency branch of the coupling between energetic particles and RWM taking into account δW_k^{fast}.

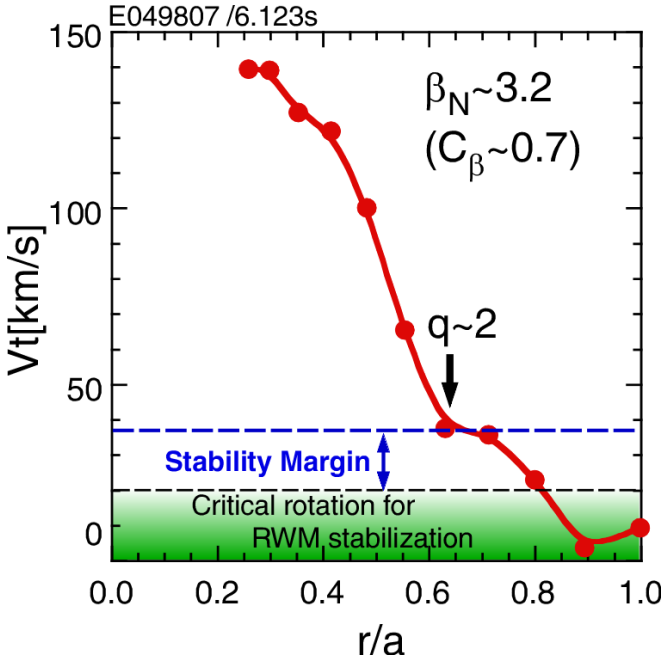
EWM can directly induce RWM despite enough rotation for RWM stabilization.



EWM can directly induce RWM, even though, rotation is enough

In the wall-stabilized high-β_N region, Energetic particle driven Wall Mode (EWM) is newly observed.





At RWM onset, rotation was enough for stabilization.

The EWM is dangerous for RWM

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Energetic Particle Wall Mode (EWM) -- JT60U

- Similar to "fishbone burst"
- Frequency ~ 6kHz (precession frequency ~ 4 kHz)
- Sensitive to the ratio of P_perp / P_para
- **However, q_min > 1.3-1.5**
  (may be difficult to be energized by energetic ions)
- **Bursting growth time ~ 1.5 ms**
- Plasma rotation Ω(at q~2) can be higher than 20 km/s
- Can be a precursor to "RWM-precursor", (like ELM does)
  which is 50ms growth and like a kink, no magnetic islands
- Can trigger a RWM at the condition of
  Ω(at q~2)~ zero at and/or $d\Omega(r)/dt$ ~zero

Energetic particle driven RWM leading to major beta collaspe

	DIIID 2/1 fishbone-driven	JT60U Energetic-particle-driven
• q-profile	q_min~ 2, flat	q(0) ~ 1.5
• Onset Plasma rotation Around q~2	nearly-zero wider area	nearly-zero, not always rotation drop, not always
• Mode propagation	co-direction (co: ion diamagnetic / Ip-direction)	co-direction
• Precession freqency	2 kHz	4 kHz
• Mode growth time	500 μsec	1.5 ms
• Hypothesis	Forced-RWM by 2/1 fishbone	Energetic particle wall mode (EWM) By energetic particle

Summary and Comments

- **Energetic particle destabilizes RWM at low rotation**
  (DIIID) 2/1 fishbone-driven RWM
  (JT60U) Energetic particle wall mode

- **Full :$\delta W_{mhd} + \delta W_{wall} + \delta W_{kinetic} + \delta W_{energetic}$**

  should coherently explain the EWM and 2/1 fishbone driven-RWM

  - Mars-K code, Hu-Betti-Manickam code or some analytical models)

  - **Results with $\delta W_{energetic}$ is useful for assessing $\delta W_{kinetic}$?**

  - how orbit effects are important?

Summary and Comments

- Rotation profile effect

  (DIIID) Rotation $\Omega(r)$ ~ zero and $d\Omega(r)/dr$~zero over some area
  (JT60U) Sometimes, mode is excited above critical rotation
  $d\Omega(r)/dr$~zero is also important

  --> not clear dependence yet

  --> Hidden parameter exists like residual error fields?