Feedback stabilization of current-driven resistive-wall-modes (RWMs) at q_{95}~4 in DIII-D

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In collaboration with

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Reproducible current-driven RWM enables us to explore the RWM feedback process

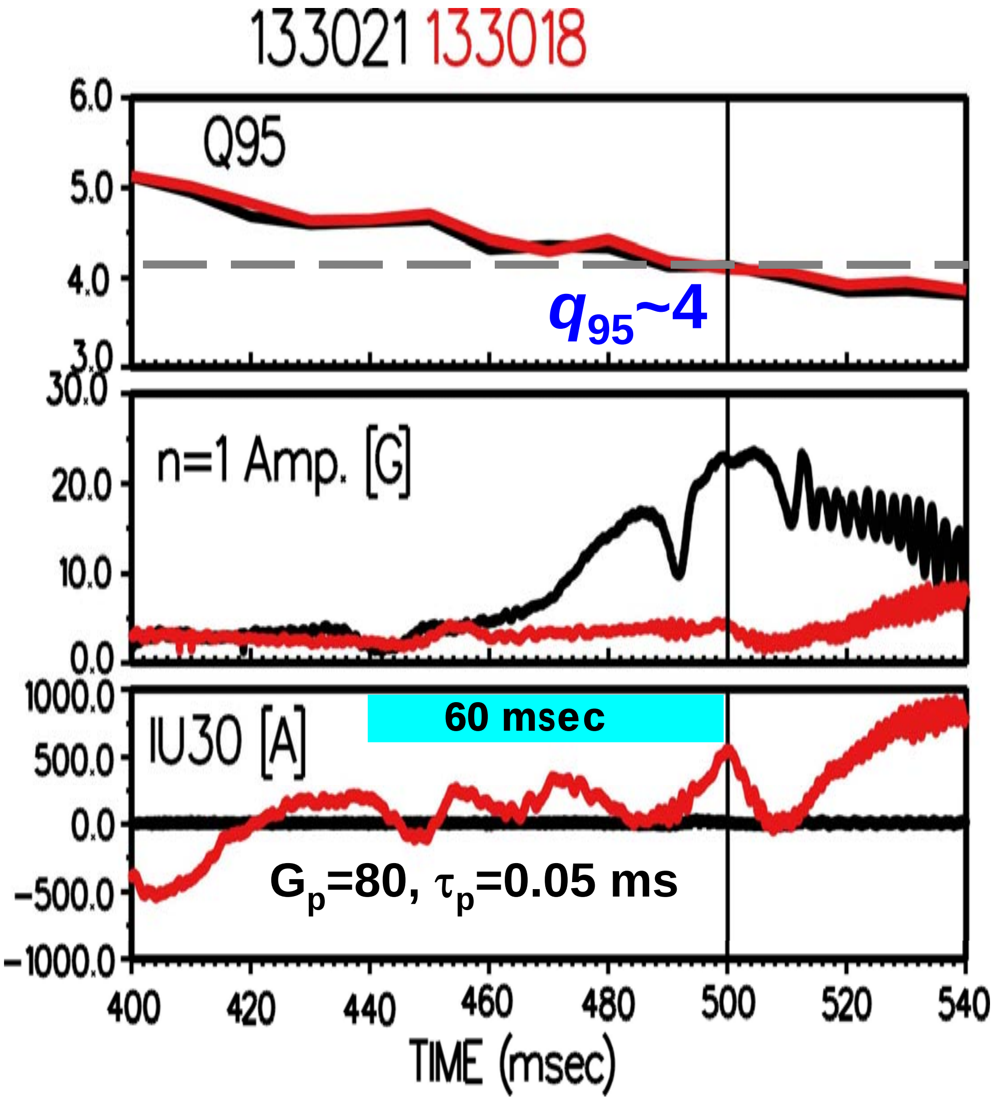
- Due to the irreproducibility of pressure-driven RWMs, the RWM feedback process has not been evaluated thoroughly.

- The RWM feedback control can be assessed using a reproducible RWM target at $q_{95} \sim 4$.

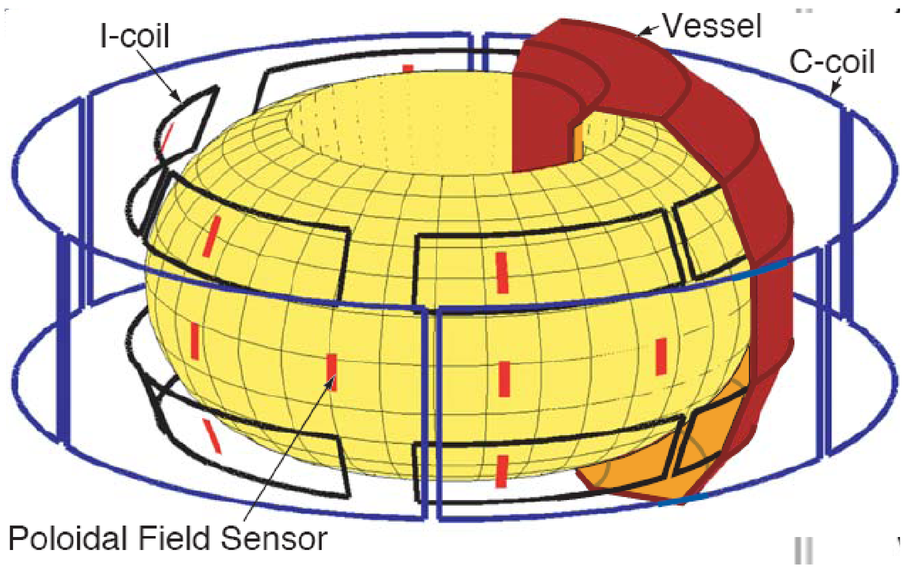
- The experimental results help us evaluate various RWM feedback performance, as well as the RWM feedback process.

DIII-D NATIONAL FUSION FACILITY

Complete feedback stabilization of current-driven RWM at q_{95}~4 has been achieved in DIII-D



- **Ohmic discharge with high current ramp-up rate**
- **Tools**
  - **Internal coils ("I-coils"): Direct Feedback + Dynamic error field correction (EFC)**
  - **External coils ("C-coils"): Static EFC**



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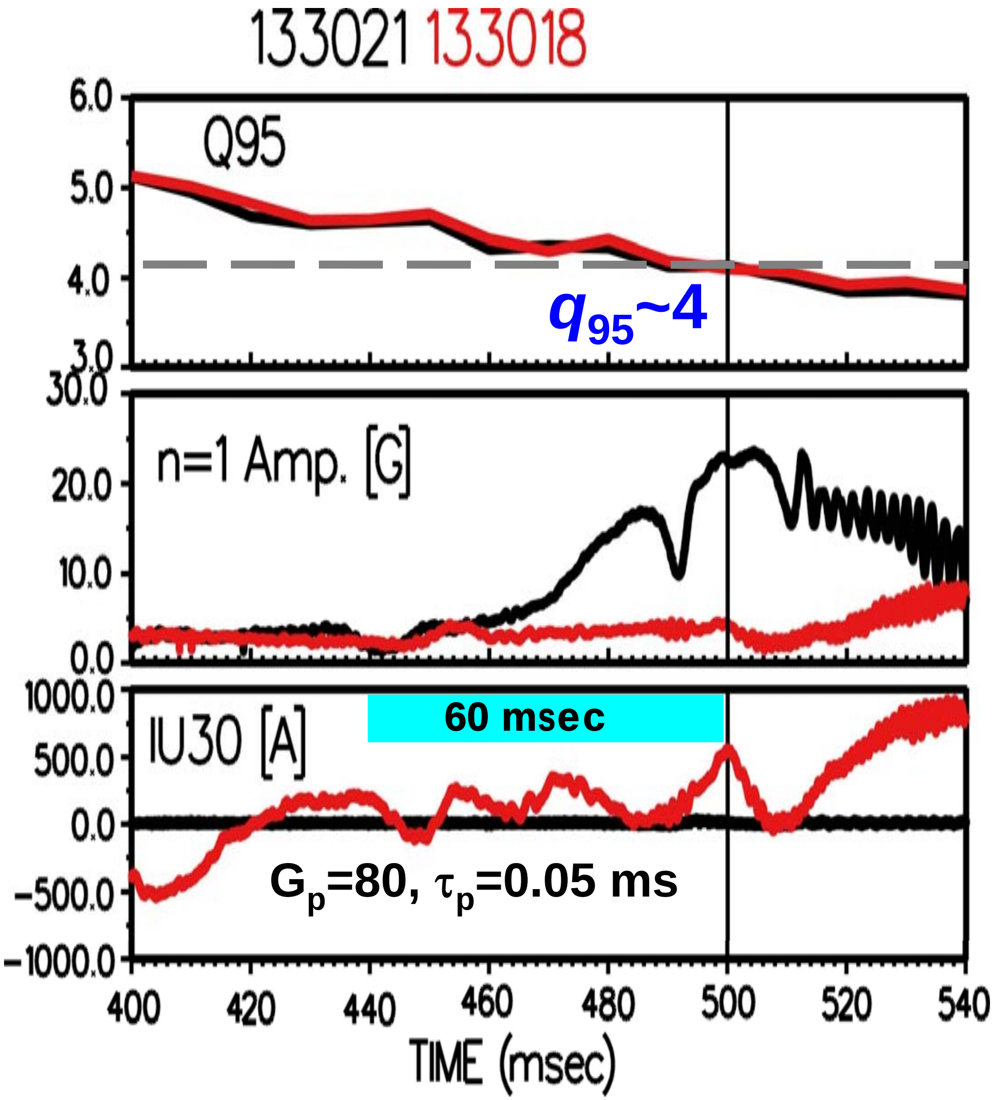
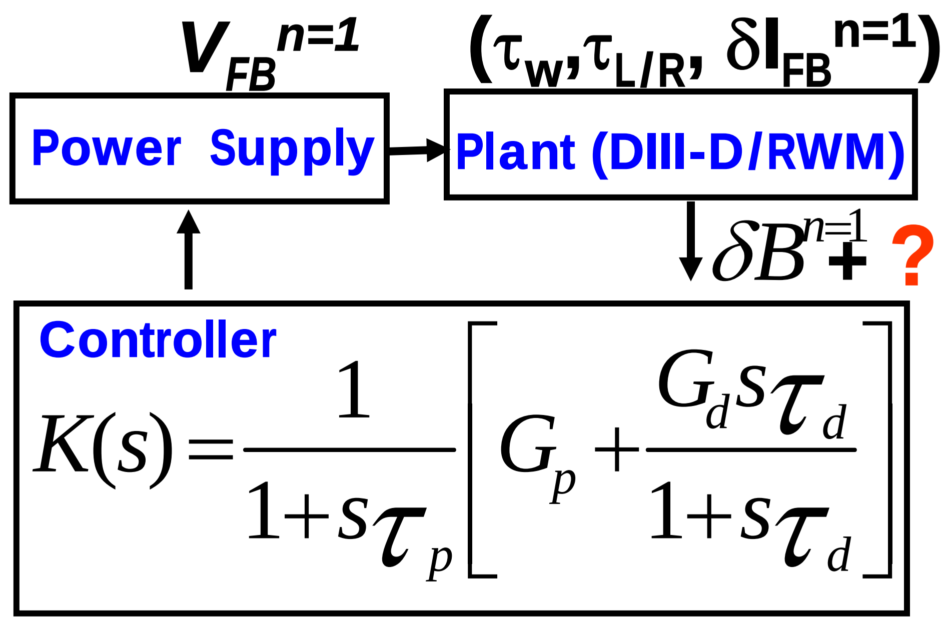


- **Ohmic discharge with high current ramp-up rate**
- **Feedback loop ($\tau_p << \tau_w$)**



$$K(s) = \frac{1}{1+s\tau_p}\left[G_p + \frac{G_d s \tau_d}{1+s\tau_d}\right]$$

$G_{p,d}$: Gain $\tau_{p,d}$: time constant
where p - proportional, and
d - derivative

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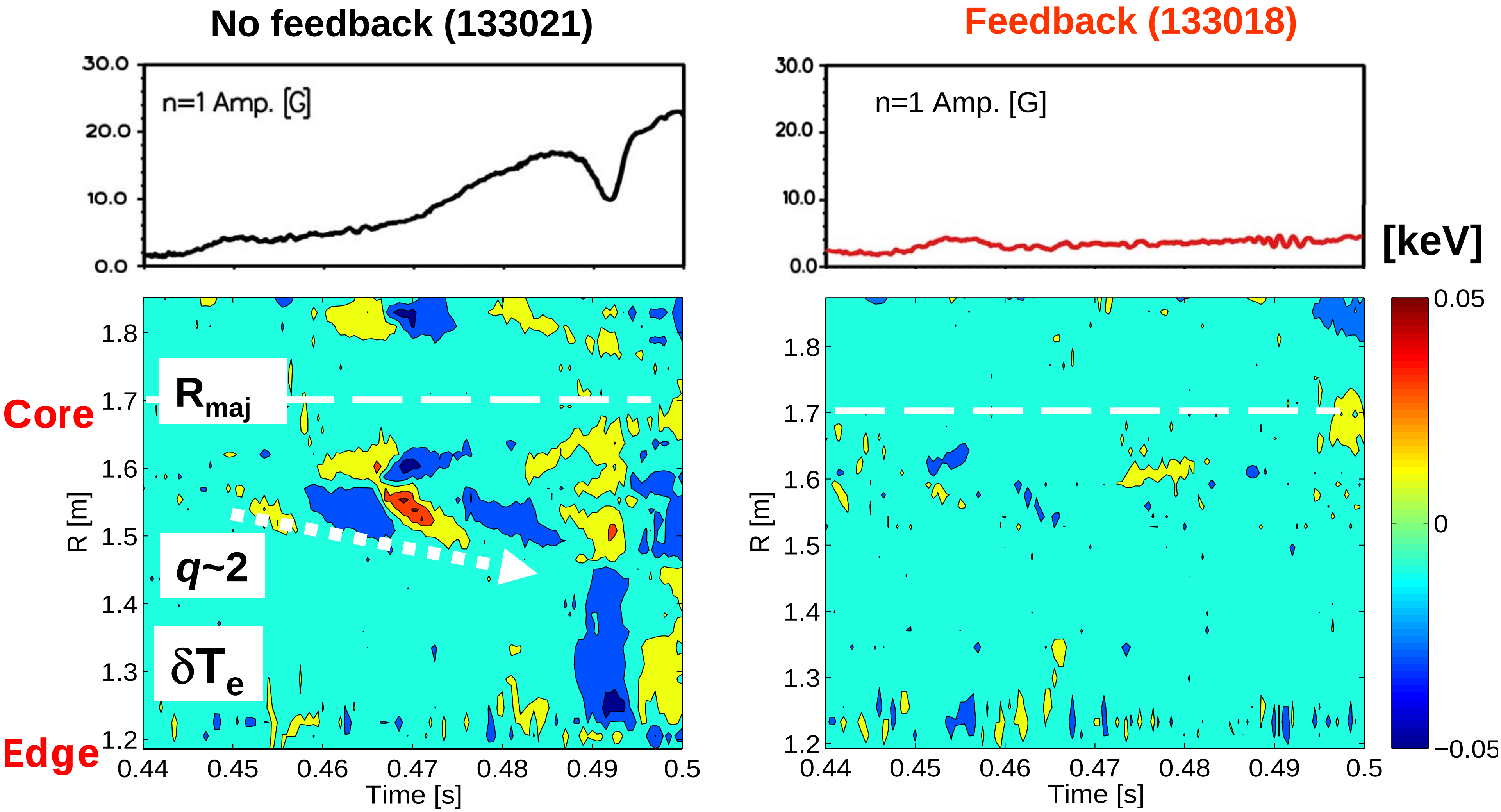
The RWM-associated internal structures are eliminated by RWM feedback control



- **RWM-induced edge disturbance is also suppressed.**

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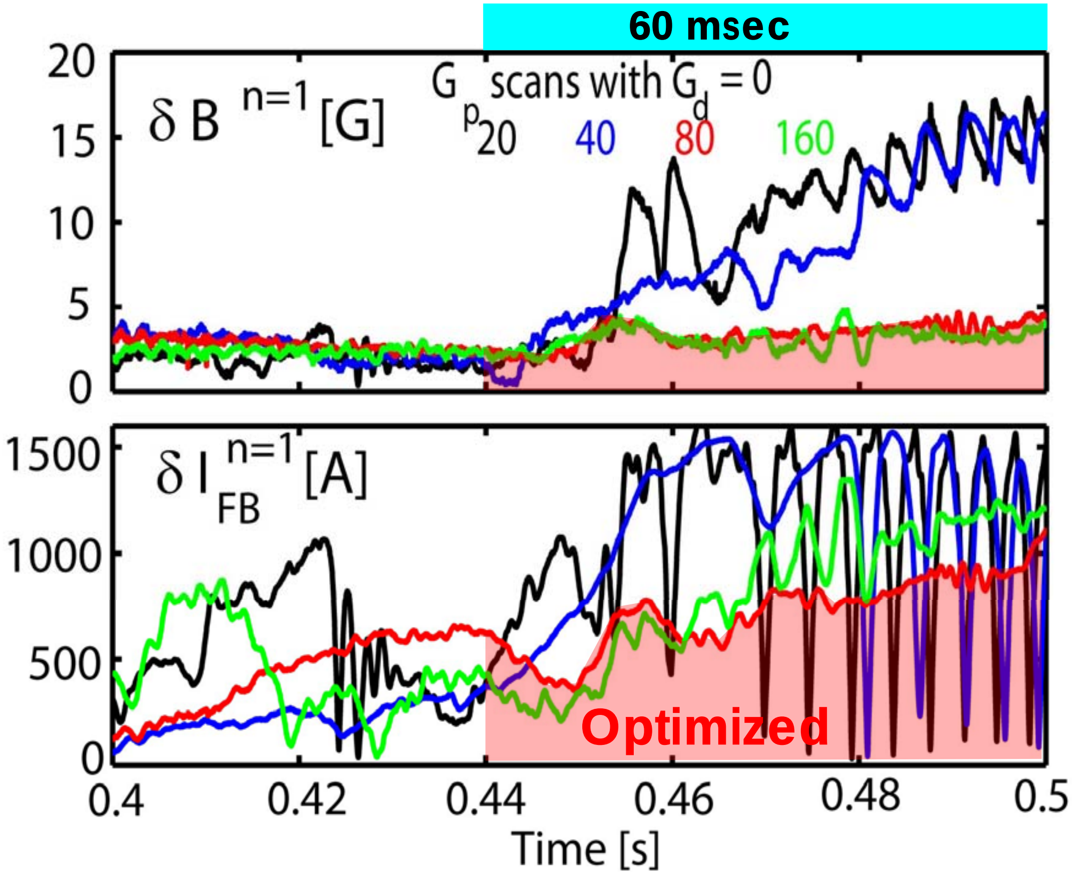
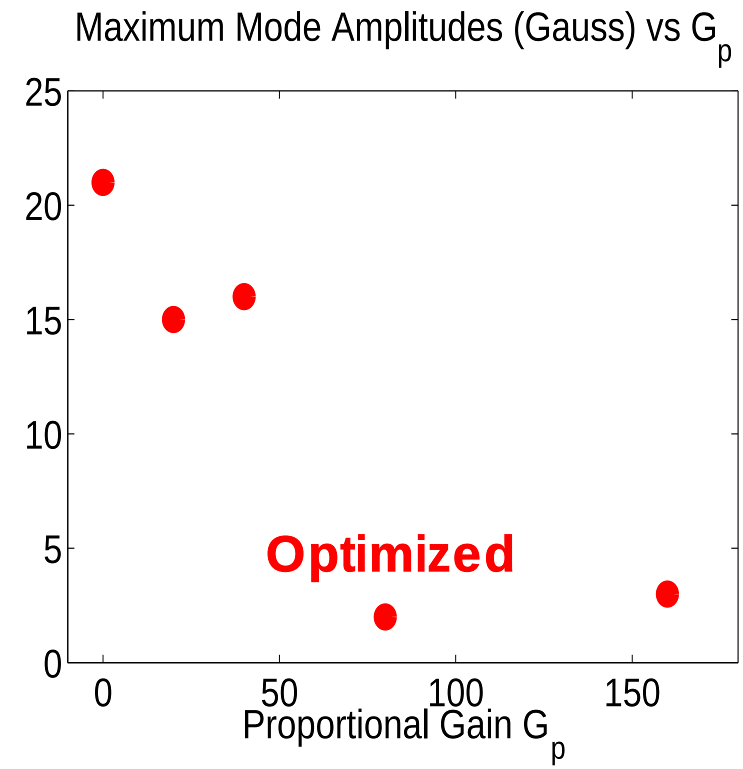
The optimized gain (G_p=80) has been found with G_p only





- **As the gain approaches the optimal level, the mode growth rate decreases as expected.**

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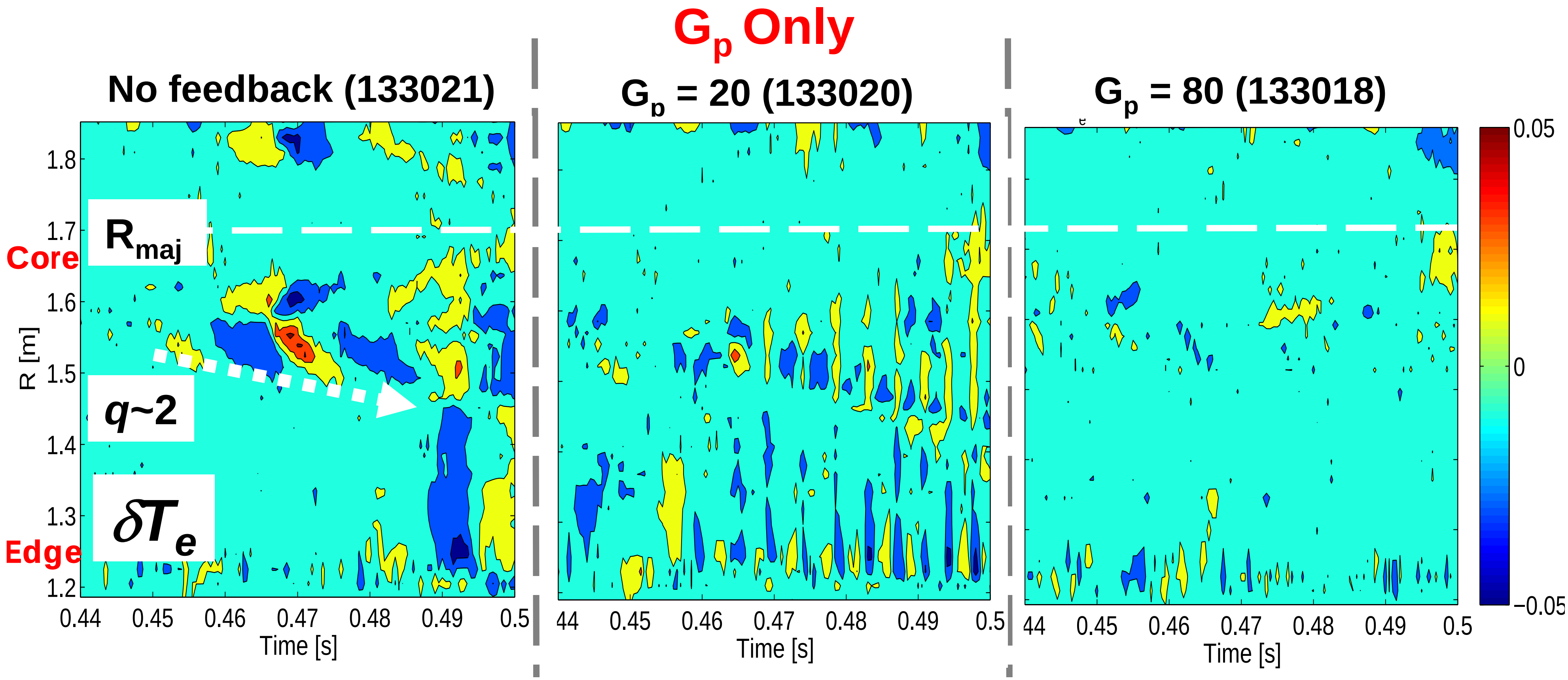
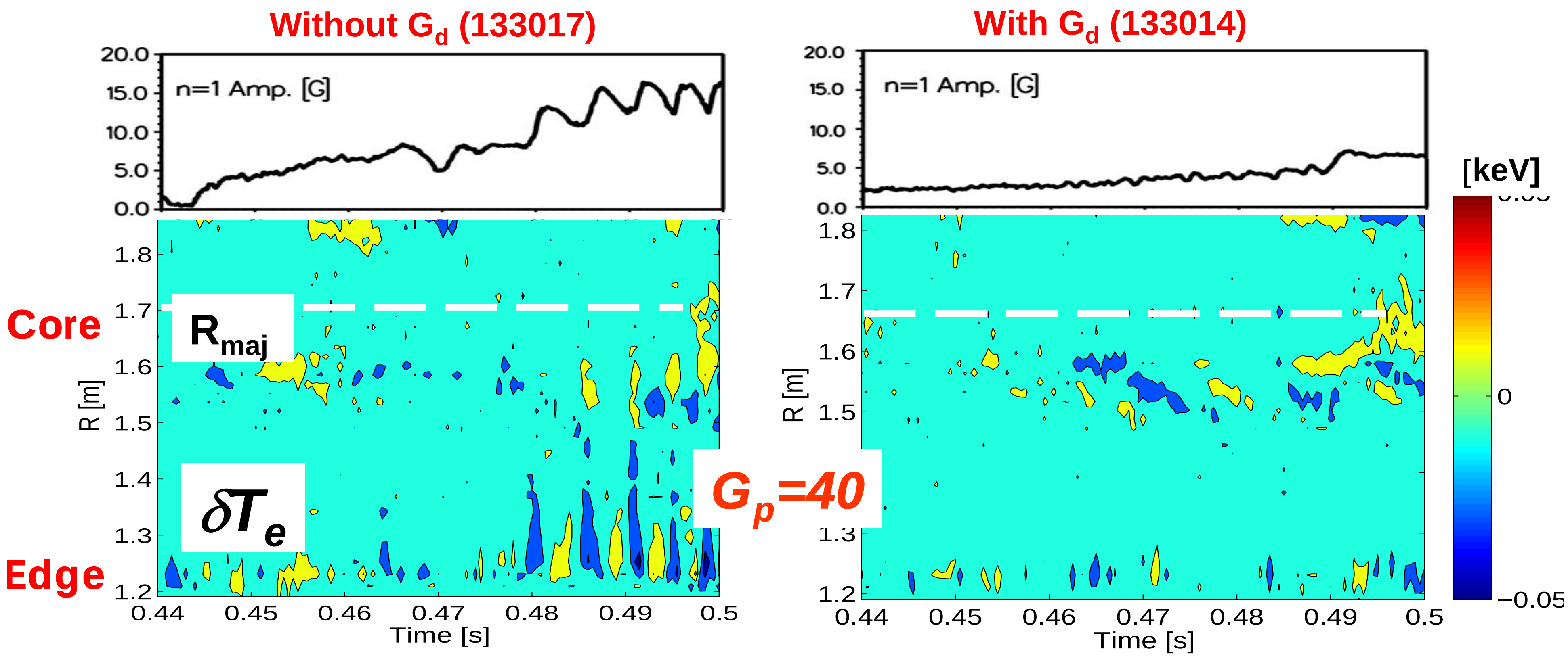
Sub-optimal gain is not only less effective in suppressing the RWM but also disturbs the plasma edge



- **Meanwhile, the edge disturbances are not observed at the over-optimal gain (e.g. G_p = 160).**

The use of derivative gain broadened the effective gain range for RWM feedback stabilization at q_{95}~4



- **A value of G_d =10G_p is chosen to use voltage controller 'effectively' as current controller, based on τ_d and $\tau_{L/R}$ of the feedback system.**
- **The addition of G_d minimizes the phase lag in time between RWM and the applied field.**

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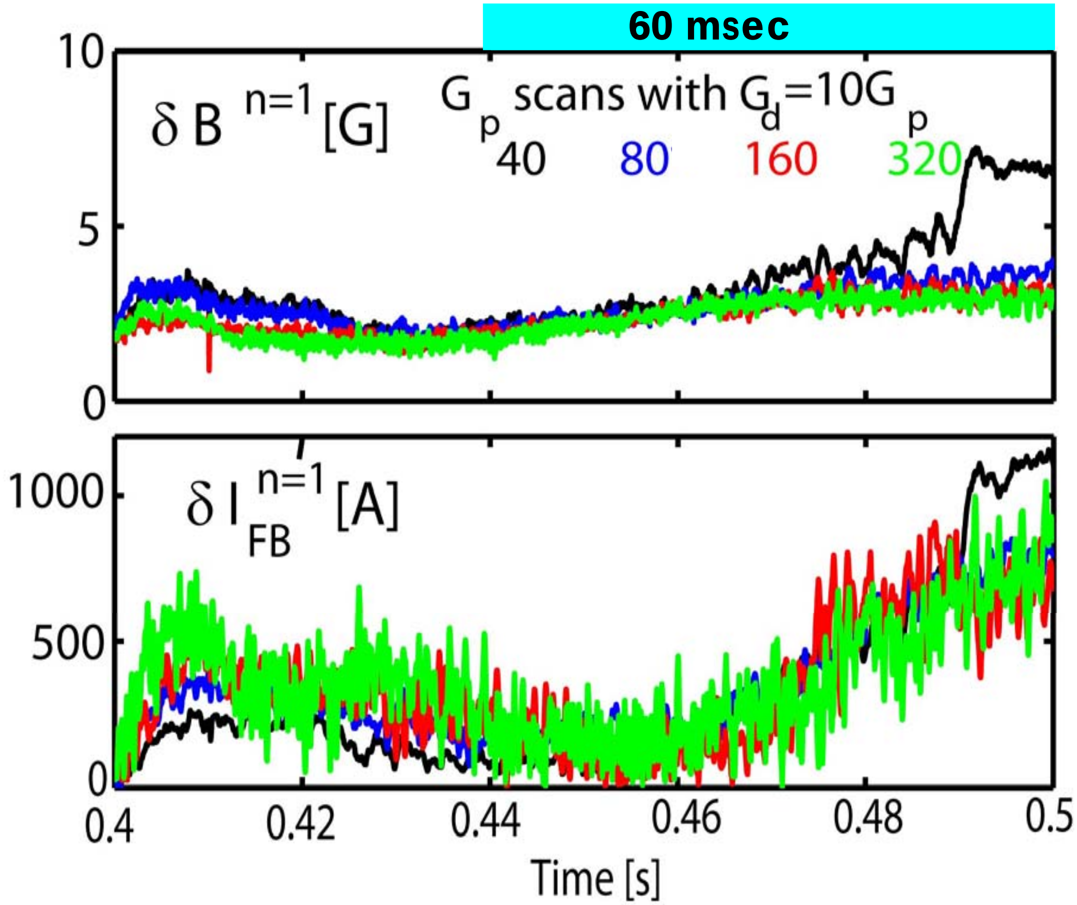
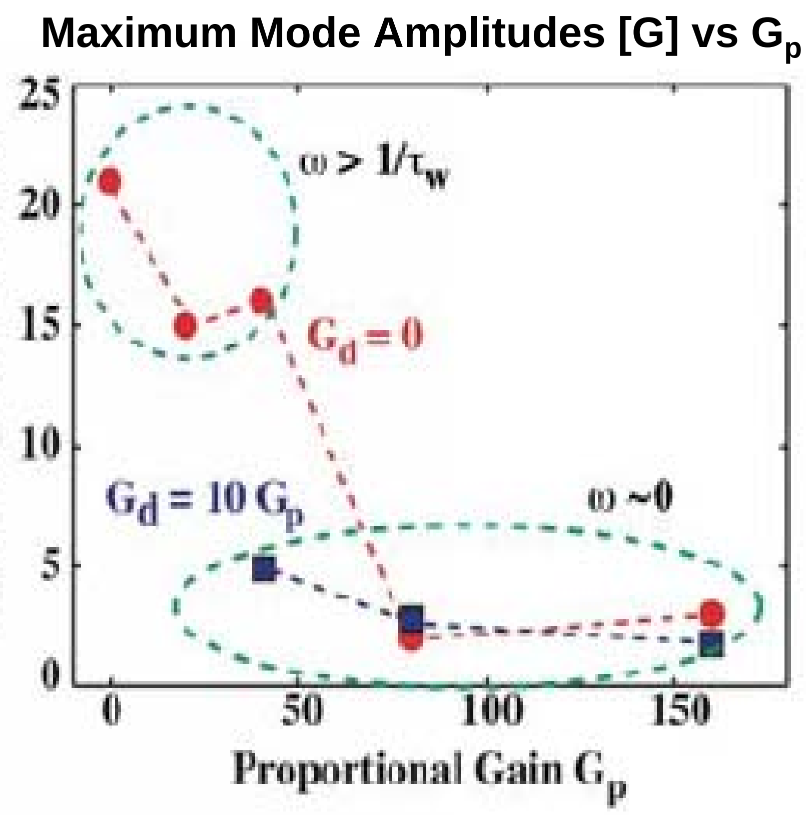
Direct RWM control is the dominant stabilization process, while good error field correction is prerequisite





- **Similarly finite amplitude of the coil currents at various G_p values indicate the EFC portion necessary for effective stabilization.**

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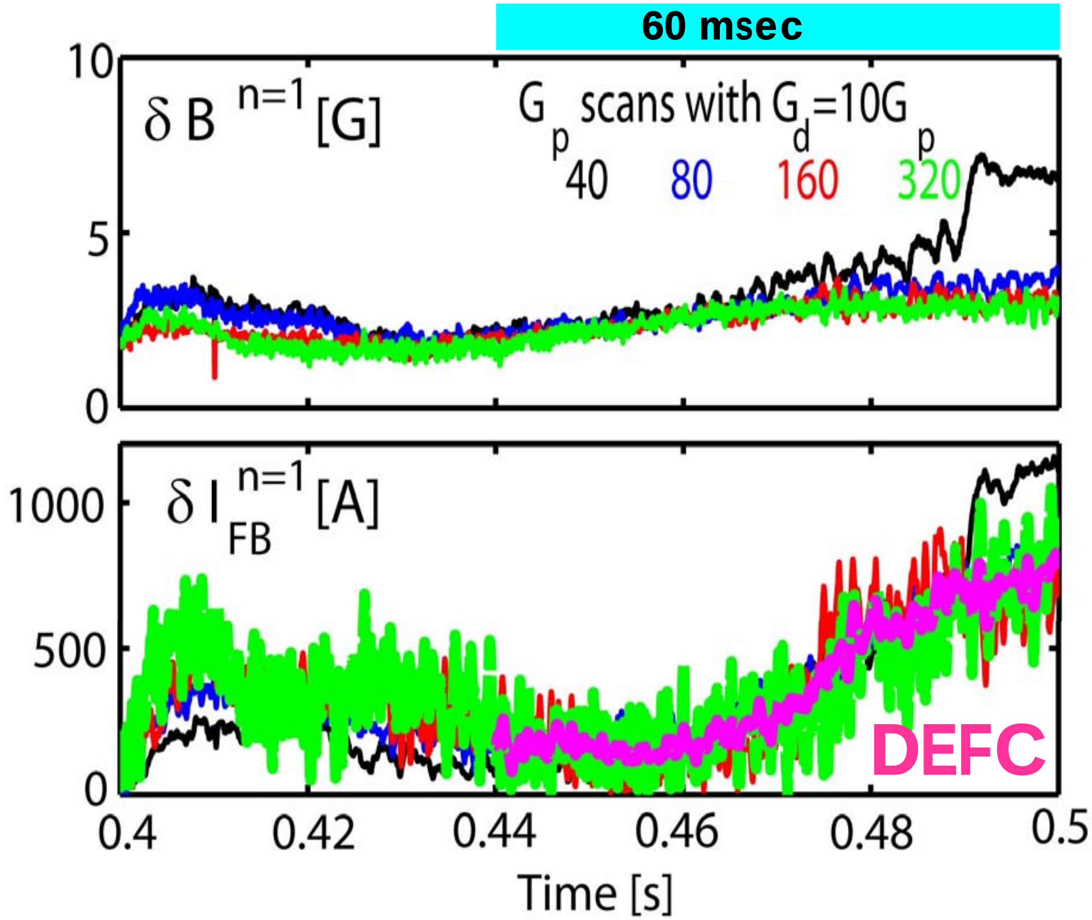

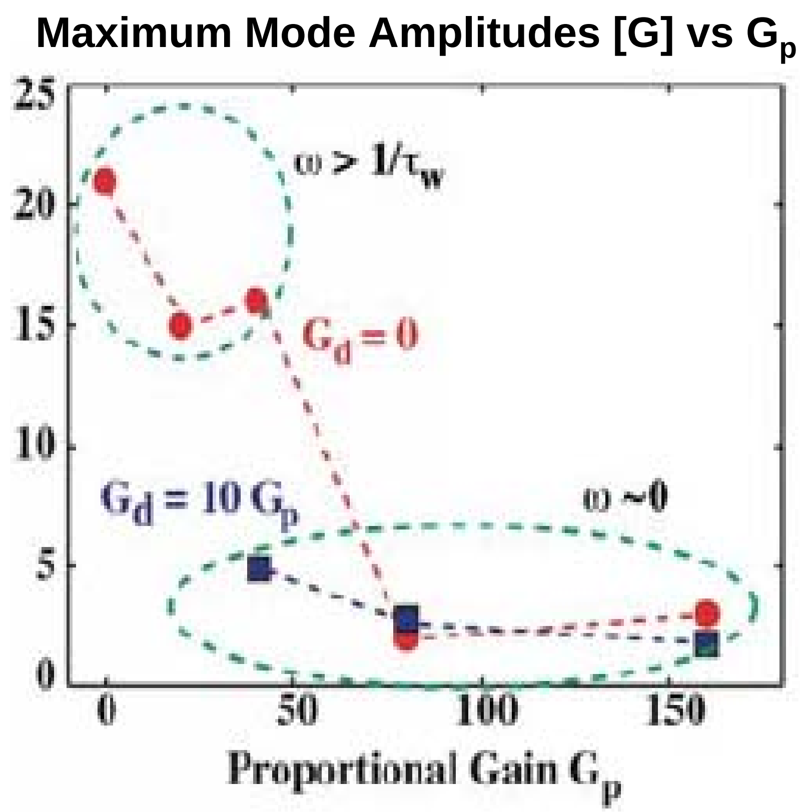

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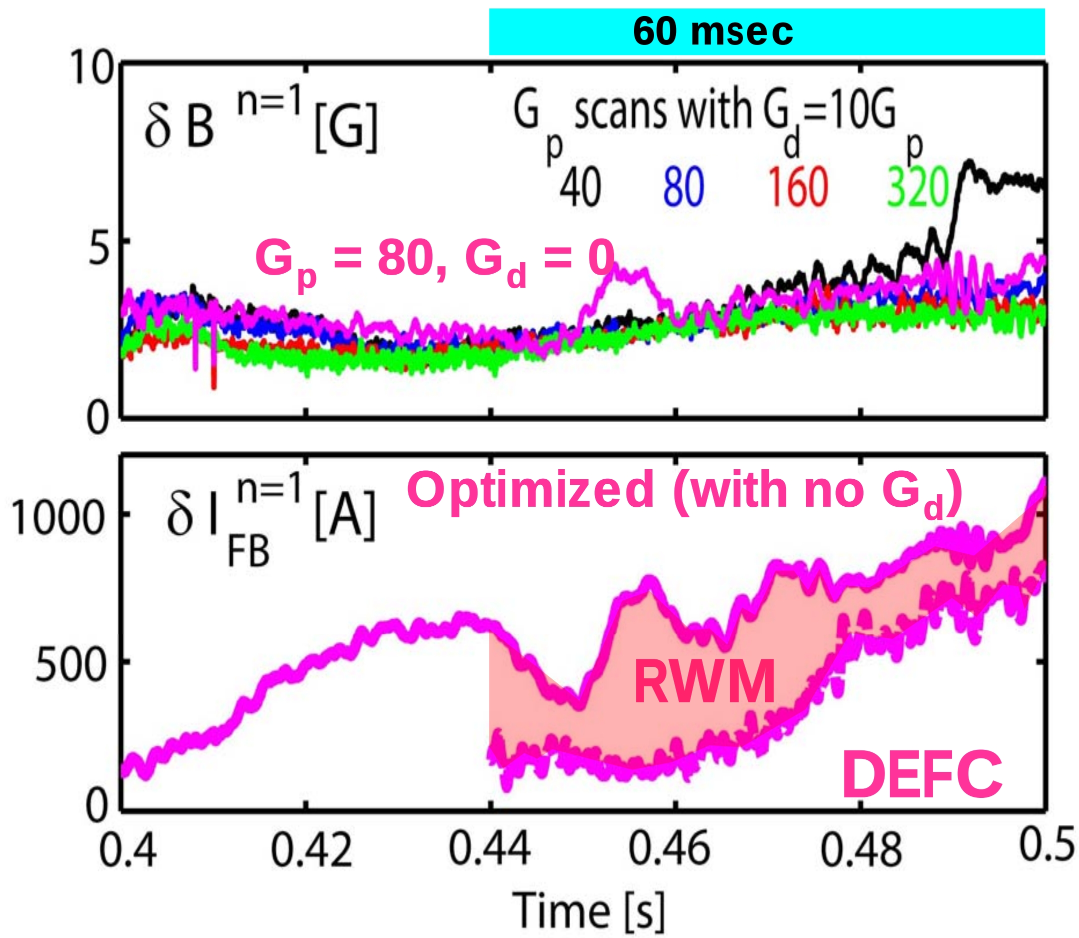
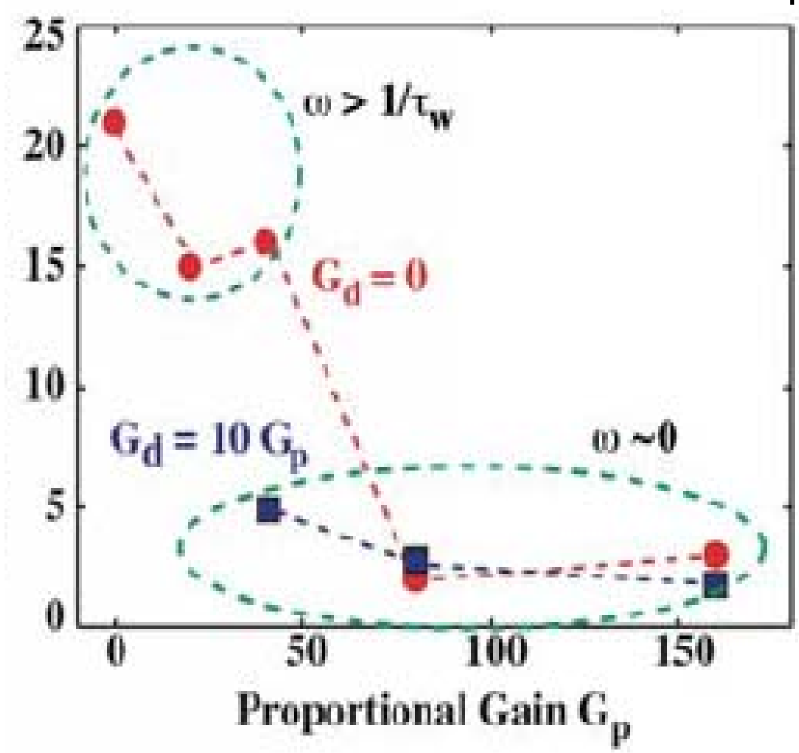


Maximum Mode Amplitudes [G] vs G_p



Complete stabilization
= RWM + DEFC

- From the known DEFC, the portion of the coil current necessary for the direct RWM control can be extracted.

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Conclusions

- Current-driven RWM at q_{95} ~ 4 was completely stabilized by the RWM feedback control.
  - An optimized proportional gain (G_p=80) has been found without using derivative gain.
  - The use of derivative gains (G_d=10G_p) expanded the stable range of proportional gains.
    - Reducing a phase lag in time avoids any mismatch between RWM and applied field.

- The success of stabilization of the current-driven RWM at q_{95}~ 4 is primarily due to the direct RWM control, while a good error field correction is overlaid.

- Similar feedback performance is expected even for the pressure-driven RWM in high-β plasmas, as long as the difference of the plasma responses between low and high-β plasmas is properly addressed.

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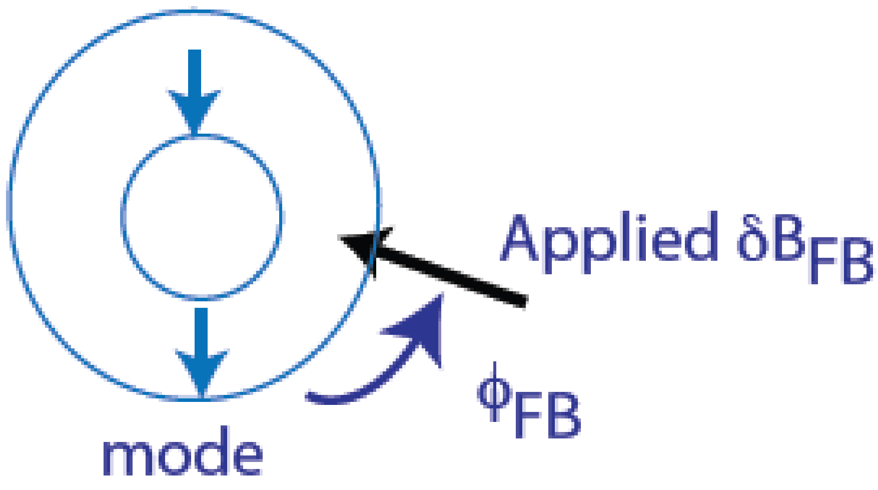
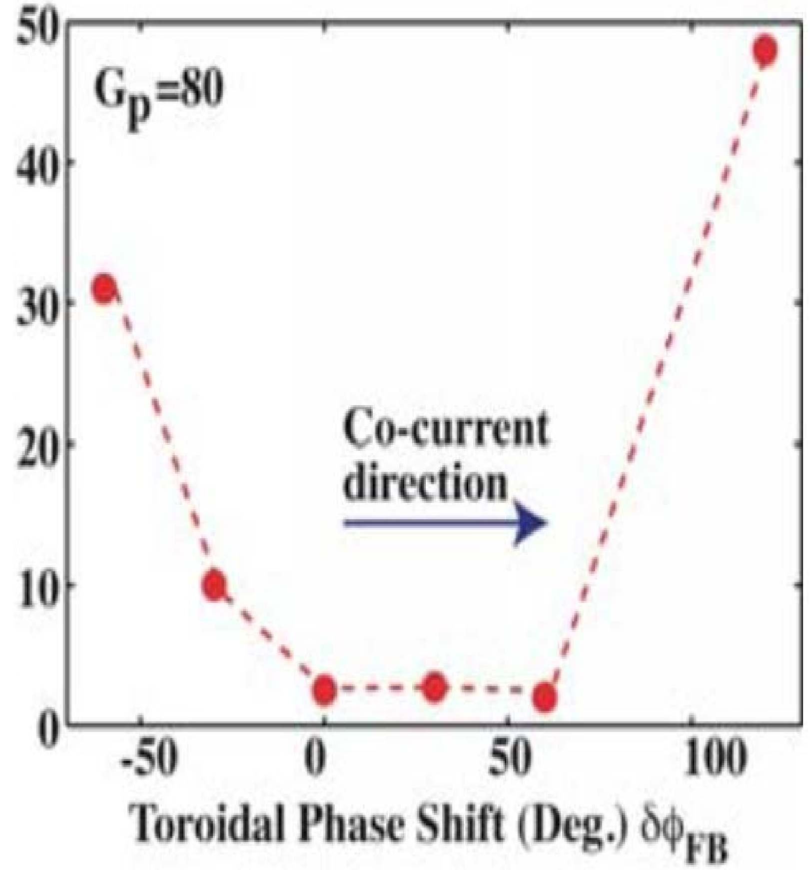
FAR-TECH

A phase-shifted n=1 field in the direction of co-I_p rotation is more effective than in the opposite direction.



Maximum Mode Amplitudes [G] vs $\delta\phi_{FB}$



- **A range of preferred toroidal phase shifts ahead of the RWM exists for effective feedback**