n=3 Braking with Optimal n=1 Error Field Correction

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Background and Motivation

- **Magnetic braking of the toroidal plasma rotation using non-resonant, n>1 magnetic fields has been carried out in both NSTX and DIII-D in the past few years**
  - On NSTX, this technique has led to the destabilization of the n=1 RWM.
  - On DIII-D, the non-resonant braking effect was observed to decrease with lower rotation. The braking becomes ~zero at an "offset" rotation which is above the rotation threshold for RWM stabilization. This non-linearity of the braking effect vs. plasma rotation is consistent with theoretical predictions from the theory of Neoclassical Toroidal Viscosity by Kerchung Shaing.
- **Why is the non-linearity of the non-resonant braking effect not observed in NSTX?**
  - because the "offset" rotation is below the threshold rotation for stabilization of the RWM
  - or because residual, uncorrected n=1 error fields give origin to resonant braking effects that dominate over the weaker non-resonant braking effects
  - or because …?

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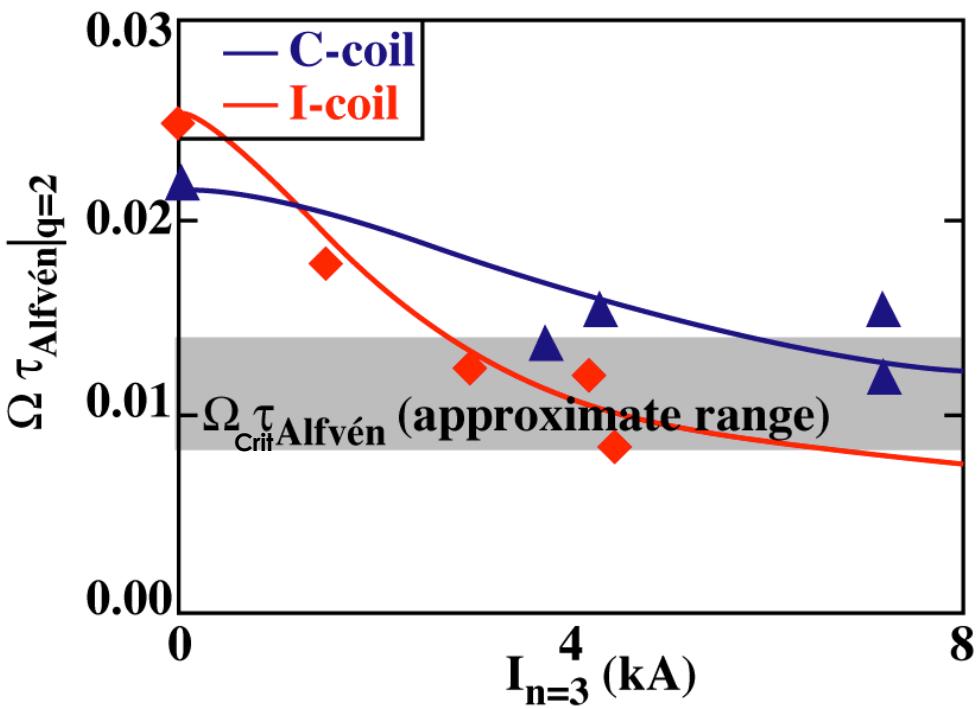
Non-Resonant n=3 Braking in DIII-D Does Not Lead to RWM Onset

- n=3 magnetic braking can create large drag torque
- RWM remains stable when correction of n=1 error field is optimal (DEFC)



$$dL/dt = T_{NB} - L/\tau_M - k(\Omega - \Omega_D)\, I_{n=3}^2$$

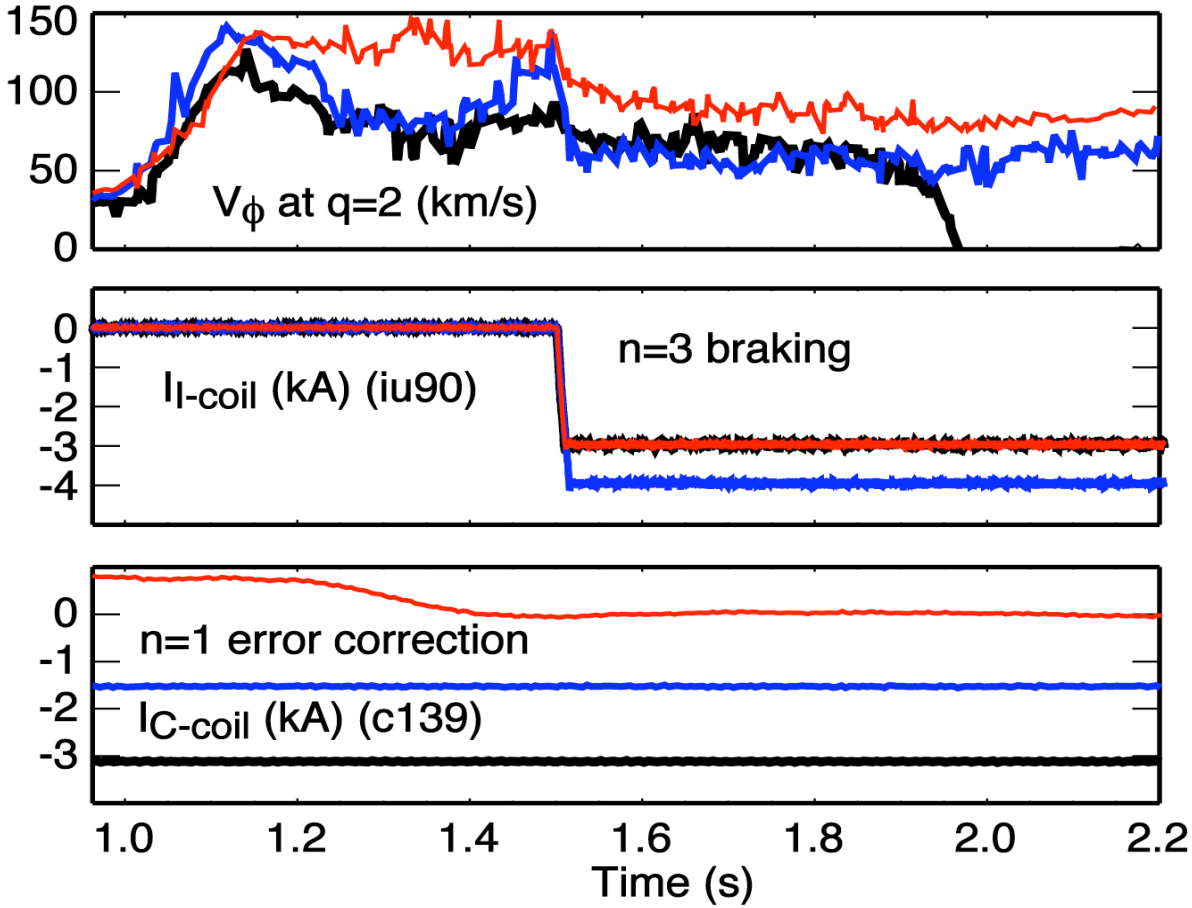
- Braking effect saturates as braking field is increased
- Saturated rotation agrees with neoclassical toroidal viscosity model

$$\Omega_D \sim 2/3\,\nabla T_i/(Z_i e B_\theta R)$$

  - K.C. Shaing, S.P. Hirshman and J.D. Callen, Phys. Fluids **29**, 521 (1986)

Non-Resonant n=3 Braking Can Lead to Unstable RWM, If n=1 Error Correction Is Non-optimal

- C-coil used for n=1 error field correction (red=optimal)
- I-coil used for n=3 magnetic braking

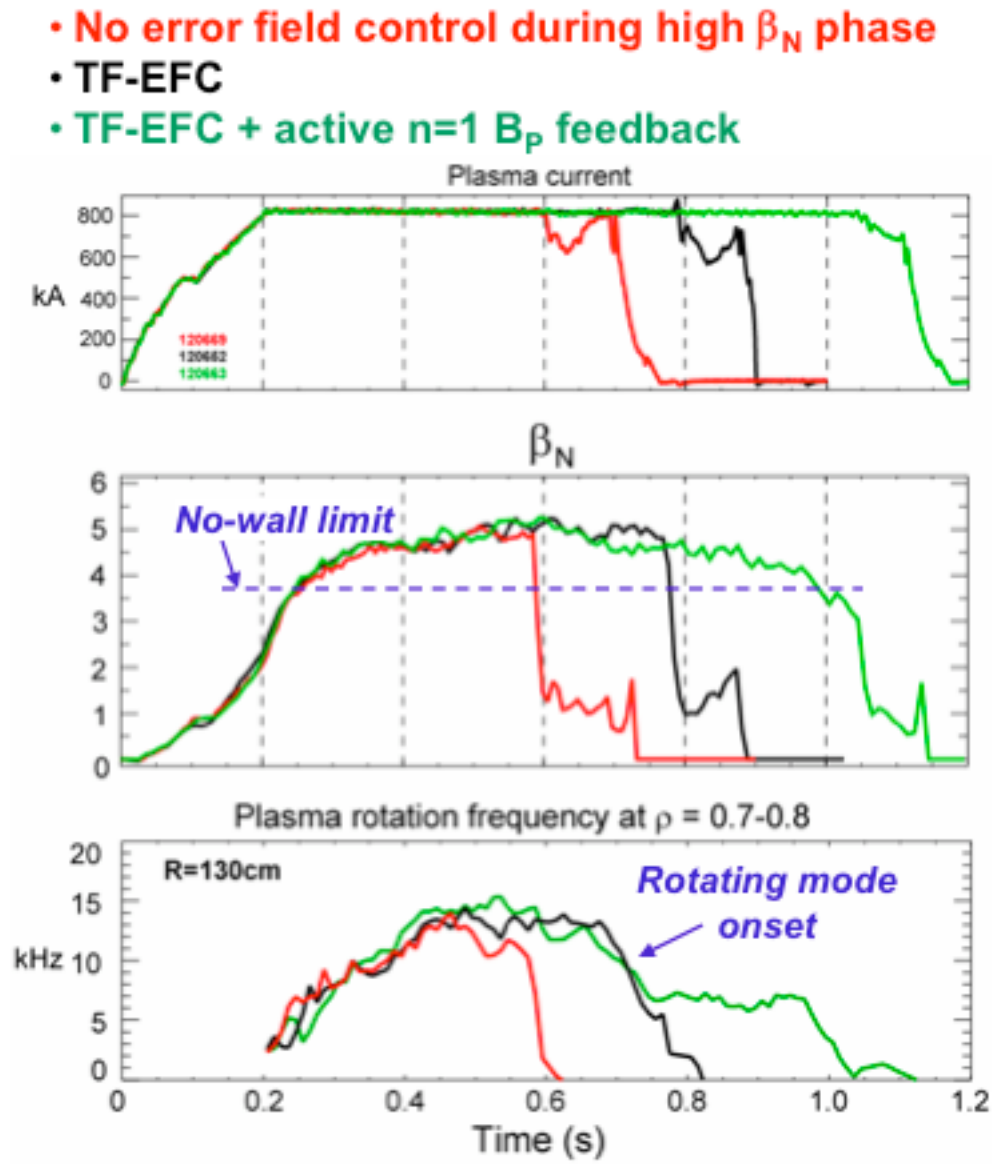


- Small n=1 error field introduced accidentally (one C-coil pair)
- RWM onset observed for sufficiently large n=3 and n=1 error field

Previous n=3 Braking Experiments in NSTX Have Been Performed Without Error Field Control

- **Menard's 2005-06 NSTX experiments on error field identification and control have shown that Dynamic Error Field Correction (i.e. using RWM feedback) optimizes plasma performance**
  - Suggests previous n=3 experiments had residual, uncorrected n=1 error fields

J.E. Menard, APS-DPP Meeting, Philadelphia, 2006



Experimental Approach

- **We propose to carry out n=3 braking in discharges for which the n=1 error field correction (EFC) has been optimized by using dynamic EFC by the RWM feedback system.**
  - **Operating above n=1 NW limit, determine the optimal n=1 EFC using n=1 RWM feedback. Could use reference discharge from previous dynamic error field correction experiments by Menard, or use Menard's procedure on a new target.** ***(4 shots)***
    - May need to pre-program the feedback-driven currents and iterate a few times with RWM feedback on, until the feedback currents do not deviate from the preprogrammed currents.

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Experimental Approach (cont.)

- **Turn RWM feedback off and add n=3 braking currents (square-step waveform) on top of the currents for optimal correction of the n=1 error field. Vary the n=3 amplitude and sign. (*5 shots*)**
  - Look for saturation of the braking effect with increasing n=3 amplitude

- **If n=3 braking alone is NOT sufficient to destabilize an RWM:**
  - **Vary q95, look for change on braking effect. *(3 shots)***
  - **Reduce the n=1 correction currents until the RWM onset is observed. *(3 shots)***

- **If n=3 braking is sufficient to destabilize an RWM:**
  - **Reduce NBI energy, look for change in rotation threshold. *(6 shots)***

  or
  - **Scale down Bt and Ip, look for change in rotation threshold. *(6 shots)***

  or
  - **Using n=3 amplitude below max allowable:**
    - **Vary q95, look for change on braking effect. *(3 shots)***
    - **Vary density, look for change on braking effect. *(3 shots)***

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