Update on Sheared Plasma Rotation and Tearing Modes in DIII–D

Presented by
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at the
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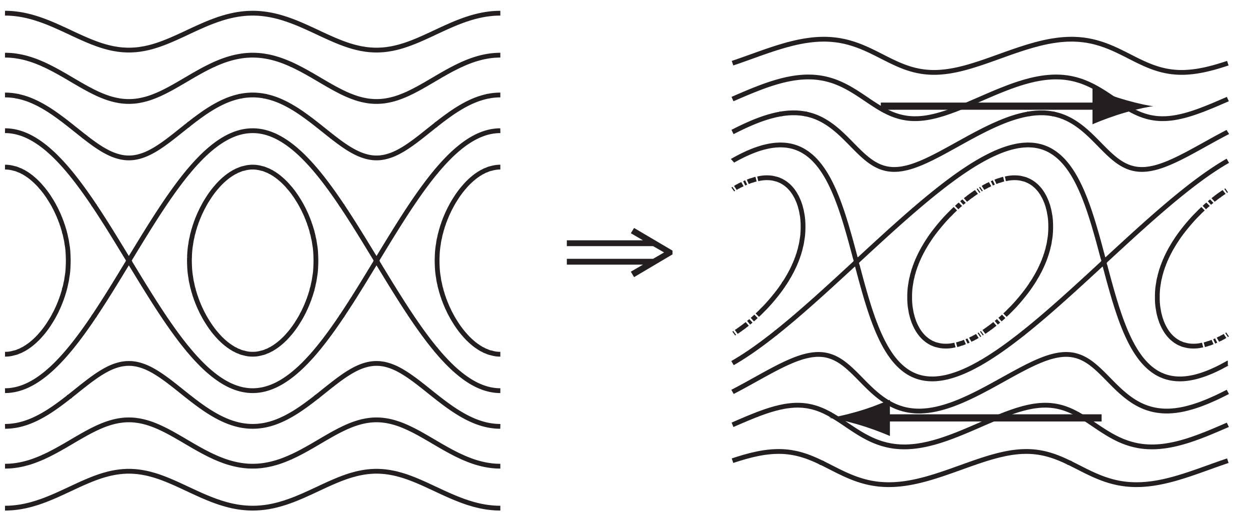
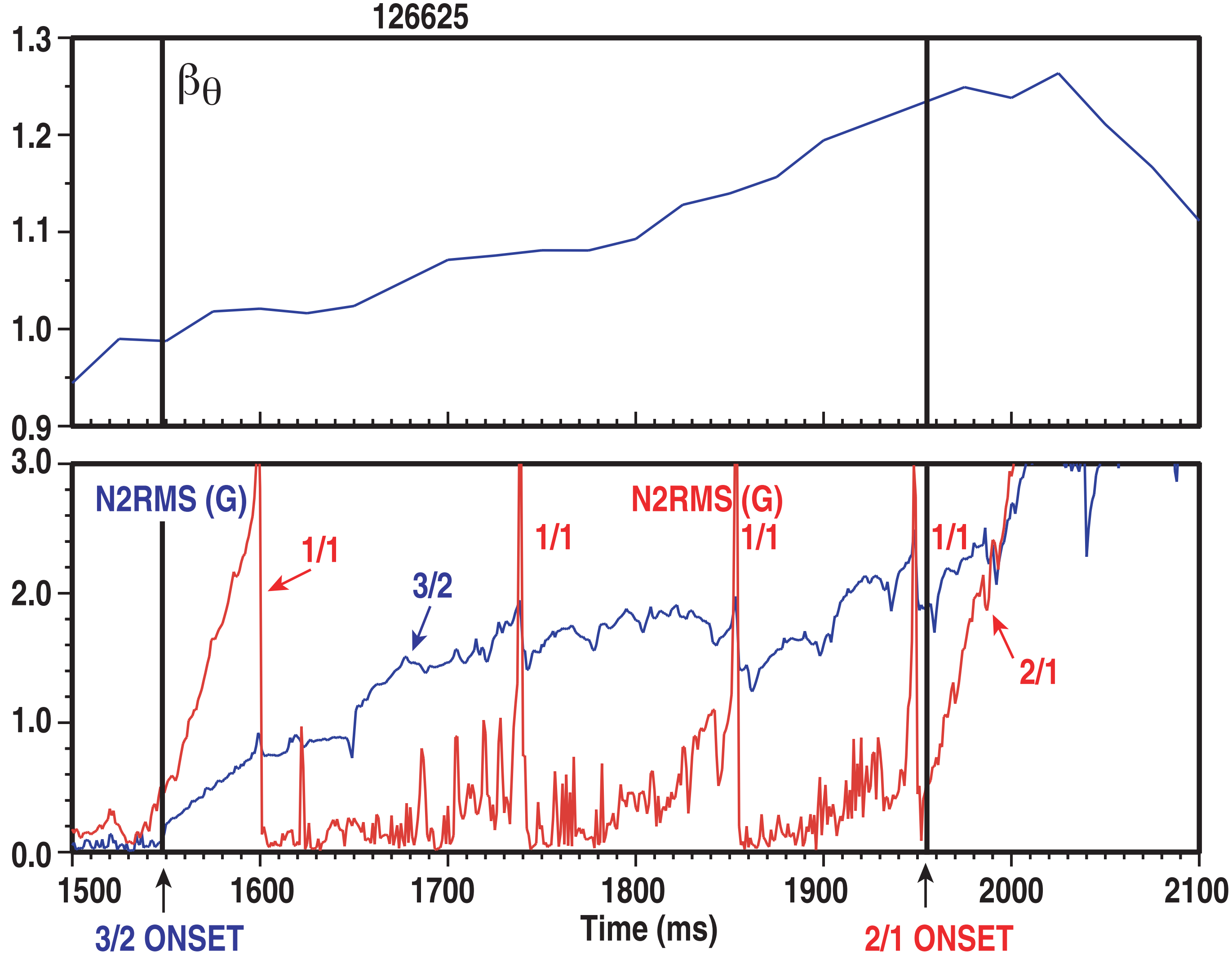


In Sawteething Plasmas, m/n=3/2 Mode Amplitude Increases as β_θ is Raised (up to Onset of 2/1 Mode)

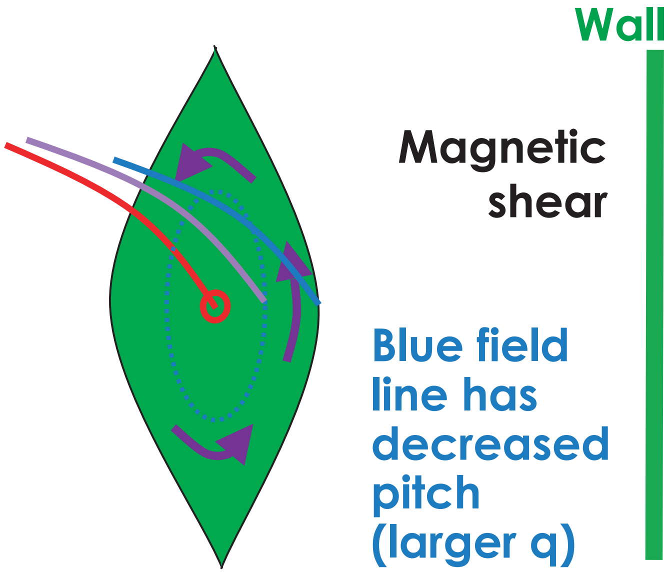
- **Rotation varied shot-to-shot by co/counter beam mix**



Theory Suggests Flow Shear Can Stabilize Tearing (Flow Shear is Radially Sheared Plasma Rotation)

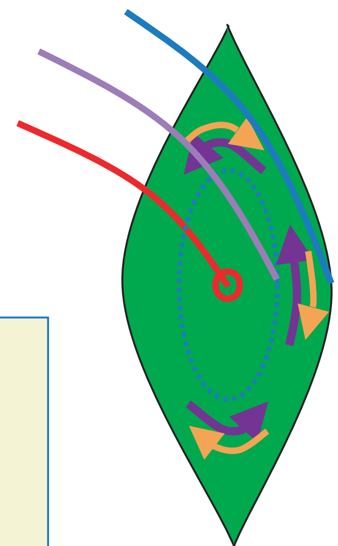
- **Chen & Morrison, PF 13 1990, "Resistive tearing instability with equilibrium shear flow"**
  - ★ When the flow shear is larger than the magnetic shear..., the flow freezes the magnetic field and stabilizes the tearing mode."
- **Ofman, Morrison & Steinolfson, PF 13 1993, "Nonlinear evolution of resistive tearing mode instability with shear flow and viscosity"**
  - ★ "shear flow decreases the saturated magnetic island width"
- **Coelho & Lazzaro, PoP 2007, "Effect of sheared equilbrium plasma rotation on the classical tearing mode..."**
  - ★ "Above a given threshold in the rot. shear, a tearing mode, unstable in the absence of rotation, can be stabilized."
    - "rather than absolute value of tor. rot., the local derivative affects stability"

Rotation Shear can Influence Tearing



Magnetic shear varies field line pitch so they travel around the island centre

- Rotation shear provides additional drive to alter field line pitch
- can **add to** or **subtract from** magnetic shear effect:



Net result is either an increase or decrease in the twist of the field about the island

- *Increases/decreases field bending energy*
- *Makes tearing easier or harder → Δ'*

Threshold Physics Makes an NTM Linearly Stable and Non-Linearly Unstable

$$\frac{\tau_R}{r^2}\frac{dw}{dt} = \Delta' + \varepsilon^{1/2}\frac{L_q}{L_p}\beta_p\left[\frac{w}{w^2+w_d^2} - \frac{w_{pol}^2}{w^3}\right]$$

Modified Rutherford Equation (MRE)

transport threshold (w_d^2)

polarization threshold (w_{pol}^2)

- **Transport threshold (R. Fitzpatrick 1995)**
  - ★ **transport along $\vec{B}$ in island is fast compared to perpendicular**
    - – helical pressure perturbation washed out if perpendicular transport dominates

$$w_d \approx \left(\frac{L_s^2}{k_\theta^2}\frac{\chi_\perp}{\chi_{II}}\right)^{1/4} \sim 1\ \text{cm}$$

- **Polarization threshold (H.R. Wilson et al., 1996)**
  - ★ **inertial effects are important in frame of E×B equilibrium flow**
    - – polarization currents induced by island propagation are stabilizing for $\omega(\omega_{*i} - \omega) > 0$

$$w_{pol} \approx (L_q/L_p)^{1/2}\varepsilon^{1/2}\rho_{\theta i} \sim 1\ \text{cm}$$

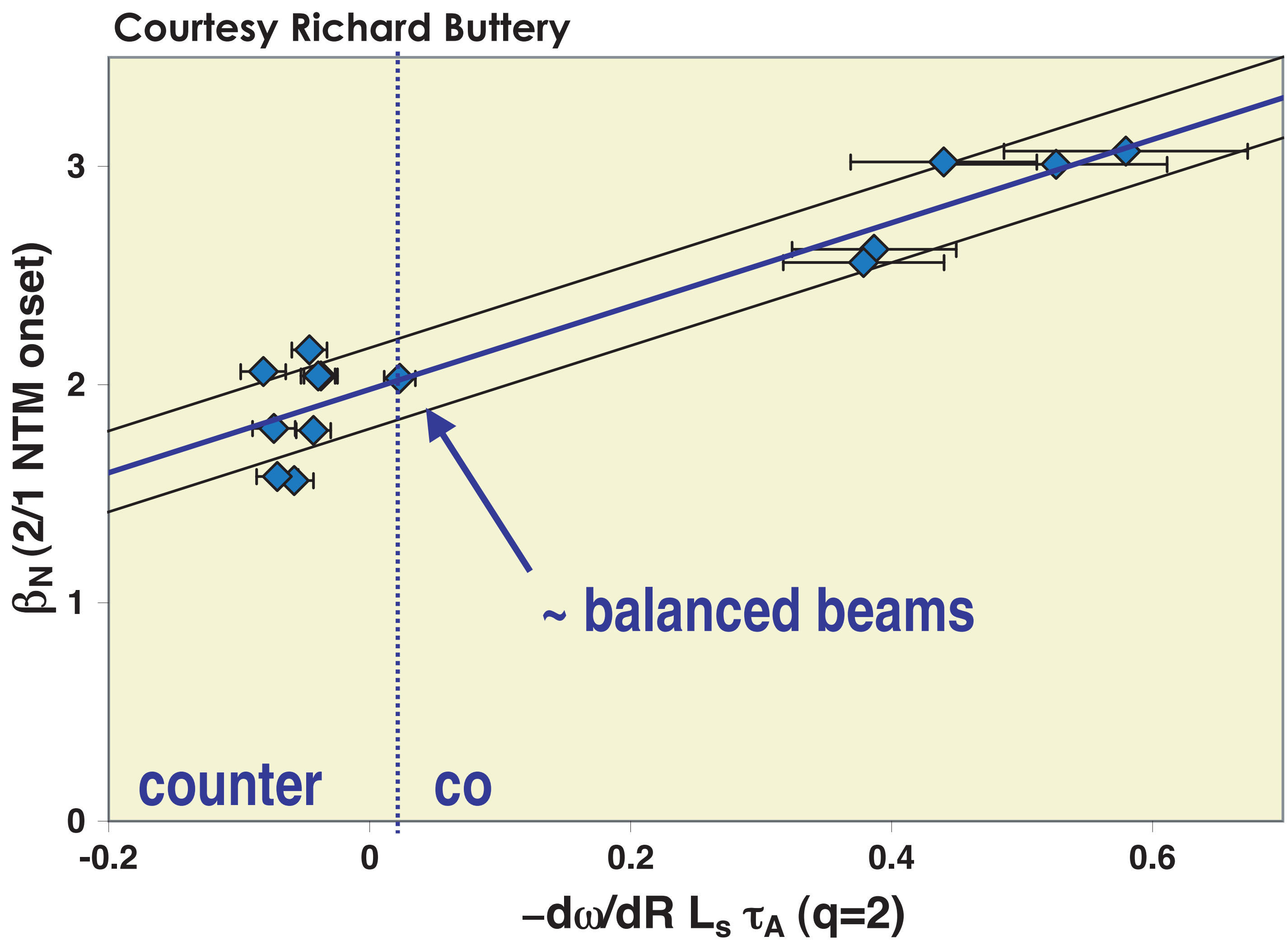
Δ' is a Key Parameter for Neoclassical Tearing Modes

- For initial growth at $dw/dt \gtrsim 0$ and $d^2w/dt^2 > 0$
  - ★ $\beta_{p,onset} \sim (-\Delta' r)$, all else equal
- For saturated island $dw/dt \approx 0$ and $d^2w/dt^2 < 0$
  - ★ $w_{sat} \sim (-\Delta' r)^{-1}$, all else equal

- Let $\Delta' r \equiv C_1 + C_2\left(-\frac{d\omega_\phi}{dR} L_s \tau_A\right)$
  - ★ as simplest empirical form for effect of flow shear
    - – normalized by magnetic shear length $L_s = qL_q/(r/R)$
    - ... and Alfvén time $\tau_A = R_0 \sqrt{\mu_o n_e m_i}/B_{To}$

m/n = 2/1 Onset Beta Larger With More Flow Shear

- $-d\omega/dR\ L_S\tau_A$ (q=2) ≈ 1 doubles beta at onset

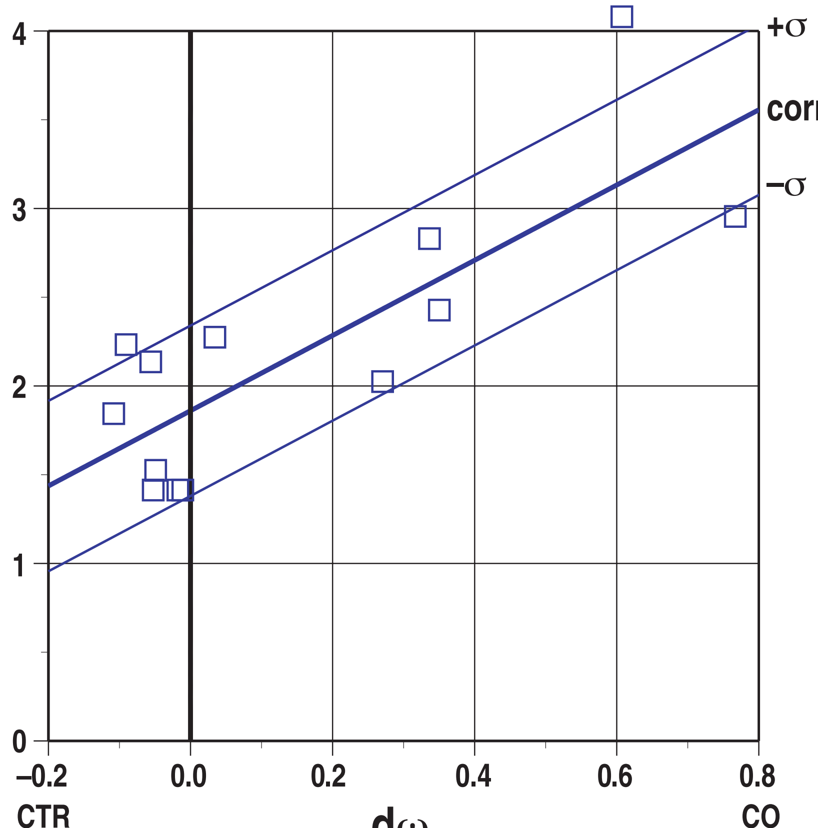


m/n 3/2 Saturated Islands Smaller With More Flow Shear

- **Bootstrap term balanced by Δ' term in MRE**

$$Y = \frac{\varepsilon^{1/2}\,\beta_{\theta e} L_q r_s}{w\,L_{pe}}$$

(Helically Perturbed Bootstrap Term in MRE)



$$X \equiv -\frac{d\omega_\phi}{dR} L_s \tau_A$$

- **Yields $\Delta' r = (-1.86 \pm 0.44) + (-2.12 \pm 1.39) * (-d\omega_\phi/dR\ L_s\tau_A)$**
  - ★ **Factor of two increase in tearing stability is $-d\omega_\phi/dR\ L_s\tau_A \approx 0.9$**

New Modeling and Analytic Theory are in Process

- **NEAR code (A. Sen, et al., IPR, Gujarat**
  - ★ **dominant effect comes from the outer layer modification to Δ'**

    . . . scaling of Δ' to velocity shear is quite close to heuristic model

    – approximate derivation under construction

- **New analytic calculation underway (C. Hegna, Univ. Wisconsin, Madison)**
  - ★ **shear flow affects the asymptotic matching data (Δ')**

    . . . analytic estimate for Δ' being developed in “large m” approximation for exterior region solution

    – APS07, more to follow

- **NIMROD code to be used to study shear effects**
  - ★ **D.Brennan, Univ. Tulsa and S. Kruger; Tech-X Corp**

A Level for Significant Plasma Rotation Radial Shear is Found

- $-\frac{d\omega_\phi}{dR} \approx \frac{\tau_A^{-1}}{L_s}$ @ q=m/n
  - ★ should have a factor of two stabilizing effect on tearing Δ'
    - – removing it makes Δ' less negative, i.e. destabilizing with "balanced beams"
      ... thus an advantage for all co beams
    - – going to counter dominated, $\frac{d\omega_\phi}{dR} > 0$,
      ... is even more destabilizing for $L_q > 0$?
      ... to be examined experimentally in 2008 with reversed I_p and B_T

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