Influence of q profile on Tearing Stability & Error Field Sensitivity

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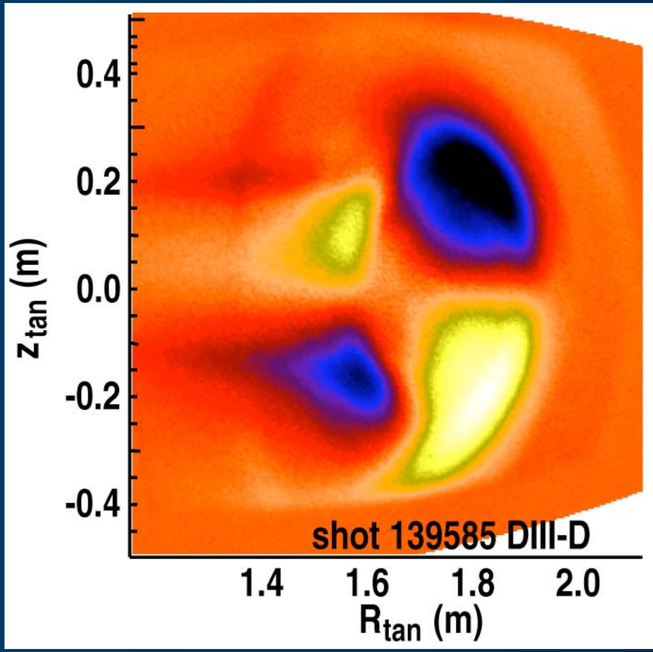

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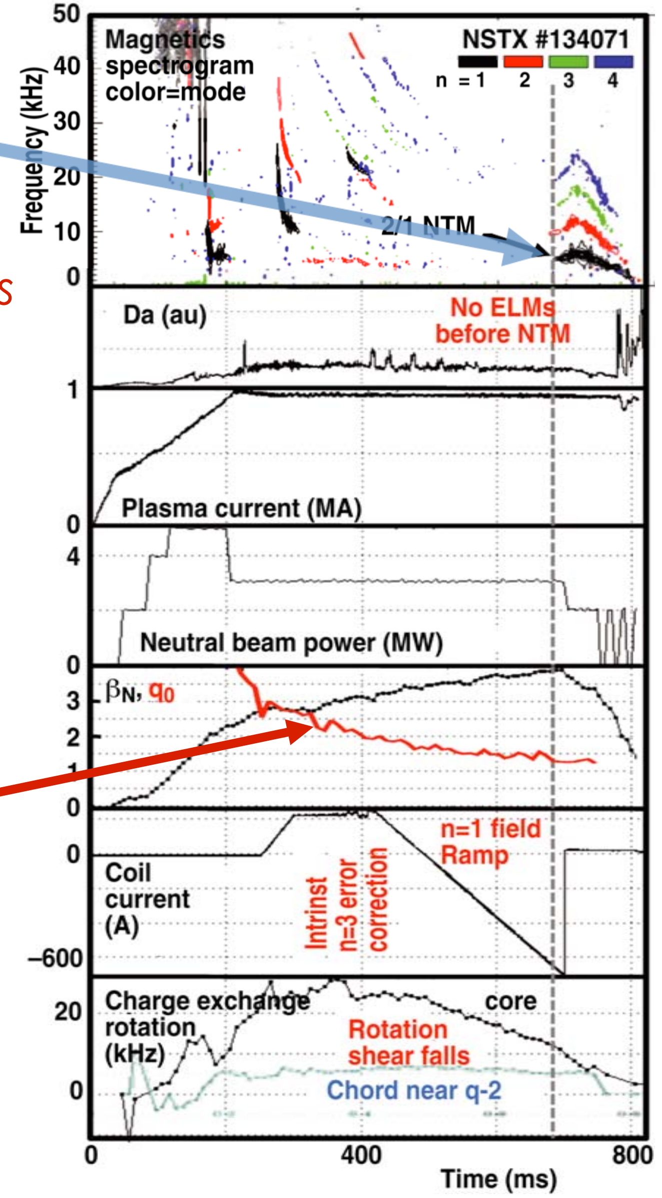
Tearing Modes are Critically Dependent on the q Profile

- **2/1 modes come out of the noise**
  - Intrinsic tearing instability, driven by dJ/dR
  - Performance limit that depends on q profile
    - *Likely source of variation in previous scaling studies*
- **Error field thresholds depend on TM stability**
  - EF brakes plasma accessing TM instability (←q)
  - May further depend on q profile if plasma response amplifies fields differently
- **Need to probe both tearing β limit & error field threshold (2 effects) vs q profile**
  - Exploit natural q profile evolution on NSTX
  - Ramps in **β or error field**; Vary ramps to scan q
  - Tune to control n_e or access higher q_{min}



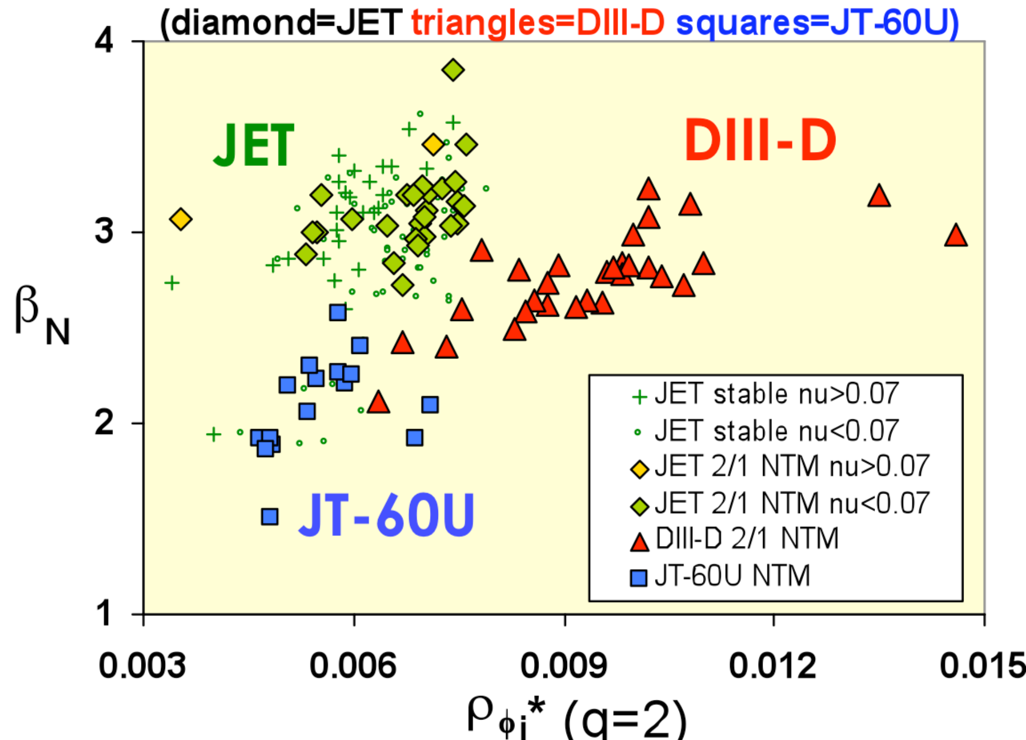
This is key to developing regimes for future devices & understanding tearing physics in general

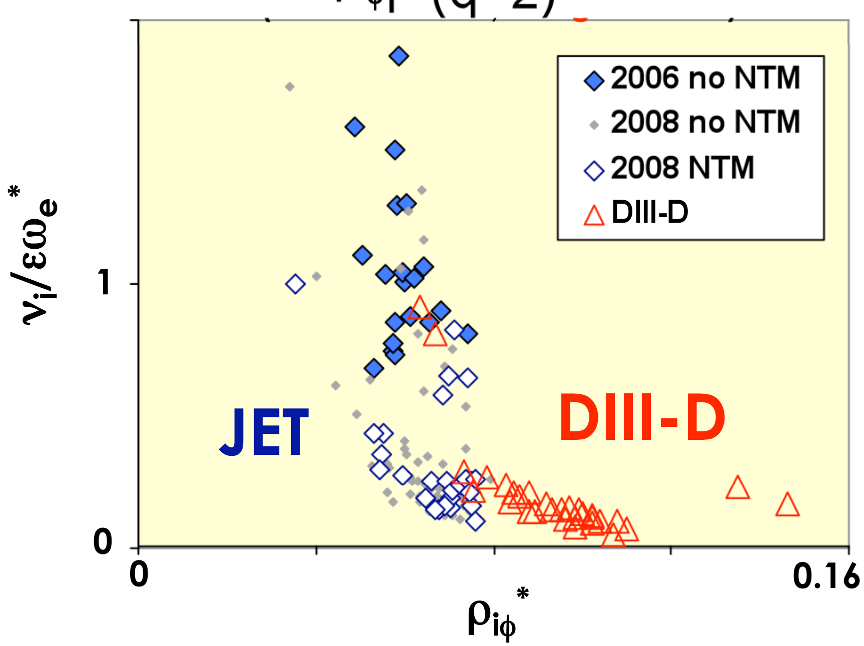
- **Extra slides for background or discussion…**

JET Hybrid Plasmas Sit Above β Limit of Other Devices: *Other parameters coming into play – q profile?*

- **JET sits above DIII-D and JT-60U trends**
  - JT-60U lower rotation →lower β_N
  - But DIII-D high rotation
- **Possible collisionality role? <u>No</u>:**
  - JET unstable at ◆ low ν^*
  - But stable at +high and ∘ low ν^*

→**Collisionality provides 'access condition' for NTM**
  - Enables q profile modification
  - Can change Δ'
  - *q profile is the parameter to test…*

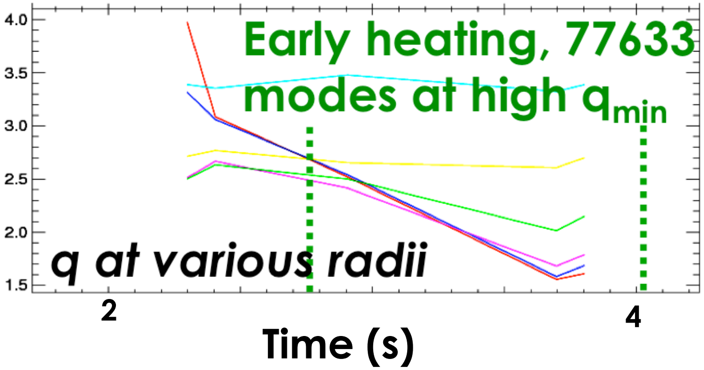




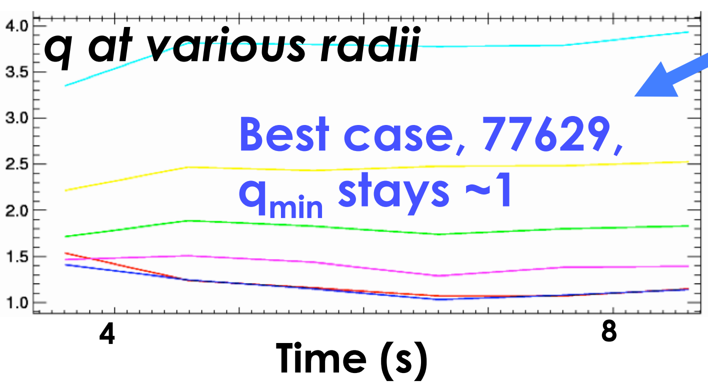
National Spherical Torus Experiment

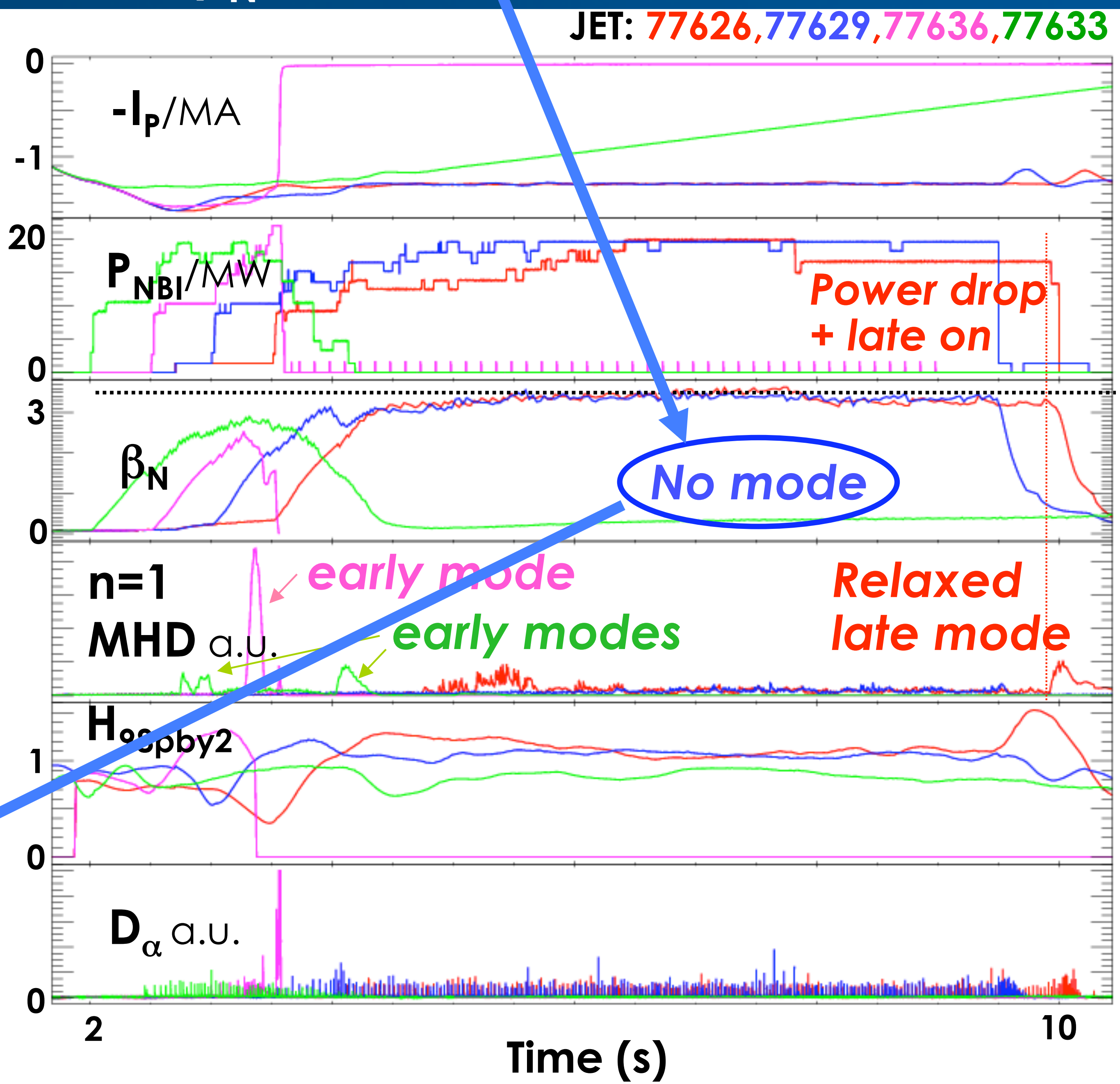
JET shows 'just right' degree of relaxation needed to maintain stability at high β_N

- **Mode if profiles too 'advanced':**

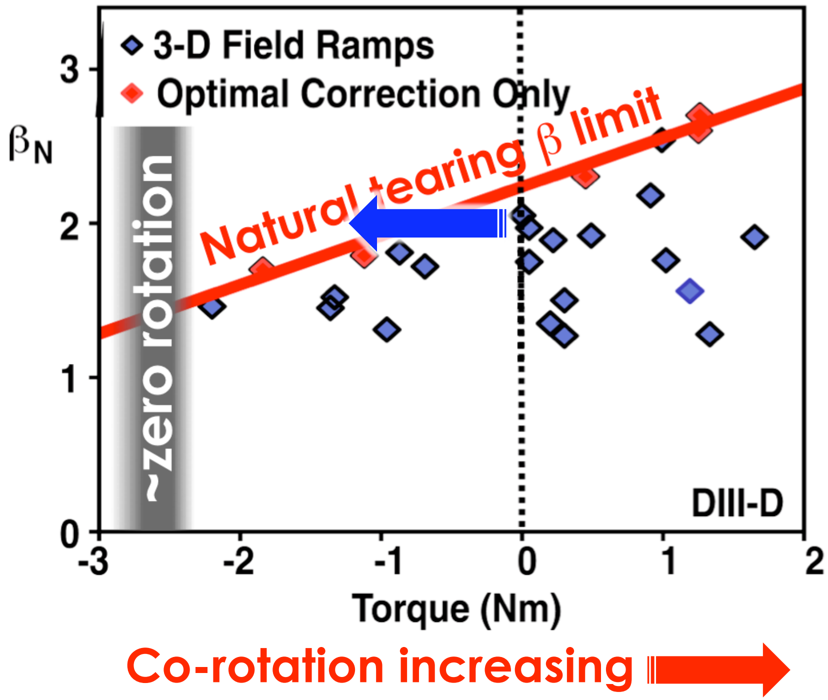


- **Fully relaxed plasma also less stable**
  - Mode at lower β_N or occurs later

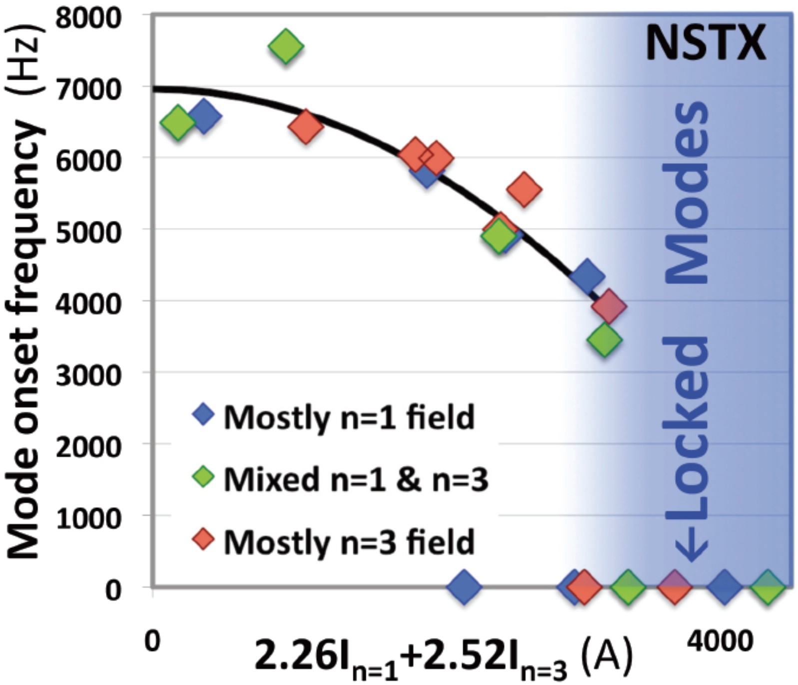




Background: Error Fields Access Tearing Instability by Lowering Rotation Shear



- **DIII-D shows operational relationship between "natural" & "error field" tearing modes**



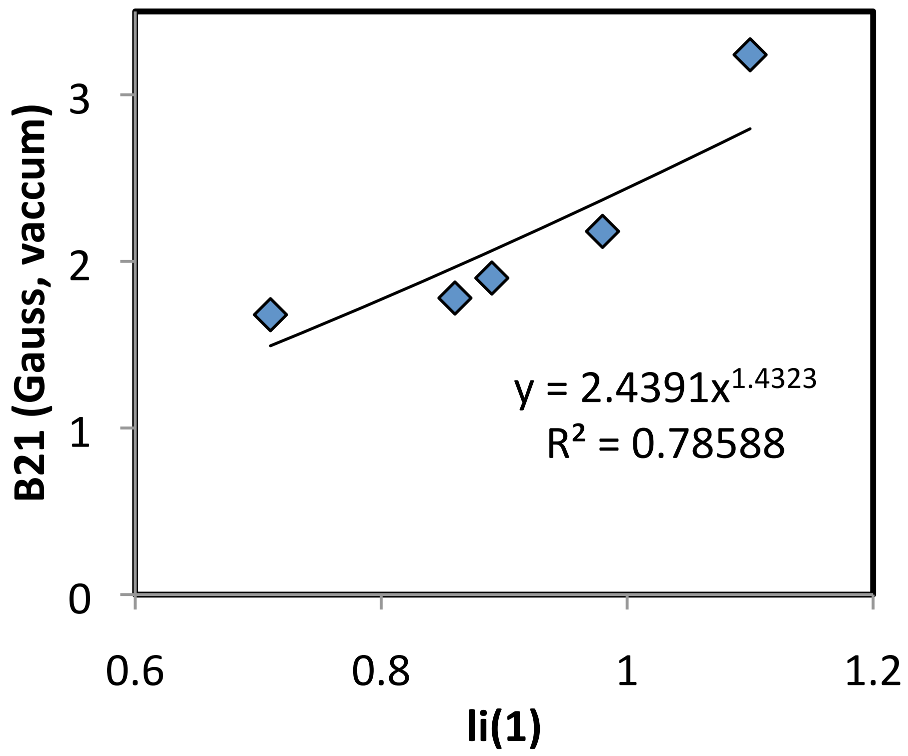
- **NSTX shows connection of rotating and locked mode onset mechanisms**

Error Field Thresholds Depend on J Profile

- **Data from Ohmic plasmas JET:**
  - Fast current ramp flattens q and moves q=2 further in

Table 4. The (2,1) field (at the $q = 2$ surface) required for the error field mode in low-l_i (2.5 MA, 2.5 T) pulses compared with the standard value corrected for density variation and intrinsic error

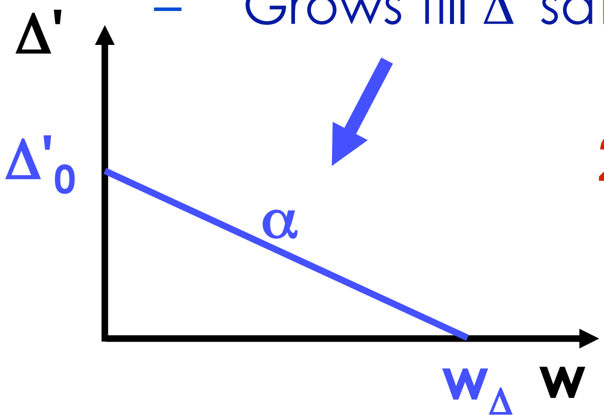
Pulse	l_i	Threshold (G)
Average of standard l_i pulses	1.1	3.24
44254	0.89	1.90
44255	0.86	1.78
44256	0.98	2.18
44258	0.71 (8 MW ICRF)	1.68



[Buttery NF 2000]

Possible 'Minimal' Δ' Model of Tearing Mode Triggering

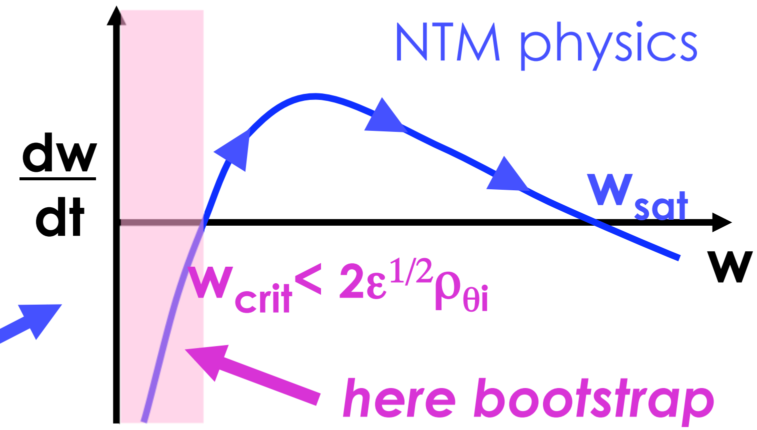
1. **Positive Δ' excites a small island**
   - Grows till Δ' saturation, $w_\Delta = \Delta'_0 / \alpha$



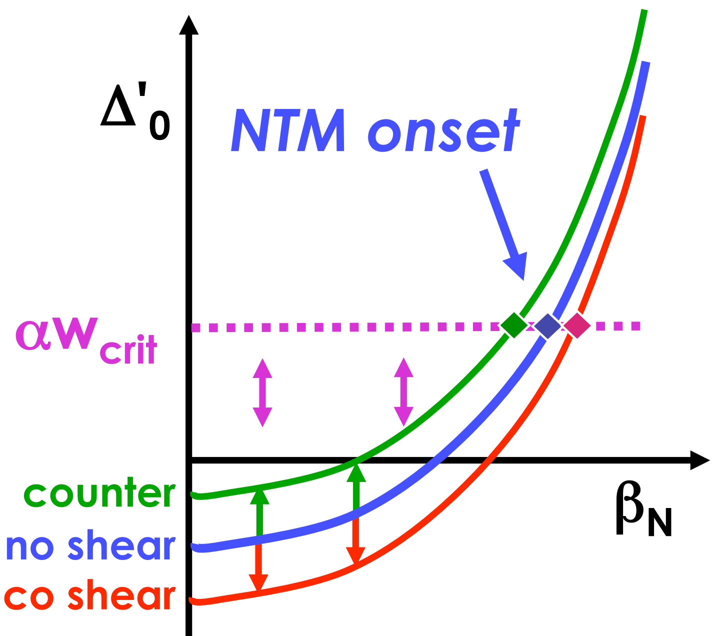
2. **Growth becomes "neoclassical" if island big enough:**

   $w_\Delta > w_{crit}$

   $\Rightarrow \Delta'_0 > \alpha\, w_{crit}$



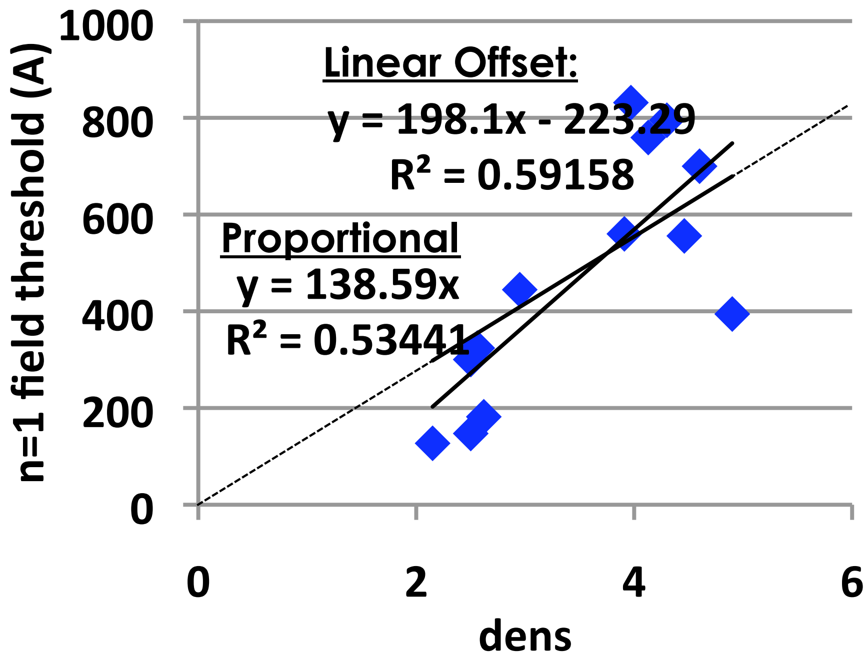
here bootstrap hole suppressed by finite island transport

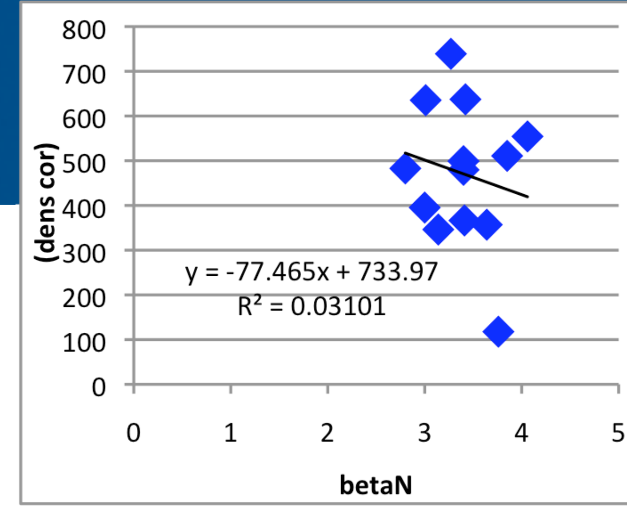


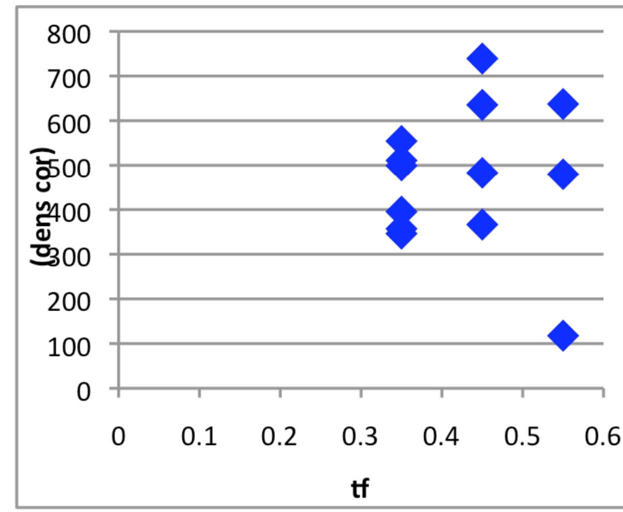
3. **Δ'_0 is function of rotation shear and β_N**
   - Increases/decreases in rotation shear will change tearing mode onset β_N
   - ρ^* variation introduced through w_{crit}
   - ***but note much harder to excite mode at low β_N away from Δ' pole***

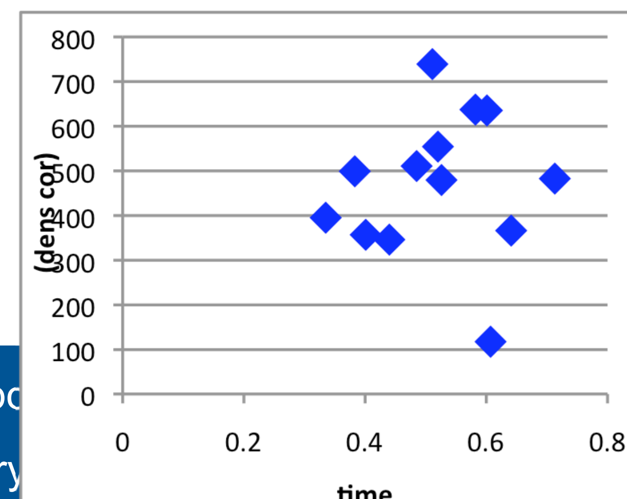
2010 NSTX EF Scaling Study Shows Considerable Scatter

- **Use offset linear density fit to correct out density variation**
  - No obvious trend in other variables now! ➔
  - Can we do better based on phenomenology?...







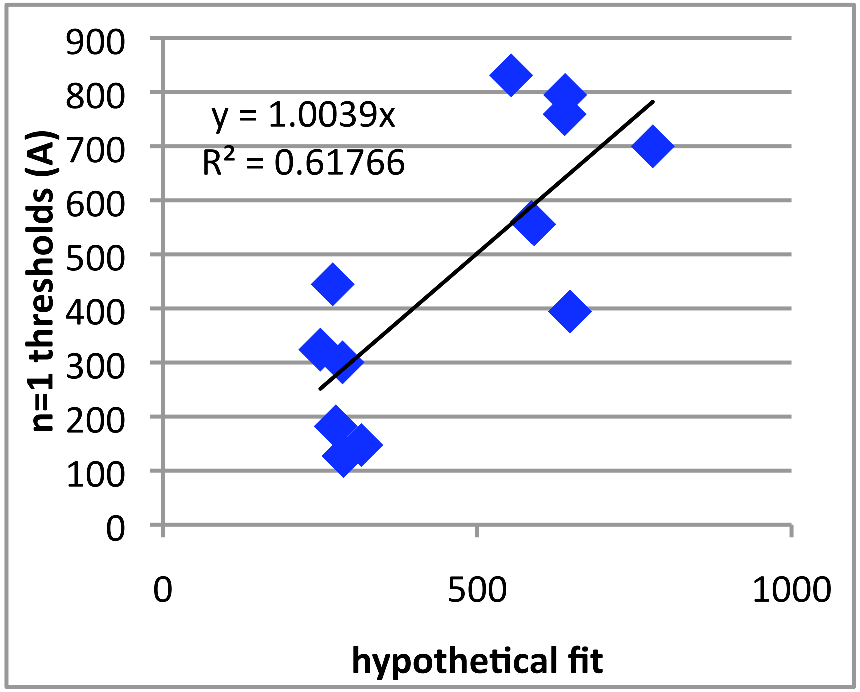


NSTX 2010: Make a fit based on intuition

- **Hypothesize power law form constructed:**
  - Positive density dependence seems clear
  - Shot phenomenology shows less or no error field needed if higher β_N – suggests negative β_N exponent
  - Arbitrary TF coefficient
- **Start from this and vary coefficents by hand to minimise residual**
  - ***Actually get a better fit than regression fitting!***
- **Form found:**

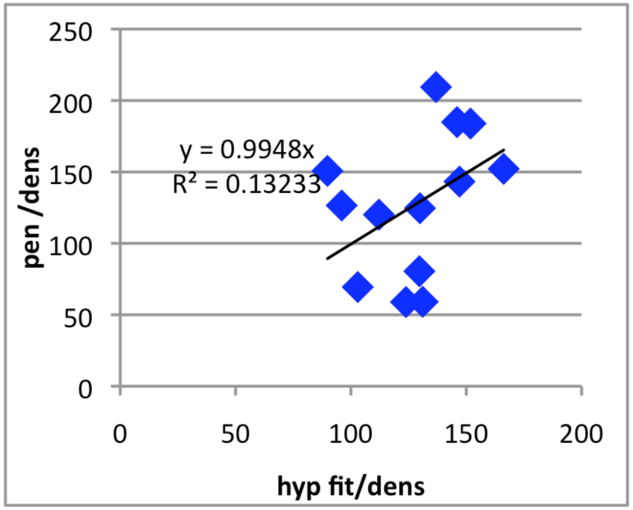
$$I_{pen} \sim n_e \ \beta_N^{-1.25} B_T^{0.6}$$

  - Can we constrain more than one variable?

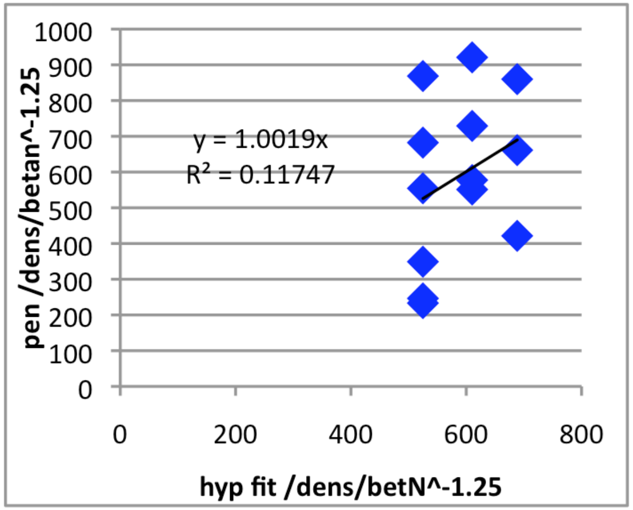


NSTX 2010: Is there a residual dependence in the fit?

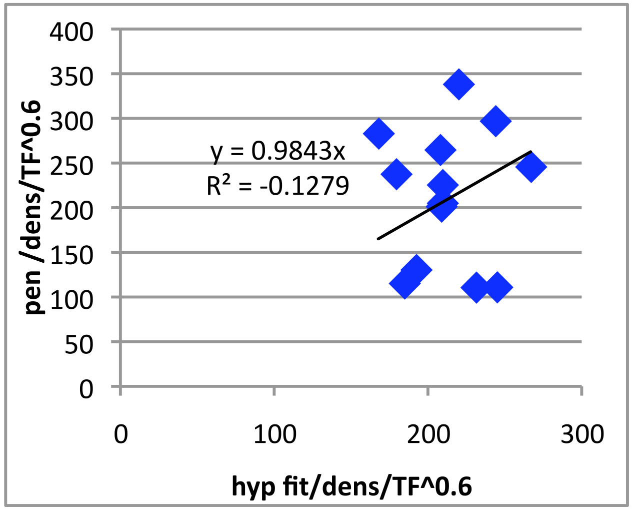
- **Stripping out density dependence ➔ leaves weak correlation**
  - Further analysis shows might be B_T or β_N,
  - but neither is well constrained & there may be no further trend!
  - **Possible further hidden variables?**
    - **Keep looking!**
    - **q profile, MHD?**



Remaining B_T variation:



Remaining β_N variation:



Governing Physics – á la old Ohmic theory…
Penetration is about overcoming the plasma rotation

- **Modes form when resonant surface is braked by resonant response to EF to half it's natural frequency**
  - Tiny static island induced by EF
  - Viscous forces try to keep bulk plasma rotating slipping past the island - *this opposes island growth*
  - Torque exerted through island and viscosity to brakes plasma
    - *N=3 NTV effects assist this process?*
  - If rotation slows enough, island can grow, increasing torque and bifurcating to a locked mode state
  - Threshold scales as $B_{pen} \sim B_T\ \omega_0\ \tau_A\ (\tau_{rec} / \tau_v)^{1/2}$
    - *ω_0 often taken to be electron diamagnetic rotation*
- **Criteria could also be regarded/generalised as condition for when we approach rapid rotation change**
- **Critical elements are:** what determines ω_0; whether plasma response changes; and how readily plasma rotation is overcome