US MHD Workshop, 23-25 Nov 2008, Austin:

Rotation and Error Field influences on NTMs

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with special thanks and considerable input from:
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Three Questions

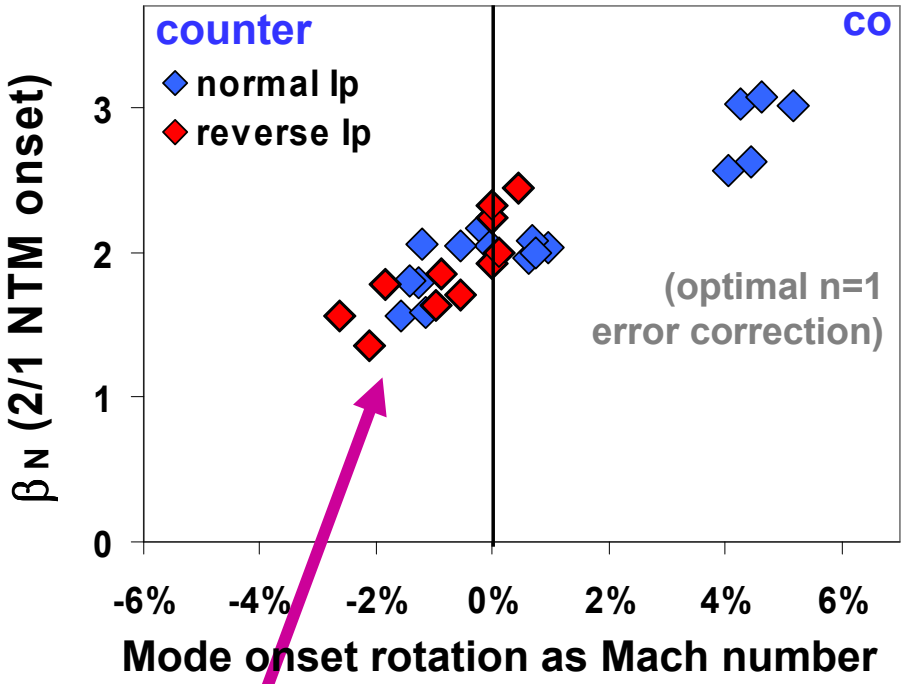
1. Is there an asymmetry in the influence of rotation on tearing stability?

2. Is 2/1 mode onset threshold mostly governed by intrinsic tearing stability?

3. Does proximity to intrinsic tearing instability lower error field thresholds?

DIII-D normal & reverse I_p data shows strong rotation trend

- Clear β_N fall with increasing counter rotation



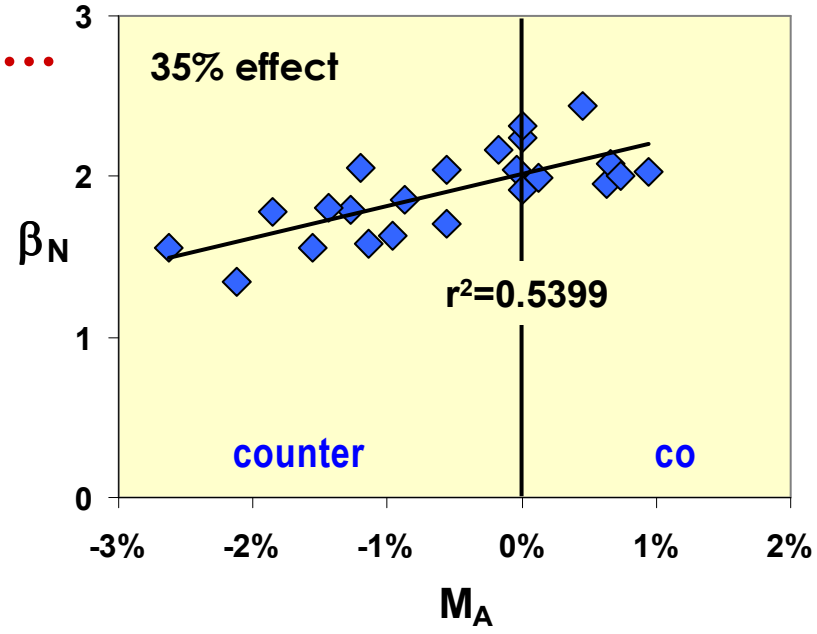
Is counter rotation trend a 'real' effect in underlying tearing physics?

– *or just profile variation?*

Fall in threshold with counter rotation is a real effect…

Consider only low rotation DIII-D data…

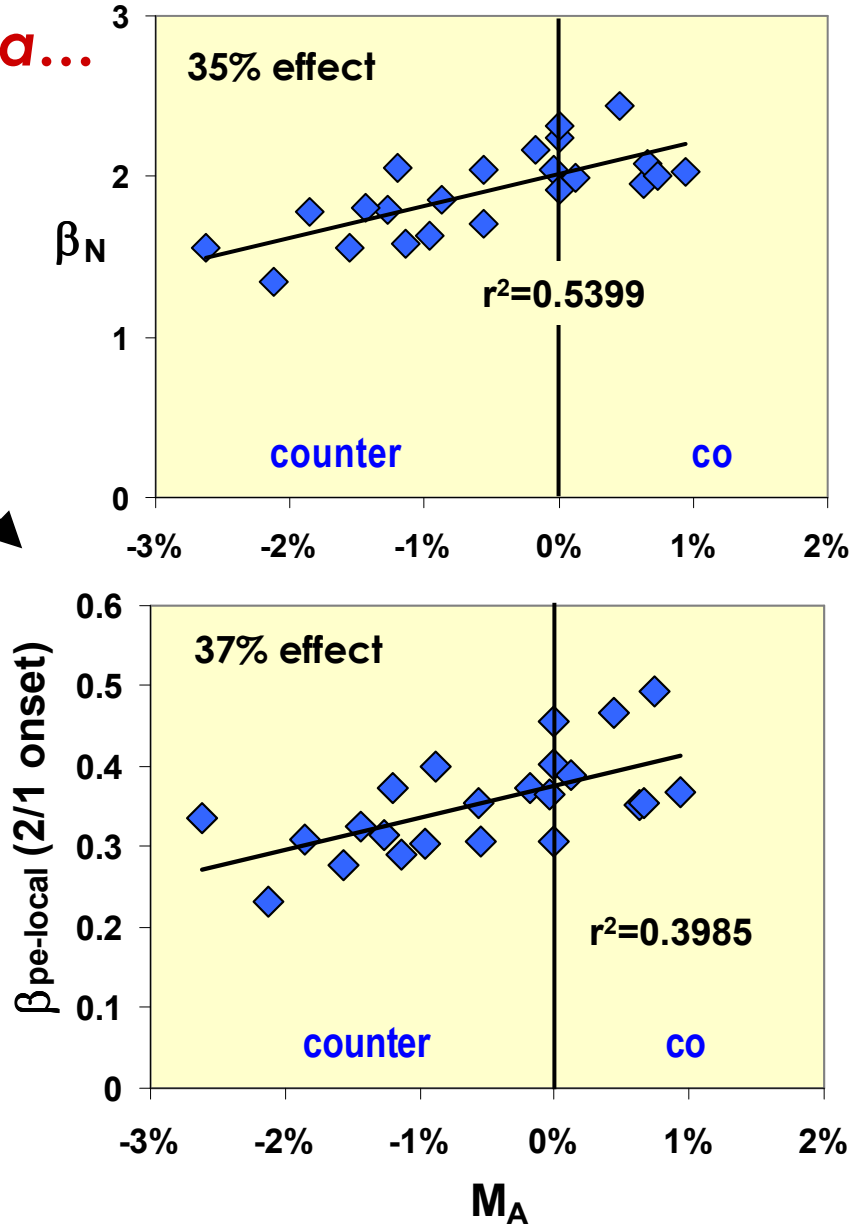
- Clear trend in β_N



Fall in threshold with counter rotation is a real effect…

Consider only low rotation DIII-D data…

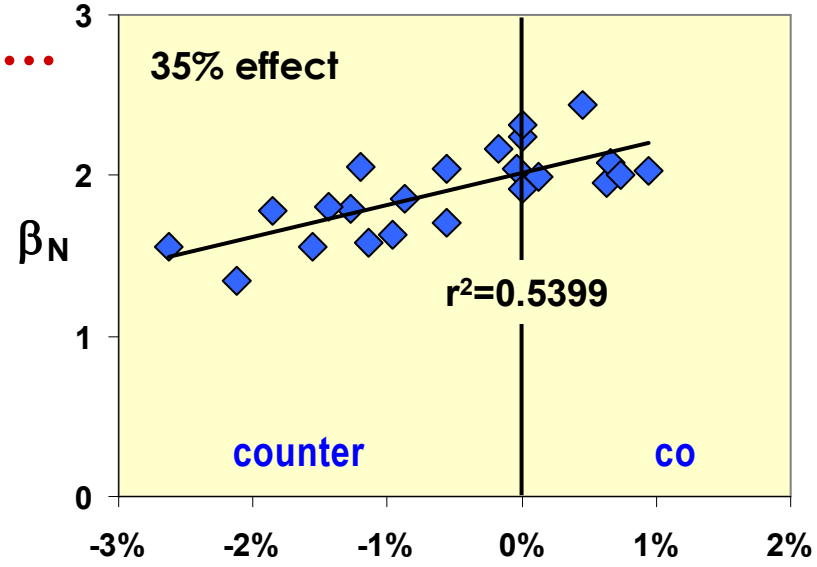
- Clear trend in β_N
- Similar trend in local β_{Pe}

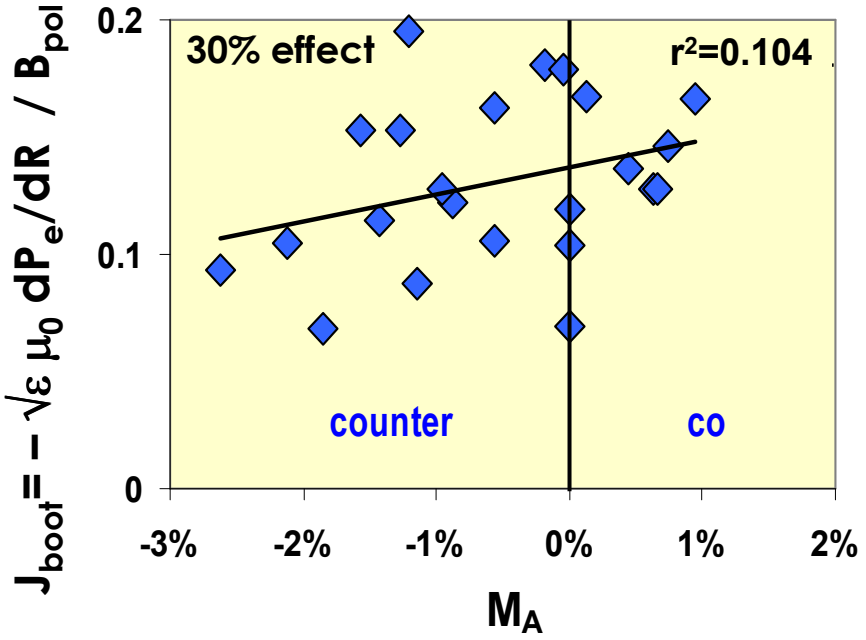


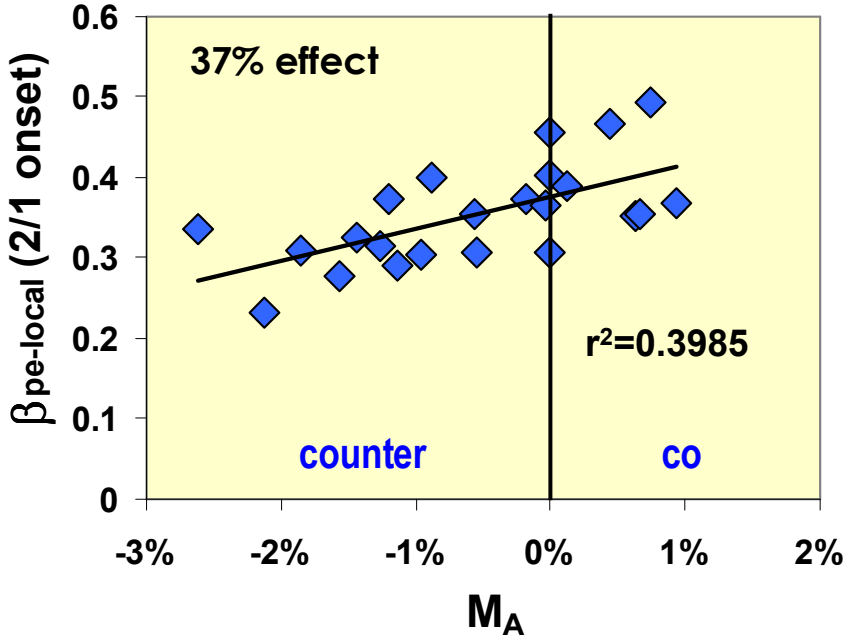
Fall in threshold with counter rotation is a real effect

Consider only low rotation DIII-D data…

- Clear trend in β_N
- Similar trend in local β_{Pe}
- …and in bootstrap measure (?)
  - *noisier – more local gradients used*



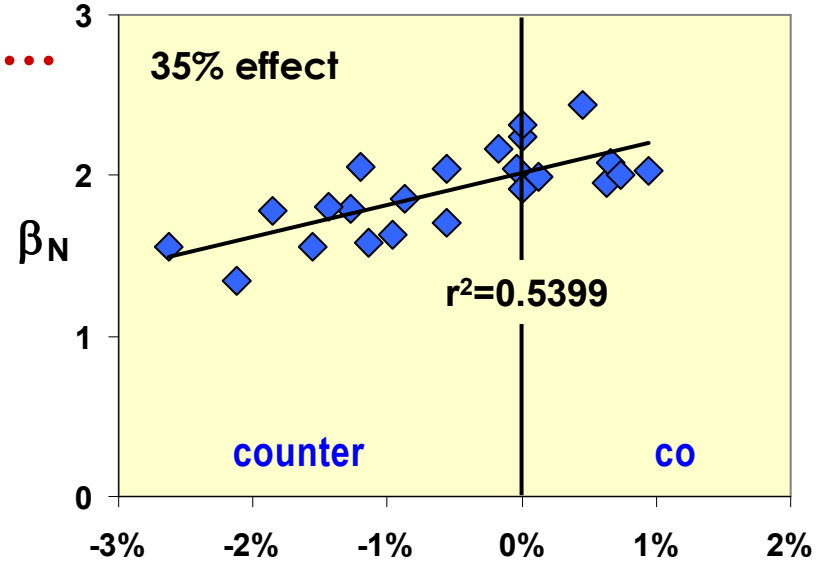


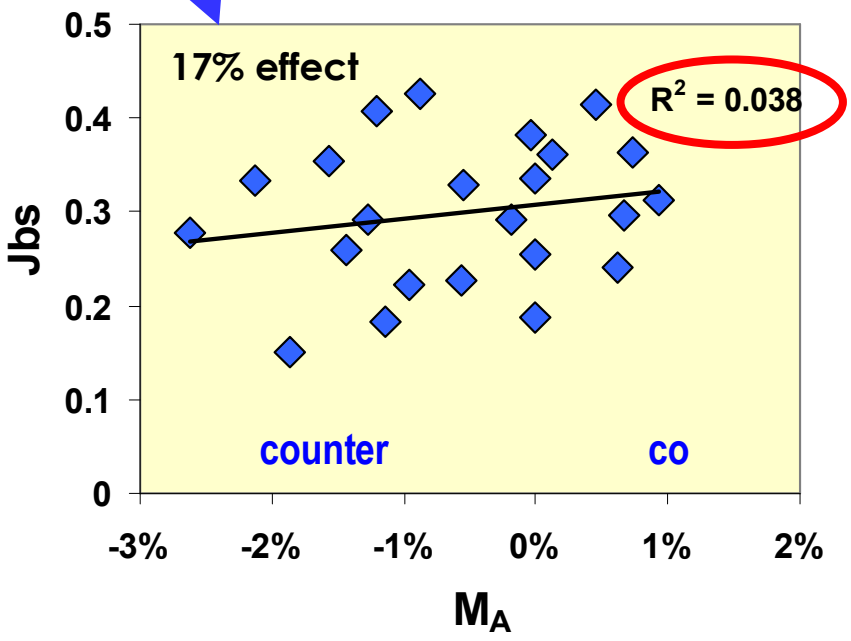


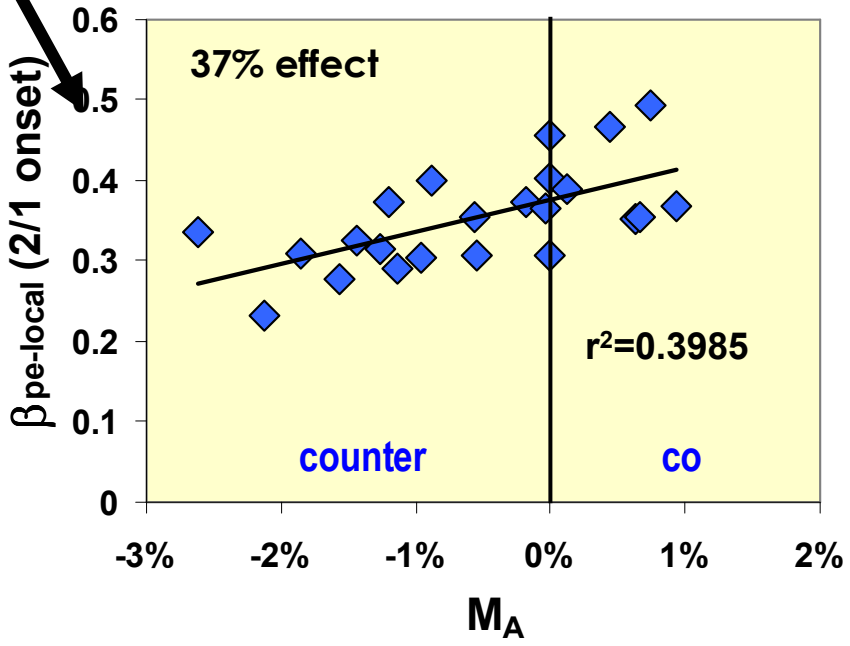
Fall in threshold with counter rotation is a real effect

Consider only low rotation DIII-D data…

- Clear trend in β_N
- Similar trend in local β_{Pe}
- …and in bootstrap measure (?)
  - *noisier – more local gradients used*
  - ***Even noisier with full bootstrap***



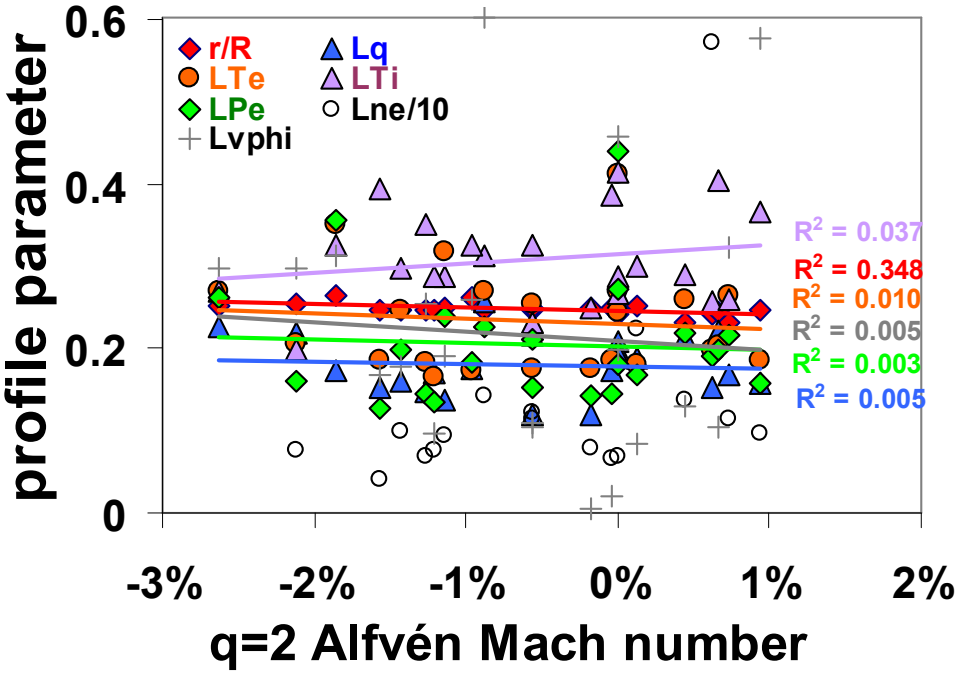




Is there a real trend in local parameters? Yes…

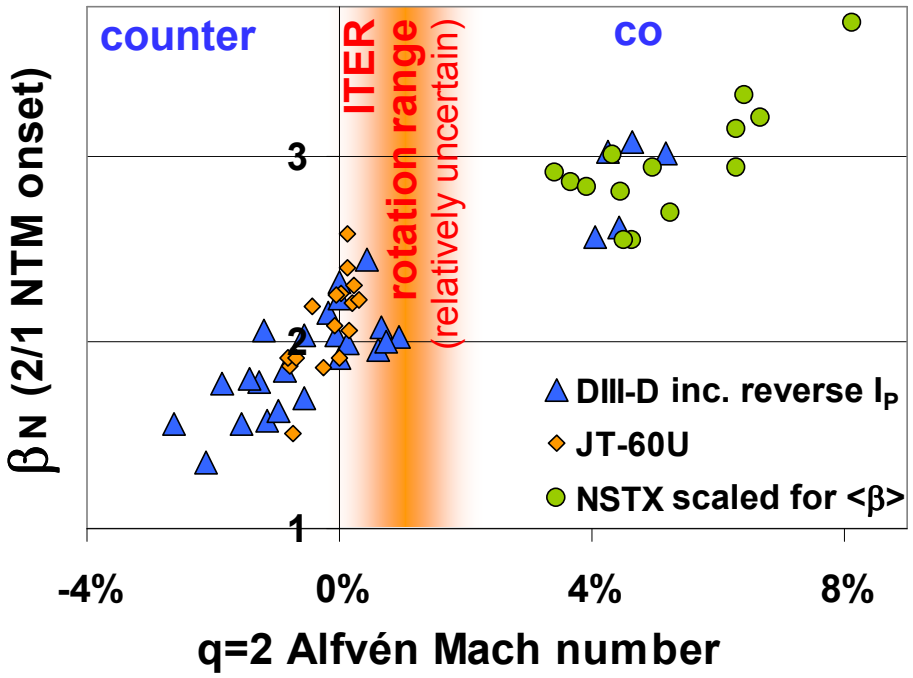
Examine local scale lengths:

- **No significant trends** ⟶
  - ➢ ***No systematic variation in profiles with rotation***
  - ➢ ***Effect observed in β_N and 'rough' local calculations corresponds to a real variation in NTM drives***
    - ***Effect weakened in J_{BS} mainly due to noise***



Cross-machine comparison confirms asymmetry

- **JT-60U also shows a possible asymmetry in rotation role**
  - *Possibly steeper?*



[Buttery et al., IAEA 2008]

First Question…

1. Is there an asymmetry in the influence of rotation on tearing stability?
   - Yes

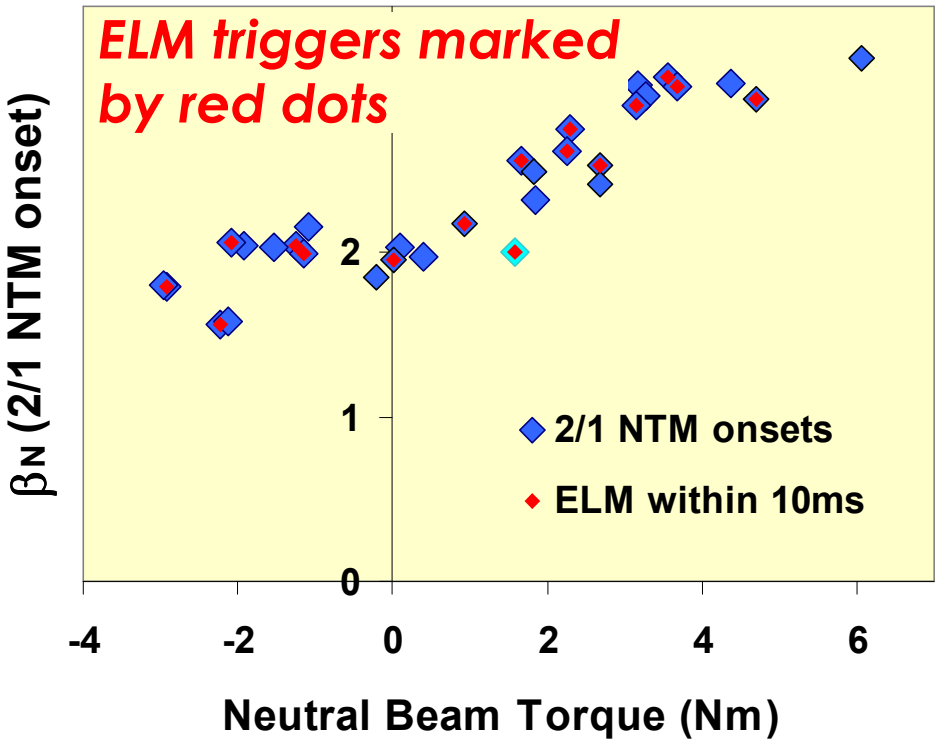
2. Is 2/1 mode onset threshold mostly governed by intrinsic tearing stability?

3. Does proximity to intrinsic tearing instability lower error field thresholds?

ELM role in 2/1 triggering appears incidental

ELMs 'trigger' about half the 2/1 NTMs:

- ***But trigger has no influence on NTM onset β_N***
  - *And trigger type not correlated with rotation*



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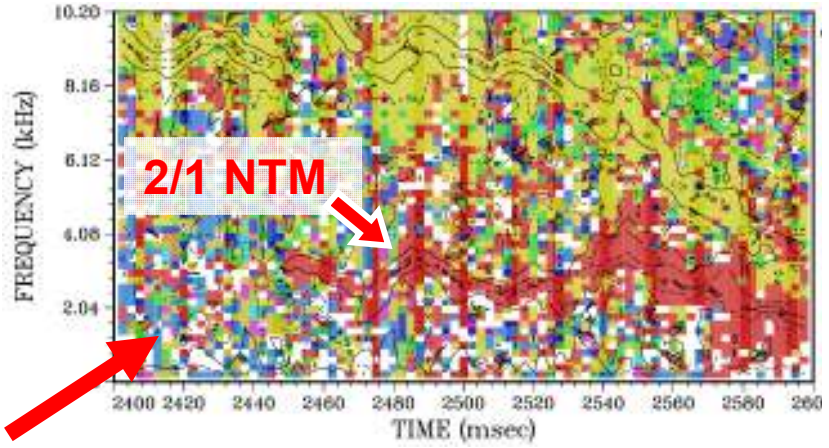

Triggerless NTMs come out the noise

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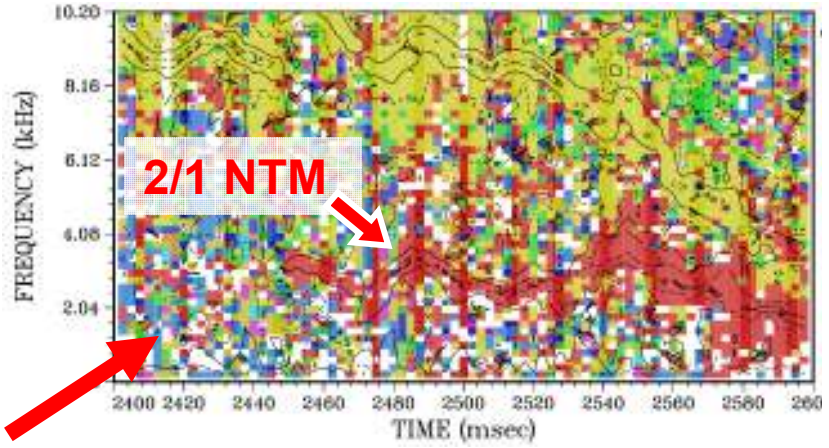


Triggerless NTMs come out the noise

➔ ***NTM onset β is <u>not</u> about "triggered seed exceeding threshold width"*** ←ρ* dependent

➔ ***Instead: dictated by changes in the intrinsic tearing stability that govern the trigger-less modes***

➔ ***Raises question of whether to expect a ρ^* dependence in $\beta_{NTM\ onset}$?***

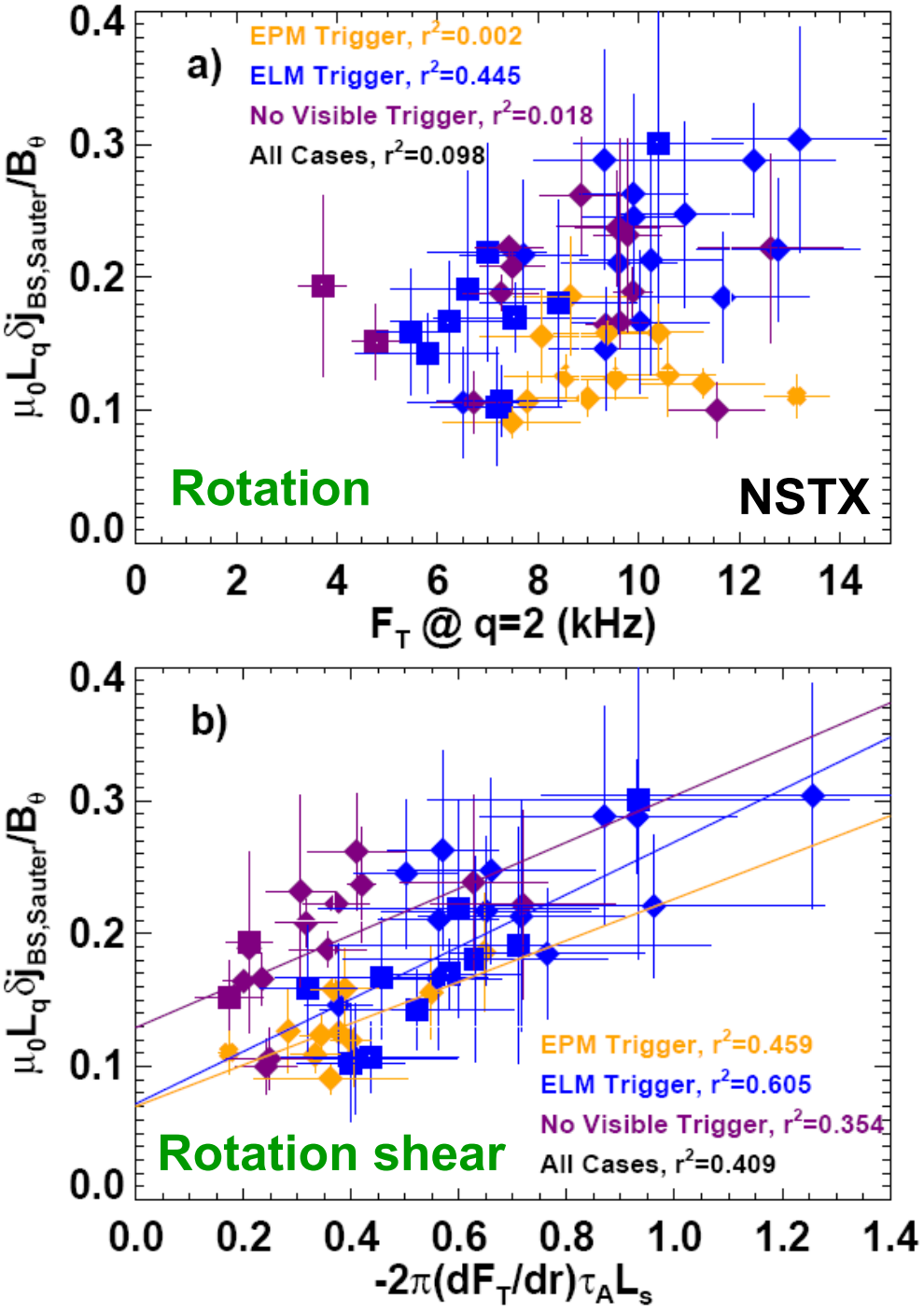
NSTX observations suggest it is about intrinsic stability

NSTX can deconvolve rotation from rotation shear:

- ***Rotation shear gives visibly clearer trends***

➢ ***Suggests an action through intrinsic tearing stability***

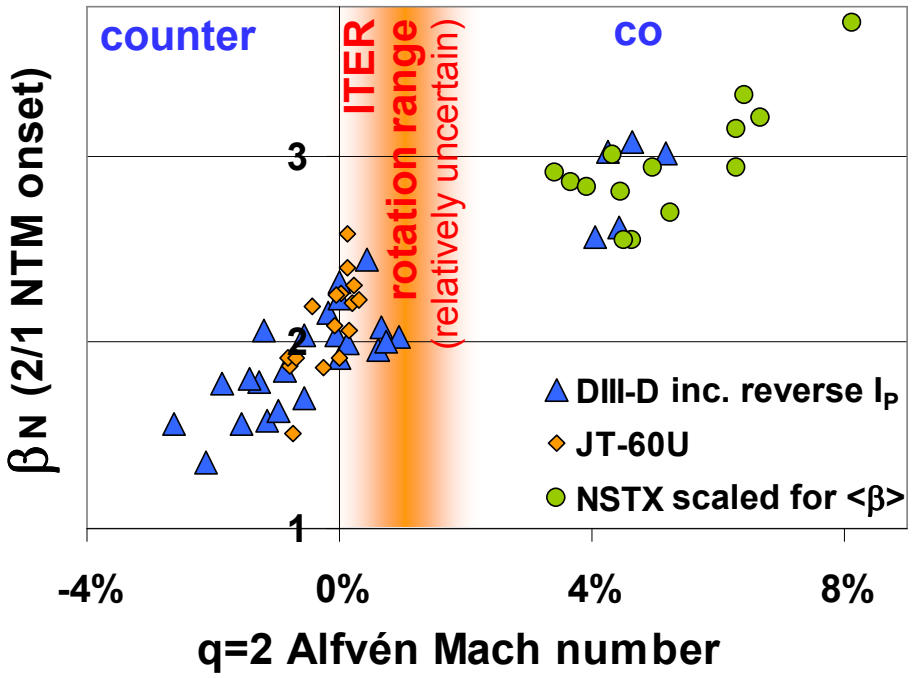
- External effects such as coupling, walls, etc. would depend on rotation
- Though trigger type can play some role…



[S. Gerhardt, NF letter submitted]

Cross-machine comparison confirms asymmetry & suggest limit related to ideal MHD

- **JT-60U also shows a possible asymmetry in rotation role**
  - *Possibly steeper?*
- **Devices line up when plotted with correction for $<\beta_N>$**
  - NSTX data scaled to get this
  - $<\beta_N>$ relates to ideal limit
  - 'poles in Δ'' model



[Buttery et al., IAEA 2008]

- **Phenomenology suggests:**
  - **Tearing threshold arises from change in intrinsic tearing stability as ideal limit is approached**
  - **But rotation (relative to Alfvén) further changes the tearing stability**

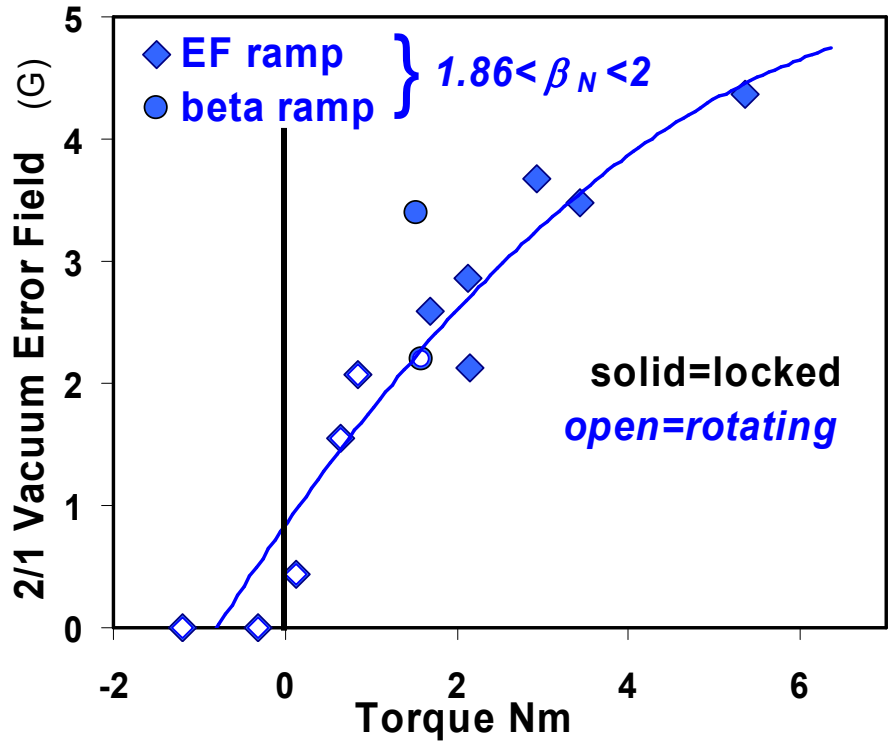
Second Question…

1. Is there an asymmetry in the influence of rotation on tearing stability?
   - Yes
2. Is 2/1 mode onset threshold mostly governed by intrinsic tearing stability?
   - Yes
3. Does proximity to intrinsic tearing instability lower error field thresholds?

Error fields assist medium β_N tearing mode formation

Hold β_N~1.9 and vary torque from shot to shot:

- ◆ Error field threshold falls with torque
- ◇ But rotating modes at low torque!
  - ***Intrinsic tearing stability is being modified…***
  - ***…by rotation perturbation?***



(◆Similar to advanced scenario observations of Reimerdes: PO3.00011)

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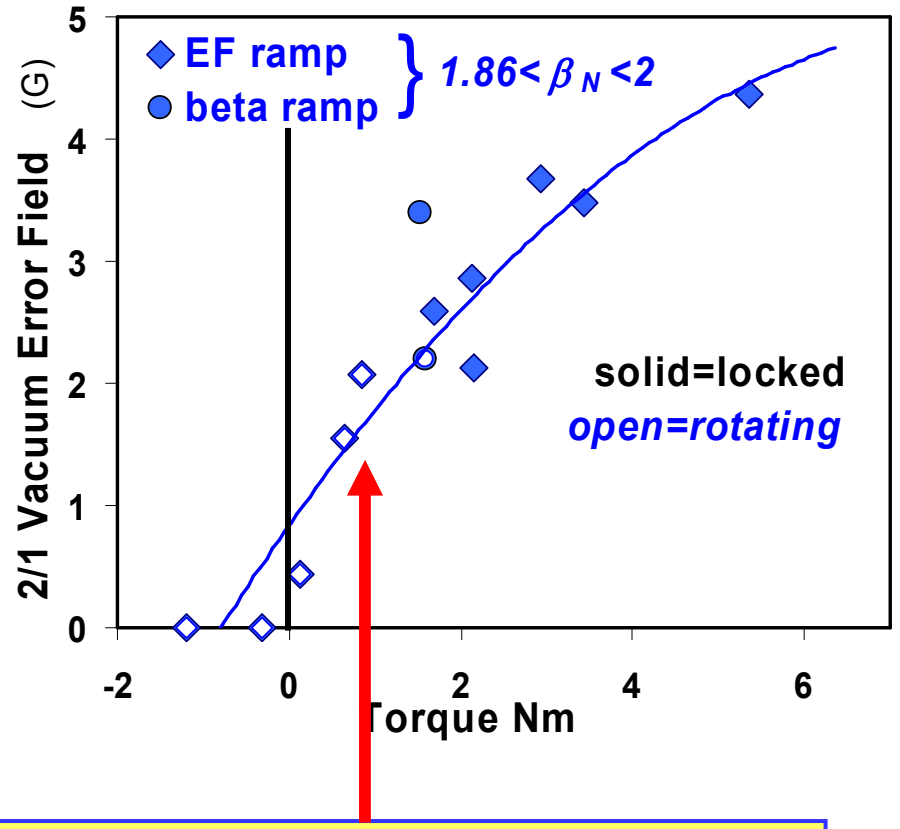

ITER relevant torques/rotations just stable with good error correction:

$\delta B_{21}/B_T < 1.10^{-4}$

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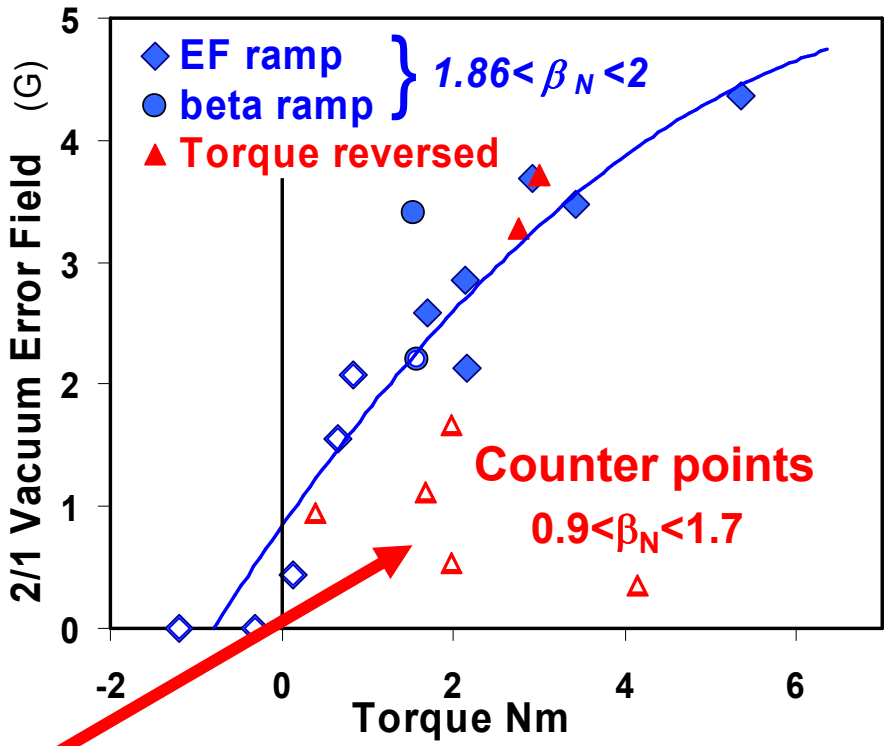


Compare with counter torque (Δ)

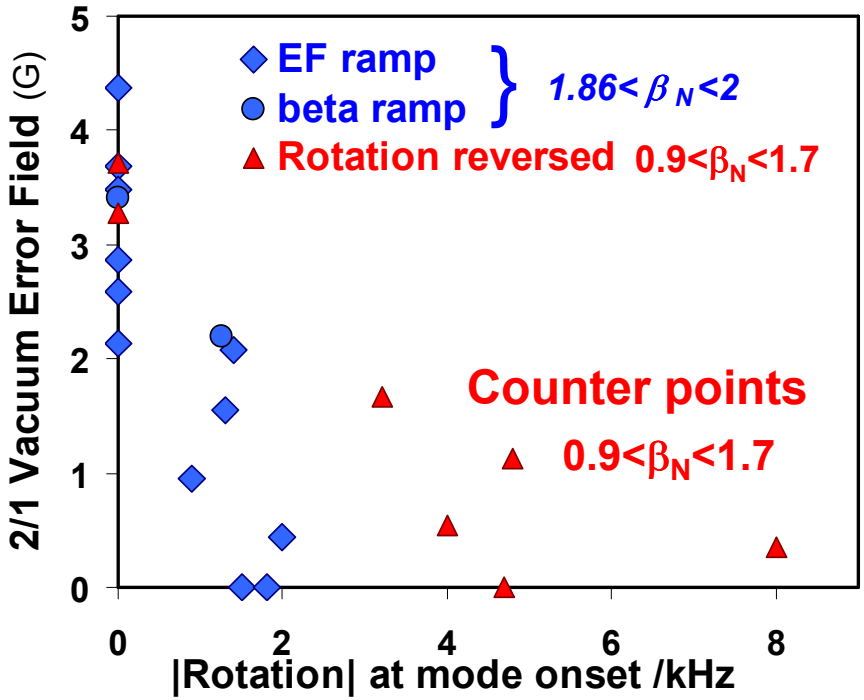
- **Error field thresholds are lower!**
  - ***Despite generally being at lower β_N values!***
    - *Is this to do with mode rotations?...*

Error fields assist medium β_N tearing mode formation

Compare co and counter rotating cases:

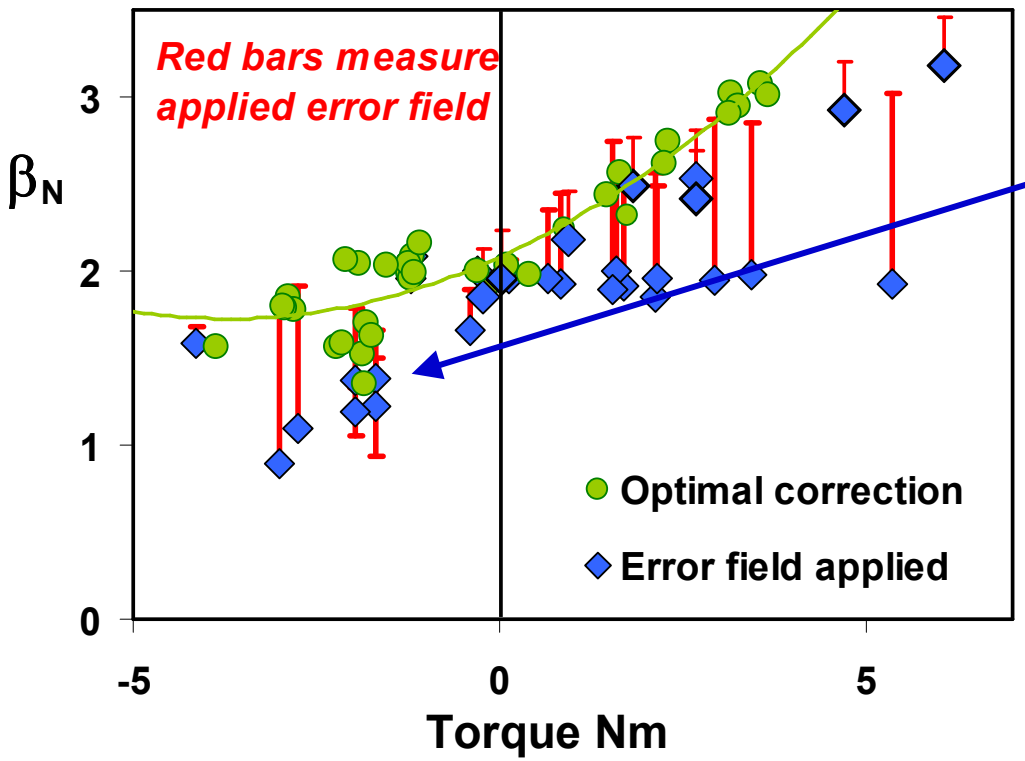
- **Counter points rotate faster!**
  - *Once again:* ***Counter rotation seems intrinsically less stable than co***
    - ***This time seen through error field thresholds***
  - ***Is error field sensitivity picking up on decreased intrinsic tearing stability at low & counter rotation?***

Re-plot vs mode onset rotation:



Amount of error field needed depends on proximity to NTM limit at a given torque?

Full data set gives an interesting picture:



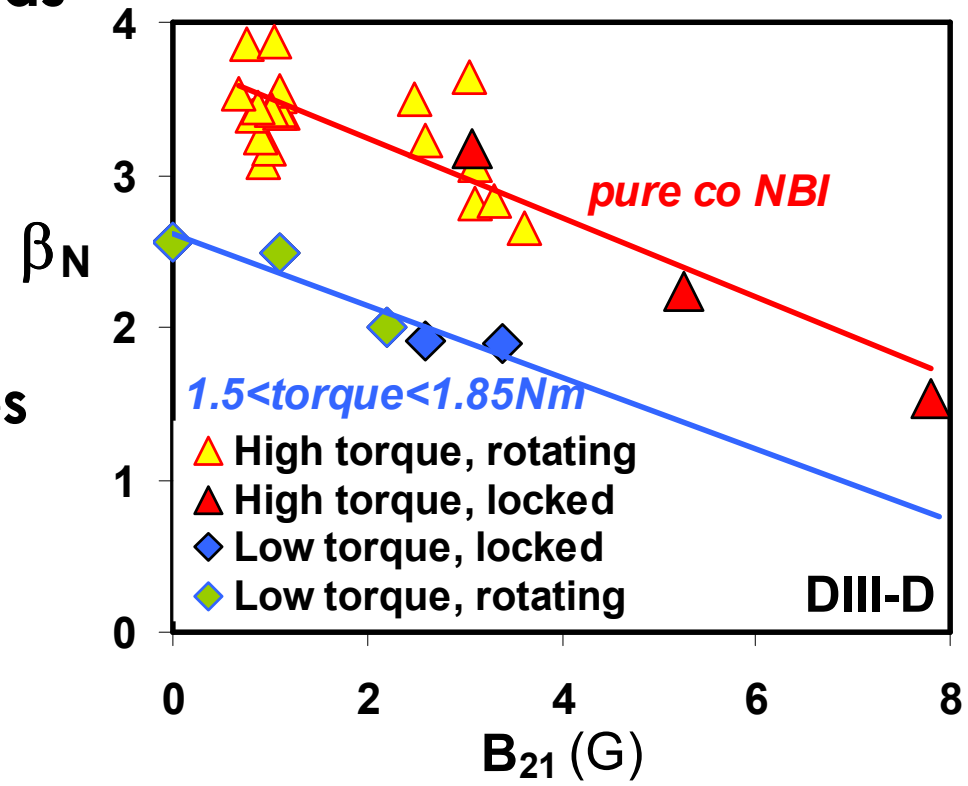
- **Error fields 'close the gap' in β_N with NTM β_N limit (o)**
  - *note low β_N points needing little error field to lower $\beta_{N\text{-onset}}$ further*
- ***Is this a new error field amplification effect?***
  - **Brought on by proximity to classical tearing?**
  - **Or asymmetry in rotation influence?**

Amount of error field needed depends on proximity to NTM limit at a given torque?

- β_N threshold falls as error fields increase

or equivalently

- Error field sensitivity increases at high β_N & low rotation
  - ***Should it?***
    …shielding still strong?



- ***Suggests revised error field correction requirements required for ITER at baseline and hybrid operating points***

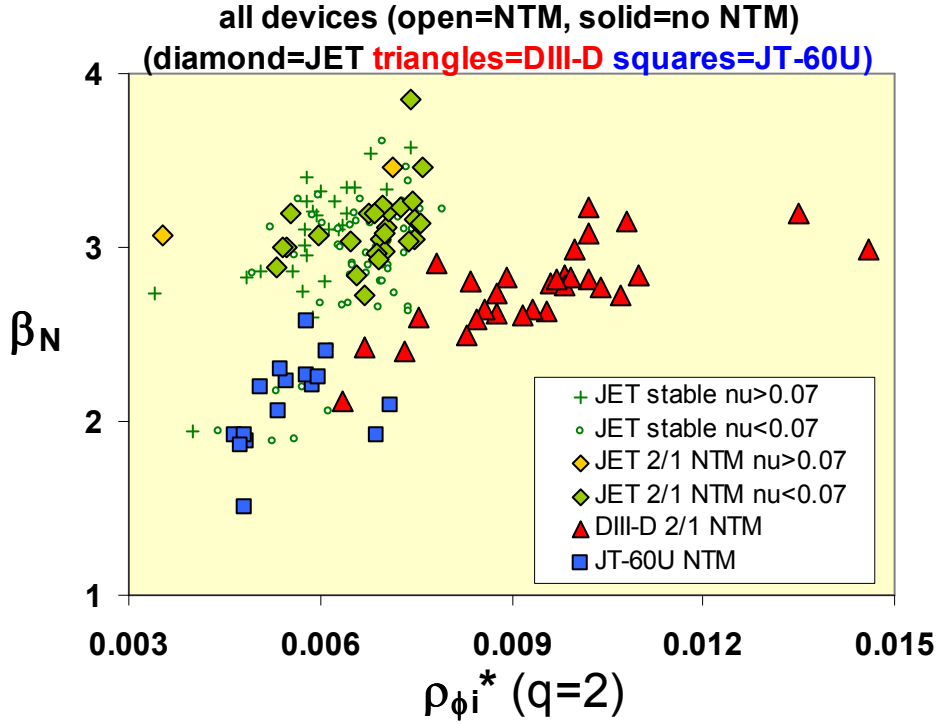
Conclusion: Three Questions Answered

1. Is there an asymmetry in the influence of rotation on tearing stability?
   - Yes
2. Is 2/1 mode onset threshold mostly governed by intrinsic tearing stability?
   - Yes
3. Does proximity to intrinsic tearing instability lower error field thresholds?
   - Yes

This is good news – ρ^* dependent physics may not be dominant

Explore hybrid scenario 2/1 NTM β limits:

- **JET** sits well above trend in ρ^* from **DIII-D**
  - In 2/1 thresholds & stable data
- JET even somewhat higher in absolute β_N
  - Possibly q profile and/or fast particle effects
- **JT-60U** lower due to low rotation



But that's another talk…!

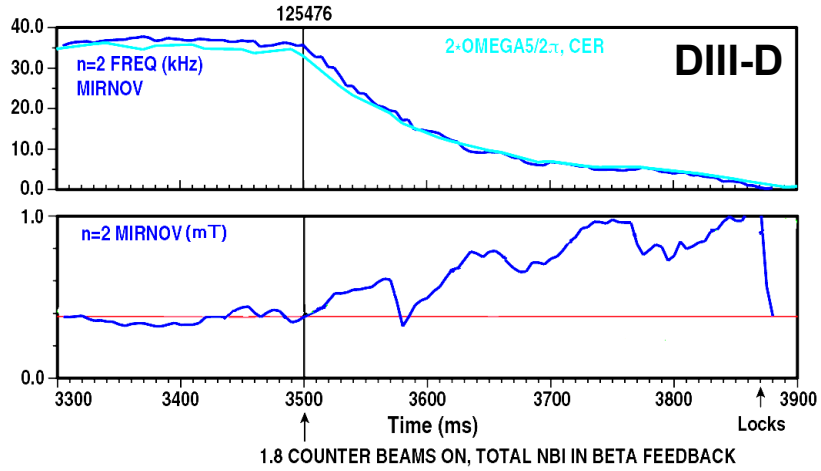
More experiments needed!

- Measure n_e,B_T scaling of error field sensitivity for ITER-like baselines so we can extrapolate
- Scan error field sensitivity in low β_N and rotation regime to deconvolve effects more thoroughly
- Test rotation effect in hybrid scenarios, which rely on high β_N access
- Look for minimum with counter rotation

Reserve slides…

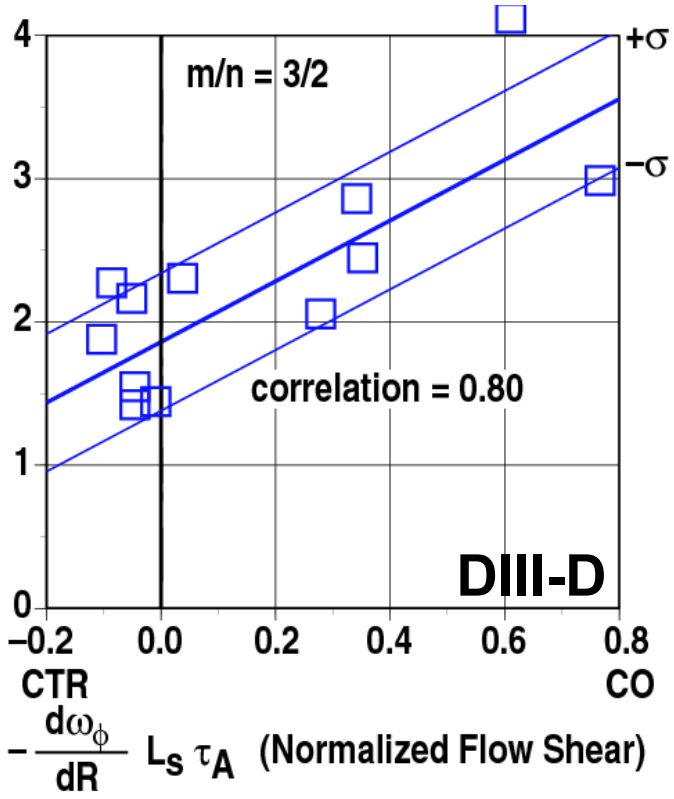
Saturated 3/2 behaviour shows rotation improves intrinsic stability

- **Islands get bigger as rotation falls→**
  - ***Calculate matching Δ' from modified Rutherford eqn:***



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

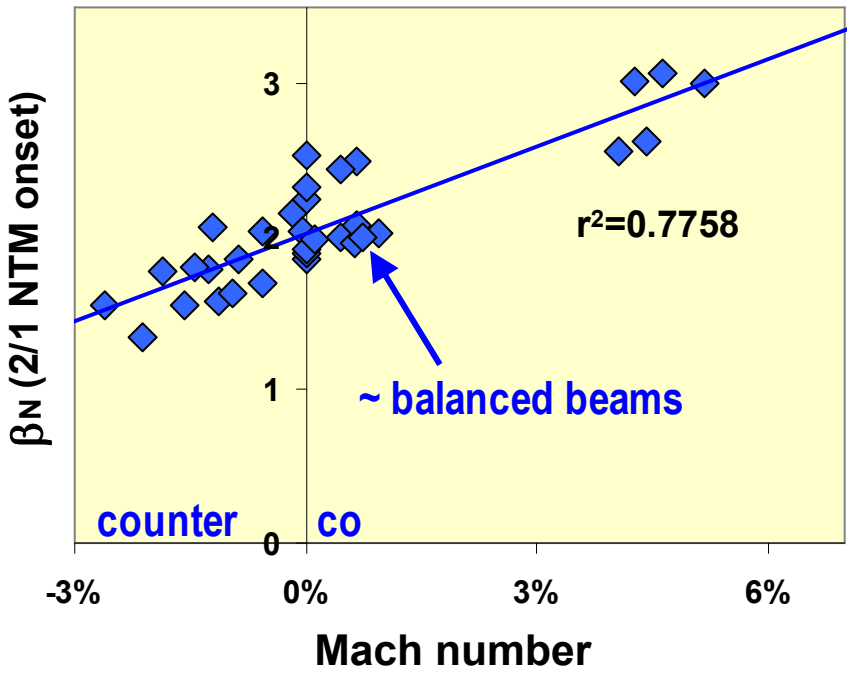
(Helically Perturbed Bootstrap Term in MRE)

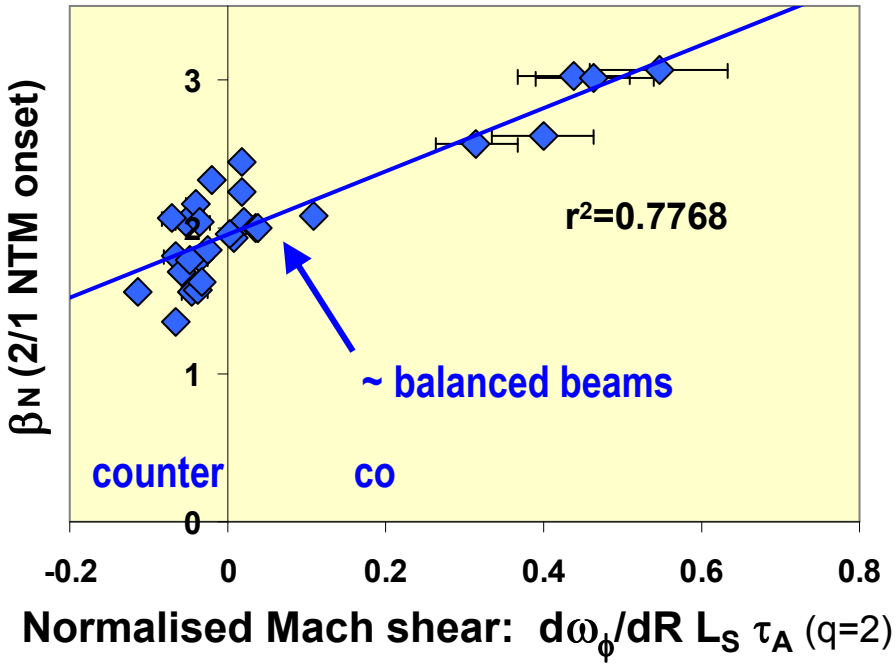


- **Fits show mode less stable at low rotation**
  - Larger w (note 1/w term)
- **Not clear if rotation ^1 or ^2**
  - …or if sign dependence

Flow shear could play stabilising role

- Theoretically <u>flow shear</u> impacts intrinsic tearing stability
  - But flow and its shear are degenerate in DIII-D
    - → see *NSTX* [1]
    - & see [2] for study of DIII-D saturated modes



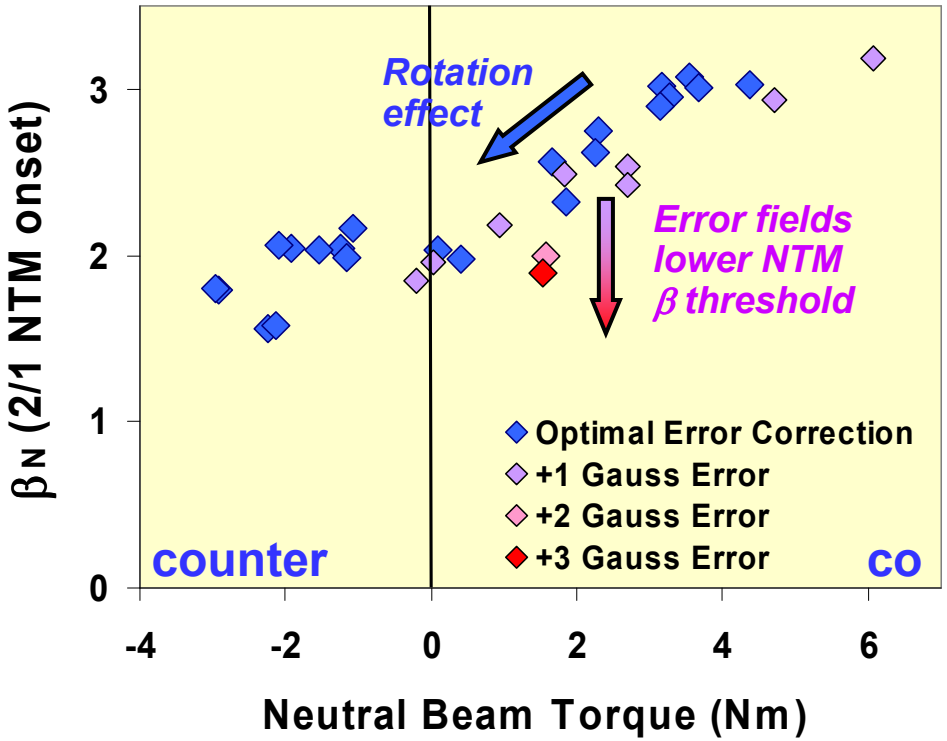


<u>See:</u>
[1]S. Gerhardt poster APS 2008 NP6.00100
[2]R J La Haye poster APS 2008 JP6.00087

Previous NTM & error field study raised many questions

DIII-D 2006 showed lower rotation has lower 2/1 onset β_N

– *and error fields can lower it further…*



But:

- Is it tearing stability or triggering physics changing?
- Is counter rotation destabilising?
- How do error fields influence thresholds?
  – *especially at low rotation*

Understanding is important:

- Prevalence of 2/1 NTMs
- ECCD control requirements
- Error field correction needs
- Rotation requirements