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Studies of 2/1 NTM onset threshold vs. rotation and rotation shear in NSTX

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S.A. Sabbagh[1] / S.P. Gerhardt[2]

[1]Department of Applied Physics, Columbia University, New York, NY, USA
[2]Plasma Physics Laboratory, Princeton University, Princeton, NJ, USA

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12th Meeting of the ITPA MHD Stability Topical Group

October 20-22, 2008

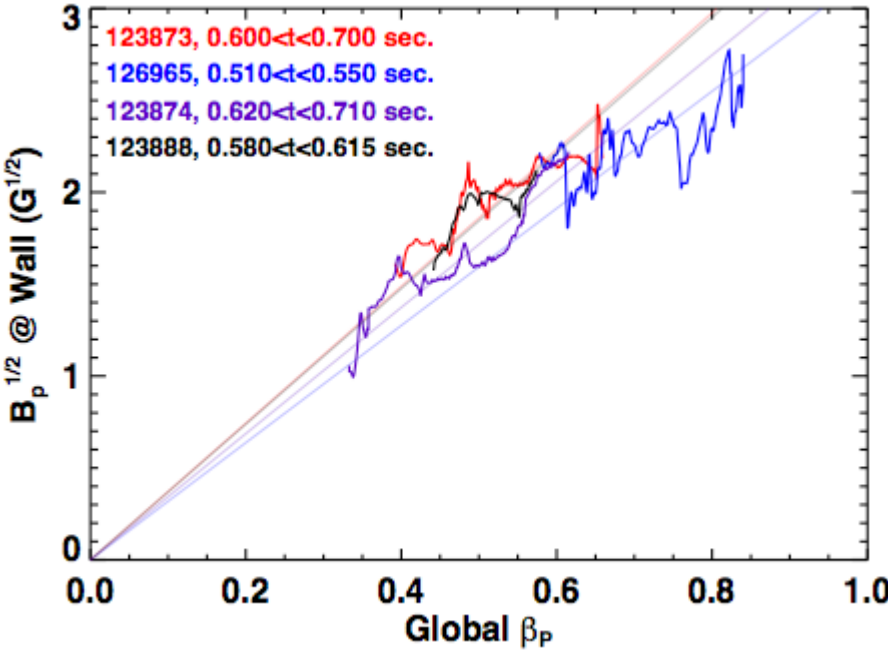
CRPP, Lausanne, Switzerland

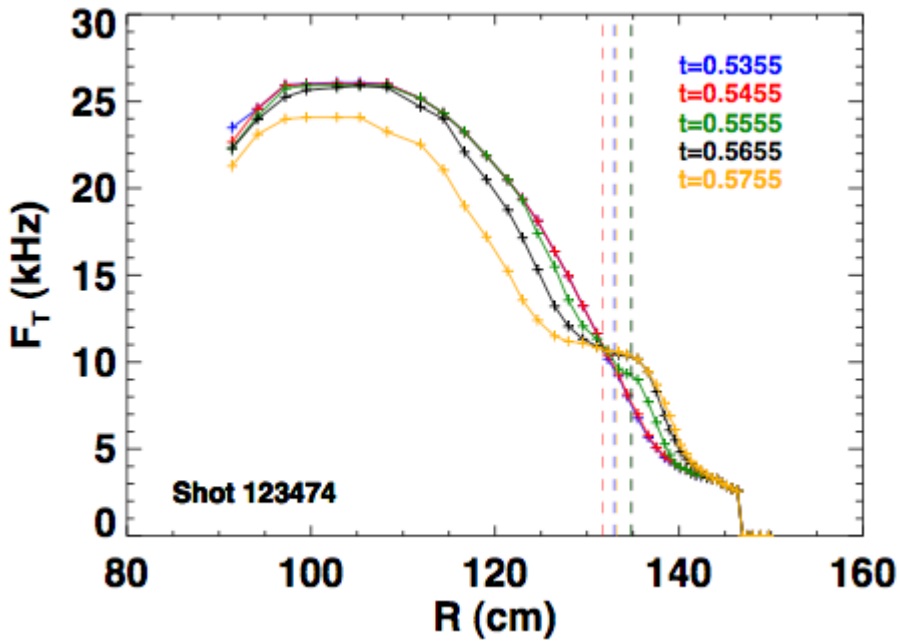
Research to determine NTM onset conditions in high beta ST

- Goals
  - Categorize NTM trigger mechanisms in a high-β, rapidly-rotating plasma
  - Determine onset and stabilization criteria for NTMs

- Outline
  - NTM characteristics in high beta ST plasmas
  - Various NTM triggering mechanisms
  - Relation of NTM onset and magnitude of plasma rotation
  - Correlation of NTM onset with toroidal flow shear at q = 2 surface

Observed characteristics indicate 2/1 NTM



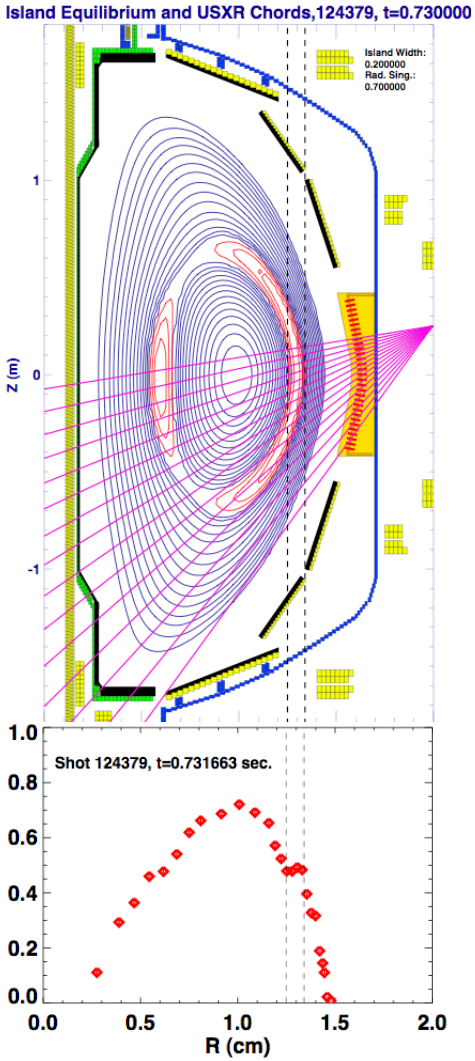


- NBI rampdown for studying the β dependence of mode amplitude
- Characteristic linear dependence of island width ~ $B_p^{0.5}$ on β_p
- Restabilization (before locking or H→L) achieved in a single case

(R. LaHaye NSTX XP810)

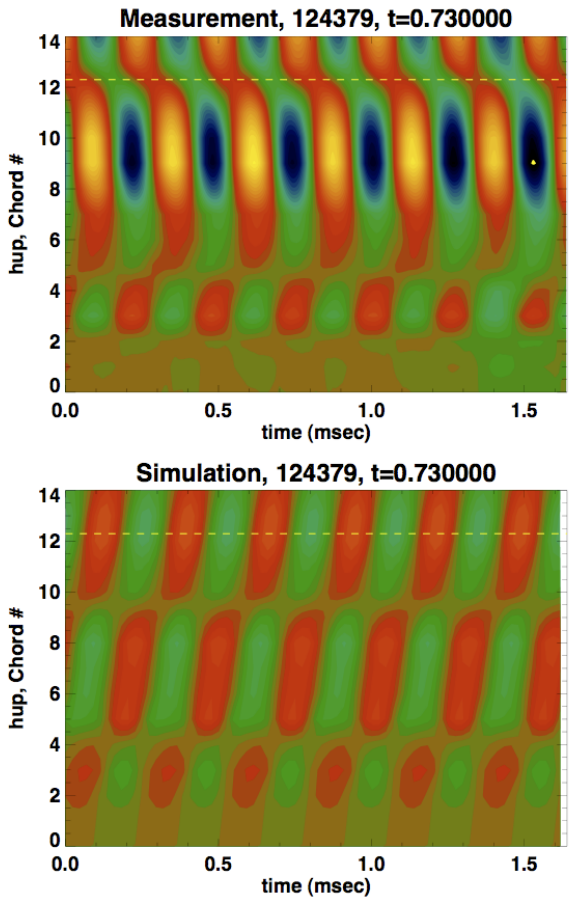
- Resonant plasma rotation braking at q = 2 surface
- Clear outward momentum transfer across q = 2
- Saturated state has rotation constant inside of q = 2 (rigid rotor core)

Core 1/1 mode associated with 2/1 NTM



Island model parameters fixed by reconstruction and T_e flat-spot

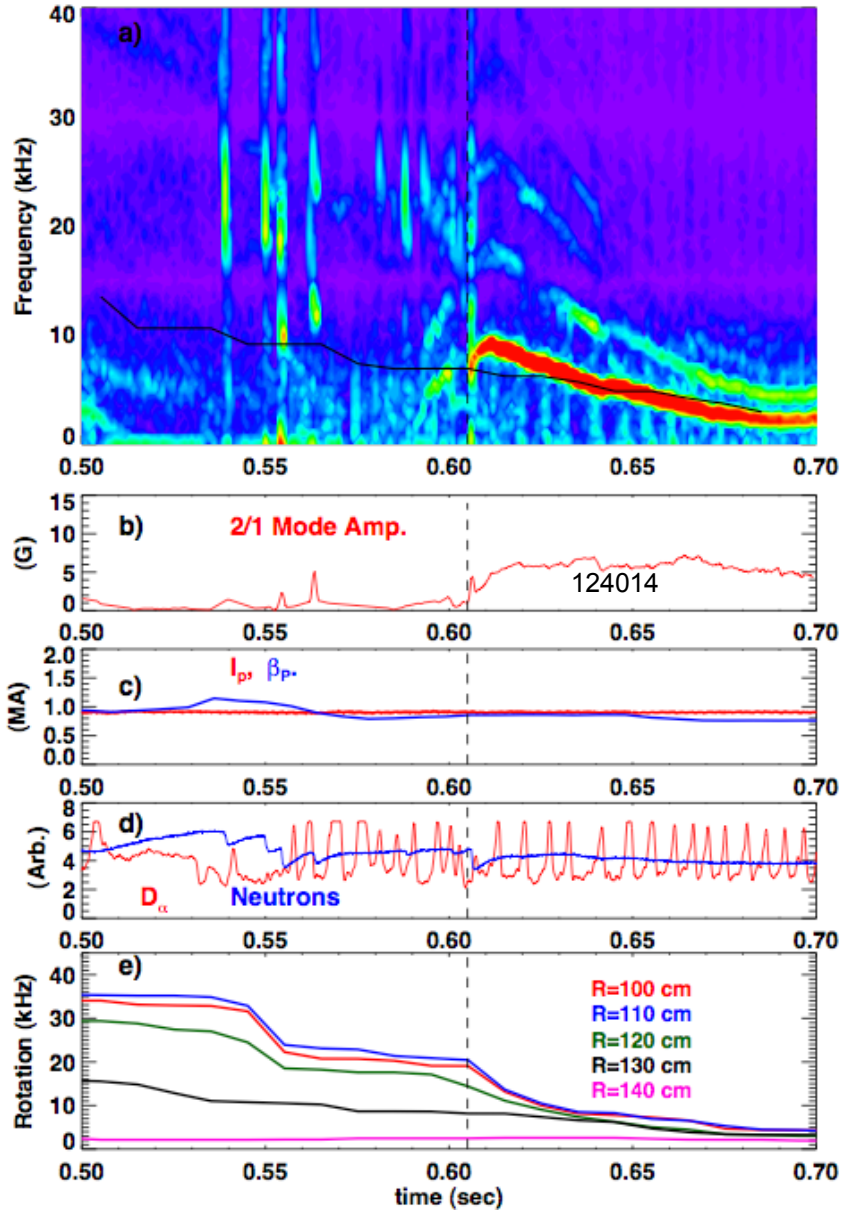
USXR measurement and simulation



- No free parameters in model
- Phase inversion across q = 2 surface in both experiment and simulation
- USXR oscillation frequency matches that of magnetic pickup coils
- Additional phase inversion seen in experiment on axis
  - Indicates odd-m in core region (m=1)
  - Not included in the island model

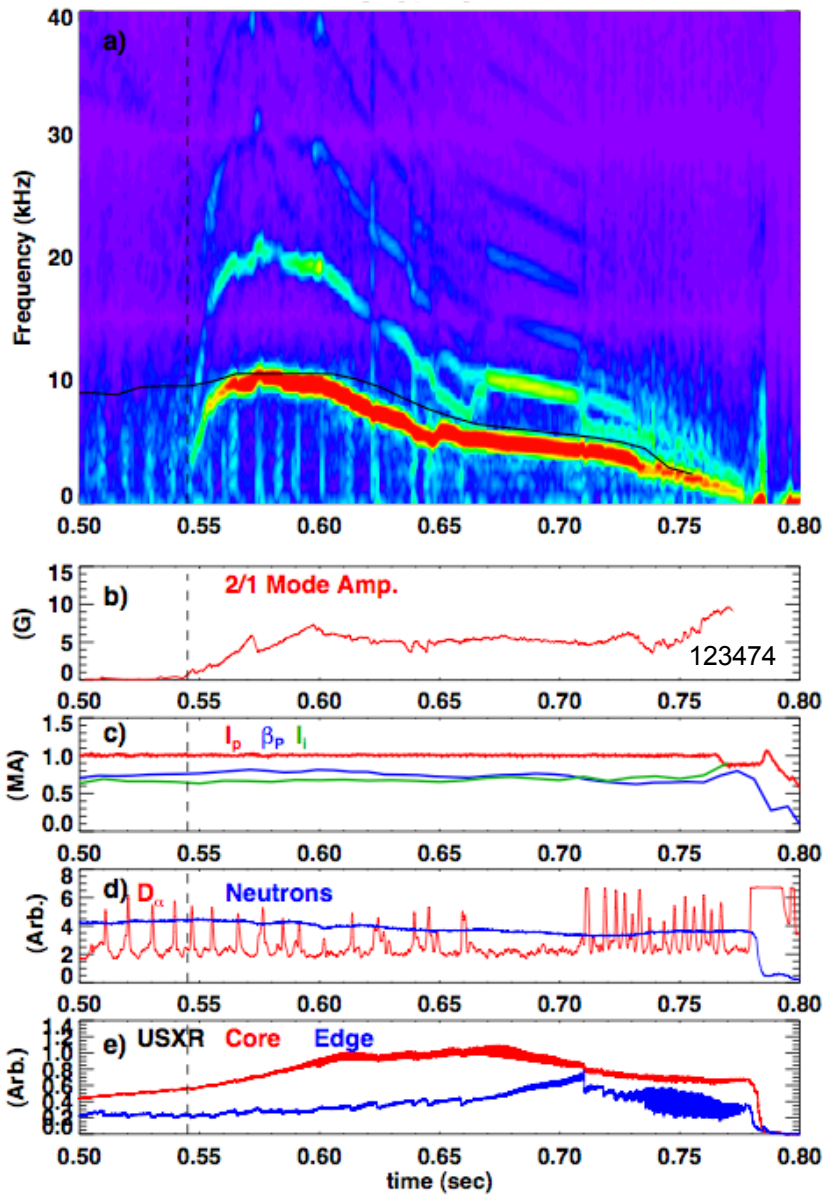
NTM onset observed triggered by EPMs

- Energetic particle mode (EPM) trigger
  - Chirping mode activity
  - NTM onset coincident with EPM; drop in the neutron rate
  - Mode onset frequency close to, or a bit above V_ϕ at q = 2



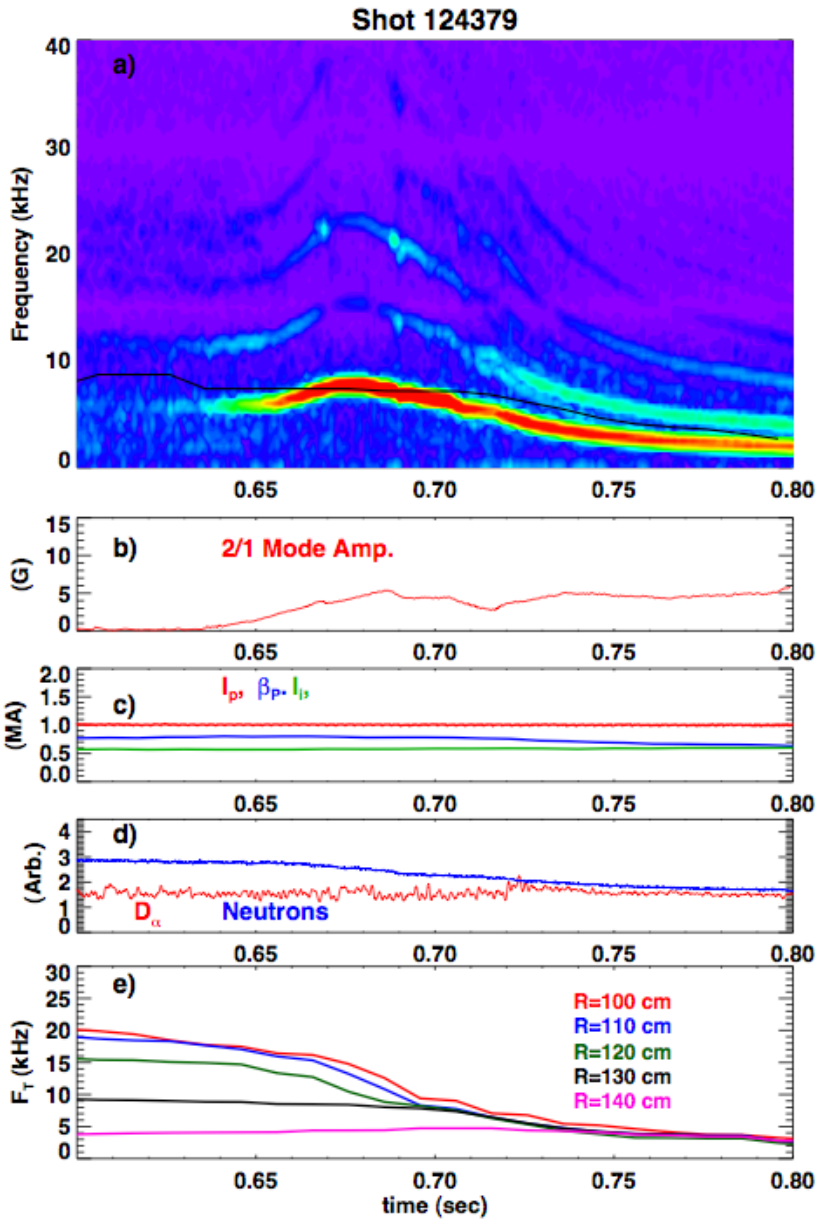
NTM onset observed triggered by ELMs

- ELM Trigger
  - Mode onsets with an ELM (Dα)
  - frequency at onset is much less than q=2 rotation frequency



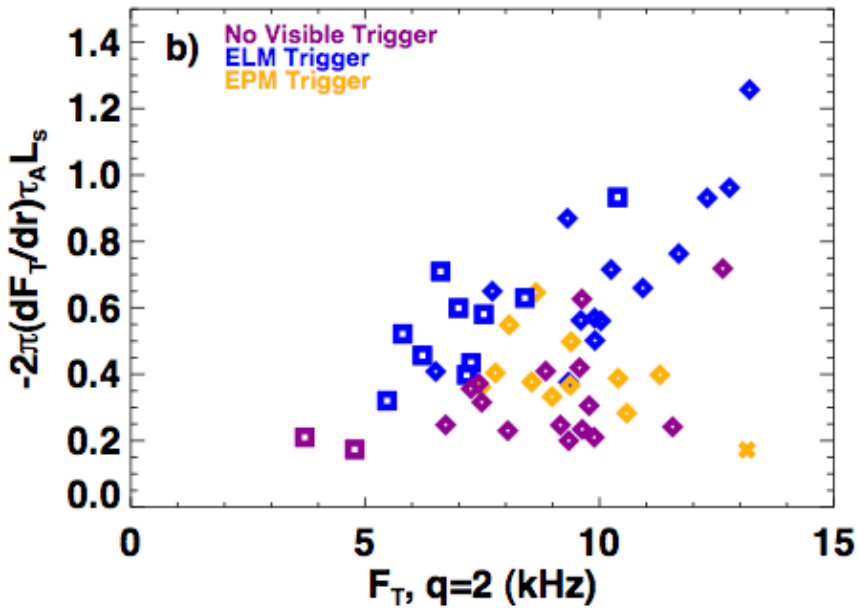
NTM onset can occur with no apparent trigger

- Spontaneous NTM
  - "Triggerless": No observed seeding instability in USXR, neutrons, or D_α
  - Mode onset frequency near V_ϕ at q = 2
- All trigger mechanisms share common features
  - Frequency quickly approaches that of the q=2 surface
  - T_e flat-spots at q=2, collapse of rotation inside of q=2



Database of 53 Discharges Assembled to Study Trends

- Include different beam timing
- Various V_ϕ by varying n=3 non-resonant braking levels
- Consider limited range of shapes, I_p, B_t:
  - *2.1<κ<2.42*
  - *0.57<l_i<0.8*
  - *0.5<δ_l<0.83*
  - *900kA<I_p=1000kA*
  - *B_T=0.45T*



Trigger Type Indicated with Symbol Color

"Spontaneous"

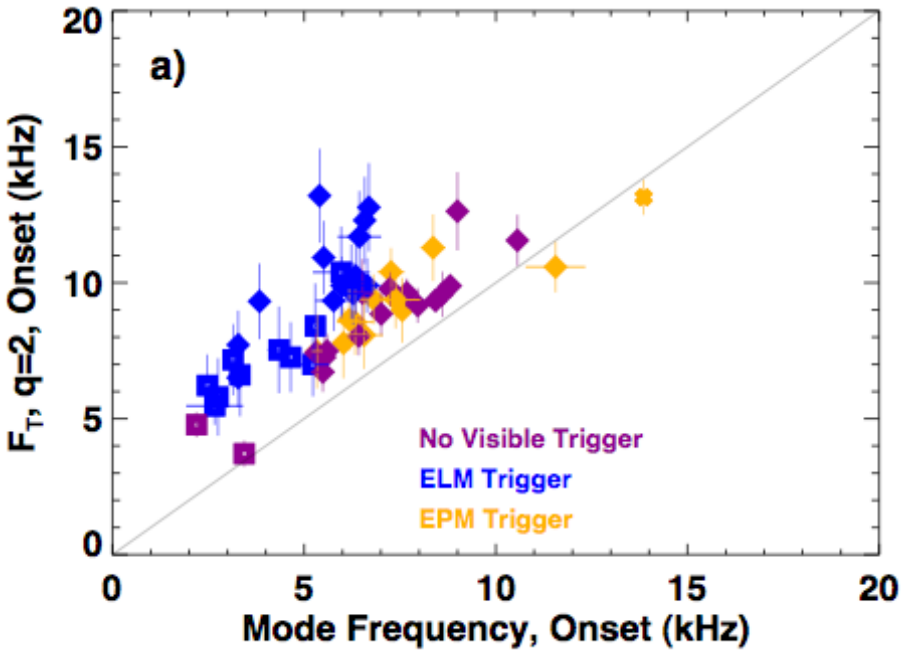
EPM Trigger

ELM Trigger

- Range of Shots Allows Separation of Rotation and V_ϕ Shear Effects
  - Unfortunate Co-Linearity for ELM Trigger Cases

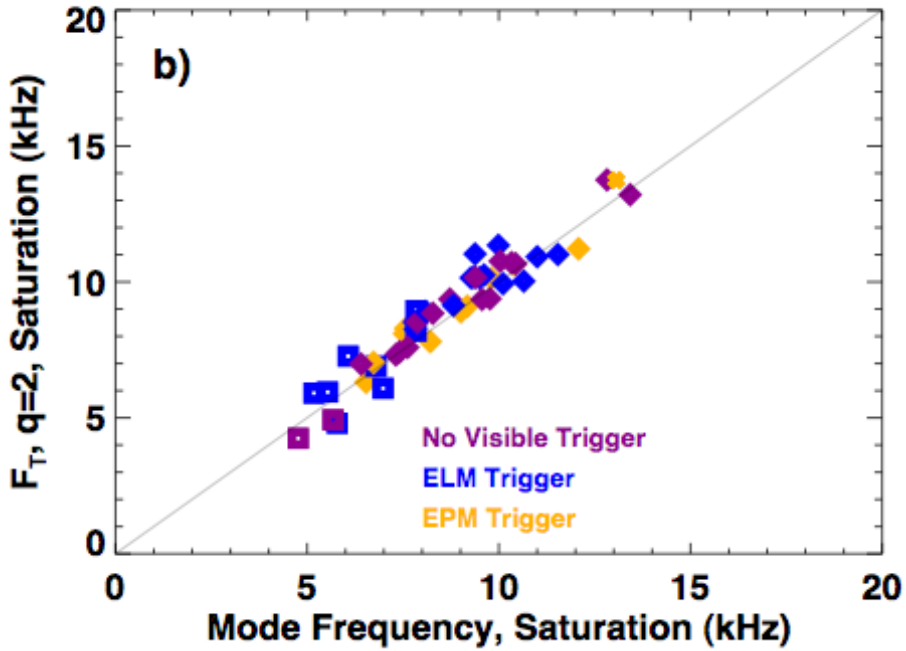
NTM onset frequency depends on triggering mechanism

At mode onset



- At onset, NTM frequency depends on triggering mechanism:
  - ELMs: much less than q=2
  - EPM: larger or smaller than q=2
  - Triggerless: slightly less than q=2

At mode saturation



- Mode frequency approaches and tracks q=2 frequency

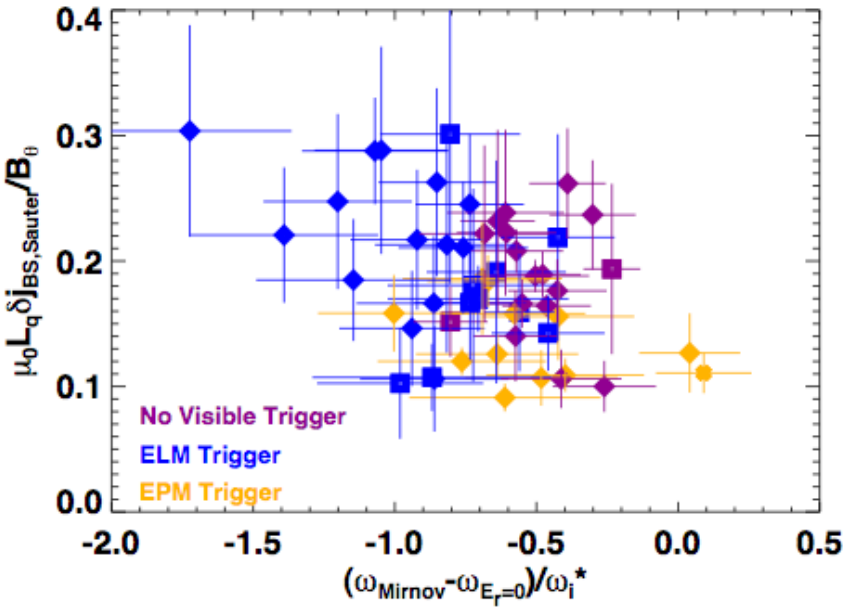
Required drive for NTM onset is independent of mode propagation frequency

Modified Rutherford Equation

$$\frac{\tau_R}{r_s^2}\frac{dw}{dt} = \Delta' + \frac{C_{BS}\mu_0 L_q}{B_\theta}\delta j_{BS}\left(\frac{w}{w^2+w_d^2} - \frac{w w_{pol}^2}{w^4+w_b^4}\right) - \frac{6D_R w}{w^2+w_d^2}$$

Drive due to Missing bootstrap current

Polarization current term (depends on island propagation speed in E_r = 0 rest frame)

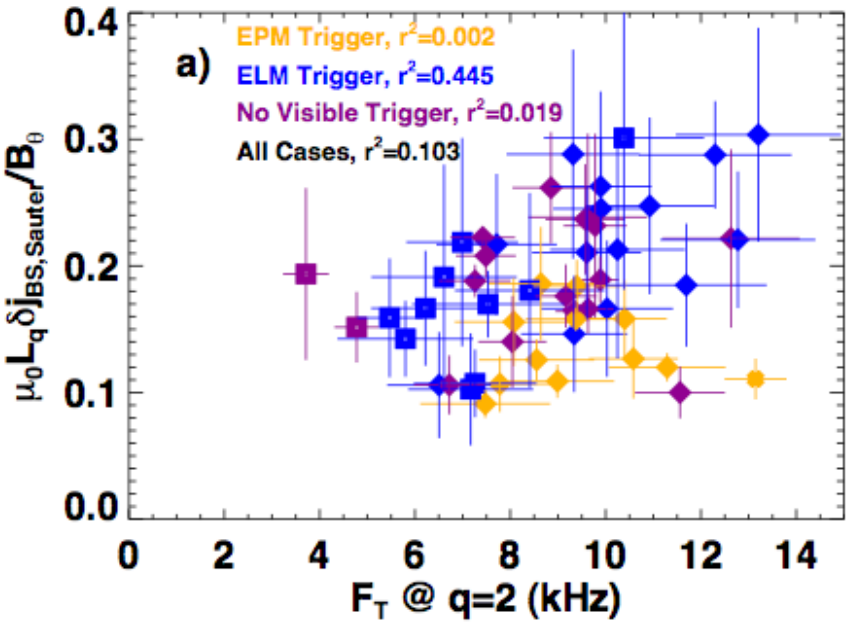


- More than a factor of 3 range in NTM drive at mode onset

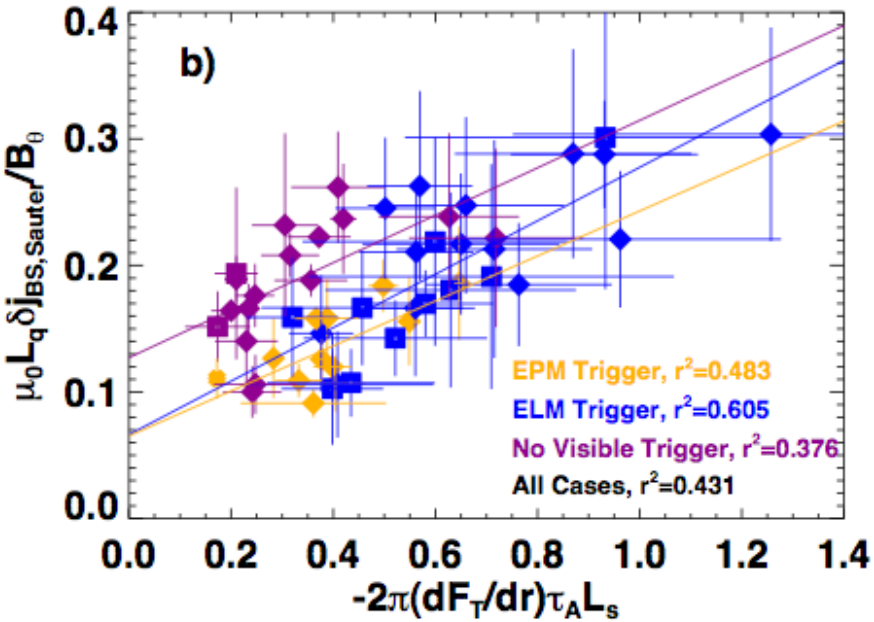
- NTM drive at onset uncorrelated with frequency in E_r = 0 frame
  - rotation dependence of polarization term suggest that this term is not playing a large role

Required drive for NTM onset better correlated with rotation shear than rotation magnitude

NTM Drive at Onset Only Poorly Correlated with q=2 (Carbon) Rotation



NTM Drive at Onset Better Correlated with Local Flow Shear



- For fixed V_ϕ, order of increasing onset drive: EPM triggers, ELM triggers, and "Triggerless"
- All trigger types have similar dependence on flow shear
  - Dependence likely to related to intrinsic tearing stability, not triggering

Statistically, NTM Drive Best Correlated with Local Flow Shear

	All Cases	EPM Triggered	ELM Triggered	ŅTriggerlessÓ
1: F_T @ q=2	0.098	0.002	0.445	0.018
2: dF_T/dr @ q=2	0.048	0.085	0.114	0.075
3: $L_s\tau_A(dF_T/dr)$	**0.409**	**0.456**	**0.605**	**0.354**
4: $(F_{T,q=2}-F_{T,q=3})$	0.153	0.092	0.336	**0.365**
5: $\tau_A(F_{T,q=2}-F_{T,q=3})$	0.195	0.162	0.395	**0.376**
6: $\tau_A^{2/5}\,\tau_R^{3/5}\,(F_{T,q=2}-F_{T,q=3})$	0.222	0.103	0.426	0.310
7: $\rho_{\theta,i}\varepsilon^{1/2}$	0.284	0.009	0.416	0.139

EPM Cases

• The ONLY correlation is with rotation shear.

ELM Cases:

• Lots of colinearity in the data (flow vs. flow shear. Vs differential rotation), but best correlation is with flow shear.

"Triggerless" Cases:

• More scatter in data, equally good correlation with flow shear and differential rotation.

• Additional physics may be playing a role, including q_0~1 and β_N near ideal kink limit

NTM onset examined in high beta ST plasmas

- m/n = 2/1 NTMs observed, typically coupled to 1/1 core modes.
- Large variation in NTM drive at the time of onset for a dataset of limited I_p, B_T, and shape, but with a large variety of V_ϕ profiles,
- Three typical onset conditions, in order of increasing NTM drive at onset:
  - Triggered by an EPM, often near saturated width, along with drops in the neutron rate
  - Triggered by an ELM, with the mode frequency starting much less than the q=2 frequency
  - No visible trigger
- Best correlation is found between NTM onset drive and flow shear at q=2 (inferior correlation with flow magnitude or differential rotation)
- As in DIII-D, results tend to indicate the flow-shear effect is related to intrinsic tearing stability