NSTX-U

NSTX-U is sponsored by the
U.S. Department of Energy Office of Science
Fusion Energy Sciences

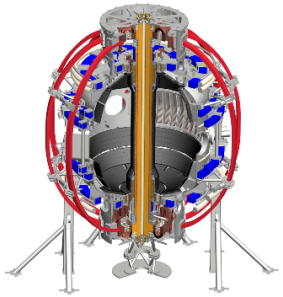
A first look at resistive MHD stability differences between NSTX and NSTX-U high beta discharges

Lucas Morton

R. J. La Haye, Z. R. Wang, J.-K. Park, D. P. Brennan, J. E. Menard, S. P. Gerhardt, J. W. Berkery, N. M. Ferraro, S. A. Sabbagh, L. F. Delgado-Aparicio, K. Tritz, R. E. Bell

ORAU

GENERAL ATOMICS



Tearing-type modes must be understood & tamed

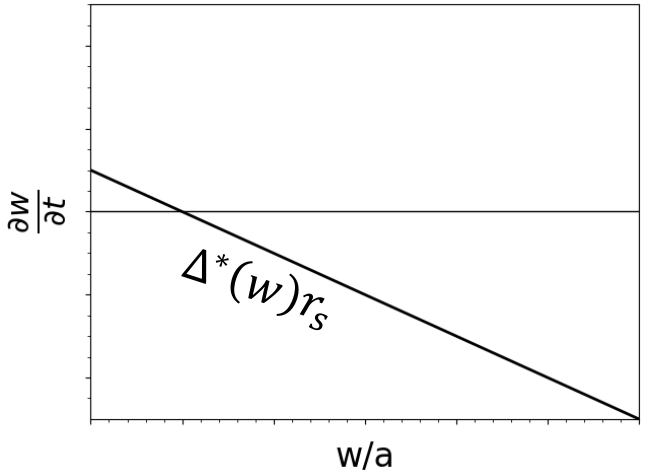
- Neoclassical tearing modes (NTM) unacceptable for reactor
  - Saturated modes → loss of confinement / disruptions
- Prediction: Large inverse aspect ratio $\epsilon = \frac{r}{R}$ stabilizing
  - Favors spherical tokamak approach
- NSTX Upgrade provides controlled experiment in ϵ
  - Compare to NSTX pre-upgrade

Nonlinear NTM predicted more stable at low aspect ratio

- $\frac{dw}{dt} = \frac{\eta^*}{k_0}\left[\Delta^*(w)r_s + \frac{w}{w^2+w_d^2} D_{bs} - \sqrt{\frac{1}{w^2+0.2w_d^2}} \frac{|D_R|}{\alpha_s - H}\right]$

Hegna *PoP* **6** 3980 (1992)

- Bootstrap: destabilizing $\propto \beta_\theta$
  - Typically larger than interchange
- Interchange: stabilizing $\propto \epsilon^{3/2}\beta_\theta$
  - Same scaling with β_θ
- Prediction: $\epsilon \uparrow$ increases stability
  - Small aspect ratio (large ϵ) favorable

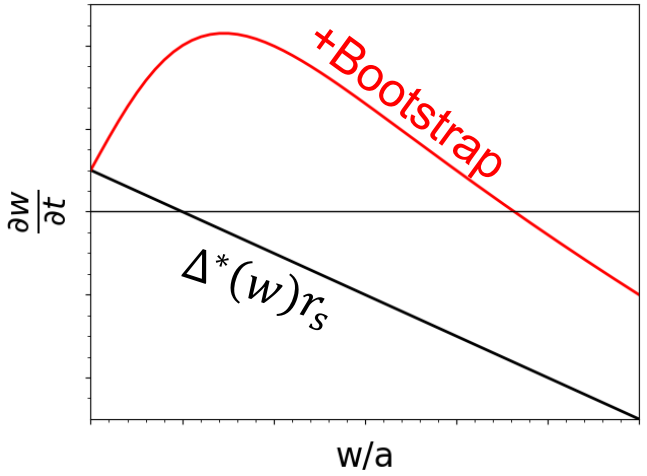


Nonlinear NTM predicted more stable at low aspect ratio

- $\frac{dw}{dt} = \frac{\eta^*}{k_0}\left[\Delta^*(w)r_s + \frac{w}{w^2+w_d^2} D_{bs} - \sqrt{\frac{1}{w^2+0.2w_d^2}} \frac{|D_R|}{\alpha_s - H}\right]$

Hegna *PoP* **6** 3980 (1992)

- Bootstrap: destabilizing $\propto \beta_\theta$
  - Typically larger than interchange
- Interchange: stabilizing $\propto \epsilon^{3/2}\beta_\theta$
  - Same scaling with β_θ
- Prediction: $\epsilon \uparrow$ increases stability
  - Small aspect ratio (large ϵ) favorable

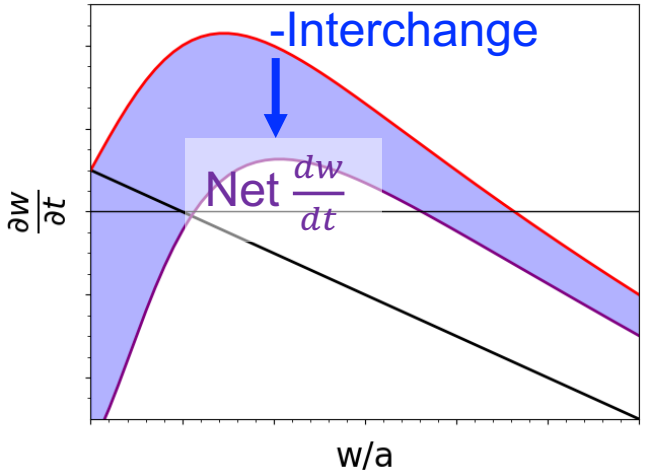


Nonlinear NTM predicted more stable at low aspect ratio

- $\frac{dw}{dt} = \frac{\eta^*}{k_0}\left[\Delta^*(w) r_s + \frac{w}{w^2+w_d^2} D_{bs} - \sqrt{\frac{1}{w^2+0.2w_d^2}} \frac{|D_R|}{\alpha_s - H}\right]$

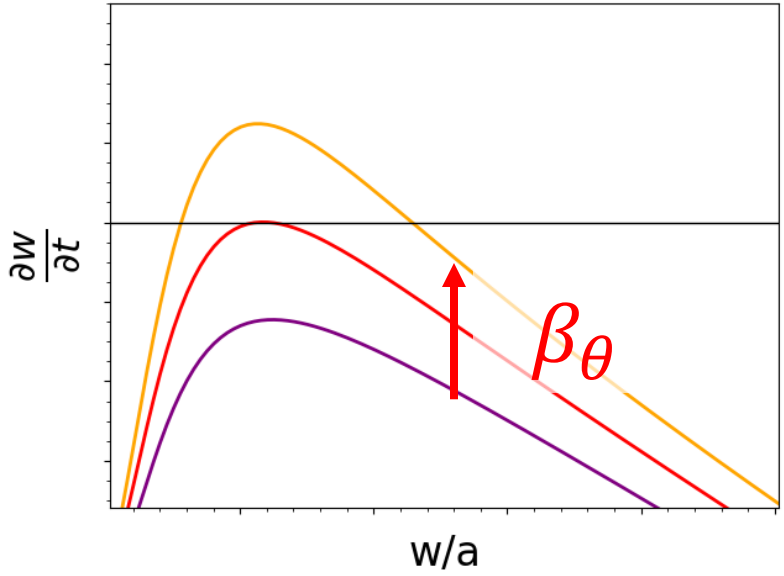
Hegna *PoP* **6** 3980 (1992)

- Bootstrap: destabilizing $\propto \beta_\theta$
  - Typically larger than interchange
- Interchange: stabilizing $\propto \epsilon^{3/2}\beta_\theta$
  - Same scaling with β_θ
- Prediction: $\epsilon \uparrow$ increases stability
  - Small aspect ratio (large ϵ) favorable



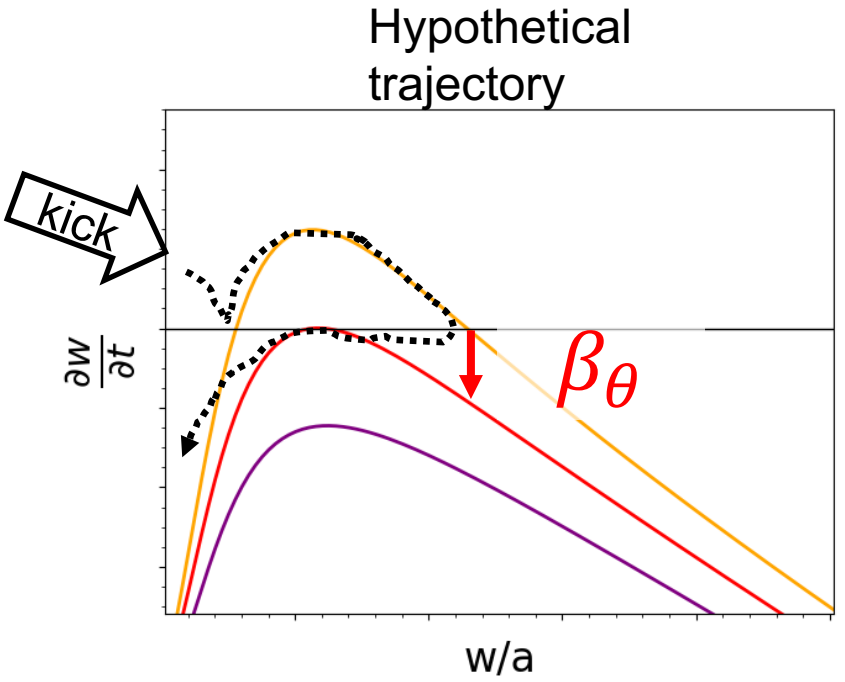
Modified Rutherford equation describes NTM lifecycle

- $\frac{dw}{dt} = \frac{\eta^*}{k_0}[\Delta^*(w)r_s + \beta_\theta f(w, \epsilon, q, \kappa, \dots)]$
- NTM often metastable
  - Kick/seed required to onset
  - Growth to saturation
  - Decay as β_θ reduced
  - Self-stabilization if $\beta_\theta < \beta_{\theta,marg}$



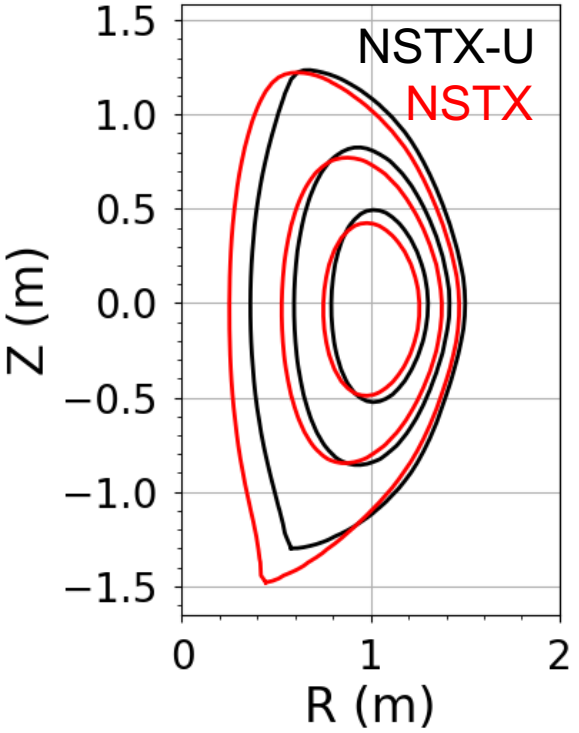
Modified Rutherford equation describes NTM lifecycle

- $\frac{dw}{dt} = \frac{\eta^*}{k_0}[\Delta^*(w)r_s + \beta_\theta f(w, \epsilon, q, \kappa, \dots)]$
- NTM often metastable
  - Kick/seed required to onset
  - Growth to saturation
  - Decay as β_θ reduced
  - Self-stabilization if $\beta_\theta < \beta_{\theta,marg}$



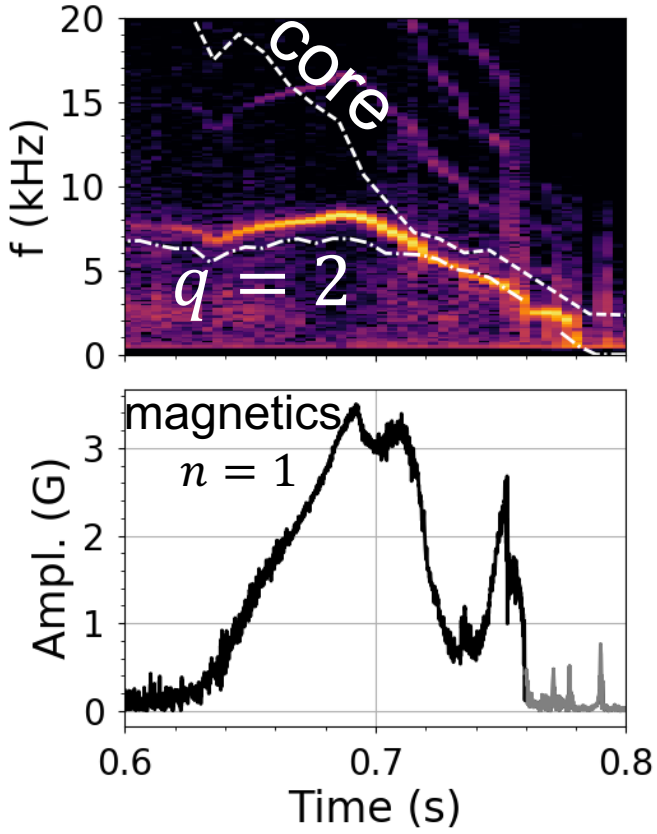
Comparable discharges obtained before & after upgrade

Quantity	NSTX (134020)	NSTX-U (204112)
r_s/R	0.35	0.29
q_{95}	8.3	7.4
κ	2.2	2.2
δ_u, δ_l	0.45, 0.54	0.48, 0.57
β_N/l_i	6.0	6.5
I_p	880 kA	860 kA
B_T	0.44 T	0.63 T



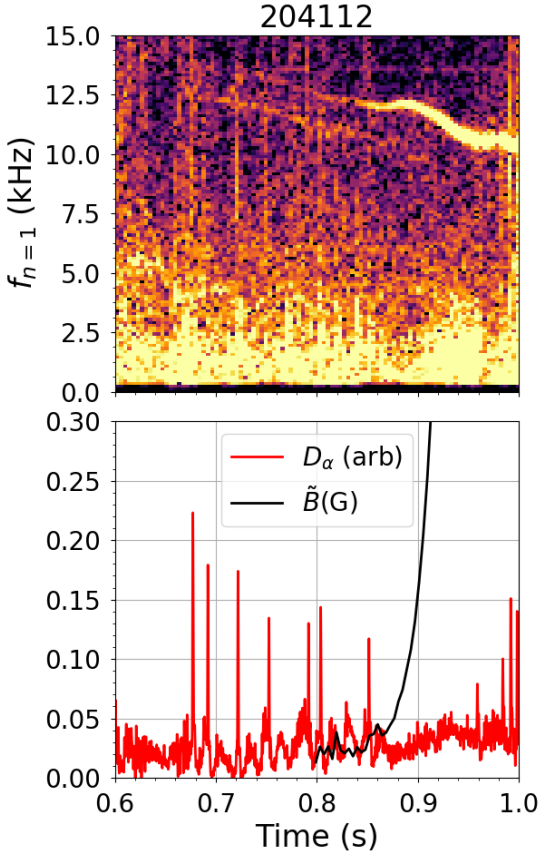
NSTX: Large $m, n = 2,1$ mode produced

- Resonant q from $f_{tor} + q$-profile
- Mode width from T_i profile & $\tilde{b}$
  - ST over-dense to ECE
  - Calibrate $w \propto \sqrt{\tilde{b}}$ from T_i flat-spot
- Growth, saturation & decay
  - NBI, β reduced→ marginal point
- D_α → ELM at onset
  - Possible trigger of mode



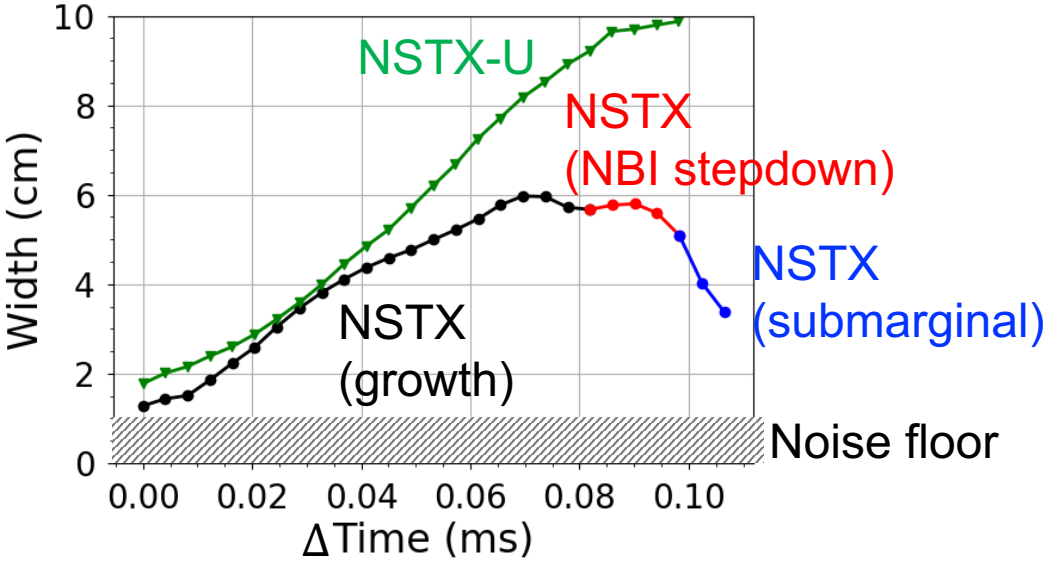
NSTX-U: Similar phenomenology

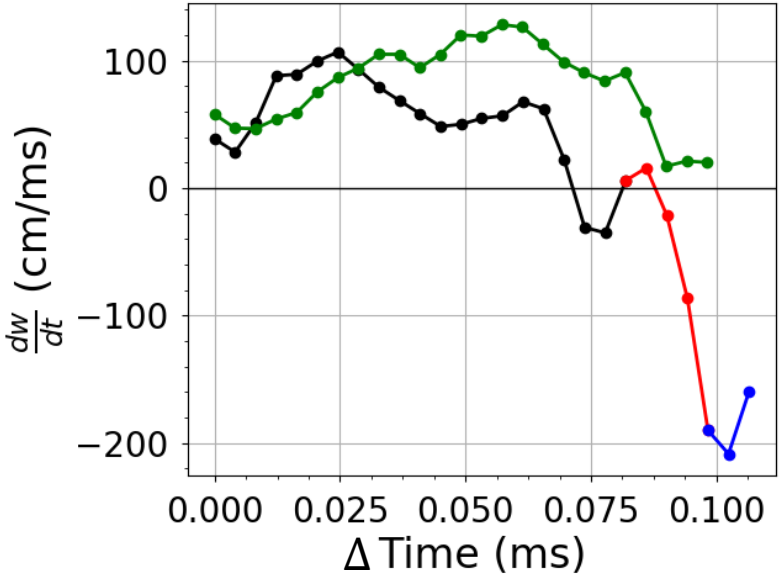
- NBI:
  - No step-down before disruption
  - Using off-axis beam as well
- Diagnostics:
  - MSE, CHERS unavailable
  - Use TS, SXR for mode identification
- Mode:
  - $m, n = 2,1$
  - Onset near ELM



NSTX-U shot has stronger mode

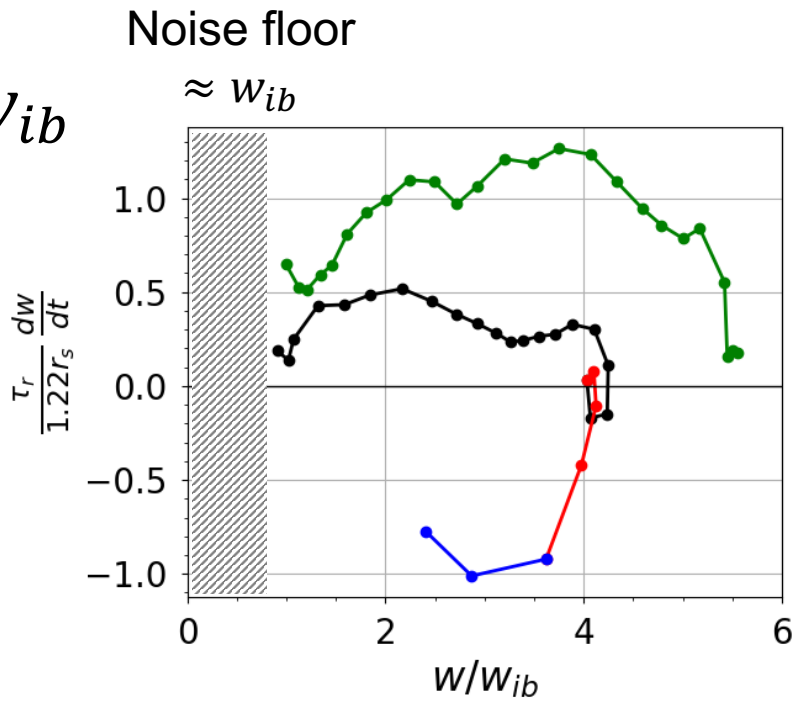
- Larger saturated width
- Slightly larger growth rate





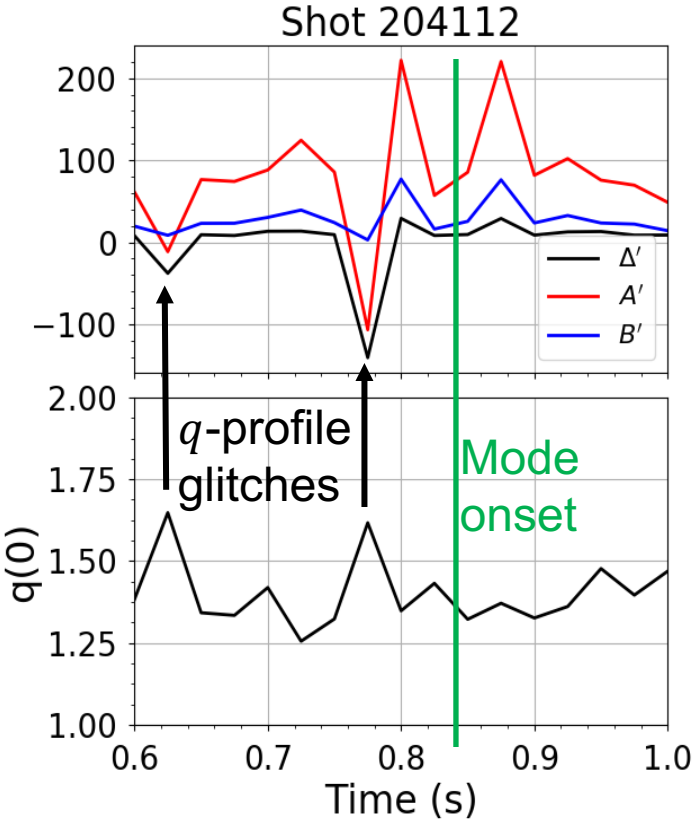
NSTX-U shot has larger normalized growth rate

- Due to longer τ_R
  - From higher B, T_e in NSTX-U
- Island onset observed at w $\approx w_{ib}$
  - Ion banana width $w_{ib} = \epsilon^{1/2}\rho_{\theta i}$
  - Consistent with NTM
    - Threshold width $w_d \approx w_{ib}$
  - Caveat: $w_{ib} \approx$ noise floor
    - Low-amplitude precursors?



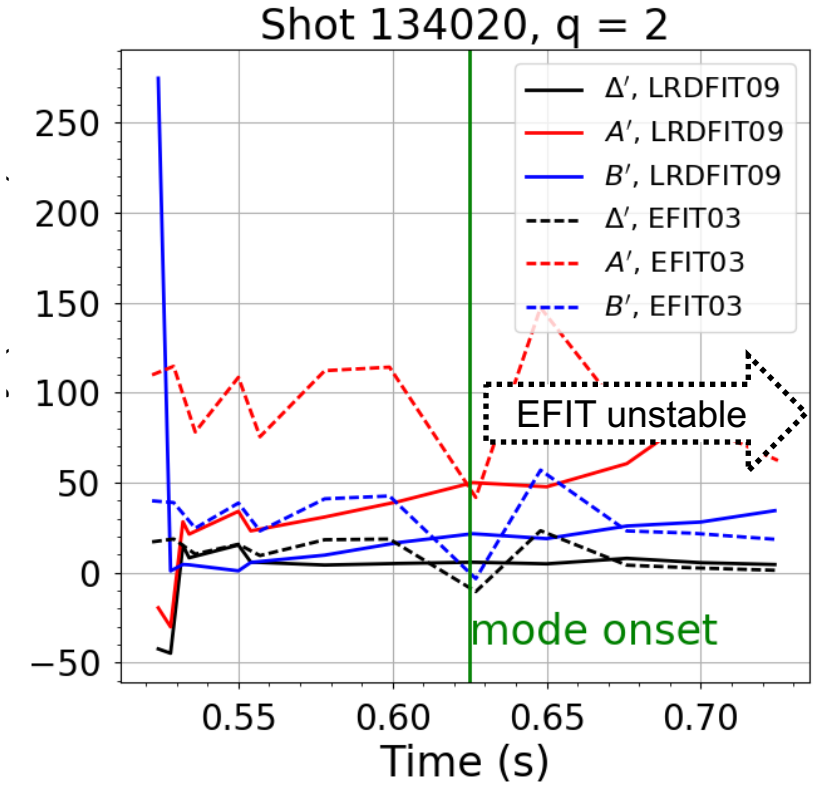
Resistive DCON applied to NSTX-U shot 204112

- Resistive DCON: linear stability
  - Toroidal, finite β
- Kink A' and tearing Δ' positive
  - A' drive couples to tearing via B'
- MSE-less LRDFIT reconstructions
  - Core current profile ill-constrained
  - Jags reflect uncertainty, sensitivity



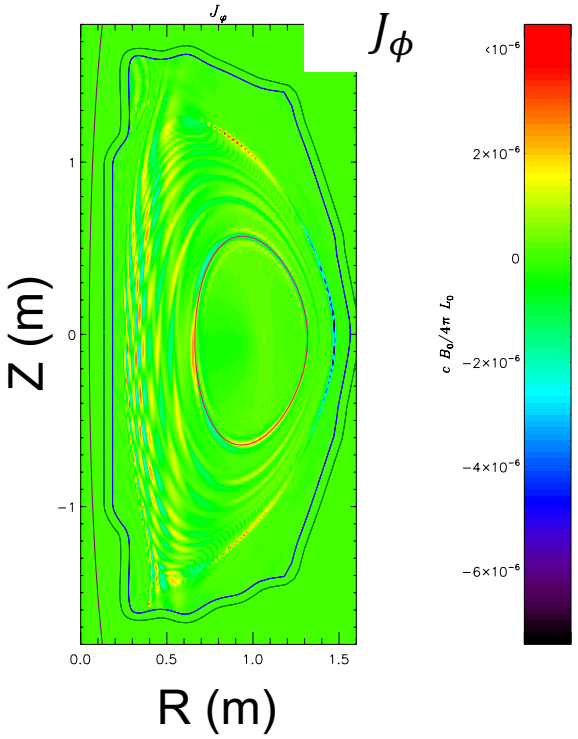
Resistive DCON applied to NSTX shot 134020

- Kink A' and tearing Δ' positive
  - EFIT, LRDFIT agree qualitatively
- EFIT → ideally unstable
  - Due to $q(0) \approx 1$



M3D-C1 shows edge instability in NSTX 134020

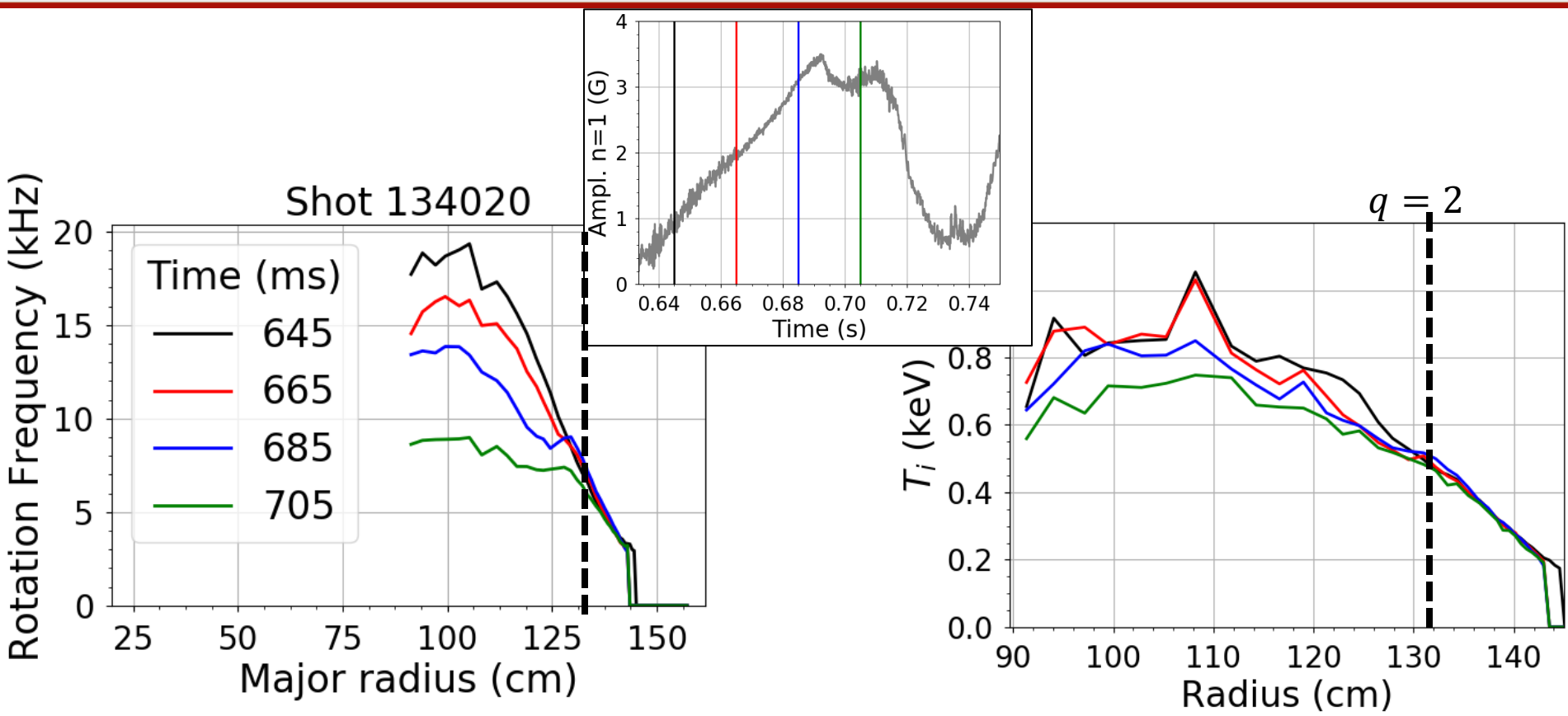
- *If* rotation is lowered by 25% or more
  - Using EFIT reconstruction
- Growth rate depends on resistivity
  - Driven by large edge bootstrap gradient?
- Consistent with ELM triggering NTM



Conclusions & future directions

- Key points:
  - NSTX-U example shot has more virulent mode
    - Consistent with predictions from aspect ratio change
  - RDCON suggests classical tearing linearly unstable
  - M3D-C1 indicates resistive edge instability @ onset
- Future:
  - Dedicated experiments to scan β, q_{min}
    - Fully diagnosed
    - Off-axis neutral beam scan
  - Validation of stability predictions
  - Test control strategies

Profile diagnostics indicate $n = 1$ mode at $q = 2$



TS and SXR combined for NSTX-U 204112

- SXRFIT (by J. Menard) fits emissivity structure
- Resulting flux surfaces agree with TS T_e flat spots
  - Synergistic use of SXR phase resolution +TS radial resolution