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-β discharges

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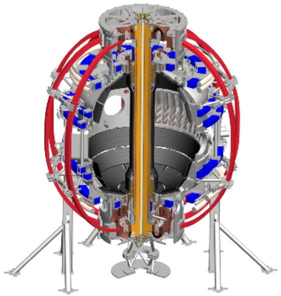
ORAU

GENERAL ATOMICS



Tearing-type modes must be understood & tamed

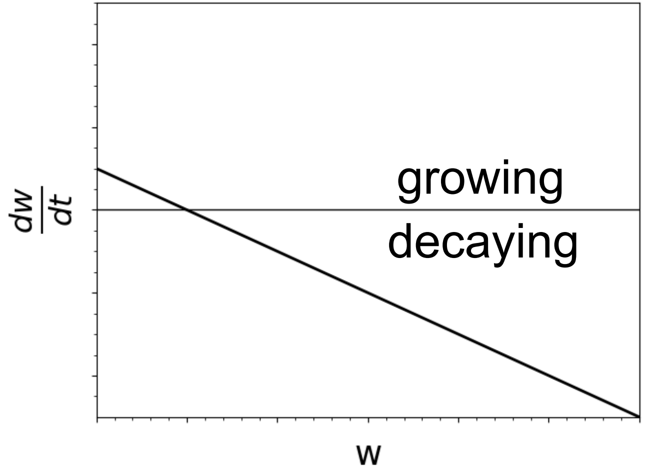
- Neoclassical tearing modes (NTM) unacceptable for reactor
  - Saturated modes → loss of confinement / disruptions
- Prediction: Large inverse aspect ratio $\epsilon = \frac{r}{R}$ stabilizing
  - Favors spherical tokamak approach
- NSTX Upgrade provides controlled experiment in ϵ
  - Compare to NSTX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

The modified Rutherford equation describes NTM growth

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

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

- Classical $\Delta^*(w)r_s$
  - w is magnetic island full width



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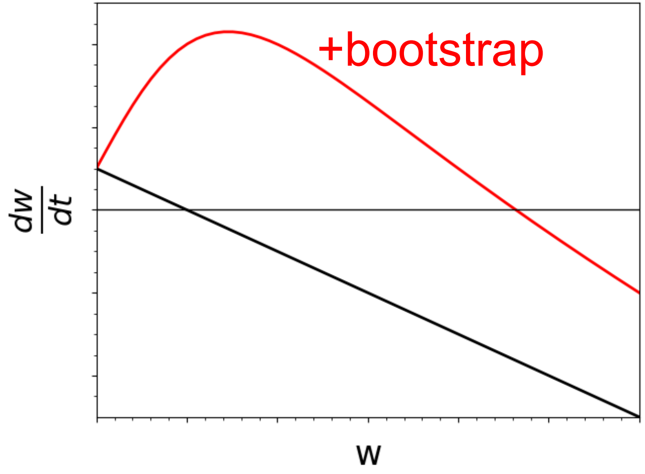
- Bootstrap: destabilizing $\propto \beta_\theta$



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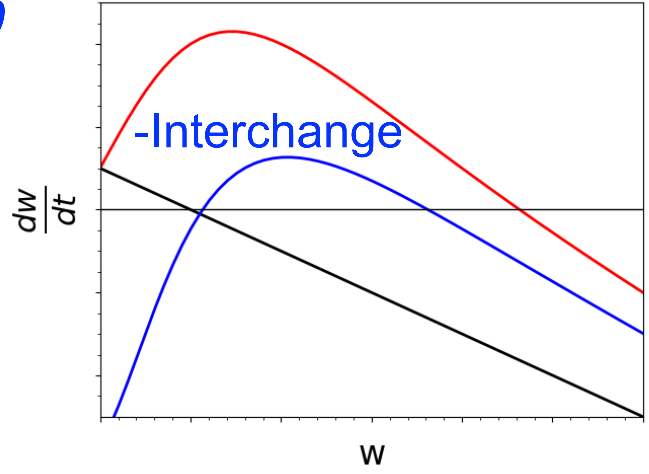

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- Bootstrap: destabilizing $\propto \beta_\theta$
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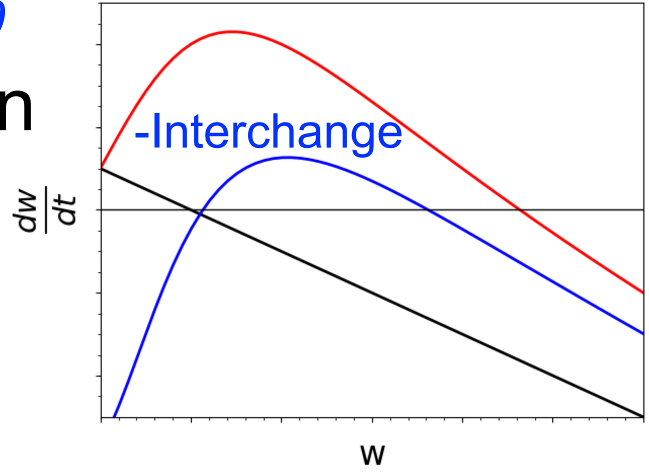
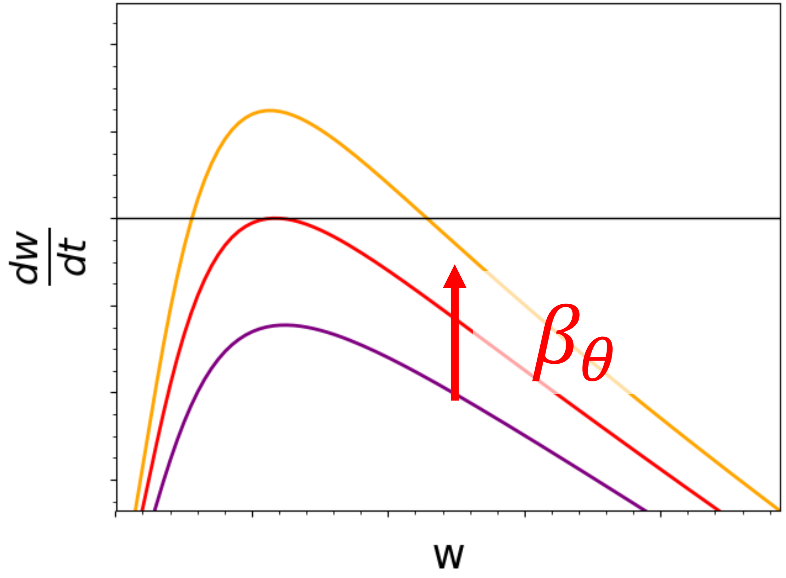
- Prediction: $\epsilon \uparrow$ increases stabilization
  - Favors spherical tokamak



NTMs may be metastable depending on β_θ

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



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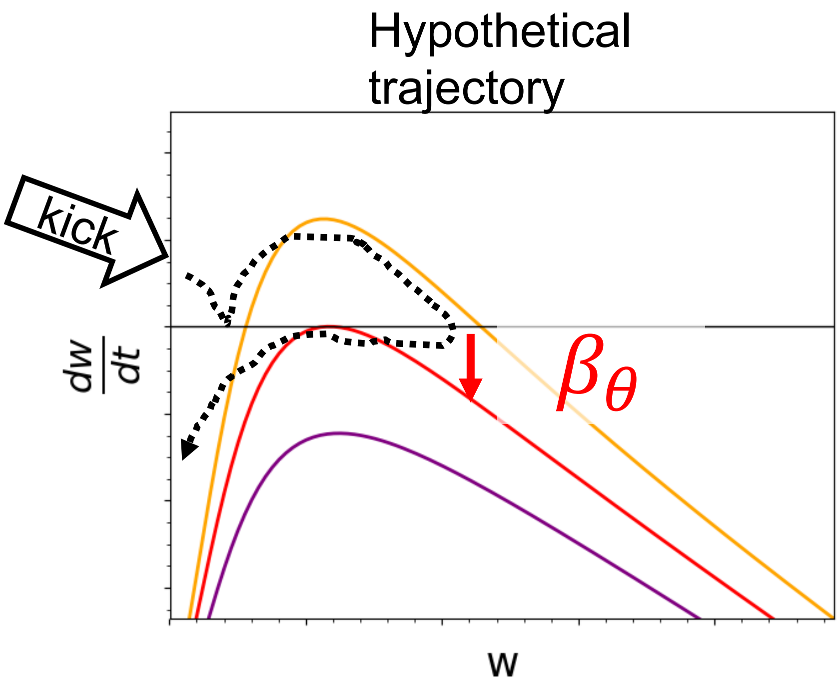
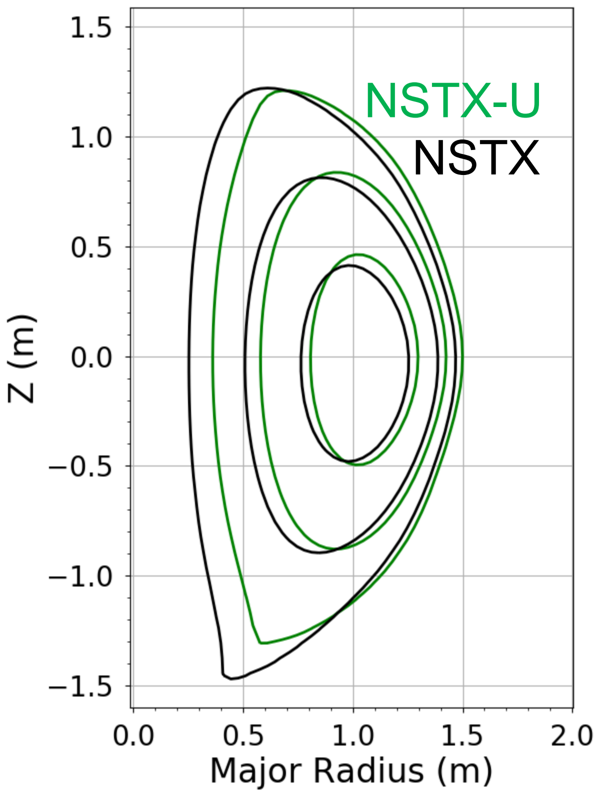


Comparable discharges obtained before & after upgrade

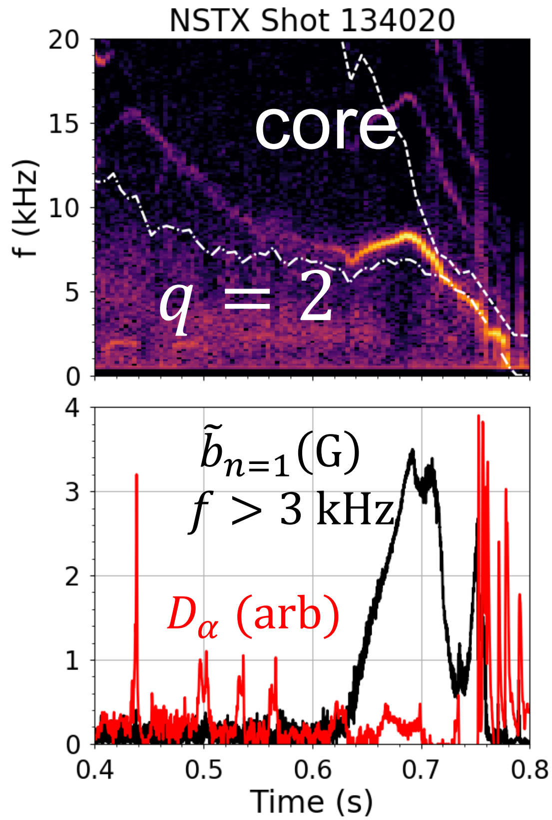
Quantity @ onset	NSTX (134020)	NSTX-U (204112)
r_s/R	0.35	0.29
q_{95}	8.3	7.4
κ	2.2	2.2
β_N	3.9	4.1
β_N/l_i	6.0	5.7
I_p	880 kA	860 kA
B_T	0.44 T	0.63 T

−18%



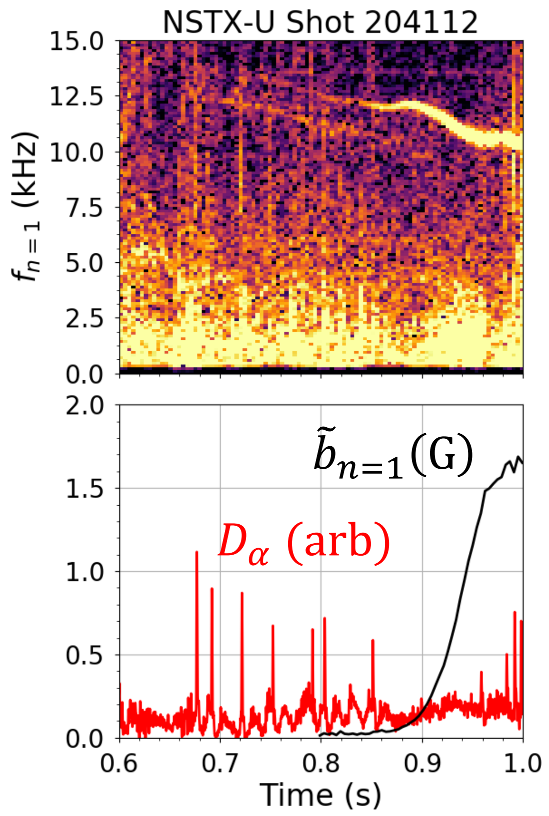
NSTX 134020: Large $m, n = 2{,}1$ mode produced

- Resonant q from f_{tor} + q-profile
- Mode width from T_i profile & $\tilde{b}$
  - 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



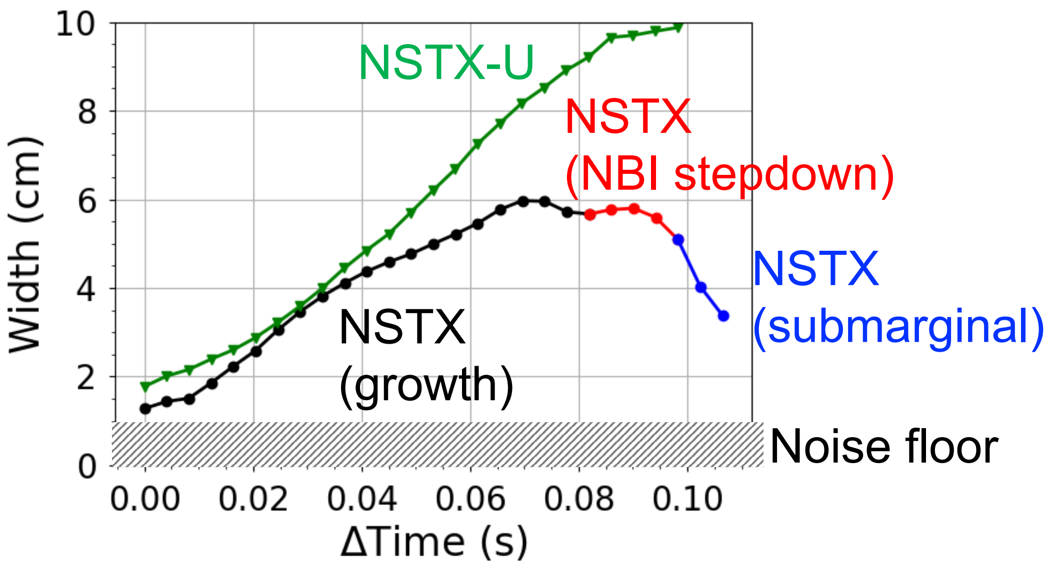
NSTX-U 204112 also has large $m, n = 2,1$ mode

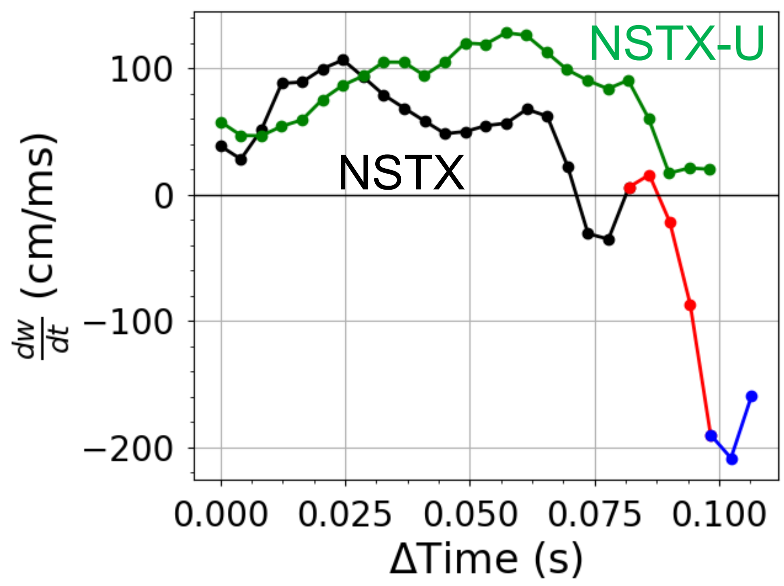
- NBI:
  - No step-down before disruption
  - Using off-axis beam as well
- Diagnostics:
  - MSE, CHERS unavailable
  - Use TS, SXR for mode identification
- Onset near ELM



NSTX-U 204112 mode has larger growth rate, larger saturated island width

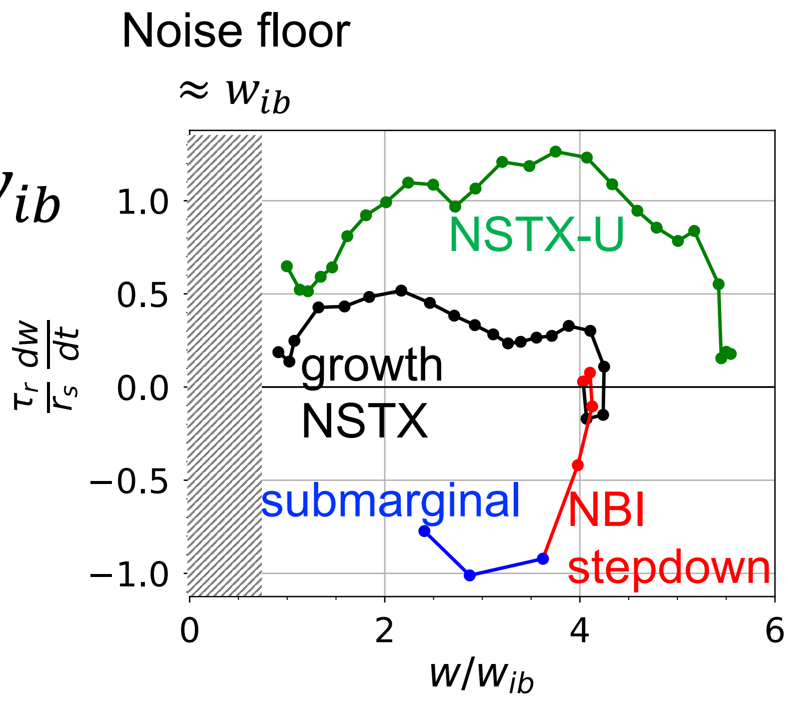
- Larger saturated width
  - Longer to saturate
- Slightly larger growth rate
  - That lasts longer





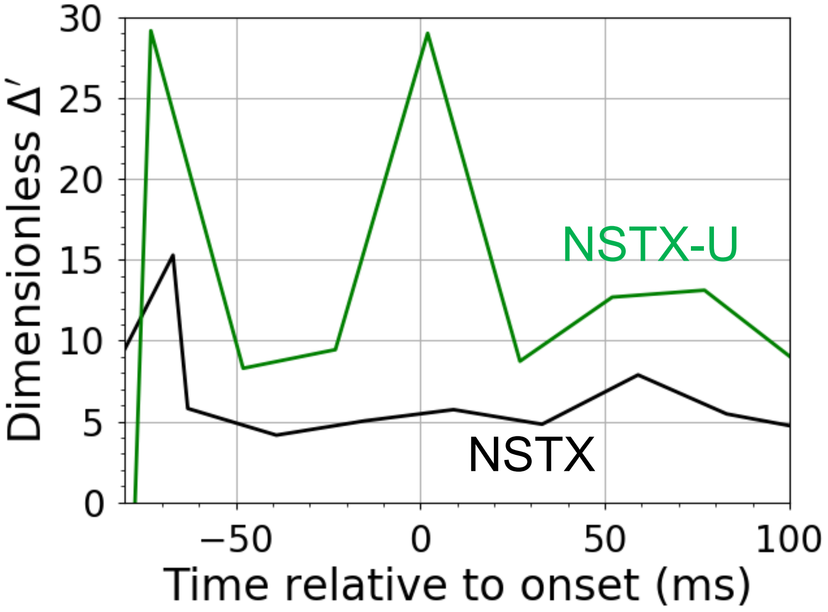
NSTX-U 204112 has much larger normalized growth rate

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



Newly-deployed Resistive DCON applied to NSTX & NSTX-U

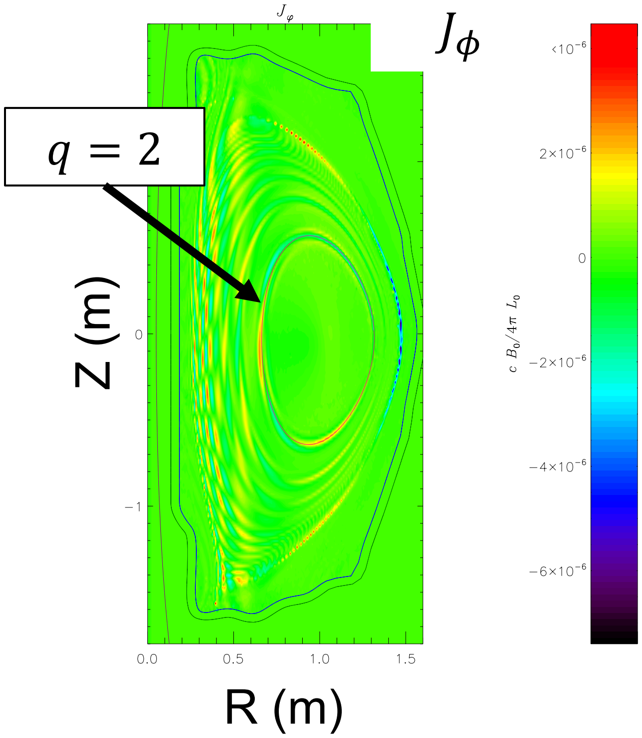
- Resistive DCON:
  - Linear stability
  - Toroidal, finite β
- Both shots have positive Δ'
  - Interchange needed to stabilize at small w
  - Onset not due to Δ' crossing >0



M3D-C1 shows edge instability in NSTX 134020

- Edge mode consistent with NTM 'seed'
  - Couples to $q = 2$
  - Growth rate sensitive to edge resistivity

134020, $t = 0.625$ ms



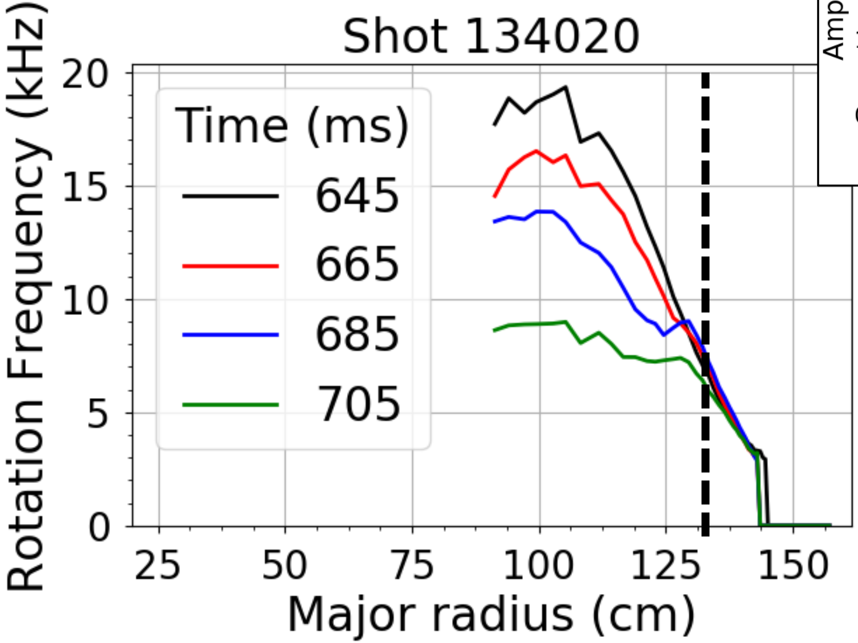
Conclusions & future directions

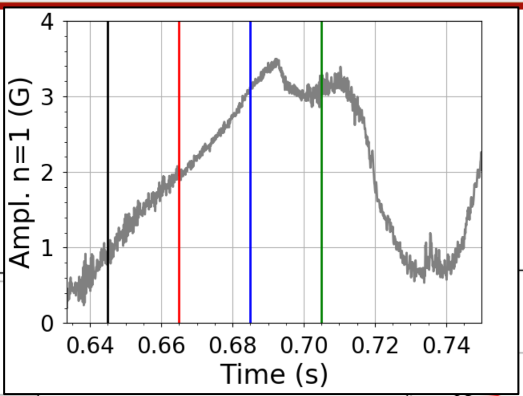
- NSTX-U example has larger growth rate, large saturated mode
  - Consistent with predictions from aspect ratio change
- RDCON finds classical tearing linearly unstable
  - In both NSTX & NSTX-U examples
- M3D-C1 indicates resistive edge instability @ onset
  - Consistent with NTM triggering
- Future directions:
  - Validation of stability predictions
  - Dedicated experiments to scan β, q_{min}
    - Off-axis neutral beam
  - Test control strategies

Reserve slides

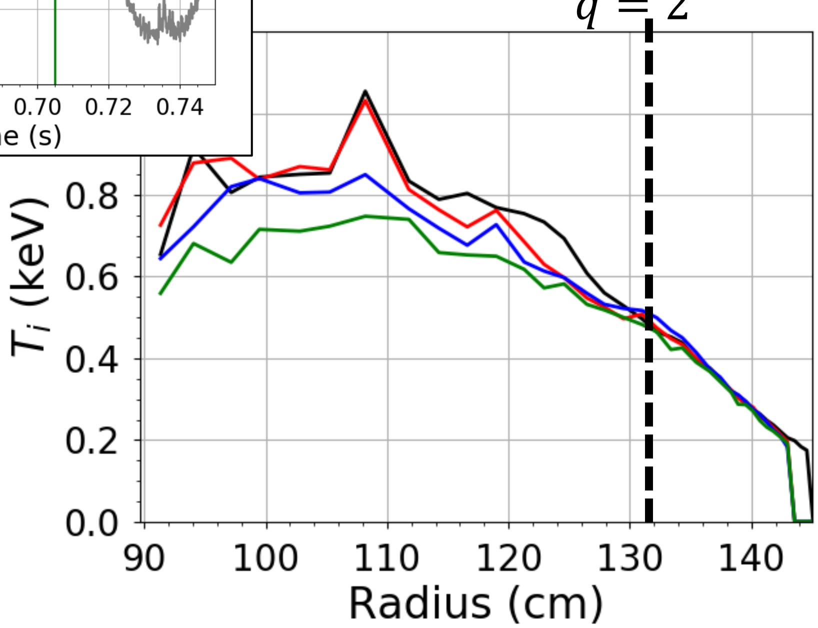
NSTX 134020: Profile diagnostics indicate $n = 1$ mode at $q = 2$

- Rotation ↓ inside $q = 2$
  - Not outside





- T_i also reduced
  - Consistent with Chang-Callen belt model



NSTX-U 204112: T_e profile has flat spots at $q = 2$