# An Alfven Mode Similarity Experiment between NSTX and DIII-D

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The major radius dependence of Alfvén mode stability is studied by creating plasmas with similar minor radius, shape, magnetic field (0.5 T), density ($n_e \simeq 4 \times 10^{19}$ m$^{-3}$), electron temperature (1.0 keV) and beam-ion population (near-tangential 80 keV deuterium injection) on both NSTX and DIII-D. The major radius of NSTX is half the major radius of DIII-D. The super-Alfvénic beam ions that drive the modes have nearly identical values of $v/v_A$ in the two devices. The plasma current was varied to match either the edge $q$ or the beam-ion banana width. Observed beam-driven instabilities include toroidicity-induced Alfvén eigenmodes (TAE) and com-

pressional Alfvén eigenmodes (CAE). Analysis indicates that the stability threshold for the TAE is similar in the two devices but the most unstable toroidal mode number $n$ increases with major radius.

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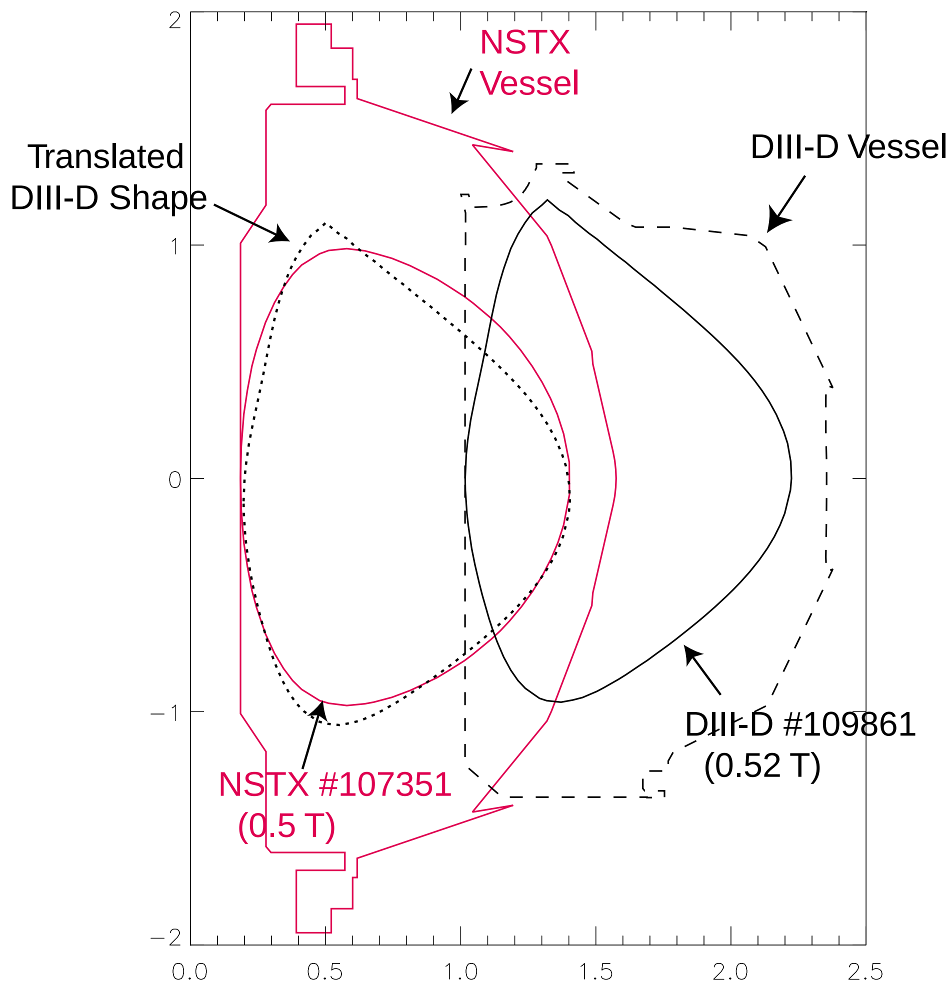
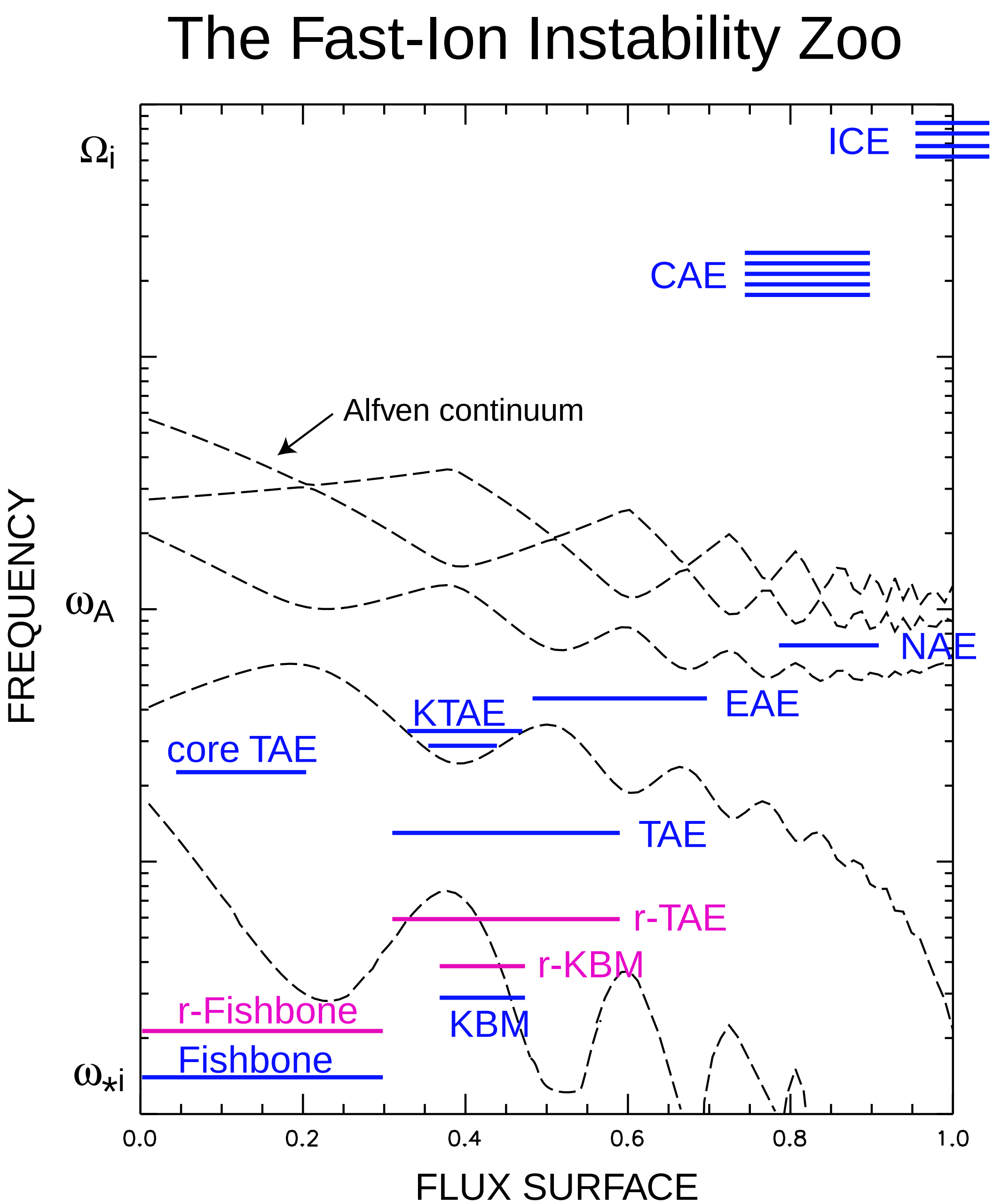
# Alfven Mode Similarity Experiment

Goals: Match NSTX field and shape to study R dependence.
(The beams are similar, so this matches $v_b/v_A$.)
Measure stability threshold.
Measure most unstable toroidal mode number n.

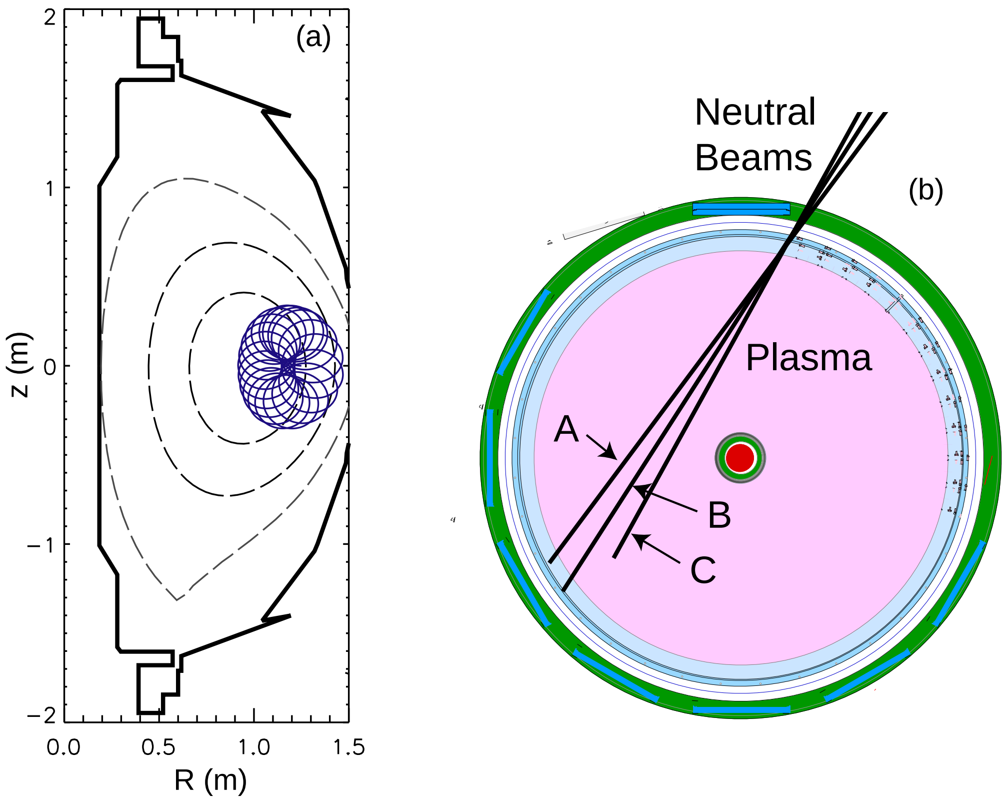


# Motivation

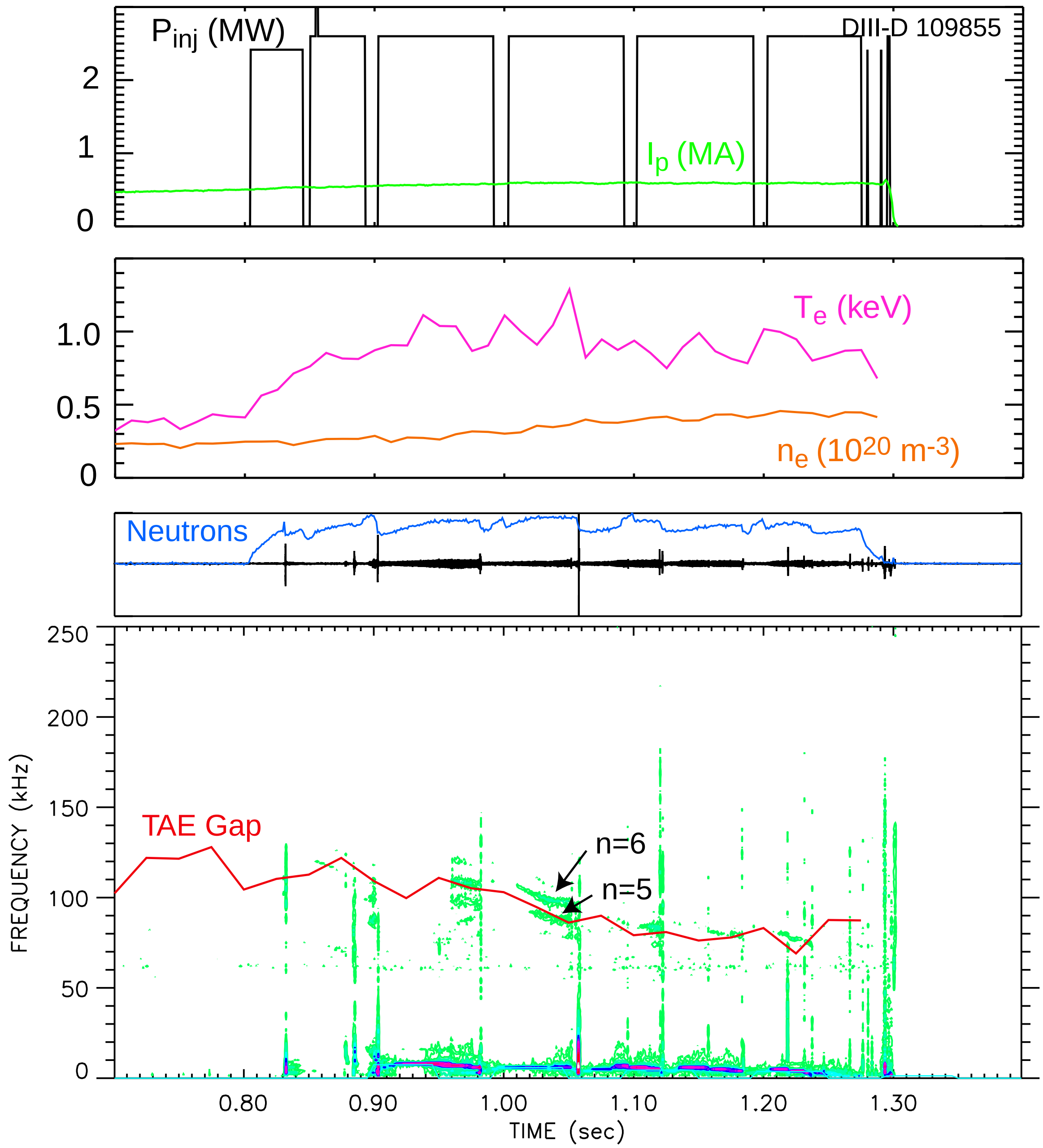
- Larger gaps in the Alfvén continuum in a spherical tokamak (ST). Is it more unstable? Does the transition from normal modes to energetic particle modes occur at higher beta?
- The stronger field variation in a ST alters the particle drifts. Does this alter the resonances?
- Major radius scaling of the most unstable mode–important for prediction of a "sea" of unstable modes in a burning plasma experiment.
- Necessary to avoid Alfvén modes in a thermal confinement similarity experiment.


The Fast-Ion Instability Zoo
FREQUENCY
$\Omega_i$
$\omega_A$
$\omega_{*i}$
FLUX SURFACE
0.0
0.2
0.4
0.6
0.8
1.0
Alfven continuum
ICE
CAE
NAE
EAE
KTAE
core TAE
TAE
r-TAE
r-KBM
KBM
r-Fishbone
Fishbone

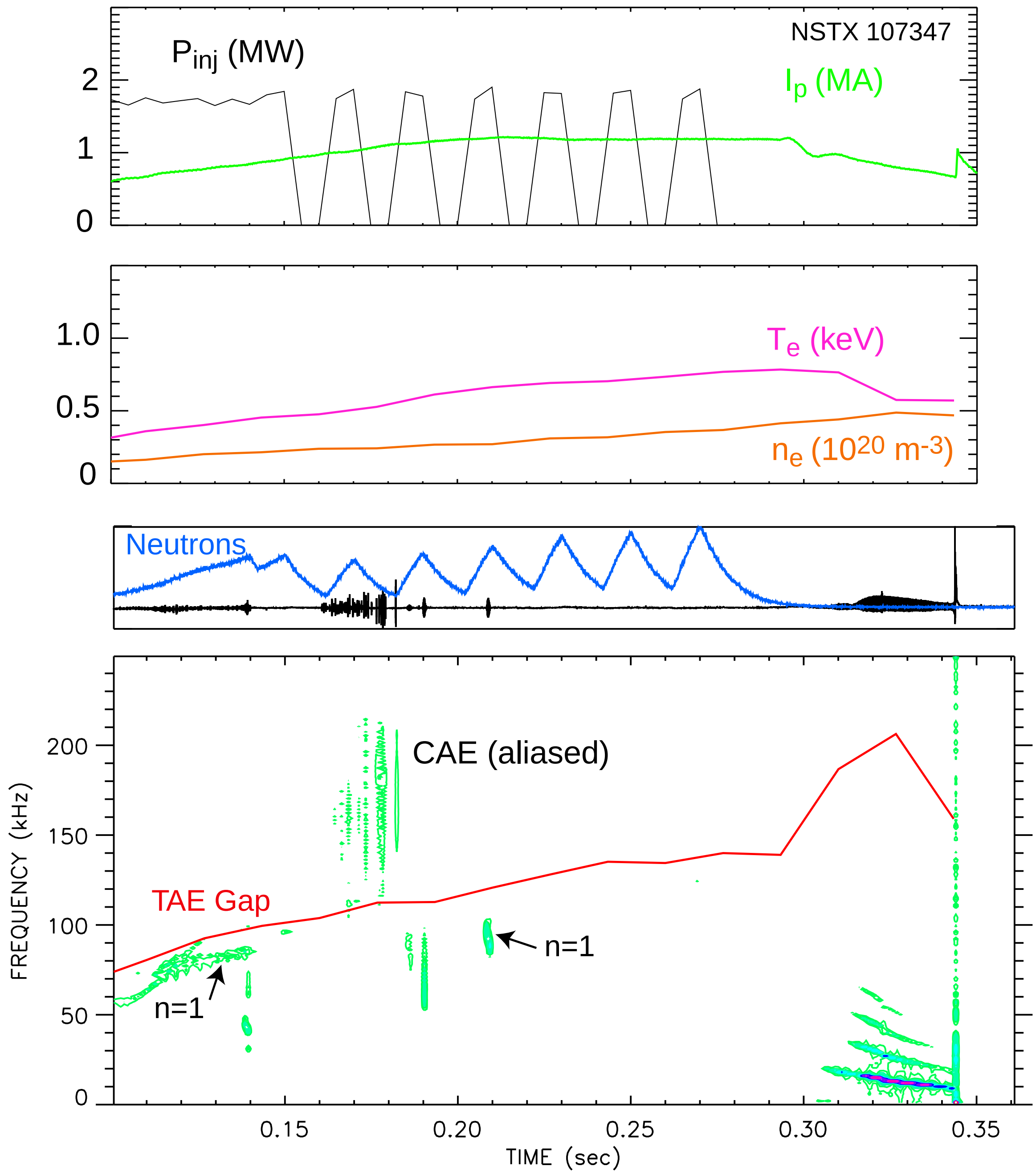
# Beam-ion Orbits Span Most of the Plasma



# A typical 0.6 T DIII-D Discharge

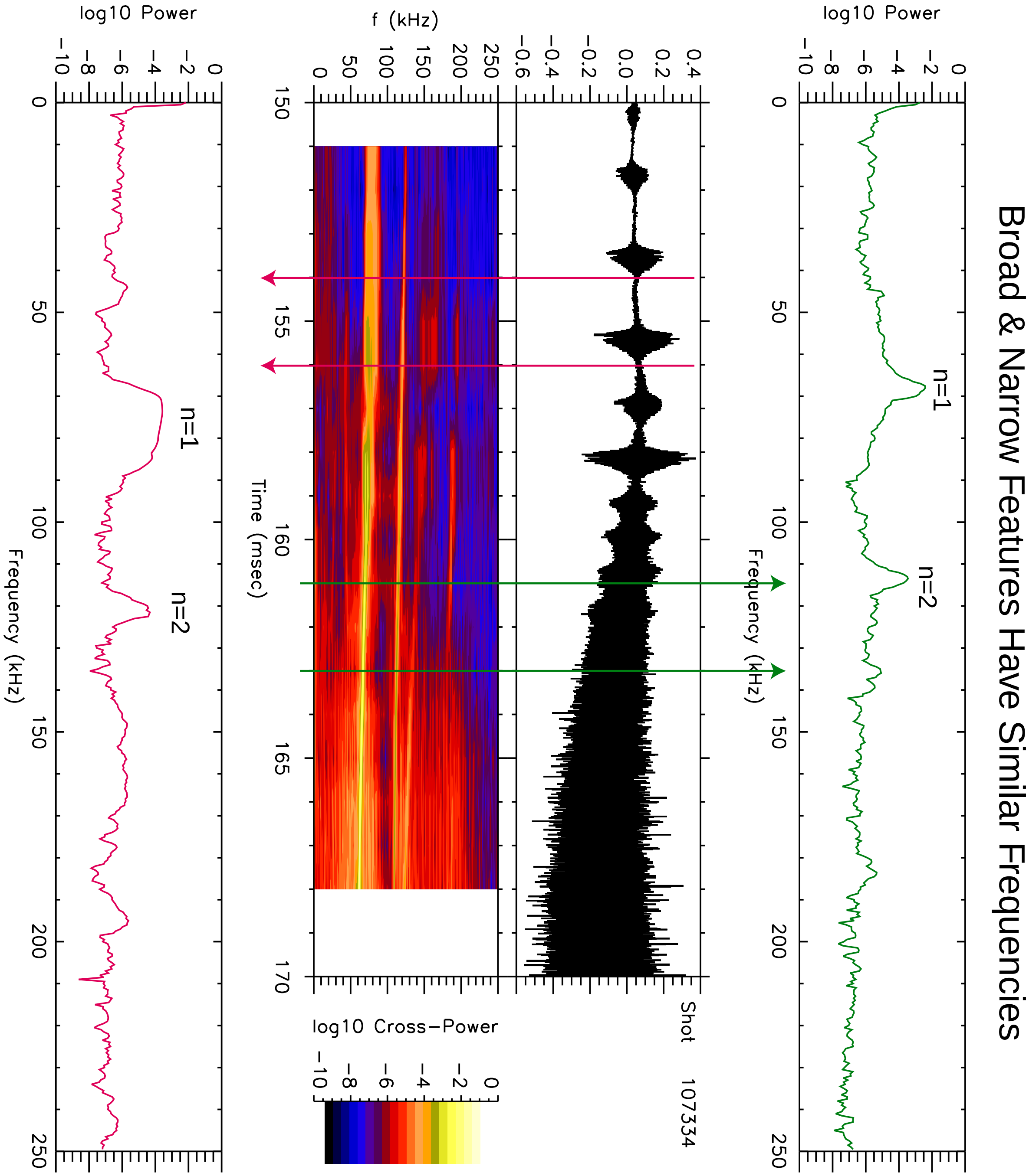


# A typical NSTX Discharge



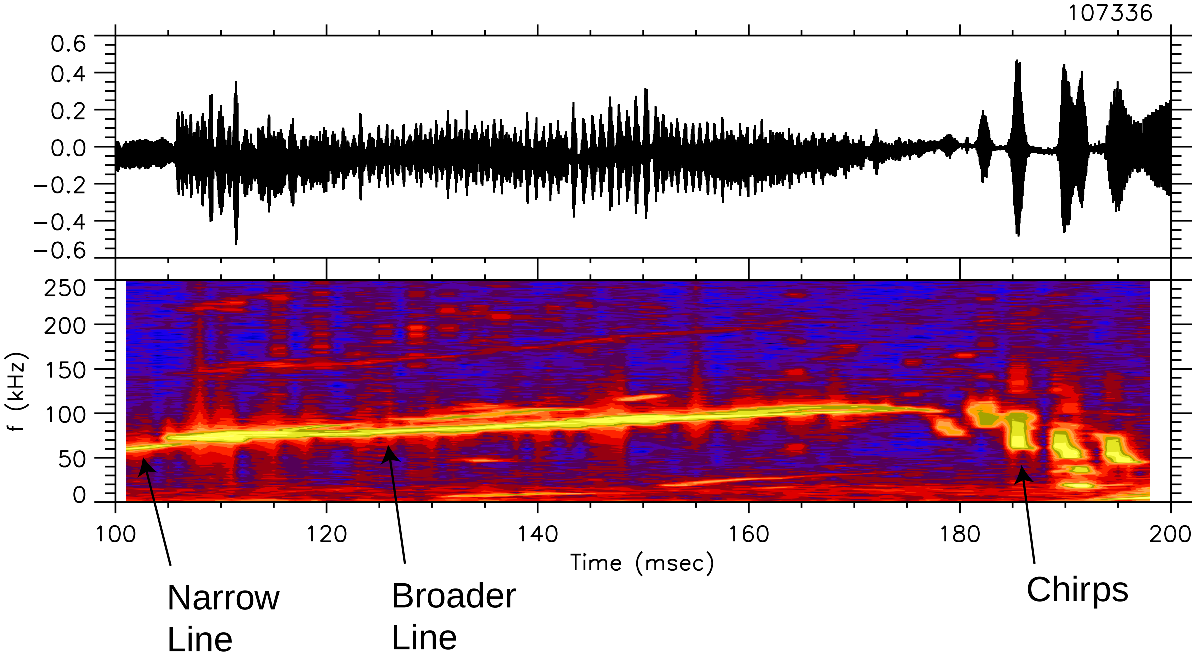
# How do we distinguish between a bounce-resonance fishbone and a TAE?

- A complication in the interpretation of the experiment is the appearance in NSTX of modes that may be bounce-resonance fishbones (GP1.109) with frequencies that are indistinguishable from the TAE.
- Are these really different modes? Or is nonlinear saturation just different? (We aren't sure.)
- Adopt conservative criteria for a "TAE" in this study:
  1. Frequency in TAE band
  2. Narrow linewidth
  3. Simultaneous appearance of higher $n$ lines

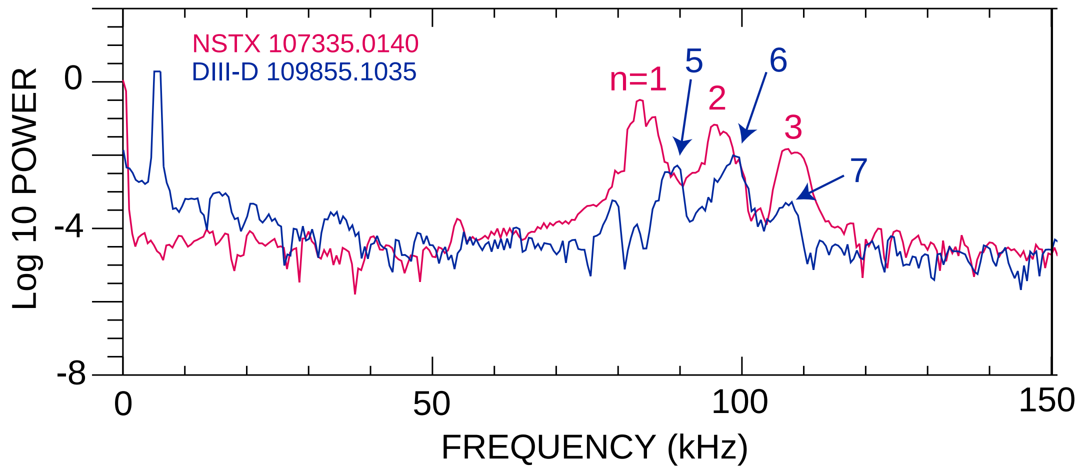


Broad & Narrow Features Have Similar Frequencies
log10 Power
n=1
n=2
Frequency (kHz)
Shot 107334
f (kHz)
Time (msec)
log10 Cross-Power

## Three Linewidths in this Shot (~2, 10, and 30 kHz)

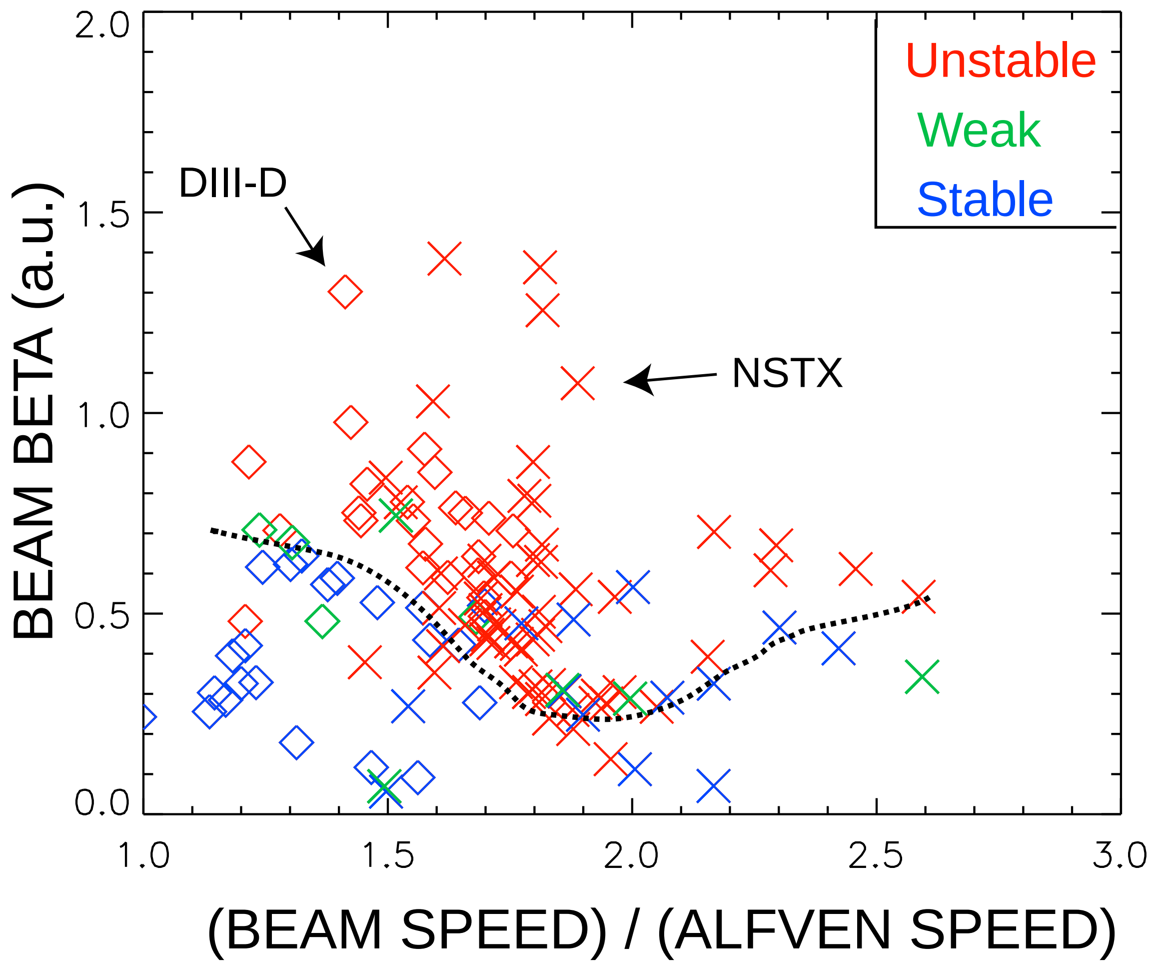


# Classic "TAE" Spectral Feature in Both Devices



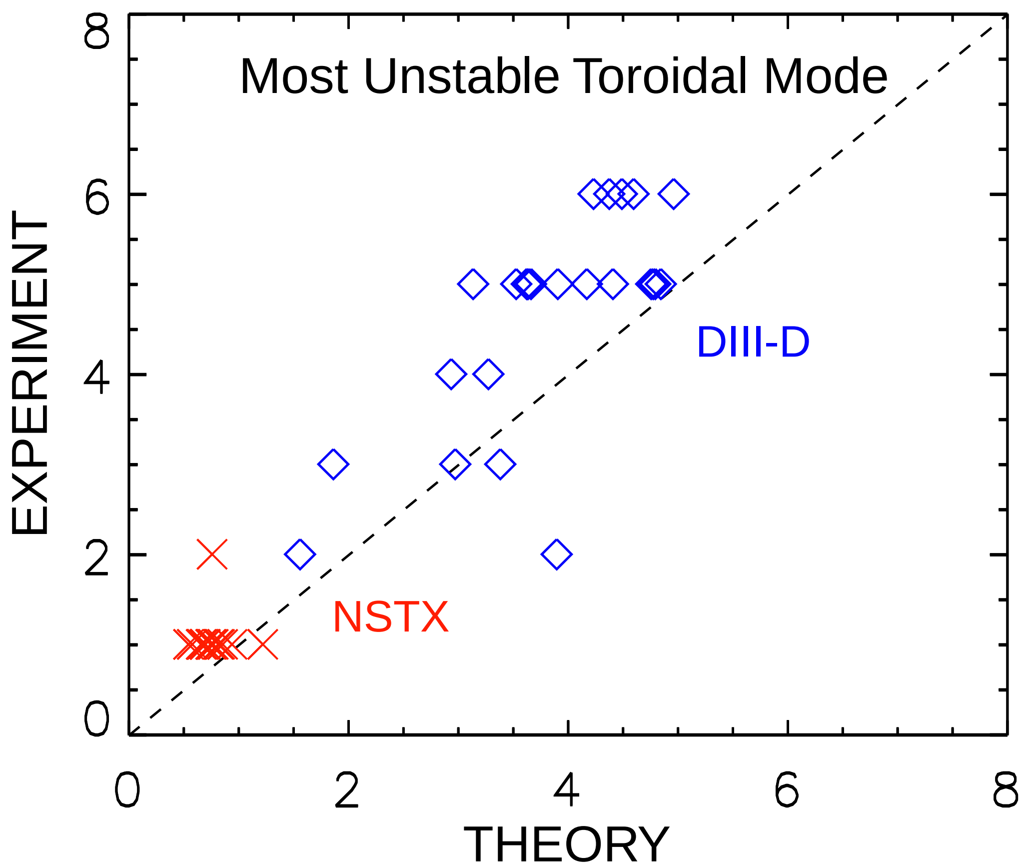

- Many NSTX discharges have a $n = 1$ spectral feature with $f \simeq f_{TAE}$ that is $\sim 10$ kHz wide–possibly a bounce-resonance fishbone.
- Use narrow line & coexistence of other $n$ numbers as TAE signature.
- For DIII-D, inferred frequency in plasma frame $\sim 80\%$ of nominal TAE frequency.
- Classic "chirping modes" ($f \simeq \frac{1}{2} f_{TAE}$, $\Delta f/f \sim 50\%$, $\sim 1$ ms bursts, $n = 1$, 2 or 3) also occur on most NSTX discharges.

# Similar TAE Thresholds




- One steady 80 keV beam is usually unstable in both devices.
- $\beta_{beam} \propto (Neutrons)/(density * volume * B^2)$.

# TAE Mode Number Scales as Expected

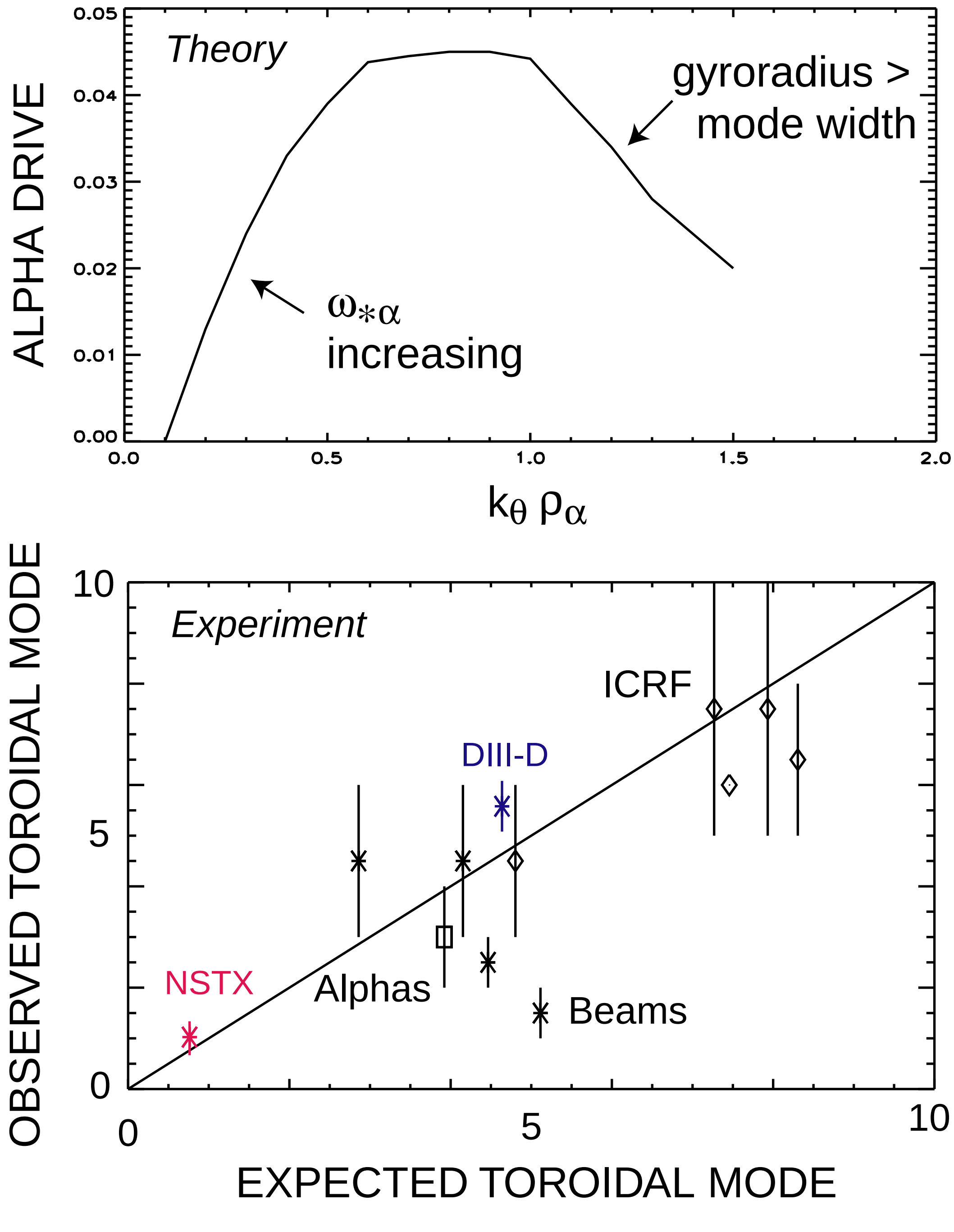


- Theoretically, the most unstable toroidal unstable mode occurs when $k_\theta \rho_f \sim 1$, or $n \simeq a/(\rho_f q^2)$ with no explicit dependence on $R$.

  Fu & Cheng, Phys. Fluids B**4** (1992) 3722; Breizman & Sharapov, Plasma Phys. Cont. Fusion **37** (1995) 1057.

- The new data expand the inter-machine database.

  Heidbrink, Phys. Plasmas **9** (2002) 2113.

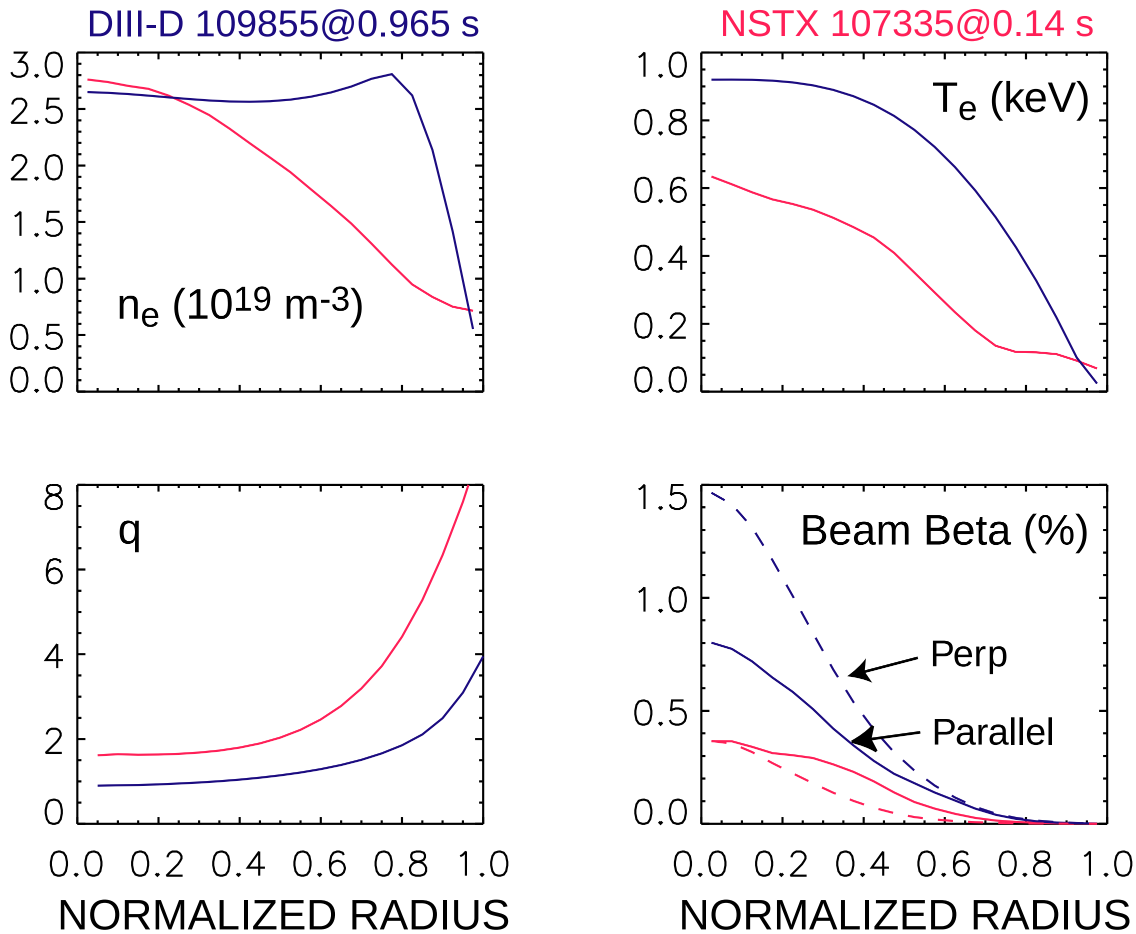


Theory
ALPHA DRIVE
0.00
0.01
0.02
0.03
0.04
0.05
0.0
0.5
1.0
1.5
2.0
gyroradius >
mode width
ω∗α
increasing
kθ ρα
Experiment
OBSERVED TOROIDAL MODE
EXPECTED TOROIDAL MODE
0
5
10
ICRF
DIII-D
NSTX
Alphas
Beams

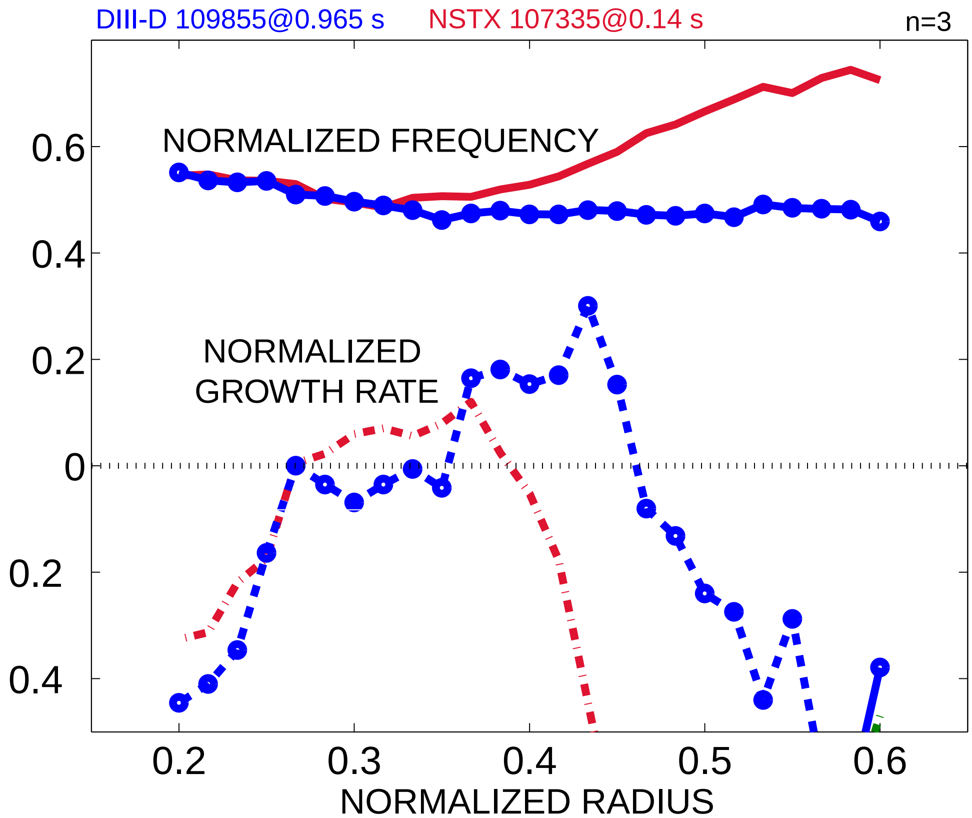
## Stability Analysis with the HINST Code

- Two representative discharges are analyzed by TRANSP.
- The HINST code is a non-perturbative, high-$n$ code that performs a local stability analysis. (Global effects are likely to be important in NSTX, however).
- HINST predicts TAE instability in both discharges and comparable growth rates.
- The predicted frequency is consistent with experiment.
- The prediction for most unstable toroidal mode number is close to the experimental value in both cases.

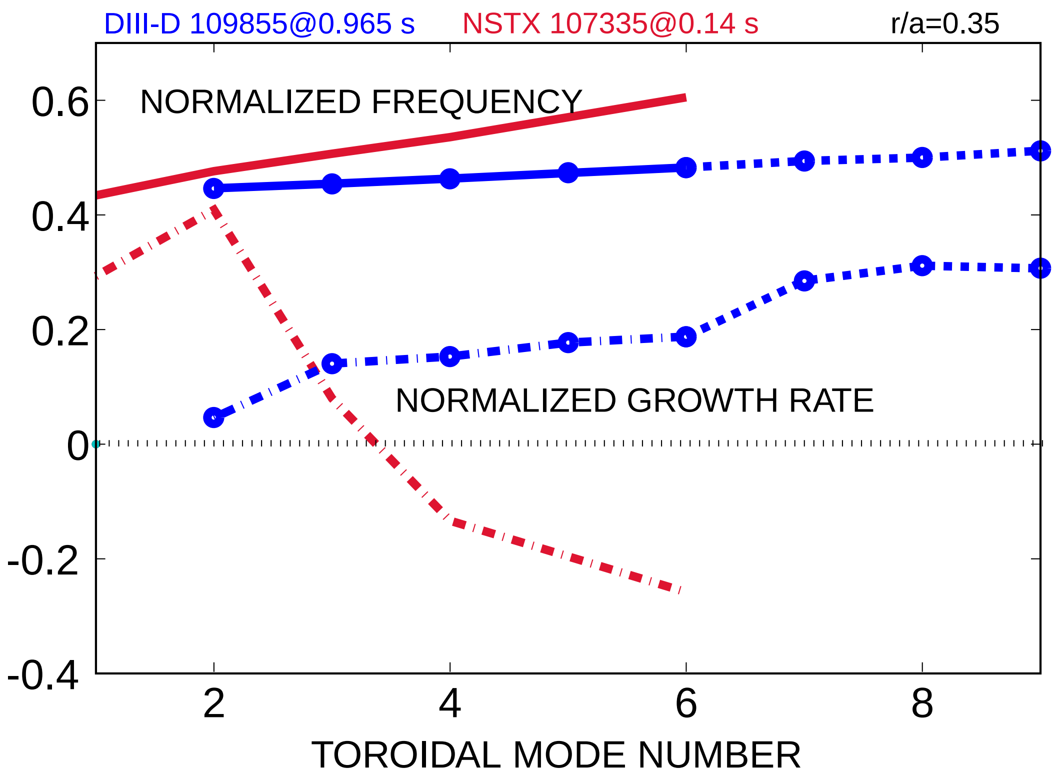
# TRANSP profiles for Discharges Analyzed by HINST



# HINST predicts TAE instability in the Core



## HINST predicts $n = 2$ for NSTX; $n \gtrsim 6$ for DIII-D



# Conclusions

- Made 0.52 T discharge on DIII-D and approximately matched shapes. Future similarity experiments will be easier.
- Chirping modes common on NSTX but not observed on DIII-D. Why? Larger shear? Larger gap? Will calculate radial dependence of orbital frequencies.
- Empirical TAE thresholds comparable; consistent with theory.
- TAE $n$ number larger in DIII-D as expected. Scaling law works.
- Observed CAE activity in DIII-D. Hope to study CAEs quantitatively in the next campaign.