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Toroidal Alfvén Eigenmode Avalanches

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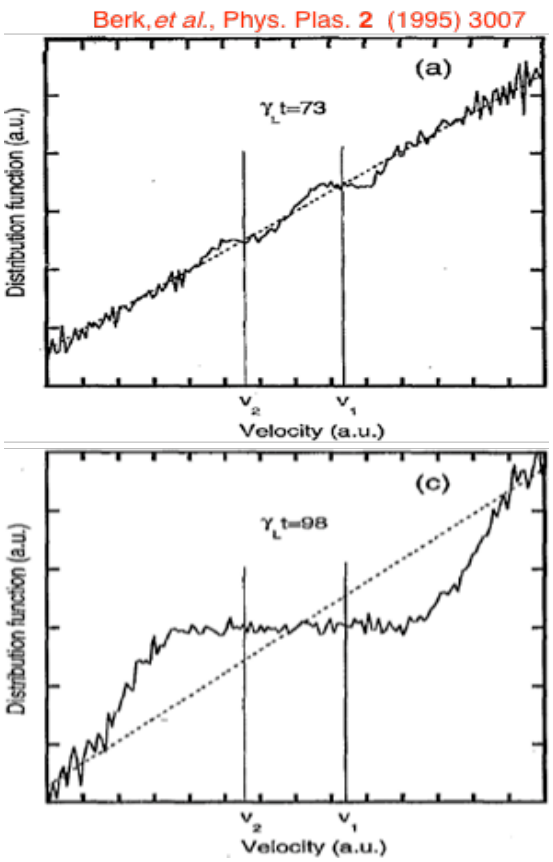
Introduction to talk

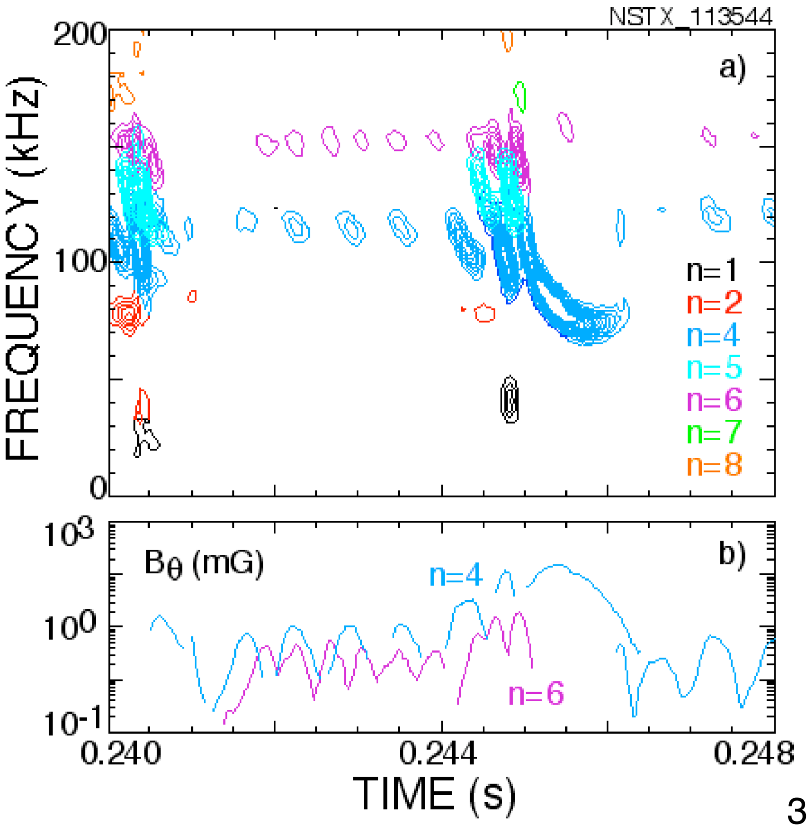
- An experiment to determine the threshold β_{fast} for excitation of TAE and TAE avalanches is described.
- Identified quiescent plasma conditions for benchmarking TRANSP beam current drive models.
- Provided detailed equilibrium data at TAE threshold to benchmark NOVA.
- Provided detailed equilibrium data at avalanche threshold to benchmark M3D-k or NOVA/ORBIT.
- Made detailed measurements of the internal structure of the modes, for comparison with NOVA predictions and ORBIT simulations.

TAE bursts suggest "Avalanche" physics

- No correlation of repetitive small bursts; increased amplitude leads to strong multiple mode burst


Berk, *et al.*, Phys. Plas. **2** (1995) 3007

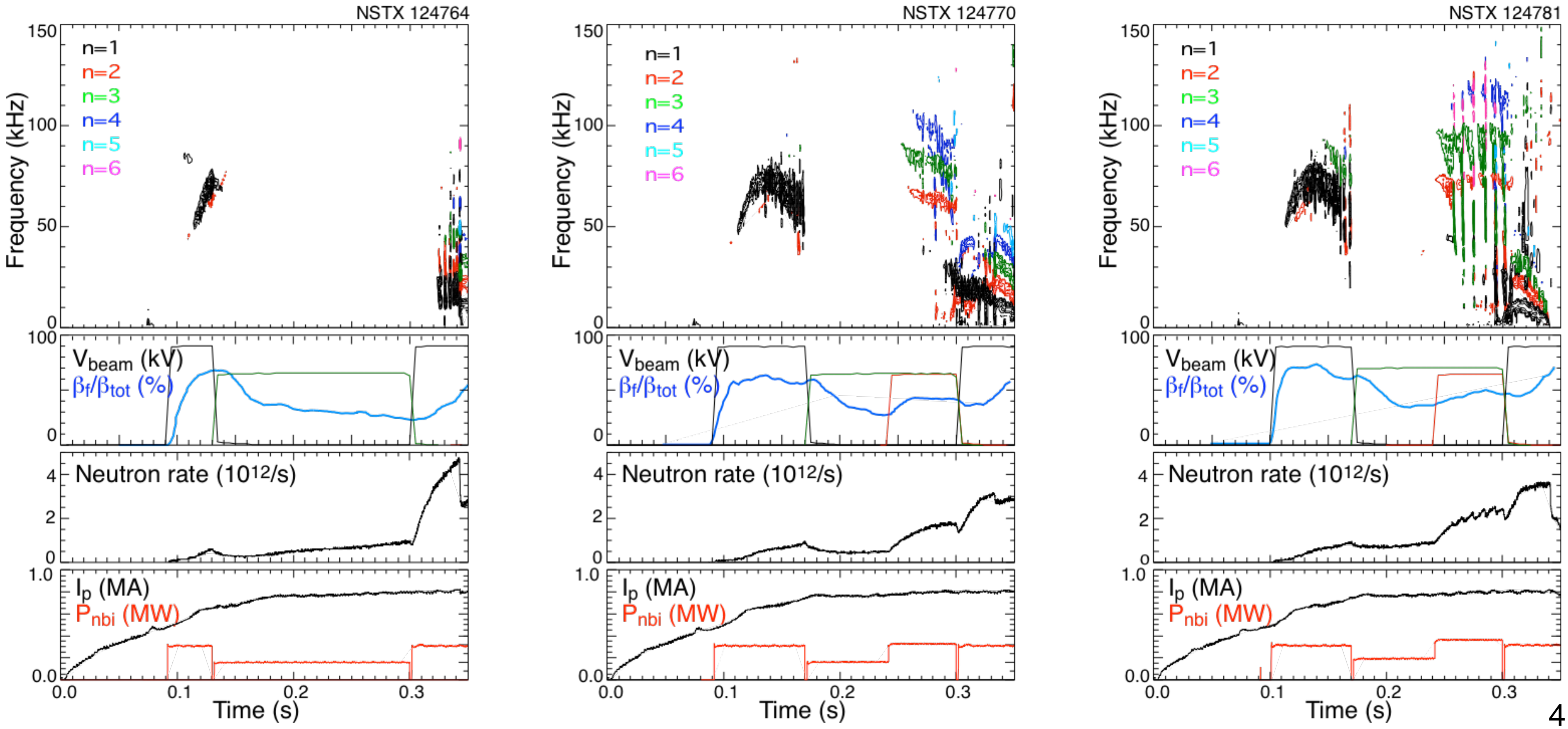
Berk, et al., PoP **2** 2007



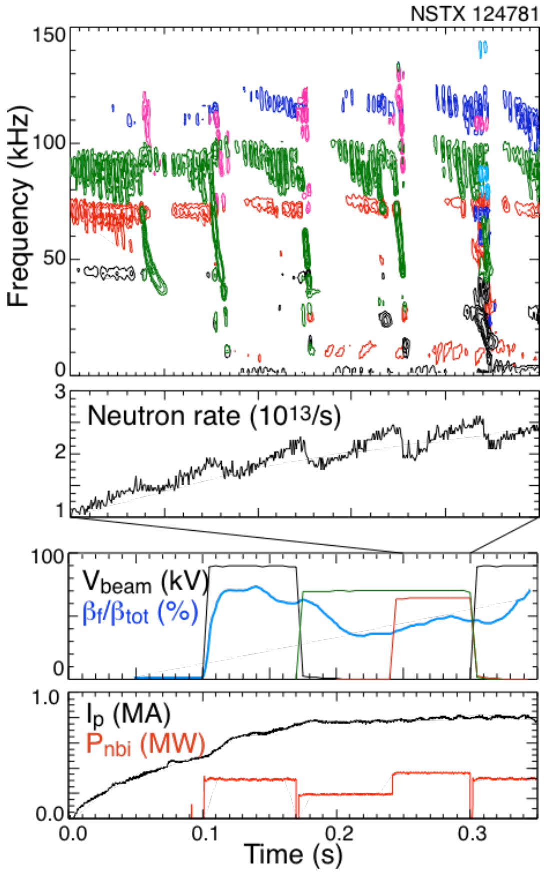
- Large amplitude modes overlap in fast-ion phase-space.
- Interaction results in stronger modes, destabilizes new modes; more fast ion transport
- TAE have multiple resonances, more complex physics

β_{fast} scan determines threshold for TAE, TAE-avalanche

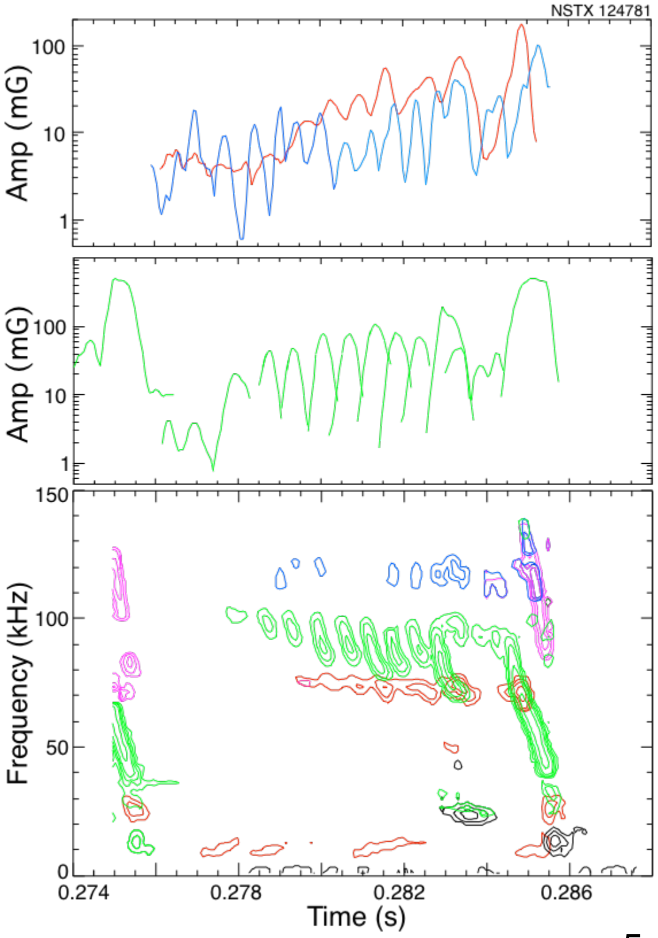
- Beam power avalanche threshold 10% above TAE threshold
- q-profile evolution measured before/after TAE window



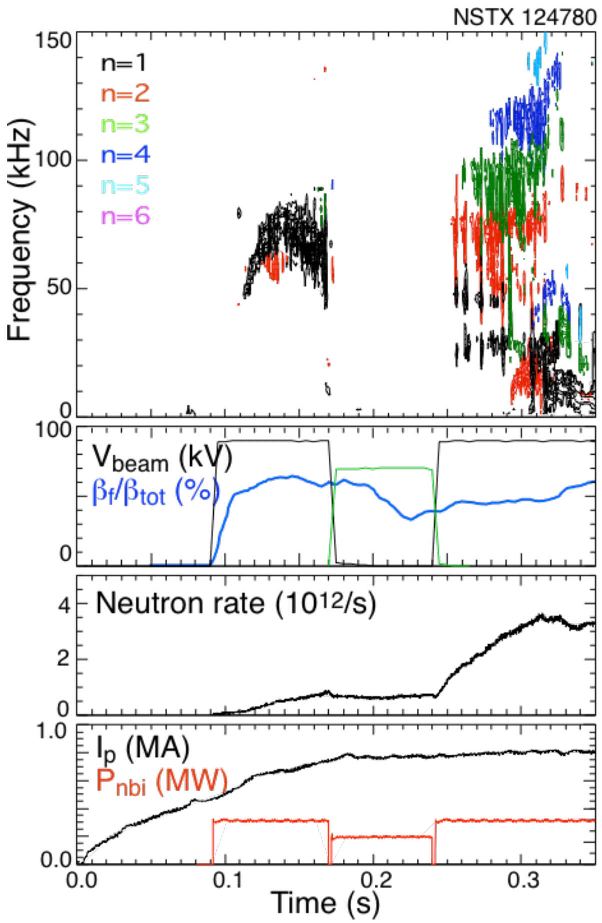
Mode amplitude increases x10 during avalanche sequence



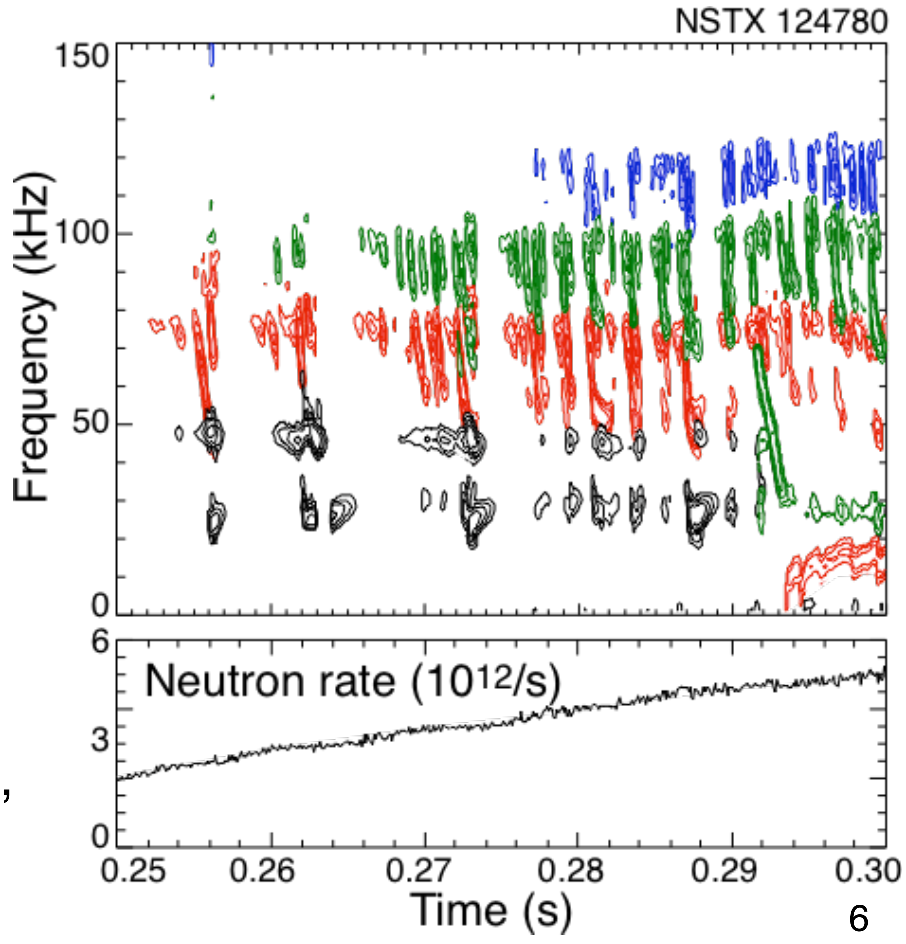
- Three independent TAE modes all show similar evolution of burst amplitude.



- Bursts here are weakly correlated.
- In final large bursts, TAE bursts are accompanied by EPMs, additional modes.
- TAE also show large downward frequency chirps.



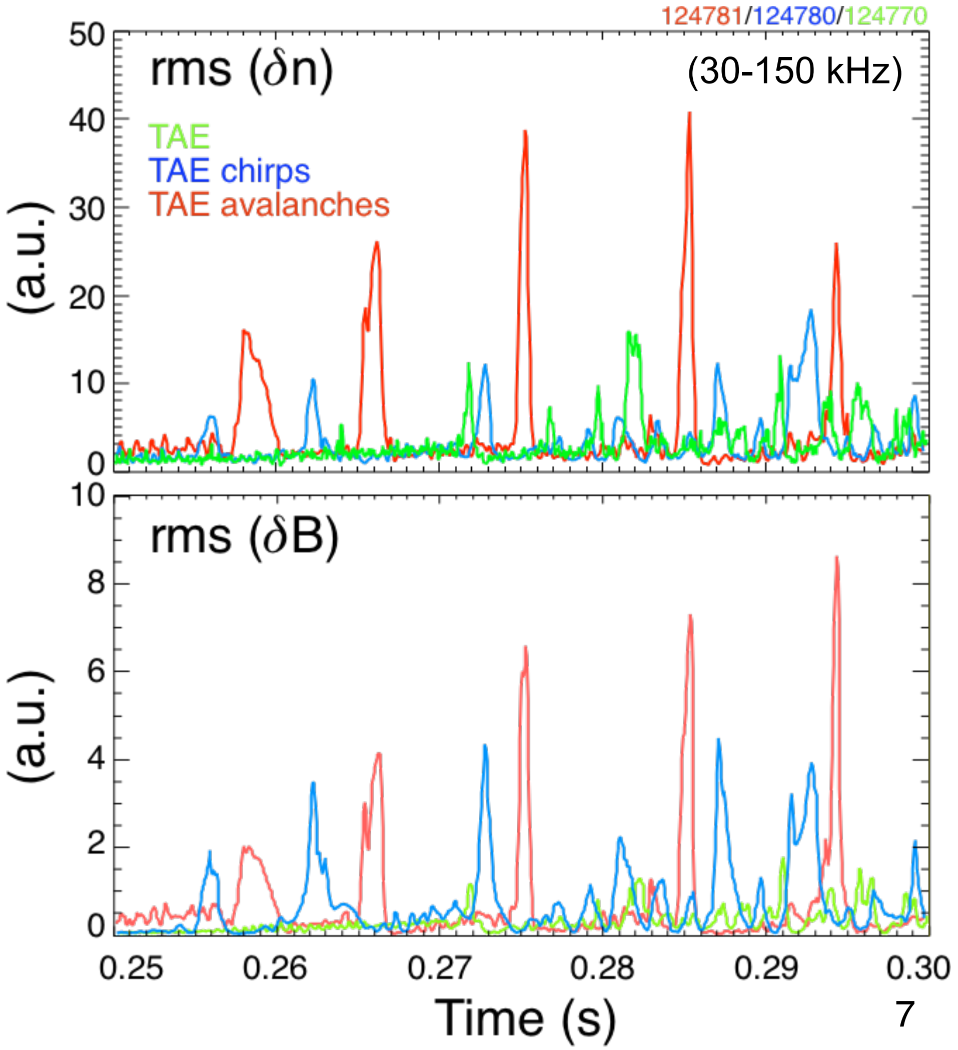
Strong chirping, neutron drops not always correlated



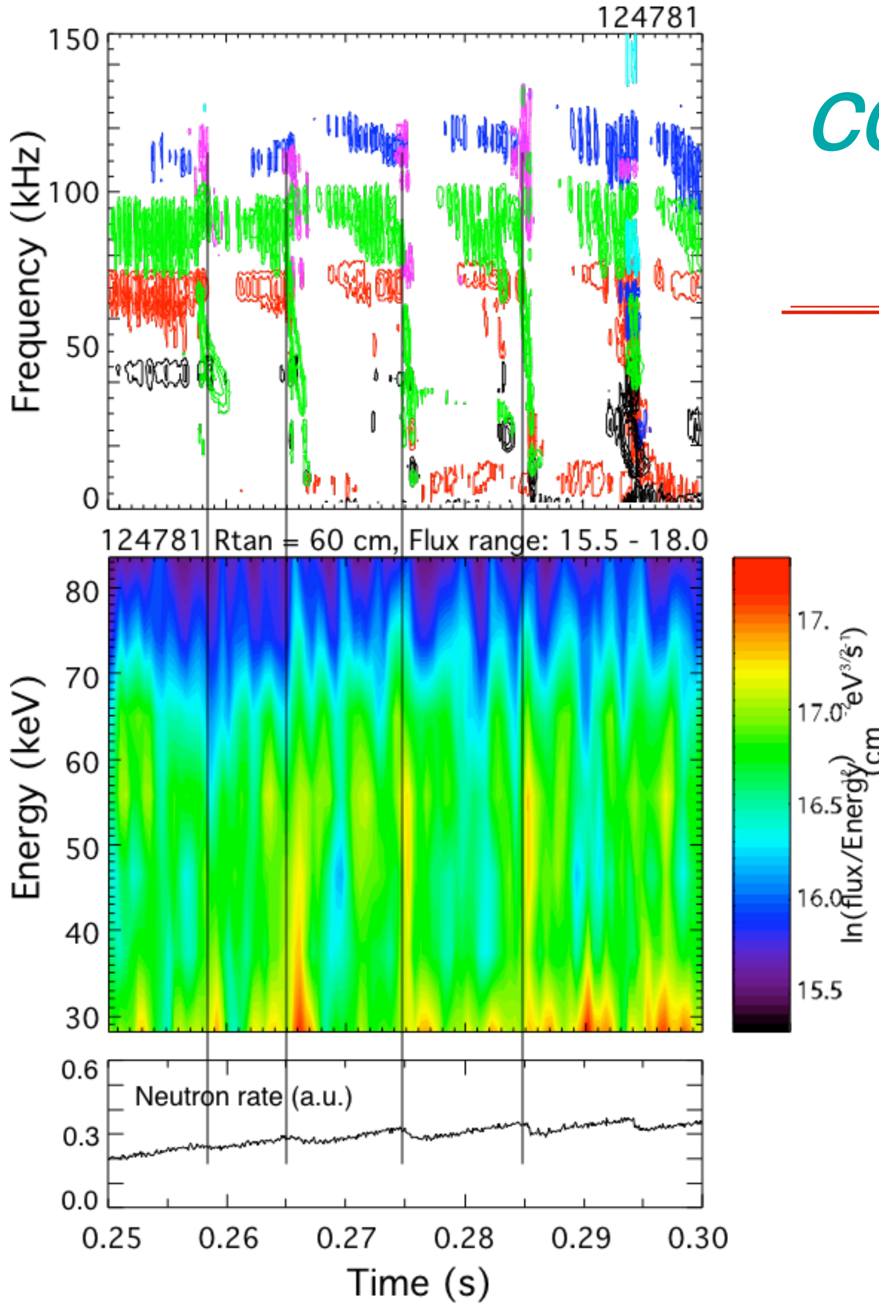
- Multiple modes present here, also.
- Stronger chirping shot has higher voltage beams, more tangential injection.
- Mode amplitudes, by some measures, comparable to avalanches, by other measures ≈ 2-3 times weaker

rms Fluctuation Amplitude largest for the TAE Avalanches

- Internal (core) mode amplitude reaches 2 - 3 times larger in amplitude than in TAE or TAE-chirping cases.
- Magnetic fluctuation amplitudes closer in TAE-chirping and avalanche cases.
- Strong chirping, multiple modes, similar amplitude, no neutron drops or quiescent periods.



Avalanche onset correlated with fast ion losses

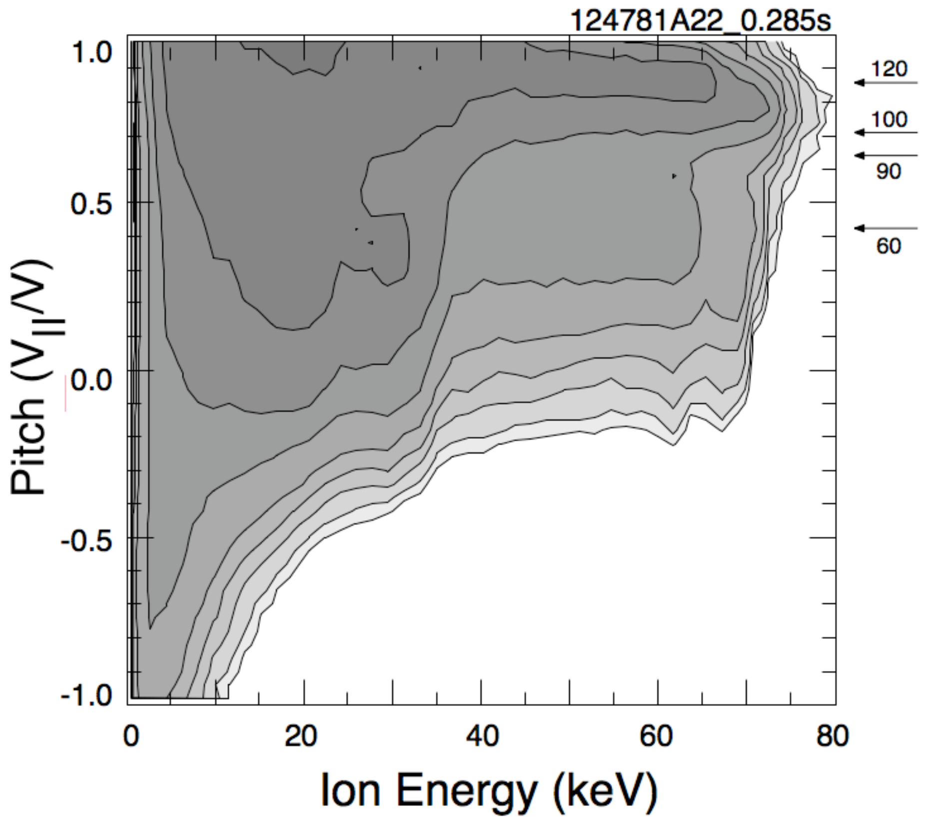


- Chirping may play important role in fast ion loss.
- Neutron drops correlated with D-alpha spikes - fast ions are lost.
- Neutral particle analyzers (NPA) measure spectrum of charge-exchanged neutral ions from plasma.
- Transport appears largest at lower energies.

D. Liu, W Heidbrink

ssNPA measured ions most likely from plasma edge

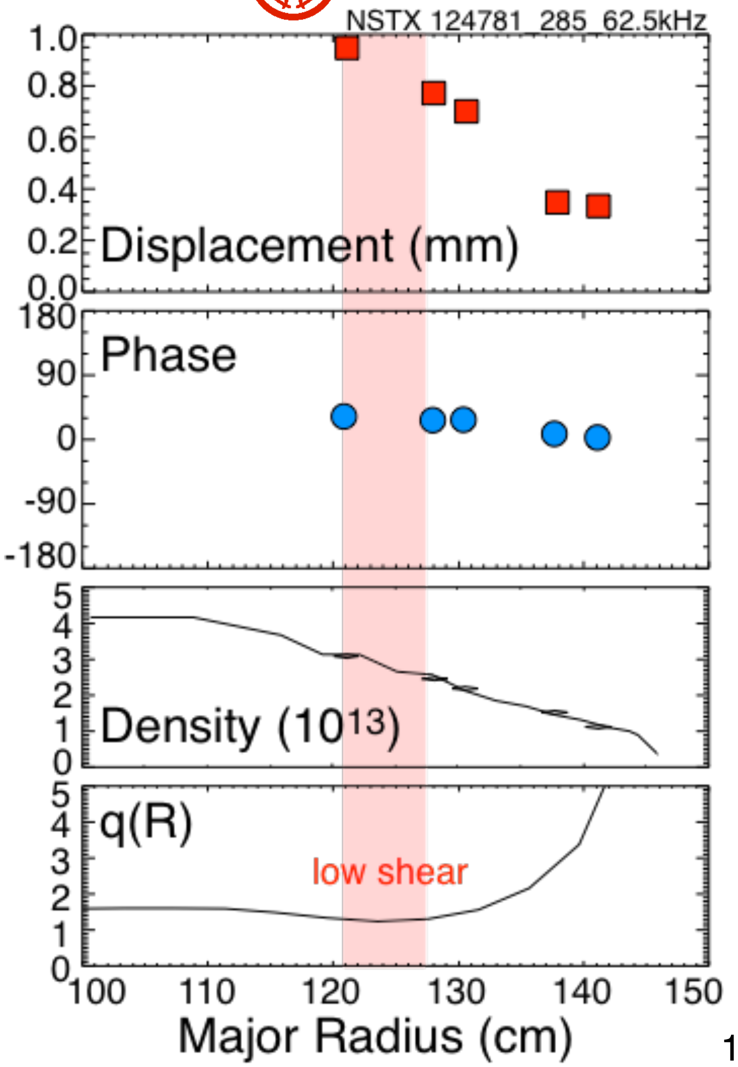
- Fast ion transported from mode location (r/a ≈ 0.5) to plasma edge.
- Charge-exchange with edge neutrals gives signal.
- Pitch angle deduced from this model.
- Classical fast ion distribution shown for r/a ≈ 0.5, outboard midplane.



(More complete description in D. Liu's talk)

Reflectometers provide internal measurement of amplitude, shape*

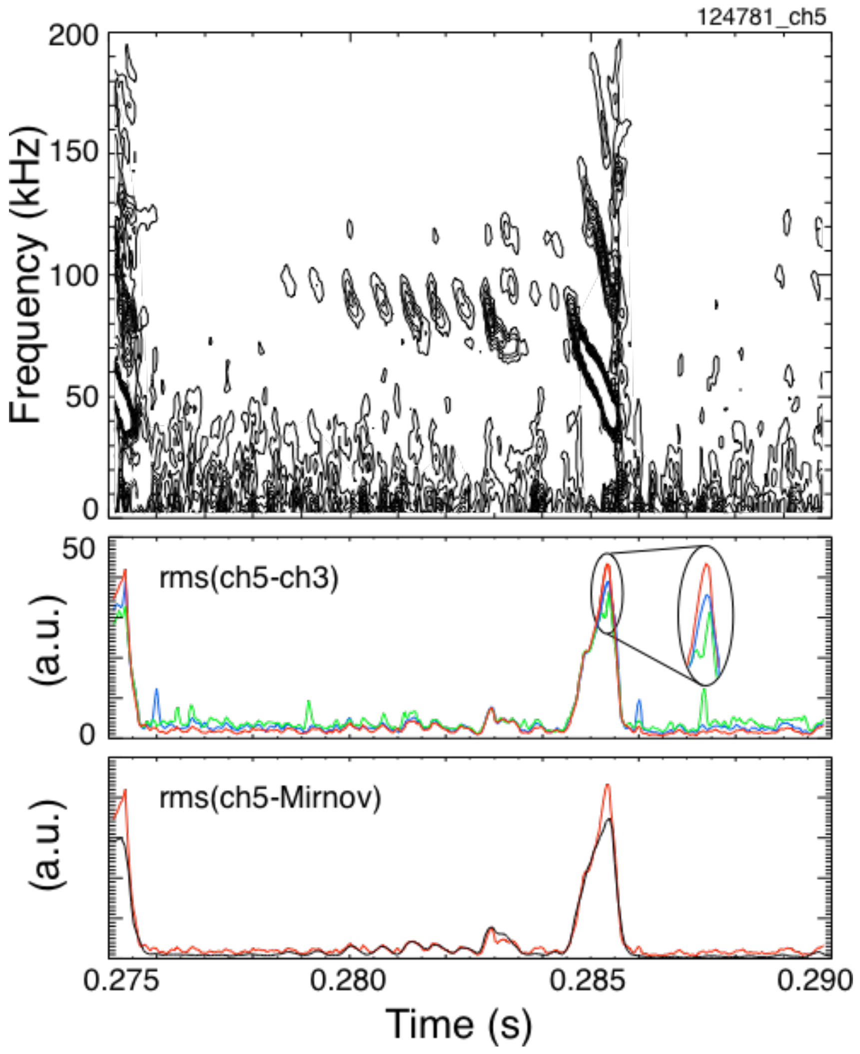
- Modes are fairly well localized (n = 3 mode is shown).
- No phase-inversion seen over range of reflectometer data; deepest reflectometer channel is near q_{min}.
- Amplitude deduced using simple "mirror" model; probably under-estimates actual amplitude (N. Crocker).
- q-profile calculated with LRDFIT, constrained by MSE data.



*Kubota, et al., Rev. Sci. Instrum. 72 (2001) 348.

Mode structure fairly constant through avalanch, chirp evolution

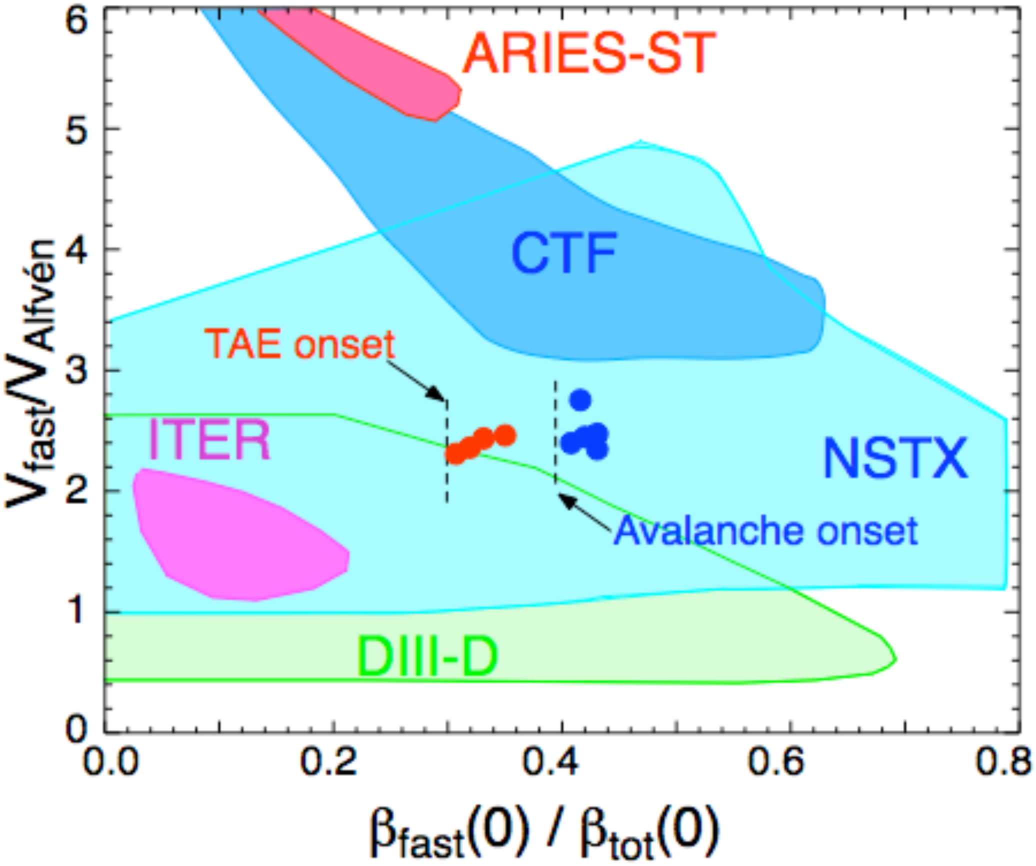
- Amplitude at time of avalanche much greater than earlier bursts.
- Relative amplitude tracks well through multiple modes, suggesting fixed mode structure...
- …except toward end of last burst, suggesting mode becoming more core-localized.



*Kubota, et al., Rev. Sci. Instrum. 72 (2001) 348.

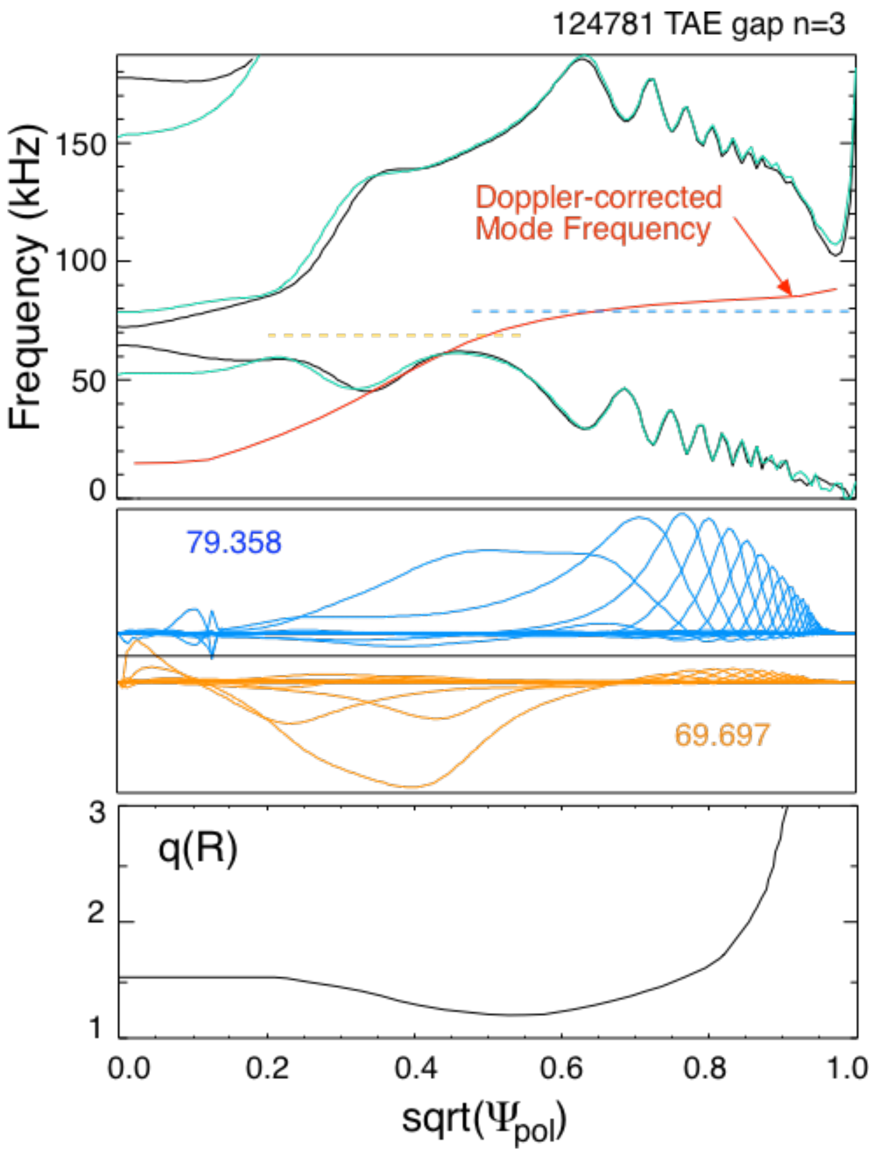
TAE threshold above ITER β_α

- The ITER β_{fast} includes only the alpha component; NBI is needed to destabilize TAE.
- The TAE threshold very likely is also dependent on the density and current profiles.
- The avalanche threshold is is less than 30% above the onset threshold for TAE



- In future experiments we can push towards CTF regime by increasing density and lowering toroidal field.

Mode frequency in TAE gap



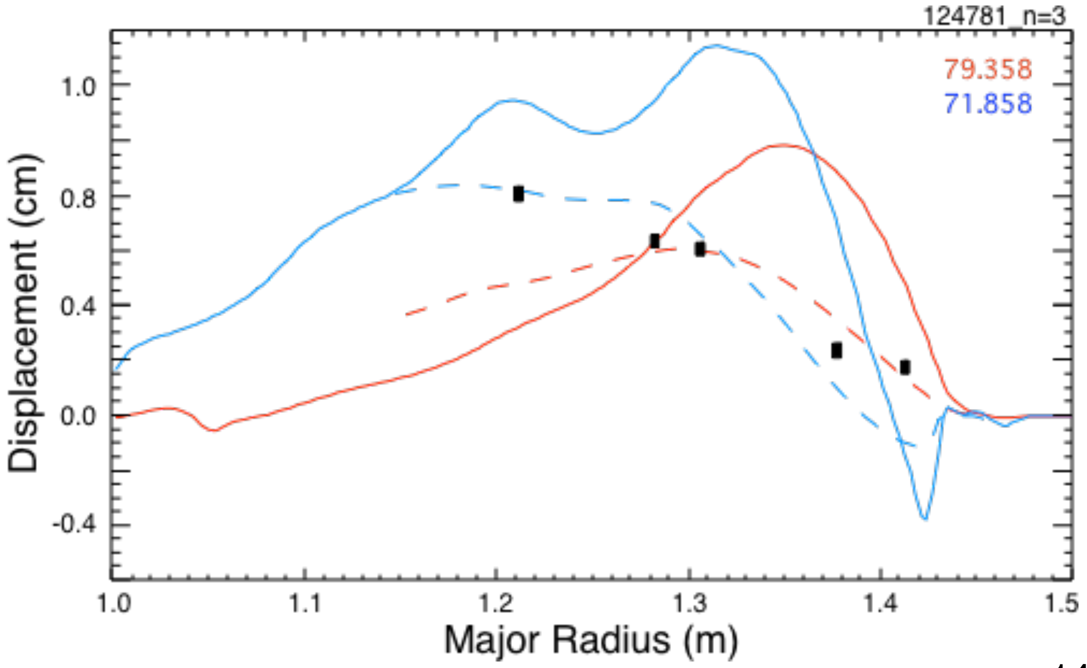
- Solid curves show "Chu-filtered" TAE gap.
- Solid red line shows n = 3 mode frequency, with radial Doppler correction profile.
- TAE mode structure shows strong coupling to plasma edge.
- Also, rsAE-like mode at lower frequency

N N Gorelenkov, G Kramer, NOVA code.

NOVA finds multiple TAE-like eigenmodes in TAE gap

- Two representative TAE-like eigenmodes are shown here at frequencies of ≈ 72 kHz and ≈ 79 kHz (solid curves).
- In black are shown the five reflectometer measurements of mode amplitude, interpreted by simple "mirror" model.
- Dashed lines are simulated reflectometer signals for NOVA eigenmodes

- Neither is good match to experimental measurement.
- Sensitivity of eigenmode structure to equilibrium data is being explored.



Summary

- Quiescent, beam heated plasmas have been made on NSTX, necessary for benchmarking TRANSP beam driven current model.
- The threshold in β_{fast} for exciting TAEs has been found.
- The threshold in β_{fast} for exciting TAE avalanches is found to be only slightly higher.
- The internal structure and amplitude of the modes has been measured with a multi-channel reflectometer array.
- Mode frequencies are consistent with NOVA predictions.
- Further work needed to converge NOVA eigenmodes to experimental data.