Summary of XP 32: Effect of CAE on Plasma Performance

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CAE study group

Summary of Experimental Observations

- New sub-ion cyclotron frequency instability was observed on NSTX.
- The frequency spectrum has many peaks, hierarchy of peak spacing.
- Frequency scales with Alfvén speed.
- Instability is driven by fast, super-Alfvénic NBI particles.
- The spectrum of excited instabilities is sensitive to the injection angle of the NBI sources.
- Often a low frequency cut-off; no activity below $f_c \approx 0.4\text{-}0.6\ MHz$.
- Modes observed with Mirnov coils and reflectometer.
- Modes are bursting or quasi-continuous.
- Enhanced fast ion losses correlated with mode activity not observed.

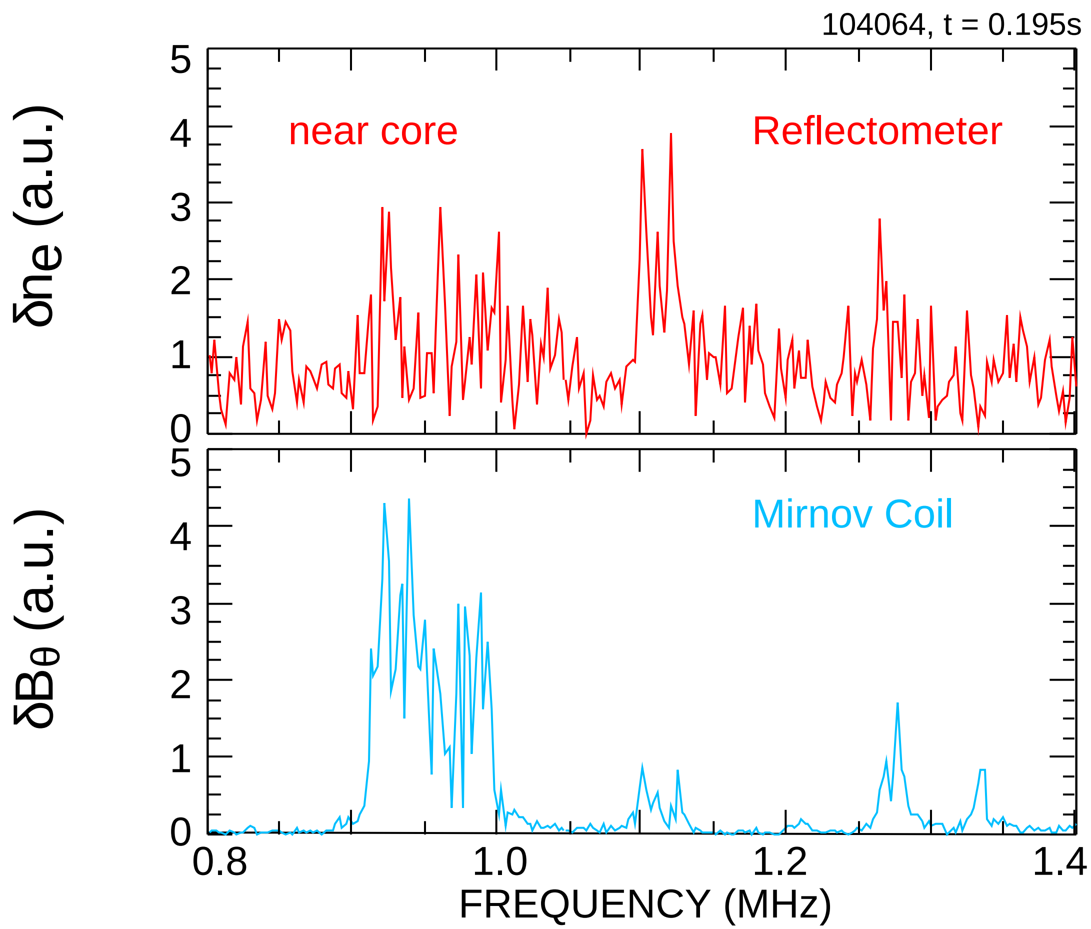
Issue raised was possibility of stochastic ion heating by CAE

- Measured Ti - Te larger than is comfortably explained - implied new physics.
- Recent theoretical work by R. White inspired timely interest CAE.
- CAE presence correlated with δT anomaly.
- Previous experimental studies of stochastic ion heating by drift-Alfvén waves bolstered this idea [McChesney, et al. PRL **59** 1436 (1987)].

Estimation of heating power from given mode spectrum

- An estimate of the heating power can be made from the total energy in the wave and the damping rate,
  - $P_{heat}(MW) \approx E_{wave}\, \gamma_{damp}$
  - $\approx 4x10^{-4} \langle \delta B^2(G) \rangle_{vol}\ [V/V_{plasma}]\ \gamma\ (10^4/s)$
  - $\approx N_{mode} \langle [\delta n/n(\%)]^2 \rangle_{vol}\ [V/V_{plasma}]\ \gamma\ (10^4/s)$
- For 1 MW of ion heating, B_{rms}(all modes) $\approx$ *50 G*;
  - δB/B $\approx$ 50/3500 $\approx$ δn/n $\approx$ 1.5 %
  - peak measured mode amplitude δn/n $\approx$ 0.1-0.2 %

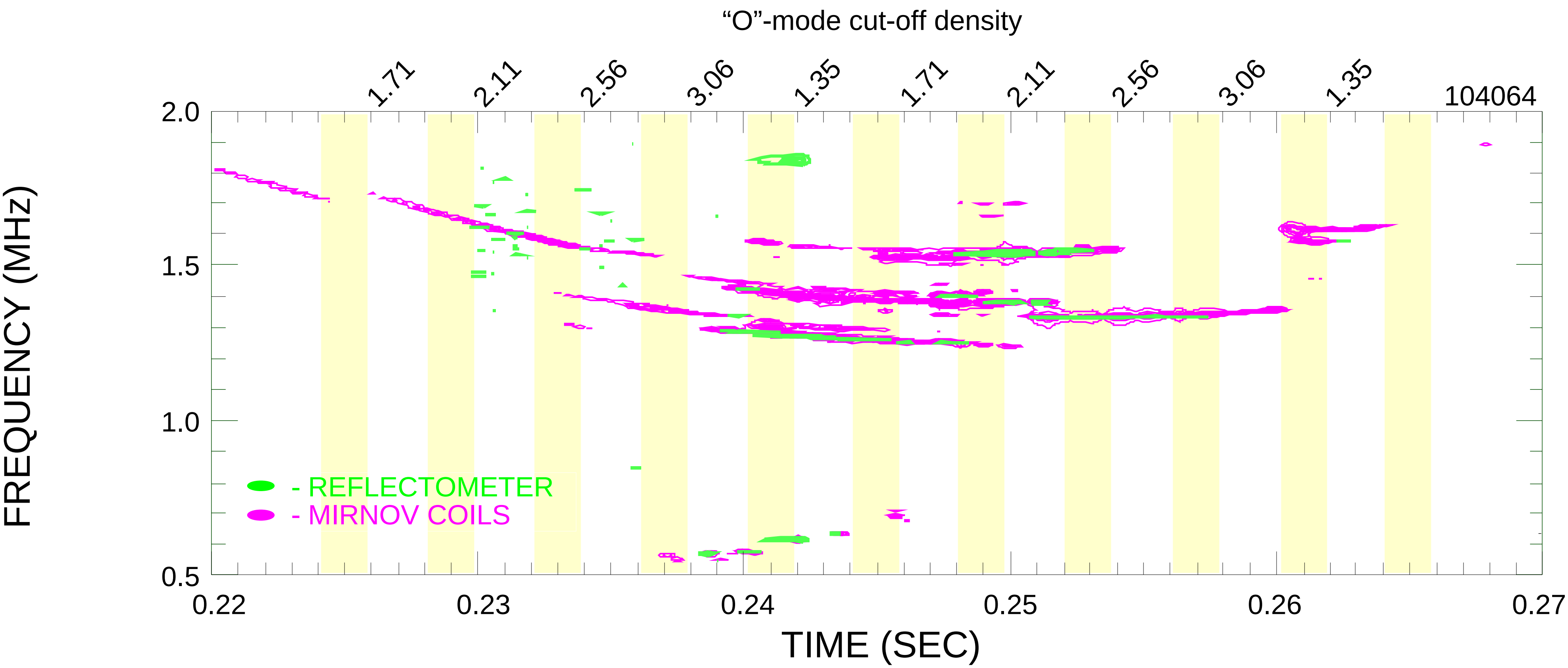
Mode amplitude measured with Reflectometer, but coils more sensitive



- The reflectometer measures density fluctuations.
- The density fluctuations are related to CAE amplitude by:
  - $\delta B_\theta / B \approx k_{||}/k \;\; \delta n/n$
  - $\delta B_\theta / B \approx V_A / V_{b||} (1 - \omega_{ci}/\omega) \delta n/n$

Reflectometer has potential for radial profile measurement of mode

- The reflectometer step scans the frequency (cut-off density), dwelling at each frequency for ≈ 4 ms.

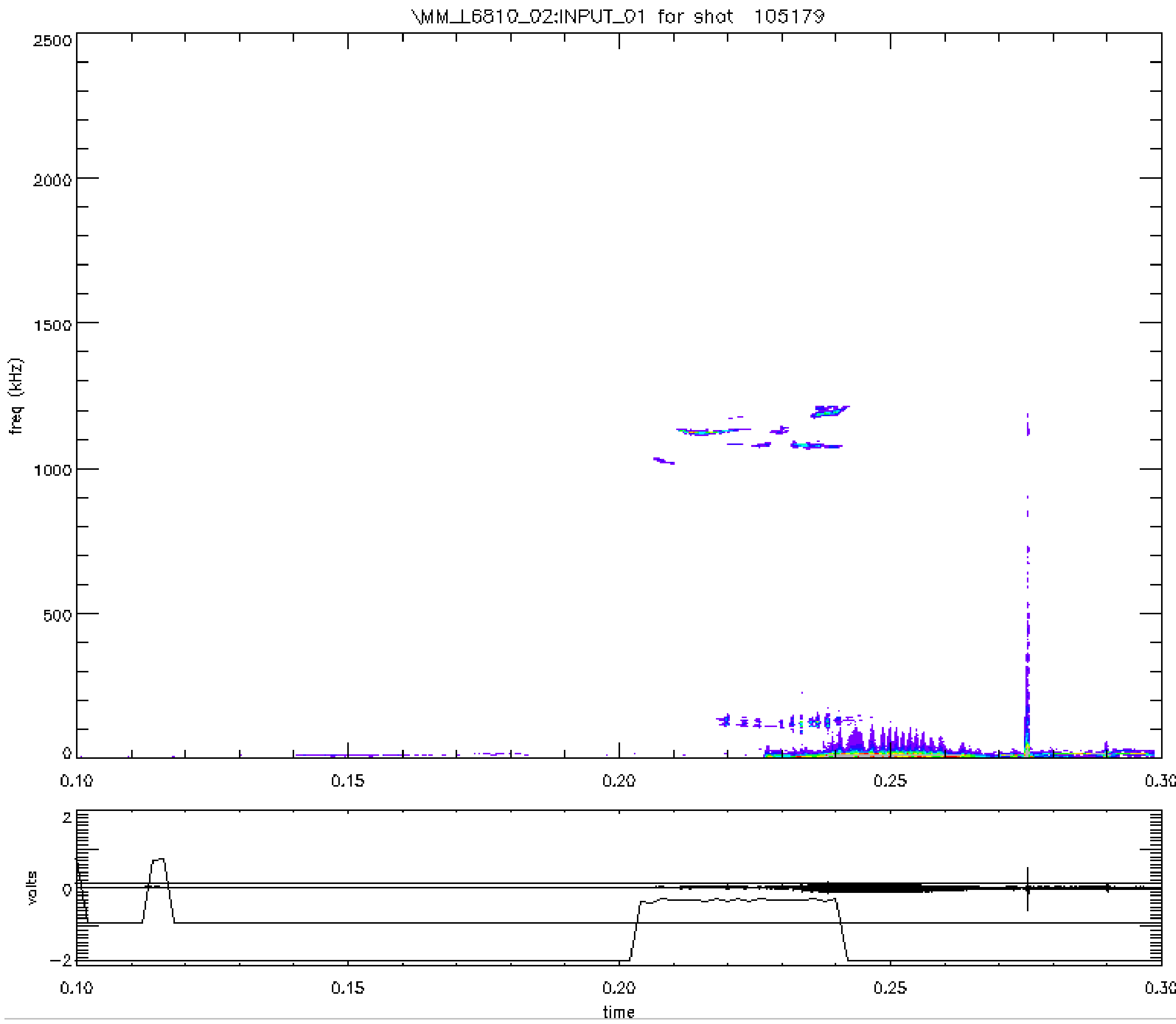


Goals of XP #32

- Use choice of source to control CAE amplitude (not fruitful).
- Beam voltage scan to control CAE amplitude.
  - Effect of mode amplitude on ion temperature.
  - Implies modes can't access much beam power?
- New measurements of mode amplitude with heterodyne reflectometer.
  - Perhaps better information on spatial structure.
- Optimized beams for ion temperature measurements.

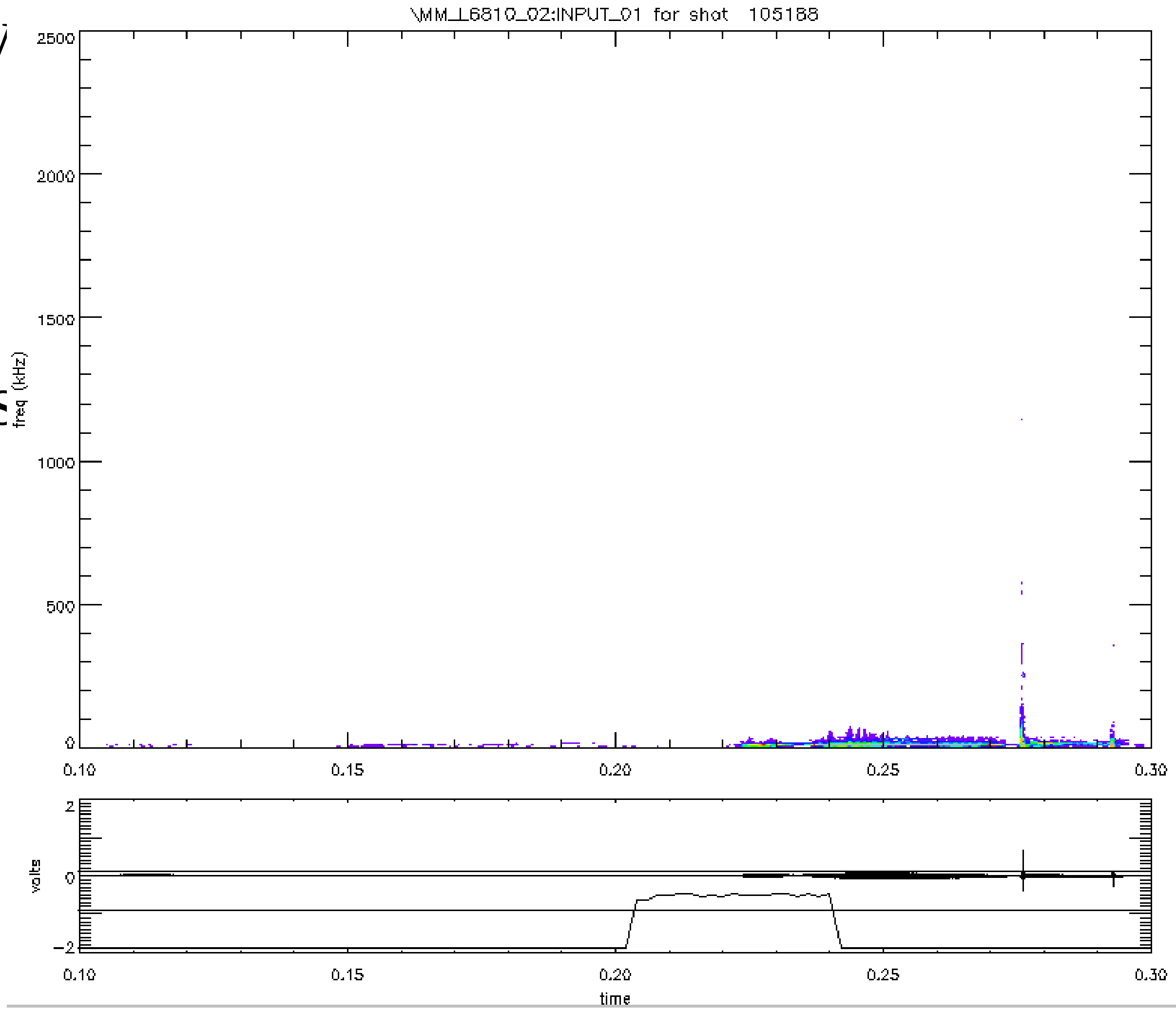
Reference shot, as is common, had only a few clear modes

- Standard NBI pulse (source A) at 80 kV.
- Mode amplitude is low, but several clear modes.
- Ion temperature data not available yet.

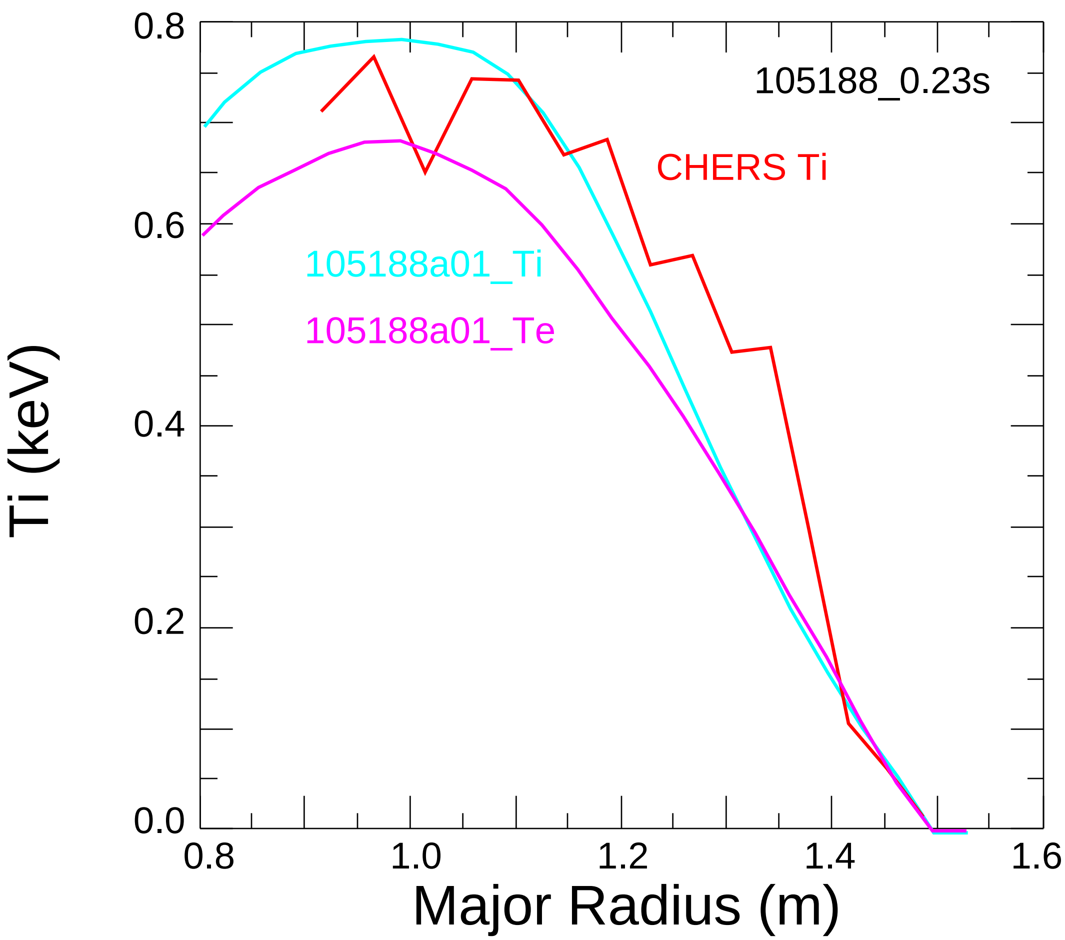


At 70 kV, modes are absent.

- Very sharp velocity threshold in resonance condition?
- Implies that there is not much beam energy accessible to modes?
- Consistent with rapid mode quench at end of NBI.



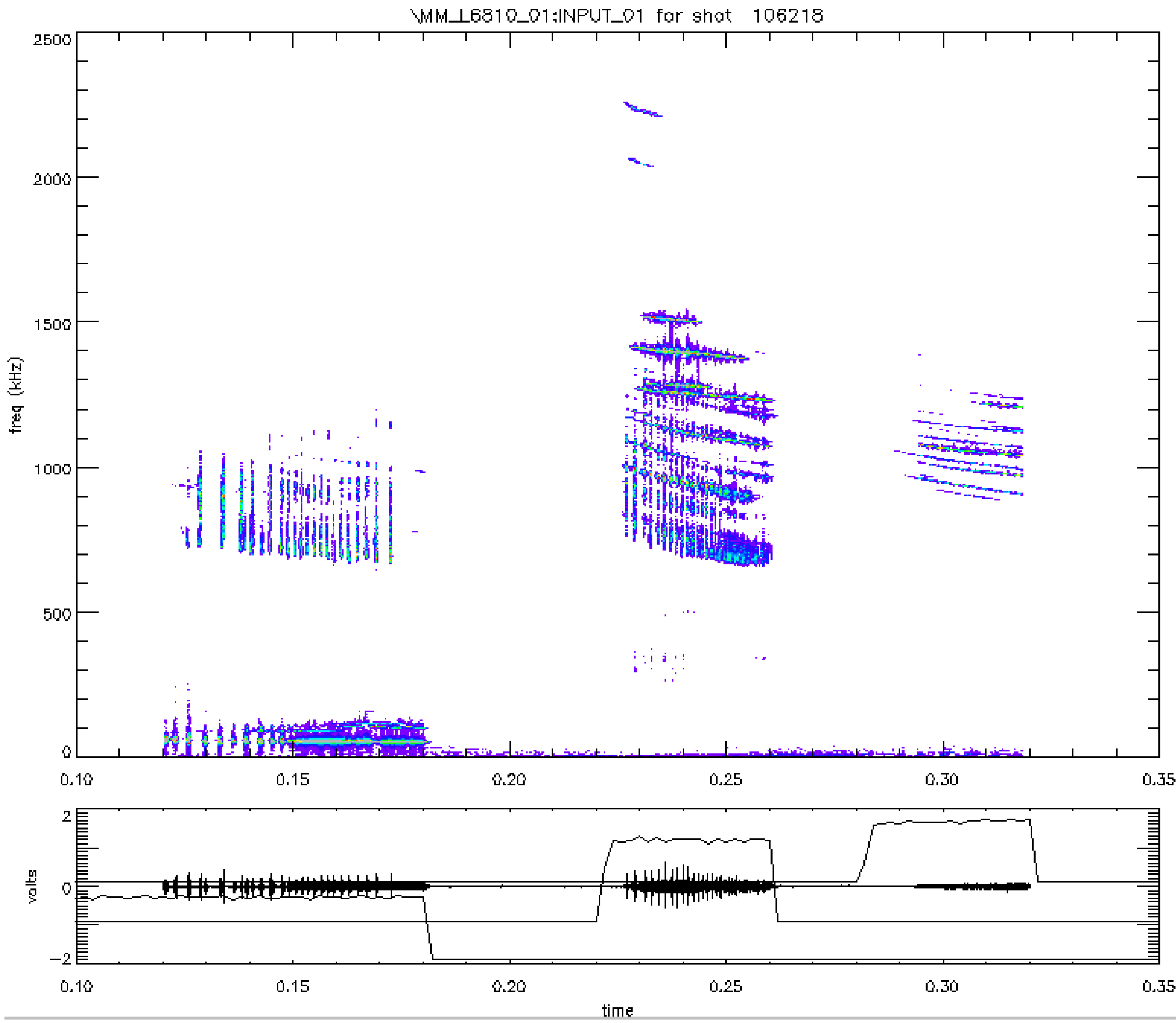
Provisional ion temperature agrees reasonably with TRANSP simulation



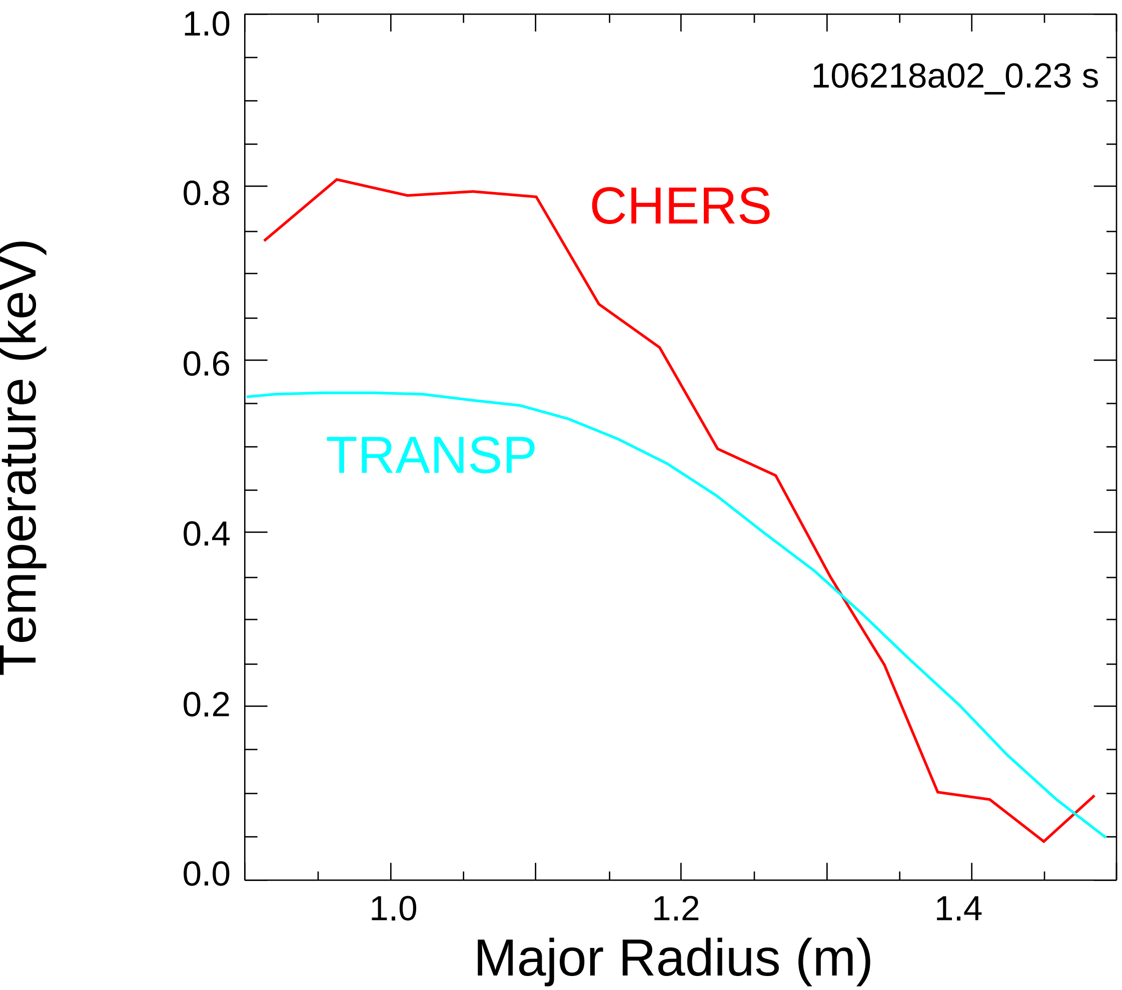
- Simulates ion temperature assuming Chang-Hinton neoclassical transport.
- Ion temperature still somewhat higher at mid-radius.
- Still awaiting blessed ion temperatures.

Higher beam voltage can drive more modes

- Source B (0.22 - 0.26s) is at 90 kV.
- Source C (0.28 - 0.32s) is still at 80 kV.
- Source A is at 80 kV.

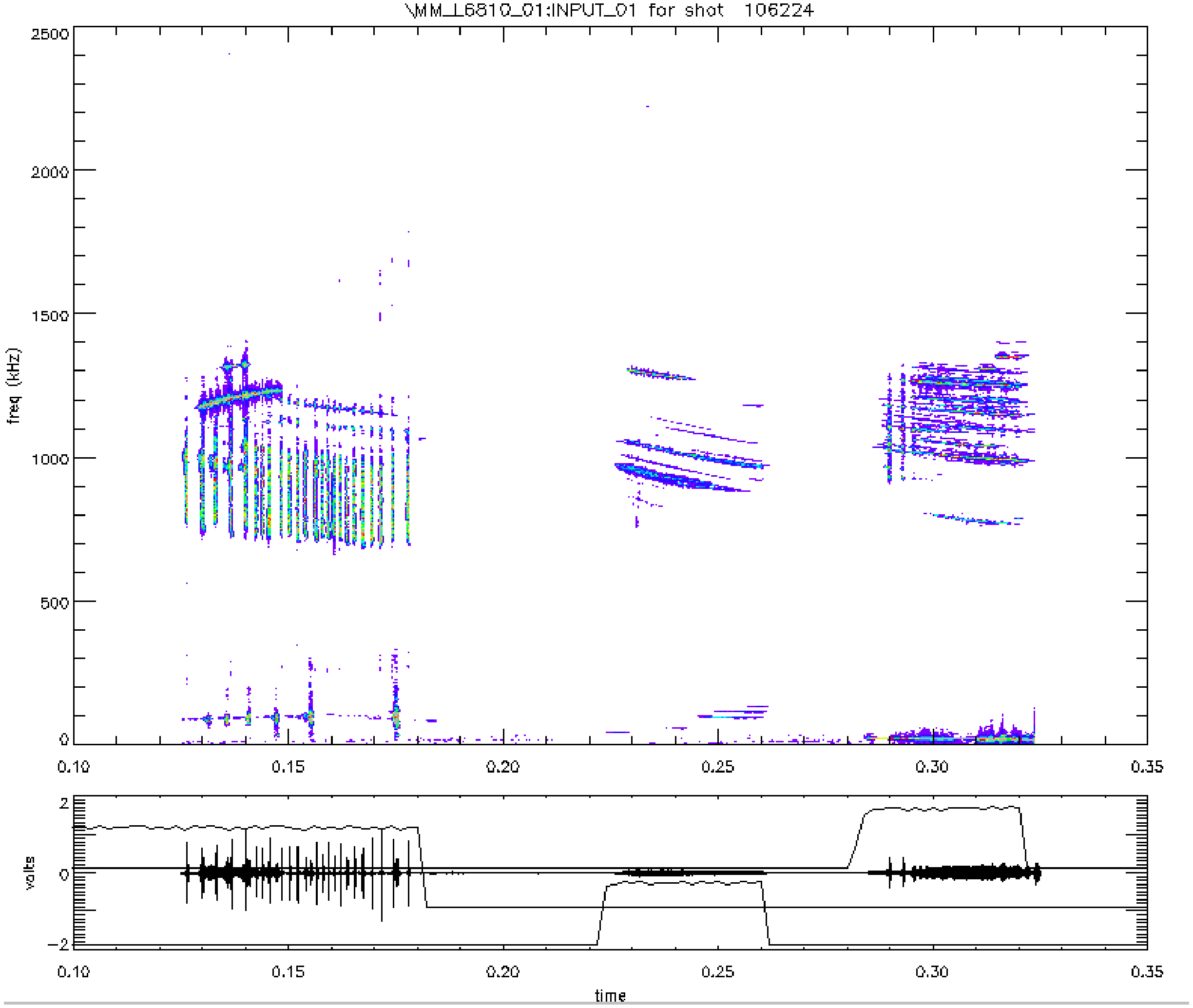


Ion temperature shows poorer agreement with TRANSP simulation

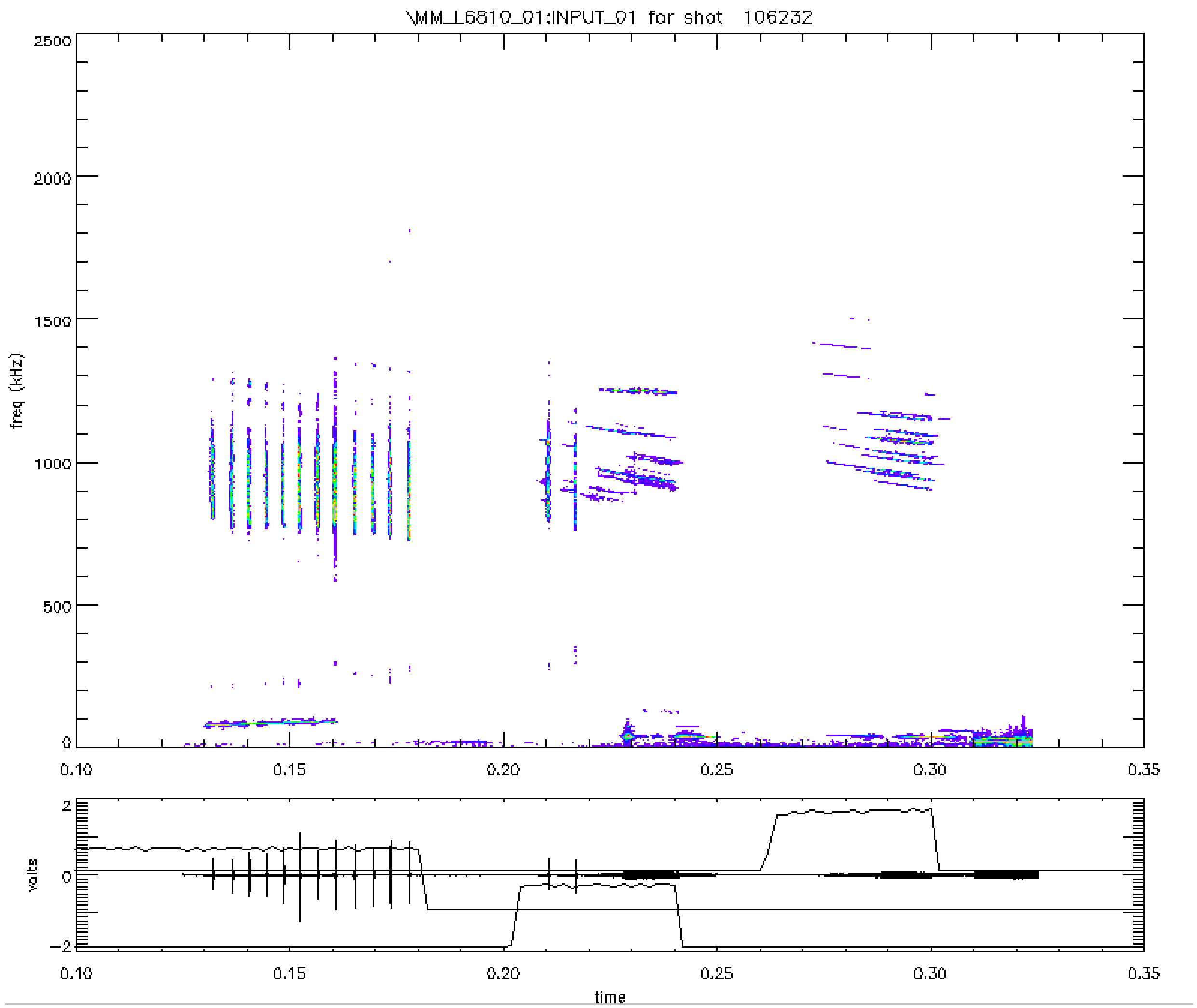


- Low on edge, high in core.
- Still one times neoclassical simulation.
- Neoclassical model may be challenged in ST geometry?

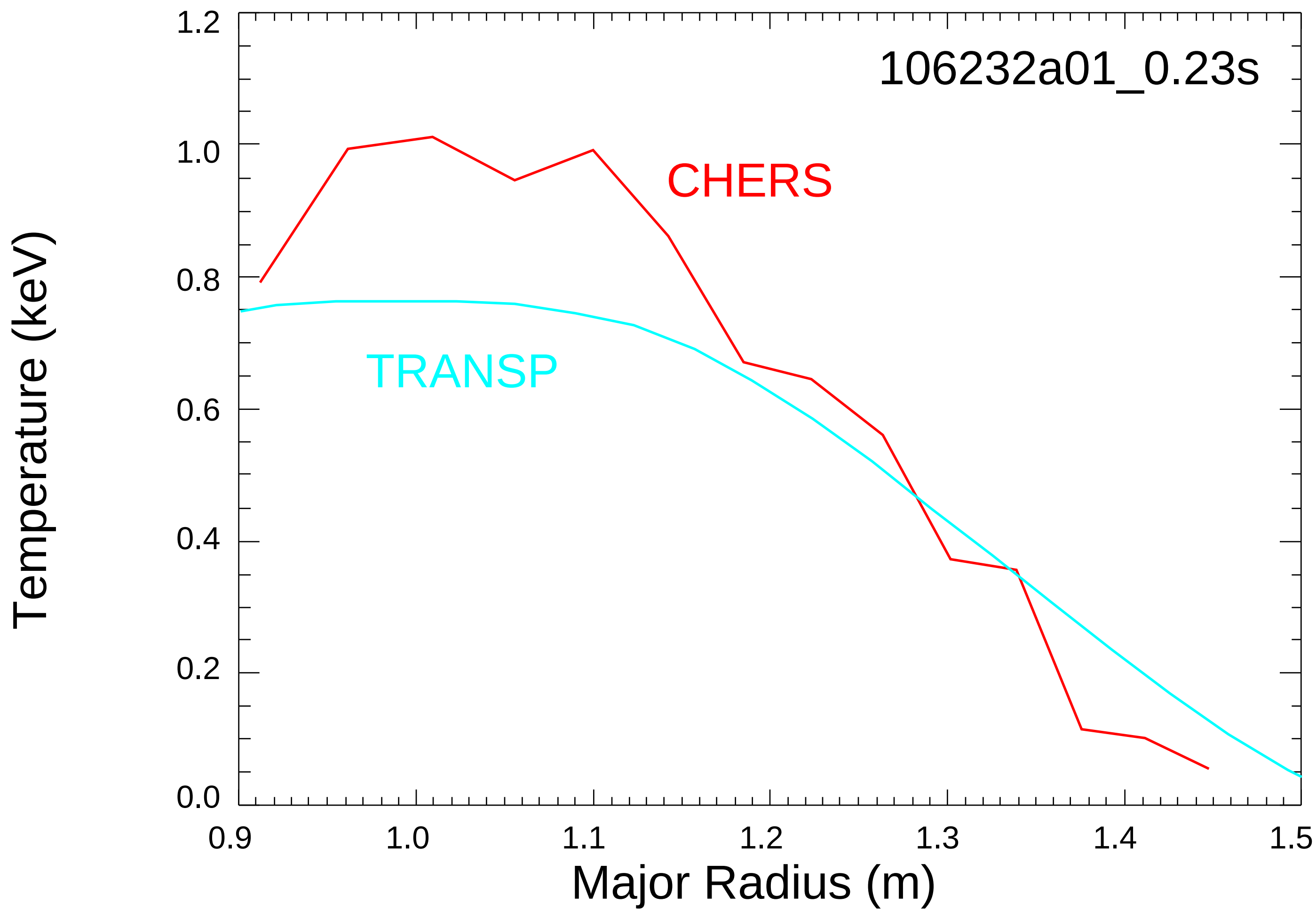
But mode amplitude depends on other factors as well.



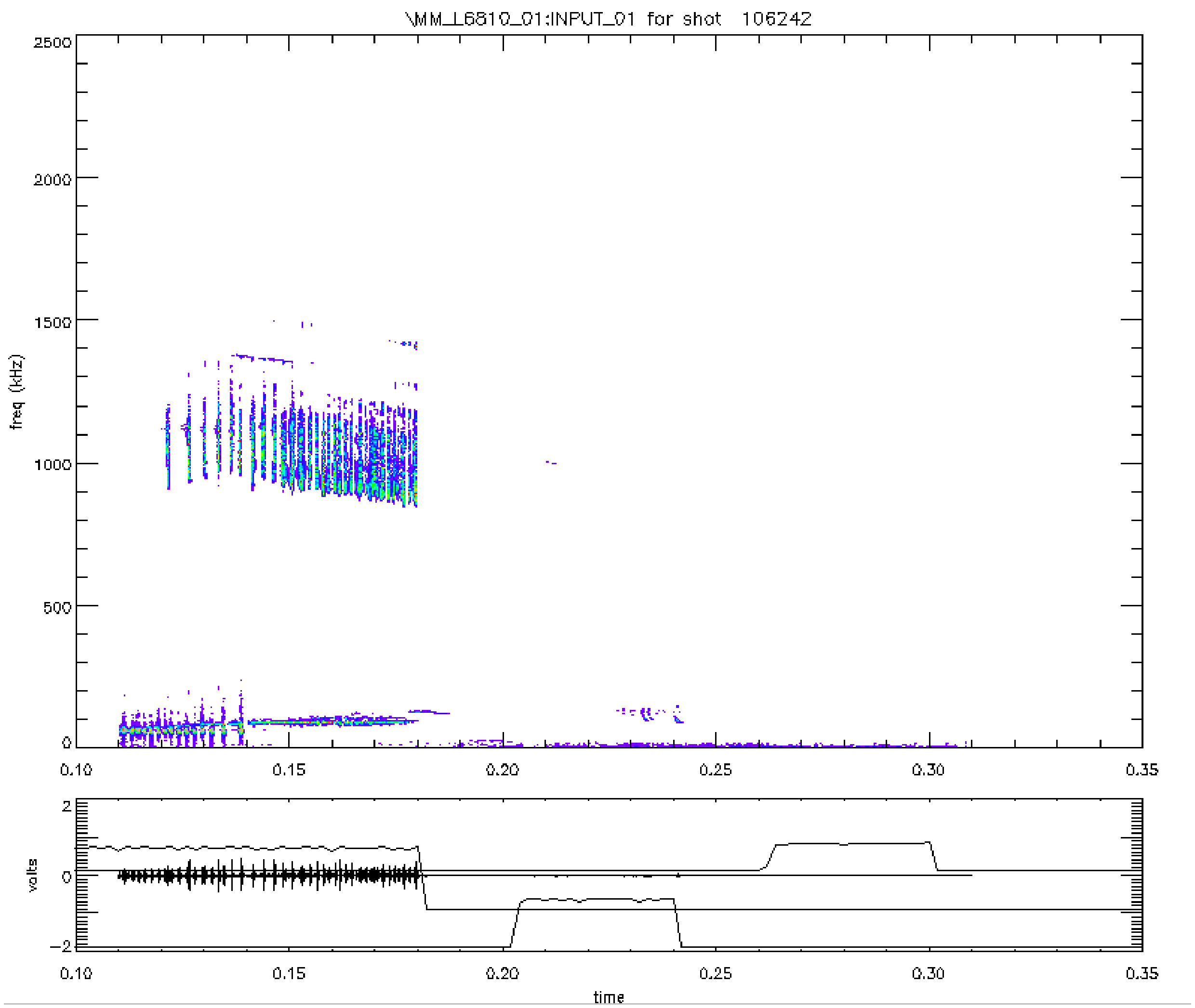
80 kV beams give typical mode response.



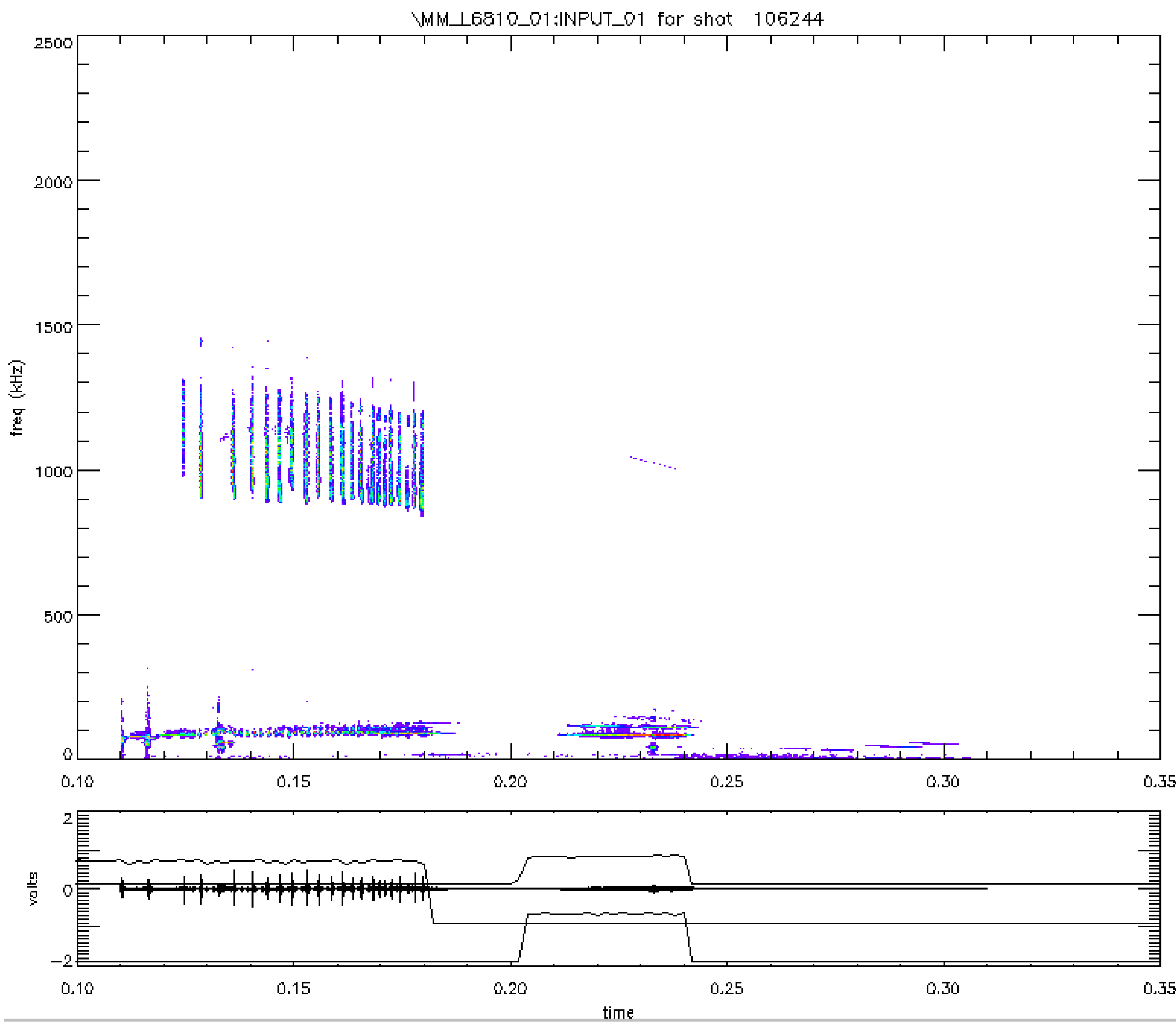
Provisional ion temperature agrees outside of core region?



70 kV and 60 kV beams barely excite modes, as before



Even beams together, with ≈ 2 MW, result in very small modes



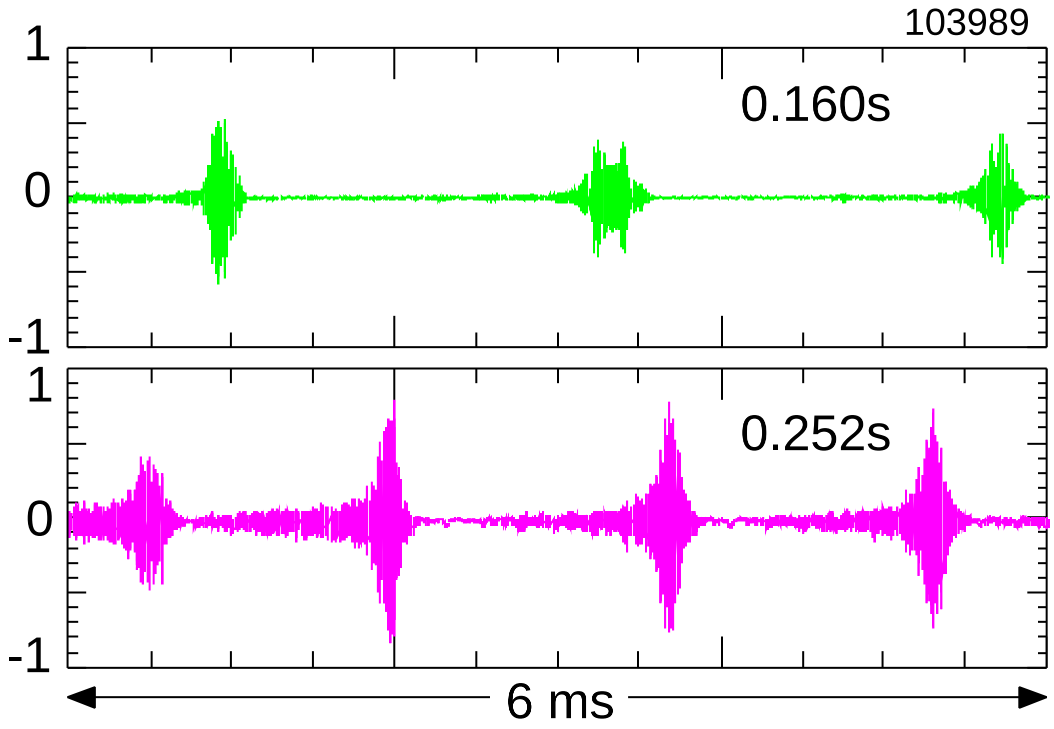
- Source A is at 70 kV, Source C is at 60 kV.
- Total power is 2 MW, more than for 90 kV source.
- Plasma stored energy is lower - poorer confinement?

Summary

- Mode amplitude controlled through beam voltage, threshold to drive mode is around 70 kV.
- Threshold is not a power issue, two low voltage sources with more power still don't drive modes.
- Good CHERS data available, but waiting for analysis method to be developed.
- Some heterodyne reflectometer data; confirms earlier estimates of mode amplitude; new data not all analyzed.
- TRANSP analysis started with first cut for most shots of interest.
- Theoretical modeling will be challenging.

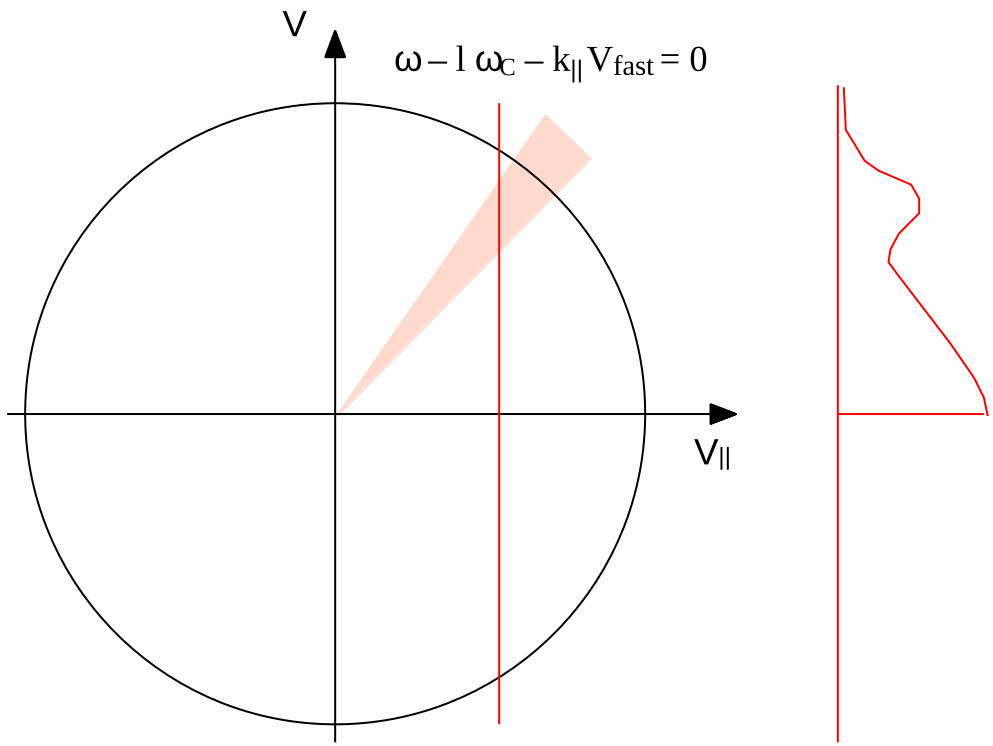
CAE Modes can be quasi-continuous or bursting in character

- Bursts yield growth/damping rates ≈ 10^4/s or $\gamma/\omega \approx 0.15\%$.
- All modes grow/damp together.



Peak rms fluctuation level (0.5-2.0 MHz) at probes is ≈ 10-15mG

Modes are driven by "bump-on-tail" in perpendicular energy



- V_{fast} / R ≈ 700 kHz, n number of modes should be greater than unity.
- "Bump-on-tail" may be consistent with beam injection geometry.