Beam Voltage Threshold for Excitation of CAE modes

(Progress on other fast ion driven instabilities.)

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Outline

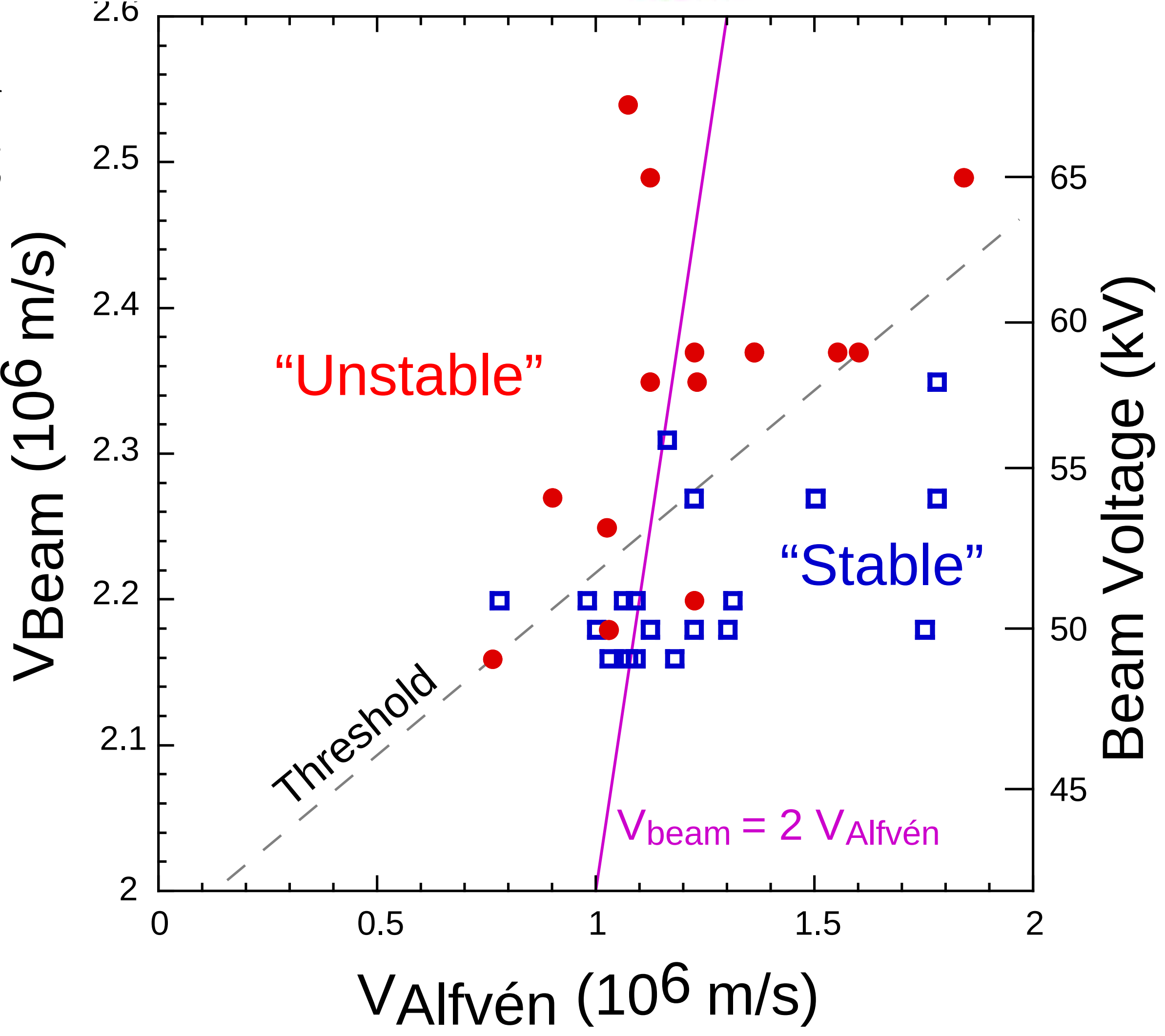
- Summary/status of CAE studies.
- Recent discoveries TAE studies
- Bounce/precession resonance fishbone modes.

CAE studies status

- XP to document voltage threshold dependence on density, toroidal field was successfully completed.
- Threshold has strong dependence on beam energy, weaker dependence on toroidal field.
- Dependence on density awaiting further analysis, but appears to be there.

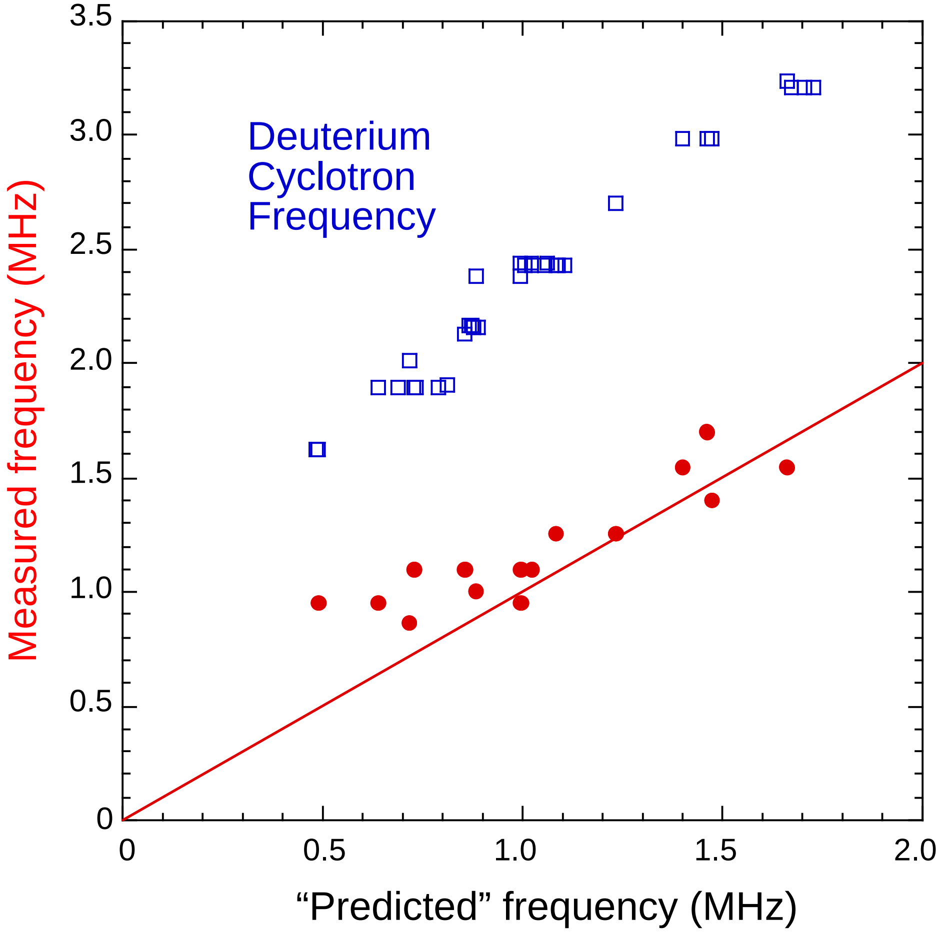
Weak dependence of threshold on Alfvén velocity

- Analysis done with 'global' parameters; scatter in threshold may be reduced with more careful, local analysis.
- "Stiff" dependence on beam voltage over factor of two in Alfvén speed.



Frequency in reasonable agreement with prediction

- Mode frequency to first order $\omega \approx k_{\perp} V_{\text{Alfvén}}$, where…
- $k_{\perp}$ estimated from resonance condition, $\omega \approx \omega_C - k_{\perp} V_{\text{drift}}$.
- Dominant scaling is with toroidal field, in this data set.

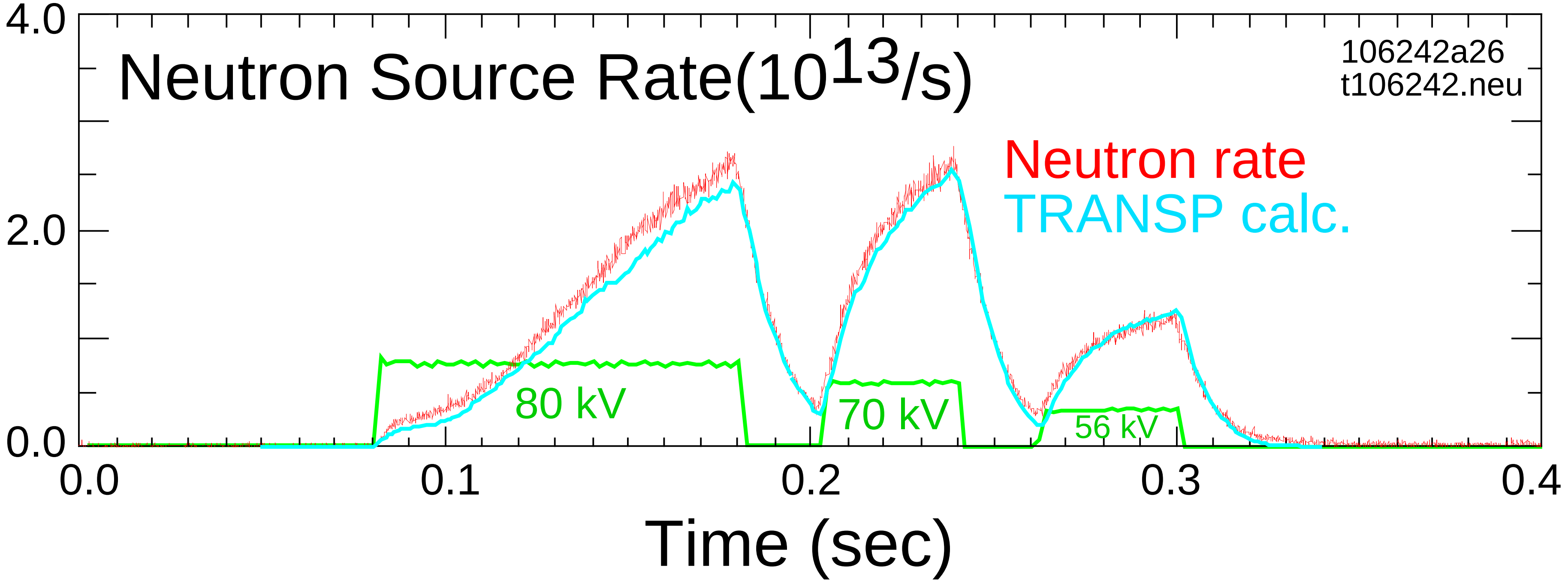


More detailed analysis awaiting theoretical tools, data analysis

- 16/25 shots TRANSPed (without Ti data).
- Some comparisons of shots with/without modes at "similar" parameters (different field, same density/ beam voltage, same field/density, different voltage)
  - May need to compare shots from last year and this year…
- I can provide equilibria and fast ion distributions around CAE threshold.

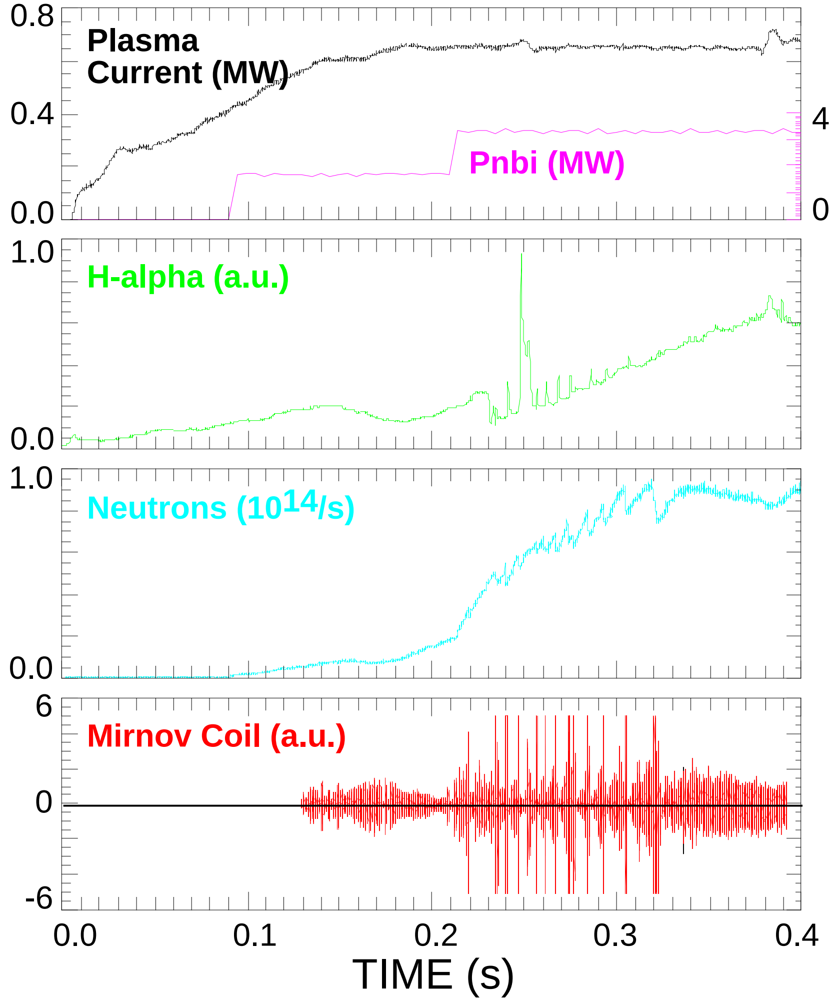
Neutron decay rate shows no strong anomaly with new Te

- Previously, TRANSP neutron prediction low, decay rate too fast.
- New TRANSP calculation with recalibrated Thomson Te shows very good agreement.
- Ion temperature anomaly weaker, but still present.



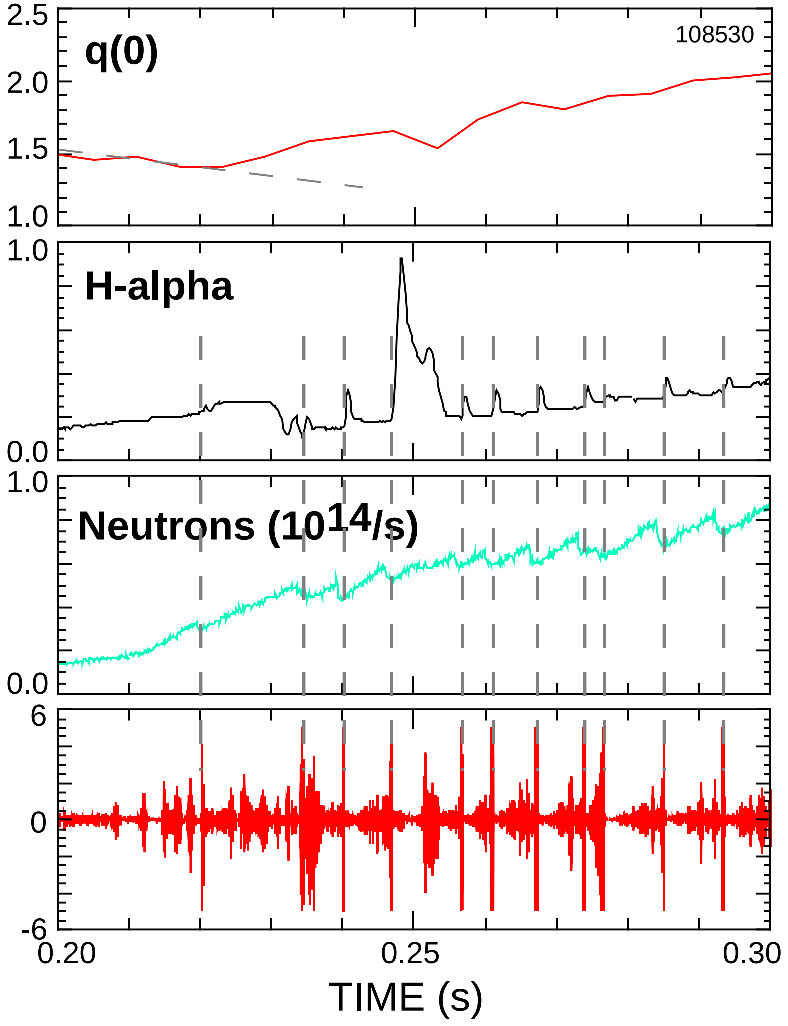
New, large amplitude and bursting TAE modes cause fast ion loss

- Not observed before.
- Fast neutron drops correlated with H-alpha bursts; fast ions hitting wall?
- First neutron drops precede H-mode transition; also occur during "dithers".
- Small impact on soft x-ray emission.



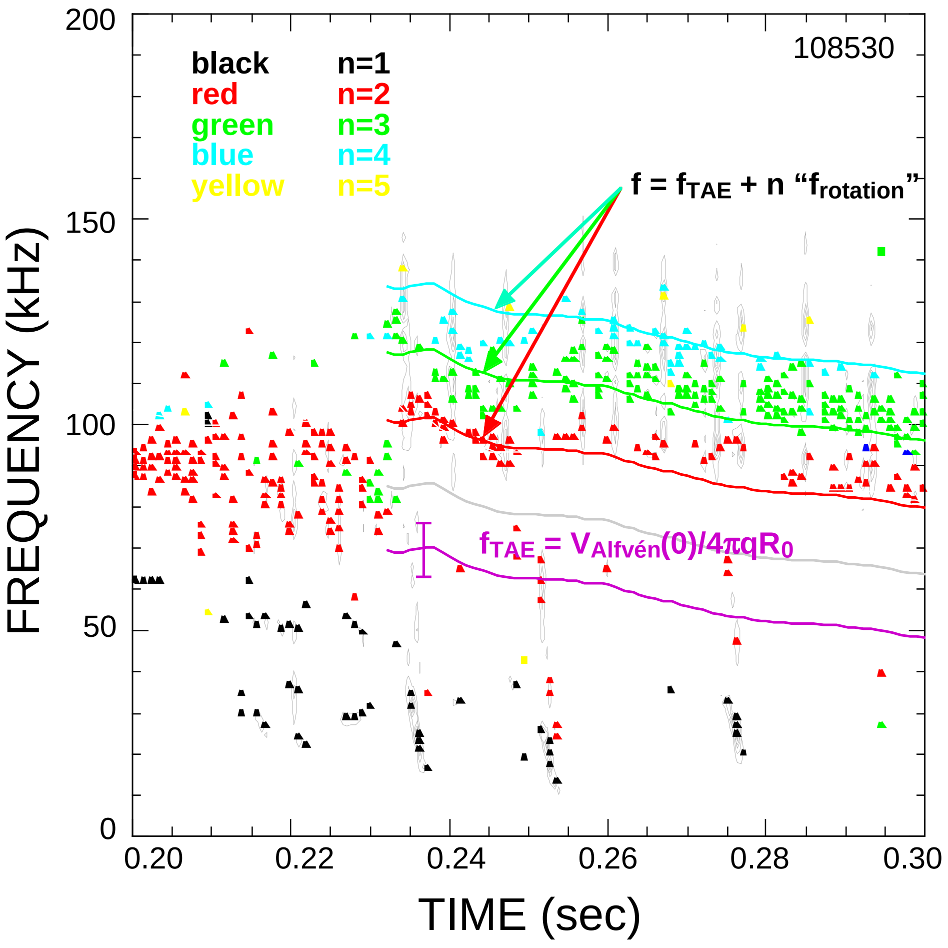
TAE bursts are clearly correlated with neutron drops, fast ion losses

- Strong TAE most commonly seen in H-mode plasmas where q(0) is inferred to be high.
- First strong burst precede H-mode transition.
- Fast ion losses seen on IFLIP.
- Strong bursts may reflect broader gap structure.



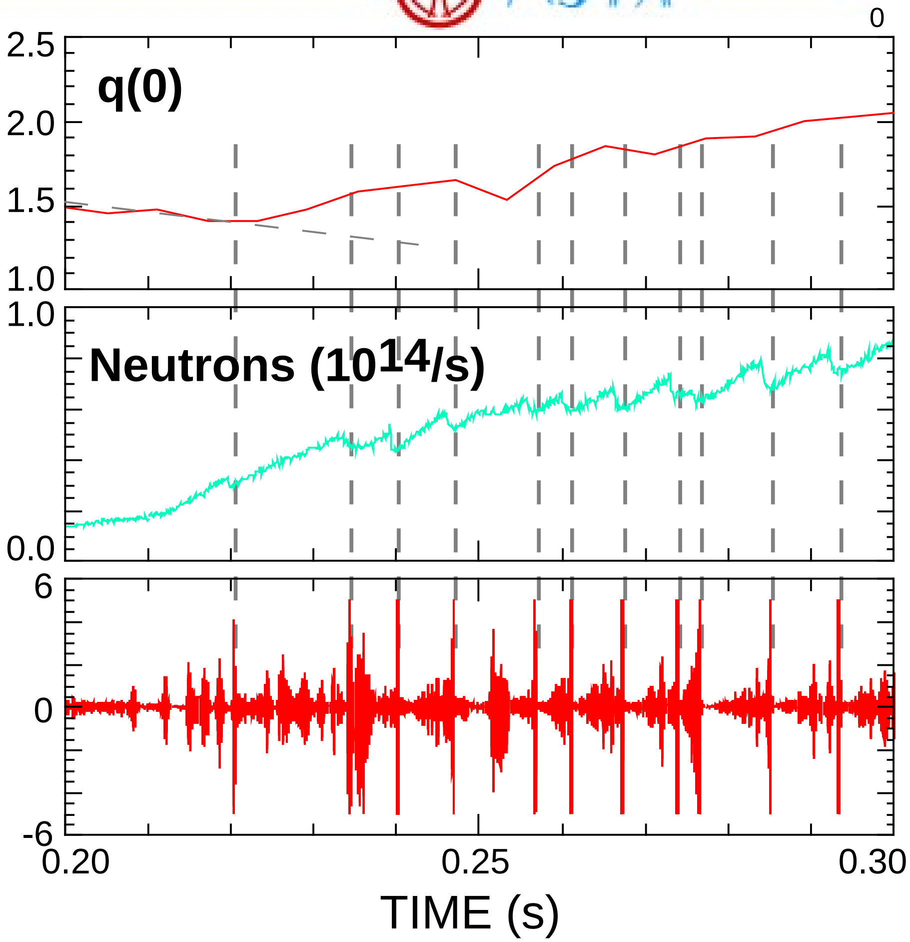
The bursting modes are in the TAE frequency range

- Multiple modes burst at the same time.
- Toroidal mode number, n, ranges from 2 - 5 with the dominant mode being n=2 or 3.
- Mode frequencies in reasonable agreement with expected TAE frequencies.



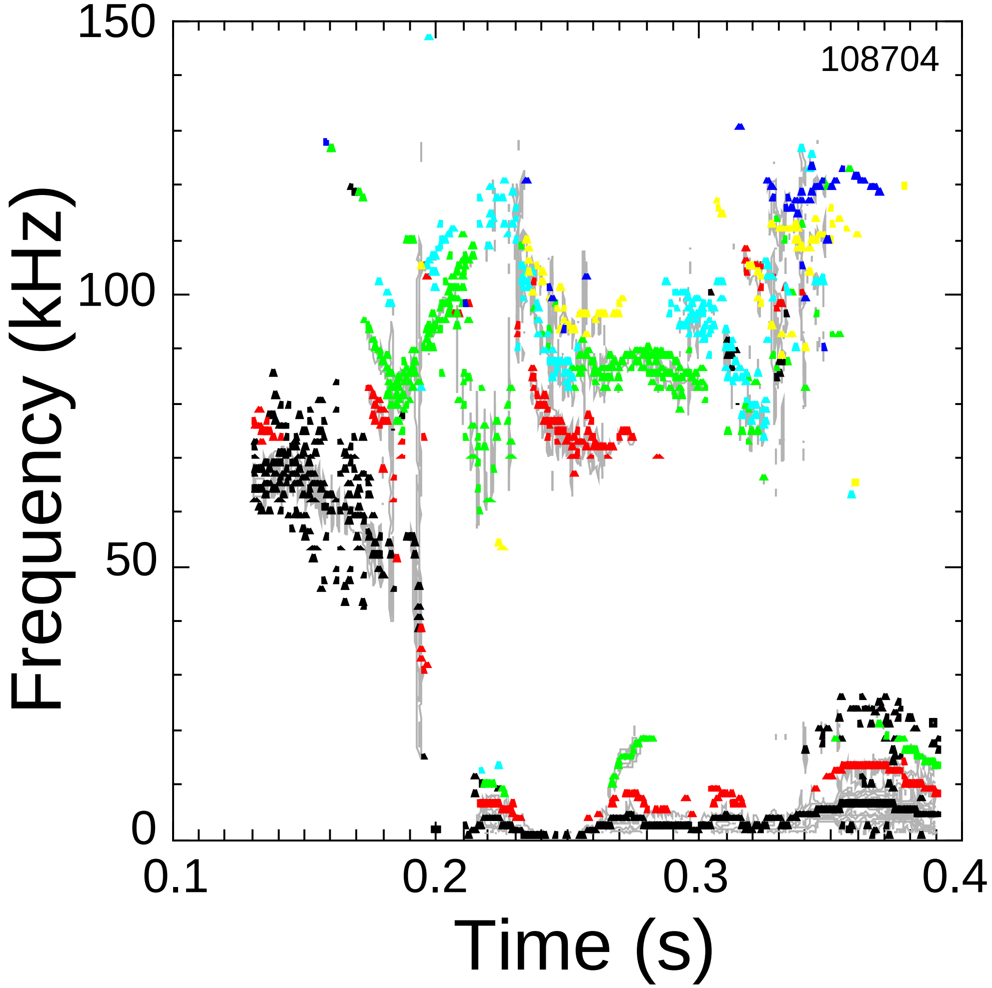
Bursting character of mode roughly correlated with increase in q(0), H-mode transition

- However, first burst precedes both events...
- Change in q-profile *could* be opening gap, decreasing continuum damping…
- …but not evident from measured density and q(0).



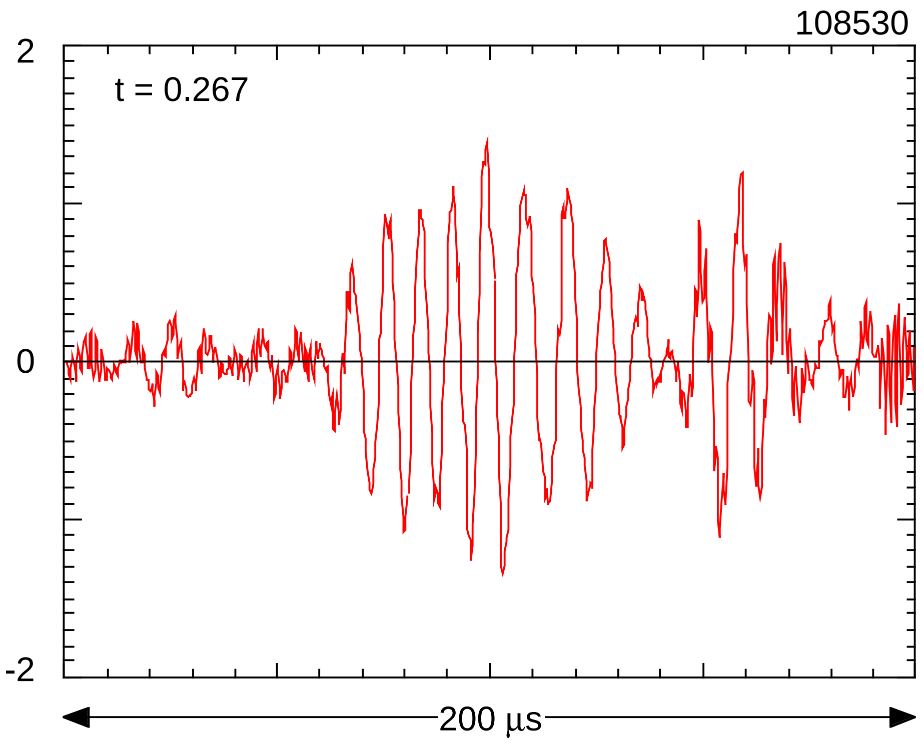
Normal TAE do not cause measurable fast ion loss

- Continuous or weakly bursting TAE/EPM are more common.
- No clear correlation in reduced neutron rate or fast ion losses in IFLIP.
- Detailed analysis of mode stability/structure in progress.



The final mode growth and decay is very fast

- Some of the mode amplitude modulation represents "beating" of the multiple modes.
- Mode growth and decay times are approximately 50 - 100 µs.

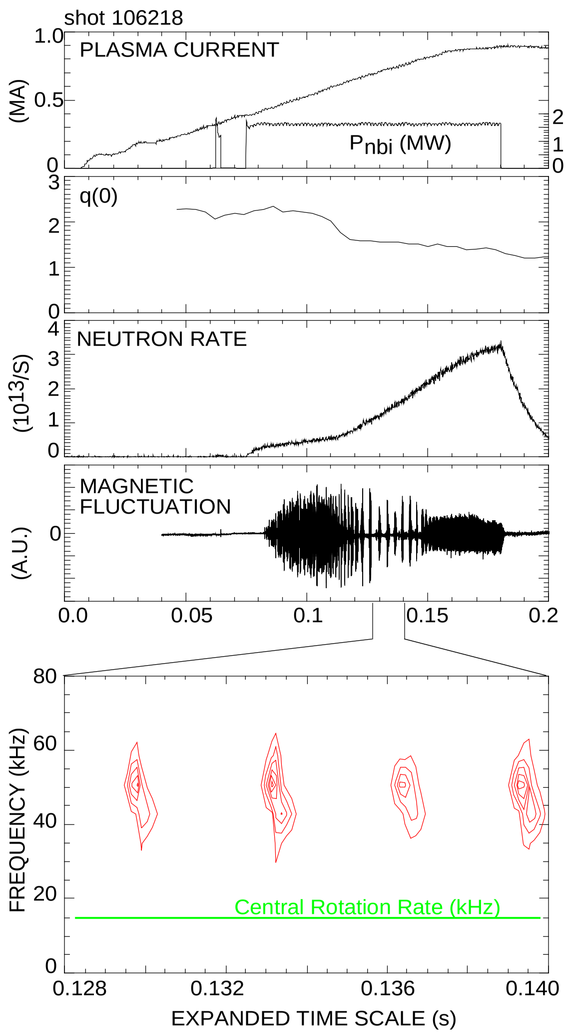


Fishbone activity

- High and low frequency fishbones were found this year on NSTX.
- Theoretical work is ongoing, but these are believed to represent resonances with the precession and bound frequencies and beat frequencies of these.
- High frequency fishbones also overlap the "TAE frequency band".

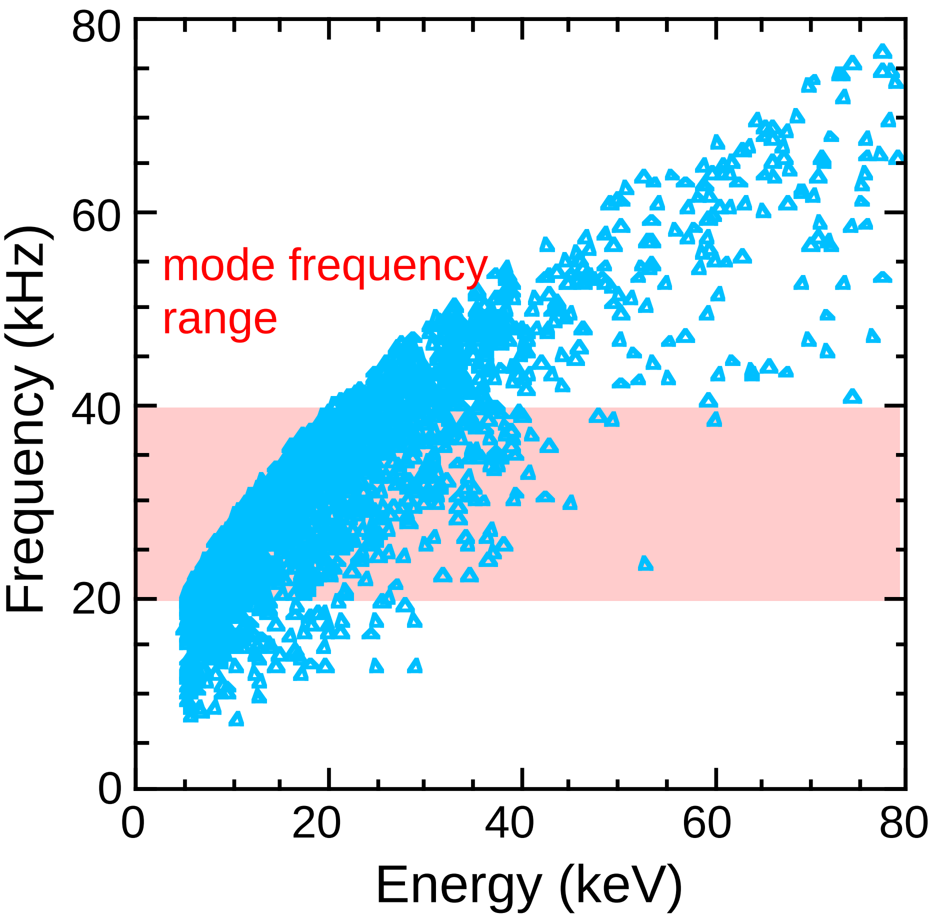
New fishbone resonant drive found in beam heated NSTX plasmas

- Bounce resonance drives f.b.
- Predicted to be important in plasmas with significant trapped fast ion population with large bounce angle.
- Such a distribution often stable to precession-resonance fishbone
- Could be important in ignited plasmas, driven by alphas.



Range of frequency chirps in good agreement with bounce frequency

- Beam fast-ion distribution calculated in TRANSP.
- Bounce frequency/angle calculated in ORBIT.
- Mostly lower energy beam ions interact with bounce fishbone mode in NSTX.

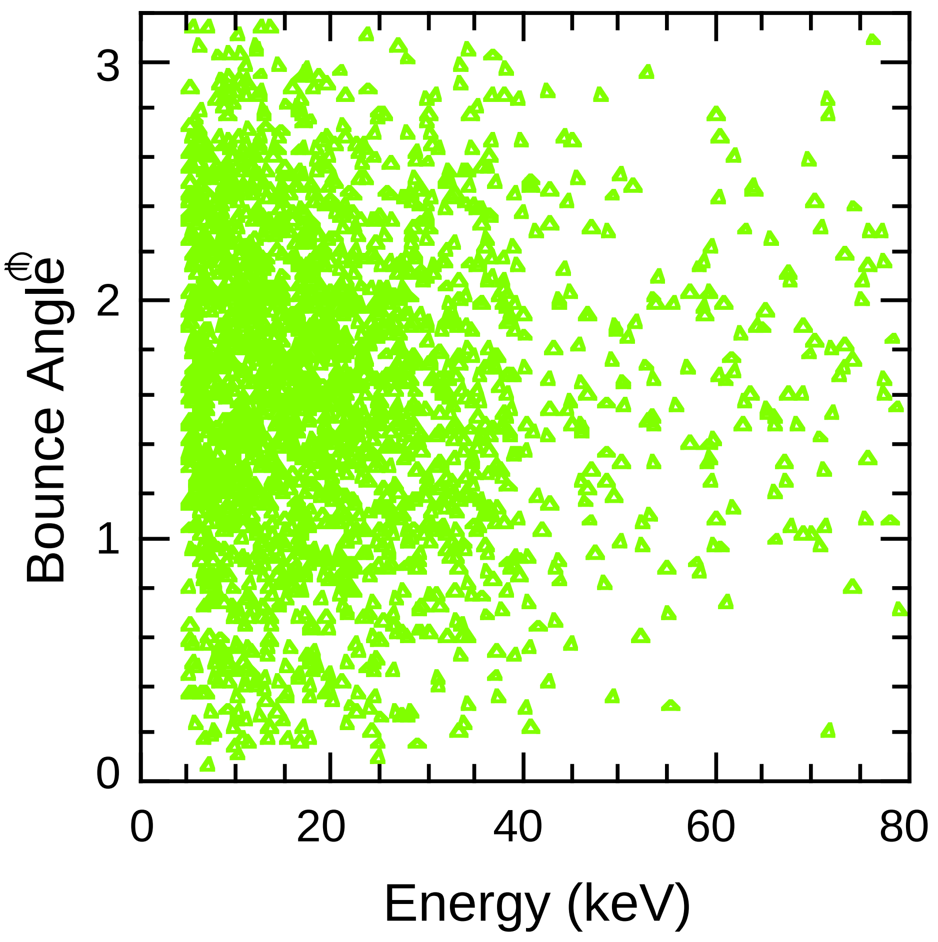


The average bounce angle is large, resulting in strong drive at f_{bounce}

- The equation for energy change of a trapped particle is:

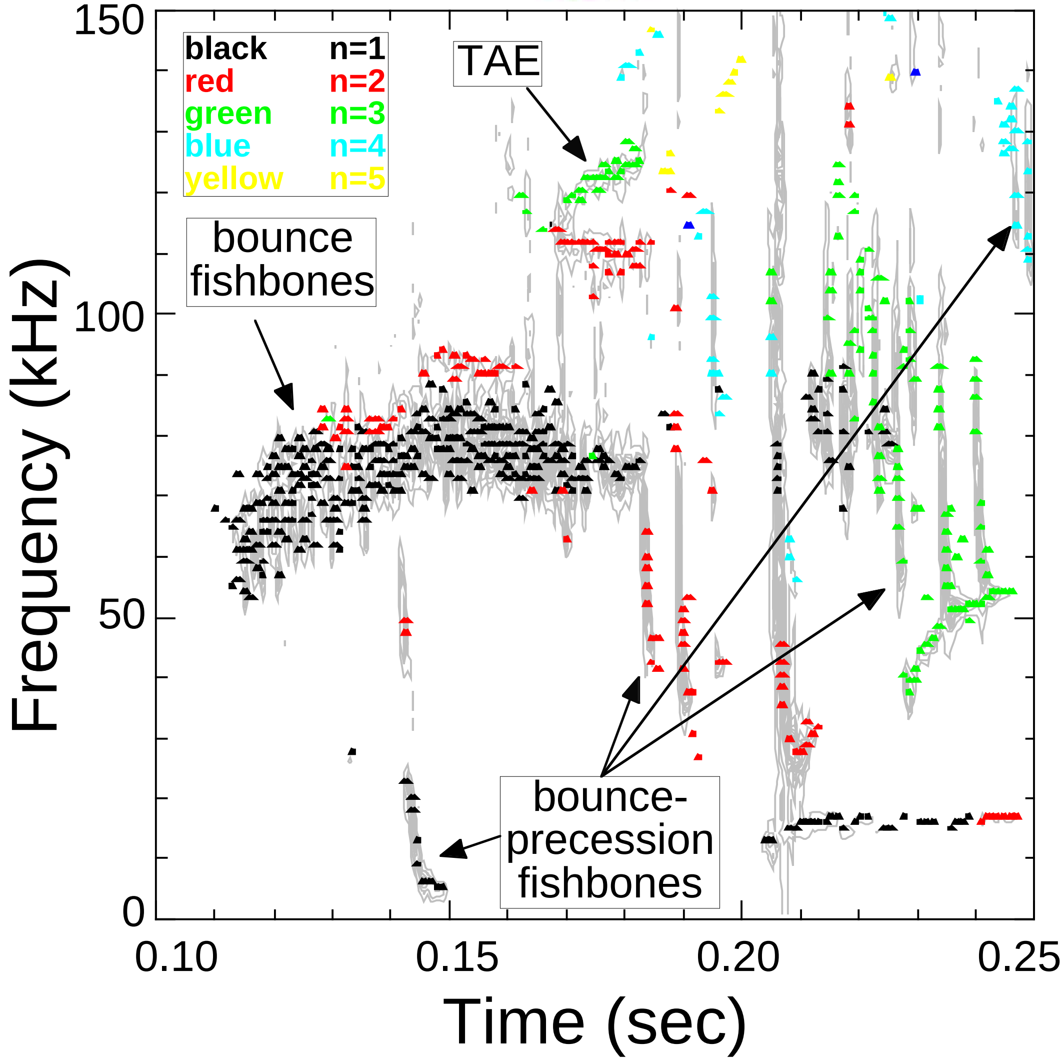
$$\frac{dE}{dt} = -\frac{n\omega_d}{q}\Phi_{mn}\sum_l J_l\left((m-nq)\theta_b\right)\left\langle e^{i(\omega_d + l\omega_b - \omega)t}\right\rangle_{bounce}$$

- For large bounce angles, the l=1 Bessel function dominates, introducing drive at the bounce frequency



Complicated spectrum below 200 kHz in beam heated plasmas

- Beginning to identify some modes, understand drive.
- TAE, MHD and fast ion frequency ranges overlap - many resonance possibilities.
- Chirping suggests EPM-type modes - generically f.b.'s.



Summary

- Progress has been slow over summer
- Theory making progress in CAE modeling, TAE modeling and f.b. studies
- More data needs to be analyzed [reflectometers (f.b., TAE structure, CAE amplitude), sxi (f.b. structure), magnetic fluctuation data (CAE/TAE polarization, wavelength)].