Beam Voltage Threshold for Excitation of Compressional Alfvén Modes

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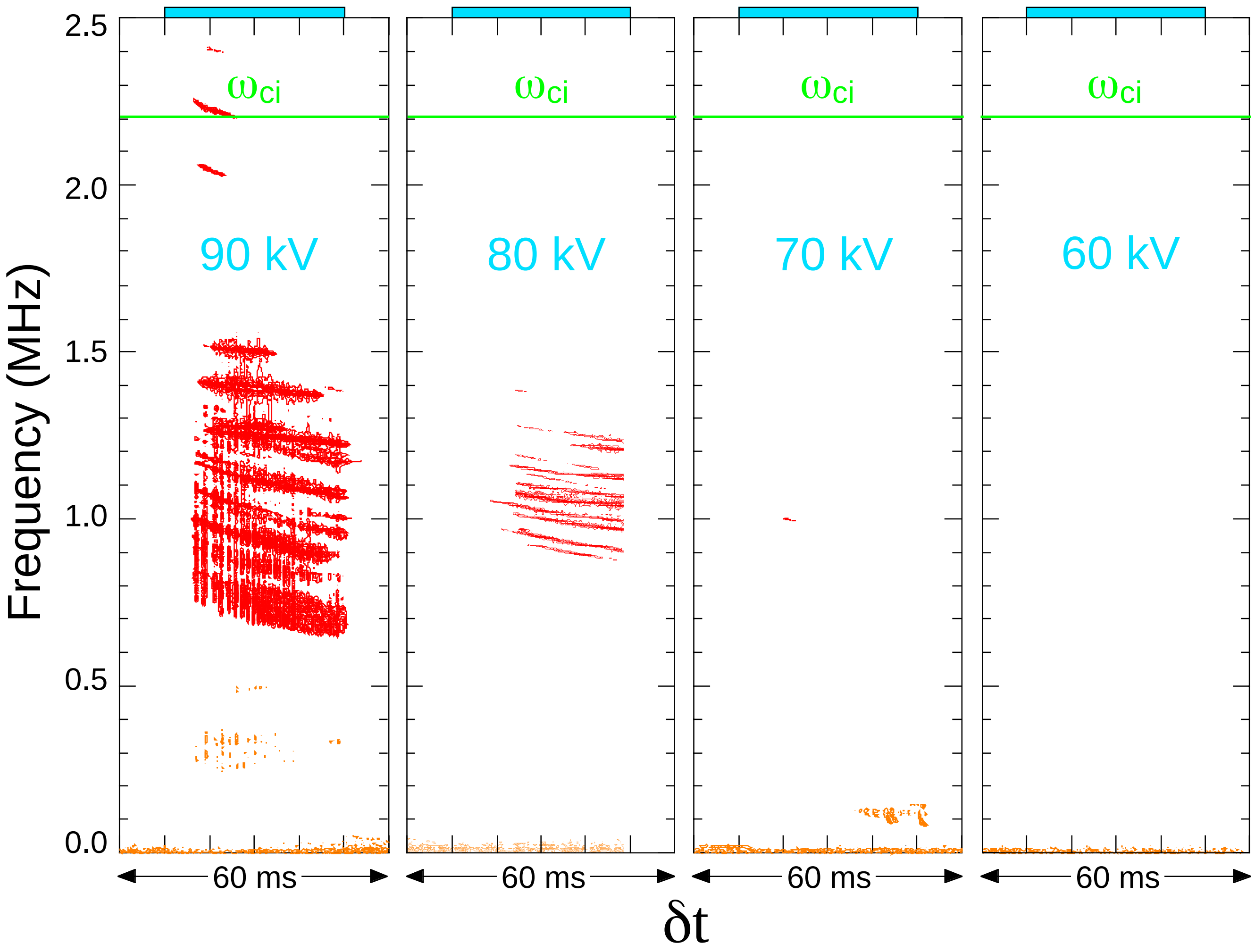
Goal: Improved understanding of CAE instability

- Fast ion instabilities have potential to impact ignition threshold in fusion reactors.
- ST's, with intrinsic low field, are particularly susceptible to fast ion driven instabilities.
- This experiment documents which fast ions drive mode, necessary for benchmarking theoretical models.
- Sharp threshold in beam energy, but not in $V_{beam}/V_{Alfvén}$, is found.

Amplitude, number of modes, strong function of voltage above threshold.

- More CAE with higher voltage.
- Change in beam velocity only 6% from 70-80kV.
- Beam power weak factor.



CAE have sharp beam voltage threshold, weak $V_{Alfvén}$ dependence

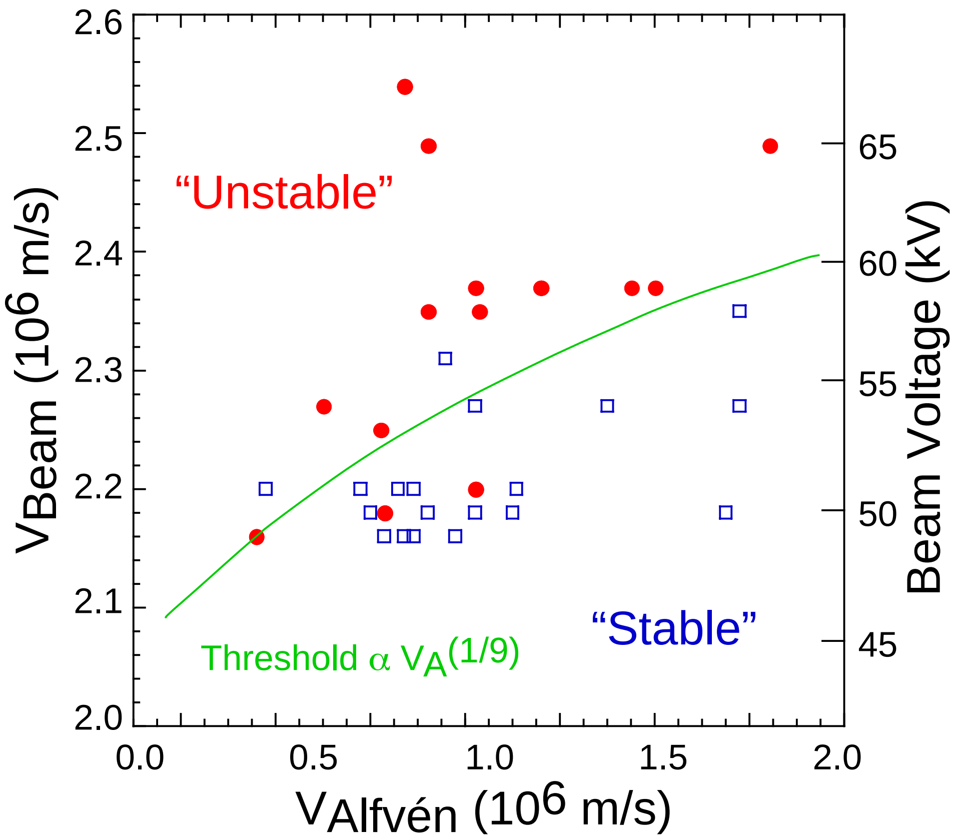
- B_{tor} varied from 3 - 6 kG, small change in threshold;
  - $V_{beam} \approx 2.1 - 2.4 \times 10^6$ m/s.
  - $V_{beam}^{thr} \propto V_{Alfvén}^{(1/9)}$
- Drive is doppler-shifted cyclotron resonance:

$$\omega = l\,\omega_C - k_\theta V_{drift} - k_{\|} V_{Beam}$$

$$(k_\theta V_{drift} << k_{\|} V_{Beam})$$

- Most change in $V_{Alfvén}$ from B_{tor}; could be ρ_{beam}.

- Only fast ions, above ≈ 50 keV, drive waves.



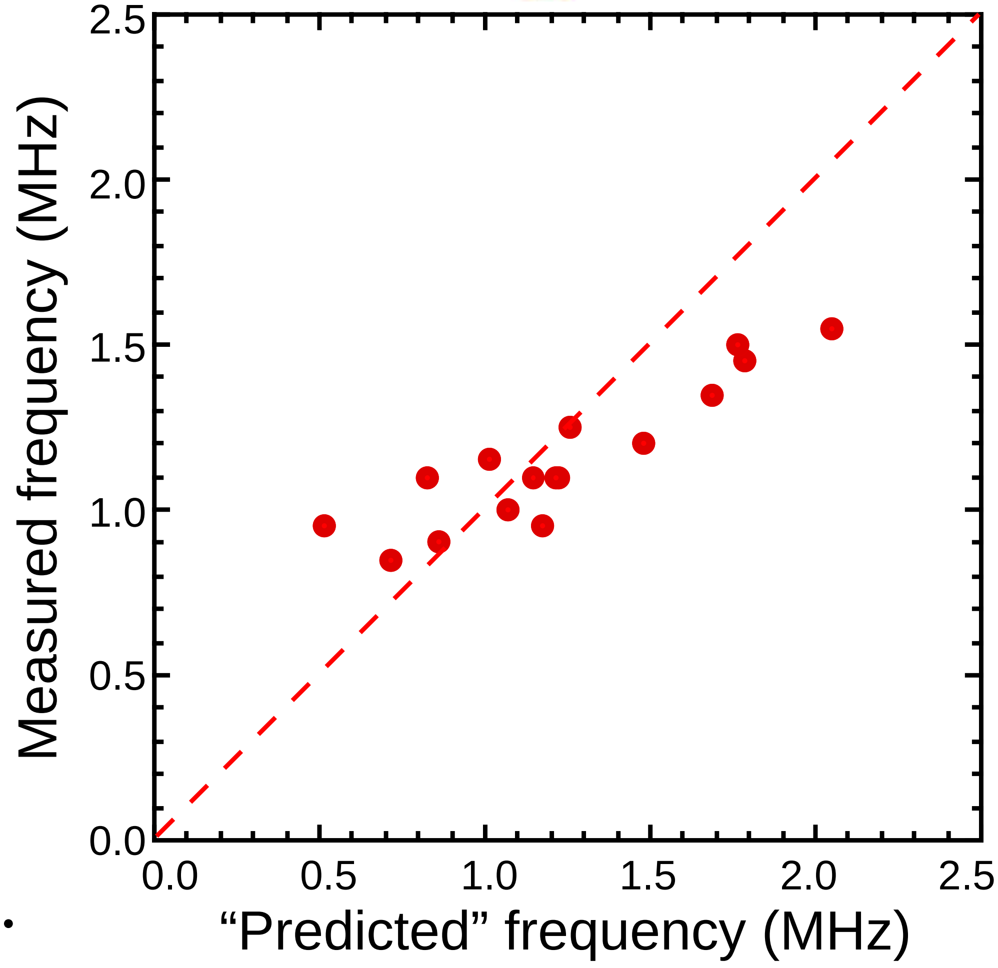
Mode frequency consistent with resonance condition, dispersion.

- Mode frequency predicted from simplified dispersion:

  $\omega \approx k_\perp V_{Alfvén}$

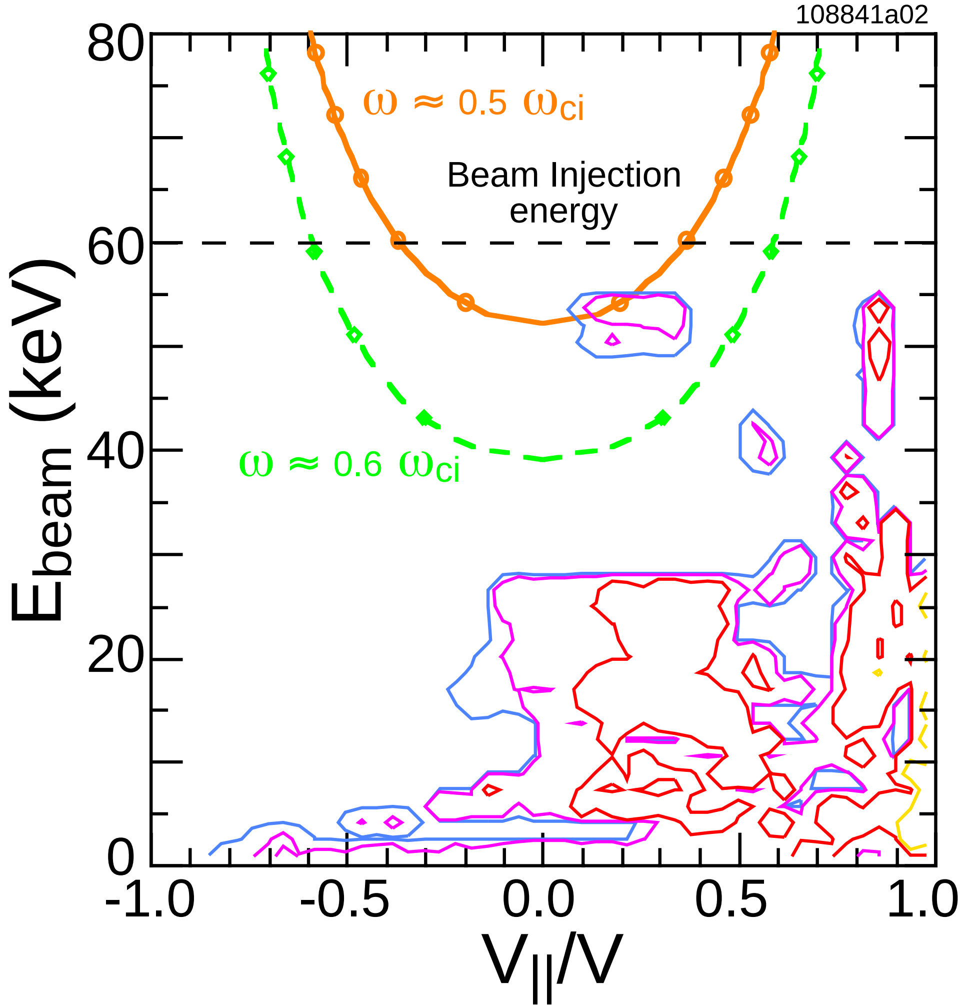
  and resonance condition:

  $\omega \approx \omega_C - k_\perp V_{drift} - k_{||} V_{b||}$
- $k_{||}$ is adjustable, but range is reasonable.
- Mode frequencies are typically $\approx (0.5 - 0.6)\ \omega_{ci}$.



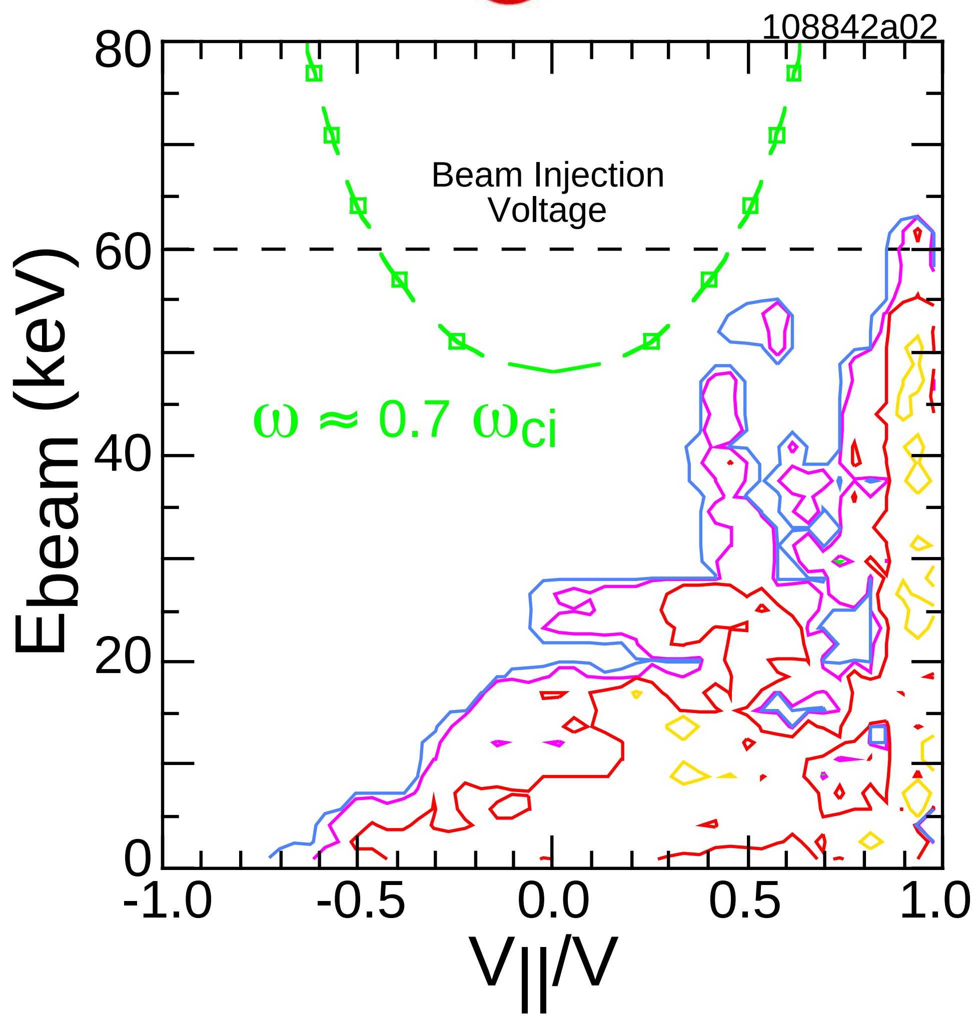
Fraction of fast ion population available to drive mode is small

- Fast ions which can drive CAE must satisfy $1 < k_\perp \rho_b < 2$ => $1<(\omega/\omega_{ci})(v_{\perp b}/V_A)<2$
- Resonance condition means ions must be above $\omega \approx 0.5\text{-}0.6\ \omega_{ci}$ curve.
- Small fraction of fast ions drive mode.



At higher field, essentially no fast ions available to drive mode.

- Fast ion population sensitive to density profile, temperature, etc.
- Threshold change primarily from increase in $V_{Alfvén}$.
- More perpendicular fast ions destabilizing.
- "Bump-on-tail" in perp direction also req'd.



Summary

- Theoretical advances are finding qualitative and quantitative agreement with experimental determinations of CAE stability boundaries.
- Presently, the CAE appear to be relatively weakly driven modes with access to only a small fraction of beam injection power.
- Consistent with measured low growth rates.
- Fusion-α population may or may not more effectively drive CAE.
- GAE's also believed observed…

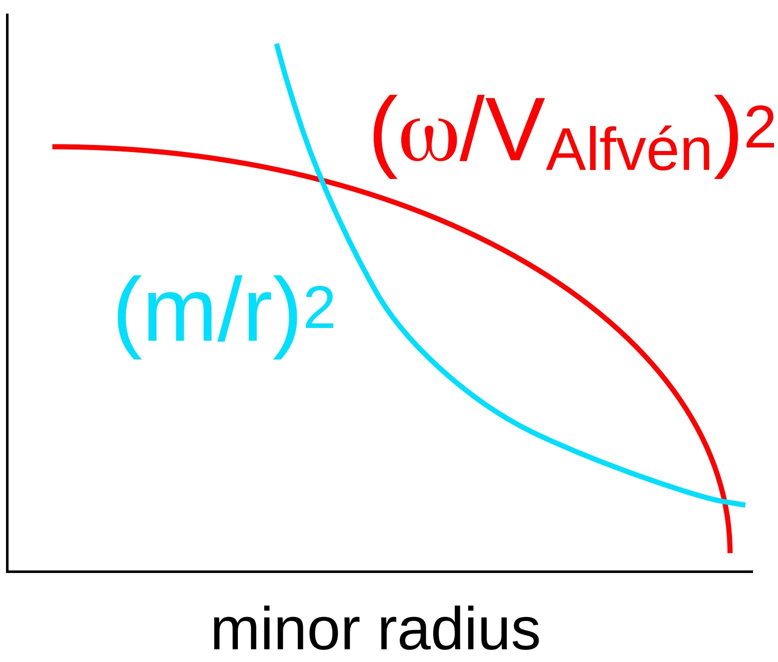
N Gorelenkov, Tuesday afternoon, poster session IV

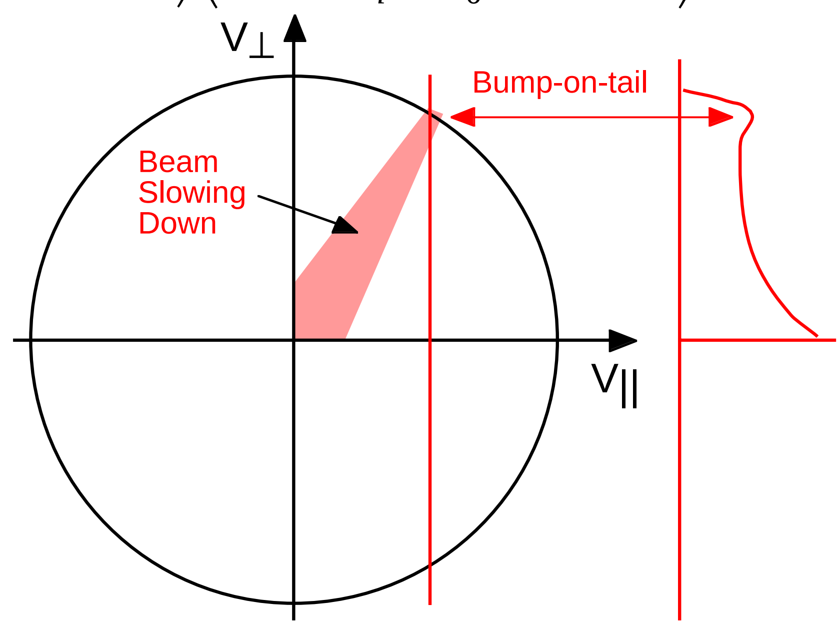
Model of Compressional Alfvén waves

NSTX

- Simple "harmonic oscillator" model can be derived from dispersion relation: $d^2/dr^2 = m^2 / r^2 - \omega^2 / V_{Alfvén}^{\;2}$.
- De-stabilized by "bump-on-tail" with resonance condition $\omega - l\,\omega_C - k_\theta V_{drift} - k_{||} V_{Beam} = 0$, $(l = 0,1)$
- Frequency:

$$\omega^2 = \frac{m^2 v_A^{\;2}}{k^2 r^2}\left(1 + \frac{k_{||}^2 \kappa^2 r^2}{m^2}\right)\left(1 + \frac{1+\sigma_i}{\sigma_i}\frac{\Delta^2}{r_0^2}(2s+1)\right)$$





Neutron decay rate shows no strong anomaly

- Strong stochastic coupling of fast ions to CAE to thermal ions should affect fast ion population, neutron rate, decay rate.
- TRANSP calculation, recalibrated Thomson Te.