Draft FY09-13 NSTX energetic particle physics research plan

- Research goals
- Results from NSTX EPP studies
- FY09-13 Research plan

NSTX Wave-Particle Research Planning Meeting

Energetic particle studies aid fusion energy development

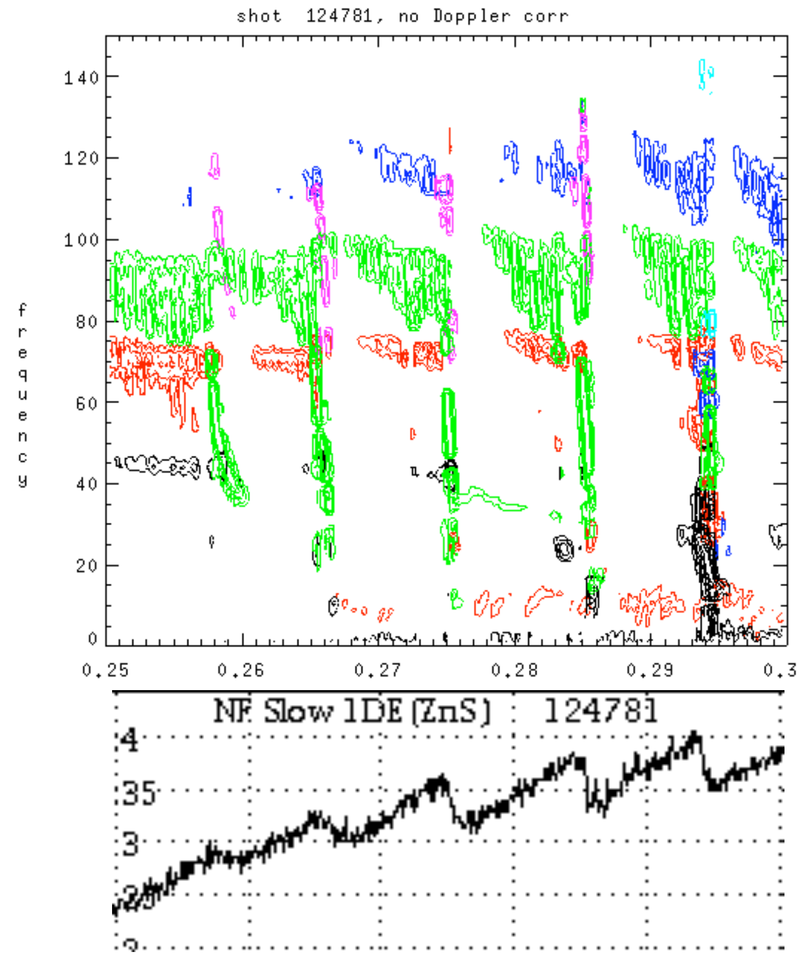
- Confinement of fusion alphas key to fusion reactors
  - Alphas required to ignite fusion plasma
  - Loss of energetic alphas will damage PFC's
  - Of particular concern to ST's with large alpha ρ^*
- Much progress has been made with Mirnov coils, reflectometers, NPA, equilibrium diagnostics…
- …but questions remain that can only be answered by new capabilities:
  - FIDA to measure confined fast ion distribution function
  - Higher spatial resolution of mode structures
  - Faster diagnostics
  - Active control of *AE modes (RF beatwave, "low frequency" sources for HHFW antenna

≈30 journal articles on NSTX energetic particle studies

- Discovery documentation of CAE/GAE modes
  - Doppler-shifted cyclotron drive
- Studies of multi-mode transport (TAE modes)
- New understanding of chirping modes (CAE angelfish, TAE chirping modes)
  - HHFW stabilization of Angels
- Bounce-resonance fishbones
- Beta-induced Alfvén Acoustic Modes
- Beta scaling of Alfvén Cascades, validation of AC-GAM coupling model.
- Measurements of mode polarization

TAE Avalanches cause large fast ion loss

- Sequence of avalanches produced demonstrating multi-mode fast ion transport.
- Strong drops in neutron rate were seen, correlated with avalanche events.
- Many avalanches did not have n=1 "fishbone" modes.
- Avalanches typically involved strong frequency chirping - maybe as important as multi-mode.
- q-profile documented with Source A timing scan.

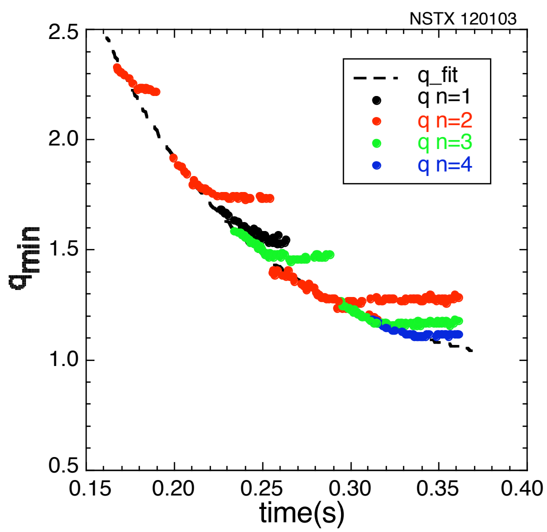


Alfvén Cascades discovered at low β on NSTX

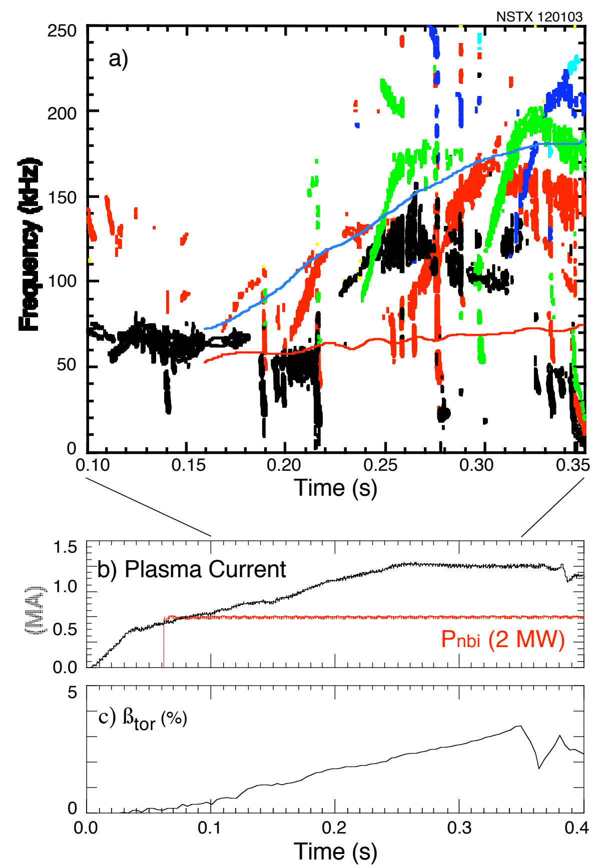
Observations support recent theoretical models suggesting modes stable at typical ST β's.

Shots had exceptionally low density, $\approx 10^{13}/cm^3$ on axis, β less than $\approx$ 3%.

Mode frequency sweeps upwards, saturates near TAE frequency.



Progression of toroidal mode numbers consistent with Alfvén Cascades (2, 2+1, 3, 2, 3, 4) including "grand" Cascade around 180 ms at q_{min} = 2 crossing.

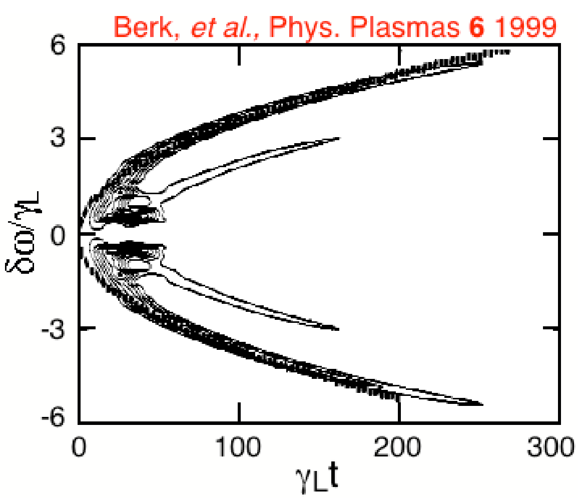


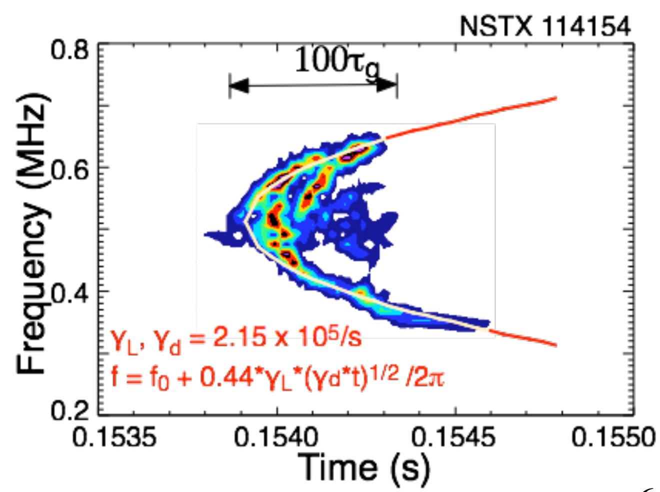
Study of hole-clumps addresses important area of physics for ITER

NSTX

- Hole-clumps give insight on instability drive, damping, and ν_{eff}.
  - Non-linear physics of mode saturation; vital for predicting impact on fast ion confinement
- Heating the fast ion population with HHFW, increases ν_{eff}, provides a window on fast ion distribution.

- Red curve is single parameter fit to frequency evolution using model of hole-clump pair creation*.





New regimes lead to new instabilities - unsafe at any β_{fast}?

- Grey, red and green shaded regions show frequency range for n=1, n=2 and n=3 BAAEs, respectively.
- Upper black, red and green lines are core n=1, 2 and 3 TAE frequencies.

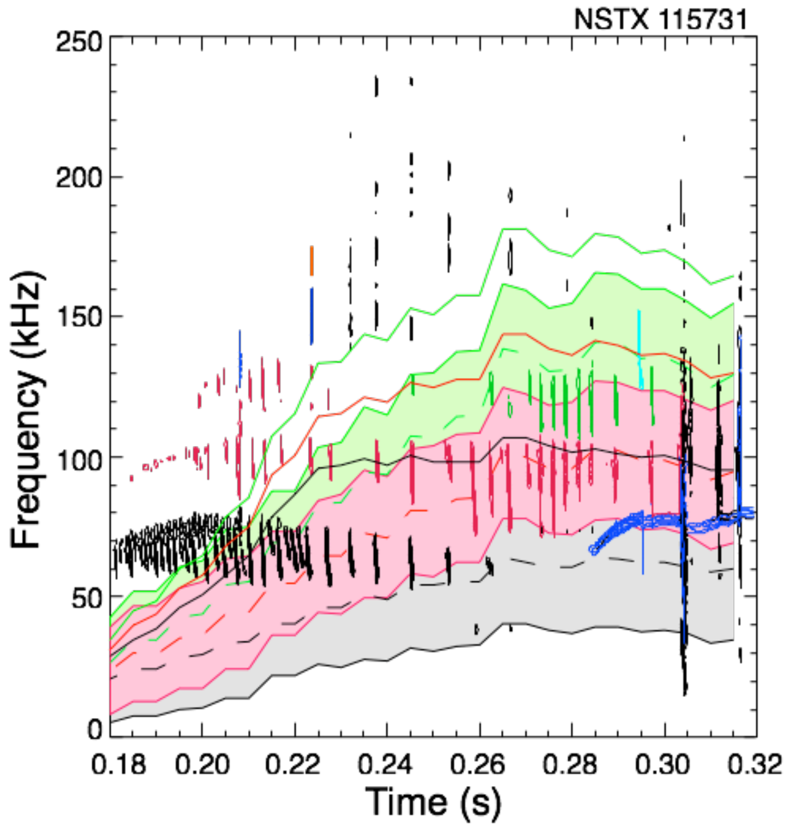
$$\omega_0^2 = \omega_+^2 [1 + \{\frac{\delta(1+2q^2)}{1+\delta}\}^{1/2}]^{-2}$$

$$\omega_+^2 = \omega_{Alfvén}^2 \frac{\delta}{1+\delta}$$

$$\omega_{Alfvén} = \frac{V_{Alfvén}}{R_0}$$

$$\delta = \frac{\gamma \beta_{tor}}{2}, \ \gamma = \frac{5}{3}$$

$$\omega_- = 2\omega_0 - \omega_+$$



Advances in theoretical understanding spurred by NSTX results

- Alternative resonant drives, e.g., bounce resonance driven fishbones, Doppler-shifted cyclotron resonances
- NOVA
  - Coupling to acoustic modes
- M3D-K
  - Non-linear code up and running
  - Chirping TAE modes
  - Towards TAE avalanches?
- HYM
  - Non-linear growth of CAE and GAE

Outline of goals for next five years

- Multi-mode driven Energetic Particle effects (ITPA relevant)
  - mode saturation, avalanche physics
  - transport of EP, modification of distribution function
  - effects on current drive (similarity with DIII-D)
  - interplay between different modes (fishbones, EPMs, NTMs...)
  - B, P, rho scalings to explore uniqueness of STs
- Phase space engineering through high frequency mode physics
  - CAE/GAE chirping effects to study velocity diffusion
  - Study energy channeling via CAE/GAE excitations
  - Stochastic thermal ion heating
  - Measure higher cyclotron harmonics of CAEs
  - Excitation of *AE by beat RF wave

5-year goals, cont.

- Address unique ST physics
  - High beta (normal to NSTX) study of two fundamental MHD branches interaction: Alfven and acoustic
  - MHD spectroscopy at high beta via RSAEs (cascades), Alfven-acoustic modes
  - Bounce frequency fishbones
  - NTM interaction with EP (high beta, low aspect ration)
  - Make use of mode chirping to address chirping frequency physics: potentially can be used to diagnose mode growth rate and amplitudes of modes

Diagnostic/hardware investments

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- FIDA, extended SSNPA?
- Additional fast Mirnov coils,
  - better polarization measurements
  - Better poloidal arrays
  - Center-stack measurements
- Faster scanning reflectometer
- Extend Firetip to ≈2.5 MHz bandwidth
- Beatwave capability for HHFW to 1.5 MHz
- Low frequency sources for HHFW antenna

Energetic Particle Studies Research Plan

FY09

- Extensive documentation of fast ion redistribution with FIDA, NPA, FLIP and multi-channel reflectometers for TAE avalanches and fishbones.
- Develop beatwave capability for TAE range of frequencies
- Extend polarization and toroidal Mirnov coil arrays
- Passive observation of CAE/GAE with HHFW antenna.

FY10

- Extend beatwave capability to CAE/GAE range of frequencies - measure mode damping rates
- Faster "scanning" reflectometer to measure TAE mode structure.
- Low power, low frequency excitation of TAE/CAE

FY11-13 Research Plan

FY11

- Control mode chirping with HHFW
- Study multi-mode interactions (f.b., TAE, CAE, …)
- Determine stochastic ion heating thresholds
- Measure antenna loading

FY12-13

- Add high power, low frequency source to excite CAE to stochastic heating threshold
- Study multi-mode interactions (f.b., TAE, CAE, …)