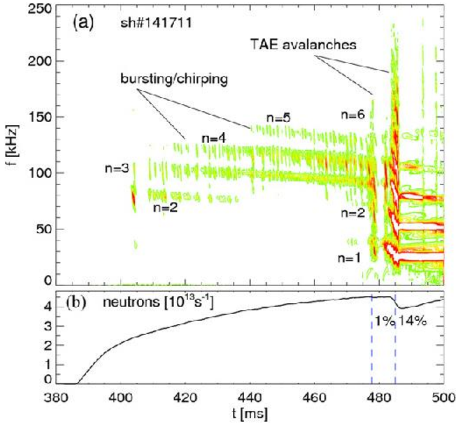
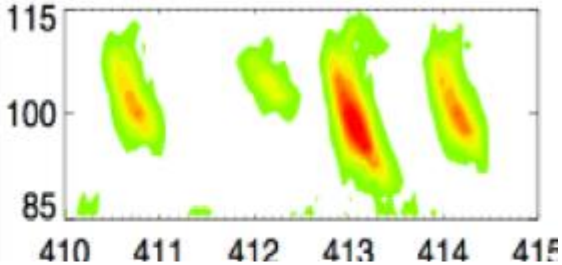
Chirping and bursting of TAEs in NSTX #141711

- Significant excitation of toroidicity-induced Alfven eigenmodes (TAEs) were observed in NSTX 141711 with NBI (Podesta NF 2012)
    - Down-chirping and chirping of TAE with n=1-6 characterized by period of <1ms.
    - TAE avalanche can be triggered by large down-chirping, resulting in significant EP loss.

TAE spectrum in NSTX #141711





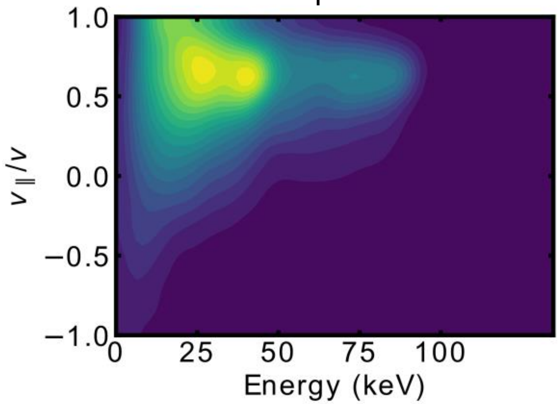
Frequency and amplitude evolution during TAE chirping

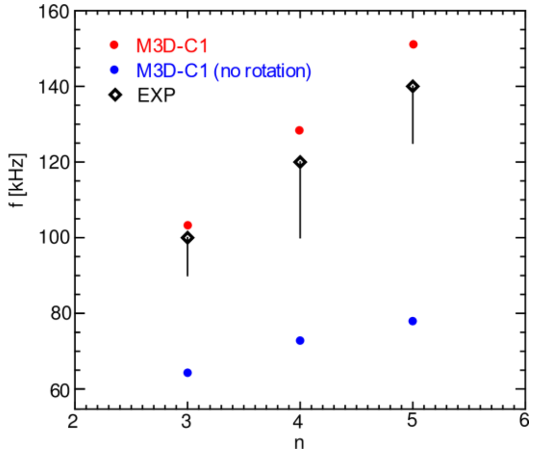
Kinetic-MHD simulation TAE in NSTX

- Kinetic-MHD code M3D-C1-K was upgraded to simulate Alfven eigenmodes in NSTX driven by high-energy beam particles.
  - Classical EP distribution calculated using NUBEAM was used for particles initialization and δf calculation.
  - Toroidal rotation profile can be included in both MHD and particle simulation.

- TAE frequencies from linear simulation are consistent with experiments and previous M3D-K results (D. Liu PoP 2015)
  - Frequency spacing between different n modes comes from both dispersion of TAE and Doppler shift of rotation.

EP distribution at core read from NUBEAM output





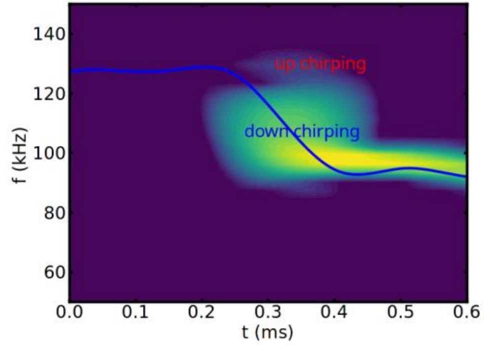
TAE frequencies from linear simulation compared with experiments

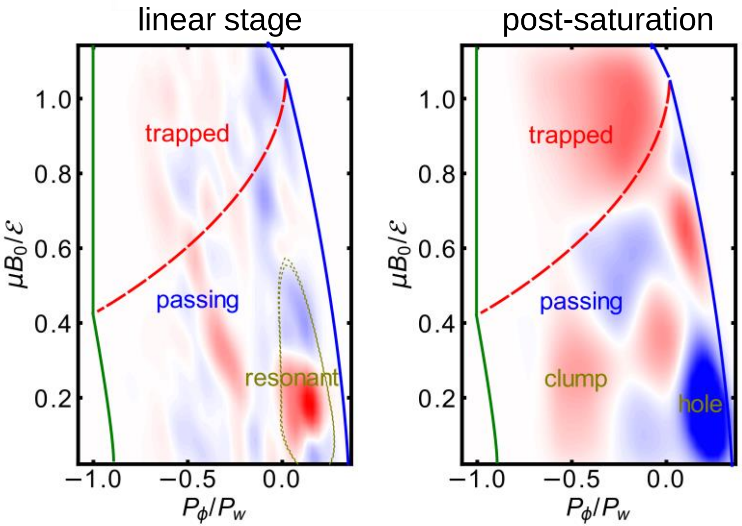
Down-chirping of TAE captured with nonlinear kinetic simulation

- By enabling the nonlinear terms in the kinetic simulation, the frequency chirping of the mode can be reproduced.
  - Down-chirping dominates, which is consistent with experiments
  - Chirping timescale consistent with experiment (<1ms)

- Analysis of particle phase space reveals the dominant wave-particle resonance comes from passing particles near resonant flux surface.
- In the saturation stage, resonant particles get splitted into clump and hole regions moving in different directions, consistent with the frequency chirping theory.

TAE spectrogram from nonlinear M3D-C1 simulation





Numerical issues with M3D-C1 when enabling rotation

irot=1 eqsubtract=1

- Numerical instability can arise when using ifbound=1
  - Setting ifbound=2 seems help. Maybe due to this damping term:

```
if(ifbound.eq.2) then
        r_bf = r_bf – regular*intx3(trial(:,:,OP_1),r2_79,lin(:,OP_1))
end if
```

  - May also be related to non-zero edge rotation

- Using semi-implicit method with thimp=1.0 can lead to suppression of TAE when rotation velocity is large
  - Can be avoided by forcing Crank-Nicholson for convection due to v0

```
    tempx = v2vun(trialx,vz079,lin,rho79)
 ssterm(:,u_g) = ssterm(:,u_g) -    0.5     *dt*tempx
 ddterm(:,u_g) = ddterm(:,u_g) + (1.-0.5*bdf)*dt*tempx
```

- Using Caramana method (imp_mod=1) can lead to numerical instability when irot=1