MHD-Induced Beam Ion Loss from NSTX Plasmas

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Abstract

Bursts of MHD activity in the range of ~50-70 kHz occur commonly in NSTX plasma, accompanied by bursts of neutral beam ion loss over a range in pitch angles. These losses have been measured with a scintillator type loss probe coupled to a high speed video camera, allowing resolution of the energy and pitch angle distributions of the lost neutral beam ions the bursts. The instability occurs below the TAE frequency in NSTX (~100 kHz) in high beta plasmas and may be a beta driven Alfvén acoustic (BAAE) mode.

The data from one representative burst that causes a >10% reduction in the neutron rate has been studied thoroughly and has several interesting features. The burst commences with the mode having a purely n=1 character, sweeping downward in frequency. However, there is no change to the underlying prompt loss signal during this interval. This indicates there is no phase space transport of fast (80 keV D) ions into the loss cone from the frequency sweeping. As the burst evolves further in time, a concurrent n=2 mode arises, followed quickly by a concurrent n=3 mode. During this period when multiple modes are present, loss is seen over a wide range of pitch angles, suggesting stochastization of the beam ion orbits. There is no evidence of any sweeping in pitch angle of the loss in either phase of the burst, at least not on the 100 microsecond time scale.

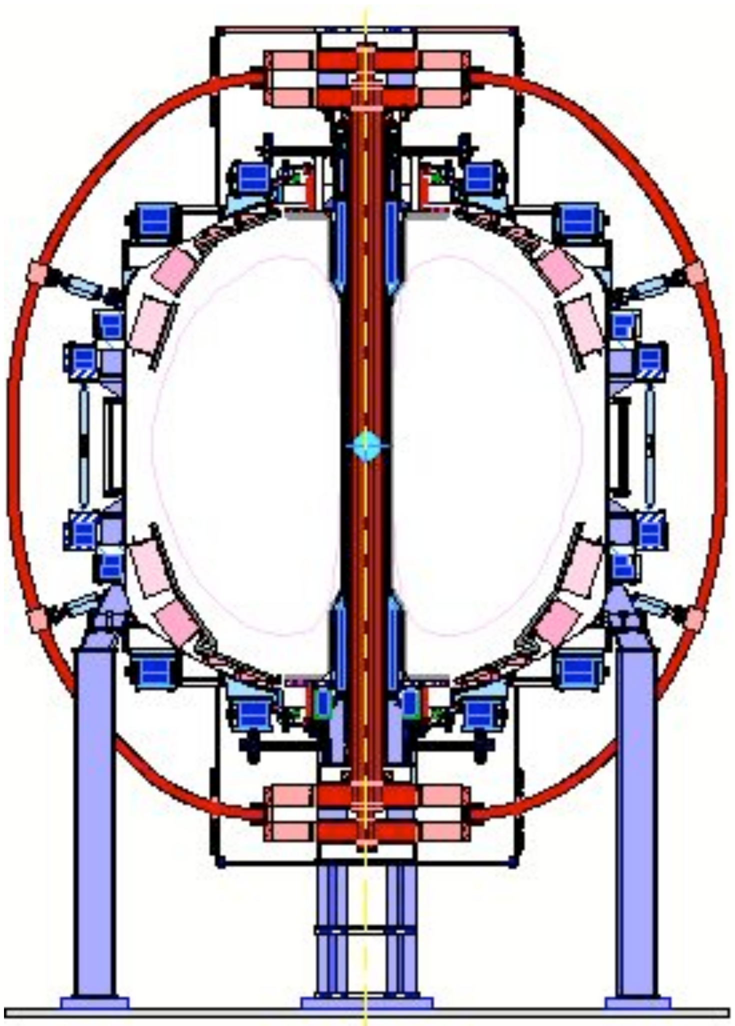
Motivations

- Dimensionless parameters of beam ions similar to 3.5 MeV αs in DT spherical tokamak (good model system)
- Lost beam ion characteristics can reveal internal physics, especially effects of MHD instabilities
- MHD-induced loss often seen in NSTX plasmas

Fast ion loss mechanisms

1. Prompt orbit loss: fast ion born in loss cone
2. Radial transport to wall: arises from changes in $\mathbf{P}_\phi$ (toroidal momentum) due to
   – MHD
   – TF ripple
3. Pitch angle scattering into loss cone (arises from changes in μ (magnetic moment) due to
   – Classical collisions
   – ICRF heating

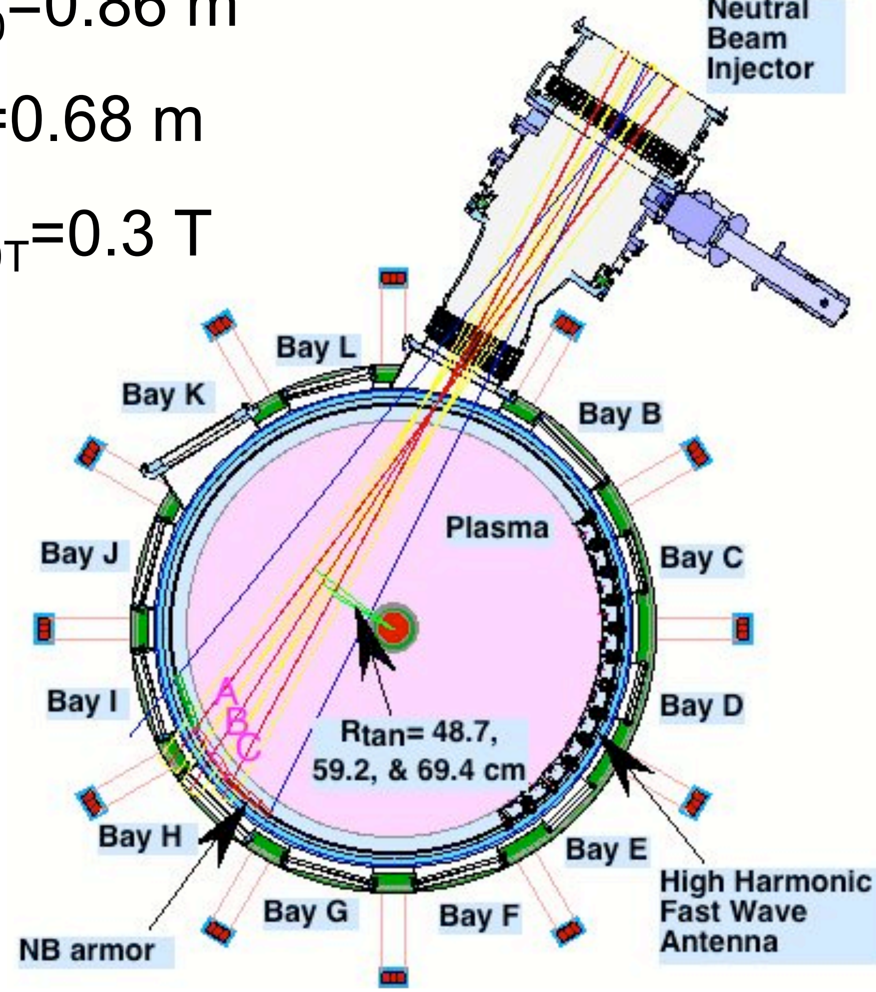
NSTX heated by 3 neutral beams



R_0=0.86 m

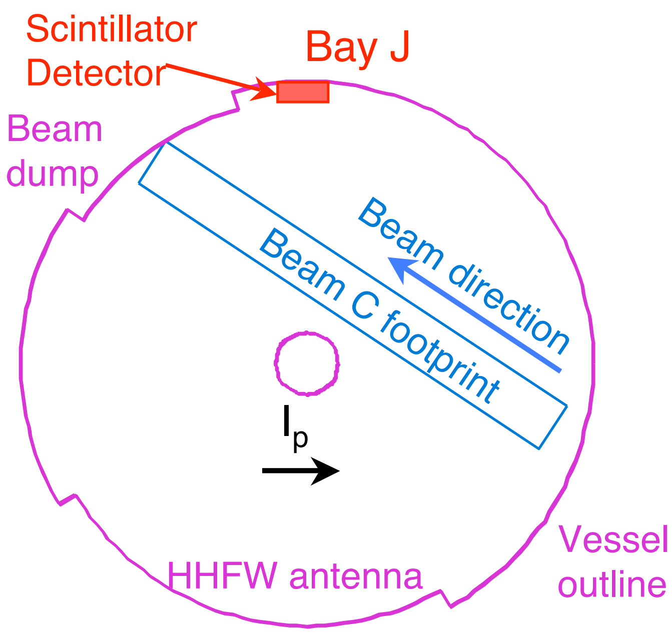
a=0.68 m

B_{0T}=0.3 T

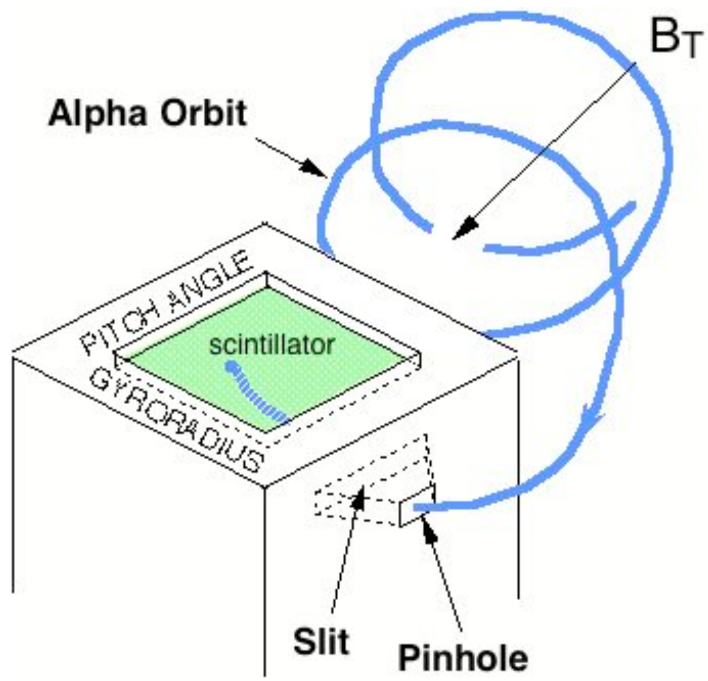


Fast ion losses measured by scintillator detector (sFLIP)

- Combination of B and aperture geometry disperse different pitch angles and energies on scintillator plate

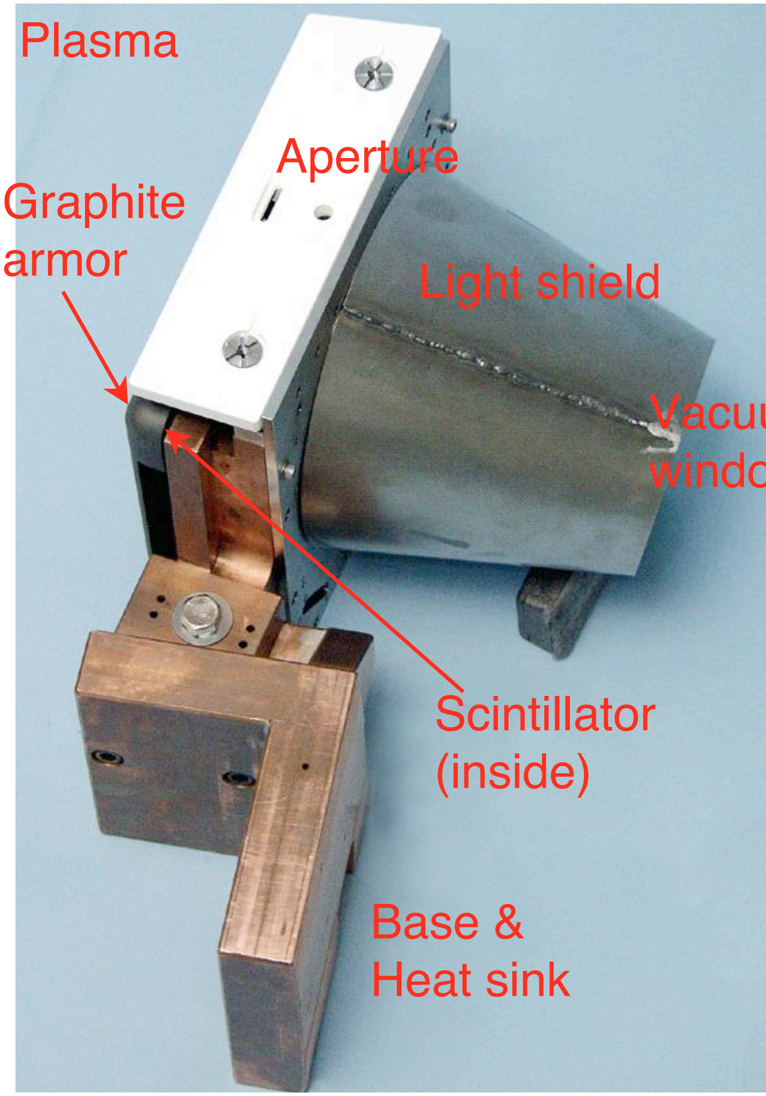


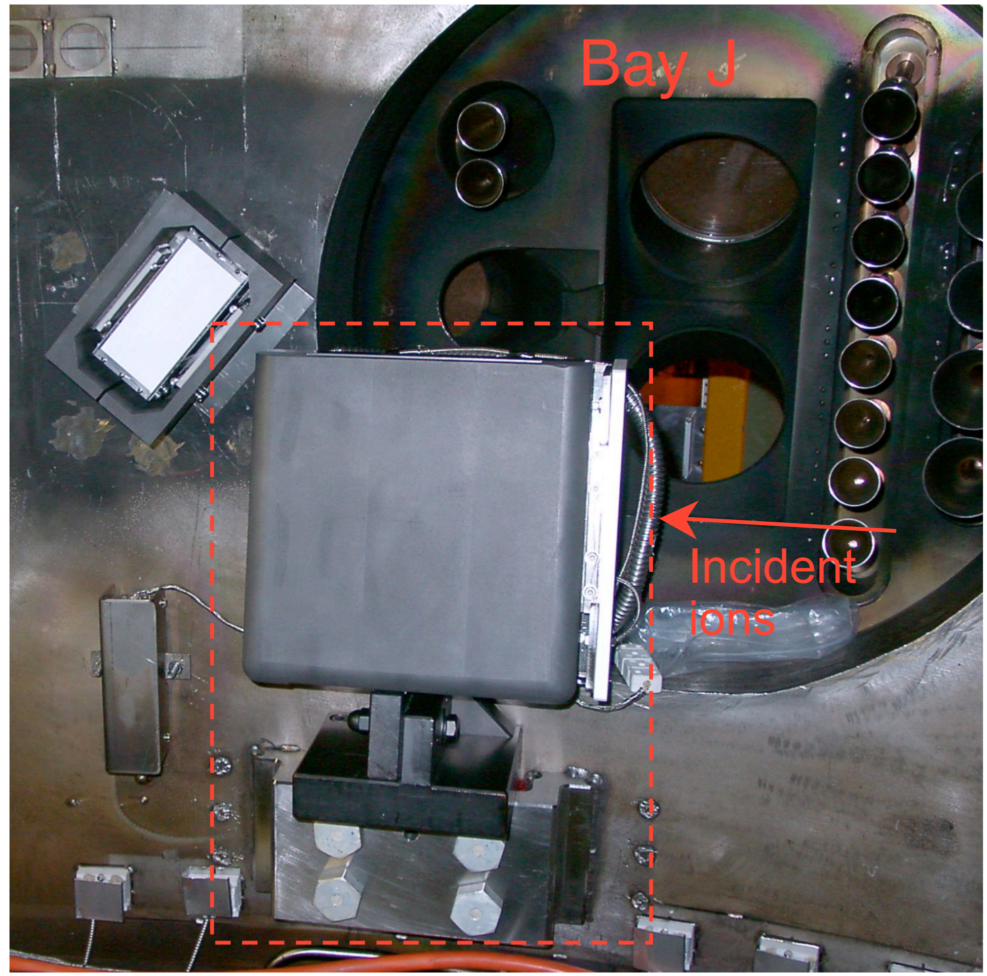
NSTX Midplane



Scintillator detector: principle of operation

Scintillator probe assembly





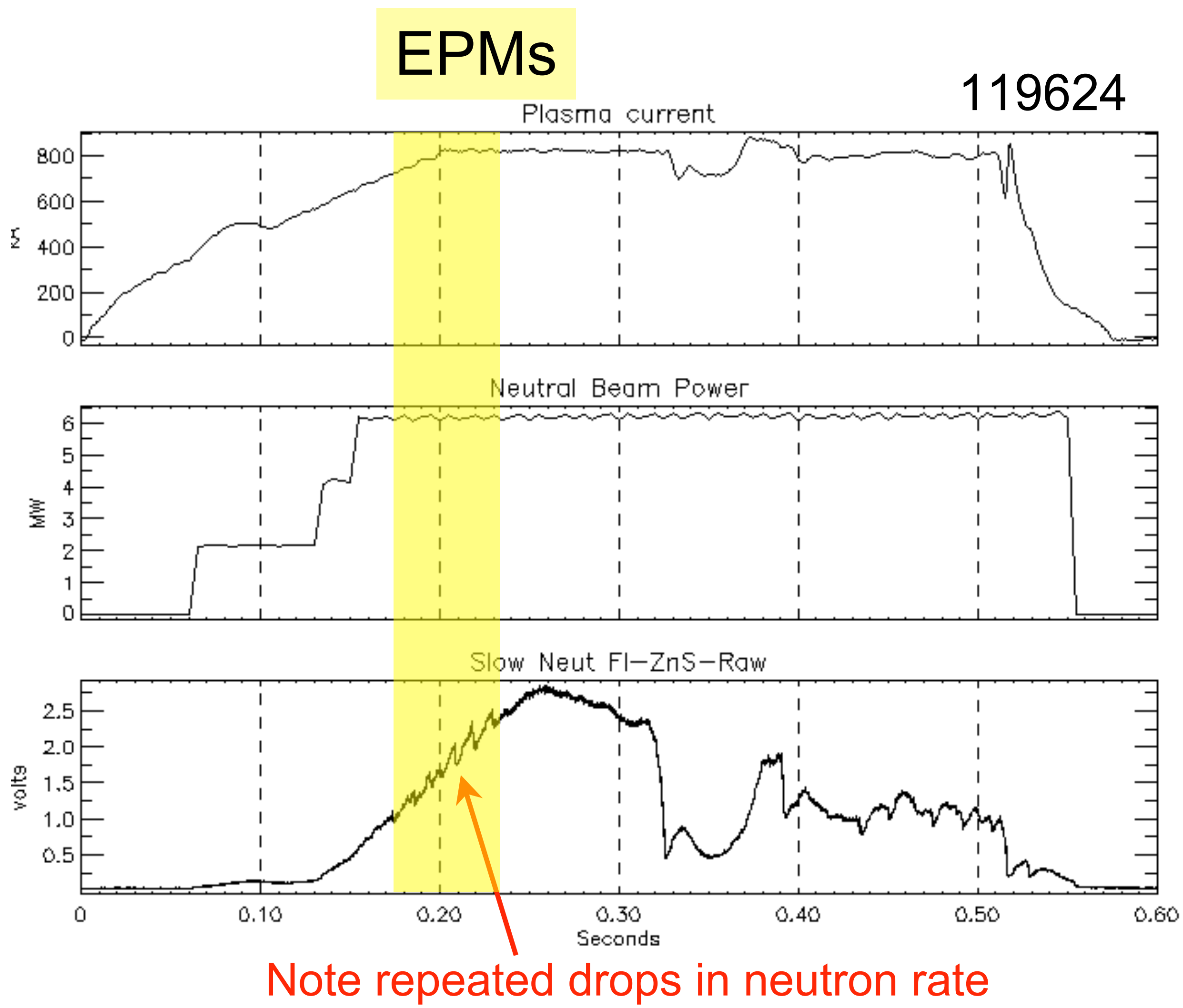
ρ: 5–60 cm, χ: 10°–70° (typ.)

Scintillator images recorded by fast videocamera

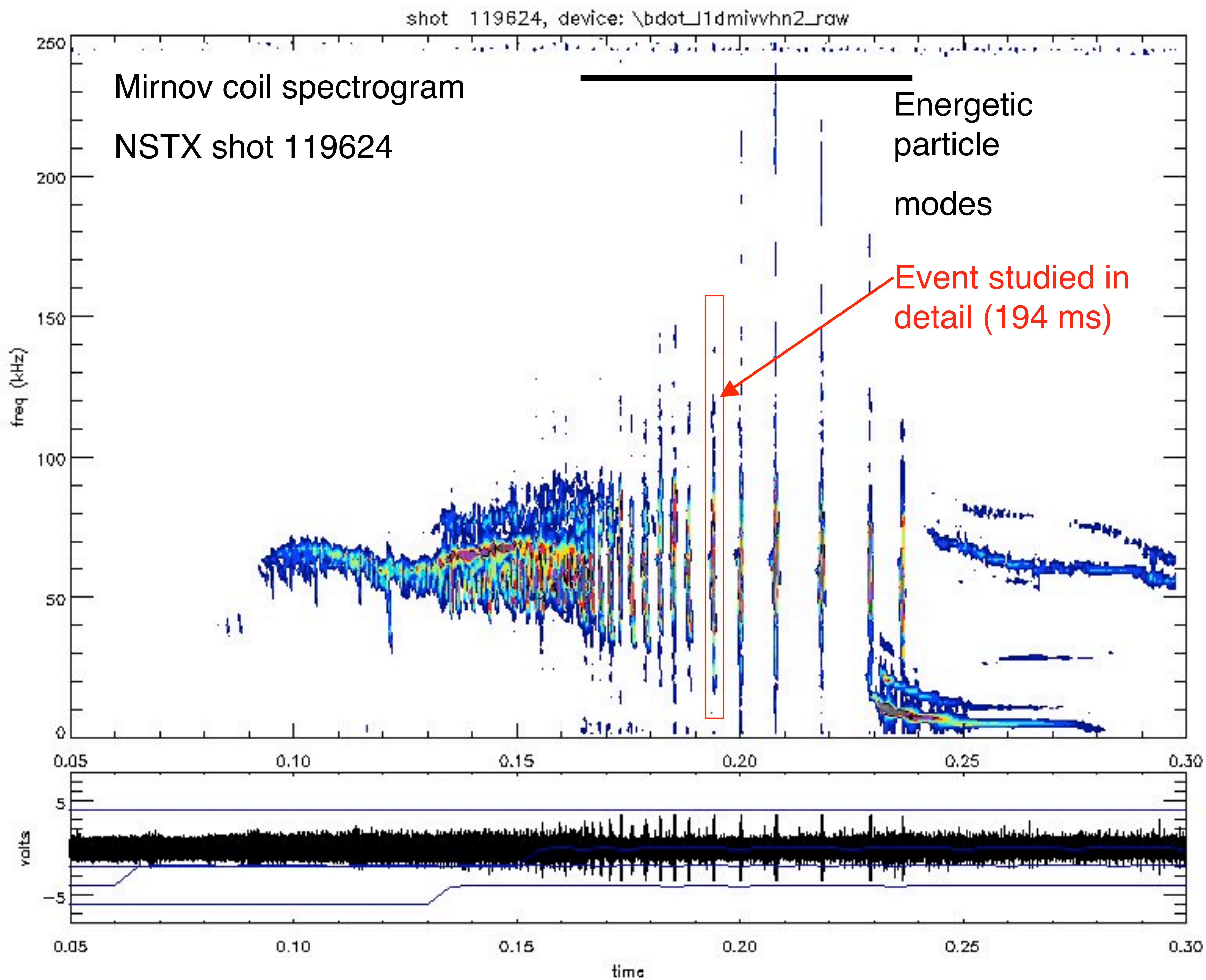
NSTX

- Photron Fastcam on loan from JAEA for 2005 & 2006 campaigns
- Gives ≤40,500 frames/s
- Good for resolution of MHD & other rapidly-varying loss

Energetic Particle Modes produce strong beam ion loss

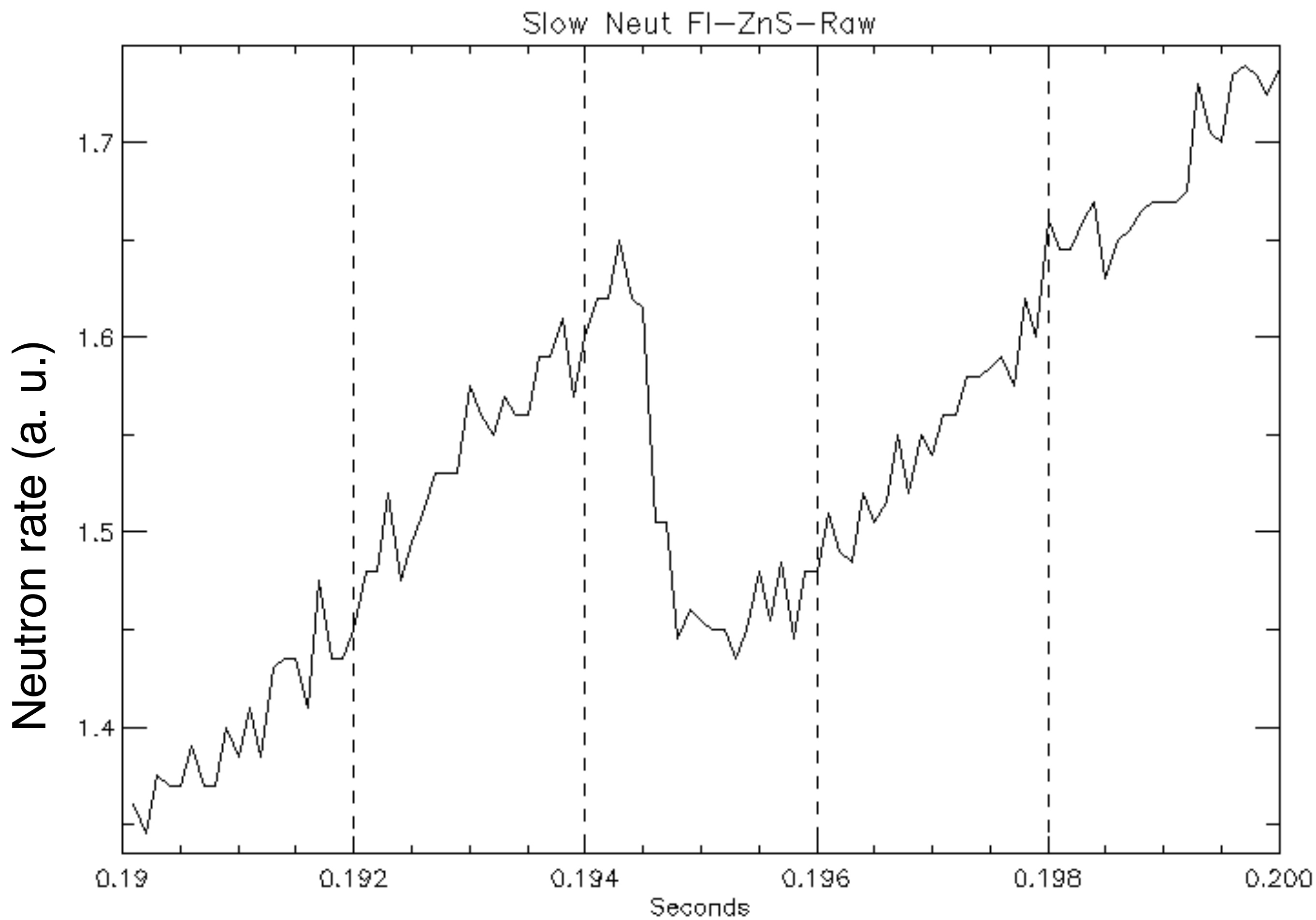


- EPMs common in NSTX plasmas
- Often multiple bursts in single shot

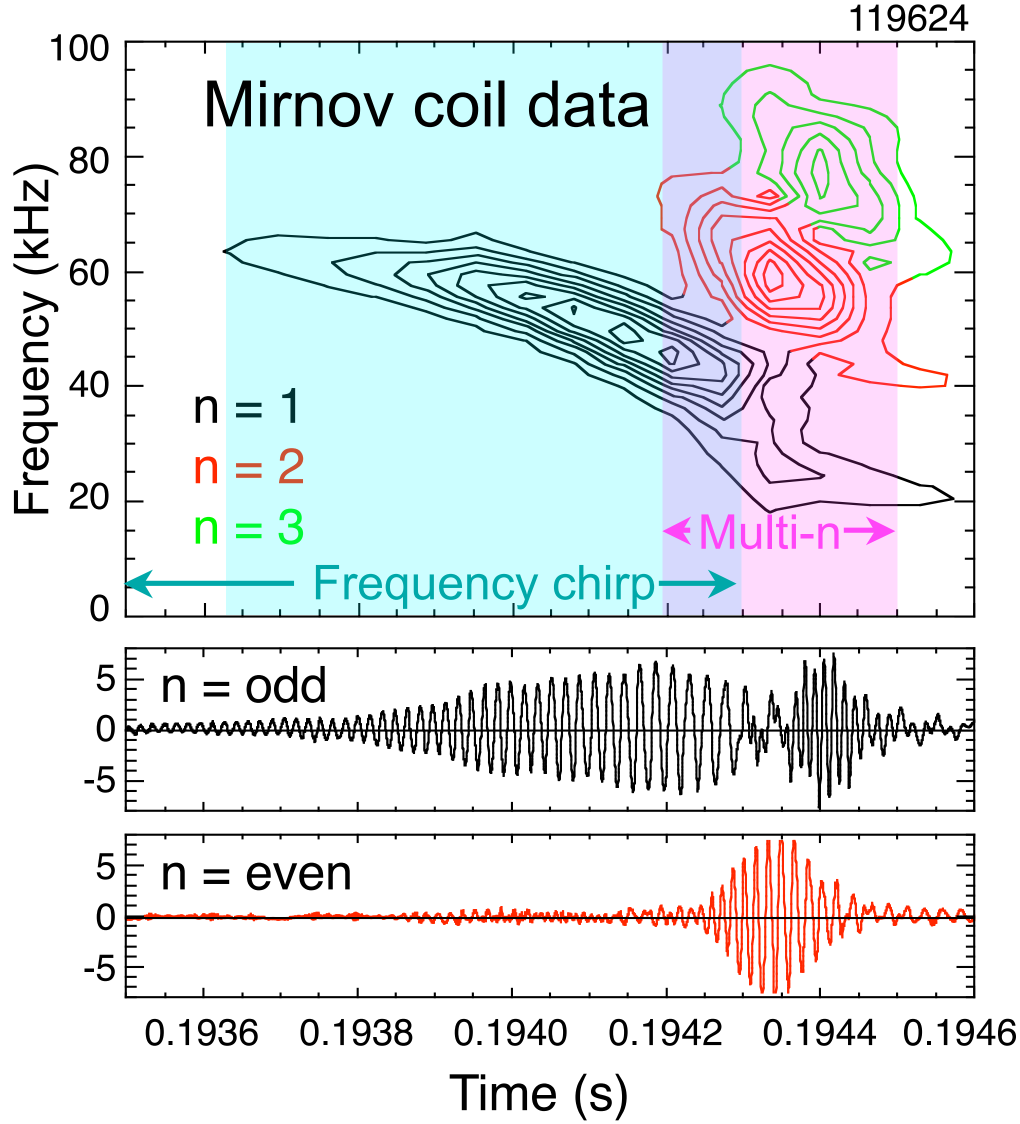


shot 119624, device: \bdot_l1dmivvhn2_raw
Mirnov coil spectrogram
NSTX shot 119624
Energetic
particle
modes
Event studied in
detail (194 ms)
freq (kHz)
250
200
150
100
50
0
0.05
0.10
0.15
0.20
0.25
0.30
volts
5
−5
time

Event at 194 ms reduces neutron rate by 13 %

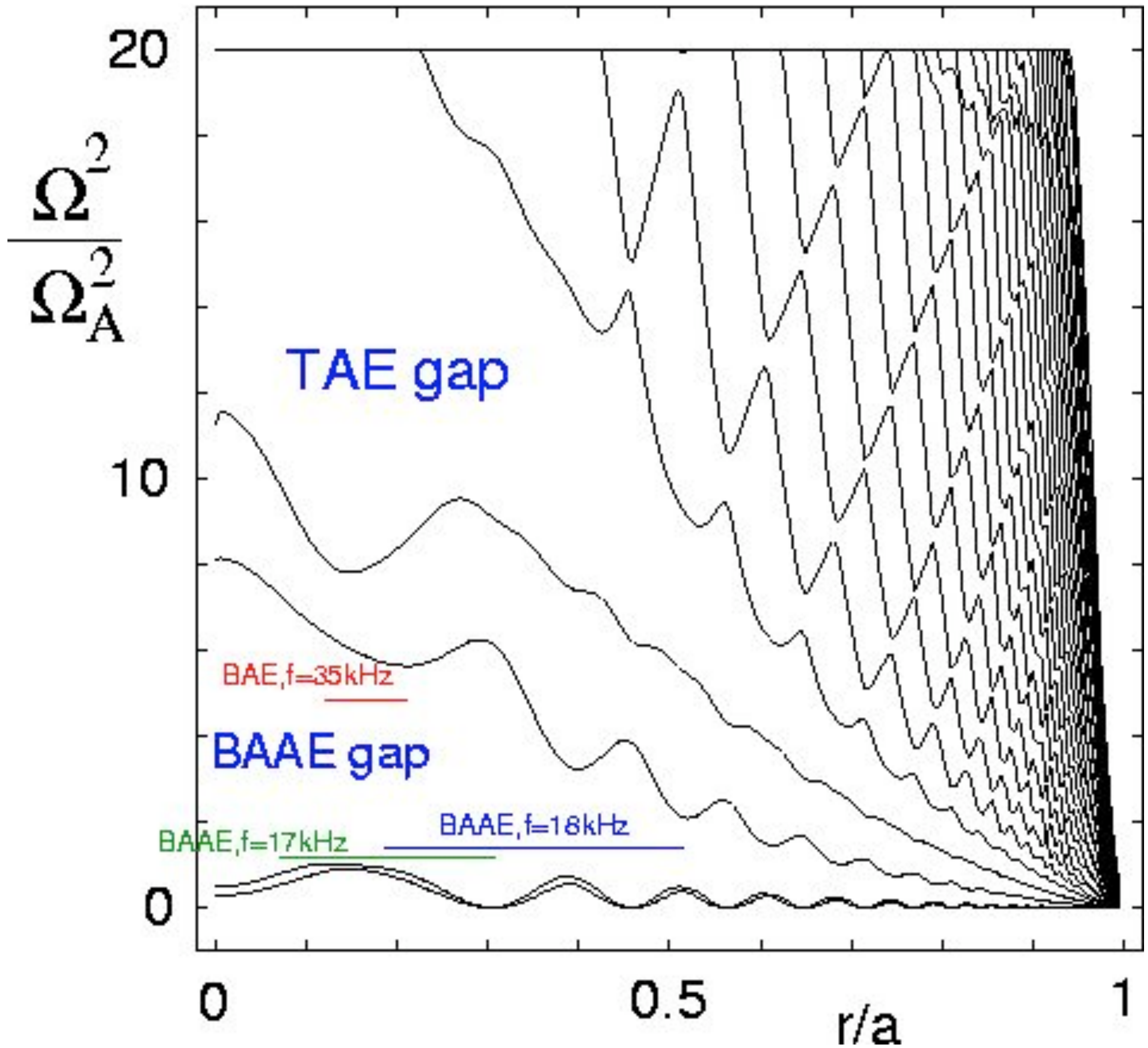


Event has significant frequency chirping, multiple n values



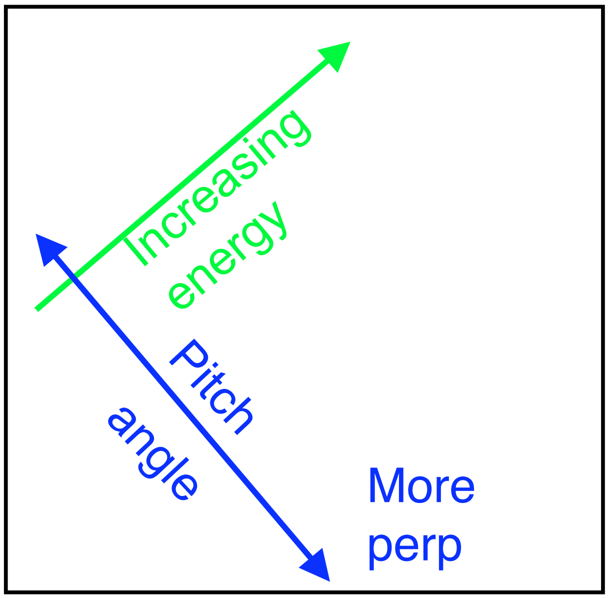
- n=1 chirps 65 to 40 kHz in 500 μs
- n=1, 2, & 3 all present

n=3 mode frequency lies in BAAE gap



- BAAE=beta-induced Alfvén coustic eigenmode
- f_{rot}=20 kHz
- For n=3 mode:
  - f_{BAAE}=78 kHz
  - f_{obs} =78 kHz
- Good agreement

Scintillator image interpretation



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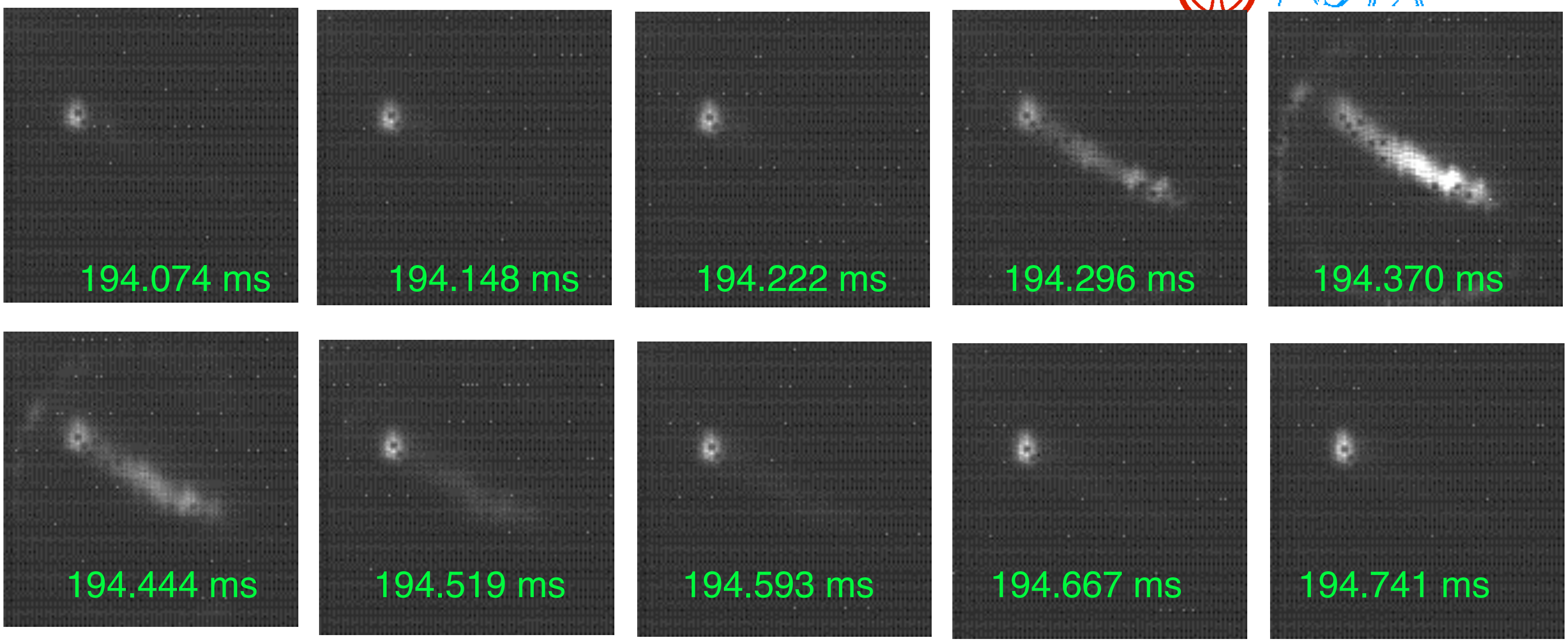
following pages)

Beam ion loss varies rapidly in time

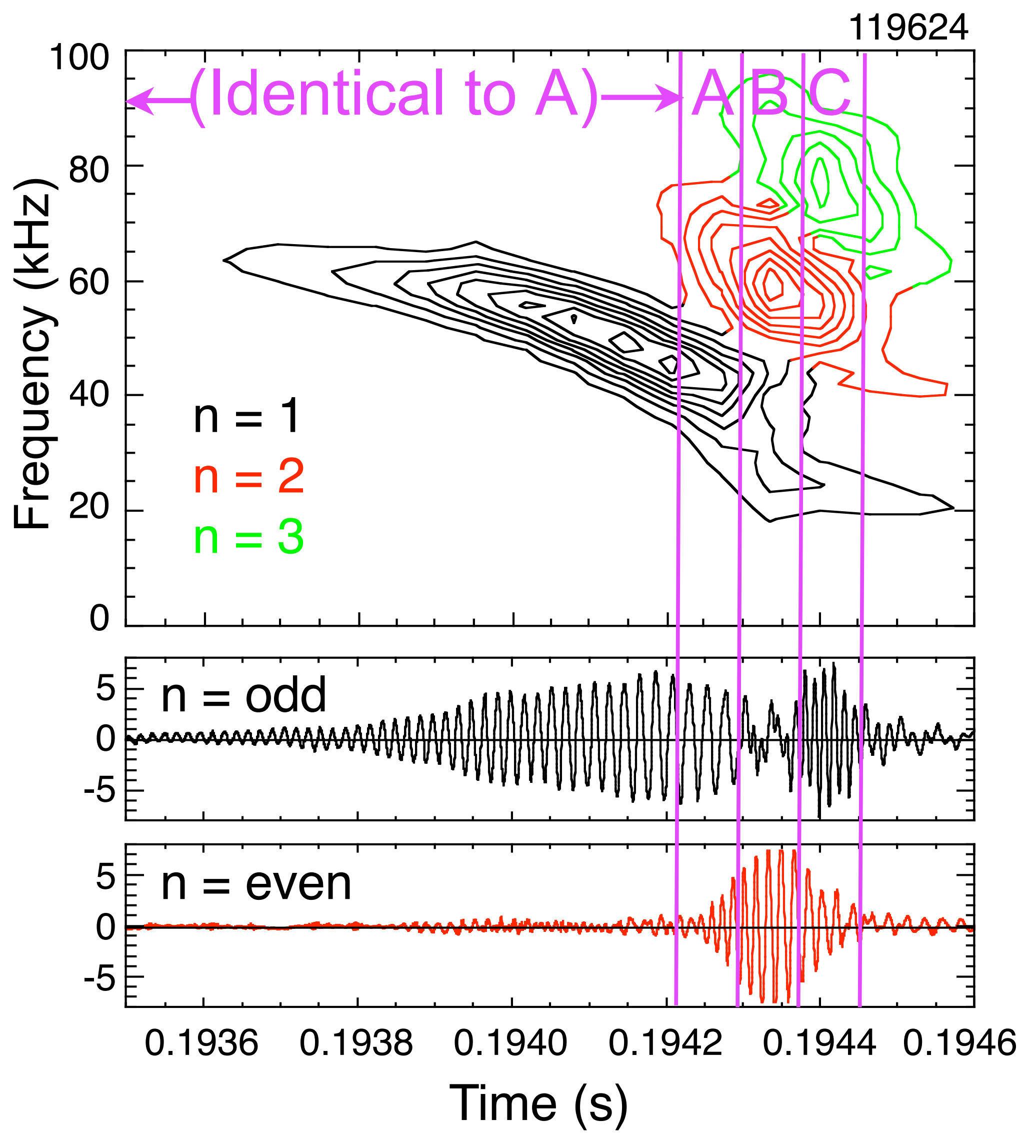


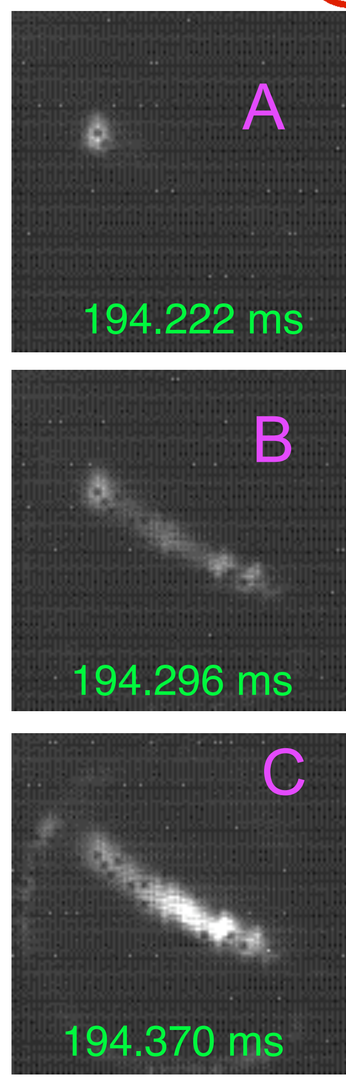
- 13,500 frames/s
- Full beam energy loss only (90 keV D)
- Upper left loss spot is source C prompt loss and is constant before, during, & after, (i.e. **not** MHD loss)

Broad range of pitch angles lost

- Wide range of pitch angles lost in single frame (<100 μs)
- No evidence of sweeping in pitch angle at this time scale, i.e. loss spot does not move through a succession of pitch angles from one frame to another, but only appears as a single discrete pitch angle or a broad range within each individual frame.

Loss characteristics do not change during frequency sweeping

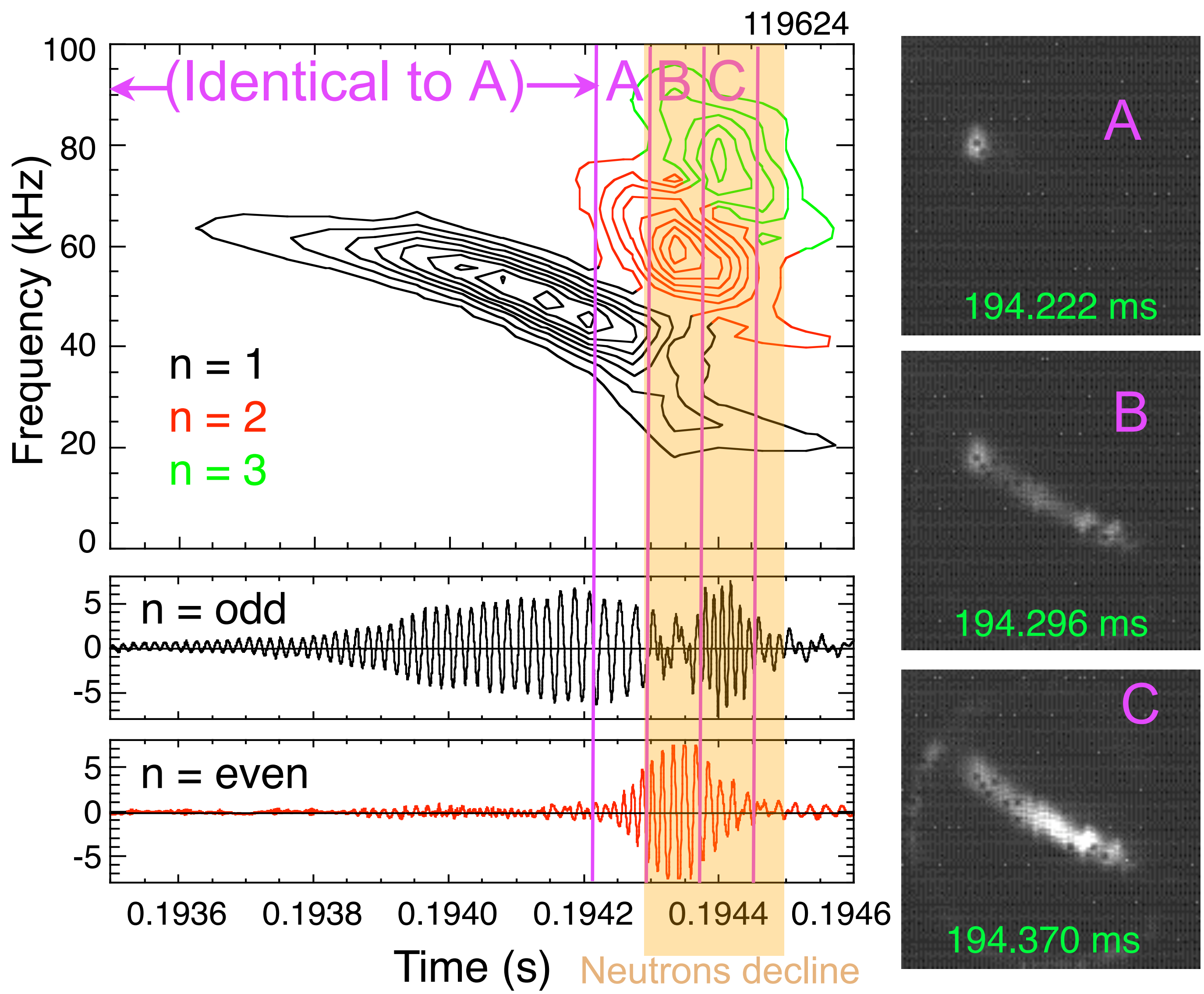




Frequency chirping does not enhance loss rate

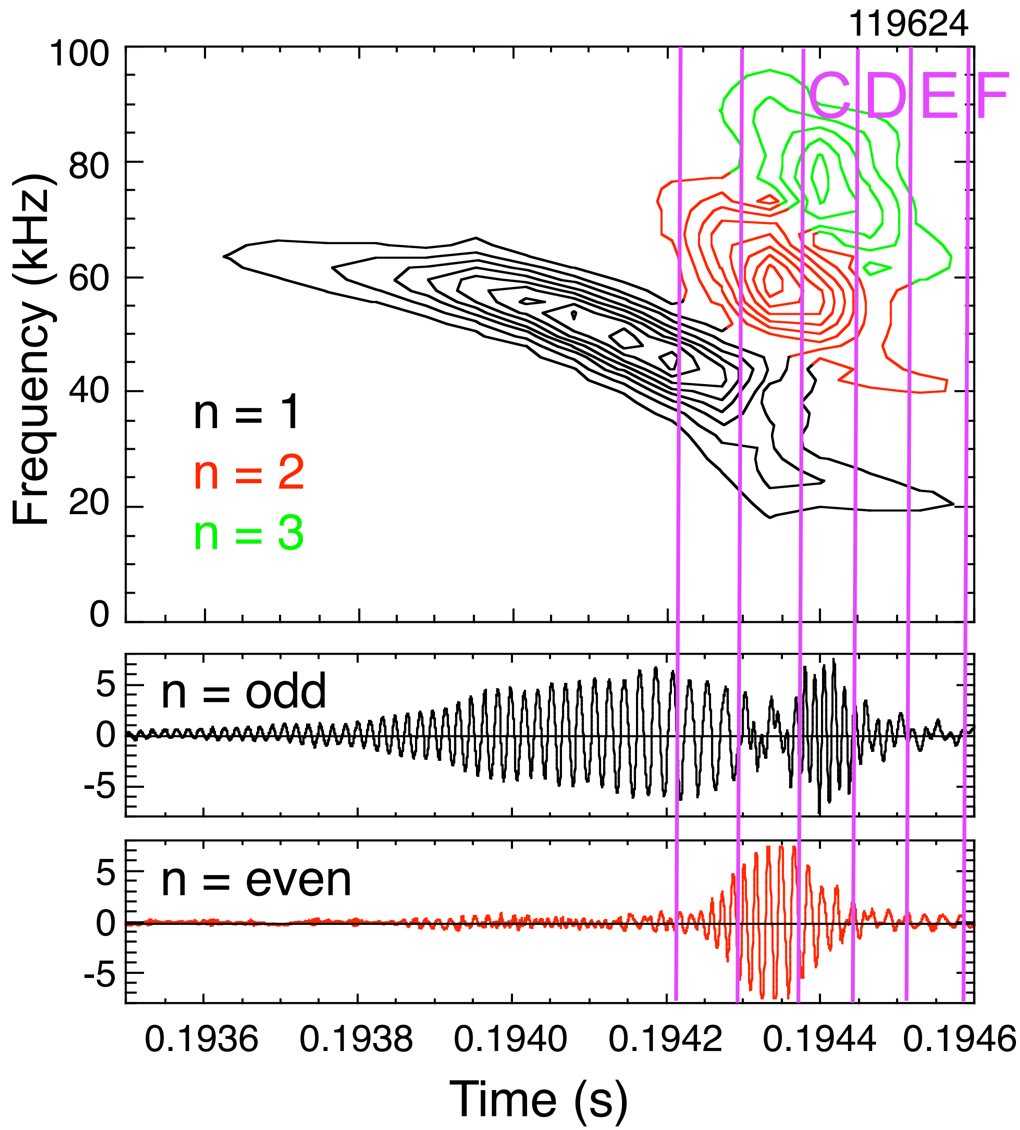
- No increased loss intensity or additional pitch angle features arise during interval when n=1 mode is chirping in frequency
- Implies that chirping does not move beam ions into loss cone, at least for these parameters, and at least not the portion of loss cone visible to this diagnostic
- Chirping also does not measurably alter lost particle energy or pitch angle, implying there is no time-varying resonant interaction

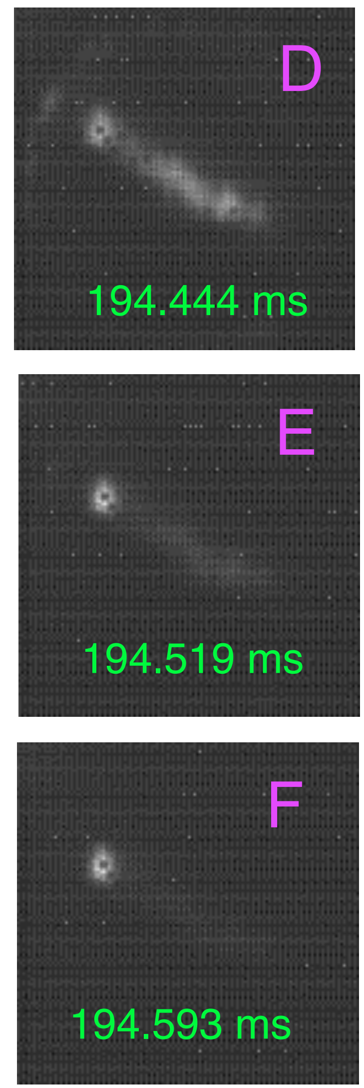
Broad pitch range lost when multiple n values present



- Camera sync to digitizer verified to < half frame time (~36 μs)
- Neutron rate declines when multiple n values present & broad pitch angle loss seen

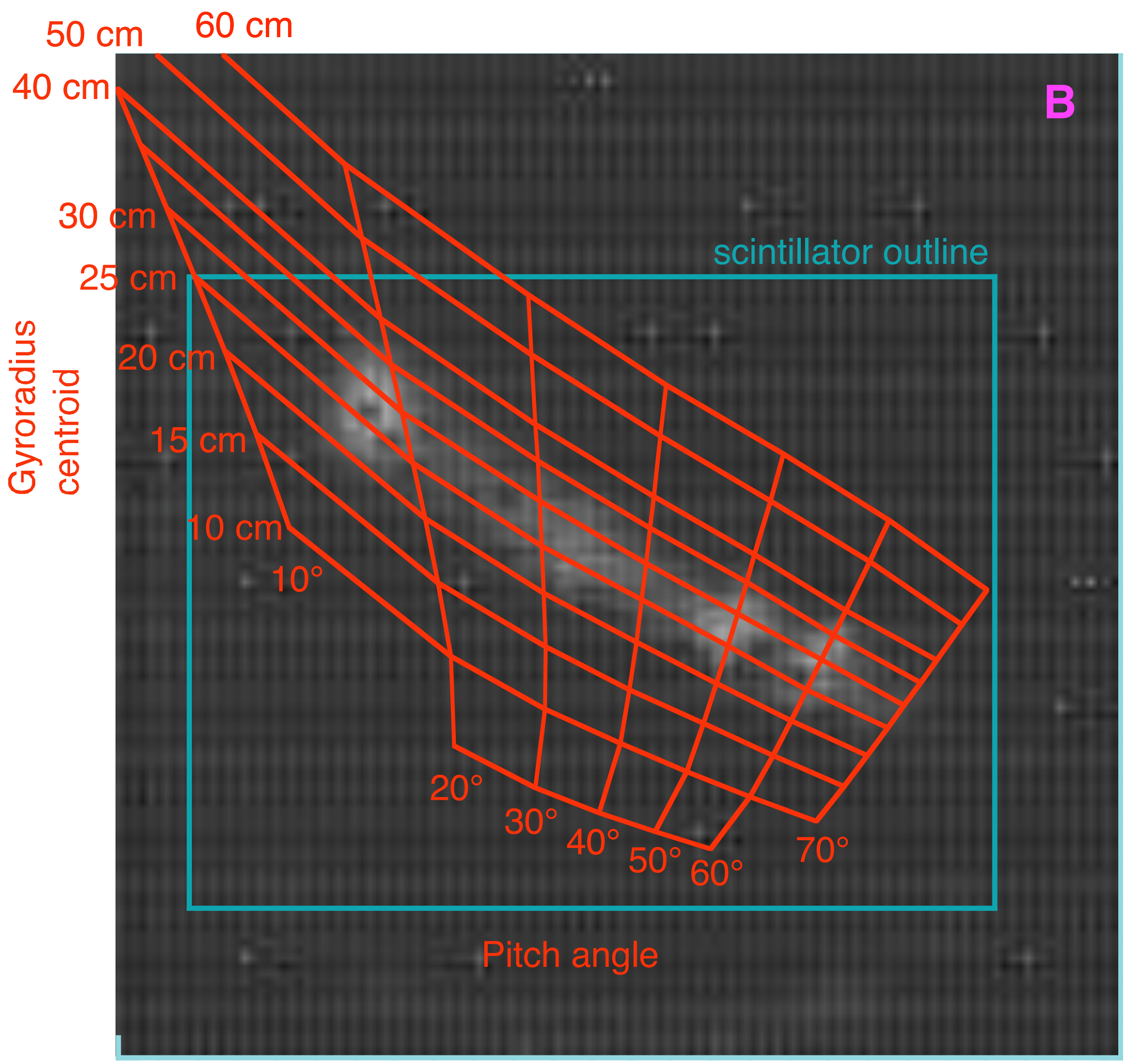
Broad pitch loss vanishes after mode overlap ends





- Returns to pre-burst steady prompt loss spot

All pitch angles lost near injection energy



- All pitch angles are at ρ~25 cm
- Predict ρ=20 cm for 90 keV D at this condition
- Discrepancy most likely due to residual calibration errors, not mode physics

Loss over broad pitch angle range from multi-n overlap?

NSTX

- Wide pitch angle distributions seen during times when Mirnov signal shows multiple n values present, but not at other times
- Suggests some MHD-induced fast ion loss arises from phase space stochastization
- Drop in neutron rate starts at same time as broad pitch angle loss appears, confirming that mode overlap affects a wide population of beam ions
- Wide range of pitch angles involved and lack of sweeping in pitch angle makes loss from mode-particle resonance unlikely

Mode overlap transport is concern for ITER

NSTX

- If a TAE is driven unstable on one surface in an ITER plasma, movement of fast ions to the next surface outward may destabilize a mode on that surface also (“TAE avalanche”)
- These results suggest that 2 modes in close spatial proximity could induce very rapid radial transport of fast ions, **perhaps all the way to the wall**
- Present observation can guide & benchmark ITER modeling

Summary

- EPM bursts seen often in NSTX discharges with neutron rate drops and fast ion loss
- Modes lie in BAAE gap
- Initally, this is n=1 only, with down-chirping frequency, but no change in fast ion loss rate
- Later, mode splits to concurrent multiple n numbers, with stronger losses spread over wide range in pitch angle–most consistent with stochastic transport of fast ions