NSTX

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Fast Ion Loss and Search for Current Redistribution due to Energetic Particle Mode Bursts in NSTX

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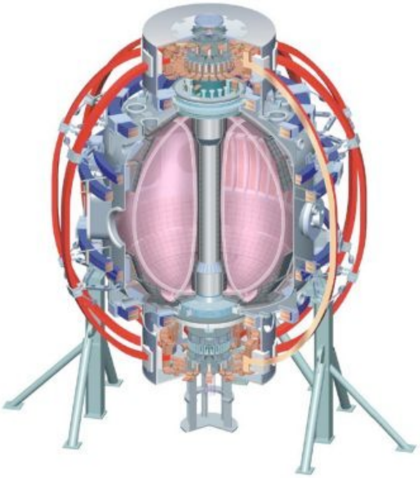

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Abstract

Bursts of MHD modes driven by neutral beam ions, termed Energetic Particle Modes (EPMs) are frequently observed in NSTX plasmas. These bursts typically comprise multiple n number modes in the 20-100 kHz frequency range and they are believed to be beta induced Alfvén acoustic eigenmodes (BAAEs). The bursts can result in sizable drops in the neutron rate, with drops as large as 36% occurring over a 100 us interval in one instance. These bursts result in the simultaneous loss of beam ions over a wide range of pitch angles. Details of confined and lost beam ion diagnostic results will be presented. In addition to quantifying the effect of these modes on fast ions, an effort has been made to determine whether these modes also alter the current profile of the discharge. Initial results indicate some changes in MSE pitch angle profiles concurrent with the bursts. However, these changes are comparable to those seen with other types of MHD activity and with the general level of fluctuations seen in virtually every NSTX discharge. Consequently, it is inferred that any effect these bursts have on the current profile is no greater than that created by other frequently occurring phenomena.

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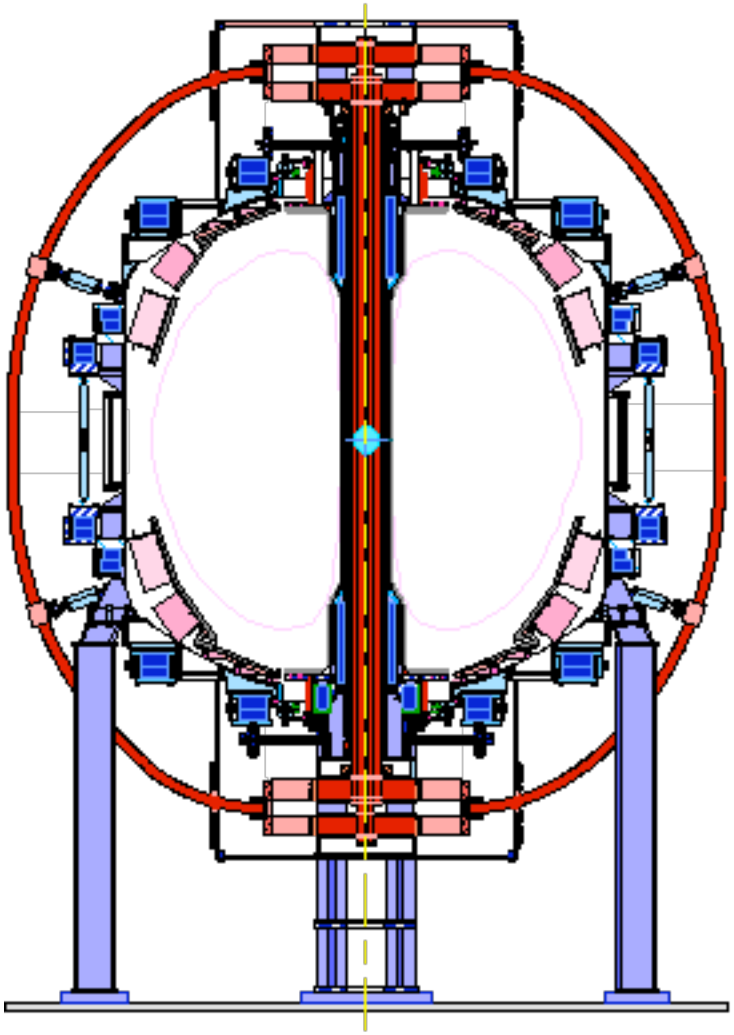
Motivation

- ITER will have sizable population of fast ions
  - αs, MeV NB ions, & ICRF tail ions
- Important to know what fast ion modes may be unstable in ITER
- Also important to understand mechanisms of mode-induced fast ion transport an loss to predict fast ion losses & resultant heat fluxes in ITER
- EPM bursts are prominent loss processes in NSTX

MHD loss experiments done on NSTX

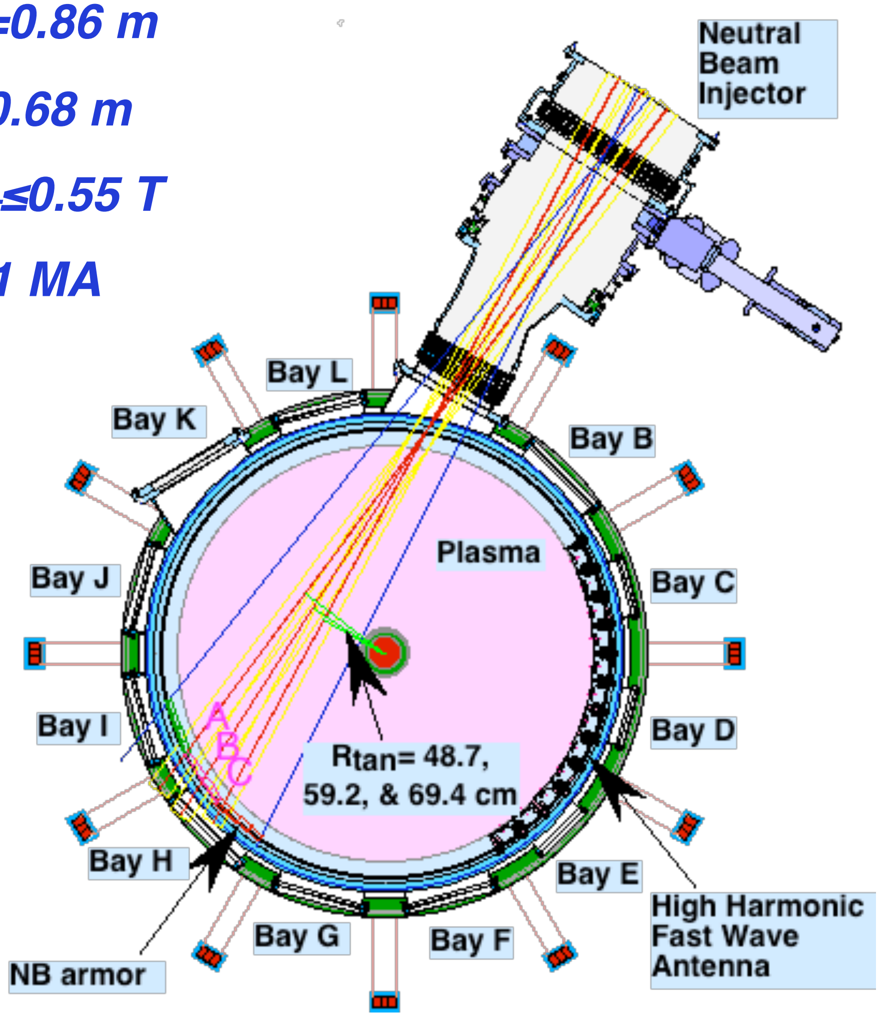


$R_0=0.86$ m

$a=0.68$ m

$B_{0T}\leq 0.55$ T

$I_p\leq 1$ MA

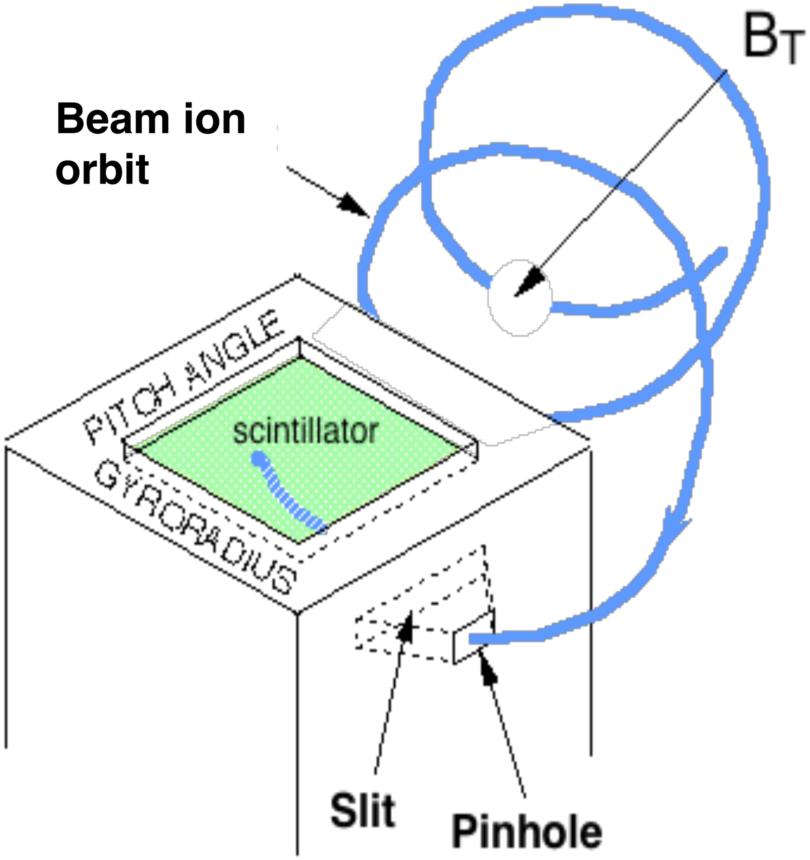


- 3 beam sources inject 80-90 kV D, ≤6 MW

EPM bursts are multimode fast ion driven events that cause significant loss

- EPM bursts: mode characteristics consistent with BAAEs
  - Frequencies (20-80 kHz) in BAAE gaps below TAE band (~100 kHz)
  - Multiple n numbers simultaneously present

Fast ion diagnostics are neutrons, scintillator probe, & FIDA



Scintillator probe:

Combination of aperture geometry & **B** acts as magnetic spectrometer

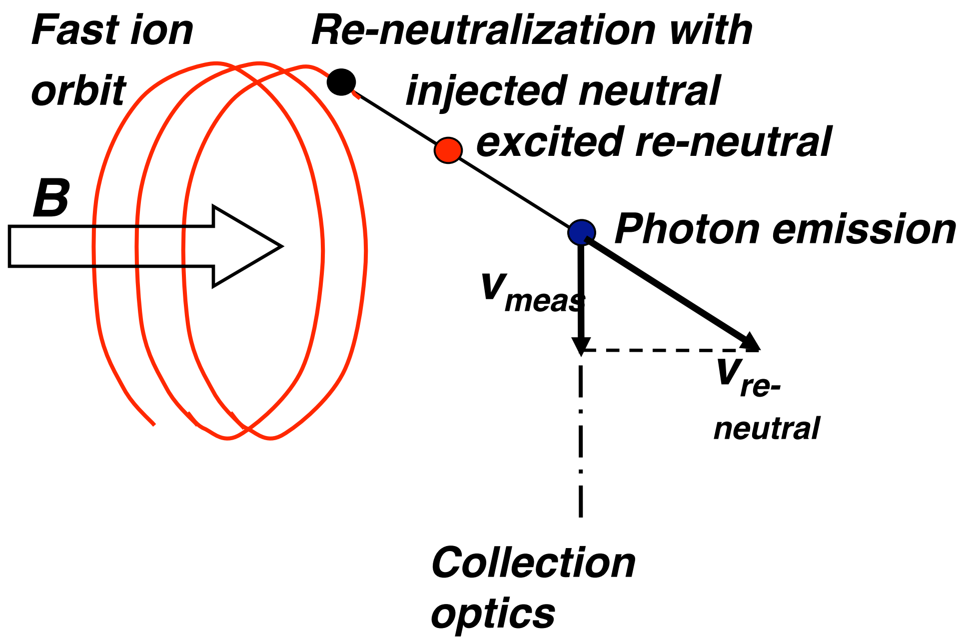
Fast video camera captures luminosity pattern on scintillator as function of time

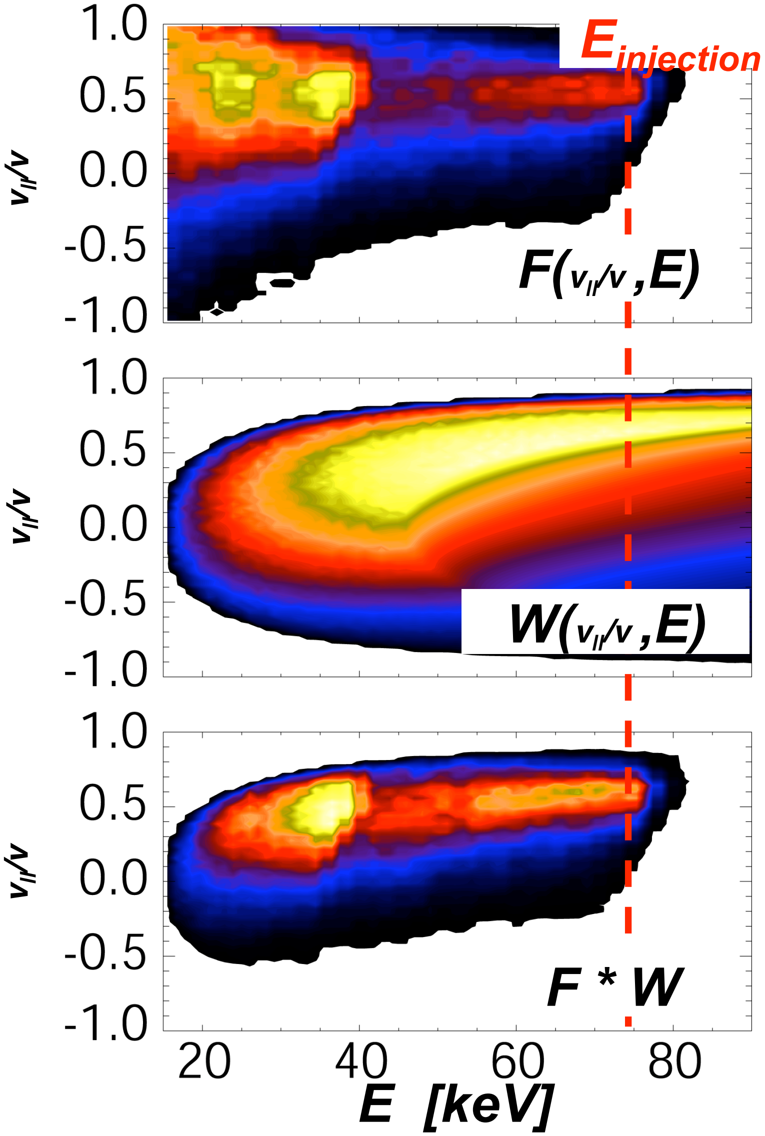
$\Gamma_{loss}(\rho, \chi, t)$

For 2009 campaign, images taken at 30,000 frames/s

- Neutron rate $S_n \sim n_b n_i$, so $\Delta S_n \sim \Delta n_b$

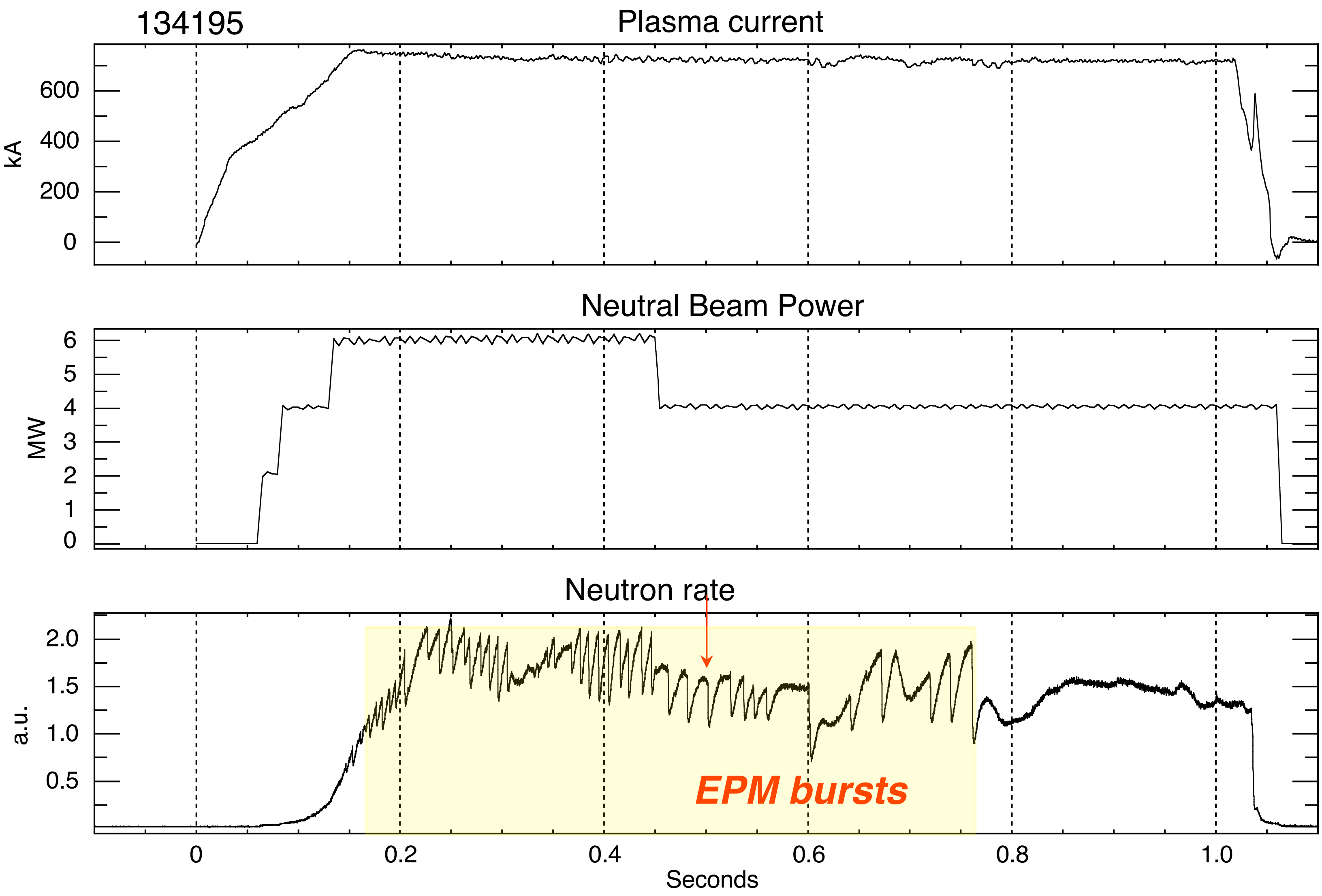
Fast ion D-alpha diagnostics measure Doppler-shifted emission from re-neutralizing fast ions



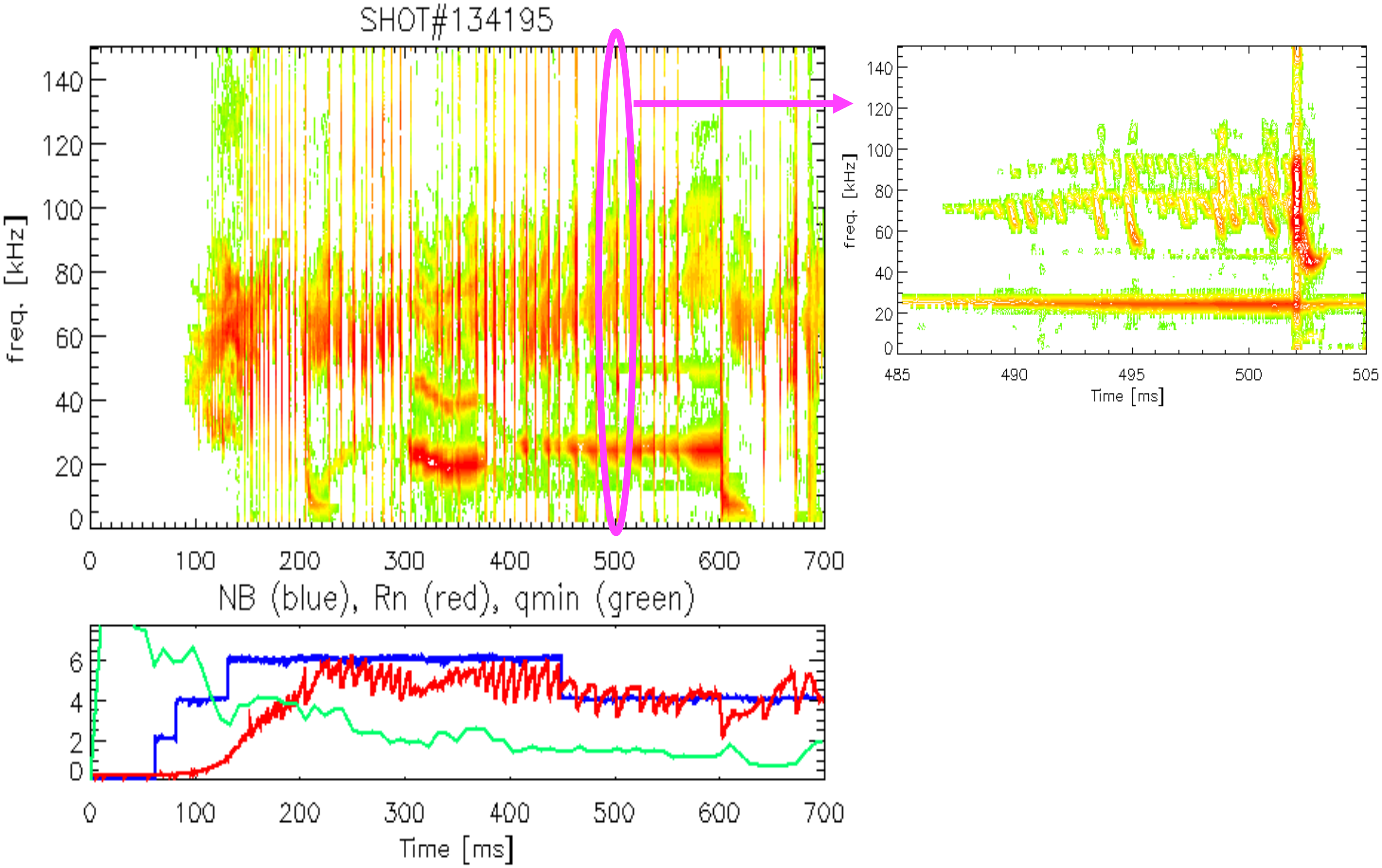


- Large $\mathbf{v}_{meas}$ → Doppler shift → fast-ion features separate from cold D-alpha emission in measured spectrum
- FIDA signal results from "filtering" fast ion distribution ***F*** through the instrument response function ***W***
  - Integrated over pitch $v_{||}/v$
  - Vertical views: signal more weighted toward perpendicular fast ion velocity
  - ***W*** from numerical code
- *Passive* views missing the neutral beam for background subtraction

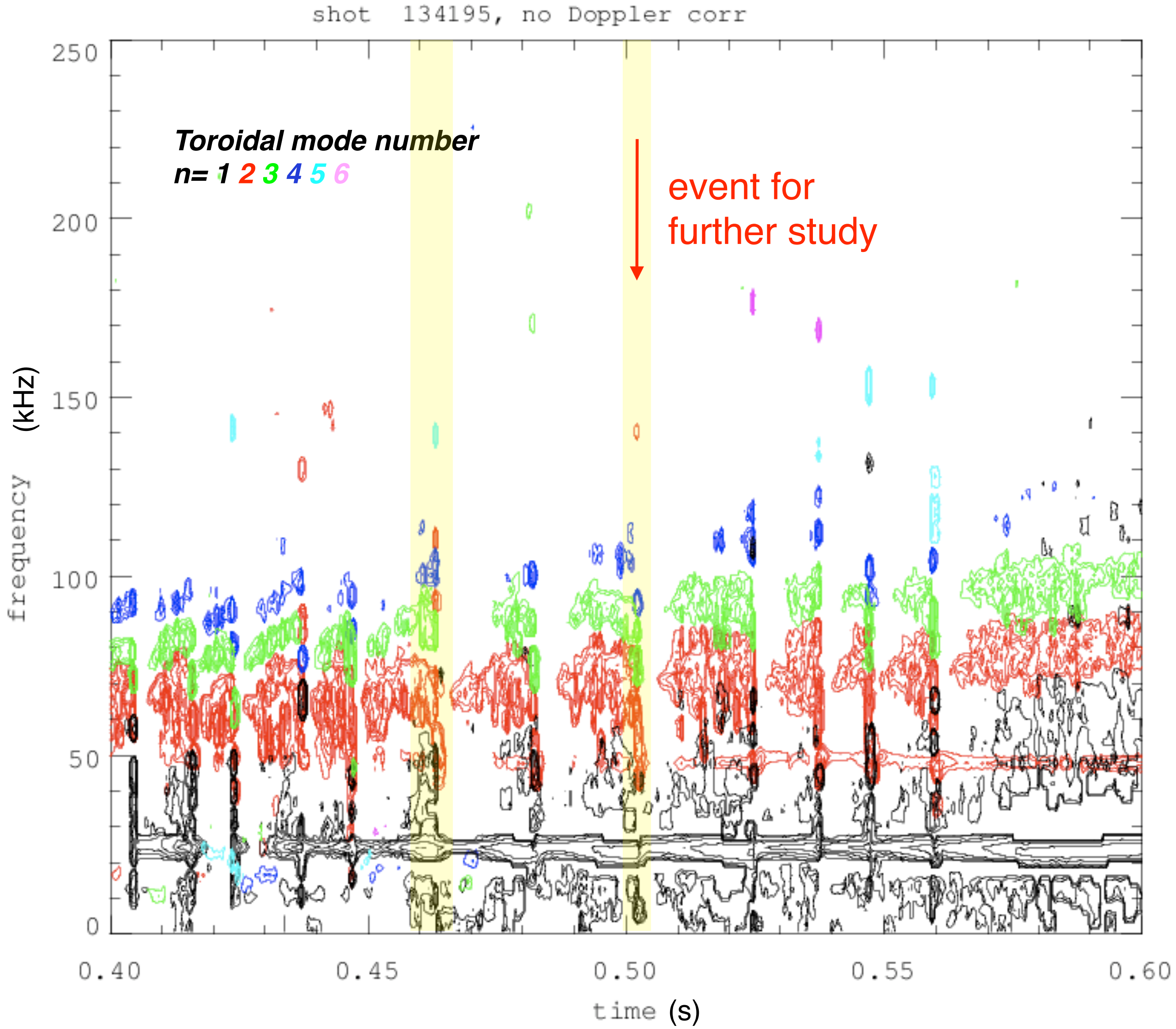
EPM bursts expel fast ions & reduce neutron rate



MHD spectrogram shows repeated EPMs



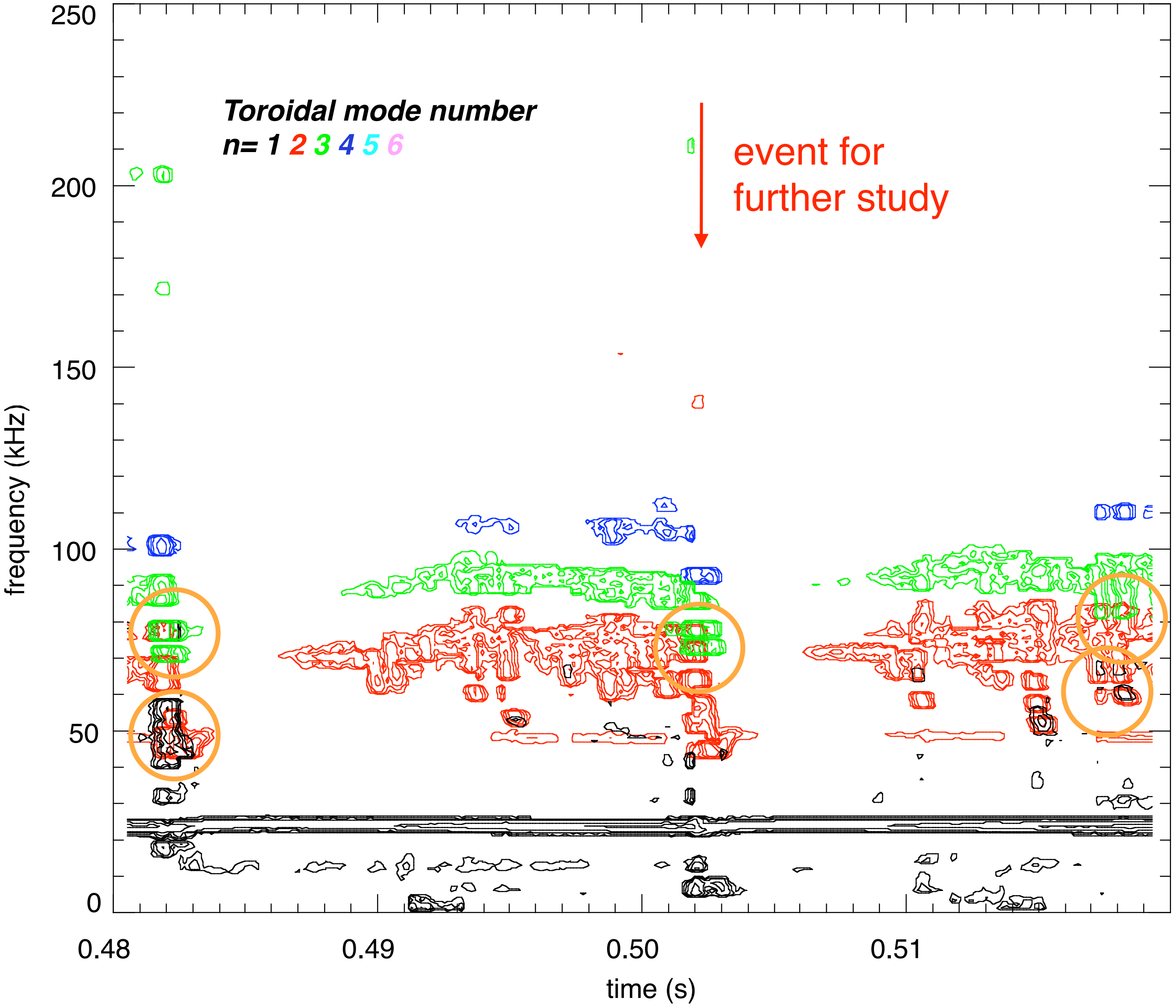
EPM bursts comprise multiple n modes simultaneously destabilized



Mirnov spectrogram of numerous EPMs shown

Smaller activity preceding events produces no fast ion loss

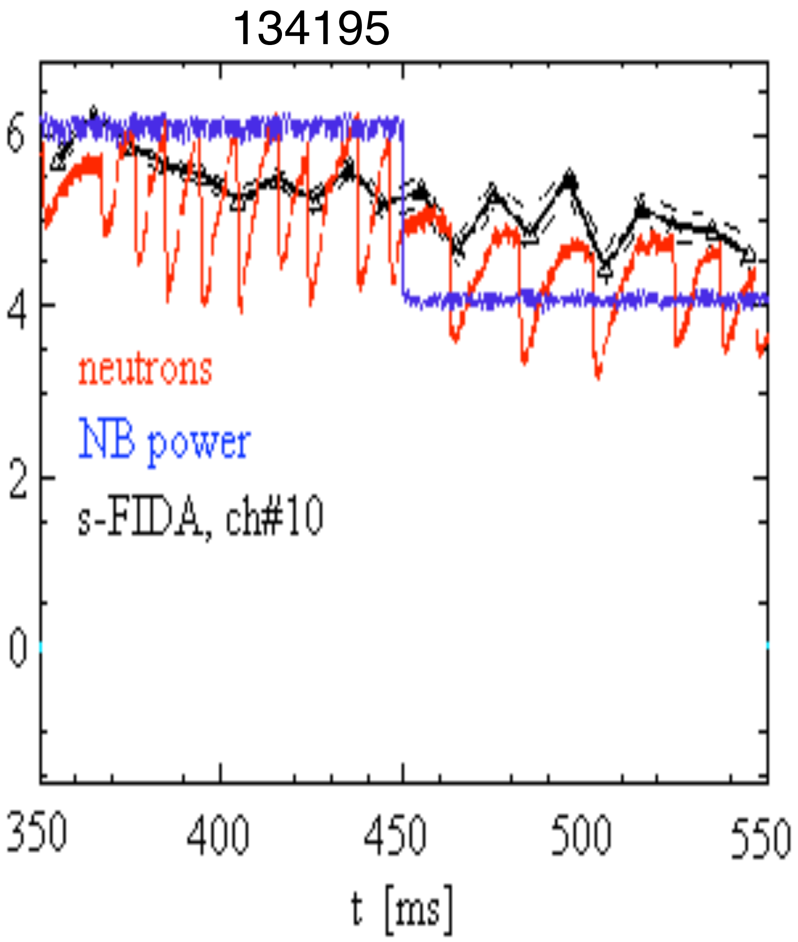
Mode number spectrogram shows frequency overlap of multiple *ns* during bursts

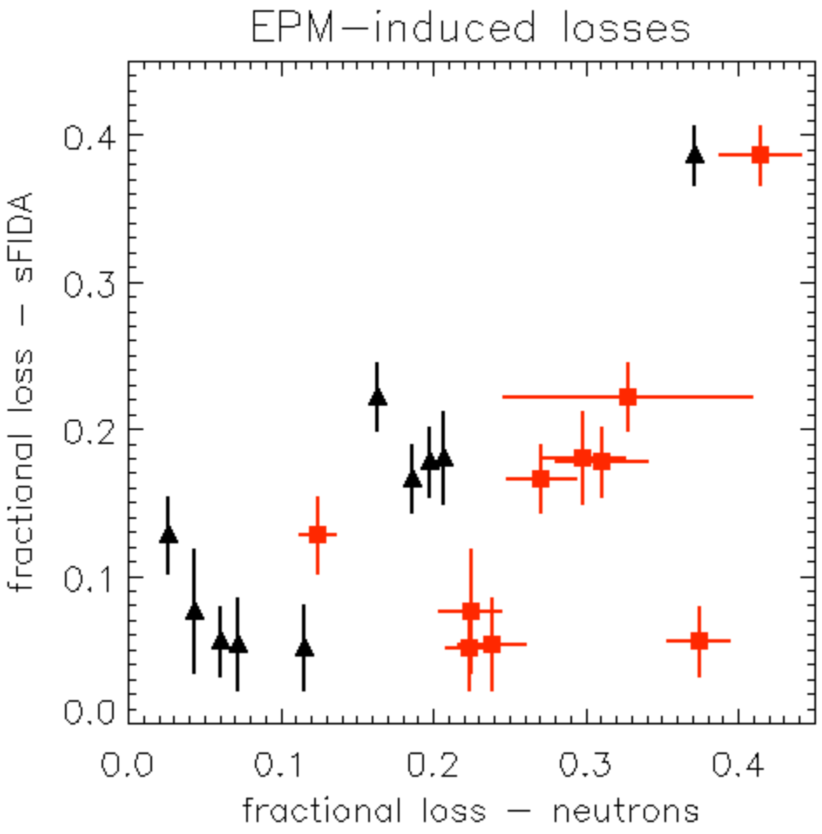


event for further study

- Overlap is almost nonexistent during times between bursts when loss is negligible

Neutron drops correlate with drops in FIDA confined beam ion density

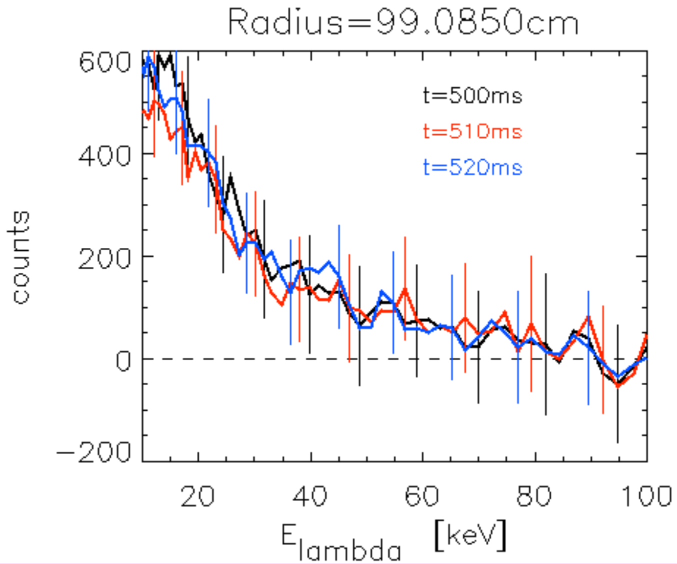


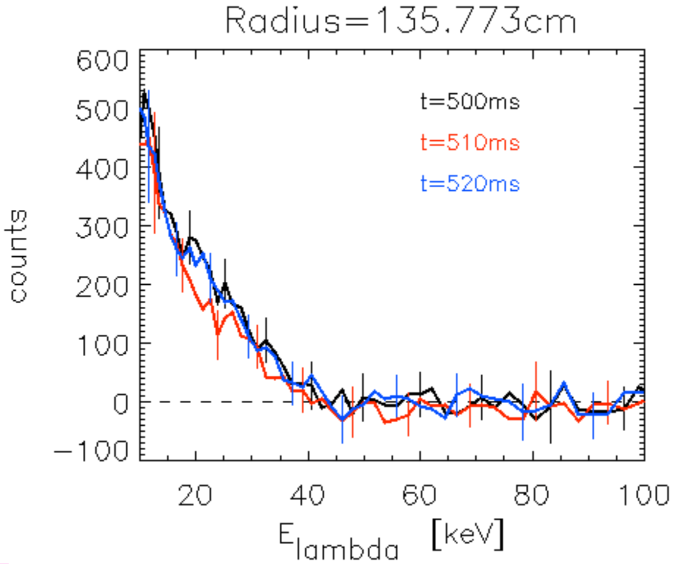


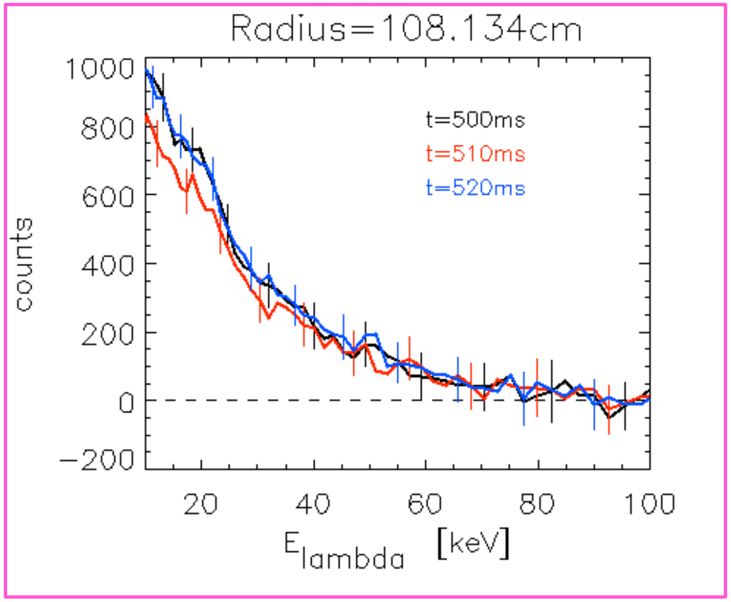
Red: raw neutron data

Black: neutron data integrated over same time bins as FIDA

FIDA shows reduced beam ion density at R=108 cm after EPM burst at 502 ms

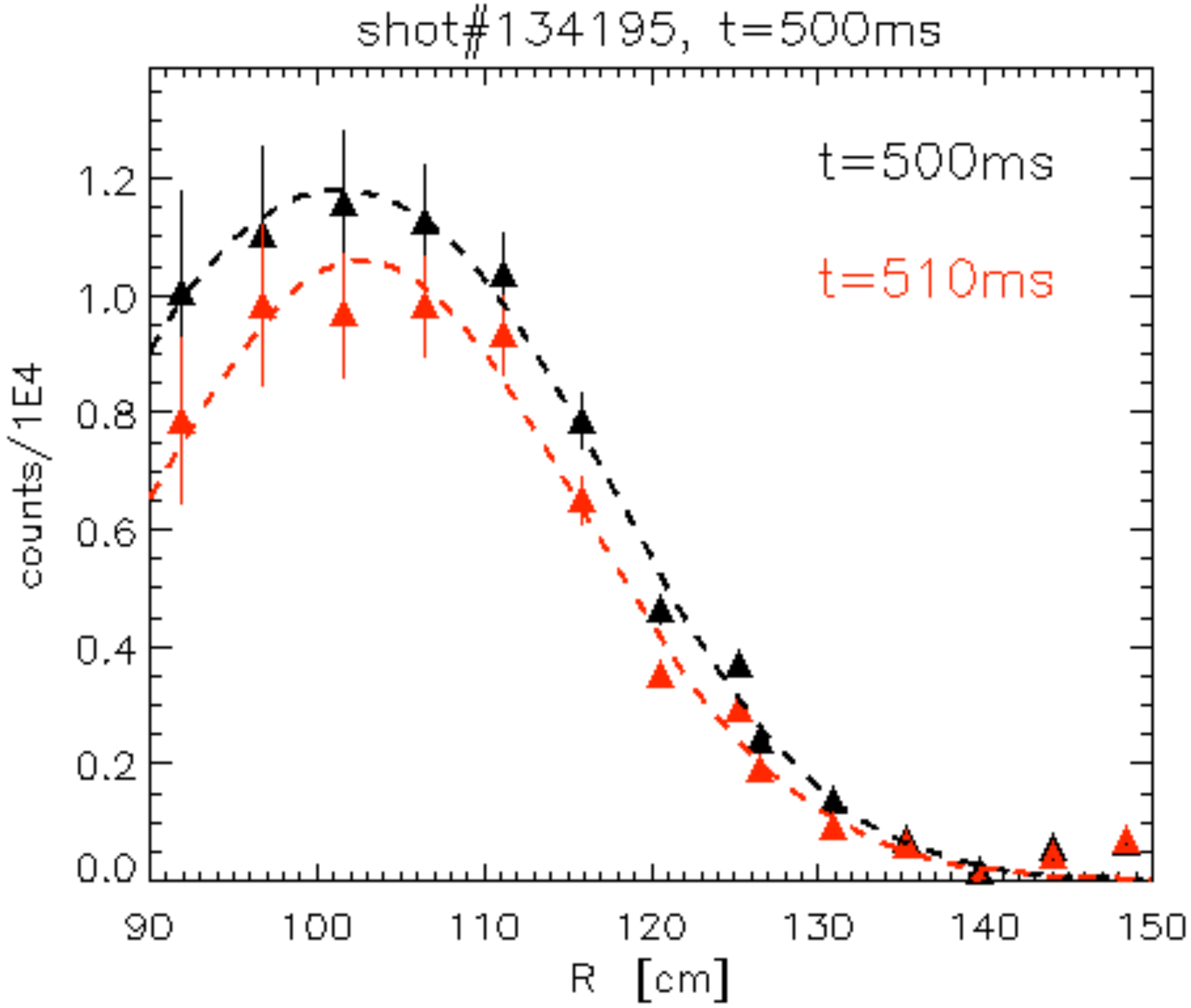

Radius=99.0850cm


Radius=135.773cm


Radius=108.134cm

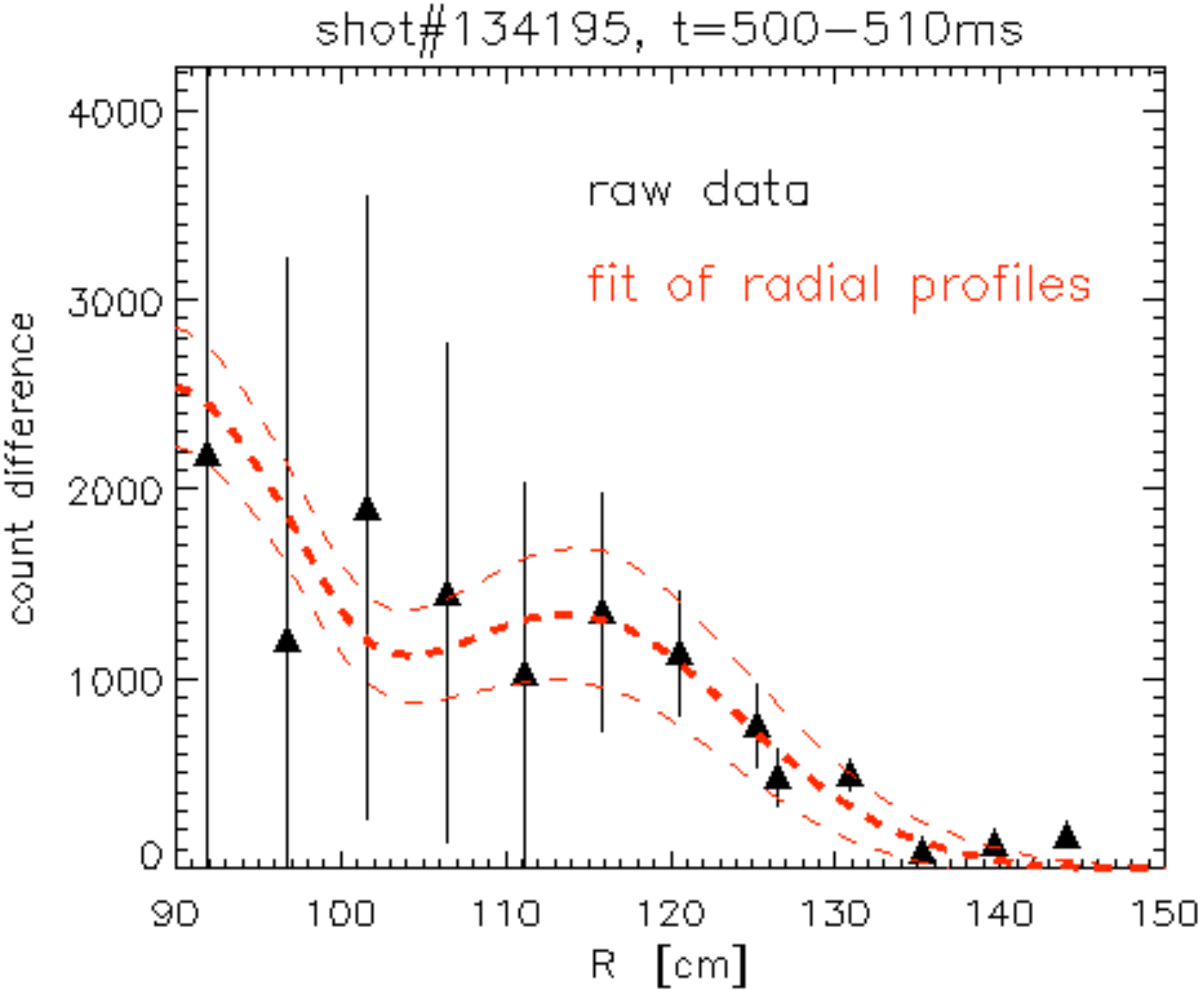
- Spectra before and after burst match well at all radii

FIDA shows differing fast ion density profiles before & after burst



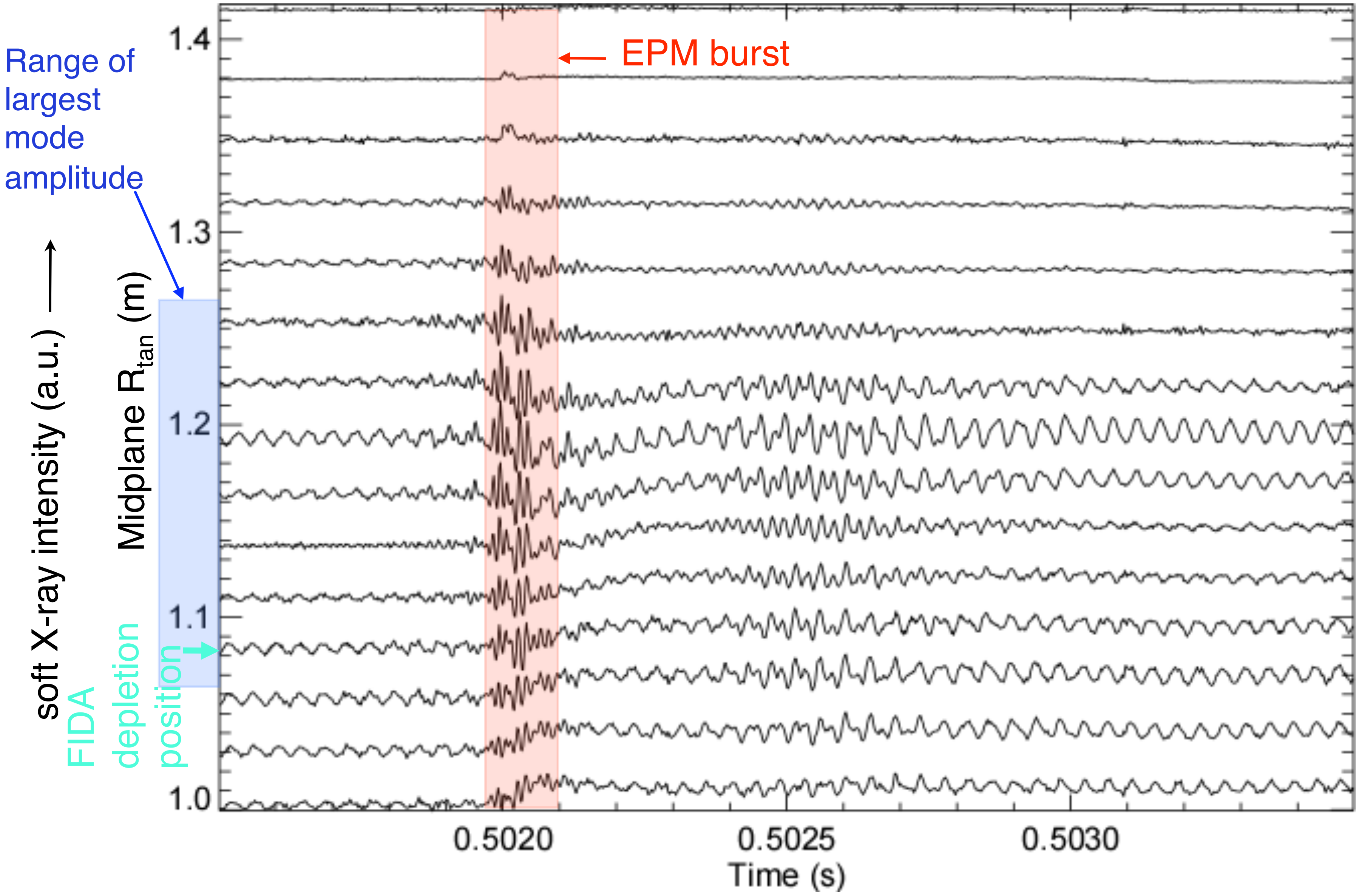
- 500 ms profile is just before EPM burst
- 510 ms profile is first profile after burst

Beam ion density reduced for 90 cm < R < 135 cm



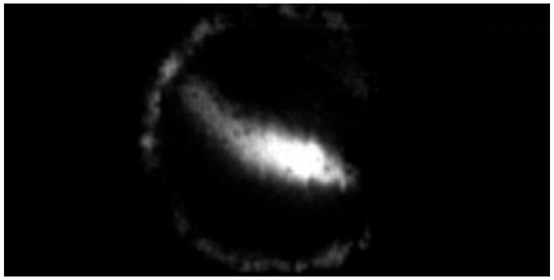
- Effect of EPM modes spans a wide range in radius
- R_{ax}=106 cm at this time

Soft X-ray array shows area of significant internal mode amplitude roughly matches region of beam ion depletion

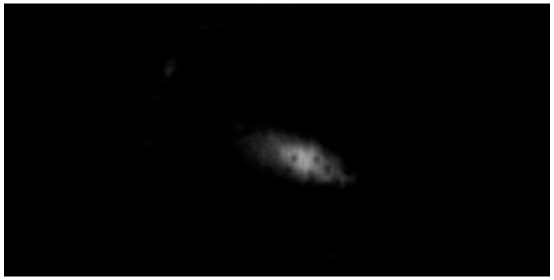


Scintillator probe shows fast ion loss takes <100 μs

502.000 ms



502.033 ms



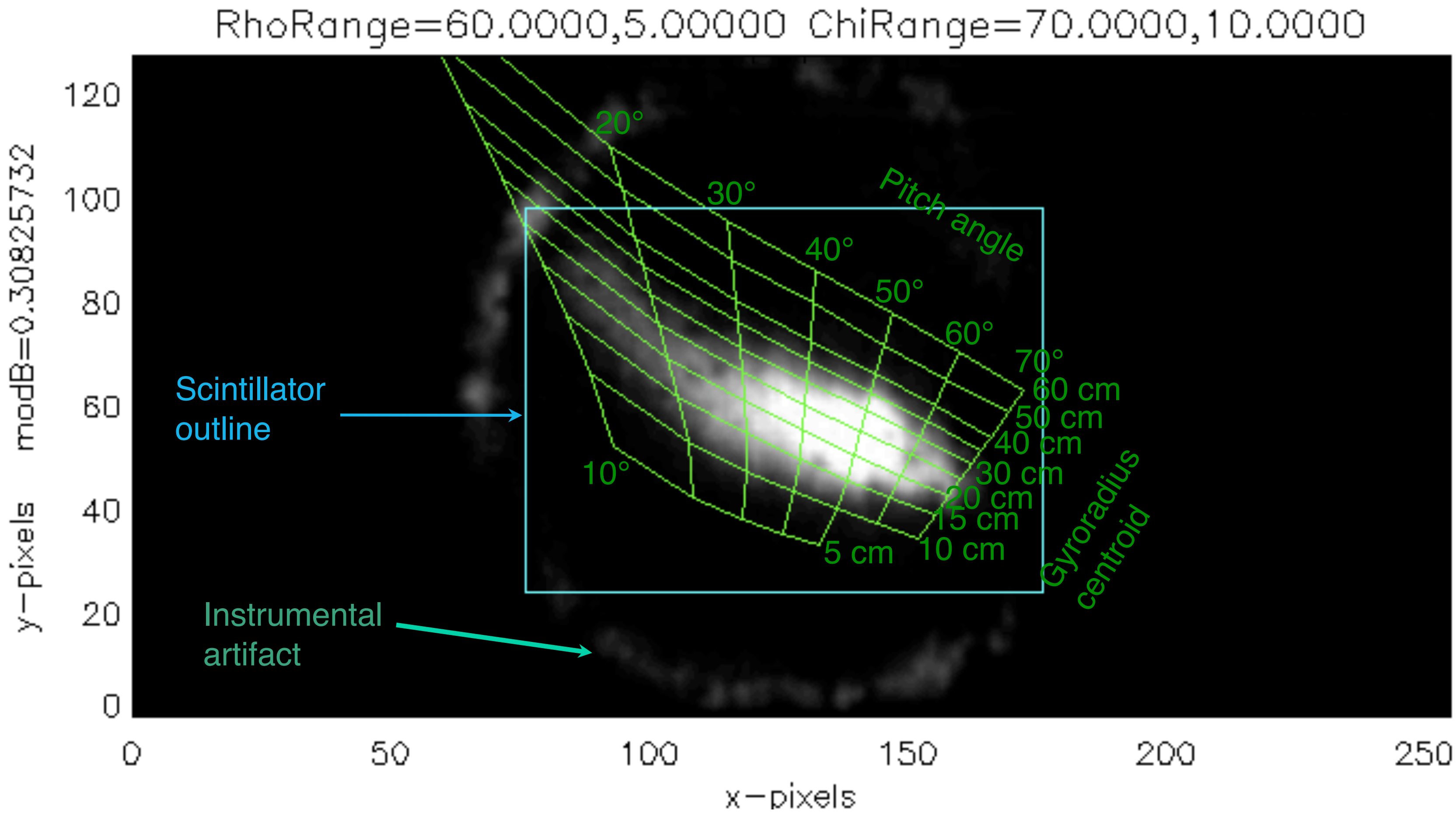
502.033 ms

502.100 ms

502.100 ms

- Successive frames shown, at rate of 30,000 frames/s
- Loss arises & vanishes within 2-3 frames (67-100 μs)
- >1/3 of beam population lost during this short time!

Loss covers wide range of pitch angle and gyroradius



- Pitch angle range spans ~15° (very parallel) to 70° (quite perp)
- Gyroradius range much wider than instrumental function

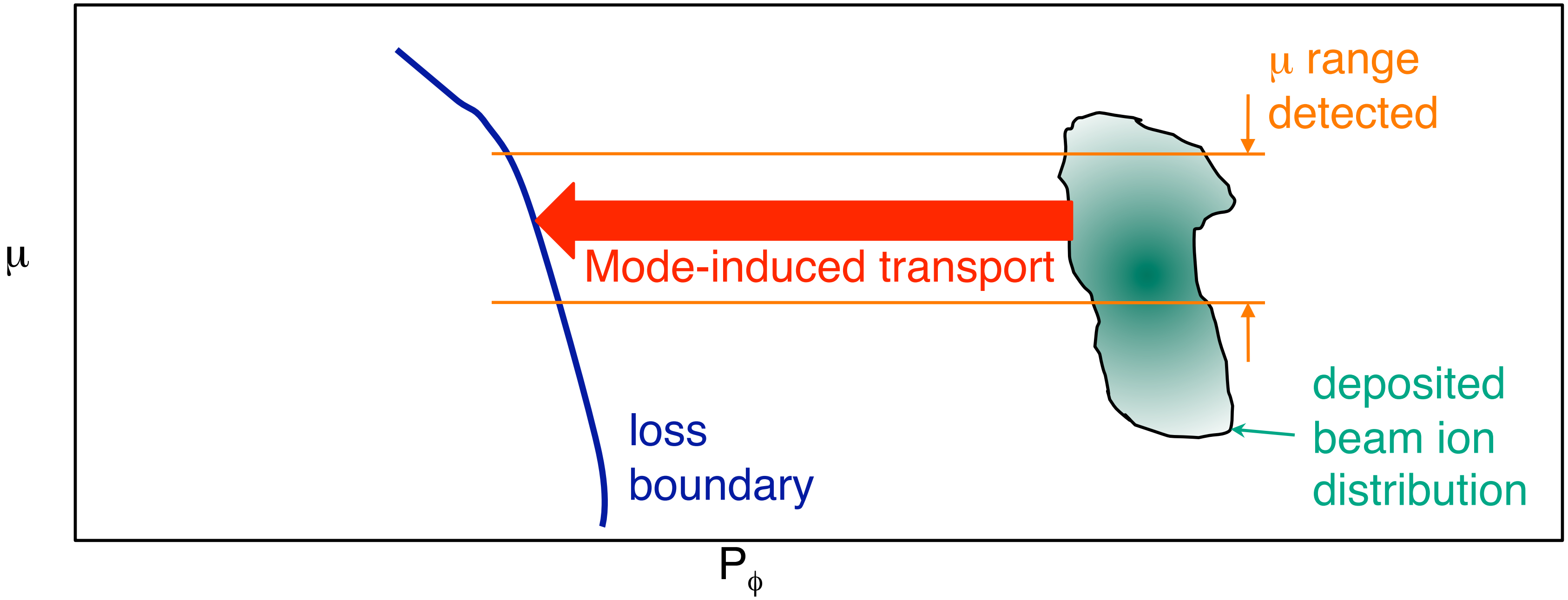
Interpretation of gyroradius and pitch angle range lost

- Although mode frequency chirps downward during burst, range of lost pitch angles is not seen to sweep, at least not within the 33 μs time resolution of the camera; all pitch angles are seen to turn on and off synchronously
- Similarly, loss at all gyroradii turns on and off synchronously
- The wide range of the loss in gyroradius and pitch angle and the synchronization in time could plausibly be explained by a transient stochastization of the particle phase space due presence of multiple modes above some threshold amplitude
- Alternatively, the loss might be due to multiple mode-particle resonances, but the range of particles affected suggests a dense set of resonances

Estimate EPM transport with simple phase space model

- Observed frequencies $<<\Omega_{ci}$, so μ will be conserved
- Mode destroys toroidal symmetry, so P_ϕ no longer constant
- Assume E roughly conserved (as observed)
- Mode convects ions at constant μ across loss boundary
- Use observed μ range at scintillator probe to define affected population

Beam ion phase space



Ratio of observed to modeled loss gives measure of transport strength

- Calculate beam deposition using known beam geometry, magnetic equilibrium, and measured density profile, assuming electron impact ionization; record μ for each particle
- Count fraction of fast ions with μ in lost pitch angle range; this sets upper bound on loss fraction
- Ratio of fractional neutron rate drop to fraction of model particles with μ in observed range of pitch angle gives a measure of that population's relative depletion by avalanche and, hence, strength of radial transport

Transport by EPMs is strong

- Using the estimation methodology described above,
- Beam A: 80% of ions are within observed range of μ.
- Beam B: 71% of ions are within observed range of μ
- ; average of the 2 beams: 76% are within observed μ range
- Observed neutron drop was 36%
- 36/76 = **47%** of particles in selected μ range are lost—**relatively strong** radial transport by EPM

Summary

- EPM bursts cause loss of particles over a wide range of pitch angles and gyroradii simultaneously
- Loss potentially attributable to transient stochastization of the particle phase space, though could also be multiple mode-particle resonances
- Up to ~50% of available particle population in affected range of μ can be lost
- EPM loss happens in <100 μs

Could similar bursting modes arise in ITER?