NSTX

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Investigation of an 'Anomalous' High-Energy Feature Observed on Energetic Ion Spectra in NSTX using the E||B Neutral Particle Analyzer

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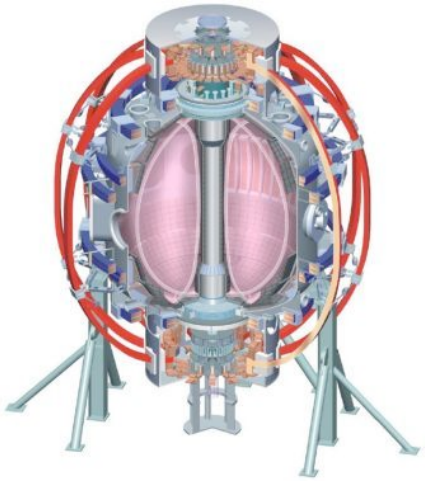
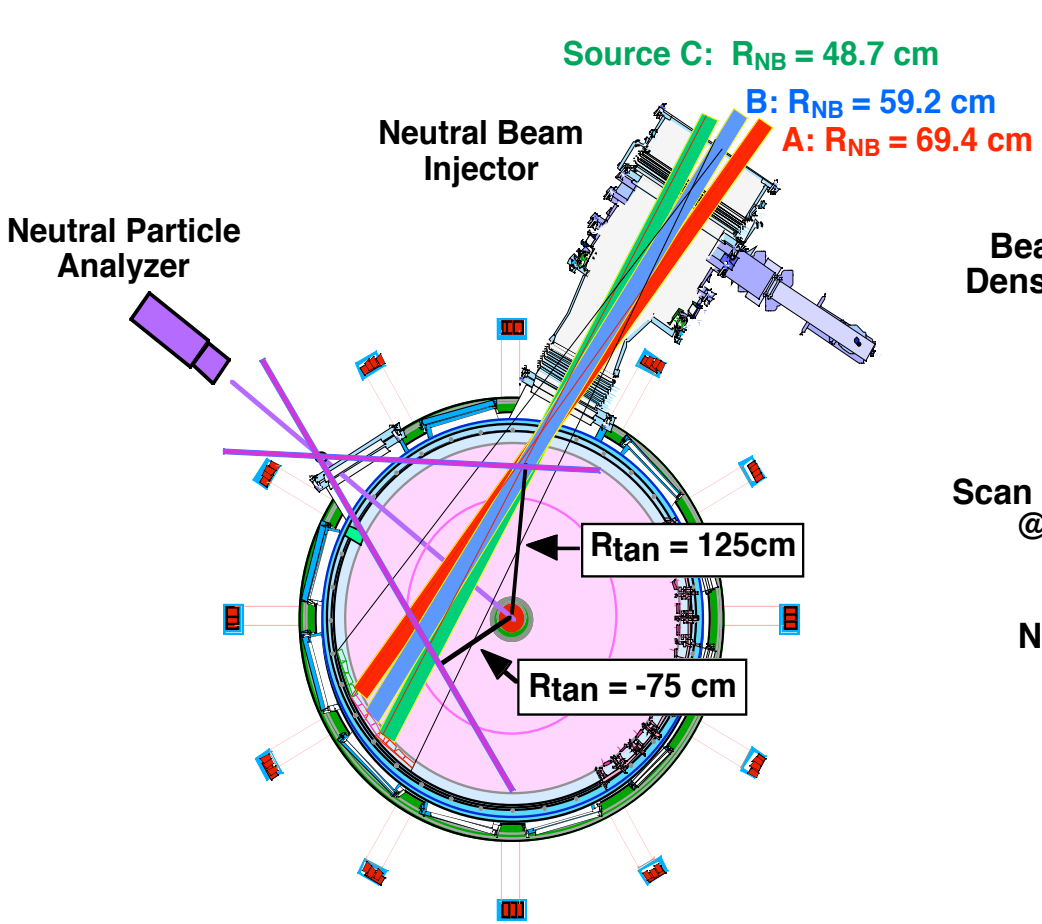
High-Energy Feature (HEF)

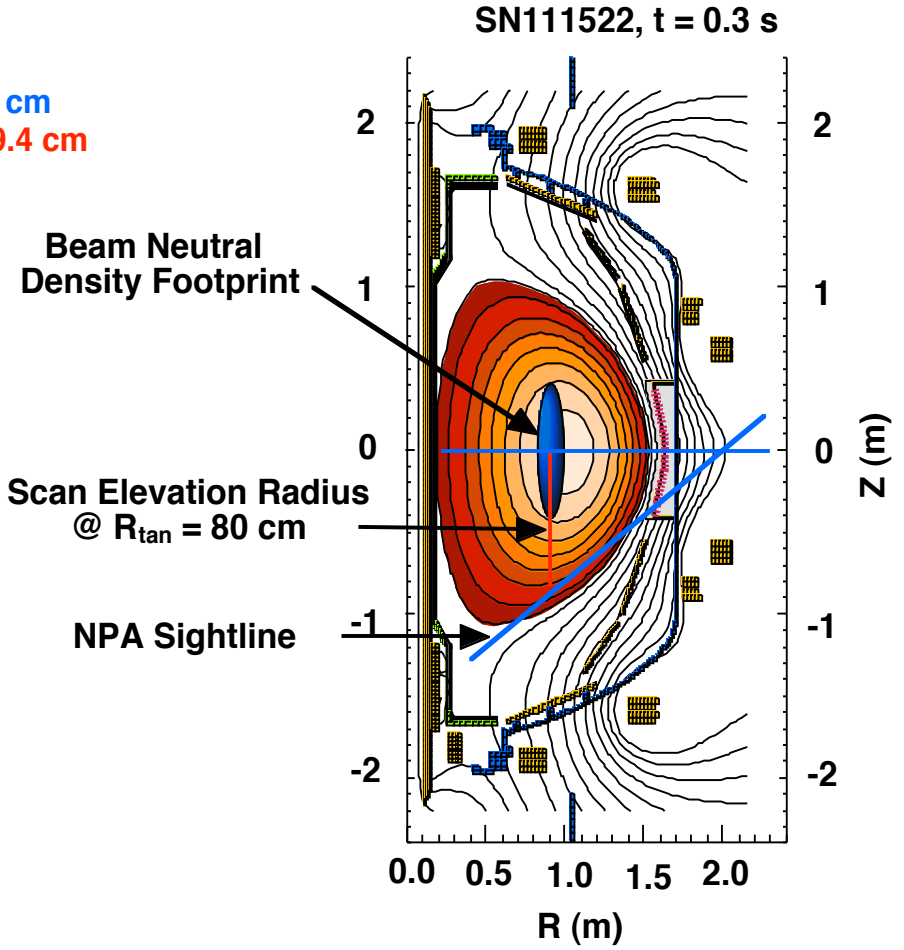
A strong increase (~ 3x) in the EllB NPA charge exchange flux that is localized around the NB full energy: E_b ~ 90.

- the HEF is a transient mid-discharge phenomenon with durations ~ 100 - 600 ms.



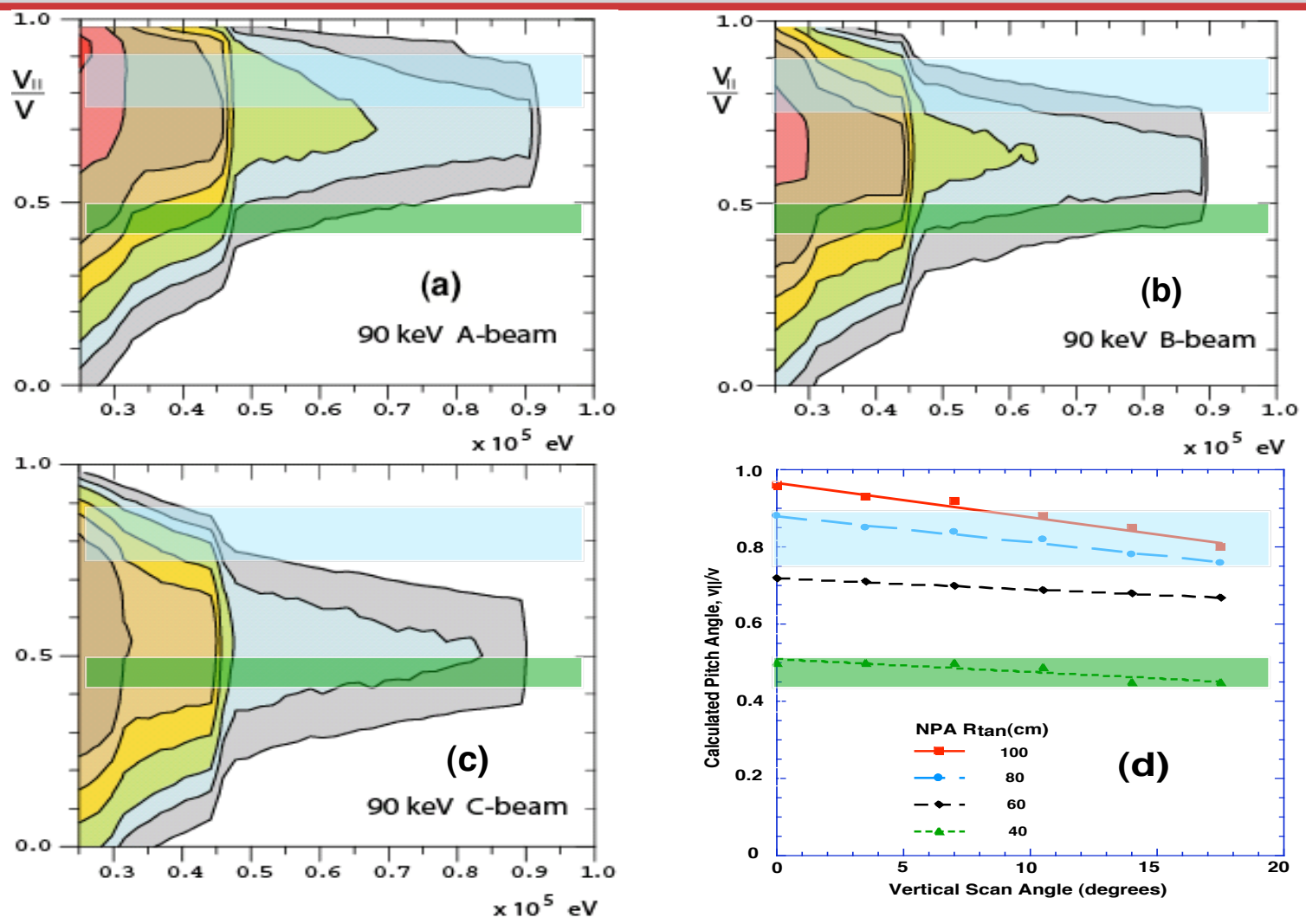
The Neutral Particle Analyzer (NPA) on NSTX Scans Horizontally and/or Vertically on a Shot-to-Shot Basis





- Intersection of NPA sightline with beam neutrals (primary and halo) localizes the charge exchange flux measurement in space and field pitch, vll/v.
- The line-integrated NPA measurements have a spatial resolution ~ 3 cm in elevation and ~ 20 cm in major radius with a pitch resolution $v_{||}/v$ ~ 0.1.

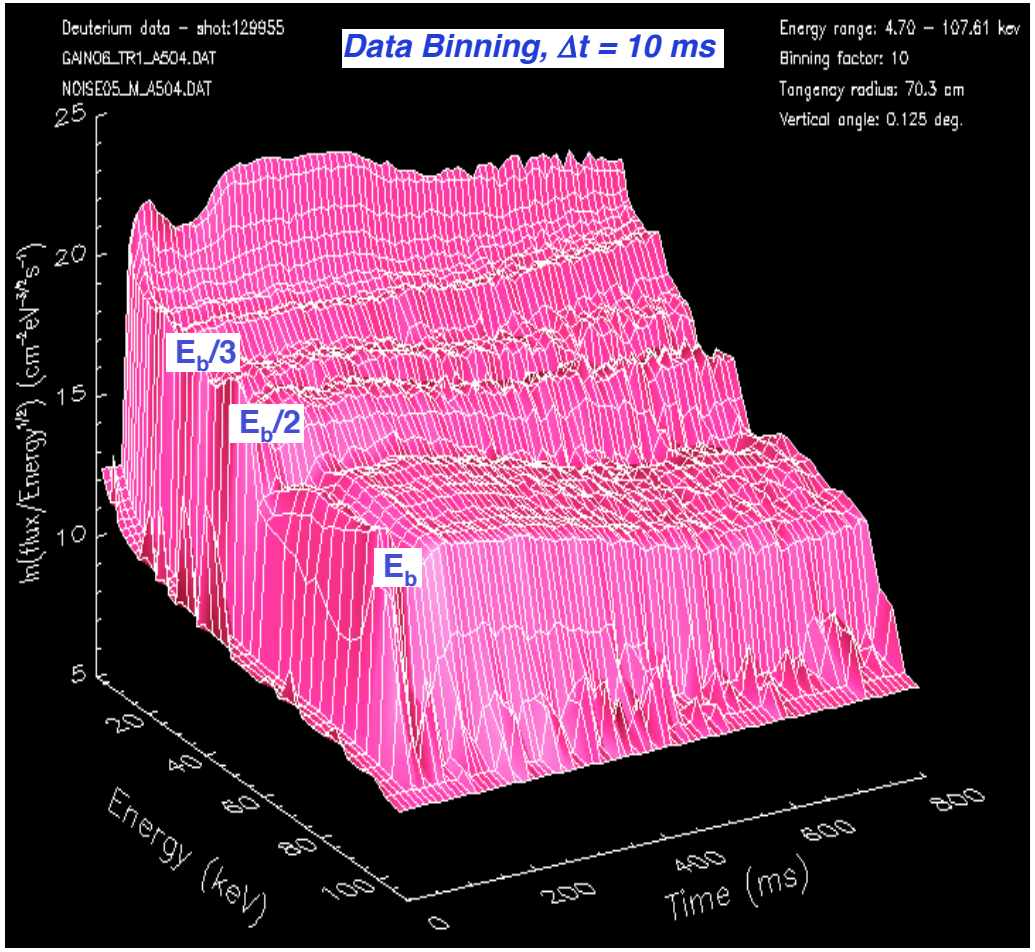
The Field Pitch, $v_{||}/v$, Viewed by the NPA Depends on Both the Horizontal and Vertical Sightline Setting

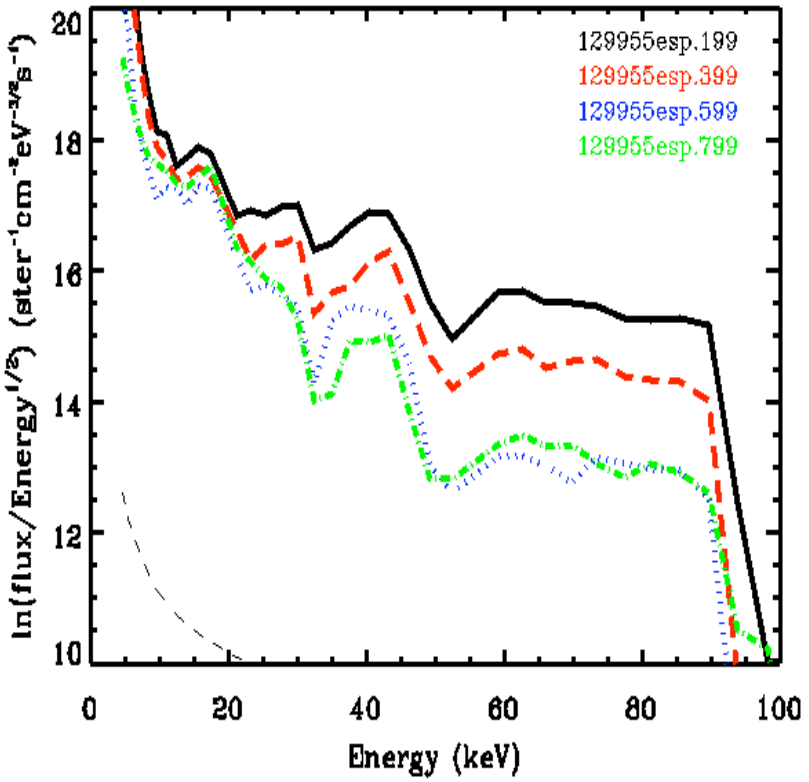


- For 'standard' values of the NPA R_{tan} ~ 70 - 80 cm, $v_{||}/v$ ~ 0.80 ± 0.1 (blue bar).

‘Normal’ NPA Energetic Ion Spectra: H-mode with Robust MHD Activity

H-mode with I_p = 0.9 MA, B_T = 5.0 kG, P_{NB} = 4 MW, $n_eL \sim 4x10^{13}$ cm^{-2}

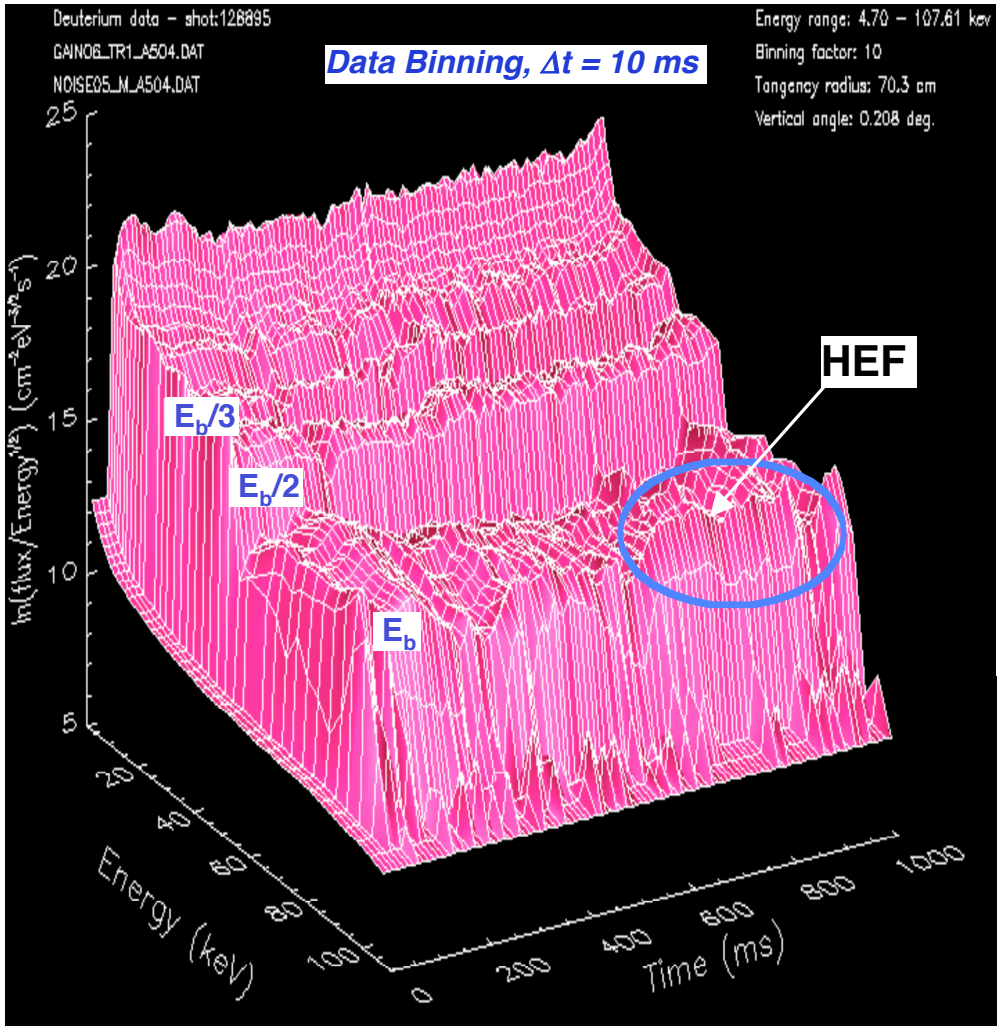


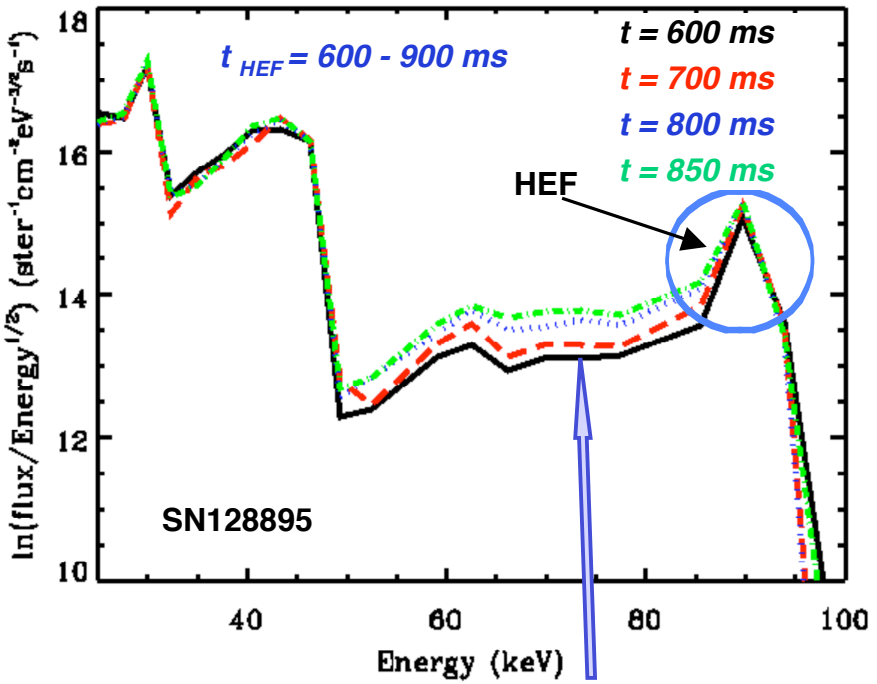


- Depletion of the NPA spectrum in the range $E_b/2 \le E \le E_b$ by ~ 3 e-foldings is due to the combined effects of n_e ramp-up and MHD-induced energetic ion redistribution.

Illustration of a High-Energy Feature (HEF) at t ~ 0.6-0.9 s

H-mode with I_p = 1.2 MA, B_T = 4.5 kG, AB&C @ 90 keV, P_{NB} = 6 MW, n_eL ~ 6.6x10^{13} cm^{-2}





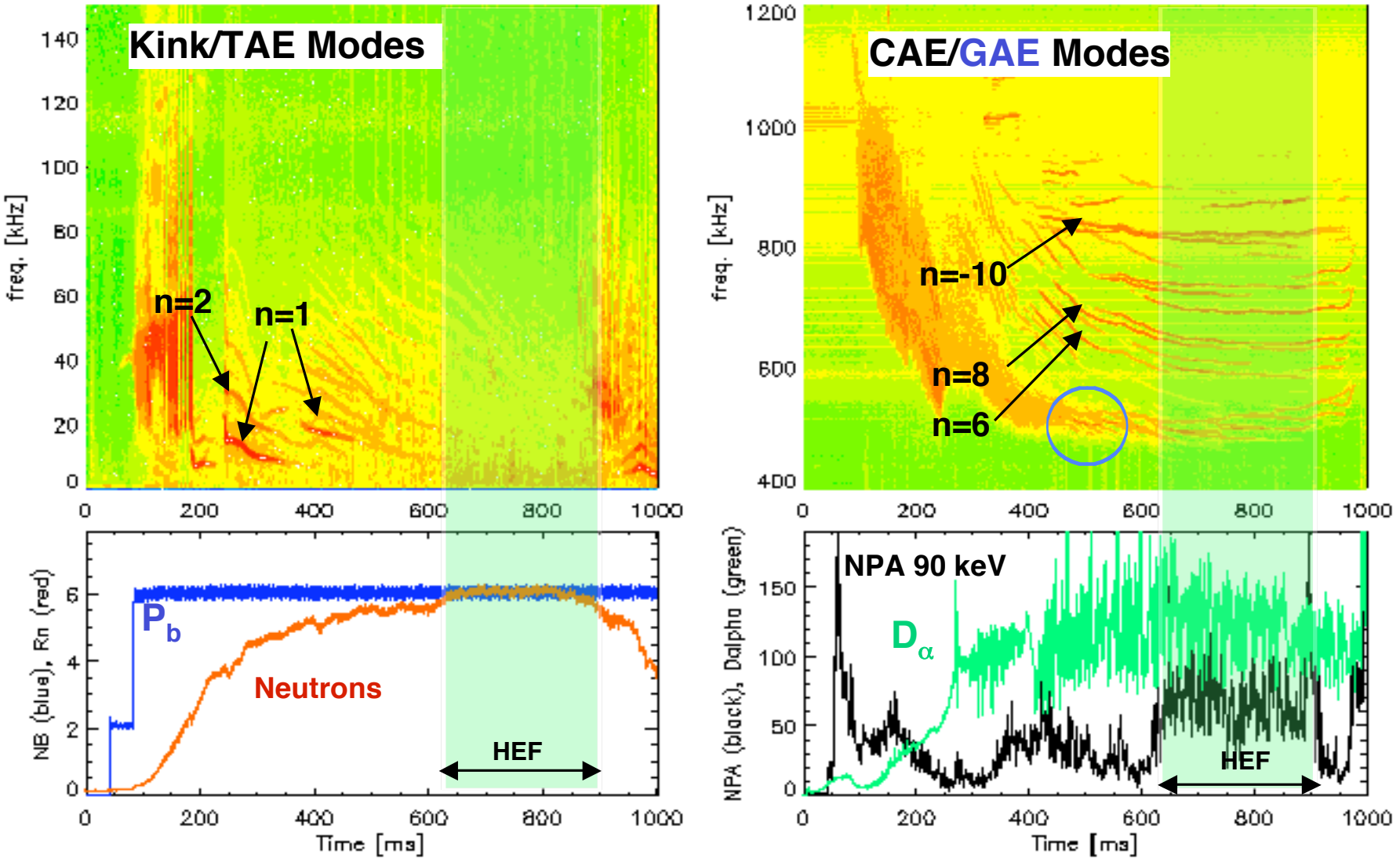
- Spectrum exhibits strong slowing down of fast ions from the HEF energy region.
- The slowing down distribution continues to grow over a period of 300 ms.

- SN128895: HEF appears only on Anode # 35 @ 90 keV.

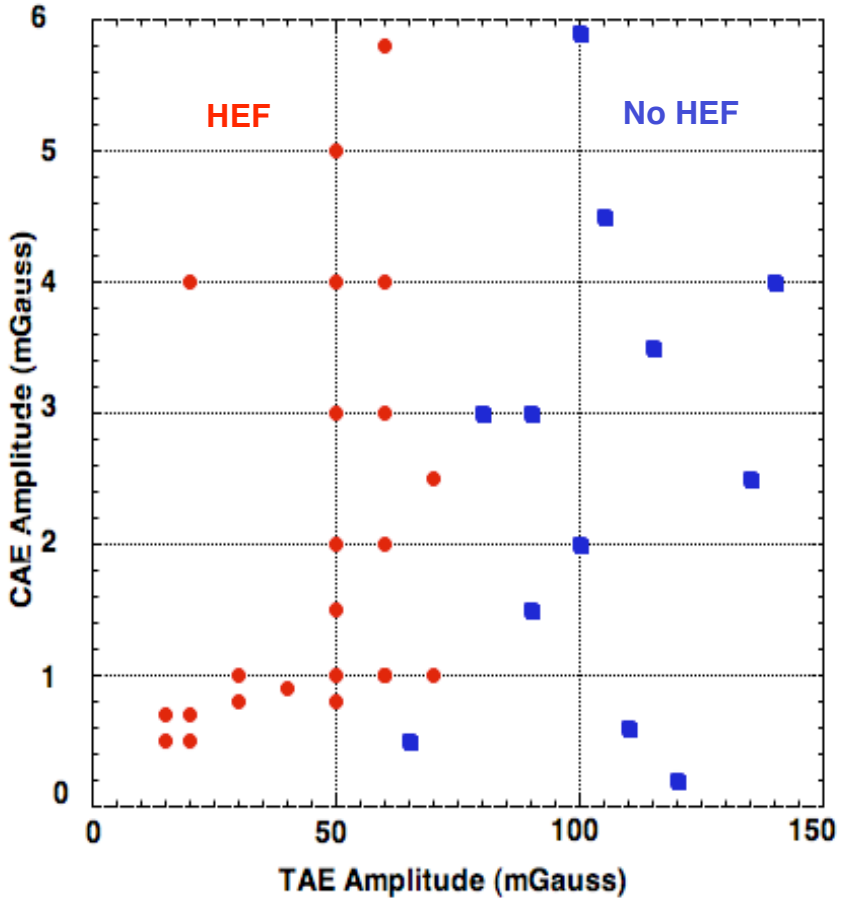
HEF Existence Requires Feeble Kink/TAE MHD Activity: SN128895

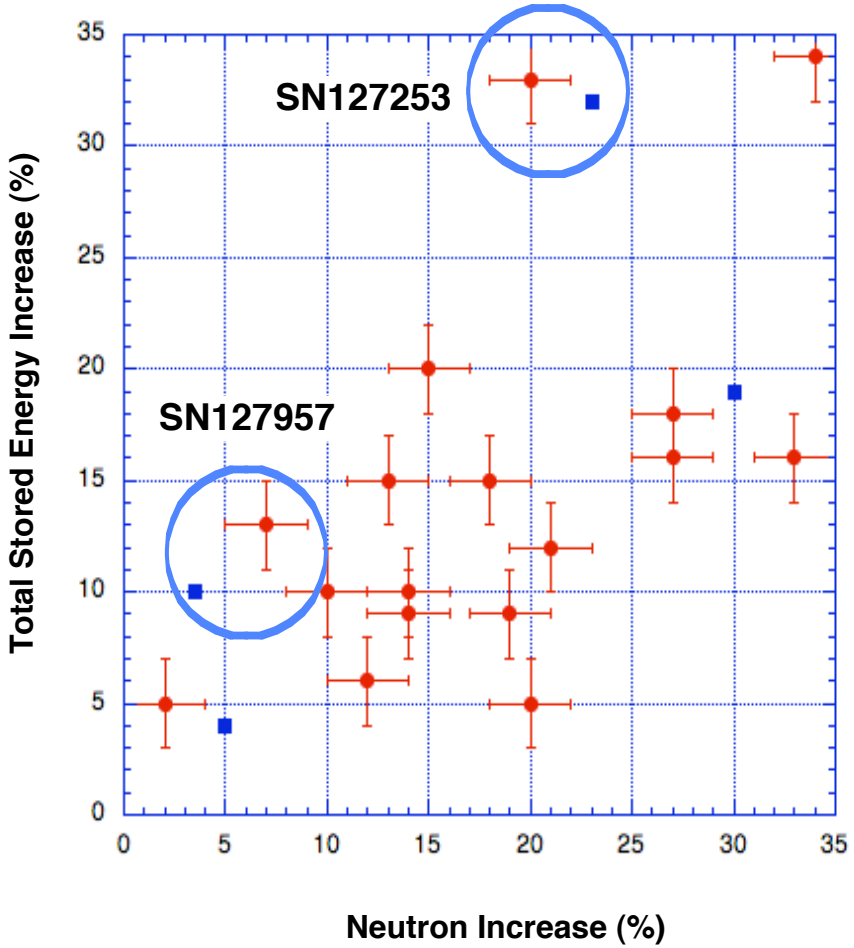
- no MHD 'chirping' is observed on Mirnov signals during HEF interval

SN128895



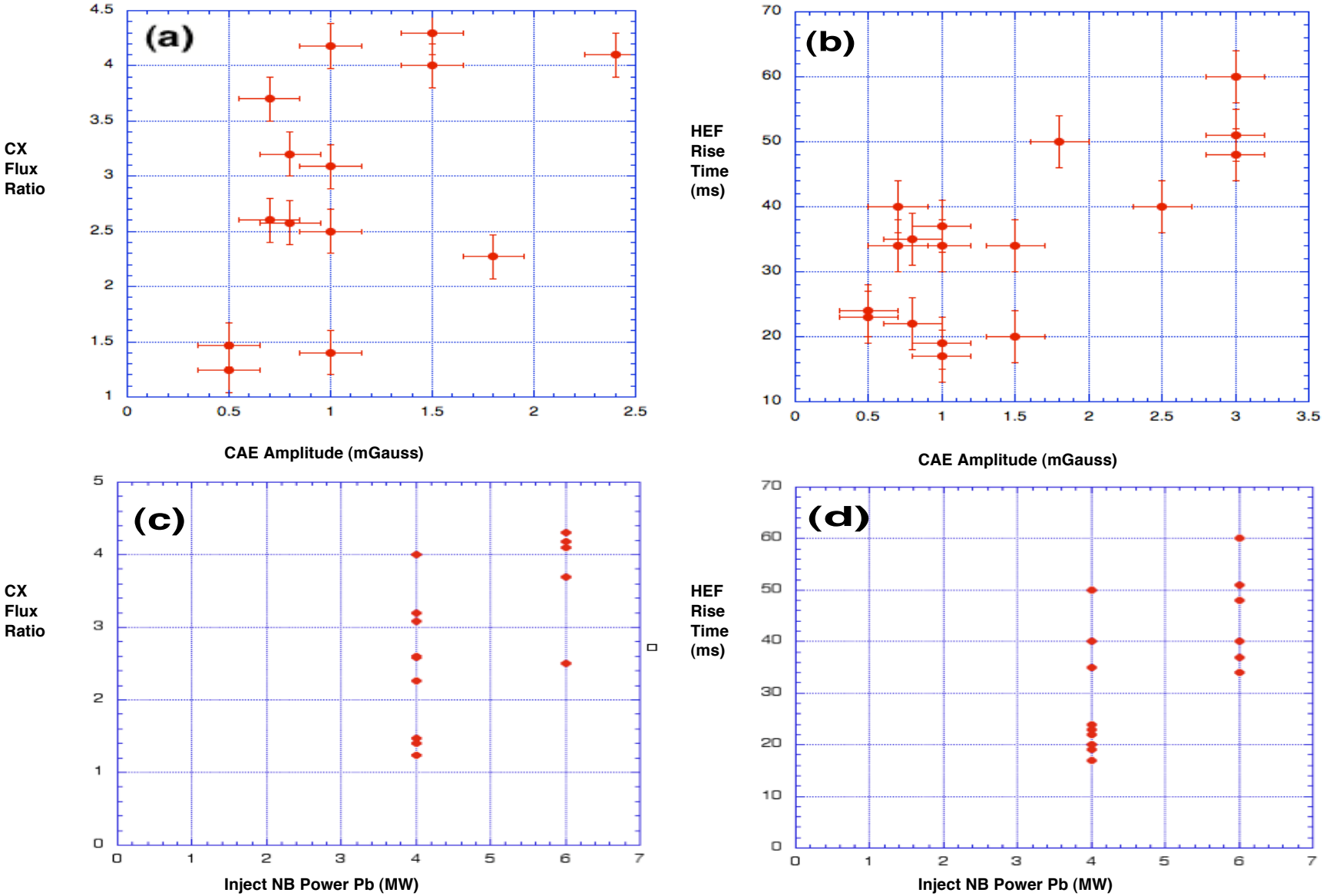
HEFs occur at *low* TAE activity ($\delta B_{rms} < 75$ mGauss) but over a wide range of CAE MHD.





• The experimental neutron rate and total stored energy increase during the HEF (right plot). Similar increases are observed in some TRANSP analyses (blue circles).

HEF Rise-time and Flux Ratio Vary with CAE Strength and NB Power



Physical Explanation of the High-Energy Feature?

(…with acknowledgments to Herb Berk and Nikolai Gorelenkov)

• The NPA is typically operated in the mid-plane with R_{tan} ~ 60 - 80 cm. At these settings, the NPA views passing energetic ions ($v_{||}/v \sim 0.8 \pm 0.1$) injected primarily by Source A with contributions being less from Source B and negligible from Source C (due to increasing trapped ion deposition).

• During robust TAE/Kink activity preceding the HEF, MHD-induced redistribution and/or loss causes depletion of the high-energy region of the NPA spectrum.

• In the subsequent TAE/Kink 'quiescent' phase, the above depletion relaxes allowing the fast ion distribution to rebuild first at the NB full energy: i.e. at the observed HEF .

• A mechanism that does not absorb energy but transfers v_{perp} energy to $v_{||}$ would augment the observed HEF growth by 'pumping' Source B&C ions (more trapped) into the $v_{||}/v$ range viewed by the NPA (more passing). Could a CAE/GAE 'resonance' near the beam full energy be a driver? Could a particle 'pinch' effect exist that 'pumps' trapped ions onto passing orbits observed by the NPA?

• This 'pumping' of energetic ions toward passing orbits might also cause the observed increase in measured neutron yield and stored energy.

XP for Exploration of the High-Energy Feature(HEF)

Total ~ 37 Shots: Extended Run Day (0.5 w/o Scans)

- Does the HEF track E_b?
  - E_b scan with ABC @ 100, 90, 80, 70 keV
    (Fiducial + 3 shots…Lithium free)
- Does the HEF depend on NB sources?
  - Select E_b from above scan: run with AB, AC, BC (need P_b > 4 MW)
    (3 shots)
- Does the HEF occur with NB sources @ mixed E_b?
  - For example, A @ 100 keV, B@ 90 keV, C@80 keV
    (3 shots for permutations)
- Does NB modulation affect HEF behavior?
  - AB + C blips, AC + B blips, BC + A blips, 60 ms blips
    (3 shots)
- Does Lithium suppress HEFs?…use a robust scenario from above
  - LITER deposition @ 50, 100, 150, 200 mg/shot (4 shots)
- Horizontal and vertical NPA scans with all NBs at a selected E_b
  - Hscan requires ~ 12 shots and Vscan ~ 8 shots
    (20 shots)

Backup

Summary of 'Factiods' Related to Observation of HEFs: I

• **High-Energy Features (HEFs)**

- Observed as enhanced CX flux near the NB full energy E ~ 90 keV (i.e. does not exhibit an 'ion tail' aka HHFW heating). Not observed at the beam fractional energies.

-HEFs can 'turn-on' and 'turn-off' multiple times during a discharge, in 'counter-sync' with f < 140 kHz MHD activity.

- Onset of the HEF is not 'abrupt' but exhibits a growth time of ~ 20 - 60 ms.

• **MHD Activity**

- Not observed in the presence of n=1 kink modes or robust (δB_{rms} > 75 mGauss) TAE activity.

-The magnitude of the HEF flux is modulated by strong bursting MHD EPM activity, just like the slowing down ion distribution.

- HEFs appear to coincide with the frequency down-sweeping phase of CAE activity and usually terminate at sweep reversal (i.e. ramp down of toroidal rotation, v_Φ).

Summary of 'Factiods' Related to Observation of HEFs: II

- **Discharge Parameters**

- Not observed during L-mode discharges (only in H-modes).

- Not observed for $P_b < 4$ MW (even during brief P_b notches to lower power).

- Suppressed during robust LITER operation (e.g. > 50 mg/shot or at a level sufficient to suppress ELMs).

- **NPA Instrumental Effect?**

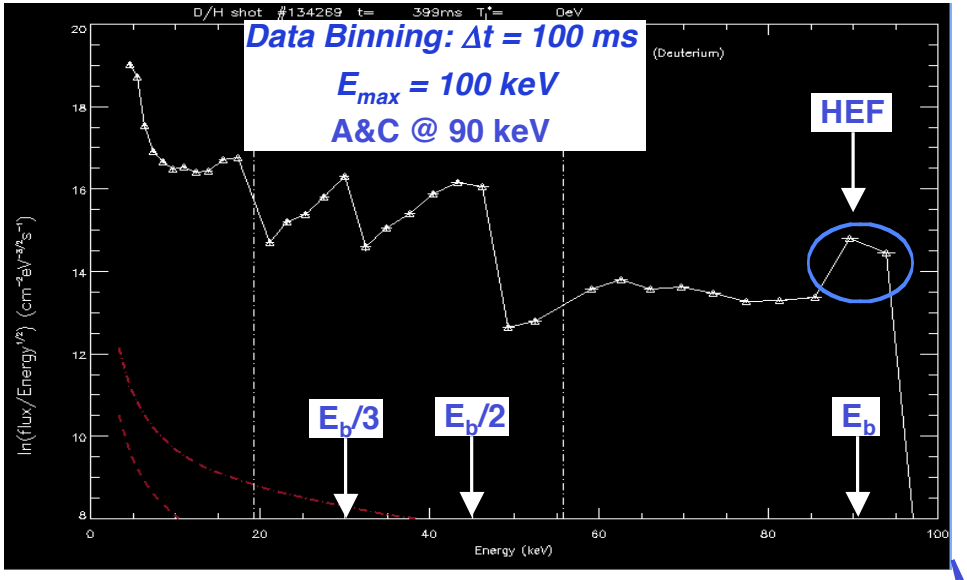
- Not due to 'quirky' anodes because feature moves to other MCP anodes as the EIIB NPA fields are adjusted. Only observed at ~ E_b, never at $E_b/2$ or $E_b/3$.

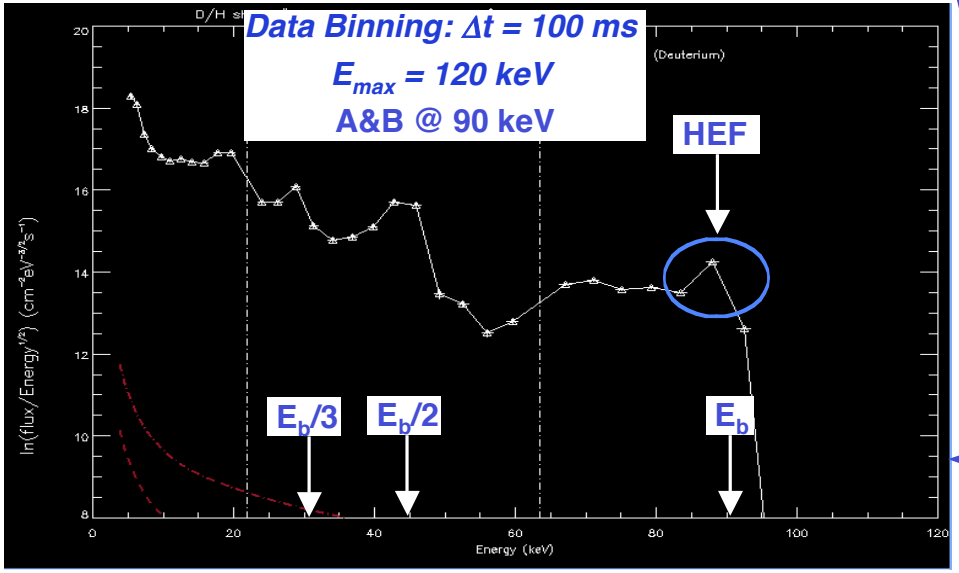
- HEFs have been observed for mid-plane NPA sightlines in the range R_{tan}~ 55 - 86 cm corresponding to $v_{||}/v$ ~ 0.7 - 0.9 (but no horizontal or vertical scan data exist).

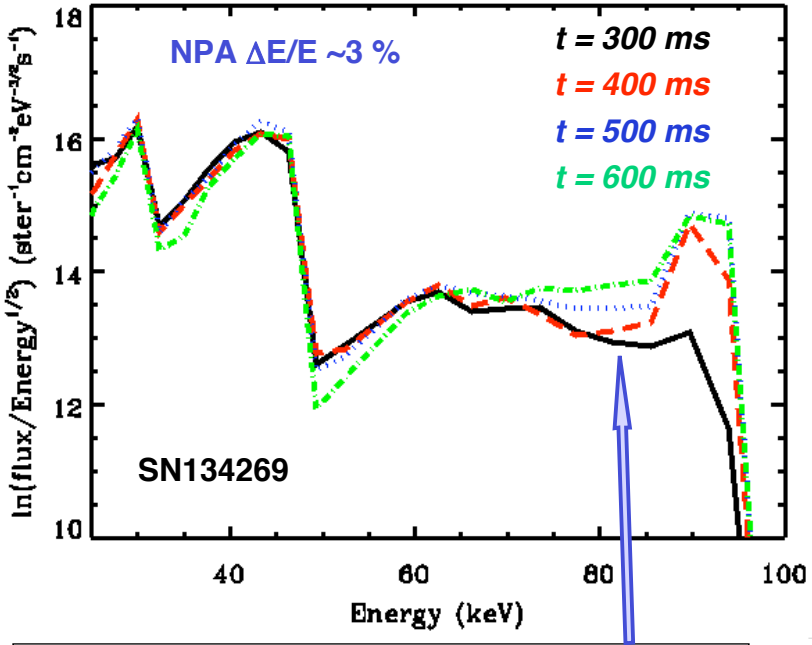
-No sFLIP energetic ion loss signatures are observed which also implies that the HEF flux is not due to orbit excursions into the high edge neutral density region.

The High-Energy Feature is not a NPA Instrumental Artifact

H-mode with I_p = 1.2 MA, B_T = 5.0 kG, P_{NB} = 4 MW, $n_e L \sim 6 \times 10^{13}$ cm^{-2}



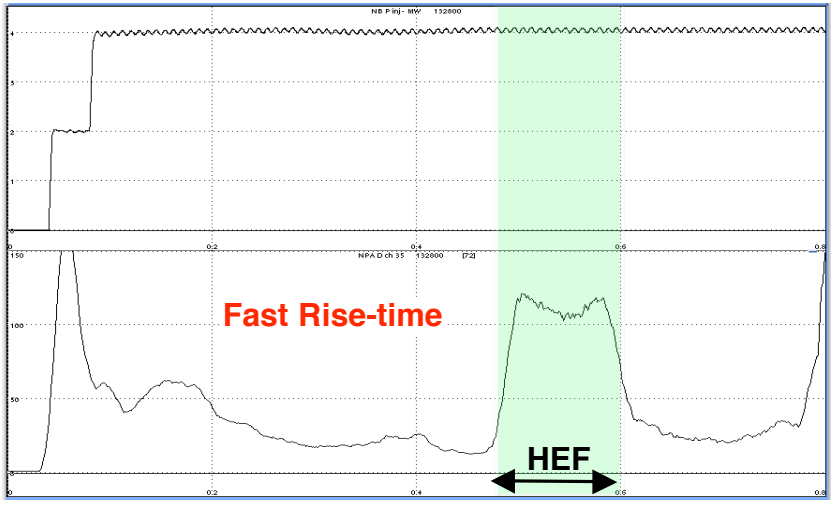




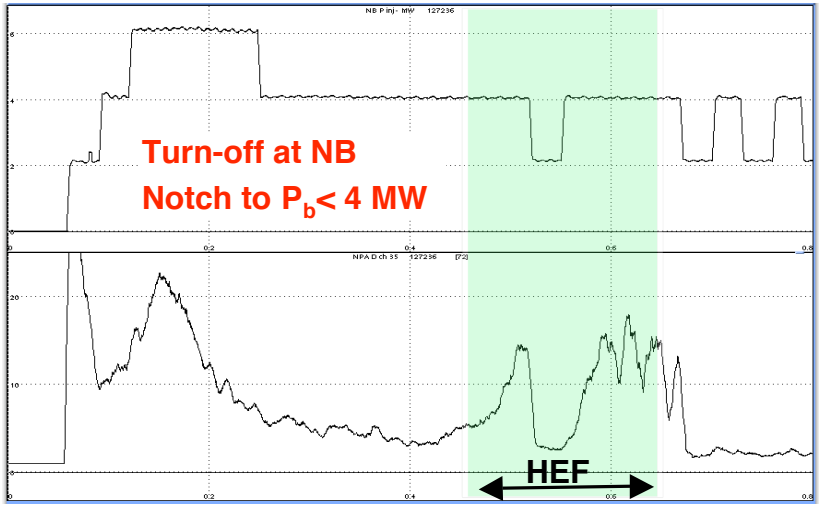
- Spectrum exhibits slowing down of fast ions from the HEF energy region.
- SN134269: HEF appears on Anode # 35 @ 90 keV and Anode 36 @ 93 keV.
- SN134270: HEF appears on Anode # 32 @ 90 keV.

HEF Rise-time and Duration Show Considerable Variation

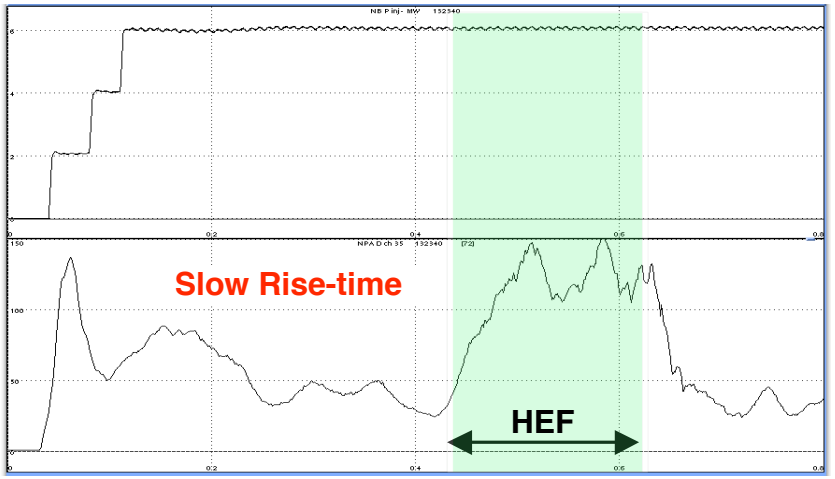
- NPA data at 90 keV



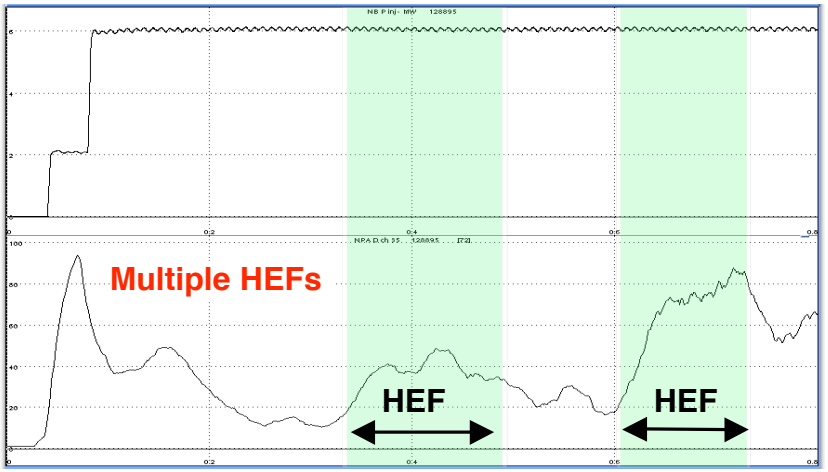
• SN132800, P_b= 4 MW, t_{rise}= 20 ms



• SN 127236, P_b= 4 → 2 MW, t_{rise}~ 55 ms



• SN132340, P_b= 6 MW, t_{rise}= 80 ms



• SN128895, P_b= 6 MW, t_{rise}~ 50 ms

Abstract- APS09

Observation of ‘ Anomalous’ Energetic Ion Spectra by the EllB Neutral Particle Analyzer o n NSTX, S. S. Medley, R. E. Bell, D . S. Darrow, E. D. Fredrickson, N. N. Gorelenkov, B. P. LeBlanc, A. L. Roquemore (PPPL), M. Podesta (UC Irvine) – An ‘anomalous’ increase in EllB NPA charge exchange neutral flux (~4x) localized at the neutral beam(NB) injection full energy, E_b = 90 keV, is observed in NSTX. This so-called ‘High-Energy Feature (HEF)’ appears in discharges only when kink-type modes (f < 10 kHz) are absent, TAE activity (f ~ 10-150 kHz) is weak (δB_{rms} < 75 mGauss) and CAE activity (f ~ 400 – 1200 kHz) is robust. The HEF exhibits a growth time of ~ 20-80 ms and develops a slowing down distribution that evolves over 100-400 ms, a time scale lo ng compared with the ~ 50 ms equilib ration time of the NB injected particles. Increases of ~ 10-30% in the measured neutron yield a nd total stored energy are observed to coincide with the HEF alo ng with broadening of the CHERS $T_i(r)$ profile. The HEF is observed only in H-mode (not L-mode) discharges with injected NB power above 4 MW and is suppressed by vessel conditioning using lithium deposition at rates ~ 100 mg/shot sufficient to suppress ELM activity. Though a d efinitive mechanism has yet to be developed, the HEF appears to be driven by a form of CAE resonance.

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