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

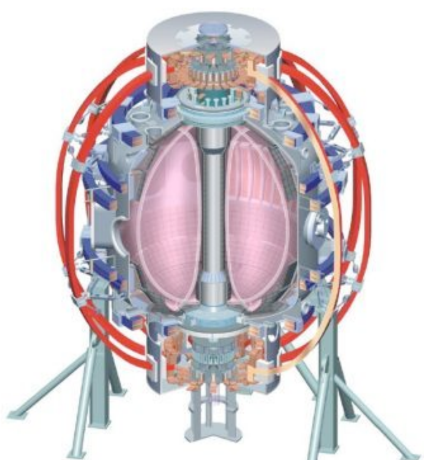
S. S. Medley

College W&M
Colorado Sch Mines
Columbia U
CompX
General Atomics
INEL
Johns Hopkins U
LANL
LLNL
Lodestar
MIT
Nova Photonics
New York U
Old Dominion U
ORNL
PPPL
PSI
Princeton U
Purdue U
SNL
Think Tank, Inc.
UC Davis
UC Irvine
UCLA
UCSD
U Colorado
U Illinois
U Maryland
U Rochester
U Washington
U Wisconsin

High-Energy Feature (HEF)

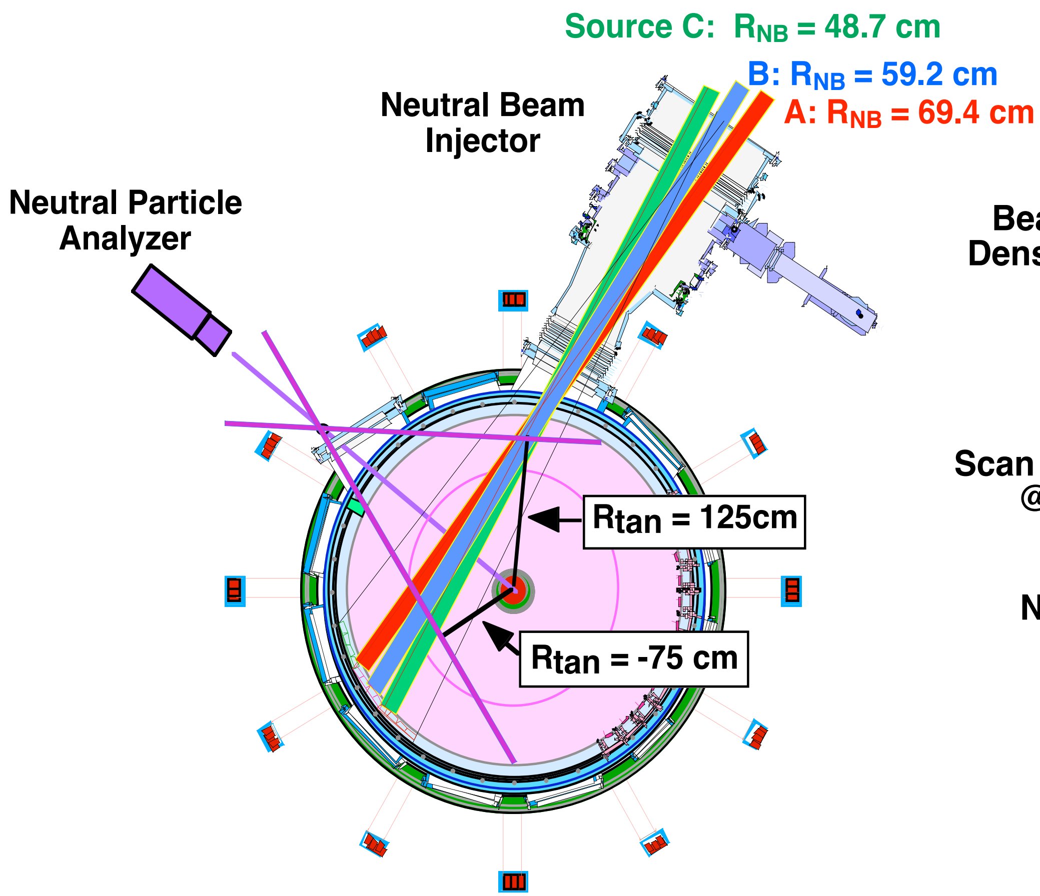
A strong increase (~ 3x) in the E||B NPA charge exchange flux that is localized around the NB full energy: $E_b \sim 90$ keV.

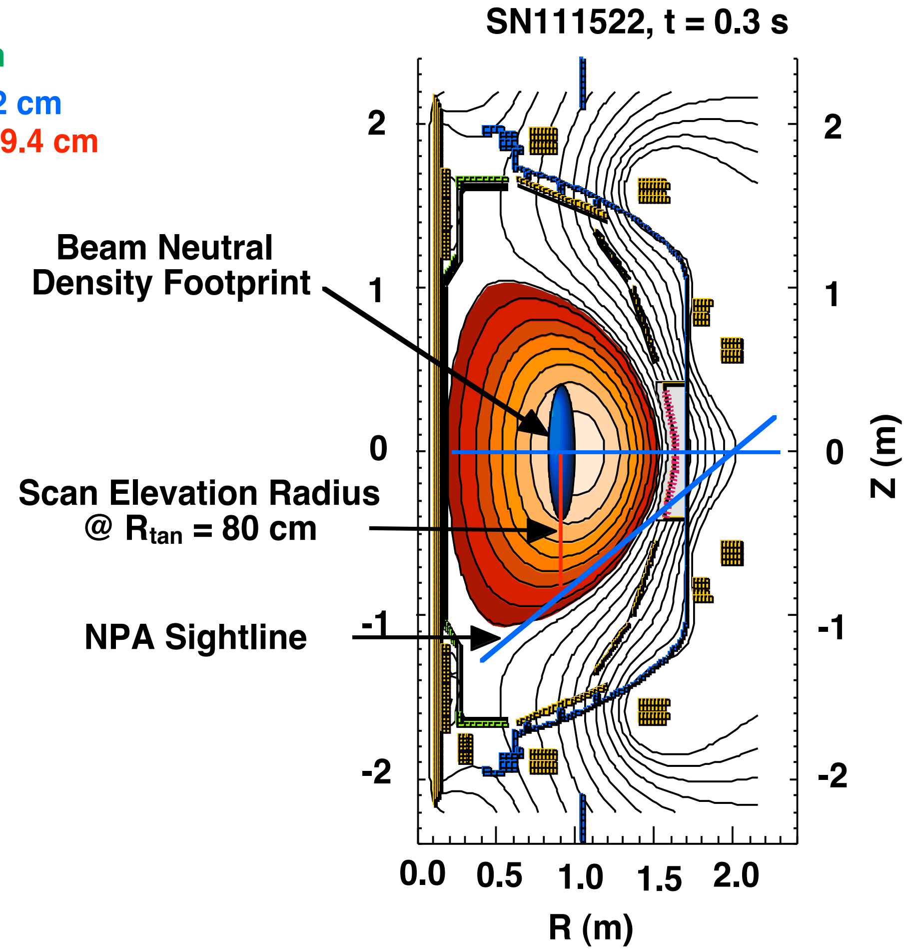
- the HEF is a transient mid-discharge phenomenon with durations ~ 100 - 600 ms.



Culham Sci Ctr
U St. Andrews
York U
Chubu U
Fukui U
Hiroshima U
Hyogo U
Kyoto U
Kyushu U
Kyushu Tokai U
NIFS
Niigata U
U Tokyo
JAEA
Hebrew U
Ioffe Inst
RRC Kurchatov Inst
TRINITI
KBSI
KAIST
POSTECH
ASIPP
ENEA, Frascati
CEA, Cadarache
IPP, Jülich
IPP, Garching
ASCR, Czech Rep
U Quebec

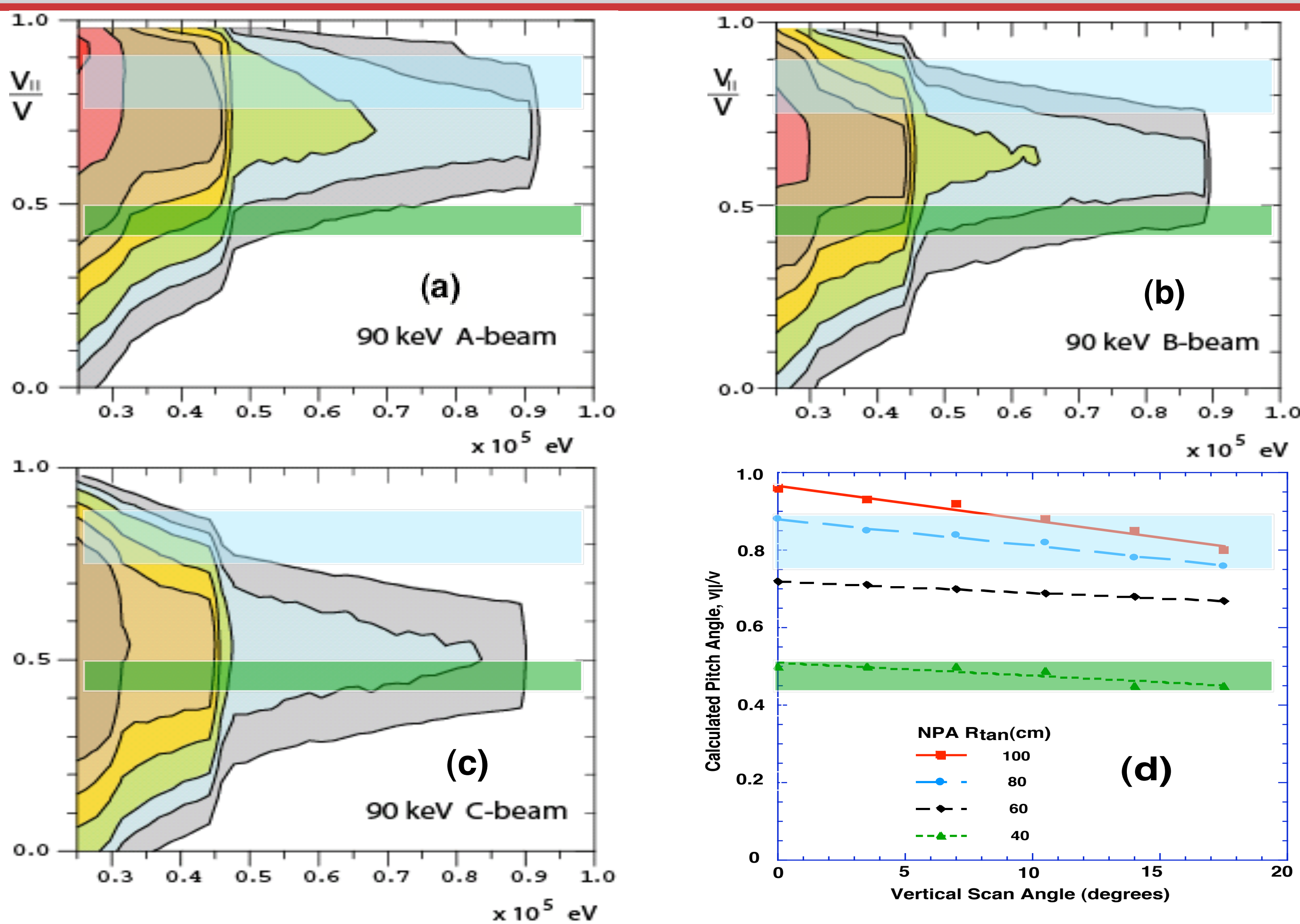
The Neutral Particle Analyzer (NPA) on NSTX Scans Horizontally and/or Vertically on a Shot-to-Shot Basis





- Intersection of NPA sightline with beam neutrals (primary and halo) localizes the charge exchange flux measurement in space and field pitch, v||/v.
- The line-integrated NPA measurements have a spatial resolution ~ 3 cm in elevation and ~ 20 cm in radius with a pitch resolution $v_{||}/v$ ~ 0.05.

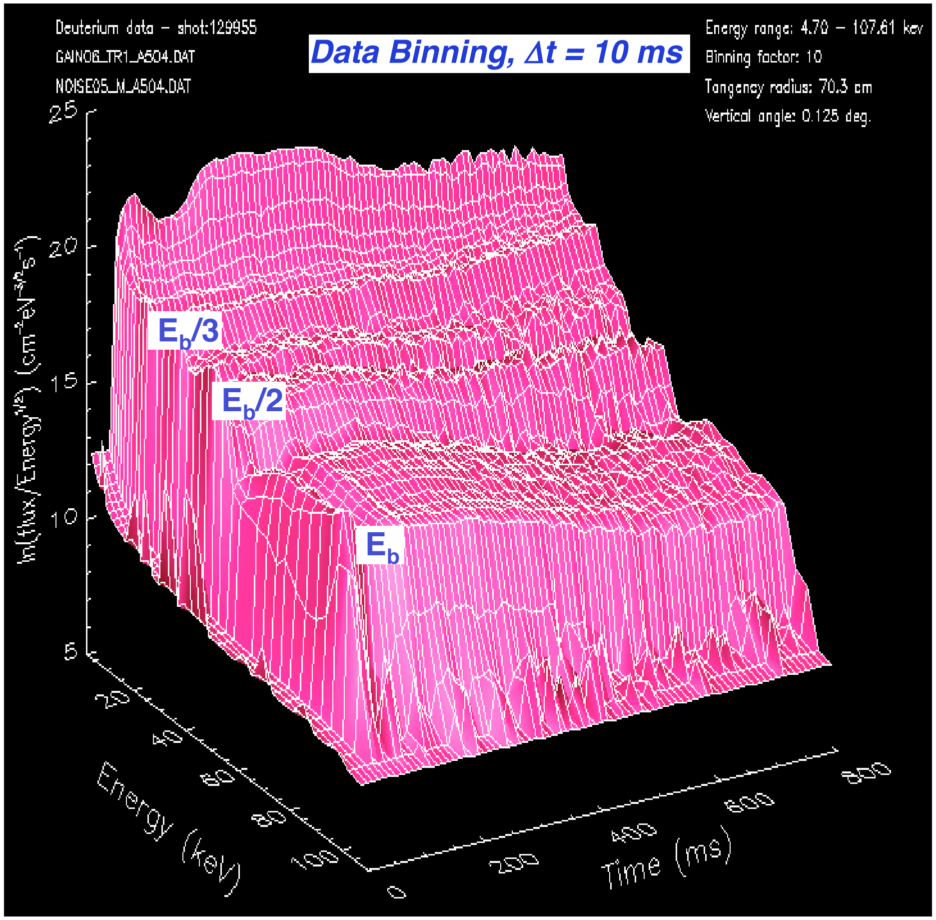
The Field Pitch, $v_{||}/v$, Viewed by the NPA Depends on Both the Horizontal and Vertical Sightline Setting

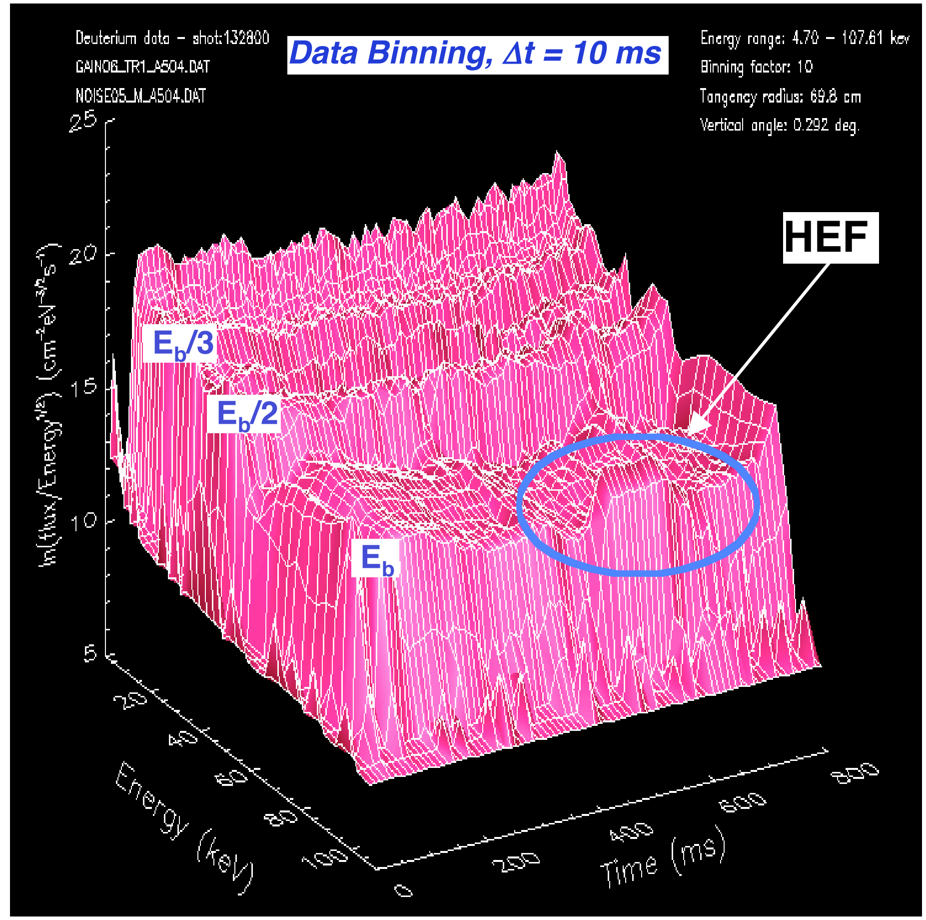


- For 'standard' settings of the NPA, R_{tan} ~ 70 - 80 cm, $v_{||}/v$ ~ 0.80 ± 0.05 (blue bar).

Illustration of the High-Energy Feature (HEF) at t ~ 0.5-0.6 s

H-mode with I_p = 1.0 MA, B_T = 4.5 kG, A& C @ 90 keV, P_{NB} = 4 MW, $n_eL \sim 6 \times 10^{13}$ cm^{-2}



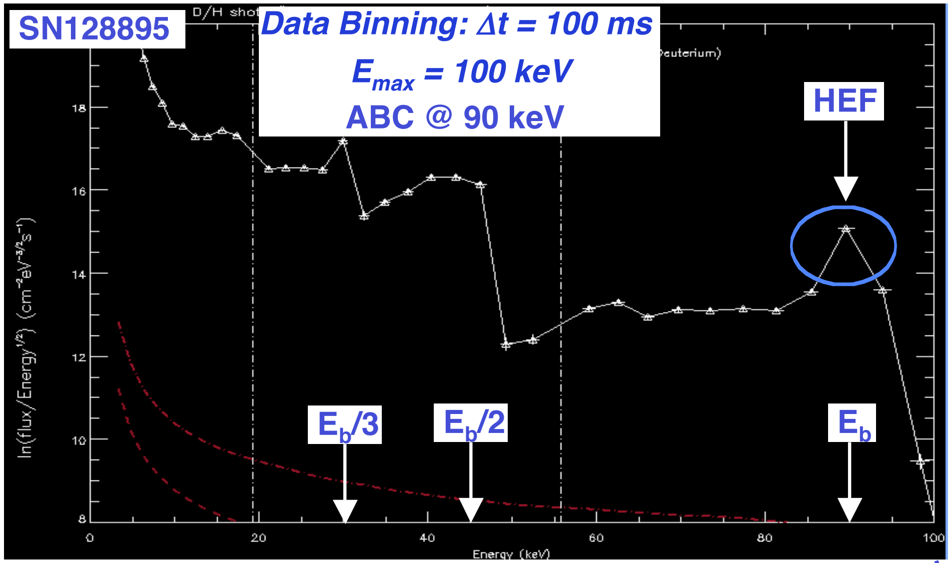


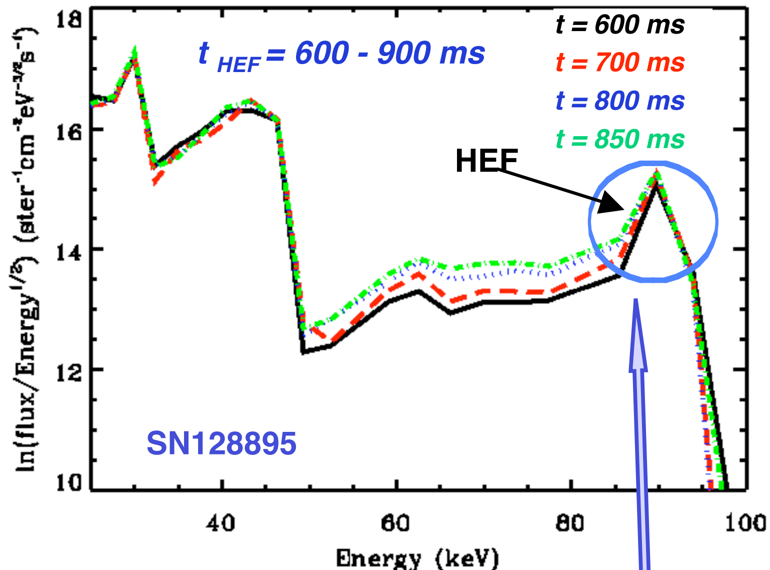
- **Typical NPA spectrum depletion in the range $E_b/2 \le E \le E_b$ due to combined effects of n_e ramp-up and MHD-induced loss.**

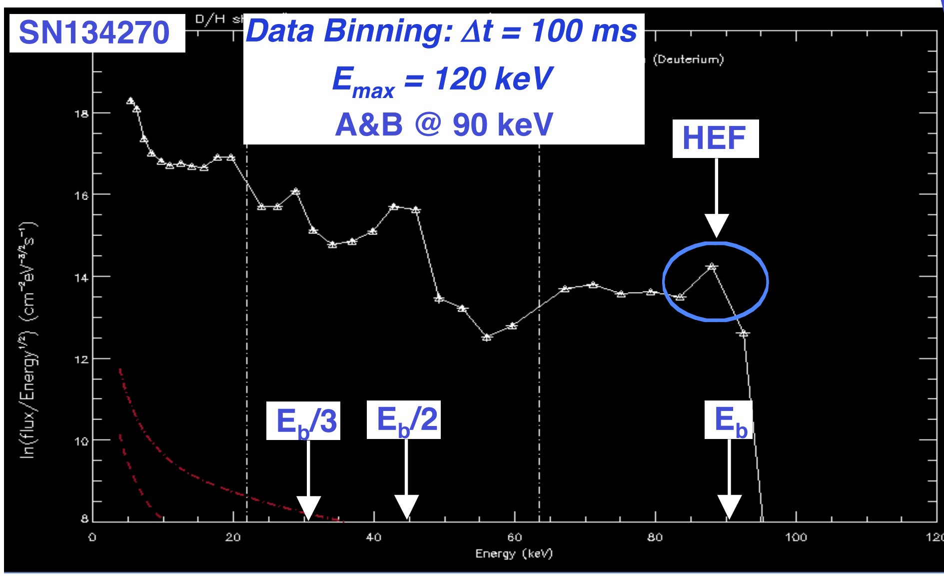
- **HEF: NPA spectrum exhibits a transient signal enhancement only near $E \sim E_b$ (e.g. never at $E_b/2$ or $E_b/3$).**

The High-Energy Feature is not a NPA Instrumental Artifact

H-mode with I_p = 1.2 MA, B_T = 4.5 kG, P_{NB} = 6 MW, n_eL ~$7x10^{13}$ cm^{-2}







- **Spectrum exhibits slowing down of fast ions from the HEF energy region.**
- **Slowing down continues to evolve over the duration of the HEF: ~ 300 ms.**

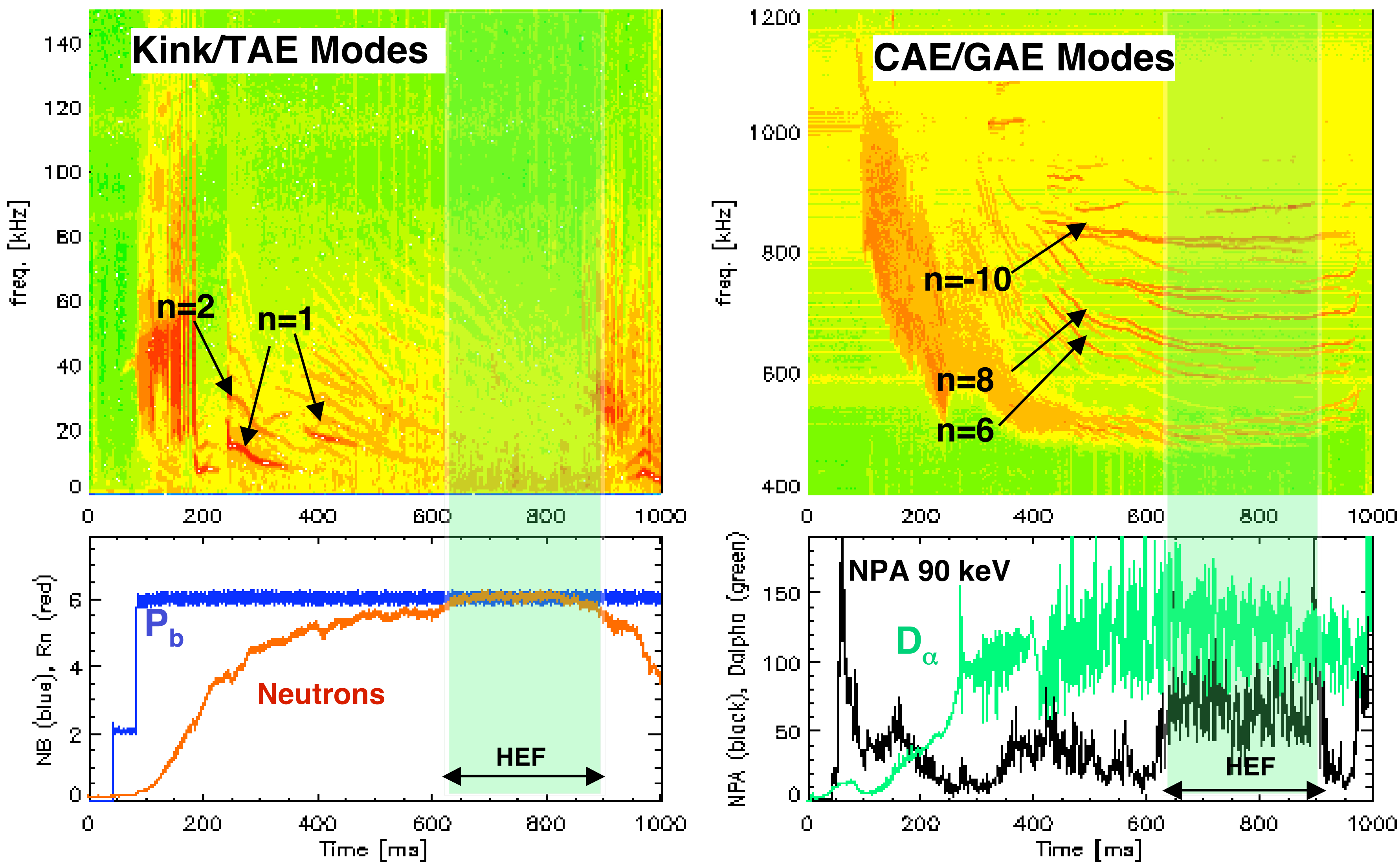
- **HEF appears on Anode # 35 @ 90 keV.**

- **HEF appears on Anode # 32 @ 90 keV.**

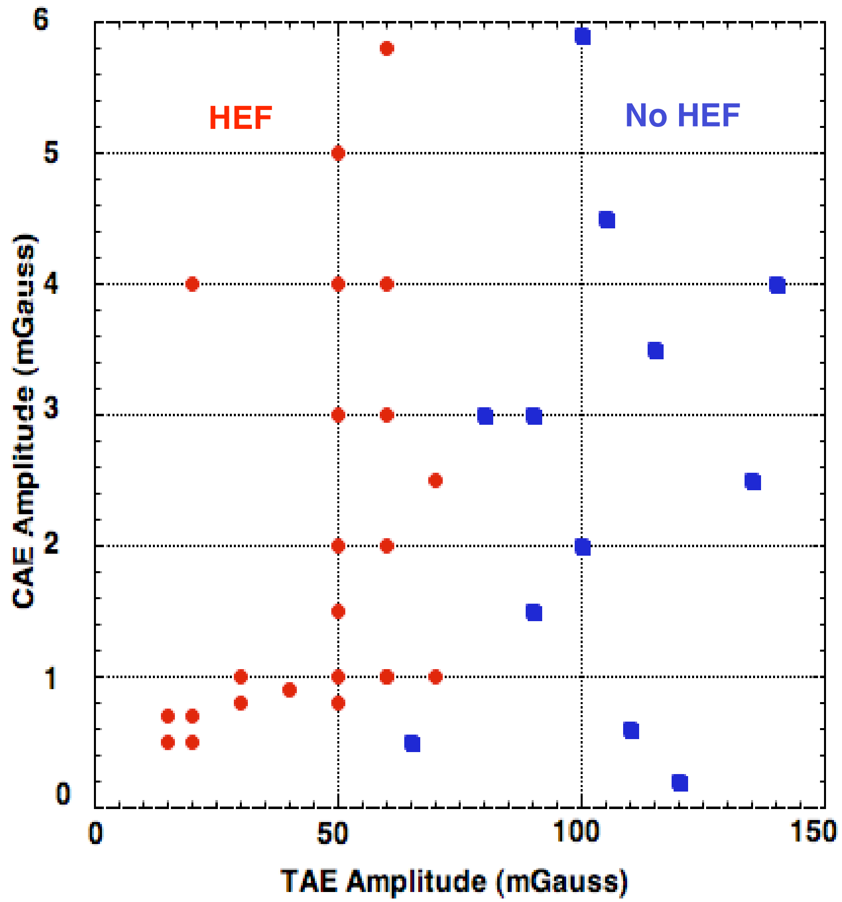
HEF Existence Requires Feeble Kink/TAE MHD Activity: SN128895

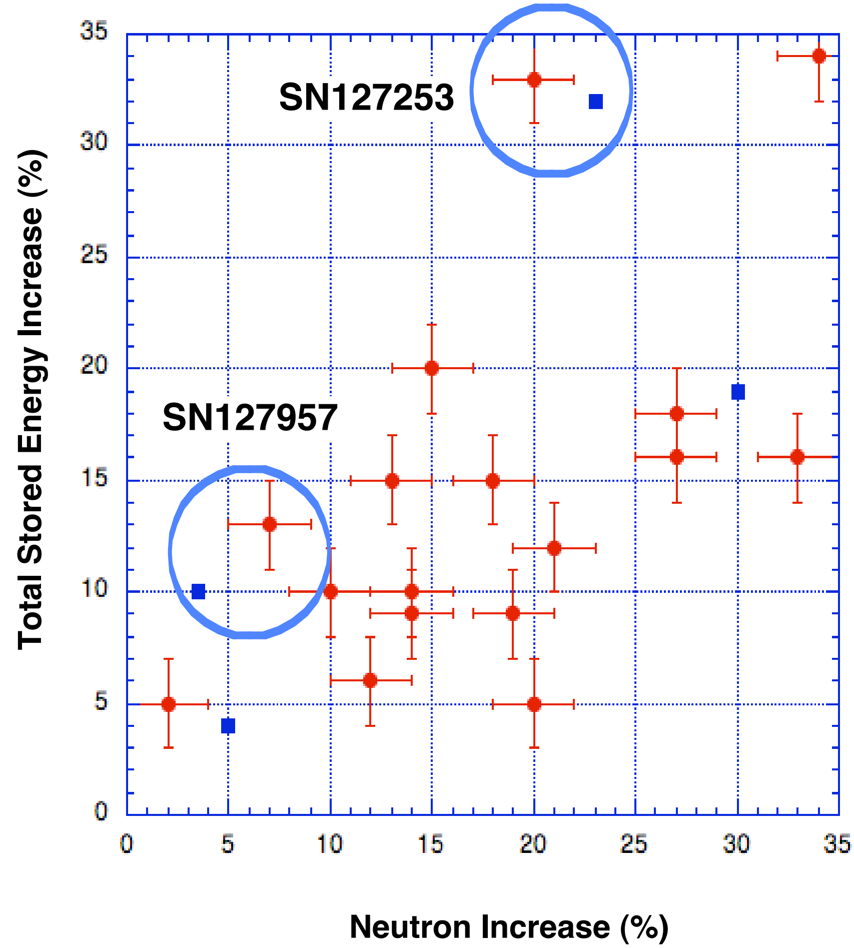
- no MHD 'chirping' is observed on Mirnov signals during HEF interval

SN128895



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

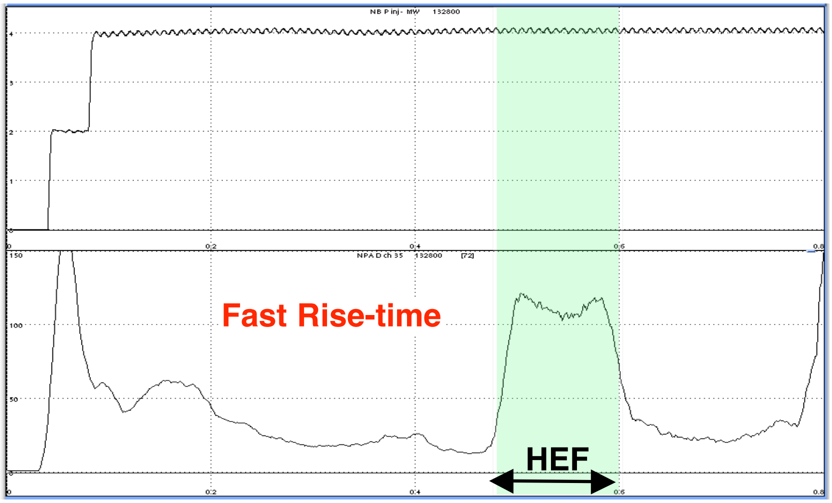




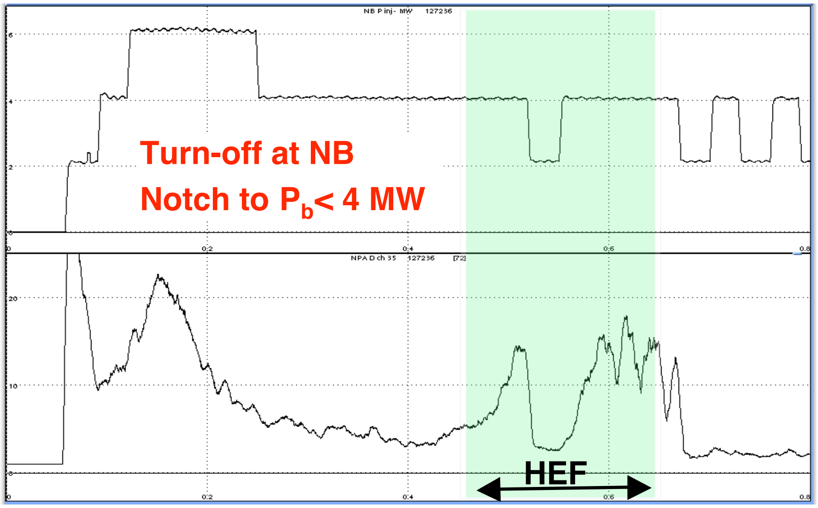
• The experimental neutron rate and total stored energy increase during the HEF (right plot). Similar increases are observed in some TRANSP analyses (blue squares).

HEF Rise-time and Duration Show Considerable Variation

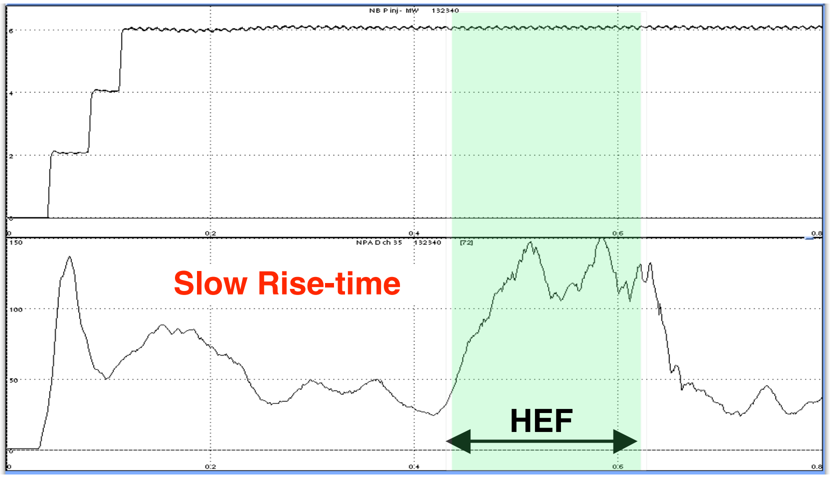
- NPA data at 90 keV



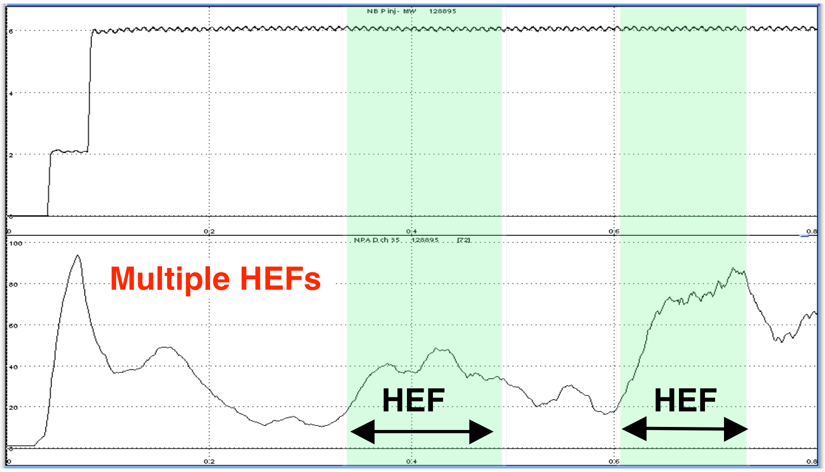
• SN132800, P_b= 4 MW, t_{rise}= 20 ms



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

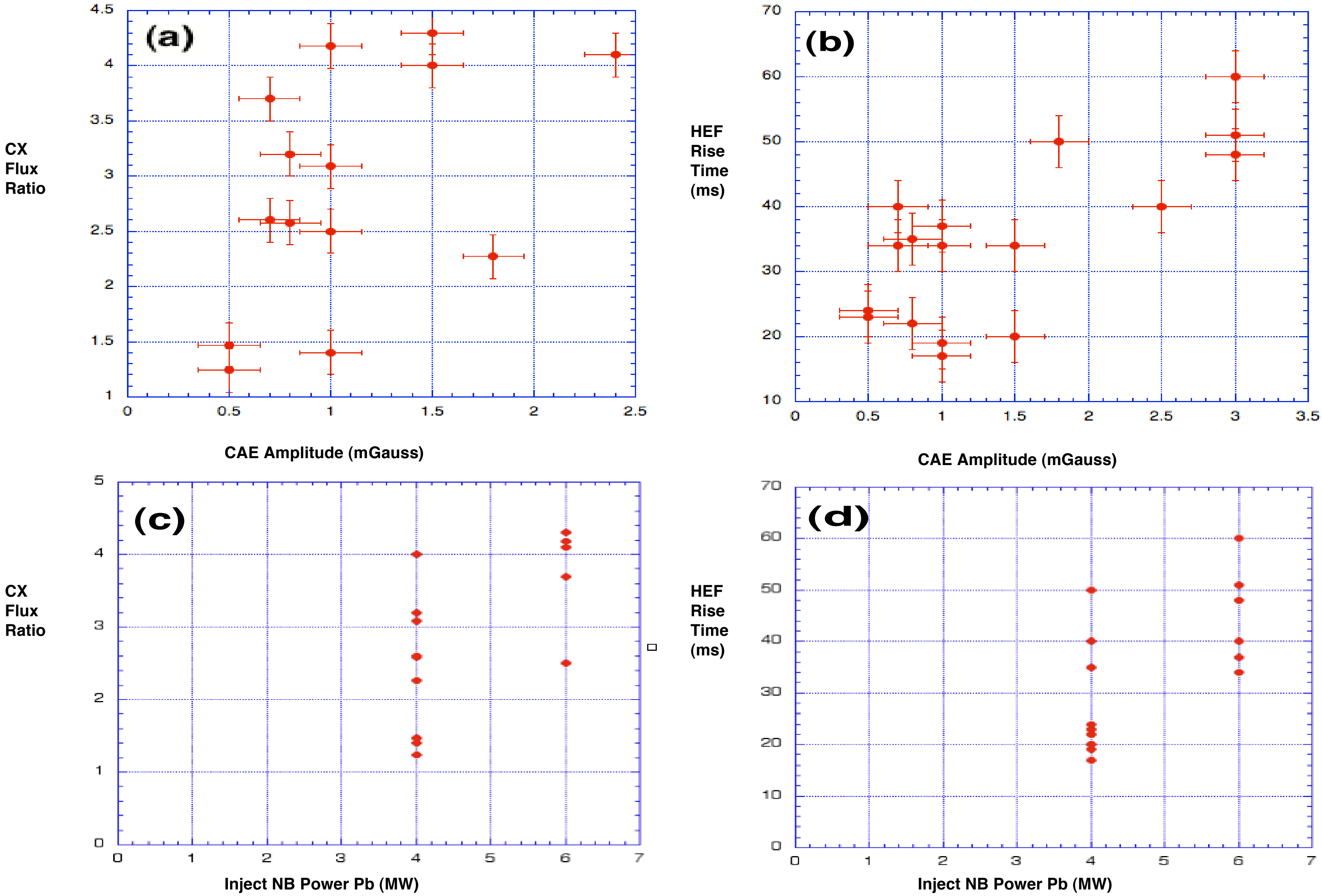


• SN132340, P_b= 6 MW, t_{rise}= 80 ms



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

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



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 and can persist for ~100 - 600 ms.

-Onset of the HEF is not 'abrupt' but exhibits a growth time of ~ 20 - 80 ms.

• **Not a 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.

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

- **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, similar to other energies in 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}).

- **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).

Physical Explanation of the High-Energy Feature?

- 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 as reported in earlier work. Thus there would be a deficiency of the high energy component during the MHD active phase.

- In the TAE/Kink 'quiescent' phase, the above depletion could relax thus building the observed HEF fast ion distribution first at the NB full energy.

- 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.