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Neutral Particle Analyzer Vertical Scanning Measurements of MHD-induced Energetic Ion Redistribution or Loss in NSTX

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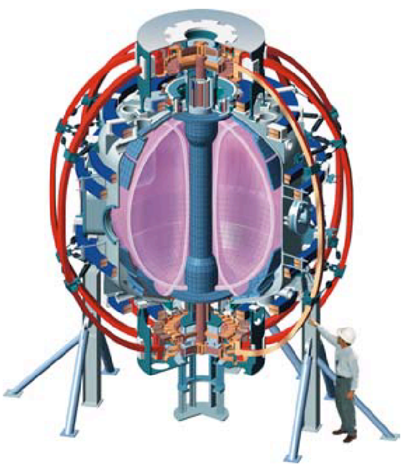
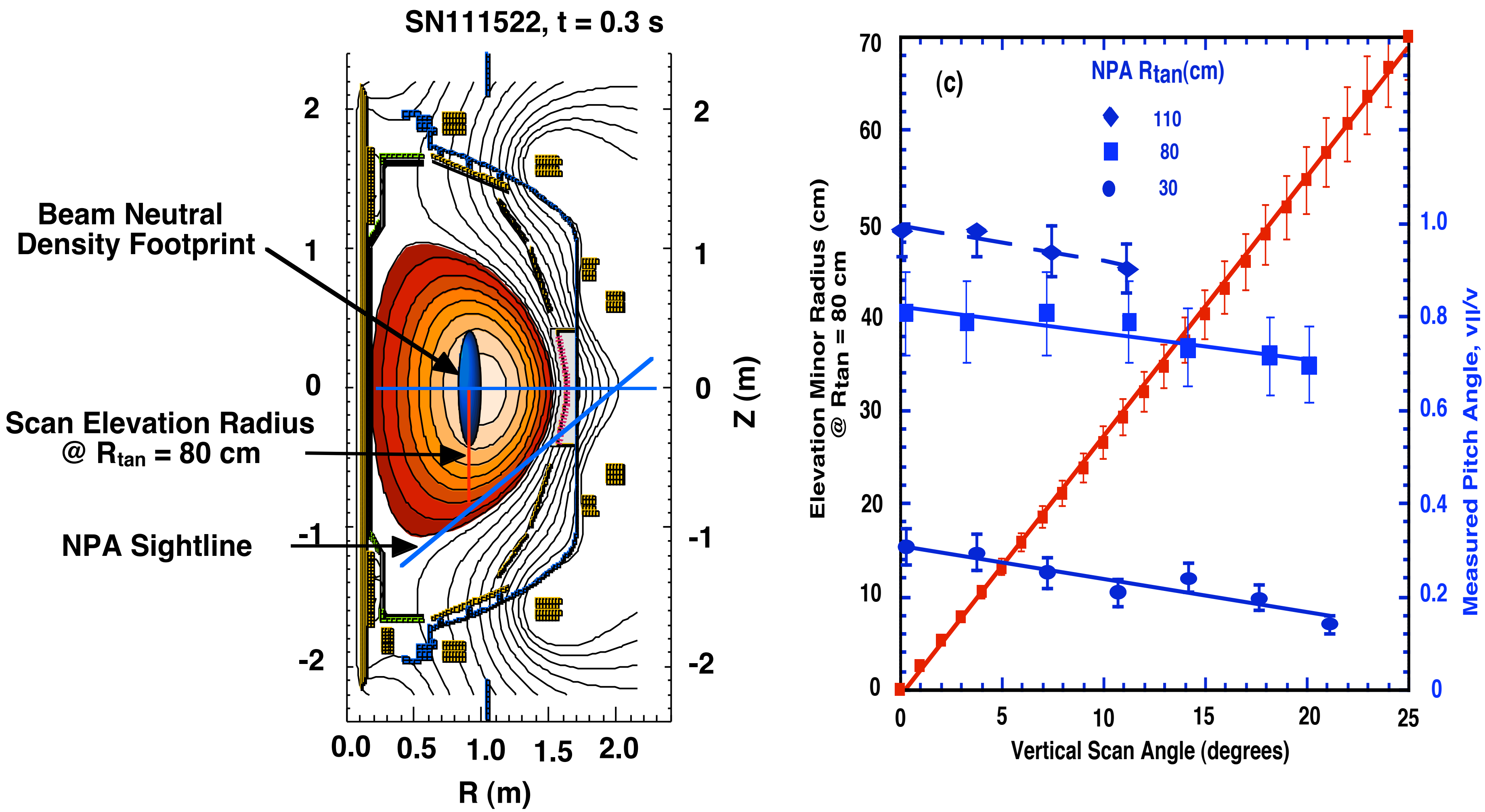


Report on XP707

NSTX Physics Meeting

June 4, 2007

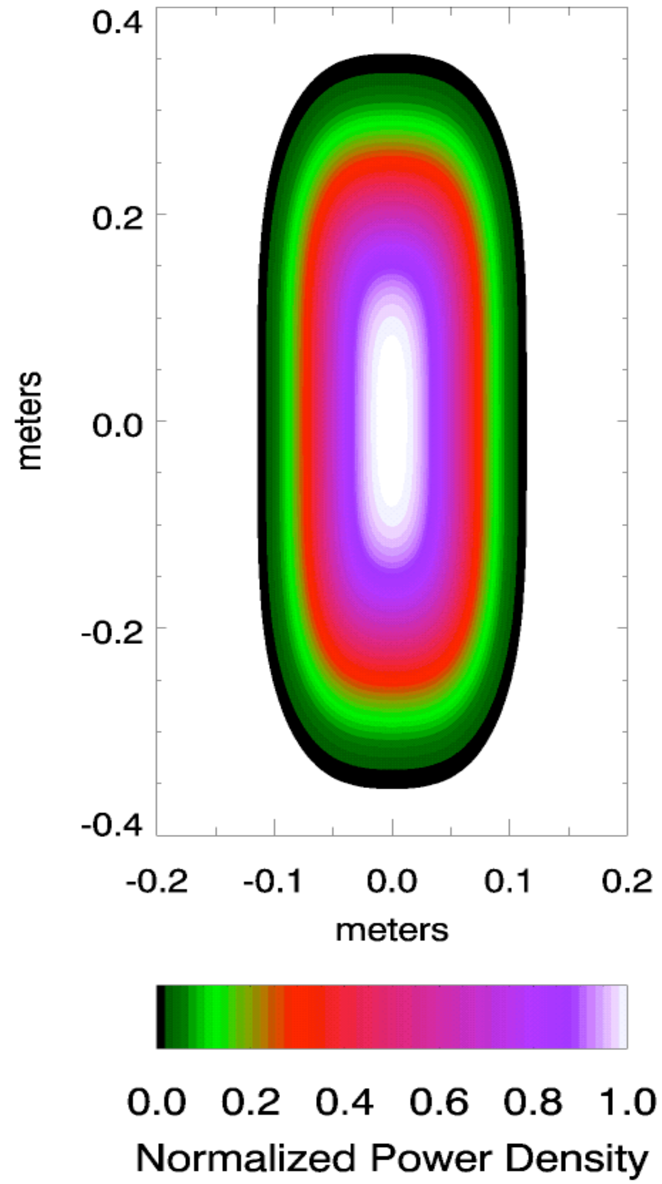
The Neutral Particle Analyzer (NPA) on NSTX Scans Vertically Over a Wide Range of Angles on a Shot-to-Shot Basis

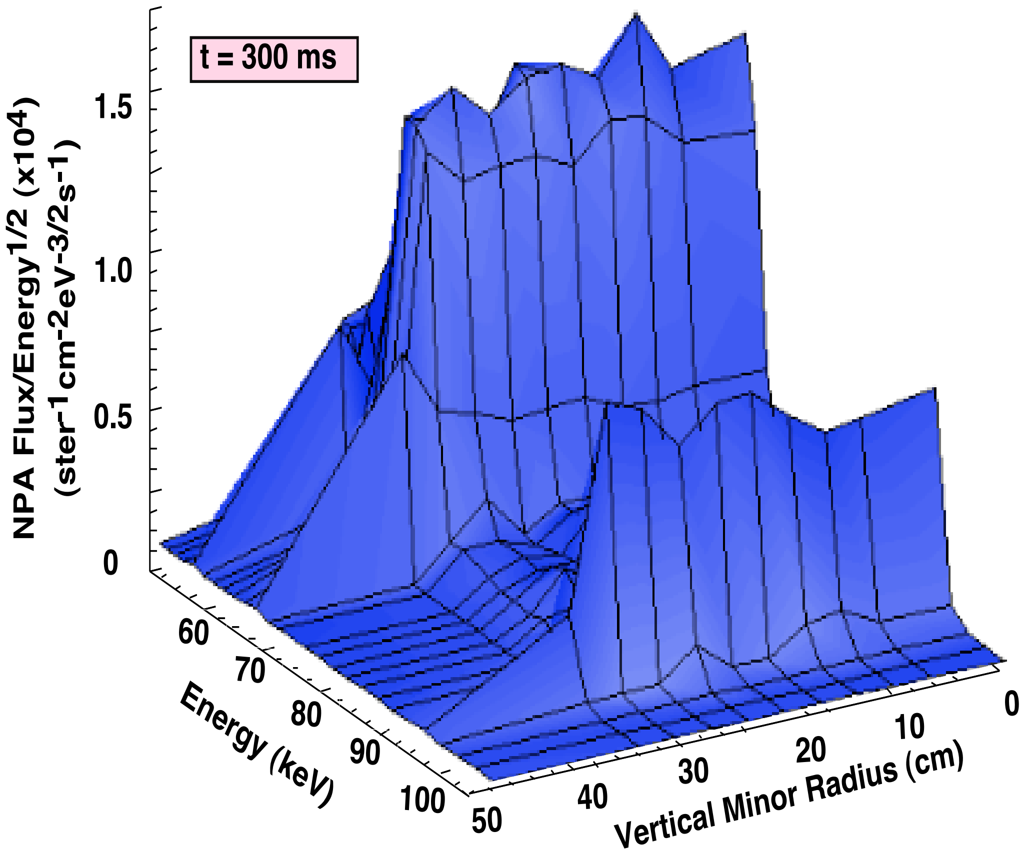


- **Dominance of charge exchange emissivity by beam neutrals results in both field pitch and spatial localization of NPA measurements.**

NPA Vertical Scanning Measurement of the Neutral Beam Footprint Agrees with NB Calibration

NSTX



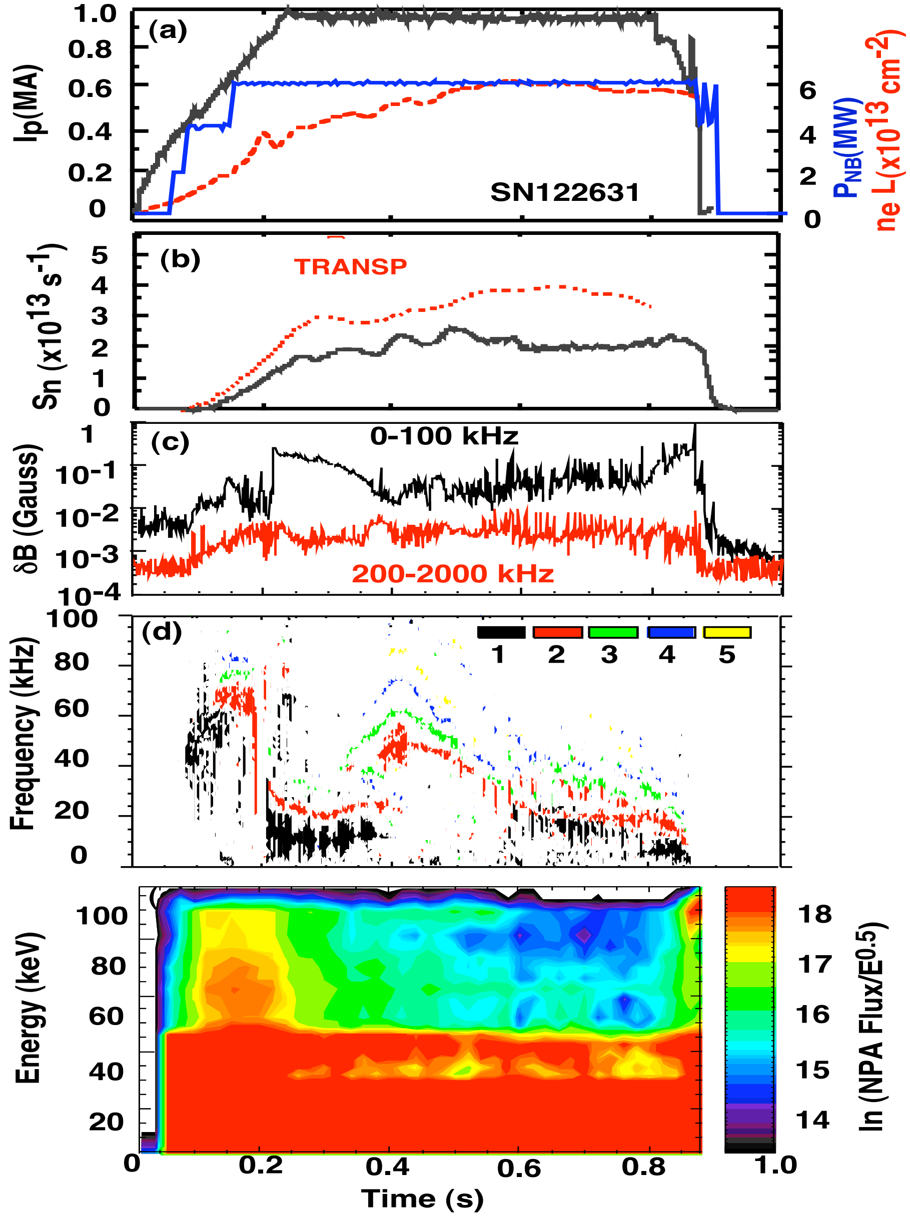


- **Neutral Beam Particle Fractions**

NPA Data: $E_b/3: E_b/2:E_b$= 0.42:0.42:0.16

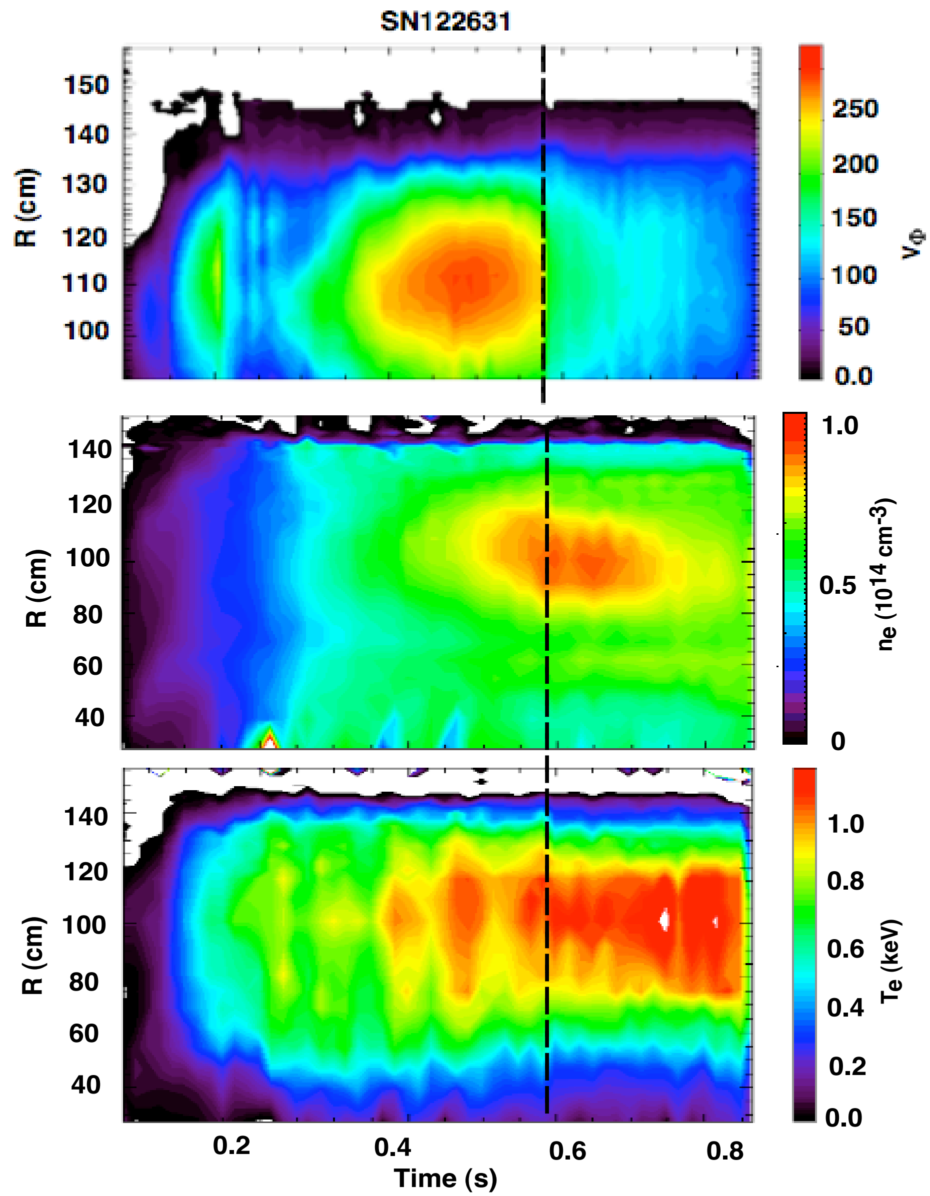
NB Calibration: $E_b/3: E_b/2:E_b$= 0.44:0.39:0.17

Vertical Scan Discharge Characteristics: 122631



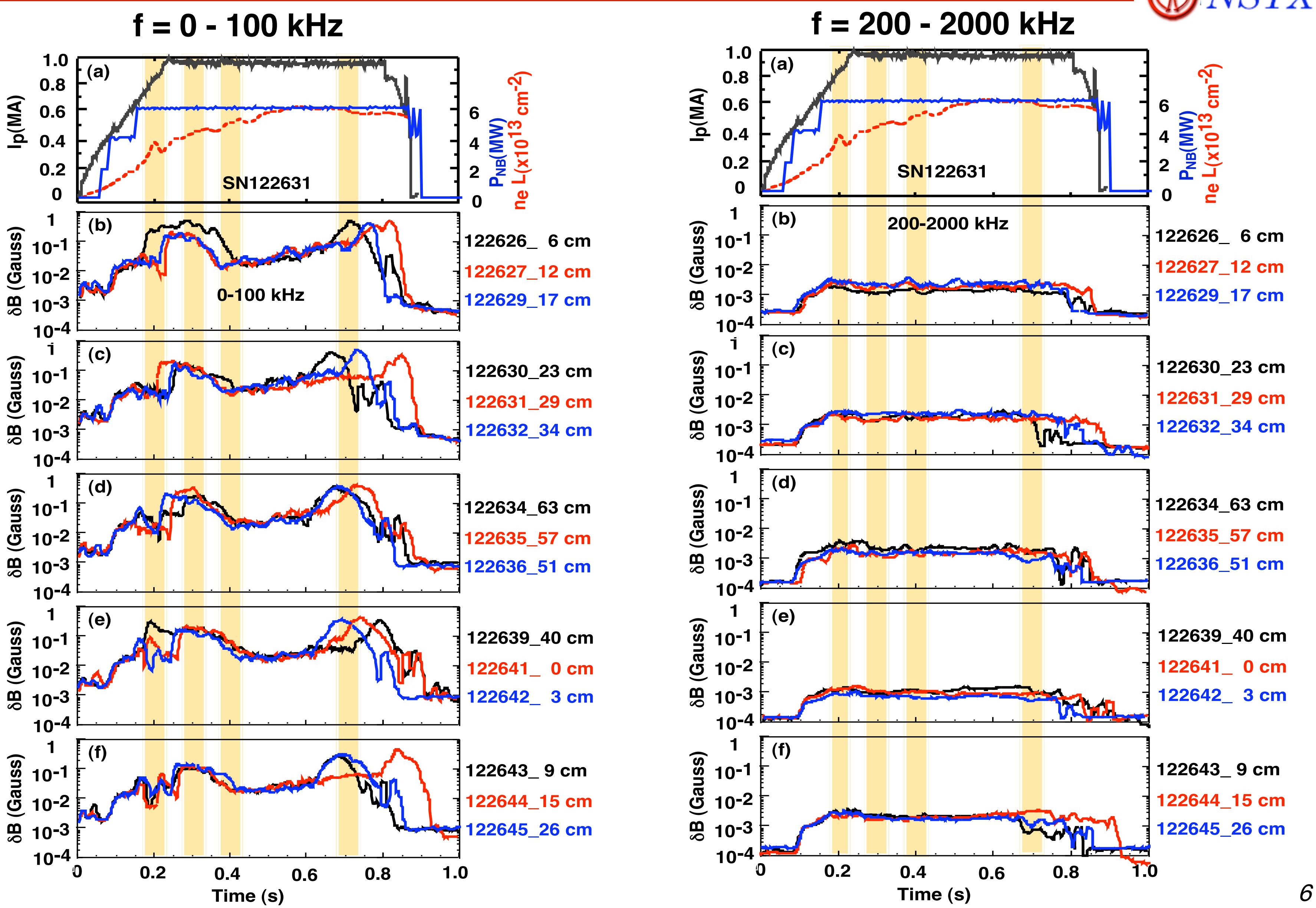
- Ip = 1 MA, B_T = 4.5 kG H-mode ($t_{flattop}$ ~ 0.8 s) with A, B, C @ 90 keV and P_{NB} = 6 MW.
- Shot range: 122626 - 122645 (15 good discharges).
- Stable outer gap ~ 10 cm early in discharge and n_e(r) 'flattop' after t ~ 0.5 s.
- Wide range of reproducible *AE and MHD activity.
- Strong depletion of the NPA energetic ion spectrum primarily above E/2.

Collapse of v_Φ at t ~ 0.55 s Triggers Changes in Plasma Profiles and MHD Activity



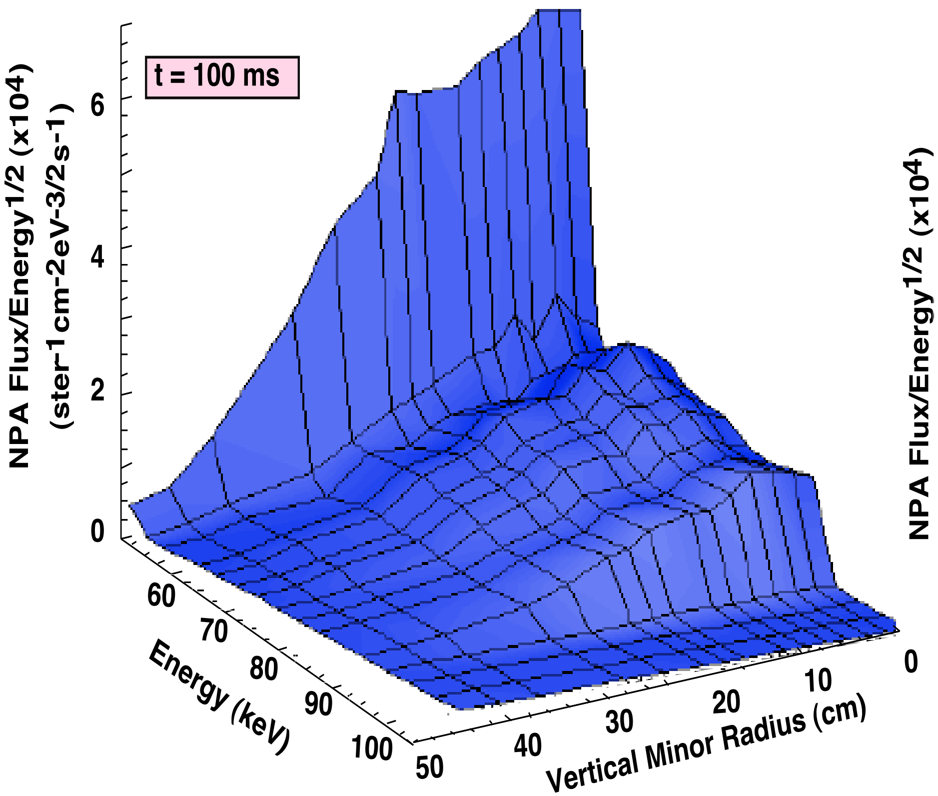
- v_Φ, Z_{eff}, n_e and T_e were reproducible to within ~ 10% during the scan.
- Maximum v_Φ ~ 250 kms^{-1} at t ~ 0.5 s drops to v_Φ ~ 150 kms^{-1} at t ~ 0.6 s.
- Modest Z_{eff} ~ 1.2 at t ~ 0.2 s rises to Z_{eff} ~ 1.6 ± 0.1 at t ~ 0.6 s.
- $n_e(0)$ ~ 6.5x10^{13} cm^{-3} at t ~ 0.55 s transitions to $n_e(0)$ ~ 8.5x10^{13} cm^{-3} at t ~ 0.7 s.
- $T_e(0)$ ~ 0.2 keV at t ~ 0.2 s increases to $T_e(0)$ ~ 0.7 ± 0.1 keV at t ~ 0.7 s.

Low and High Frequency MHD Activity was Reproducible

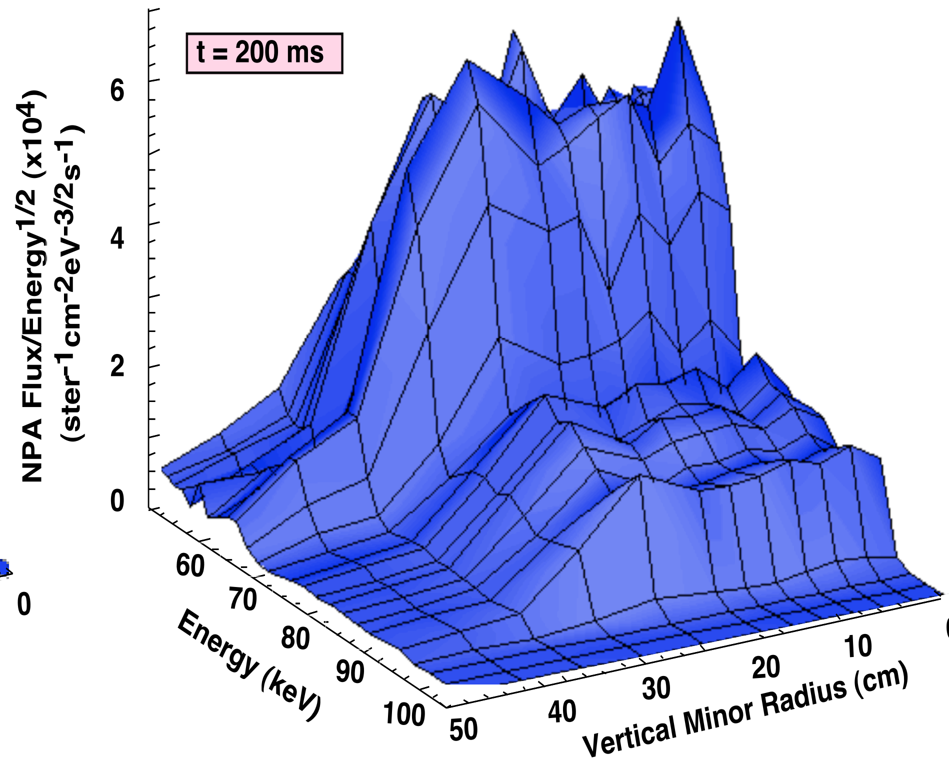


Initially Monotonic NPA Vertical Scan Profile is Flattened by MHD-induced Fast Ion Redistribution

L-mode "Quiescent"



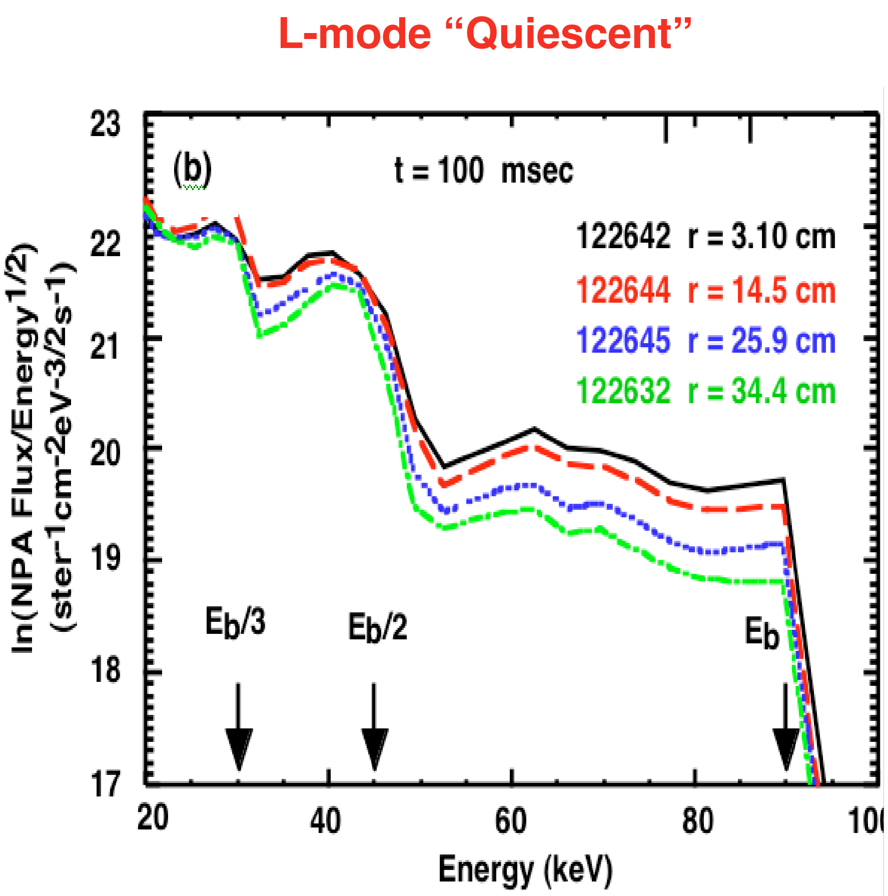
H-mode "MHD Active"

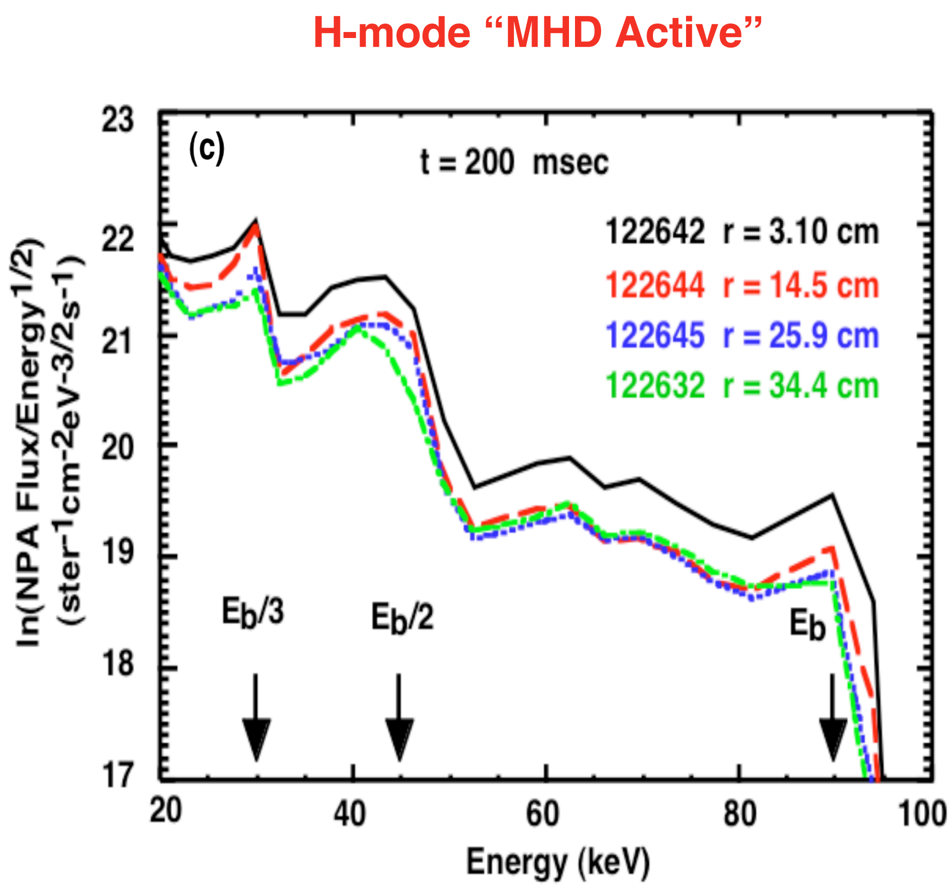


- **Later in the discharge, the vertical scan profiles remained flat (or became hollow in the core) and the magnitude of the efflux slowly diminished.**

Detail of NPA Vertical Scan Energetic Ion Distributions

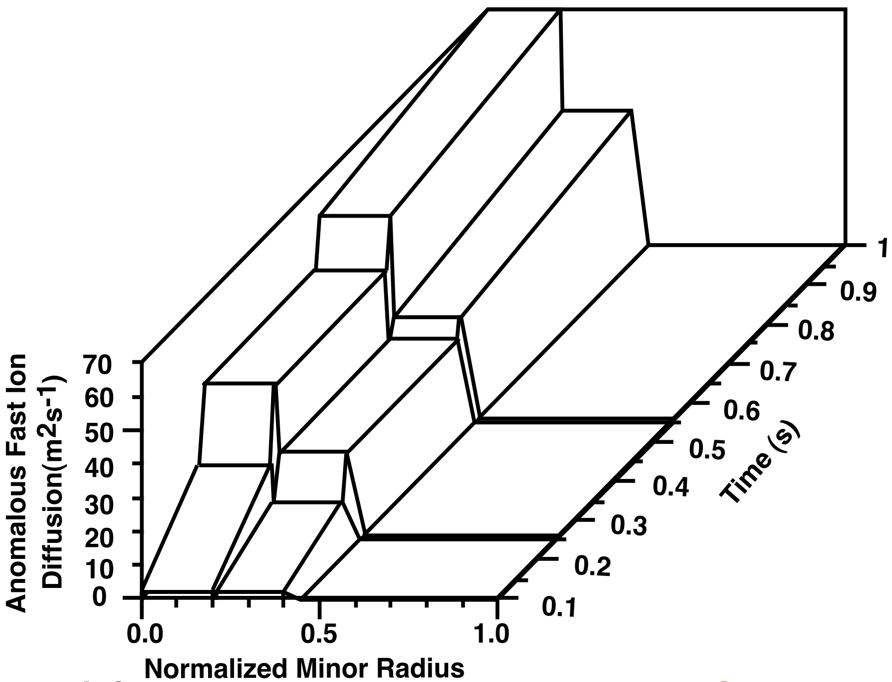
NSTX

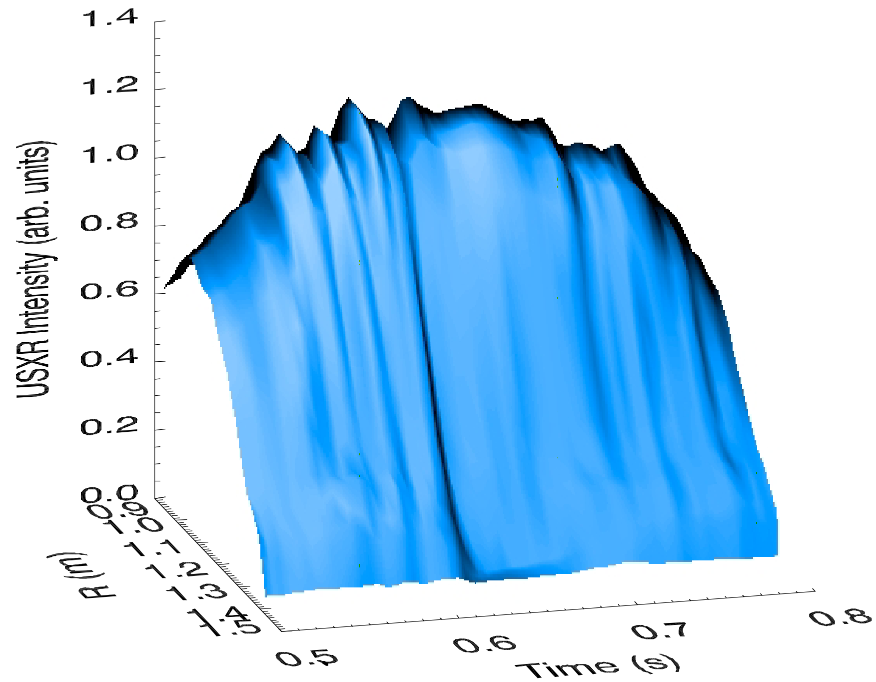


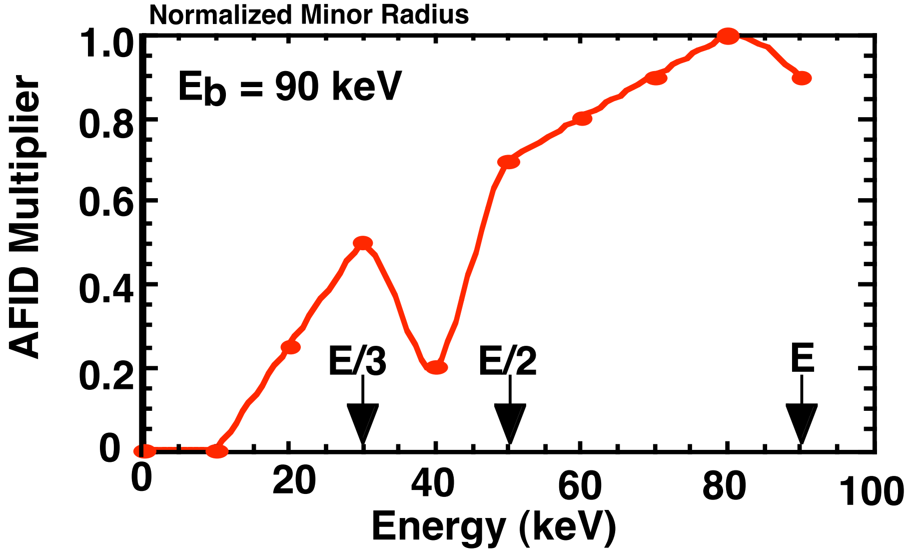


- Energetic ion distributions are show for selected radii during the vertical scan.

TRANSP Anomalous Fast Ion Diffusion (AFID) can be Specified in Time, Space and Fast-ion Energy





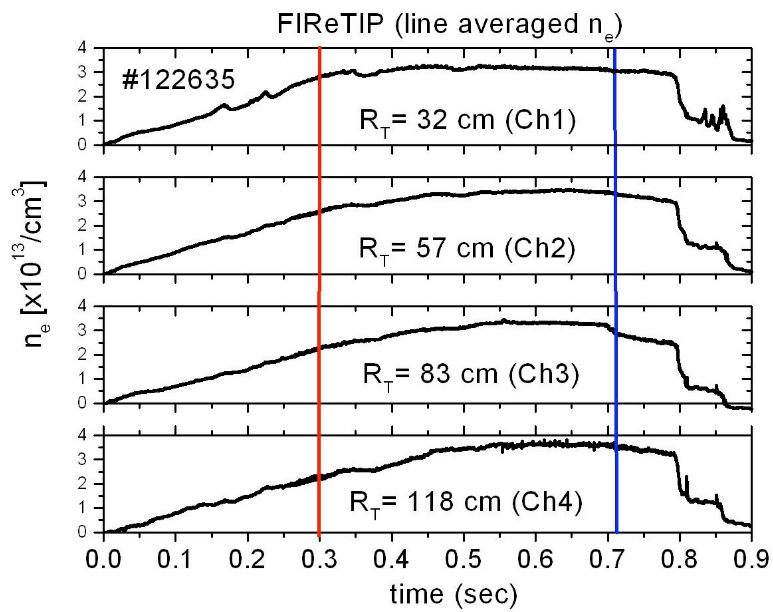


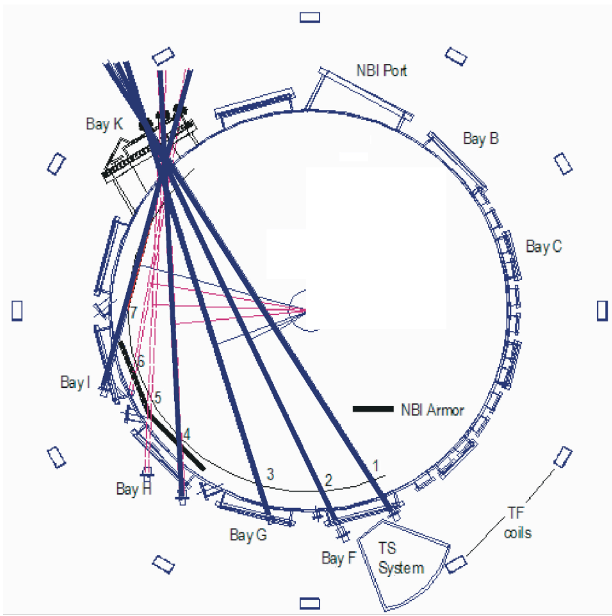
- Core-weighted AFID for MHD-induced fast-ion redistribution is consistent with USXR measurements.

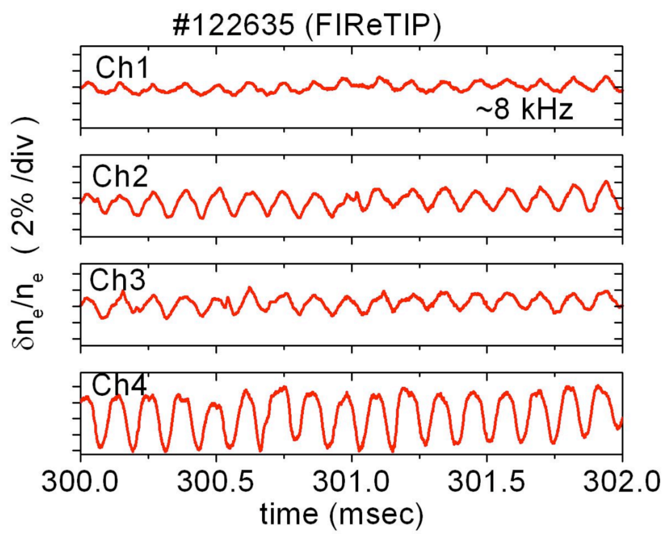
- Energy dependence is chosen to emulate the measured NPA spectrum distribution.

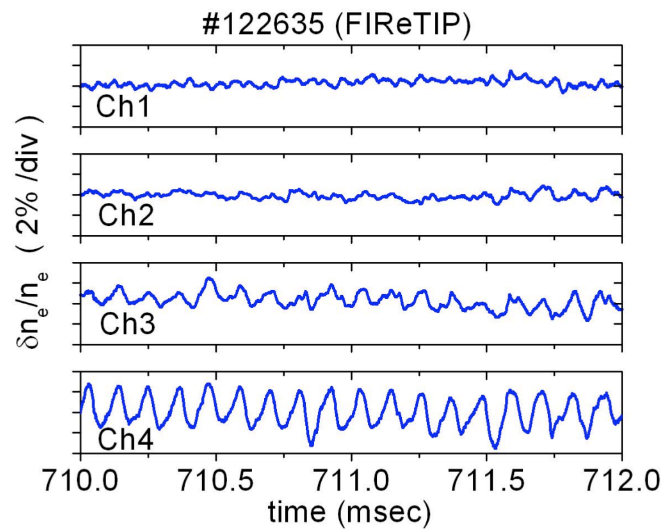
FIReTIP Measurements Localize the MHD Activity to the Plasma Core: $\delta n_e/n_e$ ~ 6% @ R ~ 118 cm

NSTX

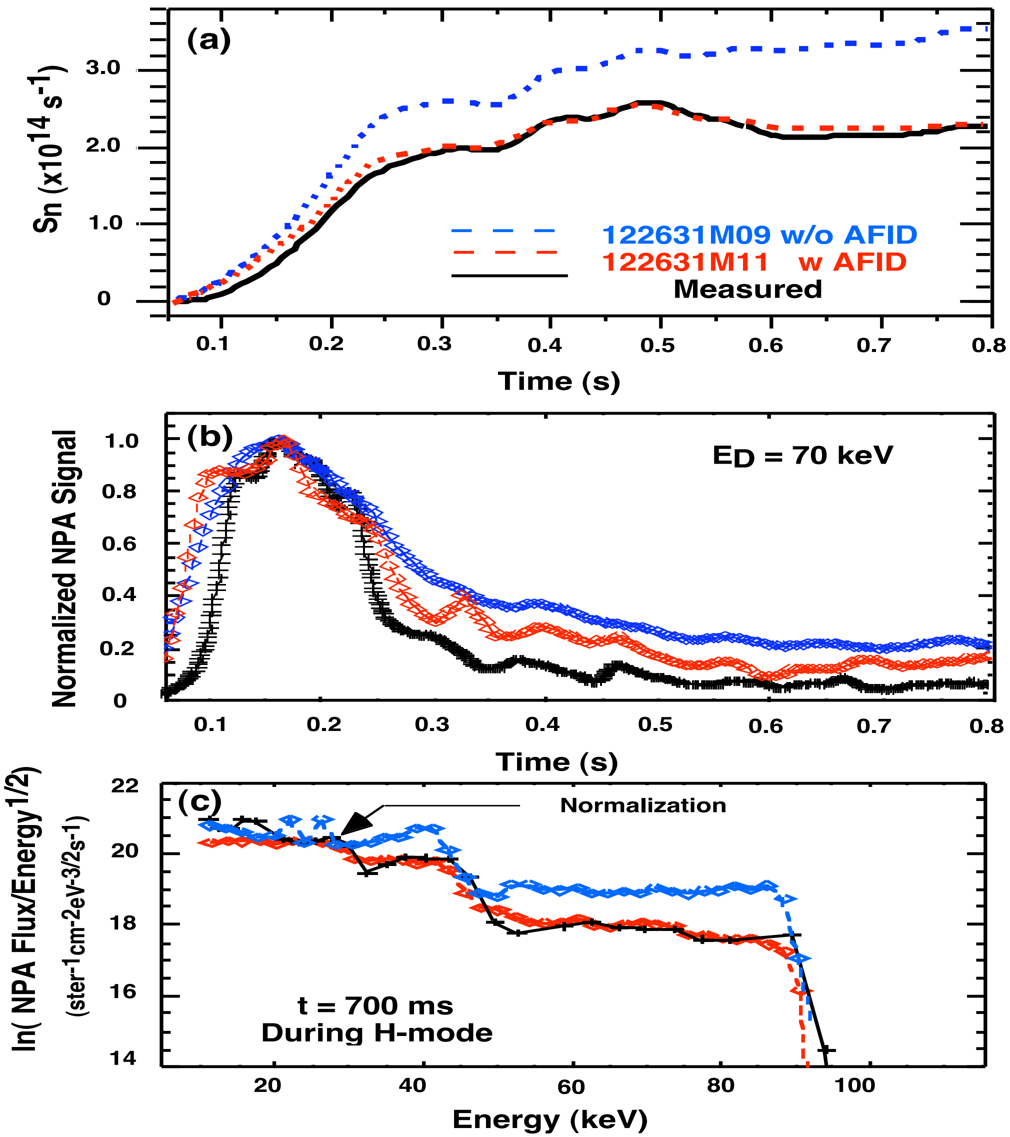








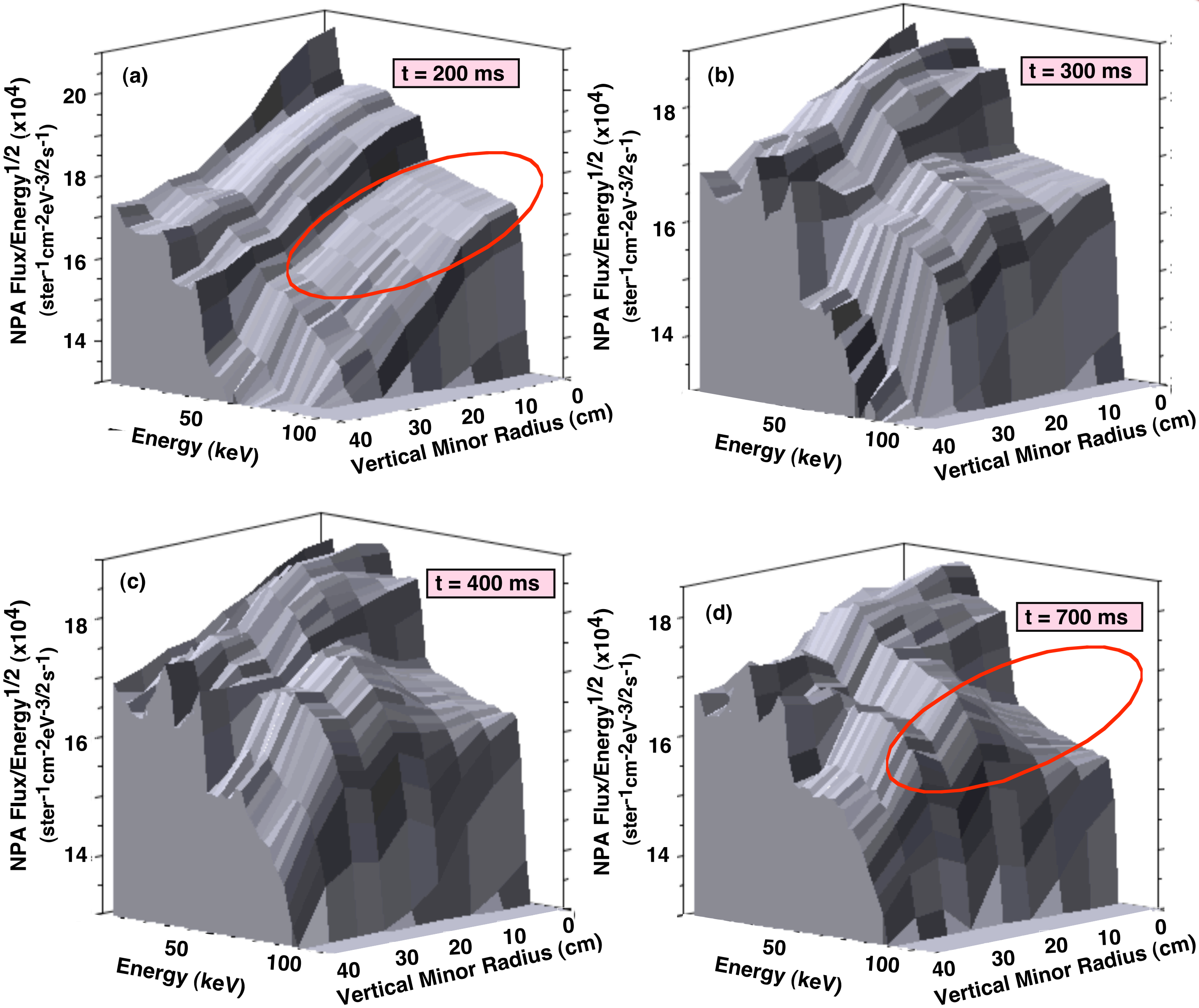
TRANSP Anomalous Fast Ion Diffusion (AFID) Can Simultaneously Match $S_n(t)$, $S_{npa}(t)$ and $f_{npa}(E)$



- The core-weighted AFID model in TRANSP was optimized to match measured and calculated neutron yield throughout the discharge.
- For t > 0.5 s, good matching of the NPA efflux evolution and energy spectra are obtained.
- Outboard-weighted AFID model cannot match neutron and NPA measurements.
- Inadequate treatment (volume averaged rather than NB localized) of beam halo neutrals in TRANSP remains an unresolved issue.

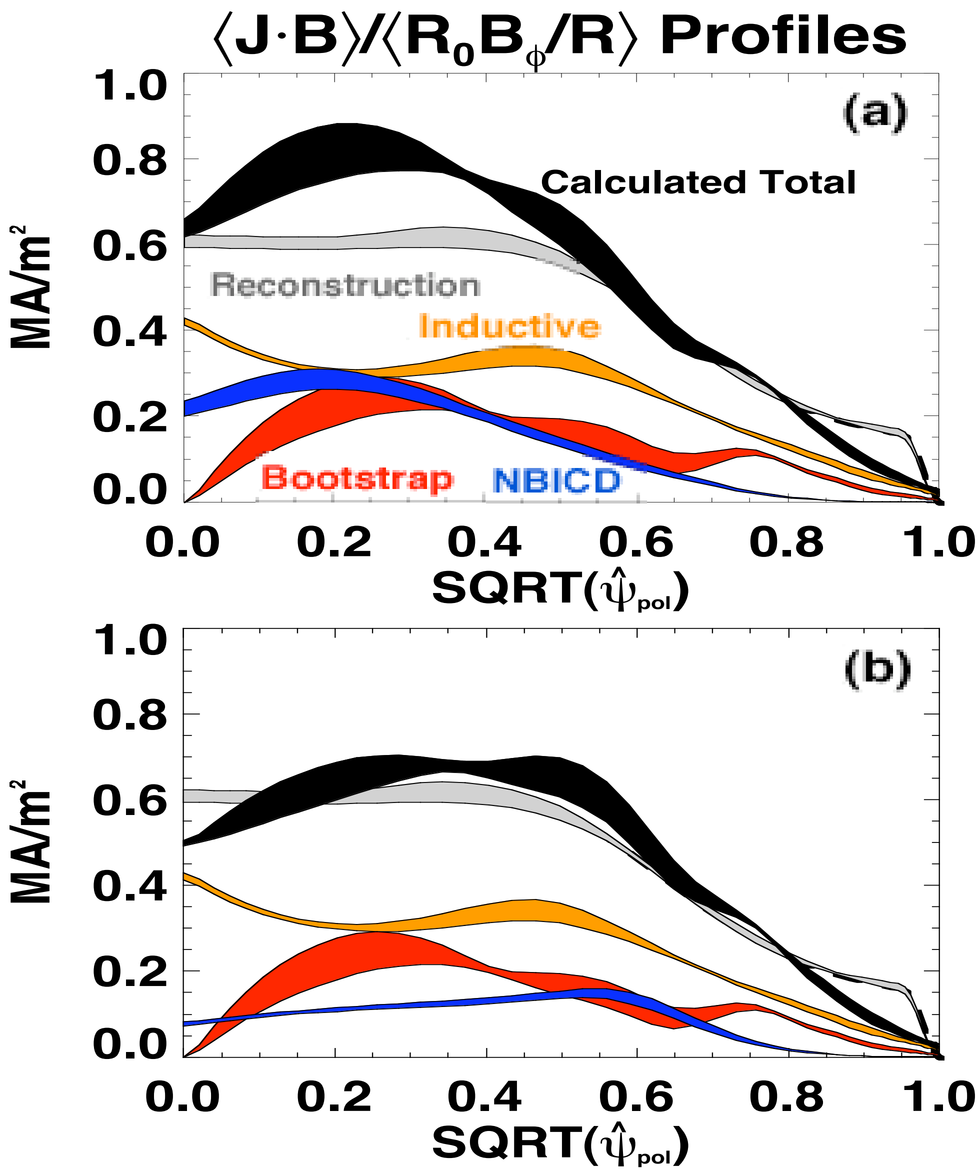
TRANSP Simulation of a NPA Vertical Scan with AFID Shows Outward Redistribution of Core Fast Ions

NSTX



Use of NBICD Redistribution Enables Matching of Calculated Toroidal Current Profiles with MSE Measurements

NSTX



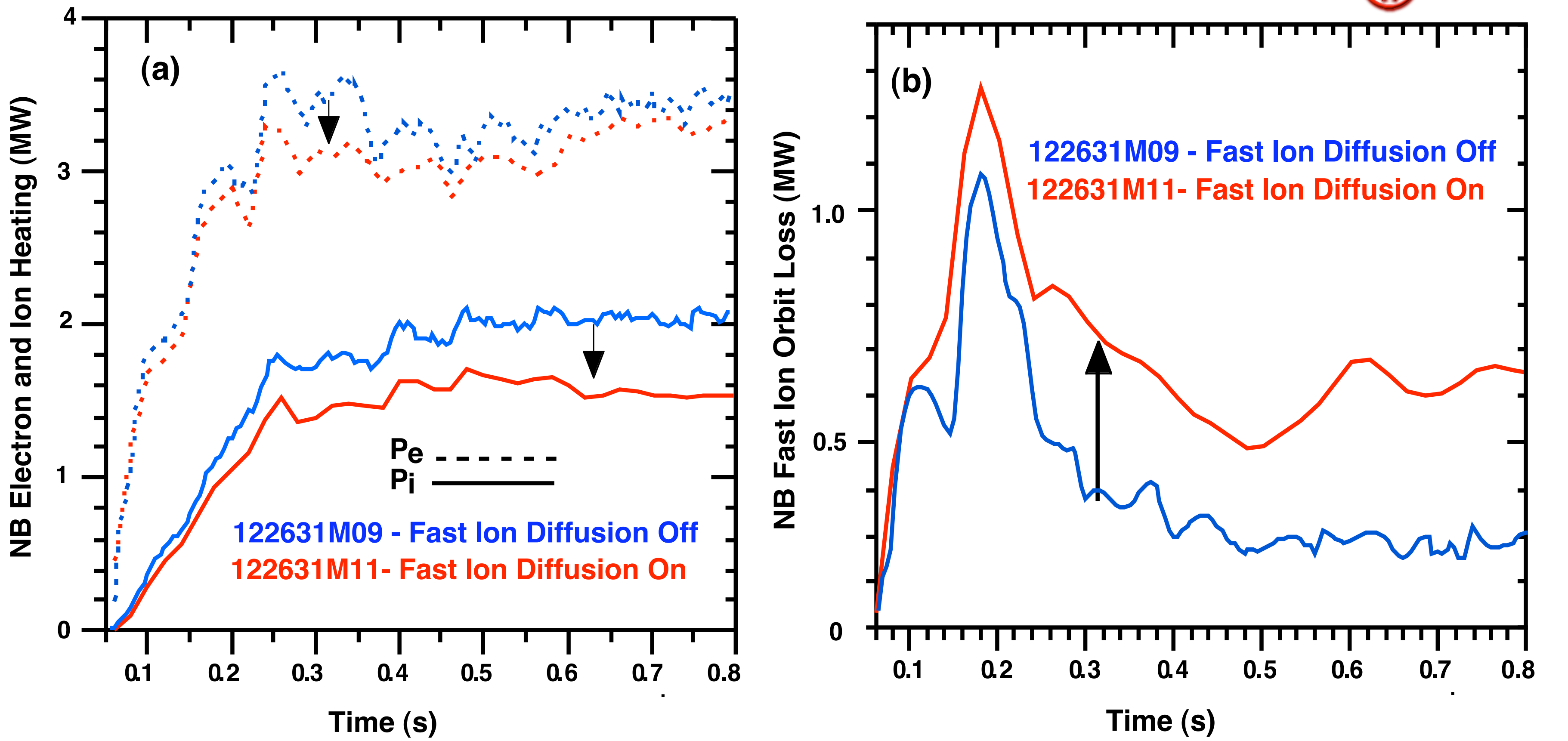
- An equilibrium code calculates the inductive (orange) and bootstrap (red) current profile components.

- The neutral beam injection current drive (NBICD, blue) profile is calculated in TRANSP. Summation yields the calculated total current density (black).

- In panel (a), the calculated total (black) exceeds the MSE-reconstructed value (gray) by 20-30% when NBICD redistribution is neglected.

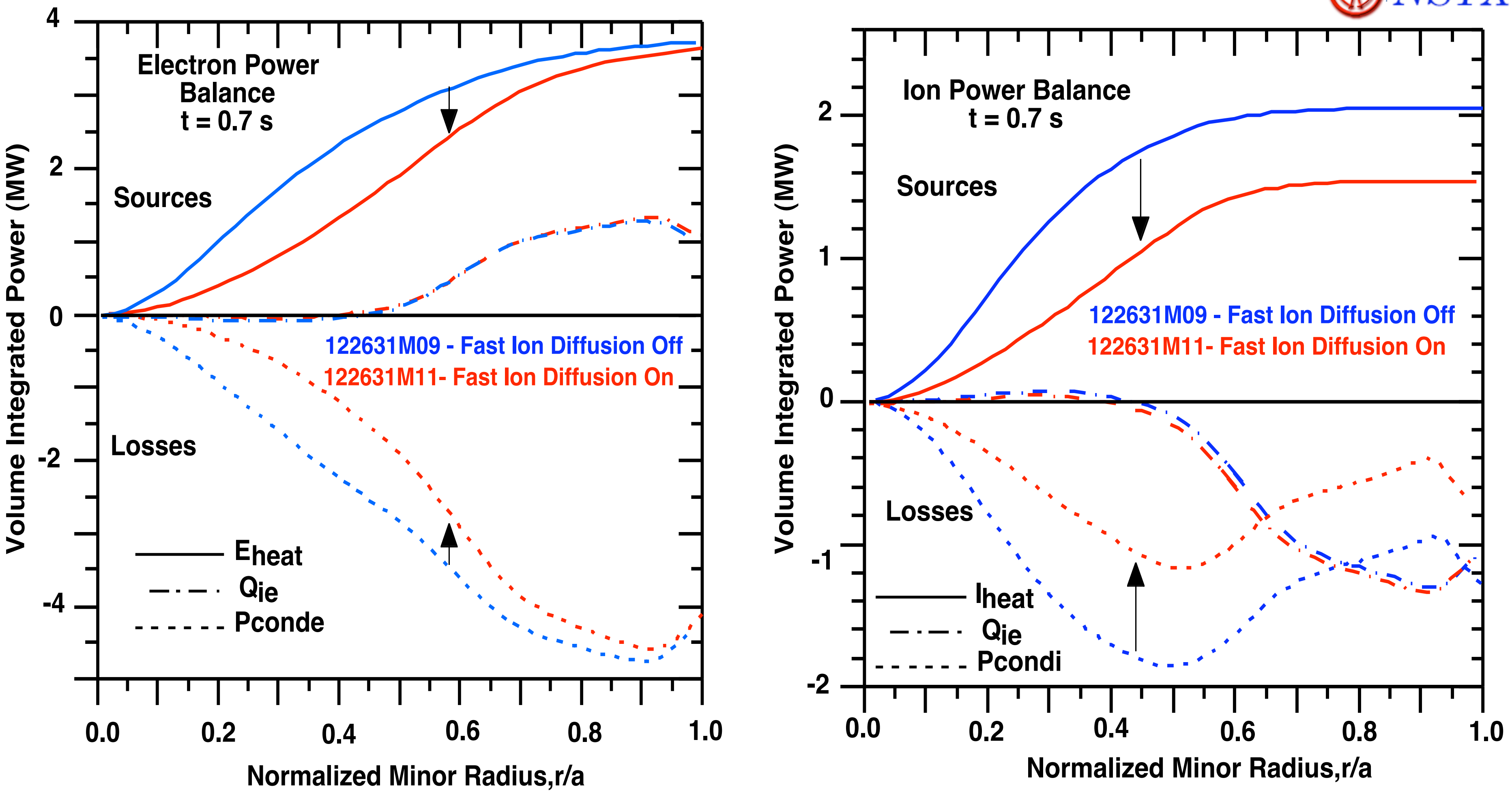
- In panel (b), including core AFID of ~ 70 m^2/s in the TRANSP-calculated NBICD component yields good agreement between the calculated total and MSE-constrained reconstruction current profiles.

AFID Reduces Electron and Ion Heating and Increases Fast Ion Orbit Loss



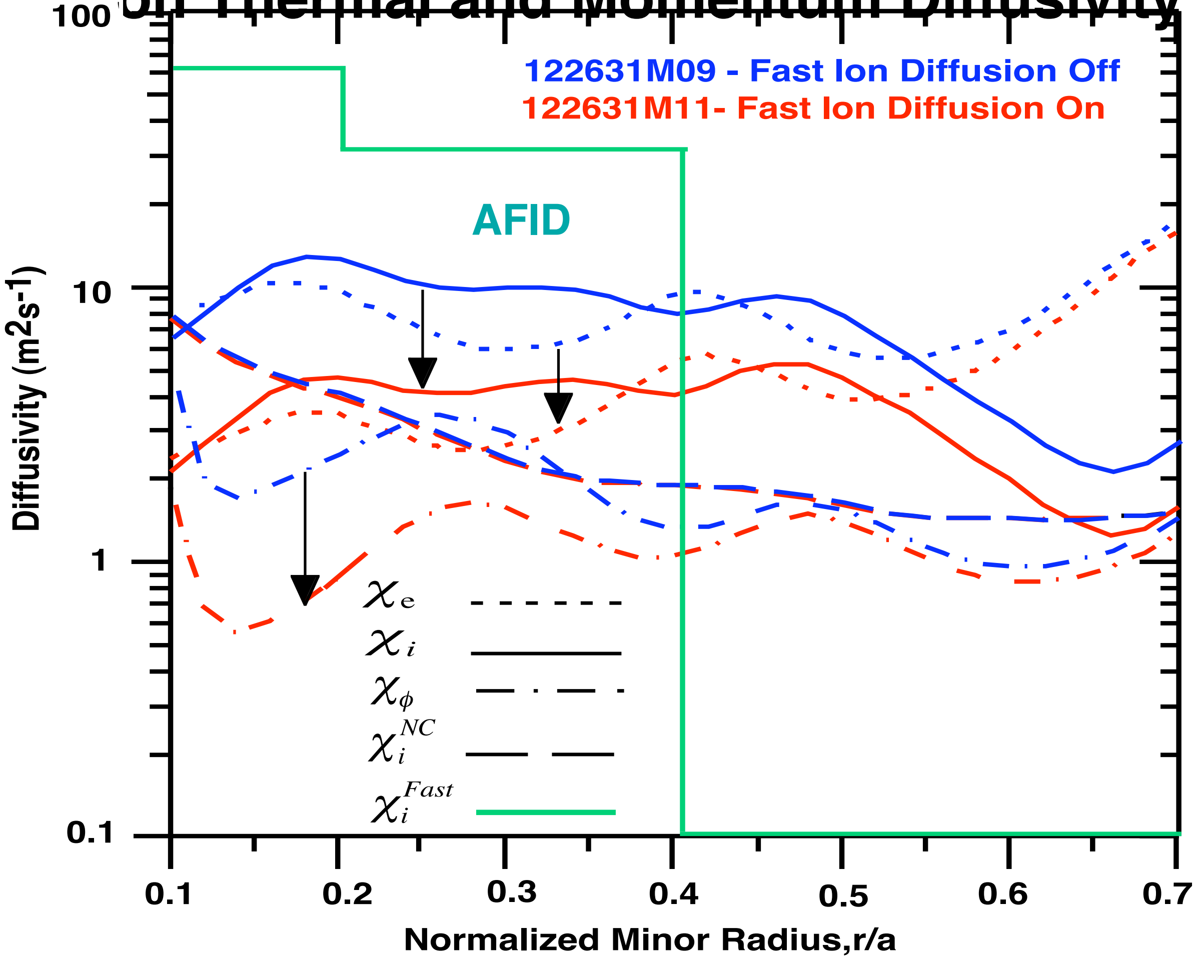
- **Electron heating is reduced by ~ 10% and ion heating is reduced by ~ 25%.**
- **Fast ion orbit loss approximately doubles, increasing by ~ 0.25 MW and reaching ~ 10% of the injected beam power.**

Effect of Anomalous Fast Ion Diffusion on Electron and Ion Power Balance



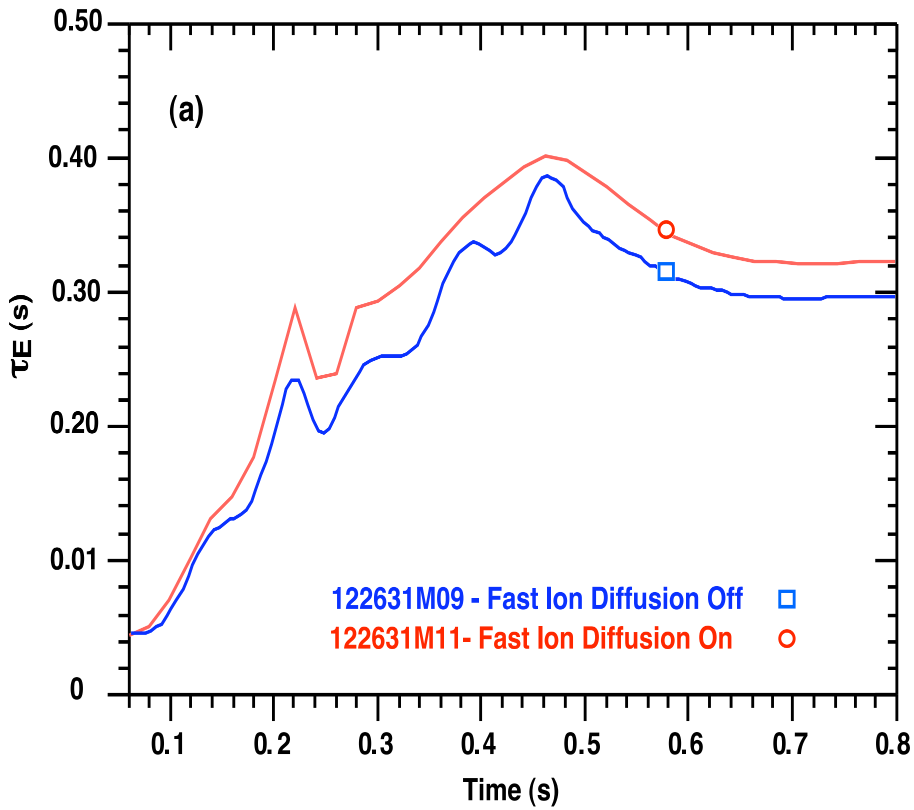
- Particle heating and hence conduction losses are reduced when fast ion diffusion is applied while Q_{ie} is relatively unaffected.

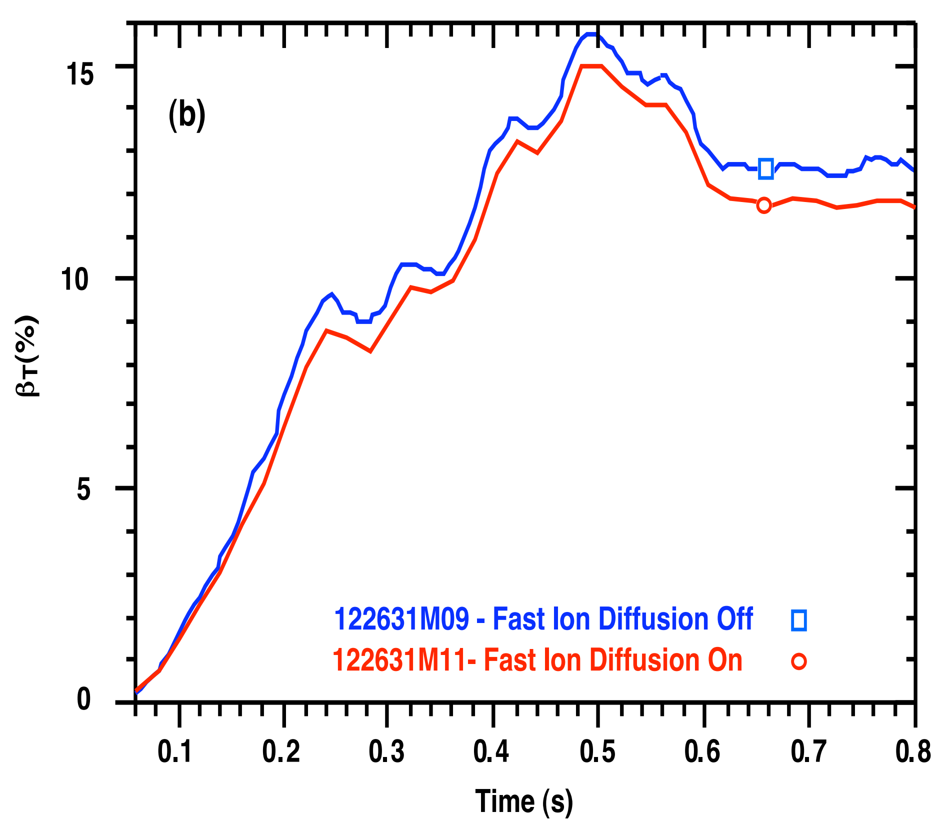
Effect of Anomalous Fast Ion Diffusion on Thermal and Momentum Diffusivity



- All diffusivities are reduced (except for χ_i^{NC} that ignores fast ions) when fast ion diffusion is applied. χ_Φ decreases primarily in the region of applied AFID.

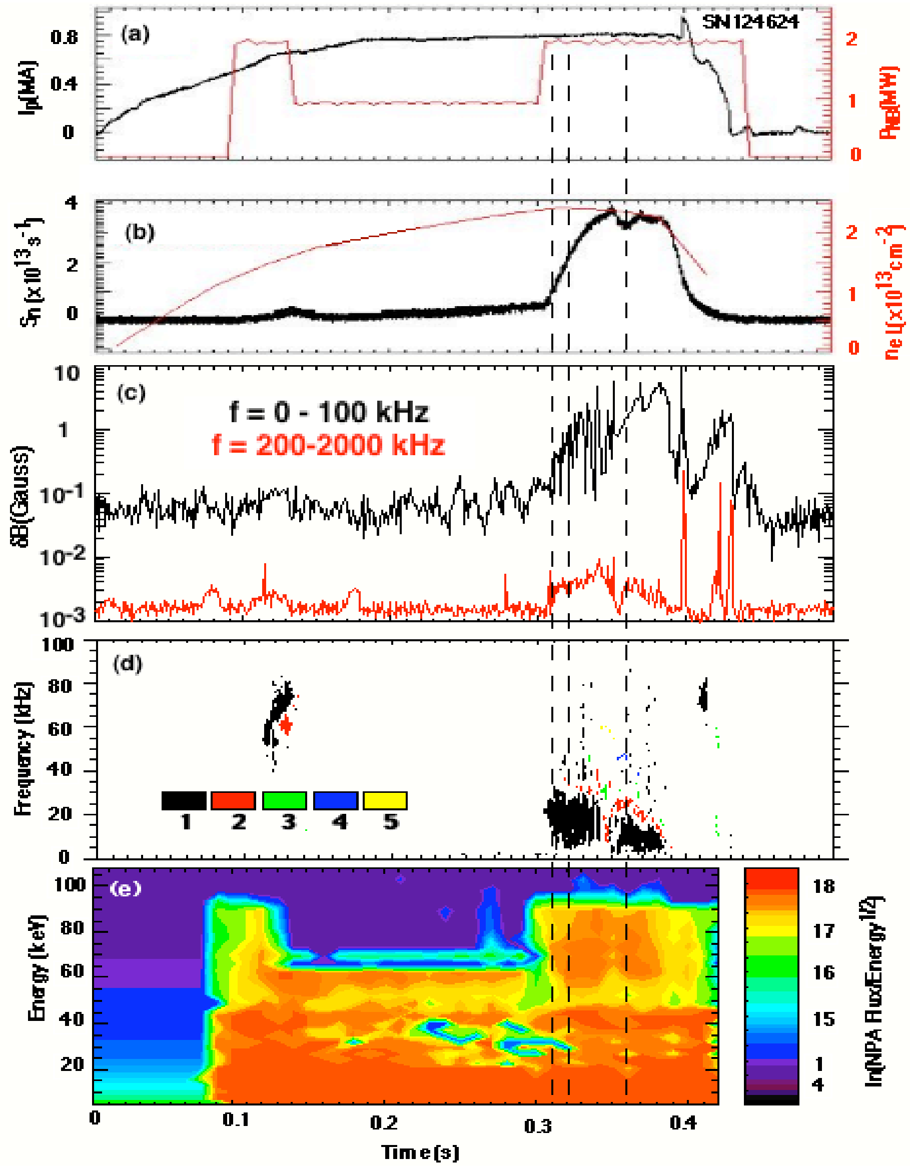
Effect of Anomalous Fast Ion Diffusion on Energy Confinement and Toroidal Beta

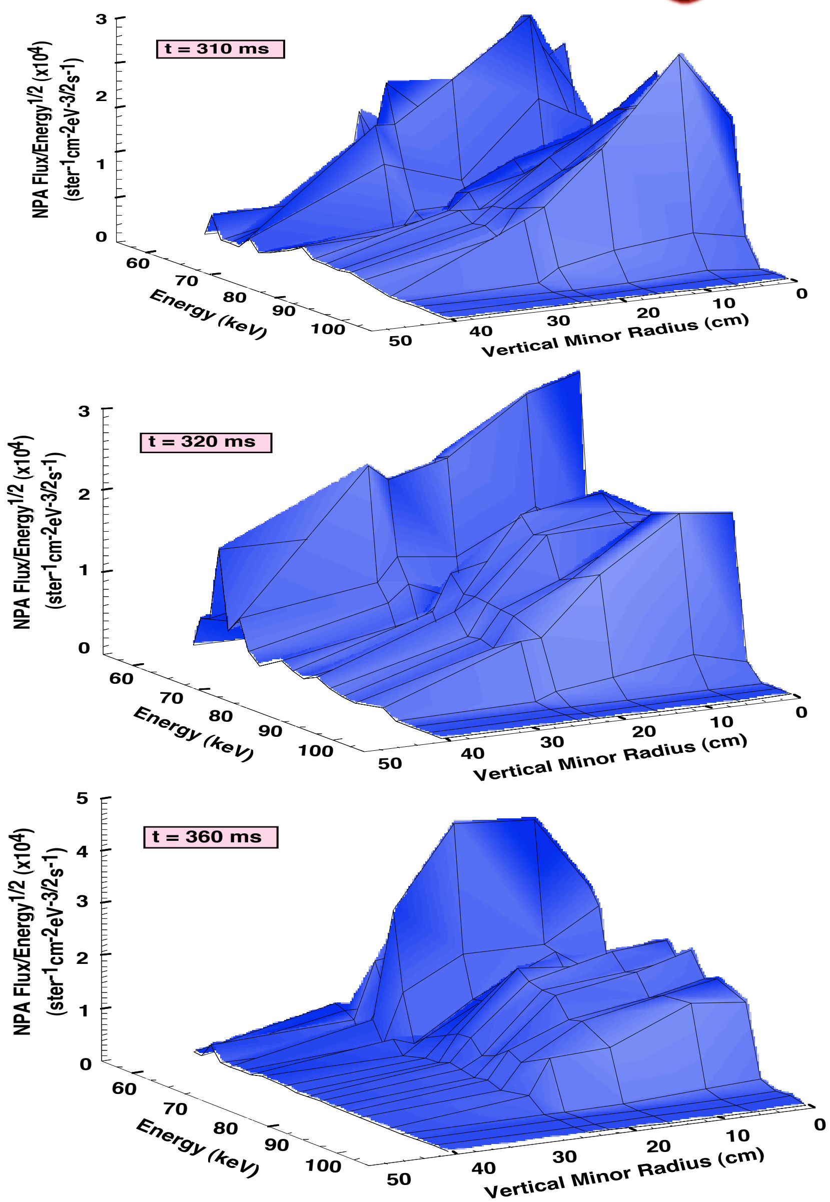




- **Anomalous fast ion diffusion causes modest reduction in τ_E and β_T.**

First Observation of MHD-induced Energetic Ion Redistribution in He L-mode Plasmas (Fredrickson, XP-705)





Summary

- NPA vertical scanning provides a direct measurement of MHD-induced energetic ion redistribution.

- The NPA vertical scan presented herein views passing energetic ions having a narrow range in field pitch: $v_{||}/v \sim 0.78 \pm 0.6$.

- MHD-induced energetic ion redistribution modeling using anomalous fast ion diffusion reduces the TRANSP-calculated neutron yield, NPA fast ion efflux and core-driven NBICD.

- sFLIP was not available during the vertical scan. A re-run of 122631 is desirable to complete the data set.

- First observation of MHD-induced energetic ion redistribution in He L-mode plasmas was made during a vertical scan in XP-705.