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DOUBLE-NSTX Code Analysis of Ion Temperature Profiles Measured by NPA Vertical Scanning

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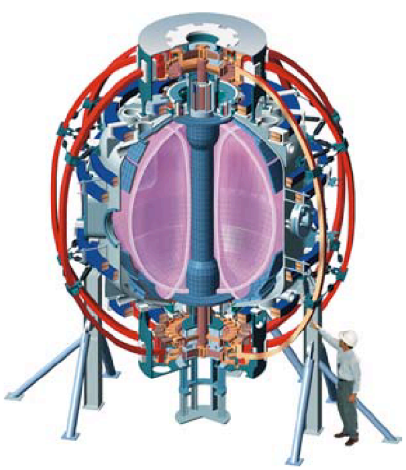

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August 1, 2005

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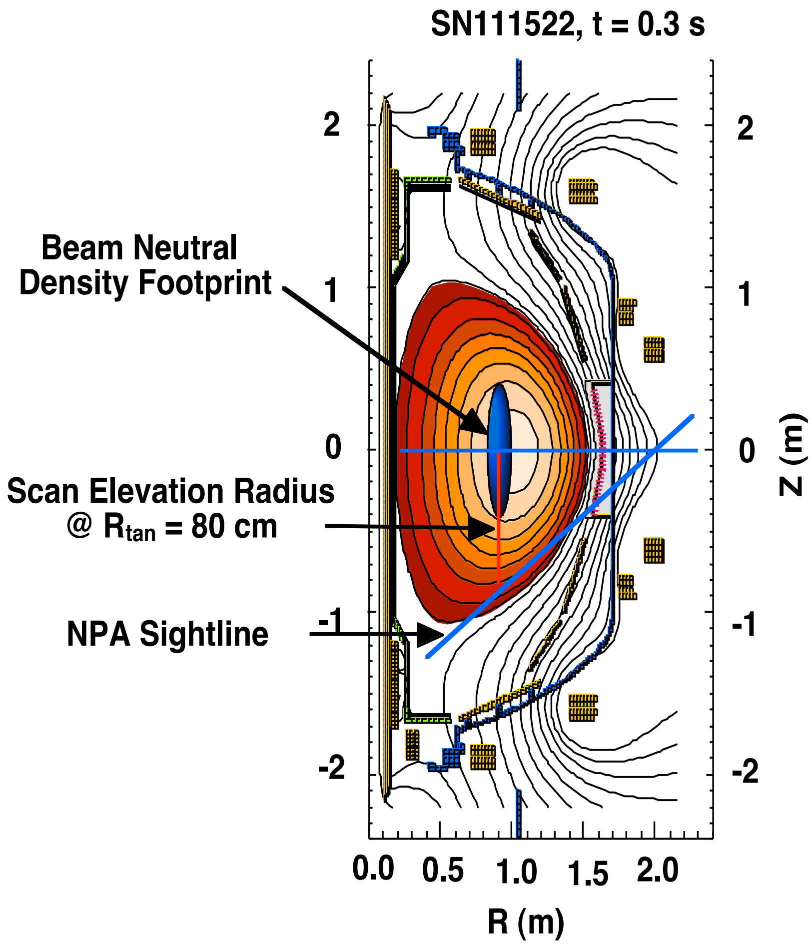
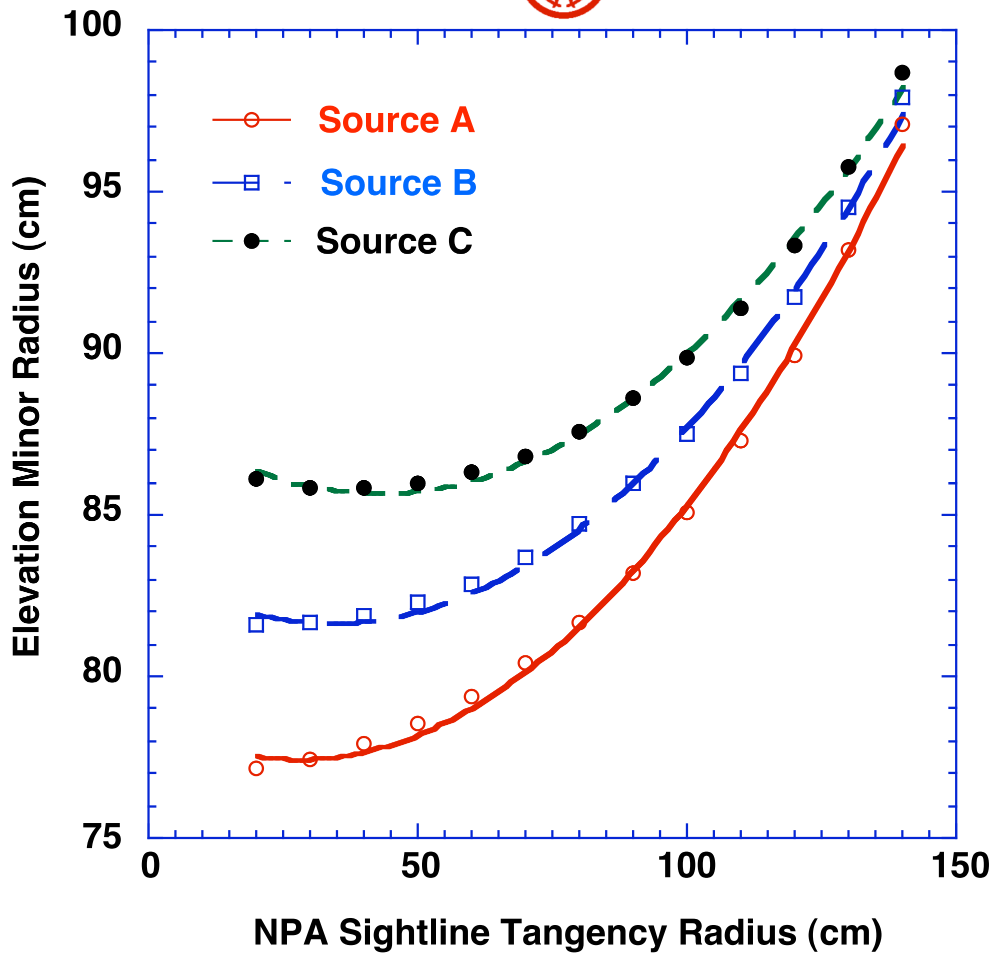
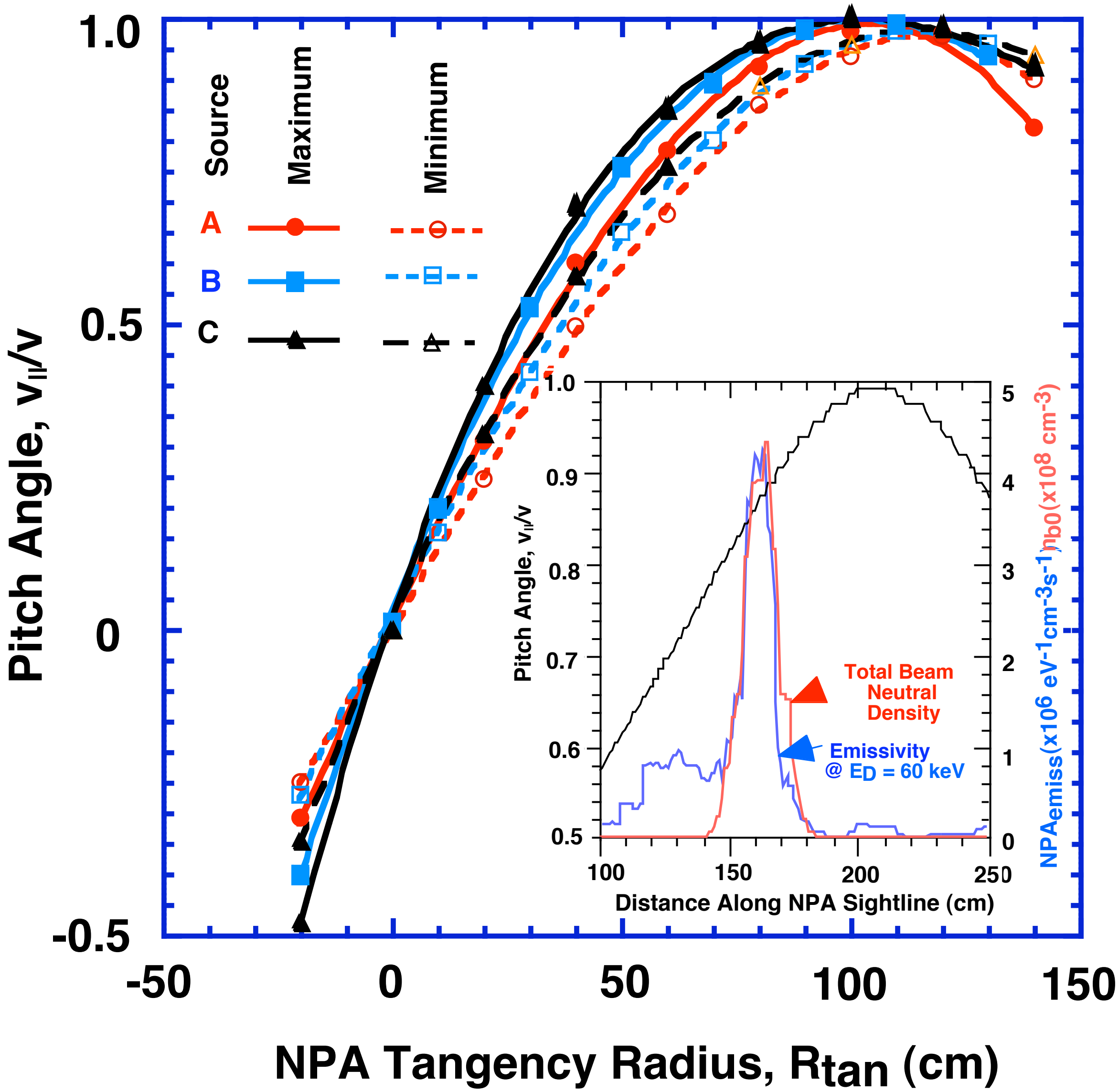
The NSTX NPA Can Scan 26º Vertically Downward





The elevation minor radius at the intersection of the NPA sightline with a given neutral beam line depends on the NPA mid-plane tangency radius.

NPA Measurements are Spatially Localized by Beam Injected Neutrals



- The beam injected neutrals spatially localize the NPA signal (insert).
- Up to 2/3 of the line-integrated flux can originate in the NB region.
- This spatial localization also constrains the range of pitch angles viewed by the NPA (main panel).
- The spatial localization weakens with increasing NB penetration distance (due to attenuation of the beam neutrals) and increasing n_e.

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Features of the DOUBLE-NSTX Thermal Analysis Code

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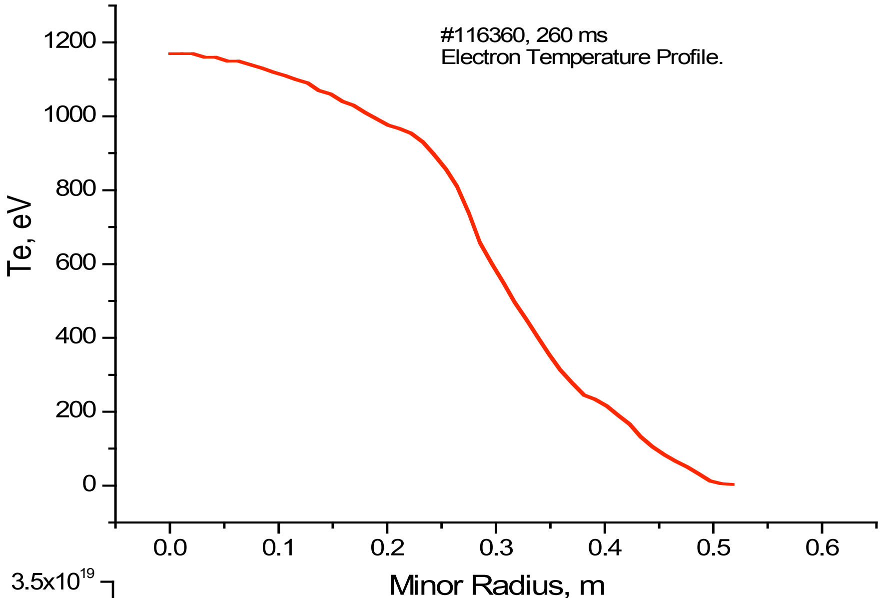
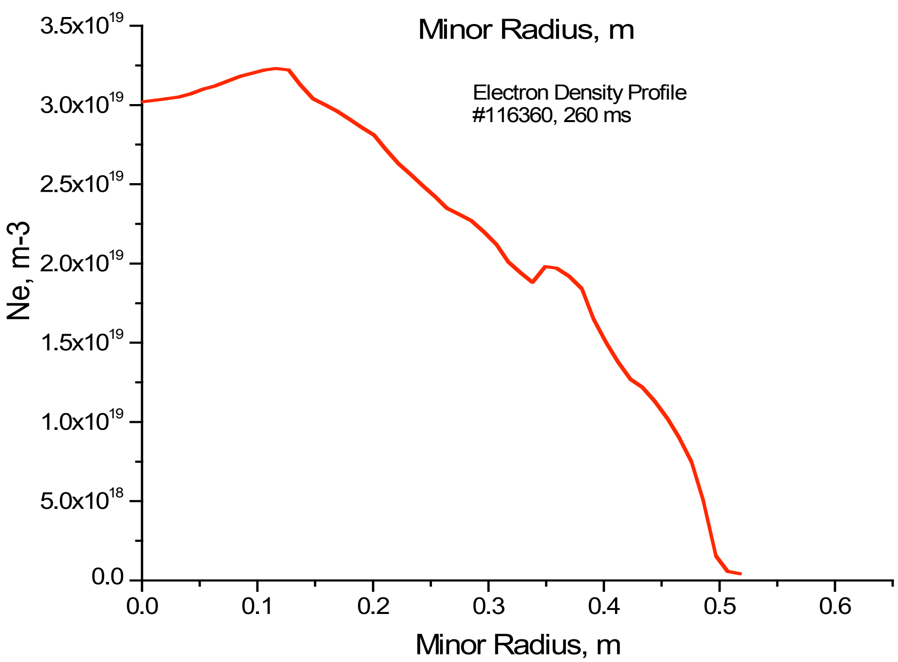
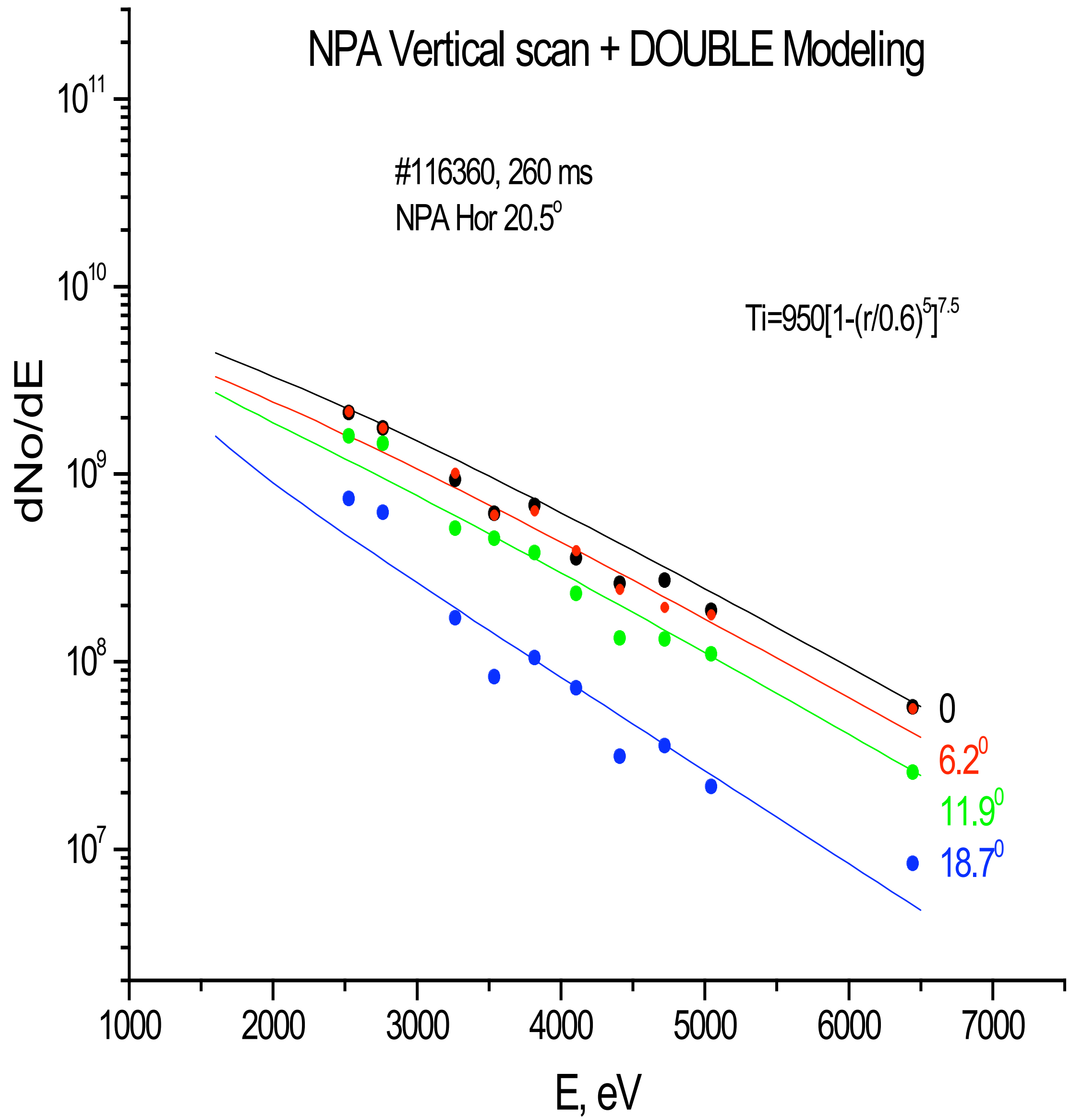




- **The legacy Ioffe code DOUBLE was upgraded for NSTX to incorporate:**
  - **- toroidal geometry**
  - **- Monte-Carlo transport of beam and edge neutrals**
  - **- EFIT magnetic equilibrium**
  - **- horizontal and vertical NPA scanning**
- **Input parameters include:**
  - **- $T_e(r)$, $n_e(r)$, $T_i(r)$, Z_{eff}, NB parameters, and EFIT equilibrium at a selected time**
- **Code outputs are:**
  - **- neutral density radial profile**
  - **- charge exchange emissivity profiles**
  - **- thermal flux spectra**
  - **- emissivity-corrected NPA T_i**
- **A code run takes 3 - 5 minutes on a desktop PC**

DOUBLE-NSTX Code $T_i(r)$ Analysis Procedure



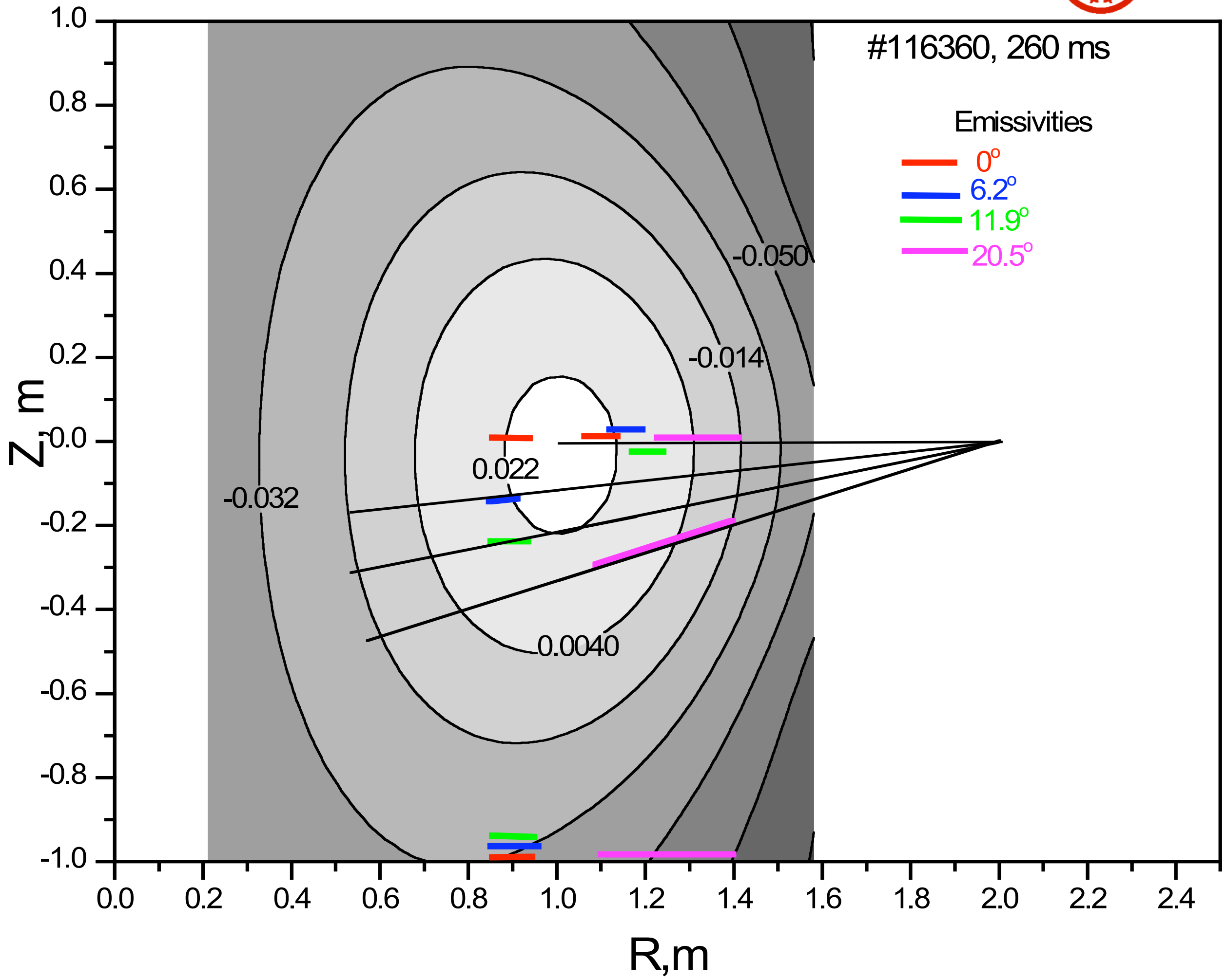
- **DOUBLE-NSTX analysis procedure:**
  - **define an trial analytic ion temperature profile of the form**

$$T_i(r) = T(0)[1 - (r/a)^x]^y$$

(usually based on CHERS)

  - **vary T(0) for the core data (r/a = 0) to match the NPA spectrum and normalize the DOUBLE spectrum (once only)**
  - **iteratively vary the trial profile to obtain a single profile that matches all of the NPA profile spectra simultaneously**
  - **flux surface map the vertical $T_i(r)$ profile onto the horizontal mid-plane for comparison with the CHERS profile**

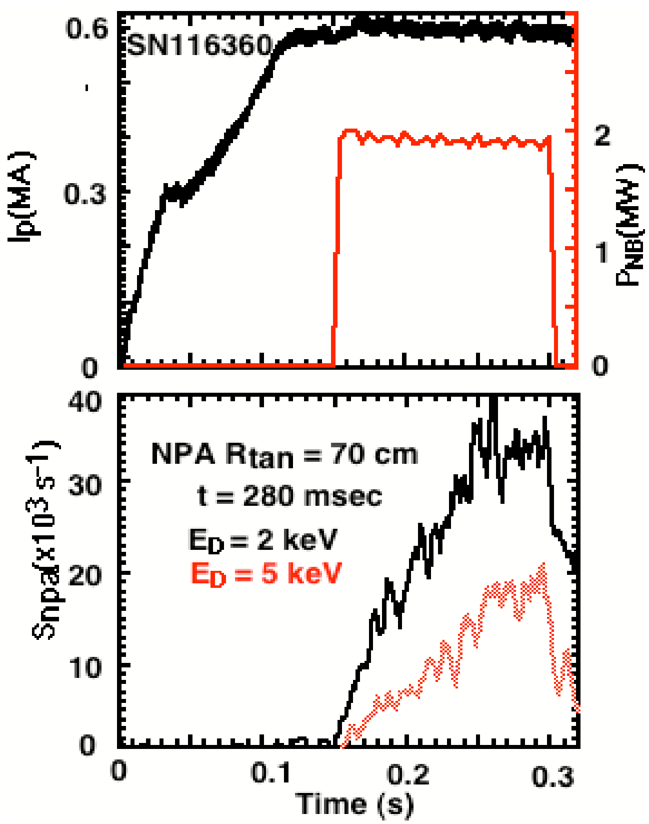
Mapping the NPA Vertical $T_i(r)$ Profile To the Mid-plane CHERS Profile

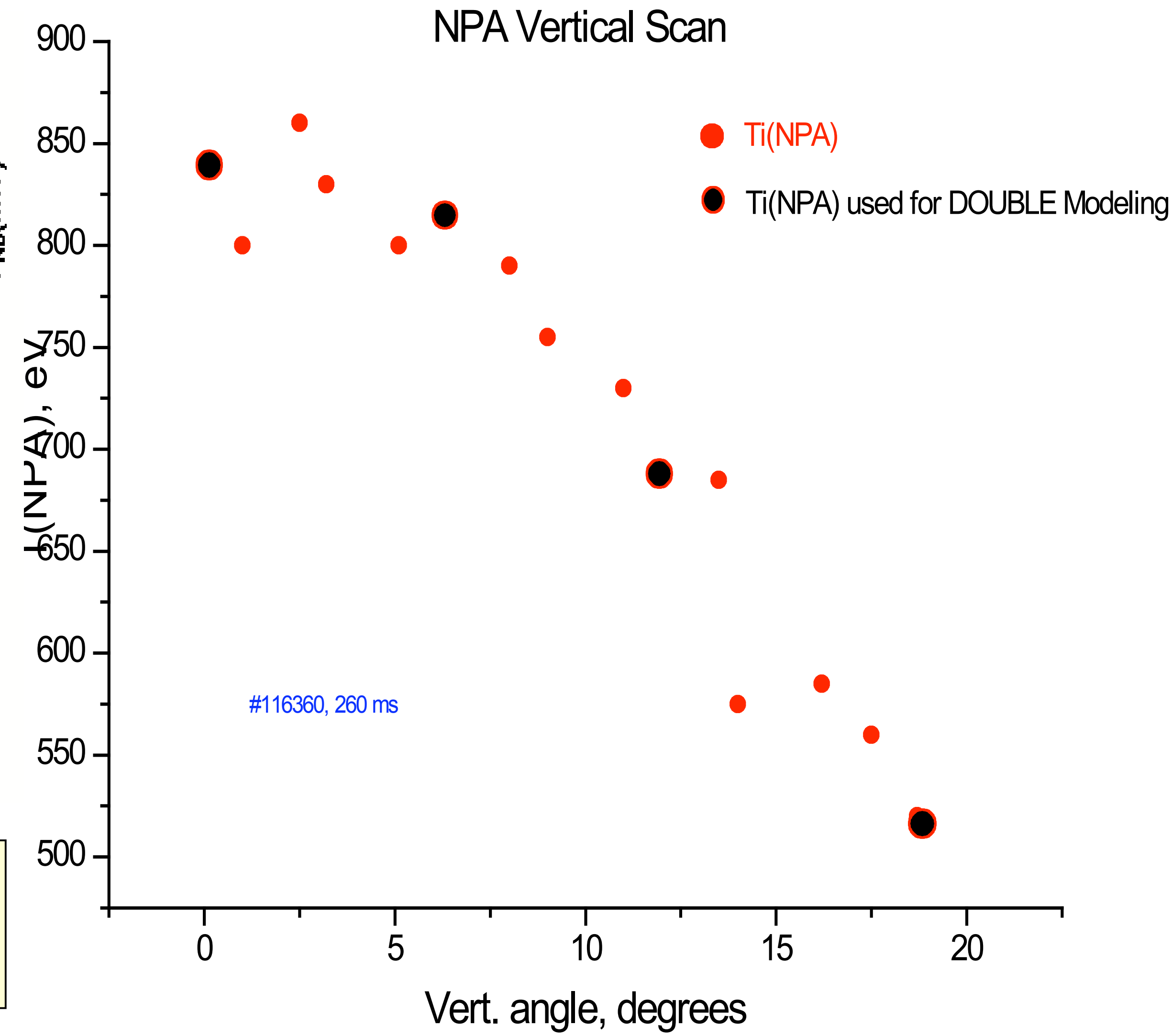


Color bars on the NPA sightlines show regions of emissivity localization. Companion bars show flux surface mapping to the outer mid-plane.

NPA Ti(r) Measurement during Deuterium NB Injection into a He Plasma

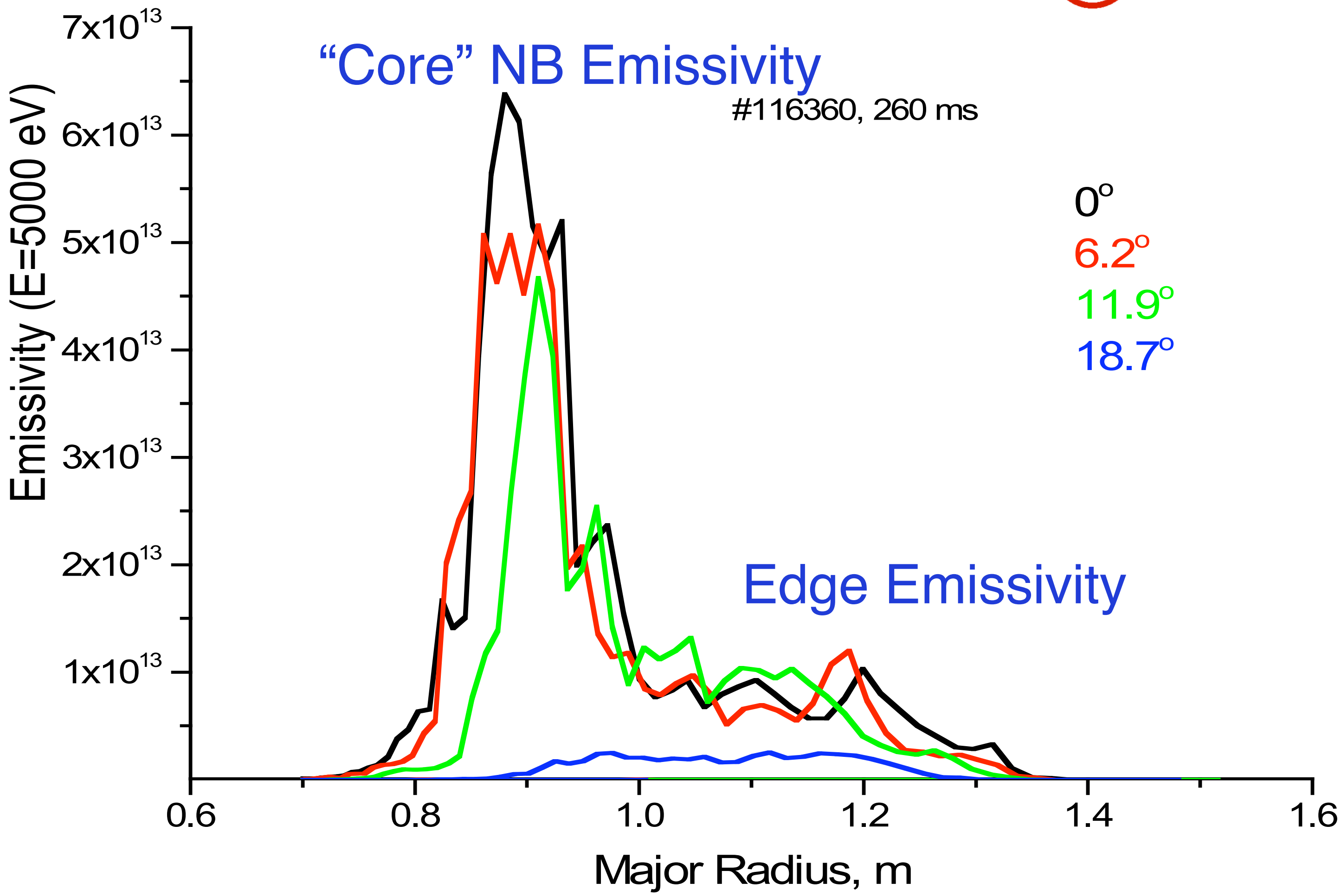
NSTX





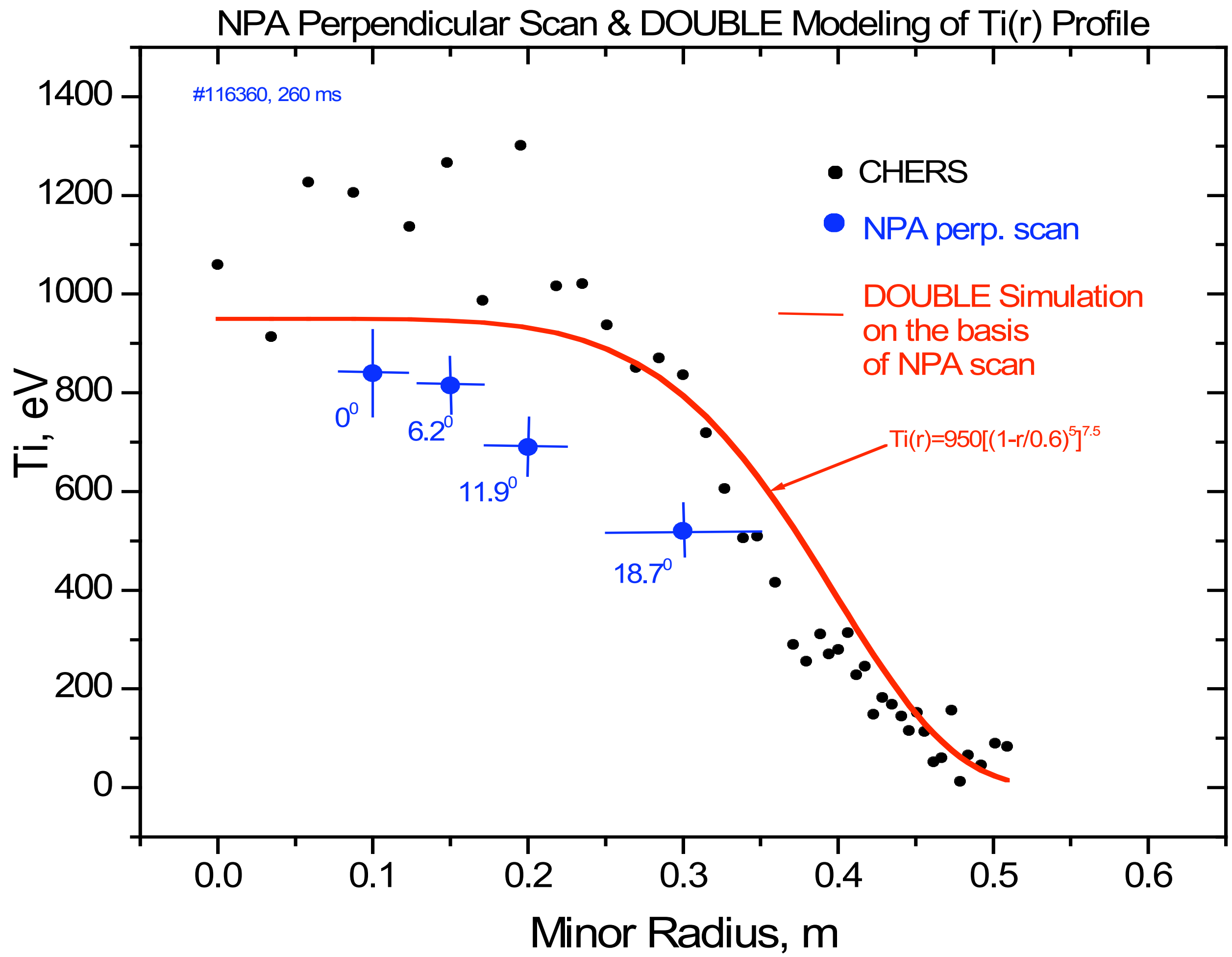
L-mode He discharges with I_p = 0.6MA, $n_e \sim 2\times10^{13}$ cm^{-3}, B_T = 4.5 kG, NB A @ 90 keV.

NPA $T_i(r)$ Measurements Require the CX Emissivity to be "Core-localized"



The necessary "core-localization" restricts NPA $T_i(r)$ profile measurements to NB-heated L-mode discharges (excludes Ohmic and H-mode discharges).

Comparaison of the Emissivity-corrected NPA $T_i(r)$ With CHERS



The emissivity-corrected core ion temperature derived from DOUBLE-NSTX analysis is ~ 15-20% above the raw NPA T_i value but ~ 10-15% below the CHERS measurement.

Effect of Toroidal Rotation the NPA T_i Measurement

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- Definitions: E - energy of the detected particle
  E_ϕ - toroidal rotation energy
  T - ion temperature

- For rotation towards the NPA, the Mawellian ion energy in the plasma rest frame is

$$E_+ = (\sqrt{E} - \sqrt{E_\phi})^2 \quad \text{and the source flux is} \quad f_+ \propto e^{-\frac{(\sqrt{E}-\sqrt{E_\phi})^2}{T}} \left| \sqrt{E} - \sqrt{E_\phi} \right|$$

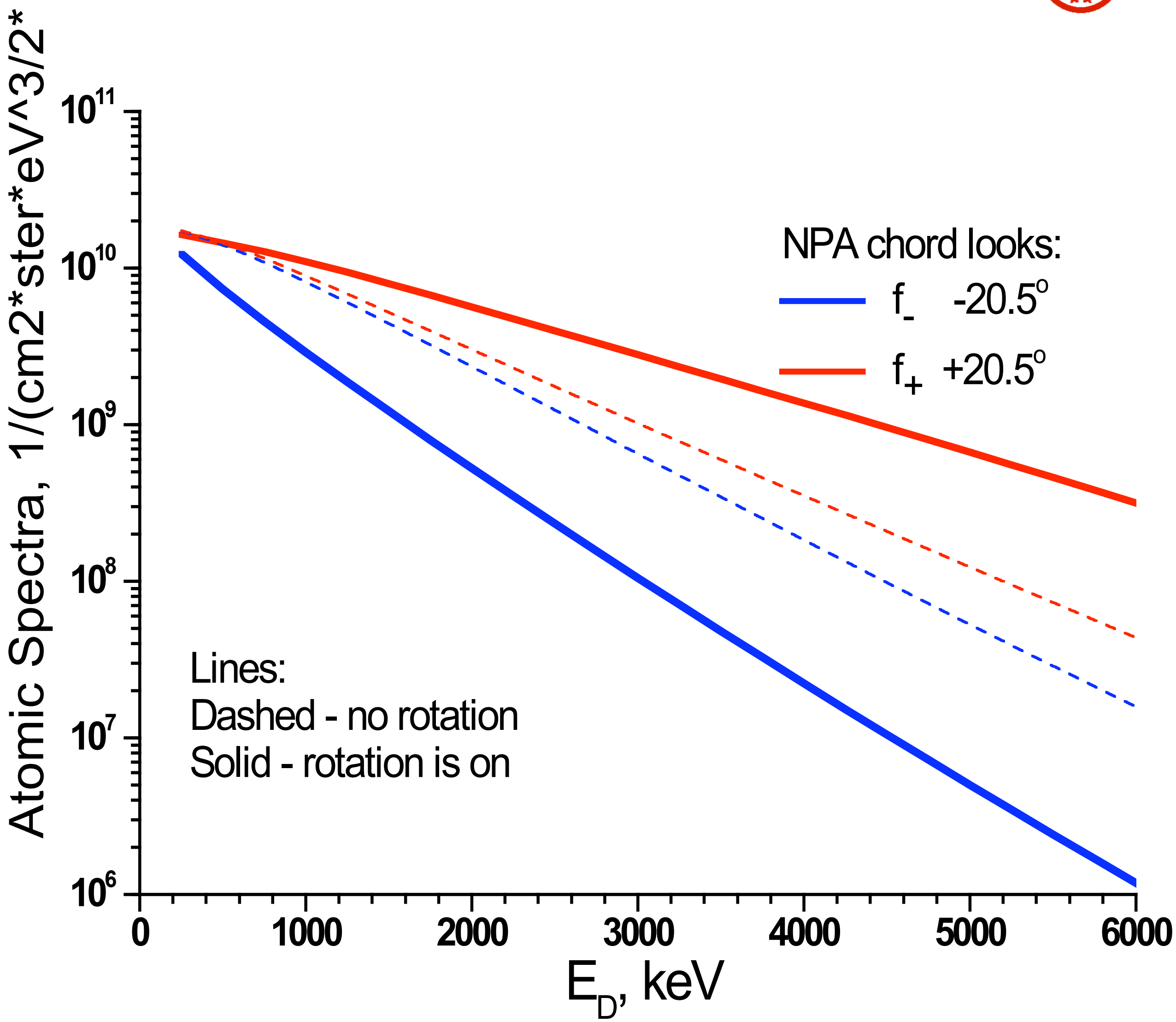
- For rotation away from the NPA, the Mawellian ion energy in the plasma rest frame is

$$E_- = (\sqrt{E} + \sqrt{E_\phi})^2 \quad \text{and the source flux is} \quad f_- \propto e^{-\frac{(\sqrt{E}+\sqrt{E_\phi})^2}{T}} (\sqrt{E} + \sqrt{E_\phi})$$

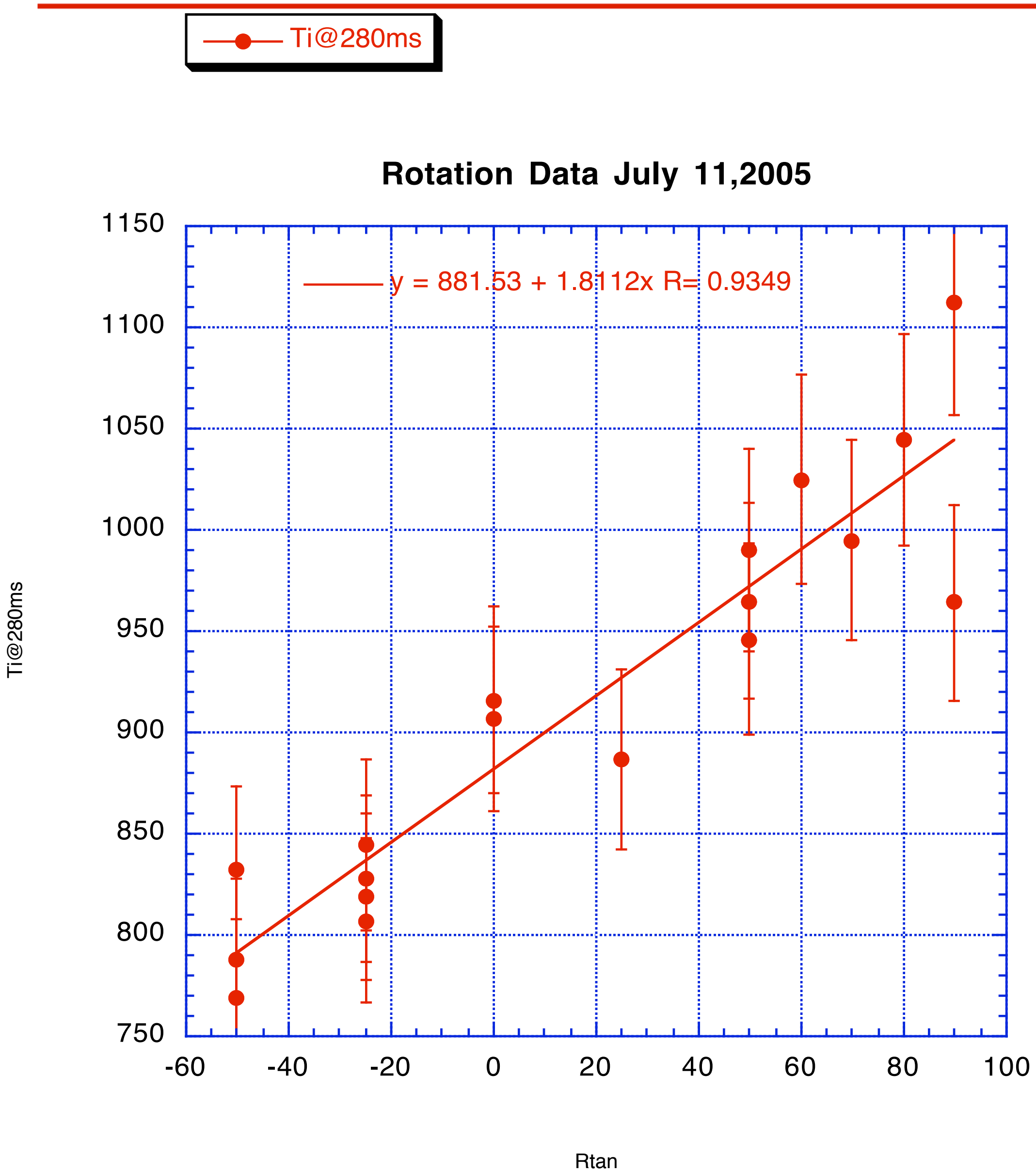
- The 'towards' to 'away' NPA flux ratio varies exponentially with toroidal rotation velocity

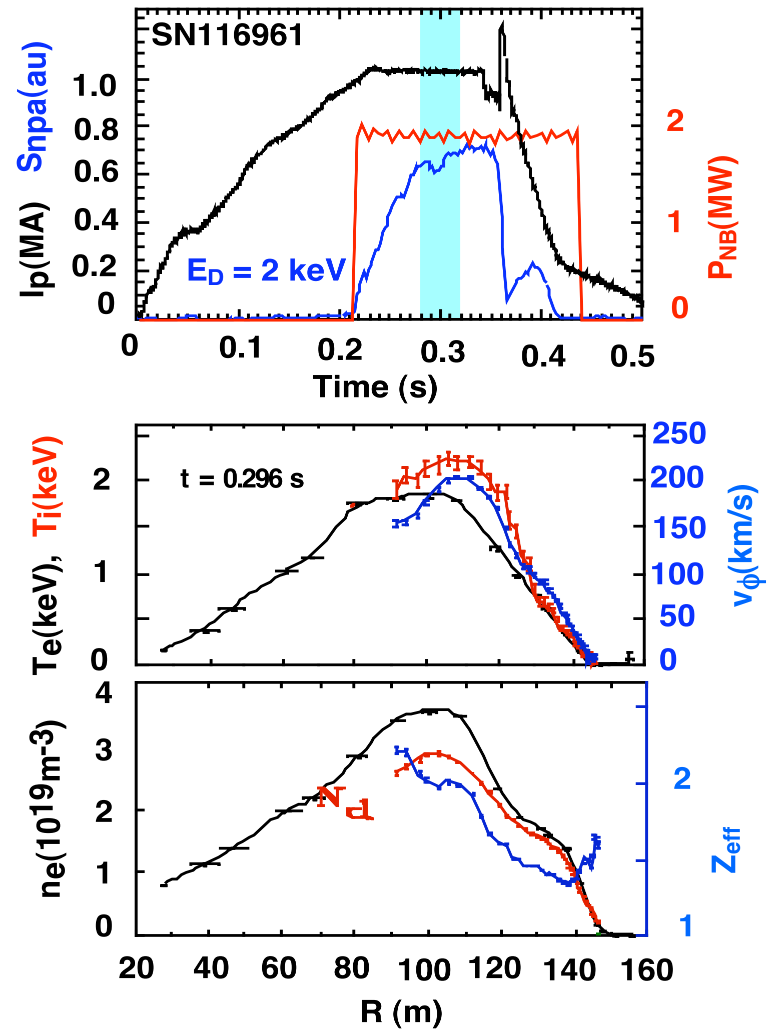
$$\frac{f_+}{f_-} = \frac{e^{-\frac{(\sqrt{E}-\sqrt{E_\phi})^2}{T}} (\sqrt{E} - \sqrt{E_\phi})}{e^{-\frac{(\sqrt{E}+\sqrt{E_\phi})^2}{T}} (\sqrt{E} - \sqrt{E_\phi})} = e^{4\frac{\sqrt{E_\phi E}}{T}} \frac{\left| \sqrt{E} - \sqrt{E_\phi} \right|}{(\sqrt{E} + \sqrt{E_\phi})}$$

Illustration of Toroidal Rotation Effect on DOUBLE-NSTX Analysis

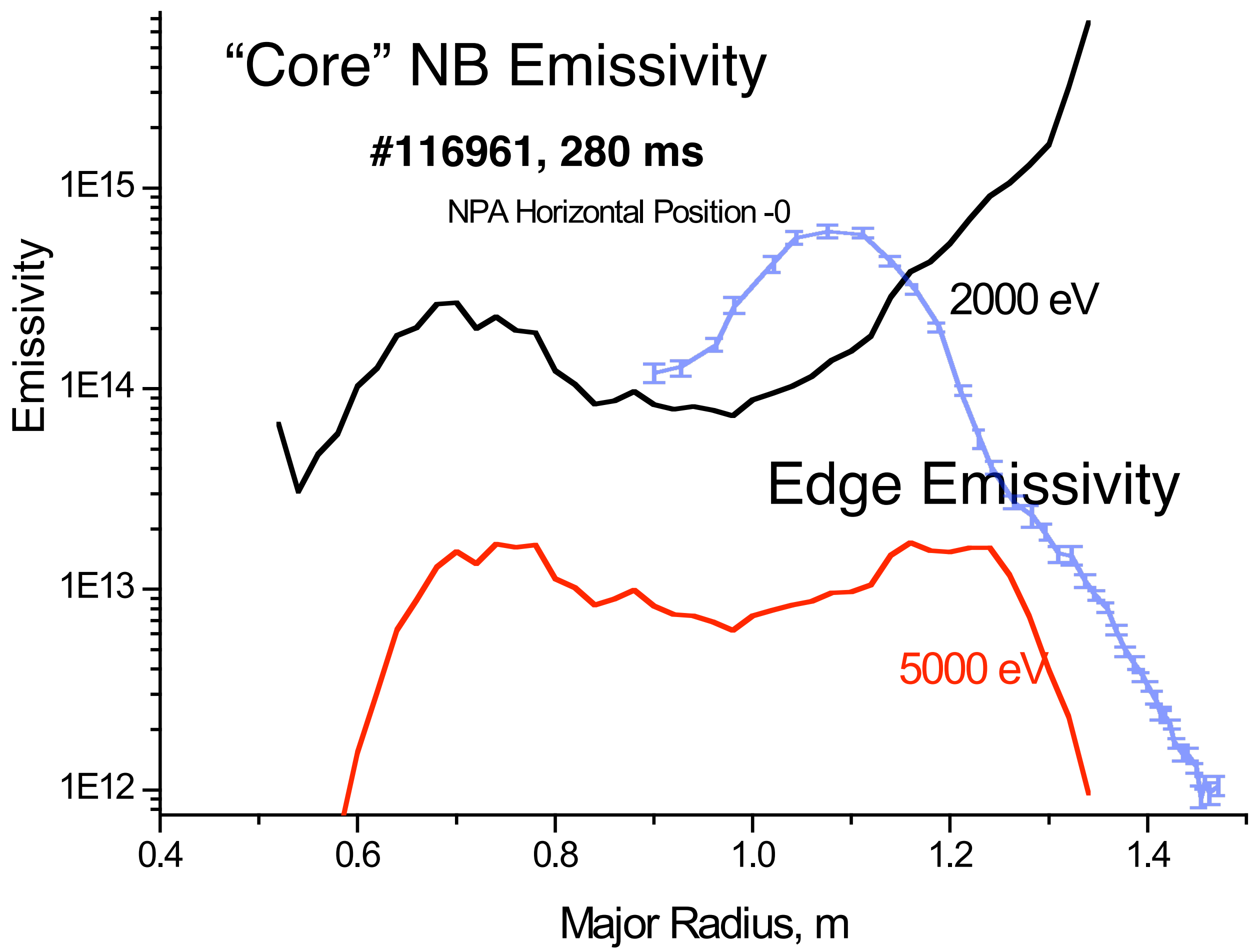


NPA Horizontal Scan to Assess Effect of Toroidal Rotation on T_i Measurement



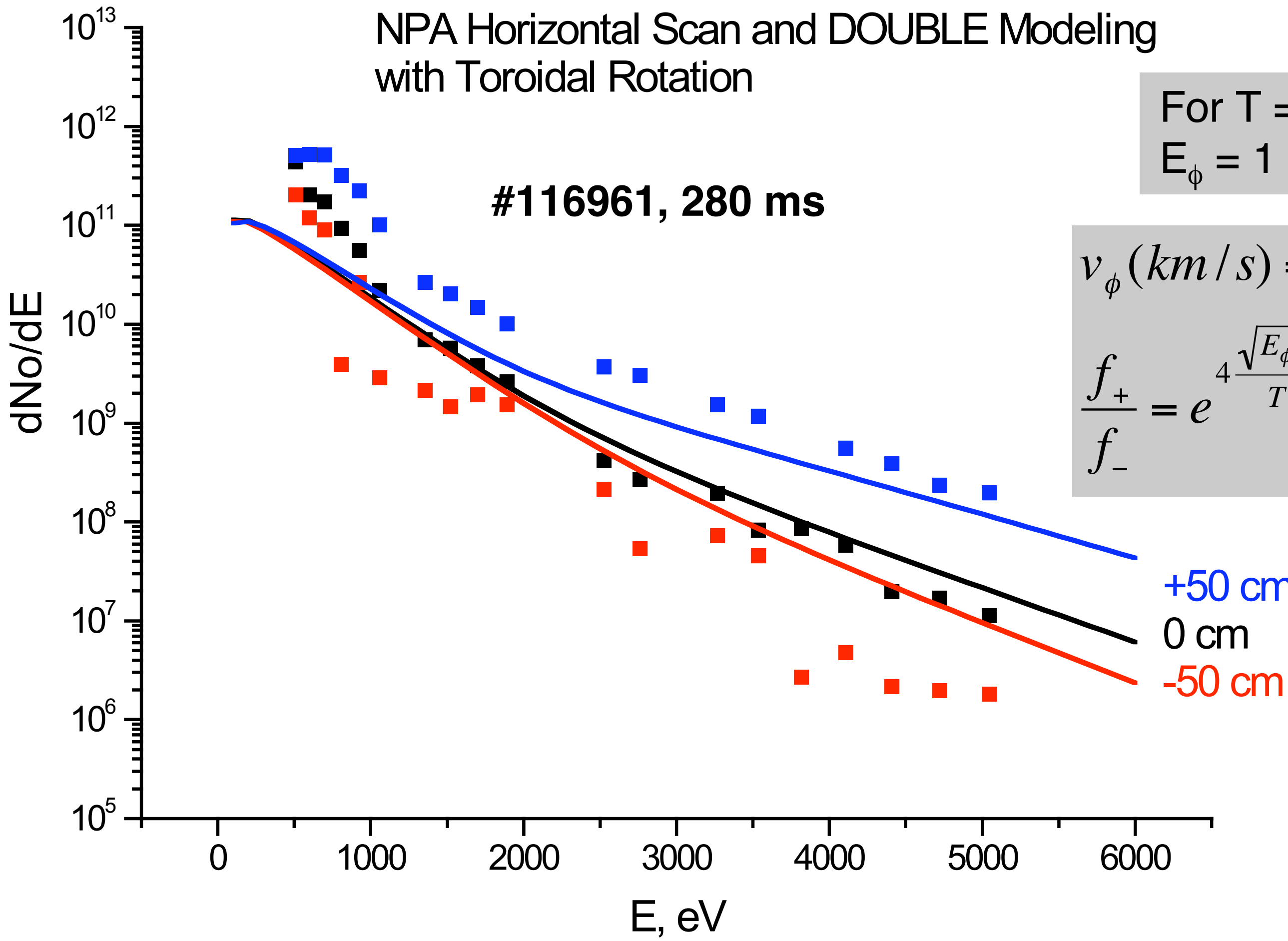


Sample Emissivity Profiles for Rotation Scan



For proper modeling, CHERS $v_{\phi}(r)$ must be imported into DOUBLE (in progress).

Preliminary DOUBLE-NSTX Rotation Analysis Reflects Trend in NPA Measurements



For T = 2.2 keV, E = 5 keV, E_ϕ = 1 keV (v_ϕ = 200 km/s)

$$v_\phi(km/s) = 2.01\times 10^2 E_\phi(keV)^{1/2}$$

$$\frac{f_+}{f_-} = e^{4\frac{\sqrt{E_\phi E}}{T}} \frac{|\sqrt{E}-\sqrt{E_\phi}|}{(\sqrt{E}+\sqrt{E_\phi})} = 22$$

Preliminary analysis used constant, peak v_ϕ. Next step is to incorporate CHERS v_ϕ profile in DOUBLE-NSTX analysis.

Conclusions

- The DOUBLE-NSTX code proved to be a very effective tool for interpreting the NPA vertical $T_i(r)$ measurements.

- Only a small fraction of the recently obtained NPA $T_i(r)$ data has been analyzed to date. So far, the emissivity-corrected core $T_i(0)$ derived from DOUBLE-NSTX analysis is ~ 15-20% above the raw NPA T_i value but ~ 10-15% below the CHERS measurement.

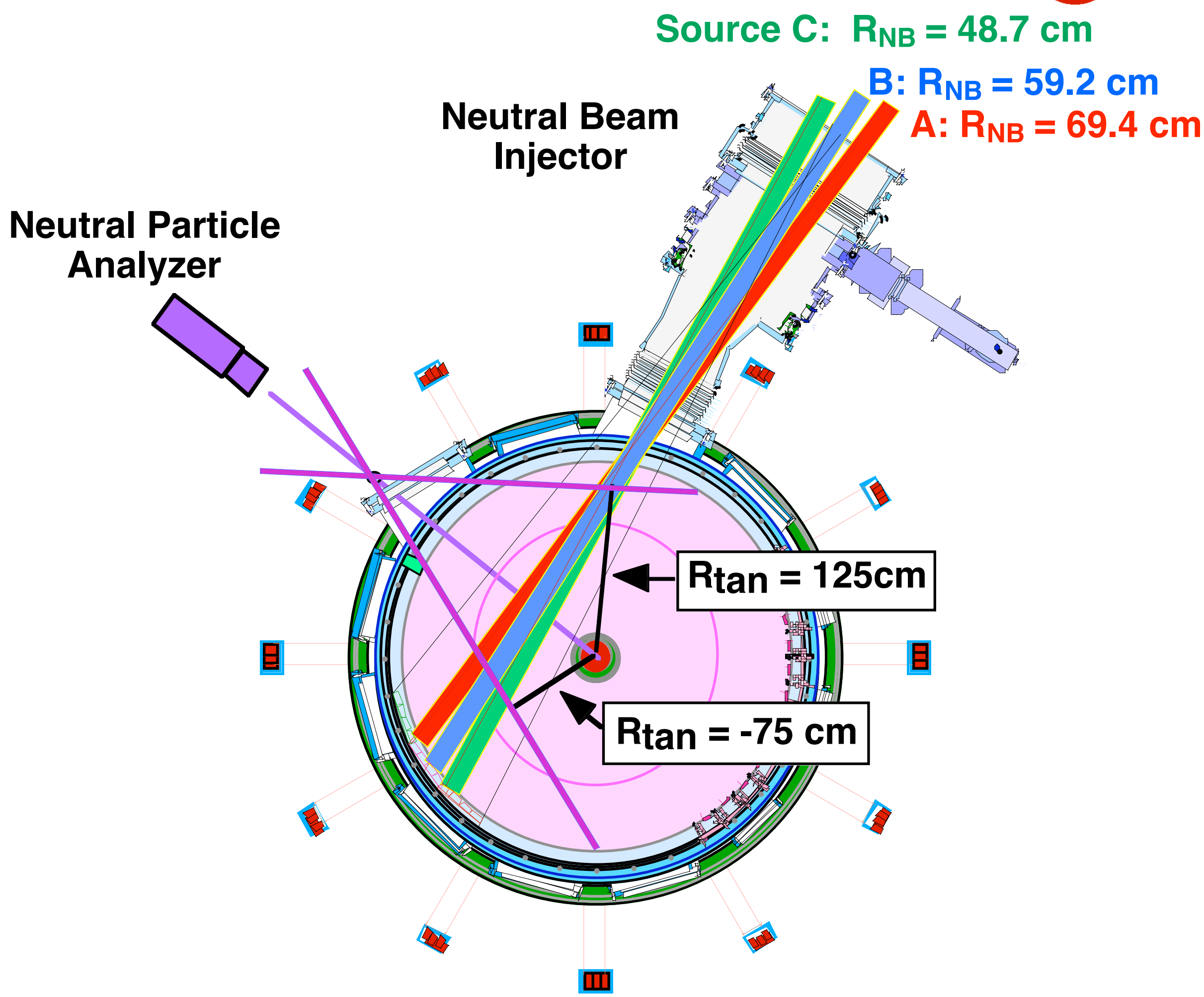
- NPA Ti(r) measurements are limited to NB heated L-mode discharges with peaked density profiles due to emissivity effects (required core-localization excludes Ohmic & H-mode).

- Large toroidal rotation velocity in NSTX significantly impacts NPA Ti(r) measurements.

B A CK U P

S l i d e s

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



- Covers Thermal (0.1 - 20 keV) and Energetic Ion (≤ 150 keV) Ranges

CHERS & MPTS Data for NPA Horizontal Scan of July 11, 2005