Supported by

Effect of Halo Neutrals on Neutral Particle Measurements

D. Liu and W. W. Heidbrink

University of California, Irvine, CA 92697

S. S. Medley and A. L. Roquemore

Princeton Plasma Physics Laboratory, Princeton, NJ 08543

R. J. Akers

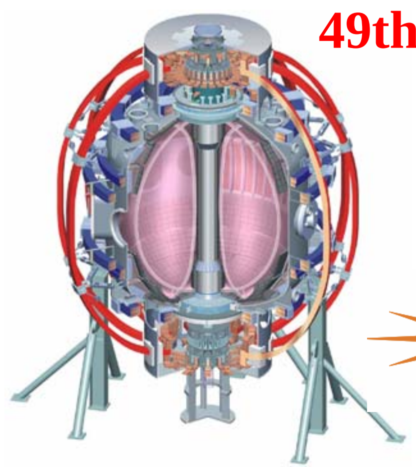
Euratom-UKAEA Fusion Association
Abingdon, OX14 3DB, UK 11

49th Annual Meeting of Division of Plasma Physics

American Physical Society

November12 - 16, 2007

Orlando, FL



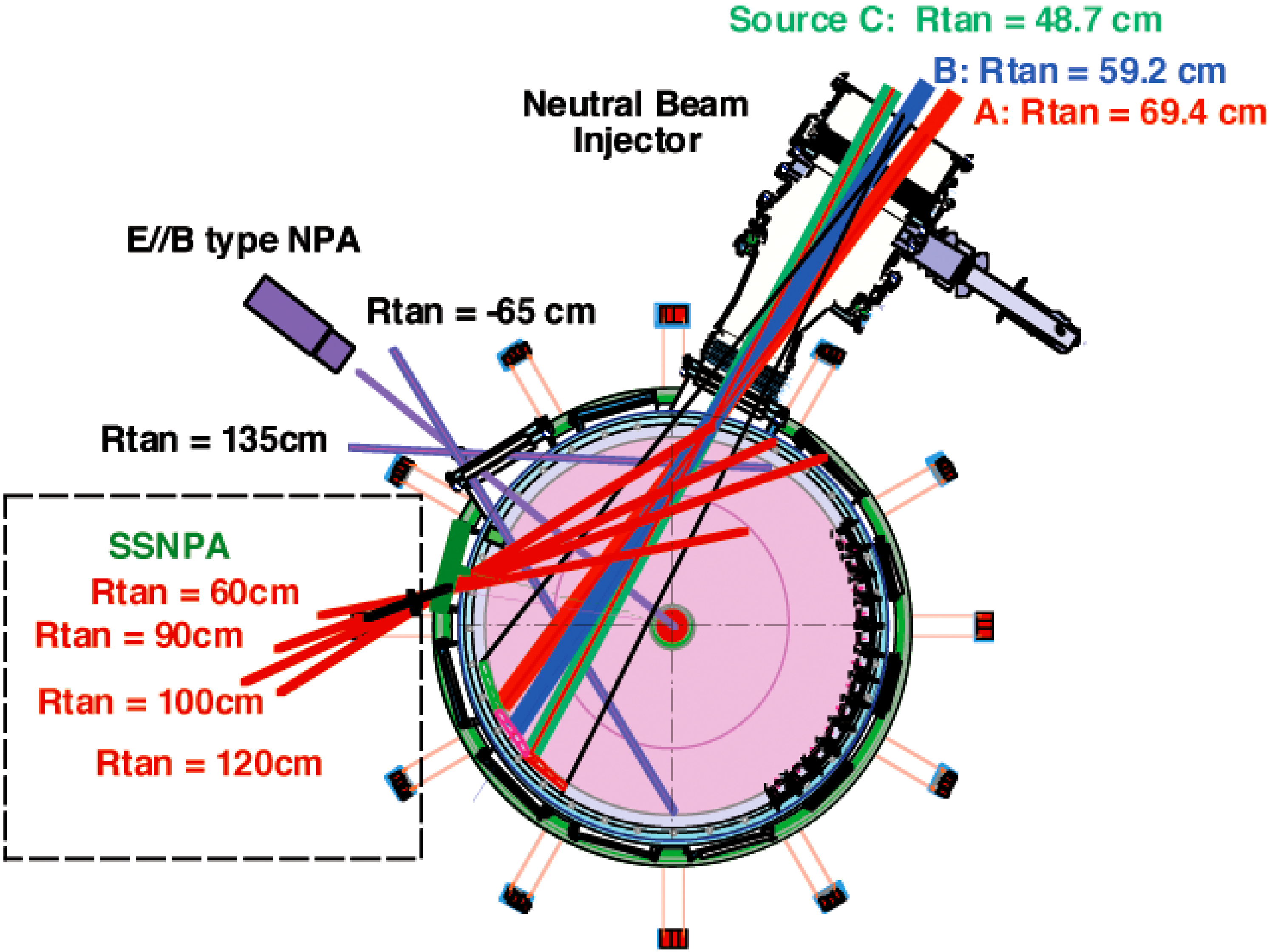
Columbia U
Comp-X
General Atomics
INEL
Johns Hopkins U
LANL
LLNL
Lodestar
MIT
Nova Photonics
NYU
ORNL
PPPL
PSI
SNL
UC Davis
UC Irvine
UCLA
UCSD
U Maryland
U New Mexico
U Rochester
U Washington
U Wisconsin
Culham Sci Ctr
Hiroshima U
HIST
Kyushu Tokai U
Niigata U
Tsukuba U
U Tokyo
JAERI
Ioffe Inst
TRINITI
KBSI
KAIST
ENEA, Frascati
CEA, Cadarache
IPP, Jülich
IPP, Garching
U Quebec

Abstract

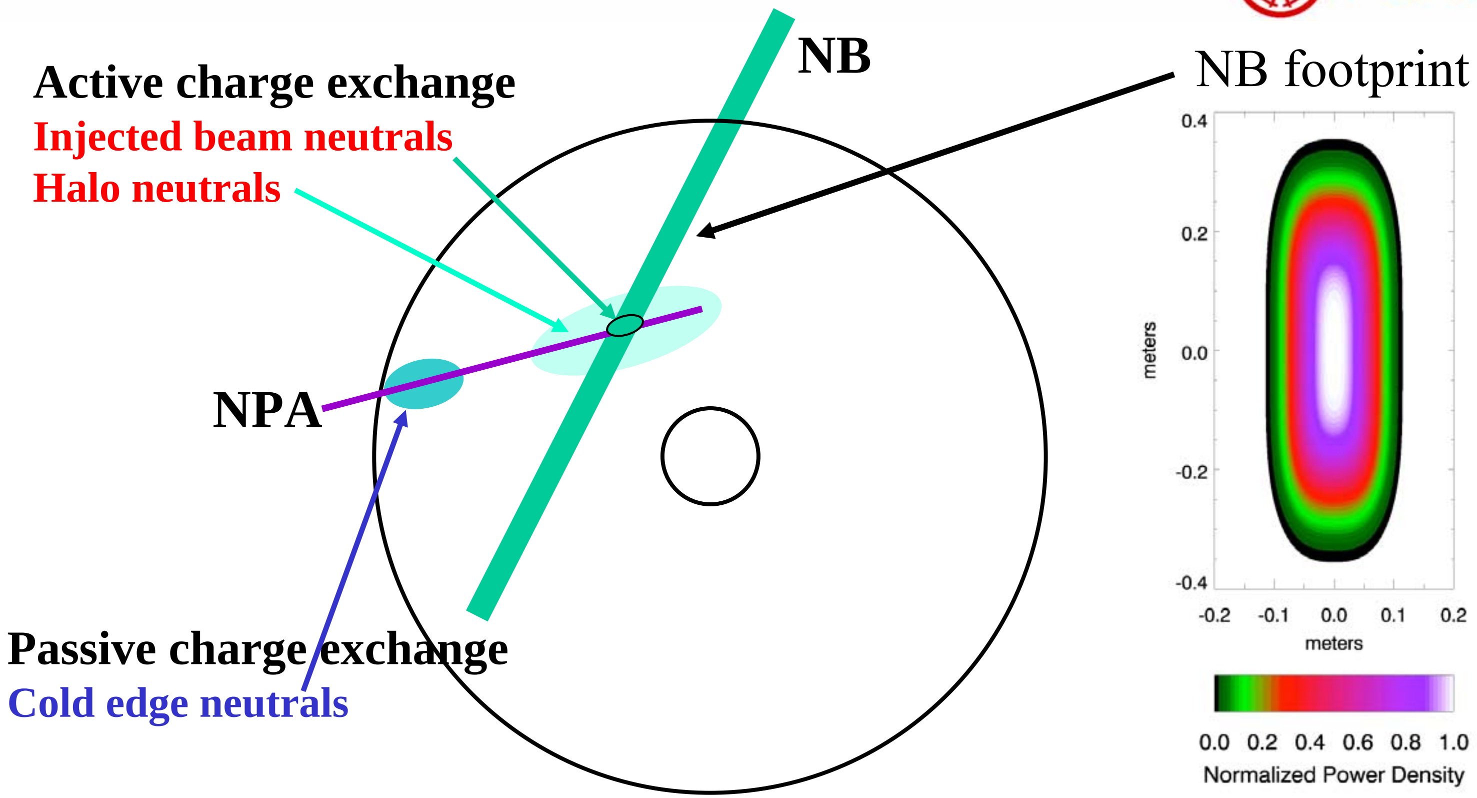
The Neutral Particle Analyzer (NPA) diagnostics including the E||B type NPA and Solid State NPA (SSNPA) array on the National Spherical Torus Experiment (NSTX) measure neutral production in charge exchange reactions between energetic ions and beam primary and halo neutrals. A Monte Carlo simulation code called FIDA_NPA has been developed to analyze the effect of primary neutrals and halo neutrals on the NPA flux temporal evolution and energy spectrum. The simulation results show that the density of halo neutrals around the beam footprint is comparable to that of primary neutrals and they can contribute significantly to the neutral flux measured by NPA diagnostics. Although they barely change the NPA spectrum, they could change the NPA temporal evolution for typical NSTX conditions. Experimental data show that the NPA signals for the sightlines that intersect the injected neutral beams mainly come from active charge exchange reactions (with injected beam neutrals and halo neutrals).

** This work was supported at PPPL by DOE contract DE-AC02-76CH03073 and US DOE Grant DE-FG03-02ER54681.*

NSTX has Four NPA Sightlines that Intersect the Three Heating Beams and One Sightline that Misses the Beams



NPA Diagnostics Measure Fast Ions that Charge Exchange with Three Kinds of Neutrals



<u>Goal</u>: Use NPA diagnostics to detect fast-ion transport by instabilities

→Must know where signals originate spatially

→ Must determine relative contributions of injected, halo, and edge neutrals

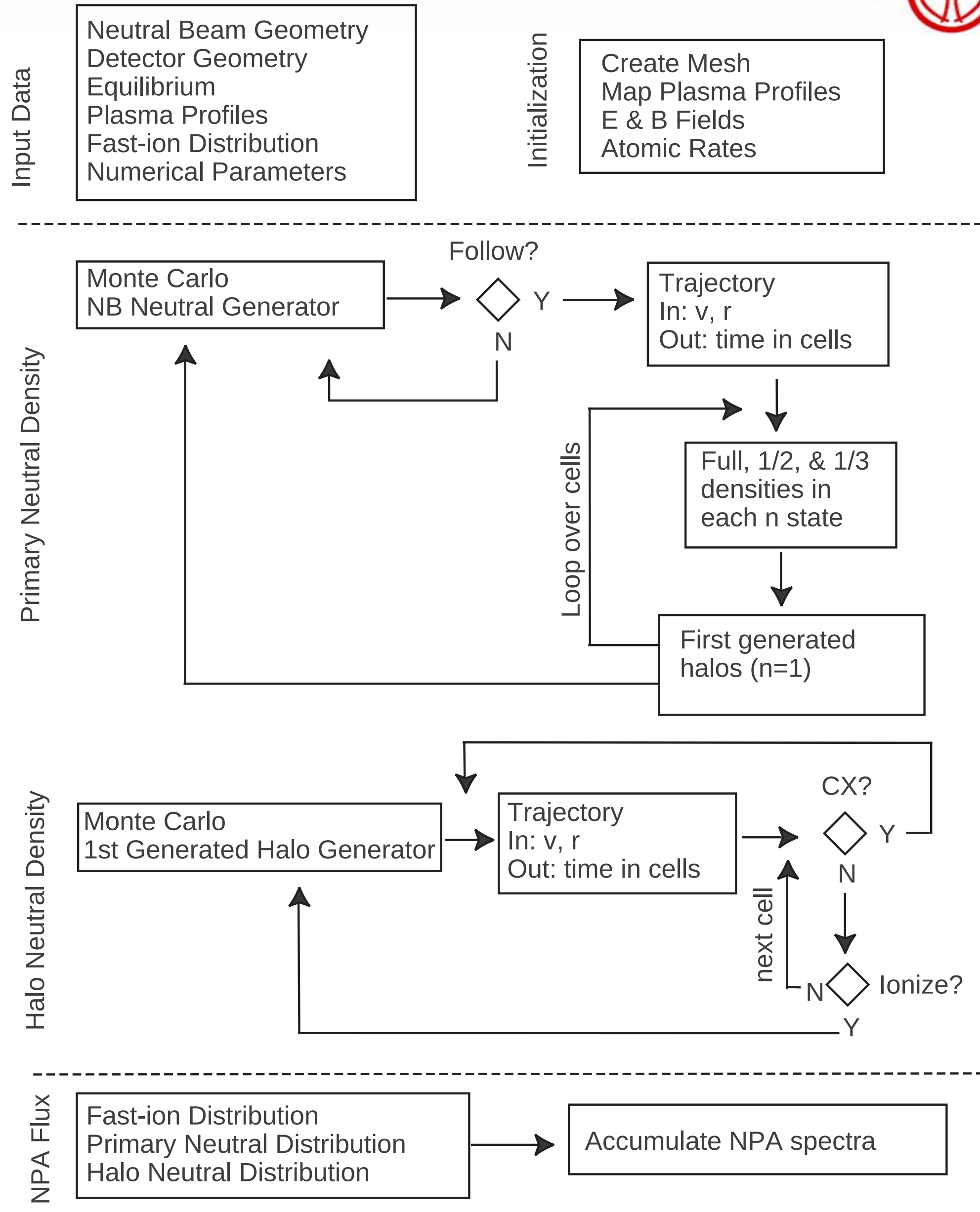
Modeling of Halo Neutrals in Deuterium Discharges

Halo Neutrals May Alter the Neutral Particle Spectrum and Spatial Resolution

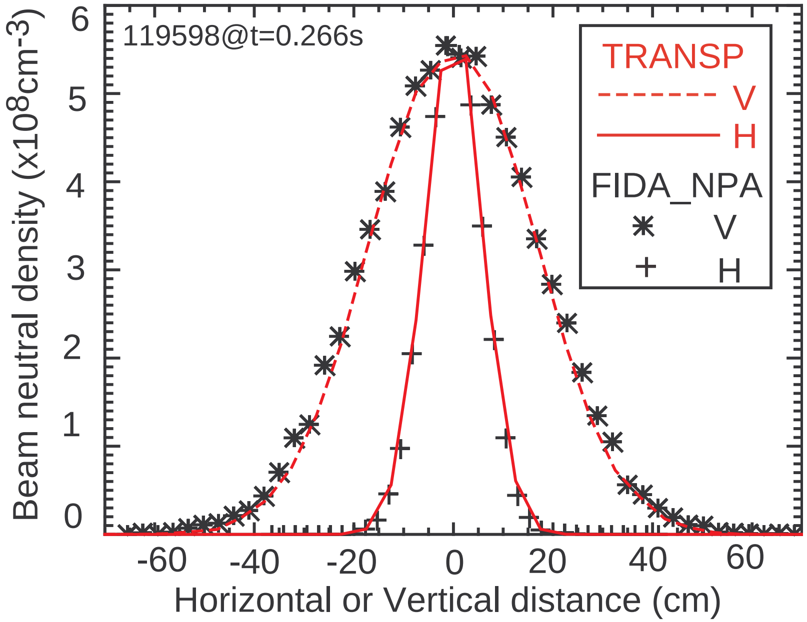
- **Halo neutrals can contribute significantly to the neutral flux measured by NPA diagnostics.**
  - **The densities of primary beam and halo neutrals can be comparable .**
  - **Charge exchange cross section for halo neutrals is larger than that for primary beam neutrals.**
- **Halo neutrals could affect the spatial resolution of NPA, thus induce ambiguous in the fast ion profiles deduced from the NPA measurements.**
- **TRANSP does not handle halo neutrals properly.**
  - **Halo neutrals are volume averaged both poloidally and toroidally in TRANSP rather than remaining near the beam footprint.**
  - **There are some discrepancies between NPA measurements and TRANSP simulation.**
- **Correctly Modeling halo neutrals is also important for the simulation of Fast-ion D-alpha (FIDA) diagnostic.**

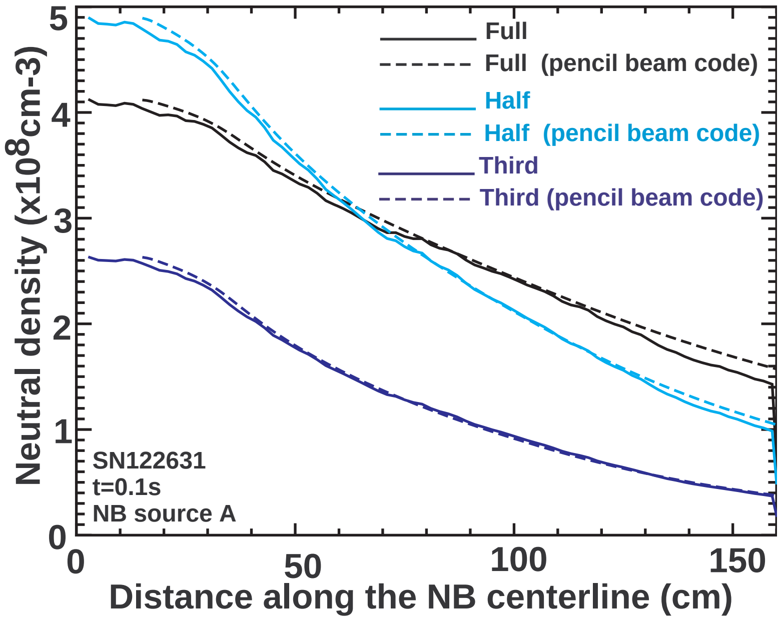
Monte-Carlo Method is Applied to Calculate Beam Primary and Halo Neutral Density

FIDA_NPA Code Flow Diagram



Neutral Beam Profile and Attenuation Agree with Known Models





- **Neutral beam profile agrees with the neutral beam calibration data and TRANSP prediction.**
- **Attenuation of NB three energy components agrees with the prediction from a pencil beam code. (The small discrepancy is probably caused by using different atomic cross sections.)**

Halo Neutral Simulation is Validated by Comparing with a 1-D Diffusion Model

NSTX

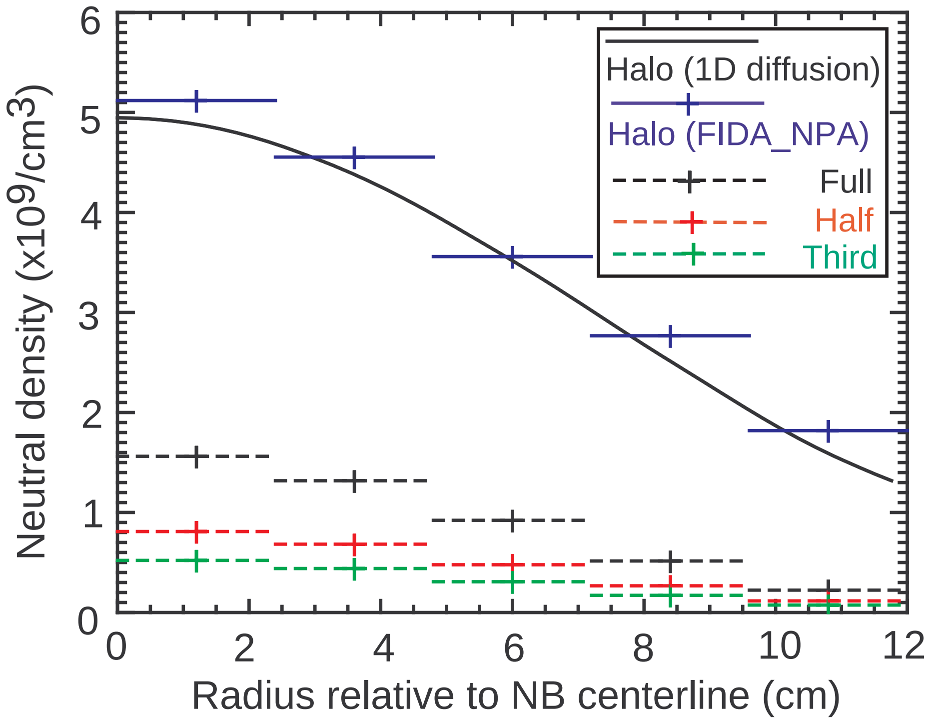
If we assume

- **a uniform plasma with a circular NB beam injection**
- **No beam attenuation along the NB centerline,**

Halo neutrals will diffuse only in the radial direction and the density can be calculated form the following simple 1-D diffusion model

$$D_{n0}\frac{\partial}{r\partial r}\left(r\frac{\partial n_0}{\partial r}\right)=\sum_{k=1}^{3}n_i n_b\langle\sigma v\rangle_{cx,k}-n_0 n_e\langle\sigma v\rangle_{ei}$$

Halo formation **Halo decay**



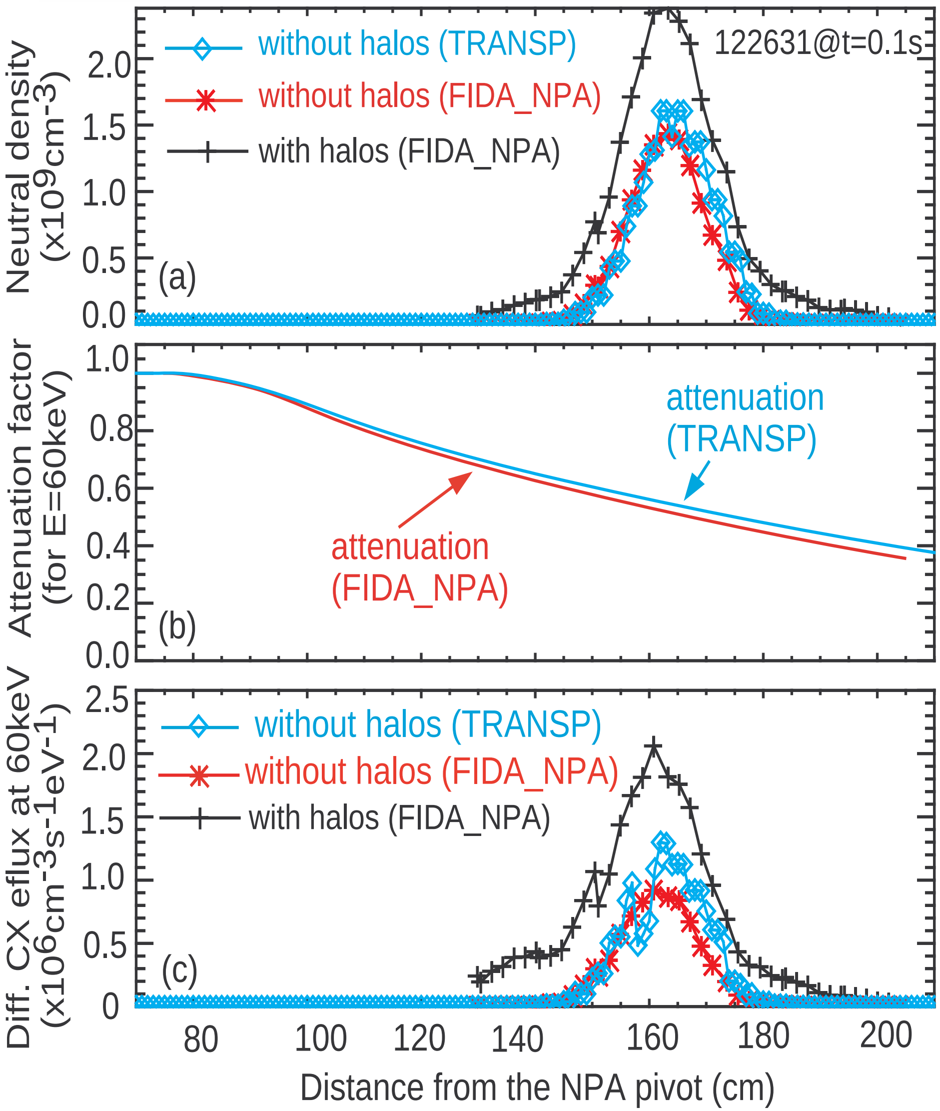
Plasma parameters

$n_i = n_e = 1.1\times10^{14}cm^{-3}$ $T_e = 2.5keV$

$T_i = 1.25keV$ $D_{n0} = k_b T_i / m_d \gamma_{cx}$

$\gamma_{cx} = n_i\langle\sigma v\rangle_{cx,mp}$

Halo Neutrals Contribute Significantly to the NPA Flux, but Minor Discrepancies between Our Code and TRANSP Simulation are Found



➢**Halo neutral density is comparable to beam primary neutral density along the NPA sightline.**

➢**Halo neutrals contribute significantly to the NPA flux.**

➢**Halo neutrals reduce the localization of NPA signals.**

Discrepancies

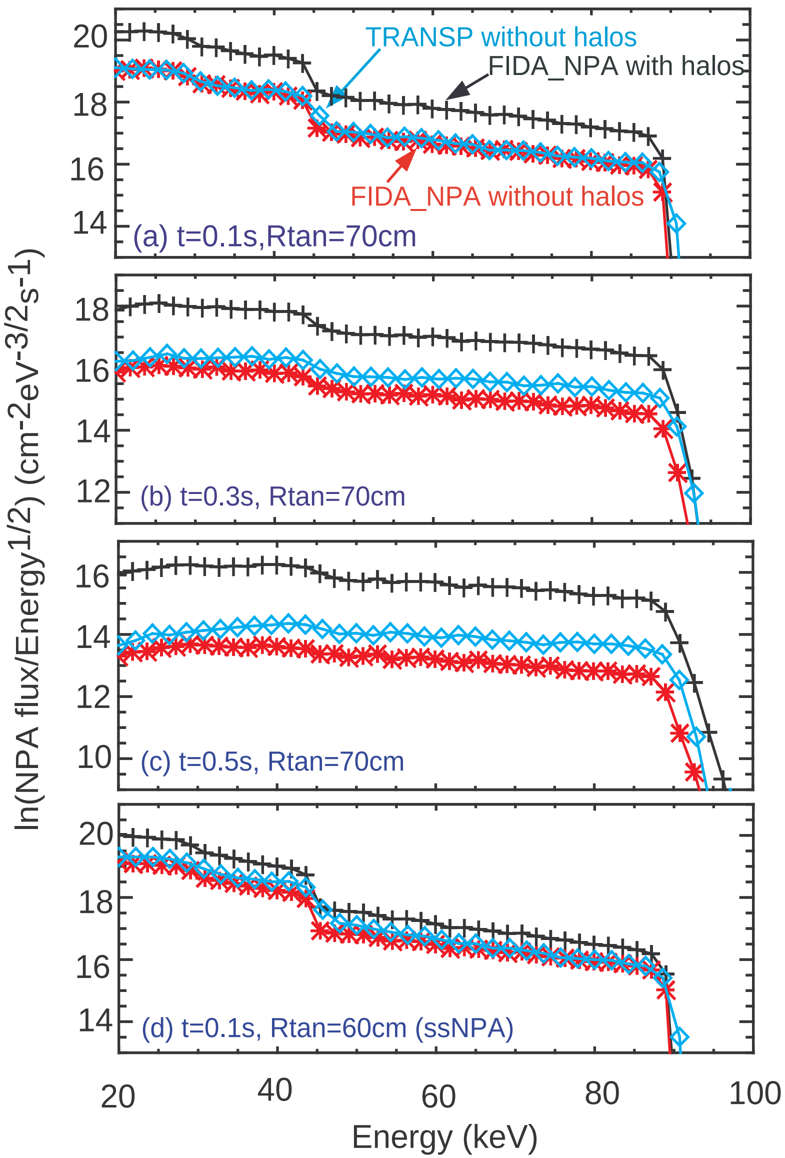
➢**Primary neutral density from FIDA_NPA code is a little lower than the prediction from TRANSP.**

➢**Neutrals attenuate a little faster in our code than the prediction in TRANSP.**

Because different atomic cross sections are used?

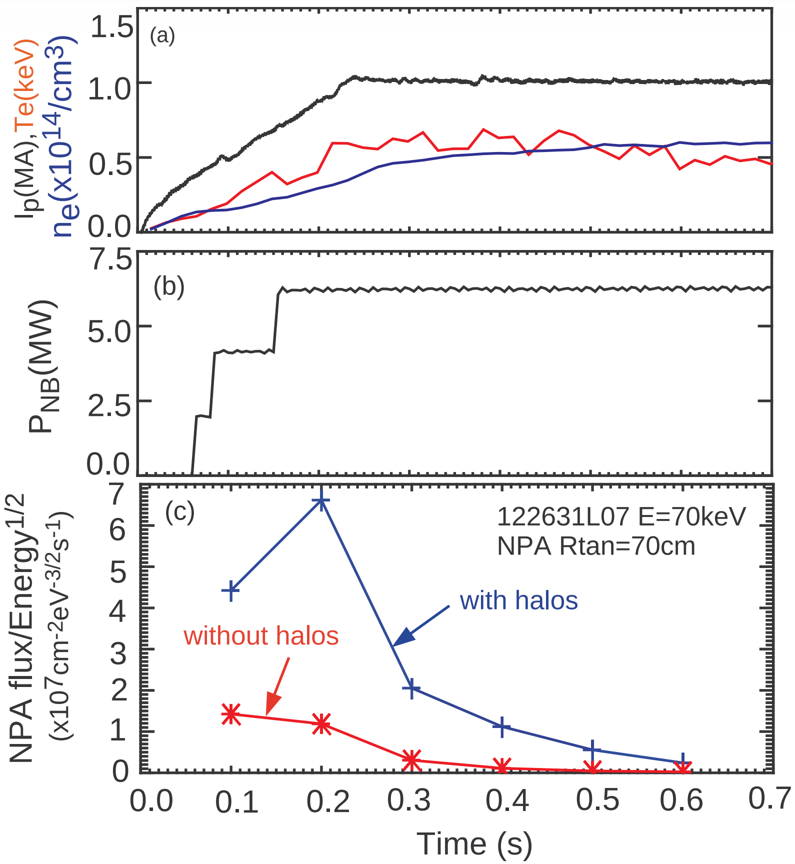
NPA Spectral Shape Barely Changed by Halos

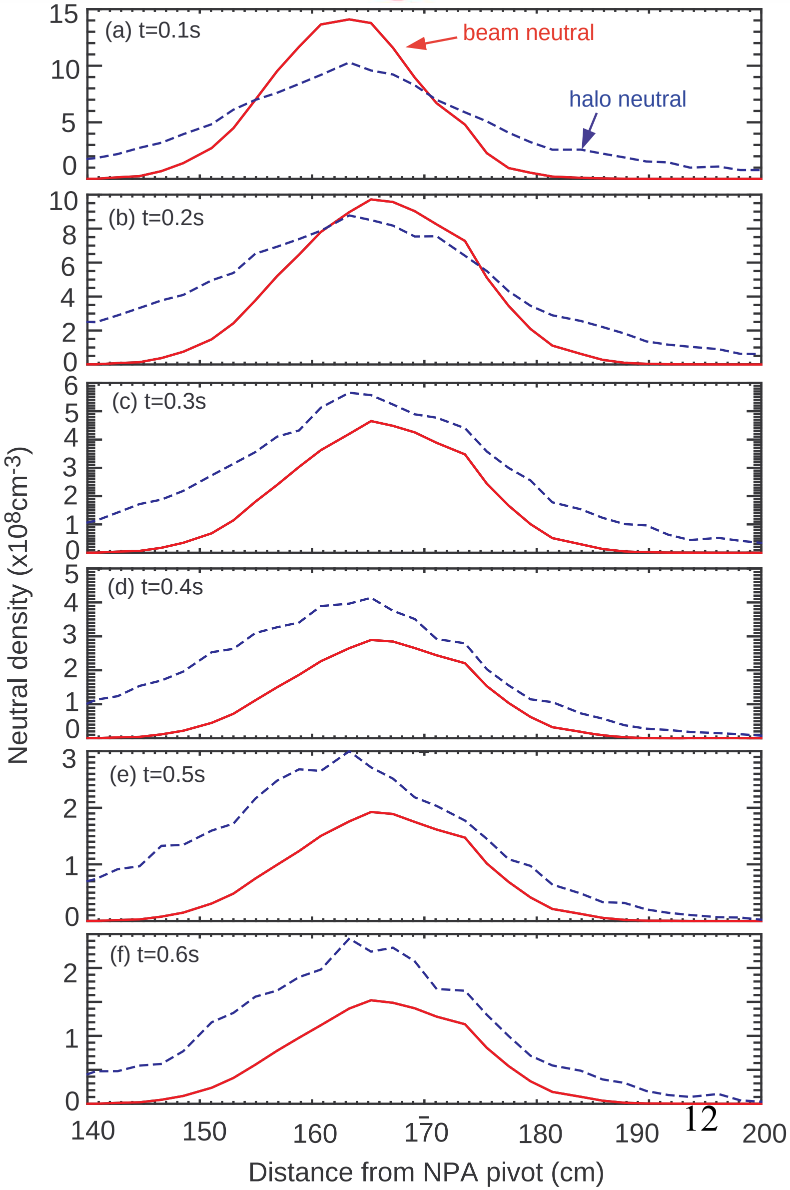
TRANSP run 122631L07, NPA Rtan=70cm



- ➢Charge exchange with halo neutrals can double the neutral flux for typical NSTX conditions.
- ➢Halo neutrals have minor effect on the shape of NPA energy spectra.
- ➢Minor difference was seen between TRANSP NPA spectra and FIDA_NPA spectra, which is probably because different atomic cross sections used in two codes.

Halos can Affect the Temporal Evolution of NPA Flux





Halo neutrals increase significantly the NPA neutral flux, but they depend on plasma profiles (for example, n_e, T_e). Thus they can change the NPA flux temporal evolution.

Comparison between Simulation and Measurements is Difficult

Since our code uses the fast ion distribution dumped out from TRANSP (which assume fast ions behave classically) to simulate the NPA spectrum, a quiescent Deuterium plasma is needed to compare simulation results with measurements.

However,
(1) Quiescent Deuterium plasma shots are very rare on NSTX.

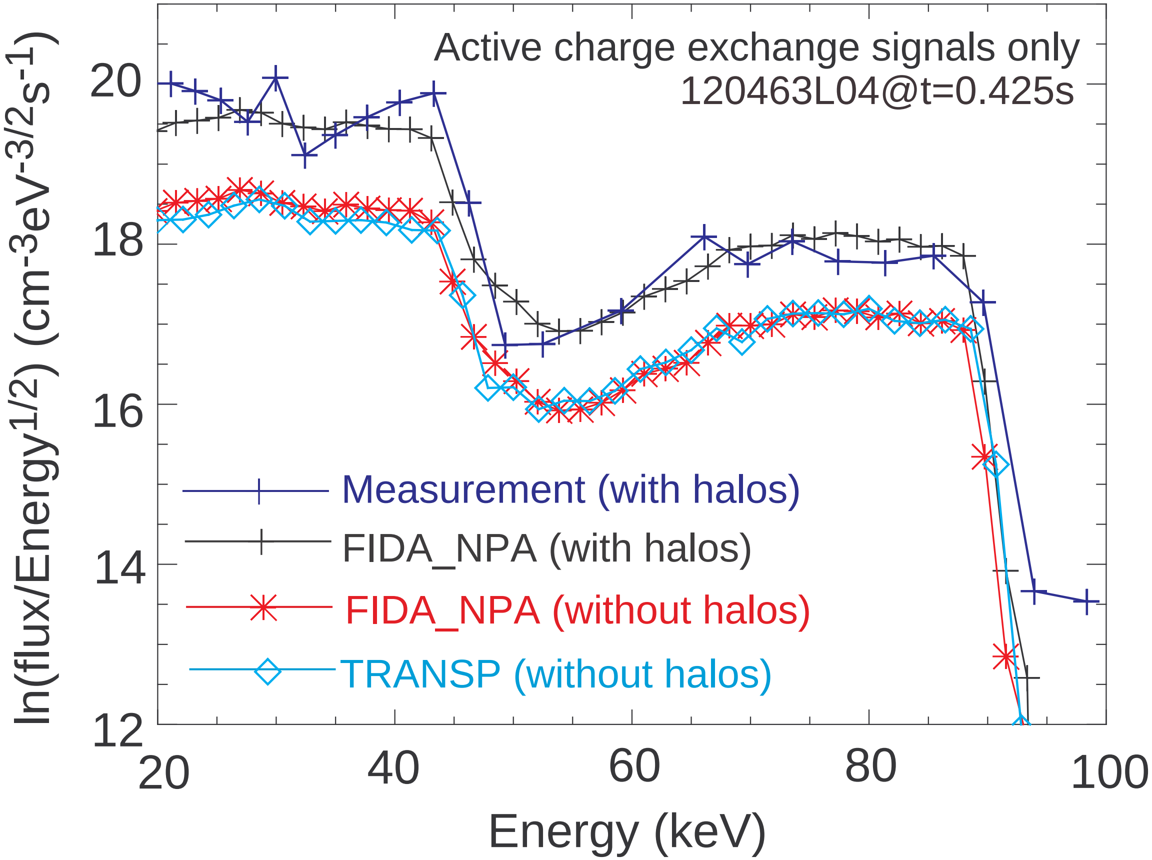
(2) Edge neutral contribution is unknown.

(3) The absolute neutral flux from TRANSP prediction is one order larger than the E||B type NPA measurements. The discrepancy seems due to change of the MCP detection efficiency.

(4) The absolute calibration of SSNPA is not done.

So it is difficult to compare the absolute magnitude and spectral shape of our simulation with experimental measurements.

Theory and Experiment Disagree in the Absolute Magnitude of NPA Flux for This "Quiet" Shot



- Beam blip shot with some weak MHD
- NPA data are normalized to theory
- Our code agrees well with the TRANSP prediction when the halos are turned off.

Summary of Halo Modeling

- The density of halo neutrals around the beam footprint or along the NPA sightline is comparable to that of primary neutrals.

- Charge exchange with halo neutrals contribute significantly to the neutral flux and thus change the NPA temporal evolution, but they have minor effect on the shape of the NPA energy spectrum.

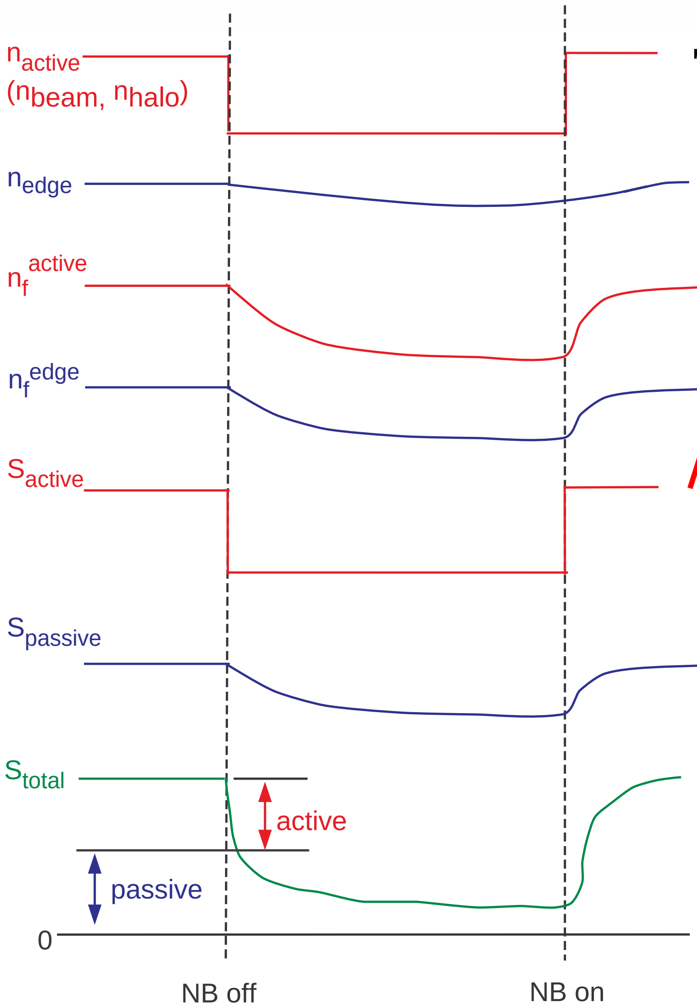
- Halo neutrals reduce the localization of the NPA diagnostics (FWHM is increased by 40 percent).

- There are some discrepancies on the beam neutral density and attenuation factors between our simulation and TRANSP NPA simulation. Due to using different atomic cross sections?

Analysis of Experimental Data:

Relative Contributions of Injected, Halo, and Edge Neutrals

Beam-blip Shots can be Used to Separate Active Charge Exchange and Passive Charge Exchange Signals



The amount of the neutral flux on NPA

$$\overline{\Gamma}(E) \propto \int n_n(\mathbf{x})\, n_f(\mathbf{x}, E, v_\parallel / v) < \sigma v >_{cx(\mathbf{x}, E, v_\parallel / v)} e^{-\lambda(\mathbf{x}, E)} d\mathbf{x}$$

$$\boxed{\propto \int n_n^{beam}(\mathbf{x})\, n_f(\mathbf{x}, E, v_\parallel / v) < \sigma v >^{beam}_{cx(\mathbf{x}, E, v_\parallel / v)} e^{-\lambda(\mathbf{x}, E)} d\mathbf{x} + \int n_n^{halo}(\mathbf{x})\, n_f(\mathbf{x}, E, v_\parallel / v) < \sigma v >^{halo}_{cx(\mathbf{x}, E, v_\parallel / v)} e^{-\lambda(\mathbf{x}, E)} d\mathbf{x}}$$

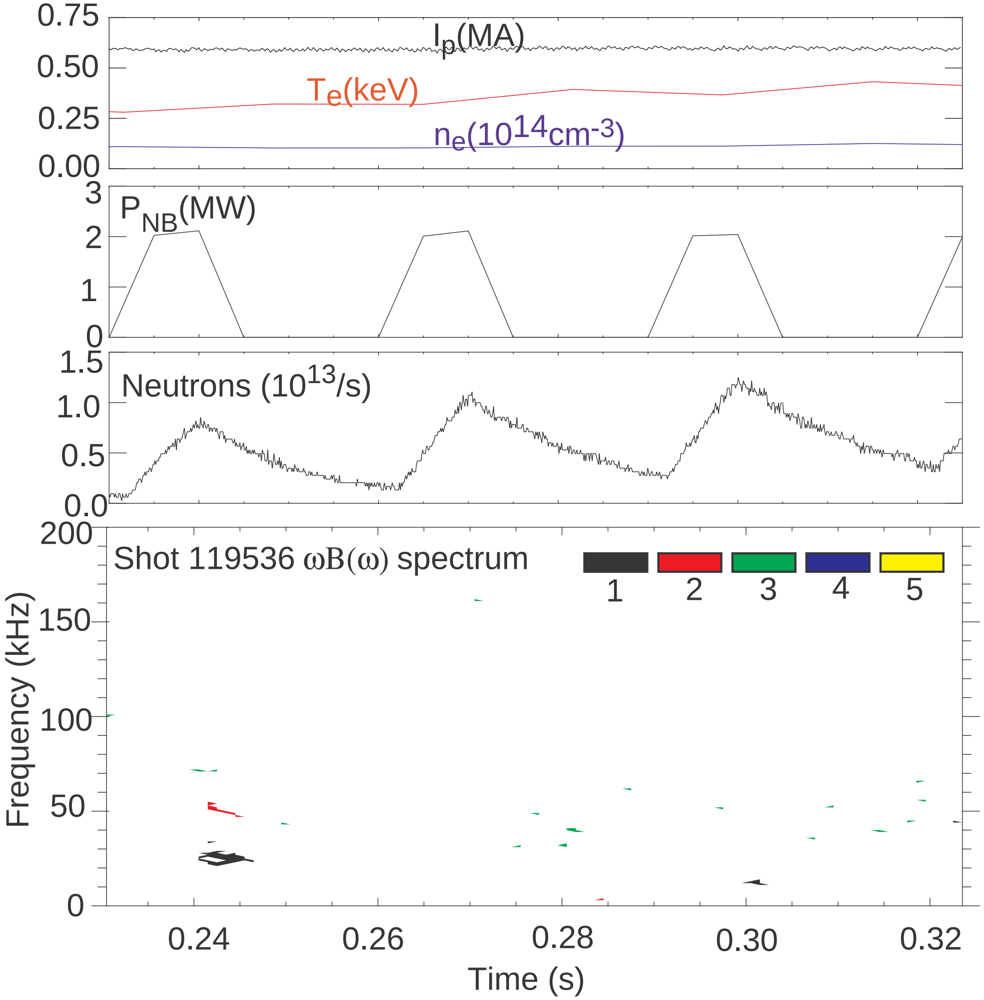
$$\boxed{+ \int n_n^{edge}(\mathbf{x})\, n_f(\mathbf{x}, E, v_\parallel / v) < \sigma v >^{edge}_{cx(\mathbf{x}, E, v_\parallel / v)} e^{-\lambda(\mathbf{x}, E)} d\mathbf{x}}$$

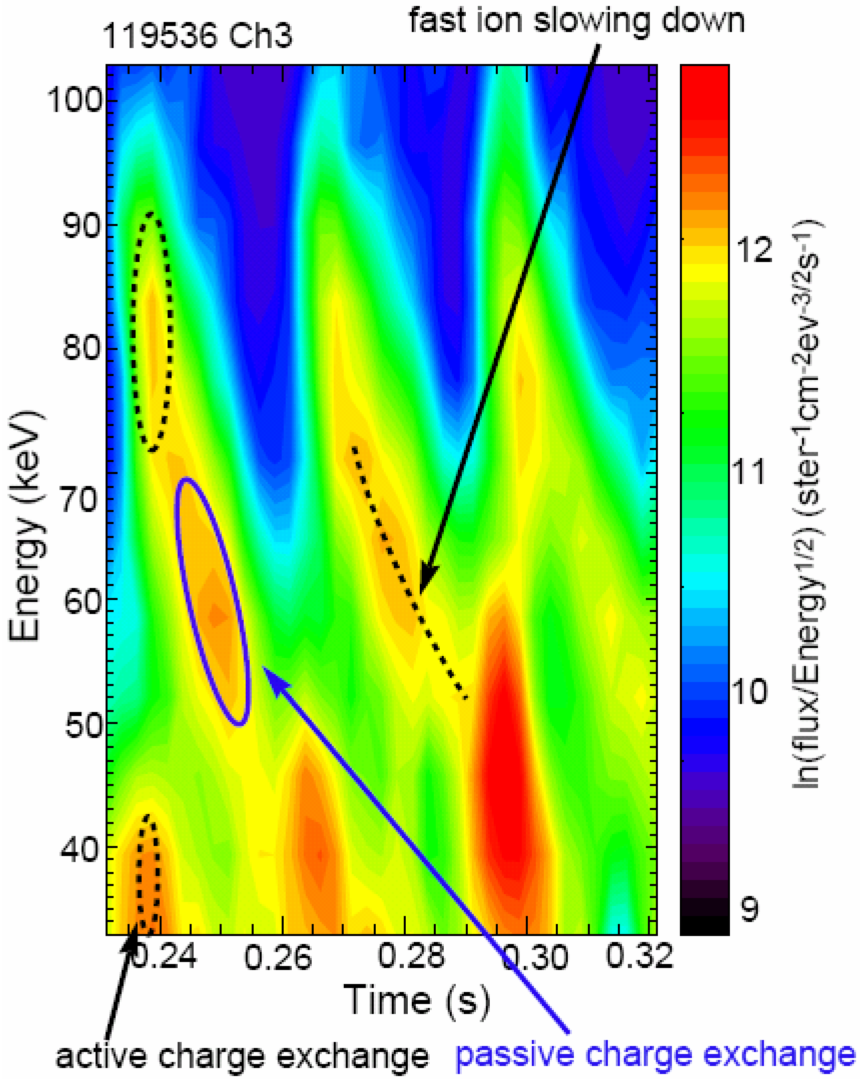
When the NB is just turned off,

- **Beam neutrals density => 0**
- **Halo neutral life time: ~10 μs**
- **Fast ion slowing down time: ~50 ms**
- **Edge neutral density varies slowly.**

So the jump of NPA signals due to NB turned off is active charge exchange signals, the rest part is the passive charge signals.

Active Charge Exchange and Passive Charge Exchange Contributions are Clearly Observed on NPA Diagnostics





Halo Neutrals Should Barely Contribute to the NPA Signals in Helium Discharges

Deuterium plasma + Deuterium beam	Helium plasma + Deuterium beam
Charge exchange with primary neutrals	Charge exchange with primary neutrals
$D^+ + D^0 \to D^0 + D^+$	$D^+ + D^0 \to D^0 + D^+$
Charge exchange with halo neutrals	Charge exchange with halo neutrals
$D^+ + D^0 \to D^0 + D^+$	$D^+ + He^+ \to D^0 + He^{++}$
Charge exchange with edge neutrals	Charge exchange with edge neutrals
$D^+ + D^0 \to D^0 + D^+$	$D^+ + He^0 \to D^0 + He^+$

Since

- $\langle\sigma v\rangle_{cx}$ for D^+ and He^+ is one order smaller than that between D^+ and D^0

→ **Halo neutrals should barely contribute to the NPA signals in Helium plasmas with Deuterium beam injection.**

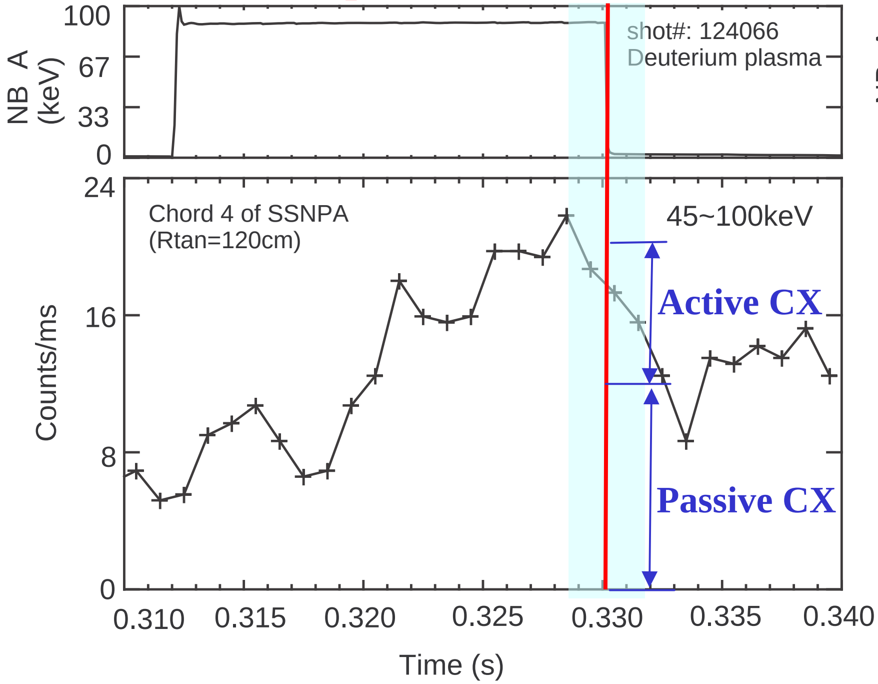
- $\langle\sigma v\rangle_{cx}$ for D^+ and He^0 is in the same order as that between D^+ and D^0

→ **Edge neutrals should contribute comparable signals in Helium and Deuterium plasmas**

The Chord that Misses the NB Demonstrates the Small Contribution of Halos to NPA signals in Helium Discharges

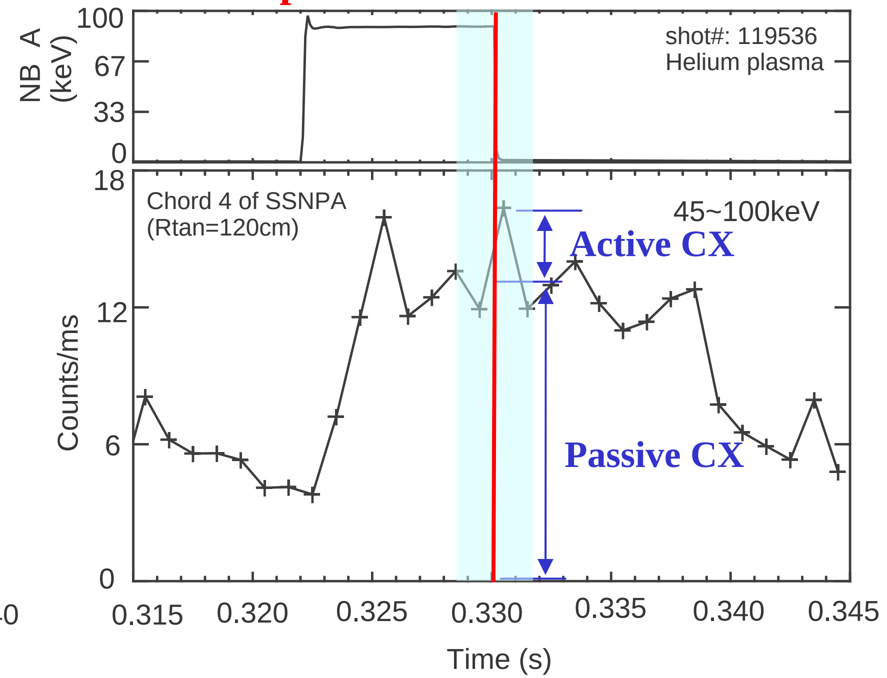
NSTX

Deuterium plasma + Deuterium beam



$n_e = 2.4 \times 10^{13} cm^{-3}$ **@t=0.33s**

Helium plasma + Deuterium beam

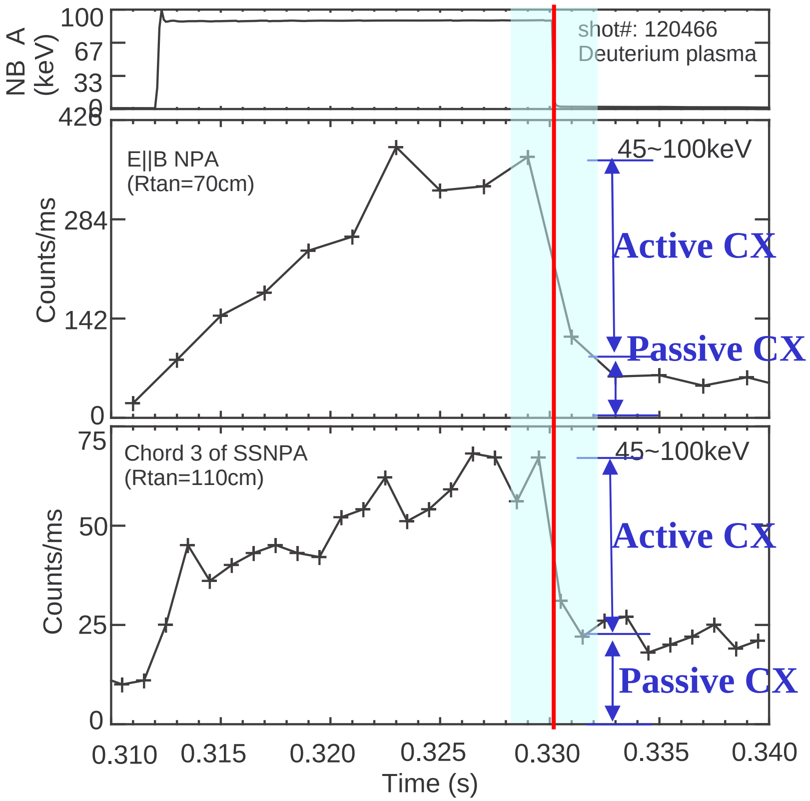


$n_e = 1.0 \times 10^{13} cm^{-3}$ **@t=0.33s**

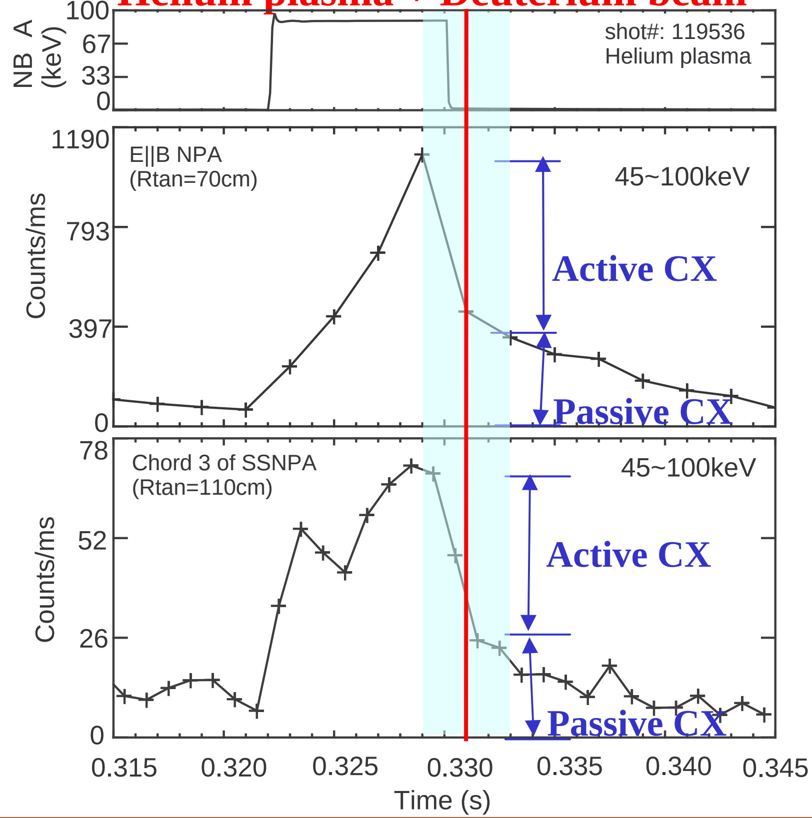
- Halo neutrals barely contribute to the NPA signals in Helium discharges.
- Edge neutral contribution don't dramatically decrease after the NB is turned off in both Deuterium and Helium discharges.

The Signals of NPA sightlines that Intersect the NB Mainly Come from Active Charge Exchange Reactions in Beam-Blip Shots

Deuterium plasma + Deuterium beam



Helium plasma + Deuterium beam



- ➢**The signals of NPA and inner three chords of SSNPA that intersect the injected neutral beams mainly come from active charge exchange reactions.**
- ➢**Analysis of 17 beam blip shots show that the active:passive ratio is higher in deuterium (4.4±1.8 for E||B type NPA at Rtan=70cm) than that in helium discharges (1.5±0.7 for E||B NPA), which means halo contribution is negligible in helium plasmas.**

Conclusion

- **The signals of NPA and inner three chords of SSNPA that intersect with the injected neutral beams mainly (>50%) come from active charge exchange neutrals in low density (n_e~$10^{13}cm^{-3}$) discharges. The signals of the sightline of SSNPA that misses the beams are from passive charge exchange reactions in helium and from edge & halo neutrals in deuterium**

- **Halo neutrals in Helium discharges have minor contribution to the NPA signals since the charge exchange cross sections between D^+ and He^+ is much smaller than others in the energy range of 30keV~100keV.**