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Study of Fast Ion Confinement in MHD-quiescent NSTX Plasmas

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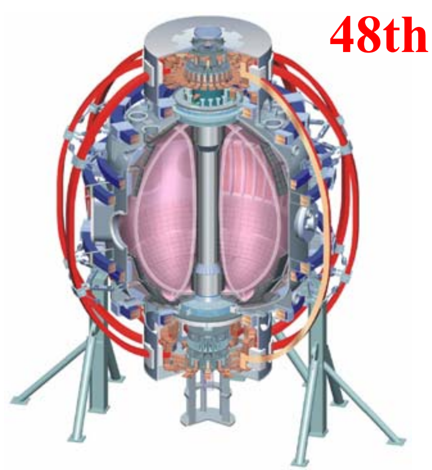

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Abstract

The NSTX with its extensive set of fast-ion diagnostic (neutron detectors, E||B-type neutral particle analyzer, scintillator-based beam ion loss probe and newly developed solid state neutral particle array) provide a good test-bed to study the confinement of beam ions in quiet spherical tokamak plasmas. Ten ms pulses ("beam blips") of 90keV deuterium neutrals are injected into helium plasmas with plasma current between 0.5 and 1.0 MA, and toroidal fields between 3.0 and 4.5 kG. Pitch angle scattering and slowing down of beam ions are studied by measuring the decay of the neutron and charge-exchange neutral particle signals following the "beam blip" and they are in good agreement with the expectations of TRANSP simulation, which includes beam deposition calculations, Coulomb collisions and charge exchange loss. Examples of deviations from classical behavior during instabilities are also given.

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Background

➢ Motivation

- Benchmark the newly developed solid state neutral particle array (SSNPA) diagnostic which utilizes Si diodes to measure the energy distribution of charge exchange fast neutral particles.
- Confirm that fast ions behave classically in MHD-quiescent plasmas.

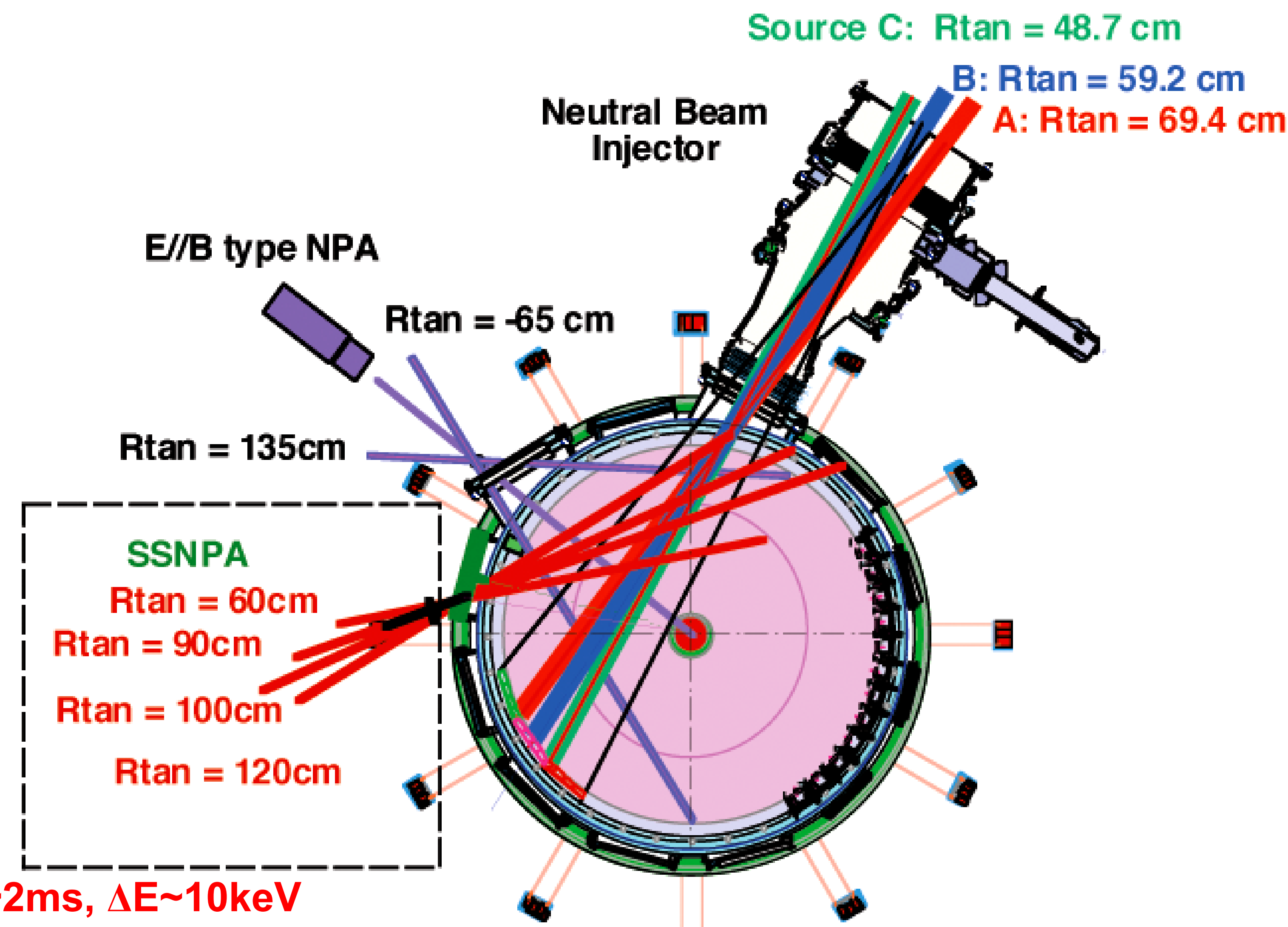
➢ Current diagnostics of fast ion confinement

- Neutron detectors
- E||B type NPA and SSNPA
- Scintillator-based fast ion loss probe (sFLIP)

➢ Final goal

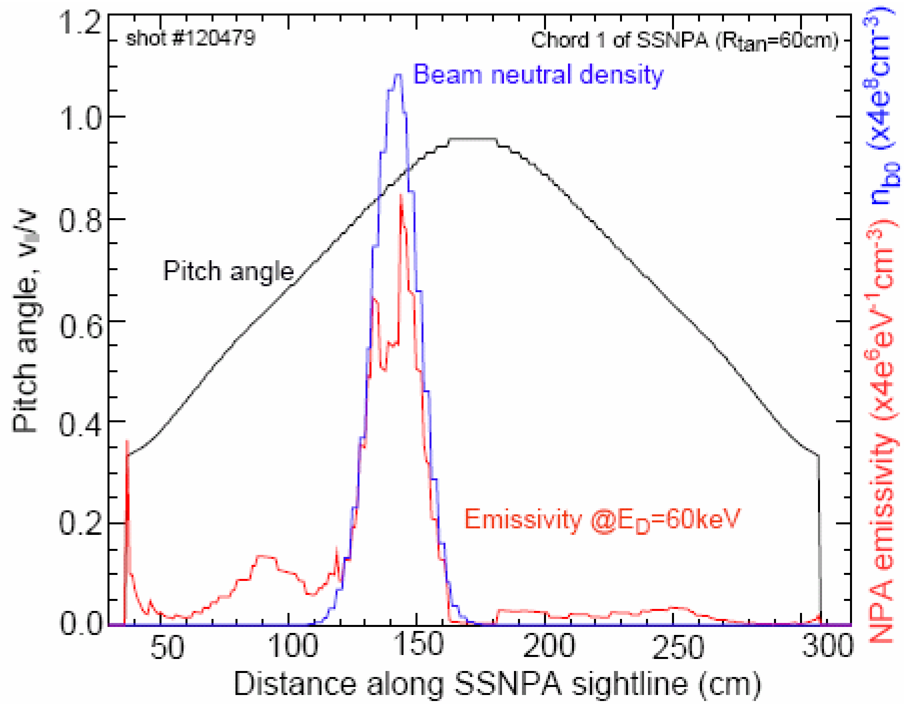
- Understand the influence of instabilities on fast ion distribution and the interaction mechanism.

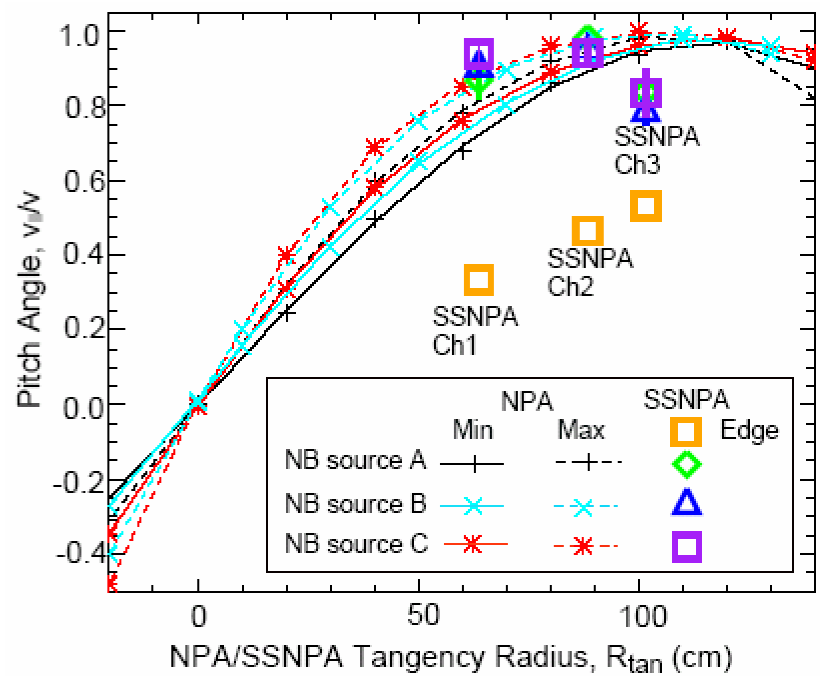
Both NPA & SSNPA Measure Fast Ions that Charge Exchange with Injected Beam Neutrals



Δt~2ms, ΔE~10keV
Energy range (35~110keV)

Measurements of NPA and Chord 1~3 of SSNPA are Constrained in Pitch and Space, but not Chord 4





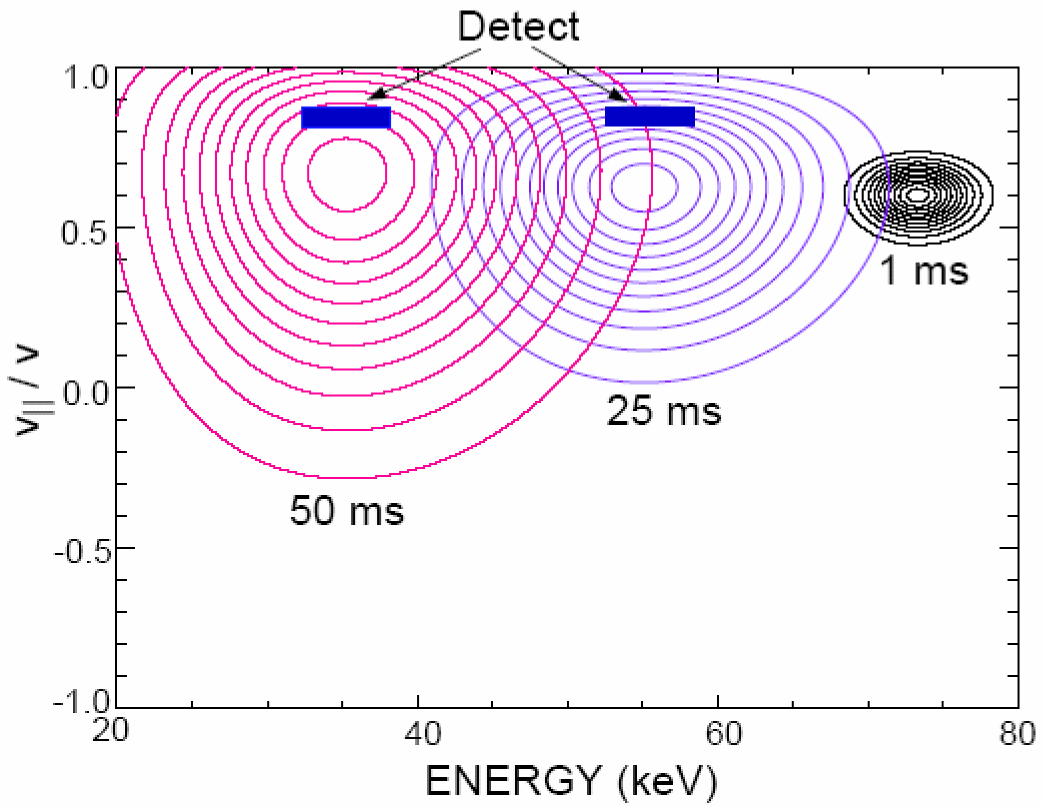
The NPA part, see S.S. Medley et al. Nucl. Fusion* **44 *(2004) 1158*

•The injected neutrals spatially localize the signal of NPA and Chord 1~3 (Rtan=60, 90, 100 cm) of SSNPA (left graph) and constrain the pitch angle range that can be detected (right graph).

•The signal of chord 4 (Rtan=120cm) of SSNPA is not well localized in space or pitch angle since the intersection is near to plasma boundary where less fast ions are deposited.

•The localization weakens in high density plasmas due to attenuation of the beam neutrals.

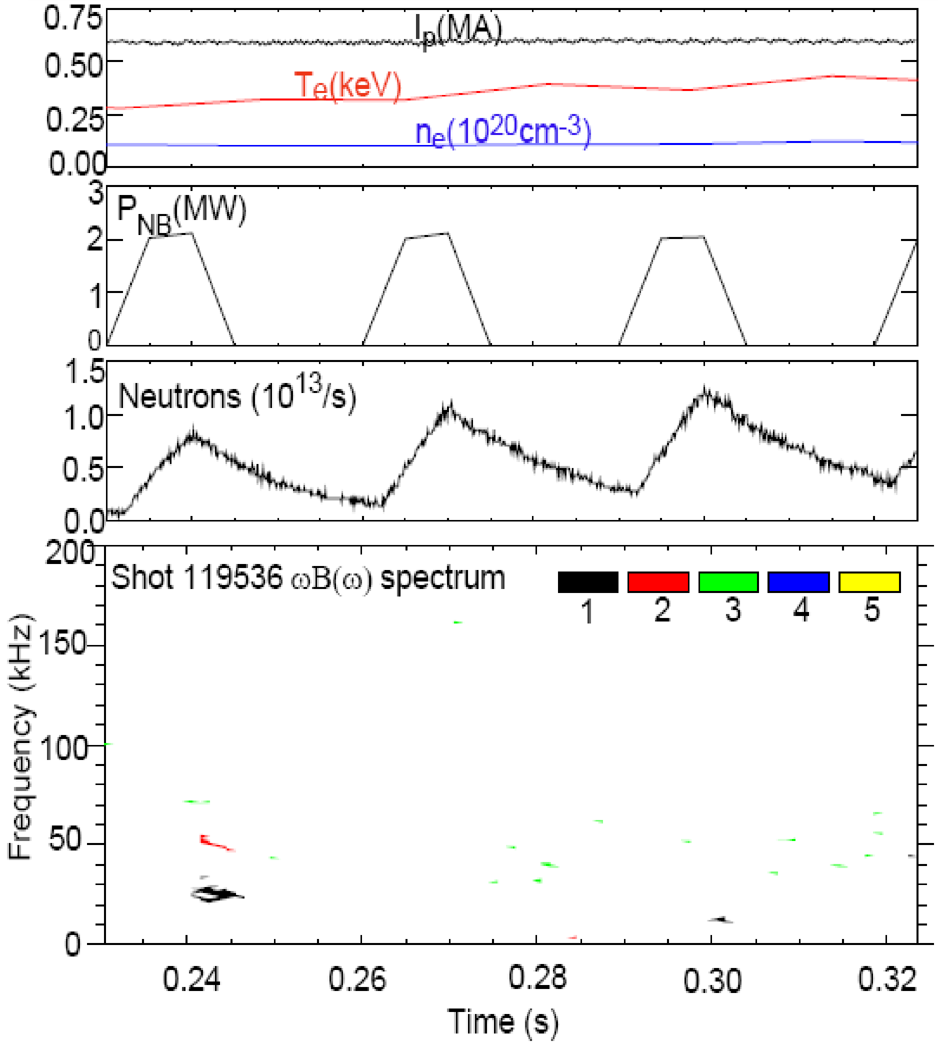
Neutral Particle Diagnostics Measure Fast Ions in Phase Space

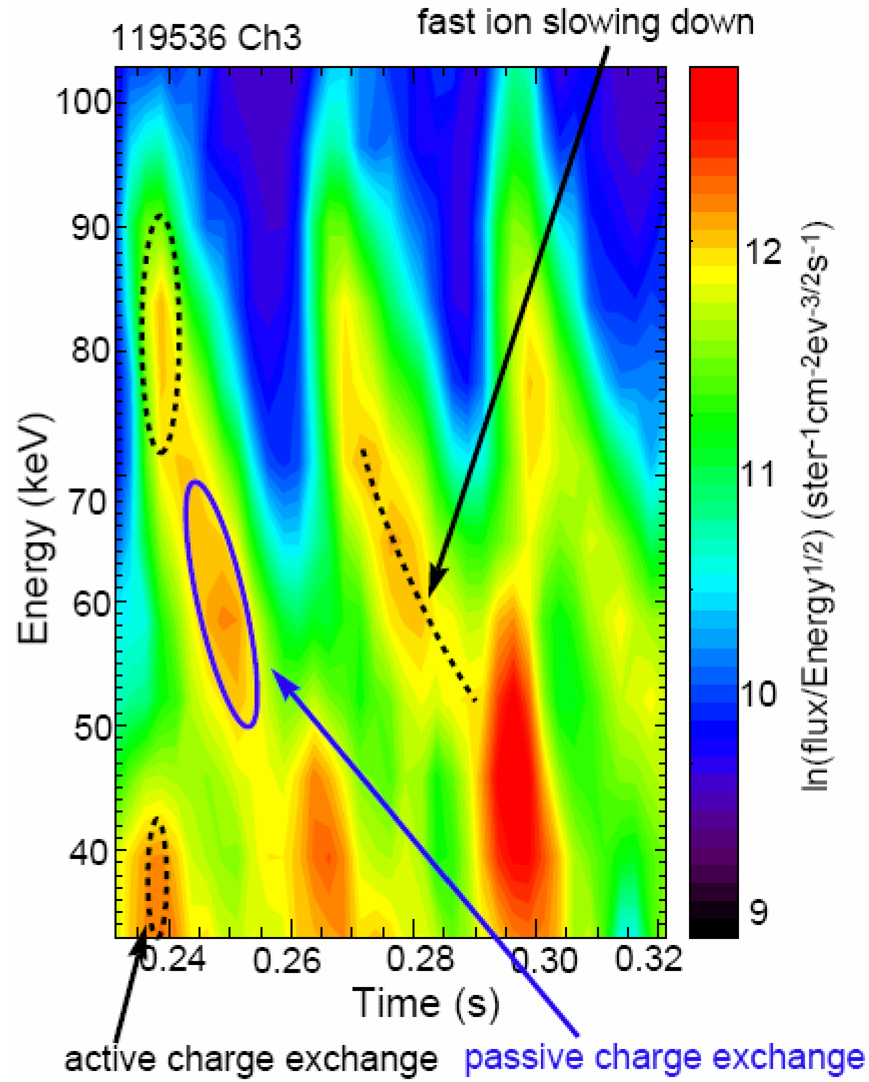


•**Fast ions are born with an initial energy and pitch by neutral beam injection. As time evolves, fast ion distribution slows and spreads due to energy diffusion and pitch-scattering. (The above graph shows a model calculation based on Fokker-Planck equation.)**

•**NPA & SSNPA measure fast ions in a small phase space.**

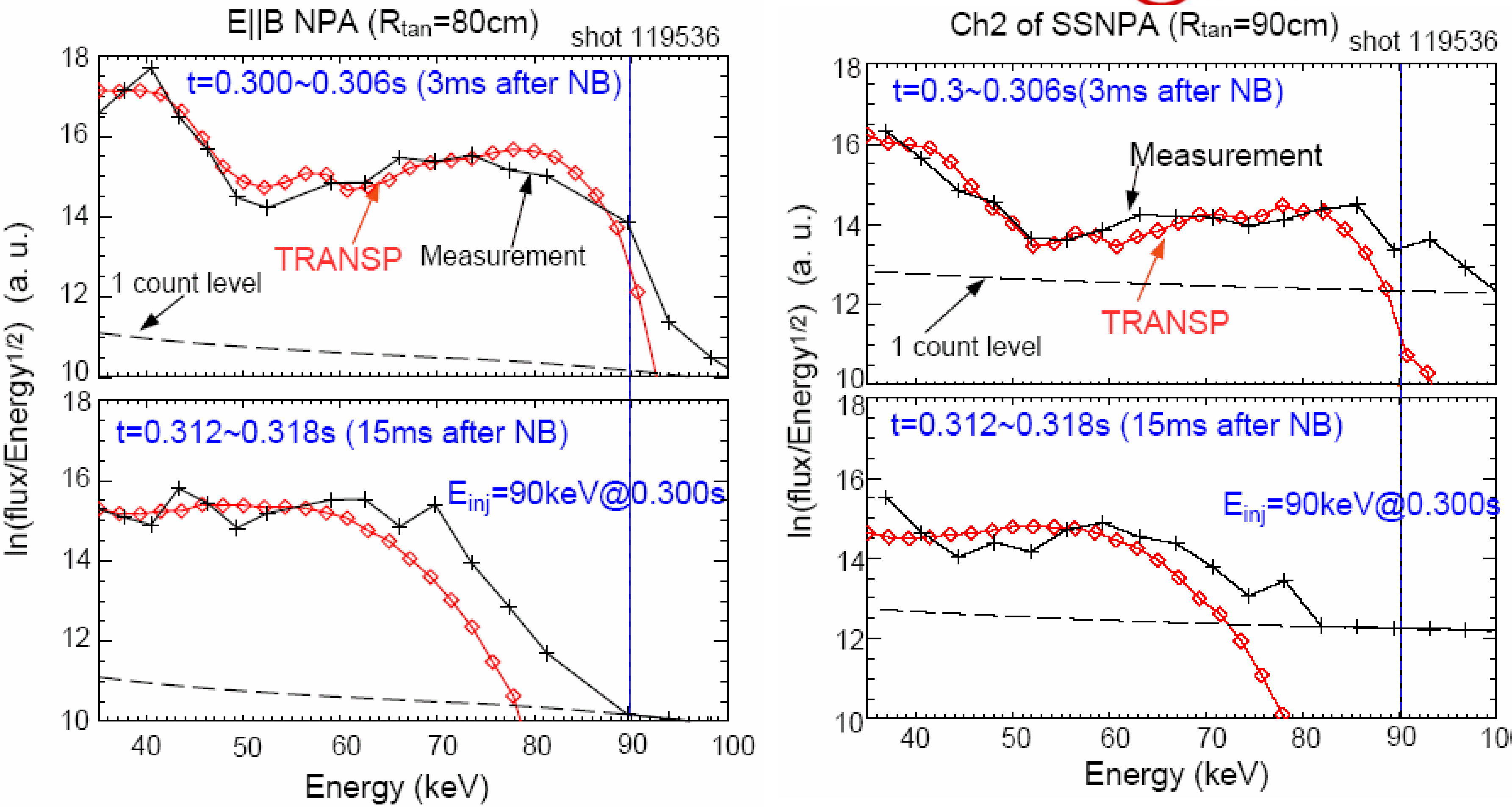
Slowing Down of Fast Ions in MHD-quiescent Plasmas is Observed on NPA and SSNPA





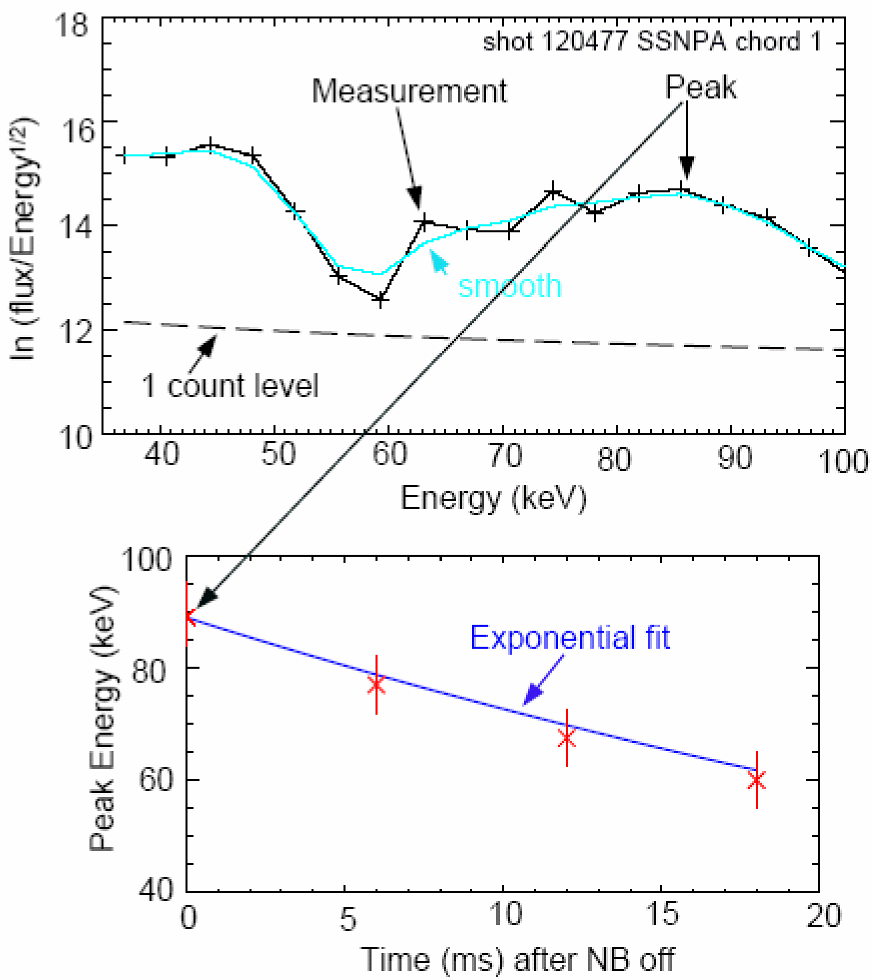
Note the absence of MHD in this shot

Slowing Down of Fast Ions in MHD-quiescent Plasmas is Observed on E||B type NPA and SSNPA (cont'd)



Slowing down of fast ions is observed on NPA (left graph) and SSNPA energy spectrum (right graph), but the experiment decays more gradually than TRANSP expects.

Calculation of Fast Ion Slowing Down Time



Experiment

(1) Find the full energy component position at several time slices after NB is off. (upper panel)

(2) Fit the points to a exponential curve

$$E = E_{inj} \exp(-t\gamma_E)$$

Where E_{inj} is beam injected energy and γ_E^{-1} is considered as the measured fast ion slowing down time. (lower panel)

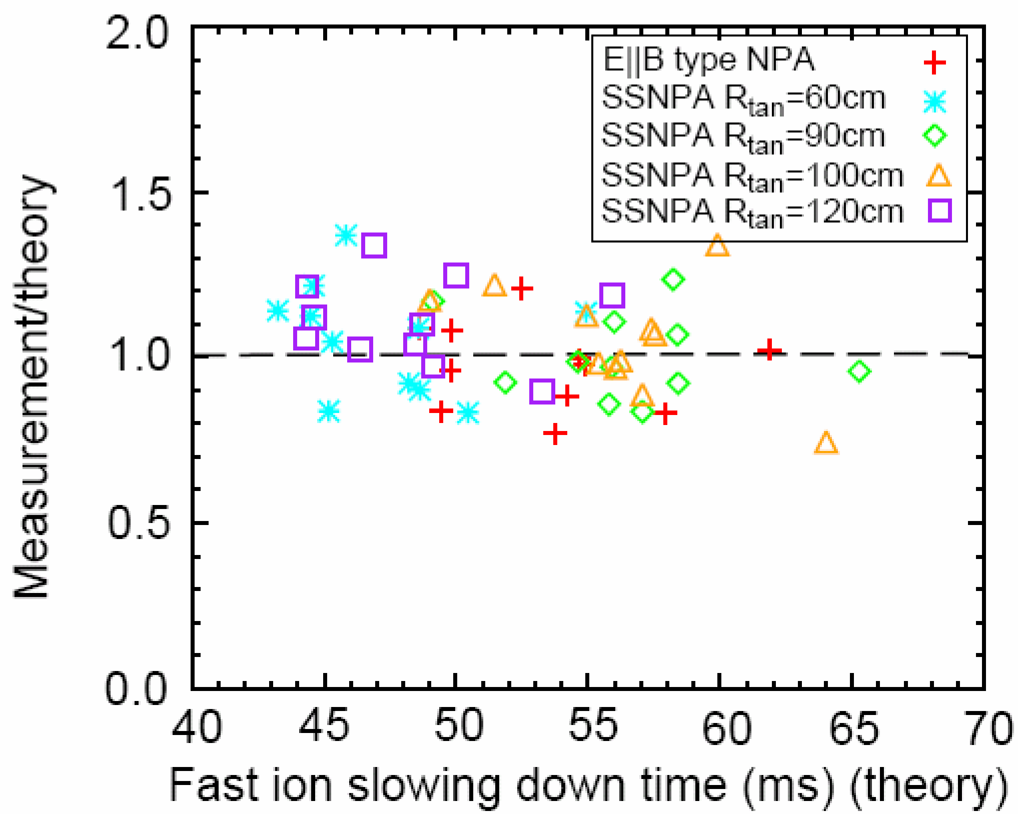
Theory

Fast ion slowing down time is

$$\gamma_E^{-1}$$

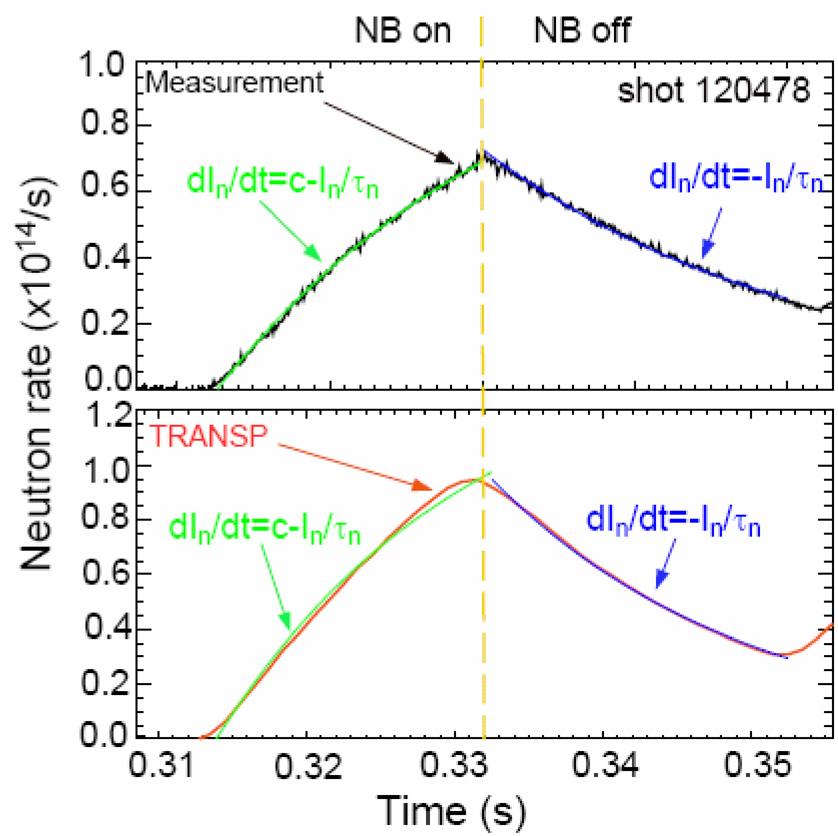
Where γ_E is classical deceleration rate that is calculated with the formula in NRL Plasma Formulary.

Slowing Down of Fast Ions in MHD-quiescent Plasmas is Consistent with Classical Behavior



Measurements of fast ion slowing down time on NPA and SSNPA agree with classical theory.

Calculation of Neutron Decay Time



*See W. W. Heidbrink et al. Nucl. Fusion **43**,883 (2003)

During the "beam blip"

$$\frac{dIn}{dt} = c - In/\tau_n$$

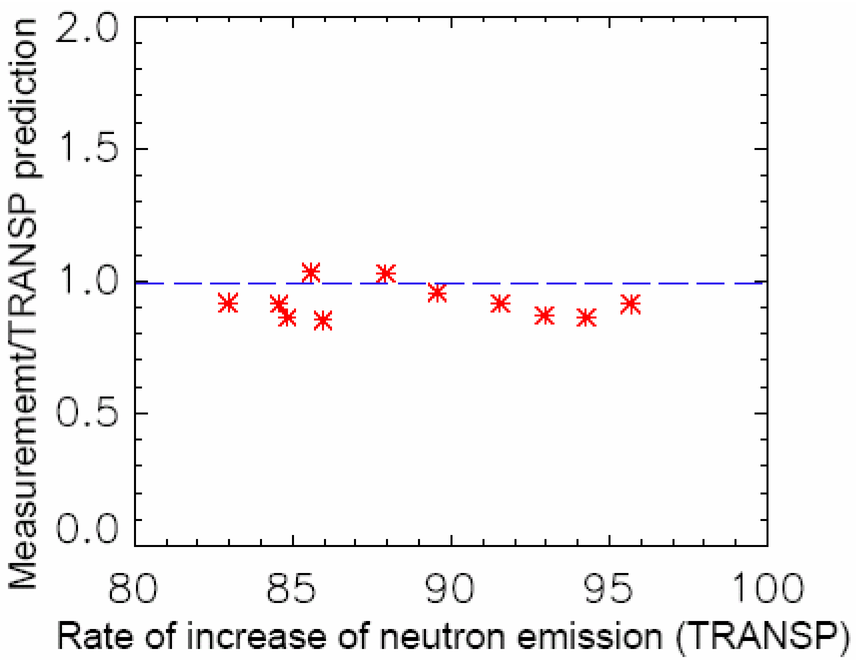
where *In* is the neutron emission rate, τ_n is neutron decay time and c is related with prompt confinement of beam ions.

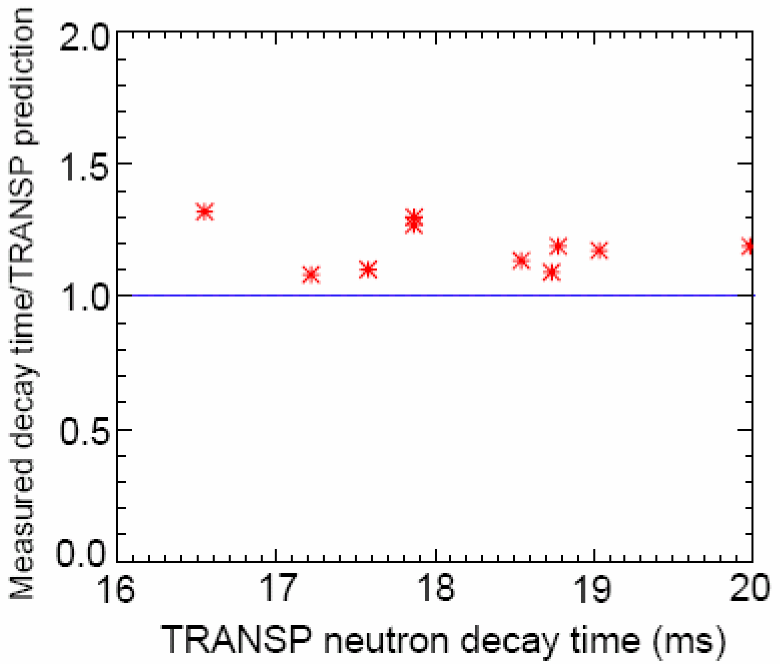
Following the "beam blip", the neutron emission decays approximately exponentially.

$$\frac{dIn}{dt} = -In/\tau_n$$

Fit the rise part and decay part for both measurement and TRANSP prediction. We can get TRANSP predicted neutron decay time and measured neutron decay time.

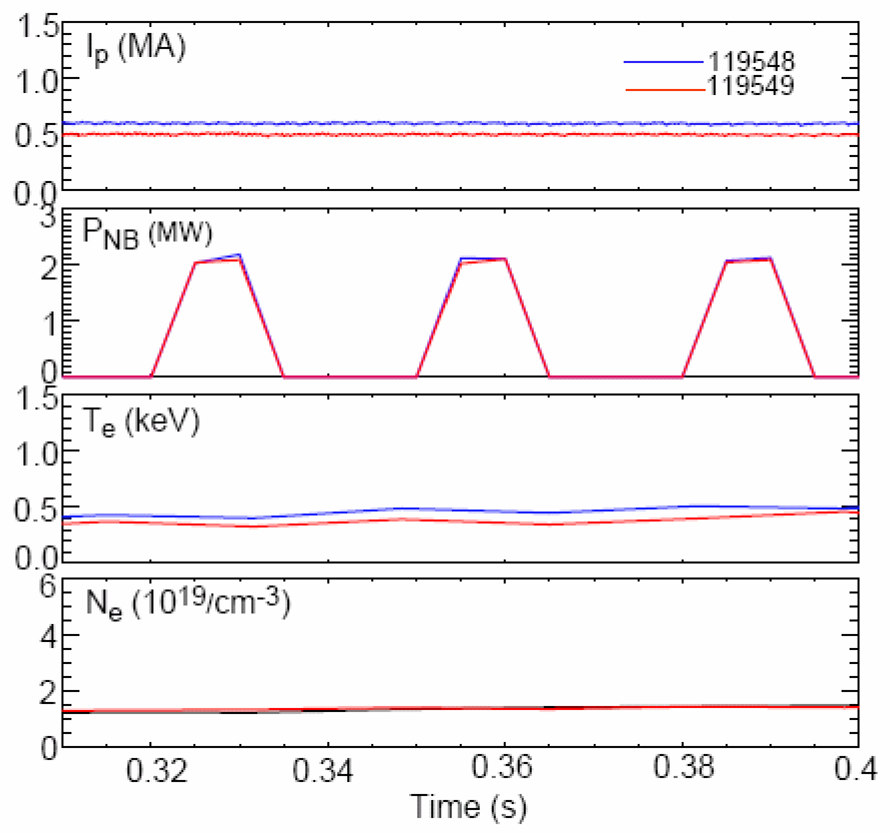
Temporal Evolution of Neutron Signal is Close to TRANSP Prediction

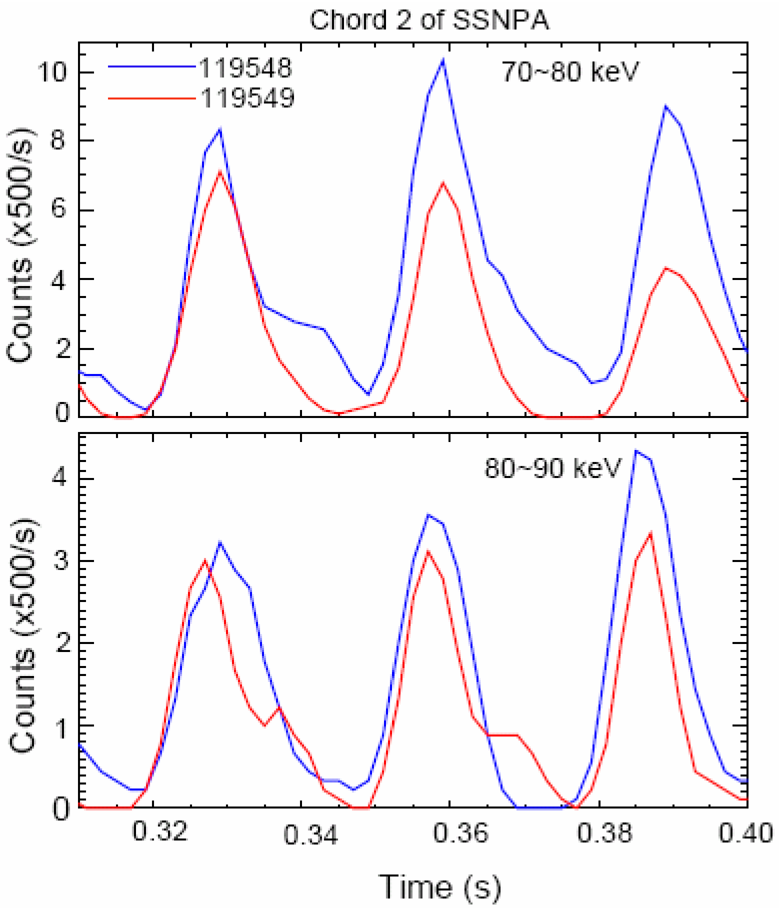




Measured rate of increase rate of the neutron signal agrees with TRANSP prediction. (left graph)
Measured deuteron decay time is close to TRANSP prediction (15% discrepancy). (right graph)

Larger Charge-exchange Neutral Particle Flux at Higher Te





Note that in 119548 and 119549, n_e are similar, but T_e is a little higher in 119548.

So SSNPA observed stronger signal in 119549 due to more fast ion in higher T_e

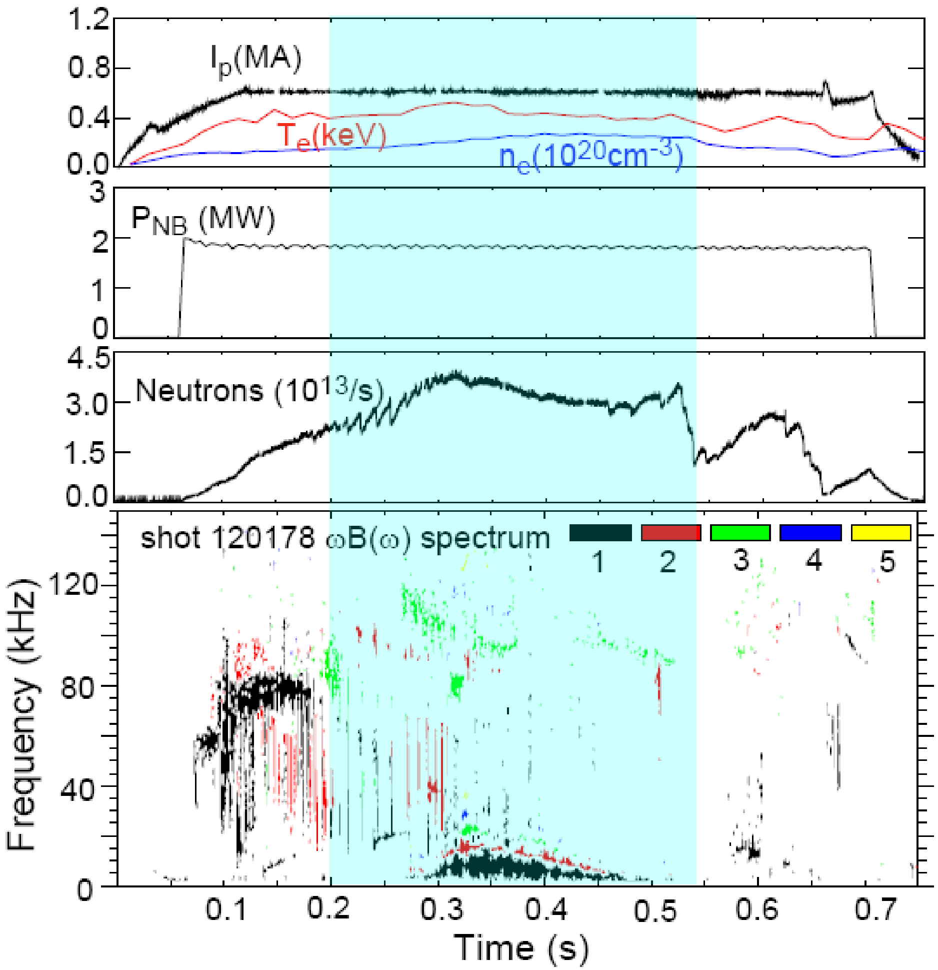
Conclusions

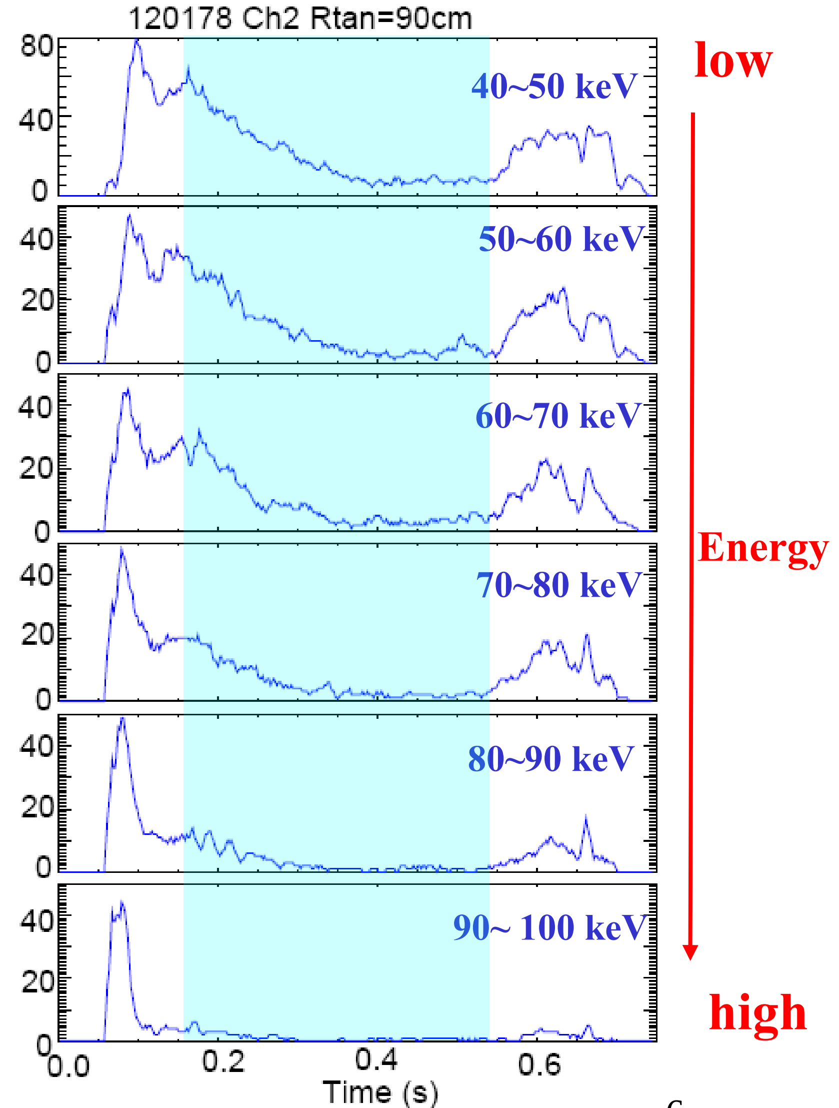
- **SSNPA diagnostic works.**
  - **Temporal evolution obtained on SSNPA is similar to that on E||B type NPA.**
  - **Slowing down of fast ions of full energy component is observed on SSNPA and E||B type NPA**
- **In MHD-quiescent Plasmas, fast ions behave classically.**
  - **Measured fast ion slowing down time from E||B type NPA and SSNPA is consistent with classical theory**
  - **Neutron decay time also agrees with classical theory with 20% error.**

Future work

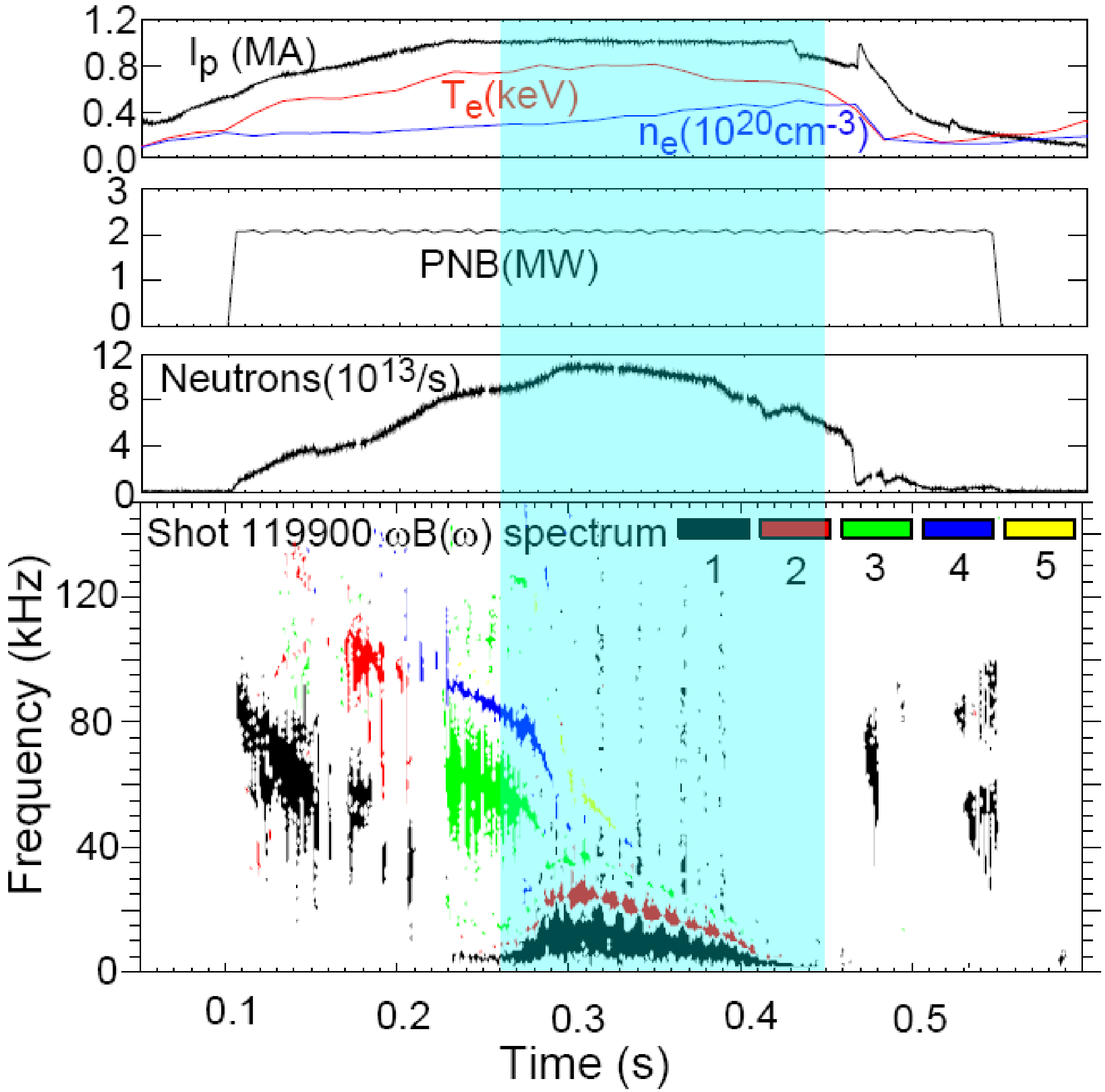
- **In the presence of MHD activity, SSNPA measurements shows several different types of fast ion behavior**
  - **MHD activity can cause the signals of all chords of SSNPA to be depleted**
  - **MHD activity can cause inner chords to decrease, but outer chords to increase.**
  - **Signals of some SSNPA channels are often correlated with neutron drops and MHD activity;**
- **Typical shots will be chosen to study the effects of MHD activity on fast ion distribution.**

Case 1: All Four Chords are Depleted





Case 2: Inner Chords Decrease, Outer Chords Increase



Case 2: Inner Chords Decrease, Outer Chords Increase (cont'd)

NSTX

At t=0.25~0.45s, Ch1 decreased, Ch3 higher energy channels and Ch4 Increased.

40~50 KeV

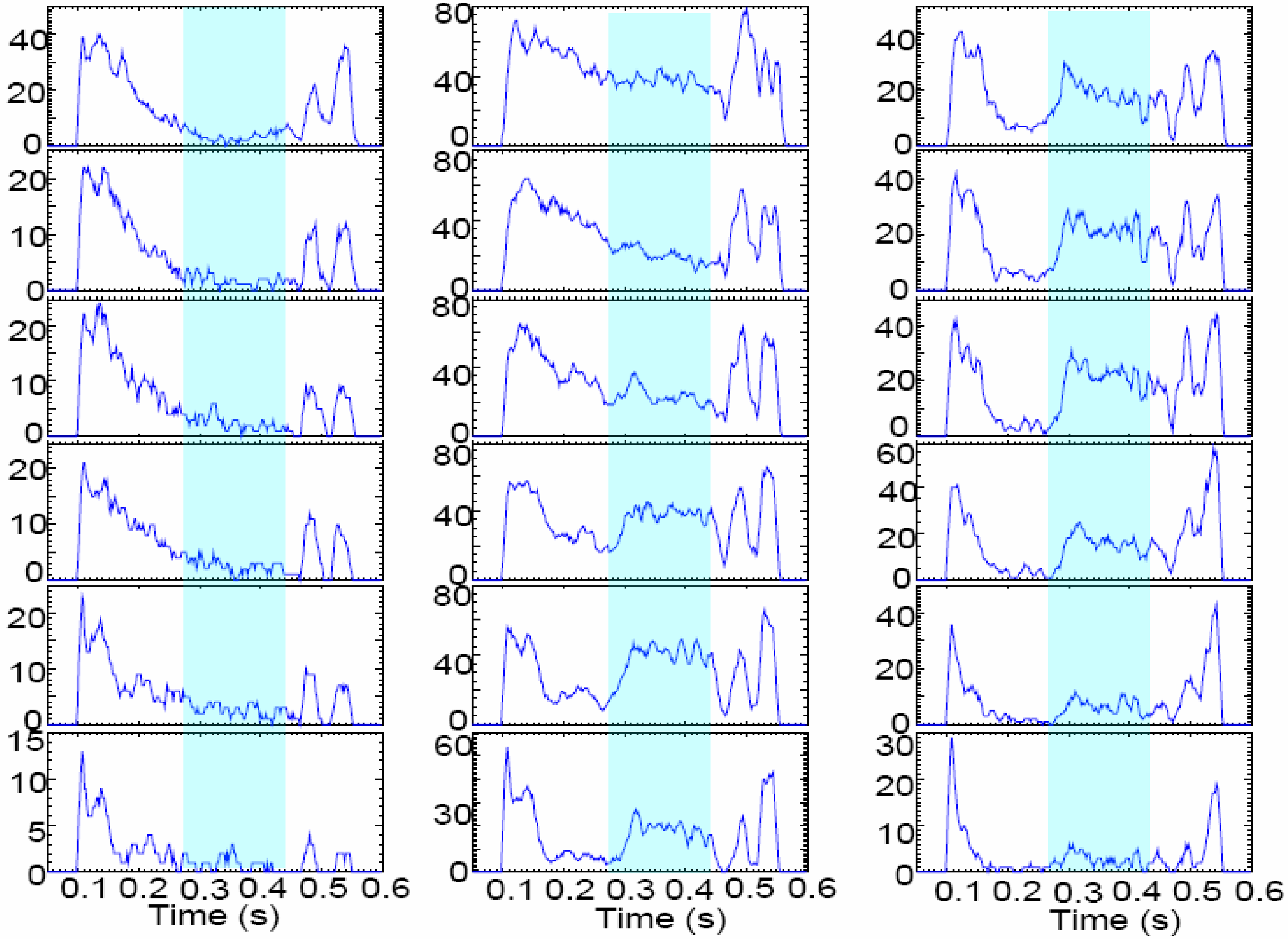
50~60 keV

60~70 keV

70~80 KeV

80~90 KeV

90~ 100KeV



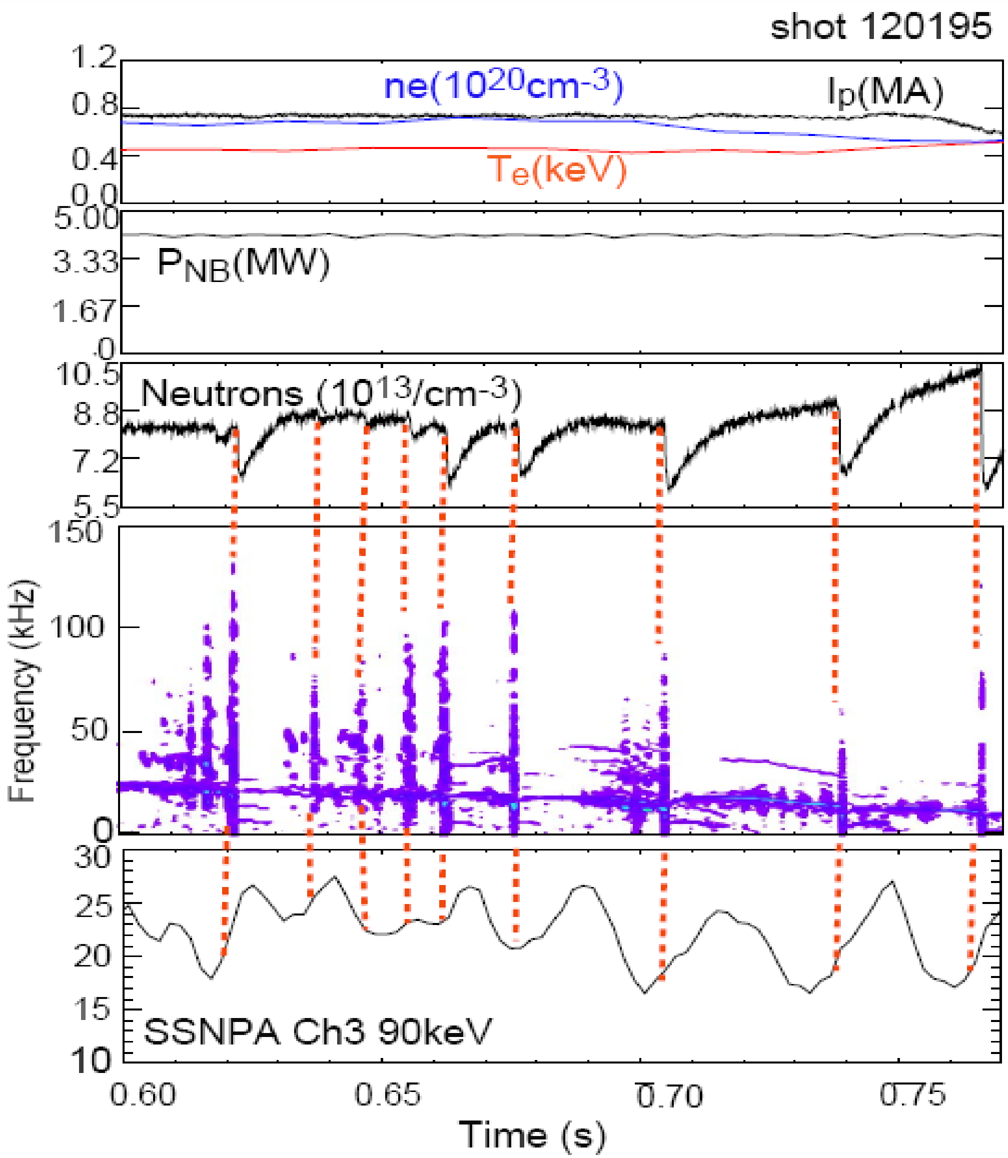
Shot 119900

Chord 1 Rtan=60cm

Chord 3 Rtan=100cm

Chord 4 Rtan=120cm

Case 3: Some Channels are Correlated with Neutron Drops



- **Some channels of SSNPA are correlated with neutron drops and MHD activity.**
- **The dips lead, bursts lag.**
- **Larger effects on high energy channels.**