Supported by

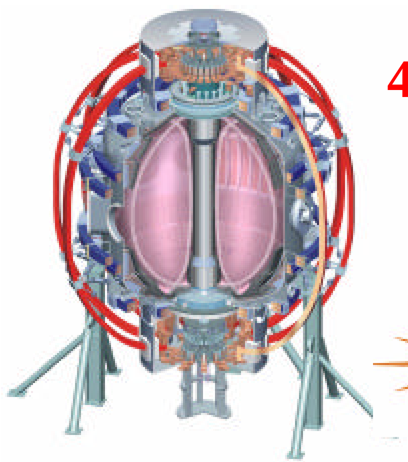
Initial Measurements of Beam Ion Profile in NSTX with Solid State Neutral Particle Analyzer

D. Liu, W. W. Heidbrink

University of California, Irvine, CA 92697

D. S. Darrow, A.L. Roquemore and S.S. Medley

Princeton Plasma Physics Laboratory, Princeton, NJ, 08543



47th Annual Meeting of Division of Plasma Physics

American Physical Society

Oct. 24-28, 2005

Denver, Colorado

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 Solid State Neutral Particle Analyzer (SSNPA) array on the National Spherical Torus Experiment (NSTX) utilizes Si diodes coupled to fast digitizers to measure the energy distribution of charge exchange fast neutral particles (35~100KeV) at four fixed tangency radii (60, 90, 100, and 120cm) to obtain the corresponding beam ion profile. The results have been compared with those on the scanning E//B type Neutral Particle Analyzer (NPA) and good agreement was achieved. The redistribution and loss of beam ions during MHD activity have been observed. Example data from plasma discharges will be presented along with the noise reduction techniques required to operate in the Tokamak environment and post-shot pulse height analysis (PHA) methods.

Motivation

- **Fast ion confinement on NSTX could differ from conventional tokamaks.**
  - MHD-induced fast ion radial transport may be stronger since magnetic moment μ may not be well conserved.
  - Orbit topology and particle drifts could be different.
- **NSTX is susceptible to fast ion driven instabilities.**[1]
  - $V_{fast\ ion} / V_{Alfvén} >> 1$ ($V_{Alfvén} = B_0/(\mu_0\rho_m)^{1/2}$; fast ion energy available to drive modes
  - $\rho^* = \rho_{fi}/a$ (ρ_{fi}: fast-ion larmor radius, a: plasma radius) sets mode structure scale
  - The gaps in the Alfven continuum are larger
- **Beam ion profile measurements will help understanding the influence of instabilities on beam ion distribution and the interaction mechanism.**

[1]See Fredrickson et al. *Phys. Plasma* **10**, 2852 (2003)

Solid State Neutral Particle Analyzer (SSNPA) Operating Principle

SSNPA can measure the cross section weighted line-integrated energy spectrum of charge exchange fast neutral particles emitted from the plasma.

- **Injected beam neutrals, Cold edge neutrals, Halo neutrals**
- **Fast neutrals generated from the charge exchange reaction between beam ions and D^0, or hydrogen-like-carbon-ion, C^{5+}.**

$$\underset{\text{beam ion}}{D^+} + \underset{\text{injected neutrals / halo neutrals}}{D^0} \rightarrow \underset{\text{reneutral}}{D^0} + D^+$$

The amount of the neutral flux on SSNPA

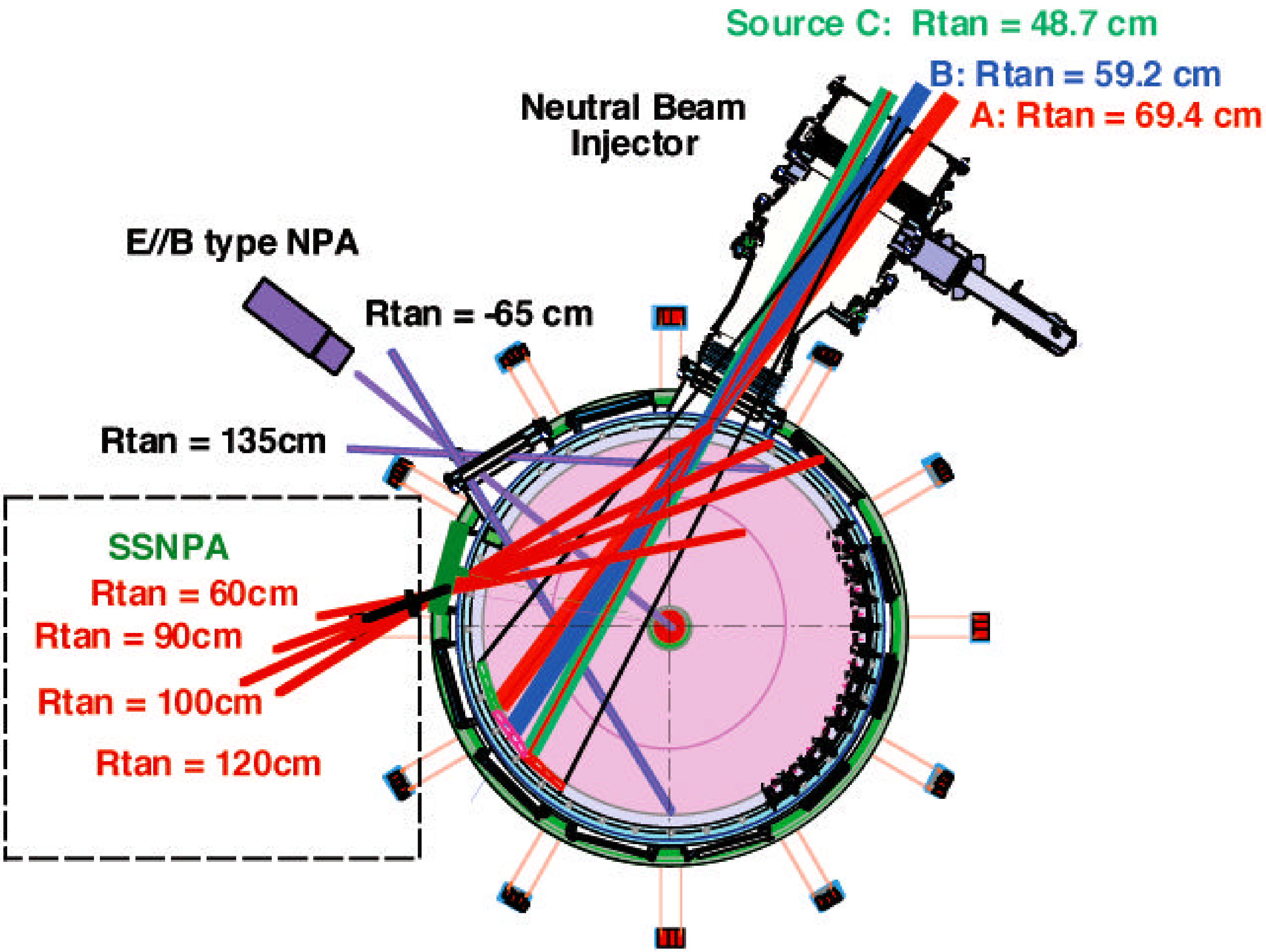
$$\overline{\Gamma}(E) \propto \int F(E, l, x)\, n_t(x) < s_{CX} v_r >_{E,X} g(E, x)\, dx$$

energy distribution

neutralization probability

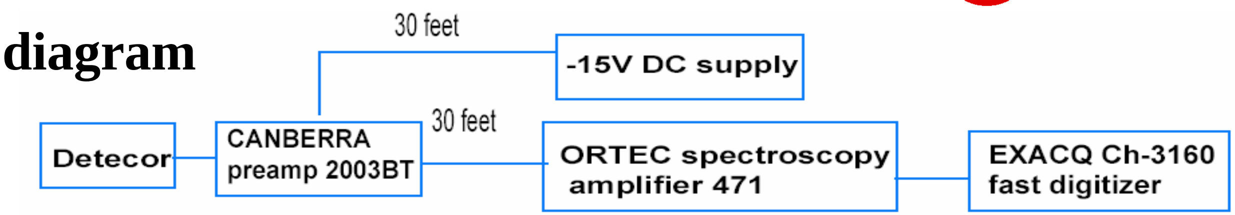
transparency

SSNPA Sightlines



SSNPA Specifications and Features

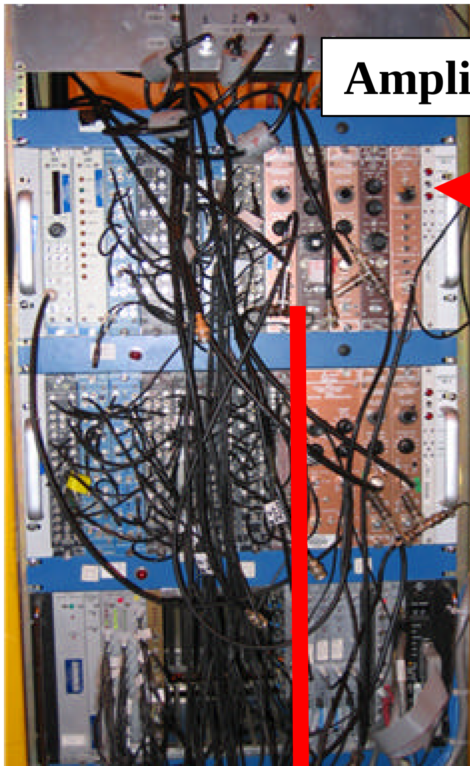
- **Electronics diagram**



- **2ms time resolution (mainly determined by amp. shaping time) and 10KeV energy resolution (mainly determined by detector) .**
- **4 chords at tangency radius 60, 90,100 and 120cm.**
- **1 mm^2 IRD SXUVHS5 Silicon photodiode operated at bias of -15V. A 0.15*mm*Aluminum foil mask is put in front of detector to block visible light and a 25~50*mm* diameter aperture is used to limit the neutral efflux. Deuterium atoms will lose about 10KeV energy due to the Aluminum foil and detector dead-layer.**
- **Good linearity of detector in the range of 35 to 120 KeV. FWHM is almost constant in this range.**
- **Canberra 2003BT charge sensitive preamp at 20mV/MeV coupled with Ortec 471 shaping amp. at gain X500 and shaping time 0.5*ms* .**
- **2 EXACQ Ch-3160 12-bit 10k-40Msamples/s Digitizer boards with 64MB on-board memory are used to store data and do post-shot pulse height analysis.**

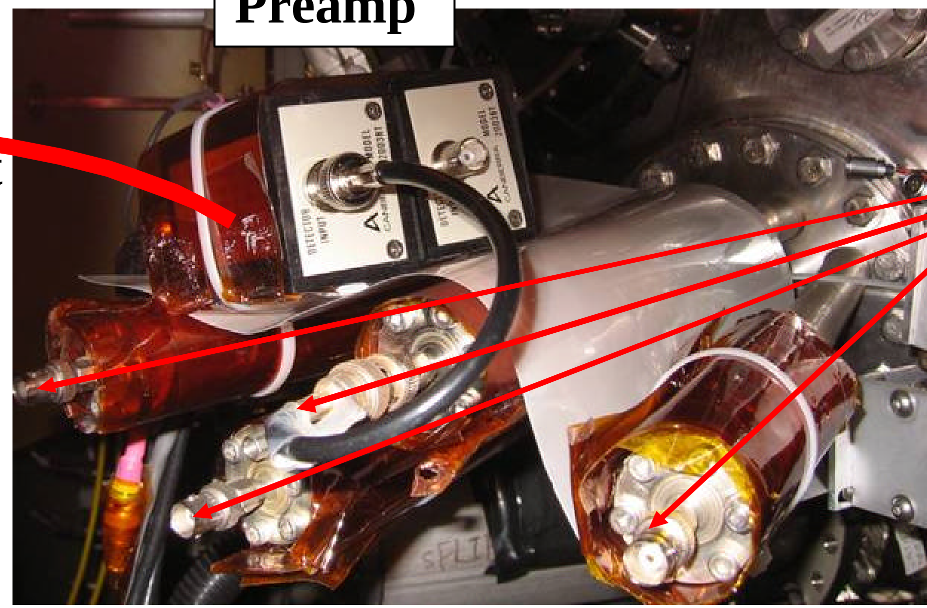
SSNPA Hardware

Amplifier



30 feet

Preamp



SSNPA modules

5 feet

Connected to digitizer boards

Al foil

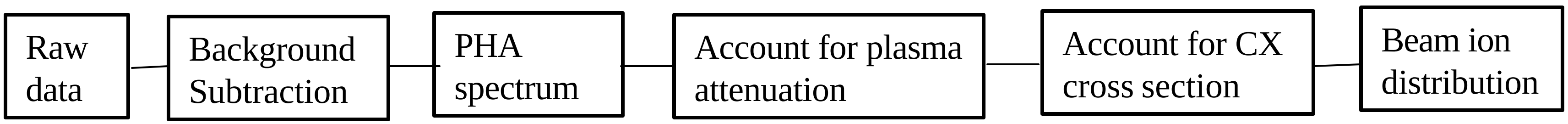
IRD Inc.
SXUV HS5
Silicon
Photodiode

SSNPA Noise Reduction Techniques

NSTX

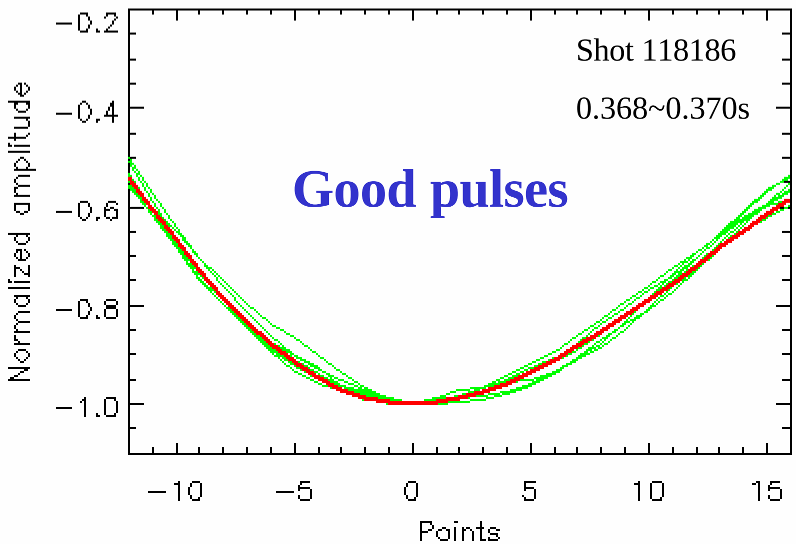
- **Detector is shielded in a copper cylinder.**
- **Preamp is connected to detector directly and all connections and preamp are shielded in a copper box.**
- **The cables between preamps and amps are twisted, wrapped with magnetic shielding foil Metglas 2605CO, covered with braid and shielded in a Aluminum conduit.**
- **Instead of coaxial cable, shielded twist-pair cable is used as signal cable and transformer is in series in order to get rid of possible ground loops.**
- **Voltage signals after amps are sampled by fast digitizer boards and post-shot pulse height analysis programs find each individual pulse baseline and pulse height and compare pulse shape with pulse model.**

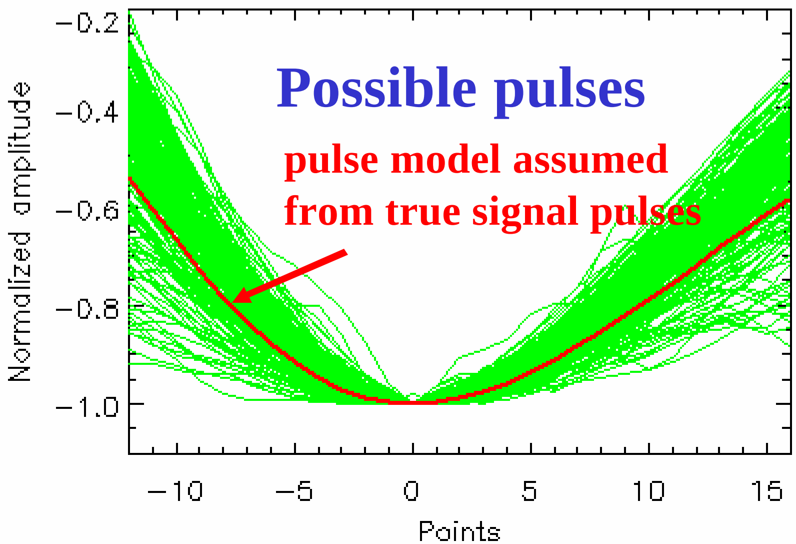
Beam Ion Distribution Extraction

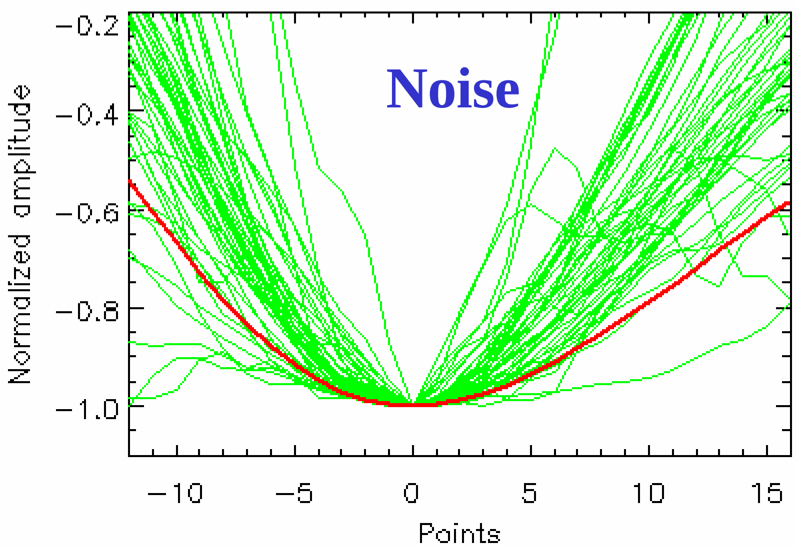


- **Assuming the signal detected is caused only by injected neutral beam induced charge exchange neutrals, the beam ion distribution can be calculated from the above chain.**
- **The neutral attenuation calculation uses the magnetic equilibrium, the neutral beam parameters, and fitted temperature and density profiles.**
- **In typical NSTX plasma shots, there are significant x-ray and neutron emissions. This background must be excluded from the PHA spectrum.**

Signals Differ from EM Noise in Pulse Shape







- **Pulse height analysis method**

(I) Find all points below threshold

(II) Find the peak for conjunct points

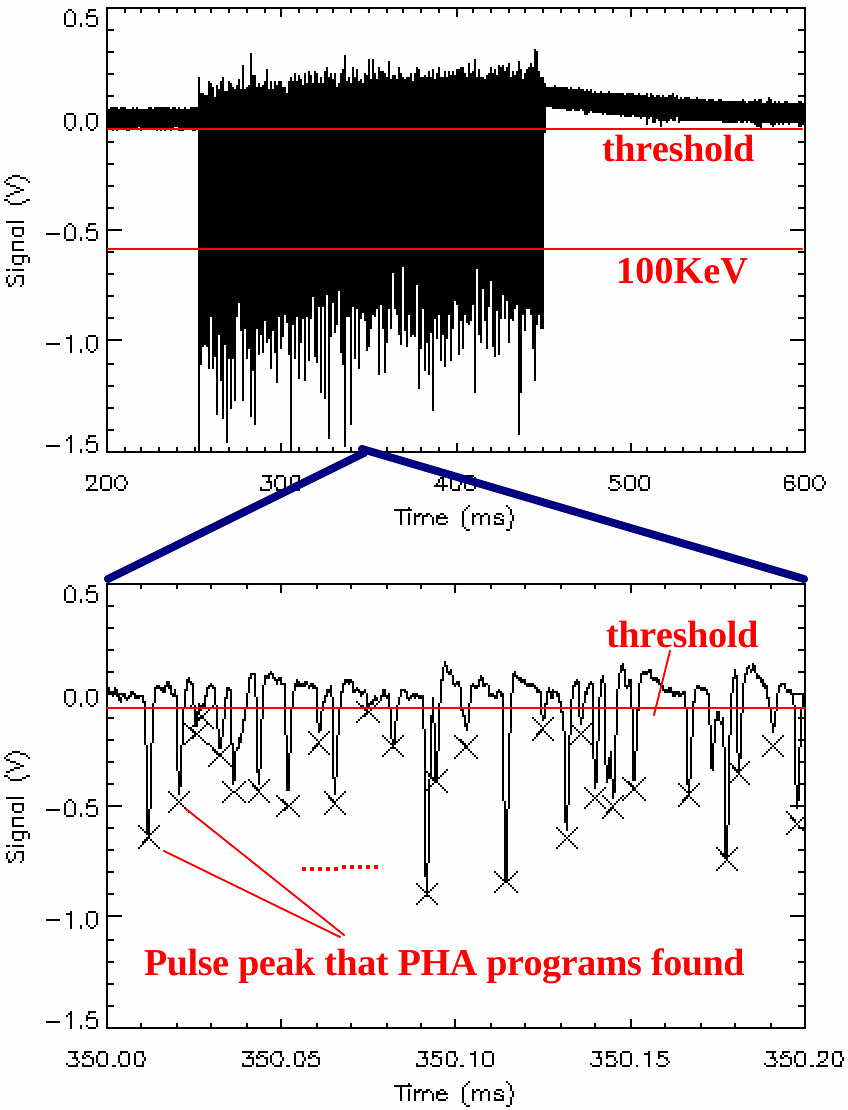
(III) Find baseline and pulse height for every individual pulse

(IV) compare pulse shape with pulse model and calculate chi-square.

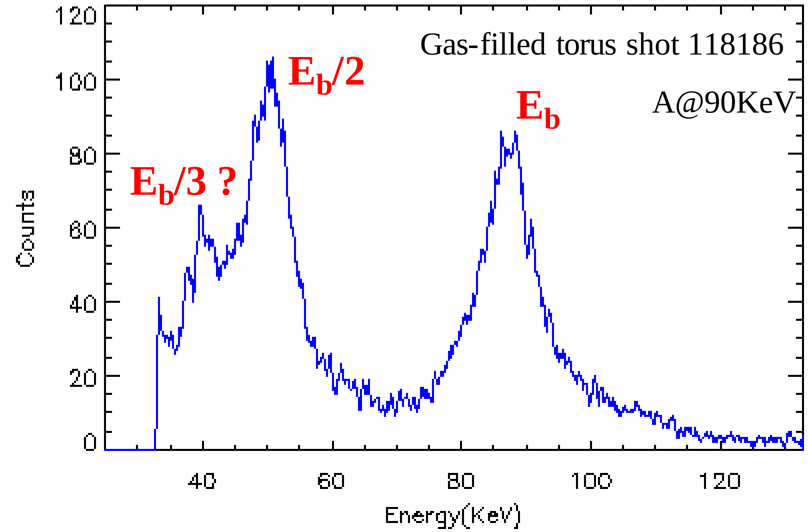
- **Signals (good and possible pulses) can be told from EM noise with pulse shape comparison.**

Energy Resolution of ~8KeV Achieved

Raw data

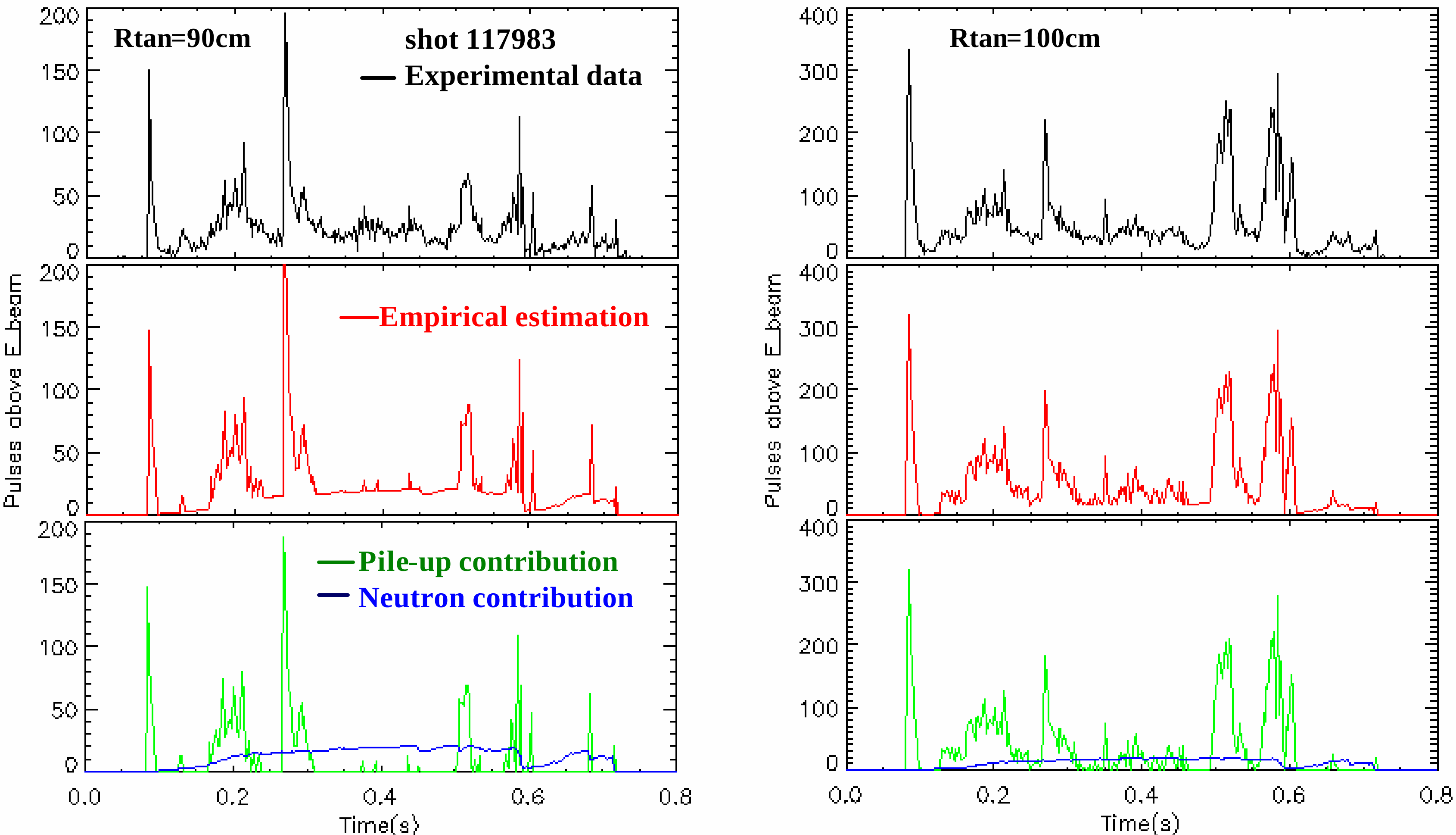


Energy spectrum



- In gas-filled torus shots, full energy (E_b) and half energy ($E_b/2$) components are clearly seen in the above energy spectrum.
- In some gas-filled torus shots, there is a big tail above the injected beam energy in the energy spectrum that is caused by pulse pile-up.

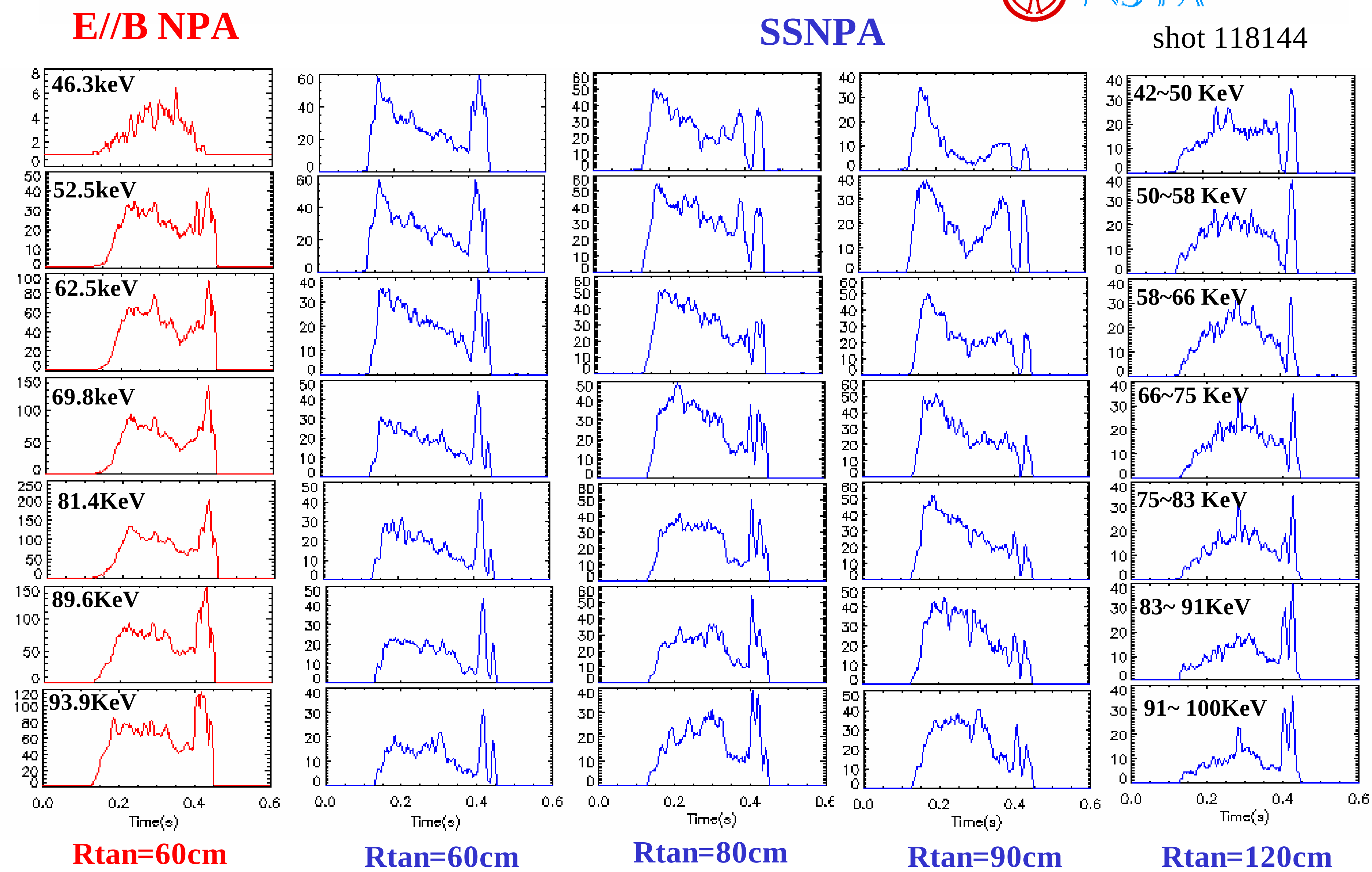
Pulse Pile-up and Neutron Radiation Caused Pulses above Injected Beam Energy



The empirical linear combination of pulse pile-up and neutron radiation (red curve) can fit well with experimental pulse count evolution above injected beam energy (black curve) for almost every shot.

Similar Temporal Evolution Obtained on E//B NPA and SSNPA

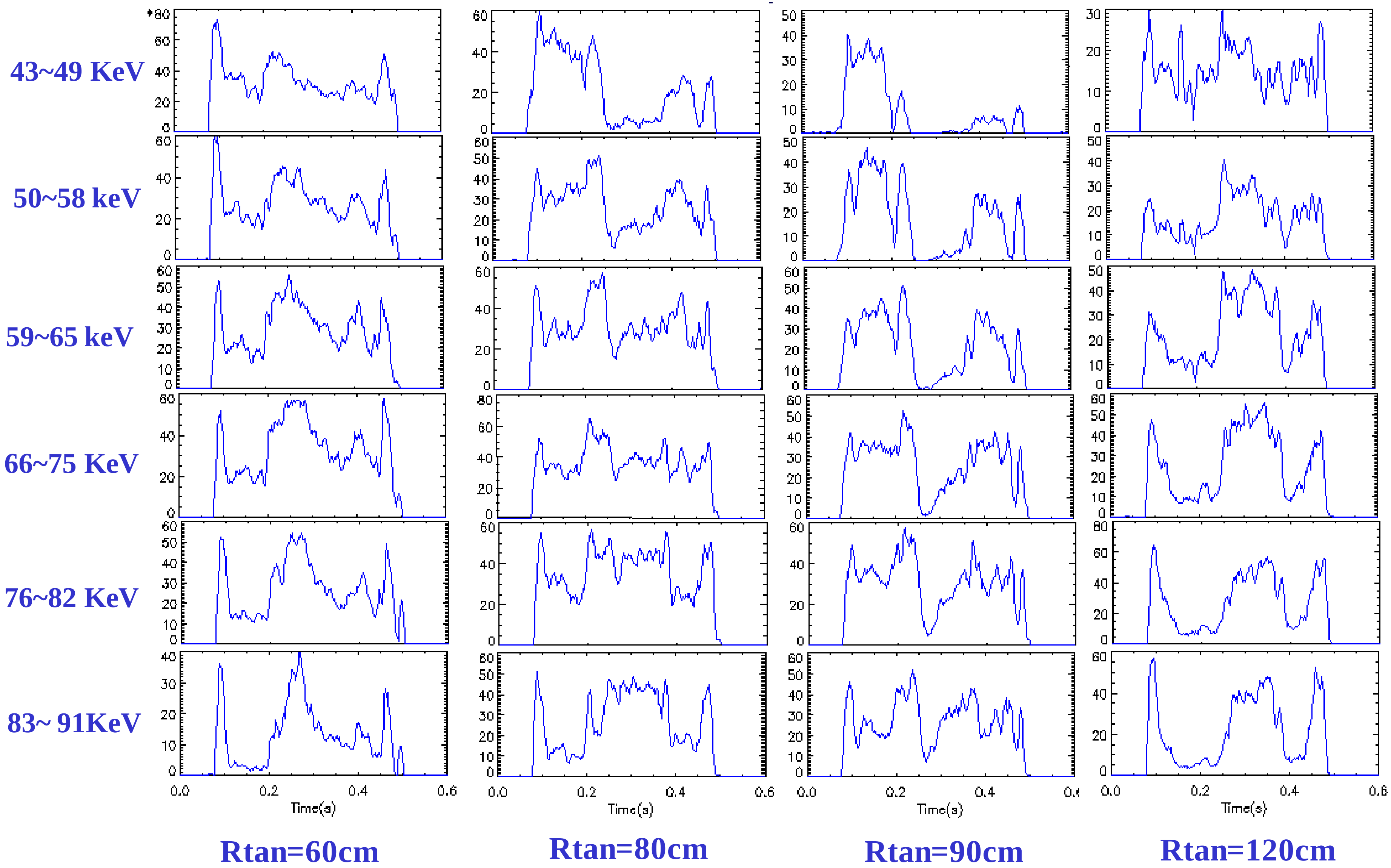
NSTX



Beam Ion Redistribution Observed on SSNPA

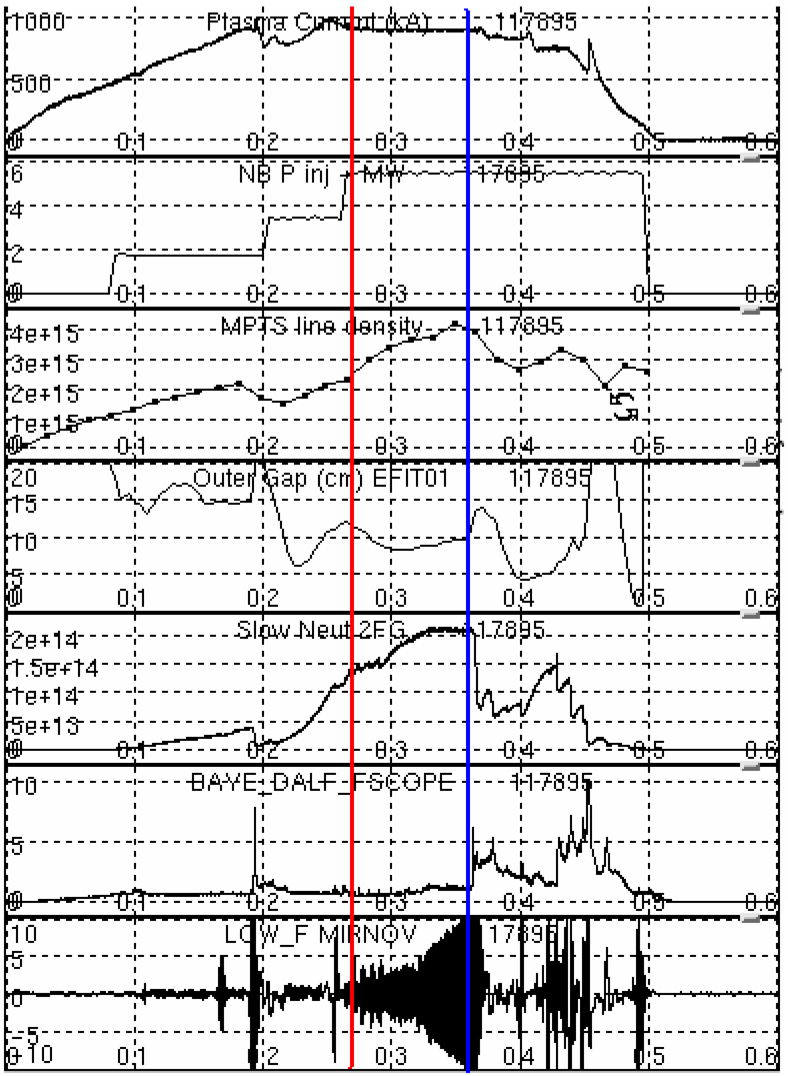
NSTX

shot 117895

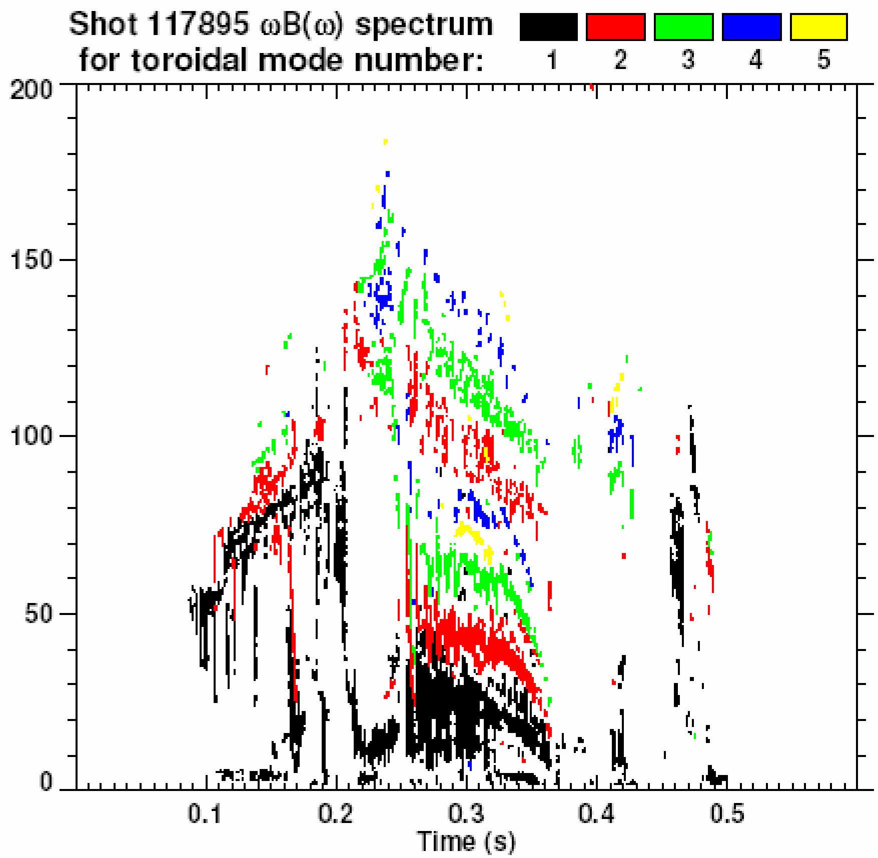


Parameters and MHD Spectrum of Shot 117895

NSTX

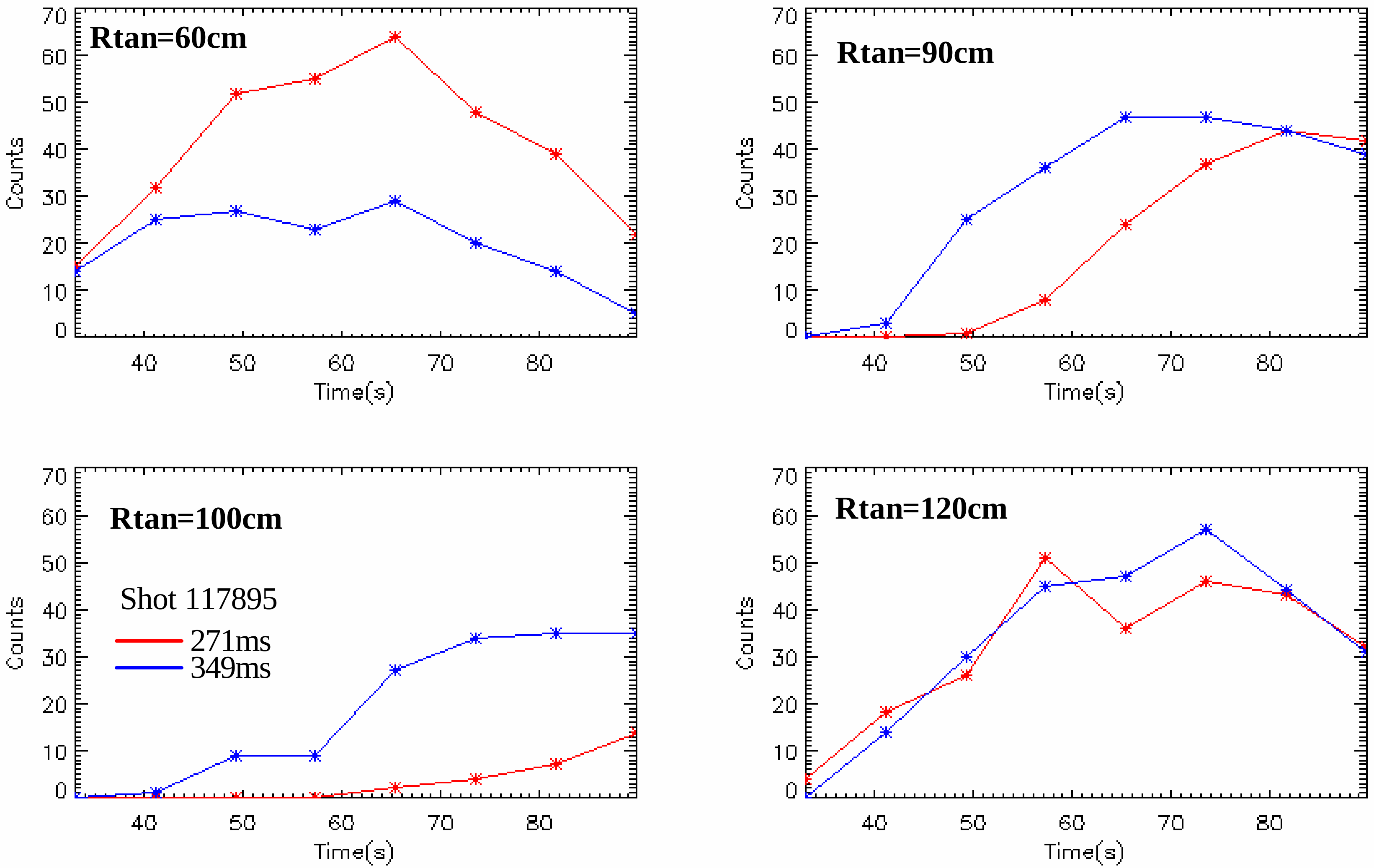


0.271s 0.349s



Strong MHD activity happened in the time period of 0.271~0.349s.

Neutral Flux Interchanged at Rtan=90,100cm implies Beam Ions Move Outward



Current Challenges and Future Plans

- **AXUV detectors are supposed to have lower noise level and better energy sensitivity than SXUV detectors, but they never survived on SSNPA because of high temperature in the baking. It's planned to test AXUV detectors again without baking. Smaller cross section detectors are also considered since they could decrease the noises generated by radiation.**
- **The thin aluminum foil before detector is easily broken during pump-down. It's planned to coat the foil directly on detector.**
- **To improve SSNPA resolution, count rate need to be higher. But it's limited by amp. shaping time. We are seeking faster (~0.1 micro second) and lower noise shaping amplifier.**
- **Since SSNPA signal is very small (mV after preamp), it requires the common ground of NSTX to be very stable.**
- **If budget permitted, a set of selectable collimating apertures and more channels will be installed on SSNPA. The detector and preamp will be cooled to reduce noise and increase energy resolution.**

Summary

- **The noise of SSNPA has been decreased to 1/4 of that in 2004 and reasonable signals have been obtained on SSNPA.**
- **Energy resolution of ~8KeV and time resolution of 2ms have been achieved.**
- **The redistribution and loss of beam ions during MHD activity have been observed.**
- **A number of hardware improvement should allow for extensive study of beam ion profile and the interaction between beam ions and MHD instabilities.**