Measurements of fast ion confinement and transport using dual-view Fast Ion D-Alpha Diagnostics on NSTX-U

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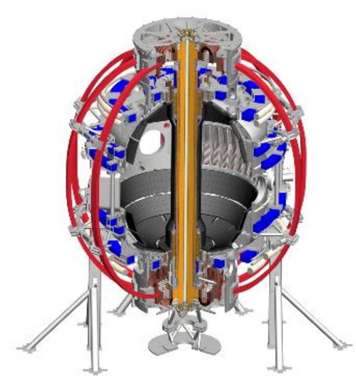
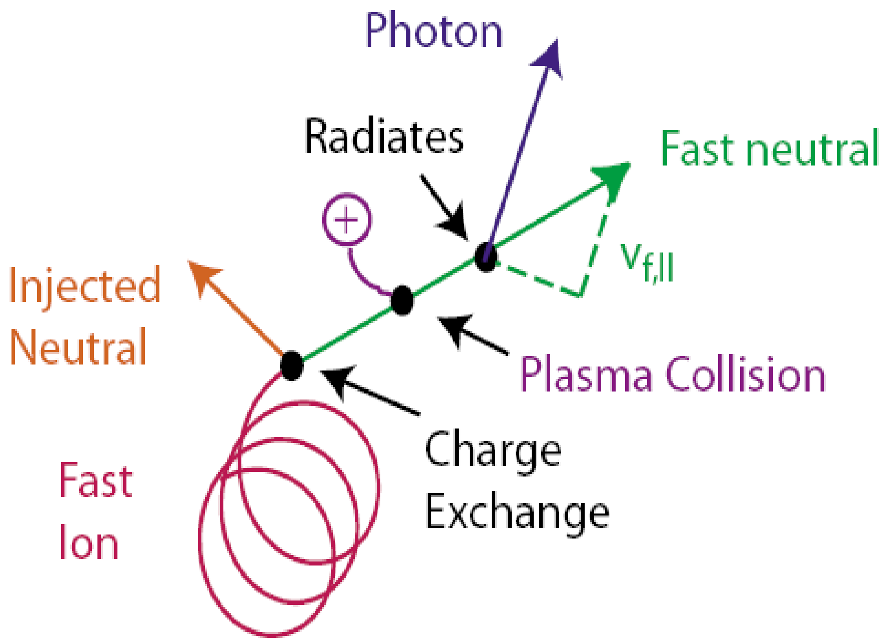
58th Annual Meeting of the APS Division of Plasma Physics
San Jose, CA
Oct. 31 - Nov.4, 2016

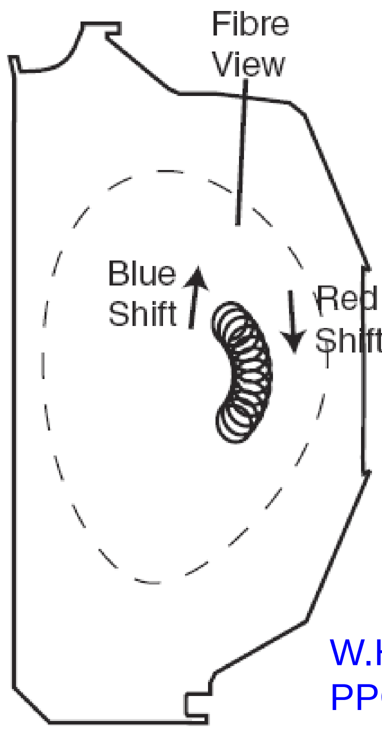


Outline

- Introduction to FIDA
- Performance of vertical/tangential-FIDA diagnostics on NSTX-U
- Measurement of fast ion confinement
  - For beam source 1C(R_tan=50cm)
  - For beam source 2A(R_tan=130cm)
- Effect of sawtooth on fast ion transport
- Influence of tearing mode on fast ion transport
- Summary

FIDA measures fast ion density profile through active charge-exchange spectroscopy





W.Heidbrink,RSI(2010), PPCF(2004)

- Fast ion exchanges an electron with the injected/edge neutral
- Doppler-shifted wavelength of the emitted photon depends on the fast ion velocity
- FIDA: collect the Doppler-shifted Balmer-alpha light

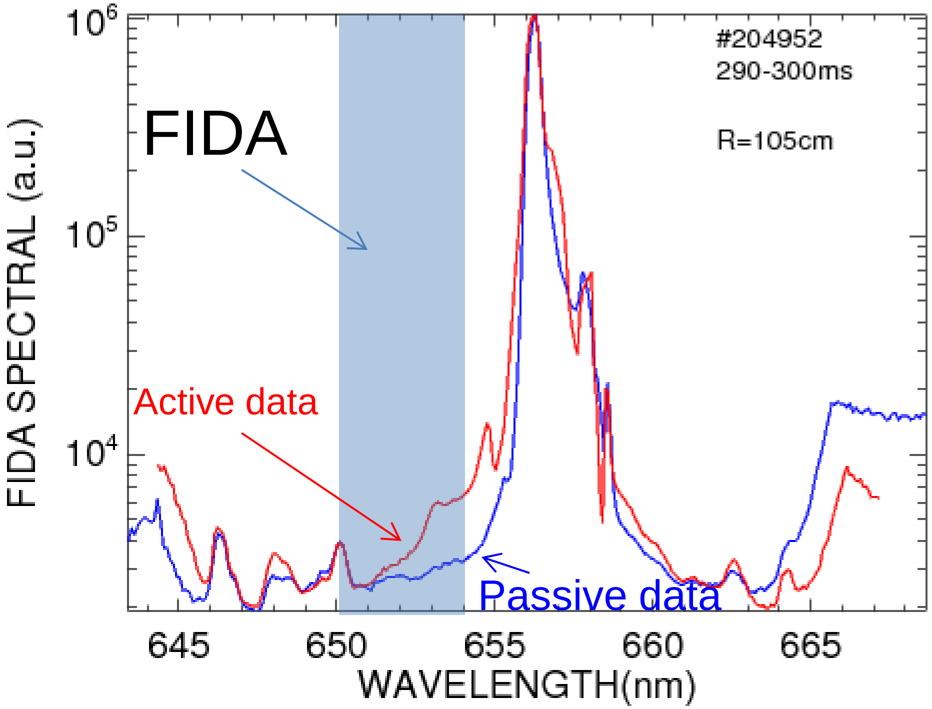
FIDA measures light in active and passive views

- The FIDA signal is the difference between the active and passive data; The shape of the FIDA spectrum provides information about the energy dependence of the distribution function.

- Only blue-shifted side is considered in this work;Wavelengths of interest : 650~654nm

- Integrate the signal over the selected wavelength to get integrated FIDA signal.

- FIDA signal: $S \propto W_{\phi} n_b n_f$



Velocity space weighting function

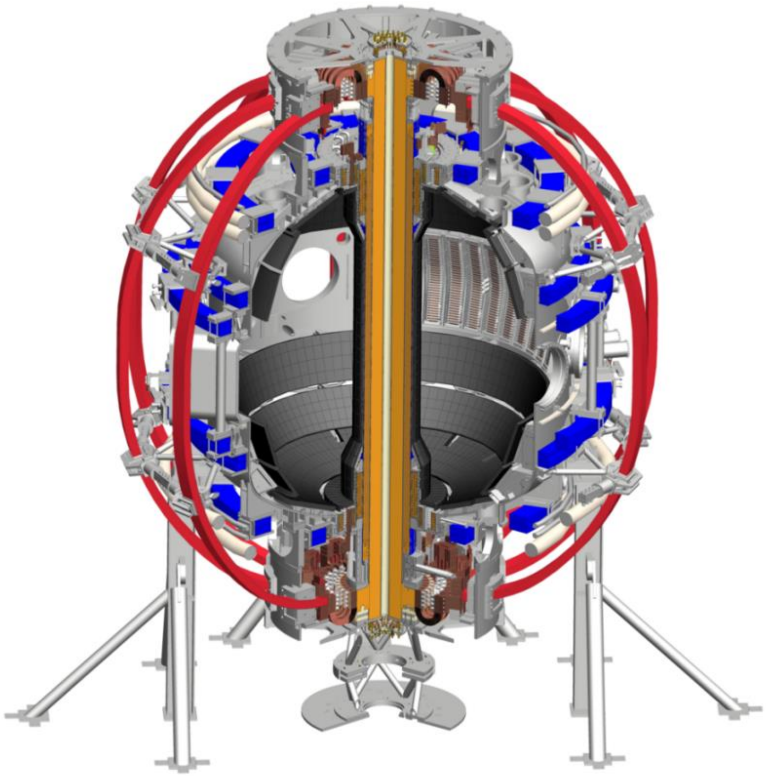
Neutral density

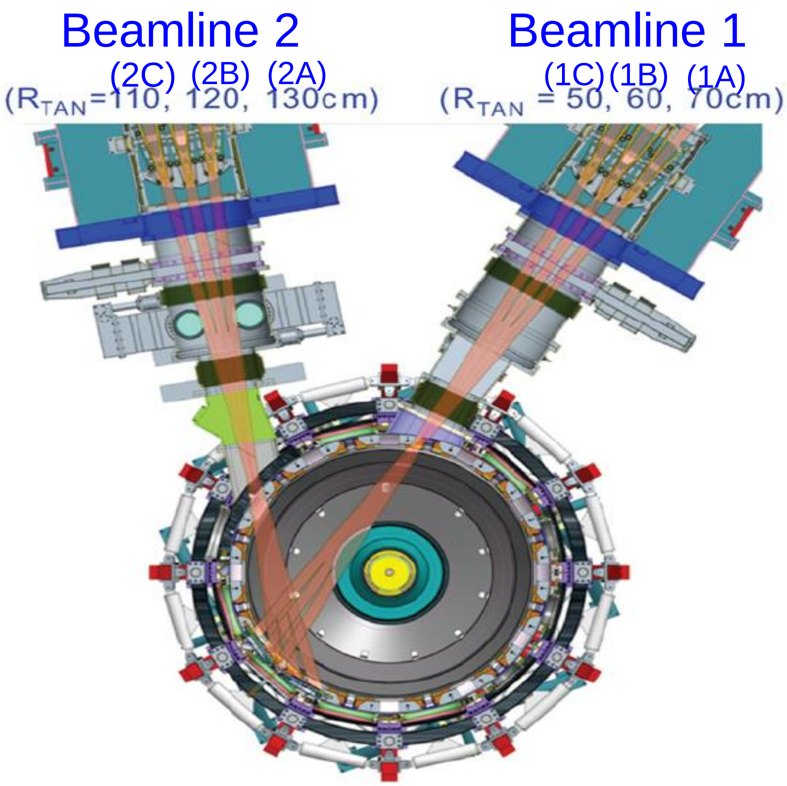
Fast ion density

[Y. Luo,RSI(2007)]

Basic parameters of NSTX-U

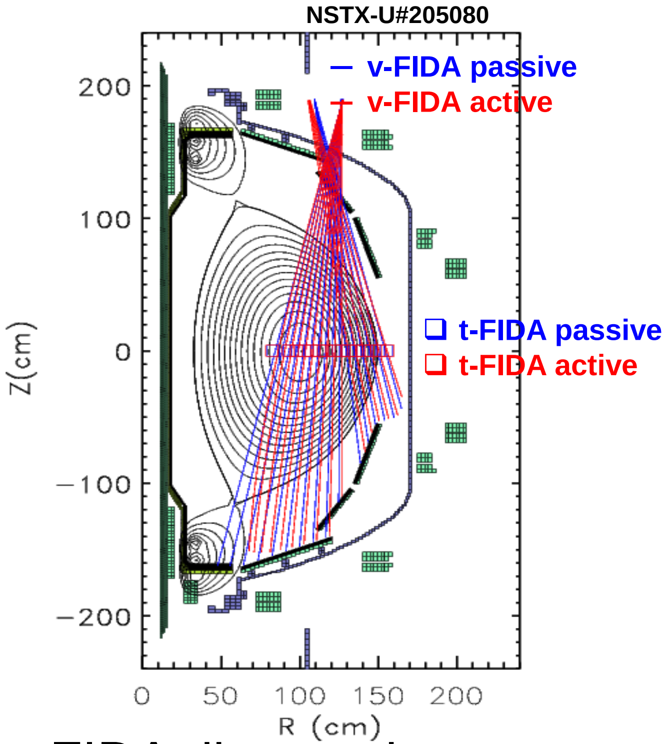
Major Radius R_0[m]	0.94
Aspect Ratio R_0/a	$\geq$1.5
Plasma current [MA]	$\leq$2
Toroidal Field [T]	$\leq$1
NBI power [MW]	12



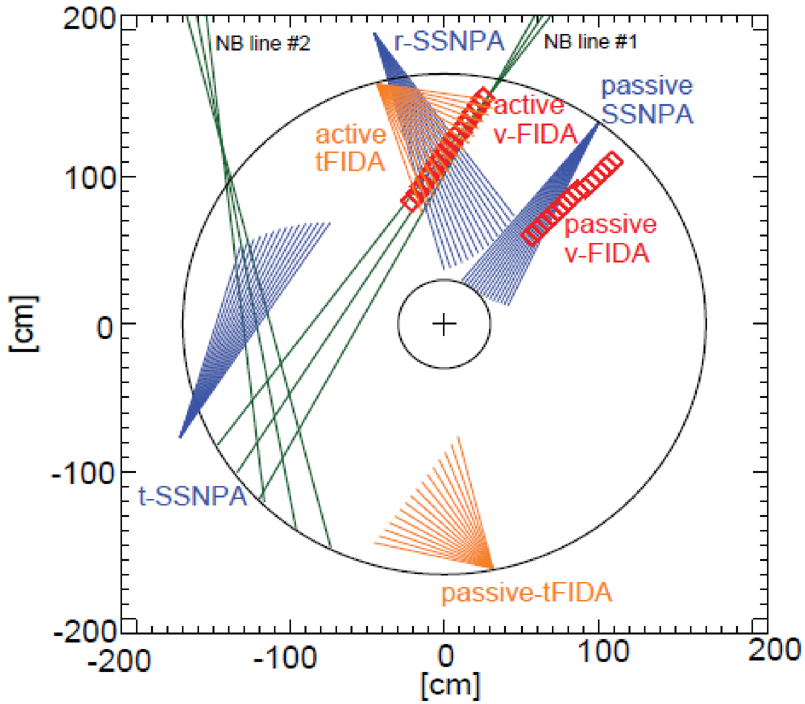


FIDA diagnostics are operational on NSTX-U

Elevation view of FIDA geometry

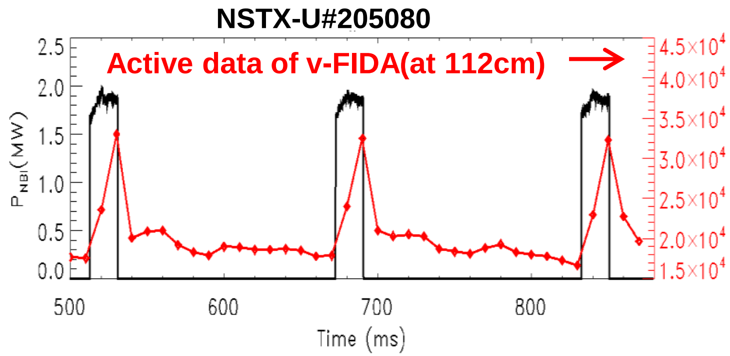


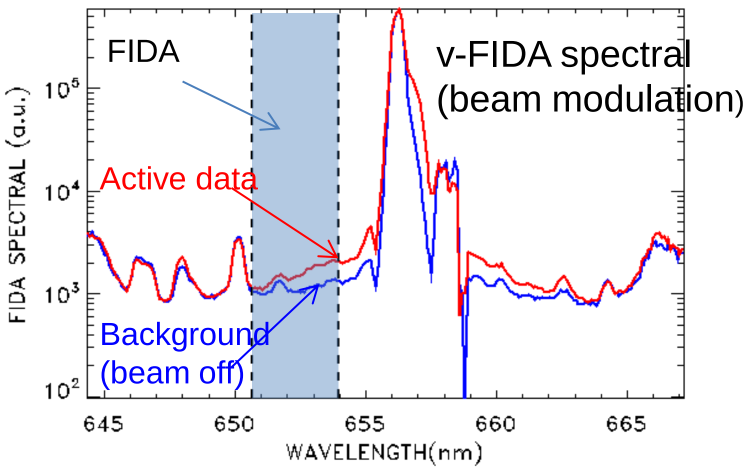
Plan view of FIDA geometry

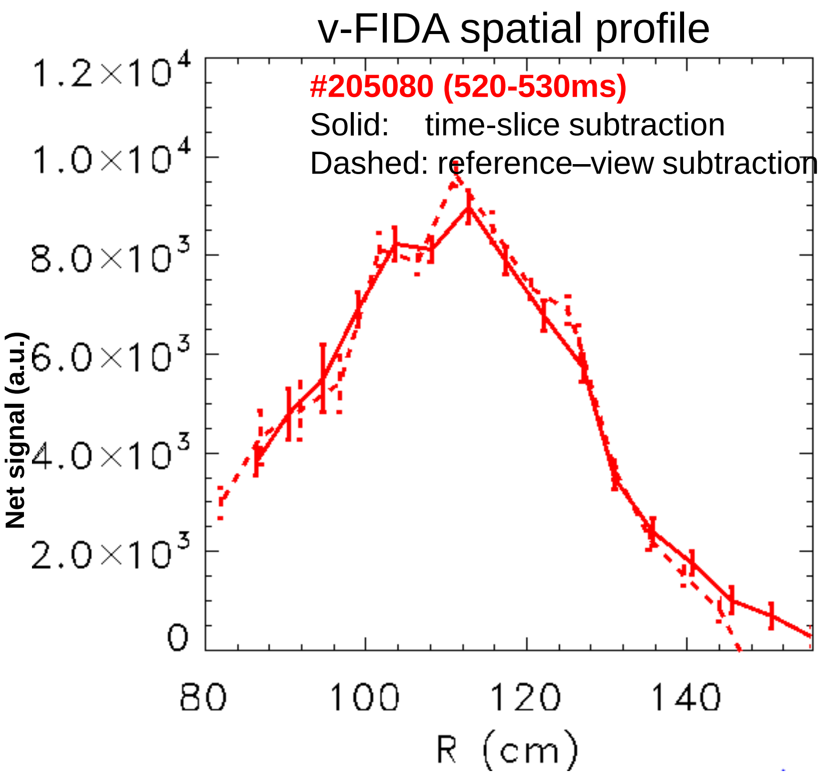


- FIDA diagnostics:
  - 16 channels cover 85~150cm region, with ~5cm space resolution
  - 10ms temporal resolution for vertical-FIDA which was installed on 2008
  - 10 or 5ms temporal resolution for tangential-FIDA which was installed in 2011
  - The v/t-FIDA are sensitive to the trapped and passing particles, respectively.
- The active beam for FIDA is beamline 1

v-FIDA worked well during NSTX-U 2016 campaign

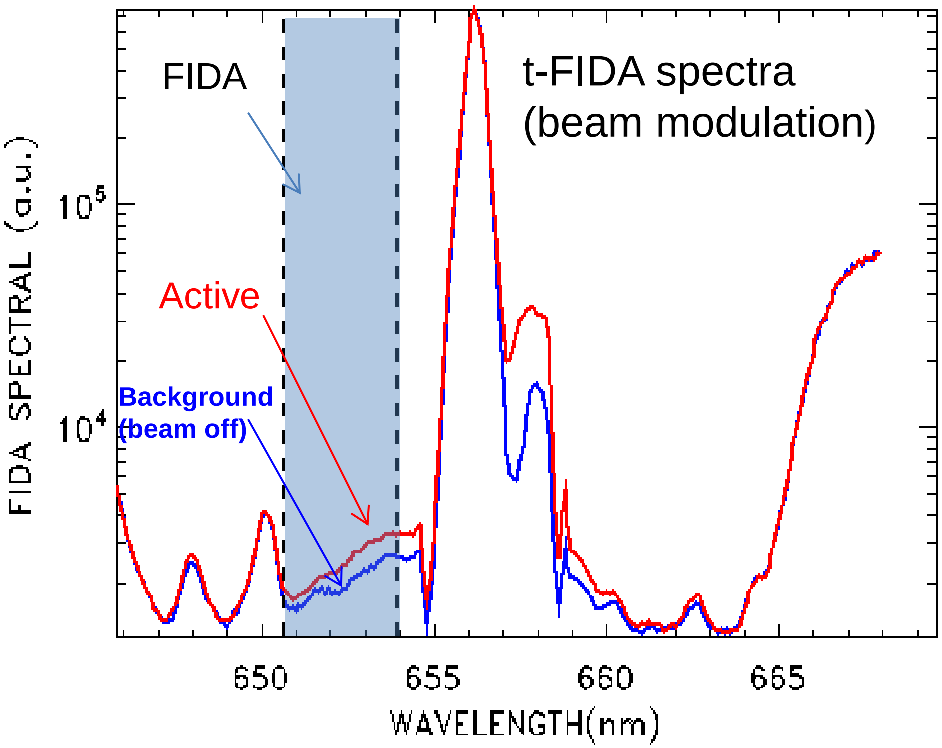


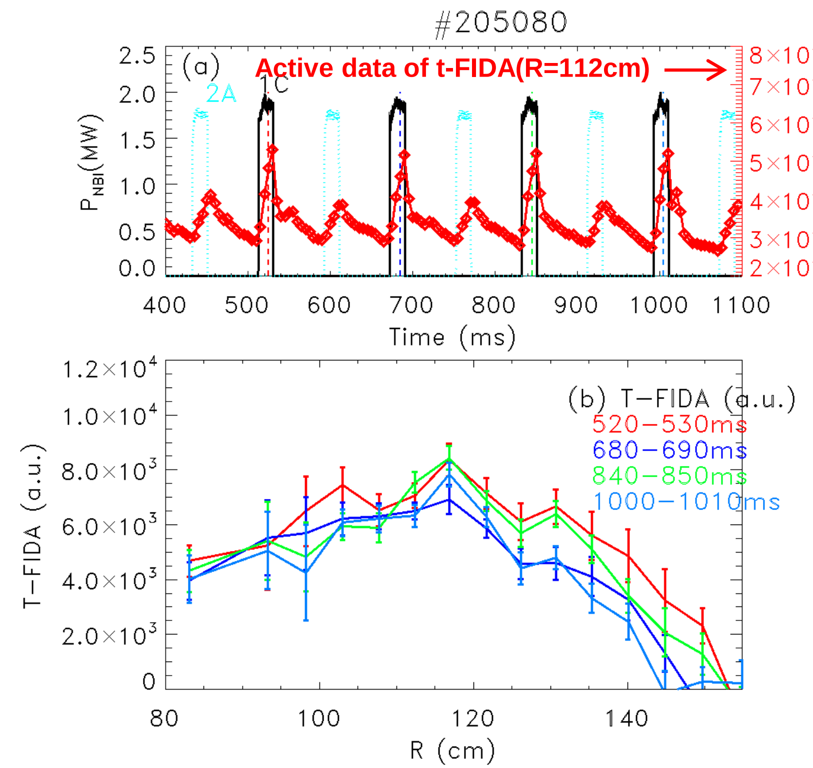




- ➢ v-FIDA has clear response to the beam source blips
- ➢ The signal profile using time-slice subtraction agrees well with that using reference-view subtraction, which identifies the good performance of v-FIDA diagnostic

Fast-ion signals are observed on t-FIDA



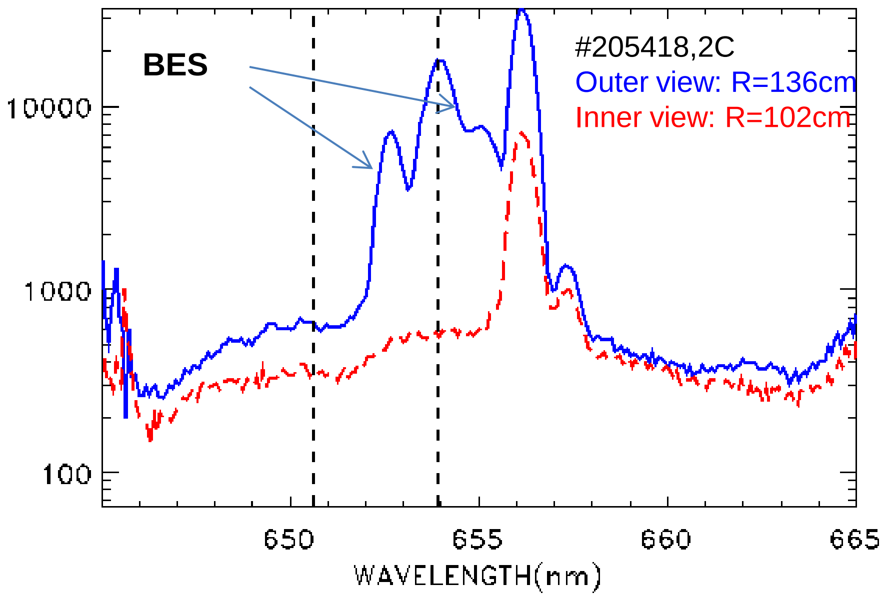


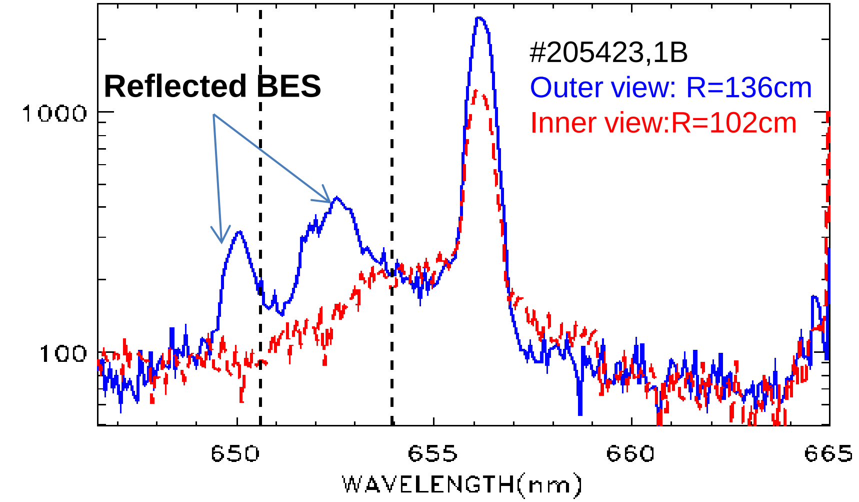
- t-FIDA has clear response to the beam source blip
- The signal profiles are reproducible on different time slices based on the time-slice subtraction
- For t-FIDA, the signal profile has a bigger discrepancy between the time-slice subtraction and reference-view subtraction, owing to light contamination on edge channels of passive view.

Some t-FIDA reference views are compromised

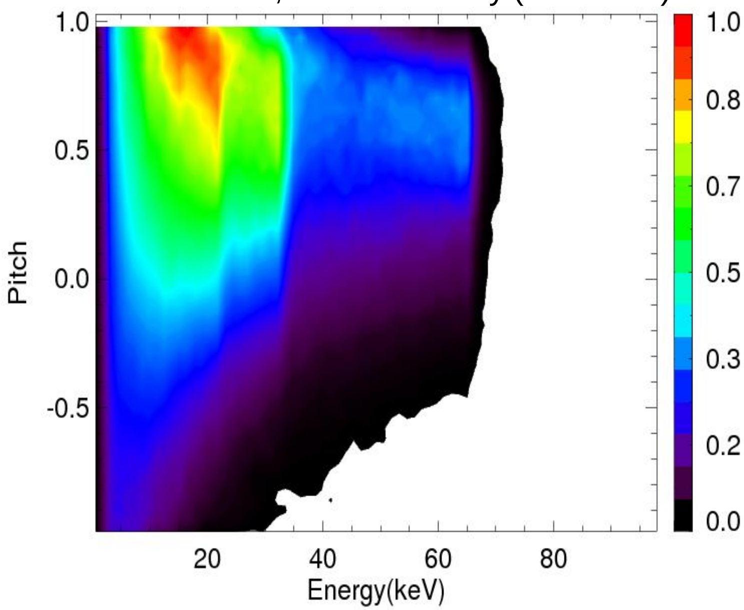
- Beam-into-gas explained many troubling features
  - ➢ outer reference views see beam emission from beamline 2
  - ➢ Some views see reflected beam emission from beamline 1 → from shiny objects in sightline?
  - ➢ Most channels see strong background light
    → from shiny objects in views?

Passive spectral of t-FIDA

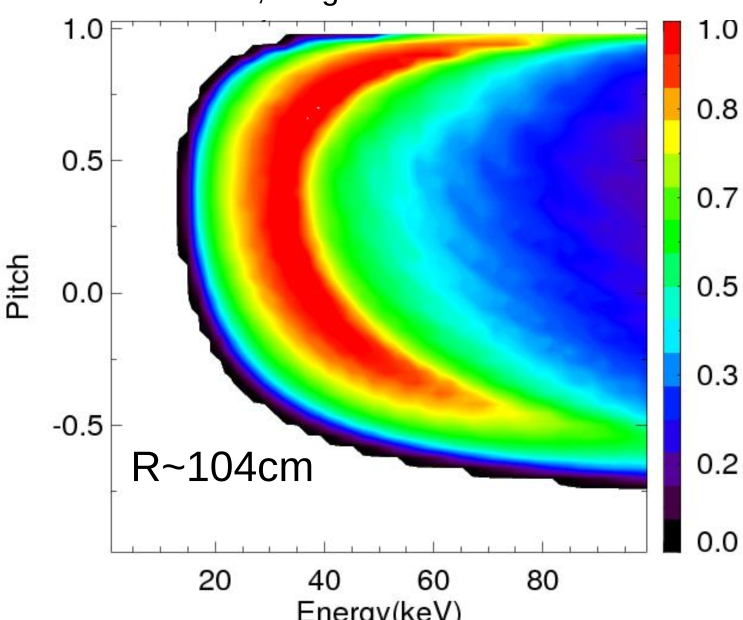




Use FIDASIM to simulate FIDA signal



Spatially averaged classical fast-ion distribution function calculated by NUBEAM in NSTX-U discharge 204092 at 565 ms.



Velocity-space sensitivity of the FIDA chord at 104 cm after integration between 652.095 and 653.478 nm (15~35keV) for 204092 at 565ms

- The predicted fast ion distribution by NUBEAM is input to FIDASIM
- The required plasma profiles needed by FIDASIM are extracted from the TRANSP output
- 'weight function' (or velocity space sensitivity) describes the dependence of the signal on fast ion energy, pitch and the related charge exchange cross-section

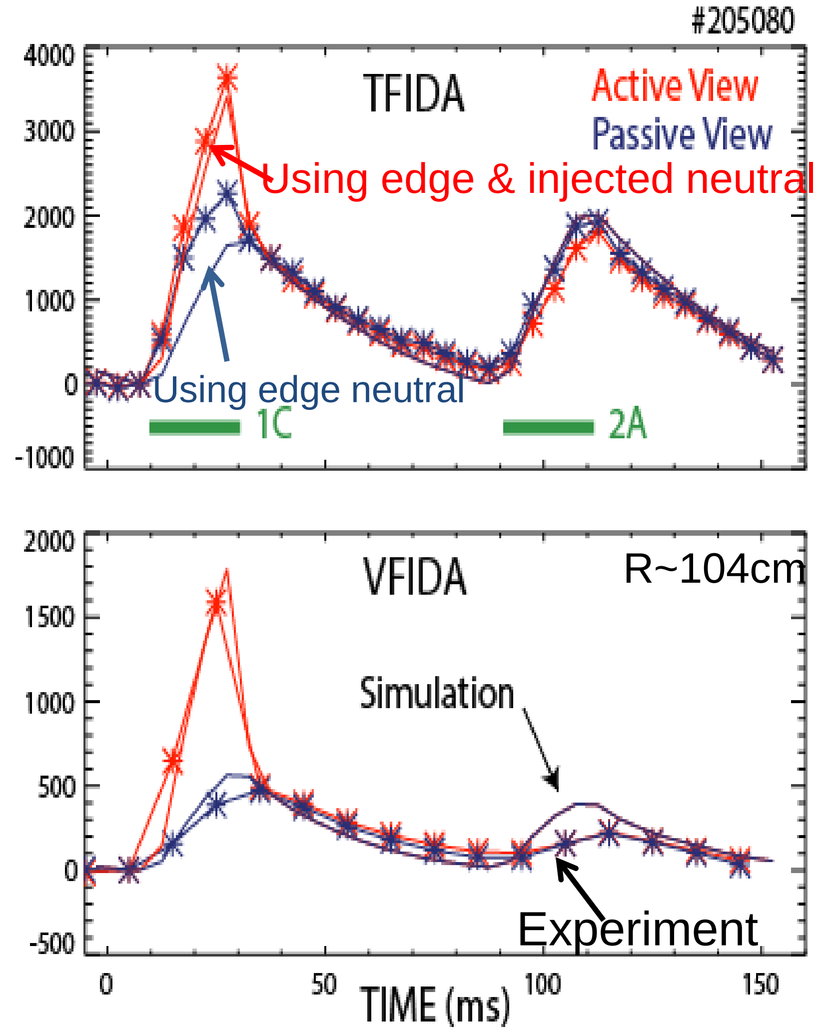
Injected and Edge Neutrals Produce FIDA Signals

- These experimental data are based on 20 ms beam blips under steady L-mode conditions. Conditionally average 6 cycles

- t-FIDA: the active and passive signals are comparable in magnitude.

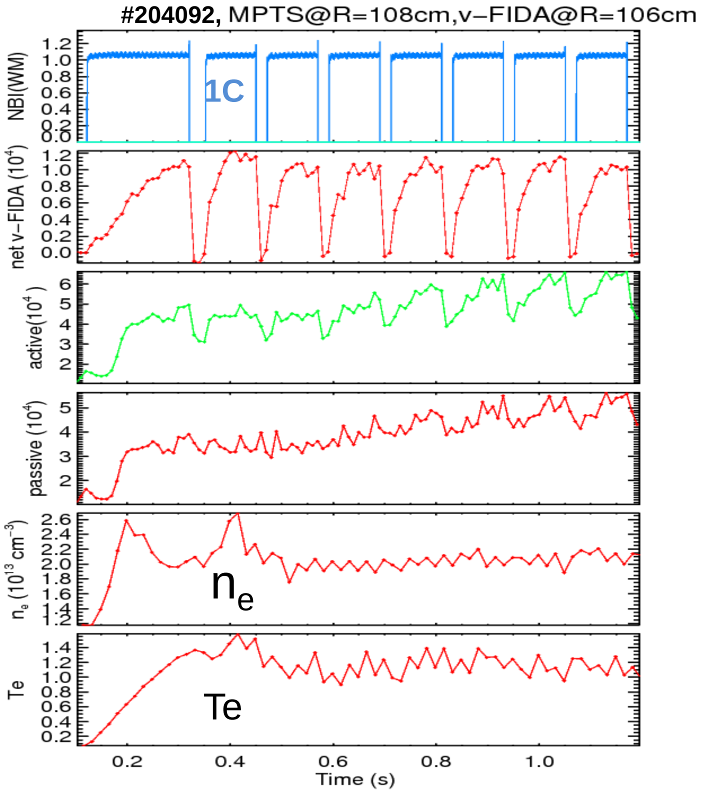
- Good agreement between data (v/t-FIDA) & FIDASIM for central channels
  - Simulate passive signals using edge neutrals from TRANSP
  - Simulate active signals using neutrals from 1C& edge neutrals

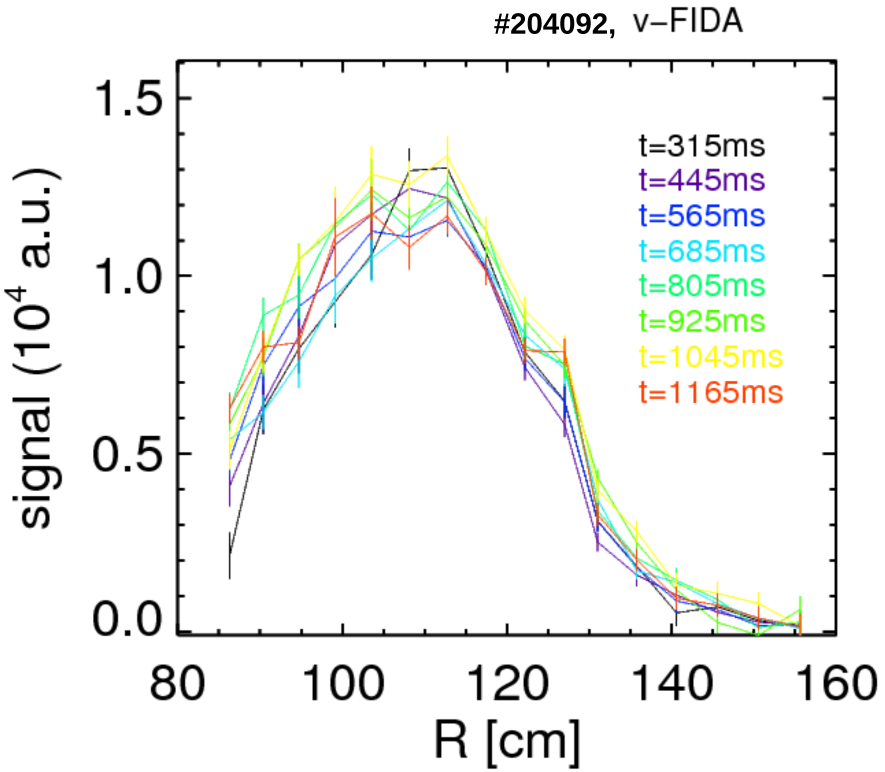
- As expected, 2A produces a small passive signal on v-FIDA



Note: Not all chords agree this well

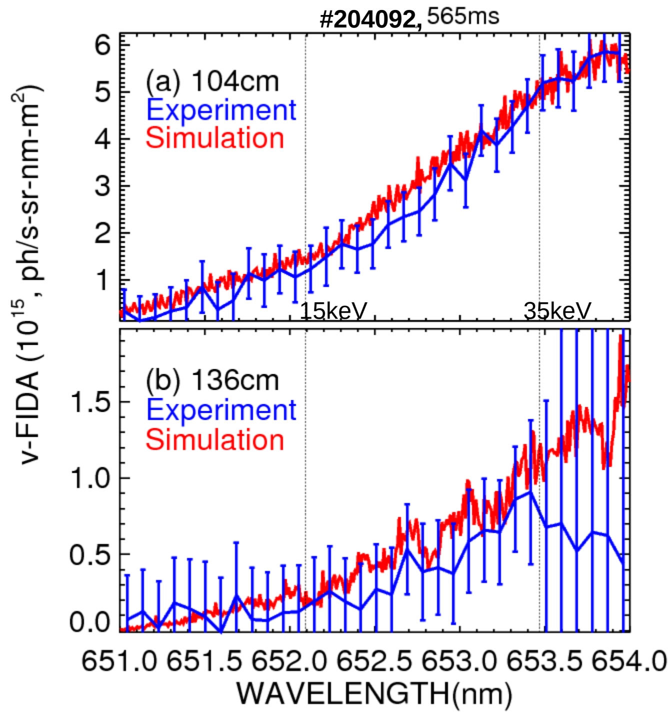
Most trapped fast ions from 1C(R_tan=50cm) are at R<140cm

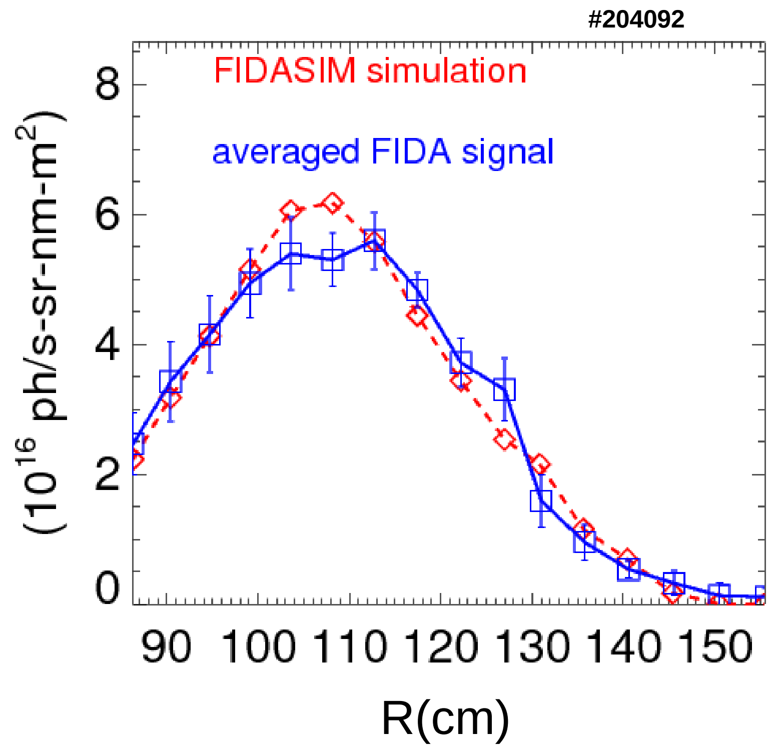




- v-FIDA signal suggests that the fast ion distribution reaches the steady-state in ~40ms
- v-FIDA profile reveals that the peak position of trapped fast ion signal for beam source 1C is 105~115cm

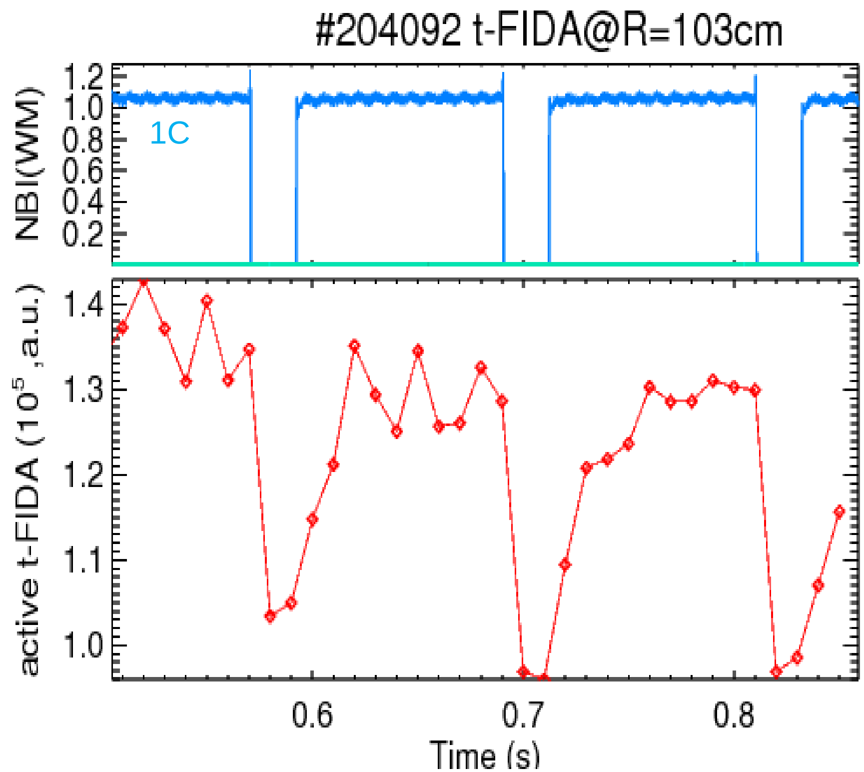
FIDASIM prediction roughly agrees with the v-FIDA measurement

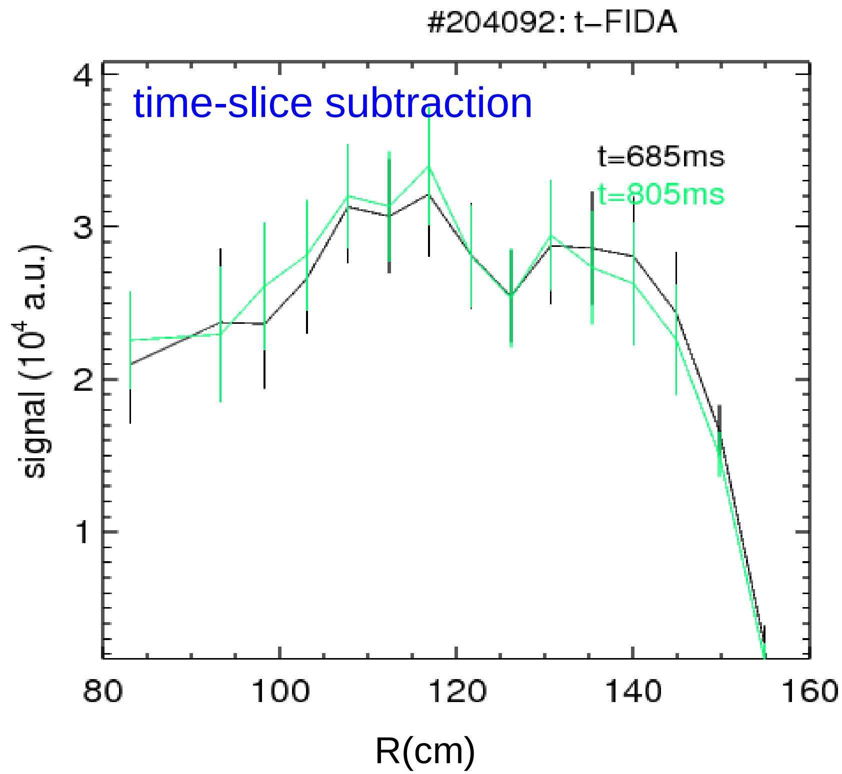




- The predicted and experimental (using time-slice subtraction) spectra have better agreement in the core(104cm) channel than at 136 cm
- The predicted v-FIDA profile generally agrees with experiment, although there is a discrepancy in the region (100~110cm)

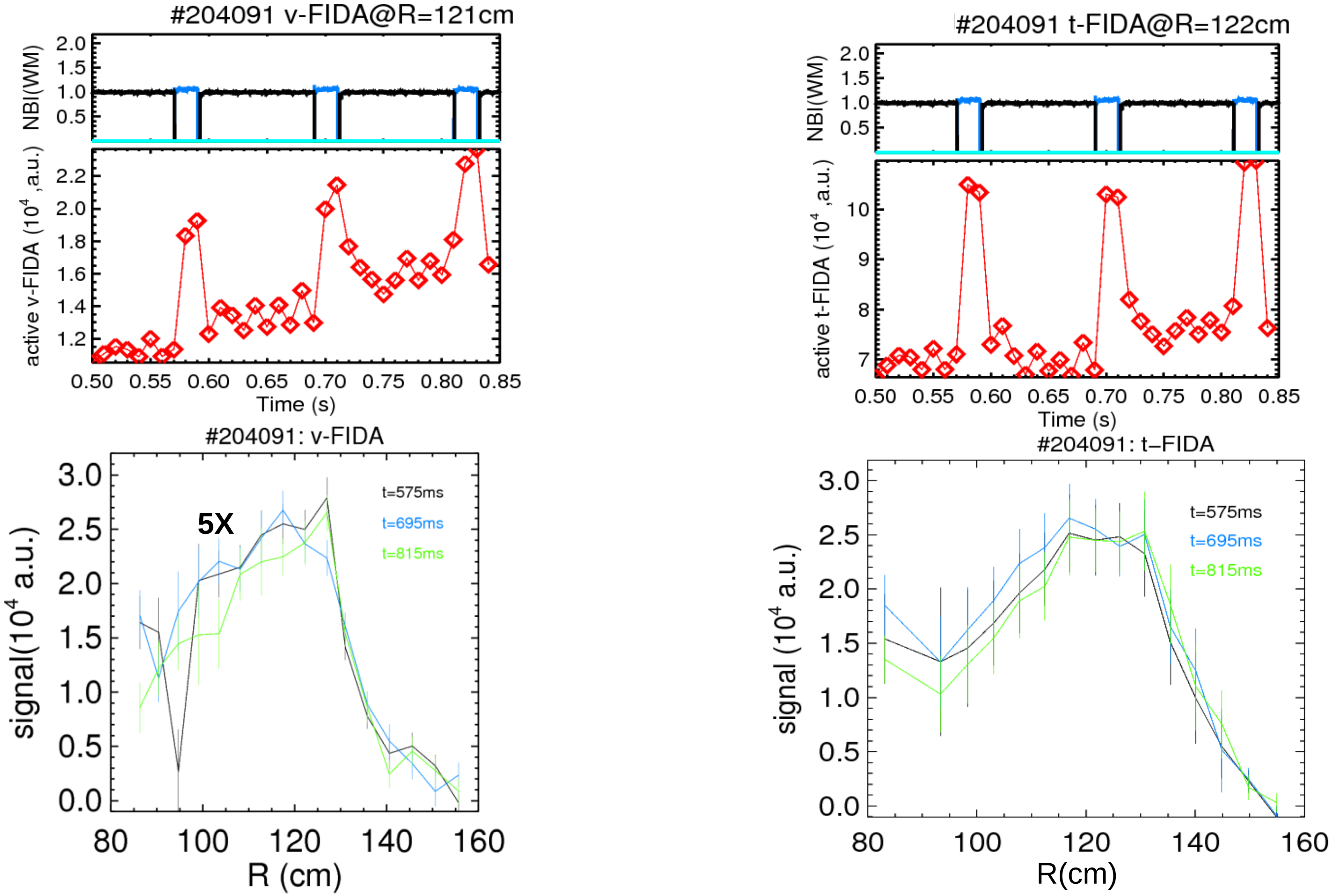
The tangential FIDA profile for 1C(R_tan=50cm) is broad





- Passing fast ion signal is derived from active data of t-FIDA, based on the time-slice subtraction.
- Time slices with sawteeth are excluded
- Signal from edge neutrals may elevate the signal on outermost channels.

For beam source 2A(R_tan=130cm), the passing fast ion signal is much larger than the signal of trapped fast ions

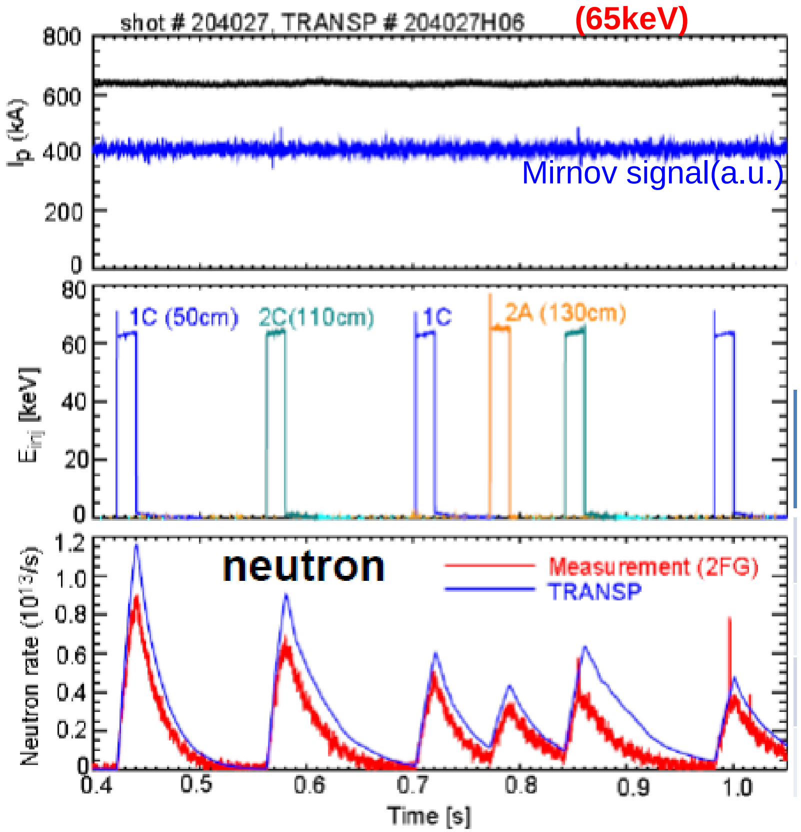


- Using the combined beam blips to study the confinement of fast ion from beam source 2A; using time-slice subtraction
- As expected, the amplitude of net t-FIDA signal is much larger than that of v-FIDA.
- t-FIDA signal suggests that 2A deposits in the region 115~130cm

For E_inj=85keV, beam ions are well confined based on neutron decay

Source (E_{inj}=65keV)	Neutron Rise (Exp/TRANSP)	Neutron Decay (Exp/TRANSP)
1B (R_{tan} 60cm)	0.56	**0.93**
1C (R_{tan} 50cm)	0.60 +/- 0.03	**0.88 + /- 0.18**
2A (R_{tan} 130cm)	0.56 +/- 0.03	**0.79 +/- 0.09**
2C (R_{tan} 110cm)	0.59 +/- 0.03	**0.71 +/- 0.07**

Source (E_{inj}=85keV)	Neutron Rise (Exp/TRANSP)	Neutron Decay (Exp/TRANSP)
1B (R_{tan} 60cm)	0.58 +/- 0.02	1.02 +/- 0.08
1C (R_{tan} 50cm)	0.72 +/- 0.05	0.92 +/- 0.09
2A (R_{tan} 130cm)	0.66 +/- 0.03	1.01 +/- 0.09
2C (R_{tan} 110cm)	0.62 +/- 0.04	1.02 +/- 0.08



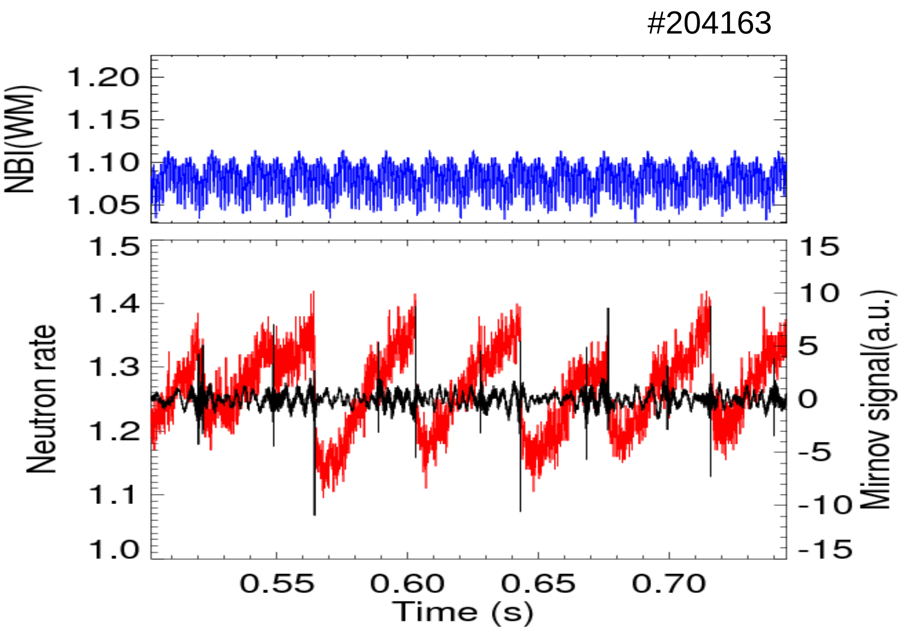
- Measured decay time of neutron rate are close to the modeling value for 85kev, which indicates that the beam ions are well confined. However, the Rise time is 65% of the prediction.
- There is still discrepancy between the measured value and the modelling value for 65kev case. The reason is being studied.

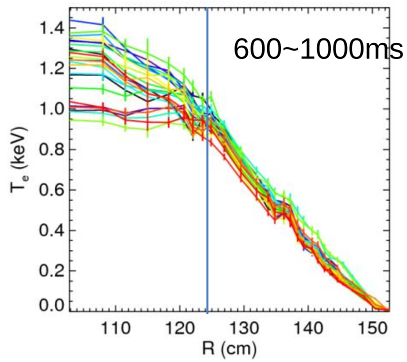
[D.Liu, 2016APS talk, GO6.00005]

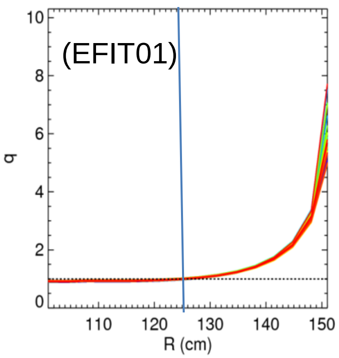
The neutron rate drops ~13% at sawteeth

- Sawteeth reduce the neutron rate ~ 13%, which implies a redistribution or loss of fast ions

- The Te profile and the reconstructed q-profile suggests the inversion radius ~ 125cm





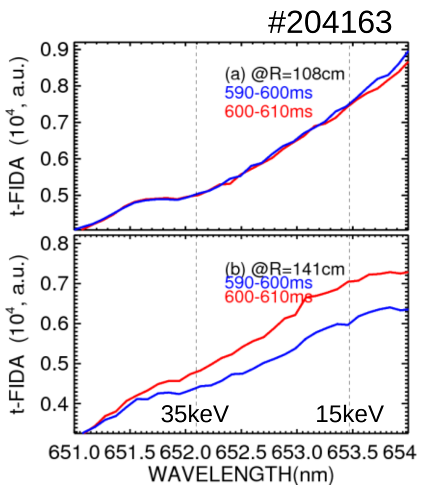


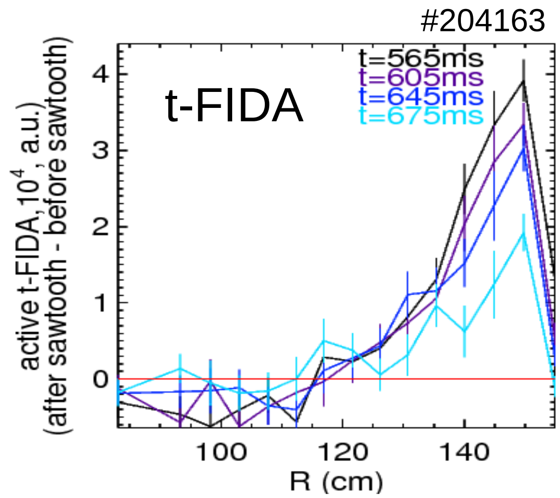
Sawteeth increase the number of passing fast ions in the edge region

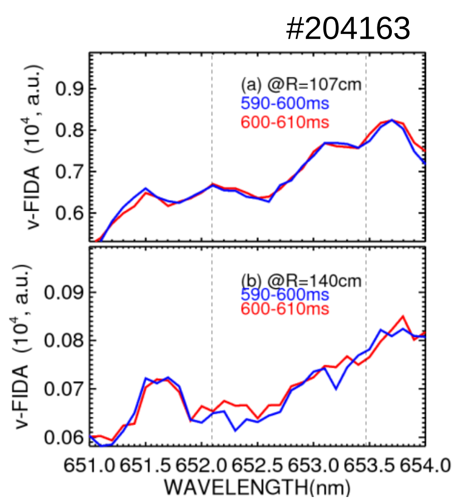
- t-FIDA signal indicates that the sawtooth induces the increase/weak-decrease of passing fast ion in the outside/inside region of the inversion radius

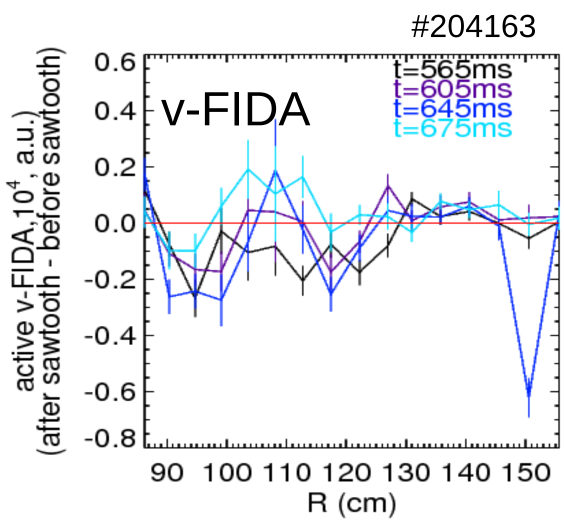
- Note: the increase of the t-FIDA signal is the combined result of the fast ions moving to the edge and increase of the edge neutral density

- v-FIDA signal indicates the sawtooth hardly affects the trapped fast ions



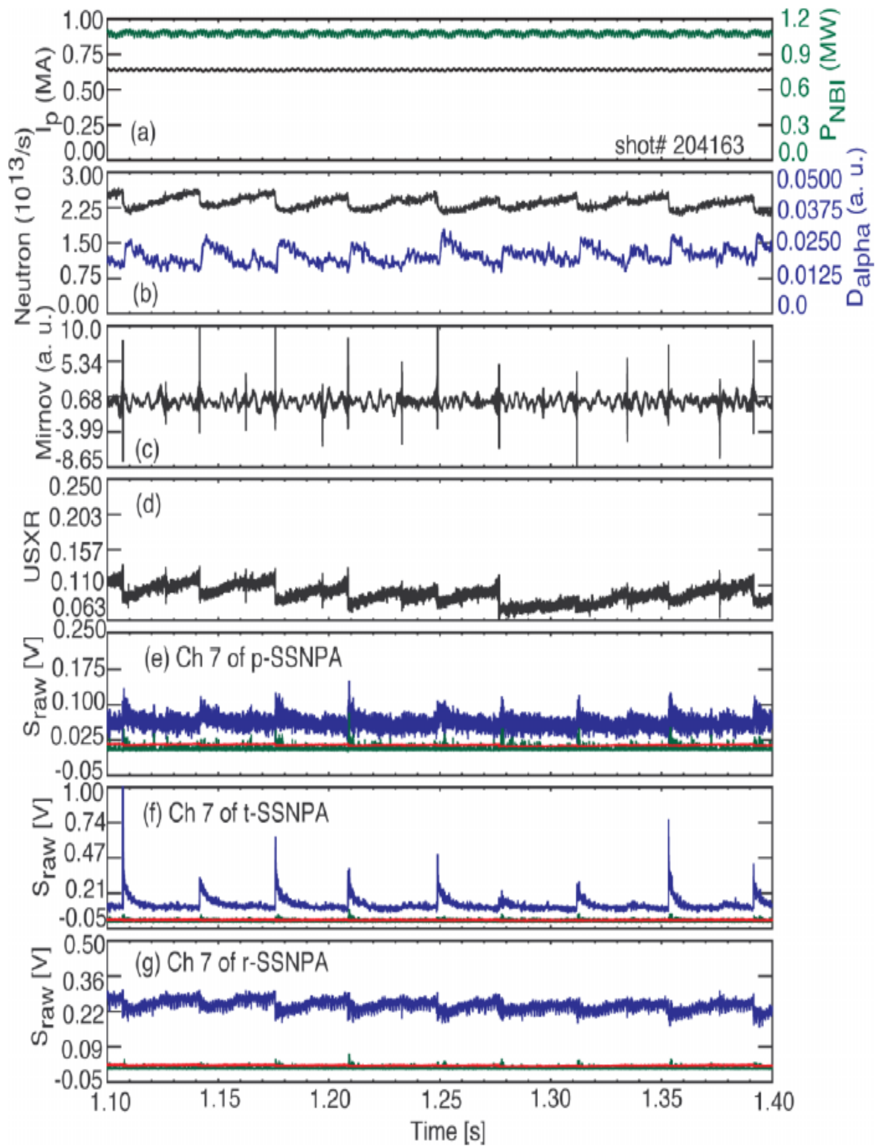






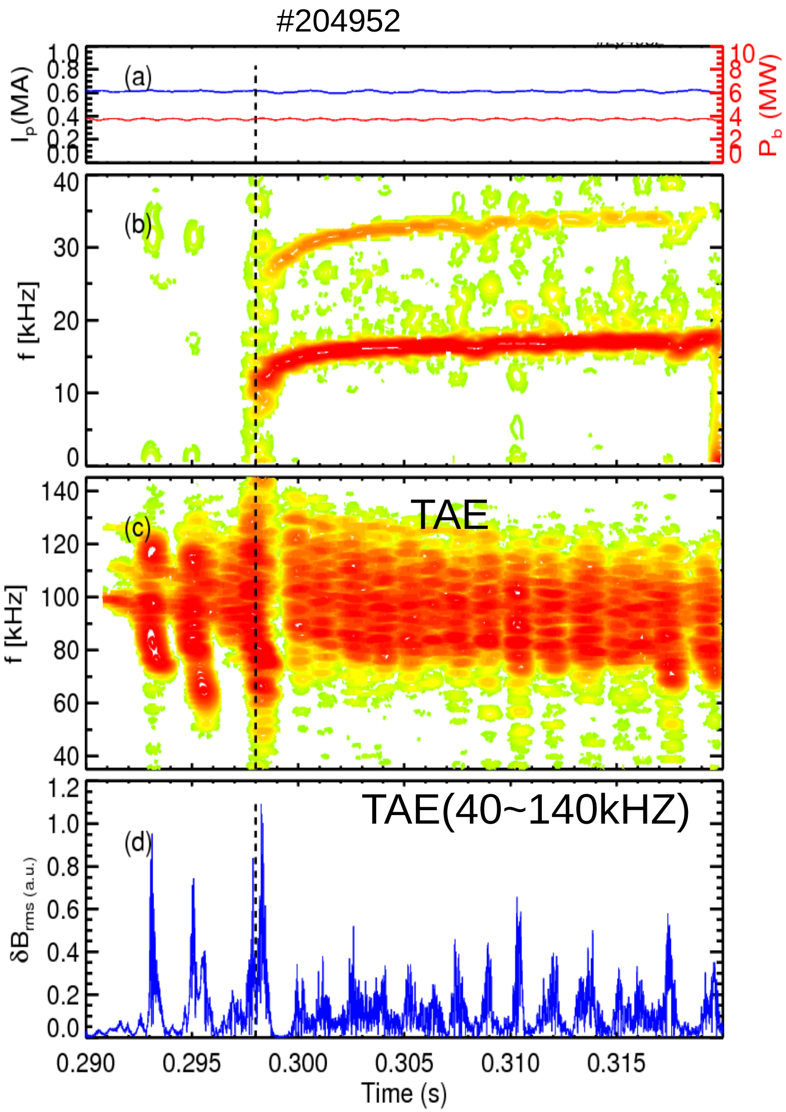
SSNPA data suggests that there are significant passing fast ion losses during sawteeth

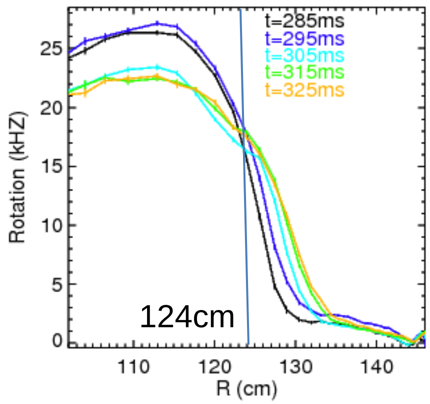
- The t- and r- SSNPA system are sensitive to passing and trapped particles, respectively.
- t-SSNPA burst are the combined result of fast ions moving to the edge and increase of the edge neutral density.
- The SSNPA data suggests that there are significant passing fast ion losses during sawteeth, while trapped particles are weakly affected.

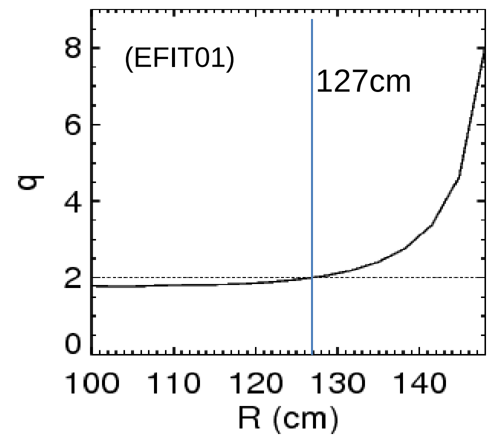


D.Liu,RSI(2016)

Effect of tearing mode on fast ion transport



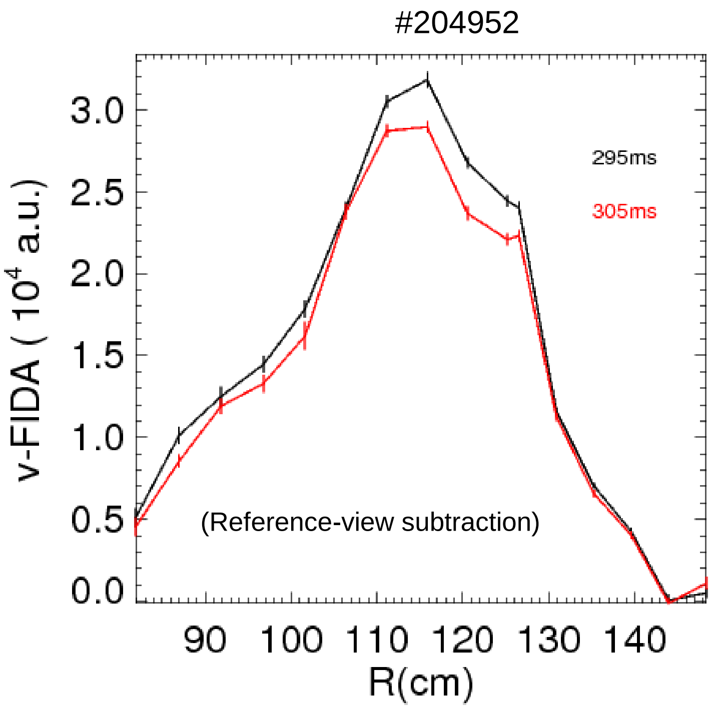




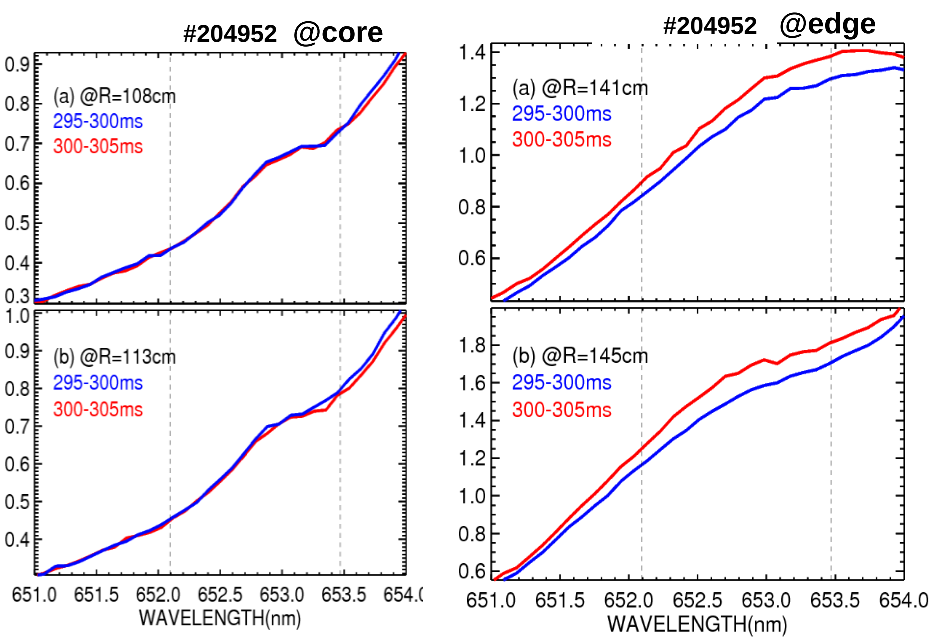
- The change of the rotation profile and the reconstructed q-profile suggests the mode (~15kHZ) is a tearing mode
- The mode damps the toroidal rotation in the q<2 region, while it enhances the rotation in the q>2 region
- Tearing mode significantly reduces the peak amplitude of TAE

Tearing mode reduces the trapped fast ion in the core region

v-FIDA spatial profile



t-FIDA active view (10^4, a.u.)



- TM reduces the trapped fast ions in the core region 110~130cm.
- The mode hardly affects t-FIDA signal in the core region, while it enhances t-FIDA signal at the edge region. It suggests that the TM induces an increase of passing particles at edge.

Summary

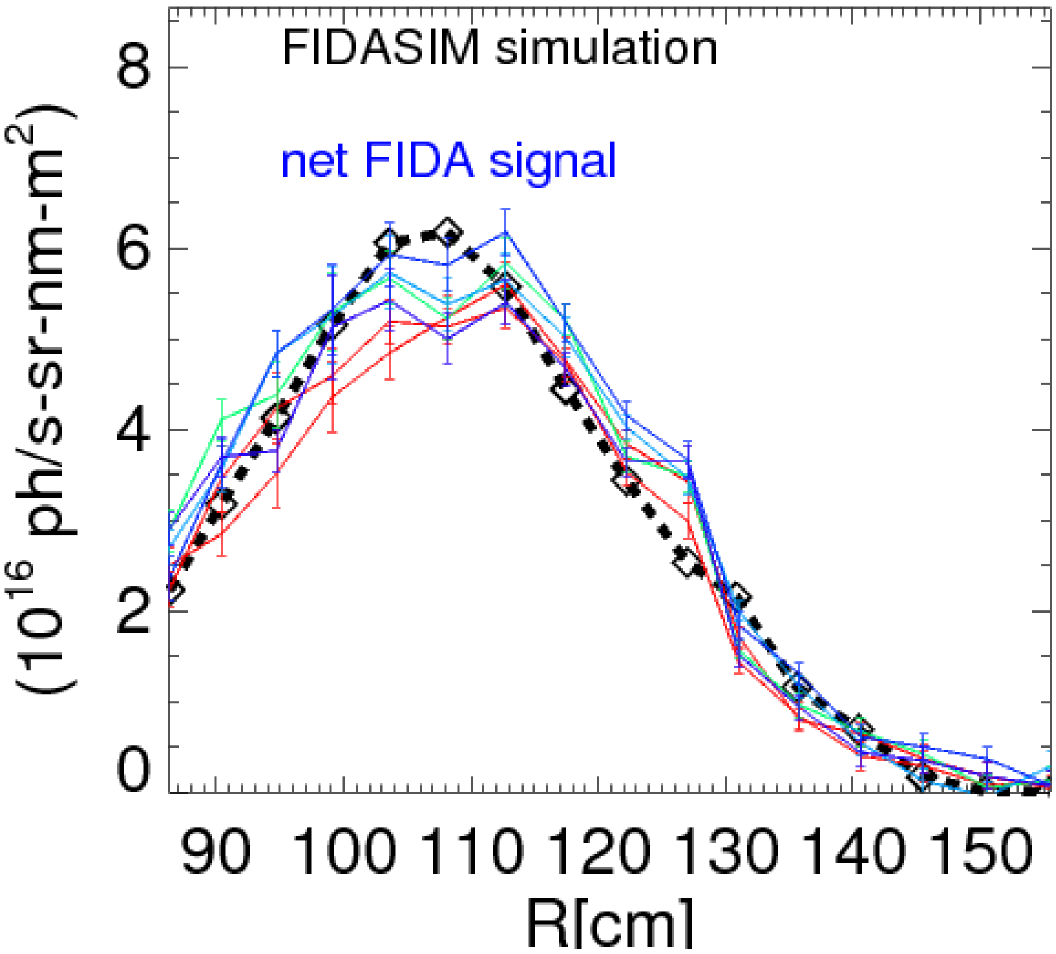
- Performance of vertical/tangential-FIDA diagnostics on NSTX-U
  - V-FIDA works well during FY-16 campaign of NSTX-U
  - T-FIDA
    - Has robust response to beam injection
    - Spatial profiles are available when beamline 1 is modulated
    - Reference views usable for selected channels

- FIDASIM prediction roughly agrees with the v-FIDA measurement; For t-FIDA signal, the edge and injected neutrals make comparable contributions. And, at the central channel of t-FIDA, the predicted signal agrees with the experiment value

- Sawteeth cause an increase of passing fast ions outside the sawtooth inversion radius but hardly affects trapped fast ions

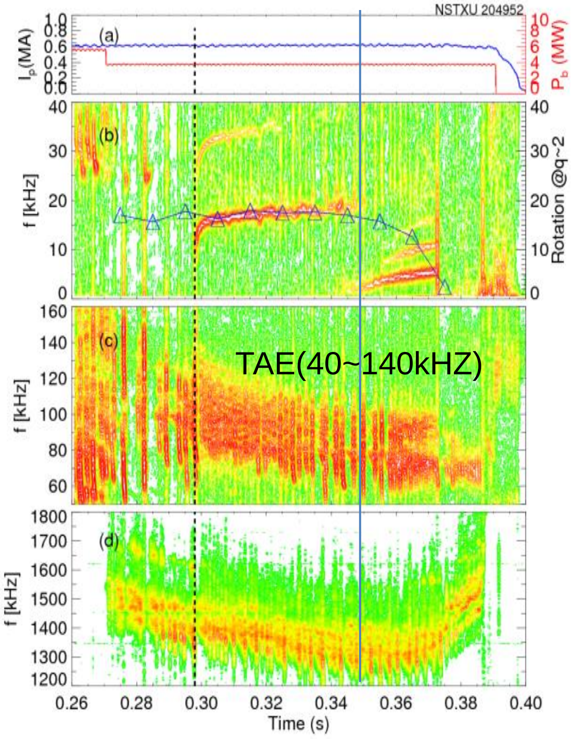
- Tearing mode reduces the trapped fast ions in the core and increases the number of passing particles in the edge region.

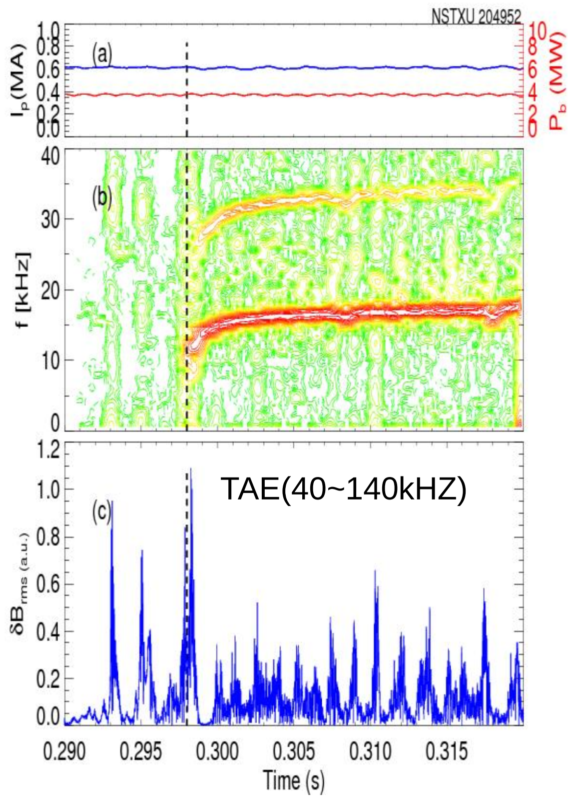
Backup slides

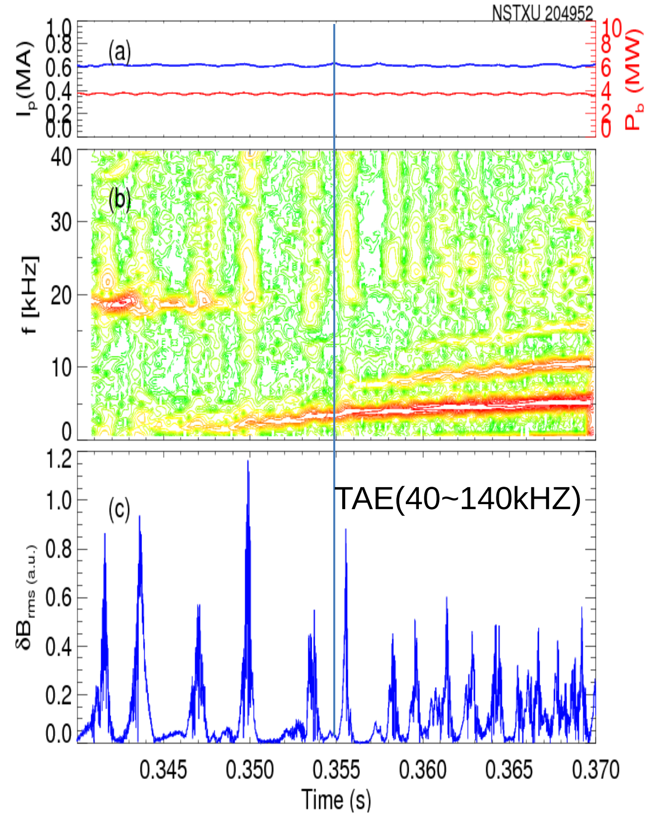


solid color-curves are the experiment data using time-slice subtraction at different time points

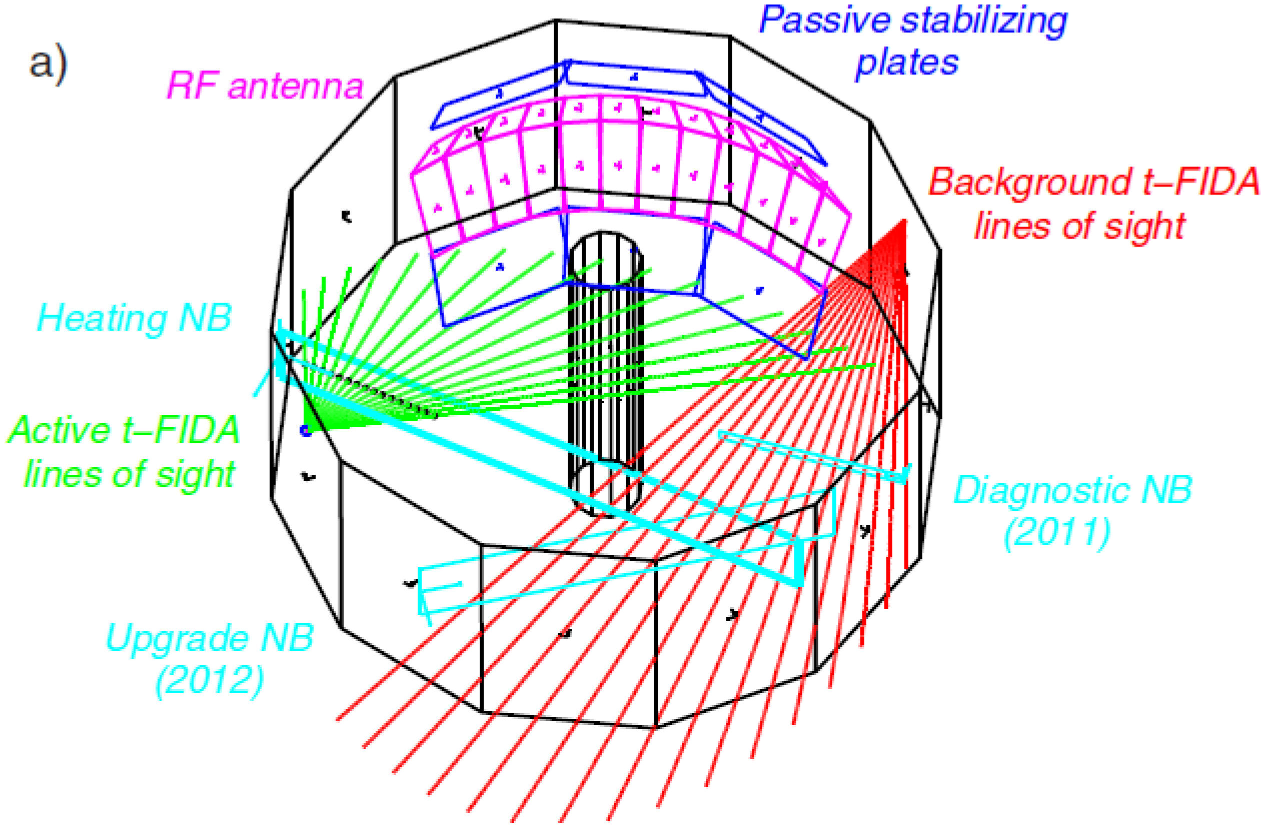
Effect of tearing mode on TAE amplitude



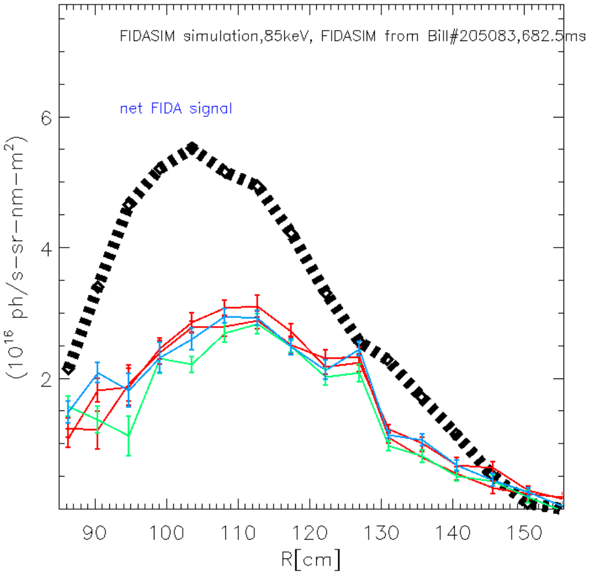


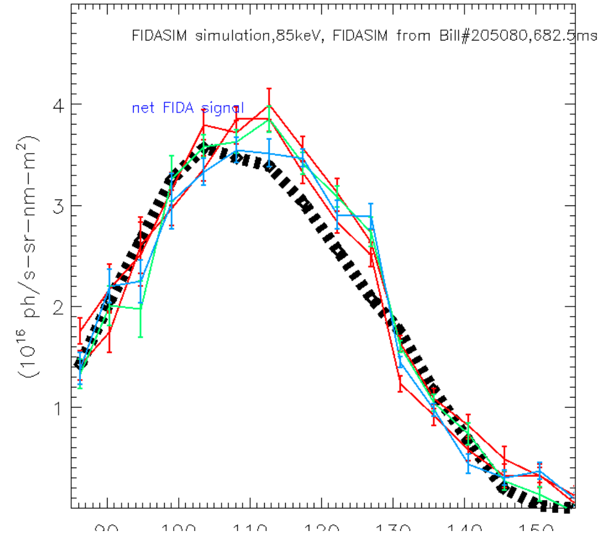


3D geometry of t-FIDA



Bortolon,RSI(2010)


FIDASIM simulation,85keV, FIDASIM from Bill#205083,682.5ms
net FIDA signal
(10^16 ph/s-sr-nm-m^2)
R[cm]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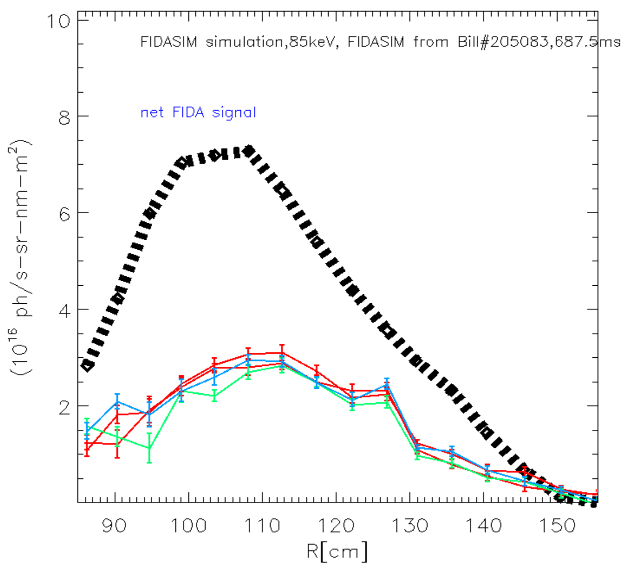
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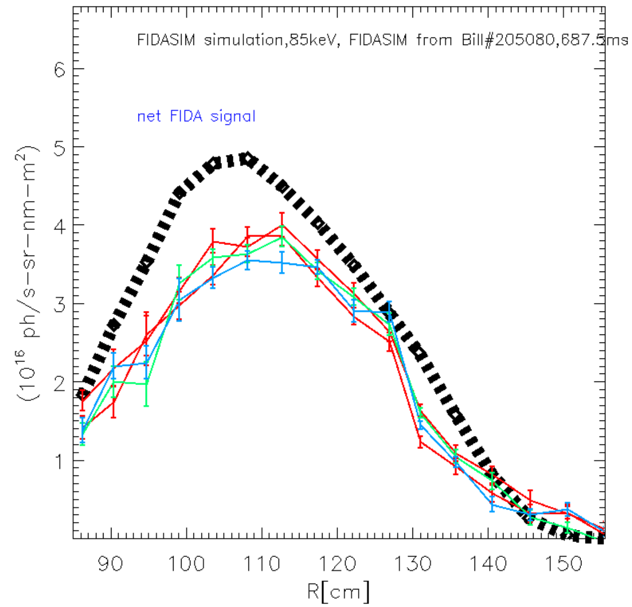
R[cm]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