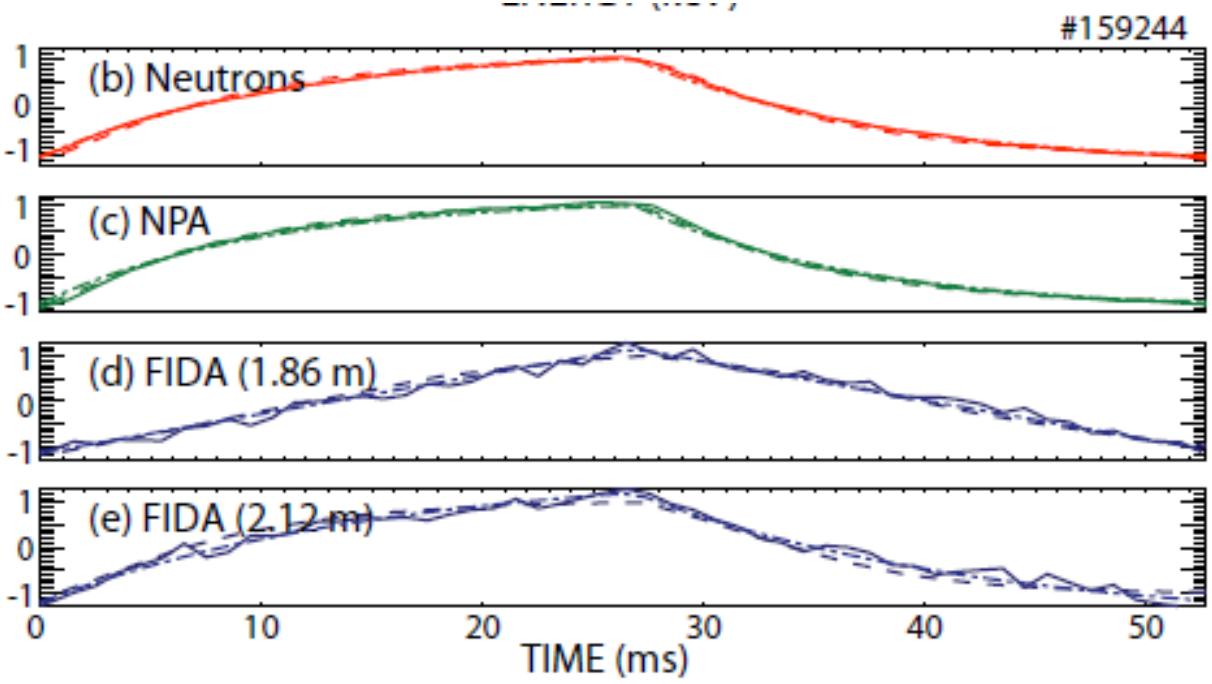
TRANSP Modeling of Fast-ion D_α (FIDA) Signals

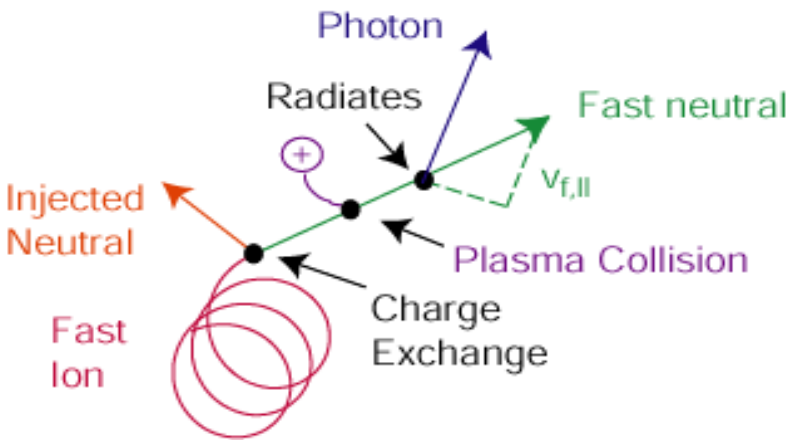
- **Beam modulation experiments with active FIDA and NPA signals**
- **Passive FIDA Signals**

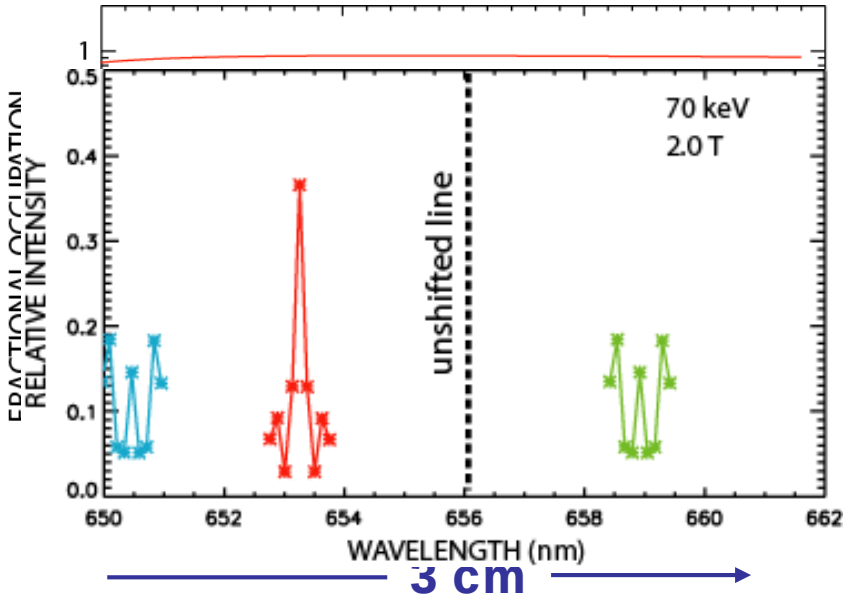
Bill Heidbrink, Nathan Bolte, Cami Collins, Deyong Liu, Guangzhou Hao, Luke Stagner



UCIrvine
University of California, Irvine

FIDA is an application of Charge Exchange Recombination Spectroscopy

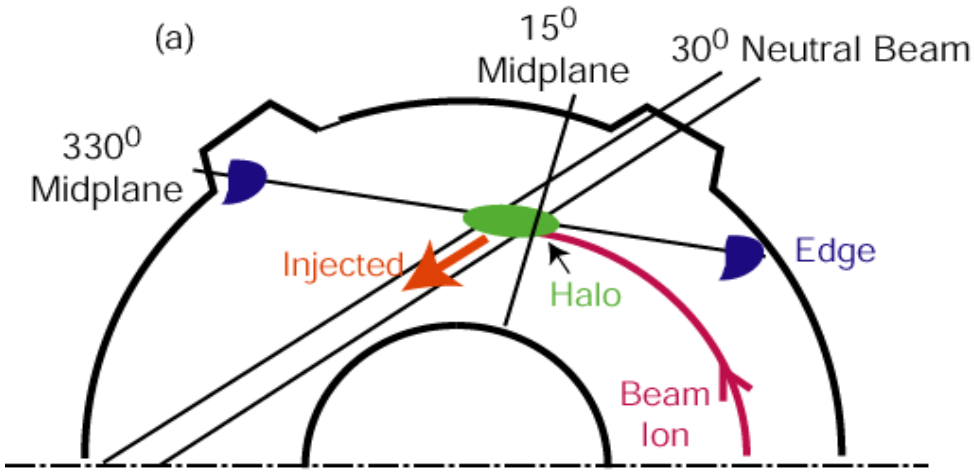




1. The fast ion exchanges an electron with a neutral
2. Neutrals in the n=3 state relax to an equilibrium population; some radiate
3. The Doppler shift of the emitted photon depends on a component of the fast-ion velocity

Heidbrink, RSI 81 (2010) 10D727

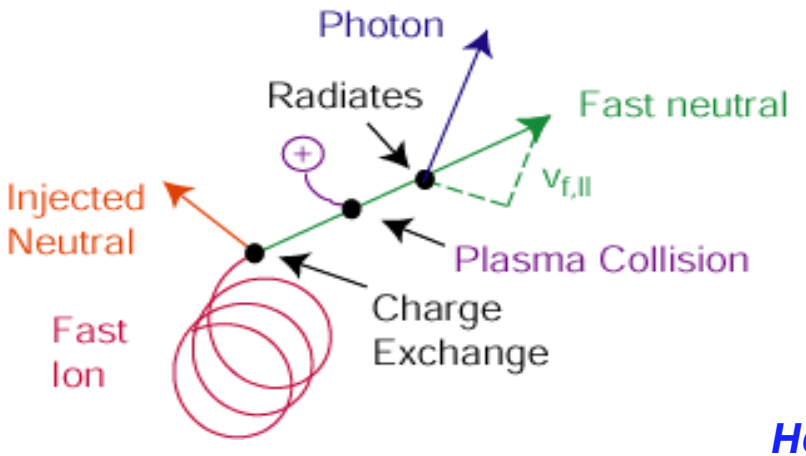
Active FIDA measurements use an injected neutral beam



- **Reactions with edge neutrals produce passive FIDA light**

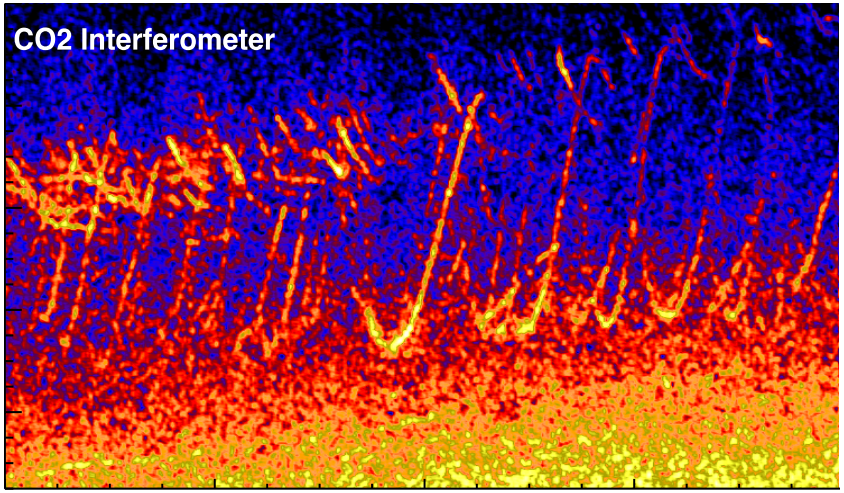
FIDASIM is a synthetic diagnostic code

- **A calculated fast-ion distribution function is input to the code—often use "dumped" TRANSP NUBEAM distributions**
- **Computes four neutral populations: Full, half, & third energies from injected beam + halo**
- **Solves energy-level resolved time-dependent collisional-radiative equations**
- **Doppler shift and Stark splitting of radiated photons**



Heidbrink, Comm. Comp. Phys. 10 (2011) 716

Experiment compares modulated fast-ion signals to “classical” TRANSP predictions



ency (kHz)

- **Transport by Alfven eigenmodes causes differences between measured & calculated signals**

Modulated Neutrons

Collins NF 57 (2017) submitted

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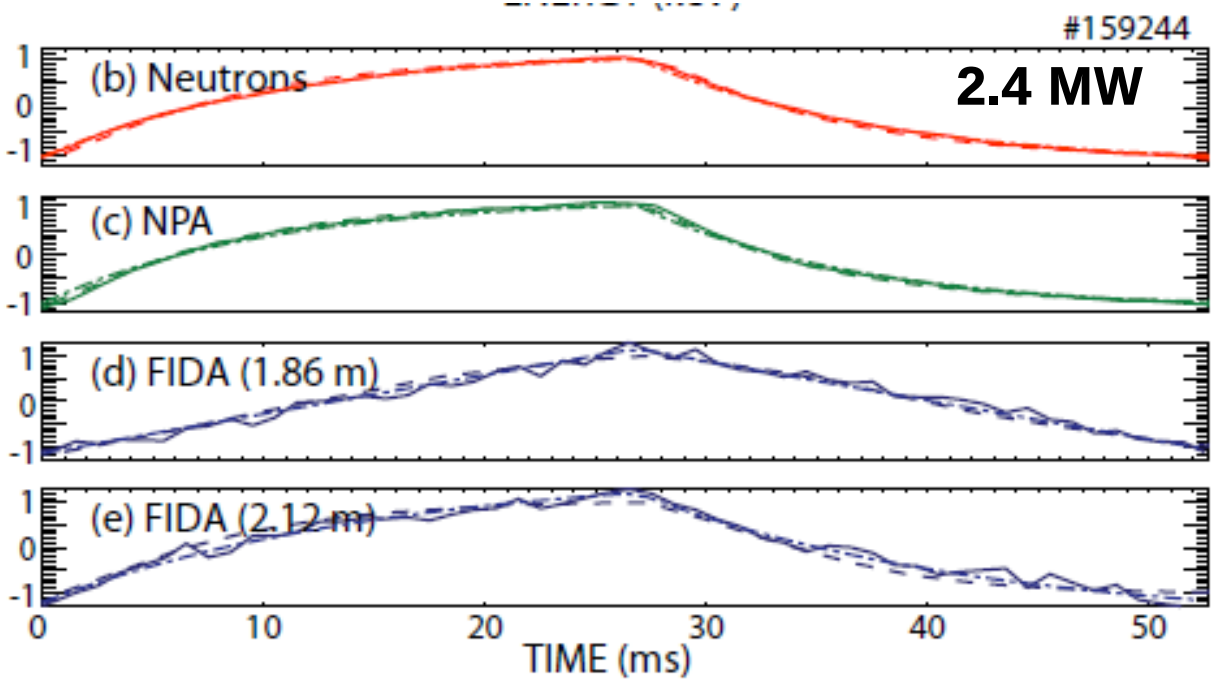
Conditionally average signals & predictions for FIDA & neutral particle analyzer (NPA) signals

TRANSP Workflow

1. Special run with only the modulated beam & 10^6 markers (good MC statistics)
2. Dump distribution function every 2.5 ms for 6 beam cycles (~ 120 times)
3. Run FIDASIM for each timeslice
4. Conditionally average FIDASIM output

Solid = Data
Dashed = TRANSP



Heidbrink, NF 56 (2016) 112011

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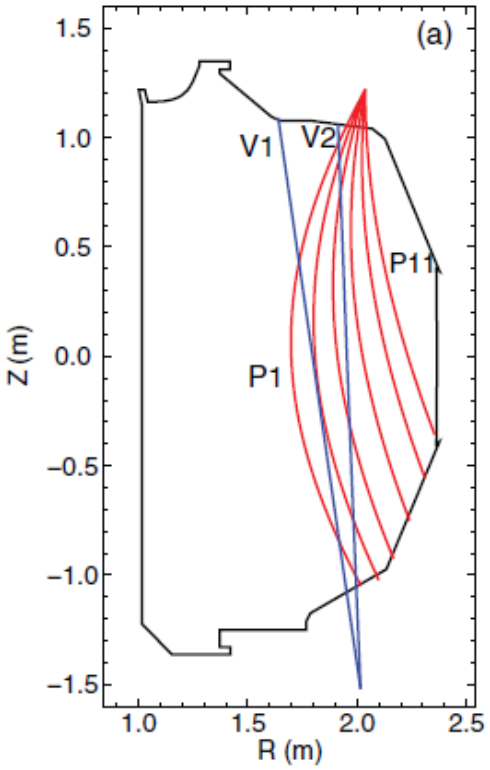
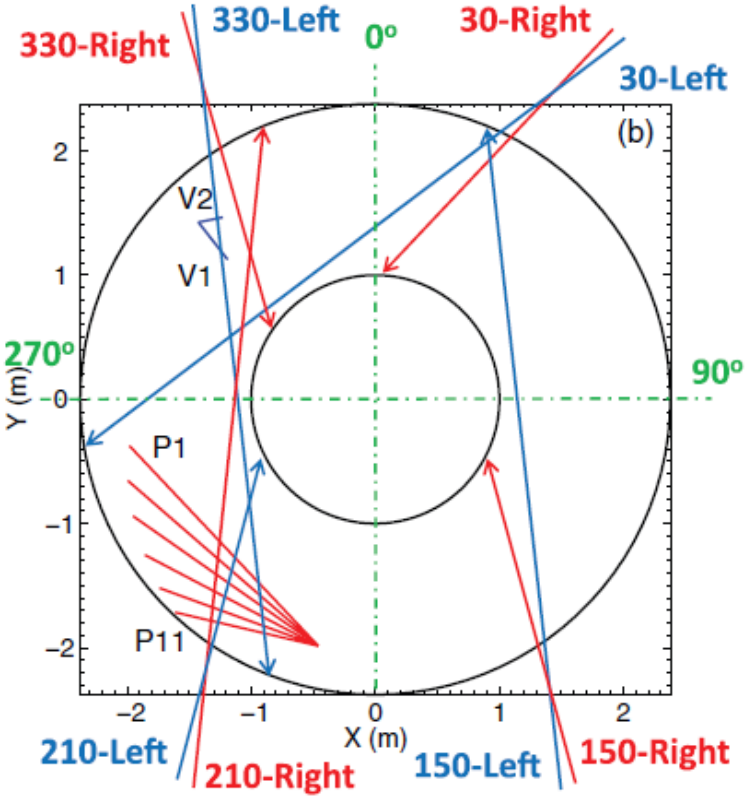
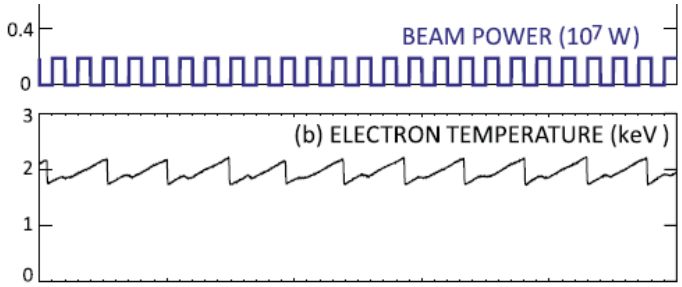
A dedicated study of passive FIDA light was performed on DIII-D





- **The active beams were always off → <u>no</u> active signal**
- **Other beams were modulated to produce fast ions**

Bolte, NF 56 (2016) 112023



- **Conditionally average the signals on either the beam modulation or the sawteeth**

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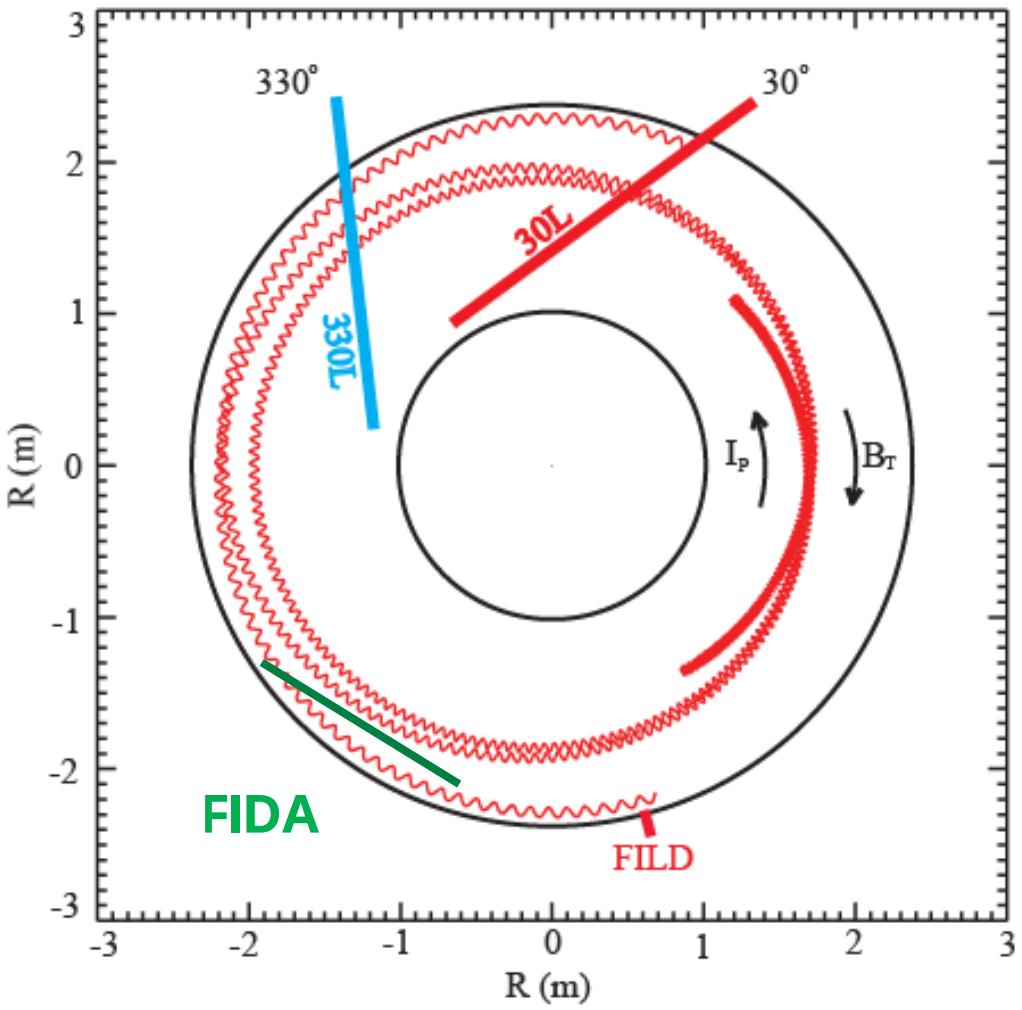
Three distinct fast-ion populations produce the measured signals: First orbit

Plan view of DIII-D



- "Light-ion beam probe" technique: arrange conditions so orbit passes close to a loss detector → measure displacement of orbit by instabilities
- **Orbits that traverse edge produce passive FIDA light**

TRANSP does not compute this fast-ion population

Xi Chen, Phys. Rev. Lett. 110 (2013) 065004

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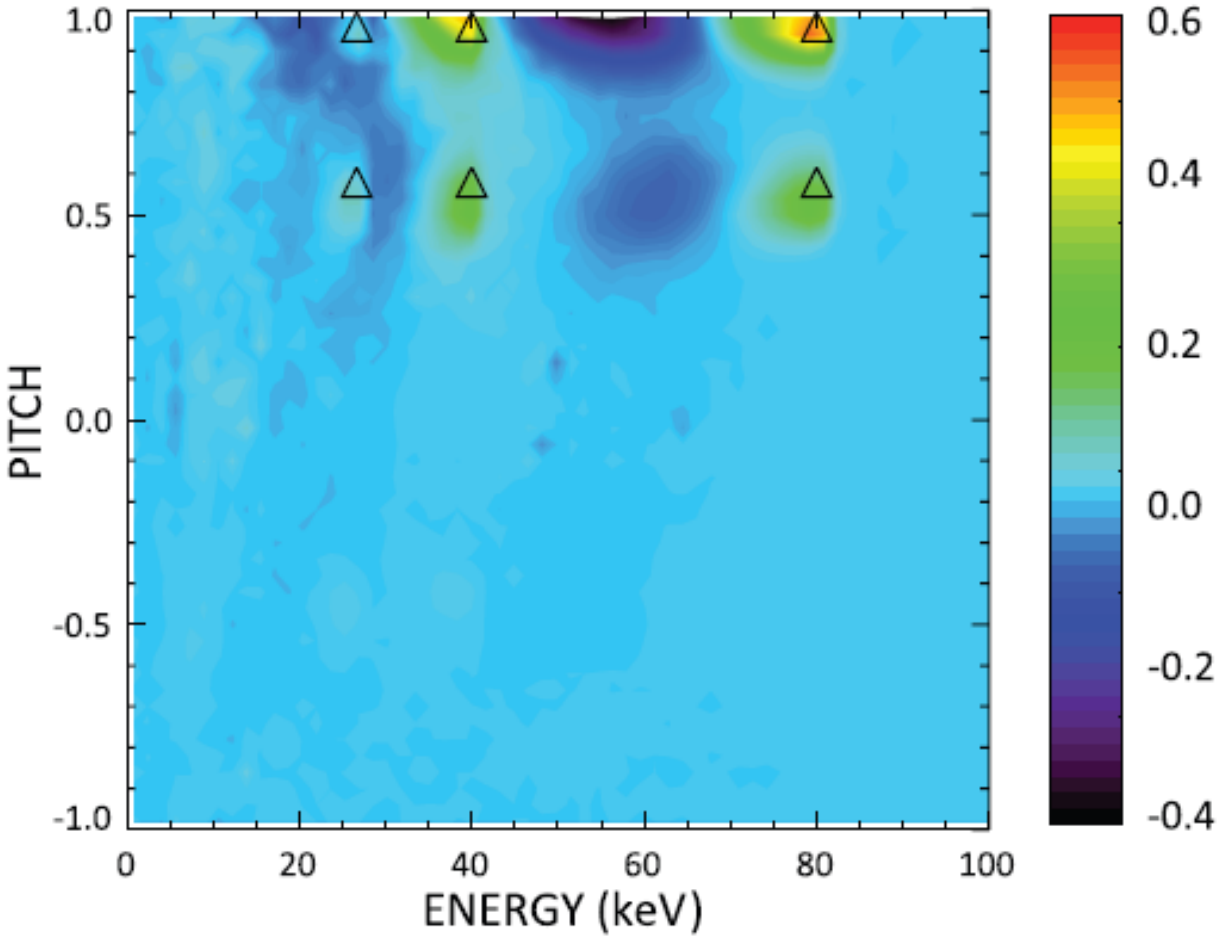
Three distinct fast-ion populations produce the measured signals: Edge axisymmetric

Conditionally averaged modulated distribution function (with average subtracted)



Bolte, NF 56 (2016) 112023

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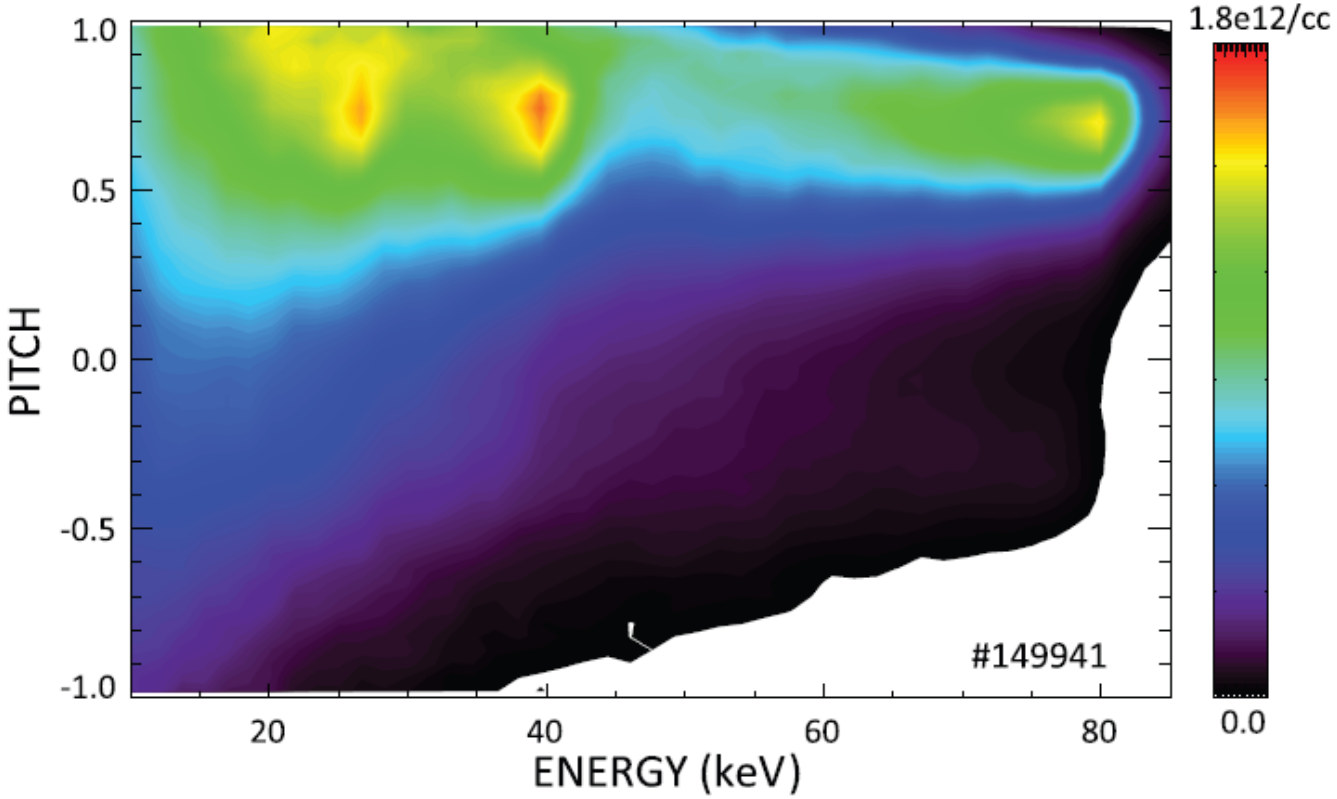
Three distinct fast-ion populations produce the measured signals: Expelled by sawtooth

Core fast-ion population prior to sawtooth



- **Use TRANSP sawtooth model to predict # that are expelled**
- **Estimate expected signal using core distribution function**

Bolte, NF 56 (2016) 112023

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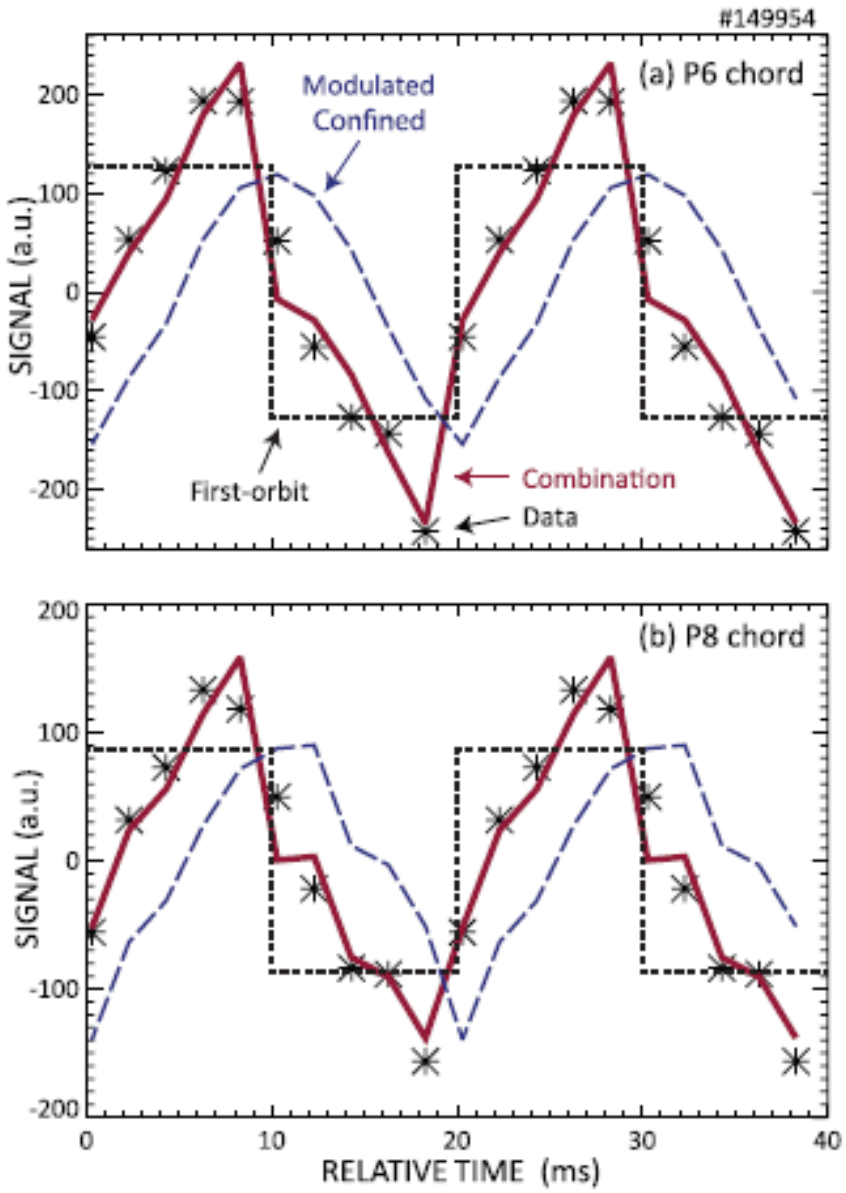
Use TRANSP cold neutrals to estimate passive FIDA signal

Analysis Workflow

- Dump distribution function every few ms
- Extract 1D neutral profile from TRANSP output
- Insert as a cold neutral population into FIDASIM
- Conditionally average FIDASIM output



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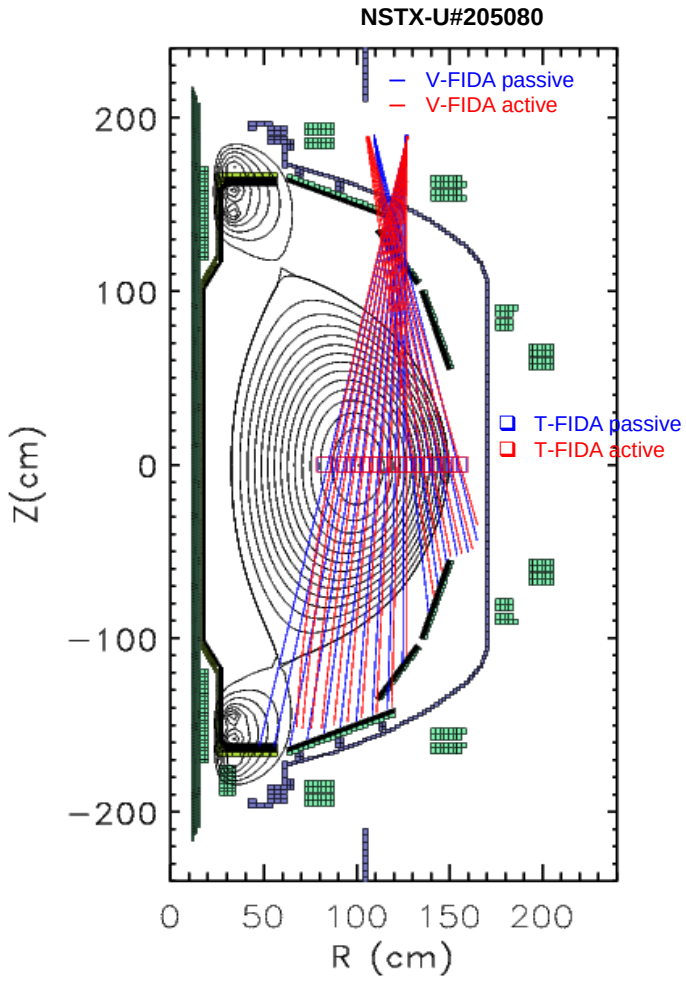
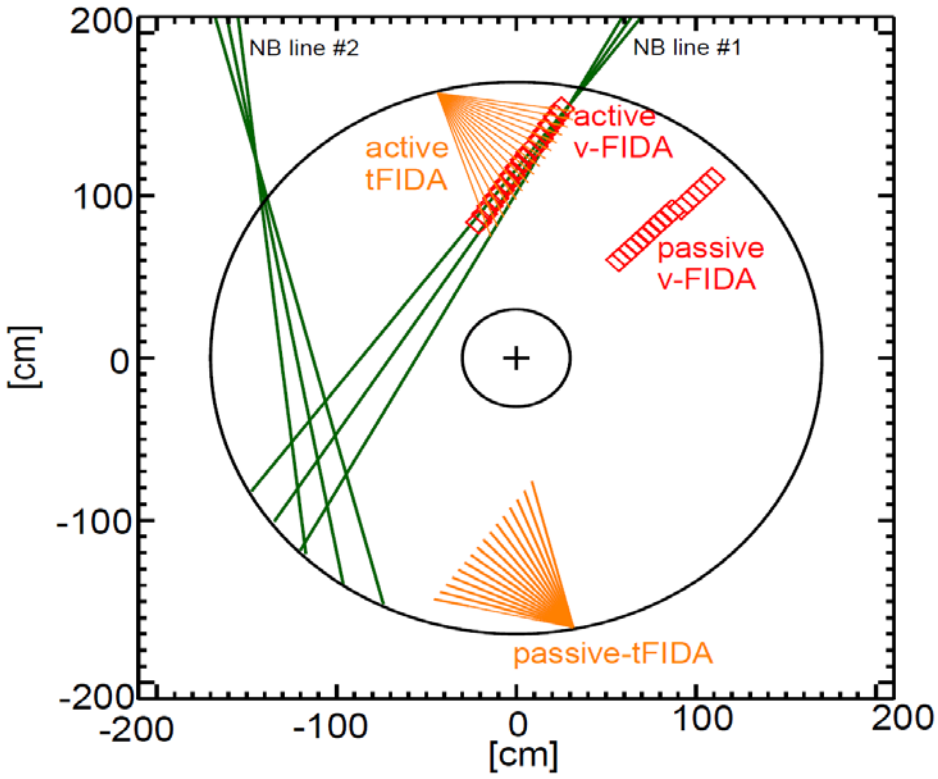
Passive signals are relatively large on NSTX-U

Elevation view of FIDA geometry



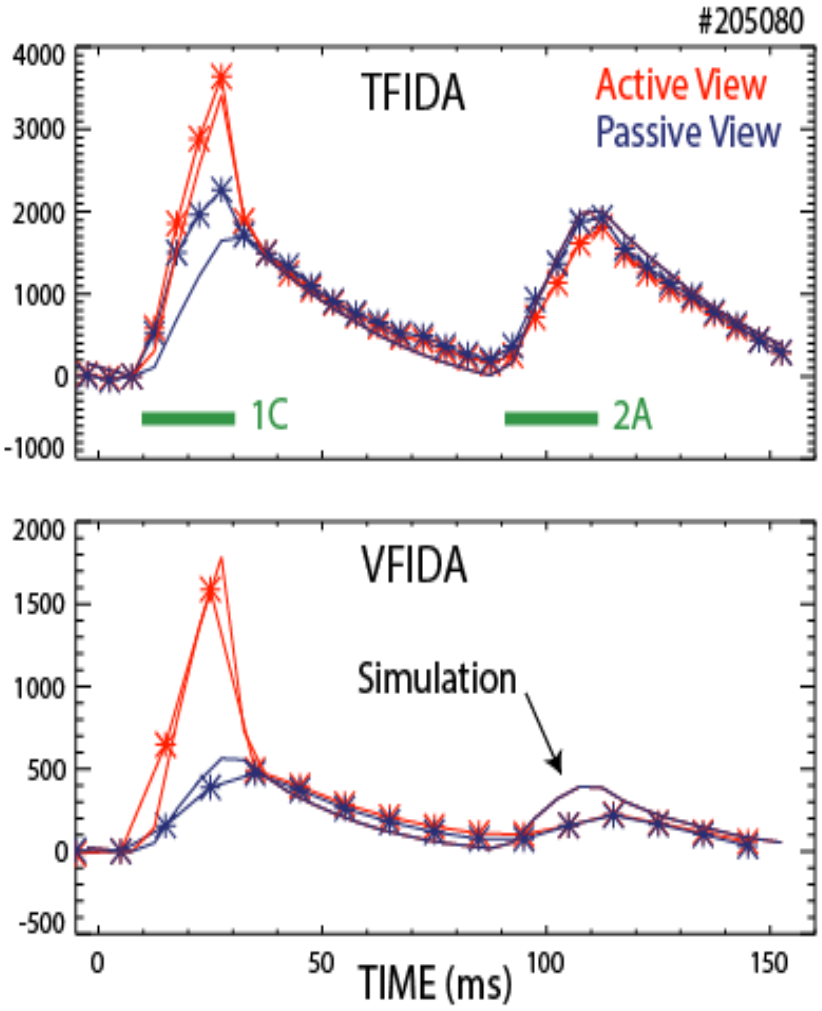
Plan view of FIDA geometry



- **Active views of Beamline #1**
- **Large orbit & gyroradius → many ions traverse cold-neutral region**

Injected and Edge Neutrals Produce FIDA Signals

- Use “passive FIDA” workflow developed for DIII-D
- T-FIDA: the active and passive signals are comparable in magnitude.
- For geometrical reasons, the passive contribution is smaller on V-FIDA



Note: Not all chords agree this well

Conclusions & Outlook

- TRANSP-based workflow works well for modeling *active* FIDA & NPA data in modulation experiments
- Passive signals can be significant
- A better neutral density model within TRANSP is desirable
- FIDASIM will be modified to include cold neutrals as a standard neutral species

Desired TRANSP Upgrades

- **2D “cold” neutral density model (? & ?)**
- **Beam deposition outside the Last Closed Flux Surface (Gorelenkova & Van Zeeland)**
- **Fast-ion distribution function in constants-of-motion coordinates, including smooth derivatives (Breslau & Liu)**