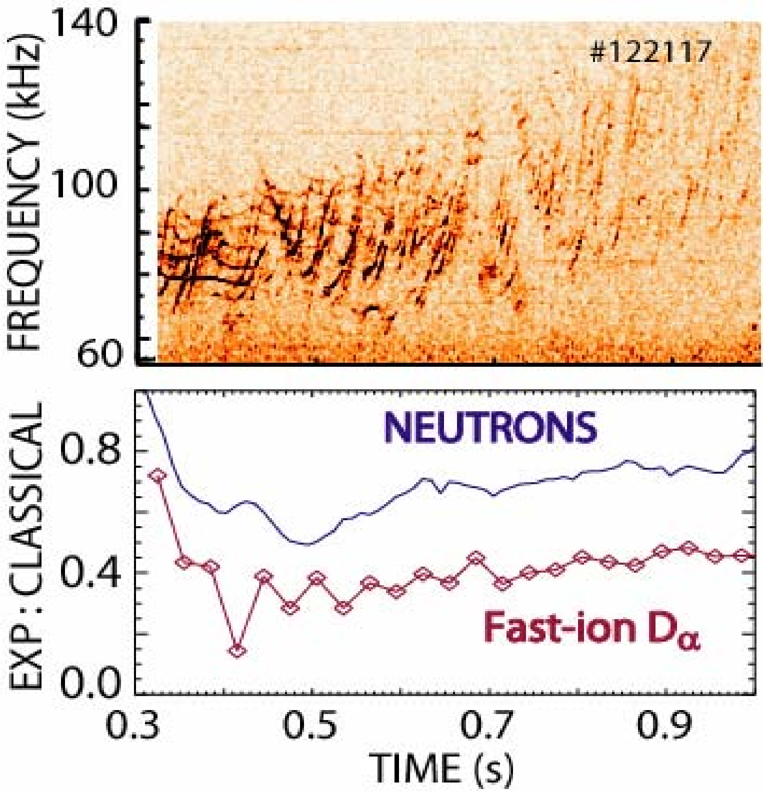
Fast-ion Transport by Alfven Instabilities in DIII-D



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Goal: Detailed measurements of fluctuations and fast ions to predict alpha transport in ITER

- **Flattened fast-ion density profile**
- **More profile measurements**
- **Modeling status**

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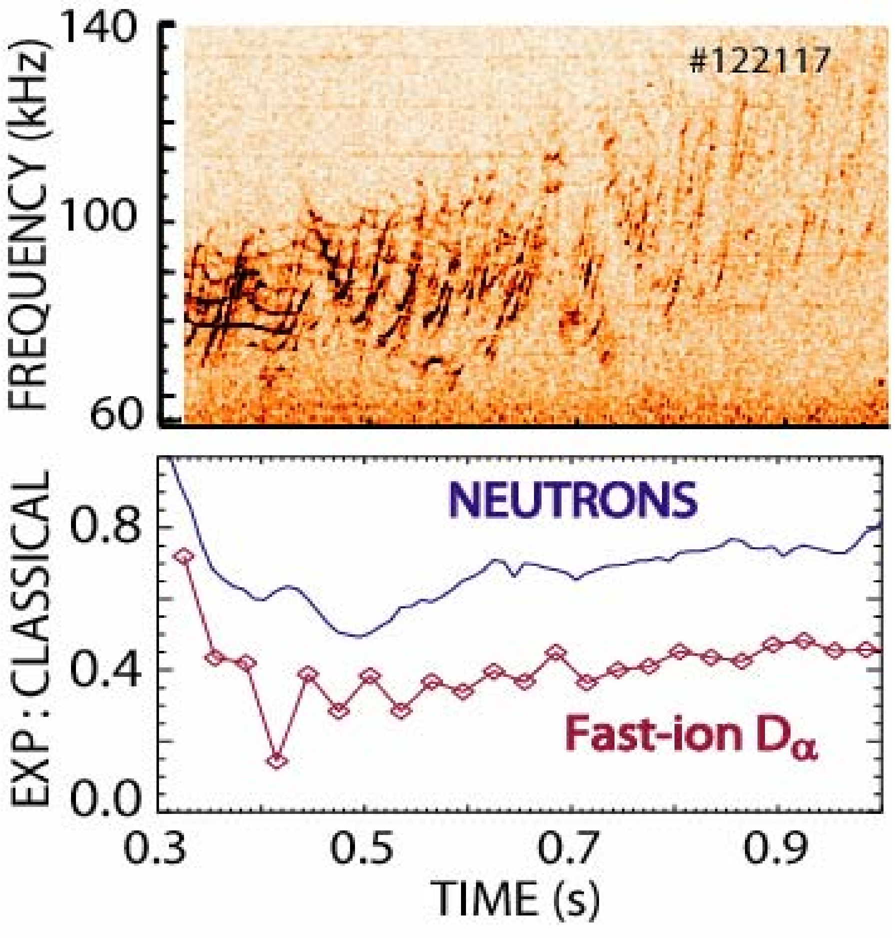
Alfven Modes Degrade Fast-ion Confinement

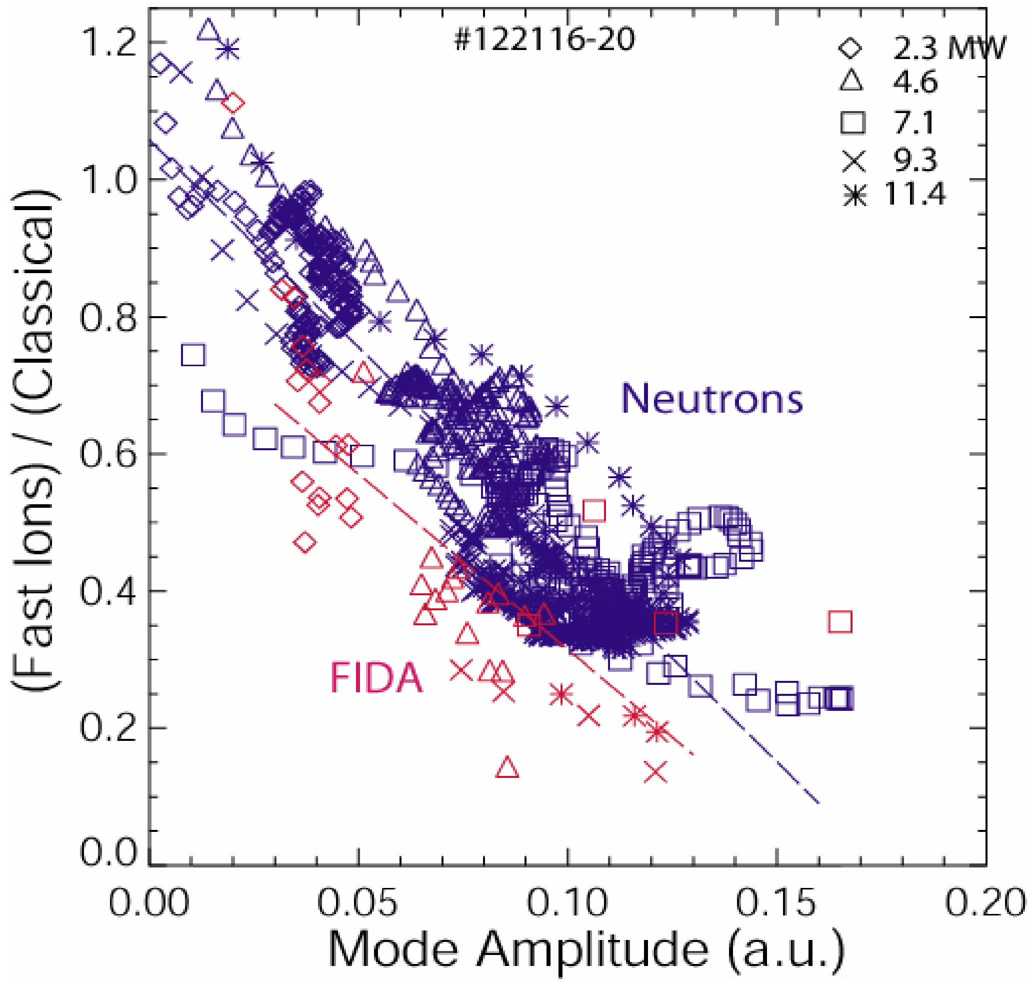


- **Volume-averaged neutron rate is below the classical TRANSP prediction during the strong Alfven activity**
- **Fast-ion D_α (FIDA) diagnostic measures the spectrum of fast ions with 4 cm spatial resolution***
- **FIDA "density" near ρ_{qmin} is reduced during the strong Alfven activity**

****Heidbrink, PPCF 46 (2004) 1855; Luo, RSI 78 (2007) 033505.***

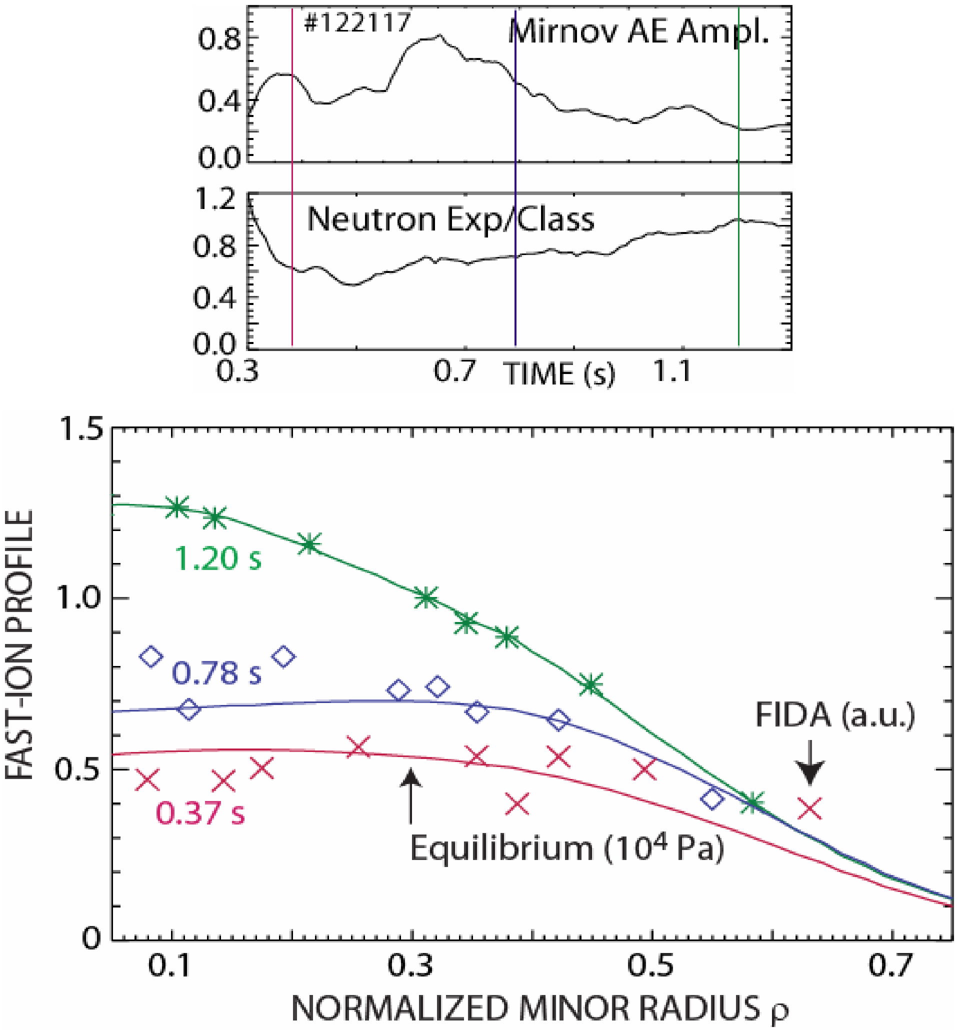
The Fast-ion Deficit Correlates with Alfven Activity

- **The strength of the Alfven activity tends to increase with beam power in similar plasmas.**
- **The discrepancy between the classical prediction and the data is largest when the Alfven modes are strong**
- **The FIDA deficit is larger than the neutron deficit**



****For this comparison, the FIDA density and neutron rate are normalized by their values at 2.0 s in the 1-source shot (when Alfven activity is undetectable).***

The Fast-ion Density Profile is Flattened



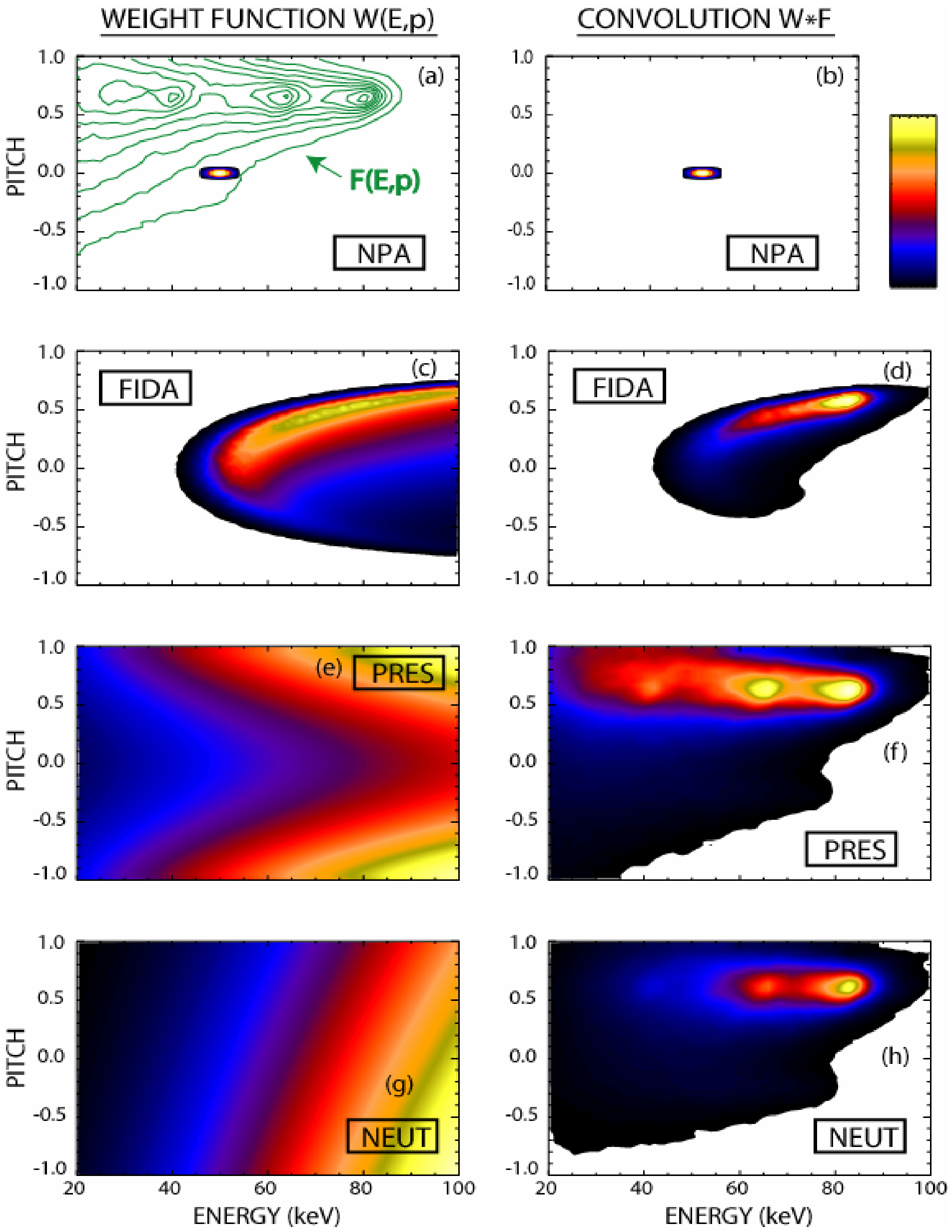
- During the strong Alfven activity, the fast-ion density profile from FIDA is nearly flat
- The fast-ion profile inferred from the equilibrium* is also very flat
- The classical profile computed by TRANSP peaks on axis

*The kinetic EFIT equilibrium uses MSE and magnetics data to compute the pressure profile. Subtraction of the thermal pressure yields the fast-ion pressure. The FIDA data are normalized to the 1.20 s pressure profile.

My Questions (as of Fall '06)

- The FIDA and fast-ion pressure diagnostics do not measure the same thing: should their profiles be similar?
- Are the FIDA spatial profiles valid?
- Can the measured modes explain the flattened profile?

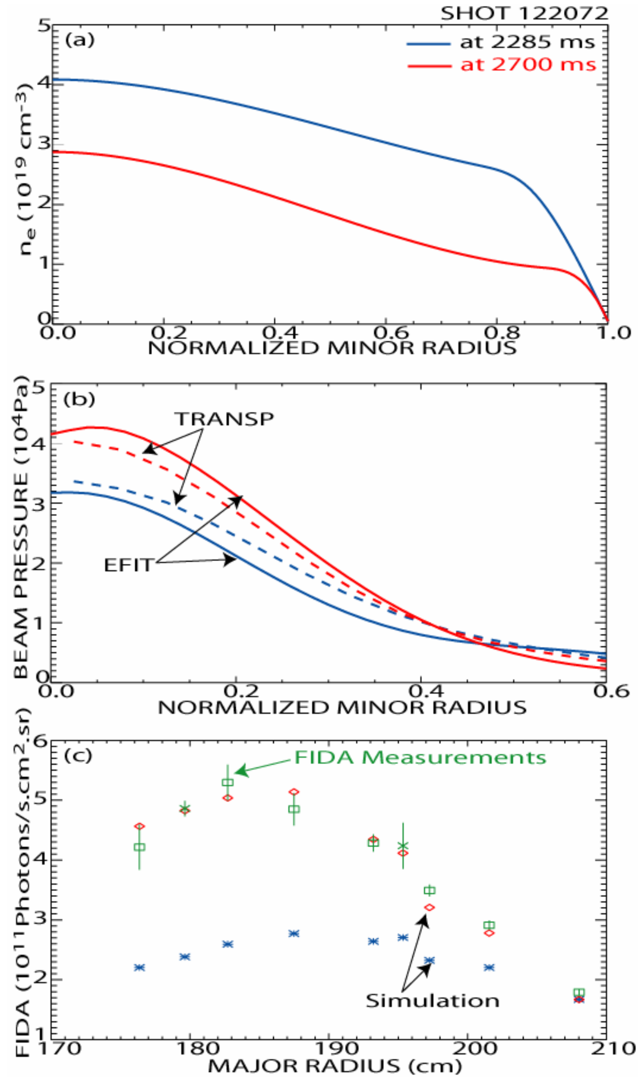
The Pressure and FIDA techniques diagnose the same parts of velocity space



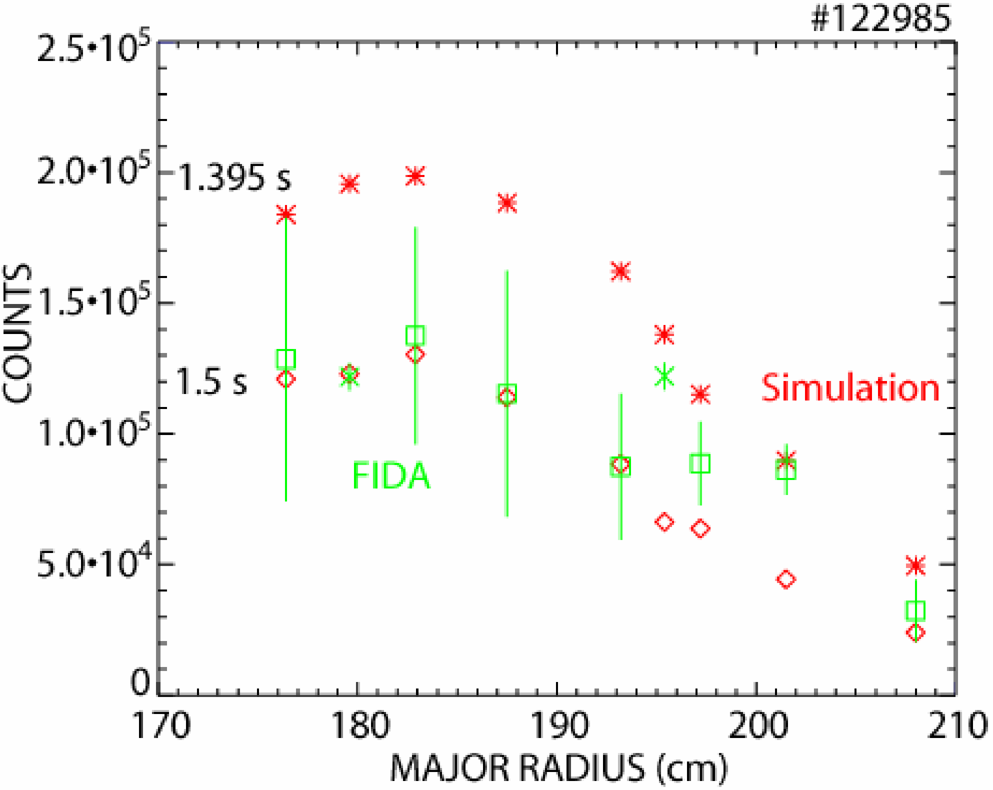
- Different fast-ion diagnostics weight velocity space differently.
- The FIDA weighting shown here is for E_λ= 50 keV.
- After averaging over the distribution function F(E,p) and over wavelengths, the FIDA and pressure diagnostics have similar weightings.

FIDA relative radial profile agrees well with TRANSP prediction in quiet plasmas

- Fast-ion distributions from TRANSP are dumped to the simulation code.
- Simulated profiles are higher as expected at the later time when electron density is lower.
- At the early time, FIDA profile is normalized to the simulated profile.
- At the later time, FIDA profile agrees with the simulated profile.
- Radial profile of fast-ion pressure inferred from kinetic EFITs (MSE data) are also consistent with TRANSP.



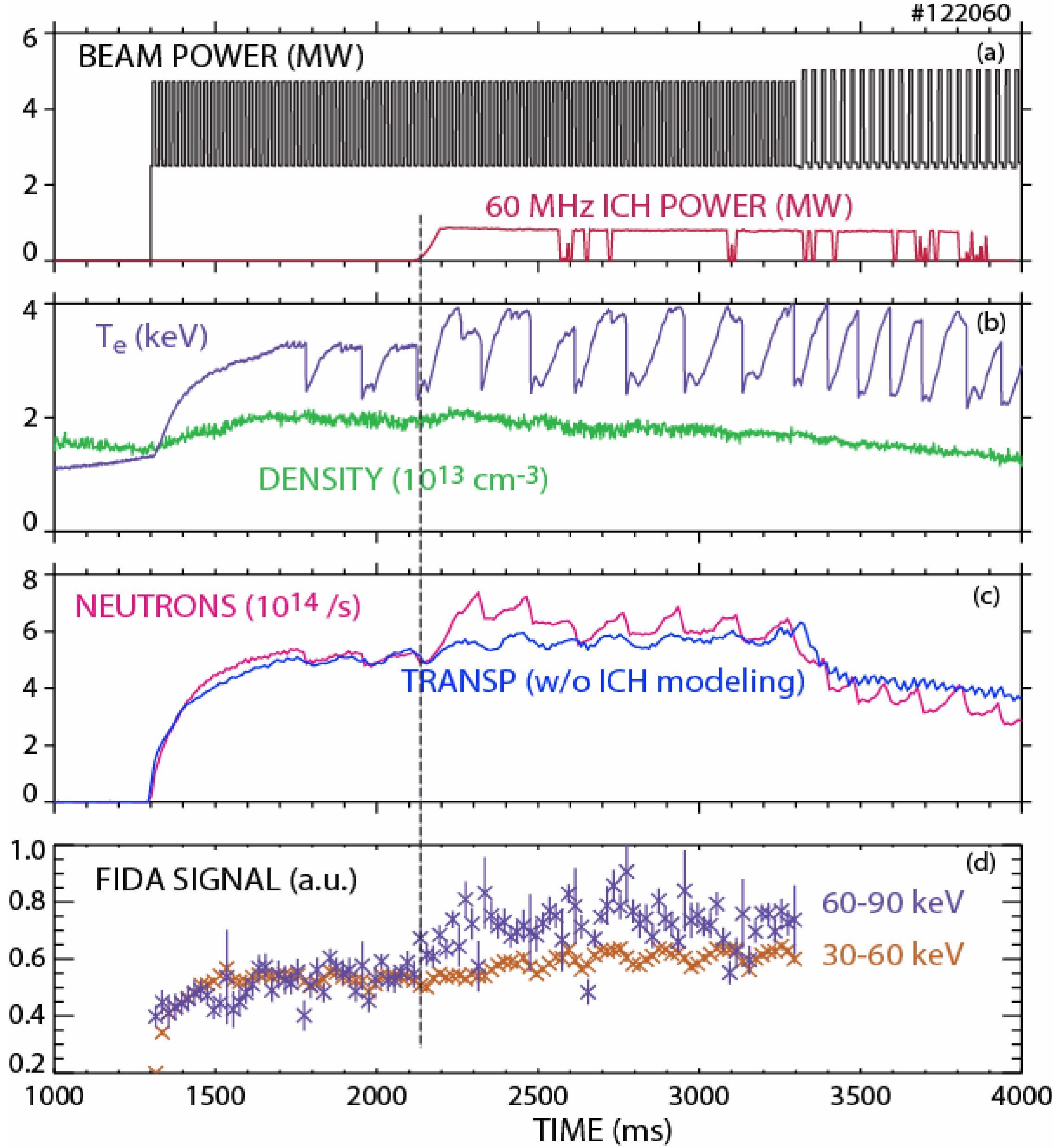
First Try at Radial Profile in Quiet Plasma showed Disagreement



- This one-source L-mode plasma has modest Alfven activity!
- The EFIT fast-ion pressure profile differs from TRANSP as well

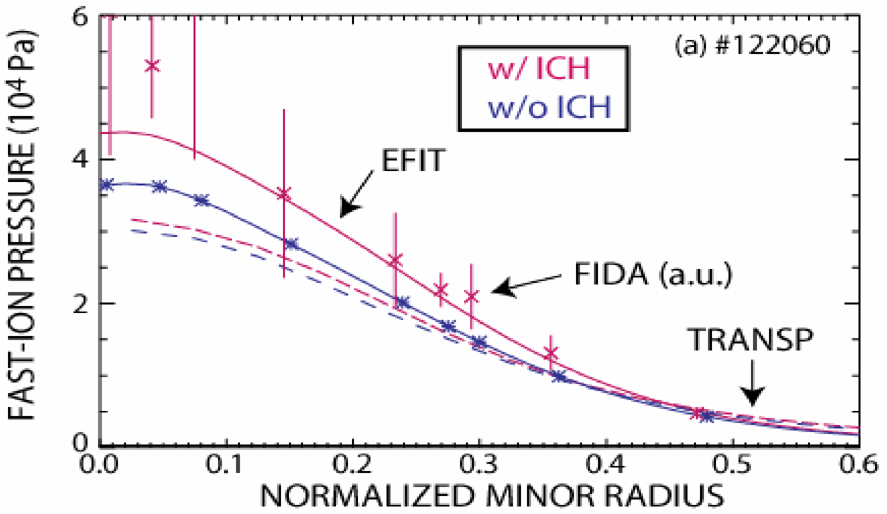
Perpendicular Fast-ion Acceleration at 4th Cyclotron Harmonic

- Neutron enhancement during ICH → fast-ion acceleration
- FIDA data → distribution function distorts
- Slight increase in bulk; perpendicular tail forms



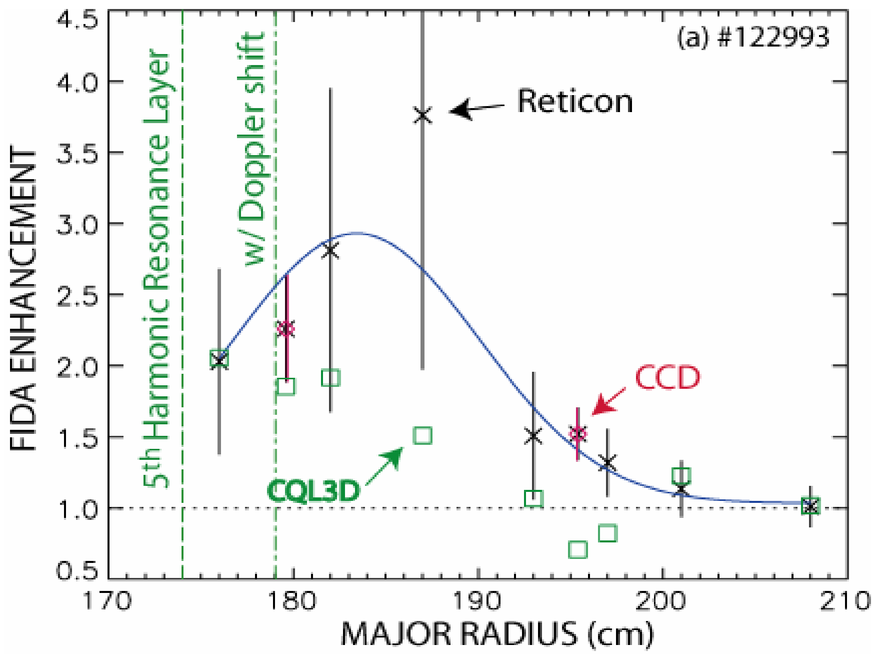
Profiles agree well during ICH acceleration

- Fast-ion pressure exceeds classical (no RF) prediction.
- FIDA profiles show similar trends.
- The FIDA data are averaged over wavelength and time, then normalized to the no-RF profile.

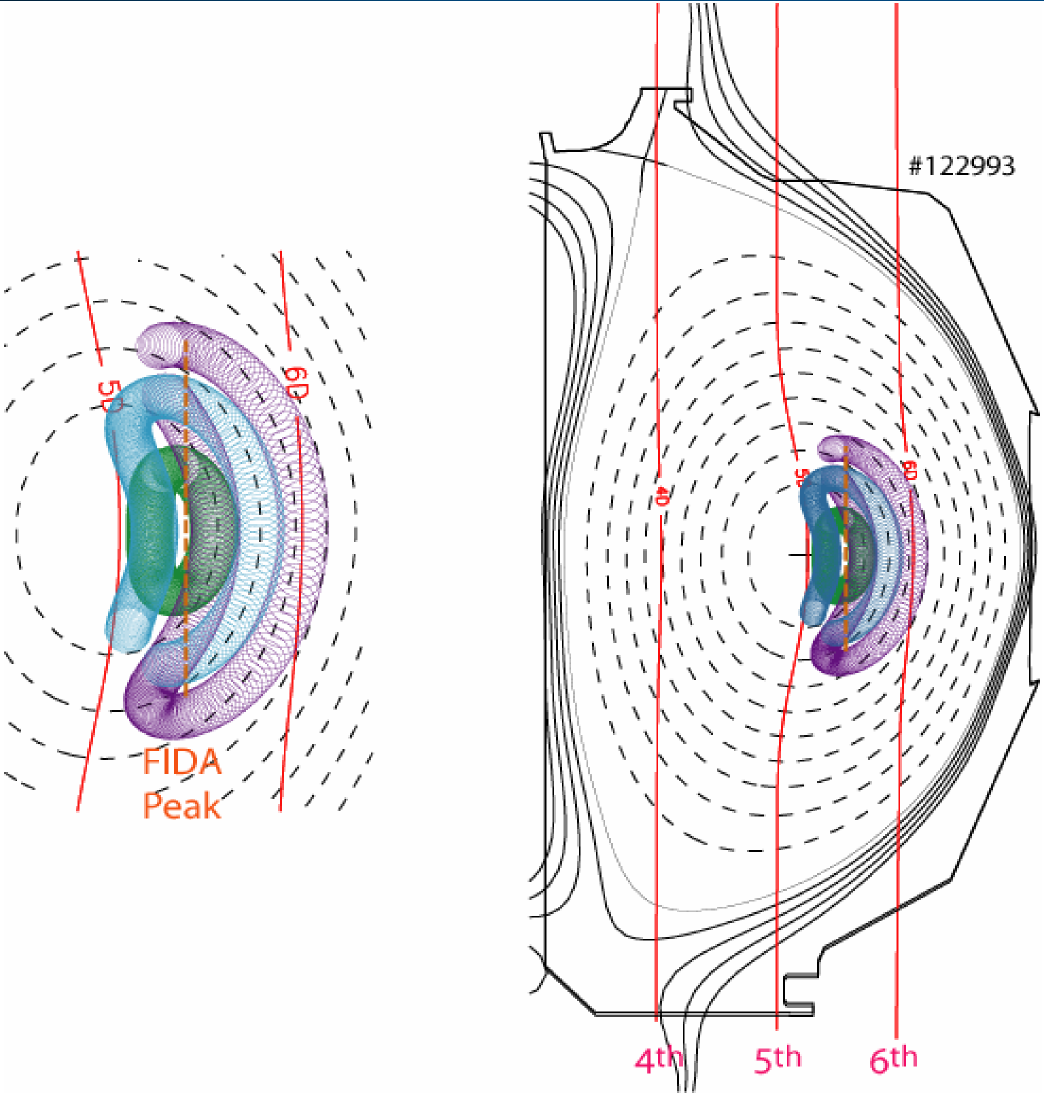


Reasonable values for the spatial profile of ICH acceleration

- The profile peaks ~10 cm farther out than the nominal resonance layer.
- Calculate the expected fast-ion distribution function in CQL3D, then calculate the expected FIDA spectra and profile.
- The CQL3D prediction is close to the data.



Likely Explanation for Outshifted FIDA Signal: Orbit Effects



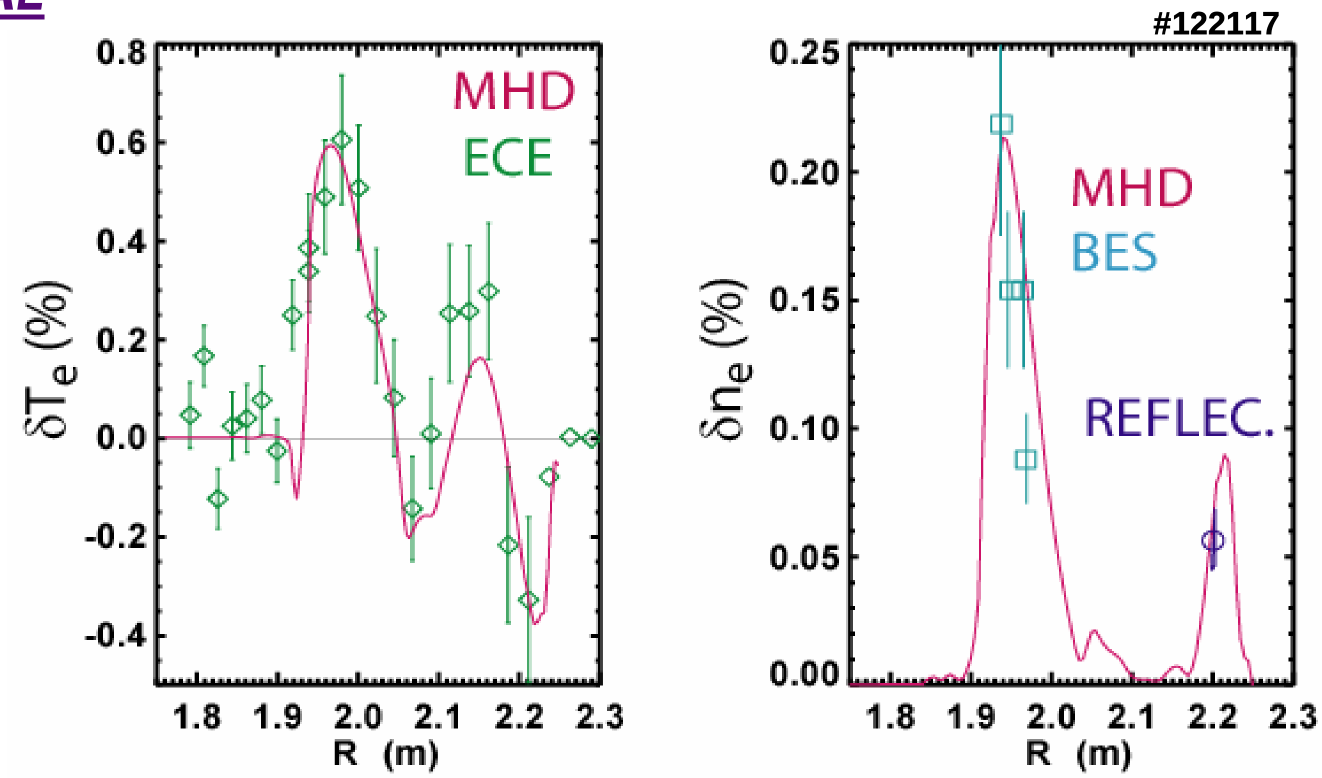
- Launch orbits in FIDA spatial volume with values of v_z that contribute strongly to the FIDA enhancement
- Representative orbits have turning points near the Doppler-shifted resonance layer.

Original Analysis Plan for Alfven Mode Transport

1. Match linear NOVA-K eigenfunctions to ECE data.
2. Insert these modes (with experimental amplitudes) into ORBIT drift orbit code. Compute fast-ion transport.
3. Dump ORBIT distribution function. Use diagnostic simulation codes to predict signals. Compare with data.

The Mode Structure agrees with linear ideal MHD Theory

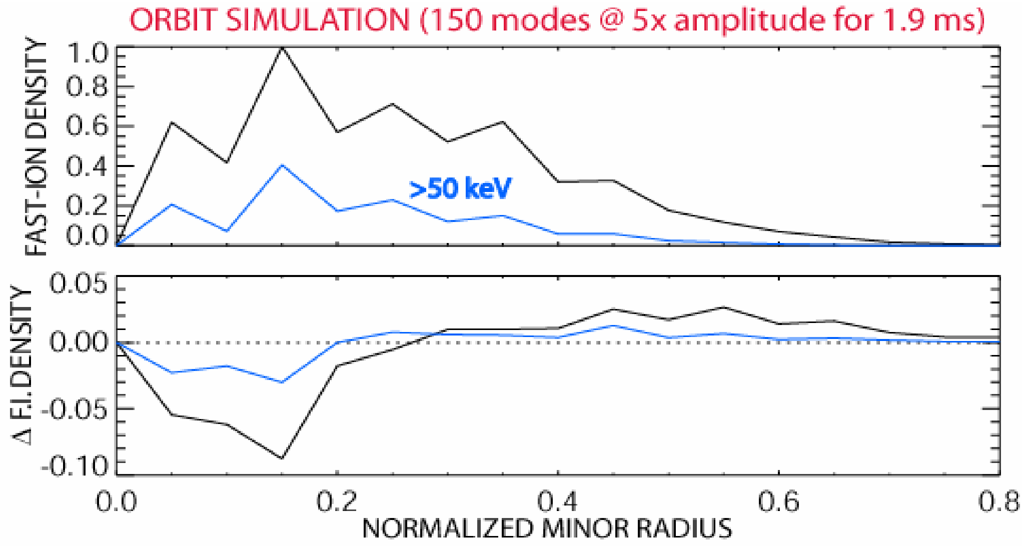
n=3 RSAE



- The MHD δT_e amplitude is scaled to match the ECE data
- Easy to match strongest TAE and RSAE modes
- More ambiguity in weaker modes. Used 11 toroidal modes.

Van Zeeland, PRL 97 (2006) 135001.

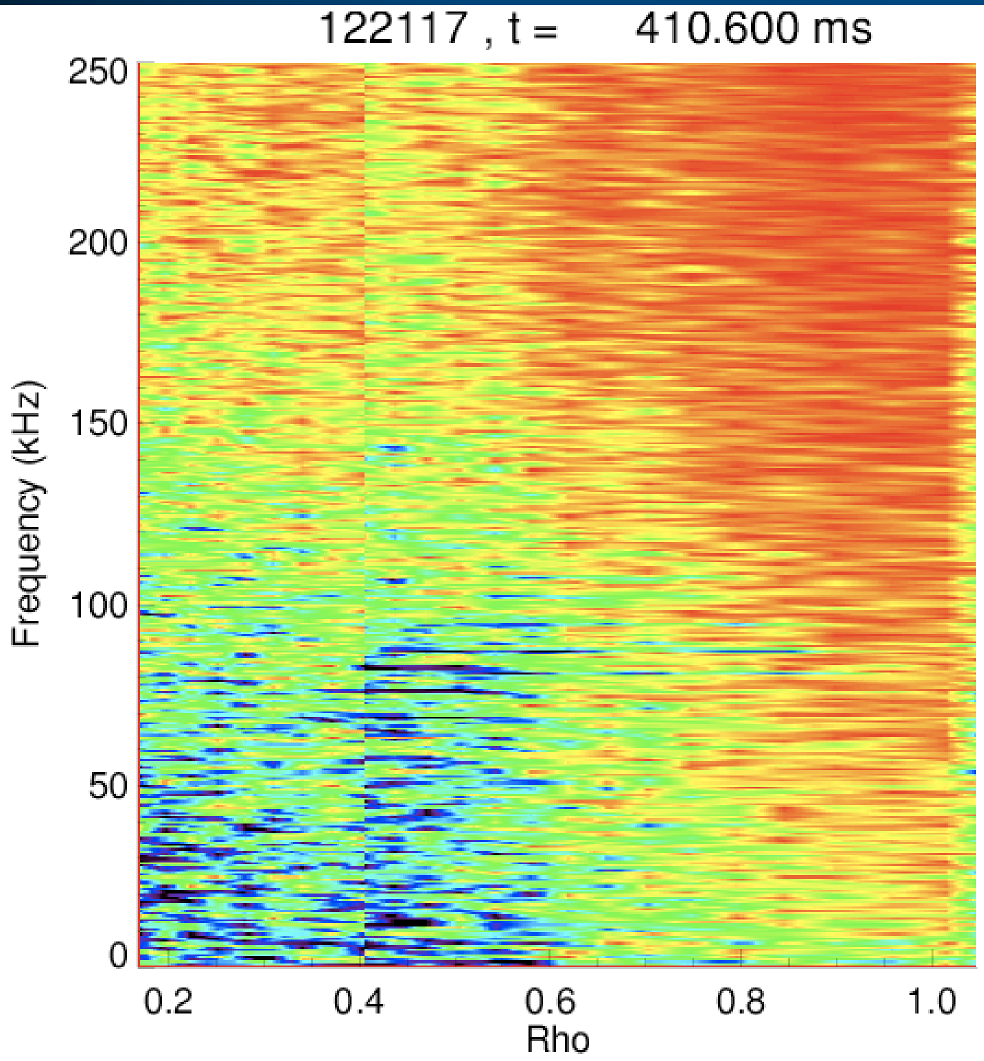
Modes move fast ions from magnetic axis to half-radius



#122117

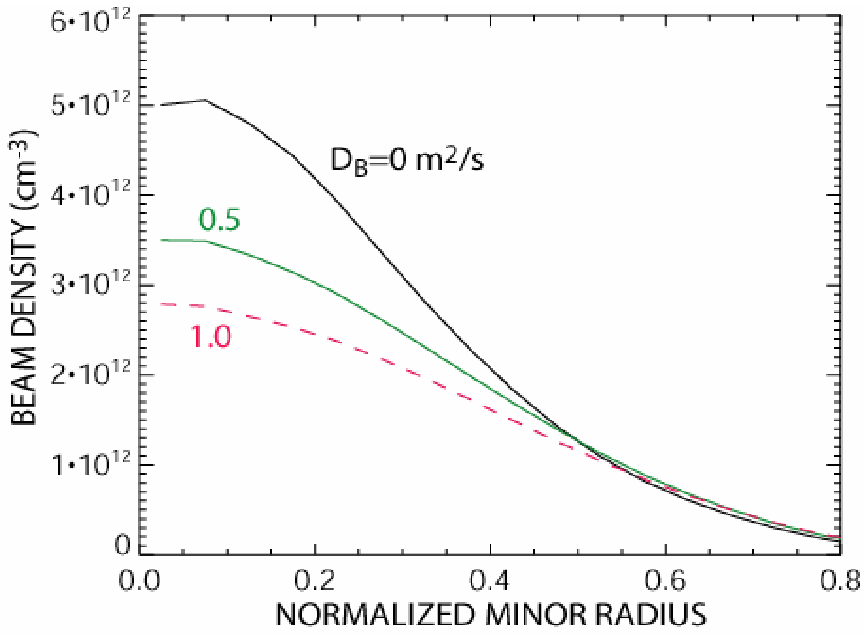
- Pitch-angle scattering is included @ experimental level of ~2 Hz
- Mode amplitudes are scaled up to investigate effect.
- The change in the distribution roughly doubles for a 3.8 ms run.

Does the "Sea" of Activity Cause Diffusive Transport?



- ECE Data (Blue is strong)
- Many modes that constantly change

Can use *ad hoc* beam-ion diffusion in TRANSP to match experimental profile



- Used spatially uniform D_B in this initial run.
- Need a large D_B in core, smaller outside 0.6 to match experiment.

Revised Analysis Plan for Alfven Mode Transport

1. Match linear NOVA-K eigenfunctions to ECE data. OK
2. Insert these modes (with experimental amplitudes) into ORBIT drift orbit code. Compute fast-ion transport for a few milliseconds.
3. ~~Dump ORBIT distribution function. Use diagnostic simulation codes to predict signals. Compare with data.~~

3. Estimate diffusion from ORBIT run. Compare with TRANSP *ad hoc* diffusion coefficient that matches the data.

My Questions & Answers (as of 4/07)

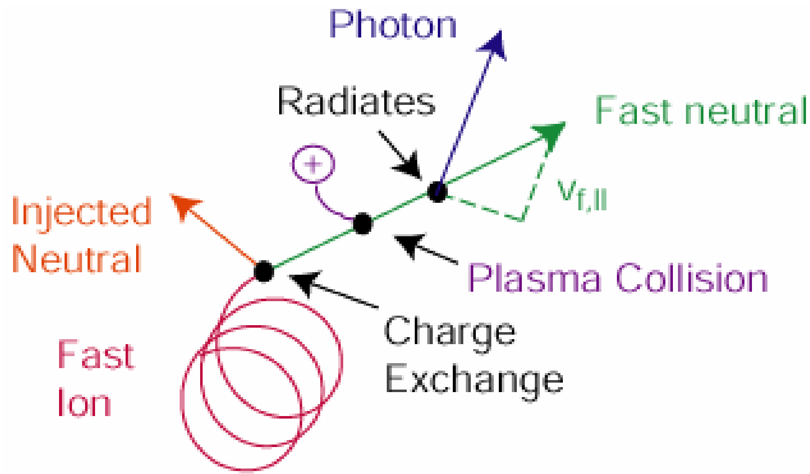
- The FIDA and fast-ion pressure diagnostics do not measure the same thing: should their profiles be similar? Yes, they detect the distribution function in the same portion of velocity space.
- Are the FIDA spatial profiles valid? Yes, profiles analyzed the same way in quiet and ICH-heated plasmas make sense.
- Can the measured modes explain the flattened profile? I don't know yet.

Backup slides

My Questions (as of 11/06)

- **Are the FIDA spatial profiles valid?**
- **The FIDA and fast-ion pressure diagnostics do not measure the same thing: should their profiles be similar?**
- **Can the measured modes explain the flattened profile?**

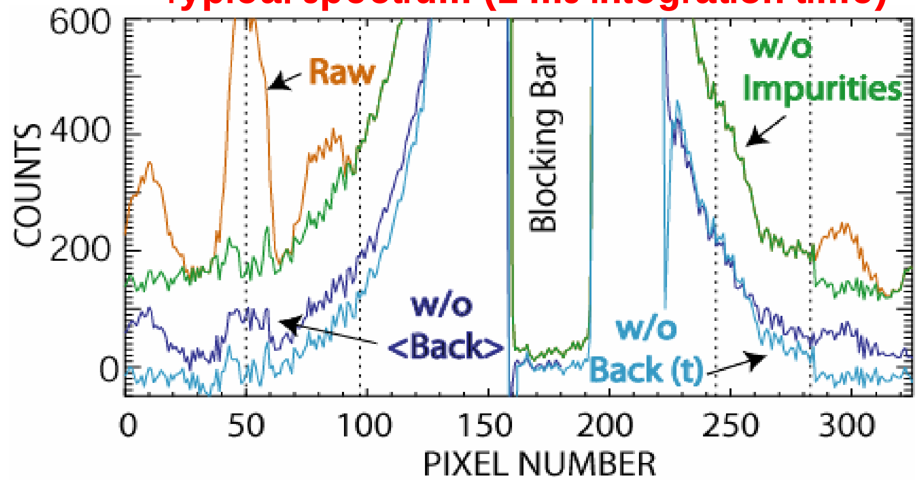
Fast-ion D_α (FIDA) Diagnostic



- A type of Charge Exchange Recombination Spectroscopy
- Use vertical view to avoid bright interferences
- Exploit large Doppler shift (measure wings of line)

- Background subtraction usually dominates uncertainty
- Achieved resolution: ~ 5 cm, ~ 10 keV, 1 ms.

Typical spectrum (1 ms integration time)



Heidbrink, PPCF 46 (2004) 1855; Luo, RSI (2006) submitted.