Development of a Fast-Ion D-Alpha diagnostic for NSTX

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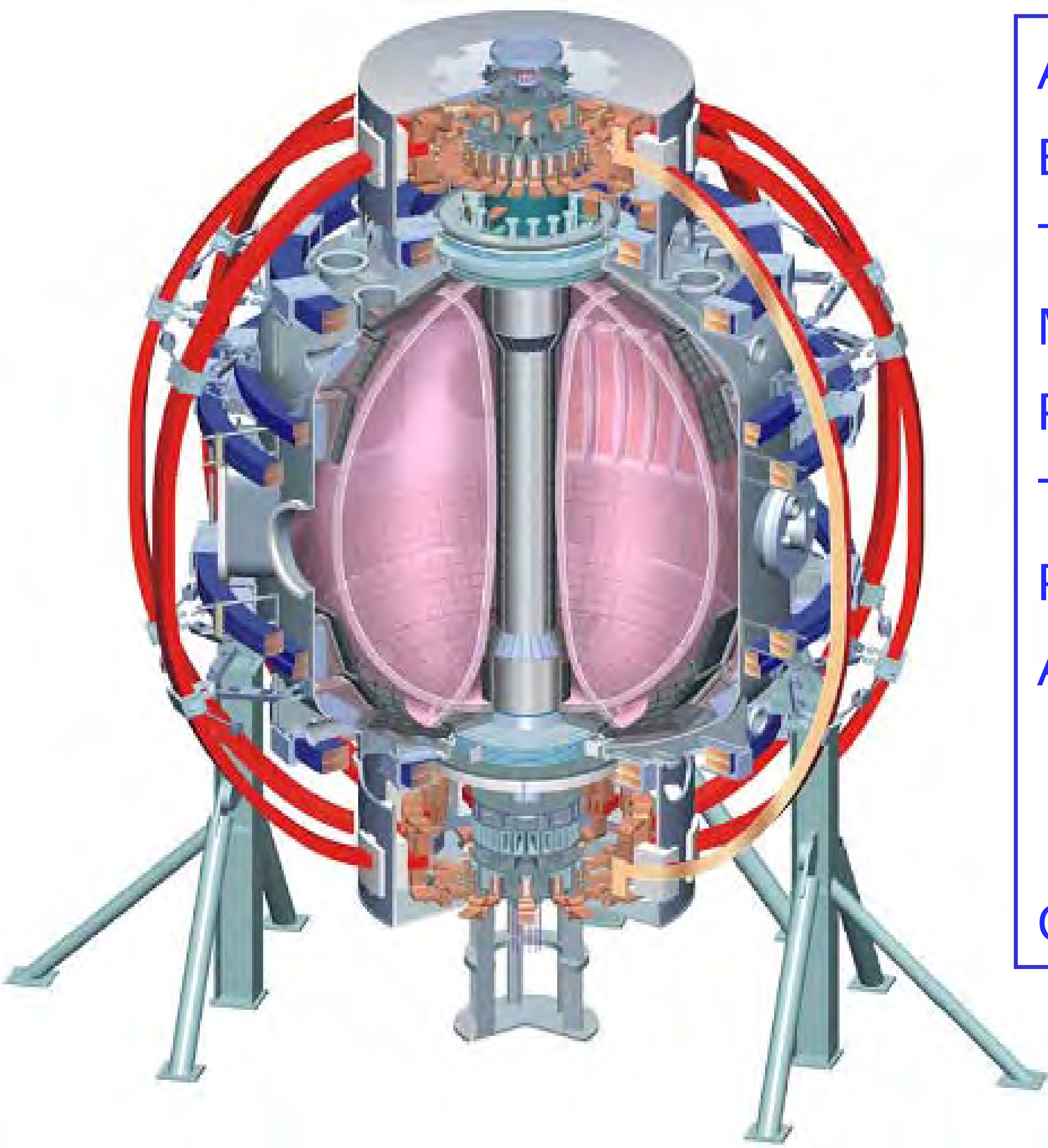
Abstract

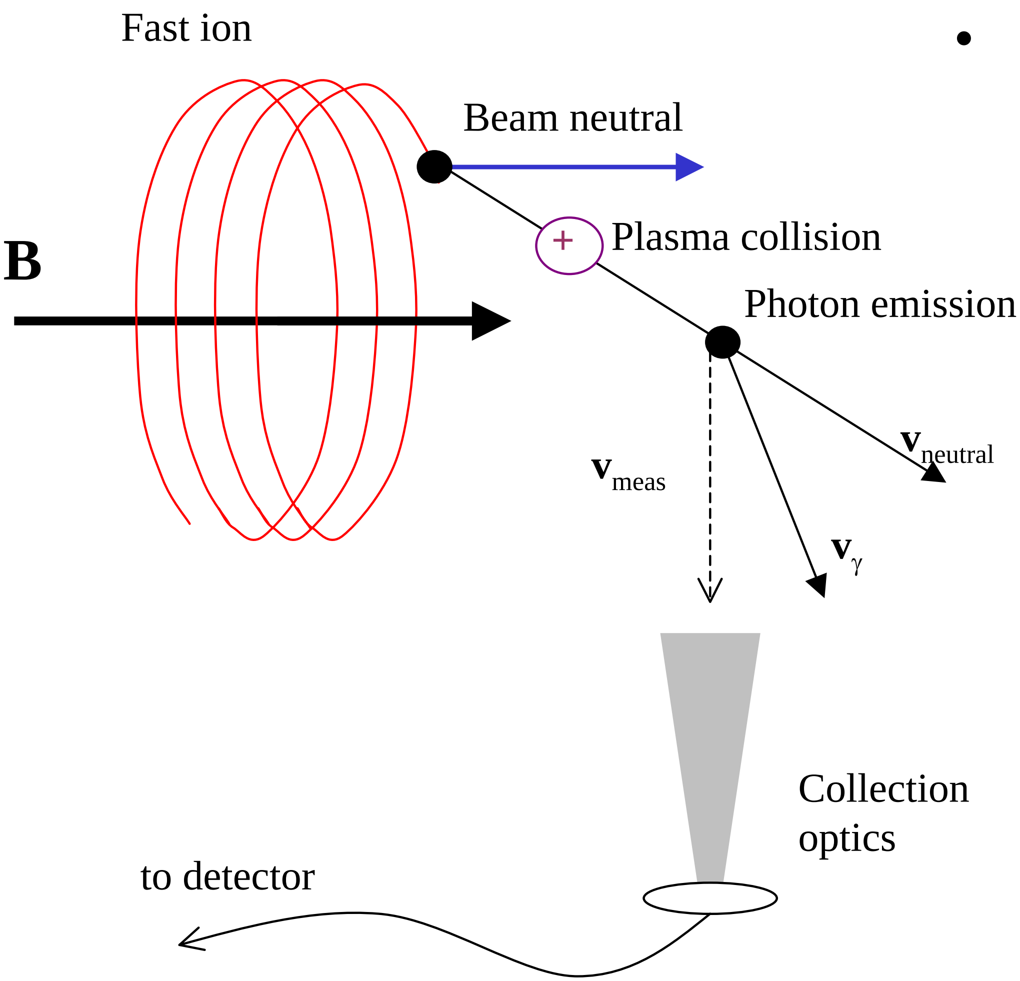
A Fast-Ion D-Alpha diagnostic based on active charge exchange recombination spectroscopy is being developed for NSTX. Results from the 2007 run, obtained with a prototype setup, indicate that fast ion signals have been successfully detected. The signals show a clear time correlation with the neutron emission from beam-plasma reactions. During modulation of the injected neutral beam power, variations on the fast ion slowing down time-scale are observed. The signal amplitude from different spectral regions scales accordingly with the fast ion D_α spectrum. Good correlation with other diagnostics is found. For the 2008 run, sixteen channels will cover the outboard poloidal cross-section with a resolution in space, time and energy of 5cm, 10ms and 10keV. In addition, three dedicated channels will monitor the signal from suprathermal ions on time-scales ~10μs at different radii. Each channel includes two views inside the plasma, intercepting/missing the neutral beam for a direct subtraction of the background signal not associated with fast ions.

NSTX parameters

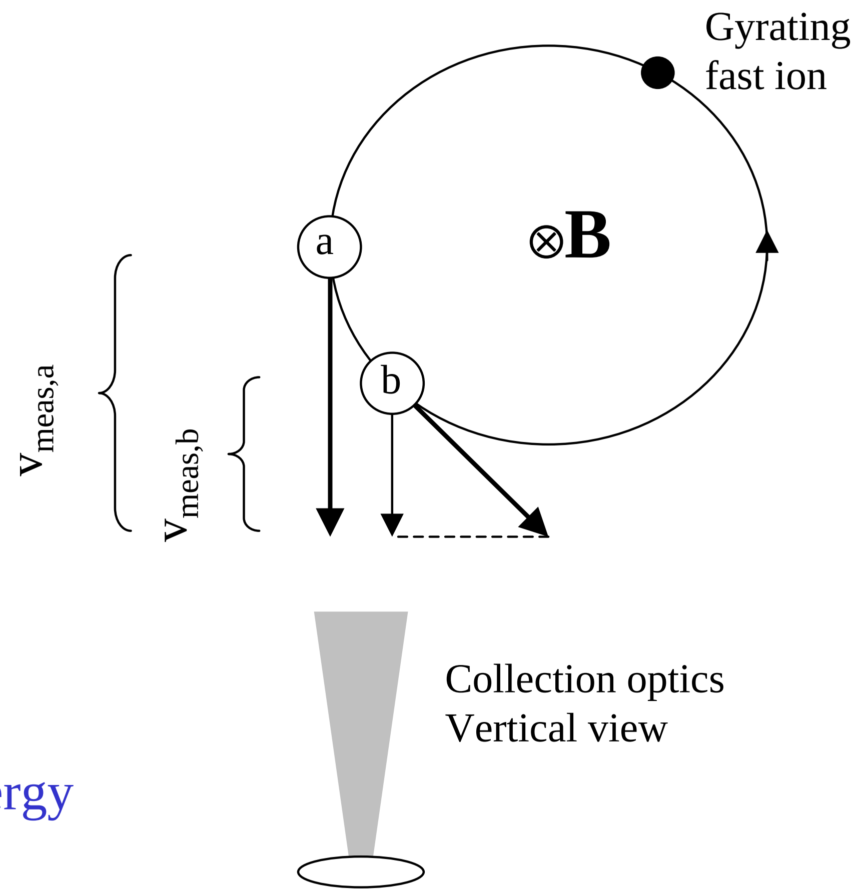


Aspect ratio A	1.27
Elongation κ	2.5 (3.0)
Triangularity δ	0.8
Major radius R_0	0.85m
Plasma Current I_p	1.5MA
Toroidal Field B_{T0}	0.55 T
Pulse Length	1.5s
Auxiliary heating:	
NBI (100kV)	7 MW
RF (30MHz)	6 MW
Central temperature	1 – 3 keV

FIDA diagnostic, principles



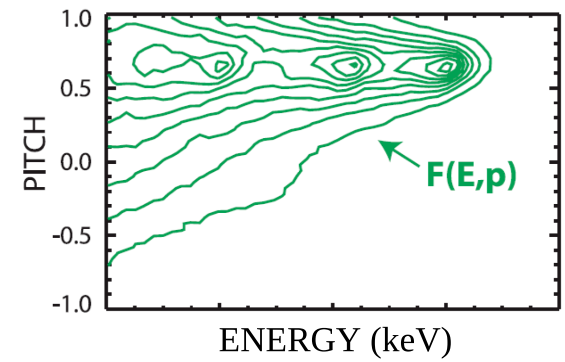
- **Fast Ion D-Alpha diagnostic**:
  - Based on active charge-exchange recombination spectroscopy
  - Exploit large wavelength Doppler shift of photon emitted by re-neutralizing fast ions
    - Measure wings of D_α line

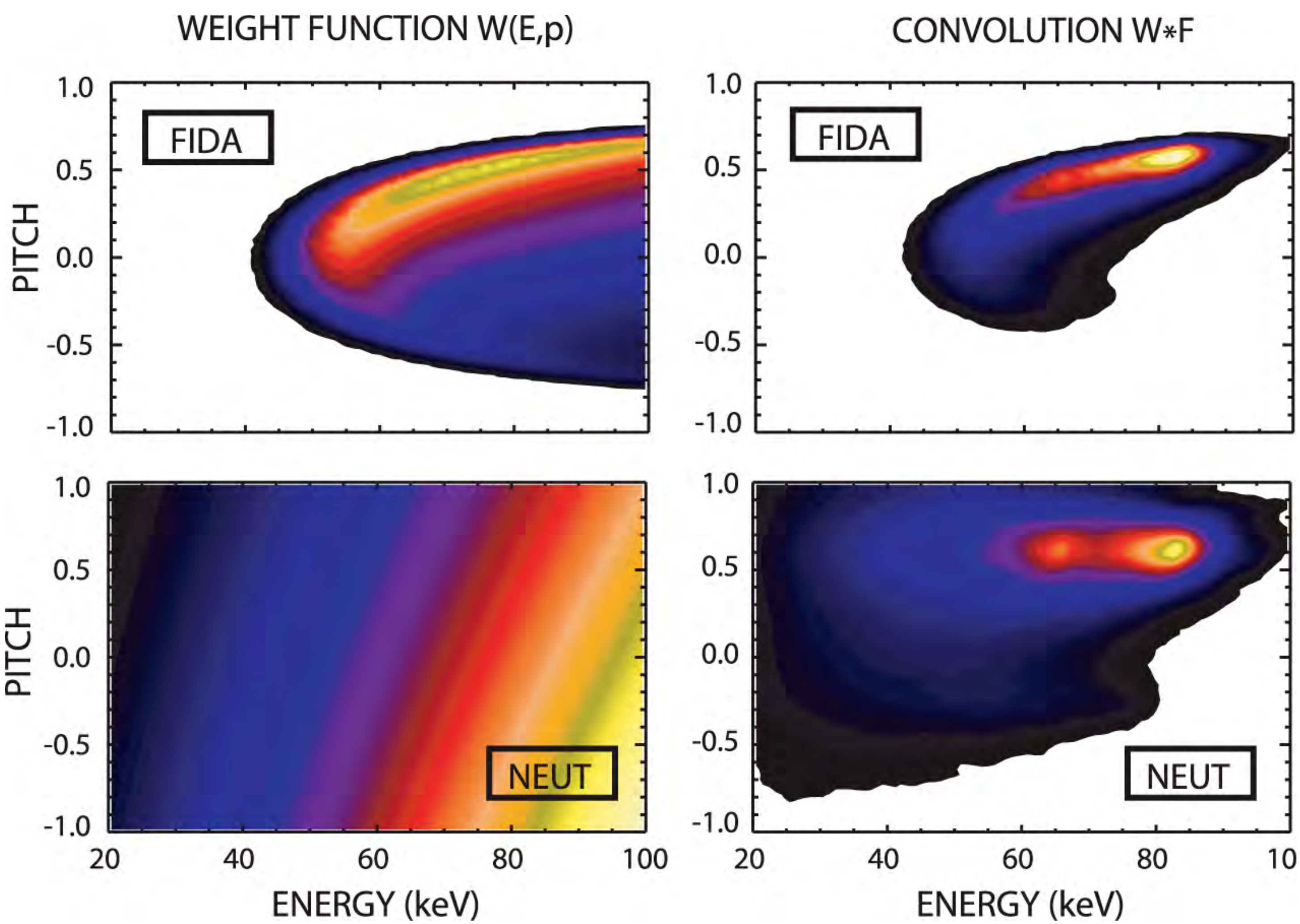


- Vertical view, perpendicular to **B**:
  - Avoid bright emission from beam ions
  - Effective integration over perpendicular energy

FIDA response

- FIDA sampling of fast ion distribution function:
  - Integration over phase-space
    - Higher energies and pitch more efficiently sampled





Example:

Weight Function, DIII-D

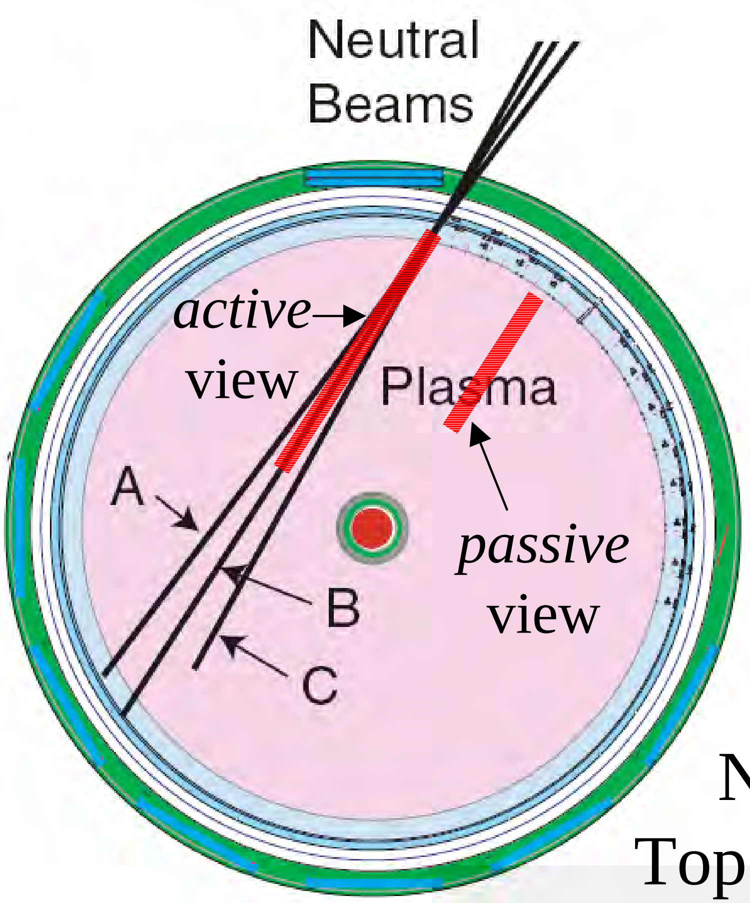
E_λ=50keV

Similar weight function for **FIDA** and **neutron rate** measurements

[W.W. Heidbrink *et al.*, PPCF **49** (2007) 1457]

NSTX - FIDA setup, 2007

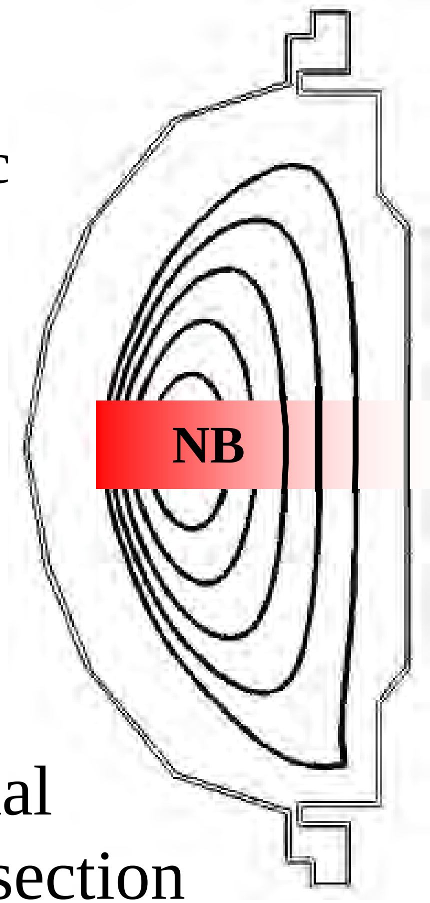
- Six fiber optic bundles, seven fibers each
- Two positions available: 100 or 120cm (swap on shot-to-shot basis)
- Vertical views at two toroidal positions
  - Intercepting/missing the beam for **direct background subtraction**
  - Assume toroidal symmetry



NSTX
Top view

- *Active* view along beam B path
- High throughput collection optic
  - Focus on equatorial plane

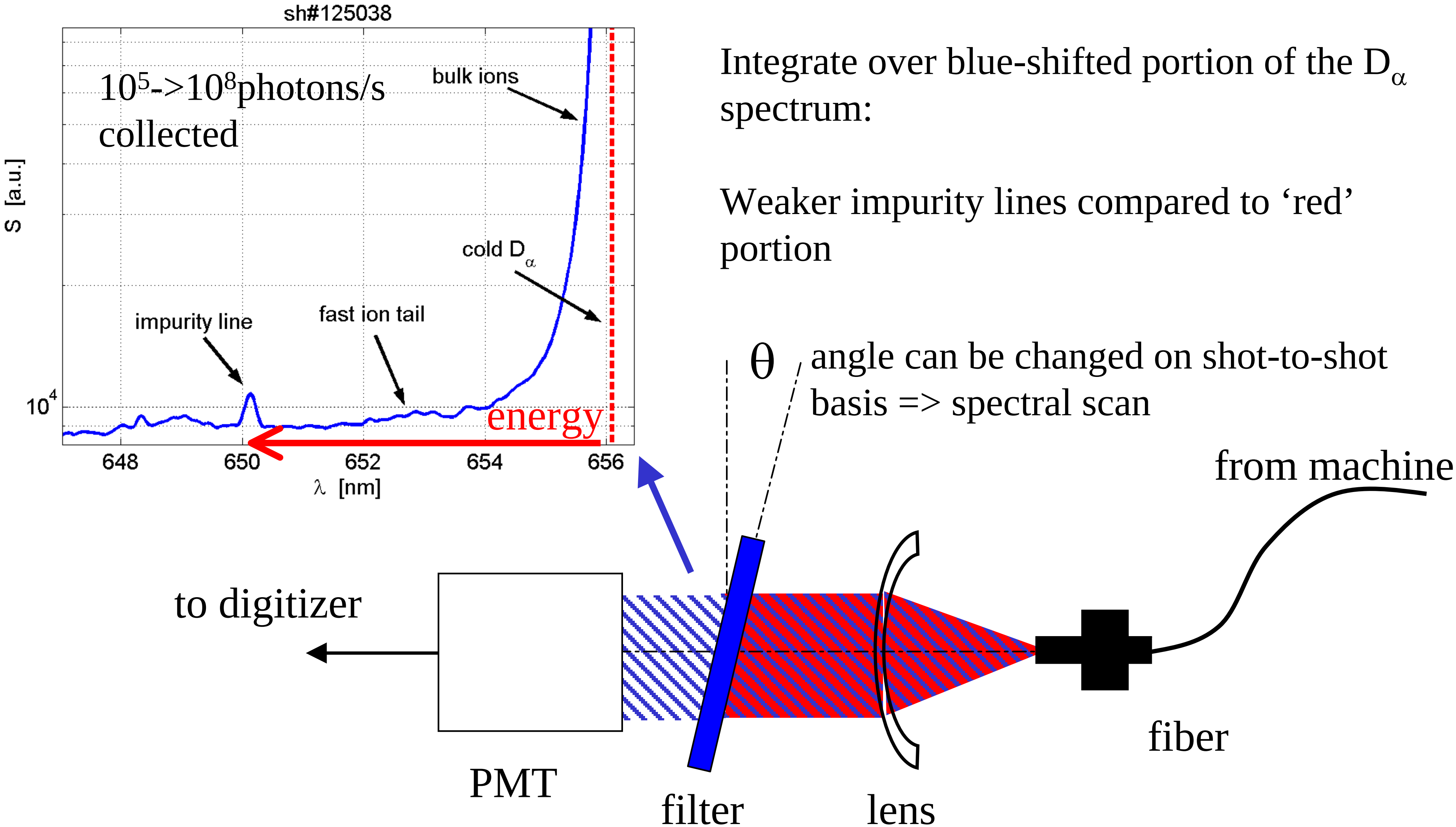
- Up to 6MW of NB power
- Density $<10^{20}m^{-3}$
- Temperature <1.5keV



Poloidal
cross-section

2007 setup : detector

- 2007 run: one prototype channel, integrating over 20 => 80keV range
- Borrowed photomultipliers and digitizer
  - Low quantum efficiency, noisy signals… can do much better in 2008!

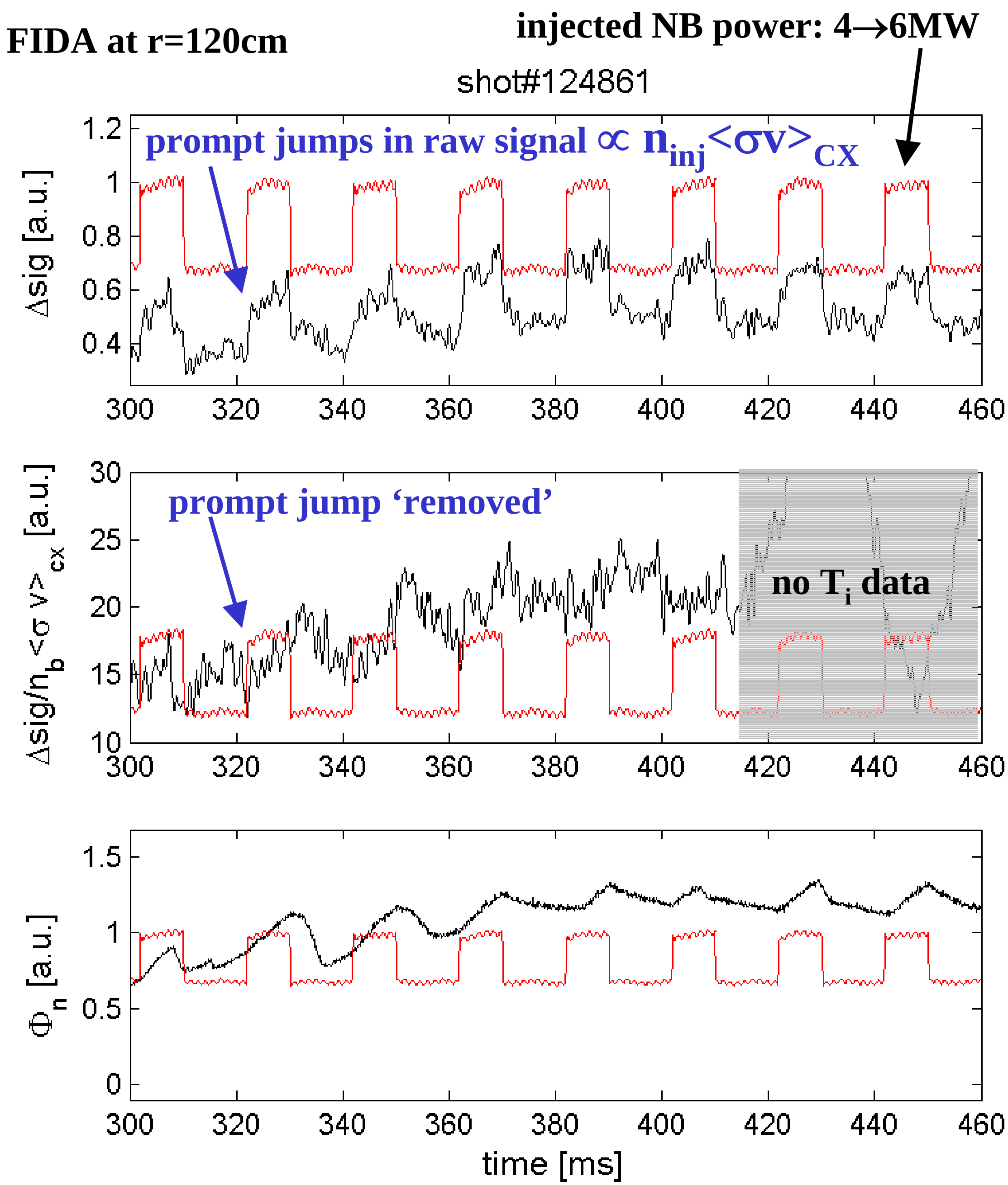


Integrate over blue-shifted portion of the D_α spectrum:

Weaker impurity lines compared to 'red' portion

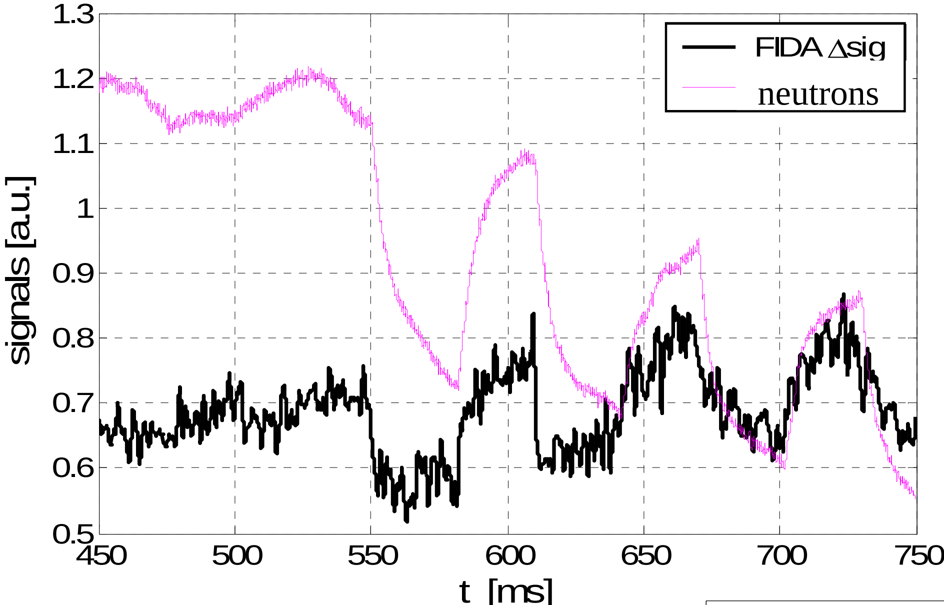
θ angle can be changed on shot-to-shot basis => spectral scan

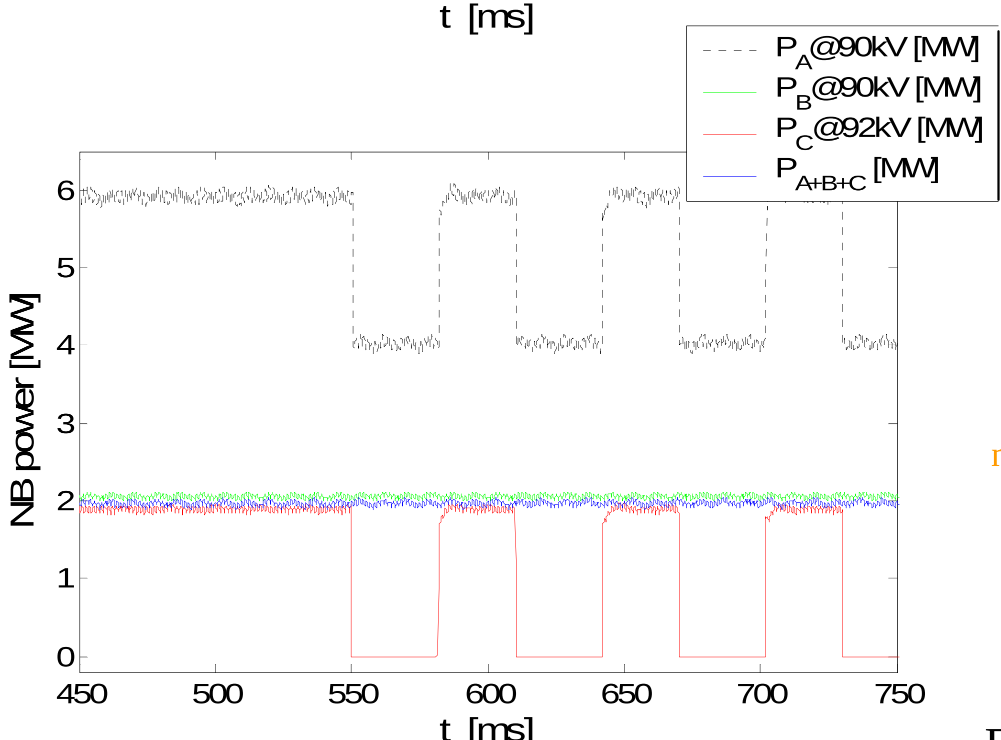
Signals consistent with s(t) ∝ $n_{\text{fast ions}}\, n_b \langle\sigma v\rangle_{CX}$



- Behavior for active/passive views follows expectations
  - n_b from beam attenuation code
  - Charge-exchange cross-section includes T_e, n_e, Z_{eff}, ...
- Clear response to beam modulation
- Signals deteriorate for increasing densities (>10^{20}m^{-3})
  - Consistent with neutron flux
  - Consistent with 1st-order interpretation, neglecting weighting function
  - Need quantitative analysis and comparison with simulations

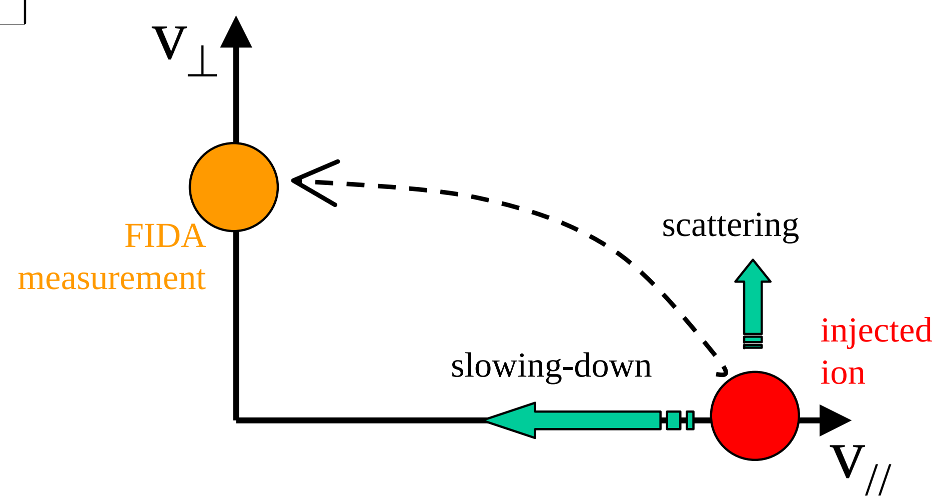
Response to Neutral Beam modulation





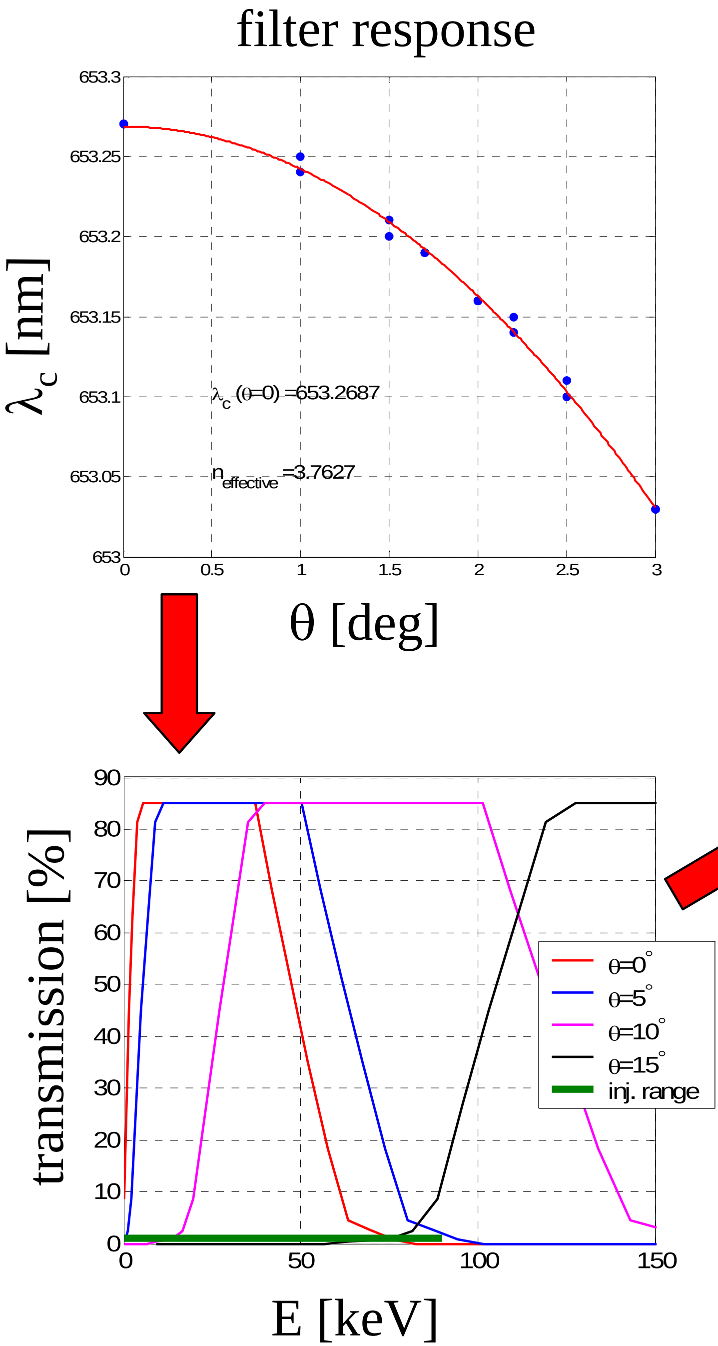
- FIDA signals *vs.* neutron rate
  - Average over 4 ‘identical’ shots

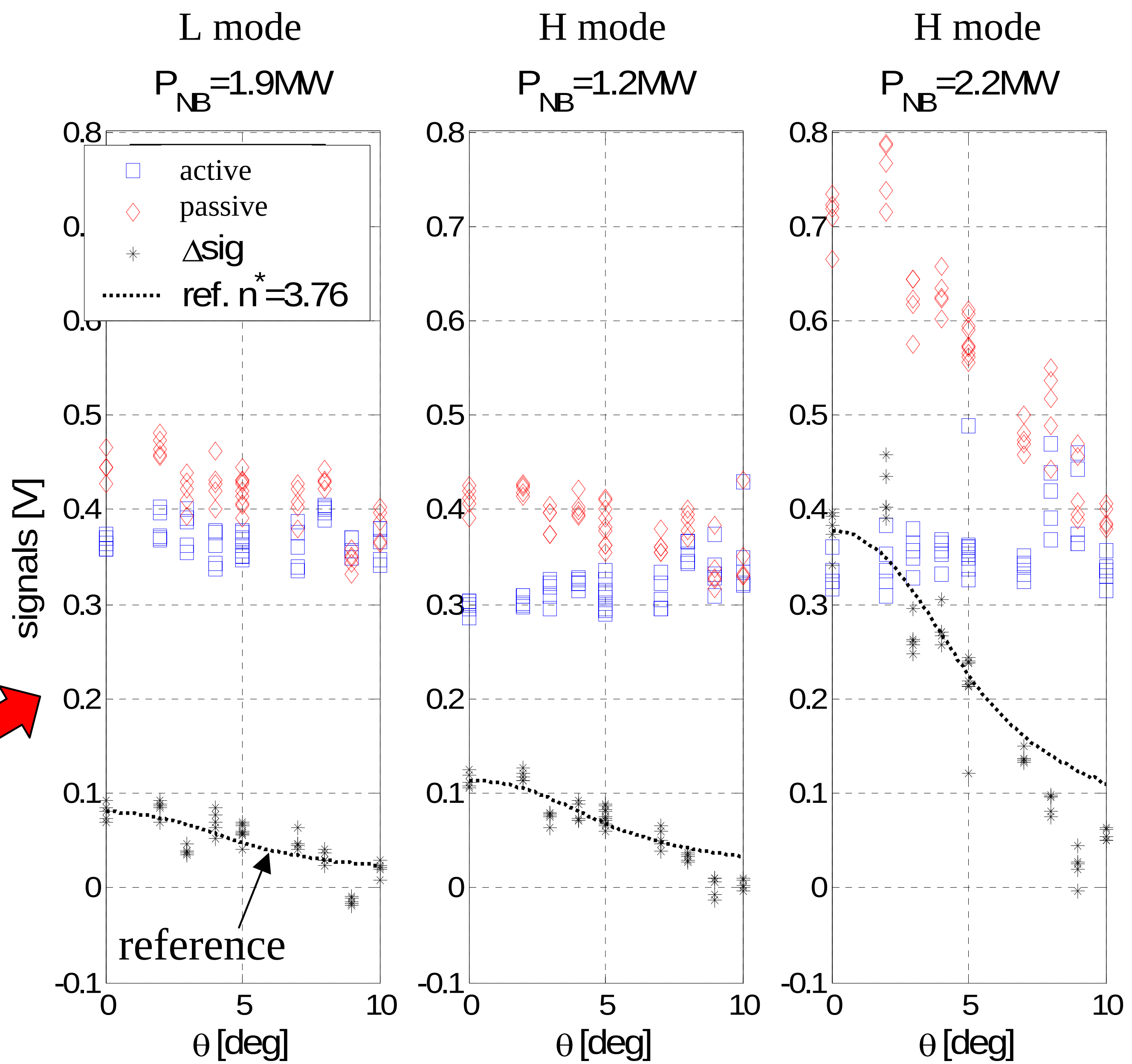
- Clear response to beam modulation
  - Prompt rise/drop, consistent with beam ON/OFF
  - Slower rise/drops on ~10ms time scale (fraction of slowing-down time for beam ions)



Example: Deuterium plasmas, 4-6MW of NB power

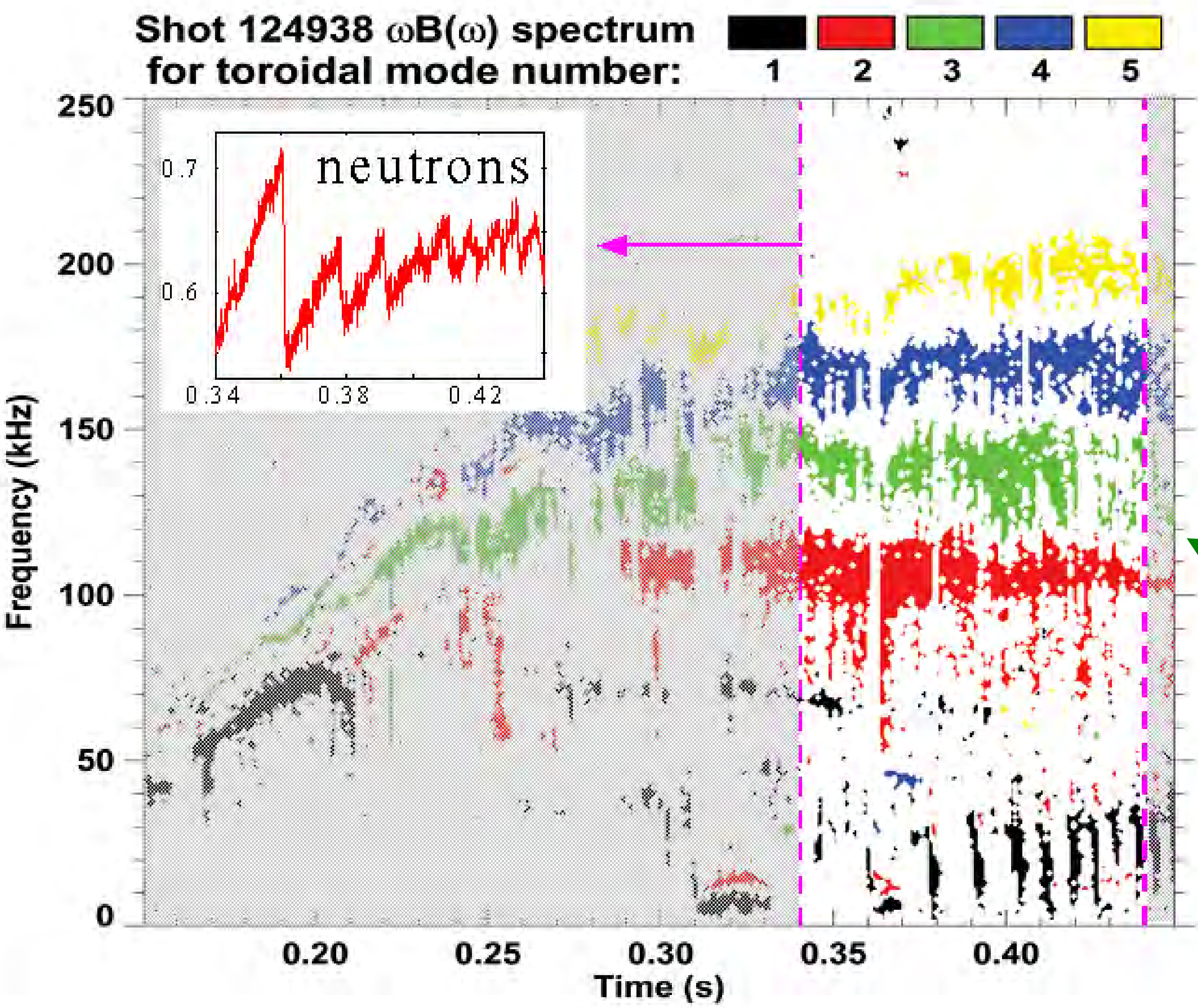
Filter angle scan shows qualitative agreement with expected spectral shape





Fast ion dynamics *vs.* MHD instabilities

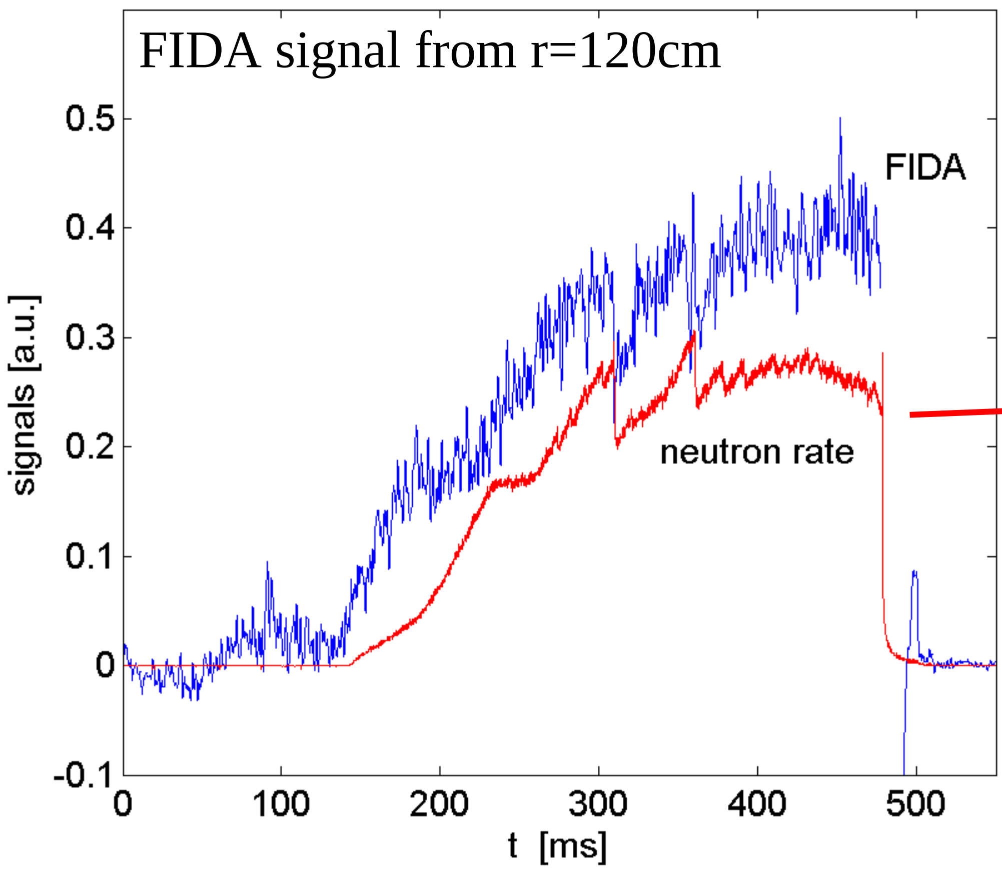
- Effects of instabilities - ***scenario***



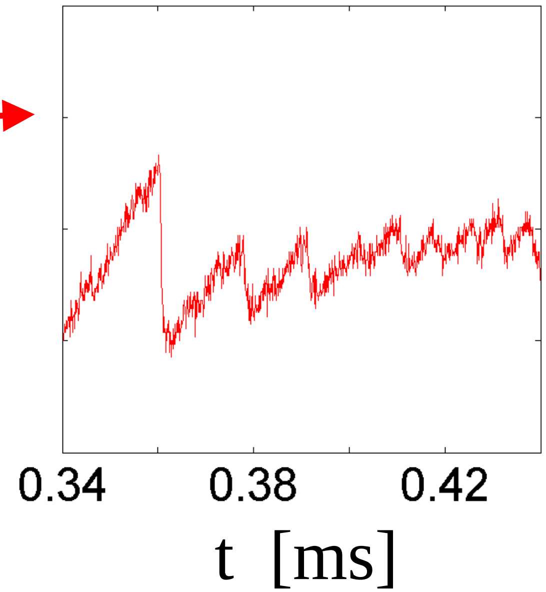
- Helium plasmas
- Low density: $n < 4\text{x}10^{19}\ \text{m}^{-3}$
- One NB source @ 90kV
- Strong Alfvén activity:
  - Alfvén modes – TAE band
  - Fishbone-like modes (bursts)

Fast ion dynamics *vs.* MHD instabilities/2

- FIDA signal consistent with temporal evolution of neutron rate
  - Response to ’catastrophic’ events clearly visible
  - Details on fast time-scales buried into noise
    - Need more careful analysis

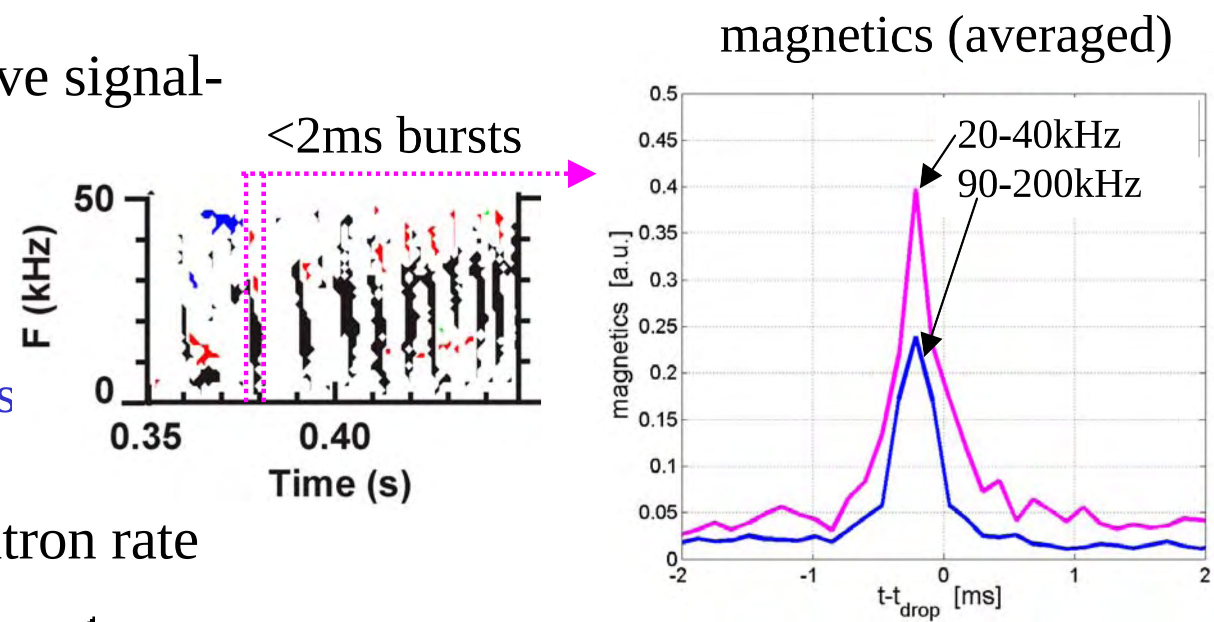


- Frequent drops of neutron rate:
  - Decrease <10%
  - **Losses? Redistribution? Both?**

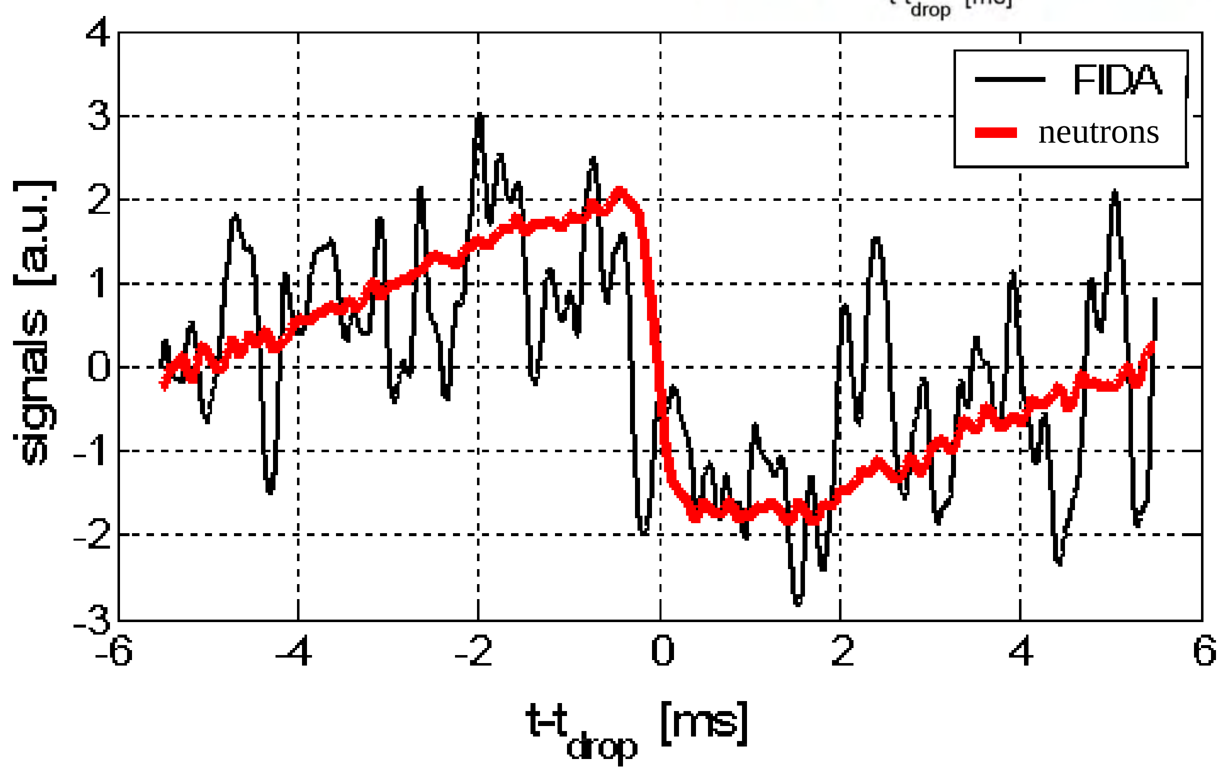


Fast ion dynamics *vs.* MHD instabilities/3

- Use *conditional average* to improve signal-to-noise
  - Neutron rate is “reference”
- Effect of instabilities: ***ion losses***
  - Correlation with enhanced signals magnetic probes



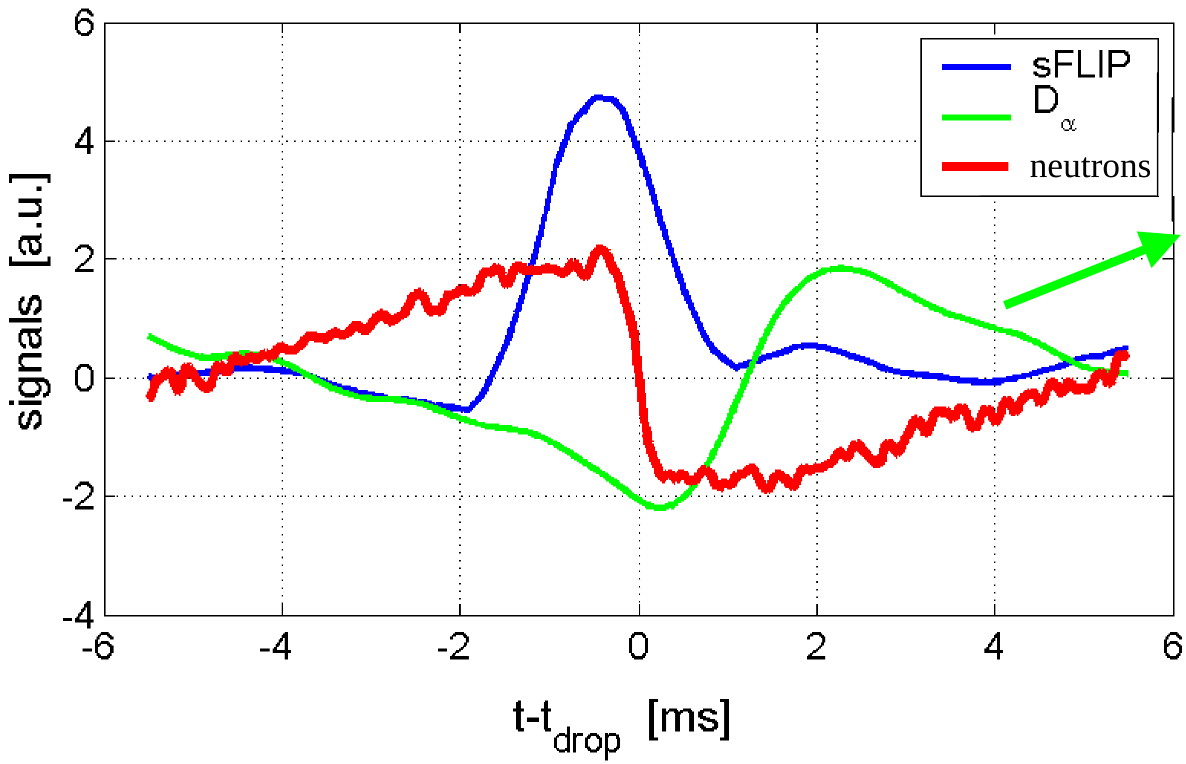
- Excellent correlation between neutron rate and FIDA emerges:
  - Fast ions lost from core plasma on time scales <<1ms
  - Plateau during fishbone-like bursts?



- Example:
  - **Average over 7 shots**
  - ~35 events selected
  - FIDA at r = 120cm

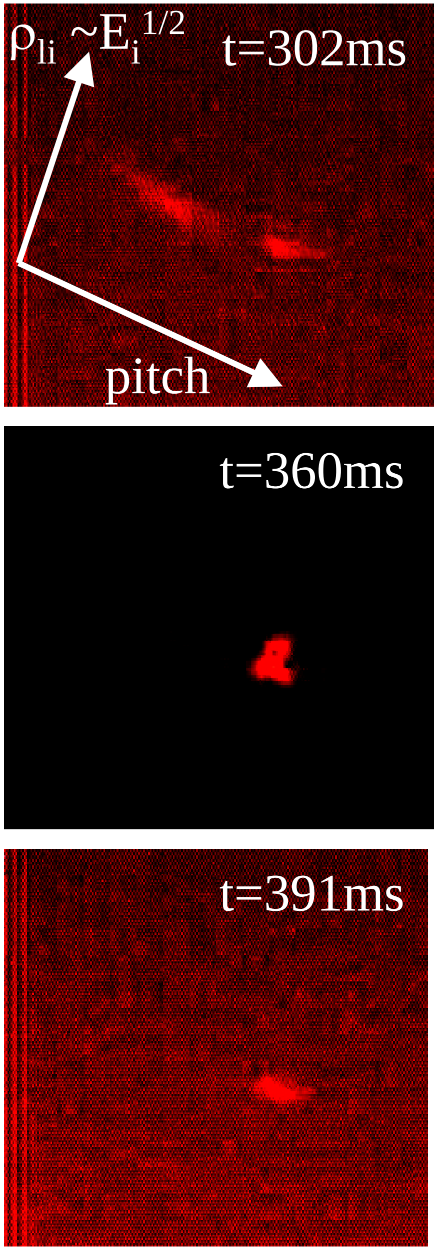
Correlation with sFLIP edge loss diagnostic

- Look at energy-averaged sFLIP signal
  - Measuring fast ion losses at the edge, time resolution: 1ms
- Spikes in sFLIP signals correlate with neutron rate and FIDA signal drops
- Fast ion losses confirmed **(see D.S. Darrow, TP8.82)**
  - High energy ions primarily lost



Cold D_α from edge undergoes oscillation during fast ion bursts

- Interpretation?



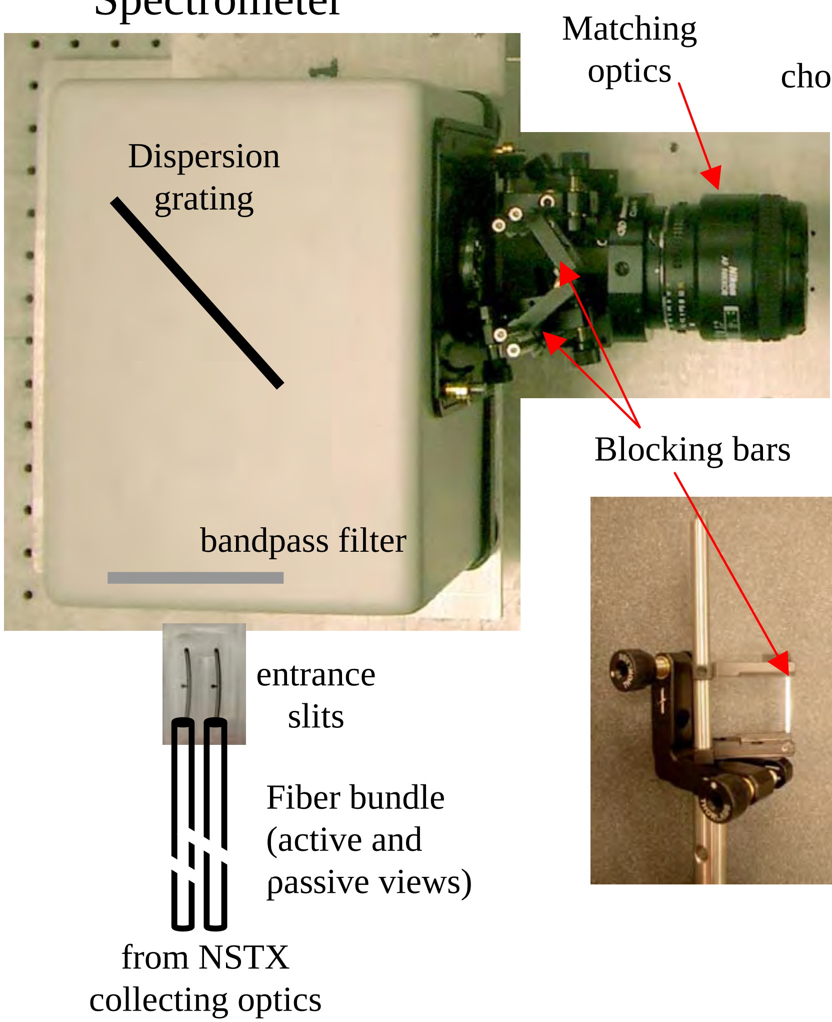
2008 setup: spectrometer

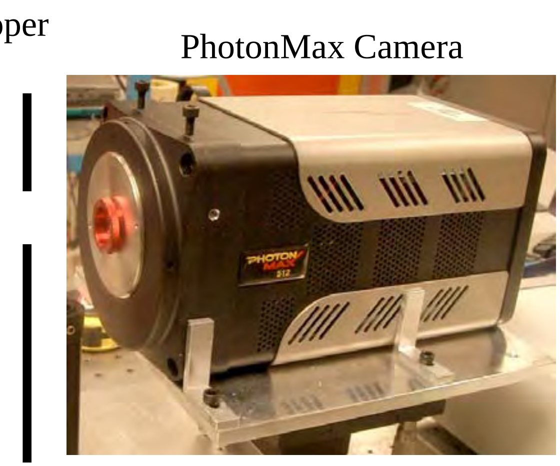
- 2x16 channels (active and passive views)
  - CCD detector
  - Block cold D_{α}, measure red/blue-shifted wings

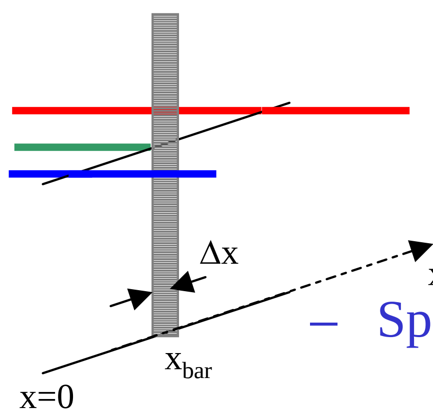
Resolution:

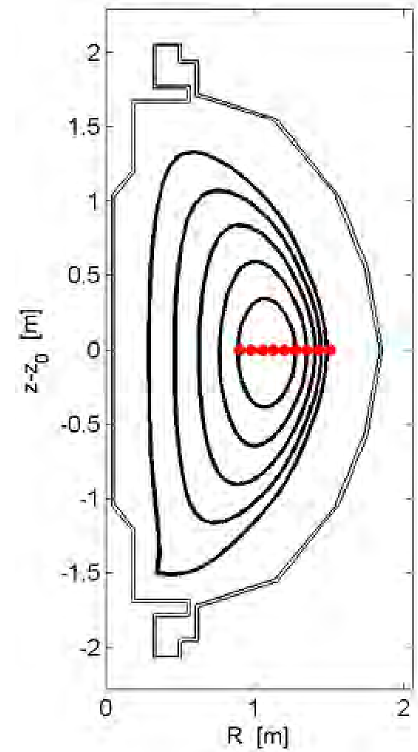
10keV, 5cm, >5ms

Spectrometer









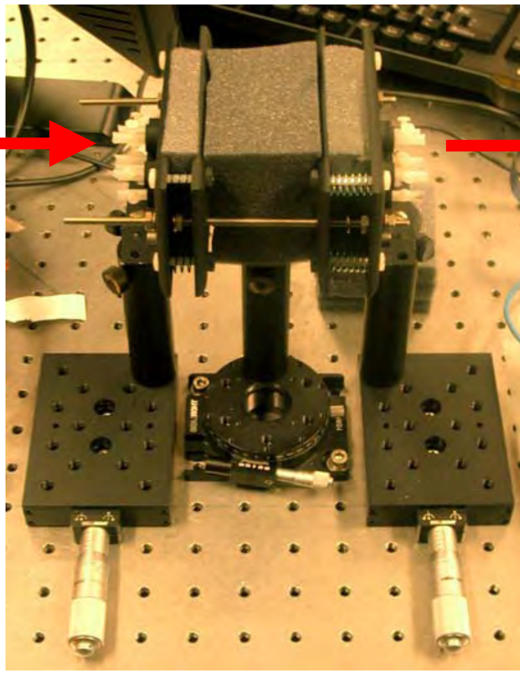
- Spatial calibration done
- Spectrometer delivered December 2007, all other parts already received
- Final assembly, alignment and spectral calibration expected before end of December

2008 setup/2: 'fast' system

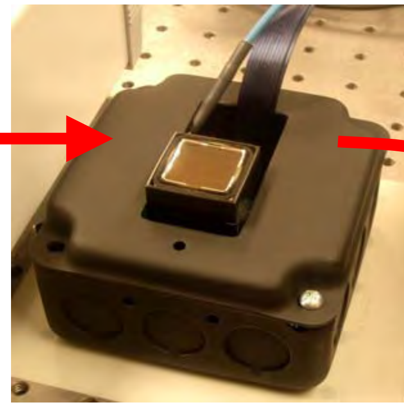
- 2x3 channels (active and passive views)
  - PMT detector, expected bandwidth ≥ 20kHz

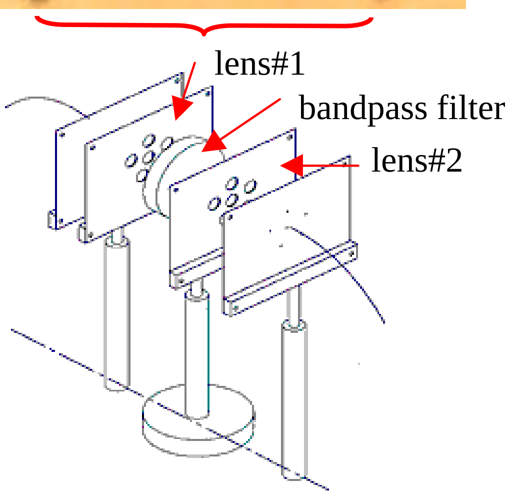
Resolution:
- Energy-integrated
- Measure at 100, 120, 140cm
- Time <1ms

Optics + bandpass filter

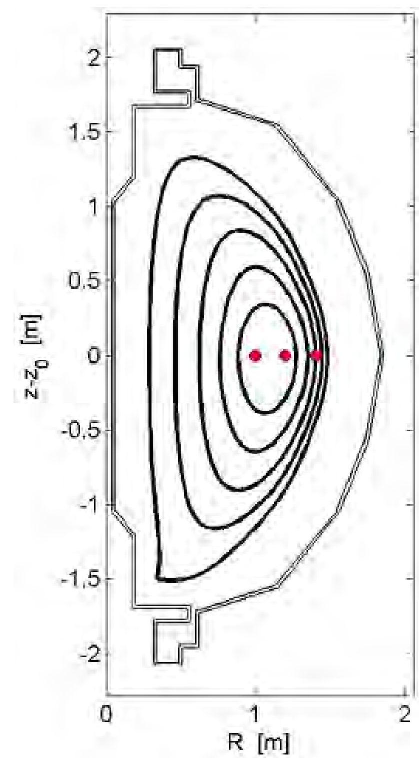


Detector





Acquisition and control PC



- Spatial calibration done
- Final assembly and alignment in progress

Summary

- First results from 2007 prototype setup encouraging
  - Fast ion signals measured on NSTX
  - Good consistency with other diagnostics (neutron rate, cold D_α emission, sFLIP, …)
    - Background subtraction based on active/passive views works
  - Correlation between fast ion dynamics and MHD instabilities observed => evidence for fast ion losses from the core
- Installing complete FIDA setup for 2008 Run
  - Two complementary instruments:
    - Spectrometer: high spatial resolution, energy and time resolved
    - ‘Fast’ system: three radial position, energy-integrated, high temporal resolution <1ms
    - Spatial calibration done, spectral calibration under way

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