First results from a 4-channel charged fusion

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Content

- Introduction
- Principle of diagnostic
- 4-channel design and installation
- Data analysis
- First results
- Installation in NSTX-U
- Future: 16-channel instrument
- Summary

Introduction

- Determine the time dependent fusion rate profile
- Check of TRANSP simulations
- Study MHD instabilities: TAE, NTM, EPM, IRE
- Study effect of instabilities on fast ion redistribution and loss
- Probed ion distribution function weighted toward high energies, complements FIDA and ssNPA
- Expected to work well at high densities
- Cross check to total neutron rate measurements

Principle

Detect charged particles from:

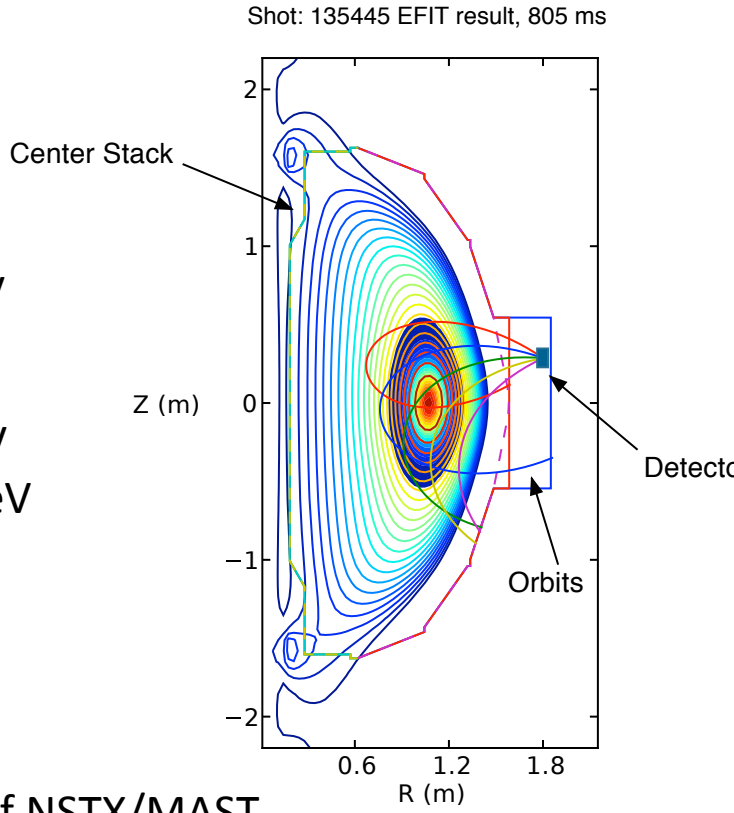
$$d + d \rightarrow p + {}^3H$$

T_p = 3.02 MeV
T_T = 1.01 MeV

$$d + d \rightarrow n + {}^3He$$

T_n = 2.45 MeV
T_{3He} = 0.82 MeV

dominated by neutral beam and plasma ion interactions



Advantage at NSTX and MAST:

- Proton/triton is not confined in the magnetic field of NSTX/MAST
- Proton/triton is quickly lost
- Trajectory similar to a view chord of neutral particle detection system
- observed particle rate is a measure of the integrated emissivity along the trajectory path

Proton measurements have been carried out previously:

• W.W.Heidbrink, J.D.Strachan, Rev. Sci. Instrum, **56**, 501 (1985)
•J.D. Strachan, Rev. Sci. Instrum., **57**, 1771 (1986)

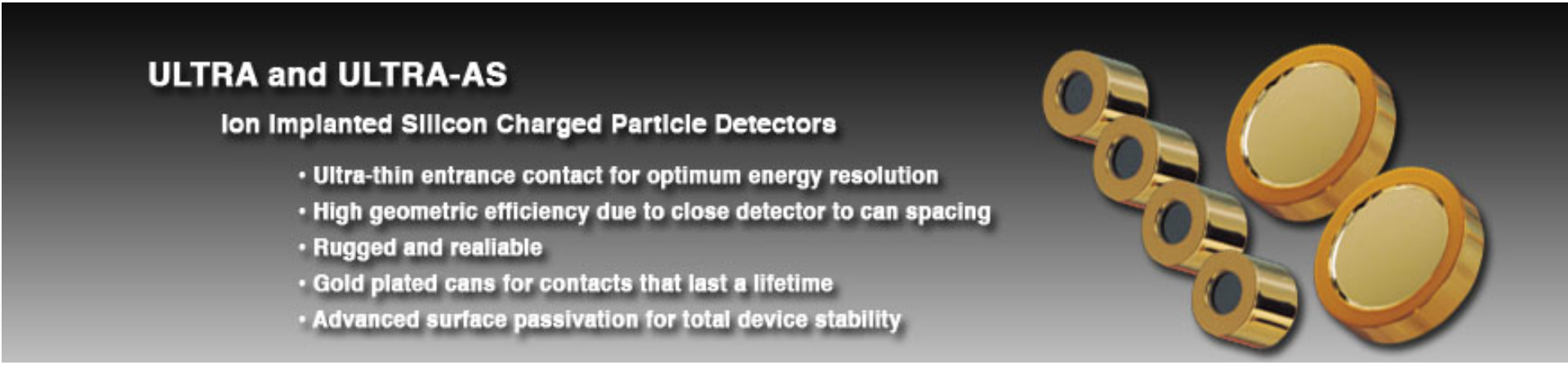
Particle Types:

- Protons
  - Highest energy (3MeV, p = 75 MeV/c, q = 1)
  - Easy to detector with surface barrier detectors
  - 100% efficient
  - Future: diamond detectors (less sensitive to radiation damage)
- Tritons:
  - Same orbit as protons (1 MeV, p = 75 MeV/c, q = 1)
  - More sensitive to electrical noise
  - Provide more statistics
- ^{3}He:
  - Lowest energy (0.82 MeV, p = 67.9 MeV/c, q = 2)
  - Different orbits than tritons and protons
  - Provide additional orbit data

Focus on protons

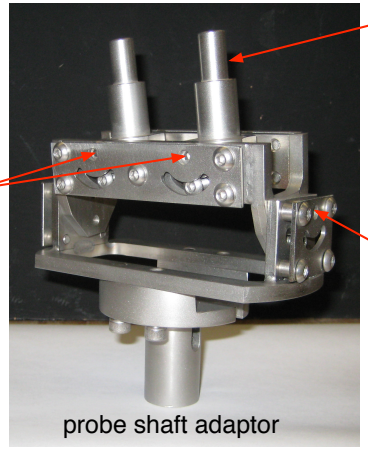
Surface Barrier Detectors

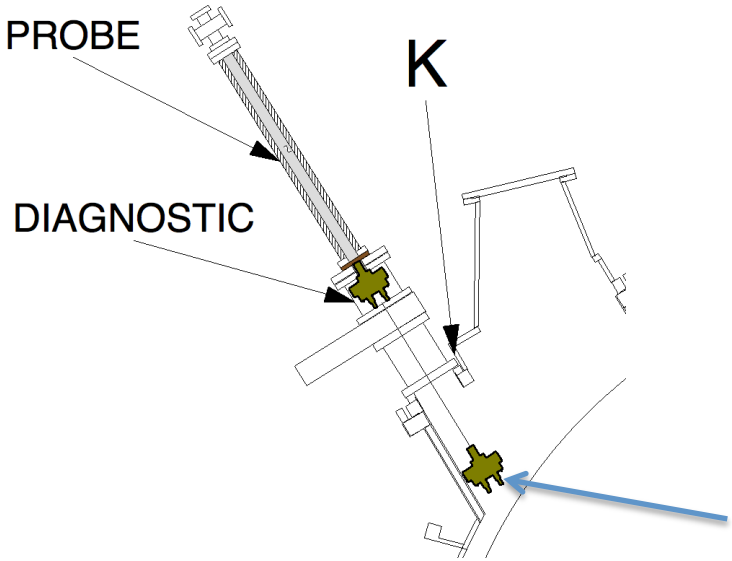
- Commercially available Ortec/Canberra
- Bakeable (up to 200 C)
- Can be operated in UHV
- Have been used previously
- Good energy resolution (1%)



Detectors used : CU-014-050-100-S ULTRA by AMETEK/ORTEC

Original Prototype

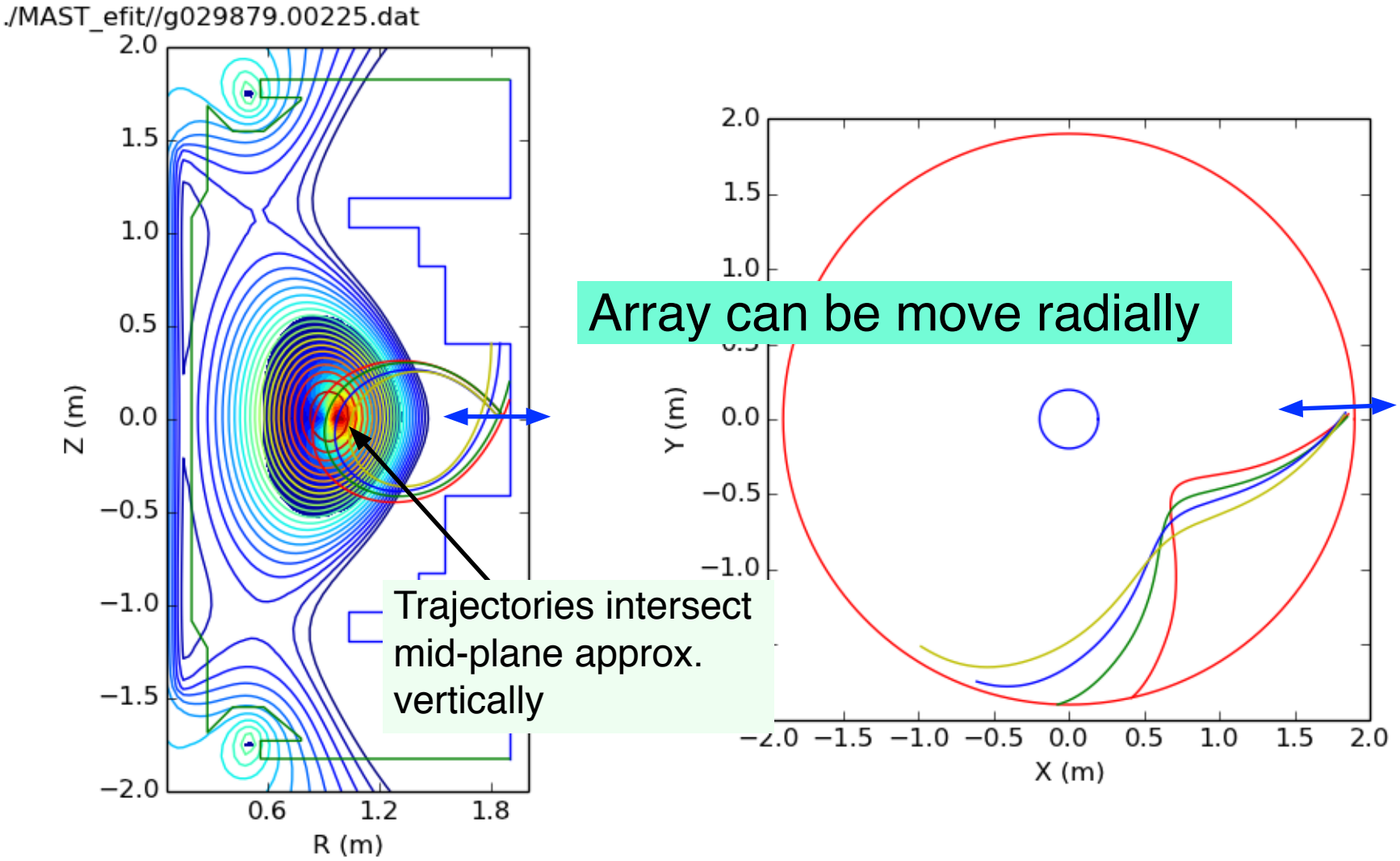




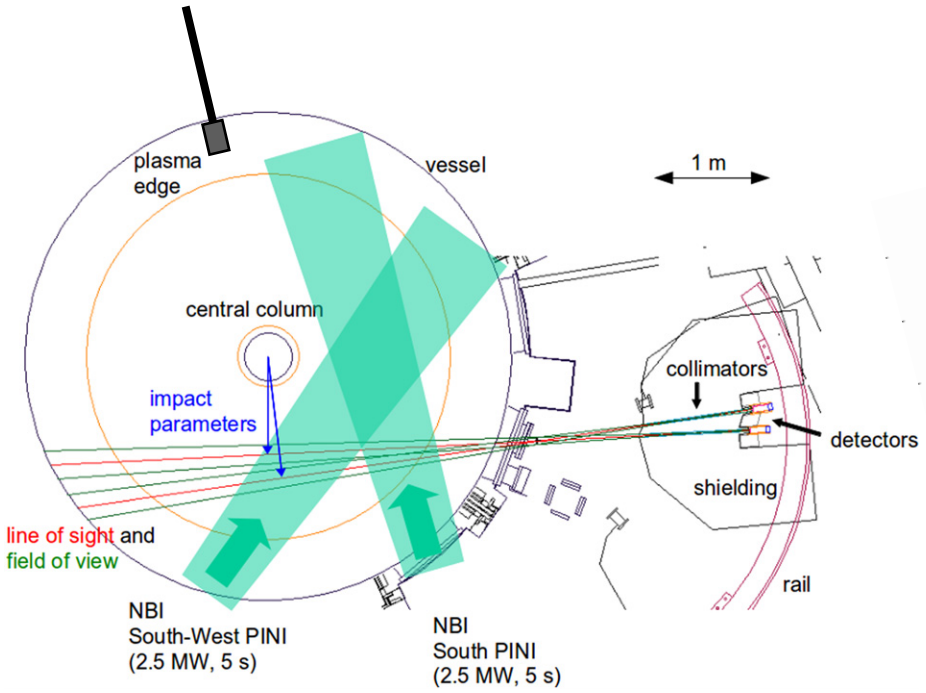
- Prototype: 2 detectors
- Flexible orientation around 3 axes
- Study signals and rates
- Optimize detector arrangement and location for full array of 8 detectors
- Location: Bay K
- Mounted on moveable probe shaft
- IN-position: R=1.7m, Z = 0.286m

Could not be tested

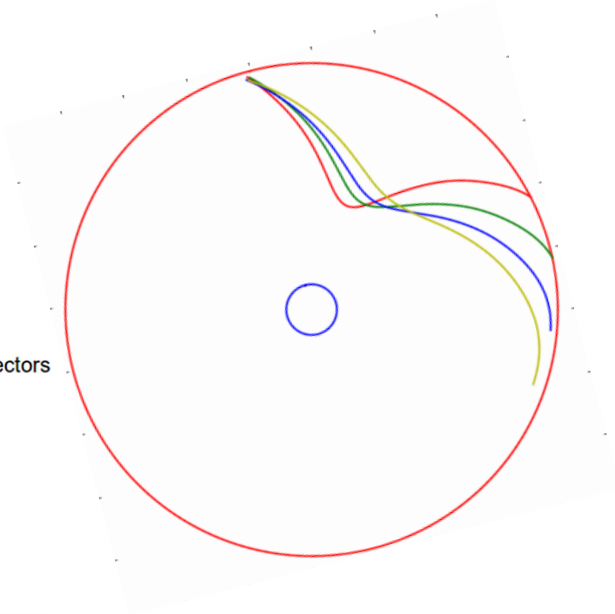
MAST Design


./MAST_efit//g029879.00225.dat
Z (m)
R (m)
Y (m)
X (m)
Array can be move radially
Trajectories intersect mid-plane approx. vertically

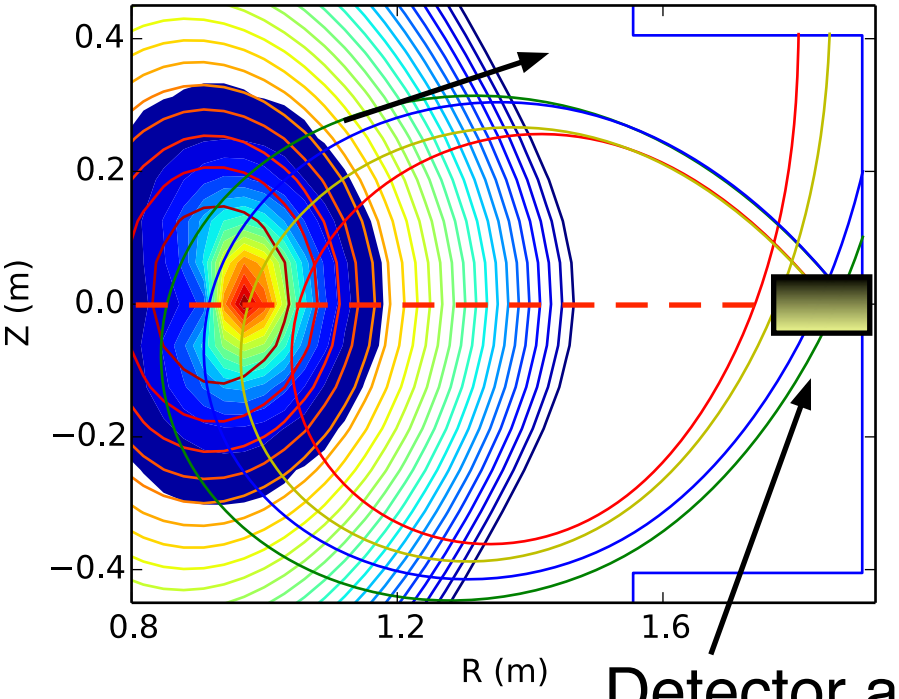
Approx. location of probe arm



Central Orbits



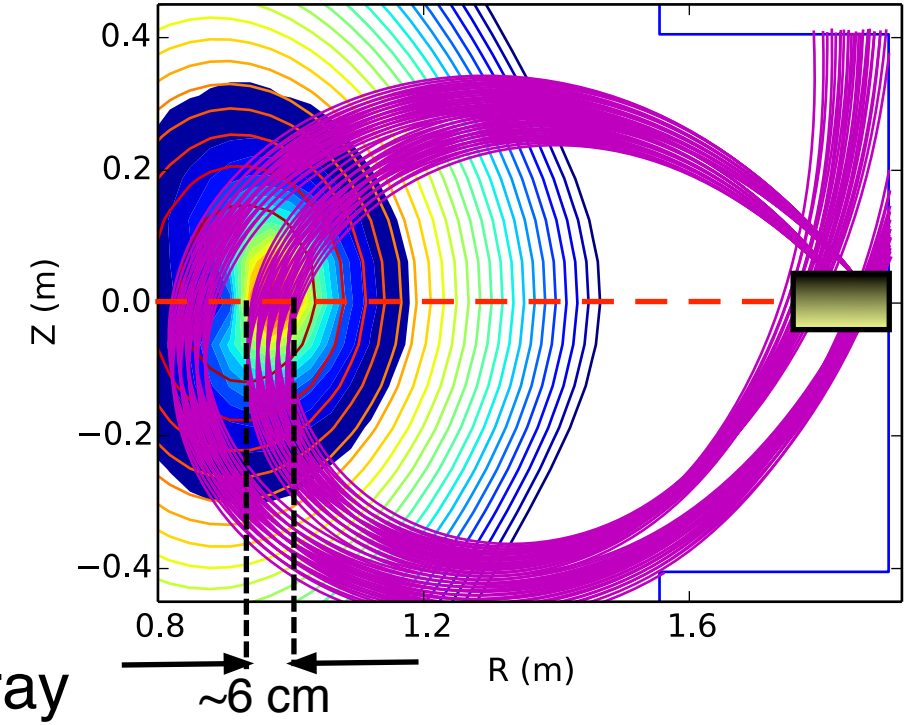
Acceptance: Poloidal



Detector array

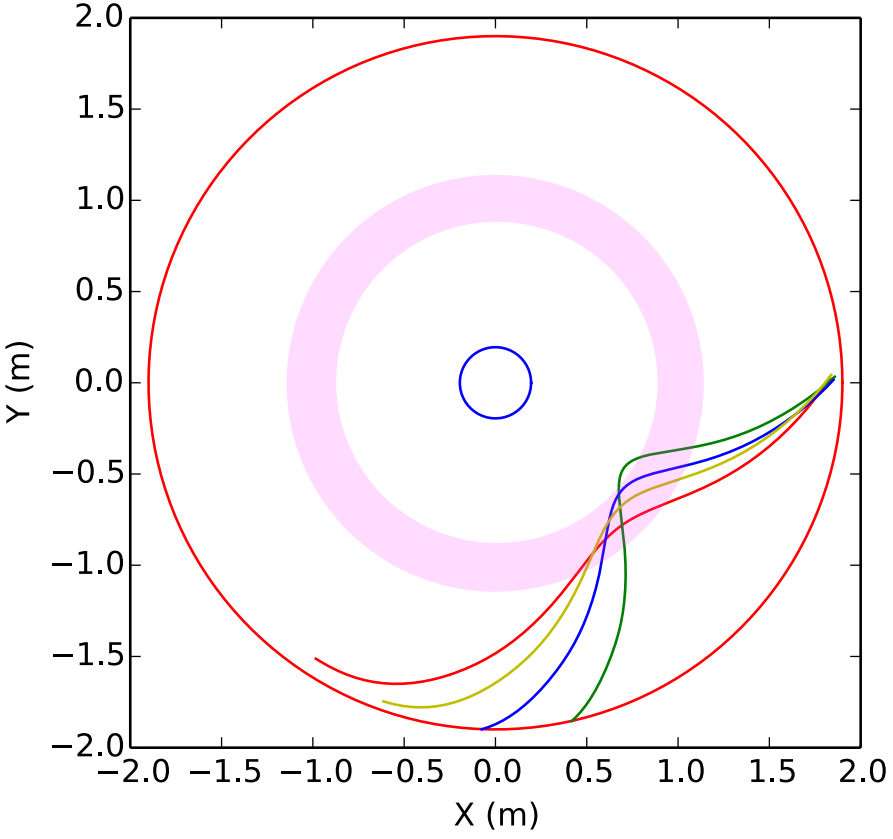
Central orbits

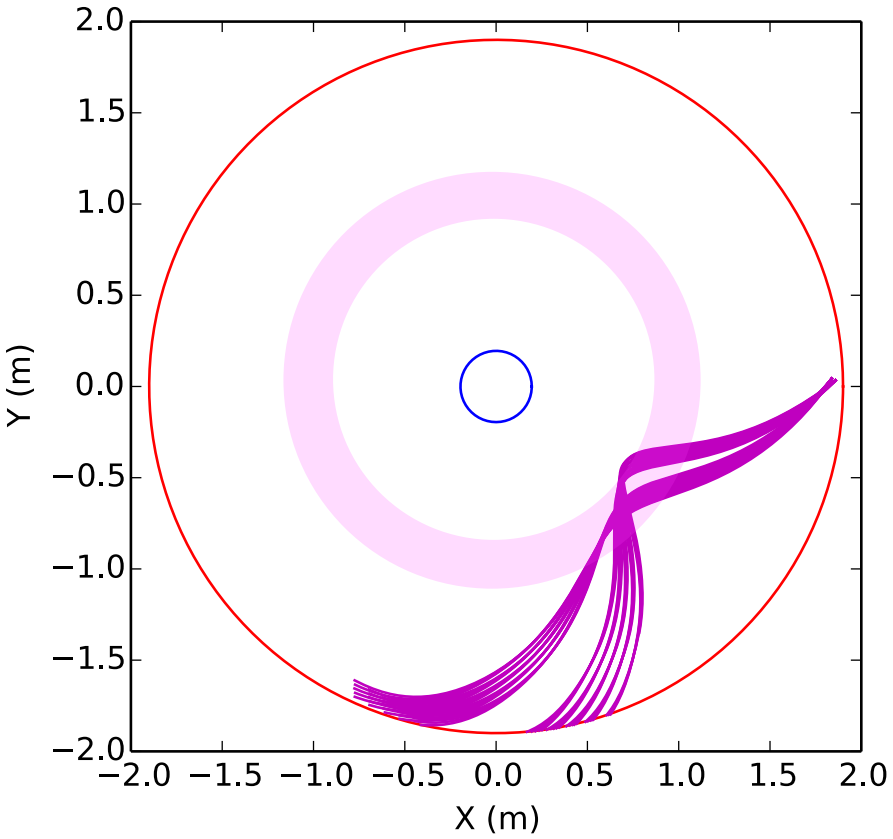
Radial Positions: +/- 3cm



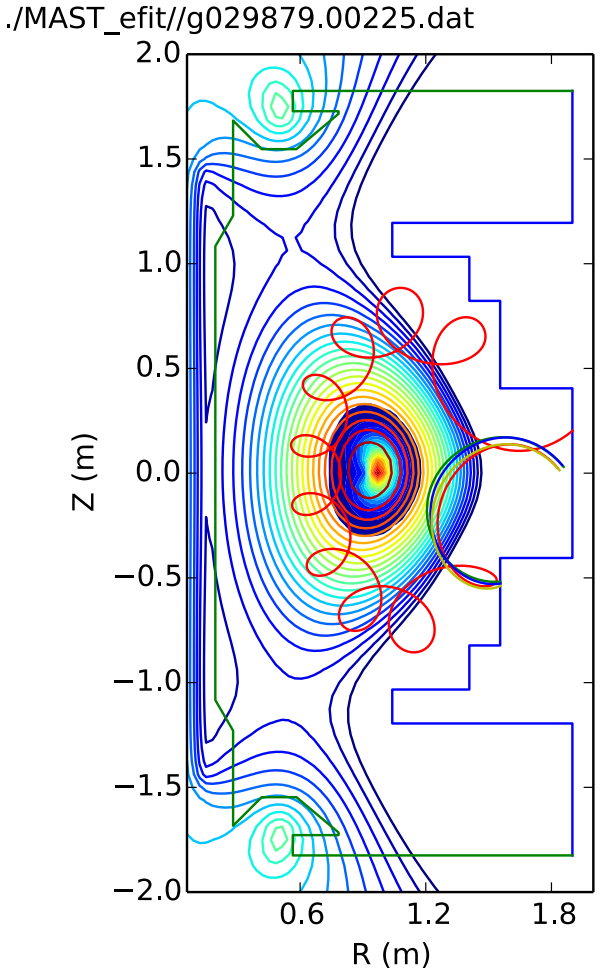
Integration region (not weighted by acceptance)

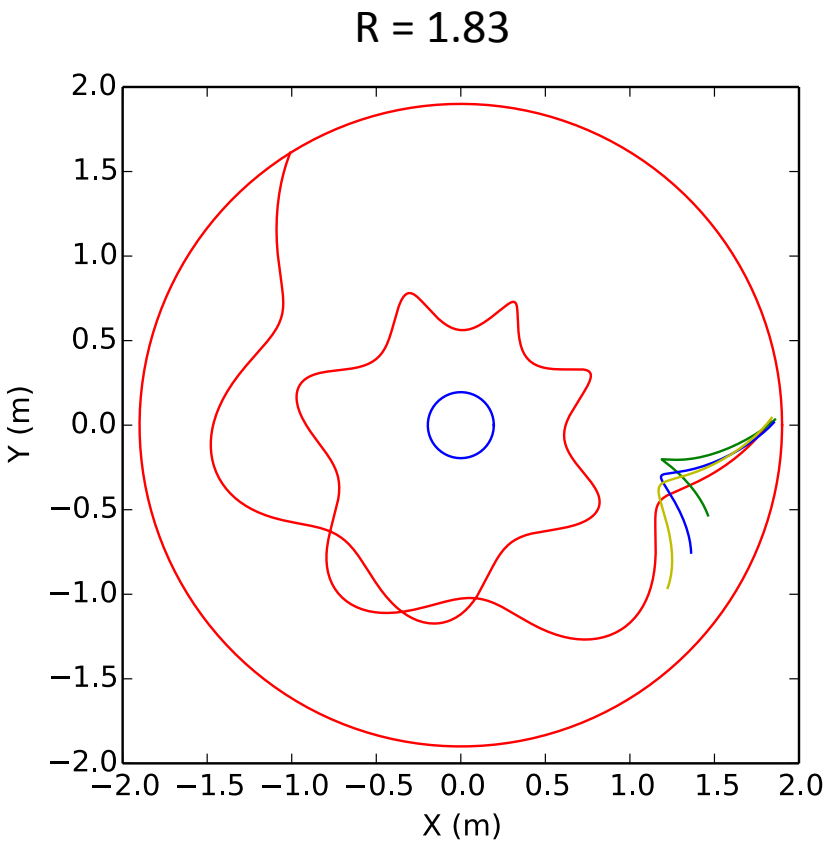
Acceptance: Toroidal View



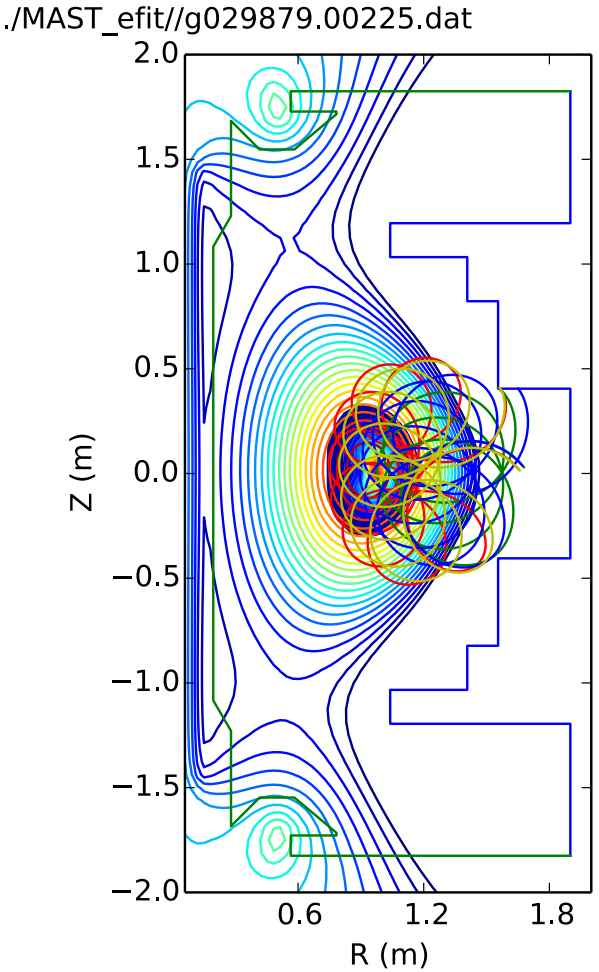


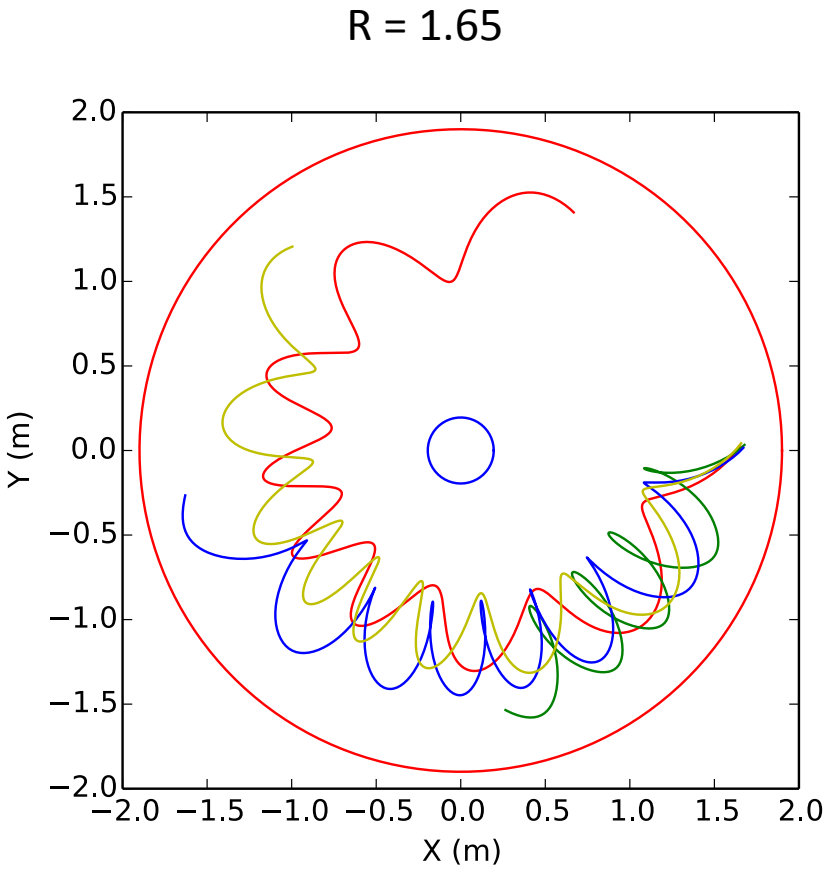
^{3}He Orbits





very small ^{3}He rate

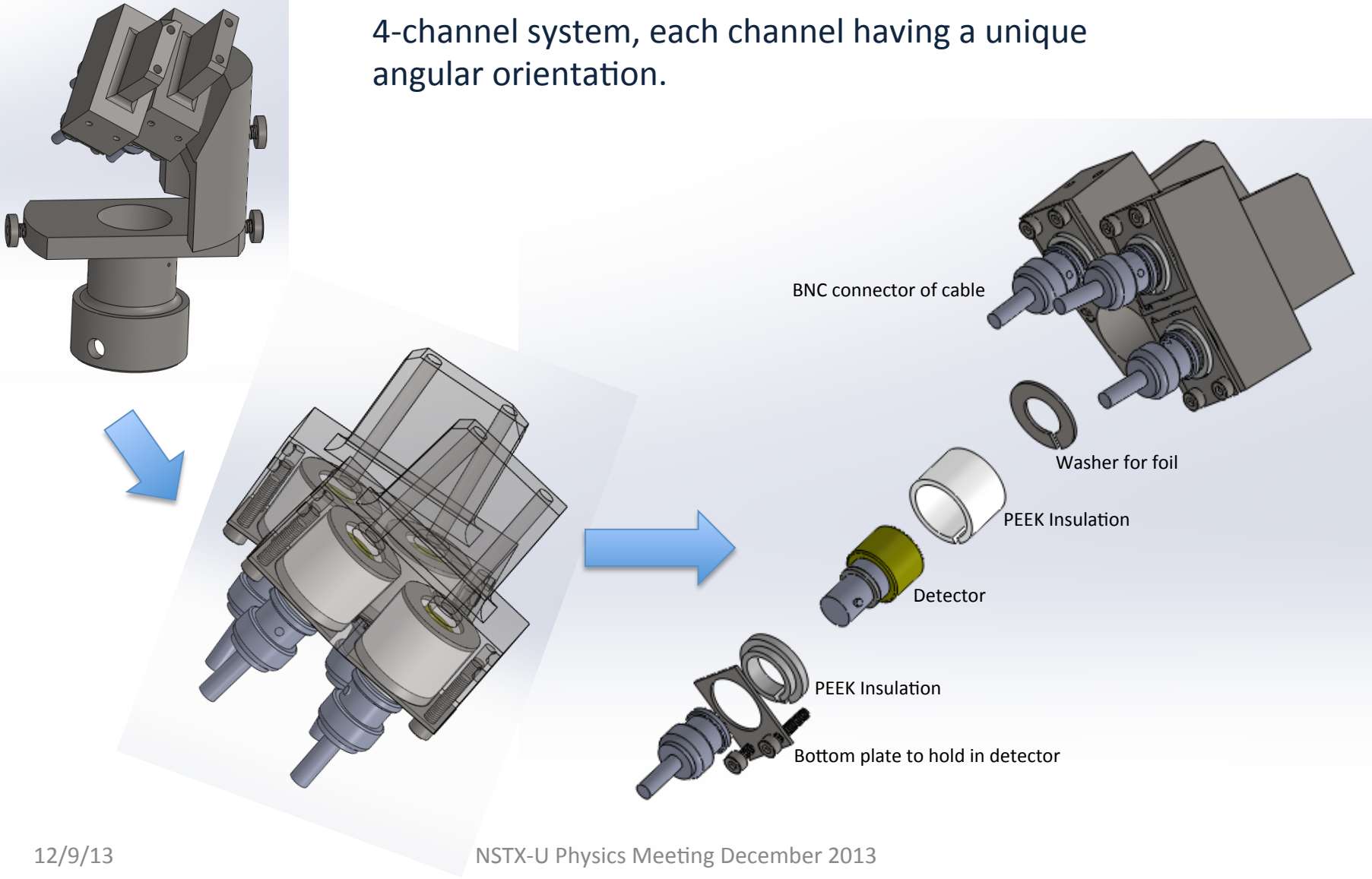




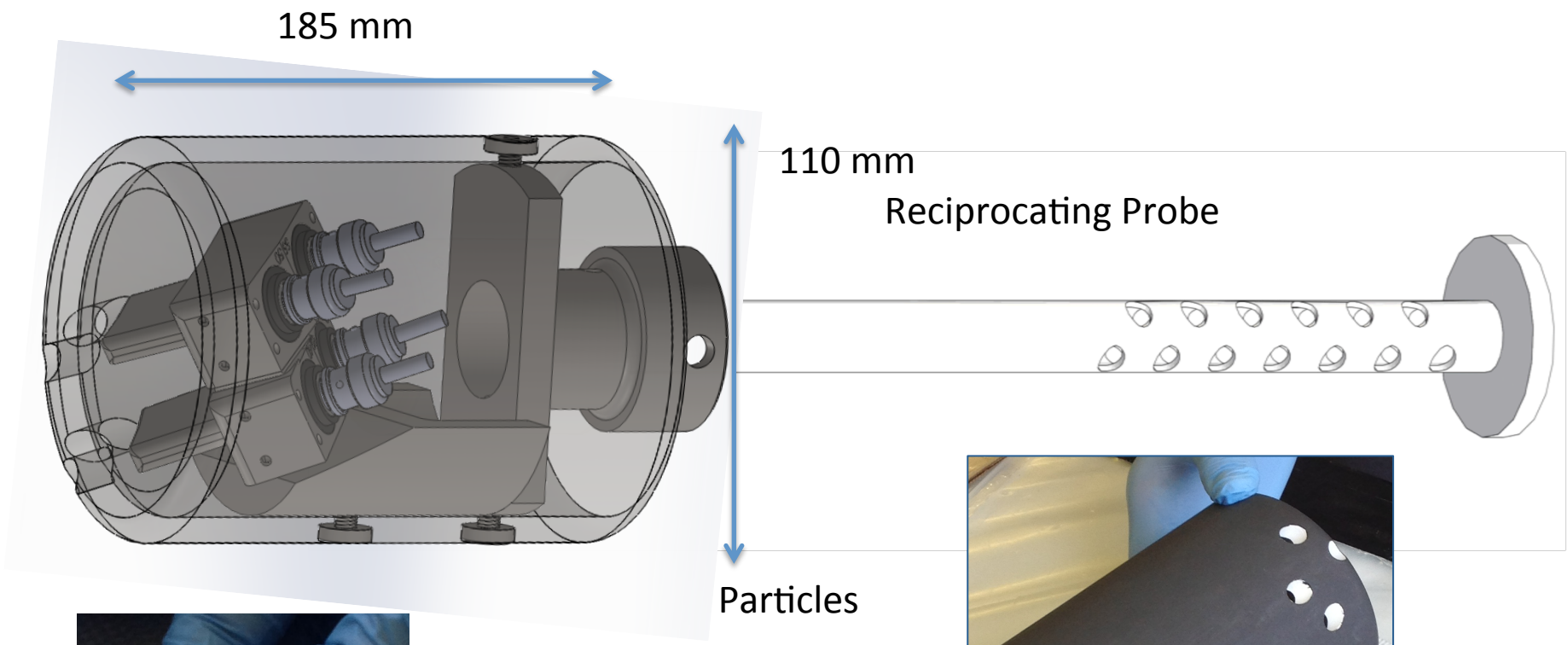
^{3}He rate about 3 – 10 times higher than proton/triton rate

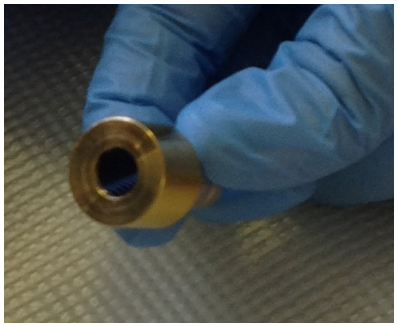
Proton Detector (PD)

4-channel system, each channel having a unique angular orientation.

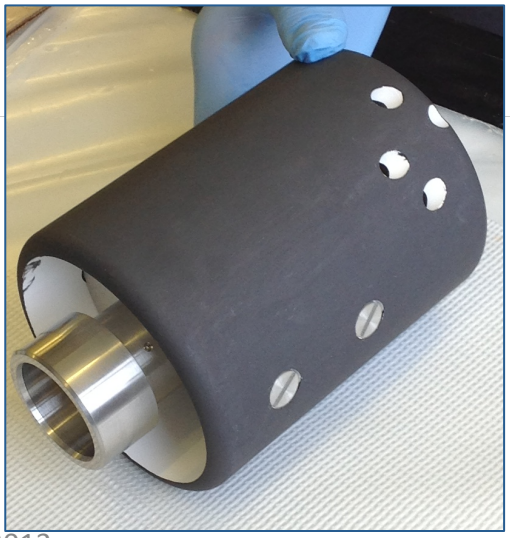


PD Assembly



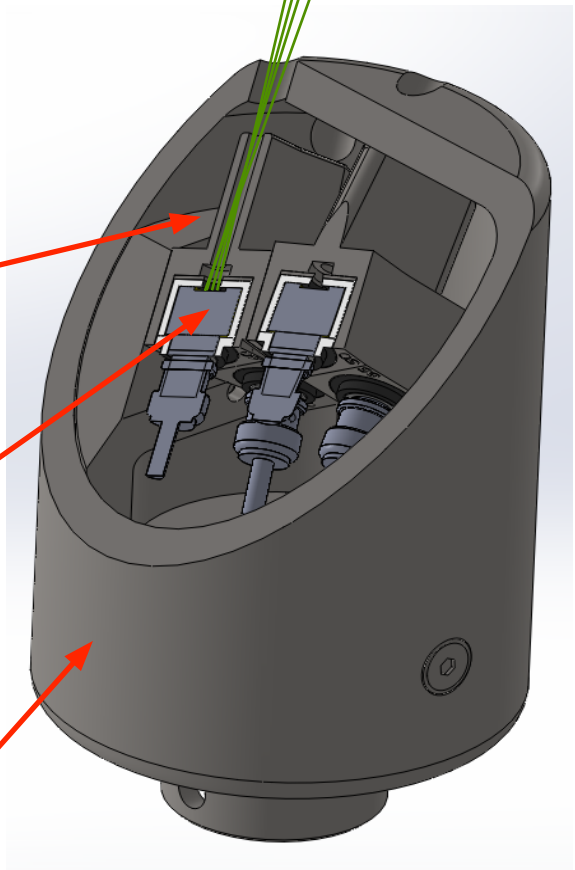


Detector with BN shield on



Cross-Sectional View

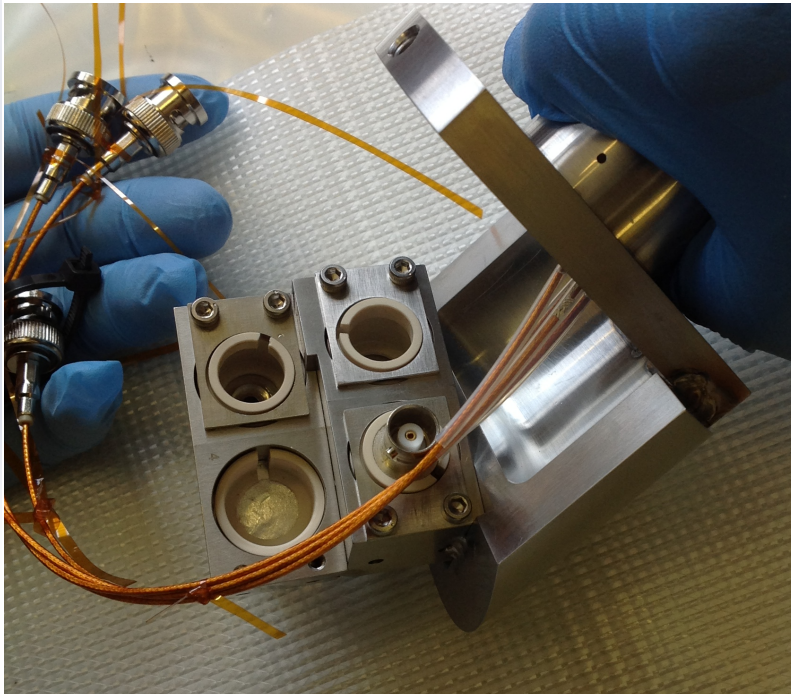
Particle trajectories

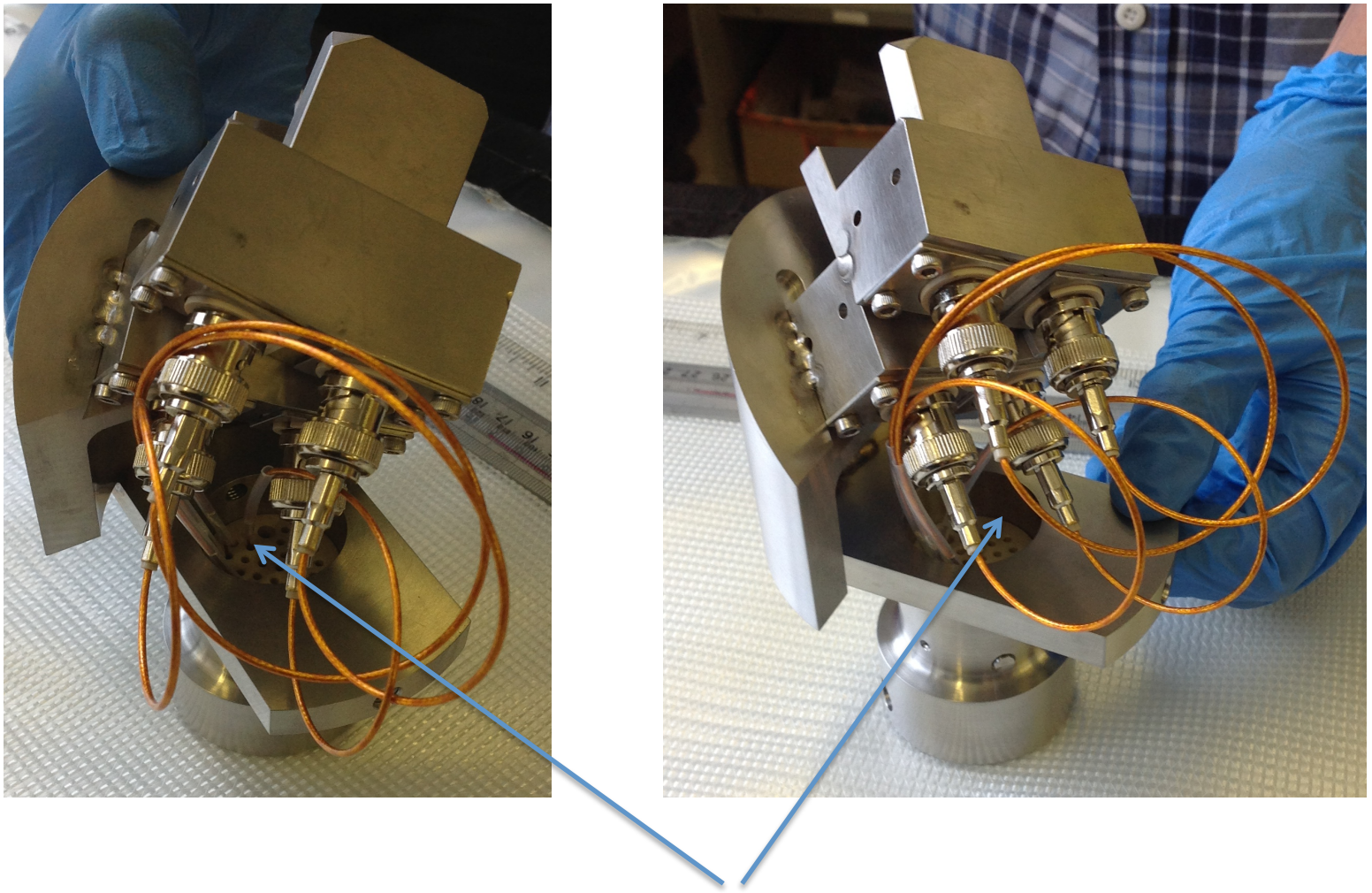


Collimator

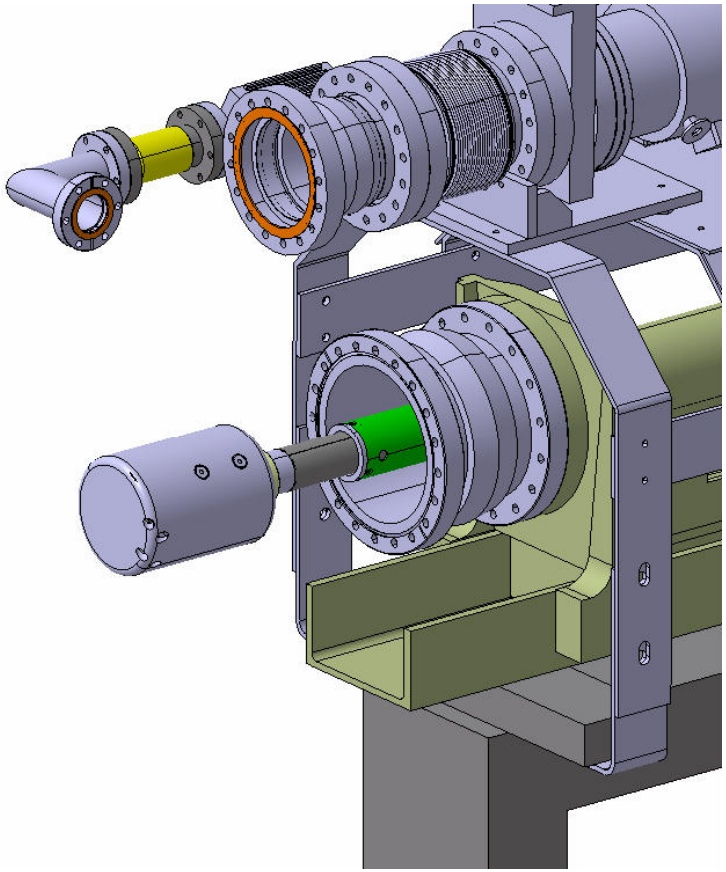
SSB detector

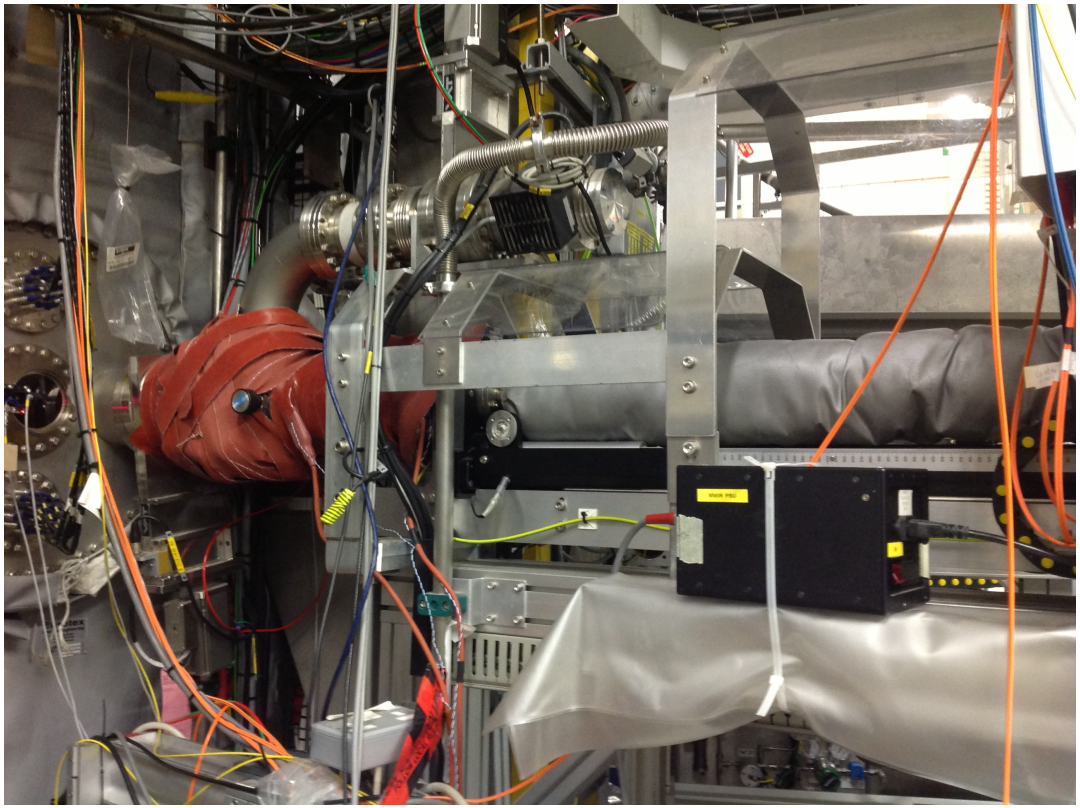
BN heat shield



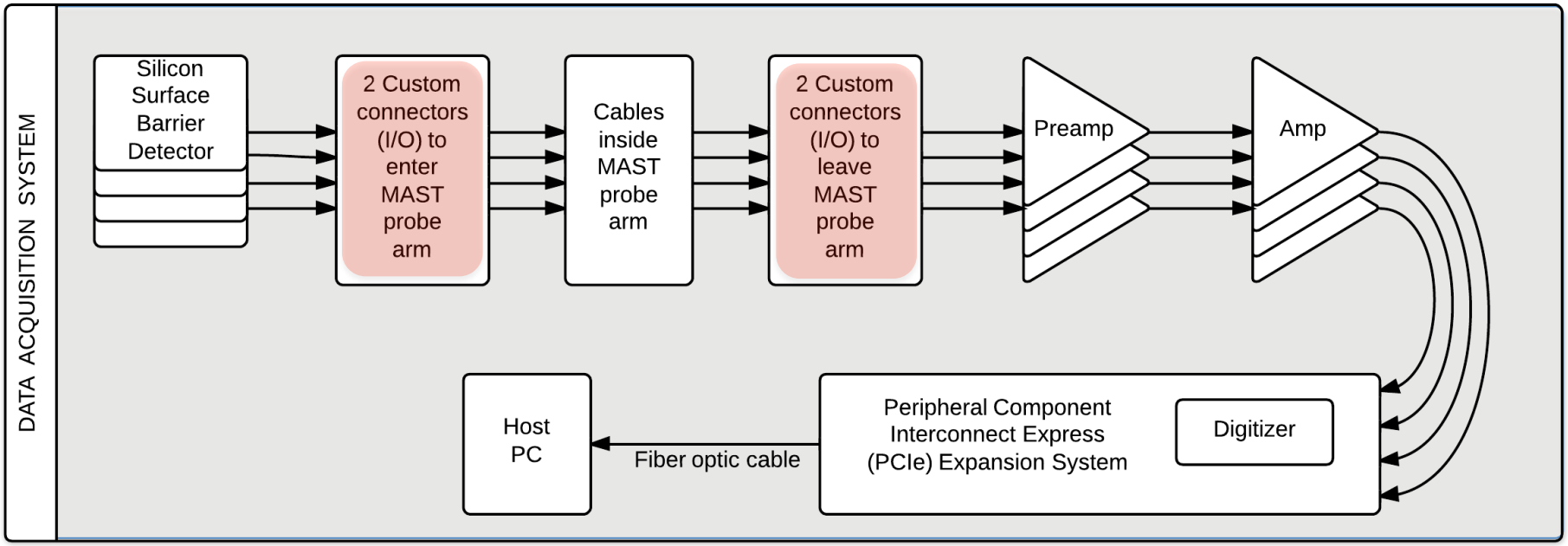


multi-pin probe head connector



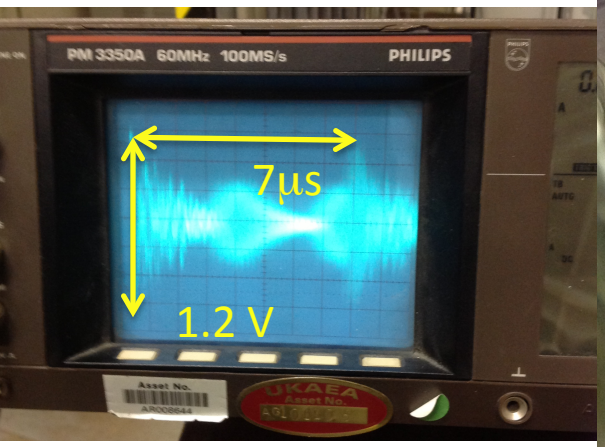


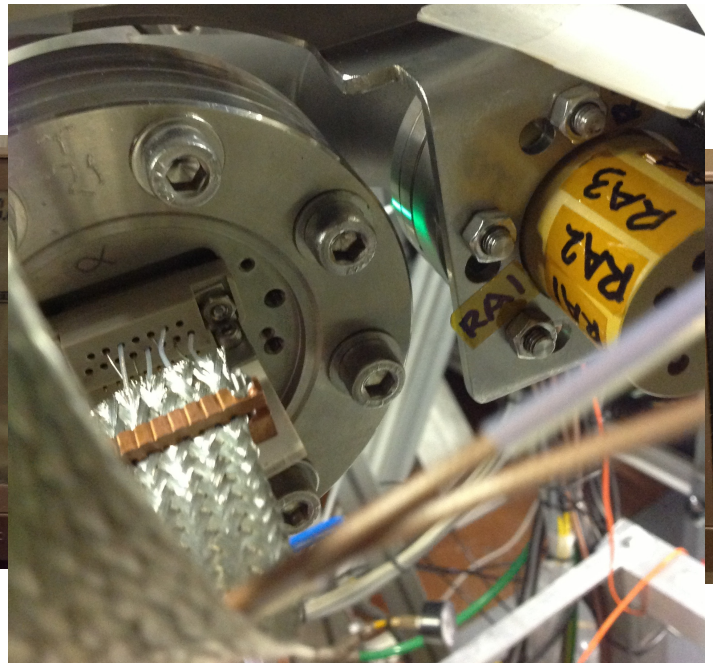
Data Acquisition

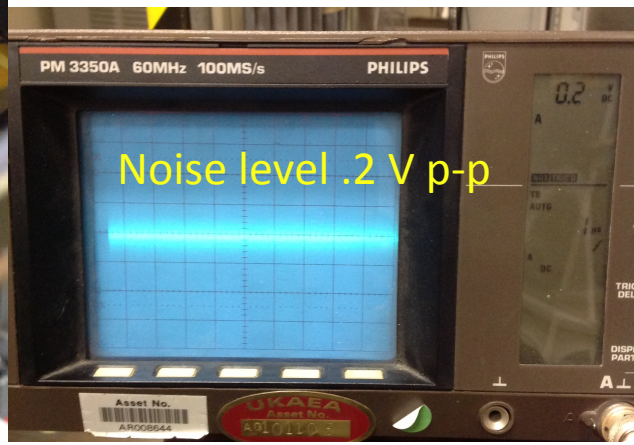


- Custom written software in LabVIEW controls how the digitizer collects data during shots and then writes the data files.
- Sending the signal through custom connectors considerably contributes to noise levels. Floating coaxial feed-throughs should be used to transfer the signal between air and vacuum and any mechanical probe arm flanges.

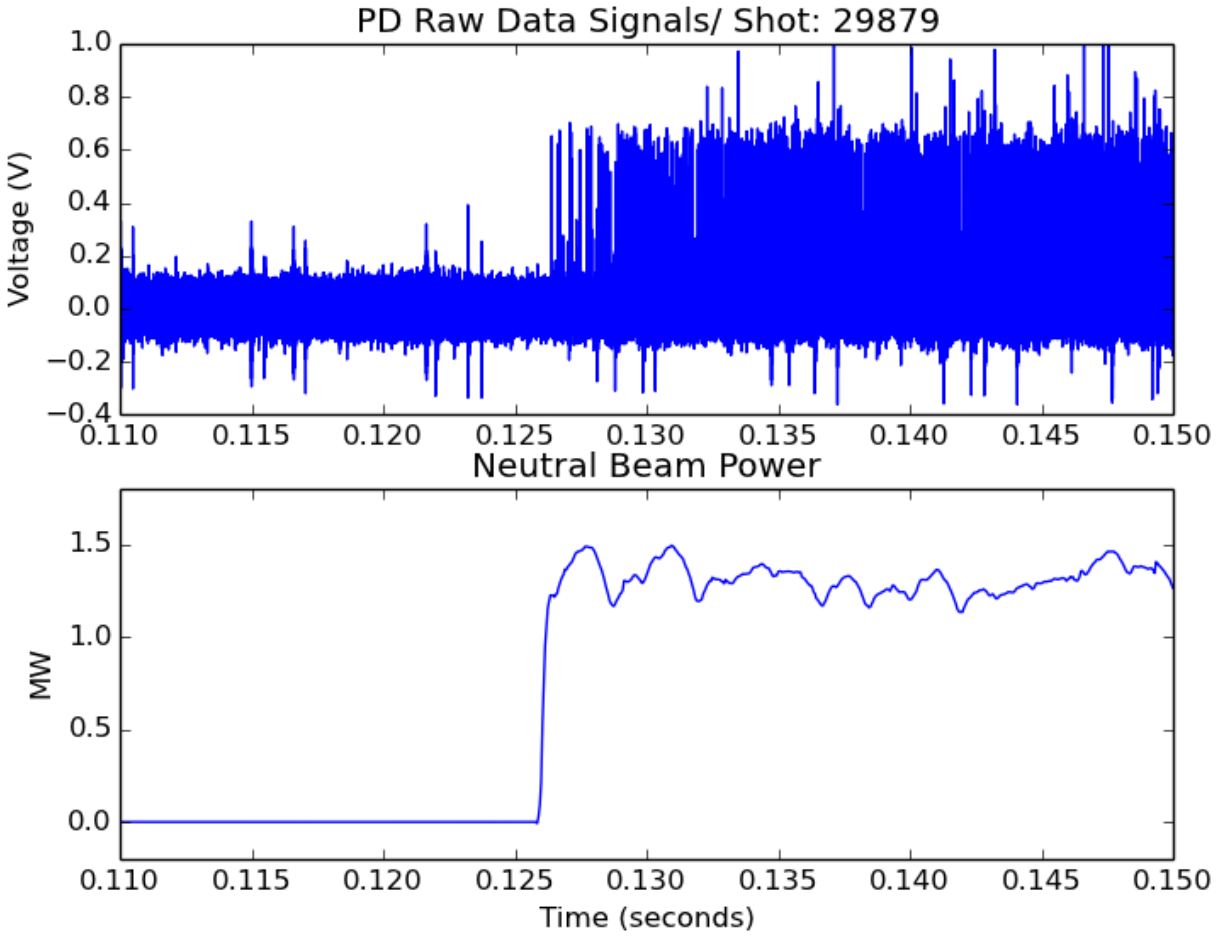
Electrical Noise





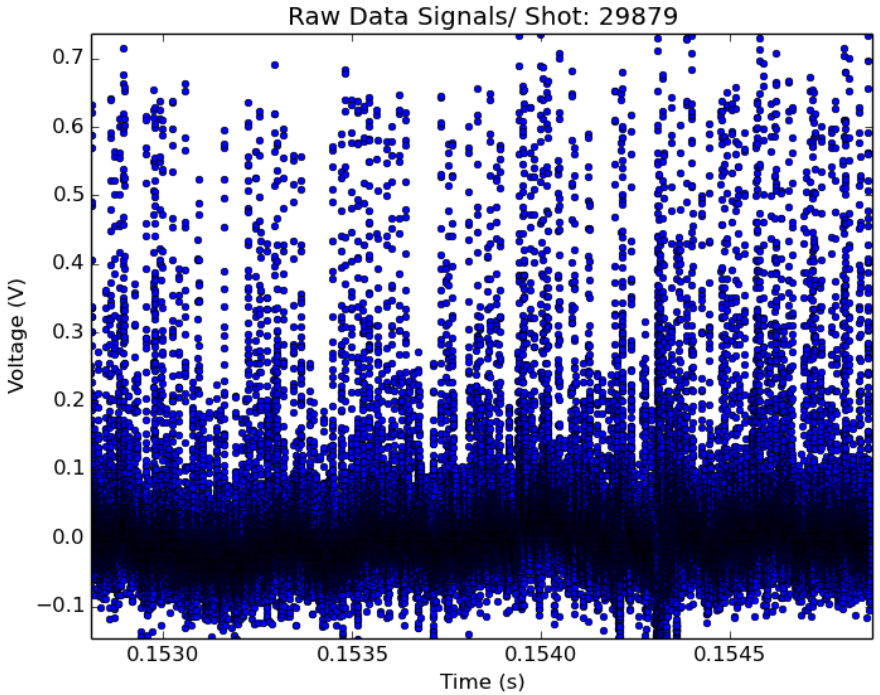


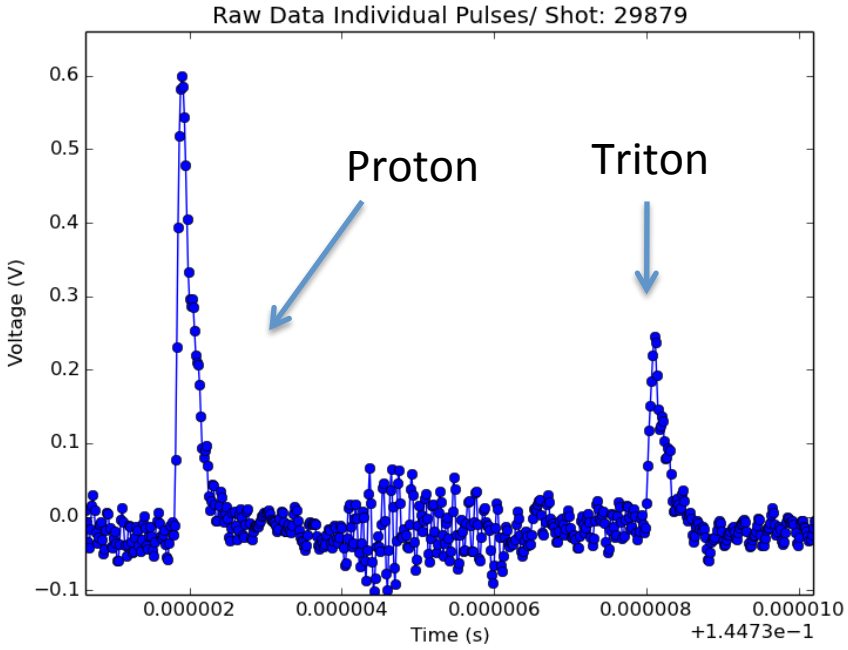
Raw Data: Signals



- Data was continuously sampled during the shot at 60MHz with a high-speed digitizer.
- The observed count rates and pulses showed a clear dependence on the neutral beam power.
- The voltage signals are proportional to the particle's initial energy deposited into the silicon surface barrier detector.

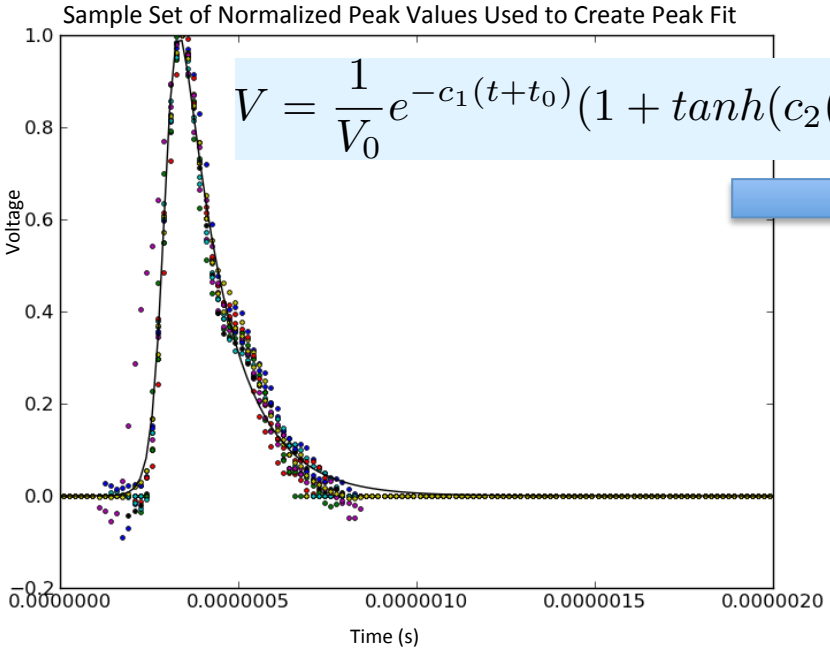
Raw Data: Particle Pulses



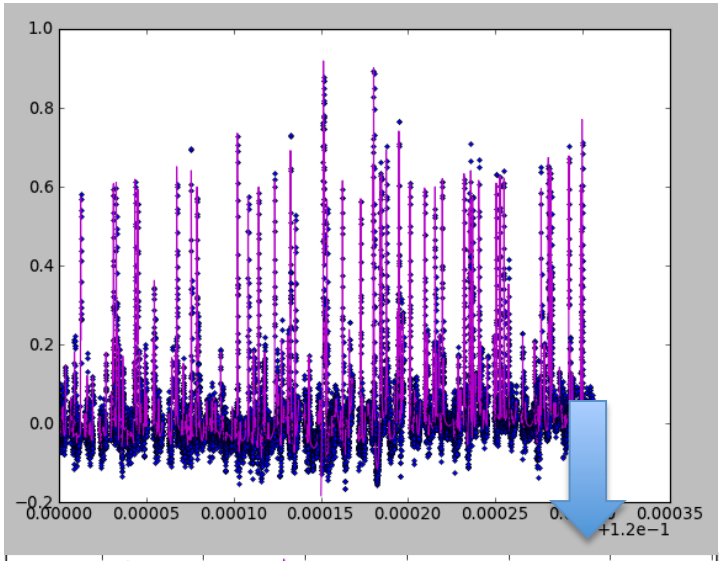


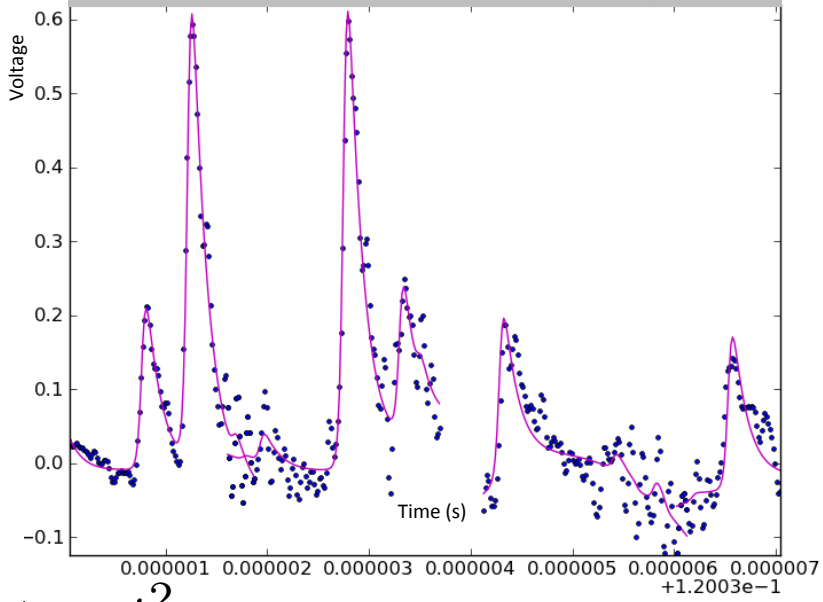
- Average peak height ~0.6V for 3MeV Proton and ~0.2V for a 1MeV Triton. The average peak width is ~100 - 500ns, epending on shaping parameters
- 0.8 MeV ^{3}He ion would have an average height of ~0.15V (or less due to energy loss in foil)
- ^{3}He could be identified so far

Peak Fitting



$$V = \frac{1}{V_0} e^{-c_1(t+t_0)}(1 + tanh(c_2(t + t_0)))$$

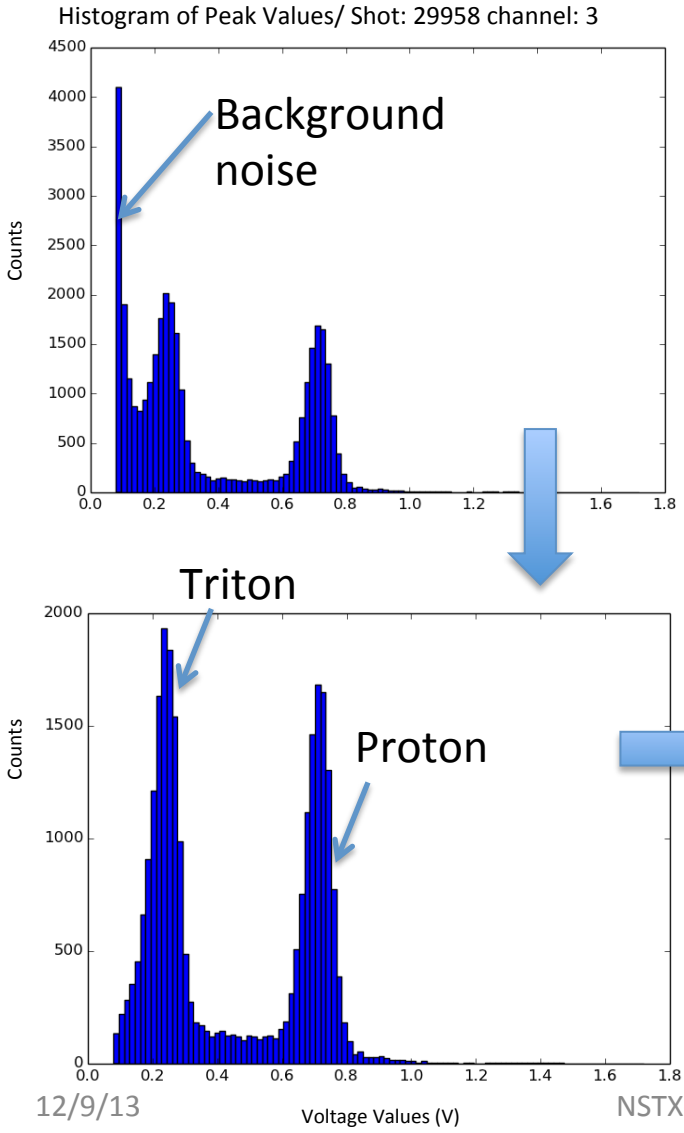




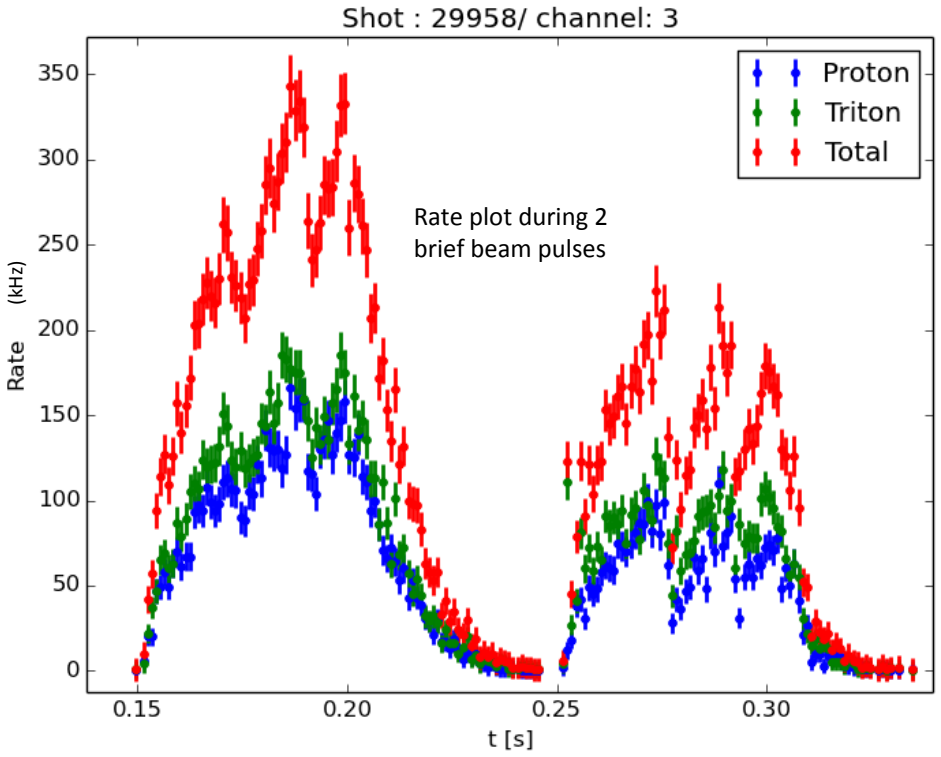
- A peak shape function from sampled peaks within each data channel.
- Sampled data are normalized to a maximum value of 1
- Normalized data are fitted determining C_1 and C_2 fit.
- Groups of peaks fitted with:

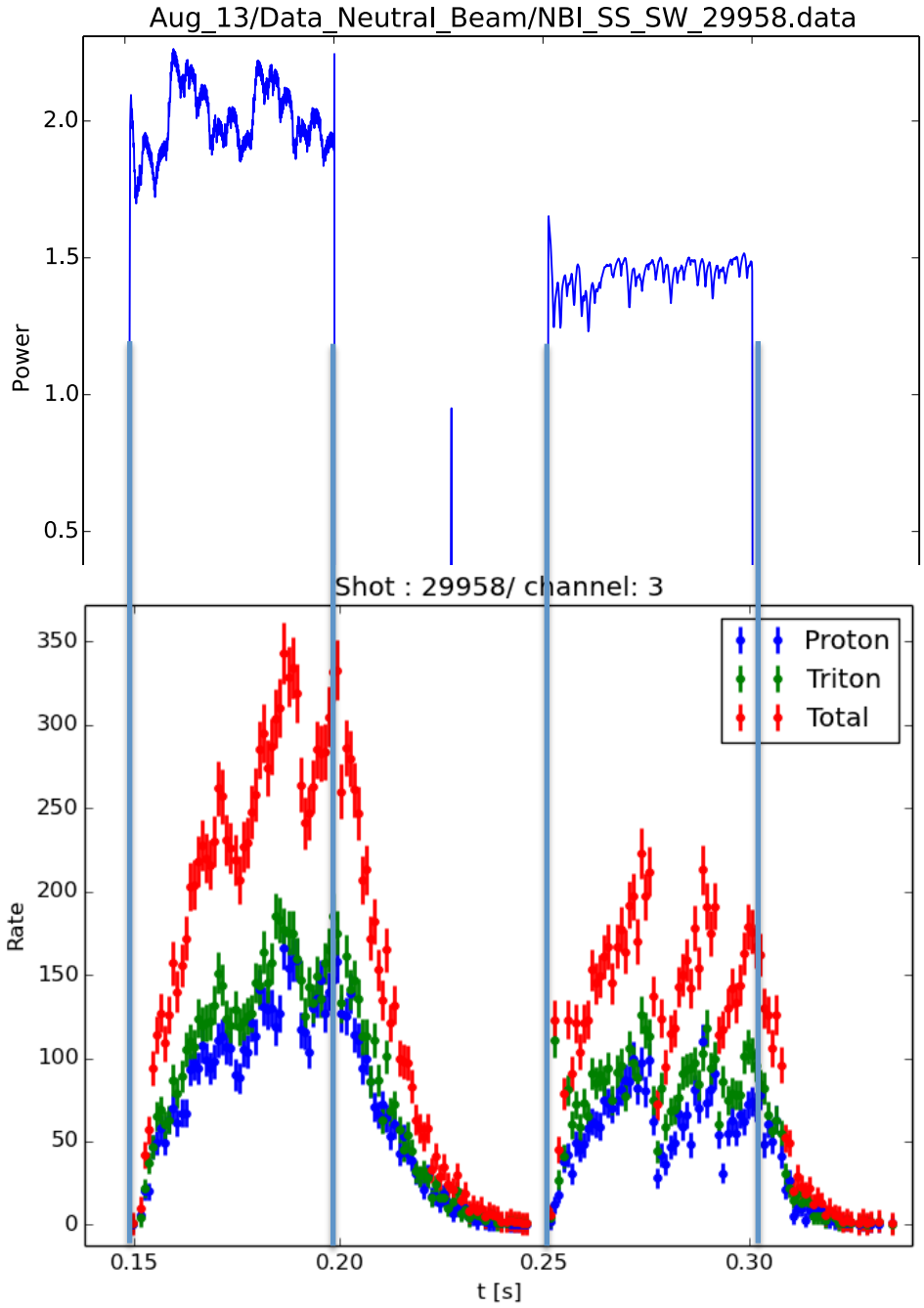
$$S(t, t_0) = AV_N(t, t_0) + a_0 + a_1 t + a_2 t^2$$

Particle Rates: Beam pulses

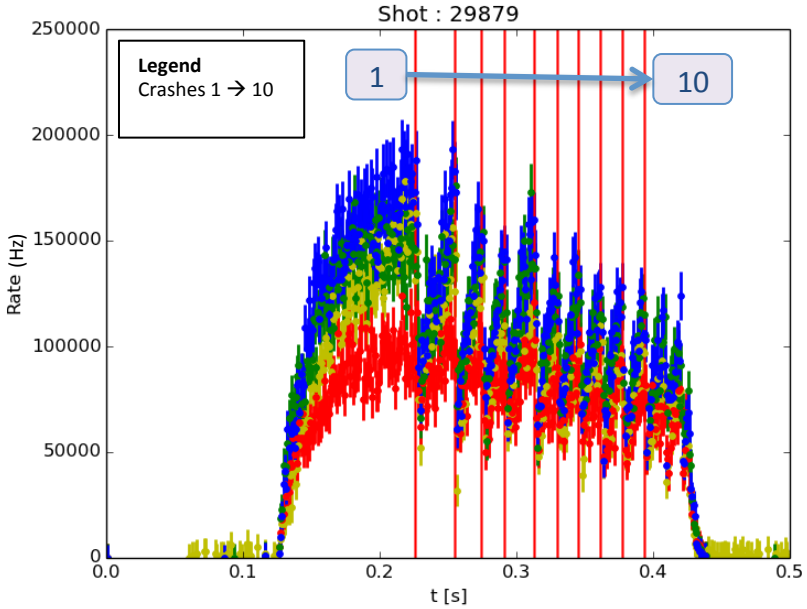


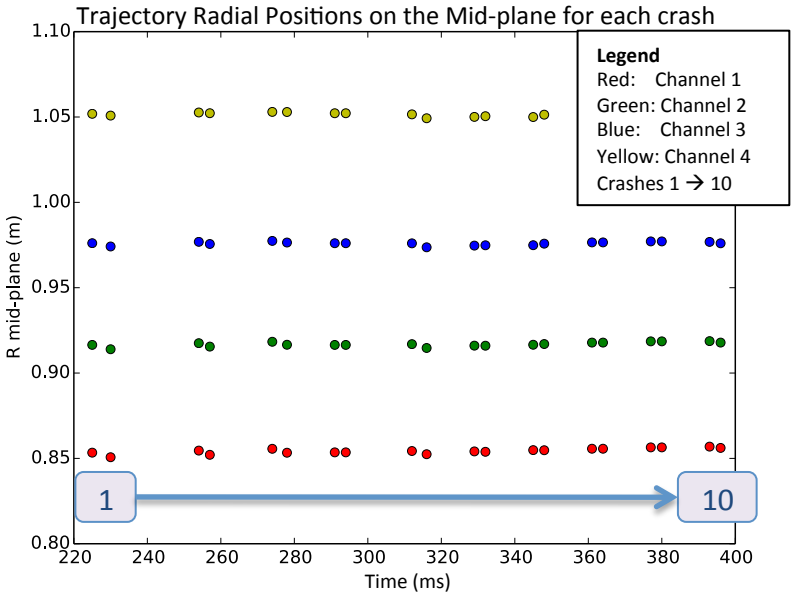
- Criteria of good signals: ratio of fitted amplitude error to amplitude value
- Cut on ratio to suppress noise
- Histogram amplitudes for given time bin
- Proton and triton are mono energetic
- Integrate over time bin



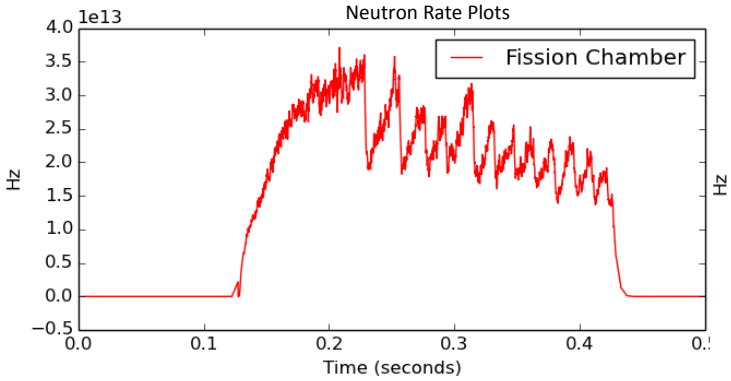

Aug_13/Data_Neutral_Beam/NBI_SS_SW_29958.data
Power
2.0
1.5
1.0
0.5
Shot : 29958/ channel: 3
Proton
Triton
Total
Rate
350
300
250
200
150
100
50
0
0.15
0.20
0.25
0.30
t [s]

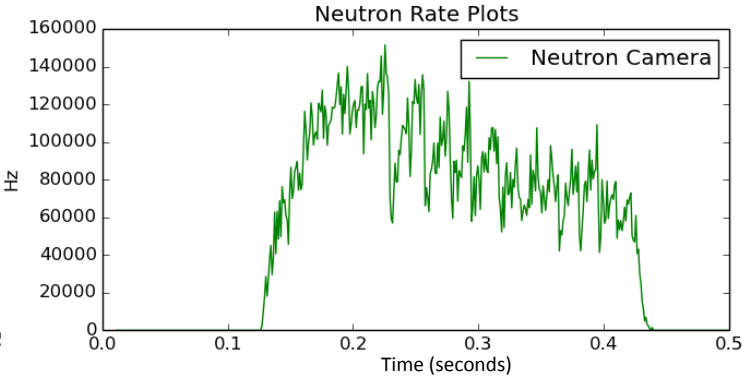
Sawtooth Scenario



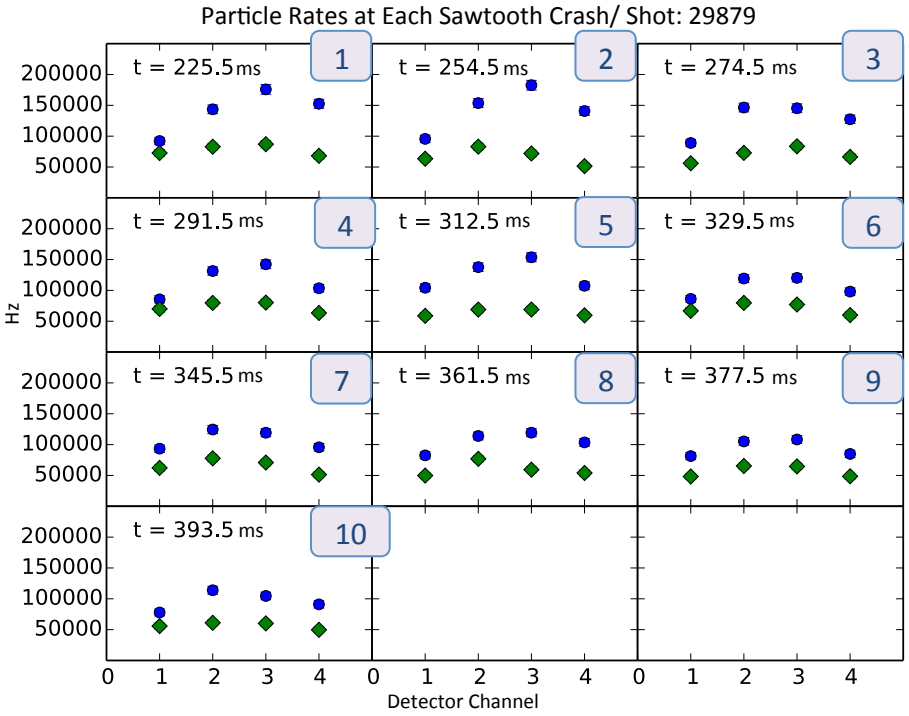


- The PD sawtooth crash rate plot is shown in the above left image. In the above right image, the mid-plane radial position before and after each crash is plotted.



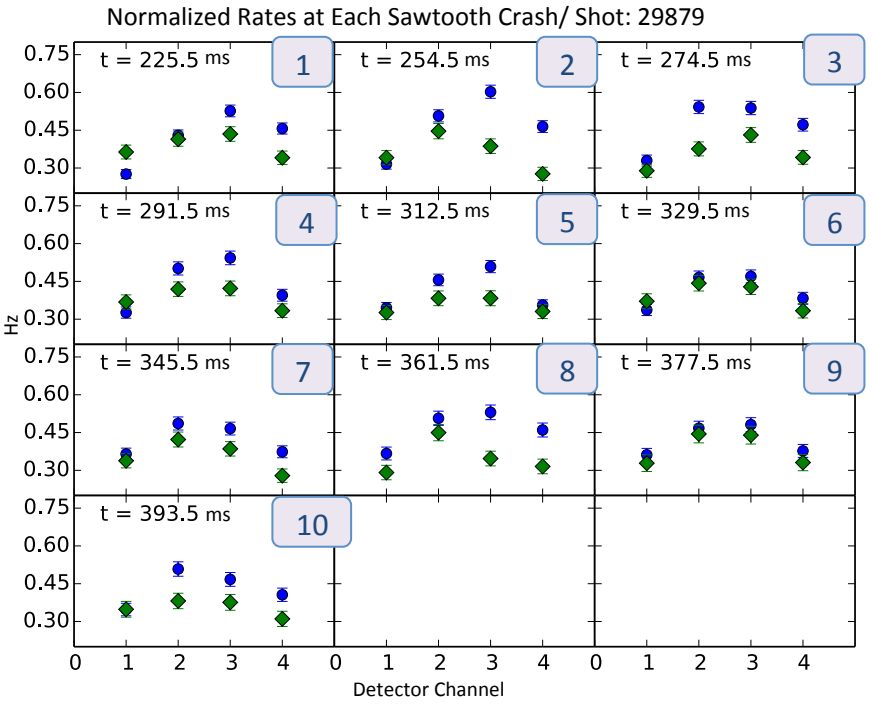


Results: Sawtooth Scenario



Before crash
After crash

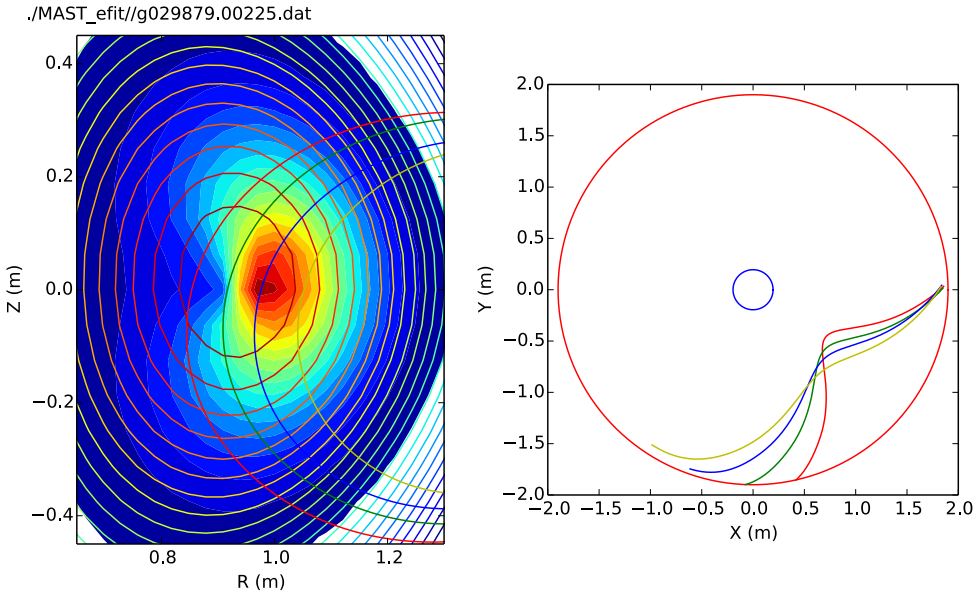
Normalized to Fission Chamber

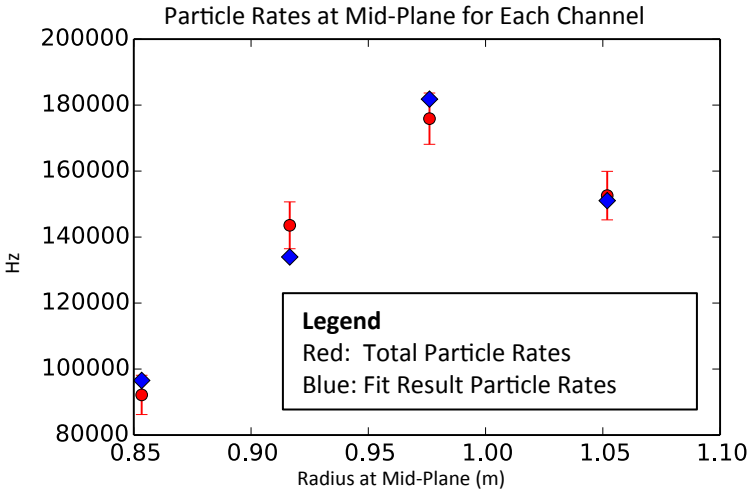


Before crash
After crash

- Combining repeat shots difficult
- Planned: combined analysis PD and neutron camera

Results: Emission Profile 1 Before

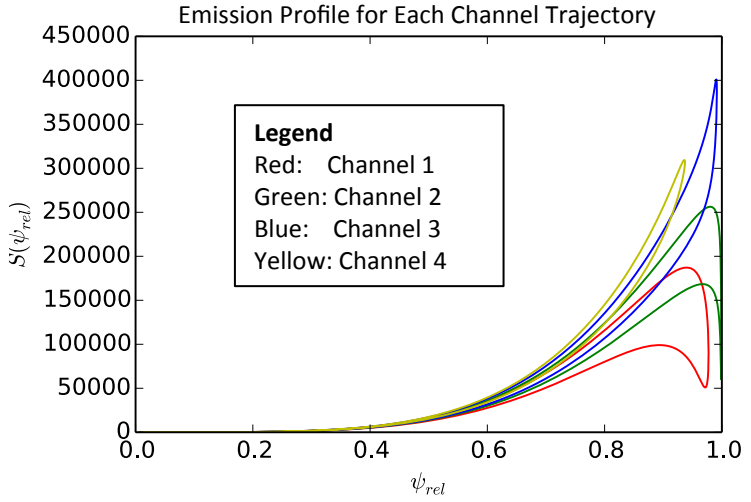




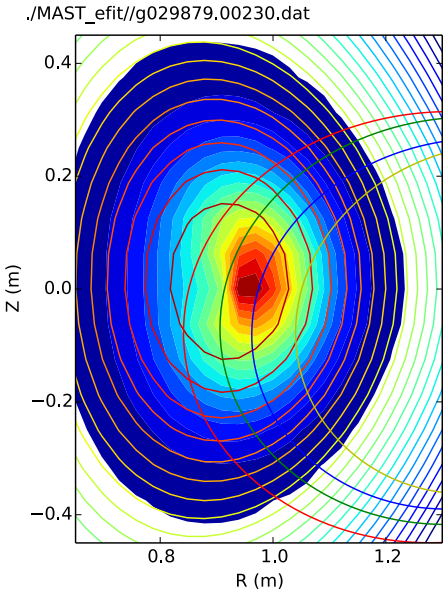
Reconstructed emission profile (particle yield) model function:

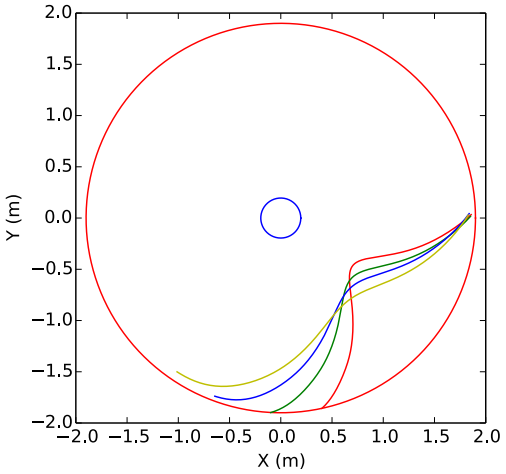
$$S(r, z, \psi_{rel}) = \alpha {\psi_{rel}}^{\lambda}(1 + Acos\theta)$$

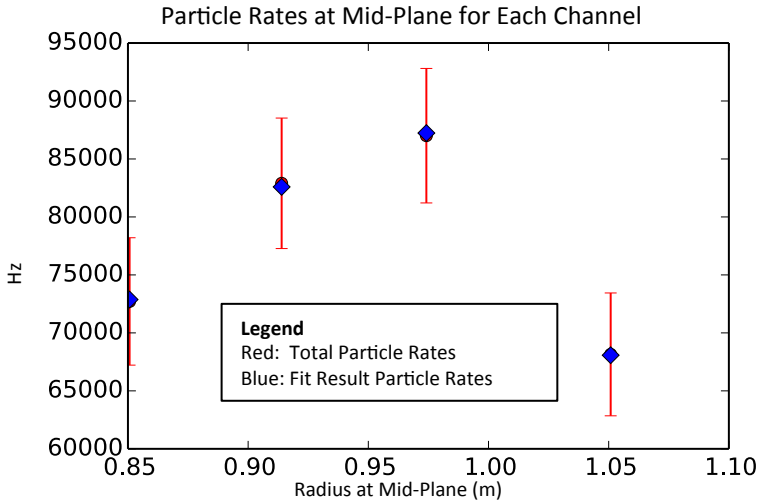
S is integrated along particle orbits and the integral is fitted to the observed rate taking the detector acceptance into account.



Results: Emission Profile 1 After

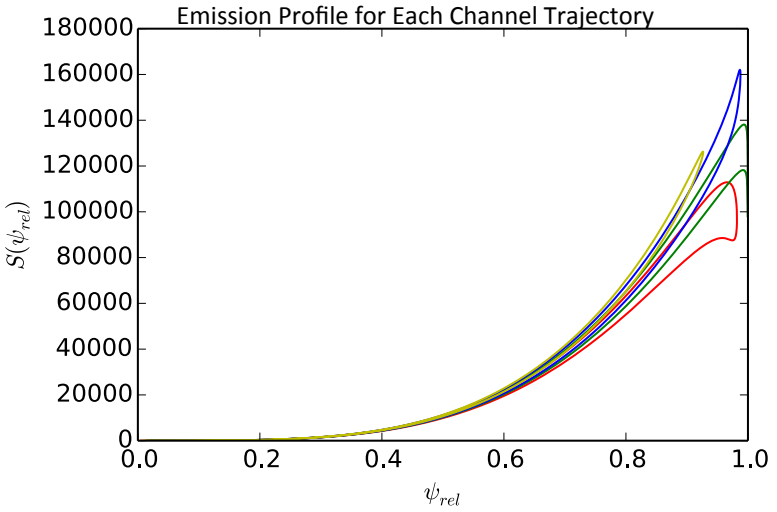




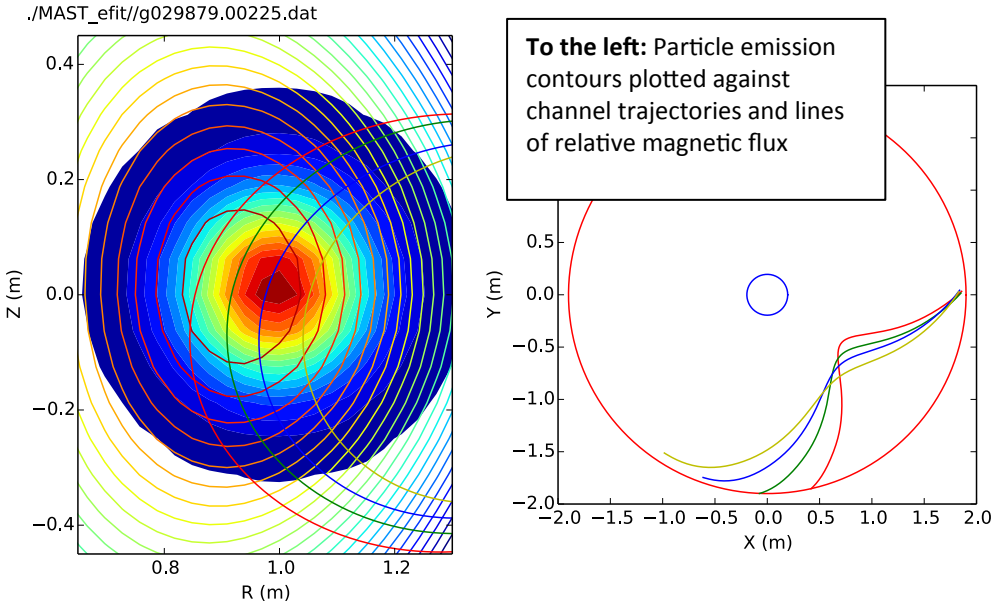


- S not constant on the flux surfaces
- Profile seems to get wider after crash

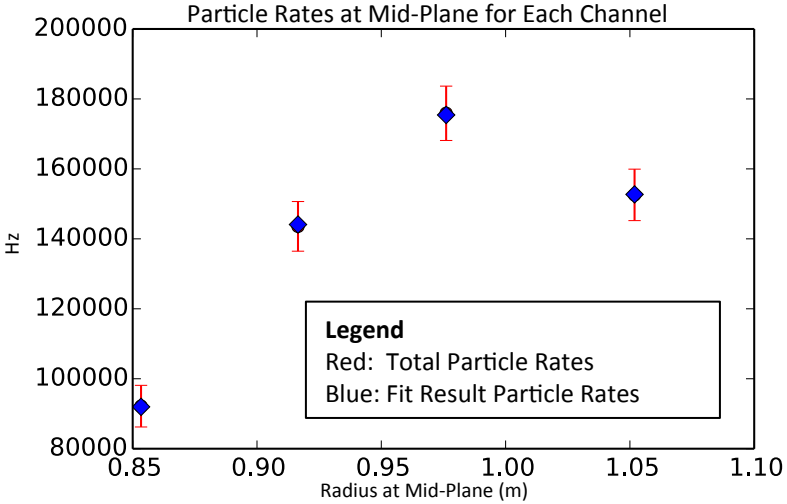
- Profile has a strong model dependence because there are only 4 channels.



Results: Emission Profile 2 Before

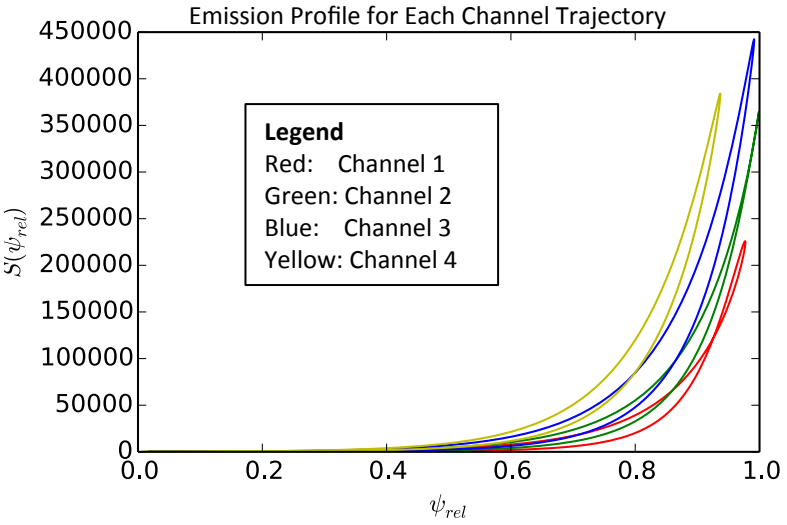


To the left: Particle emission contours plotted against channel trajectories and lines of relative magnetic flux

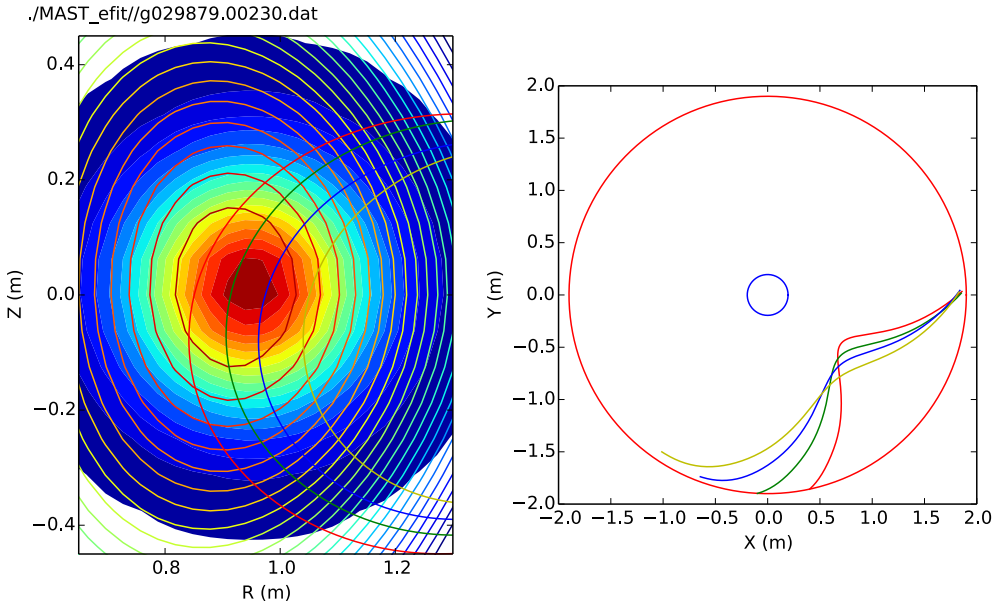


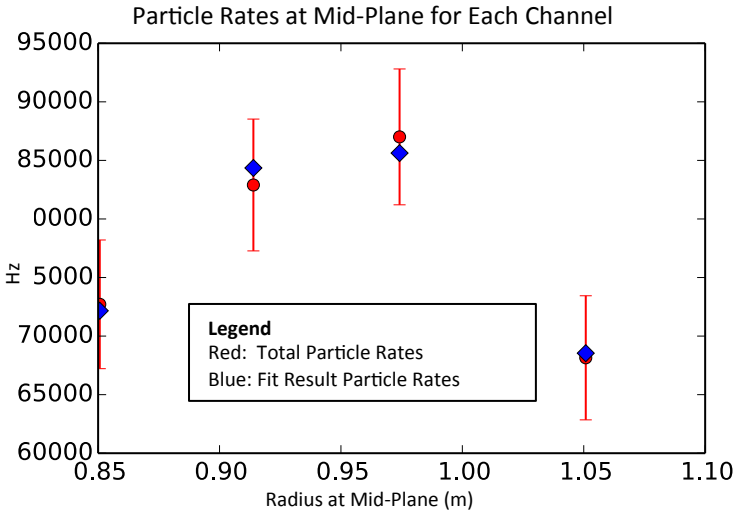
Reconstructed emission profile model function (Gaussian):

$$S_g(r,z) = Ae^{-\frac{((r-r_0)^2+z^2)}{\sigma^2}}$$

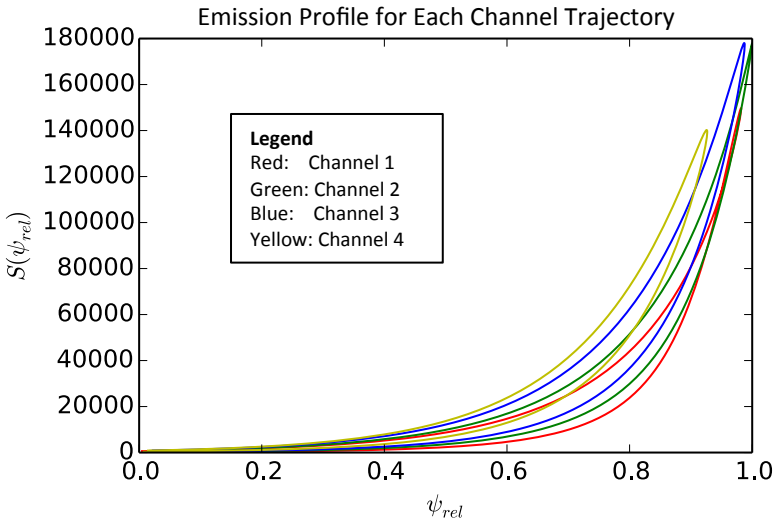


Results: Emission Profile 2 After

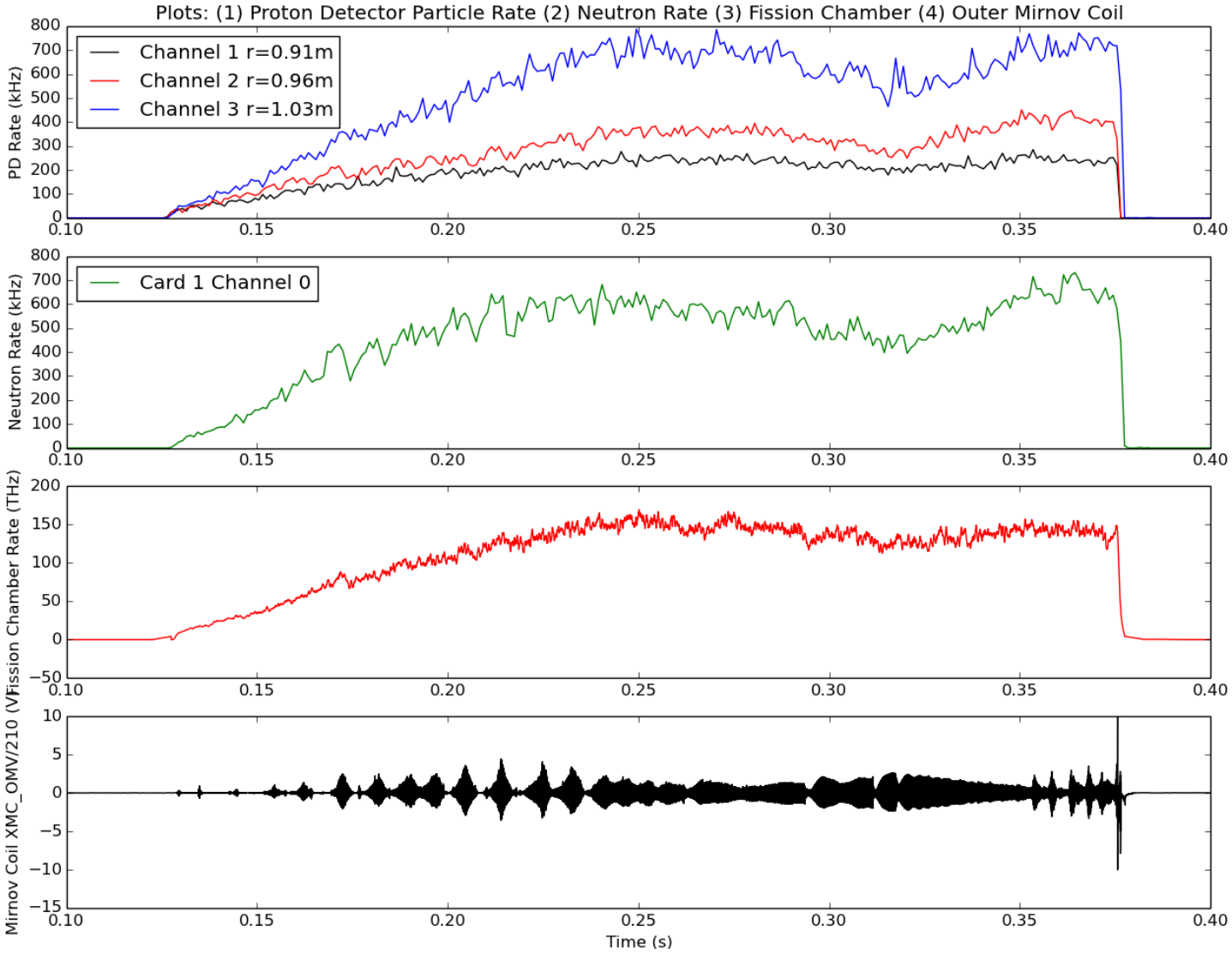


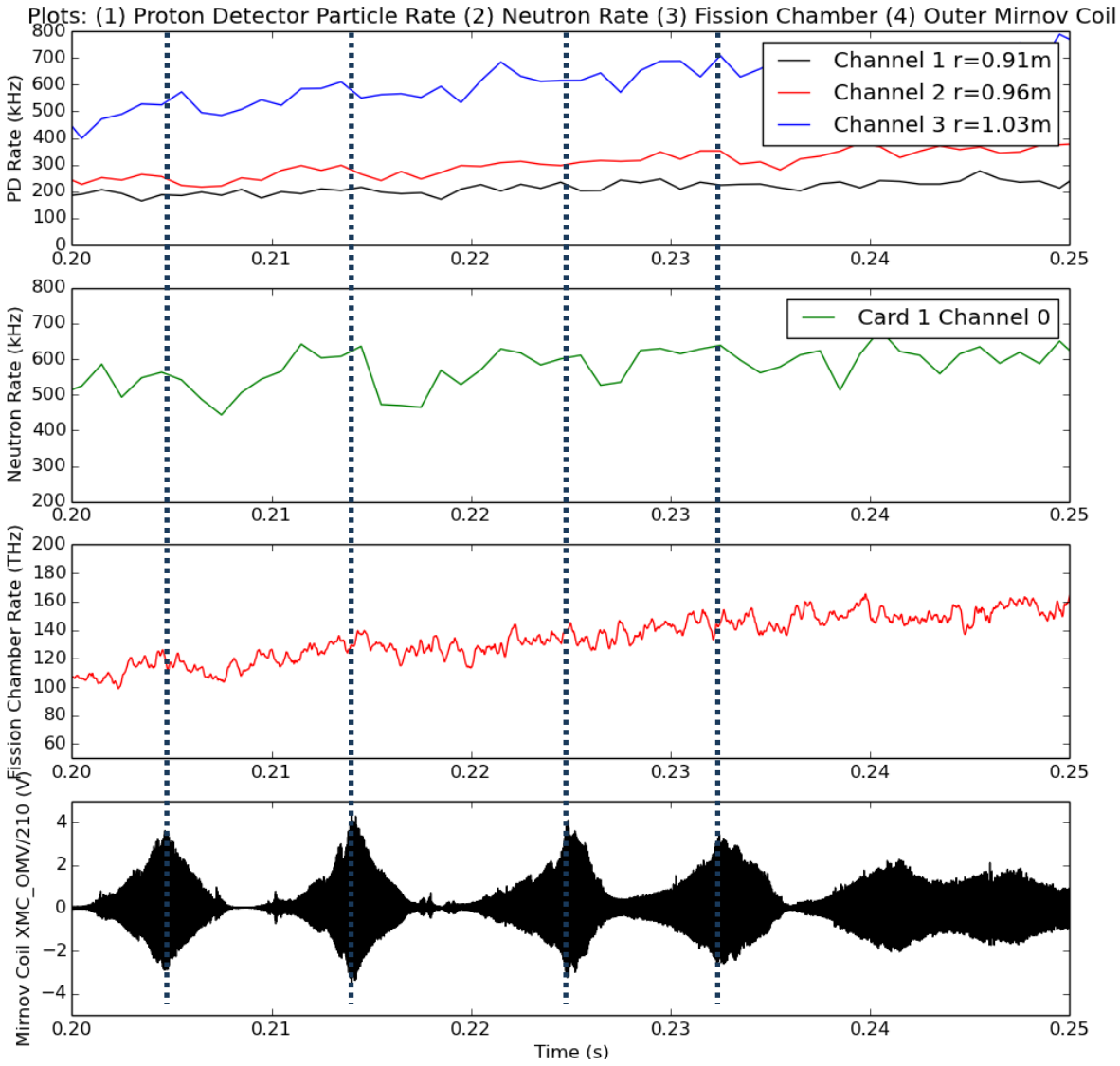


- S shifted to larger R
- S is wider

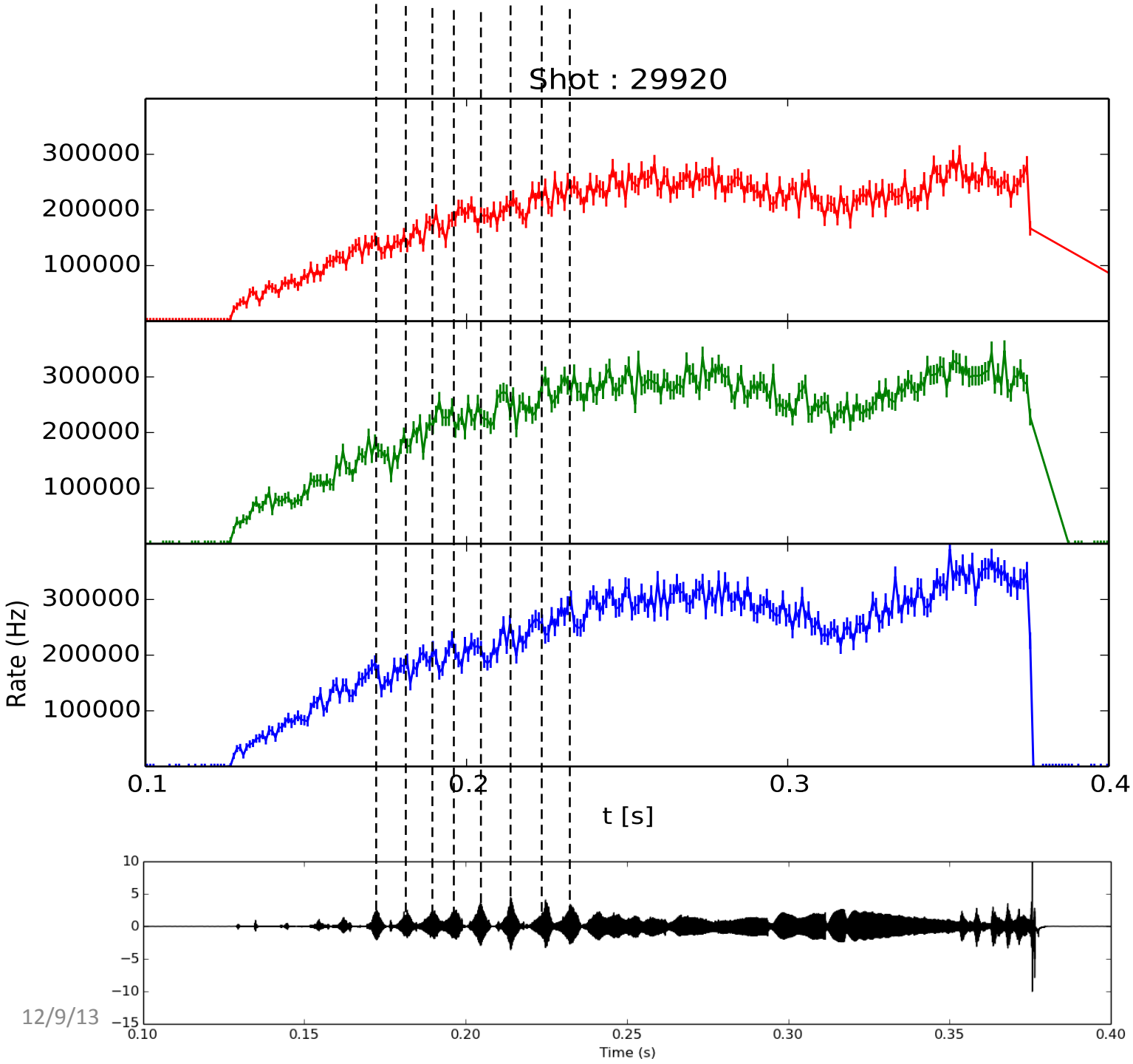


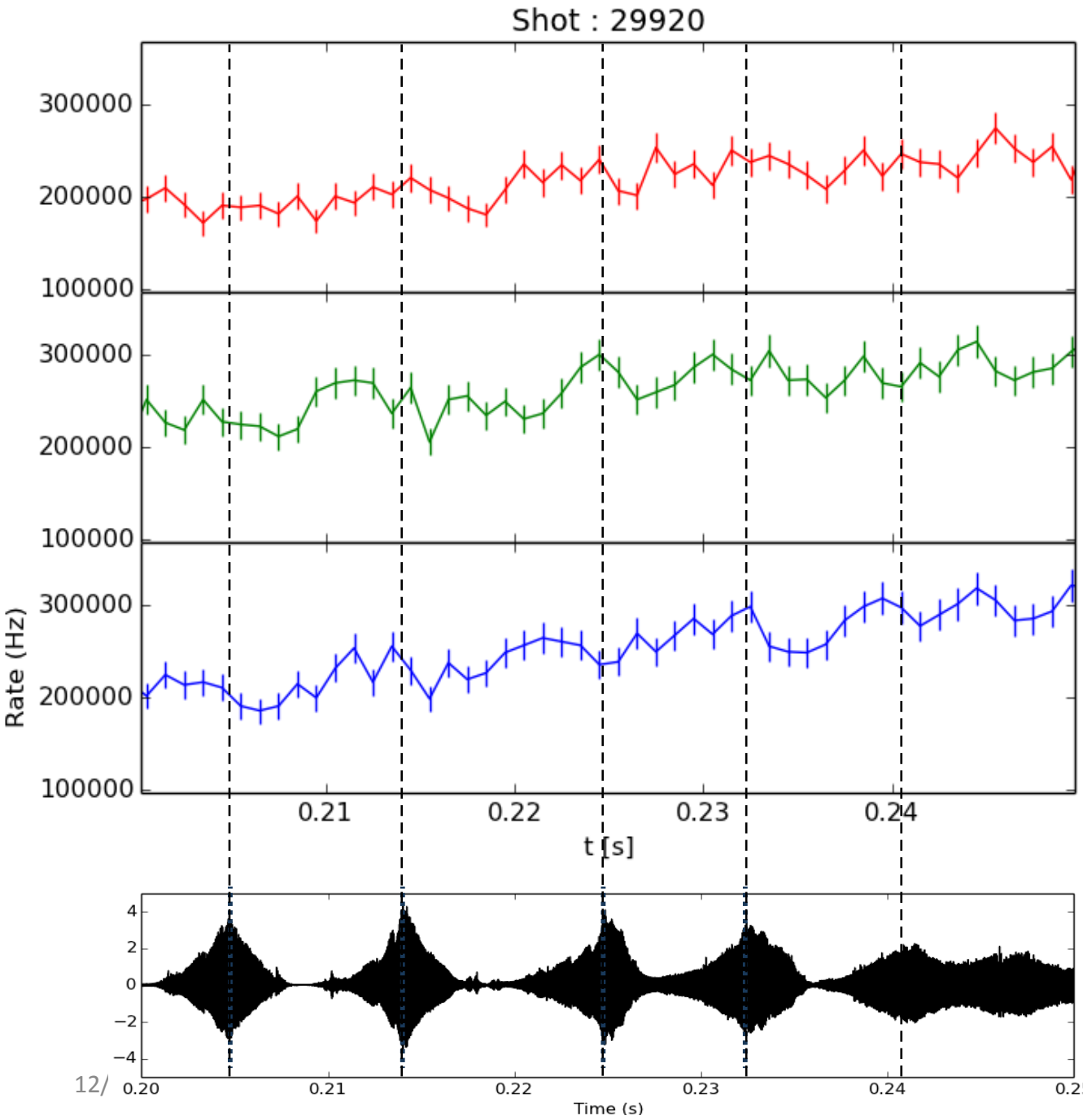
Fishbone Scenario: 29920





- Simple pulse height analysis
- No fitting
- Total rate: protons and tritons


Shot : 29920
Rate (Hz)
300000
200000
100000
0.1
0.2
0.3
0.4
t [s]
10
5
0
−5
−10
−15
0.10
0.15
0.20
0.25
0.30
0.35
0.40
Time (s)



- Good particle identification is needed for detailed information
- Noise suppression is important

Installation in NSTX-U

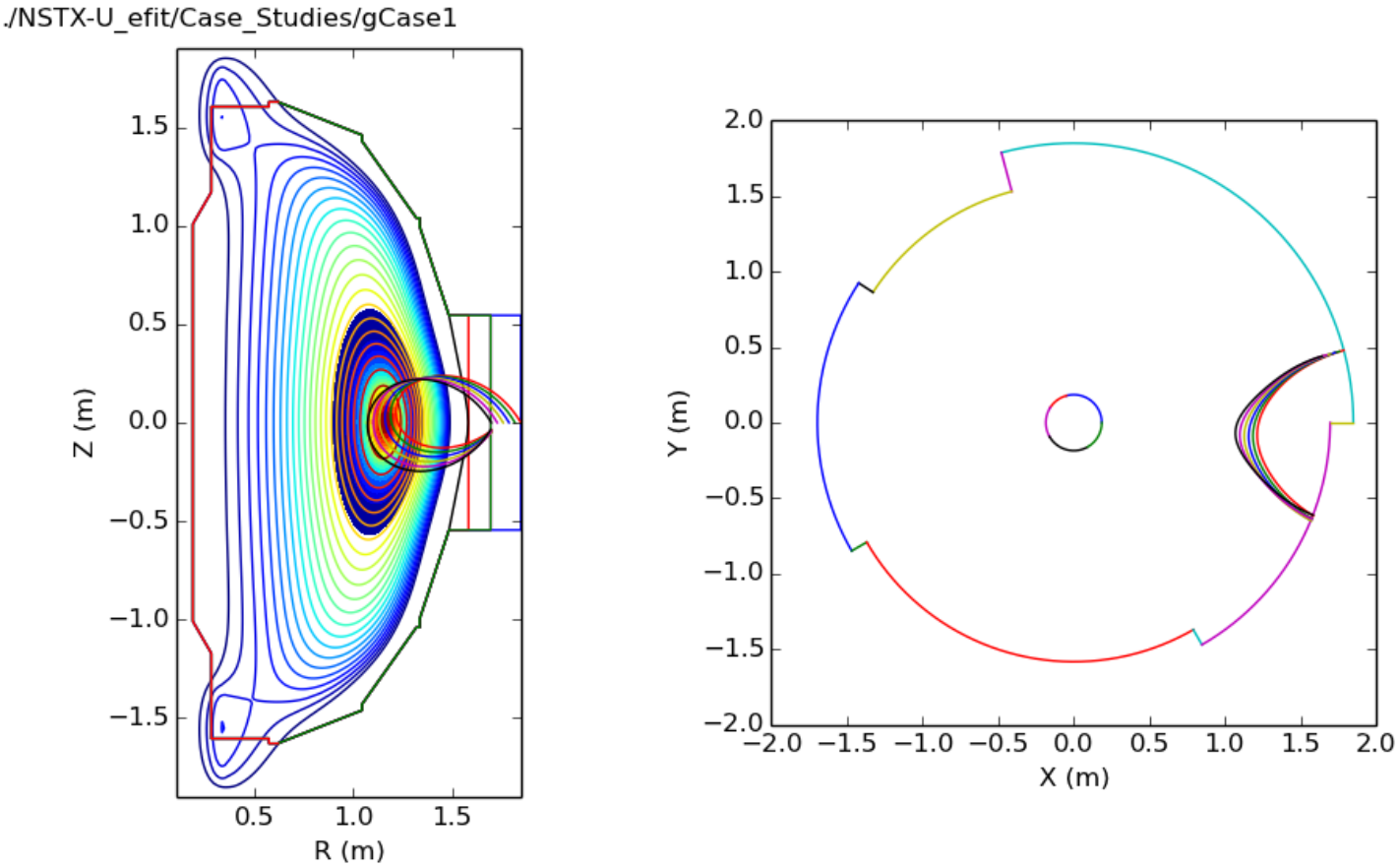
- New high I_p and B_T: very different orbits
- New detector mount is needed
- Fully instrumented 4 channels
- With existing (old) hardware number of channels can be increased to 6
- Mount on probe arm that allows axial rotation is crucial

Potential Orbits in NSTX-U

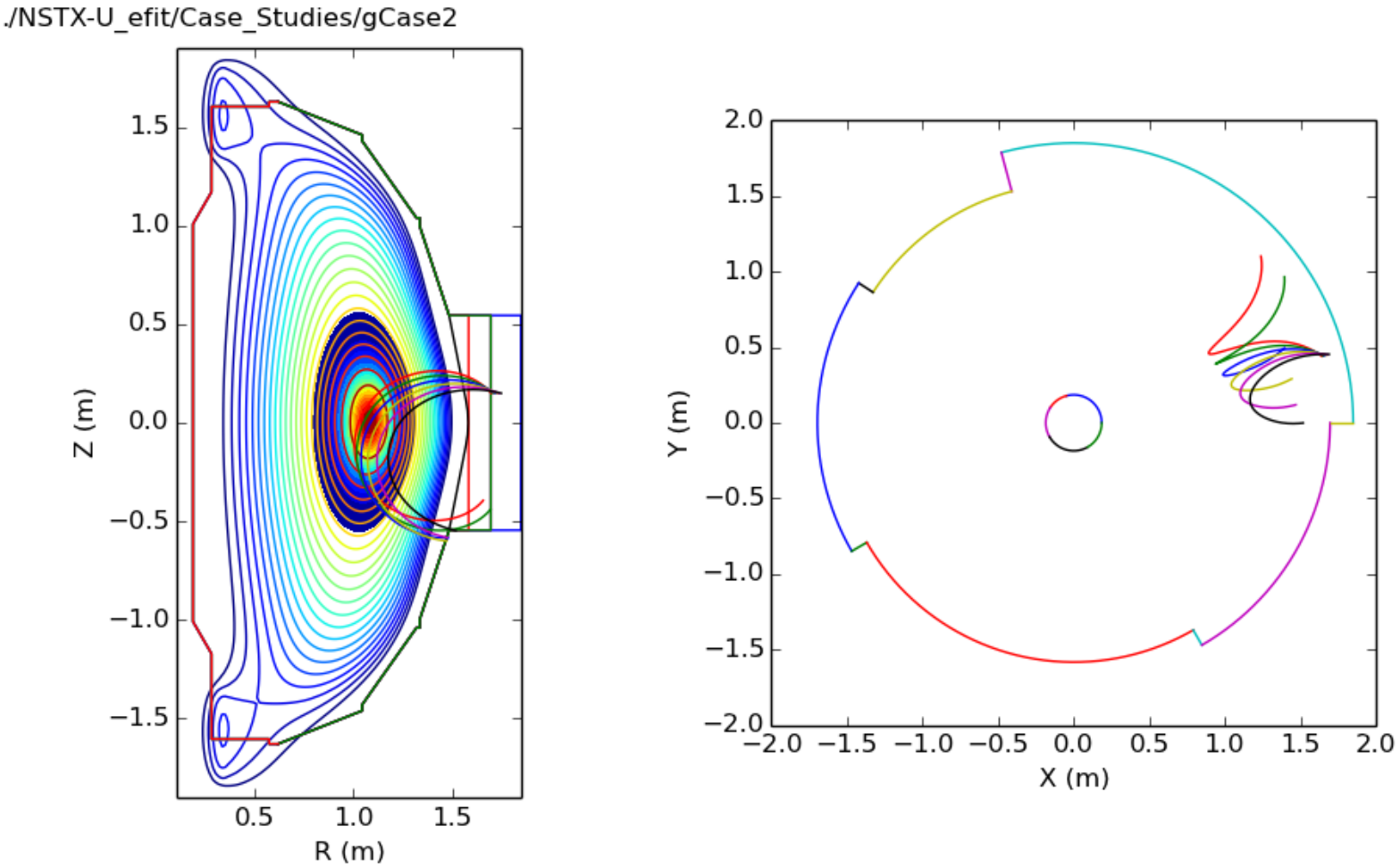
Initial studies on three main configurations

1. B_T = 0.95T I_P = 1 MA
2. B_T = 0.73T I_P = 1.5MA
3. B_T = 1.0 T I_P = 2.0MA

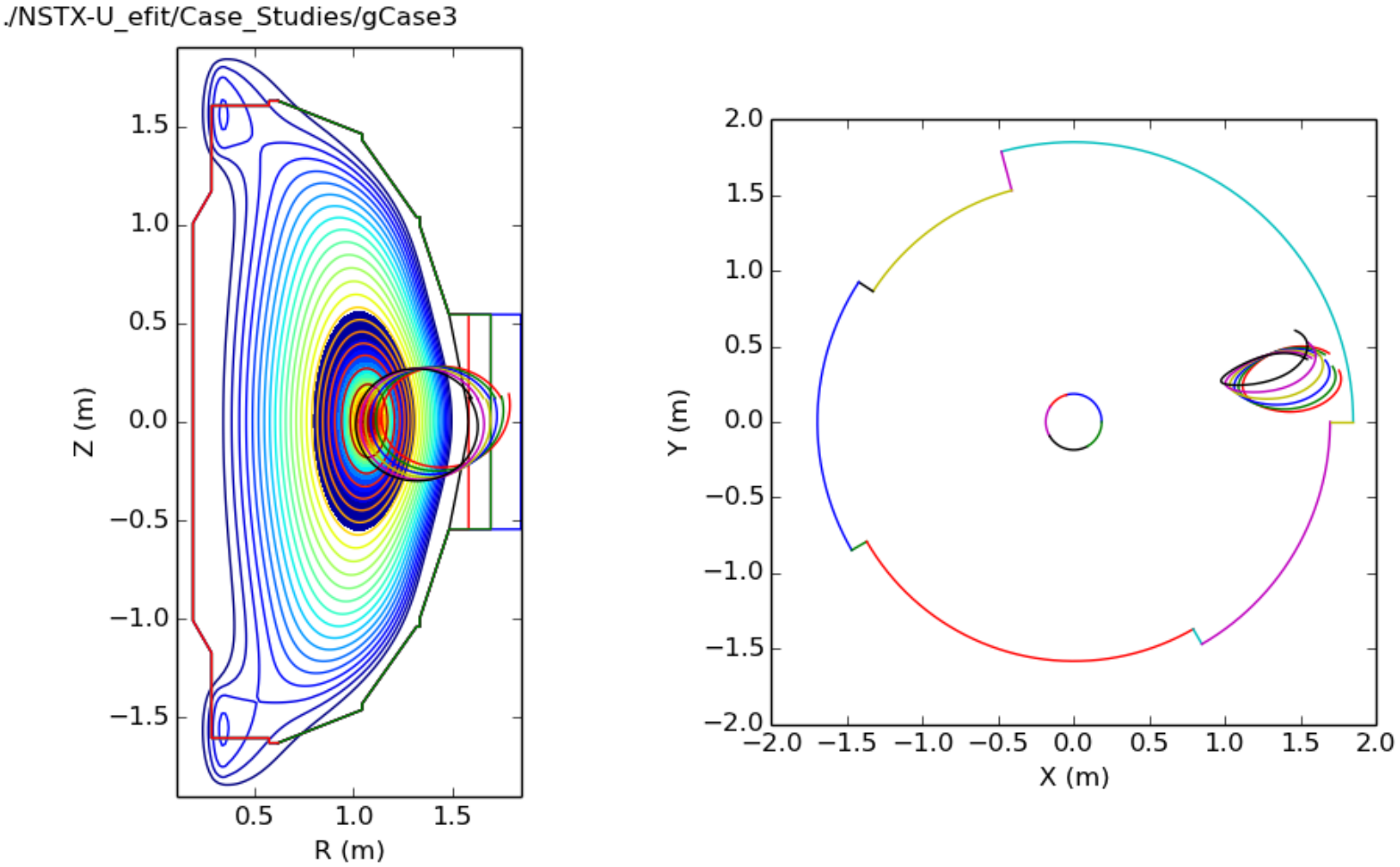
B_T = 0.95 T, I_P = 1 MA



B_T = 0.74 T, I_P = 1.5 MA

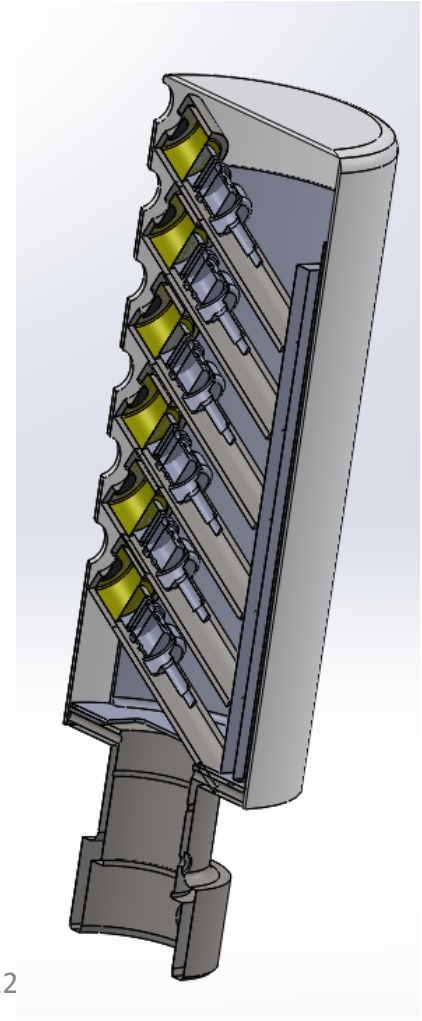


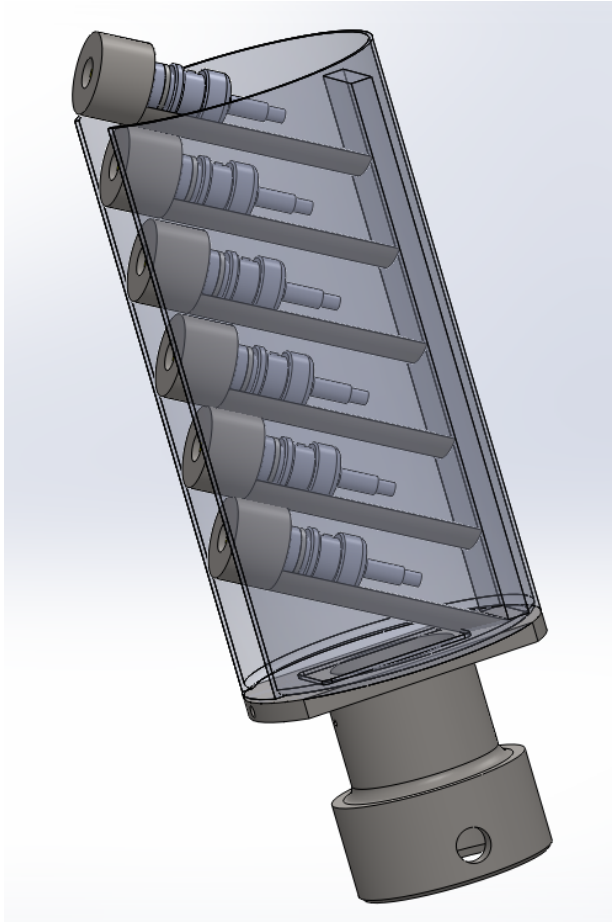
B_T = 0.74 T, I_P = 1.5 MA

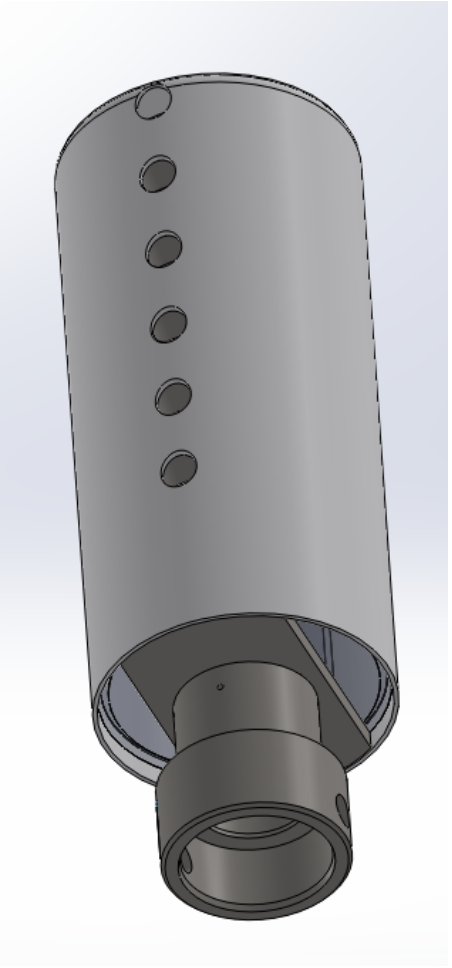


Conceptual Designs for NSTX-U

Linear array fits in 100 mm port opening

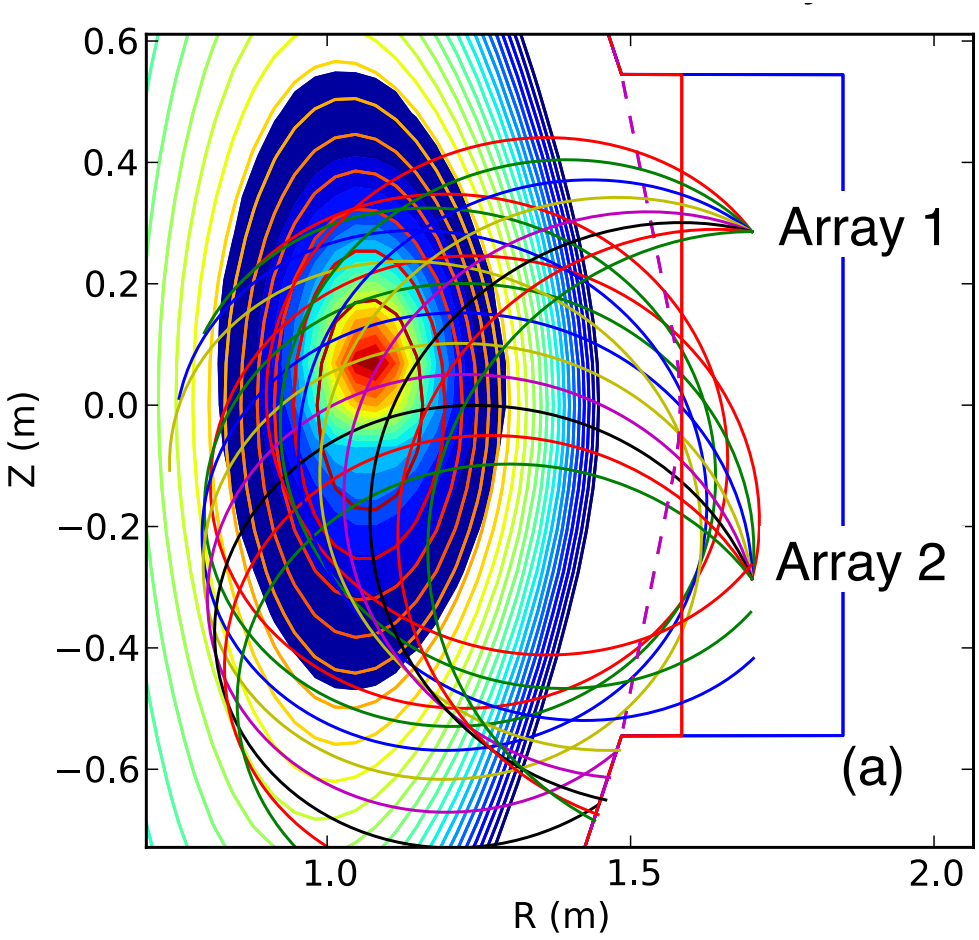




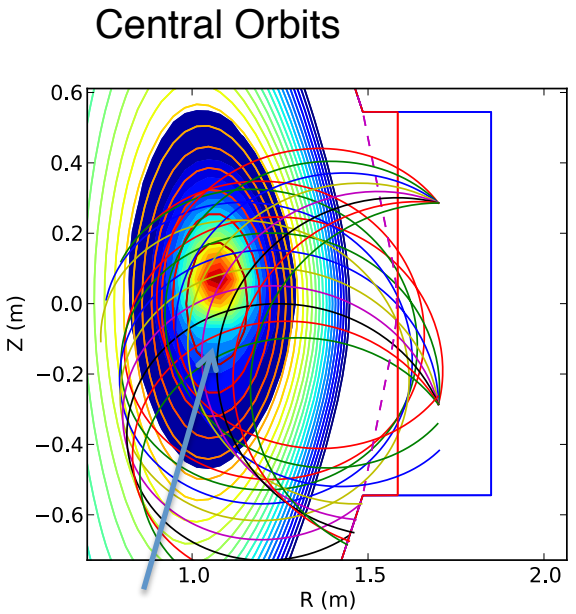


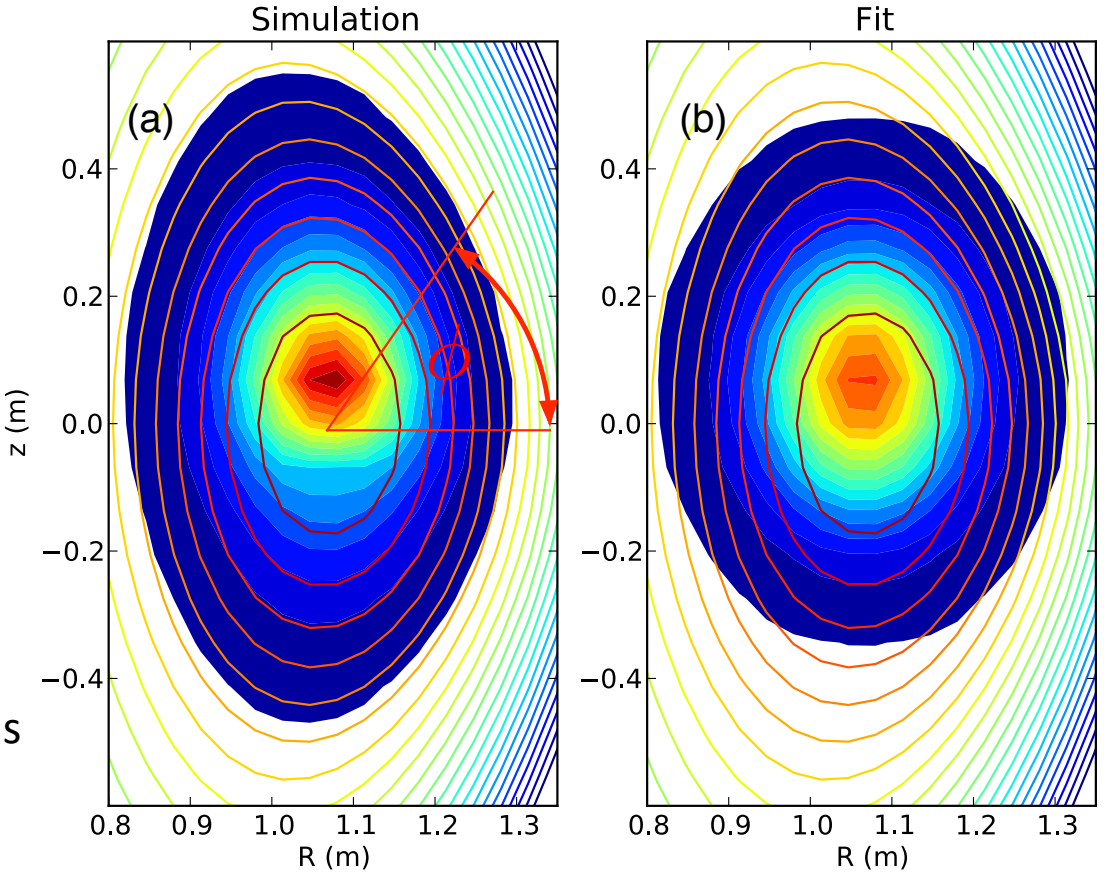
16 Channel System for NSTX-U/MAST

- 2 units of 8 channels each
- 2 fixed units
- One fixed, one on probe drive (with axial rotation)
- Various collimator arrays possible, can be optimized for specific experiments
- Parameters similar to JET neutron camera (19 channels)
- Much more detailed reconstructions possible
- Use custom array detector for compact instrument



Profile Reconstruction





- Orbits cross central plasma region
- Act like 'curved' sight chords in X-ray tomography

Simulation: $S(\psi) = \psi^{\lambda}(1. + Asin(\phi)), \lambda = 11.45, A = 0.5$

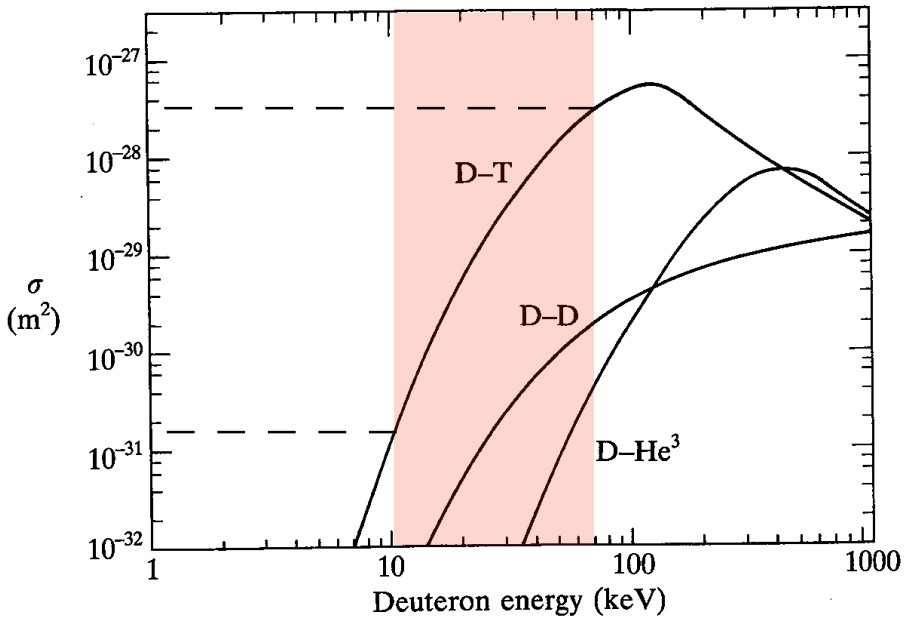
Fit function: $S_{fit}(R,z) = Ae^{-\frac{1}{2}\left(\frac{R-R_0}{\sigma_R}\right)^2} e^{-\frac{1}{2}\left(\frac{z-z_0}{\sigma_z}\right)^2}$

Summary

- Successful data taking at MAST, data comparable to neutron camera
- Noise can be controlled
- Protons can be well identified, ^{3}He difficult with window
- Good time resolution of 1 ms at 10%
- Sawteeth oscillations and Fishbone activities could be observed and studied
- Adaptable to NSTX-U
- More channels are necessary

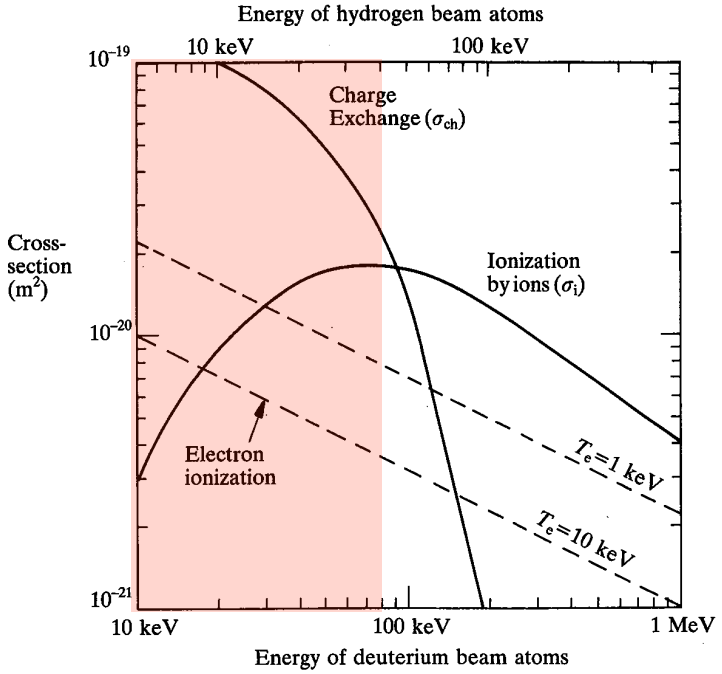
Cross Sections

Nuclear Reaction Cross Sections



Cross section droppes 3 orders of magnitude

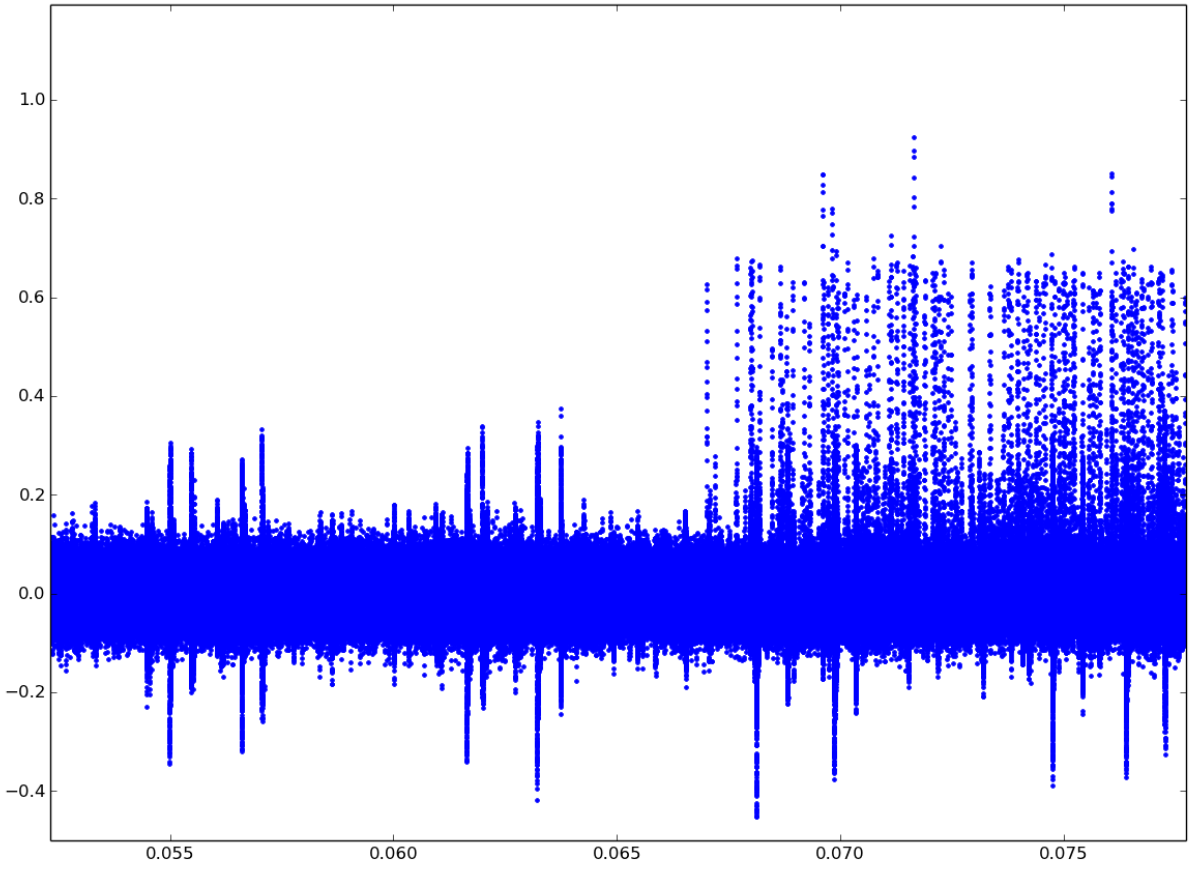
Neutral Atoms Cross Sections



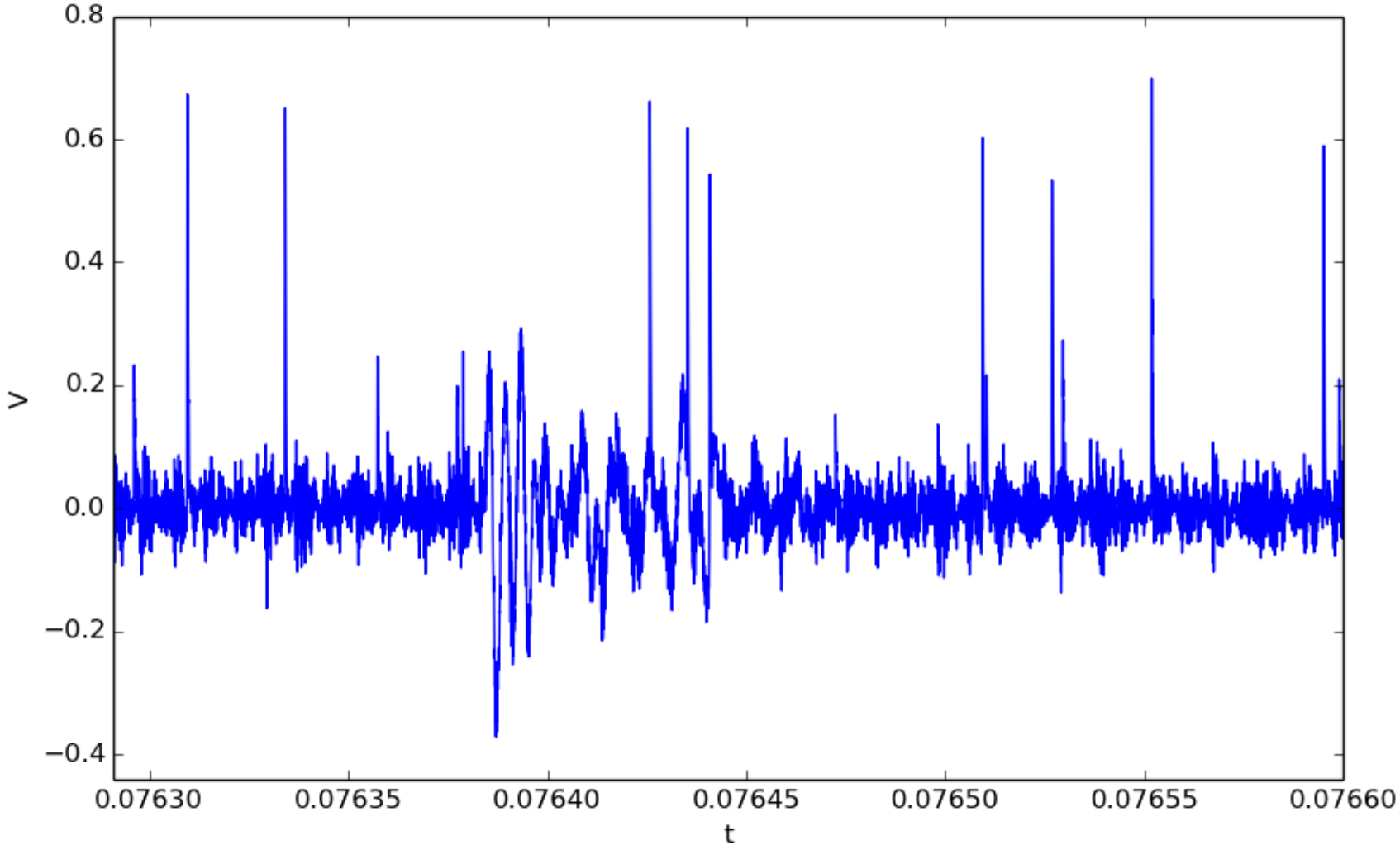
Cross section increases by factor of ~10

(pictures from J. Wesson, Tokamaks)

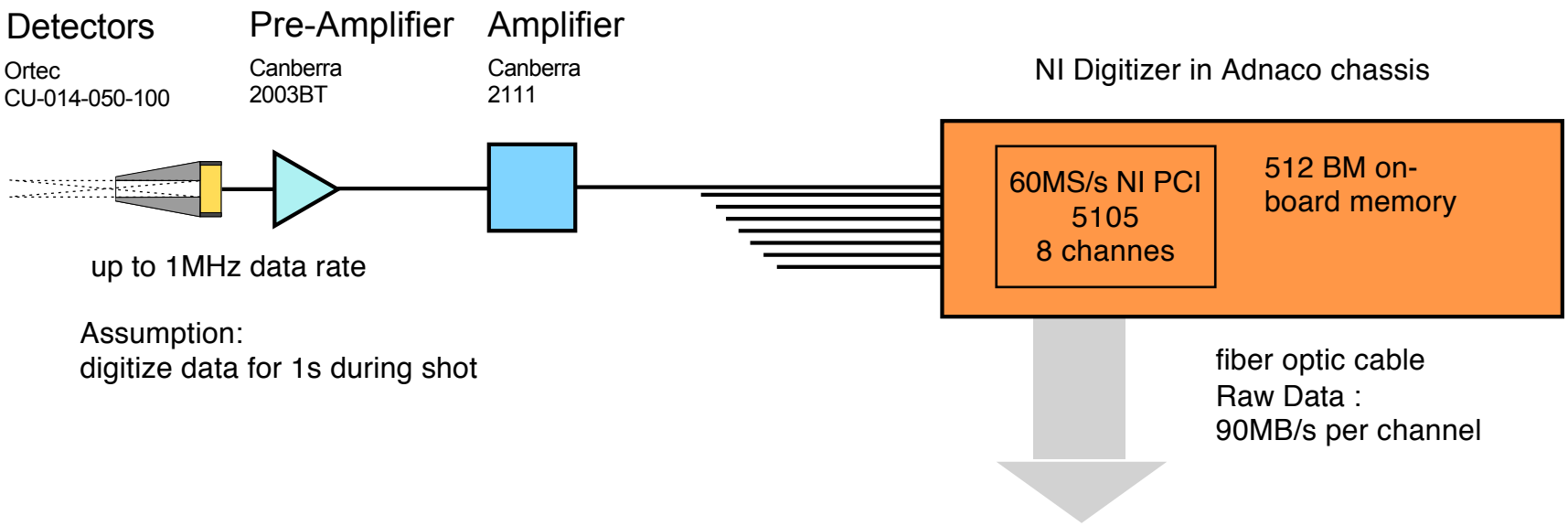
Noise in Particle Pulses



Noisy Signals (detail)



Backup: DAQ setup



Files written to disk:

HDF format:
46MB per channel per shot

TOTAL: 8 channels: 368 MB/shot

DAQ PC:

SuperMicro 50161-MTF 1U rackmount server

150GB data storage