Experimentally Investigating Fusion Plasma Instabilities Using MeV Proton Emissions

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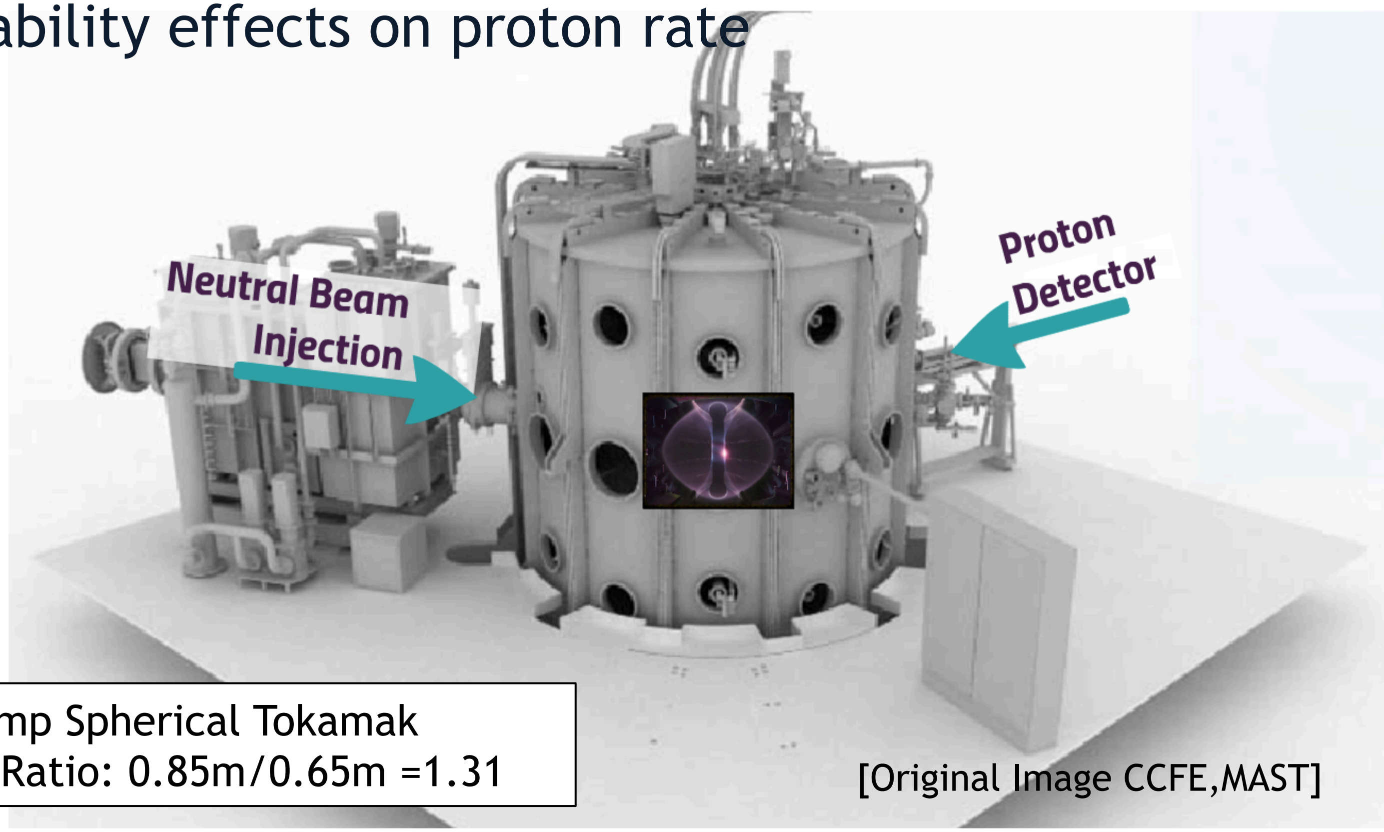
iter[5] the way to new energy

MeV Proton Emission Diagnostic Motivation

- Proof of concept: advantage in size, cost, and energy resolution
- Successful prototype 3MeV proton detector at the Mega Amp Spherical Tokamak (MAST)
- Measure DD proton fusion rate profile
- Study MHD instability effects on proton rate

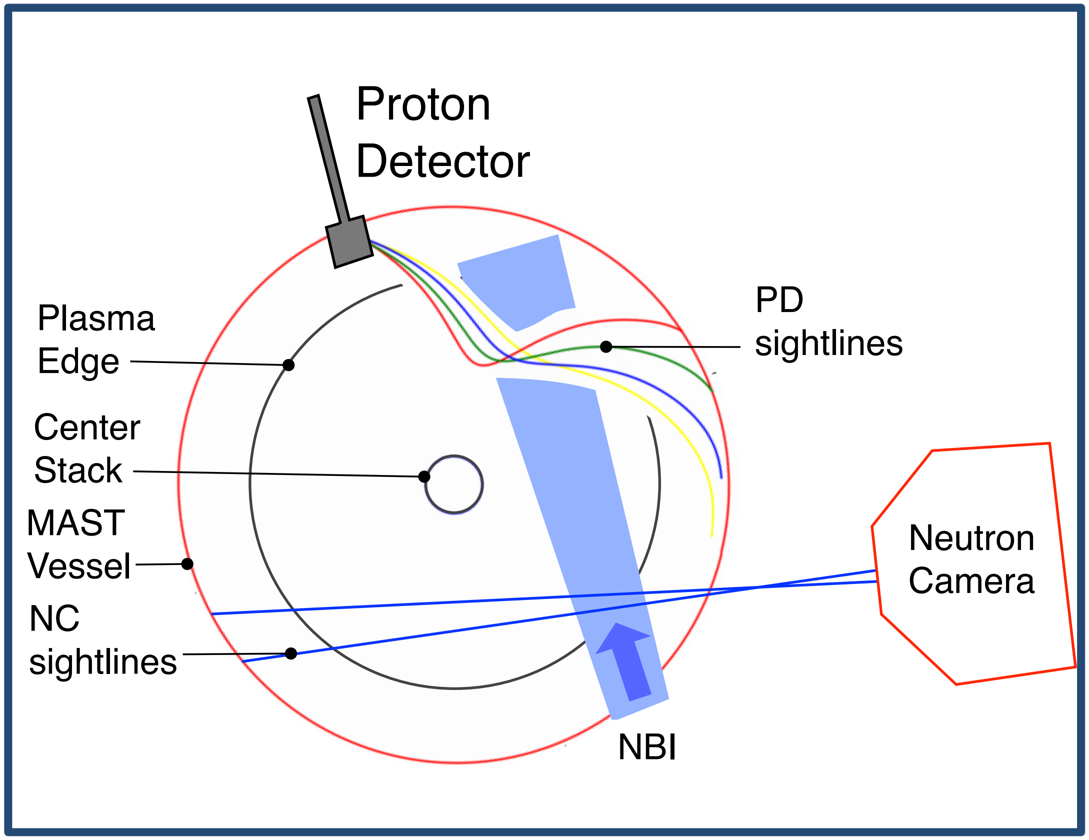


Mega Amp Spherical Tokamak
Aspect Ratio: 0.85m/0.65m =1.31

[Original Image CCFE,MAST]

Prior Work with DD Charged Fusion Products

- Collimated silicon detectors surface barrier detectors for detecting ions - Strachan (1986) and Lo *et.al.* (1995)
- 3MeV proton energy spectra in conventional tokamaks - Chrien *et.al.* (1983), Heidbrink *et.al.* (1985), and Bosch (1990)
- MAST fast ion diagnostics - Jones *et.al.* (2013), Cecconello, *et. al.* (2014)
- MAST neutron camera (NC) measures same profile using 2.5MeV neutrons



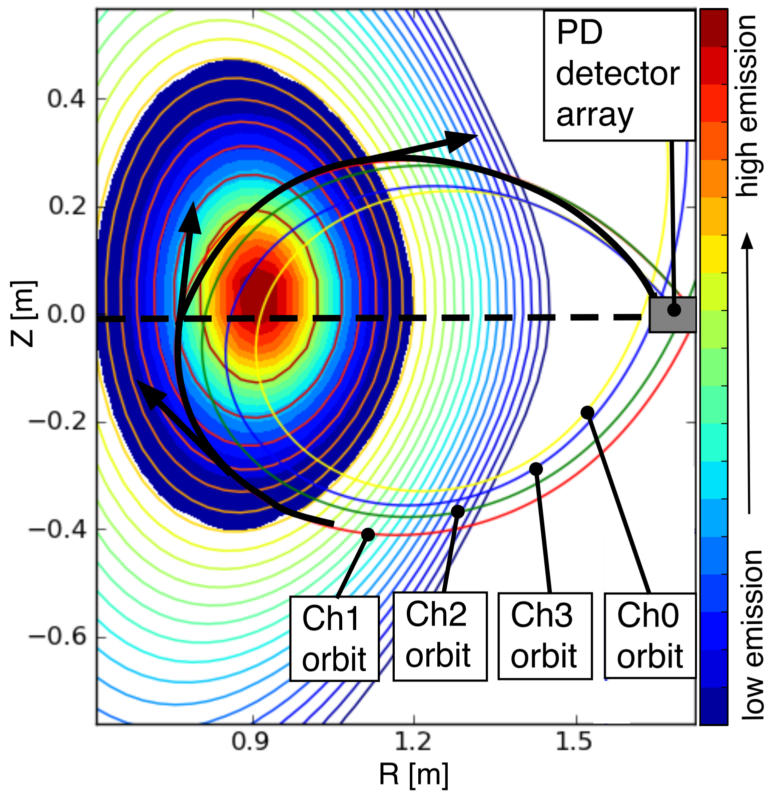
[Original Image Cecconello *et al.* (2012)]

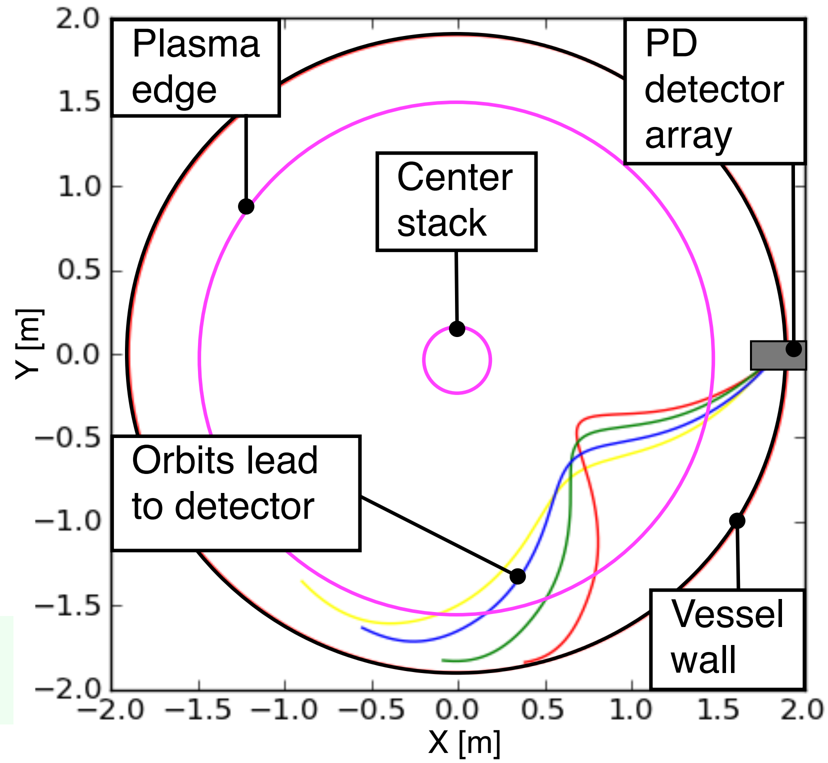
DD Charged Fusion Product Emissions of Interest

- Primary
  - D + D → P (3MeV) + T (1MeV)
  - D + D → N (2.5MeV) + ^{3}He (0.8MeV)
- Secondary
  - D + T → N (14.1MeV) + ^{4}He(3.5MeV)
  - D + ^{3}He → ^{4}He (3.6MeV) + P(14.7MeV)

- Dominant signal from beam-plasma fusion events during Neutral Beam Injection (NBI)
- Potential application of proton detector (PD) to study beam ion confinement and heating profile

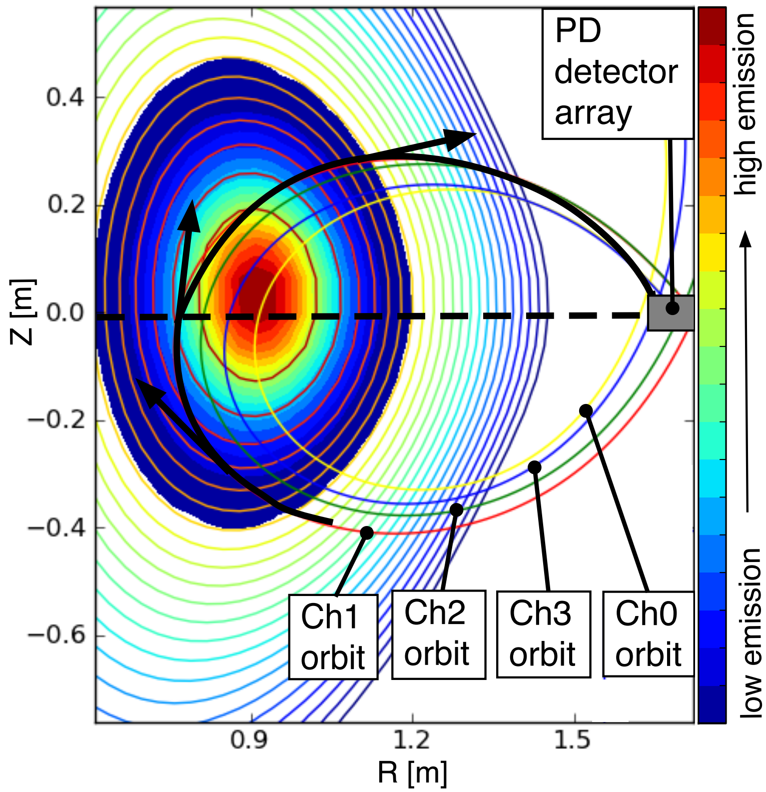
Poloidal and Toroidal Orbit Trajectories

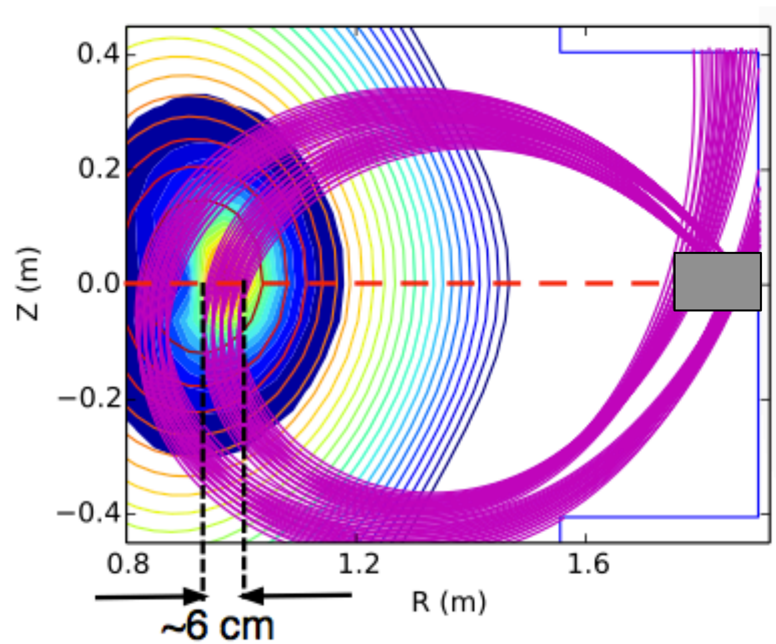




Note an isotropic DD cross section is assumed

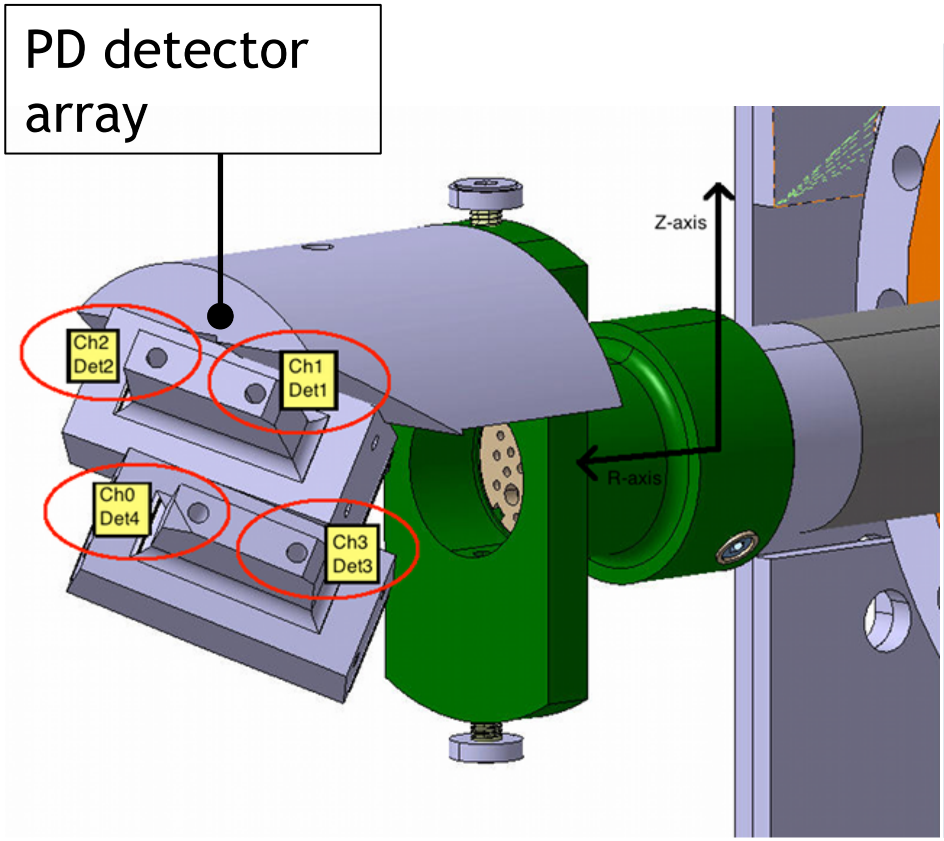
Orbit bundles for central trajectories

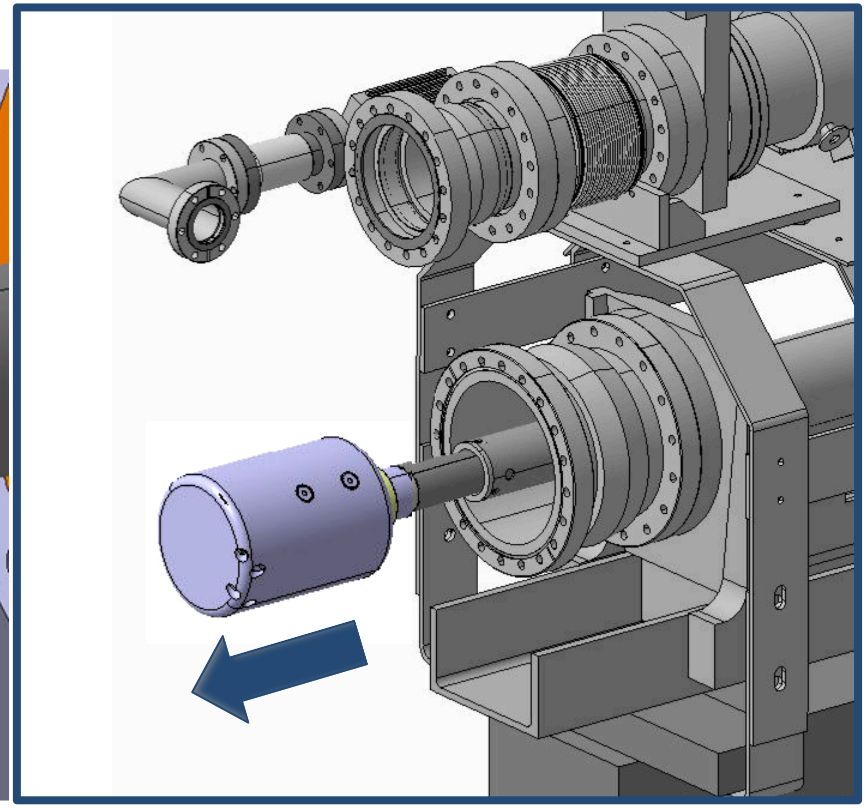




Finite acceptance of collimator-detector system

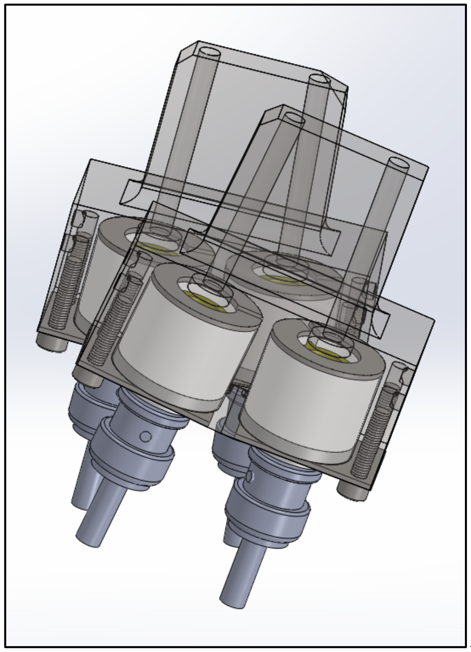
Mechanical probe arm pushes PD towards plasma

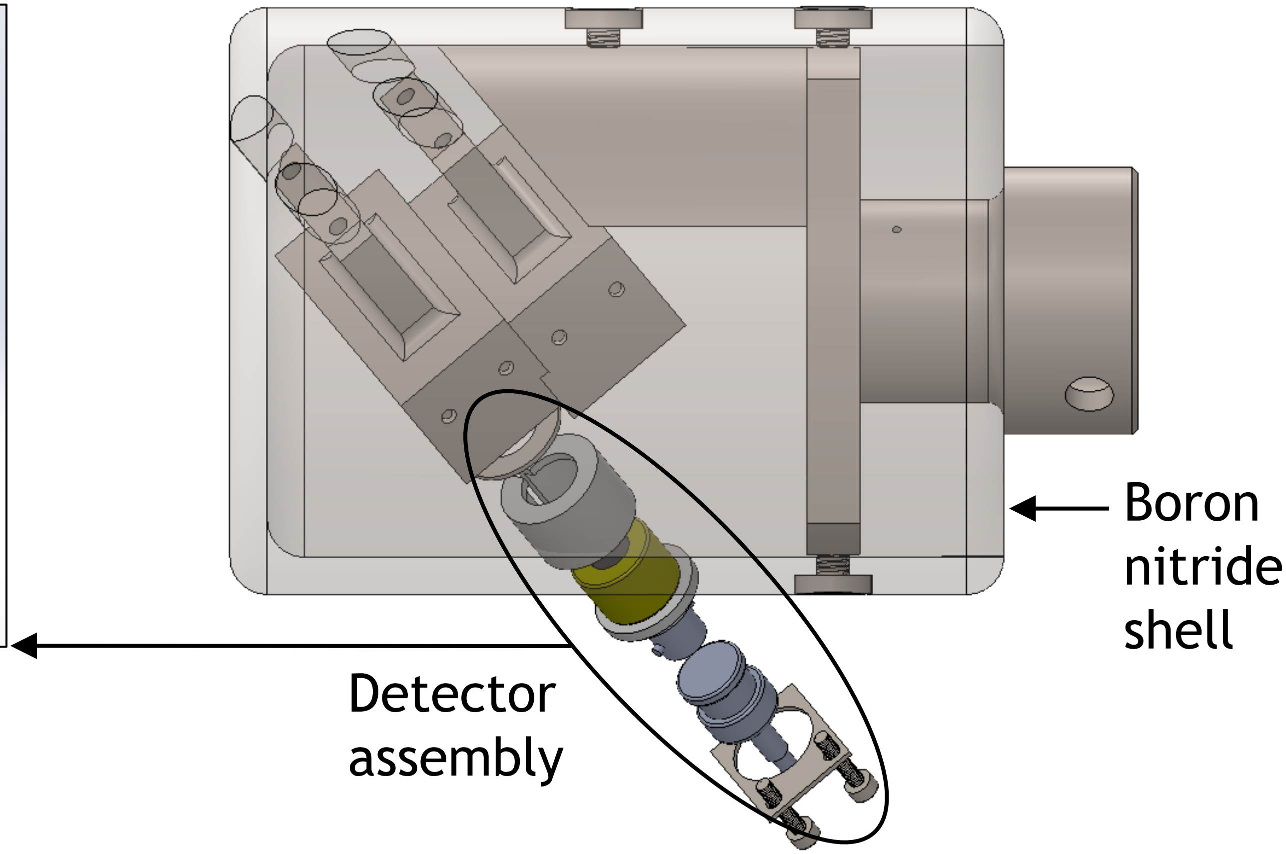




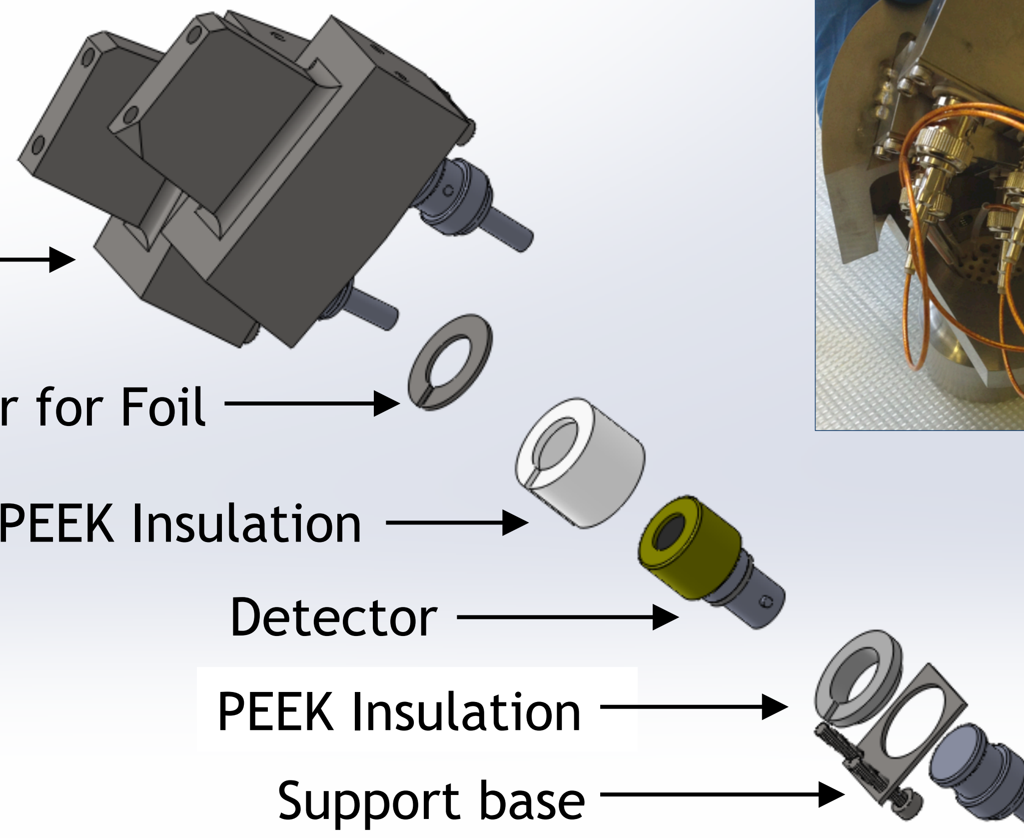
[Original Images CCFE,MAST]

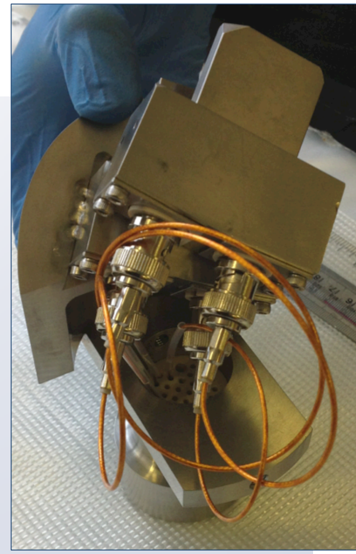
Compact Housing: 110mm diameter, 185mm length





Main housing: detector assembly components





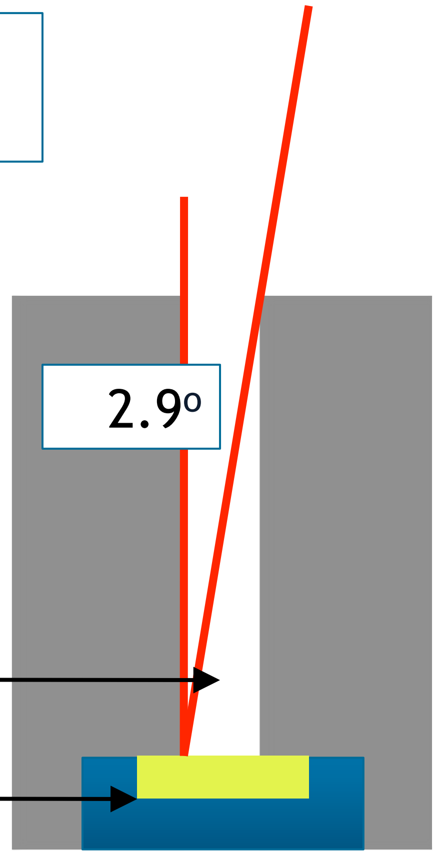
- <u>Energy loss through 0.8μm foil</u>
- Proton 18.4 keV
- Triton 34.6keV
- ^{3}He 282keV

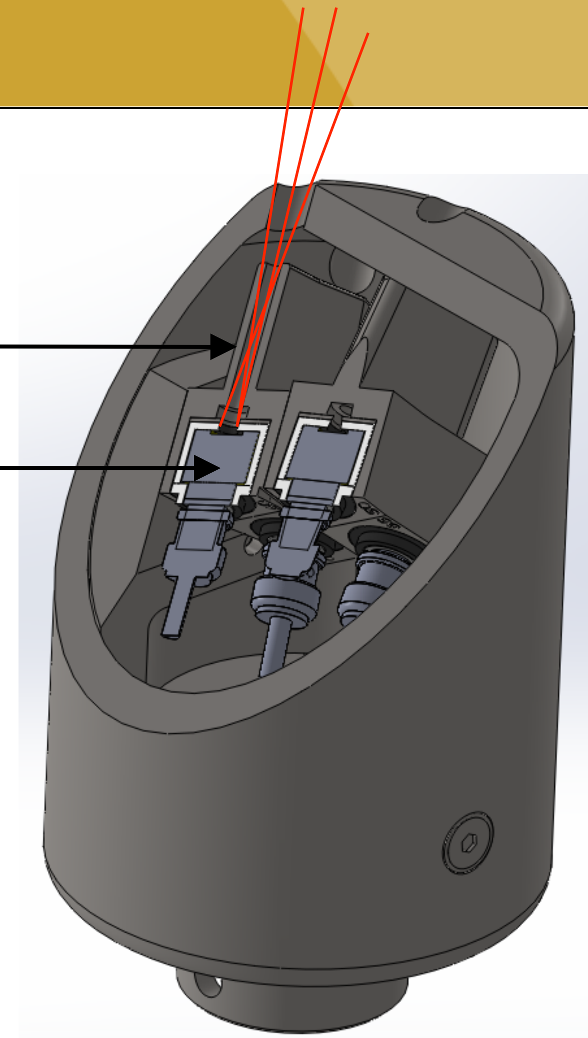
- Detective active layer 100μm

Note: we use silicon surface barrier detectors and not silicon photodiode detectors.

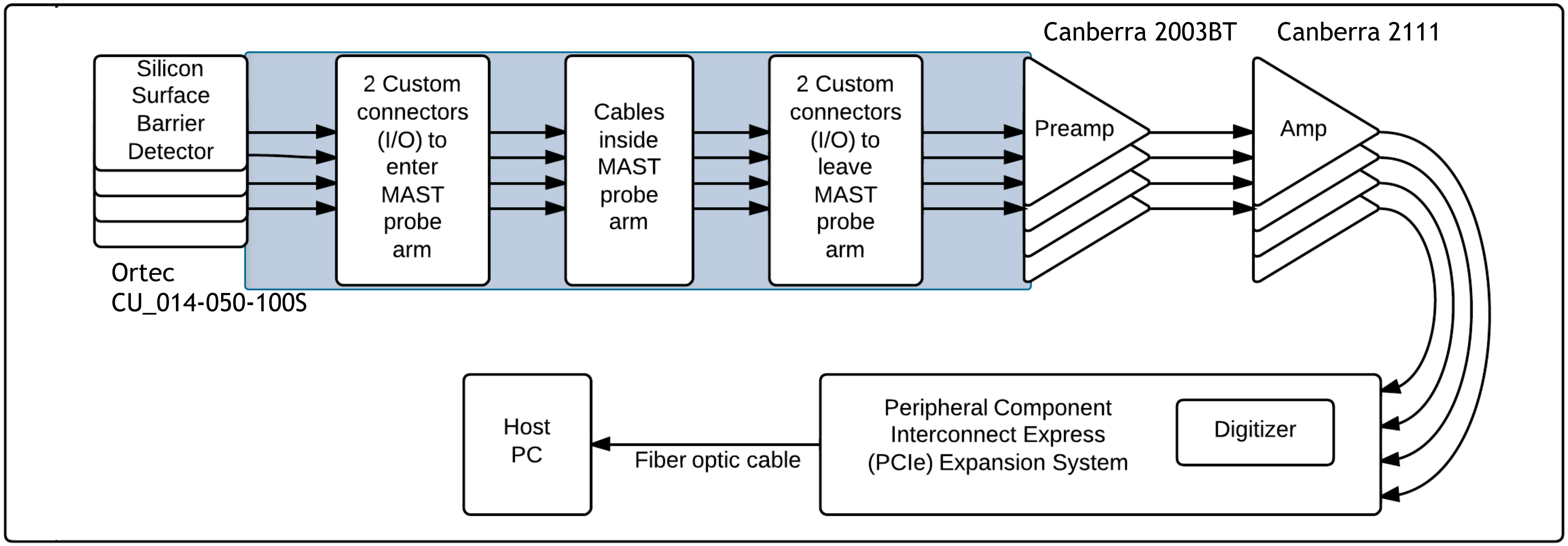
Acceptance of collimator

Acceptance:
9.83×10^{-8} (Srm^2)





Data acquisition schema



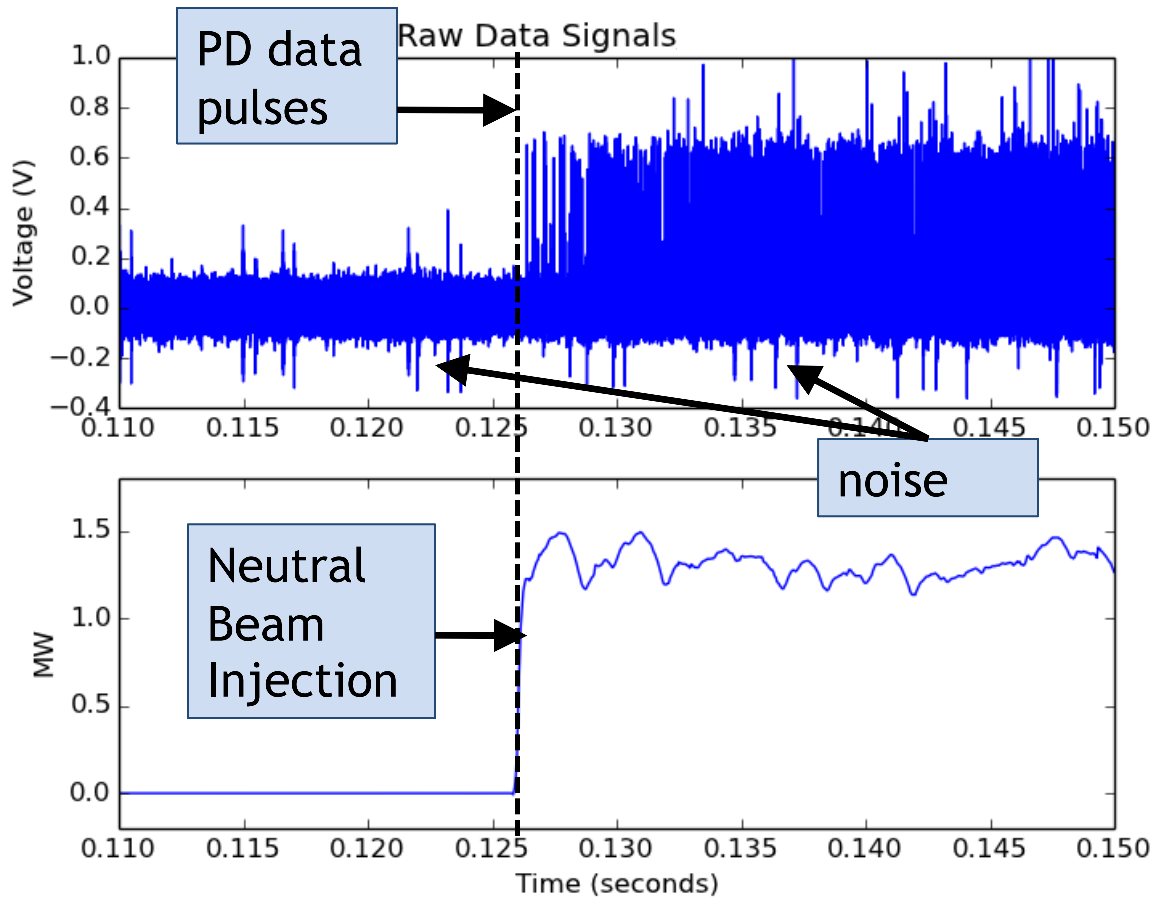
Supermicro5016I-MTF

Adnaco-S2 PCIe and NI PCI-5105 high-speed digitizer
LabVIEW software

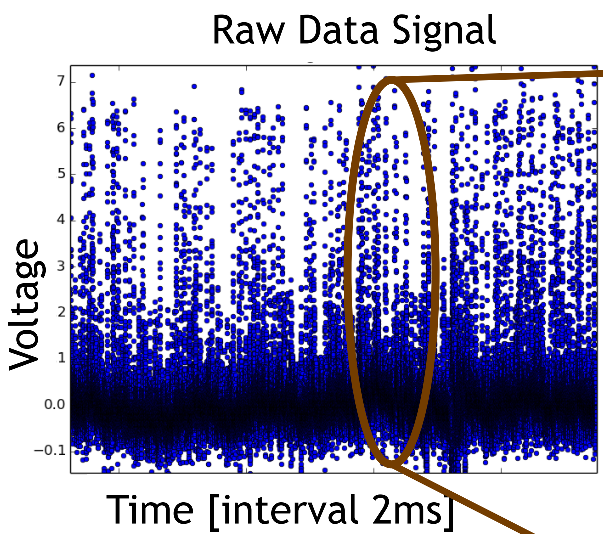
3m (not drawn to scale) from detector to preamp was not part of the original design but was an unavoidable constraint caused by the logistics of installation on the mechanical arm

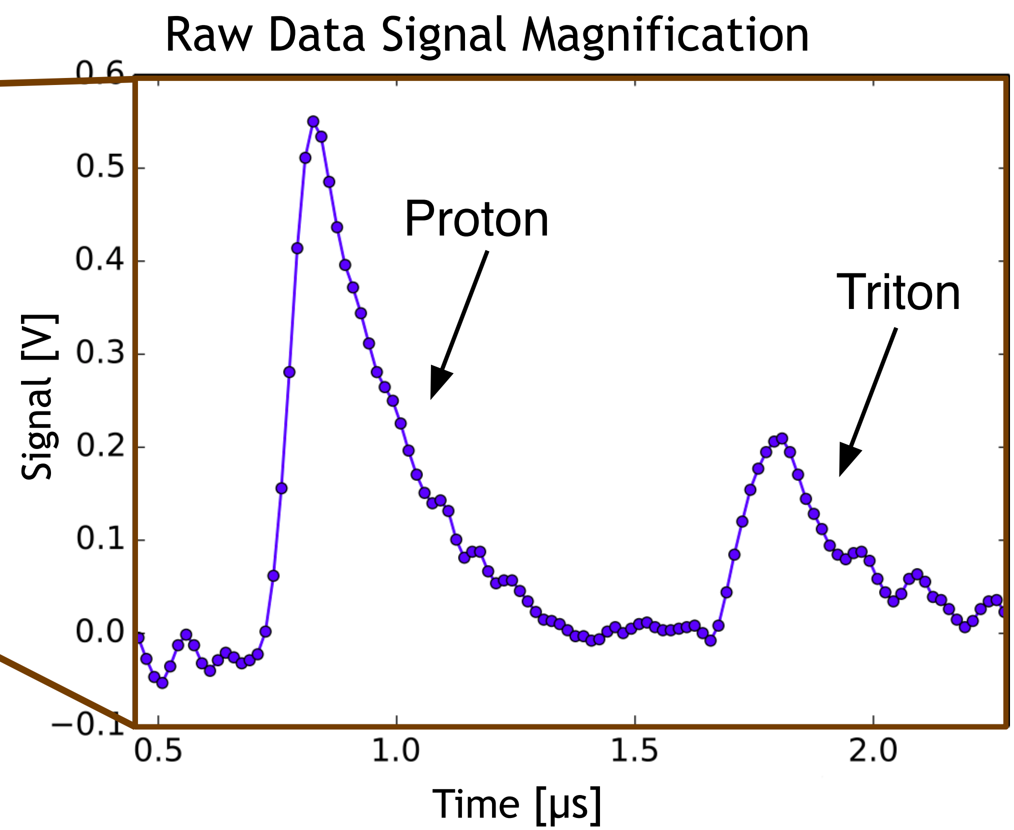
Signal dependence on Neutral Beam Injection

- Data continuously sampled at 60MHz
- Length of plasma discharge ~ 0.5s
- Signals/ pulses showed clear dependence on neutral beam power



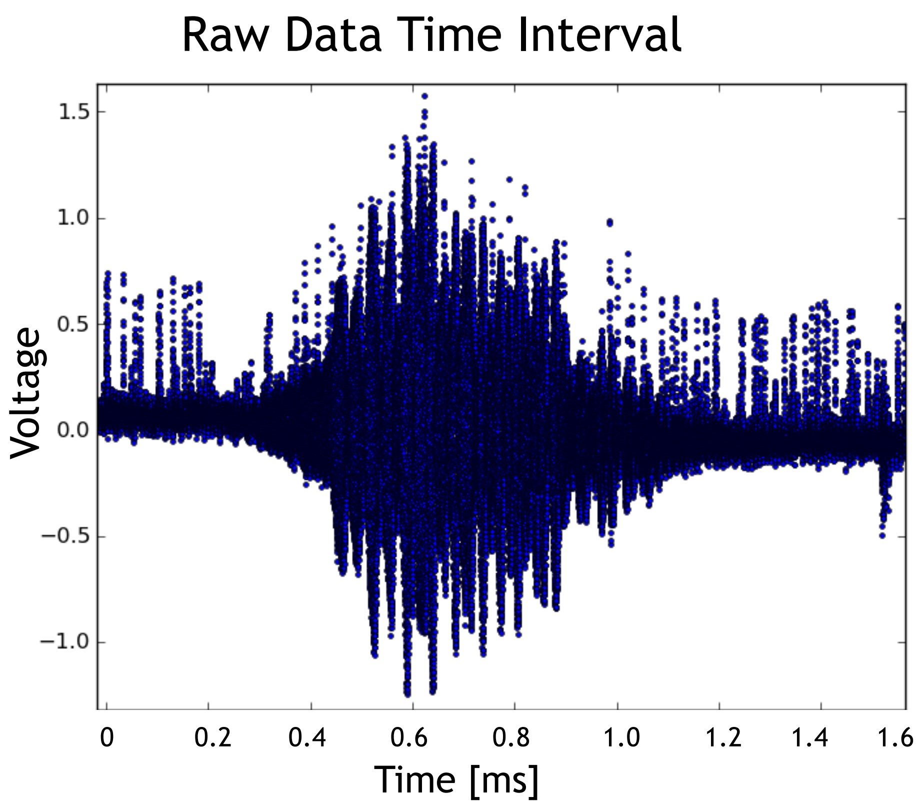
Characteristic particle signals found in data

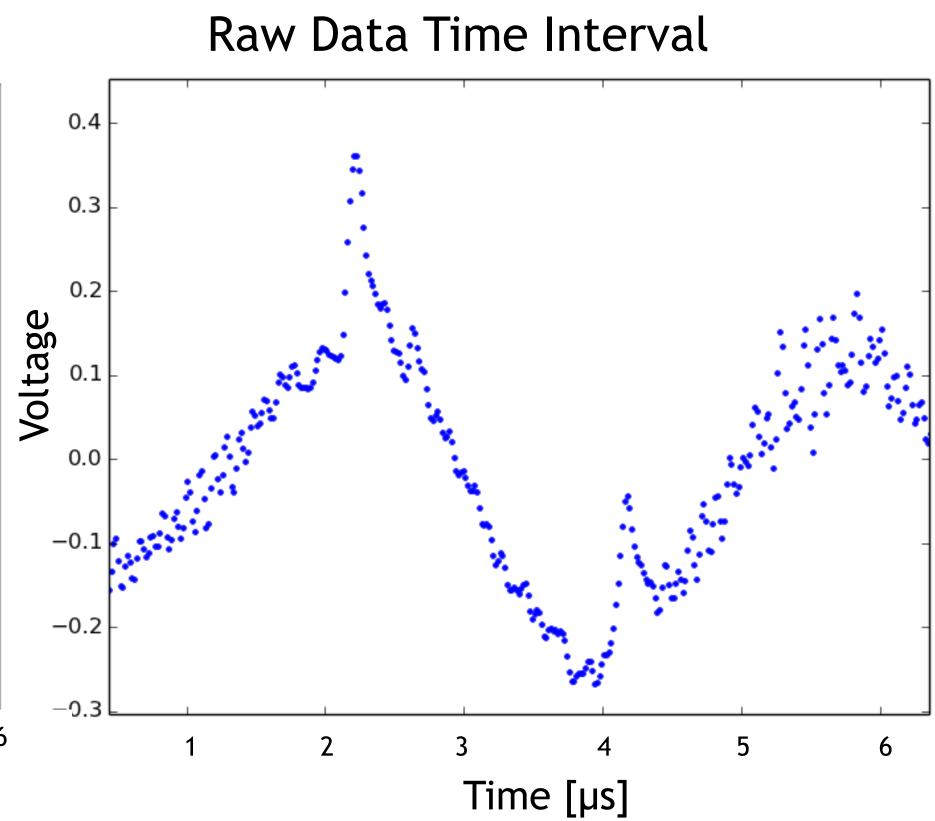




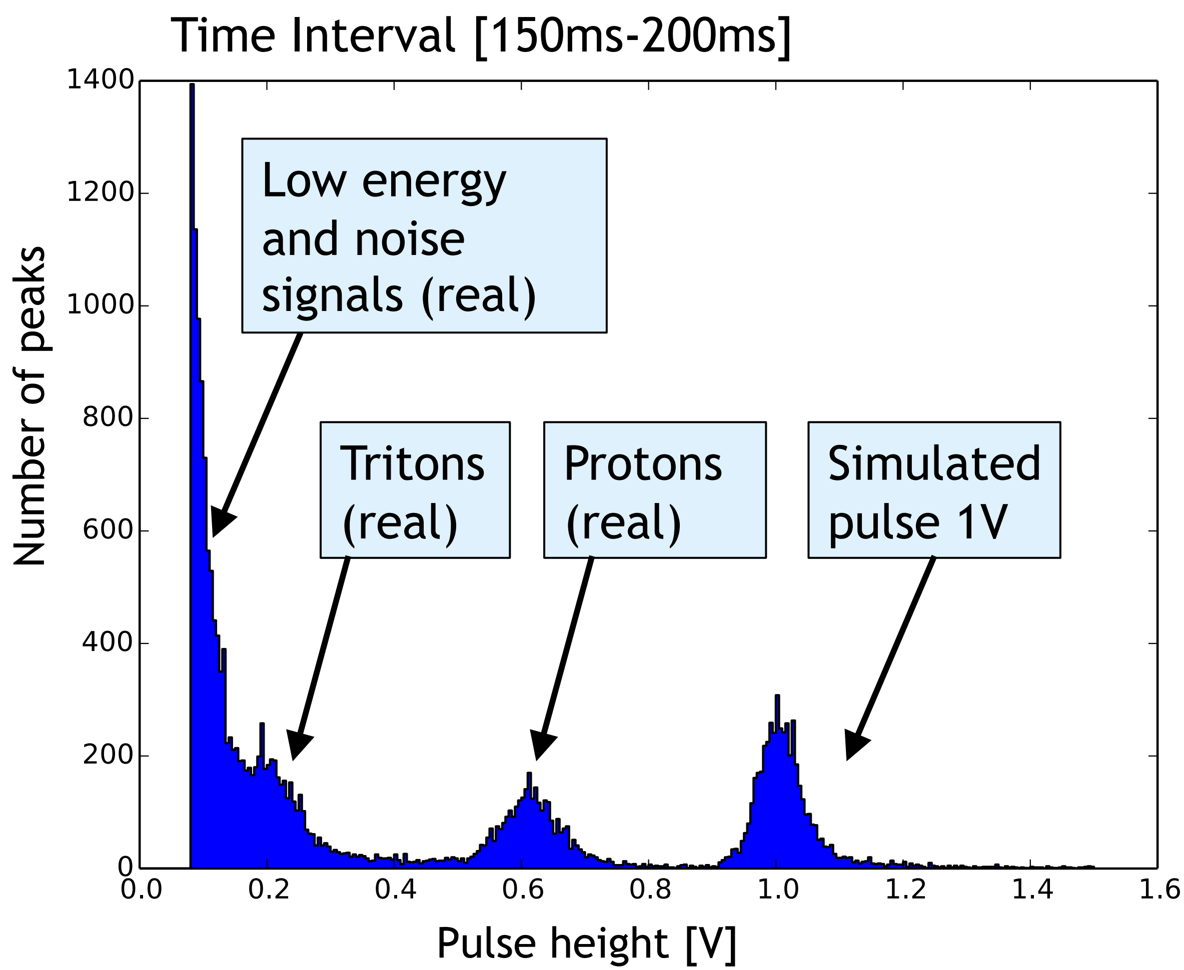
- Peak/ pulse shapes:
- Height ~0.6V for P (3MeV)
- Height ~0.2V for T (1MeV)
- Width ~100ns

Example noise signals found within a data channel



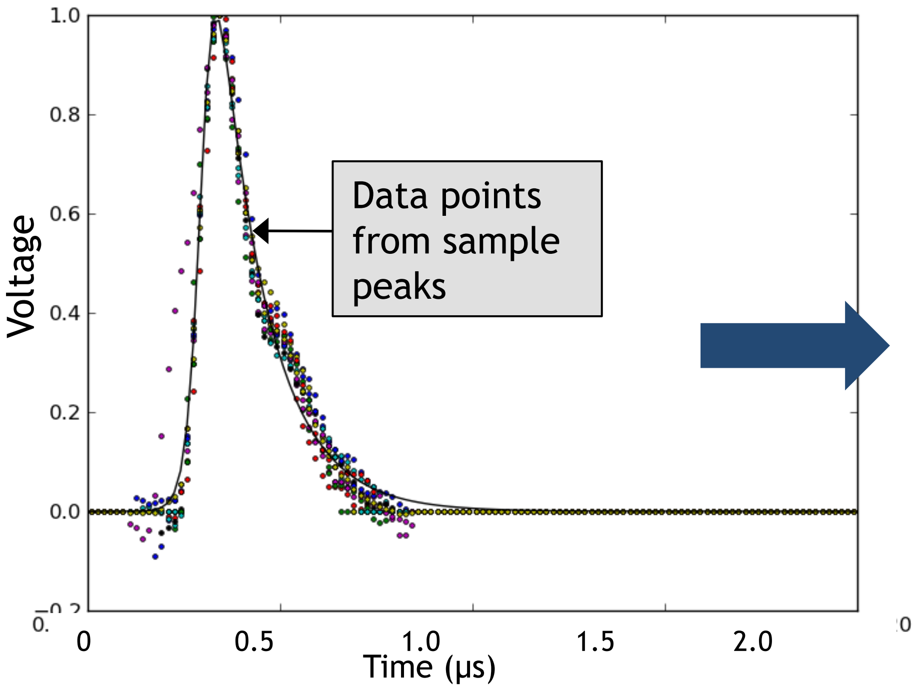


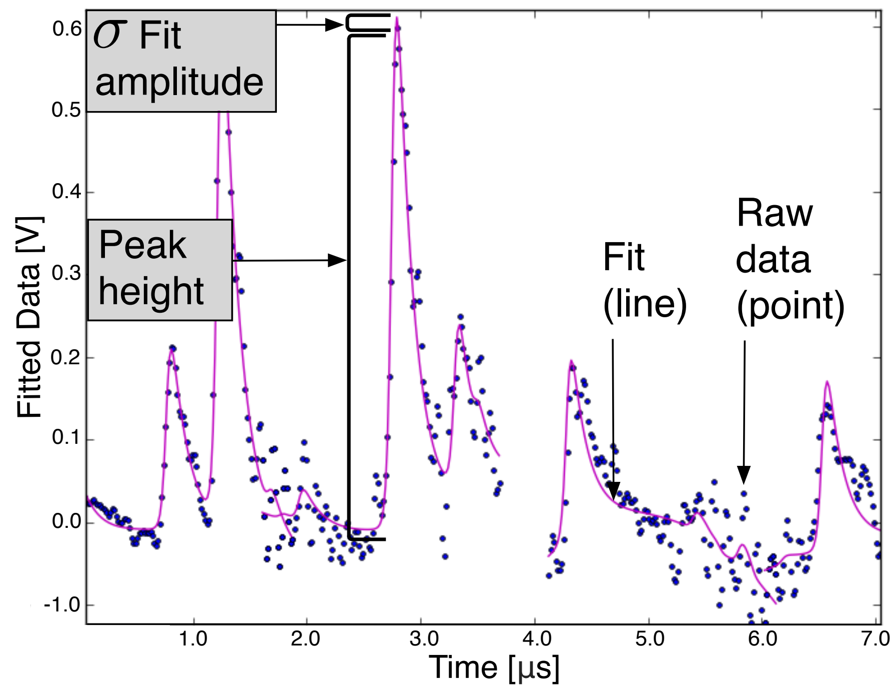
Pulse-height spectra without fitting data



- Search for peaks (within a threshold)
- Determine their pulse height
- Histogram of pulse height

Peak fitting method to mitigate noise contribution



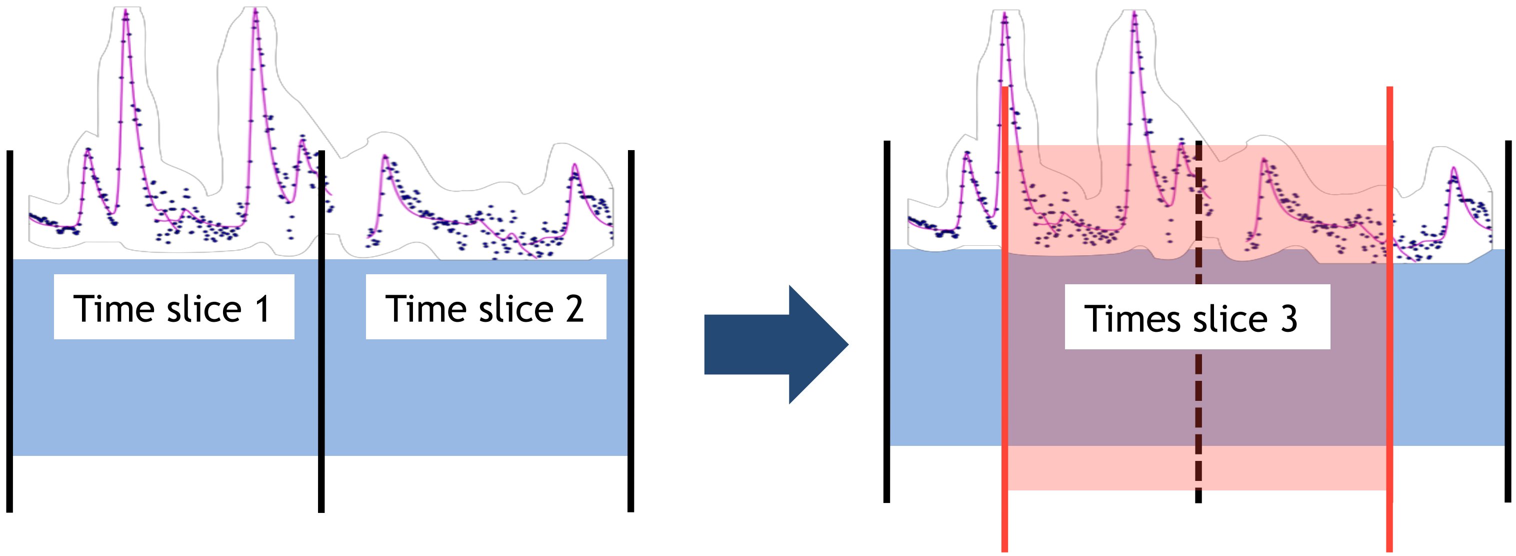


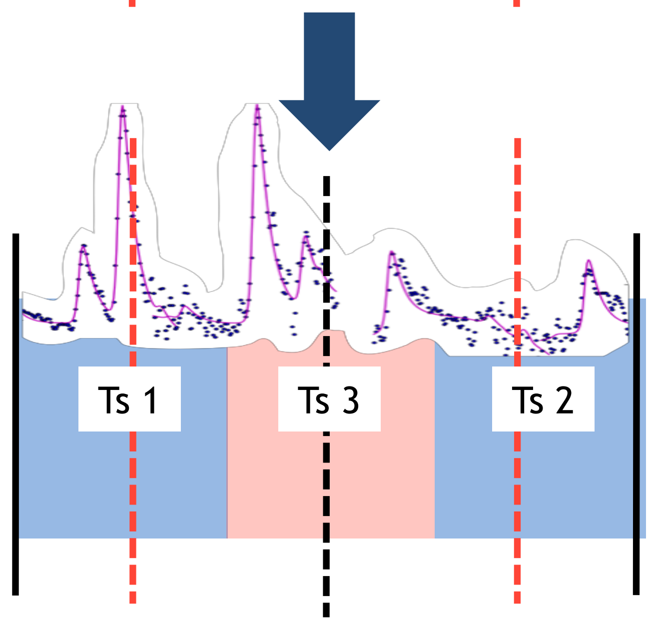
- Sample set of peaks are chosen, normalized, and used to create a peak fit function

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

- Data is fitted against quadratic background

Iteratively fit intervals of data within a channel





- Within a time slice:
  - Fix peak positions (width)
  - Vary peak height (to get fit amplitude)
  - Vary background (quadratic)