Neutron Beam Monitoring with Hybrid Pixel Detectors

Stuart George

Second Special Workshop on Neutron Detection with MPGD's
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Neutron Beam Monitoring with Hybrid Pixel Detectors

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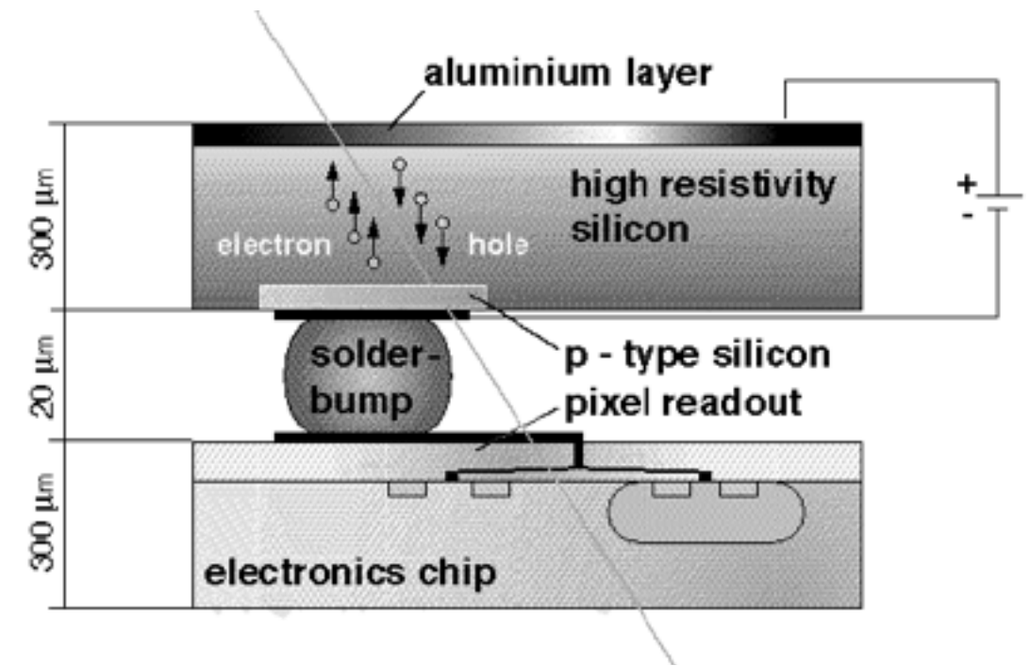
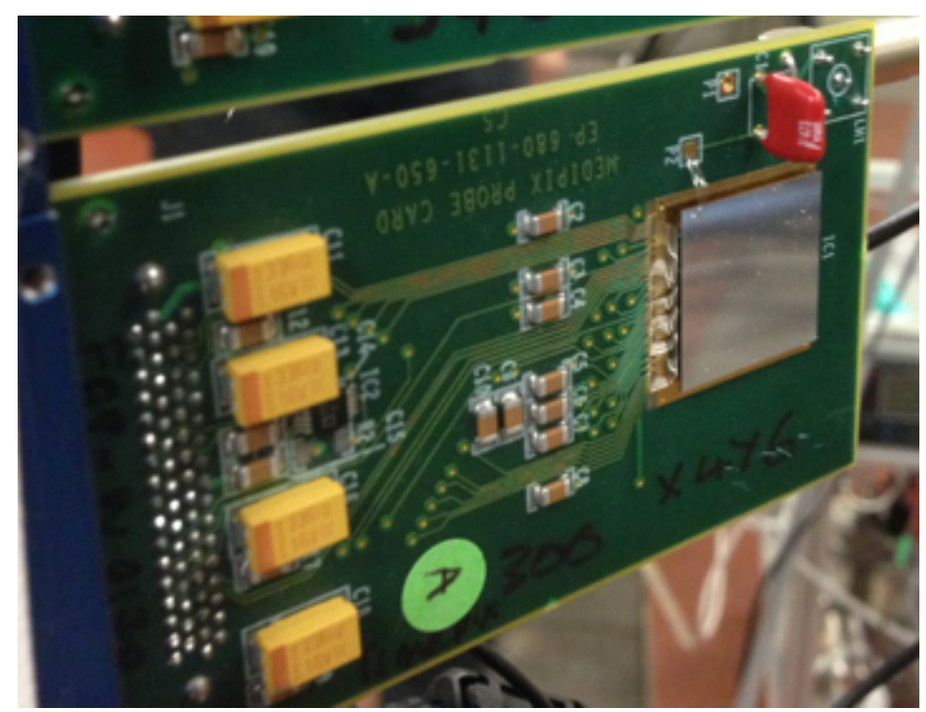
Thanks to, Eric Bosne, Erik Frojdh, Stefano Agosteo and John Idarraga

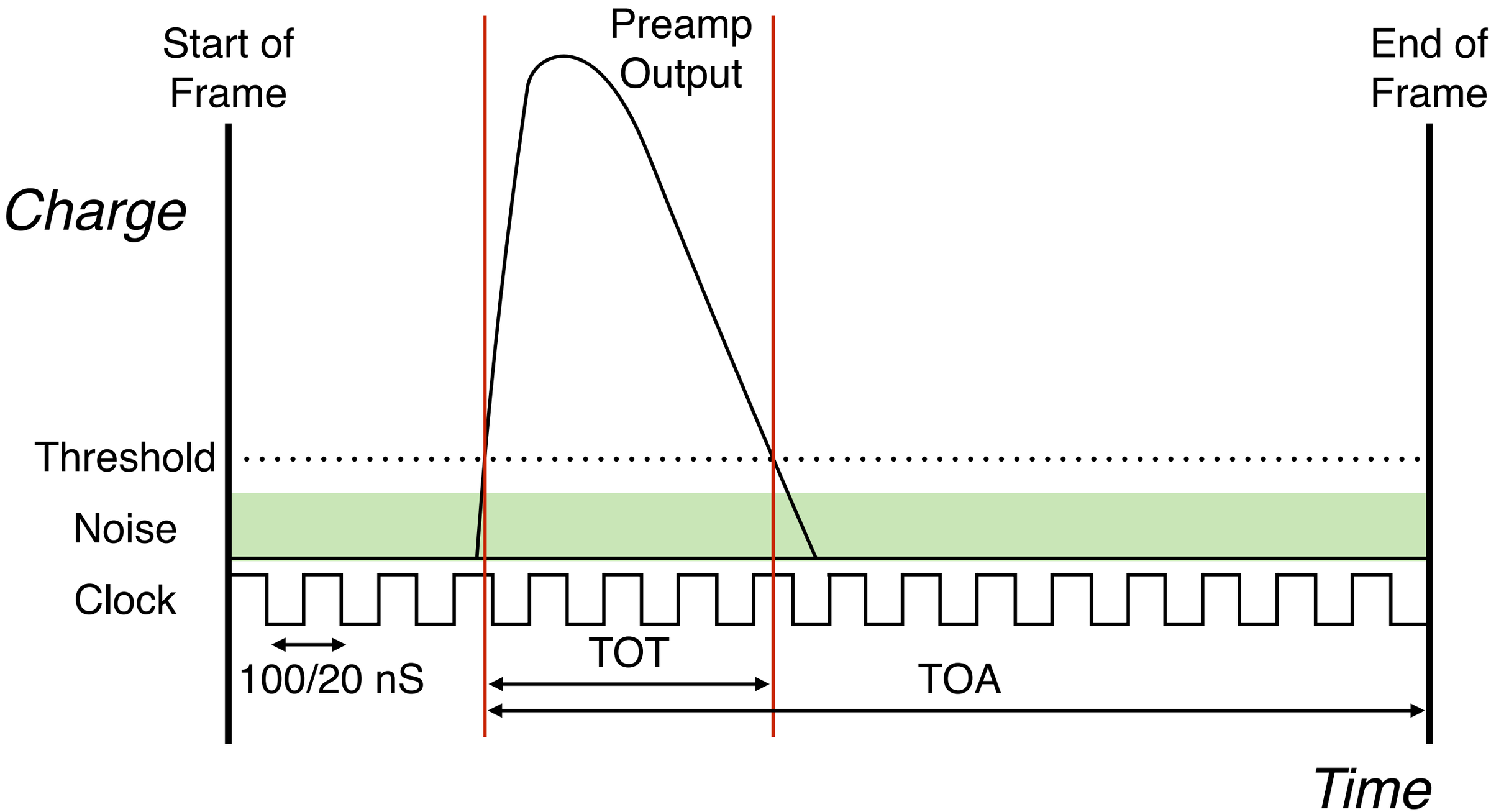
Hybrid Pixel Detectors

- A hybrid pixel detector decouples the readout system of a pixellated detector from the sensor
- The timepix is a hybrid pixel detector developed by the Medipix Collaboration
- Each pixel measures 55μm x 55μm
- 256 by 256 pixels for a $2cm^2$ area
- The detection threshold is about 1000 electrons
- We use a quad configuration with 512x512 pixels for a total of 262,144





Timepix Pixel

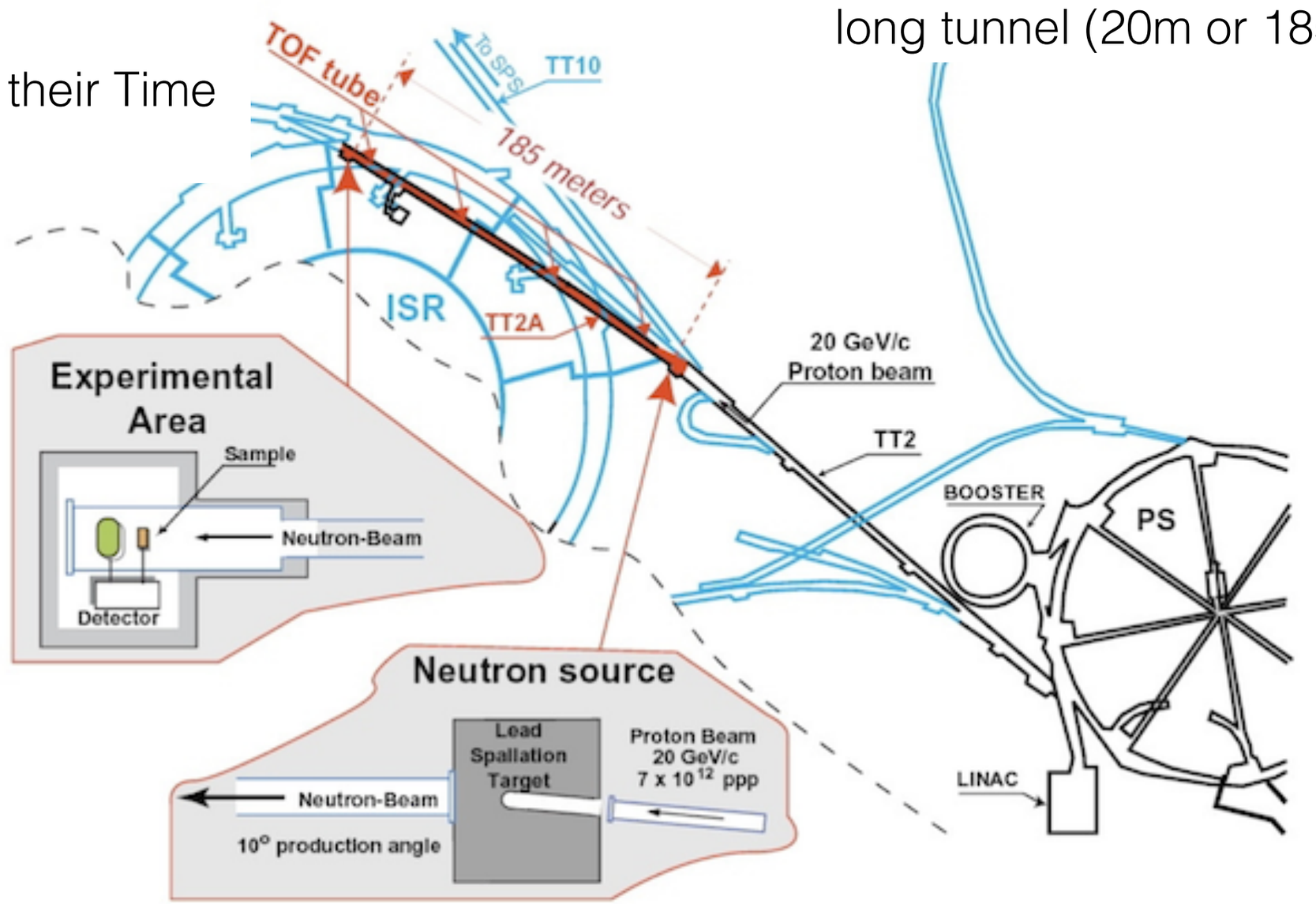


Each pixel can be individually programmed to measure TOA or TOT (and individually configurable threshold and masking)

Beam Alignment at NTOF

(3) The energy of the neutrons can be determined from their Time of Flight

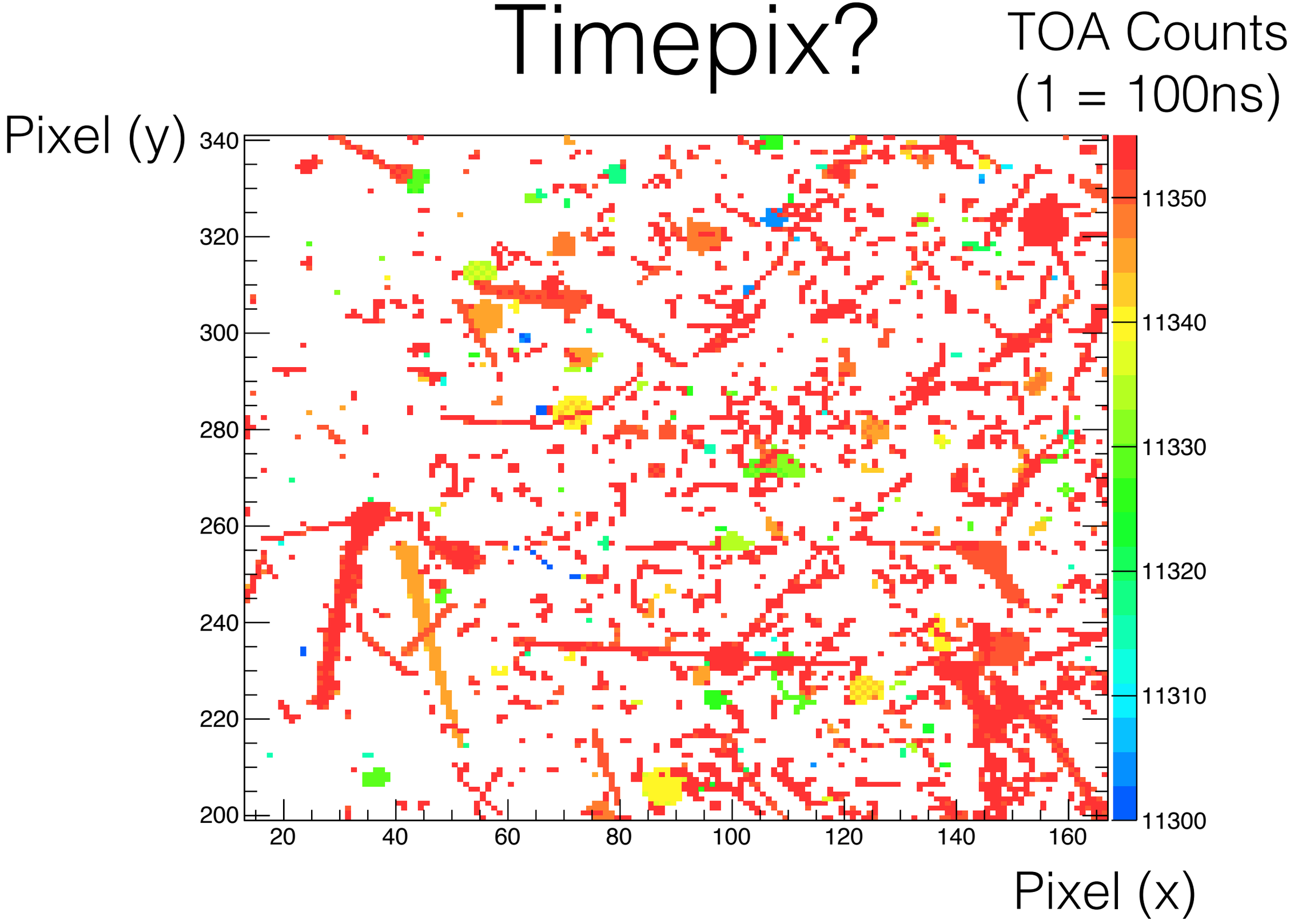
(2) These neutrons travel down a long tunnel (20m or 185m)



(1) PS Protons collide with a lead target producing neutrons

Interest in characterising the beam position for installing a new laser alignment system. Measurements using a 300 um silicon sensor with a PE converter.

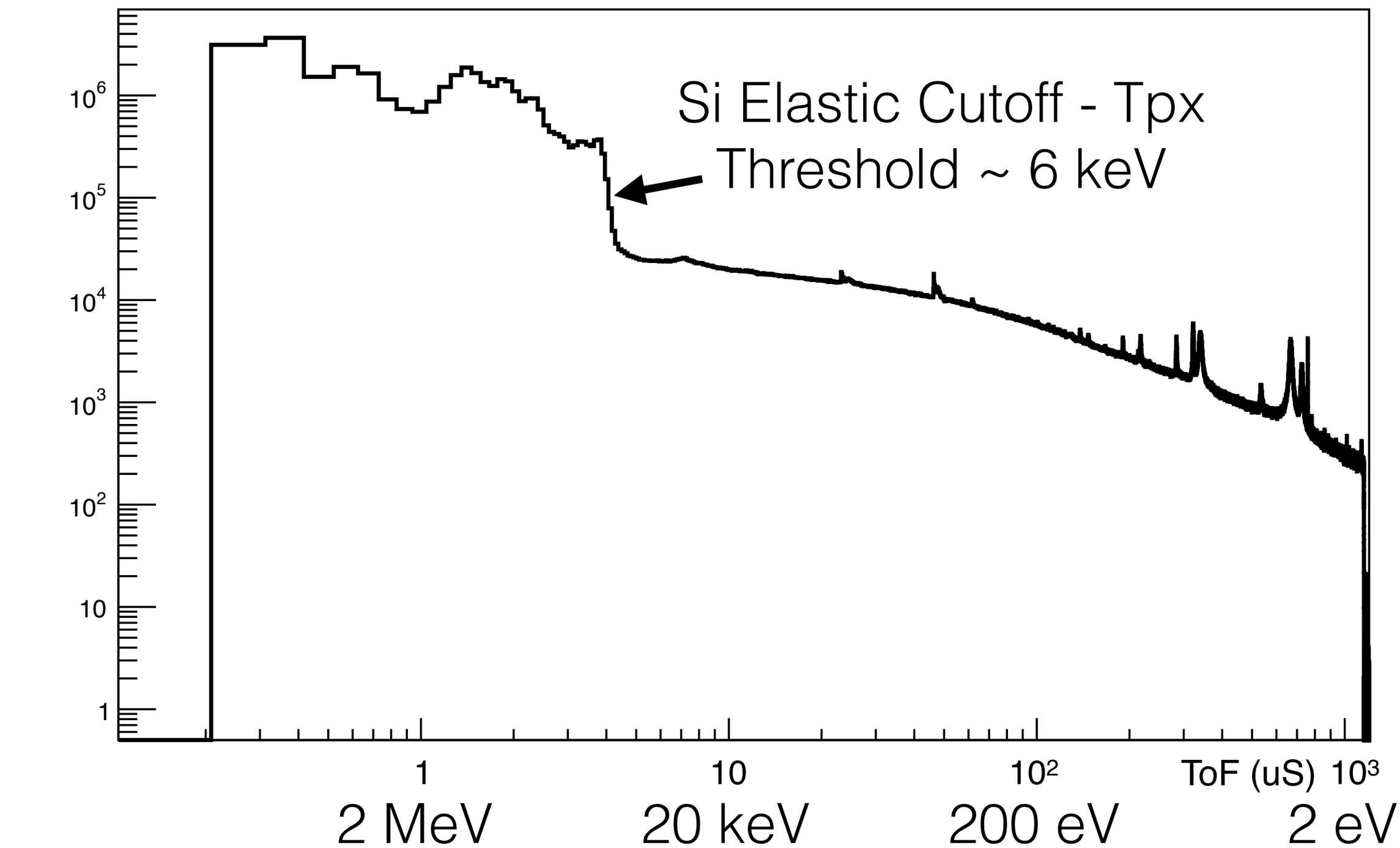
What do we measure with a Timepix?



Timepix Data

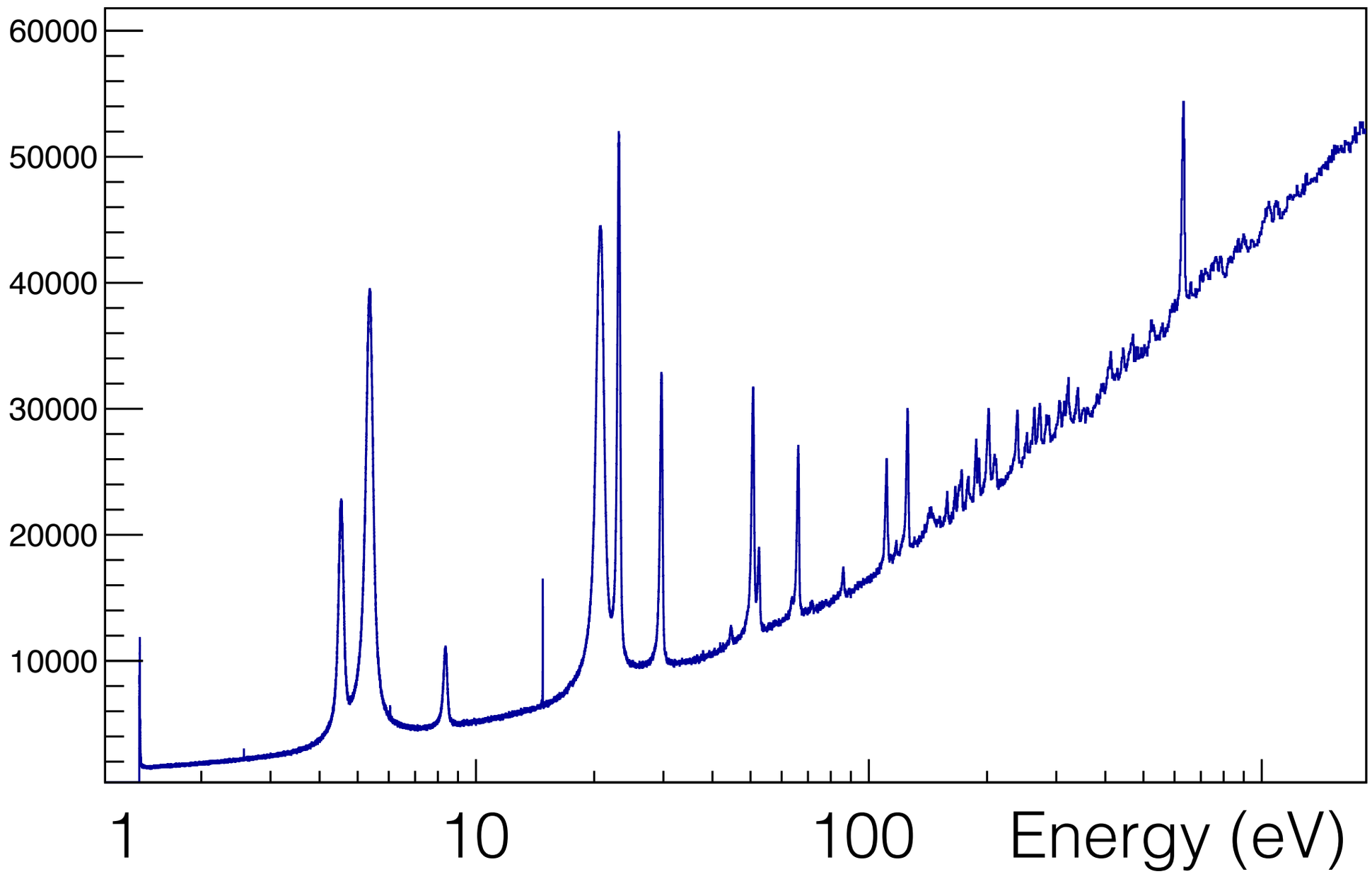
- Each track is left by the interaction of a single particle
- The tracks can be separated based on their measured time of arrival (colour scale)
- The tracks can then be separated by position, energy and type

Measured TOF Spectra at NTOF 2 (20m distance)



~3000 spills (~ 5 hrs), timepix with plastic converter

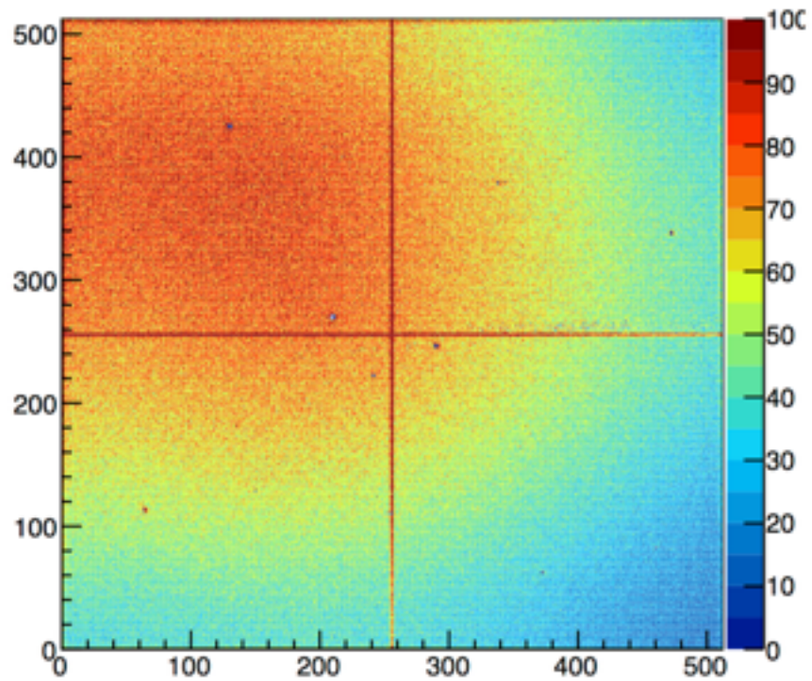
Low Energy Structure



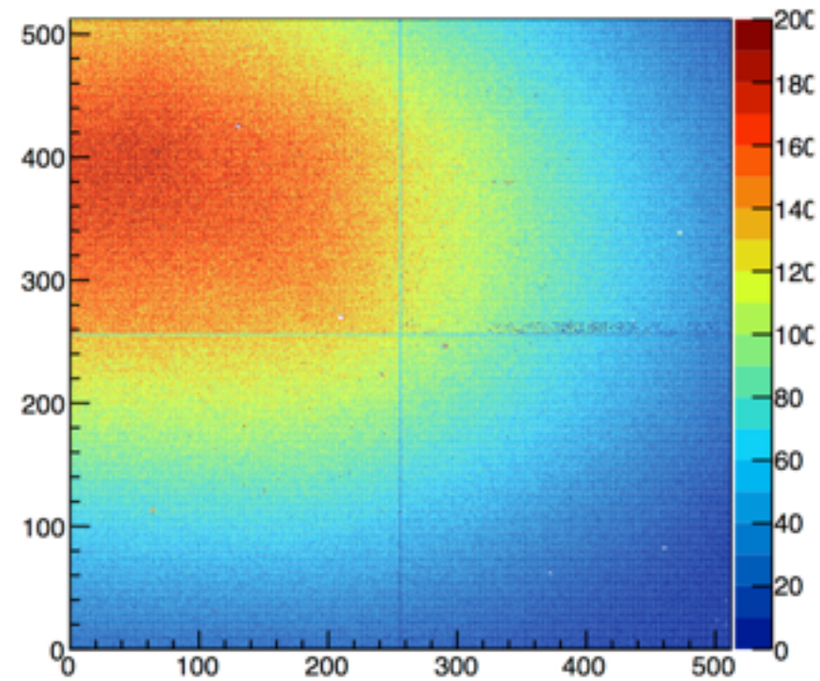
Due to neutron interactions with lead solder bumps, gold and beam line collimation elements

Beam Spot - NTOF 2

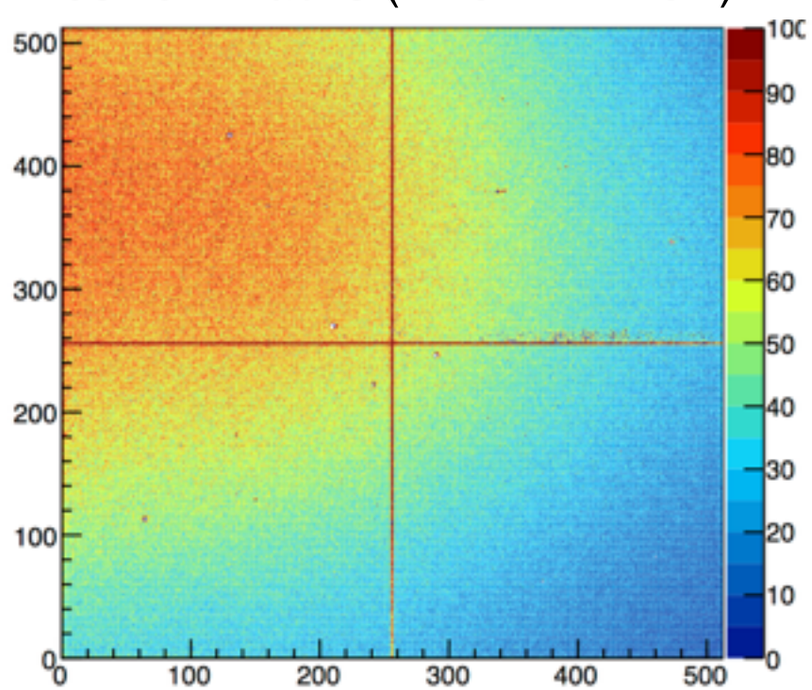
Position Tracks (20 MeV and up)



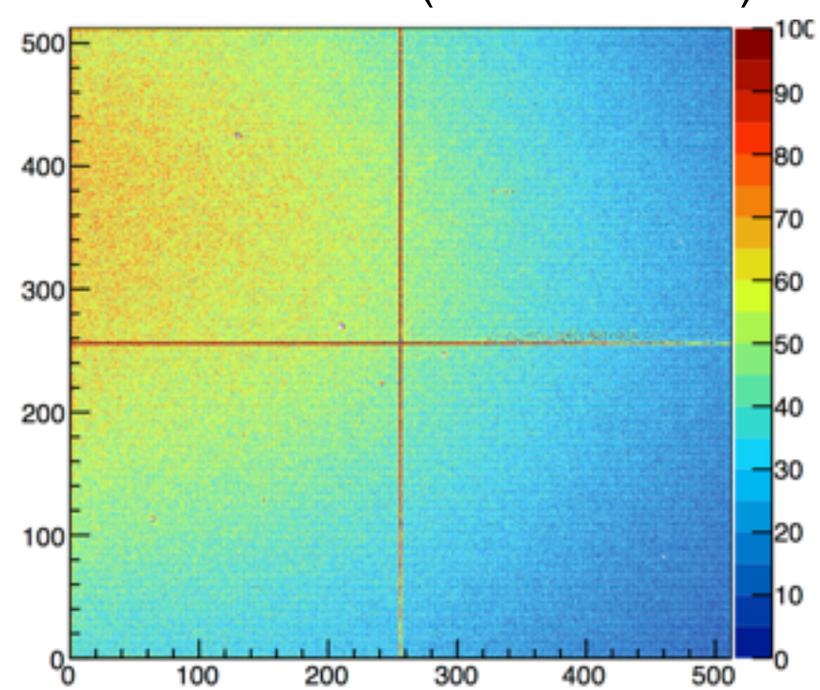
Position Tracks (1 MeV - 20 MeV)



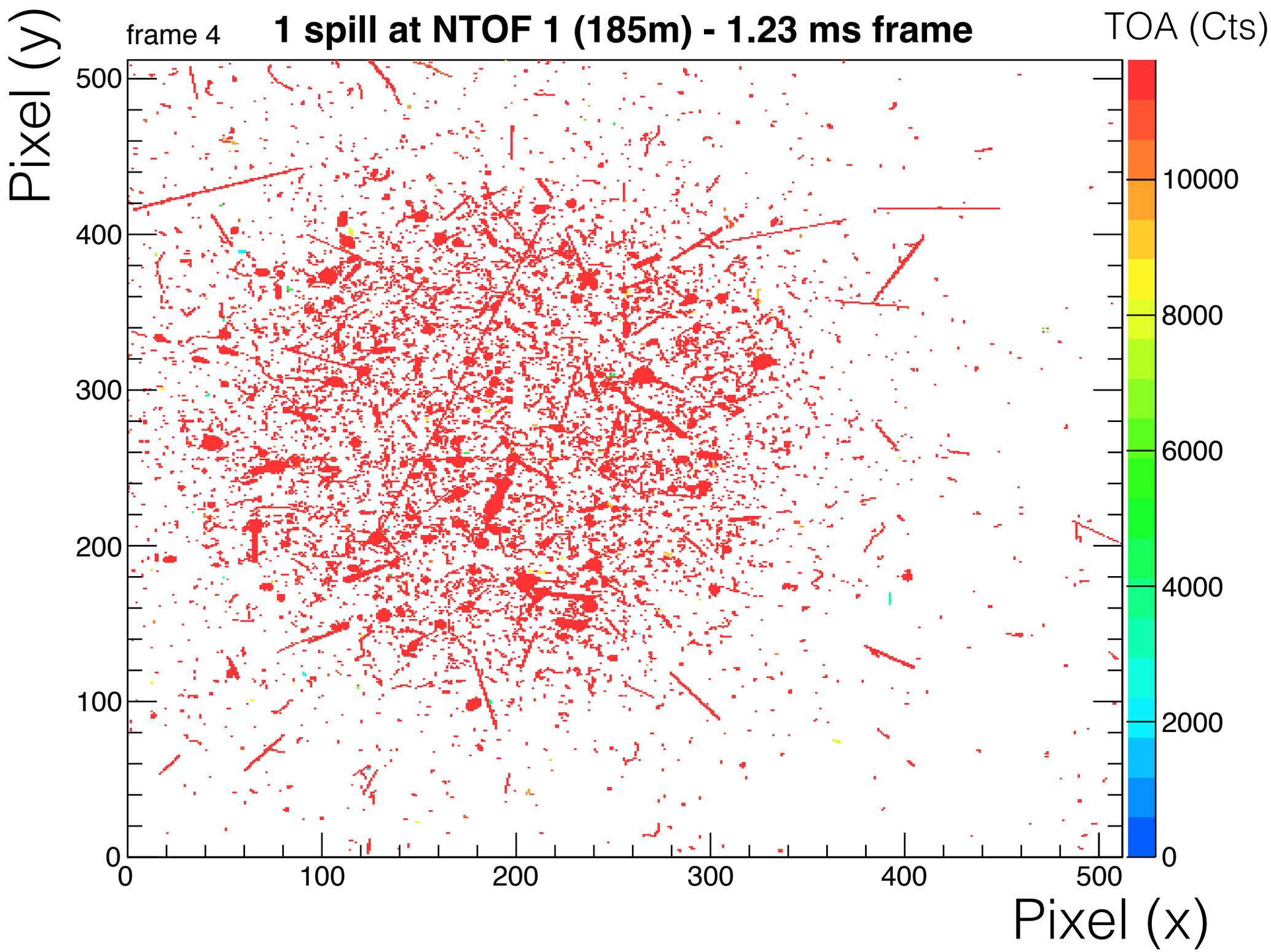
Position Tracks (1 keV - 1 MeV)



Position Tracks (20 eV - 1 keV)

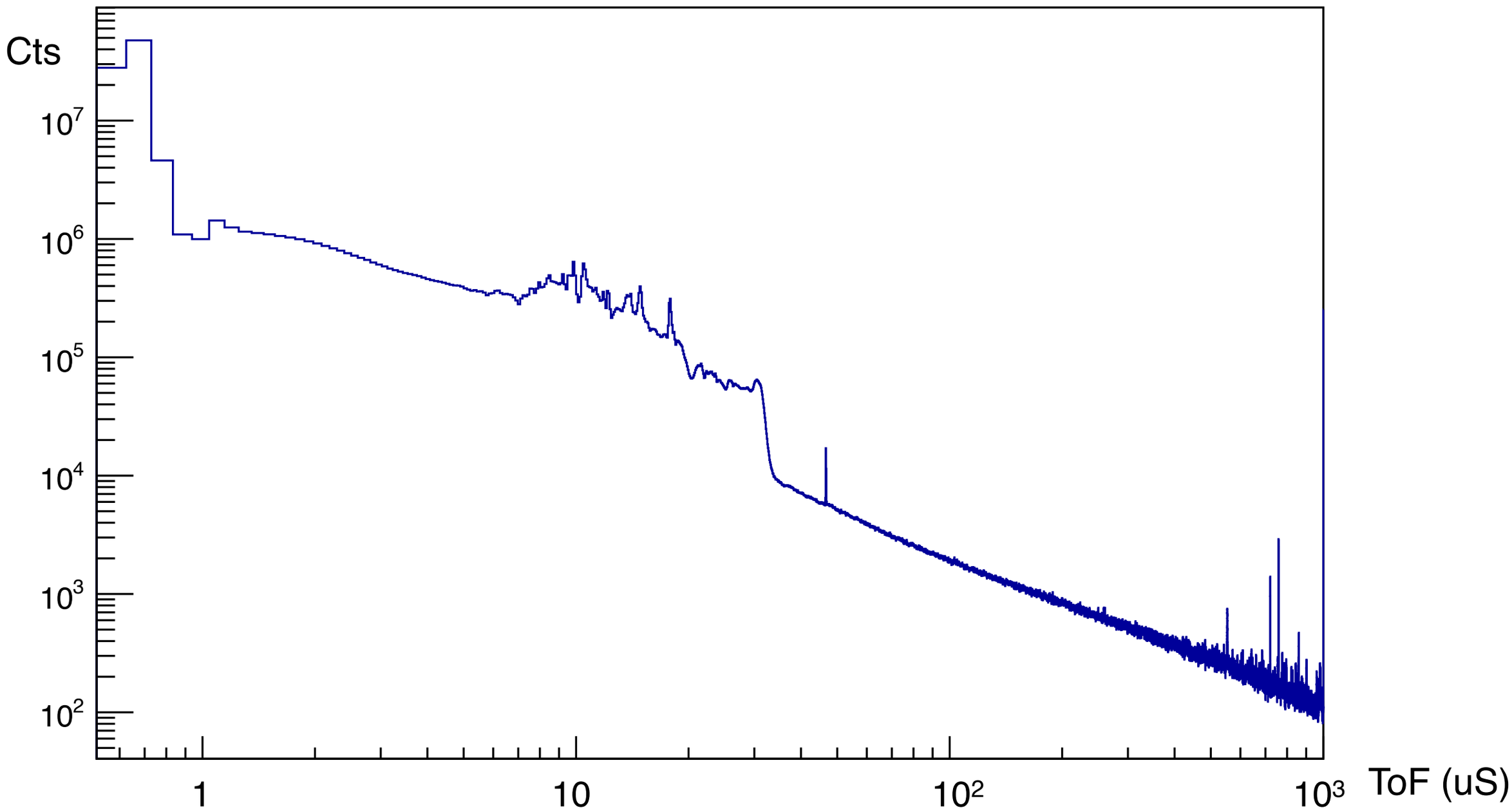


Measurements NTOF 1



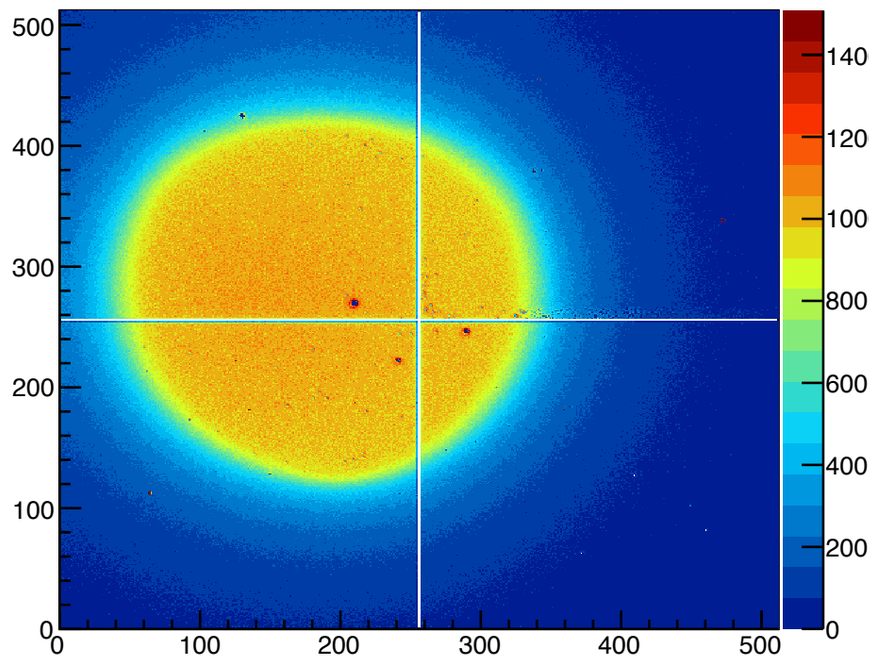
Measurements NTOF 1

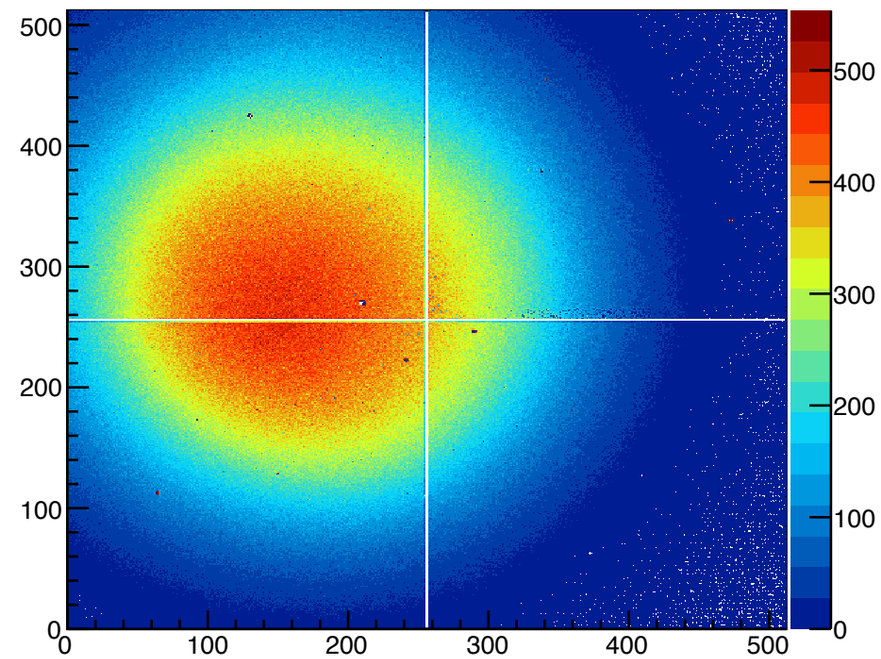
TOF Spectrum - NTOF 1 (185 m) - 9.6 Mhz Clock
Silicon sensor (.3mm) + Boron on Plastic Converter

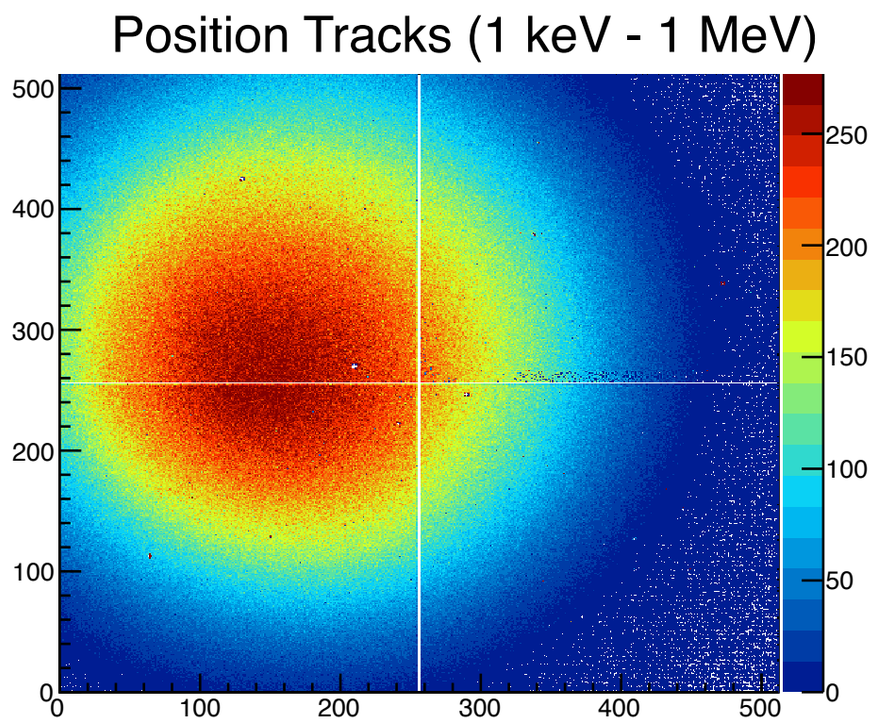


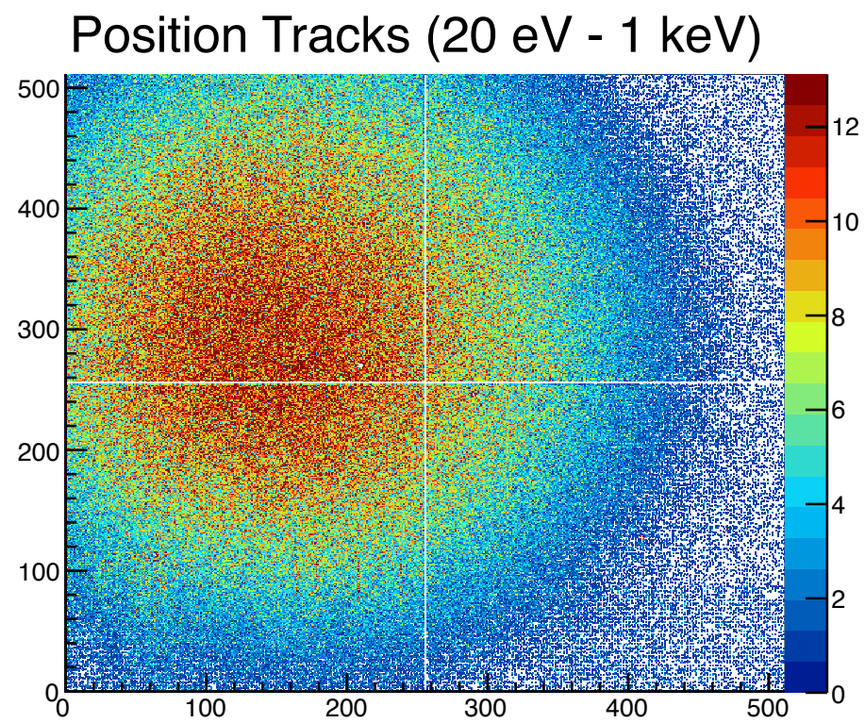
~200 MeV ~2 MeV ~20 keV ~200 eV

Beam Profiles - NTOF 1

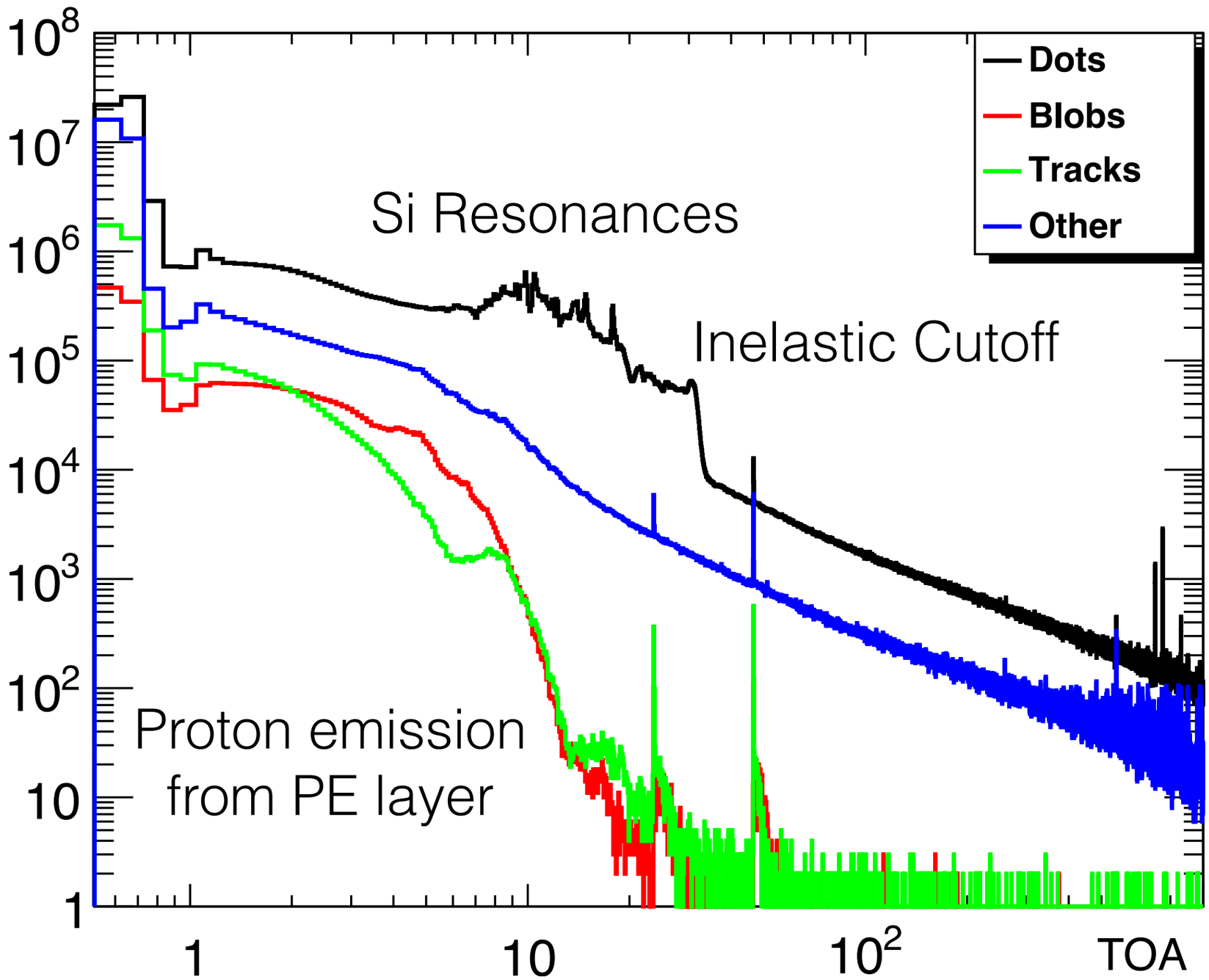








Using Morphology at NTOF 1

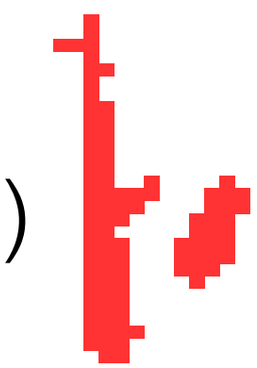


~200 MeV ~2 MeV ~20 keV ~200 eV

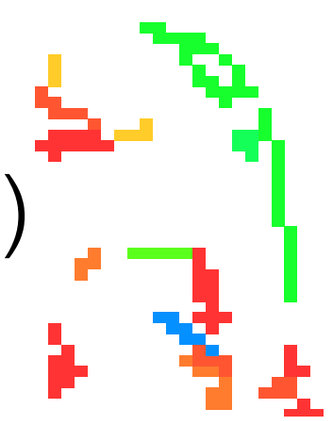
Dots
(photon-like)

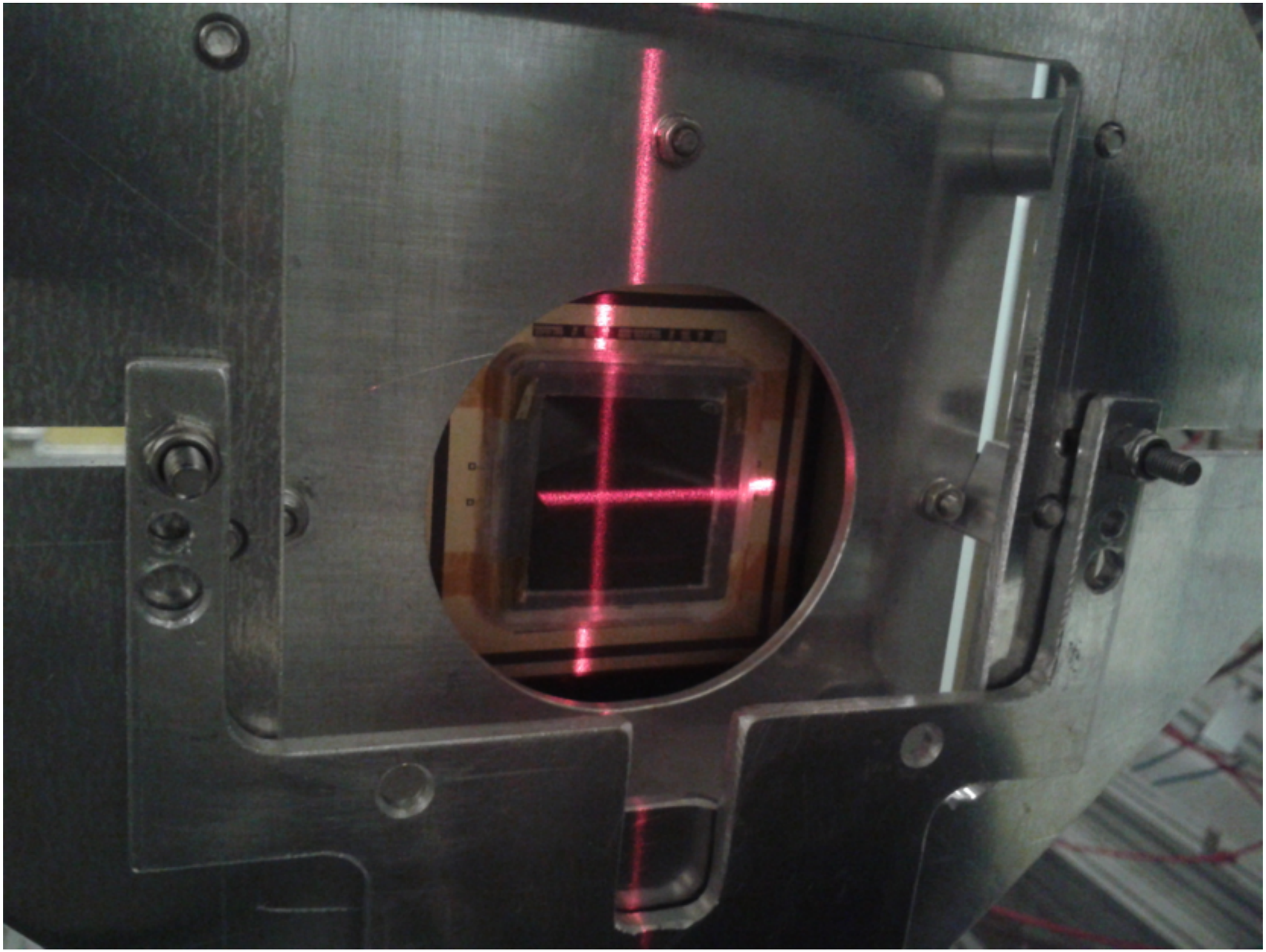
Blobs
(alpha-like)

Tracks
(proton-like)



Other
(electrons)

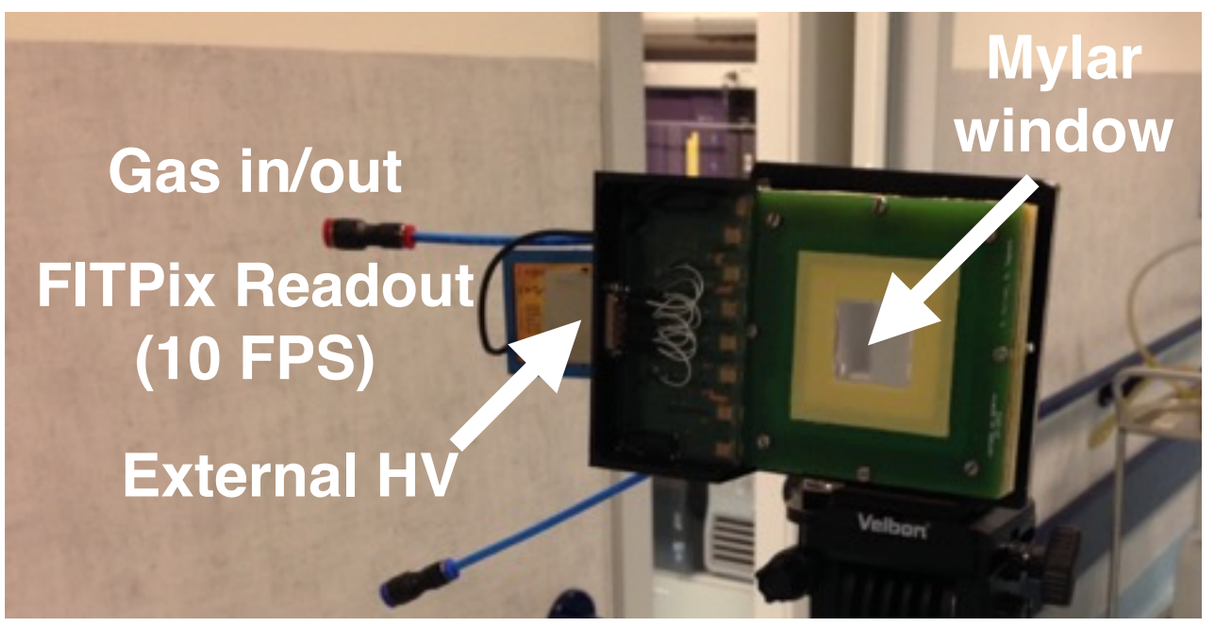


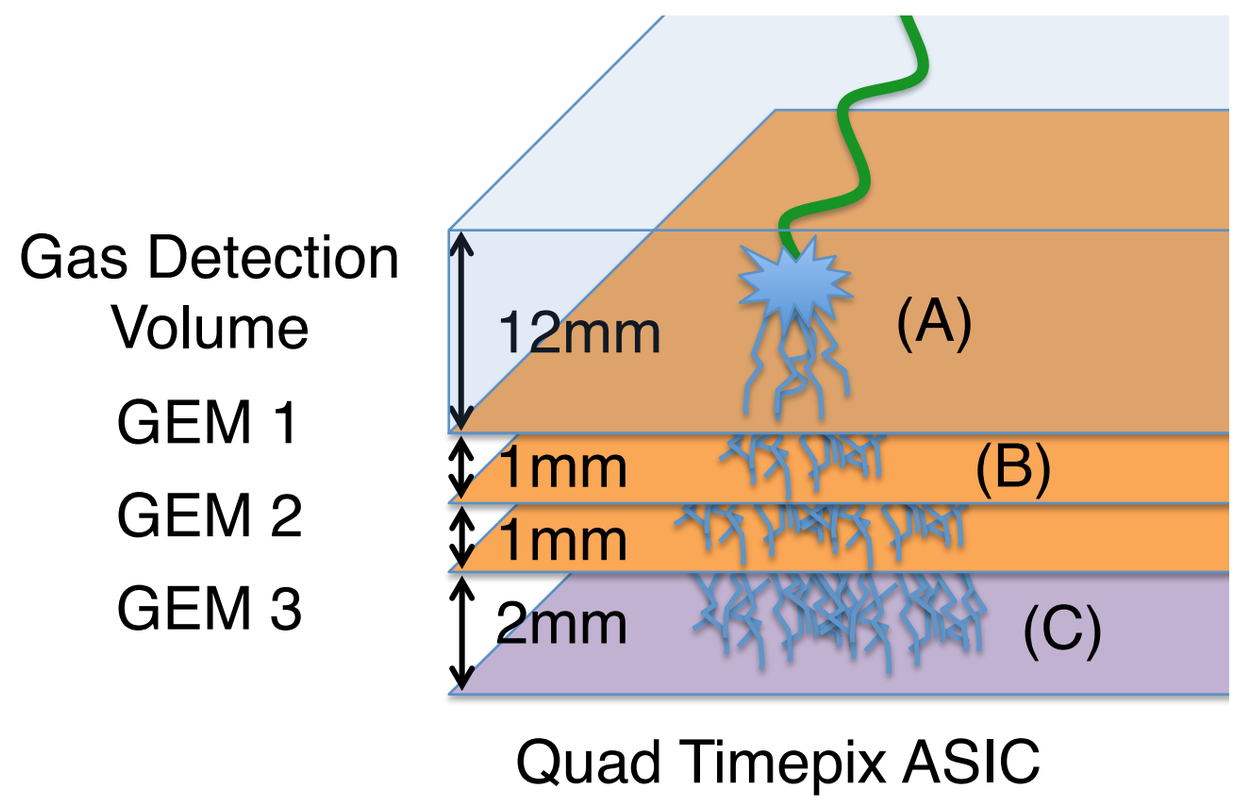


NTOF has been able to align their beam with ~0.1mm accuracy

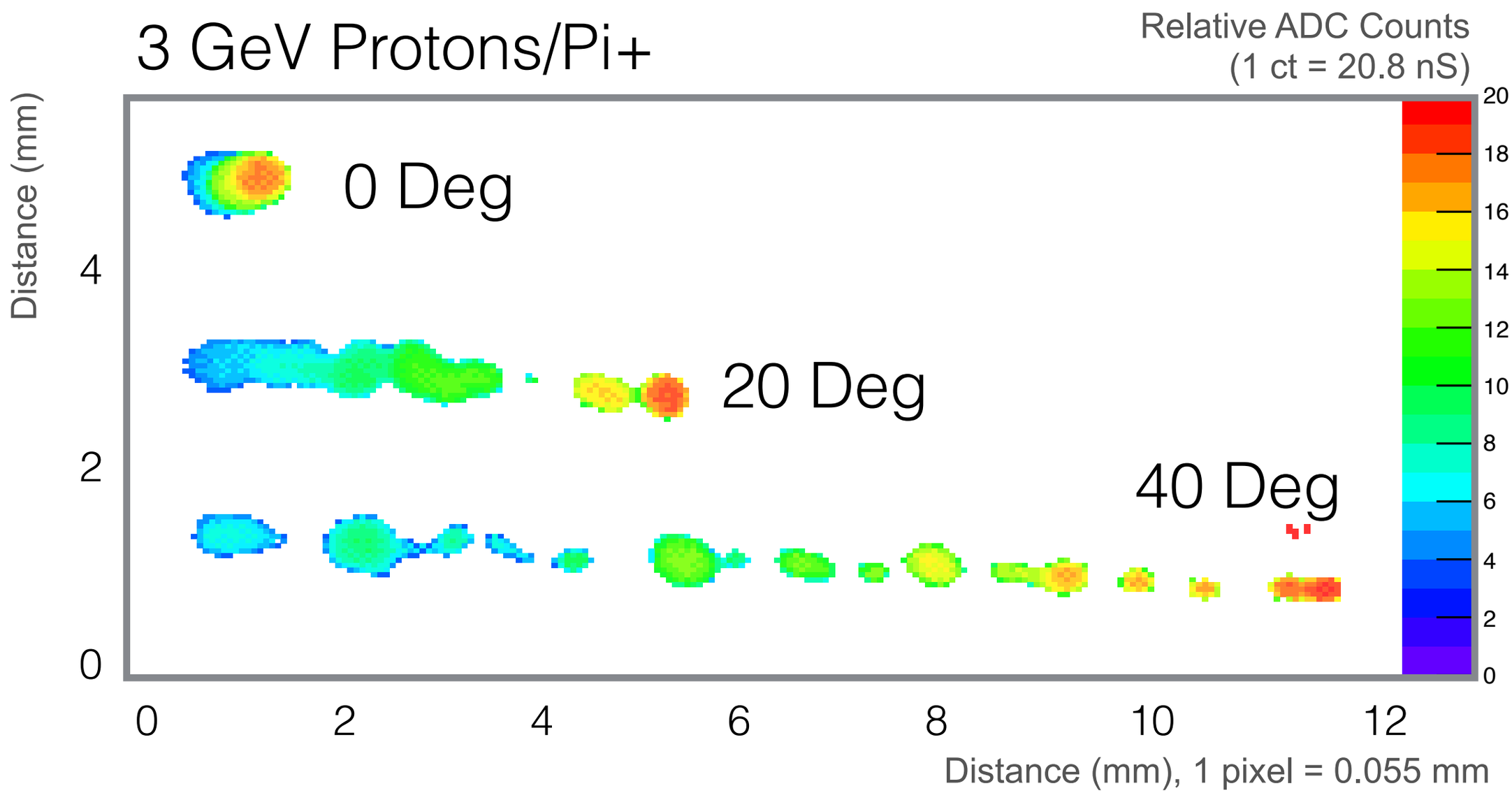
Hybrid Doesn’t Just Mean Semiconductors - The GEMPix

Standard 3cm x 3cm triple GEM setup with quad timepix output (262,144 channels)

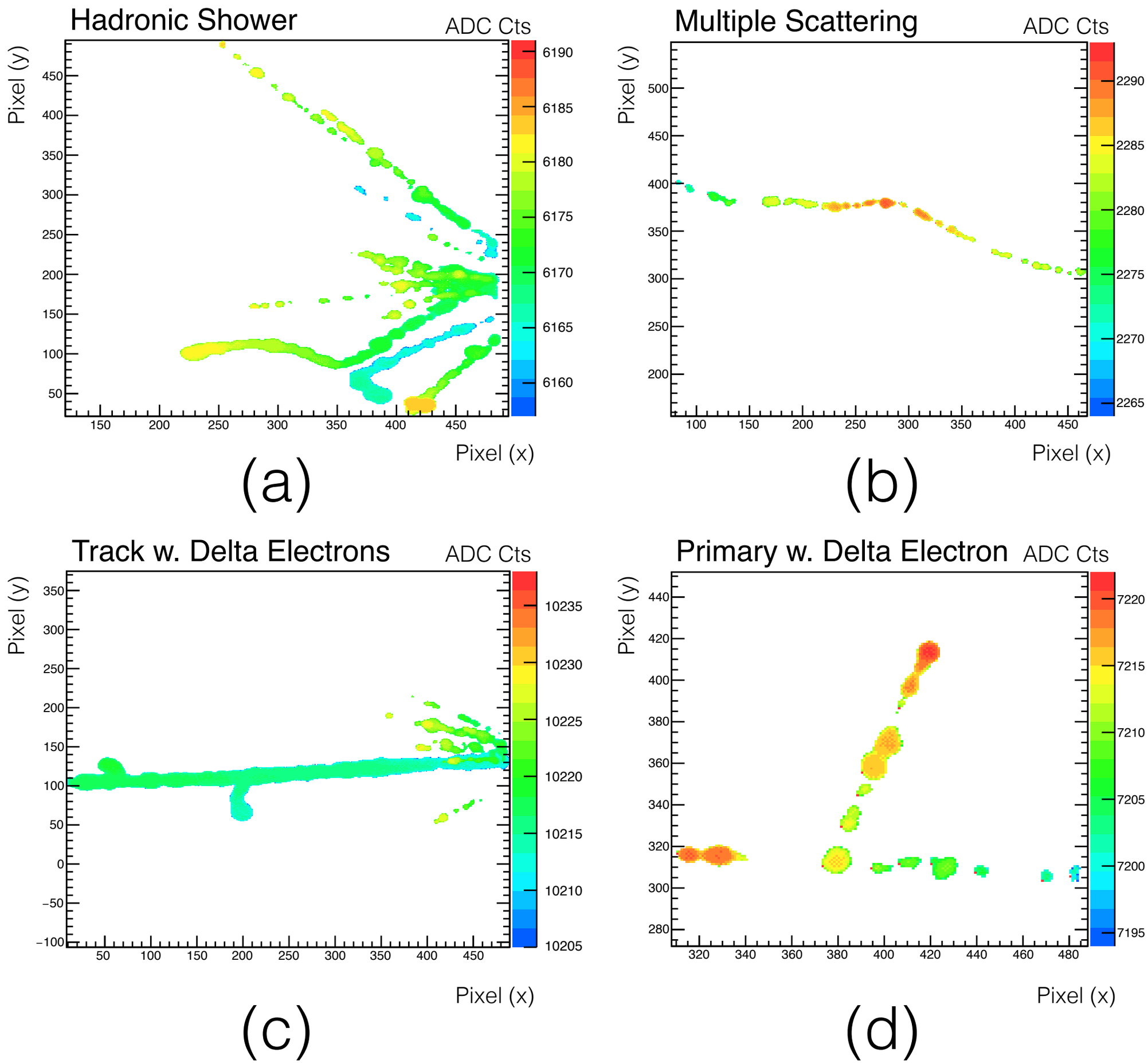




Sample Tracks - MIPS

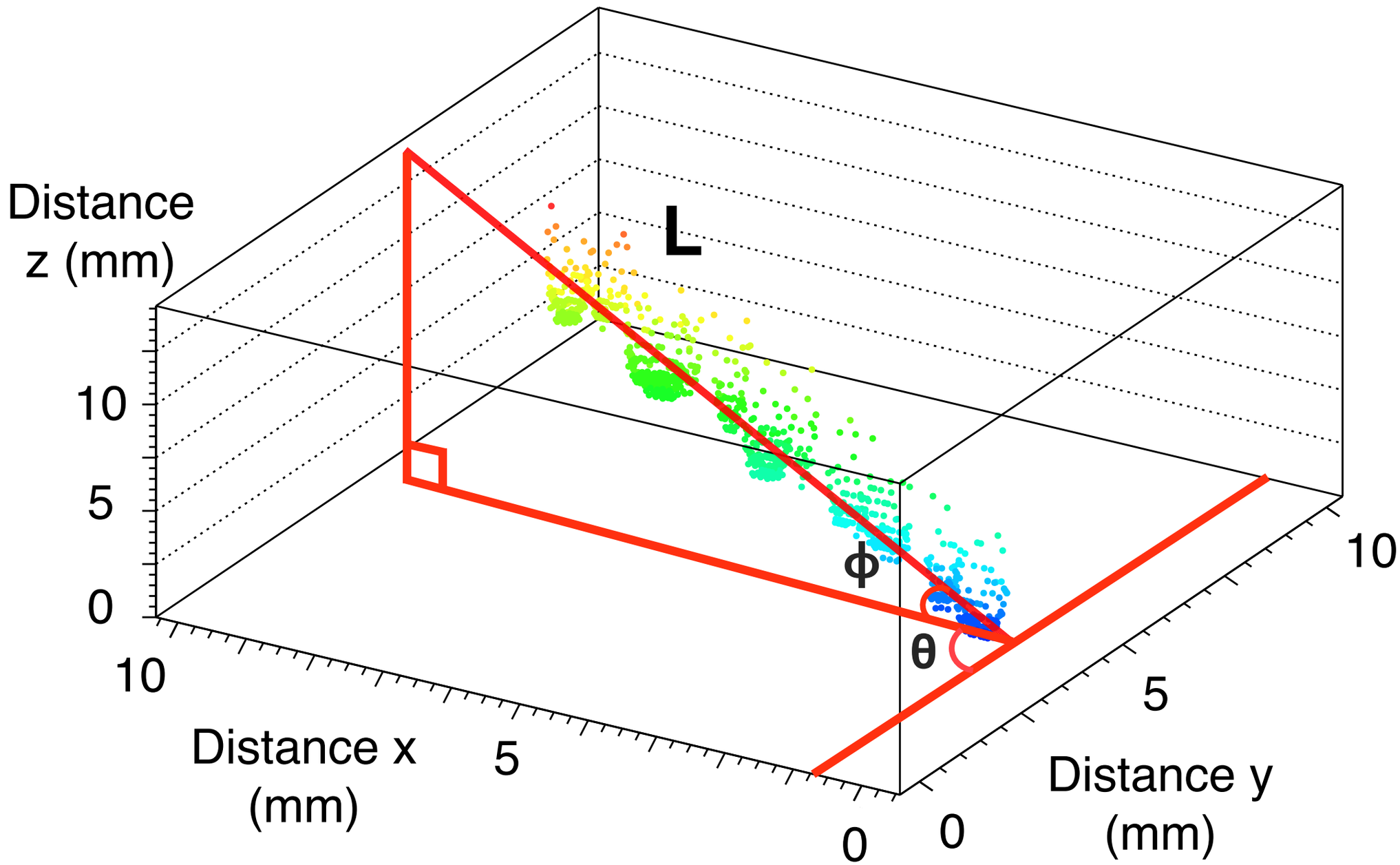


TOA Mode (48 Mhz), 1 Count ~ 20 nS, 0.25 mS frame, chamber gain = 1350 V, gas = ArCO2CF4, drift field = 0.666 kV/cm, 12 mm drift distance

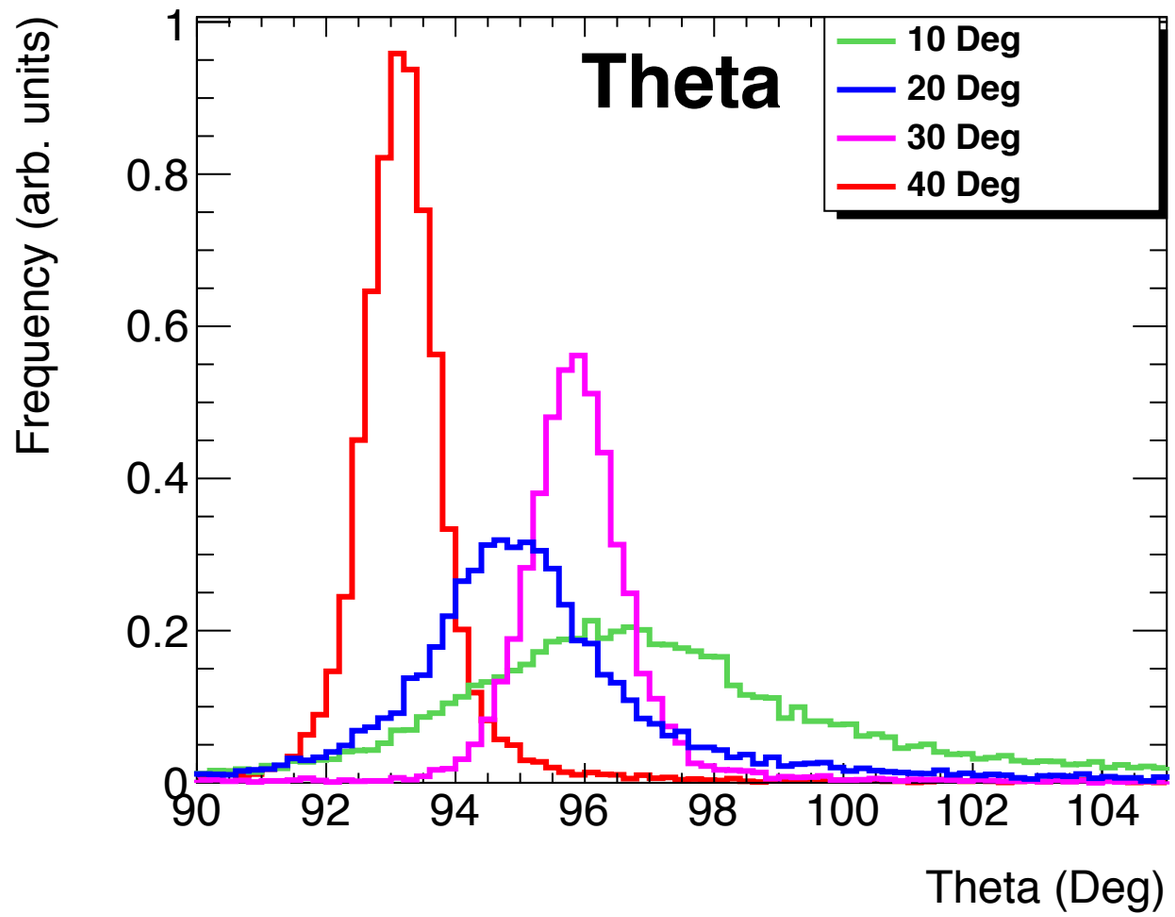

Hadronic Shower
ADC Cts
Pixel (y)
Pixel (x)
(a)
Multiple Scattering
ADC Cts
Pixel (y)
Pixel (x)
(b)
Track w. Delta Electrons
ADC Cts
Pixel (y)
Pixel (x)
(c)
Primary w. Delta Electron
ADC Cts
Pixel (y)
Pixel (x)
(d)

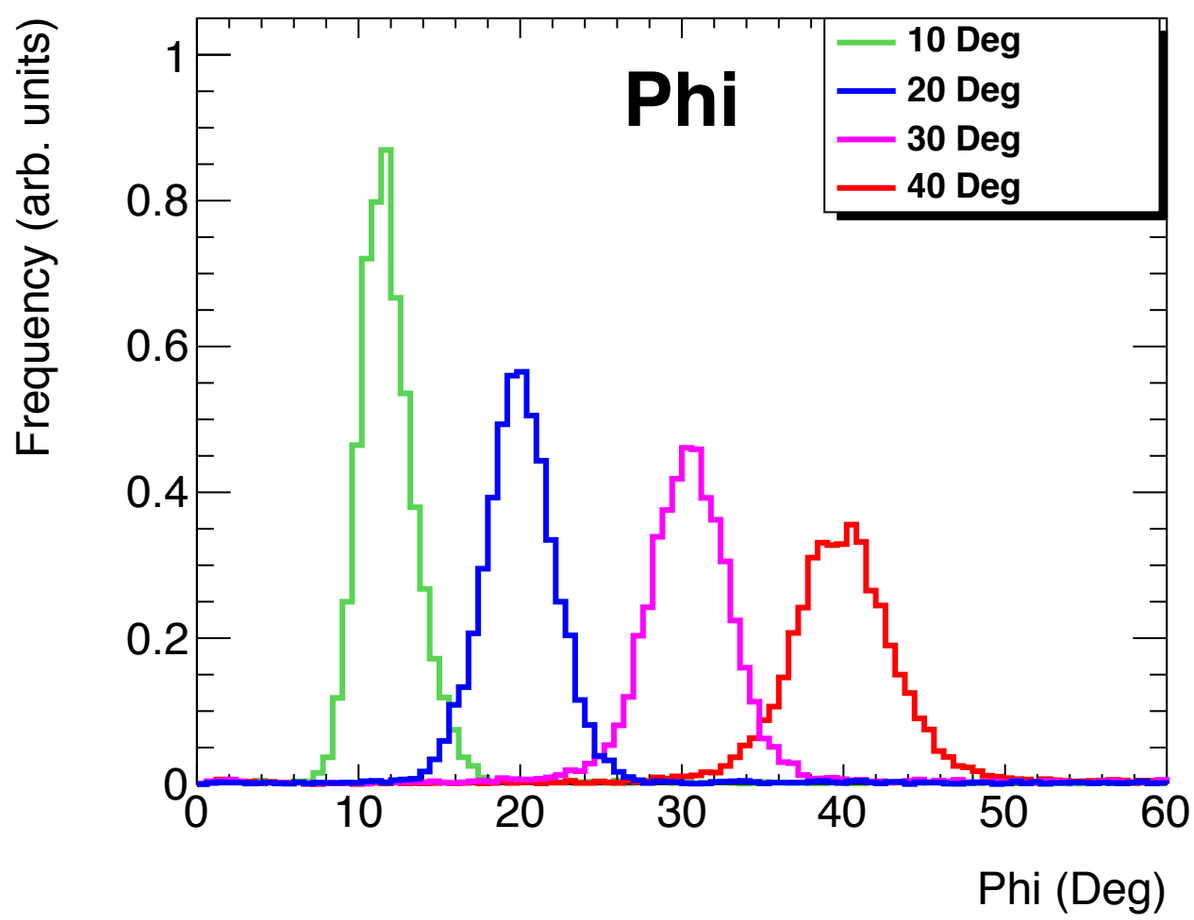
Track Reconstruction

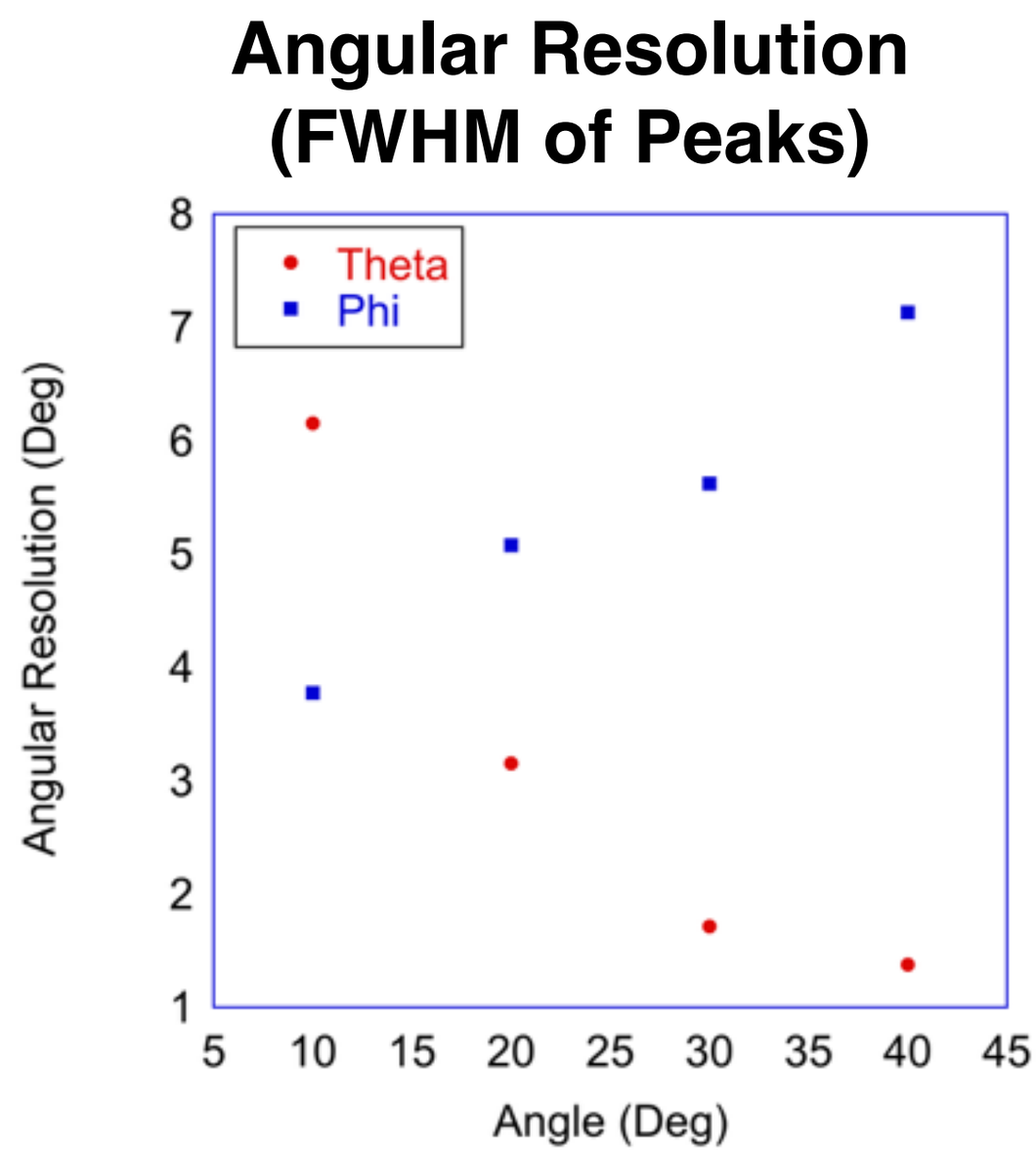
3D Least Squares Fit of 3 GeV MIP Track Incident at 30 Degrees



Illustrative (1/16 pixels drawn)





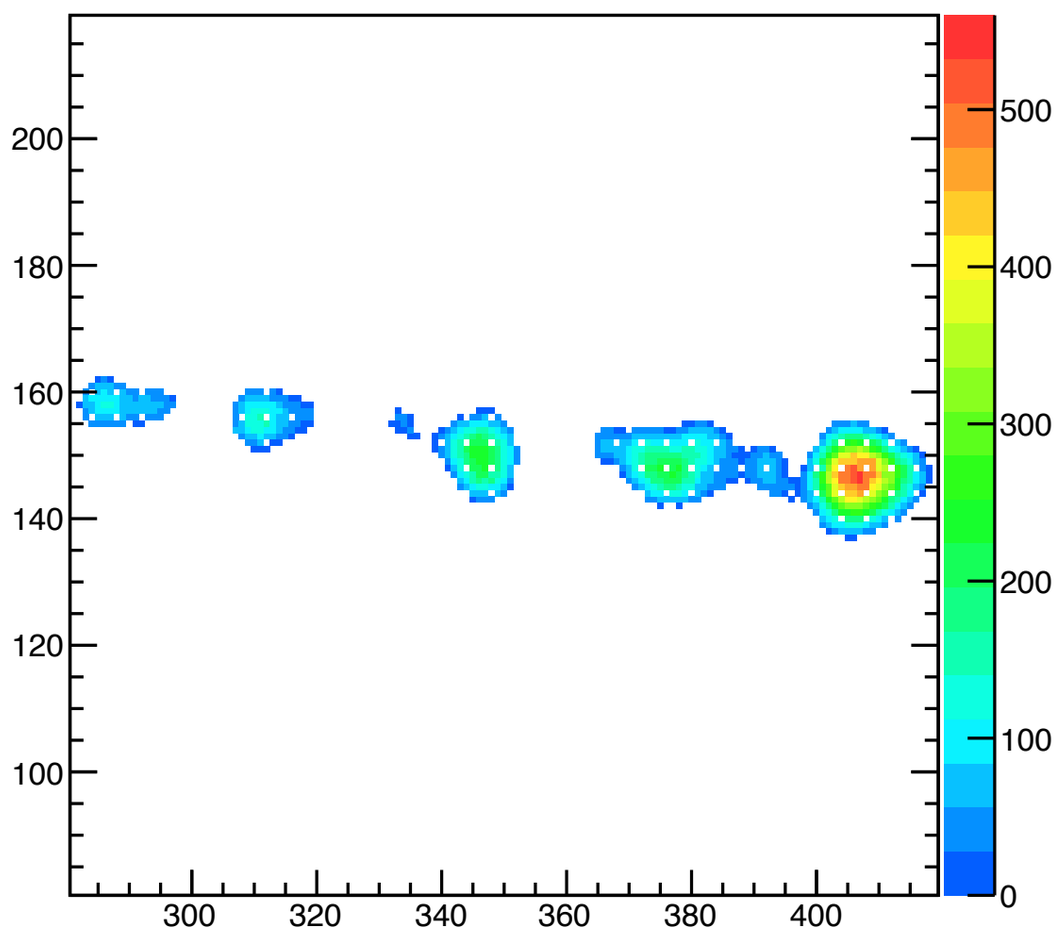


Theta (Range 0°-180°)
Phi (Range 0°-90°)

Mixed Mode Operation

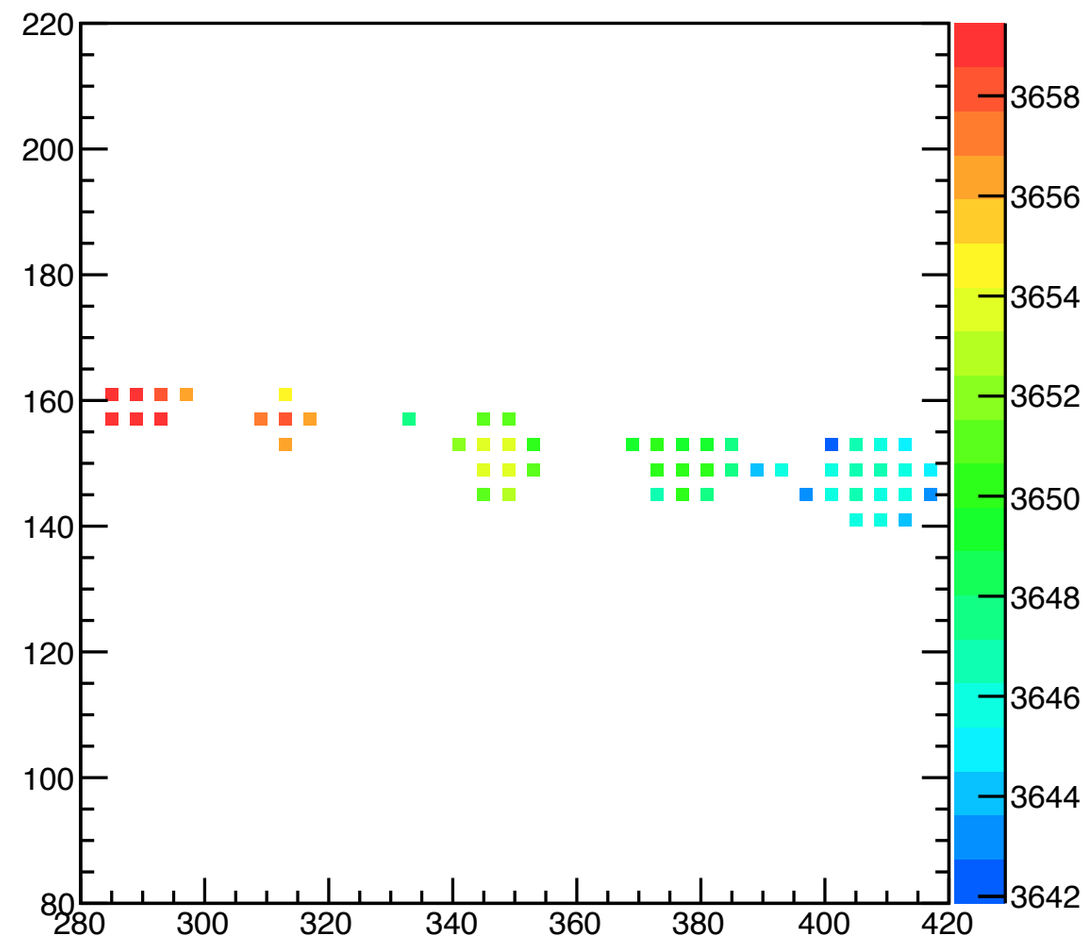
TOT Pixels

ADC Counts
(48 Mhz, Ikrum 5)



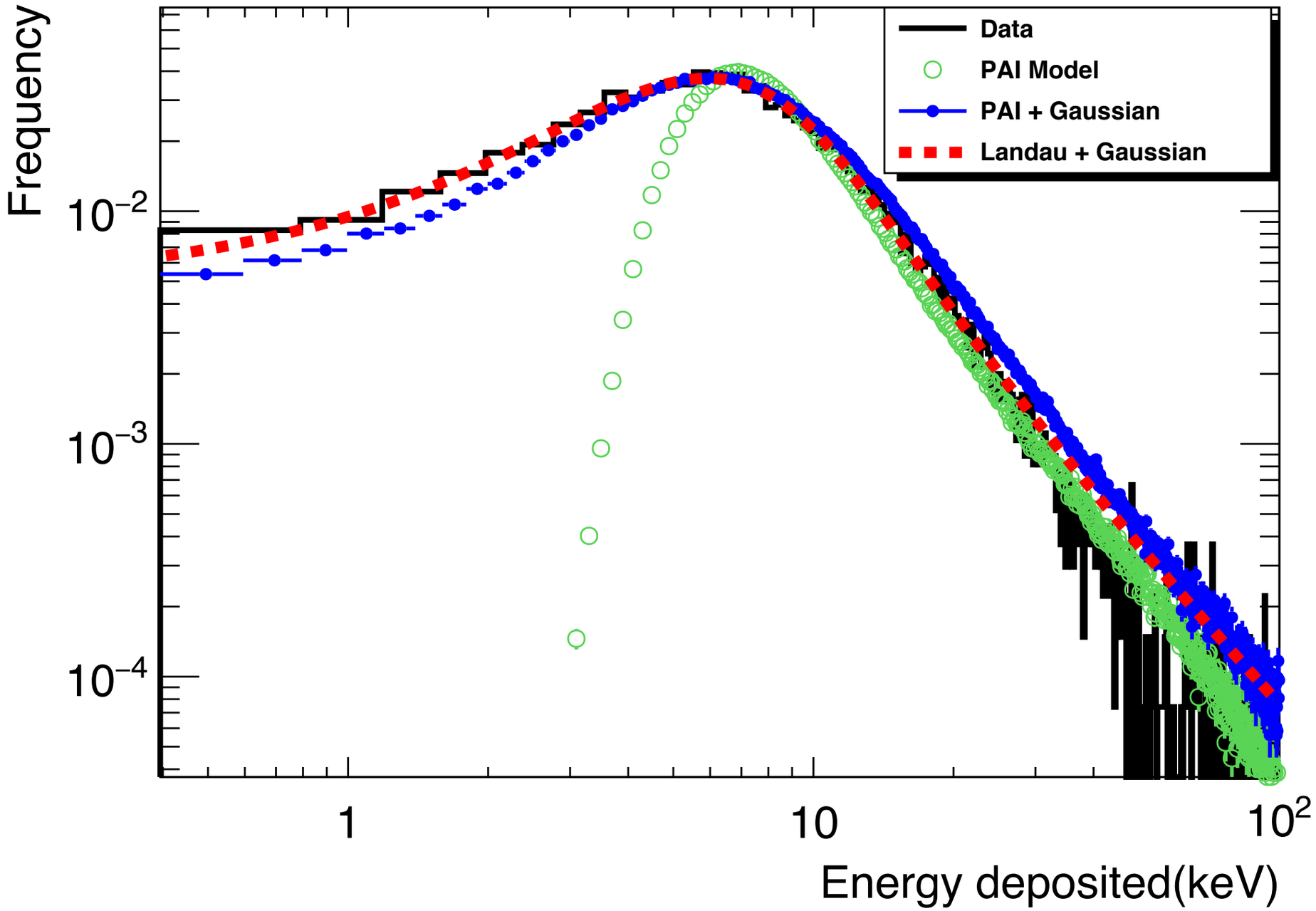
TOA Pixels

ADC Counts
(1 ct = 20.8 nS)



Note, TOA pixels are doubled in lateral size for visual effect

Gempix Energy Deposition Spectrum

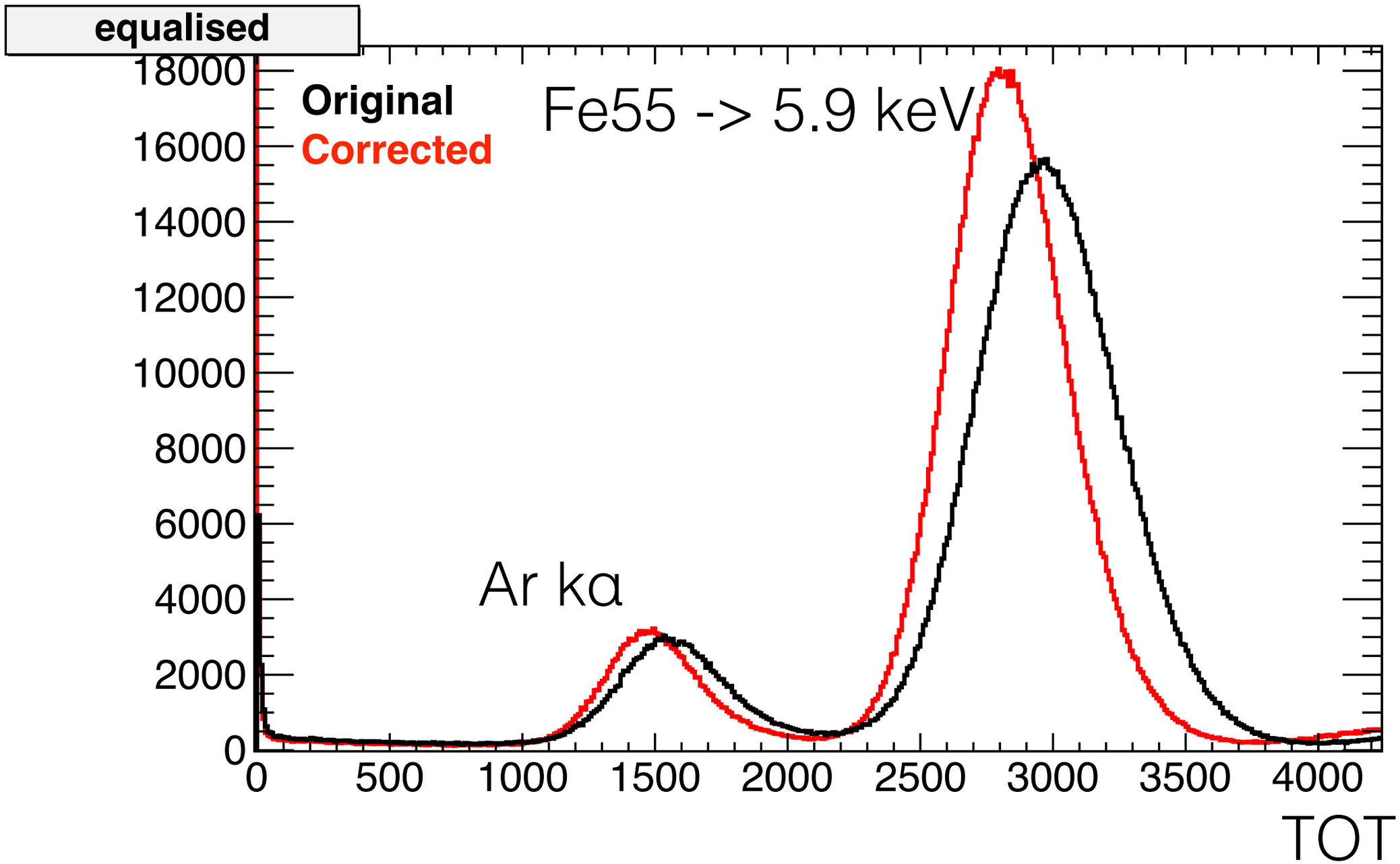


PAI -> Geant4 PAI model, range cut = 0.1 mm, mono energetic 3 GeV 2/3 proton, 1/3 pi+ pencil beam on 24 mm $ArCO_2CF_4$

Gaussian + PAI -> Smearing following: $\sigma = A\sqrt{\Delta E(\mathrm{keV})}$

[1] J. Apostolakis et al, *"An implementation of ionisation energy loss in very thin absorbers for the GEANT4 simulation package"*, NIM A, Volume 453, Issue 3, 21 October 2000, Pages 597–605

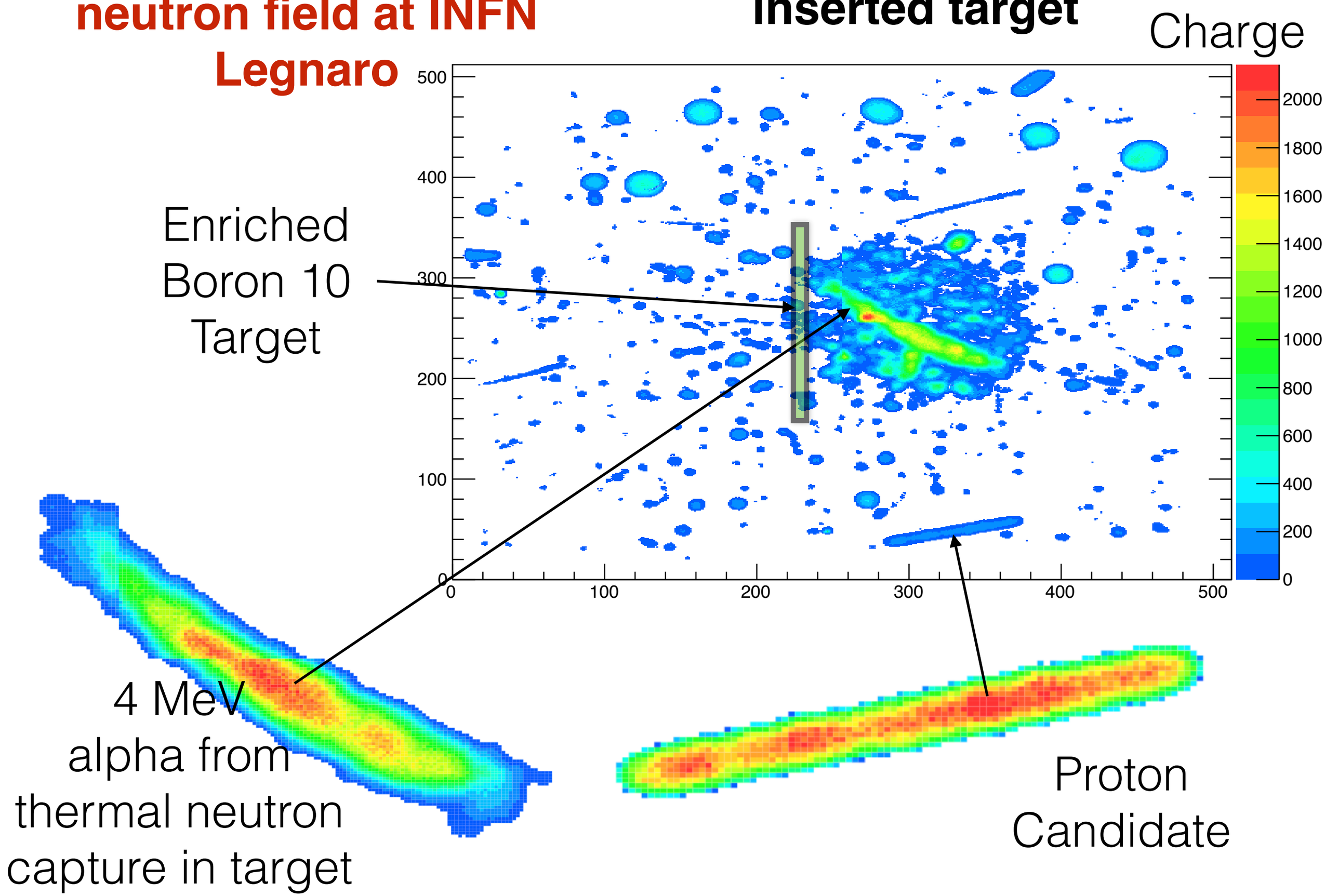
Fe55 Spectra



18.3% Energy Resolution on the corrected Fe Peak

Measurement with mixed neutron field at INFN Legnaro

3cm thick TPC with inserted target



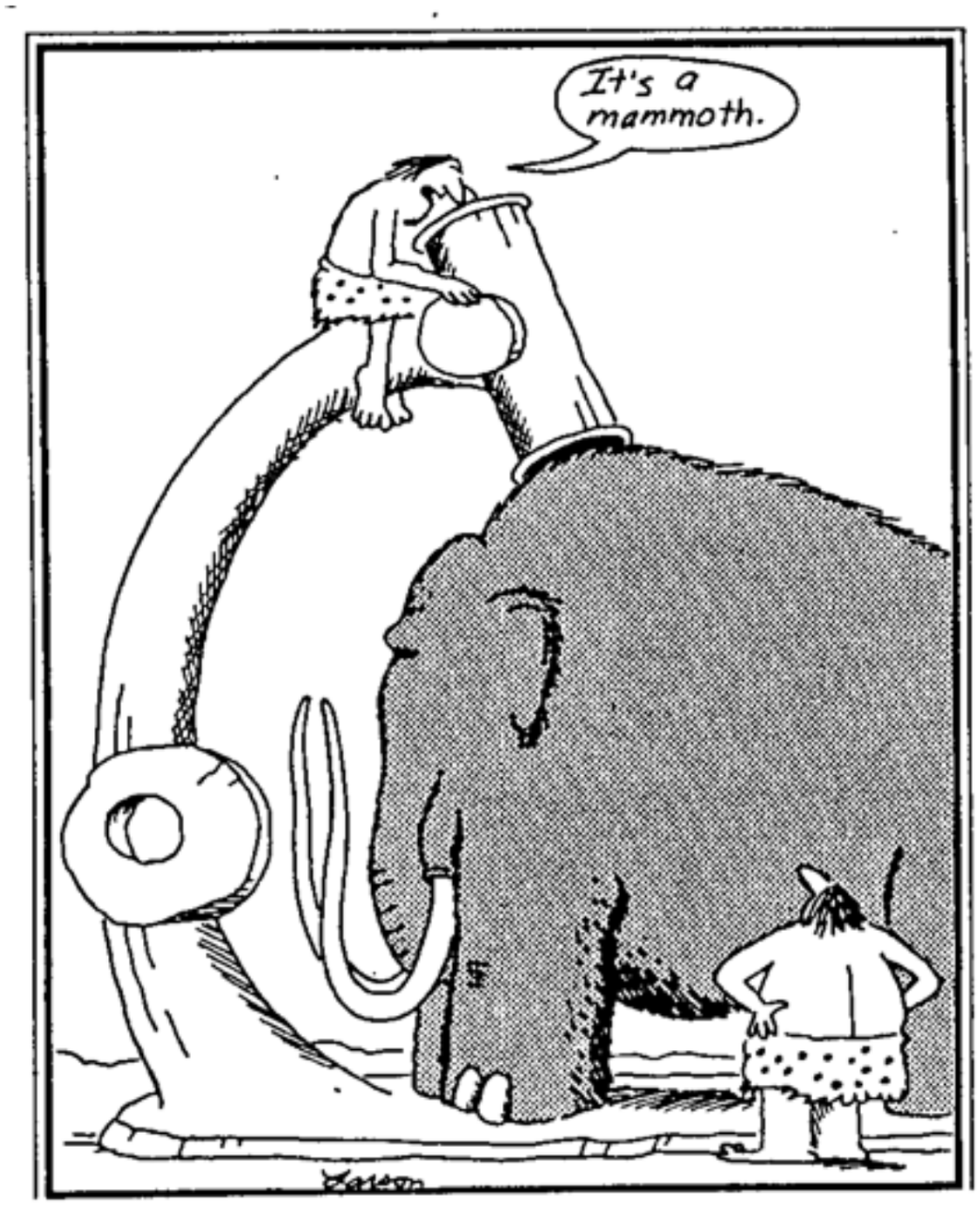
Technology Limitations and the Future

- **Timepix** -> Frame based readout (~200 fps with new systems, 20 typical), clock up to 100 MHz (10, 50 more used), counter depth = 11.5 bits

- **Timepix 3** (supply limited) -> Data driven readout (*85 MHits/sec/asic*), simultaneous TOT/TOA (1.5 nS resolution), 24 bit counters

- Lots of interesting measurements - avalanche statistics, in detail measurements of Pe/B10 Cathodes, dE/dX spectra from biological samples, neutrons in photon radiotherapy

Thanks for your attention

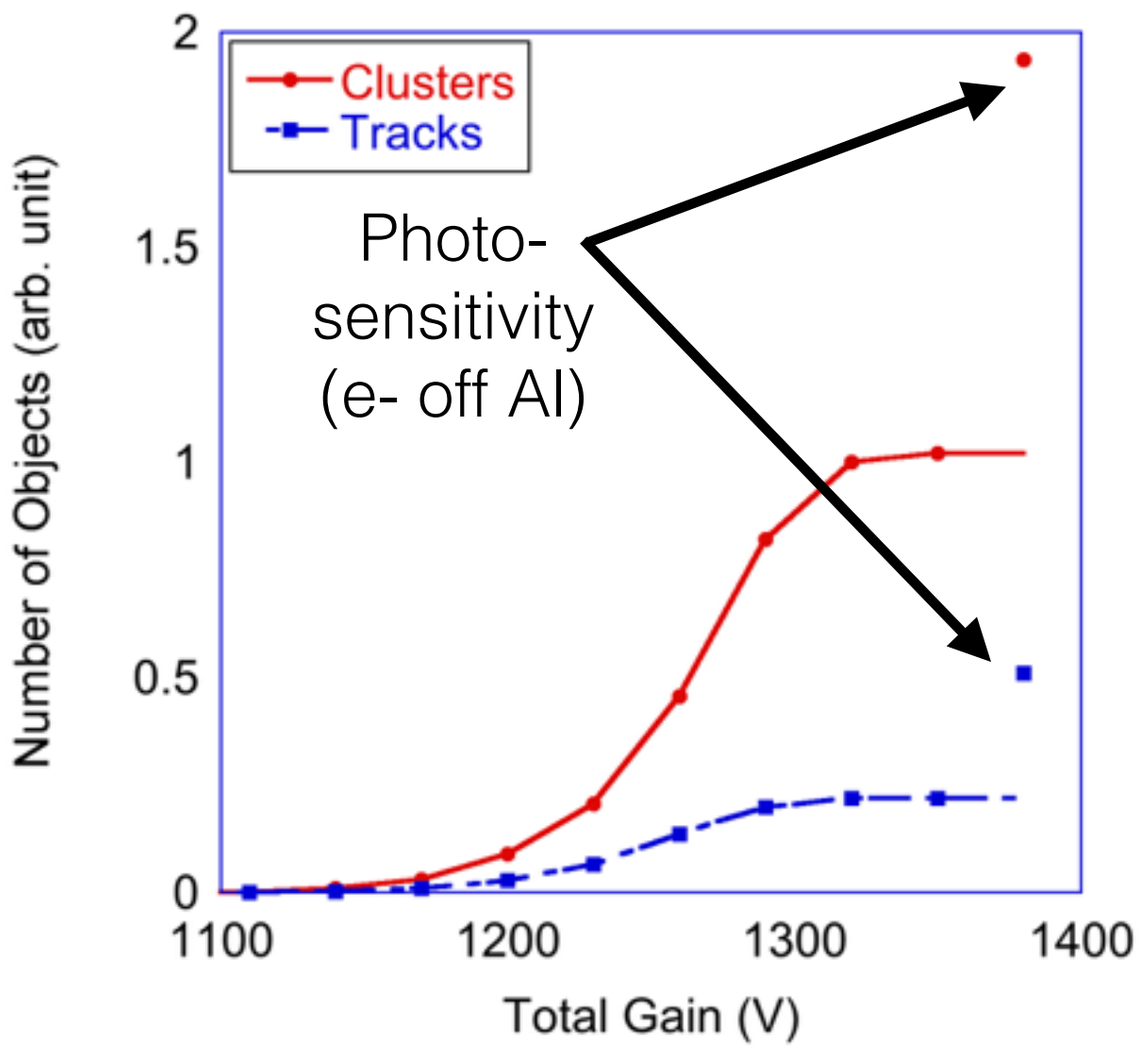


Early microscope

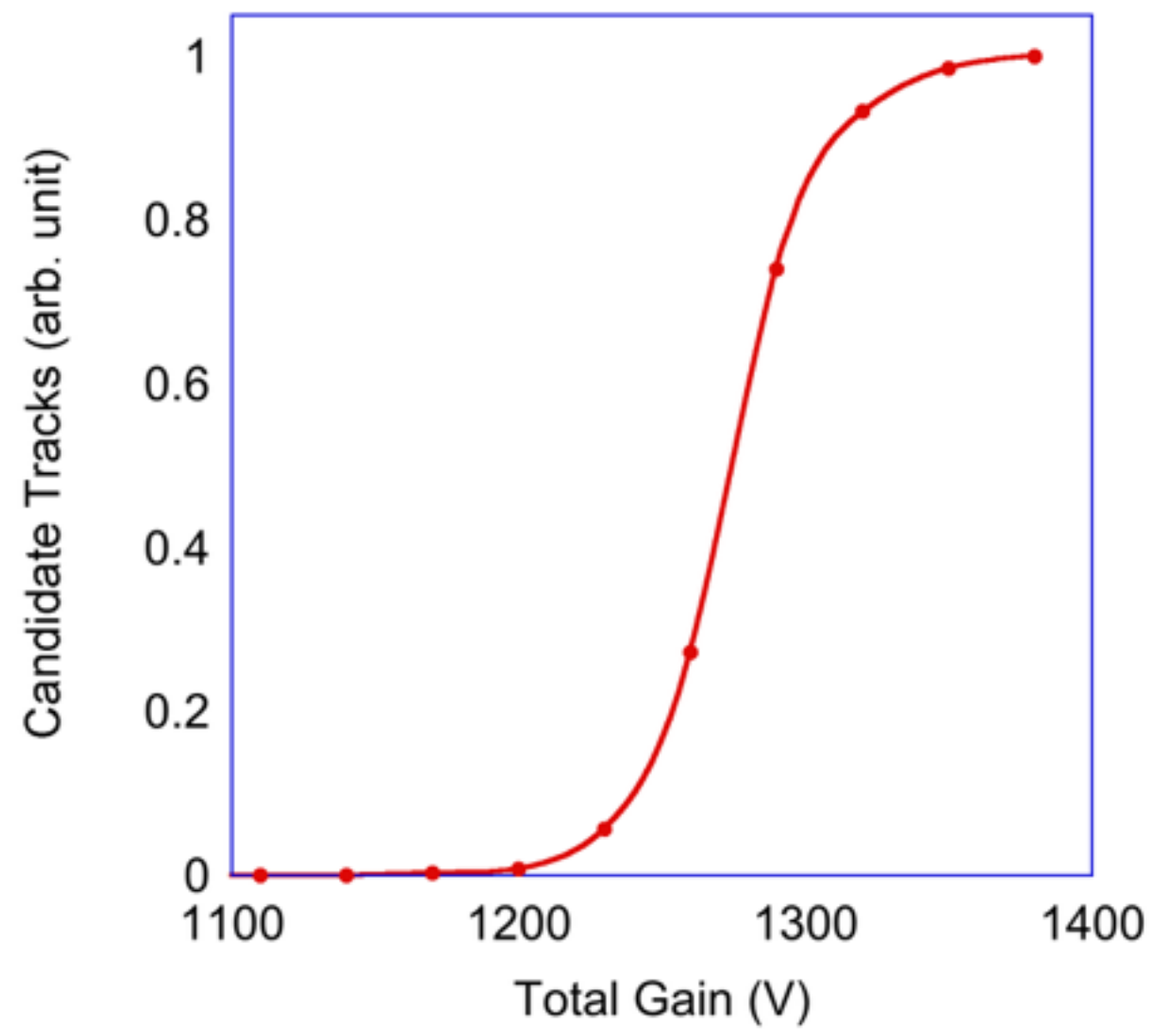
Supplemental Slides

Effect of Chamber Gain

Everything

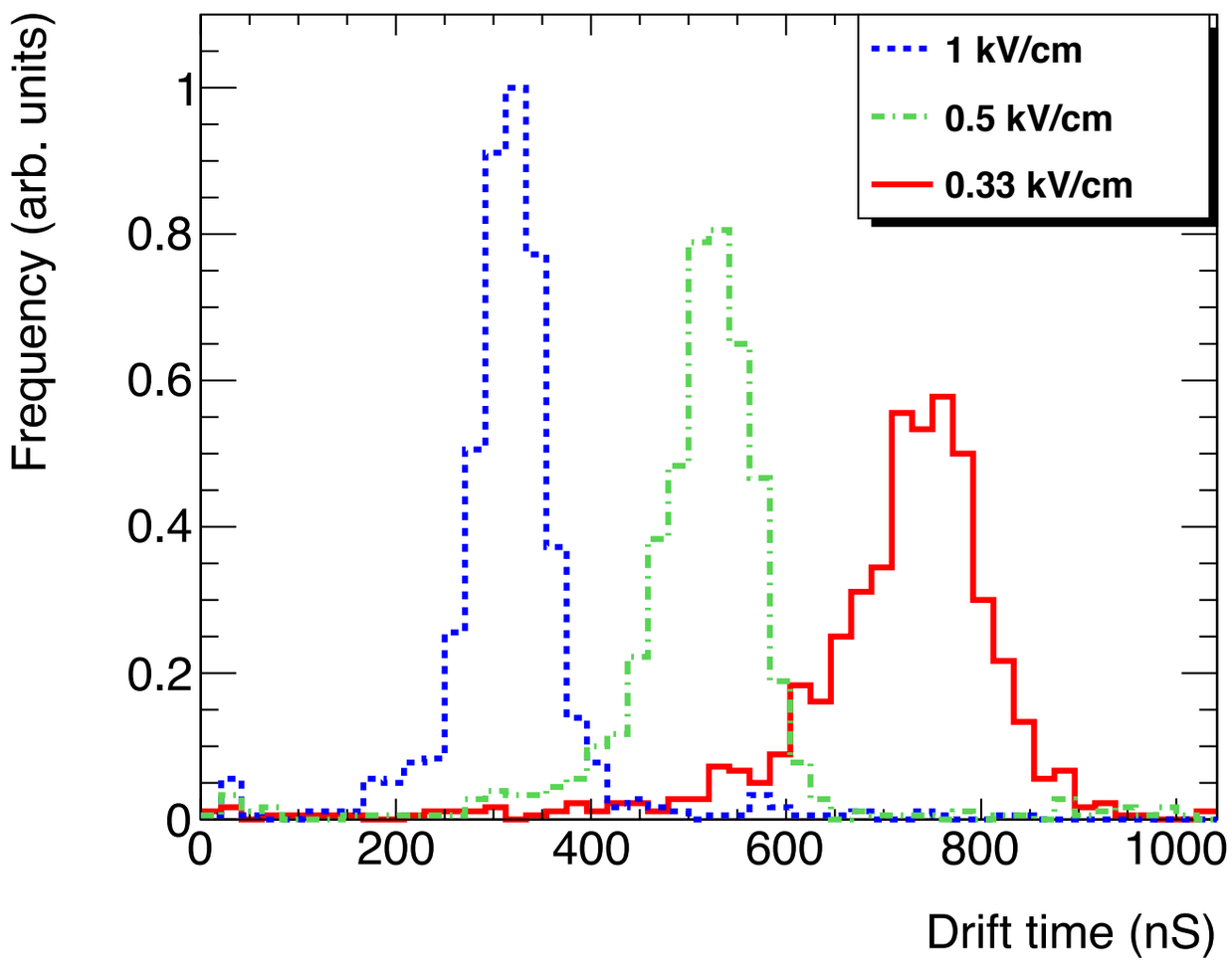


Candidate Tracks
(>100px)

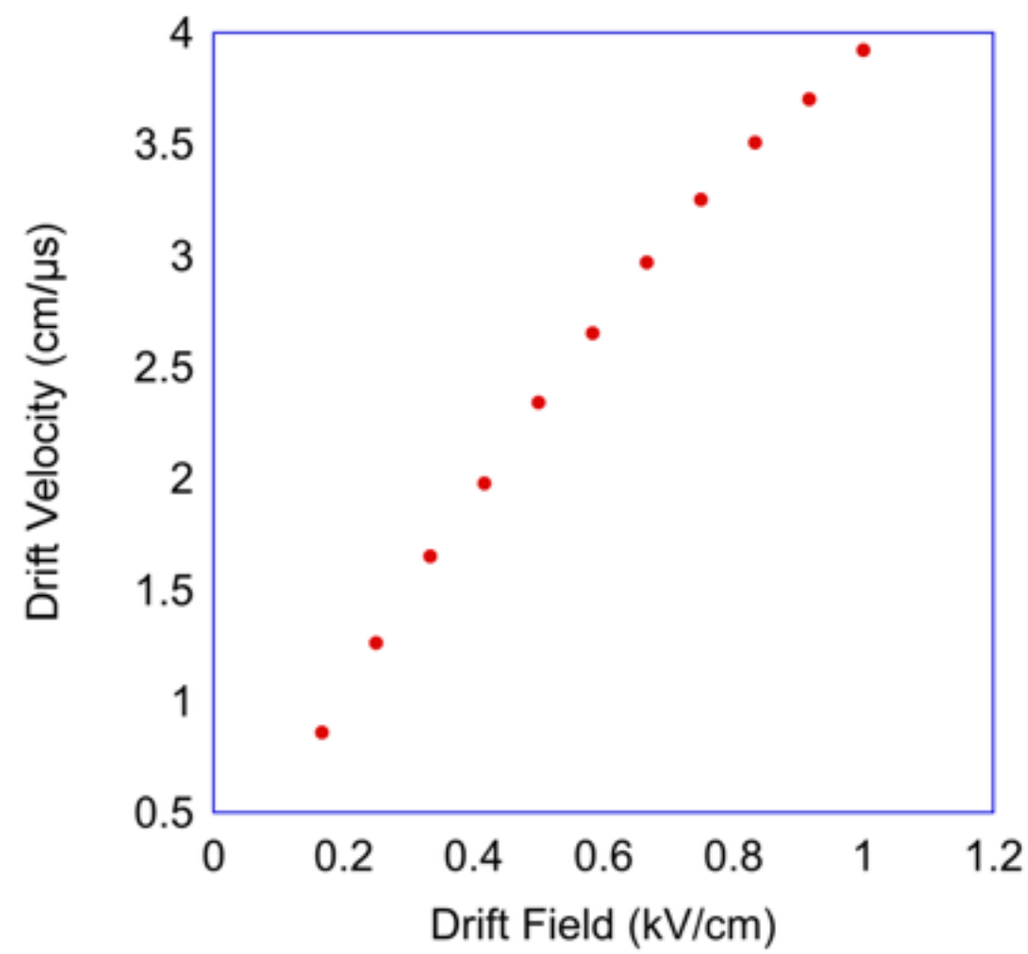


Measurement of Drift Velocity (vary drift field)

Track top/bottom delta times (morphological operator for time walk correction)

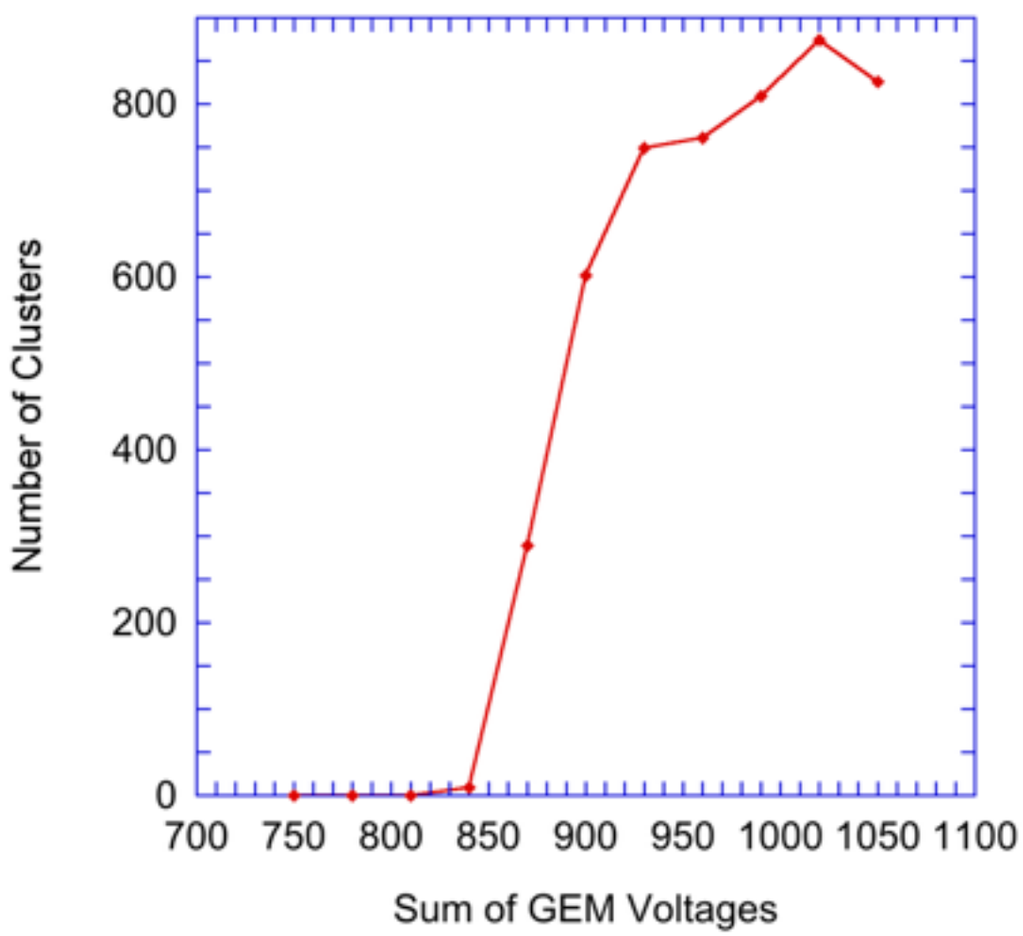


Drift Velocity (mean from gaussian fit of curves on left)

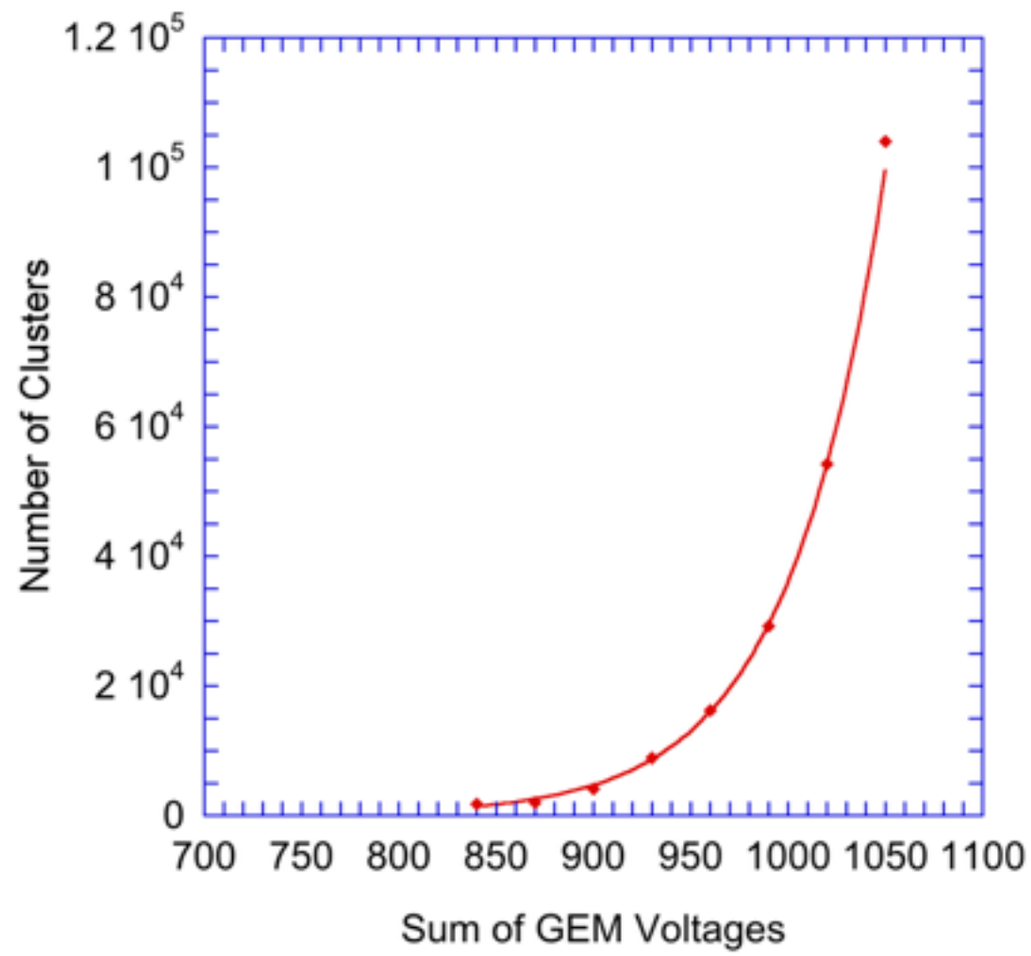


Alpha Particles (~6 MeV Am241)

Number of Clusters as a function of gain

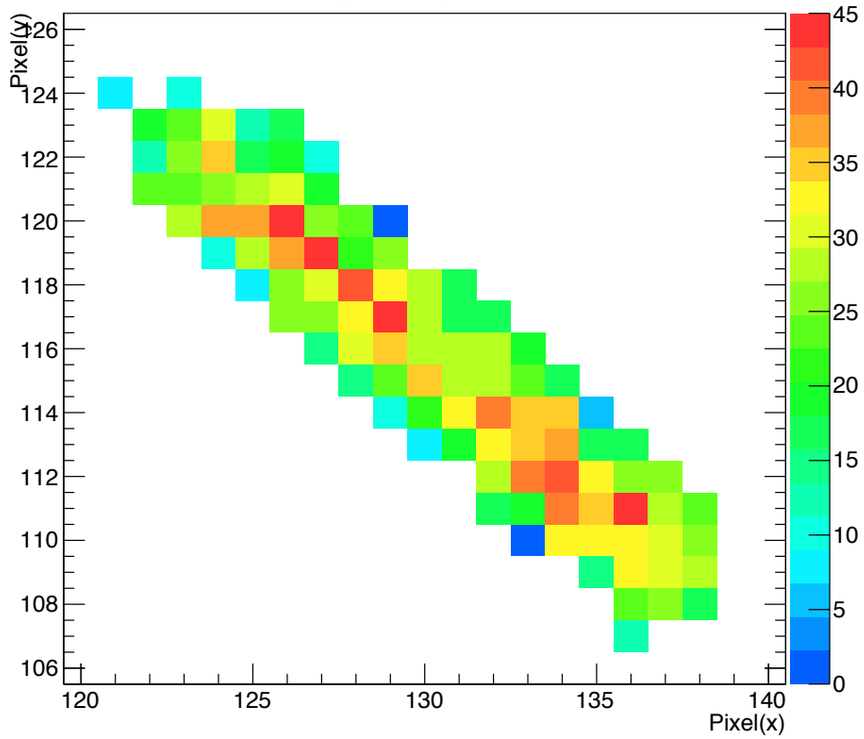


Cluster TOT as a function of gain



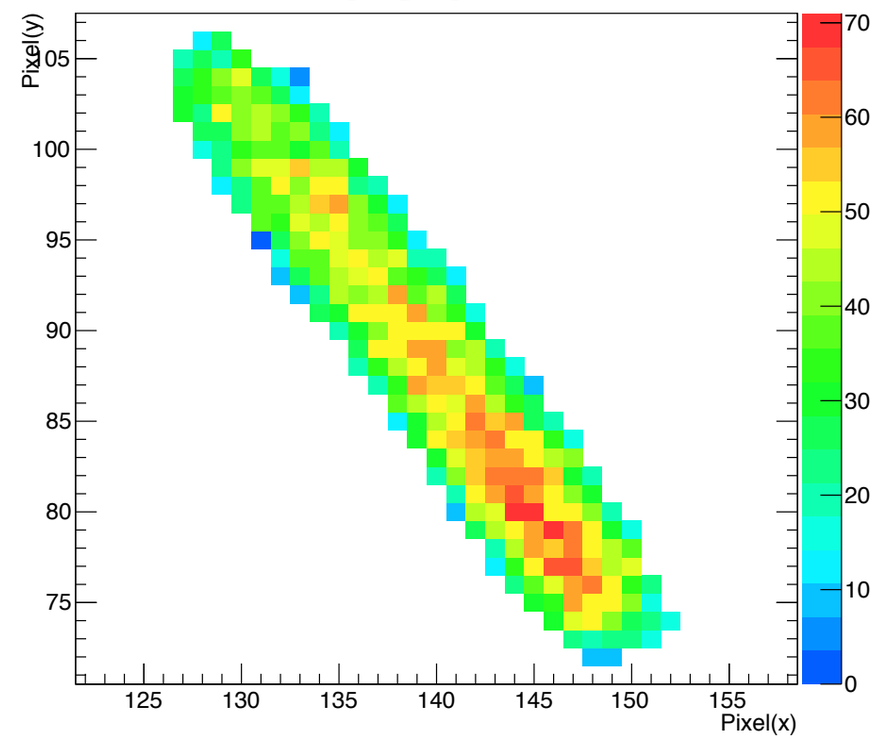
Working point at Gain ~950V, compare with 1230V for Fe55

870 V



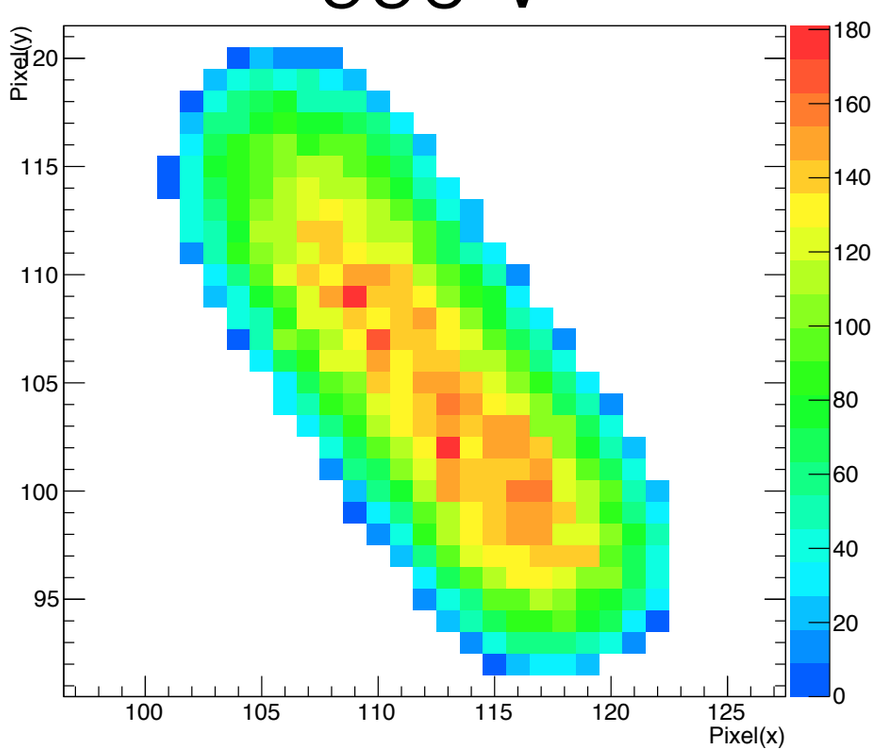
Length ~ 1 mm, vol ~70 px

930 V



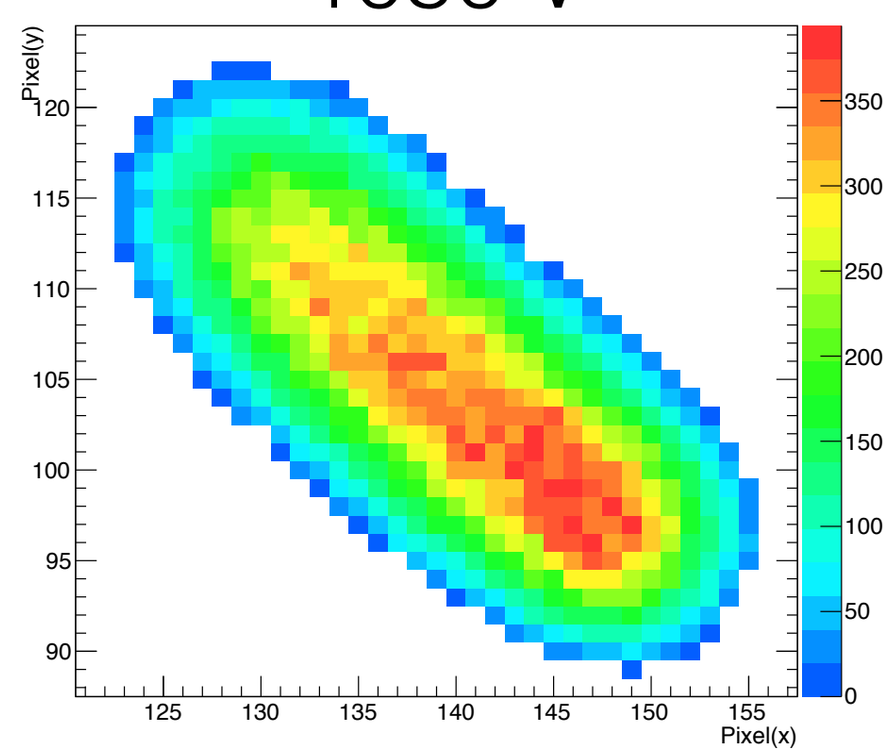
Length ~ 1.7 mm, vol ~200 px

990 V

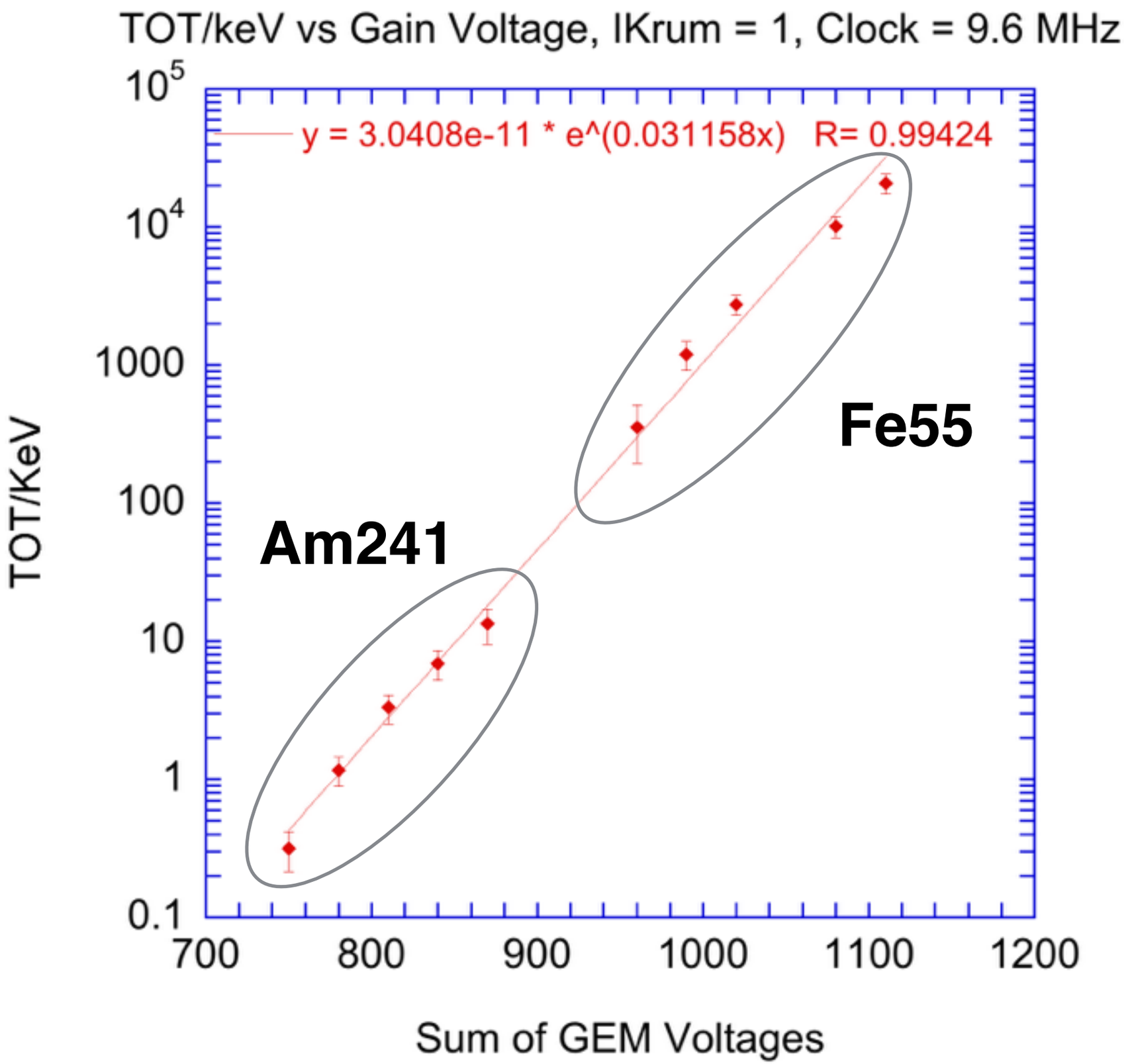


Length ~ 1.8 mm, vol ~350 px

1050 V

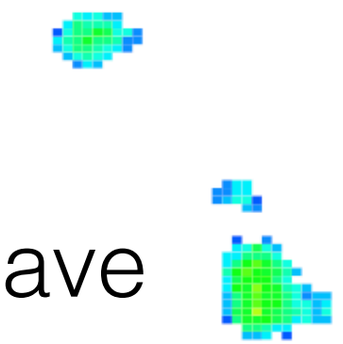


Length ~ 1.9 mm, vol ~600 px

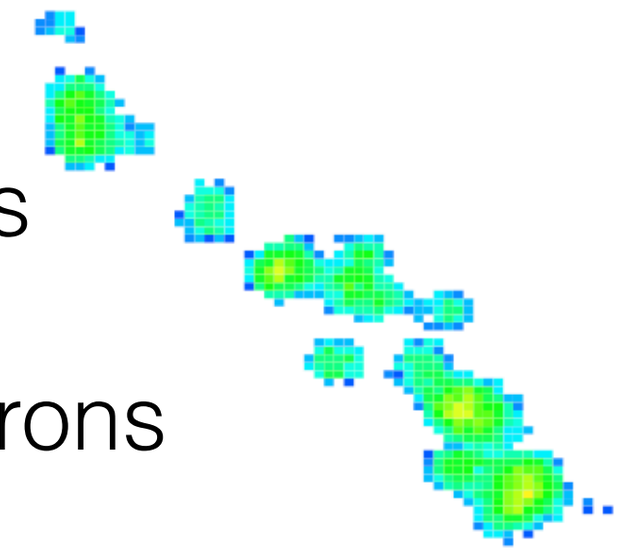

TOT/keV vs Gain Voltage, IKrum = 1, Clock = 9.6 MHz
y = 3.0408e-11 * e^(0.031158x) R= 0.99424
Fe55
Am241
TOT/KeV
Sum of GEM Voltages
10^5
10^4
1000
100
10
1
0.1
700
800
900
1000
1100
1200

Higher Energy Electrons

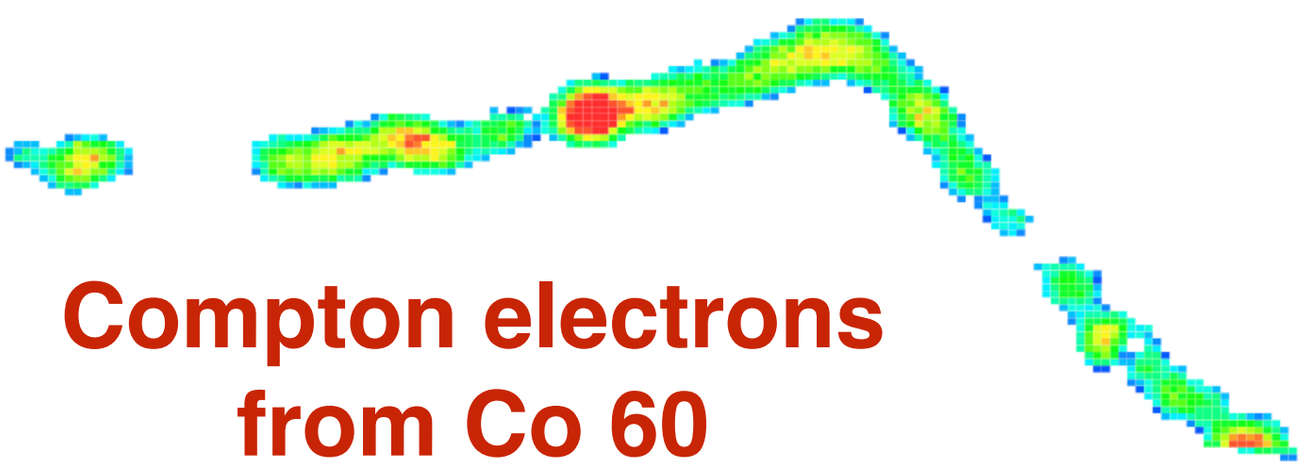
- Higher energy photons suffer a poor energy resolution because of two issues.

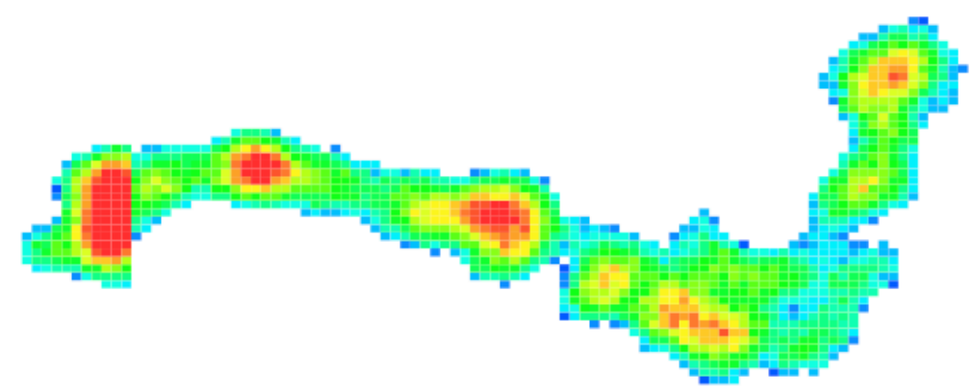


- The first is that electrons > 10 keV have ranges greater than the sensor thickness



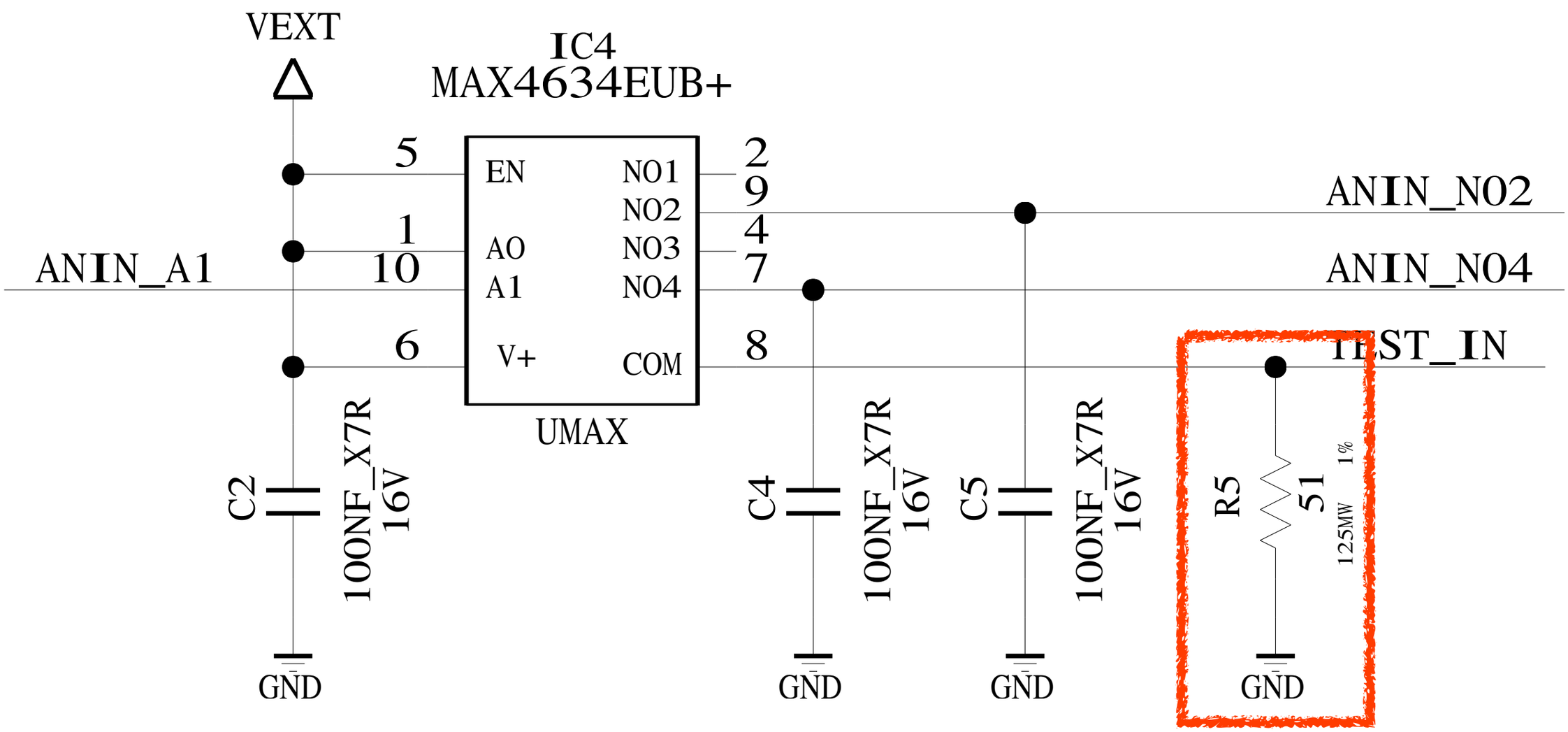
- The second is that high(er) energy electrons do not form complete tracks





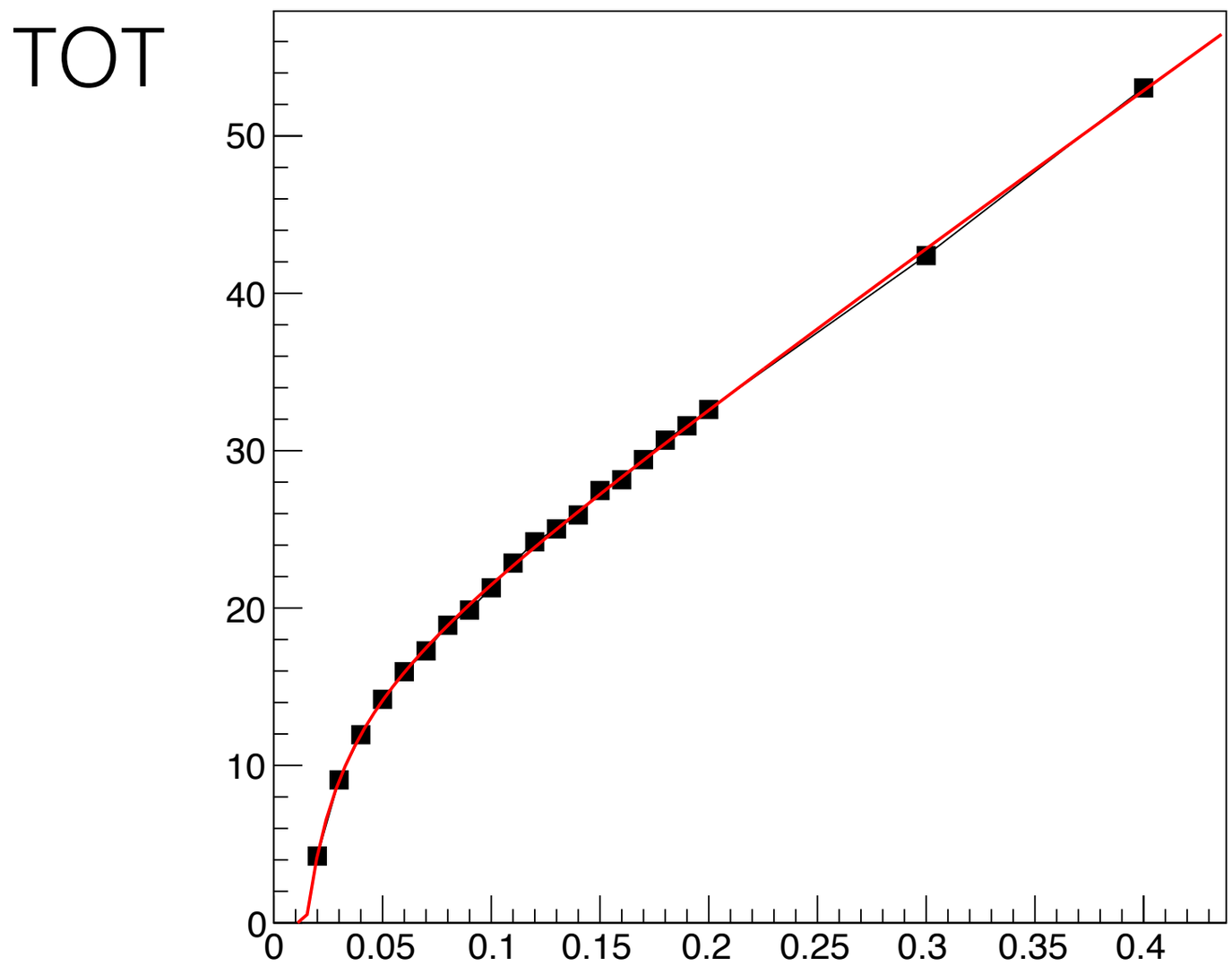
Compton electrons from Co 60

Test Pulse Calibration



Thanks to Erik Bosne (ISOLDE) and Jerome Alozy

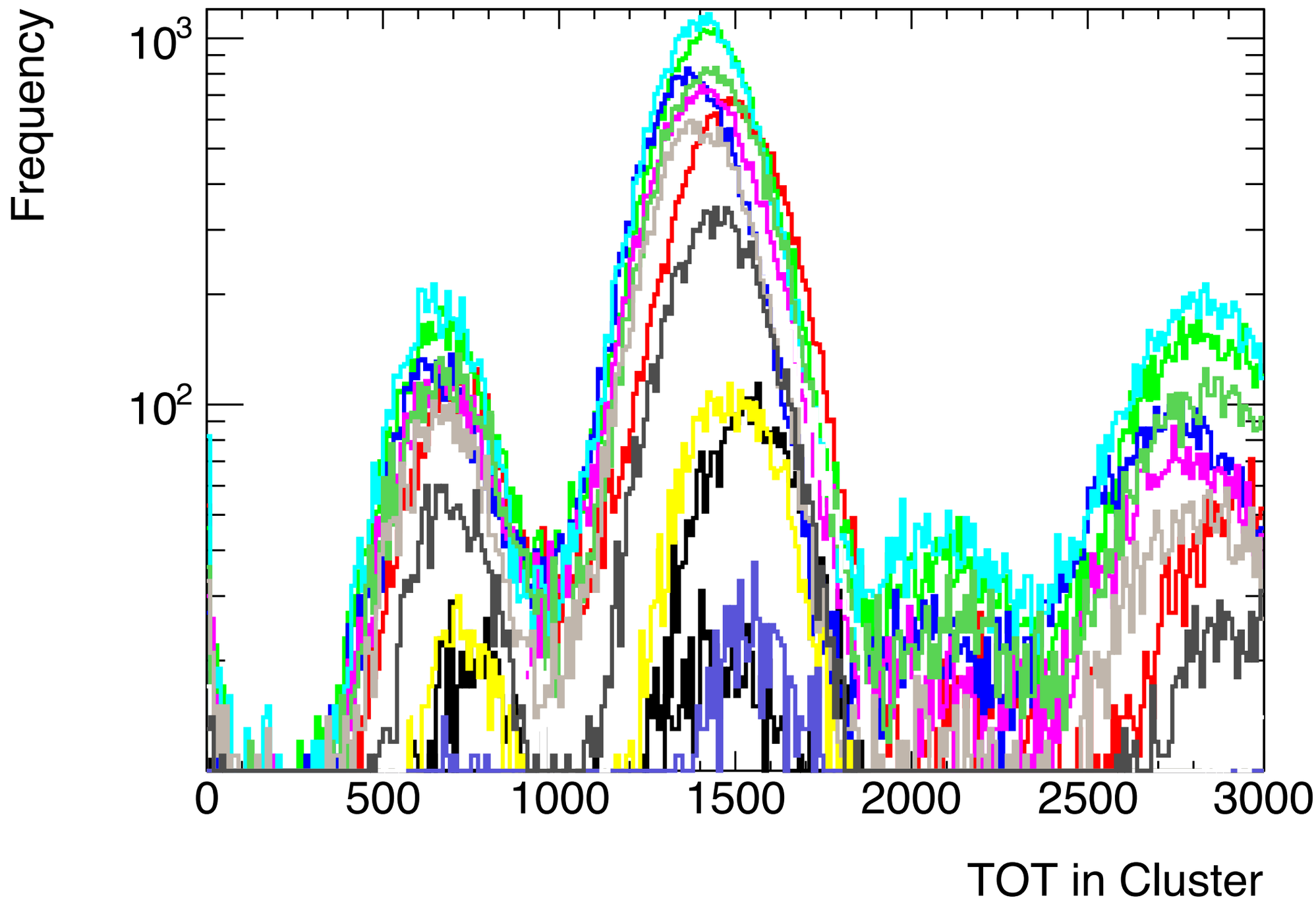
Test Pulse Calibration



Input Voltage - 1V = 50k e-

But - calibration did not improve detector energy resolution (actually made it worse…), even if only using gain parameter

Fe55 TOT Spectra in Separate Super Pixels (regions of quad asic)



Equalisation

Map of Fe55 Peak Positions