3rd Annual ARDENT Meeting

Stuart George

29th September 2014

Thanks

- Gempix - My colleagues and supervisors at CERN, the CERN Medipix Group

- Neutrons - Everyone at Wollongong, especially Susanna Guatelli, Mike Weaver and Anatoly Rosenfeld

- ISS Results - Larry Pinsky and everyone at the JSC SRAG group, especially Nick Stoffle, Ryan Rios and Amir Bahadori

- Everyone involved in ARDENT

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Mapping Particle Flux Asymmetries in the South Atlantic Anomaly

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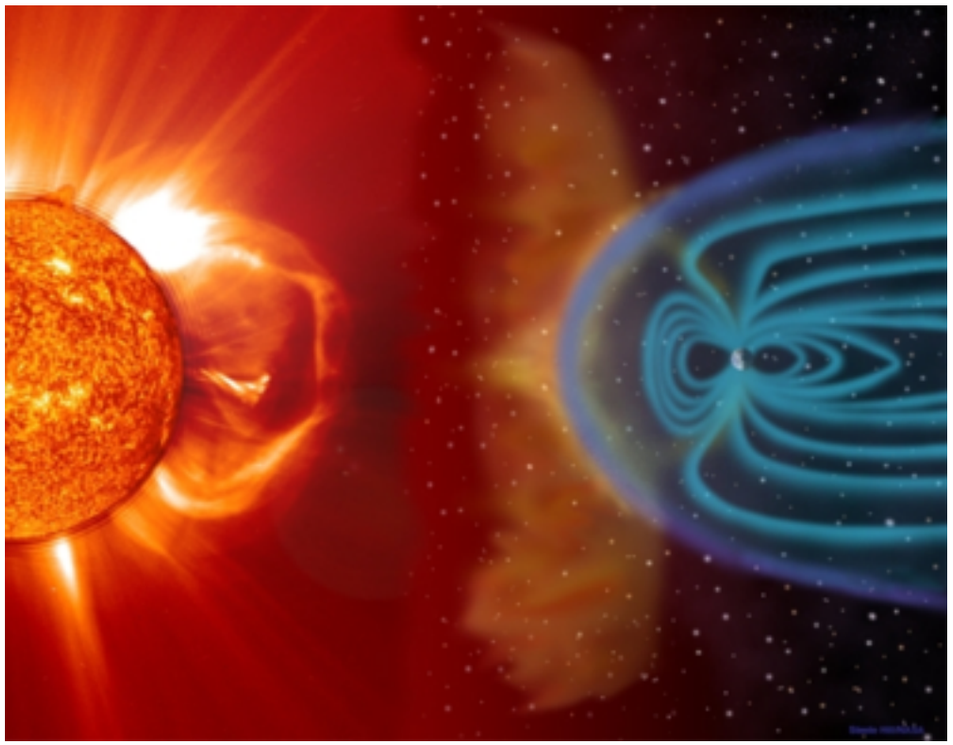
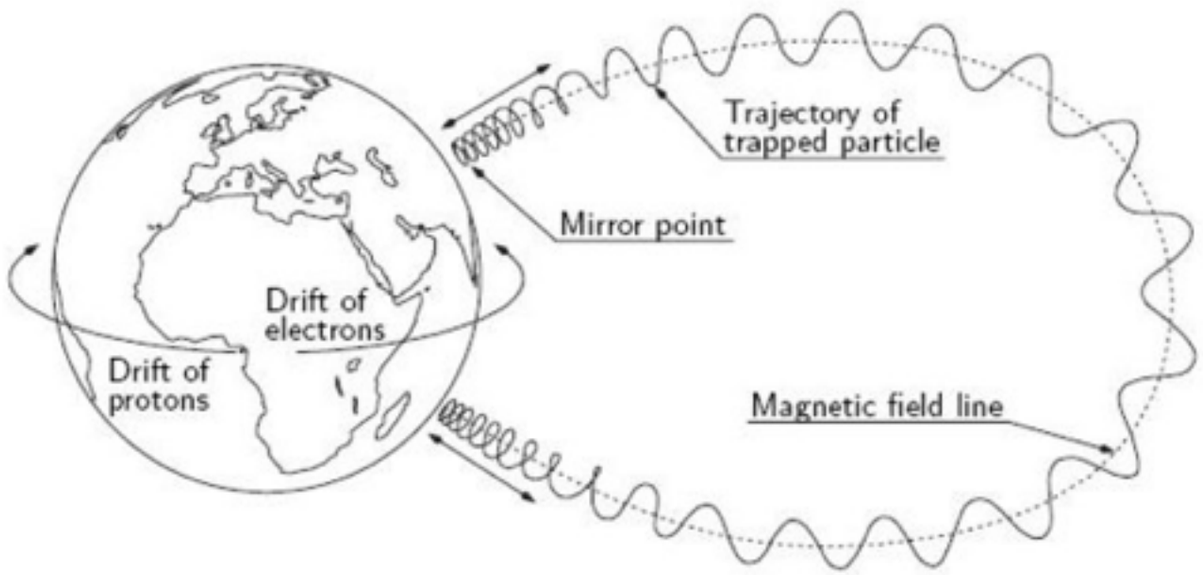
Six Timepix are flying on the ISS

Courtesy NASA

Timepix on the ISS

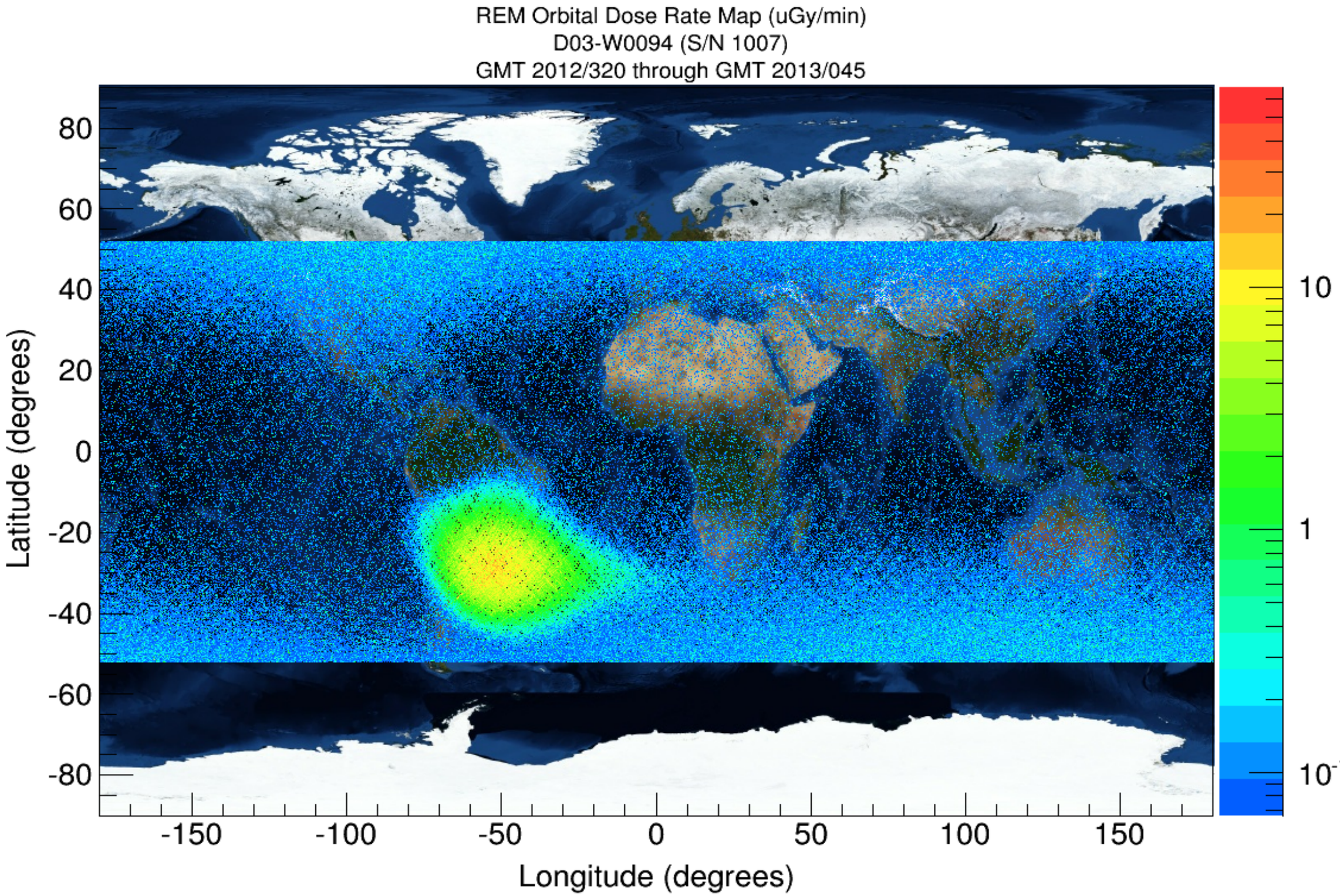
- Timepix is compact, solid state and relatively low power.
- Six units flying on the ISS
- The space radiation field in low earth orbit consists of galactic cosmic rays (SAA) and ions trapped by the geomagnetic field (GCR)
- Most of these are protons
- Also some heavier particles…





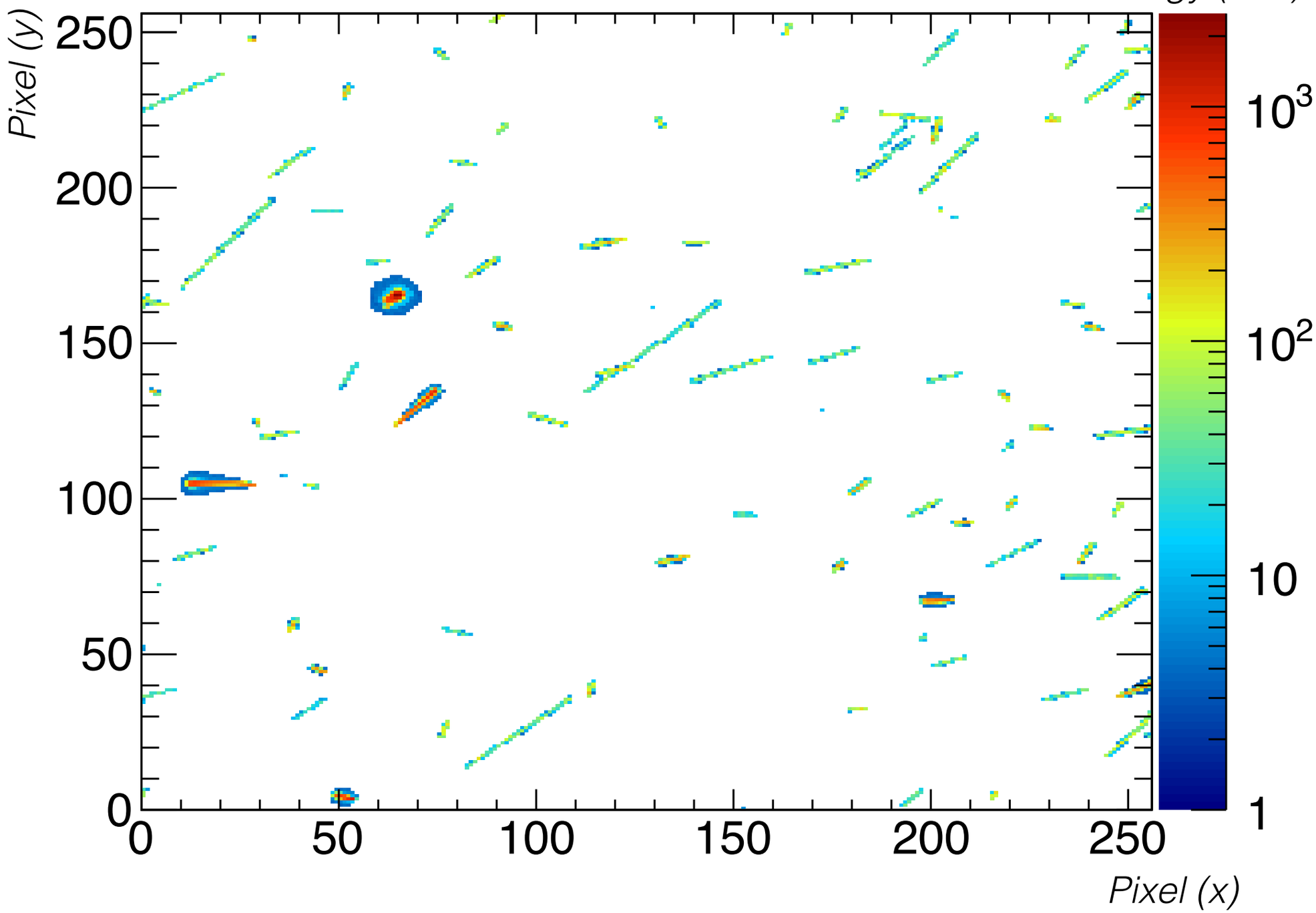
Courtesy ESA

Absorbed Dose Rate (uGy/min)



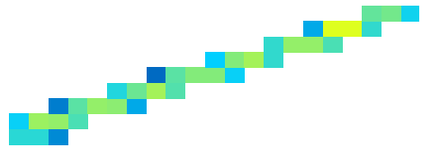
Clear distinction between trapped particles (SAA) and the rest

0.5s in South Atlantic Anomaly, Wed Apr 02 2014
12:24:03 Dose Rate = 30 uSv/hr

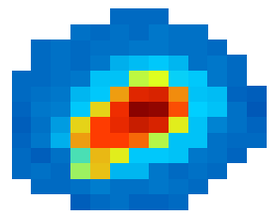


Probably…

Slow Proton

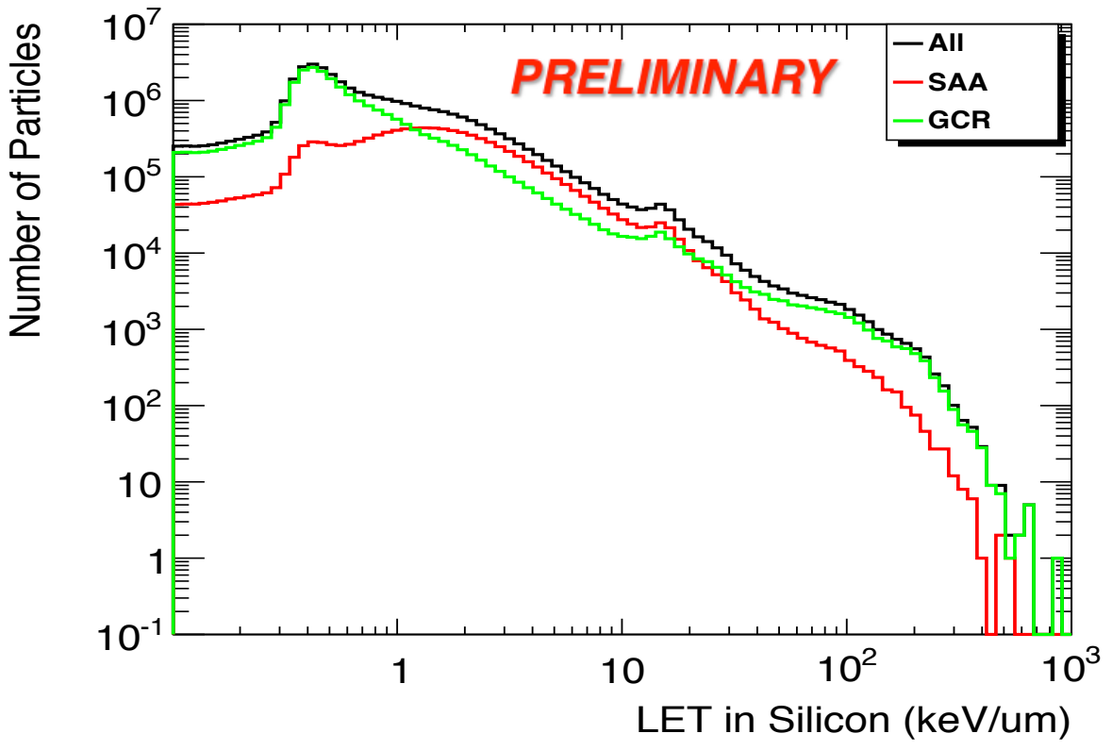


Fast Proton

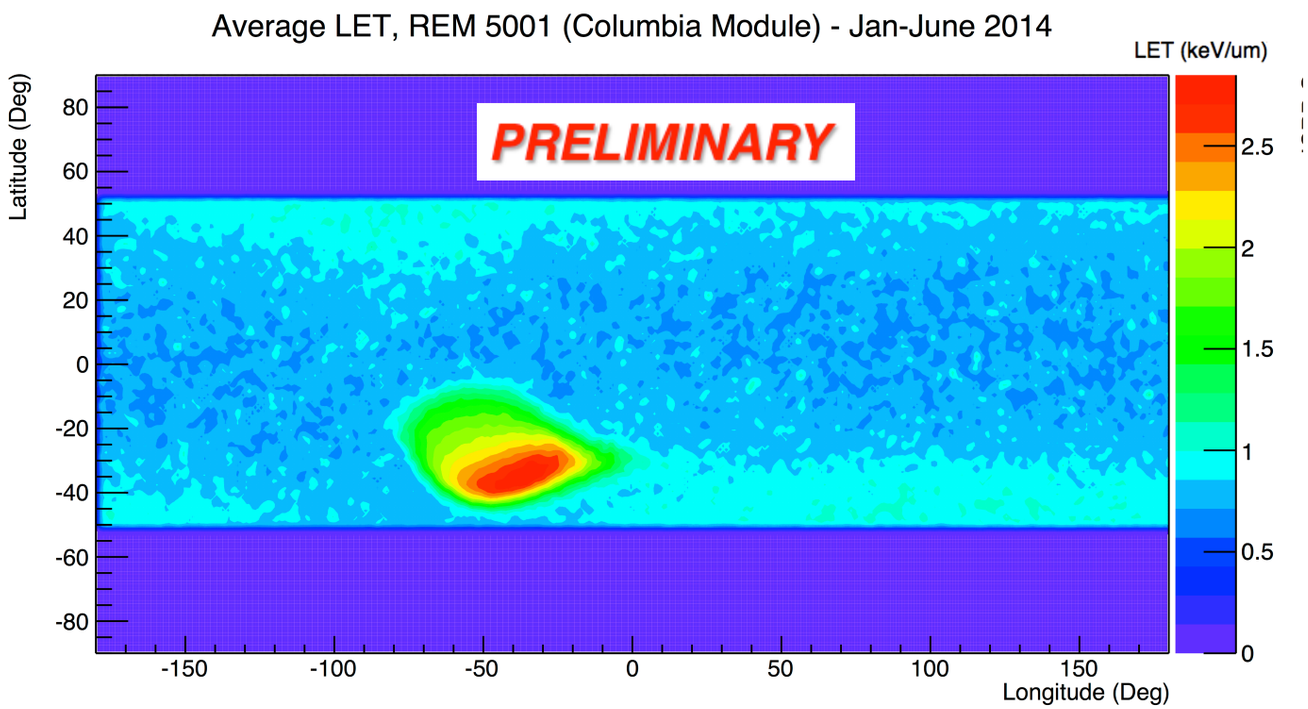


Fast Alpha

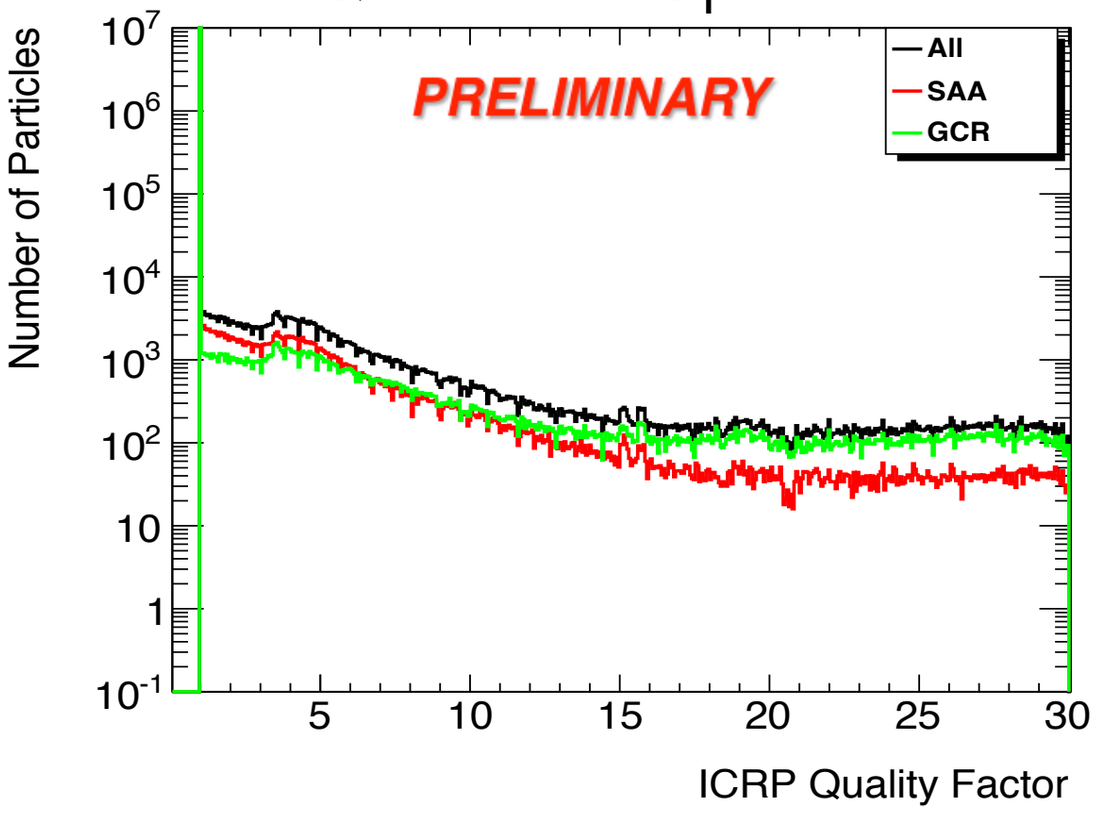
LET Spectra (Si)

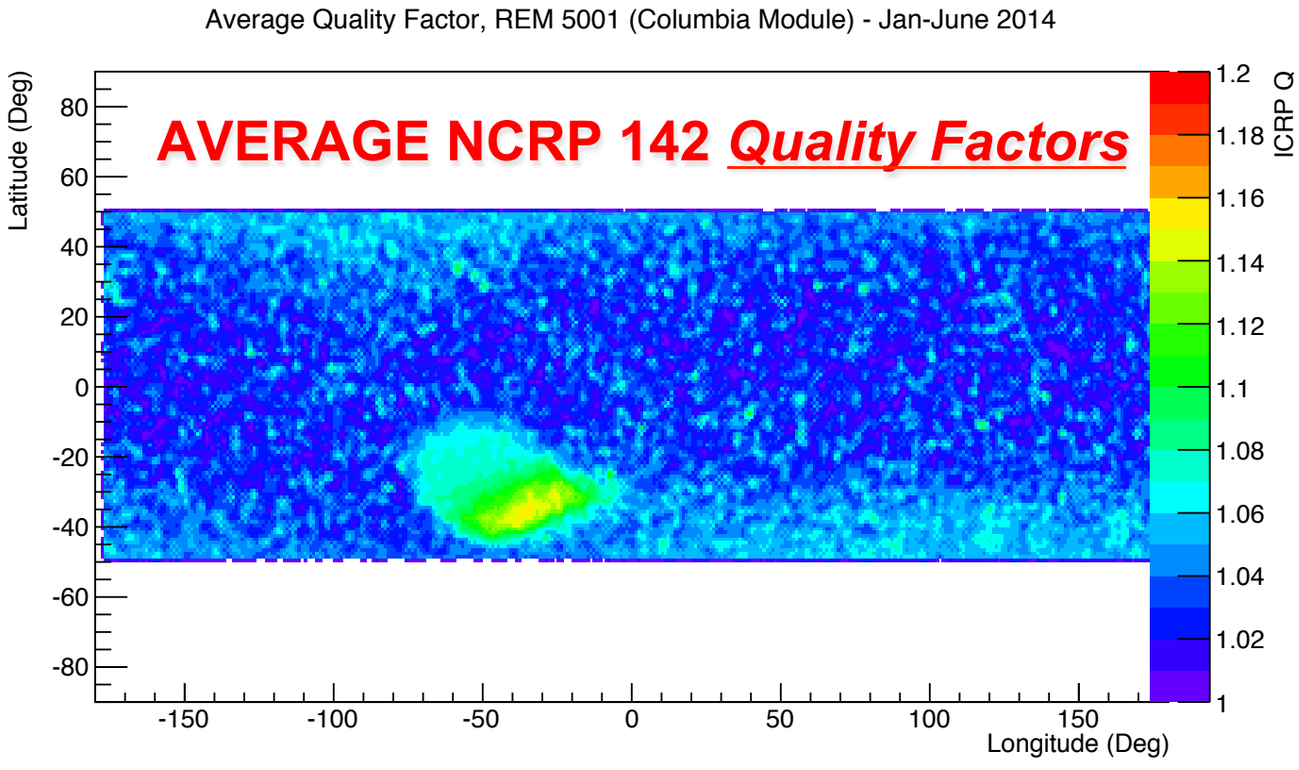


Average LET Distribution

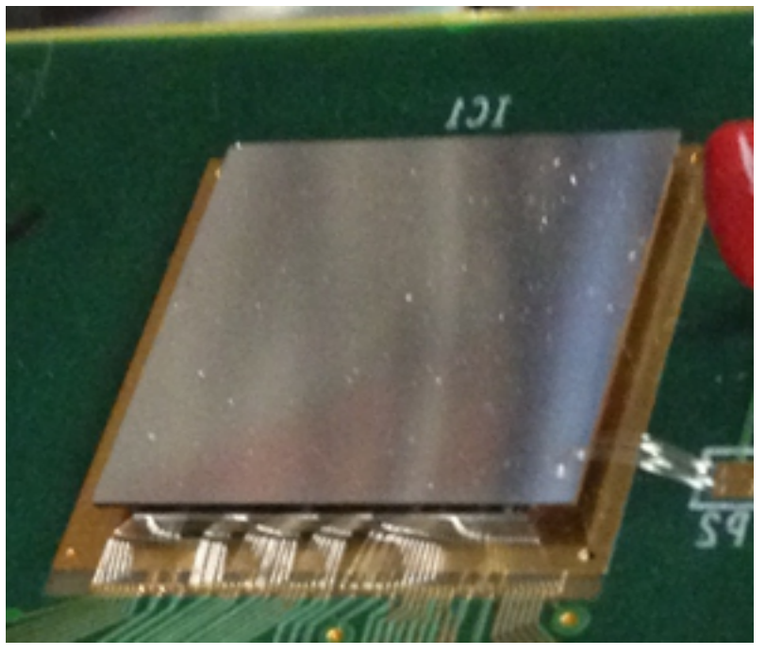


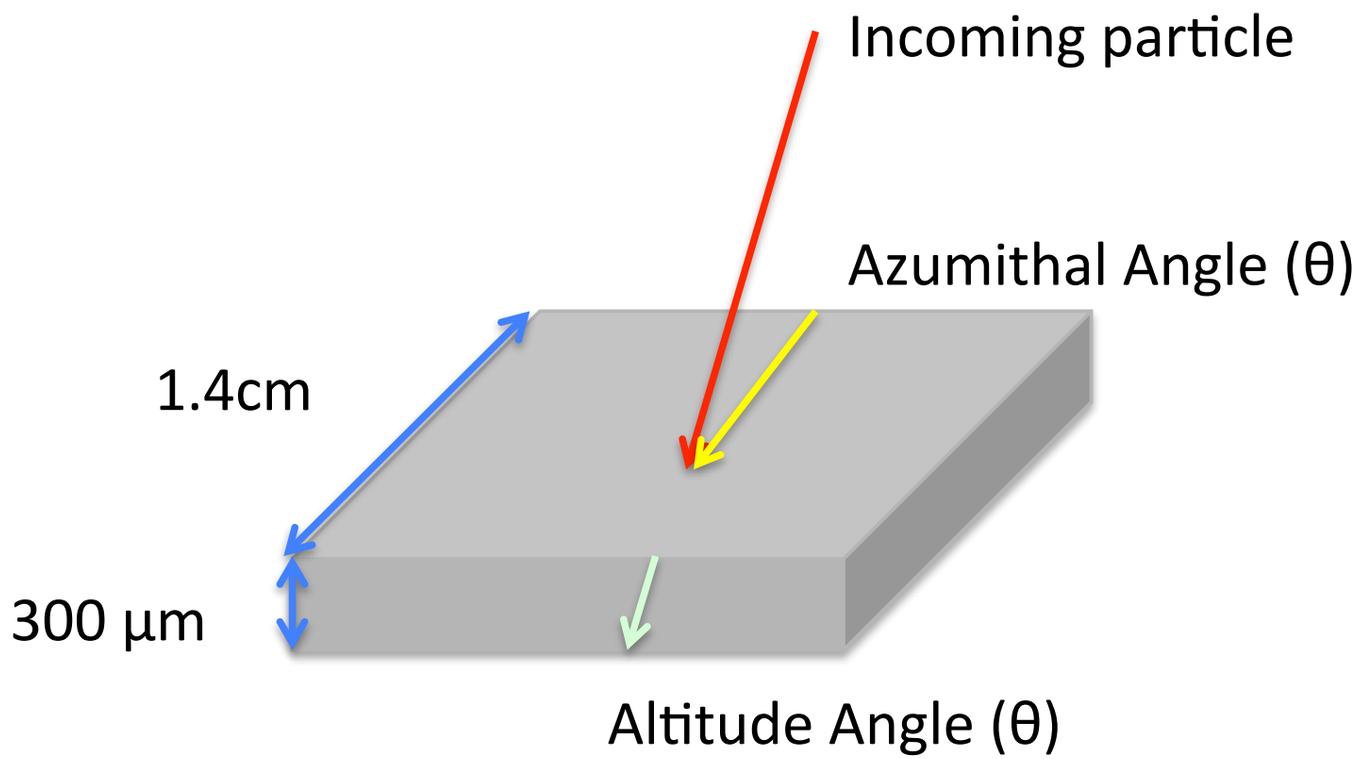
Q Factor Spectra





Calculation of Track Angles in Timepix



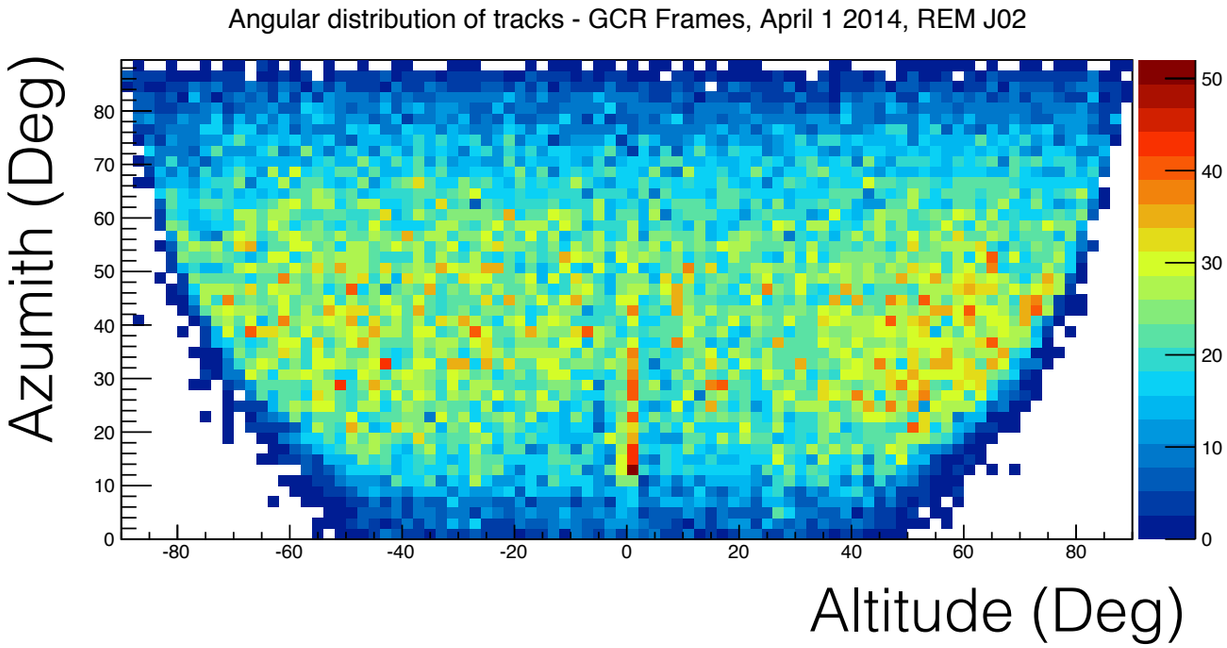


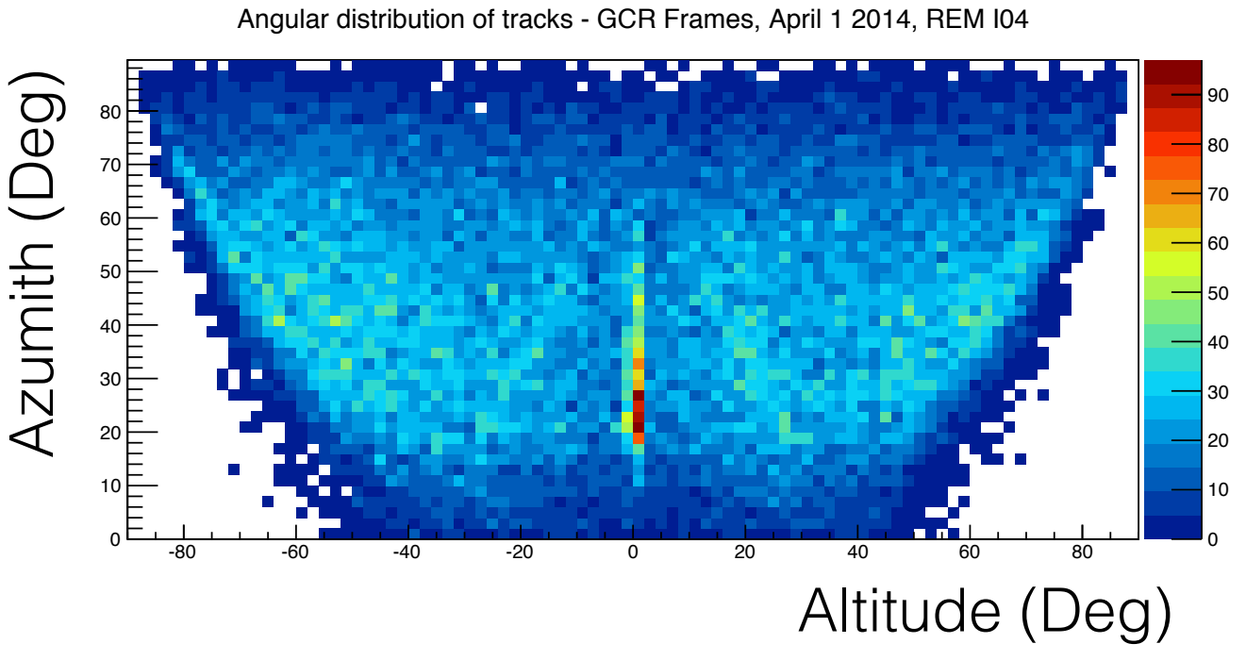
- 4π view of sky, 1π discrimination (slope cannot tell up from down, projection of a line symmetric around 180 degrees)

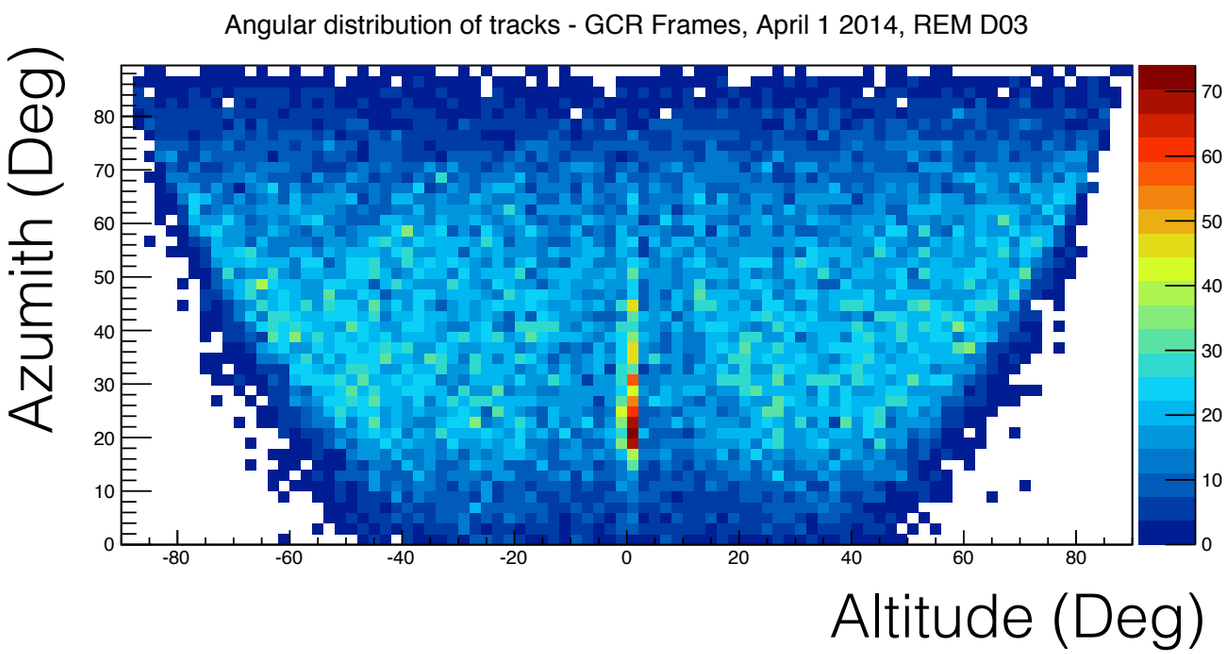
- Assumption of sensor penetration for slope, work on corrections for stopping protons in progress.

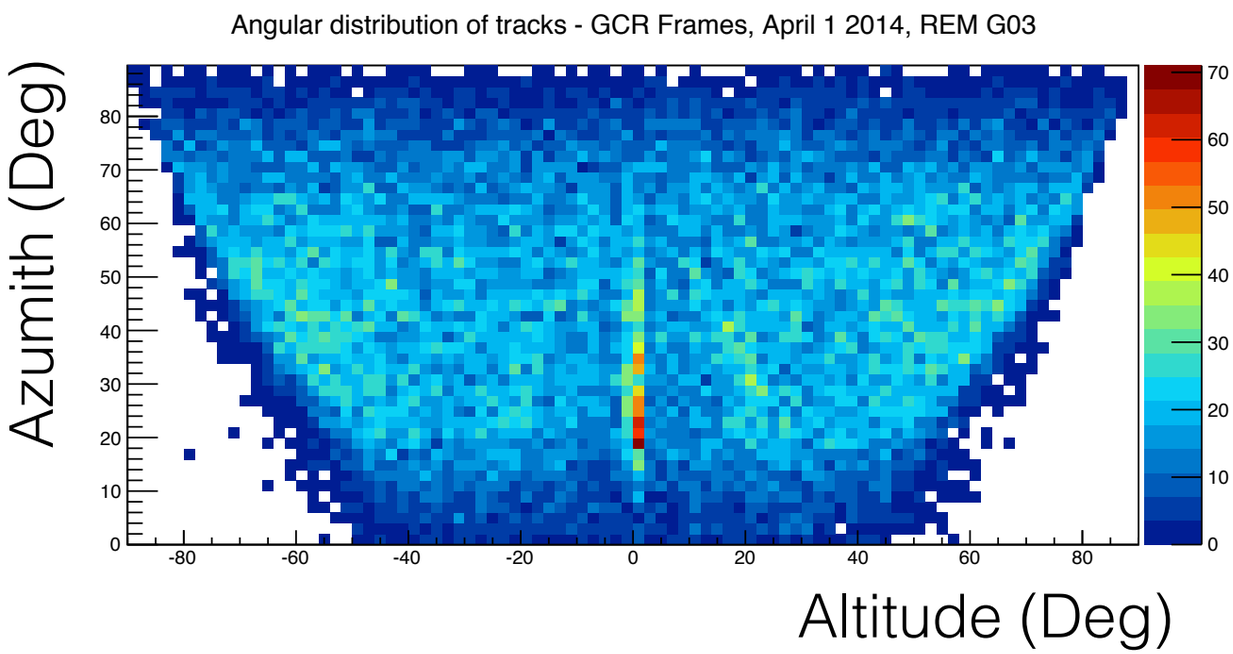
GCR Angular Distributions 1st April 2014

500 um unit



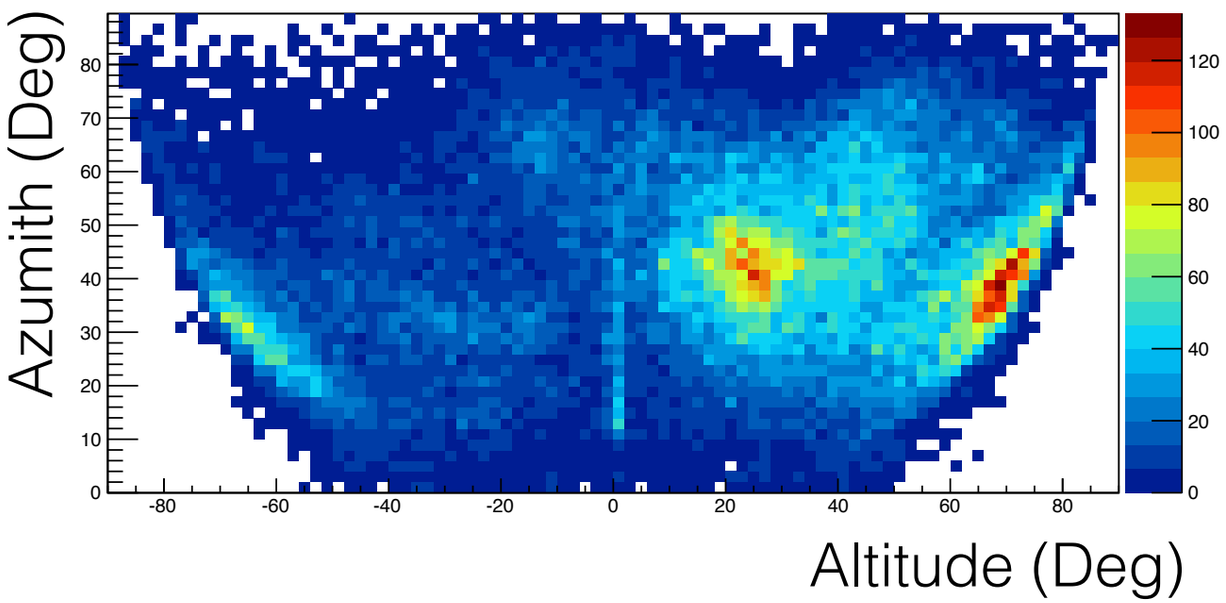


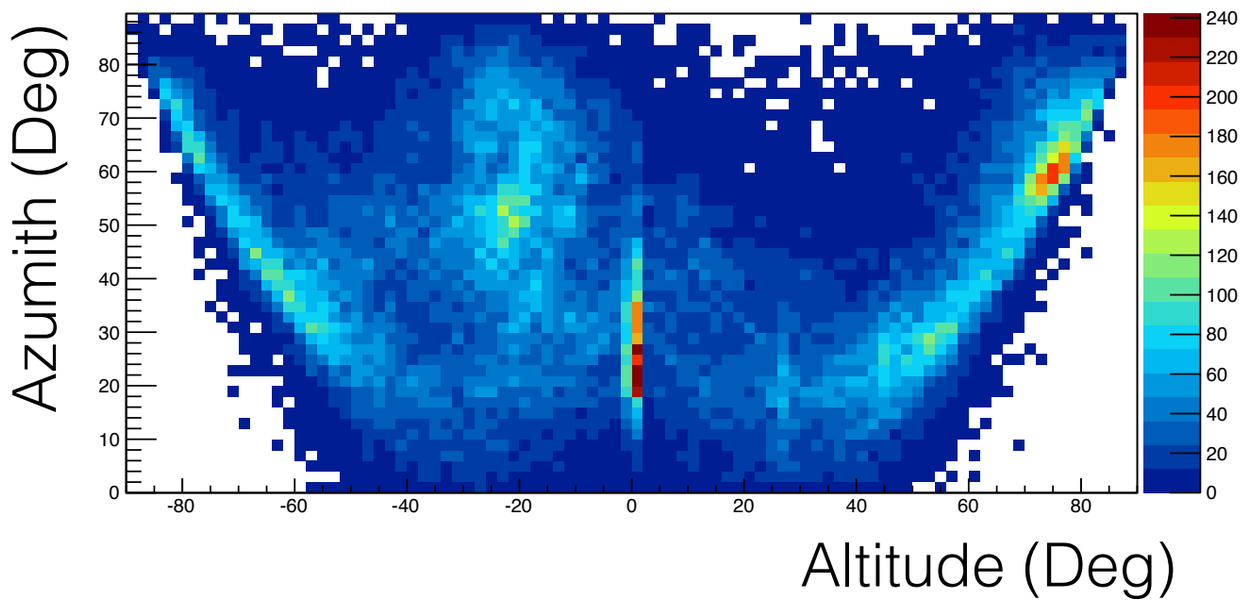


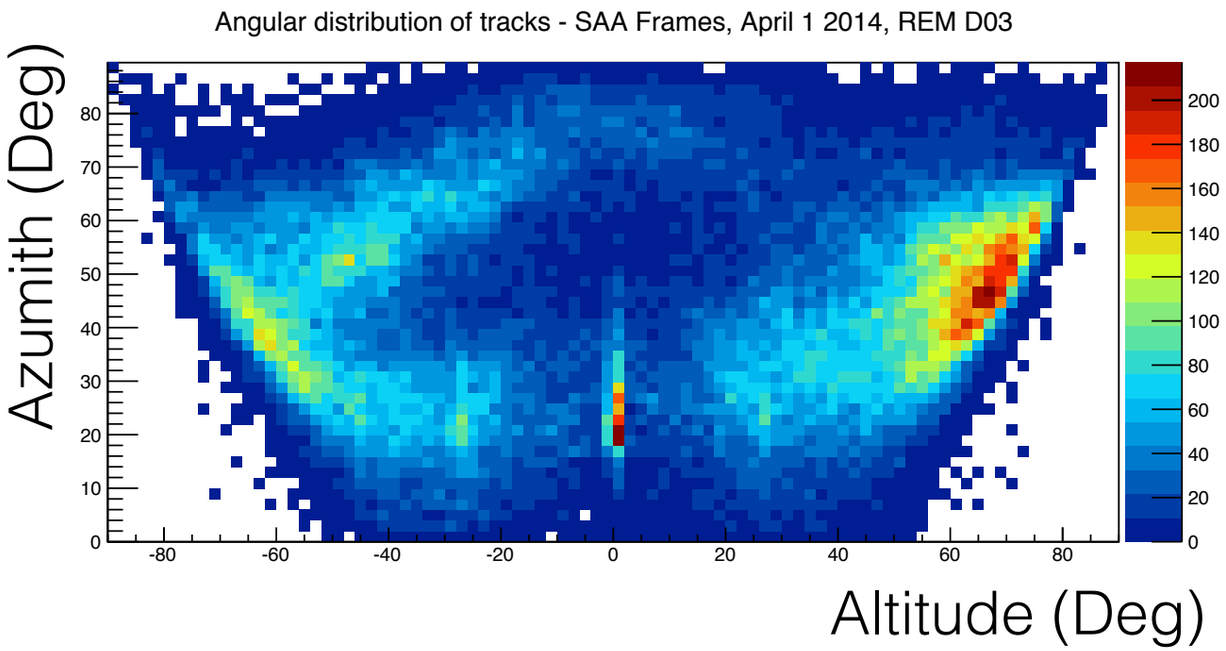


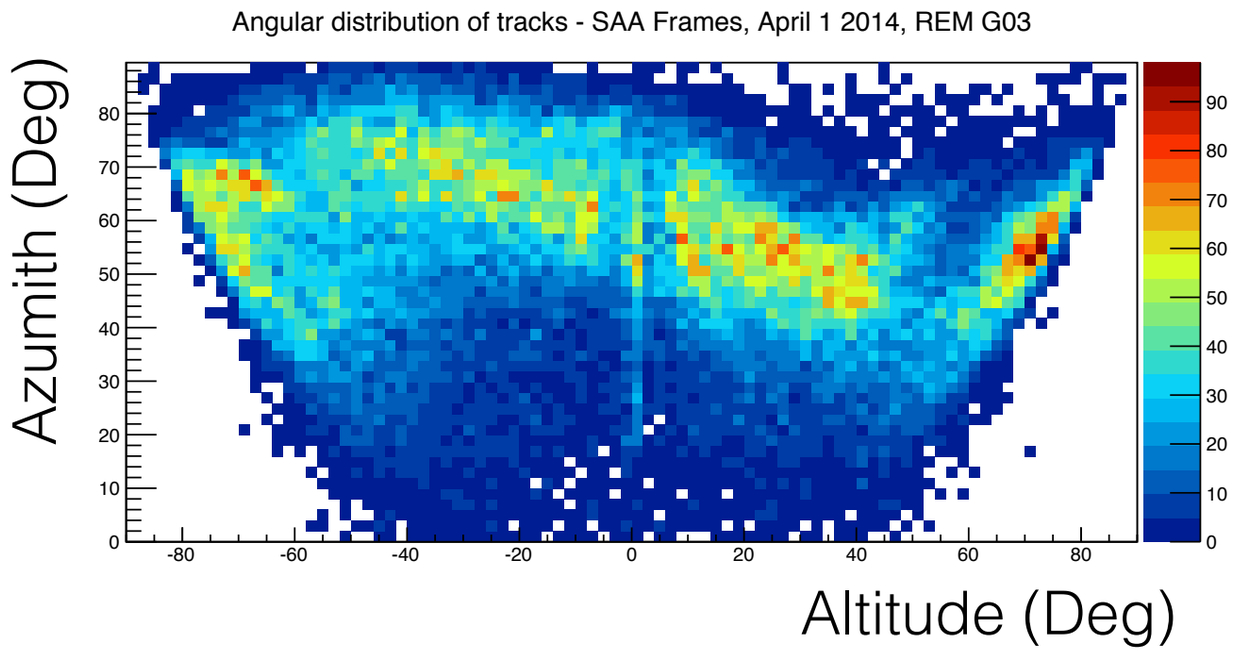
SAA Angular Distributions 1st April 2014

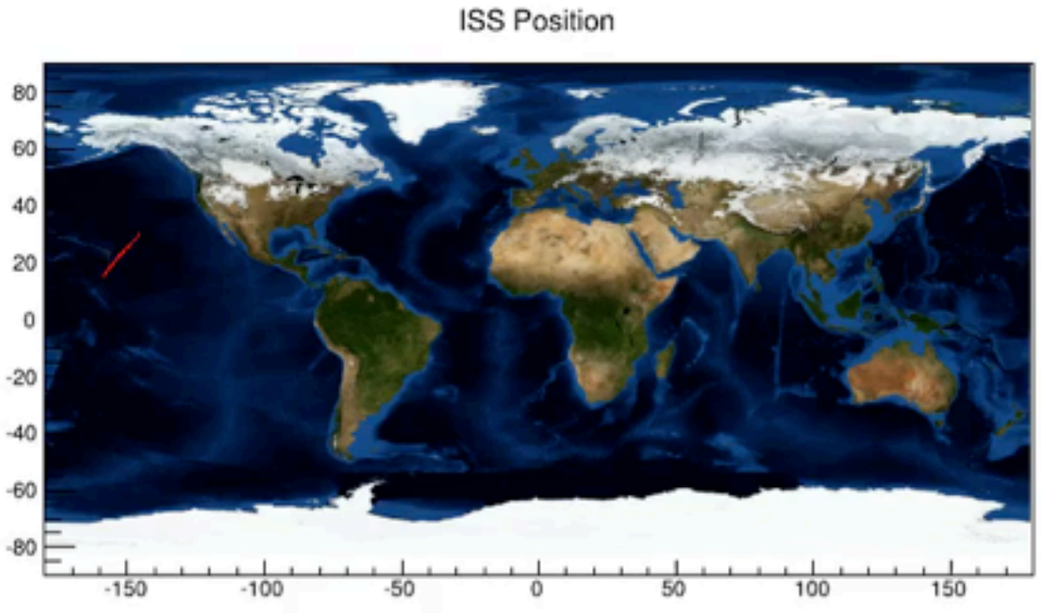
500 um unit

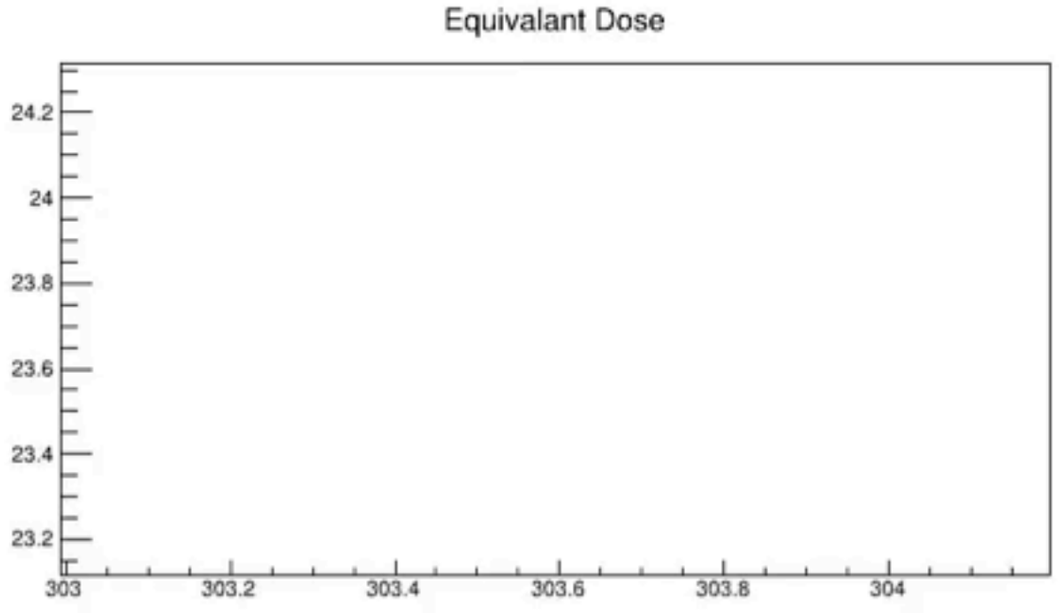


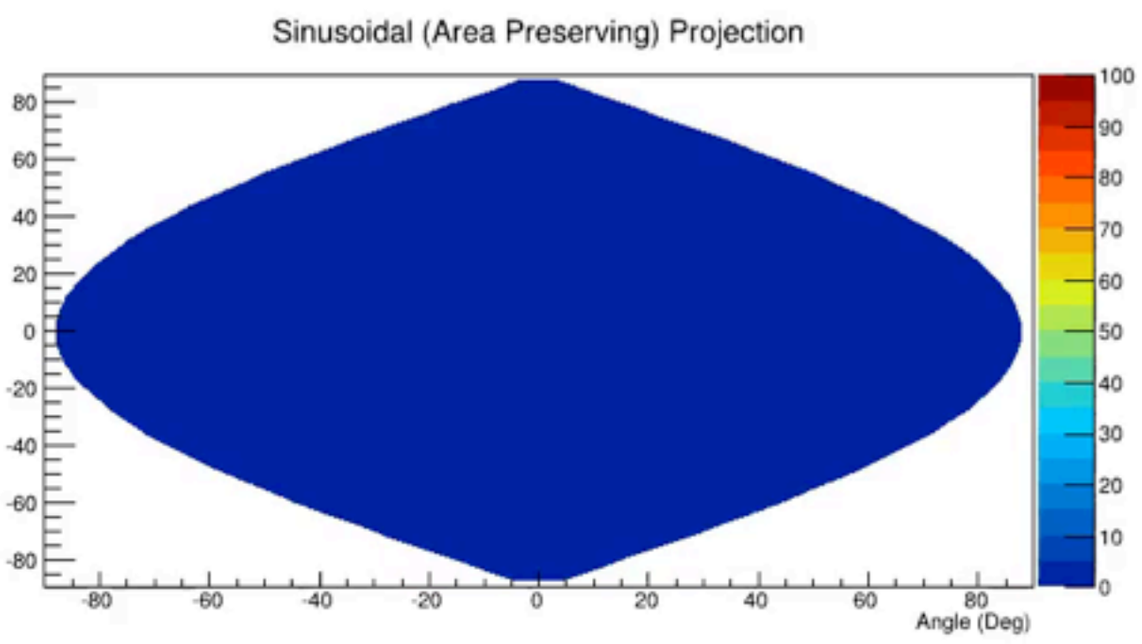


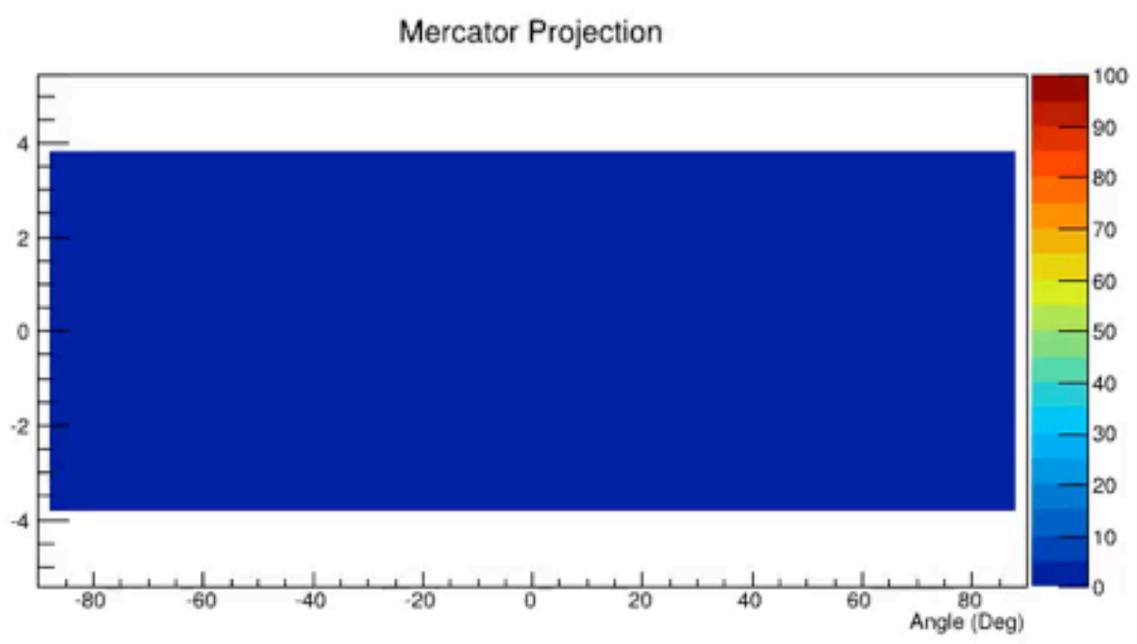












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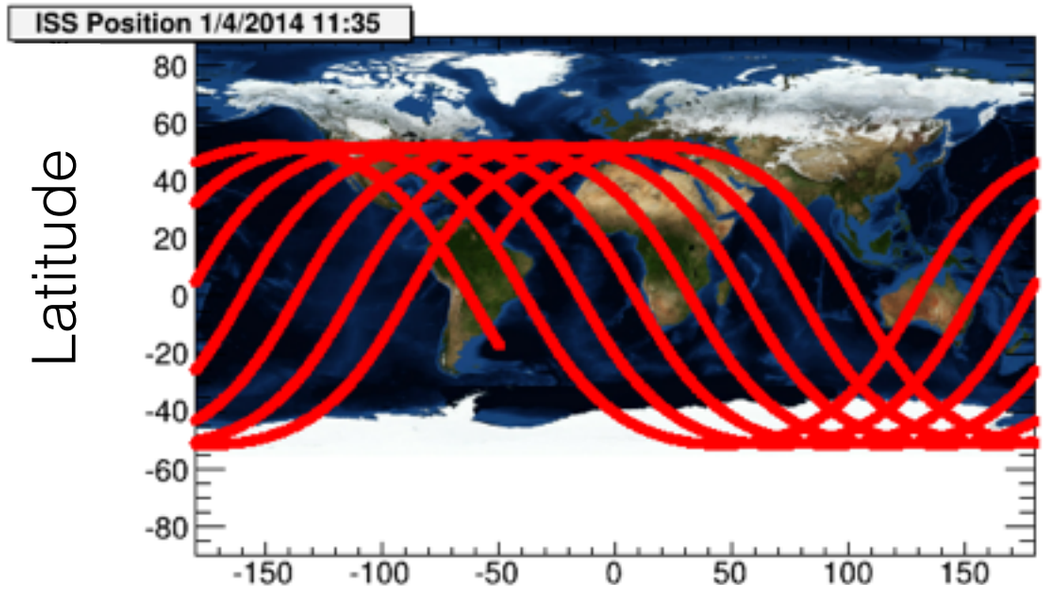
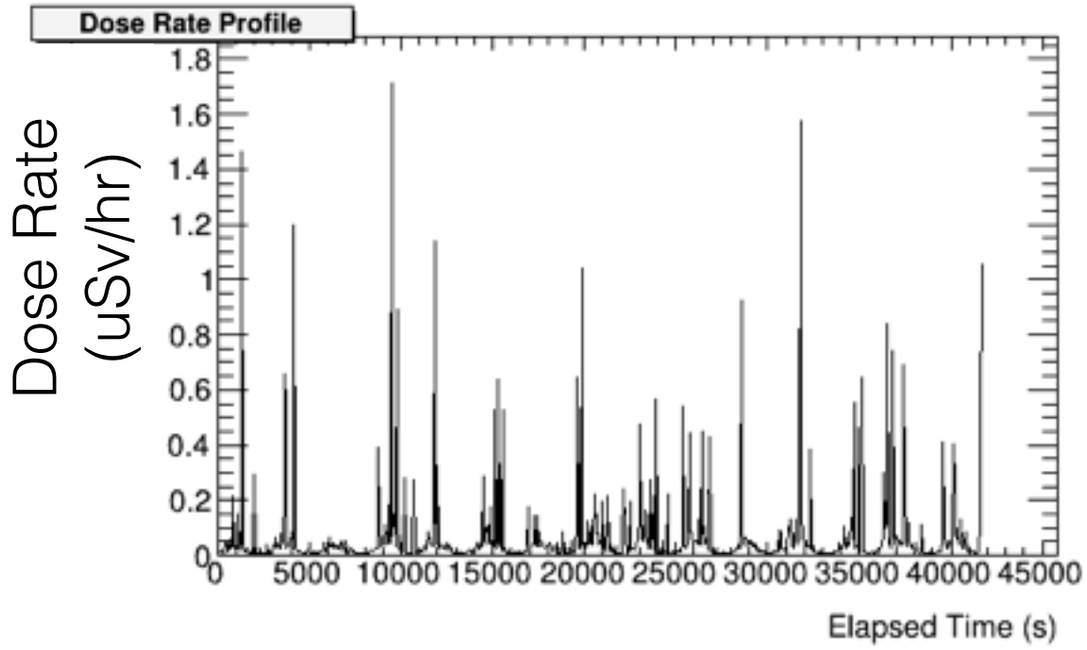
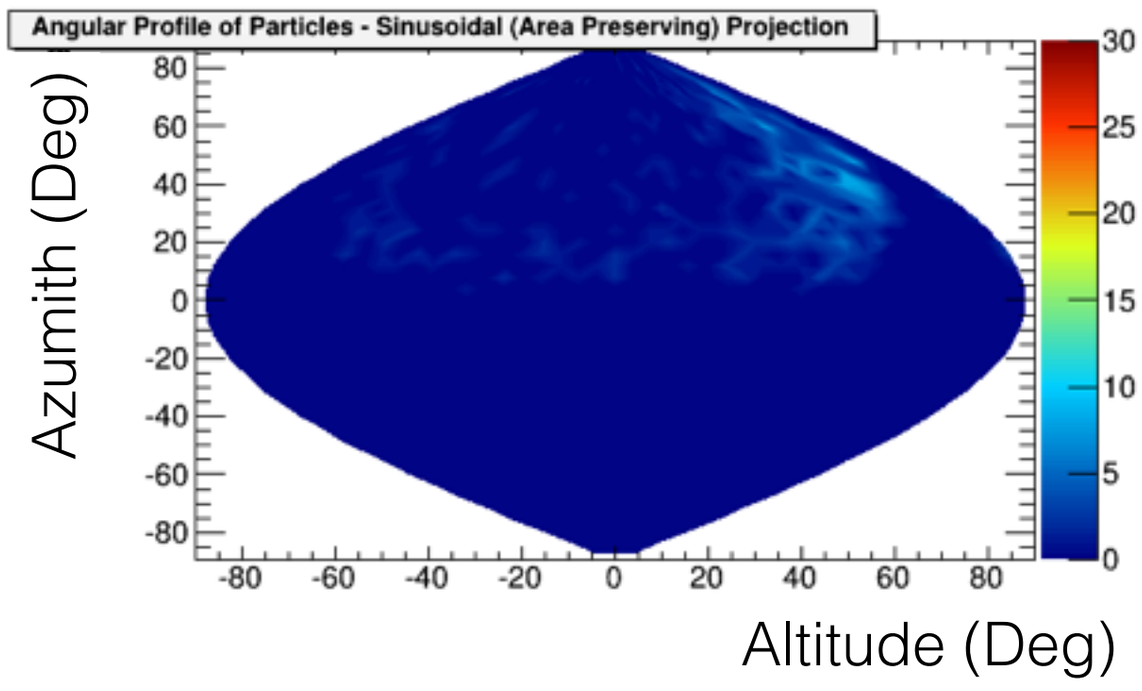
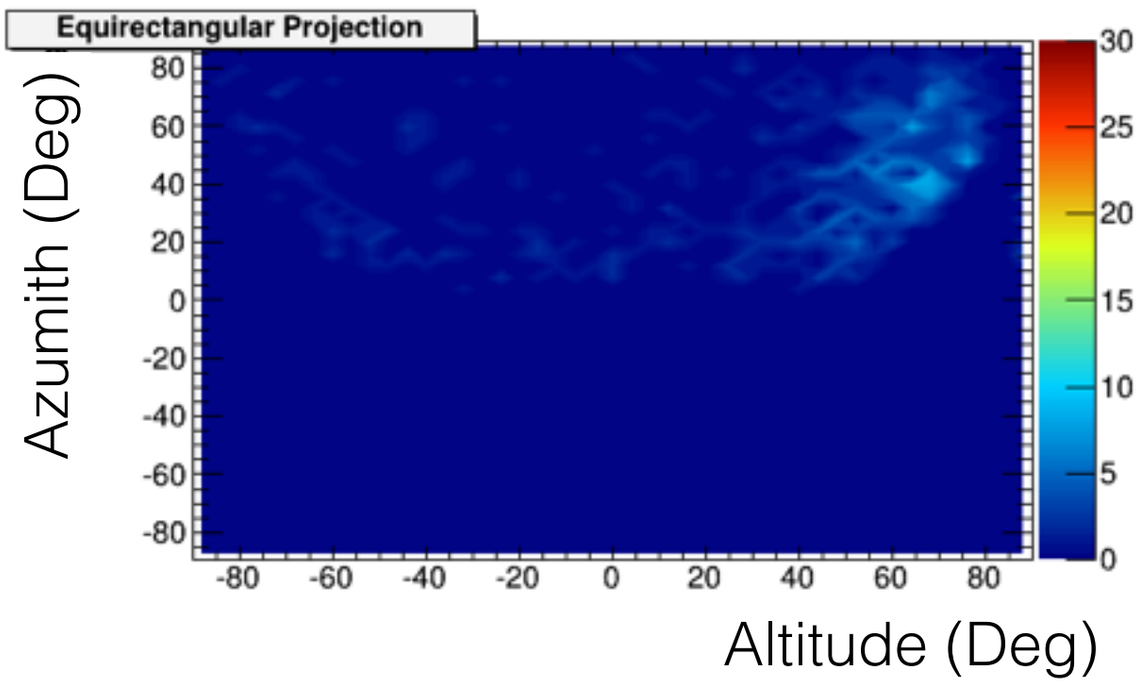
One Pass, April 1st 2014









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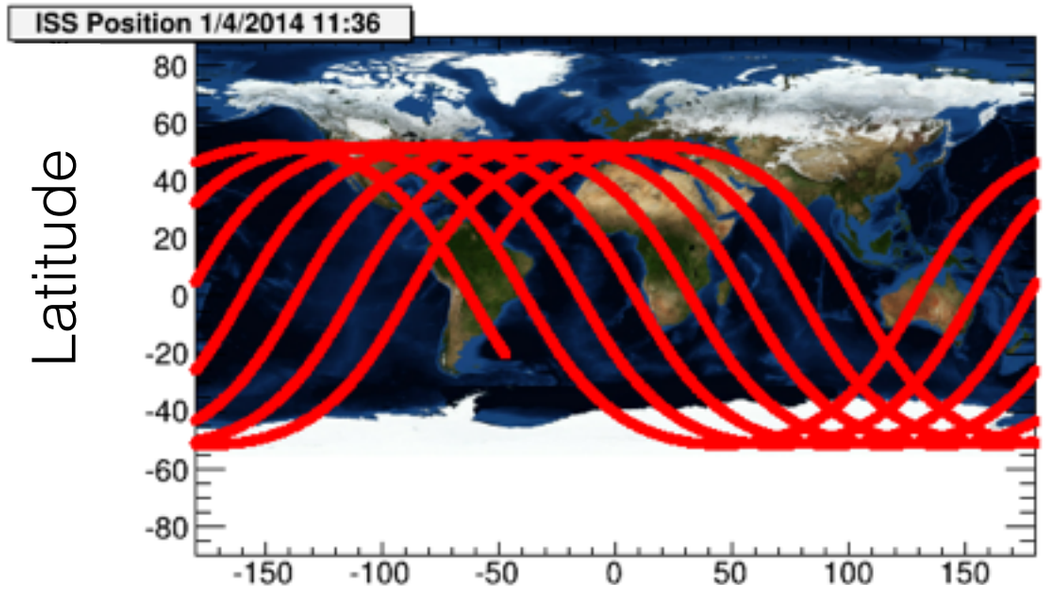

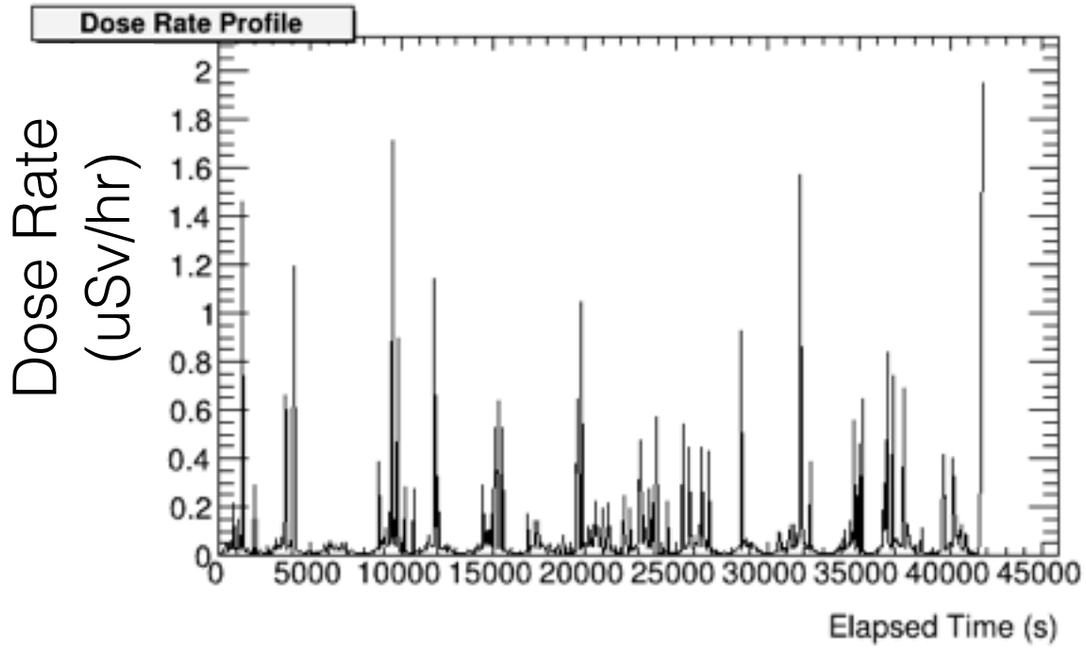

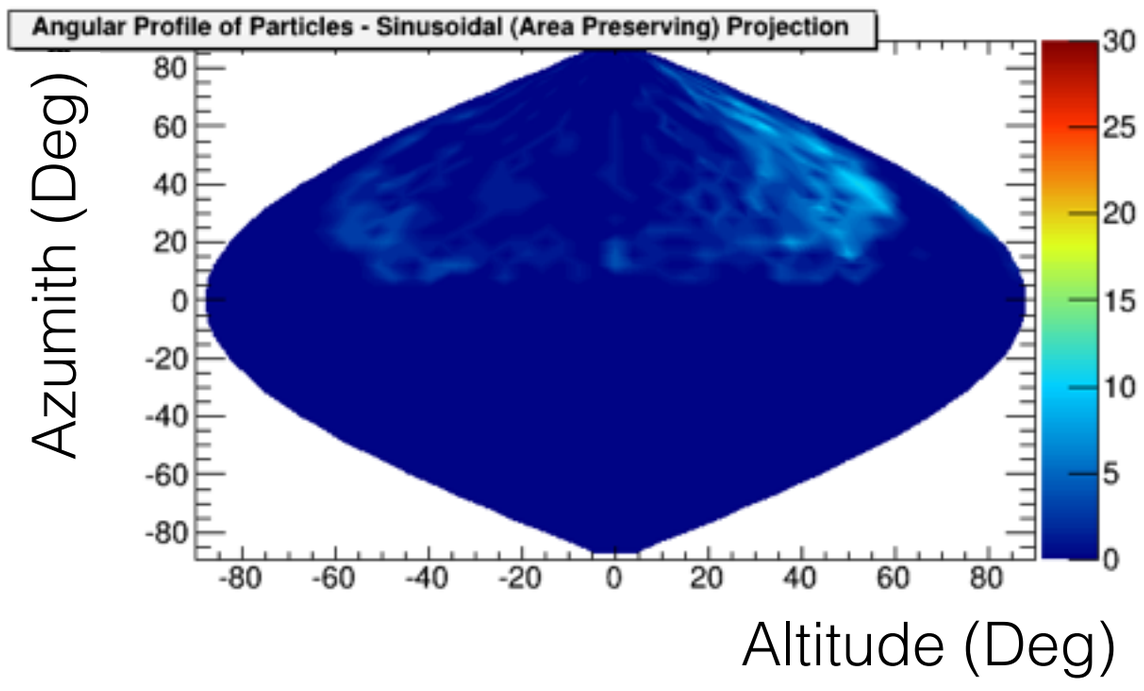

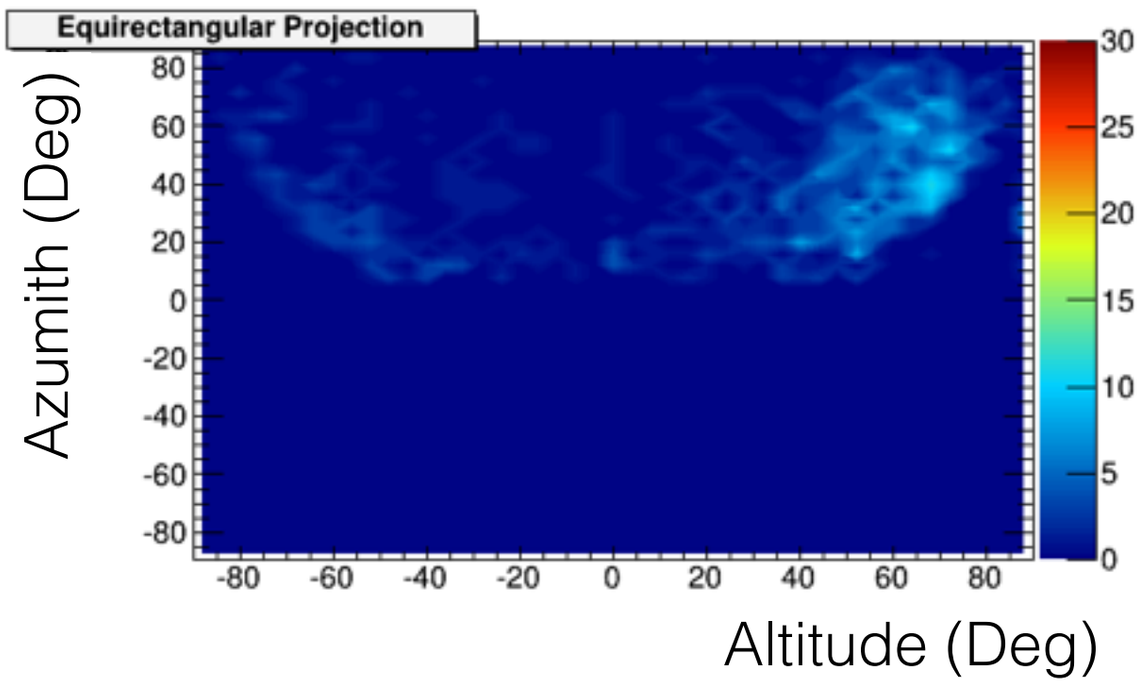

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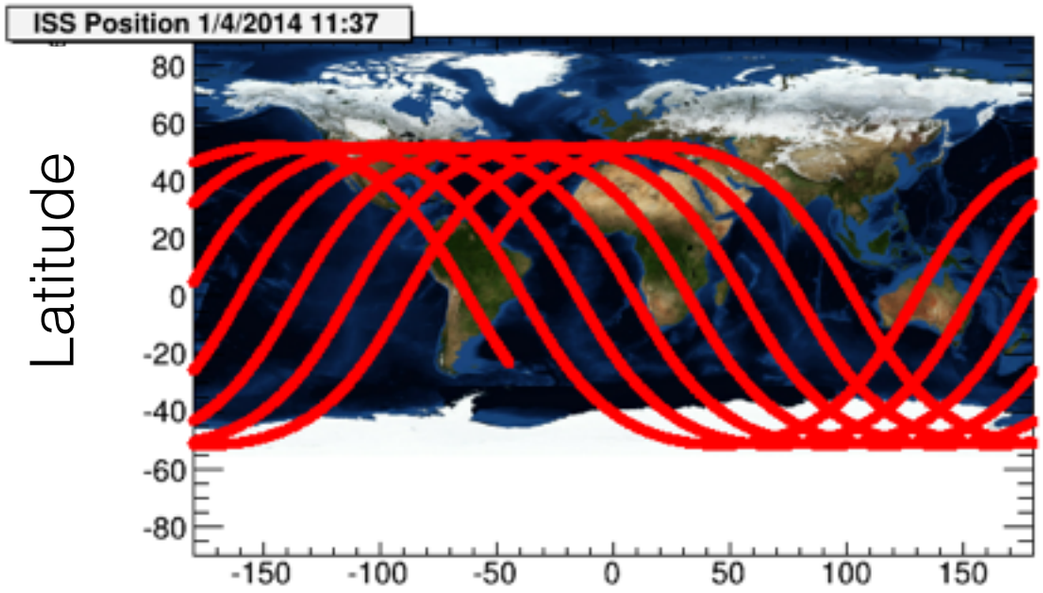

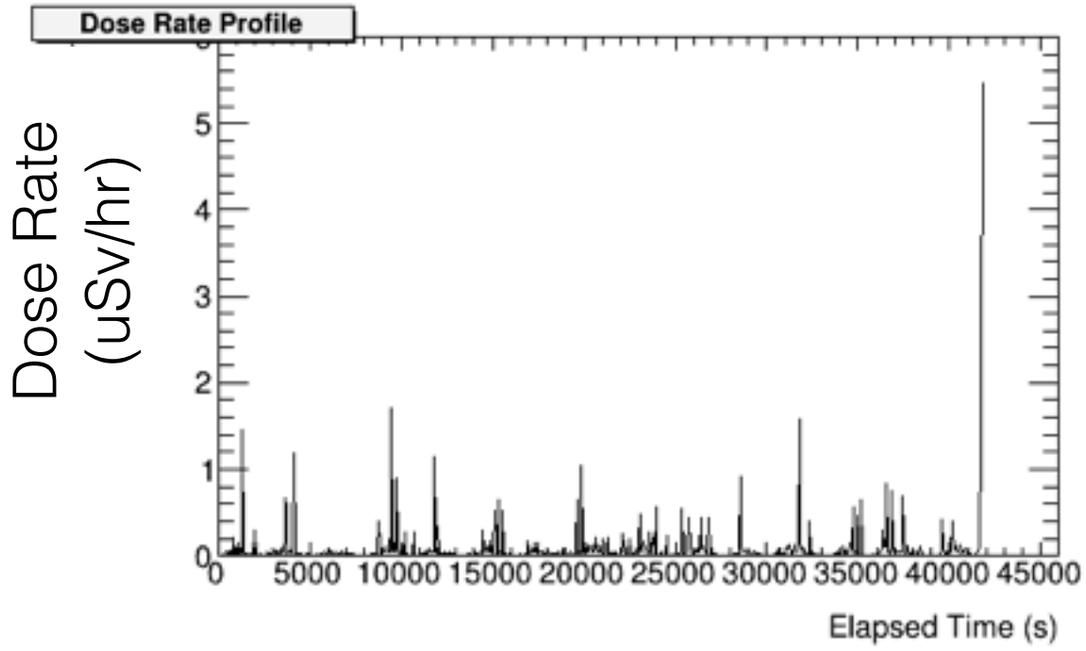

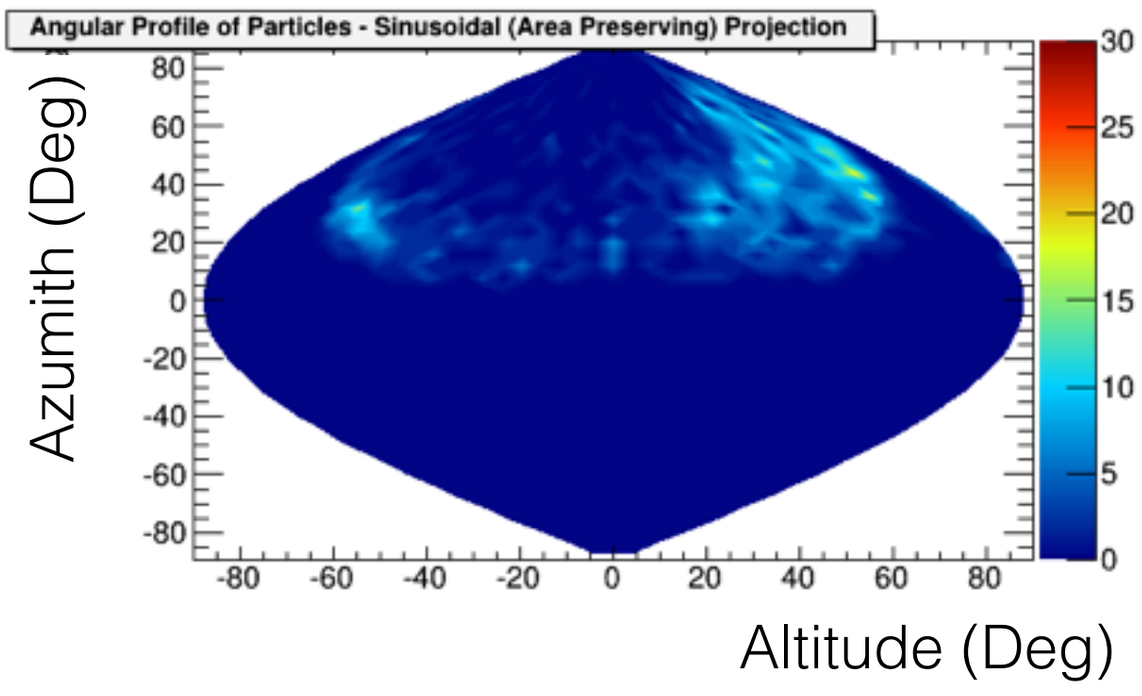

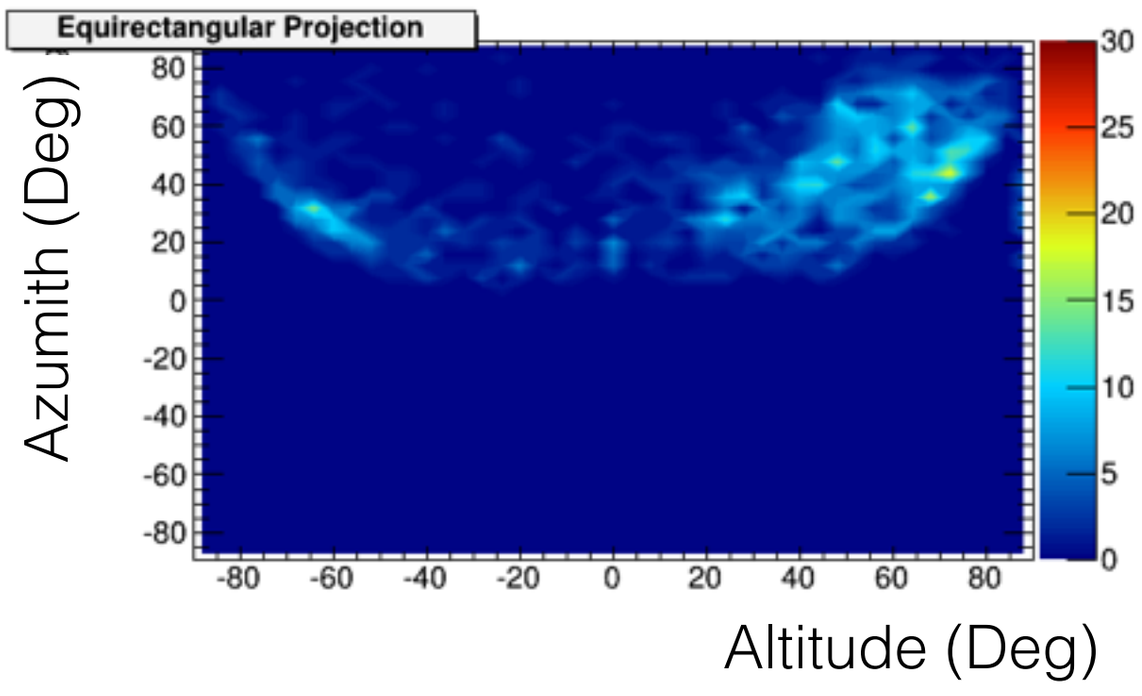

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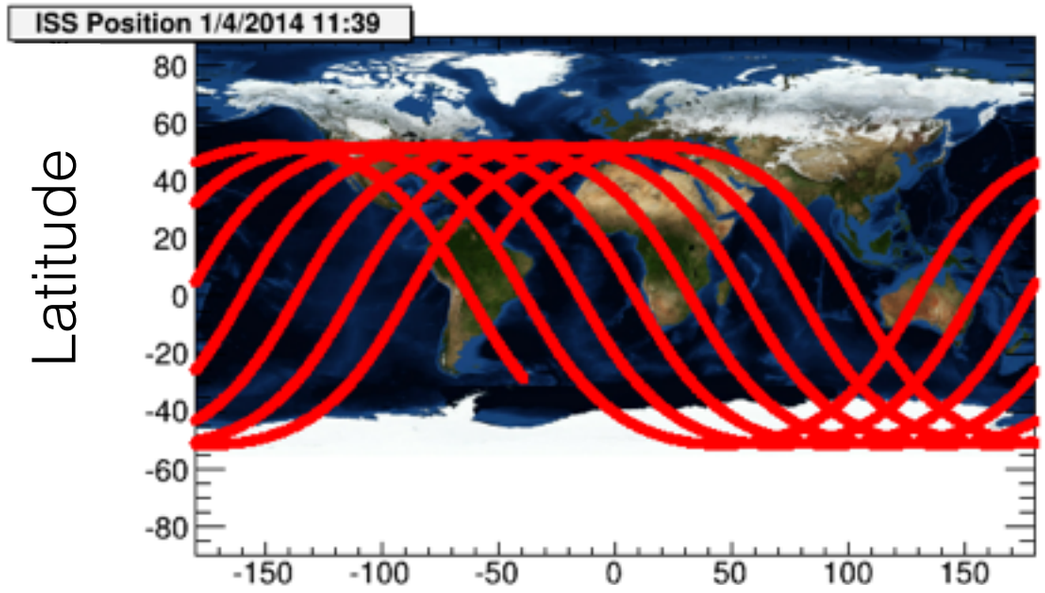

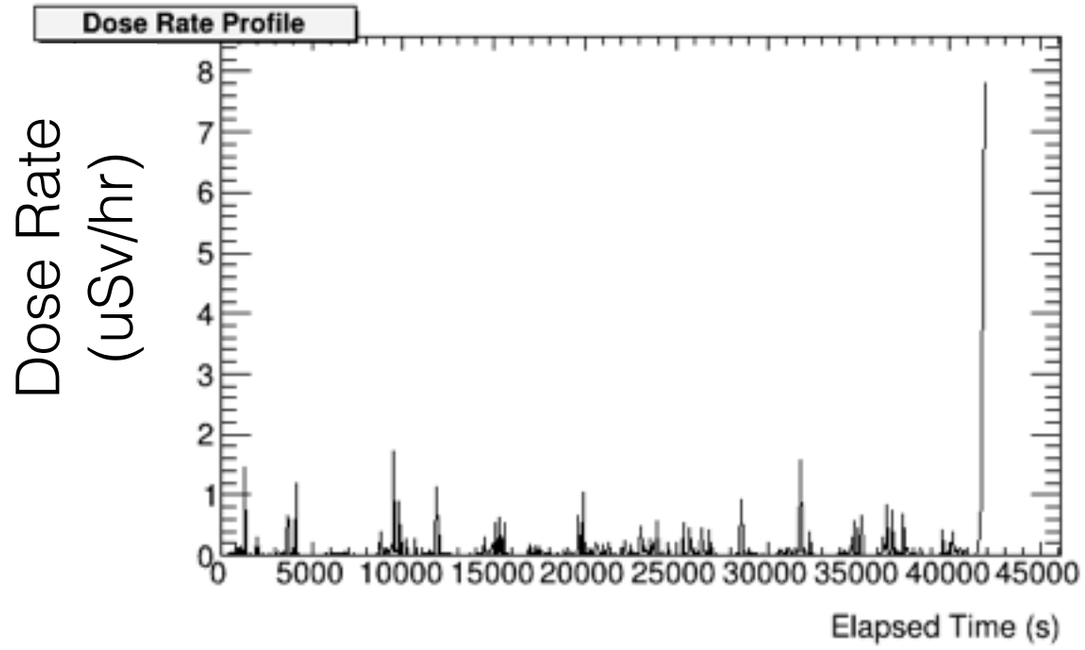

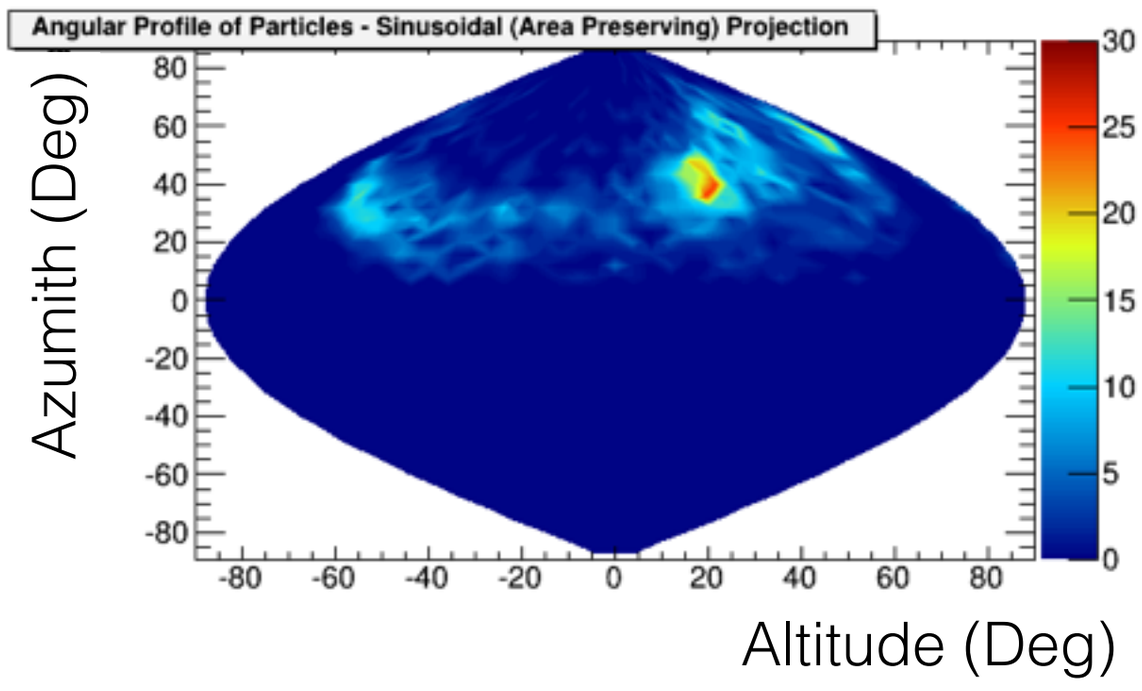

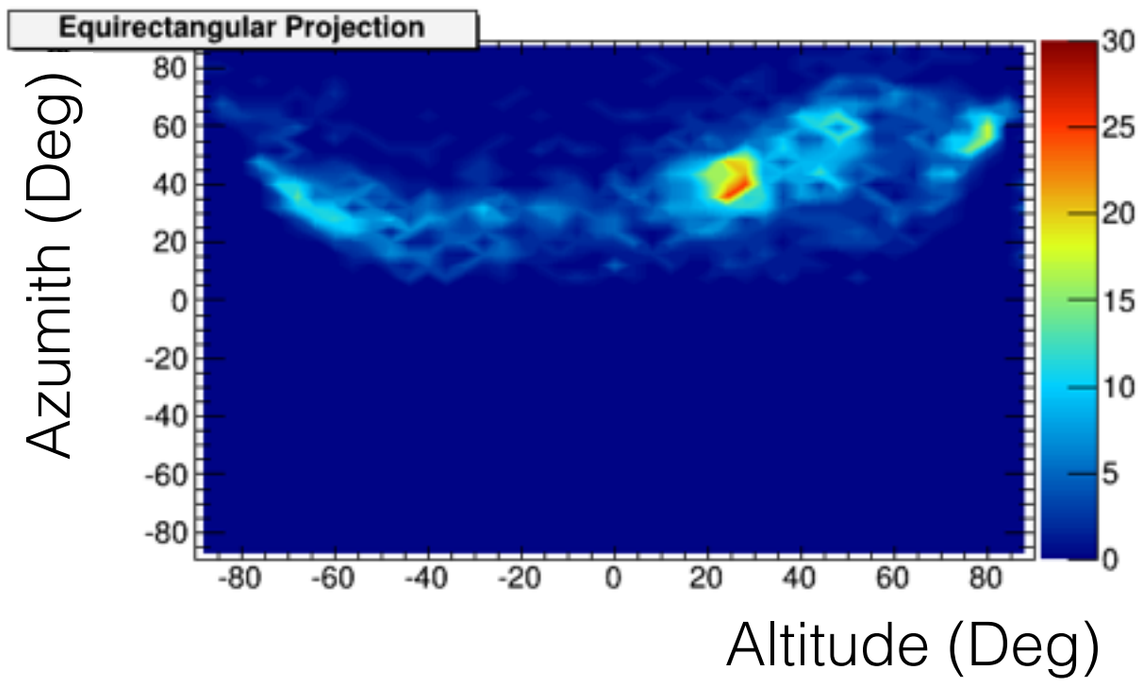

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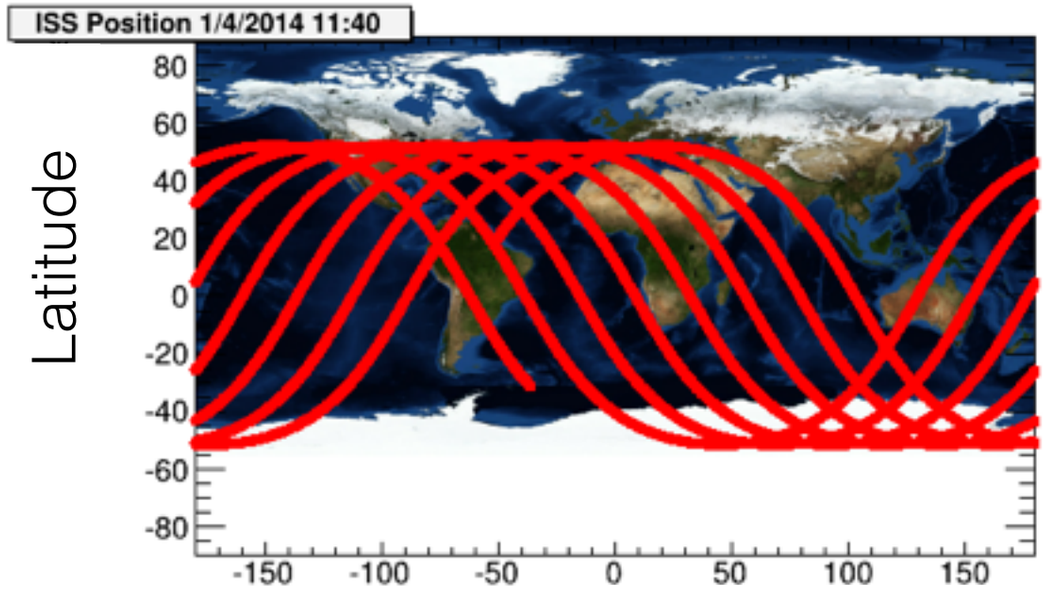

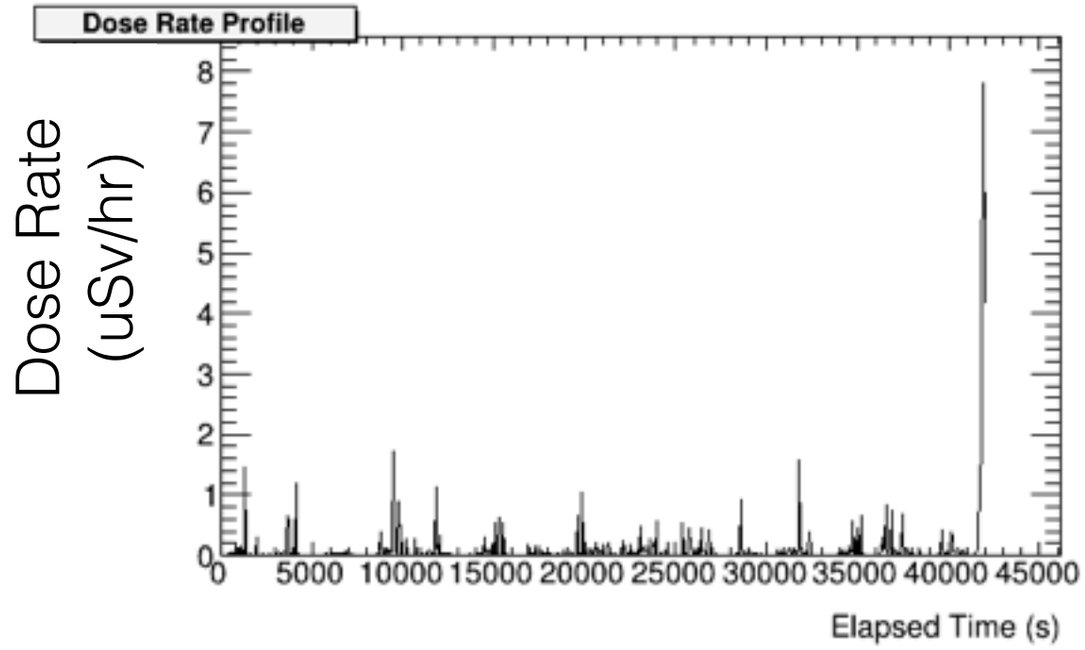

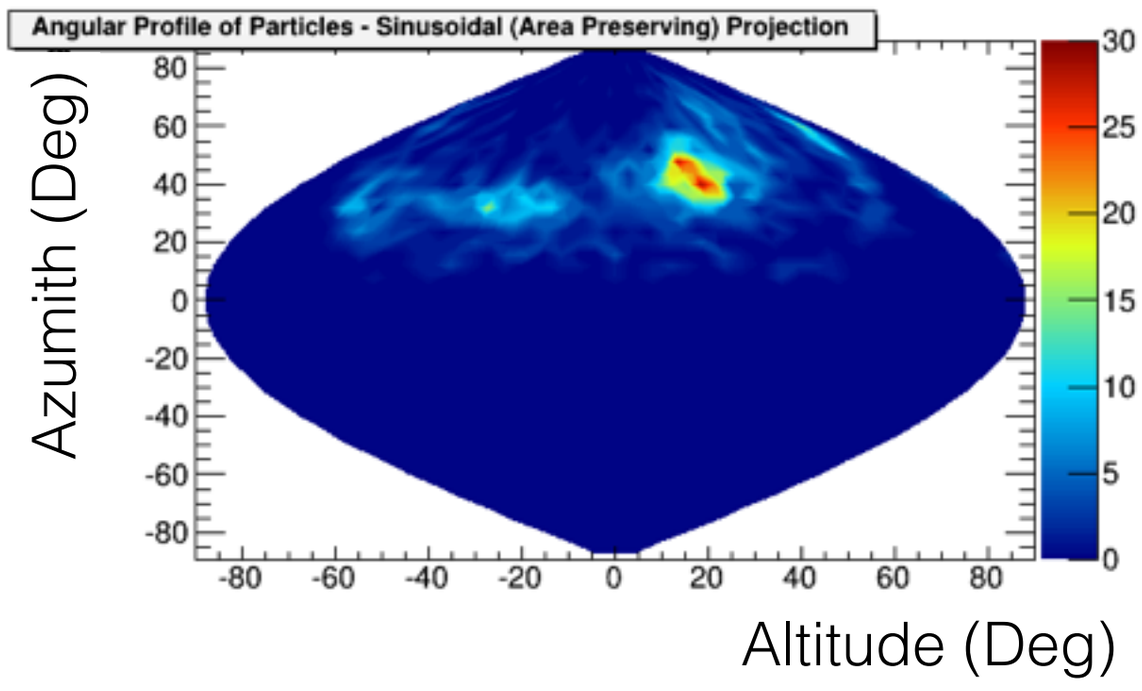

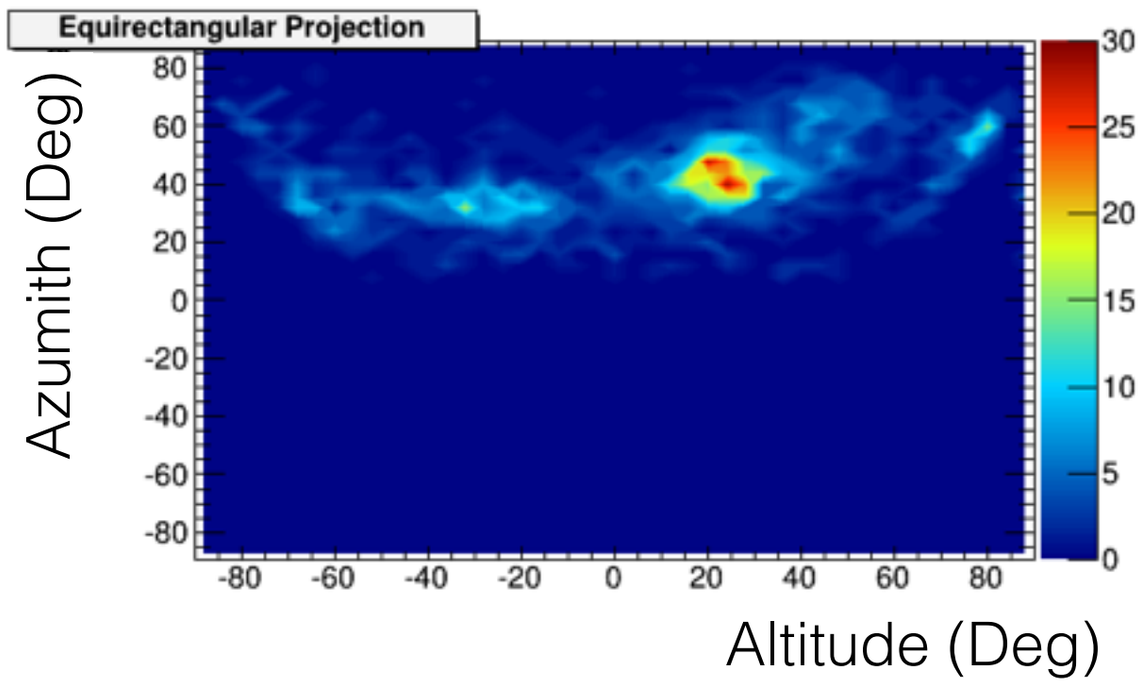

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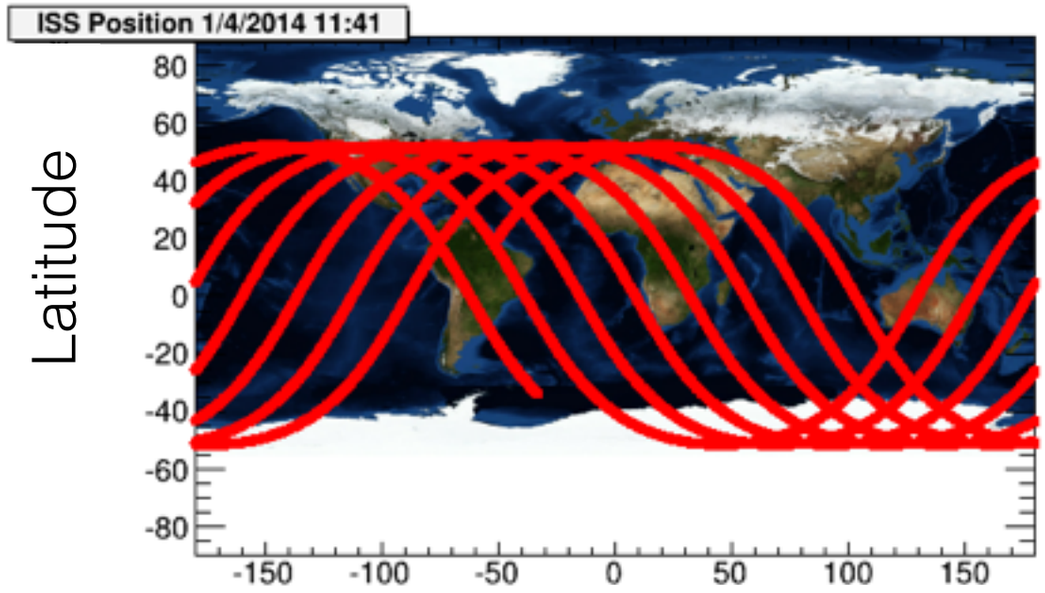

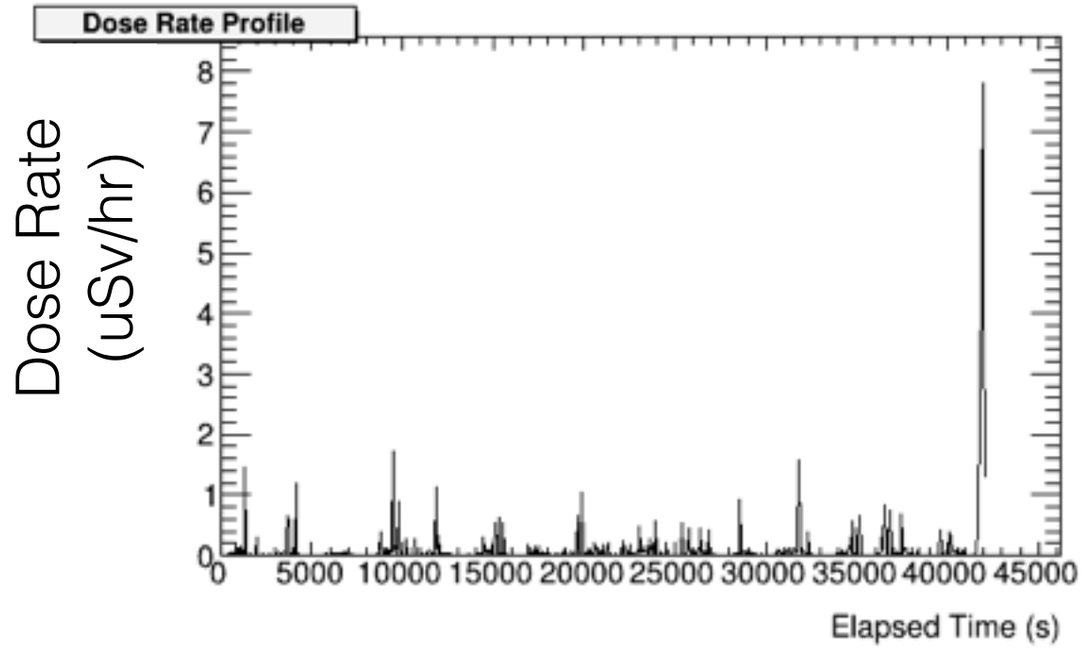

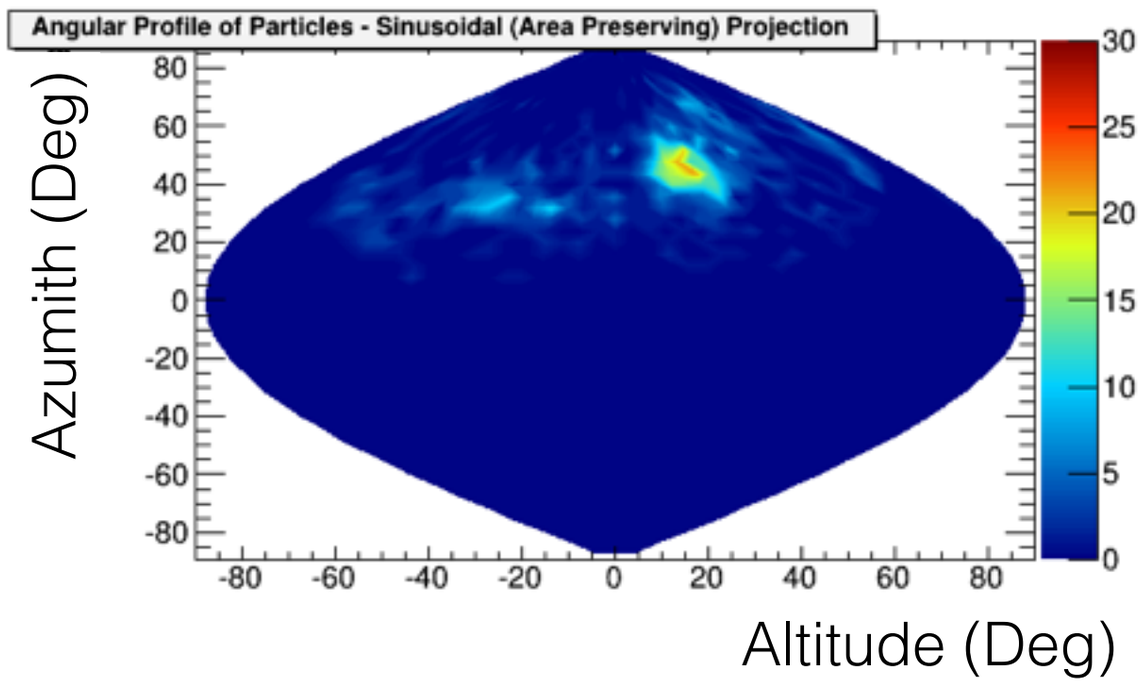

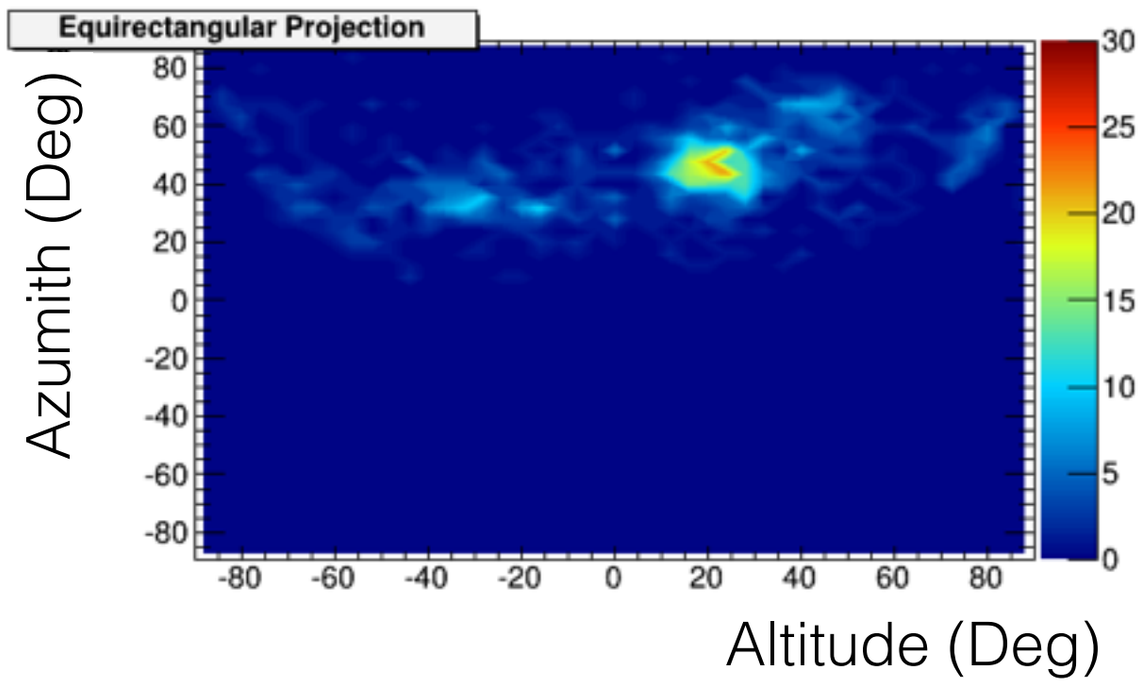

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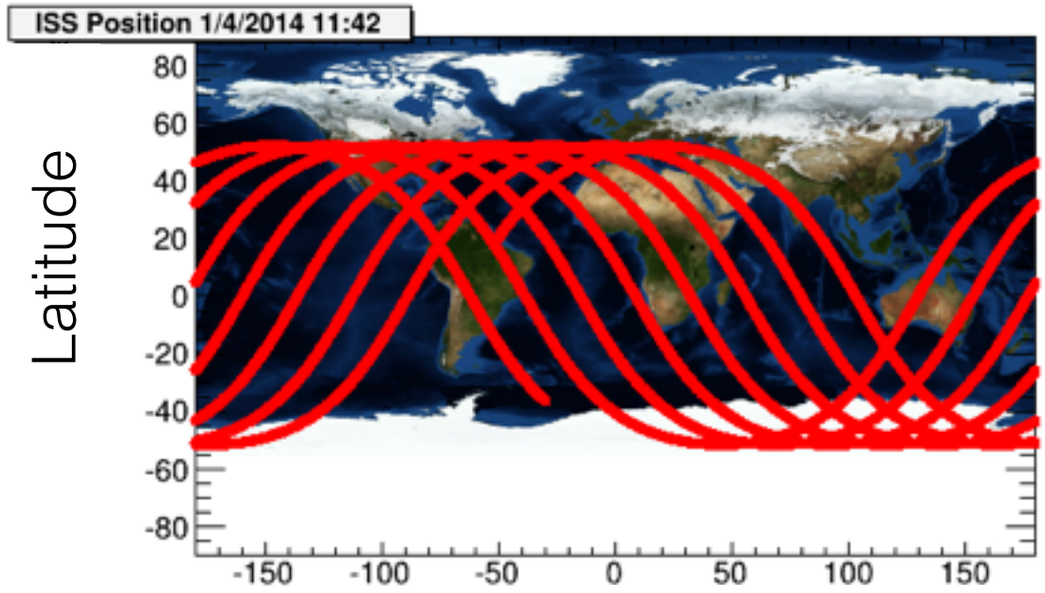

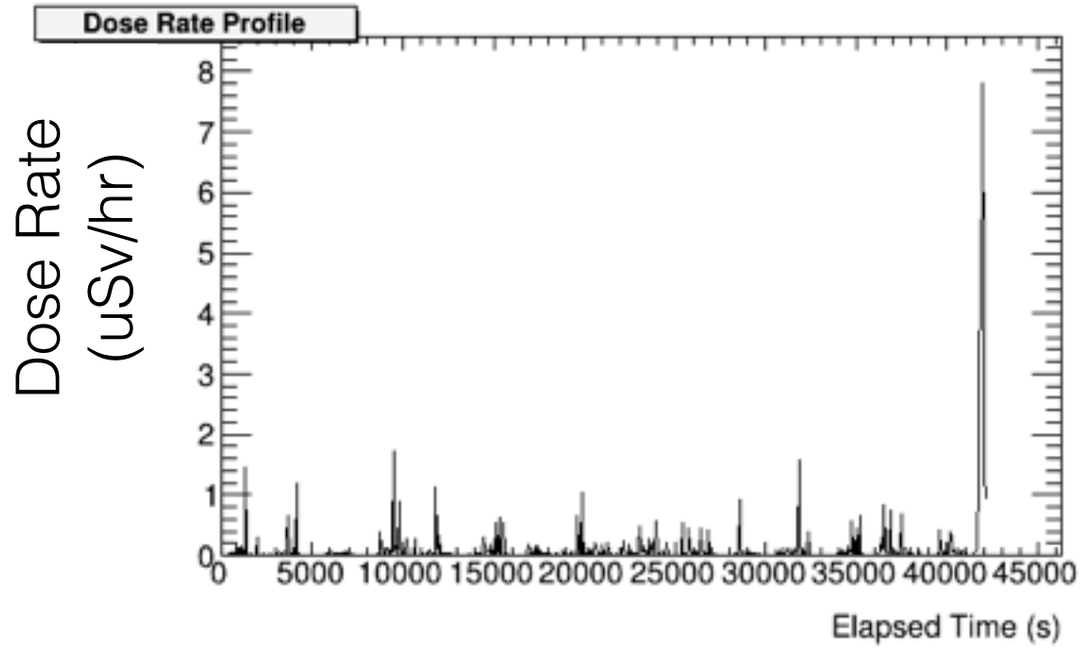

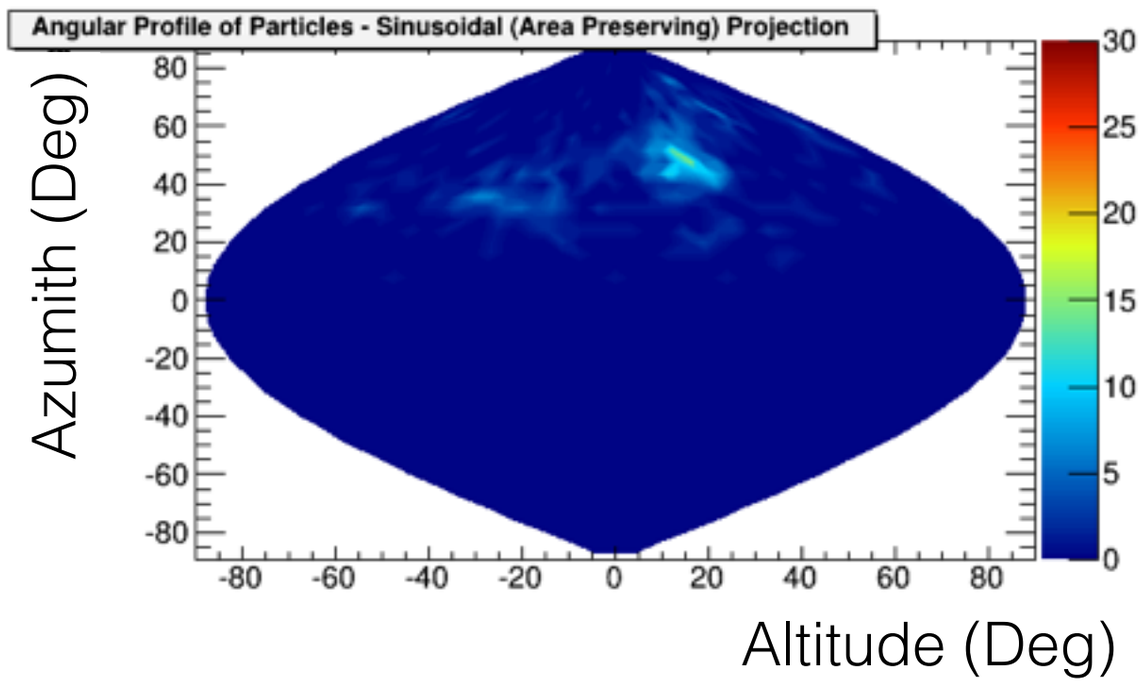

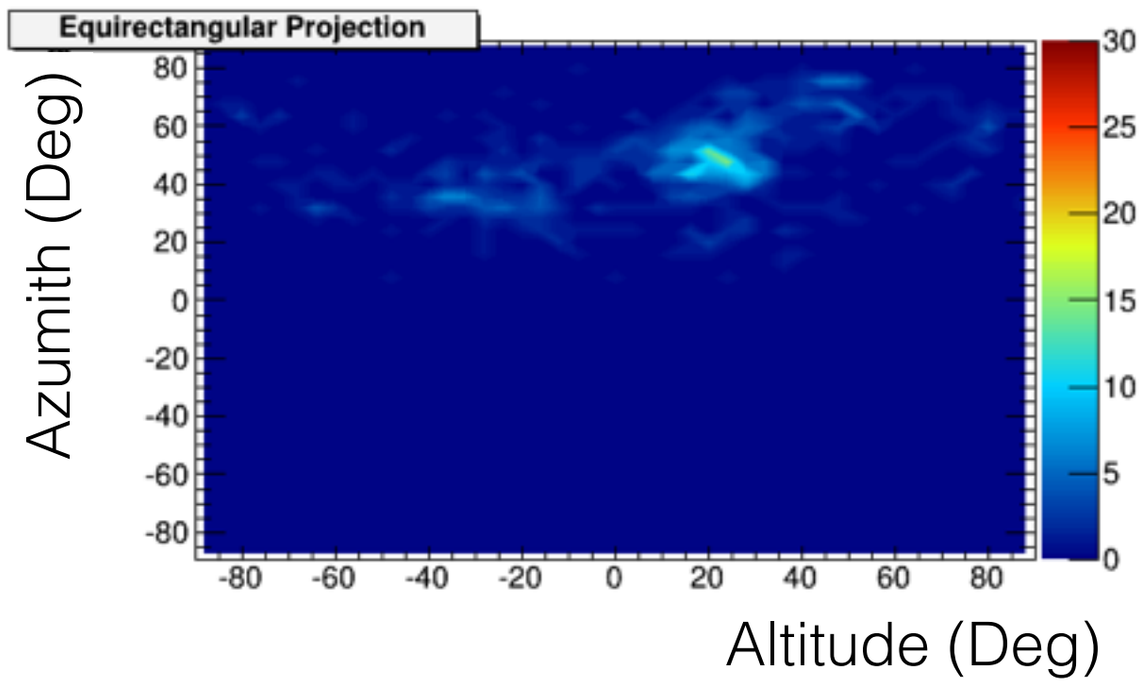

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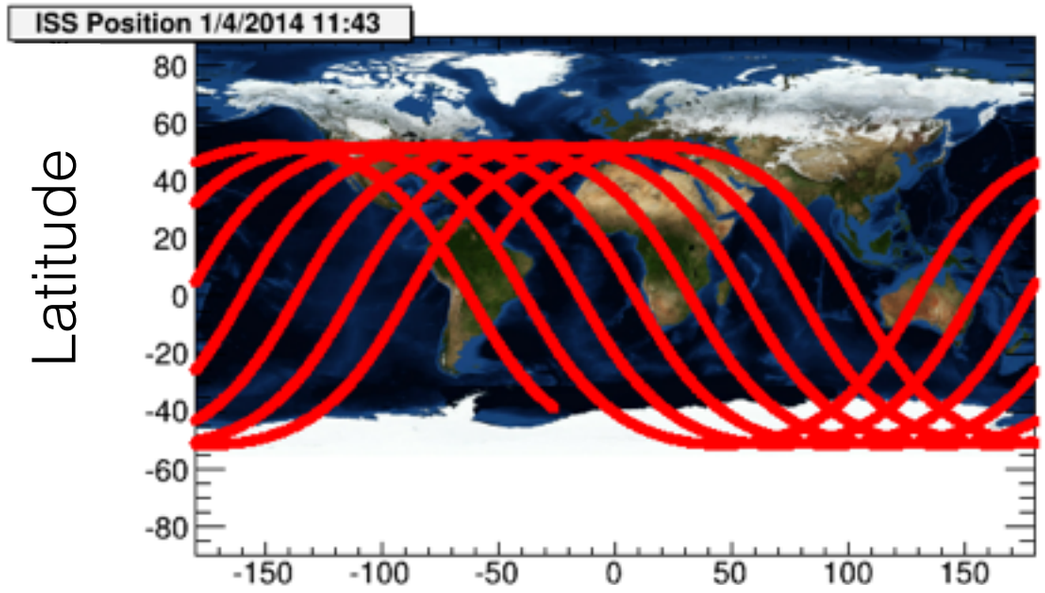
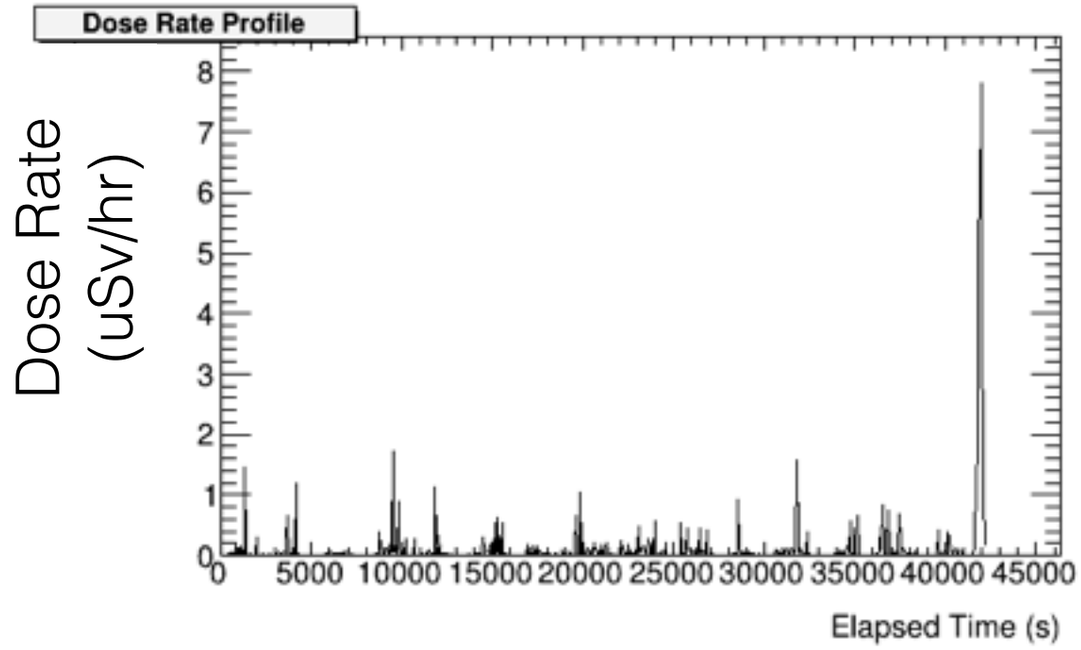
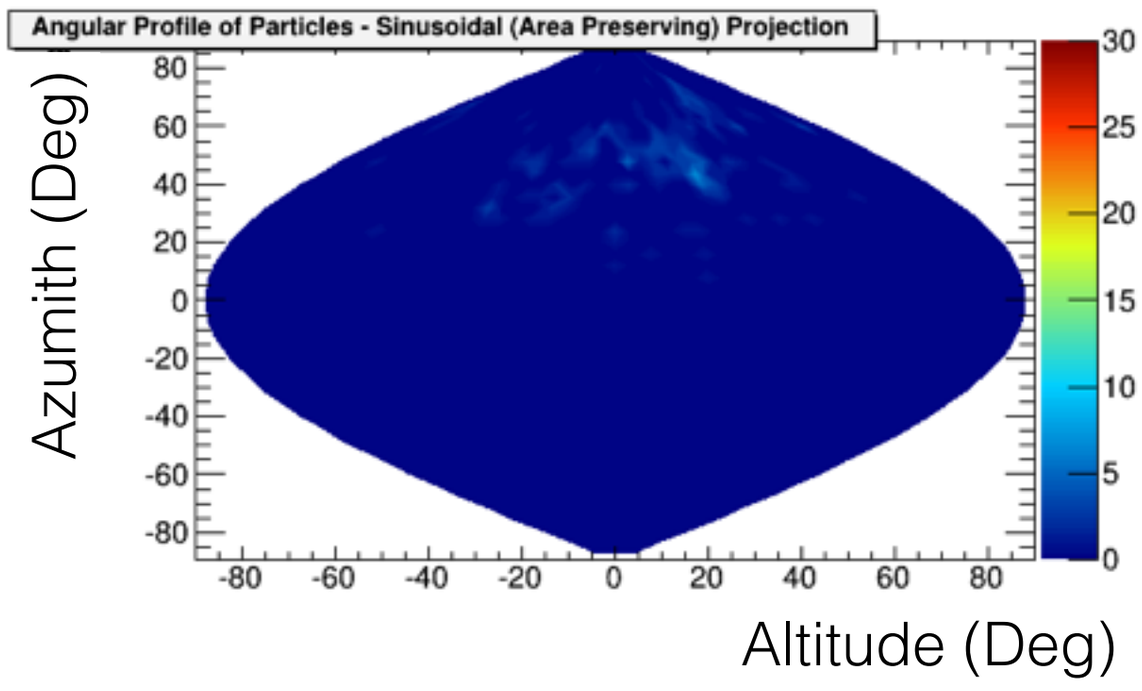
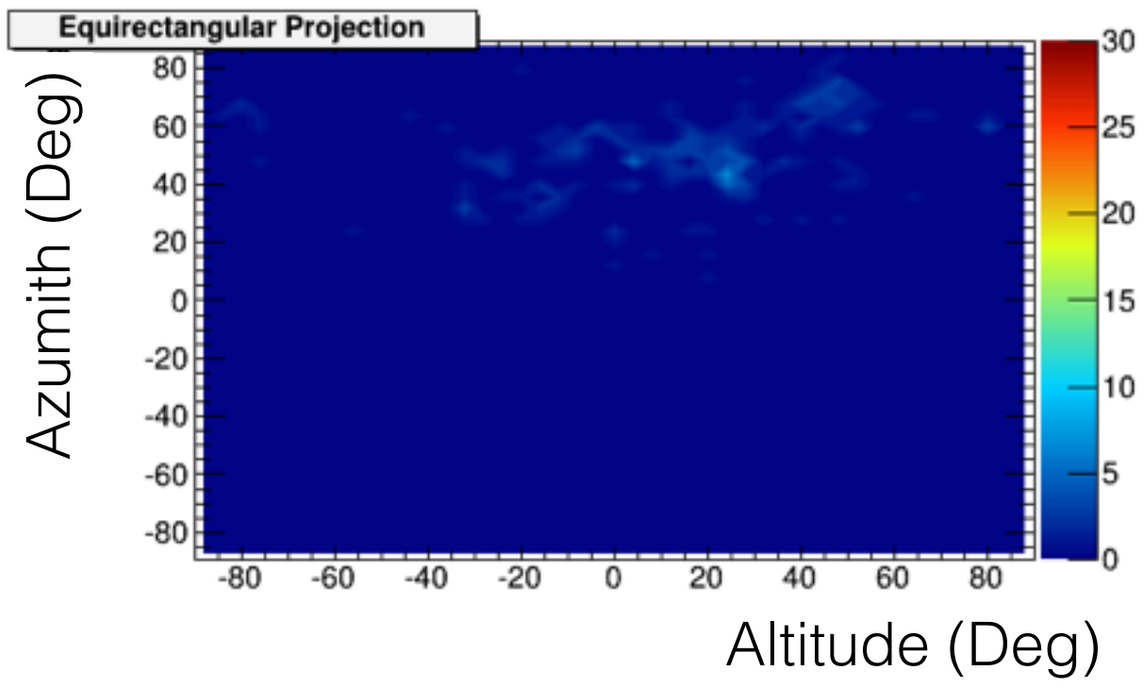






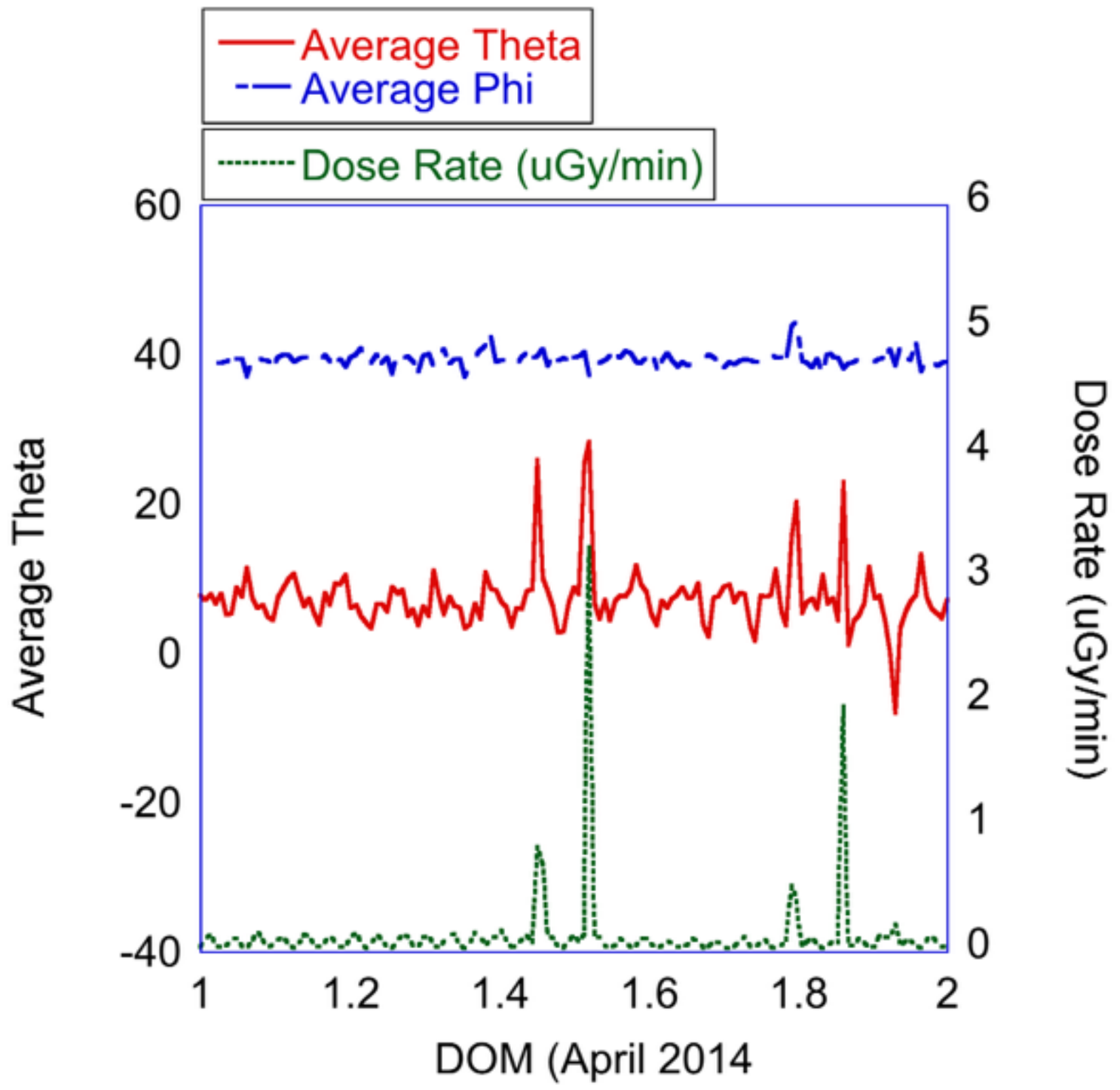


Angle and Dose Rate

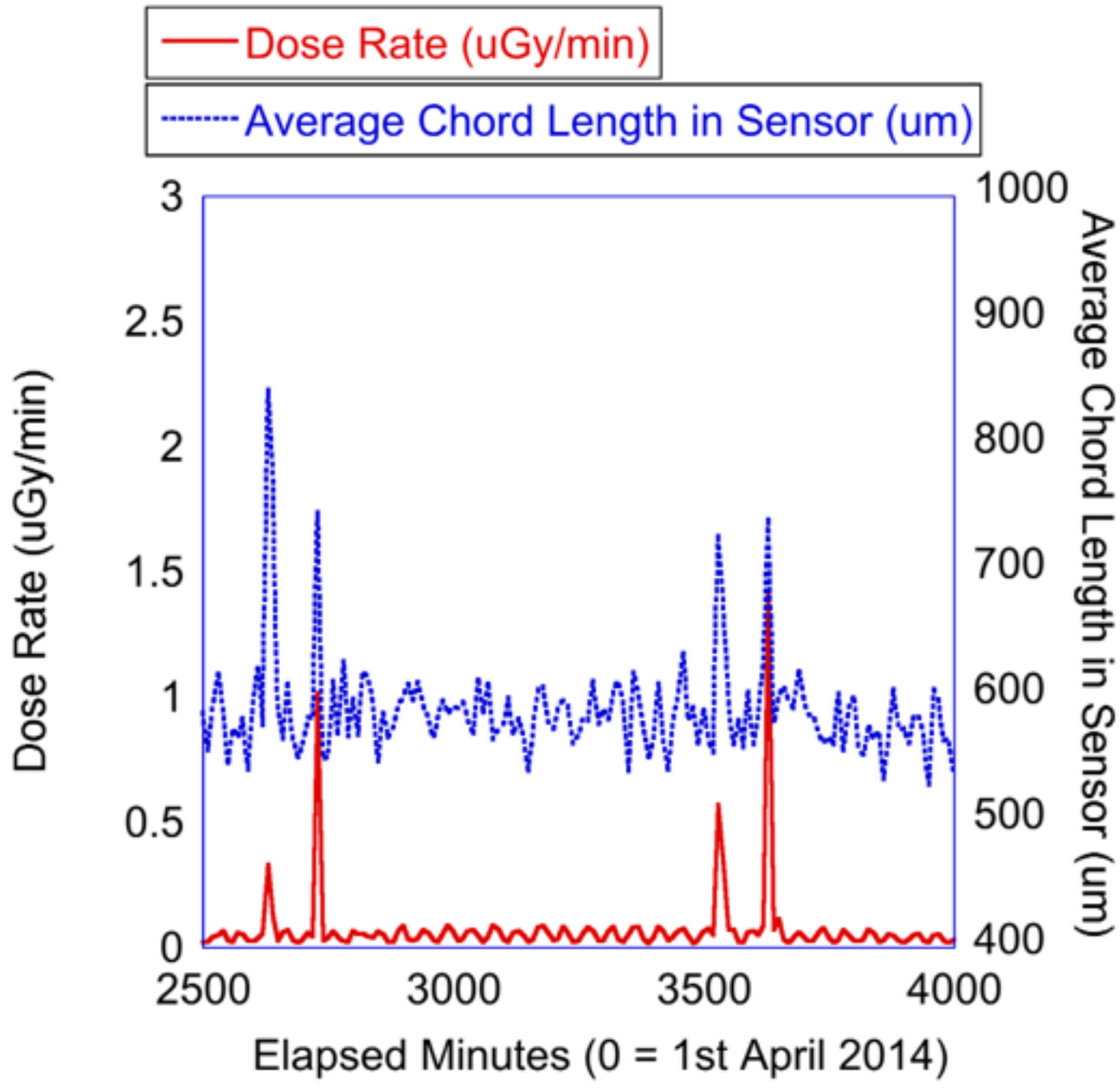
- SAA associated with change in average angle

- Average theta for GCR (~5 degrees) - offset

- Average GCR phi 40 degrees) - should be 45



Mean Chord Lengths



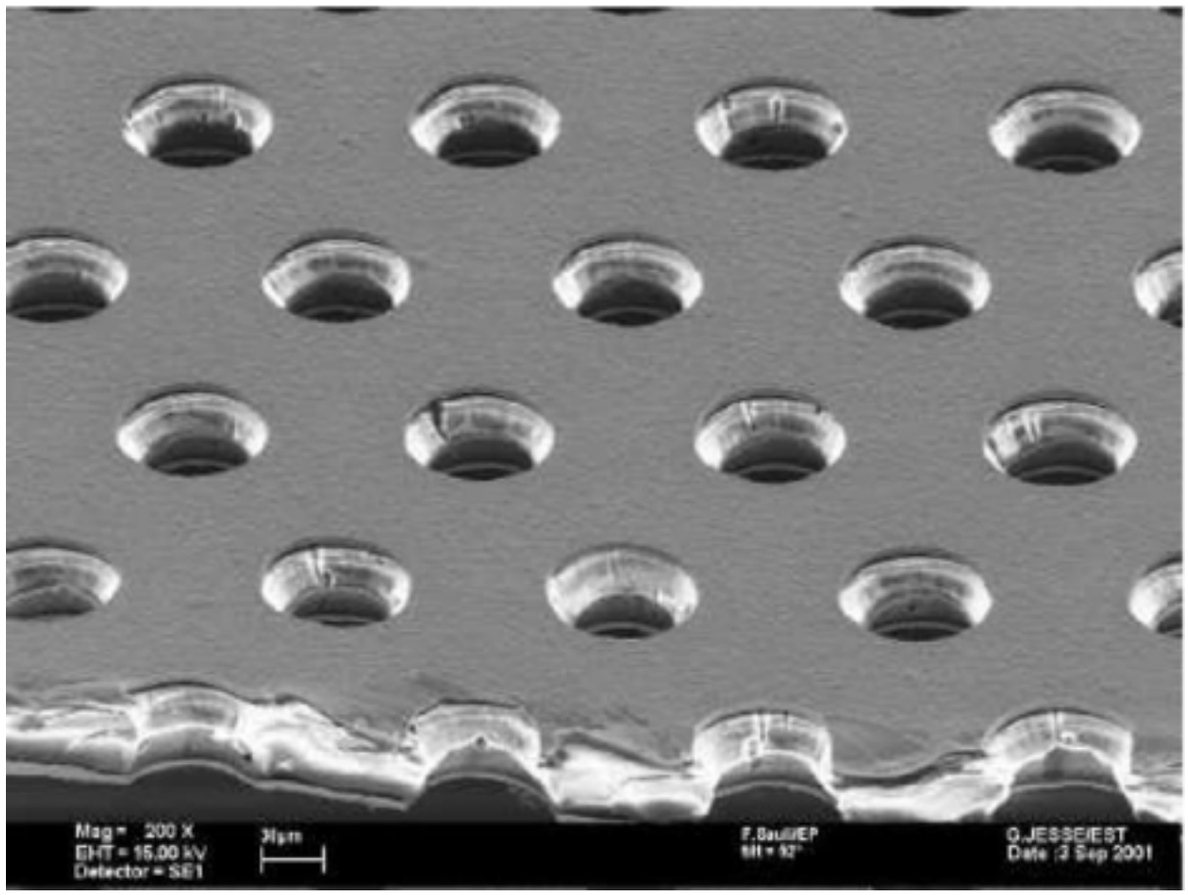
The Gempix - Finely Pixellated, Tracking, Gas Detectors for beam monitoring (and microdosimitery?)

S. P. George[1,2] ,F. Murtas[1,3], S.Puddu[1,4], E.Fröjdh[1,5], J. Alozy[1], A.B.Rosenfeld[1], M.Silari[1]

[1] ARDENT Program, CERN, Geneva, Switzerland <stuart.george@cern.ch>
[2] University of Wollongong Centre for Medical Radiation Physics, Wollongong, NSW, Australia
[3] INFN, Italy
[4] University of Bern, Bern, Switzerland
[5] Mid Sweden University, Sundsvall, Sweden

Gas Electron Multiplier (GEM) Technology

- Micro pattern gas detector
- Thin holes are etched in a metallised kapton foil and a potential is placed across it
- Very large electric field around the holes (40 kV/cm) which creates a localised electron avalanche
- Couple a timepix asic for readout



CERN GDD Group (http://gdd.web.cern.ch/GDD/)

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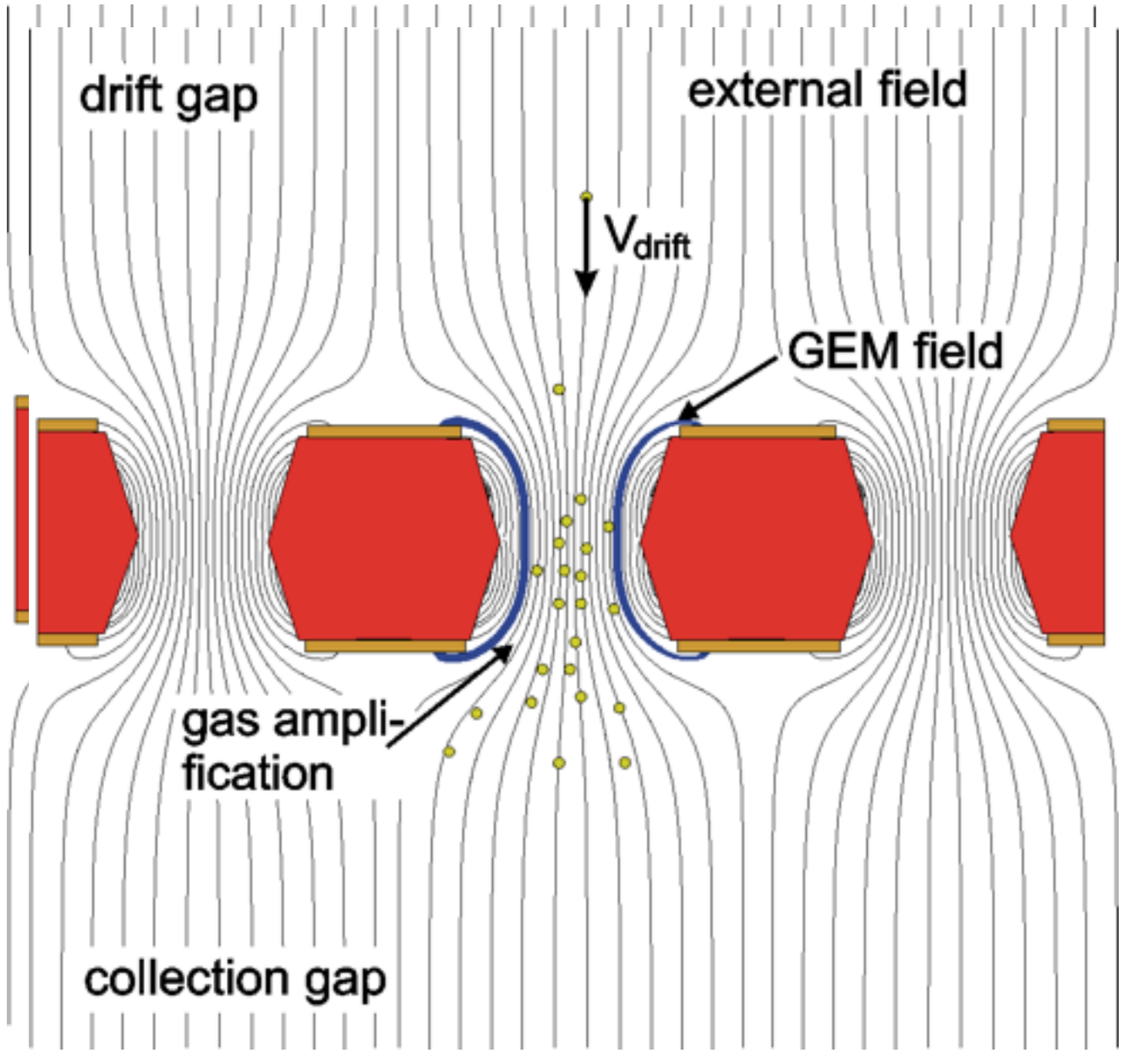

Ziegler and Straumann, Development of a triple GEM detector for particle tracking, IEEE NSS Conference Record 2005, Vol 2

Gas Electron Multiplier (GEM) Technology

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Triple GEM

Quad Timepix ASIC

Gas Electron Multiplier (GEM) Technology

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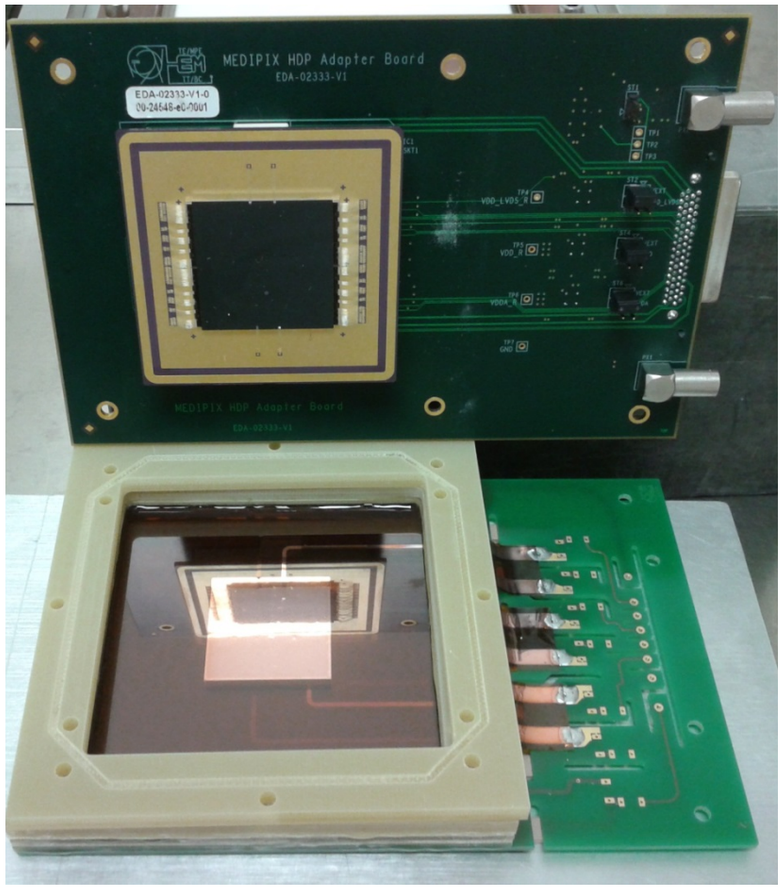
Triple GEM

Quad Timepix ASIC



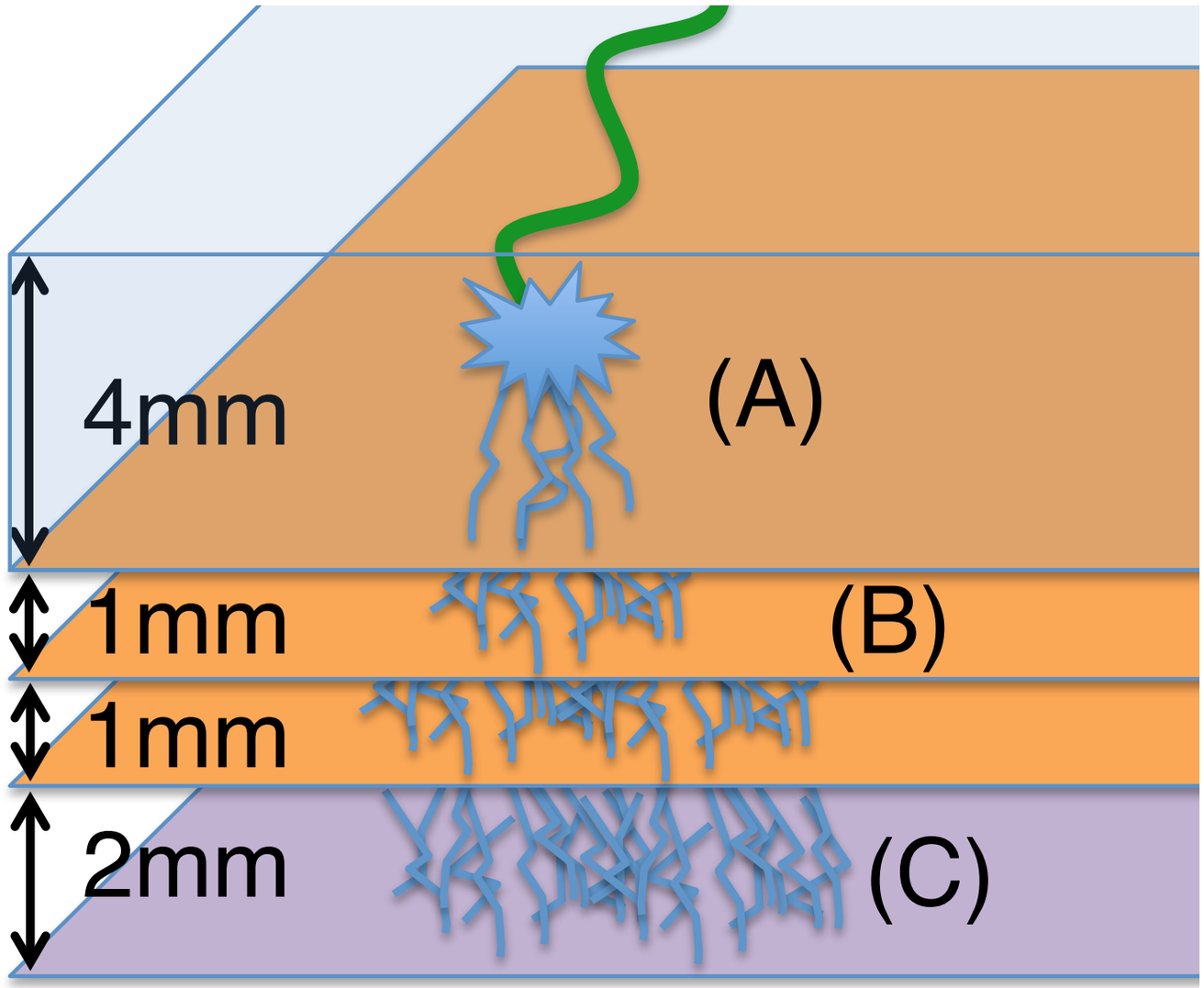
The Gempix - Introduction

Gas Detection Volume

GEM 1

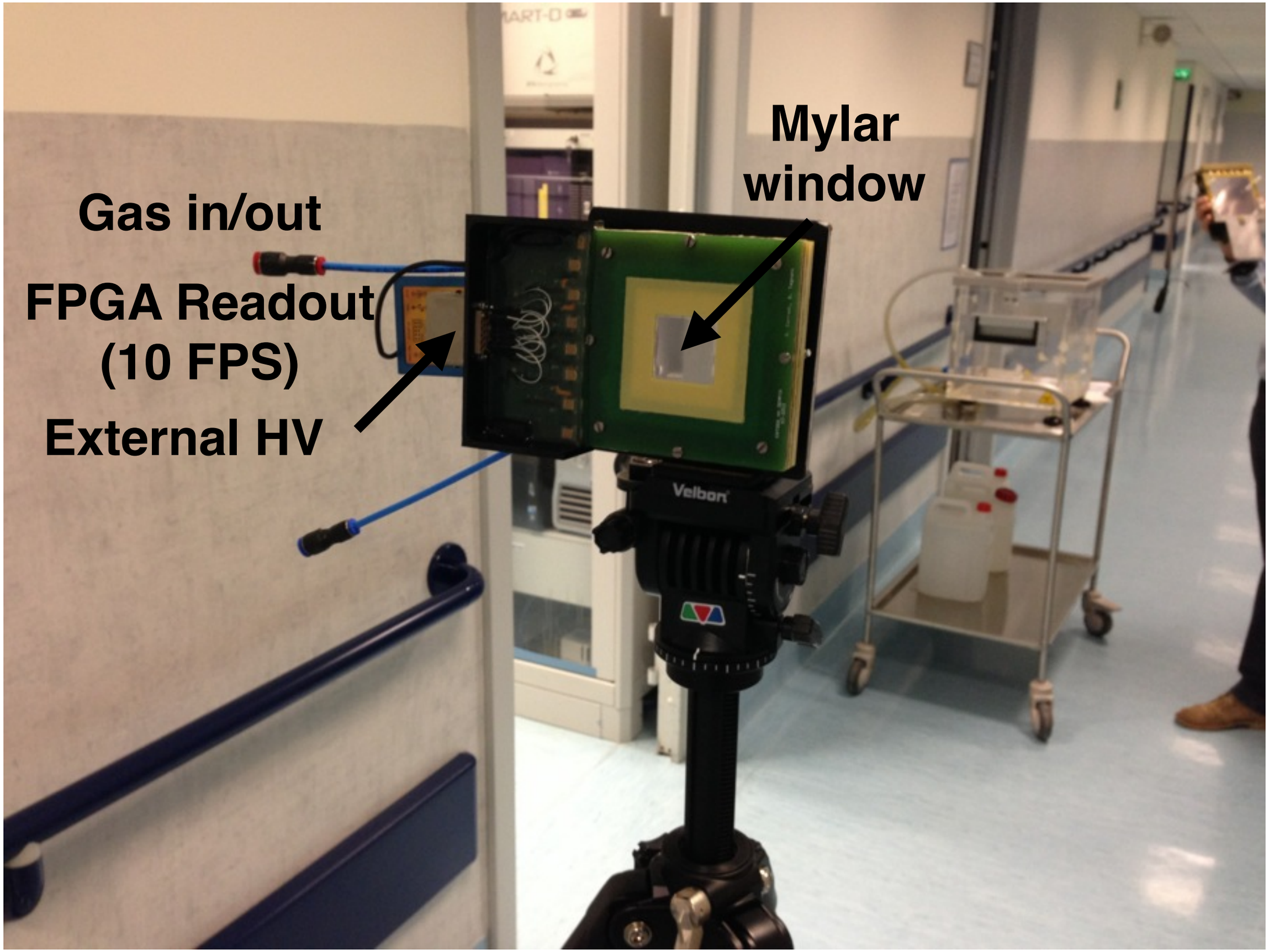
GEM 2

GEM 3

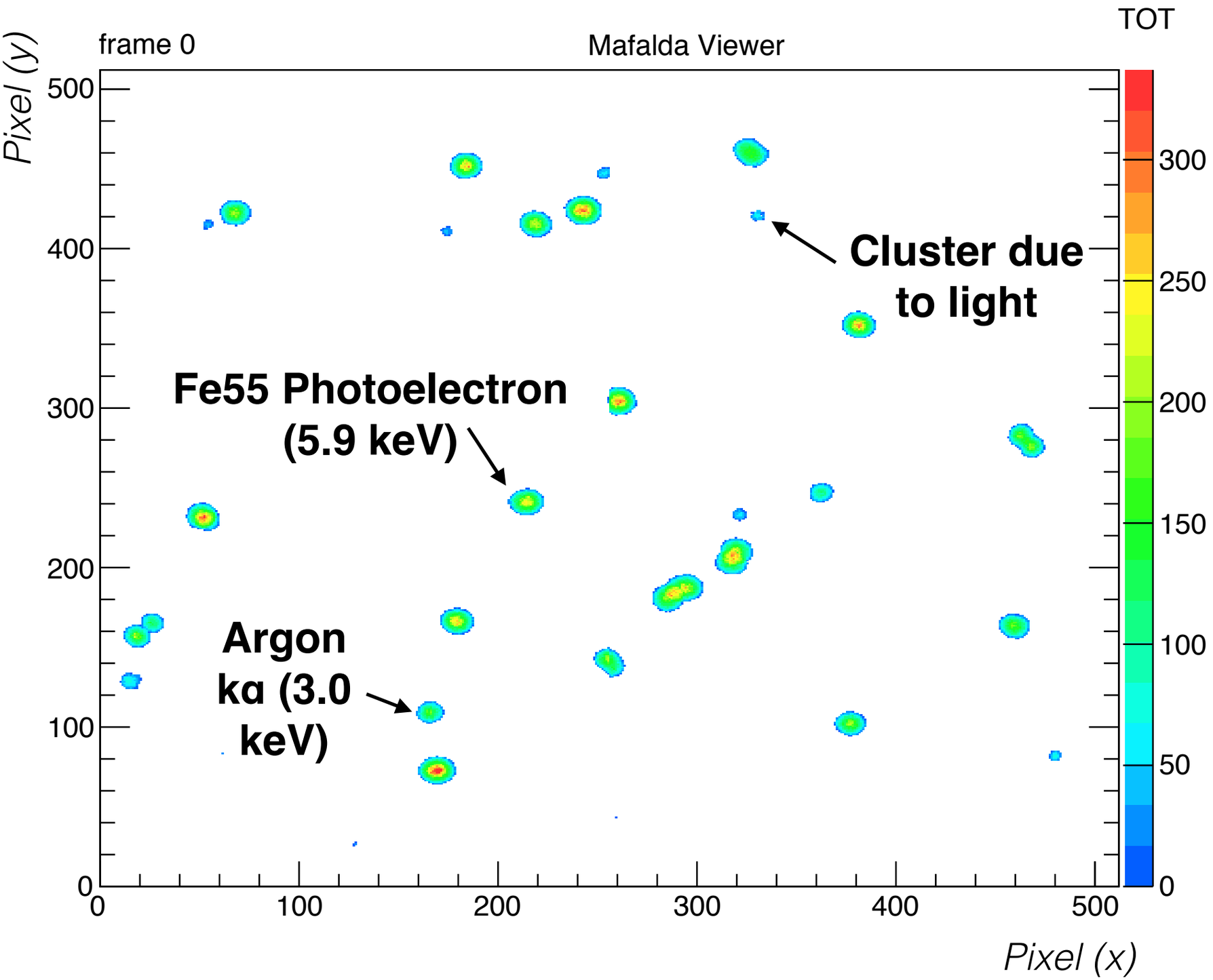


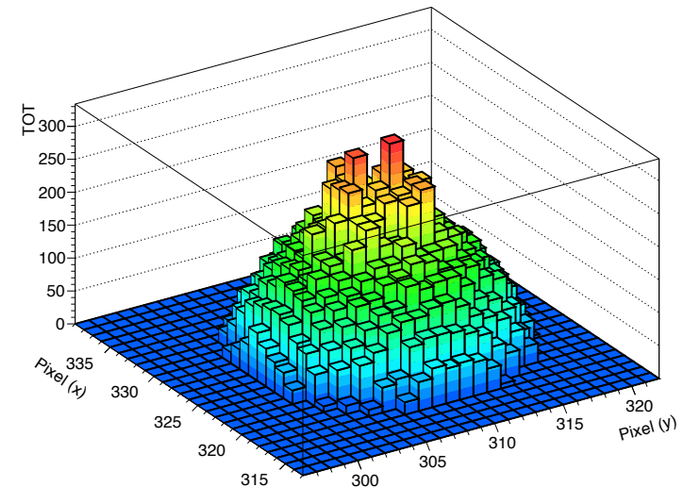
Quad Timepix ASIC

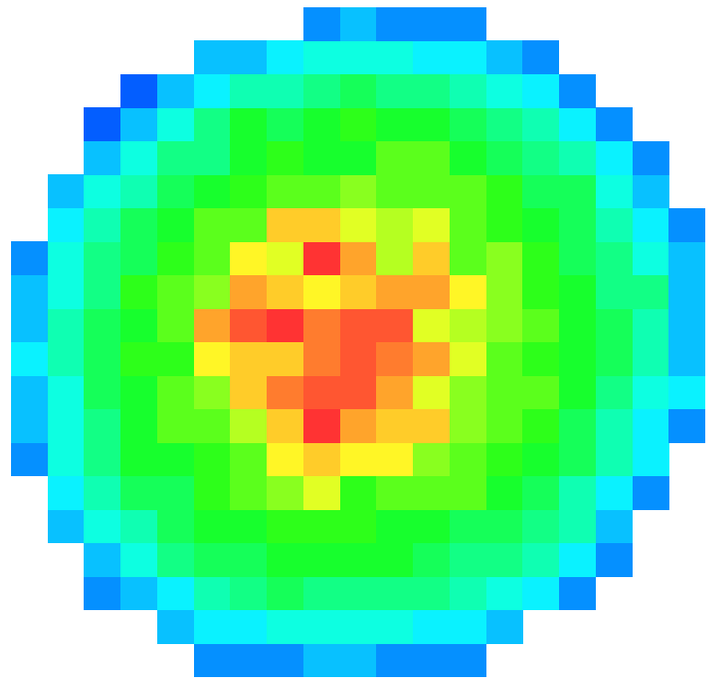
(A) Photon interaction, (B) Electron multiplication, (C) Detection/Readout


Gas in/out
FPGA Readout
(10 FPS)
External HV
Mylar
window
Velbon

Typical Frame - Fe55

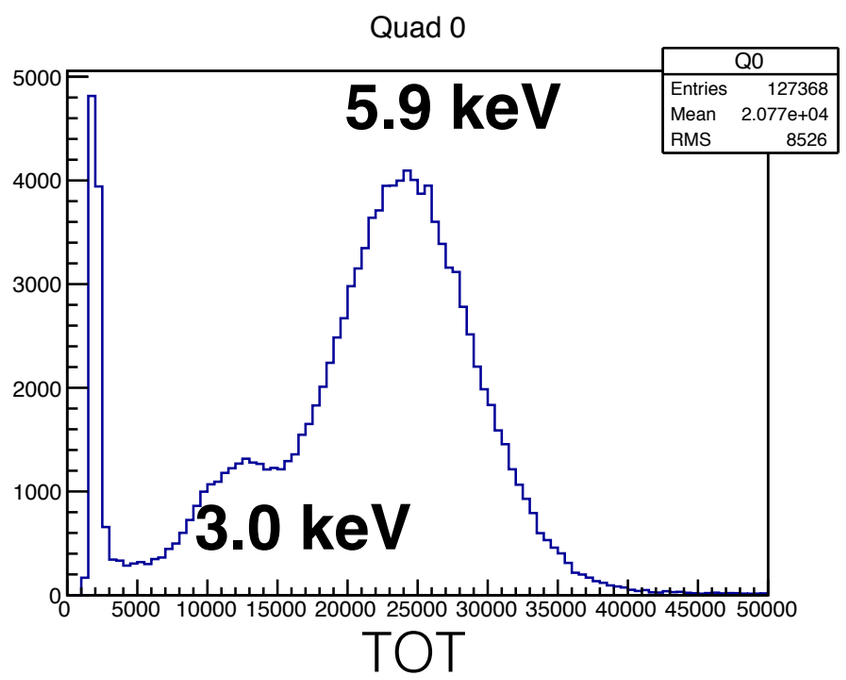


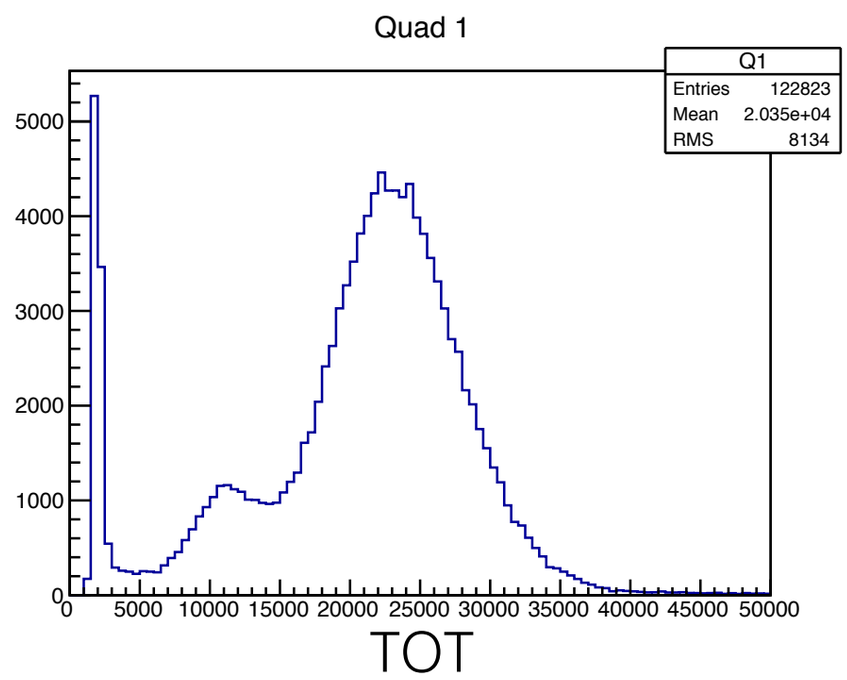


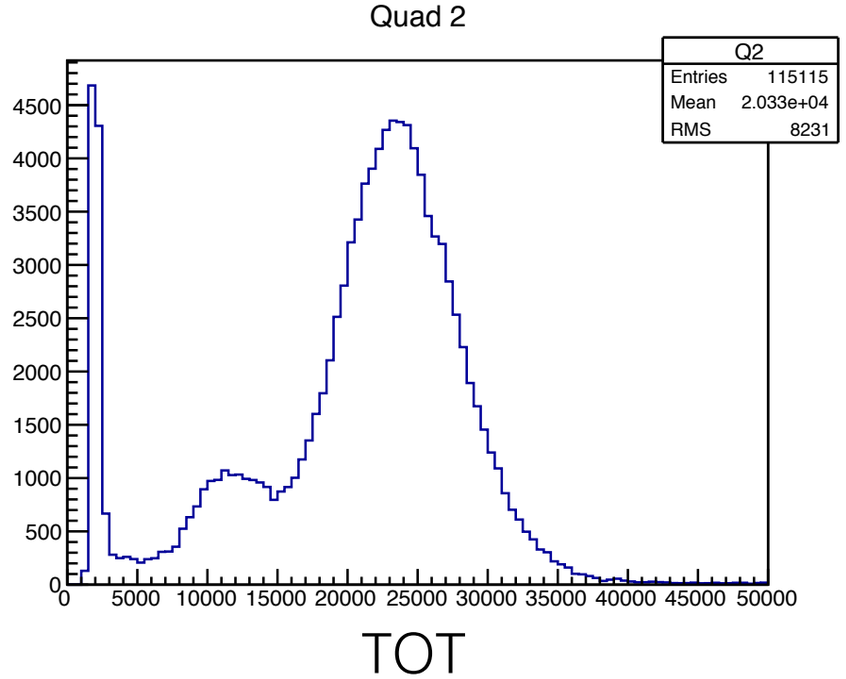


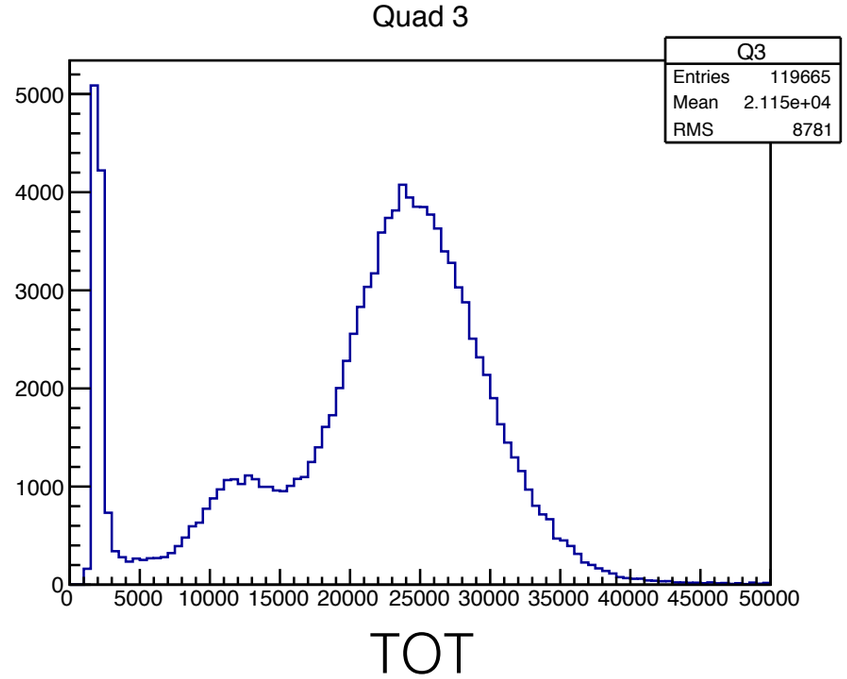
2.5 × 10^4 TOT
(9.6 Mhz)

Spectrum Fe55





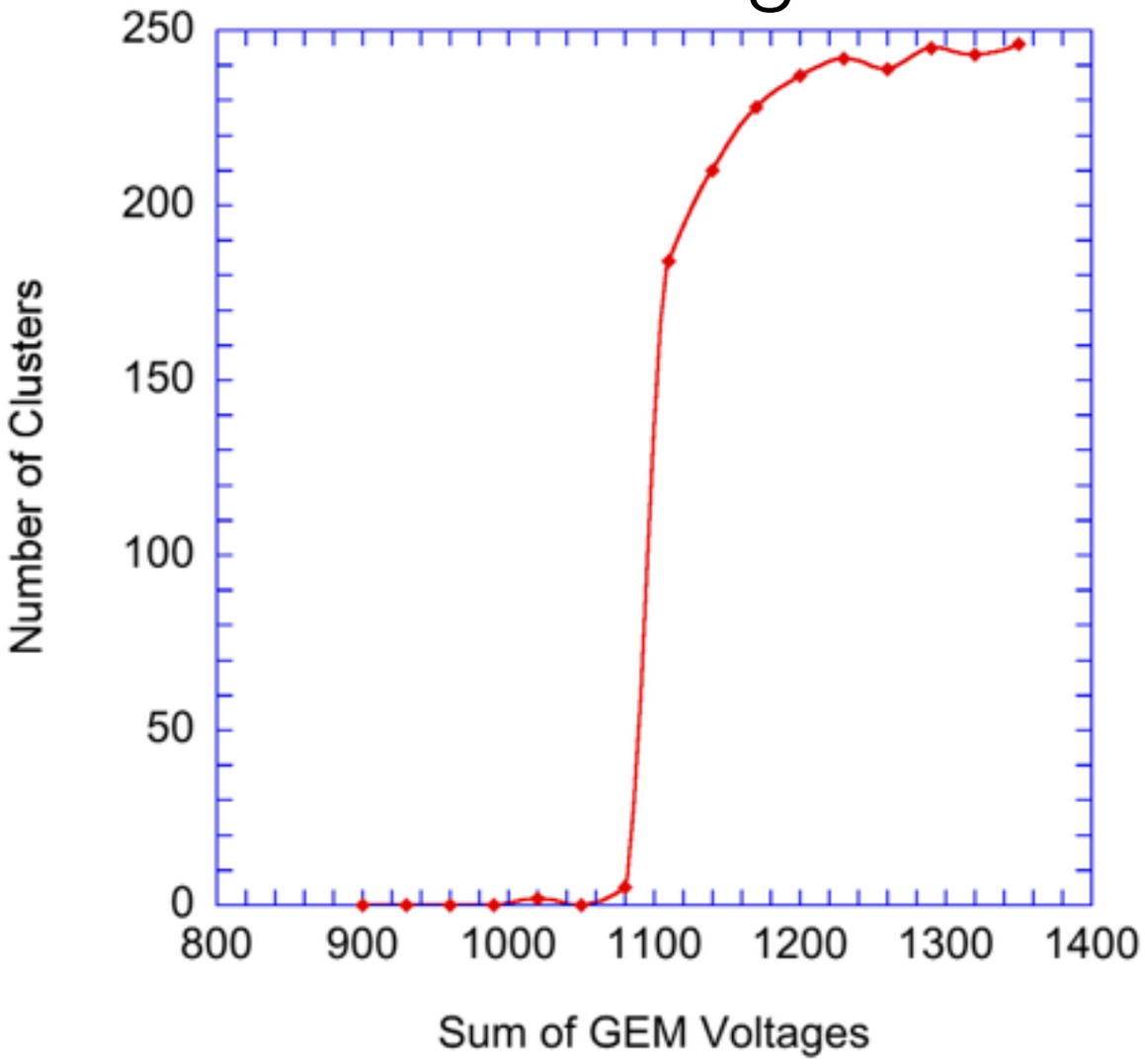




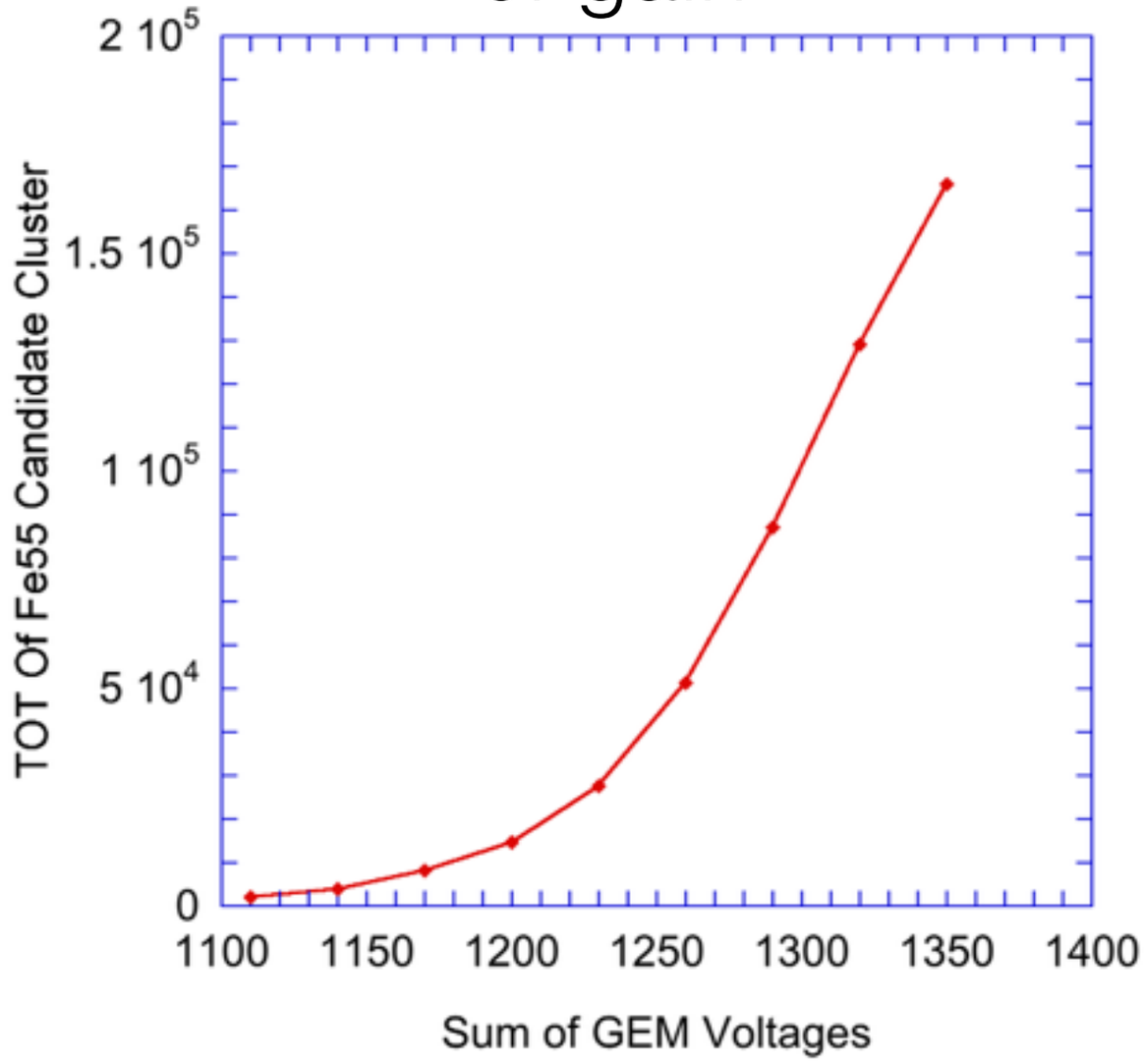
Energy resolution of ~2.3 keV at 6 keV

Gain Scan - Fe55

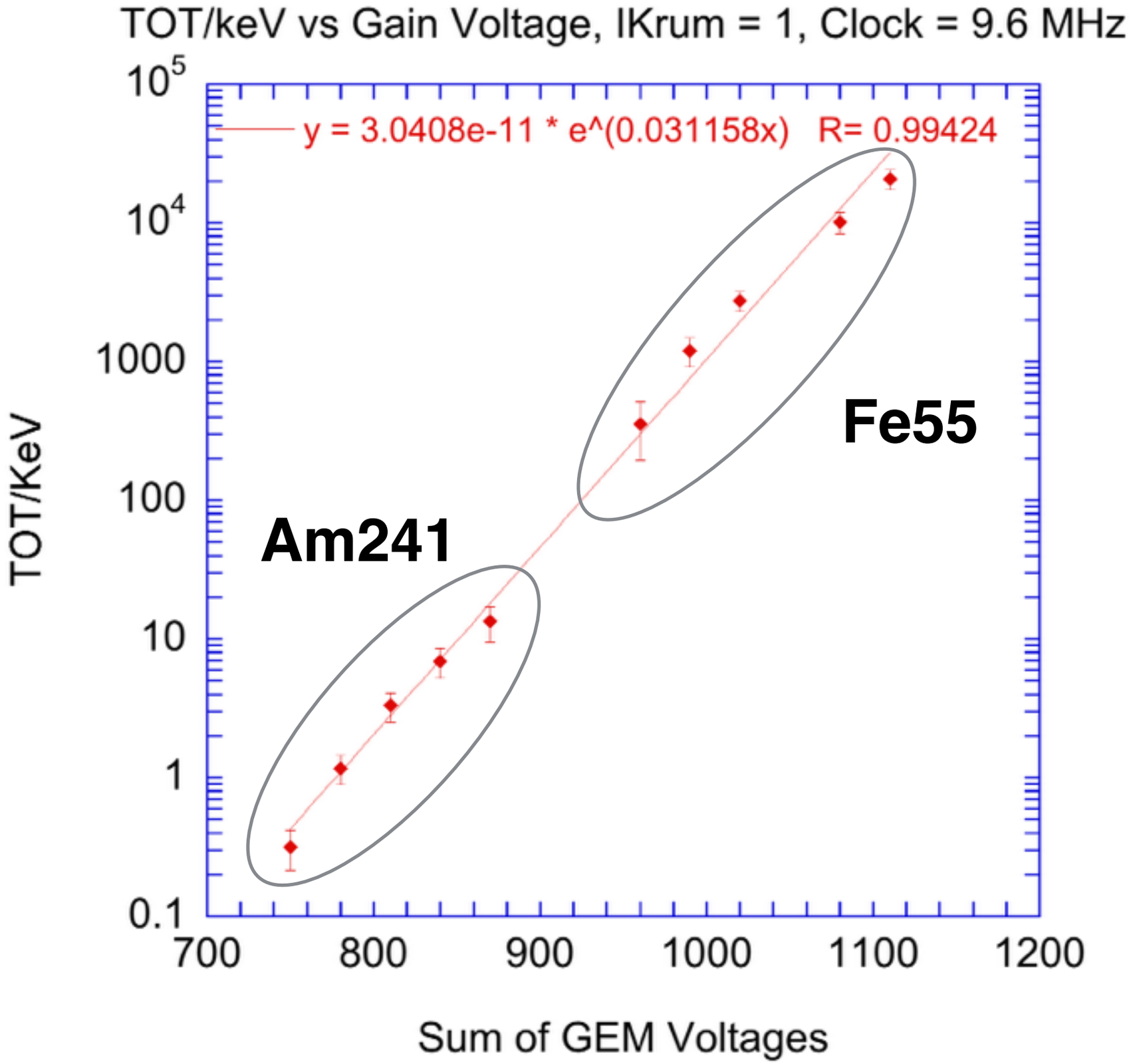
Number of Clusters as a function of gain



Cluster TOT as a function of gain

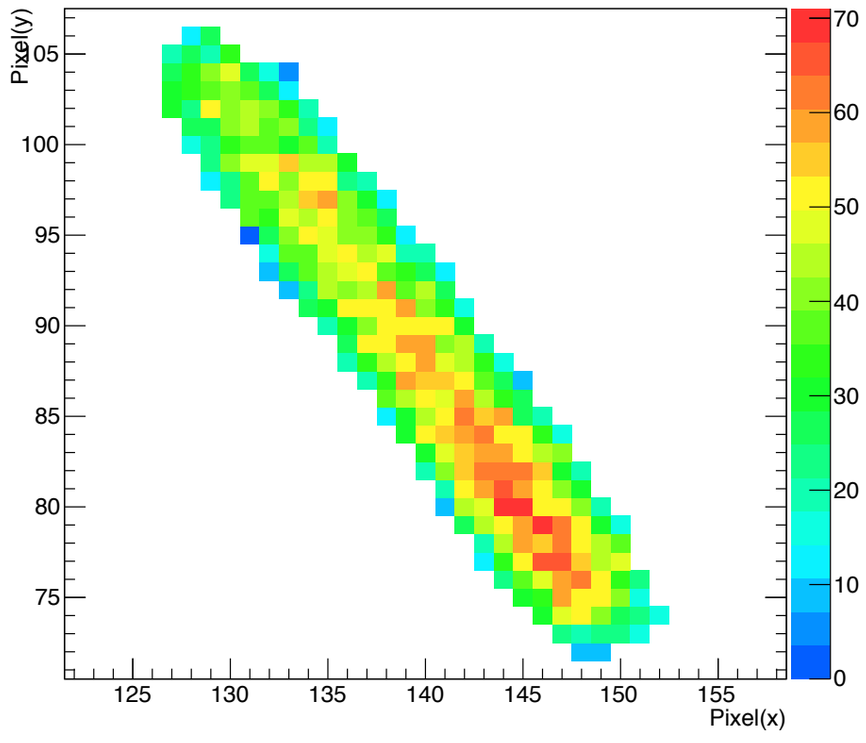


Working point at 1230 V


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

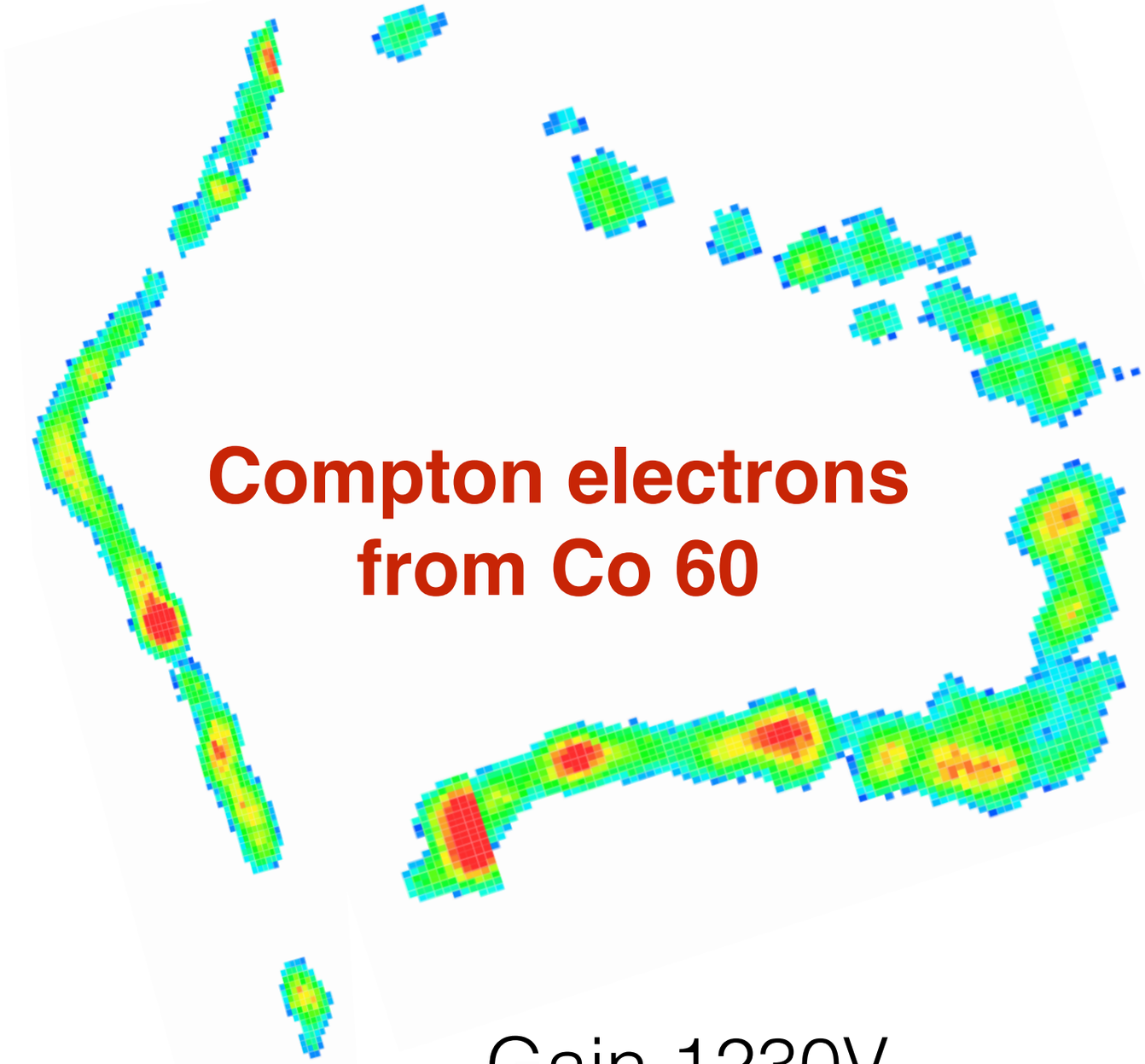
Gempix as a Particle Tracker

Am241 Alpha Particle (~5.5 MeV)



Length ~ 1.7 mm, vol ~200 px

Gain 900V



Gain 1230V

Time stamping particles

- Geometrical clustering
- Operate 1 in every 16 pixels in Time of Arrival mode (100 nS resolution)
- TOT Pixels counts cycles while the pixel is high, TOA counts clock cycles until the end of the acquisition
- Gather clusters with similar time values into a “Track”

Red pixels measure time, colours measure charge

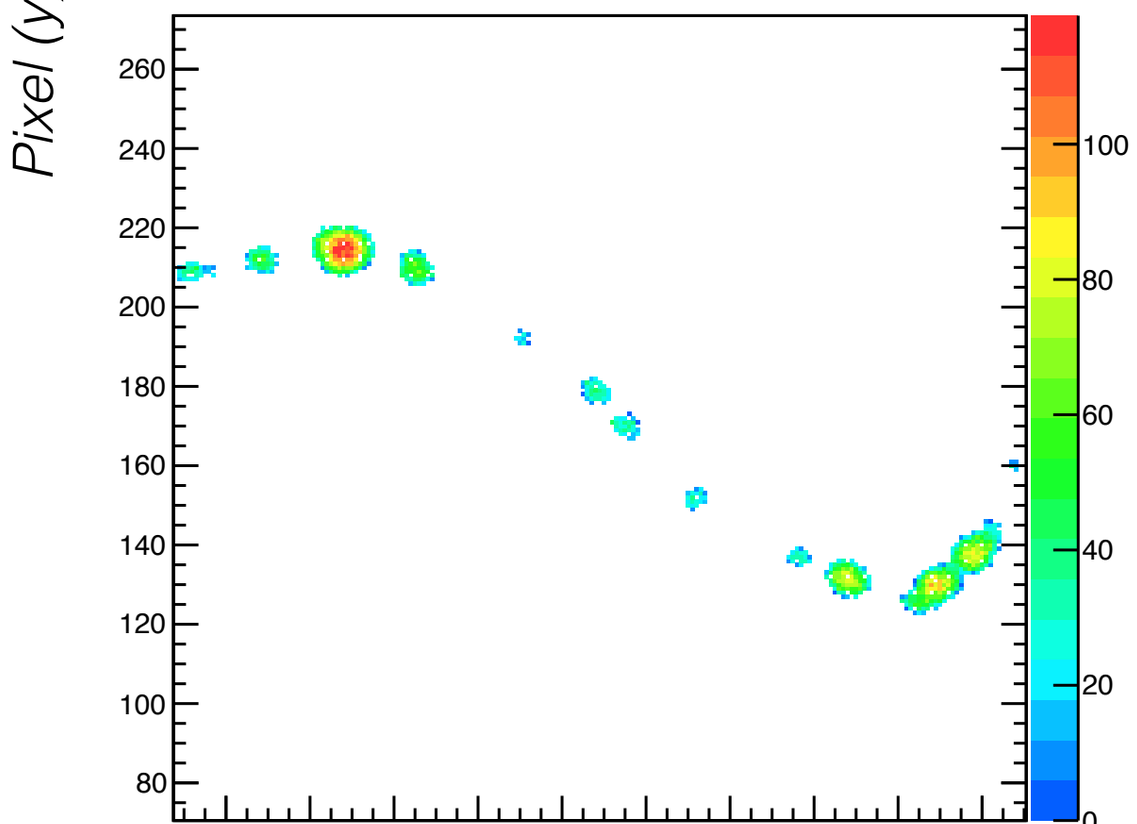
Charge

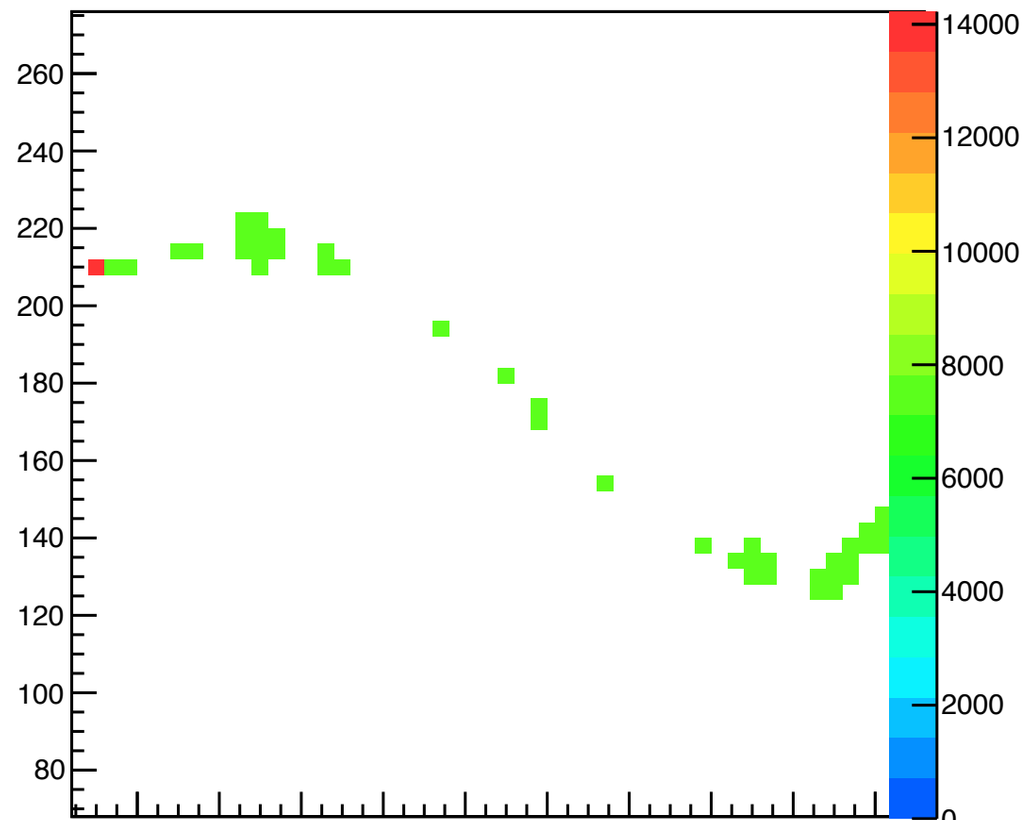
TOT Cts

Time

TOA Cts

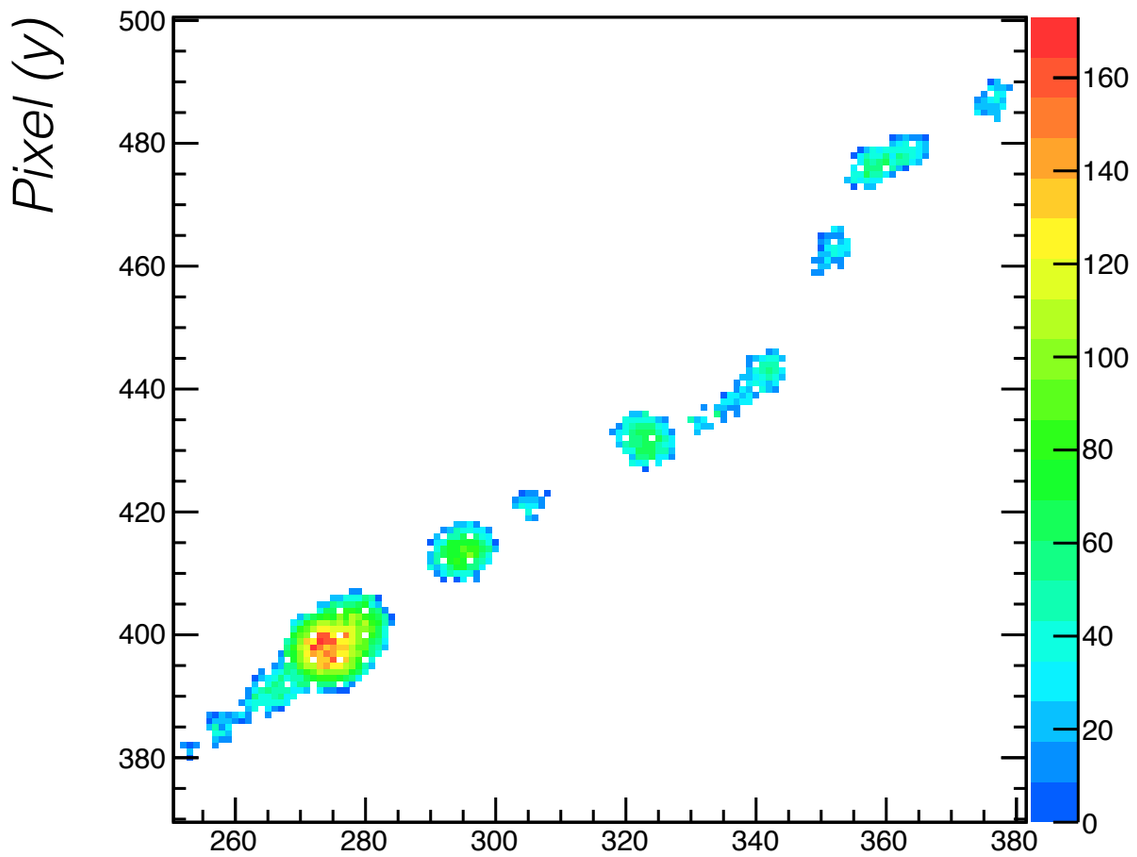
Pixel (y)

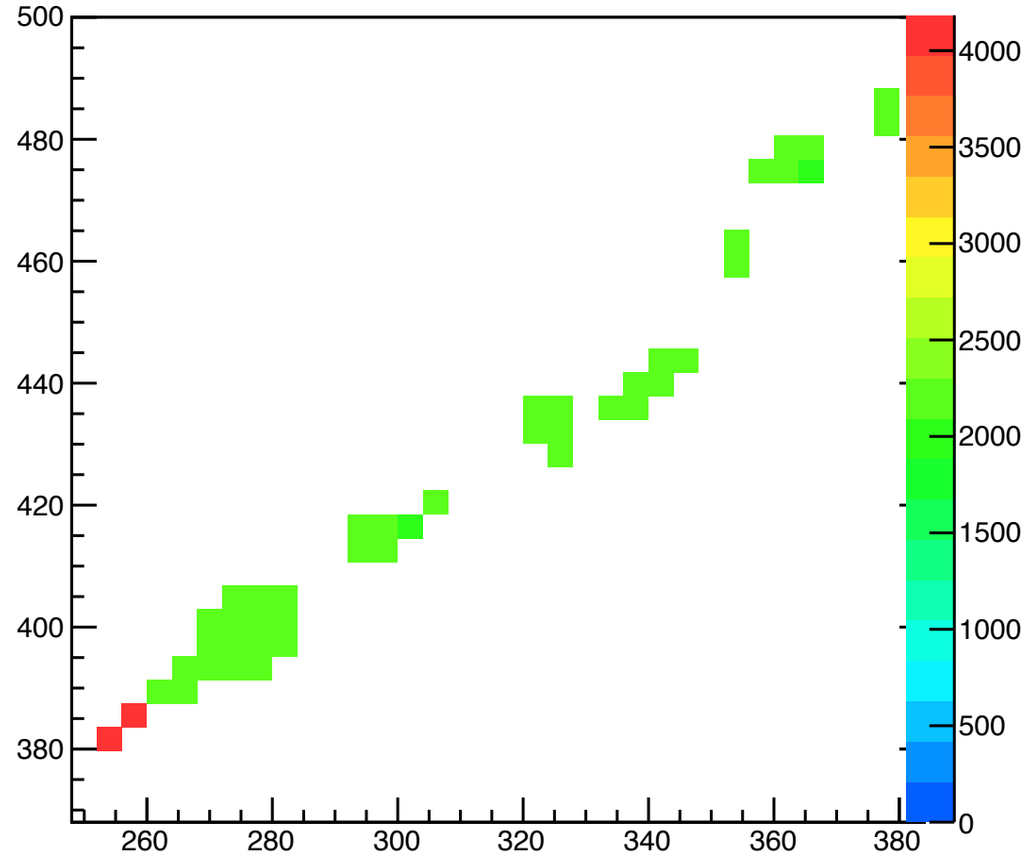




Pixel (x)

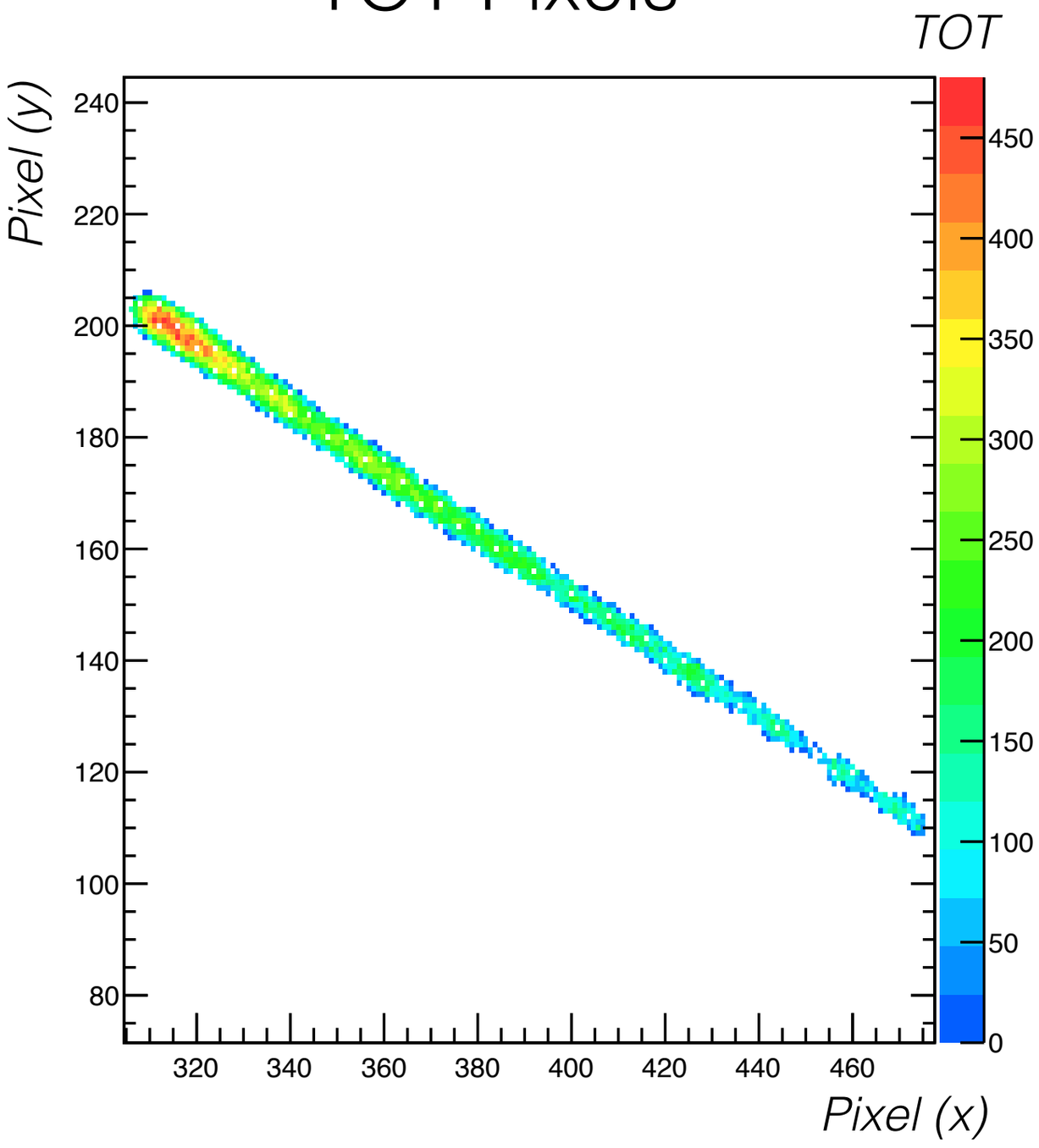
Pixel (y)



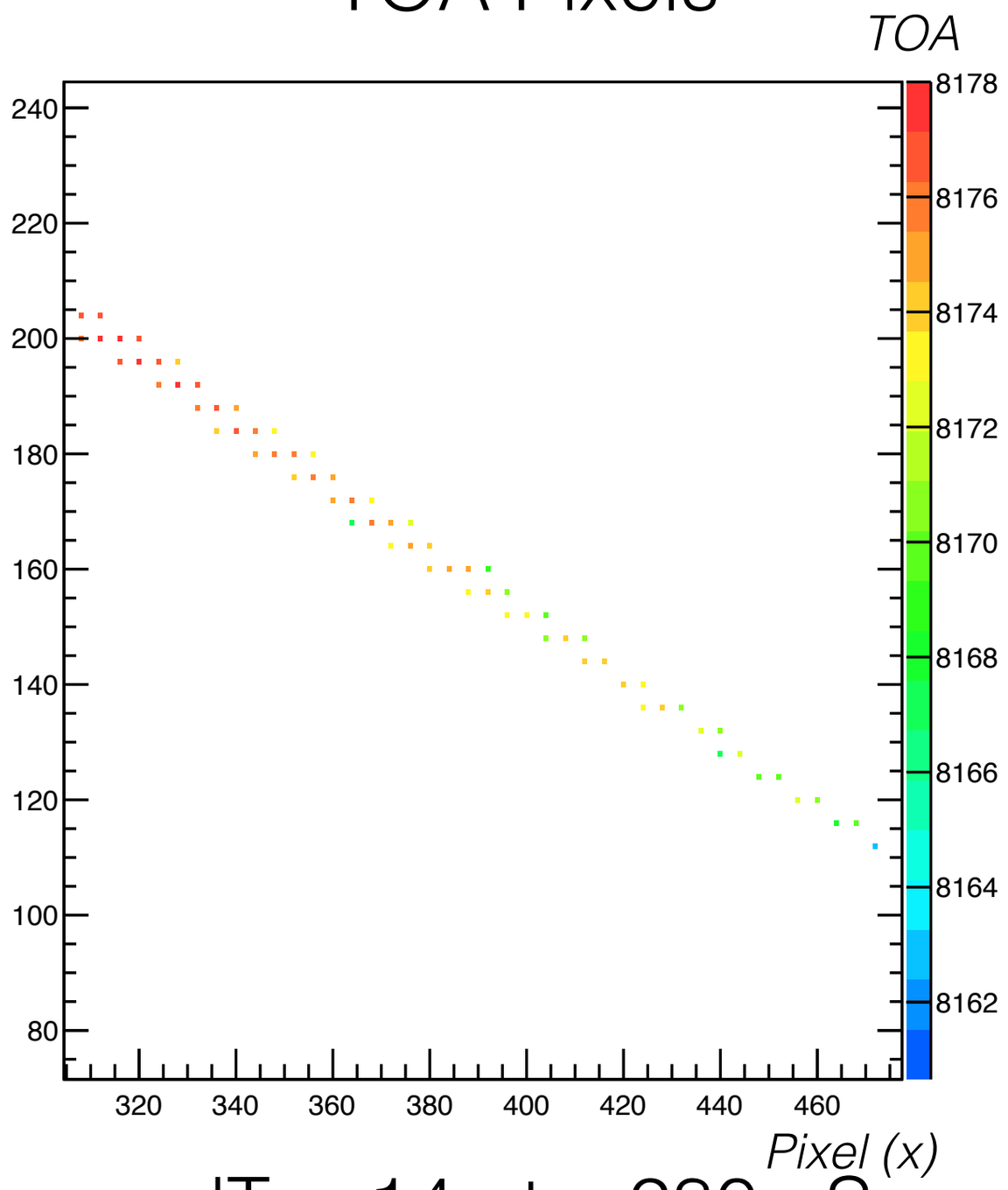


TPC Operation (50 MHz)

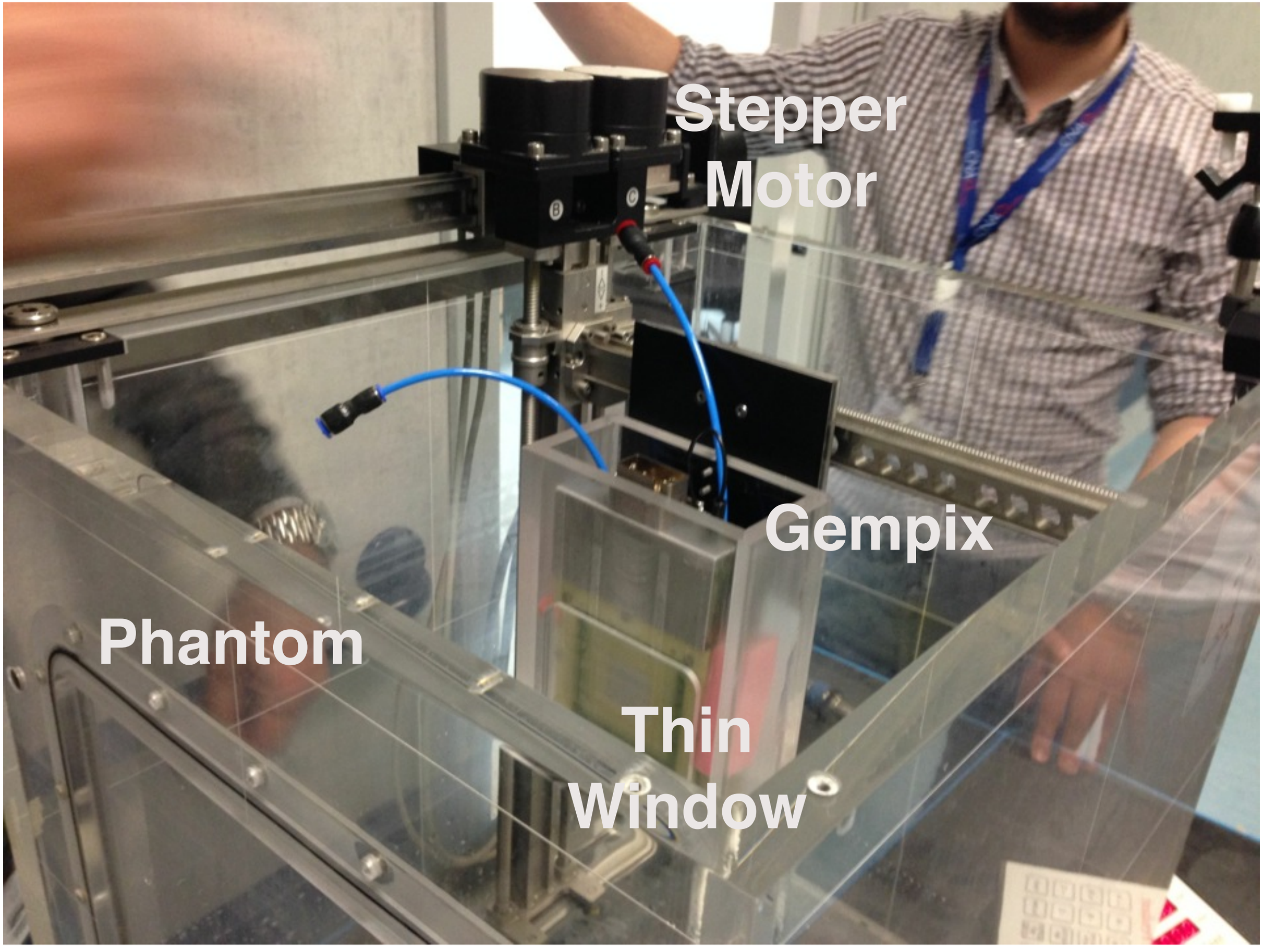
TOT Pixels



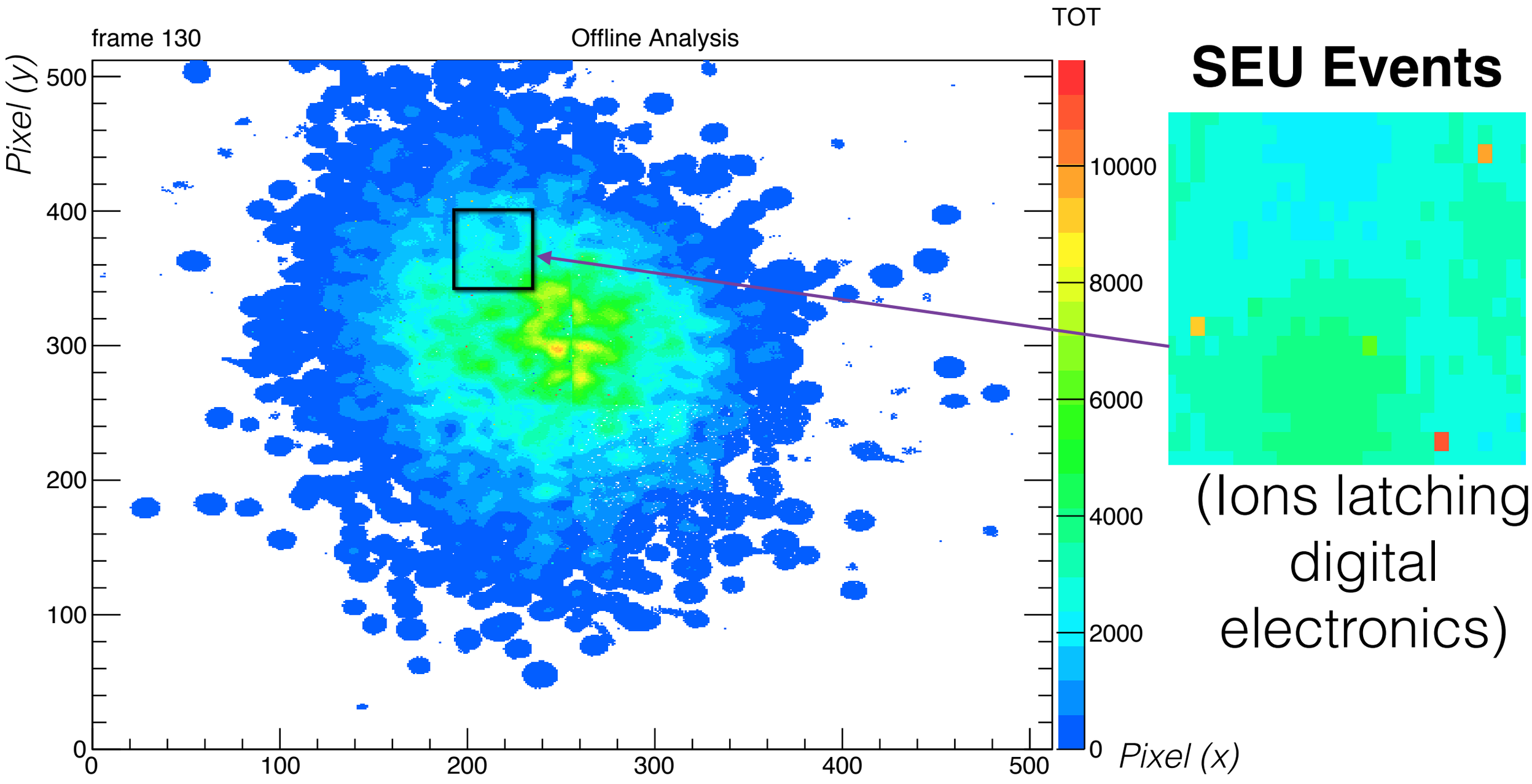
TOA Pixels



dT = 14 cts, 280 nS

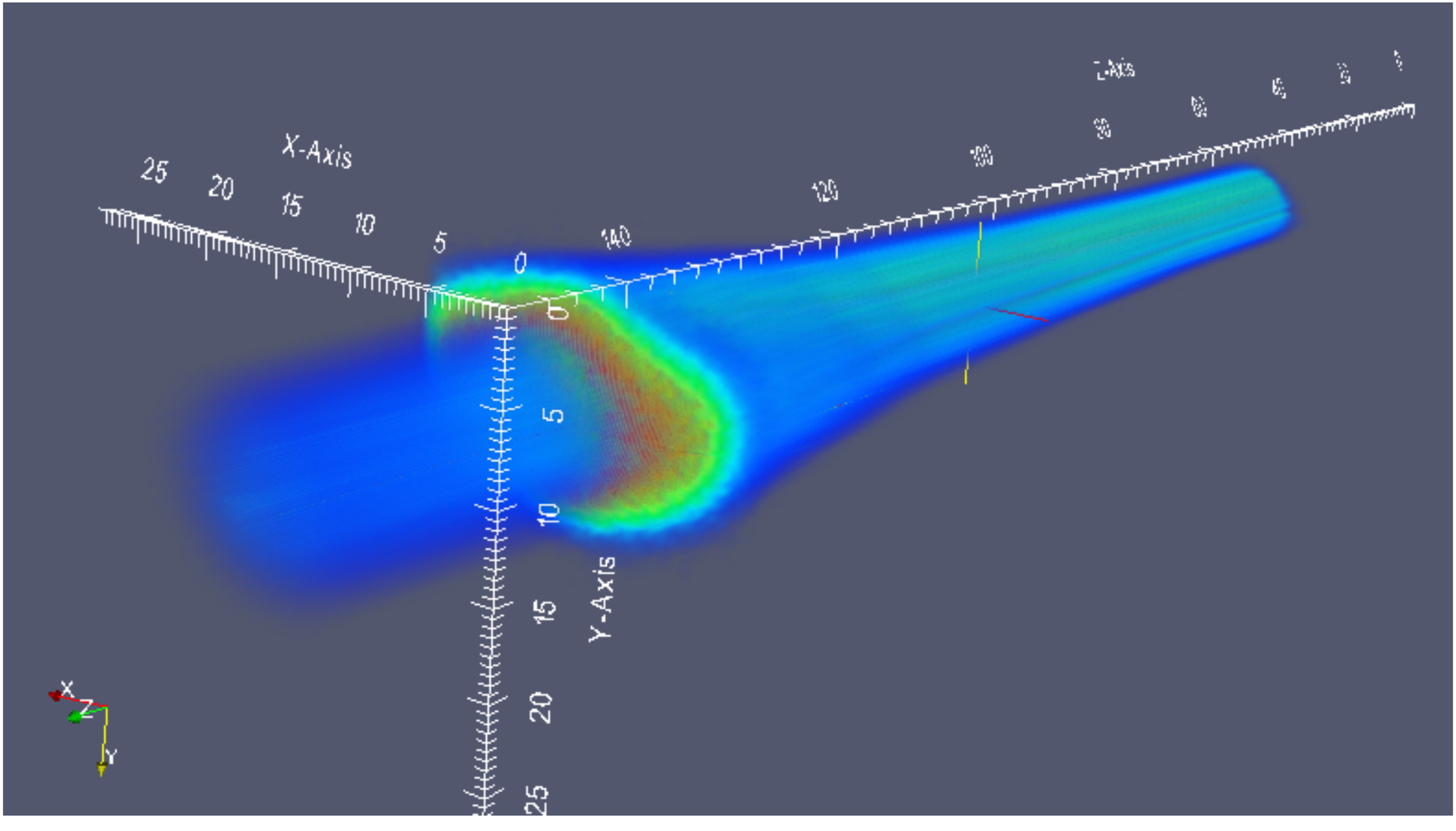

Stepper
Motor
Gempix
Phantom
Thin
Window

Typical Frame



Depth = 124 mm (In Bragg Peak), 0.43 keV/Count (9.6 MHz, TOT mode), lKrum = 1, 0.001s frame

Reconstructed Dataset



Beam enters from right, carbon fragmentation tail on left

Gempix Future Work

- Validate our tracking algorithms vs Timepix.
- Calculate LET at first in a very naive way, pull out the track length and energy deposition -> Validate vs other microdosimiters and timepix.
- Then work out what else we can do with our tracking information.
- Timepix 3 version on the way in collaboration with Nikhef.

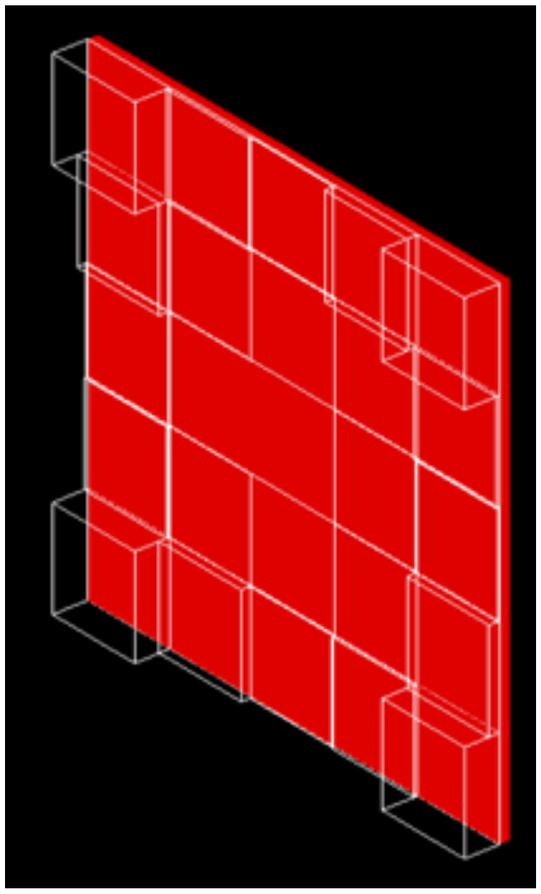
A compact, energy independent fast neutron dosimeter (and related measurements at NTOF)

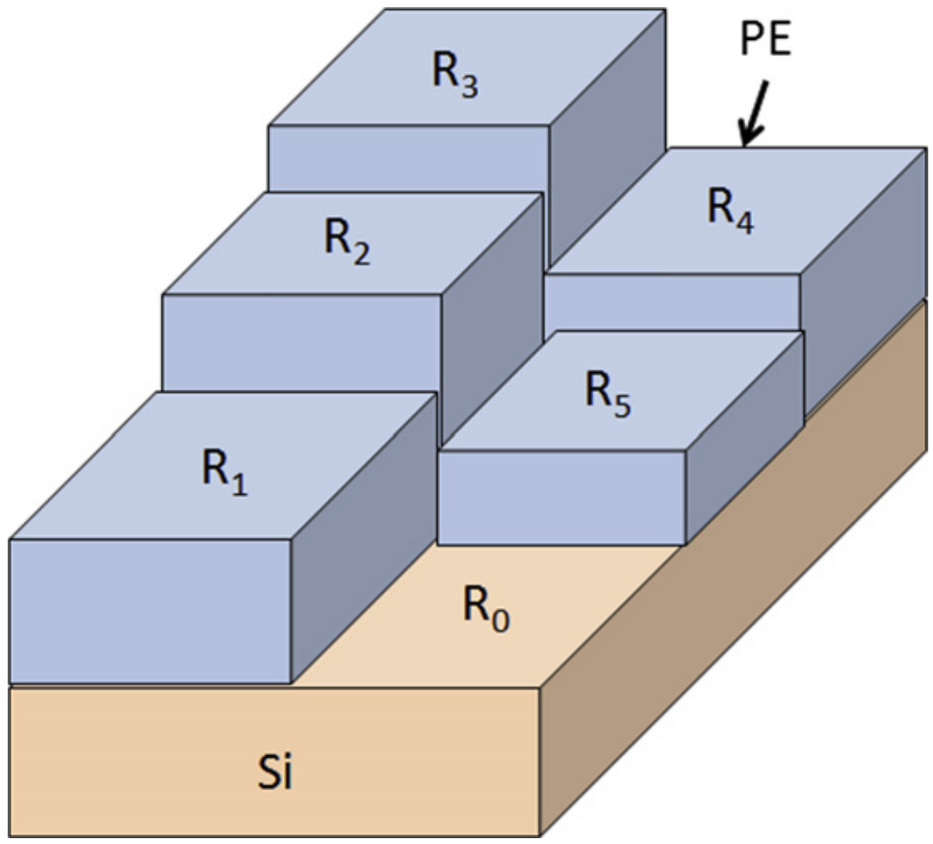
S. P. George[1,2] ,F. Murtas[1,3], M.Weaver[2], M.Silari[1], A.B.Rosenfeld[2]

[1] ARDENT Program, CERN, Geneva, Switzerland <stuart.george@cern.ch>
[2] University of Wollongong Centre for Medical Radiation Physics, Wollongong, NSW, Australia

And everyone at NTOF…

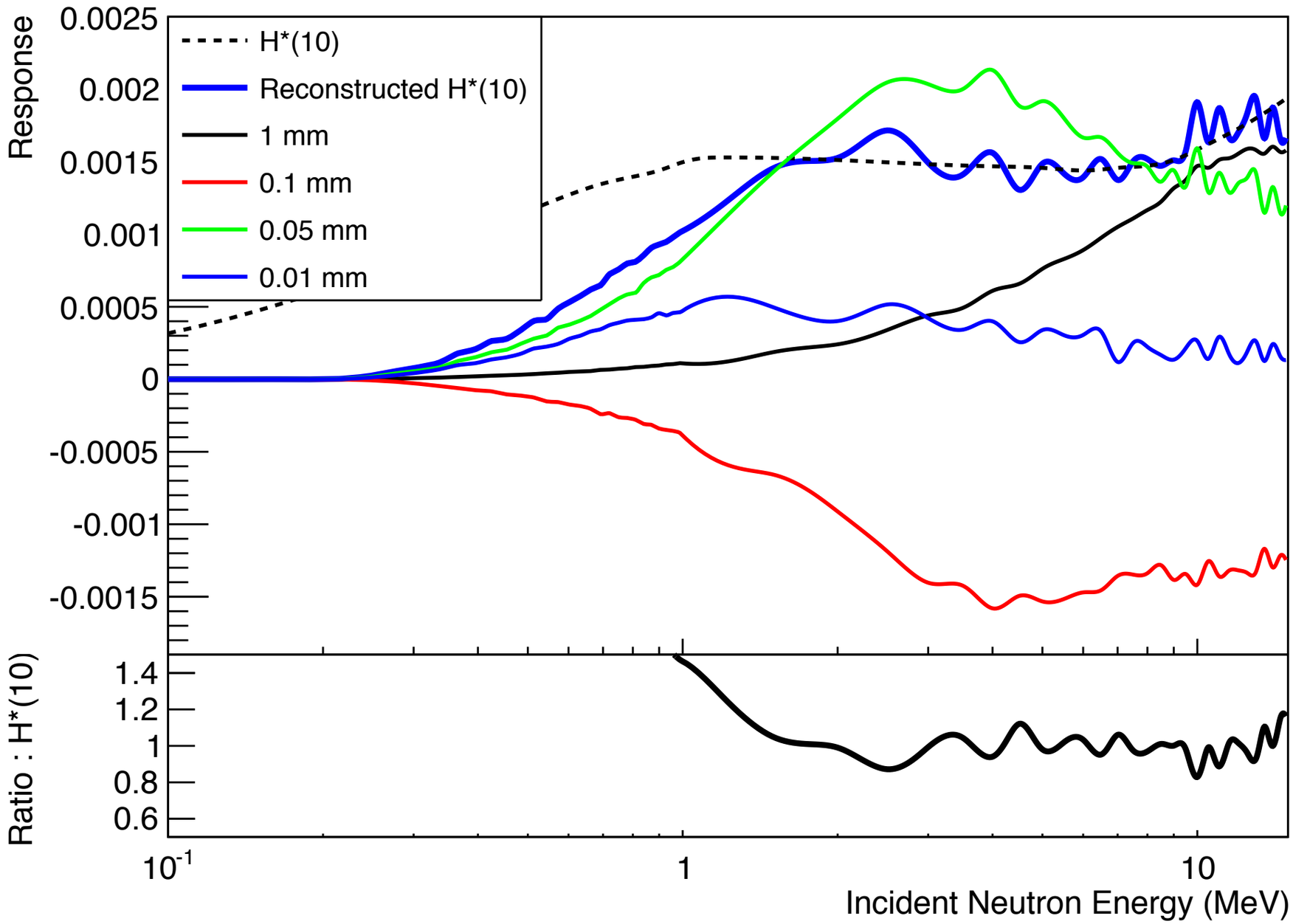
Neutron Dosimiter



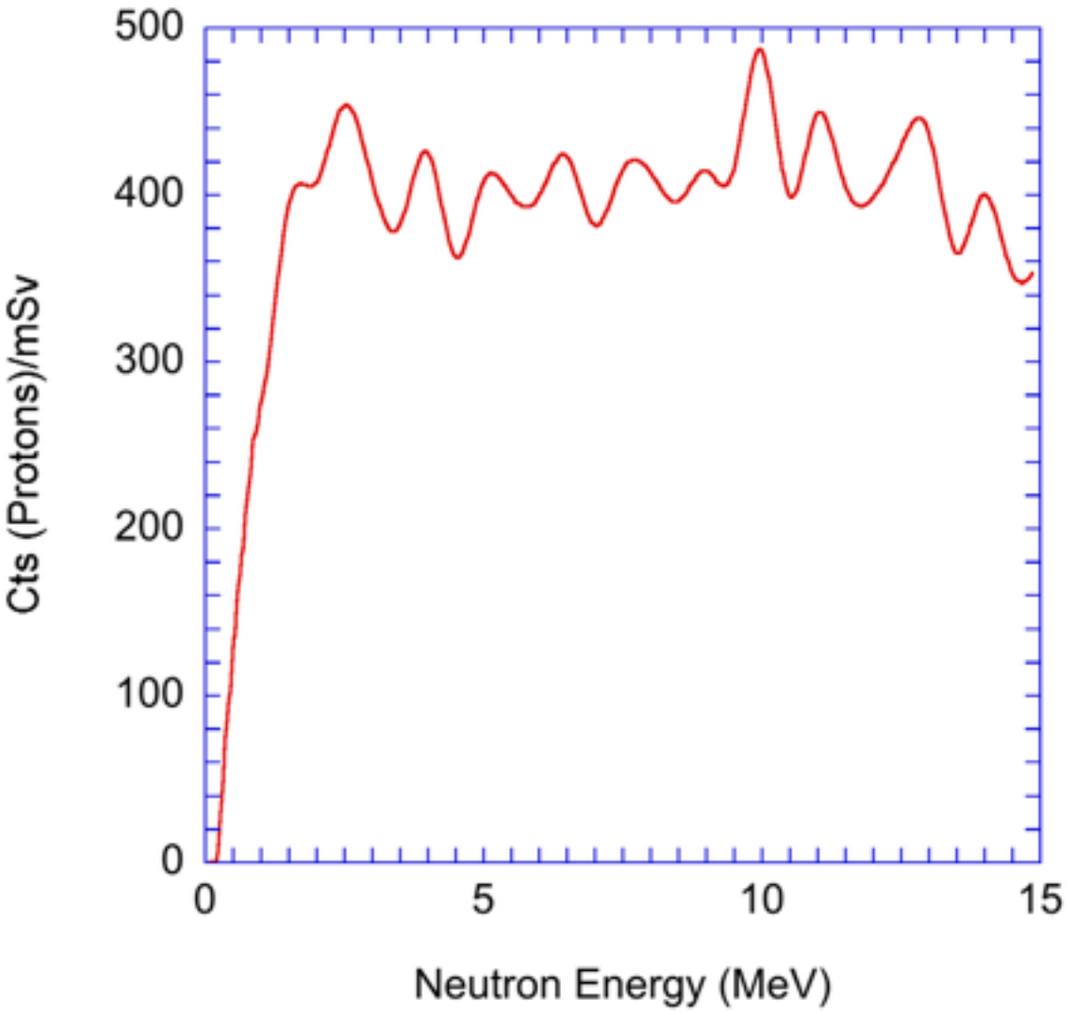


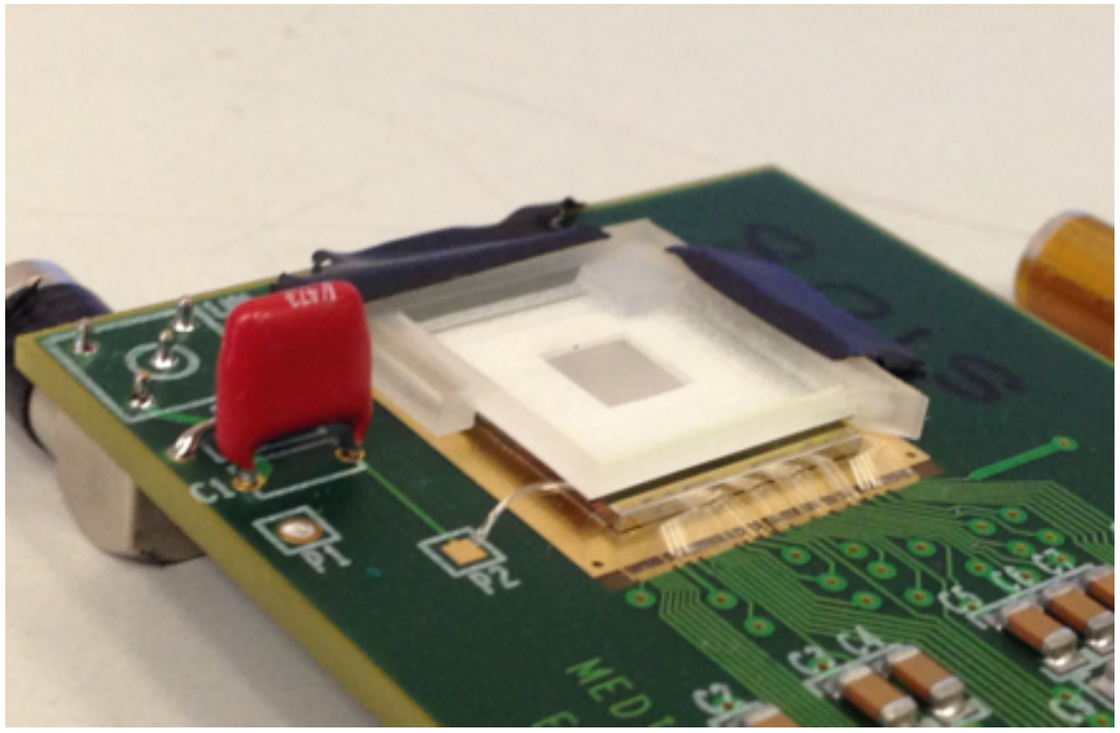
$$H^*(10)(E) = \sum_i \beta_i R_i(E)$$

4 Slab Configuration



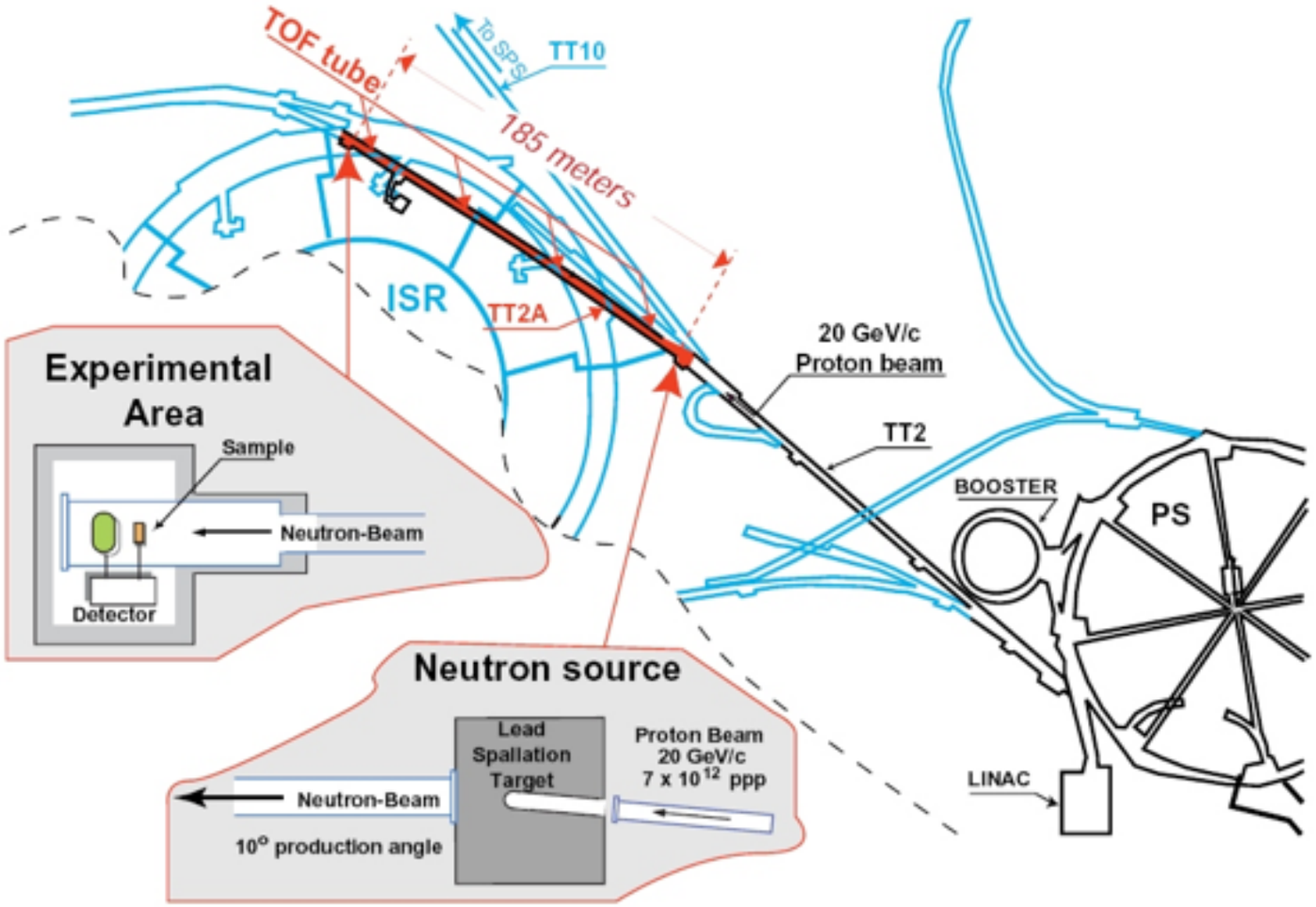
Optimised Response

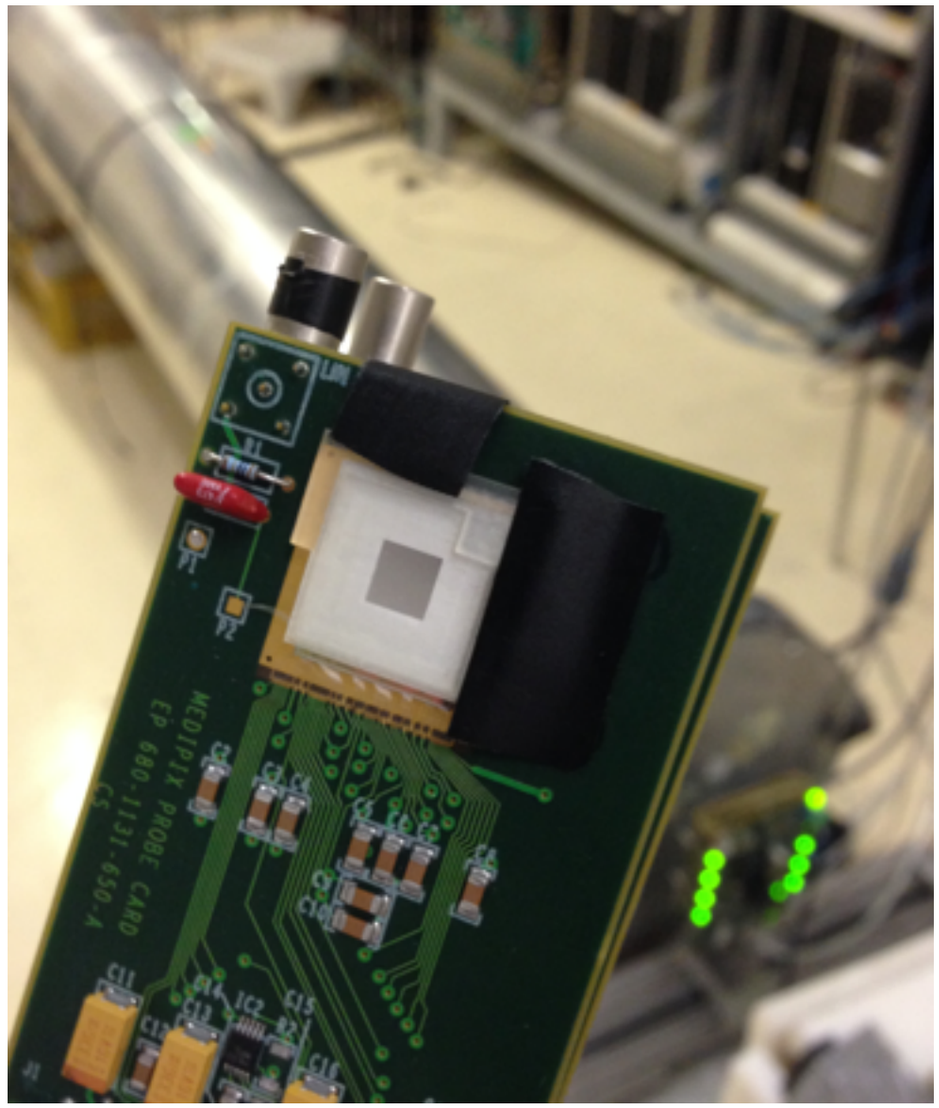




> 1 MeV average = 405 cts/mSv, standard deviation = 30 cts

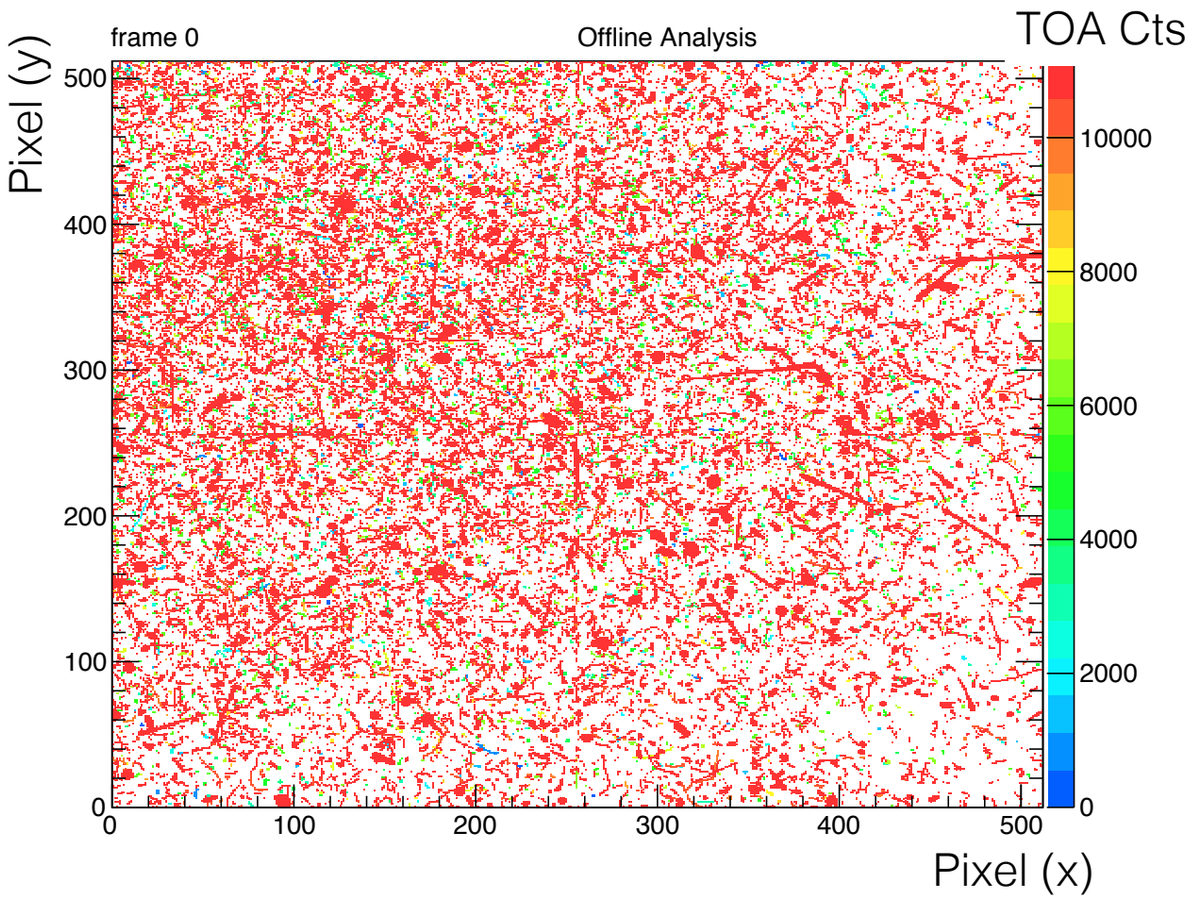
Measurements at NTOF

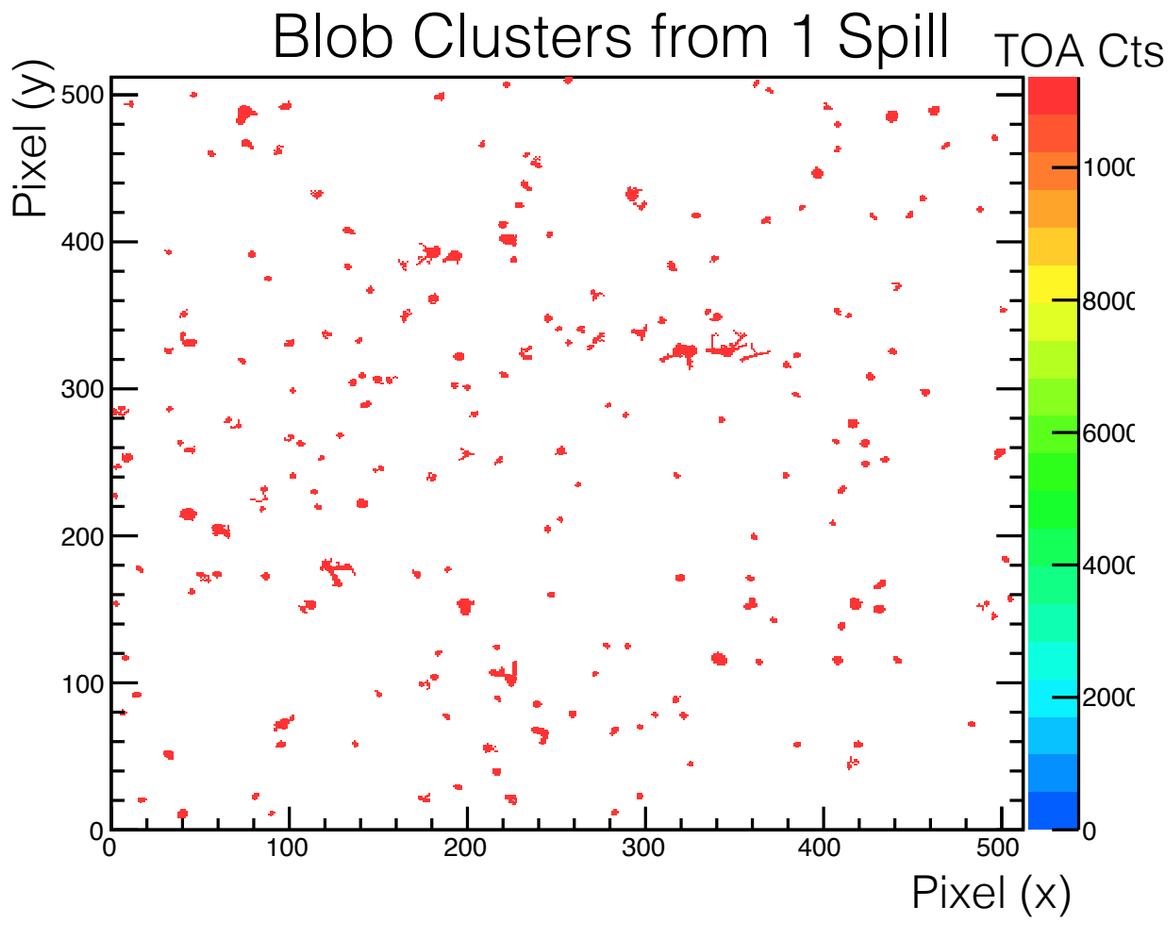




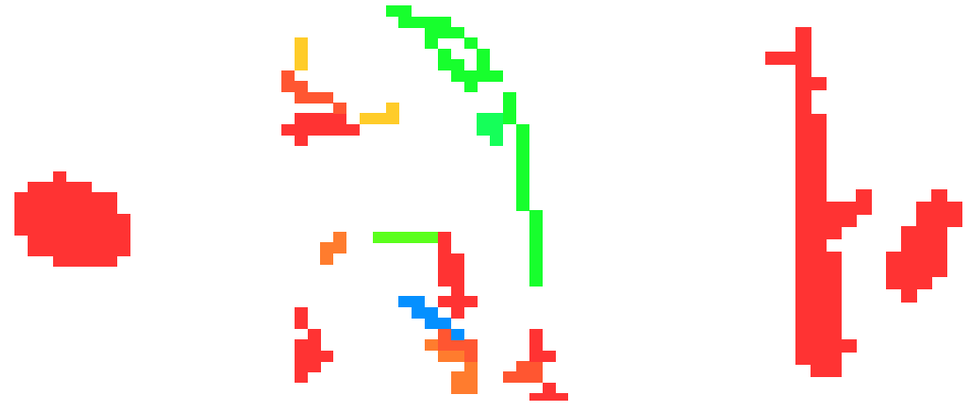
Neutron time of flight facility at CERN, 185m throw
Mostly done (so far) at NTOF-1, 20 m throw

Particle Signals - Clusters

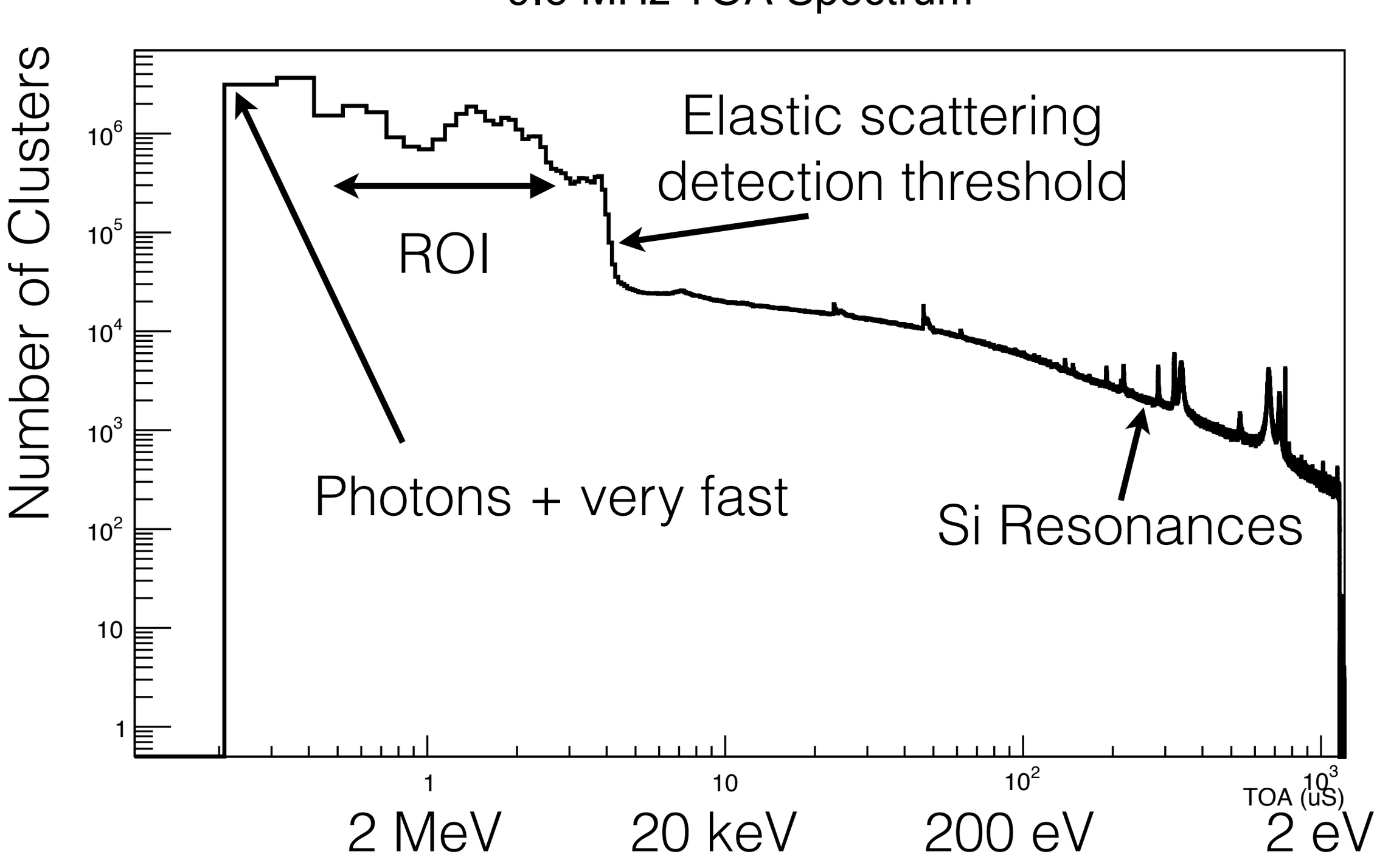




- Clustering done by search for particle contiguous in x,y,TOA

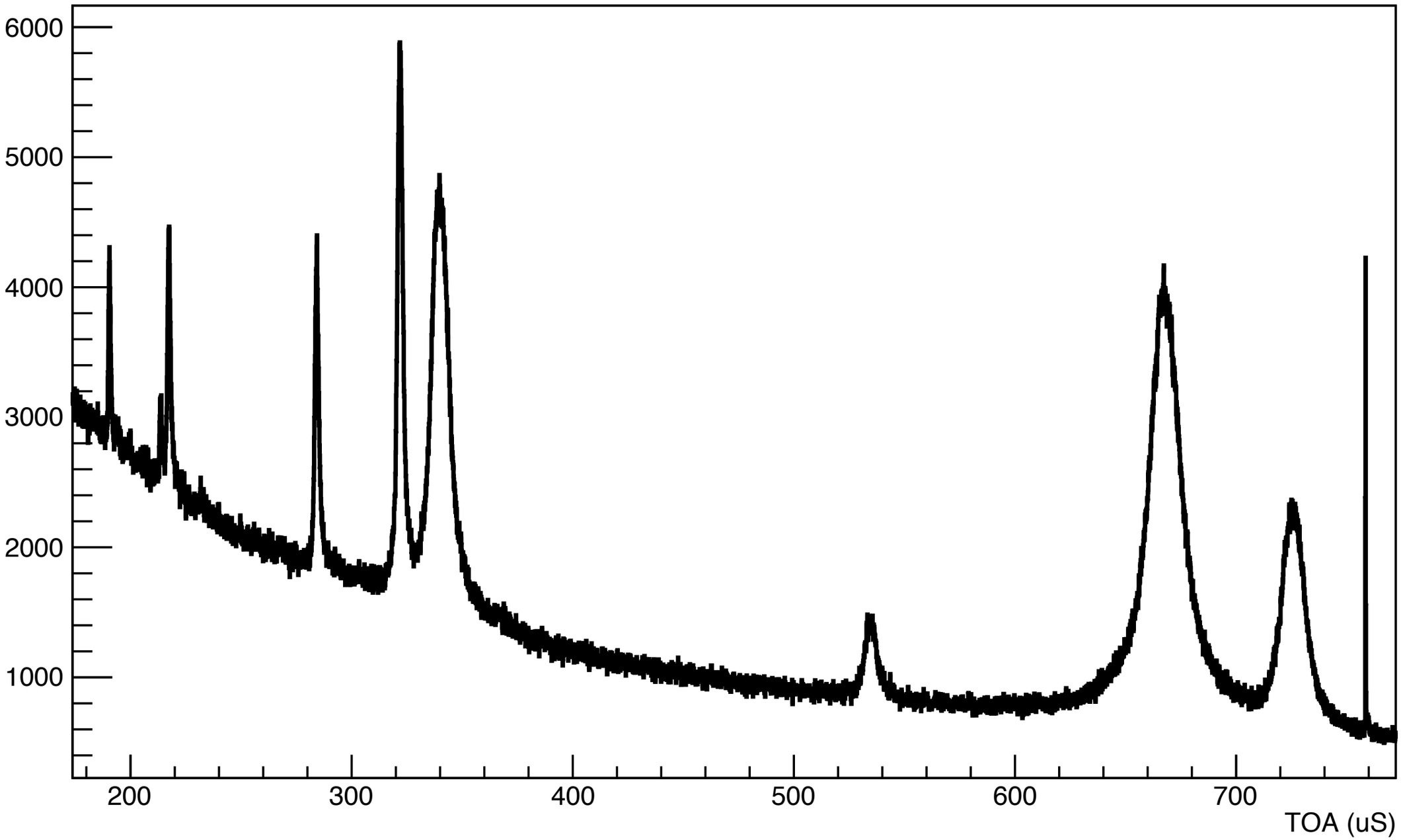


Clusters Sorted By Morphology



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

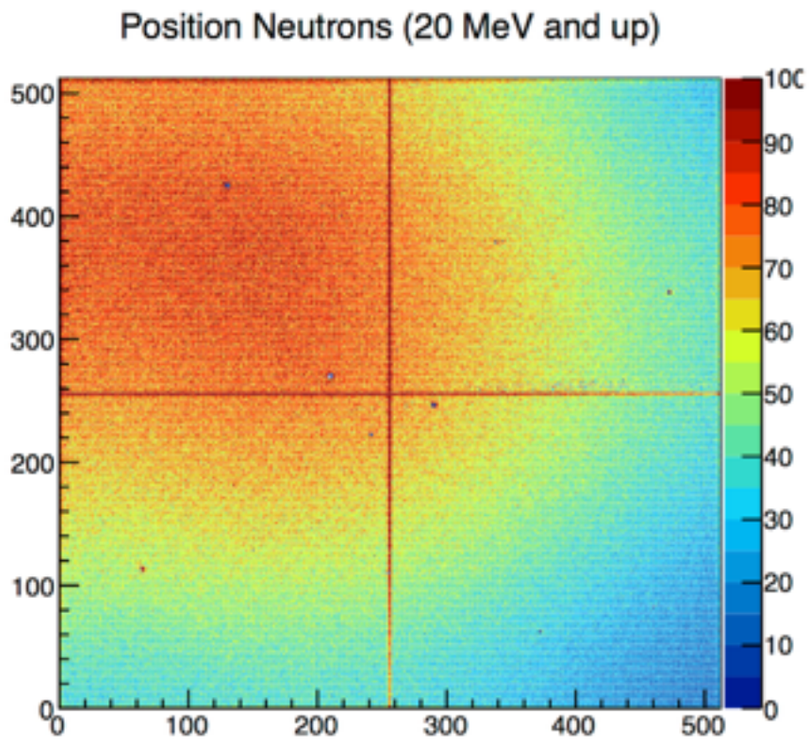
9.6 MHz TOA Spectrum

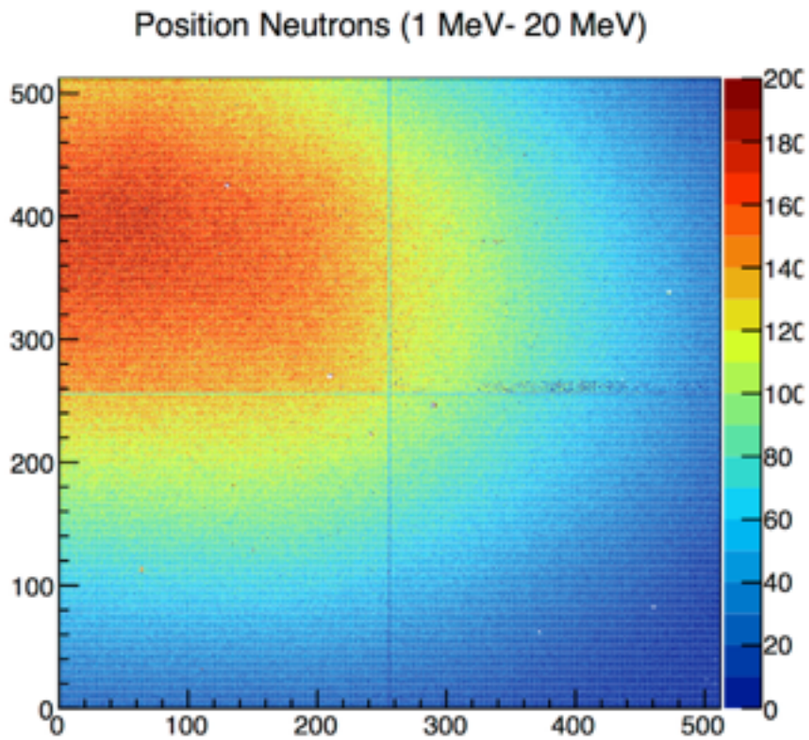


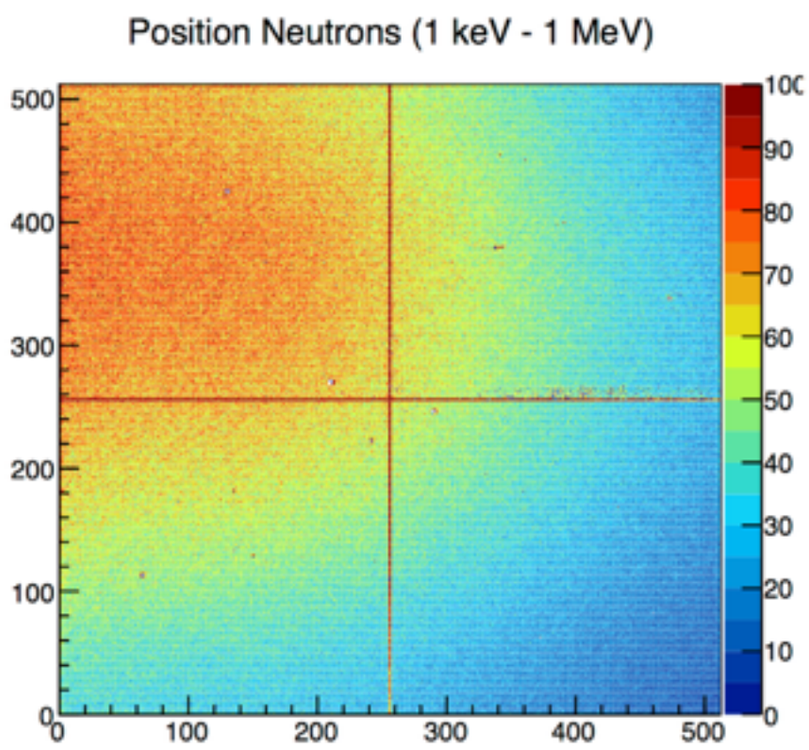
50 eV 10 eV ~5 eV

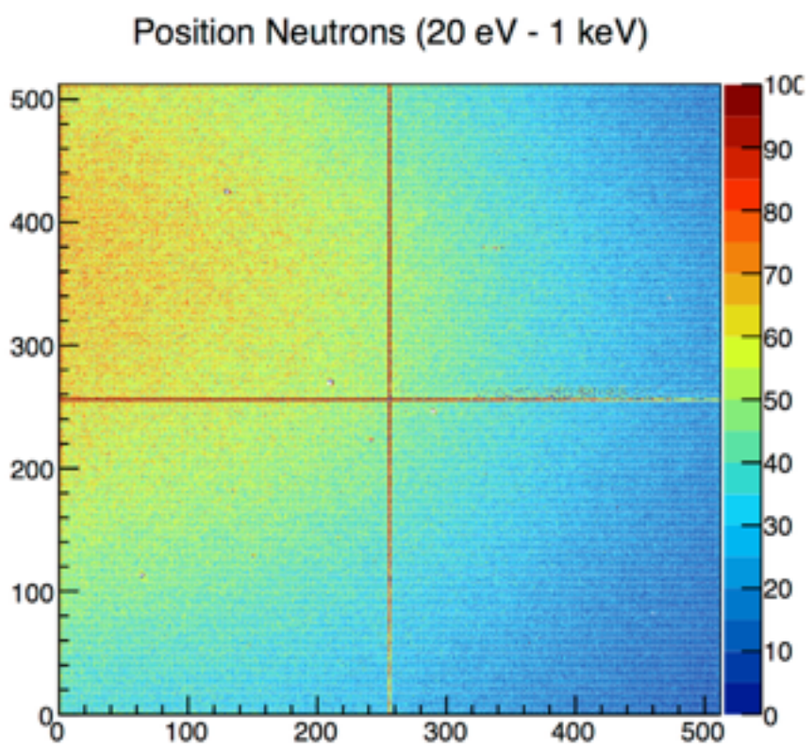
Can pull out ‘resolution function’ from resonance width, determine beam energy spread

Beam Characteristion at Different Energies







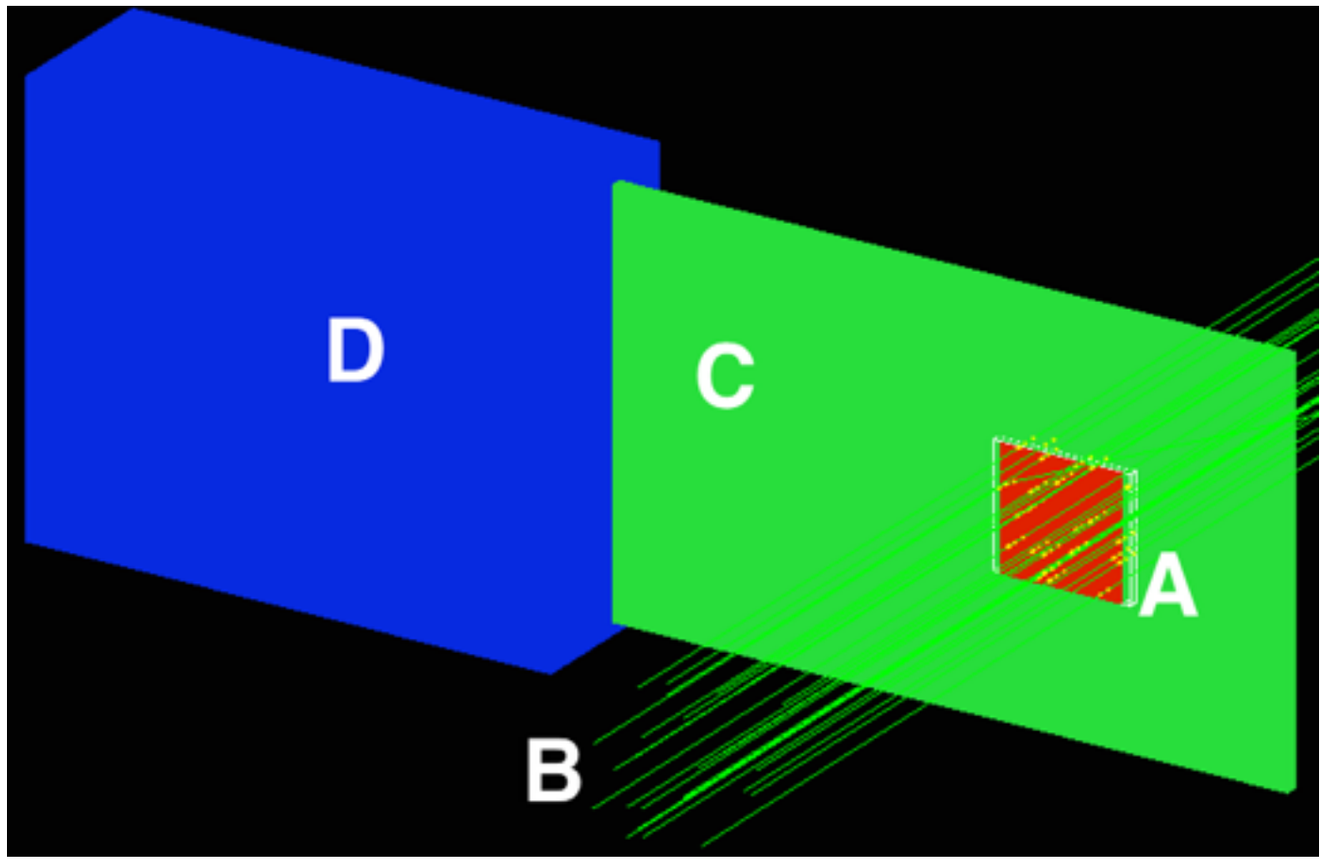


“The length of this document defends it well against the risk of its being read”

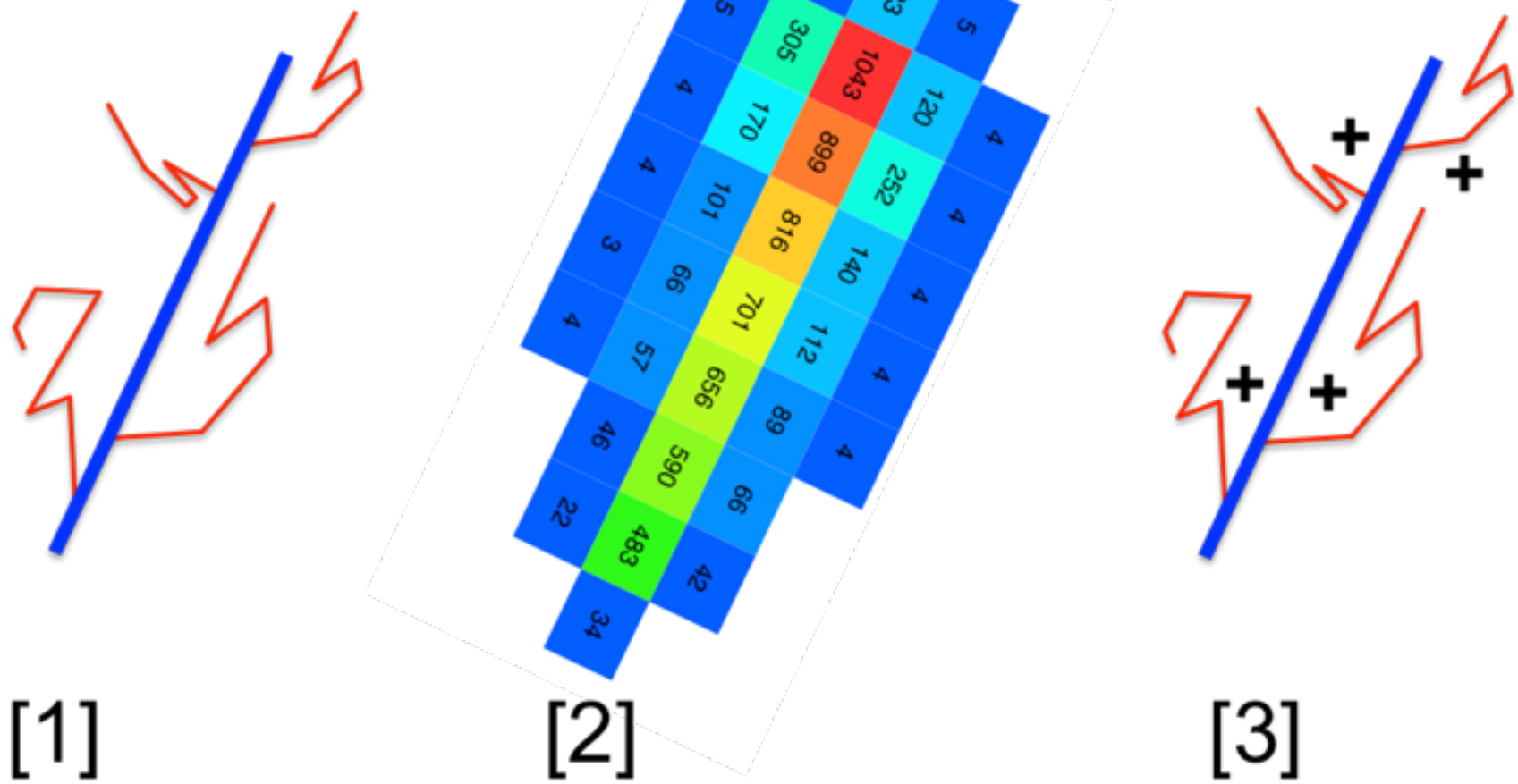
–Winston Churchill

Geant 4 Simulation

- 300 um silicon sensor
- Optional geometry switches
- “Event summing”



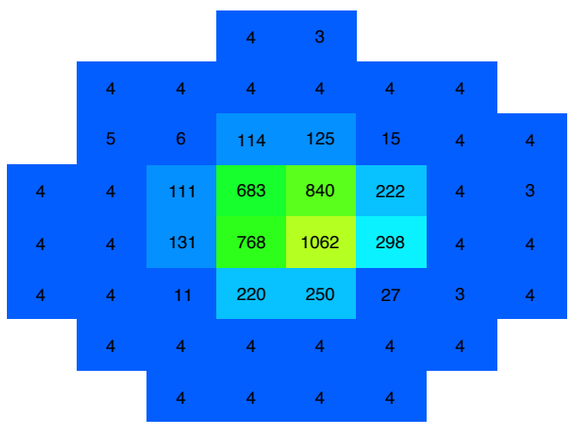
Event Summing Concept



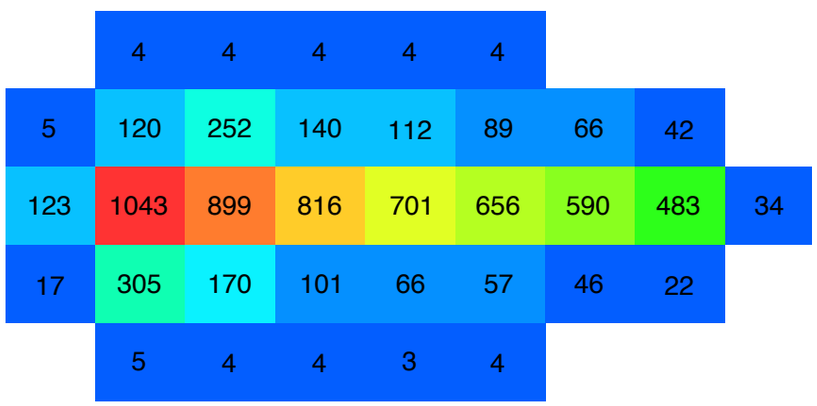
[1] [2] [3]

Goal - reproduce the quantities that a physical Timepix measures that we need -> cluster centroid and total energy

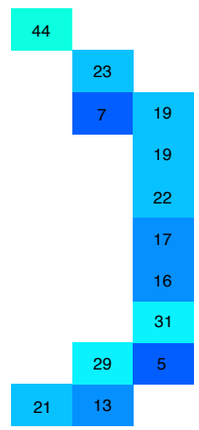
Timepix Discrimination



Alpha (Am241)



Proton (7 MeV)

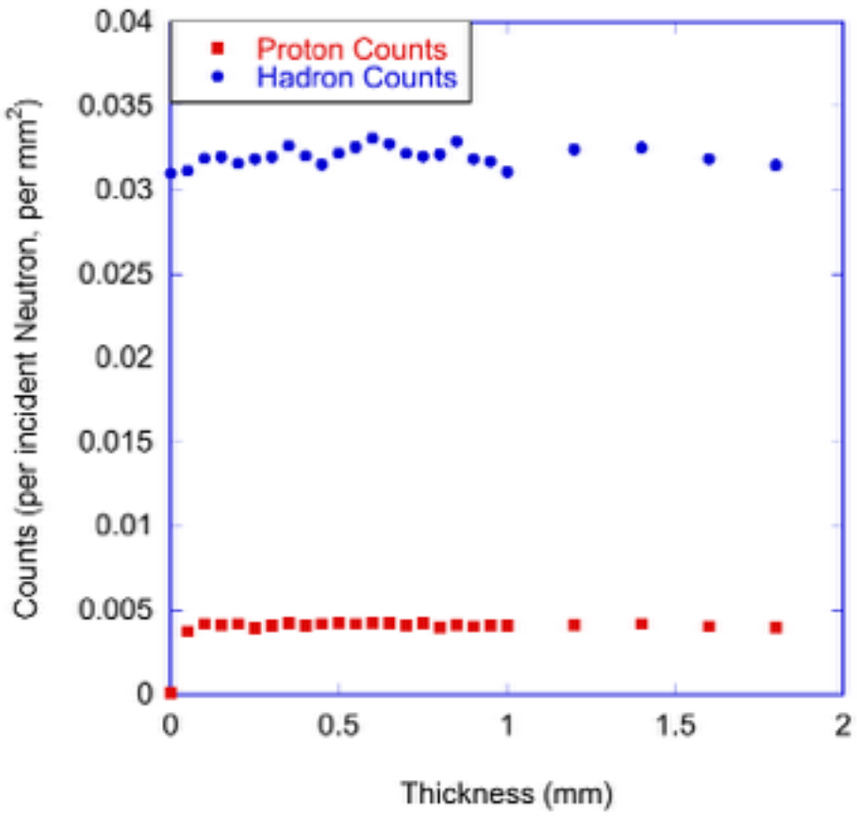


Compton (Co60)

Assumptions

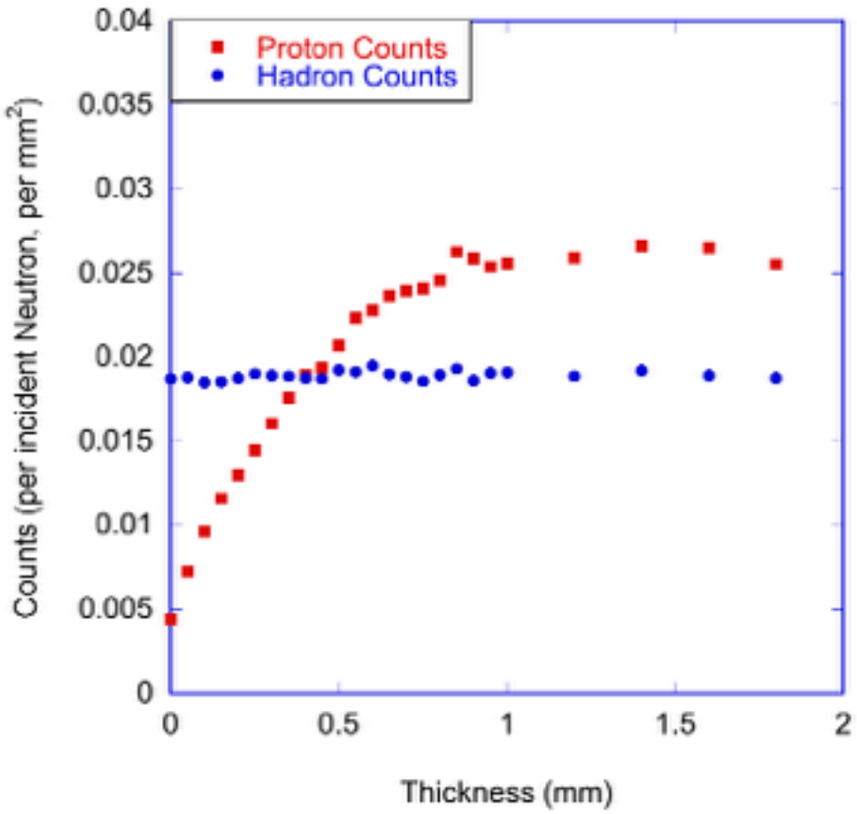
1. We can discriminate all electrons from hadrons
2. We can accurately measure the interaction point/ centroid of a hadronic cluster
3. We can accurately measure the energy of a hadronic cluster
4. For now (…) we cannot separate one hadron from another (i.e. protons from alpha particles)

2 MeV Neutrons

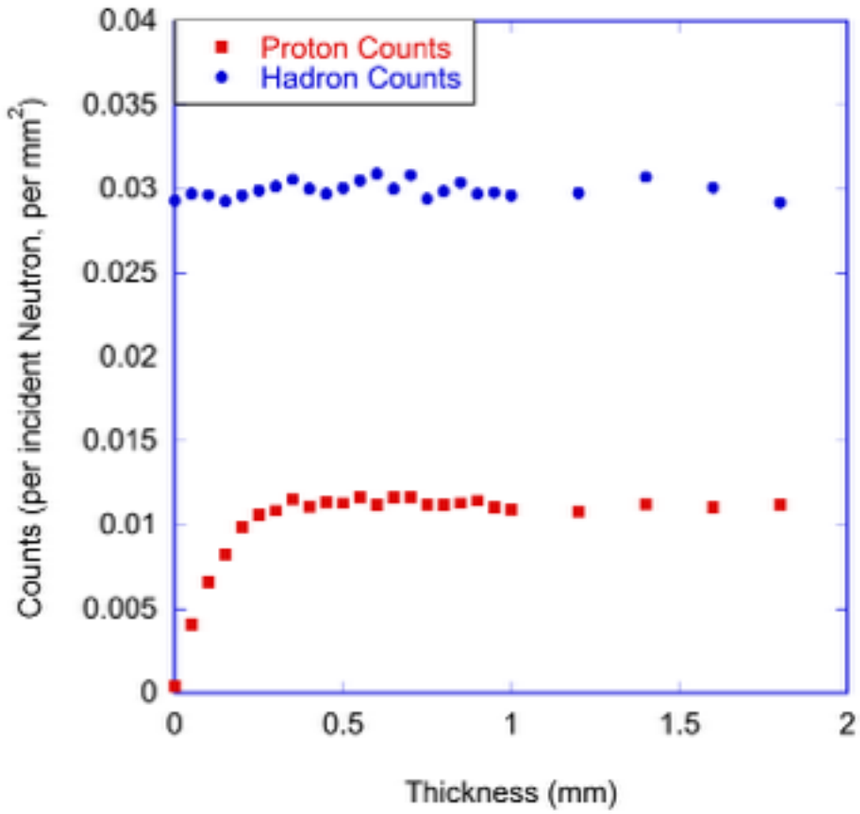


- Protons are mostly produced in the converter
- “Hadrons” are anything that is hadronic but not a proton -> (n,Si) inelastic reactions
- For 2 and 5 MeV neutrons the background dominates the signal -> this is a big problem

10 MeV Neutrons

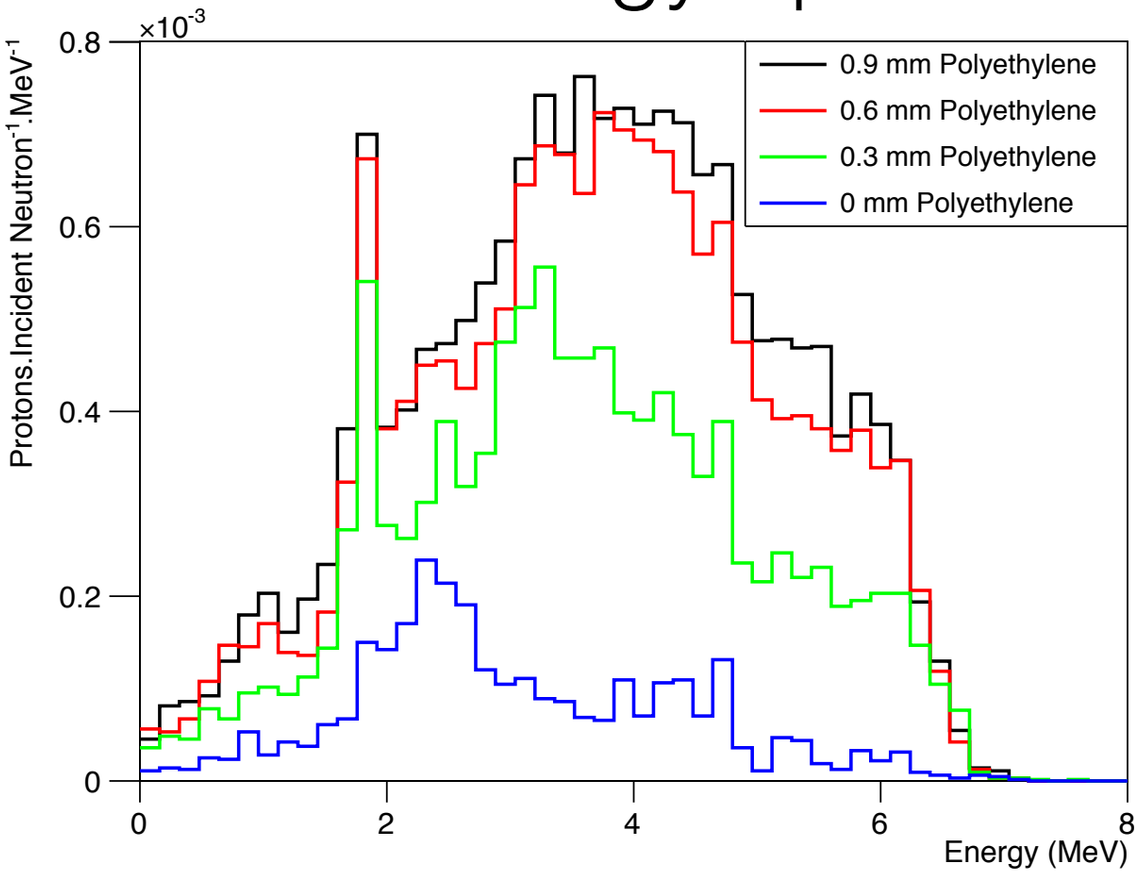


5 MeV Neutrons



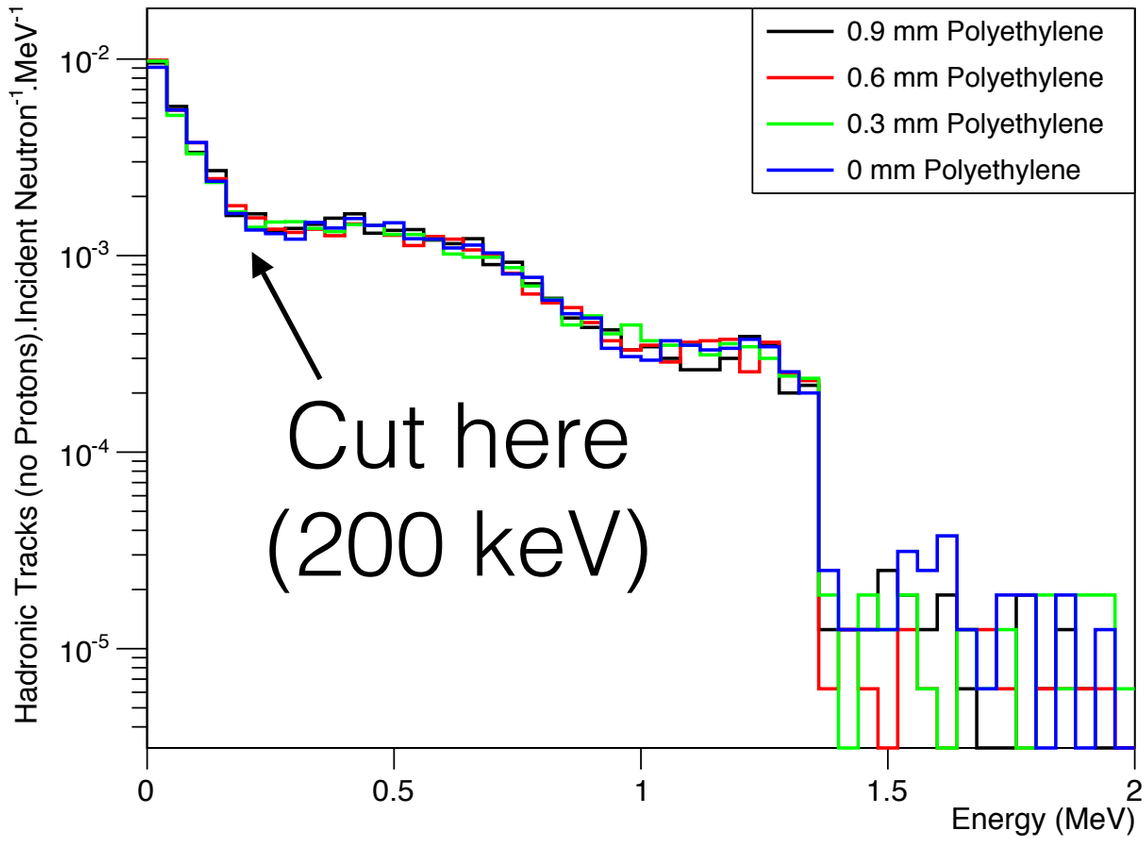
Reducing (n,Si) background - 10 MeV Neutrons

Proton Energy Spectrum



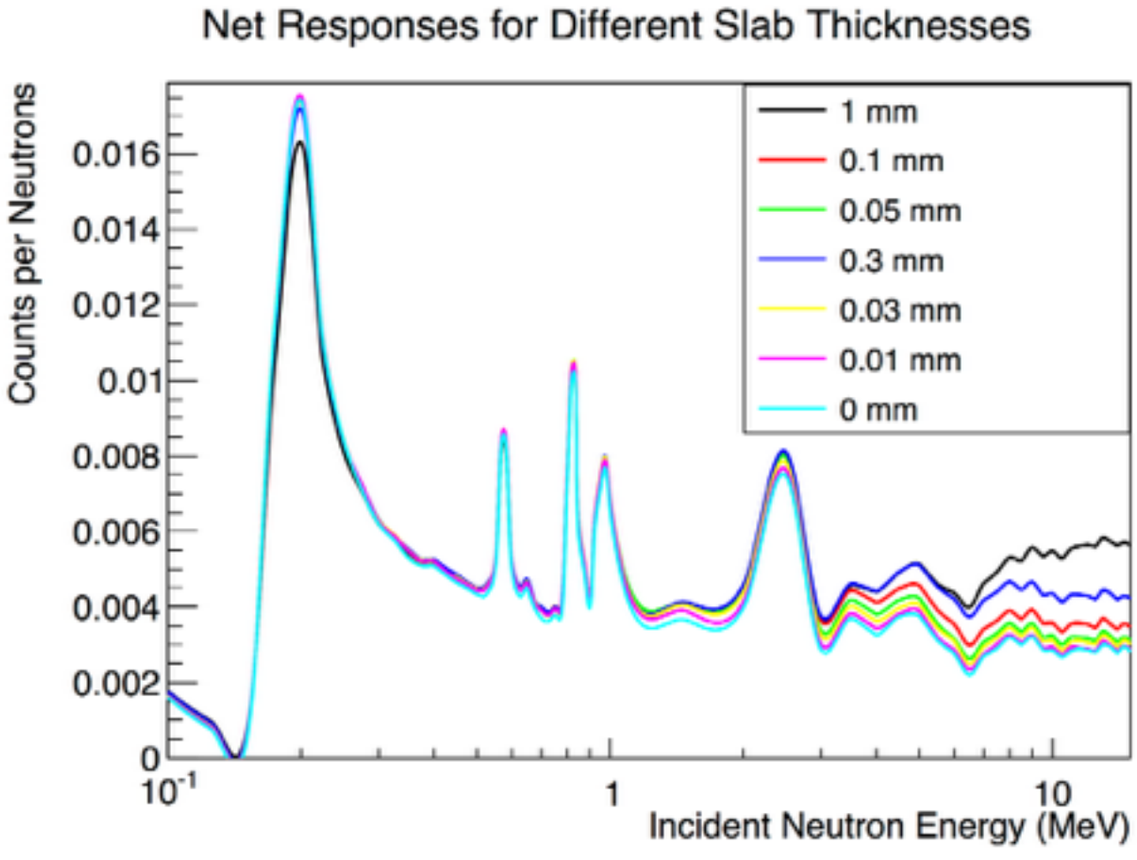
~ 7 MeV - maximum absorbed energy from recoil off hydrogen due to geometrical constraints

Hadron Energy Spectrum

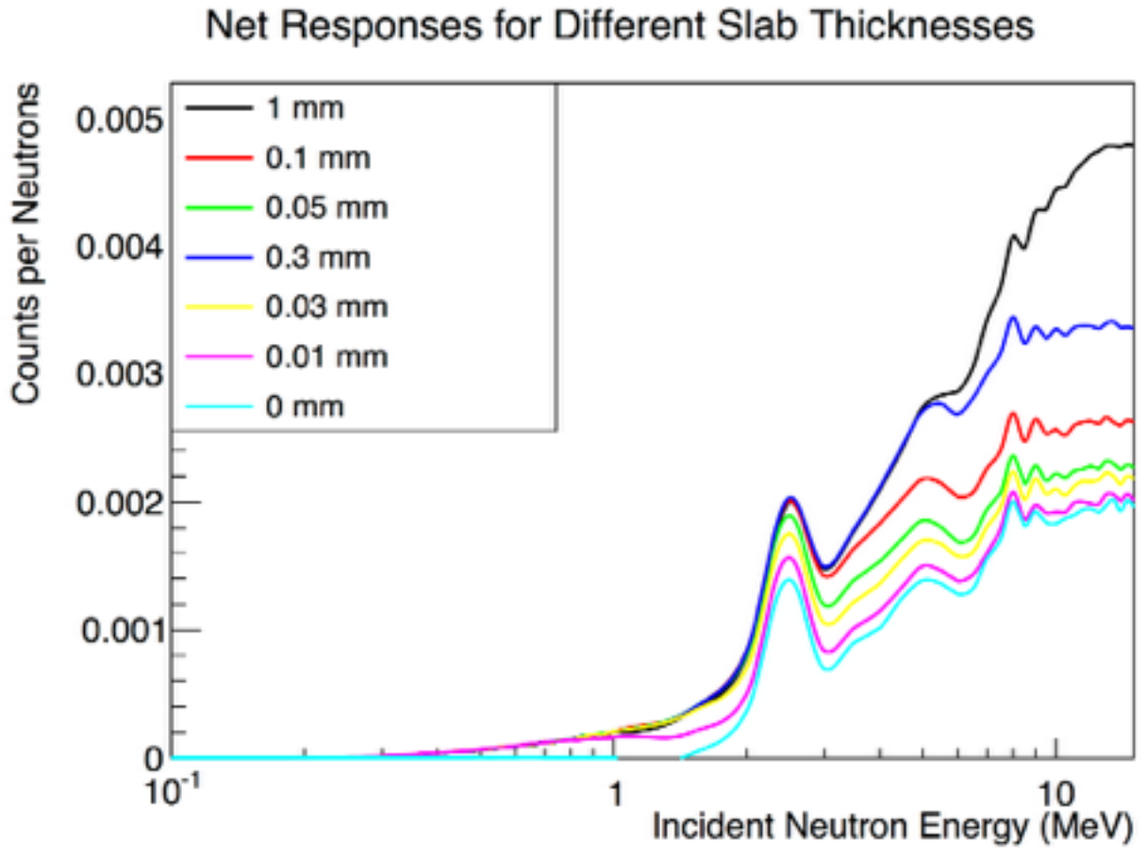


1.33 MeV = Maximum energy transferrable to an Si nucleus by a neutron

Response Functions



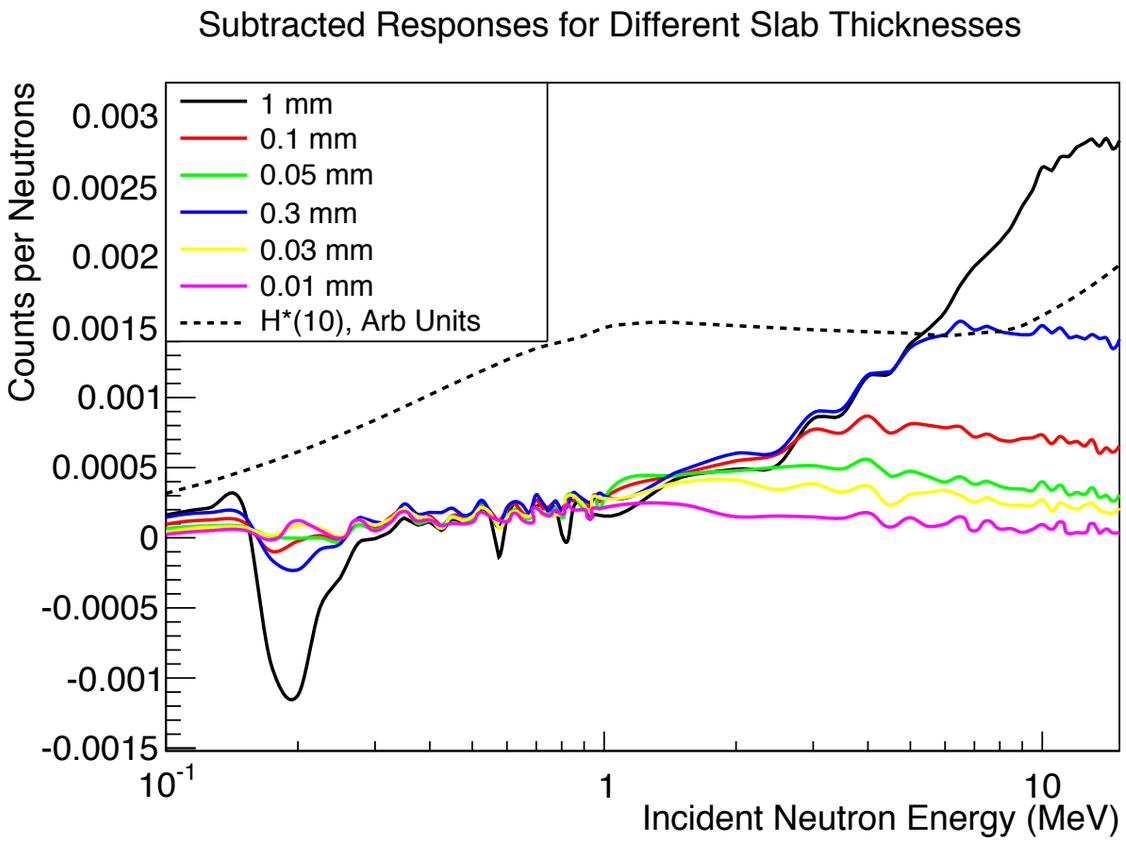
No Cut



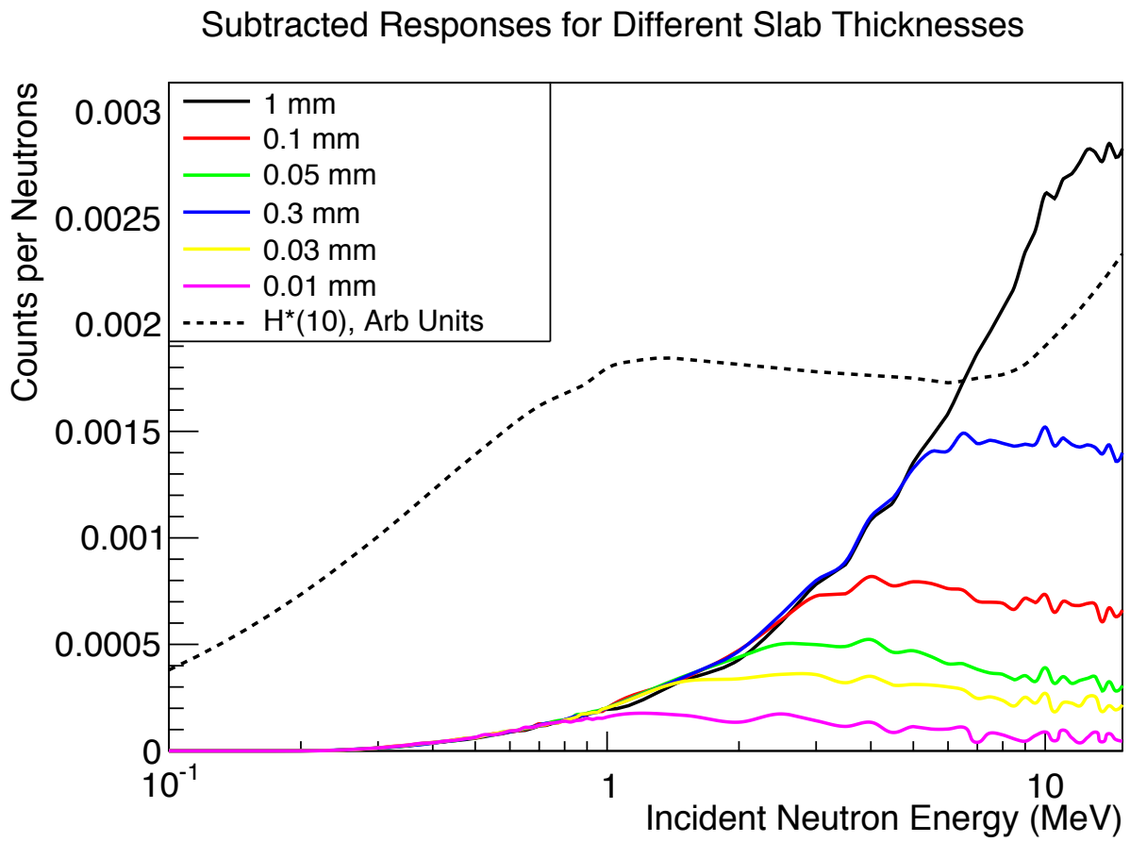
200 keV Cut

Cut removes silicon resonance signal, clearly separates regions

Subtracted Response Functions



No Cut



200 keV Cut

Cut removes silicon resonance signal, clearly separates regions

Optimise Response to H*(10)

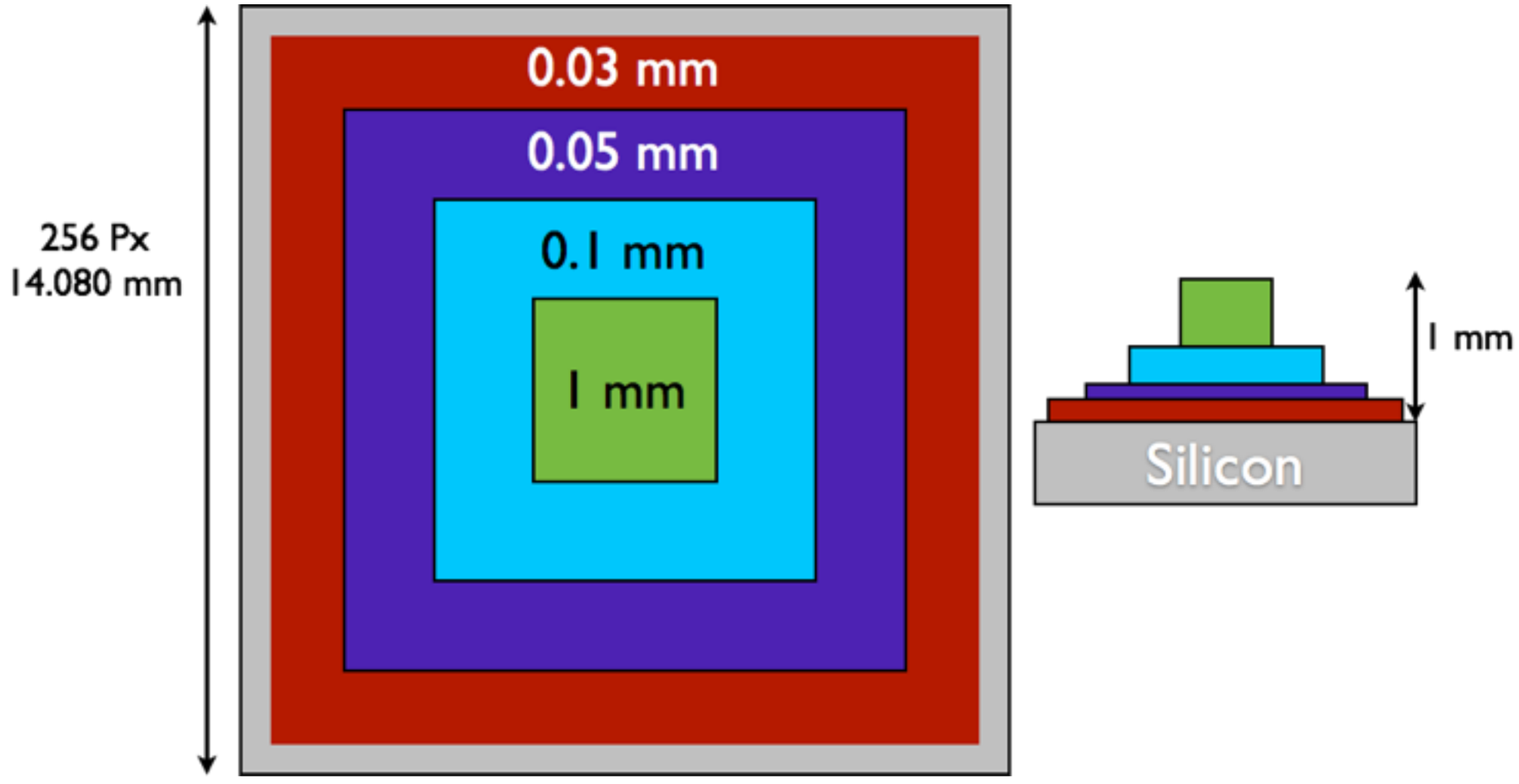
Linearly scale each response curve R(E) by a constant coefficient

$$H^*(10)(E) = \sum_i \beta_i R_i(E)$$

Minimise this equation in some way - I use simulated annealing on interpolated curves, but its probably over the top

$$F = \sum_{E_{\min}}^{E_{\max}} \left| \left[\left(\sum_i \beta_i \int_{E_n}^{E_{n+k}} R_i(E) dE \right) - \int_{E_n}^{E_{n+k}} \mathrm{H}^*(10)(E) dE \right] \right|$$

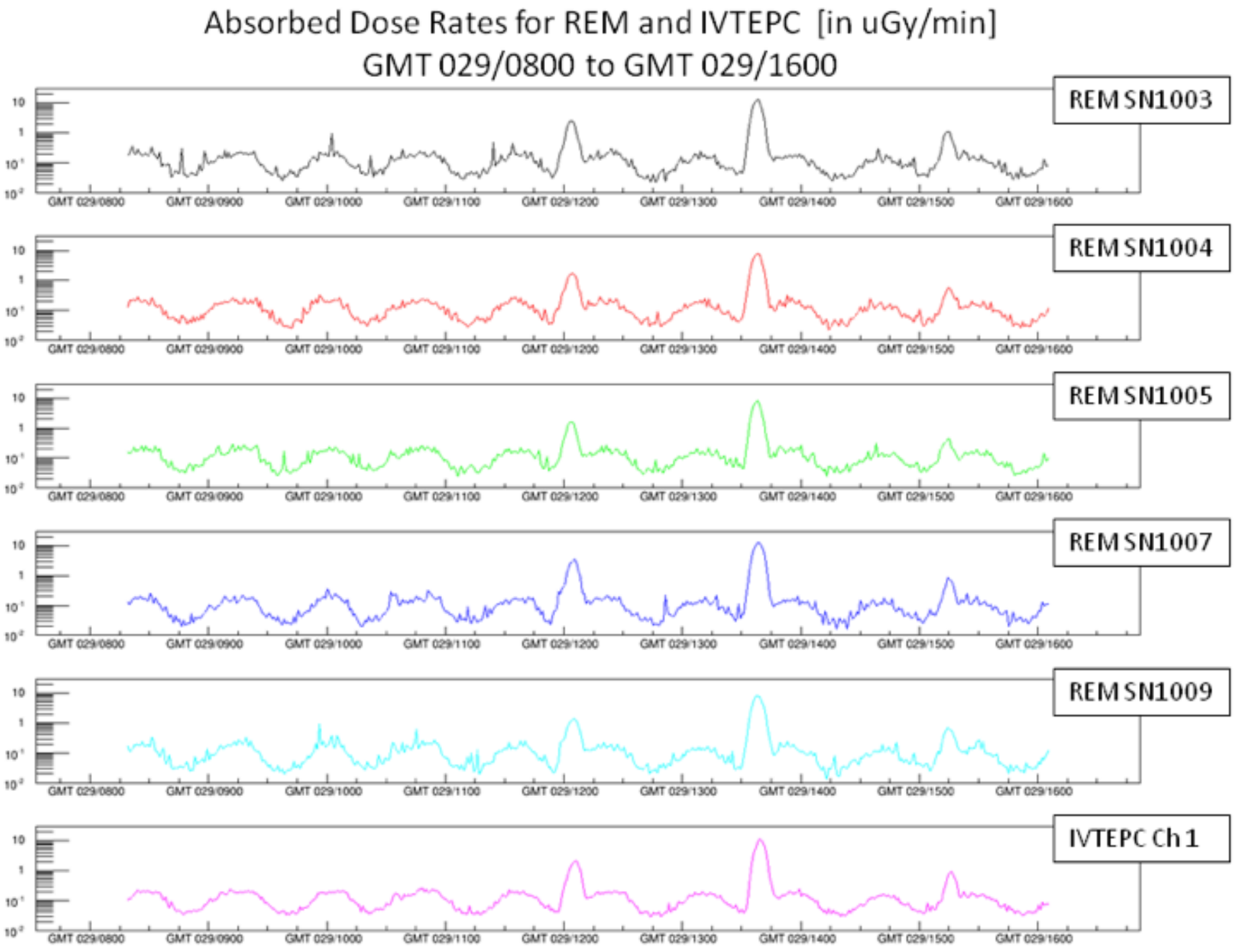
Optimised Construction



Thickness	β	Scaled Area (%)	Width (Pixels)	Width (mm)	Δ Thickness
0 mm (None)	-	15 %	256	14.08 mm	0 mm
0.03 mm	2.86	31.6 %	236	12.98 mm	0.03 mm
0.05 mm	2.50	28.9 %	187	10.29 mm	0.02 mm
0.1 mm	-1.65	18.7 %	127	6.99 mm	0.05 mm
1 mm	0.508	5.7 %	61	3.36 mm	0.9 mm

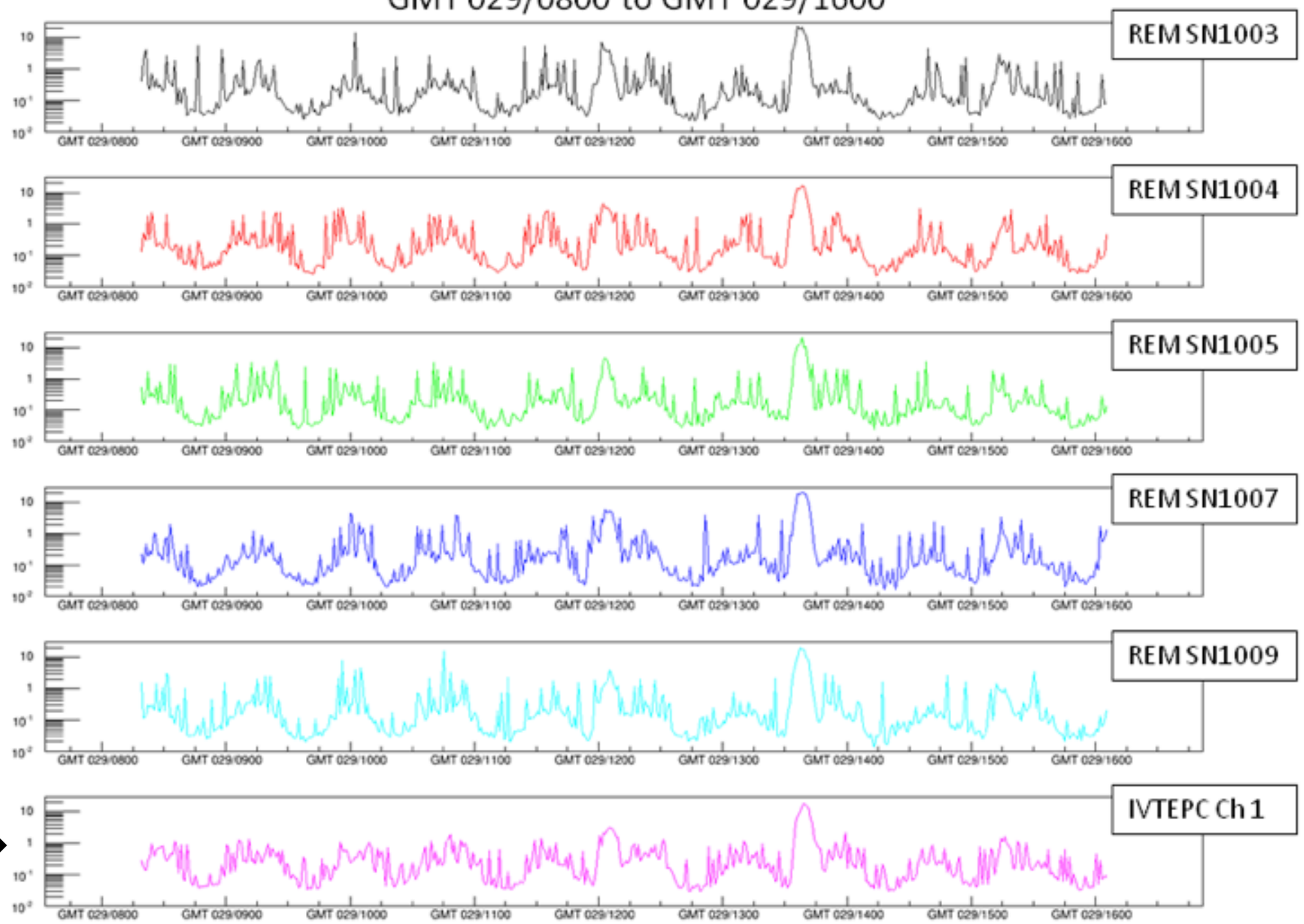
UNIVERSITY OF HOUSTON
Learning. Leading.

REM v. TEPC Absorbed Dose Rates



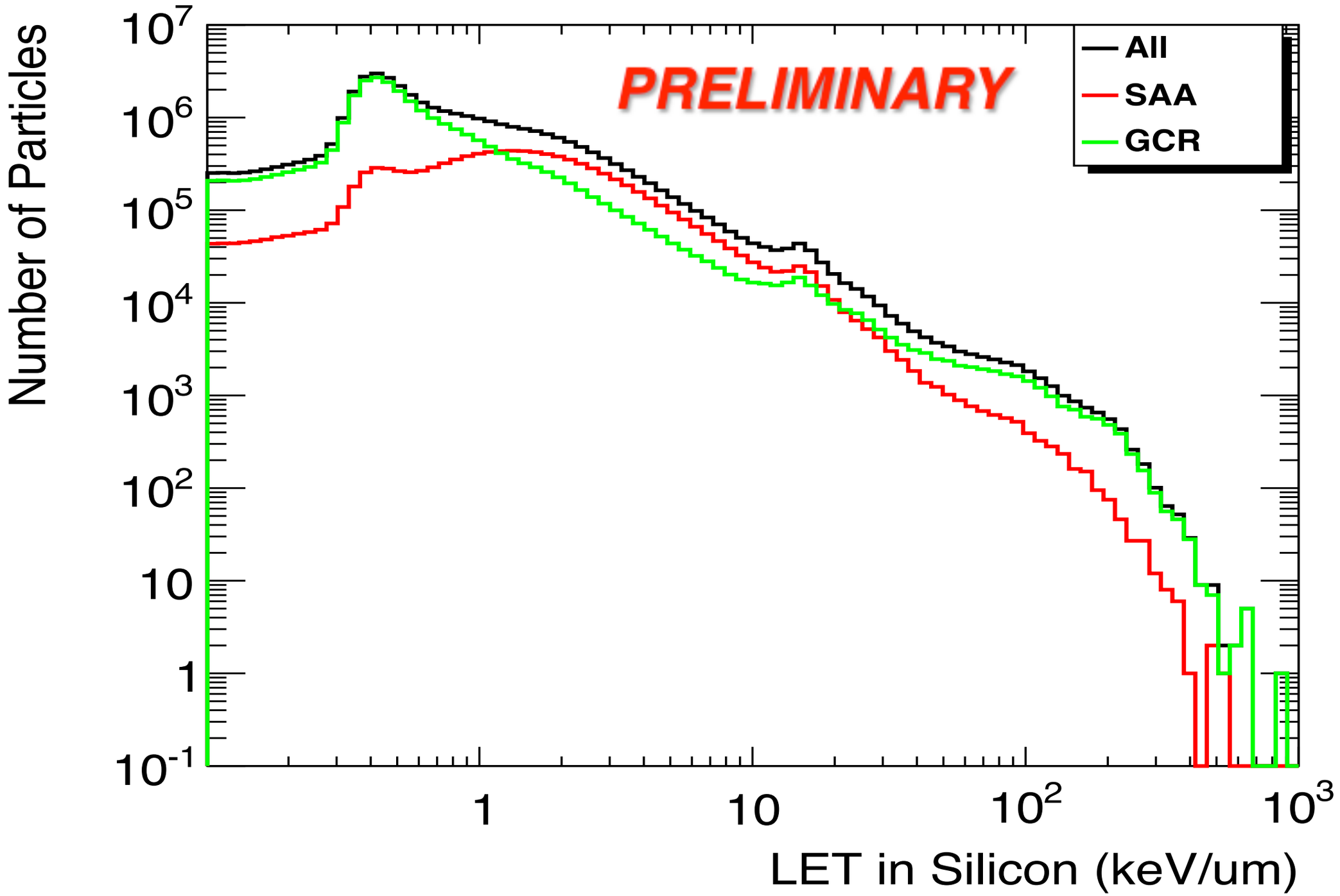
TEPC➔
Tissue-Equivalent Proportional Counter

REM v. TEPC Dose Equivalent Rates

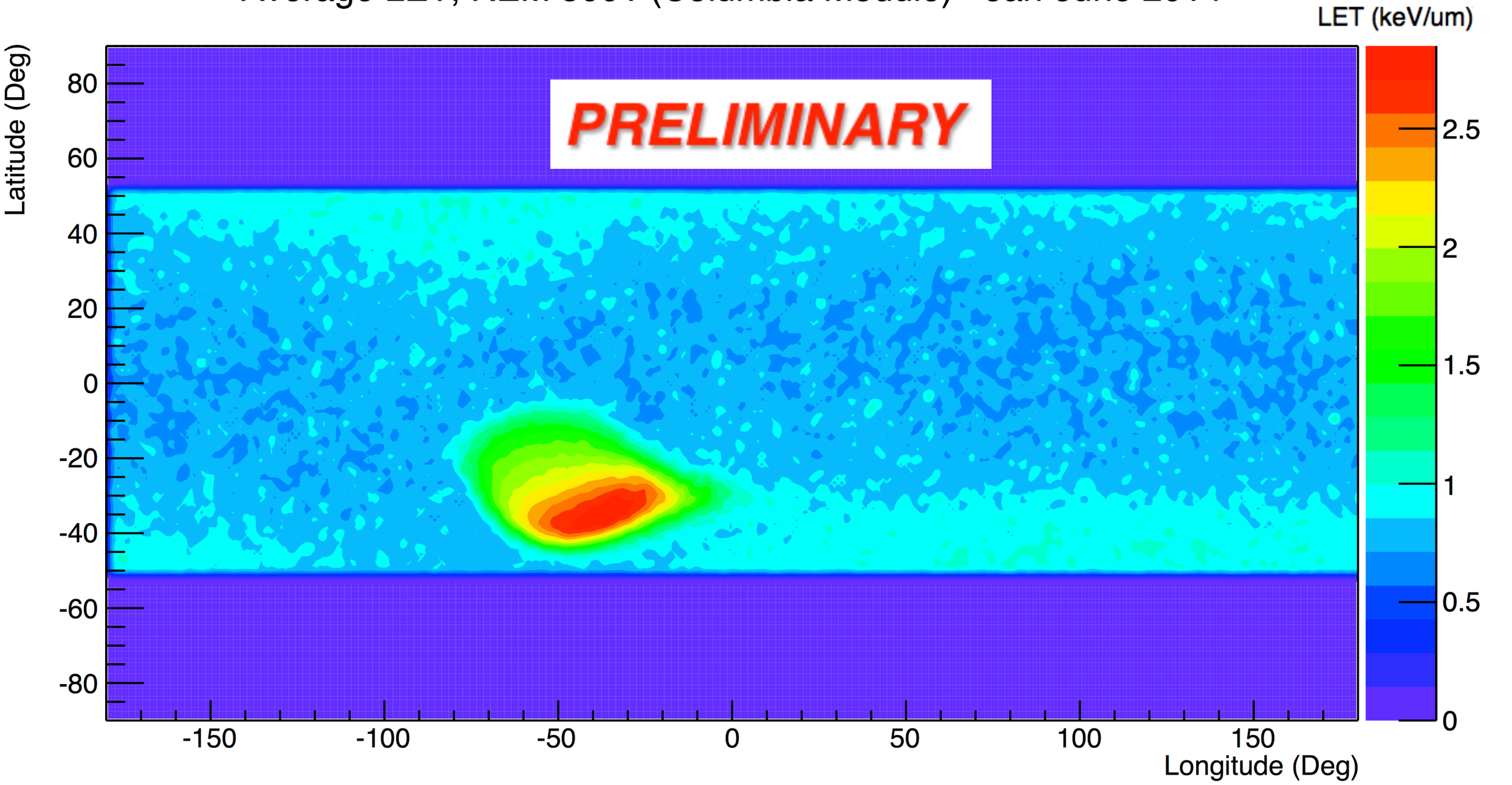


TEPC➔
Tissue-Equivalent Proportional Counter

LET Spectra (Si)

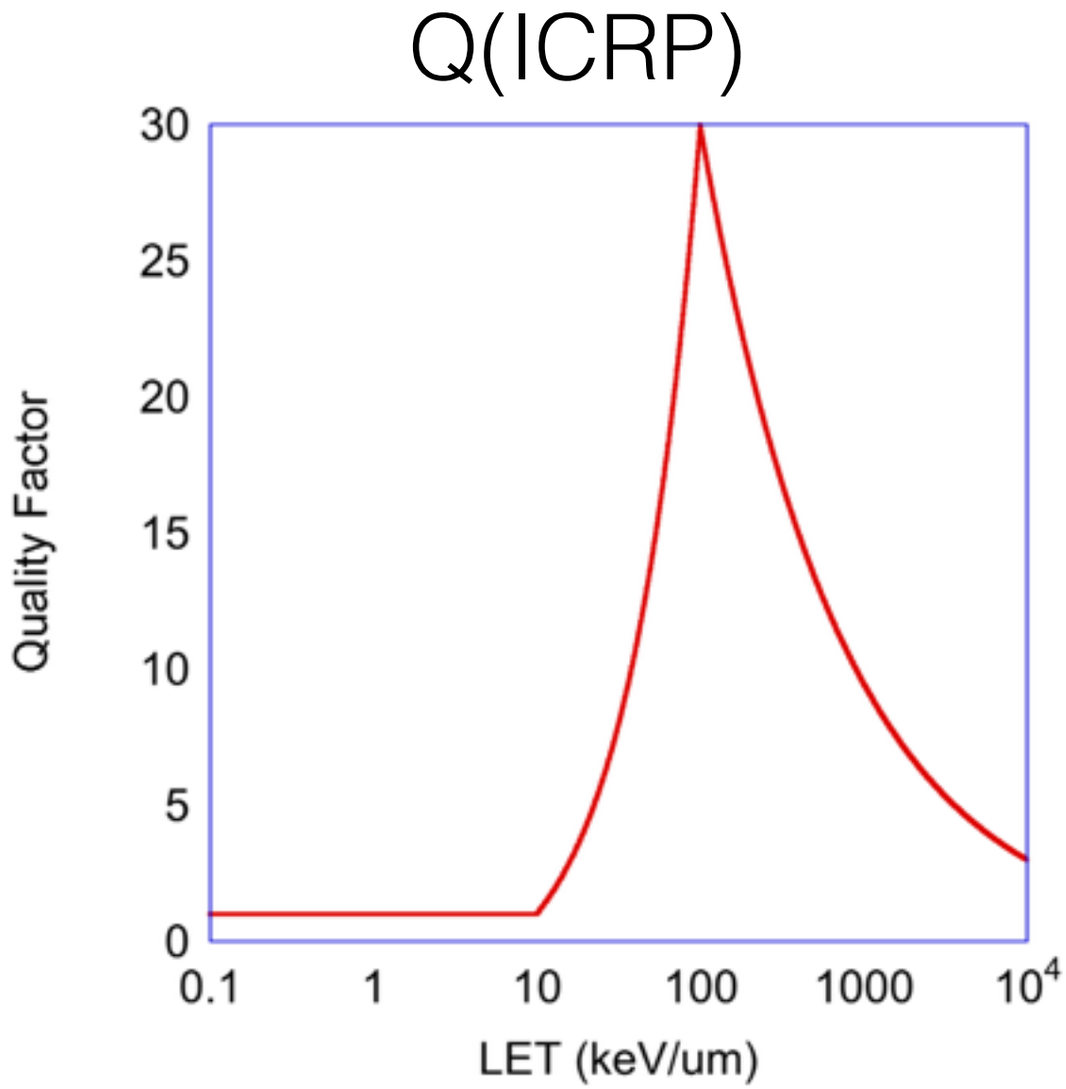


Average LET, REM 5001 (Columbia Module) - Jan-June 2014



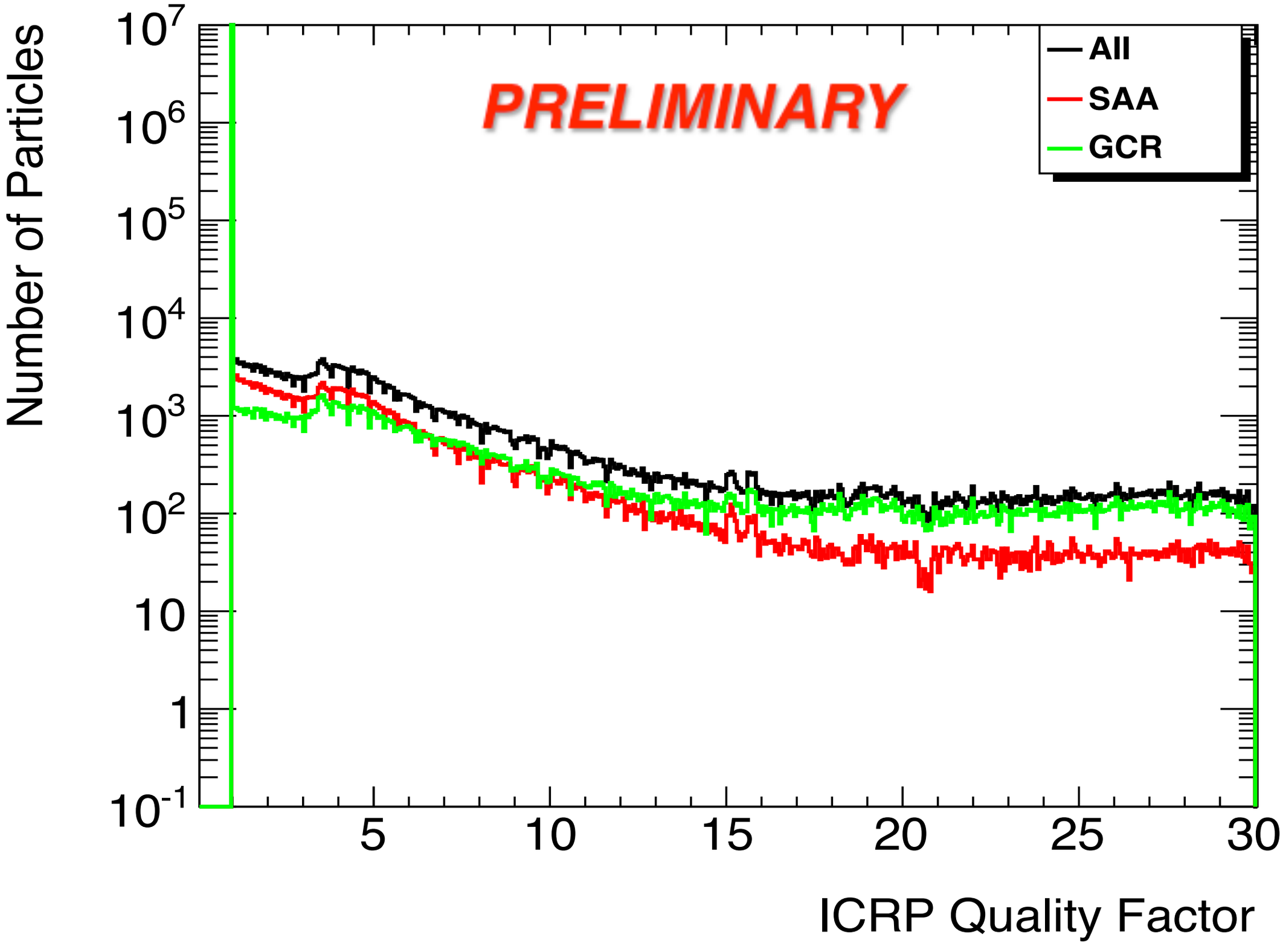
Biological Relevance - Q Factor

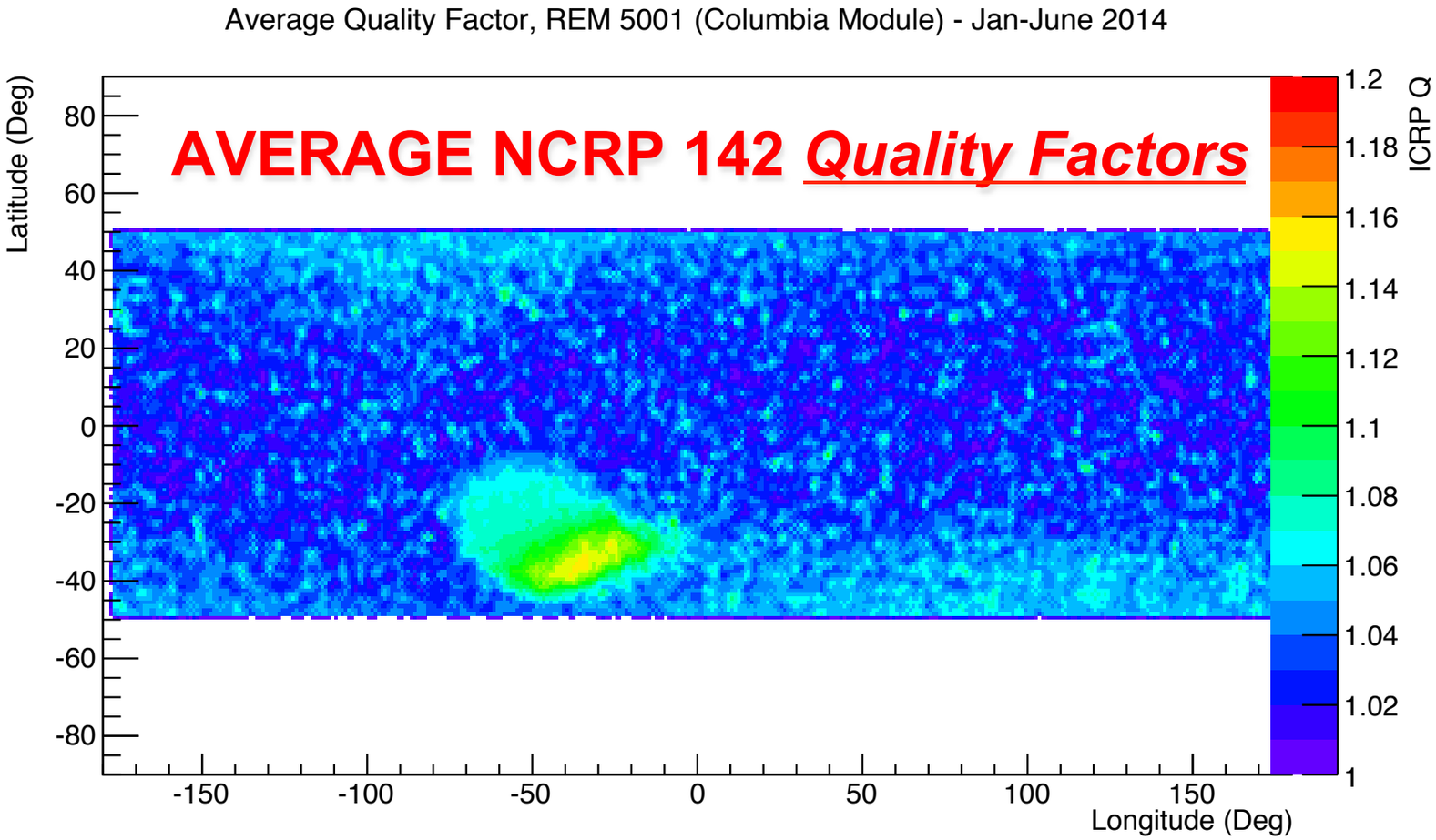
- Identify the dE/dx of the particle and apply a correction to tissue.
- Apply quality factor to the radiation based on dE/dx
- Heavy ions quality factors a matter of discussion
- Use d-Ray spectrum to identify ion charge



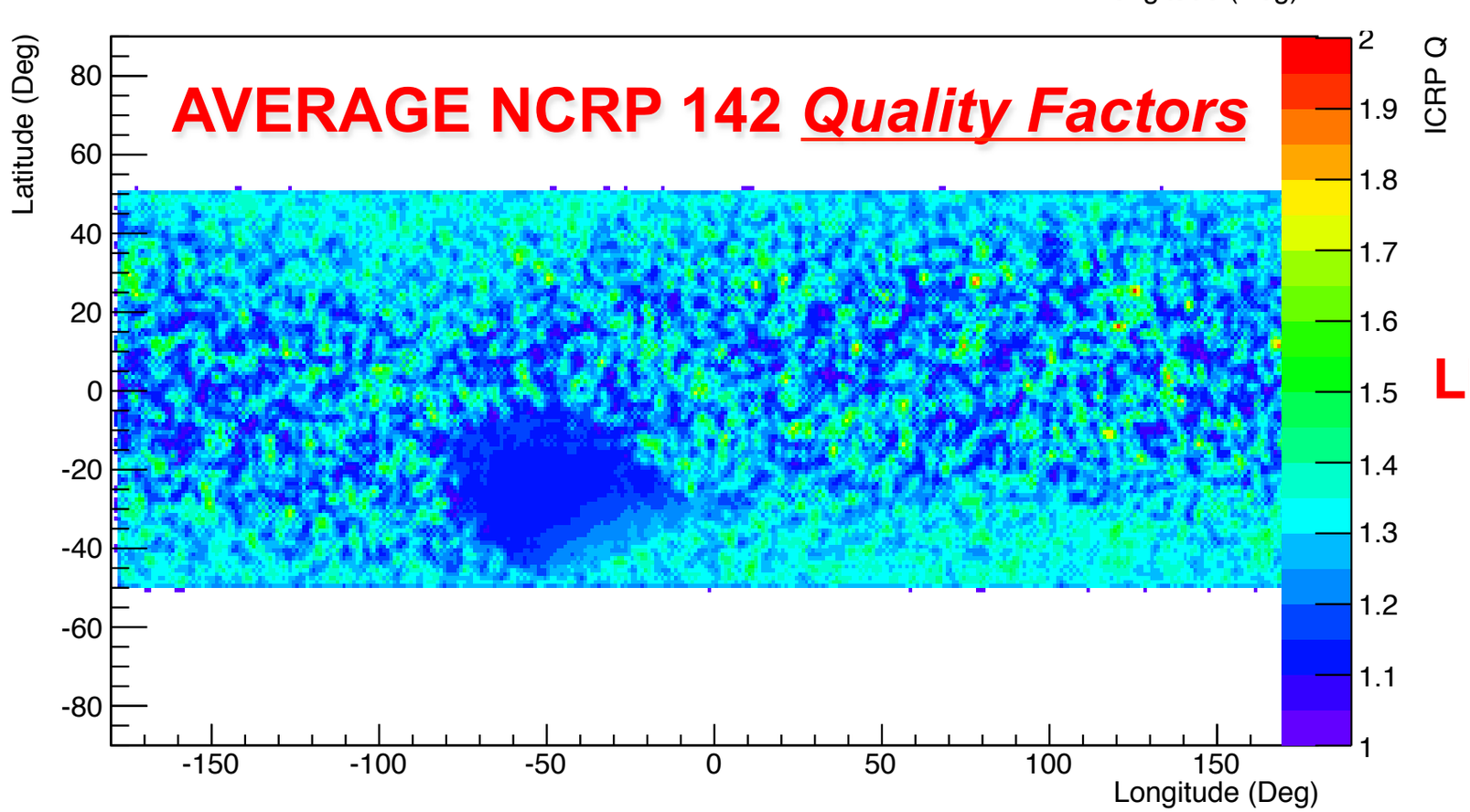
$$Q\,(\mathrm{NASA}) \propto \frac{z^2}{\beta^2}$$

Average Quality Factors





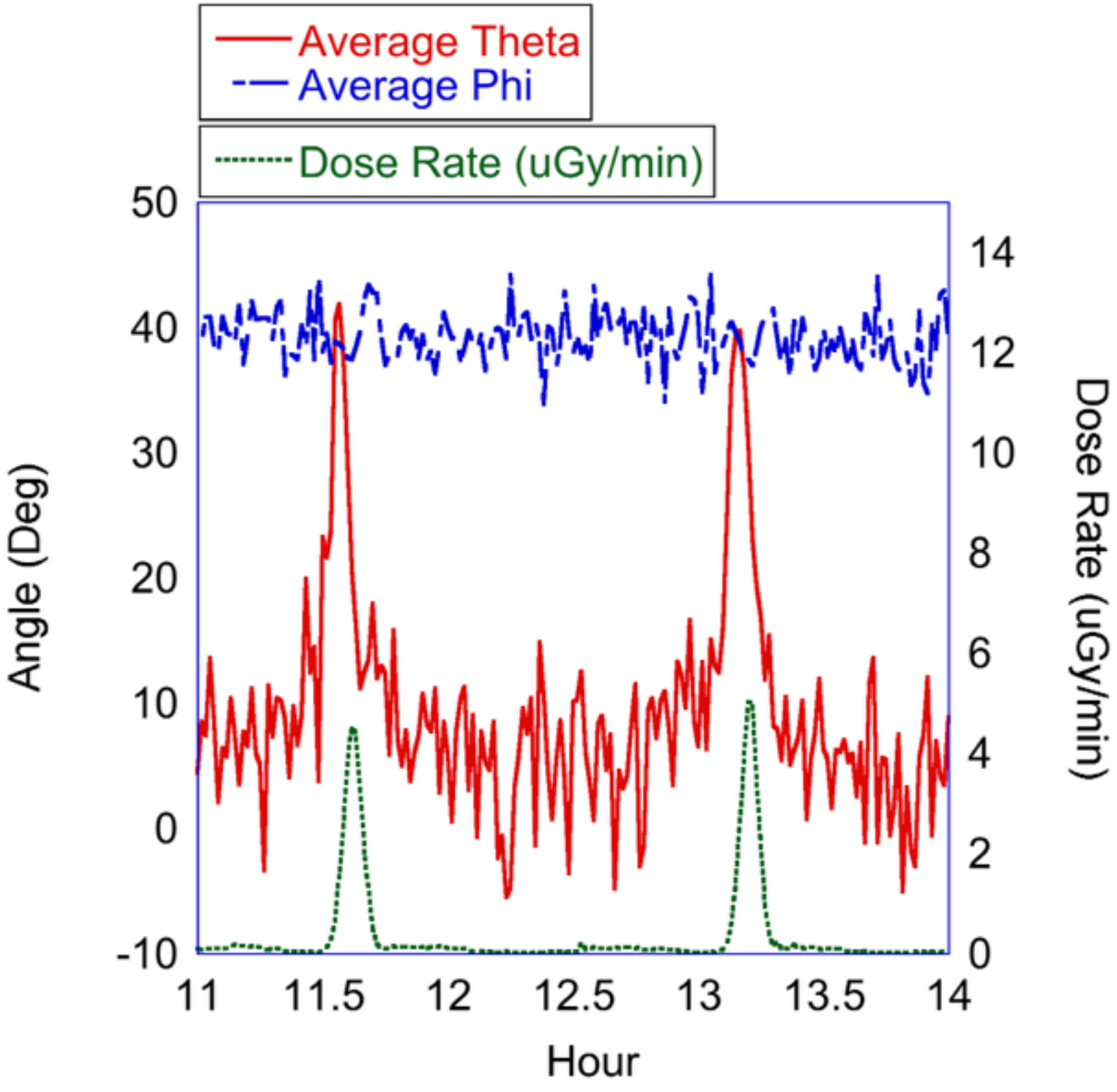
All Protons & Z > 1 Charged Particles



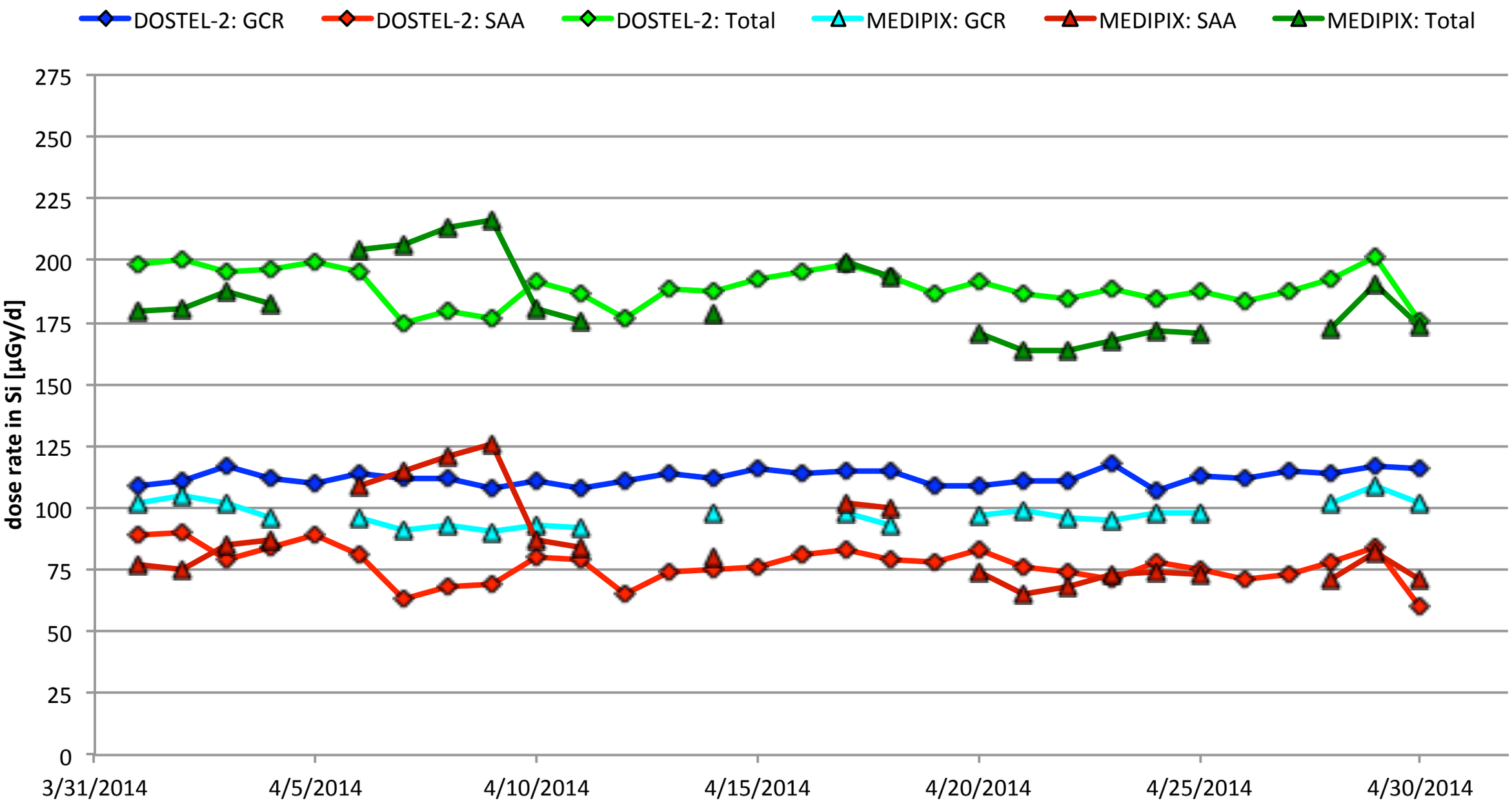
LET > 1 KeV/μm Cut

One Pass, April 1st 2014

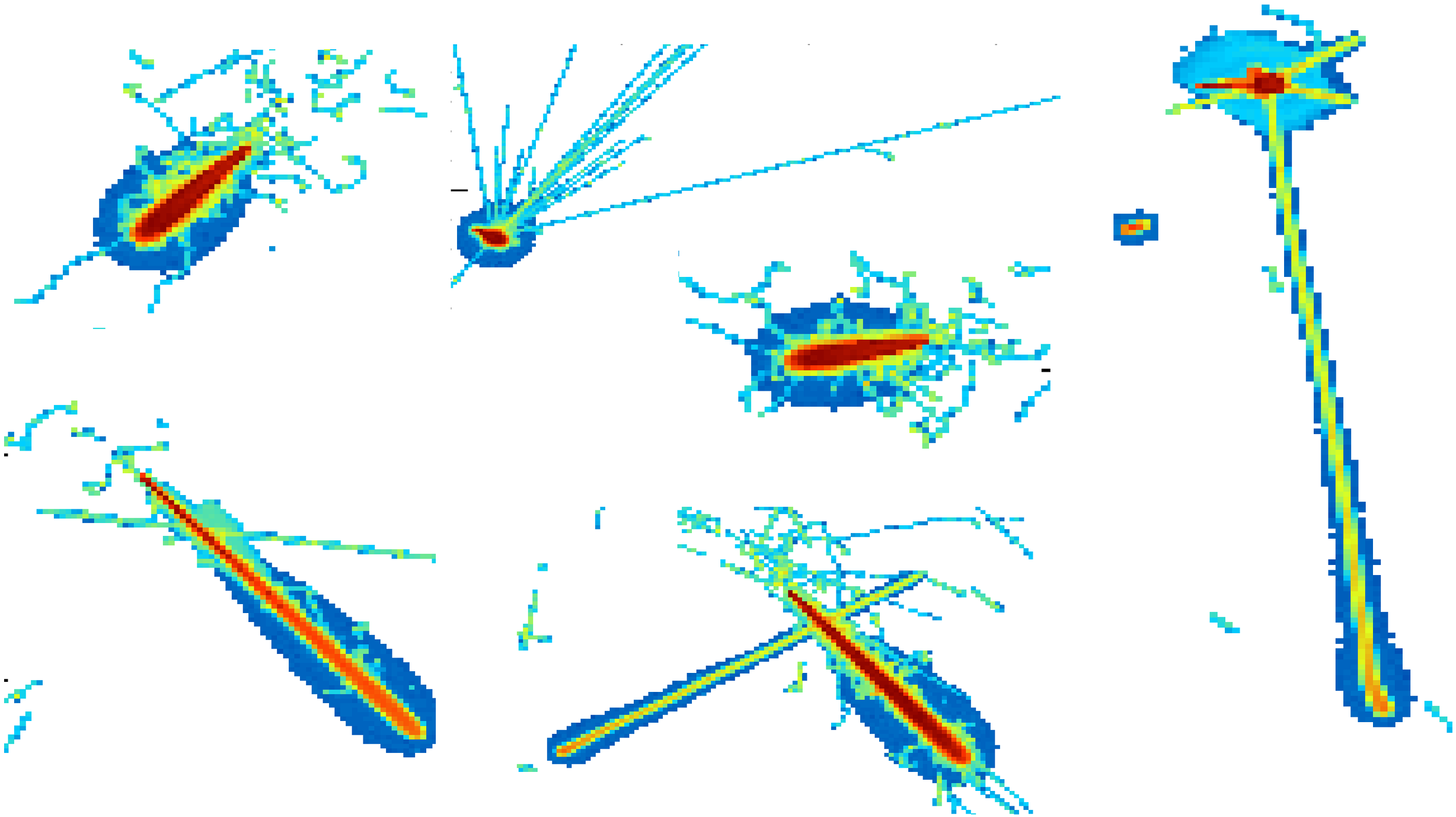
- SAA associated with change in average angle
- Average theta for GCR (~5 degrees) - offset
- Average GCR phi 40 degrees) - should be 45



Comparison to DOSTEL



Space Particle Zoo



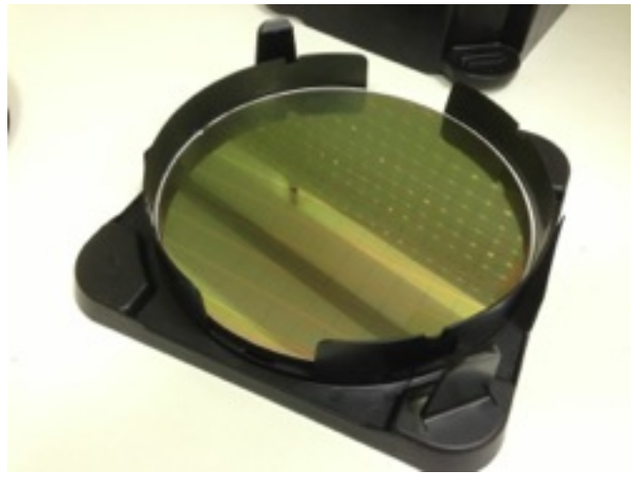
The Timepix - a quick intro

- The timepix asic consists of 256 x 256 CMOS pixels each measuring 55 x 55 um.

- Each pixel can either measure charge deposited or do single particle counting.

- The detection threshold is about 1000 electrons

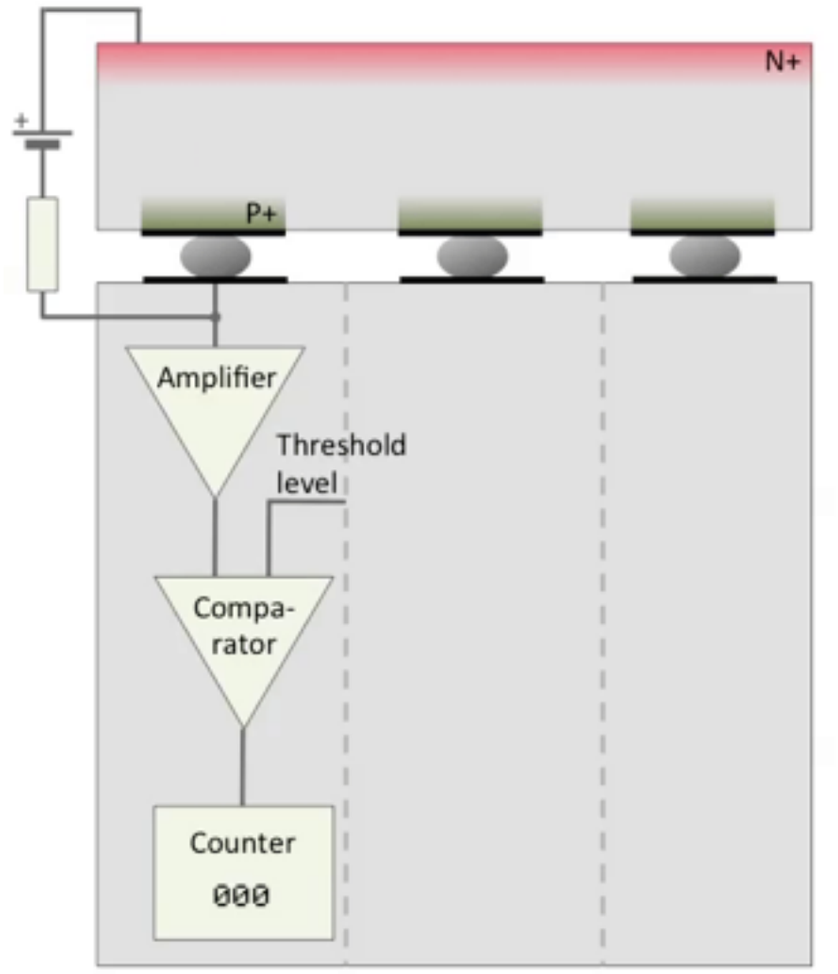
- We use a quad configuration of 512x512 pixels for a total of 262144

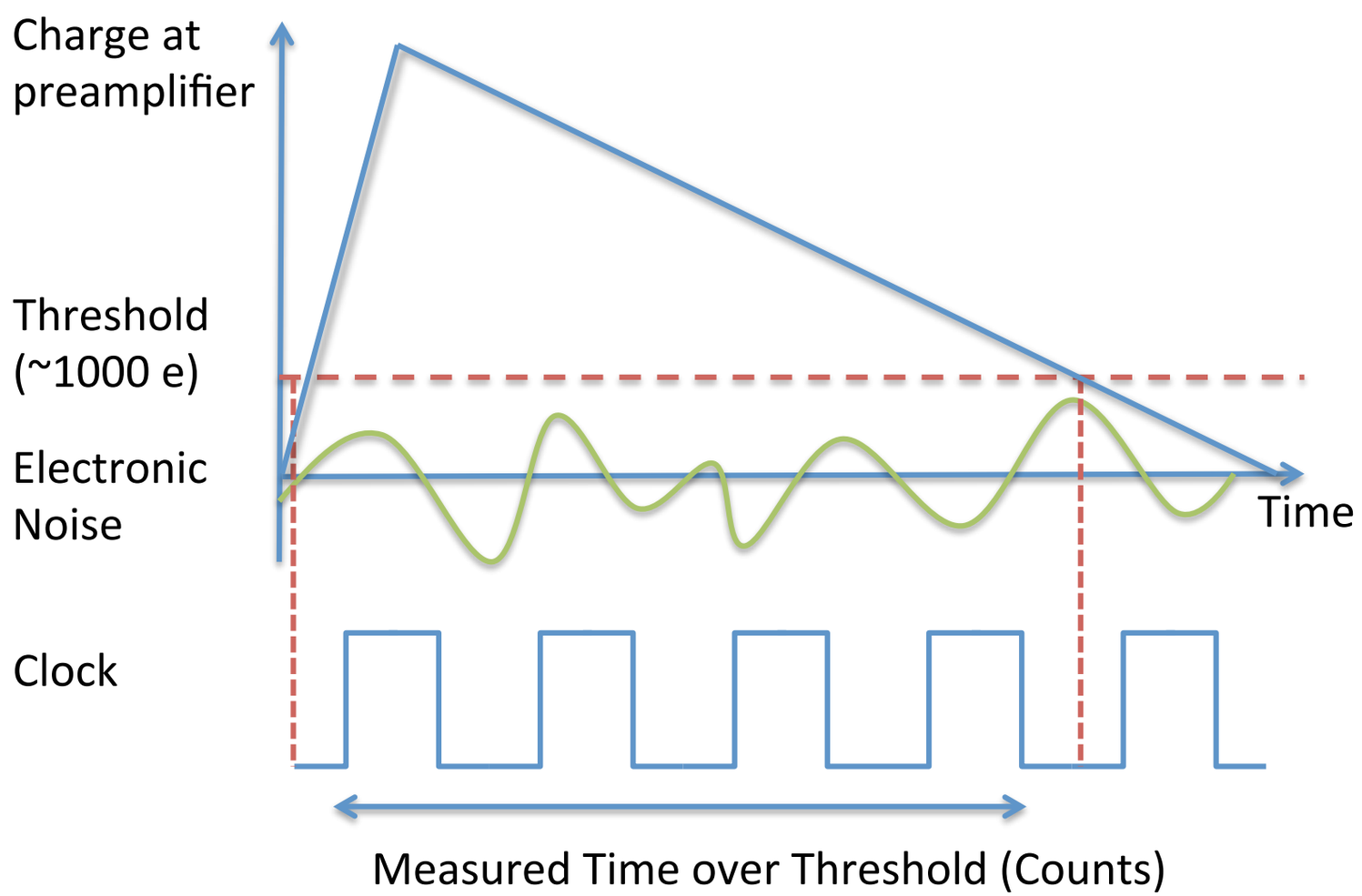


Timepix ASIC Wafer

Timepix mounted on CERN probe card

Timepix pixel

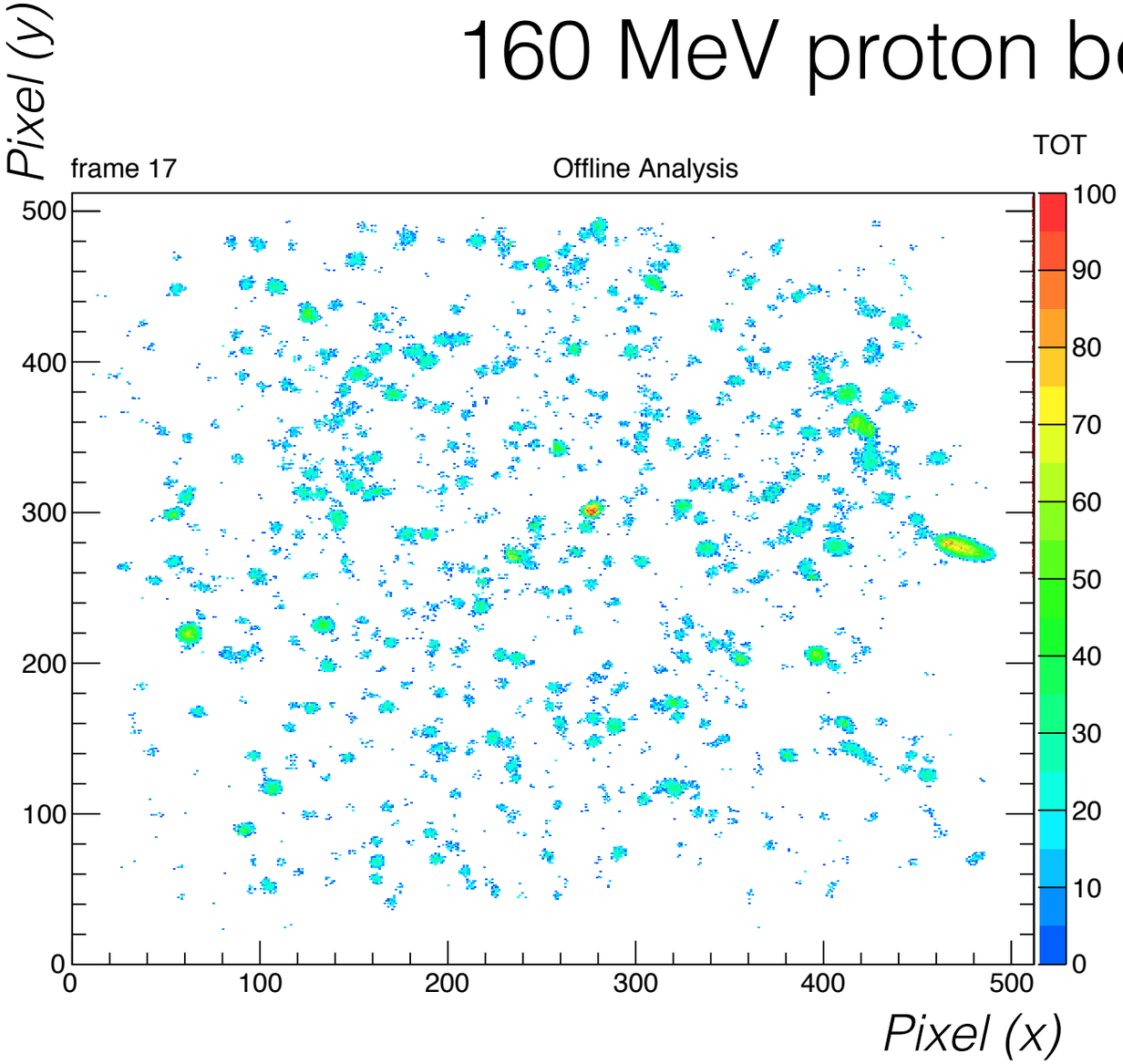




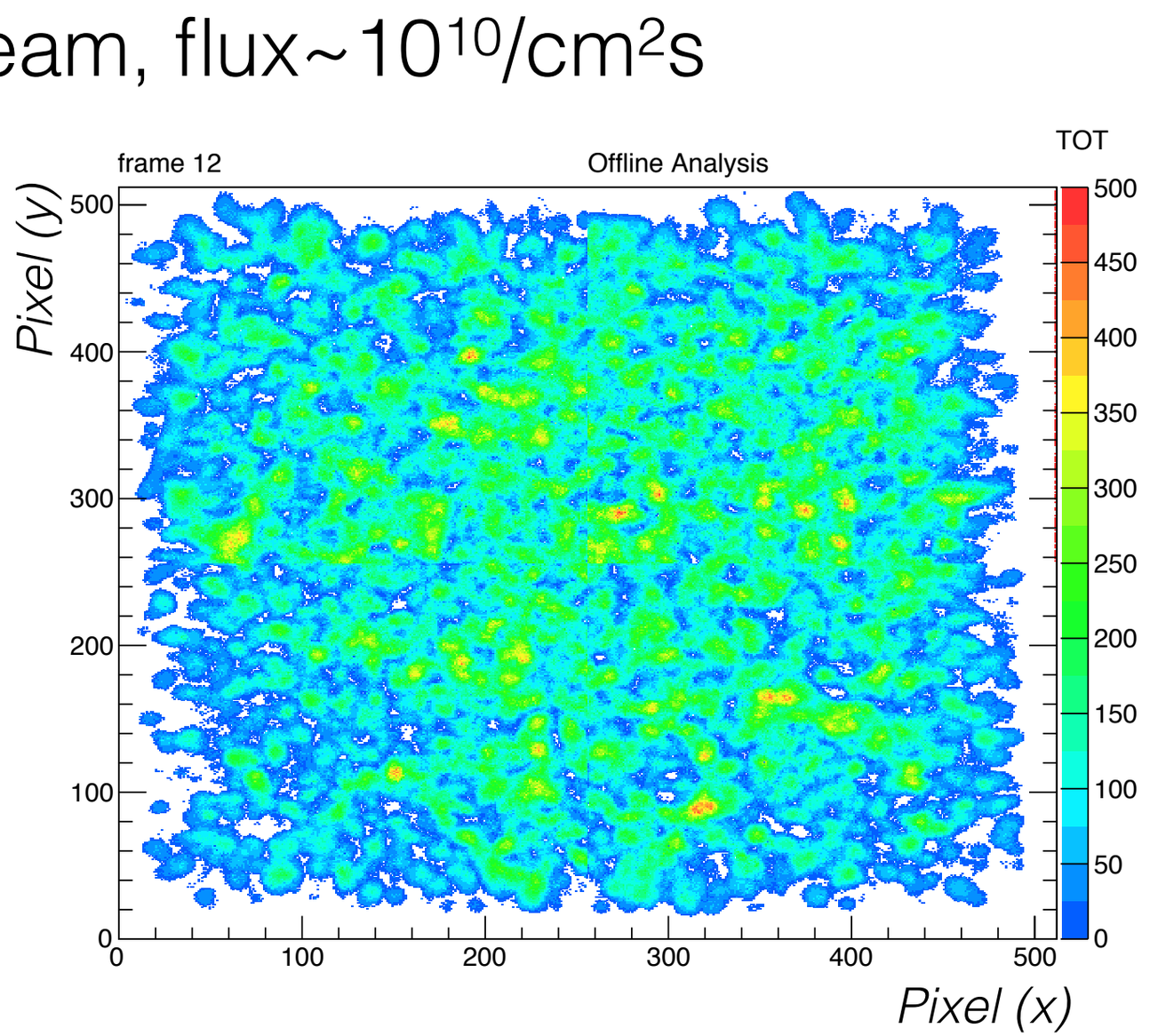
Medipix mode - Hi->Low = 1 ct
TOT mode - Count during Hi->Low interval
Timepix Mode - Count from Low till end of acquisition

Proton Beam at Different Gains

160 MeV proton beam, flux~10^{10}/cm^{2}s

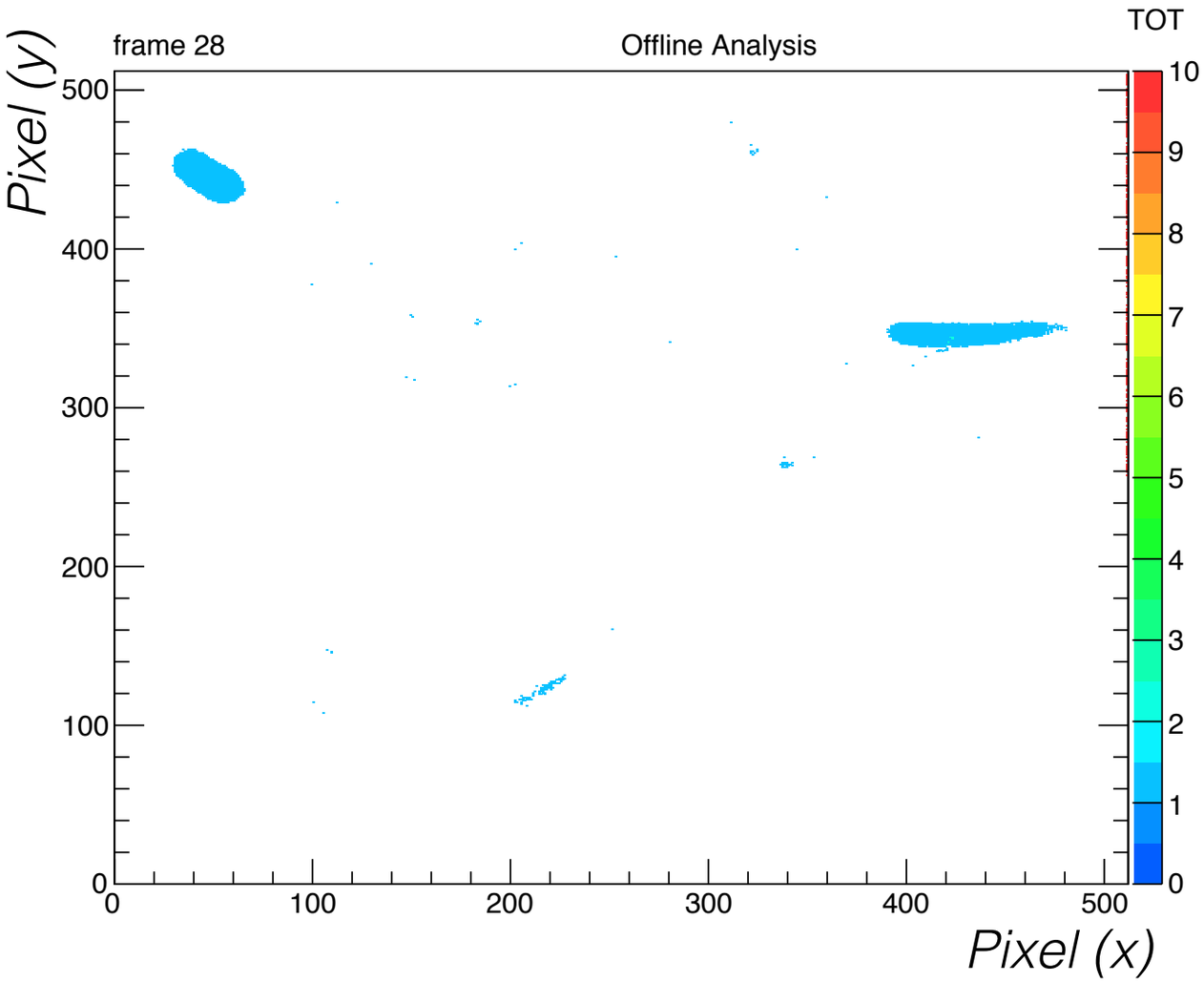


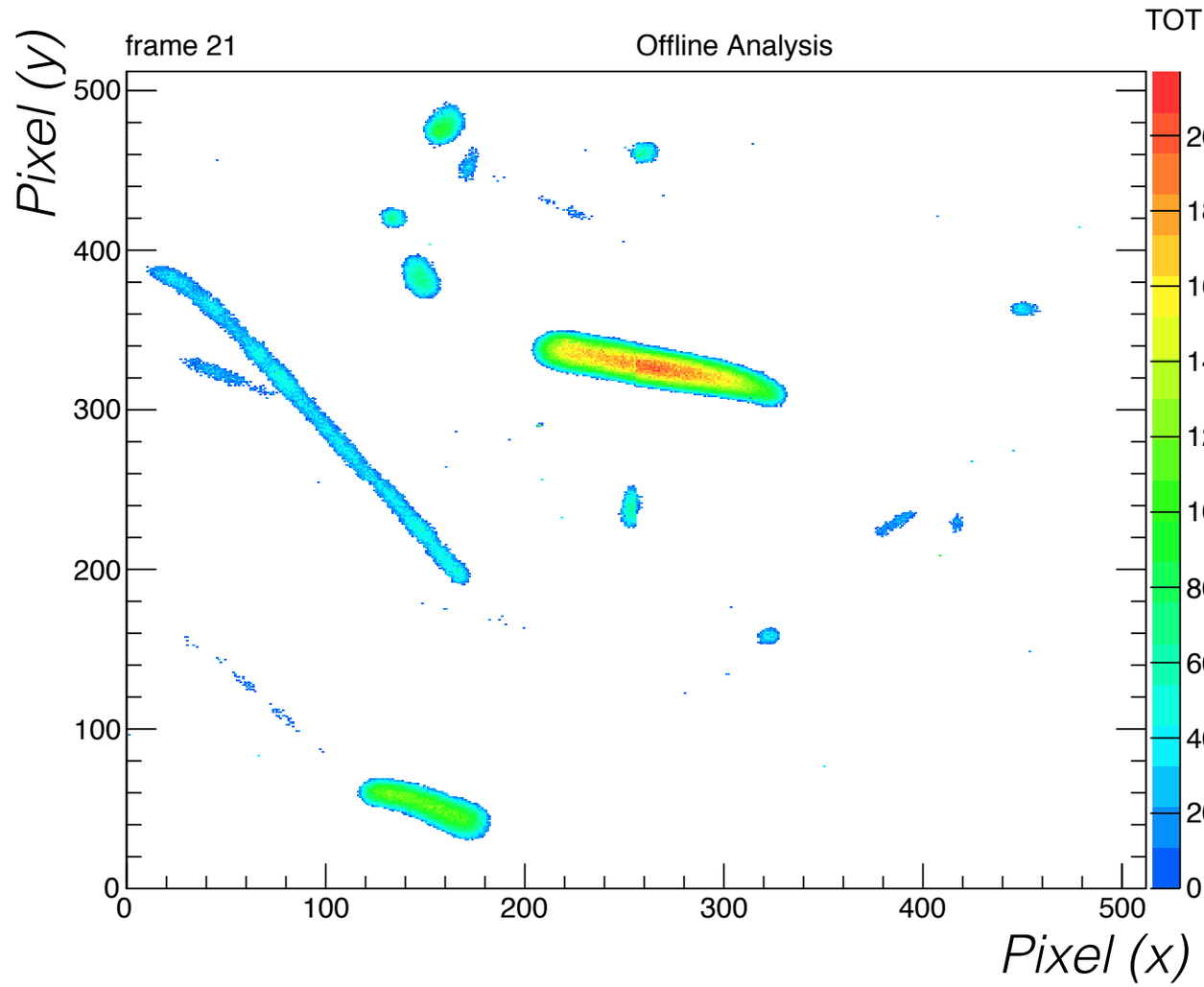
Gain 930 - 0.001s frame



Gain 990 - 0.001s frame

Proton Beam at Different Gains



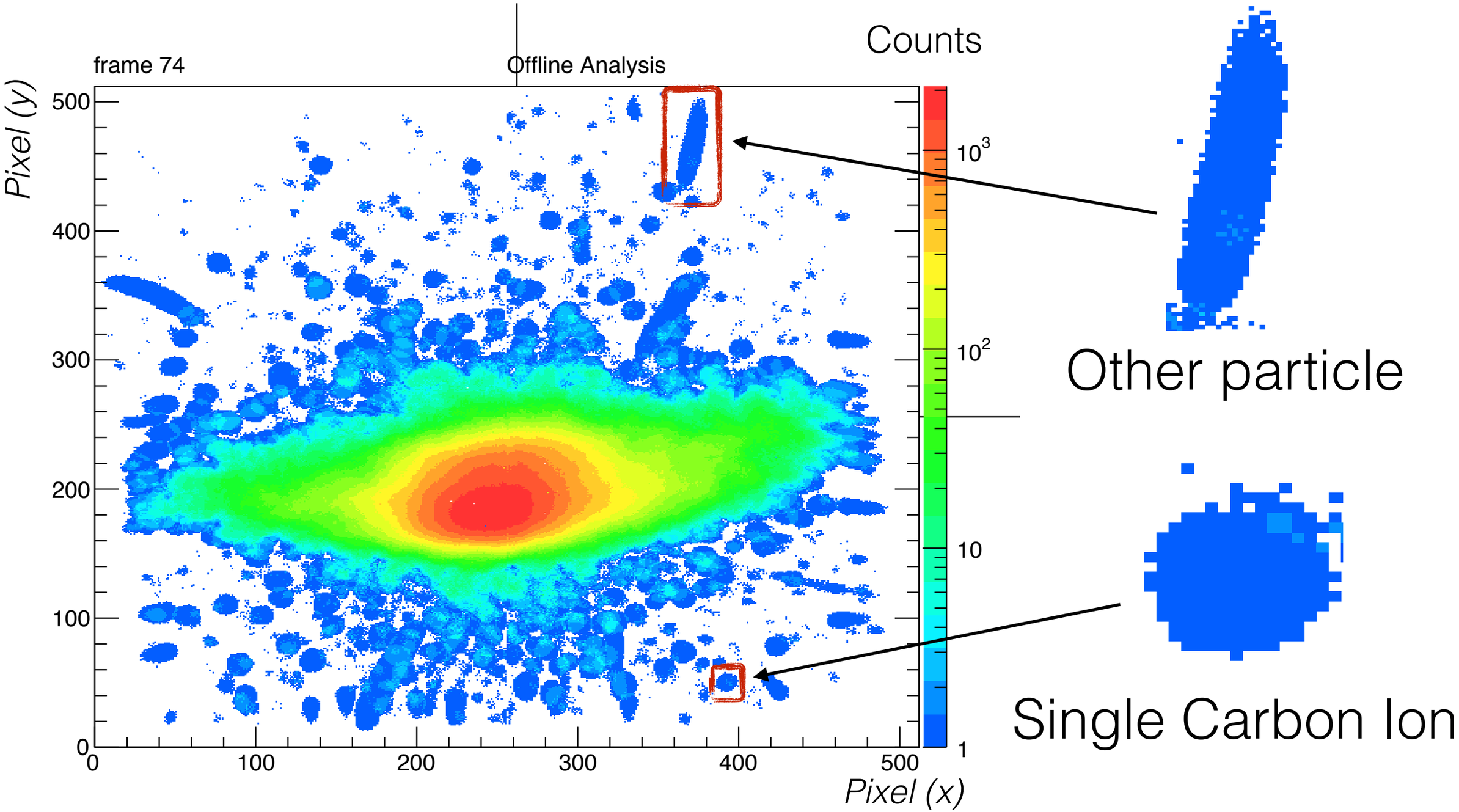


Gain 900 - 0.001s frame

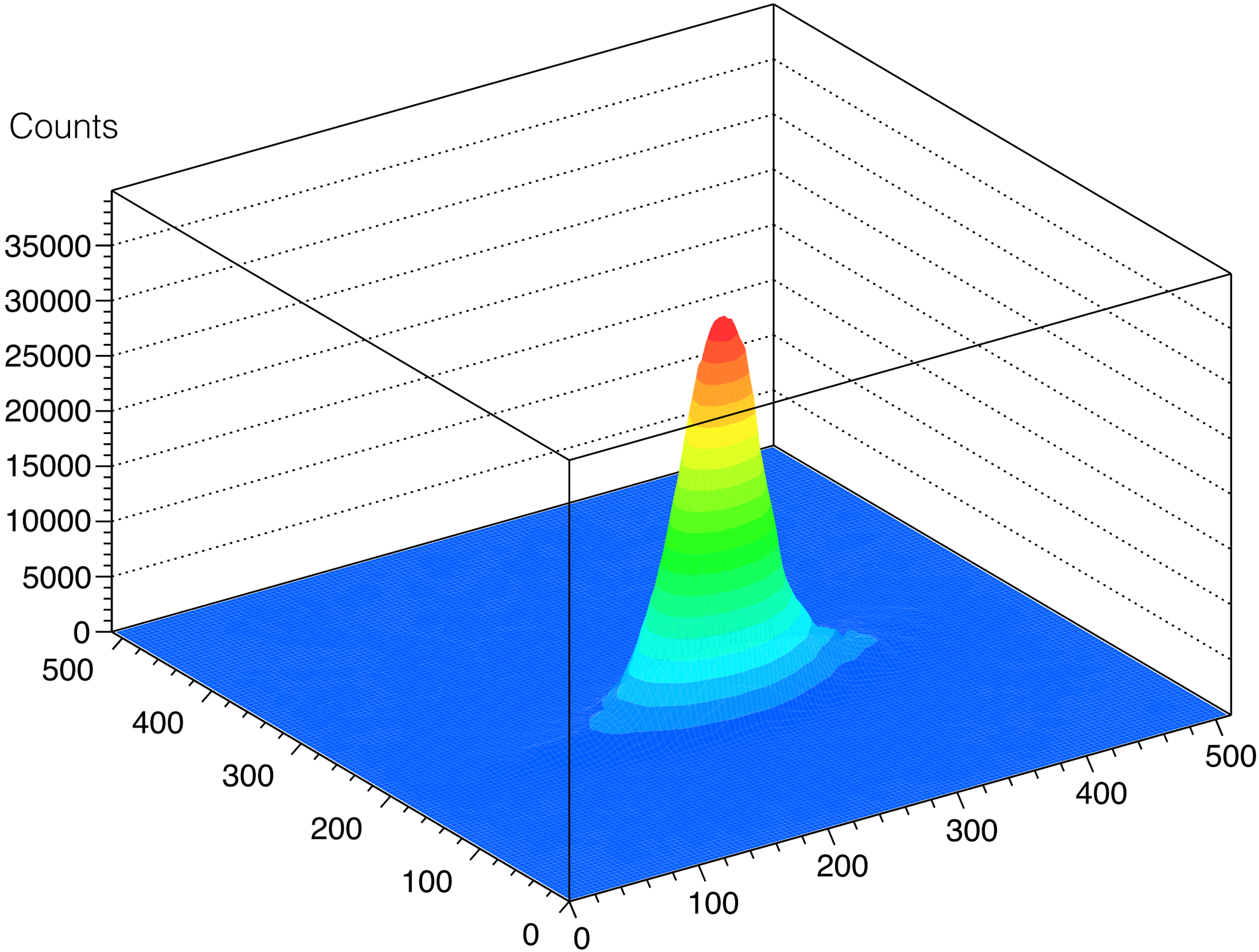
Gain 870 - 1s frame

The gain can be used to set a minimum ‘threshold’ on the per particle dE/dx - measurements of unusual events

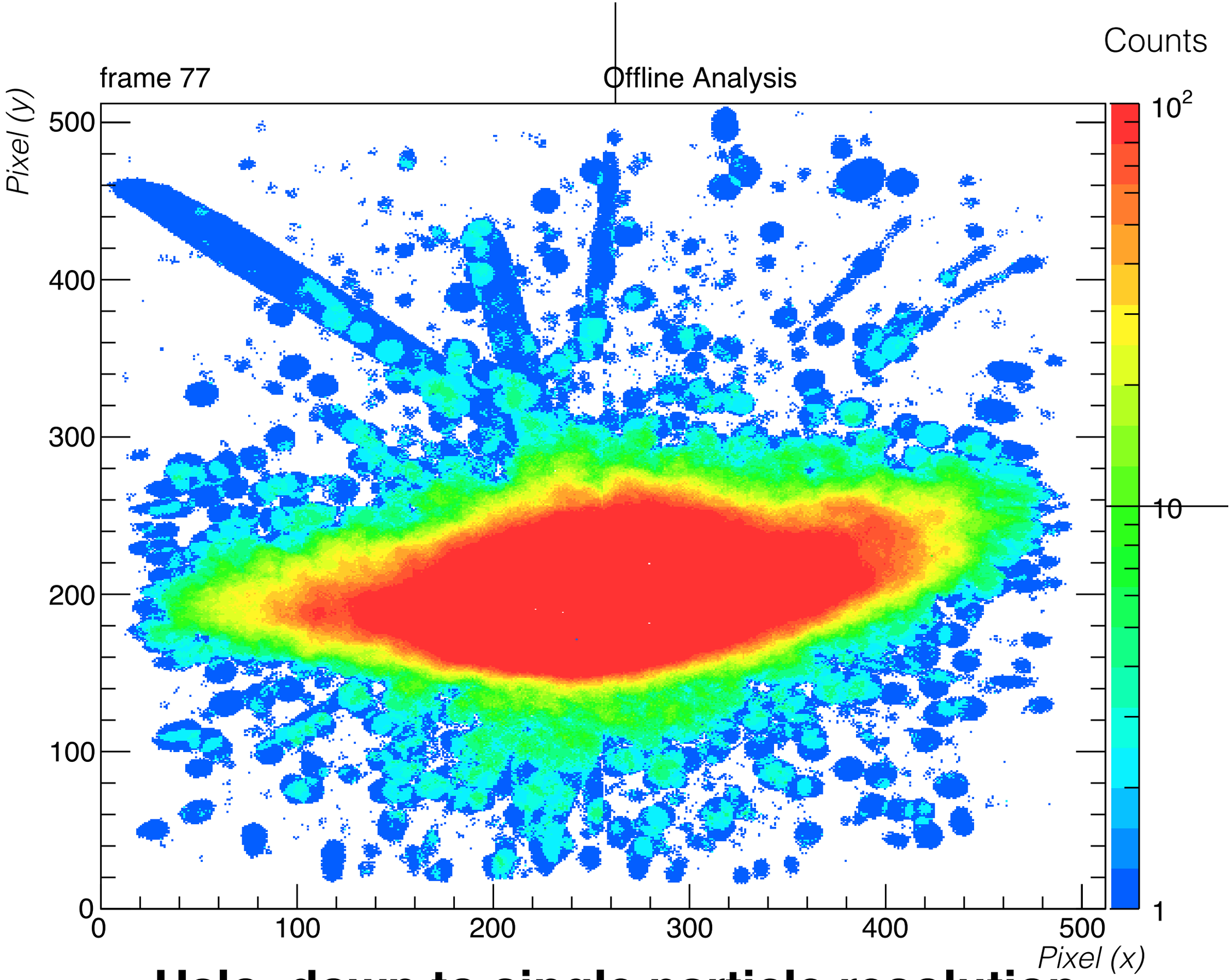
Gempix as a Beam Monitor



480 MeV/A carbon ions, 0.01s frame, **ASIC in particle counting (medipix) mode**, IKrum = 5



Overall beam shape



Halo, down to single particle resolution

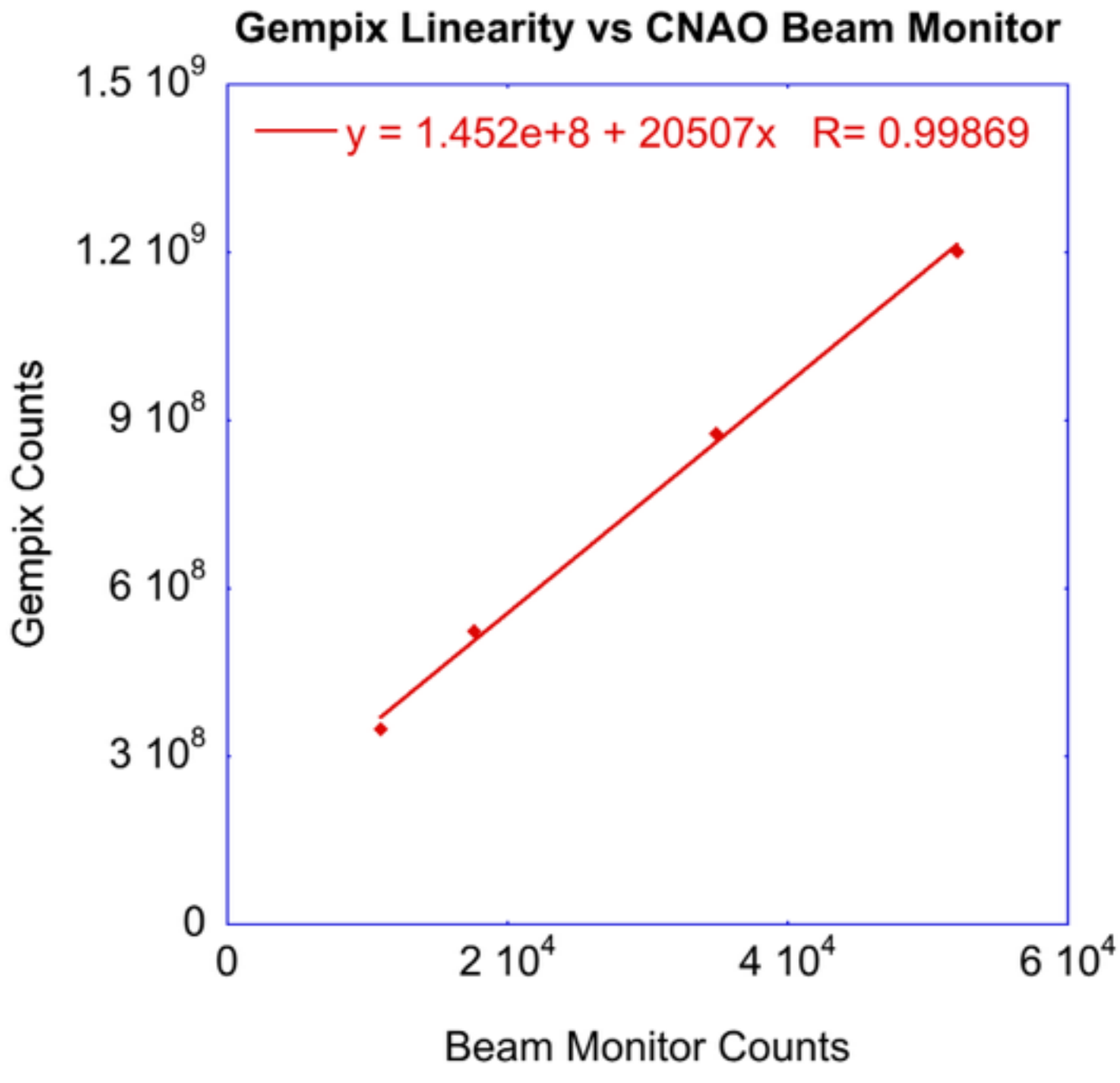
Detector Linearity

90s measurement, 1s spill, spill every 5 seconds

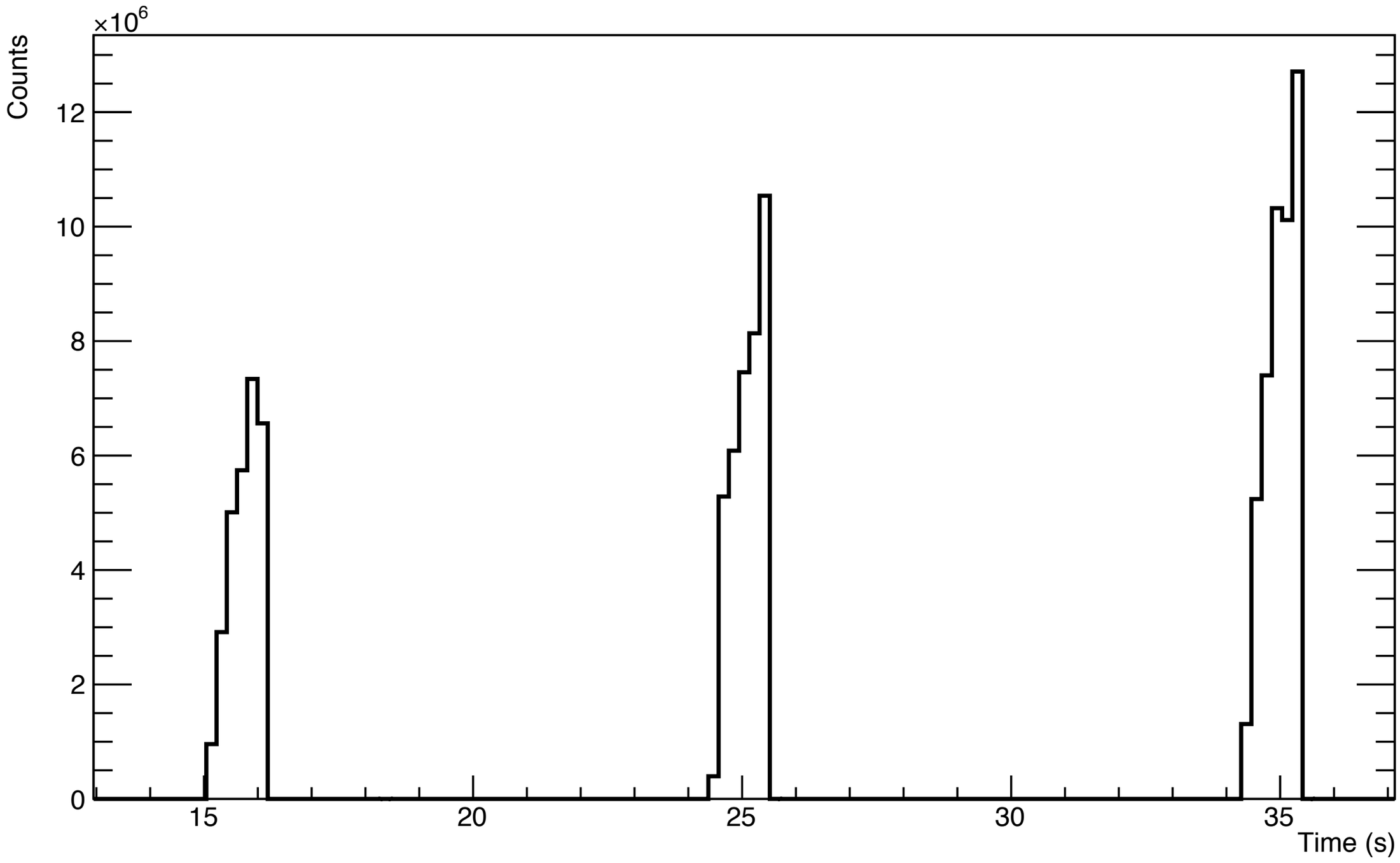
Counts are the integral over the total 90s period

Number of ions is the counts/average carbon cluster size (~130 pixels)

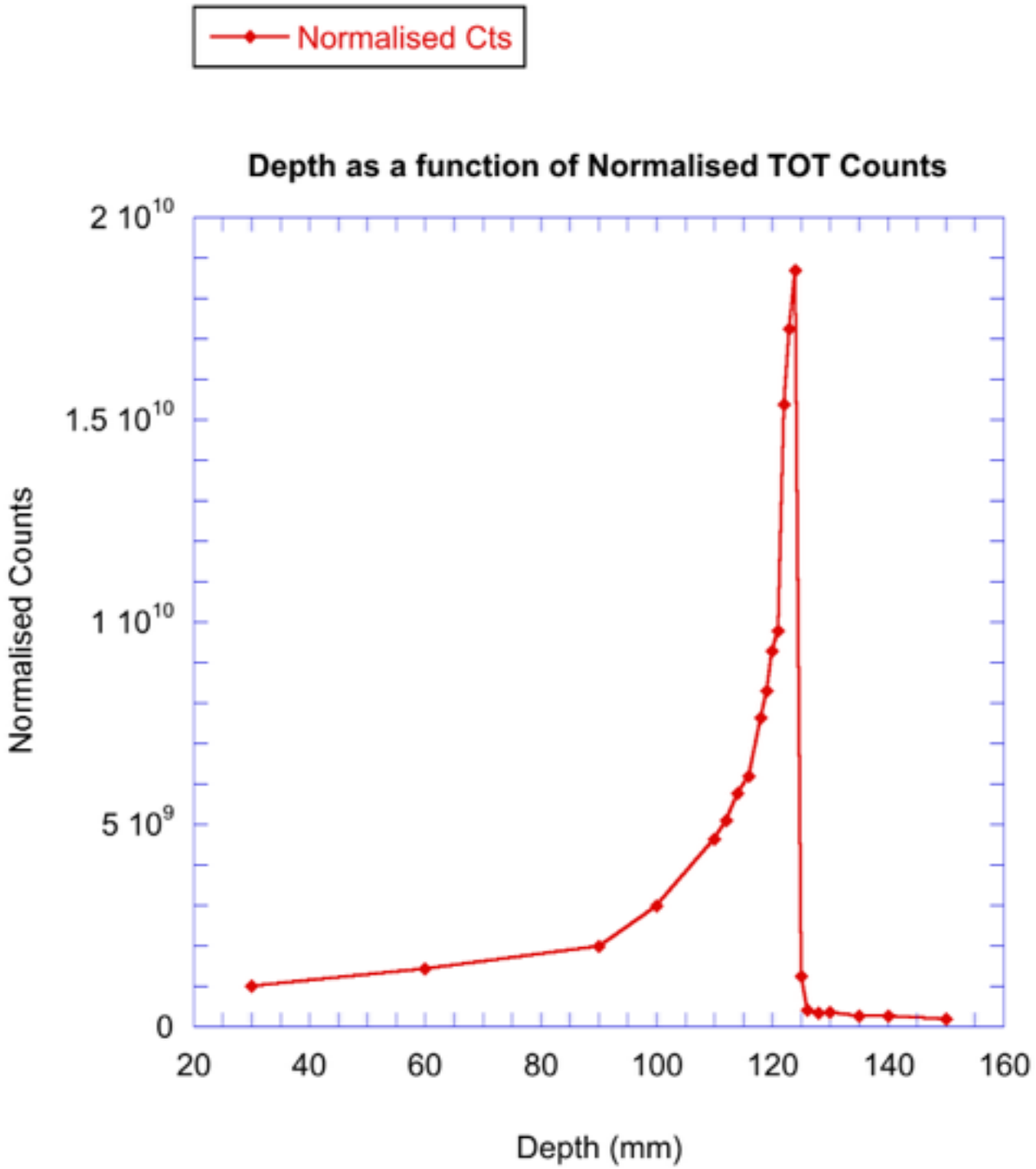
(Dead time is significant however ~1/10)



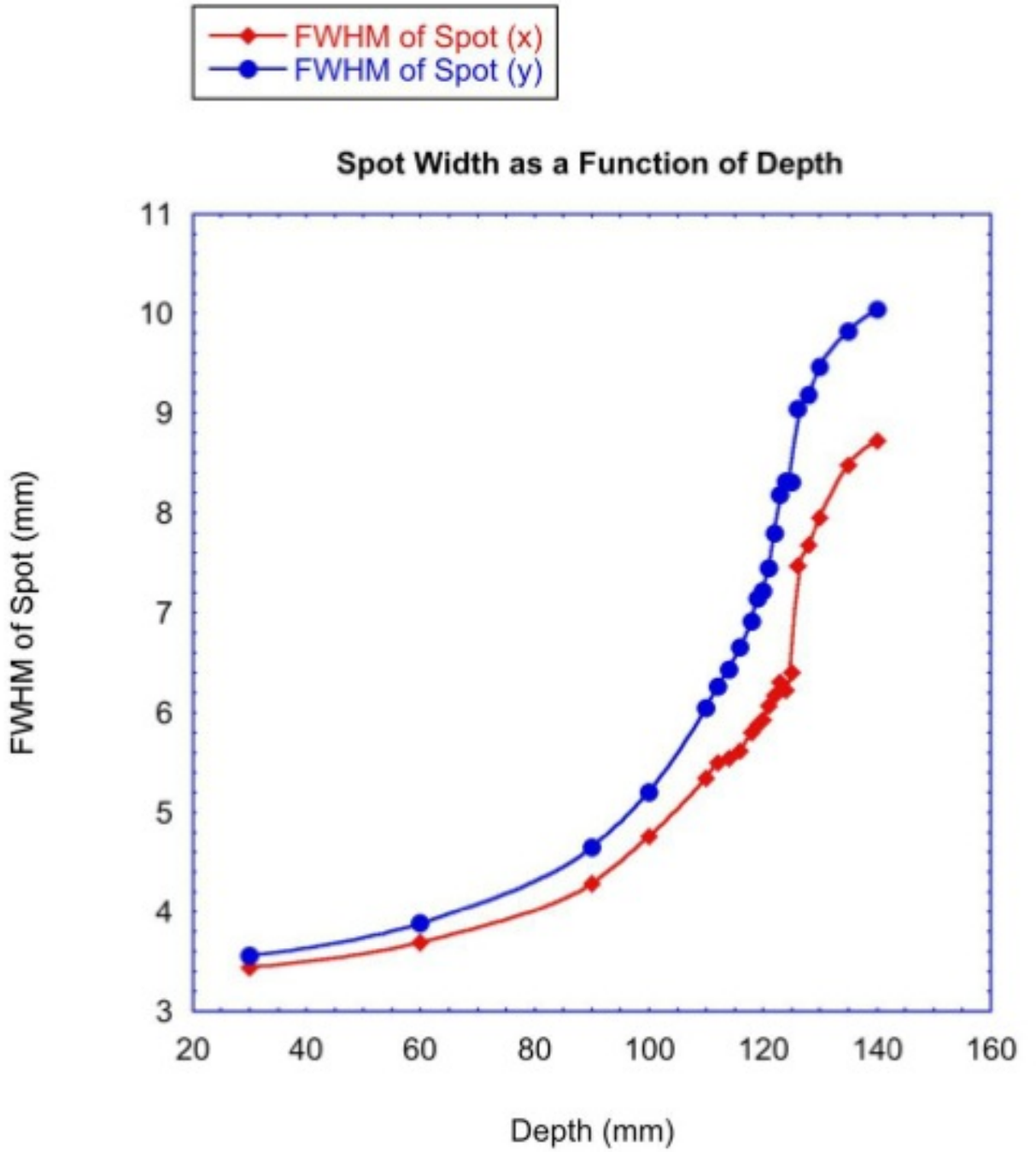
Time Profile of Particle Spill



Results - Bulk



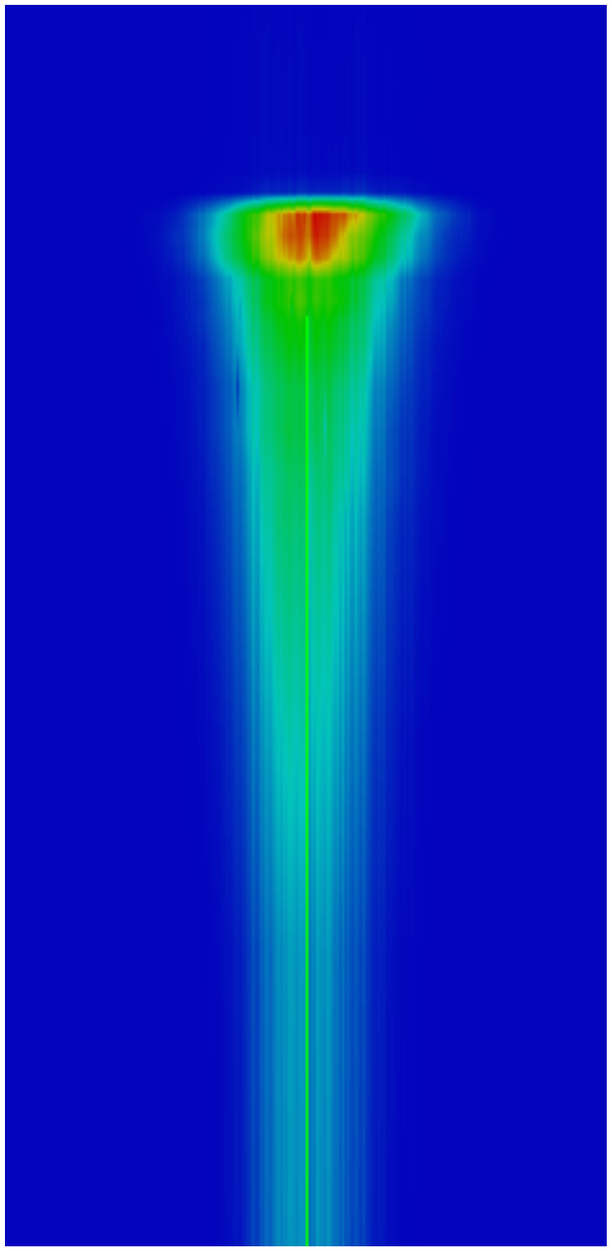
Energy deposition is 0.43 keV/TOT



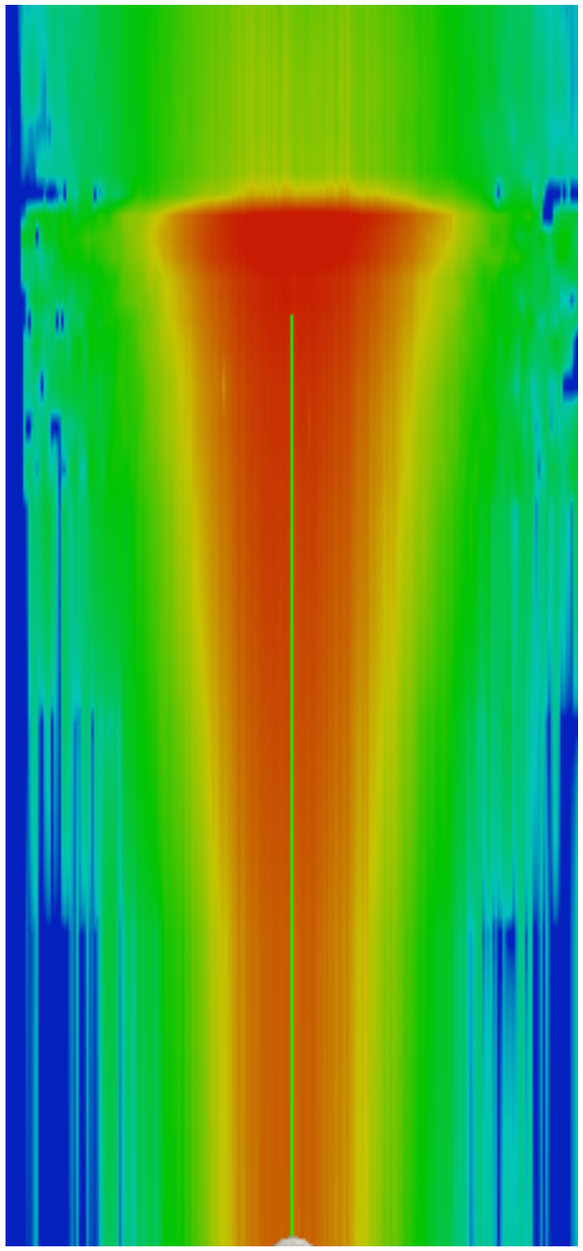
Spot width here is sigma of gaussian (FWHM = 2.3 sigma)

Reconstructed Dataset

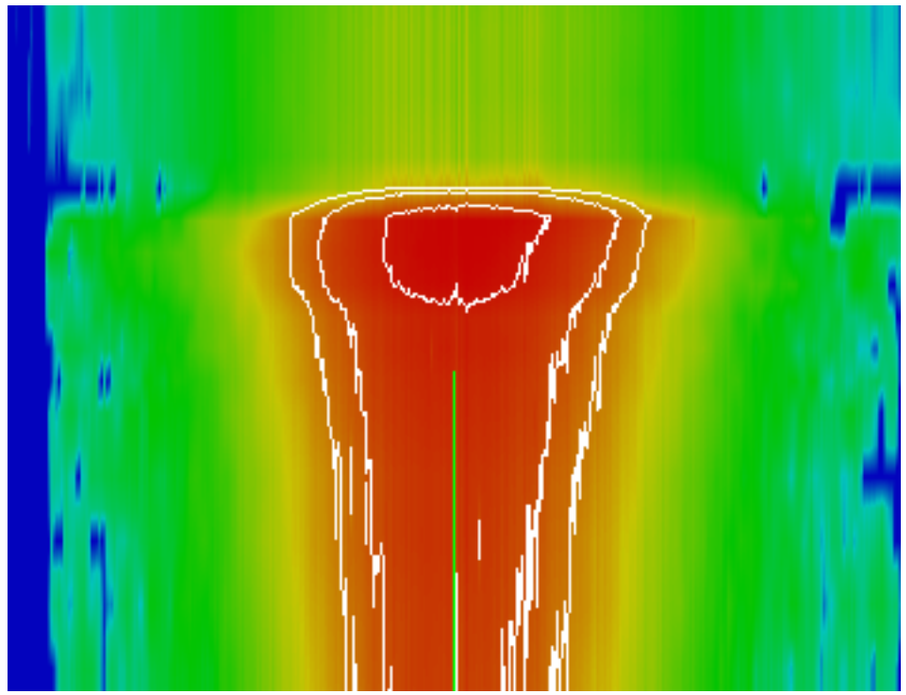
Depth in Water



Linear

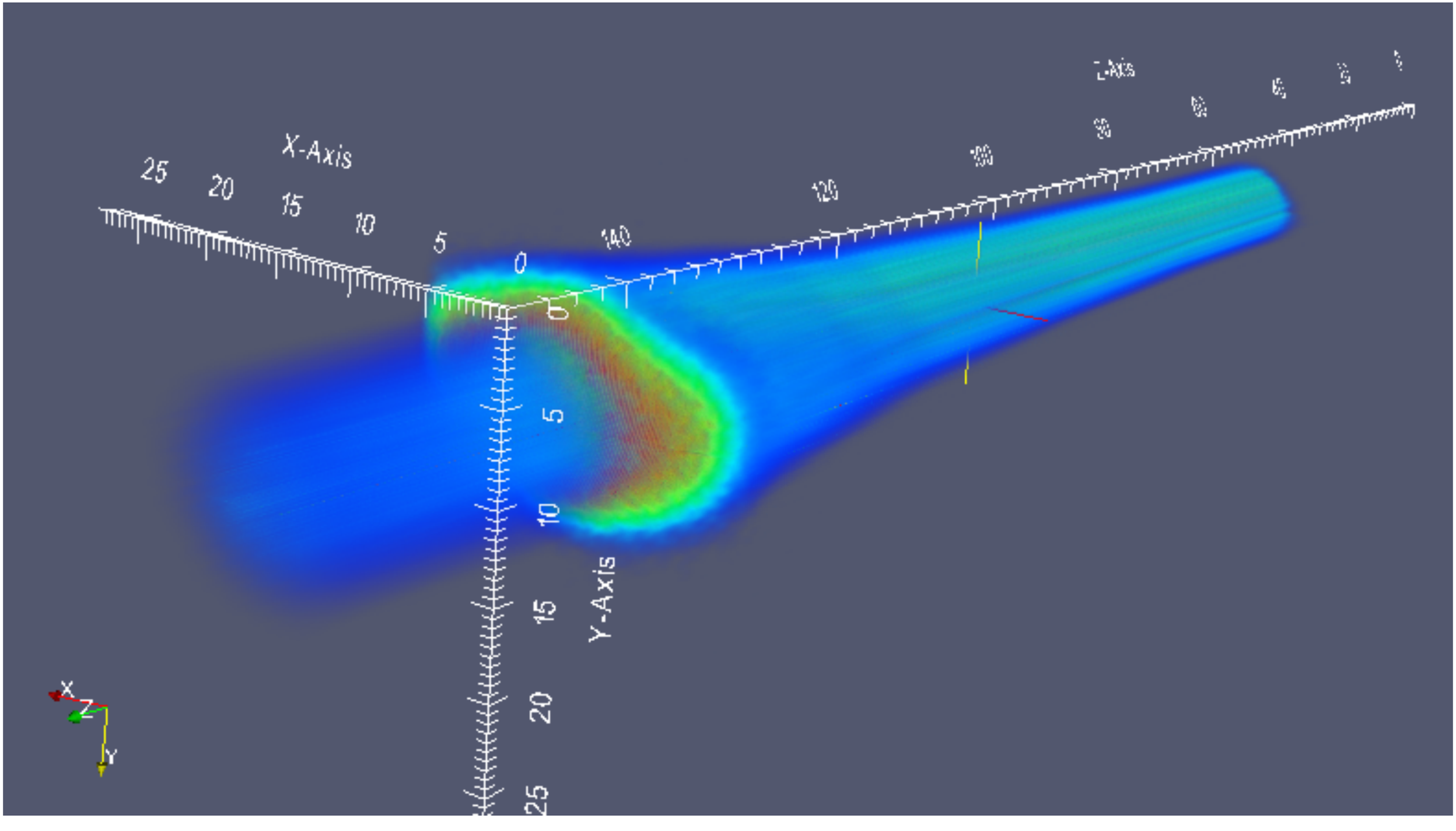


Log



Log with log spaced contours/isodose (3)

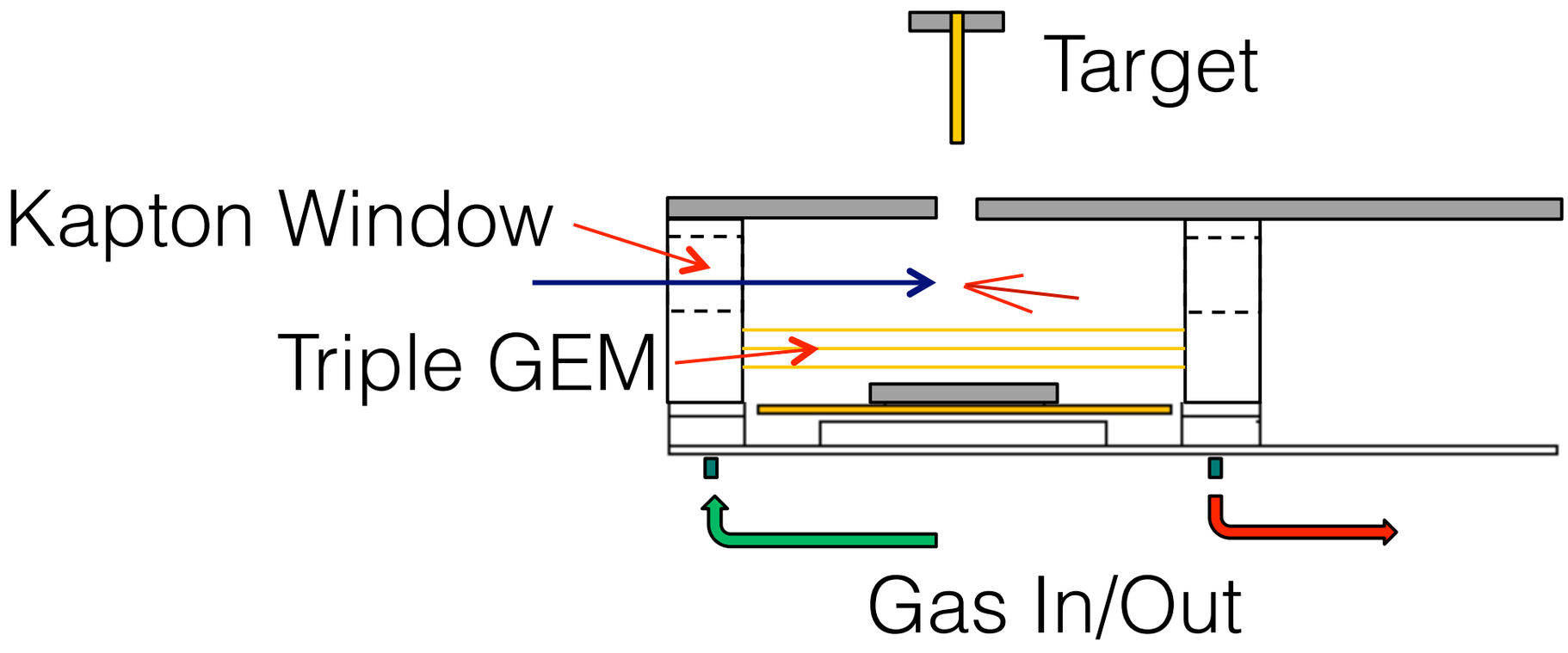
Reconstructed Dataset



Beam enters from right, carbon fragmentation tail on left

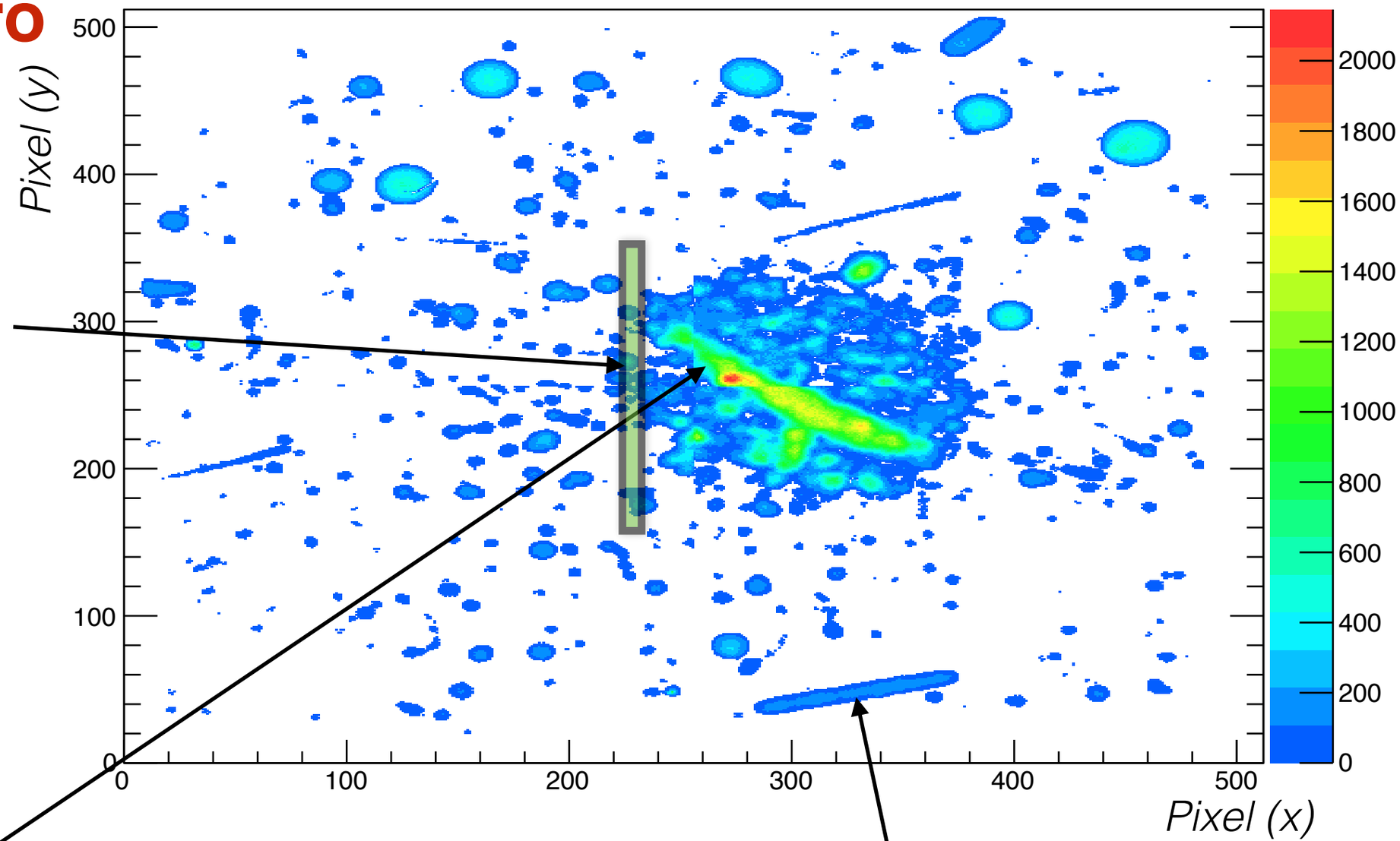
Towards Microdosimitery

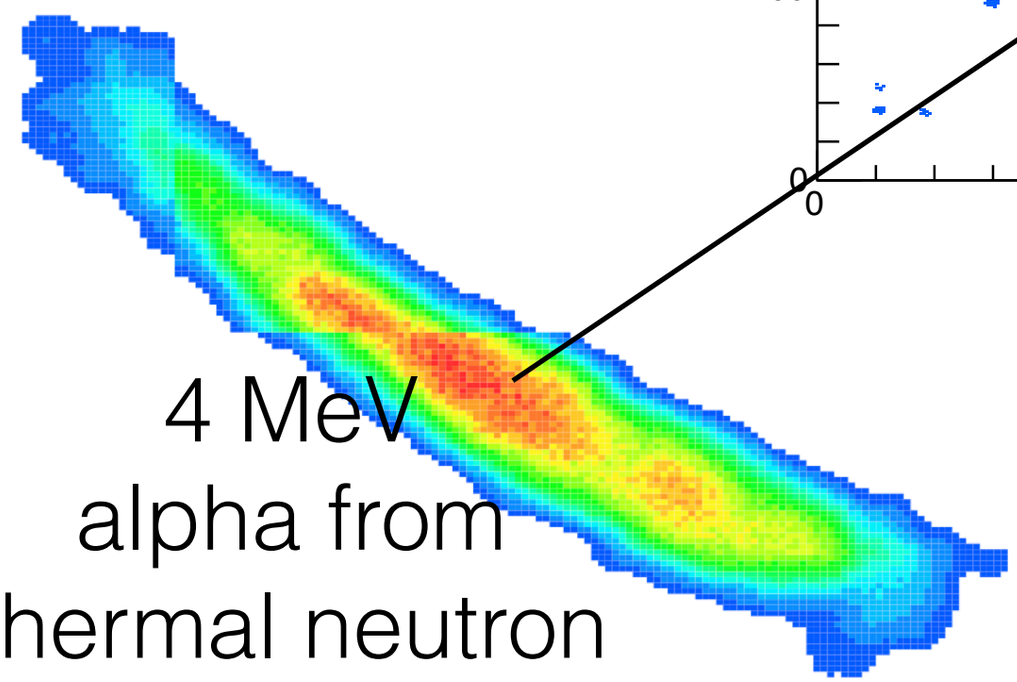
- A microdosimiter measures energy transfer over a site size of *biological interest*
- Typically a cellular volume = 1um
- For a propane tissue equivalent gas at STP 1 site ~ 10 pixels
- How do we get a relevant field?



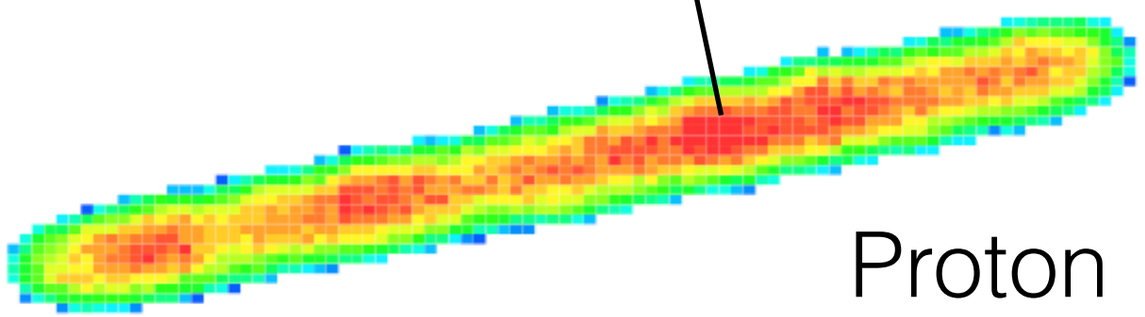
Measurement with mixed neutron field at INFN Legnaro

Enriched Boron 10 Target



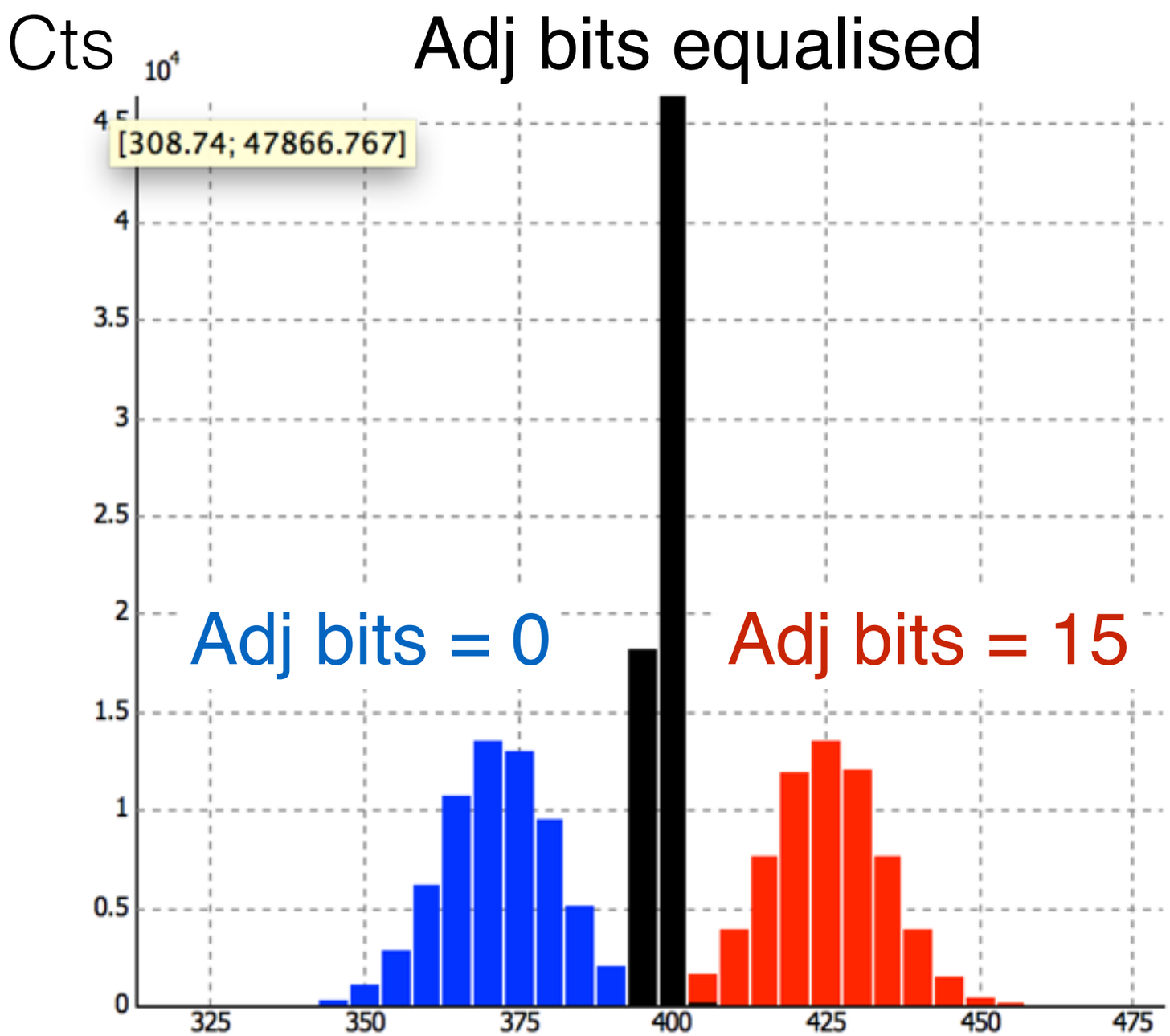


4 MeV alpha from thermal neutron capture in target



Proton Candidate

Threshold equalisation



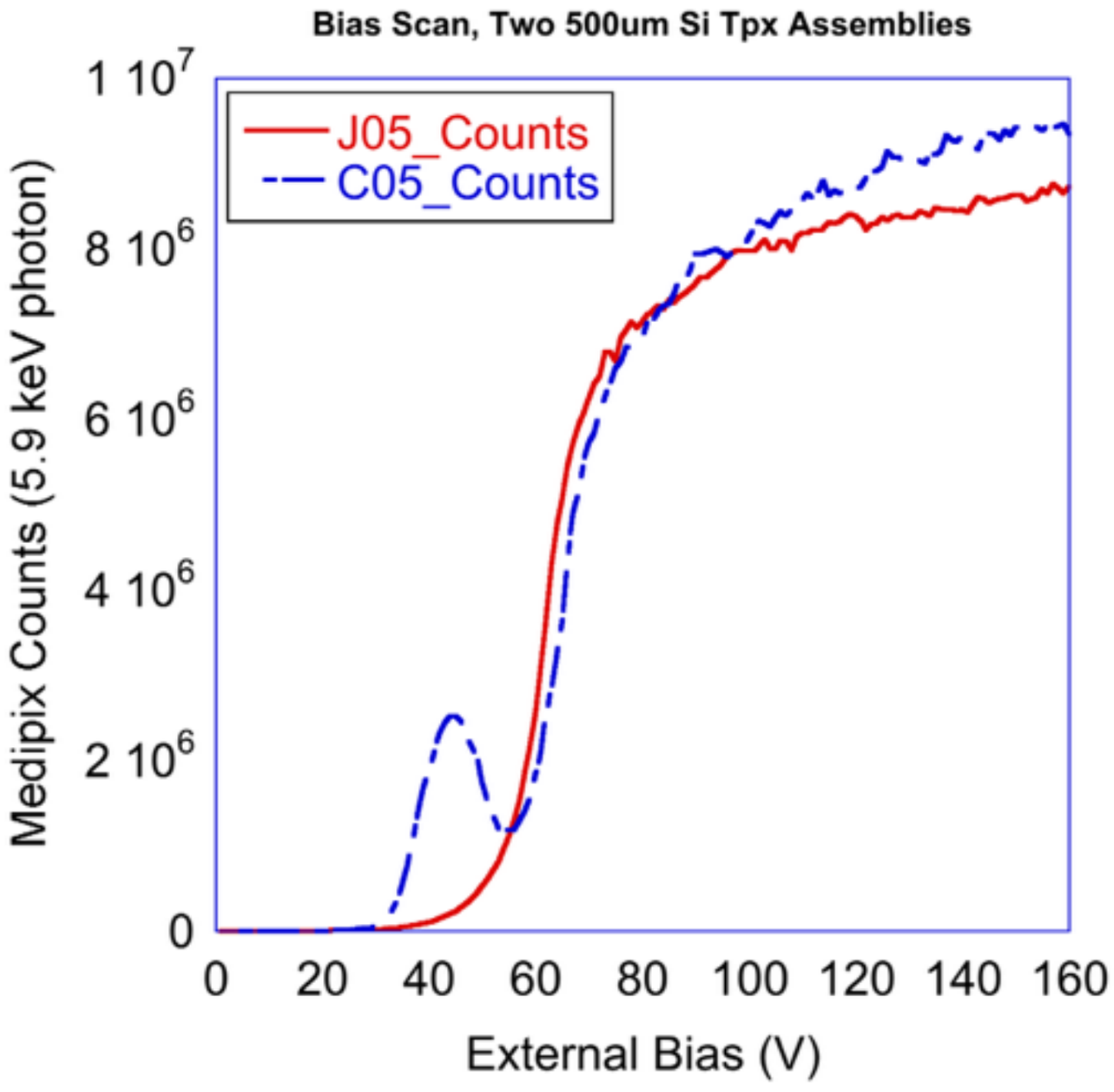
Depletion Bias Voltage

- FITPix (readout) can supply up to 100V bias voltage

- For 300um silicon this is over depleted

- For thicker sensors it may not be - bias voltage scan with Keithley source meter and photon source in photon counting mode

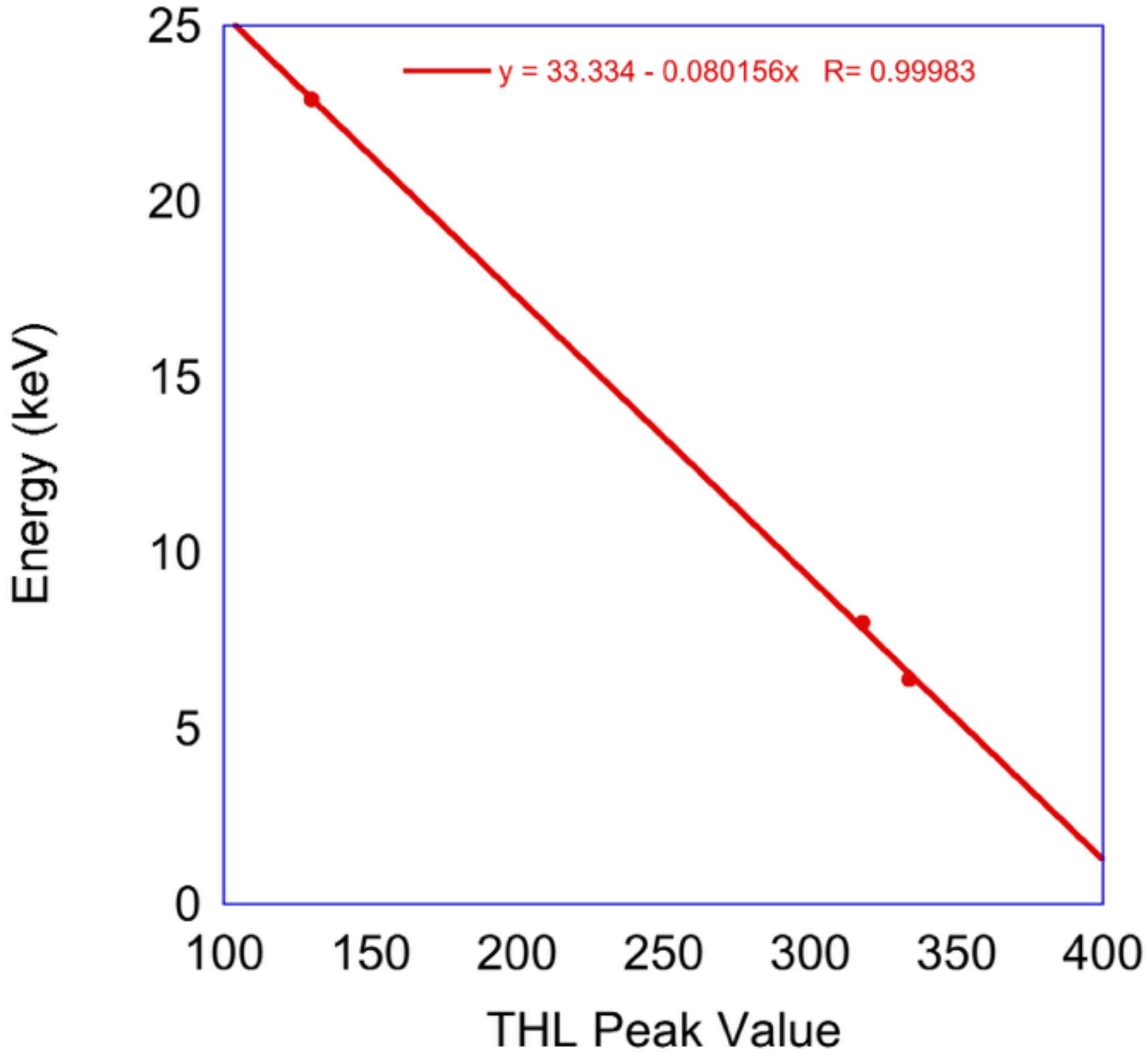
Depletion Voltage



Determination of threshold - THL Scans

- The threshold is set via a DAC -> a voltage
- But this is also an energy threshold, therefore we need a calibration of THL DAC value to energy
- Differentiated threshold scans
- Per pixel not needed due to low spread in threshold (~200 e-)

Threshold at 360 = 4.49 keV



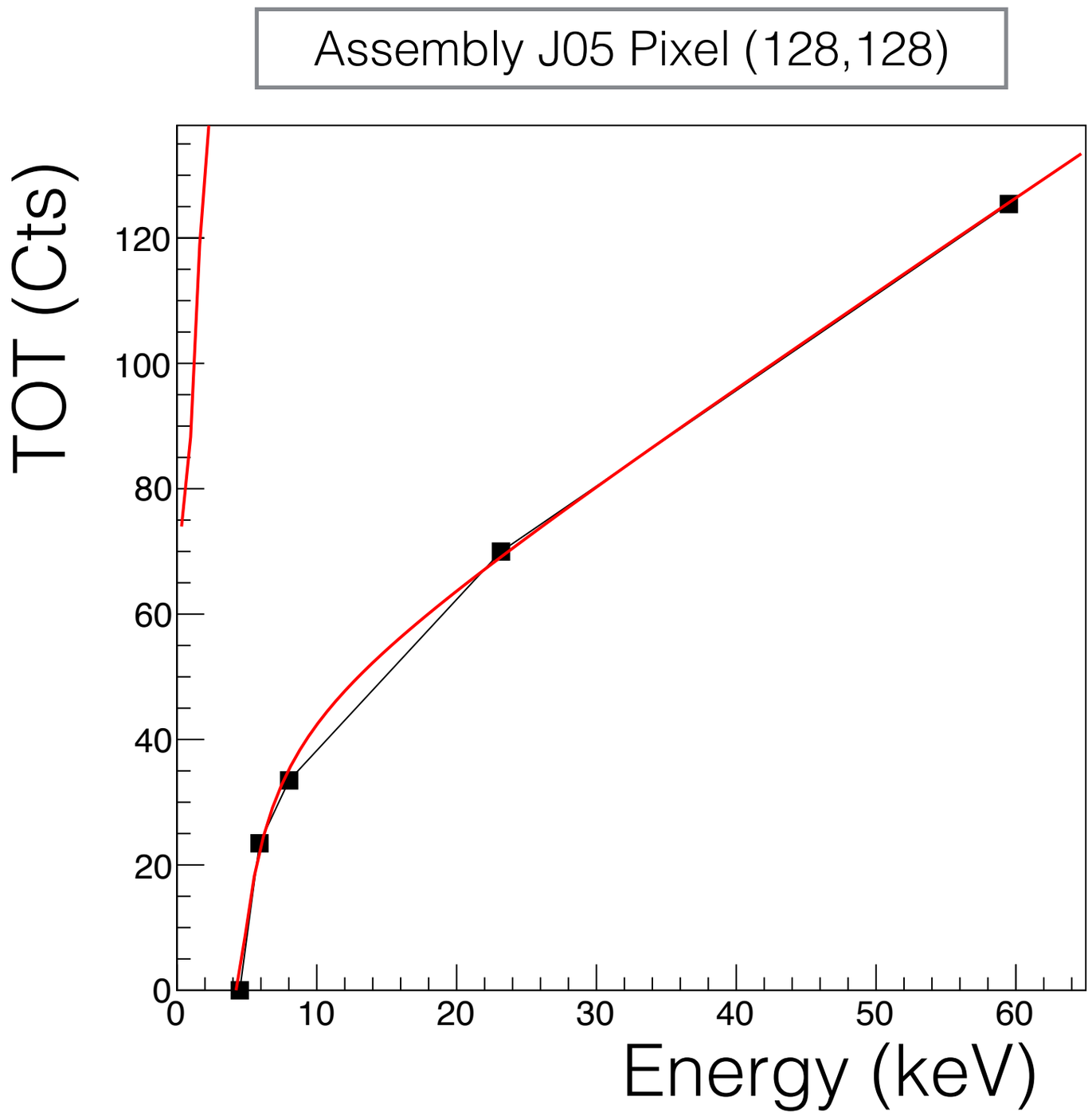
Calibration - Principle

- TOT Value and Energy are related by a surrogate function with 4 parameters

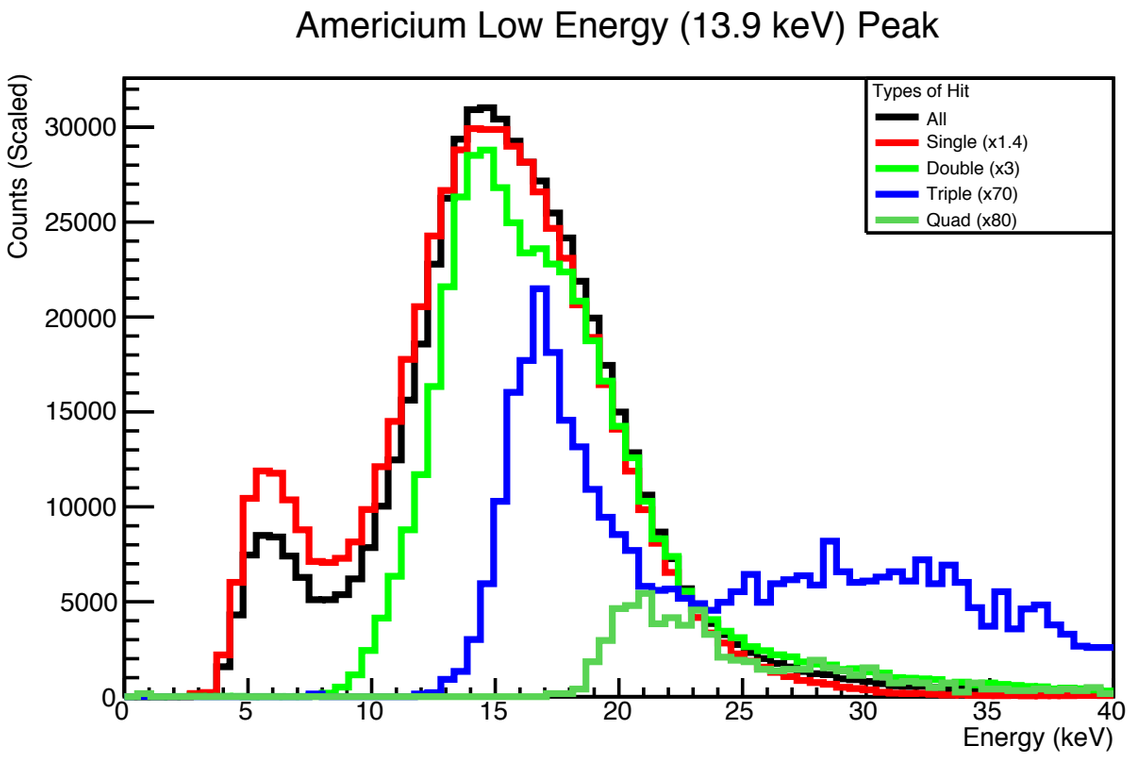
$$TOT(E) = aE + b - \frac{c}{E - t}$$

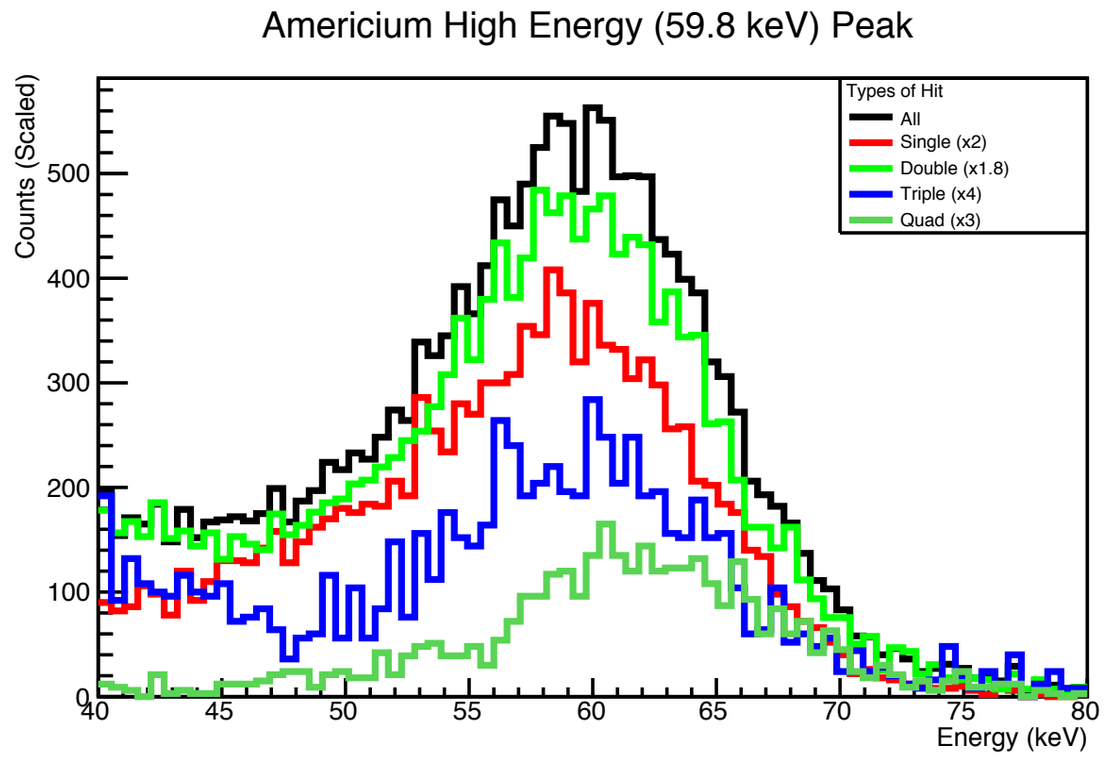
- Job is then to fit this function for each pixel
- 4 points + threshold value minimum
- Threshold is very useful for getting ‘good fits’ - surrogate has lots of local minima

$$TOT(E) = aE + b - \frac{c}{E - t}$$



Calibration - Validation

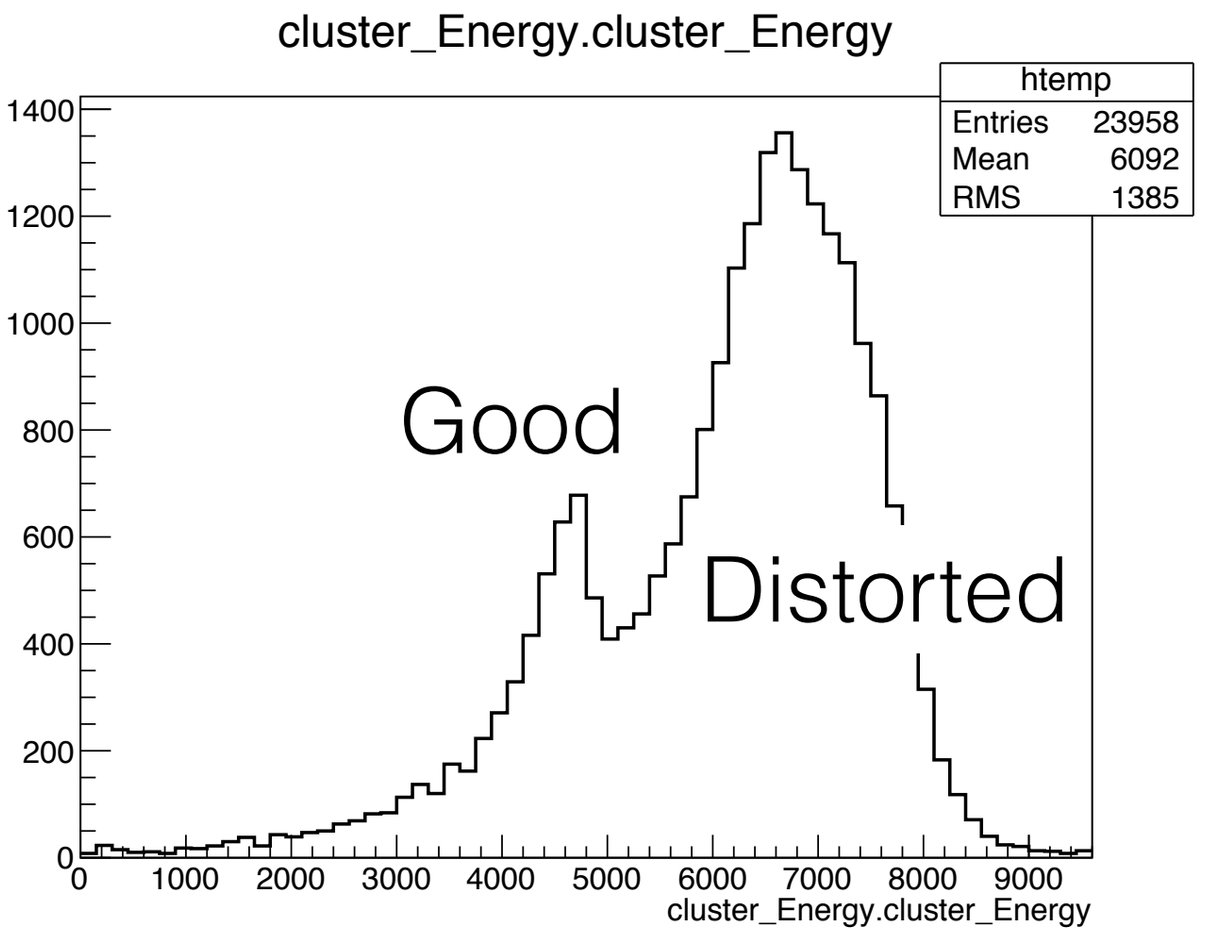


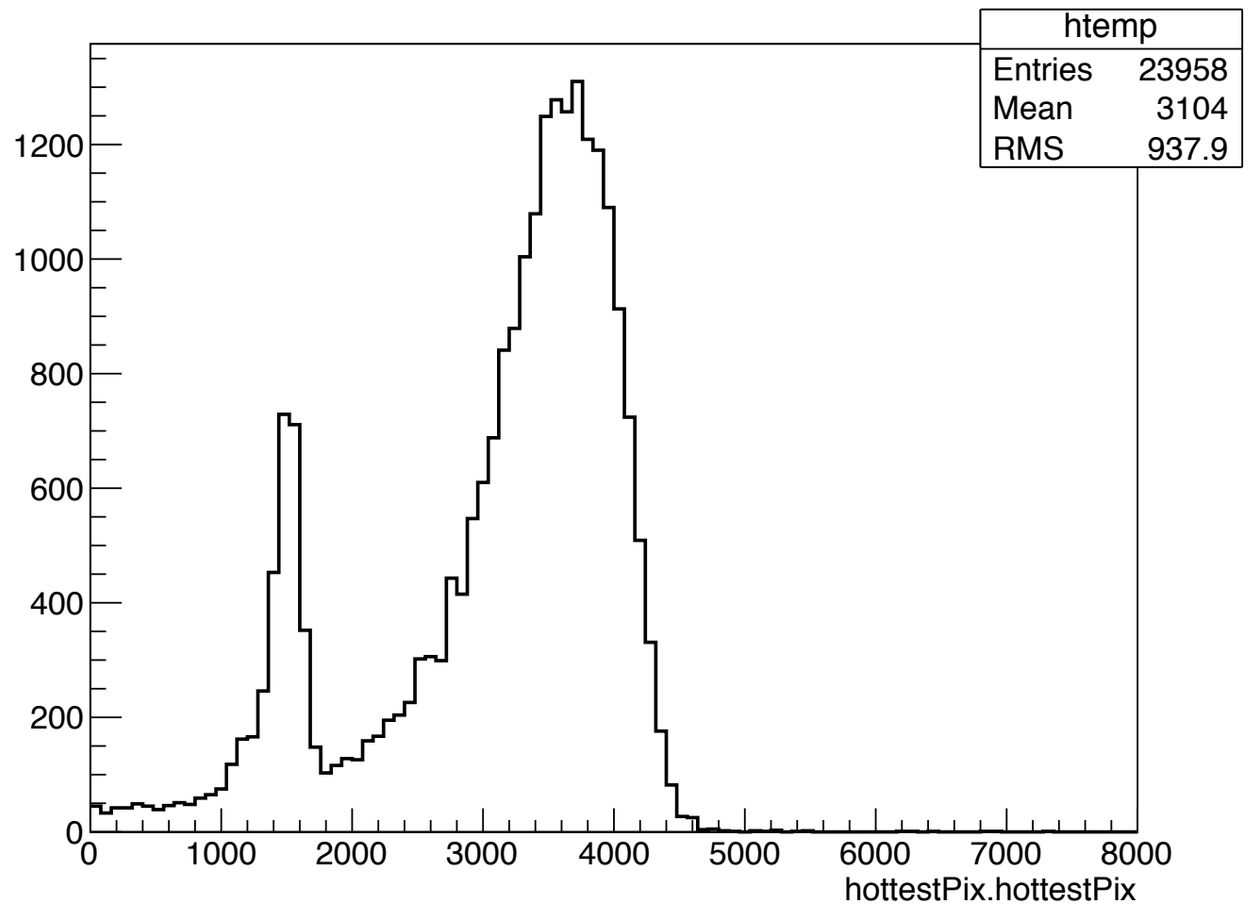


Spectroscopy of Alpha Particles

- Alpha particles stop in the first few um of the sensor and the charge diffuses into a cluster
- Timepix response becomes highly non linear for energies > 1.2 MeV in a single pixel
- Manifests as distorted spectrum for alpha particles

Spectroscopy of Alpha Particles - 300um Sensor



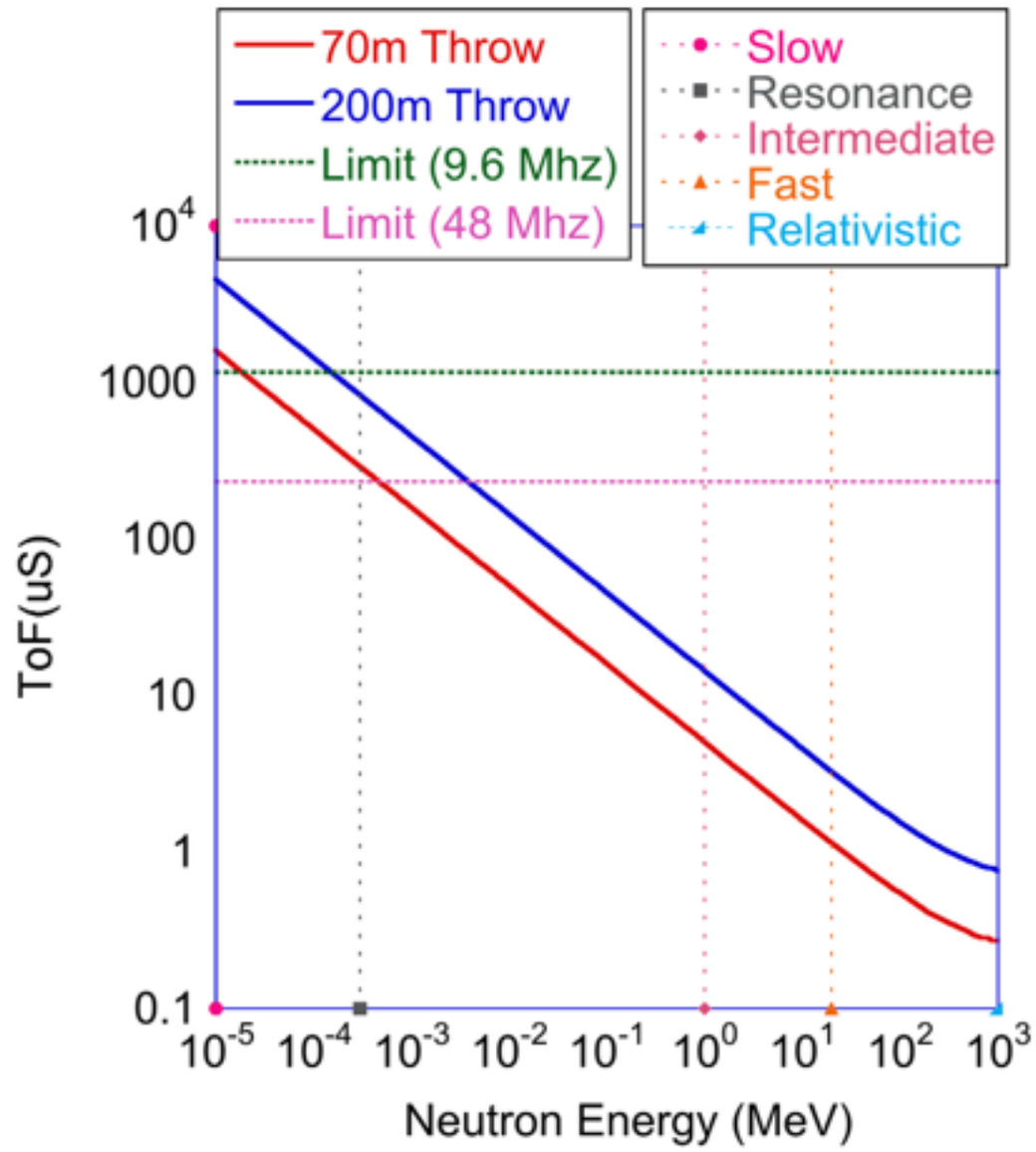


The Timepix - Timing Information

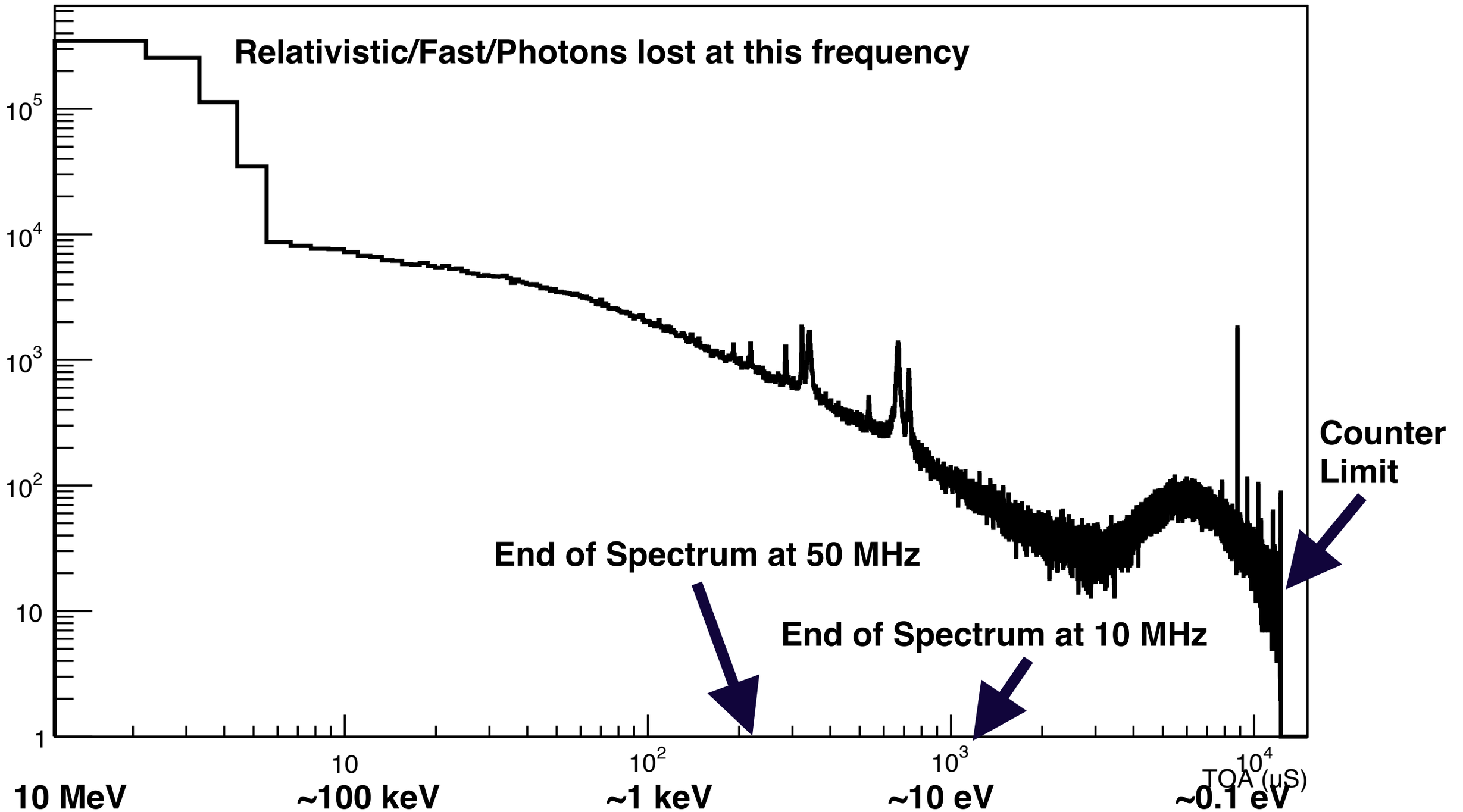
- Clock can run at 1, 10 or 50 Mhz (100 as well, but is unstable) -> 1us, 100ns, 20ns time resolution

- Counter depth is 11810 - places limits on total acq time.

- Readout ~10 mS (**slow**)



0.90 MHz TOA Spectrum



~100 spills (5 mins), timepix with boron + plastic converter