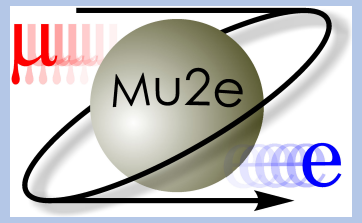

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Mu2e Calorimeter Clustering Studies

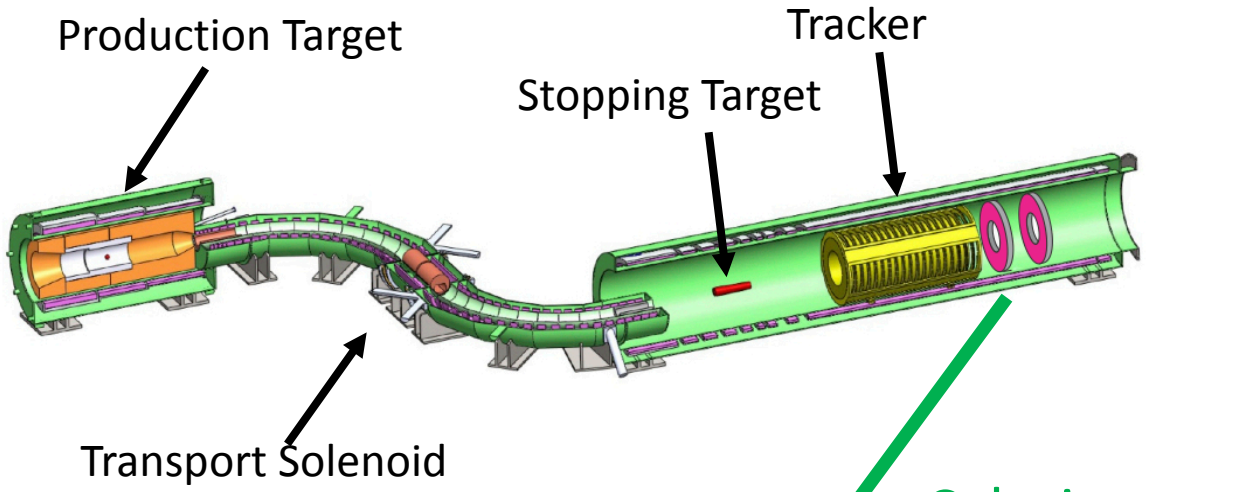
Emma Castiglia
with Giani Pezzullo and Sarah Demers
Yale University

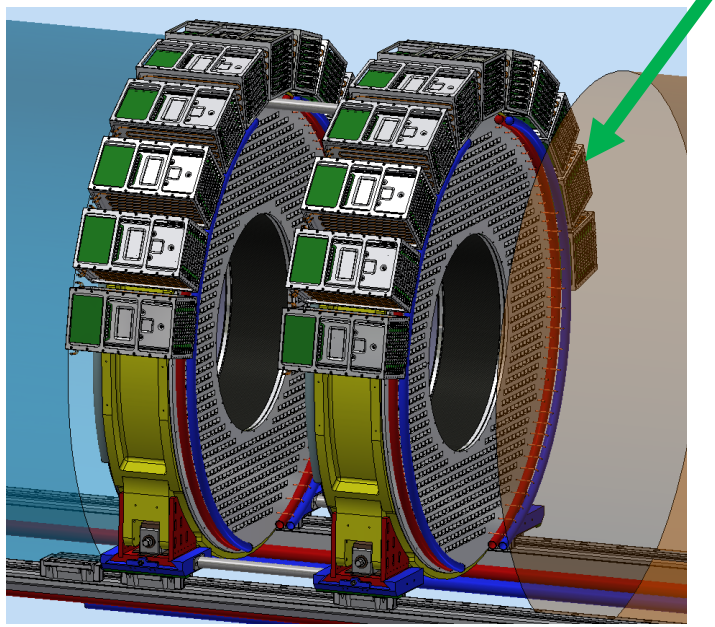
New Perspectives 2018

This document was prepared by [Mu2e Collaboration] using the resources of the Fermi National Accelerator Laboratory (Fermilab), a U.S. Department of Energy, Office of Science, HEP User Facility. Fermilab is managed by Fermi Research Alliance, LLC (FRA), acting under Contract No. DE-AC02-07CH11359.

Mu2e Calorimeter Overview

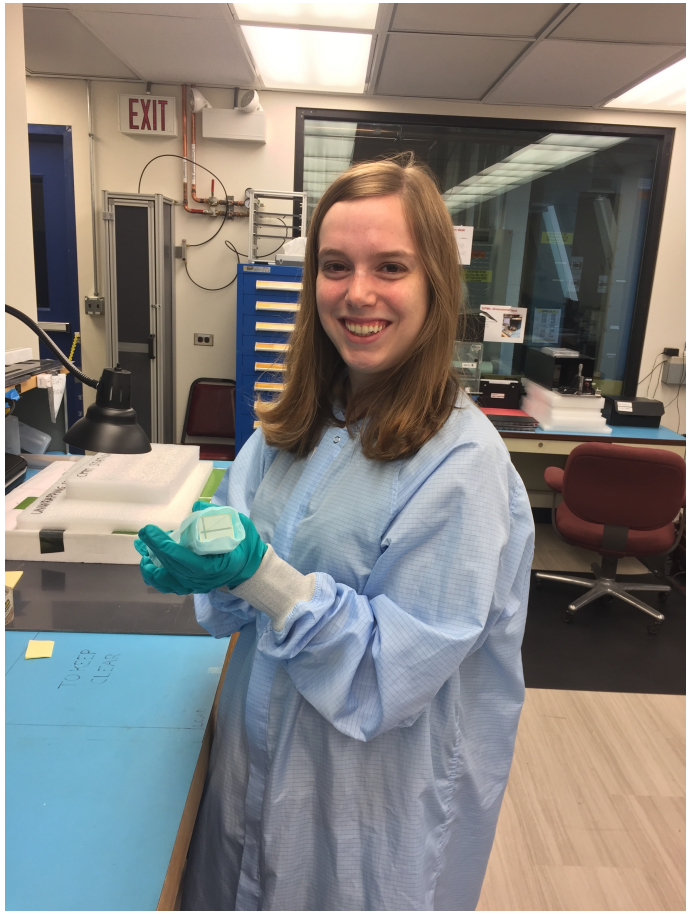
- Signal: 105 MeV Conversion Electron (CE) without neutrinos
- **Requirements of Calorimeter:**
  - Energy Resolution: ~10%
  - Timing Resolution: ~1ns
  - Position Resolution: 1cm
- **Calorimeter Role:**
  - Particle Identification – reject bkg
    - Cosmic Ray Muon
  - Needs to be a trigger for data storage!

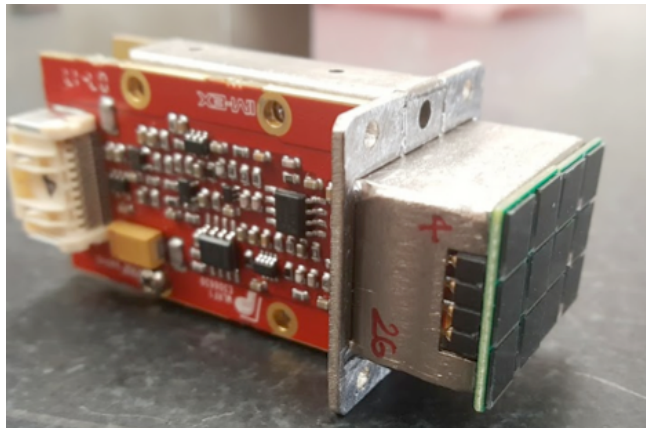


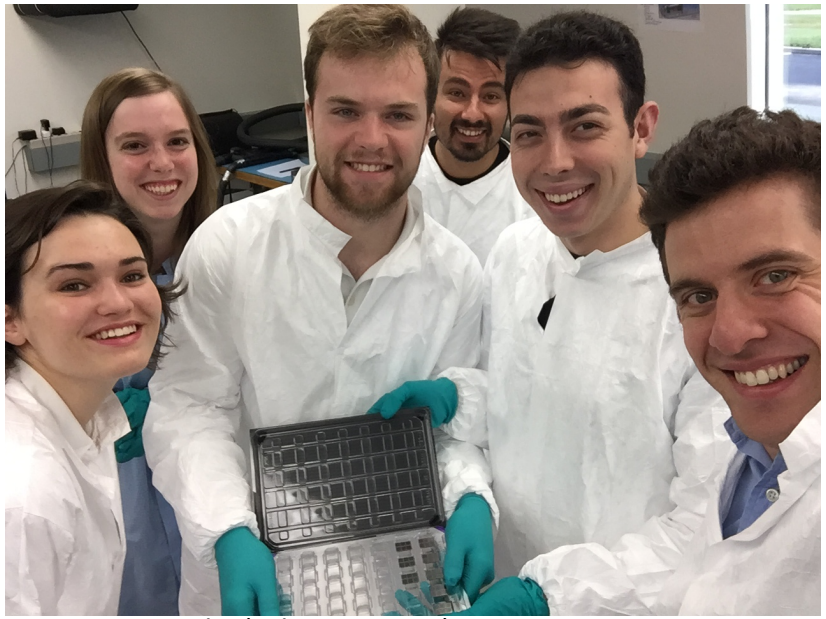


Mu2e Calorimeter Specifications

- Two annular disks of undoped CsI Crystals
  - Dimensions: 3.4x3.4x20 cm^3
  - Radiation length of 2.1 cm (~10 lengths in crystal)
  - Total of 1356 crystals
- Crystals are read out by 2x3 of 6x6 mm^2 UV-extended SiPM
- Signal digitized at 200MHz
- Measured performance at test beam (100 MeV)
  - 100ps is time resolution
  - 5% is energy resolution



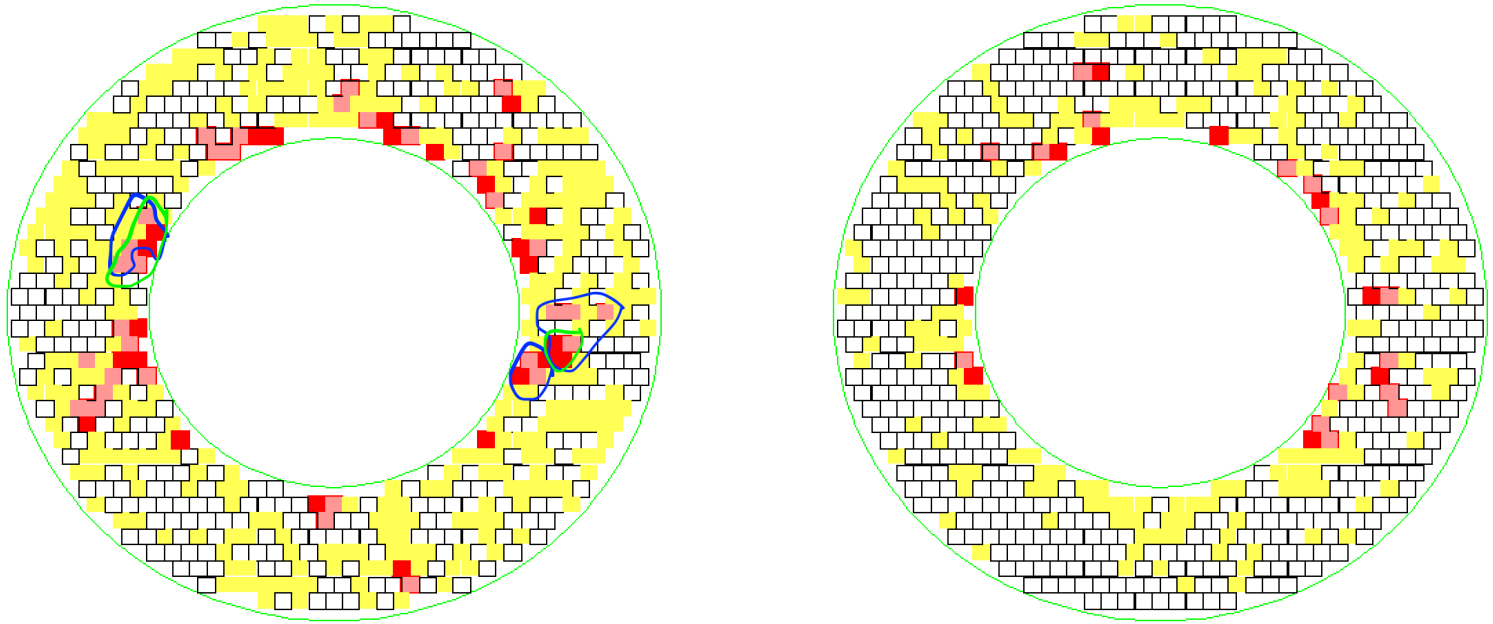




Mu2e Calorimeter Clustering

How it works?

- Sort crystal hits by energy deposited and then group adjacent ones
- 2 algorithms that do this differently
  - Full (proto): Slower but more Accurate – use in offline reconstruction
  - Fast: Quicker and Simple– could be trigger if runs in real time
- If able to identify potential signal events, can trigger on those events



Fast Algorithm for Clustering

Steps:

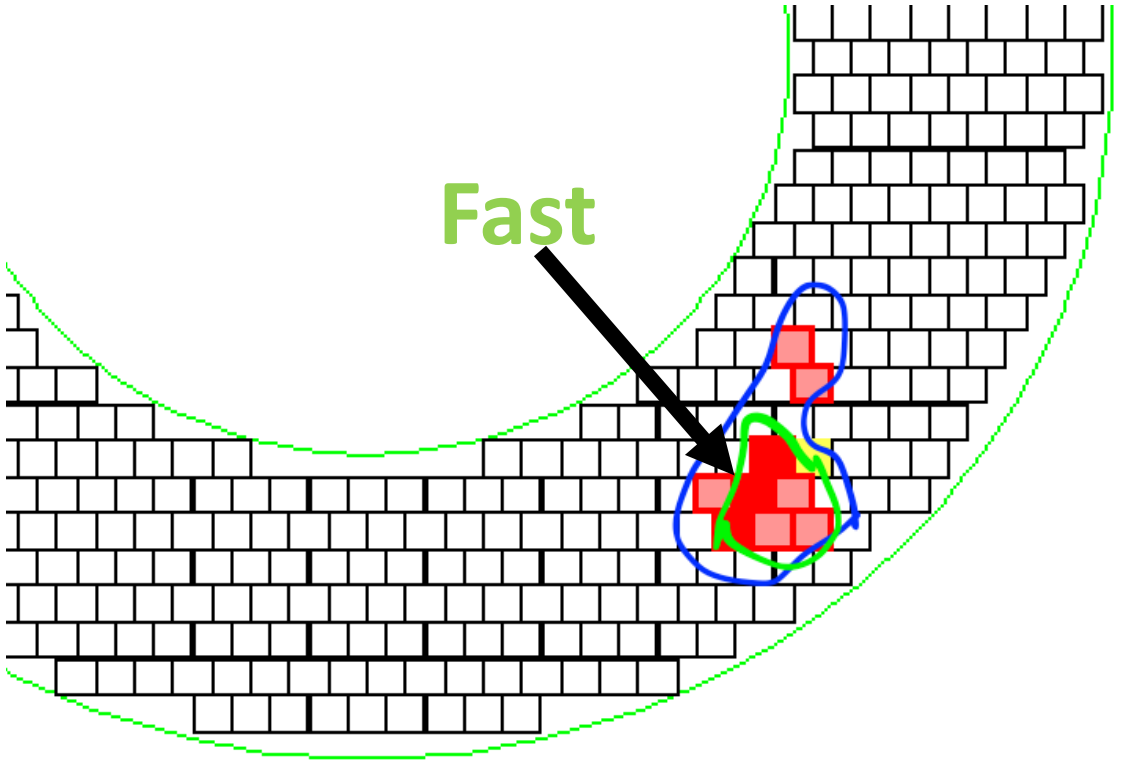
1. Take highest energy crystal – seed with >10MeV
2. Look at neighboring crystals over energy threshold and group - green
3. Remove crystals that are clustered together from list of crystals
4. Start process over with next highest energy crystal

Modification:

Include next, next to next neighbors, etc

Adds time:

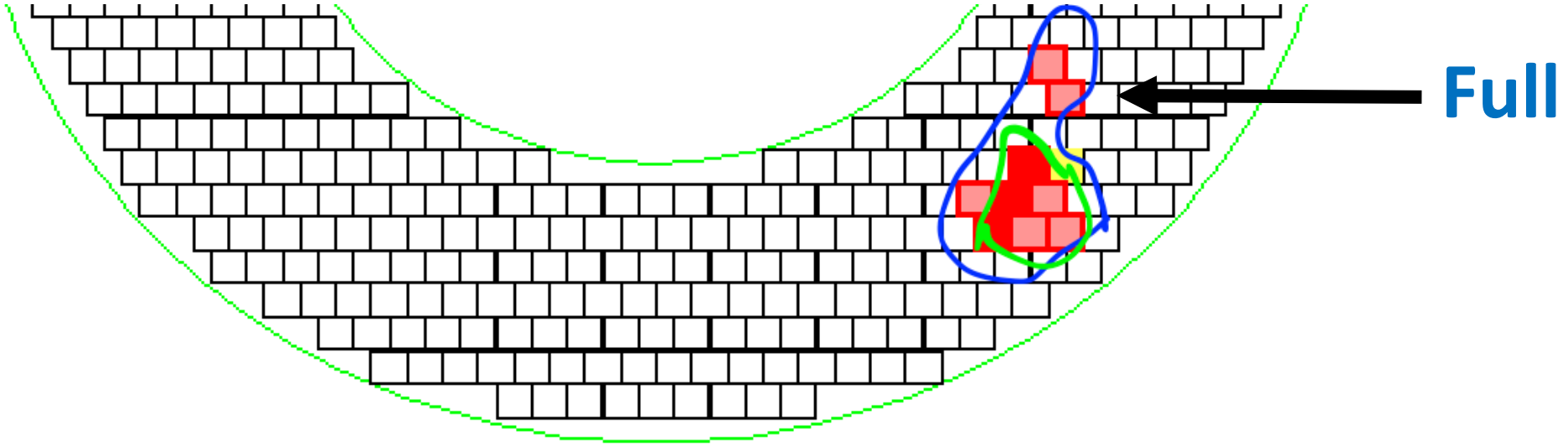
- 1 ring – 6 crystals
- 2 rings – 12 crystals
- 3 rings – 18 crystals



Full Algorithm for Clustering

Steps:

1. Take highest energy crystal –> seed with >10MeV
2. Look at neighboring crystals over energy threshold and group
3. **Look at non-adjacent crystals with large energy deposits - blue**
   -> could be deposited by photons emitted (within speed of light)
   3a. Sometimes end up grouping two smaller clusters into one larger cluster
4. Remove crystals that are clustered together from list of crystals
5. Start process over with next highest energy crystal



Goals for Clustering Studies

GOAL 1

Compare Fast and Full Algorithms for accuracy and timing performance

GOAL 2

Find discriminating variables for improving CE selection from background

How do we know if we are correctly identifying conversion electrons (CE)?

Use information from the Virtual Detector

- G4 sensitive detector right before the calorimeter that stores the information of particles passing through it without affecting them
  - Can get energy, radial position, etc. about the incoming CE
  - Truth – has conversion electron events that may miss the calorimeter

Virtual Detector – Acceptance

Acceptance: 95%

Leakage: Sharp Edge - detector is 20cm deep and 30cm wide ->shower loss due to depth/reflection

Energy resolution:

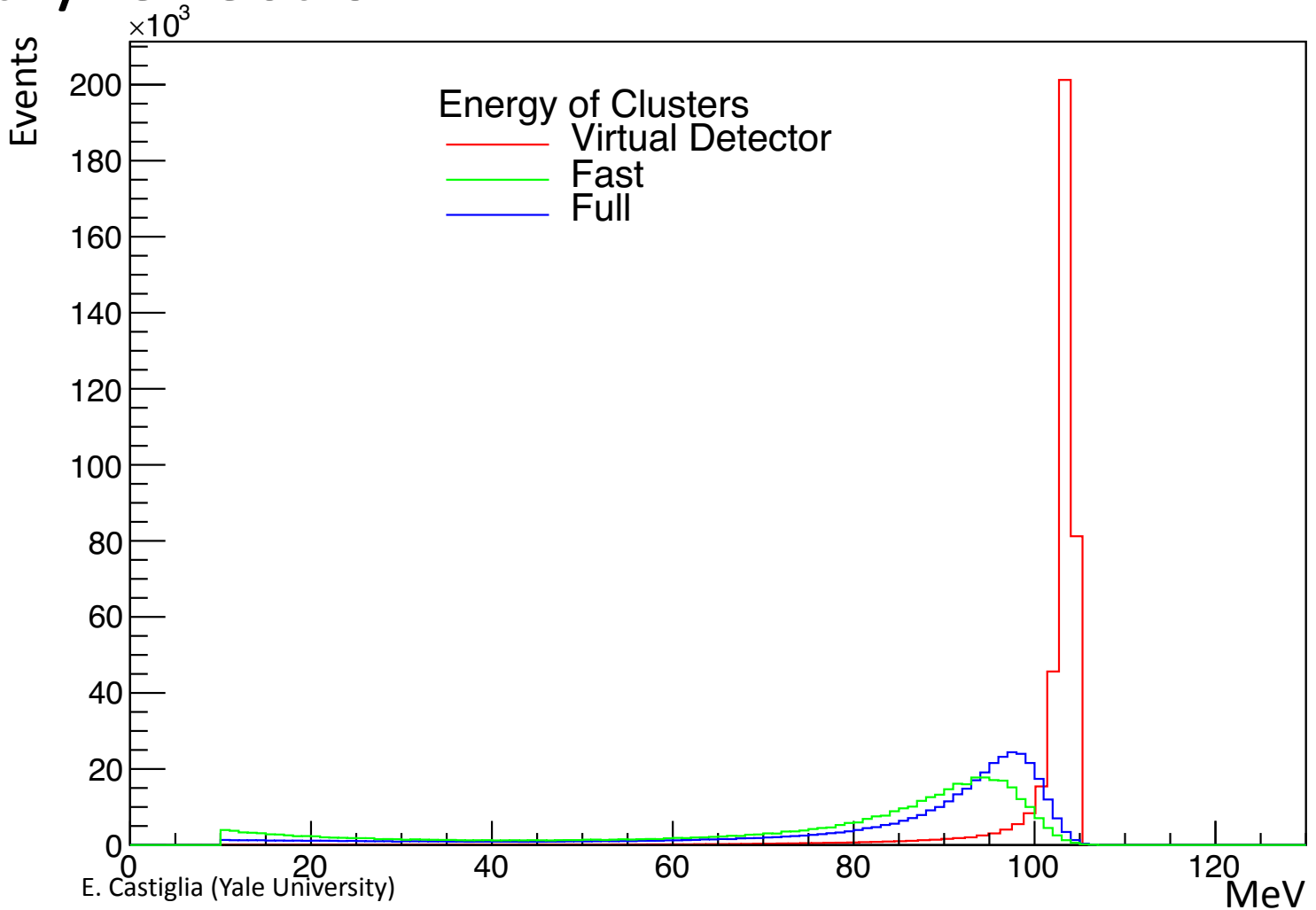
Full: 6.4%

Fast: 8.6%

FWHM:

Full: 6.2 MeV

Fast: 8.2 MeV

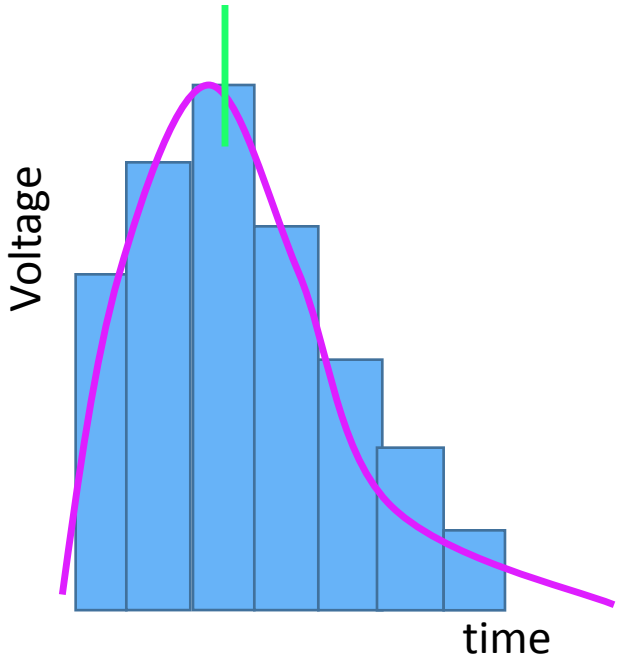


Timing Comparison

Have a few ms per event within which to trigger on or reject

Calo Cluster Fast:

- ~.2ms per event
- Includes fast processing of digitized hits

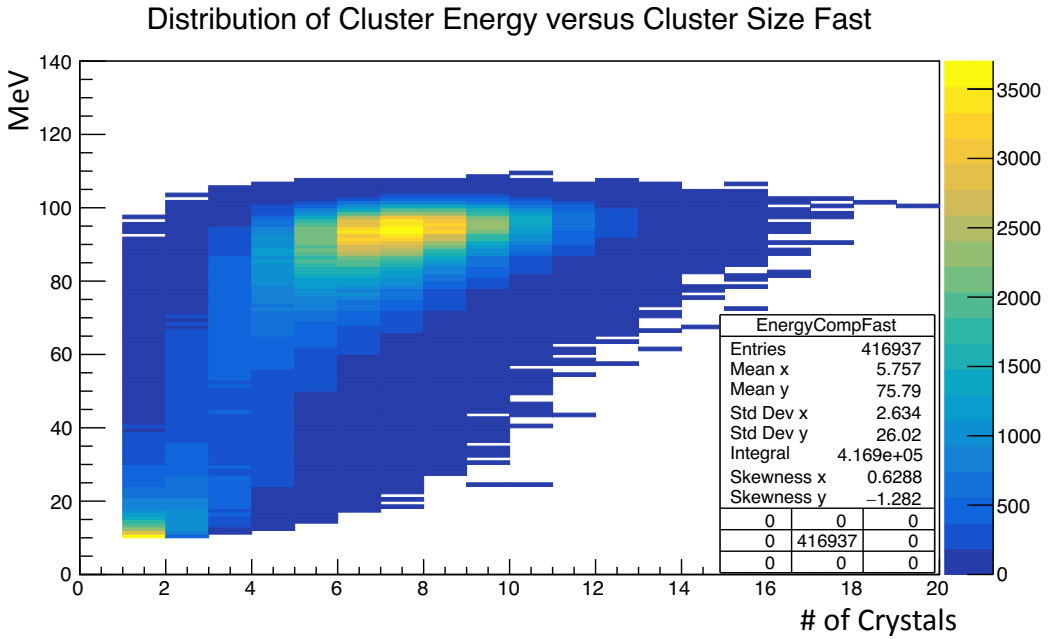


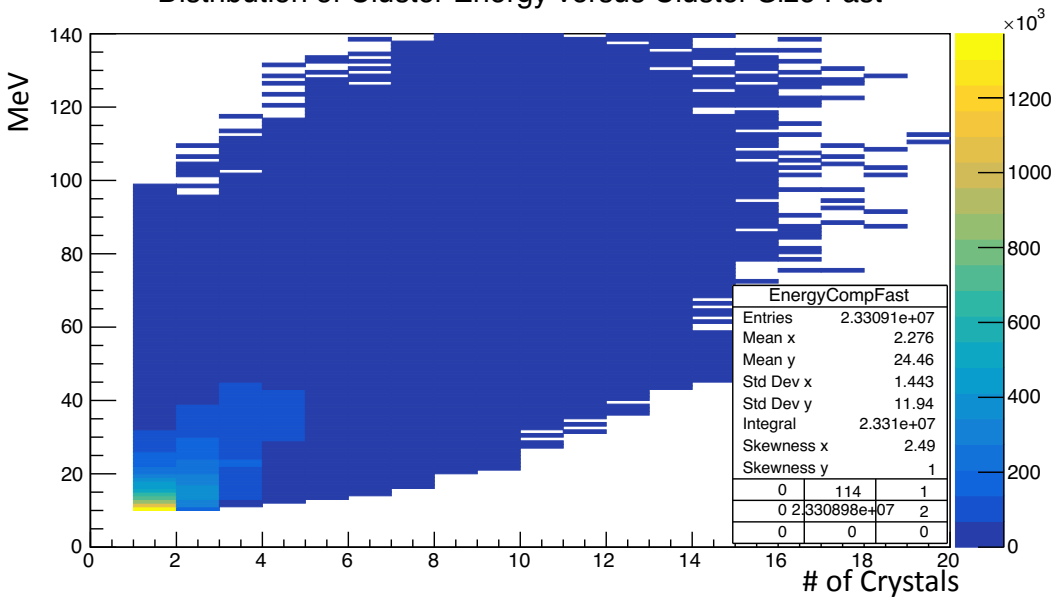
Full Clustering:

- Algorithm takes 2.3ms per event
- Needs Template Fit: 25ms per event
- Complete time for each event is >27ms

=> Fast Algorithm is more robust – could use as trigger

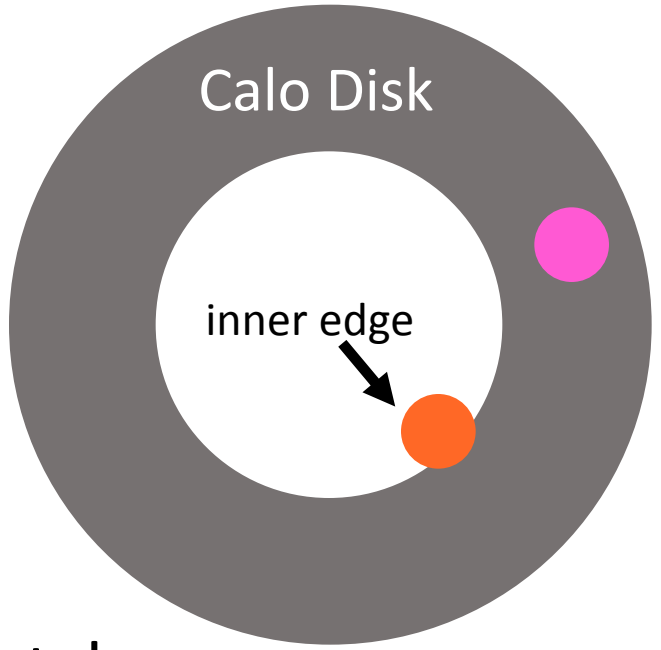
Energy versus Cluster Size - Fast





CE Only:

Peak at 80-100 MeV and 6-9 crystals



Background Only:

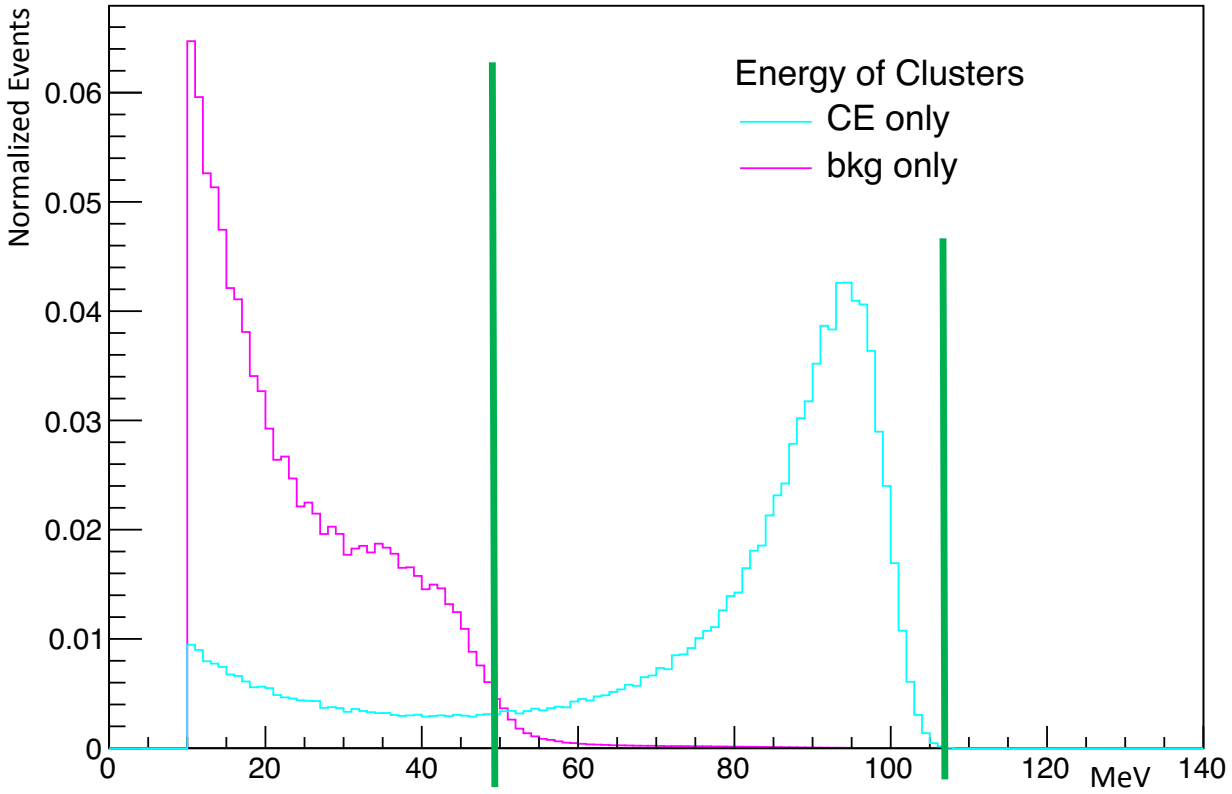
Peak at 10 MeV and 1 crystal

Comparing CE and bkg only - Fast

ENERGY

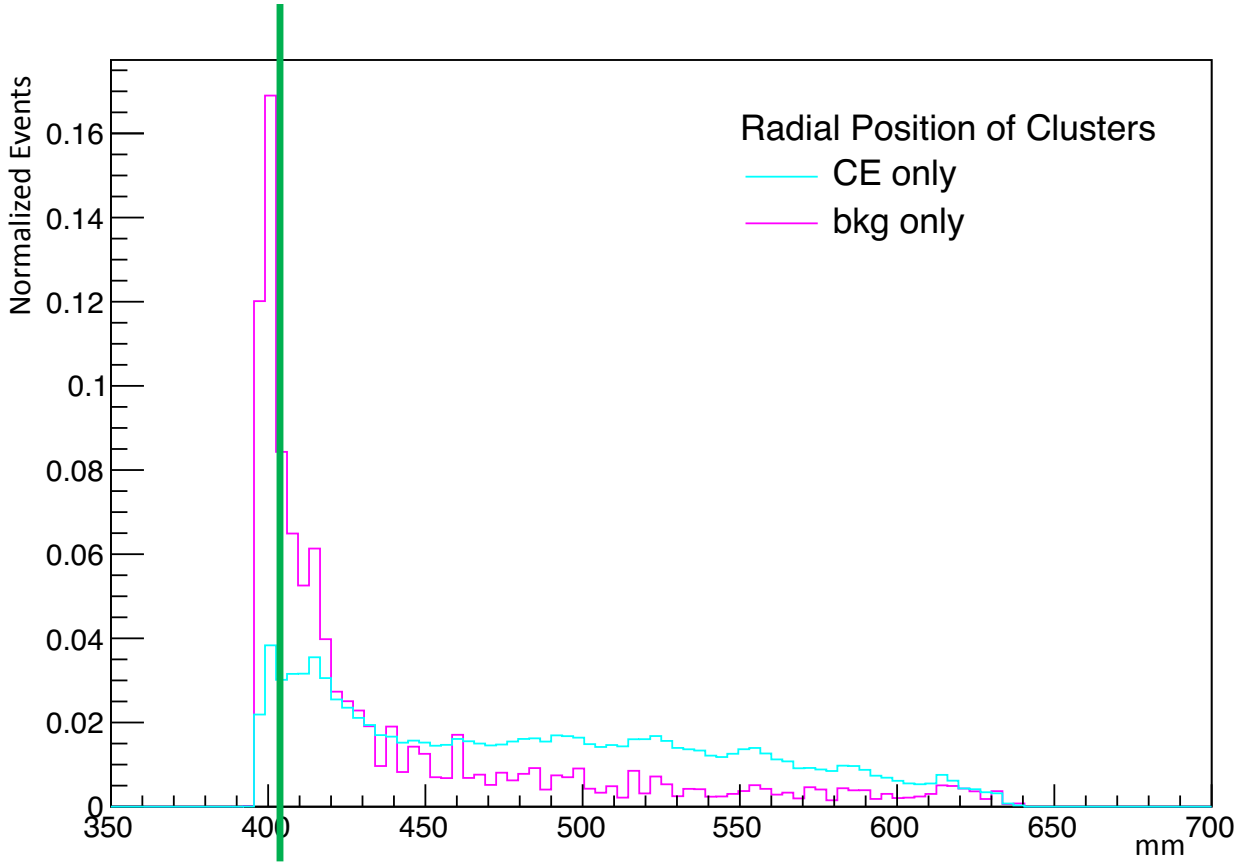
Drop off at ~50 MeV

Distinctive background shape



RADIAL POSITION

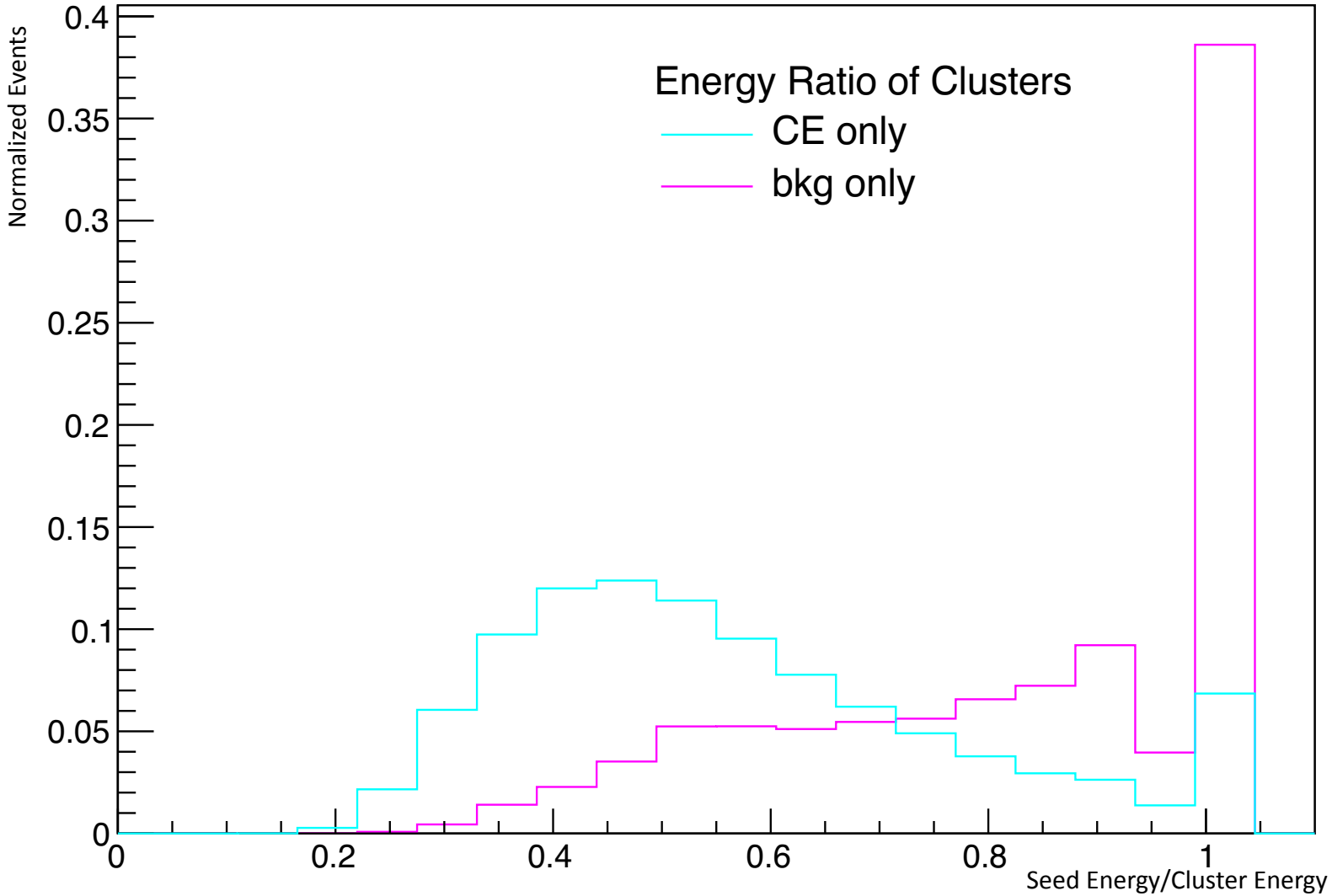
Drop off at 410mm



Comparing CE and bkg only - Fast

RATIO OF SEED TO CLUSTER ENERGY

Background has more clusters with only 1 crystal



Conclusion and Next Steps

Results so far:

- Fast is quick and performs well enough to be used during triggering
- Energy resolution of Full could be improved in Offline
- Variables that could be used to differentiate:
  - Energy and Size
  - Radial Distance
  - Ratio of Seed Energy to Cluster Energy

Next Steps:

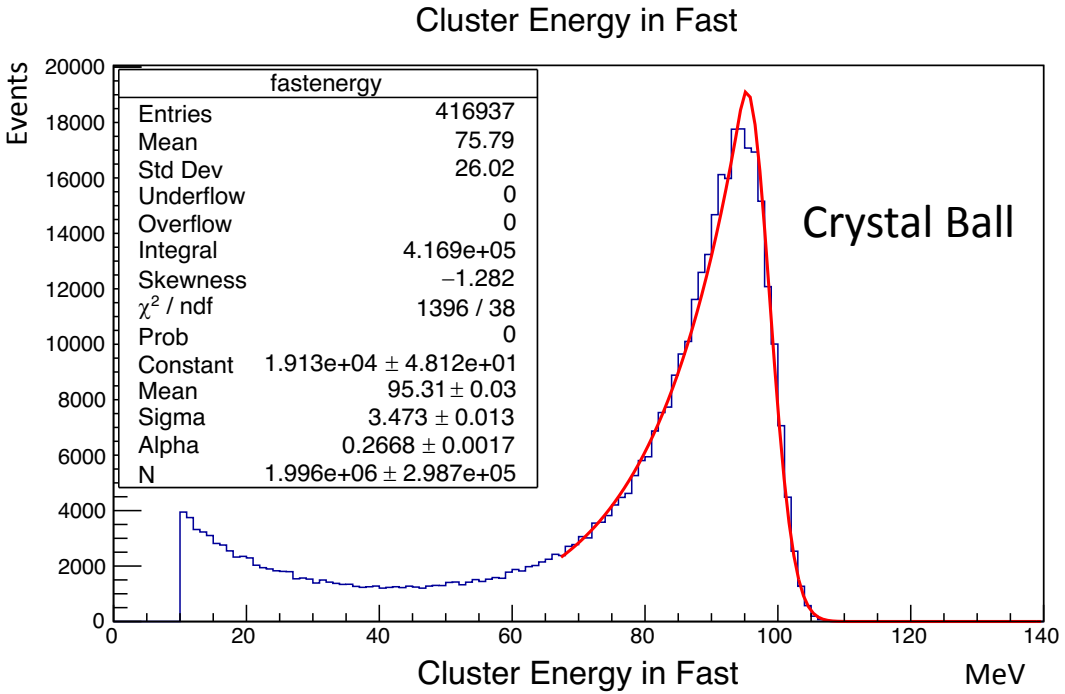
- Look at adding more rings of neighbors to Fast
- Change minimum energy cutoff for clusters – currently 10 MeV

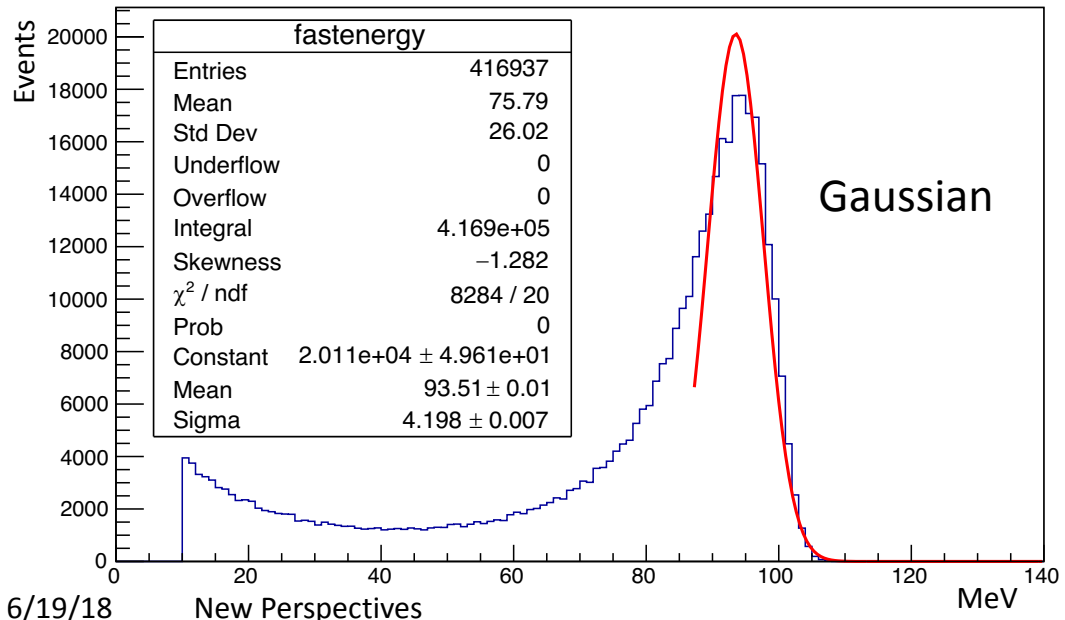
Questions?

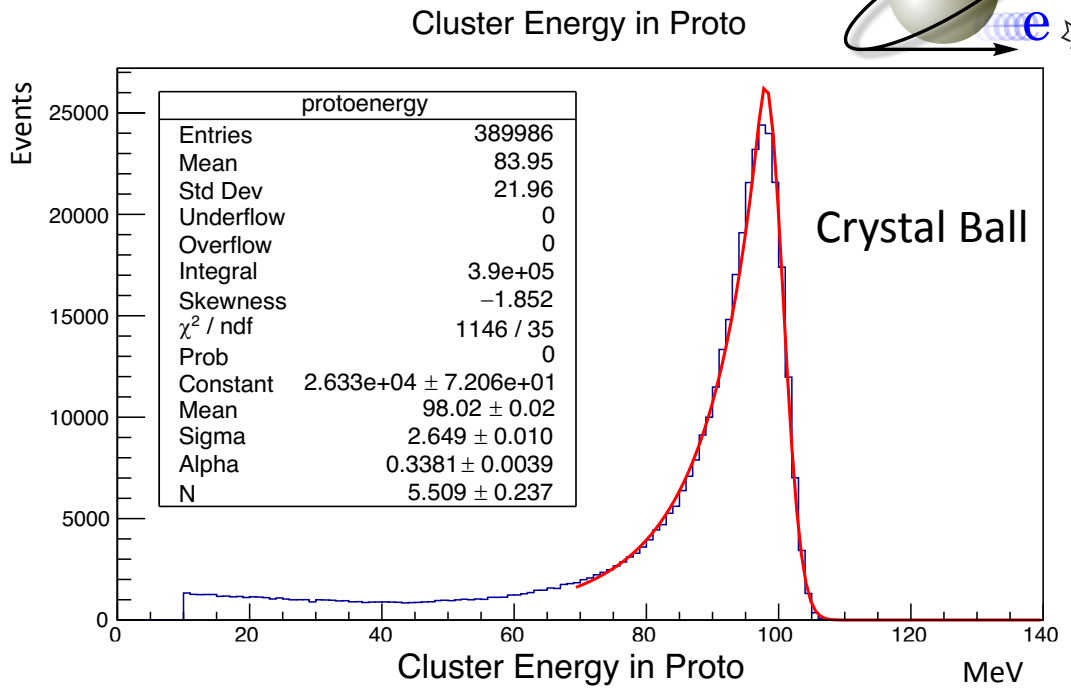
Thanks for listening!

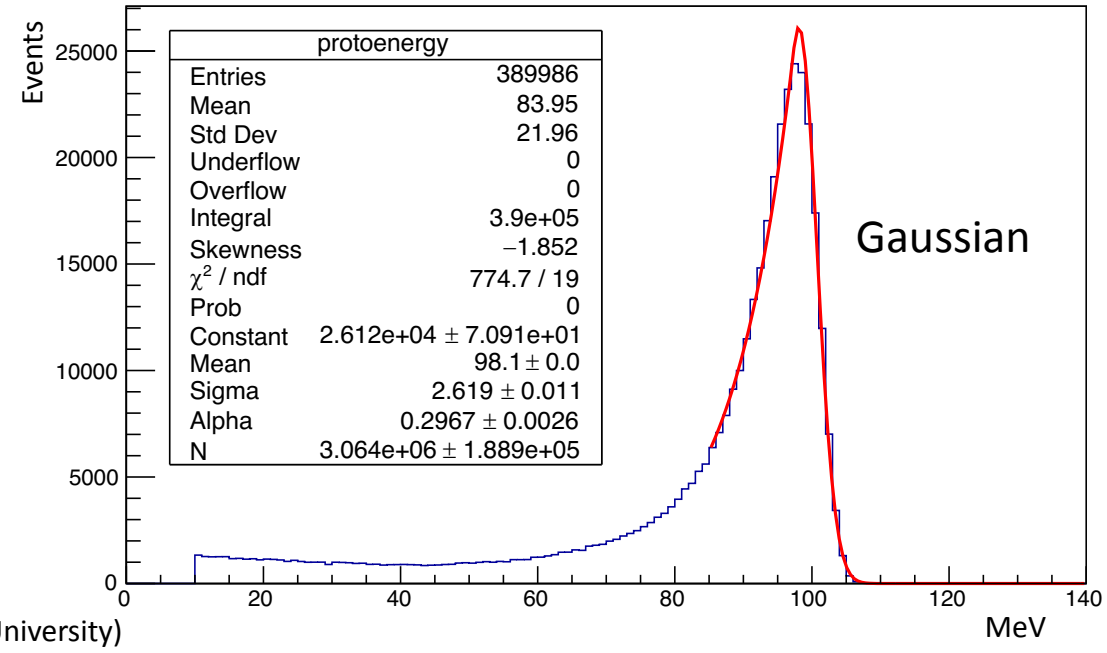
Backup Slides

FWHM Fits


Cluster Energy in Fast
fastenergy
Entries 416937
Mean 75.79
Std Dev 26.02
Underflow 0
Overflow 0
Integral 4.169e+05
Skewness −1.282
χ² / ndf 1396 / 38
Prob 0
Constant 1.913e+04 ± 4.812e+01
Mean 95.31 ± 0.03
Sigma 3.473 ± 0.013
Alpha 0.2668 ± 0.0017
N 1.996e+06 ± 2.987e+05
Crystal Ball
Events
Cluster Energy in Fast
MeV

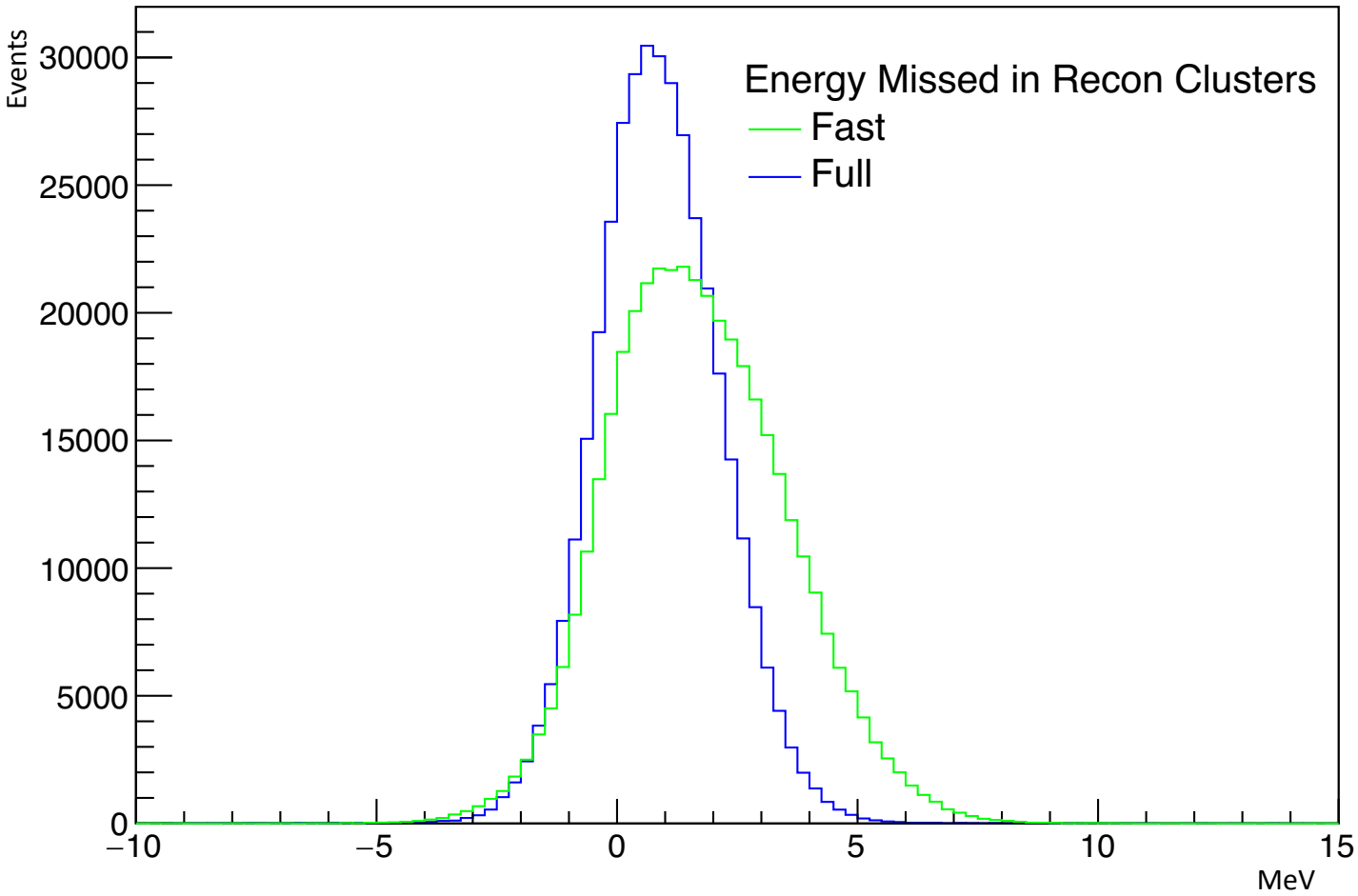

fastenergy
Entries 416937
Mean 75.79
Std Dev 26.02
Underflow 0
Overflow 0
Integral 4.169e+05
Skewness −1.282
χ² / ndf 8284 / 20
Prob 0
Constant 2.011e+04 ± 4.961e+01
Mean 93.51 ± 0.01
Sigma 4.198 ± 0.007
Gaussian
Events
MeV


Cluster Energy in Proto
protoenergy
Entries 389986
Mean 83.95
Std Dev 21.96
Underflow 0
Overflow 0
Integral 3.9e+05
Skewness −1.852
χ² / ndf 1146 / 35
Prob 0
Constant 2.633e+04 ± 7.206e+01
Mean 98.02 ± 0.02
Sigma 2.649 ± 0.010
Alpha 0.3381 ± 0.0039
N 5.509 ± 0.237
Crystal Ball
Events
Cluster Energy in Proto
MeV


protoenergy
Entries 389986
Mean 83.95
Std Dev 21.96
Underflow 0
Overflow 0
Integral 3.9e+05
Skewness −1.852
χ² / ndf 774.7 / 19
Prob 0
Constant 2.612e+04 ± 7.091e+01
Mean 98.1 ± 0.0
Sigma 2.619 ± 0.011
Alpha 0.2967 ± 0.0026
N 3.064e+06 ± 1.889e+05
Gaussian
Events
MeV

MC comparison of Recon with VD

- Reconstructed Clusters miss energy as compared to the MC energy
- Proto Algorithm has more accurate reconstruction energy



Fast:

Mean: 1.7

σ: 1.81

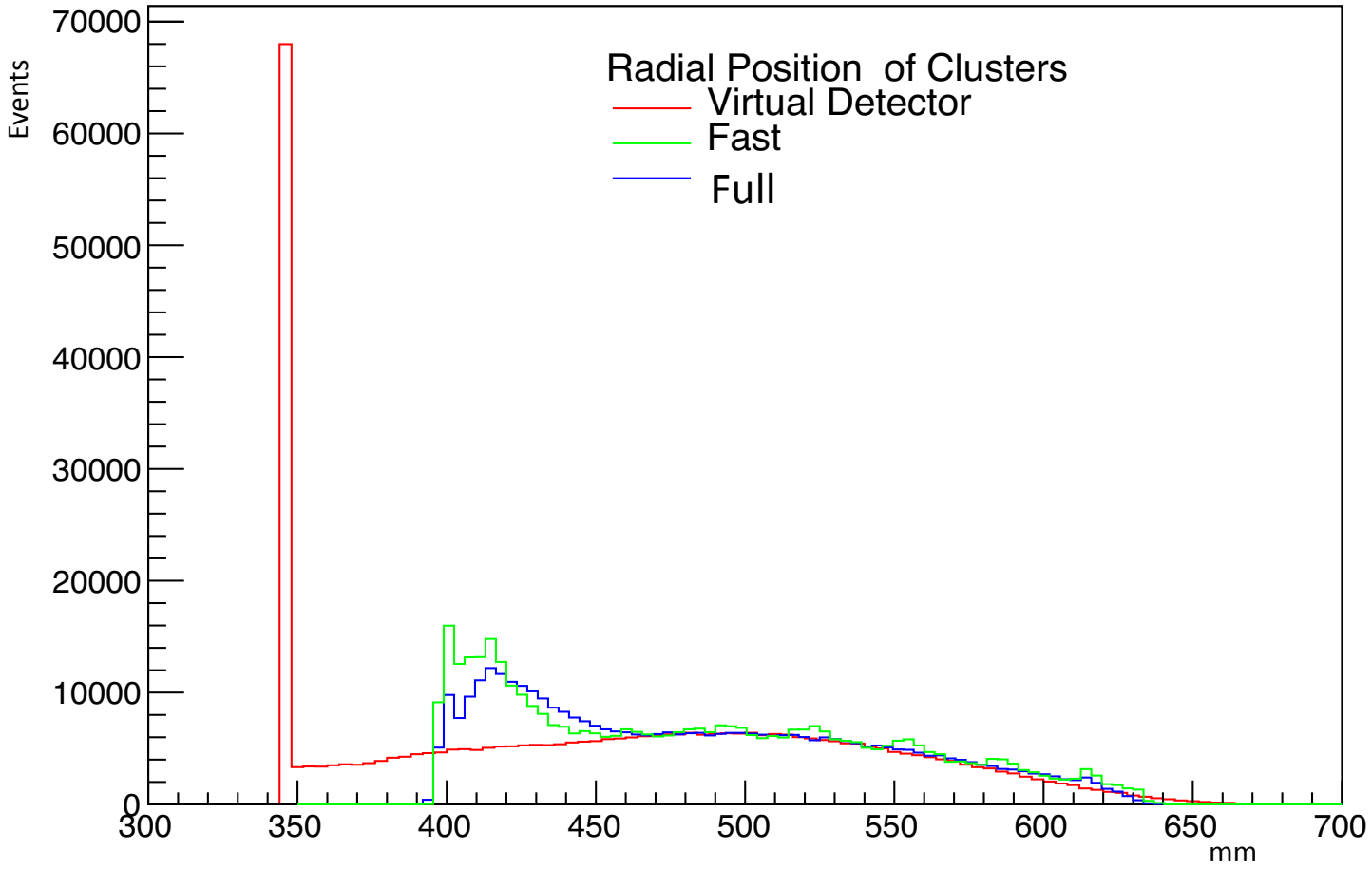
Full:

Mean: 0.87

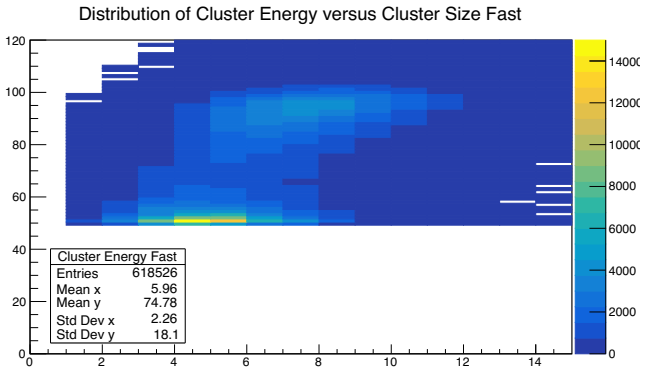
σ: 1.26

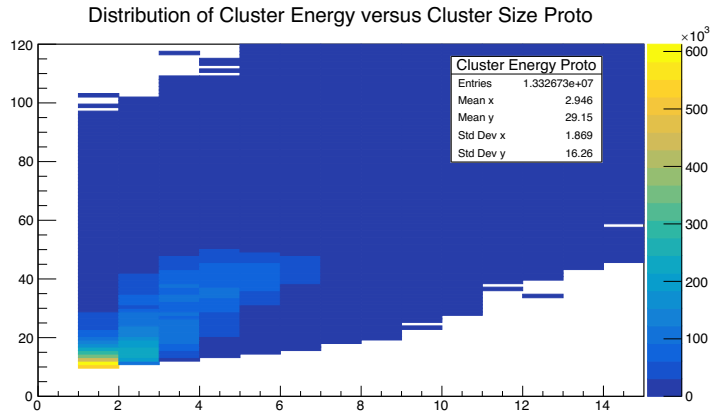
Virtual Detector Truth – Radial Position

CE Only



Current list of histograms





1 –D

Timing of cluster
Energy of cluster
Energy of clusters over 50MeV
Radial position of cluster
Energy of clusters outside 450mm
Angle of Cluster
Angle if cluster >2 crystals
Cluster Size
Seed Energy
MC truth w/recon energy
MC truth w/MC energy
Energy diff (MC – Recon)
Ratio of Seed Energy to cluster energy

Highest Energy Cluster:

Recon Energy of cluster
Radial position of cluster
Angle of cluster
Size of cluster

2 –D

Energy vs. Cluster Size
Energy vs. Angle
Energy vs. Time
Energy vs. Radial positon
Comp of MC and Recon crystal energy
Comp of MC and Recon Seed Energy
Comp or Ratio to Cluster Energy
Comp of Seed and Cluster Energy

Virtual Detector

Radial of True
Energy of True
Energy Missed by Fast
Energy Missed by proto