Mu2e Calorimeter Clustering Studies

Emma Castiglia
with Giani Pezzullo and Sarah Demers
Yale University

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Mu2e Calorimeter Overview

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

Mu2e Calorimeter Specifications

- Two annular disks of undoped CsI Crystals
- Rectangular Prism Crystals:
 - Dimensions: $3.4 \times 3.4 \times 20 \text{ cm}^3$
 - Total of 1356 crystals
- Crystals are read out by 2x3 of $6 \times 6 \text{ mm}^2$ 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 – red and yellow crystals
- Work through highest crystal seeds in order and cluster with their neighbors
 - 2 algorithms that do this differently
 - **Full (proto)**: Slower but more Accurate – reconstructed with template fit
 - **Fast**: Quicker but less accurate – could be trigger if runs in real time
- If able to accurately identify potential signal events, can trigger on those events

Full Algorithm for Clustering

Steps:

1. Take highest energy crystal $\rightarrow$ seed
2. Look at neighboring crystals over certain energy threshold and group
3. Look at non-adjacent crystals with large energy deposits
 $\rightarrow$ could be deposited by photons emitted (within speed of limit)
 - 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

Fast Algorithm for Clustering

Steps:

1. Take highest energy crystal – seed
2. Look at neighboring crystals over certain energy threshold and group
3. Can add next, next to next neighbors, etc. as well
 - > Only look at crystals in adjacent rings
 - > Base set up only looks at actual neighbors
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**

- Imaginary detector right before the calorimeter that stores the information of particles passing through it before hitting the calorimeter
 - Can get energy, radial position, etc. about the incoming CE
 - Total truth – has conversion electron events that may miss the detector

Virtual Detector – Acceptance

Acceptance: 95%

Leakage: Sharp Edge, detector is 20cm deep and 30cm wide

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:

- ~ 0.2 ms per event
- Includes fast processing of digitized hits

Full Clustering:

- 2.3ms per event – Cannot use this in our final trigger

Template Fit: 25ms per event

- Used by **Full** - actual time for each event is >27 ms

=> Only **Fast** Algorithm can be used as real time trigger

Energy versus Cluster Size - Fast

Distribution of Cluster Energy versus Cluster Size Fast

CE Only:

Peak at 80-100 MeV and 6-9 crystals

Distribution of Cluster Energy versus Cluster Size Fast

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 410cm

Comparing CE and bkg only - Fast

RATIO OF SEED TO CLUSTER ENERGY

Background has many more events with a ratio of 1

→ crystal seed is cluster

Conclusion and Next Steps

Results so far:

- **Fast** greatly outperforms **Full** in timing
- Acceptance of 95% is good, but energy resolution needs to be improved
- Variables that could be used to differentiate:
 - Cluster Energy and Cluster Size
 - Radius
 - 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

Cluster Energy in Proto

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 position
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