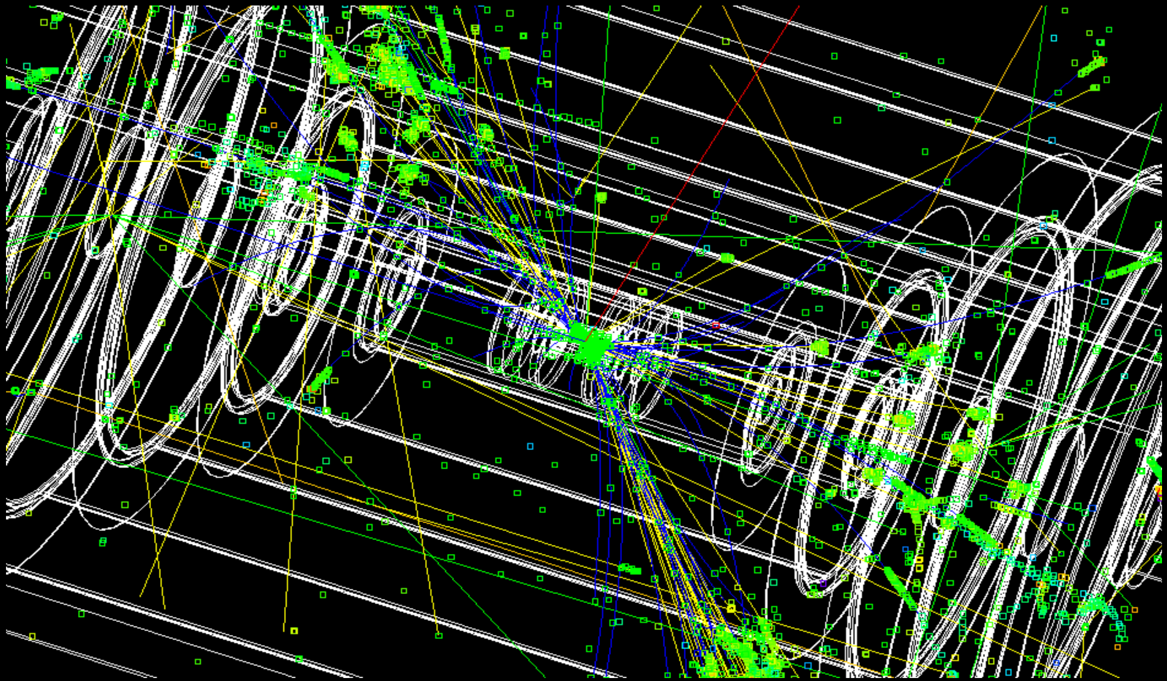
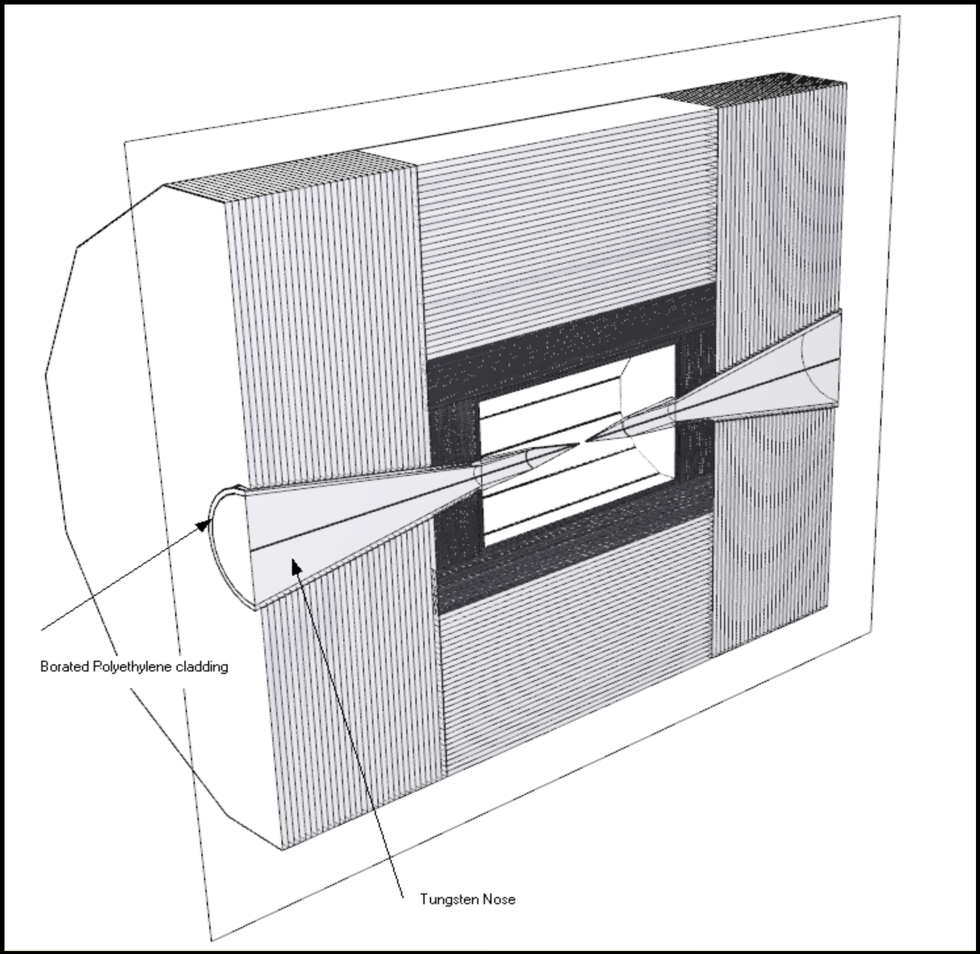
Muon Collider Detector Simulation and Calorimetry

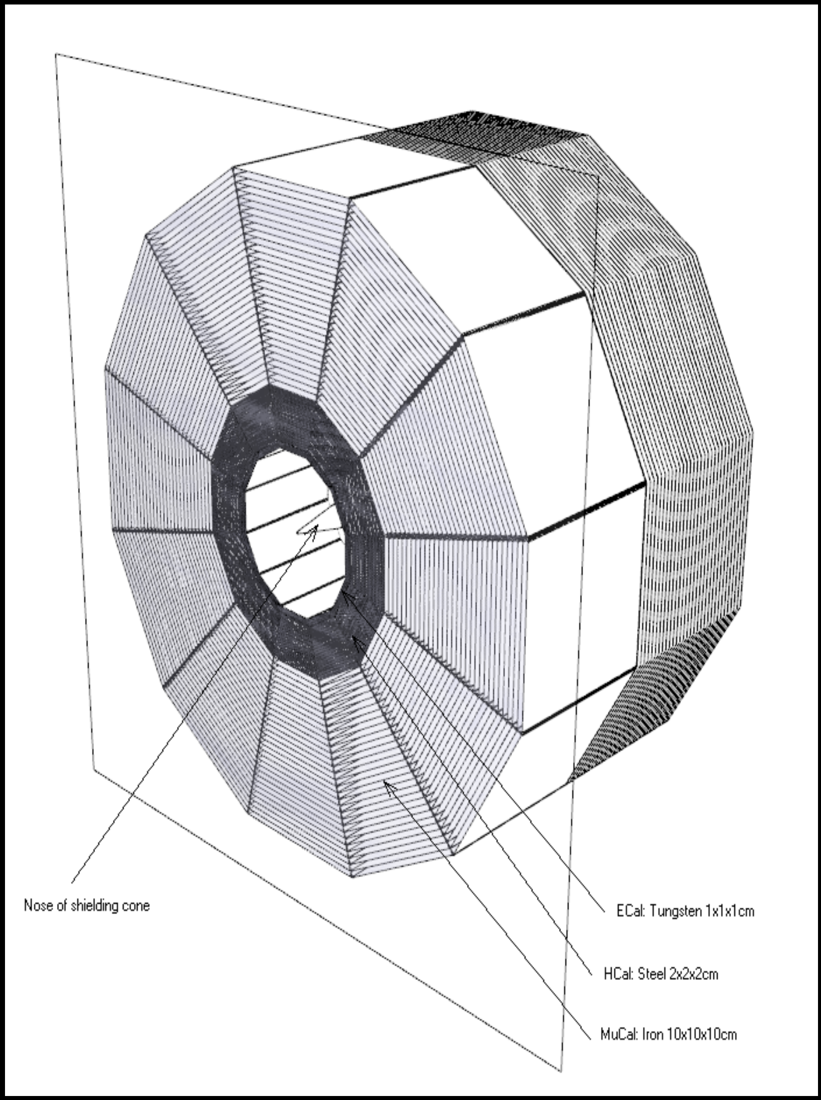
Alexander Conway

Analysis of mcd00, an ideal depth-segmented muon collider detector model.



Muon Collider Detector v.0.0 (mcd00)





Norman Graf

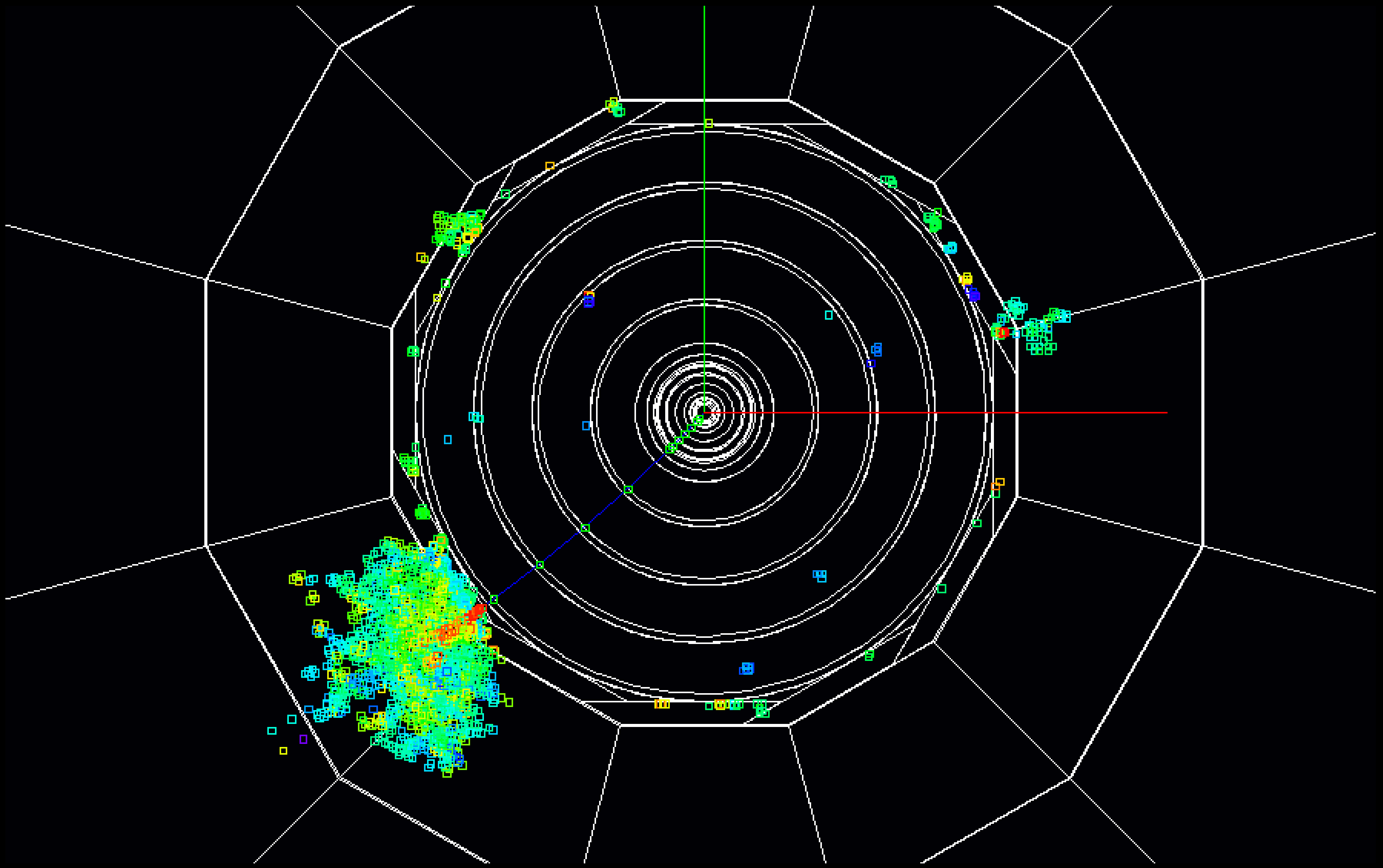
Calorimeter Properties

NUM LAYERS	EM	Hadron	Muon
Material	Tungsten	Steel 235*	Iron
Z	74	---	26
Density {g/cm^3}	19.3	7.87	7.85
Cell size {cm^3}	1	2	10
Detector Depth {cm}	10	80	300
Radiation Length	6.76 g/cm^2 0.35 cm	13.9 g/cm^2 1.76 cm	13.8 g/cm^2 1.76 cm
Nuclear Interaction Length	185 g/cm^2 9.58 cm	132.1 g/cm^2 16.8 cm	131.9 g/cm^2 16.8 cm

Data from http://pdg.lbl.gov/2010/AtomicNuclearProperties

*http://iopscience.iop.org/1748-0221/5/05/P05004/pdf/1748-0221_5_05_P05004.pdf

Beam's-eye view of a single 10GeV pion event



Studying the Detector

- Simplistic model:
  - Single particle events
  - No noise
- Calorimeter properties:
  - Total absorption
  - Homogeneous
  - Sensitive
- Establish baseline properties

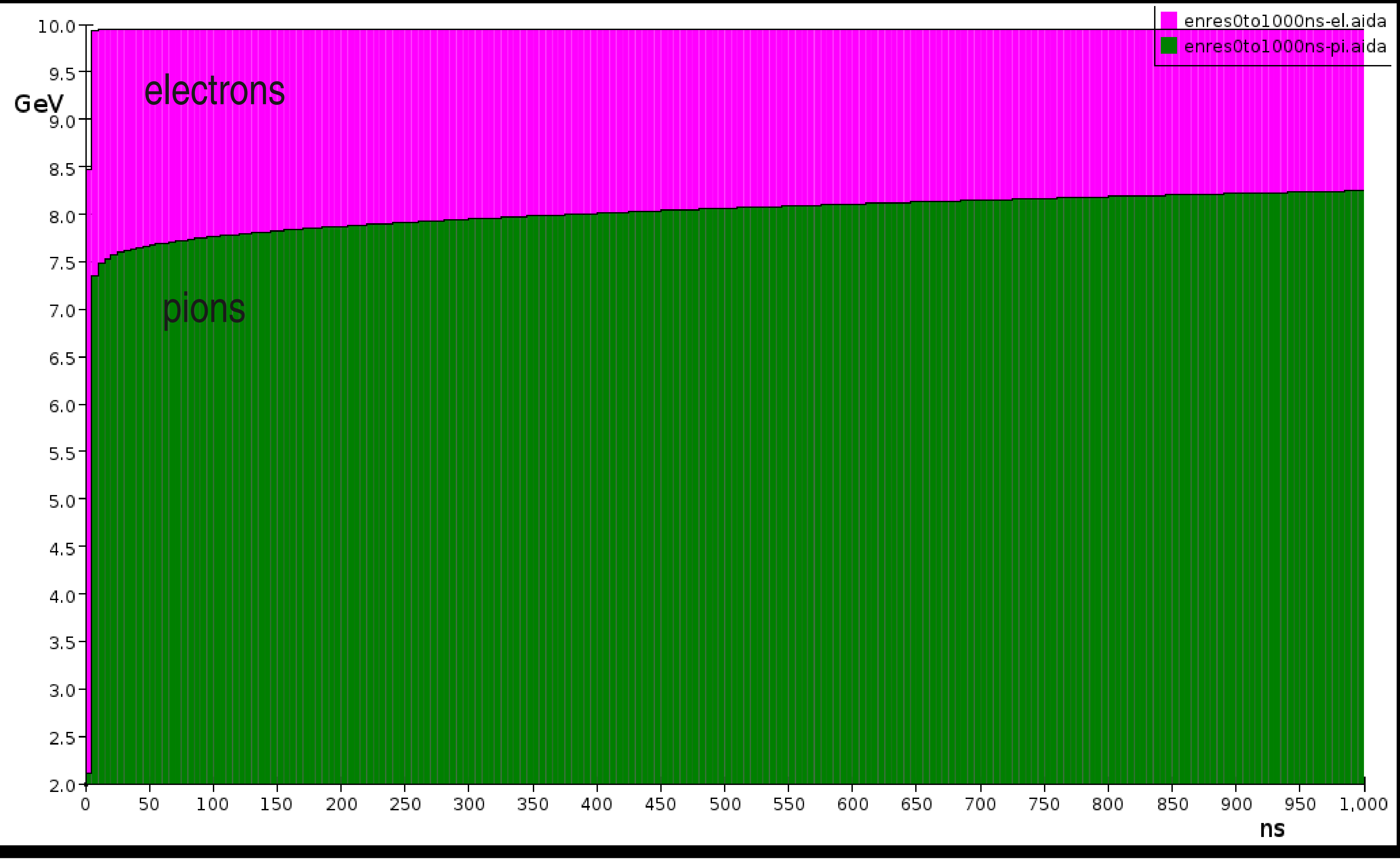
Studying the Detector

- Energy resolution
  - How much can we detect?
  - How much does signal vary?
  - Can we characterize particles?
- Constraints to add
  - Timing cuts
  - Energy deposition threshold
  - Clustering

Establishing a Baseline: Timing cuts

- Simulated 10GeV electrons and pions
- How fast do showers develop?

Energy Response with varying time cutoffs from 0 to 1000ns

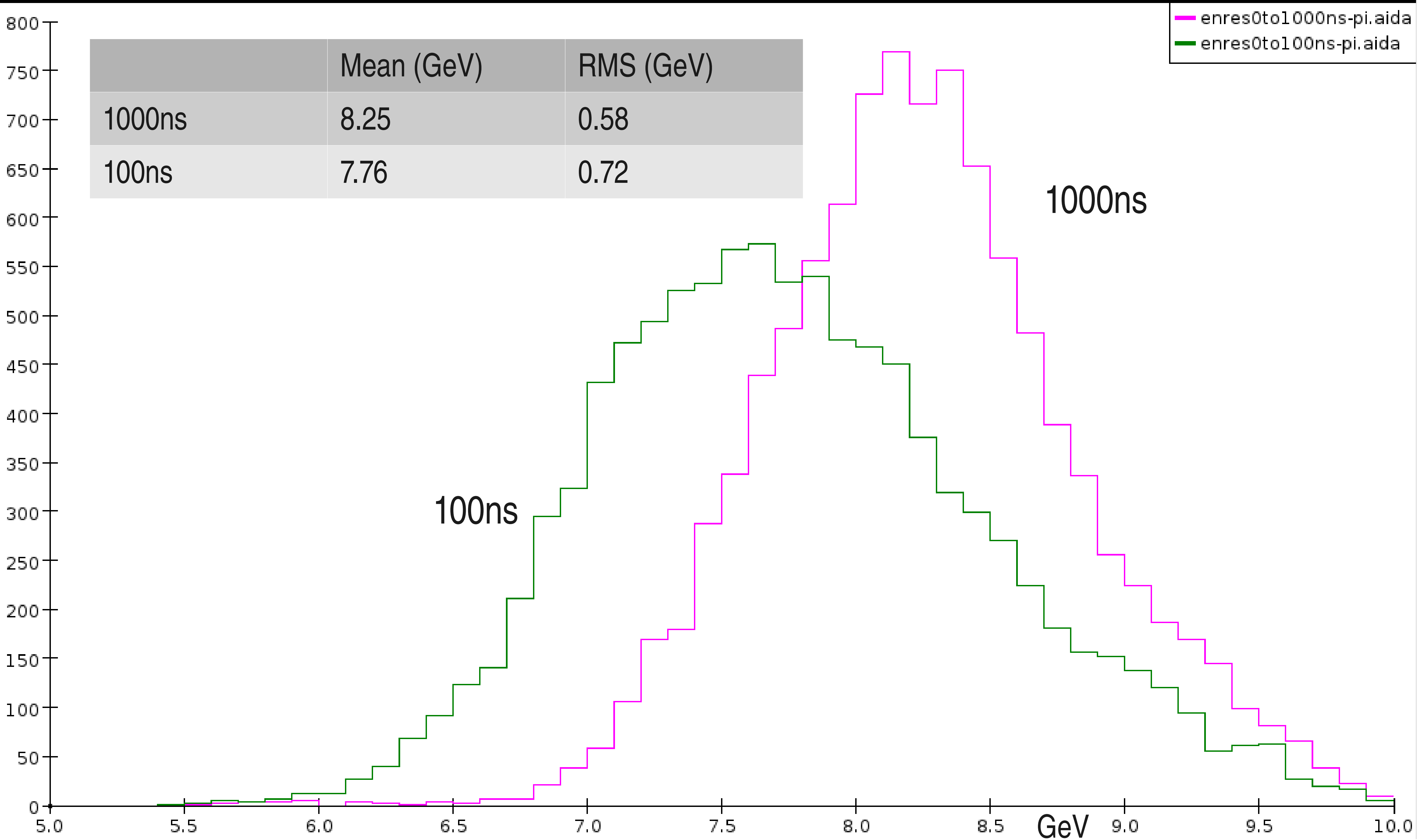


Time Cutoff Comparisons

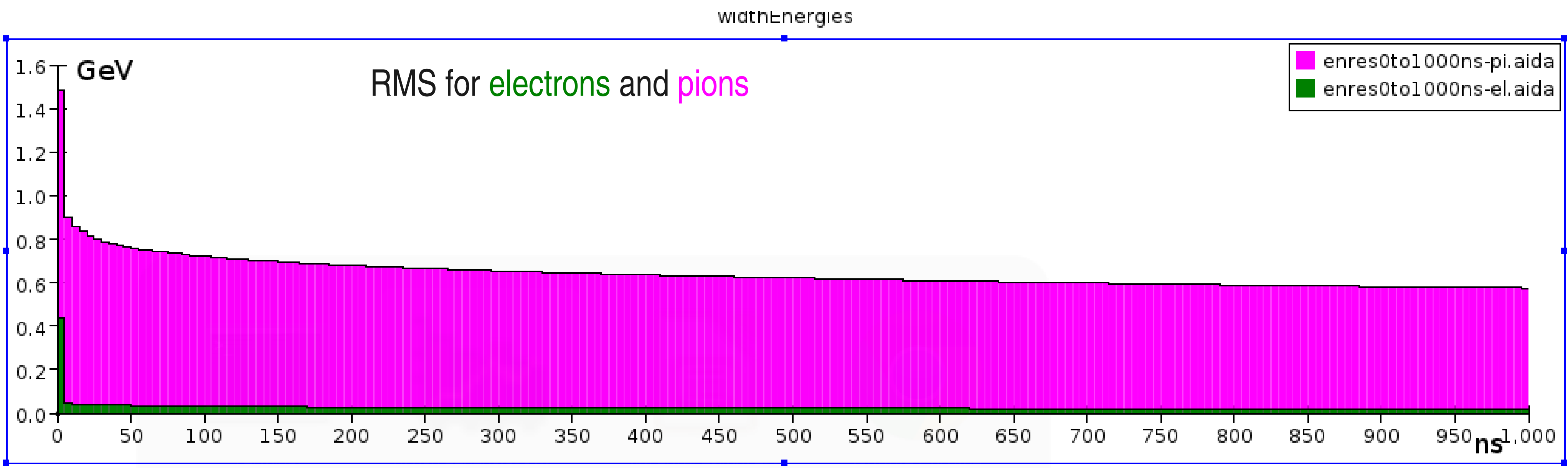
	Mean energy response (GeV)		RMS (GeV)		RMS/sqrt(E)	
	Electrons	Pions	Electrons	Pions	Electrons	Pions
1000ns	9.95	8.25	0.02	0.58	0.6%	18%
100ns	9.95	7.76	0.03	0.72	1%	23.7%
10ns	9.94	7.48	0.04	0.86	1.3%	27%

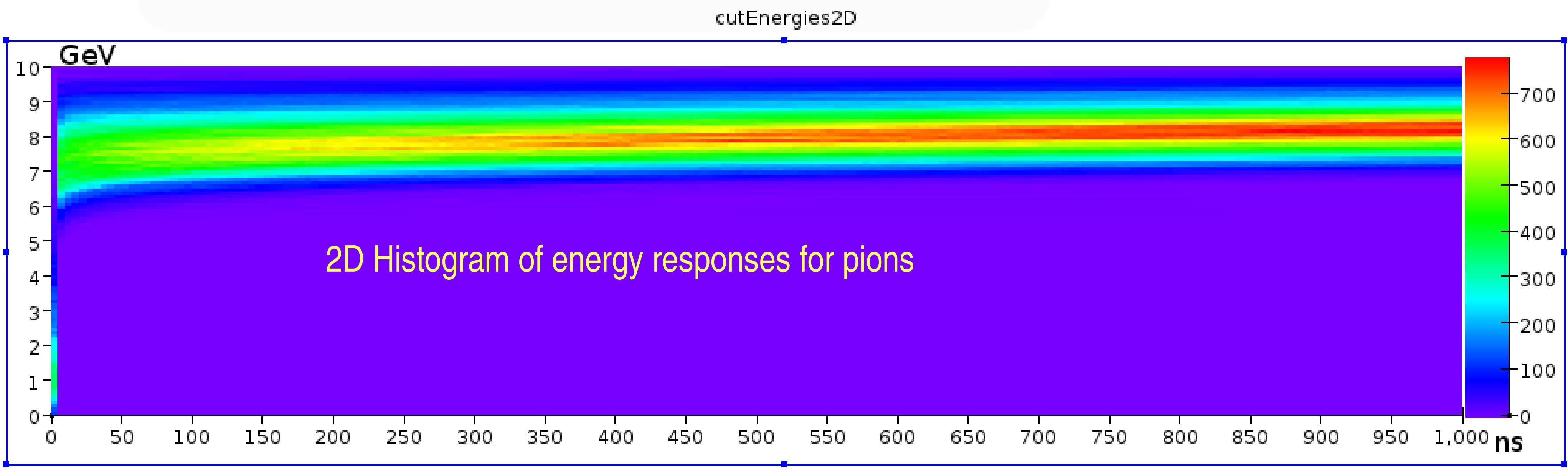
Pion energy response with 100 ns and 1000 ns cutoffs

	Mean (GeV)	RMS (GeV)
1000ns	8.25	0.58
100ns	7.76	0.72



Time Cutoff Comparisons





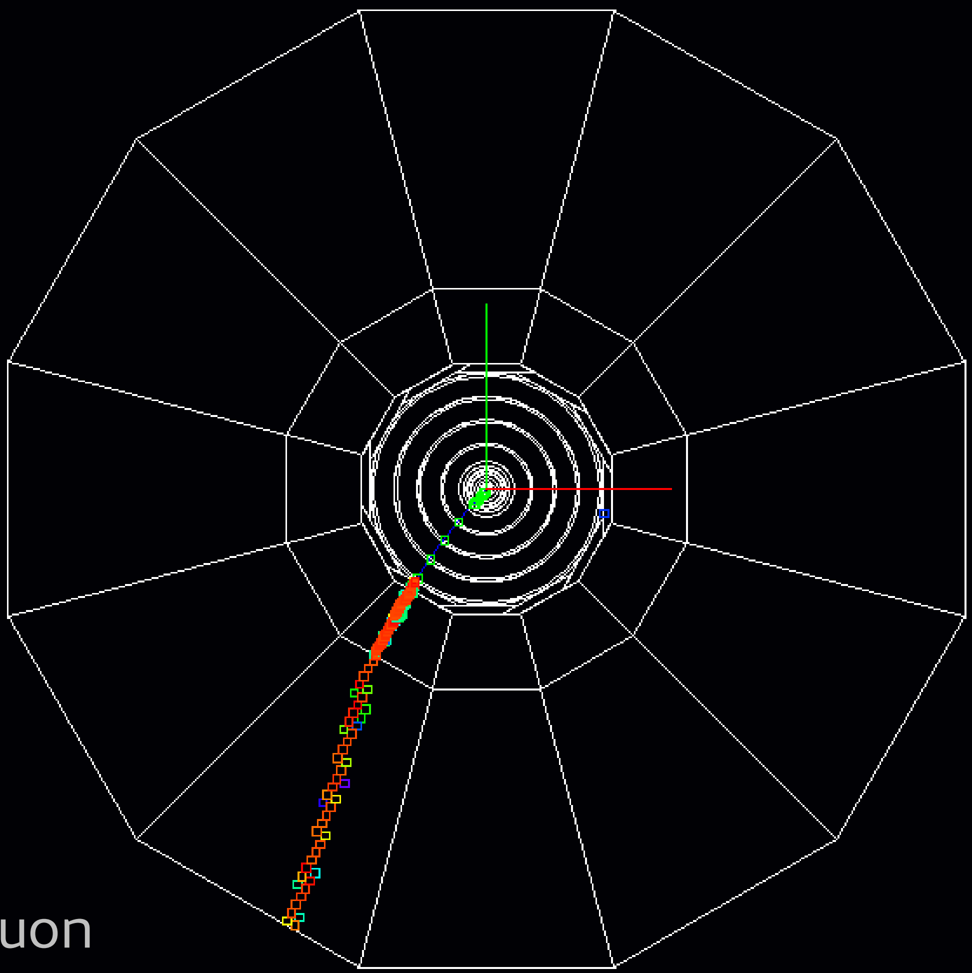
Time Cutoff Comparisons

- Electrons:
  - Characteristically fast shower development and high resolution.
- Pions:
  - Slower shower development
  - Lower energy response that varies widely
  - Will have to use other aspects of the detector to characterize these and other particles;
    - EM cal vs H cal, correction factor, shower shape, tracking, cherenkov, etc

Minimum Ionizing Particle (MIP)

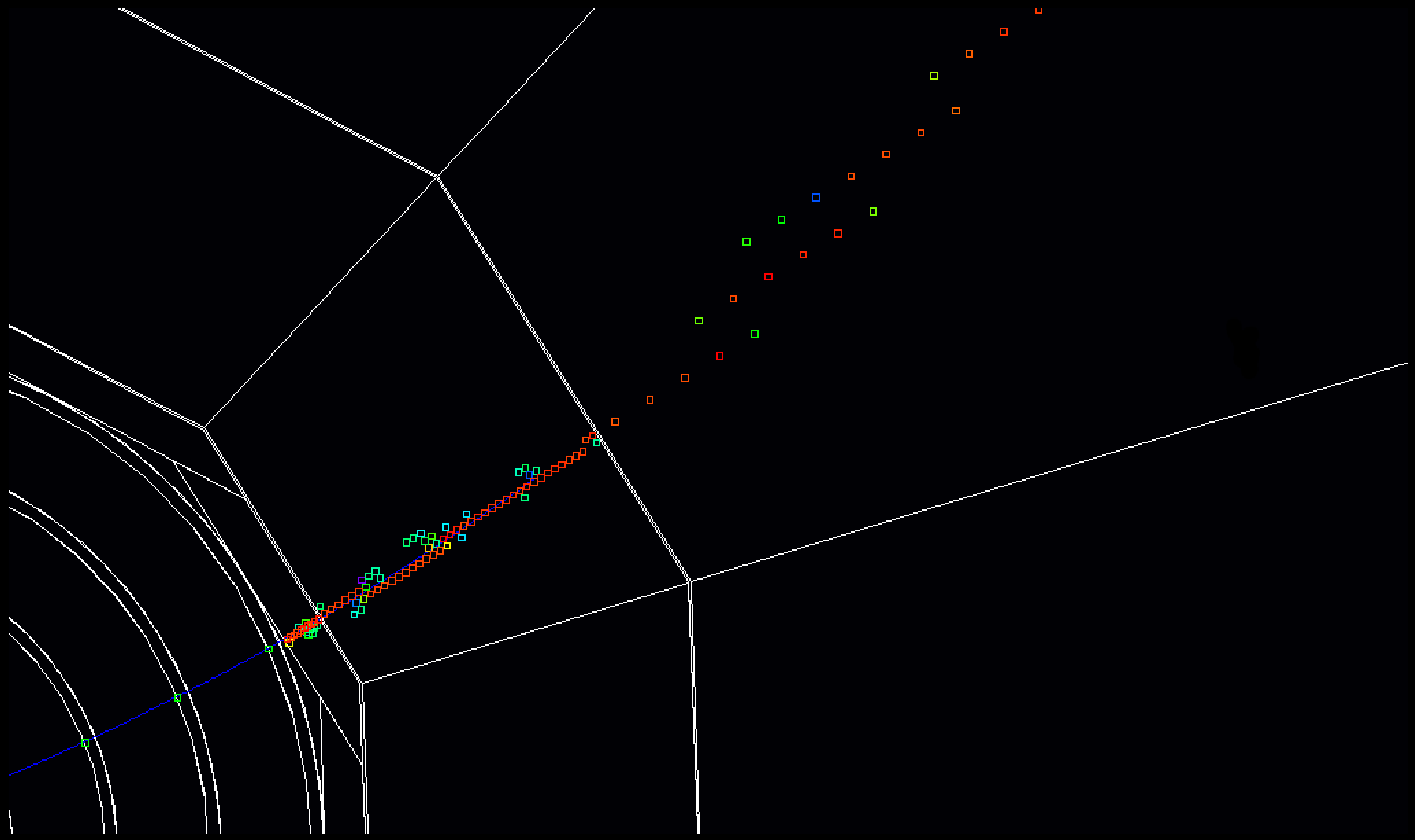
- Relativistic muons approximate MIPs
  - Little interaction with detector but with characteristic energy
  - Want to see this MIP trail
    - Energy threshold must be lower than MIP energy
  - Use muons to measure the MIP energy specific to each type of calorimeter

Minimum Ionizing Particle (MIP)

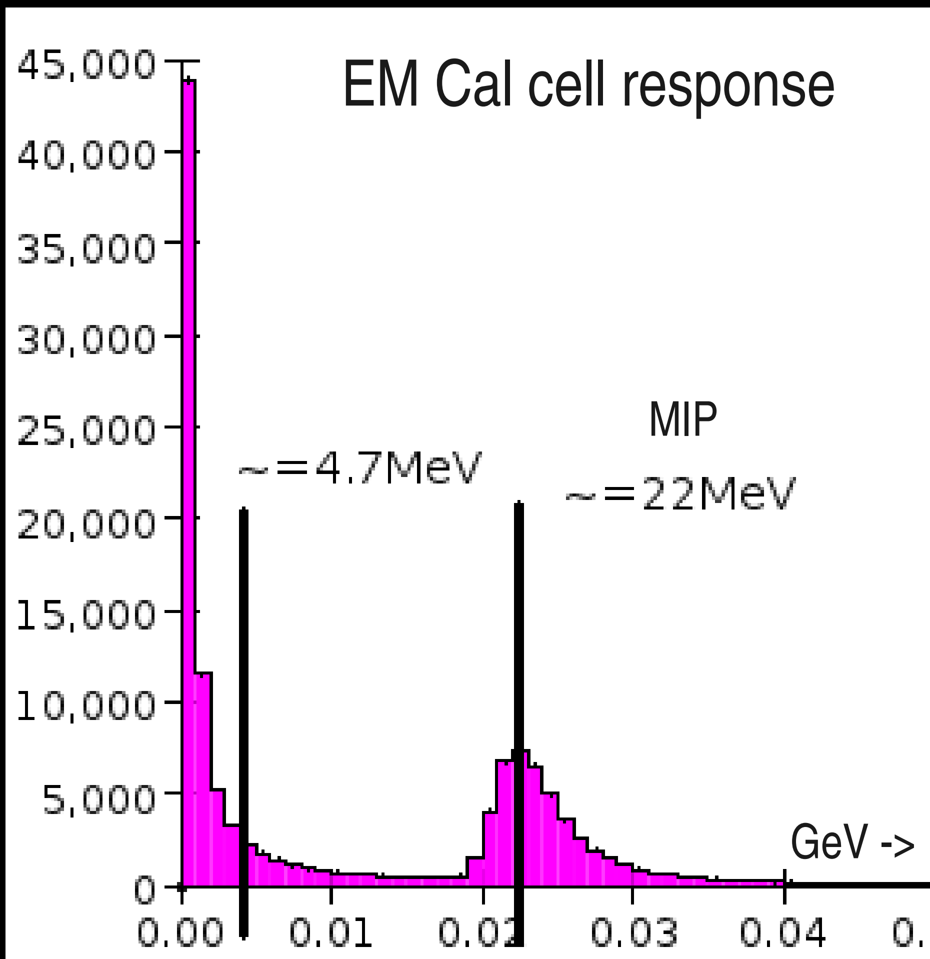


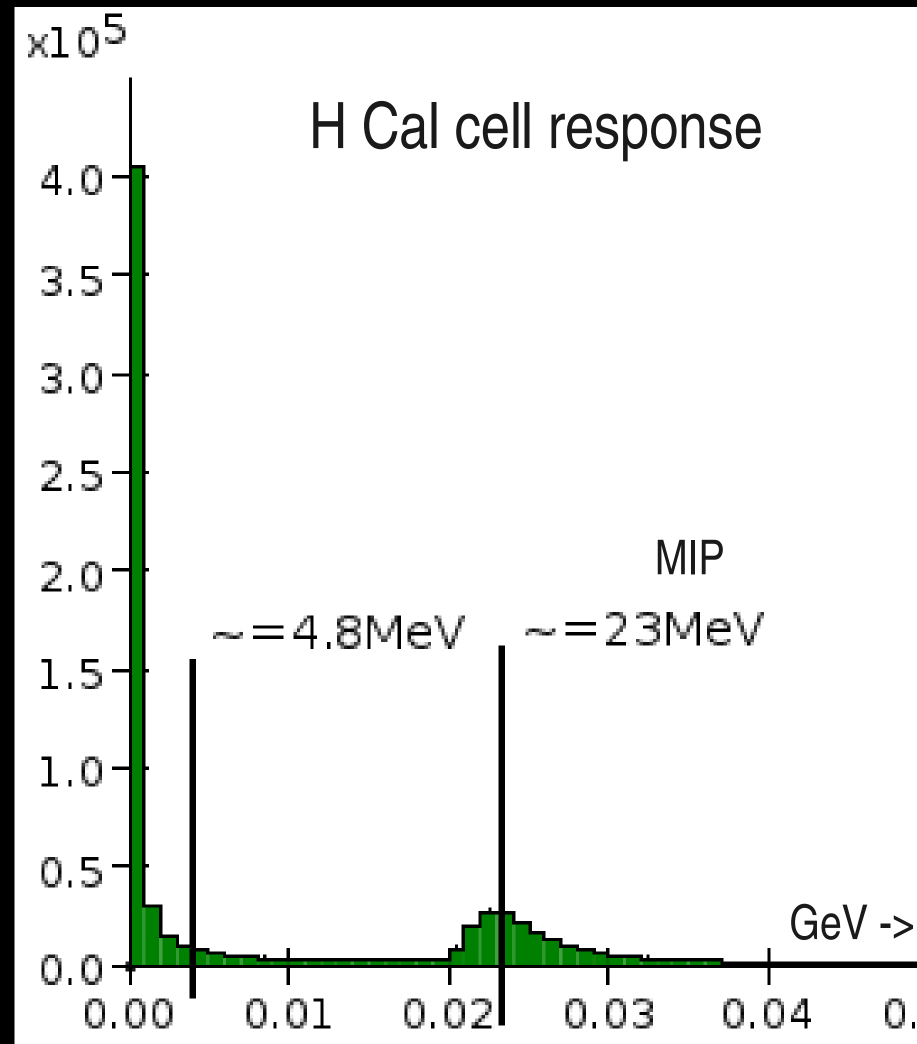
10 GeV Muon

Minimum Ionizing Particle (MIP)

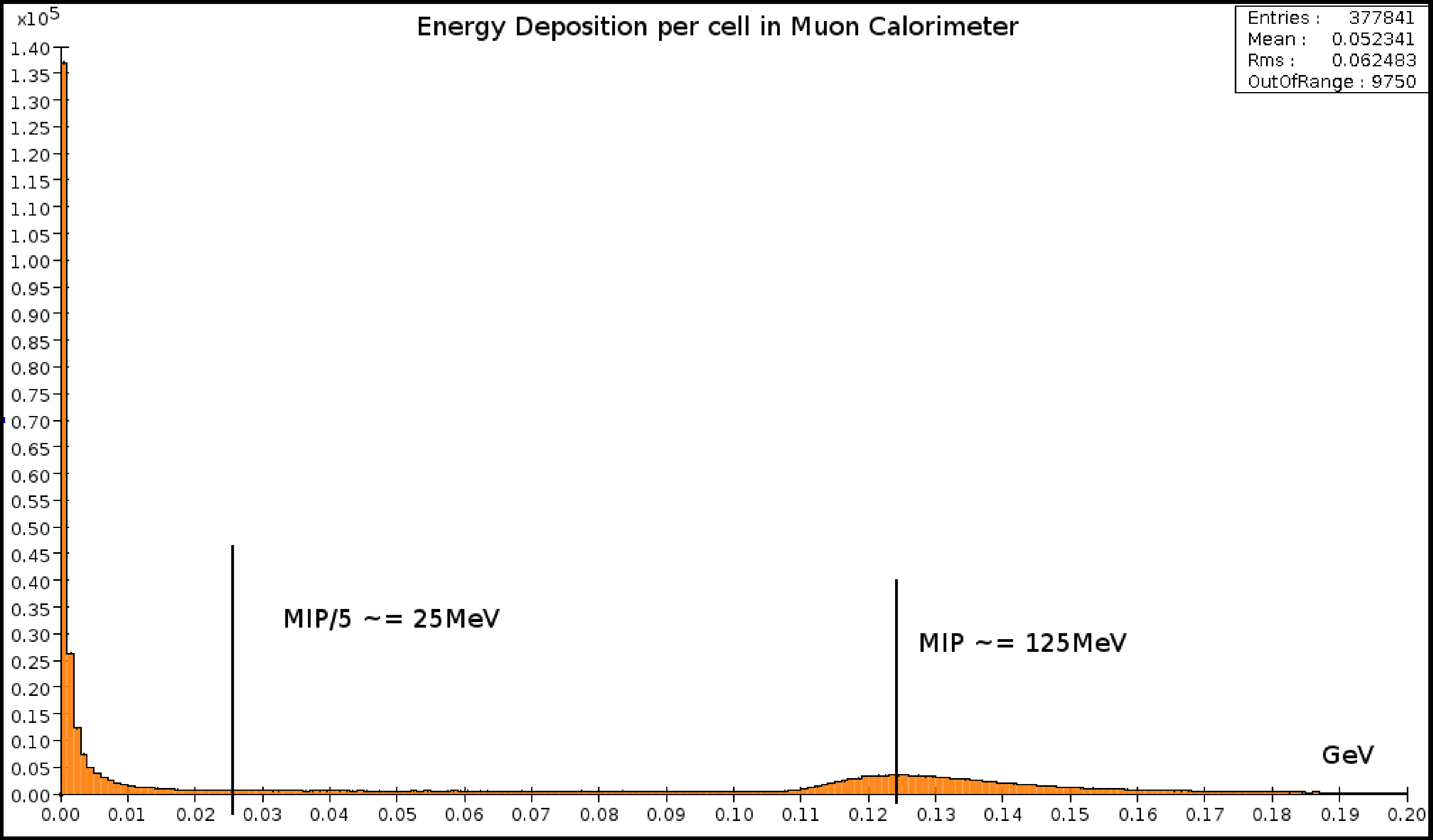


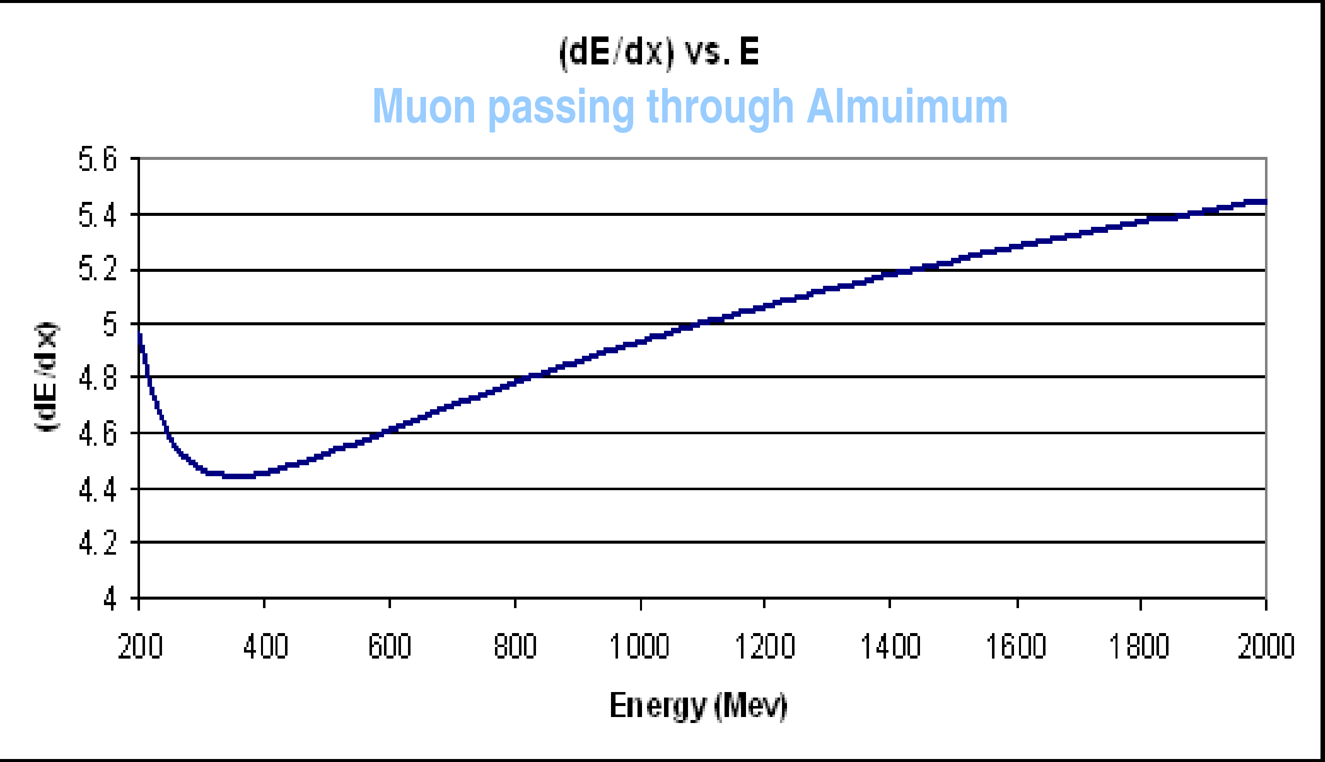
Minimum Ionizing Particle (MIP): EM and H Cals

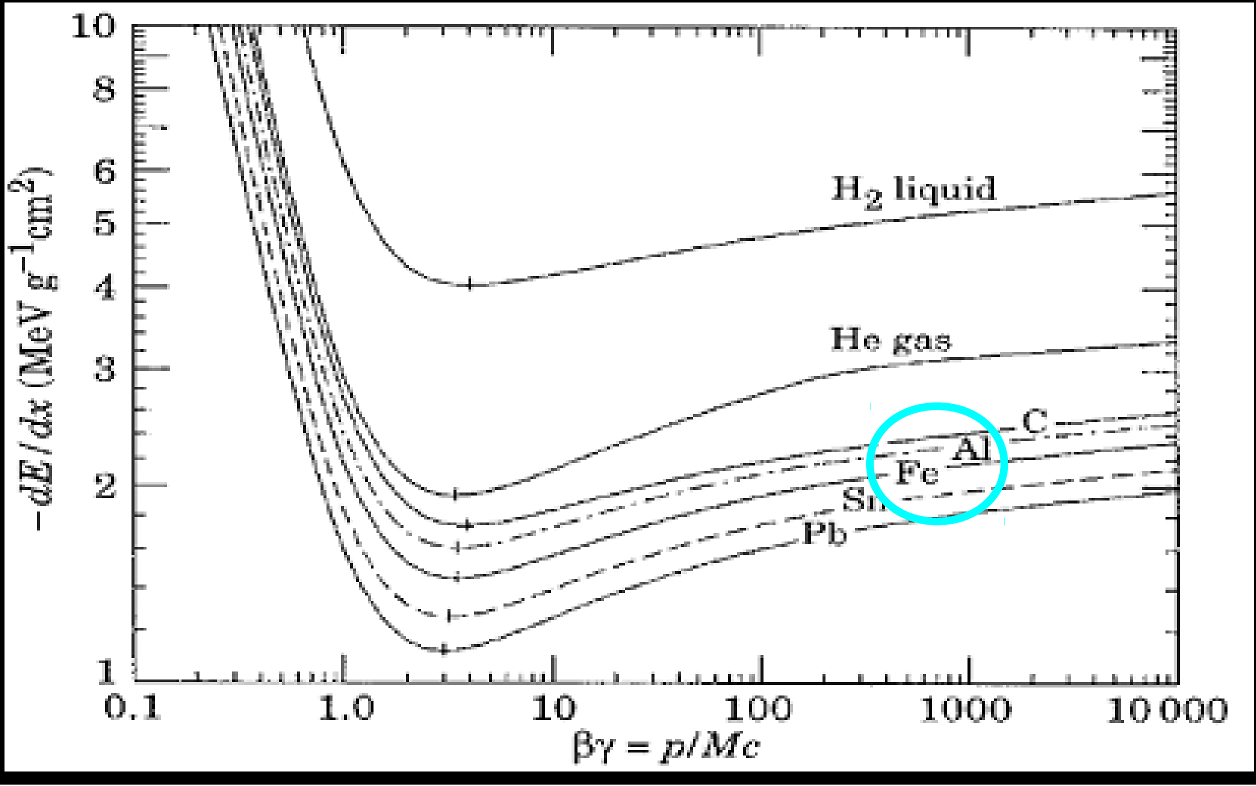




Minimum Ionizing Particle (MIP): Muon Cal







http://mxp.physics.umn.edu/s06/Projects/S06_ParticleShowerEnergy/theory.htm

Minimum Ionizing Particle (MIP)

- Minimum ionization is very clear in all detectors
  - Need to test other energies
- Muon cal's MIP energy is about five times that of the other cals
  - Muon cal cells are 5X bigger but otherwise very similar to H cal
  - Hcal cells are 2X bigger than EM but EM has approximately twice the density
- Use arbitrary value less than one MIP for energy cutoff, 1/5 MIP for preliminary studies.

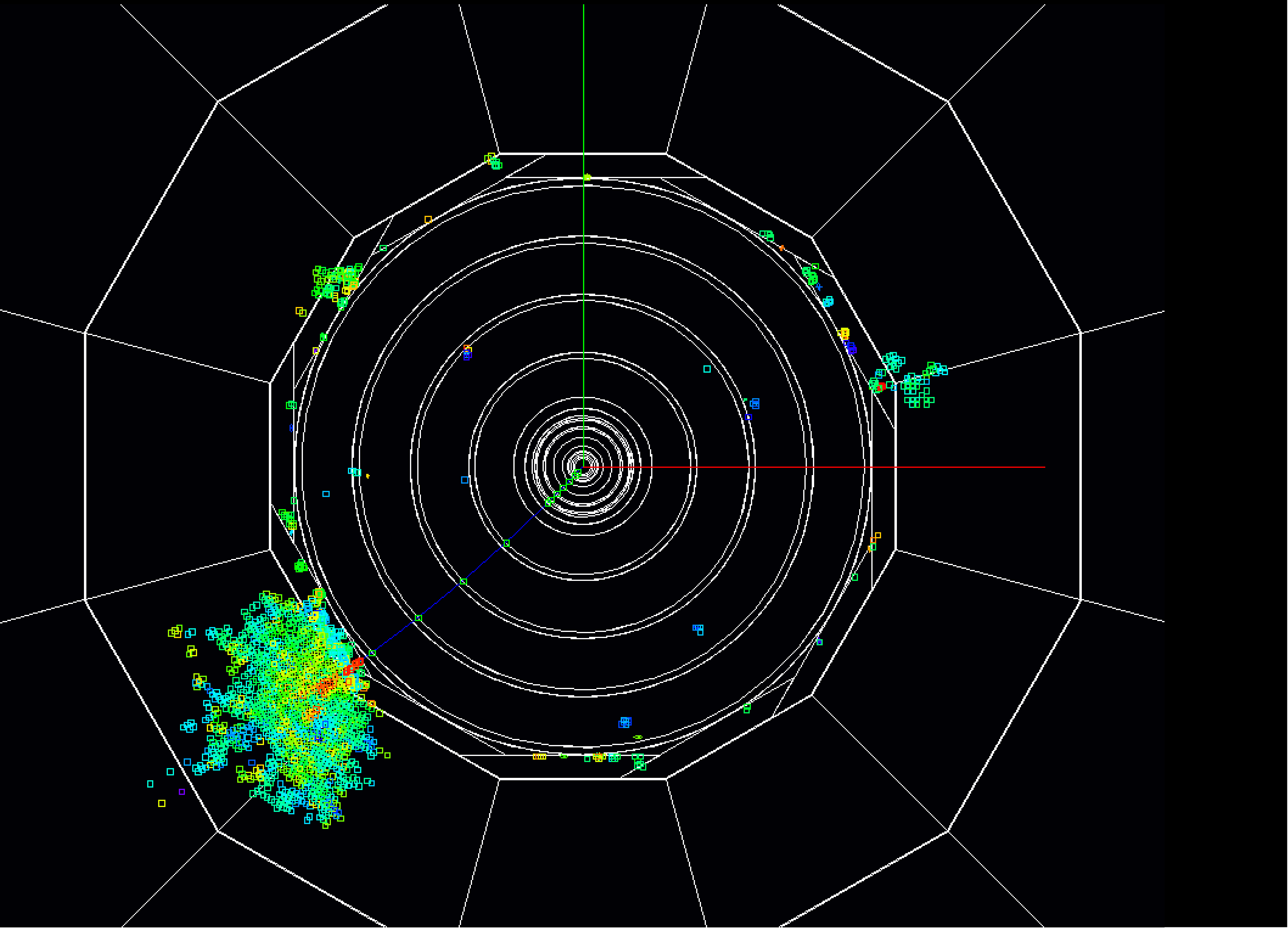
Energy Cuts: 1/5MIP

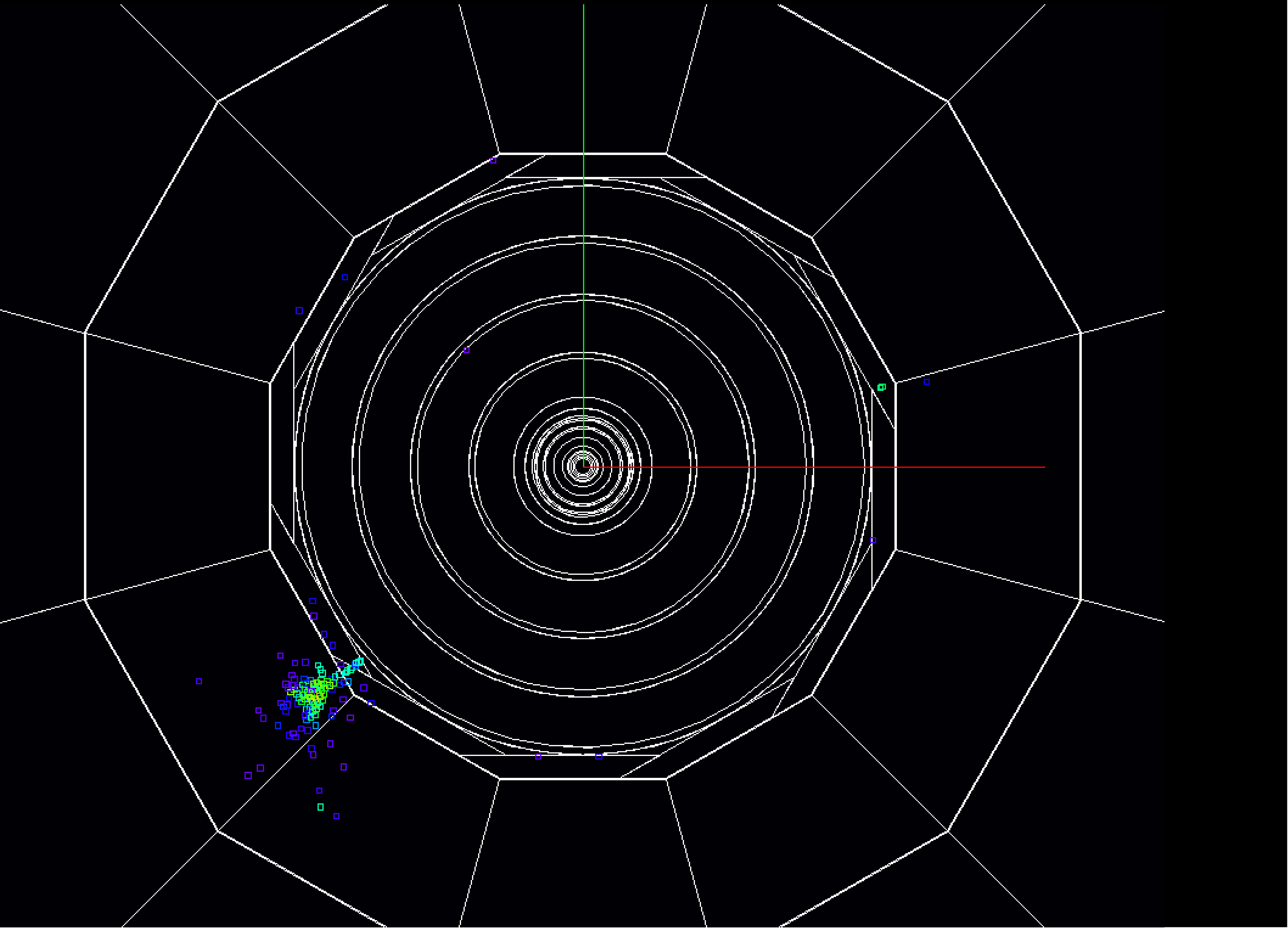
Before Cuts:

	Mean energy response (GeV)		RMS (GeV)		RMS/sqrt(E)	
	Electrons	Pions	Electrons	Pions	Electrons	Pions
1000ns	9.95	8.25	0.02	0.58	0.6%	18%
100ns	9.95	7.76	0.03	0.72	1%	23.7%
10ns	9.94	7.48	0.04	0.86	1.3%	27%

After Cuts:

	Mean energy response (GeV)		RMS (GeV)		RMS/sqrt(E)	
	Electrons	Pions	Electrons	Pions	Electrons	Pions
1000ns	9.520	7.05	0.059	0.75	1.9%	24%
100ns	9.513	6.85	0.064	0.82	2.0%	26%
10ns	9.510	6.74	0.067	0.88	2.1%	27.8%





Energy Cuts: 1/5MIP

- Pion response is drastically changed
  - Especially for longer time windows
  - 'Splashes'?
  - Some will be lost by clustering anyway
  - Low energy hit showers could be matched to high energy clusters
- Look at clusters first, then combine with energy cuts

Clustering

- Must remove hits that can't be traced to particle
- Can test different algorithms,
  - Fixed-cone clustering
  - Nearest neighbor clustering
- Fixed-cone:
  - Clusters of hits that fit within cone
- Nearest neighbor:
  - Clusters hits adjacent within x number of cells

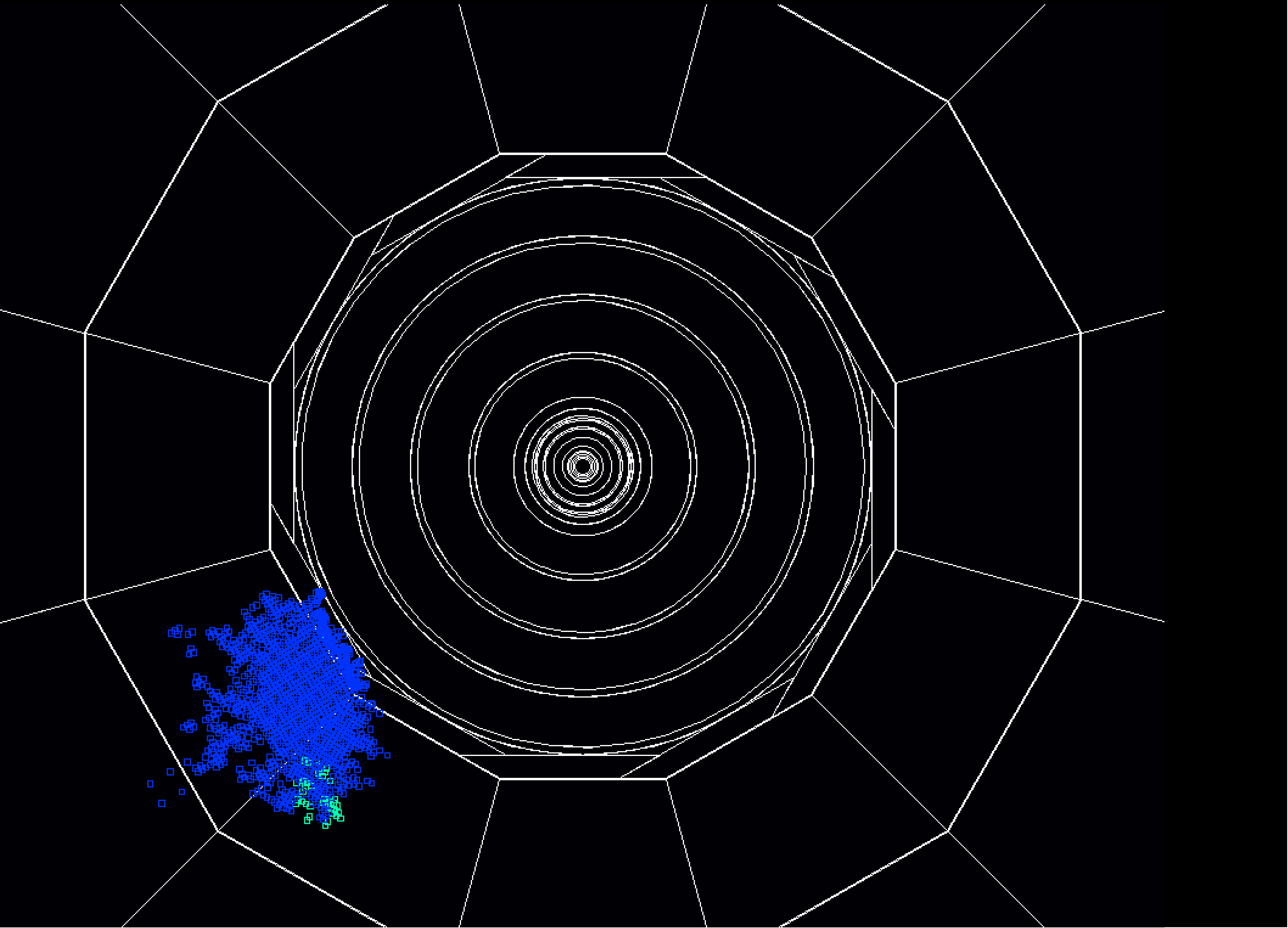
Clustering: Fixed-cone

Before Clustering:

	Mean energy response (GeV)		RMS (GeV)		RMS/sqrt(E)	
	Electrons	Pions	Electrons	Pions	Electrons	Pions
1000ns	9.95	8.25	0.02	0.58	0.6%	18%
100ns	9.95	7.76	0.03	0.72	1%	23.7%
10ns	9.94	7.48	0.04	0.86	1.3%	27%

After Clustering:

	Mean energy response (GeV)		RMS (GeV)		RMS/sqrt(E)	
	Electrons	Pions	Electrons	Pions	Electrons	Pions
1000ns	9.54	7.90	0.083	0.771	2.6%	24.4%
100ns	9.94	7.57	0.052	0.83	1.6%	26.2%
10ns	9.93	7.34	0.087	0.91	2.8%	28.8%



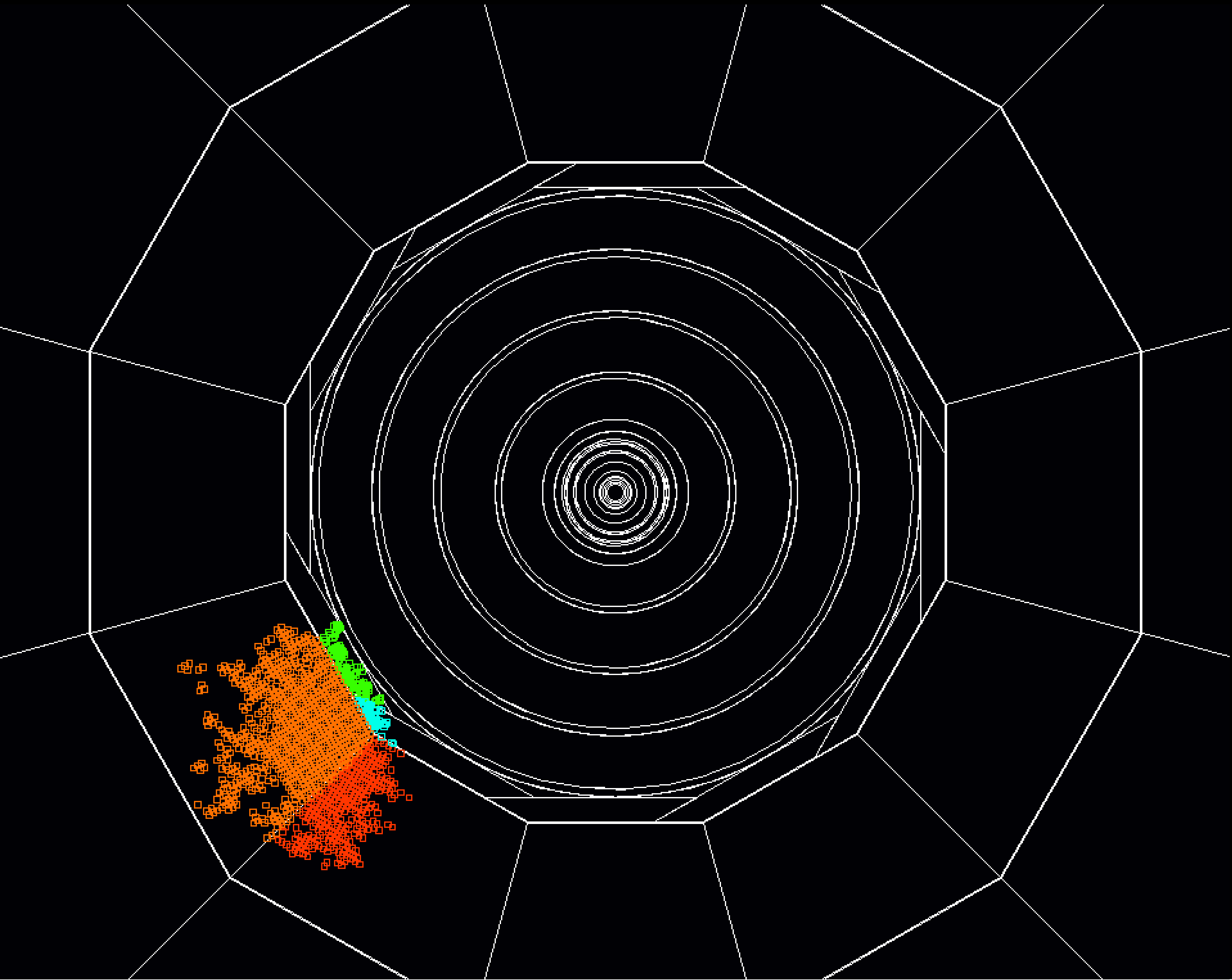
Clustering: Nearest Neighbor

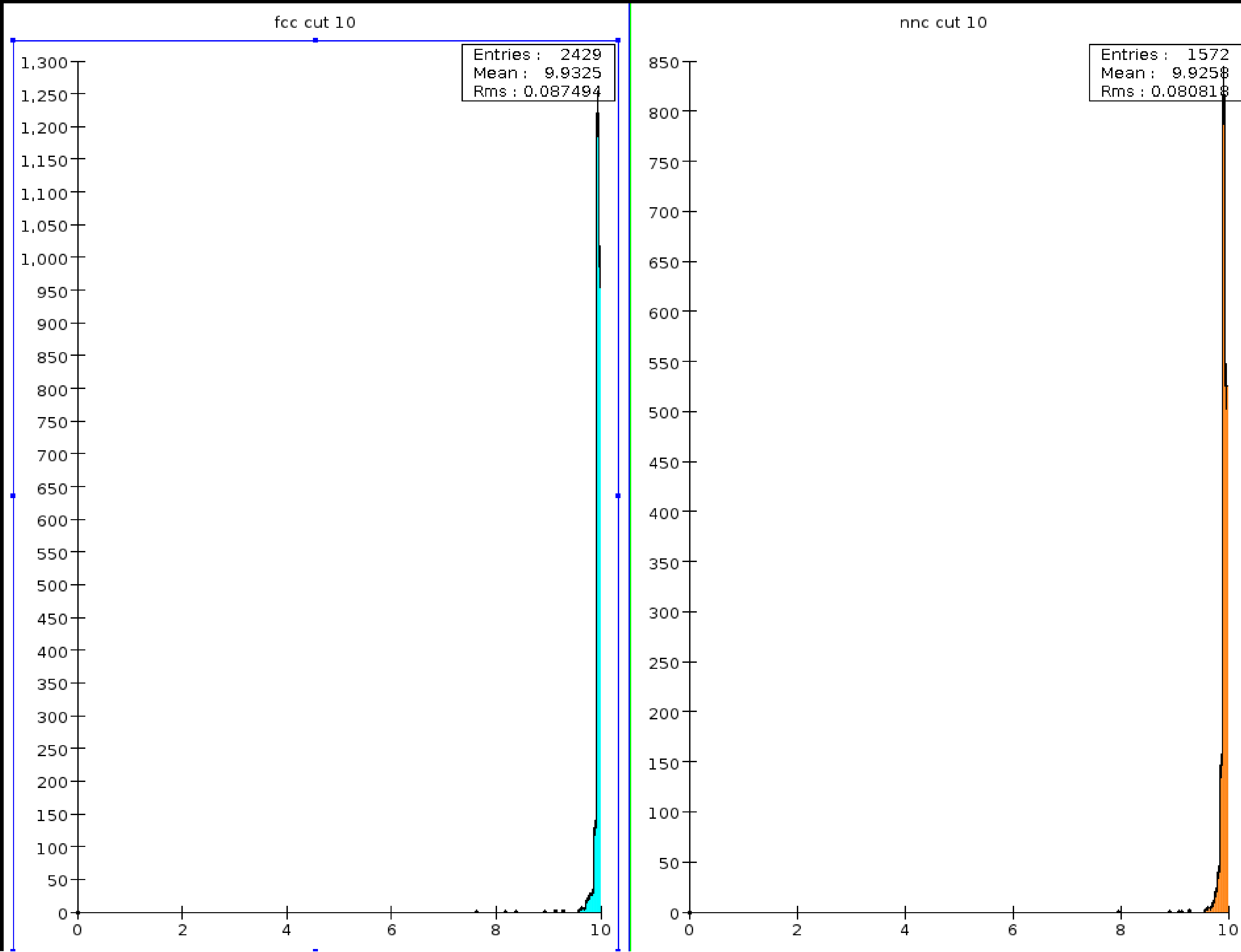
Before Clustering:

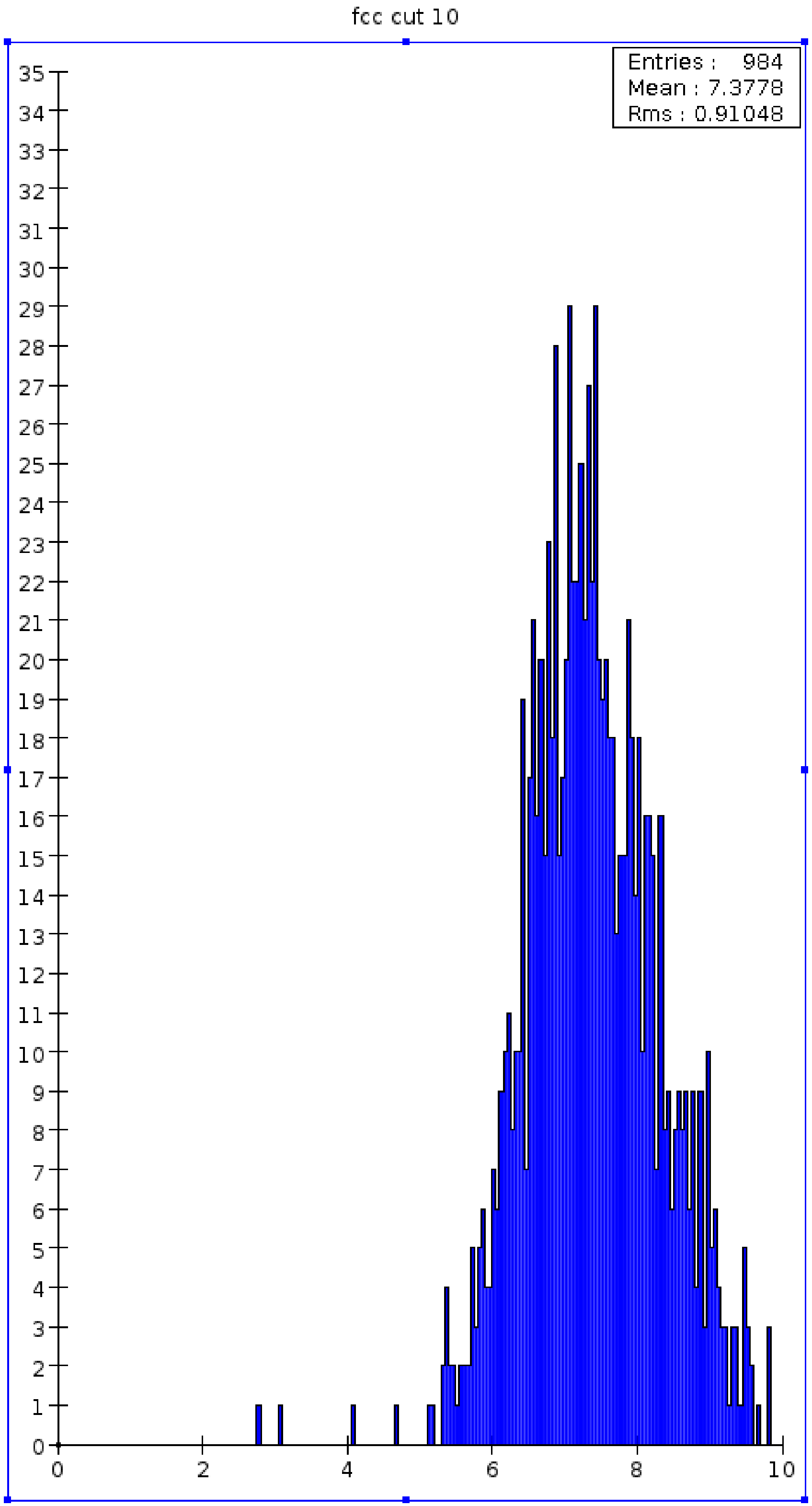
	Mean energy response (GeV)		RMS (GeV)		RMS/sqrt(E)	
	Electrons	Pions	Electrons	Pions	Electrons	Pions
1000ns	9.95	8.25	0.02	0.58	0.6%	18%
100ns	9.95	7.76	0.03	0.72	1%	23.7%
10ns	9.94	7.48	0.04	0.86	1.3%	27%

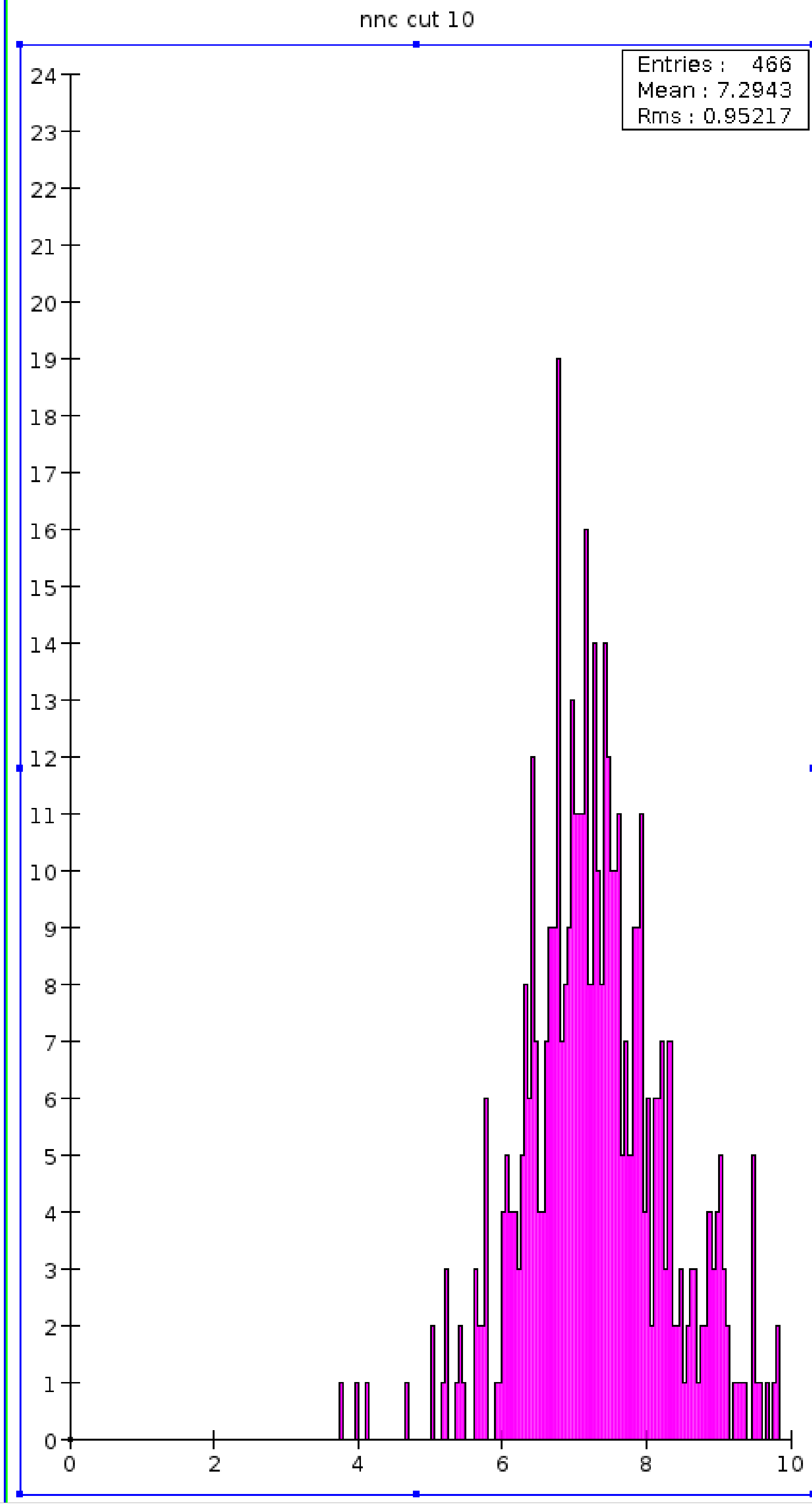
After Clustering:

	Mean energy response (GeV)		RMS (GeV)		RMS/sqrt(E)	
	Electrons	Pions	Electrons	Pions	Electrons	Pions
1000ns	9.94	7.81	0.076	0.84	2.40%	26.6%
100ns	9.93	7.50	0.078	0.89	2.47%	28.1%
10ns	9.53	7.29	0.081	0.95	2.56%	30.0%




fcc cut 10
Entries : 2429
Mean : 9.9325
Rms : 0.087494
nnc cut 10
Entries : 1572
Mean : 9.9258
Rms : 0.080818

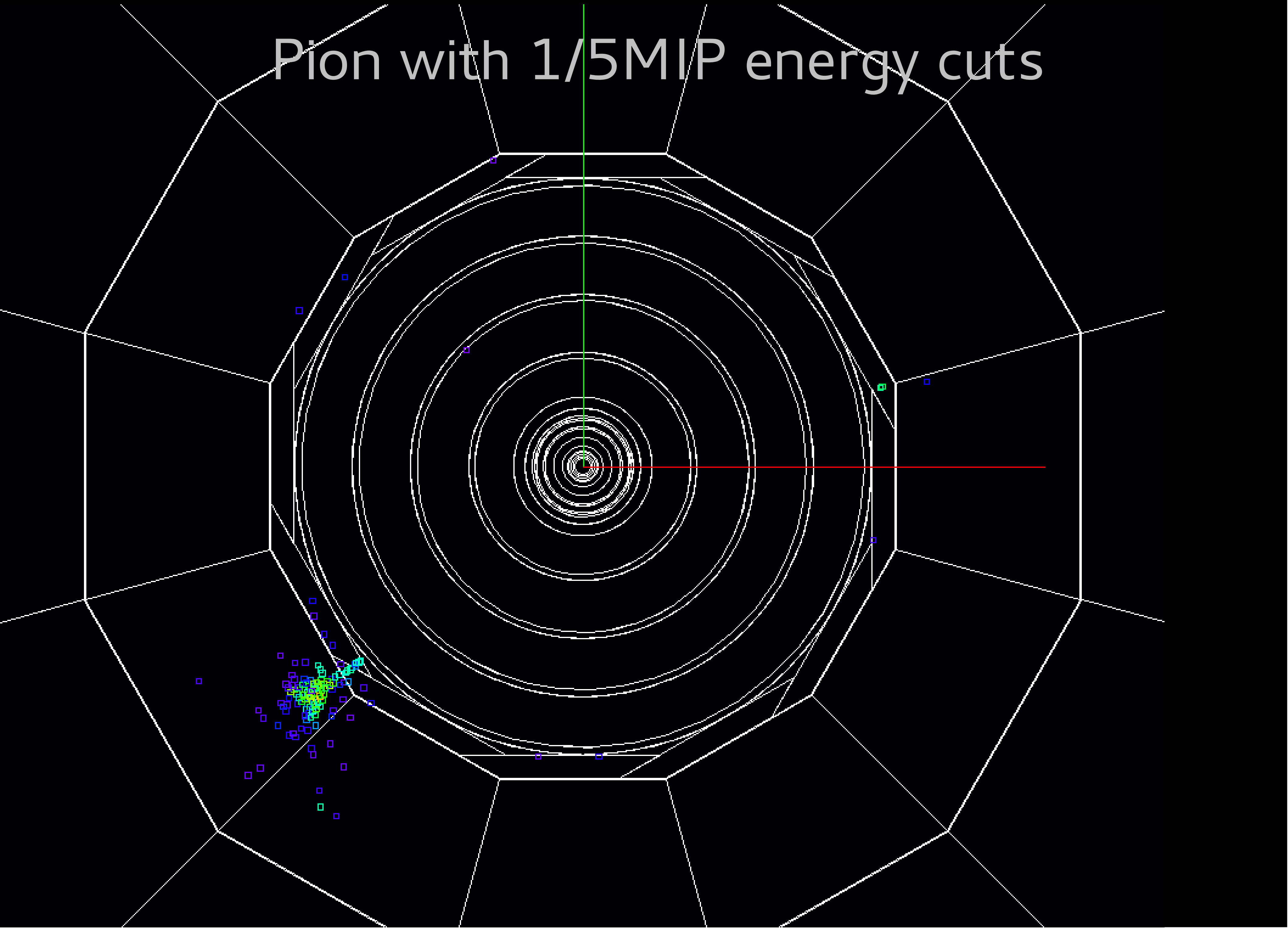

fcc cut 10
Entries : 984
Mean : 7.3778
Rms : 0.91048


nnc cut 10
Entries : 466
Mean : 7.2943
Rms : 0.95217

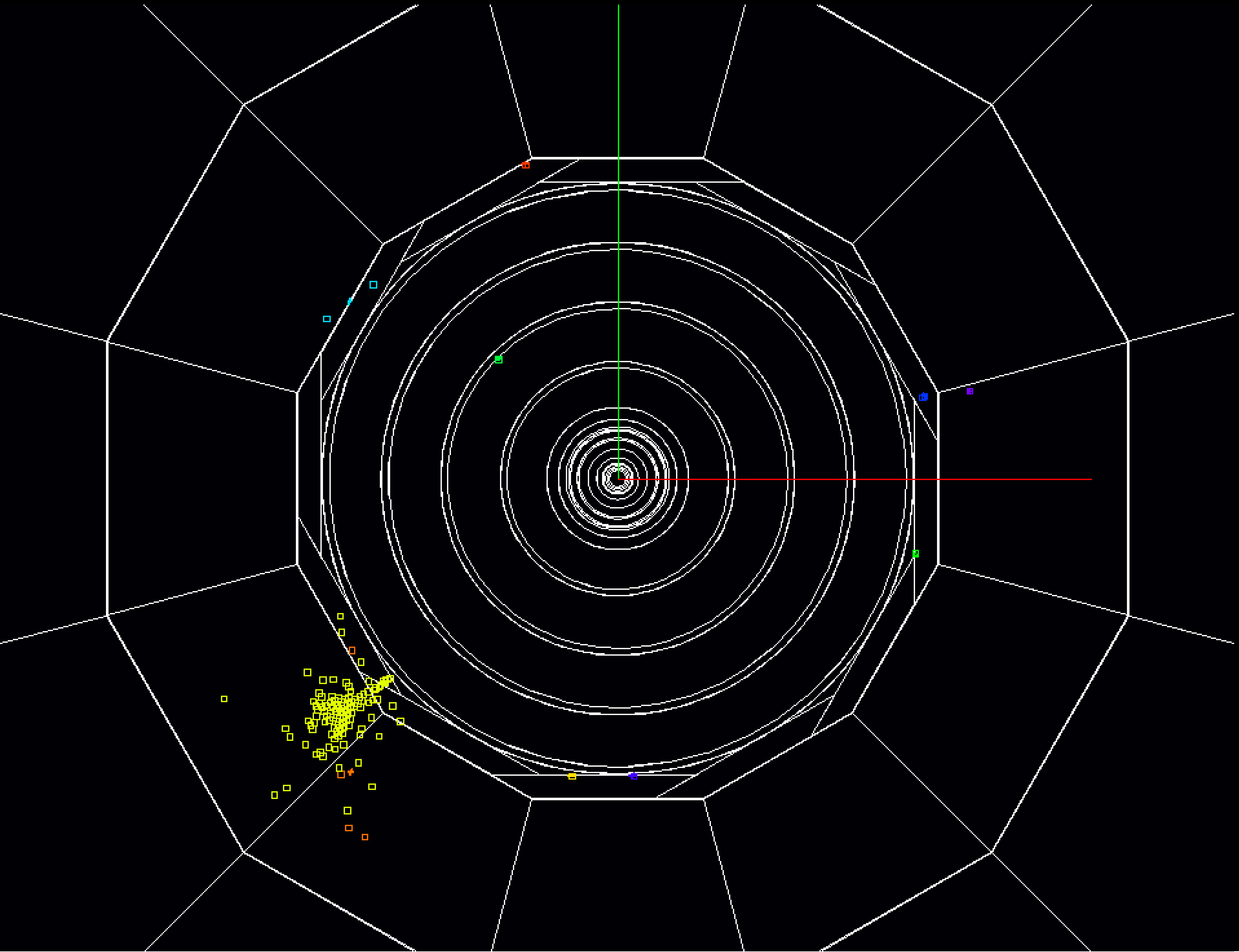
Thoughts

- Not significantly different
- Can still change parameters
  - Better test of performance will be reconstructing multiple particles
- Possible ways to improve
  - Combine nearest-neighbor clusters that fall with in fixed cone
  - Perform nearest-neighbor on fixed cone clusters
- Energy cut performance will be key

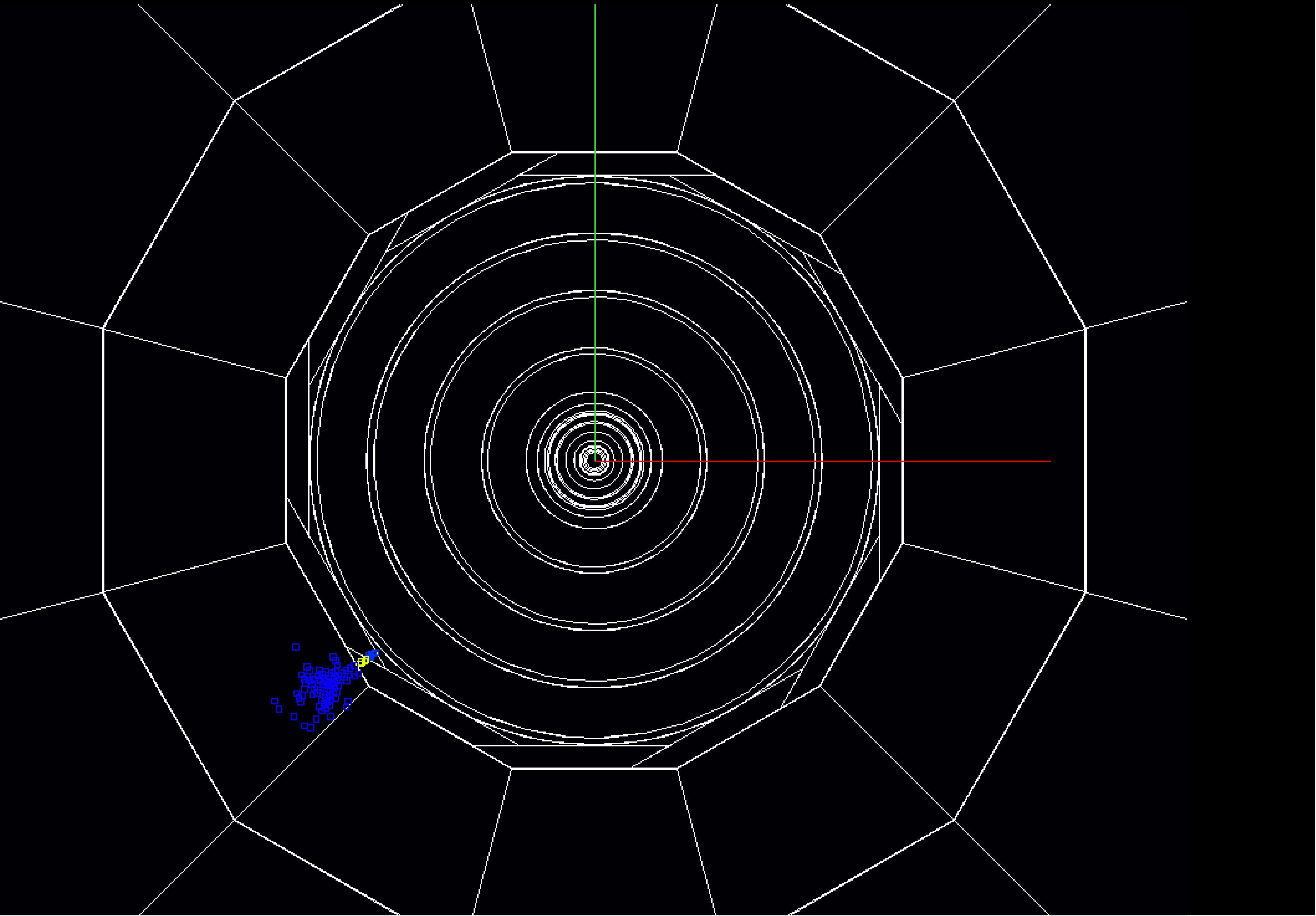
Pion with 1/5MIP energy cuts



Fixed Cone



Nearest Neighbor



Clustering/threshold: Fixed-cone

Before Cuts (fixed-cone clustering):

	Mean energy response (GeV)		RMS (GeV)		RMS/sqrt(E)	
	Electrons	Pions	Electrons	Pions	Electrons	Pions
1000ns	9.54	7.90	0.083	0.77	2.6%	24.4%
100ns	9.94	7.57	0.052	0.83	1.6%	26.2%
10ns	9.93	7.34	0.087	0.91	2.8%	28.8%

After MIP Cuts:

	Mean energy response (GeV)		RMS (GeV)		RMS/sqrt(E)	
	Electrons	Pions	Electrons	Pions	Electrons	Pions
1000ns	9.52	6.81	0.085	0.82	2.6%	25.9%
100ns	9.52	6.68	0.086	0.86	1.6%	27.2%
10ns	9.51	6.61	0.087	0.89	2.8%	28.1%

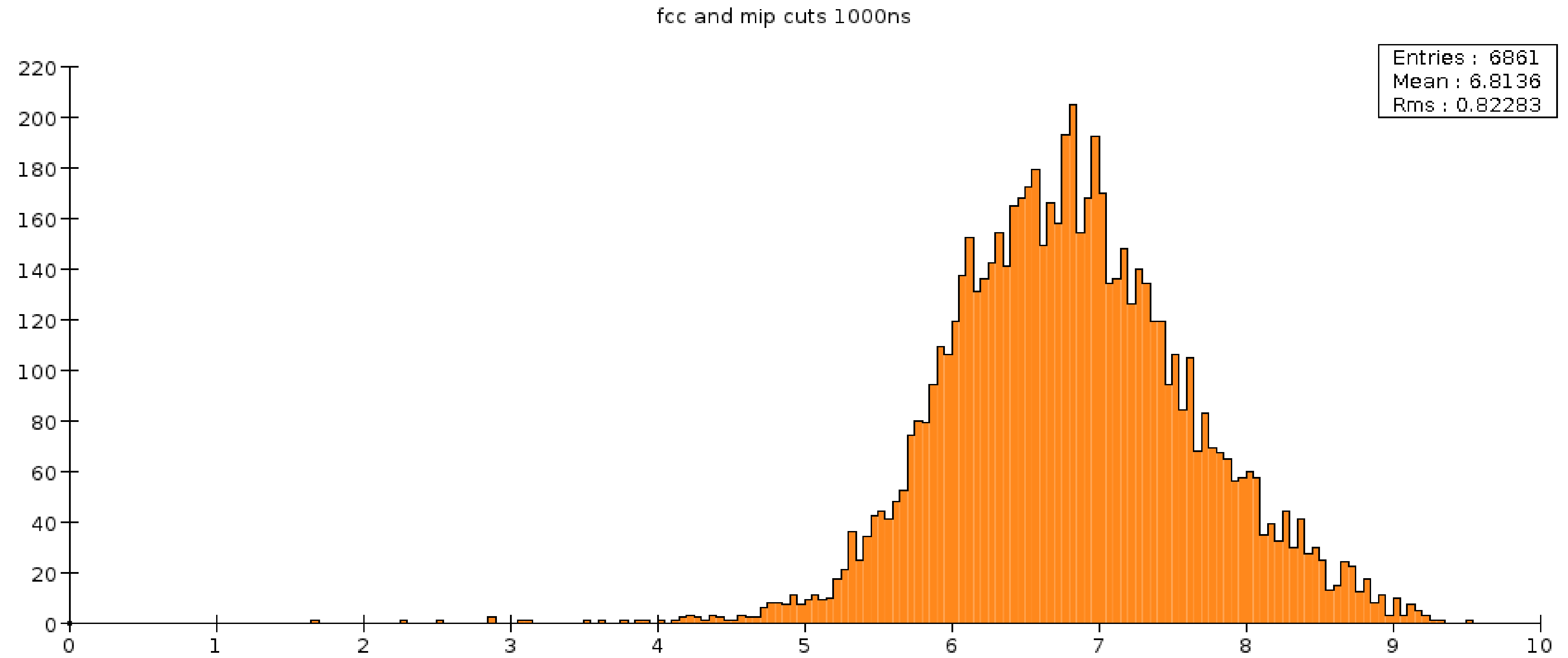
Clustering/threshold: Nearest Neighbor

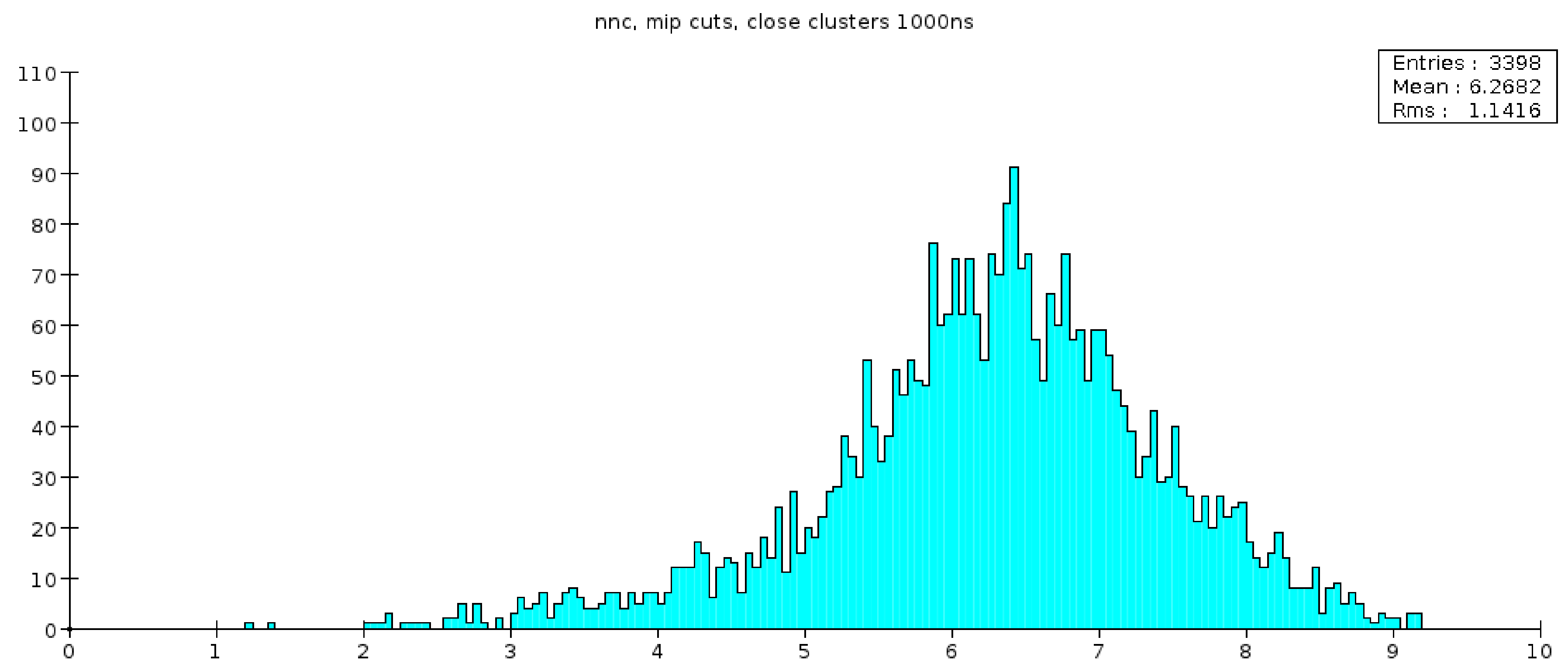
Before Cuts (nearest neighbor clustering):

	Mean energy response (GeV)		RMS (GeV)		RMS/sqrt(E)	
	Electrons	Pions	Electrons	Pions	Electrons	Pions
1000ns	9.94	7.81	0.076	0.84	2.40%	26.6%
100ns	9.93	7.50	0.078	0.89	2.47%	28.1%
10ns	9.53	7.29	0.081	0.95	2.56%	30.0%

After Cuts:

	Mean energy response (GeV)		RMS (GeV)		RMS/sqrt(E)	
	Electrons	Pions	Electrons	Pions	Electrons	Pions
1000ns	9.52	6.27	0.085	1.14	2.6%	36.0%
100ns	9.52	6.20	0.086	1.15	1.6%	36.4%
10ns	9.51	6.15	0.087	1.65	2.8%	52.2%


fcc and mip cuts 1000ns
Entries : 6861
Mean : 6.8136
Rms : 0.82283
220
200
180
160
140
120
100
80
60
40
20
0
0
1
2
3
4
5
6
7
8
9
10


nnc, mip cuts, close clusters 1000ns
Entries : 3398
Mean : 6.2682
Rms : 1.1416
110
100
90
80
70
60
50
40
30
20
10
0
0
1
2
3
4
5
6
7
8
9
10

Thoughts

- RMS not always best measure
- Most deposition at initial impact, but still a good portion in the 'cloud'
  - Useful for reconstructing tracks and eliminating confused events
  - Can use 'clumps' as starting points for cluster-building
- Noise energy dep per cell relative to signal will be important factor in recon and energy resolution.
  - Depth segmentation very useful here
    - Shower shape
    - Time cutoffs/windows

Looking forward...

- Dual-readout calorimetry
  - Cherenkov + ionization
- Simulate Physics, reconstruct
  - Noise
  - Z' → mu(+) + mu(-) (+ gammas)
  - Z' → jet + jet
  - PFA
  - Magnetic field compensation
  - ...