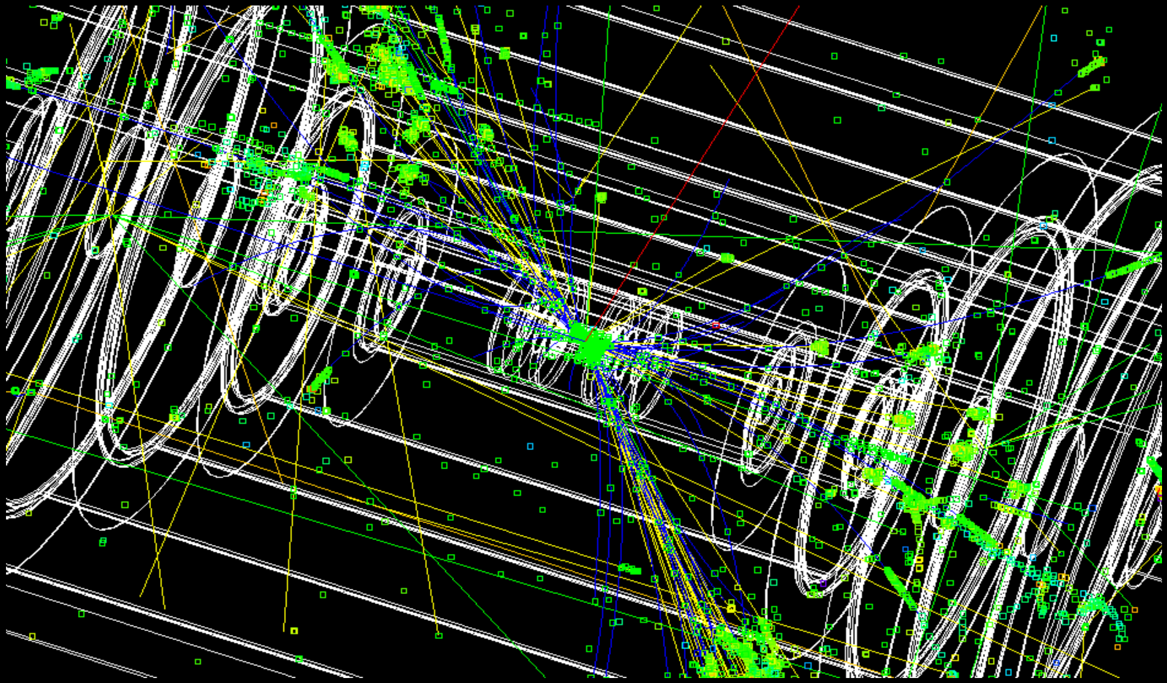
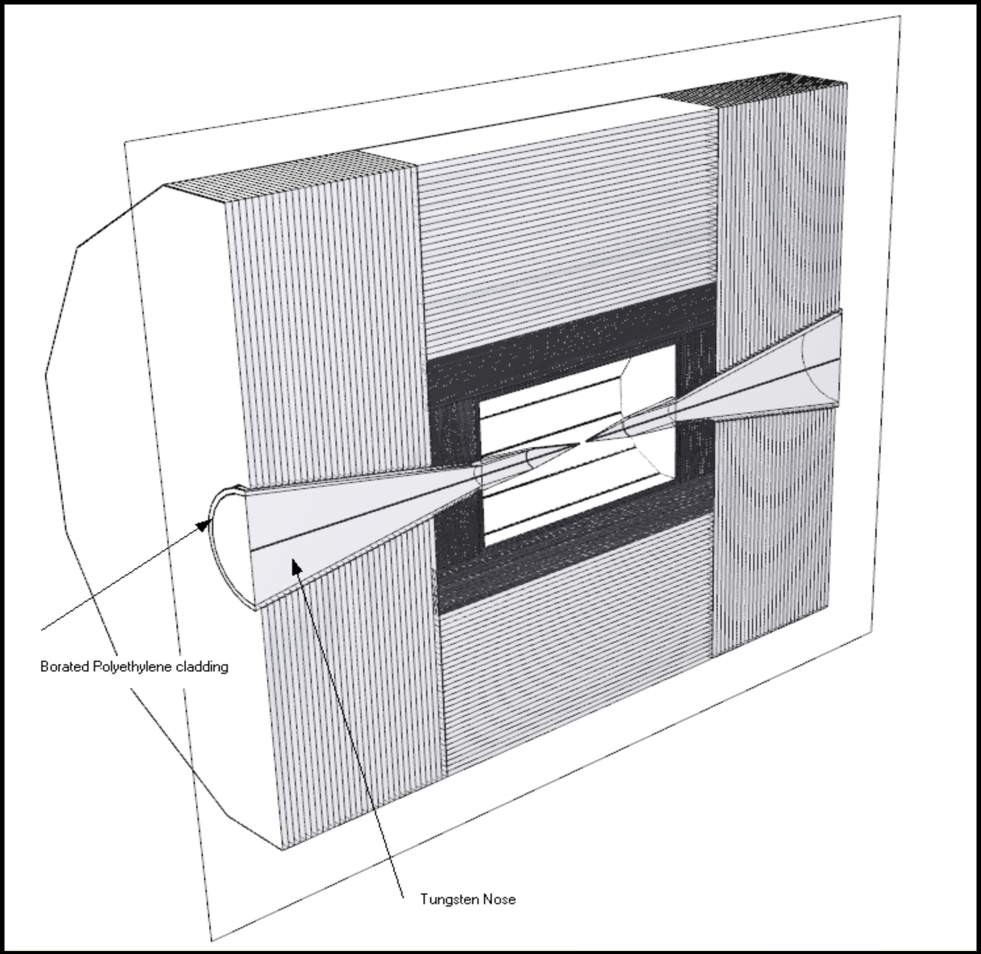
Muon Collider Detector Simulation and Calorimetry

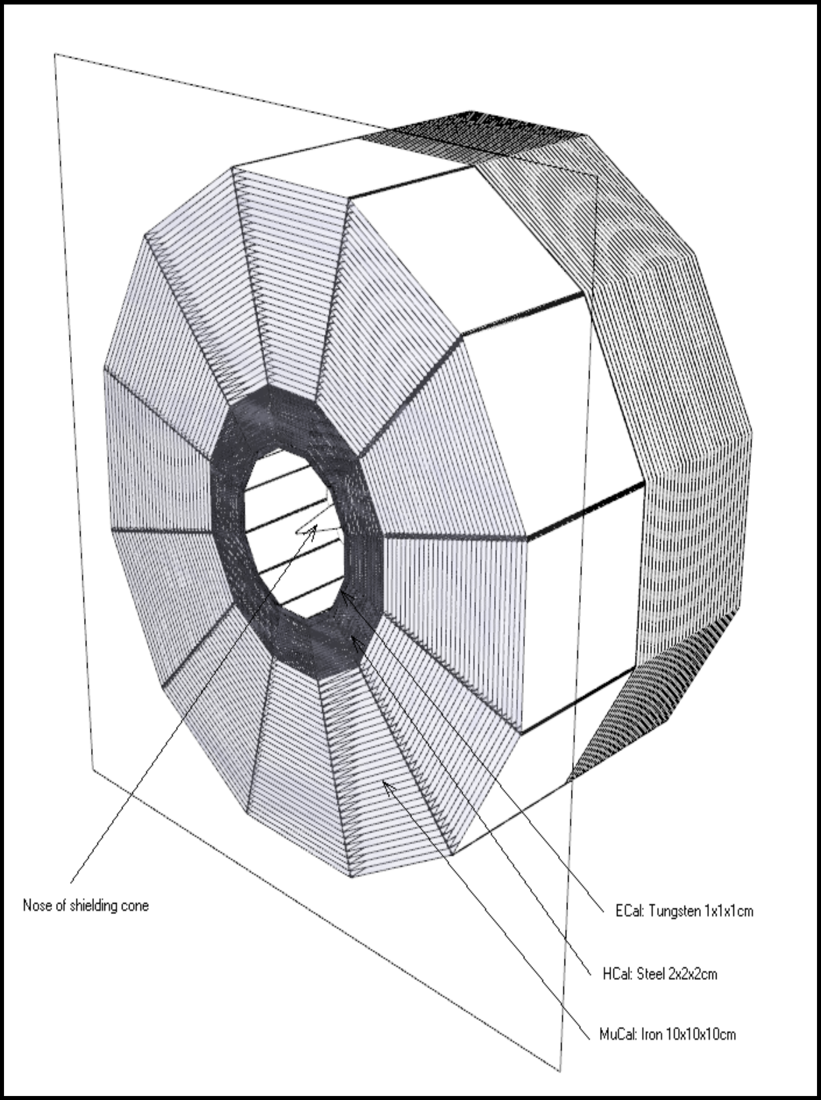
Alexander Conway

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



Muon Collider Detector v.0.0 (mcd00)





Norman Graf

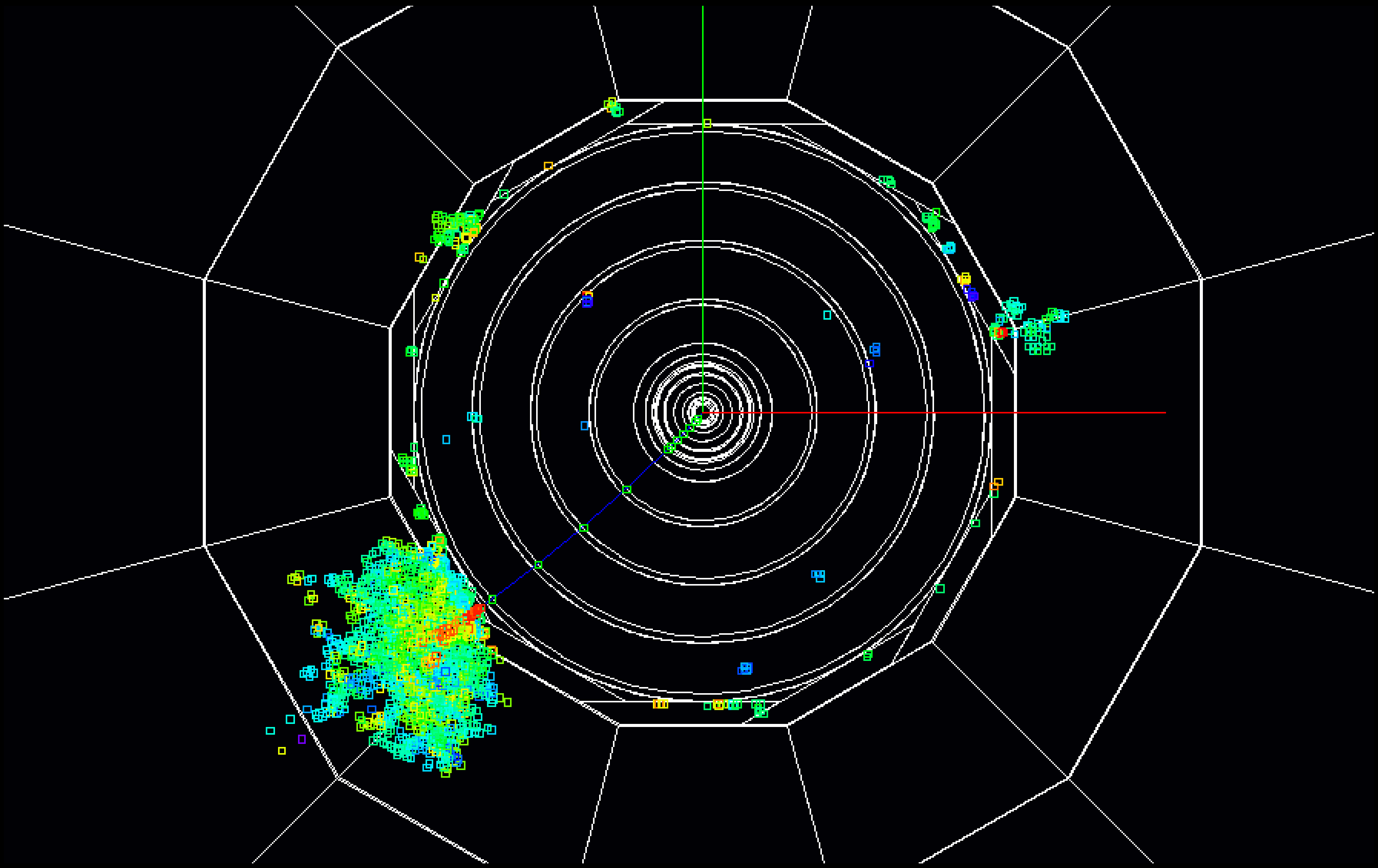
Calorimeter Properties

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	6.76g/cm^2 0.35 cm	13.9g/cm^2 1.76 cm	13.8g/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



Bernd Surrow

http://physics.bu.edu/neppsr/2006/TALKS-2006/Calorimetry_Surrow.pdf

Material	Z	A	Z/A	X_0 (cm)	λ_I (cm)	Density (g/cm^3)
H_2 (liquid)	1	1.008	0.992	866	718	0.0708
He	2	4.002	0.500	756	520	0.125
C	6	12.01	0.500	18.8	38.1	2.27
Al	13	26.98	0.482	8.9	39.4	2.70
Cu	29	63.55	0.456	1.43	15.1	8.96
Pb	82	207.2	0.396	0.56	17.1	11.4
W	74	183.8	0.403	0.35	9.58	19.3
U	92	238.0	0.387	0.32	10.5	19.0
Scint.			0.538	42.4	81.5	1.03
BGO			0.421	1.12	22.1	7.10
CsI			0.416	1.85	36.9	4.53
NaI			0.427	2.59	41.1	3.67

Studying the Detector

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

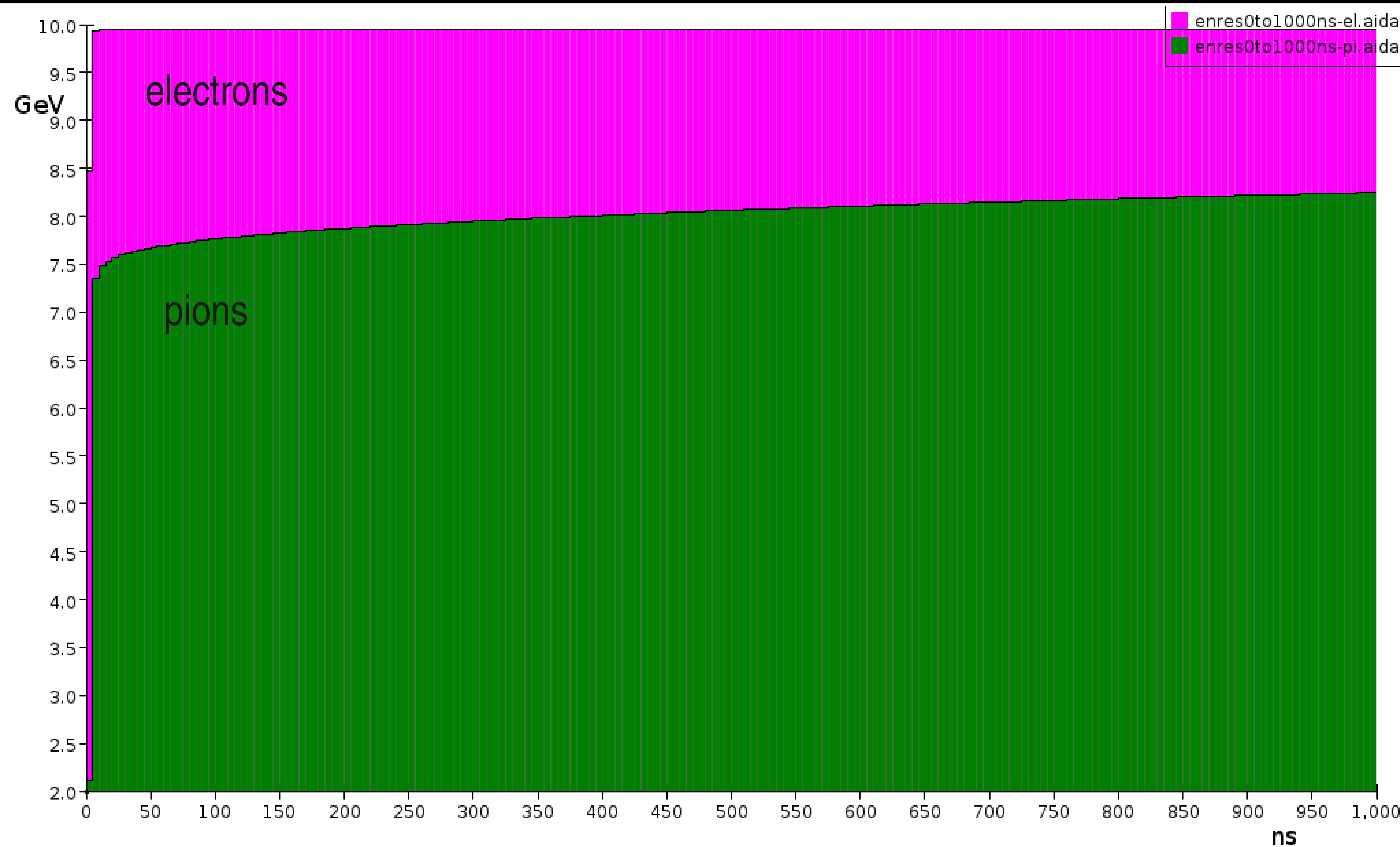
Studying the Detector

- 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

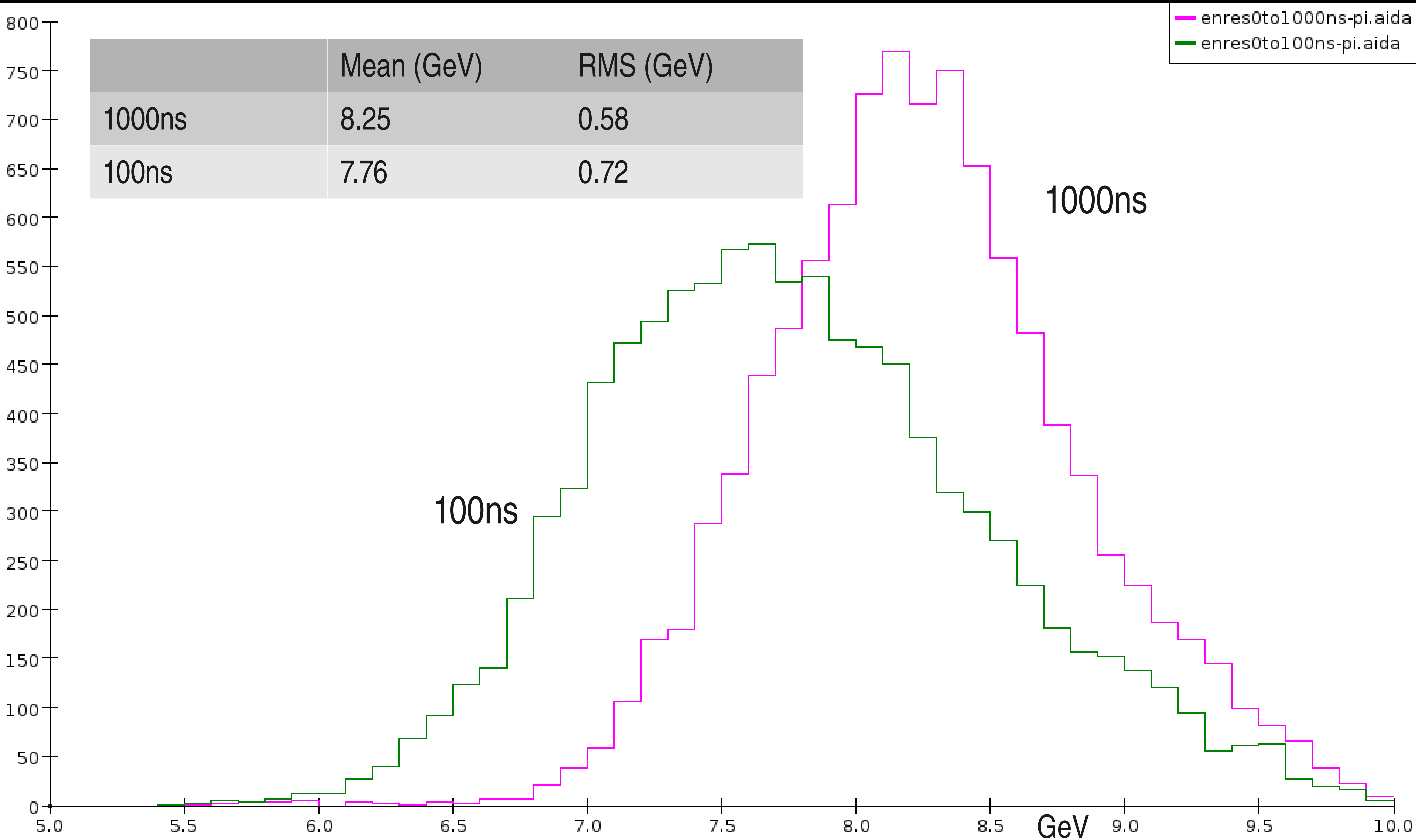


Time Cutoff Comparisons

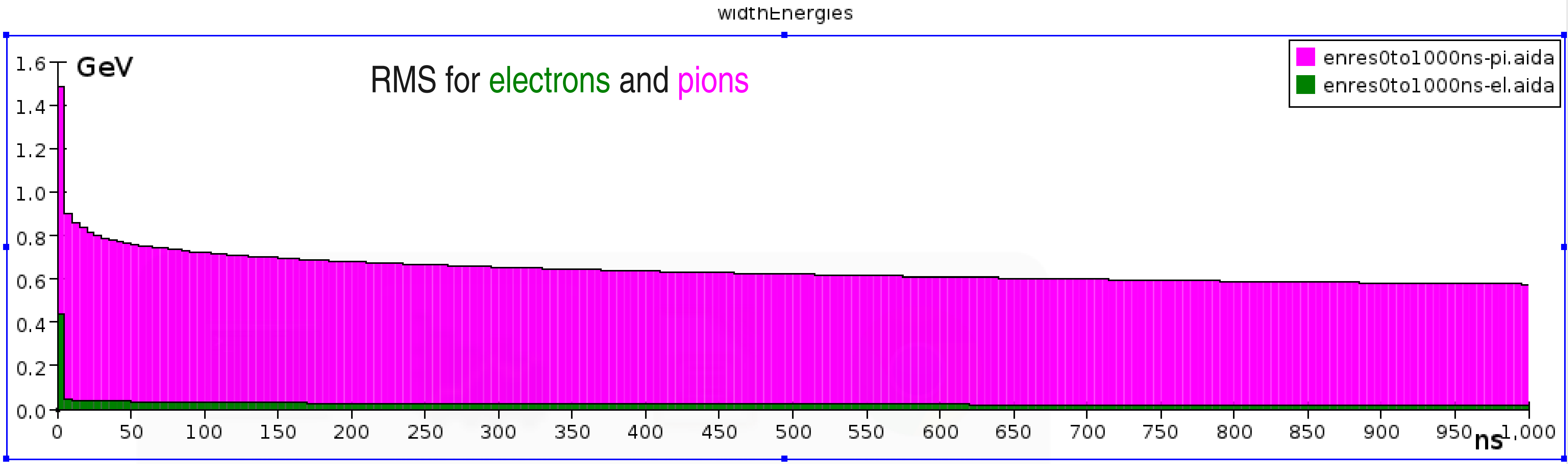
	Mean energy response (GeV)		RMS (GeV)		RMS/sqrt(E)	
	Electrons	Pions	Electrons	Pions	Electrons	Pions
1000ns	9.95	8.25	0.02	0.58	0.6%	18%
100ns	9.95	7.76	0.03	0.72	1%	23.7%
10ns	9.94	7.48	0.04	0.86	1.3%	27%

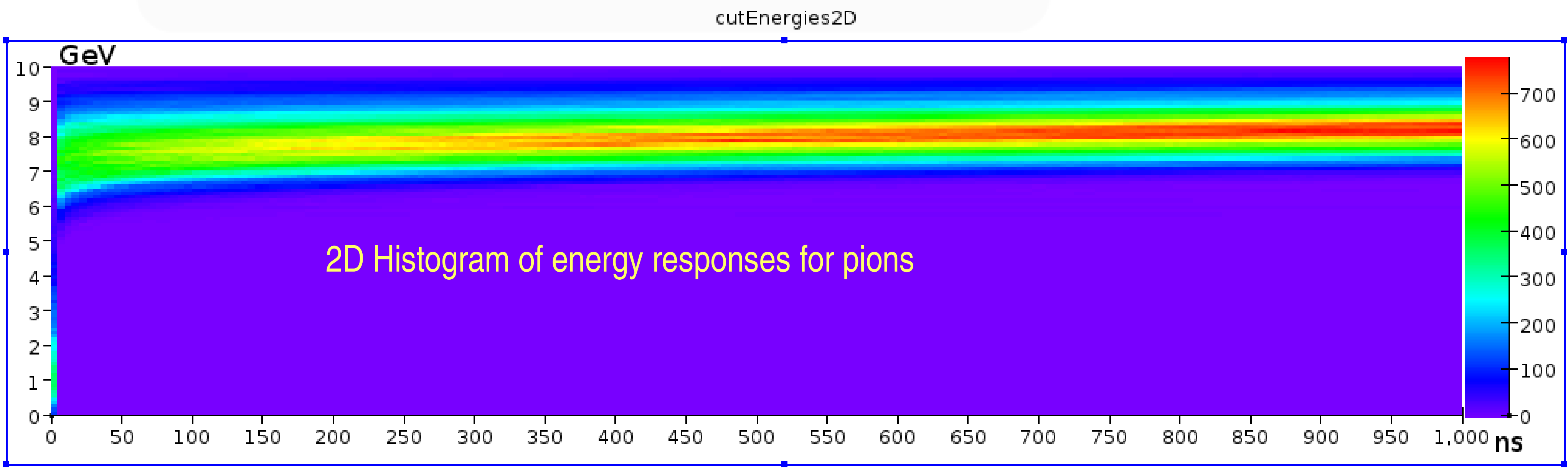
Pion energy response with 100 ns and 1000 ns cutoffs

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



Time Cutoff Comparisons





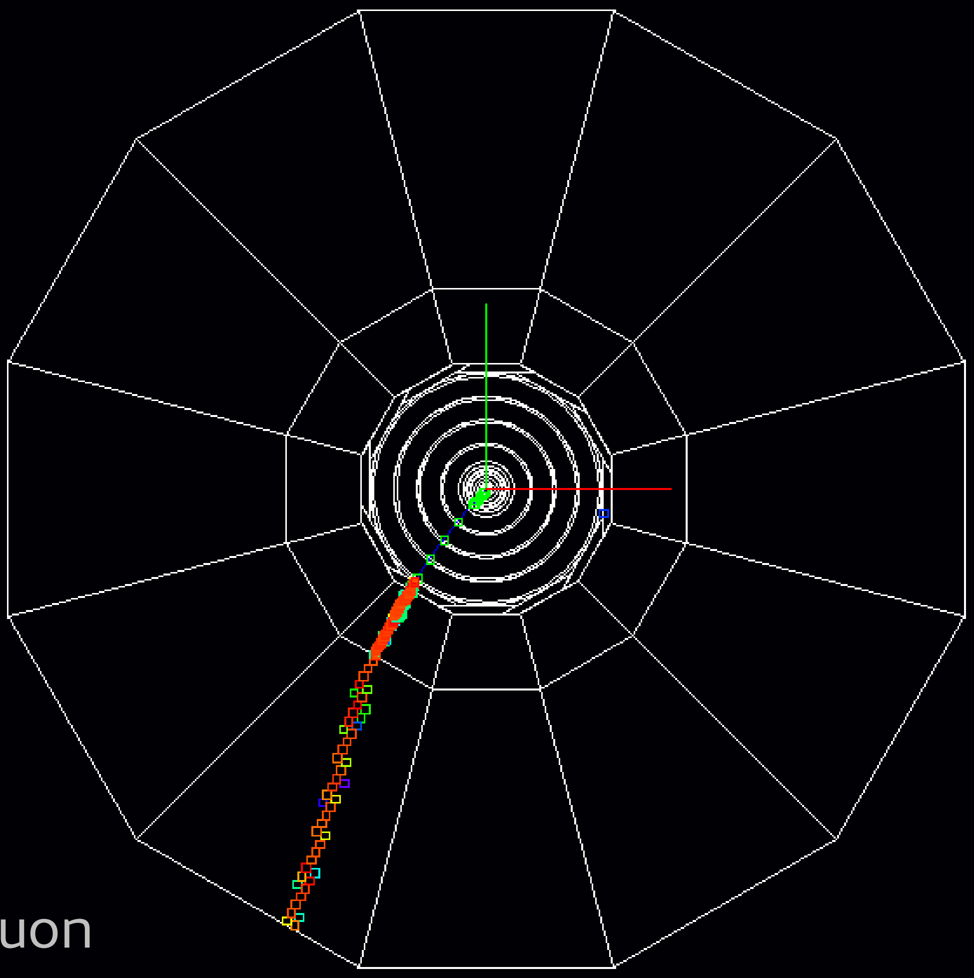
Time Cutoff Comparisons

- 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 response, shower shape, tracking, cherenkov, etc

Minimum Ionizing Particle (MIP)

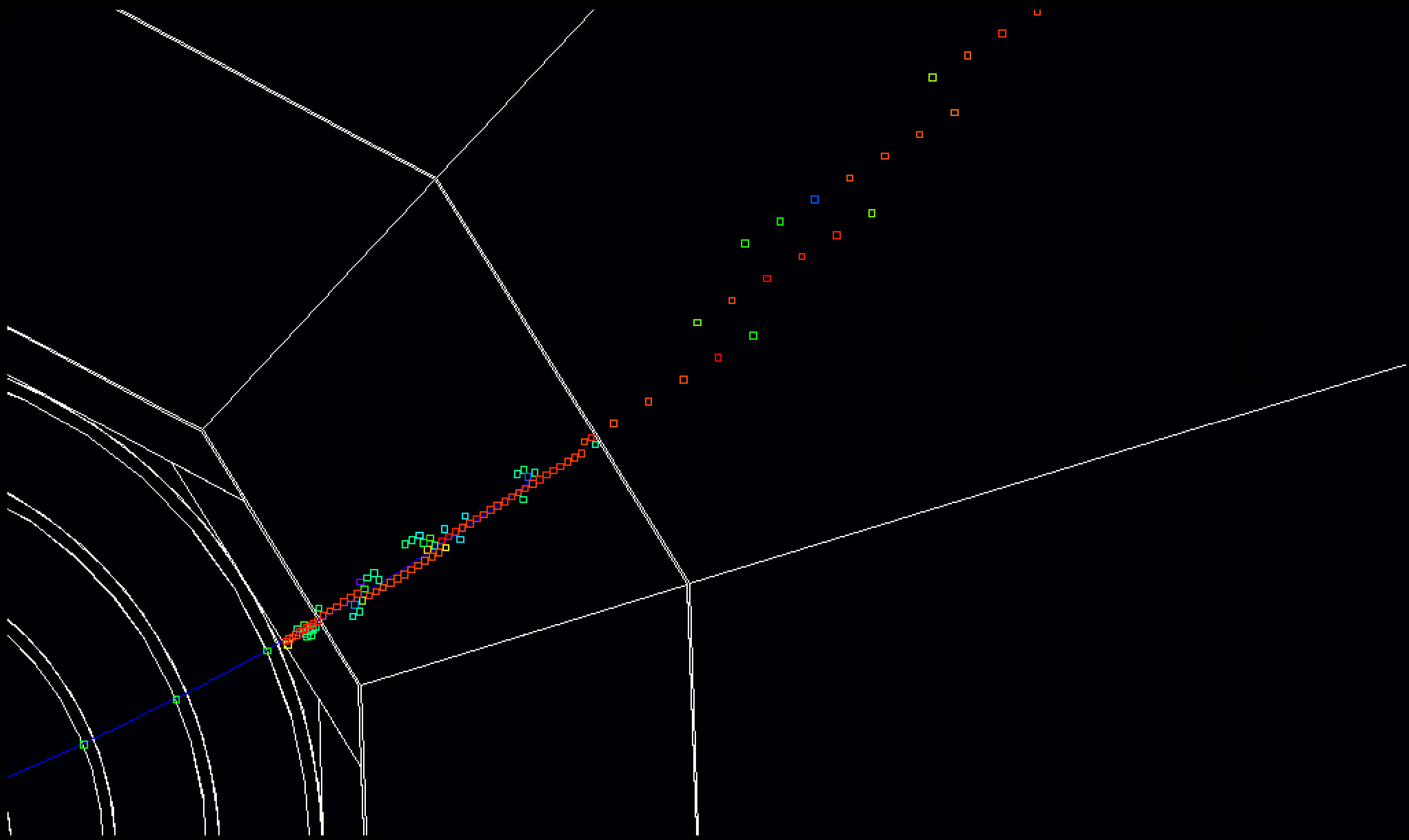
- Relativistic muons approximate MIPs
  - Little interaction with detector but with characteristic energy
  - Want to see this MIP trail
    - Energy threshold must be lower than MIP energy
  - Use muons to measure the MIP energy specific to each type of calorimeter

Minimum Ionizing Particle (MIP)

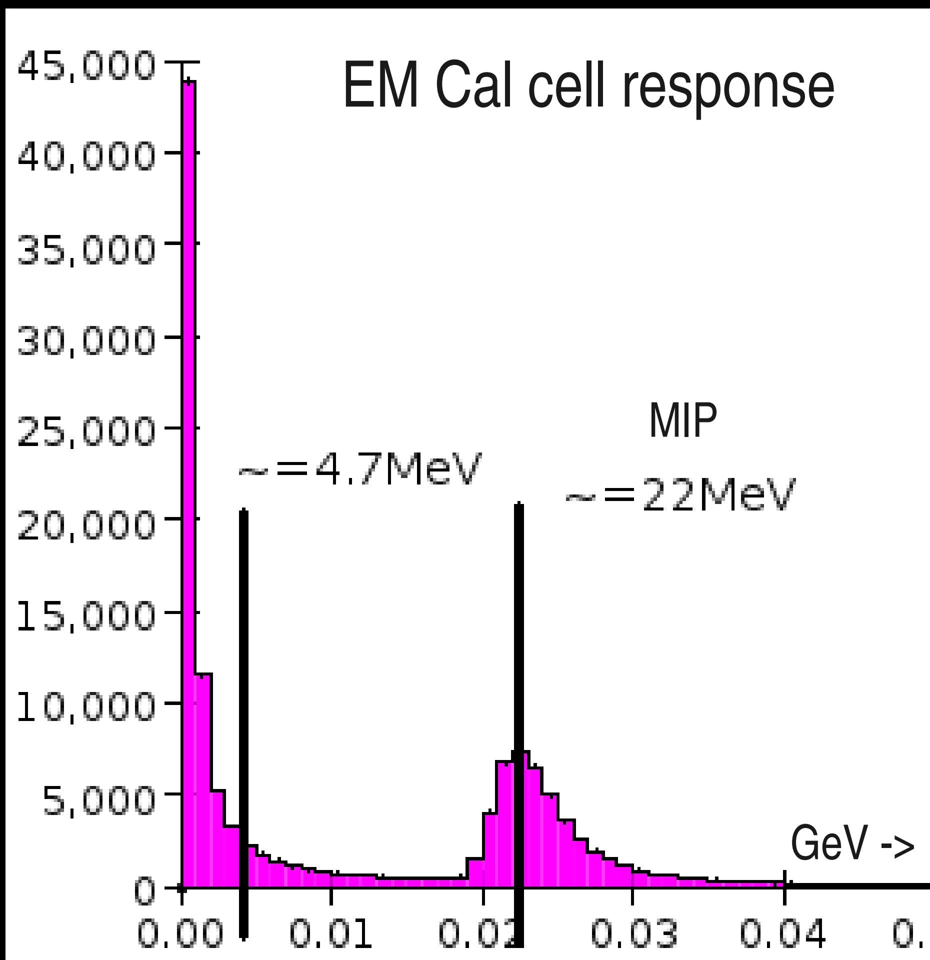


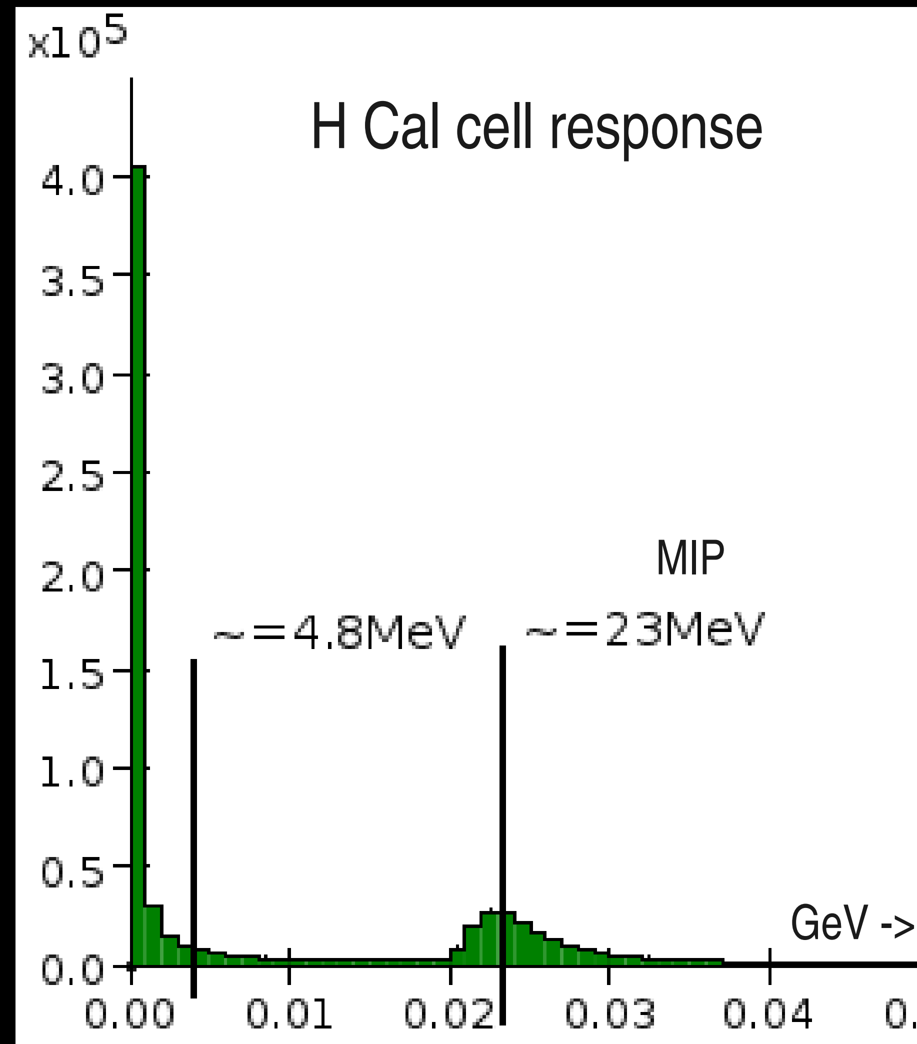
10 GeV Muon

Minimum Ionizing Particle (MIP)

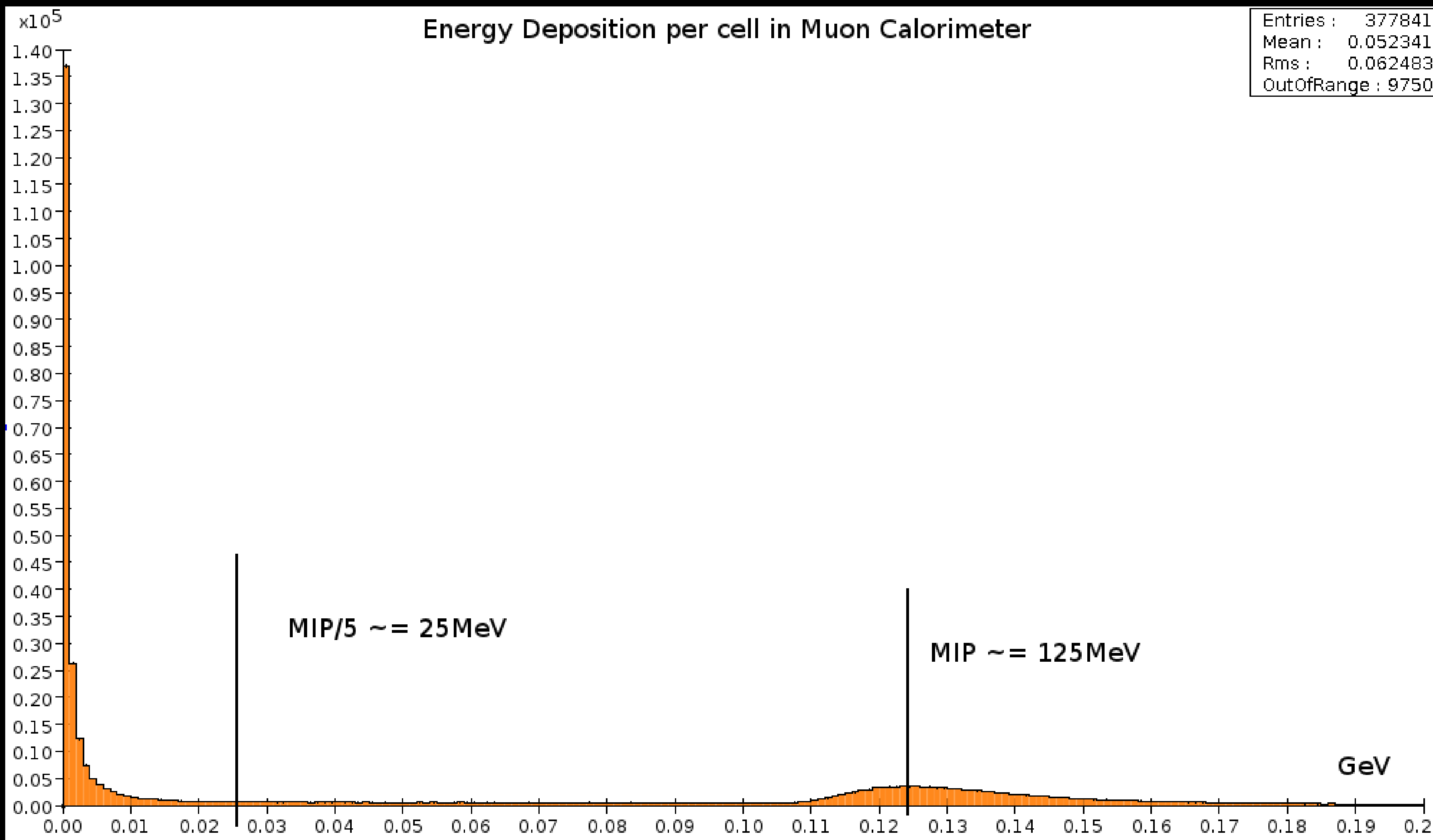


Minimum Ionizing Particle (MIP): EM and H Cals





Minimum Ionizing Particle (MIP): Muon Cal



Minimum Ionizing Particle (MIP)

- Minimum ionization is very clear in all detectors
- 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'?
  - Will this be lost by clustering anyway?
- 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 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	9.54	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 Cuts:

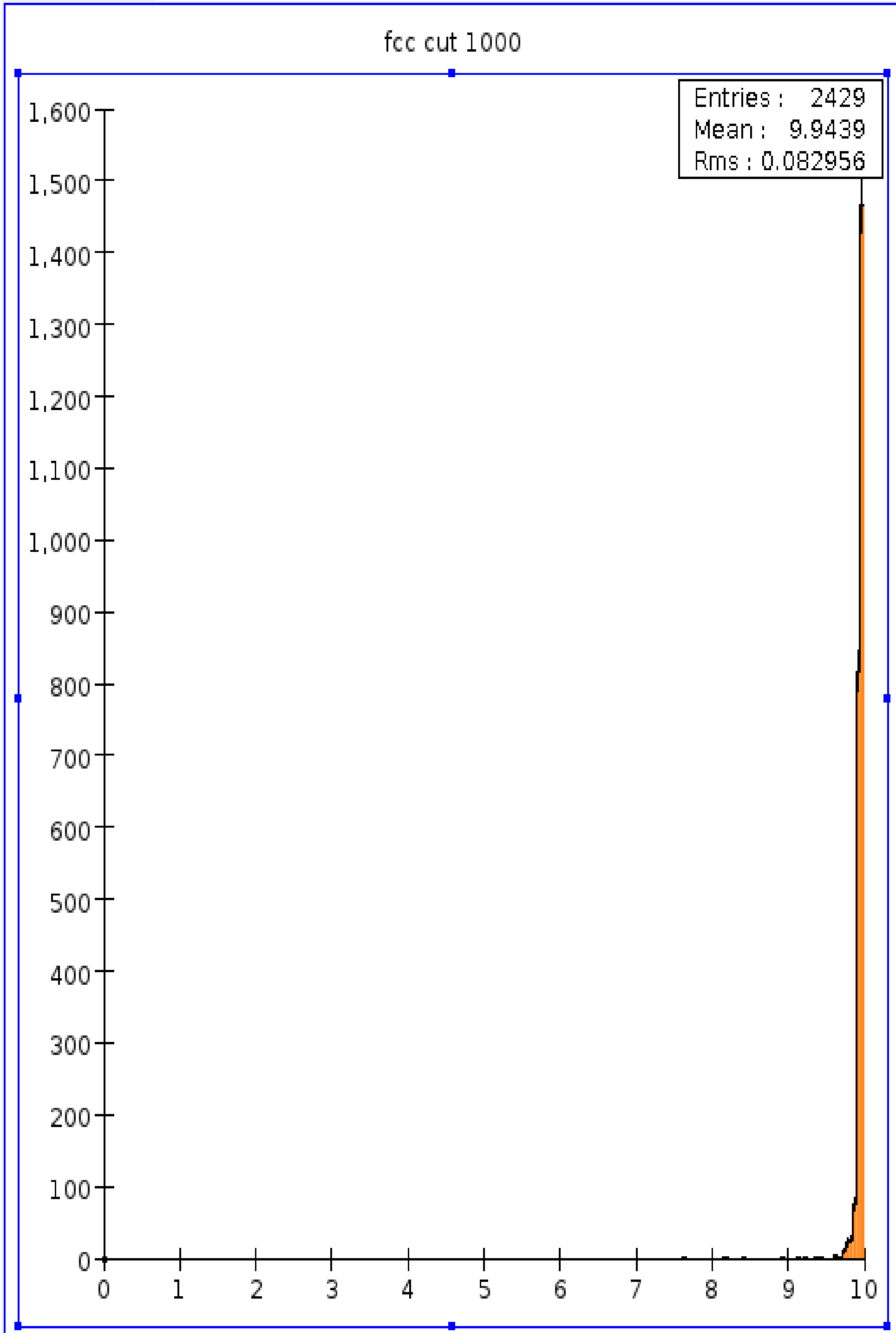
	Mean energy response (GeV)		RMS (GeV)		RMS/sqrt(E)	
	Electrons	Pions	Electrons	Pions	Electrons	Pions
1000ns	9.95	8.25	0.02	0.58	0.6%	18%
100ns	9.95	7.76	0.03	0.72	1%	23.7%
10ns	9.94	7.48	0.04	0.86	1.3%	27%

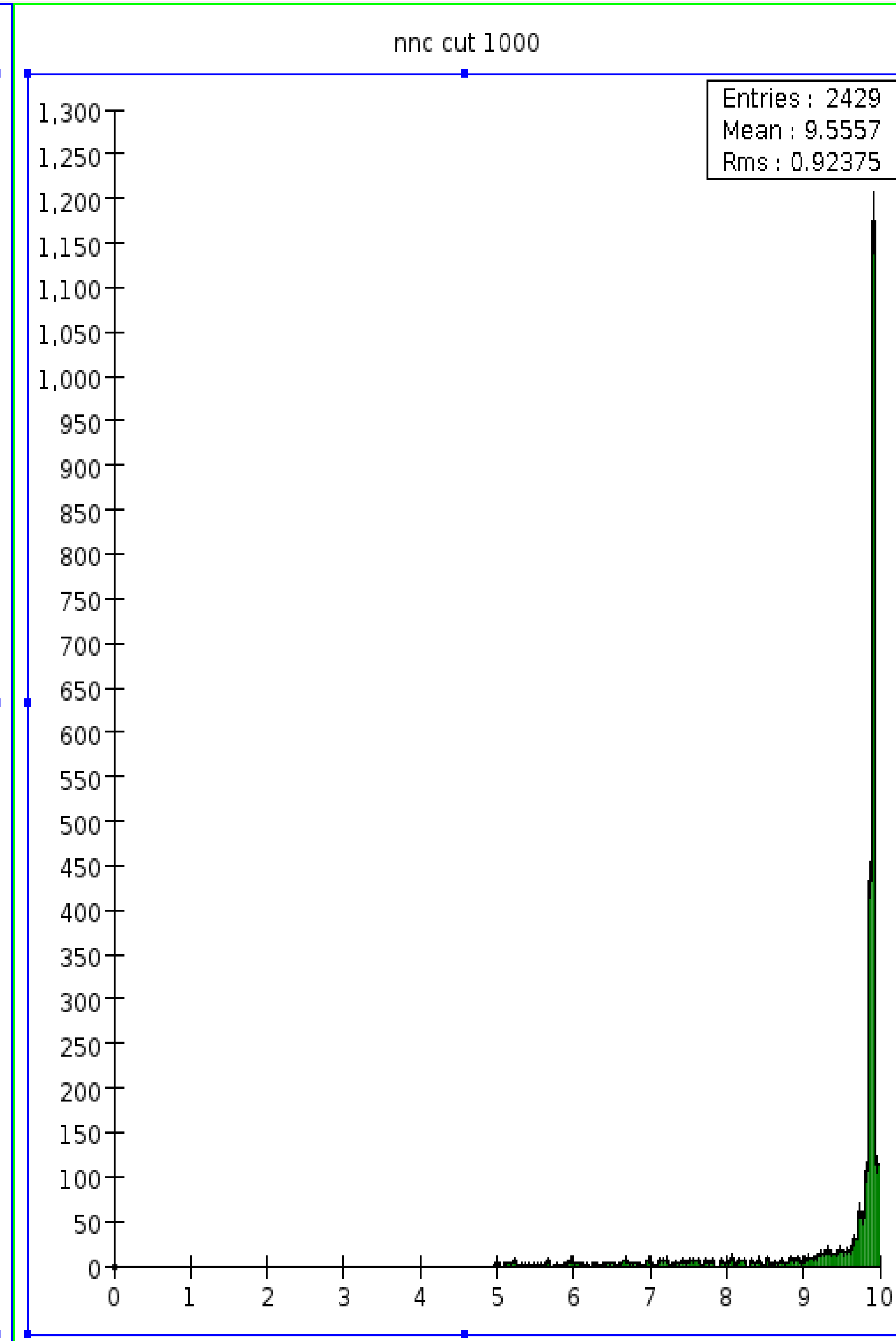
After Cuts:

	Mean energy response (GeV)		RMS (GeV)		RMS/sqrt(E)	
	Electrons	Pions	Electrons	Pions	Electrons	Pions
1000ns	9.96	5.86	0.924	1.62	29.2%	51.2%
100ns	9.95	5.71	0.924	1.62	29.2%	51.2%
10ns	9.55	5.60	0.923	1.64	29.2%	52.9%

Page 1

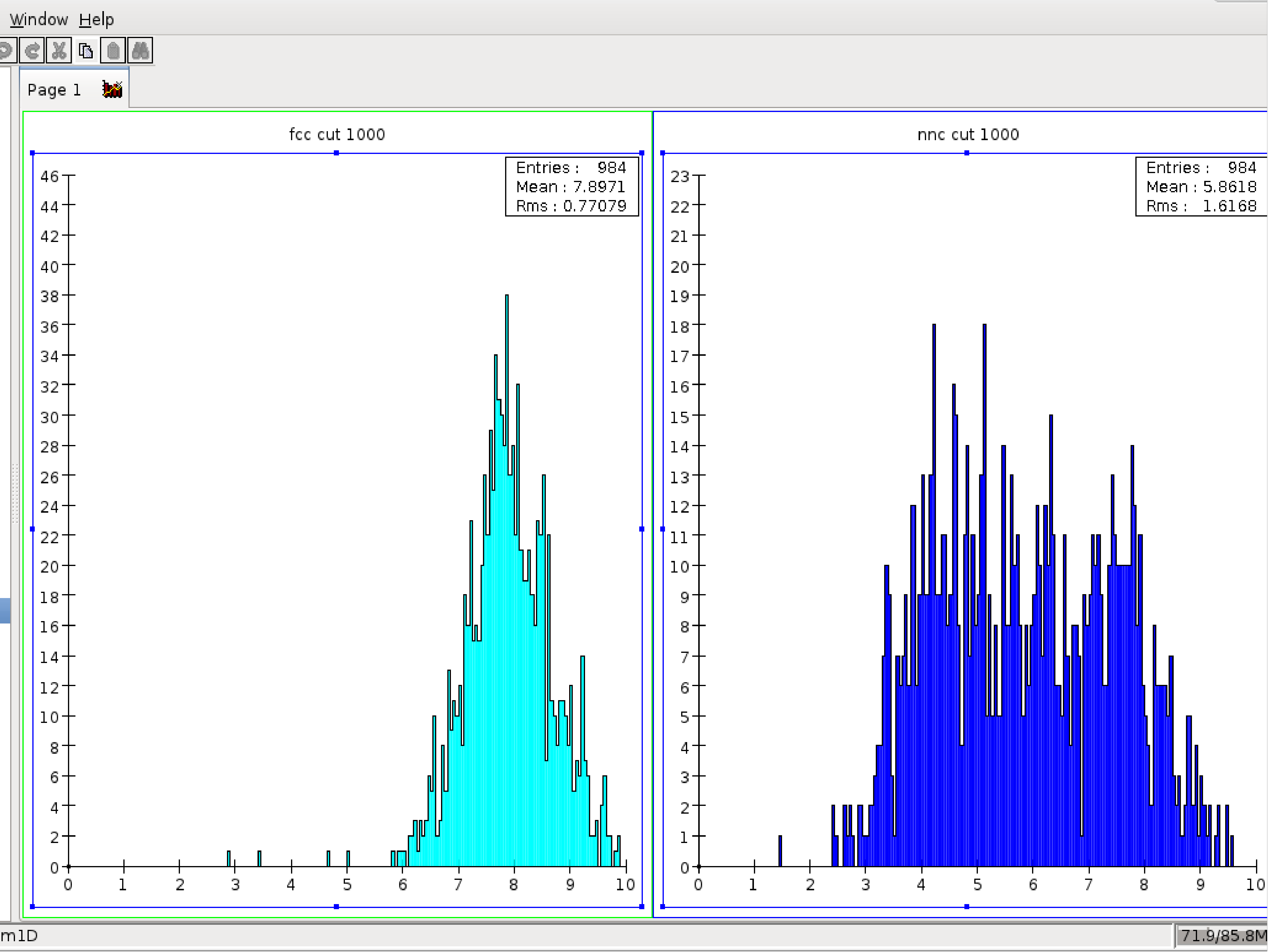
da
da





pe: IHistogram1D

28.8/97.5MB



Window
Help
Page 1
fcc cut 1000
Entries : 984
Mean : 7.8971
Rms : 0.77079
nnc cut 1000
Entries : 984
Mean : 5.8618
Rms : 1.6168
m1D
71.9/85.8M

Thoughts

- Fixed-cone clustering provides better resolution across the board
- Nearest-neighbor parameters should change
- Ways to improve energy resolution:
  - Change nearest-neighbor parameters
  - Combine nearest-neighbor clusters that fall with in fixed cone
  - Perform nearest-neighbor on fixed cone clusters

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	9.95	7.90	0.053	0.77	2.6%	24.4%
100ns	9.94	7.57	0.058	0.83	1.6%	26.2%
10ns	9.93	7.34	0.061	0.91	2.8%	28.8%