Status of calorimeter studies

- Documentation
- The MCDRCAL00 detector
  - Motivation
  - Dual readout calorimetry
- Temporal evolution of hadronic showers
- Time distribution from the muon decay bgrds
- Reconstruction of W's and Z's decaying into jets
- Conclusions

Hans Wenzel

Fermilab

Mar. 8th 2012

Muon Collider SW Documentation

Goal: get entire chain running and documented:

Evt. Generation->Simulation->adding BGR. Evts.-> reconstruction-> Analysis, benefit from the work done for the ILC and CLIC by using existing framework.

Created Confluence page:

https://confluence.slac.stanford.edu/display/MCPDS/Home

Currently:

- Overview
- Event Generation
- Timing studies
- Detector Models
- Available Datasets

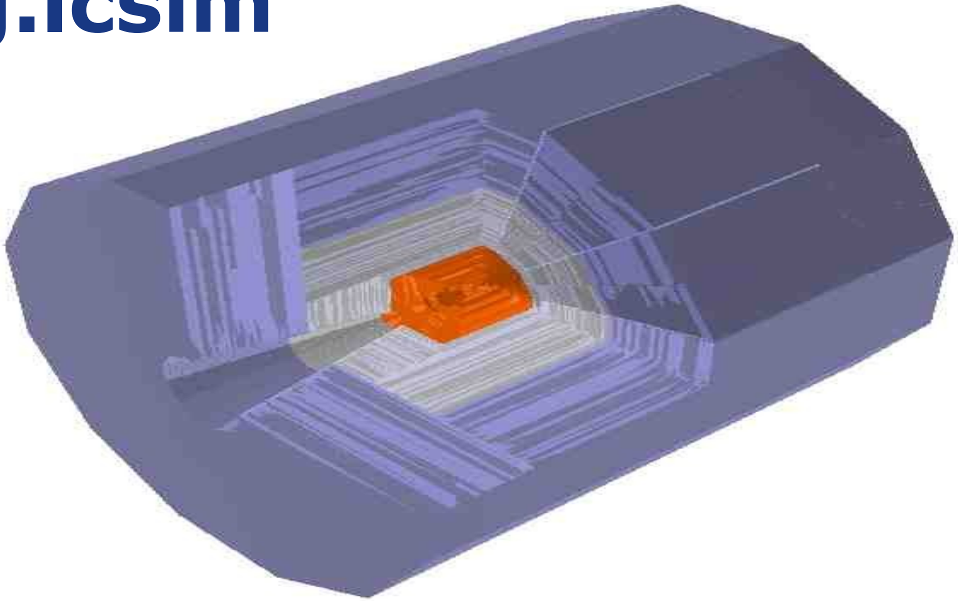
You can sign up here: https://jira.slac.stanford.edu/signup/

Input to Geant 4 simulation:

(Refraction Index, Absorption length etc..) can be found here:

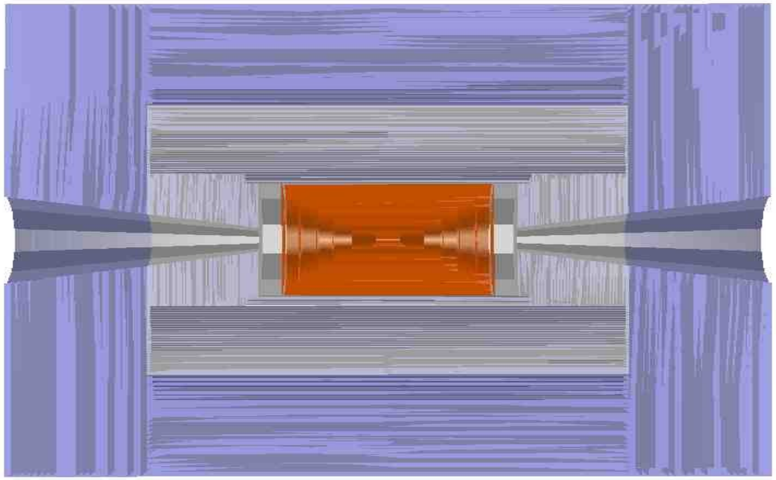
http://g4validation.fnal.gov:8080/DRImageWebApp/

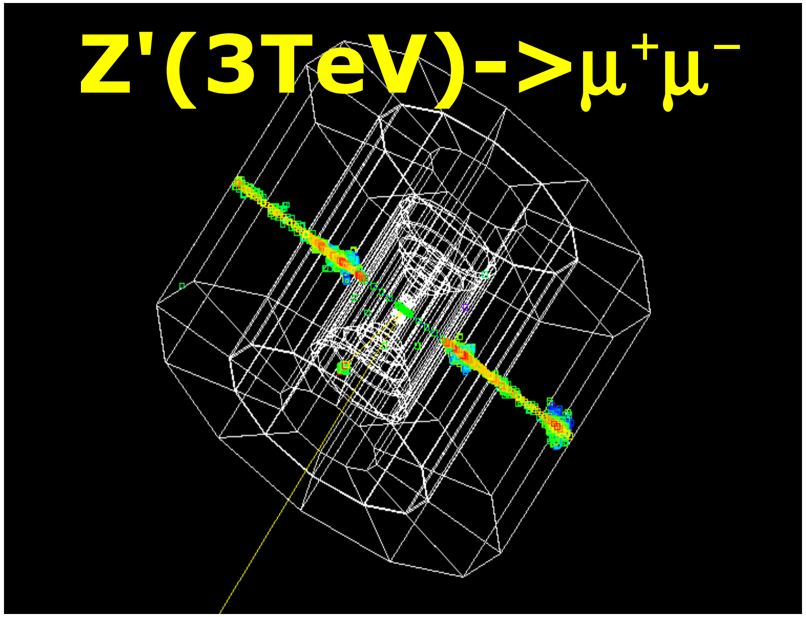
The mcdrcal00 detector in org.lcsim



5T solenoidal field,
radius=3m

Calorimeter dimensions:
Rmin: 1.25 m
Rmax: 2.96 m
Length: 2x7.4 m





Calorimeter Properties for Barrel and End caps

	EM	Hadron	Muon
Material	BGO (PbF2)	BGO (PbF2)	Iron
Density [g/cm^3]	7.13 (7.77)	7.13 (7.77)	7.85
Cell size [cm^3]	1x1x2	2x2x5	10x10x10
Layers	10	30	22
Detector Depth [cm]	20	150	220
Radiation Length [cm]	1.1 (0.93)	1.1 (0.93)	1.76
Nuclear Interaction Length [cm]	22.7 (22.4)	22.7 (22.4)	16.8
Total Nr of IA length (em+had)	**7.5 (7.6)**		

Caveats

- Tungsten cone commented out-> showers developing in the cone required a lot of CPU --> Need sensitive detector that registers particles that enter but then kills them.
- No Material for coil included
- Jas3 can't display all the calorimeter shapes used for mcdrcal00 (but we can see the hits)
- Not enough iron to return flux of 5T solenoidal field (wanted to keep outer dimensions / MDI)
- Simulation of DR (Cerenkov photons) is very slow due to the use of the Geant 4 G4Cerenkov process. Calculating the number of produced in the optical calorimeter sensitive detector class will speed up the process significantly. Currently the data sets are without optical processes enabled.

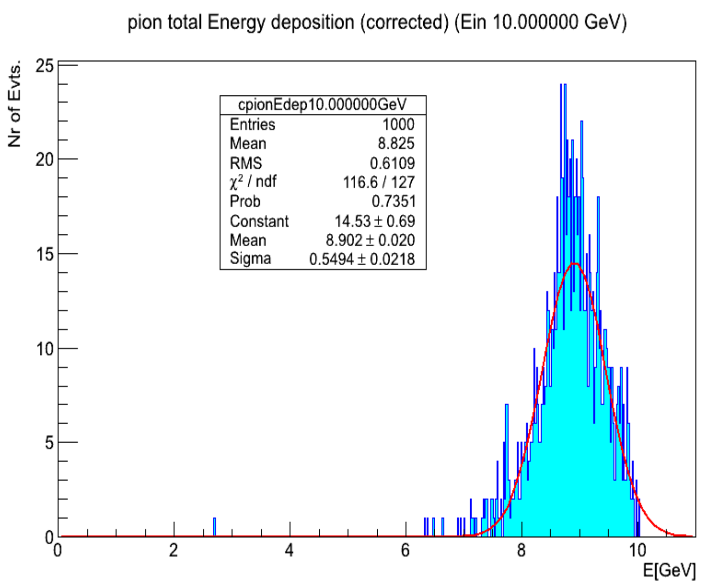
Motivation for such a calorimeter

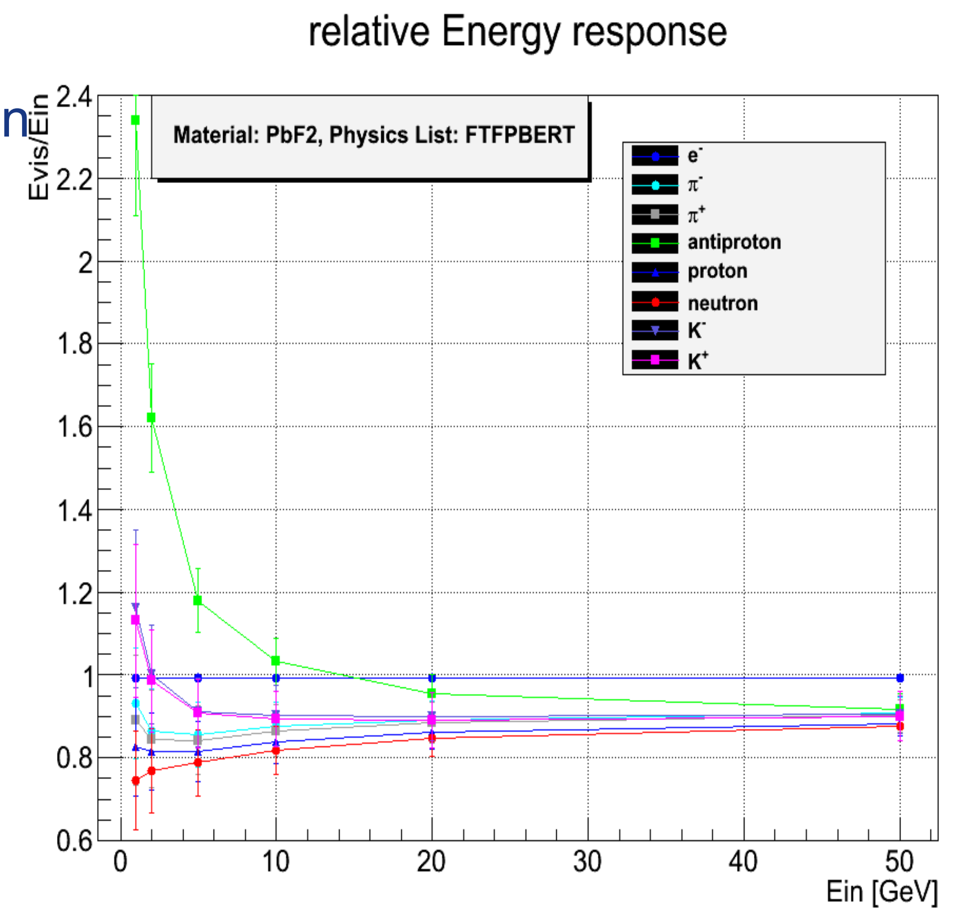
The next generation of lepton collider detectors will emphasize precision for all sub-detector systems. One of the benchmarks for new detectors is to distinguish W and Z vector bosons in their hadronic decay mode.

- **Precise:** total absorption (no sampling fluctuations), dual readout correction, homogeneous (no difference in ECAL and HCAL response) → results in excellent energy resolution and linearity.
- **Fast:** Cerenkov light is prompt, new photon detectors like SiPM (besides other advantages) show excellent timing capabilities → provides handle to get muon decay backgrounds under control.
- **Finely granulated:** Improve resolution even further with PFA algorithms.

Hadronic response of non-compensating calorimeters

non-linearity,
poor energy resolution,
non-Gaussian response function
Different response for different particles





Dual Read out

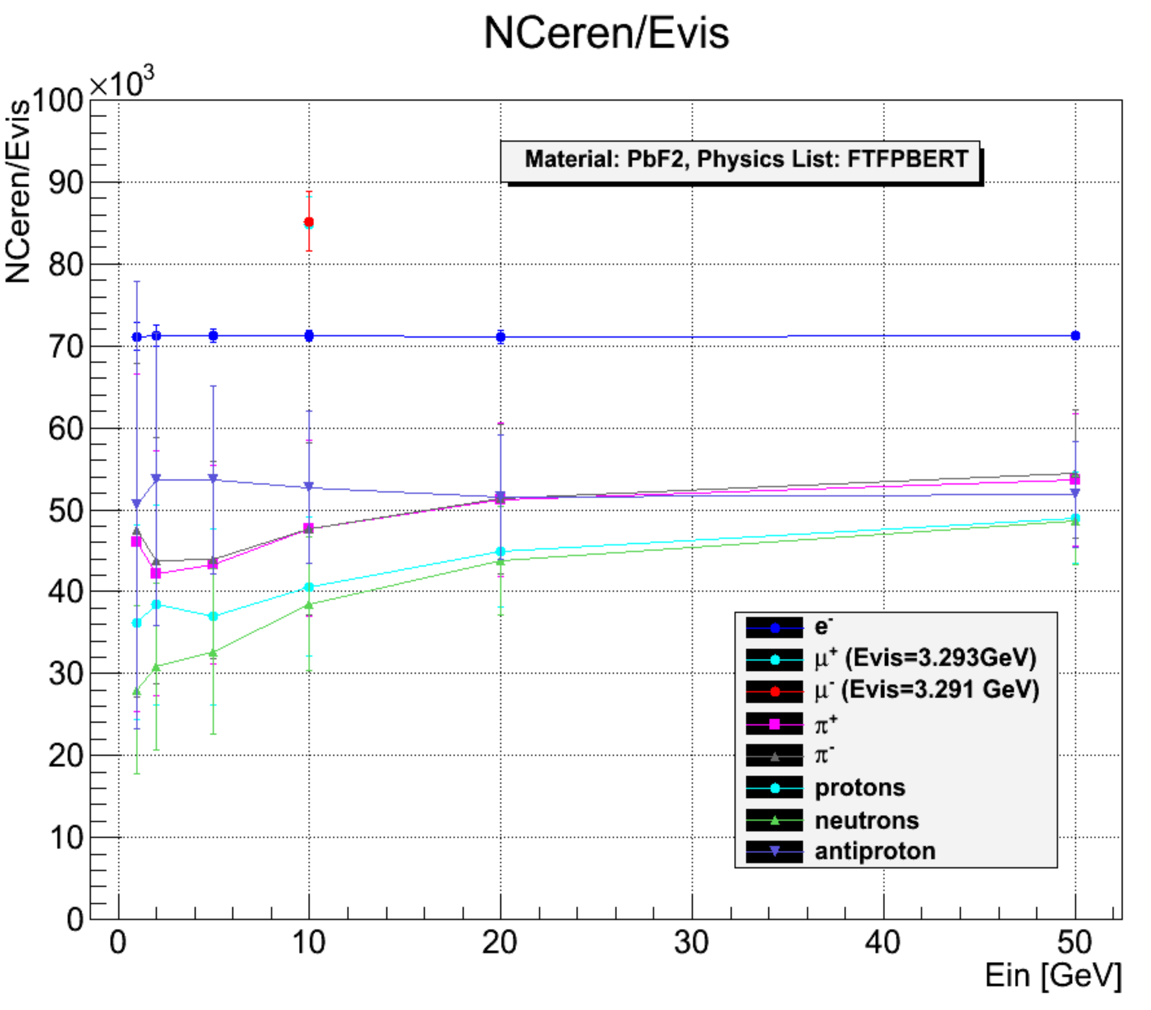
In the crystal dual read out calorimeter Scintillation and Cerenkov light are detected separately in the same Crystal.

- Scintillation light is a precise measure of the total energy released in the calorimeter by the shower particles (~total path length of the charged particles in a shower)

- Cerenkov light is produced by the charged, relativistic shower particles ($\beta>1/n$). Cerenkov light is a precise measure of the total path length of the relativistic particles ($\beta>1/n$) in the shower.

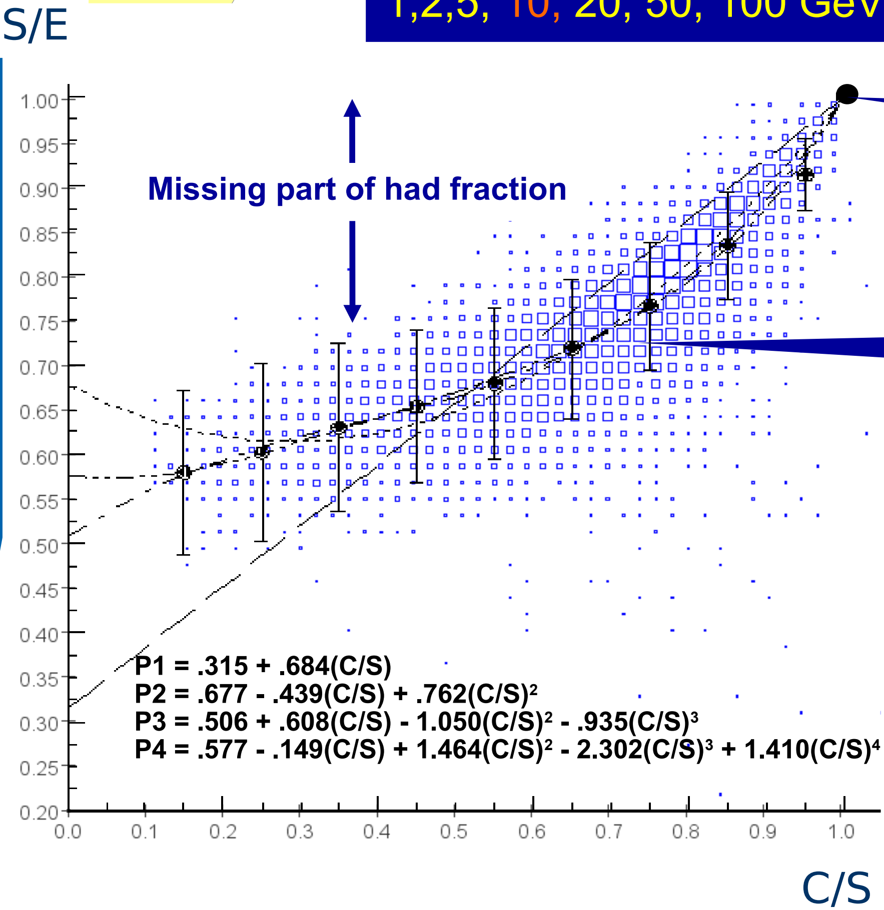
Ratio of Cerenkov/Scintillator (C/S) response

Electrons: not all charged particles in shower are relativistic
C/S ratio const with energy
→ Cerenkov based EM Calorimeter Works.



C/S Corrections

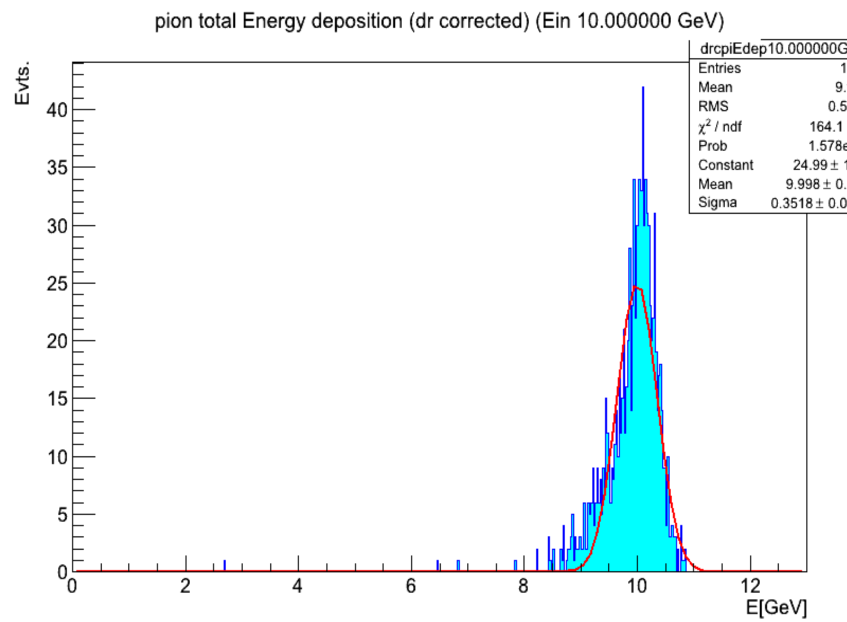
1,2,5, 10, 20, 50, 100 GeV pions



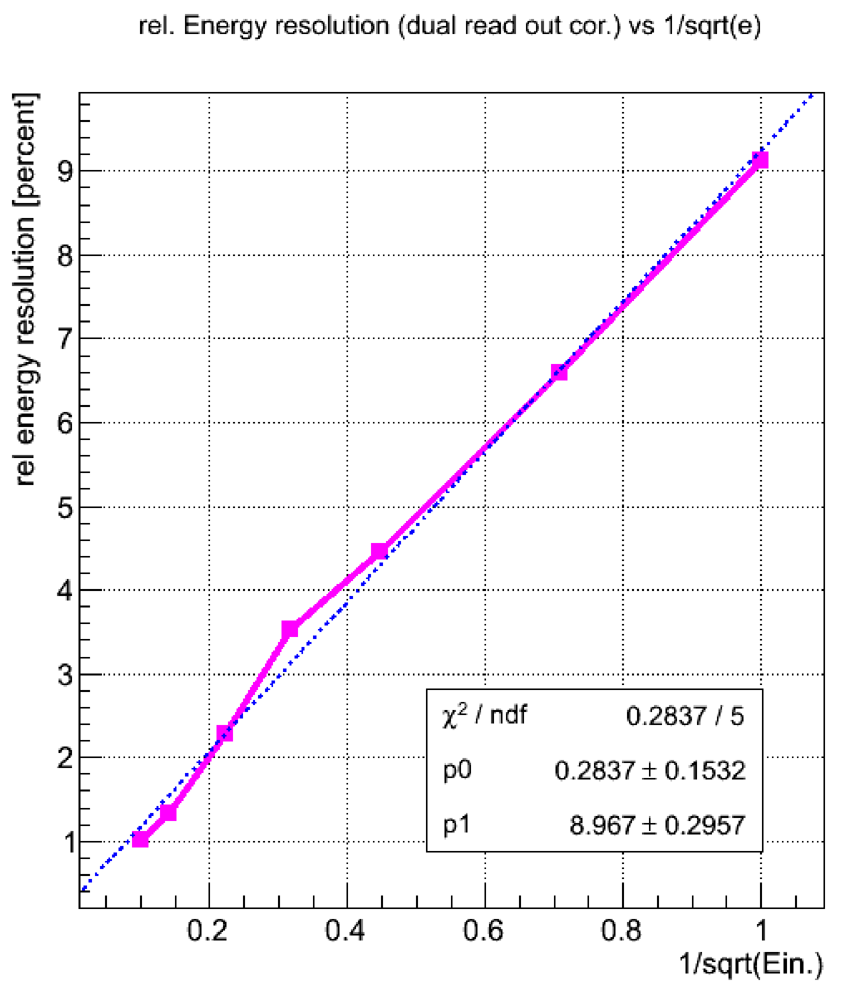
em fraction = 1
S/E, C/S = 1
-> calibration with e^-

Mean and σ/mean of fit plotted for each C/S bin
-> resolution improves with C/S

$$S_{corr} = S / f_{corr}(C/S)$$

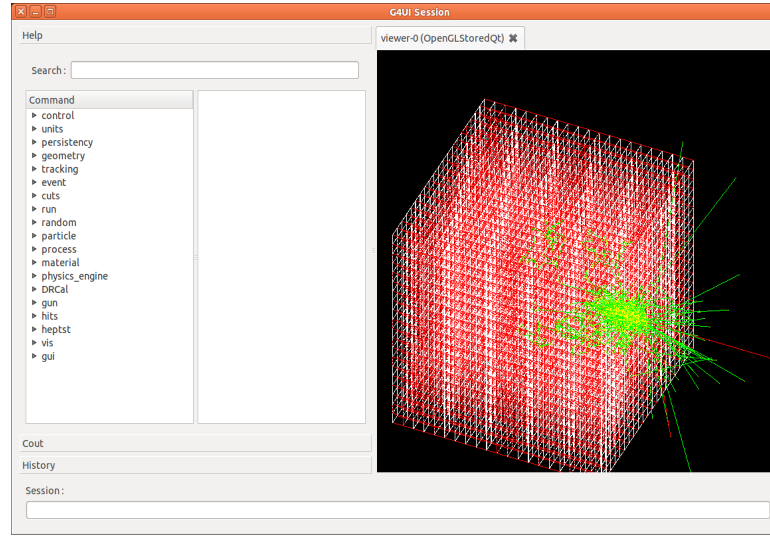


Energy Resolution for single π



Relative Energy resolution in Ideal case:
$\sigma E/E = 0.3 + 8.9 / Sqrt(E)$ %

Temporal evolution of hadronic showers

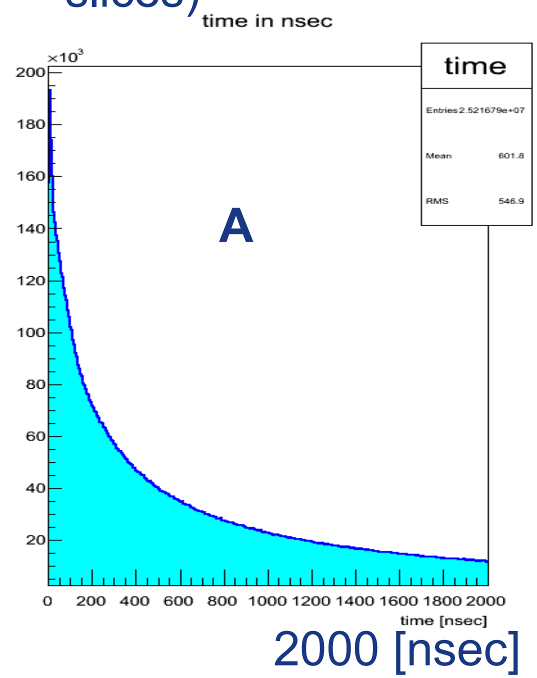


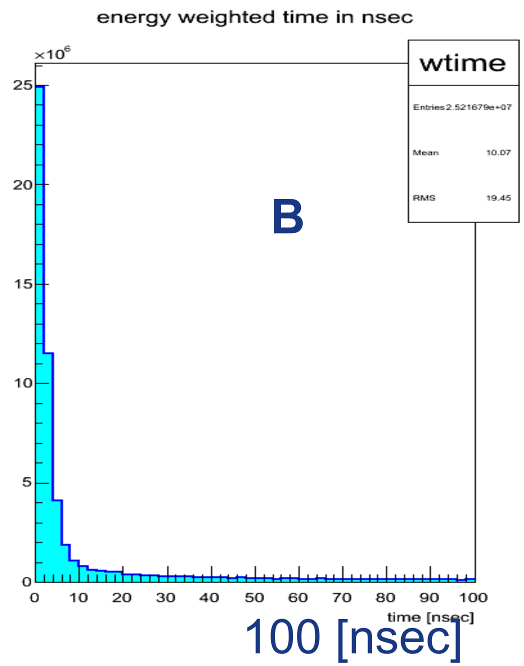
<u>50 GeV hadron shower:</u>

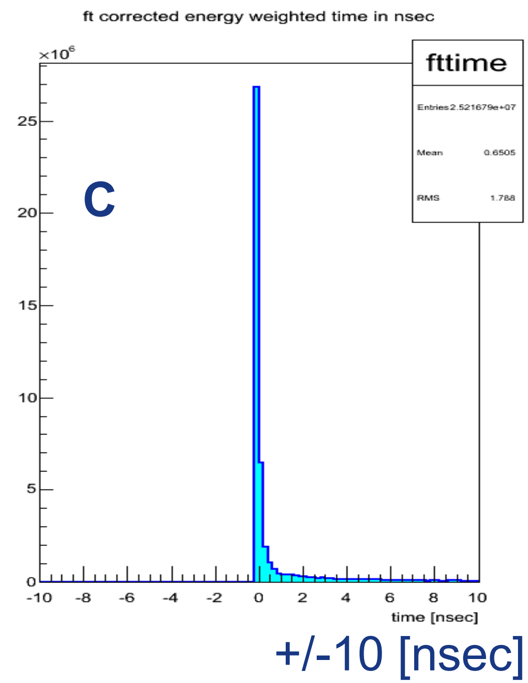
A: time distribution of all Hits independent of energy

B: time distribution weighted by energy deposited in calorimeter cell

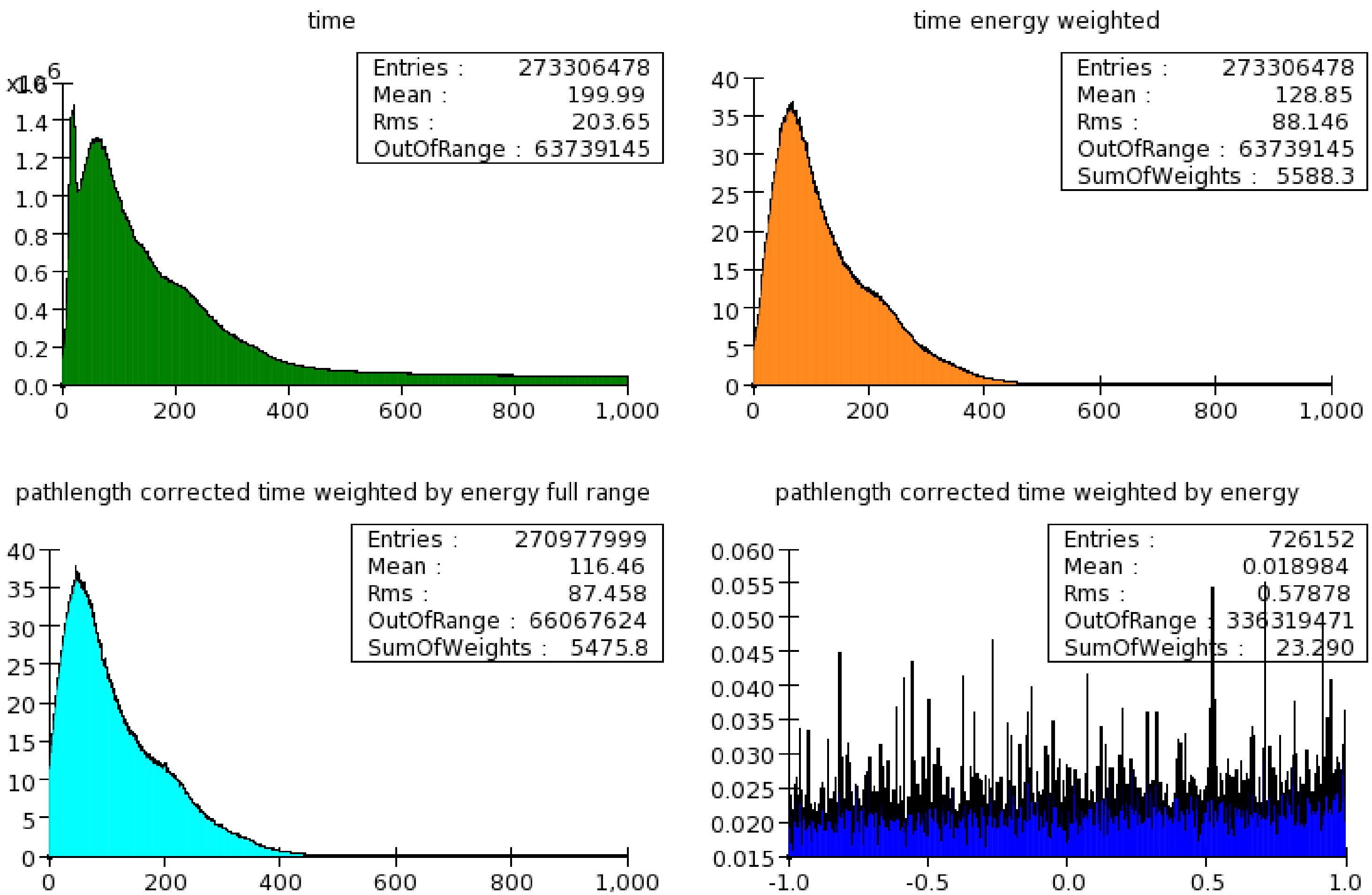
C: as B but time corrected for flight time. (muc: sliding time window, time slices)





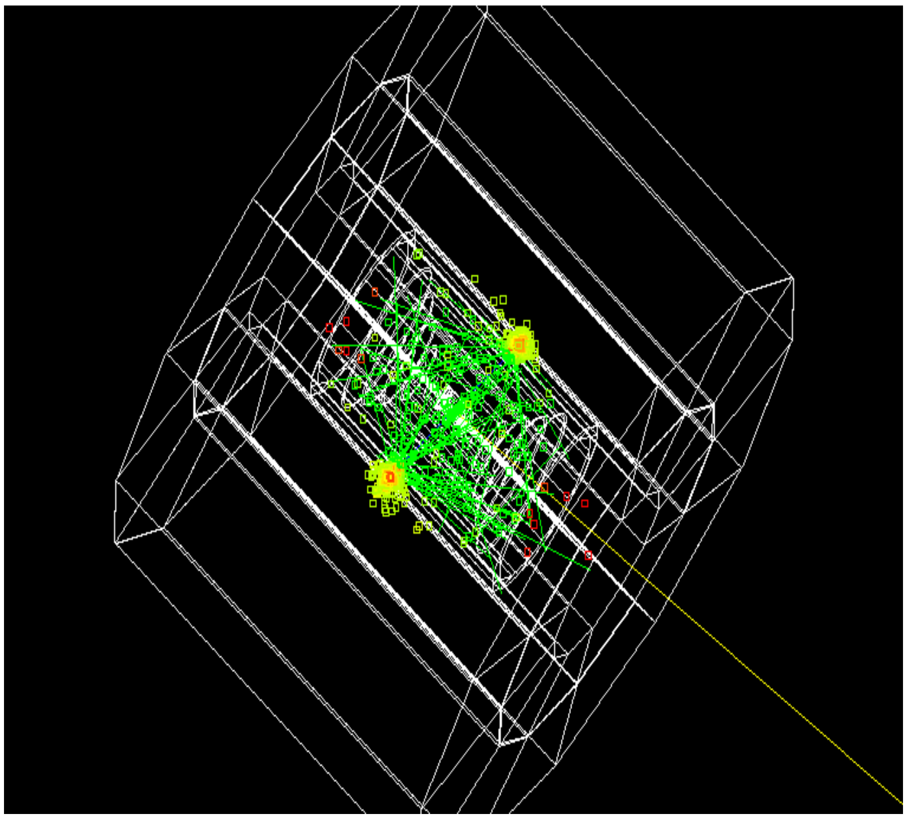


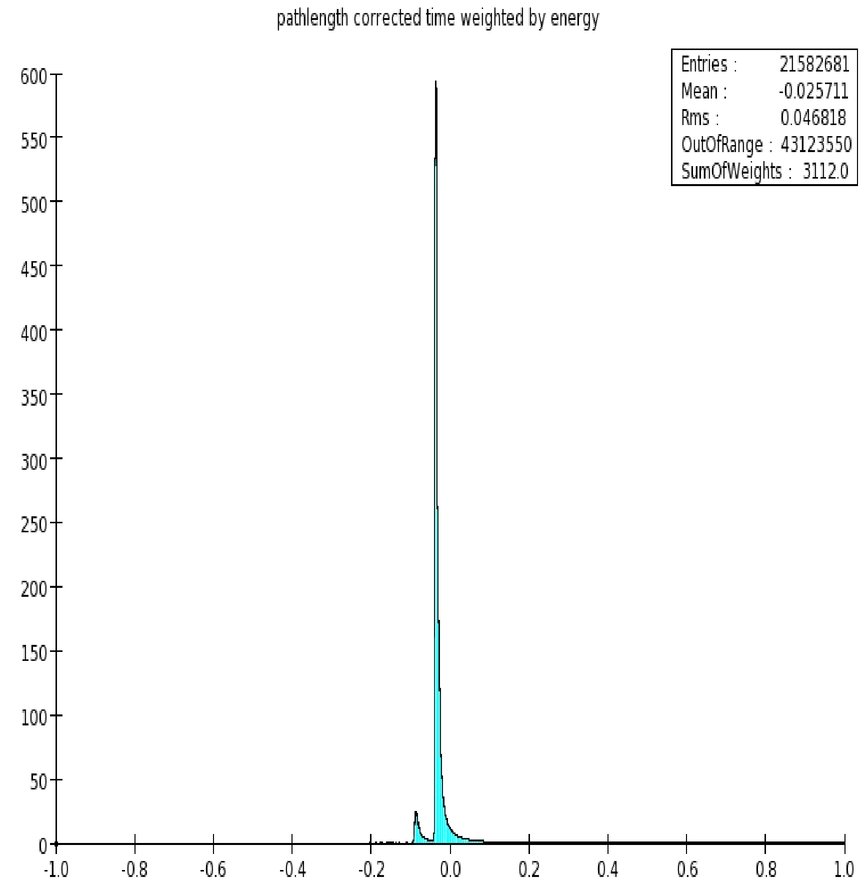
Timing of bgr. Hits in the Calorimeter



~ 4% of 1 bunch crossing, no Bethe Heitler muons

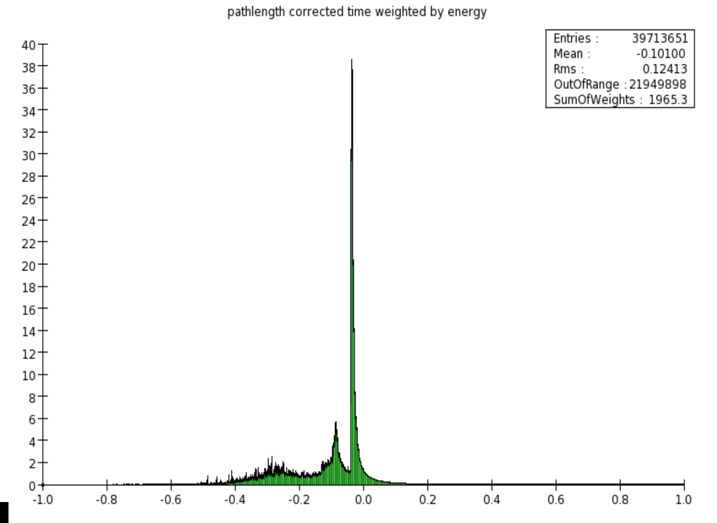
Z'(3TeV) -> e^+e^-

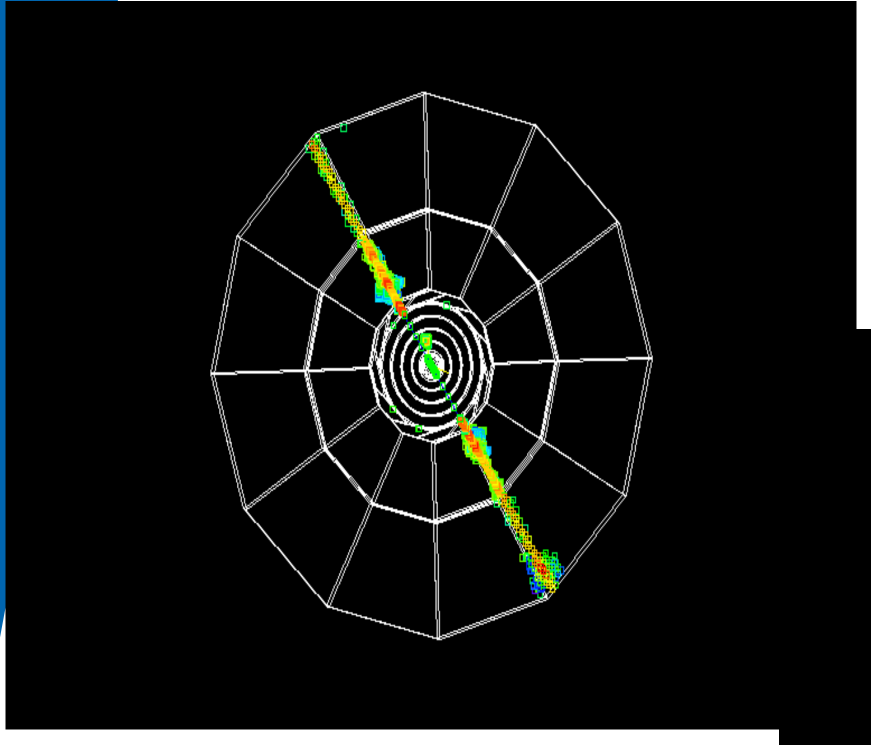


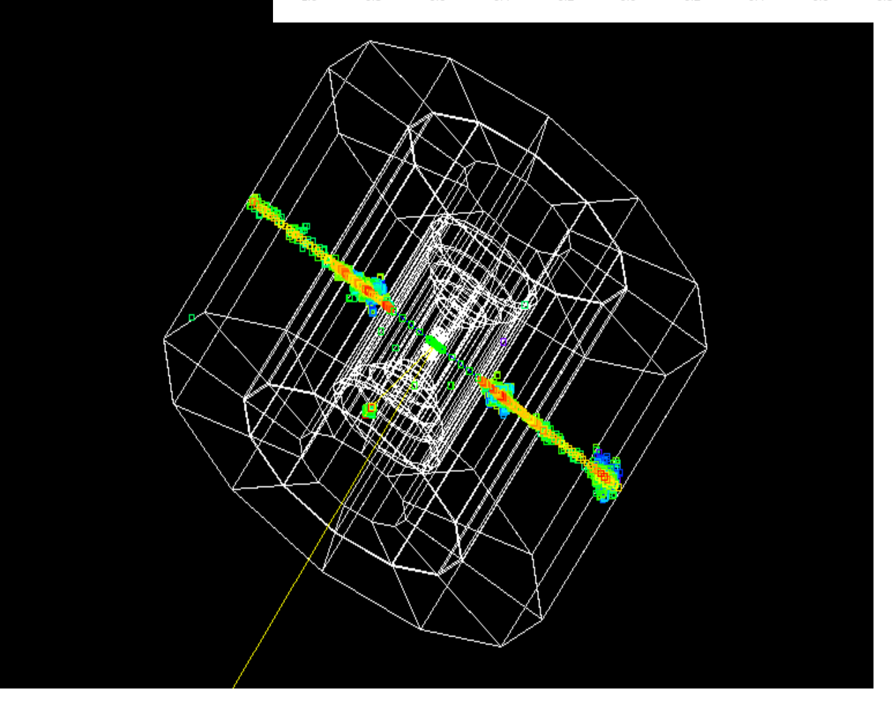


Fight time correct time weighted by energy
Range +/- 1 nsec

Z'(3TeV)->$\mu^+\mu^-$


pathlength corrected time weighted by energy
Entries : 39713651
Mean : -0.10100
Rms : 0.12413
OutOfRange : 21949898
SumOfWeights : 1965.3
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
-1.0
-0.8
-0.6
-0.4
-0.2
0.0
0.2
0.4
0.6
0.8
1.0





Reconstruction of W's and Z's decaying into jets

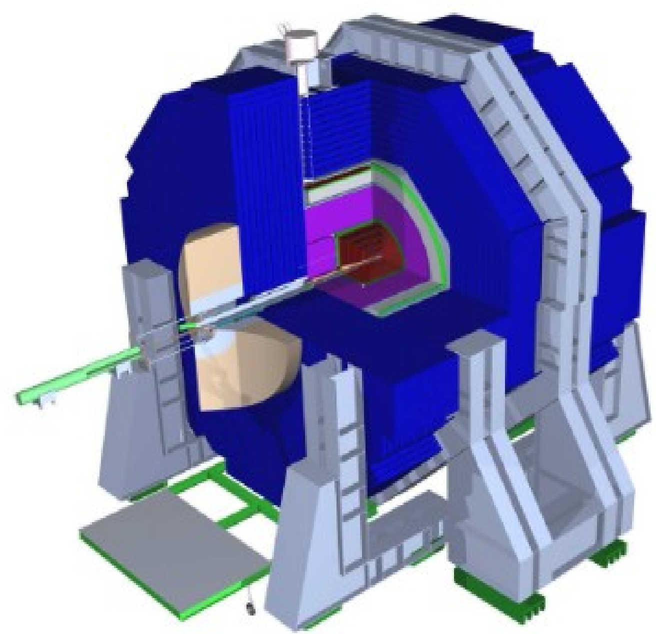
Steve Magill, Alex Conway, Hans Wenzel (ccal02)

Code is in CVS: Steve Magills contrib area name of the driver is: PFADRSelect.

This serves as an example for a complete physics analysis.

Data samples used:

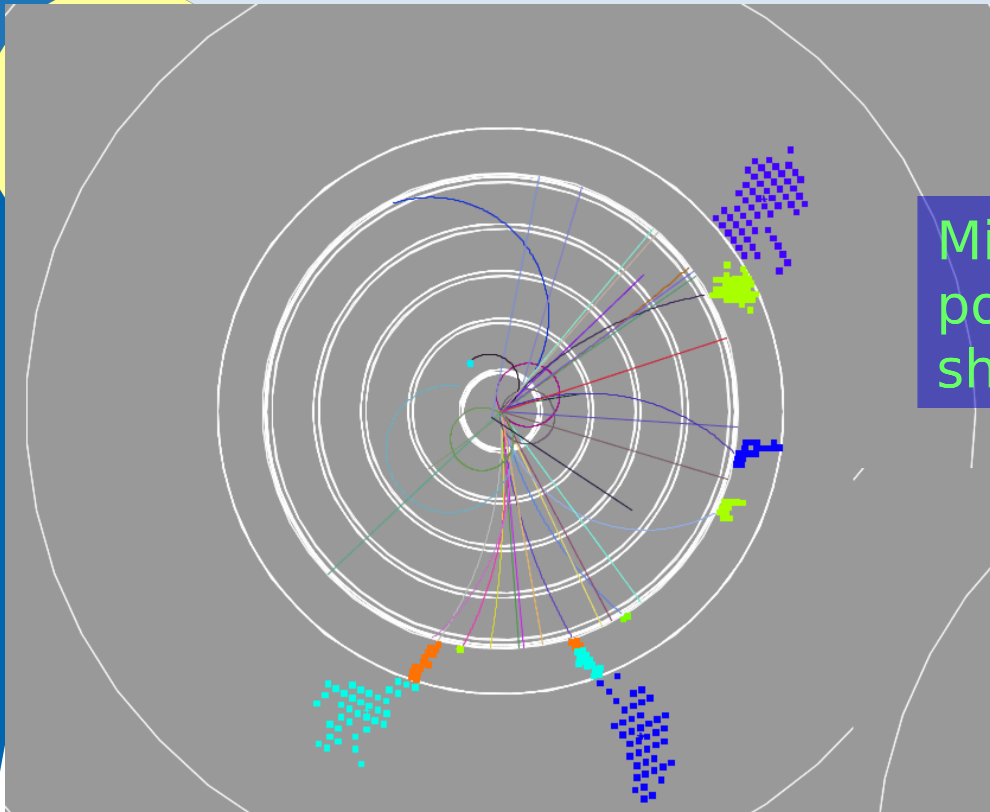
ZZ-> $\nu\nu qq$
Single W and single Z



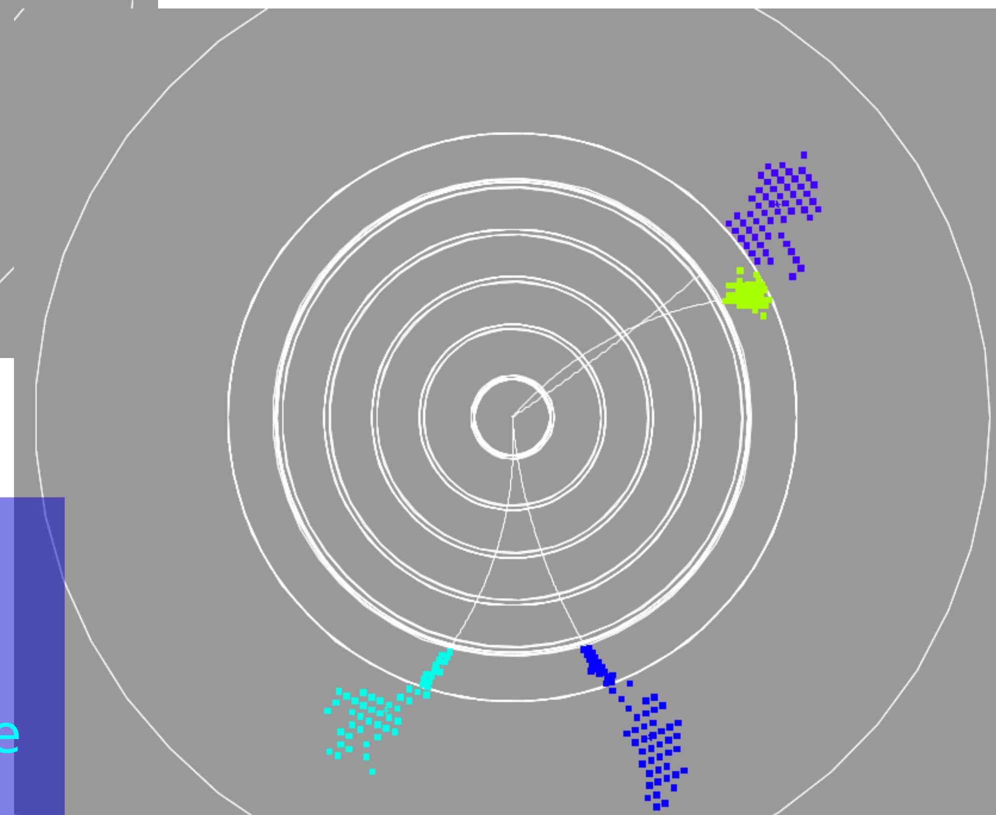
Procedure to reconstruct W's and Z's decaying into jets

- Apply threshold, timing cuts to both scintillator and cerenkov hit cells
- Extrapolate charged particle tracks to calorimeter and use cerenkov hits to define a “mip” cluster and spacepoint at start of shower
- Cluster remaining cells using Nearest-Neighbor cluster algorithm
- Correct each cluster using C/S ratio
- Apply PFAs to match clusters with tracks
  - -> Core cluster algorithm
  - -> Cluster pointing algorithm
  - -> Track/Shower cluster algorithm
- Find jets from Tracks, Clusters, PFA Particles
- Link track jets to Cluster, PFA jets
- Make ΔM corrections to Cluster, PFA jets using linked tracks
- Determine DiJet mass from jets

$e^+e^- \rightarrow ZZ \rightarrow \nu\nu qq$ @ 500 GeV



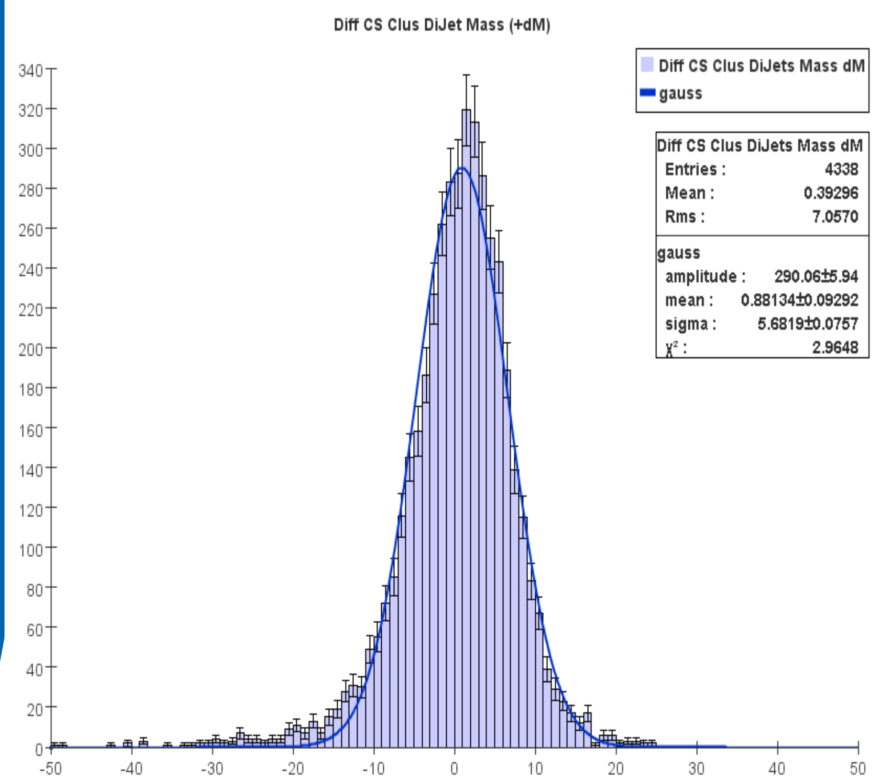
Mip clusters, core clusters, pointing clusters, and shower clusters

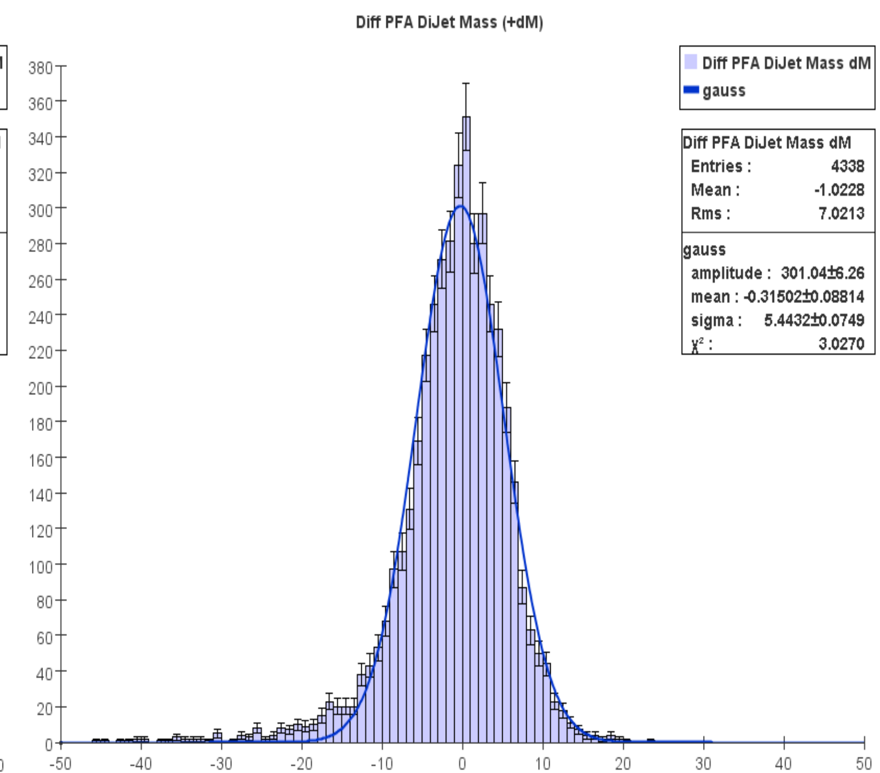


Final Track/Cal Cluster matches

-> Track 4-vectors are used in PFA, clusters are removed

Difference -> DiJet Mass – qq Mass + ΔM Correction





C/S-corrected Clusters

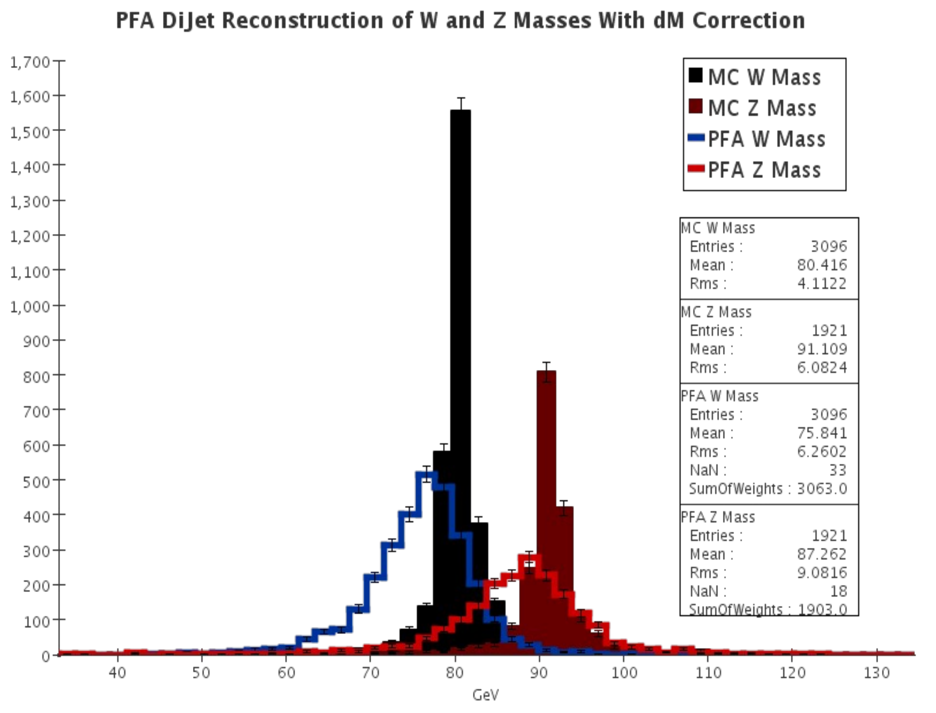
$\sigma/M = 0.062$

PFA-enhanced Clusters

$\sigma/M = 0.059$

W/Z separation

Alex Conway



Note:

Analysis not optimized yet
Tails due to leakage (ccal02)

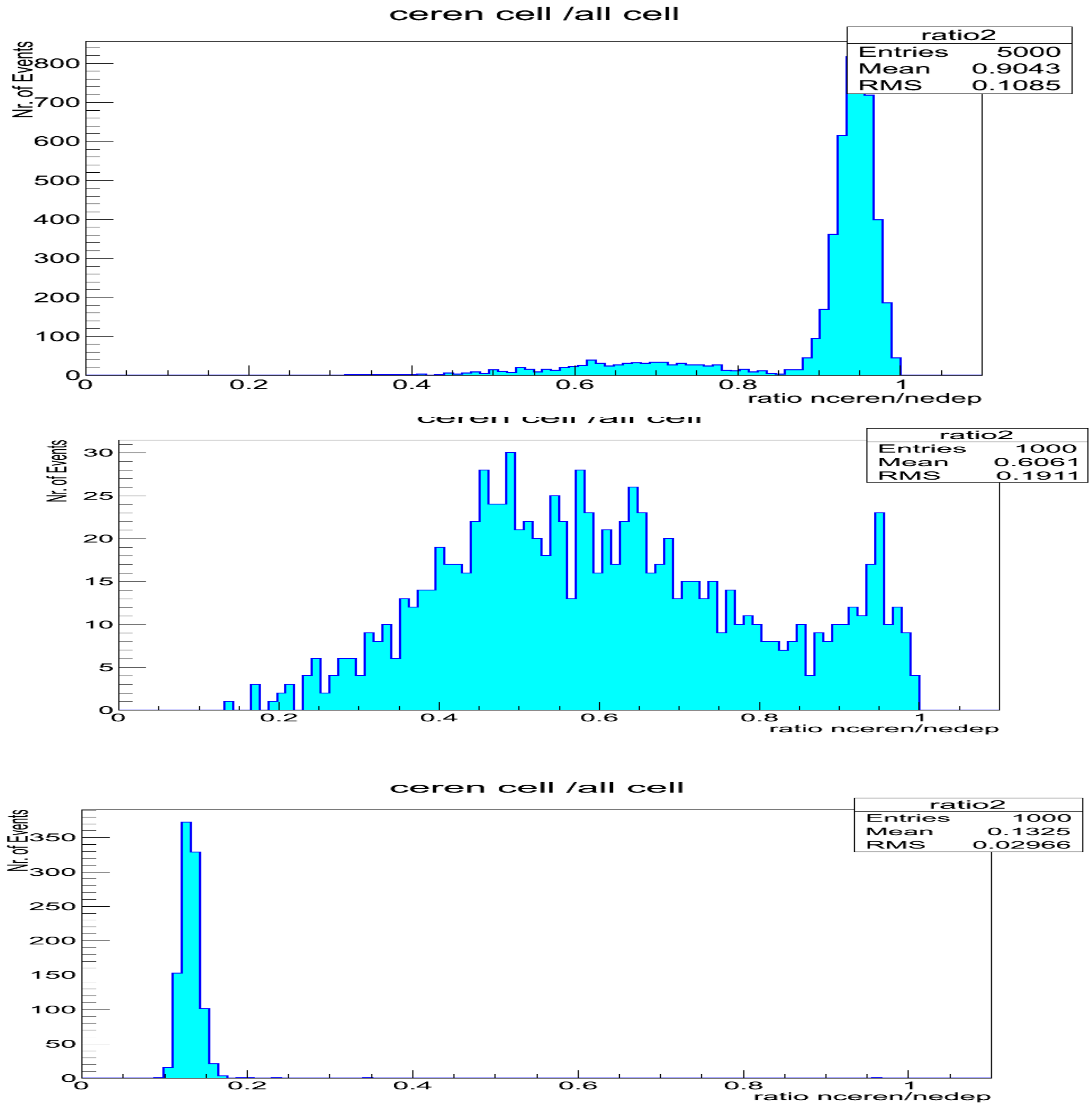
But:
Framework is in place to do physics studies

Conclusions

- Just started
- Software framework in place to do Muon Collider studies.
  - little man power (Just add more)
  - few customers
- Total absorption, dual read out calorimeter could be an option for a muon collider detector.
- High precision timing to reduce bgr while preserving good jet resolution looks possible → needs a lot more studying

Backup slides

Muon Accelerator Program



Machine Backgrounds

Precision Physics @ muon collider depends on the the ability to get the machine induced BGR. (caused by muon decay) under control

- Optimize machine parameters, proper shielding, IR, MDI
- Detector design and choice of technology--> detector simulation critical to determine detector parameters and study how it affects physics performance. Dealing with the large bgr is a huge computational problem

Plan

- Implement sensitive detector that counts the Cerenkov photons.
- Implement sensitive detector for the tungsten cone
- Generate single particle and other data samples.
- We need:
  - a functional and 'realistic' detector description
  - To add timing information to the calorimeter Hits
  - Get Driver to add Background events working
  - org.lcsim drivers to run the reconstruction and analysis
  - collect data cards for physics processes of interest (defined benchmarks) + backgrounds thereof
  - documentation to guide physicist through all the steps. Confluence is a good place for that.

Background Sources

Muon Decay Background:

- Electron Showers from high energy electrons.
- Bremsstrahlung Radiation for decay electrons in magnetic fields.
- Photonuclear Interactions --> Source of hadrons background.
- Bethe-Heitler muon production.

Collider	*μ per bunch*	*Decays/meter*
50×50 GeV	4×10^{12}	2.6×10^{7}
250×250 GeV	2×10^{12}	2.6×10^{6}
2×2 TeV	2×10^{12}	3.2×10^{5}
2.5×2.5 TeV LEMC	1.6×10^{11}	2.0×10^{4}

Lepton Collider: precision physics requires excellent tracking and calorimetry

Total absorption Dual readout calorimeter:

- Fast: Cerenkov light is prompt. (but Sz. decay time depends on Scintillator). SiPM -> very fast photo detectors.
- Precise: Total absorption (no sampling), dual readout (active compensation) --> excellent energy resolution.
- Fine granularity --> improve resolution even more with PFA algorithms

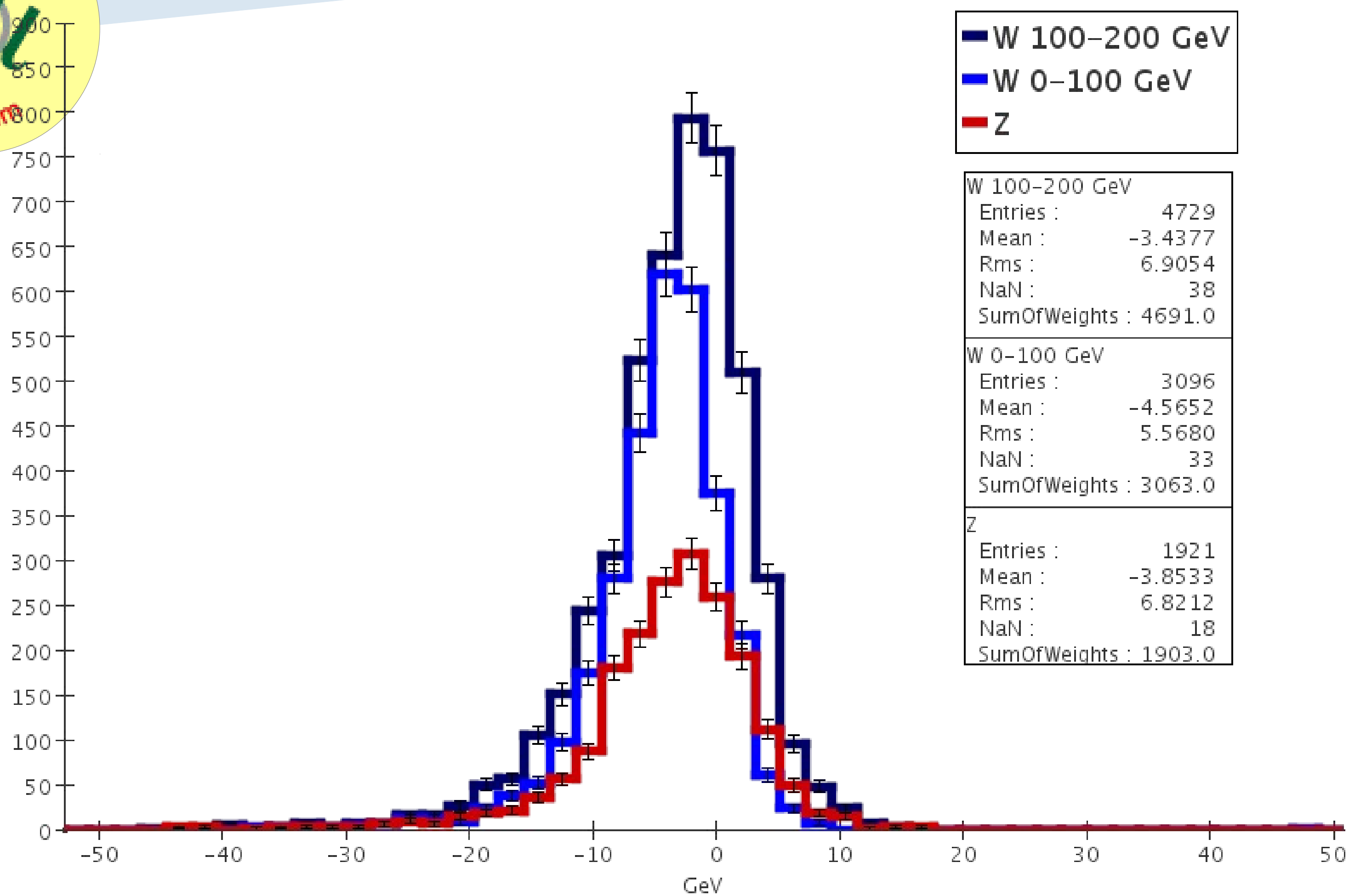
Getting muc off the ground

- Need dedicated disk area for muon collider data samples, muon collider software (currently SID)

  (may be migrate some of the ilc disk space)

- Need Muon Collider VO for grid submission + dedicated slots on fermigrid

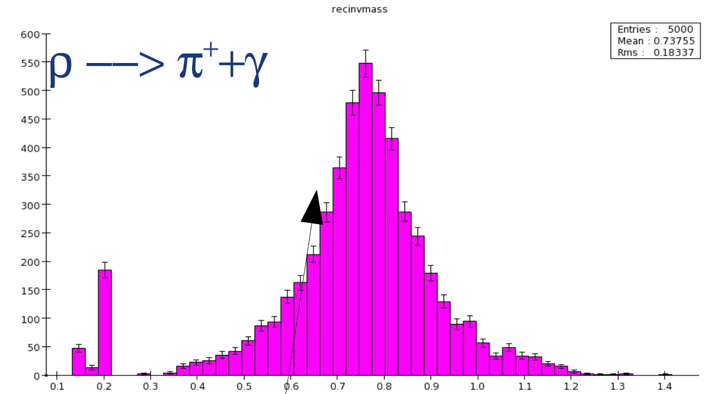
Difference Between MC Mass and PFA DiJet Reconstruction With dM Correction

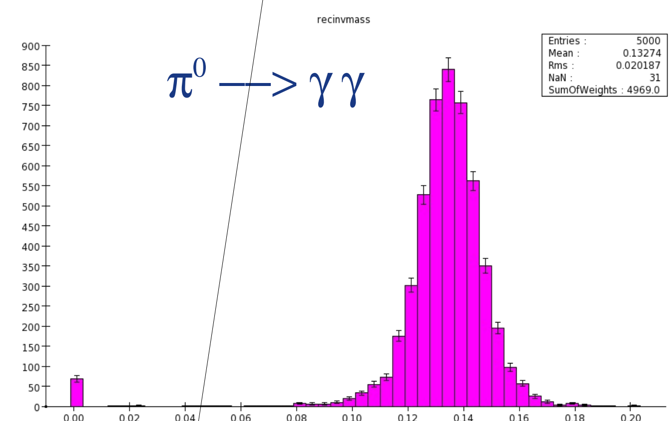


Analysis chain

- Get entire chain running at Fermilab (together with Alex Conway, YK student and Norman Graf)
  - Event generation (pythia)
  - Simulation (SLIC)
  - Event reconstruction (lcsim.org)
  - Analysis (jas3)
  - Documentation (confluence pages)

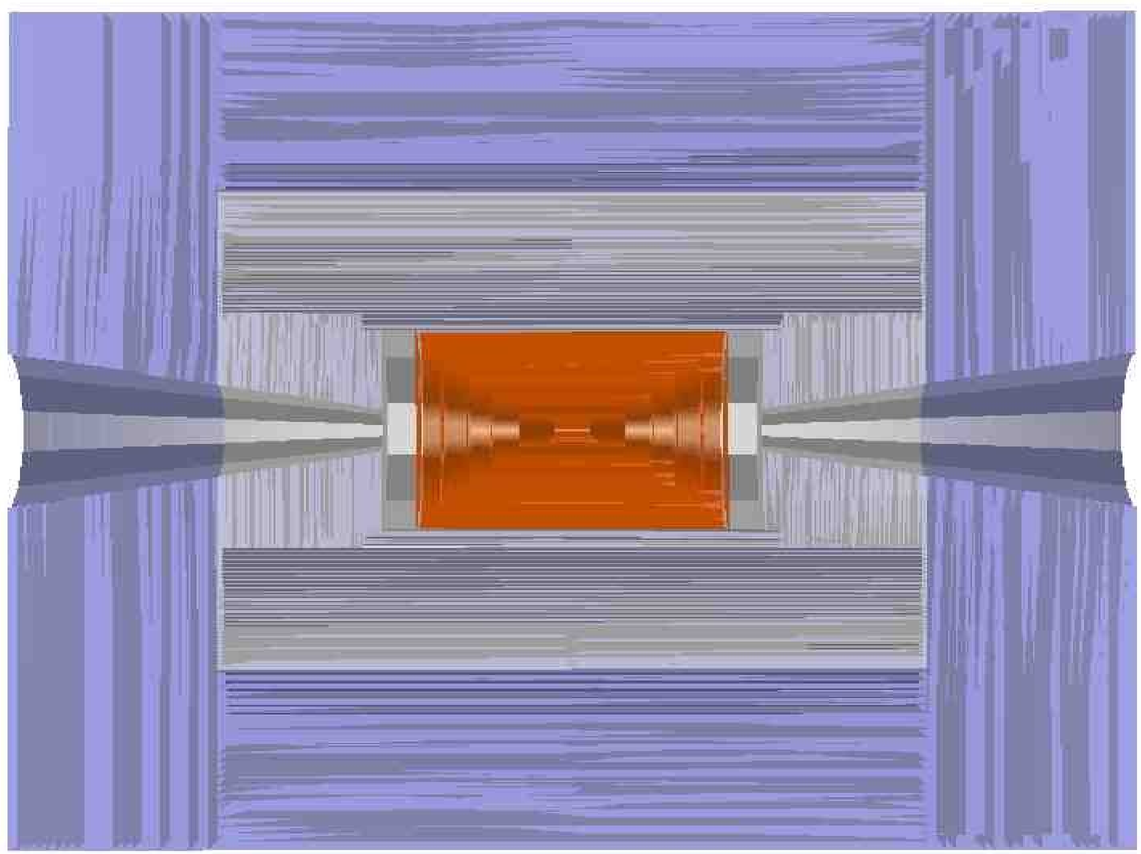
.





Needs Tracking and calorimetry

The mcdrcal00 detector in org.lcsim



Plan

- Implement sensitive detector that counts the Cerenkov photons.
- Implement sensitive detector for the tungsten cone
- Generate single particle and other data samples.

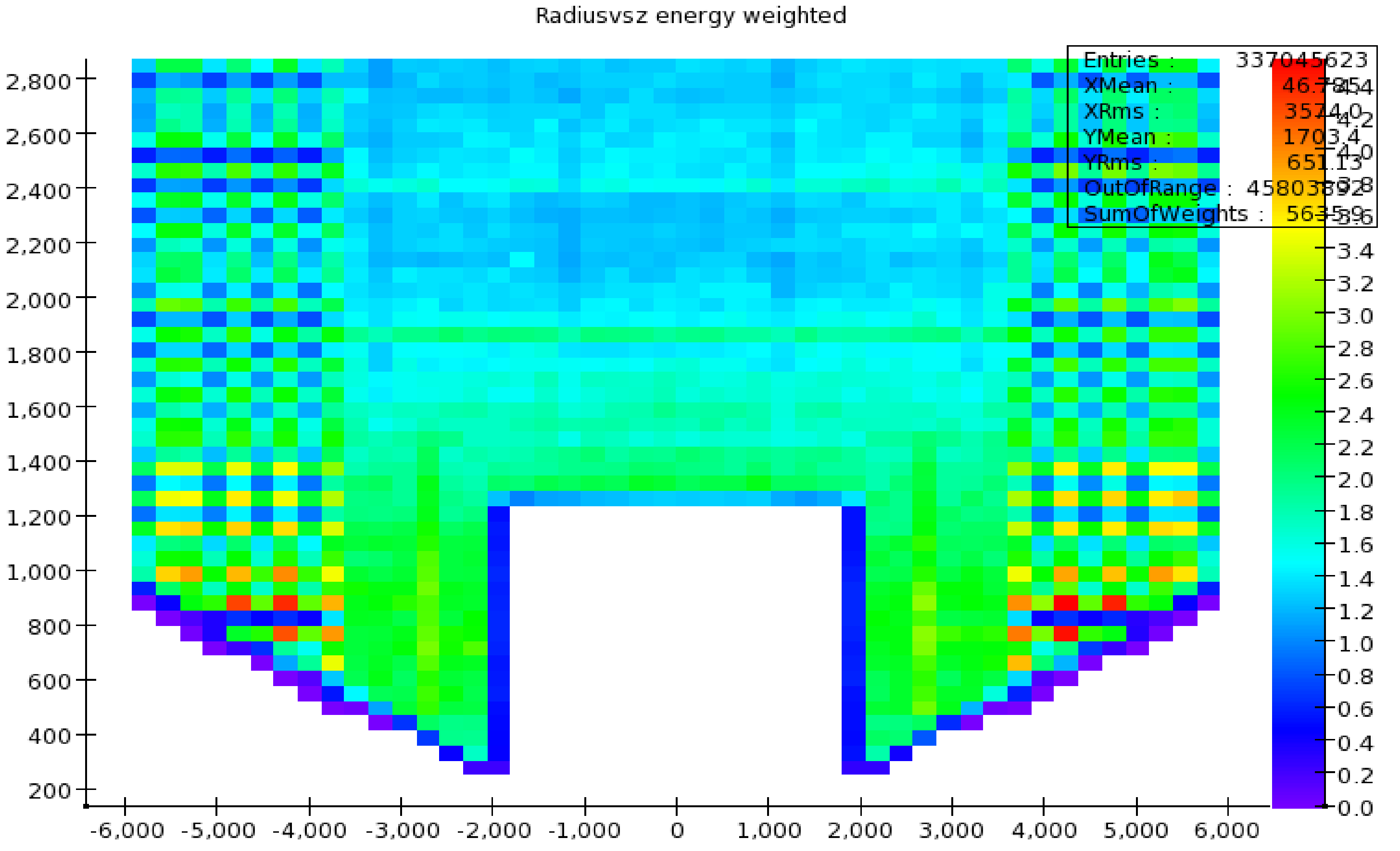
Data samples

Fully simulated events on detsim (replacement of ilcsim and ilcsim2):

/ilc/sid/wenzel/muoncolliderdata/slcio/bgr

/ilc/sid/wenzel/muoncolliderdata/slcio/signal

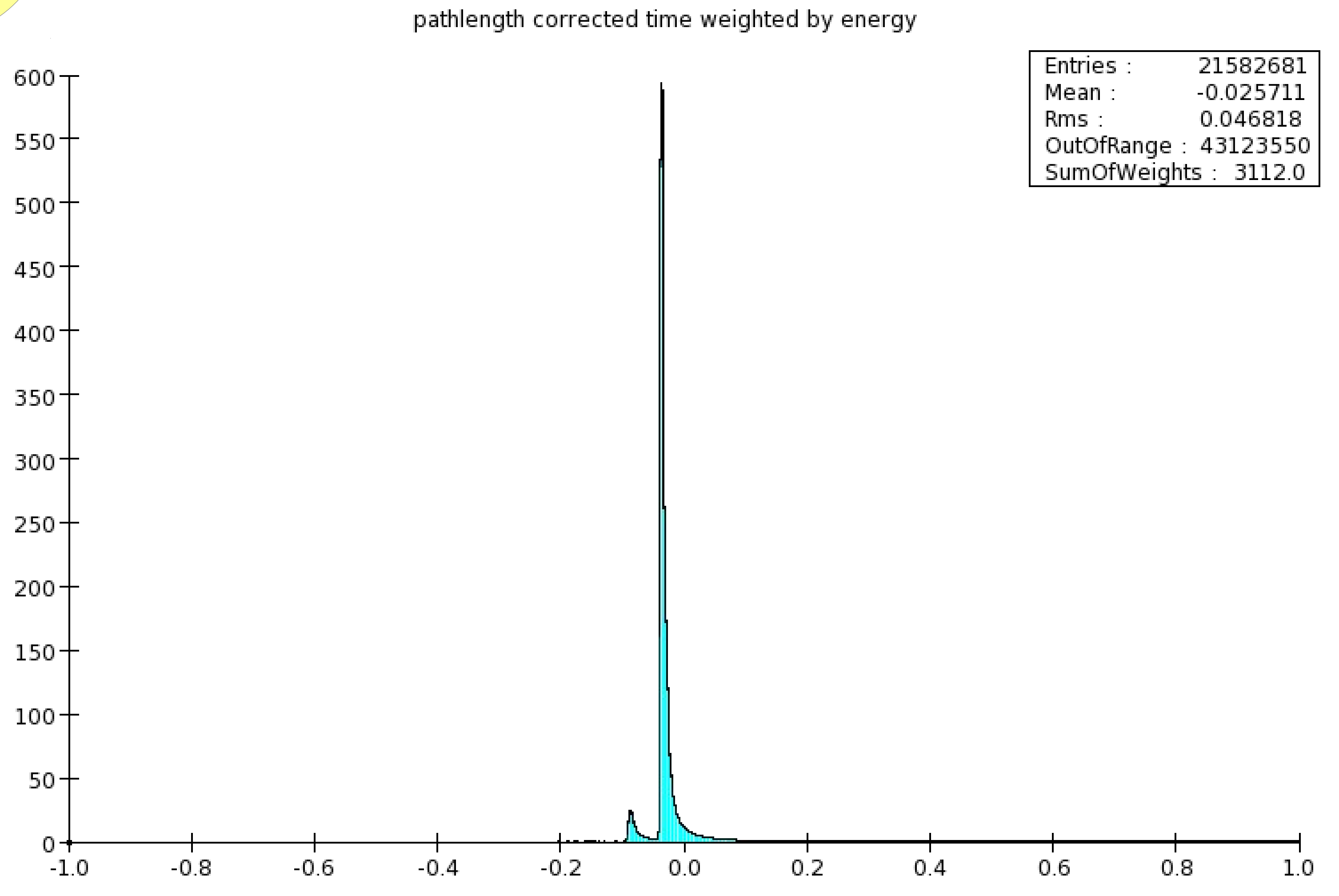
Zp3TeVtoee.slcio
Zptomumu_3TeV_mcdrcal00.slcio


Radiusvsz energy weighted
Entries : 337045623
XMean :
XRms :
YMean :
YRms :
OutOfRange :
SumOfWeights :
2,800
2,600
2,400
2,200
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
-6,000 -5,000 -4,000 -3,000 -2,000 -1,000 0 1,000 2,000 3,000 4,000 5,000 6,000
3.4
3.2
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0

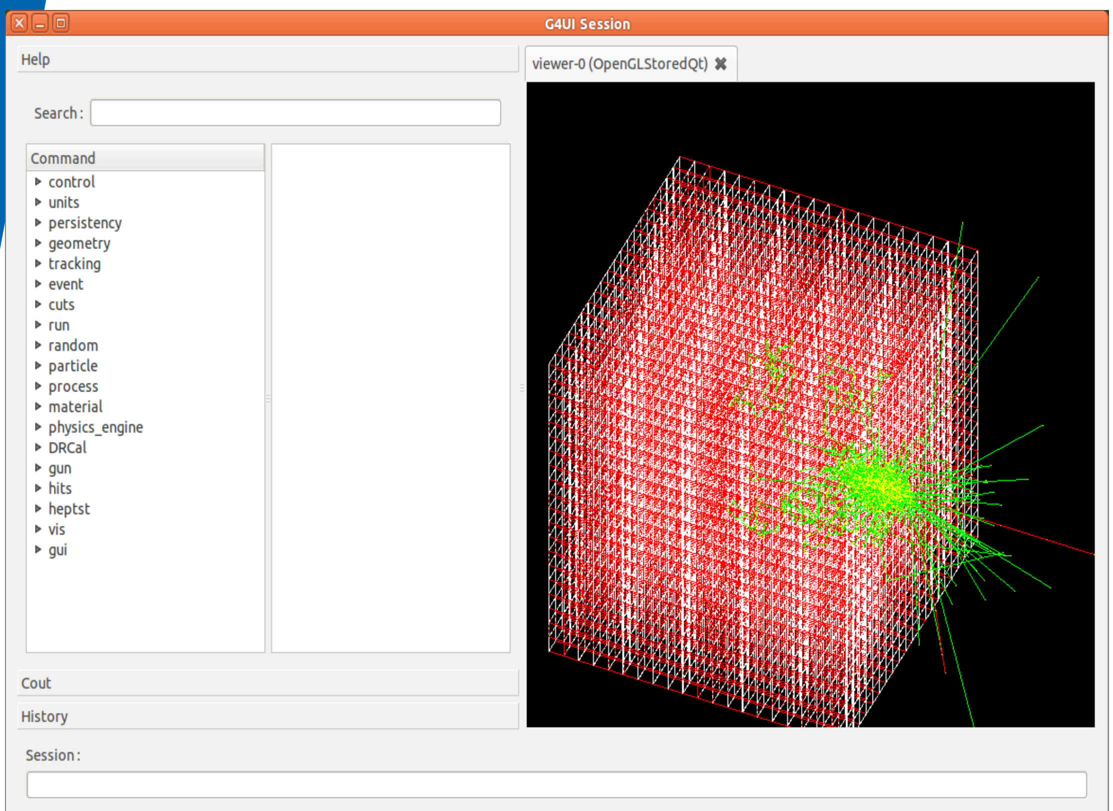
Plan

- Need a working detector model for the muon collider (Work with SLAC). Challenge is to deal with backgrounds while maintaining high precision (can it be done?). Needs detailed studies
- Calorimeter:
    - Dual readout (need to study how timing will affect the resolution after dual readout correction is applied) --> implement new optical calorimeter
    - Raja type: (digital sampling calorimeter with traveling time gate, software compensation)
- Tracker:
    - More like LHC than ILC, double or triple layers might be needed to help with pattern recognition. Need fast timing to reject background --> this will all come at a price (material budget)
- Once we have it: debug, biggest challenge will be to deal with the huge backgrounds and getting them into the simulation. (much more challenging than pile up at LHC and that was already difficult)

$Z' \to e^+ e^-$



pathlength corrected time weighted by energy
Entries : 21582681
Mean : -0.025711
Rms : 0.046818
OutOfRange : 43123550
SumOfWeights : 3112.0
600
550
500
450
400
350
300
250
200
150
100
50
0
-1.0
-0.8
-0.6
-0.4
-0.2
0.0
0.2
0.4
0.6
0.8
1.0


G4UI Session
Help
viewer-0 (OpenGLStoredQt)
Search :
Command
control
units
persistency
geometry
tracking
event
cuts
run
random
particle
process
material
physics_engine
DRCal
gun
hits
heptst
vis
gui
Cout
History
Session :