



Mice Particle Identification

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Particle ID Elements

- Upstream Detectors:
 - Time of Flight system
 - Rely on the time difference between stations TOF I and TOF II.
 - Upstream Cherenkov System
 - Verifies that the track is a muon.
- Downstream Detectors:
 - Time of Flight system
 - Verifies the existence and its time for a track exiting the detector solenoid.

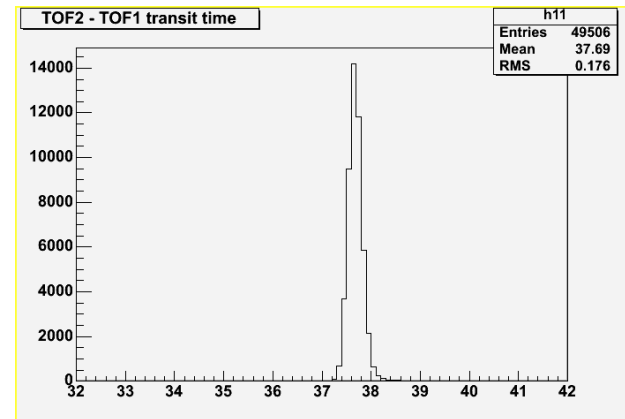
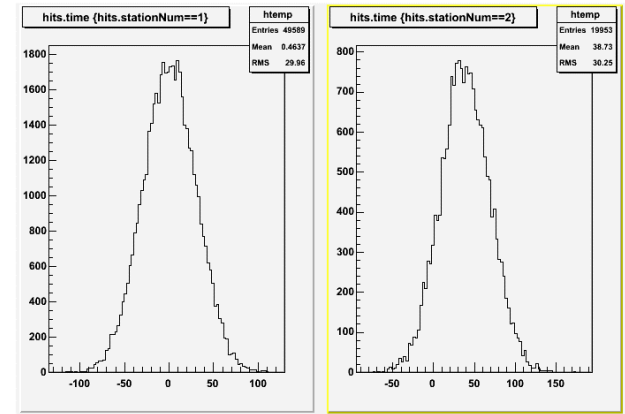


Particle ID Elements

- Downstream Detectors (cont.)
 - Downstream Cherenkov System
 - Verifies that the track seen in TOF III is an electron.
 - Not sensitive to muons.
 - EM Calorimeter
 - Shows whether a track that is seen in TOF III has an EM shower or not.
- Tracking Systems
 - Needed to know the particle momentum.

Upstream TOF System

- Plots on the right show:
 - Upper plot shows time distributions at TOFI and TOFII:
 - $\sigma_T = 30$ ns for these stations.
 - Lower plot shows the transit time of individual μ tracks.
 - $\langle \Delta T \rangle = 37.6$ ns.
 - $\sigma_{\Delta T} = 176$ ps
 - The ΔT corresponds well to what we expect for μ with $P = 200$ MeV
 - 37.6 ns.





Separating π from μ in the Real World

- We see from Tom Roberts analysis of the MICE beam line that the pion background is likely to be more energetic than the desired muons.
- The table below shows the expected time differences for π and μ at their mean momentum.
 - Since there is a $\sim 10\%$ $\Delta E/E$ spread we might expect some overlap.
 - Also we had better not scrimp on the phototubes

Particle	Kine Energy	Momentum	Beta	ΔT
Muon	120.5 MeV	200 MeV/c	0.88416	37.7 ns
Pion	177.8 MeV	285 MeV/c	0.89811	37.1 ns

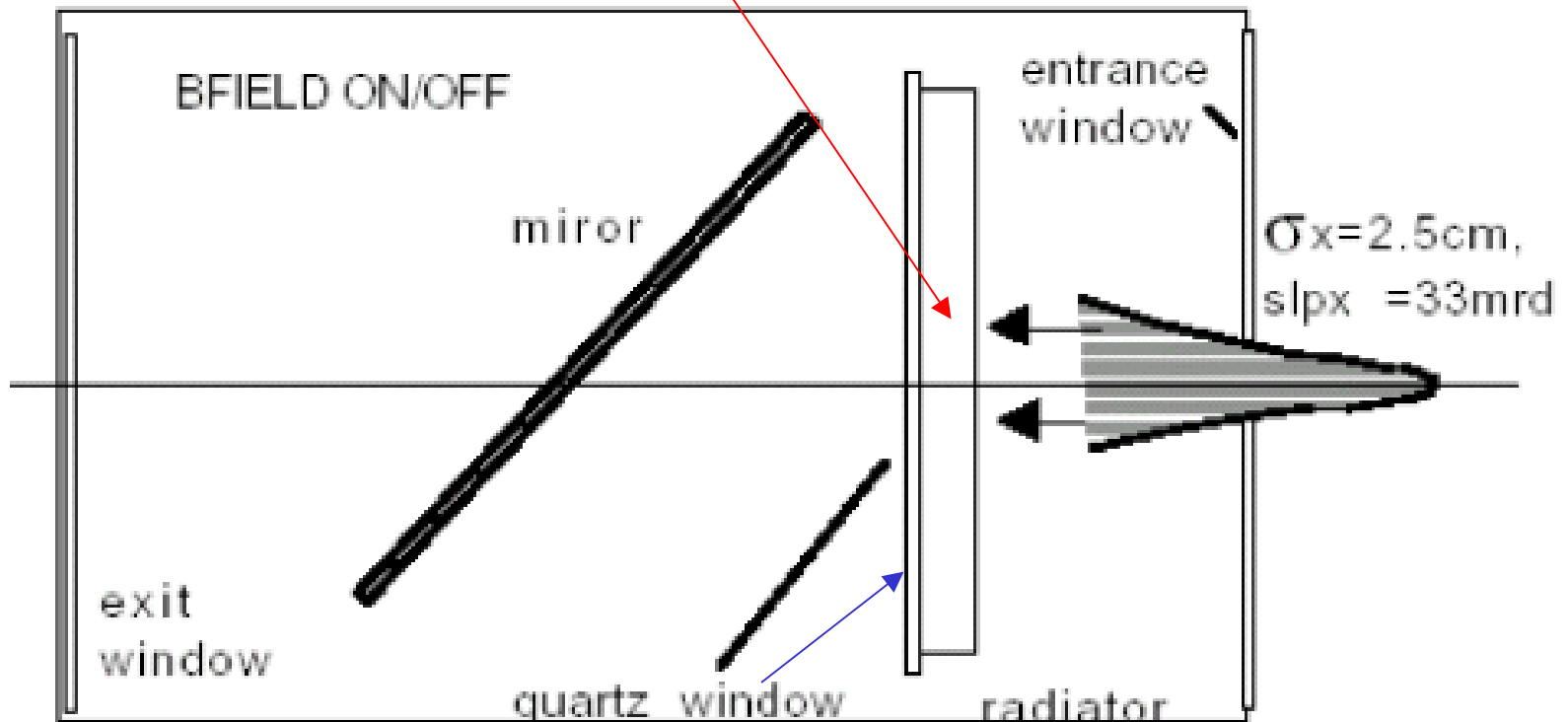


Requirements for ToF Particle ID

- The `TofParticleID` class will need:
 - Access to TOF I and TOF II *digitizations* for the same event (actually for the same track).
 - Our ROOT structure keeps digitizations separate.
 - Knowledge of the *Tracker* reconstructed momentum.
 - All of the TOF I hits in the pile-up time interval
 - We need to estimate the likelihood that a time coincidence is real or coincidental.

The Upstream Cherenkov : Ckov1

■ C_6F_{13} Radiator





Ckov1 Parameters and Status

- Status: we now see *hits* and *digits* for Ckov1.
- Radiator is C_6F_{14} with $n_{\text{refr}}=1.25$
 - Thresholds are 0.7 (e), 140 (μ) and 190(π) MeV/c respectively.
- I am not quite sure how Ckov1 will distinguish μ from π since the velocities are close as we have seen.
 - The discrimination comes from the pulse height analysis, where the $(dE/dx)_c$ is largely a function of β alone.
- With the knowledge of the momentum from the tracker we should be able to separate μ from π .
- The Ckov1 may be less sensitive to the background than TOF since TOF I is located in a position with lots of background.

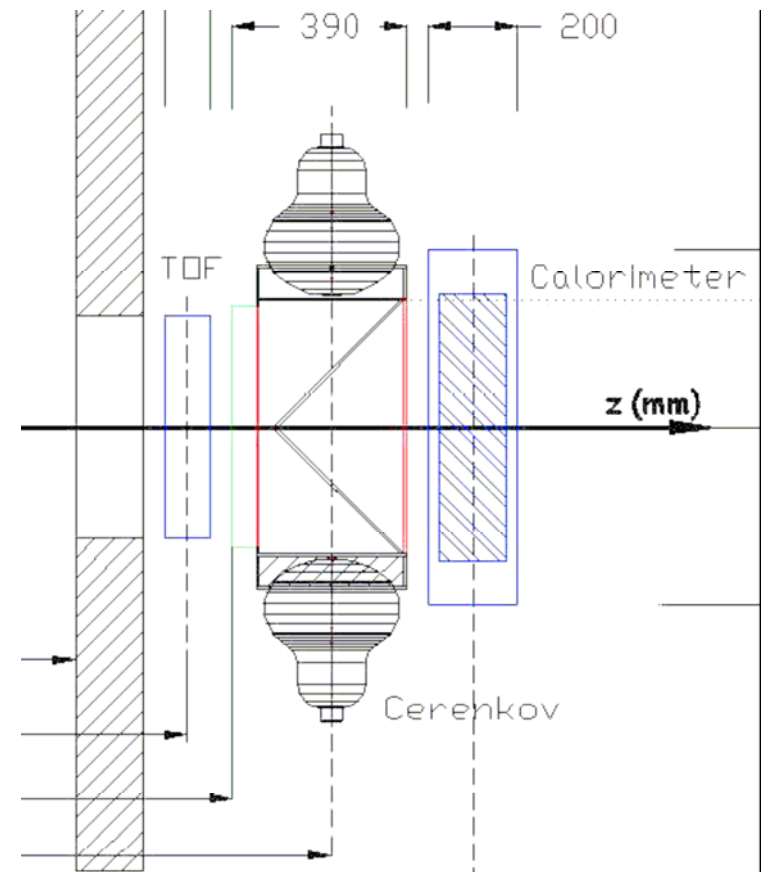


Ckov1 Particle ID Software Needs

- The Ckov1 acts independent of the other particle ID detectors.
 - Since it has a single PMT it cannot measure the radius of the Cherenkov cone.
 - It will only measure a pulse height.
- It will need to know the momentum from the *tracker* reconstruction.

Downstream Detectors

- The figure on the right shows the placement of the downstream detectors.
- Both the Ckov2 and EMcal need a coincidence with the TOF III.

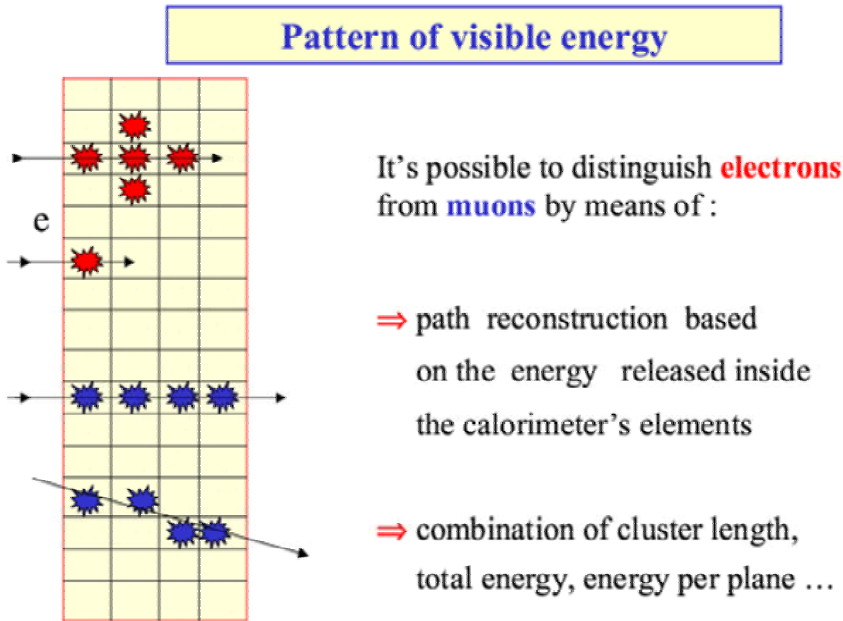




Downstream Cherenkov

- Ckov2 is a threshold Cherenkov
 - The refraction index is $n_{\text{refr}}=1.02$
 - This corresponds to $p_{\mu} > 525 \text{ MeV}/c$ for muons
 - But only $p_e > 2.5 \text{ MeV}/c$ for electrons
 - If we see a signal in Ckov2 and TOF III it is EM energy
 - Single ionizing \rightarrow electron
 - Twice minimum ionizing \rightarrow photon

Muon vs electron identification in EMcal



It's possible to distinguish **electrons** from **muons** by means of :

- ⇒ path reconstruction based on the energy released inside the calorimeter's elements
- ⇒ combination of cluster length, total energy, energy per plane ...

We only consider a “pattern-based” identification algorithm, i.e. detection efficiency in layers >1

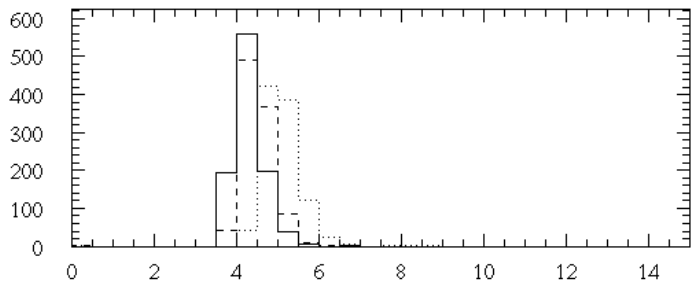
We have carried out simulation studies in G4MICE to optimize the mu/electron separation capabilities by varying:

- sampling fraction, i.e. **lead layer thickness**: 0.5-0.2 mm
- readout segmentation, i.e. **cell size**:
3.75x3.75 cm², 3.25x3.25 cm², 2.5x2.5 cm², 2.5x4.0 cm²

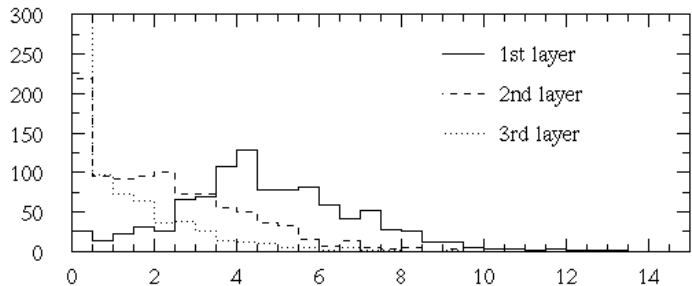
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Calorimeter signal, efficiency definition

Energy deposit



Deposited energy (MeV) - muons



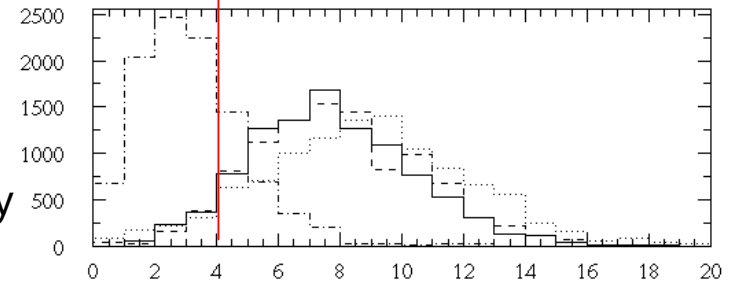
Deposited energy (MeV) - electrons



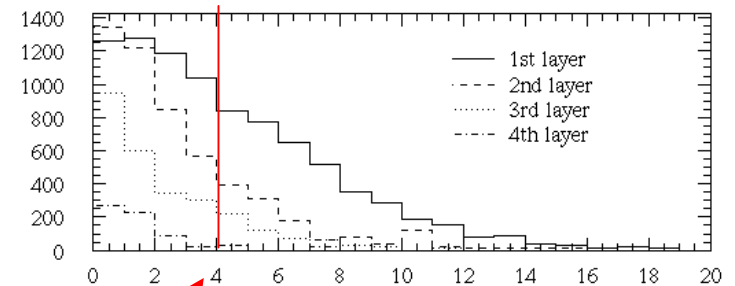
“digitization”:

- Light attenuation along fibers
- Winston cone collection efficiency
- Photocathode quantum efficiency

PMT signal



Number of photoelectrons - muons



Number of photoelectrons - electrons

Detection efficiency is defined by a cut on signal above noise threshold: 3-4 p.e.

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Software Requirements of Particle ID

- Common Requirements:
 - Need to access information from more than one detector unit:
 - Upstream TOF requires two stations
 - Downstream Ckov2 or Emcal also require TOF III
 - Need results of Tracker reconstruction.
 - Primarily the track momentum and error.
 - Need to create an *Event* class that contains:
 - All detector results
 - Digitizations for particle ID detectors
 - Reconstruction for tracker detectors.
 - We are currently not organized that way.



Particle ID Classes

- There should be a ParticleID class for each ParticleID algorithm.
 - There may be one or more than one way to handle the information from each particleID detector system.
 - Each of these ParticleID classes should inherit from a *ParticleIDBase* class



ParticleIDBase class

- Contain common quantities.
- Should contain:
 - Detector/Algorithm identification
 - Reconstructed P , δP from tracker for track.
 - Link to reconstructed track.
 - Probabilities of being μ, π, γ, e .
 - Quality factor from algorithm determination.



TOFupstParticleID, for example

- Inherit from Base class, so it has access to above information.
- Links to :
 - Vector of TOF I digitizations in an event.
 - There can be more than one!
 - Vector of TOF II digitizations in an event.
 - Upstream beam monitor information
 - Intensity of pulse
 - Timing information (unless included in TOF TDC).
- Method to chose the appropriate digitization to use at each station.
- Method to calculate velocity from transit time and compare with momentum.
 - Calculate probabilities, since there are errors and backgrounds.
 - Calculate the quality of the results.
- Method to reject event if it is strongly believed to be background.



Ckov2ParticleID

- Also inherit from Base class.
- Links to :
 - Digitizations/reconstruction from each of the four PMTs.
 - Reconstruction is not well defined at this point.
 - TOF III digitizations/reconstruction
- Method to determine consistency of Ckov2 digits to TOF III digits and to reconstructed track.
 - Assign probabilities.
 - Assign quality



Conclusions

- Where should we put this?
 - It has to go after tracker reconstruction.
 - It should go before analysis.
 - If the reconstruction becomes a monolithic program, then it could go at the end of it.
- Most of what I have said is intentionally vague.
 - I have not yet studied the algorithms for particle identification. (I may not even have the expertise to do it.)
 - It would probably be valuable for a small group to actually work through the design of a particle ID algorithms.
 - Structure diagrams, not code!