MINERvA Software Framework
Calibration & Reconstruction

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Penn
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MINERvA

Content

1. MINERvA Software Framework
2. Calibration
3. Reconstruction
4. Processing and Analysis
5. Backup

MINERvA Software Framework

Based on the GAUDI Framework

- It describes, simulates, stores and analyzes data, using mostly the Gaudi framework developed for LHCb.
- Separates **data** objects from **algorithms**. Algorithms create new data objects from more basic data objects.
- Algorithms written in C++, .h and .cpp files.
- “Options” files (.opt) help to change lots of flags without recompiling.
- **Uses CVS** and not GitHub for version control =(

Powered by httpd APACHE

AnalysisFramework/

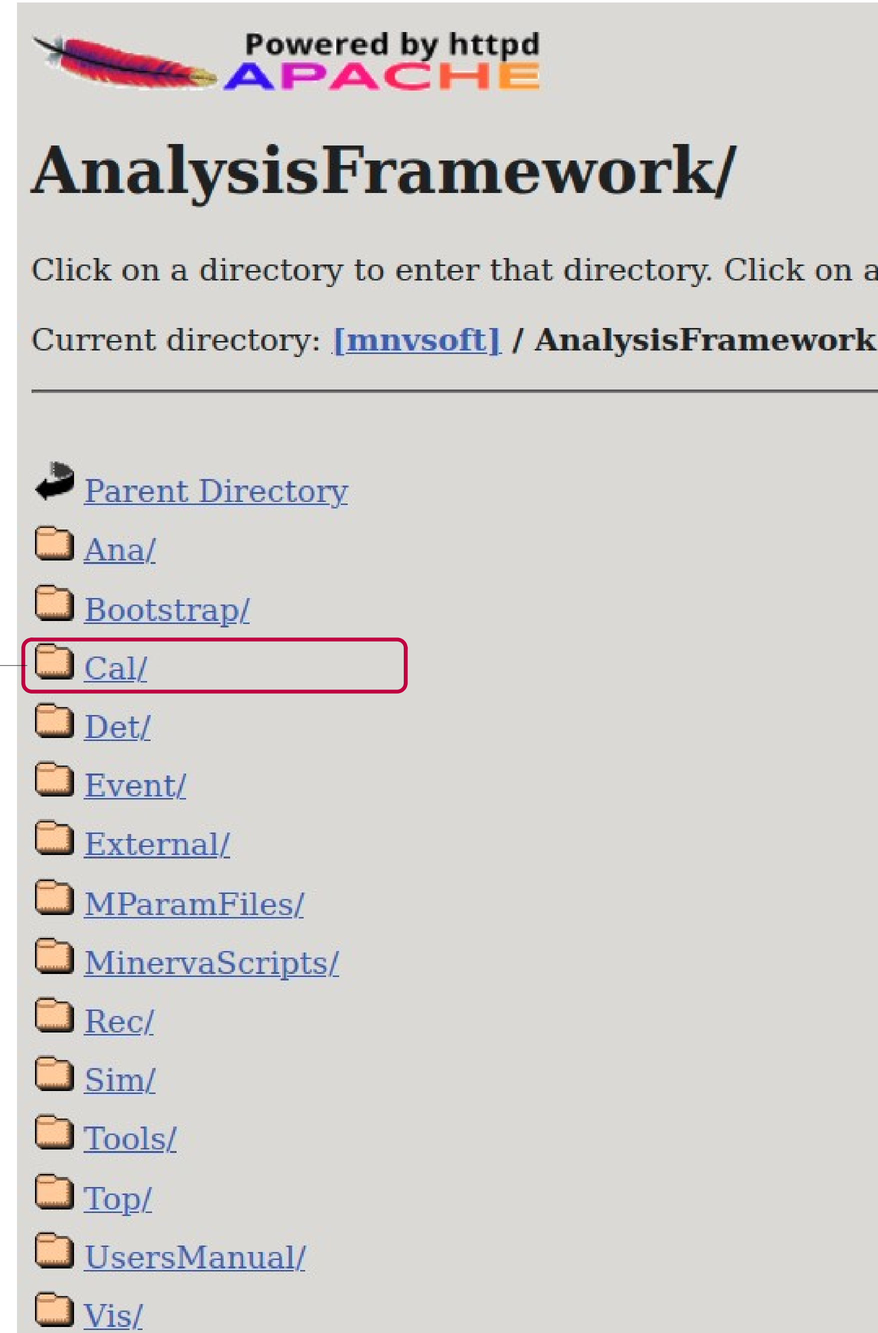
Minerva Framework

Gaudi Project

MINERvA Software Framework

Calibration Code


Parent Directory
Attenuation/
BadChannels/
CalibrationTools/
CrossTalk/
GateQuality/
PedestalSuppression/
RawDigitChecker/
RawToDigit/
RockMuonCalibration/
StripCal/
Temperature/


Powered by httpd APACHE

AnalysisFramework/

Click on a directory to enter that directory. Click on a

Current directory: [mnvsoft] / AnalysisFramework

Parent Directory
Ana/
Bootstrap/
Cal/
Det/
Event/
External/
MParamFiles/
MinervaScripts/
Rec/
Sim/
Tools/
Top/
UsersManual/
Vis/

MINERvA Software Framework

Reconstruction Code

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AnalysisFramework/

Click on a directory to enter that directory. Click on a

Current directory: [mnvsoft] / AnalysisFramework

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- Ana/
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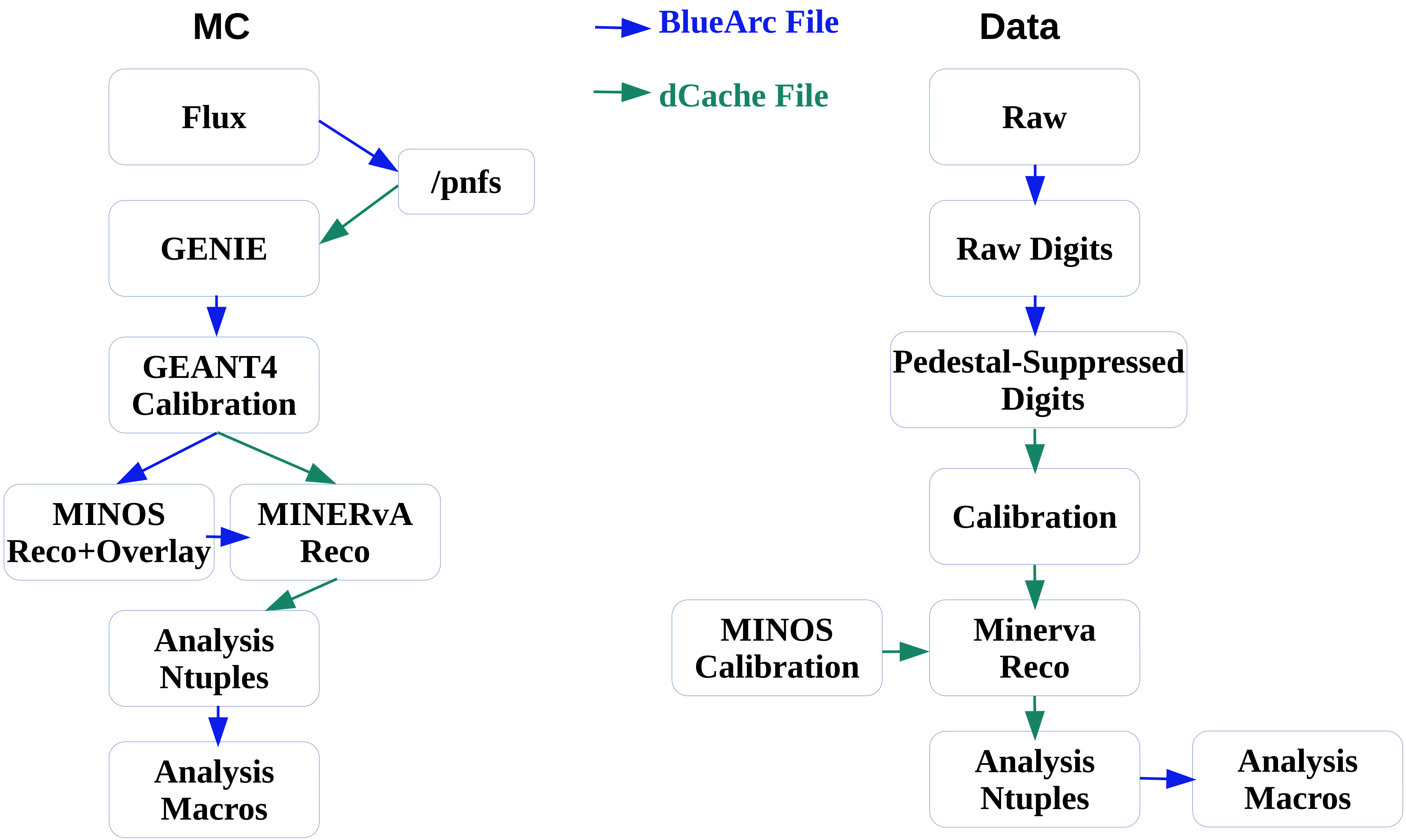
- Sim/
- Tools/
- Top/
- UsersManual/
- Vis/

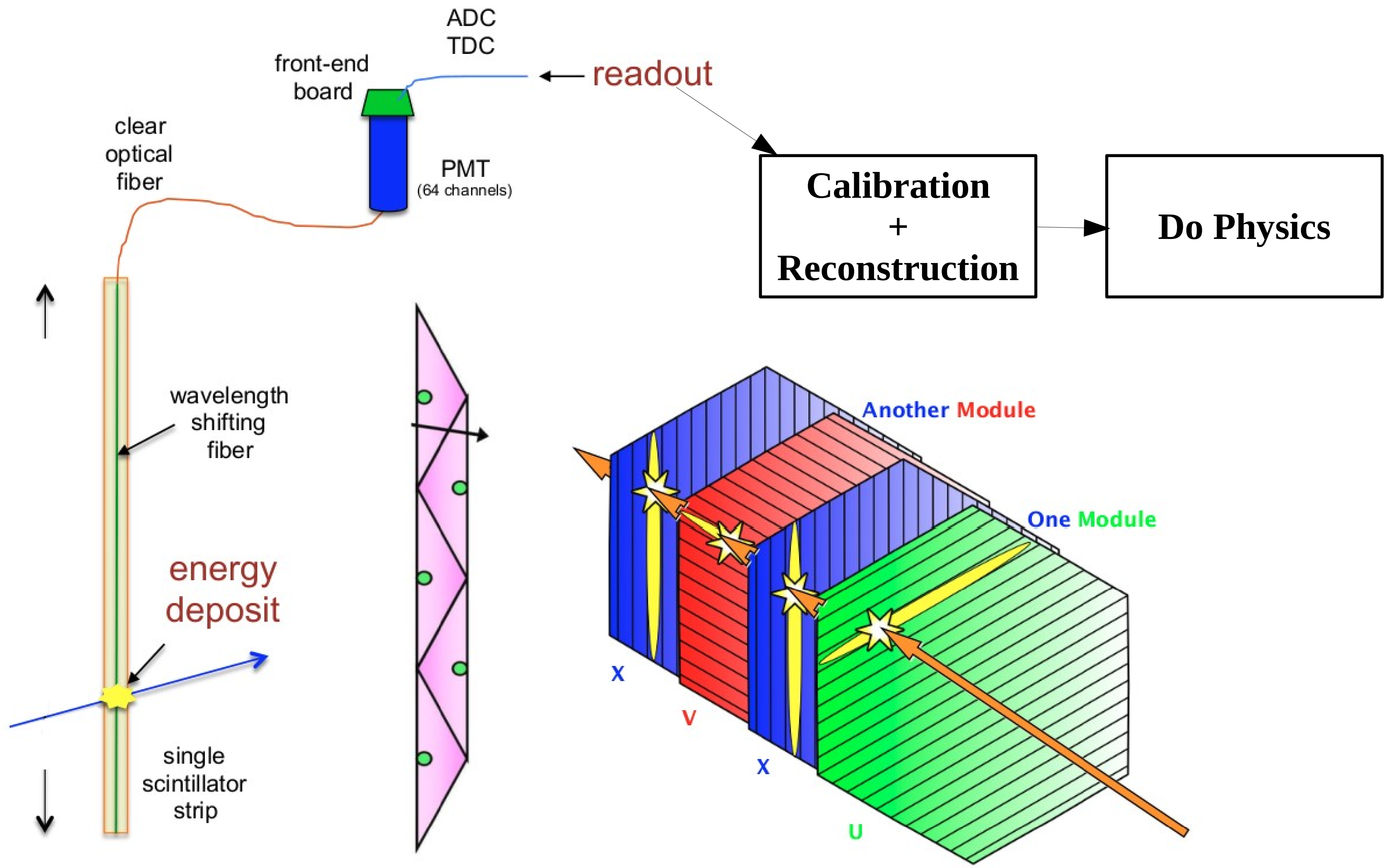
- ChronoBuncher/
- ClusterFormation/
- EnergyRecTools/
- EventRecInterfaces/
- EventReconstruction/
- GeoUtils/
- HistPatternRecognition/
- HoughVertexFinder/
- KludgeLibrary/
- ParticleAlgs/
- ParticleMaker/
- Place/
- ProngMaker/

File Flow – Production Chain



Readout

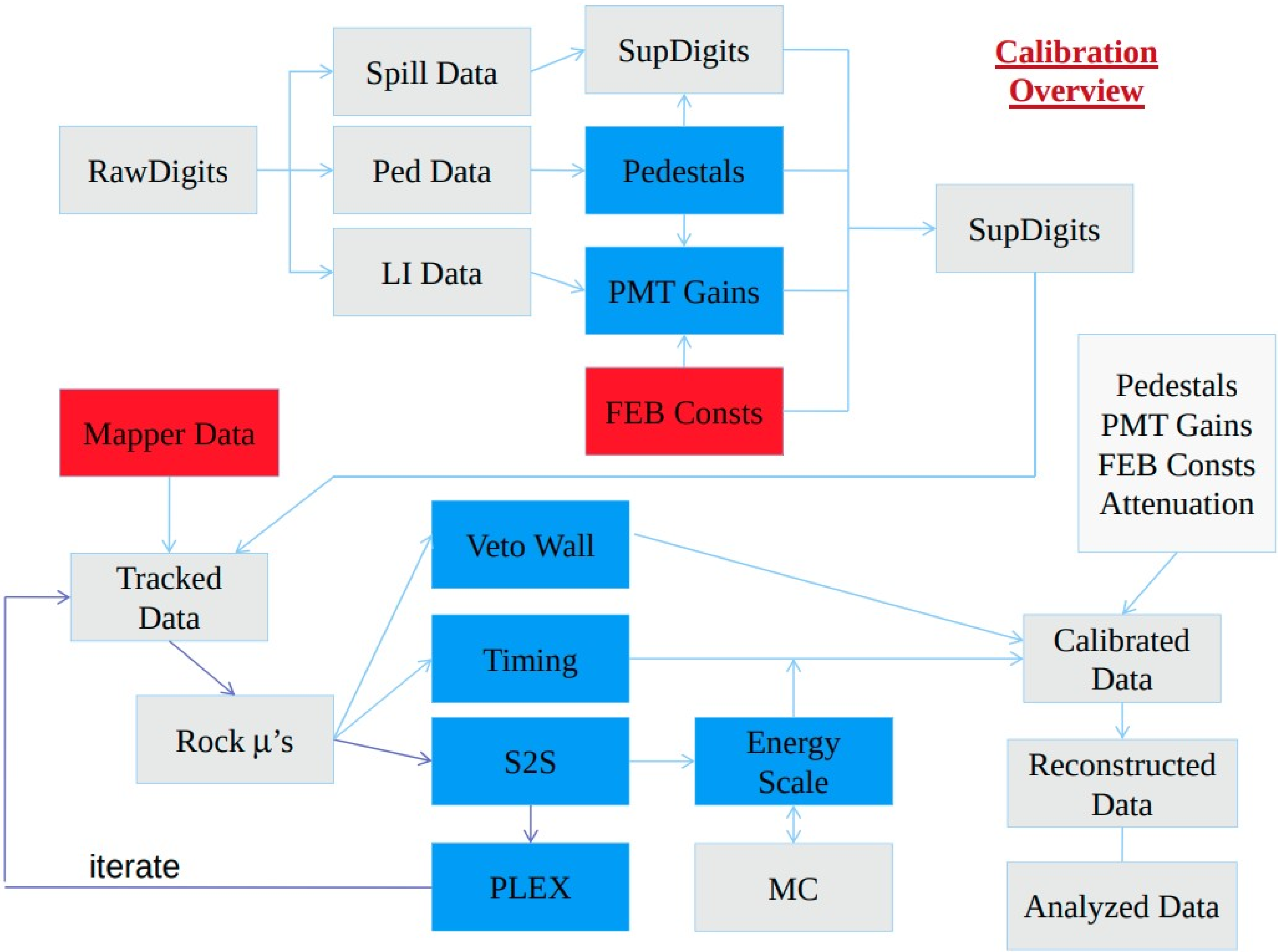
Example of an Optical Readout Channel



Calibration

Calibration

In Detail



Calibration Overview

Definition

$$E = PE(c, t) \times Att(s) \times S2S(s, t) \times F_{MEU}(t)$$

$$PE(c, t) = ADC \times FEB(c) / Gain(c, t)$$

c → electronic channel, ***t*** → time, ***s*** → strip

- ADC – ADC counts
- FEB(*c*) – FEB constants
- $Gain_i(c, t)$ – PMT pixel gains
- Att(*s*) – scintillator strip and fiber attenuation factors – **Module mapping**
- $S2S_i(s, t)$ – relative correction factor for channel *i* – **Strip-to-Strip (S2S)**
- $F_{MEU}(t)$ – overall energy scale for the entire detector – **Muon Energy Unit (MEU)**

FEB Calibration

FEB Response

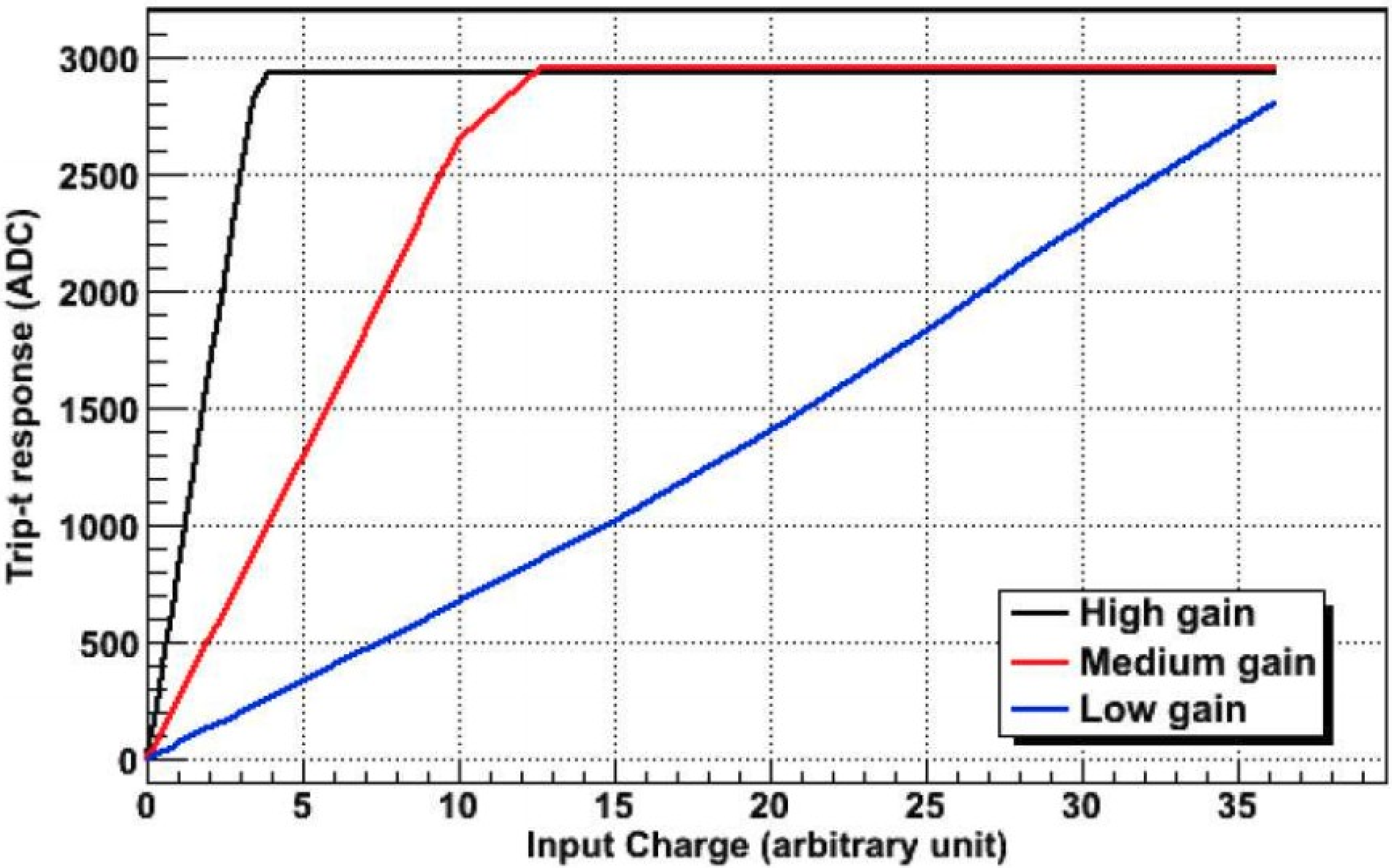
./Sim/Readout

PE(c, t) = ADC x **FEB(c)** / Gain(c, t)

- **Purpose**
  - Convert ADC to charge equivalence for the low, medium and high ADC channels.
- **Method**
  - Comparison of a known charge injection to the ADC count output.
  - Fit low, medium and high channels with tri-linear fit.
- **Correction Factor**
  - Constant per channel.
  - *Constants are updated after a board swap.

Energy Calibration

FEB Response



PMT Gain

./Cal/CalibrationTools

PE(c, t) = ADC x FEB(c) / **Gain(c, t)**

- **Purpose**
  - Monitor charge production in each pixel per incoming PE.
- **Method**
  - LED-based light injection (LI), once per beam spill.
- **Correction Factor**
  - Gain is obtained using the LI data and a PMT photostatistics model.

Pedestals

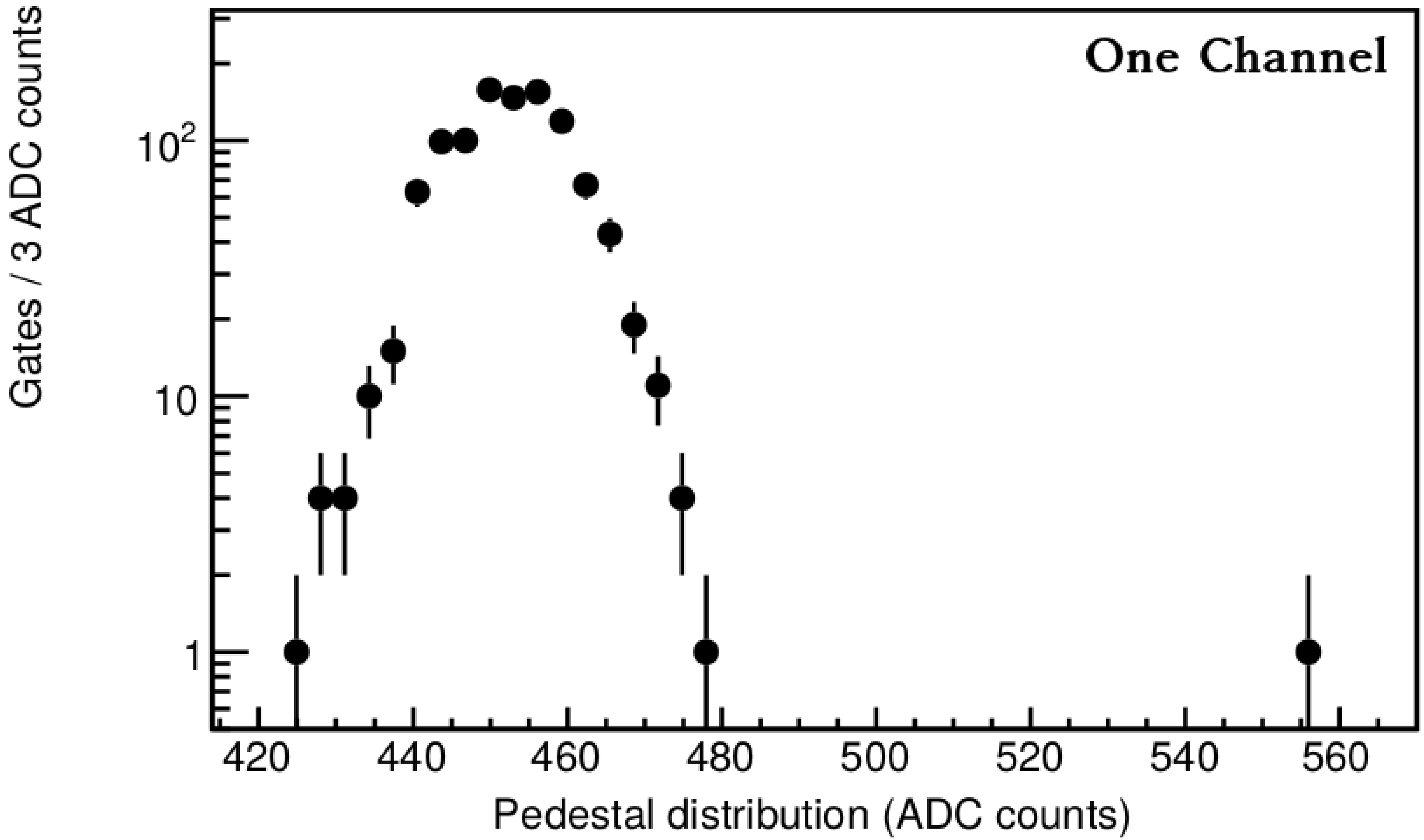
./Cal/PedestalSuppression

PE(*c*, *t*) = ADC x FEB(*c*) / **Gain(*c*, *t*)**

- **Purpose**
  - Subtract noise from beam events.
- **Method**
  - Every ~12 hours, mixed beam/pedestal data was taken in between beam spills. ~750 16-ms gates (same as beam gate) were collected each time.
  - Outliers (spurious signals) are removed using Peirce's criterion.
- **Correction Factor**
  - The constant is the mean of the ~750-gate pedestal distribution.

Energy Calibration

Pedestals



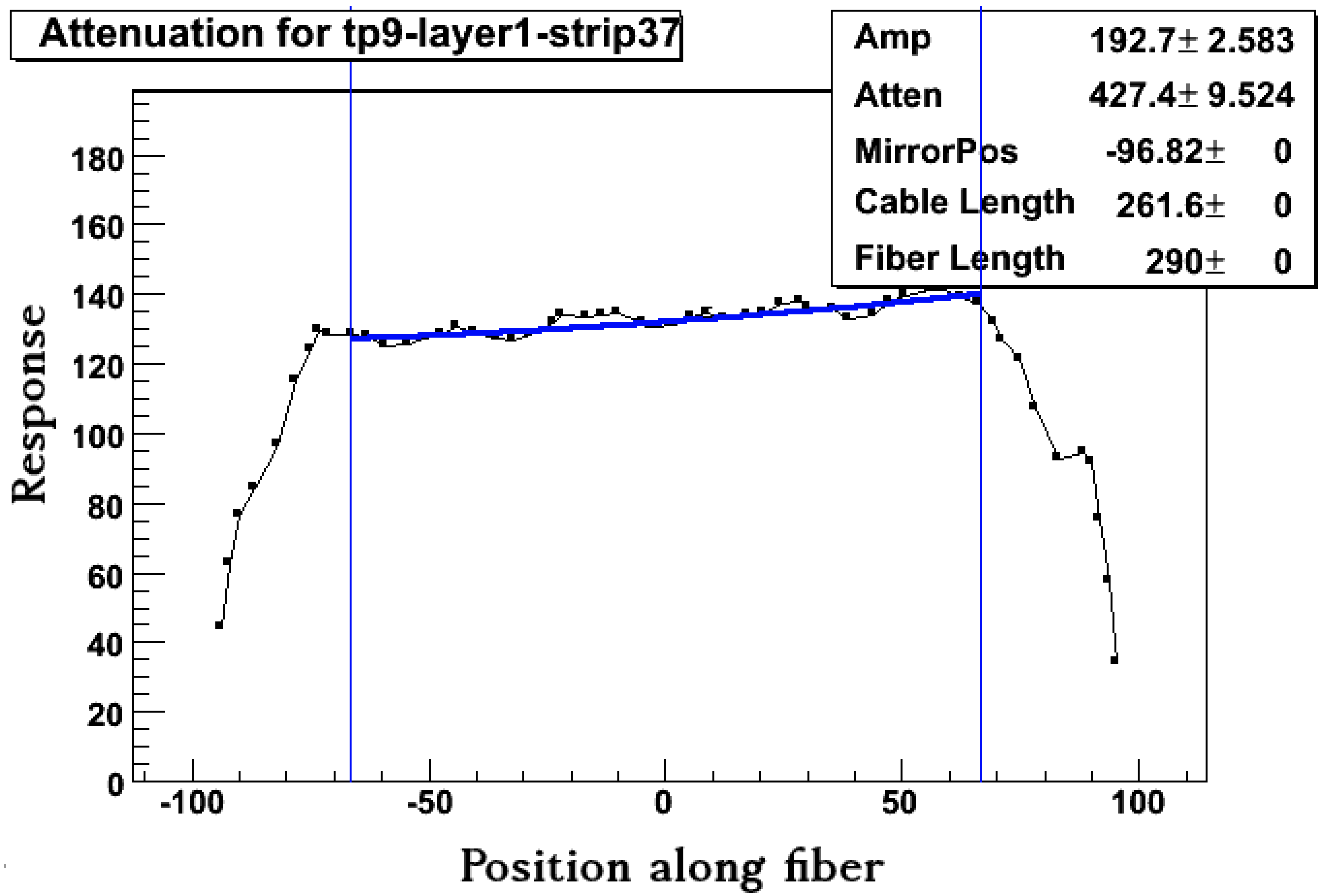
Energy Calibration

Light Attenuation (Module Mapping) *./Cal/Attenuation*

$E = PE(c, t) \times \mathbf{Att(s)} \times S2S(s, t) \times F_{MEU}(t)$

- **Purpose**
  - Check the light response of strips as a function of transverse and longitudinal position, due to light attenuation in the fiber.
- **Method**
  - Cs-137 source scanned across modules before installation.
  - Longitudinal and transverse map (module map) response obtained.
- **Correction Factor**
  - Fiber attenuation curve.

Light Attenuation (Module Mapping)



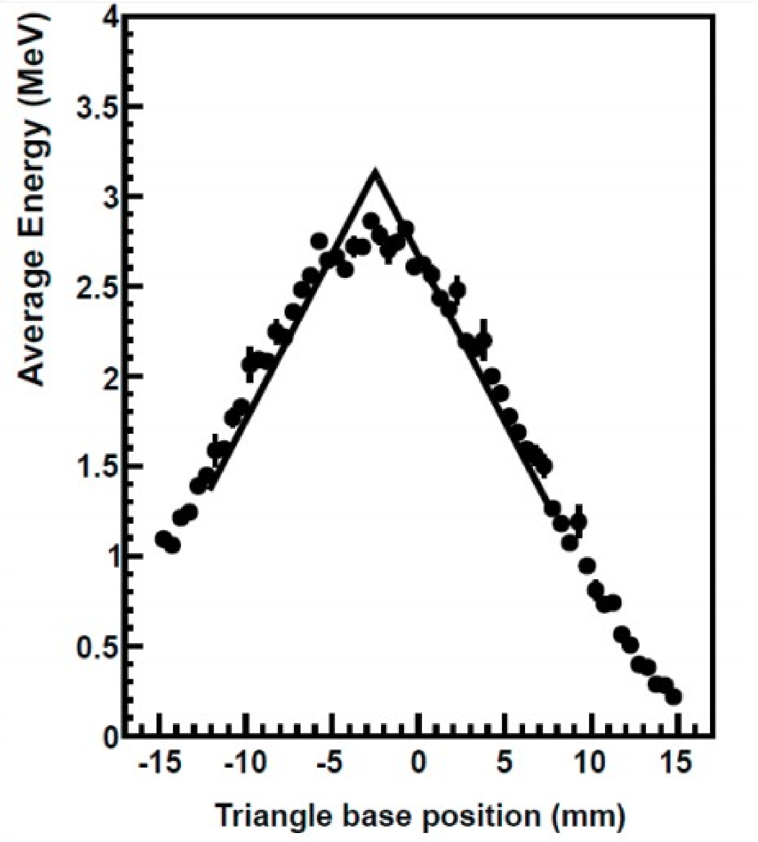
Strip-to-Strip Correction

./Cal/RawToDigit

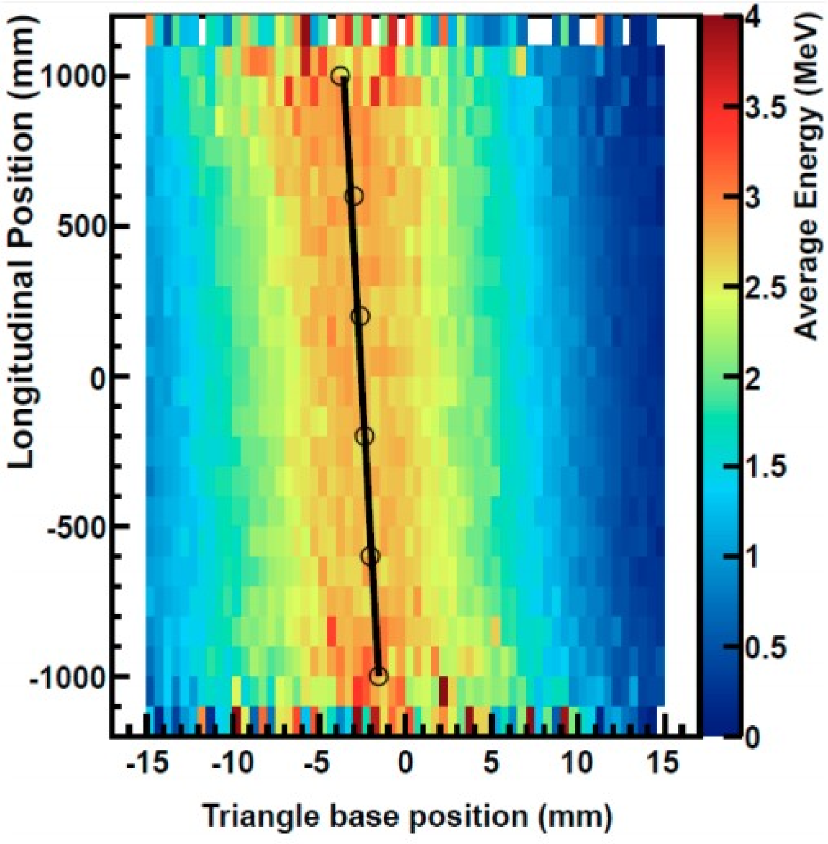
$E = PE(c, t) \times Att(s) \times \mathbf{S2S(s, t)} \times F_{MEU}(t)$

- **Purpose**
  - Have a uniform detector response through out all planes.
- **Method**
  - User “rock muon” sample to measure translational (along “plane” coordinate: x, u or v) and rotational (about z-axis) shifts of strips.
  - Iterative truncated mean.
- **Correction Factor**
  - Alignment correction per plane.
  - Strip-to-strip constants.

Strip-to-Strip Correction



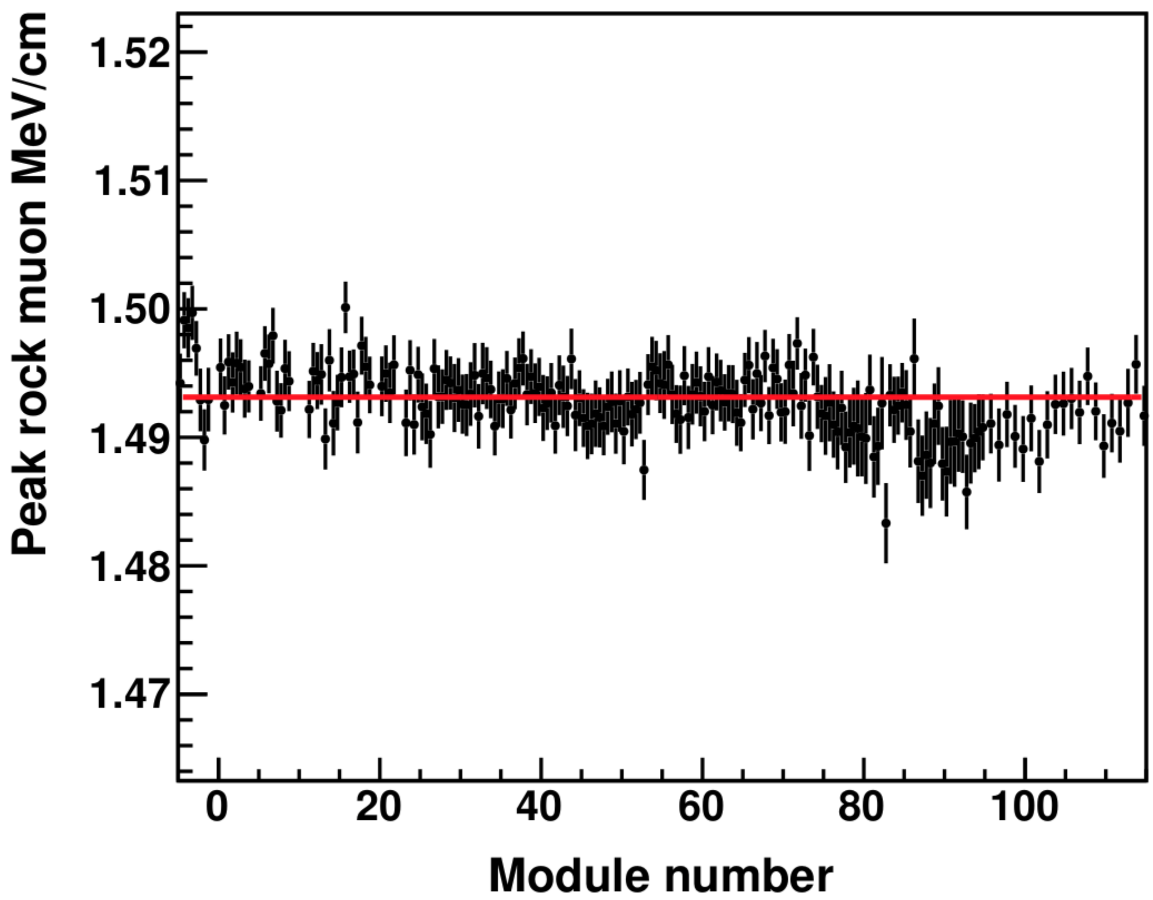
Transverse displacement



Plane rotation

Energy Calibration

Strip-to-Strip Correction



Peak energy deposit of rock muons after applying strip-by-strip and plane-by-plane corrections (see backup).

Muon Equivalent Unit (MEU)

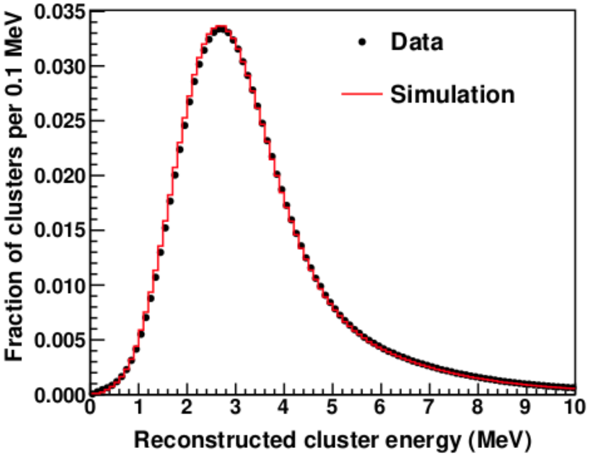
./Cal/RockMuonCalibration

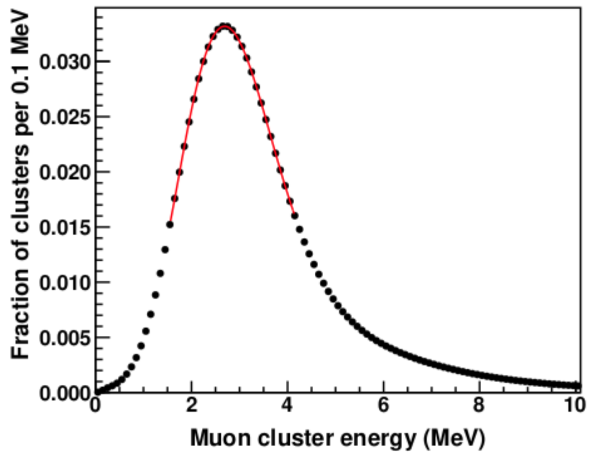
E = PE(*c*, *t*) x Att(*s*) x S2S(*s*, *t*) x $\mathbf{F_{MEU}(\mathit{t})}$

- **Purpose**
  - Get an absolute energy scale for the detector from a standard candle.
  - Light yield correction in MC to ensure the statistical fluctuations of the simulated *PE* are the same as in the data.
- **Method**
  - Use “rock muon” matched in MINOS to measure deposited energy and deposited *PE*.
  -
- **Correction Factor**
  - F_{MEU} and F_{LY}.

Energy Calibration

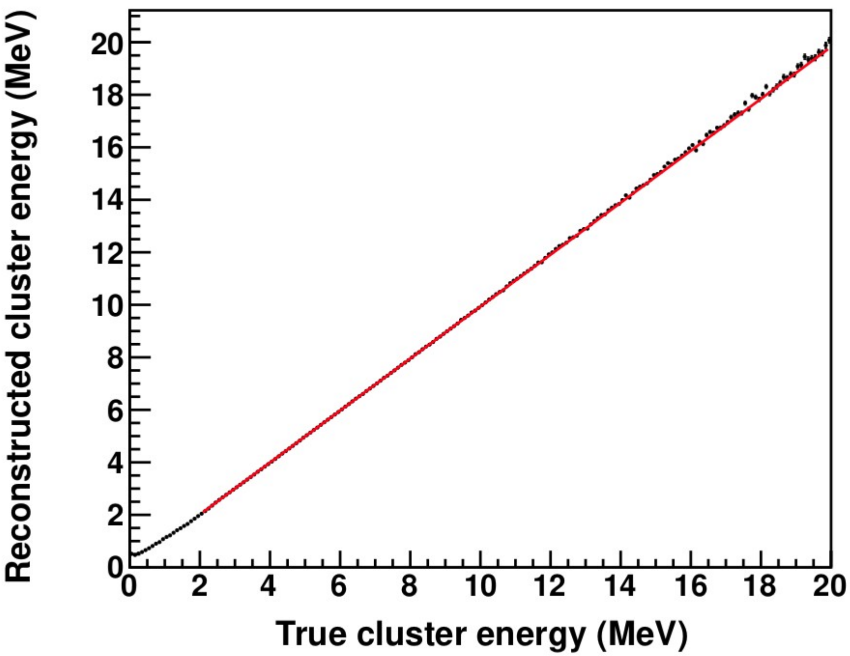
Muon Equivalent Unit (MEU)





Peak Cluster Energy

Peak Cluster Energy



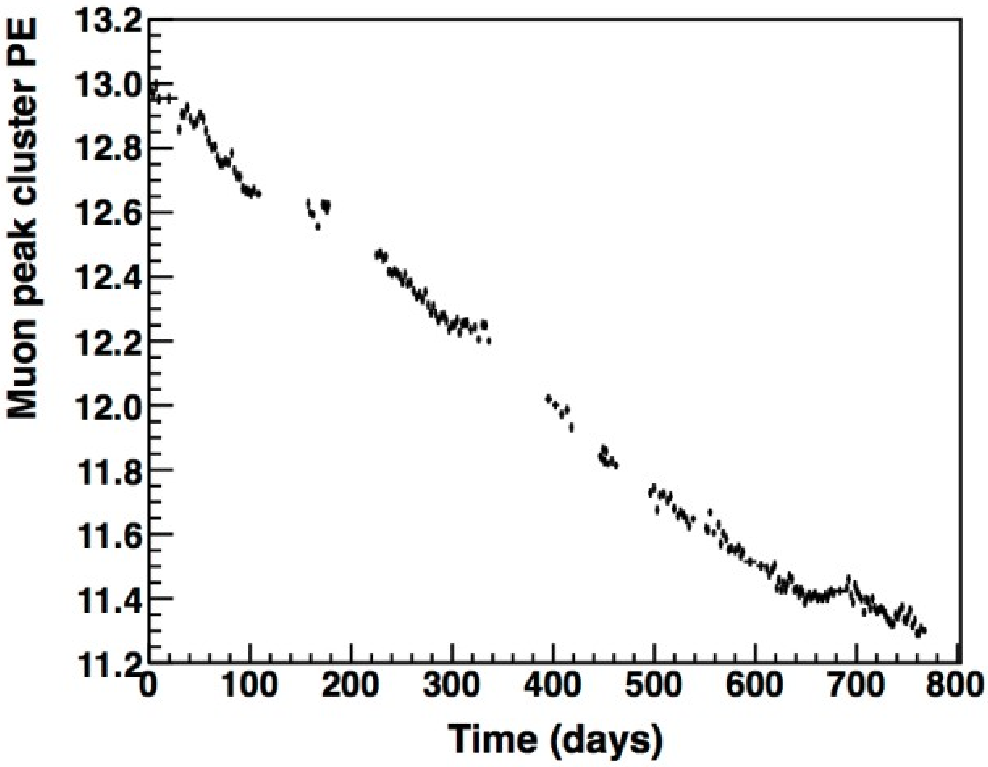
a = slope from linear fit

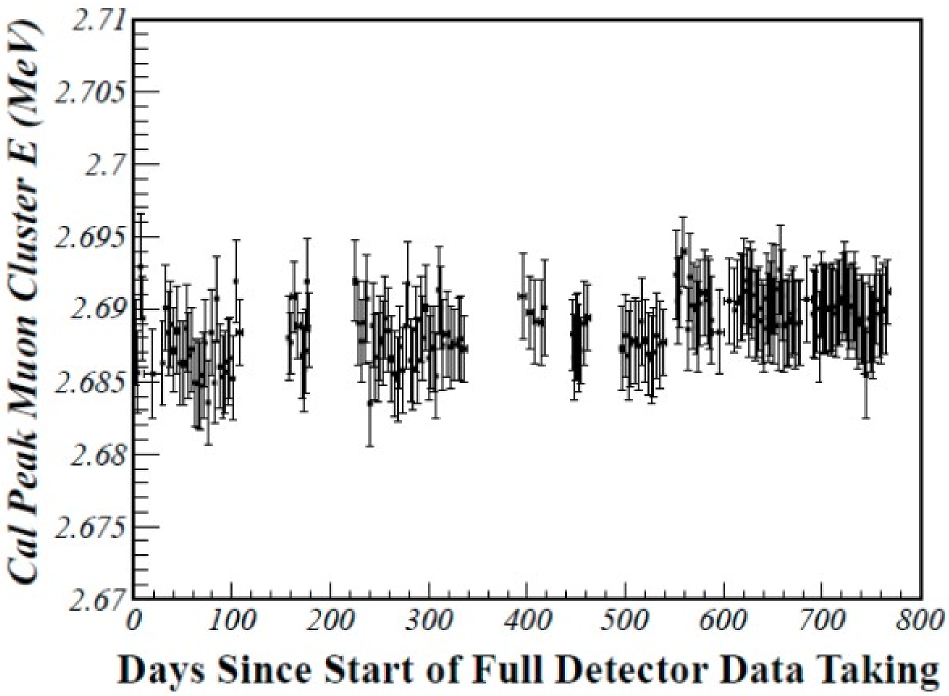
$$F_{MEU} = F_{MEU,\,Trial} \frac{E_{MC}}{a} \frac{1}{E_{Data}}$$

$$F_{LY} = F_{LY,\,Trial} \frac{P_{Data}}{P_{MC}}$$

Energy Calibration

Muon Equivalent Unit (MEU)





Time Calibration

Definition

$$T = T_{Raw} - T_{Path}(s) - T_{Slew}(t) - T_{Offset}(c, t)$$

- T – Calibrated time.
- T_{Raw} – TDC counts.
- T_{Path} – Transport time in fiber.
- T_{Slew} – Scintillator decay time, relative to the truncated mean hit time along the rock muon track and corrected for muon TOF.
- T_{Offset} – Channel-to-channel time offset between FEBs and Chains, relative to the truncated mean hit time along the rock muon track and corrected for muon TOF.

c → electronic channel, ***t*** → time, ***s*** → strip

Time Calibration

At Each Iteration

./Cal/CalibrationTools
./Cal/RawToDigit

- For the 0th iteration T_{Slew} and T_{Offset} are set to 0
- For the ith iteration T_{Slew} and T_{Offset} use the i-1 measured value
- T_{Cor}, T_{Avg}, T_{Slew}, and T_{Offset} are measured at each iteration as follows:

$$T_{Cor} = T_{Raw} - T_{Path} - T_{Slew} - T_{Offset} - T_{TOF}$$

$$T_{Avg} = \Sigma_i T_{Cor\ i} / N$$

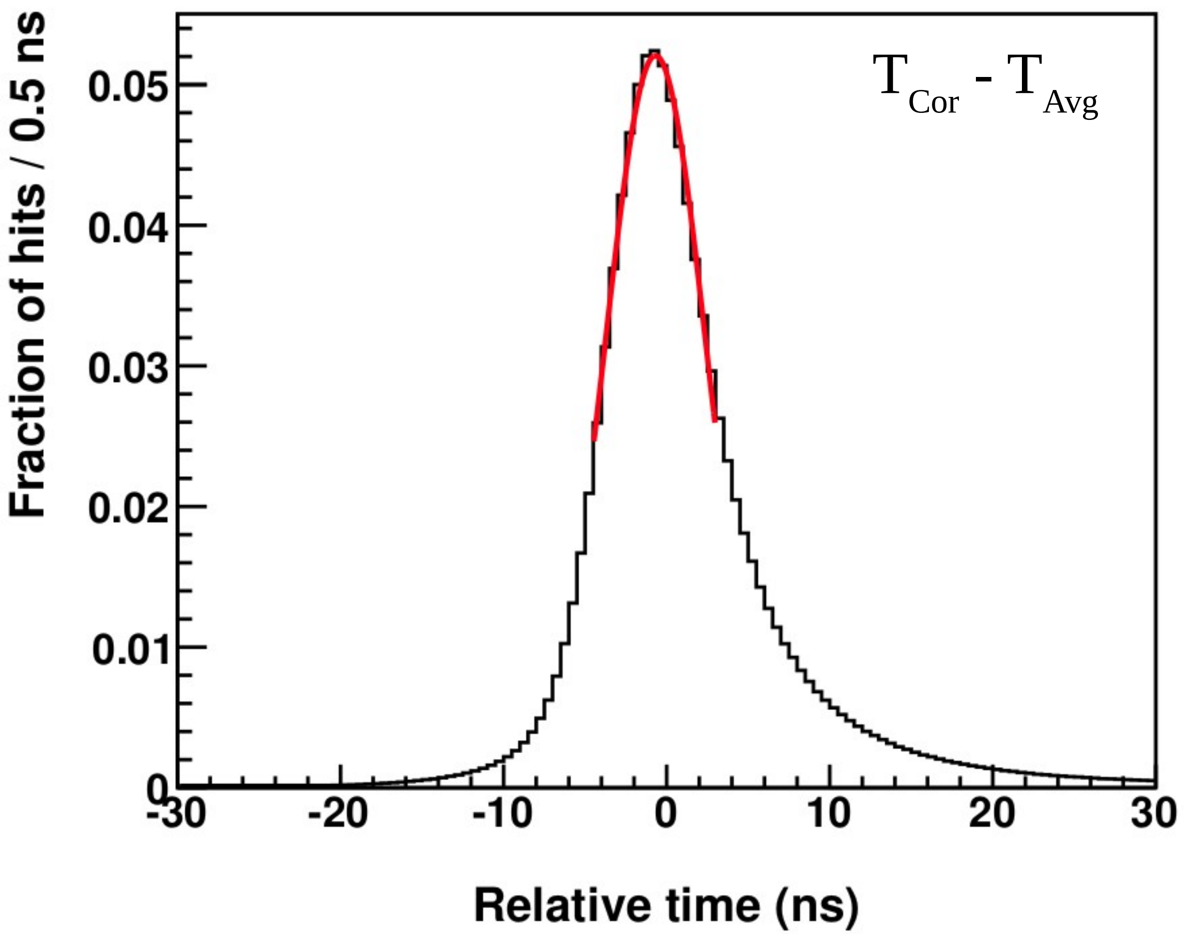
$$T_{Slew} = T_{Raw} - T_{Path} - T_{Offset} - T_{TOF} - T_{Avg}$$

$$T_{Offset} = T_{Raw} - T_{Path} - T_{Slew} - T_{TOF} - T_{Avg}$$

c → electronic channel, ***t*** → time, ***s*** → strip

Time Calibration

Calibrated Time



σ = 3 ns after 8 iterations

Event Reconstruction

Event Reconstruction

Reconstruction Chain

- **Time-Slicing**: Peak-finding and bundling hits according to the hit time distribution.
- **Clustering**: Bundle hits within a plane.
- **Long Tracking**: Look for longest track (anchor track) matched to MINOS for $\mathbf{p}_\mu$ reconstruction.
- **Vertexing**: From single or multiple tracks.
- **Short Tracking**: From interaction vertex (anchored tracks).
- **Blobbing**: Shower formation.
- **Prongs**: Reco objects attached to main vertex.
- **Particles**: Reco objects usually attached to prongs.
- **PhysicsEvent**: Reconstruction manager for particles.
- **NeutrinoInt**: Interpretation of a PhysicsEvent, hypothesis.
- **Particle ID**

Event Formation - 16 μs Gate

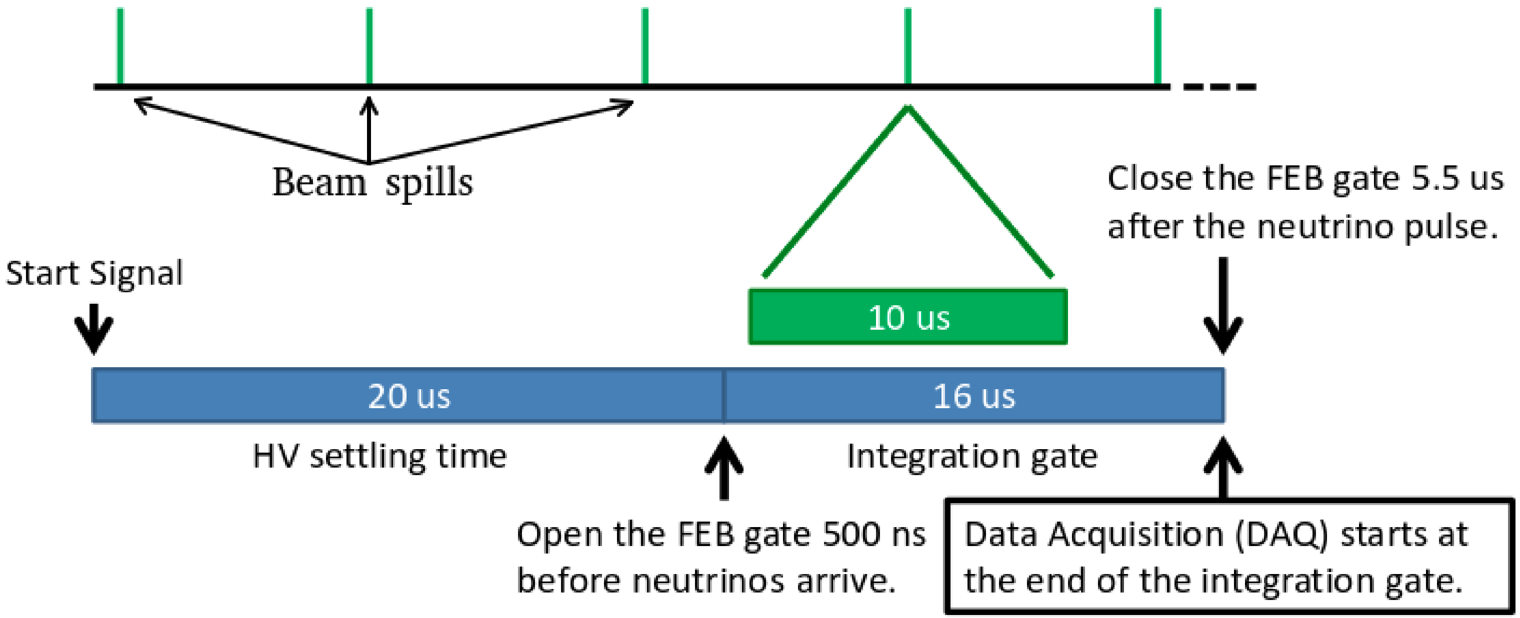
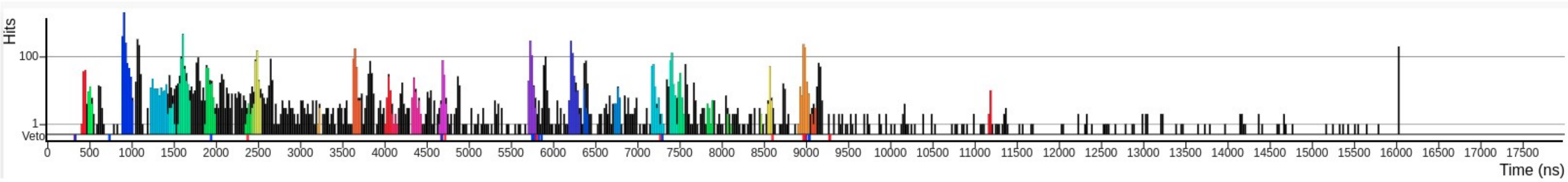


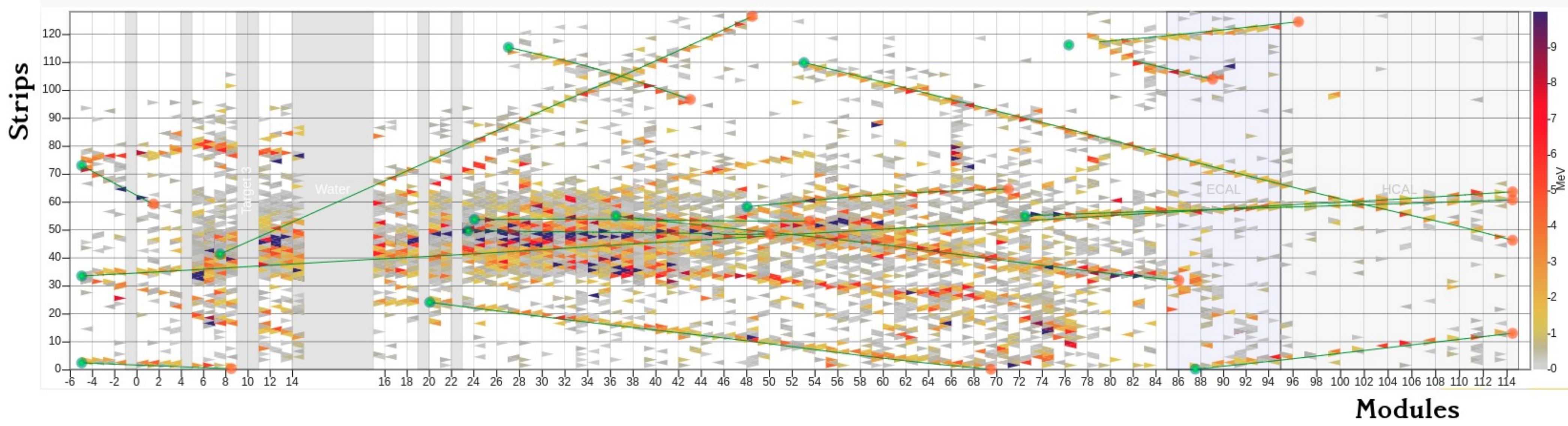
Figure by Geoff Savage

Time Slicing

One-Gate Activity

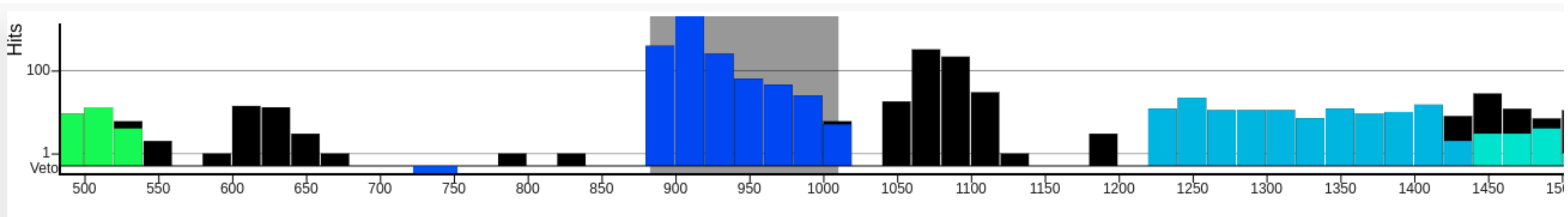
./Rec/ChronoBuncher

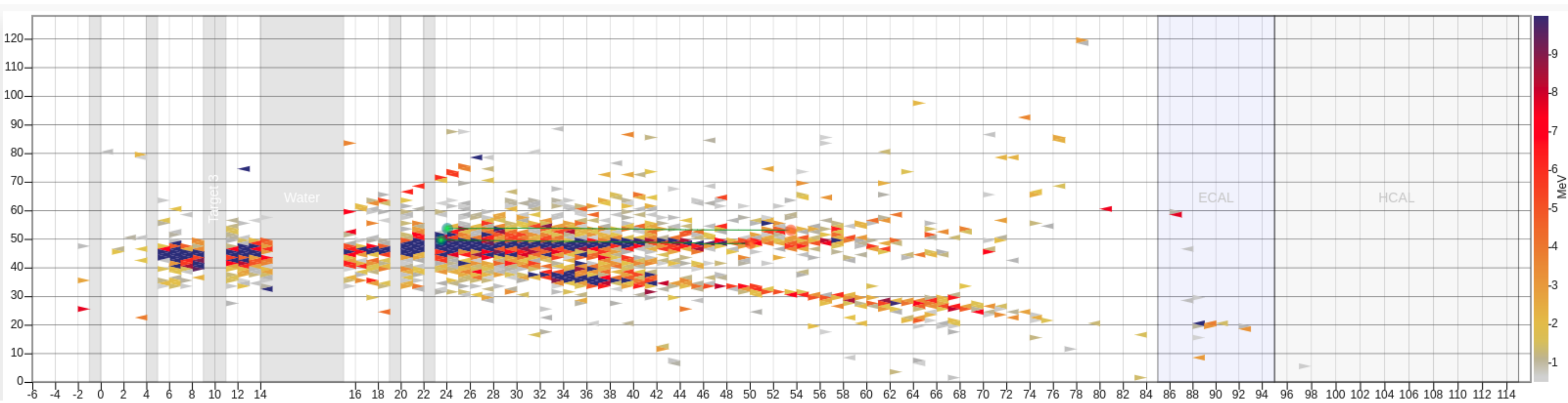




Time Slicing

Single Neutrino Candidate Event



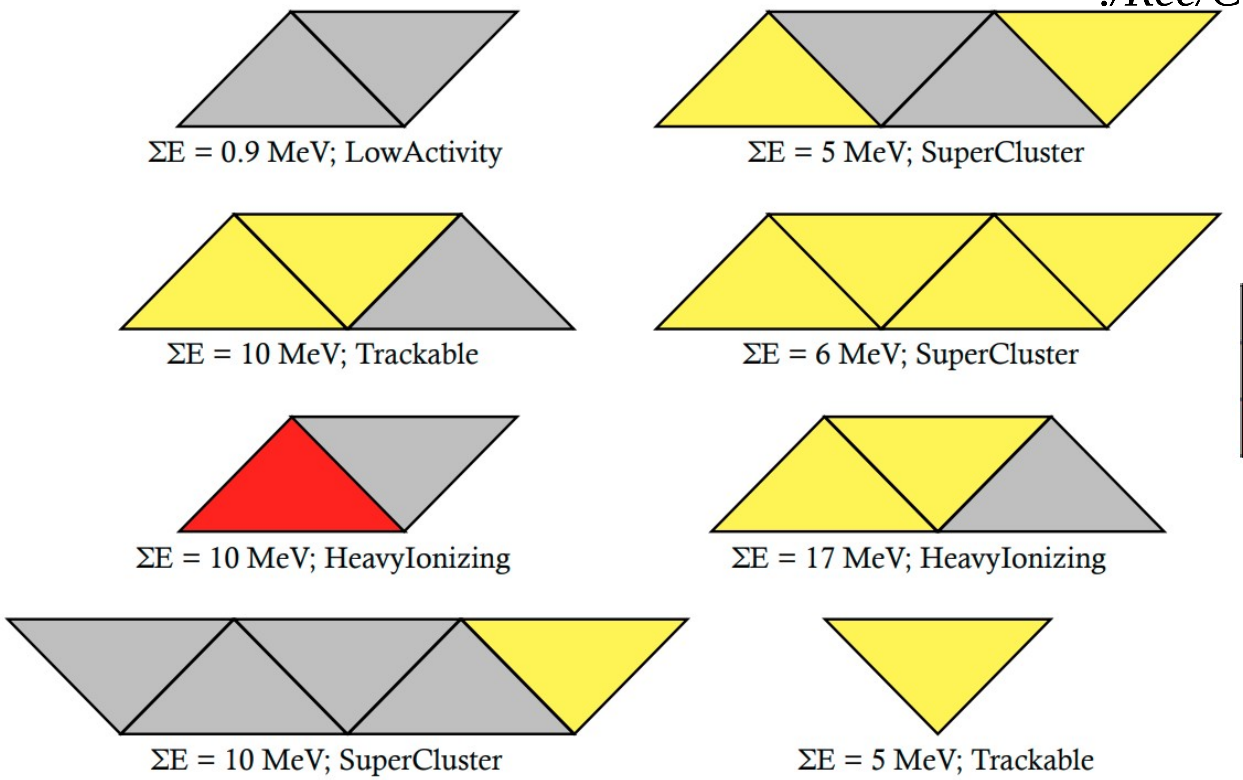


Same gate (zoomed in)

Clustering

Type of Clusters

./Rec/RecUtils
./Rec/ClusterFormation



Low E	< 1 MeV
Medium E	1-8 MeV
High E	8+ MeV

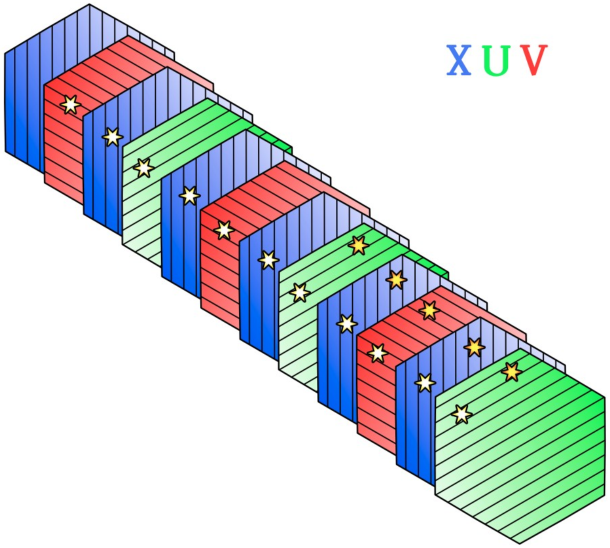
- Low Activity: Low energy.
- Trackable: MIP consistent.
- Heavy Ionizing: High energy.
- Superclusters: Broad, double-peaked, etc.

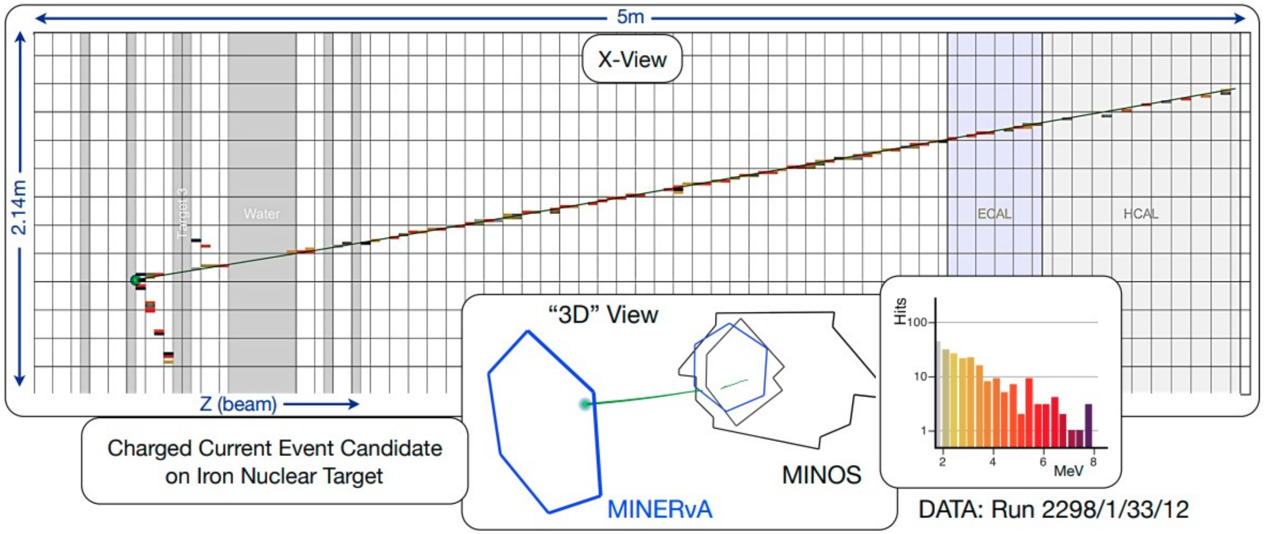
Long-Tracking

Track Construction

./Rec/TrackLongPatRec

- Uses **Trackable** and **Heavy-Ionizing** clusters only.
  - Turn off **HI** clusters for rock muons.
- Form 2D seeds with at least three hits in each view (X, U, or V).
  - It ensures a minimum of 11 planes in 3-view tracks.
- Merge seeds and look for 3D tracks.
- Fit track with Kalman Filter (includes multiple scattering).





Algorithms and Types of Vertices

./Rec/VertexCreation

- Track-based vertex finding.
  - Muon vertex (single tracks)
  - Point of Closest Approach (POCA) multiple tracks.
- Machine Learning (ML)–based vertex finding.

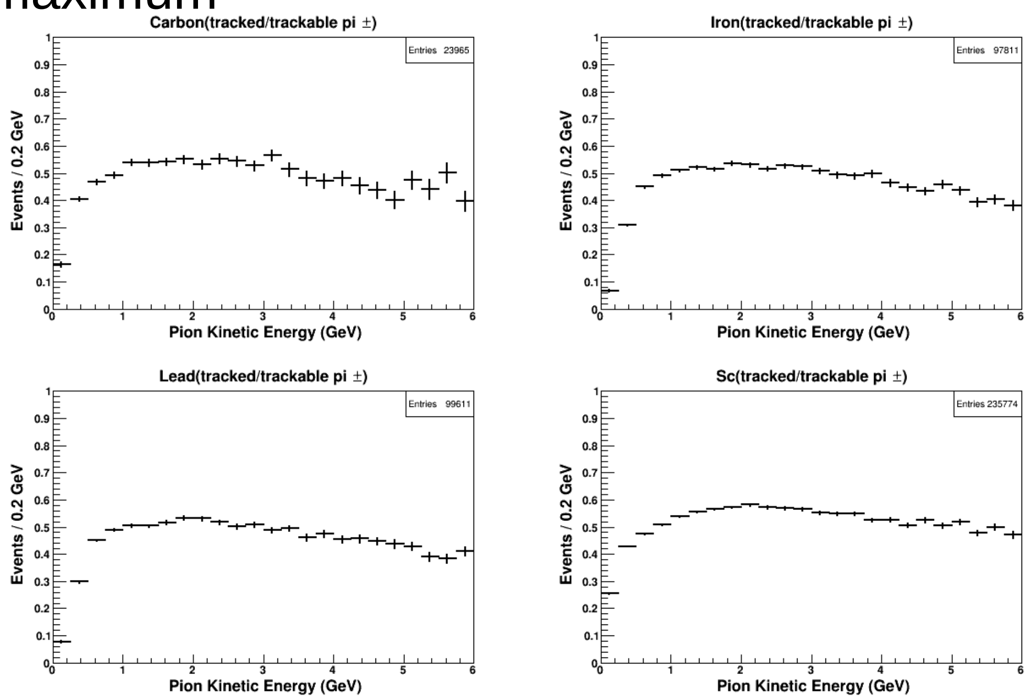
N Incoming Tracks	N Outgoing Tracks	Vertex Type
0	N > 1	StartPoint
1	1	Kinked
1	N > 1	Forked
1	0	StopPoint
N > 1	ANY	EXCEPTION!

Vertex type based on associated tracks

Track Construction

./Rec/EventReconstruction
./Ana/RecoStudies

- VertexAnchoredShortTracker (VAST)
  - Looks for short overlapping segments.
- VertexEnergyStudyTool (VEST)
  - Scan around a point and looks for peaks
- 5 clusters maximum



Track efficiency
with short tracking

Track Construction

./Rec/EventReconstruction
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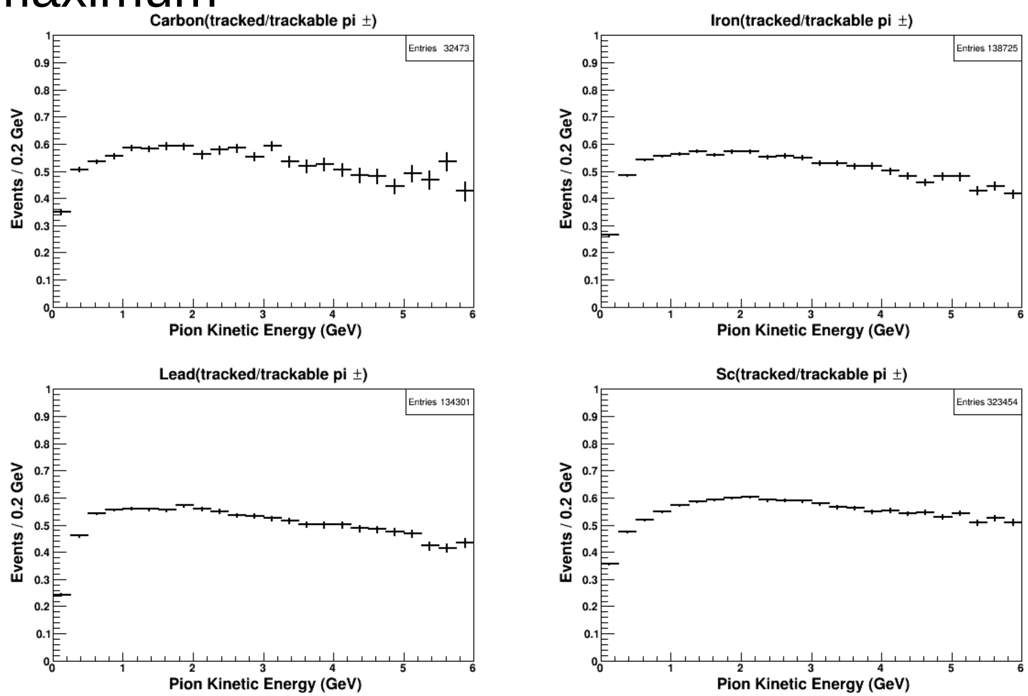
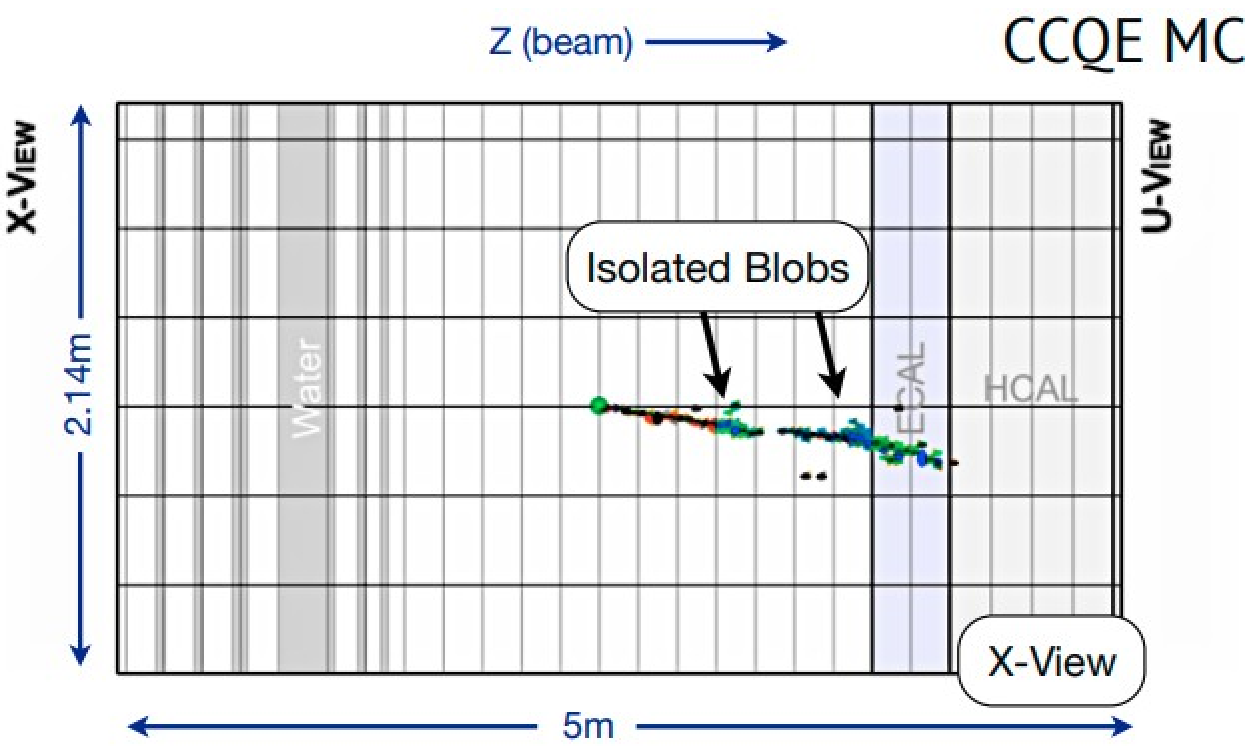


Track efficiency
without short tracking

Shower Formation (Blobbing)

Algorithms *./Rec/BlobFormation*

- Cone Algorithms.
- Peak Find and Grow.
- Spatially Anchored Searches.

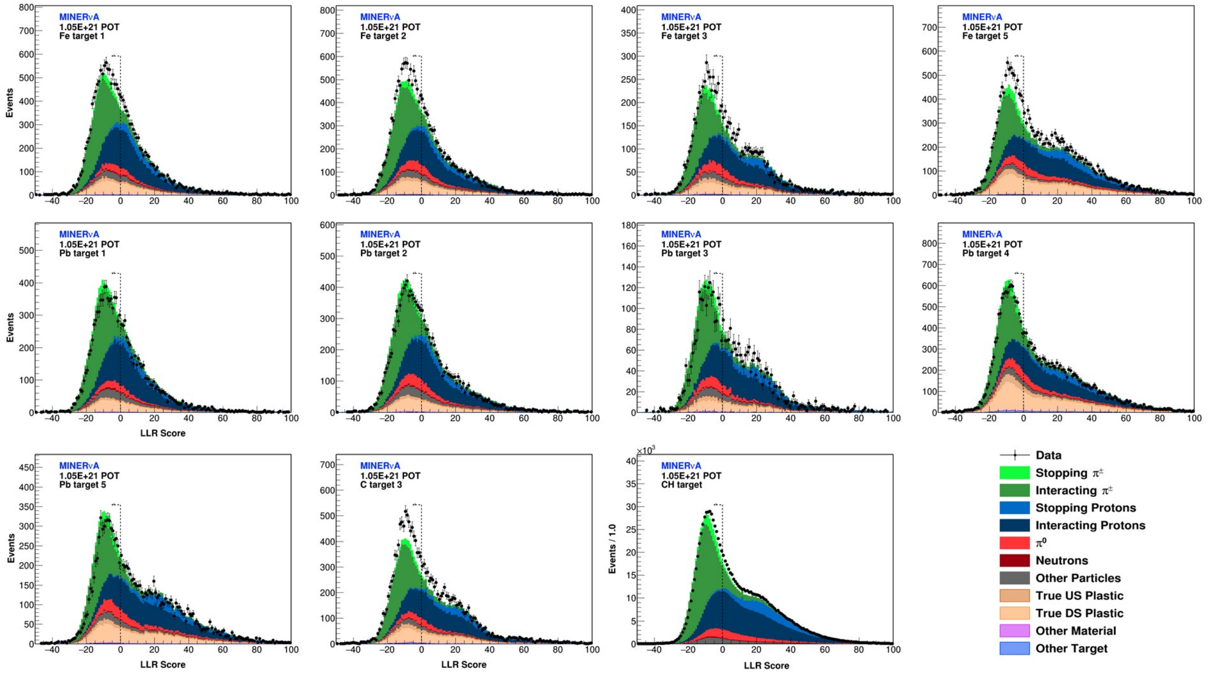


Particle ID

Methods

./Rec/ParticleMaker

- dE/dX profile for particle separation.
  - pion/proton, pion/muon
- Michel electrons tagging.
- Timing (Kaon analyses).



Log Likelihood Ratio for pion/proton separation

Processing & Analysis

MC and Data Processing

Types of Samples

./Tools/ProductionScripts

- data_scripts/
- keepup_scripts/
- mc_scripts/
- minos_scripts/

- Standard and Special MC samples.
- Full MC chain: cal+reco+ana.
- Particle cannon samples.
- Full Data chain: cal+reco+ana

- ./Tools/ProductionScripts/mc_scripts/
- ./Tools/ProductionScripts/data_scripts/

Specific Gaudi Tools

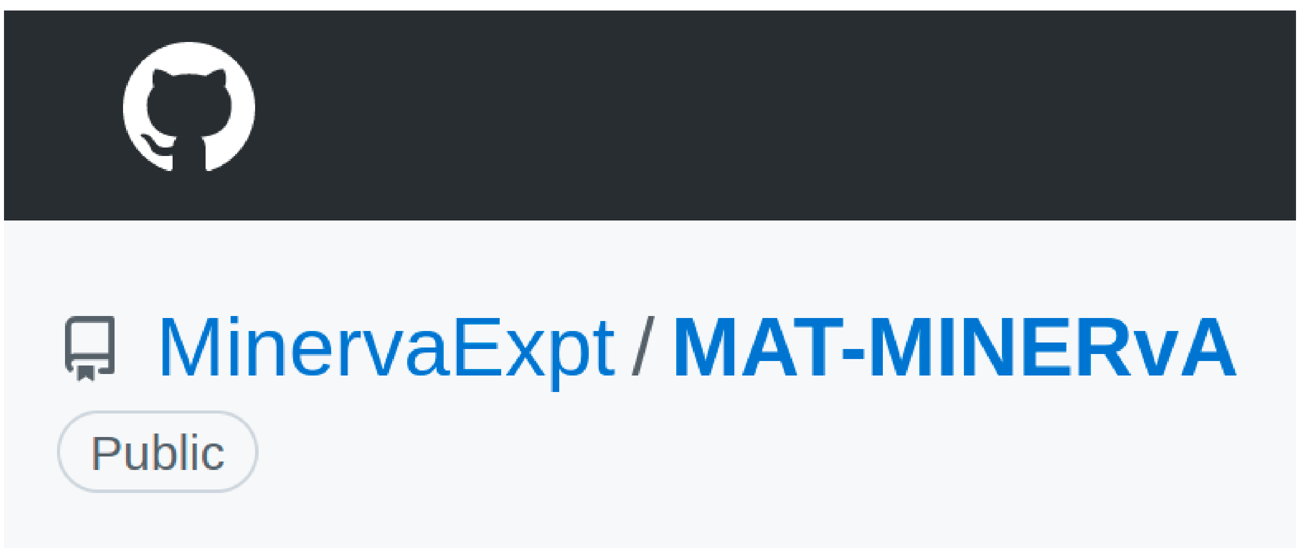
./Ana

- CC1P1Pi/
- CCCohPion/
- CCDIS/
- CCDeltaPlus/
- CCInclusive/
- CCNuE/
- CCPi0/
- CCPionInc/
- CCPionPi0/
- CCProtonPi0/
- CCProtonPi0ME/
- CCQEAntiNu/
- CCQEAntiNu2D/
- CCQENu/
- CCQENu1DME/

- Most analyses have their own Analysis Tool (AnaTool).
- Run “grid” jobs for ntuple processing.
- Call calibrated+reconstructed objects.
- Can reconstruct further objects, like short tracks.
- AnalysisFramework/Tools/ProductionScripts/ana_scripts

MINERvA Analysis Toolkit (MAT)

- Plus “Data Preservation” (public release of MINERvA data)
- https://github.com/MinervaExpt



CHECK IT OUT!

THANKS!

Backup

Calibration

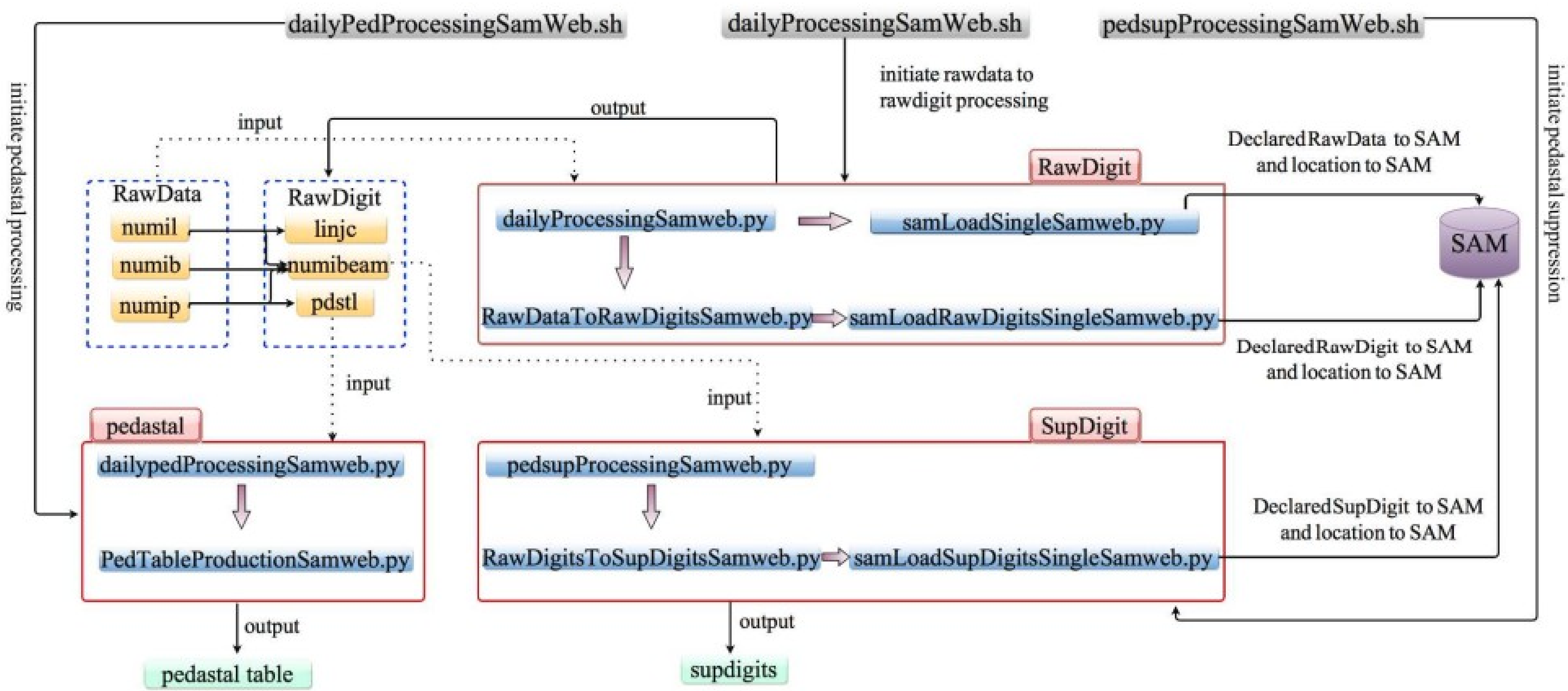
Energy Calibration

$$E_i = \left[C\left(t\right) \cdot S_i\left(t\right) \cdot \eta_i^{att} \cdot e^{l_i/\lambda_{clear}} \cdot G_i\left(t\right) \cdot Q_i\left(ADC\right)\right] \times ADC_i$$

- C(t) – time dependent overall energy scale for the entire detector – **MEU**
- S_i(t) – relative correction factor for channel *i* – **S2S and alignment**
- η_i^{att}, $e^{li/\lambda clear}$ – scintillator strip and fiber attenuation factors – **module mapping**
- G_i(t) – PMT pixel gain – **gains**
- Q_i(ADC) – ADC charge conversion factor – **FEB constants**

Calibration

Keepup Processing



Q_i(ADC) – ADC charge conversion factor – **FEB constants**

Energy Calibration – Strip-to-Strip Correction

Relative strip-to-strip

- The correction factor for the i^{th} strip:

$$C_i^{strip} = \frac{\frac{1}{x_i}}{\frac{1}{n}\sum_k \frac{1}{x_k}}$$

x_i is the truncated mean of the strip
n is the number of good channels
k is the sum over all good channels

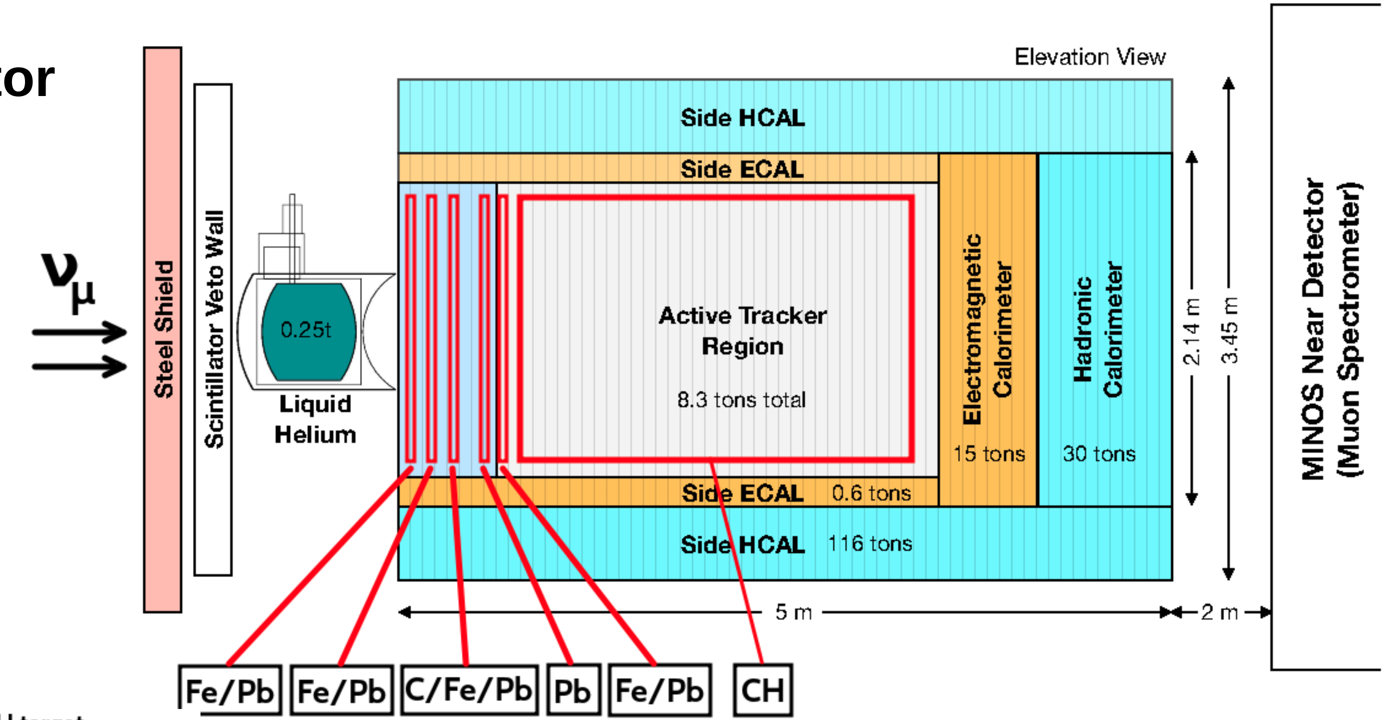
- The correction factor for the i^{th} plane:

$$C_i^{plane} = \frac{\frac{x_i}{p_i}}{\frac{1}{n}\sum_k \frac{x_k}{p_k}}$$

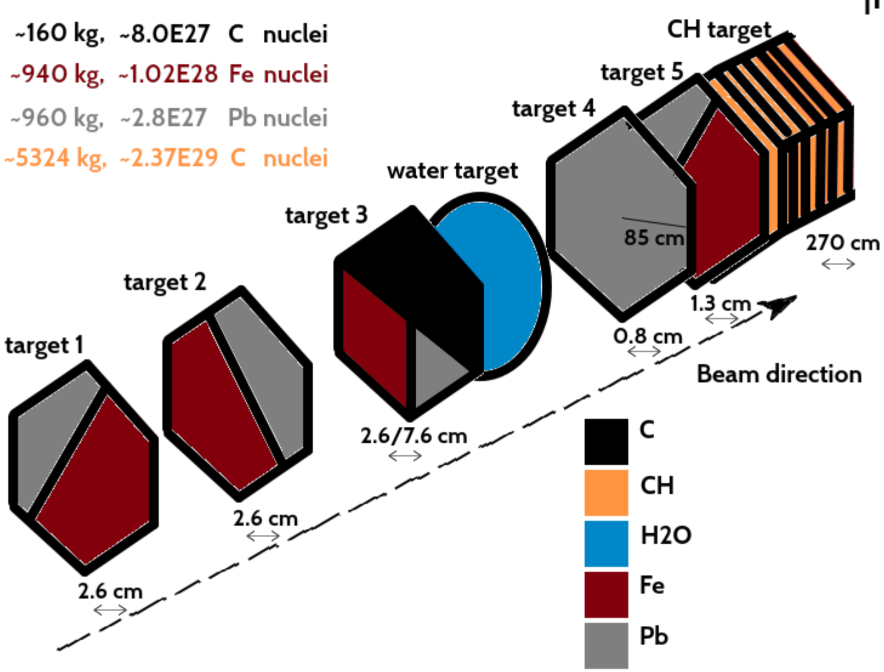
x_i is the truncated mean of the plane
p_i is the fitted peak
n is the number of planes
k is the sum over all planes

- The overall correction is $C_i^{plane} \times C_i^{strip}$

The MINERvA Detector

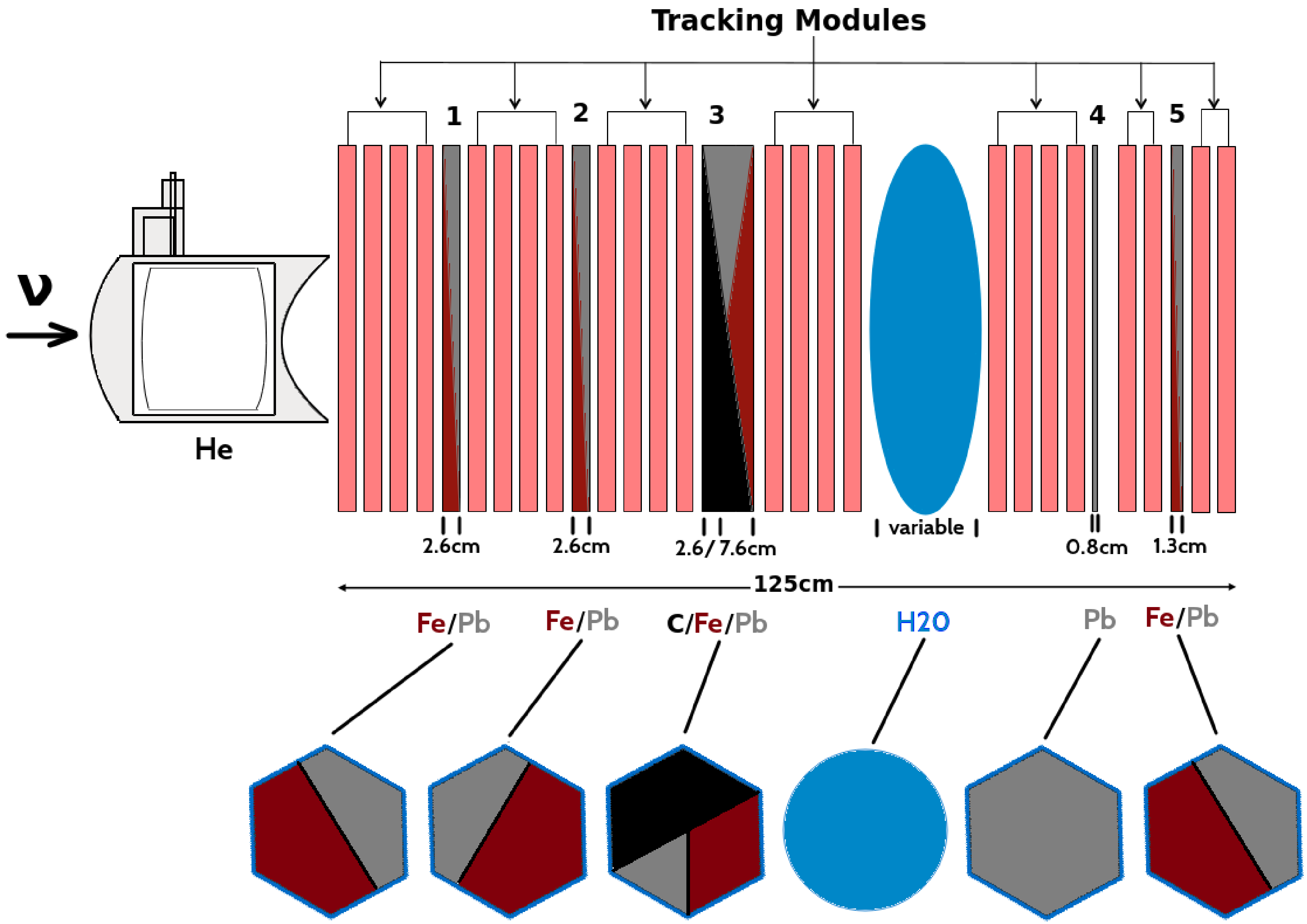


Target Region

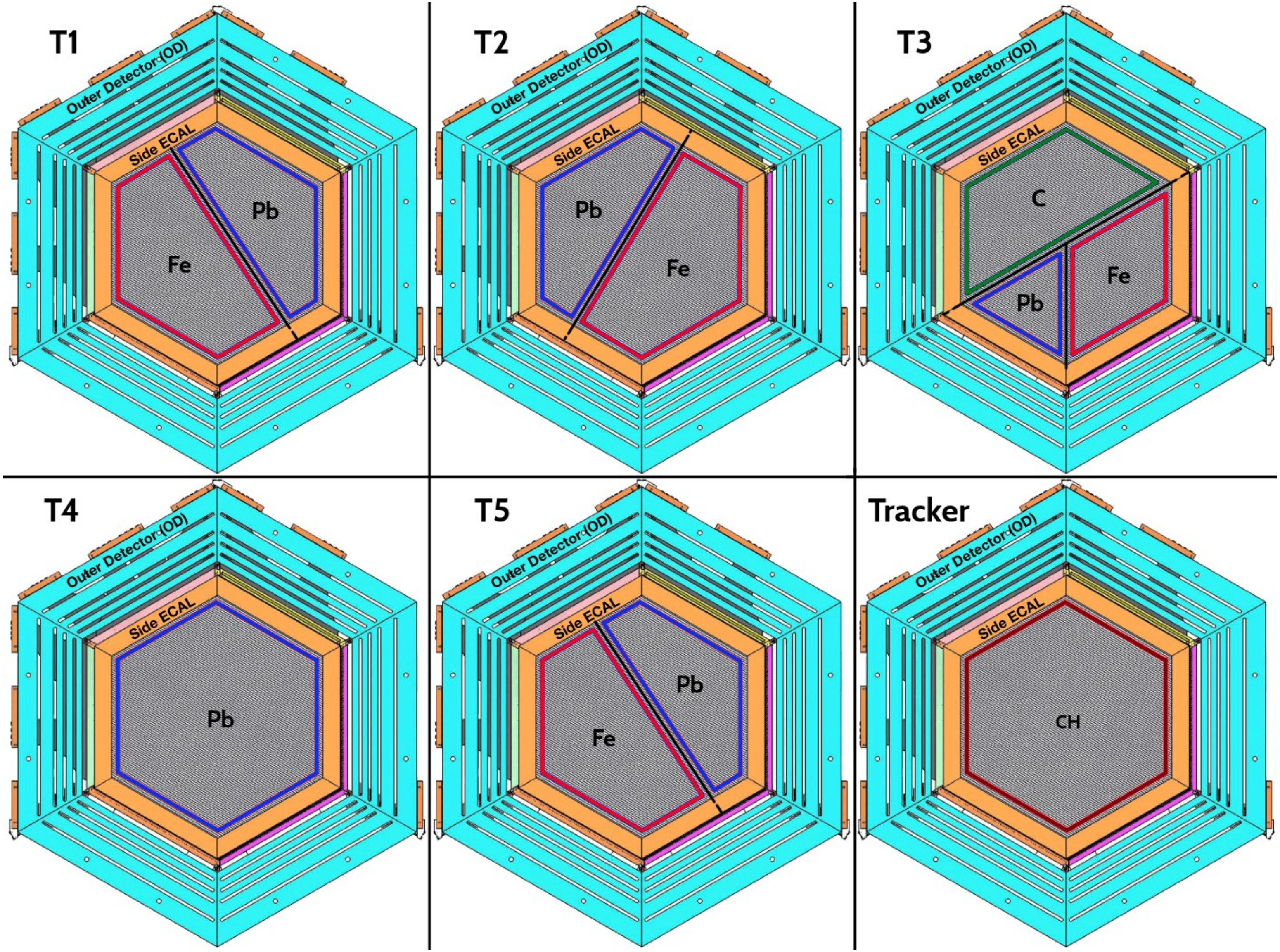


Backup – Detectors

Side View of the Passive Target Region



Target Segments (Beam goes out of the page)



The MINOS Detector