Electron Muon Ranger (EMR) Software Status

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EMR Software Structure

Processing of real data from the fADCs and DBBs:

- `EMRPlaneHits`

  IN DBB and fADC data (EMRDaq)

  OUT N+2 reconEvents with EMRPlaneHits (N primary + noise + decays)

Processing of G4 data into PlaneHits structure:

- `EMRSD` (Sensitive Detector)

  IN Geant4 steps

  OUT MC EMRHits (Bars)

- `EMRMCDigitization`

  IN MC EMRHits (Bars)

  OUT N+2 reconEvents with EMRPlaneHits (N primary + noise + decays)

Common reconstruction code (range, PID parameters, etc.):

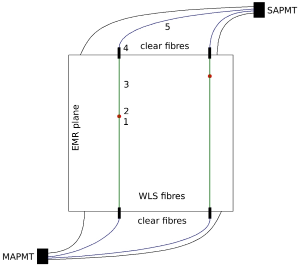
- `EMRRecon`

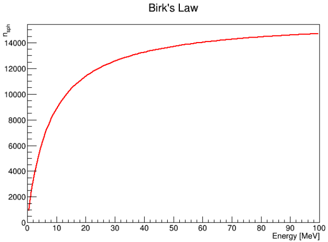
  IN N+2 reconEvents with EMRPlaneHits

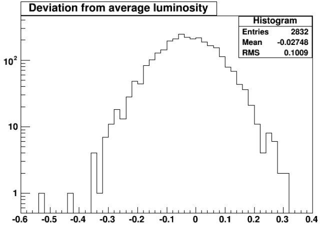
  OUT Reconstructed N+N'+1 reconEvents (N primary + N' secondary + 1)

Digitization scheme: scintillation and transport

1. Convert G4 energy deposition to a number of scintillating photons n_{sph}: 2000 ph/MeV[a] $\rightarrow$ Apply Birk's Law
2. Convert n_{sph} to a number of photons trapped in the WLSf n_{tph}: 4 %[a]
3. WLSf atten.: 2.0 dB/m[a]
4. Connector atten.: up to 30 %[b]
5. CLf atten: 0.35 dB/m[a]



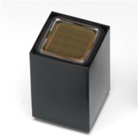


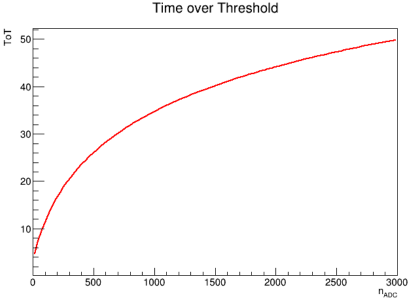


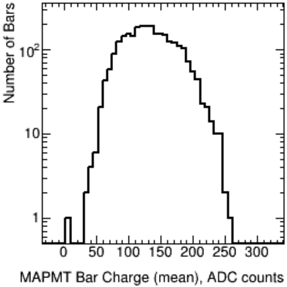
[a] Preliminary parameters (data sheets) [b] Based on LED tests

Digitization scheme: Multi-Anode PM

6. Convert the number of absorbed photons n_{aph} to the number of photoelectrons n_{pe}: 20% QE[a]
7. Correct for photocathode non-uniformity: up to 40%[b]
8. Get ADC counts n_{ADC}: 8 ADC/npe[a]
9. Convert to the Time over Threshold: ToT $= a + b\log(n_{ADC}/c + d)$
10. Convert G4 time stamp to a time Δt in ADC counts: 2.5ns/ADC



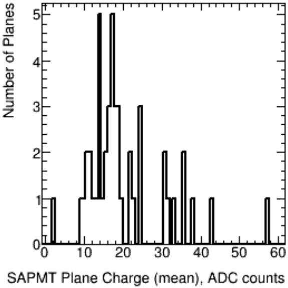


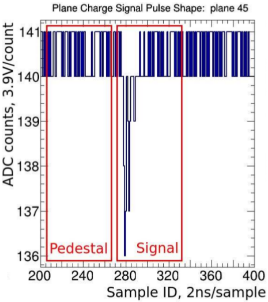


[a]Preliminary parameters (data sheets) [b]Based on cosmic calibration

Digitization scheme: Single-Anode PMT

6. Convert the number of absorbed photons n_{aph} to the number of photoelectrons n_{pe}: ~~14.5~~ 25% QE[a]
7. Correct for photocathode non-uniformity: up to ~~50~~%[ab]
8. Get ADC counts n_{ADC}: ~~1~~ ADC/npe[a]
9. Set signal baseline: $\sim$ 130 ADC[a]
10. Simulate negative voltage pulse with random noise

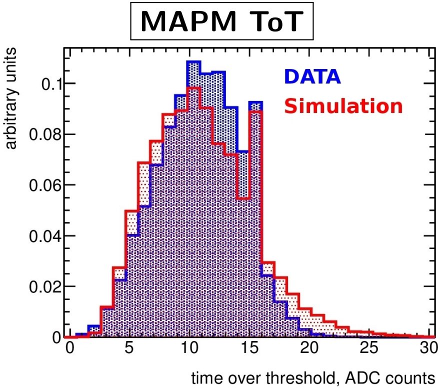


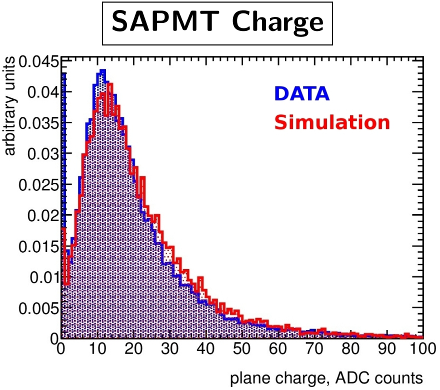


[a]Preliminary parameters (data sheets) [b]Based on cosmic calibration

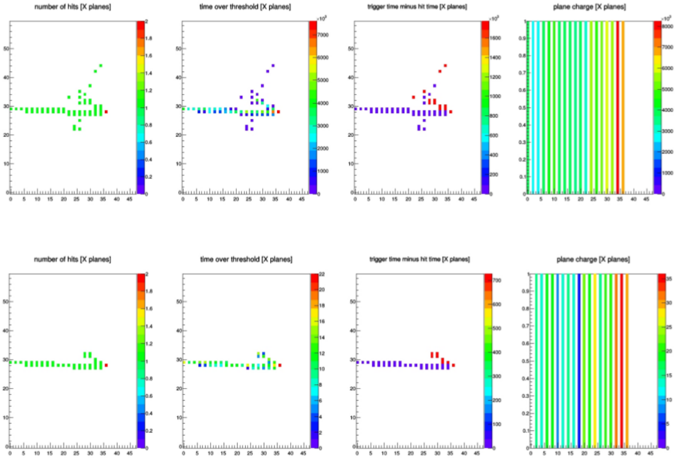
Cosmics vs Digitized MC

- 4 GeV muons compared with Digitized MC
- The agreement with cosmic data is outstanding
- Peak around 10 and 15 ADC in ToT and 11 ADC in Charge
  $\rightarrow$ The second peak in ToT is due to the shaper of the MAROC



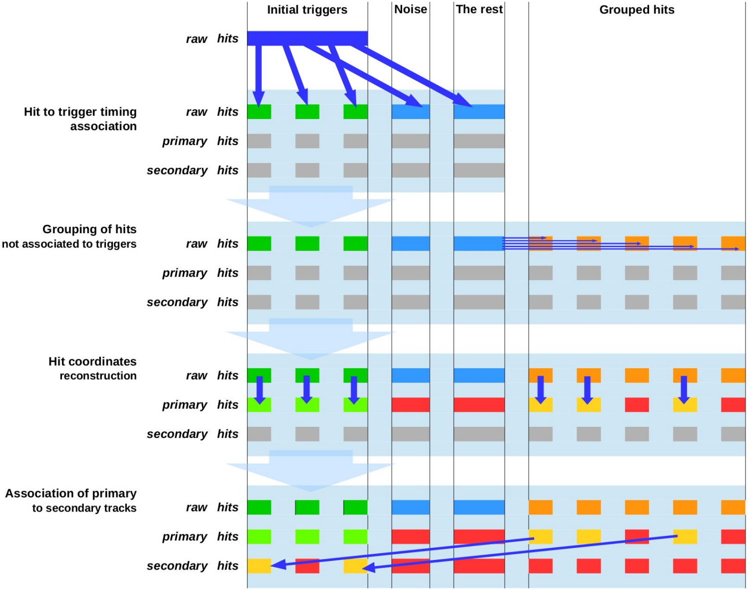


Digitized Beam Event Display

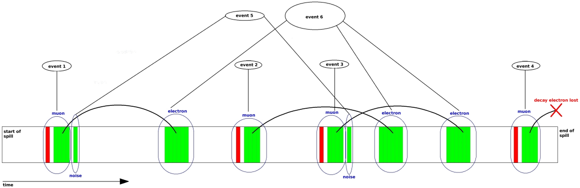


- The smallest energy depositions don't produce a signal
- The signals are converted using the calibration parameters
- Entirely **integrated into MAUS** (release 0.9.3)

Reconstruction: Scheme

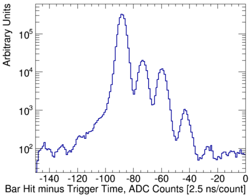


Reconstruction: Timing Association



Timing cuts are used to sort the EMR hits in different categories:

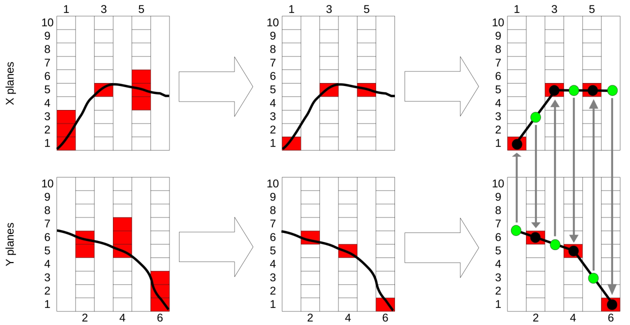
- **primary particles** (close to the trigger) are stored in separate EMR reconEvents (*Event 1, 2, 3, 4*);
- **noise** (close to the primary), in an additional reconEvent (*Event 5*);
- the rest, in one last reconEvent (*Event 6*), i.e.
  - **decay products** (e,μ);
  - **cosmic muons**.



Reconstruction: Hit Coordinates

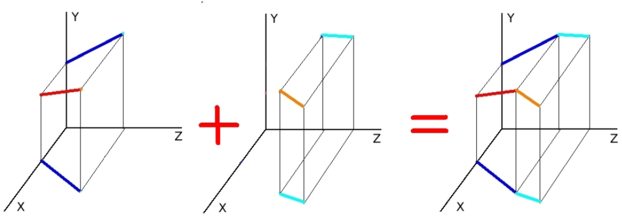
Each particle track is assembled **piecewise** in each projection:

- for each X (resp. Y) plane, the bar with the highest amplitude is selected as the x (resp. y) coordinate of the track in that plane;
- the y (resp. x) coordinate is interpolated as the average y (resp. x) coordinate of the two surrounding Y (resp. X) planes.



Reconstruction: Track matching

- An end point of a decay must match the end point of the primary
- The presence of a secondary discriminates the muons from electrons
- Reconstructed Variables:
  - Presence of a secondary track
  - Range of the primary and secondary track (function of momentum)
  - Total charge in a track
  - Ratio of the last 1/5 of the track over the first 4/5 (>1 for muons, ~ 1 for electrons), i.e. $R_Q = \frac{\sum_{i=0}^{n_1-1} Q_{pl}^i/(n_1-1)}{\sum_{i=n_1}^{n_2-n_1} Q_{pl}^i/(n_2-n_1)}$

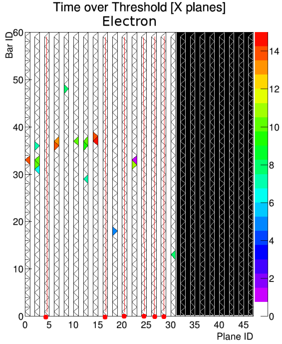


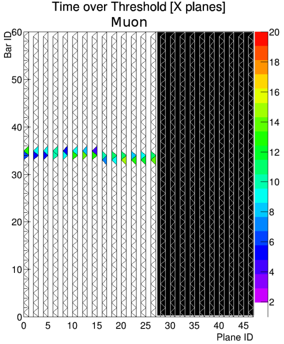
Reconstruction: Plane Density ρ_p

The plane density is defined as the percentage of the planes that record a signal on the path of the particle or its shower, i.e.

$$\rho_p = \frac{number\, of\, planes\, hit}{\Delta z} \quad (1)$$

with Δz the depth of the particle expressed in number of planes.





Electrons: 9 planes hit over a span of 15, $\rho_p = 60\%$;

Muons: 14 planes hit over a span of 14, $\rho_p = 100\%$.

Reconstruction: Spread in terms of χ^2/N

One way to express that angular spread of an electromagnetic shower is to fit it with a line a evaluate its χ^2 normalized to the amount of hits N:

$$\chi^2/N = \frac{1}{N}\sum_i \frac{(y_i - (ax_i + b))^2}{\sigma_i^2} \tag{2}$$

For a given array of hits (x_i, y_i), the exact value of this parameter is expressed in term of the spread $\sigma_y^2 = E\left[(y - \overline{y})^2\right]$ as:

$$\chi^2/N = \sigma_y^2(1 - \rho^2) \tag{3}$$

with $\rho = \texttt{Cov}(x, y)/\sigma_x\sigma_y$. This is exactly what we want as:

- Electrons have a significant spread σ_y and the hits they produce are weakly correlated ($(1 - \rho^2) \rightarrow 1$), so that $\chi^2/N \rightarrow \sigma_y^2 \gg 1$
- Muons have a small spread σ_y (centre of the detector) and are strongly correlated (line, $(1 - \rho^2) \rightarrow 0$), so that $\chi^2/N \ll 1$

Reconstruction: useful variables

Best **PID** variables to tag particles:

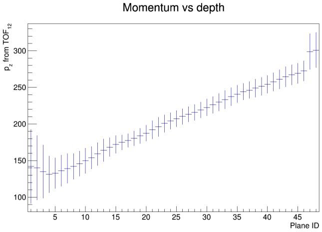
- **Range** cut provided p_z (a μ has a specific range, an e does not)
- Presence of a **secondary track** (an e doesn't decay)
- Structure of the **energy deposition** (high energy tail for a μ)

\+ **Plane density** ρ_P (e has low density)

\+ **Spread** of the event in terms of χ^2/N (e has high spread)

Momentum reconstruction variable:

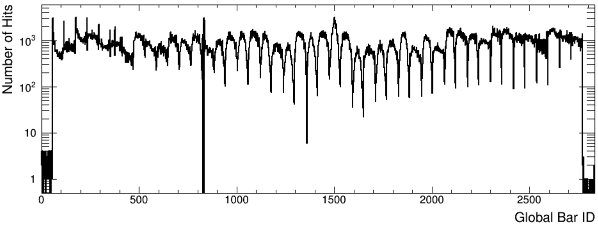
\+ The momentum of muons can be reconstructed from their range in the EMR, provided that they stop in it ($p_z < 280$ MeV/c)

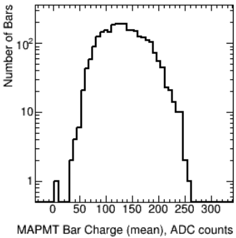


Calibration Code

A calibration program exists in standalone and improves precision:

- **calibration** uses cosmic data to evaluate the photomultipliers irregularities and give a parameter for each channel
  - ran in March 2014 and correction map included in MAUS
  - 300k (~ 1 week)cosmic tracks recorded in the EMR
  - Measurement of the mean charge for each bar i in a plane j, $\overline{Q_{ij}}$
  - Calculation of the correction factor $\epsilon_{ij} = \overline{Q_{ij}}/\overline{Q}$, with $\overline{Q}$ global average

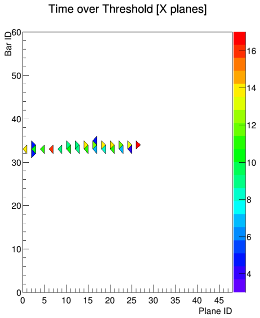


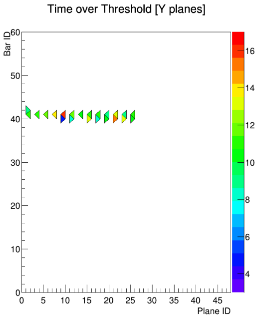


TH2EMR

New histogram class displaying the right EMR geometry (triangular bars)

- Constructed on the TH2Poly ROOT class
- Functions inspired from the well known TH2 ROOT class
  - `Fill(int i, int j, double w)` adds weight `w` to bar `j` in plane `i`
  - `Draw()` draws and saves the histogram
- Only the bars hit are drawn, faster processing, clearer display (v. 1.0)





Integration in MAUS, Step IV readiness

What has been integrated into the trunk:

- ✓ `EMRPlaneHits` map modified to accommodate two additional reconEvents (noise + decays) and fill them with data
- ✓ `EMRMCDigitization` entirely in MAUS (v. 2.1)
- ✓ Modication of the **data structure** implemented
- ✓ **Data Processors** adapted
- ✓ New **tests** for the `EMRPlaneHits` and `EMRMCDigitization`
- ✓ `EMRRecon` 0.1 integrated (range measurement, track matching)

→ **MAUS release 0.9.3**

Left to do:

- ✗ Implement a range measurement in mm with its uncertainty
- ✗ Include new PID variables into the MAUS code
- ✗ Create a reducer for the EMR (including TH2EMR)

→ **Almost completely ready for Step IV**