Electron Muon Ranger (EMR) Reconstruction Status

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EMR Reconstruction Software

`EMRPlaneHits`

- **IN** DBB and fADC data (EMRDaq)
- **OUT** N+2 reconEvents with EMRPlaneHits (N primary + noise + decays)

`EMRSD` (sensitive detector)

- **IN** Geant 4 steps
- **OUT** MC EMRHits (Bars)

`EMRMCDigitization`

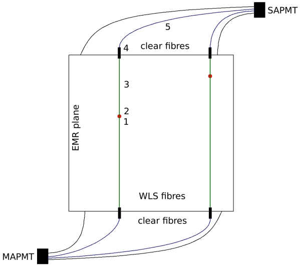
- **IN** MC EMRHits (Bars)
- **OUT** N+2 reconEvents with EMRPlaneHits (N primary + noise + decays)

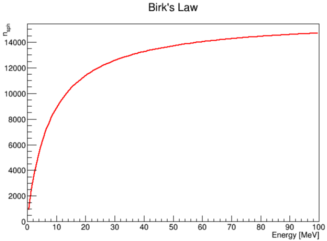
`EMRRecon`

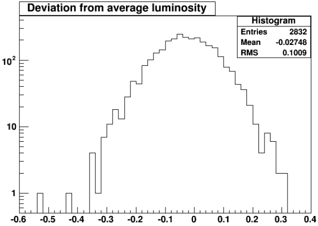
- **IN** N+2 reconEvents with EMRPlaneHits
- **OUT** Reconstructed N+N' reconEvents (N primary + N' secondary + 1)

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]



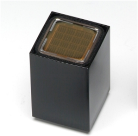


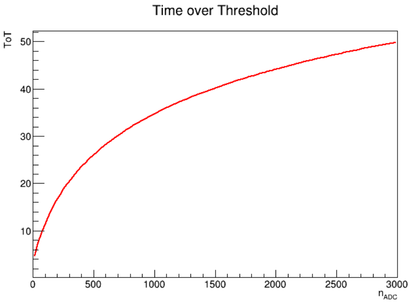


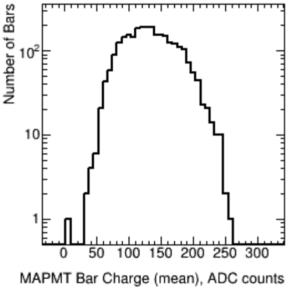
[a] Preliminary parameters (data sheets) [b] Based on LED tests

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



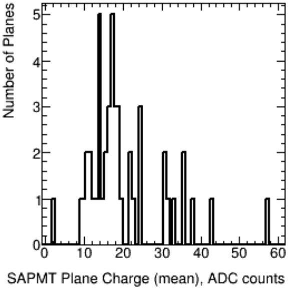


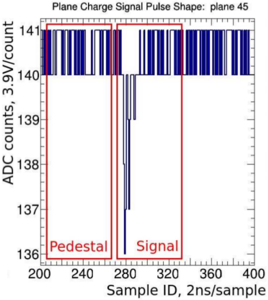


[a]Preliminary parameters (data sheets) [b]Based on cosmic calibration

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

New MCDigitization Utils

MCDigitization v. 1.1
$\rightarrow$ Calibration and attenuation constants fetched directly from looping on the correction files for each bar hit. Inefficient, slow and heavy in the main digitization code.

MCDigitization v. 2.1 $\rightarrow$ 2 new utilities:

`EMRCalibrationMap`

IN EMR channel key (planeID, barID), PMT ID (SA, MA)

OUT Calibration factor ϵ

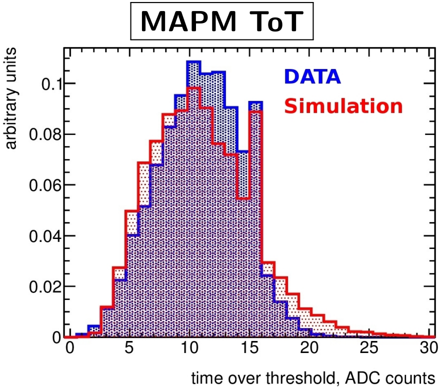
`EMRAttenuationMap`

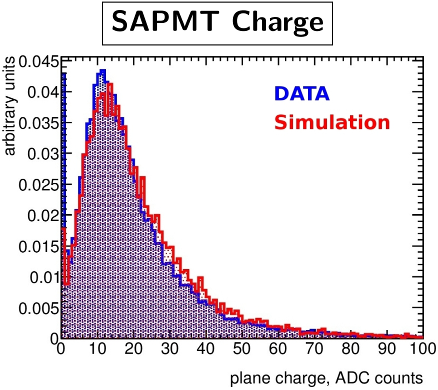
IN EMR channel key (planeID, barID), PMT ID (SA, MA), x, y

OUT 1) Connector attenuation
2) WLS and clear fibre length from IP
3) Fibre attenuation
4) Fibre delay

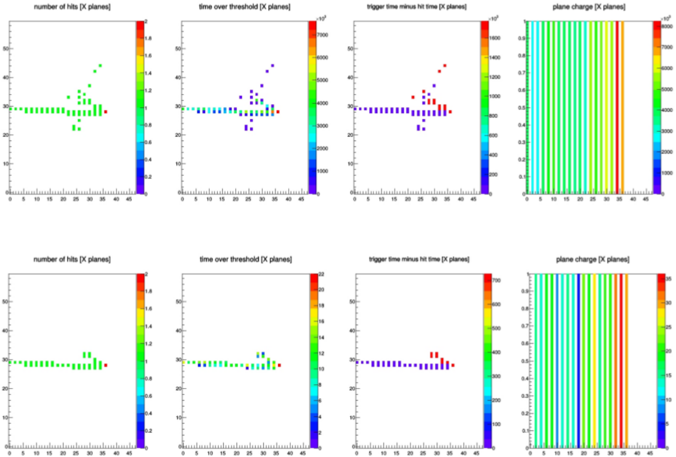
Cosmics vs Digitized MC

- 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



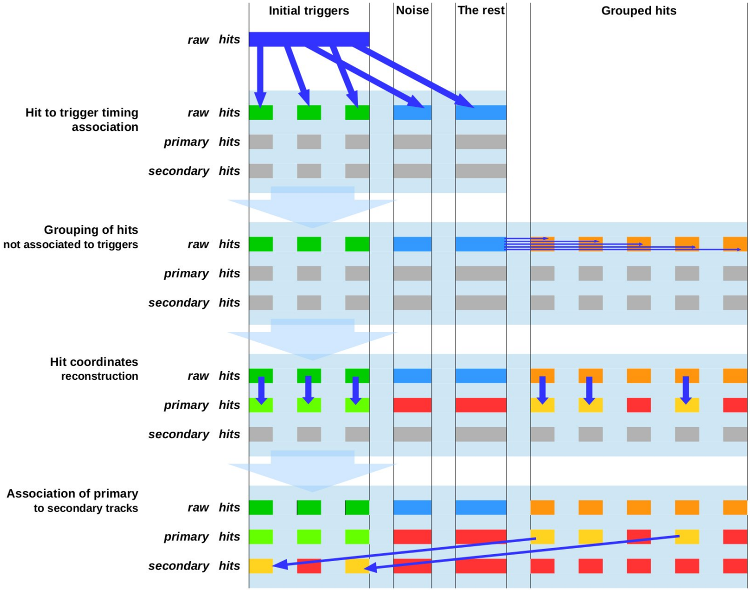


Digitized Beam Event Display

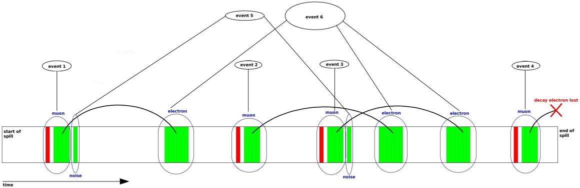


- The smallest energy depositions don't produce a signal
- The signals are converted using the calibration parameters
- Entirely **integrated into MAUS** (version 2.1)

Reconstruction: Scheme

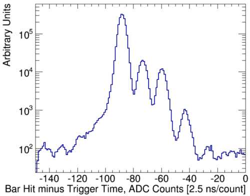


Reconstruction: Timing Association



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

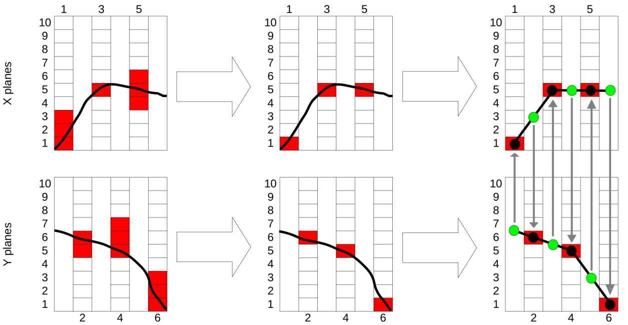
- **primary particles** (close to the trigger) are stored in separate EMR reconEvents (*Event 1, 2, 3, 4*);
- **noise** (close to the primary), in an additional reconEvent (*Event 5*);
- the rest, in one last reconEvent (*Event 6*), i.e.
  - **decay products** (e,μ);
  - **cosmic muons**.



Reconstruction: Hit Coordinates

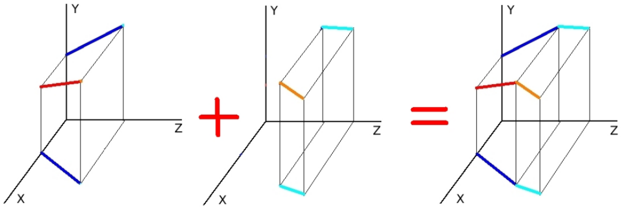
Each particle track is assembled **piecewise** in each projection:

- 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.

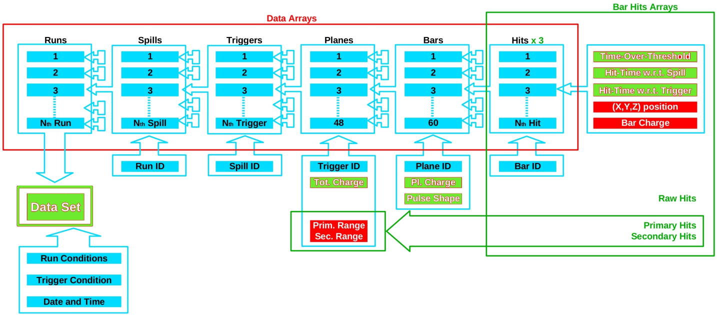


Reconstruction: Track matching

- 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: EMR Data Structure



→ Addition of **new variables** (range, presence of a secondary track, etc.) in the current data structure (EMREvent, EMRPlaneHit, EMRBarHit)
→ Modification of the corresponding **Data Processors**
→ Modification of the **reconEvent Processor Test**

Integration in MAUS

What has been done:

- EMRPlaneHits map modified to accommodate two additional reconEvents (noise + decays) and fill them
- EMRMCDigitization entirely in MAUS (version 2.1)
- Modication of the **data structure** implemented
- **Data Processors** adapted
- New **tests** for the EMRPlaneHits and EMRMCDigitization
- EMRRecon integrated, needs to be revised

To do:

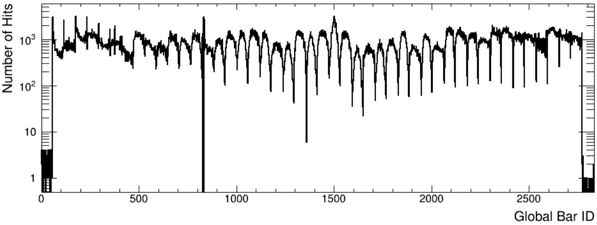
- **Test** for EMRRecon

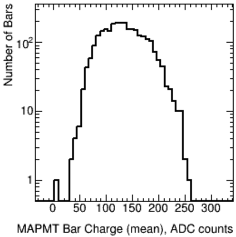
→ **Almost completely functional**

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

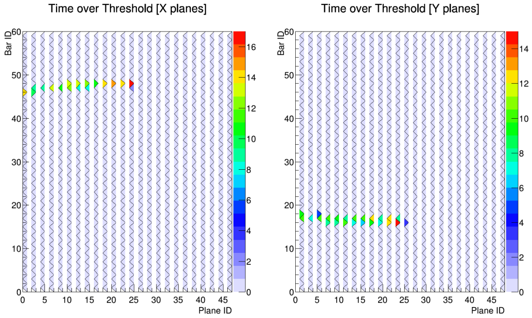




TH2EMR

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

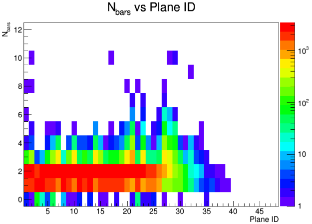
- Constructed on the TH2Poly ROOT class
- Functions inspired from the well known TH2 ROOT class
  - `Fill(int i, int j)` adds a hit in bar j of plane i
  - `Fill(int i, int j, double w)` sets weight w to bar j in plane i
  - `Draw()` draws and saves the histogram



Future prospects

Things will be done in the future to improve the existing code:

- Measurement of the digitization parameters on a test bench
- Calibrate the detector in energy using Monte Carlo simulation
- Improve reconstruction:
  - the coordinate in each plane as a weighted average of the position of the bars hit and their ToT measurements
  - include the triangular geometry in the range measurement
  - redefine the end point of the primary track using bar multiplicity
  - implement PID tag (e,μ,π) based on reconstructed variable using cut based analysis and multivariate analysis



- Further develop the new TH2EMR class