Multi-vertex event reconstruction with fiTQun (WCTE)

Focus on prefit and Multi-Ring tuning

Institut de Física
d'Altes Energies

Table of Contents

fiTQun

- FiTQun is a maximum likelihood estimation event reconstruction algorithm for WC experiments,

- FiTQun steps:
  1. Vertex pre-fitting,
  2. Hit clustering,
  3. Single-ring reconstruction,
  4. Multi-ring reconstruction.

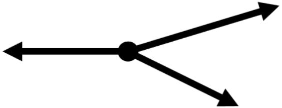
- likelihood, function of the particle parameters specifying initial condition:
  - vertex position x,
  - time t,
  - zenith angle and azimuth of the direction θ, ϕ,
  - and momentum p.

$$L(\mathbf{x}) = \prod_j^{unhit} P_j\left(unhit|\mathbf{x}\right) \prod_i^{hit} P_i\left(hit|\mathbf{x}\right) f_q\left(q_i|\mathbf{x}\right) f_t\left(t_i|\mathbf{x}\right)$$

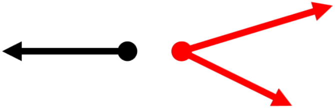
Likelihood to maximise — Candidate track hypothesis — Probability of no hit at PMT — Probability of hit at PMT — Hit charge probability density — Hit time probability density

Preparation for Multi-Vertex fiTQun

- Normal fiTQun only find the pion upstream track $\rightarrow$
- Multi-Vertex needed to find pion scattering vertex $\searrow$



1. Reconstruct the first ring
2. Search the second ring assuming the primary vertex.
3. Search the third ring assuming the primary vertex.



1. Reconstruct the first ring
2. Search second vertex
3. Search the second ring assuming the second vertex.
4. Search the third ring assuming the second vertex.

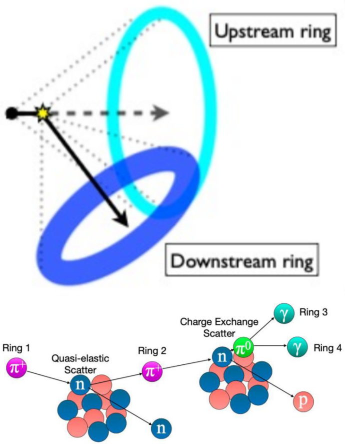
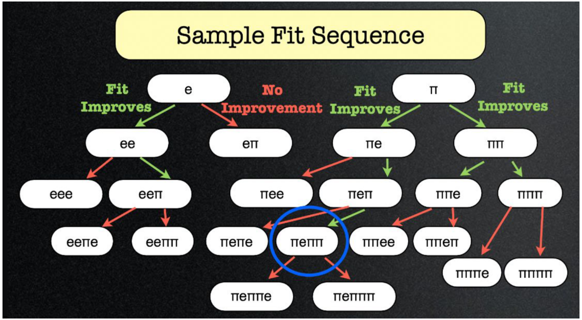


Figure: Pion scattering processes in WCTE

Multi-Ring tuning: 4 parameters

- Parameters used in the function **IsThereNewRing**:
  - $<$ fiTQun.RCCut1Ea0WCSim = 0. $>$
    For 1e/2 rings separation
  - $<$ fiTQun.RCCut1Mua0WCSim = 0. $>$
    For 1μ/2 rings separation
  - $<$ fiTQun.RCCuta0WCSim = 0. $>$
    For 2+ rings separation
  - $<$ fiTQun.RCCuta1WCSim = 0. $>$
    For new ring energy dependence $(a0 + a1 \times E_{new})$



- Used muons (1, 2 or 3) to count the number of rings at center (same position, time) with different angles (uniformly distributed).

Likelihood difference between 1 (2) and 2 (3) rings using muons of KE 300 MeV

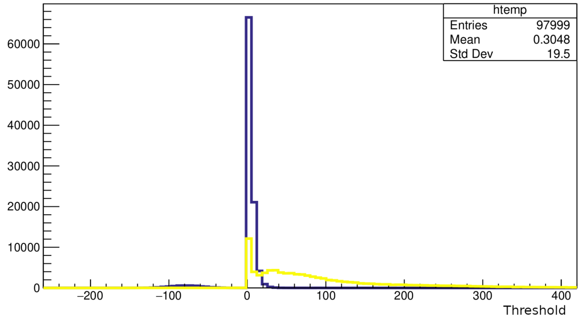


Figure: likelihood cut tuning parameter for 1 muon and 2 rings

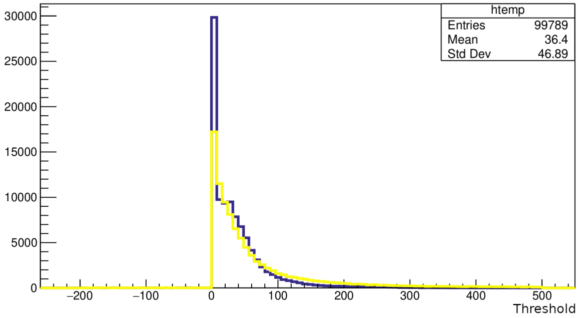
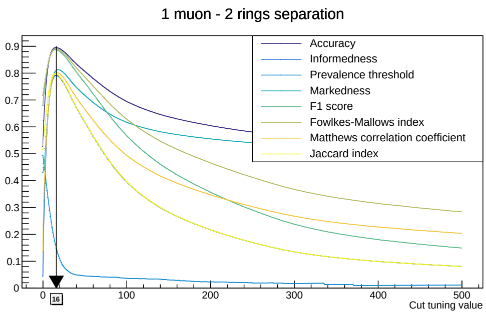
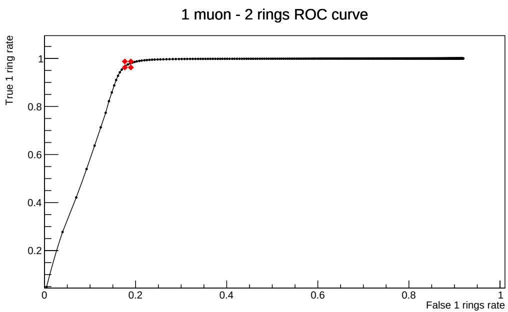


Figure: likelihood cut tuning parameter for 2 rings and 3 rings

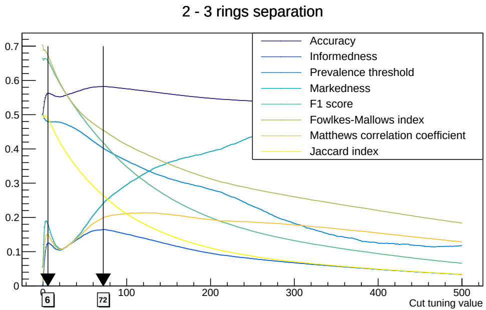
Separation for 1 muon ring and 2 rings

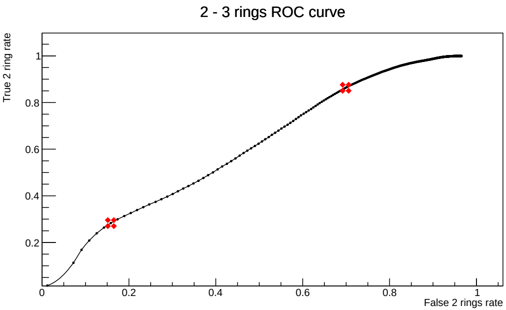




- < fiTQun.RCCut1Mua0WCSim = 16. >, assuming a1=0 and KE 300 MeV
- Definitions here!

Separation for 2 rings and 3 rings





- < fiTQun.RCCuta0WCSim = 6. or 72. > ?, assuming a1=0 and KE 300 MeV
- Difficult separation (most conservative assumption, same vertex, time).
- Definitions here!

Choice for MR parameters

- Min muon momentum for Cherenkov light: 117.86 MeV $\rightarrow$ KE 52.63 MeV
- Max muon momentum before partially contained: 460 MeV $\rightarrow$ KE 366.32 MeV

KE	100	150	200	250	300	350
a0mu	9	11	13	16	16	16

Table: With a1 = 0

- Threshold: $a0 + a1 \times E_{new}$
  - Muon/Pion: $E_{new} =$ reconstructed Eloss
  - electron: $E_{new} =$ reconstructed momentum

Choice for MR parameters

KE	a0mu	a1
100	59.51	-4.125
150	67.49	-3.405
200	82.50	-3.905
250	30.50	-0.625
300	26.50	-0.395
350	31.56	-0.521

Table: Best parameters for each KE files

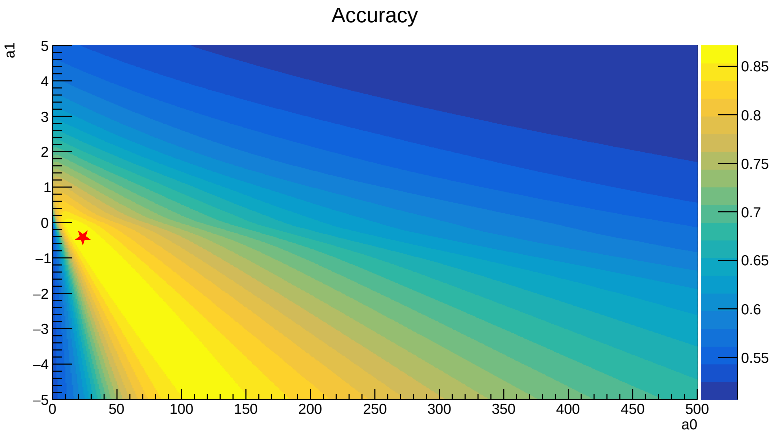


Figure: Best parameters: a0 = 23.5059 and a1 = -0.414986, for all KE

MR parameters improvement?

- a1 parameter never used before (a1 = 0 for SK)
- Relation to the new ring energy not necessarily linear.

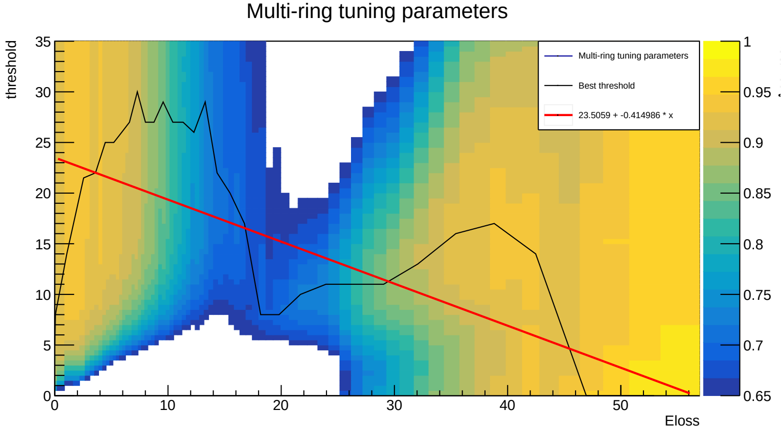


Figure: Accuracy for a chosen threshold for multi-ring separation in function of Eloss

MR parameters improvement?

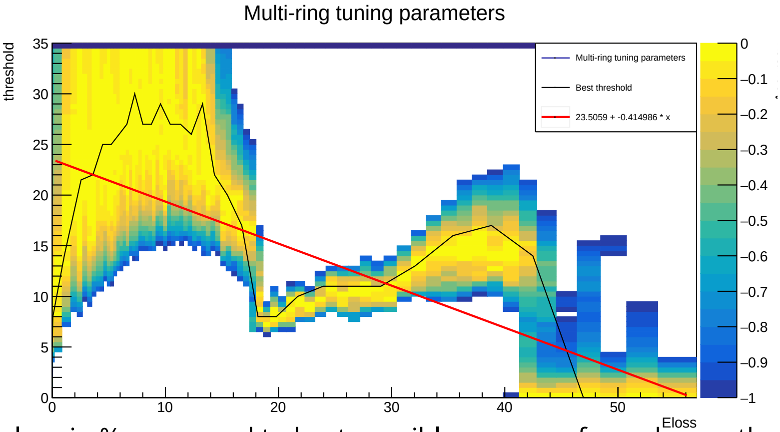


Figure: Accuracy loss in % compared to best possible accuracy for a chosen threshold for multi-ring separation in function of Eloss

Next for Multi-ring tuning?

- Preparing π^+andπ^- sample at different positions, ✓
- Filtering the tracks from WCSim to know the number of rings, ✓
  1. Build the family tree (scattering, decay...),
  2. Ignore track under Cherenkov threshold,
  3. Ignore track under 1 cm,
  4. Ignore track beyond 200 ns (Michele electron, next sub-event),
  5. Combine tracks below 20°:
     - μ/π: rings below 20°in fiTQun are merged as most likely scattering,
     - e^-/e^+: below 20°merged as from same EM shower (γ decay).
- Using muon (1 ring) sample and pion (from 0 to max rings) sample to tune for the best set of parameters.

Preliminary tuning parameters

- Tested with previous muon samples and new pion sample (π^+/π^- at 5 positions),
- comparing muon (1 ring) and pion (2+ rings):

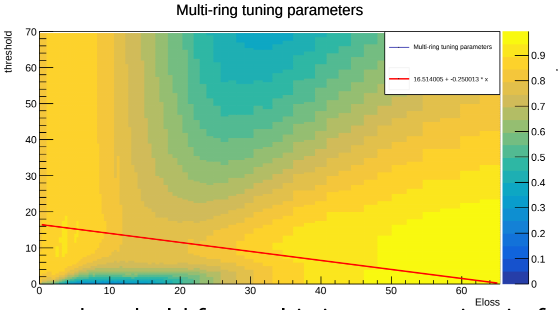


Figure: Accuracy for a chosen threshold for multi-ring separation in function of Eloss with pion sample (total accuracy of 88,6921%)

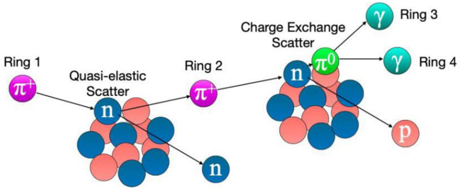
- Working on muon sample with uniformly distributed energy,
- Next is testing on performance of the filter with the newly found parameters.

Conclusion

- Multi-Ring tuning separate very well 1 and 2 rings, more difficult for 2+ rings,
- Relation to new ring energy not necessarily linear,
- Prepared filter for True ring counting for comparison with fiTQun.

Strategy

- Testing with uniformly distributed energies for tuning a1 parameter,
- Setting Multi-Vertex fiTQun is done (waiting for multi-ring cut parameters),
- Under most conservative assumption first, starting to compare unrestricted single and multi-vertex resolution for 2 rings (different 2nd ring position and time) to look for pion scattering,
- For now, keep all parameters free,
- Later, restricting first vertex to beam pipe position (fix longitudinal and set limits for transversal positions) of first ring, looking for overall improvement.



Vertex pre-fitting

- Searching for the global maximum by minimizing the negative log likelihood,
- PROBLEM: local minima of $-\ln L$ inevitably exist,
- Important to seed fit parameters with values close to global minimum,
- The vertex pre-fitter is a fast algorithm which uses only the hit time information to estimate the vertex position and time, defined as:

$$G(x, t) \equiv \sum_{i}^{\text{hit}} \exp(-(T^i_{\text{res}}/\sigma)^2/2)$$

- Where T^i_{res} is the residual hit time calculated on the assumption of a point-like light source and subtracting the photon time of flight

Longitudinal Prefit result limited by Fiducial Volume

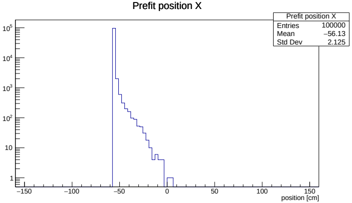


Figure: Beam at x= 0cm

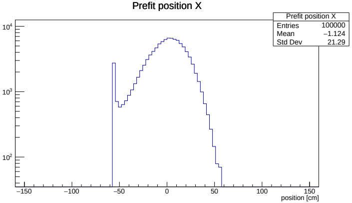


Figure: Beam at x= 80cm

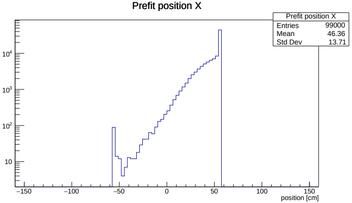


Figure: Beam at x= 130cm

- Prefit is limited to a radius of less than 60 cm,
- This is due to Fiducial Volume set in **fiTQun.parameters.dat** 1m away from wall and floor/ceiling:
  - line 57: $<$ fiTQun.PrefitVtxMinDwall = 100. $>$ Minimum dwall for pre-fit vertex(tune it for different detector size & PMT granularity)
- X position shifted.

Prefit with no dwall limit

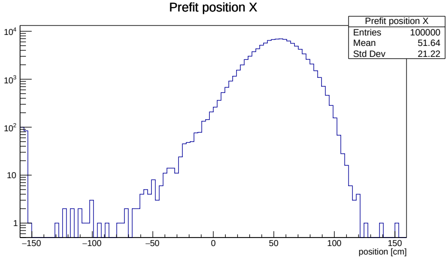


Figure: Beam at x= 130cm

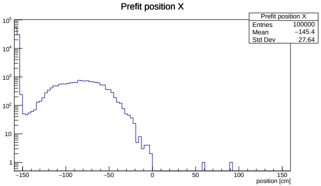


Figure: Beam at x= 0cm

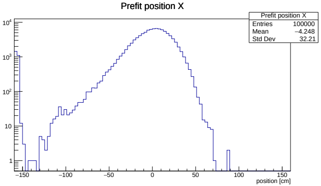


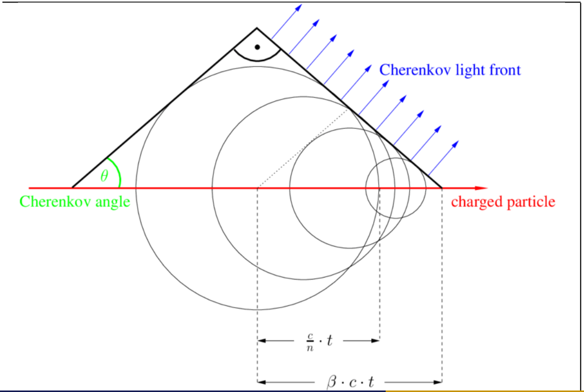
Figure: Beam at x= 80cm

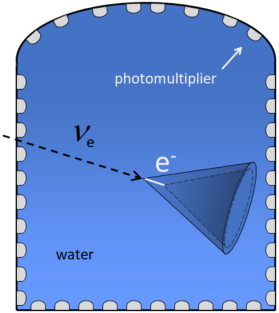
- With dwall = 0 cm, Fiducial Volume is almost the full inner detector size (fiTQun set the radius and height as the farthest PMT position),
- The X position of the prefit is shifted 80 cm.

The mouvement direction of the Cherenkov ring

WCTE has larger radius than height

- Vertex goodness: the residual hit time calculated on the assumption of a point-like light source and subtracting the photon time of flight.





PID for True electron (beam at 130 cm) with no dwall limit

the threshold is chosen such that true muons would start to leave the detector

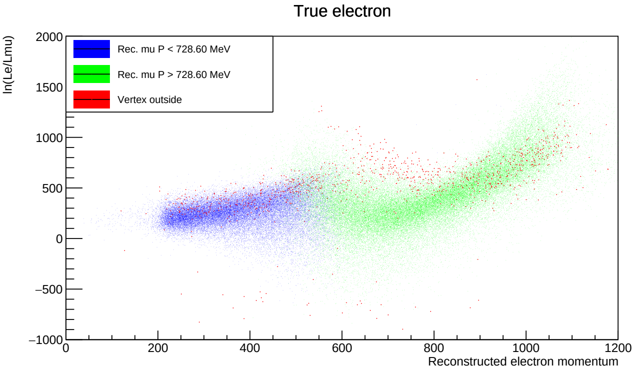


Figure: PID for e^- with dwall limit at 0 cm

- The true electron reconstructed outside the detector (in red) present in the negative range of $\ln(L_{e^-}/L_{\mu^-})$ disappeared.

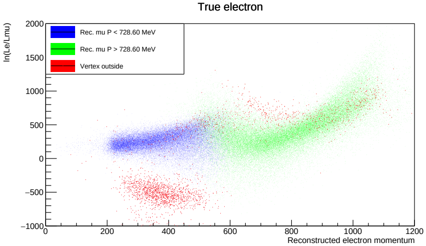


Figure: PID for e^- with dwall limit at 100 cm