Edepillim: A New Muon Energy Reconstruction Method for Large Scale Neutrino Detectors

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CHEP 2019
Large Scale Neutrino Detectors

IceCube Laboratory
Data is collected here and sent by satellite to the data warehouse at UW-Madison

Digital Optical Module (DOM)
5,160 DOMs deployed in the ice

IceCube detector
86 strings of DOMs, set 125 meters apart

Amundsen–Scott South Pole Station, Antarctic
A National Science Foundation managed research facility

60 DOMs on each string

DeepCore

Antarctic bedrock

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Edepillim

Initial muon energy

\[ E_1 = E_0 - dE_0 \]

\[ E_2 = E_0 - dE_0 - dE_1 \]

Stochastic losses
bremsstahlung,
pair production
photonuclear reactions
Edepillim

Initial muon energy

\[ E_1 = E_0 - dE_0 \]

\[ E_2 = E_0 - dE_0 - dE_1 \]

Decreasing muon energy along track

\[ E_N = E_0 - \sum_{i=0}^{N-1} dE_i \]

Stochastic losses
We refer to $E_0$ as observable

Probability is the product of the probabilities of the energy loss given muon energy.
Probability Distribution Function

PROPOSAL - Propagator with optimal precision and optimized speed for all leptons

A tool for propagation of charged leptons, in this case muons

PDFs are built using PROPOSAL, simulating a muon energy $E$ over a track length collecting the continuous and stochastic losses.
Muon Energy Loss Segment Length

In large scale neutrino detectors, accurate energy loss pattern reconstruction can be limited depending on the medium and the detector. To show the performance of Edepillim under different detector conditions the individual energy loss patterns of the simulated events were combined to make various energy loss segment lengths.
Muon Energy Loss Segment Length

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Reconstruction Distribution Using Average Likelihood Function

\[
P(E_{\text{TARG}ET}; E_0) = \sum_{i=0}^{N} P(E_0(i); E_{\text{TARG}ET}) \mathcal{L}(E_{\text{TRUE}}; E_0(i));
\]
Using a PROPOSAL simulation of muon energy loss along a 1000m track, with varying energy loss bin sizes. Using the true losses, larger bin sizes has the effect of worsening the resolution, as detail in the energy loss pattern is lost.
Edepillim Performance on Pattern Path Length

Using the true losses, shortening the track length has the effect of worsening the resolution as there are less energy losses to work with.
Idealised Truncated Mean Energy Loss Rate

Muon Energy Proxy = \frac{dE}{dx}

This is a simple version of Truncated Mean Energy Loss Rate\(^1\) using the energy loss pattern. The complete version as used in the IceCube neutrino observatory accounts for detector effects etc.

\(^1\)IceCube Collaboration, R. Abbasi and et al., NIM, 703 (2013) 190 – 198
Comparison to Truncated Mean Energy Loss Rate

- The comparison of an idealised case of the truncated mean energy method (TE) shows the large possible improvement with Edepillim in its best segment length of 1m.

- However detector effects such as energy loss resolution will affect the overall result, worsening the resolution.
Conclusion

• We have developed an new method for reconstruction of muon energy using the stochastic energy loss pattern.

• The new method Edepillim works best for long muon tracks where the energy losses can be well resolved.

• In an idealised case it is the energy reconstruction method with the higher energy resolution
Thank You!
Backup
Alternative Method- PK


\[ \ln L = \sum \ln[V P_x(V)] \quad V = dE/E \]
PK uses an average PDF in the likelihood function. At high bin lengths this accurately describe all energies. At low bin lengths it does not.