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Edepillim: Muon Energy Reconstruction for large scale neutrino detectors

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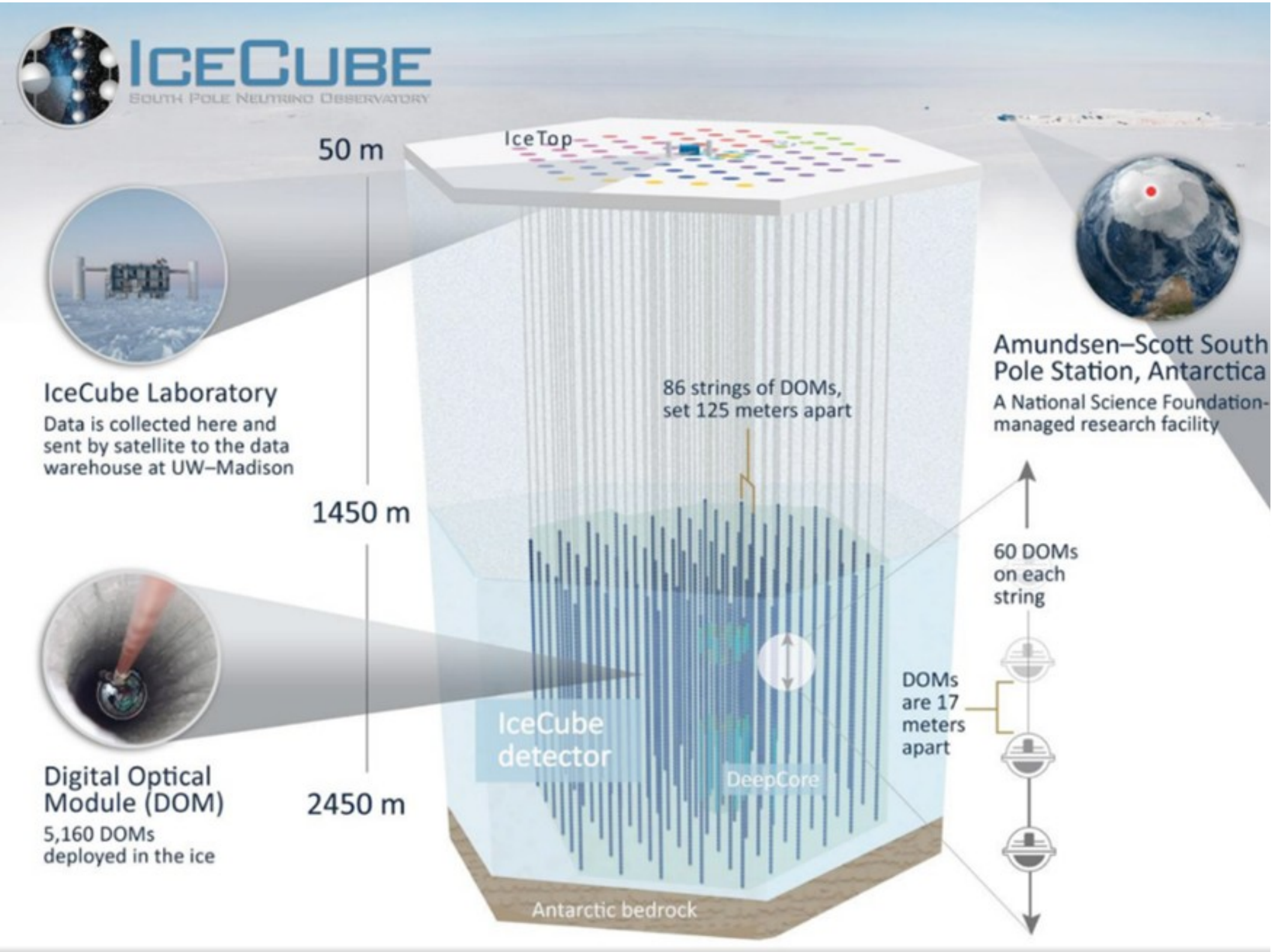
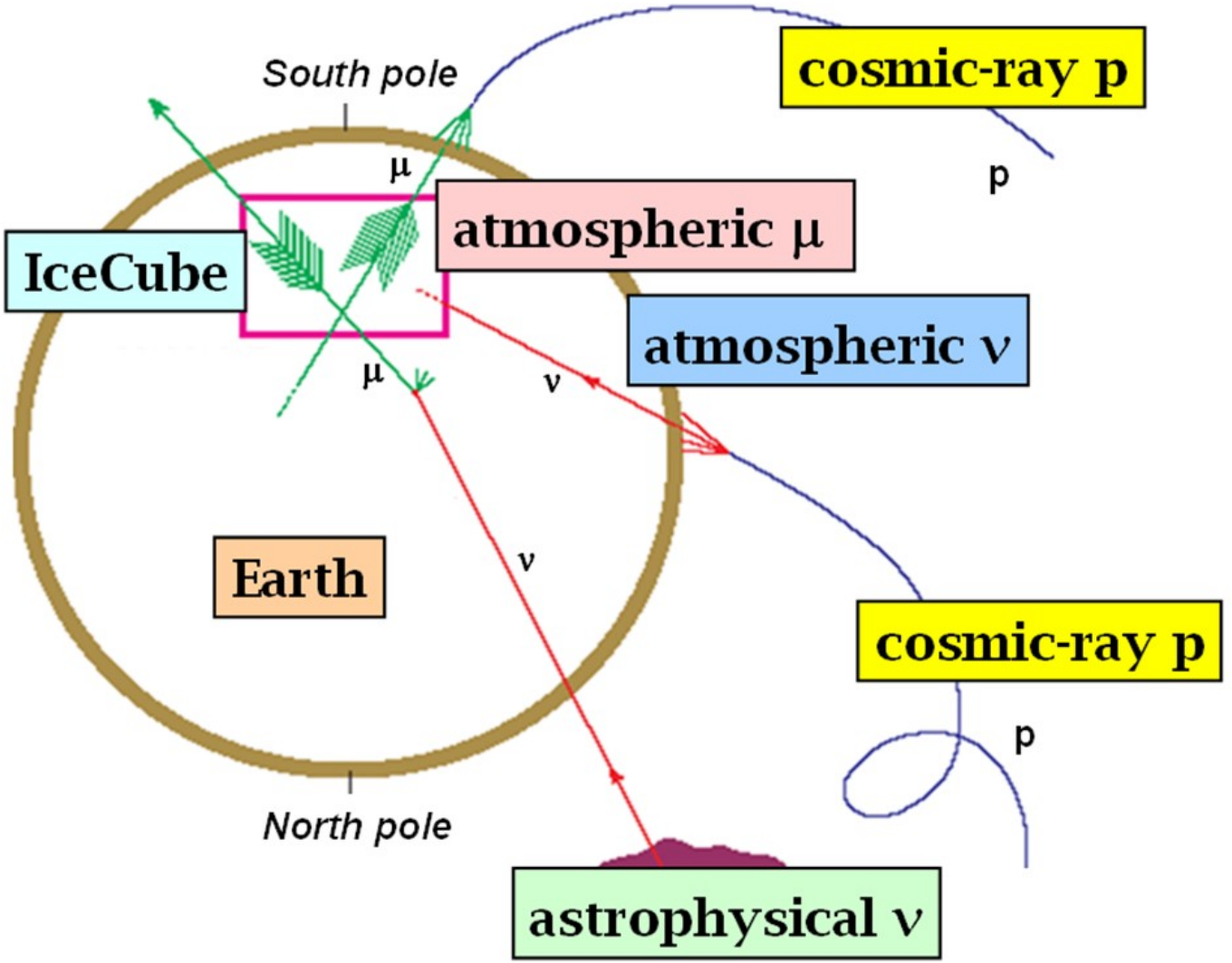

IceCube
South Pole Neutrino Observatory
50 m
IceTop
IceCube Laboratory
Data is collected here and sent by satellite to the data warehouse at UW–Madison
1450 m
86 strings of DOMs, set 125 meters apart
Amundsen–Scott South Pole Station, Antarctica
A National Science Foundation-managed research facility
60 DOMs on each string
DOMs are 17 meters apart
IceCube detector
DeepCore
Digital Optical Module (DOM)
5,160 DOMs deployed in the ice
2450 m
Antarctic bedrock

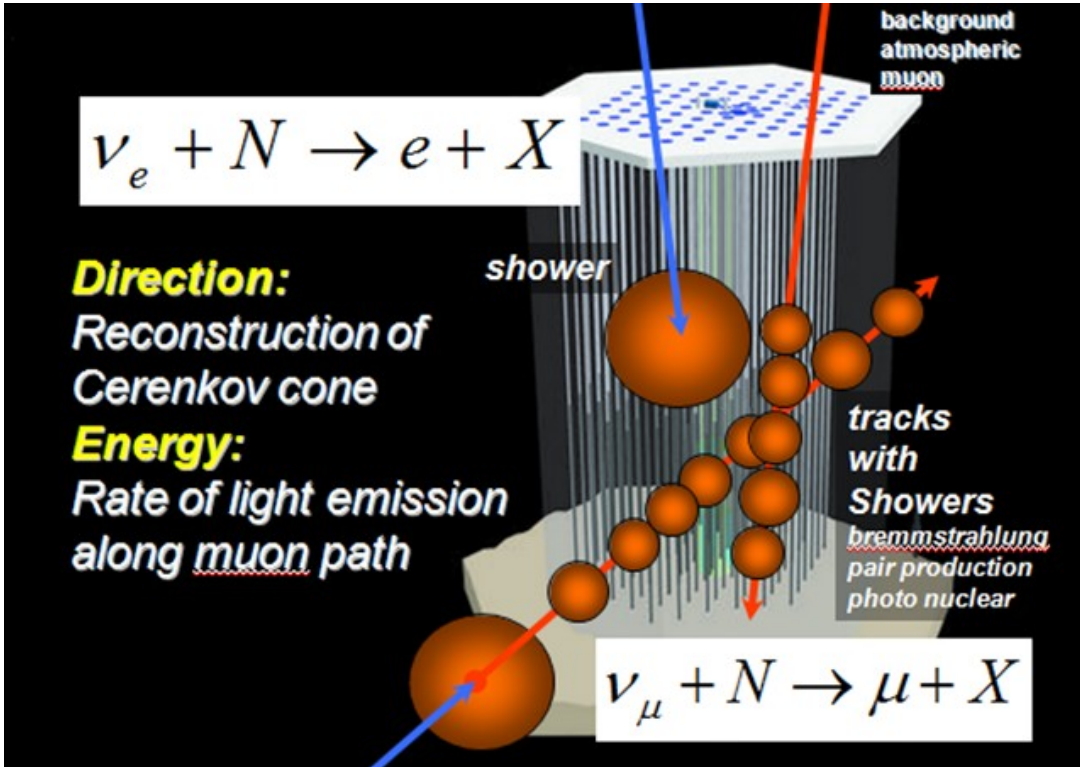
IceCube Detection Channels



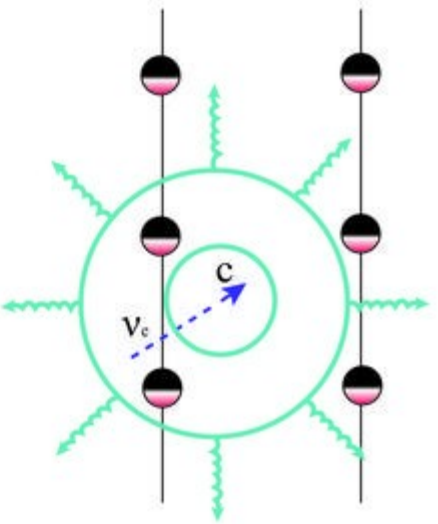
IceCube Events

Cascades: Events that occur within the detector. Good energy resolution 100% deposited. Poor angular resolution

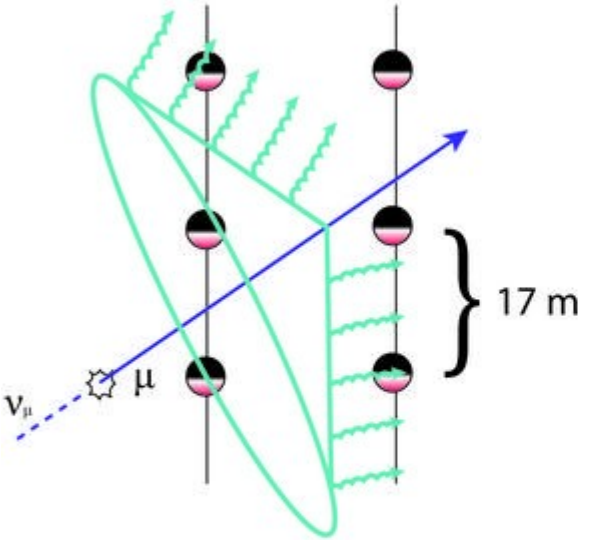
Tracks: Events going through the detector. Poor energy resolution. Good angular resolution.



~ 10m-long cascades from ν_e, ν_τ



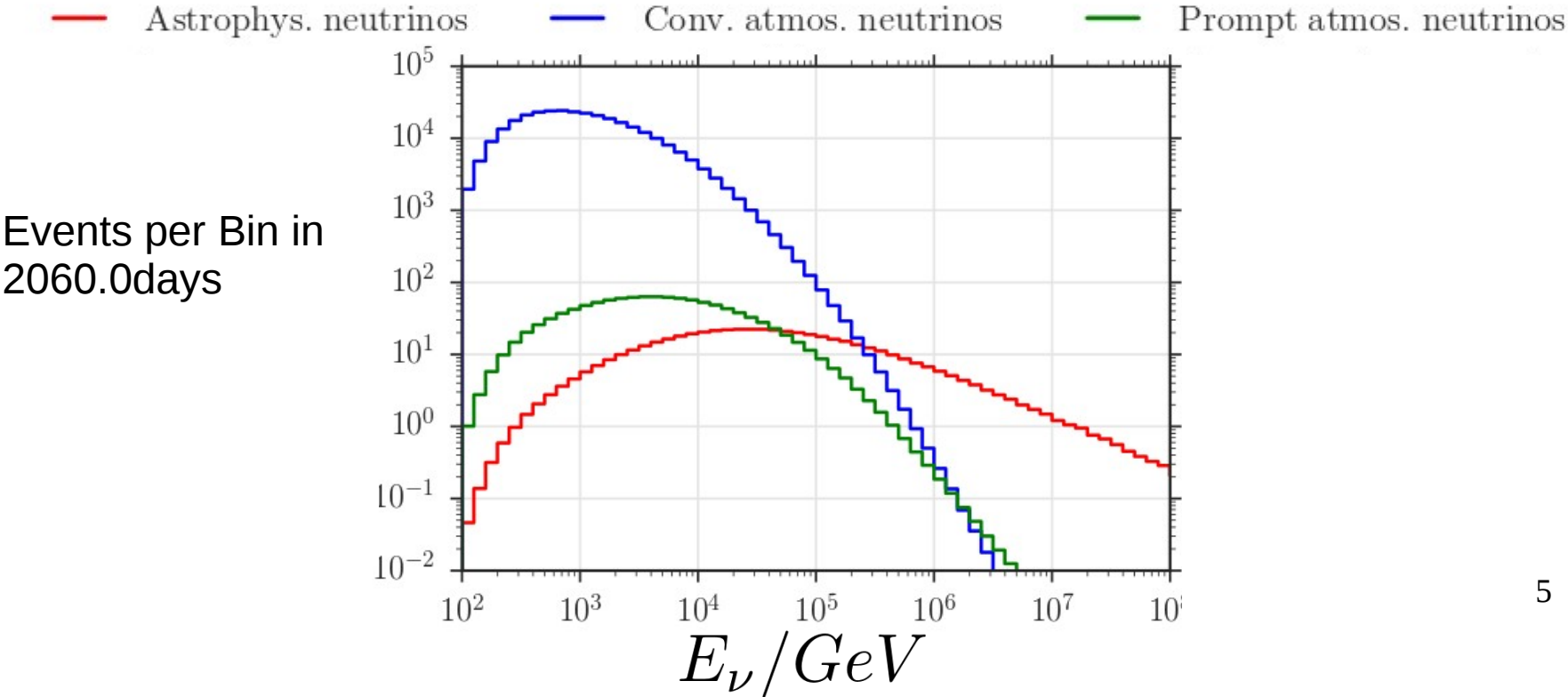
~ km-long muon tracks from ν_μ



Up-going Muon Diffuse Analysis

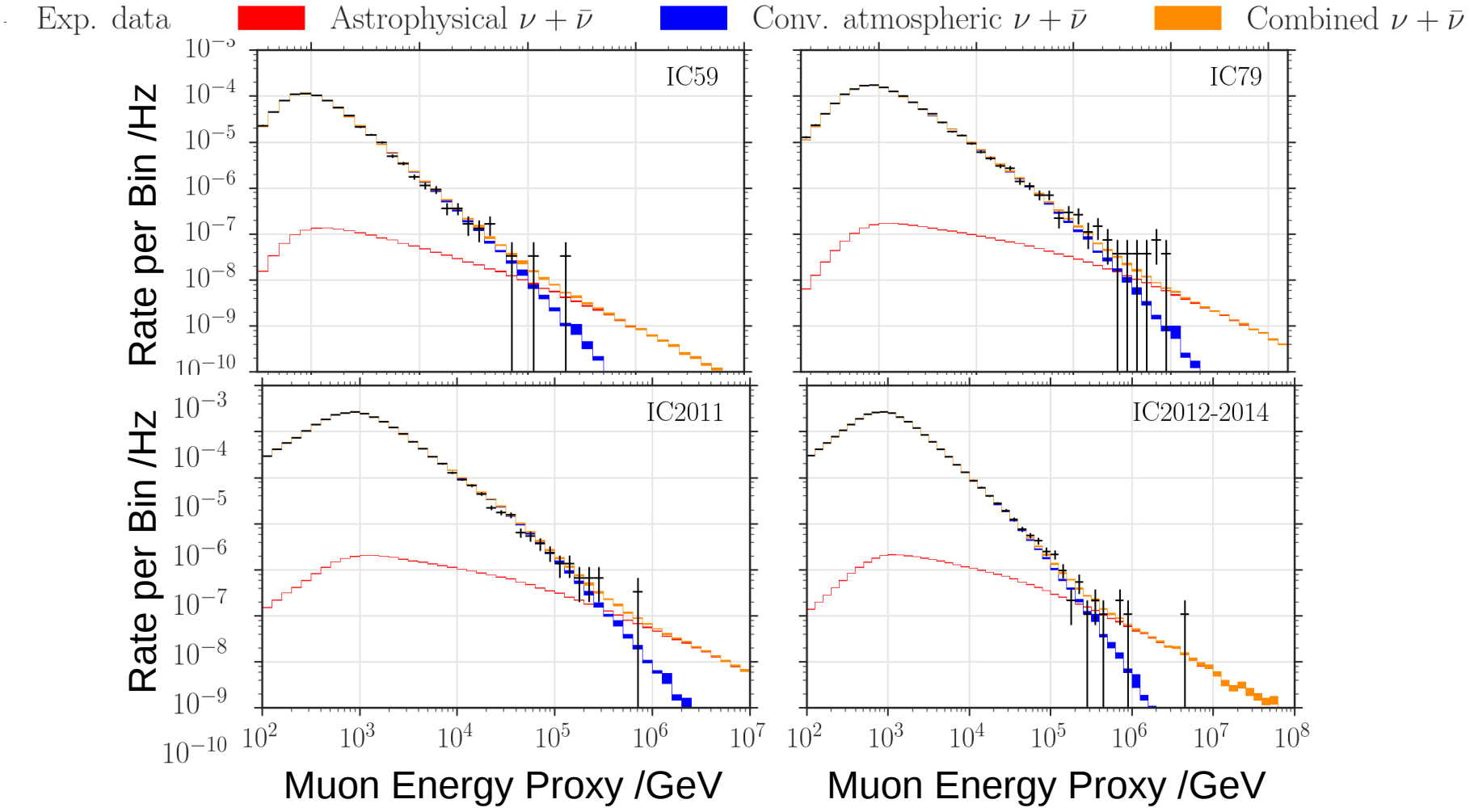
A diffuse analysis involves fitting a data to an expected flux for three components.

- Conventional atmospheric neutrinos; pion and kaon decay
- Prompt atmospheric neutrinos; charmed mesons.
- Astrophysical neutrinos



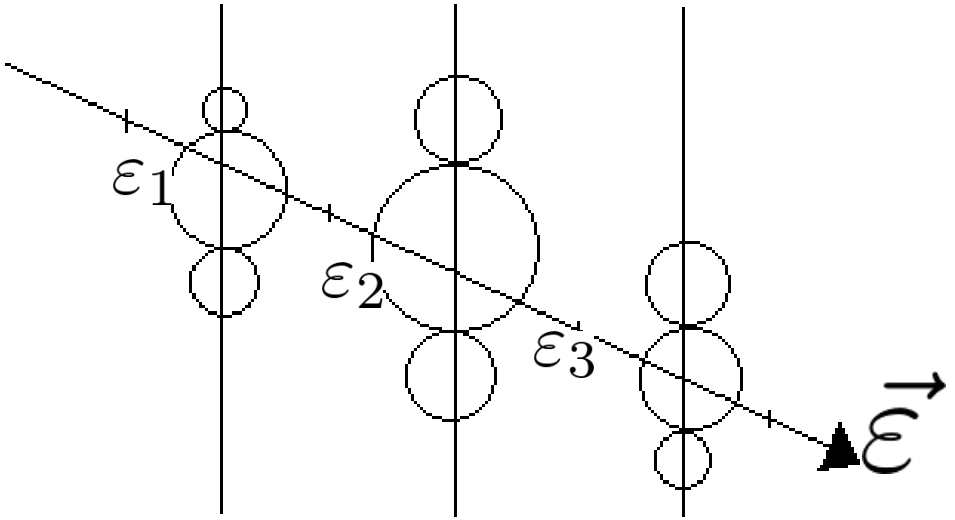
Diffuse Analysis

Most recent published diffuse results with 6 years of IceCube data. With over 350,000 upgoing charge current muon neutrinos shows a astrophysical contribution in the TeV to PeV range.



Event reconstruction: Millipede

Reconstructing the detailed light pattern in the modules to an energy loss pattern for the muon track $\vec{\varepsilon}$



$$k = \Lambda\vec{\varepsilon} + \vec{\eta}$$

Data

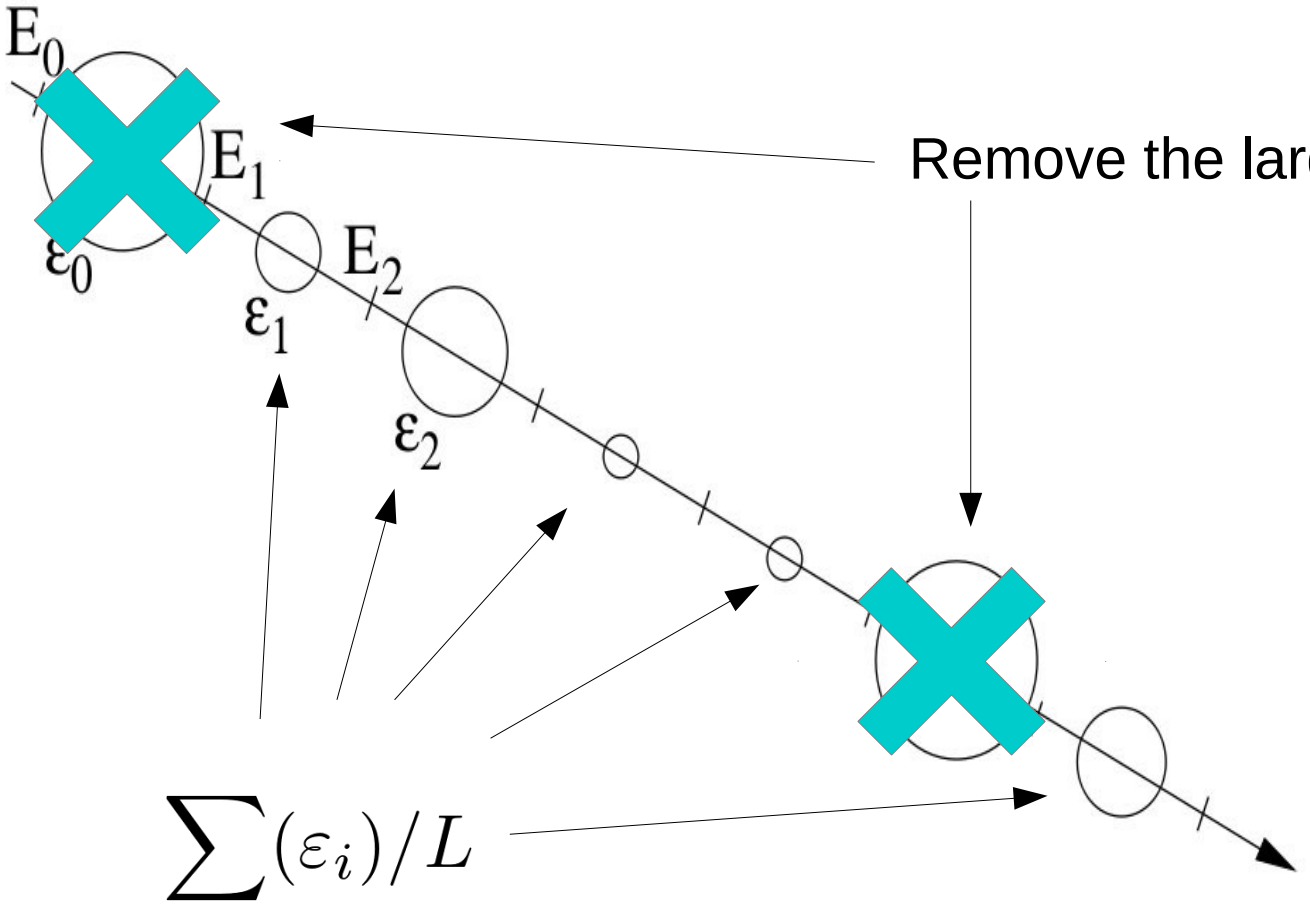
Noise

Transmission Matrix

E-loss vector

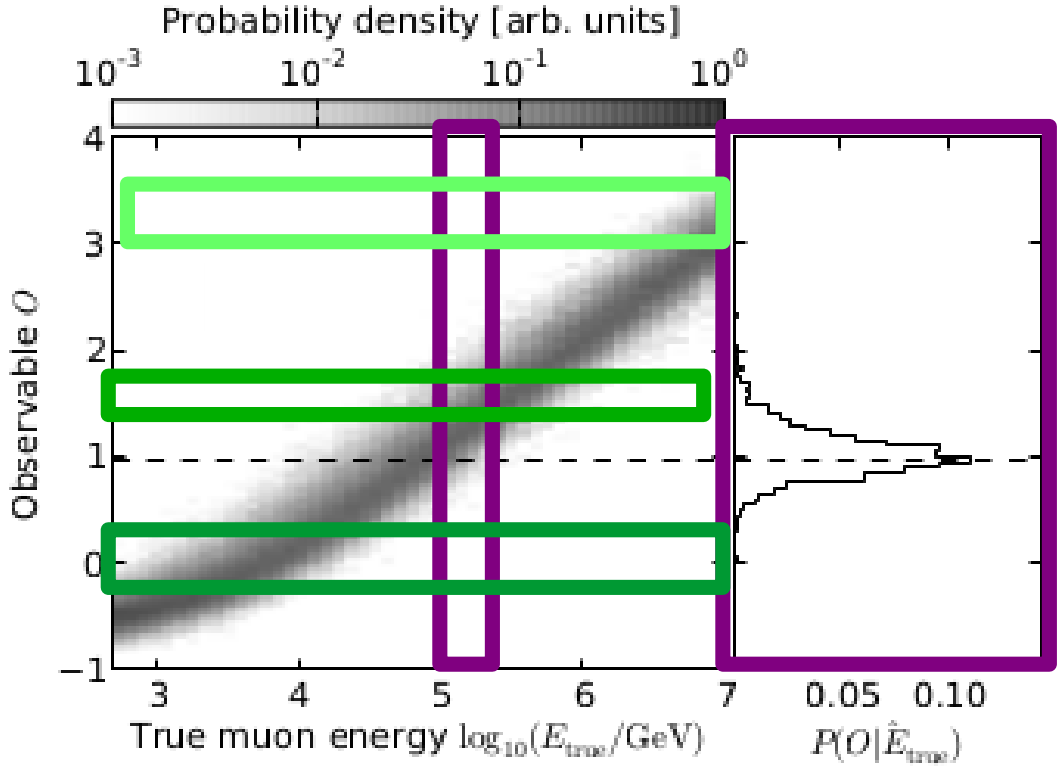
A Maximum likelihood fit is performed to reconstruct to the best $\vec{\varepsilon}$ for data observed.

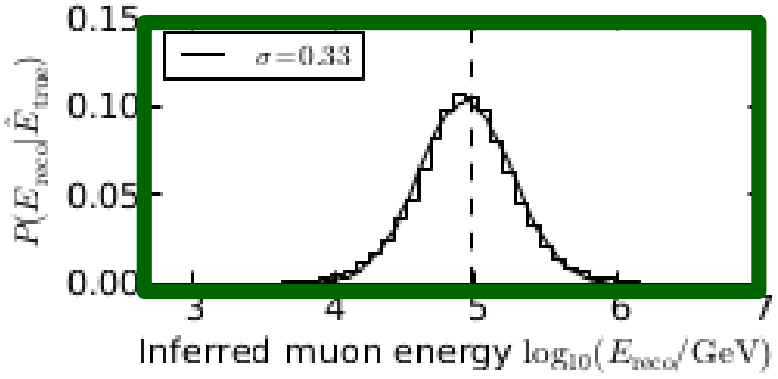
Energy Reconstruction with Truncated Mean Energy



Truncated energy (TE) finds the average energy after removing the largest losses.

Truncated Energy Resolution





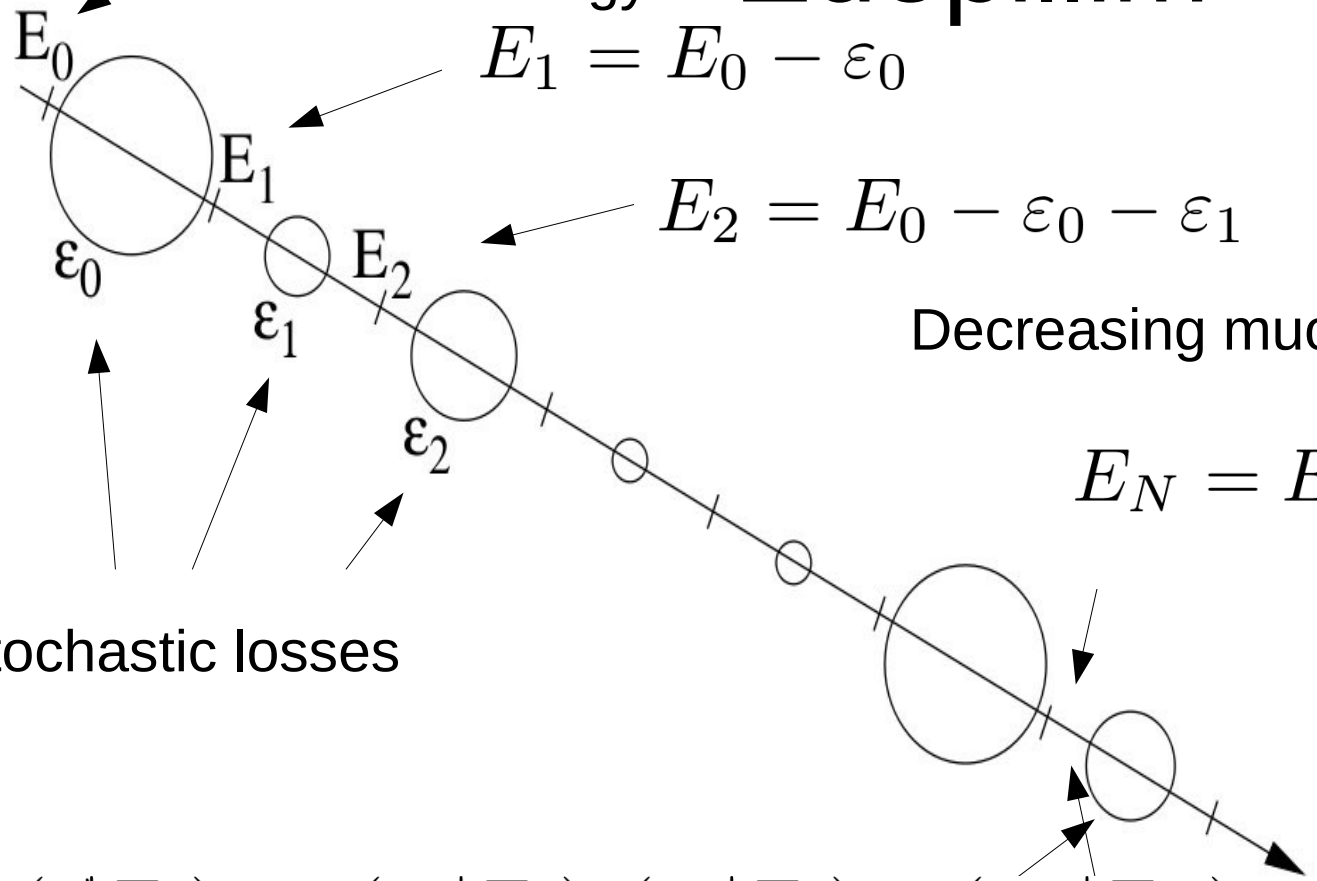
A result matrix is made with the muon energy result as the observable and the true muon energy

Each column of True muon energy is taken as a weight vector.

A slice for each observable is summed and multiplied by the weight to give a value for that inferred muon energy.

This method has the effect of mapping to the true muon energy.

Energy Reconstruction with Edepillim



Decreasing muon energy along track

$$E_N = E_0 - \sum_{i=0}^{N-1} \varepsilon_i$$

We refer to E_0 as observable

$$p(\vec{\varepsilon}|E_0) = p(\varepsilon_0|E_0)p(\varepsilon_1|E_1)...p(\varepsilon_N|E_N)$$

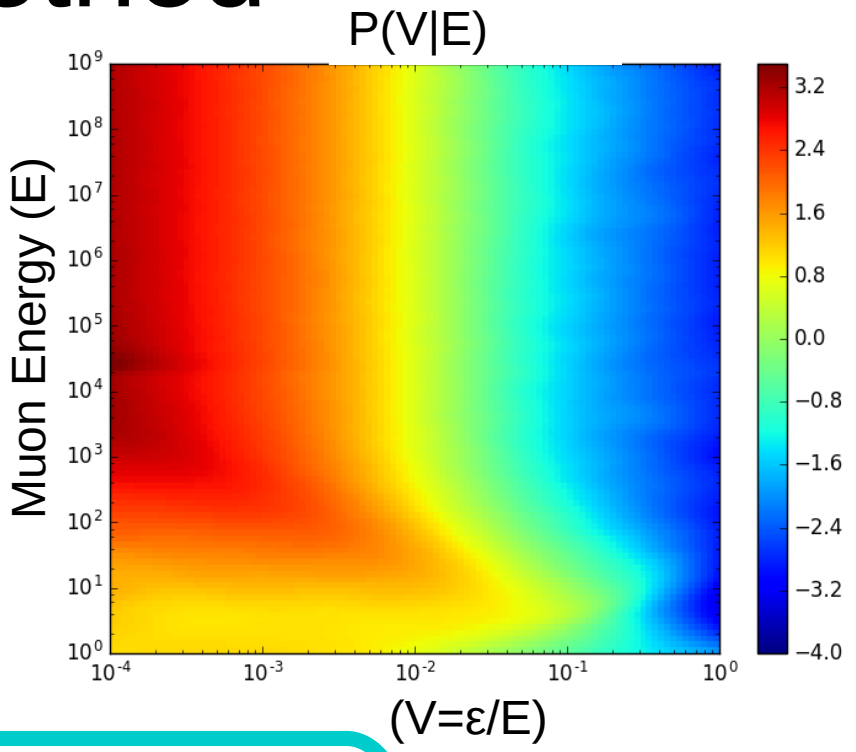
$$p(\vec{\varepsilon}|E_0) = p(\varepsilon_0|E_0)\prod_{j=1}^{N} p(\varepsilon_j|E_0 - \sum_{i=0}^{j-1}\varepsilon_i)$$

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

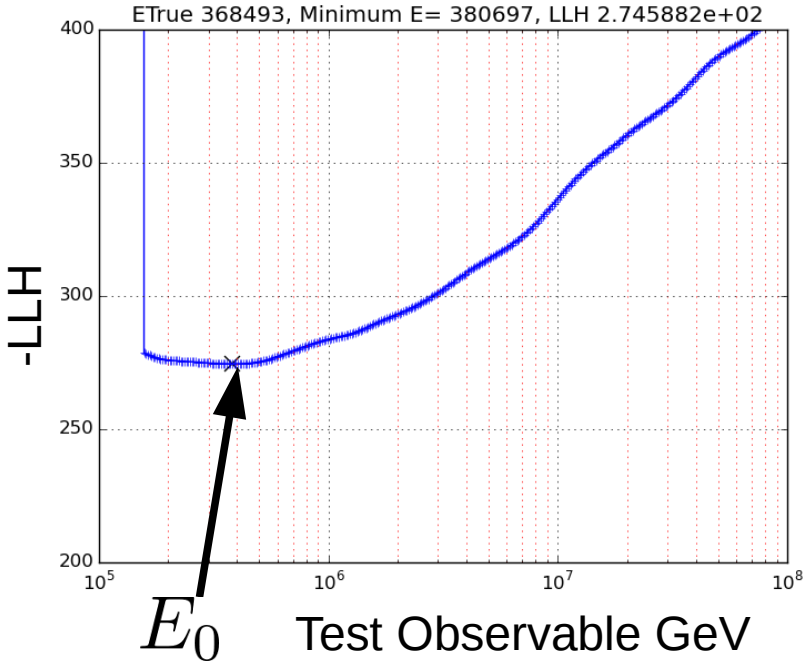
Edepillim Method

Millipede Energy Loss Pattern

Probability distribution function $P(V|E_N)$ is built from simulation.

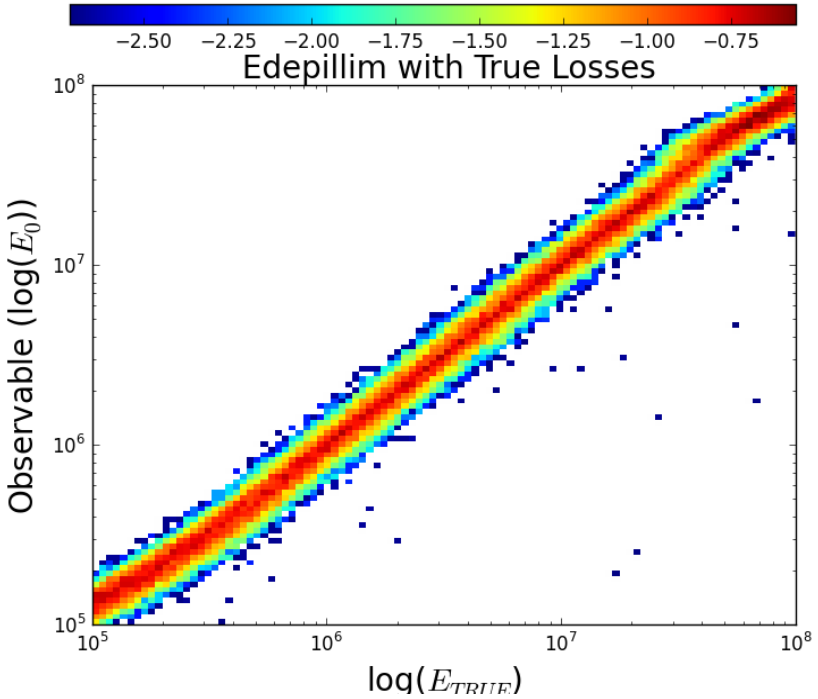


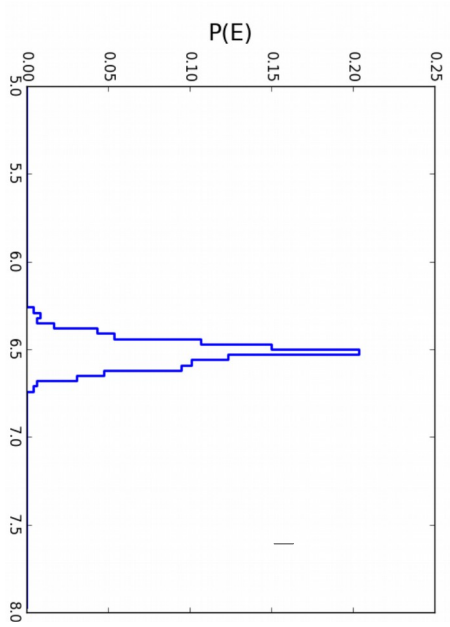
For a range of initial muon energies $p(\vec{\varepsilon}|E_0)$ is found.



Minimum Log Likelihood of energy range Observable E_0

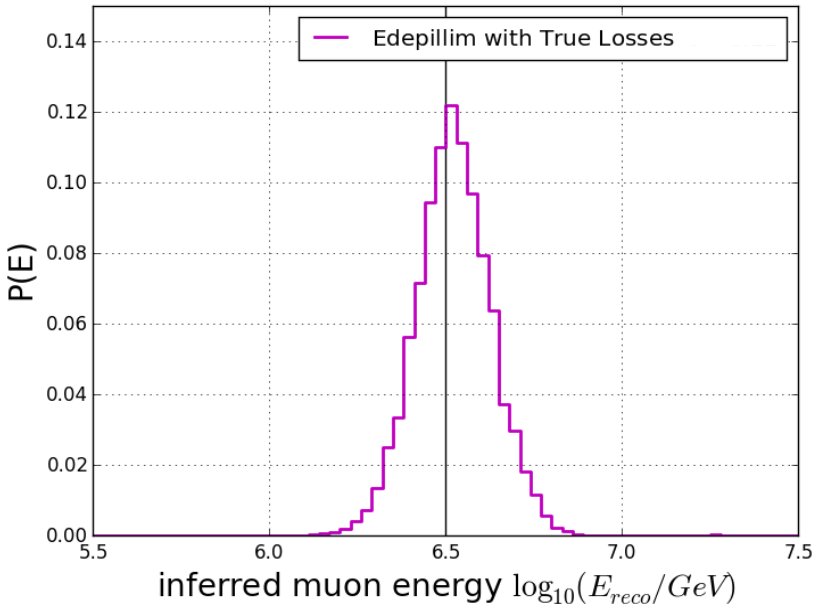
Edepillim with True Losses Resolution

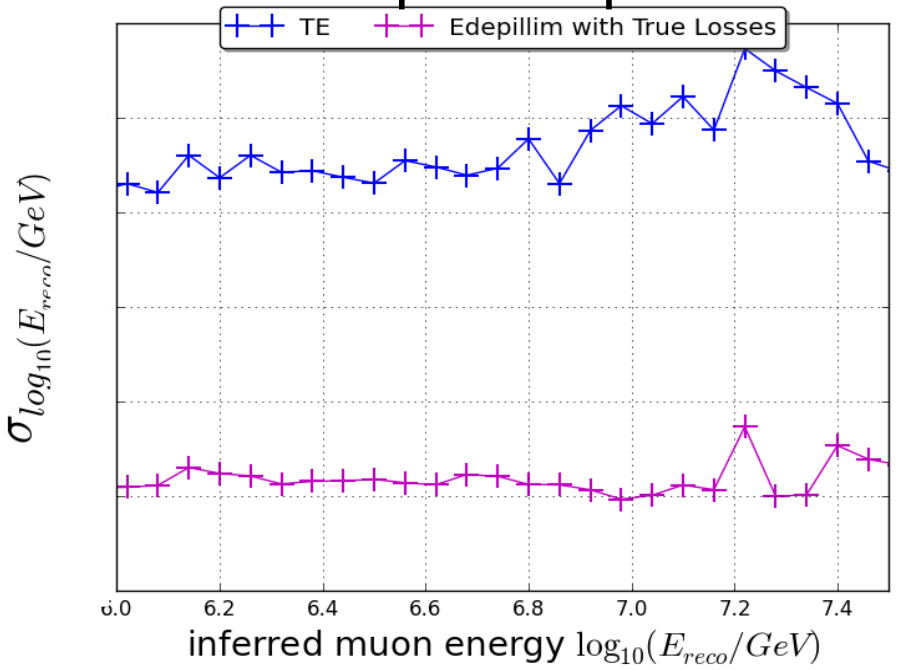




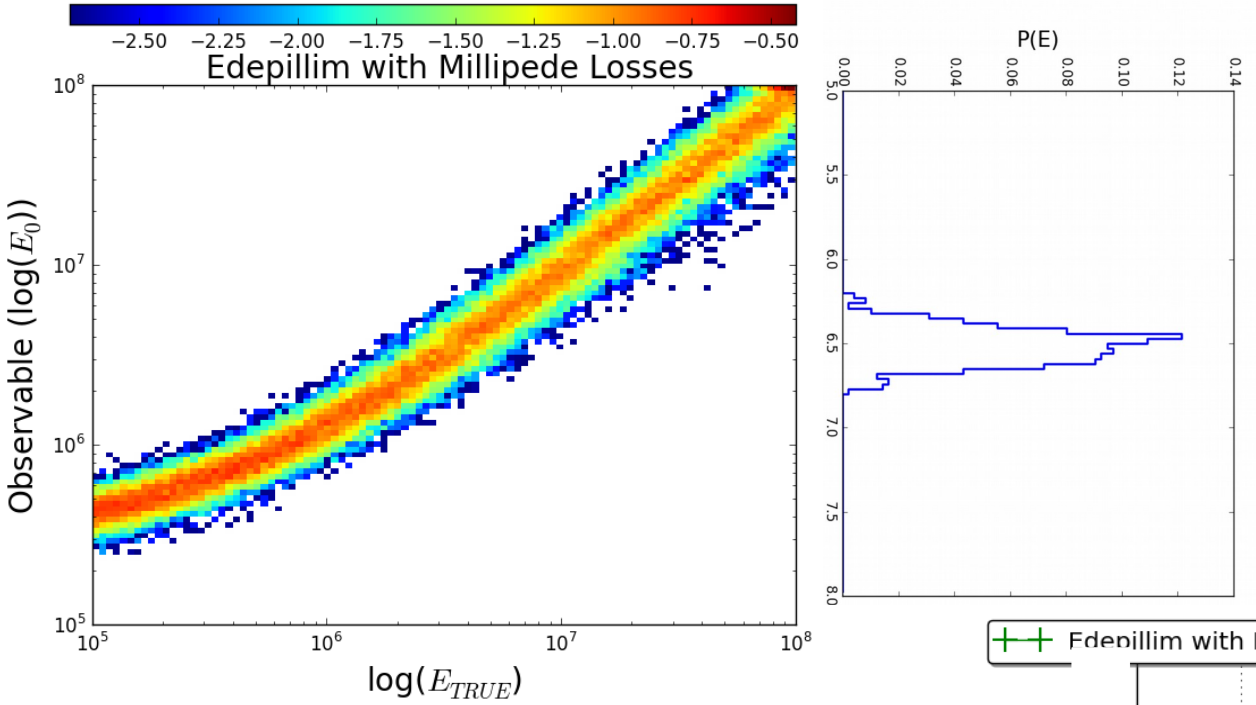
Simple illustrative toy model: (not actual IceCube performance)

Using the true simulated losses Edepillim has good energy resolution. This is the optimum of Edepillim's performance



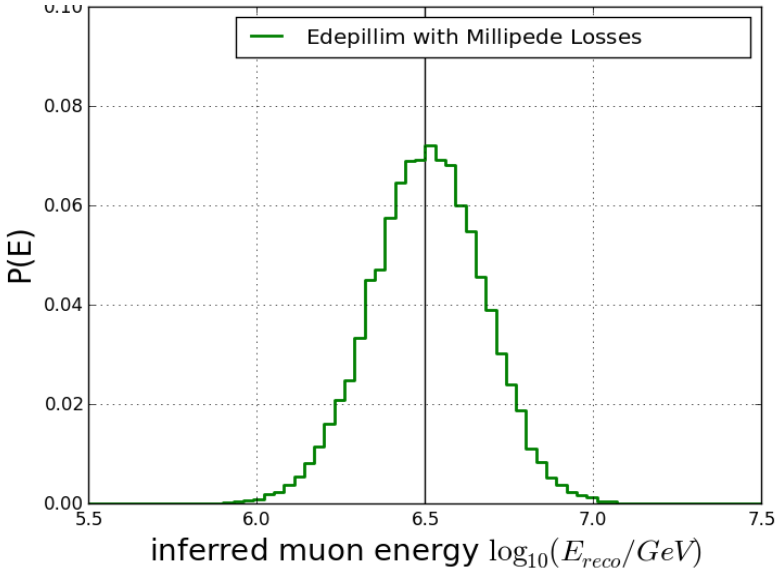


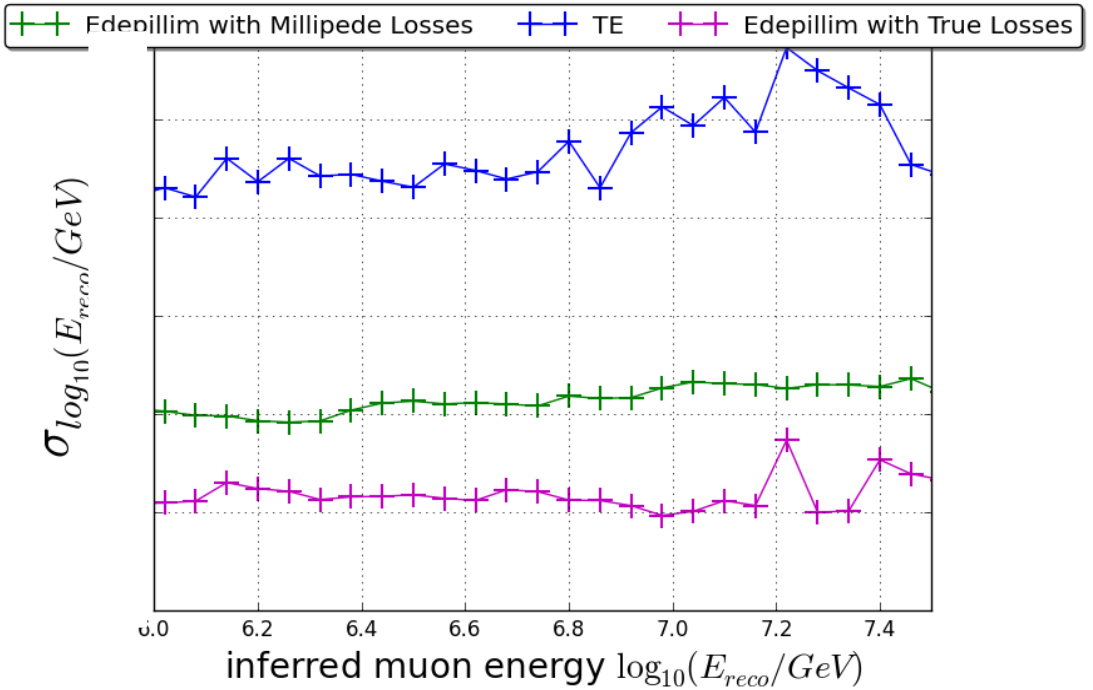
Edepillim with Millipede Losses Resolution



Simple illustrative toy model: (not actual IceCube performance)

This is an example of Edepillim's performance but will vary depending on the energy loss pattern reconstruction.





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Summary/Outlook

- IceCube has detected a high energy astrophysical flux at Tev to Pev.
- For diffuse flux analysis energy resolution is very important for improvement
- Adelaide group is developing a muon energy reconstruction technique (Edepillim) that uses the energy loss pattern to find initial energy.
- The Edepillim method has great promise as shown by simulation studies.