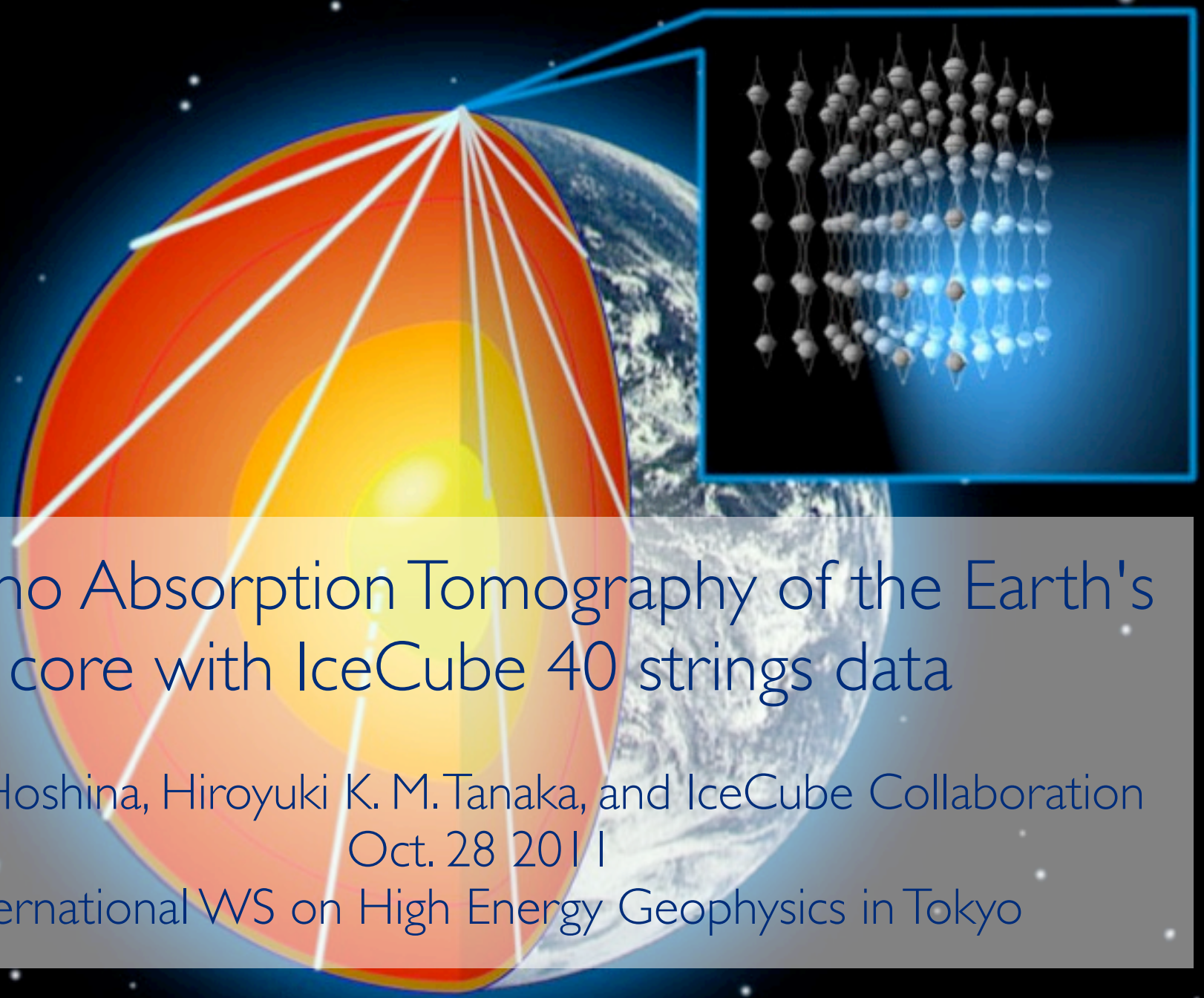


Neutrino Absorption Tomography of the Earth's core with IceCube 40 strings data

Kotoyo Hoshina, Hiroyuki K. M. Tanaka, and IceCube Collaboration

Oct. 28 2011

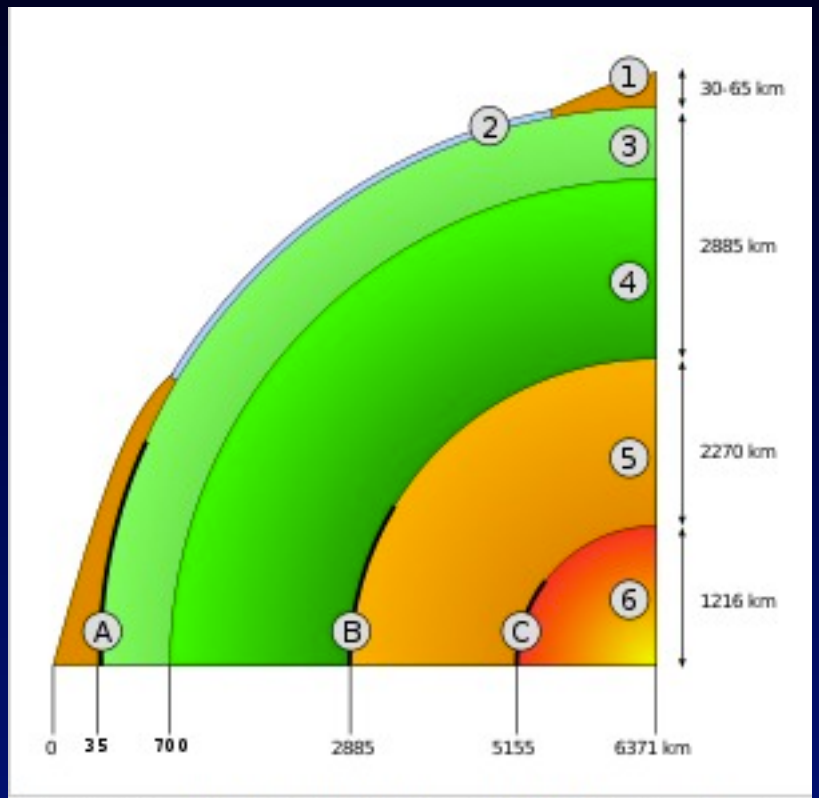
International WS on High Energy Geophysics in Tokyo

ICECUBE
DETECTOR COMPLETION 2011

Earthquake Research Institute,
The University of Tokyo

Why do we try Neutrino Tomography?

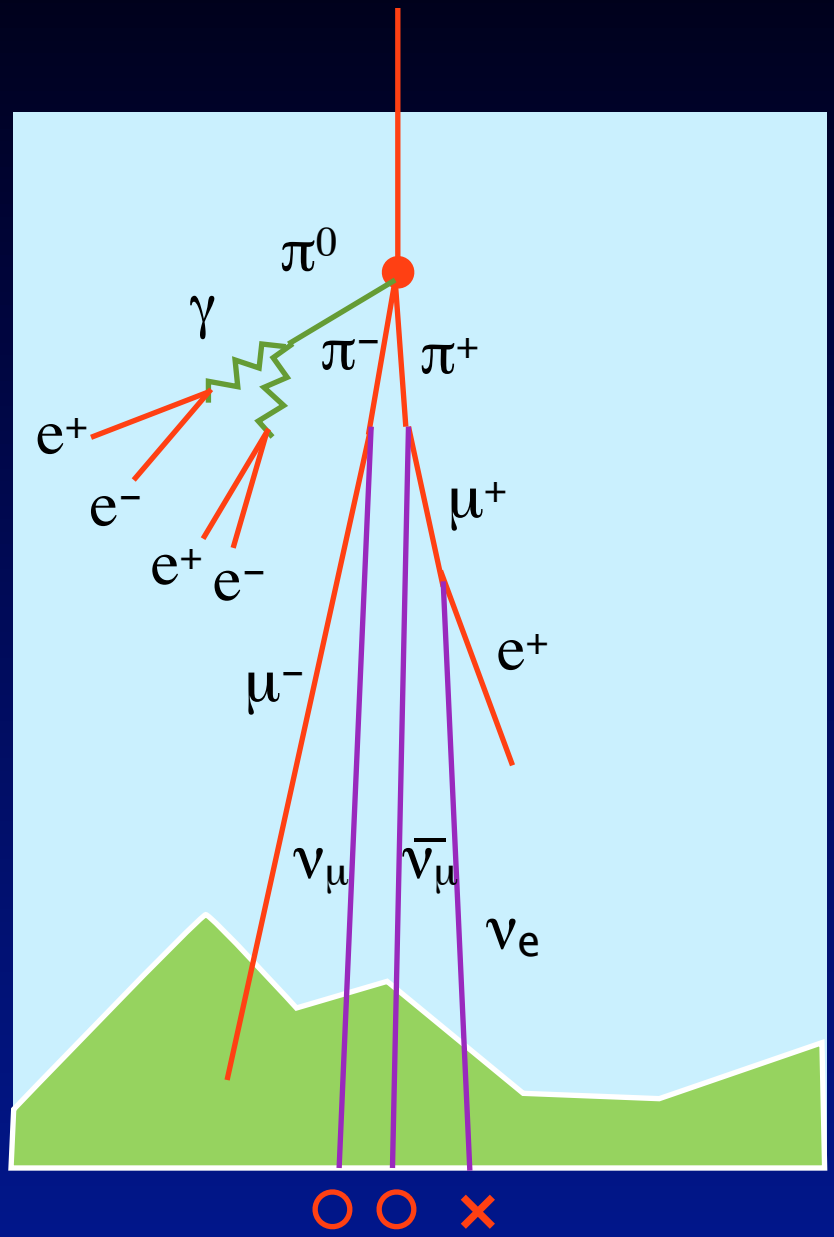
- We have the PREM model, but...
  - We have to assume chemical composition, temperature and pressure to obtain core density
  - Ultra-high pressure experiment with X-ray diffraction is unveiling Earth's deep interior, however, still it's challenging to measure liquid-core (outer core)
- Neutrino tomography gives material density independently from any geophysical model

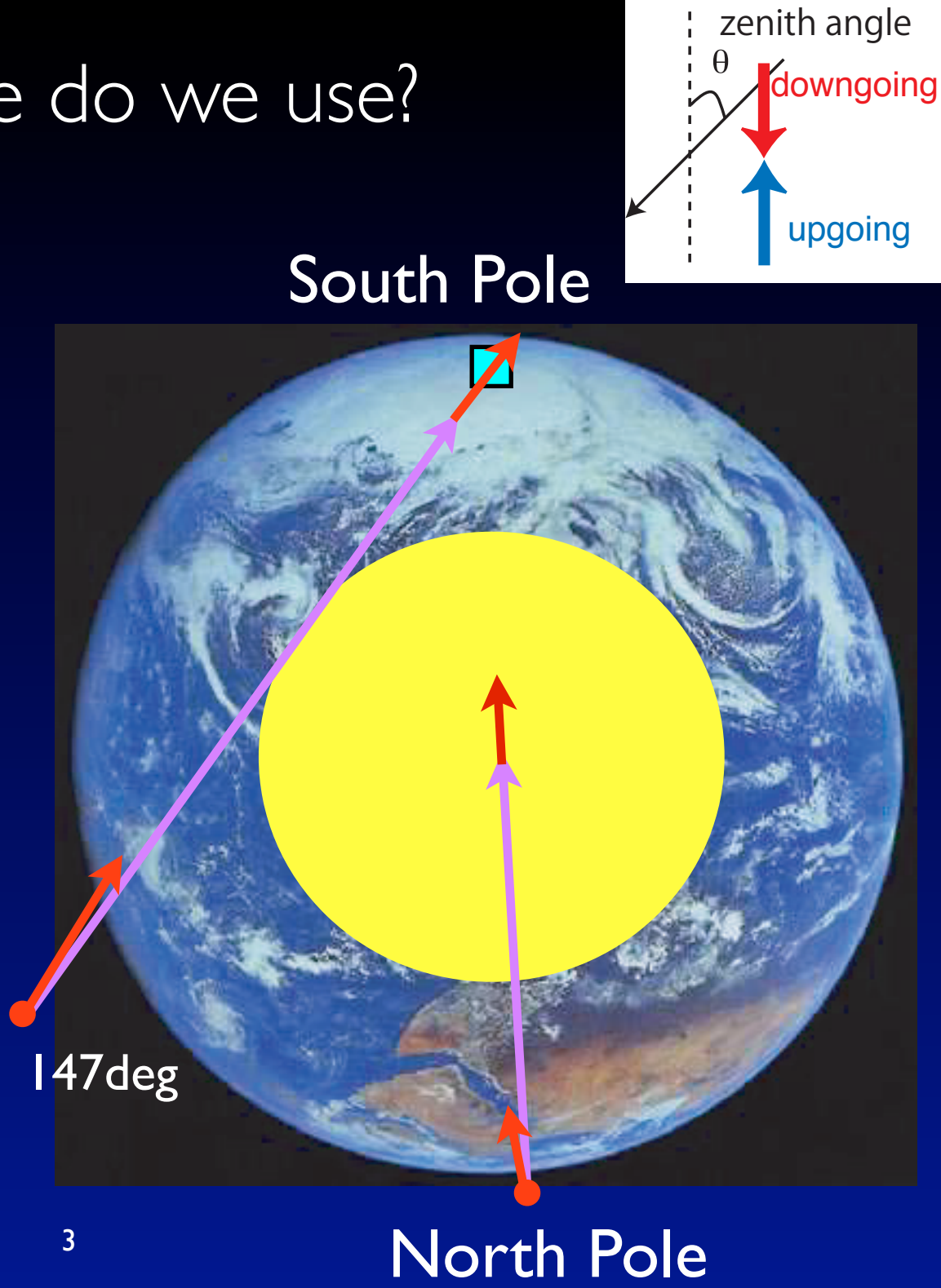


Schematic view of the interior of Earth. 1. continental crust - 2. oceanic crust - 3. upper mantle - 4. lower mantle - 5. outer core - 6. inner core - A: Mohorovičić discontinuity - B: Gutenberg Discontinuity - C: Lehmann discontinuity

PREM model
(Dziewonski & Anderson, 1981)

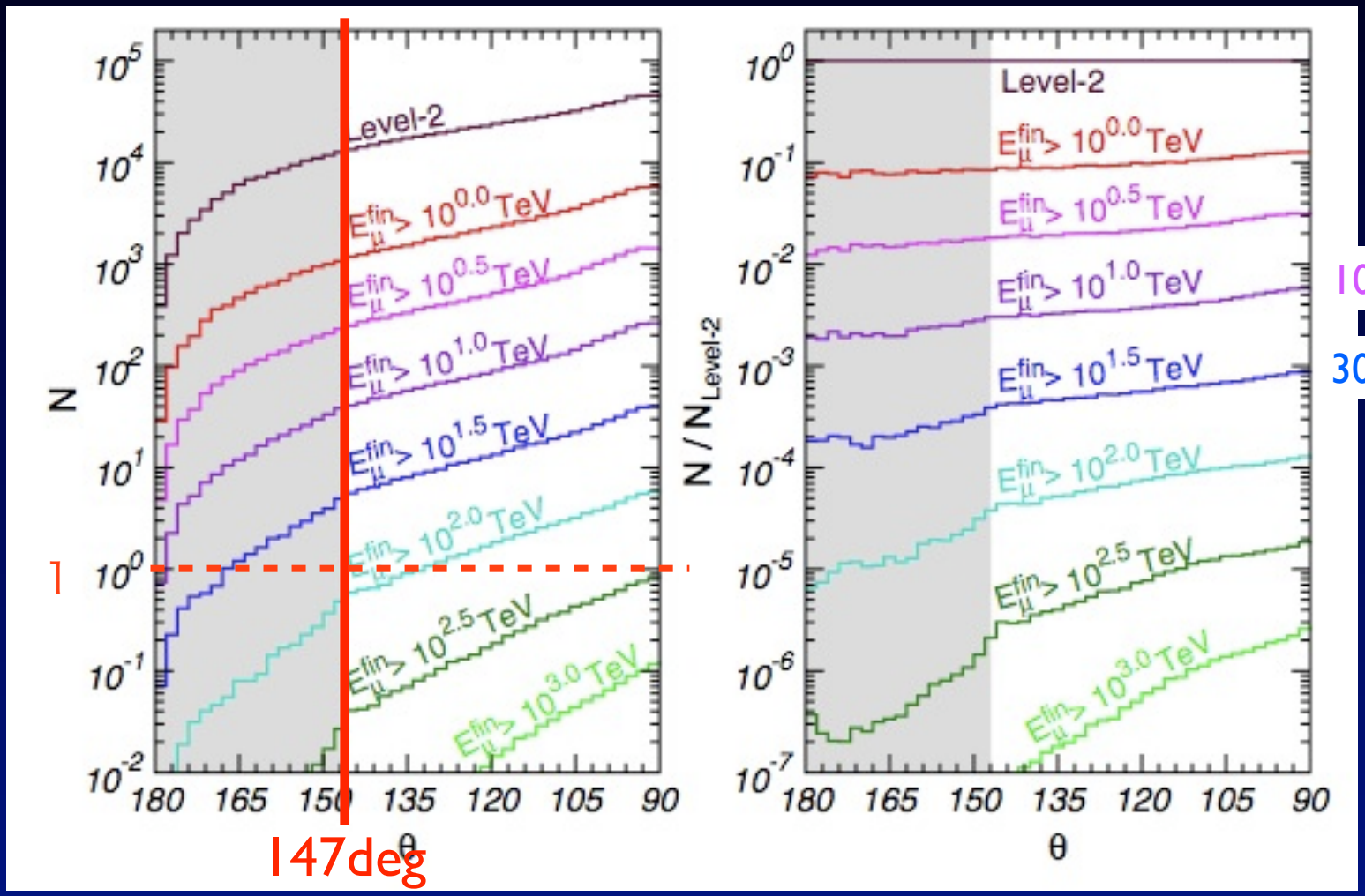
Which neutrino source do we use?





Expected Number of Neutrino detected with the IceCube in 10 years

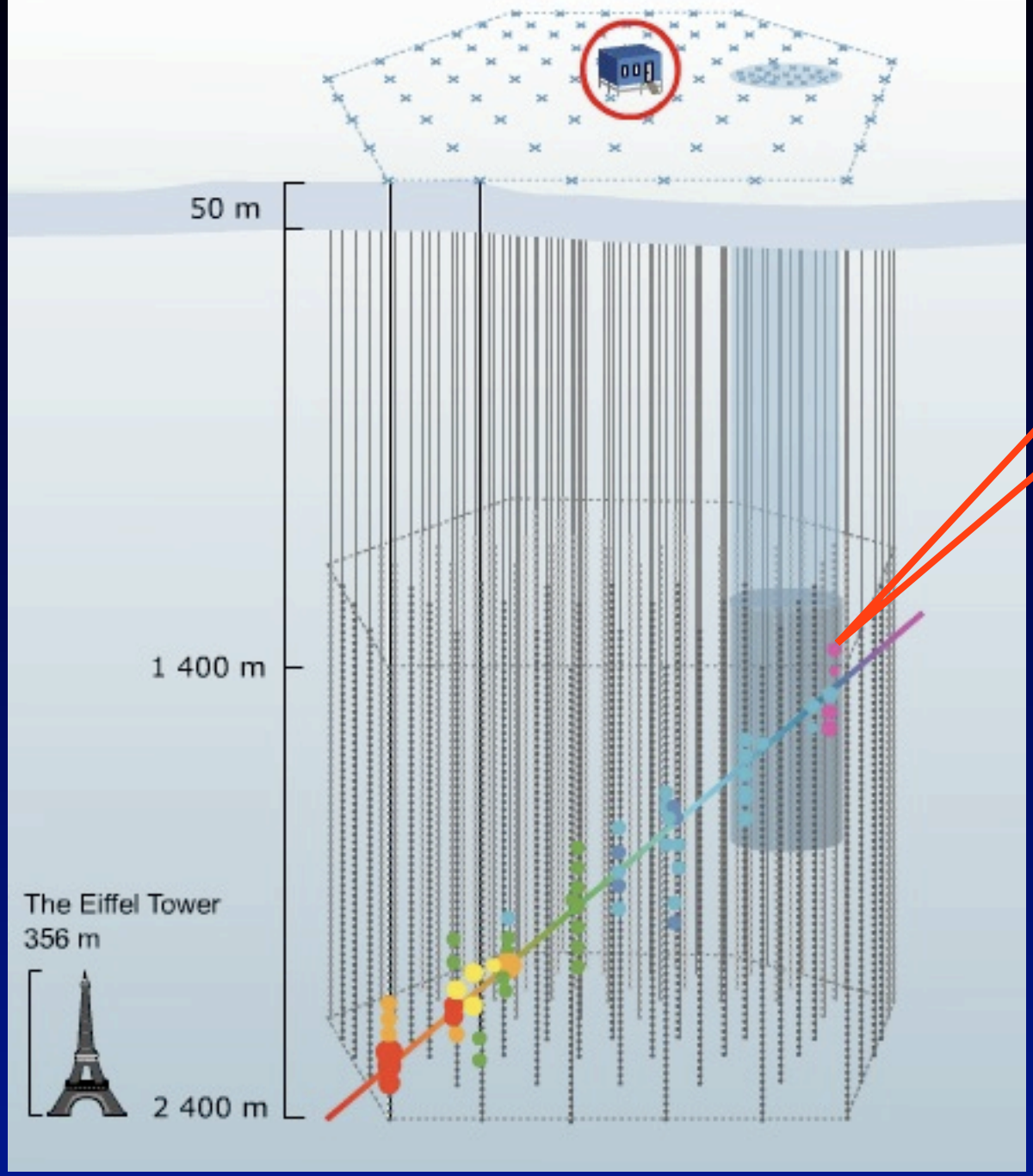
Number of Neutrino

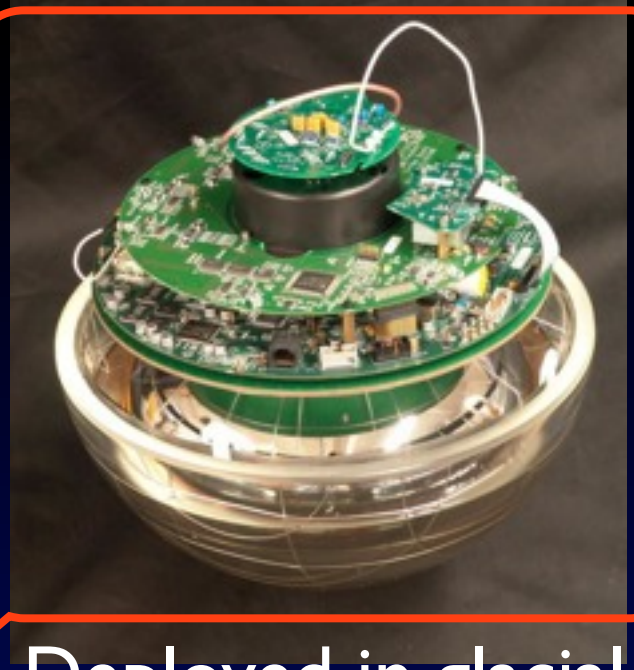


Zenith Angle

M. C. Gonzalez-Garcia, Francis Halzen, Michele Maltoni, and Hiroyuki K. M. Tanaka
Phys. Rev. Lett. **100**, 061802 (2008)

IceCube



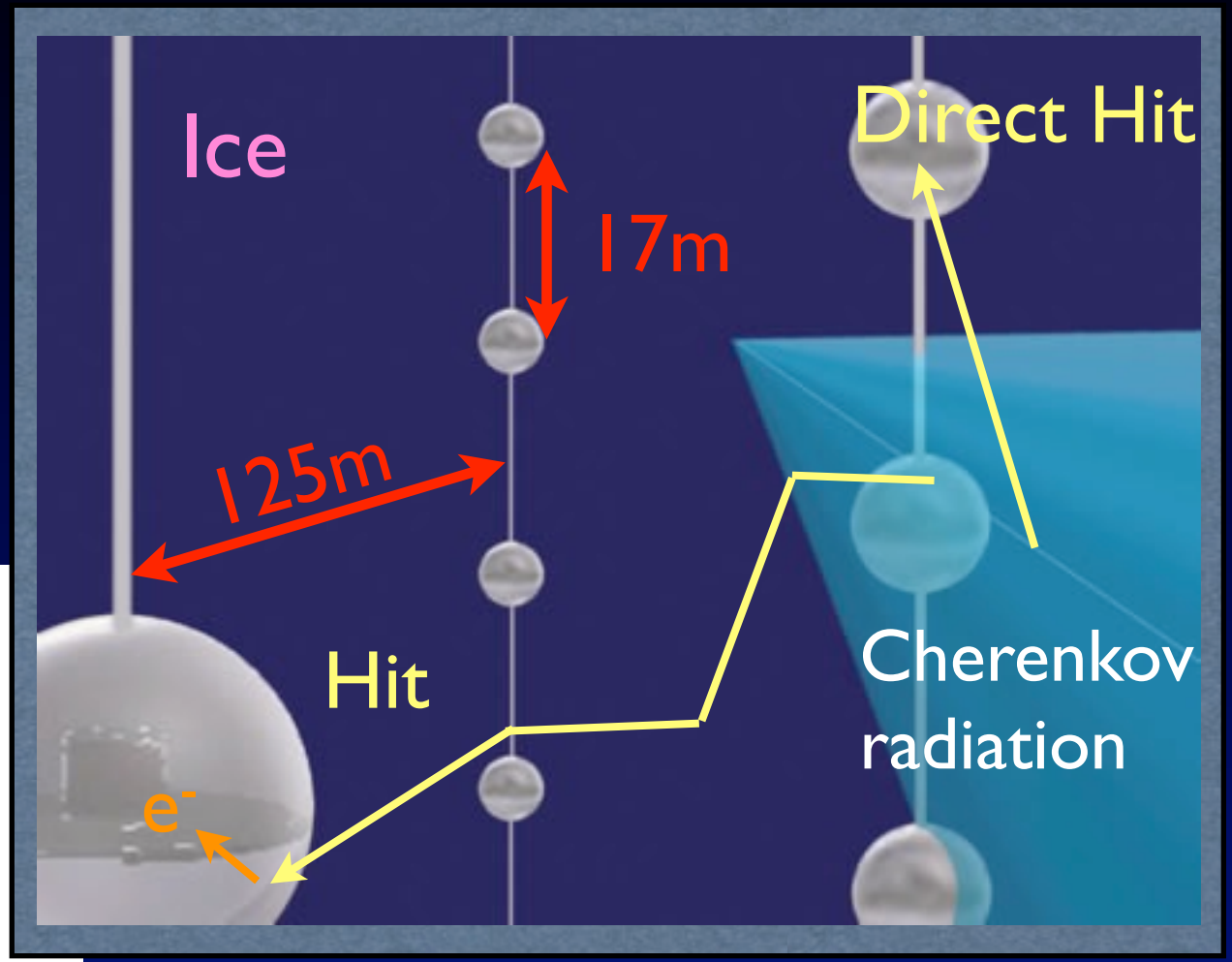


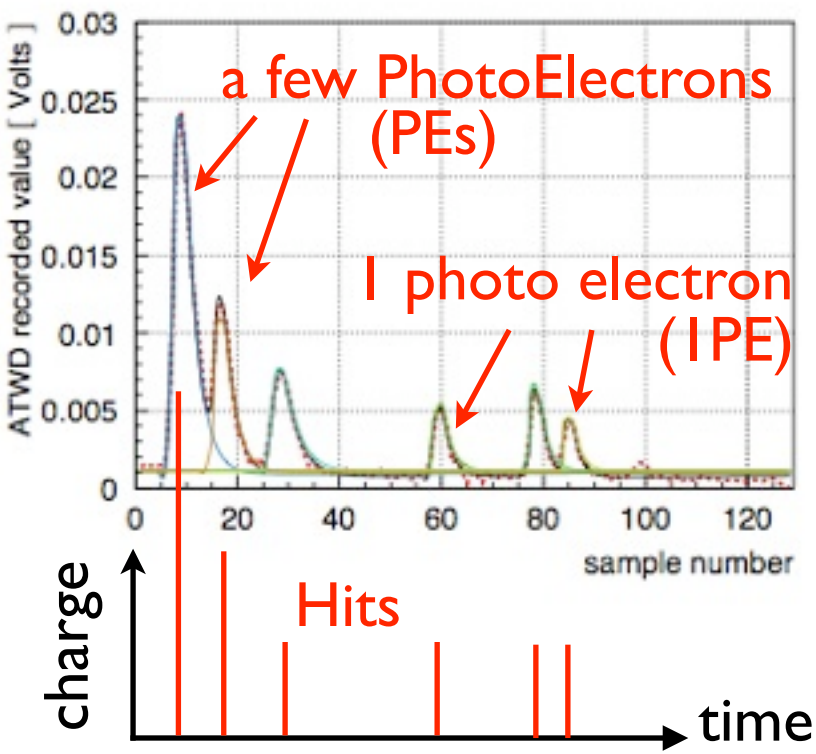
- Deployed in glacial ice at the South Pole
- Array size 1km^3, 86 strings, 60 optical sensors (DOMs) per string
- Only 40 strings one year data is used for this analysis

See Prof. Halzen's talk for more details

Detection Principle

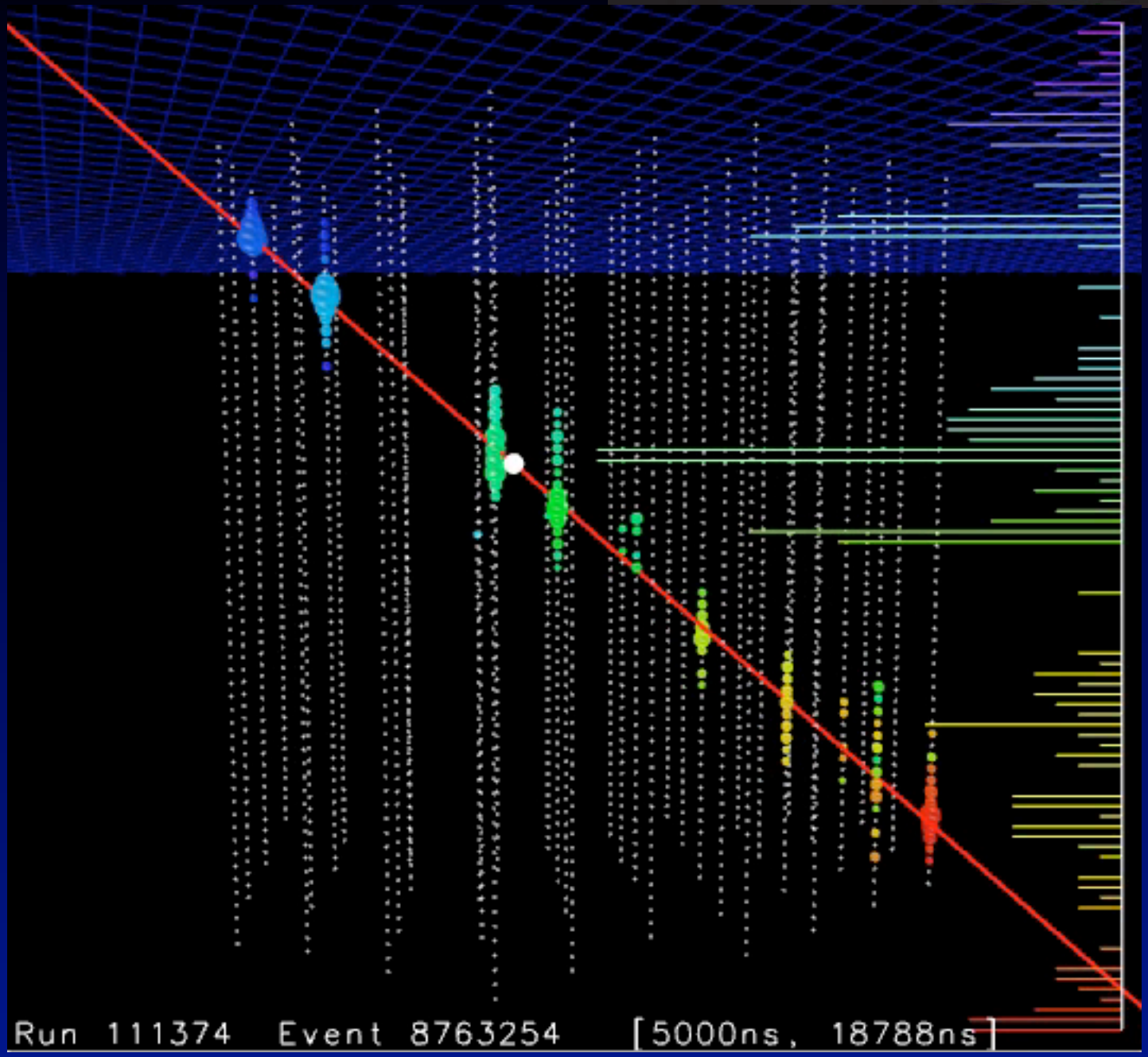
- A muon generated from an atmospheric neutrino emits Cherenkov radiation
- Detect the right with array of photo-multipliers





A waveform of photo-multiplier is converted into a series of "Hits" which contain charge and timing information

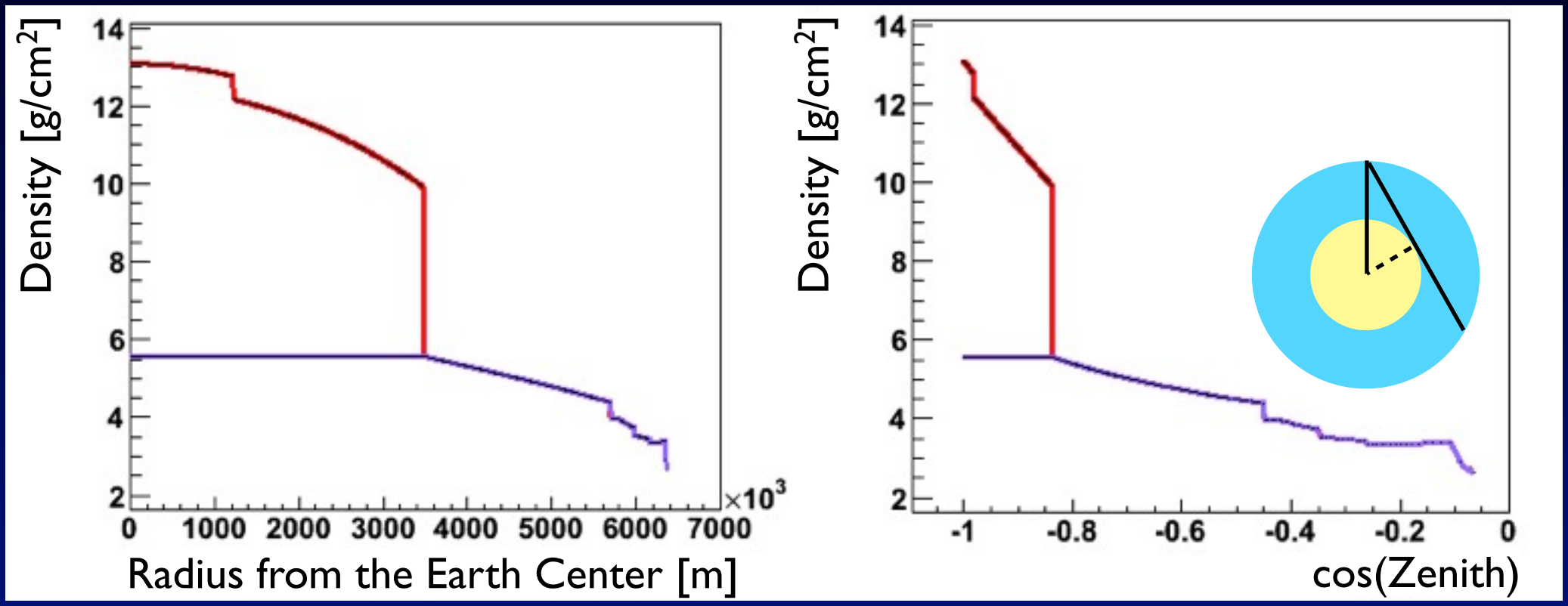
A neutrino detected with IceCube



PREM vs FLATCORE

PREM

FLAT CORE (Density of Core is constant)



FLATCORE model doesn't conserve Earth's mass, but still useful to estimate the resolution of Earth's density at core angle with the IceCube

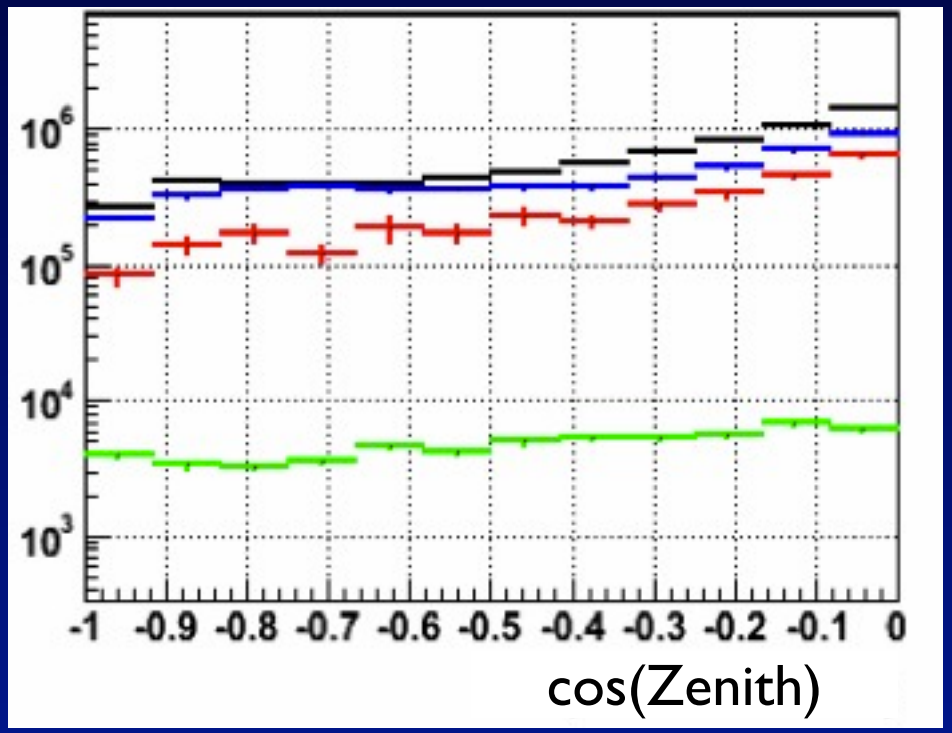
Analysis Method

1. Purify data that contains only muon events generated from upward-going neutrinos
2. Prepare atmospheric neutrino simulation events with two Earth models, PREM and FLATCORE
3. Using Mantle region data (cos(zenith) > -0.83), determine fitting parameters of atmospheric neutrino
   1) Normalization factor
   2) Energy slope deviation
   3) DOM efficiency
4. Apply best fit parameters to two simulations at Core region, then compare them to data in cos(zenith) plots

Purifying Data

Data
Atmospheric Neutrino
Atmospheric Single Muons
Atmospheric Double Muons

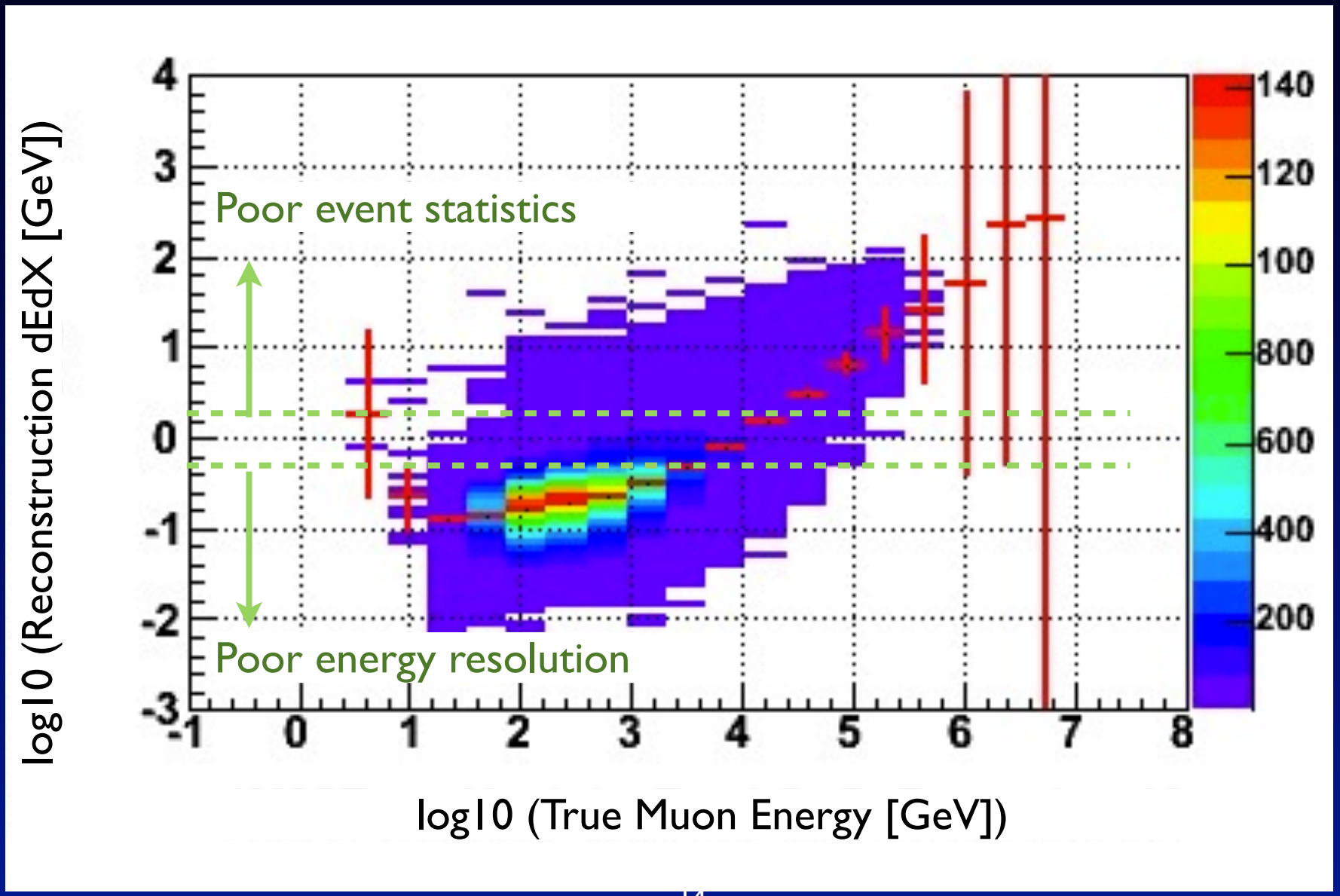
Before



After

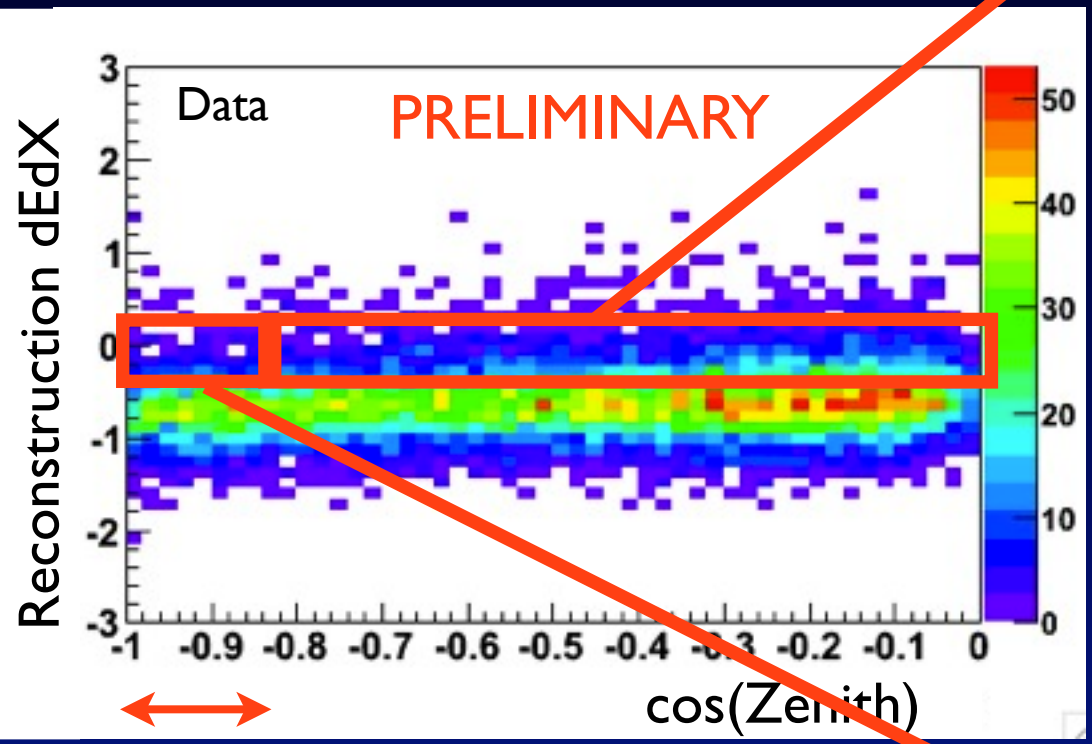
dEdX is sensitive to muon energy above 1 TeV

Simulation Atmospheric Neutrino



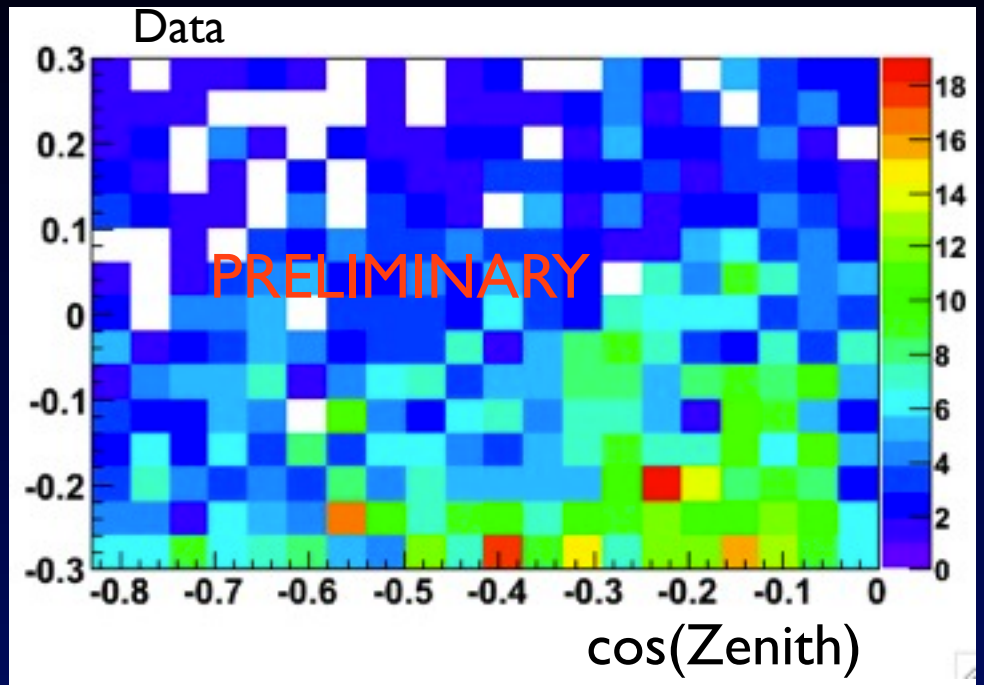
Fitting and Analysis range

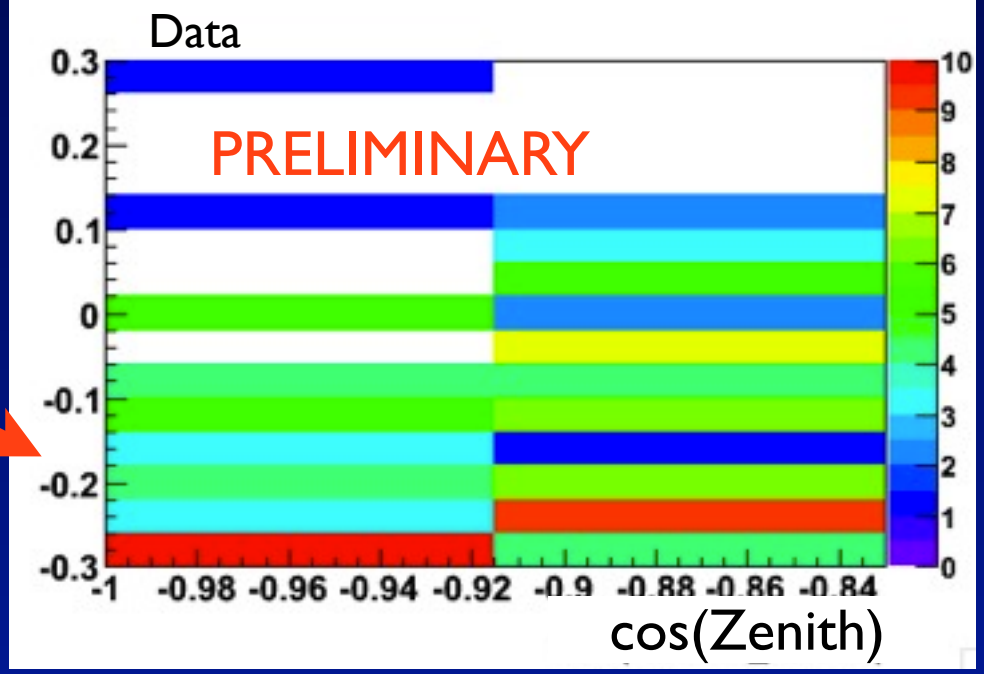
Use for flux fit



core region

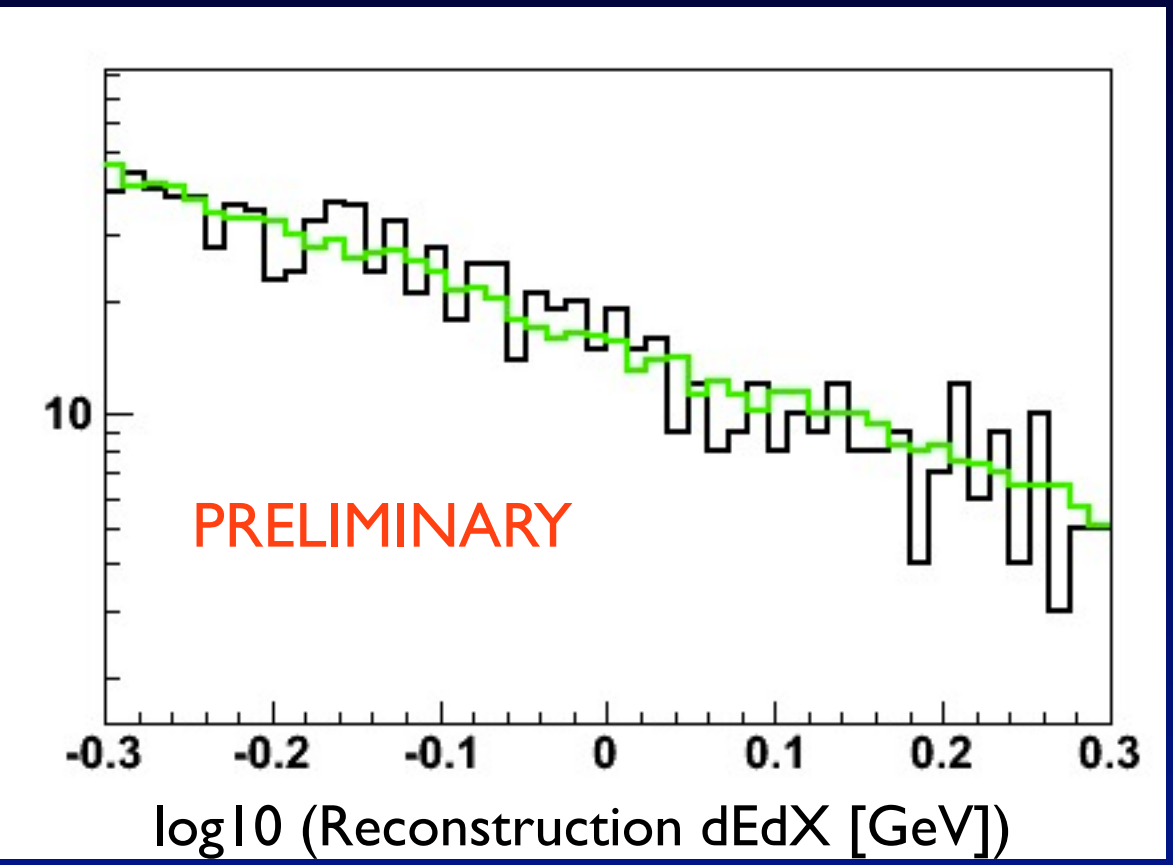
Use for analysis





Fitting simulation with data at Mantle region

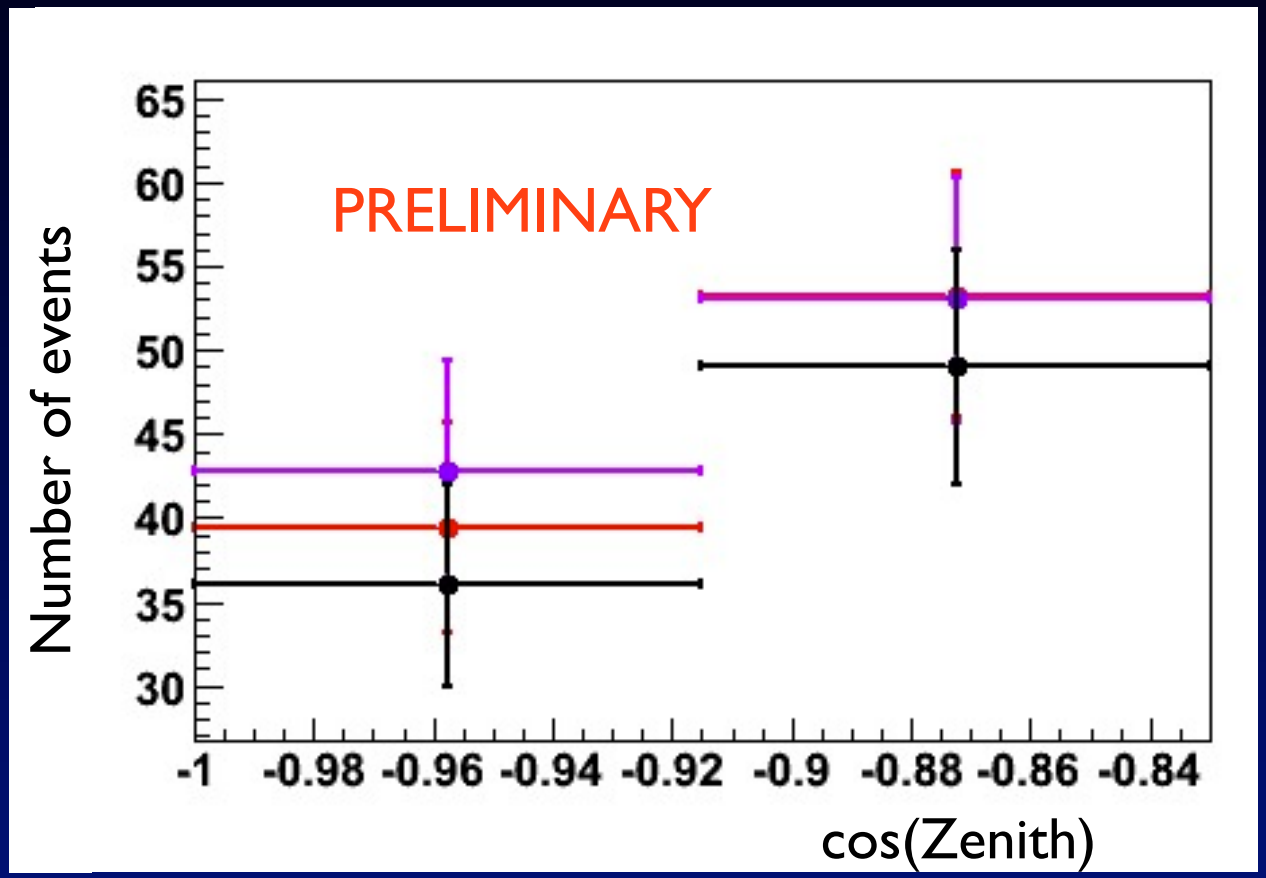
Data
Atmospheric Neutrino



- Used atmospheric neutrino model :
  Honda *et al.* 2006
- Normalization factor of atmospheric neutrino flux
  : 0.978
- Ratio between assumed and normal DOM efficiency
  : 0.998
- Spectral index correction for the atmospheric neutrino spectrum
  : -0.001

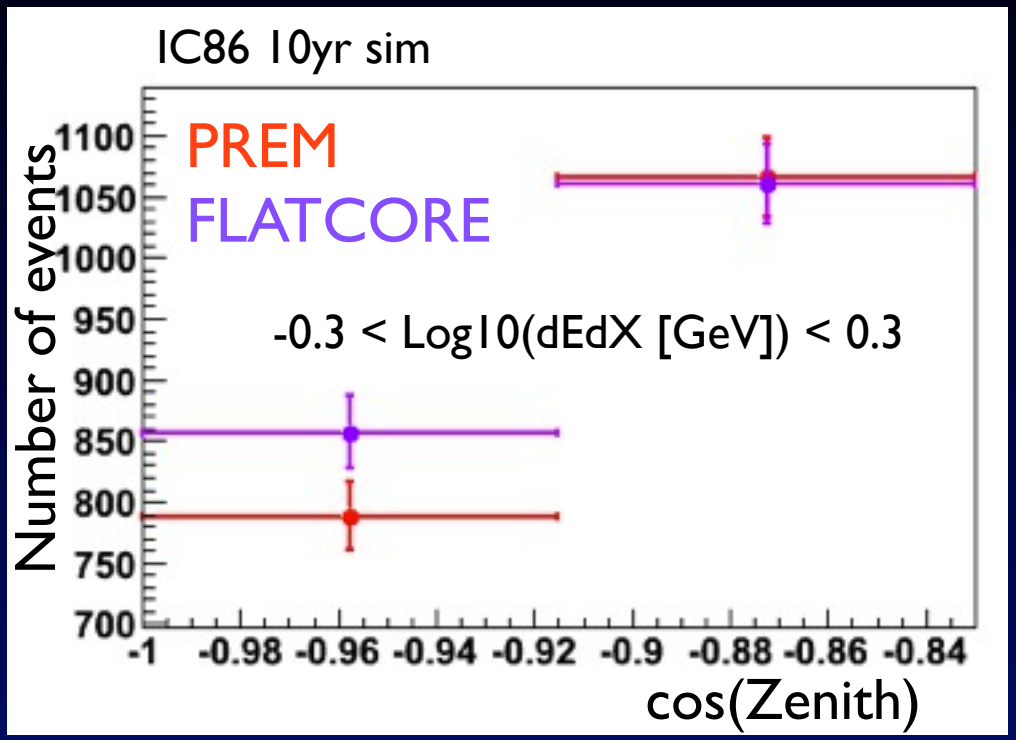
Comparison of Zenith at Core Region
Data vs Simulations

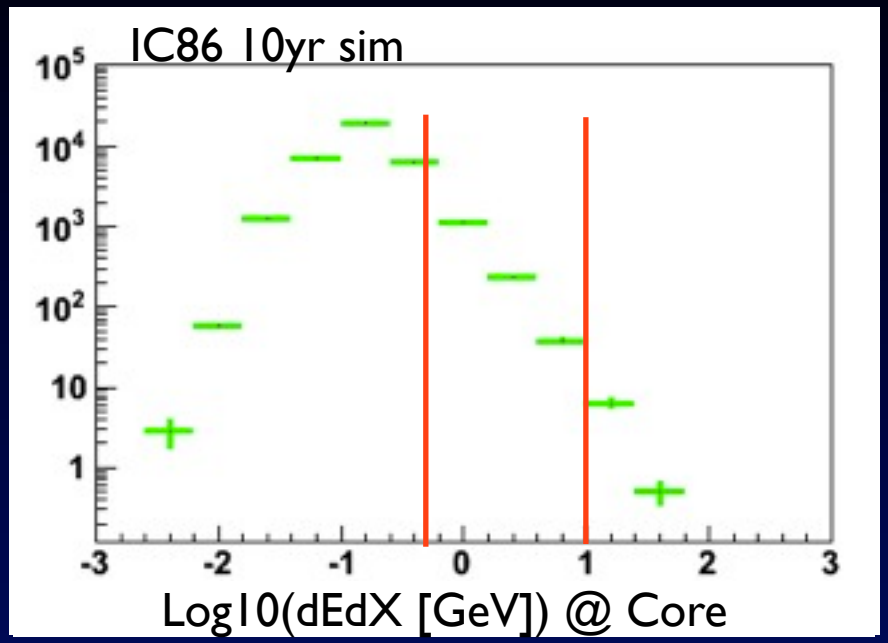
Data
PREM prediction
FLATCORE prediction



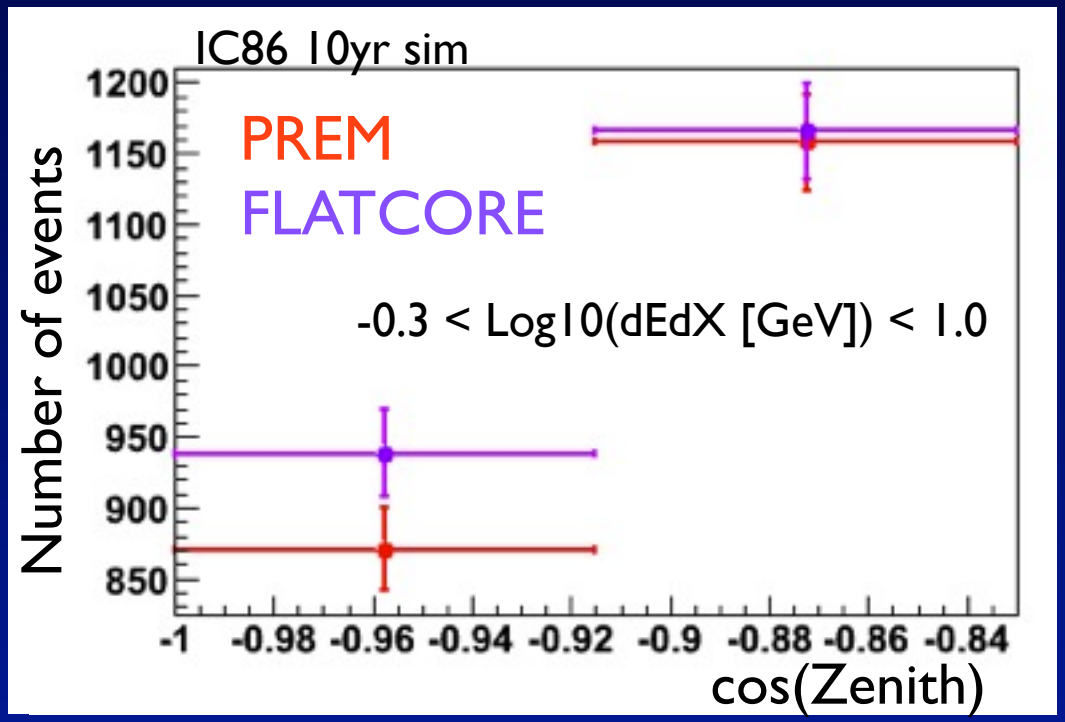
Since both PREM and FLATCORE predictions are within statistical errors of Data, IC40 one year data is not sensitive to distinguish these models

IceCube 86 strings 10 years predictions @ Core





- Cuts and simulations are not optimized for IC86
- Energy resolution and detection efficiency will be improved with optimized simulation



Summary

- We performed Neutrino Absorption Tomography with IceCube 40 strings one year data (IC40).
- Both PREM and FLATCORE models represent data within statistical errors. Event statistics are not enough to claim a difference between two models.
  Comparing mean value of predictions, PREM shows closer value to data.
- Applying same analysis as IC40, we estimated separation of PREM and FLATCORE with IceCube 86 strings 10 years (IC86) .
  Our simulation predicts one sigma separation at most vertical bin in cos(zenith) plot.
  This analysis is not optimized for IC86, this prediction will be improved in near future.

Outlook

- In order to detect core edge, we have to improve energy resolution especially around 10 TeV
  - Many calibration studies are ongoing
  - Many new energy reconstruction techniques are being developed
- Use likelihood ratio
  - 2 dimension (dEdX, cos(zenith)) likelihood fitting with data and simulation may have stronger separation power.
  - Need more than 10 times larger statistics of simulation -- Requires zenith-weighted simulation production
- Try to find an optimized energy window that keeps highest energy blinded for astrophysical neutrino search
  - We don't have to wait for data unblinding by other physics analysis
  - IC86 prediction indicates possibility of the "energy window analysis"

Yesterday Prof. Halzen said...

"We will see the core effect within 5 years"

But after the talk, he said secretly to me...

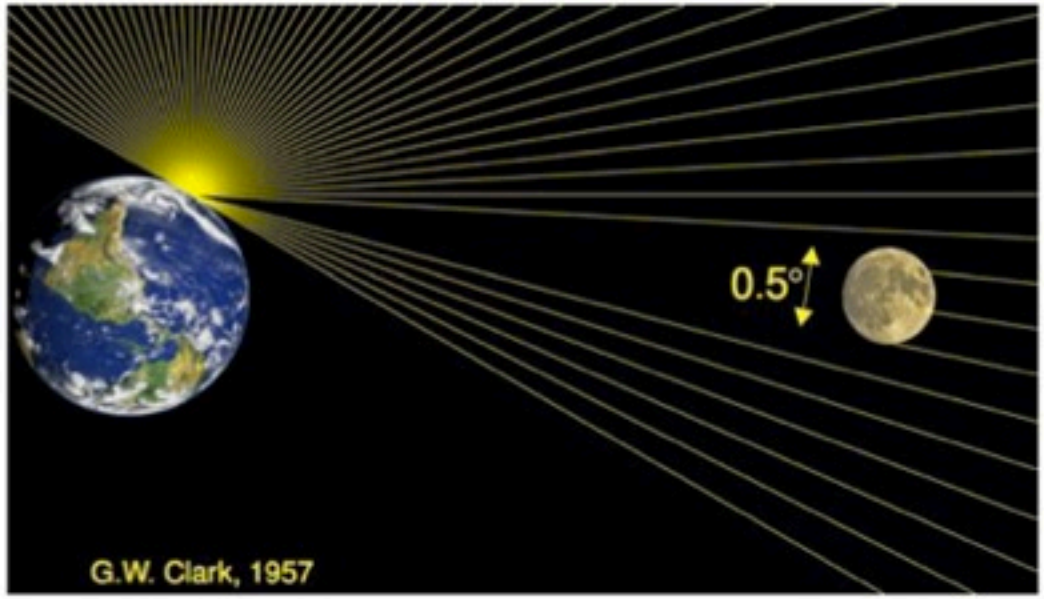
"We won't need 5 sigma or 3 sigma separation to say 'we see the core effect' :) "

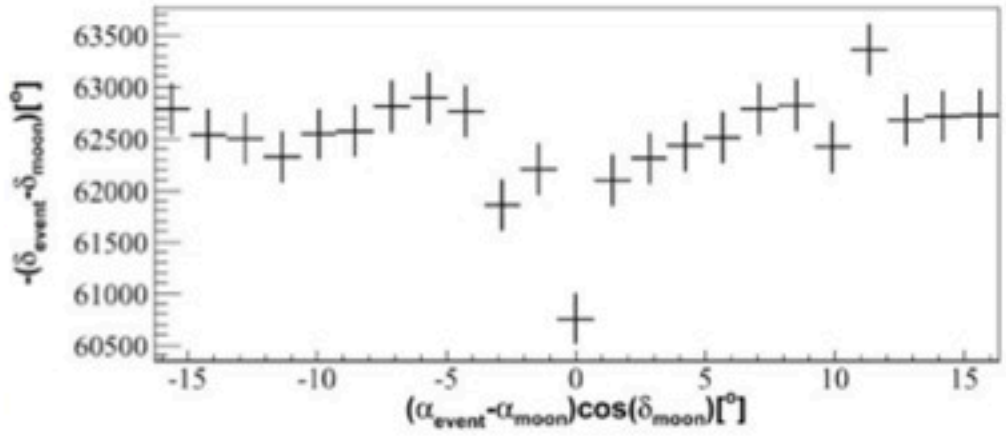
We expect to see the effect of core in 5 years :

- After improving energy resolution and understanding systematics of detector and neutrino flux
- with one sigma (or "Francis level") separation :)

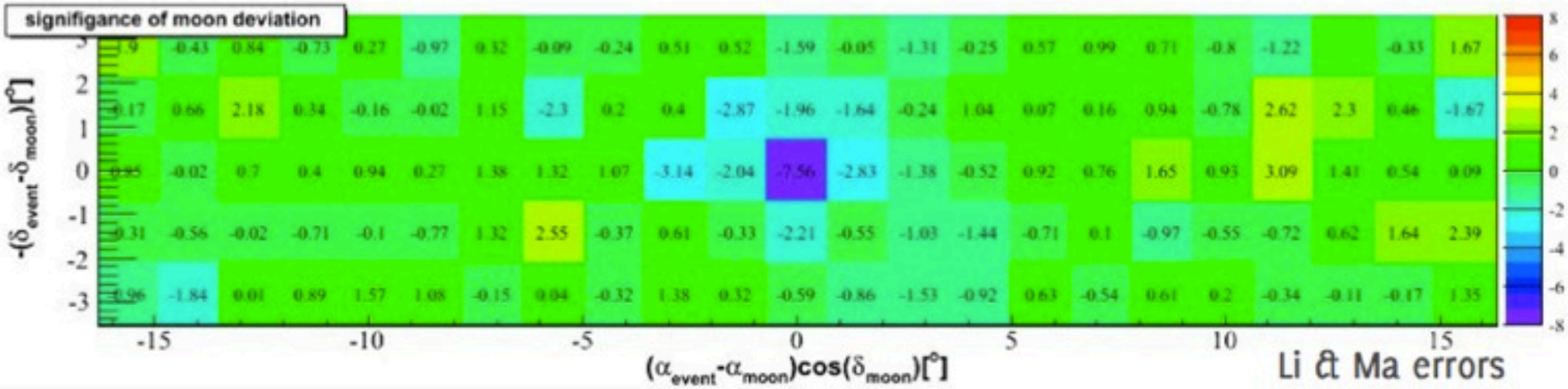
Backup slides

IceCube angular resolution

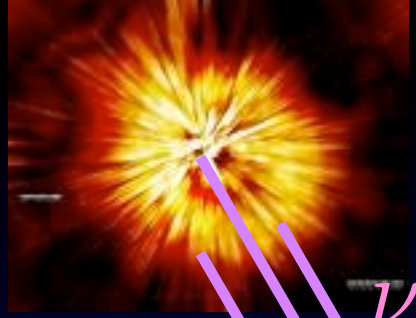




- IC40 data, 13 moon cycles
- Moon size approx. equal to IceCube angulare raesolution
- Measure background an signal from window around moon



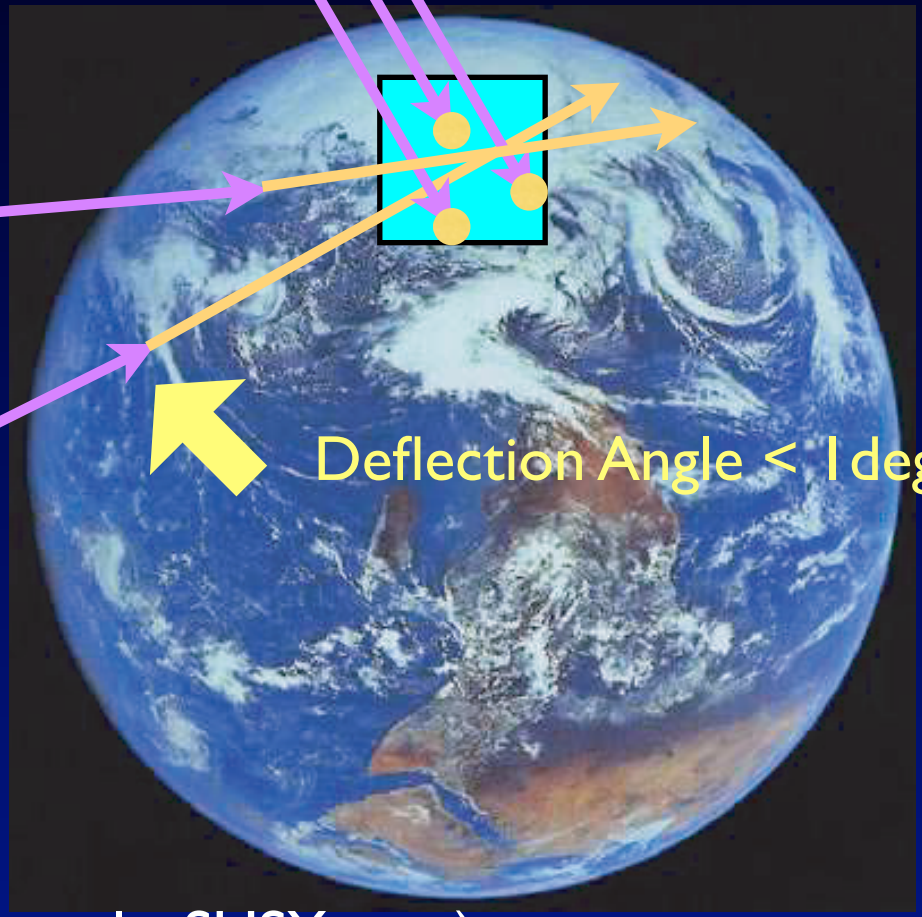
Messengers from Universe



Supernova

ν_e

Gamma Ray Burst

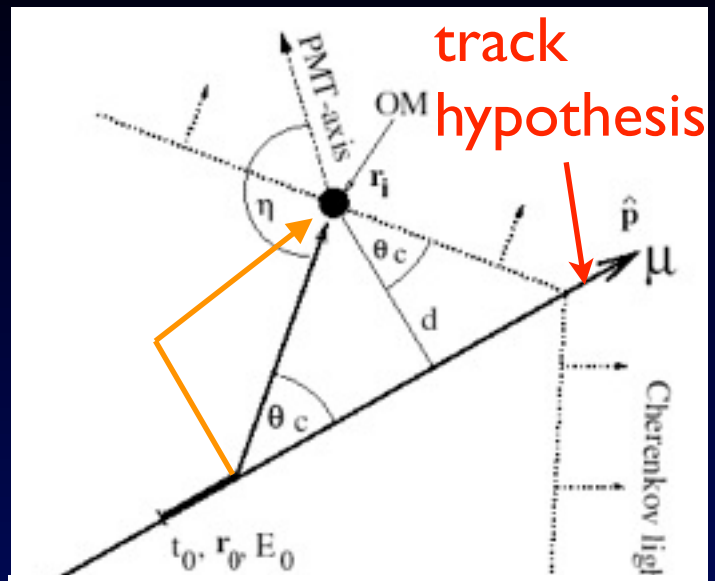


Deflection Angle < 1 deg

Active Galactic Nuclei

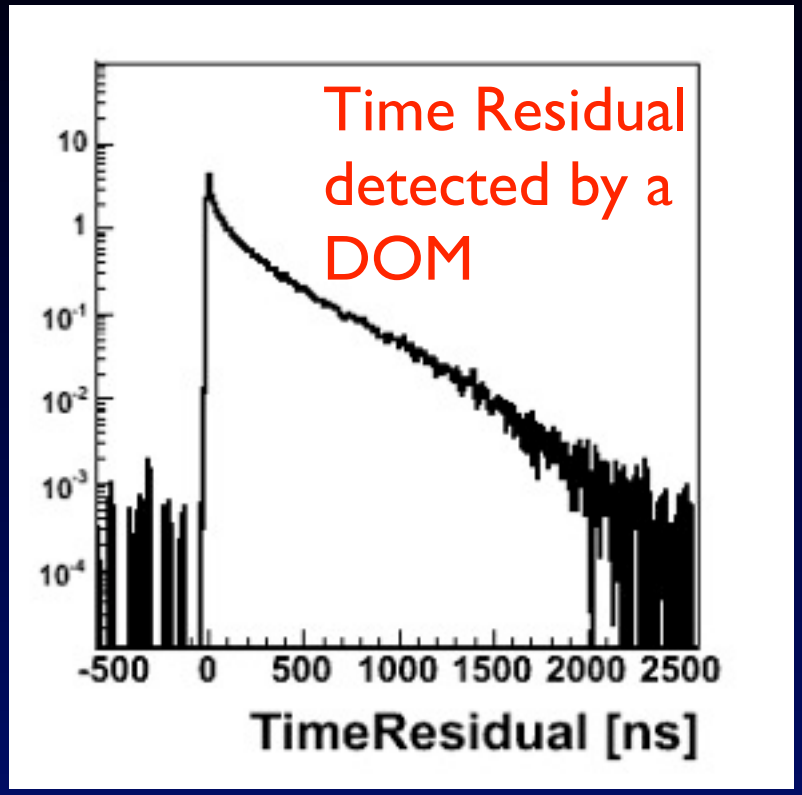
Other physics:
Exotic particles (Monopole, SUSY,etc...)
Dark Matter(WIMP), etc...

Track Reconstruction



$$t_{\text{geo}} = t_0 + \frac{\hat{\mathbf{p}} \cdot (\mathbf{r}_i - \mathbf{r}_0) + d \tan \theta_c}{c_{\text{vac}}}$$

$$t_{\text{res}} \equiv t_{\text{hit}} - t_{\text{geo}}$$



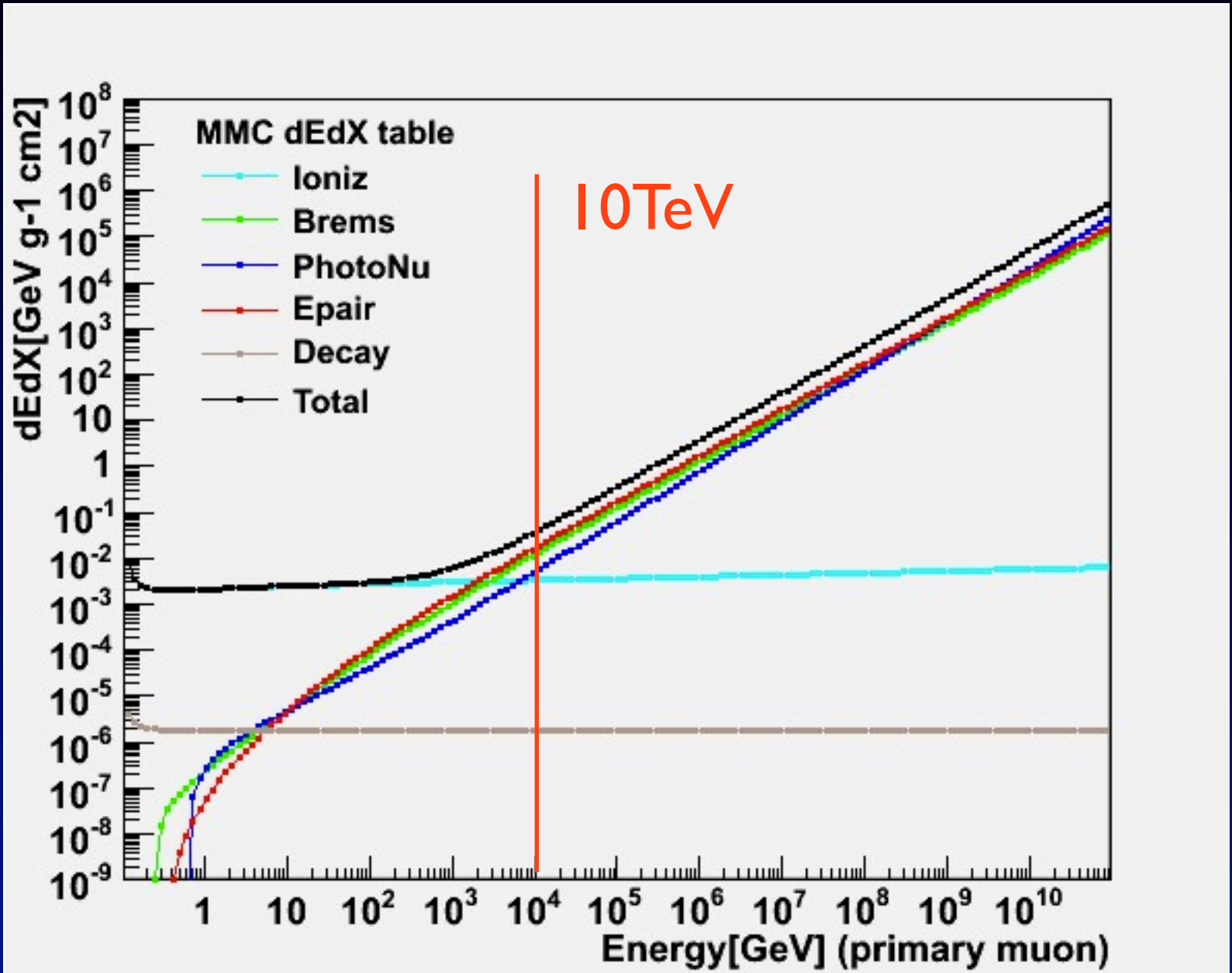
- Time Residual = Hit arrival time - Direct hit arrival time (estimated)

Construct Likelihood with time residual and hypothesis track parameters

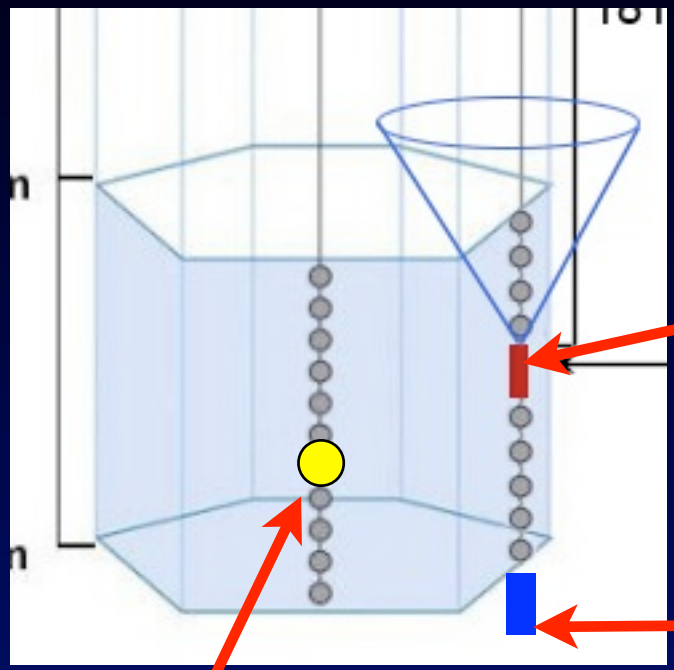
$$L_{\text{time}} = \prod P_1 \left(t_{\text{res},i} \mid a = d_{1i}, \eta_{1i}, \ldots, d_{1i}, \eta_{1i}, \ldots \right)$$

Muon Energy vs Energy Deposit in material (dEdX)

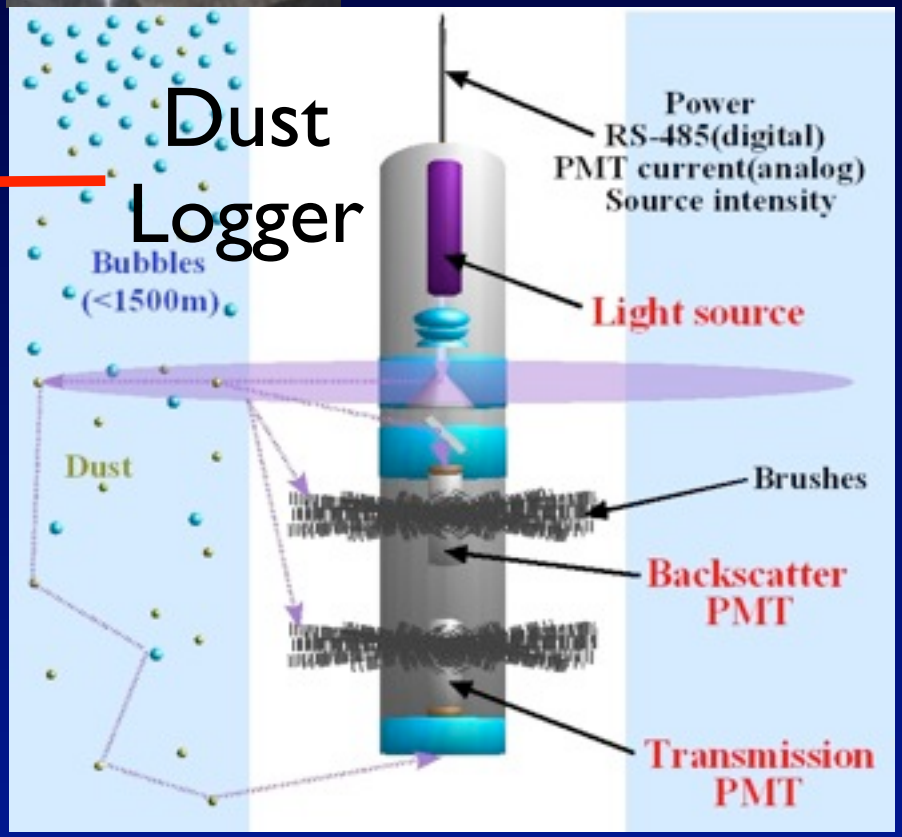
(Observable)

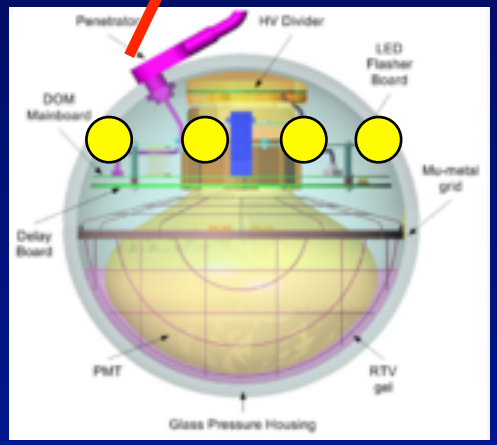


Ice calibration



Standard Candle

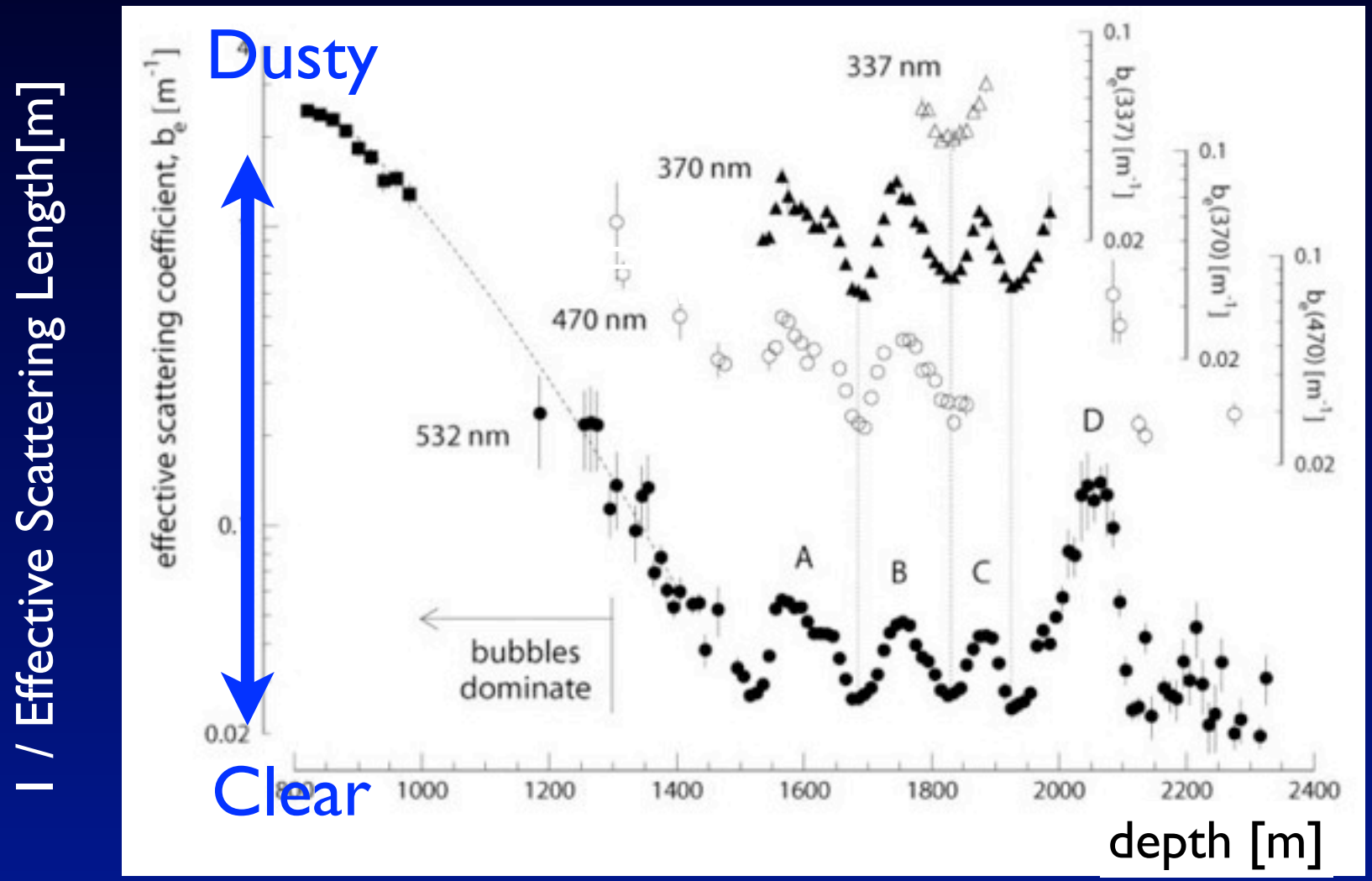




Flasher LEDs
on DOM
6 horizontal
6 tilted

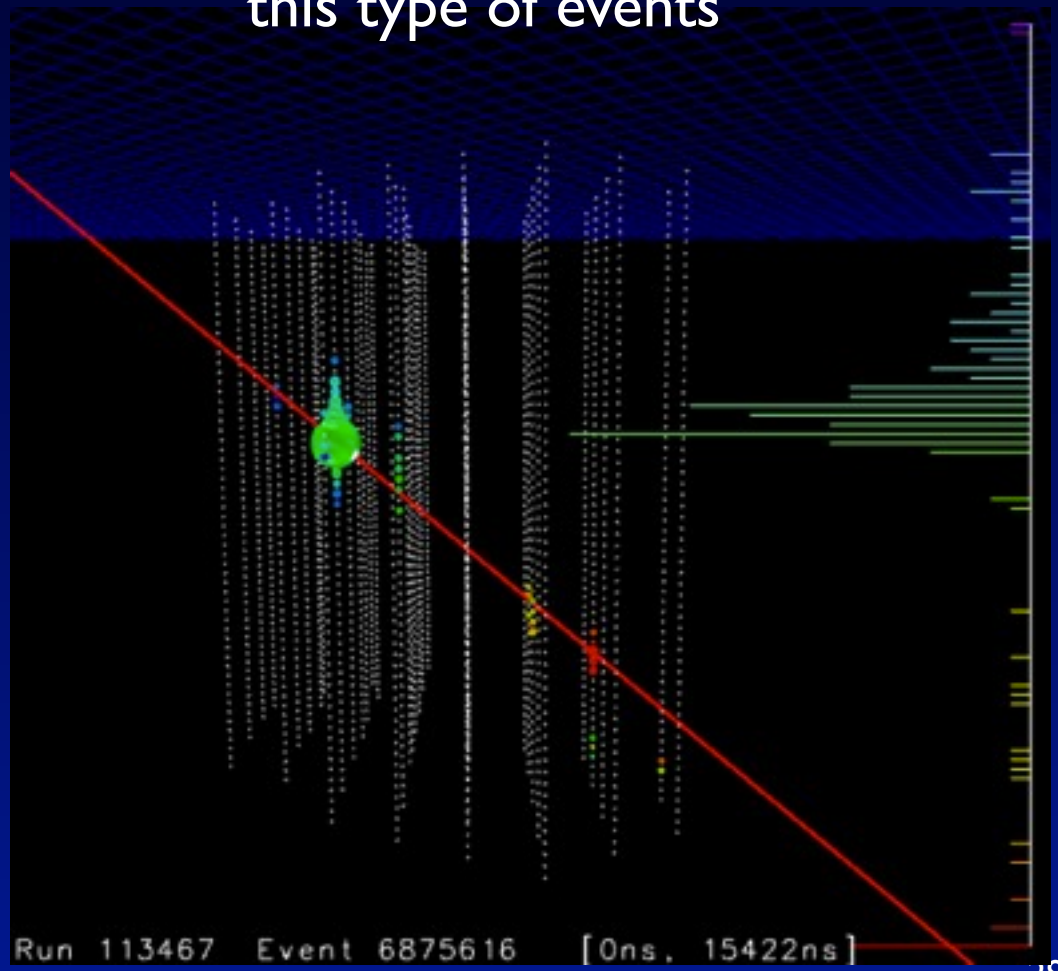
Ice Property

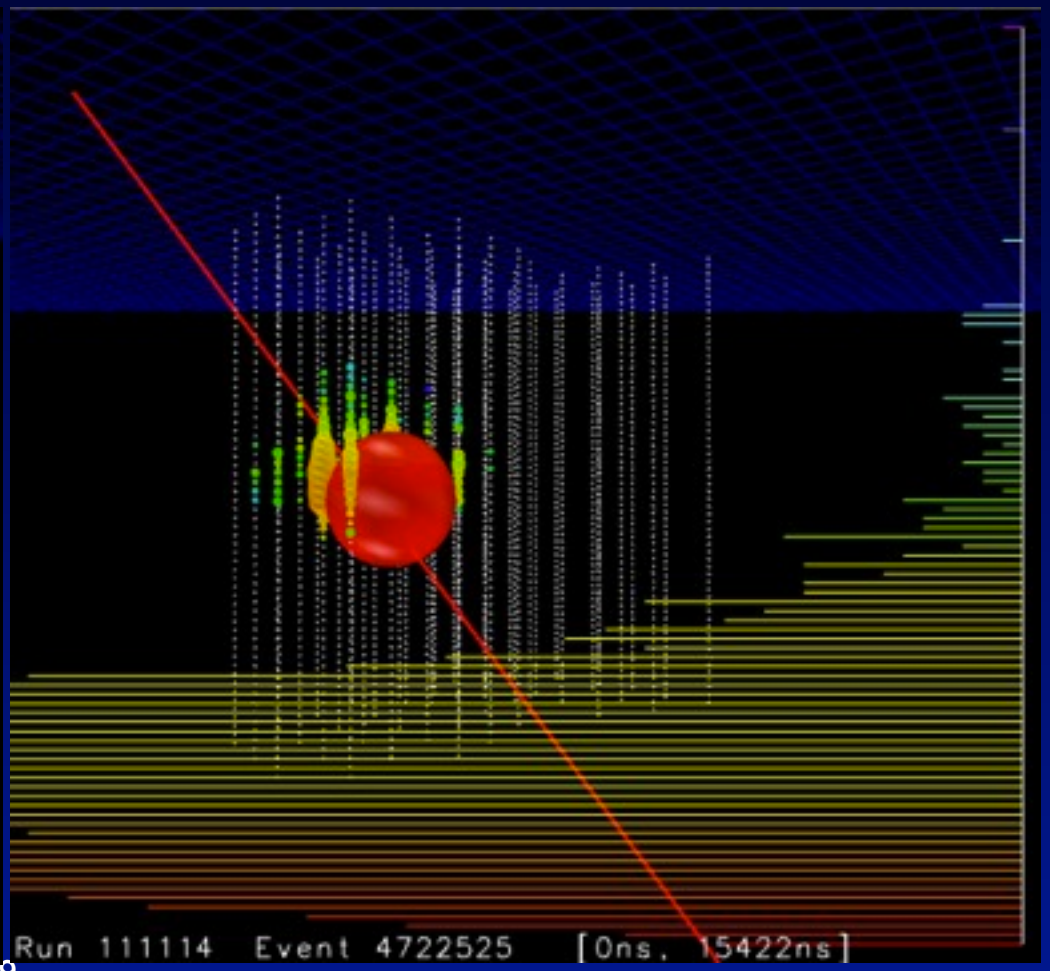
- Geometrical scattering length ~ 5m
- Effective scattering length ~30m
- Absorption length ~100m

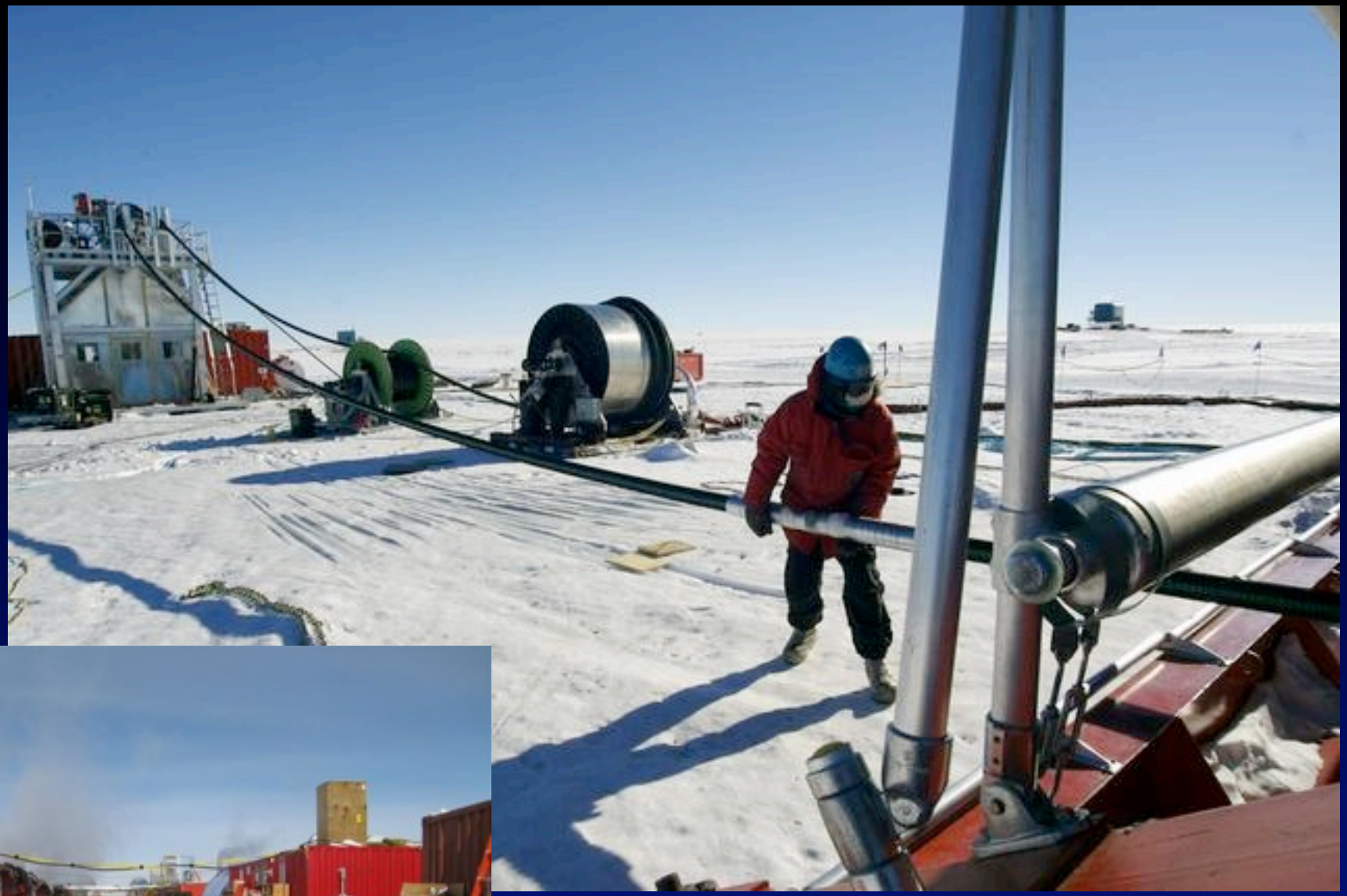


Balloon-like Events

- A large stochastic energy loss happens near by a DOM
- Large portion of total energy deposit is recorded by the single DOM
- Current energy reconstructions tend to overestimate dEdX with this type of events



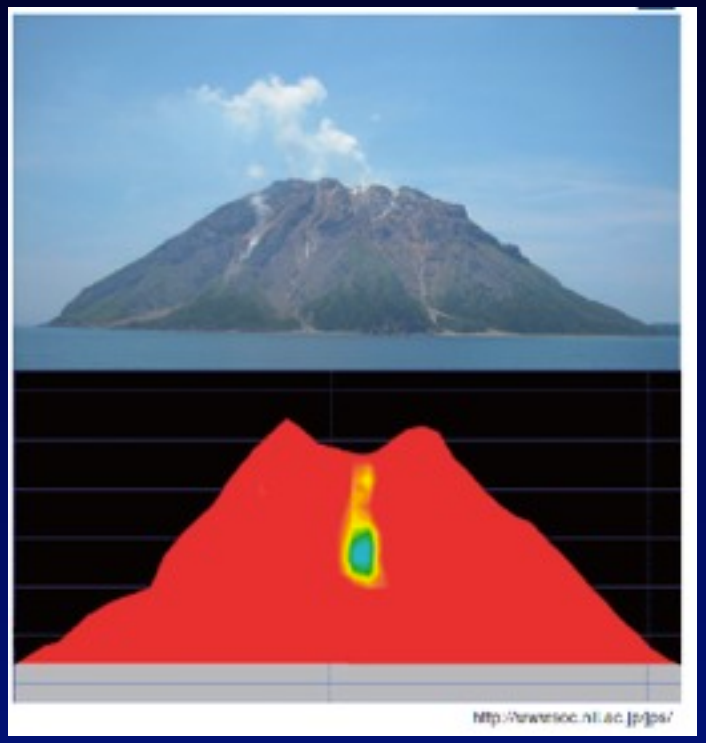




Scan our Earth with Neutrinos !

X−ray

Muon



Neutrino

small → Large

Transmittance*

*Depends on particle's energy