EarthCore analysis with the IceCube Neutrino Observatory

- Improvement plans from the first analysis -

MNR 2013

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and IceCube Collaboration

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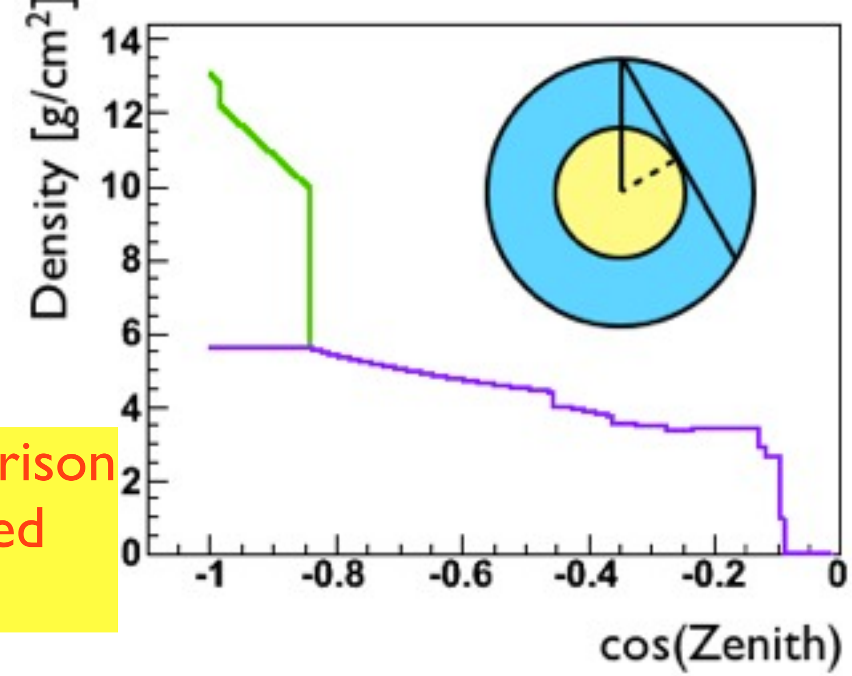
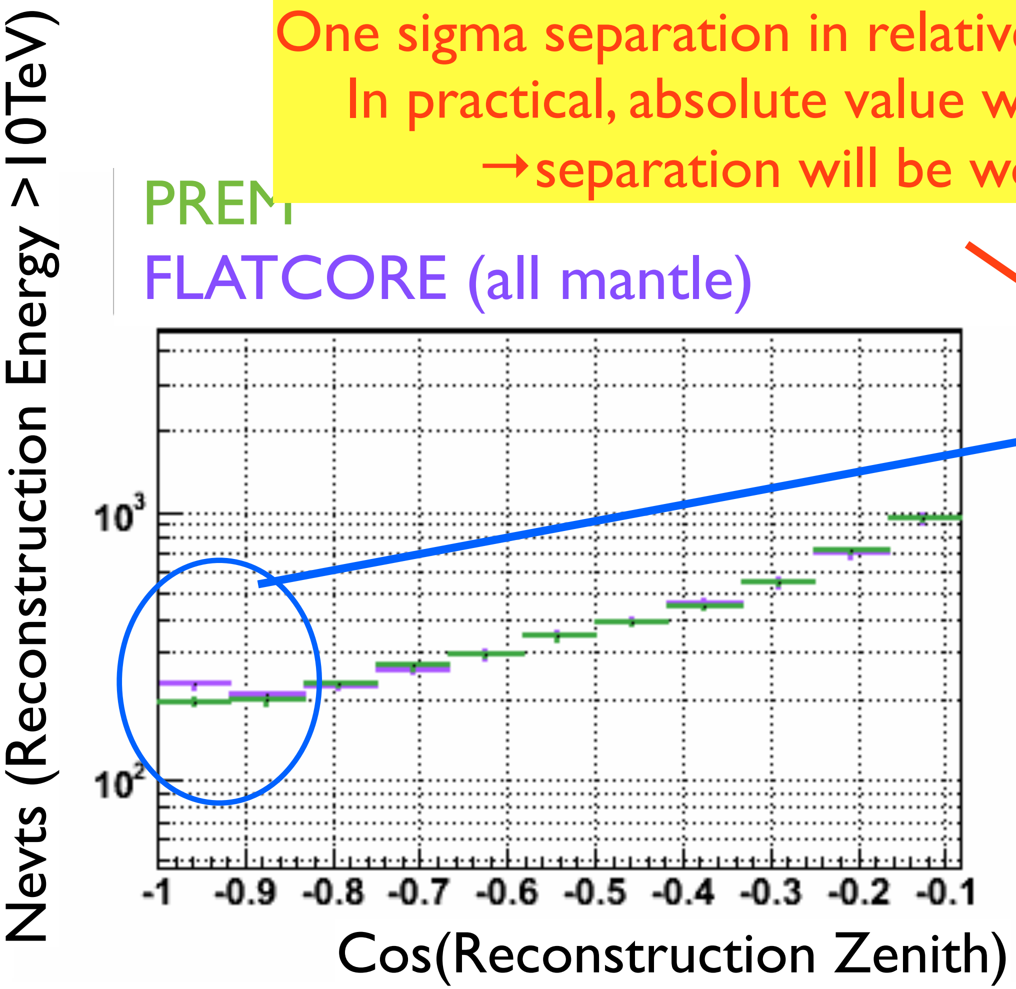
ICECUBE SOUTH POLE NEUTRINO OBSERVATORY

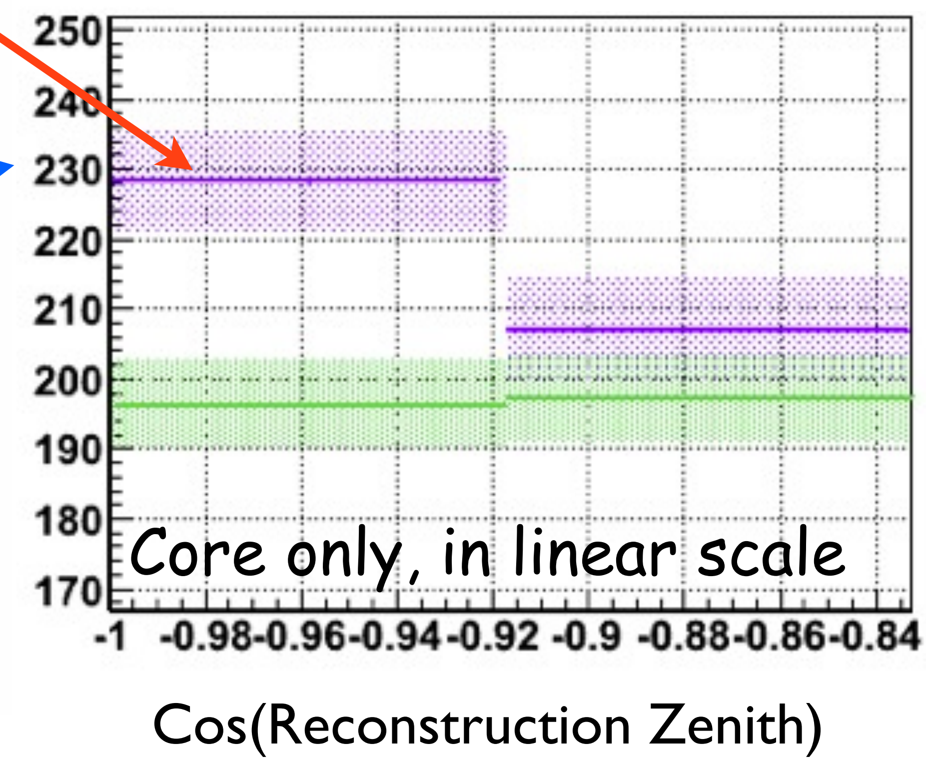
Simulation with IC79 10 years

very conservative estimation of
~10yr measurement
Calculated with IC79 simulation



One sigma separation in relative comparison
In practical, absolute value will be used
→separation will be worse!





Errors are statistical uncertainty of center prediction due to limited simulation statistics

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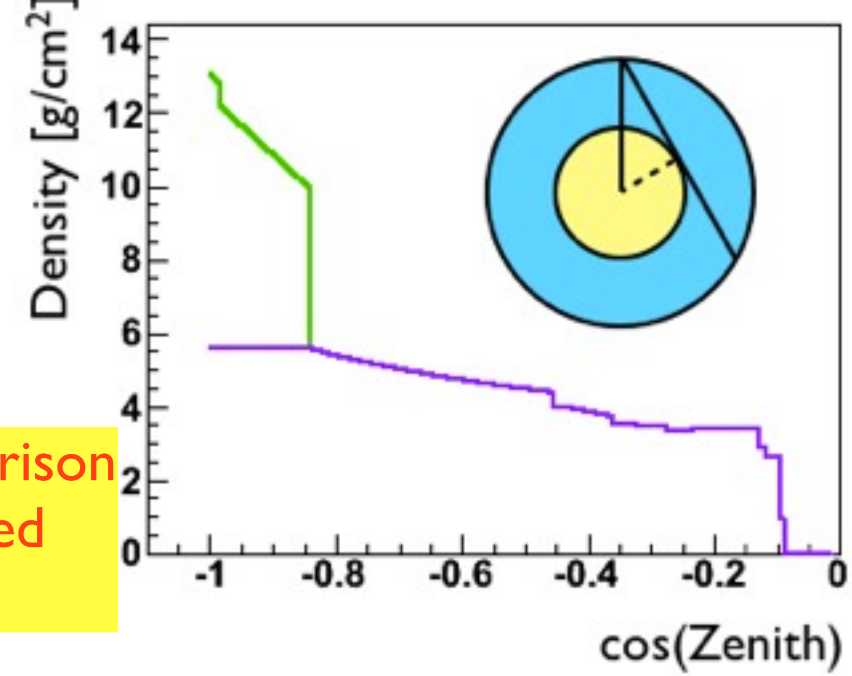

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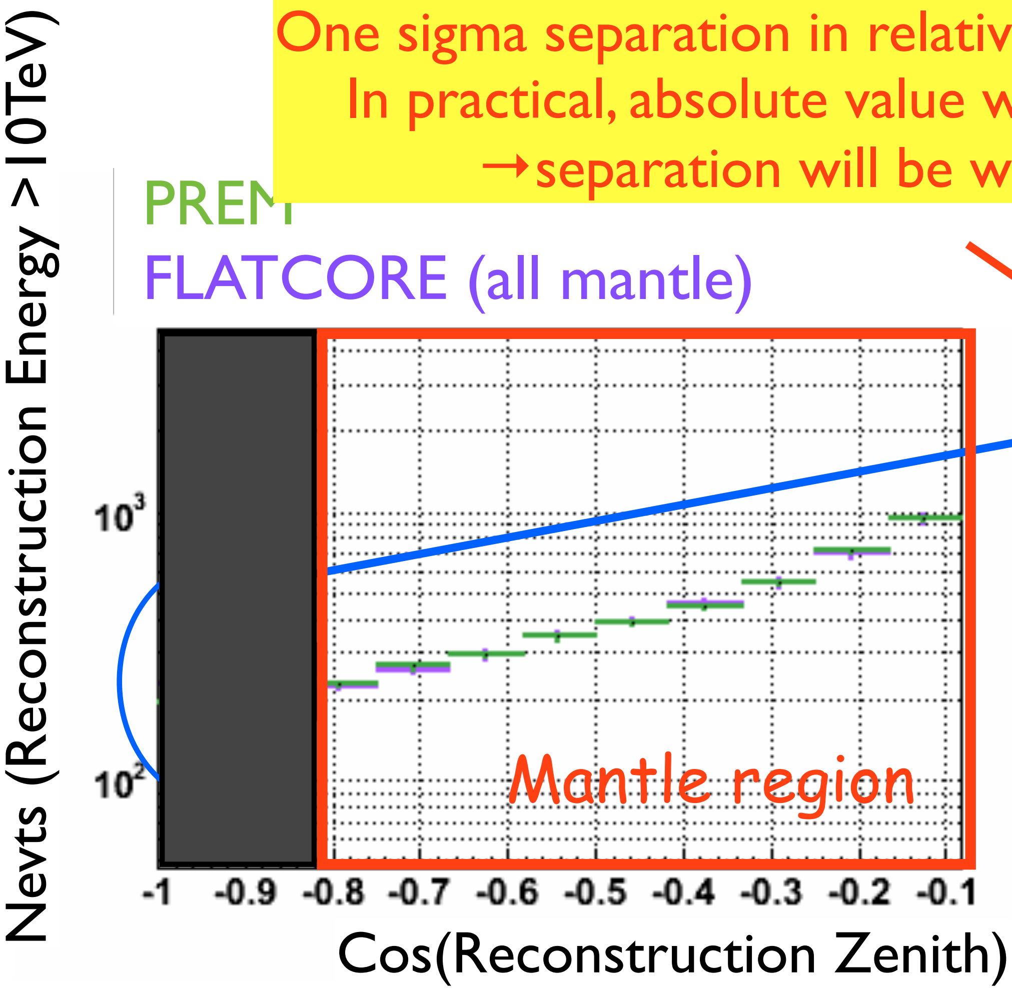

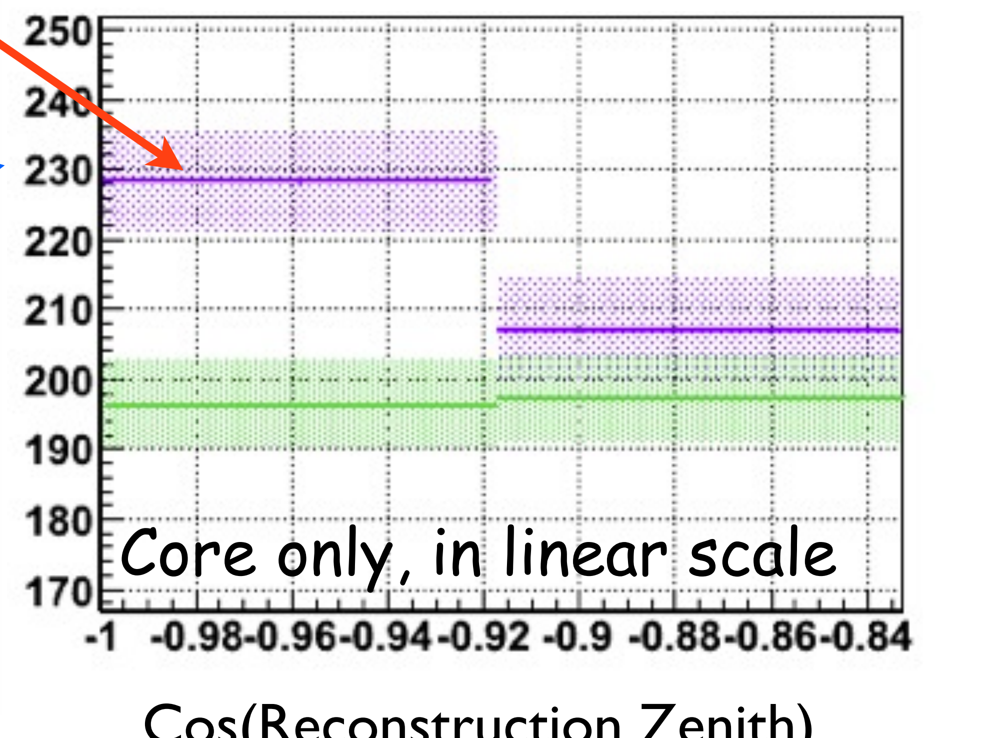

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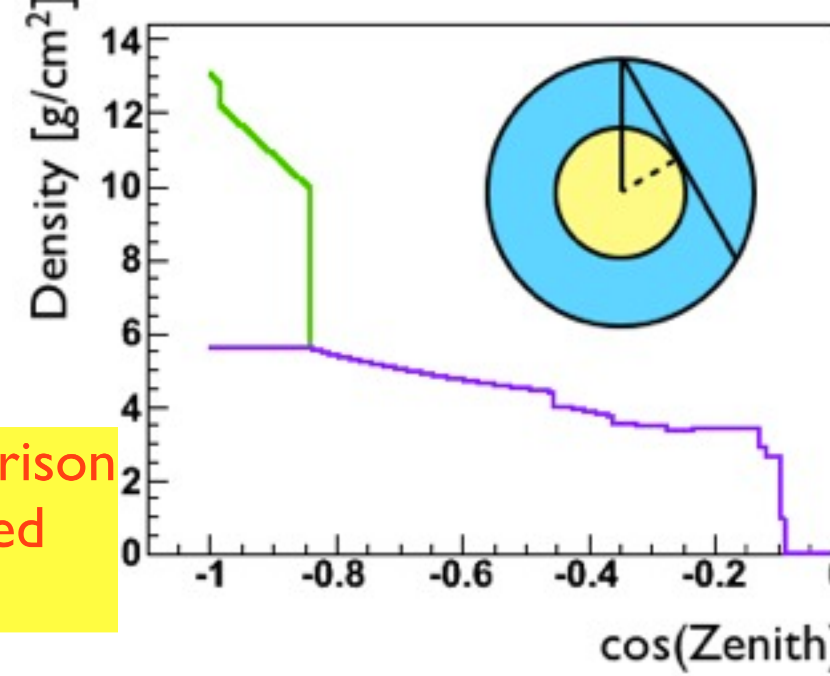

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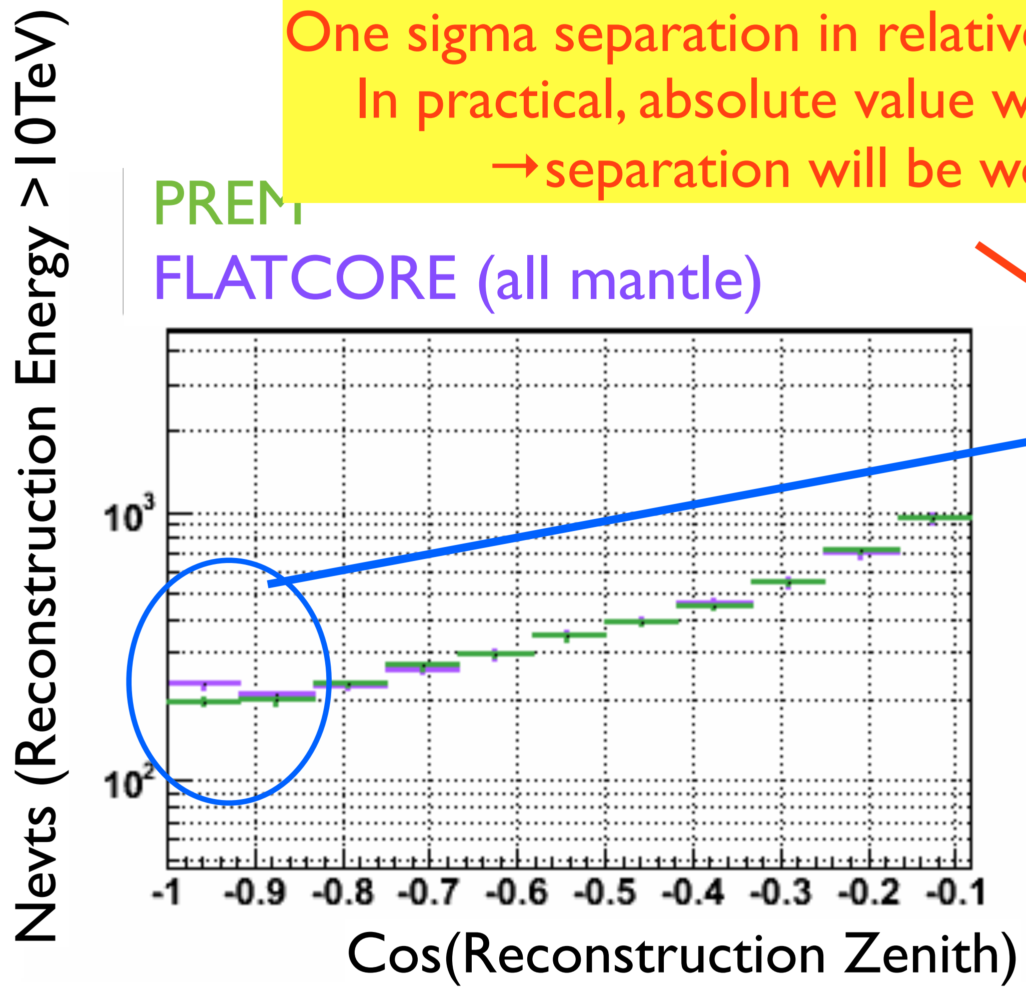

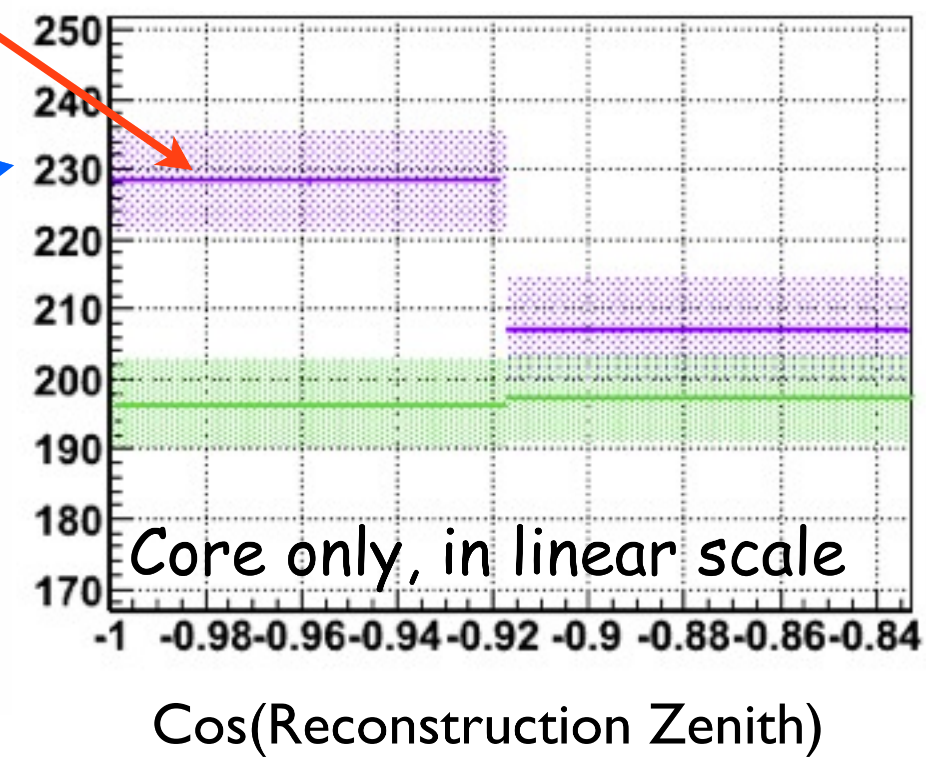

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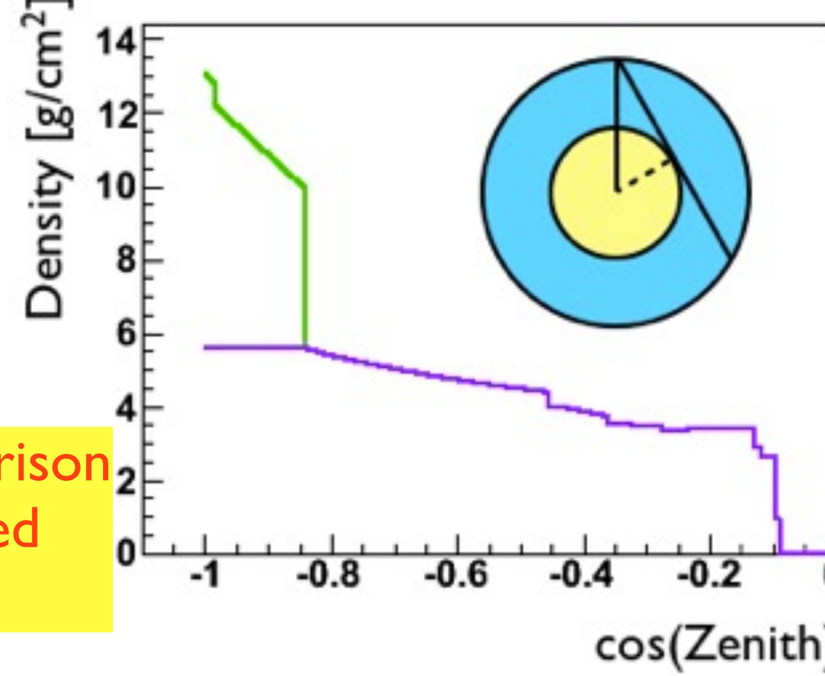

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In practical, absolute value will be used
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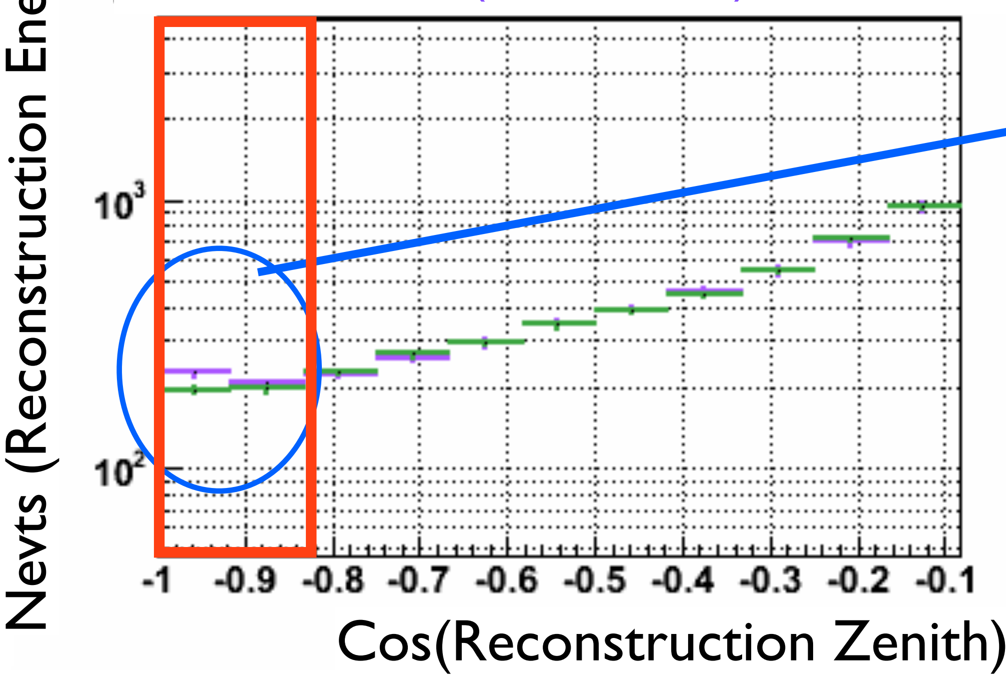
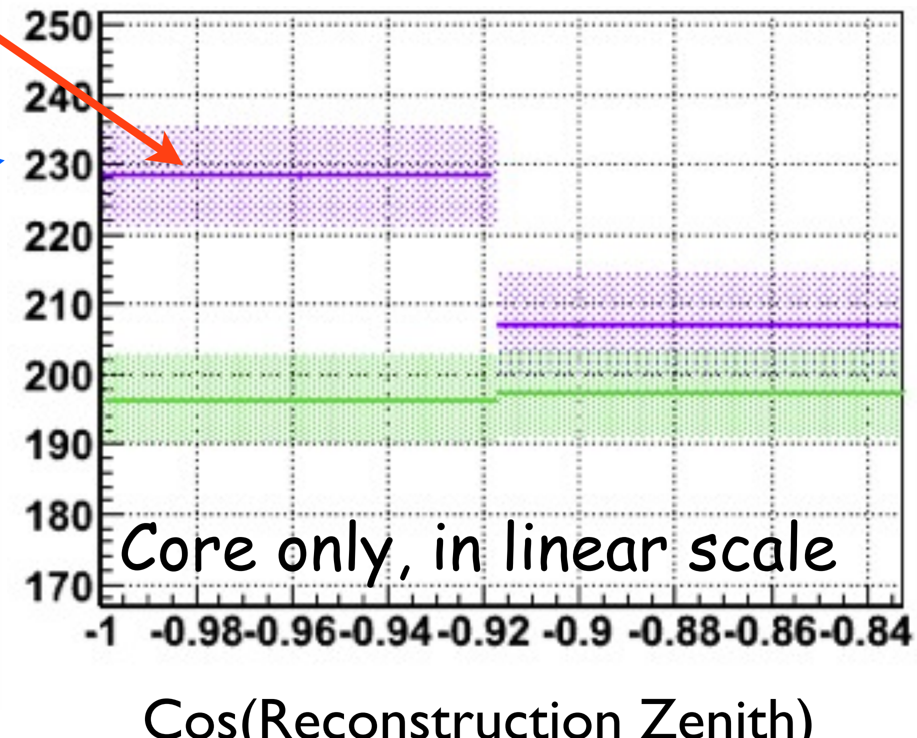
PREM
FLATCORE (all mantle)





Errors are statistical uncertainty of center prediction due to limited simulation statistics

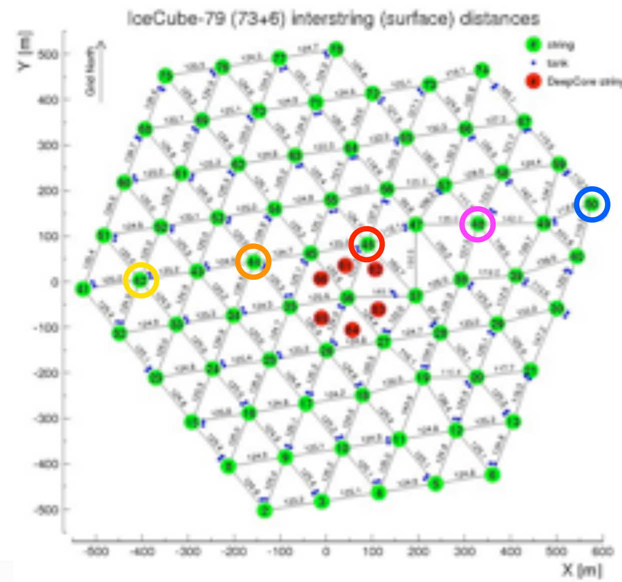
How can we improve the first analysis?

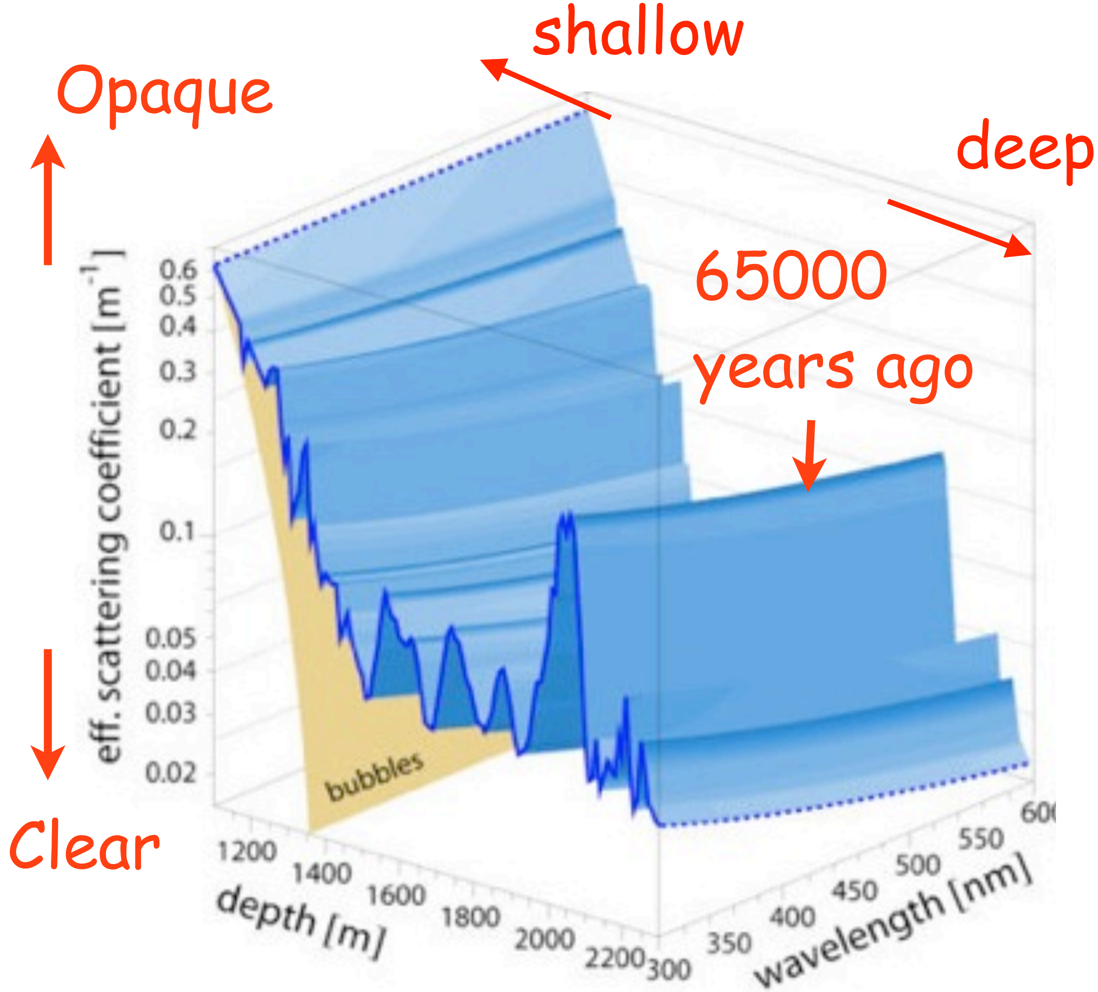
- Energy resolution
  - Systematics -- Ice property, DOM sensitivity
  - Energy reconstruction technique -- A lot of improvements have been done, still many efforts are going on
- Understanding atmospheric neutrino flux
  - Can we measure zenith distribution of neutrino flux?
    →Seasonal variation study, Starting track analysis
- Technical issues
  - Speed up simulation!

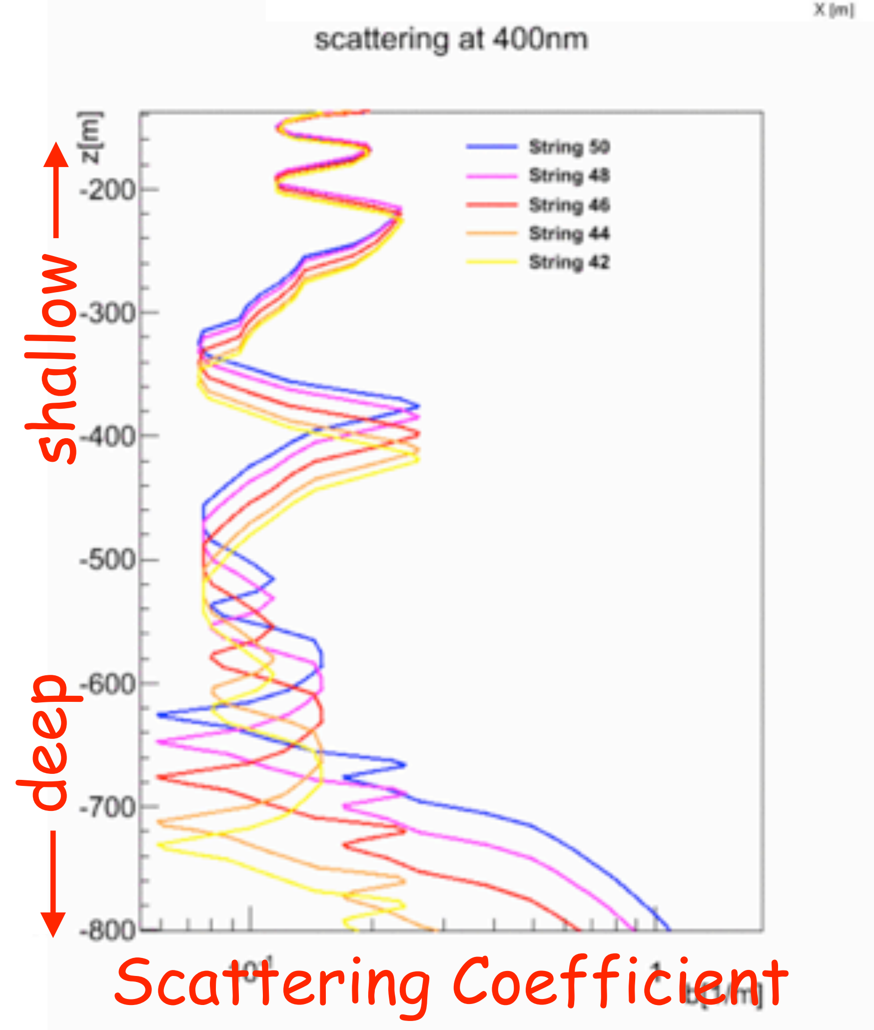
Red : today's topics

1.Ice property

Natural Ice has a lot of structures :
Depth Dependence, Tilt, Stretching...

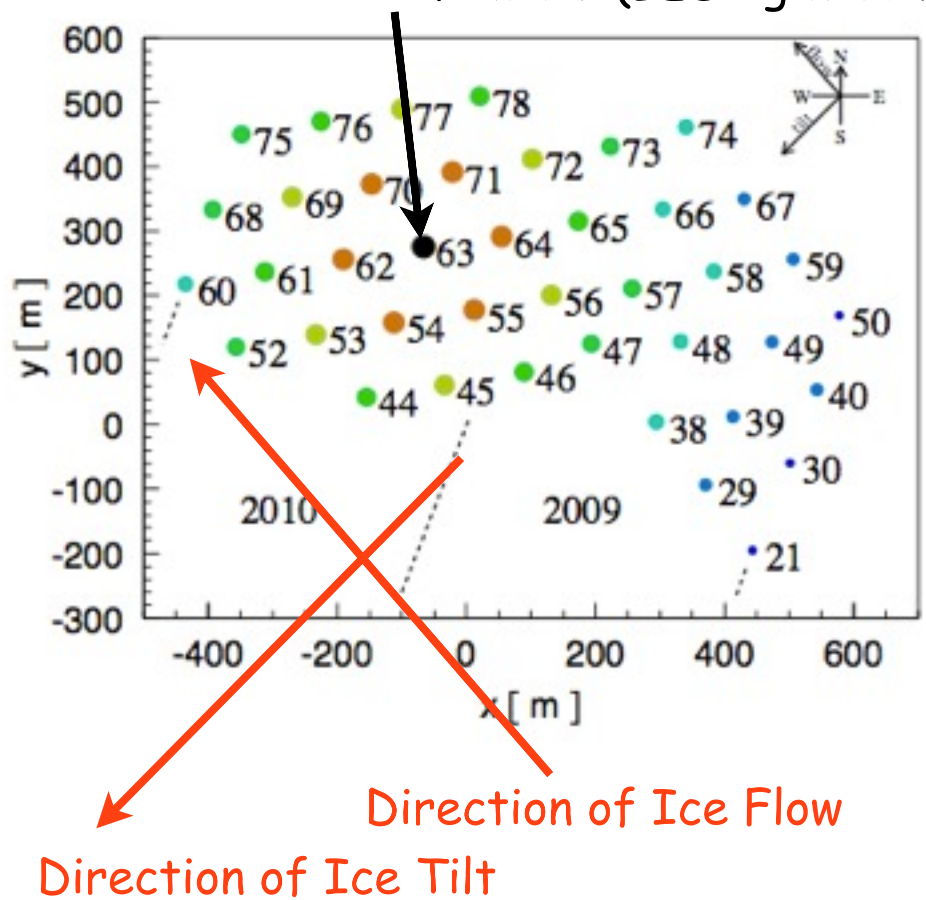


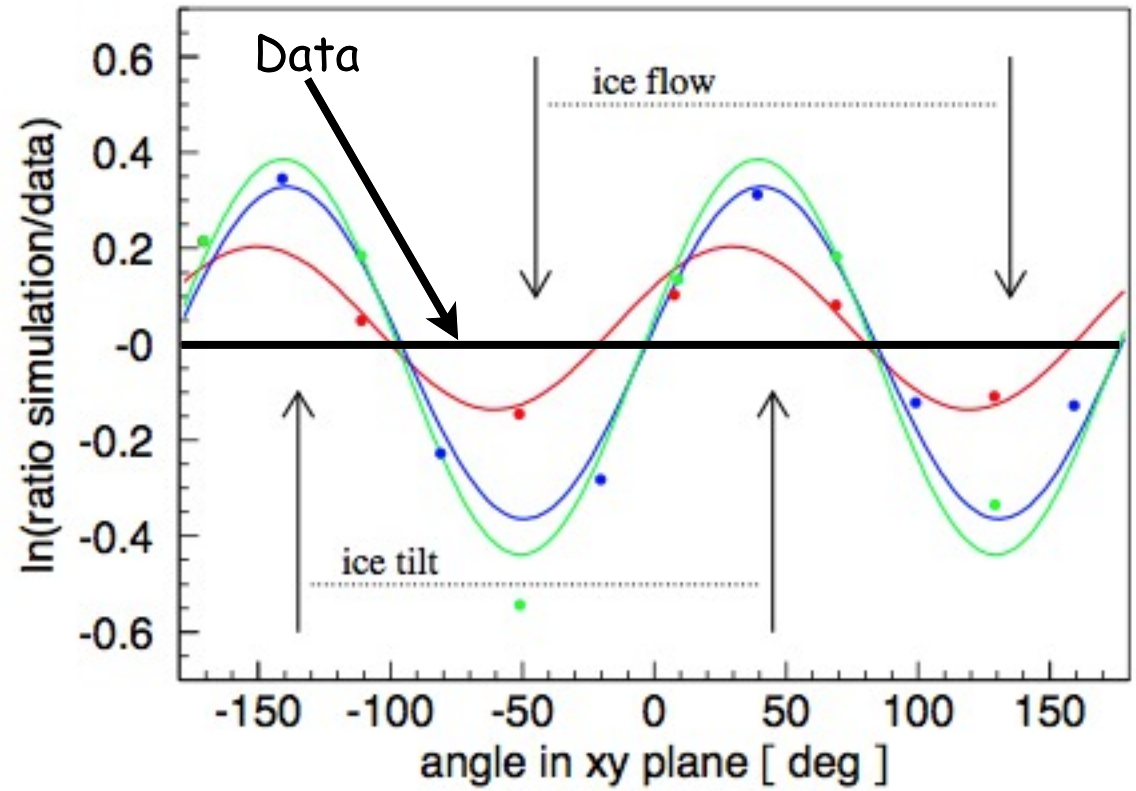




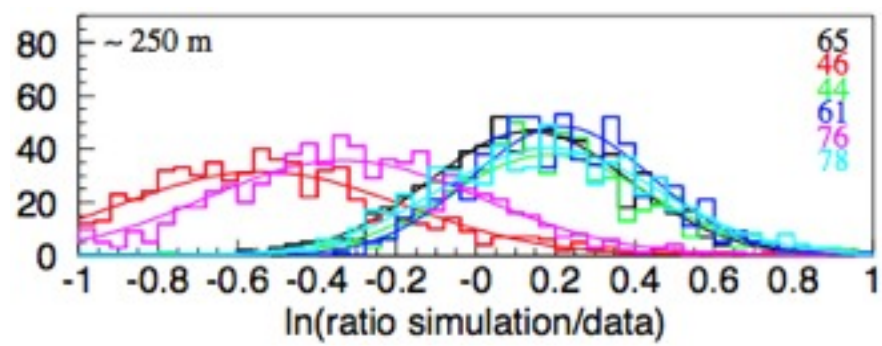
South Pole Ice has optical anisotropy!

by D. Chilkin

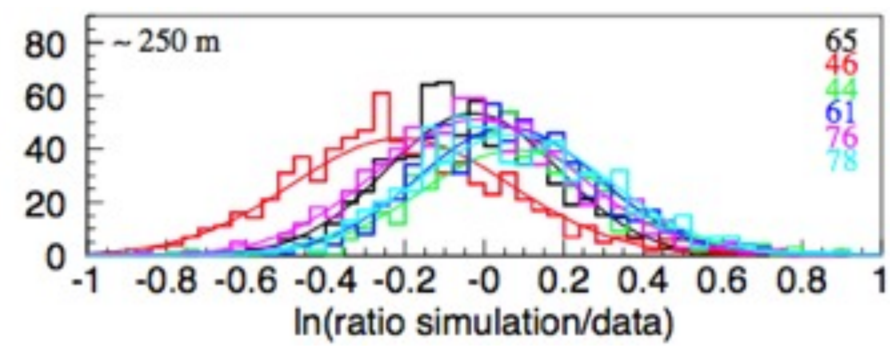




Before tilt & anisotropy correction

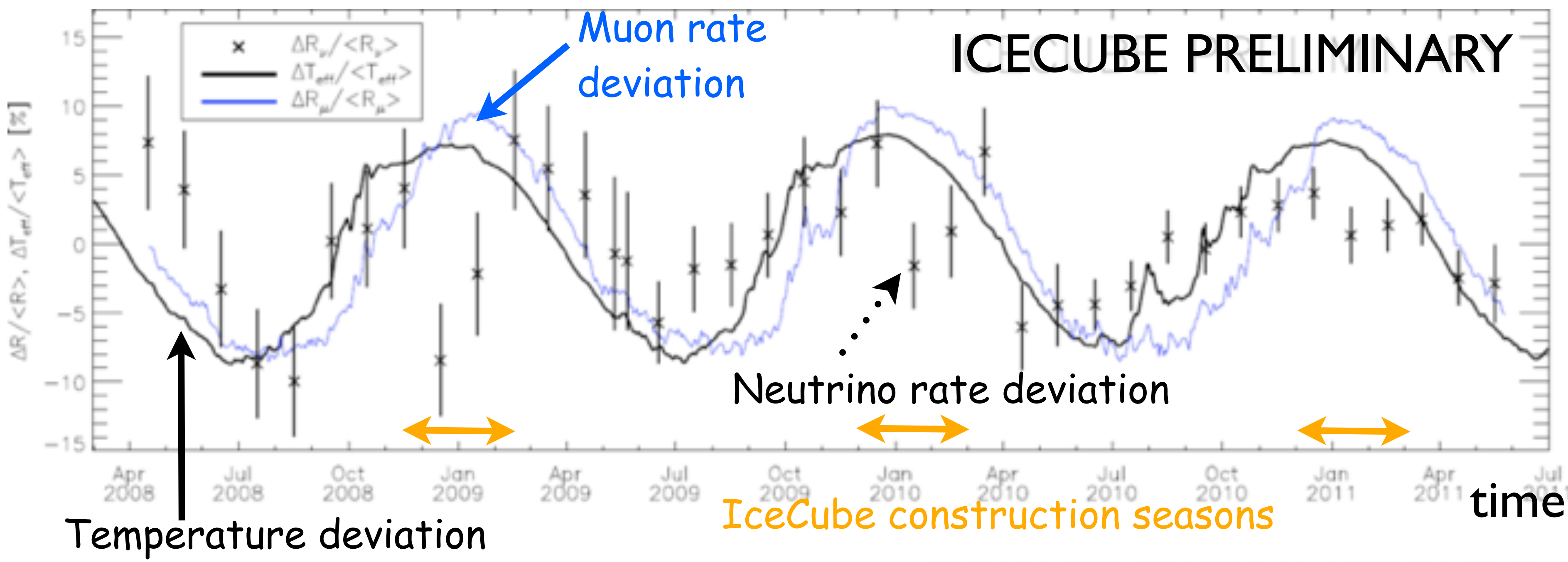


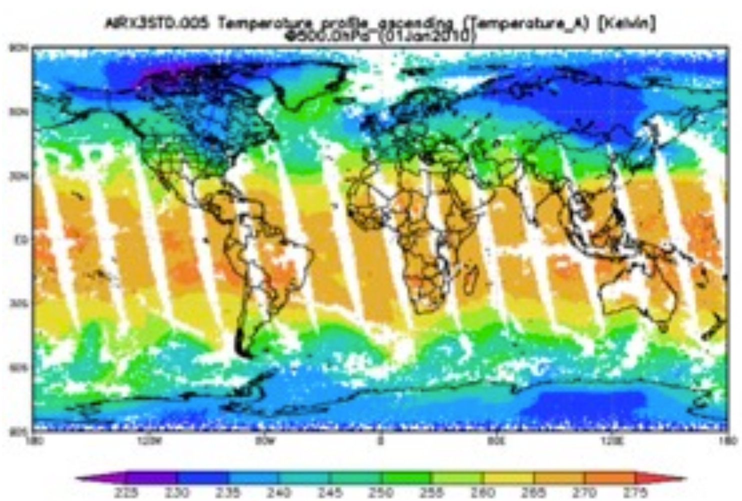
After tilt & anisotropy correction



2. Seasonal Variation of Atmospheric Neutrino

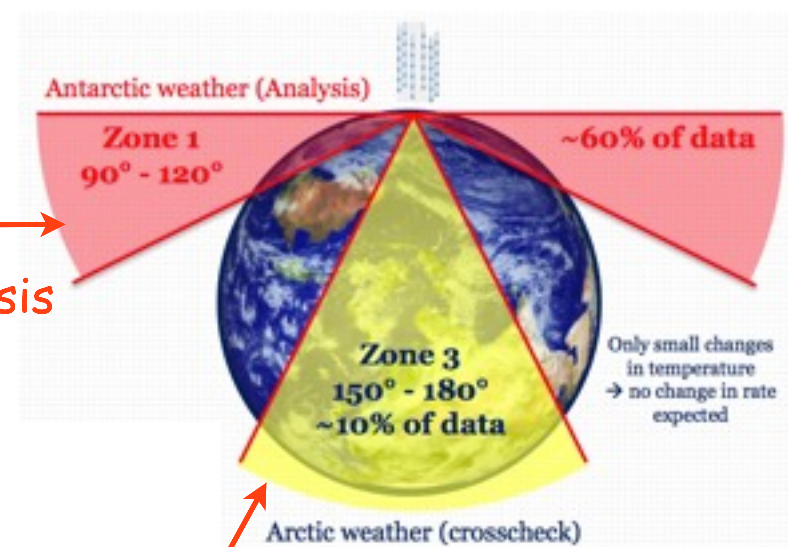
by P. Desiati, K. Jagielski, A. Schukraft, G.C. Hill, T. Kuwabara, T. Gaisser





Temperature data from NASA's satellite Aqua

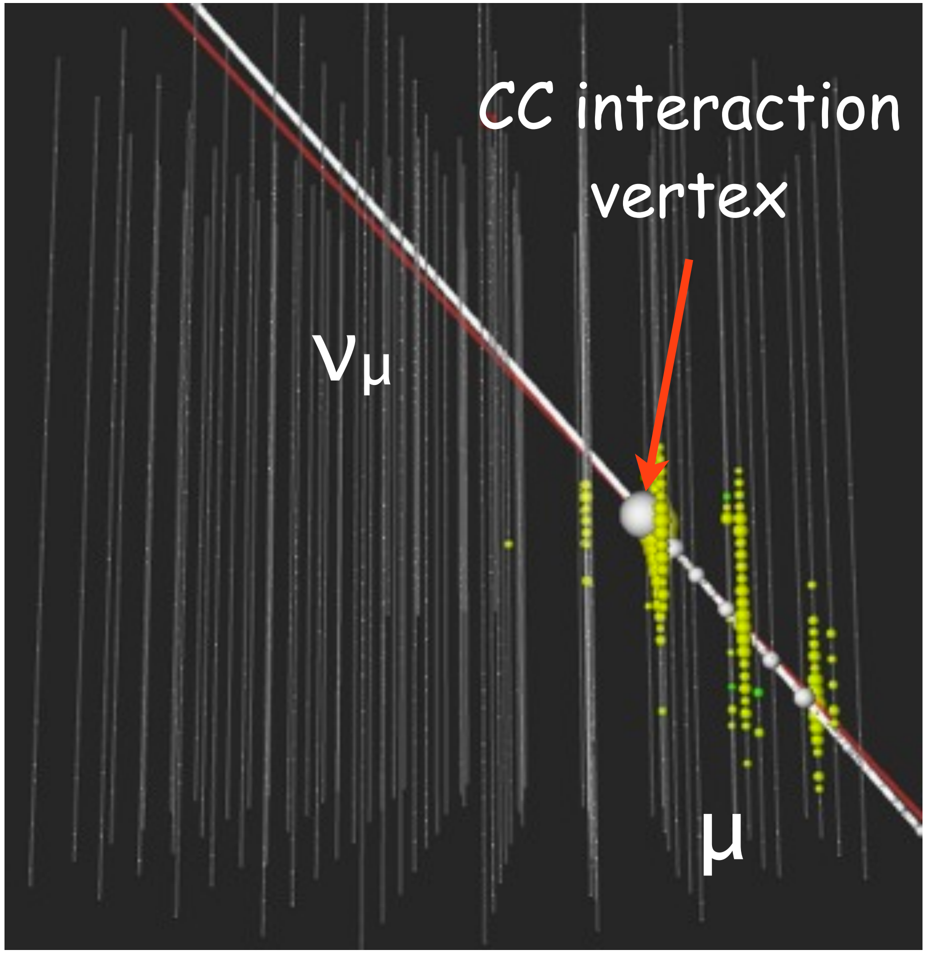
data used for this analysis



not used due to low statistics

3. Starting Track analysis

- Current analysis totally relies on simulation at core angle (cosθ < -0.83) because we filter out down-going events in order to reject background muons
  - Uncertainty of K-π ratio may affect the zenith distribution
- Starting Track = Neutrino!
  - If an event starts from INSIDE of IceCube, it should be a neutrino!
  - Recent High-energy extraterrestrial neutrino search successfully used the starting tracks
  - Can we use these down-going neutrinos for calibration?



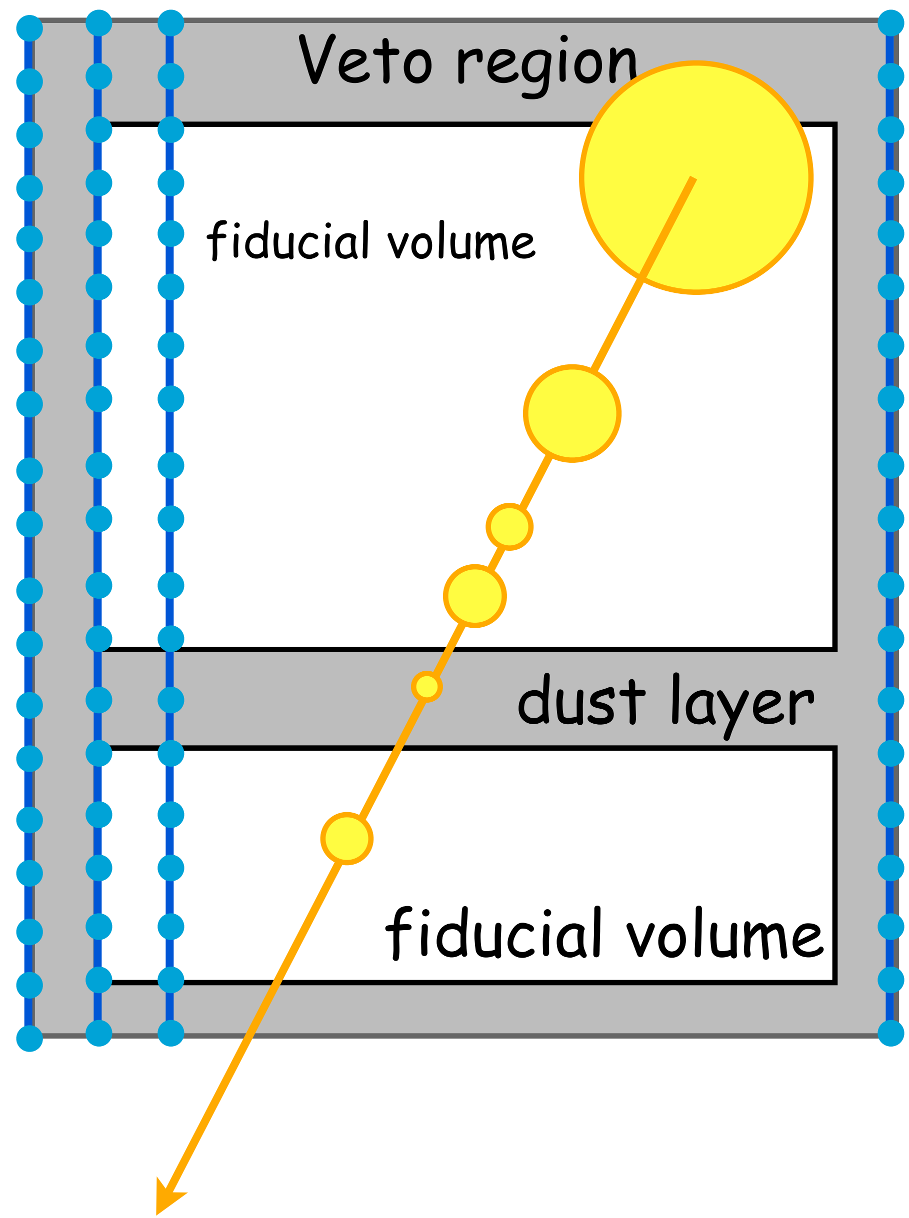
3. Starting Track analysis (cont'd)

- First photon must be observed WITHIN the fiducial volume
- Total charge > 6000 photo-electrons

↓

This setting is optimized for discovery of high-energy extra-terrestrial neutrinos.

Need optimization for EarthCore calibration study



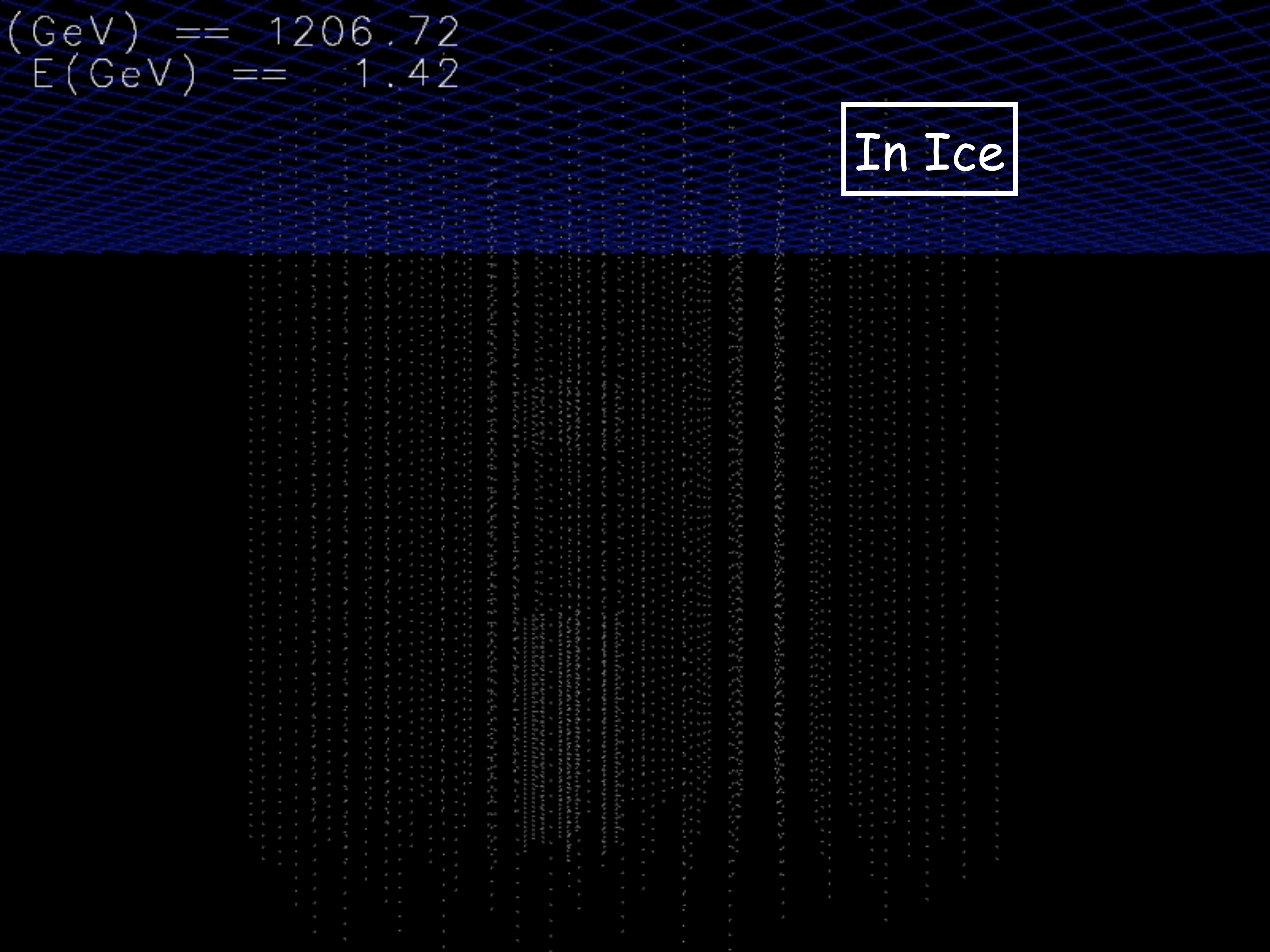
4. Technical Issues

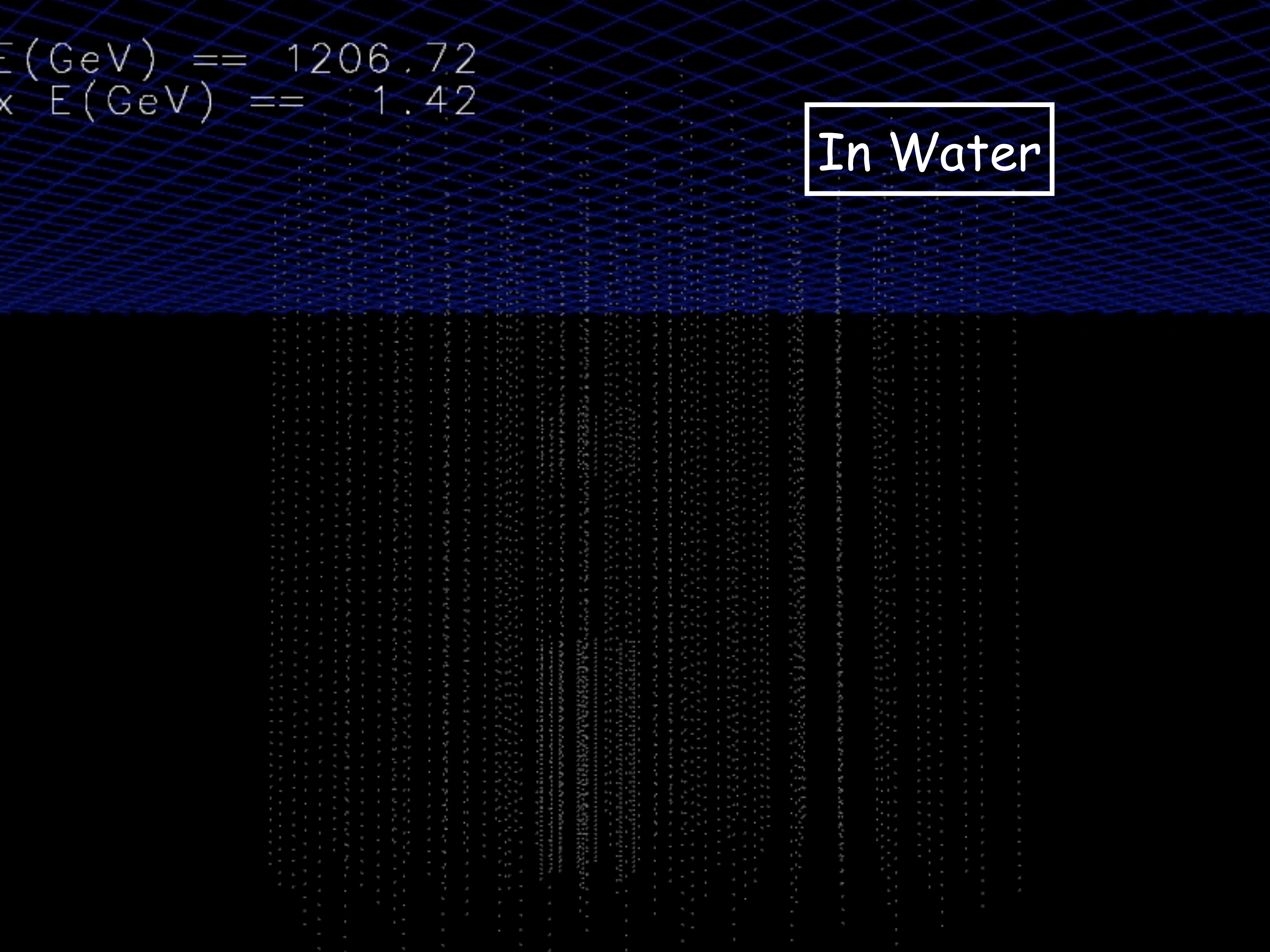
- Current EarthCore analysis requires more than 20 times larger statistics of simulations than other IceCube analysis
    - Next generation of neutrino simulator has been developed to reduce number of simulations and generate events more efficiently
- New Ice Property
    - Could be applicable for simulation (very slow, need next generation neutrino simulator)
    - Hard to apply it for event reconstruction →need to understand how it affects to energy estimation

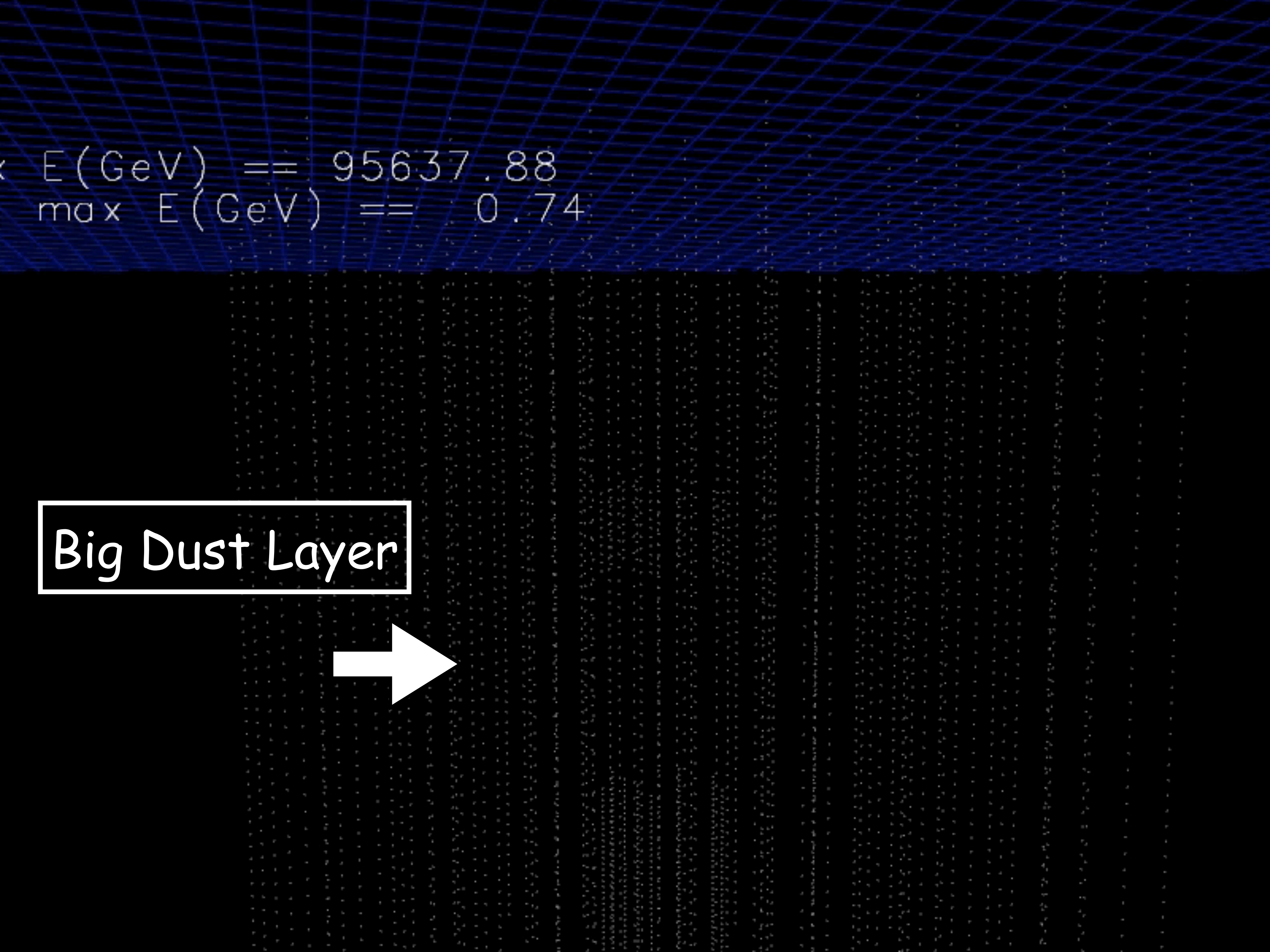
Plans

- Release new neutrino simulator ... Sep. 2013
- Calibration Study with Starting Track ... Oct. 2013
- Data unblinding request (for IC79 & IC86-1, IC86-2) ... Dec. 2013
- Establish analysis procedures for IC86-3 and later

backups

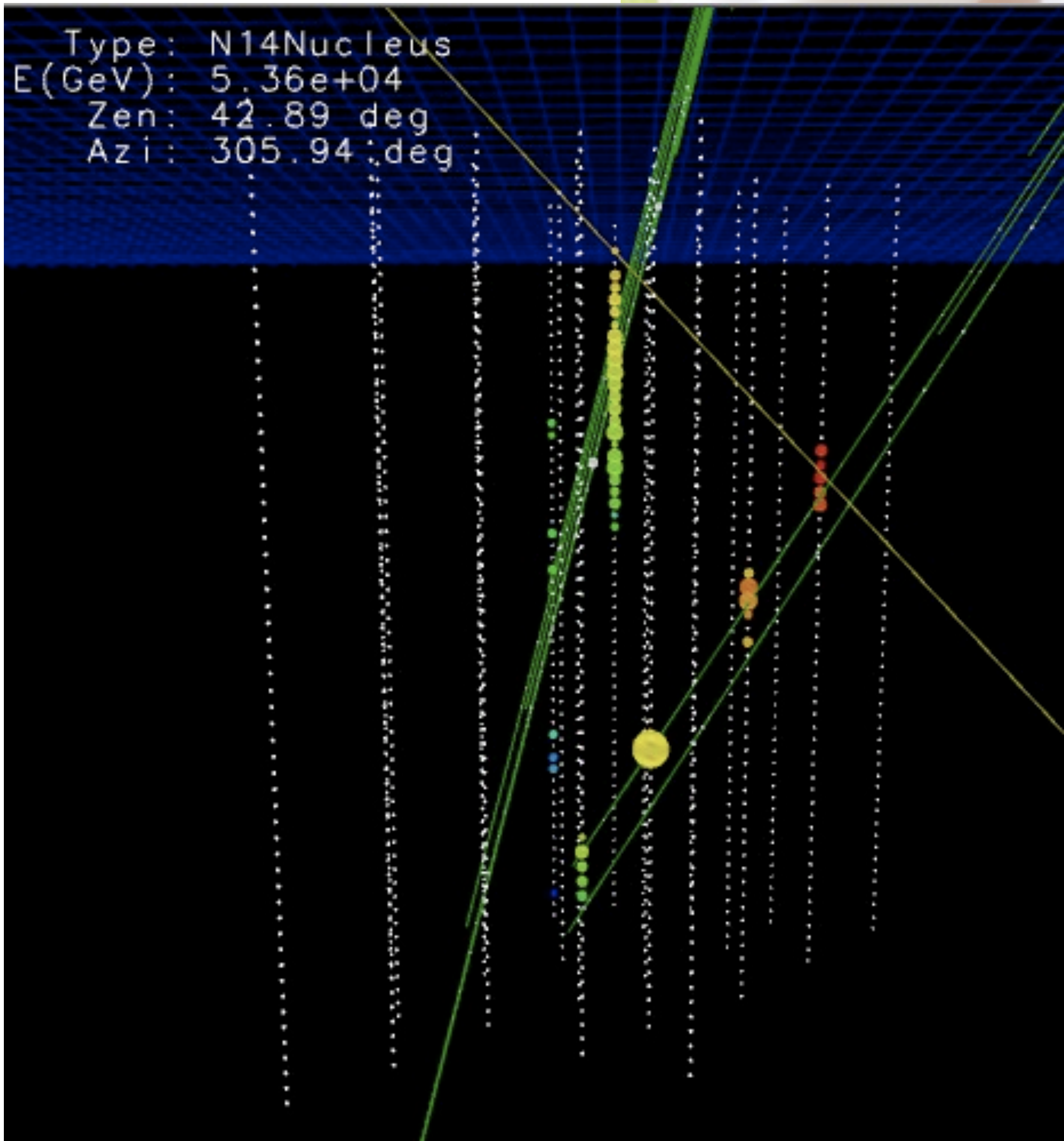

(GeV) == 1206.72
E(GeV) == 1.42
In Ice


E(GeV) == 1206.72
x E(GeV) == 1.42
In Water


E(GeV) == 95637.88
max E(GeV) == 0.74
Big Dust Layer

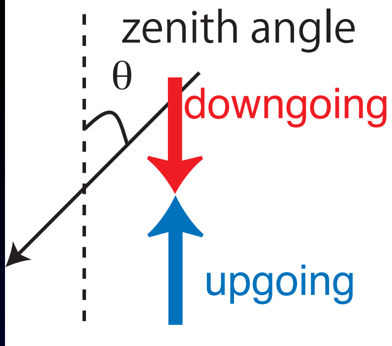
xample of Backgrounds : Coincidence event

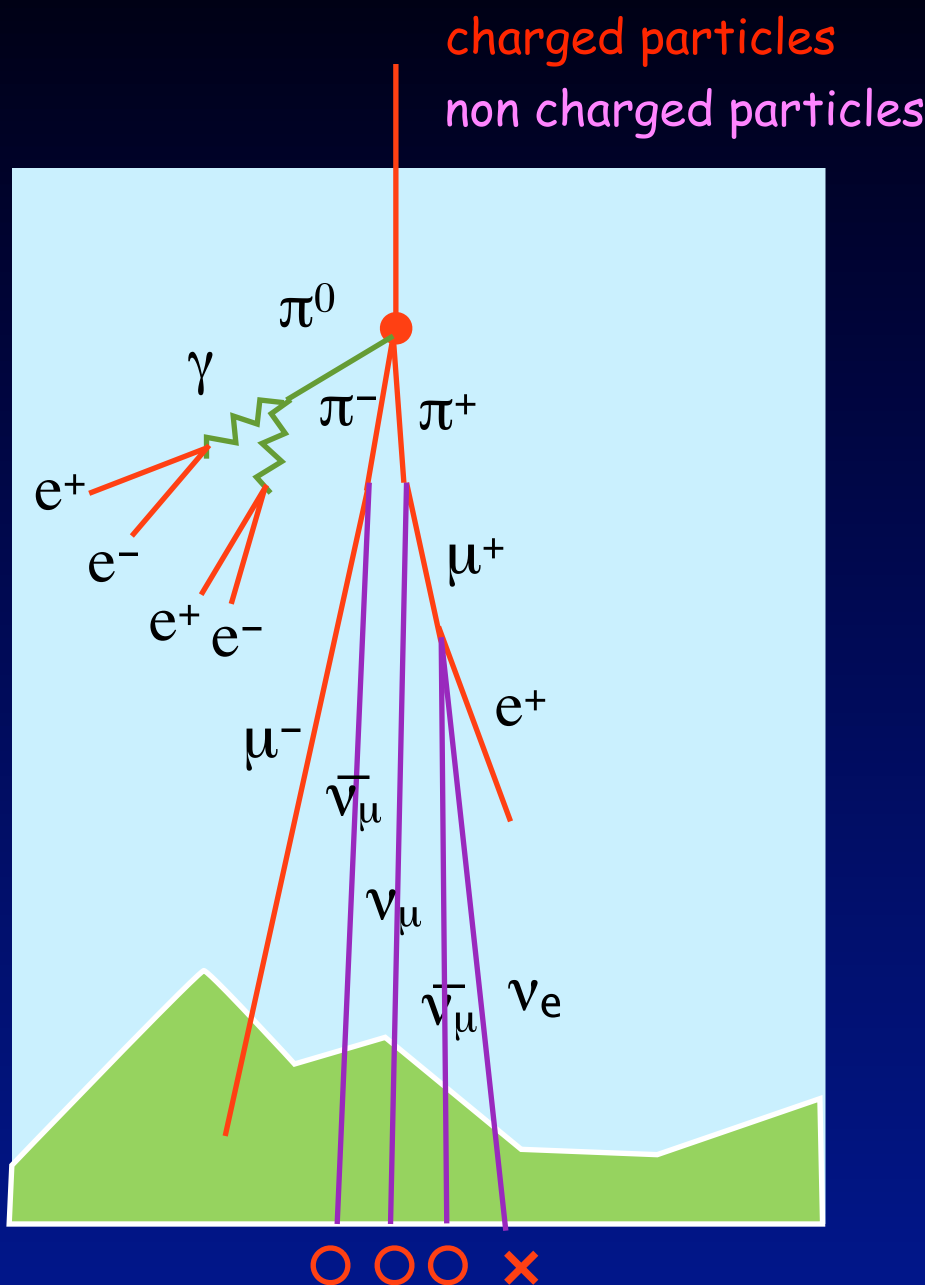
- Two muons coincidently pass through the detector within a time window
- Reads totally wrong answer for both energy and directional reconstruction
- upmu : coinc mu ratio 1 : 5000 after pole filter
- Survives fit-quality cuts due to high-multiplicity of hit DOMs



Neutrino Absorption Radiography with IceCube

Measuring Core Density of the Earth





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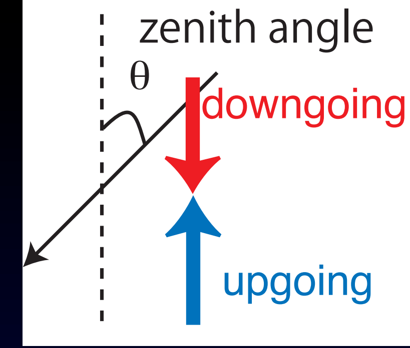
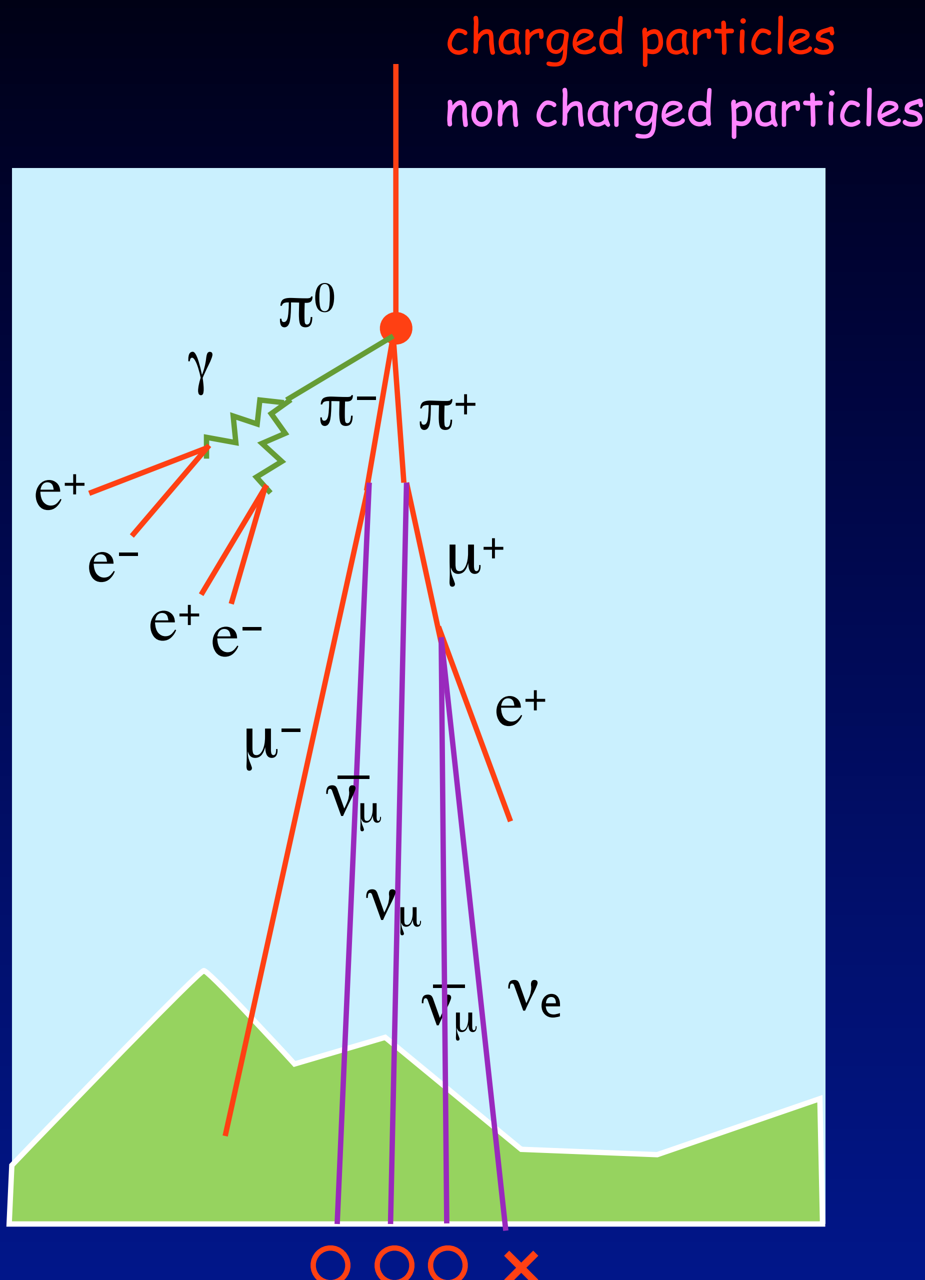
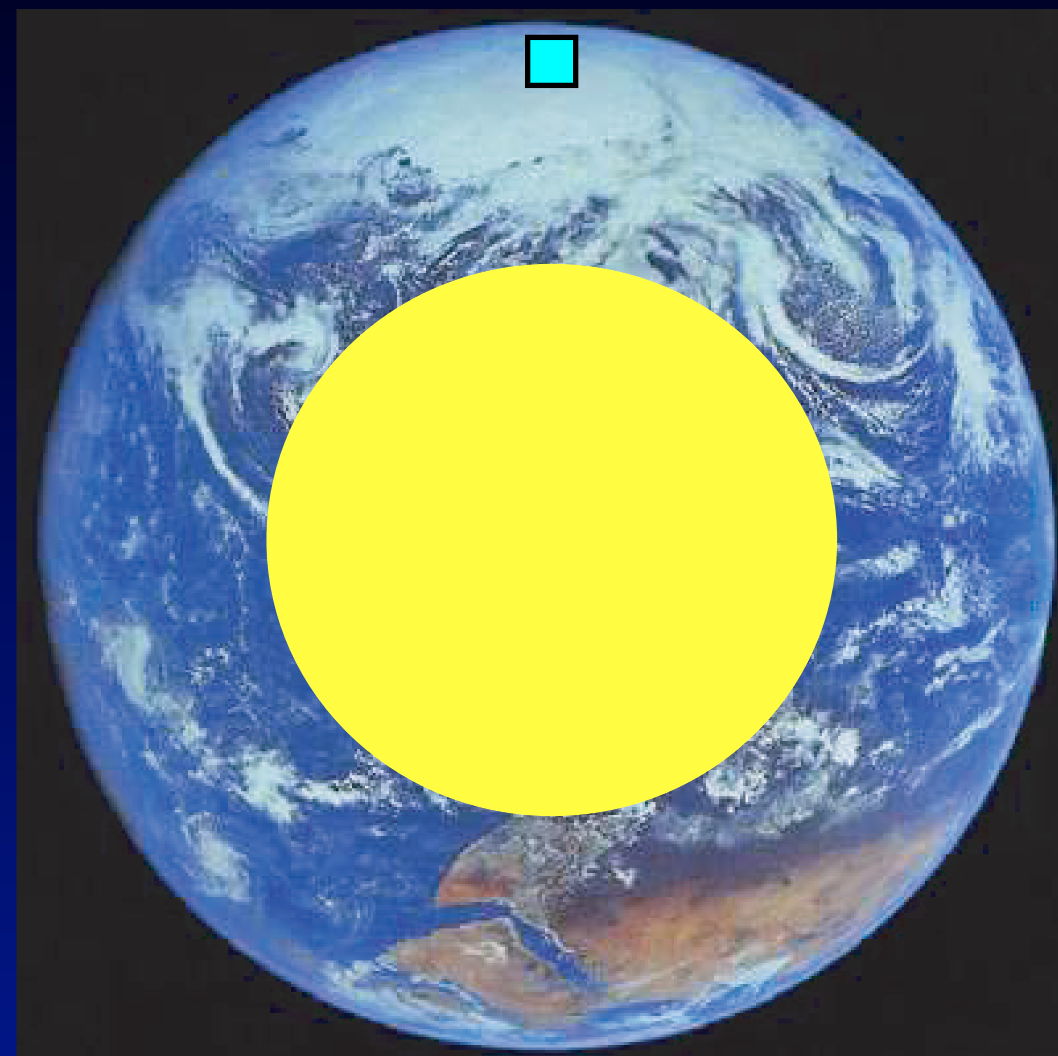




South Pole



North Pole

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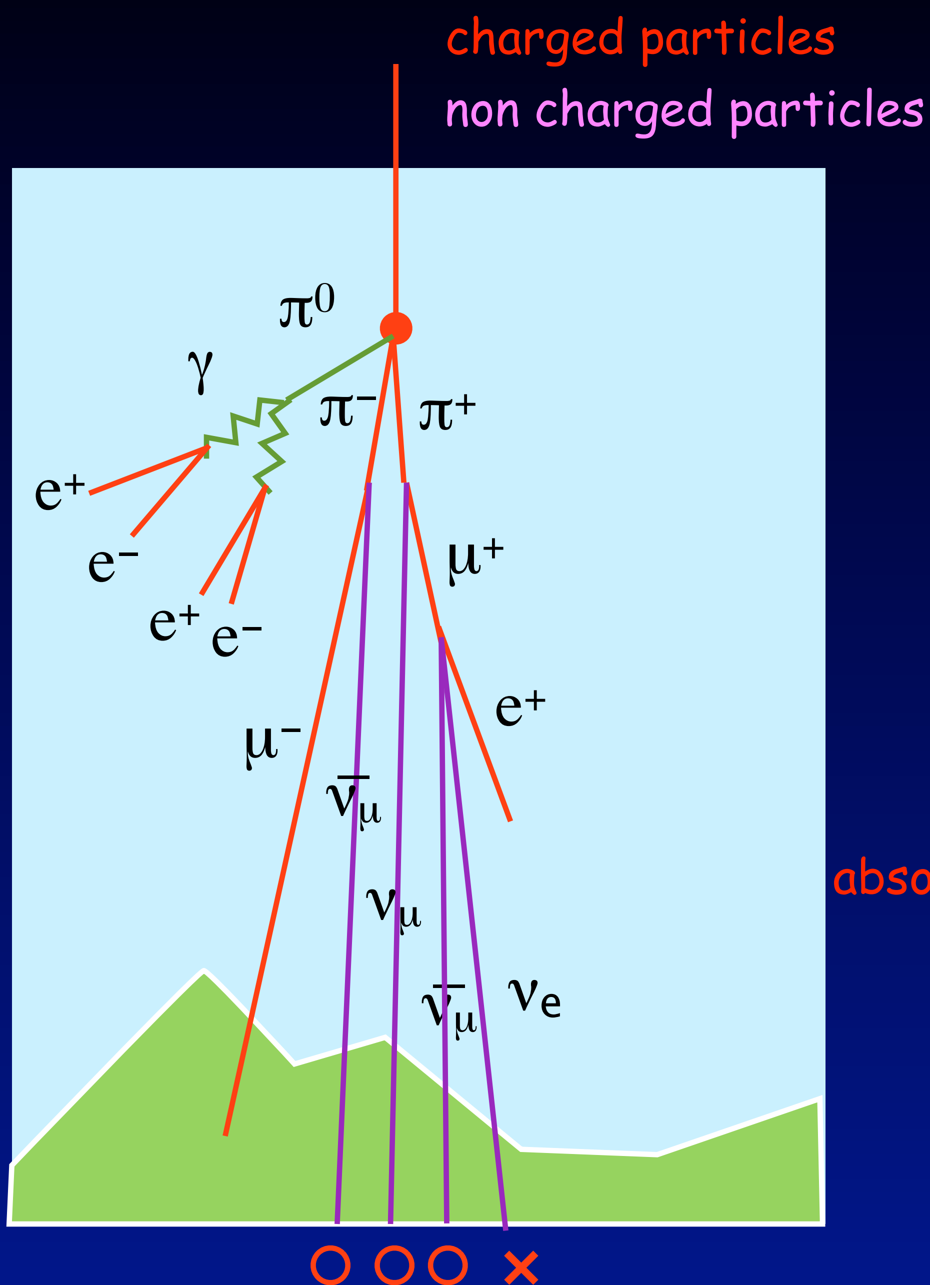

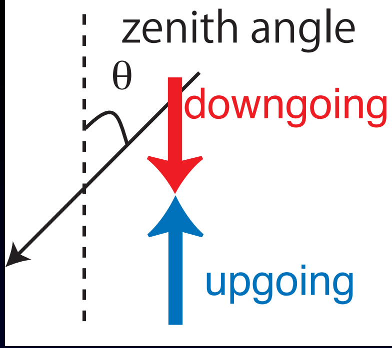

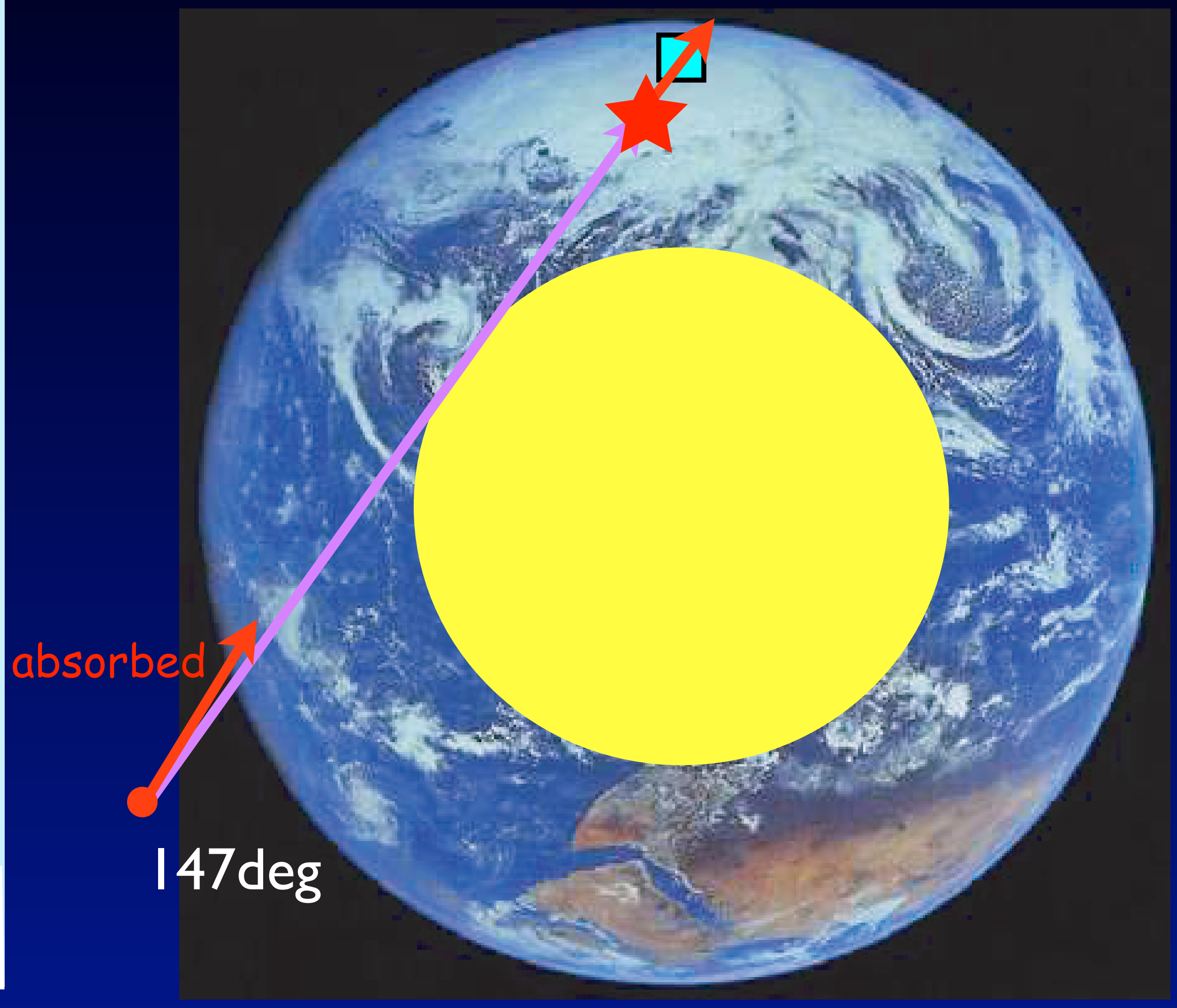

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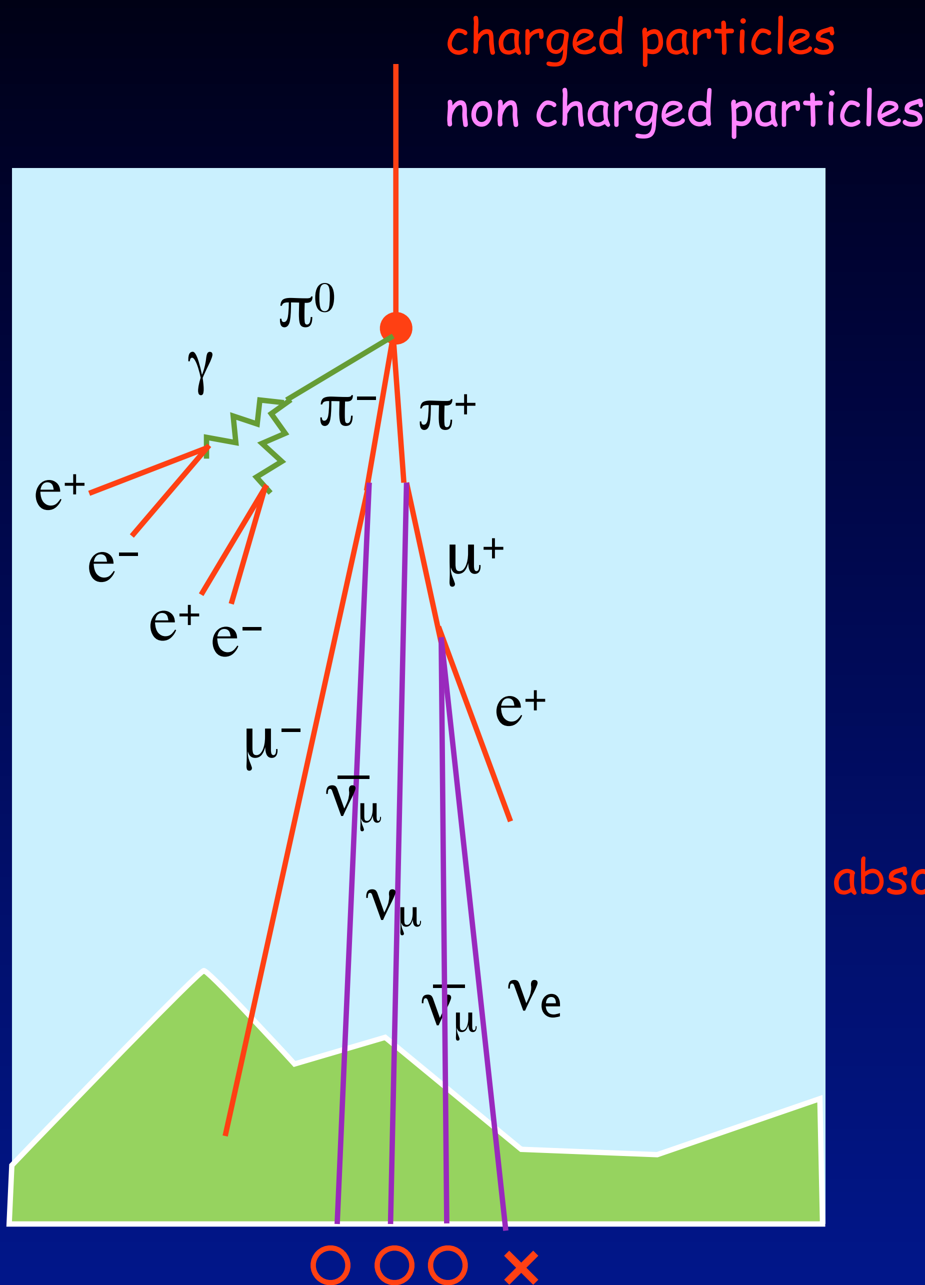
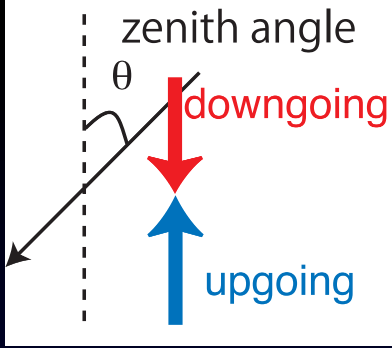
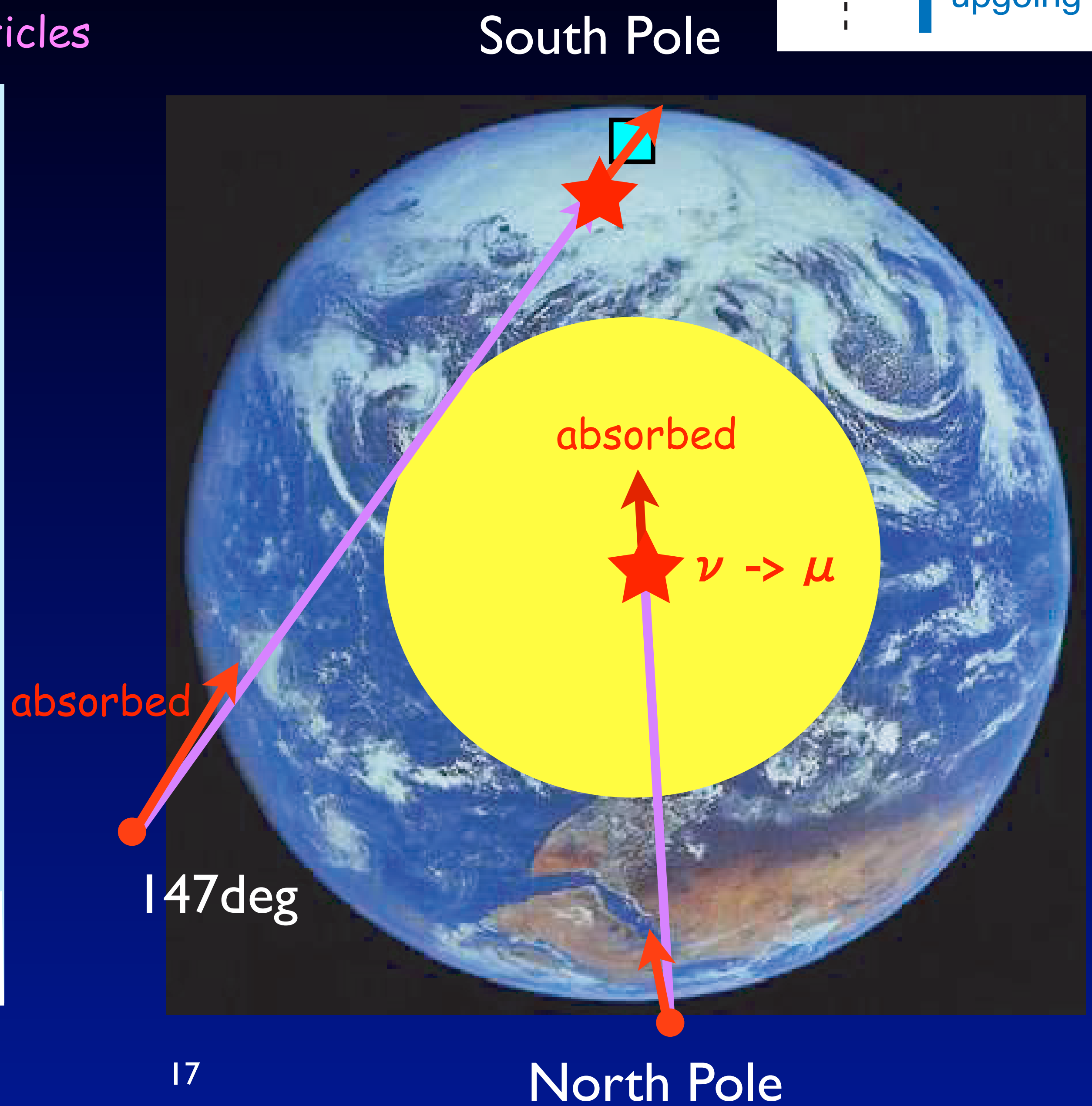
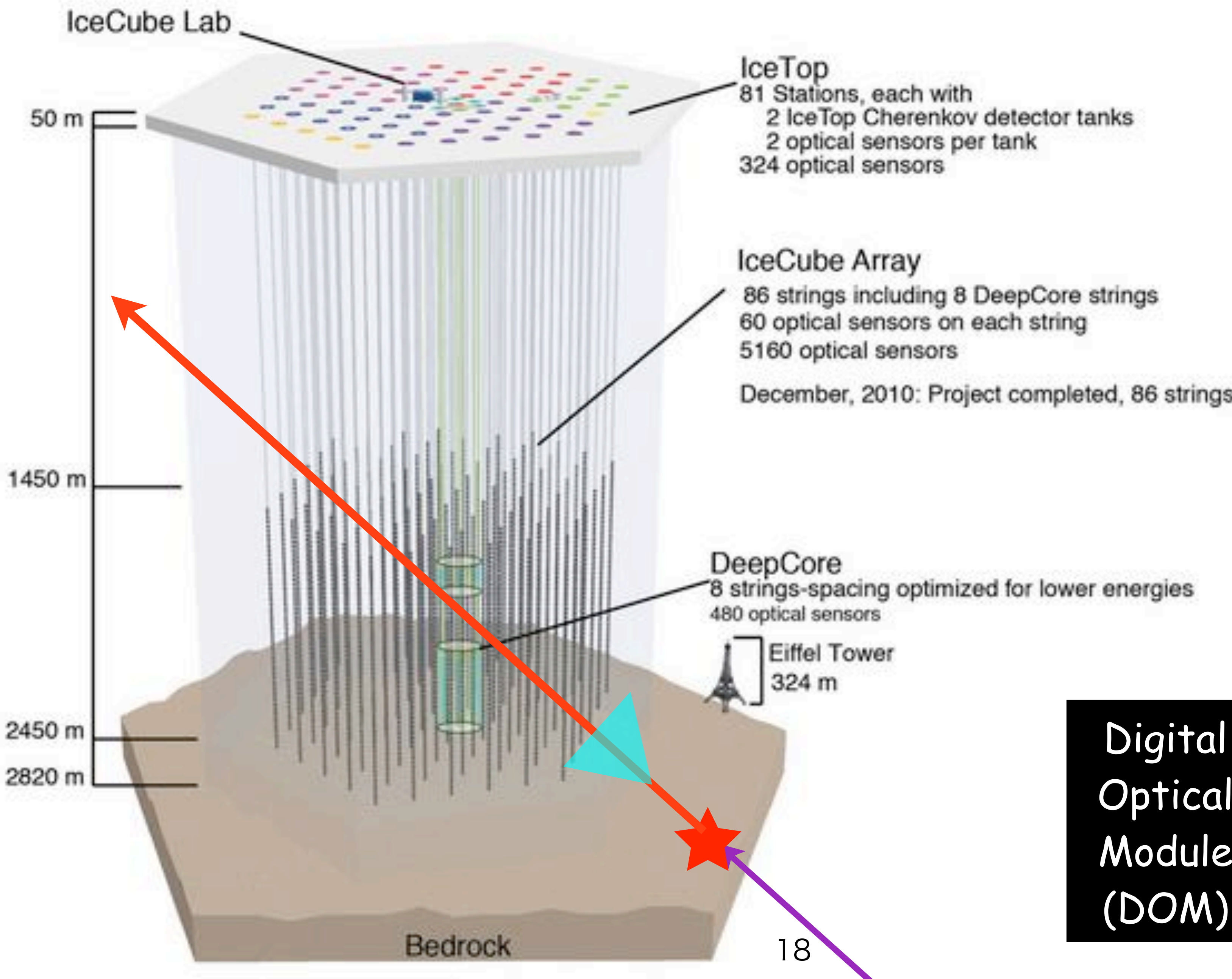
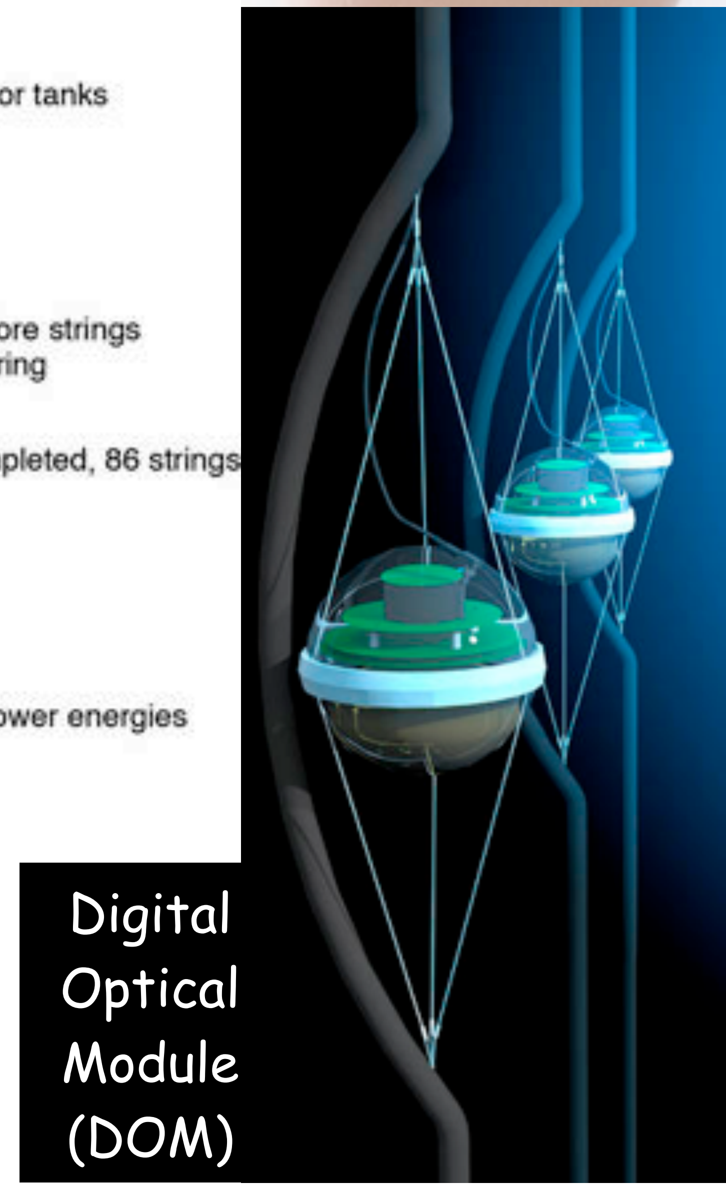






IceCube Structure





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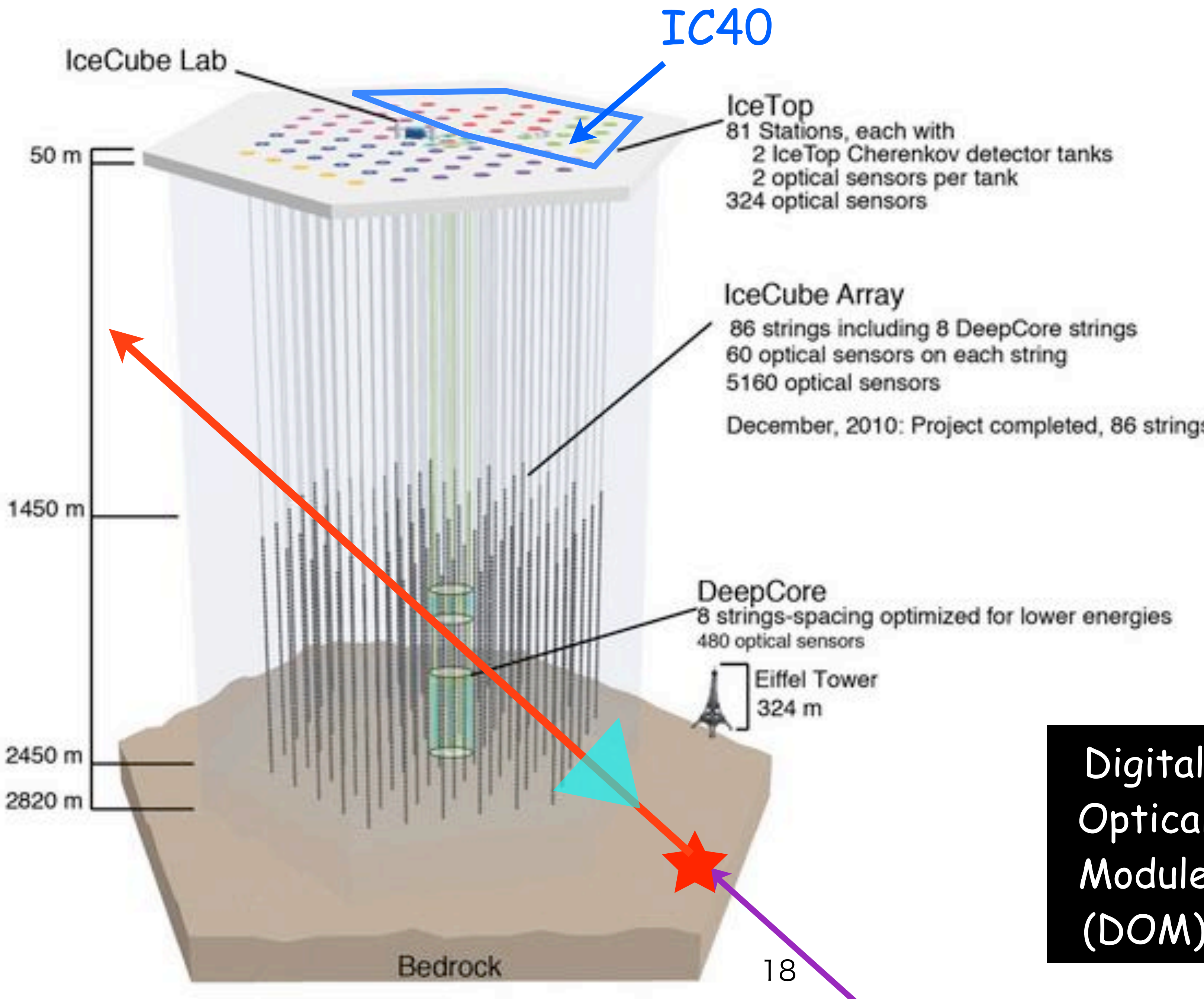

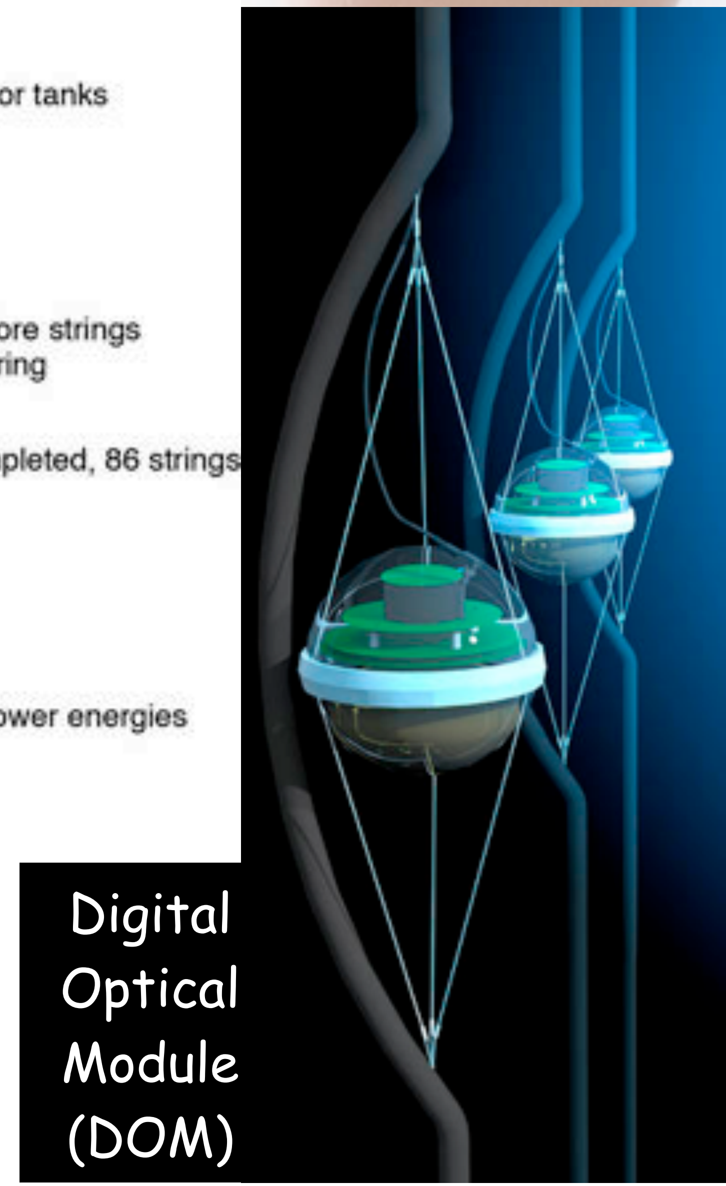

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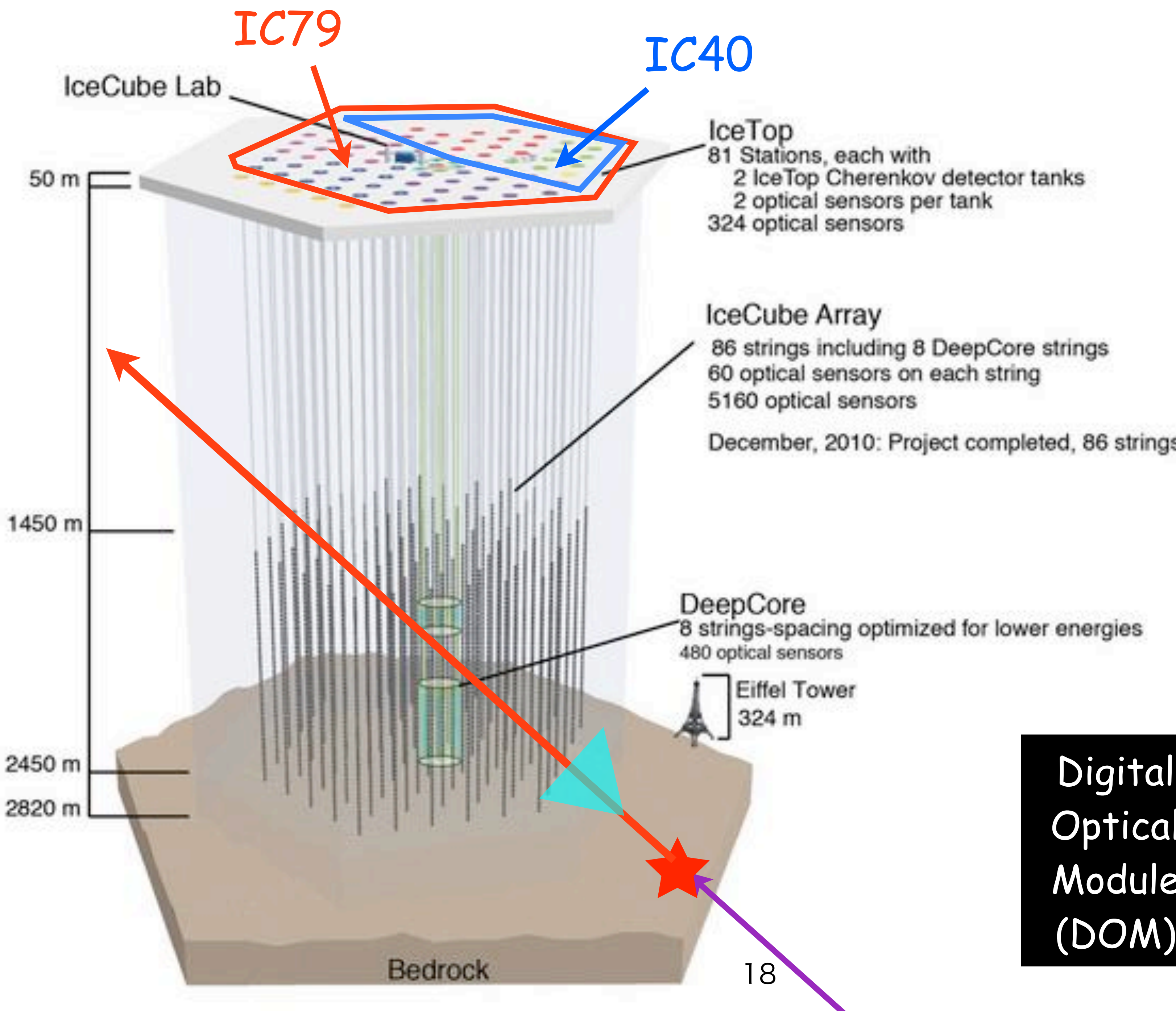
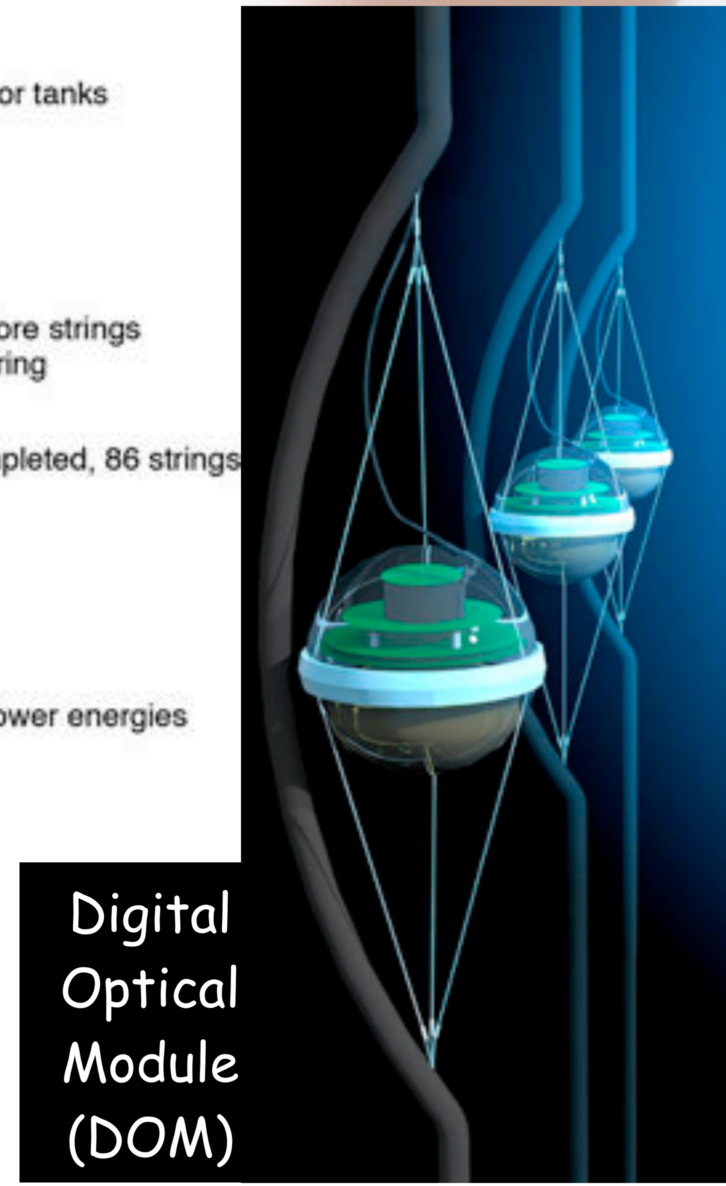
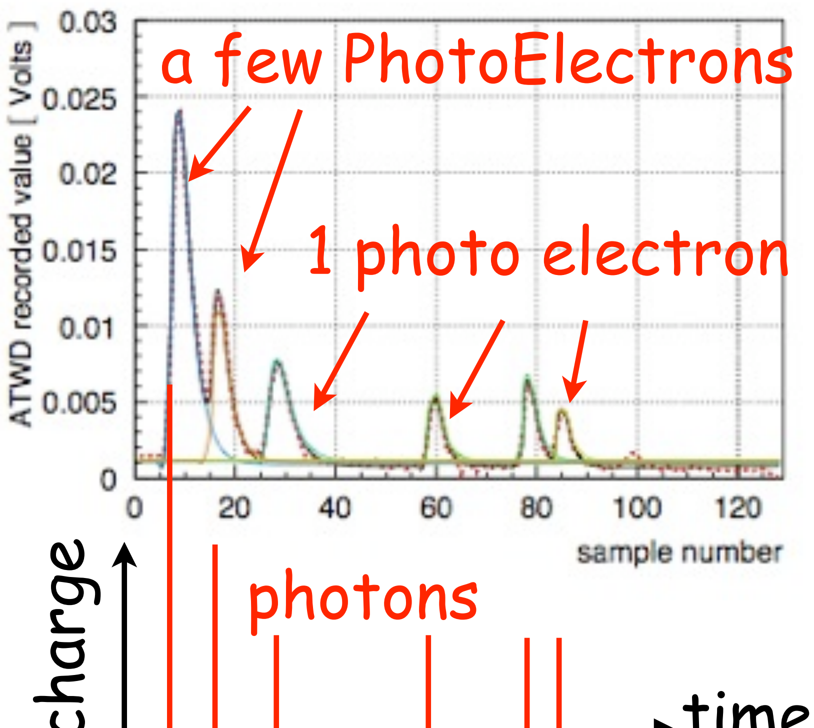
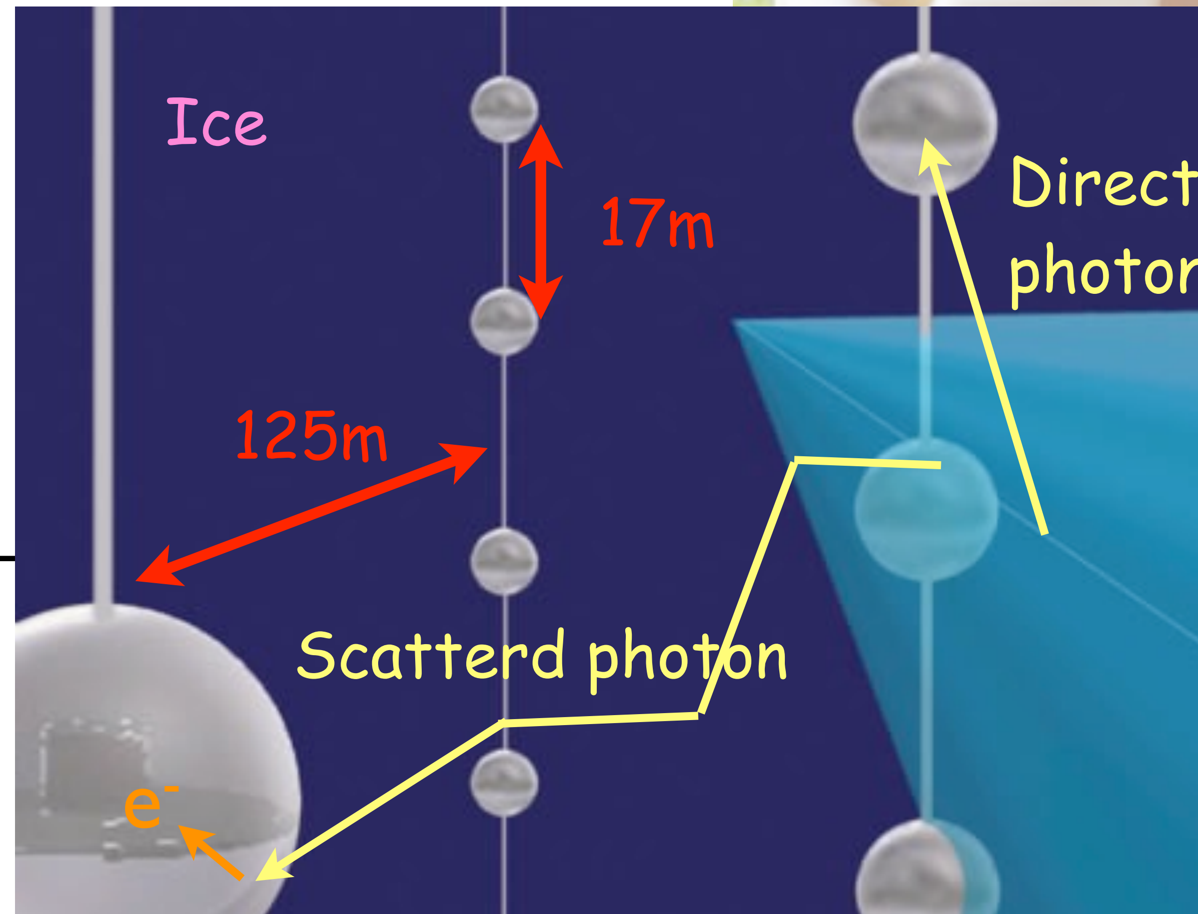




How an event is recorded?

Digital Optical Module (DOM)
10inch PMT+ electronics

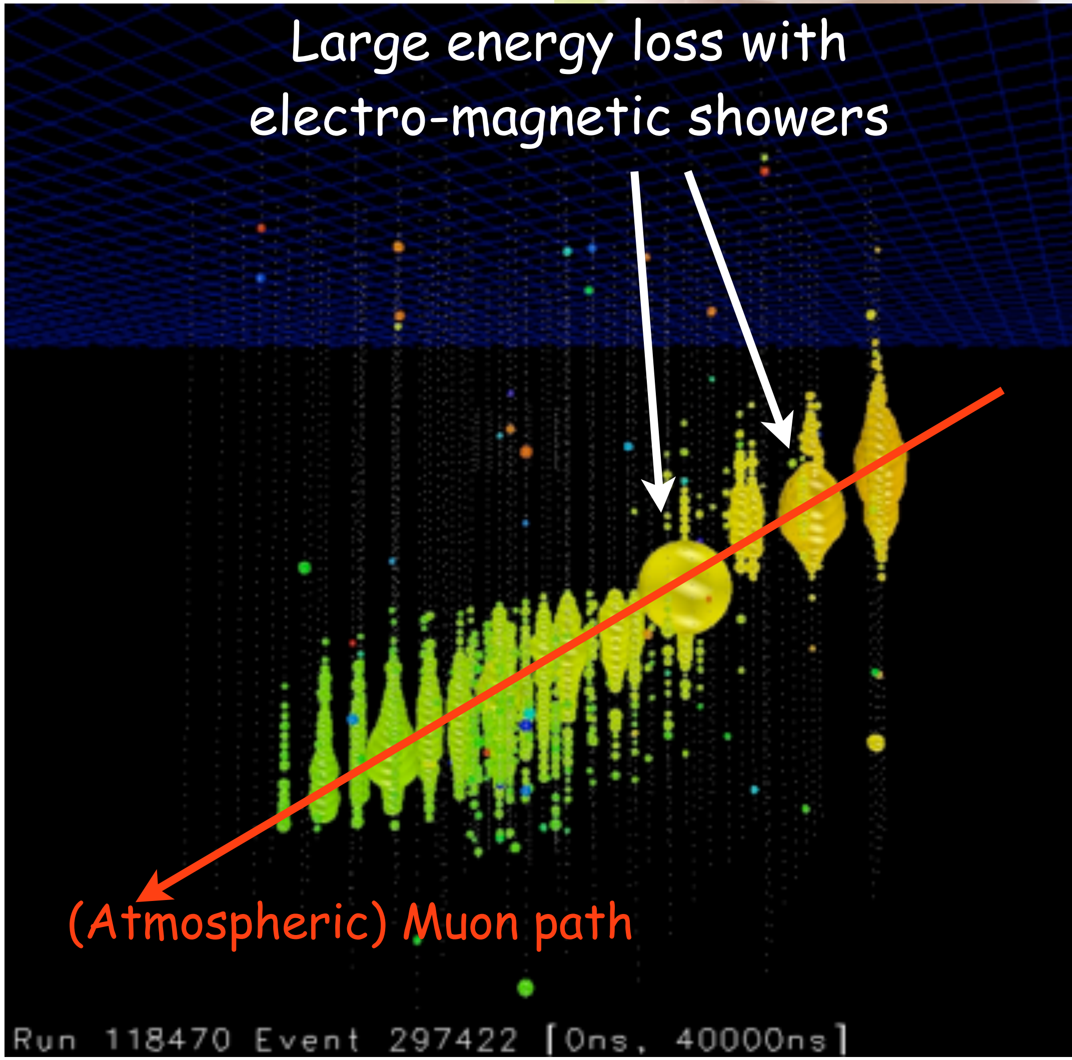




- Large amount of photons arrive after multiple scattering
- Ice property affect photon scattering and absorption

How is an event reconstructed?

- Geometry reconstruction (Direction, Position)
  - use timing and number of arrival photons
- Energy Reconstruction
  - use number of arrival photons (charge of DOMs)
- For best reconstruction we have to use our knowledge of ice properties (not uniform)

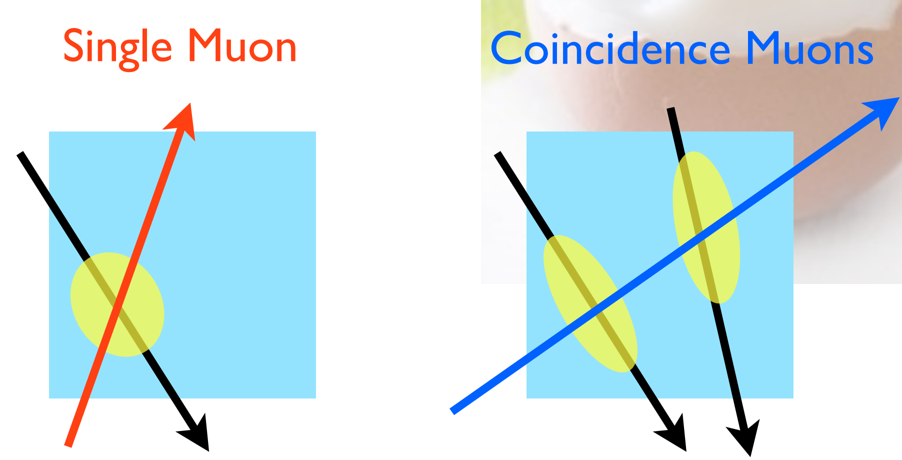


Possible future improvement (cont'd)

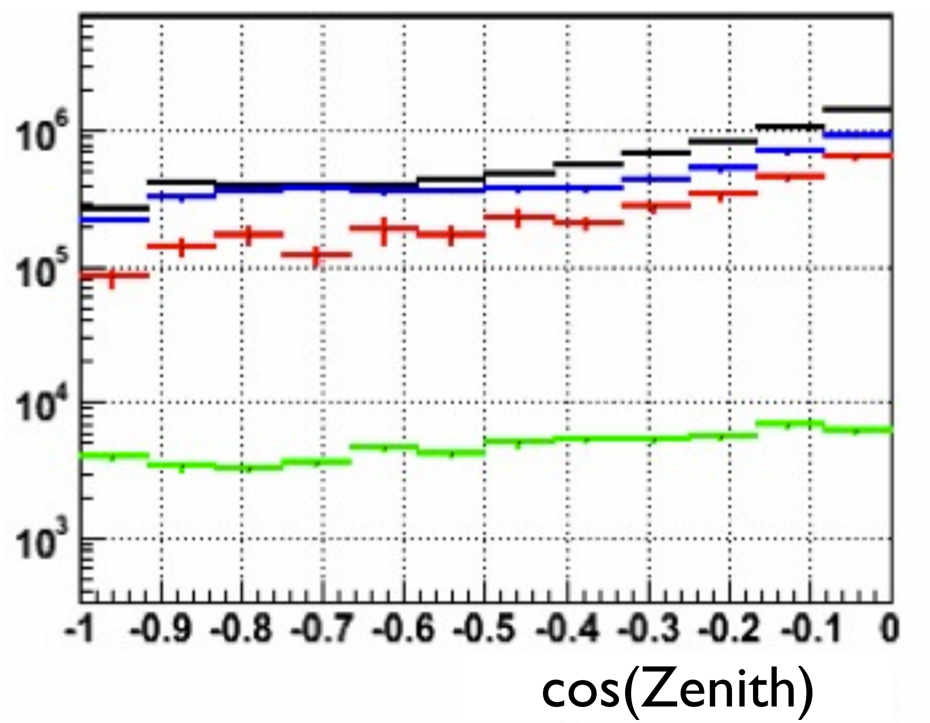
- A few ten TeV background muon may not trigger DOMs in veto area
  - Need to find optimal veto-thickness and charge-threshold
    - Since this is not discovery analysis, we don't have to remove off all possible muon backgrounds
- The air in South Pole and North Pole are not same!
  - They are always in opposite seasons, thus compensations for seasonal variation of flux need to be applied
    - A group of peoples are working for seasonal variation of atmospheric neutrino

Selecting pure neutrino induced upgoing events

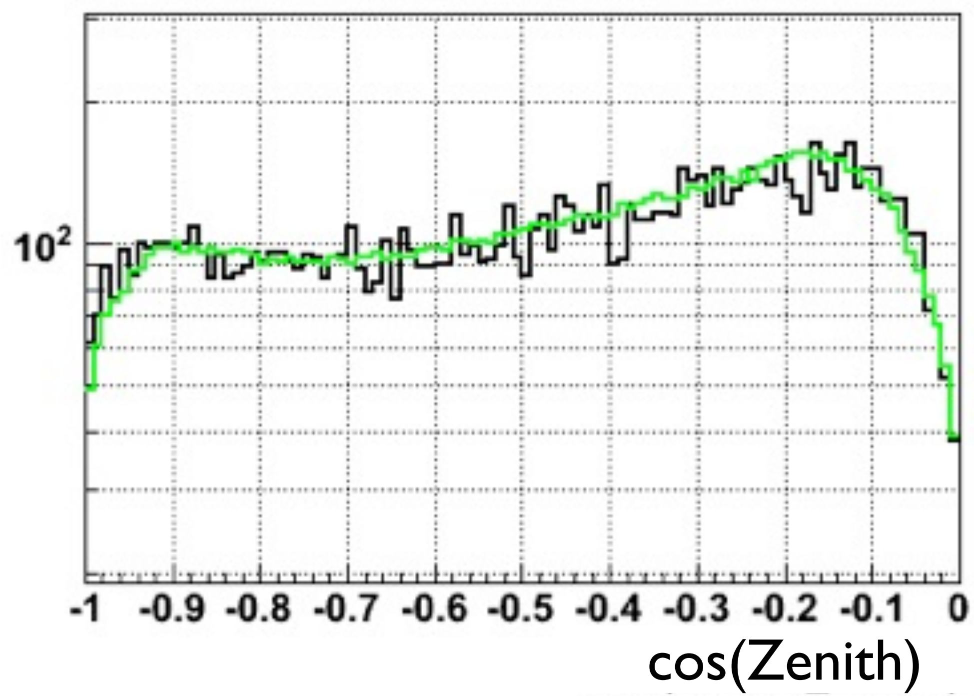
Data
Atmospheric Neutrino
Atmospheric Single Muons
Atmospheric Coincidence Muons



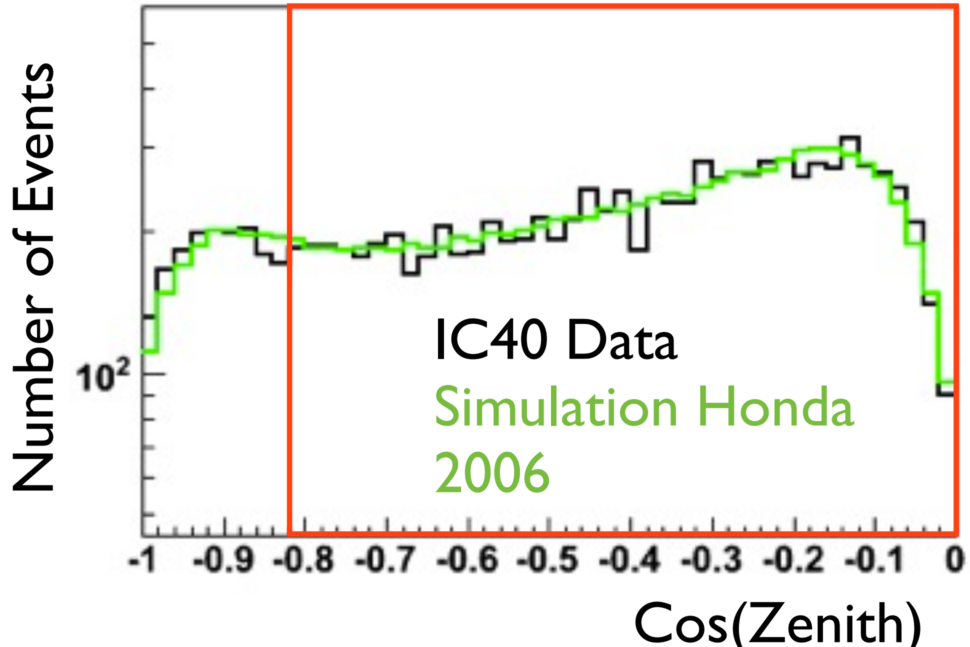
Before

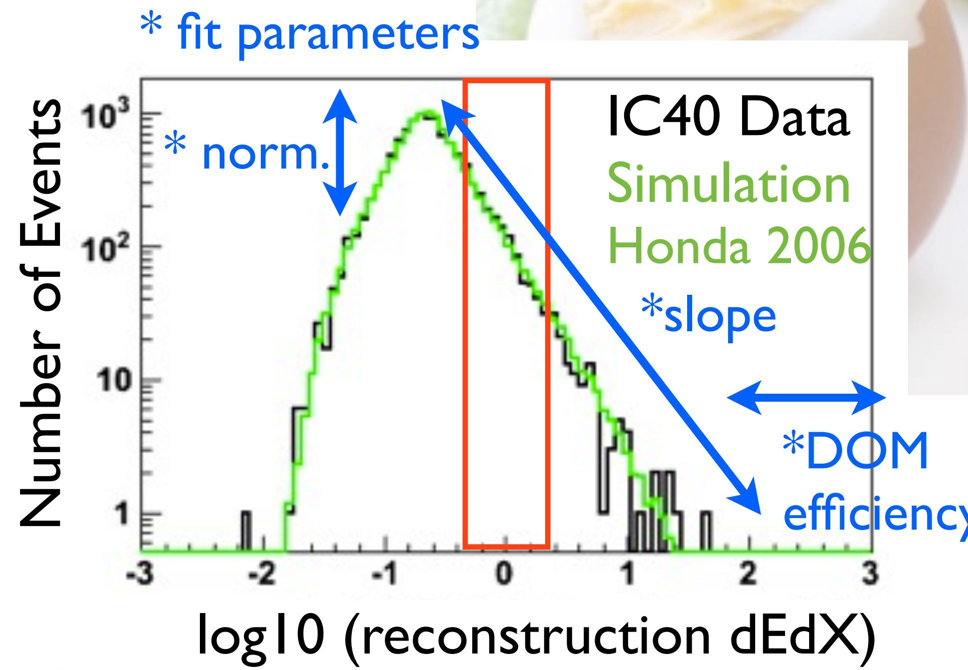


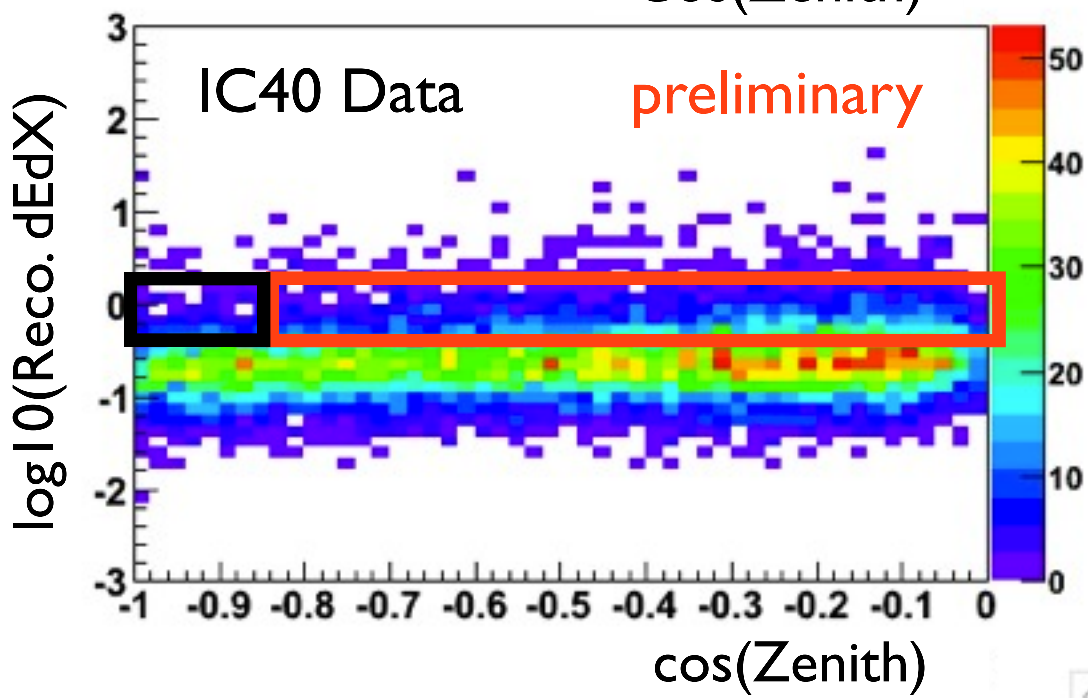
After



IC40 Analysis - After event selection





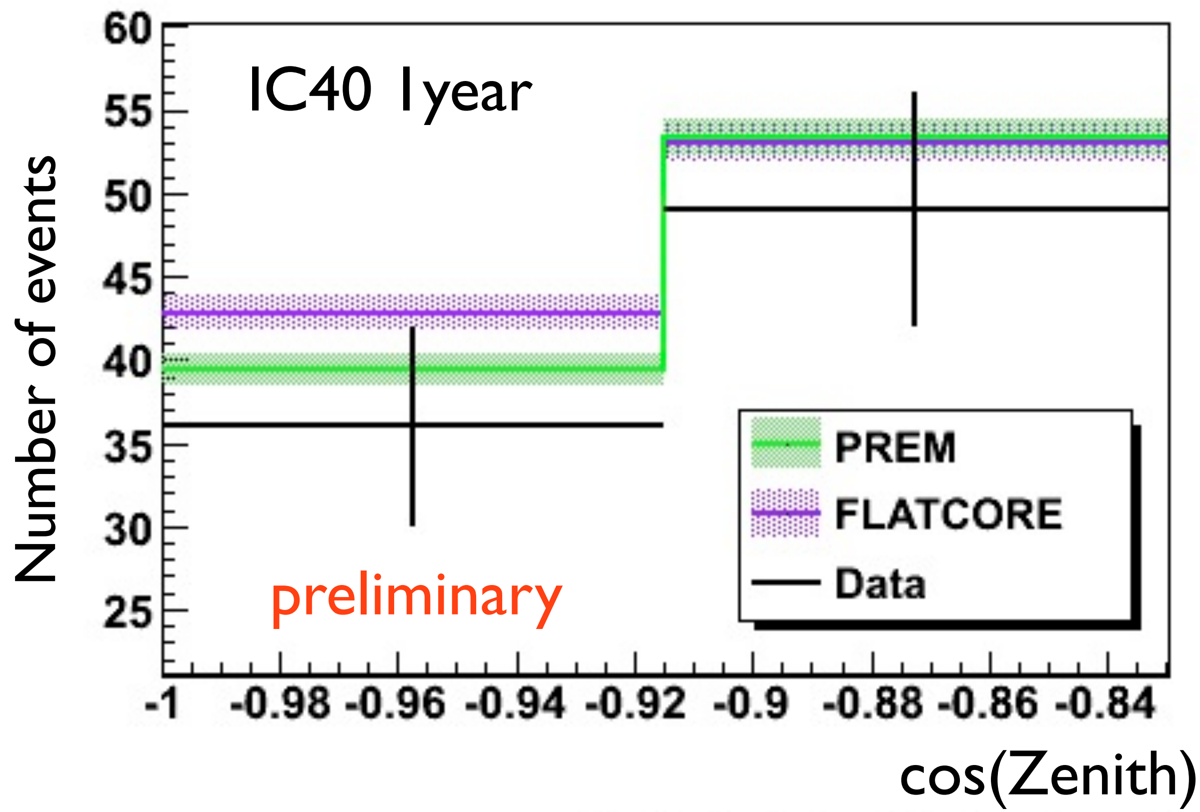


Red box - simulation is fit with data to obtain fit parameters

Black box - Using fit parameters, simulations are compared with data

Comparison of Zenith at Core Region IC40 Data vs Simulations

Color mesh shows statistical errors of center of predictions
(due to limited simulation statistics)

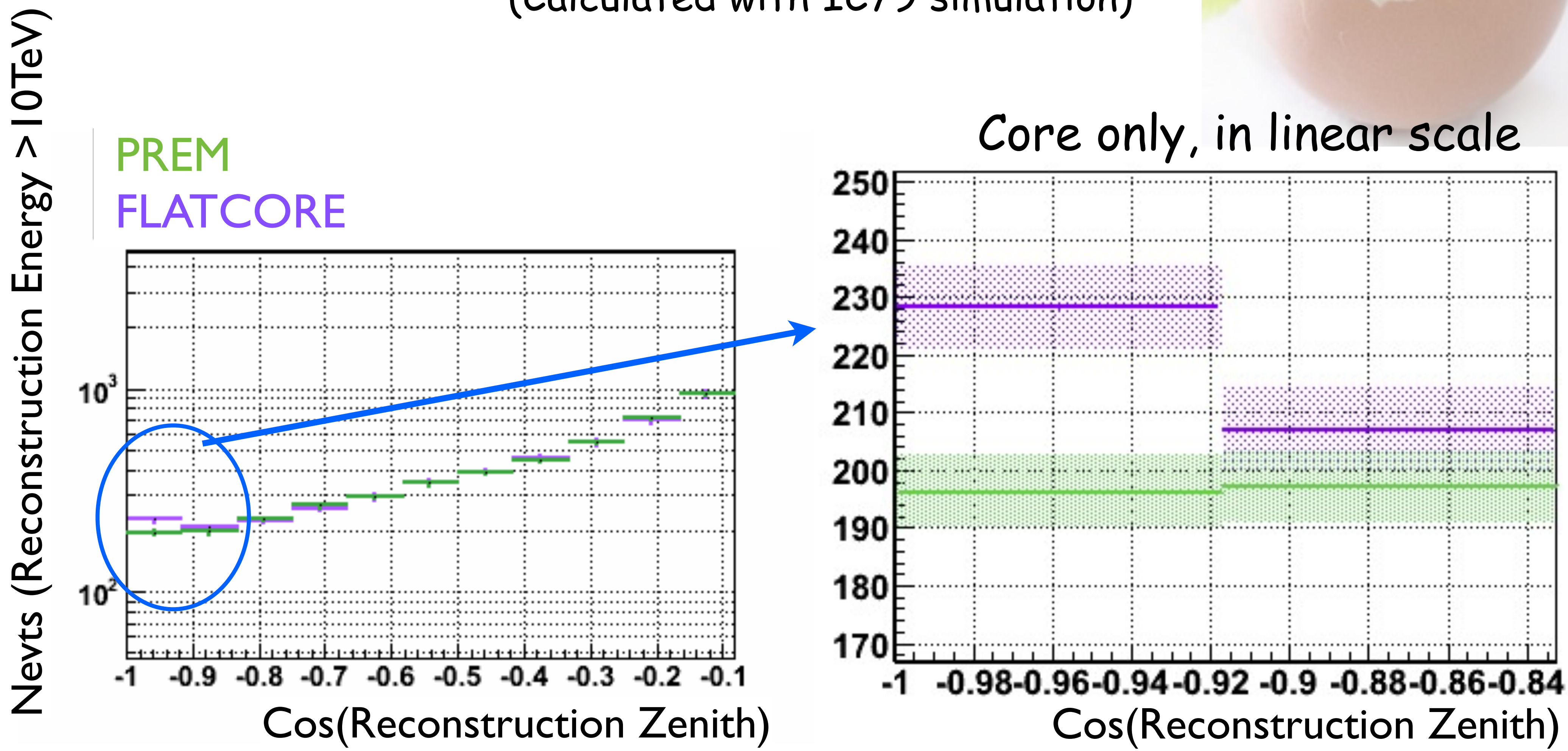


Separation of PREM and FLATCORE predictions is within statistical errors of IC40 one year data.
IC40 is not sensitive to model difference.

Simulation with IC79 10 years

very conservative estimation of ~10yr measurement

(Calculated with IC79 simulation)

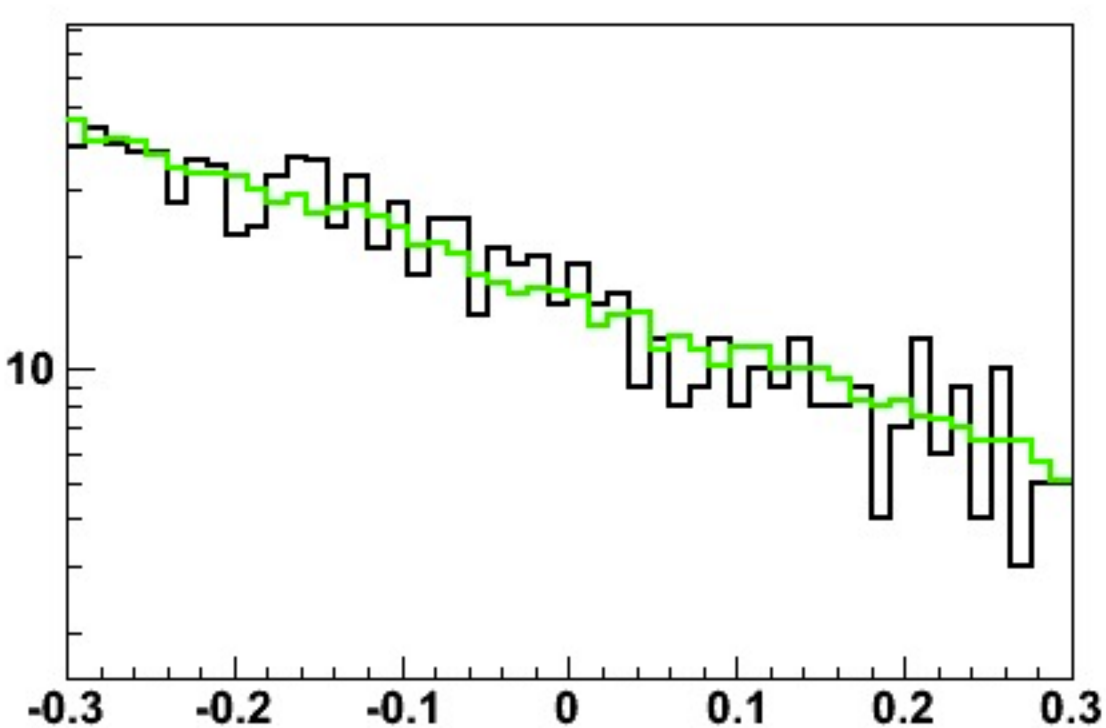


Errors are statistical uncertainty of center prediction due to limited simulation statistics

Fitting simulation with data at Mantle region

Data

Simulation Honda 2006



log10 (Reconstruction dEdX [GeV])

- 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