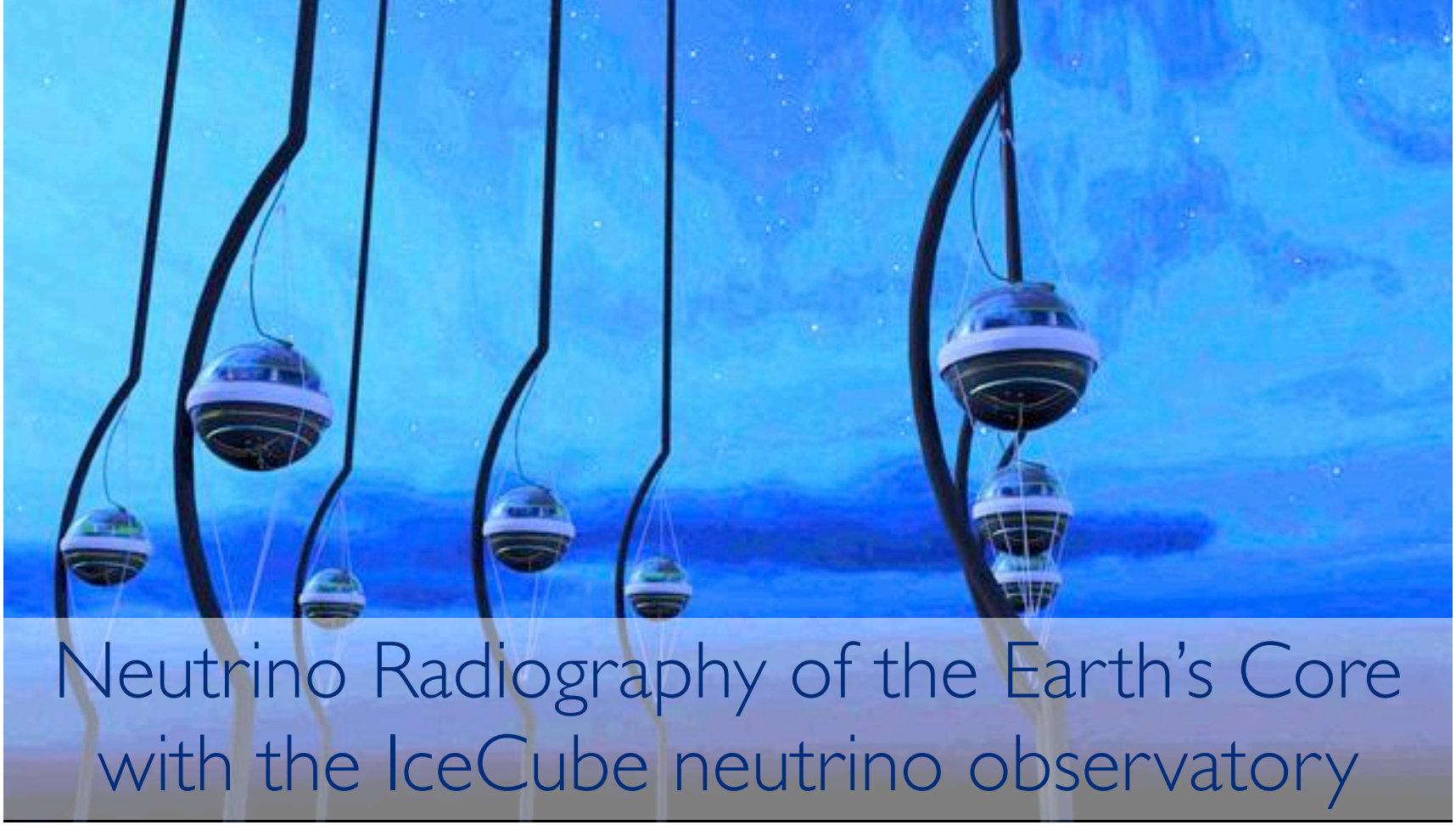

Neutrino Radiography of the Earth's Core with the IceCube neutrino observatory

Apr. 19 2012 Muon and Neutrino Radiography 2012 @ Clermont Ferrand

Kotoyo Hoshina, Hiroyuki Tanaka
and IceCube Collaboration

IceCube
South Pole Neutrino Observatory

NSF

Earthquake Research Institute,
The University of Tokyo

The IceCube Collaboration

International Funding Agencies

Fonds de la Recherche Scientifique (FRS-FNRS)
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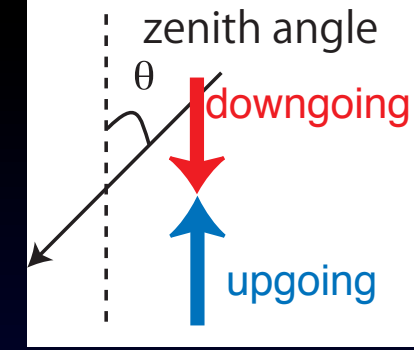
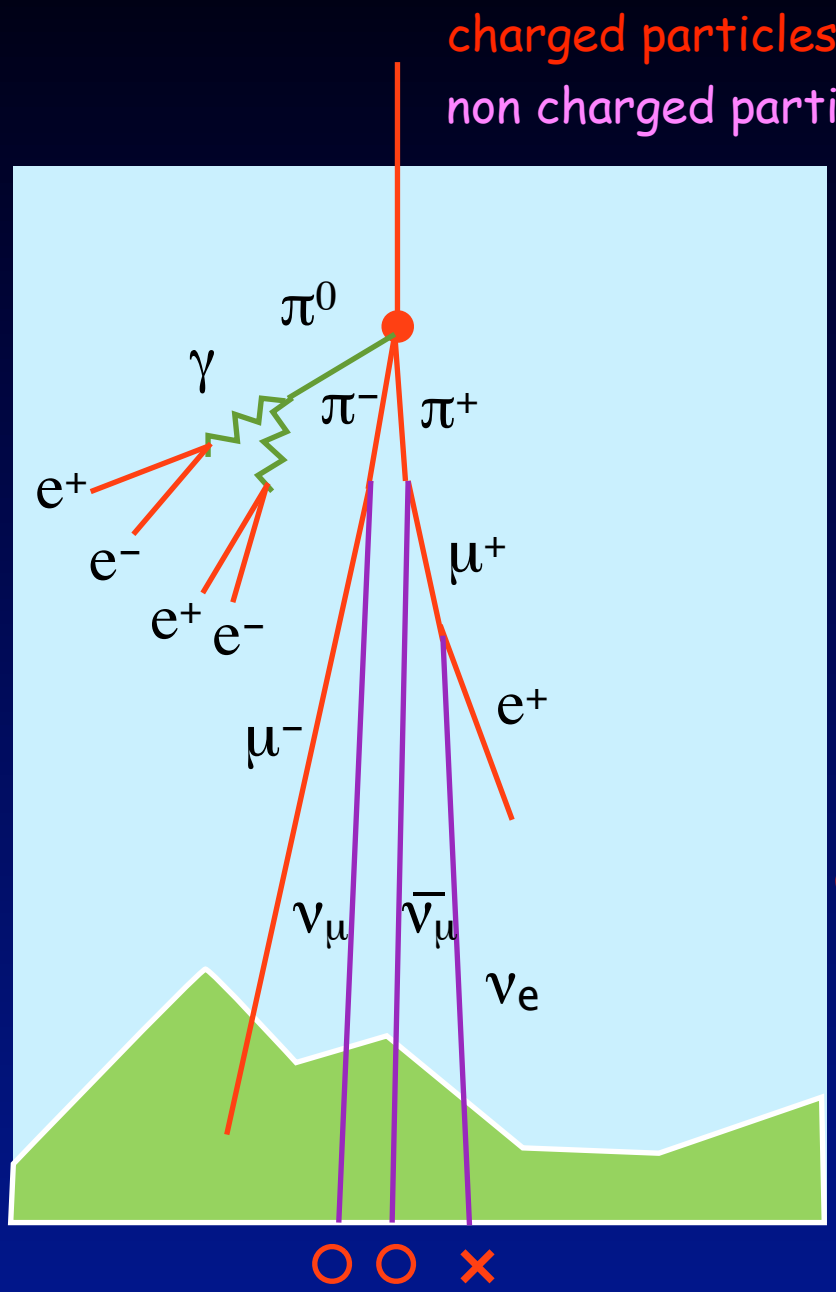
Knut and Alice Wallenberg Foundation
Swedish Polar Research Secretariat
The Swedish Research Council (VR)
University of Wisconsin Alumni Research Foundation (WARF)
US National Science Foundation (NSF)

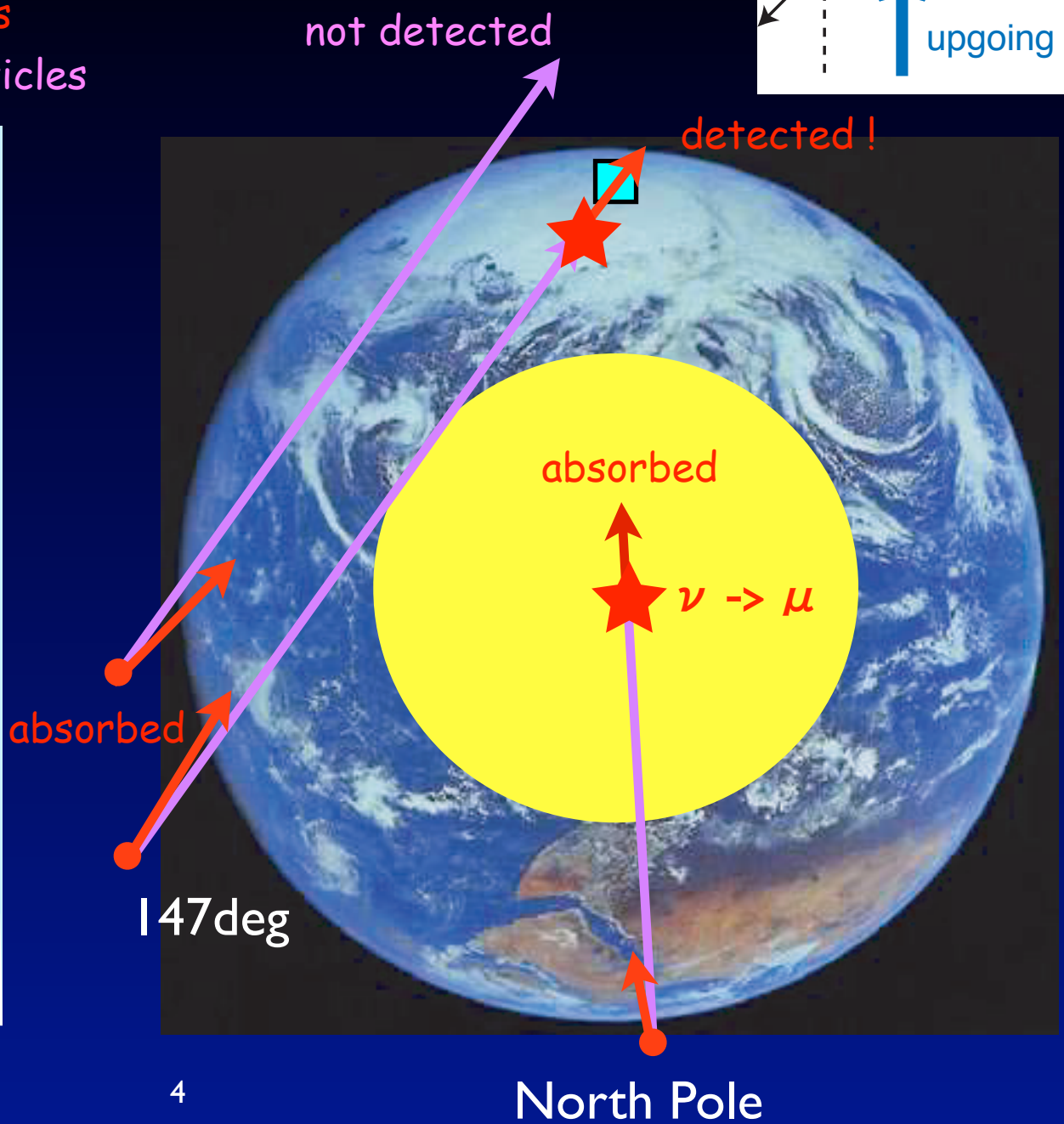
Mission of IceCube observatory

- Discoveries
  - Detection of high-energy extra-terrestrial neutrinos and exploration of their origin
  - Exotic Science (Monopole, DarkMatter, etc...)
- Measurements
  - Cosmic Ray Anisotropy
  - Atmospheric Neutrino Flax
  - Neutrino Oscillation (with DeepCore detector)
  - Neutrino Radiography -- Today's Talk!

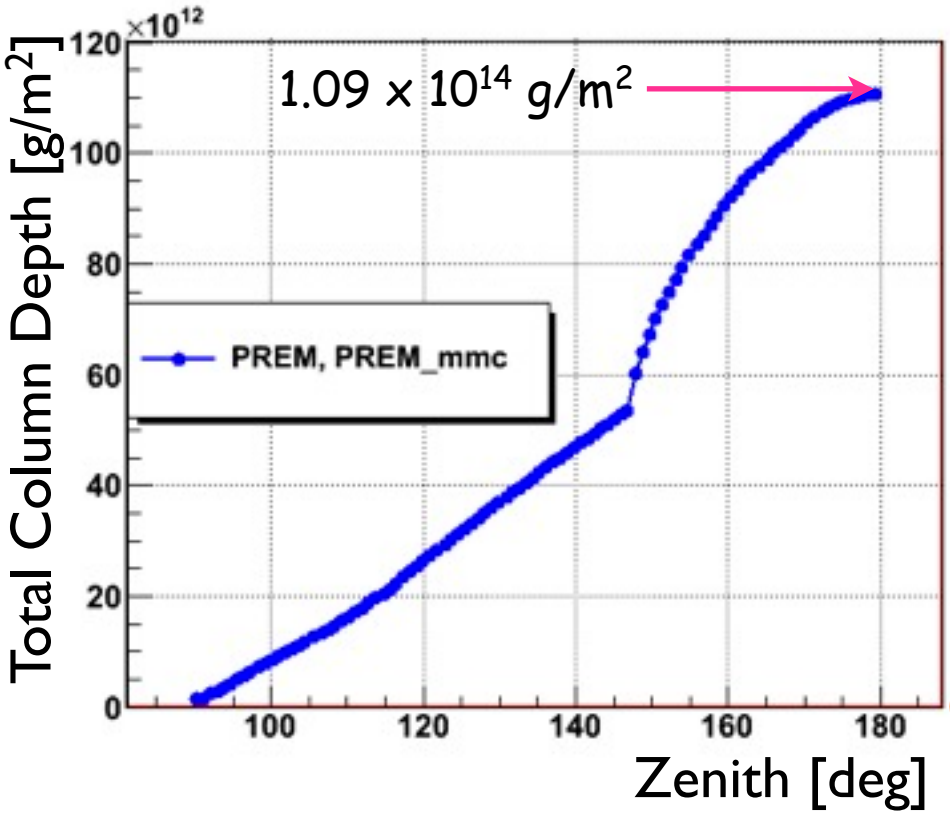
Measuring Core Density of the Earth

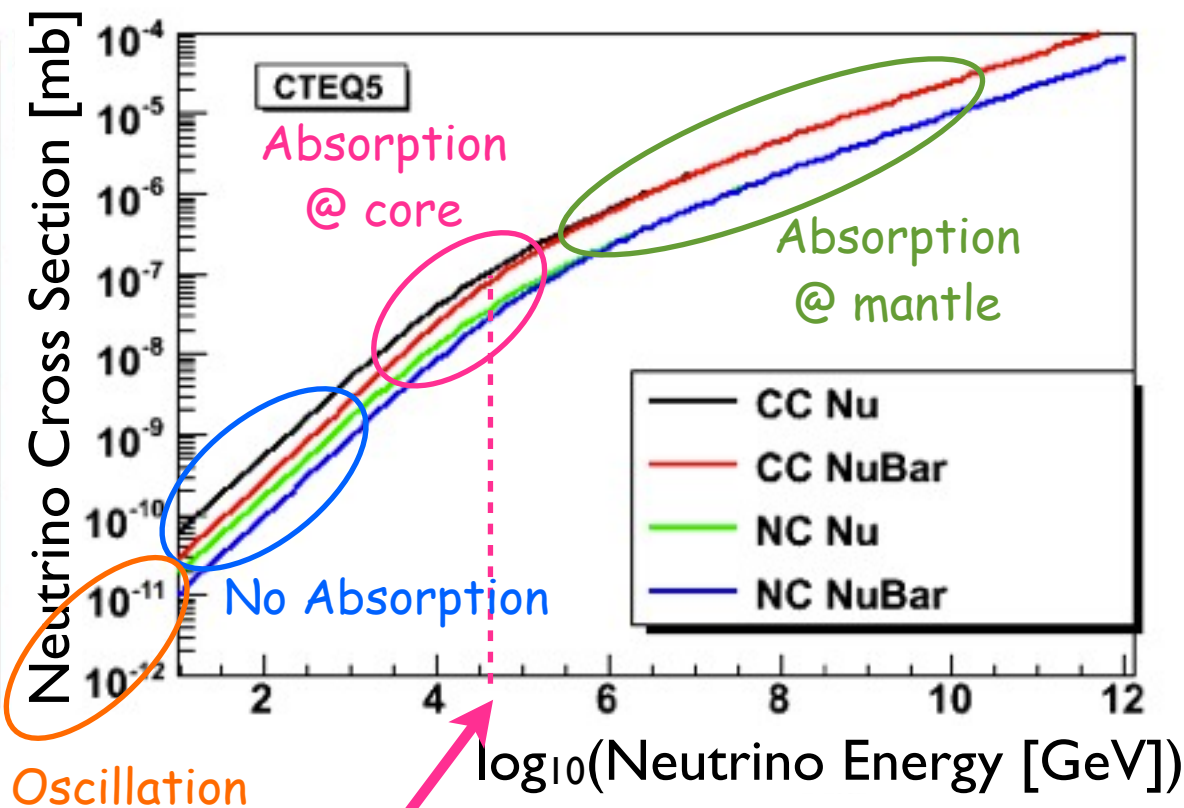






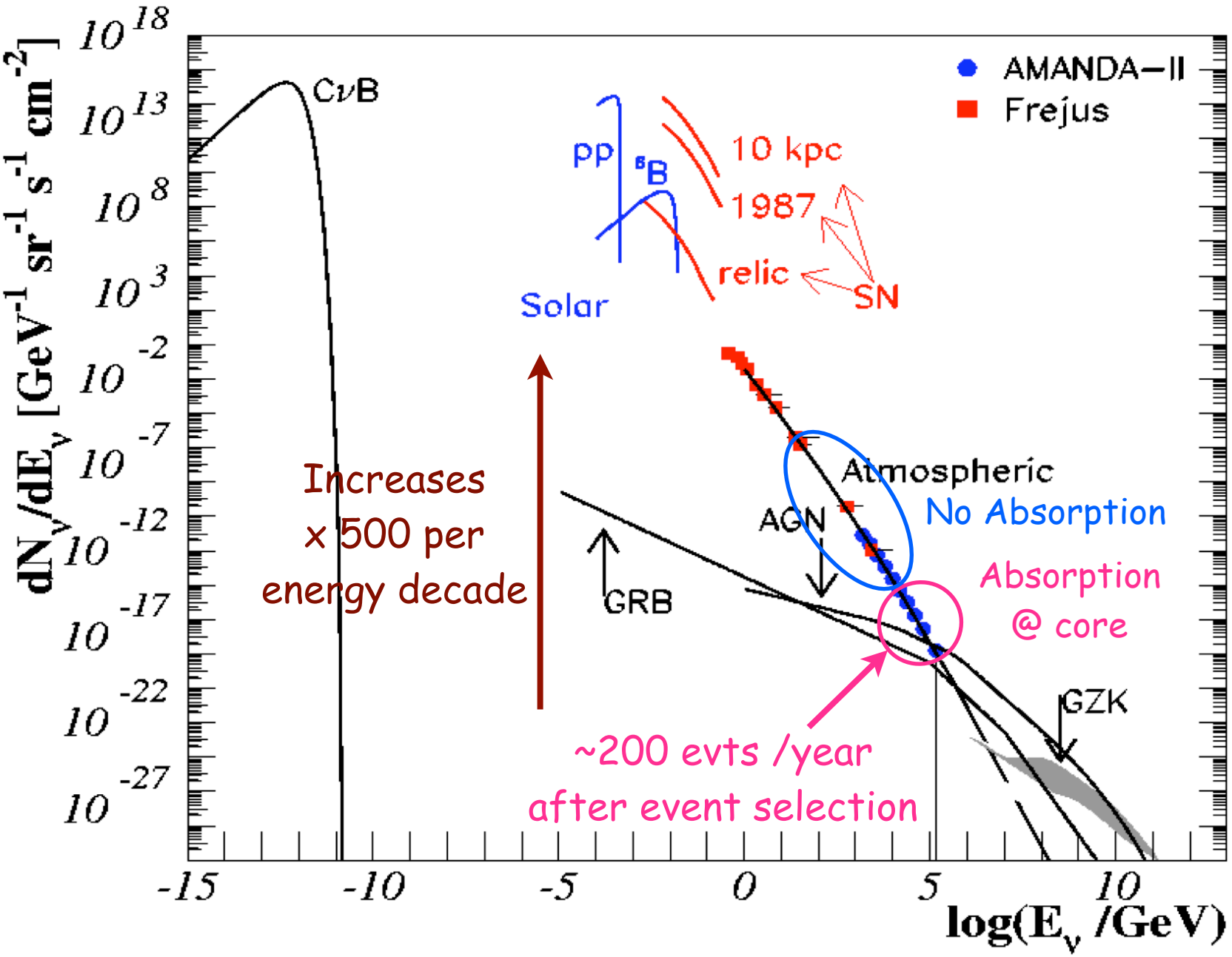
Absorption of Neutrino depends on energy





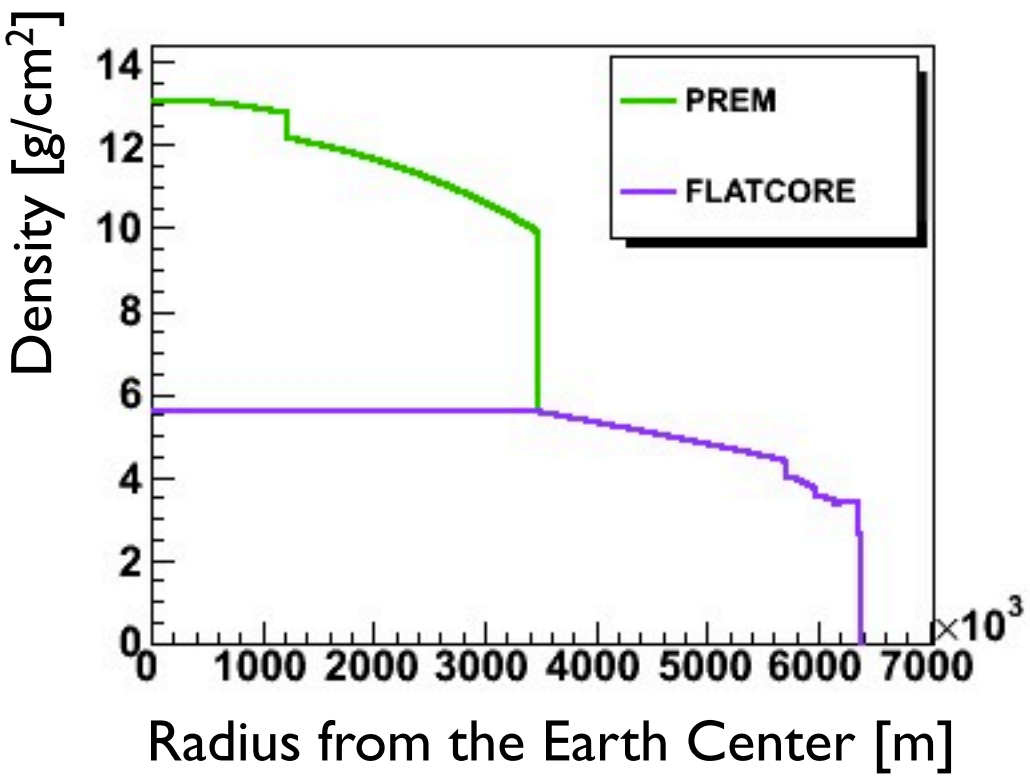
Mean free path of ~40TeV neutrino is equivalent to the Earth's total column depth at 180 deg

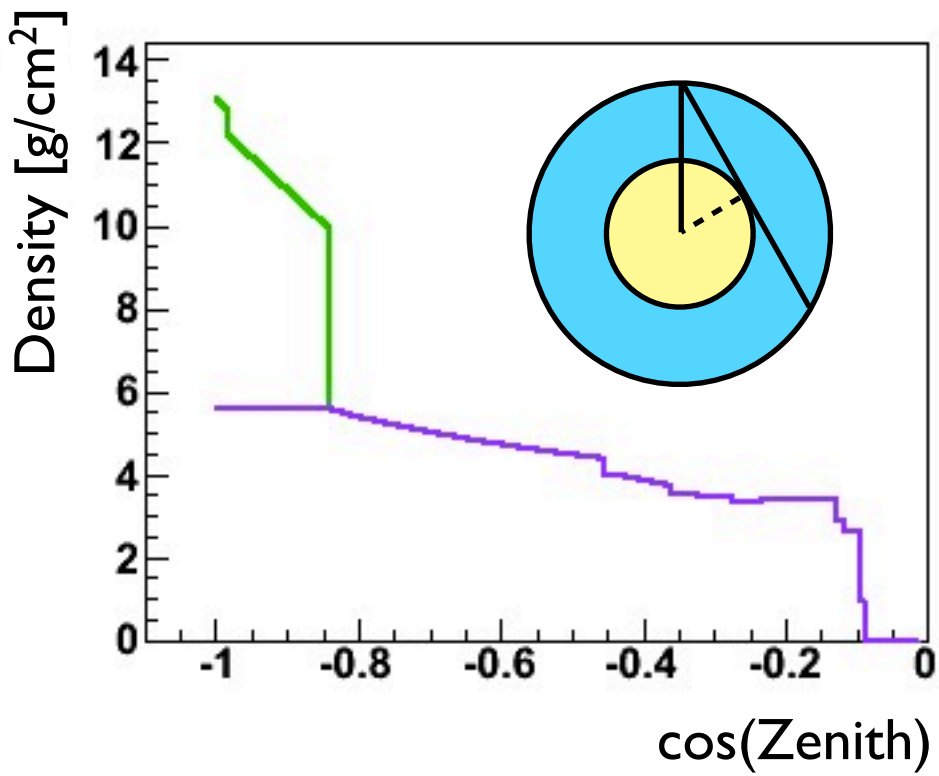
Neutrino Flux



PREM vs FLATCORE model

PREM (Preliminary Reference Earth Model)
FLATCORE (Density of Core is constant)

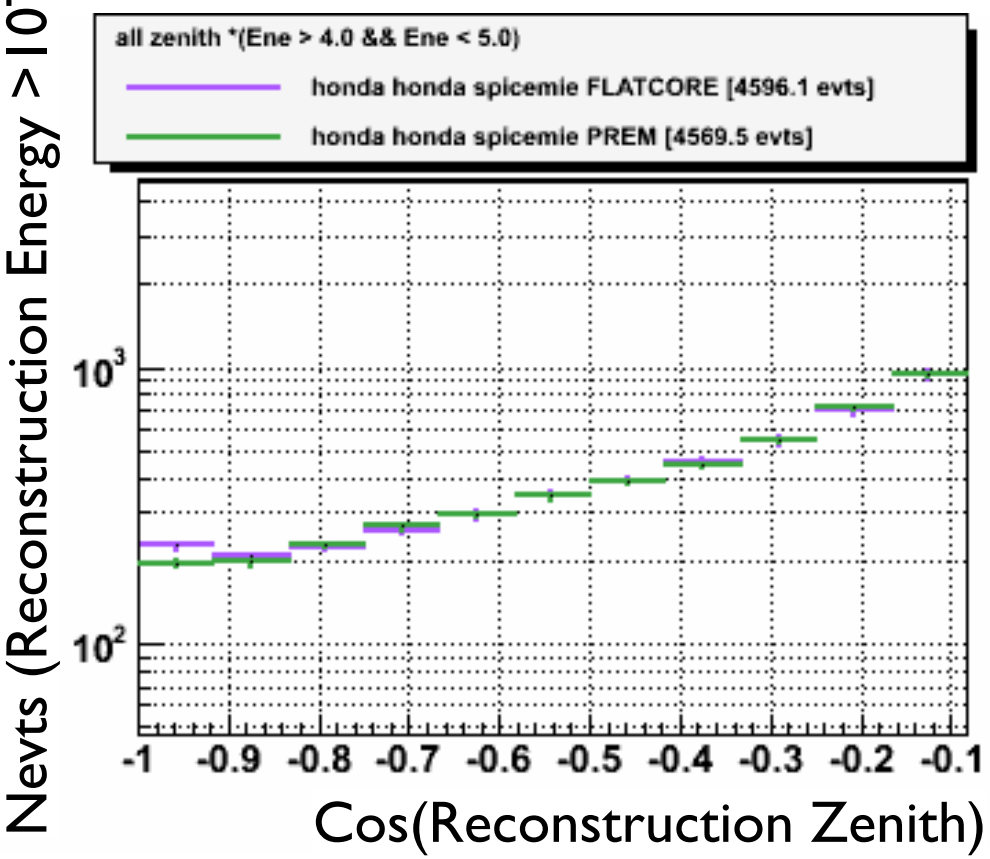


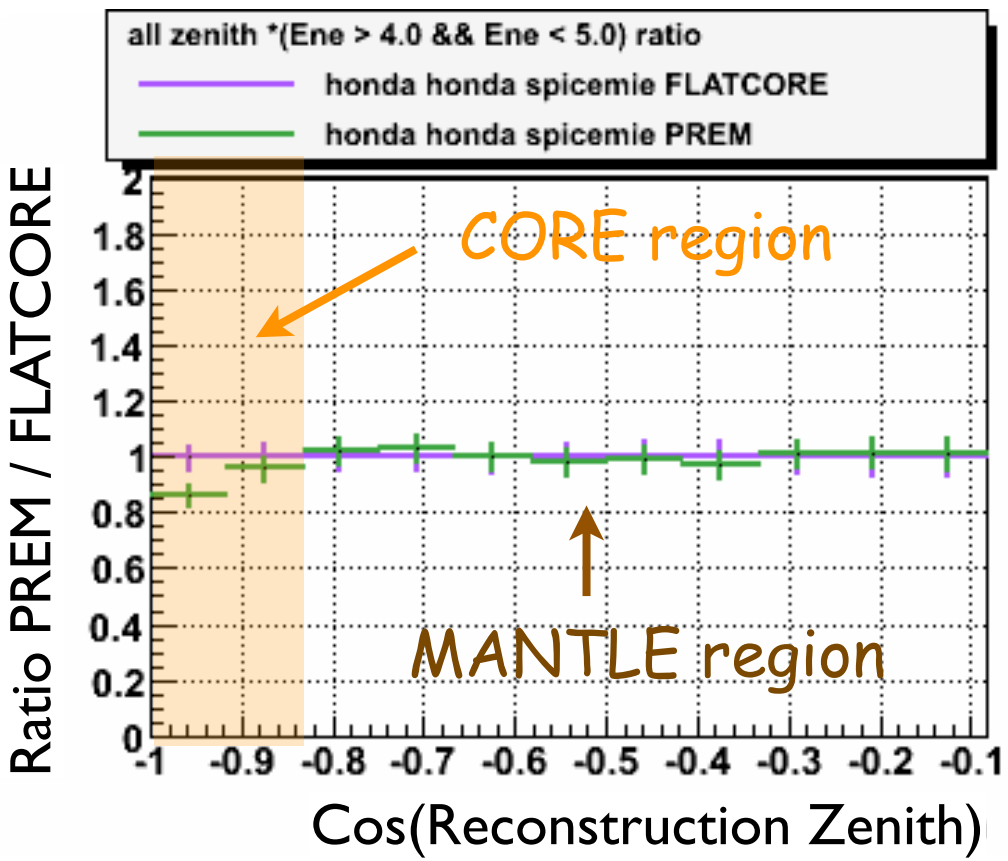


FLATCORE model doesn't conserve Earth's mass, but still useful to estimate the resolution of Earth's density at core angle with the IceCube

What do we want to measure?

Event deficit at core region in CosZenith plot!



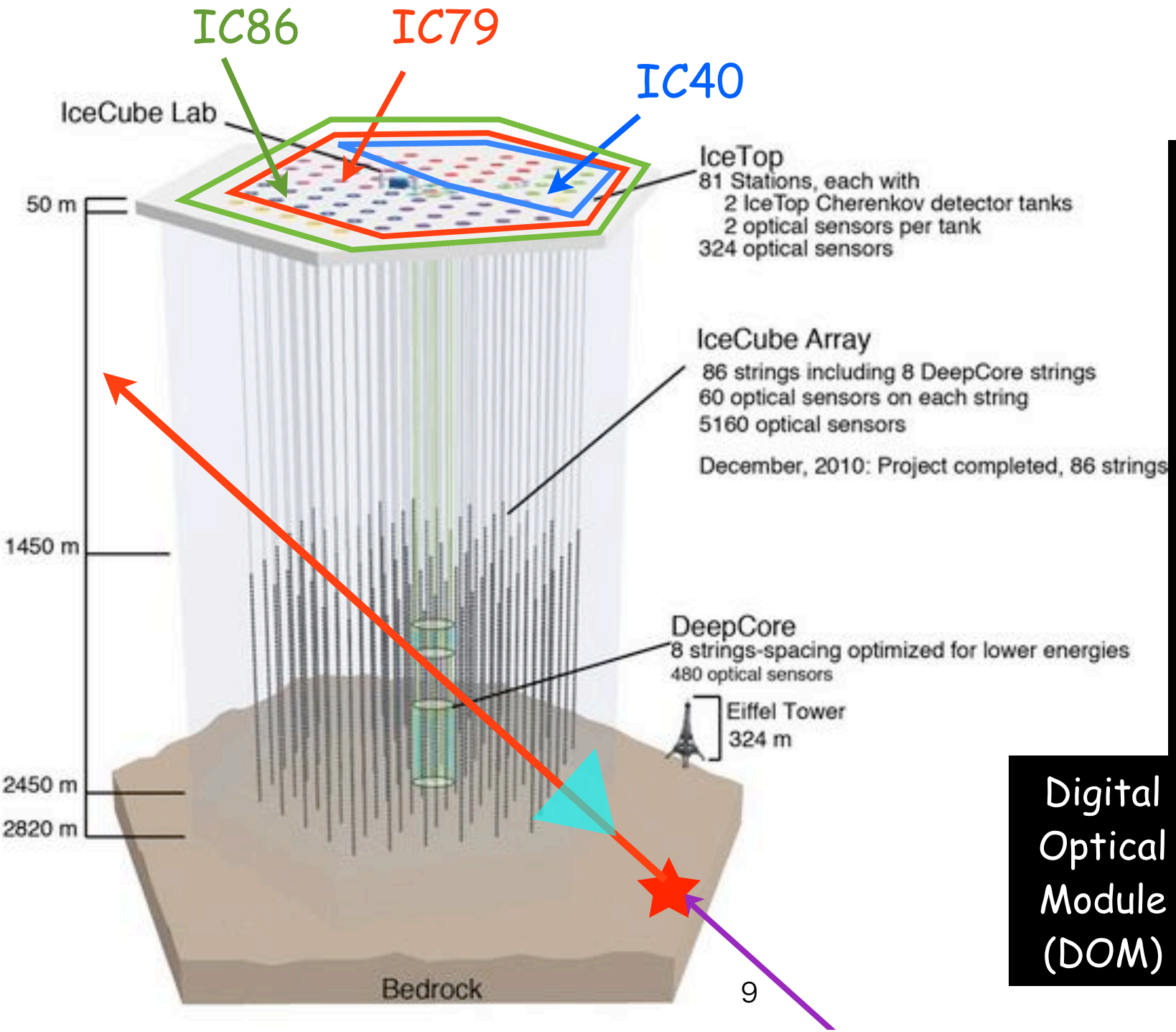


very conservative estimation of ~10yr measurement

(Event selection is NOT optimized)

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

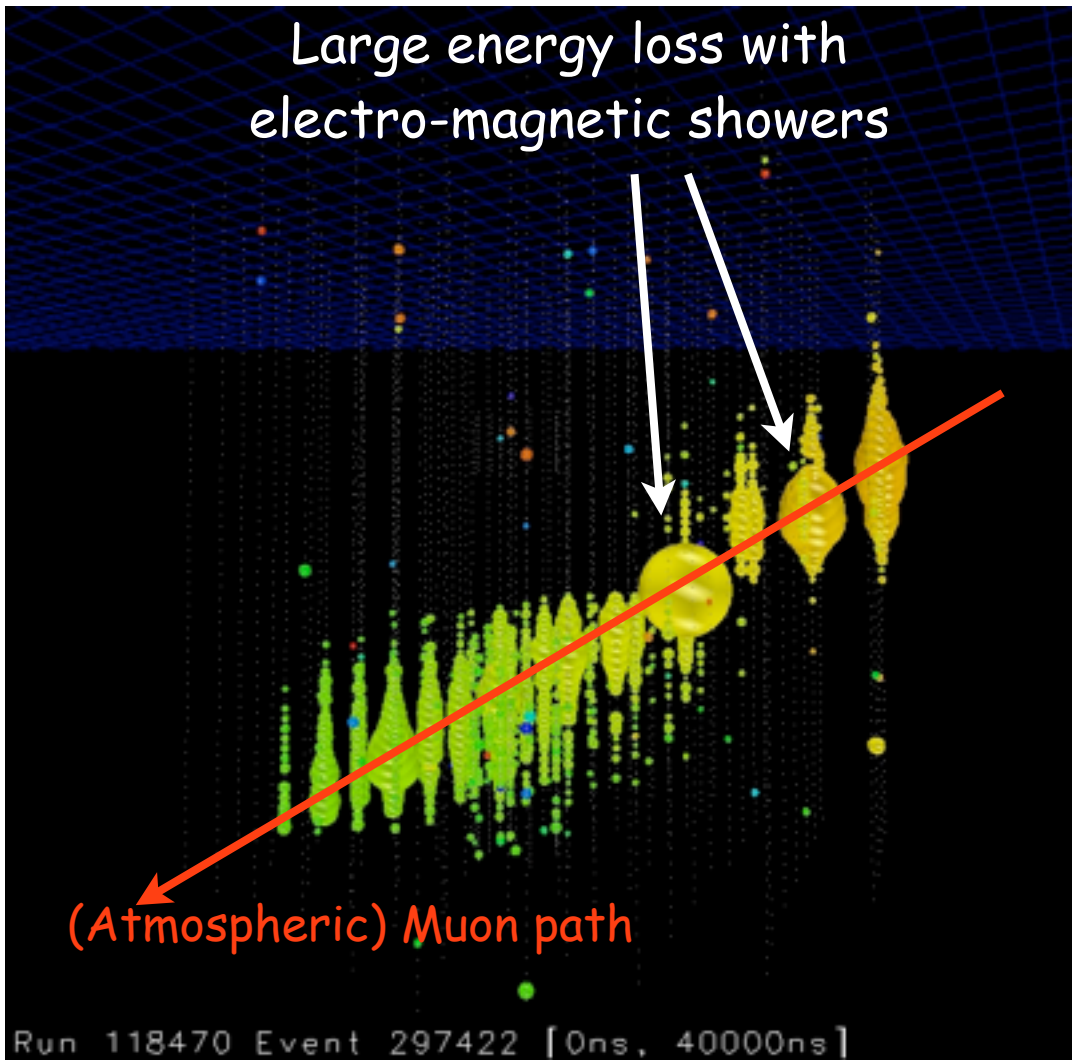
IceCube Structure



Digital Optical Module (DOM)

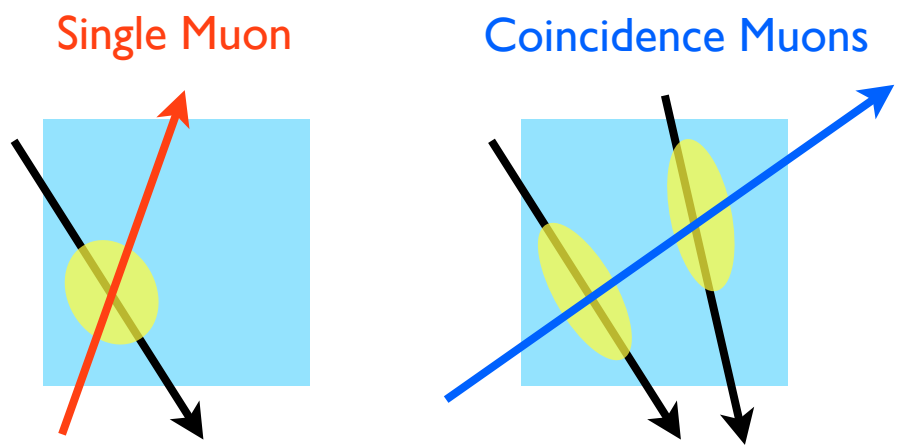
How an event is reconstructed?

- 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 property (not uniform)

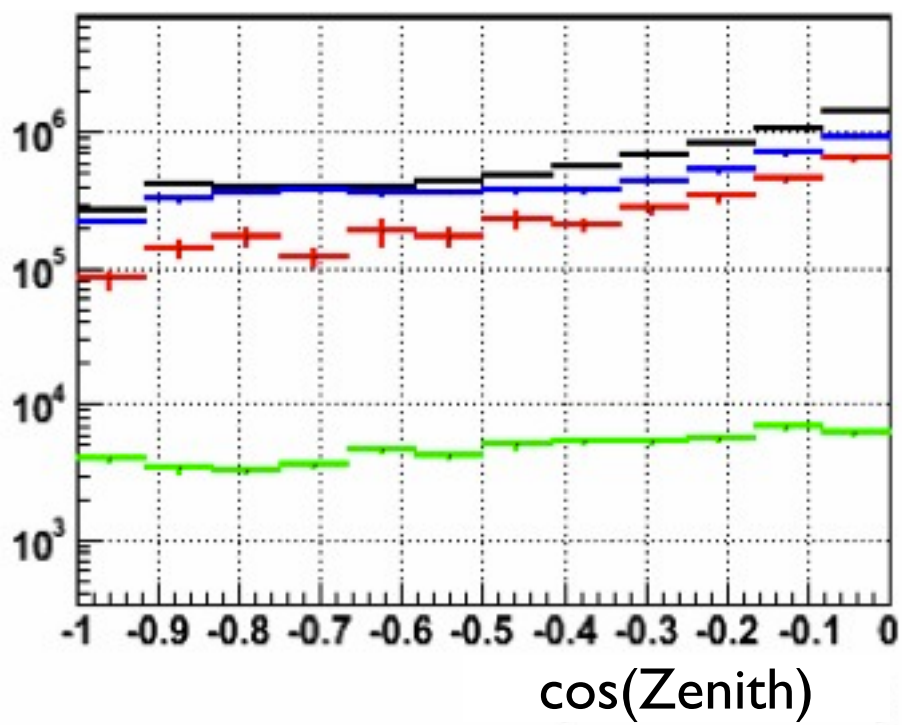


Selecting pure neutrino induced upgoing events

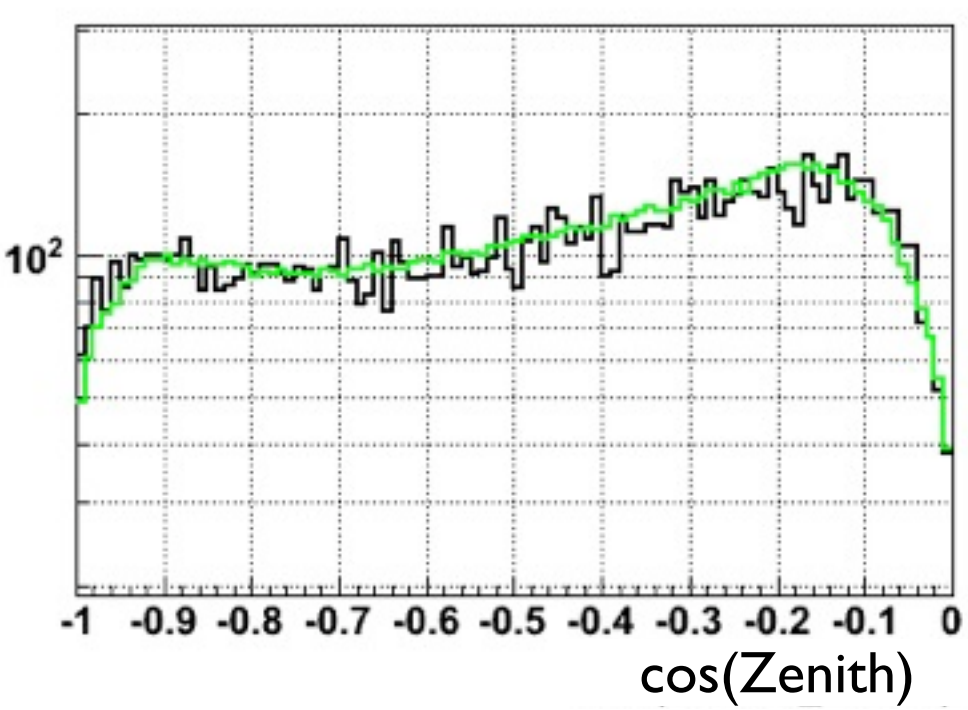
Data
Atmospheric Neutrino
Atmospheric Single Muons
Atmospheric Coincidence Muons



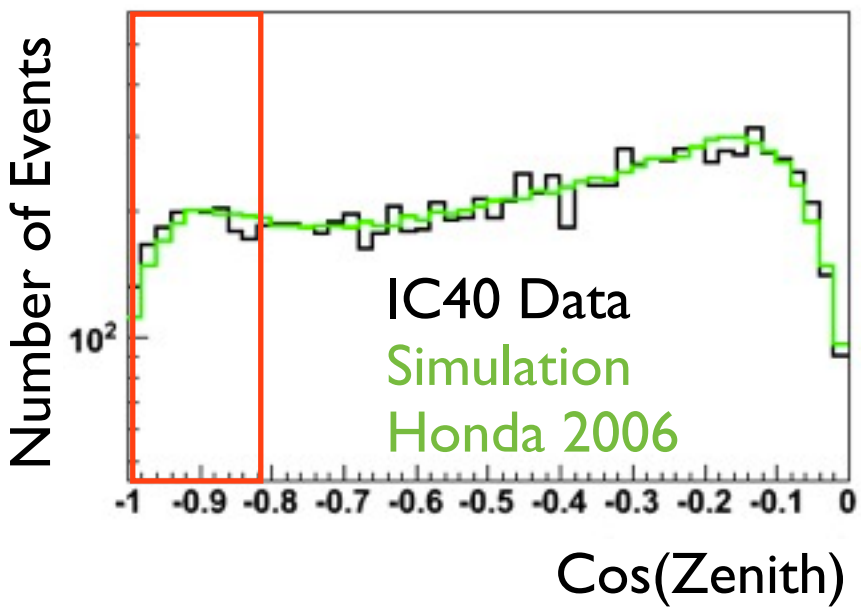
Before

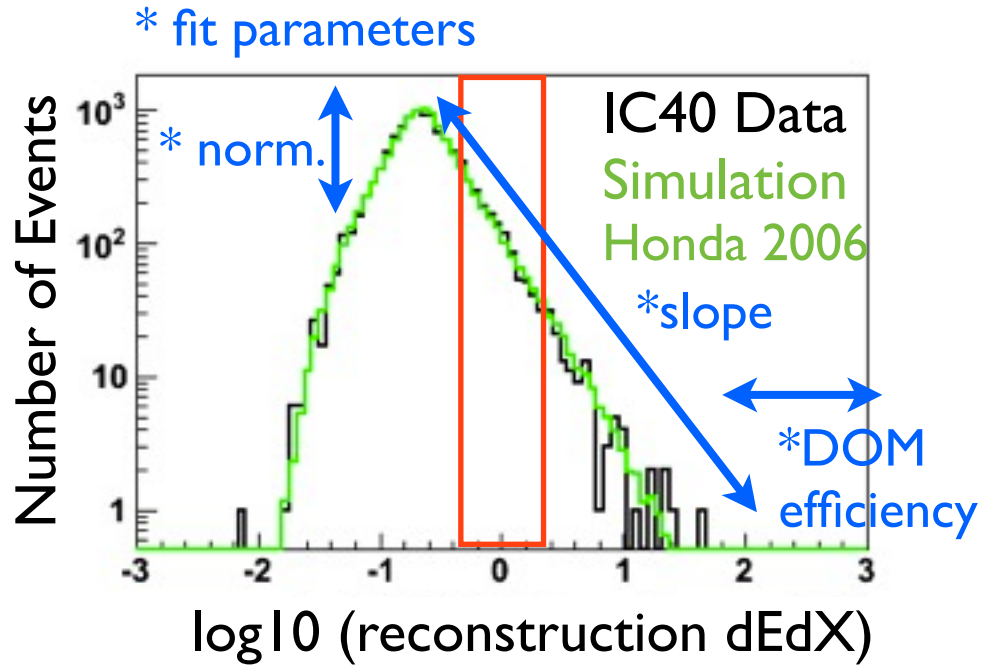


After

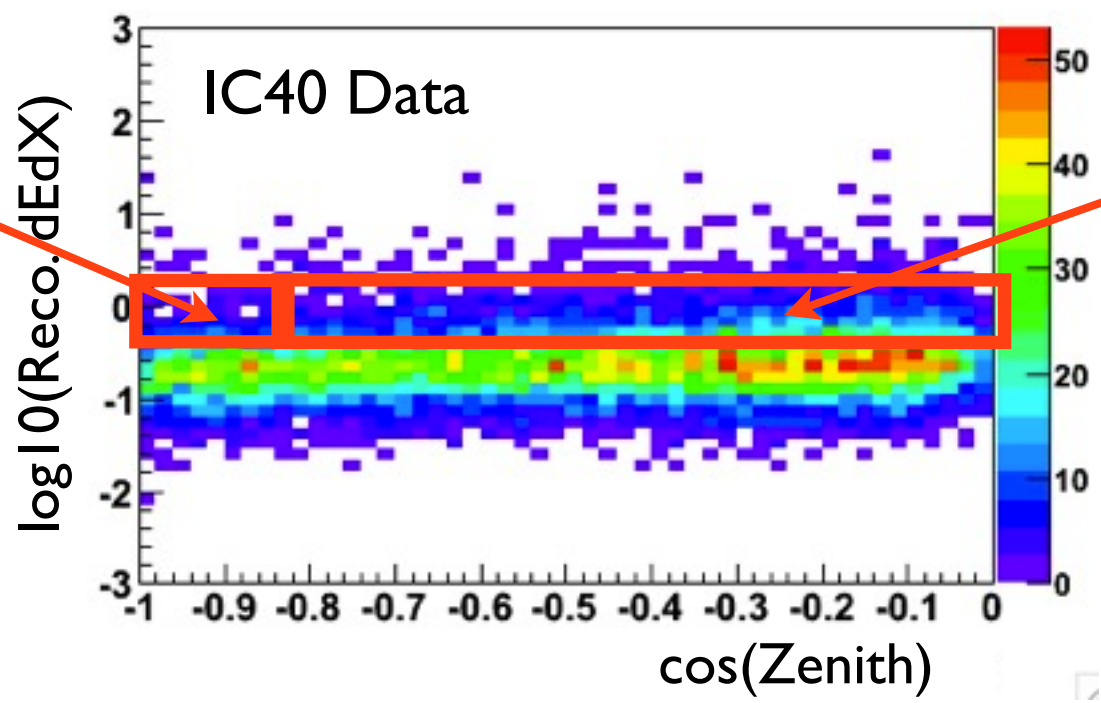


IC40 Analysis - After event selection





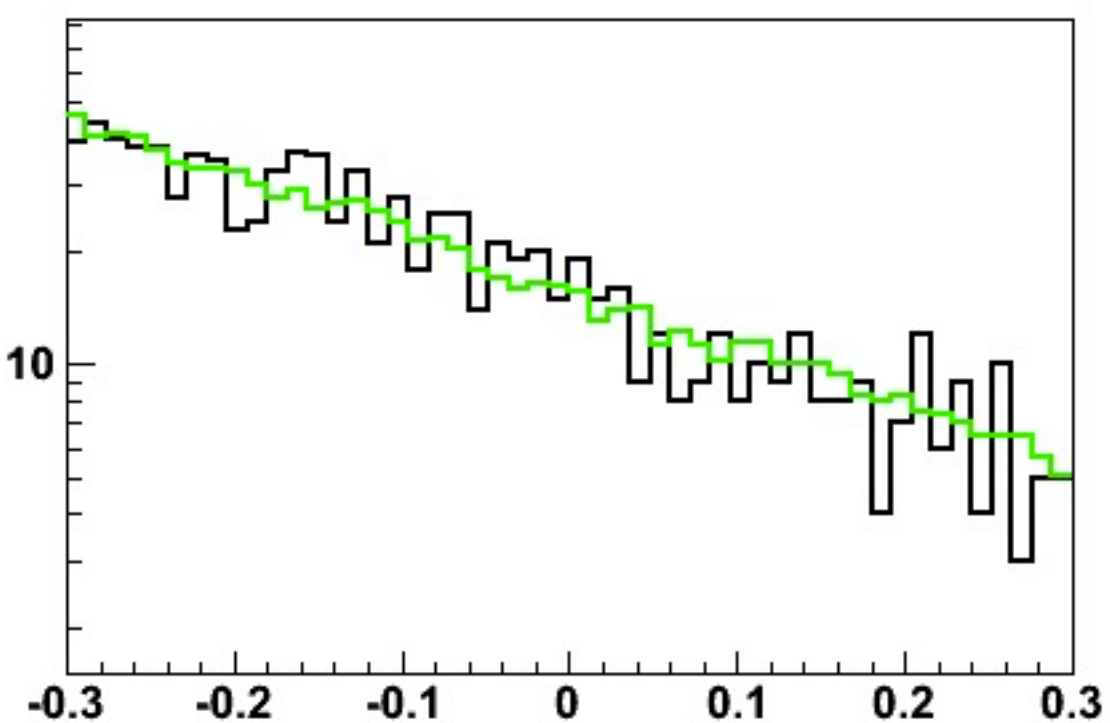
Compare this part with Honda 2006 PREM and FLATCORE simulations



Use this part for flux fit

Fitting simulation with data at Mantle region

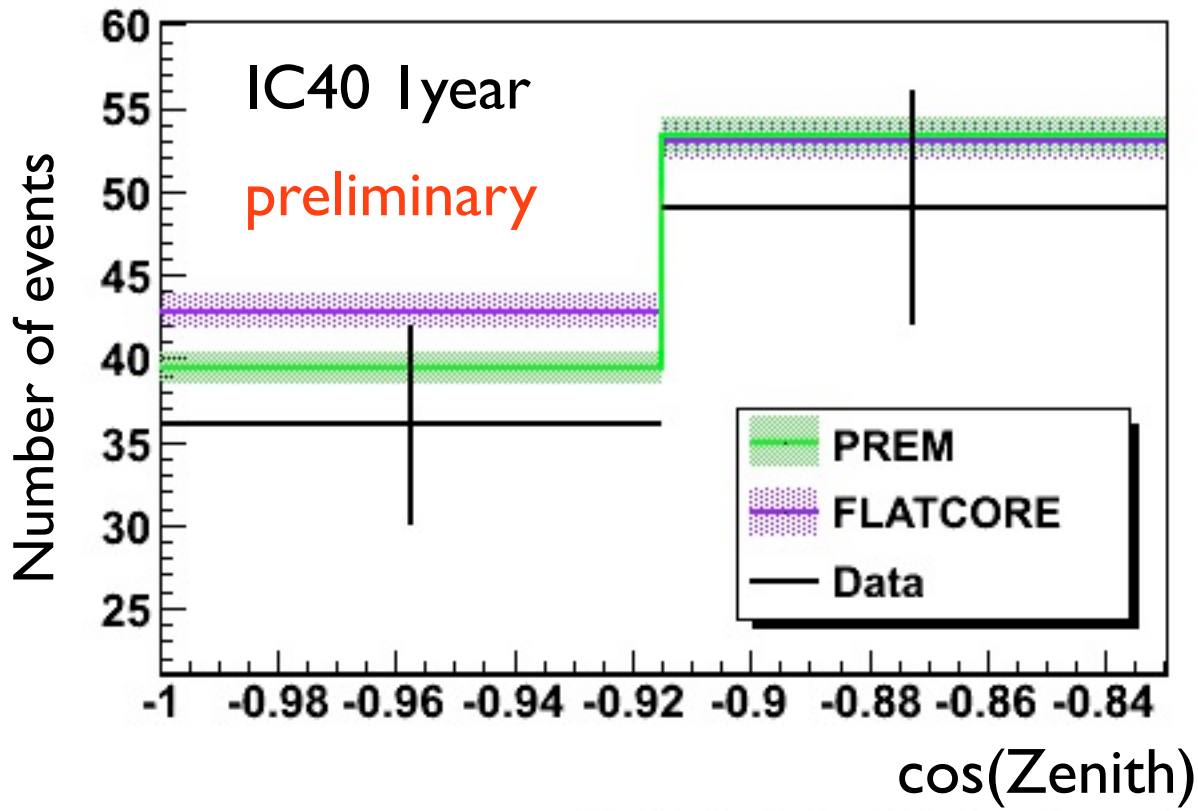
Data
Simulation Honda 2006



- 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
IC40 Data vs Simulations

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



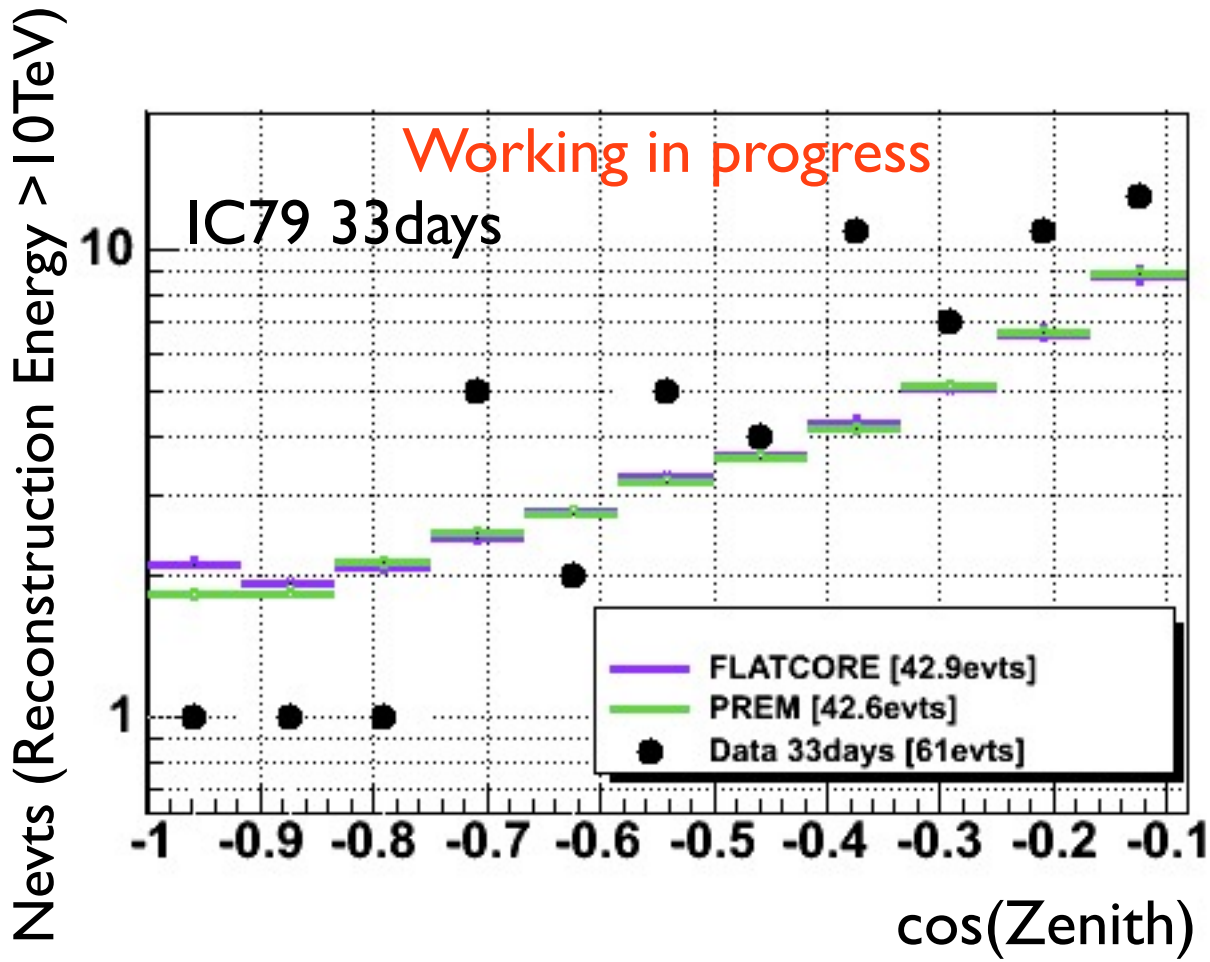
Separation of PREM and FLATCORE predictions is within statistical errors of IC40 one year data.
IC40 is not sensitive to model difference.

NEXT step : IC79?

- IC79 is double the size of IC40.
  - Number of events will be doubled from IC40.
  - Still it will NOT have separation power between PREM and FLATCORE models.
  - However, we may check if we see same trend with IC40 data or not.
- Keep everything simple -- just use IC40 analysis
  - Our current detector IC86 is different from IC79. Fine tuning should be studied with IC86.
- IC79 full year data is not unblinded yet.
  - currently only 10% data (33 days) is available.

IC79 33 days data and simulation with IC40 analysis

- Event selection and analysis are NOT optimized for IC79
- No fit applied to simulations with Data
- With one year data we have only half number of events of IC40 at CORE bins

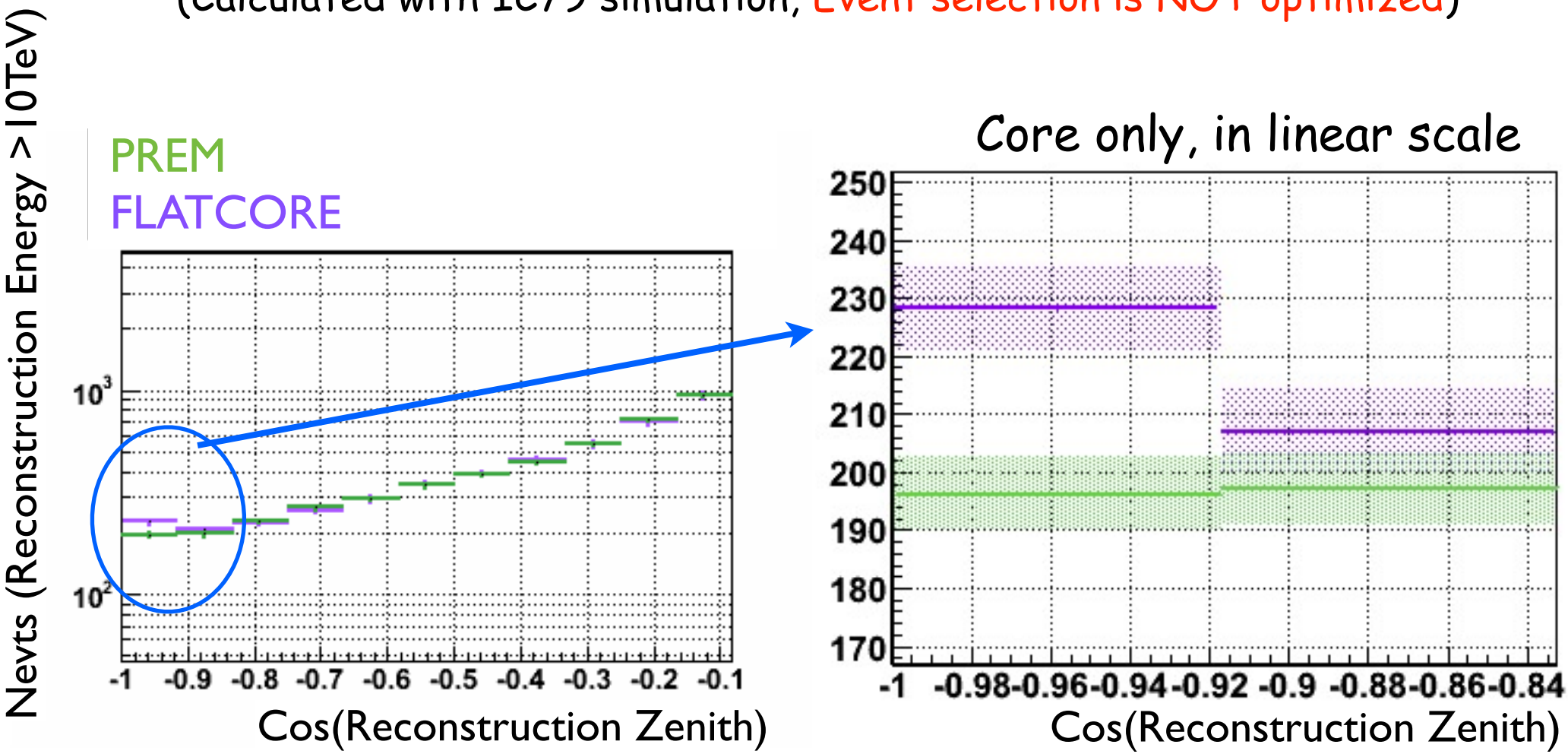


- Moderate optimizations will be needed to confirm trend of IC40 data.

Simulation with IC79 10 years

very conservative estimation of ~10yr measurement

(Calculated with IC79 simulation, Event selection is NOT optimized)



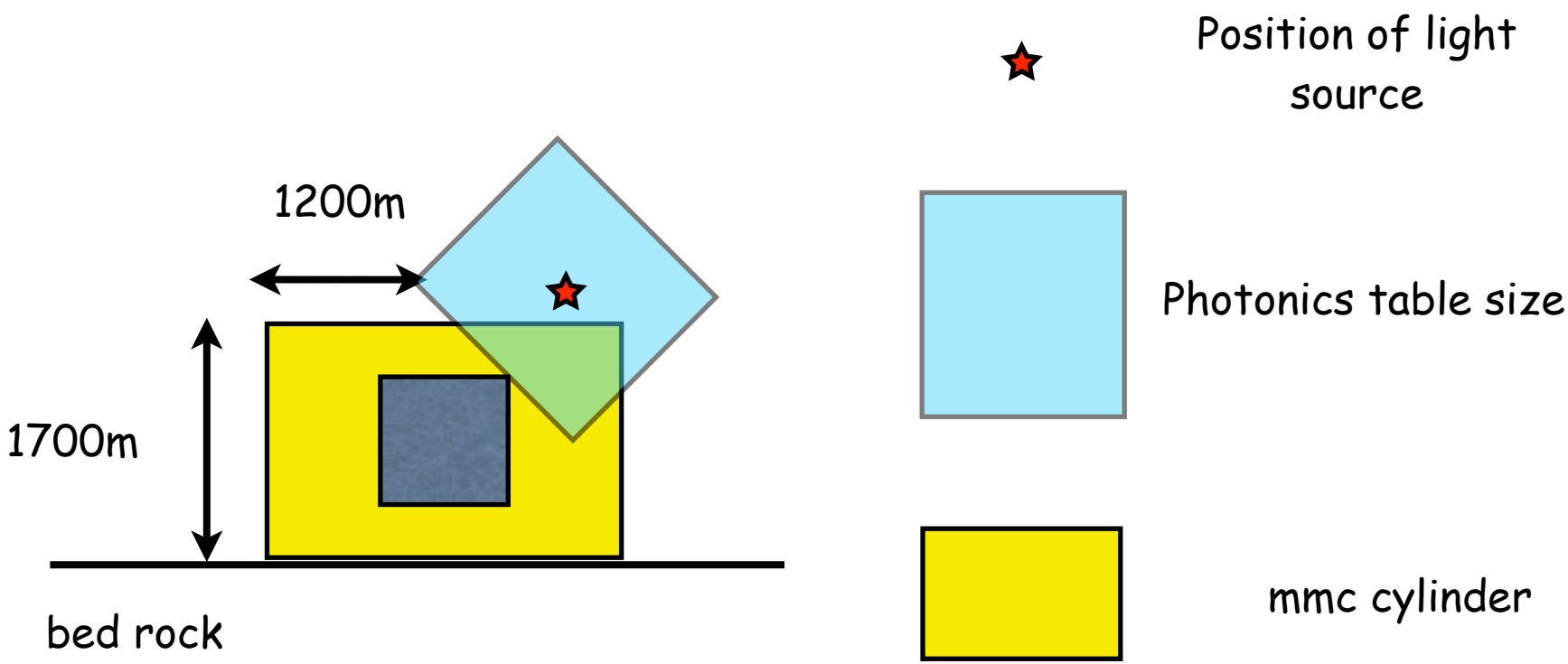
Errors are statistical uncertainty of center prediction due to limited simulation statistics

Systematics Study with Simulation

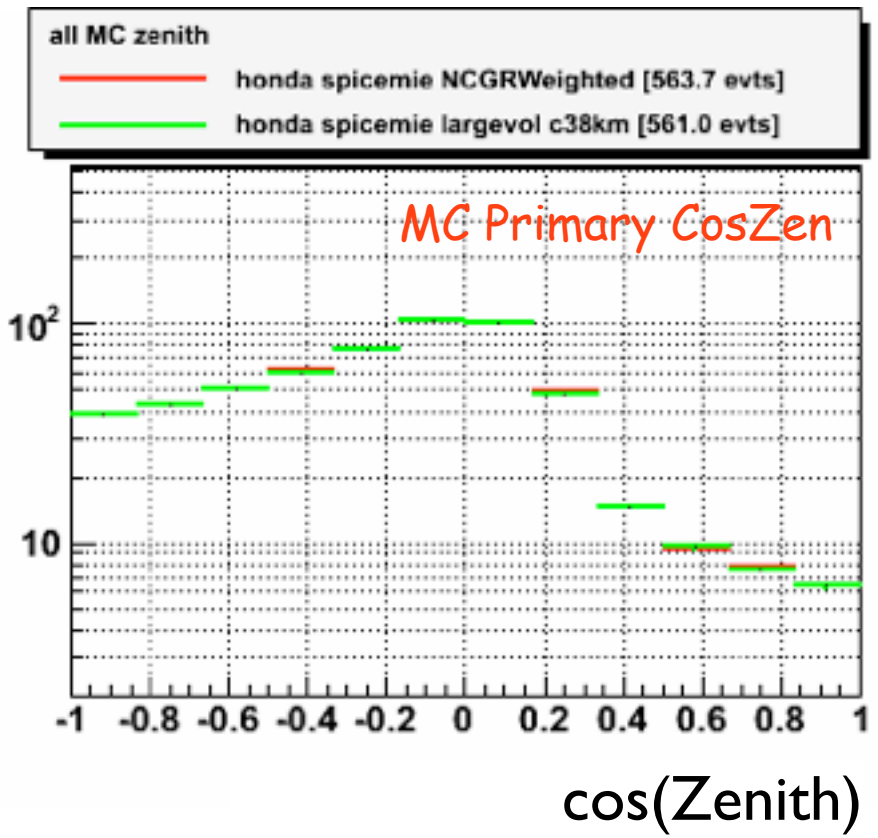
- A few percent systematics may affect EarthCore analysis
  - Since we are trying to see ~15% difference in only a few vertical bins, uncertainty of zenith angle estimation will affect directly to our analysis
- Zenith Angle simulation check :
  - Detection Volume Check
  - IceThickness systematics
  - BedRock Density
  - Ice Sheet or Ice Cap? -- NotYet

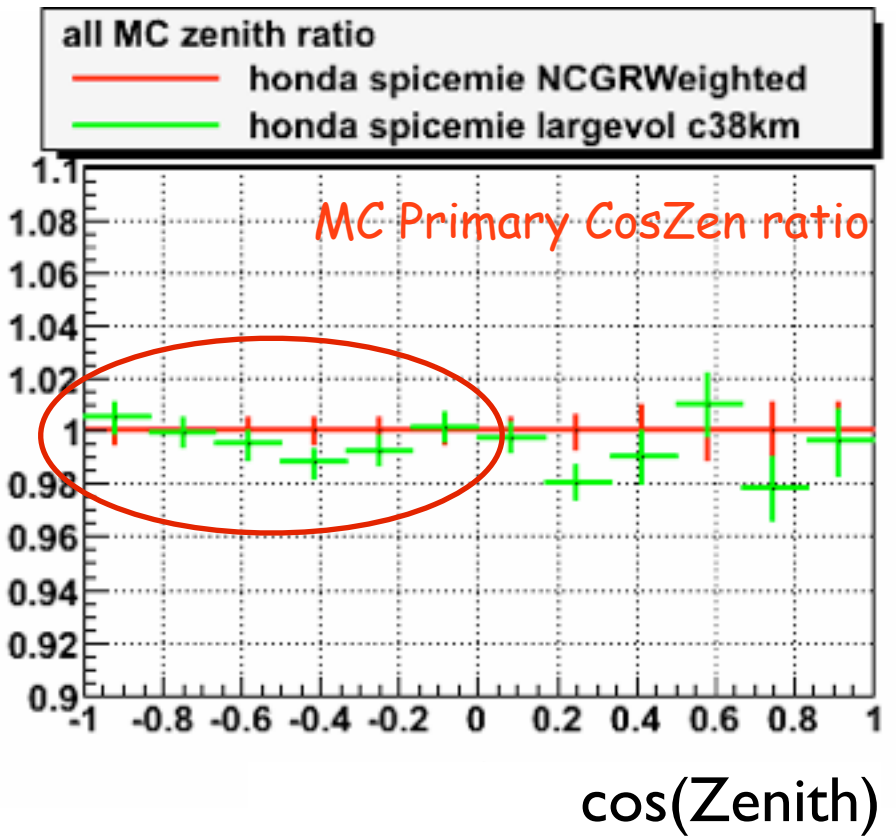
1. Geometry Study -- changing volume size

- current volume size of simulation -- 1700m tall, 1200m radius
- Extendable up to 2500m tall, 1250m radius with current geometrical extension of photon propagation table



1. Geometry Study -- changing volume size



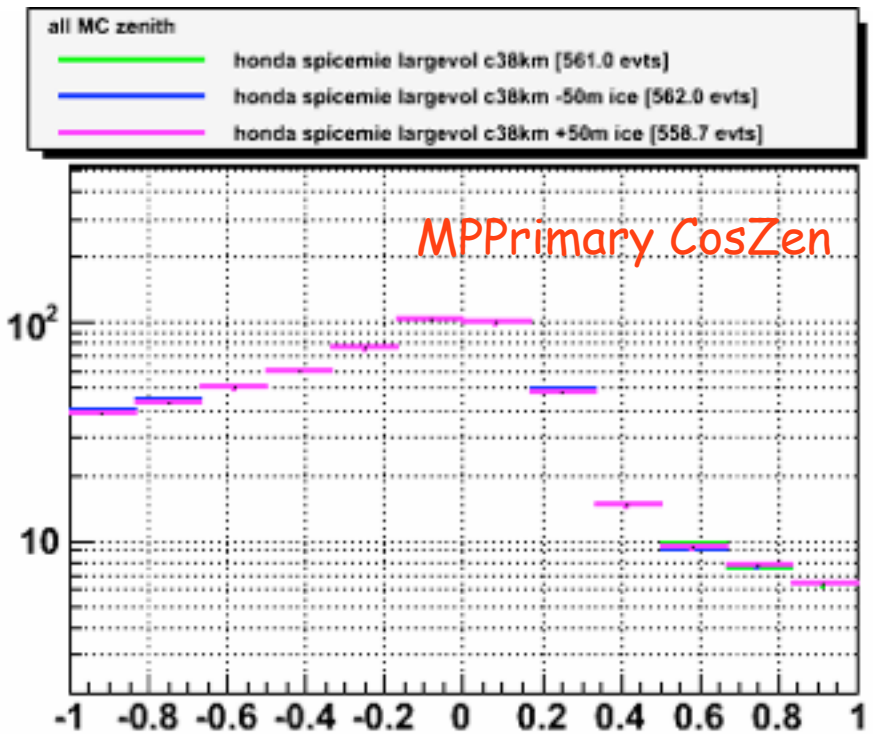


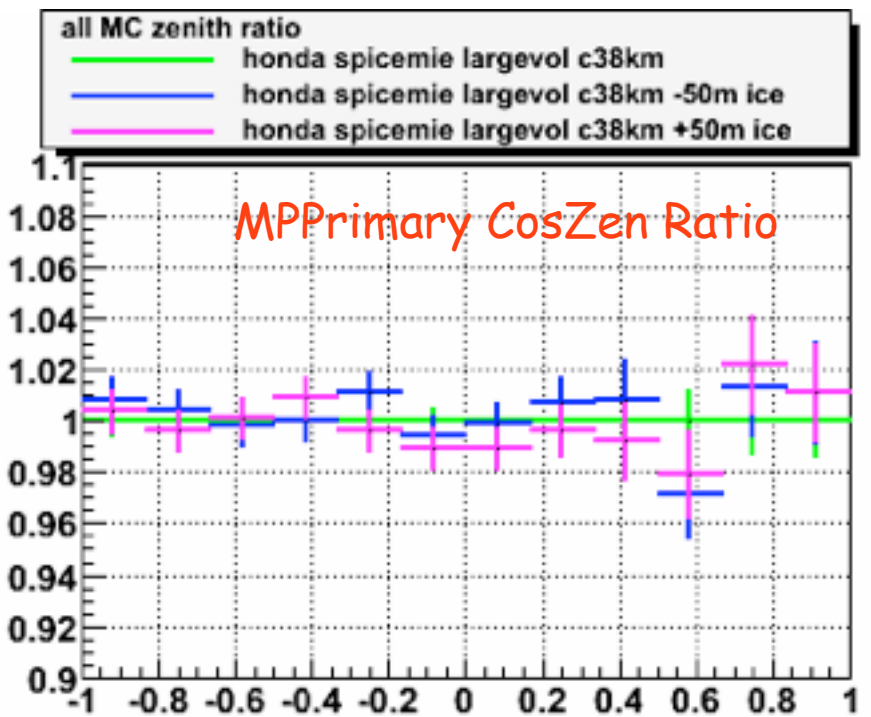
- Might be a structure within 2% effect
- Need direct comparison with same seed

2. Ice Thickness systematics

Ice Thickness : 2810m ± 50m

2810m 2760m(-50m) 2860m(+50m)

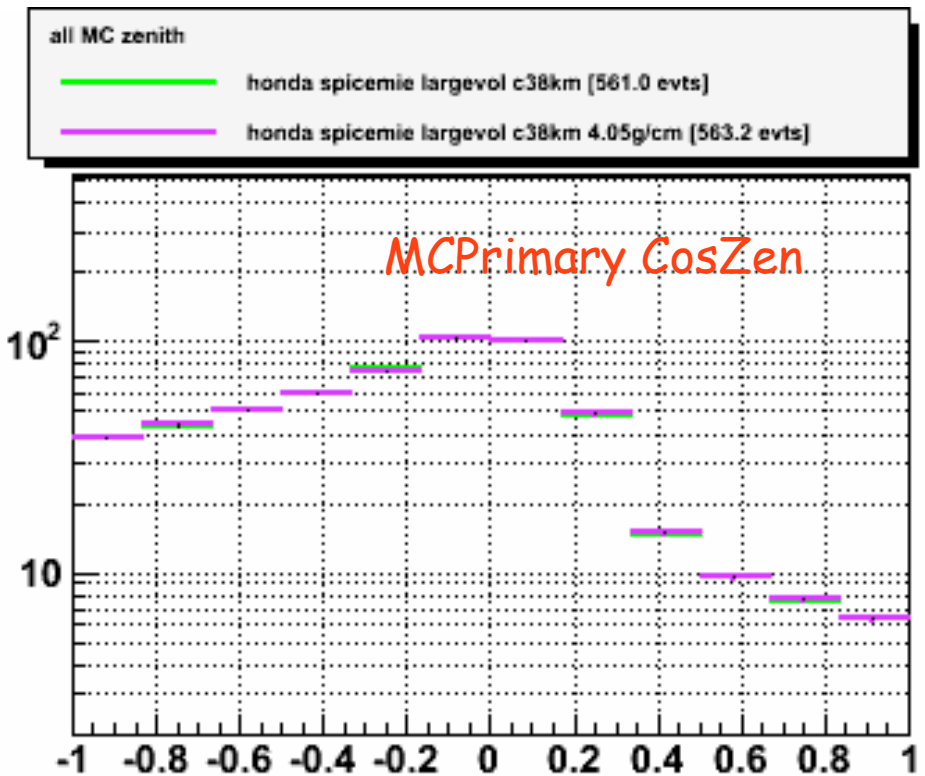




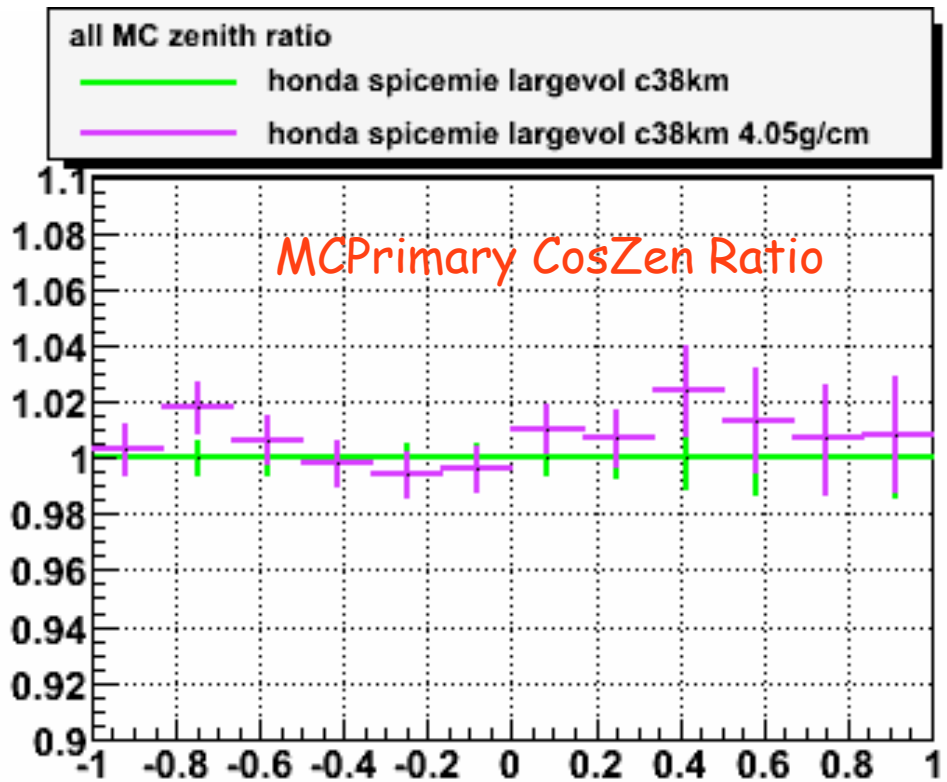
- Not clear effect with these statistics
- 1% effect if it exists

3. Bed Rock density study

Standard (2.7g/cm3)



Heavy (4.05g/cm3)



- With +50% more density of bedrock, the maximum effect could be 2%

Next Plans

- Improve IC79 analysis : work with other physics group
- Preparation for Multi-year analysis with IC86
- Study of atmospheric flux theoretical uncertainty for zenith distribution
- Try to cancel out some systematics (using relatively low energy events as an alternative of FLATCORE model, currently it introduces other systematics though)
- Investigate more efficient MC generation
  - Some improvements are done, still need a factor ~2-3 improvement in both data size and simulation time

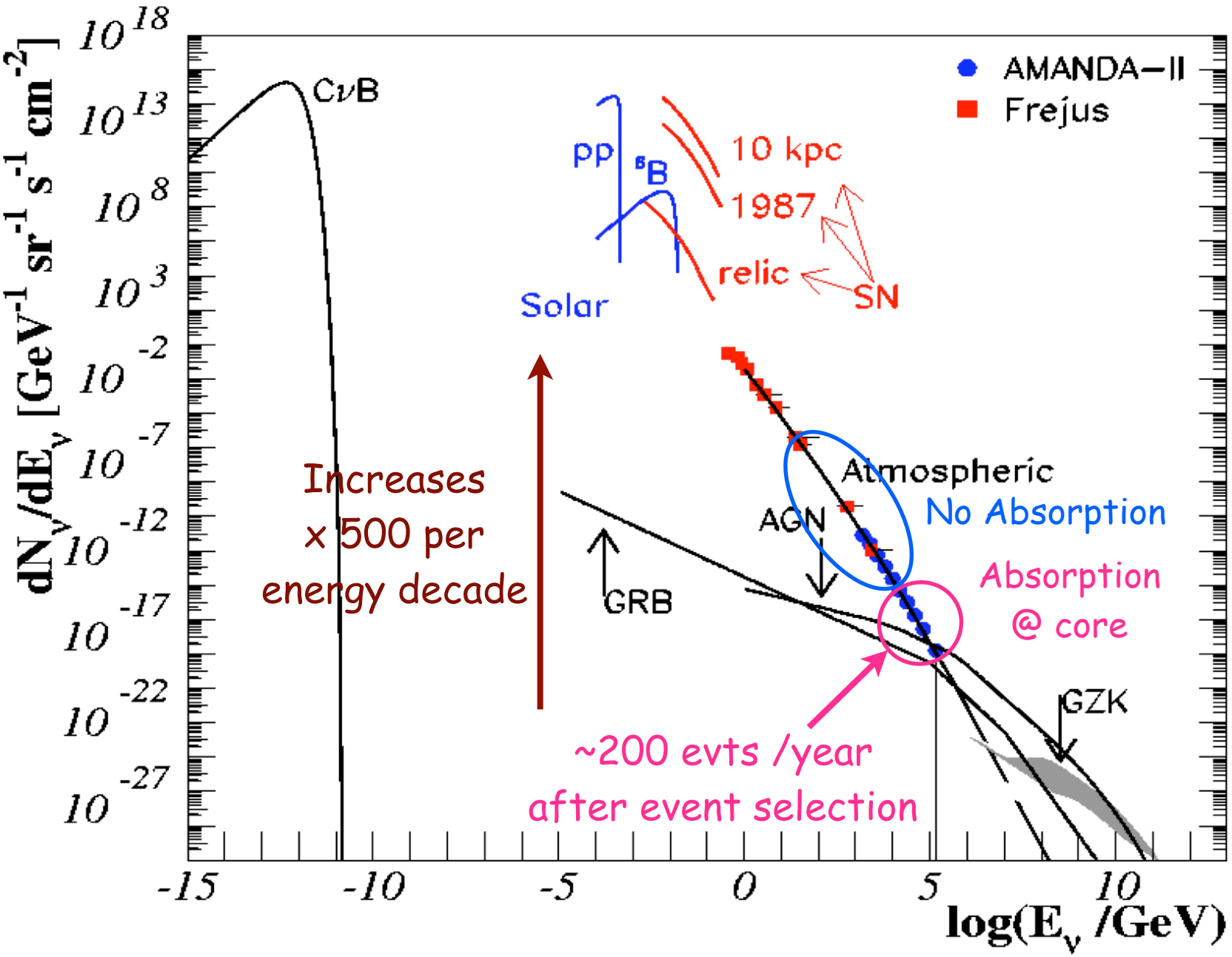
Summary

- IC40 Earth Core Analysis is performed.
- Separation of PREM and FLATCORE predictions is within statistical errors of IC40 one year data, thus IC40 is not sensitive to model difference.
- New data will be available soon (IC79, IC86)
  - Simulations are generated for IC79.
  - 10 years prediction gives 1 sigma separation at most vertically upgoing bin.
  - Optimization of event selection and analysis method for full-size detector will improve the separation.

backups

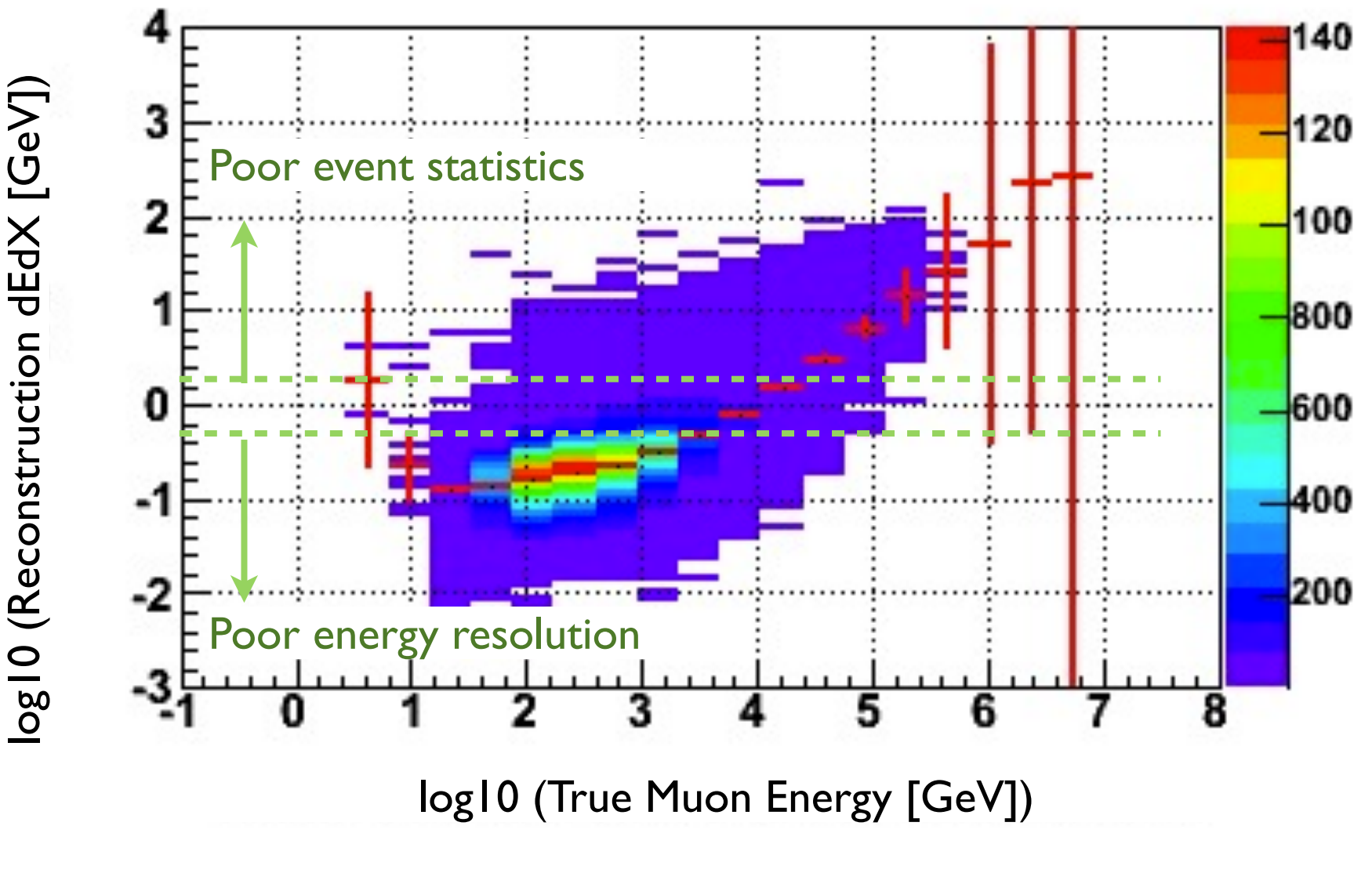

SPROUL HALL
ANTI-ν'S ARE LEPTONS TOO!
MAKE DISCOVERIES, NOT LIMITS!
1 DOM, 1 VOTE

Neutrino Flux

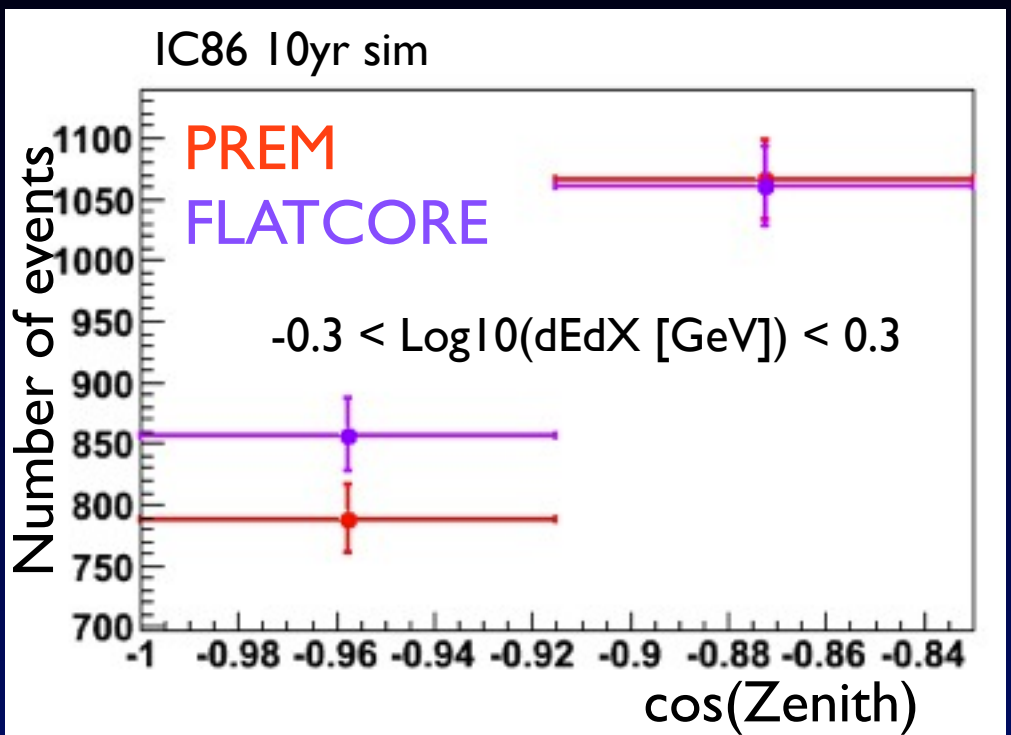


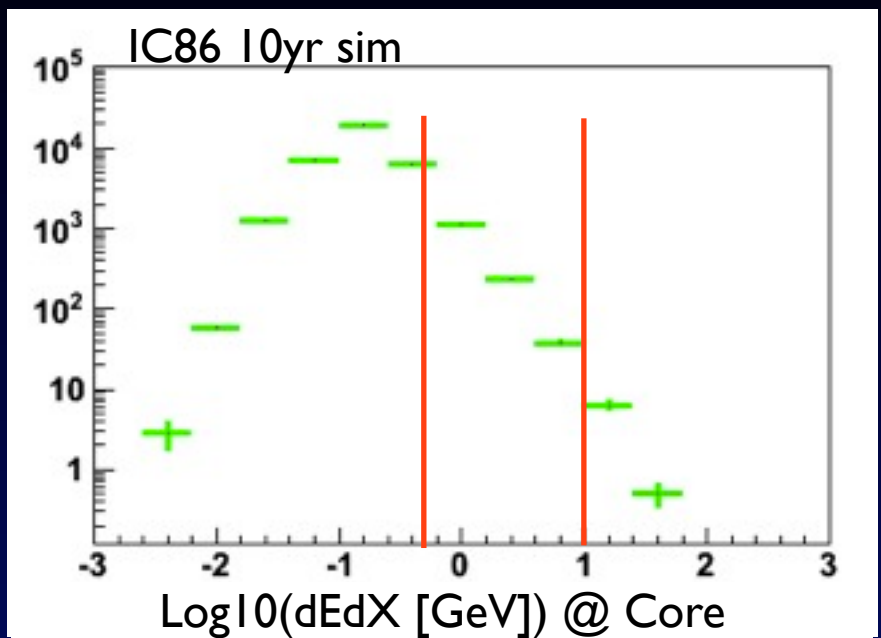
dEdX is sensitive to muon energy above 1 TeV

Simulation Atmospheric Neutrino

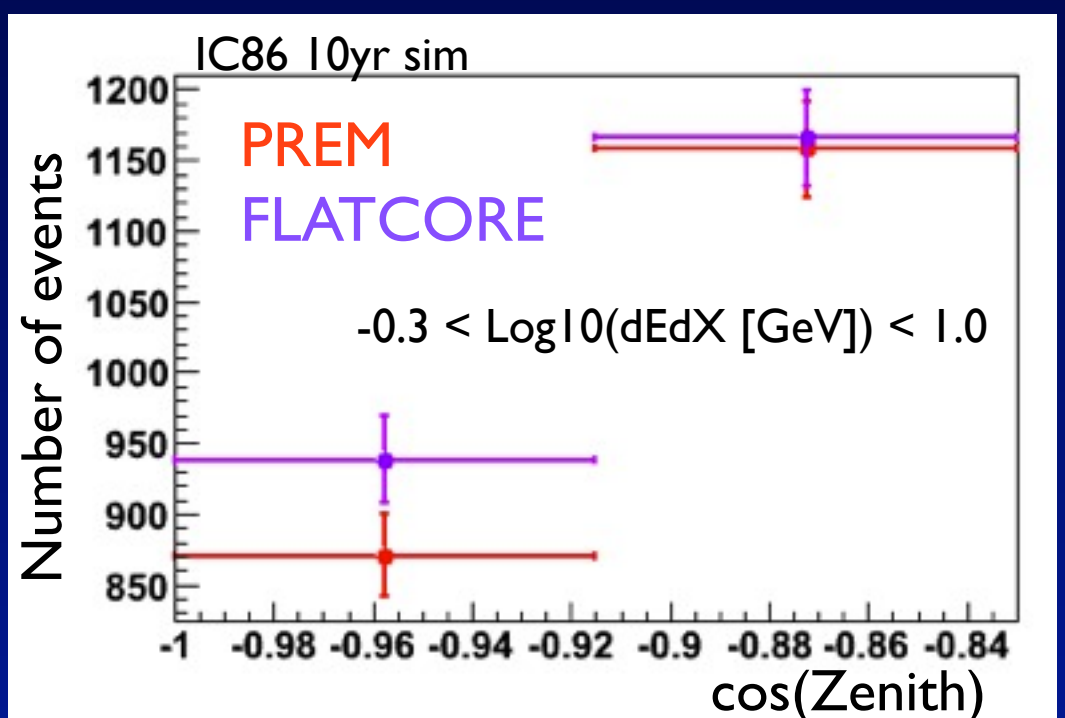


IceCube 86 strings 10 years predictions @ Core

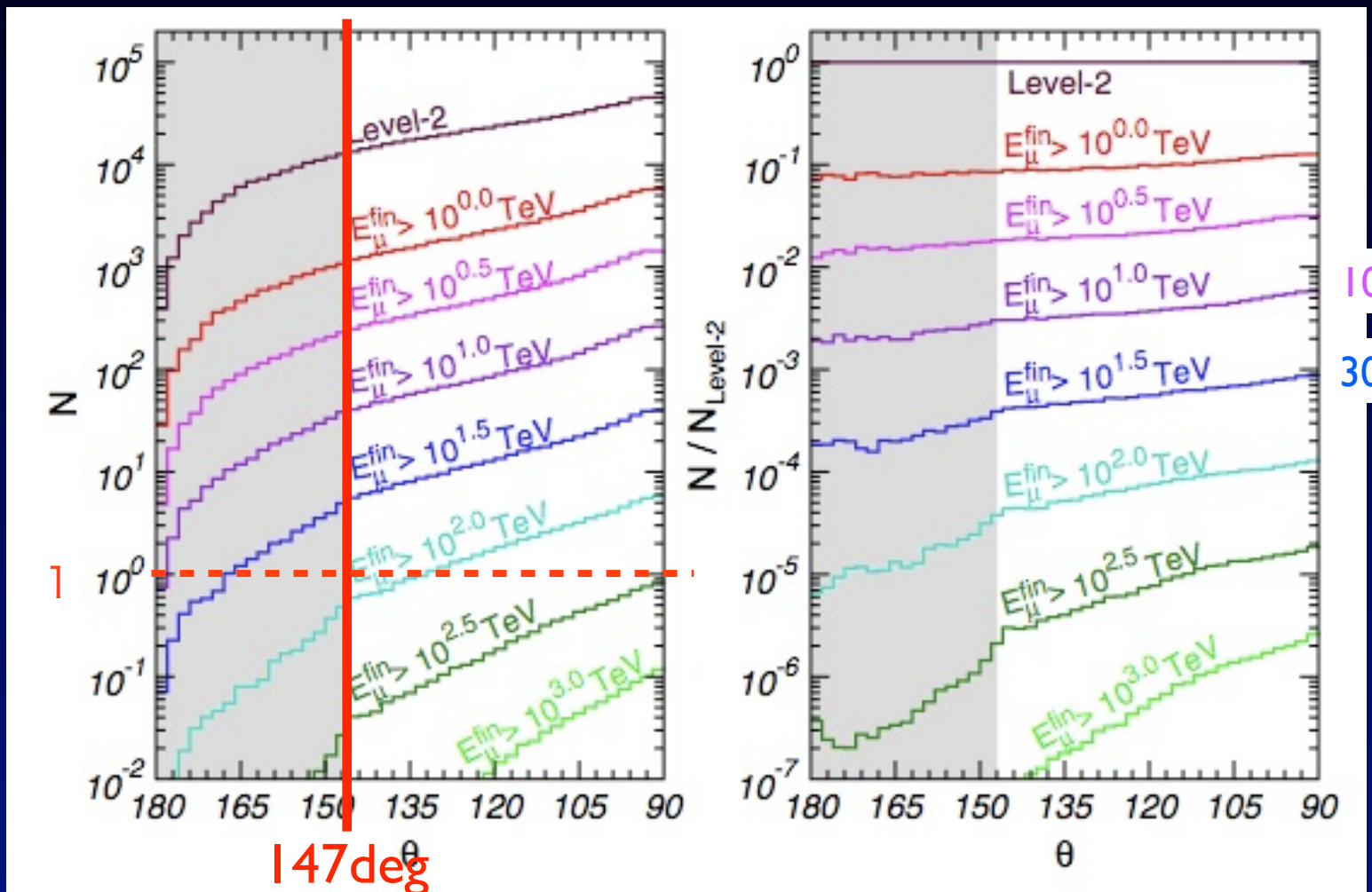




- Cuts and simulations are not optimized for IC86
- Errors are 1 sigma statistical errors



Expected Number of Neutrino detected with the IceCube in 10 years



M. C. Gonzalez-Garcia, Francis Halzen, Michele Maltoni, and Hiroyuki K. M. Tanaka
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