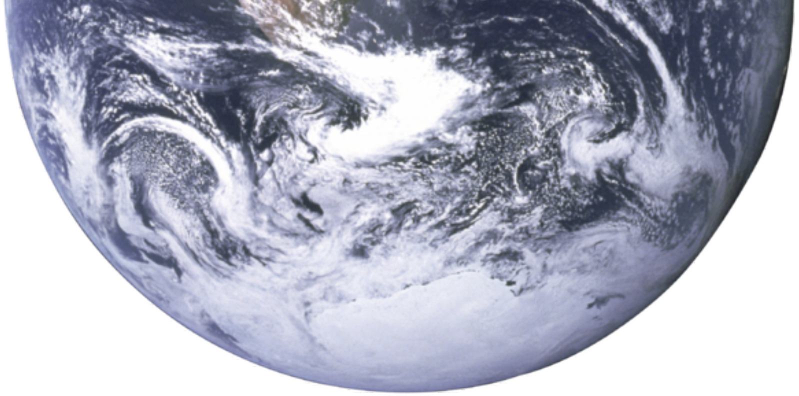


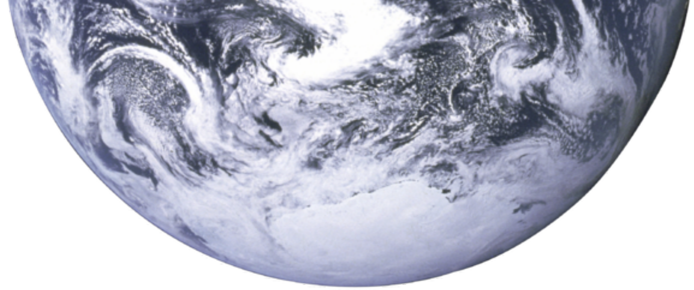
Recent developments on high energy geoneutrinography

MNR 2013

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

Earthquake Research Institute, The University of Tokyo

ICECUBE
South Pole Neutrino Observatory



Why Neutrinography?

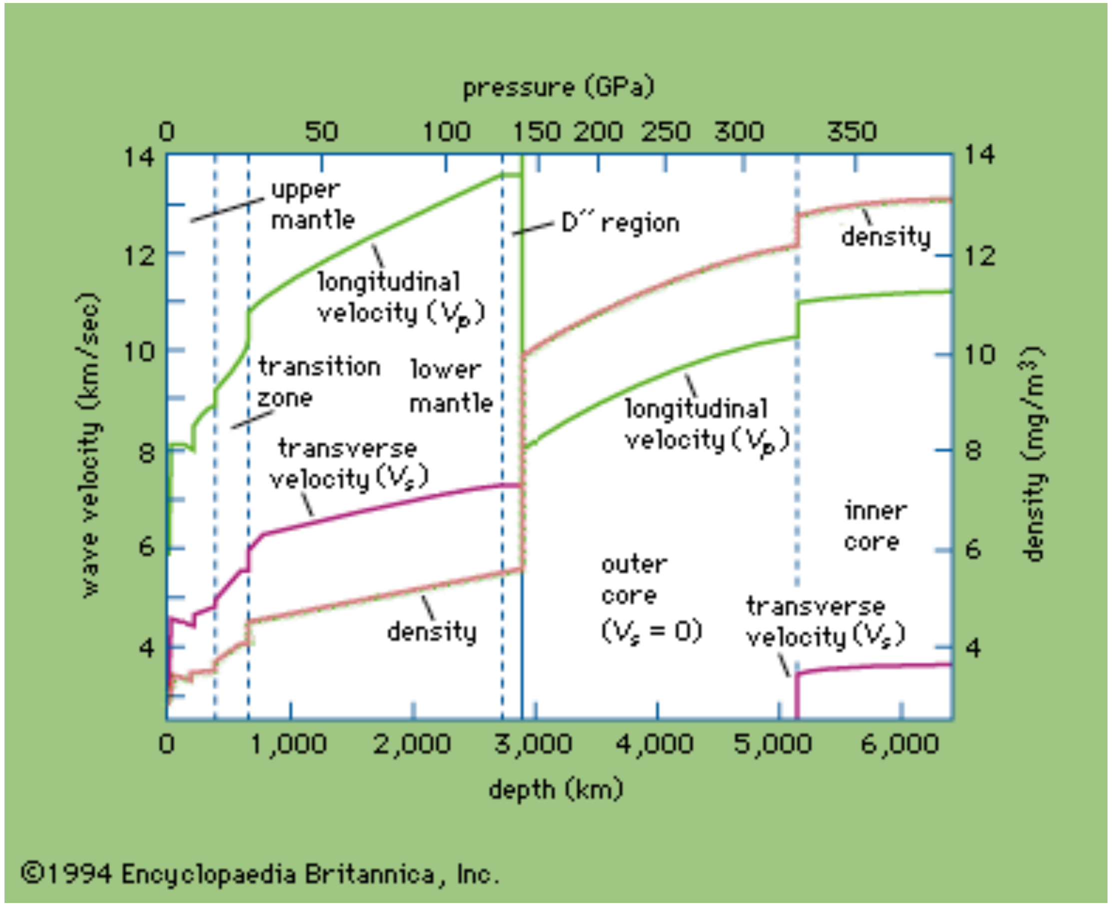
- Inner structure of the Earth is well-measured with seismic wave analysis, however...

$$v_p = \sqrt{\frac{\lambda + 2\mu}{\rho}} = \sqrt{\frac{\kappa + 4\mu/3}{\rho}}$$

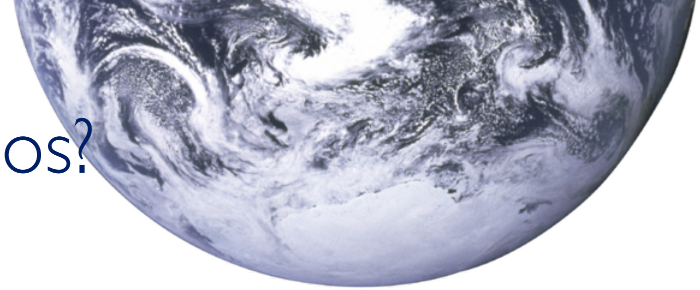
$$v_s = \sqrt{\frac{\mu}{\rho}} \; .$$

depend on geophysical models

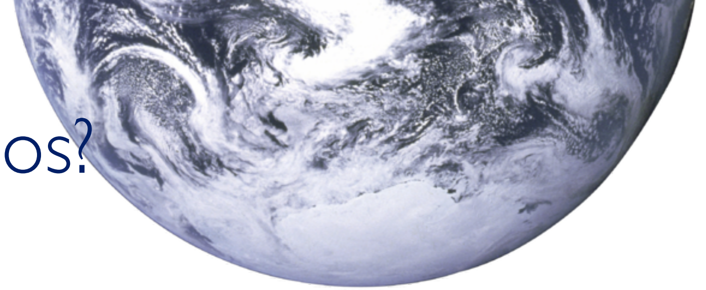
κ ... bulk modulus
μ ... shear modulus
λ ... Lamé's parameter
ρ ... density



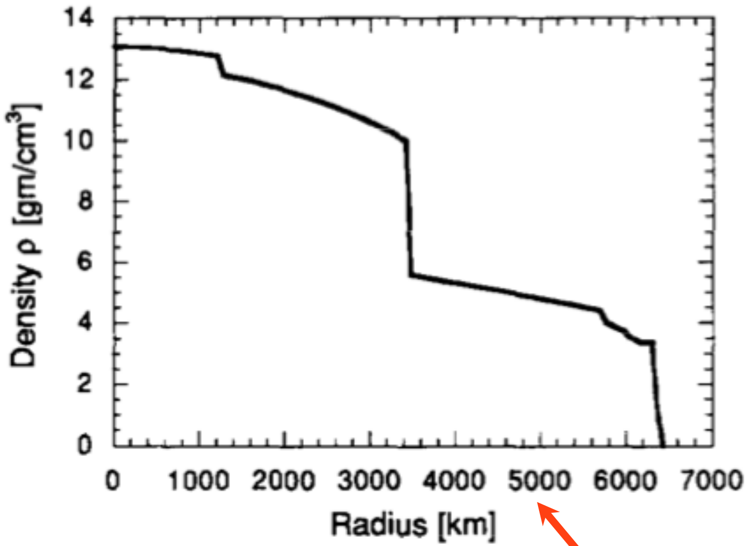
What can we do with neutrinos?



Neutrinos

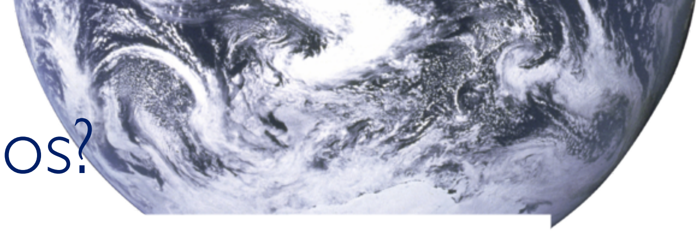


What can we do with neutrinos?

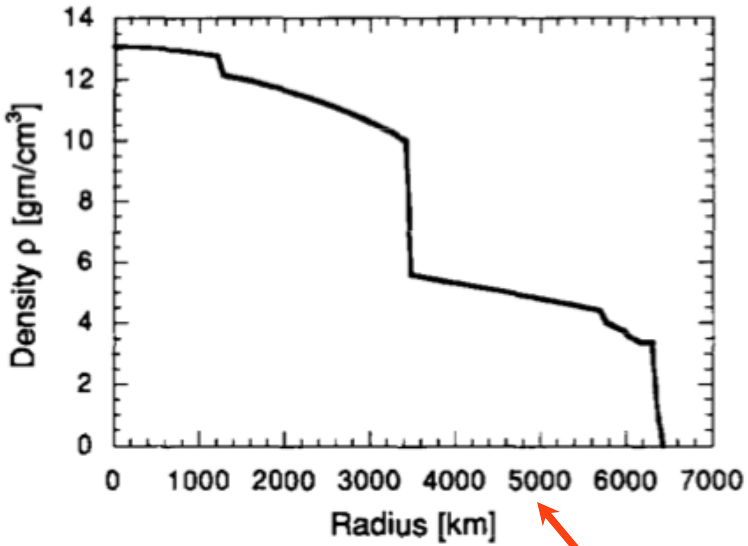


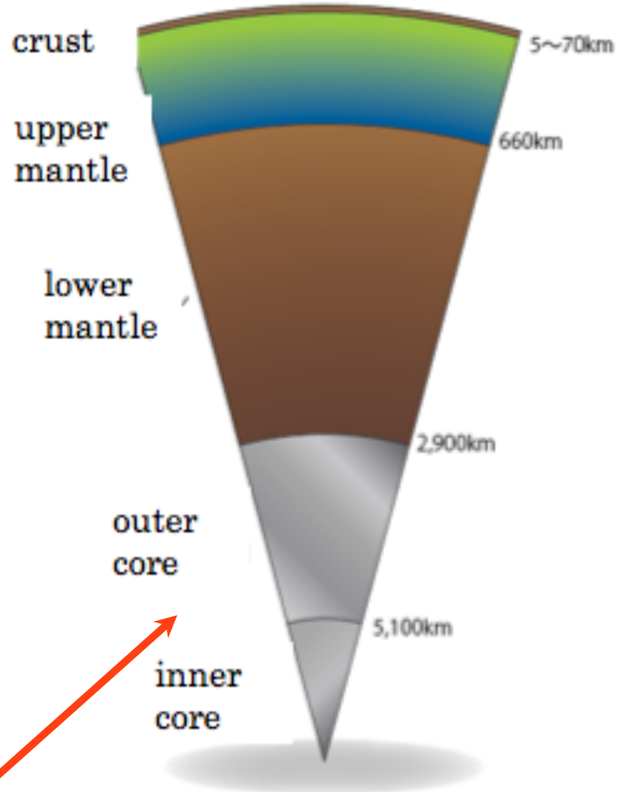
Direct Density Measurement (Neutrino Radiography)

Neutrinos



What can we do with neutrinos?



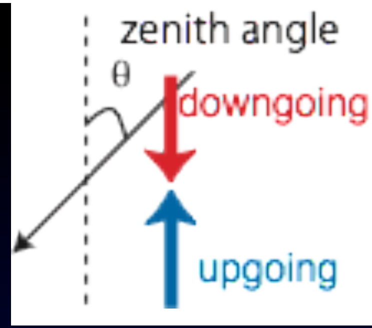


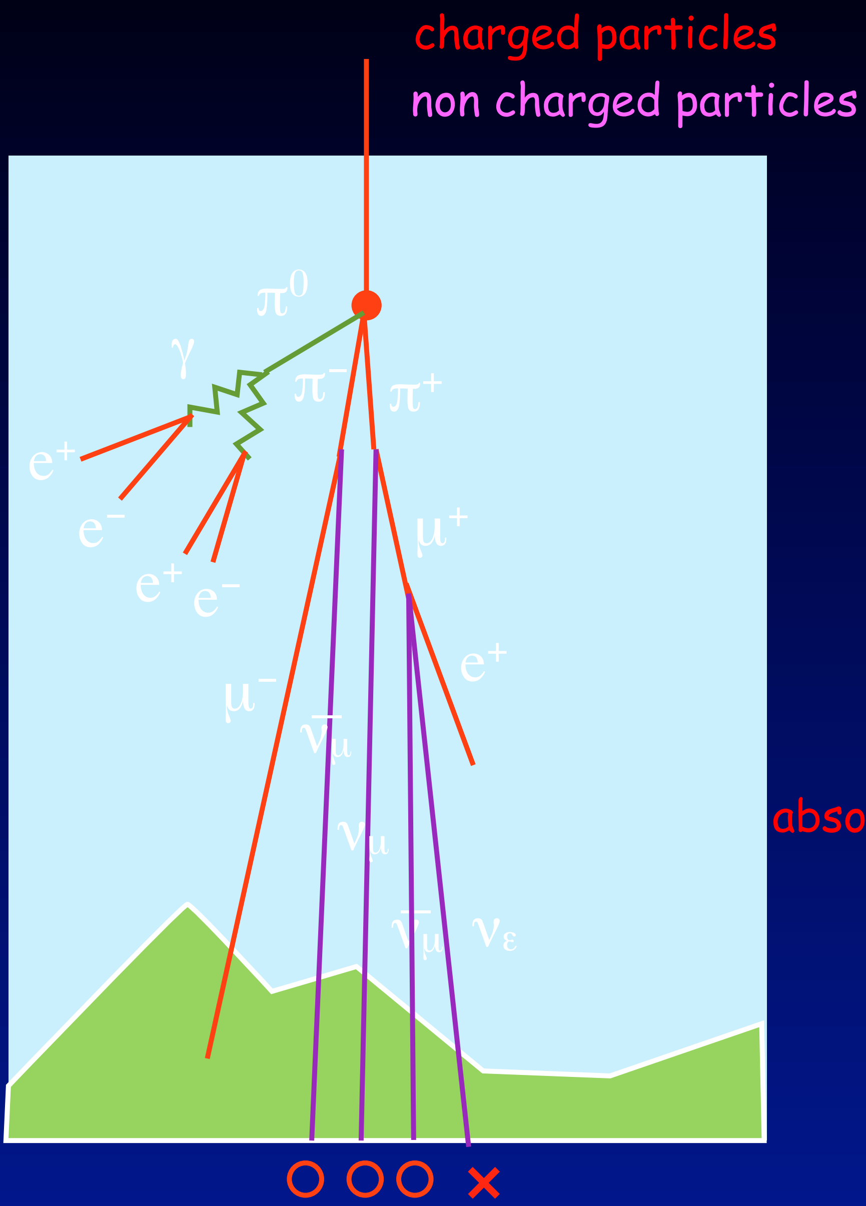
Direct Density Measurement (Neutrino Radiography)

Neutrinos

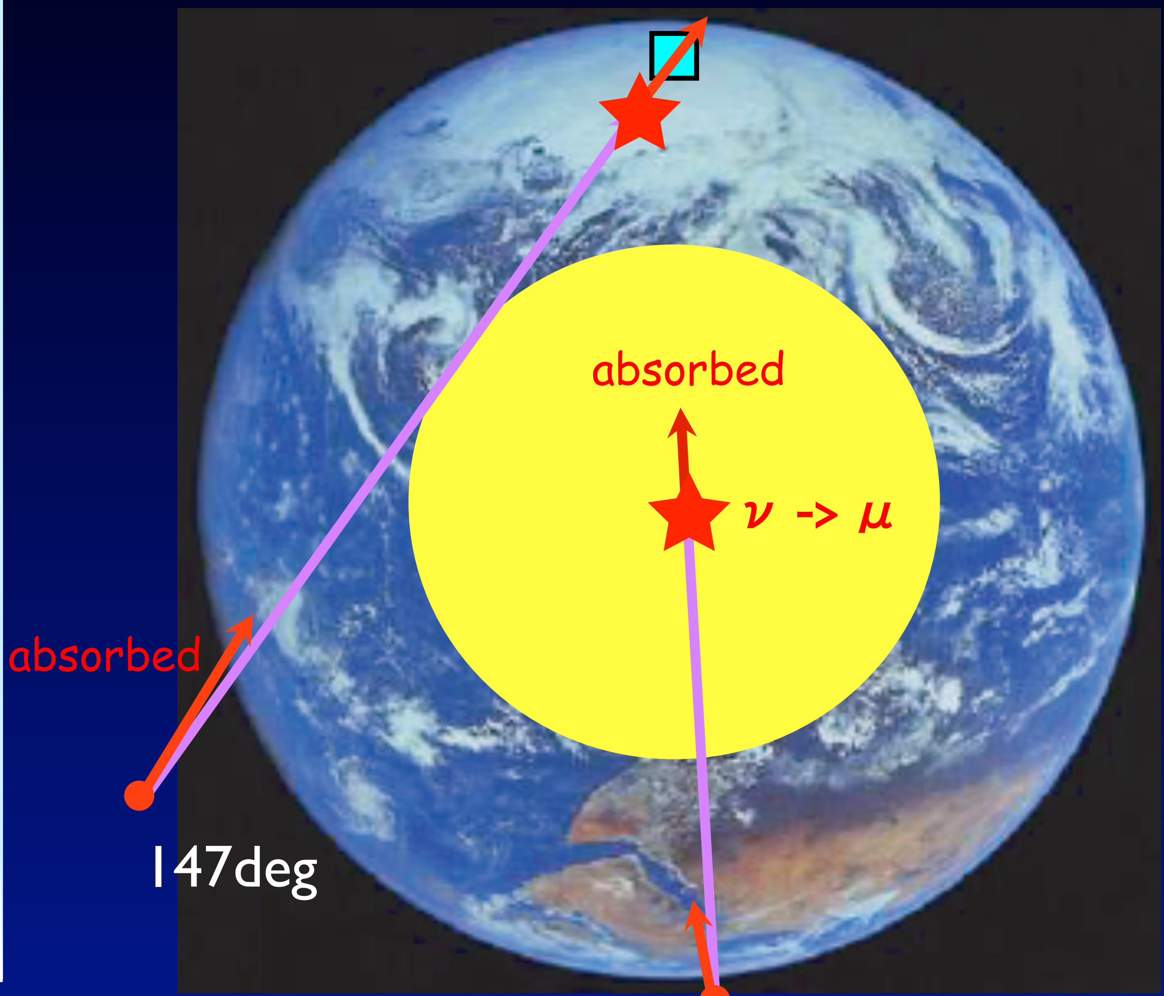
Iron? Rock? (Chemical Composition, Neutrino Tomography)

Measuring Core Density of the Earth

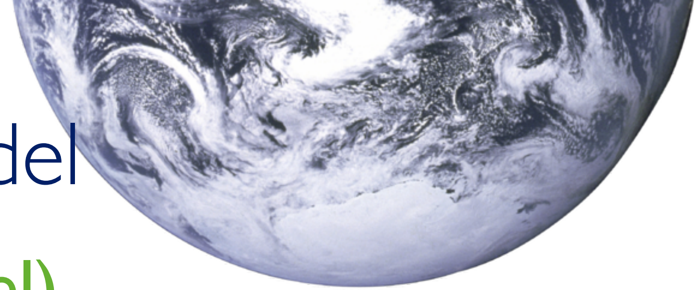




South Pole

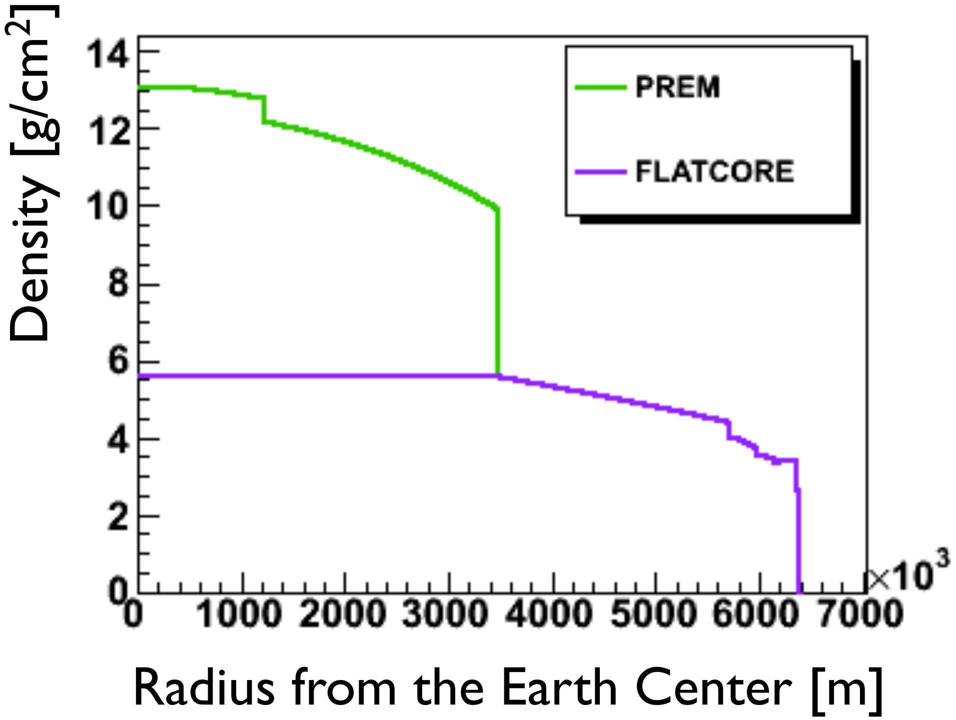


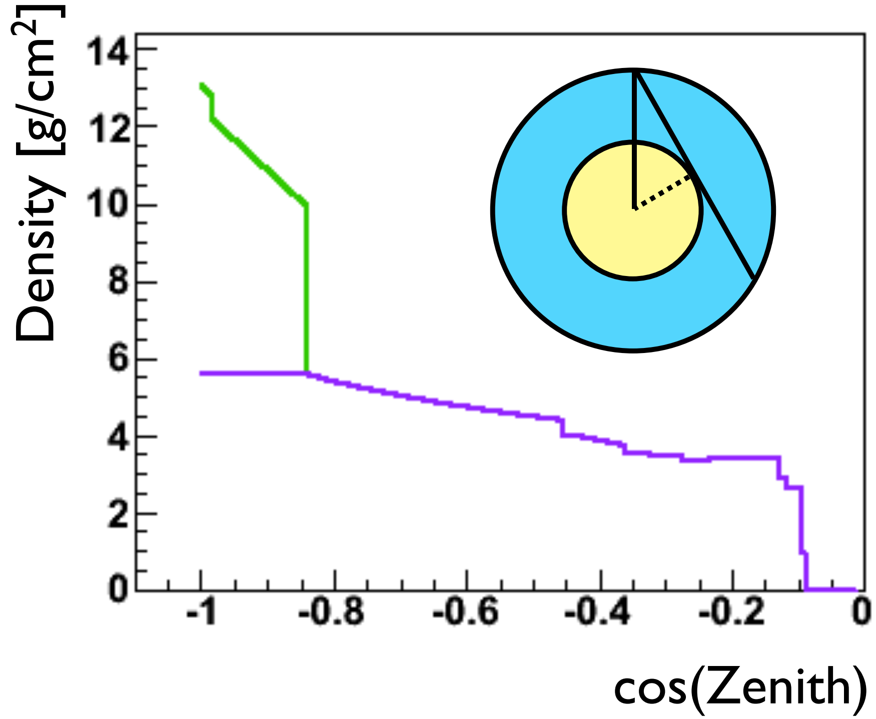
North Pole



PREM vs FLATCORE model

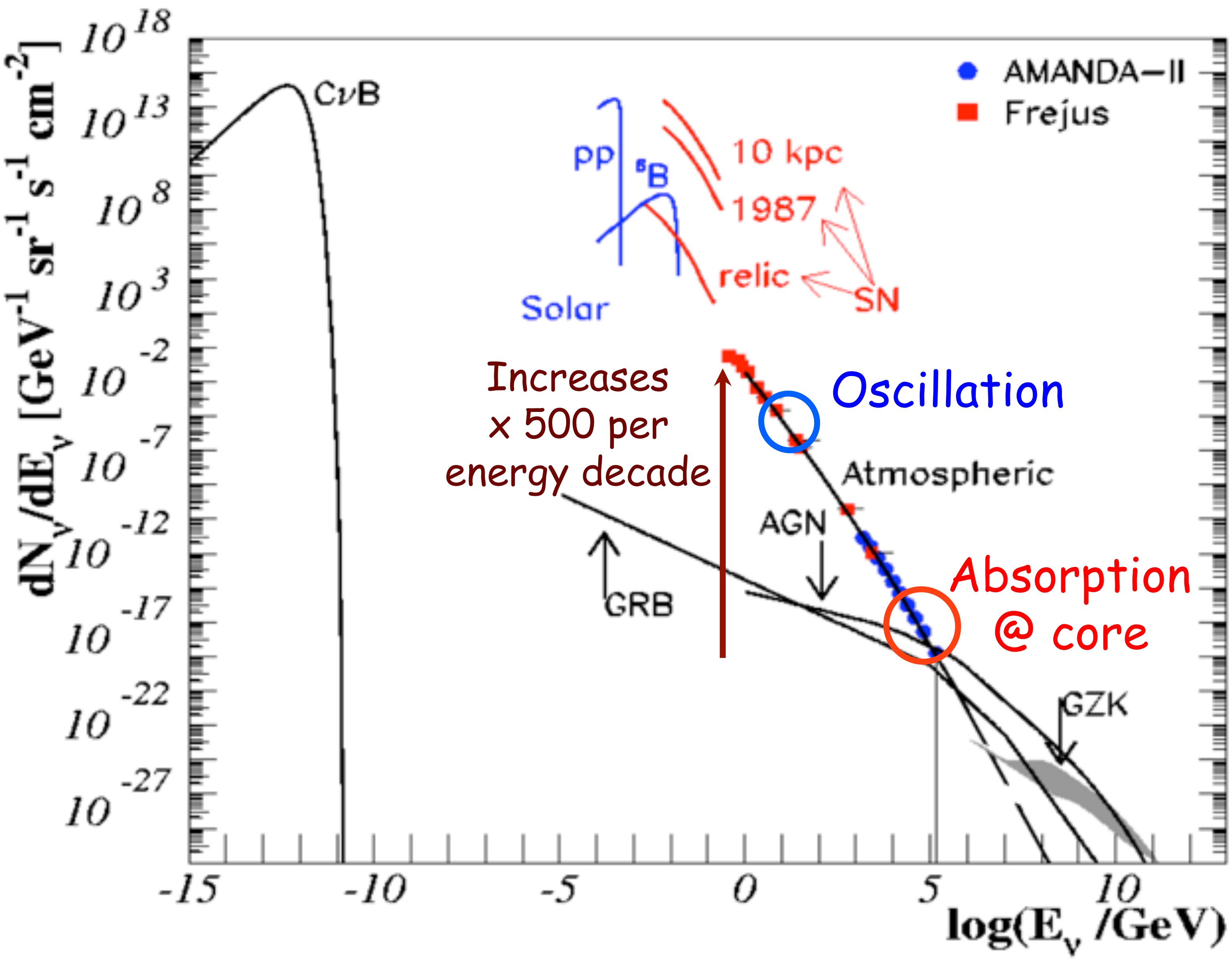
PREM (Preliminary Reference Earth Model)
FLATCORE (ROCK CORE model)



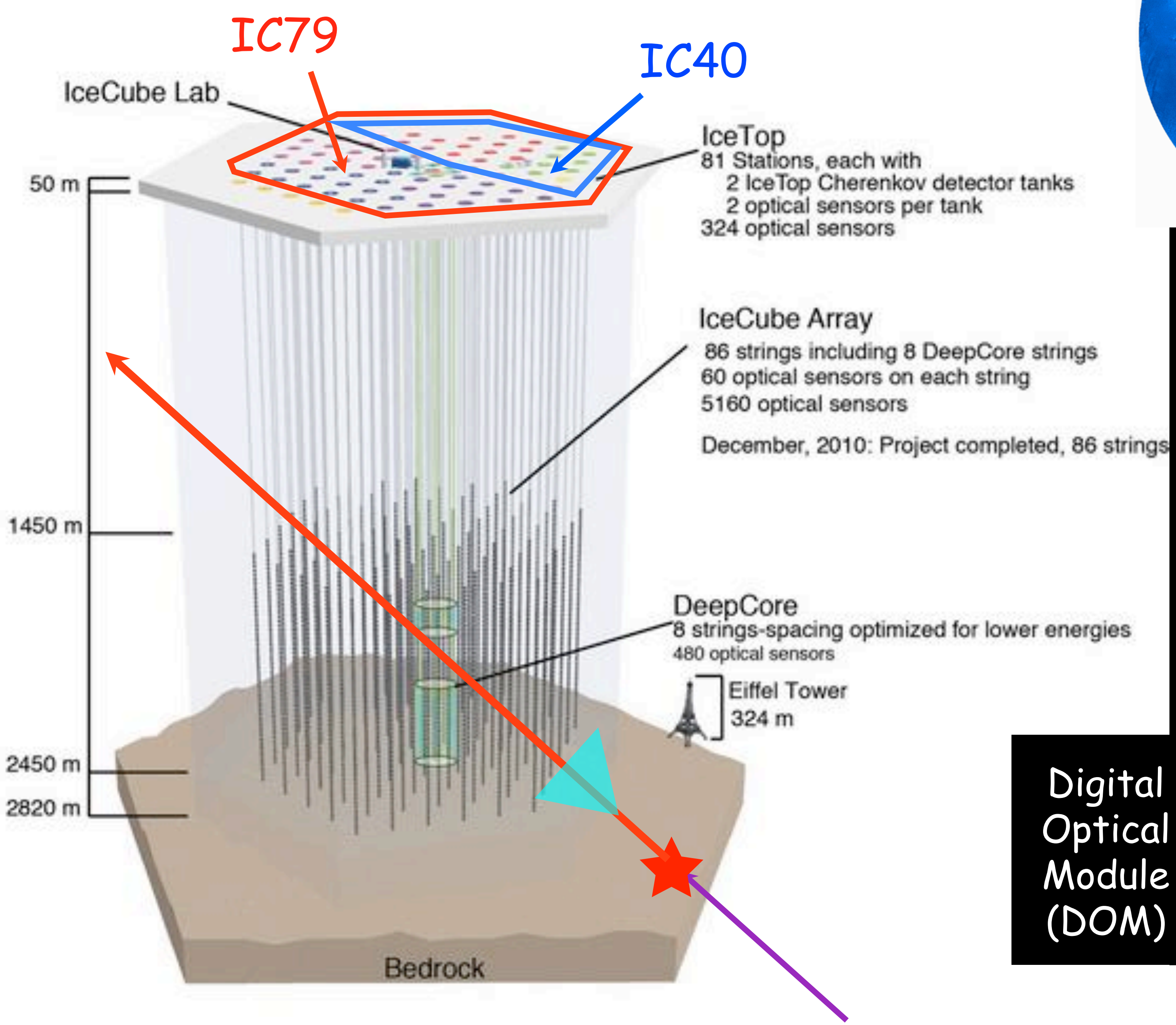


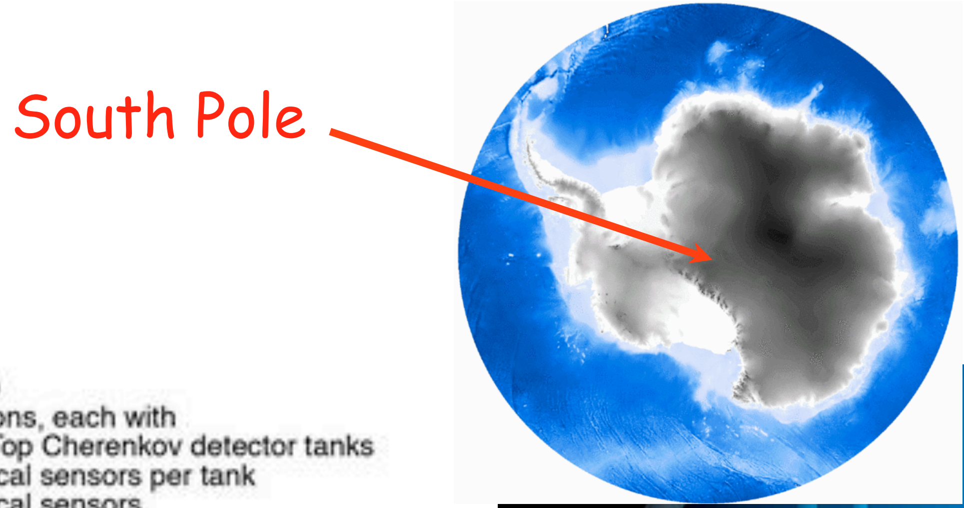
FLATCORE model doesn't conserve Earth's mass, but still useful to estimate the resolution of Earth's density at core angle with IceCube

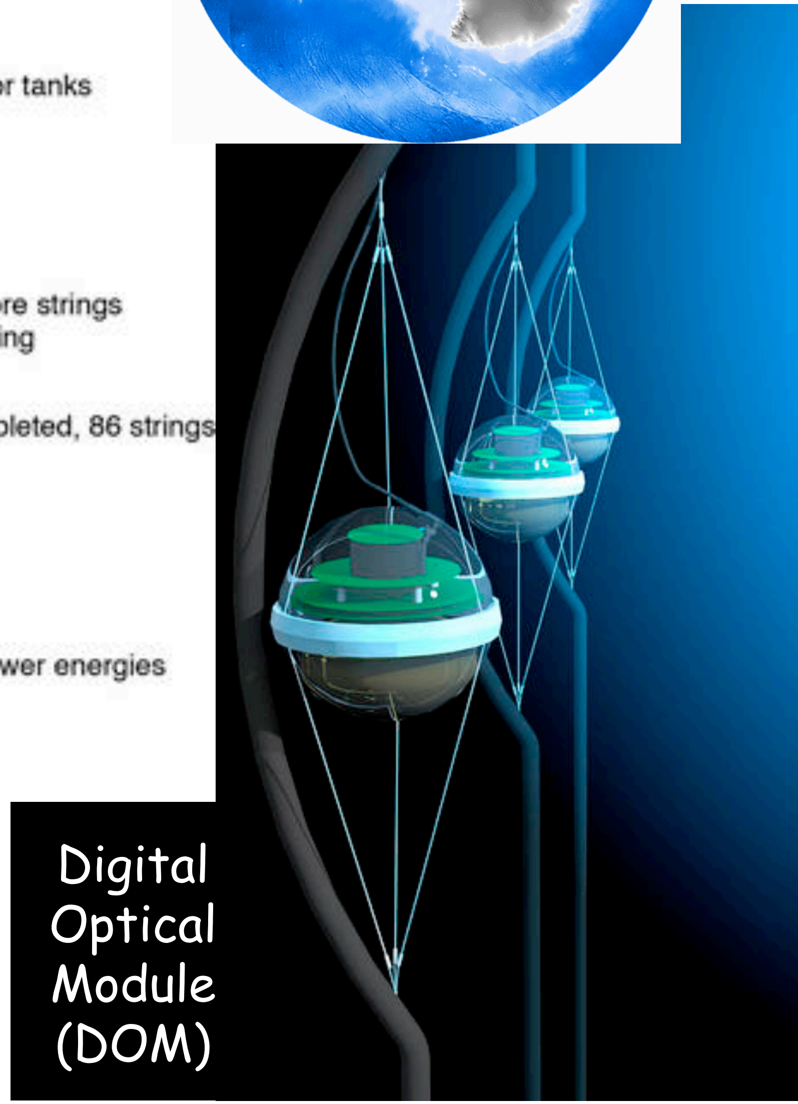
Neutrino Flux from various sources



IceCube Structure





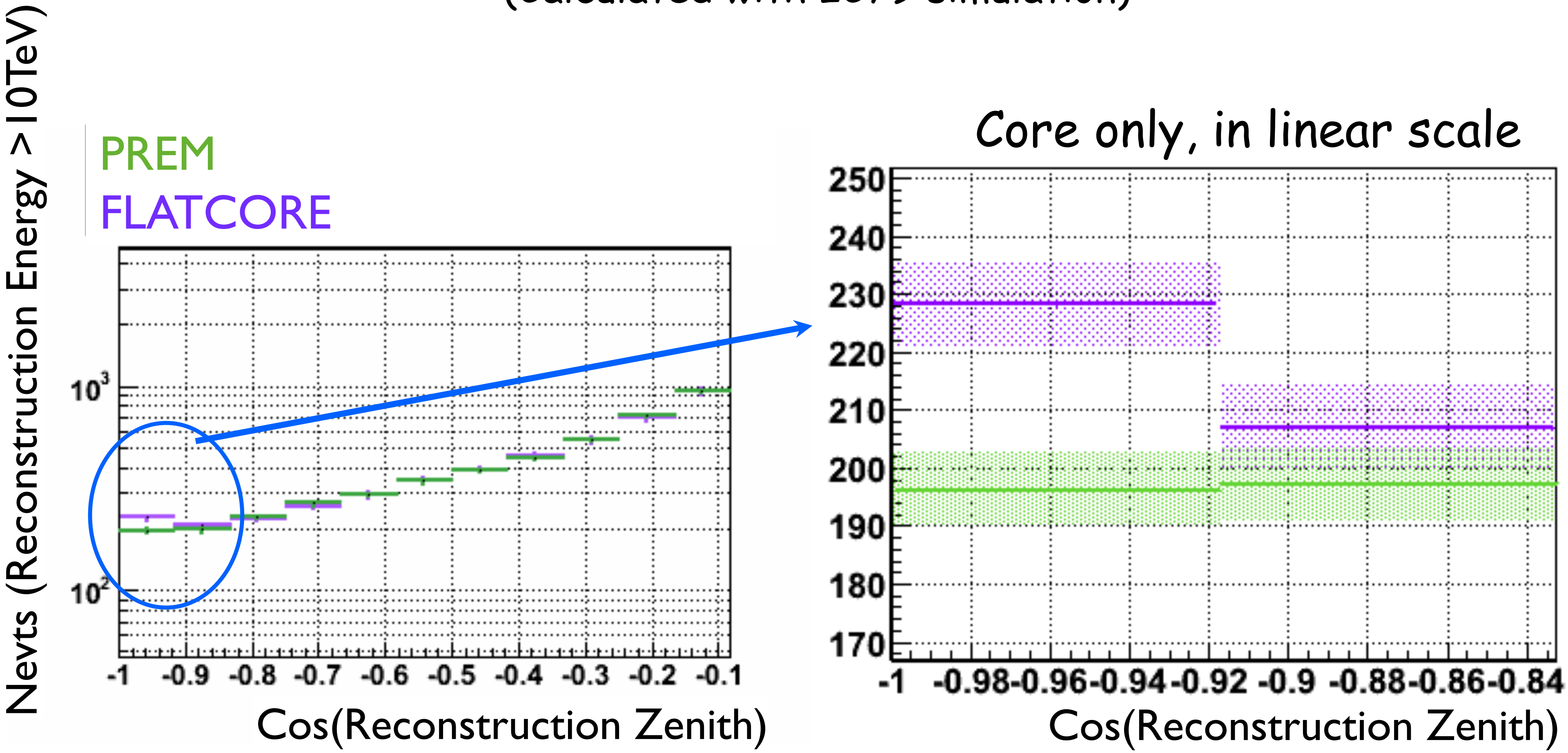


Simulation with IC79 10 years

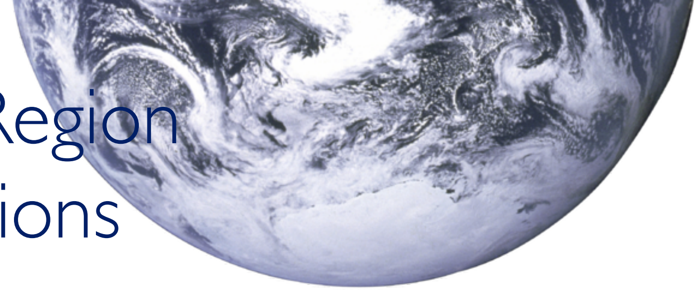
very conservative estimation of ~10yr measurement

(Calculated with IC79 simulation)

Core only, in linear scale

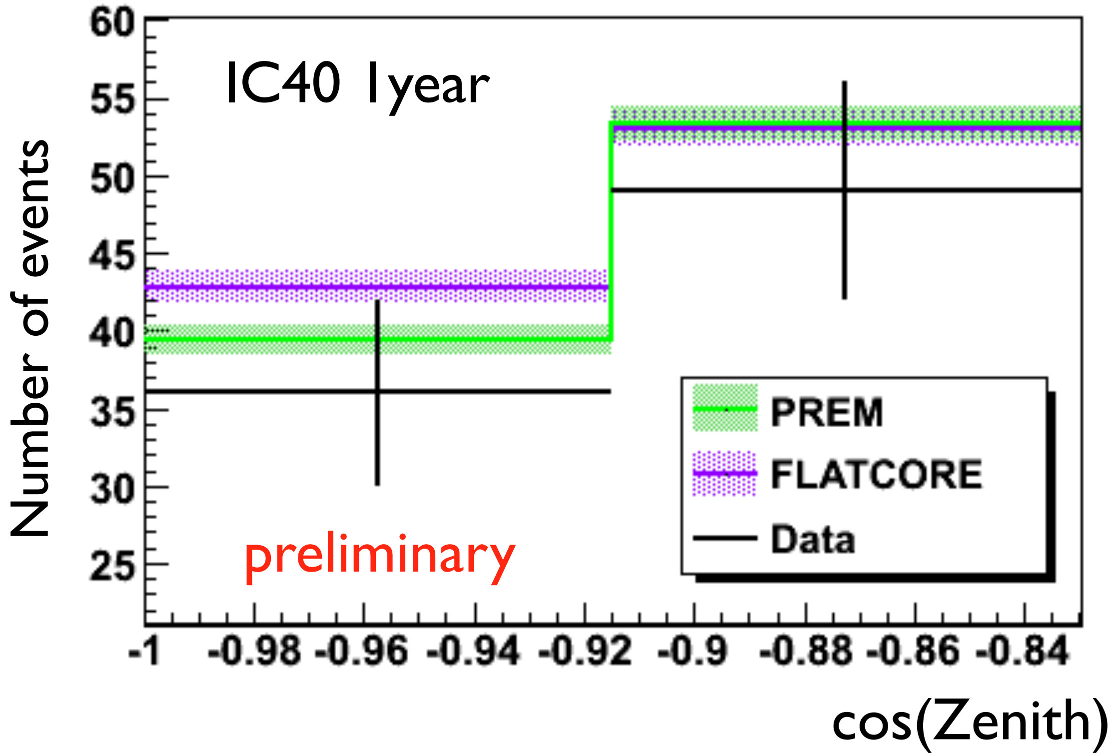


Errors are statistical uncertainty of center prediction due to limited simulation statistics



Comparison of Zenith at Core Region IC40 Data one year vs Simulations Core Region

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



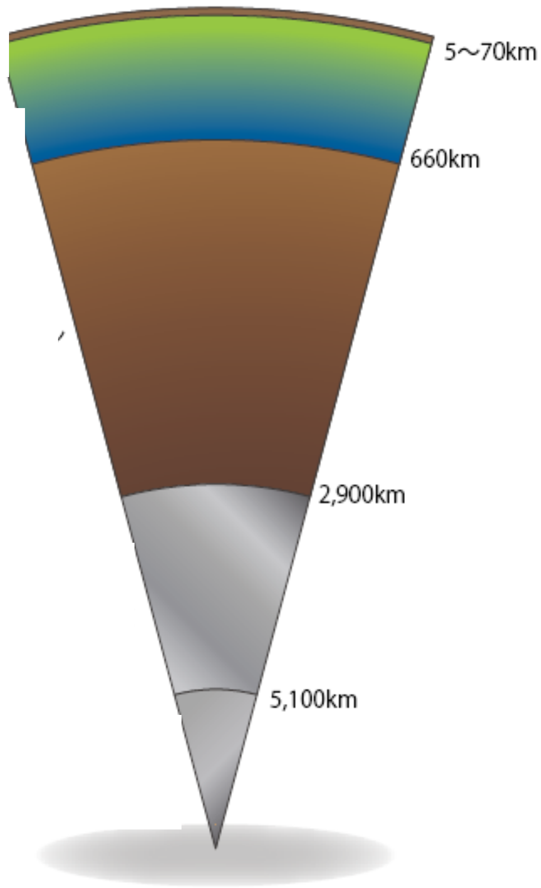
Separation of PREM and FLATCORE predictions is within statistical errors of IC40 one year data.

Related talk will be given on 7/26, P1-2 session.

by A.Taketa

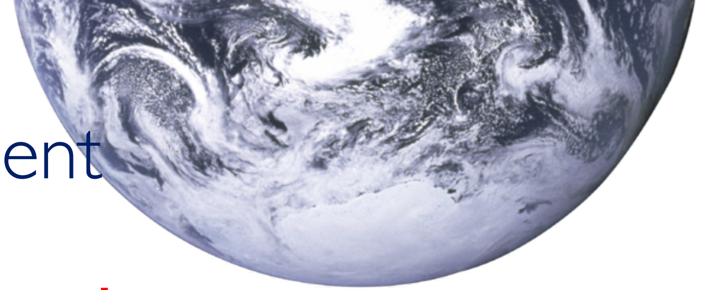
Do you know Earth's core composition ?

- What is **the geomagnetic field** ? Who order it ?
  - W. Gilbert 1600
  - A. Einstein 1905
  - It requires the metal convection : dynamo theory
- It is **believed** Earth's core mainly consists of **Iron, not rock**.
  - But it's not measured.
  - Prediction requires measurement .



by A.Taketa

Principle: composition measurement



- Oscillation probability depend on electron density, not matter density
- By using neutrino oscillation, we can measure the electron density of the medium
  - If sterile neutrino does not exist
- We have the precise matter density of the earth
  - From seismic wave tomography and free oscillation
  - They are not direct observation of matter density
- Combining matter density and electron density, **we can measure the average chemical composition of the deep earth !**
  - Ratio of atomic number to mass number (Z/A)

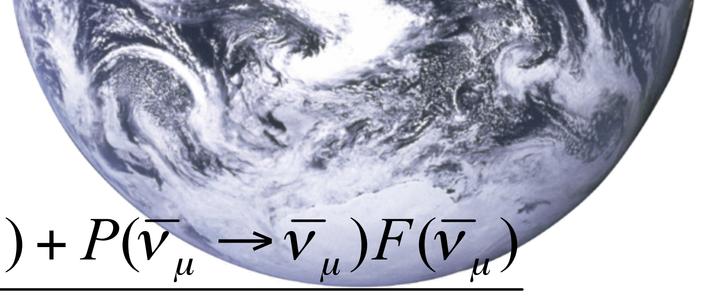
by A.Taketa

Model calculation :
Can neutrinos distinguish iron and rock ?

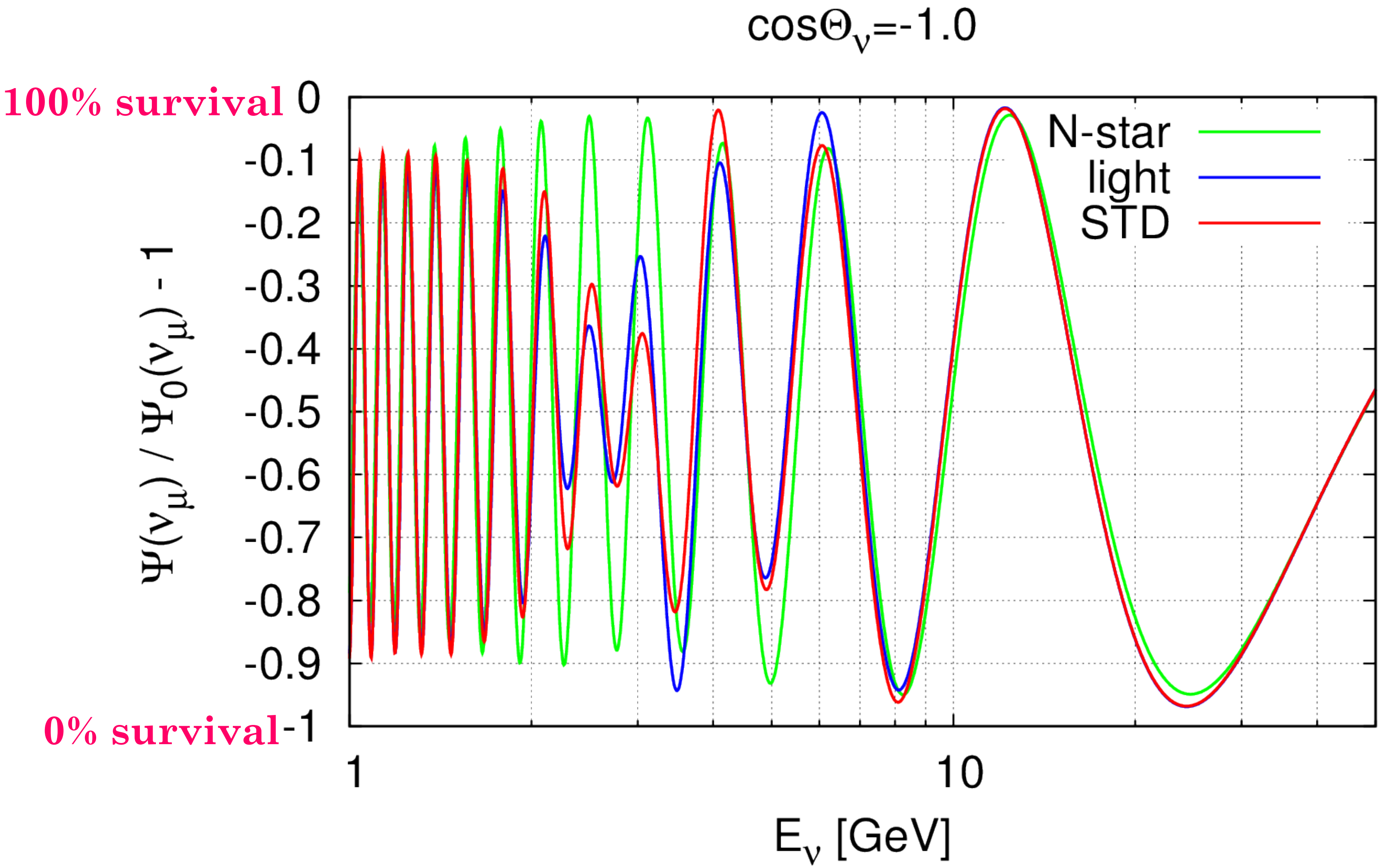
- Z/A ratio of materials
  - Fe :0.466, Light material : 0.5, Hydrogen :**1.0**
  - **More sensitive to hydrogen / water**
- Earth's core model
  - Standard Model
    - Mantle: Pyrolite
    - Outer core: 90wt% Fe + 10wt% O
    - Inner core: 100% Fe
  - Neutron core
  - Light material core

by A.Taketa

ν_μ Relative Flux Ψ_μ



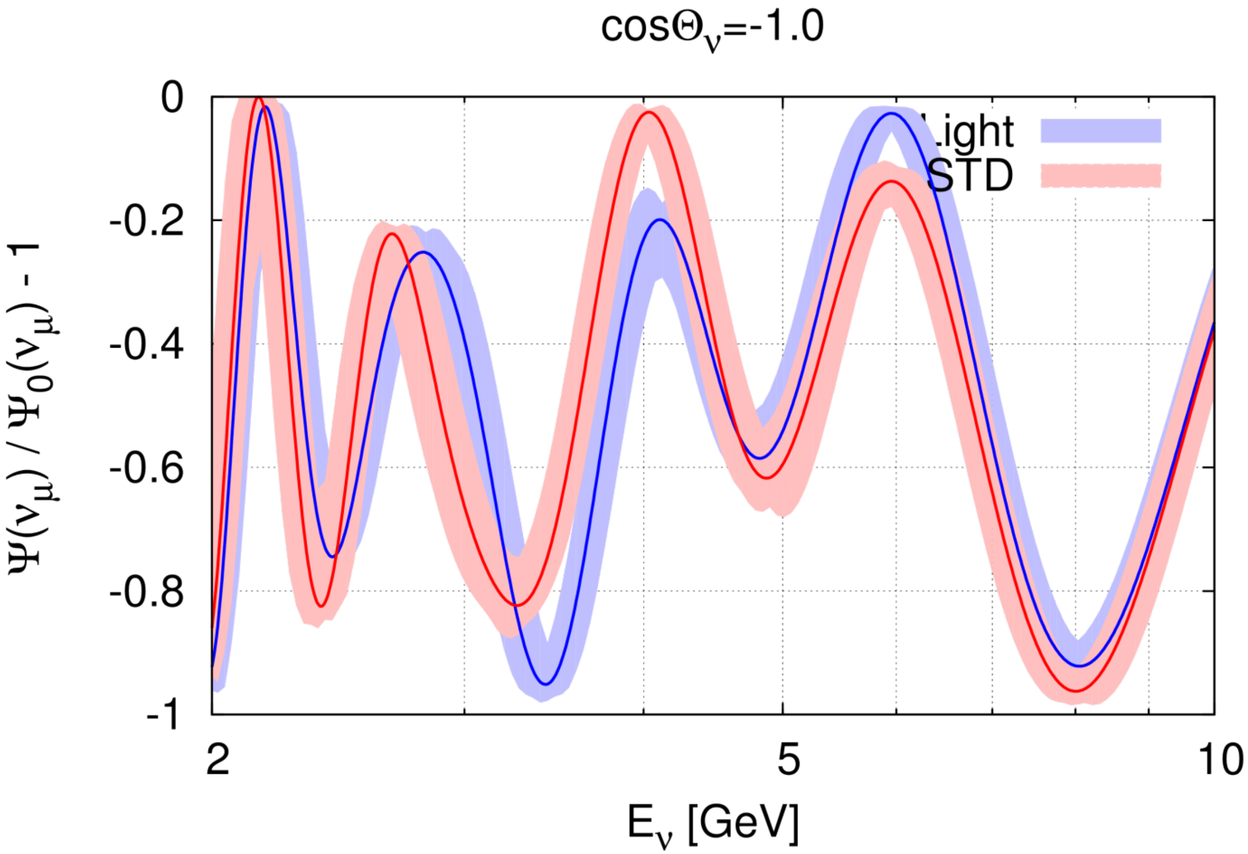
$$\frac{P(\nu_e \to \nu_\mu)F(\nu_e) + P(\nu_\mu \to \nu_\mu)F(\nu_\mu) + P(\bar{\nu}_e \to \bar{\nu}_\mu)F(\bar{\nu}_e) + P(\bar{\nu}_\mu \to \bar{\nu}_\mu)F(\bar{\nu}_\mu)}{F(\nu_\mu) + F(\bar{\nu}_\mu)}$$



by A.Taketa

Uncertainty from oscillation parameters

Global fit result after neutrino 2012



$$\sin^2\theta_{12} = 0.302^{+0.013}_{-0.012}$$

$$\sin^2\theta_{13} = 0.0227^{+0.0023}_{-0.0024}$$

$$\sin^2\theta_{23} = 0.413^{+0.037}_{-0.025}$$

$$\delta_{CP} = free$$

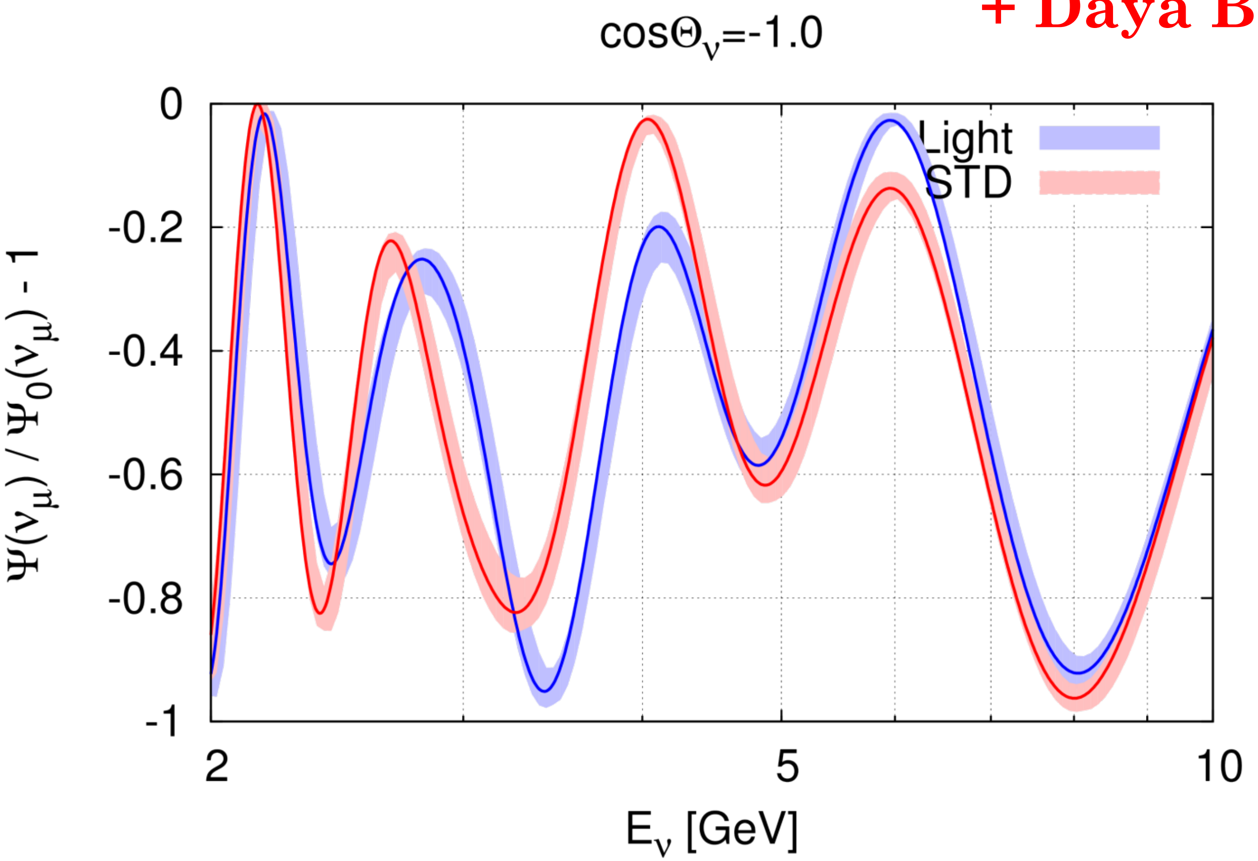
$$\Delta m^2_{21} = (7.5^{+0.18}_{-0.19})\times 10^{-5}$$

$$\Delta m^2_{32} = (2.398^{+0.042}_{-0.065})\times 10^{-3}$$

by A.Taketa

Uncertainty from oscillation parameters

Global fit result after neutrino 2012
+ Daya Bay(3yrs) + T2K(design)



$$\sin^2\theta_{12} = 0.302^{+0.013}_{-0.012}$$

$$\sin^2\theta_{13} = 0.0227^{+0.001}_{-0.001}$$

$$\sin^2\theta_{23} = 0.413^{+0.01}_{-0.01}$$

$$\delta_{CP} = free$$

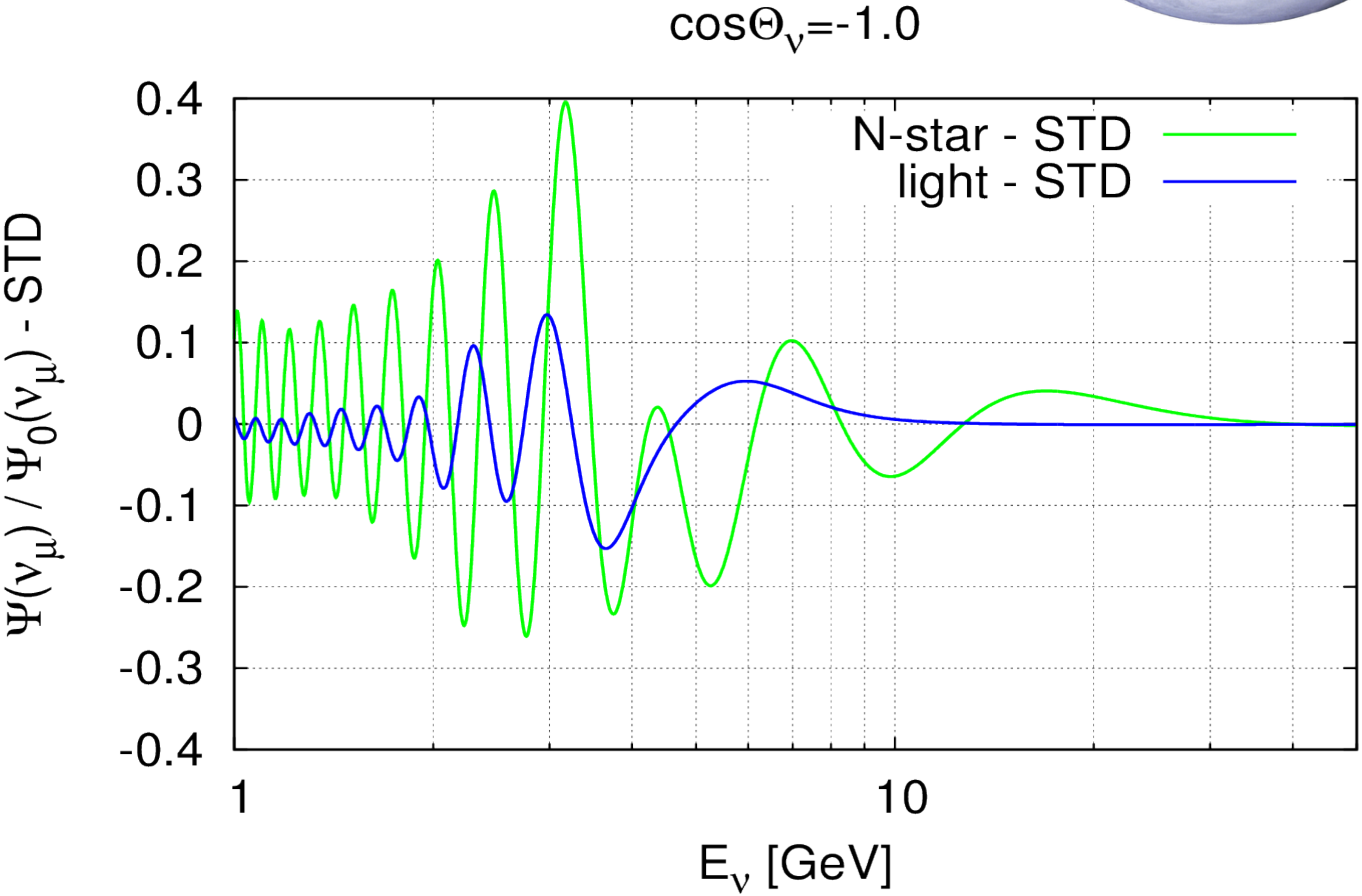
$$\Delta m^2_{21} = (7.5^{+0.18}_{-0.19})\times 10^{-5}$$

$$\Delta m^2_{32} = (2.398^{+0.042}_{-0.065})\times 10^{-3}$$

θ_{13} / θ_{23} is essential for composition measurement
MC uncertainty is not concerned
Upward / downward ratio can be used

by A.Taketa

Difference of relative flux Ψ_μ (model)- Ψ_μ (STD)

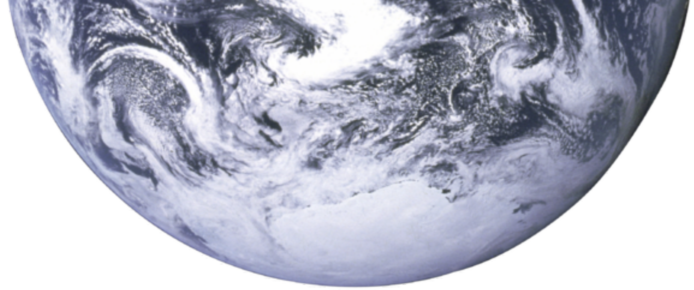


by A.Taketa

Conclusion

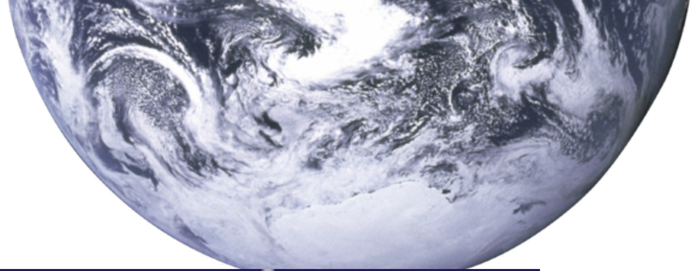
- Neutrino oscillation is sensitive to electron density of the deep earth
  - Chemical composition : if we know mass density
  - Matter density : if we know chemical composition
- Other possible measurements
  - Evidence of the compositional convection
  - Upper limit of water content in mantle
  - Fe/Mg ratio of lower mantle
  - Iron-hydoride core

Related talk will be given by C. Rott, on 7/26 P1-2 session.

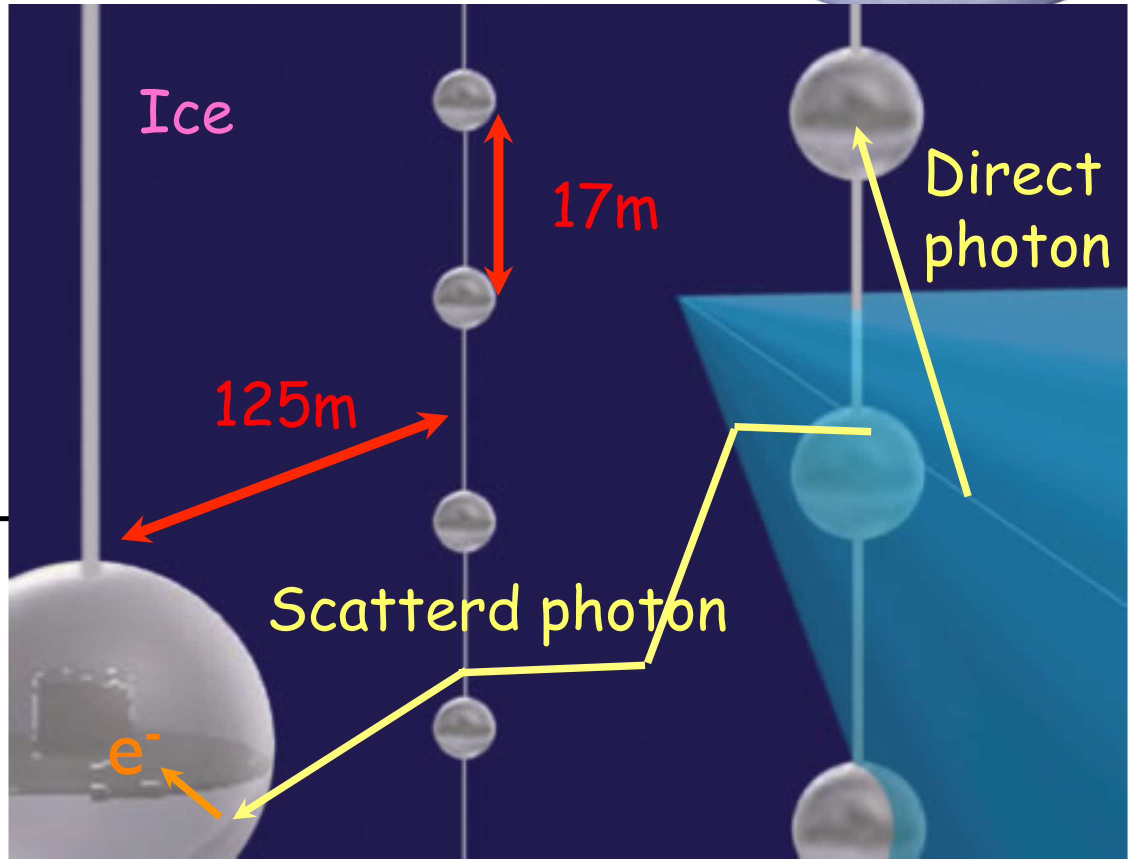


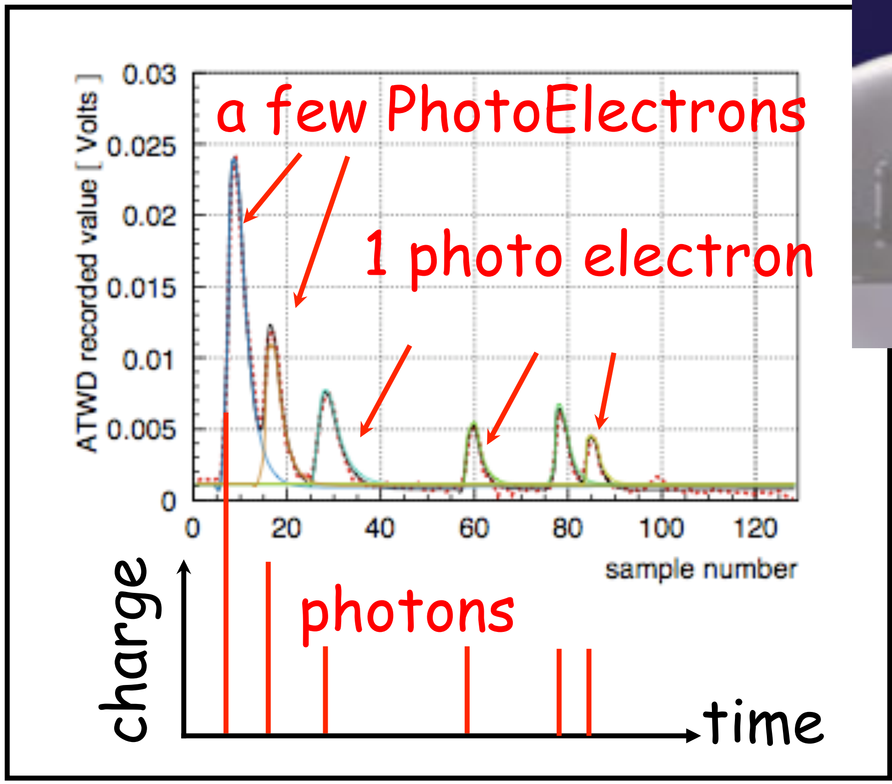
backups

How an event is recorded?

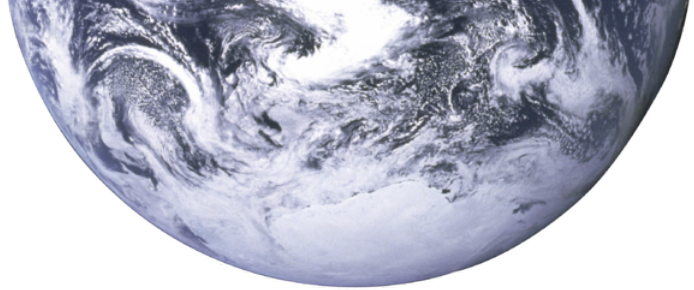


Digital Optical Module (DOM) 10inch PMT+ electronics



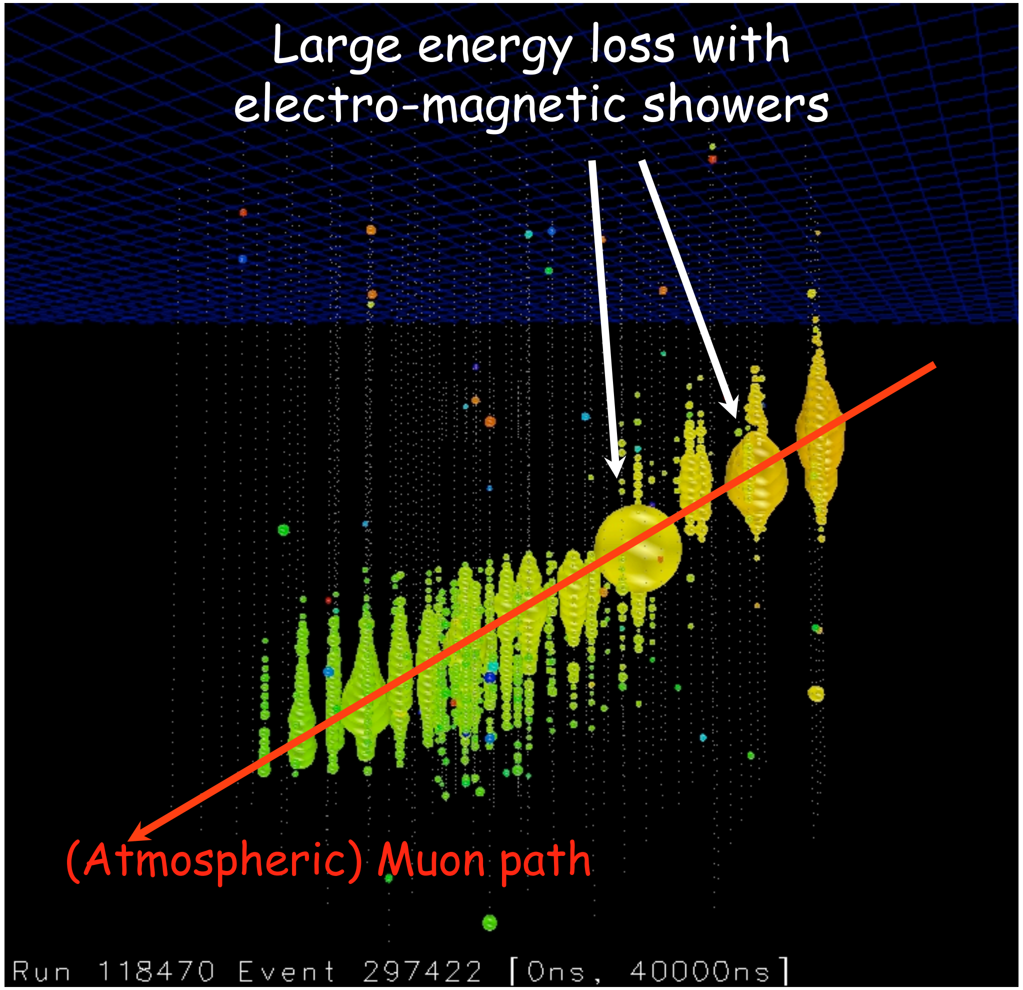


- Large amount of photons arrive after multiple scattering
- Ice property affect photon scattering and absorption



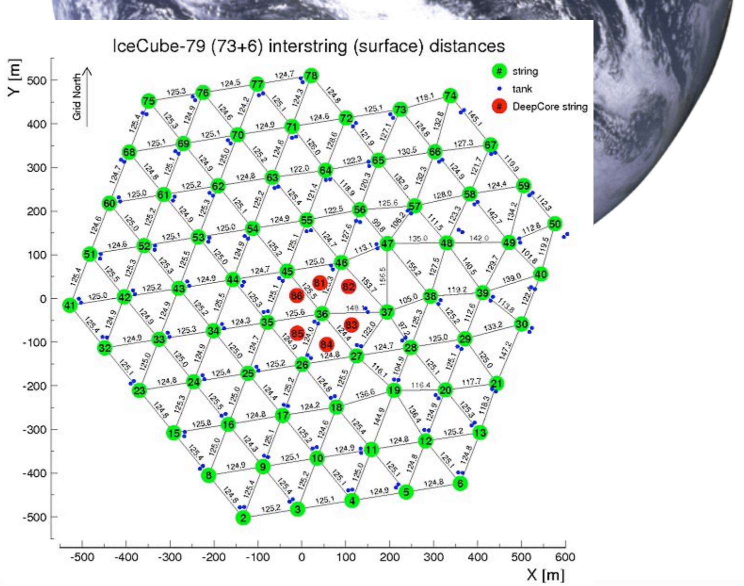
How is an event reconstructed?

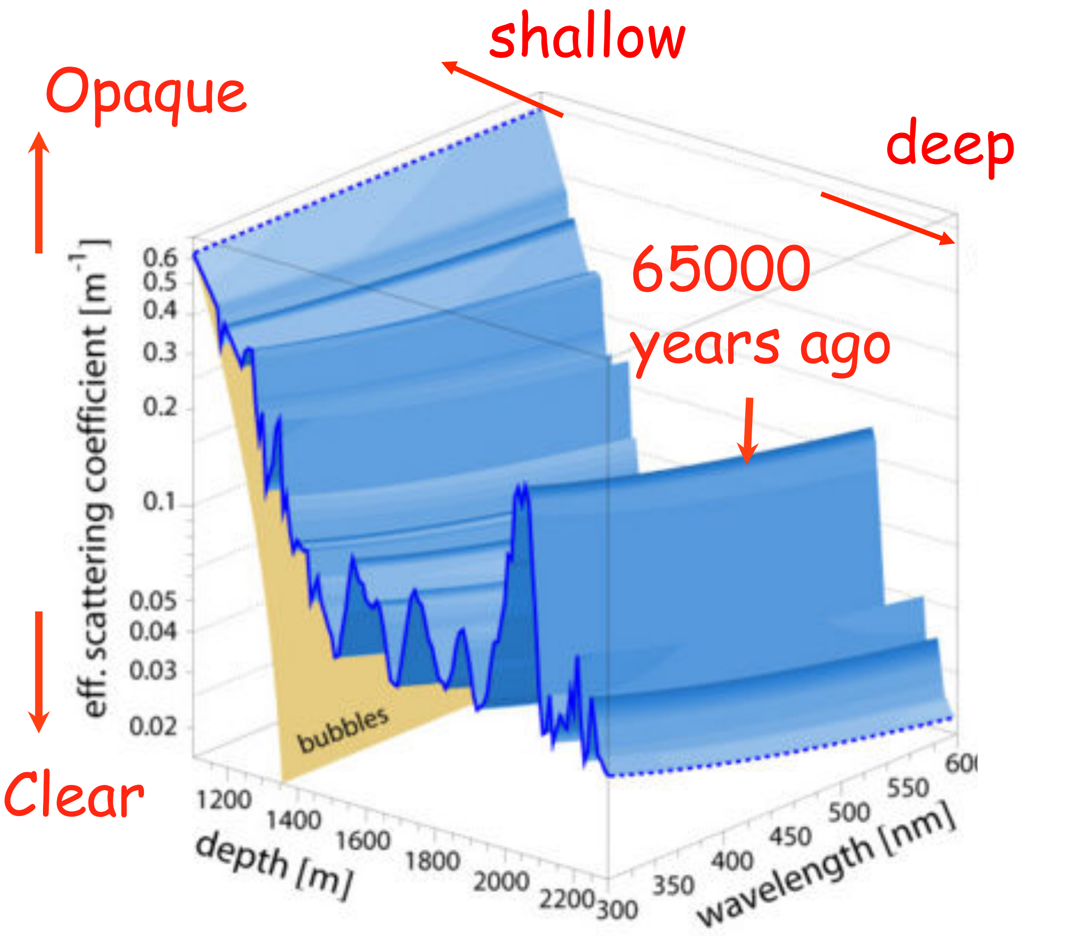
- Geometry reconstruction (Direction, Position)
  - use timing and number of arrival photons
- Energy Reconstruction
  - use number of arrival photons (charge of DOMs)
- For best reconstruction we have to use our knowledge of ice properties (not uniform)

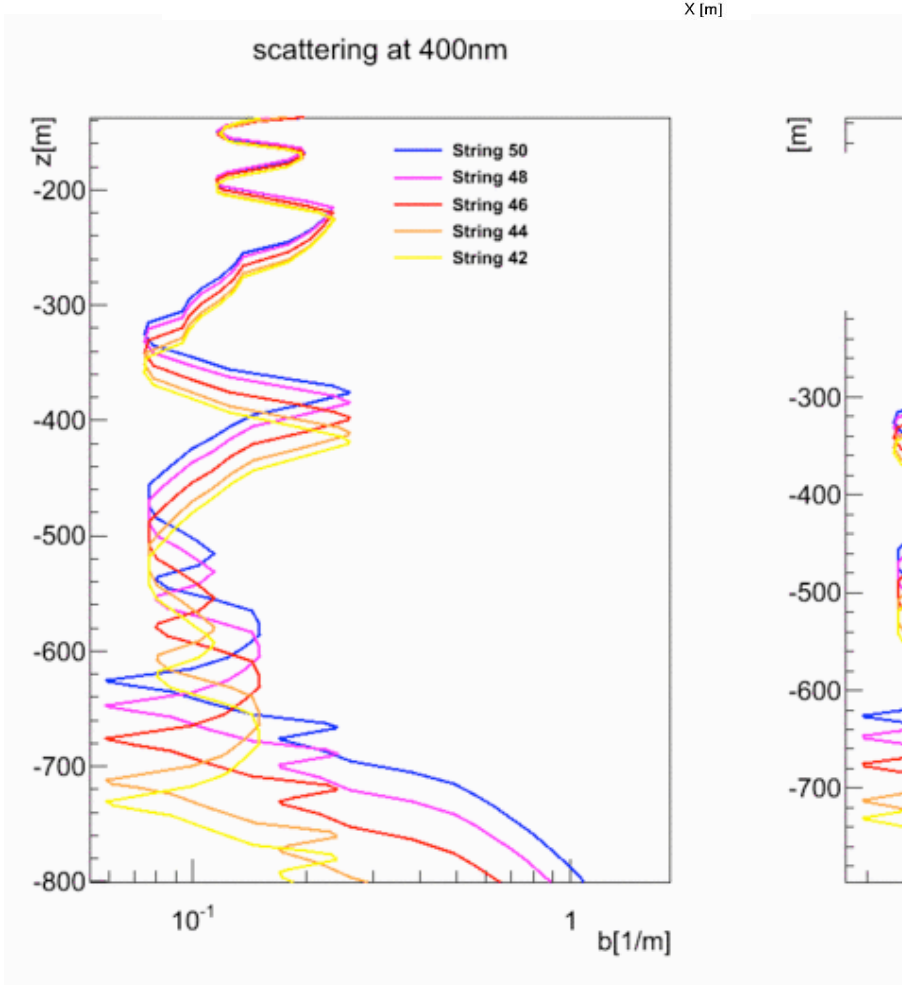


South pole Ice

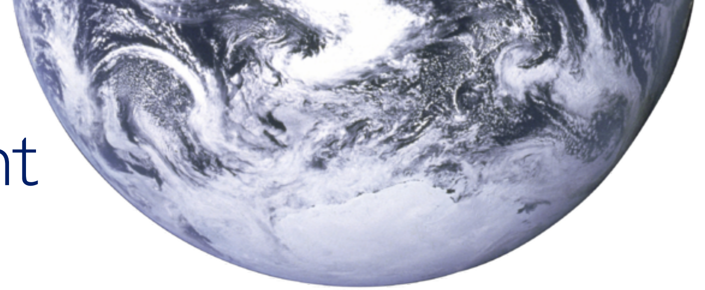
Natural Ice has a lot of structures : Depth Dependence, Tilt, Stretching...



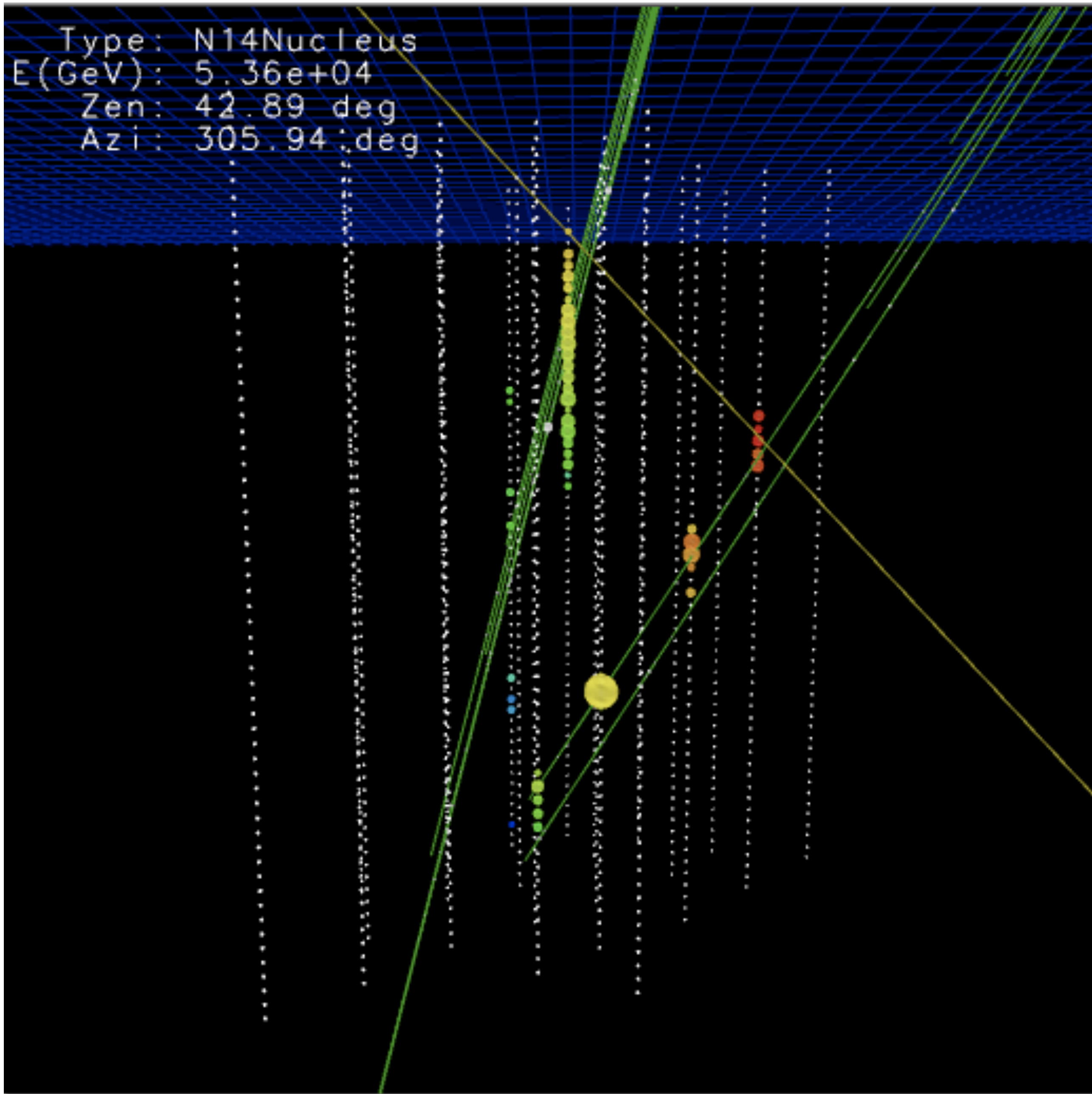




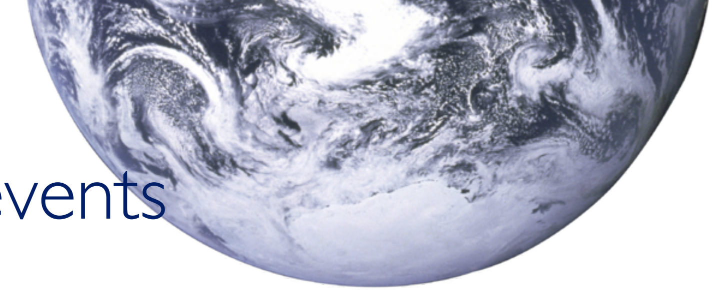
Example of Backgrounds : Coincidence event



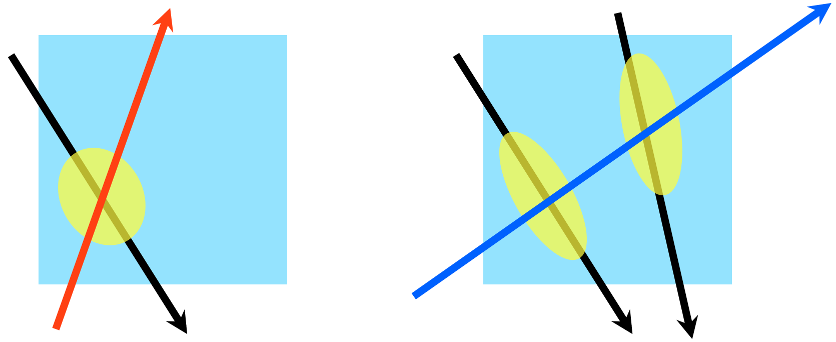
- Two muons coincidently pass through the detector within a time window
- Reads totally wrong answer for both energy and directional reconstruction
- upmu : coinc mu ratio 1 : 5000 after pole filter
- Survives fit-quality cuts due to high-multiplicity of hit DOMs

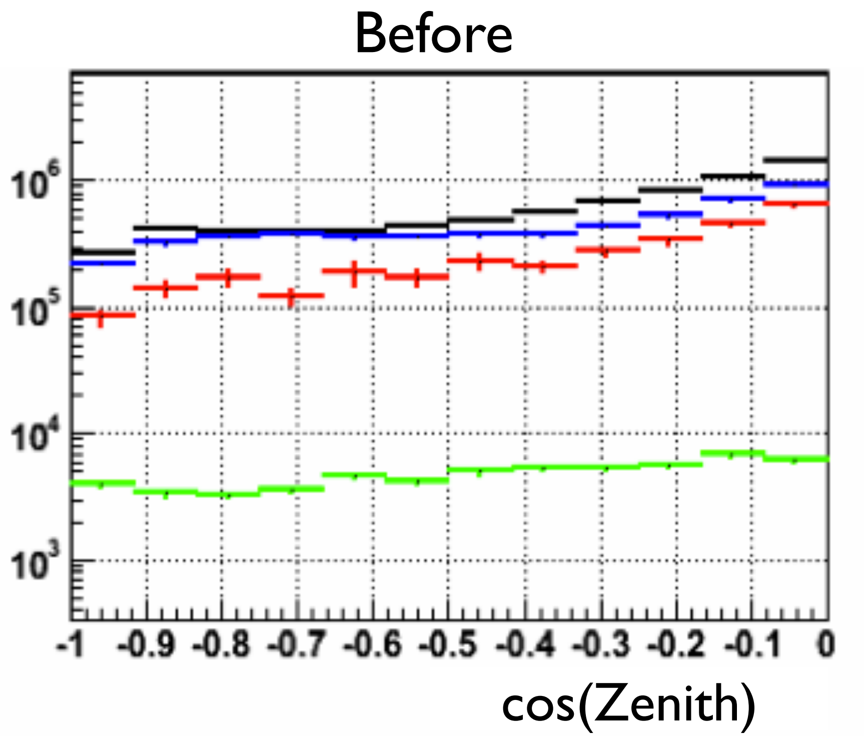


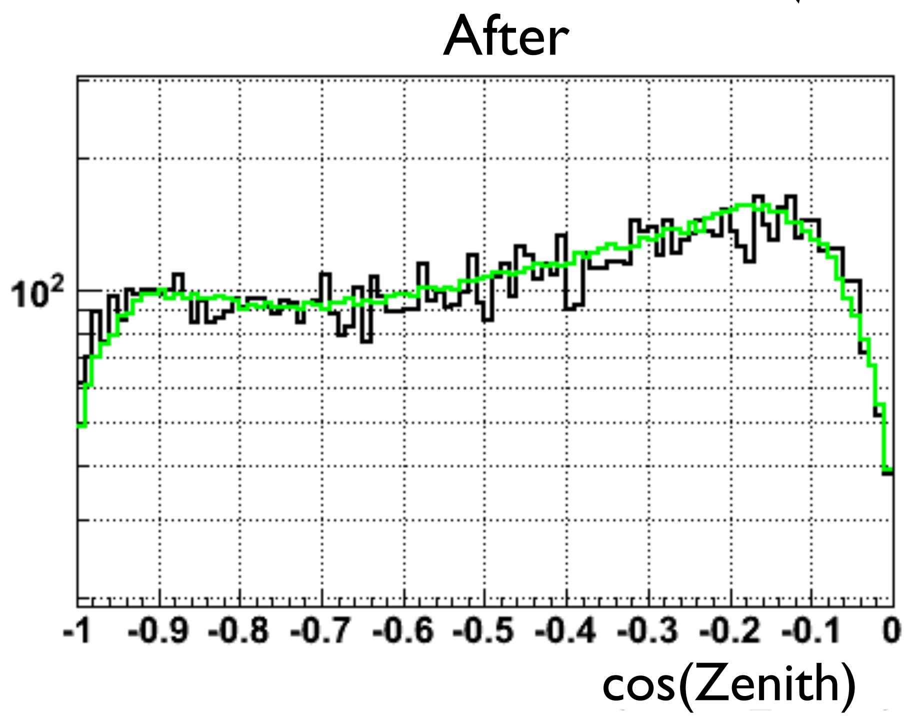
Selecting pure neutrino induced upgoing events



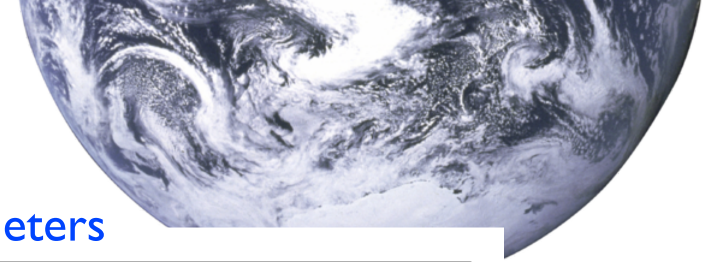
Data
Atmospheric Neutrino
Atmospheric Single Muons
Atmospheric Coincidence Muons

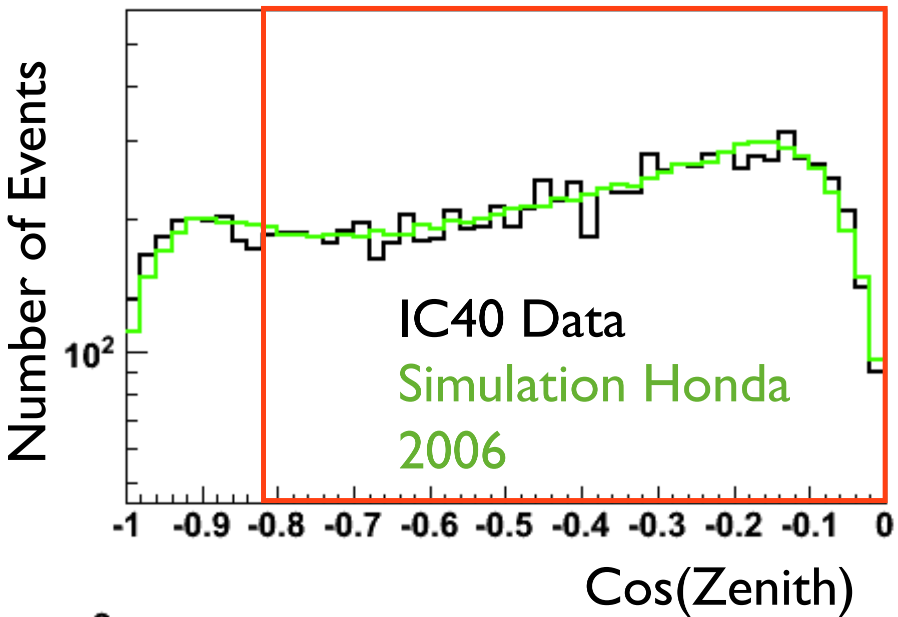


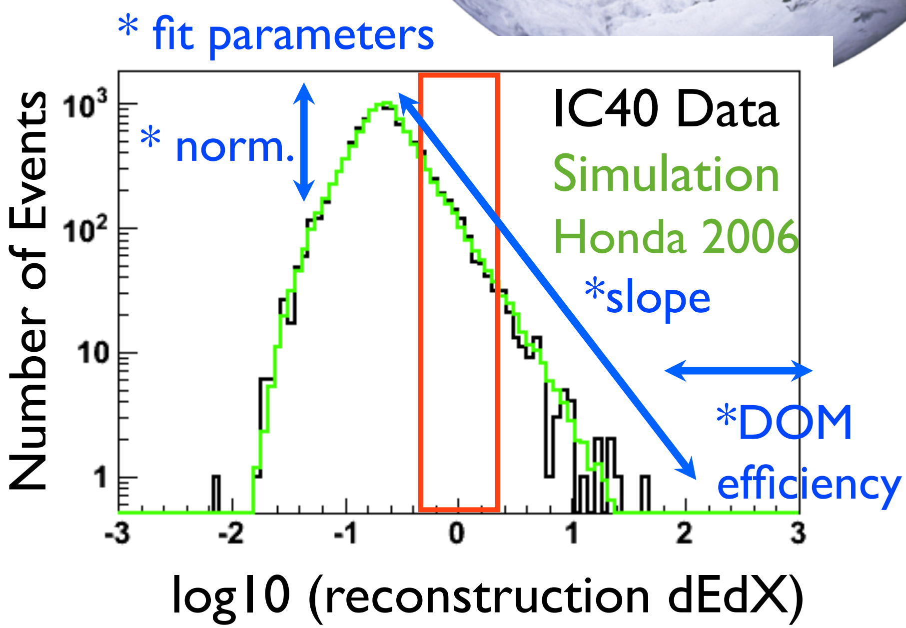


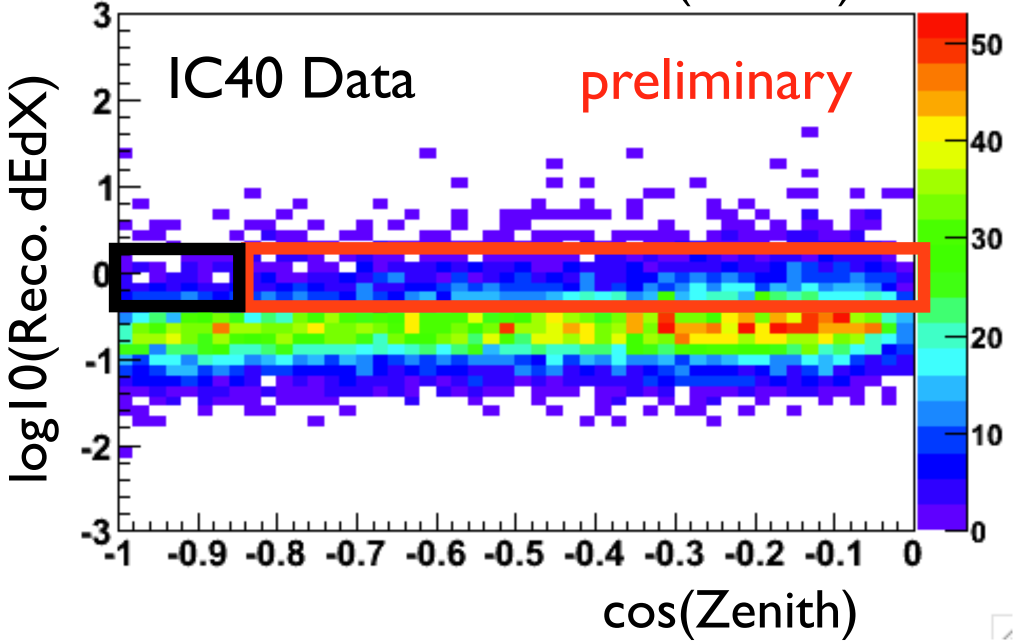


IC40 Analysis - After event selection



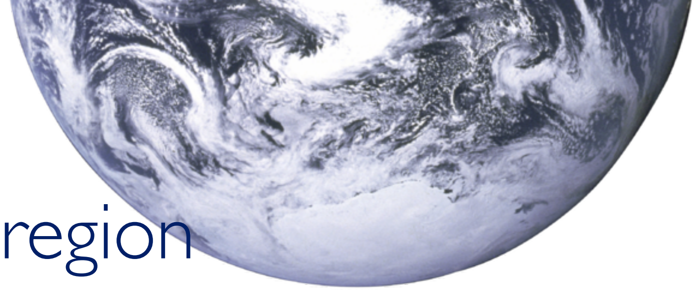






Red box - simulation is fit with data to obtain fit parameters

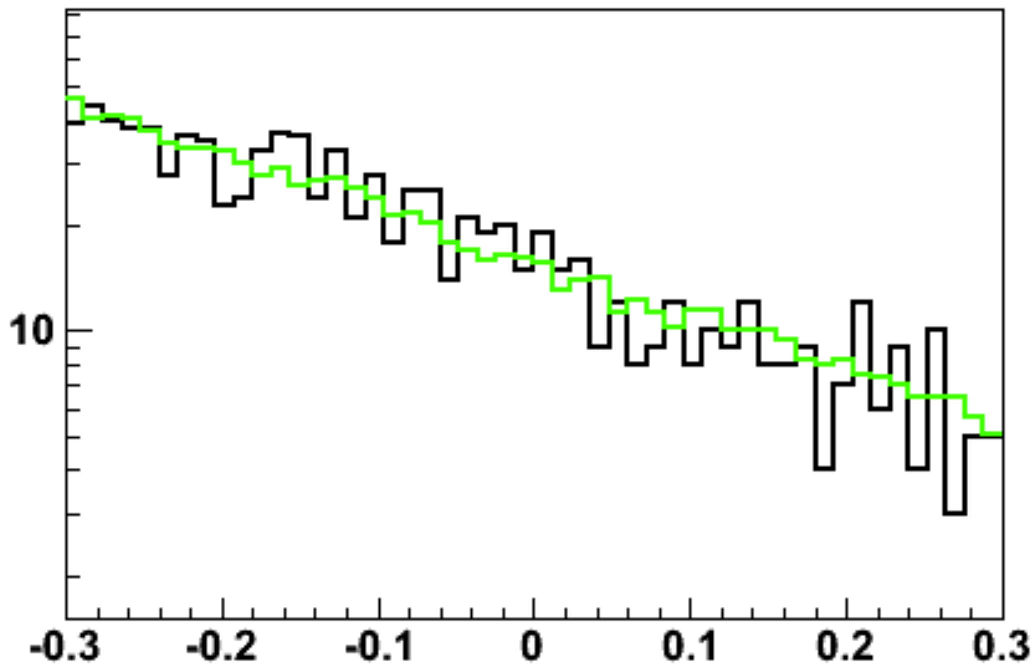
Black box - Using fit parameters, simulations are compared with data



Fitting simulation with data at Mantle region

Data

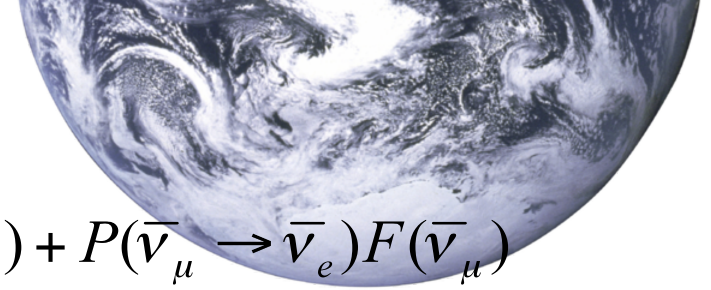
Simulation Honda 2006



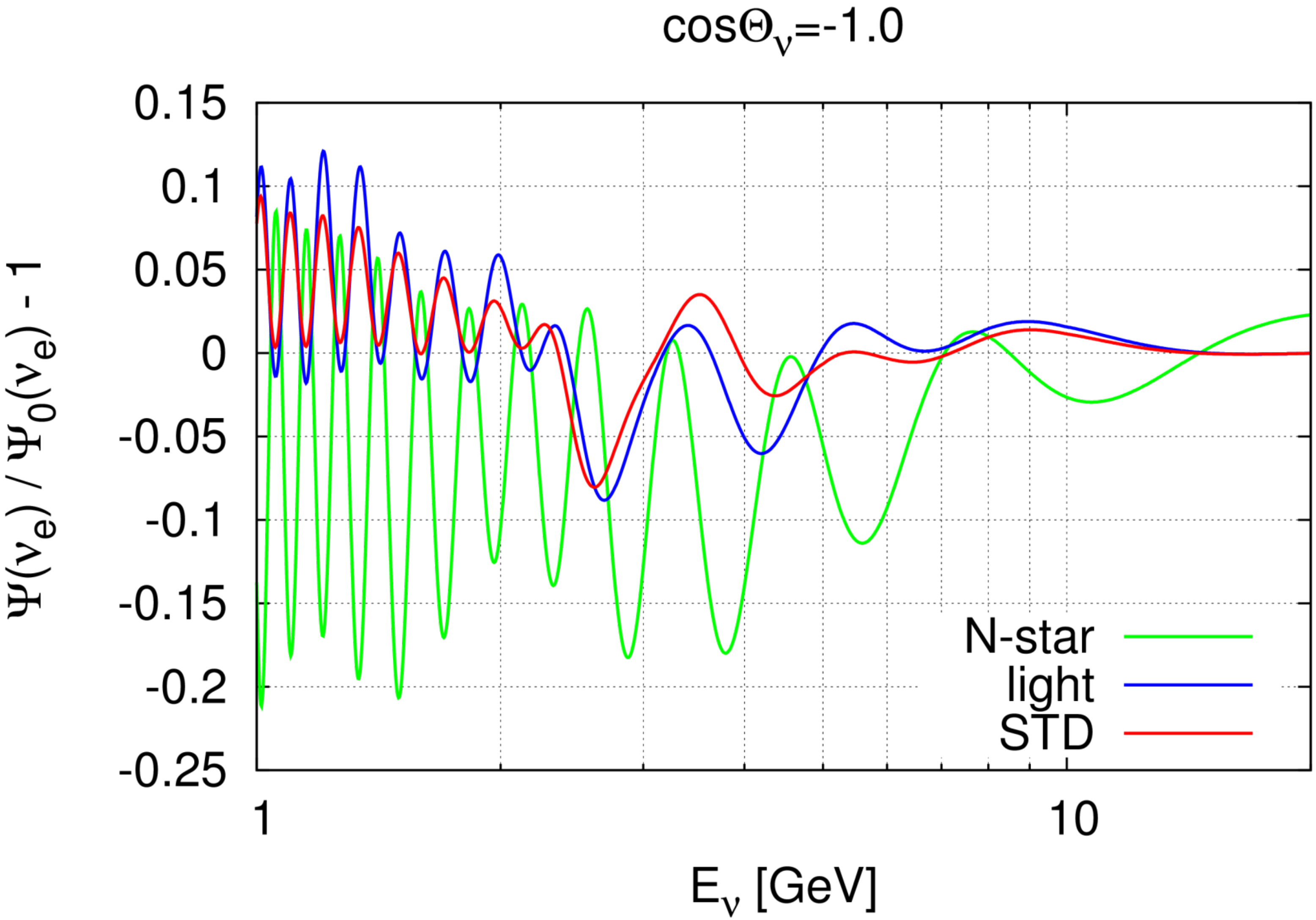
log10 (Reconstruction dEdX [GeV])

- 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

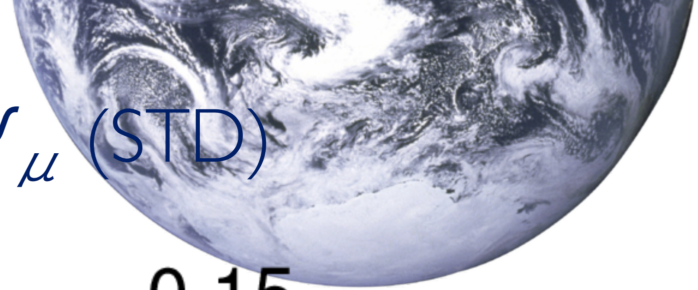
ν_e Relative Flux Ψ_e

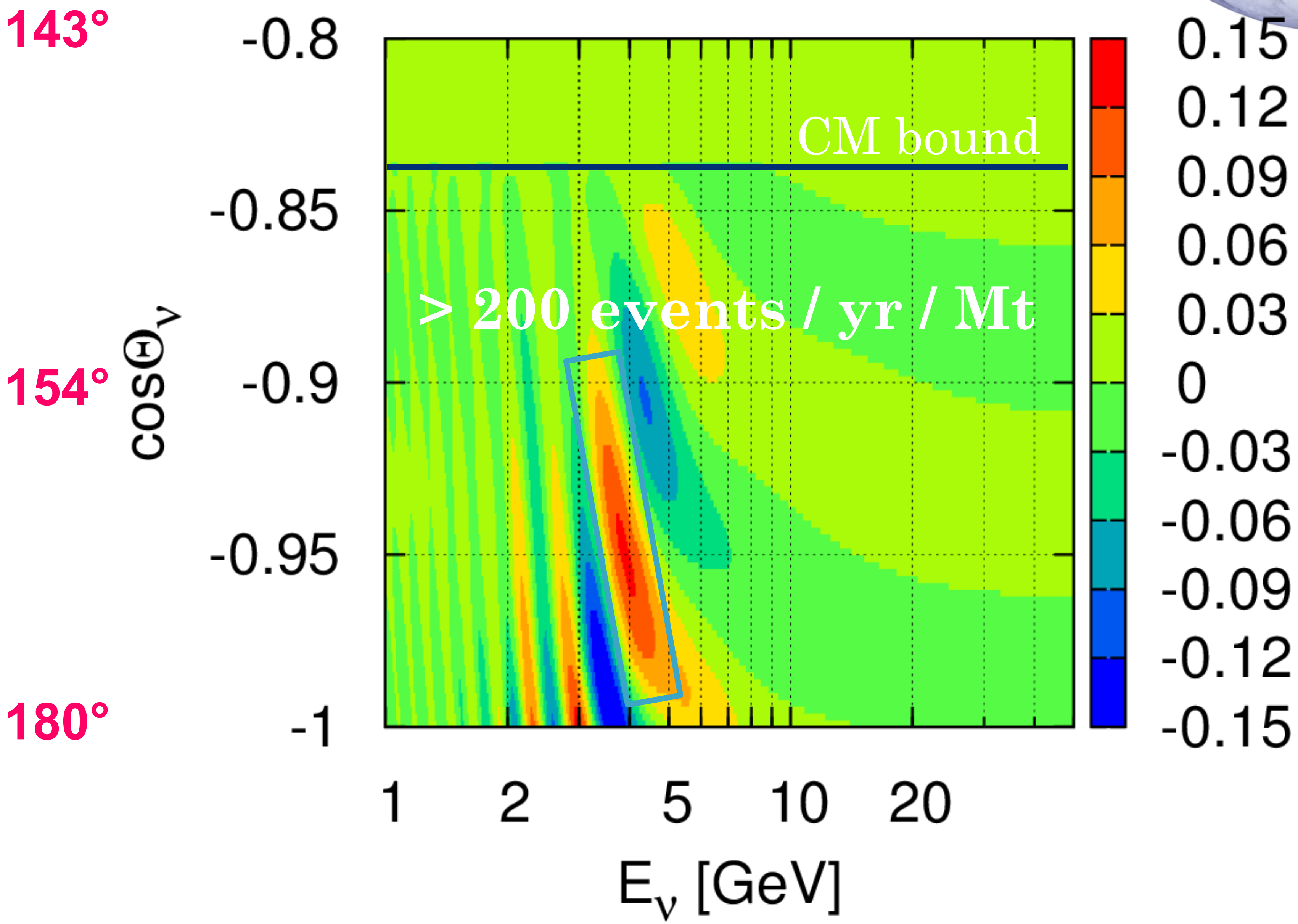


$$\frac{P(\nu_e \to \nu_e)F(\nu_e) + P(\nu_\mu \to \nu_e)F(\nu_\mu) + P(\bar{\nu}_e \to \bar{\nu}_e)F(\bar{\nu}_e) + P(\bar{\nu}_\mu \to \bar{\nu}_e)F(\bar{\nu}_\mu)}{F(\nu_e) + F(\bar{\nu}_e)}$$



Difference of relative flux Ψ_μ (light)- Ψ_μ (STD)





Survival probability of ν_e