Detector Requirements for Neutrino Oscillation Tomography

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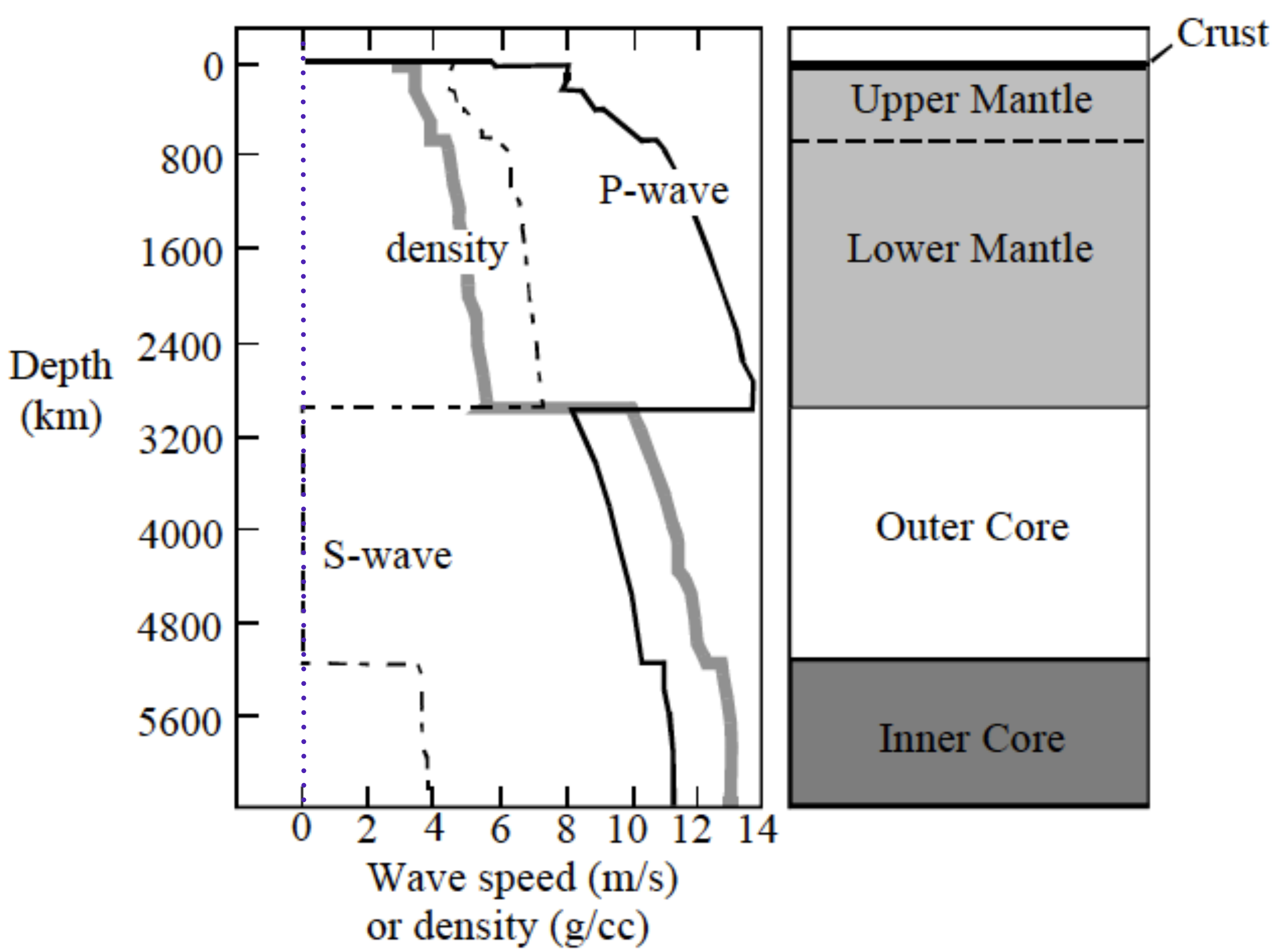
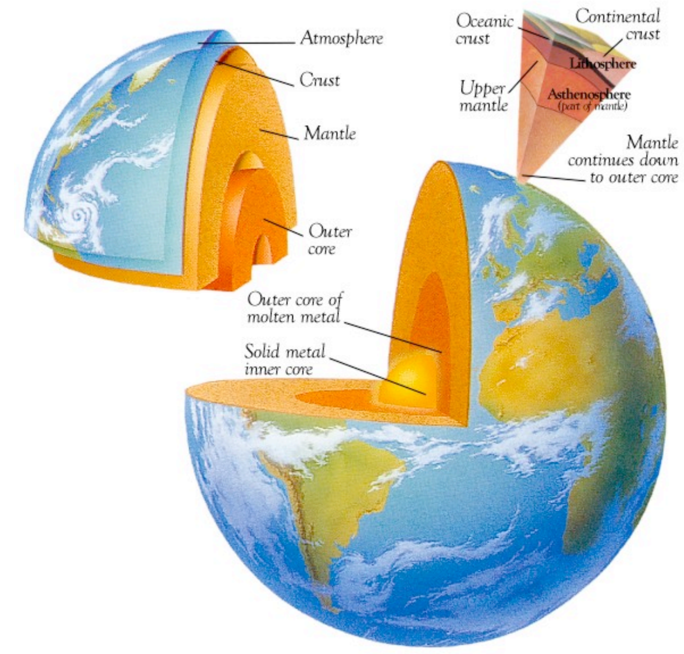
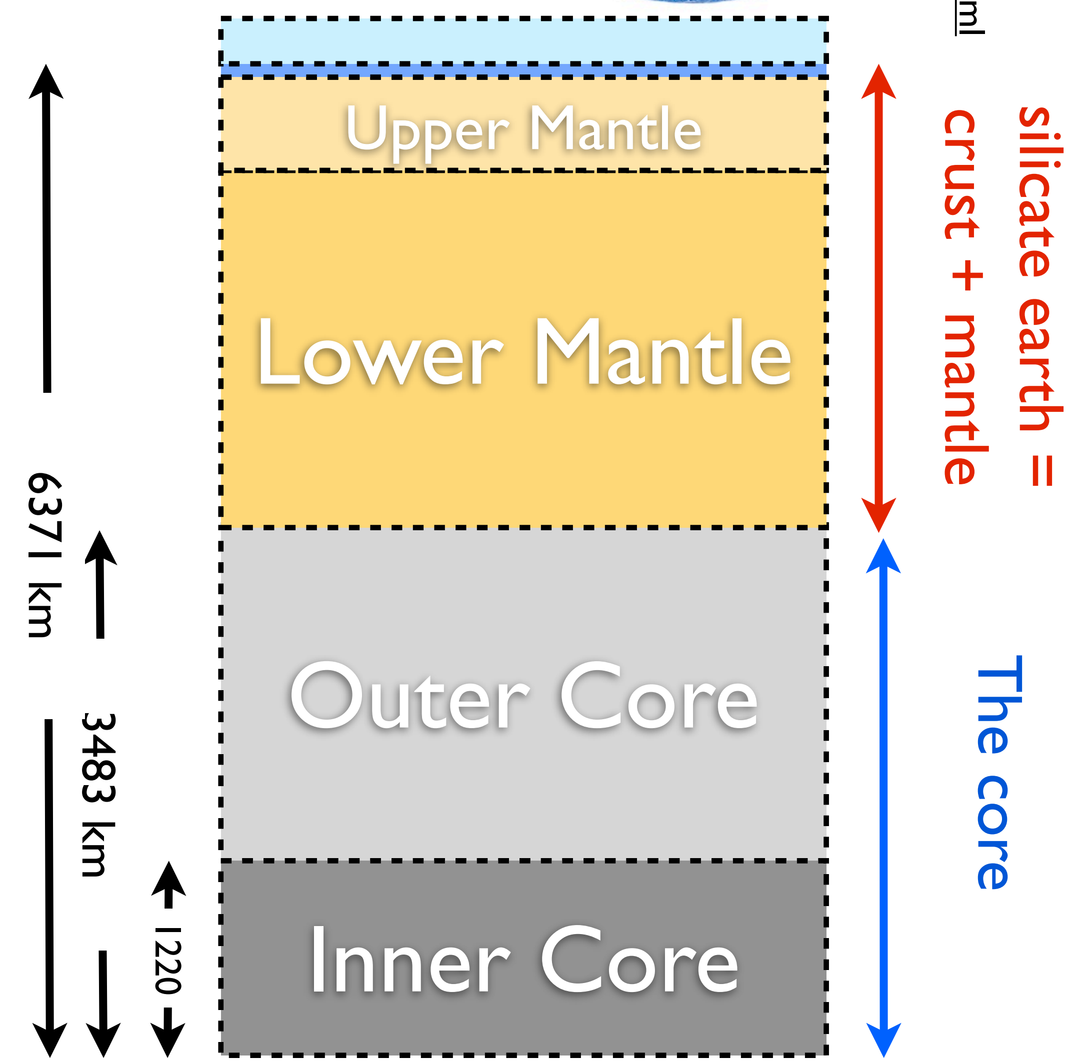
Seismological profile of the Earth



William F. McDonough "The Composition of the Earth"



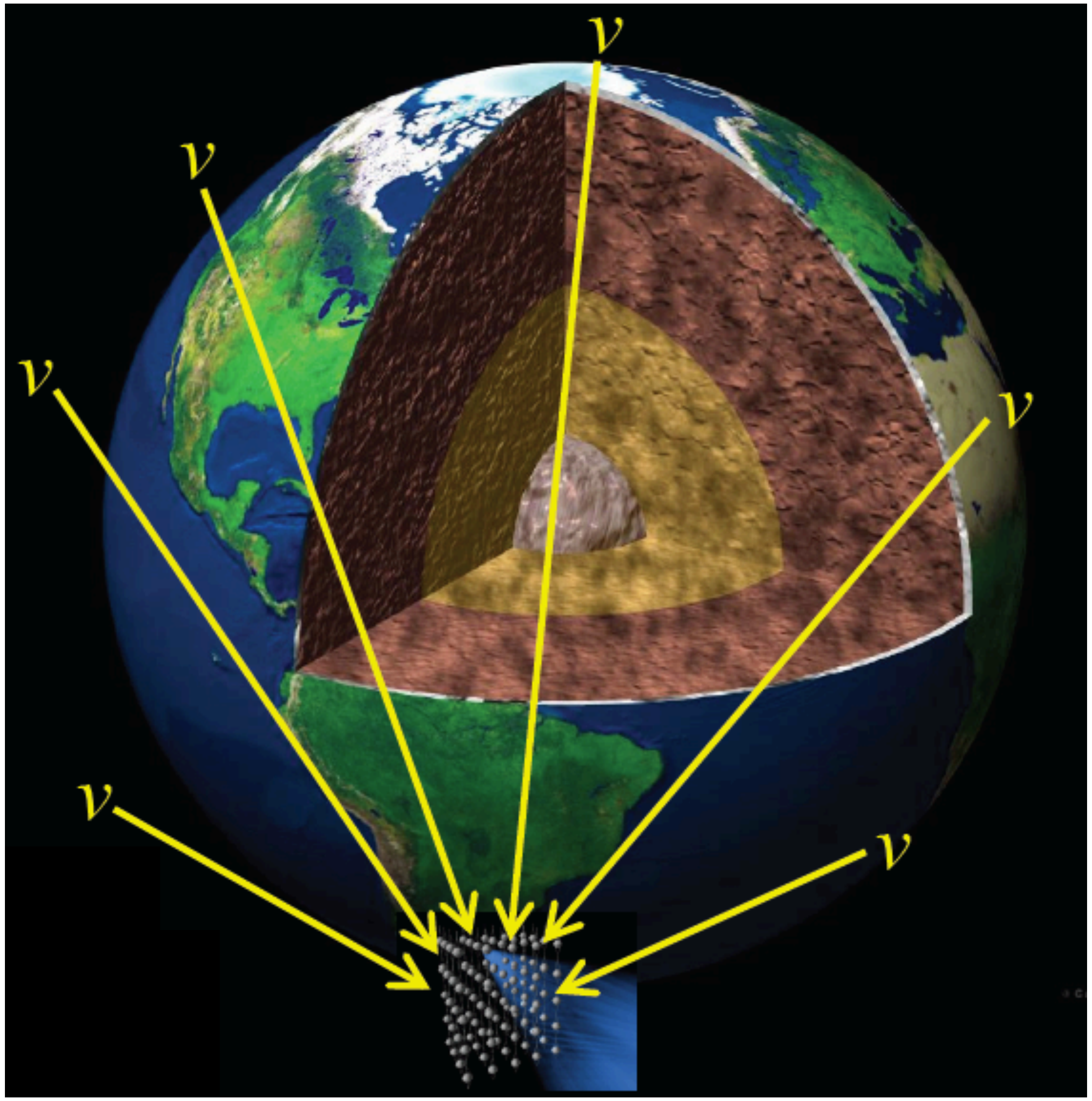
http://www.phys.hawaii.edu/~sdye/hnsc.html



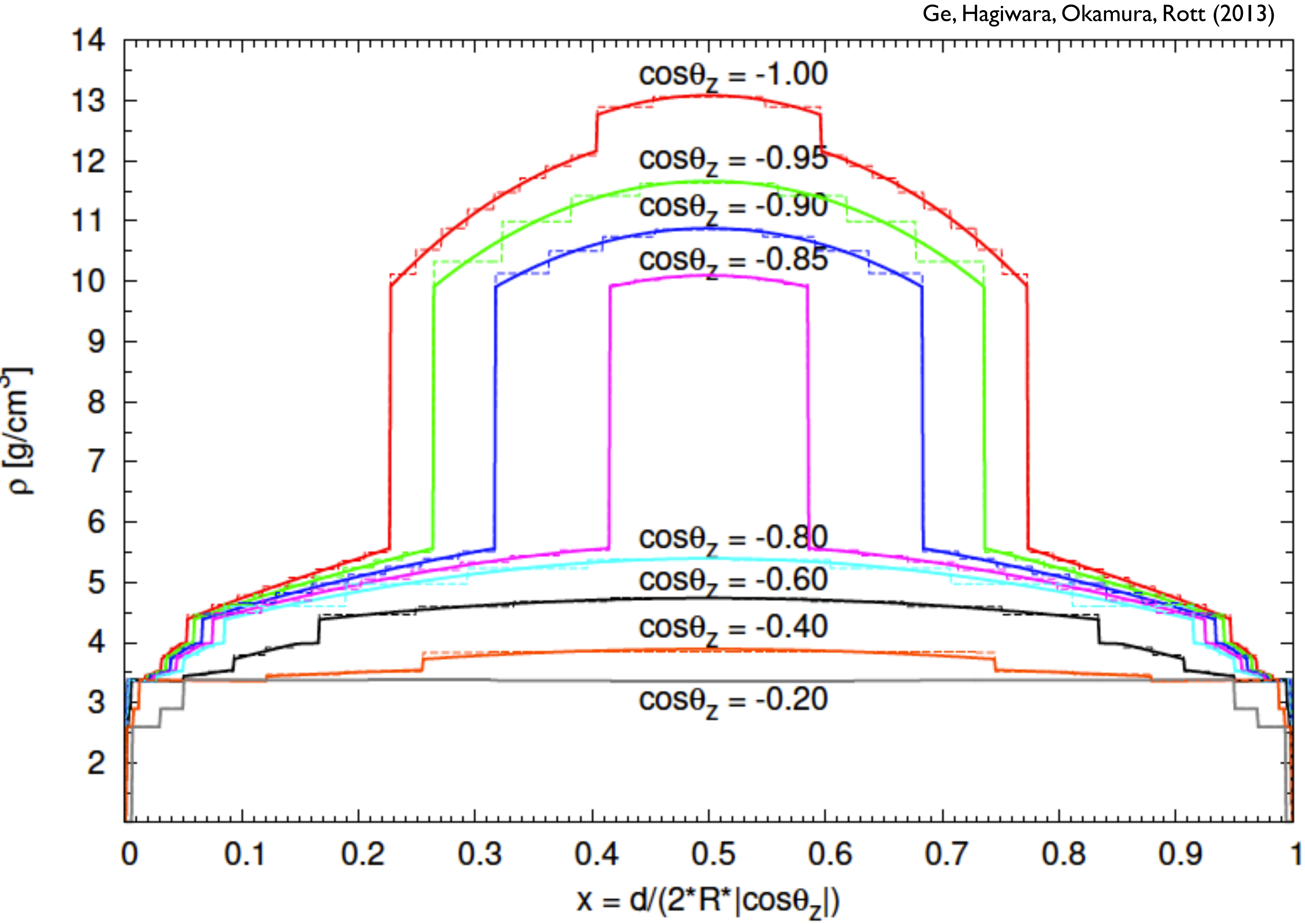
- Density relatively well described through seismic measurements (-> PREM)... but whats the composition ?

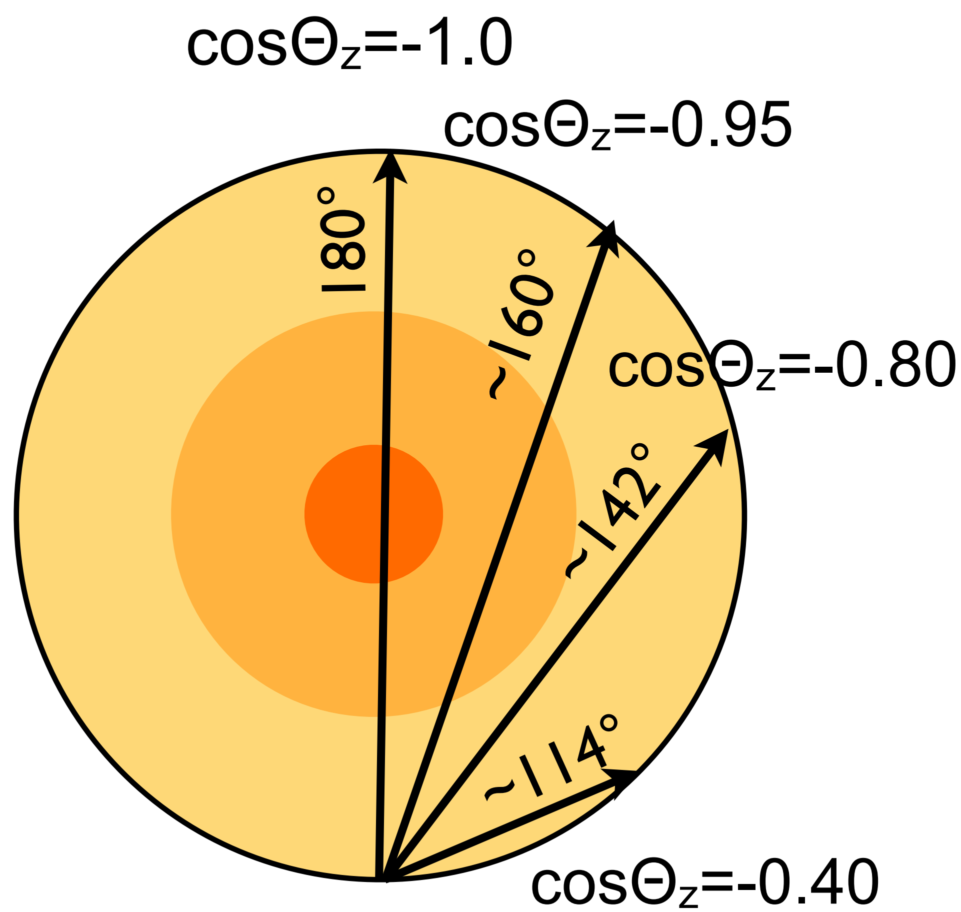
Motivation - Methodology

- The Earth matter density profile can be determined from seismic measurements
- Matter induced neutrino oscillation effects however dependent on the electron density
- Given a matter density profile the composition (or Z/A) along the neutrino path can be determined using neutrino signals (Oscillation tomography)



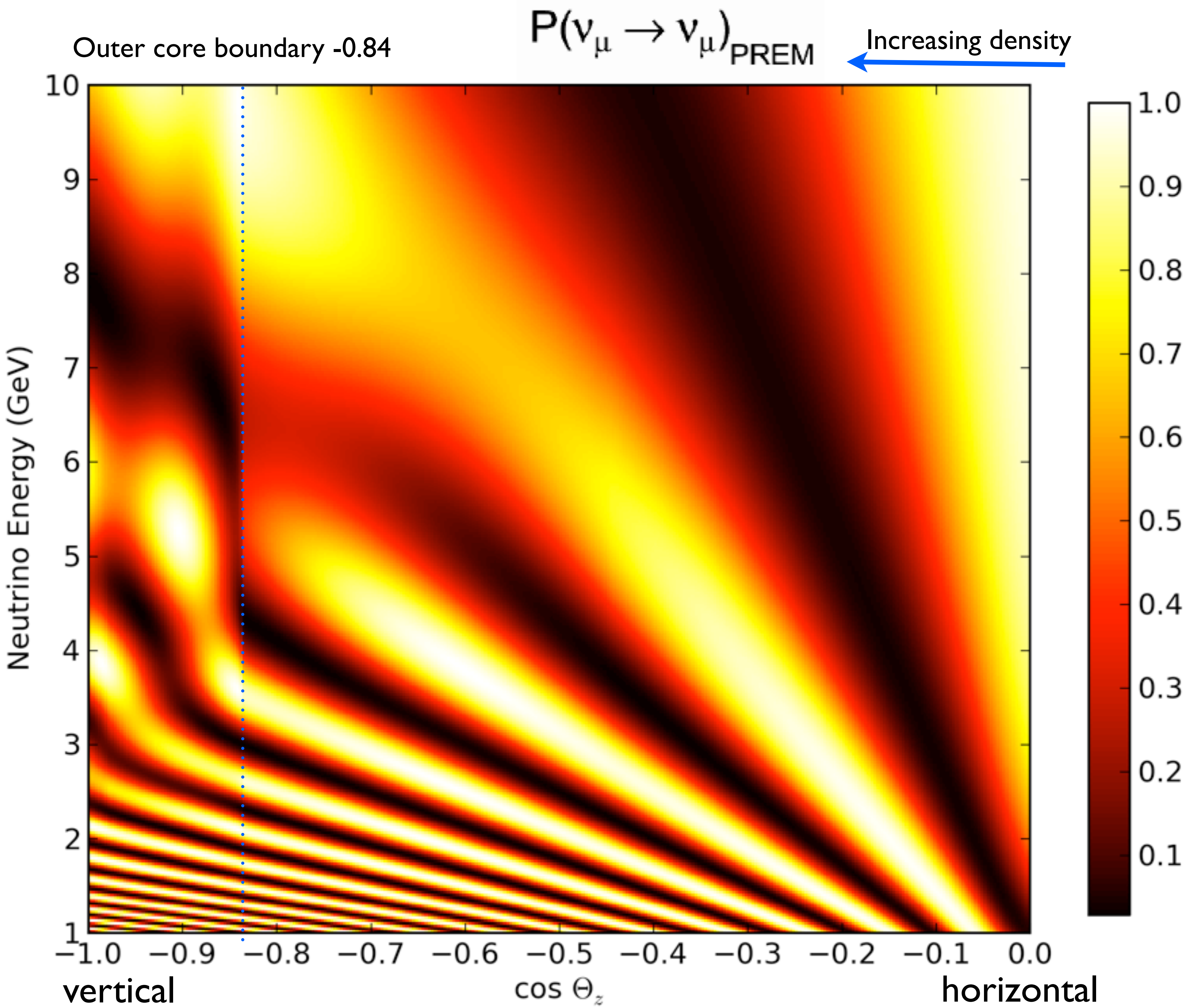
Preliminary Reference Earth Model



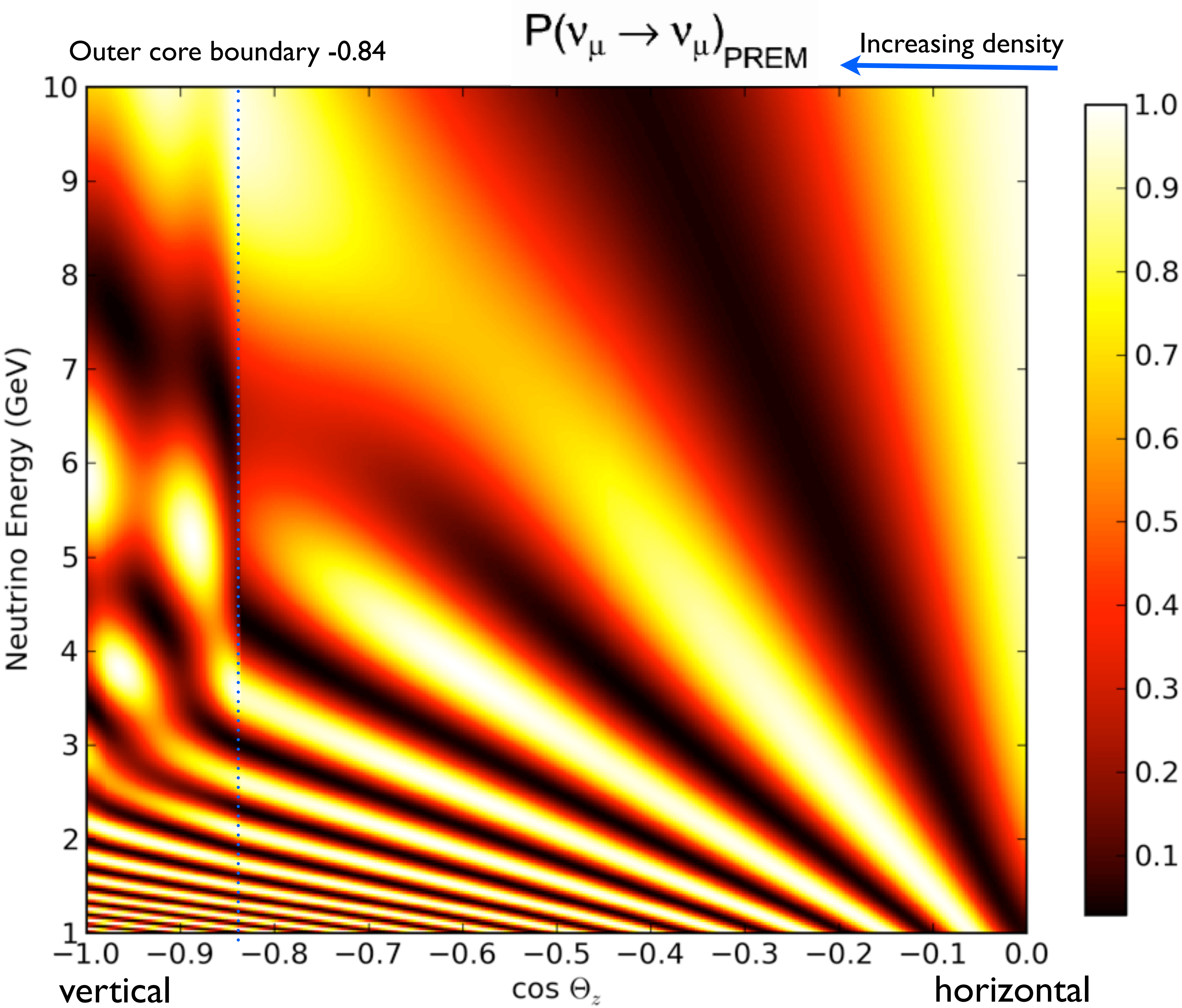


- The PREM - Preliminary Reference Earth Model is based on a paper by Dziewonski and Anderson in 1981. It still still represents the standard framework for interpretation of seismological data

Oscillograms



Oscillograms

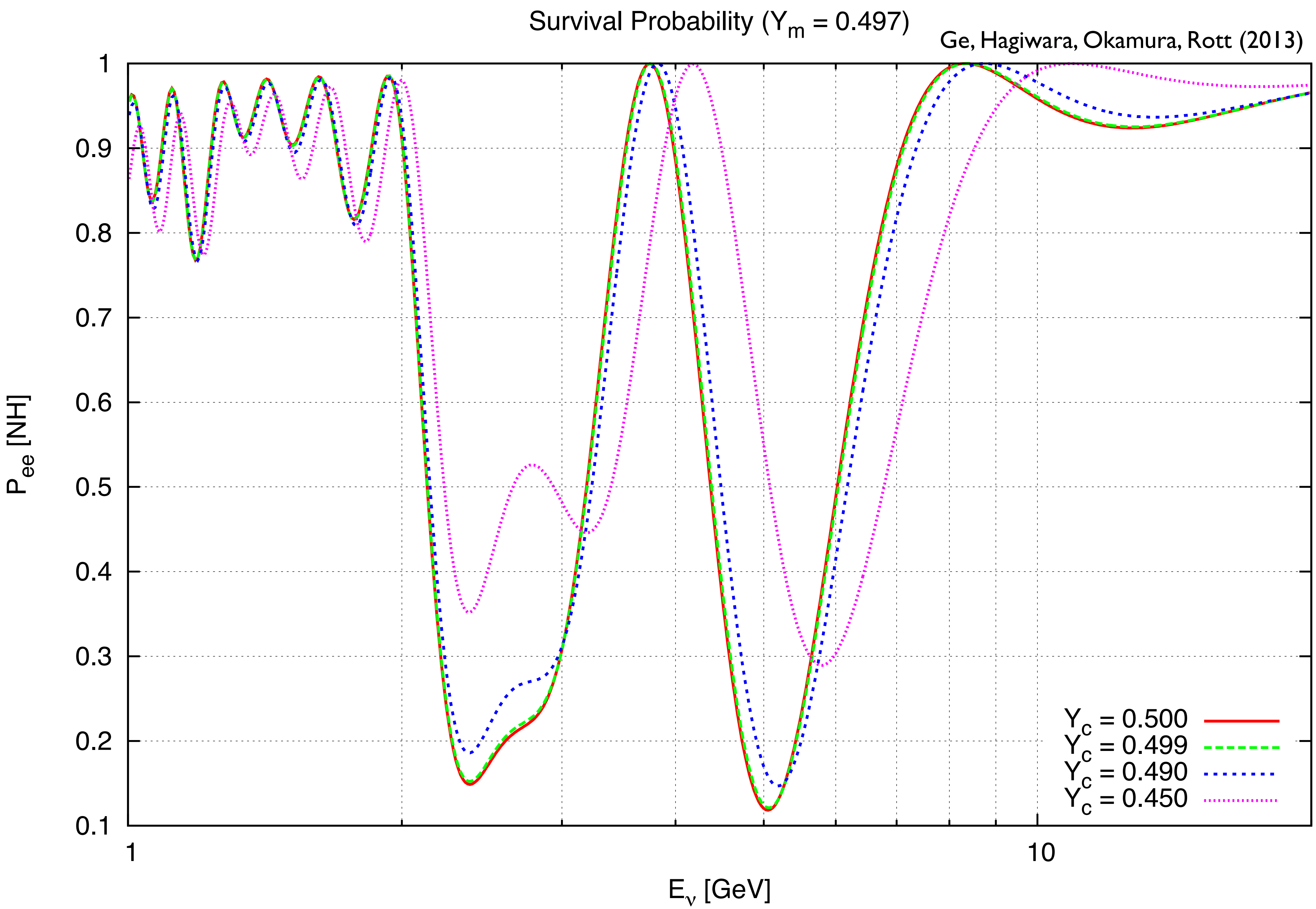


Change Earth core electron density by 10% to visualize

Most significant changes are seen in an energy range of 2-10GeV and for neutrinos passing through the core region ($\cos\theta < -0.84$)

Impact of core electron density

Change in electron neutrino survival probability if the electron density in the core is change. Mantle density is assumed constant.



Z/A determines the electron density Y_C

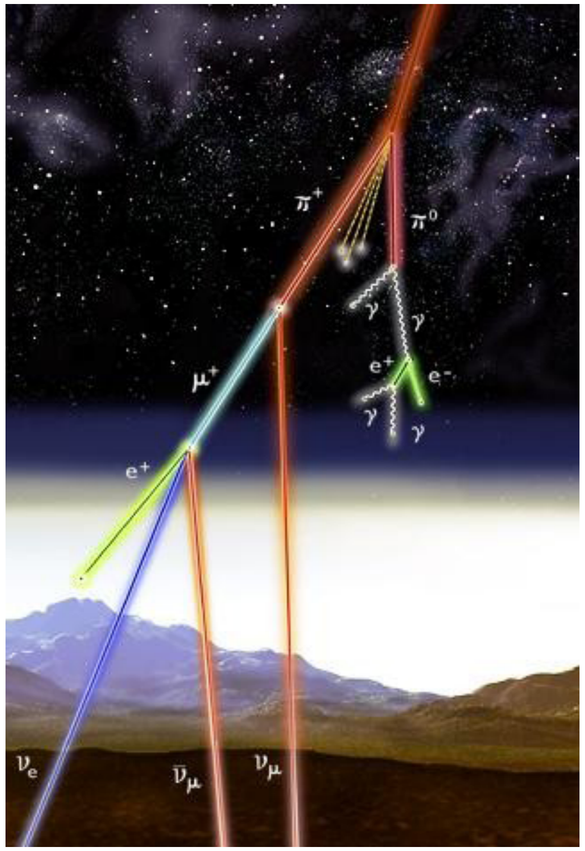
Despite large uncertainty in composition, electron density relatively minor impacted (Z/A~0.5)

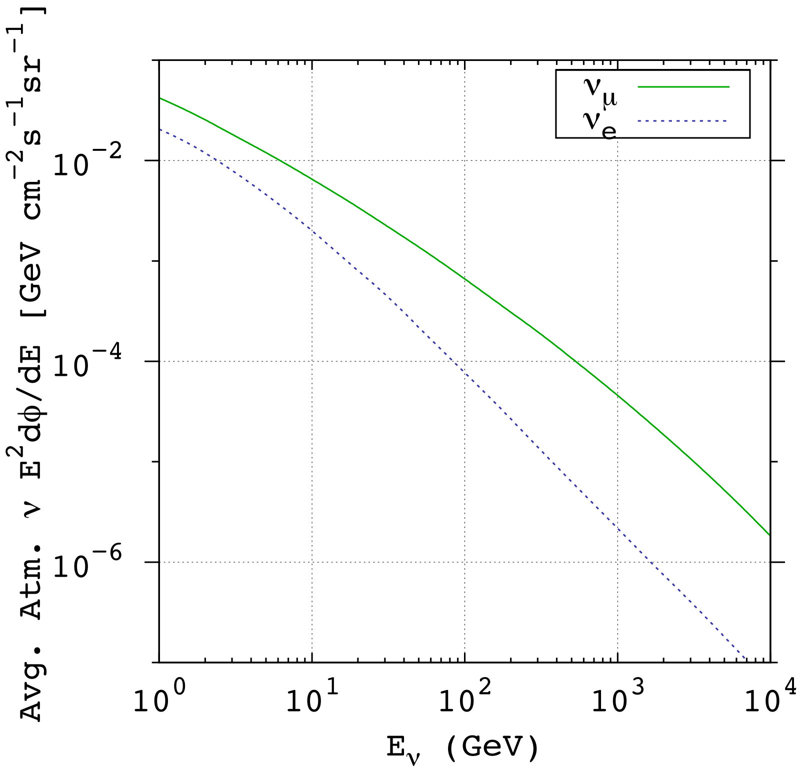
Y_C uncertainty based on Earth composition a few %

Considerations

- Y=Z/A≈0.5 is very similar for all elements
  - Even relatively large change in composition could result in small change in Y ~ 1%
  - Exception Hydrogen Y=1
- To measure an effect due to the core composition we need:
  - good energy resolution -> fully contained events, good optical coverage
  - good angular resolution -> precise timing, good optical coverage
  - high statistics sample -> large effective detector volume

Neutrino Source - Atmospheric neutrinos



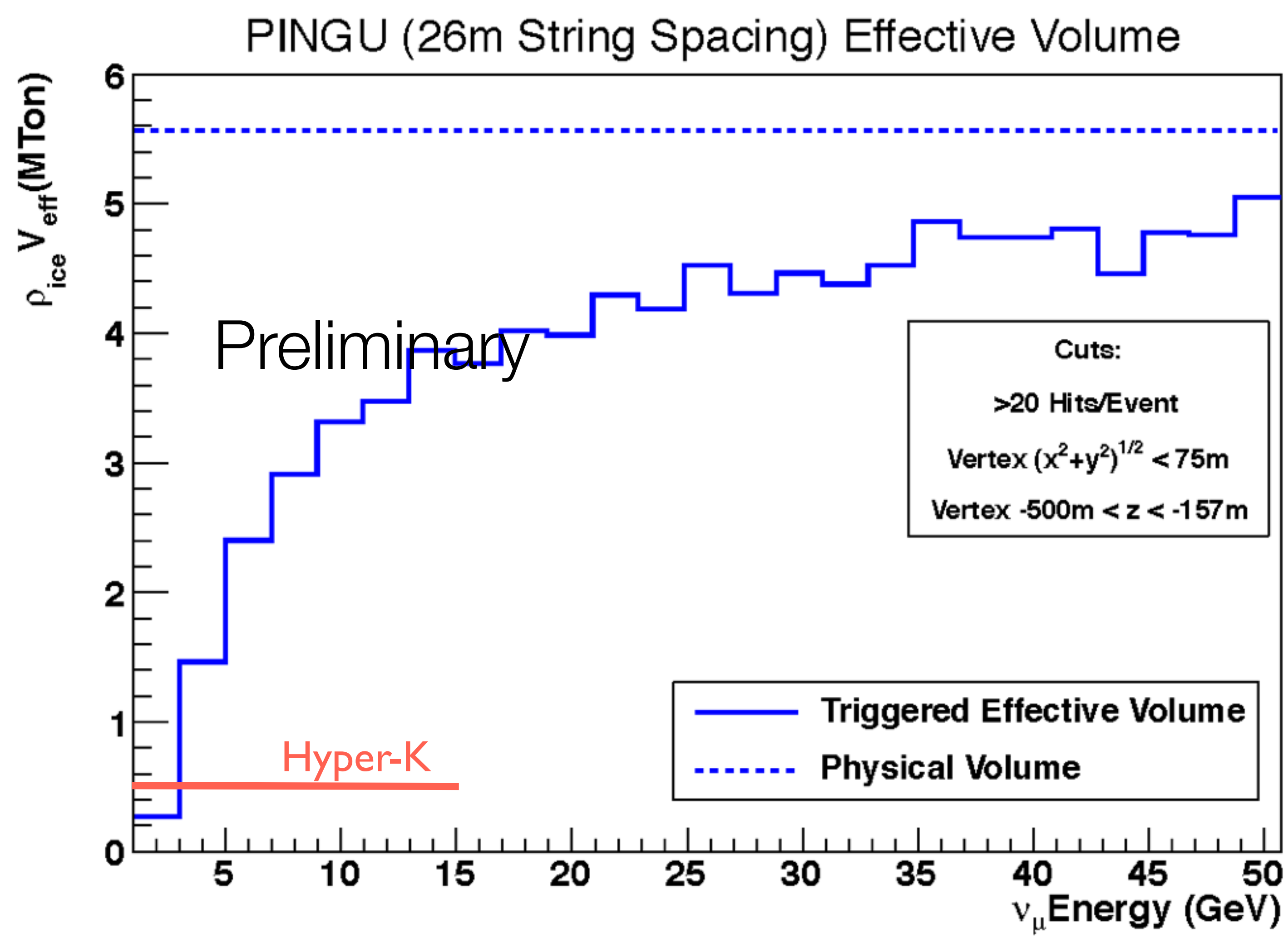


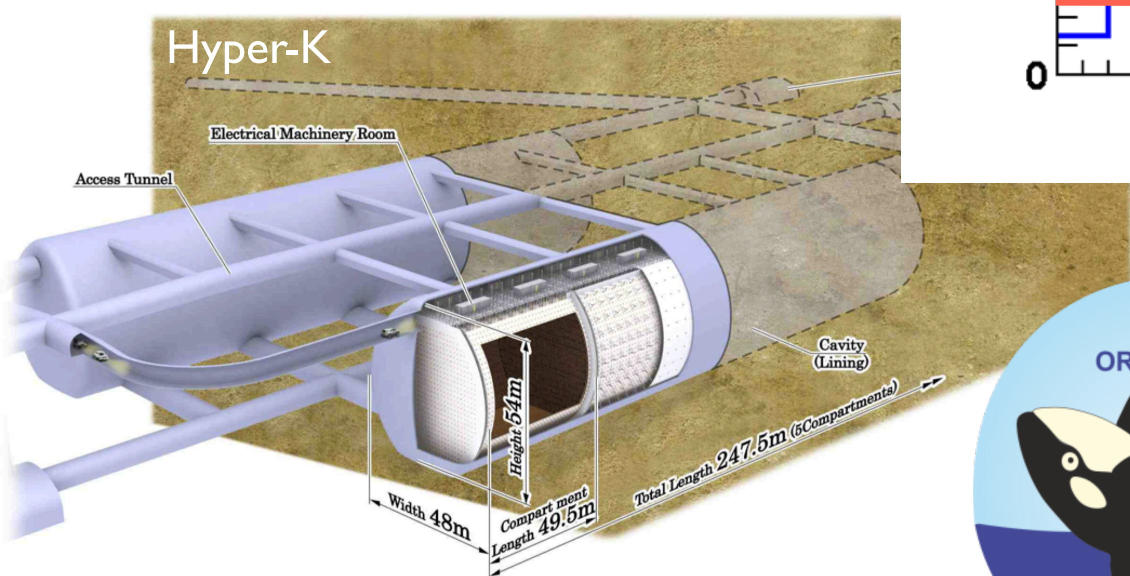
- $p + A \to \pi^\pm (K^\pm)$ + other hadrons
  - $\pi^+ \to \mu^+\nu_\mu \to e^+\nu_e\nu_\mu\nu_\mu$

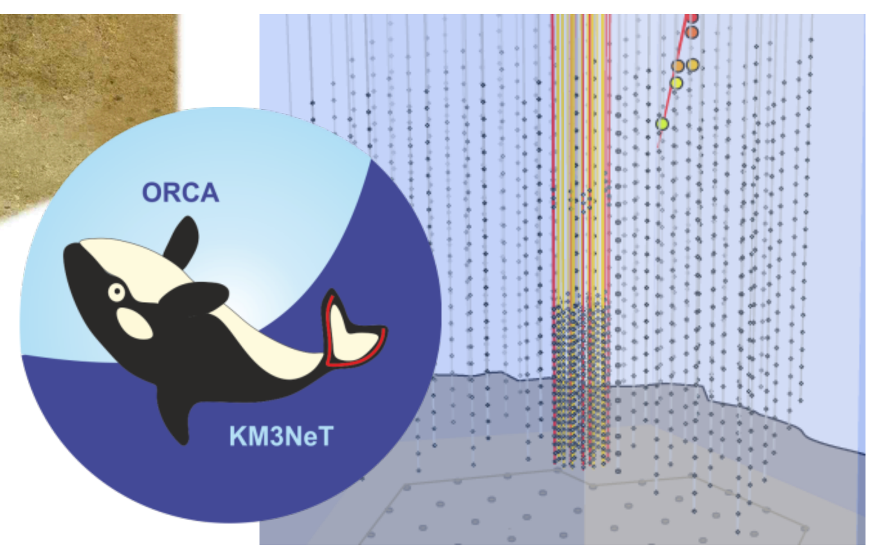
Atmospheric neutrino spectrum follows power law with spectral index of γ~3.7

Potential Detectors

- PINGU 20 additional strings
  - 26m string spacing
  - 60 HighQE DOMs per string, 5m spacing







PINGU Tomography

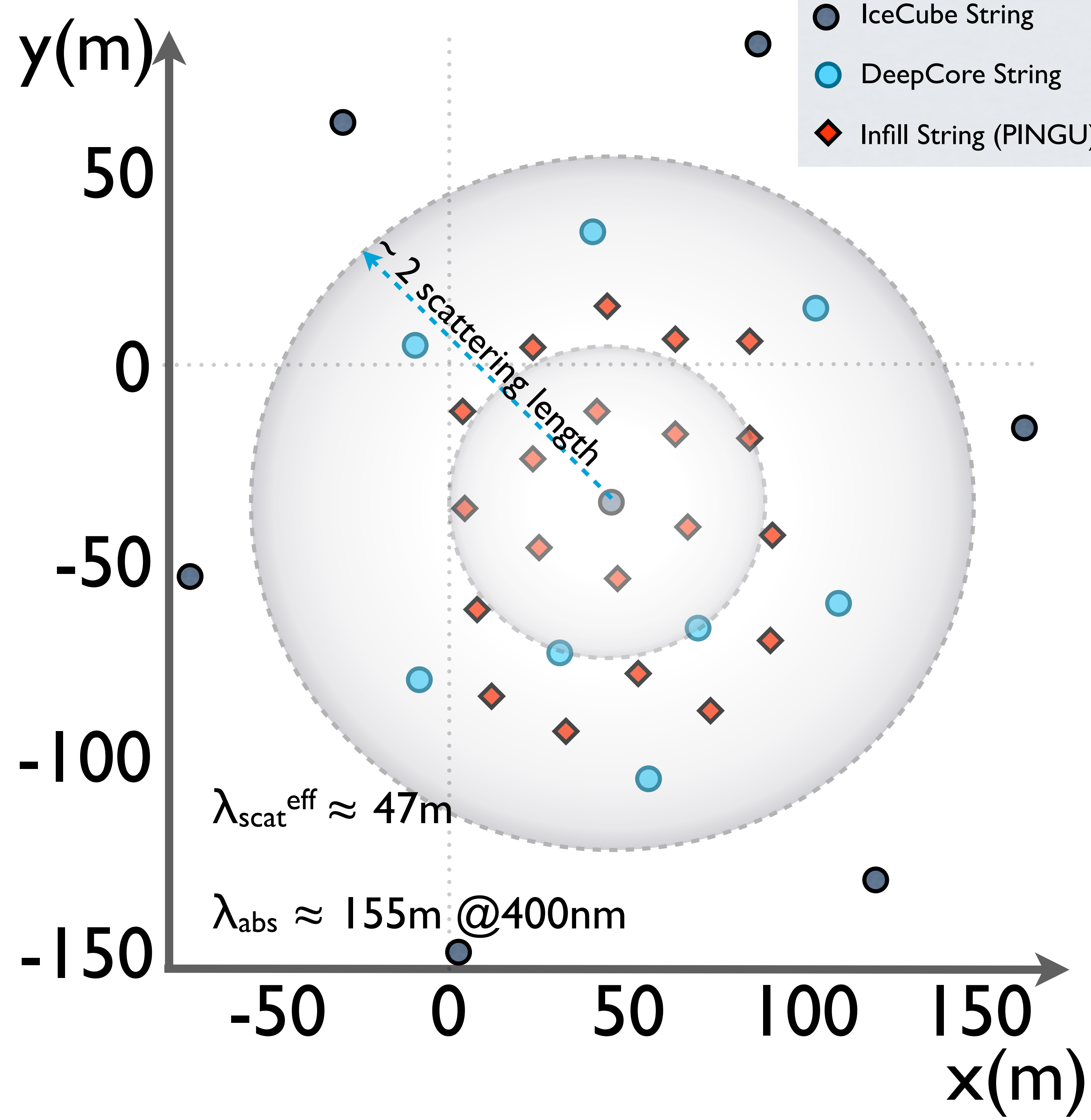
PINGU LOI Tomography
Stefan Coenders
Kotoyo Hoshina
Carsten Rott
Akimichi Taketa

Can we exploit Earth matter effects to measure the Earth composition ?

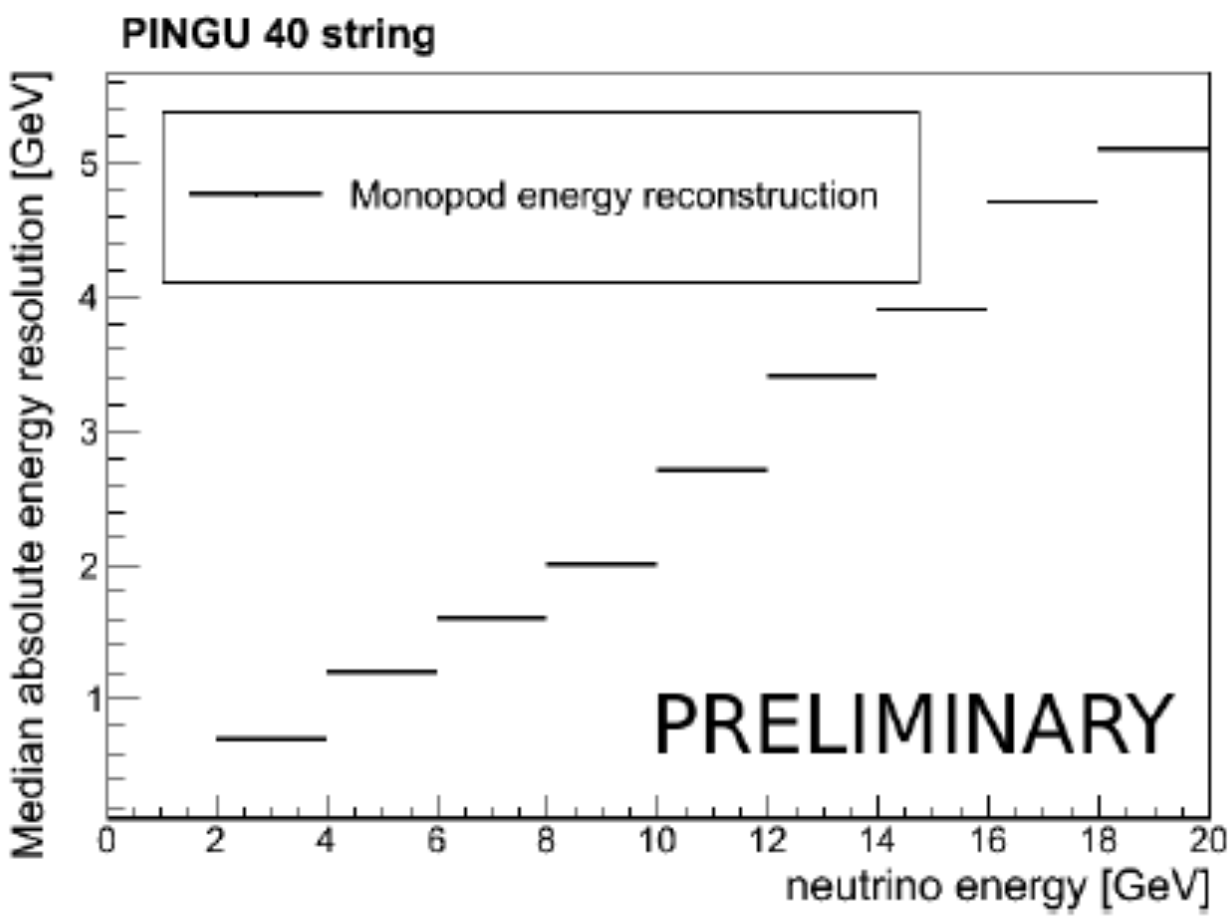
Neutrino oscillations depend on the electron density and hence can determine Z/A for a given matter density profile

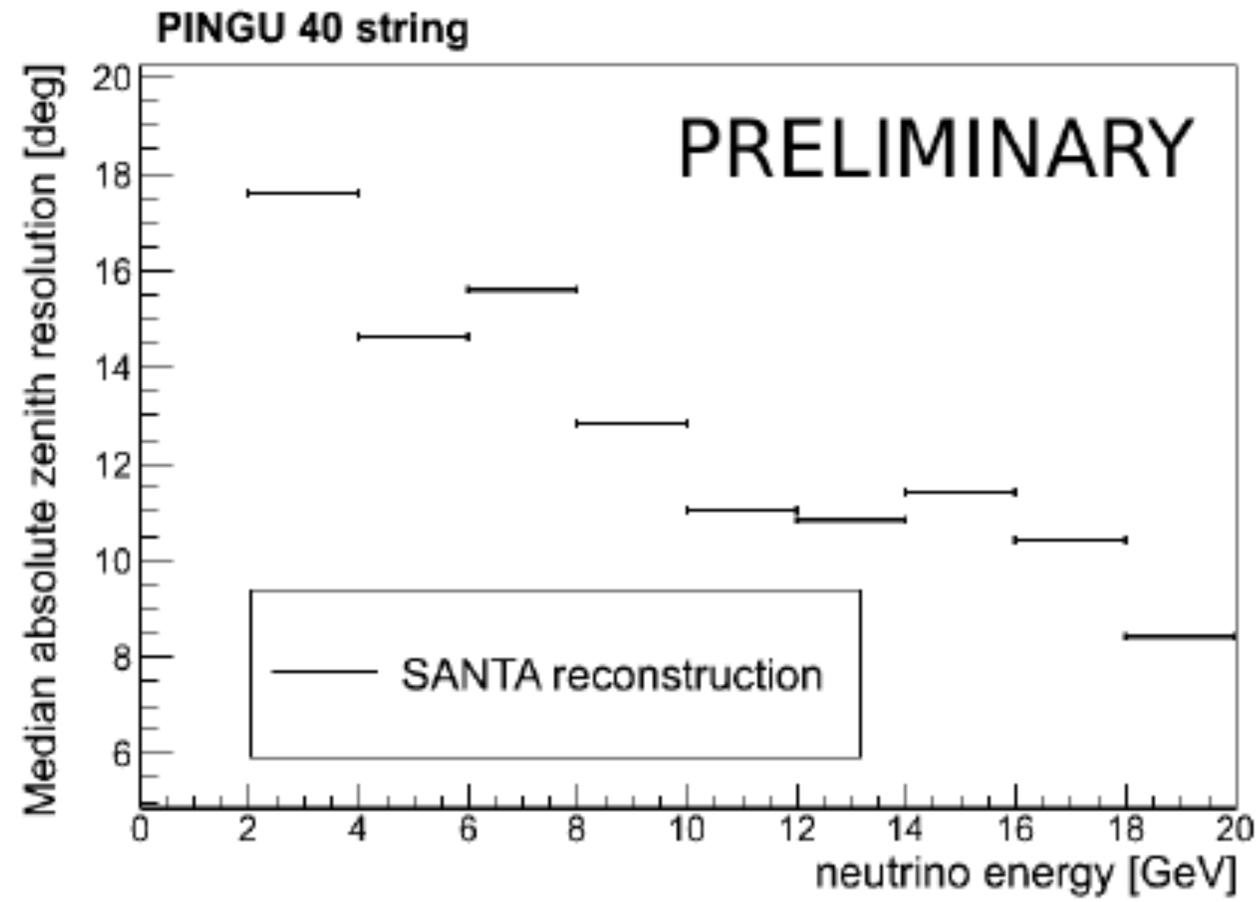
In PINGU we expect approximately **30000** upward-going neutrinos per year, with many coming from the energy region between **5–10 GeV**.

An example PINGU geometry



PINGU Detector Performance





PINGU performance simulated using DeepCore algorithms

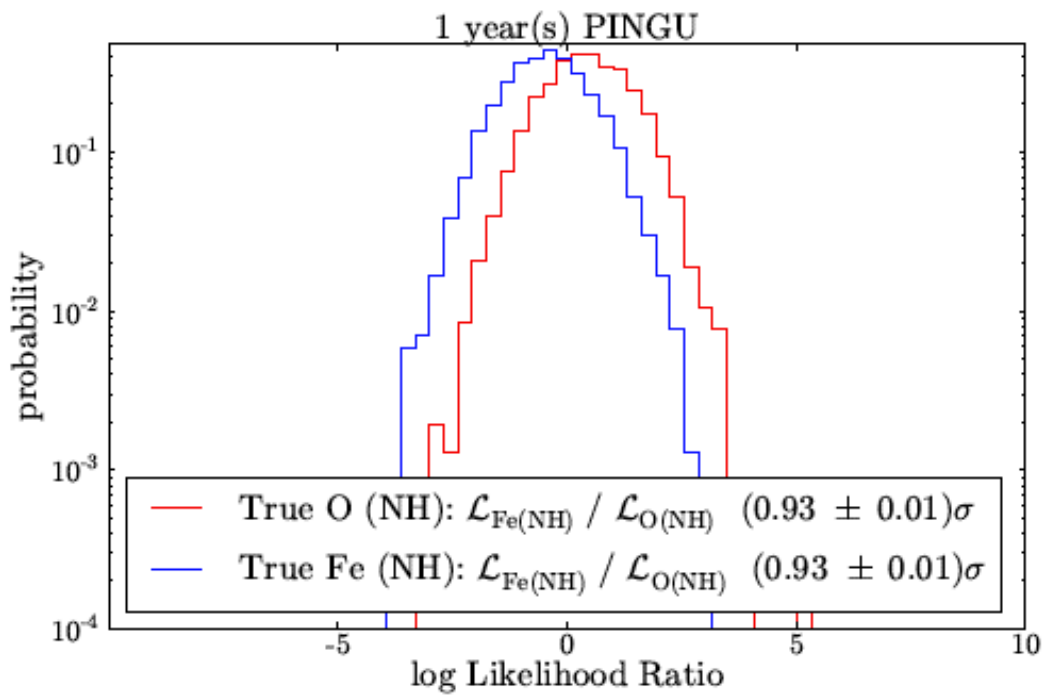
- Energy resolution: ~(0.7 GeV + $0.2E_\nu$)
- Angular resolution: 15° to 8° as energy increases from 5 GeV to 20 GeV

More computationally intensive algorithms can improve on this

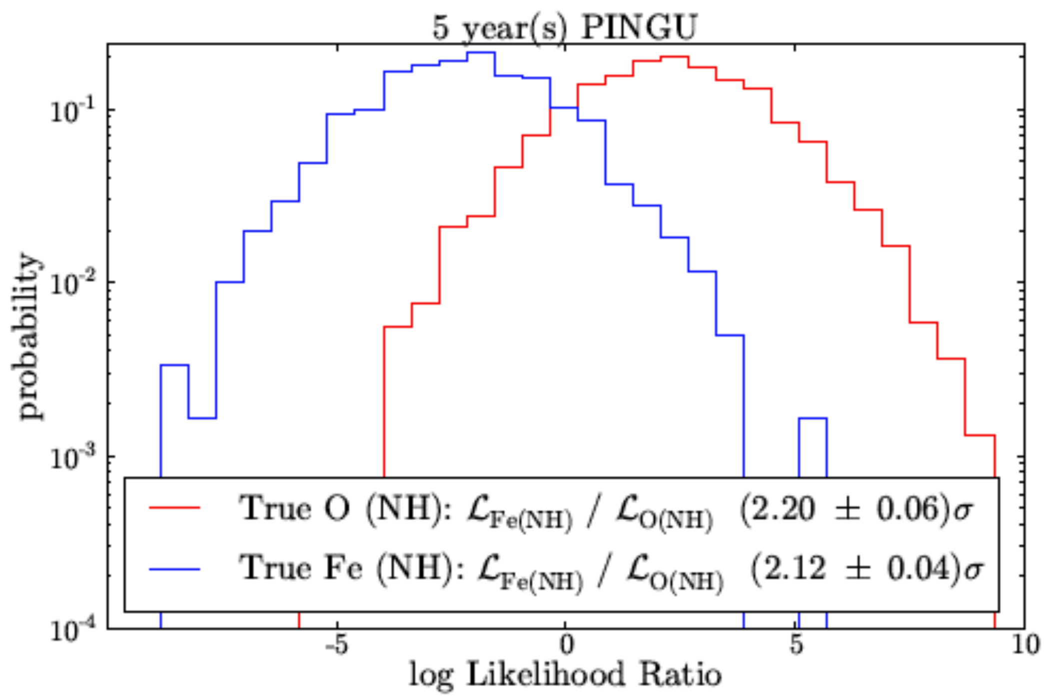
Example study for PINGU

- Two different Earth models (extreme case) are compared:
  - a pure iron core (Yc=0.4656)
  - a core with a composition similar to the mantle (Yc= 0.497)

Exclusion limits are calculated using a likelihood ratio analysis:
- 5 years of PINGU data, including reconstruction

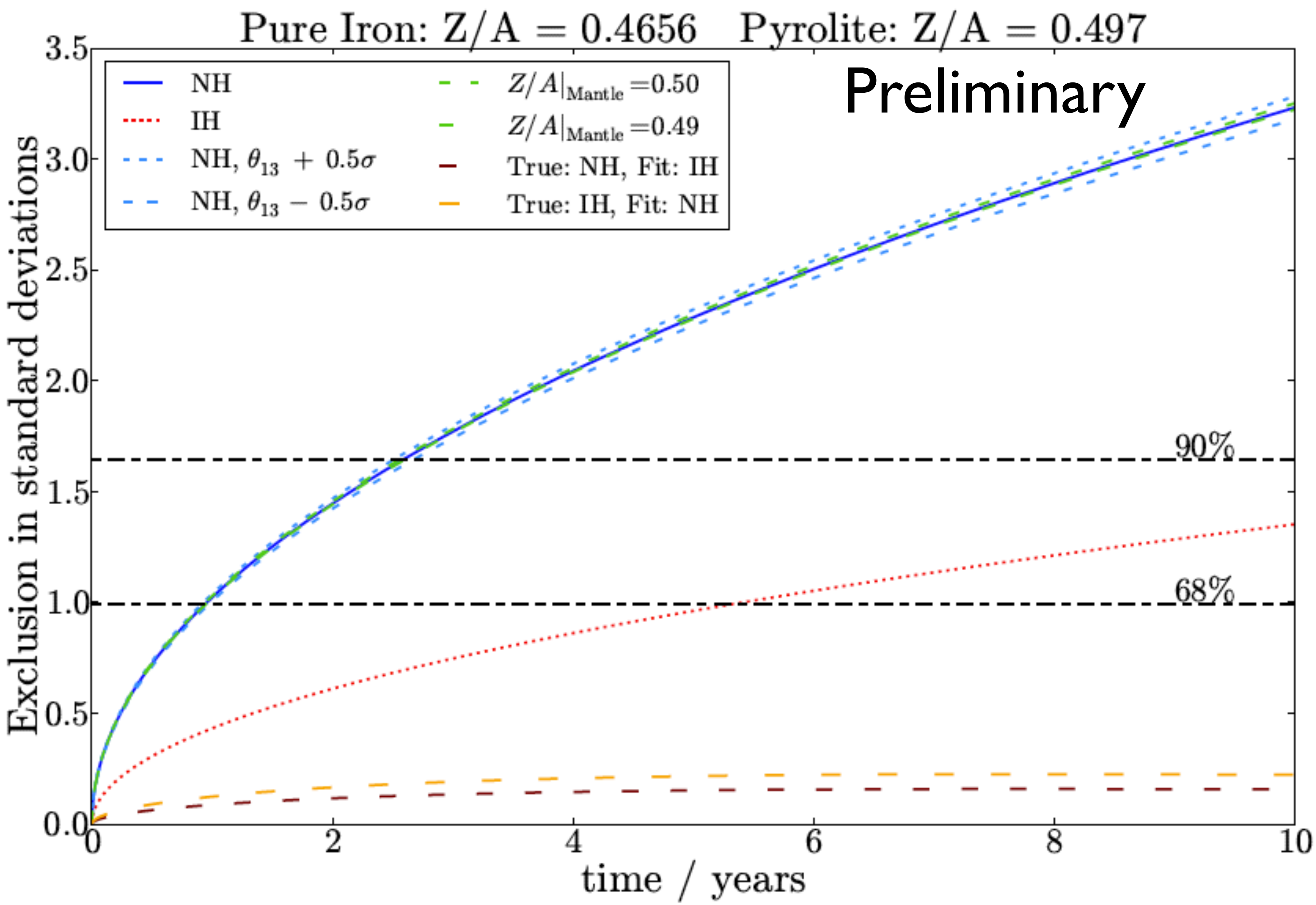


(a) 1 year of data.



(b) 5 years of data.

Earth Core Measurement



Conclusions

- Detector requirements
  - very large - high statistics sample
  - good energy resolution and angular resolutions
- Oscillation Tomography seems feasible at next generation detectors to exclude extreme models
- To study more realistic models we might have to wait for the next-next generation
- More studies are needed

MICA -Megaton Ice Cherenkov Array

Courtesy E. de Wolf & P. Kooijman

- In-fill of a few hundred strings
  - String spacings ~5 m, sensors spaced by ~1 m on a string
  - The Medium is the support structure
- An ambitious vision worth working towards:
  - Fiducial volume > 1MTon
  - Photo coverage ~10%
  - O(10 MeV) threshold for bursts
  - O(100 MeV) for single events
- IceCube and DeepCore provide active veto
  - No excavation is necessary, drilling/deployment has been refined to an industrial process – deployment costs would be well below 10% of total
- Physics extraction from Cherenkov ring imaging in the ice