An application of the neutrino oscillation to geophysics :

Study of the Earth's core composition using atmospheric neutrinos

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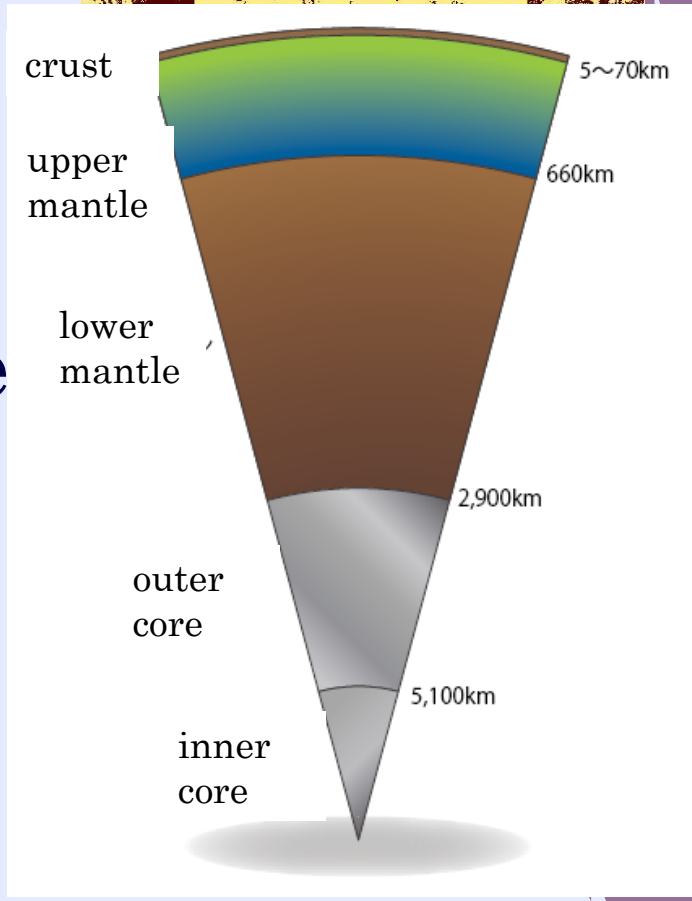
Question :

Are θ_{ij} / Δm_{ij}^2 measurements useful for physics / for science / for our life ?

Motivation : **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 confirmed.
  - Prediction requires measurement .



Principle

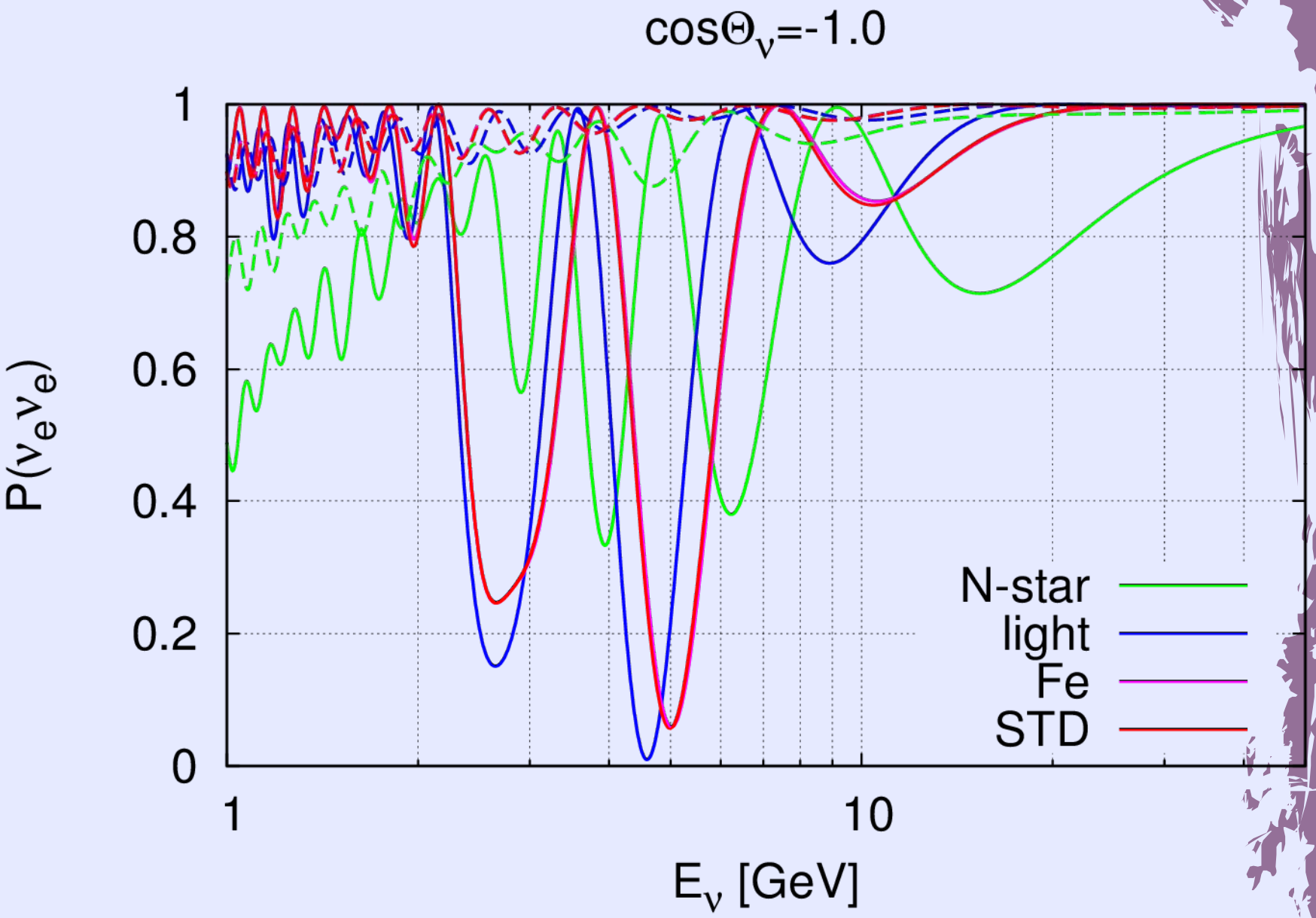
- Oscillation probability depend on electron density, not matter density
- By using neutrino oscillation, we can measure the electron density of the medium
  - If sterile neutrino does not exist
- We have the precise matter density of the earth
  - From seismic wave tomography and free oscillation
  - 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)

Model calculation :

Can Hyper-K distinguish iron and rock ?

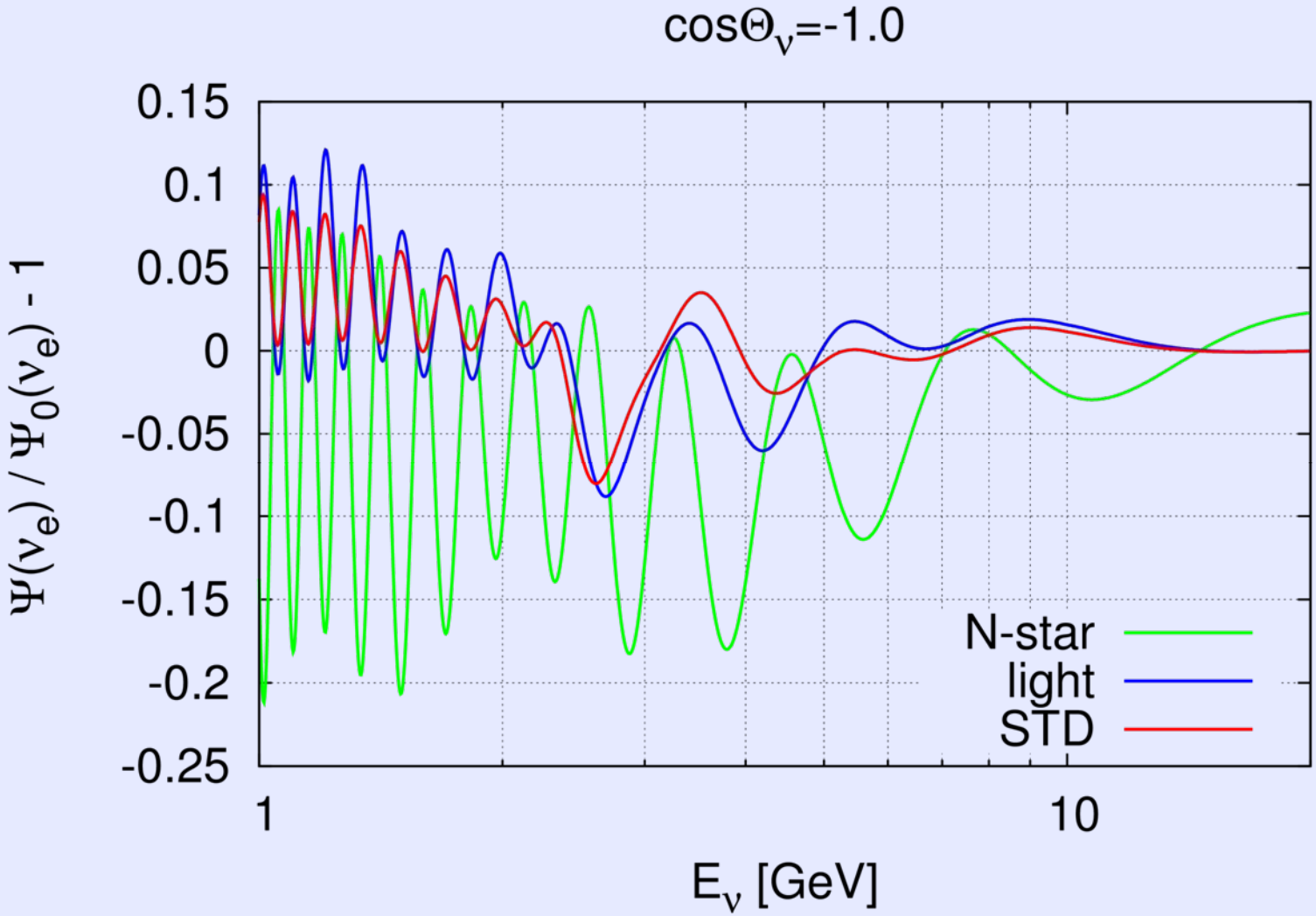
- Z/A ratio of materials
  - Fe :0.466, Light material : 0.5, Hydrogen :1
  - **More sensitive to water**
- Normal hierarchy
- Oscillation parameter : global fit result after ν 2012
- Matter density model : PREM500
- Initial neutrino flux : Honda flux 2011
- Selected model
  - Standard Model
    - Mantle: Pyrolite
    - Outer core: 90wt% Fe + 10wt% O
    - Inner core: 100% Fe
  - Neutron core
  - Light material core

Survival probability of ν_e



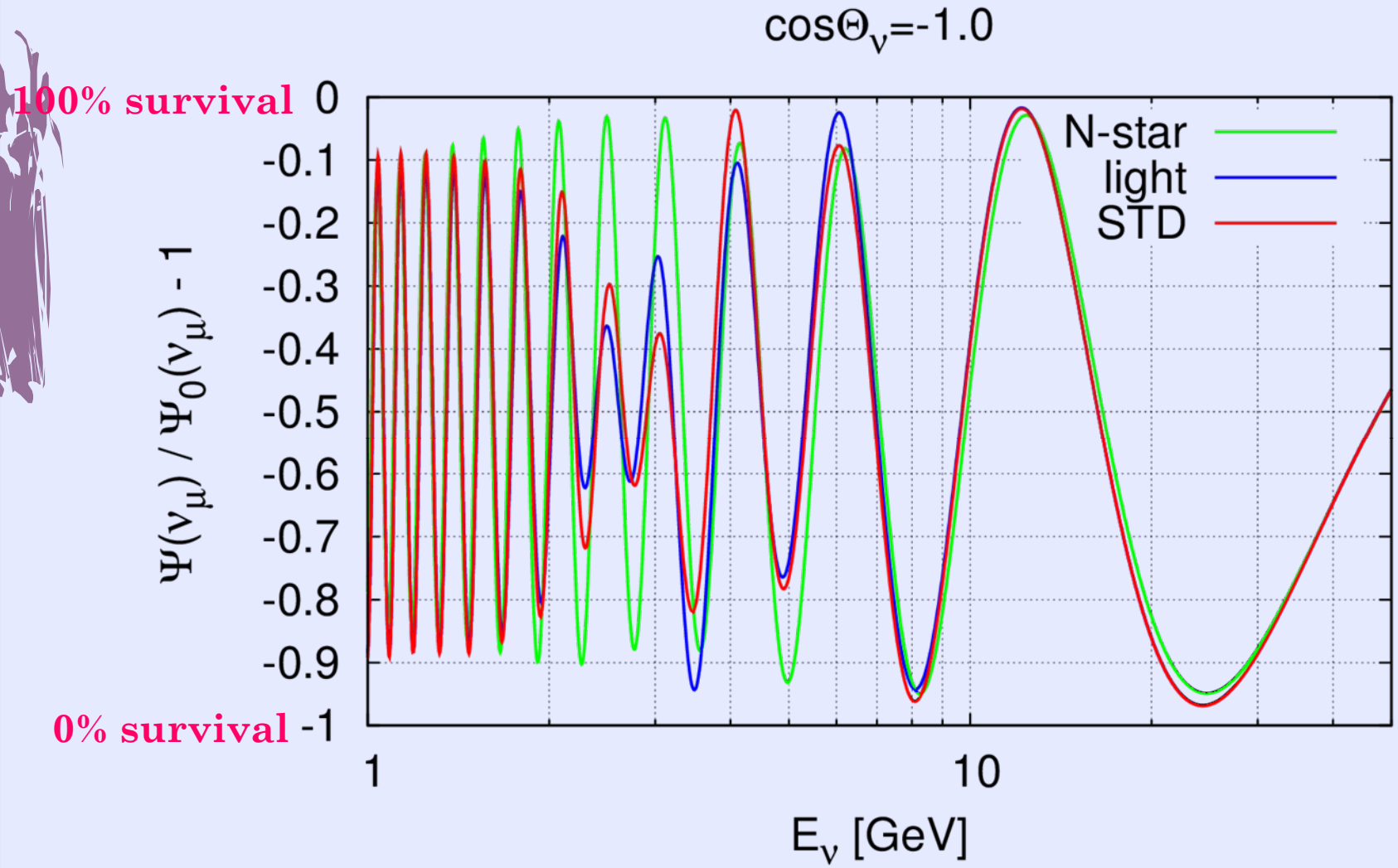
ν_e Relative Flux

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

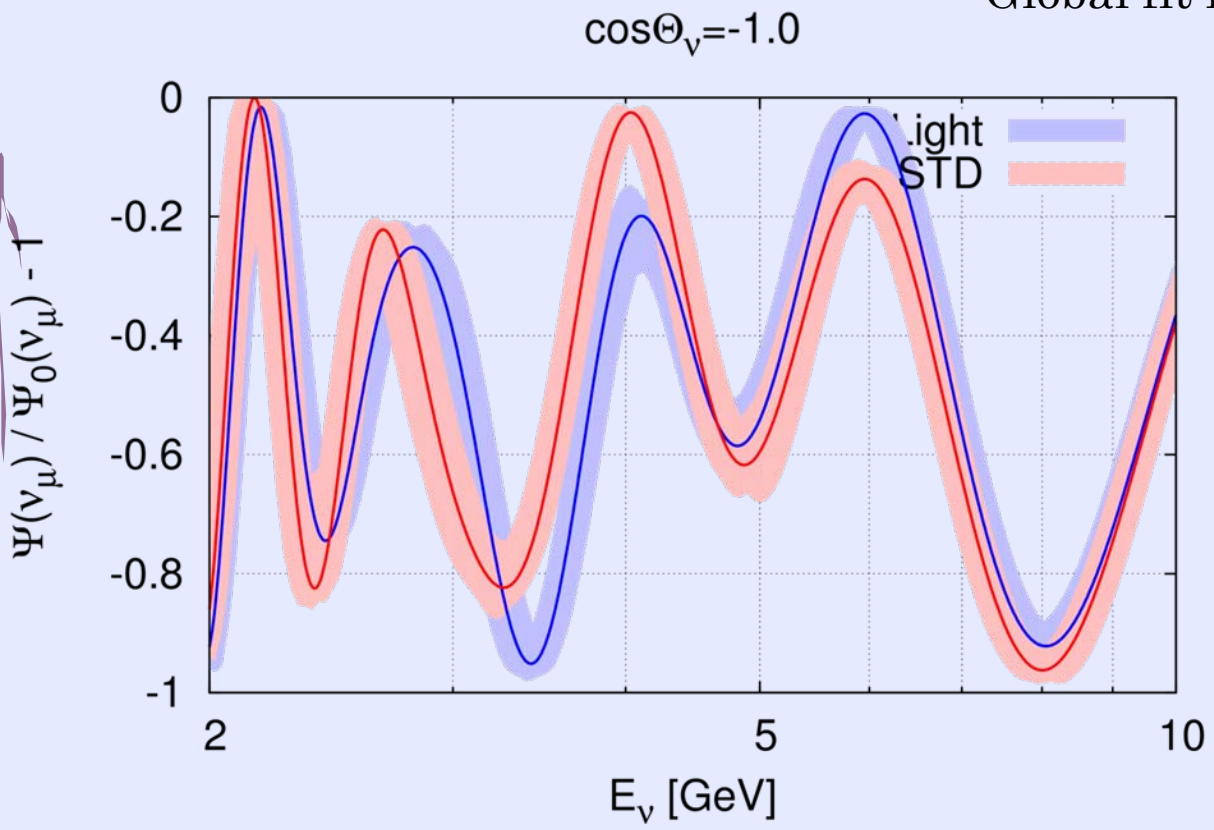


ν_μ Relative Flux

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



Uncertainty from oscillation parameters



Global fit result after neutrino 2012

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

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

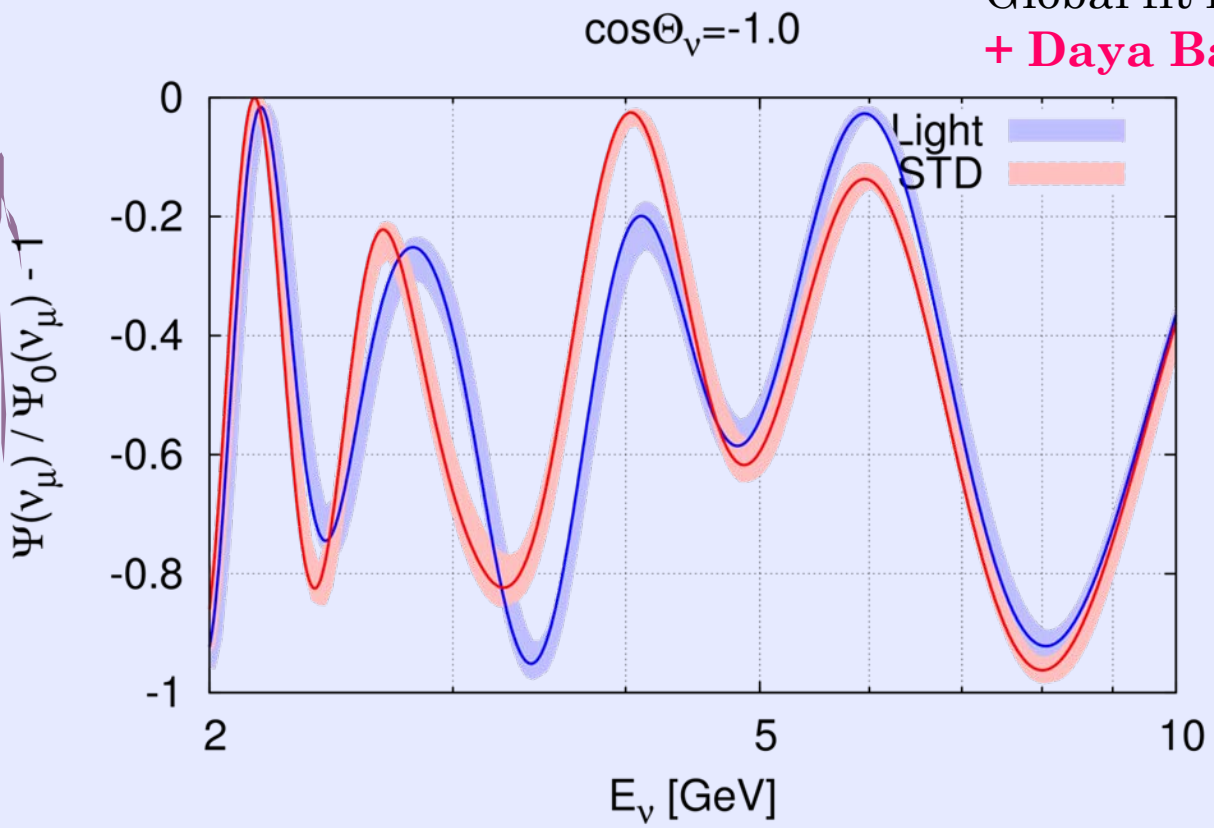
$$\sin^2\theta_{23} = 0.413^{+0.037}_{-0.025}$$

$$\delta_{CP} = free$$

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

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

Uncertainty from oscillation parameters



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

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

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

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

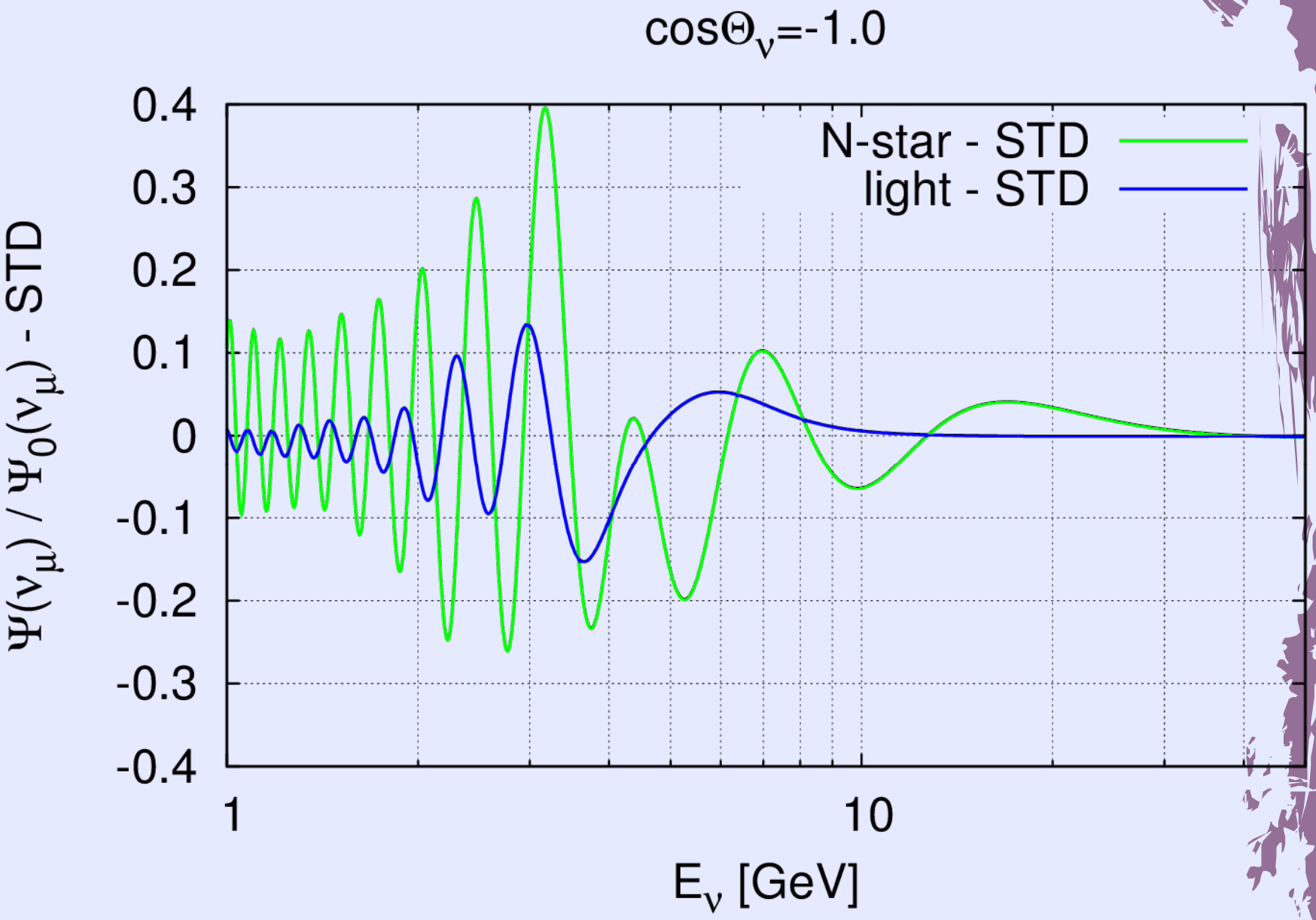
$$\delta_{CP} = free$$

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

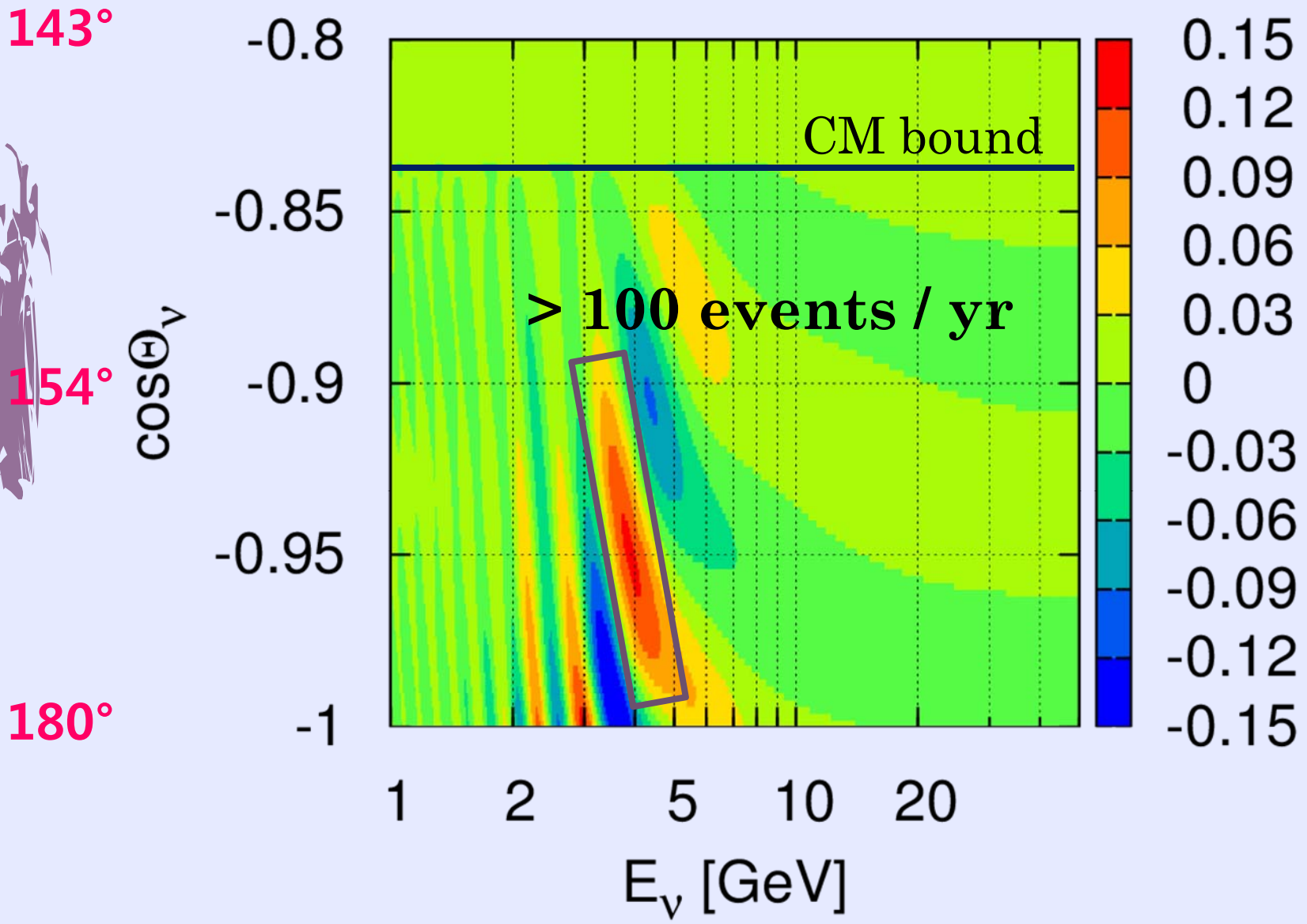
$$\Delta m^2_{32} = (2.398^{+0.042}_{-0.065}) \times 10^{-3}$$

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

Difference of relative flux



Difference of relative flux (light-STD)



Conclusion

- Neutrino oscillation is sensitive to electron density of the deep earth
  - Chemical composition : if we know mass density
  - Mass density : if we know chemical composition
- There seems to be a slight chance to distinguish iron/rock core model
  - Philosophically possible
  - E / Θ resolution is important
  - PID (ν_μ / ν_e / ant-ν_e) will be powerful tool
    - Need energy dependence
- **It's not hopeless, but very challenging !**

Other possible measurements

- Upper limit of water content in mantle
  - Important for earthquake prediction
- Exotic model rejection
  - 90wt% Fe + 10wt% Hydrogen
- Fe/Mg ratio of lower mantle
  - Essential for formation history of the Earth
  - Upper and lower limit of the extreme case

Question :

Are θ_{ij} / δ_{CP} / Δm_{ij}^2 measurements useful for physics / for science / for our life ?

Answer :

Yes, at least for geophysics.

Request:

More statistics from 2 GeV to 8 GeV

Please build Hyper-Hyper-K

Less uncertainty of mixing parameters

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