

# ICECUBE

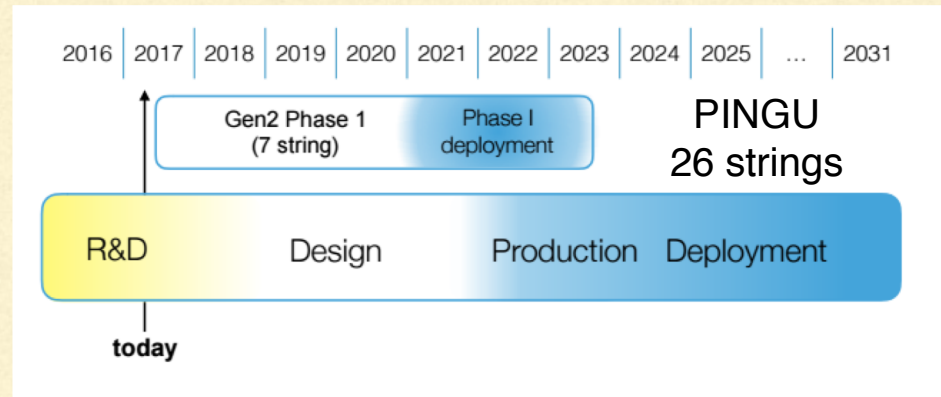
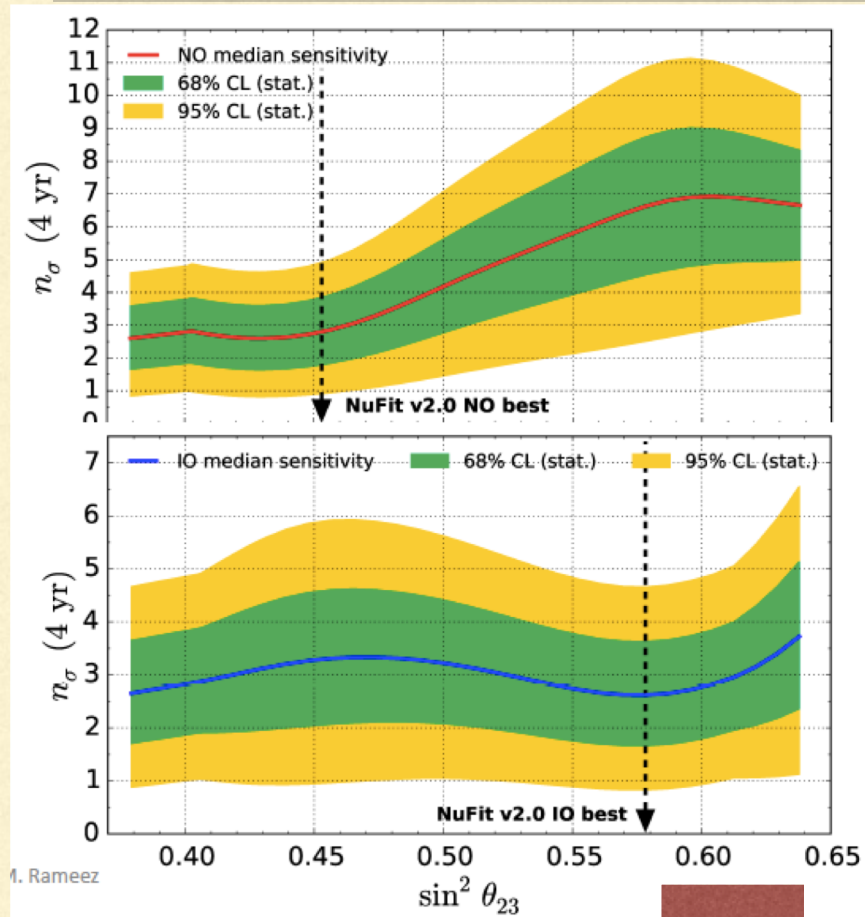
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IceCube is producing numerous results also published in Science (with the cover) and Nature on astrophysics and neutrino properties. For oscillation atmospheric neutrino measurements can shed light on the NH in 5 years. IceCube is preparing its future to which Switzerland could participate with a stronger asset.

Recent results on oscillation physics:

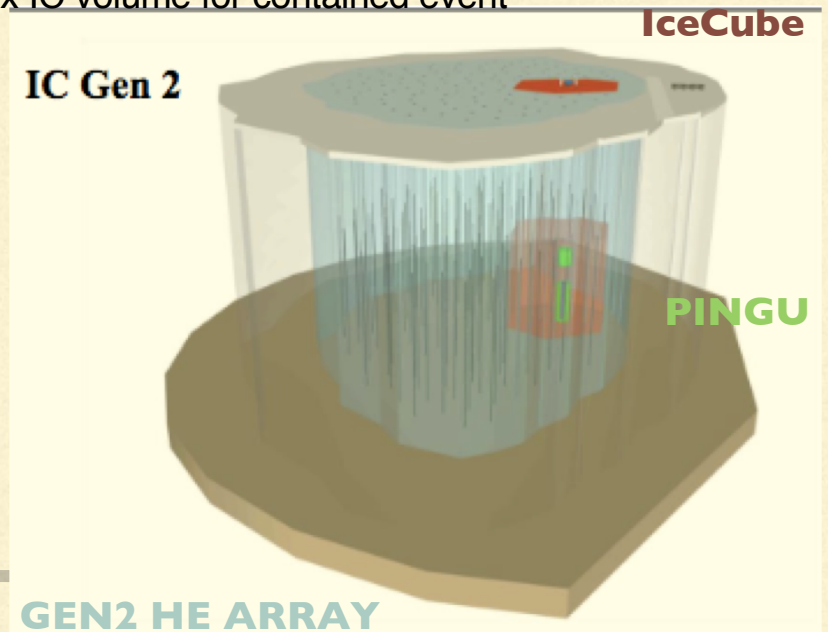
- - high-precision measurement of  $\nu_{\mu}$ - $\nu_{\tau}$  oscillation parameters
  - first neutrino  $\tau$  from oscillations from a neutrino source
  - - first measurement of neutrino cross section above 5 TeV
  - - constraints on sterile neutrinos
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# PINGU PROPOSAL AND ICECUBE-GEN2

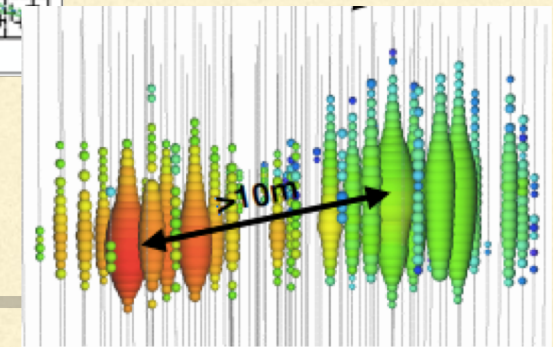
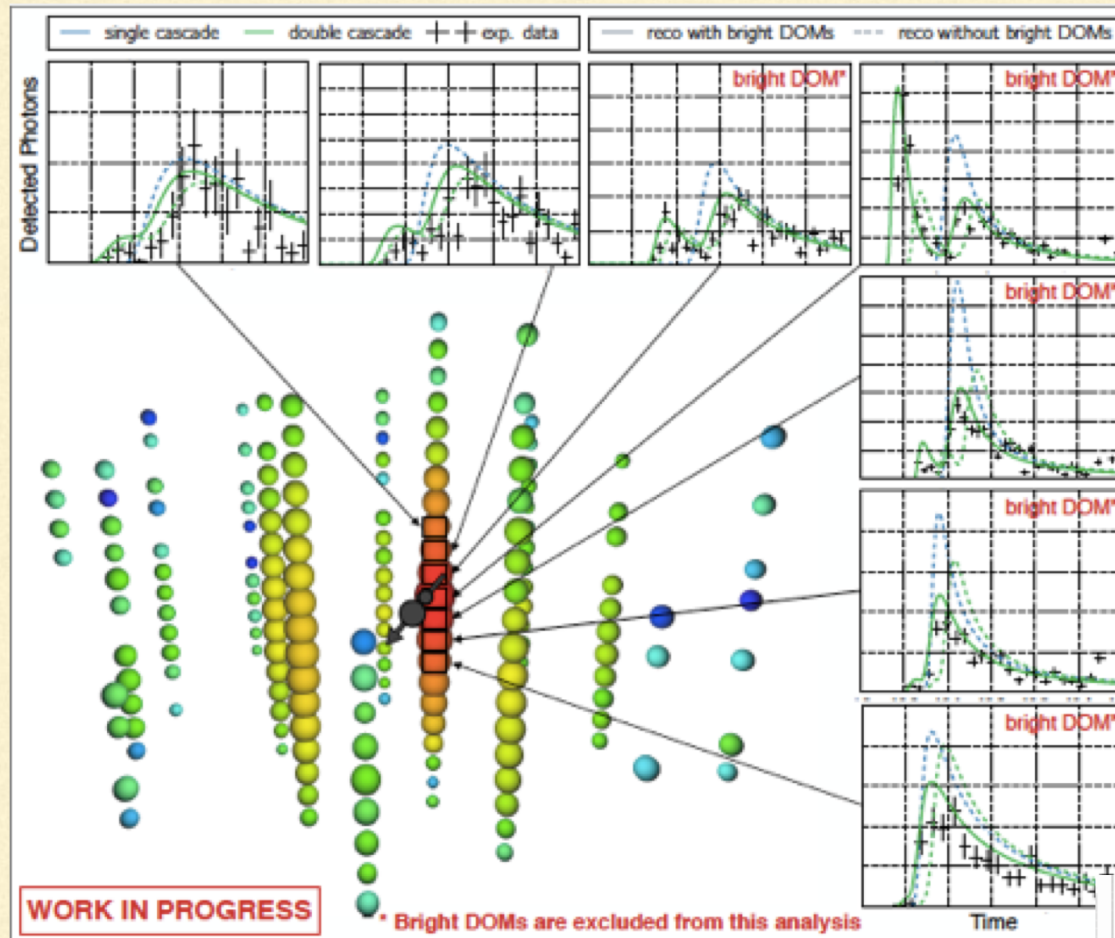


PINGU LoI: <https://arxiv.org/pdf/1401.2046.pdf>  
 update: arXiv:1607.02671

120 new strings, 80 DOMS per string  
 1.25 km long strings  
 10 x IC volume for contained event

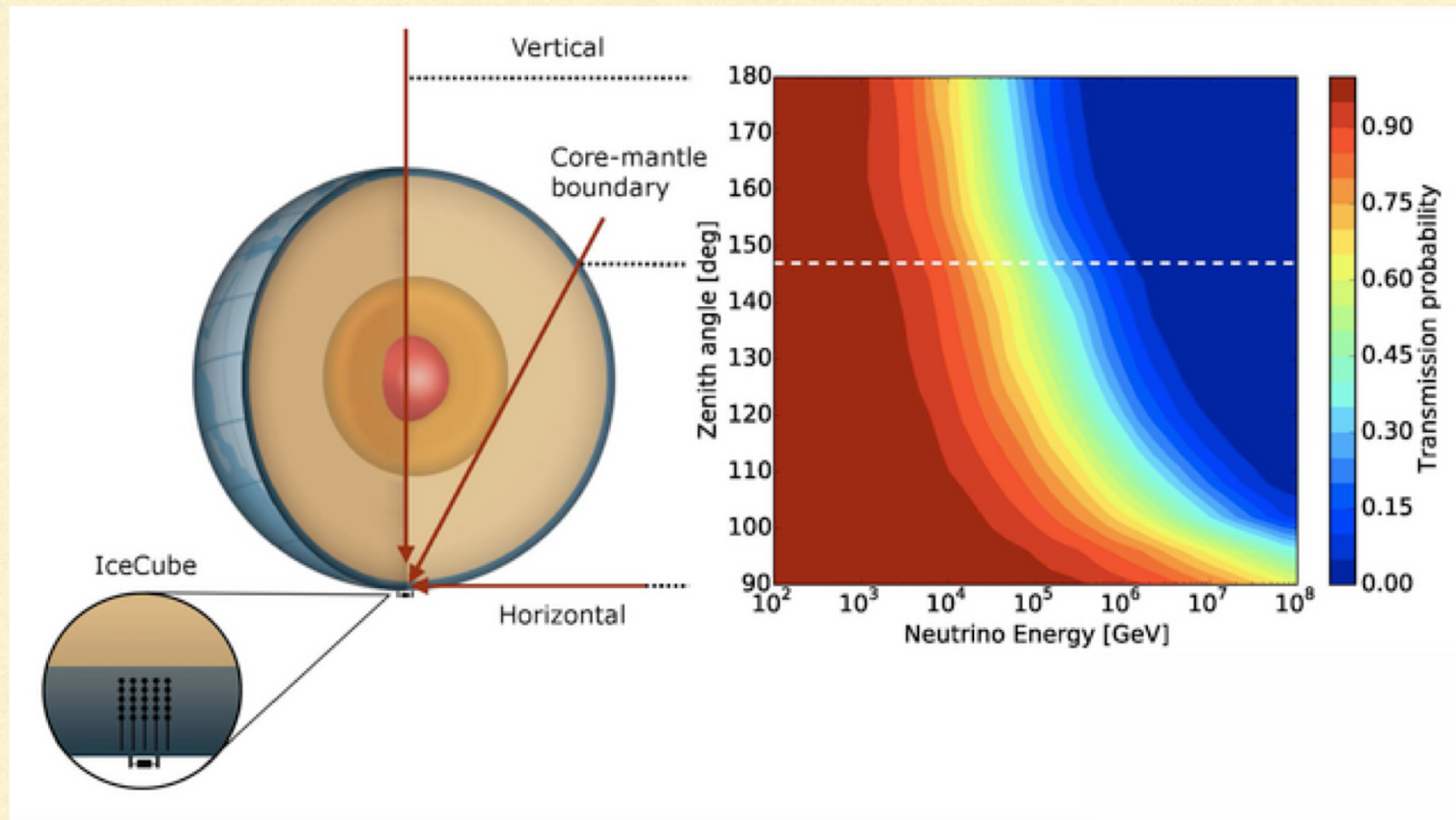


# A DOUBLE BANG EVENT



# NEUTRINO INTERACTION IN THE EARTH

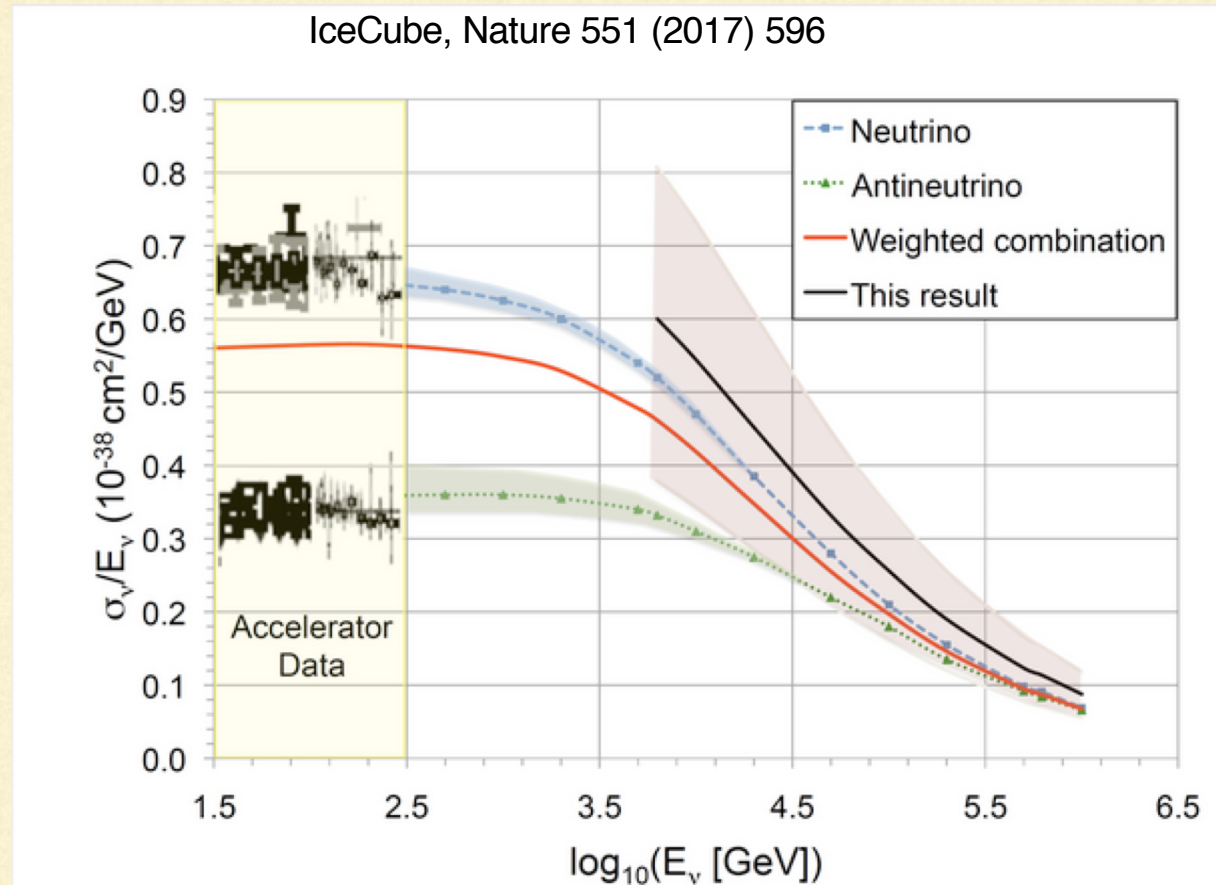
- Neutrino beam crosses 20-12700 km in the Earth where it interacts
- Absorption is measured from neutrino spectral changes with zenith



# NEUTRINO CROSS SECTION

- First cross-section measurement for a neutrino energy range  $10^3$  higher than particle accelerators where DIS cross section is no longer linear
- Measurement reflects a flux-weighted sum of  $\nu_\mu$  and anti- $\nu_\mu$

The blue and green lines are the Standard Model predictions for  $\nu_\mu$  and anti- $\nu_\mu$  with shaded band due to uncertainties on DIS cross sections. The red line is for the expected mixture of  $\nu_\mu$  and anti- $\nu_\mu$  in the IceCube sample. The black line shows the CC result, assuming that the charged and NC cross section vary in proportion, and that the ratio between the actual cross section and the SM prediction is energy-independent. The pink band is the  $1\sigma$  (stat+sys) uncertainty. Systematic uncertainties are due to the uncertainties on the density distribution of the Earth (1-2%), atmospheric pressure variations (4%), angular acceptance of DOMs (4%), atmospheric neutrino spectral slope (10%).

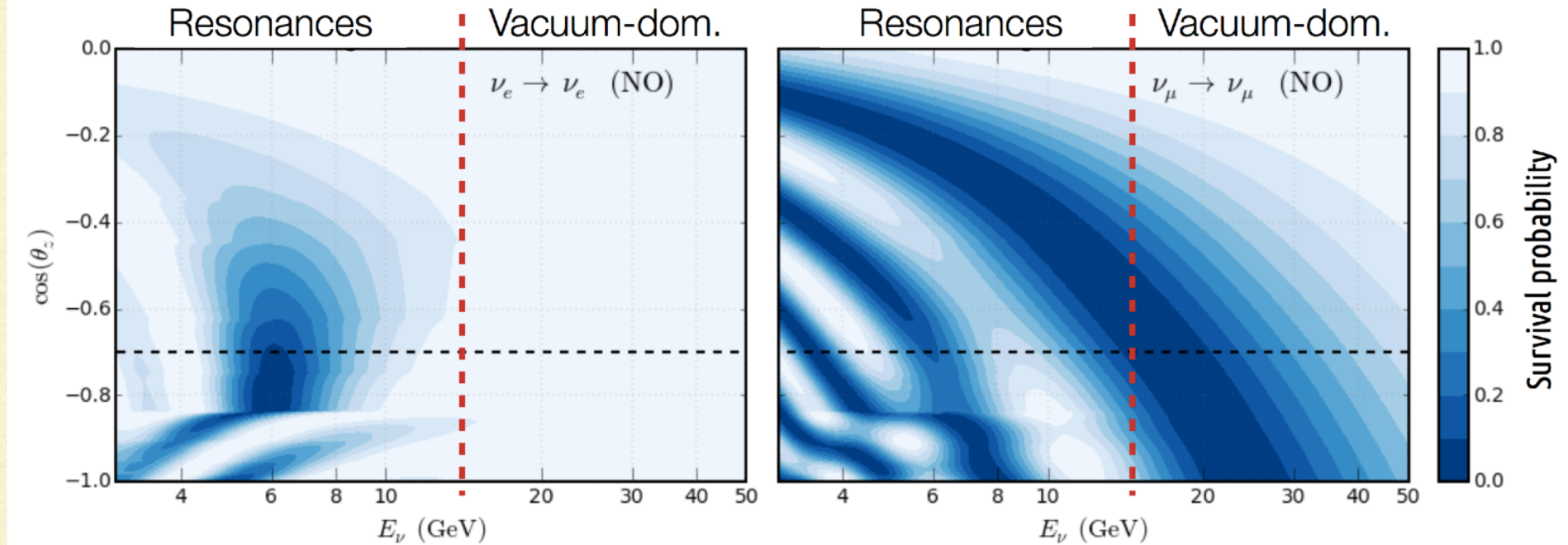


<https://www.nature.com/articles/nature24459>  
and <http://arxiv.org/abs/1711.08119>

# NEUTRINO OSCILLATIONS

Upgoing events

Yáñez and Kouchner, arXiv:1509.08404

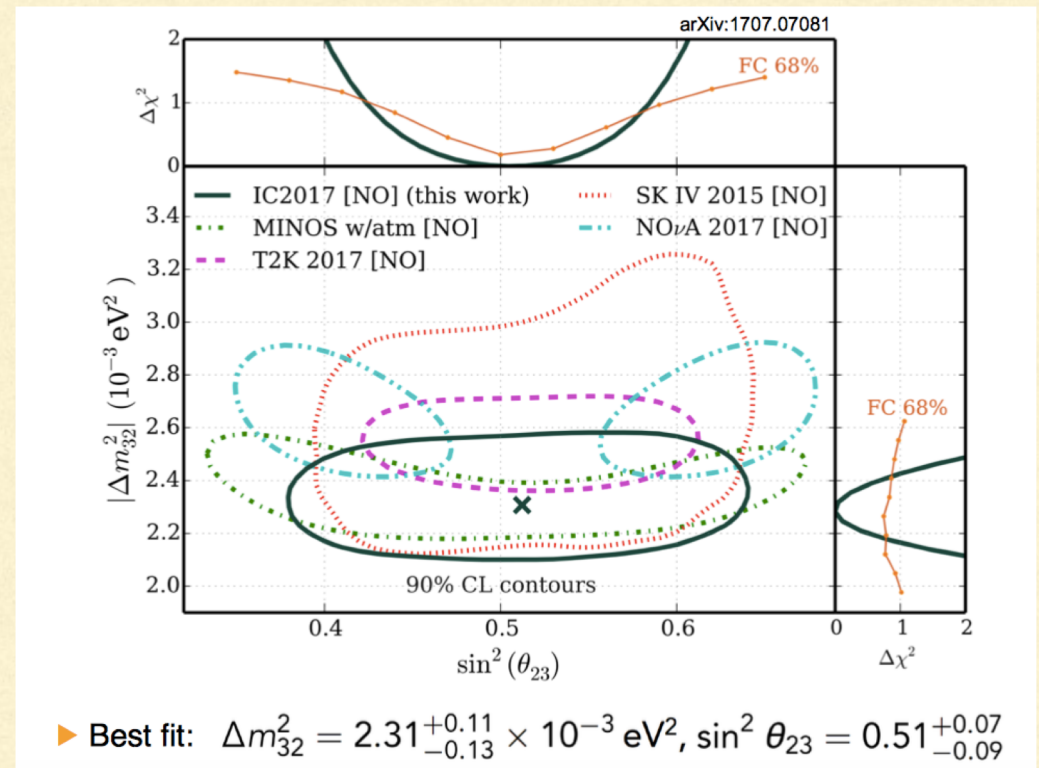
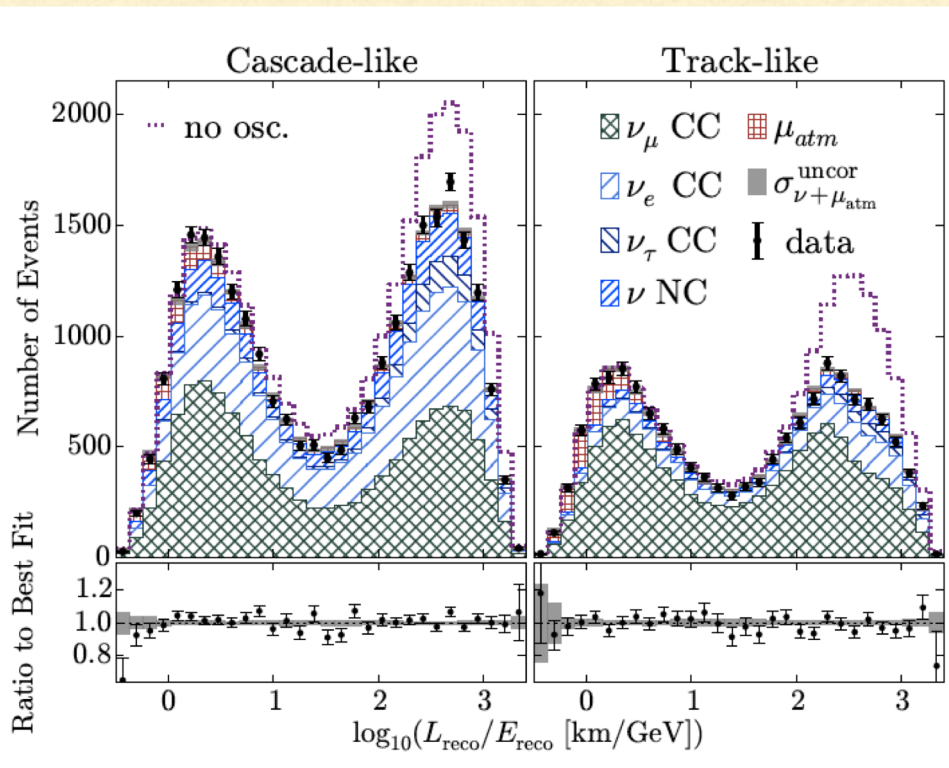


Track(cascade)-like events at neutrino energy 20 GeV have median angular resolution of  $10^\circ$  ( $16^\circ$ ) and energy resolution 24%(29%).

Upgoing neutrinos oscillating over one Earth diameter have a  $\nu_\mu$  survival minimum at  $\sim 25$  GeV  
Survival probability:

$$1 - P(\nu_\alpha \rightarrow \nu_\beta) = \sin^2(2\theta) \sin^2\left(\frac{\Delta m^2 L}{4E}\right)$$

# NEUTRINO MASSES WITH OSCILLATIONS



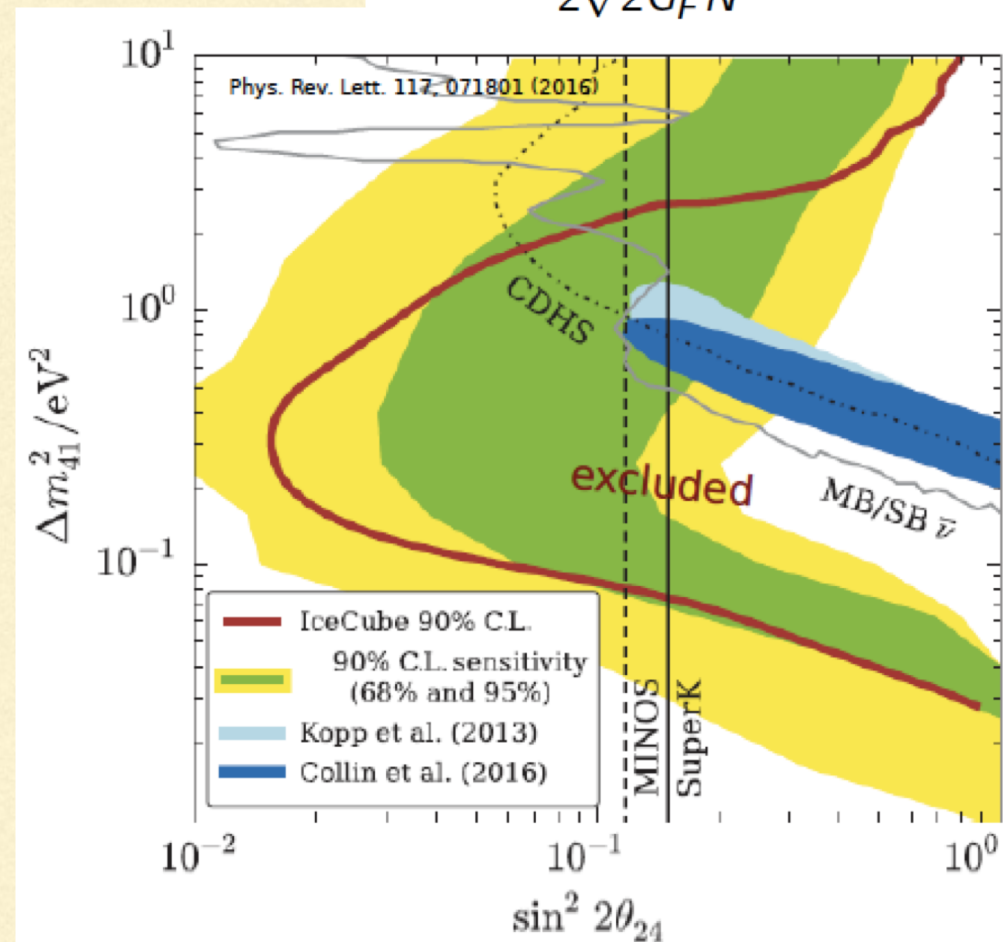
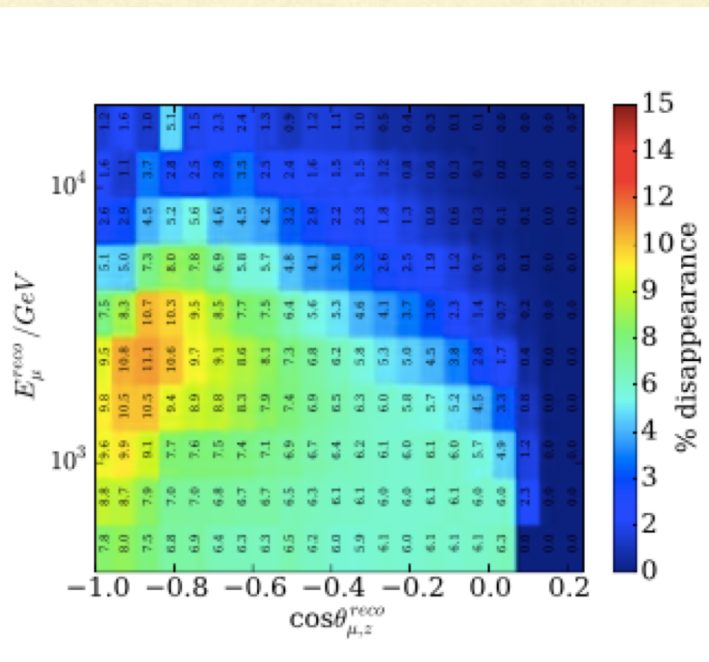
- Low Energy starting events  $E_\nu \sim 5.6 - 56 \text{ GeV}$

# CONSTRAINTS ON STERILE NEUTRINOS

In the Earth, for sterile neutrino of  $\Delta m^2 = O(1\text{eV}^2)$  there is a matter resonant effect that can produce disappearance up to 15%

$$E_\nu^{\text{res}} = \frac{\Delta m^2 \cos 2\theta}{2\sqrt{2}G_F N} \sim O(\text{TeV})$$

Observed effect for a 3+1 model



$$\Delta m_{41}^2 \approx \Delta m_{42}^2 \approx \Delta m_{43}^2 \text{ and } \Delta m_{21}^2 \approx \Delta m_{32}^2 \approx 0.$$

$$E_\nu \gtrsim 300 \text{ GeV}$$