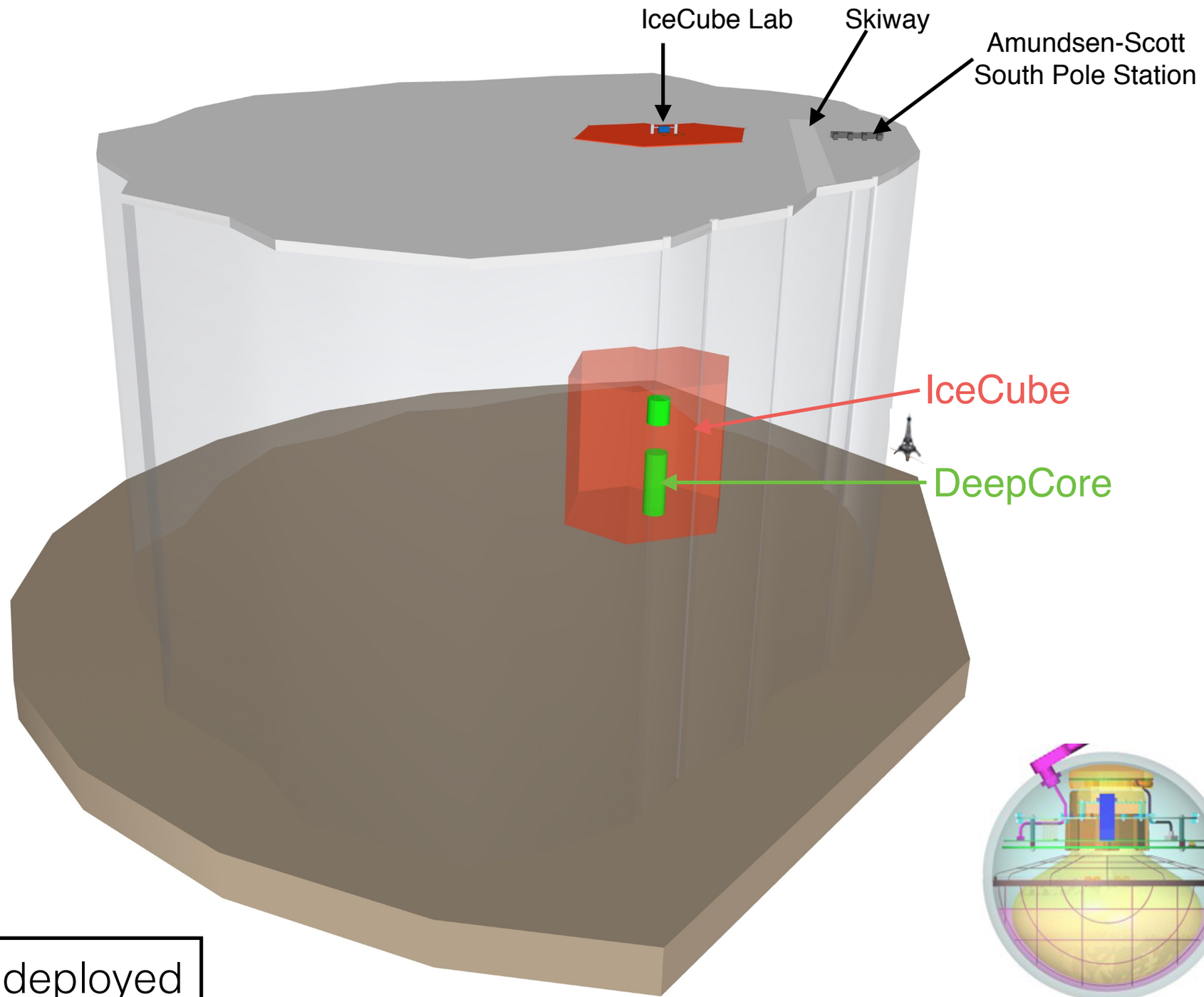
Recent results from the IceCube Neutrino Observatory

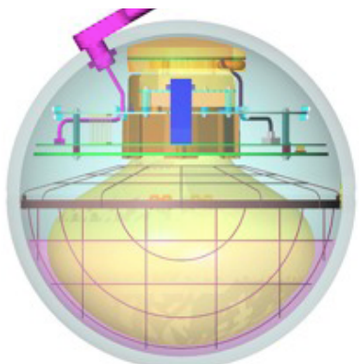
26th International Workshop on Weak Interactions and Neutrinos

June 2017

Darren R Grant

The IceCube Neutrino Observatory

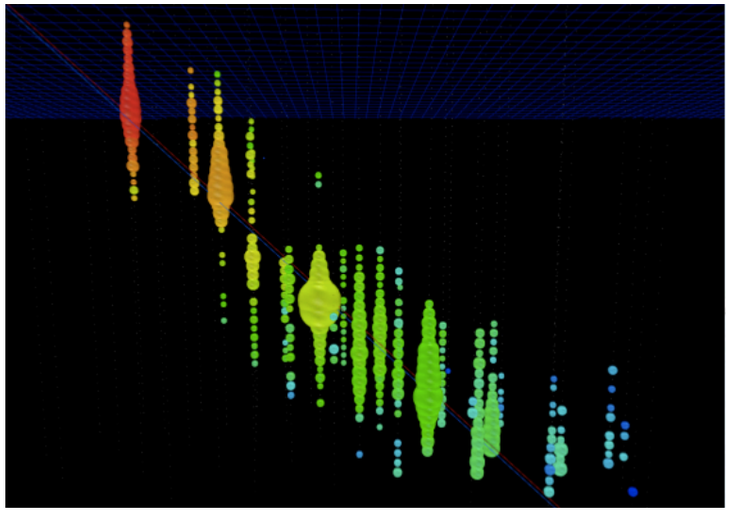




Digital Optical Module

5160 optical sensors deployed on an cubic-kilometre array of 86 “strings” at depths between 1.5 km and 2.5 km

Neutrino Telescopes - Principle of detection for 3 flavours

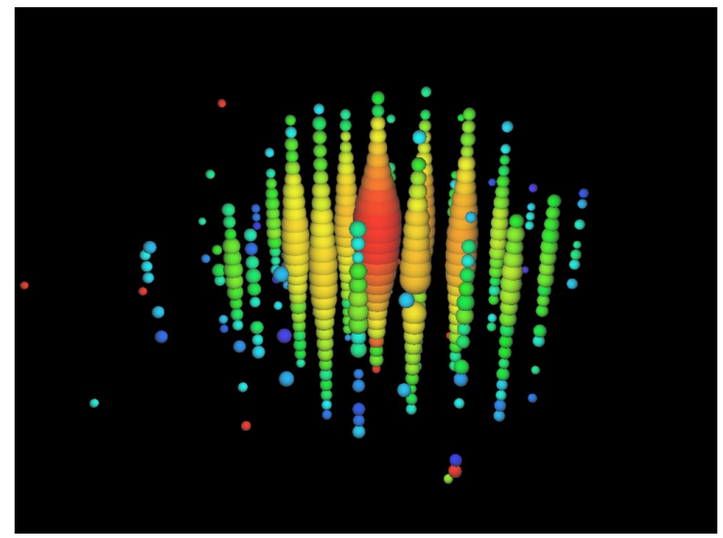


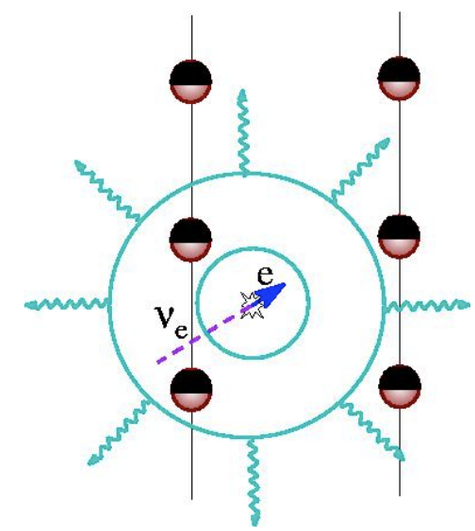
Tracks:

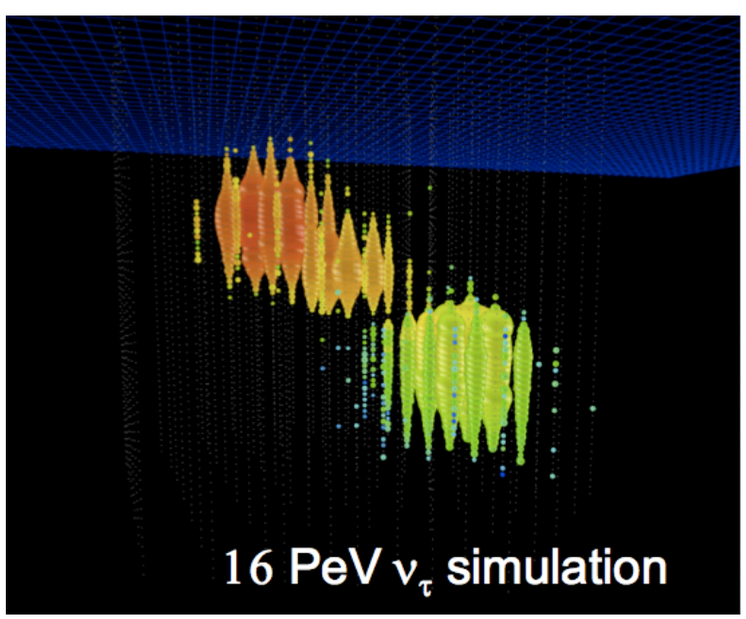
- through-going muons
- pointing resolution <1°

Cascades:

- neutral current for all flavours
- charged current for ν_e and low-E ν_τ
- energy resolution ~10% in log(E)



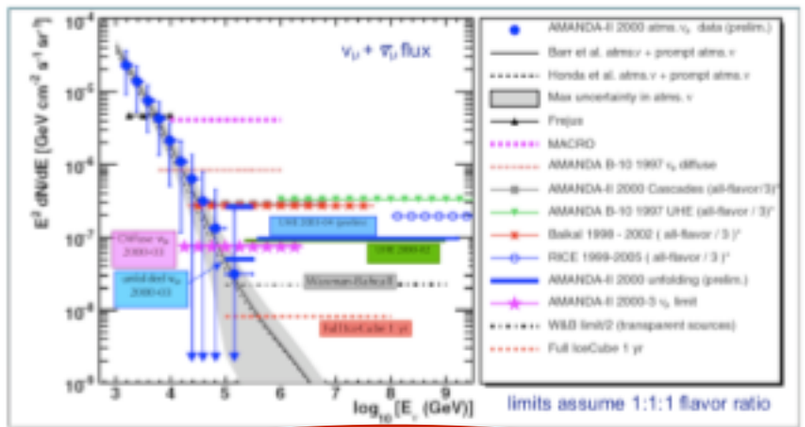




Composites:

- starting tracks
- high-E ν_τ (Double Bangs)
- good directional and energy resolution

The IceCube Neutrino Observatory Science Program



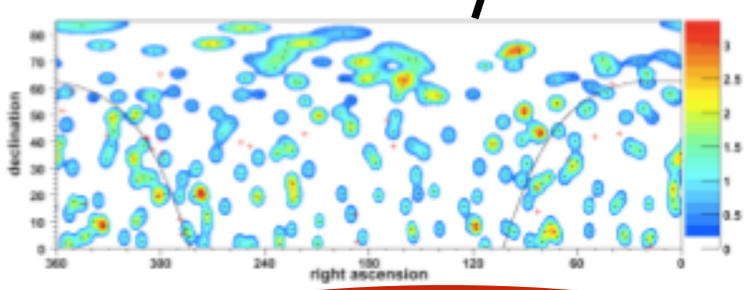
Diffuse Sources

AGNs, p+ accelerators

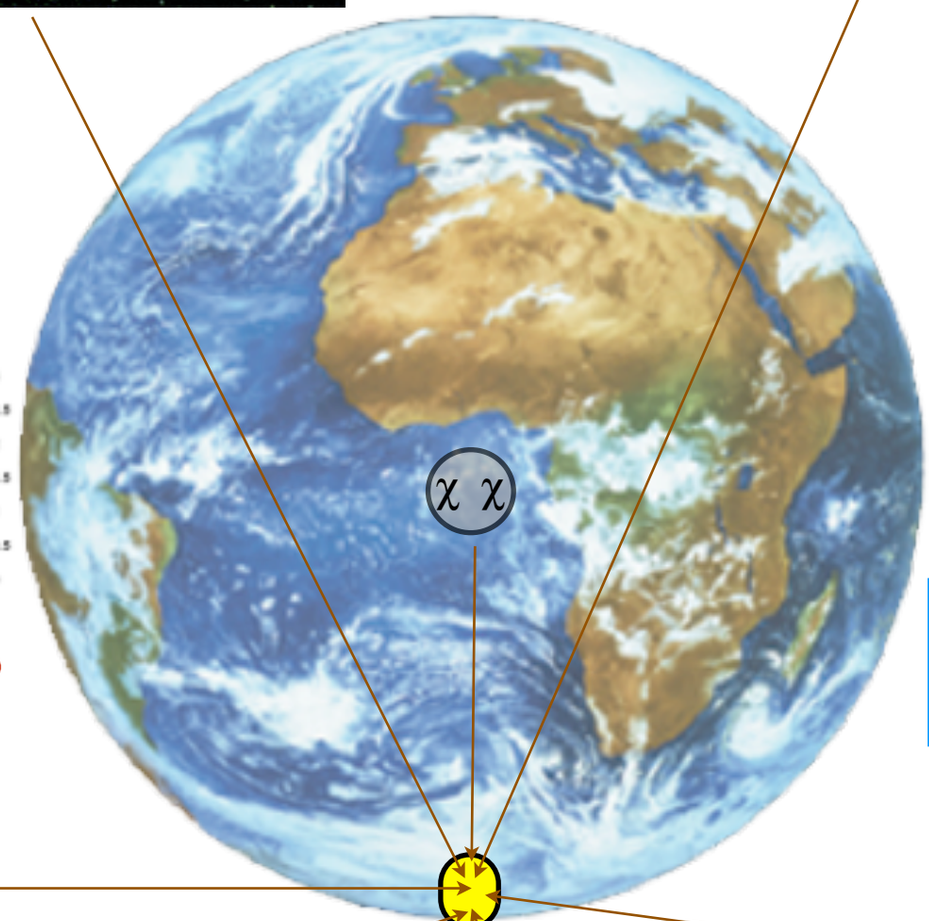
GRBs

γ

γ



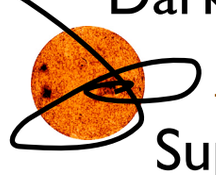
Point Sources



+ Advances in Glaciology

χ

Dark Matter



Supernovae

GZK/UHE

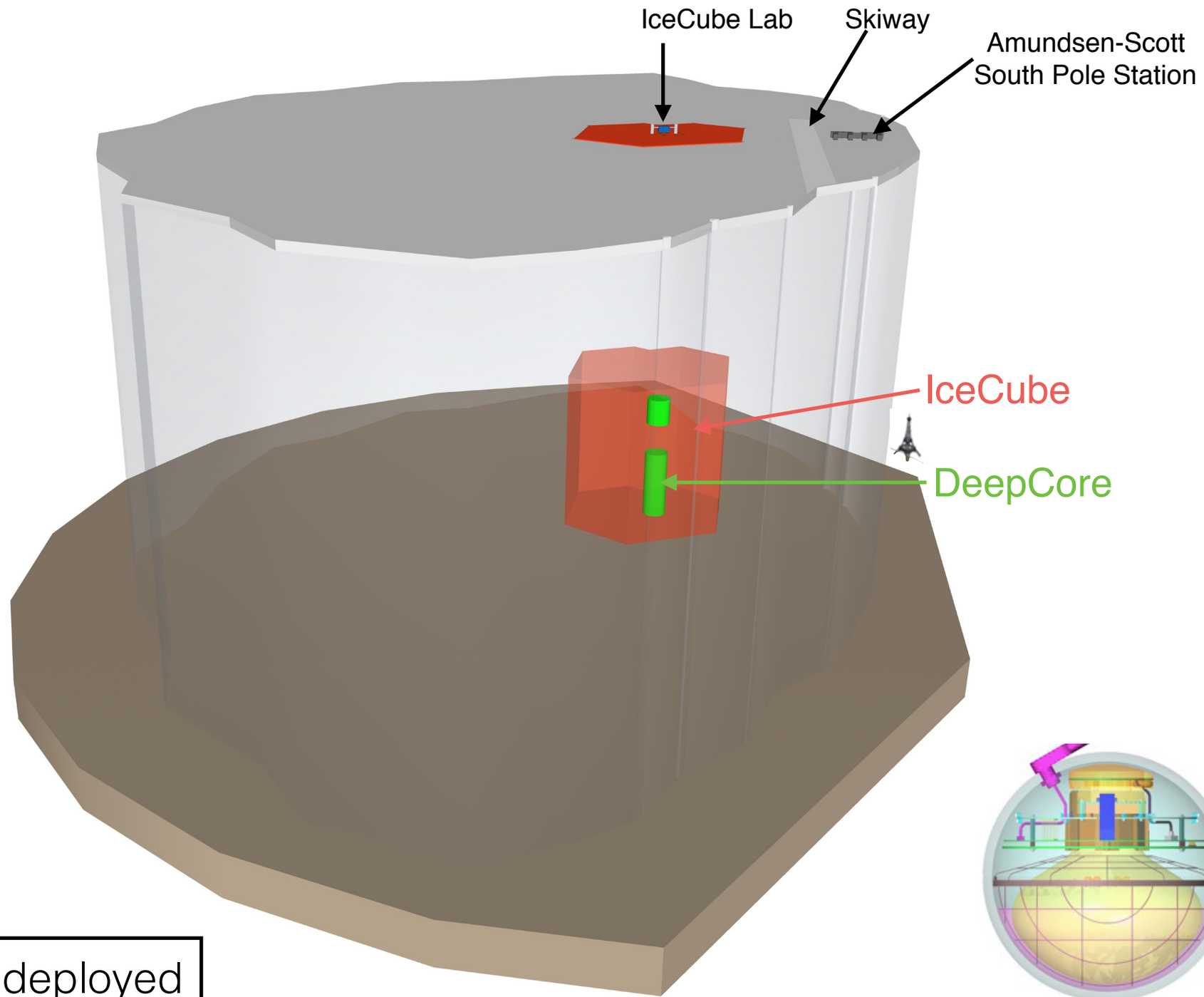
Cosmic Rays/Atm. Neutrinos/Exotics

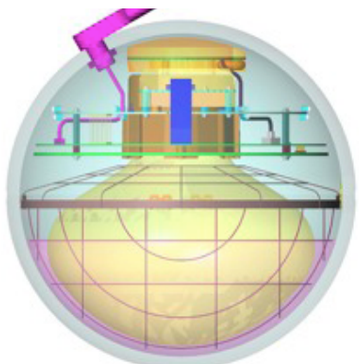
*see talks:

G. Binder - Neutrino-nucleon cross-sections at multi-TeV (Astropart. & Cosmology Tues. Afternoon session)

M. Medici - Indirect dark matter searches (Astropart. & Cosmology; Wed. Morning)

The IceCube Neutrino Observatory





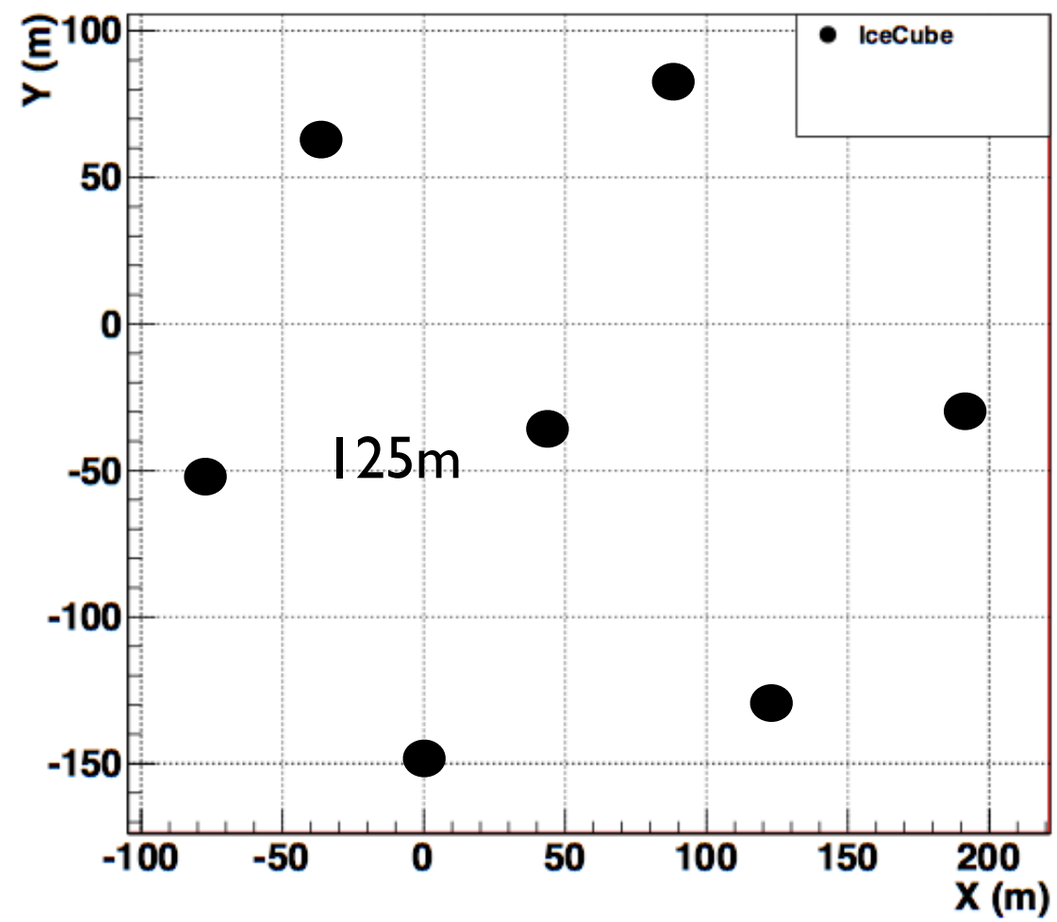
Digital Optical Module

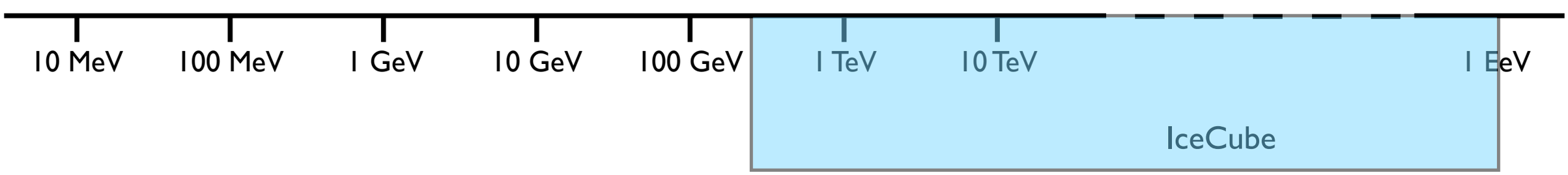
5160 optical sensors deployed on an cubic-kilometre array of 86 “strings” at depths between 1.5 km and 2.5 km

IceCube

- 78 Strings
  - 125m string spacing
  - 17m DOM spacing

IceCube (top centre view)





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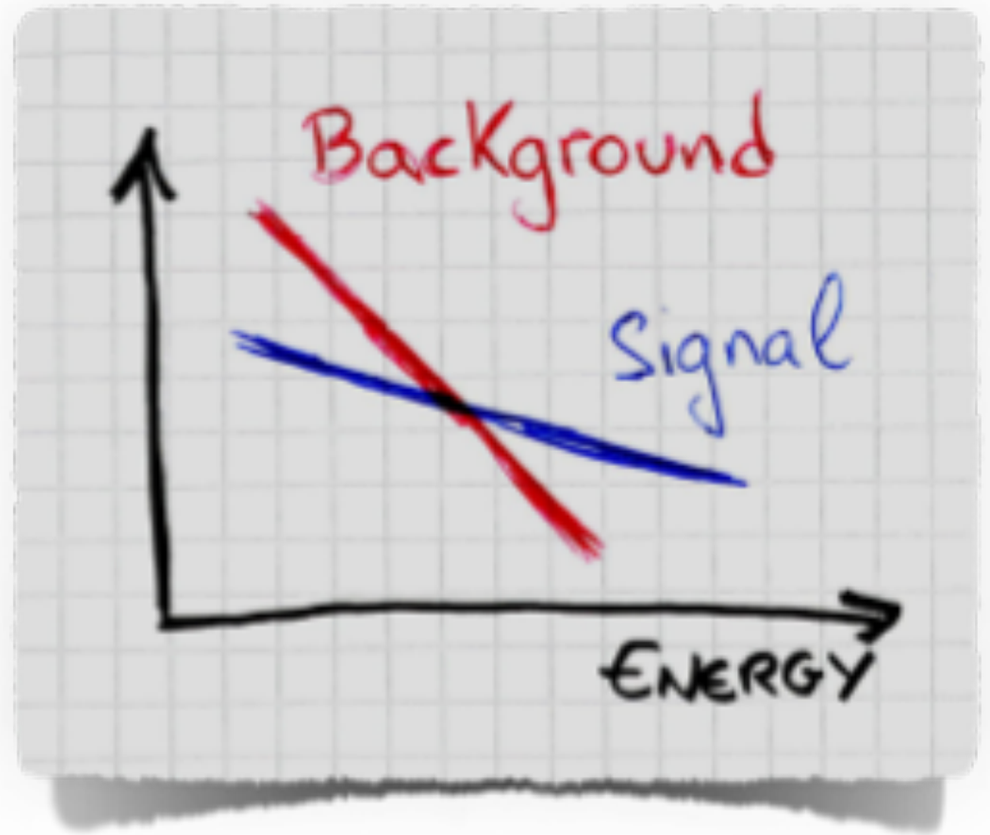
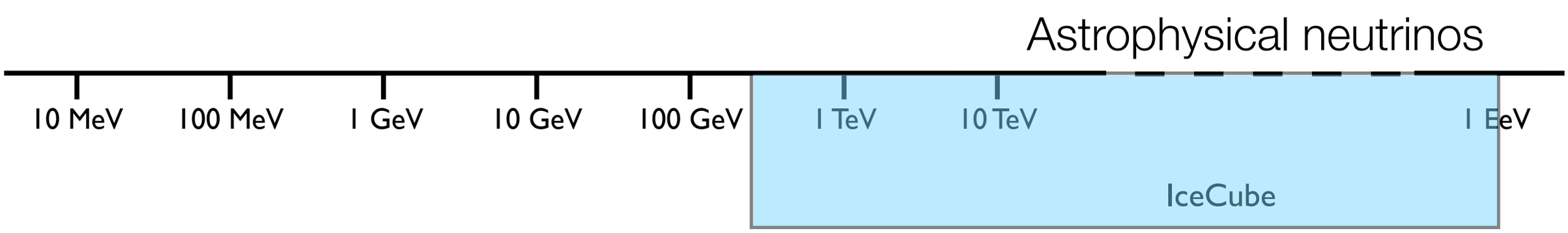
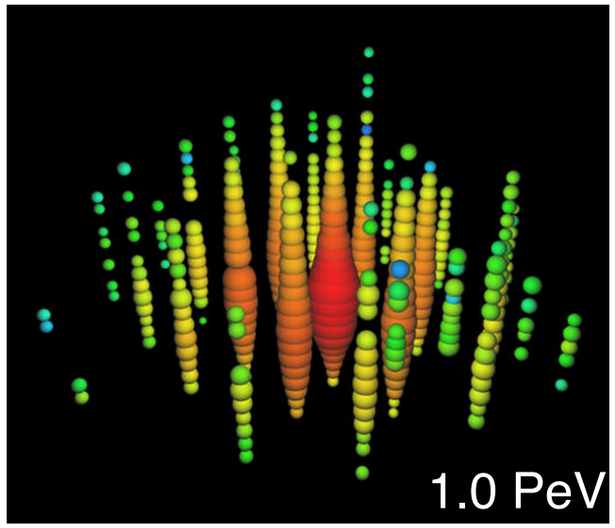
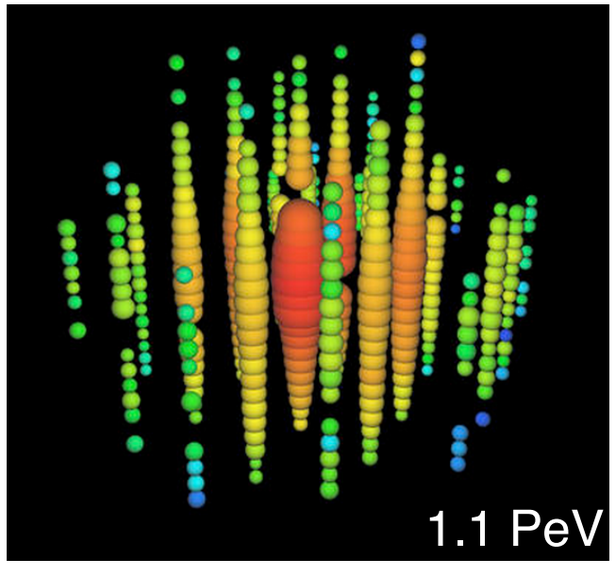


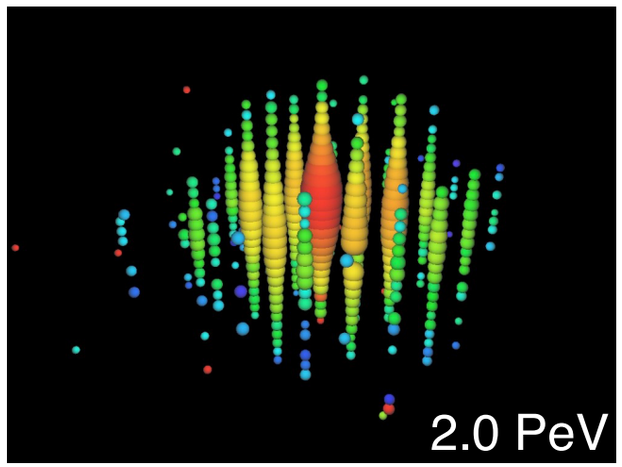


IceCube high energy starting events search

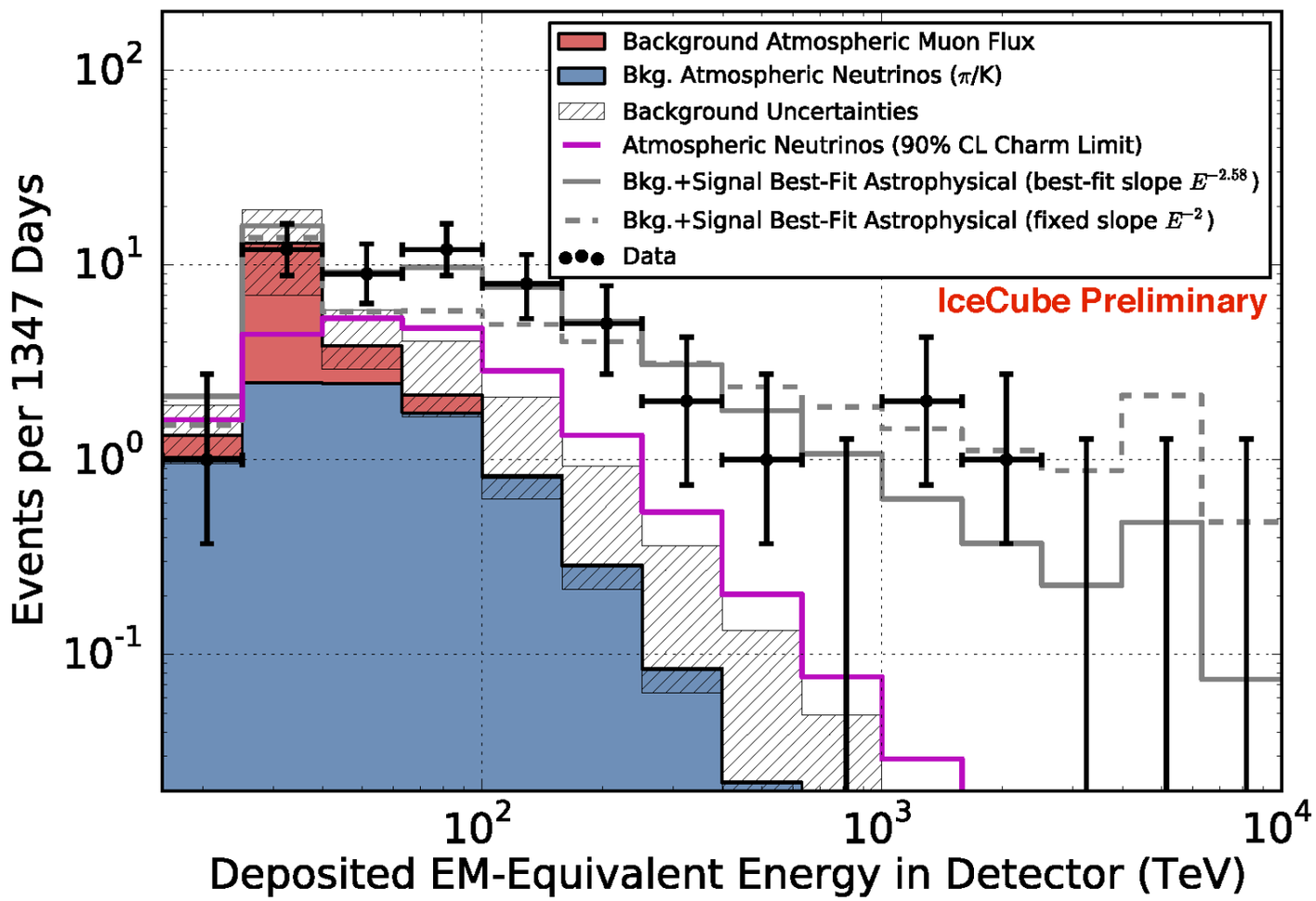
- 54 events; 15 track-like, 39 cascade-like
- Expectation from conventional atmospheric muons and neutrinos ~21.6
- ~7 sigma rejection of atmospheric only hypothesis







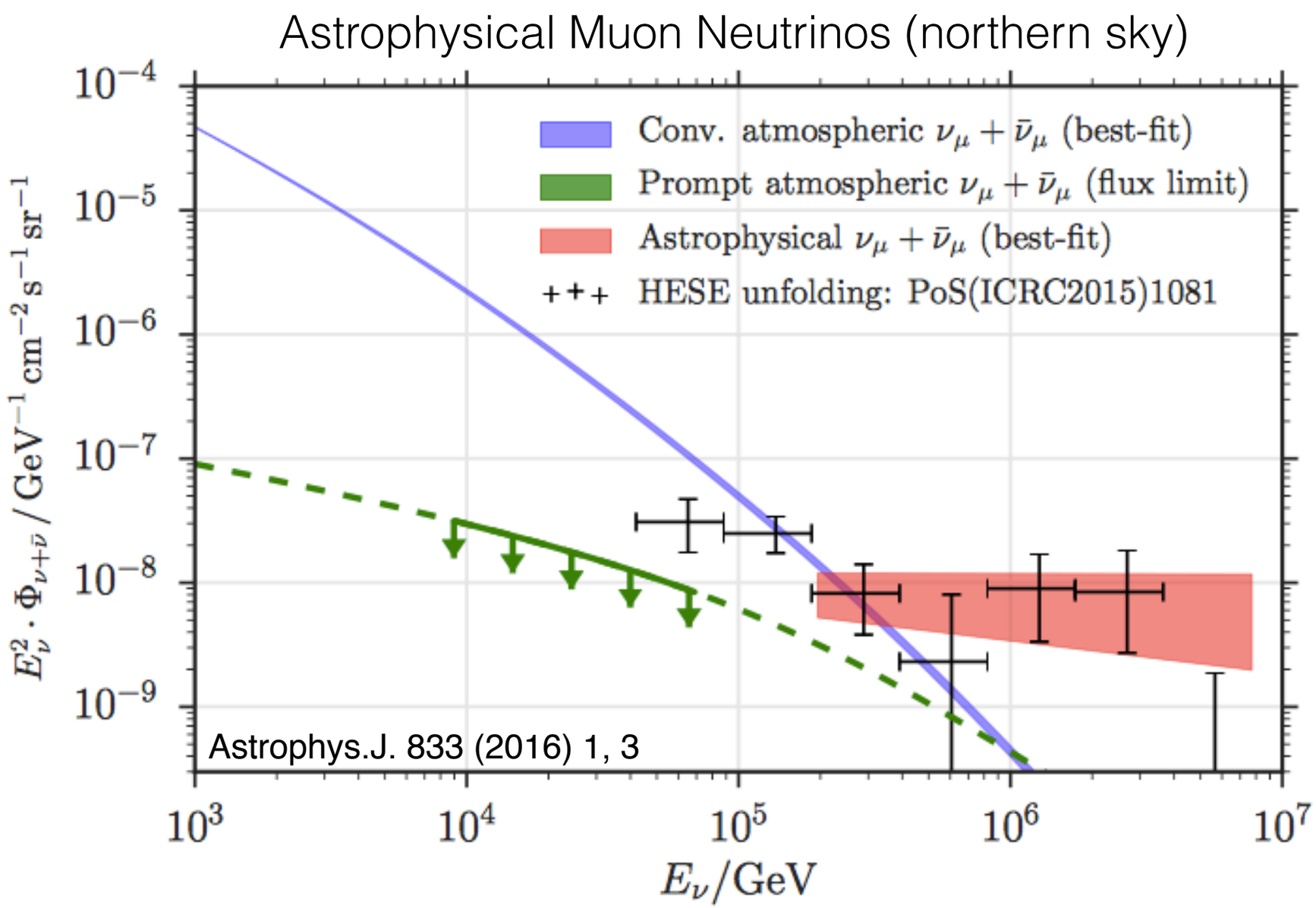
Starting Event Spectrum



ICRC 2015 proceedings
IceCube Collaboration, Science 342, 1242856 (2013),
IceCube Collaboration, Phys. Rev. Lett 113, 101101 (2014)

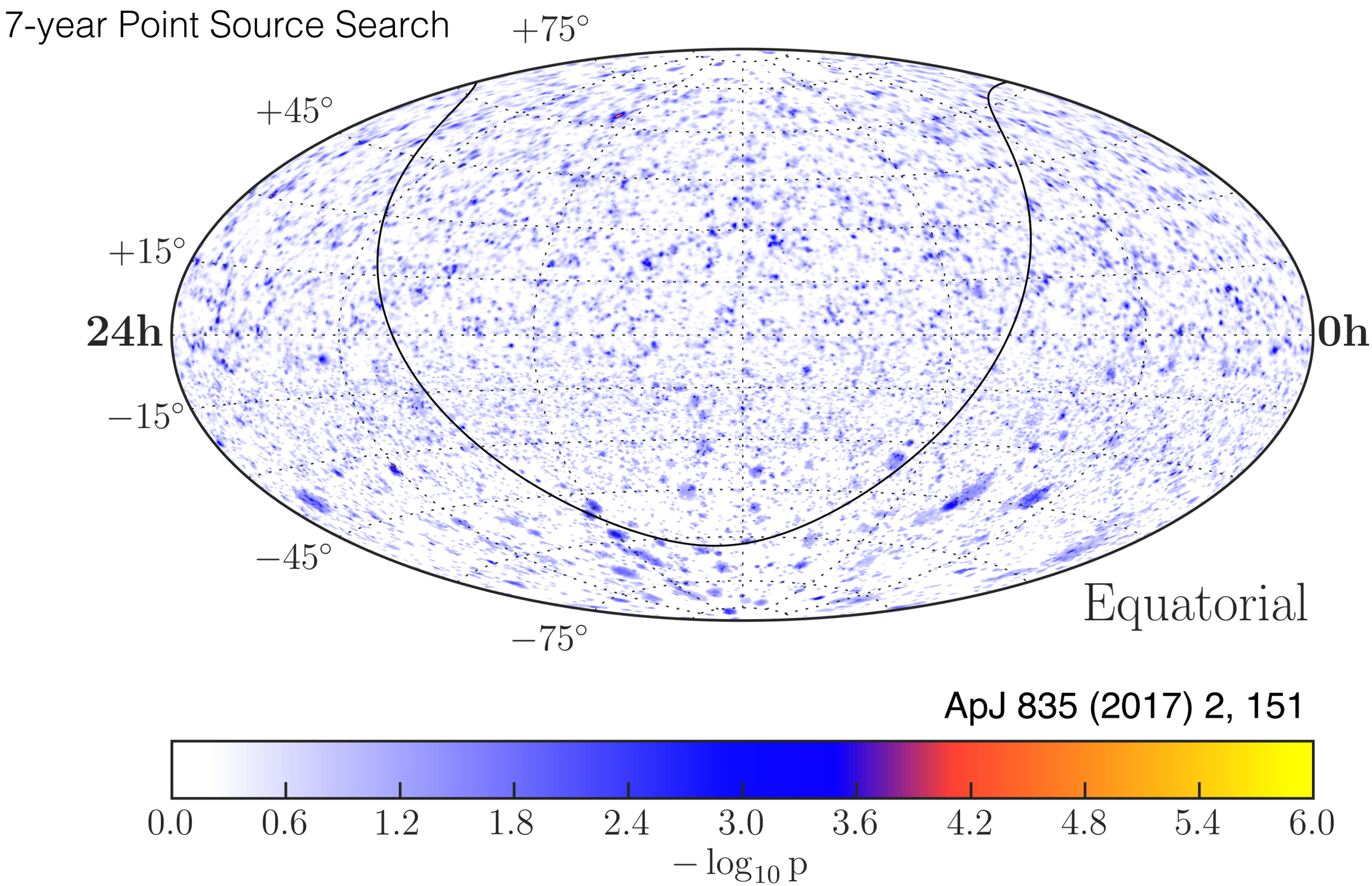
*** Look for updates @ ICRC and TeVPA**

IceCube high energy muon neutrino search



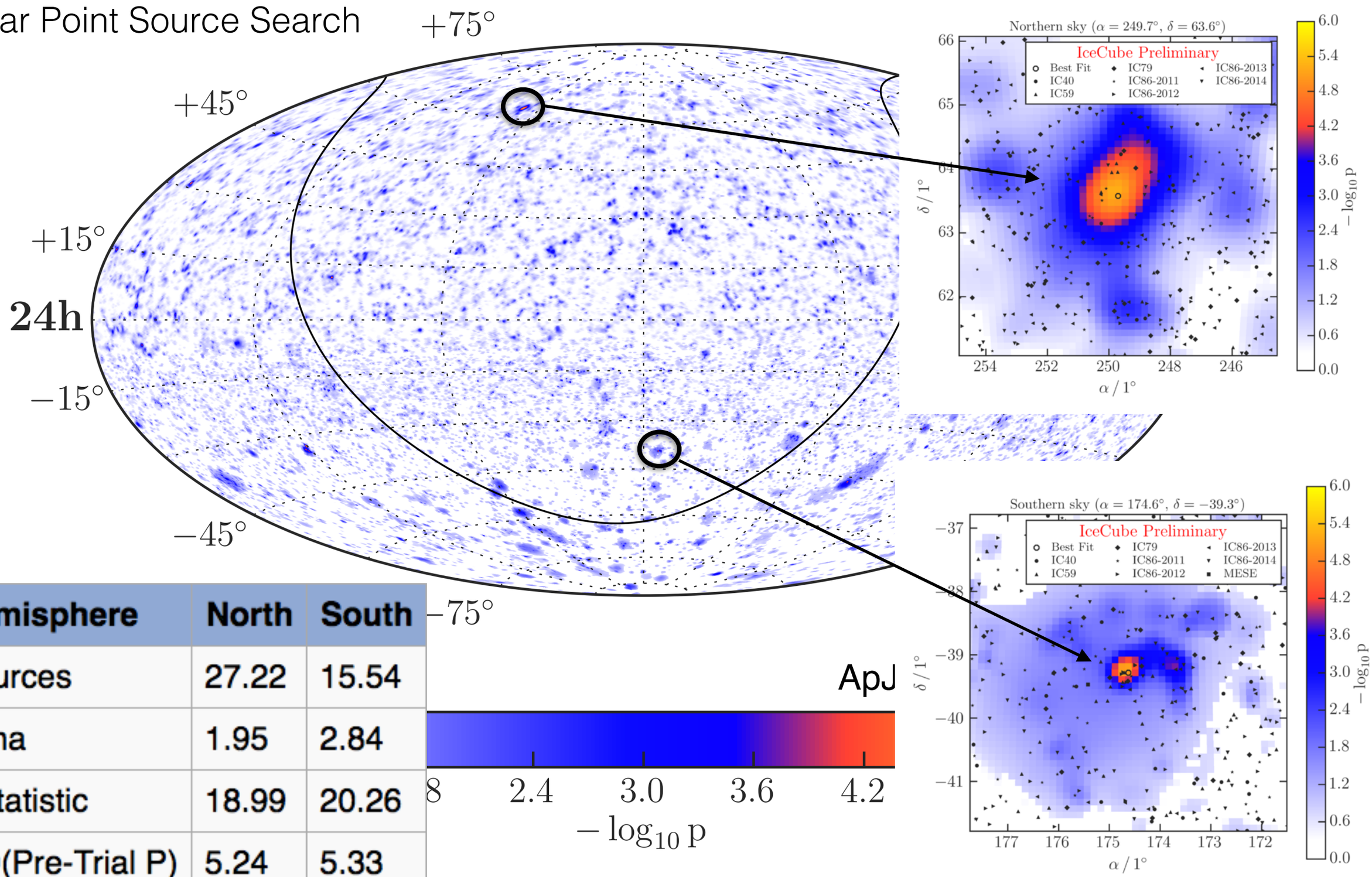
- 350 000 events in 6-year analysis
- Up-going or Horizontal track = Earth-filtered (~99.7% pure muon neutrino sample)
- 5.6σ for astrophysical flux

IceCube high energy point source search



IceCube high energy point source search

7-year Point Source Search



Hemisphere	North	South
N_Sources	27.22	15.54
Gamma	1.95	2.84
Test statistic	18.99	20.26
-log10(Pre-Trial P)	5.24	5.33
Post Trial P	44%	39%

IceCube

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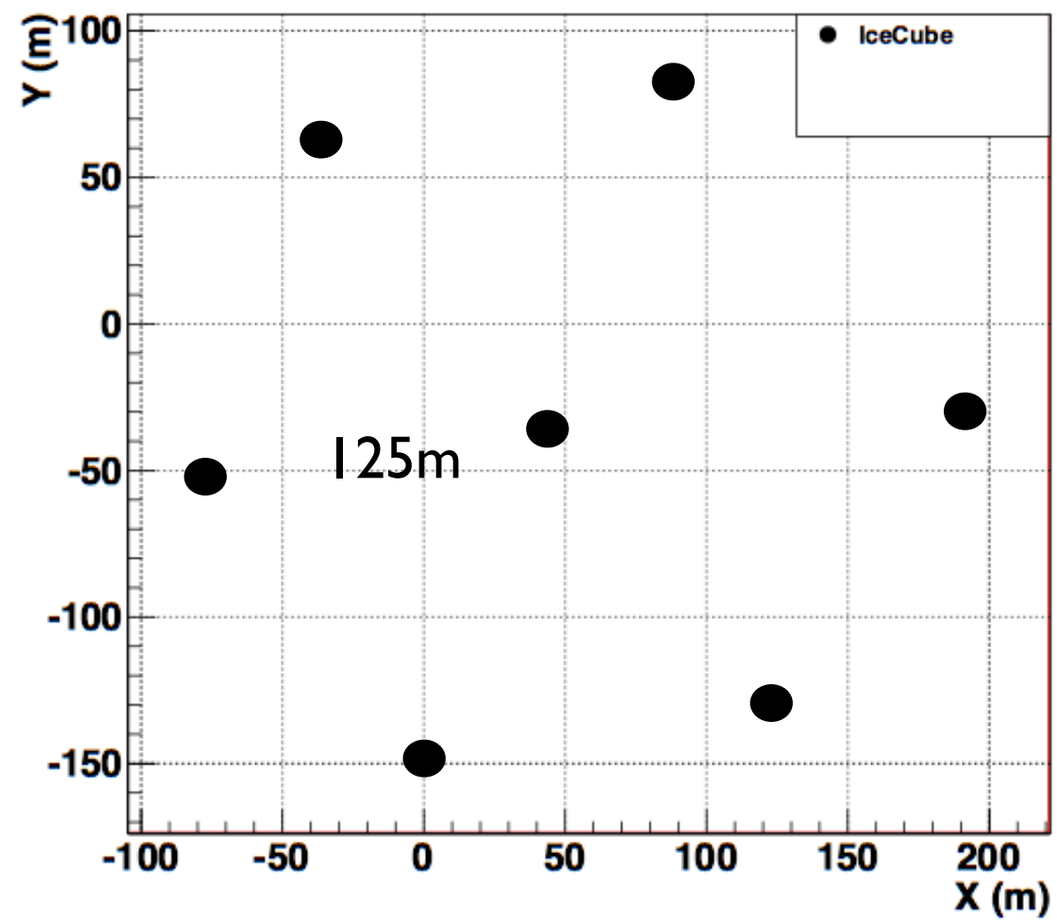
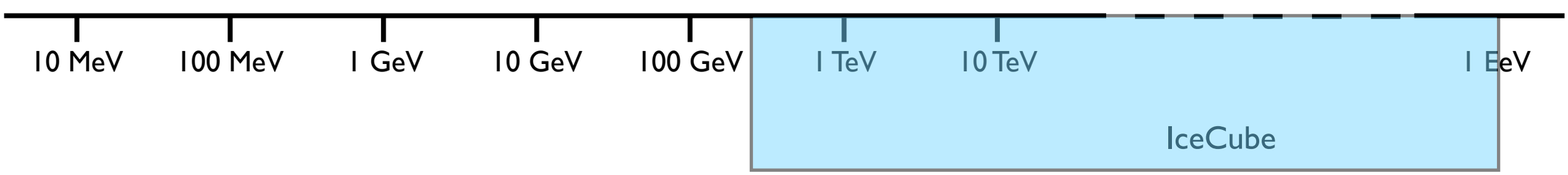
IceCube (top centre view)

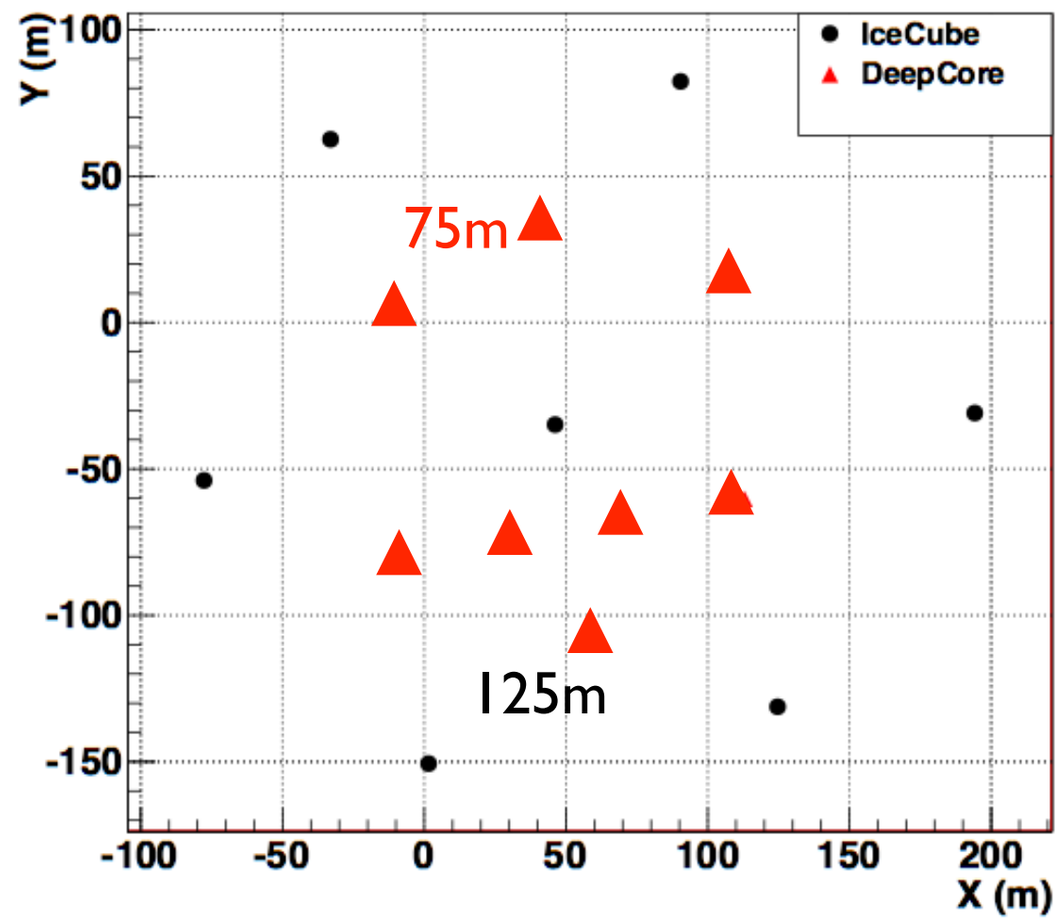


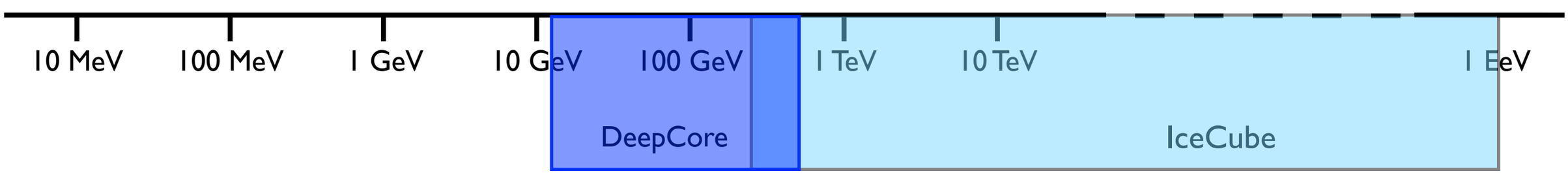


IceCube-DeepCore

- 78 Strings
  - 125m string spacing
  - 17m DOM spacing
- Add 8 strings
  - 75m string spacing
  - 7m DOM spacing

IceCube-DeepCore (top view)





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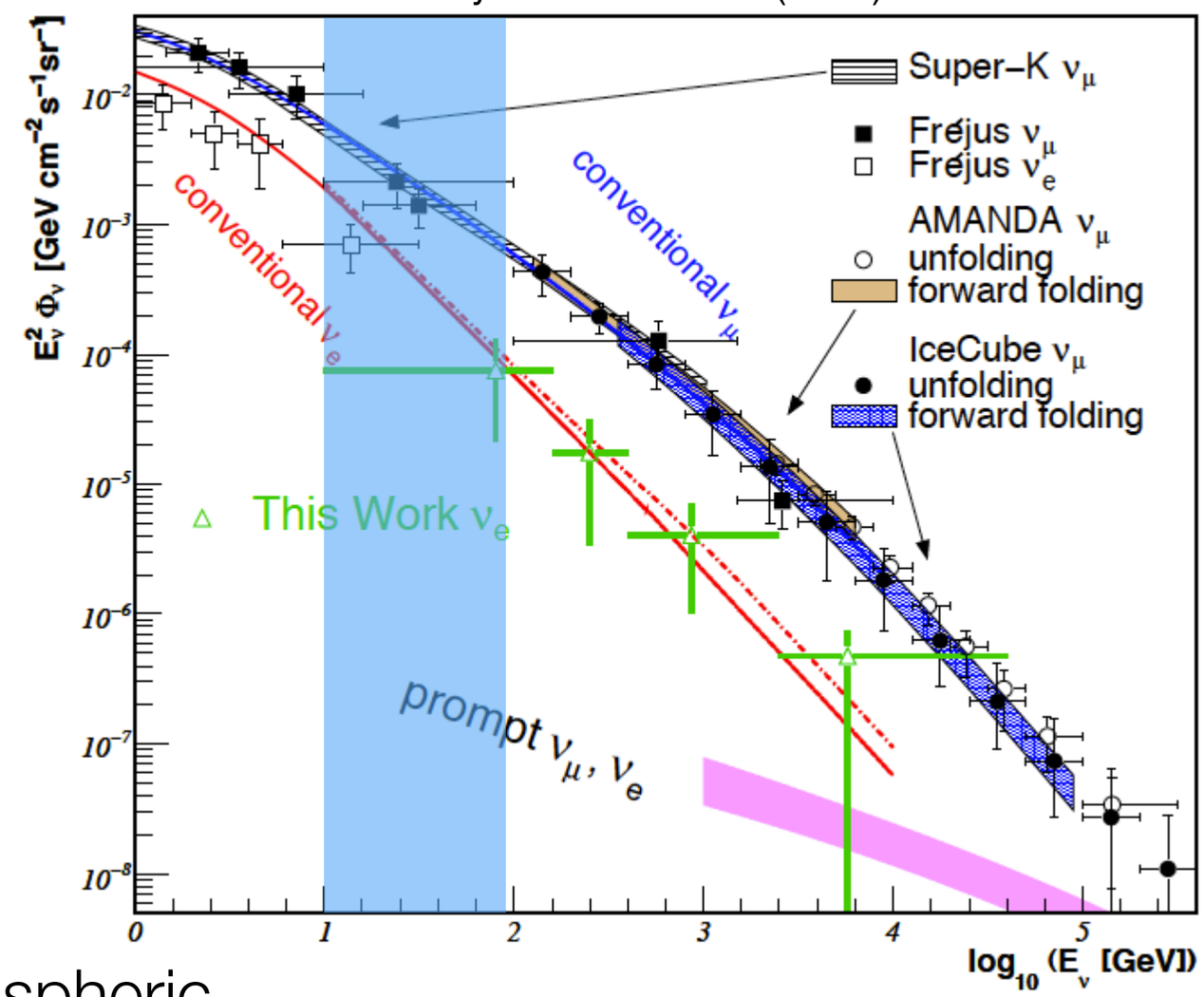
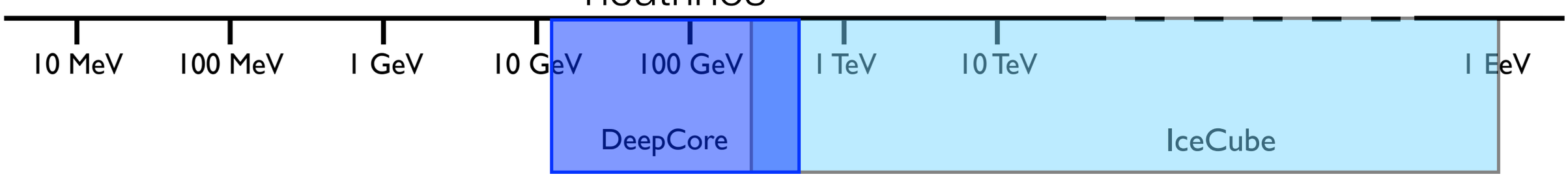
IceCube Collaboration Phys. Rev. Lett. 110 (2013) 151105 /1212.4760v2

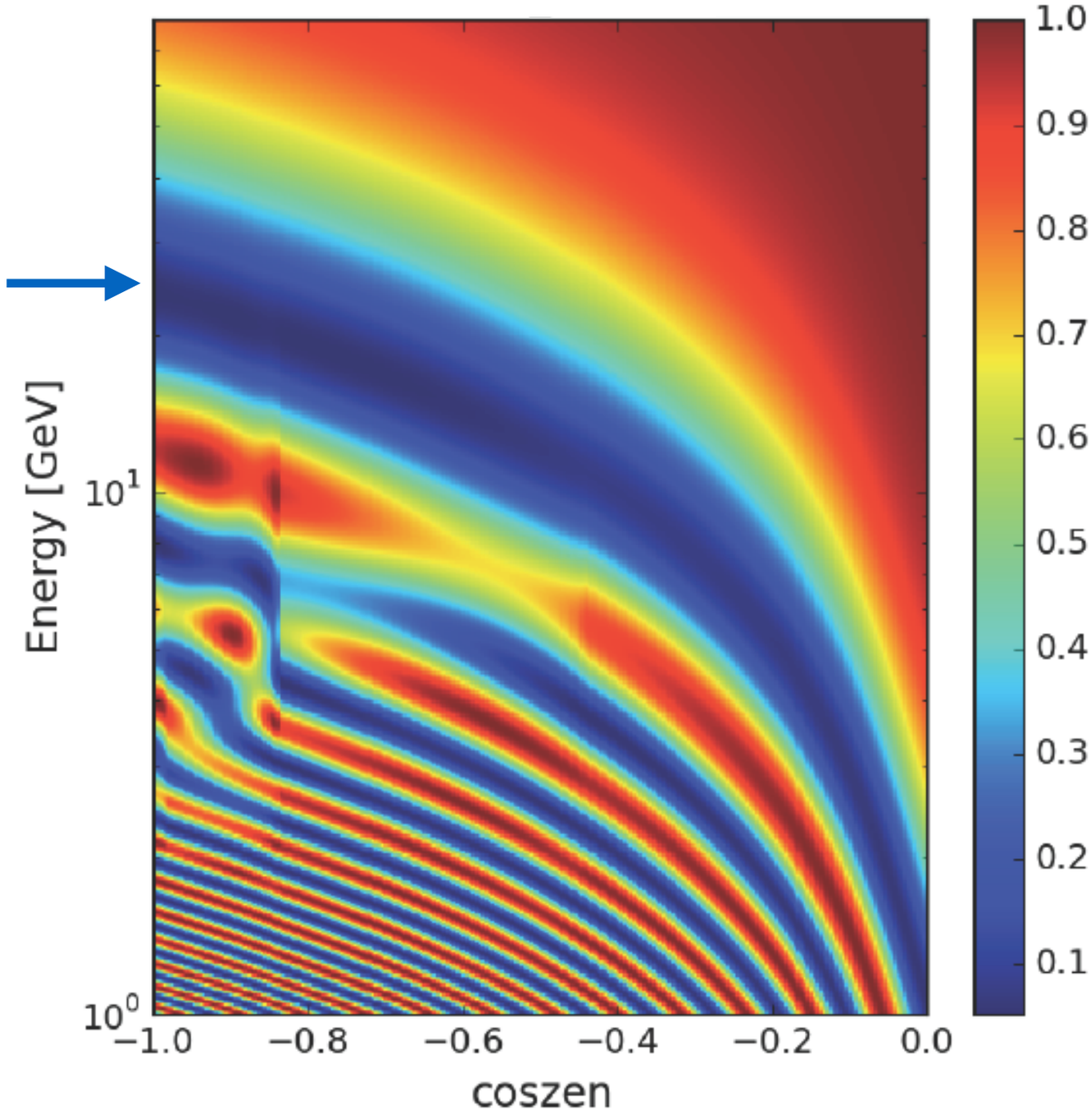


Atmospheric neutrinos



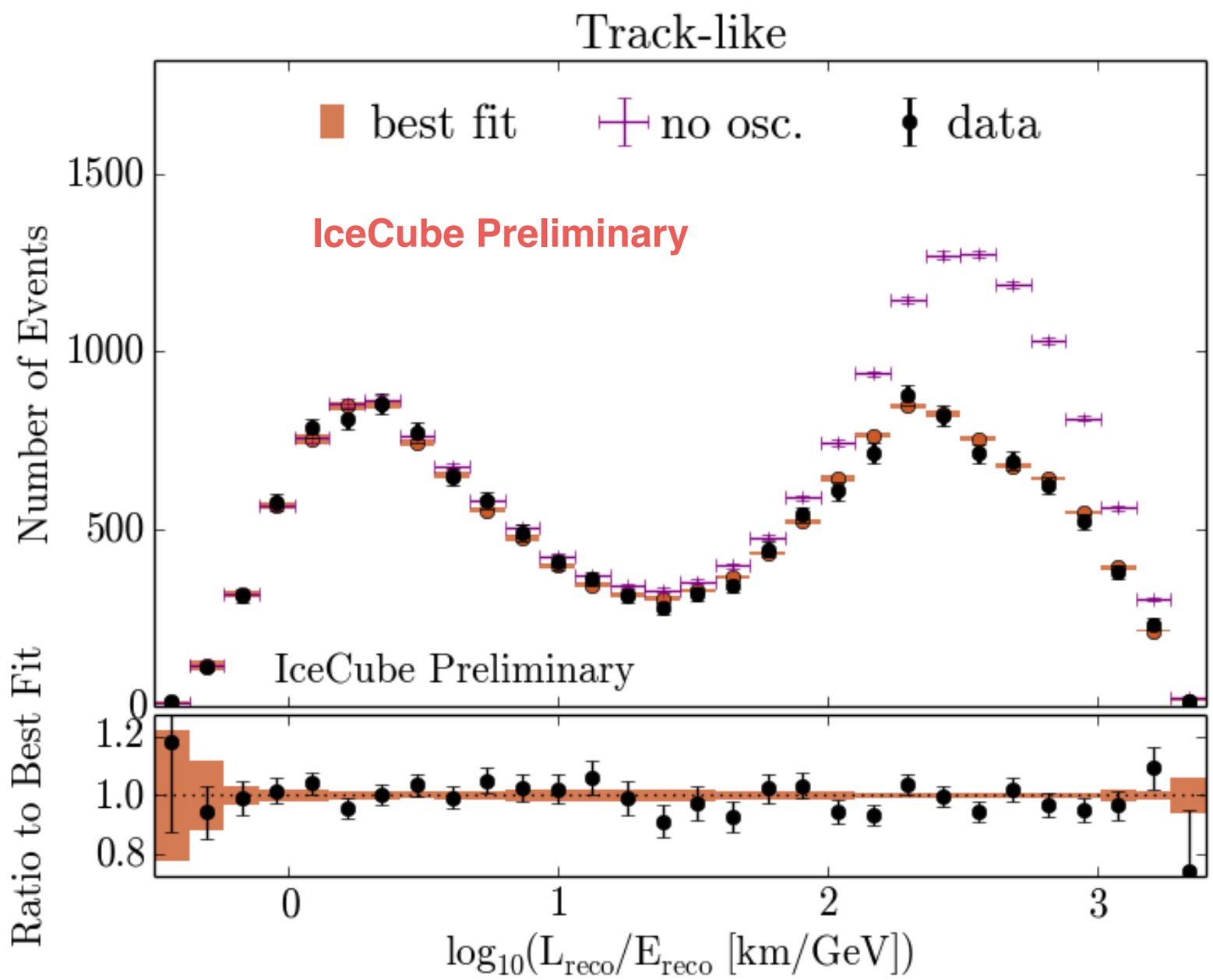
Oscillations with Atmospheric Neutrinos

- Neutrinos are available over a wide range of energies and baselines
  - Comparison of observations from different baselines and energies is crucial for controlling systematics
- Neutrinos oscillating over one Earth diameter have a ν_μ survival minimum at ~25 GeV

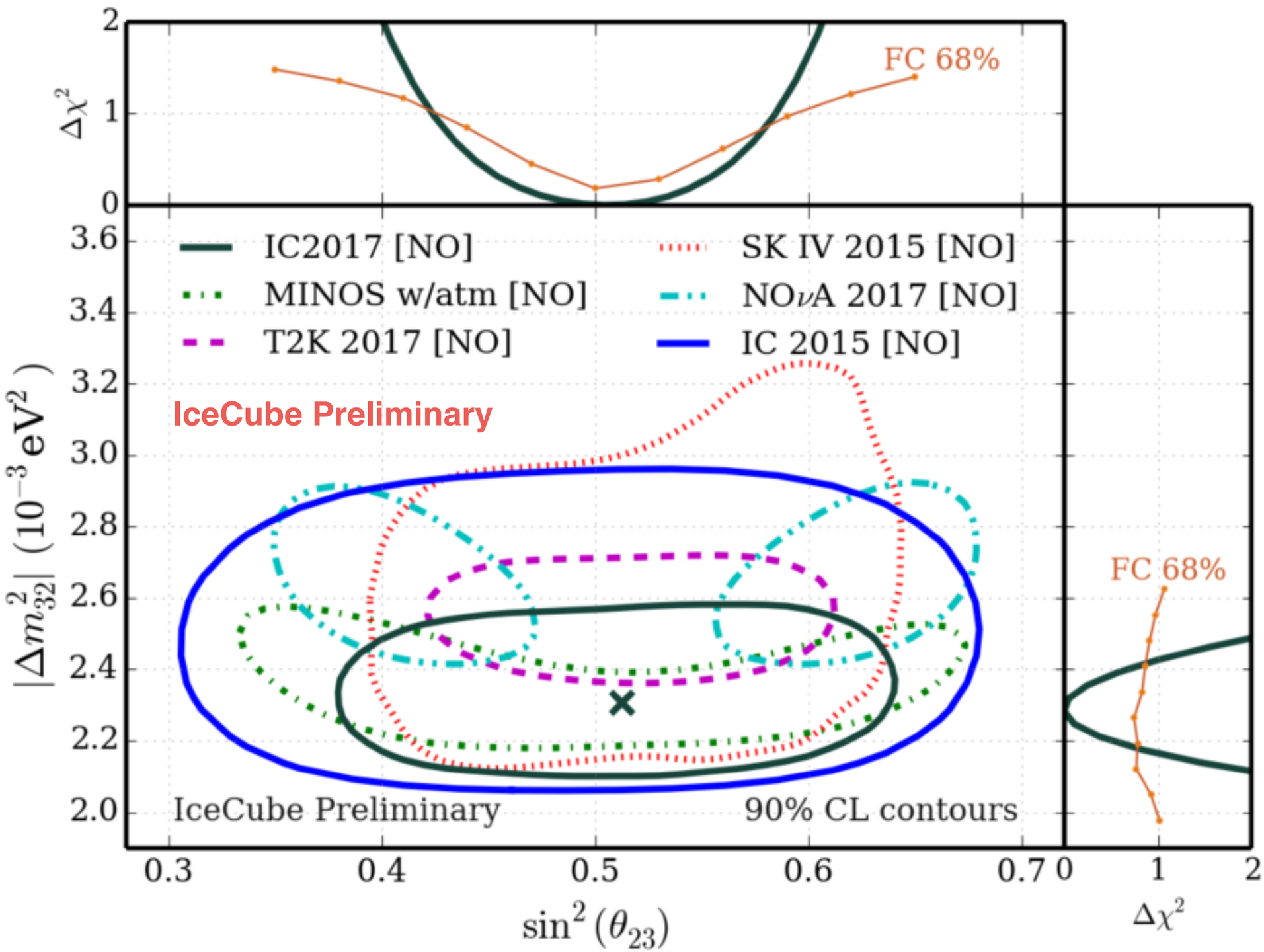


$$P(\nu_\alpha \to \nu_\beta) = \sin^2(2\theta)\sin^2\left(\frac{\Delta m^2 L}{4E}\right)$$

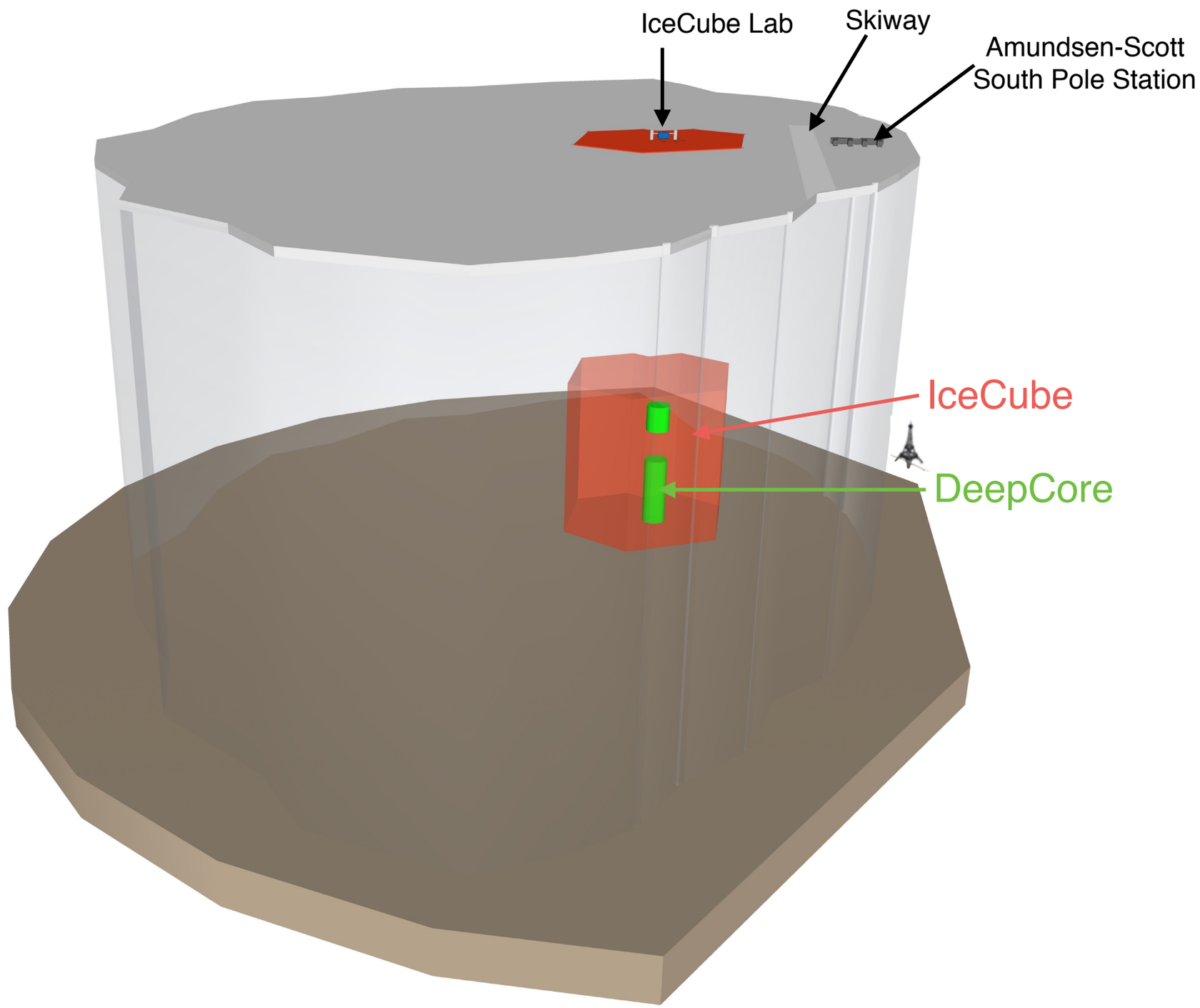
IceCube atmospheric muon neutrino disappearance



IceCube atmospheric muon neutrino disappearance



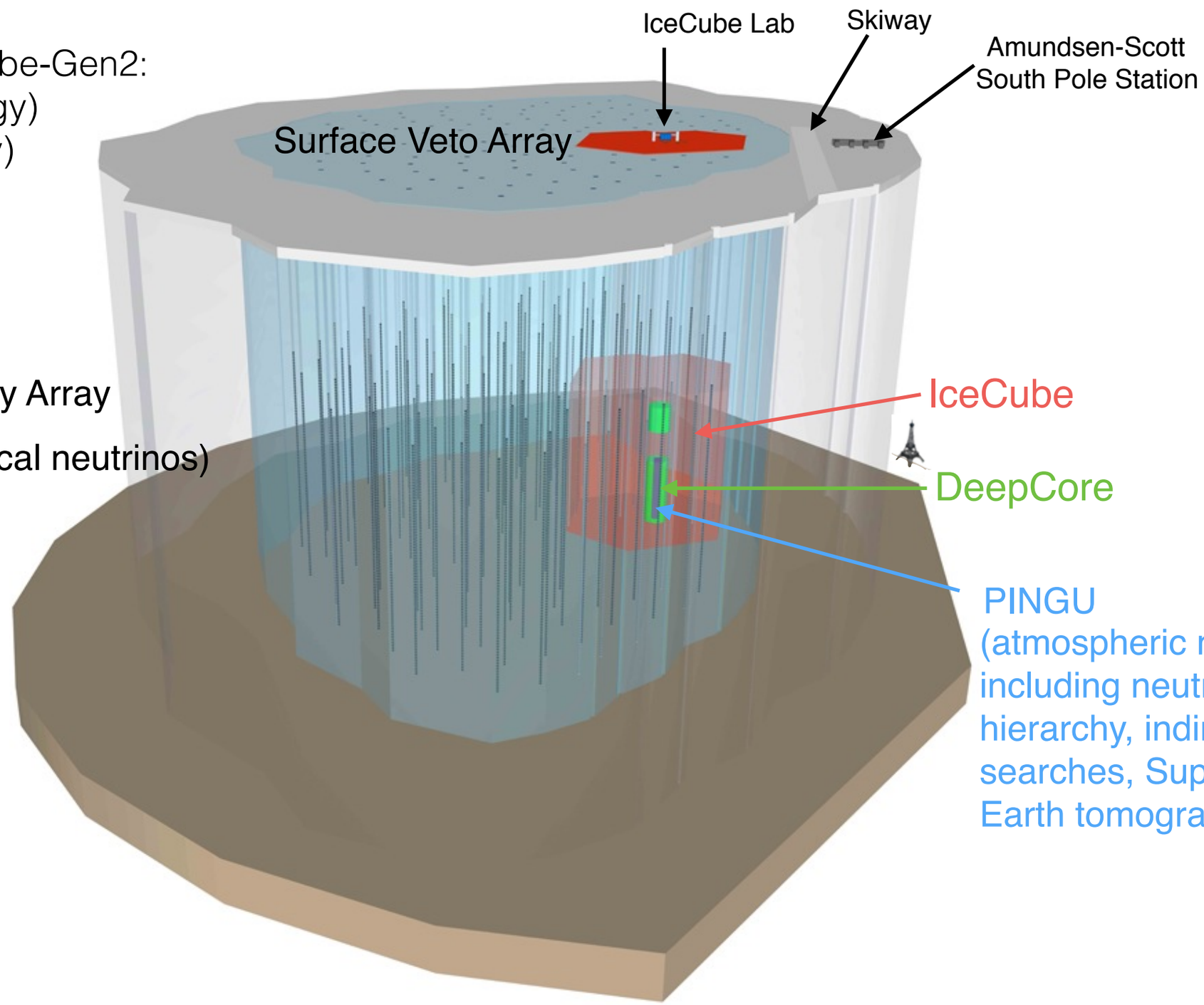
IceCube


IceCube Lab
Skiway
Amundsen-Scott
South Pole Station
IceCube
DeepCore

IceCube-Gen2

New elements of IceCube-Gen2:

- PINGU (low-energy)
- HEA (high-energy)
- Surface veto



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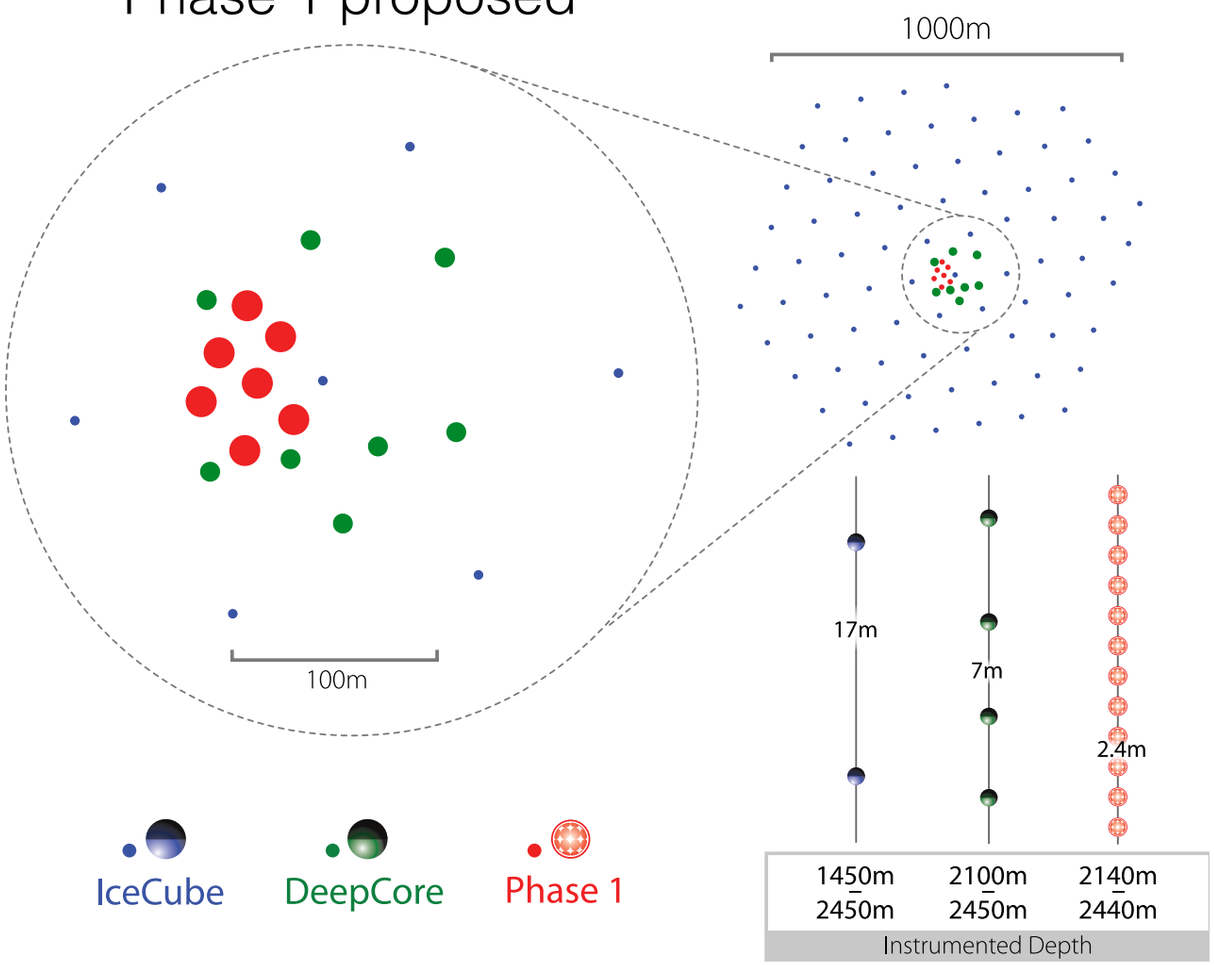
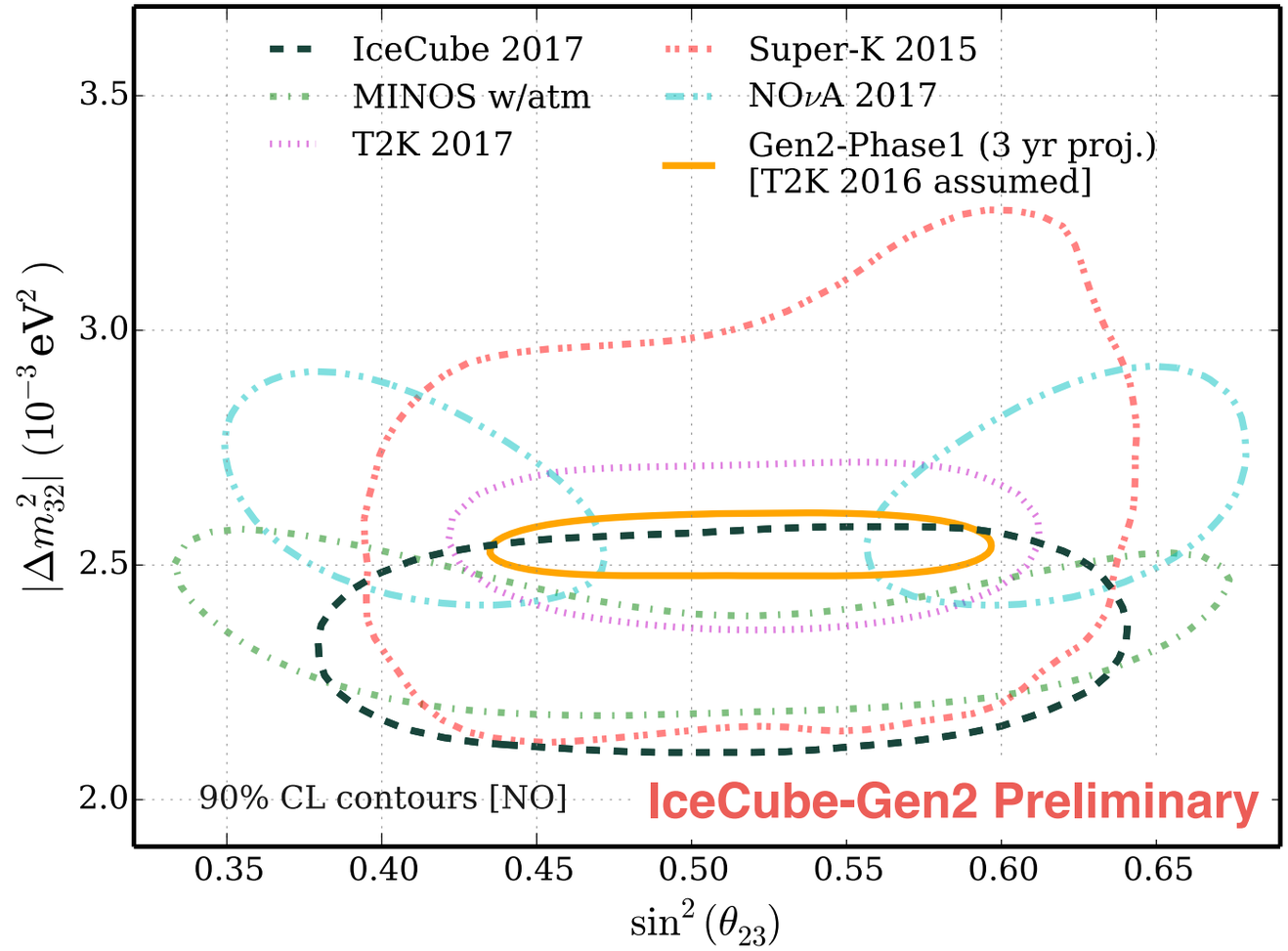
Total IceCube-Gen2 value O(IceCube w/inflation)

IceCube-Gen2 developments

Phase 1 proposed



precision measurements of muon neutrino disappearance



IceCube-Gen2 developments

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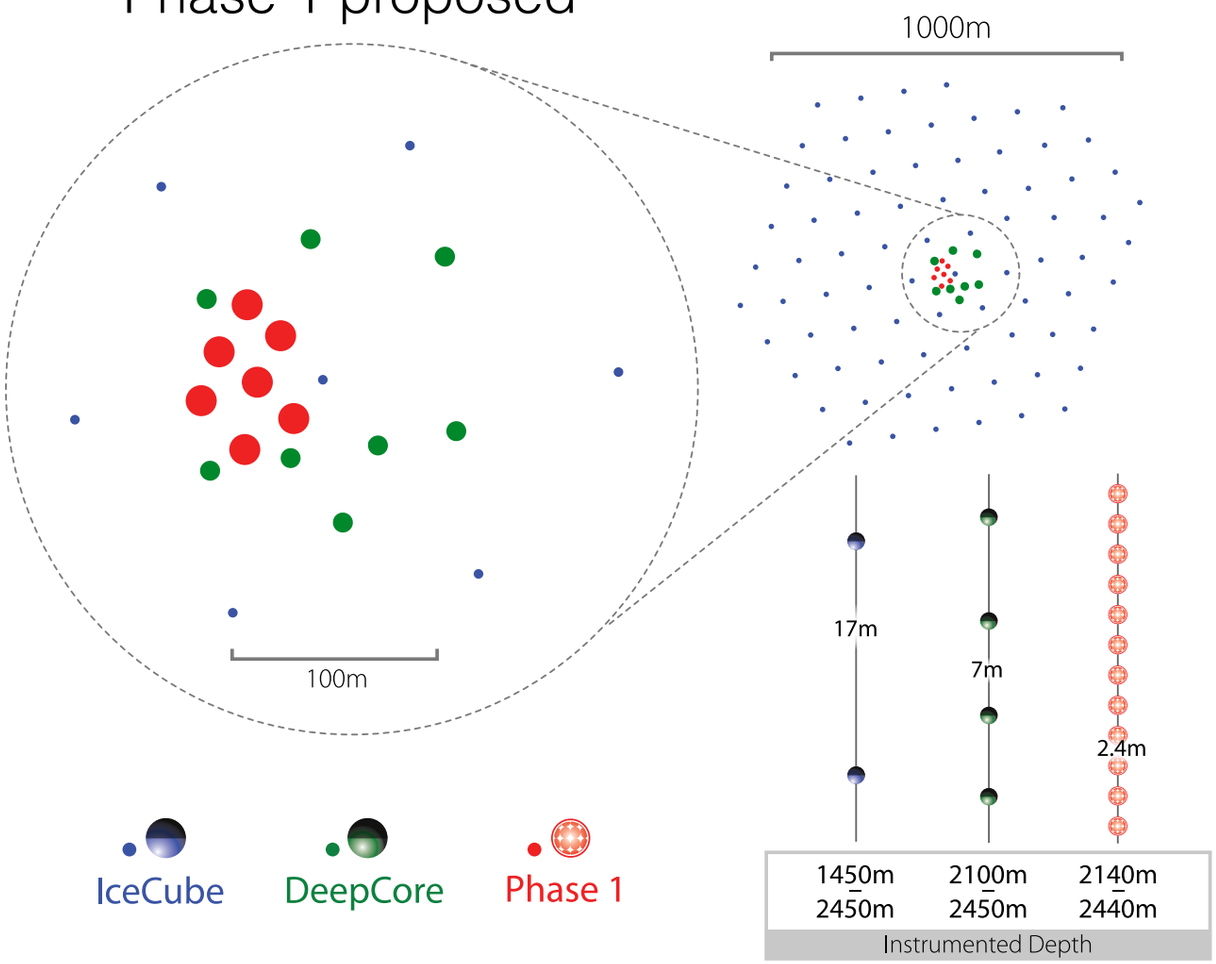
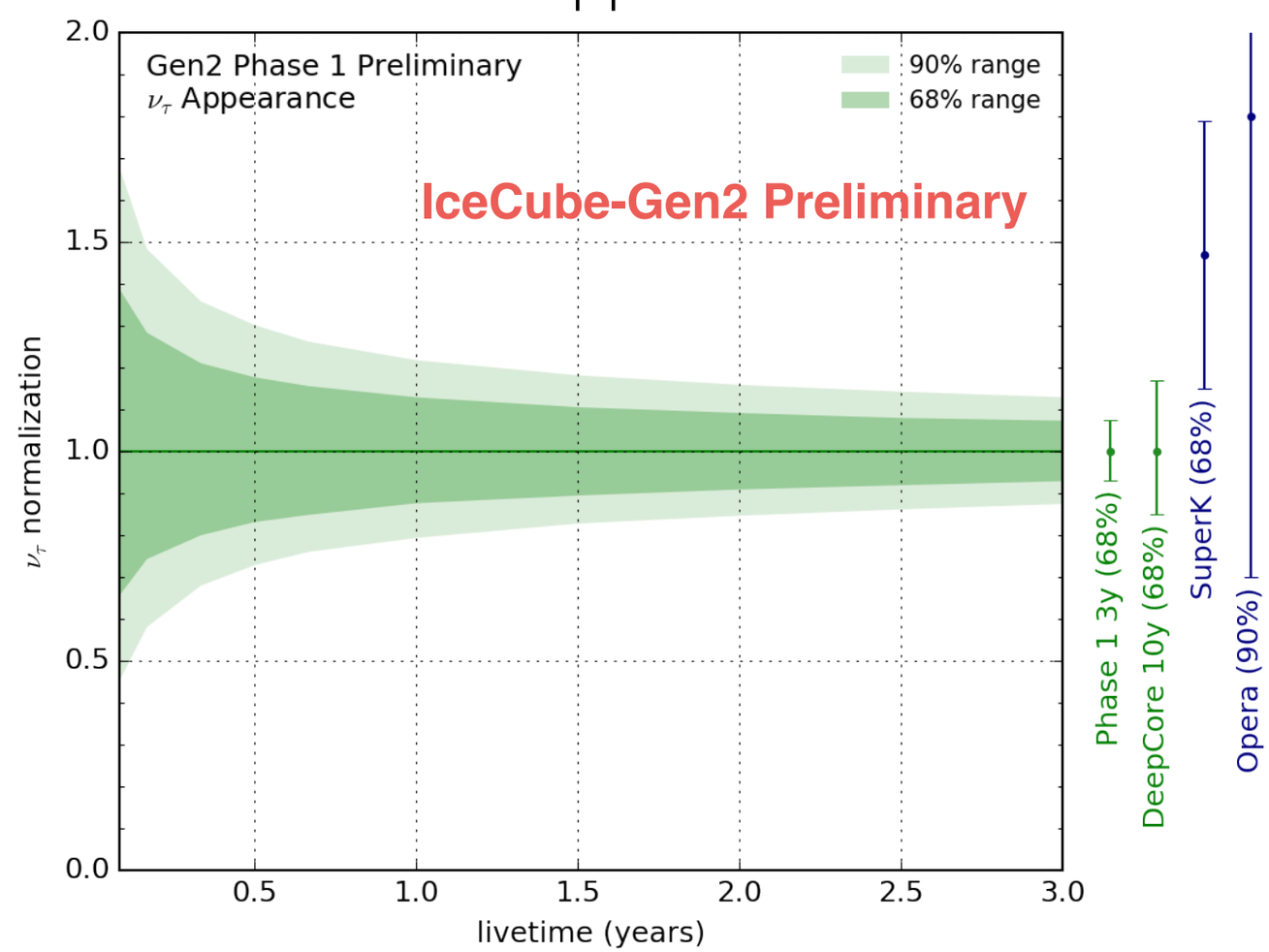


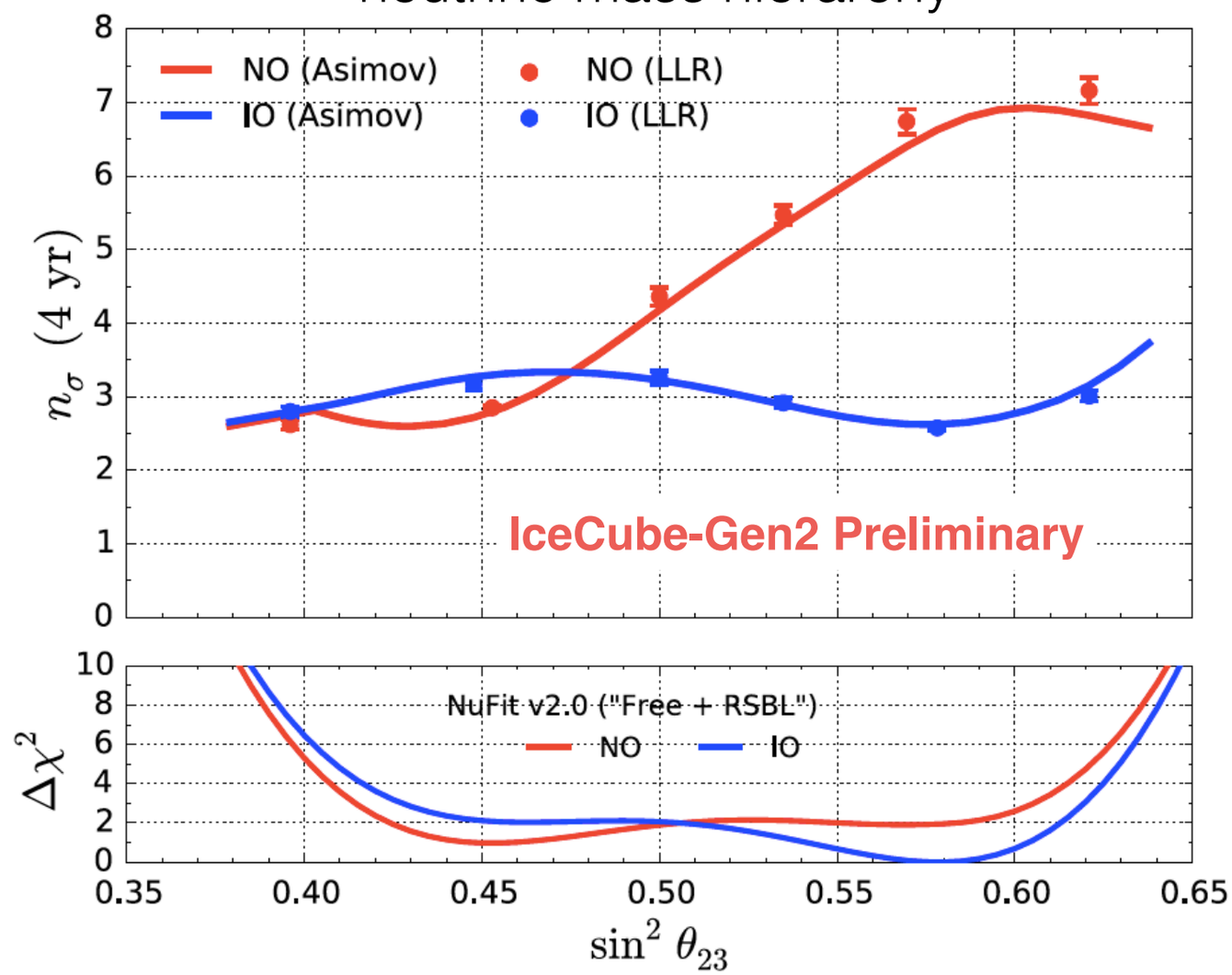
precision measurements of tau neutrino appearance



Summary

- Neutrino astronomy has opened a new window to the high energy universe.
- The IceCube discovered astrophysical neutrino dataset grows daily (>99.5% uptime) and a multi-messenger followup program is rapidly maturing.
- World-leading sensitivity to new physics, including indirect dark matter sensitivity; atmospheric neutrino oscillation measurements competitive with the accelerator-based experiments in a new energy .
- Developments now underway for the next generation detector array

PINGU sensitivity to the neutrino mass hierarchy



The IceCube Collaboration

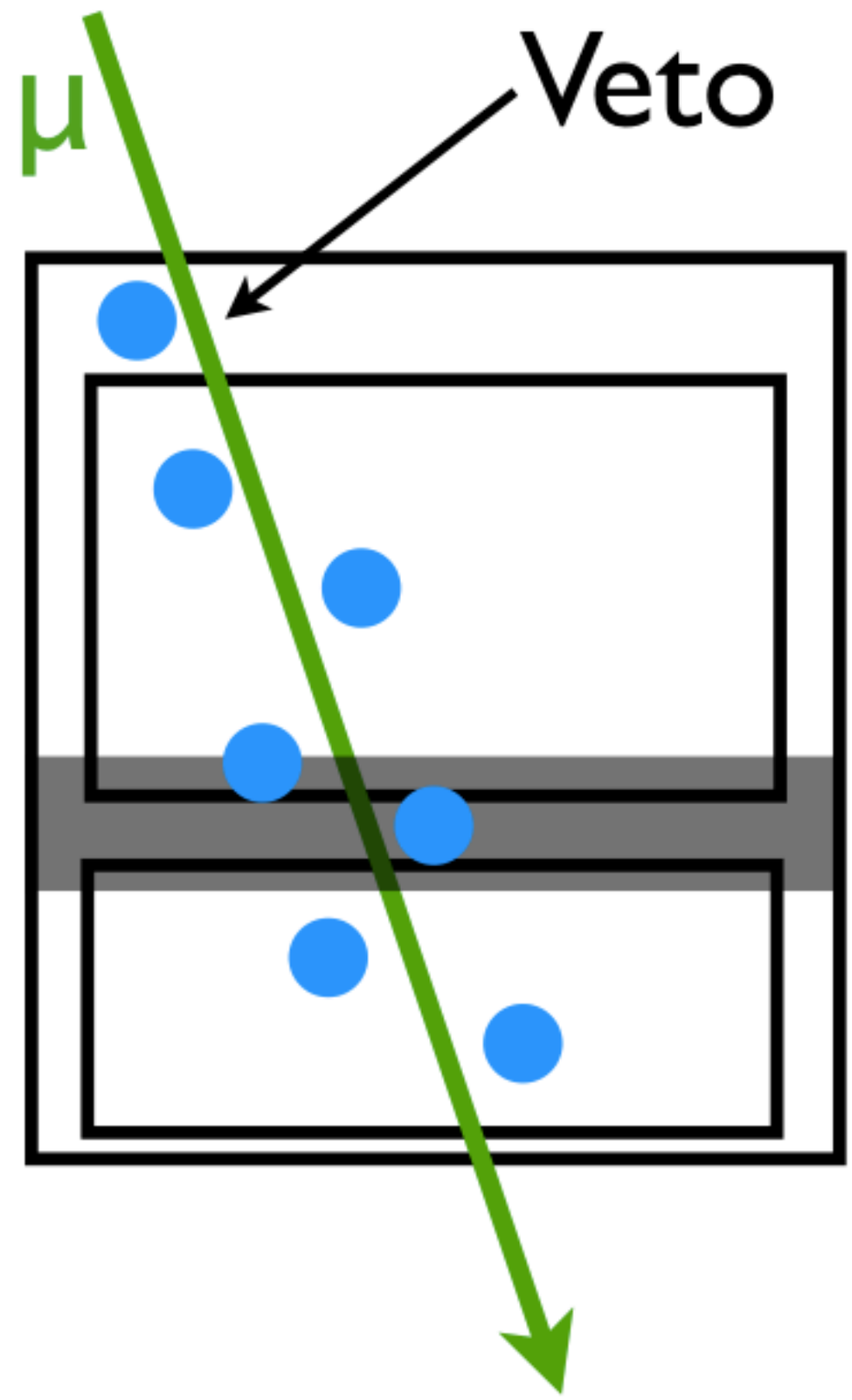
Funding Agencies

Fonds de la Recherche Scientifique (FRS-FNRS)
Fonds Wetenschappelijk Onderzoek-Vlaanderen (FWO-Vlaanderen)
Federal Ministry of Education & Research (BMBF)
German Research Foundation (DFG)
Deutsches Elektronen-Synchrotron (DESY)
Japan Society for the Promotion of Science (JSPS)
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)

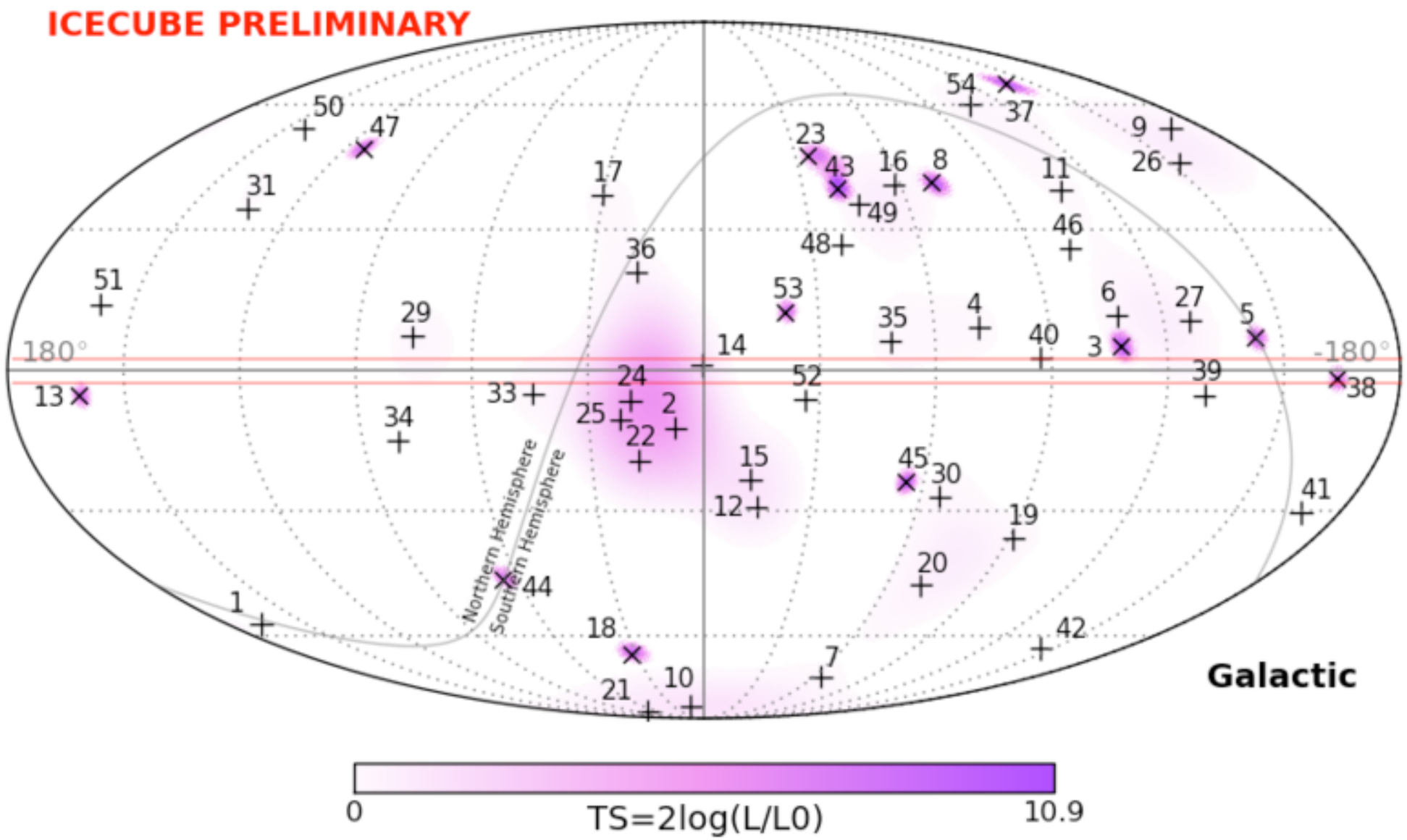
Backup Slides

IceCube high energy starting events search

- Identify starting events in the detector by applying an active veto to remove the down-going backgrounds:
  - atmospheric muons identified by using part of the detector in anti-coincidence; can estimate potential contamination by using subsequent detector regions to measure number of muons that evade the other veto layer
  - atmospheric neutrinos: starting outside the detector see above; starting inside the detector tag with a parent atmospheric muon



IceCube high energy starting events search - sky map



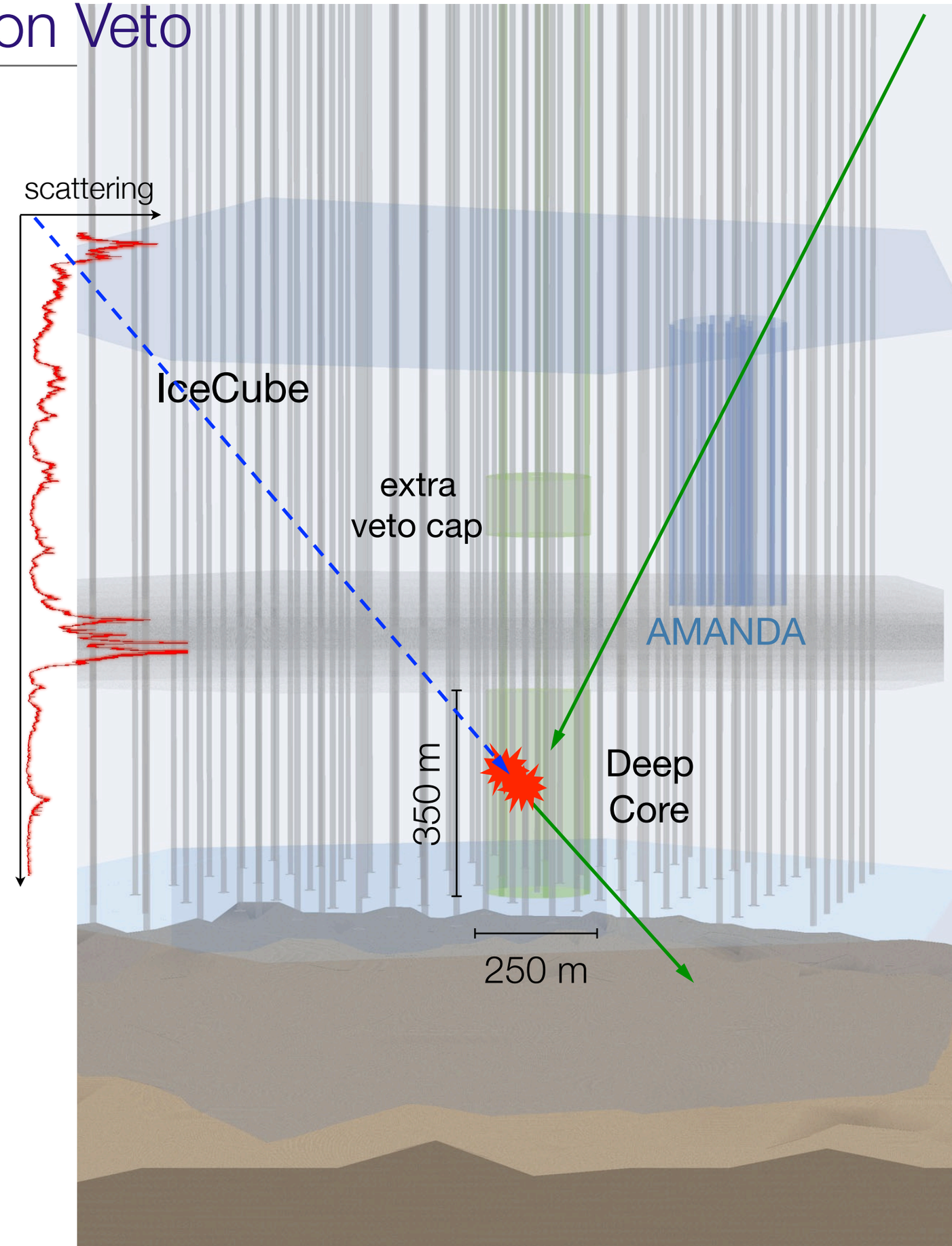
- No significant correlations in space or time
- The p-value for cascade event “clustering” is ~44%

ICRC 2015 proceedings
IceCube Collaboration, Science 342, 1242856 (2013),
IceCube Collaboration, Phys. Rev. Lett 113, 101101 (2014)

*** Look for updates @ ICRC and TeVPA**

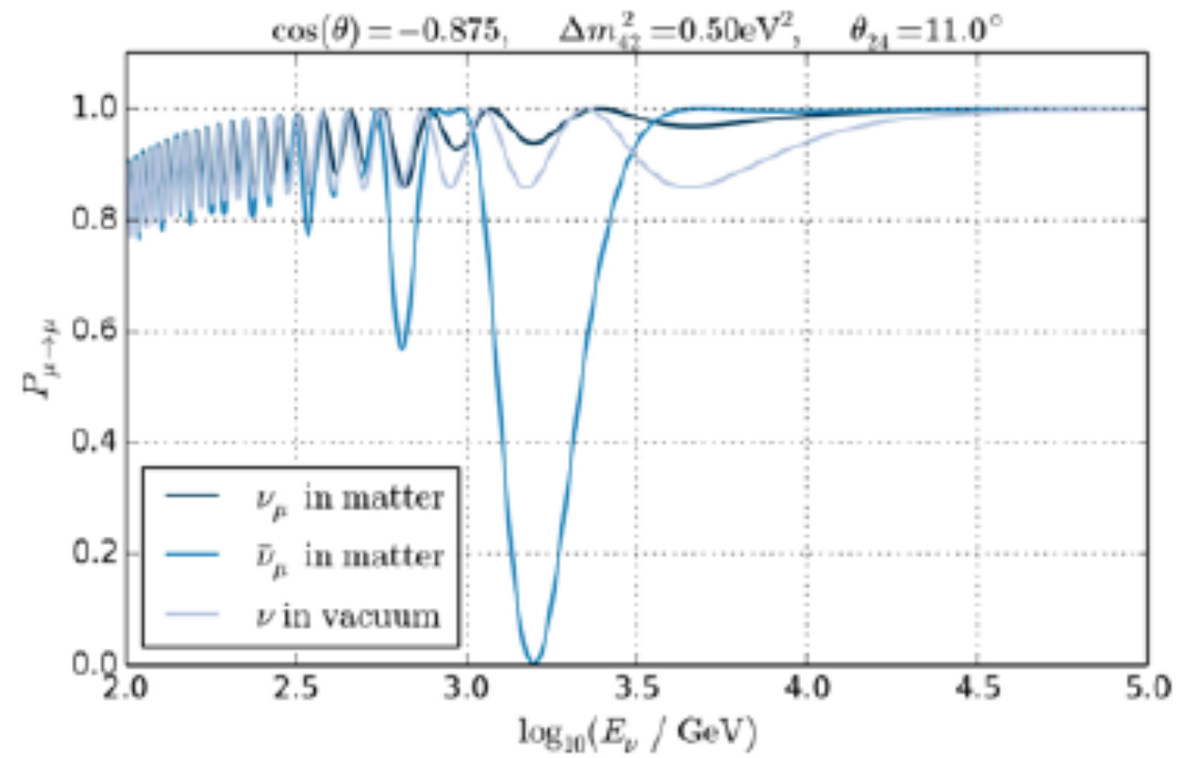
DeepCore Atmospheric Muon Veto

- Overburden of 2.1 km water-equivalent is substantial, but not as large as at deep underground labs
- However, top and outer layers of IceCube provide an active veto shield for DeepCore
- ~40 horizontal layers of modules above; 3 rings of strings on all sides
- Effective μ-free depth much greater
- Can use to distinguish atmospheric μ from atmospheric or cosmological ν
- Atm. μ/ν trigger ratio is ~10^6
- Vetoing algorithms expected to reach at least 10^6 level of background rejection



IceCube sterile neutrino search

- Existence of a sterile neutrino state would produce resonance-like ν_μ disappearance for particular neutrino energy
- Location of the resonance depends on the sterile neutrino mixing parameter
- The preferred range occurs around 1 eV^2, leading to a resonance at the TeV-scale

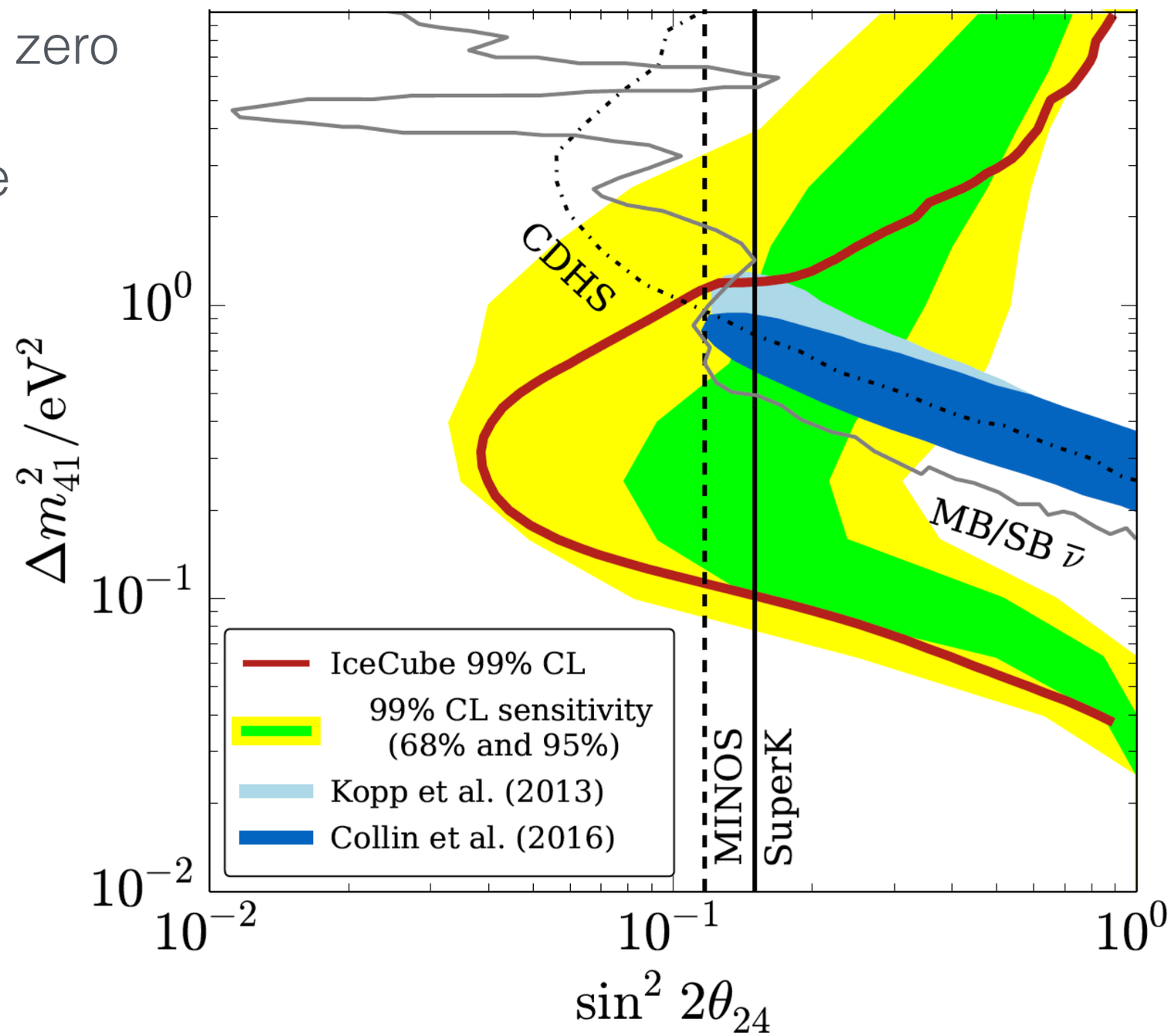


IceCube Collaboration Phys.Rev.Lett. 117 (2016) no.7, 071801

IceCube sterile neutrino search

- Strong constraints on θ_{24} for Δm^2 around 0.1 - 2 eV^2
- θ_{14} and θ_{34} assumed to be zero
- Excludes parameter space favoured by appearance experiments

IceCube Collaboration Phys.Rev.Lett. 117 (2016) no.7, 071801



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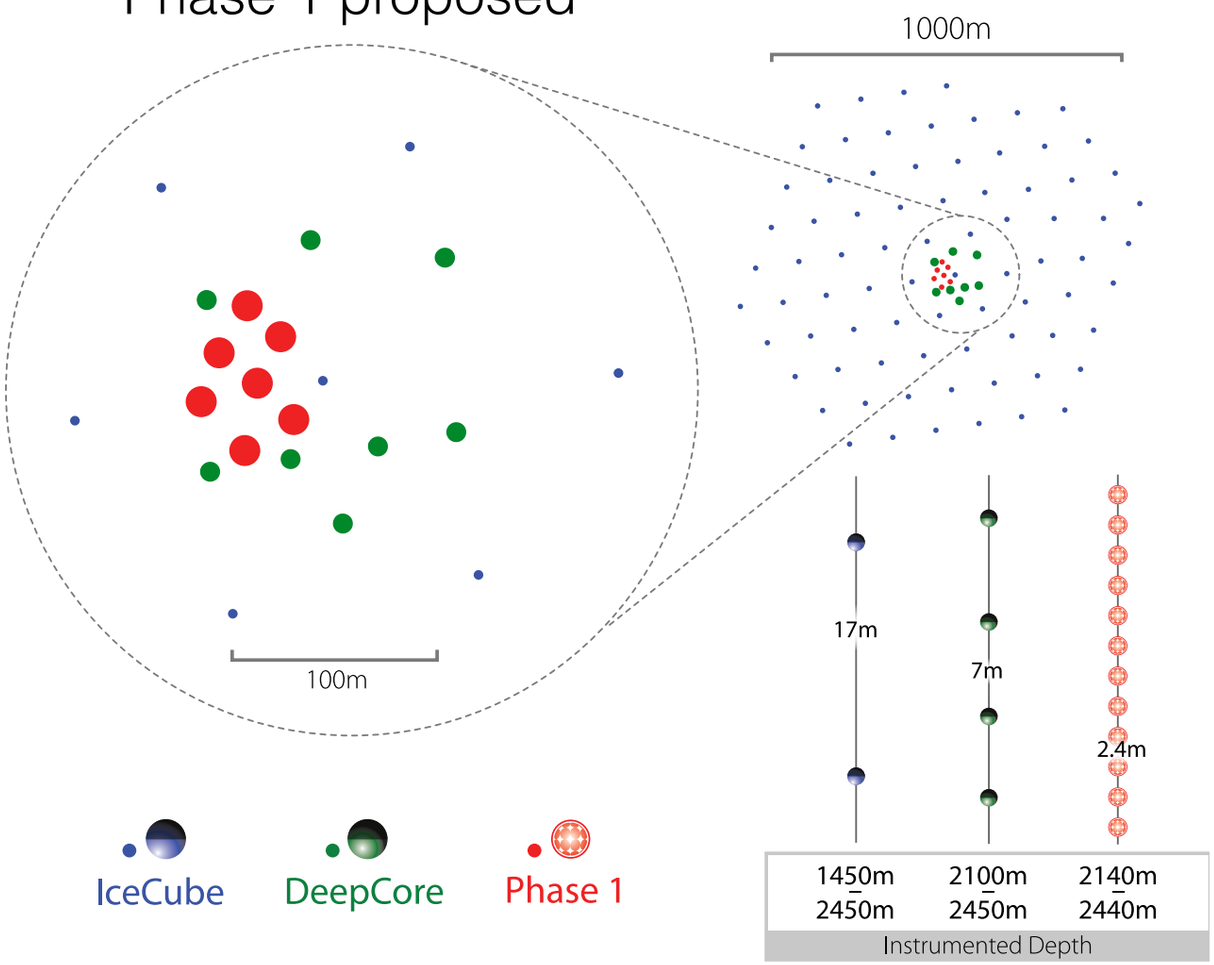
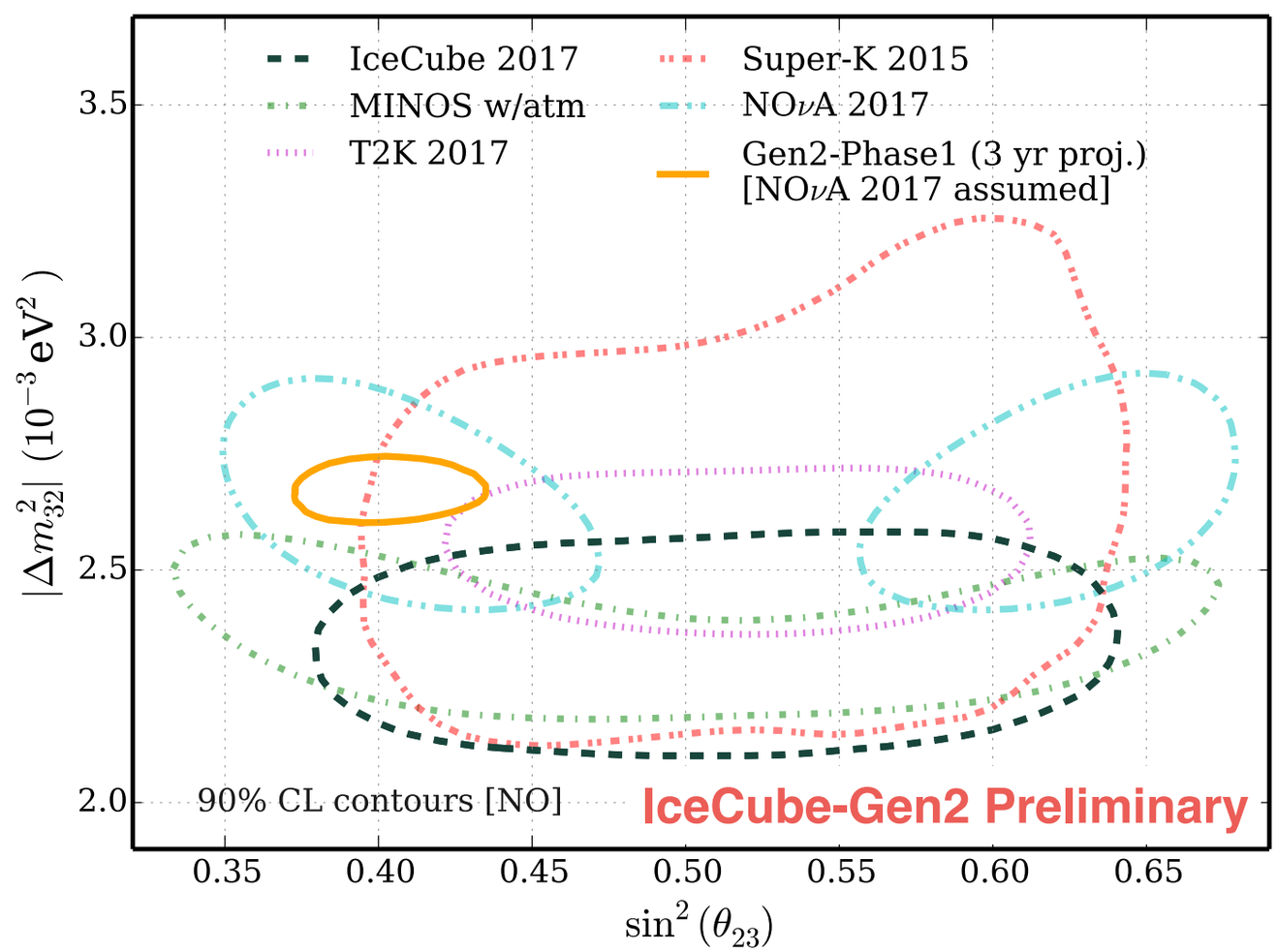
Phase 1 proposed



precision measurements of muon neutrino disappearance