

# PINGU low-energy Extension to IceCube

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*Astroparticle Neutrino Physics in Antarctica Workshop  
January 13, 2014*



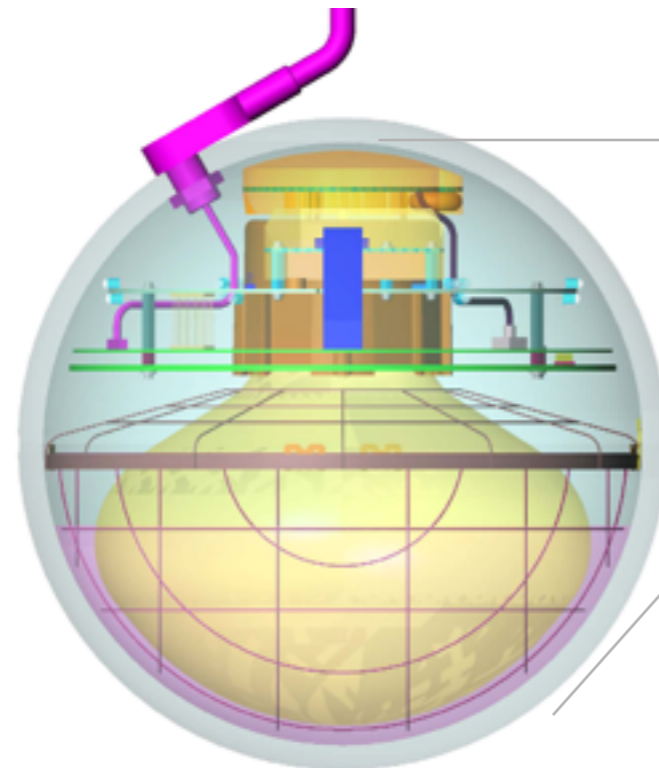
Niels Bohr Institutet



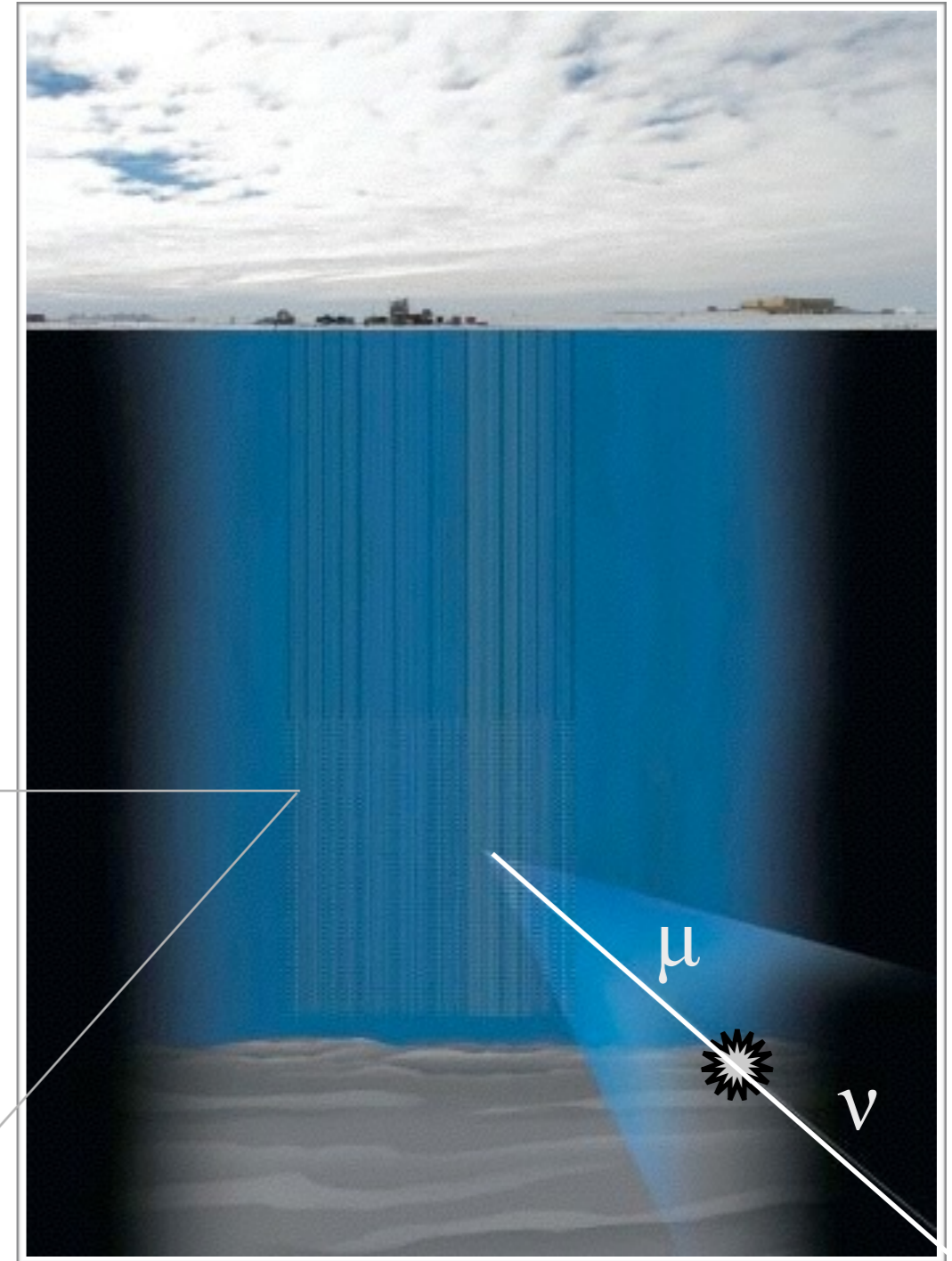
ICECUBE

- IceCube detector
- PINGU
- Resolving the neutrino mass hierarchy
- PINGU work

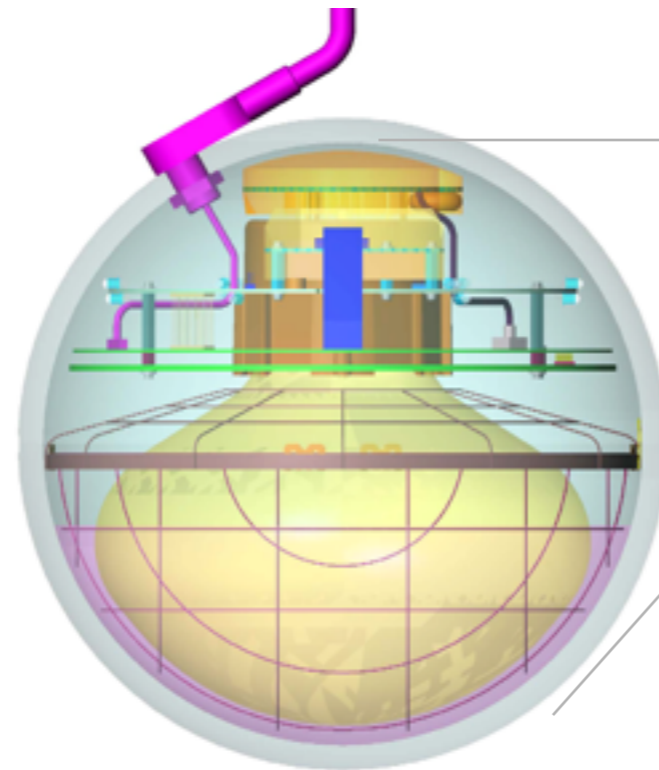
- $\sim 1\text{km}^3$  of instrumented ice
- Uses 5160 Digital Optical Modules (DOMs) across 86 vertical strings to detect blue light
- Deployed 1.5 - 2.5km below the surface



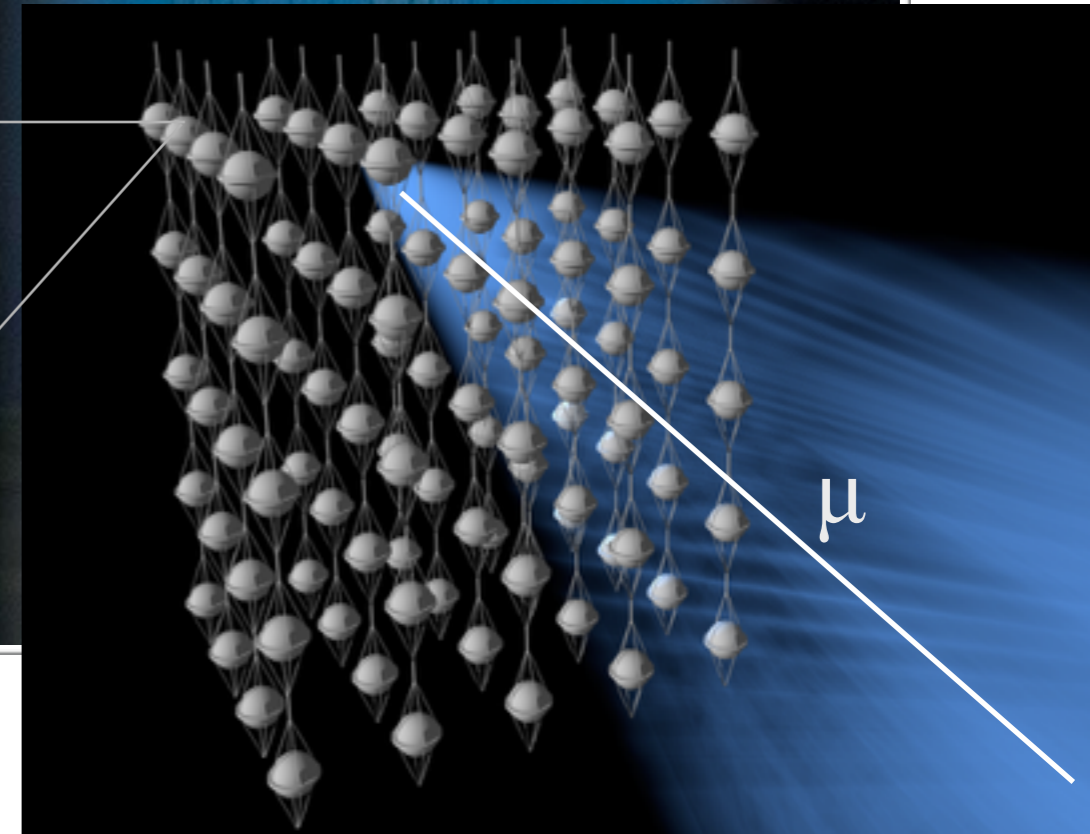
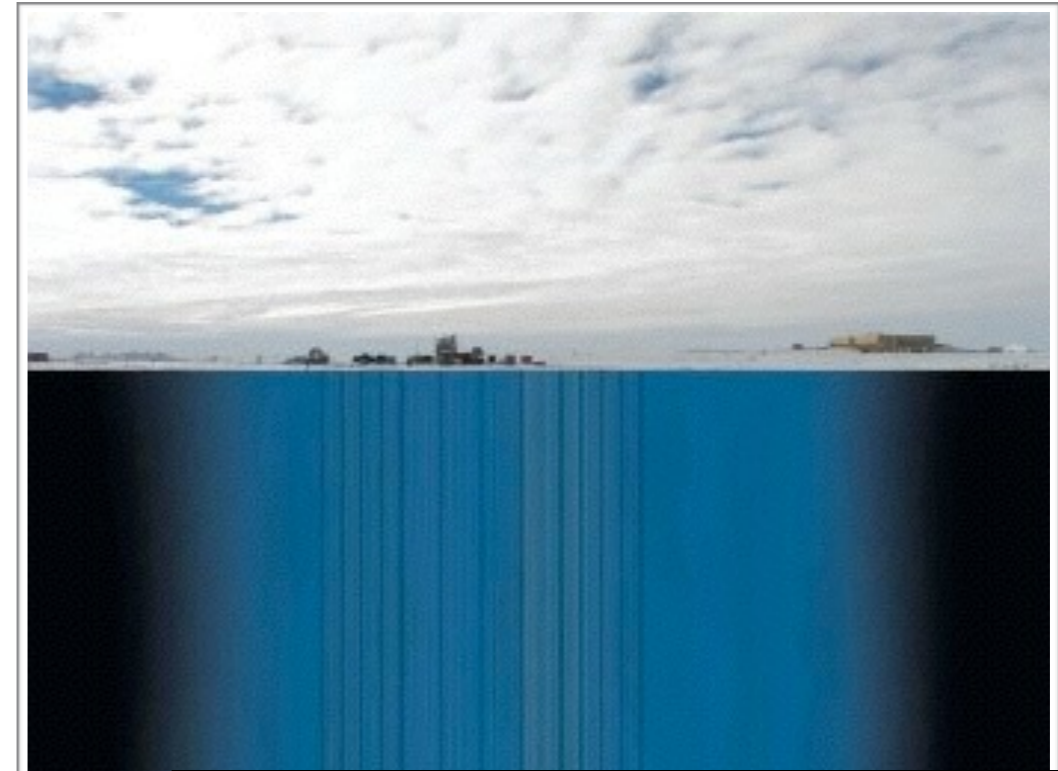
IceCube DOM



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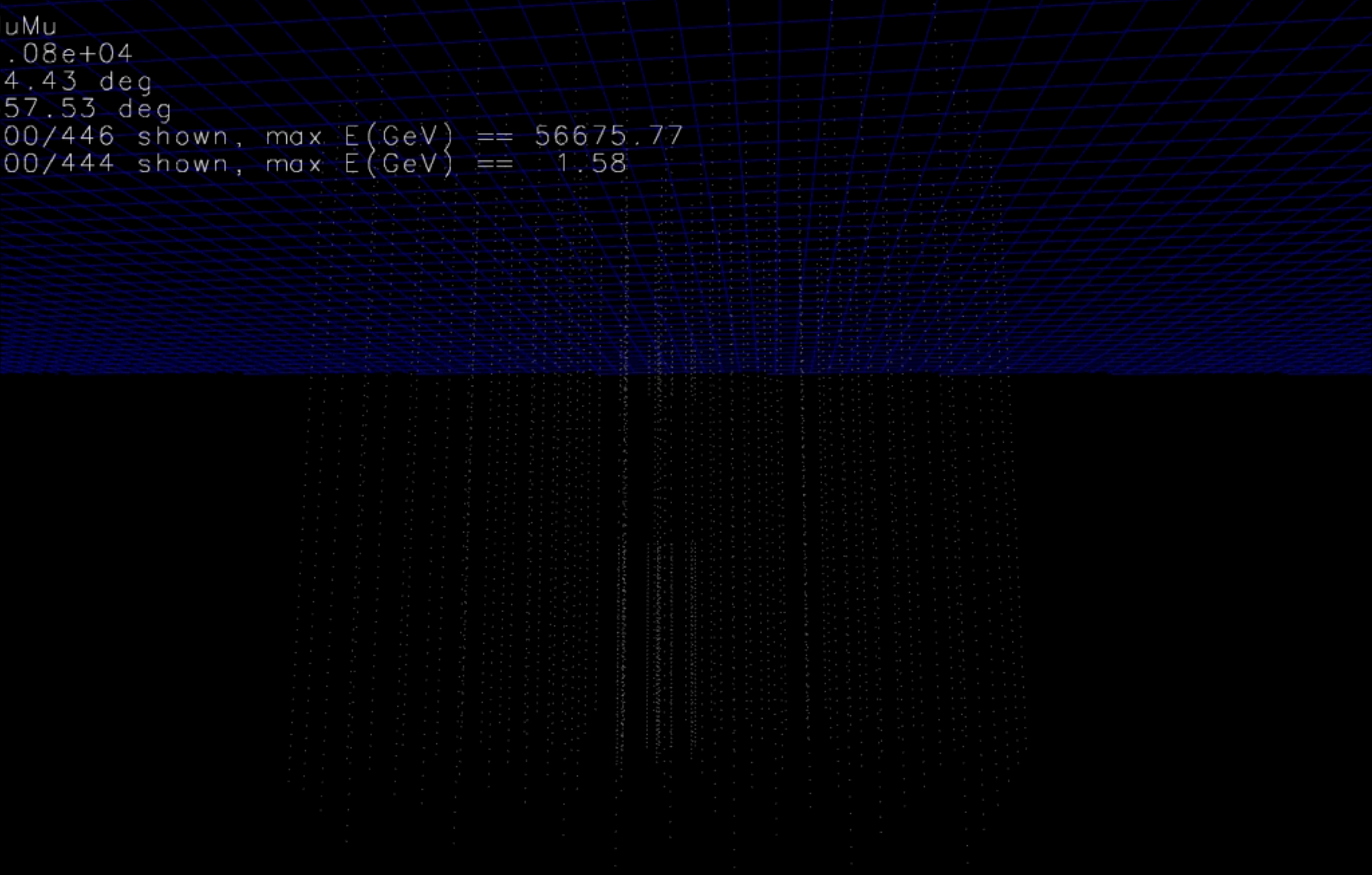


IceCube DOM



```
uMu  
.08e+04  
4.43 deg  
57.53 deg  
00/446 shown, max E (GeV) == 56675.77  
00/444 shown, max E (GeV) == 1.58
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The visualization shows a grid of detector strings in the upper half, representing the IceCube array. The lower half shows a shower of particles, with a central vertical track and several branching tracks, indicating a high-energy event. The background is dark blue with a grid pattern.

# IceCube Event Types

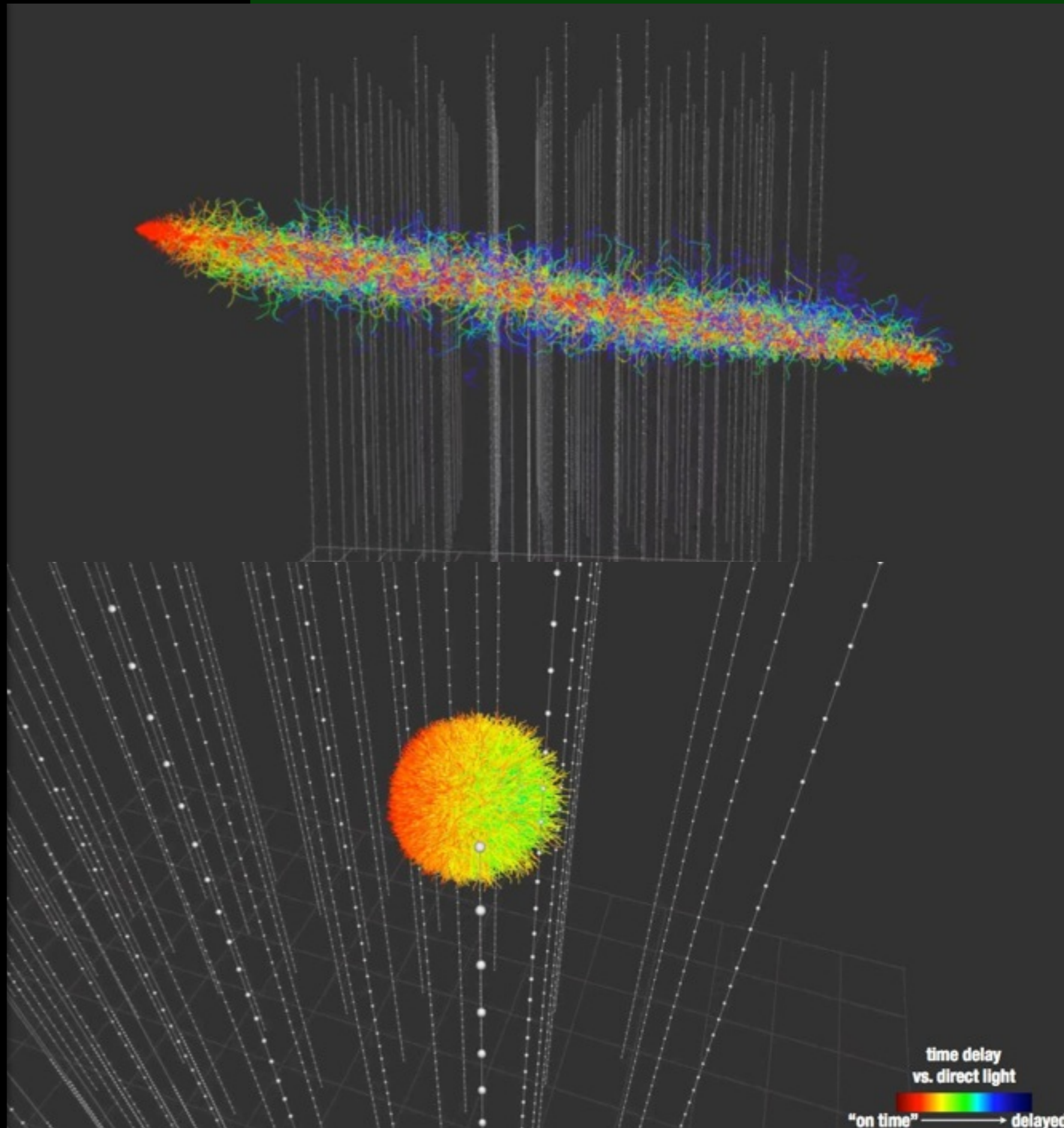
- IceCube
- DeepCore
- PINGU

Track  
topology  
(e.g. induced by  
muon neutrino)

Good pointing,  
 $0.2^\circ - 1^\circ$   
Lower bound on  
energy

Cascade  
topology  
(e.g. induced by  
electron neutrino and  
all neutral current  
interactions)

Good energy  
resolution, 15%  
Some pointing,  
 $10^\circ - 15^\circ$



- Measurements

- Cosmic Ray Anisotropy - **arXiv:1105.2326**
- Diffuse Flux - **arXiv:1104.5187**
- Atmospheric Neutrino Spectrum - **arXiv:1010.3980**

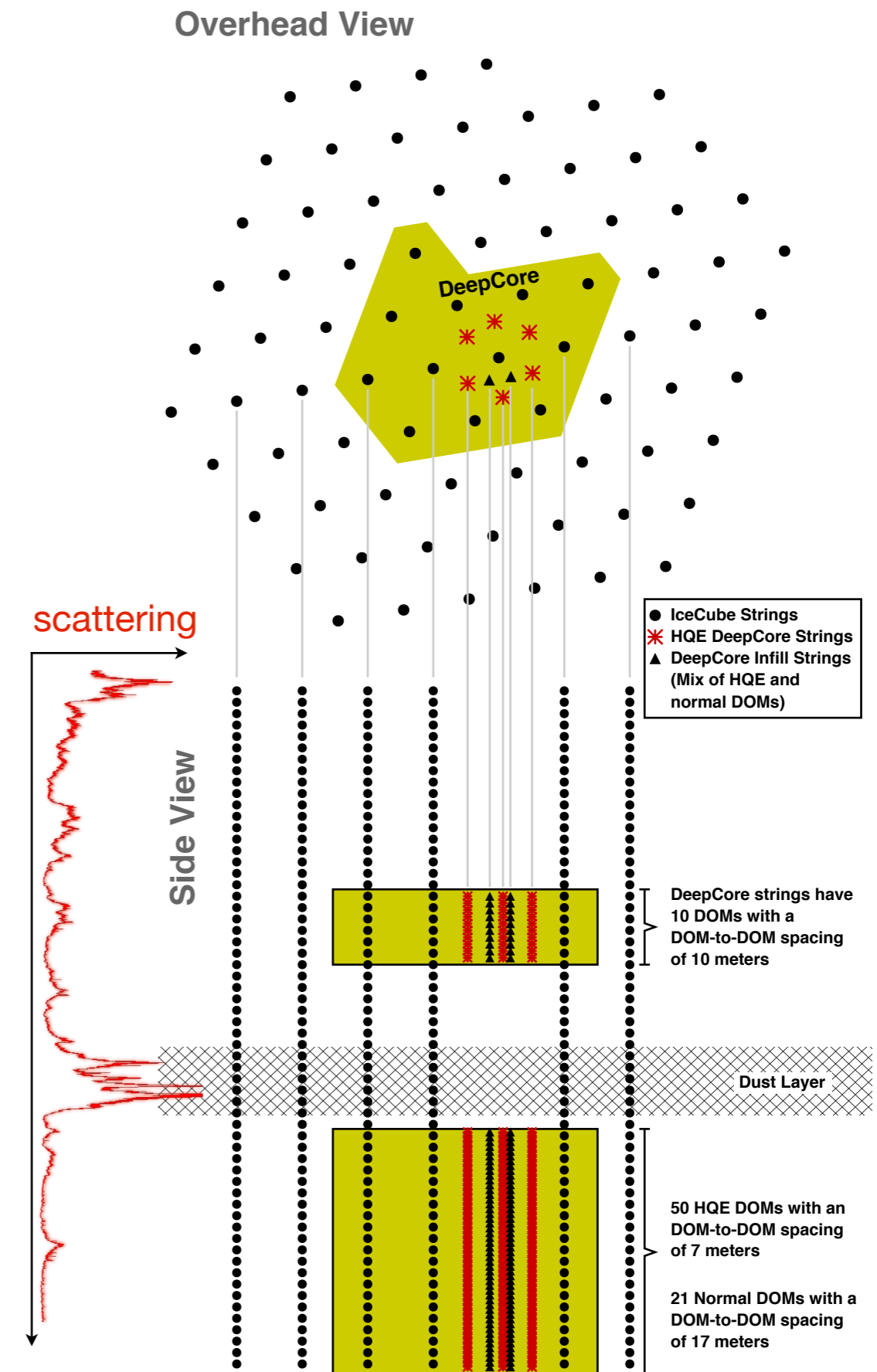
- Searches

- Supernova 2008D - **arXiv:1101.3942**
- Neutrino Induced Cascades - **arXiv:1101.1692**
- Neutrino Emission Constraints on 2010 Crab Flare - **arXiv:1106.3484**
- Point Sources - **arXiv:1307.6669**
- Gamma Ray Burst Neutrino Emission - **arXiv:1204.4219**
- High-Energy Astrophysical Neutrinos     See talk by J. Adams



# Fundamental Physics

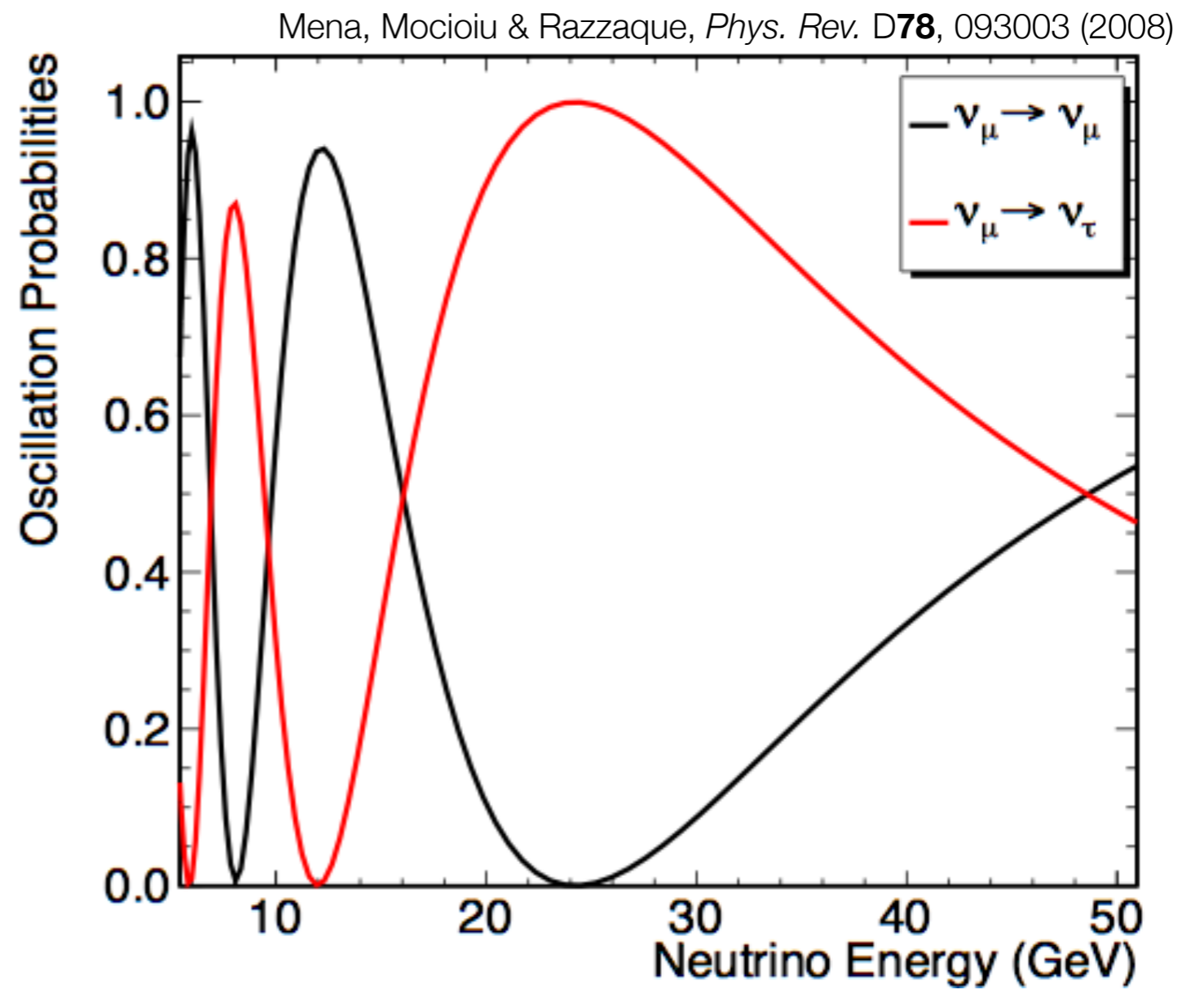
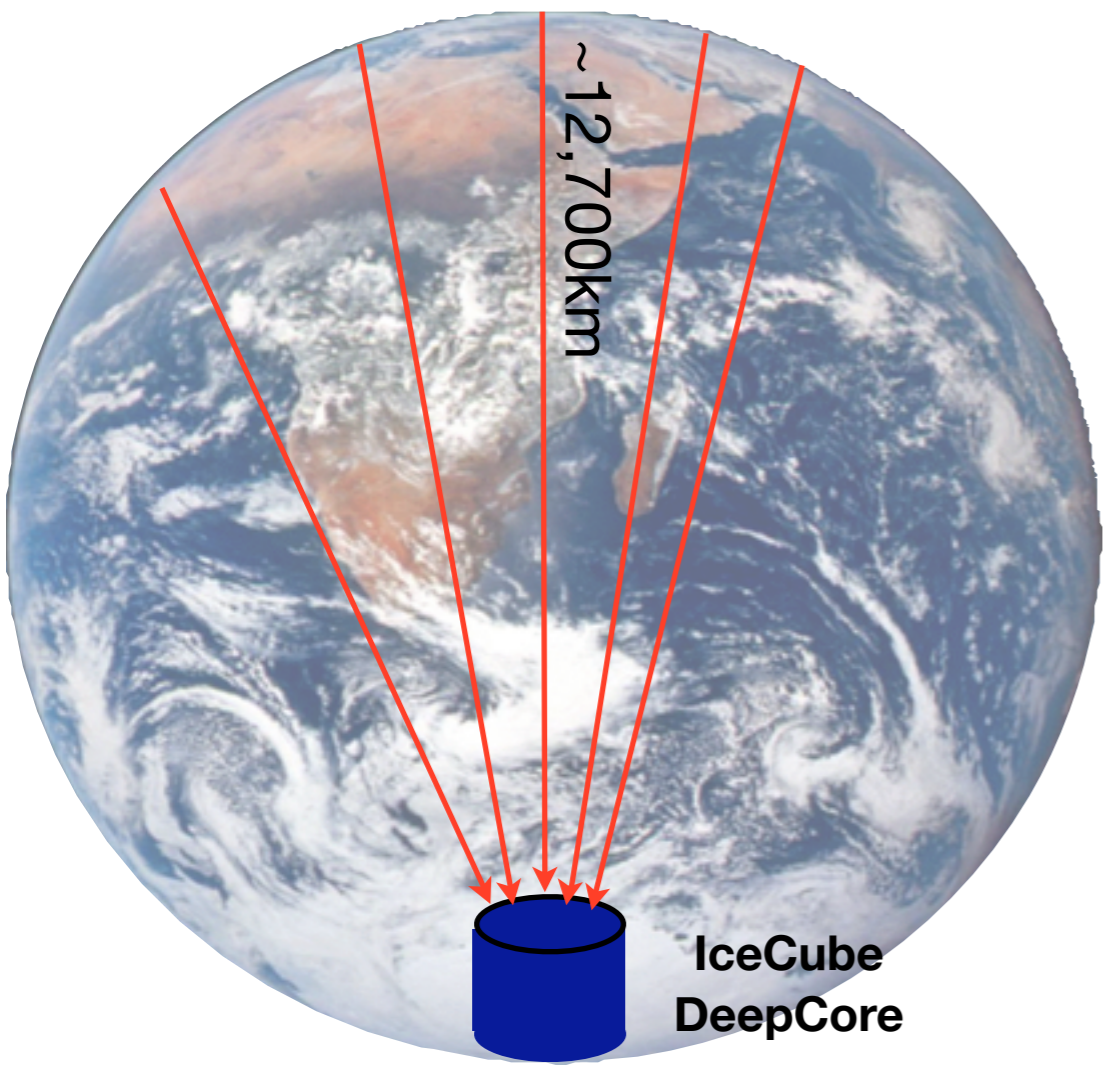
- DeepCore
    - Increased sensitivity at energies  $< 100\text{-}200$  GeV
    - Denser DOM and string spacing
    - Deepest and clearest Ice
    - Higher efficiency photon sensors
  - Huge size equates to  $O(100k)$  triggered neutrino events per year
  - Physics
    - Neutrino oscillation
    - Dark matter searches
- See talk by C. de los Heros

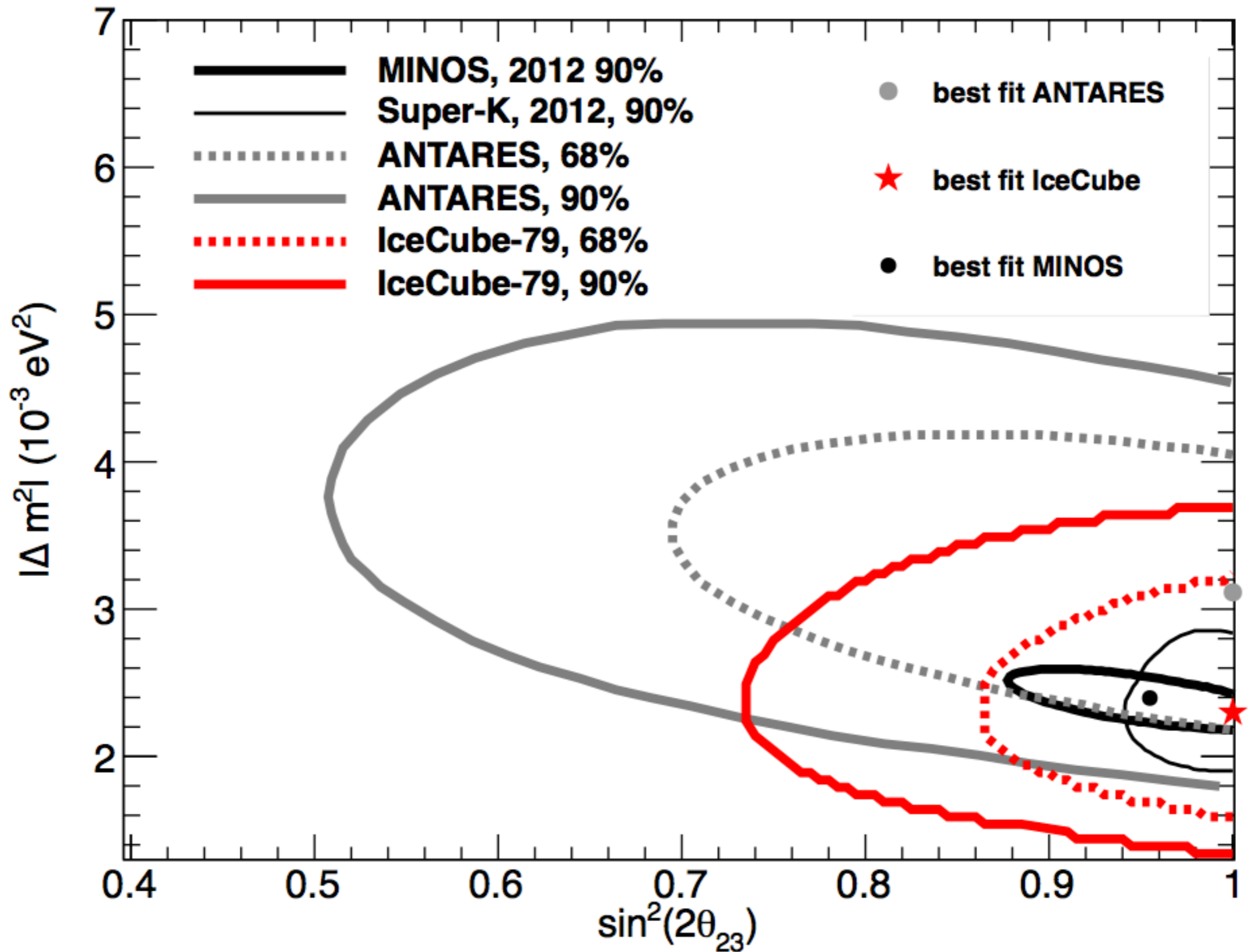


# Oscillation

- IceCube
- DeepCore
- PINGU

- Northern Hemisphere  $\nu_\mu$  oscillating over one earth radii produces  $\nu_\mu$  ( $\nu_\tau$ ) oscillation minimum(maximum) at  $\sim 25$  GeV



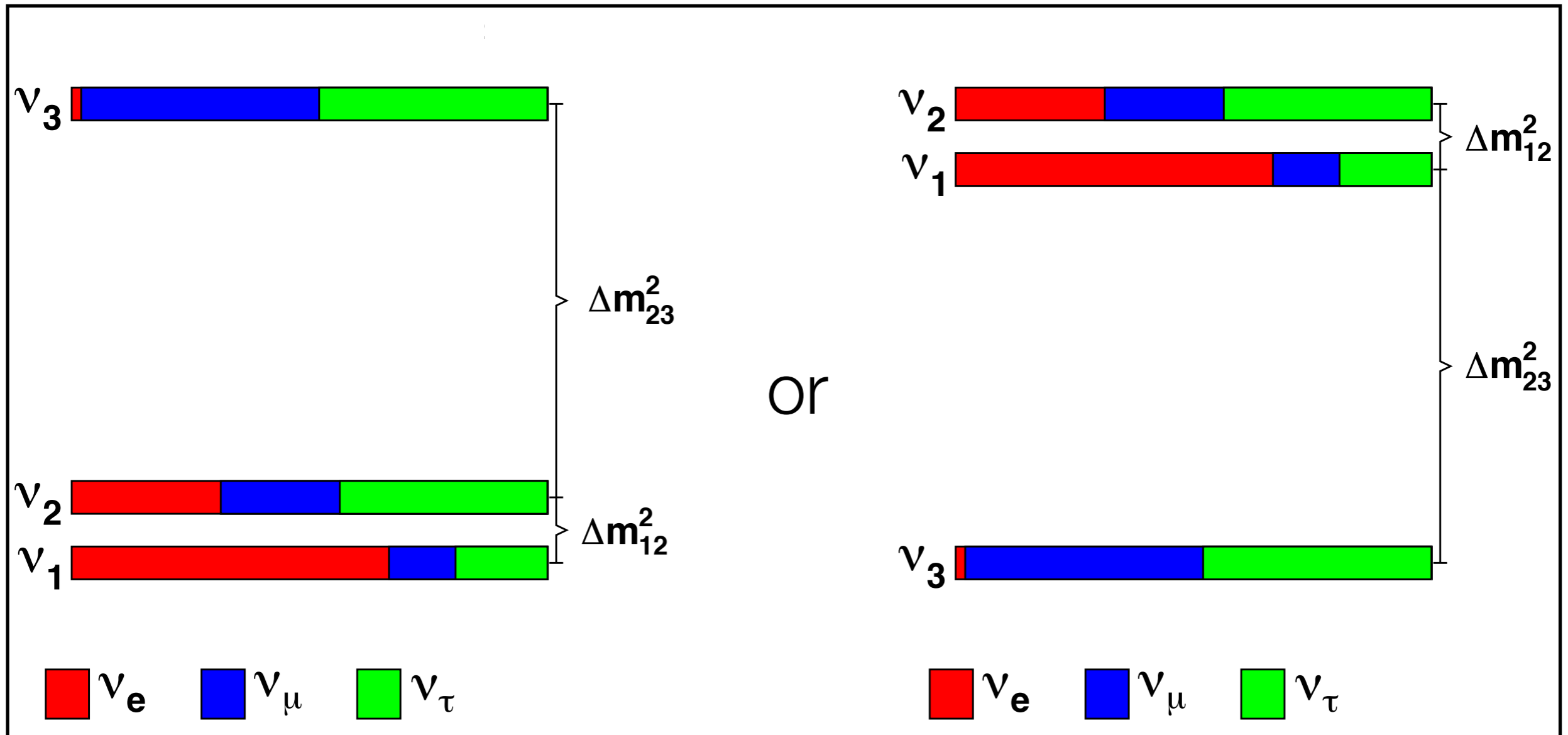


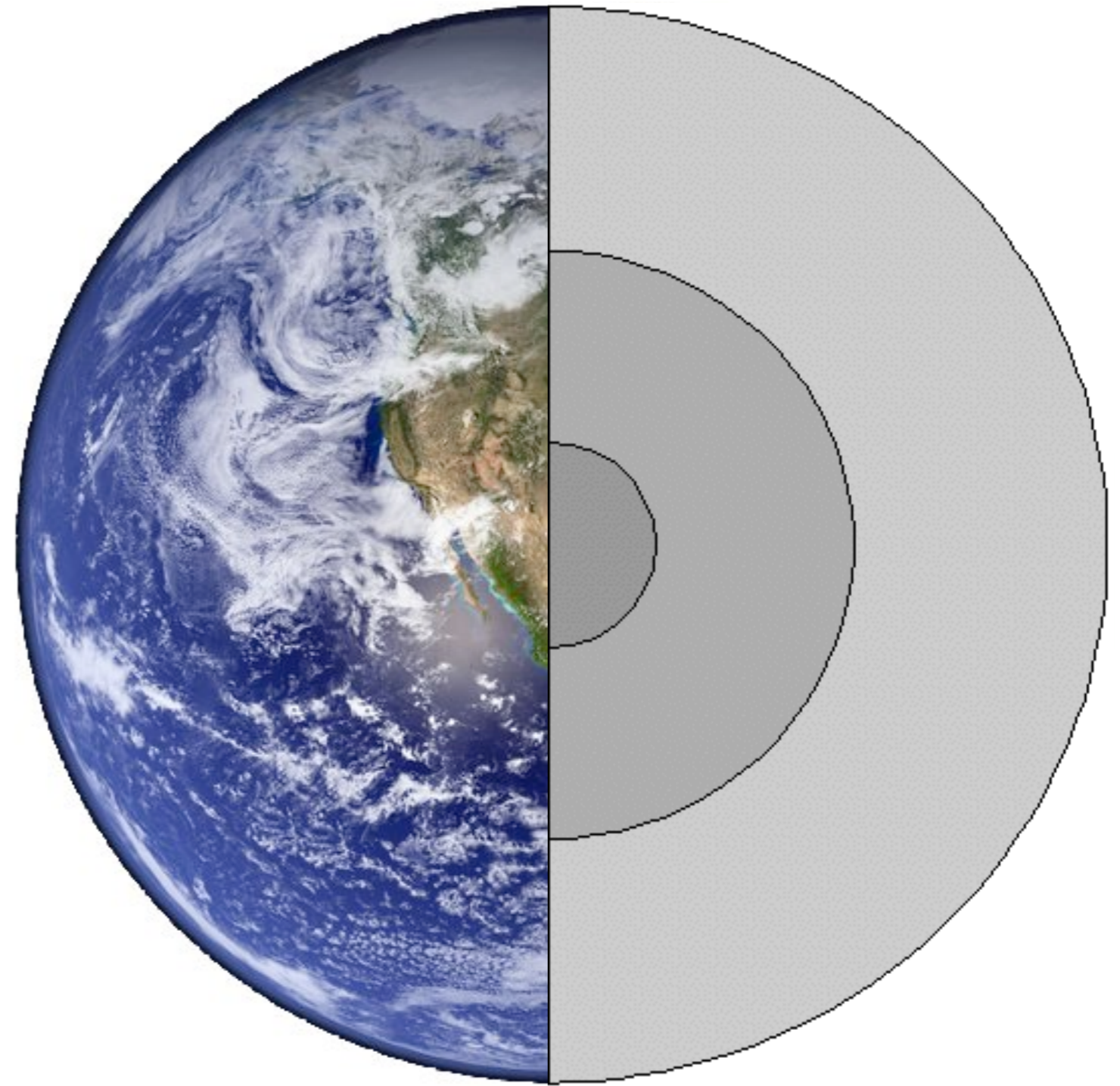
What is there at lower energies than  
what DeepCore can probe?

- Muon Neutrino Disappearance additional features
- Tau Neutrino Appearance
- Maximal Neutrino Mixing
- Lower Mass Dark Matter Searches
- Neutrino Mass Hierarchy

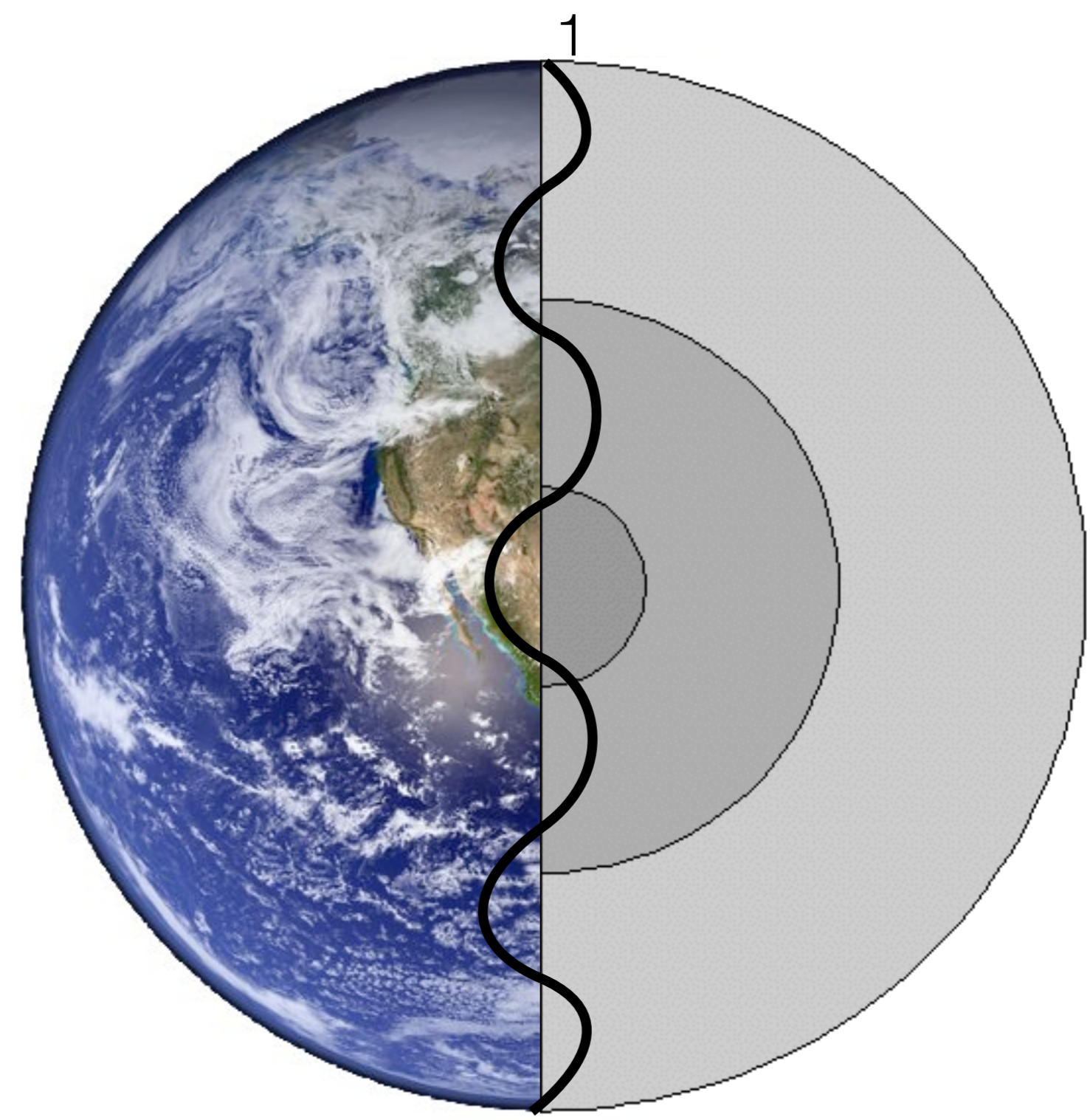
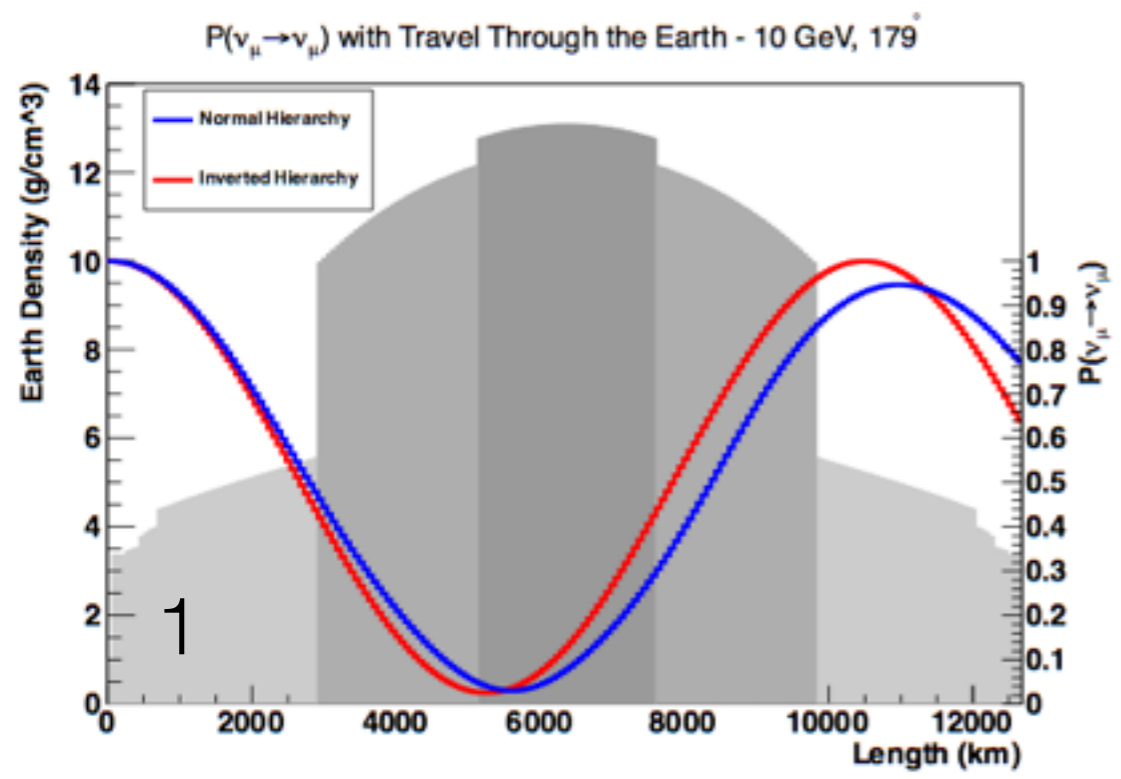
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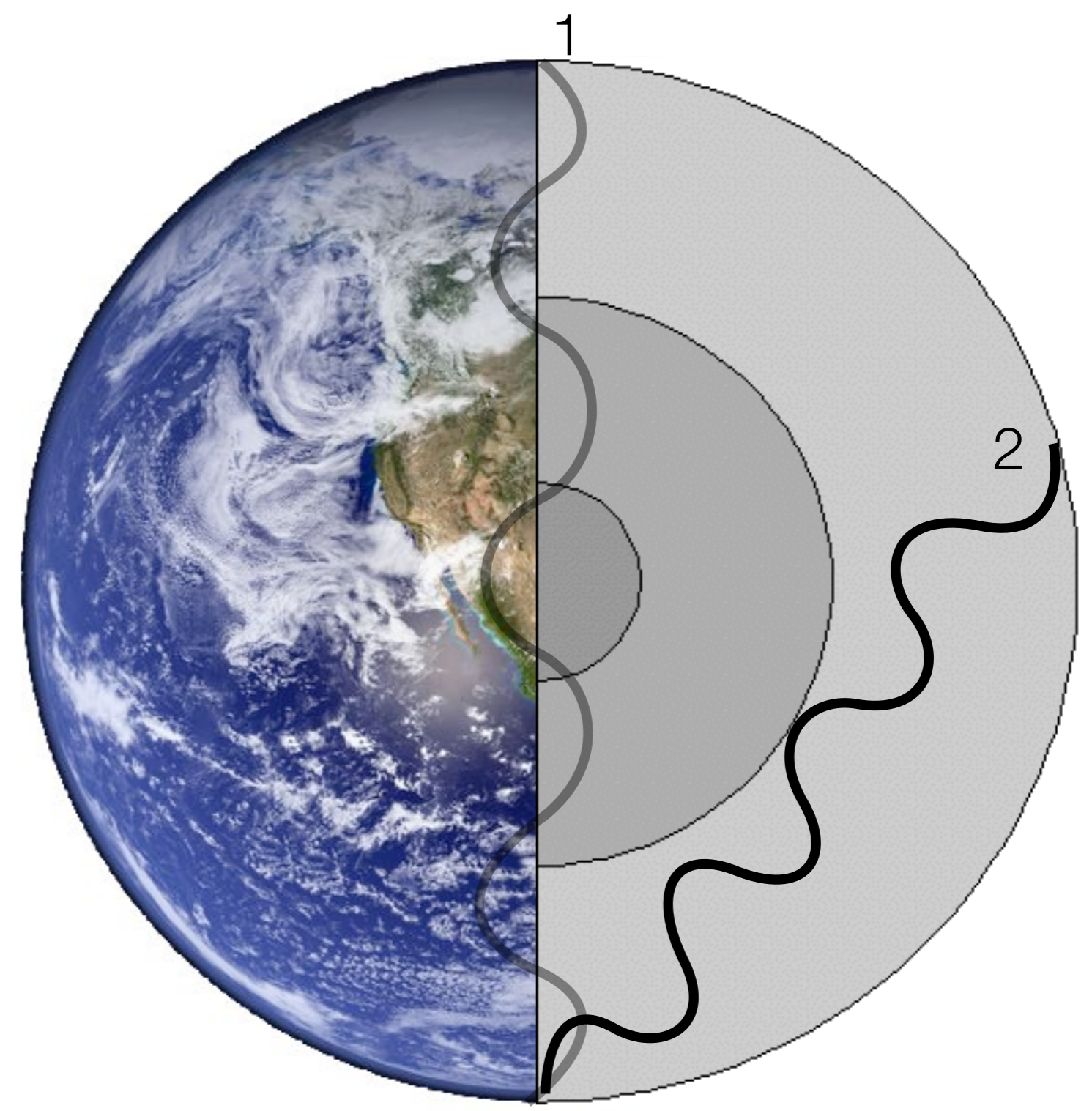
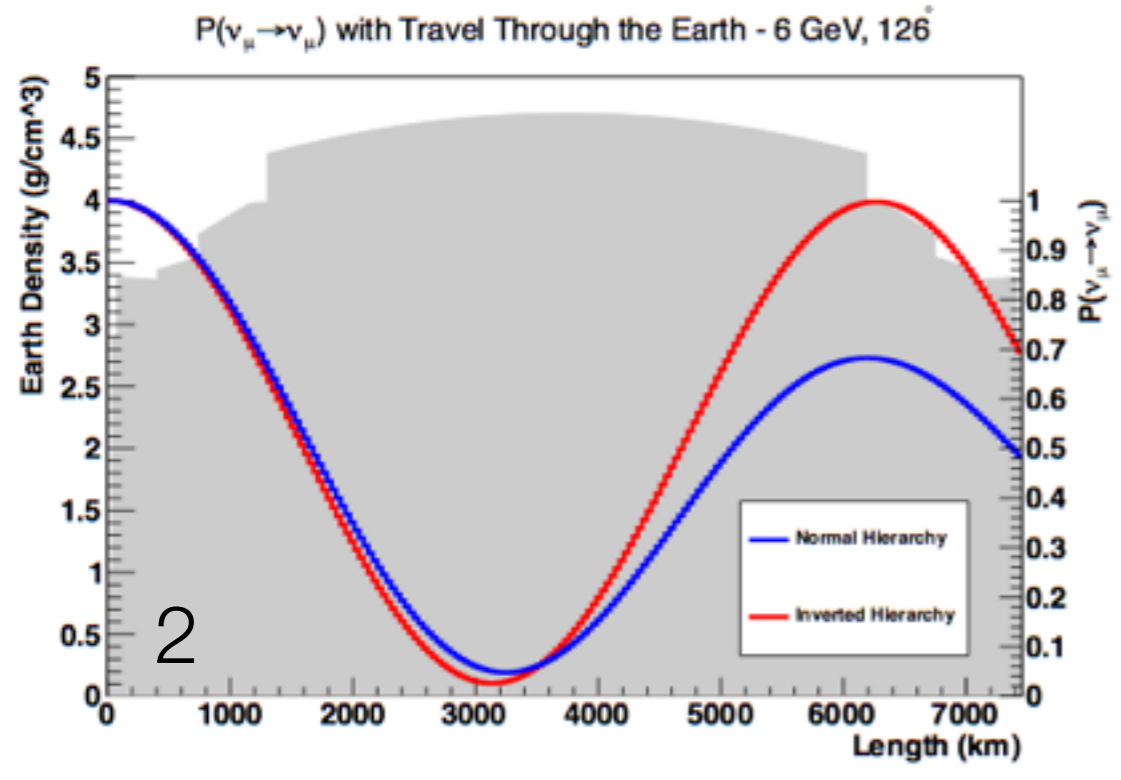
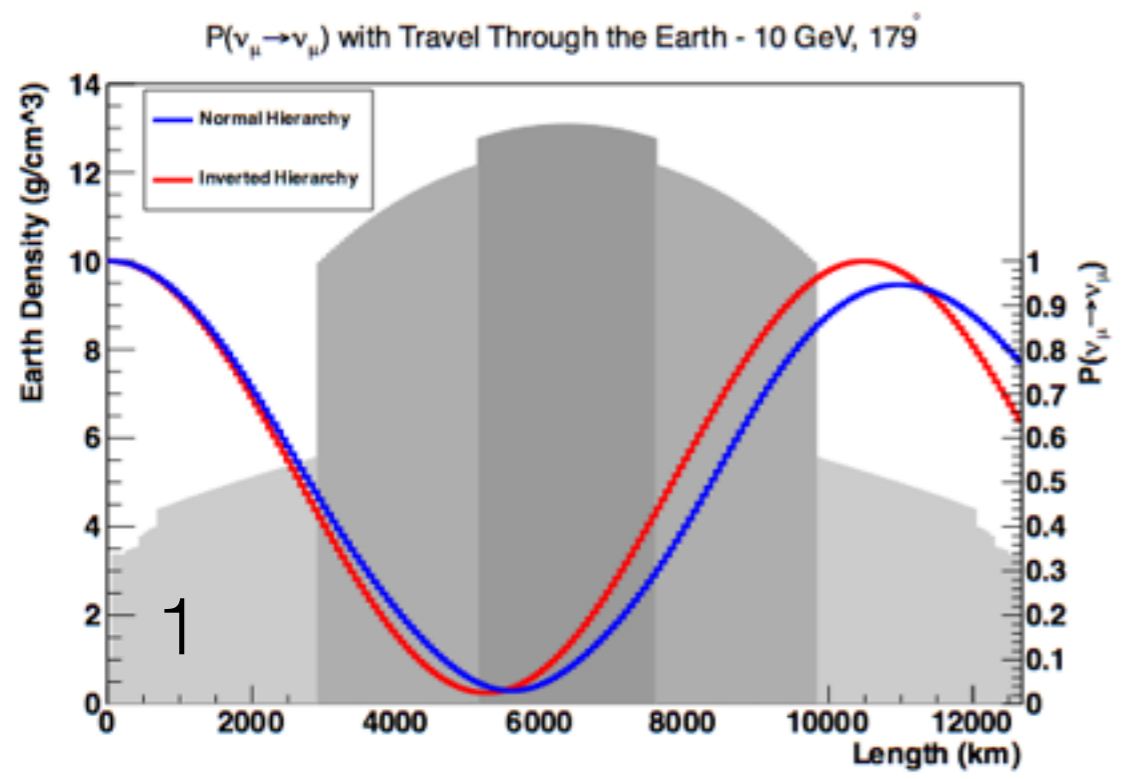
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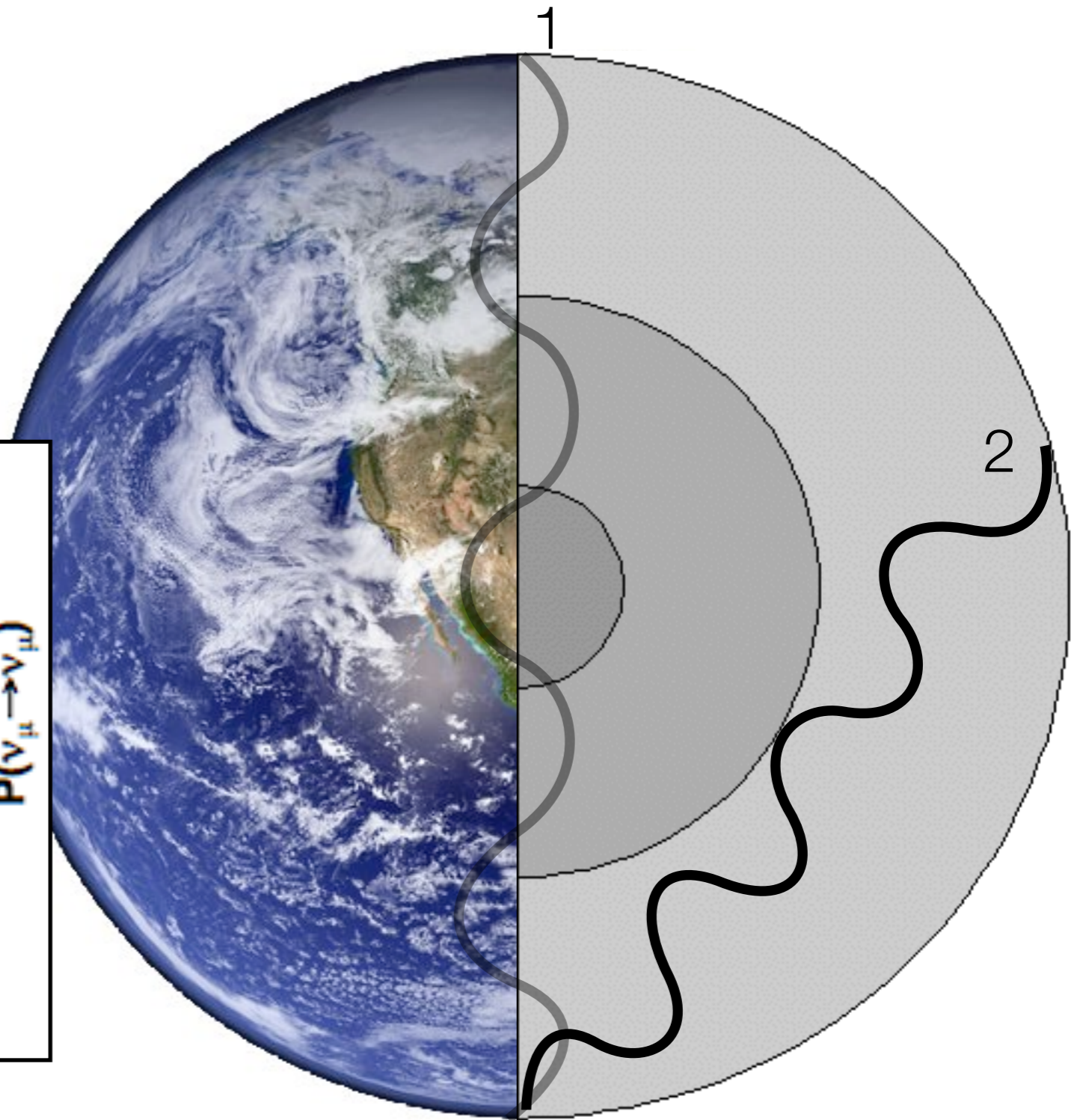
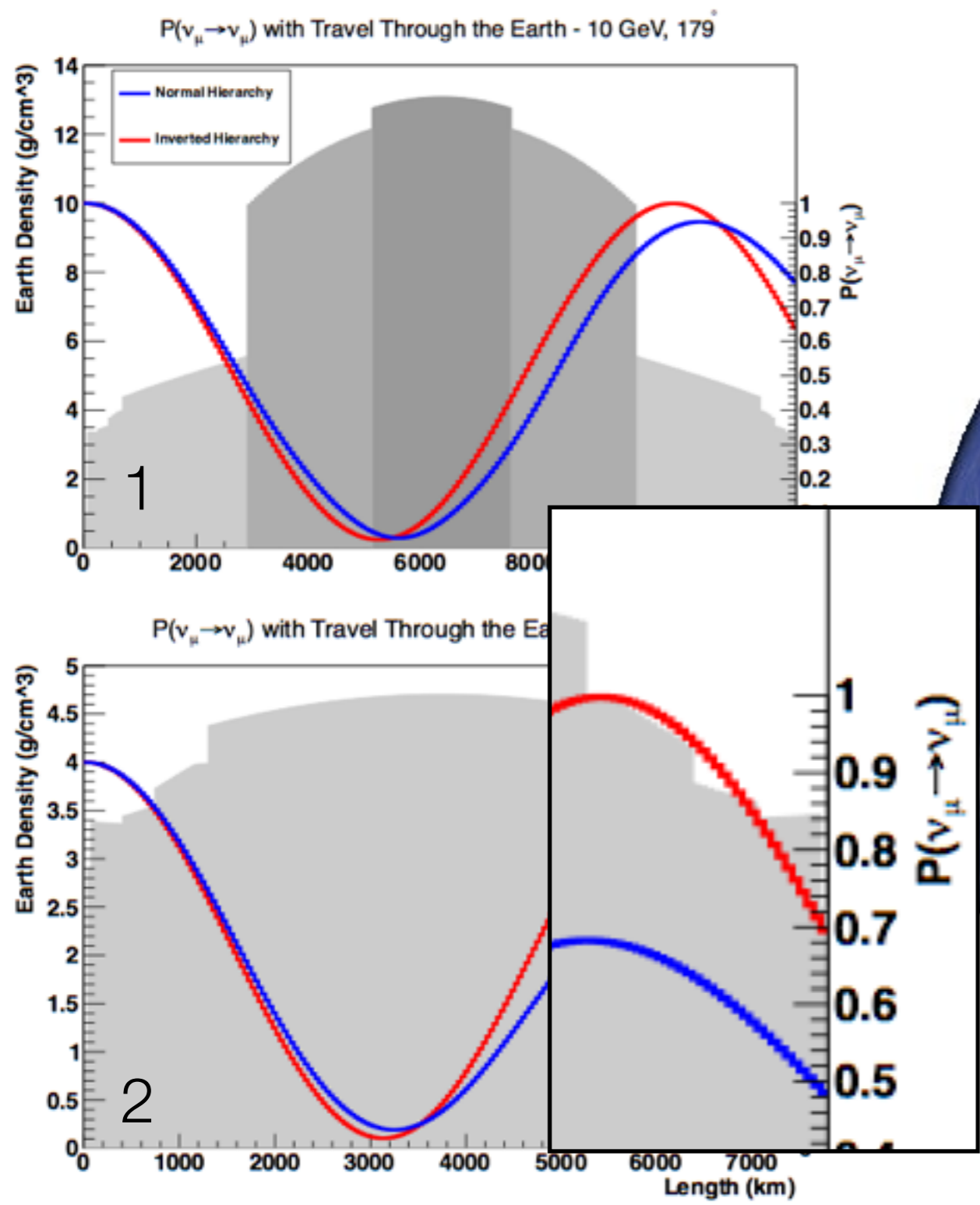






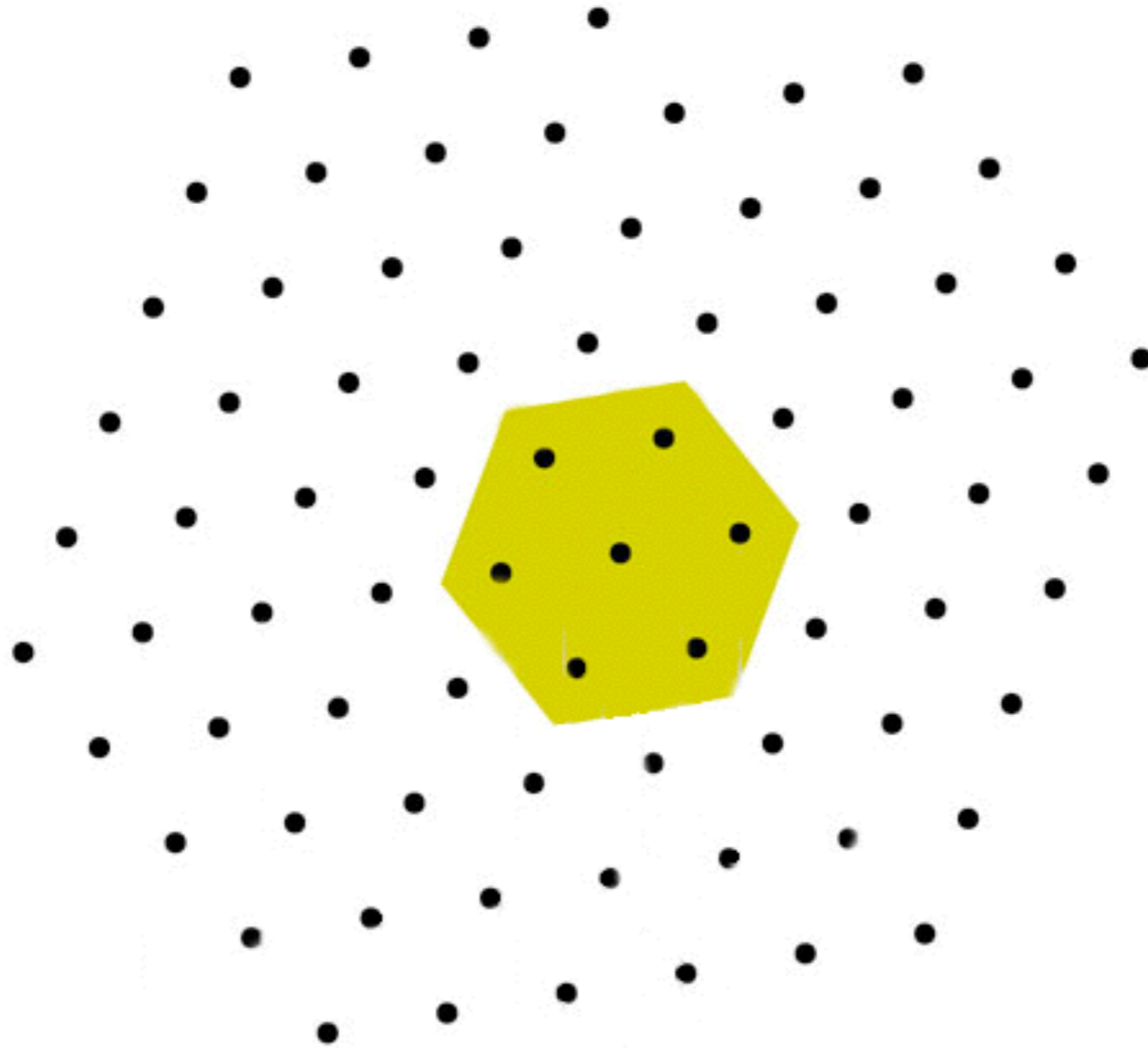


• Inverted/Normal hierarchy has up to a 20% difference in oscillation probability for specific energies and zenith angles (baselines)

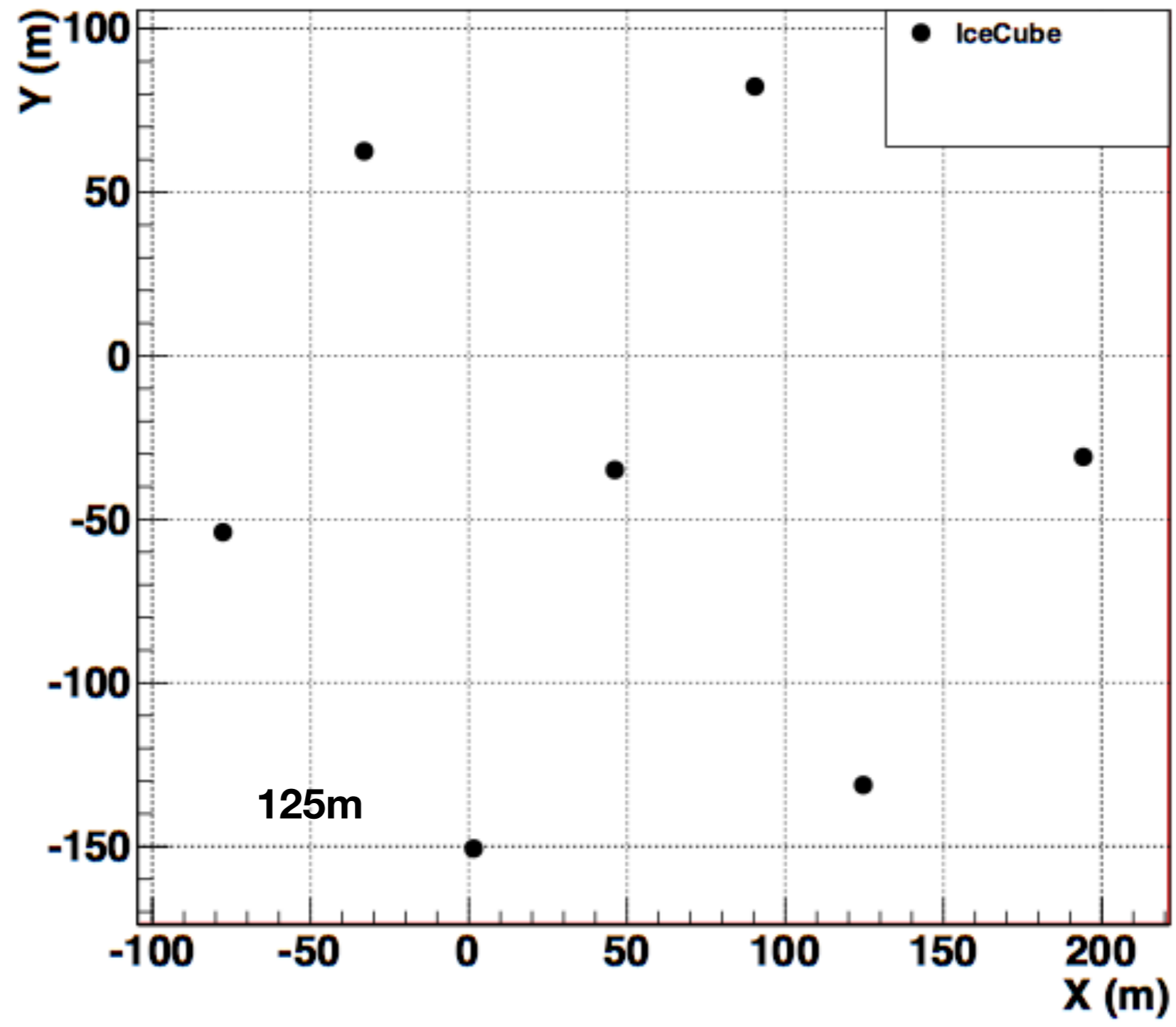


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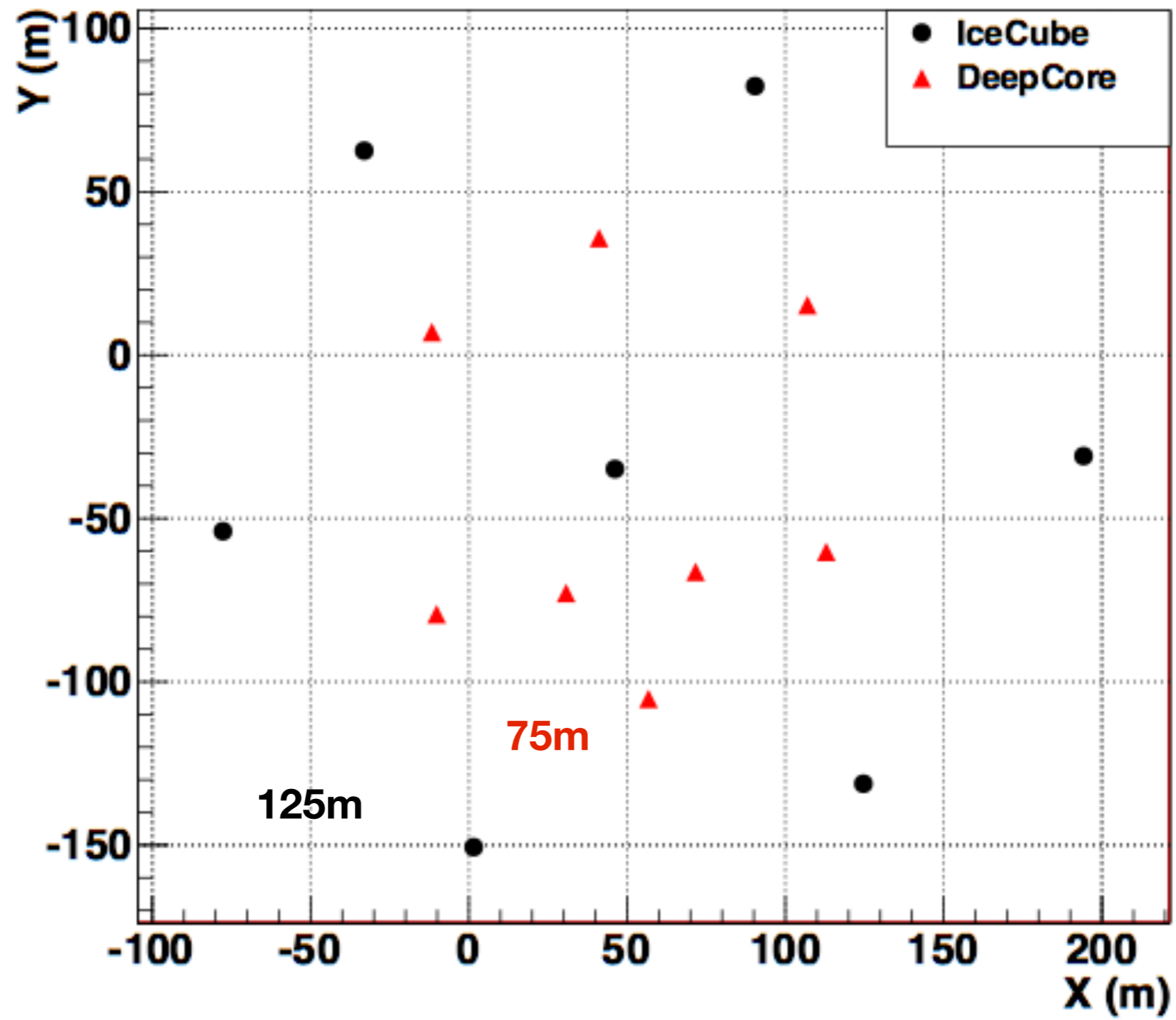
## Top View



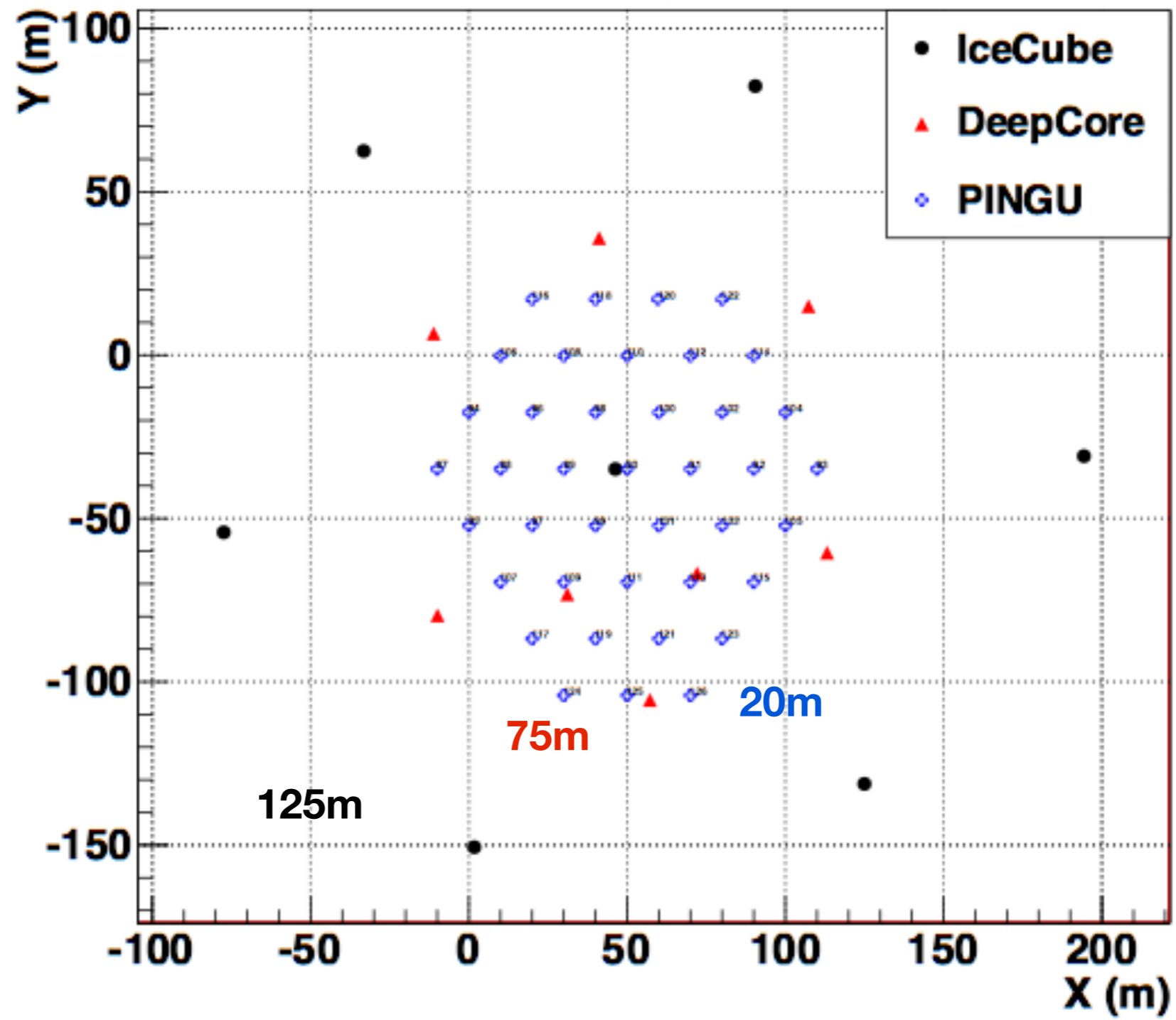
\*One of many possible geometries



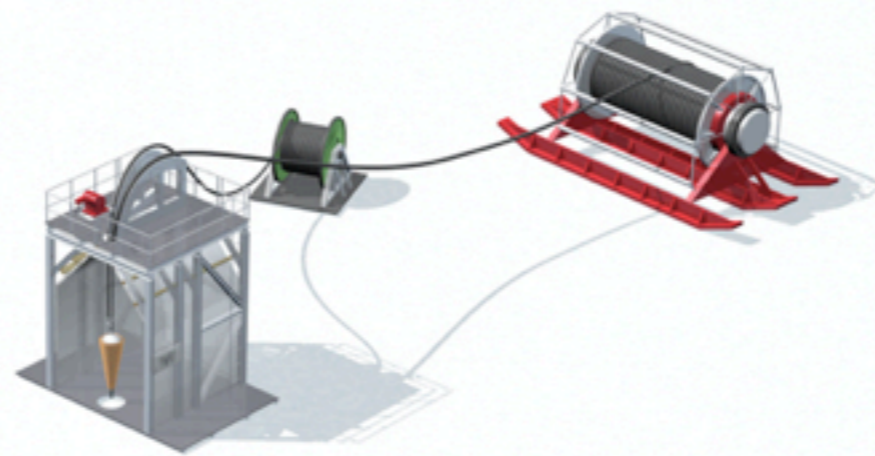
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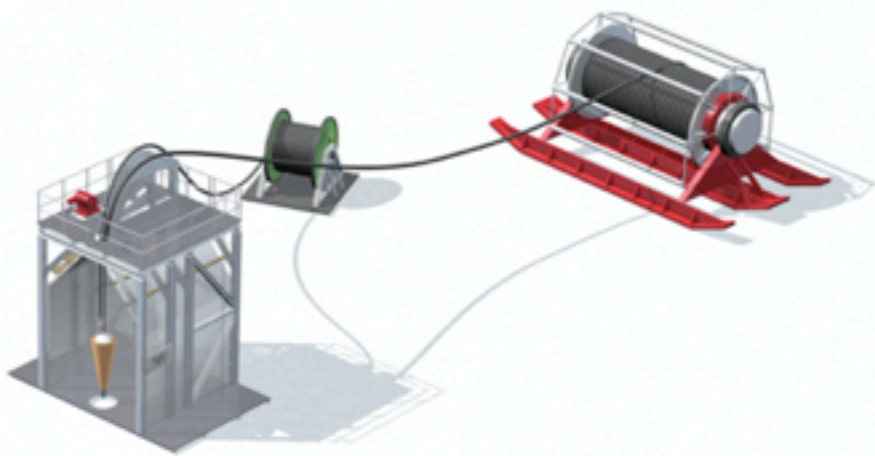
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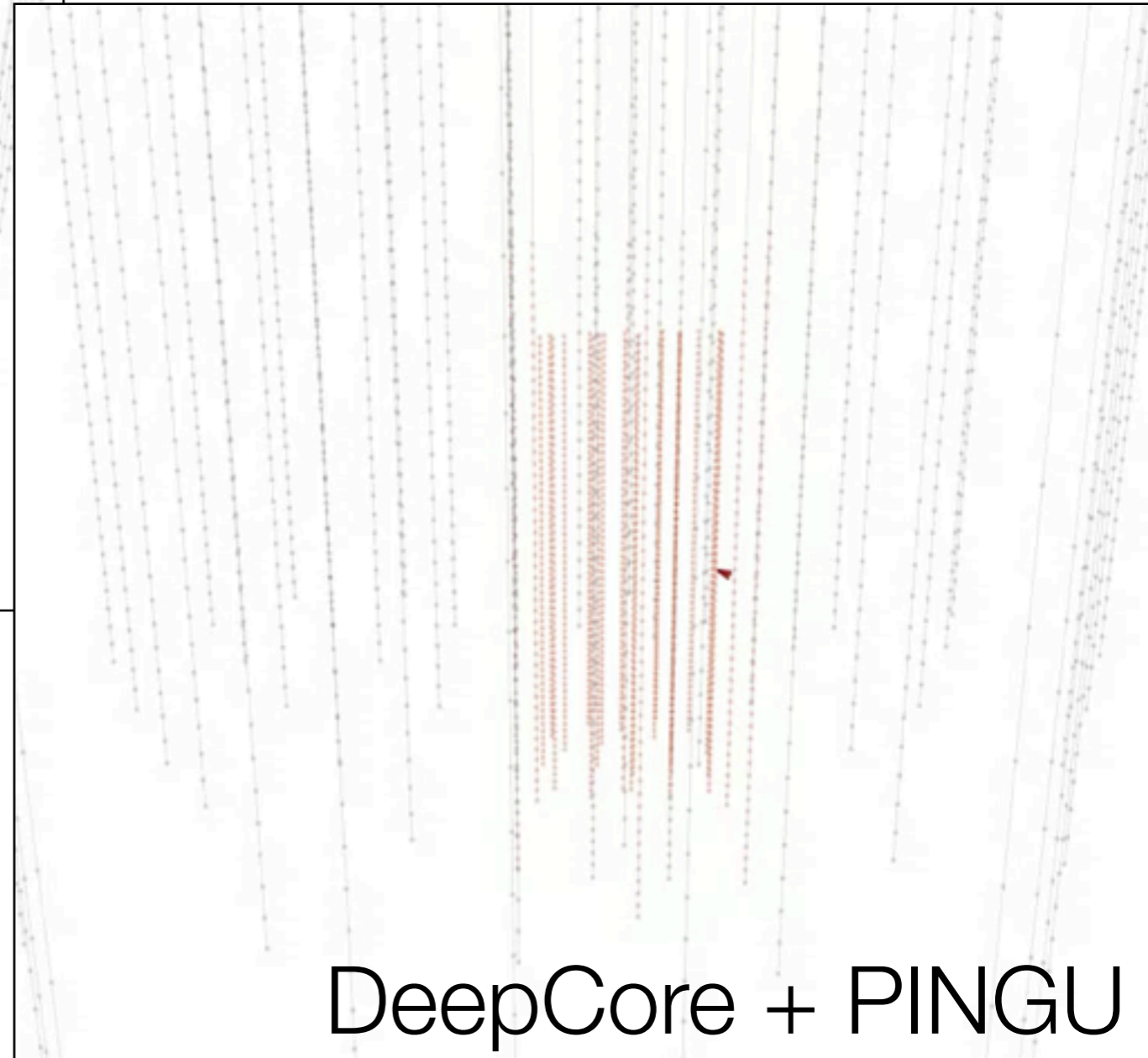
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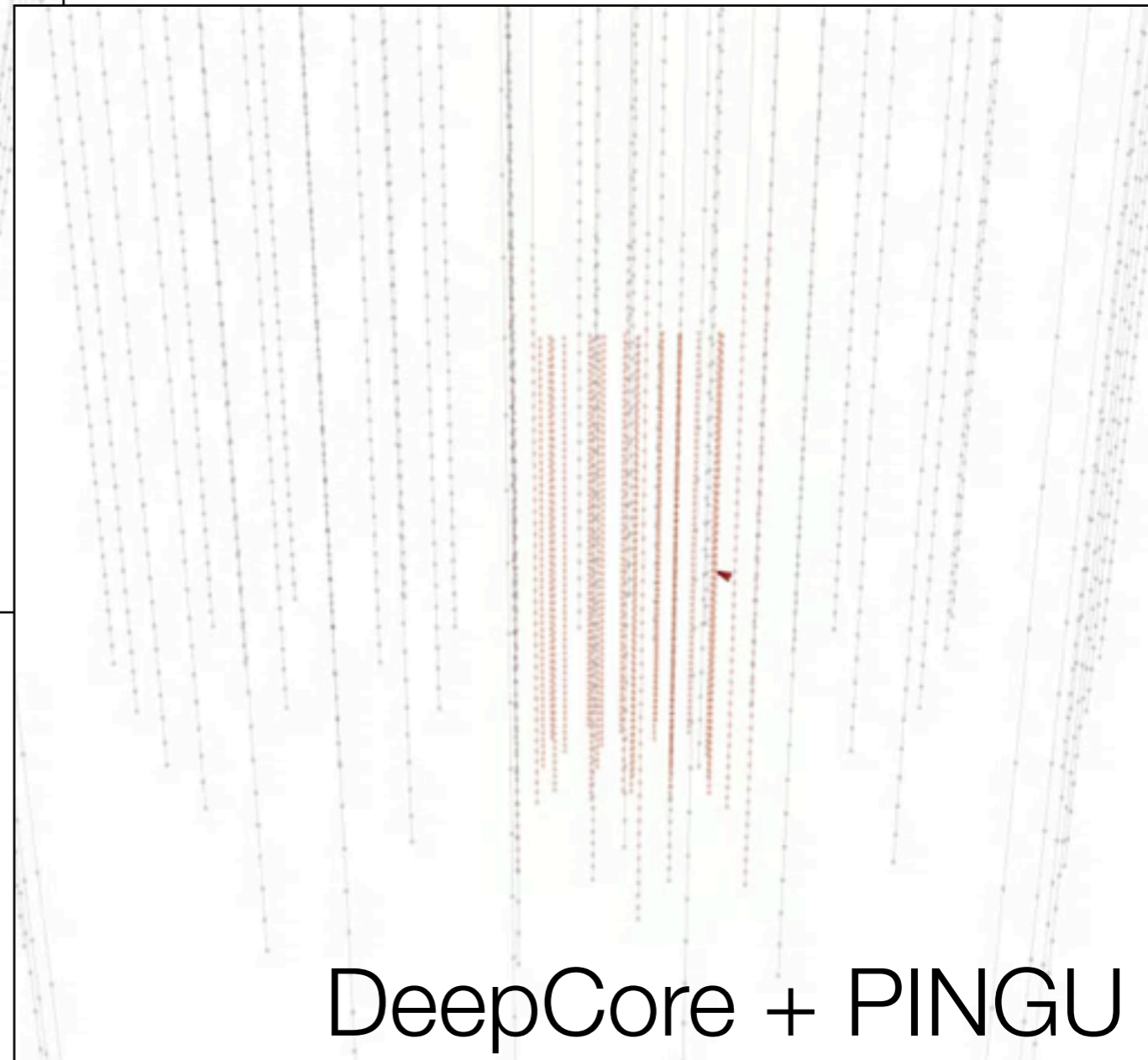
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- ~20 vs. ~50 Hit Modules





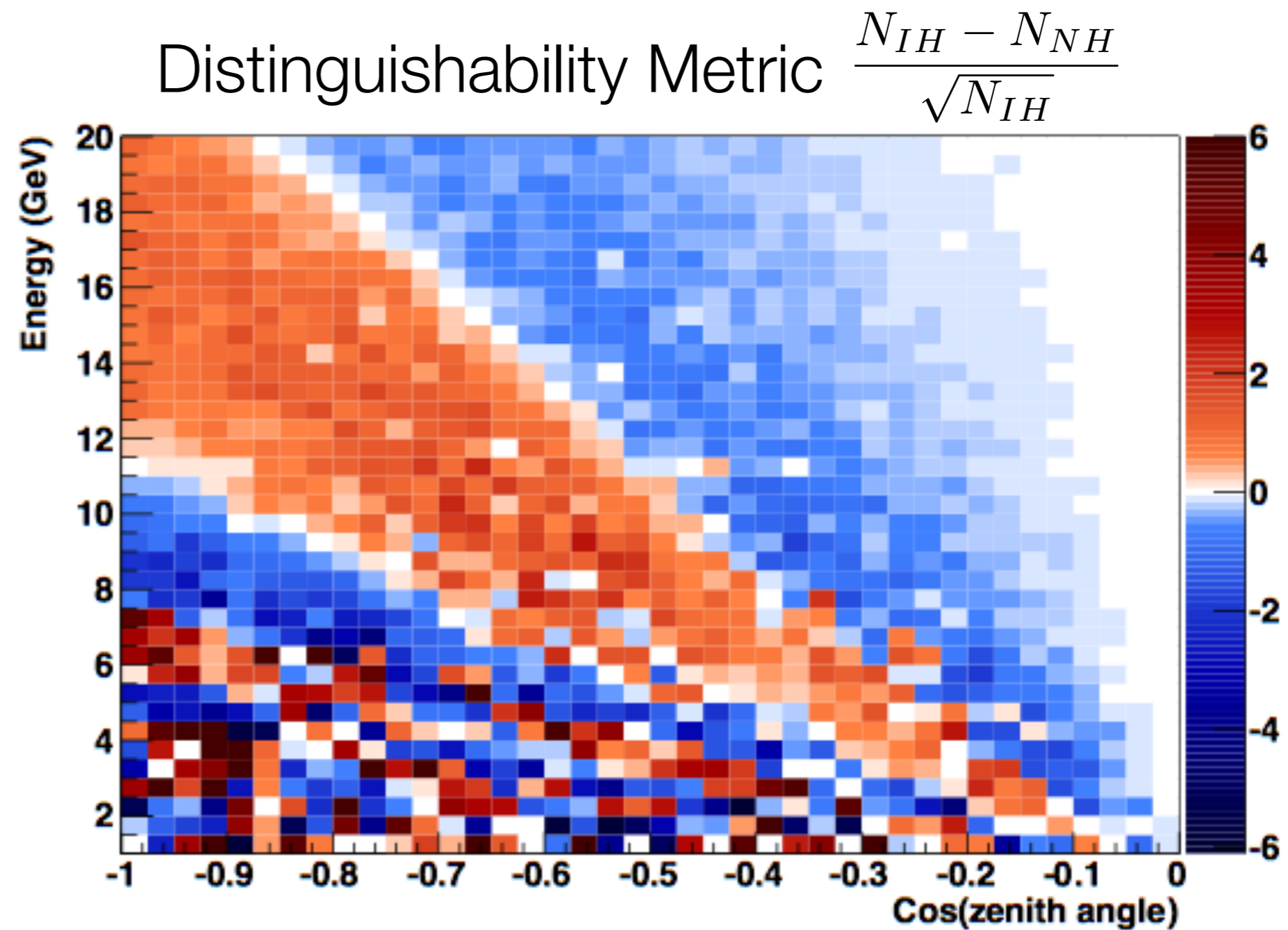
DeepCore Only

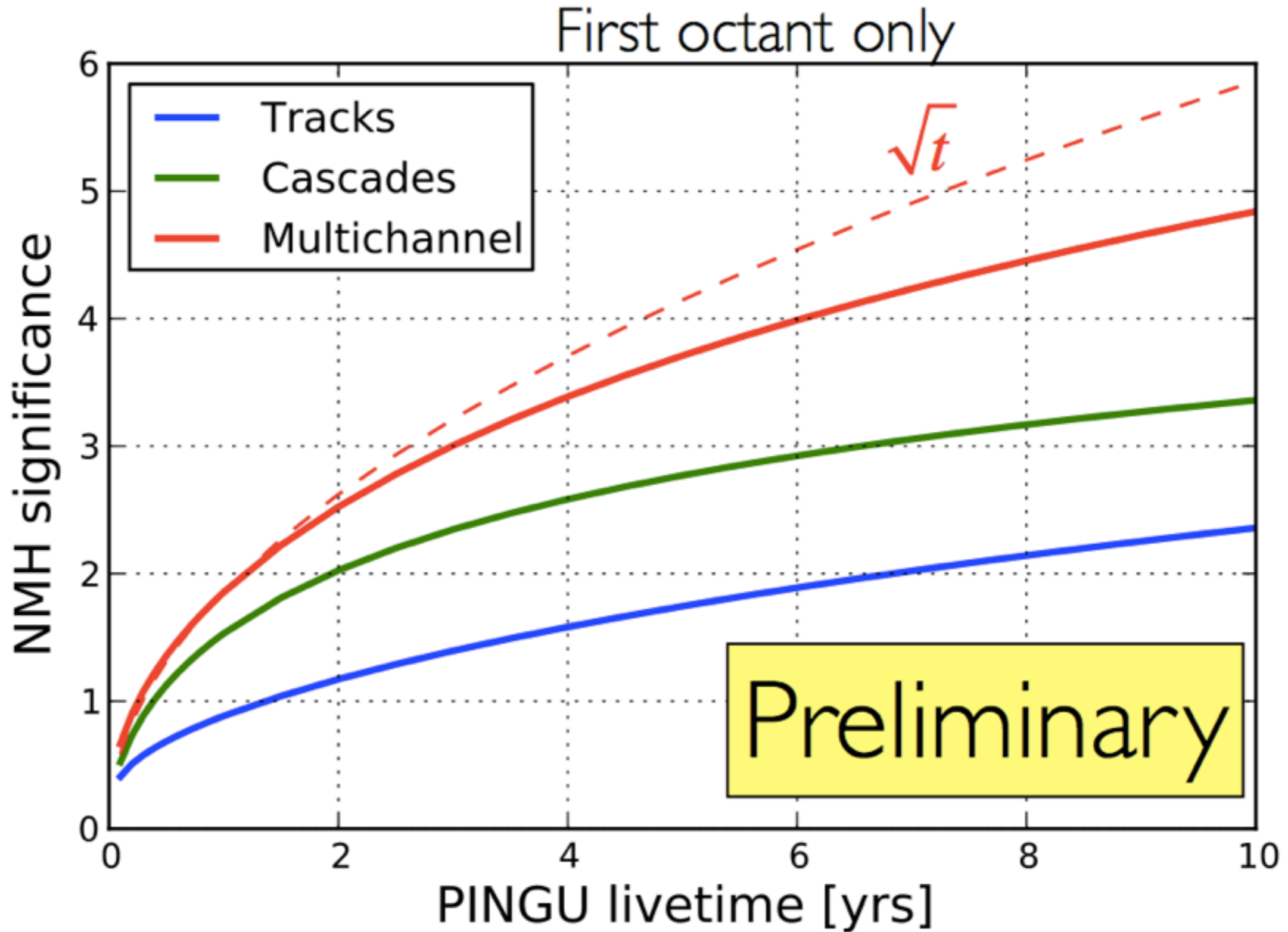
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DeepCore + PINGU

- Difference in counts between hierarchies illustrates distinguishability
- Event selection, reconstruction not included here
- Events shown are  $\nu_{\mu}$ CC

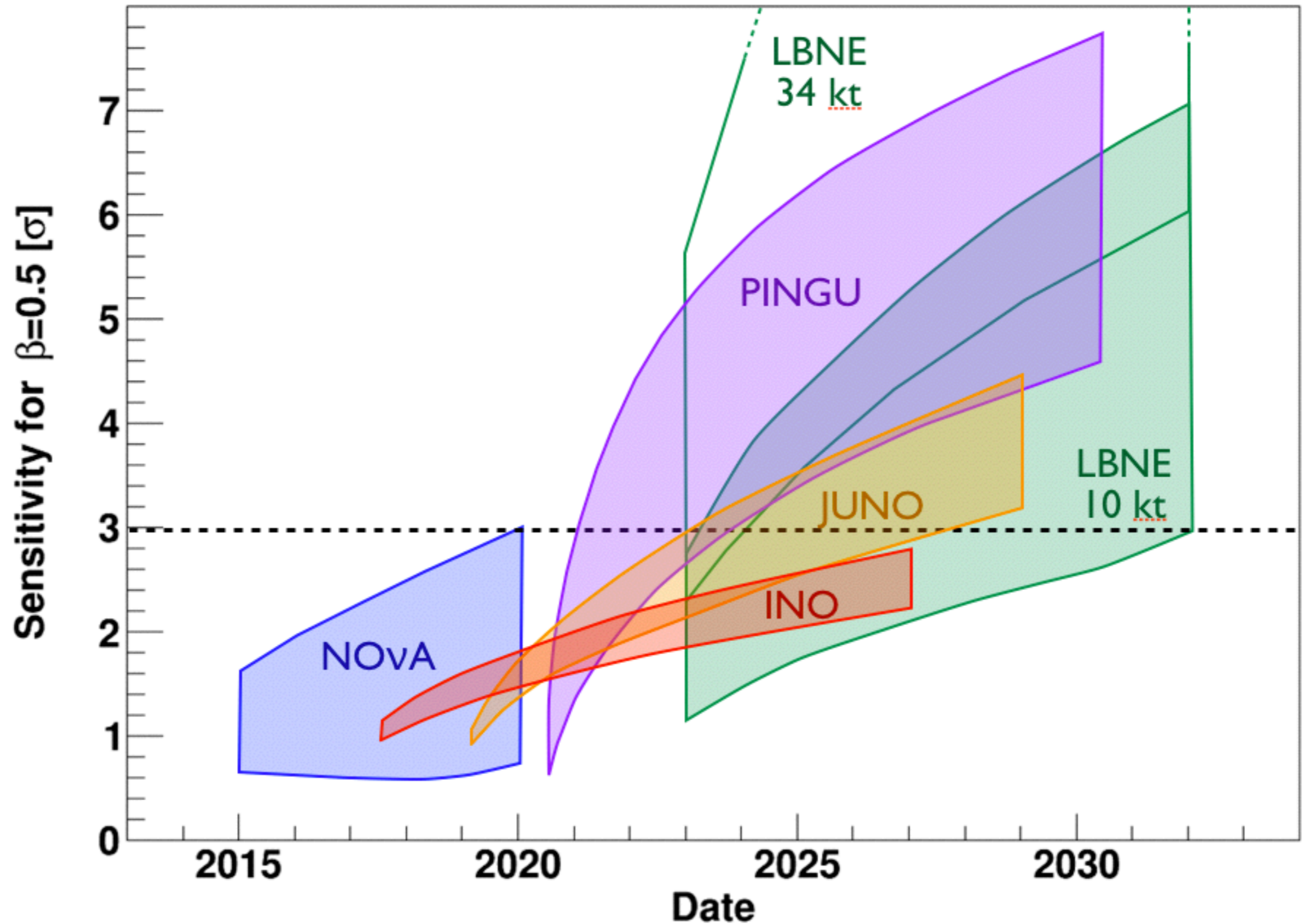




# Rejecting Wrong Hierarchy

- IceCube
- DeepCore
- PINGU

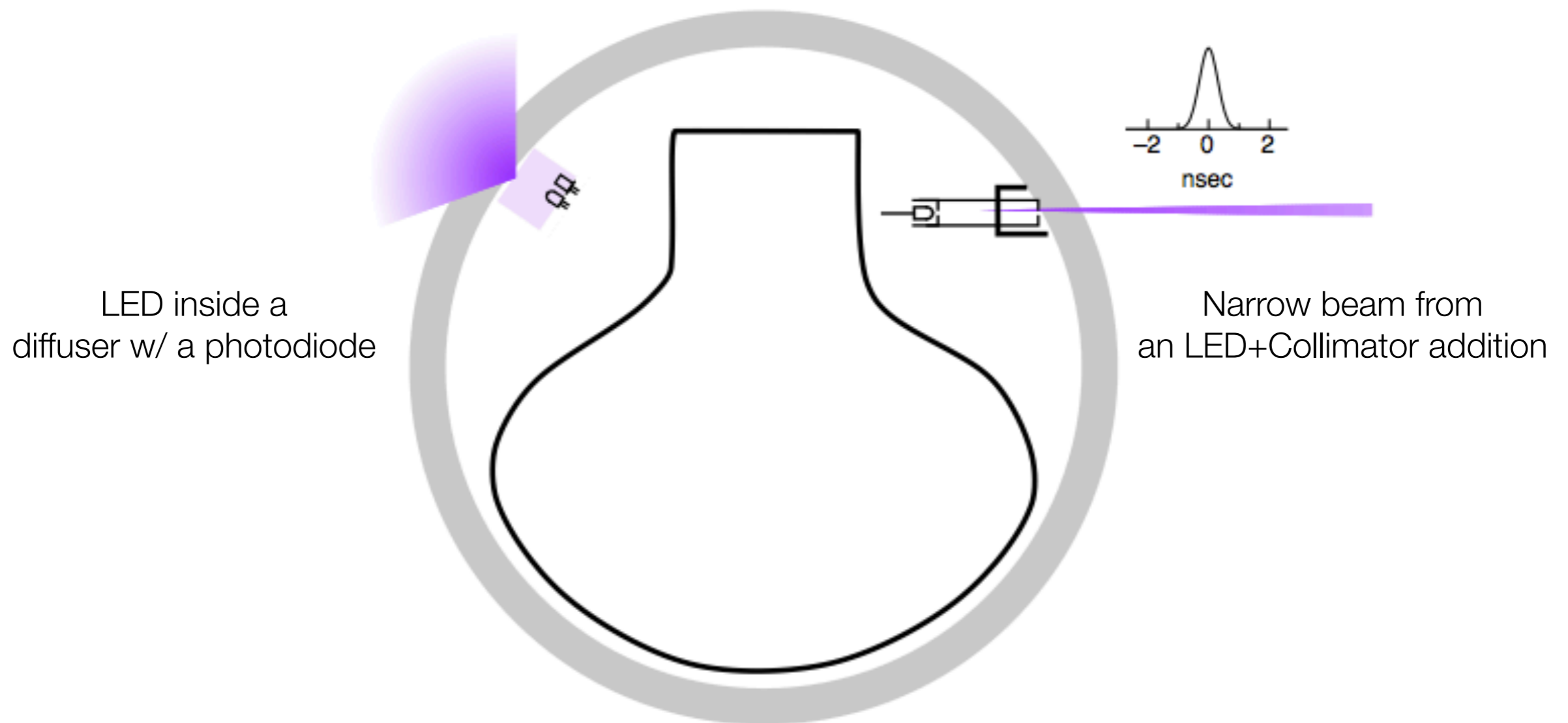
Blennow, Coloma, Huber, Schwetz – arXiv:1311.1822



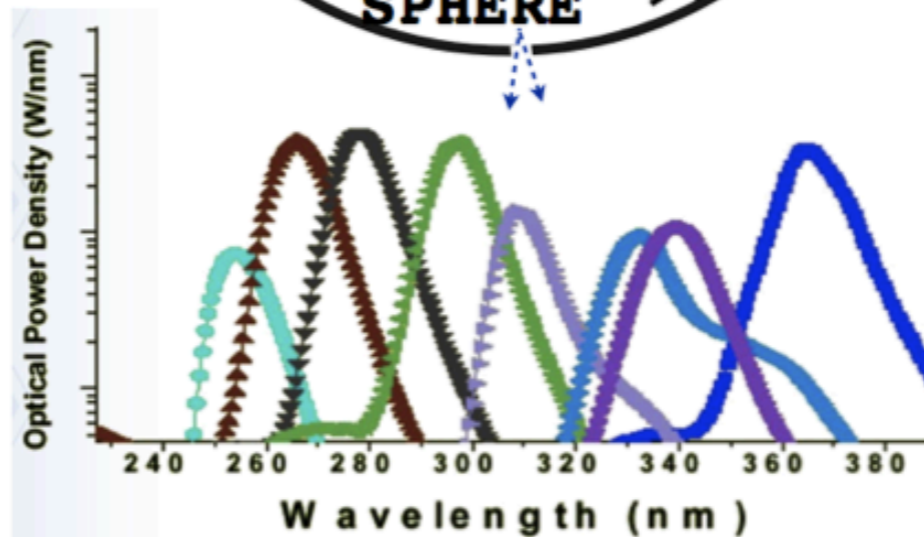
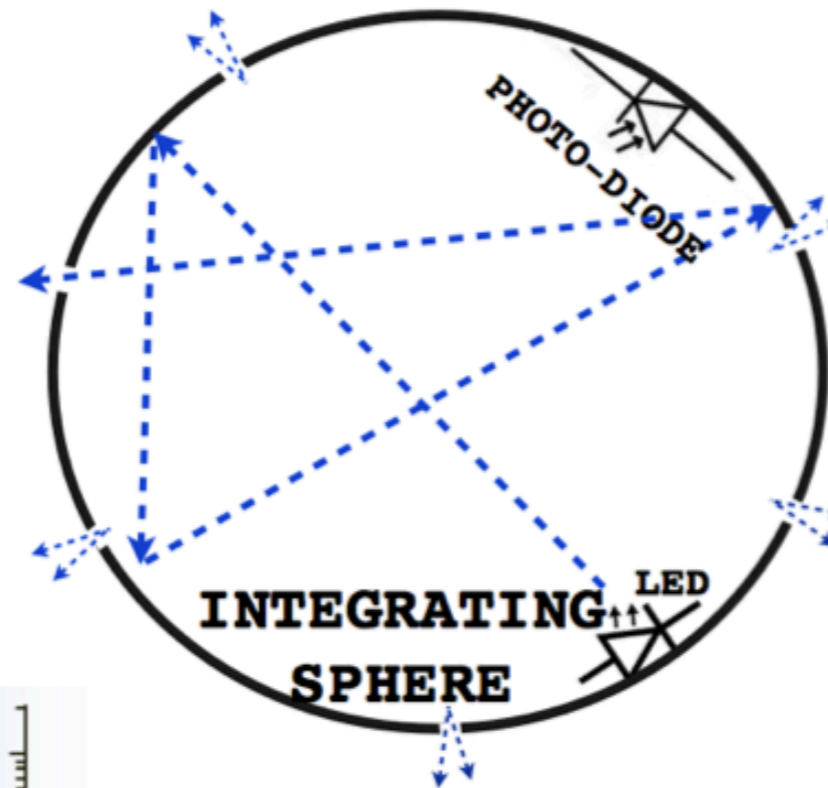
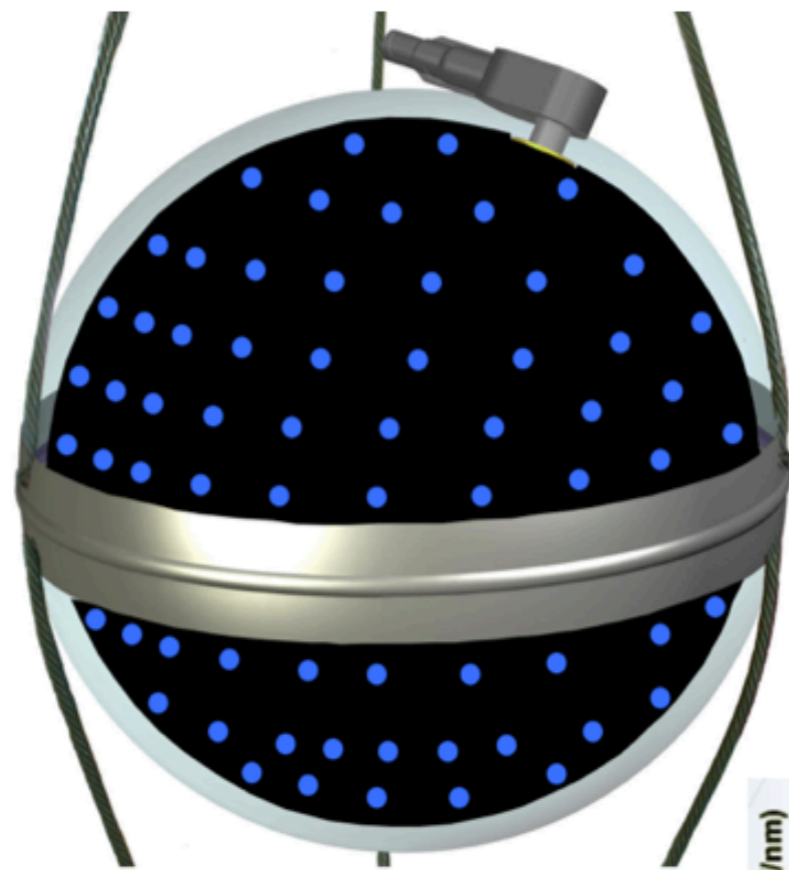


- The energy scale is an important feature for PINGU analyses and requires knowledge of the ice properties (photon absorption and scattering) and absolute photon yield
- The ice properties are also an important systematic for the IceCube high energy neutrino analyses too
- New deployment allows new calibration instruments

- IceCube has LED 'flashers' on the top of each DOM
- PINGU DOMs can include better instrumentation



- Precision Optical Calibration Module (POCAM)



- Reconstruction
- Looking at using  $y$ -inelasticity to separate neutrinos and anti-neutrinos for hierarchy analysis **Ribordy & Smirnov - arXiv:1303:0758**
- Particle identification
- Geometry optimization
- etc.

- Letter of Intent: The Precision IceCube Next Generation Upgrade (PINGU) - arXiv:1401.2046
- P5 decadal process in US asked for specific talk from PINGU
- Funding is being examined as an individual project as well as part of an NSF Major Research Equipment and Facilities Construction (**MREFC**) project

- Relatively quick, cost effective, huge and unique
  - 2-3 season deployment w/ additional ~1.5 year procurement/shipping
  - ~10M\$ start up and ~1.25M\$/string based on IceCube experience
  - Megaton size at GeV energies
  - Samples many angle, many baselines and crosses the earth core using a free beam that never shuts off
- Enhance on-going DeepCore physics
- There are projects that would benefit from additional collaboration w/ people and institutions currently outside of IceCube