PINGU and O(1) GeV cross-sections

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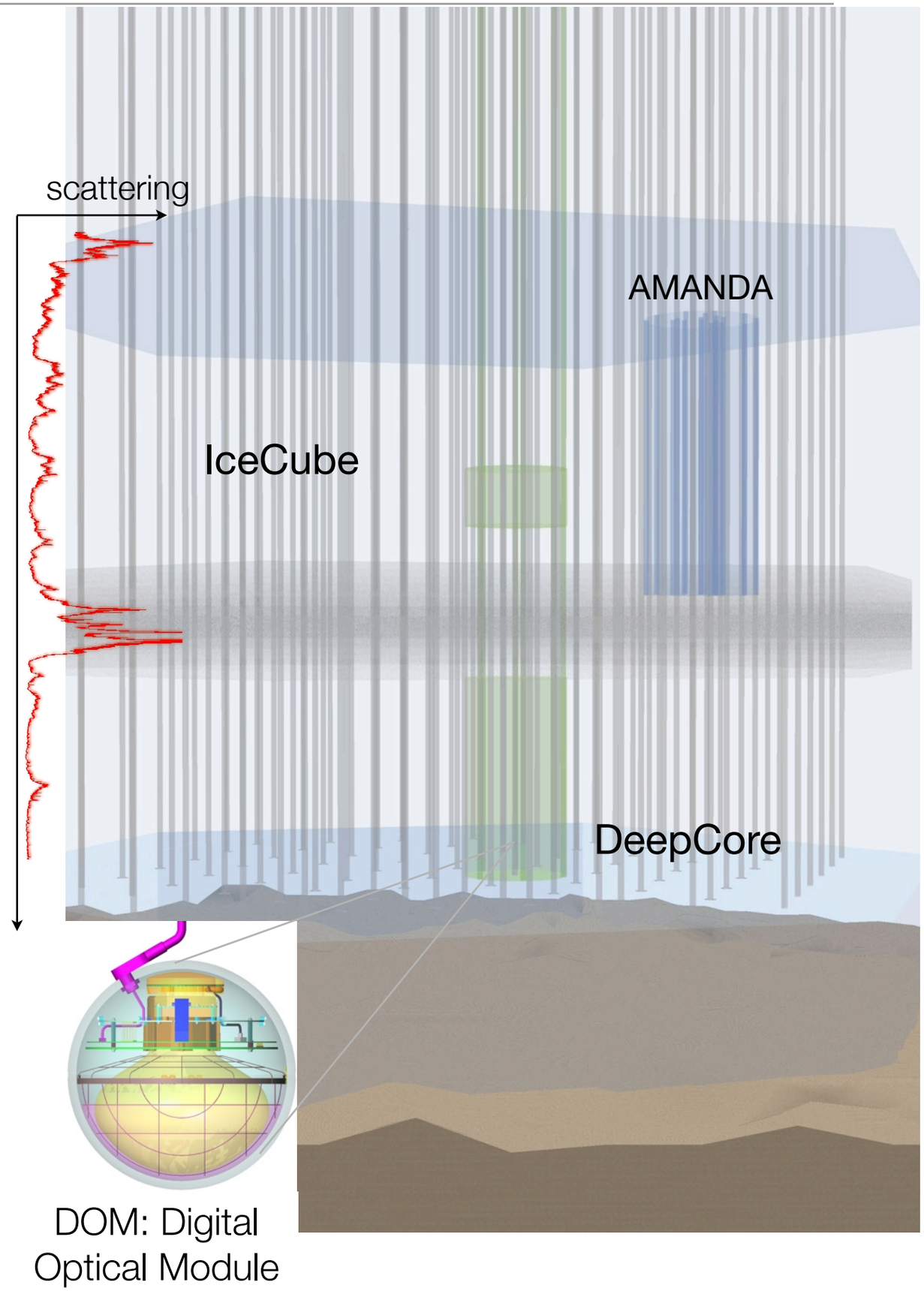
Ken Clark
For the IceCube (including PINGU) Collaboration

Flux Measurement and Determination in the Intensity Frontier Era Neutrino Beams
University of Pittsburgh
December, 2012

IceCube + DeepCore

- IceCube is ~1km^3 of ice instrumented w/ ~5k DOMs
  - 86 vertical strings w/ 60 DOMs per string
- DeepCore
  - 8 special strings plus 12 closest IceCube-standard strings
  - Denser DOM and string spacing
  - O(10) megaton trigger-level effective volume at tens of GeV
  - Higher quantum efficiency (HQE) PMTs
  - Increases sensitivity at energies < 100-200 GeV, and the neutrino physics that comes with it



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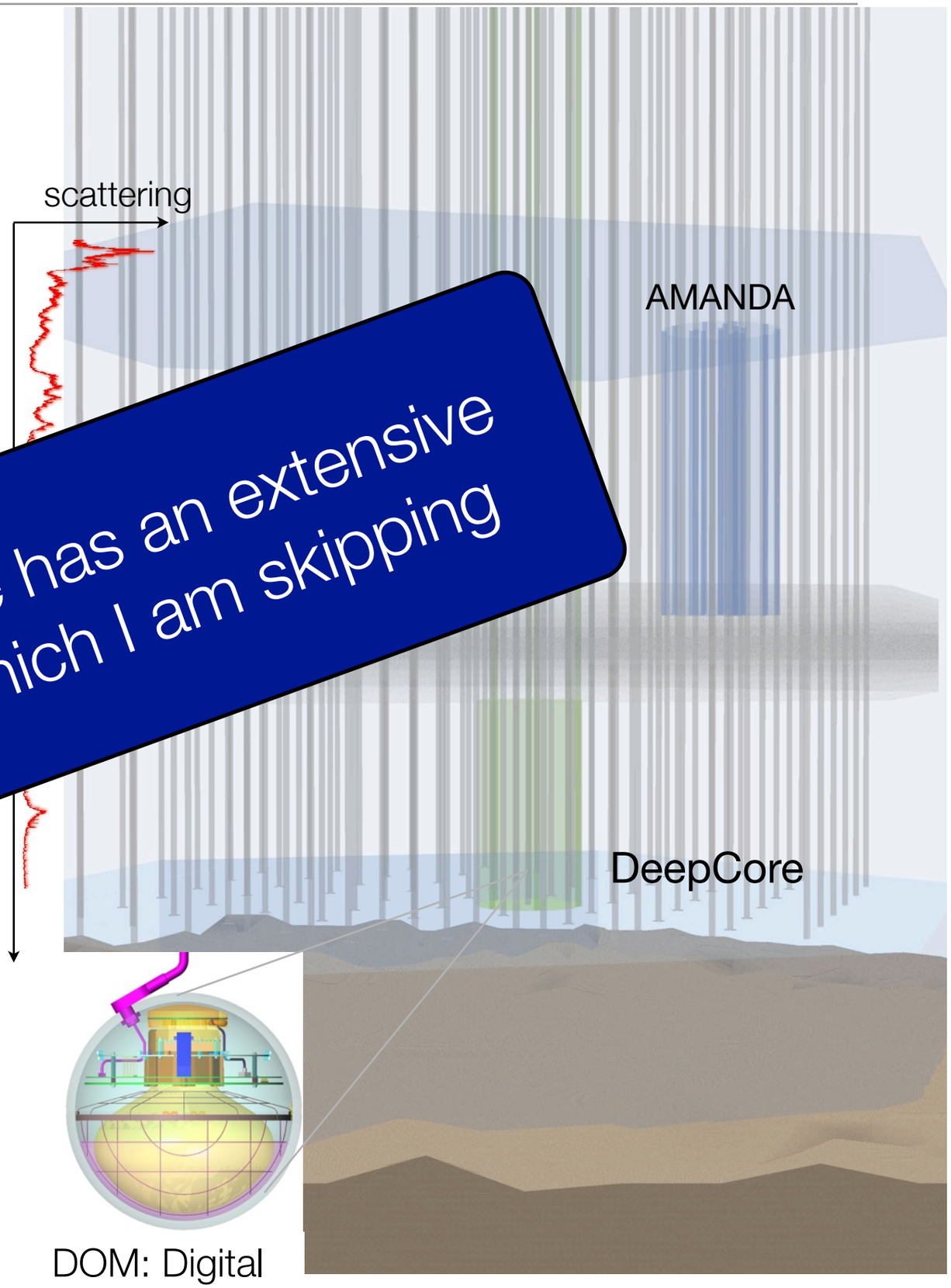
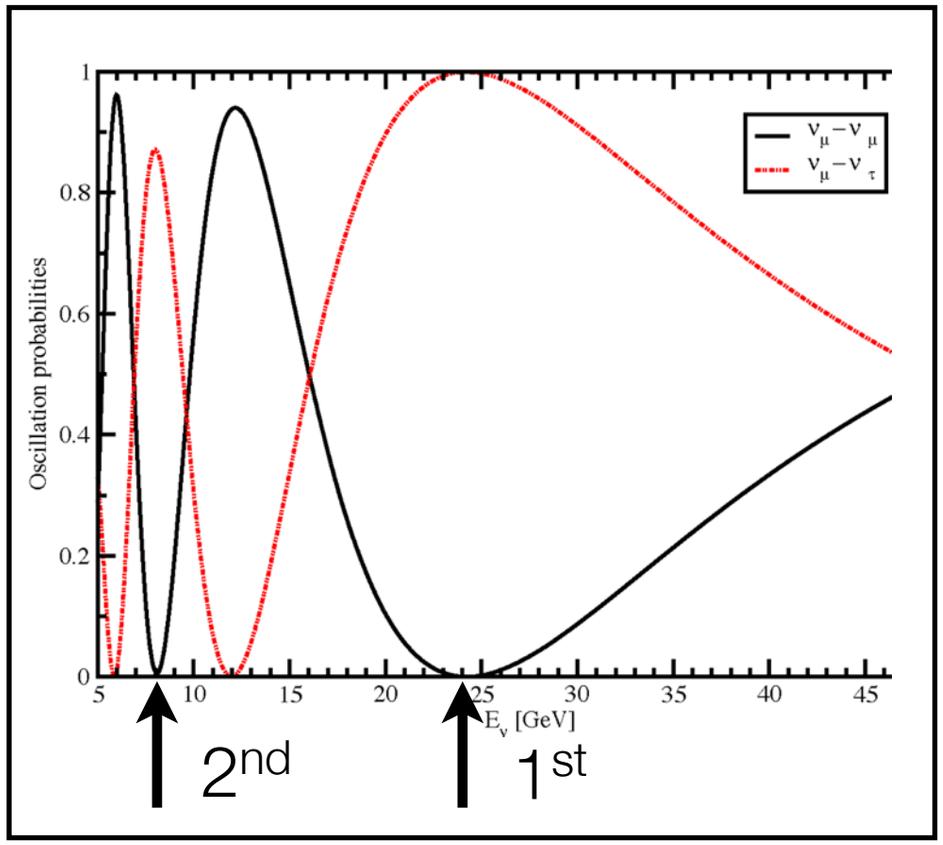
IceCube + DeepCore has an extensive physics portfolio which I am skipping



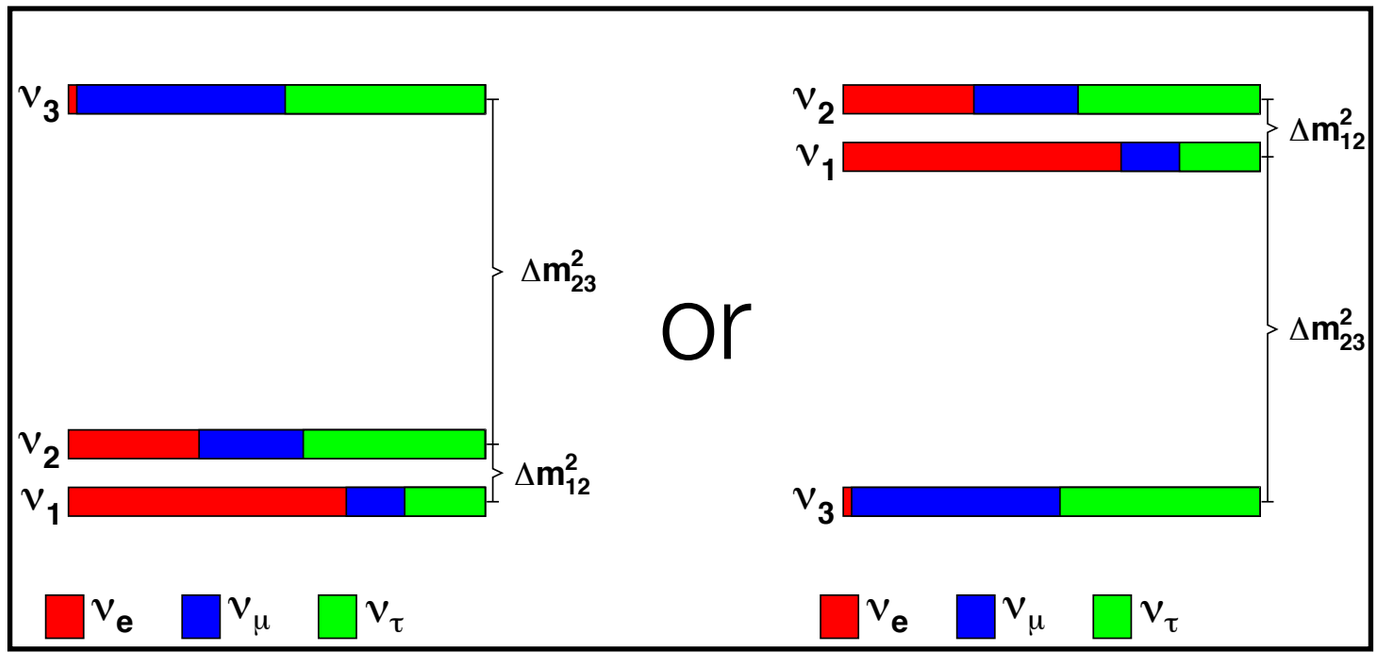
DOM: Digital Optical Module

What's Past DeepCore?

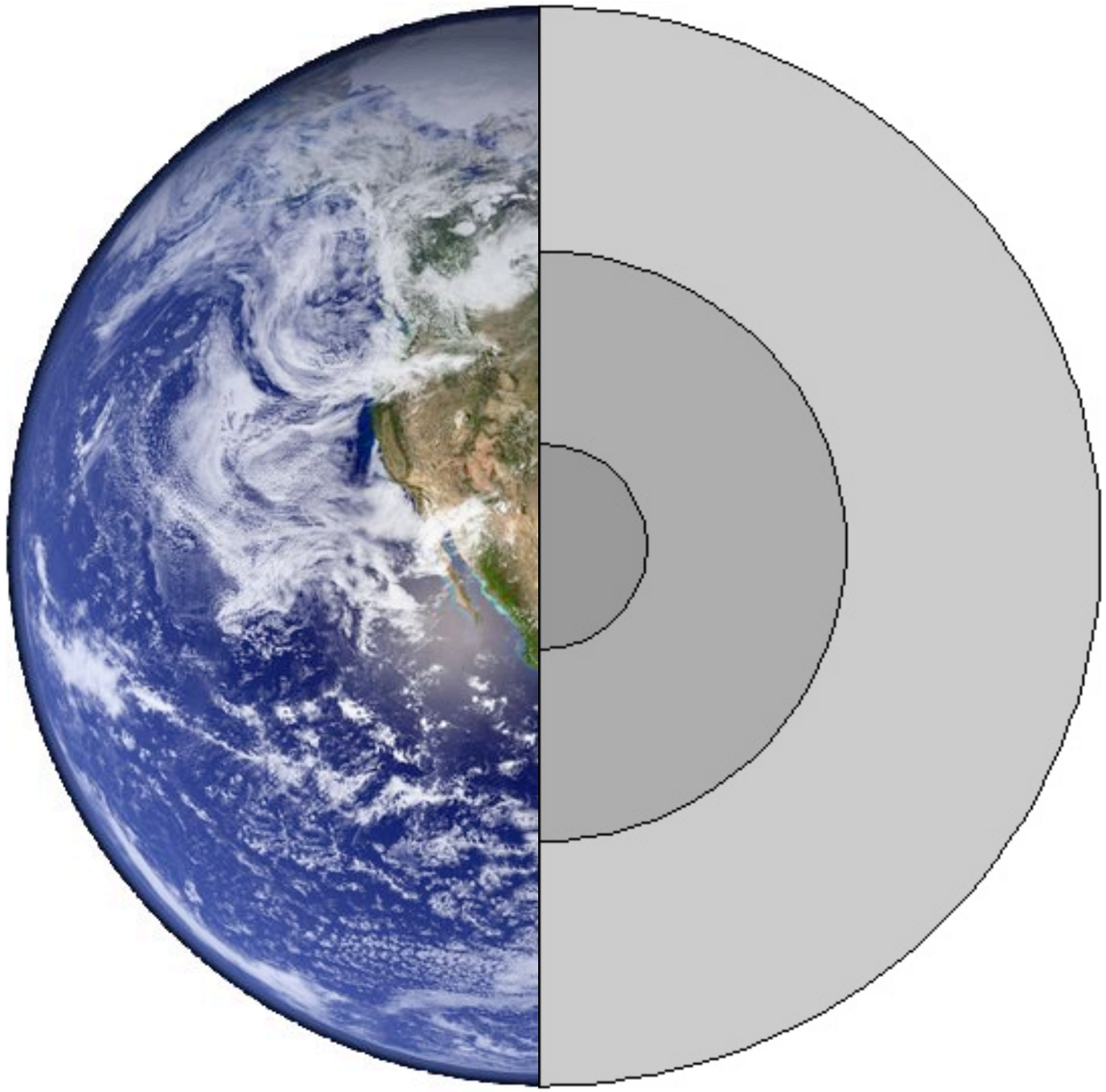
- What do we get if we push the neutrino energy reach to O(1) GeV while maintaing a multi-megaton scale size?
  - Improve ongoing DeepCore oscillation analysis (numu disappearance, nutau appearance, etc...)
  - Open up lower energy region for new analyses (neutrino hierarchy)



Mena, Mocioiu & Razzaque, *Phys. Rev.* D**78**, 093003



Matter Effects & Neutrino Hierarchy



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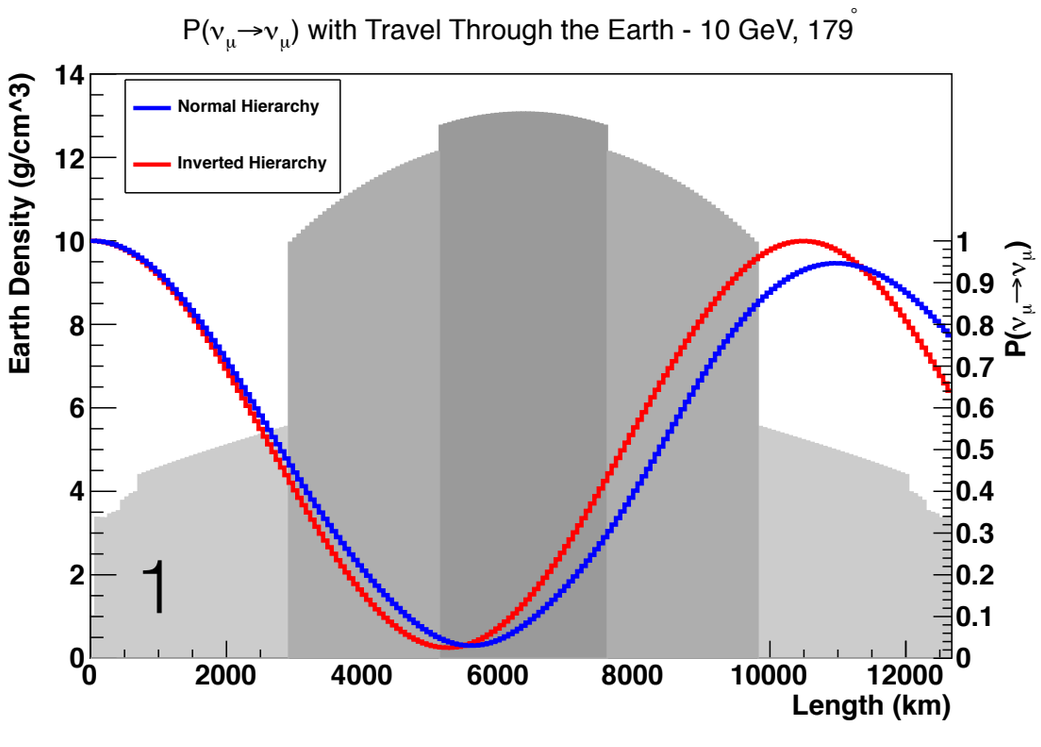

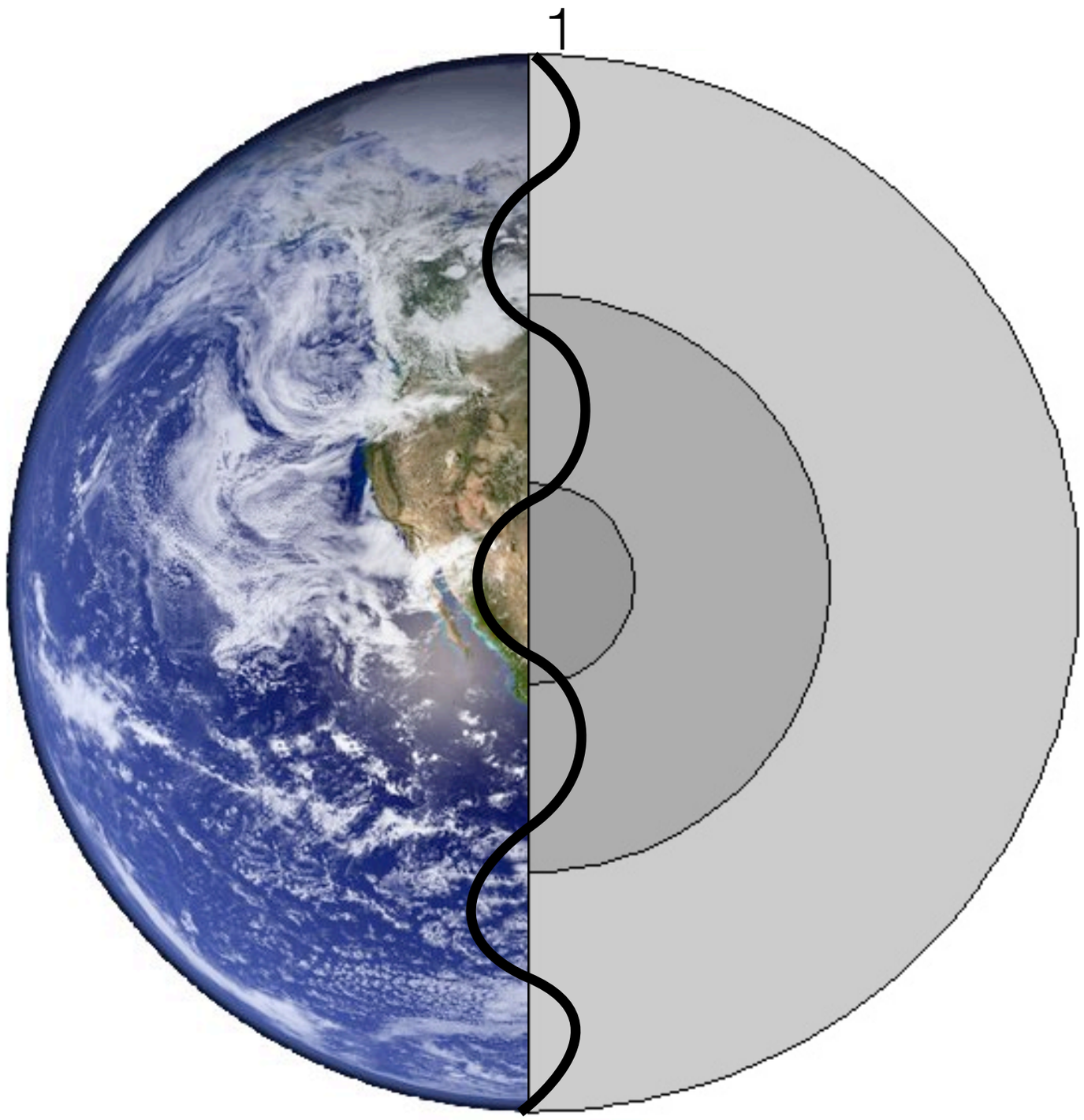

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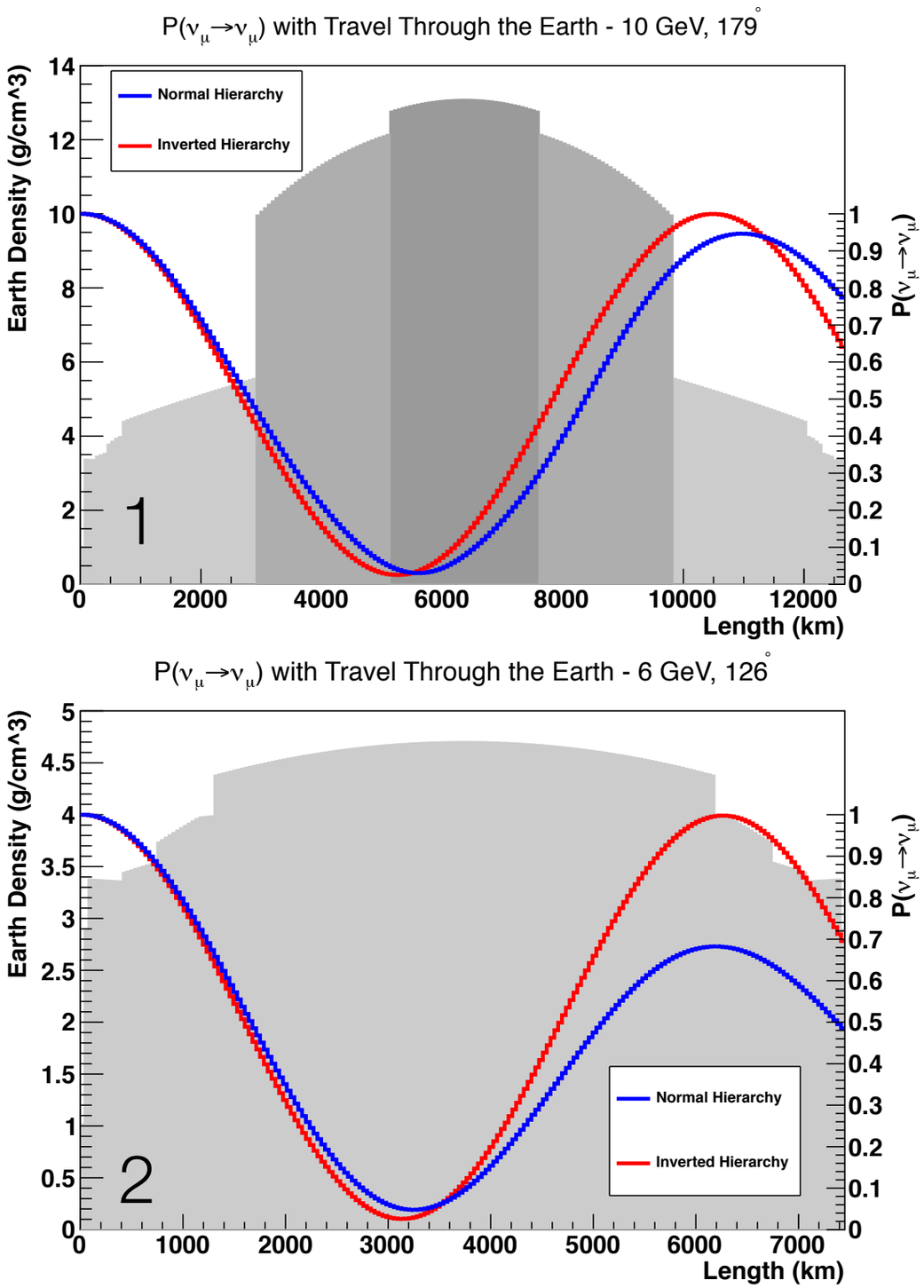

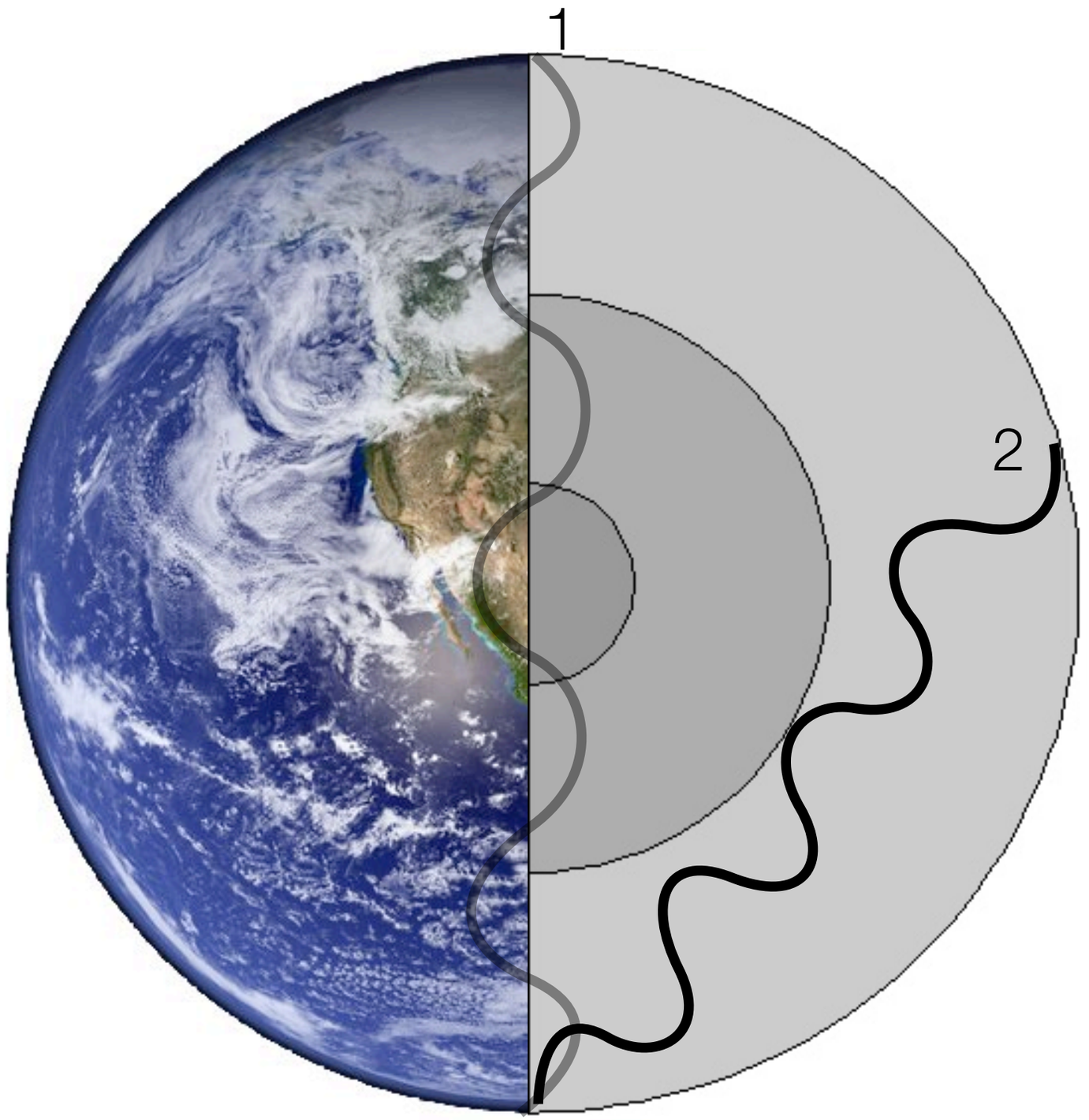

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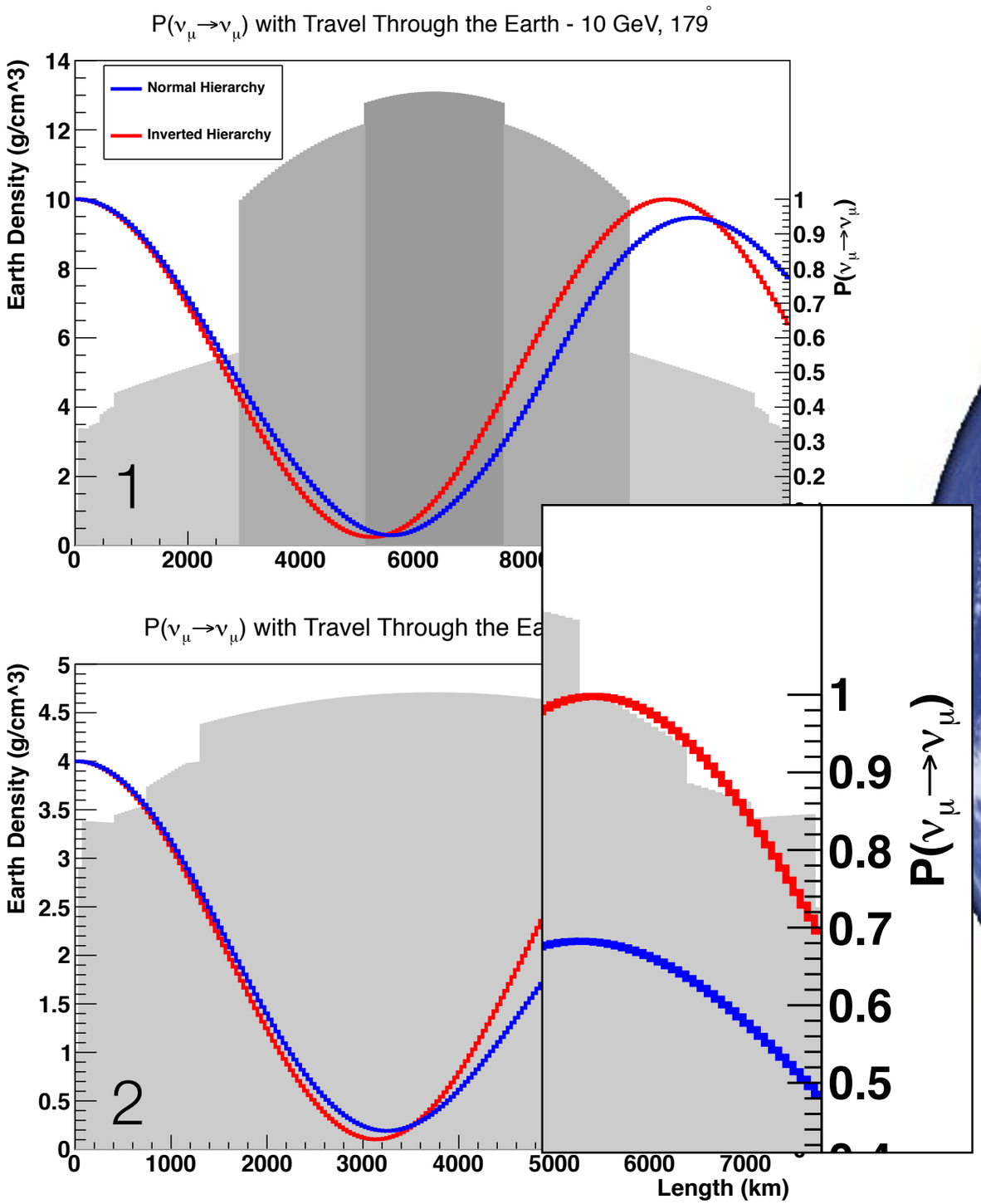

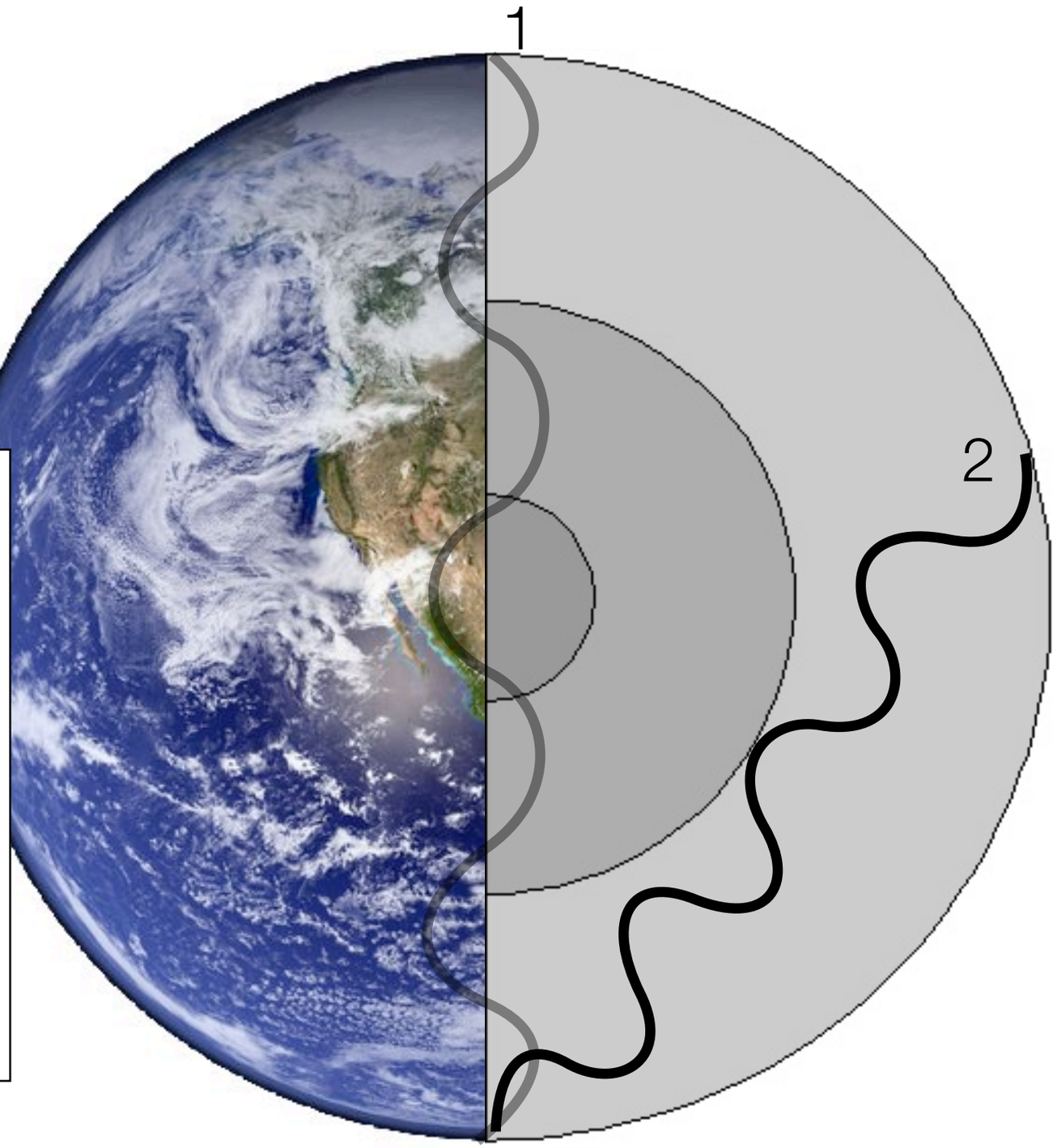

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Concept

IceCube

Concept

IceCube

DeepCore

Concept

IceCube

DeepCore

Concept

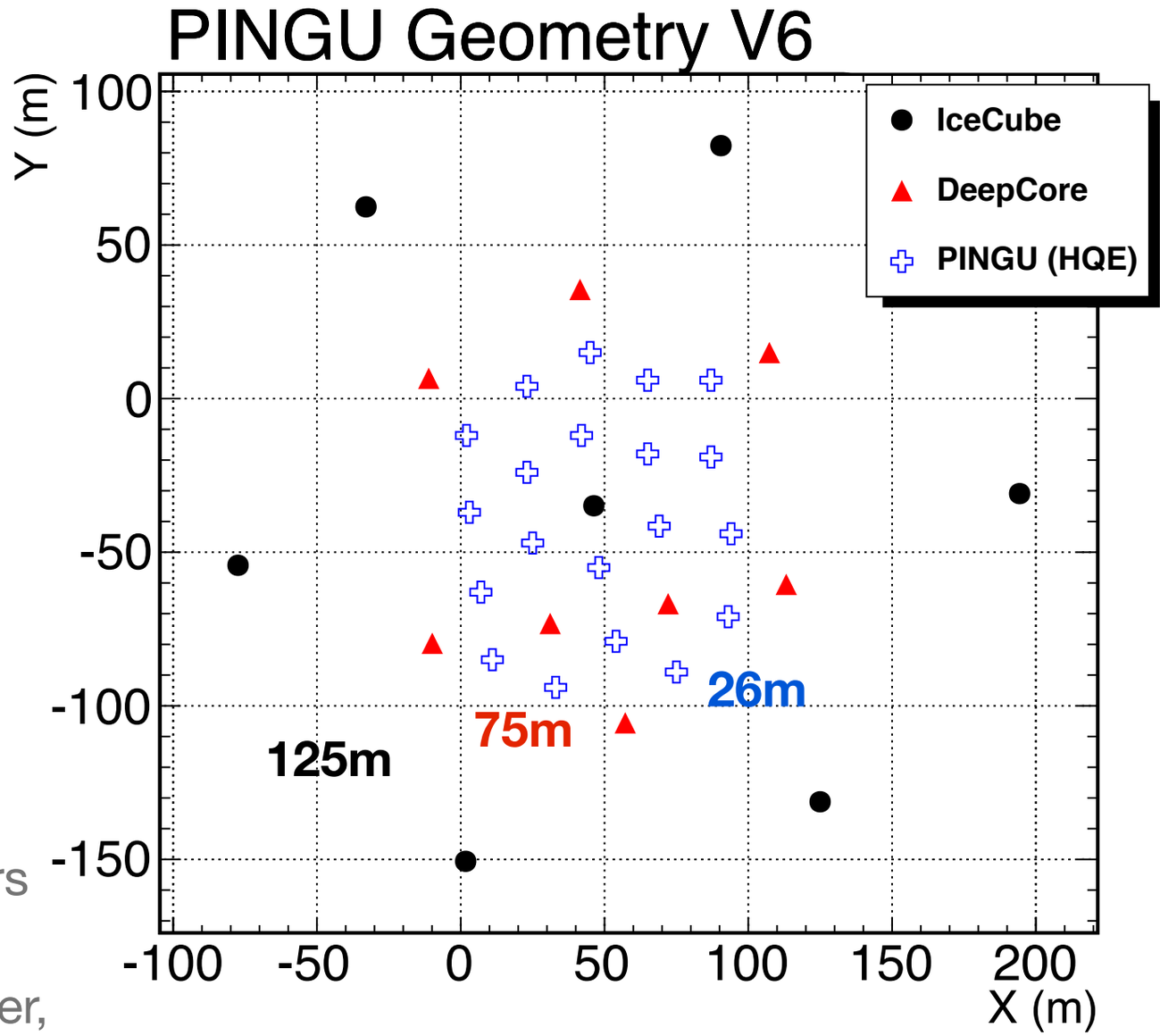
IceCube

DeepCore

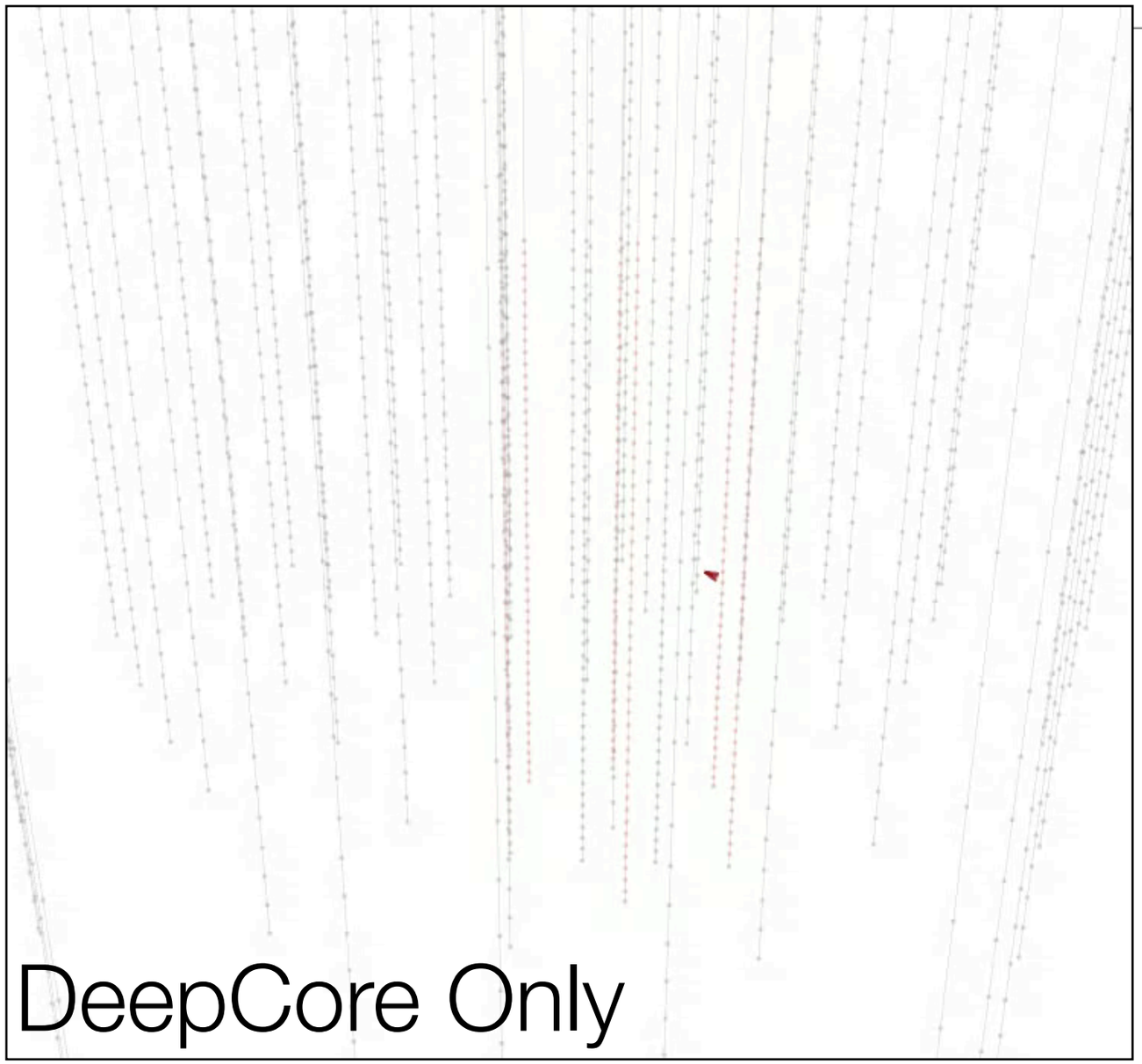
PINGU

PINGU: Possible Geometry

- **P**recision **I**ceCube **N**ext **G**eneration **U**pgrade (PINGU)
- Using existing and familiar technology (hot water drill, HQE PMT DOMs) to infill DeepCore with additional ~20 strings with shorter string-string spacing and DOM-DOM spacing
- Relatively quick, cost effective, huge and unique
  - 2 season deployment w/ additional ~1.5 years for procurement/shipping/refurbishing
  - Preliminary, exploratory, estimate, to first order, etc... cost of < *O*(50M)$
  - Megaton size at trigger level for GeV energies
  - Samples many angles, many baselines and crosses the earth core
  - Atmospheric neutrinos are a free beam



PINGU Events



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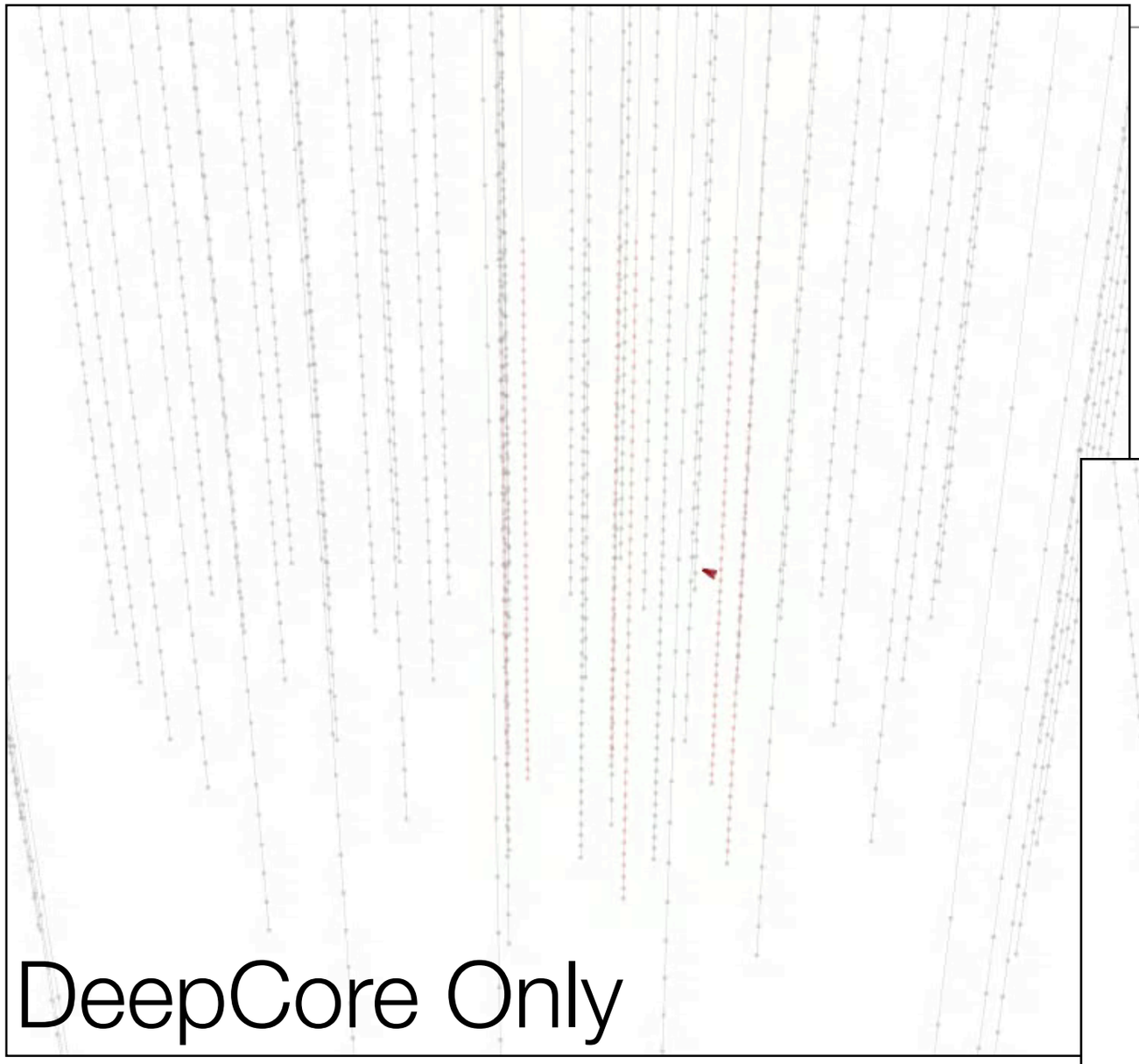
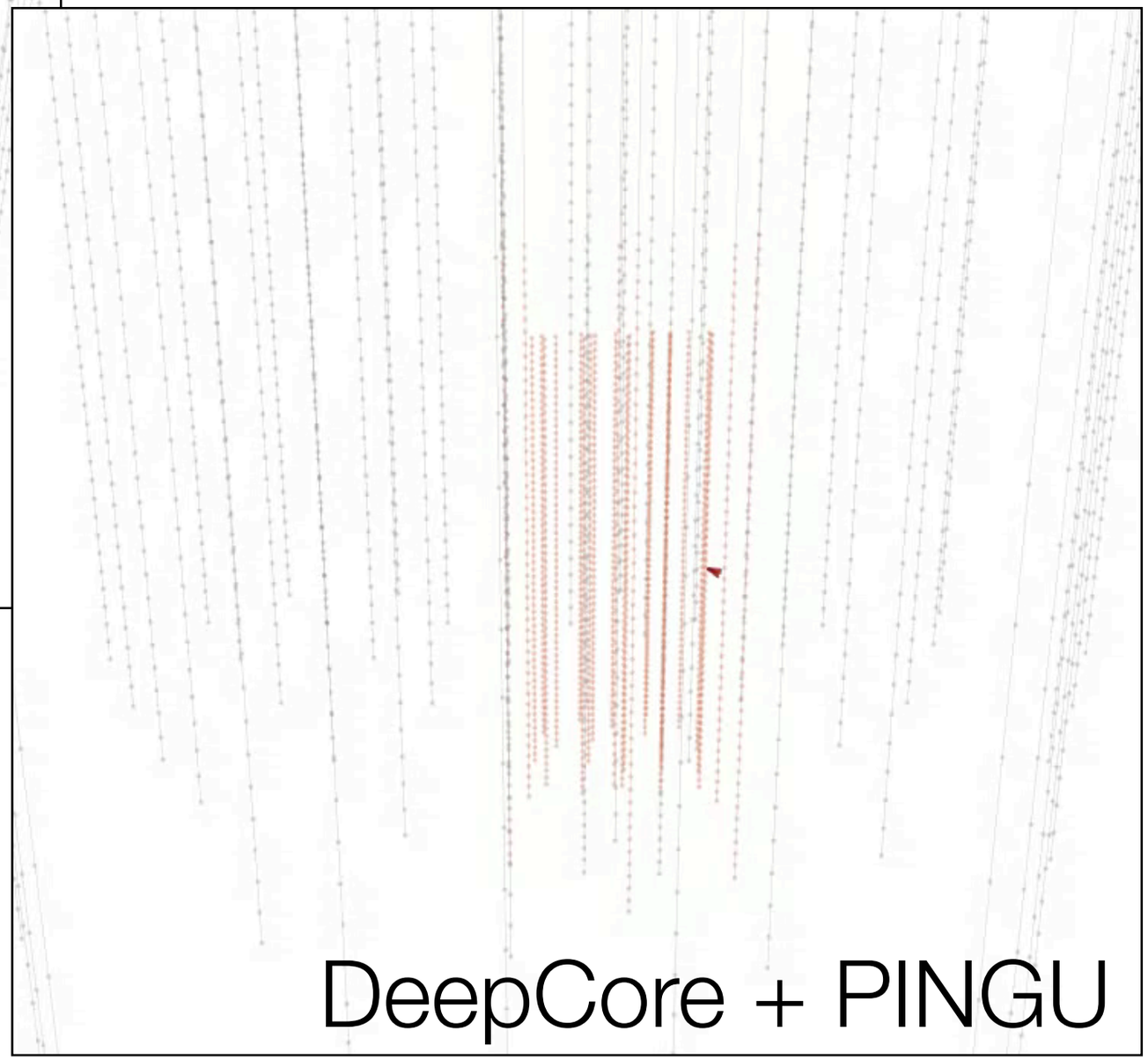
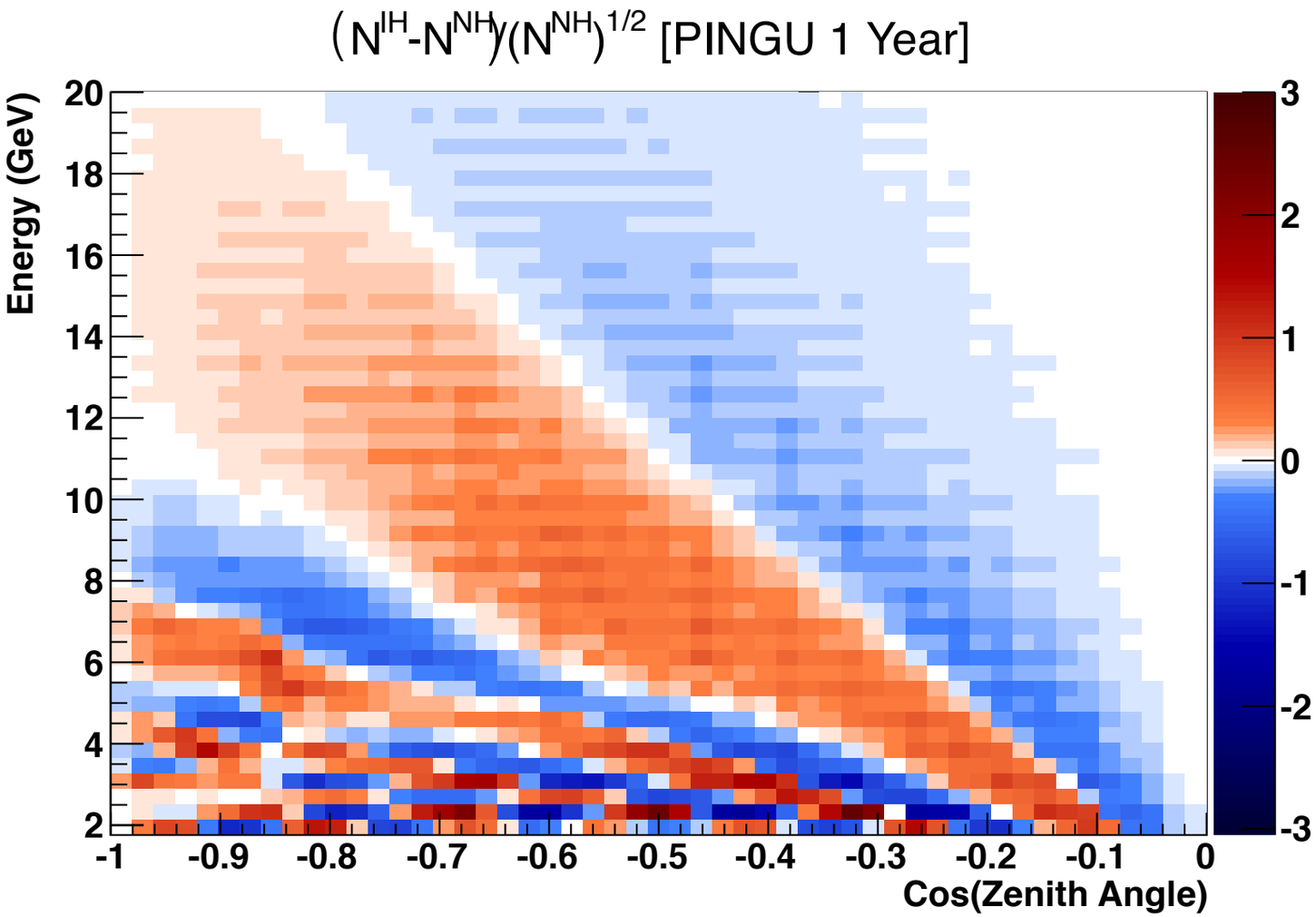


- ~20 vs. ~50 Hit Modules



Revisit Hierarchy w/ PINGU

*reproduction using of technique described in Akhmedov, Razzaque, Smirnov arXiv:1205.7071



- Idealized case w/ perfect event ID, 100% event selection efficiency, no quality cuts and no background
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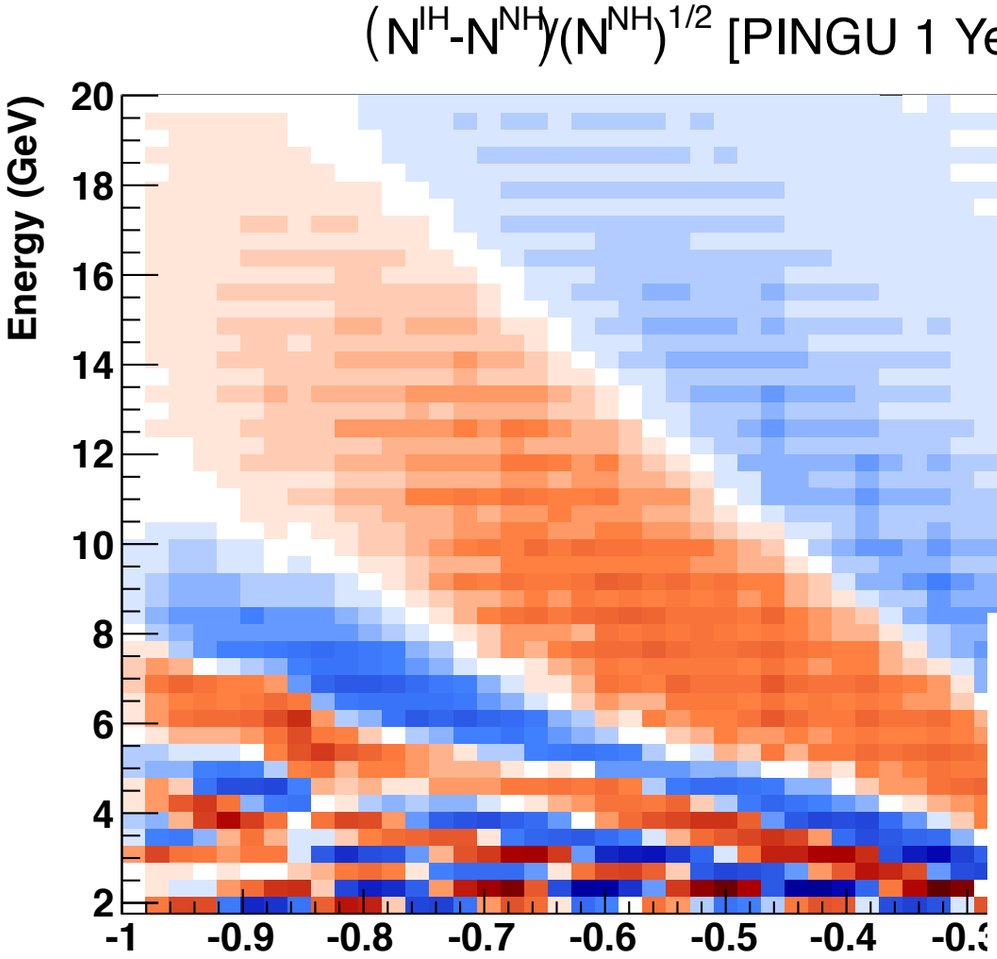
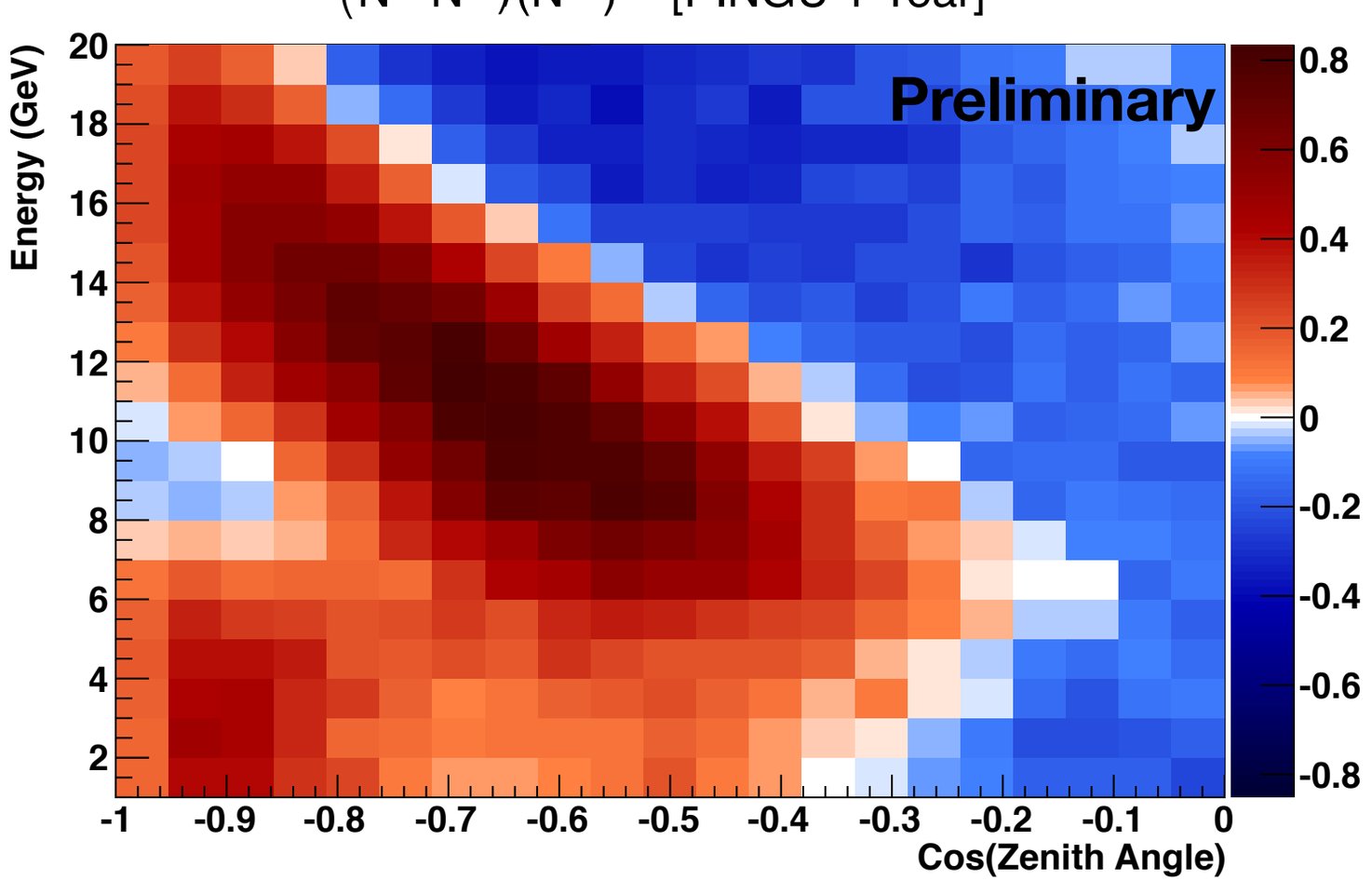


smeared: 3 GeV in energy and 11.25° in angular resolution



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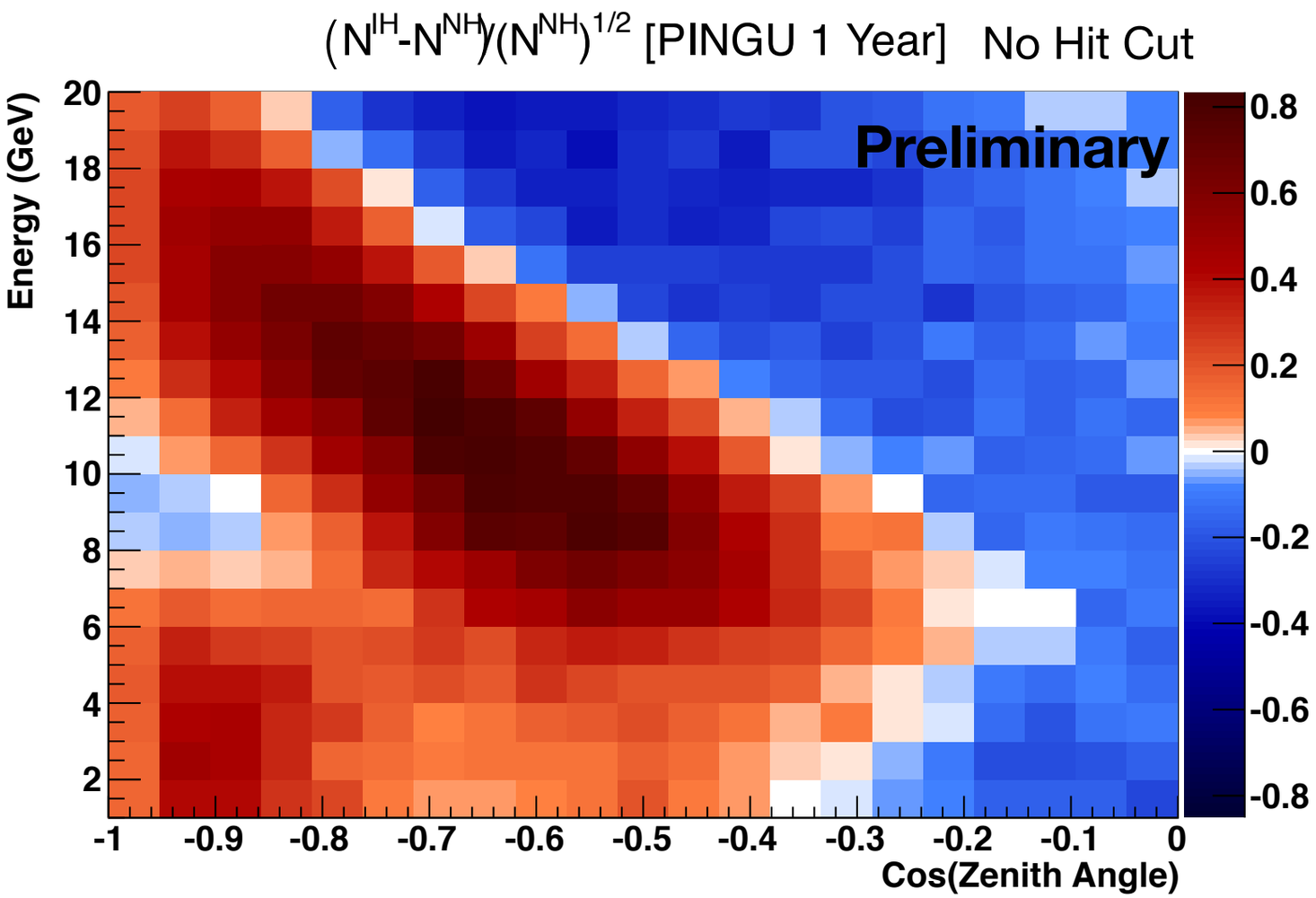
IceCube-DeepCore-PINGU

- IceCube physics and simulation were not originally developed with a focus on neutrinos < ~100 GeV
  - Important topics for different workshops (atmospheric flux models, particle identification, bkg rejection, etc...)
  - **Important aspect for this workshop is cross-section physics**
- Why are we (IceCube) at a beam x-section workshop?
  - GENIE is already in simulation for IceCube-DeepCore
  - PINGU simulation studies are maturing and nearing contact with known neutrino particle physics issues
  - With large statistics (>100k numu triggers/year) and no near detector, cross-section uncertainties from 2-10 GeV may be significant
  - If successfully realized, PINGU deployment will happen quickly
    - Requires getting in contact with experts
    - Improvements in understanding and simulating cross-section don't happen overnight

Specific Example



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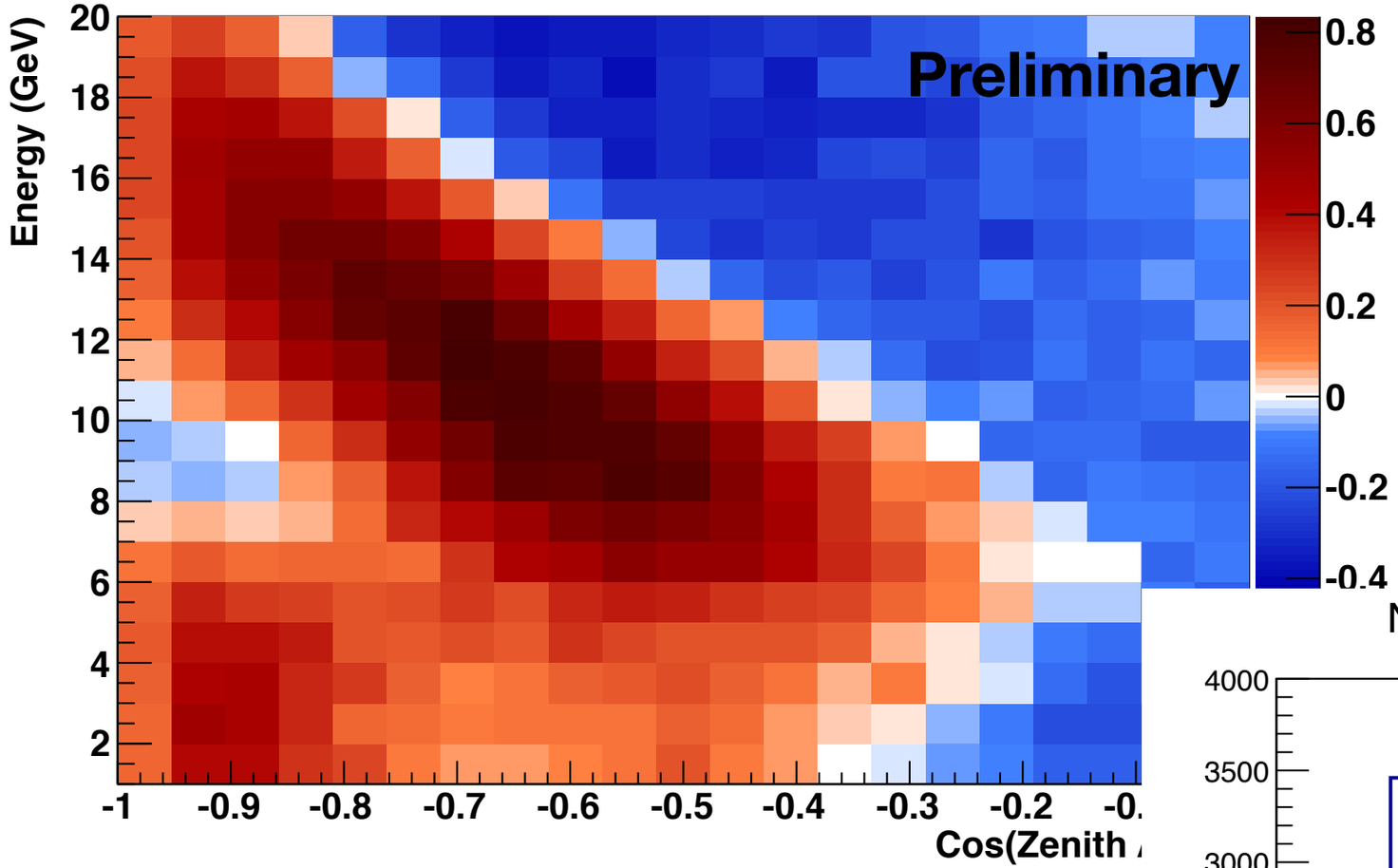

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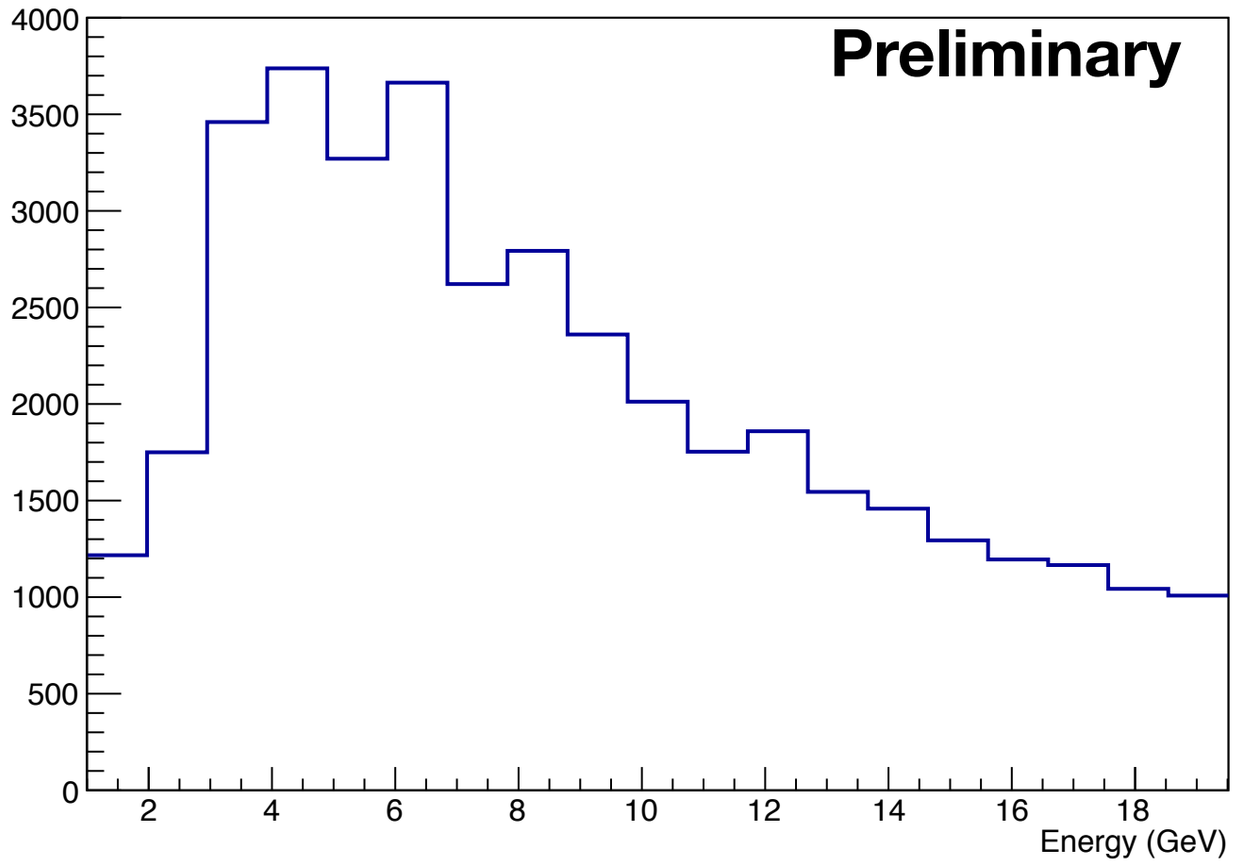

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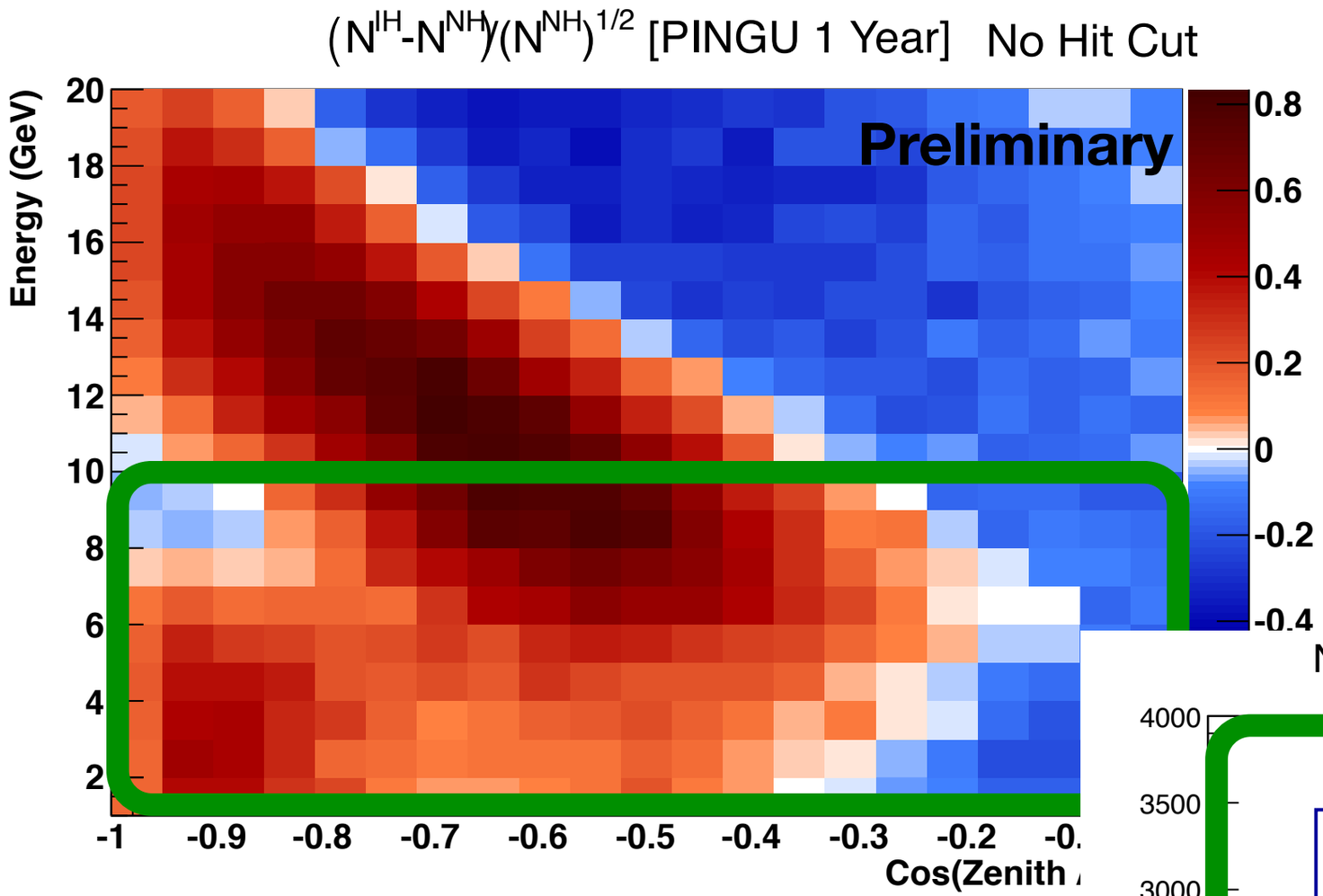

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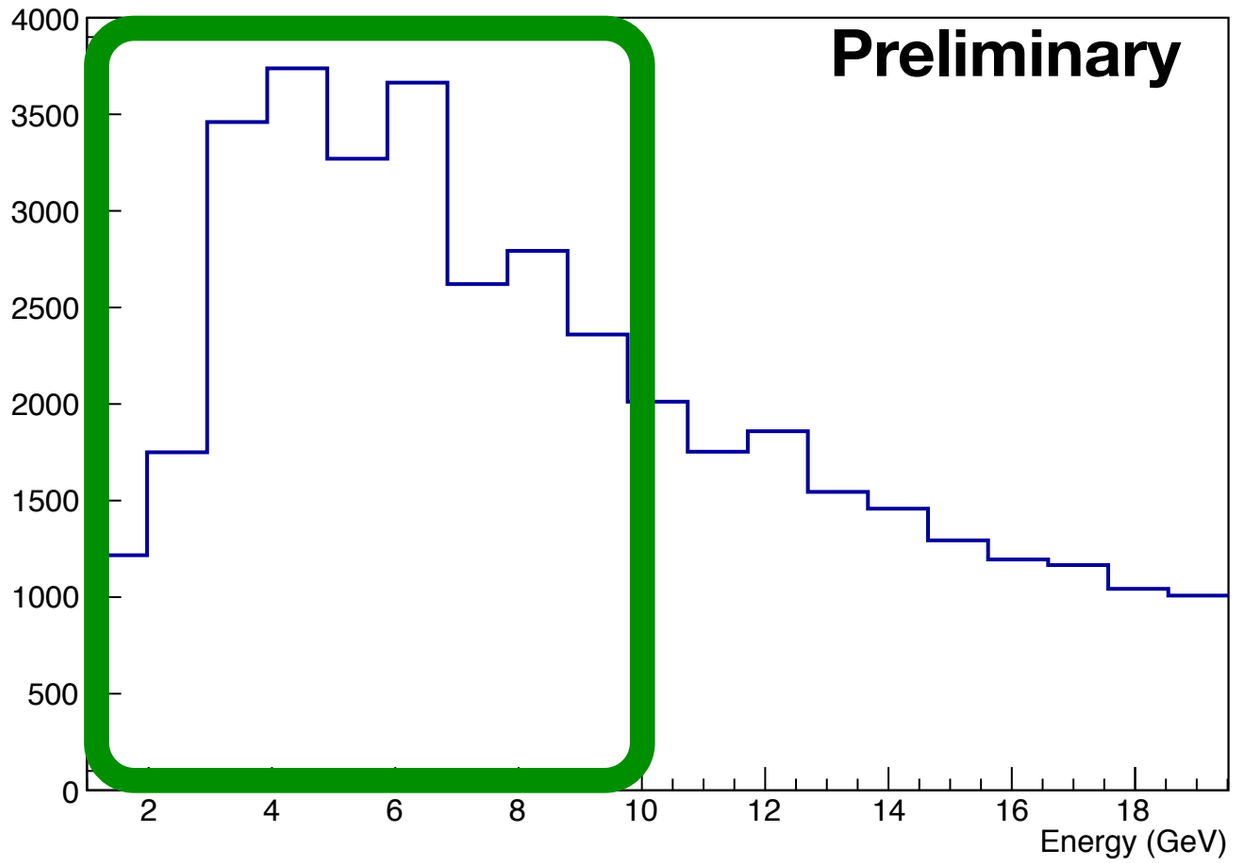


- A large region of neutrino hierarchy significance happens below 10 GeV
- Even after a rudimentary quality cut requiring > 20 hits, there are still tens of thousands of atmospheric neutrino events < 10 GeV

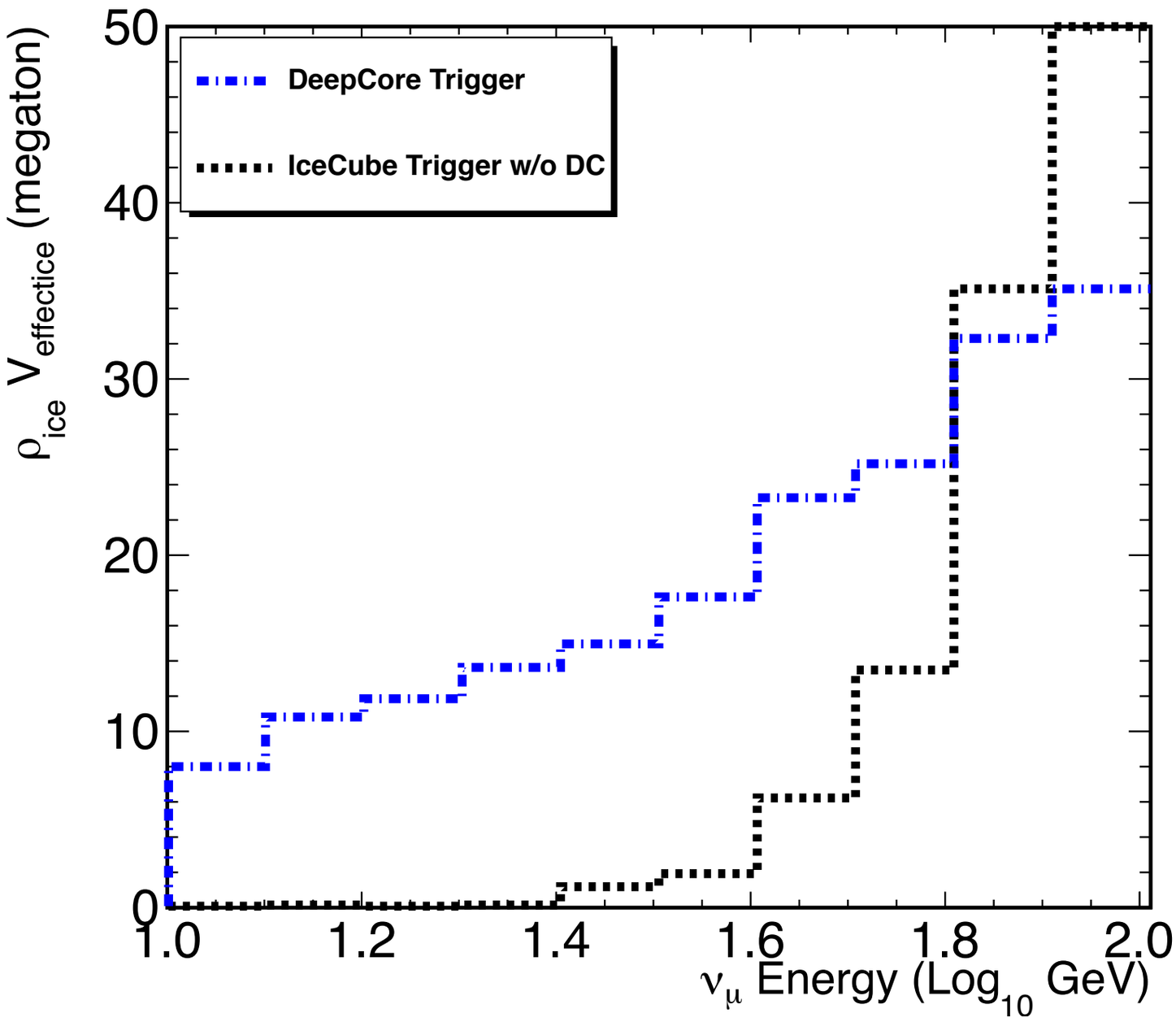
Conclusion

- Benefit of a rapid PINGU deployment turns into the curse of needing to know, incorporate, and address what we do not know sooner rather than later
- PINGU collaboration is starting to explore x-sections at O(1) GeV
  - Generators (GENIE, NUANCE, NEUT, ...)
  - Theory/Phenomenology (NLO, NNLO, PDF treatment, ...)
  - Relevant experimental data (MINOS, CCFR, NOMAD, ...)
- Additional
  - What about nutau uncertainties/predictions?
- Offline questions or comments are very welcome
  - D. Jason Koskinen (koskinen@psu.edu) Ken Clark (kjc20@psu.edu)

Backup

Oscillation

- IceCube + DeepCore will collect ~200k isotropic neutrinos at trigger level, tens of thousands have undergone oscillation



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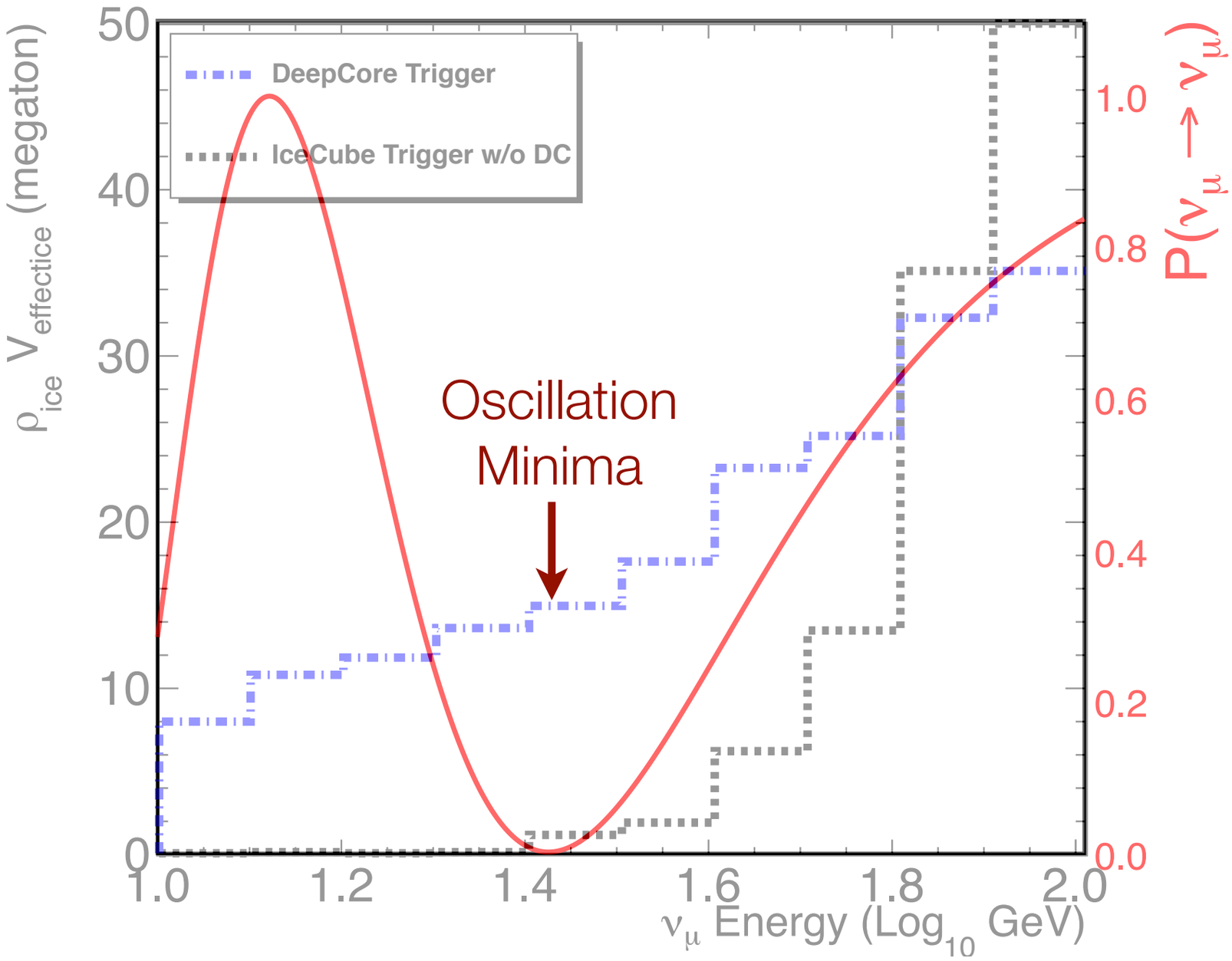
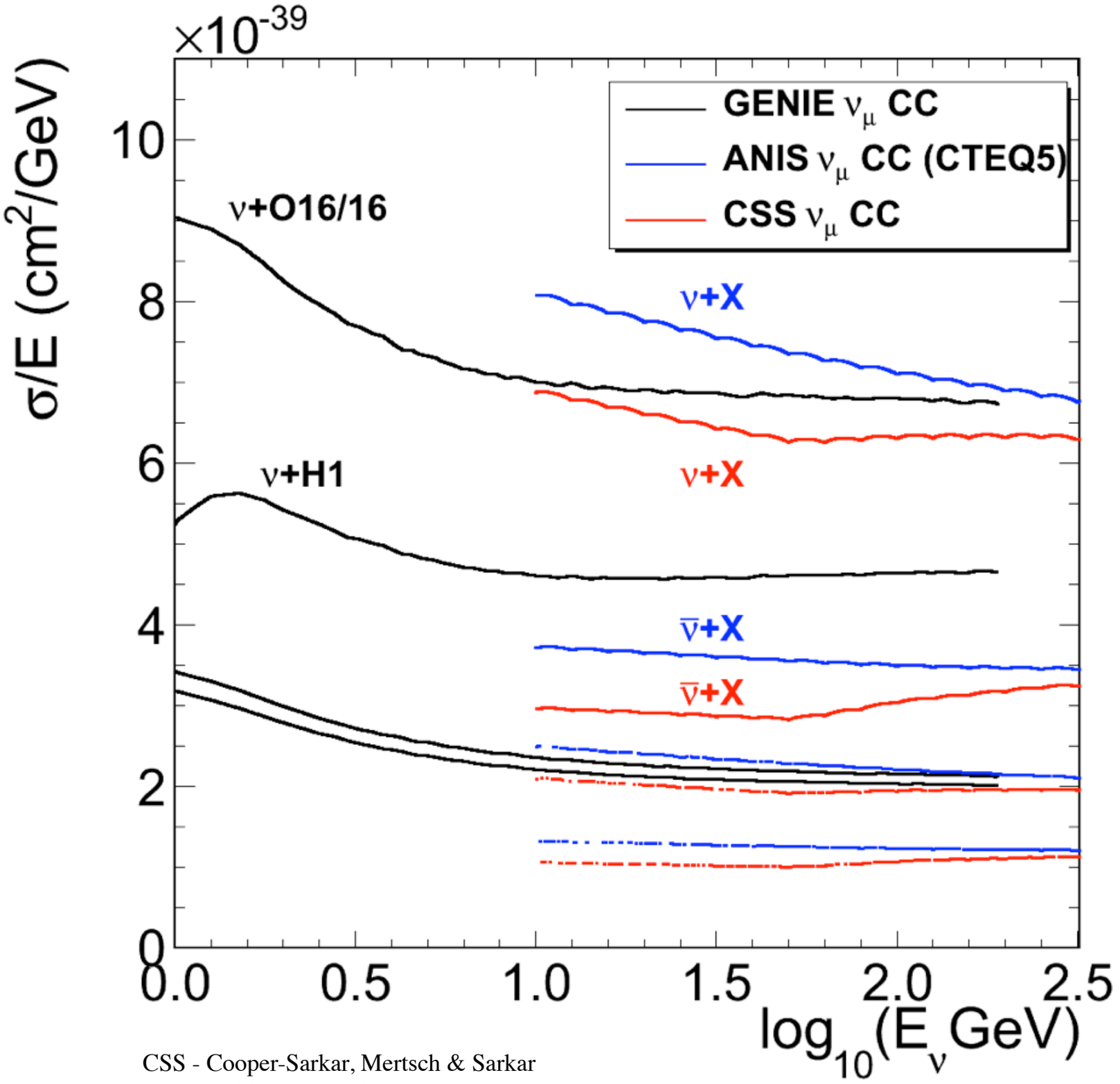


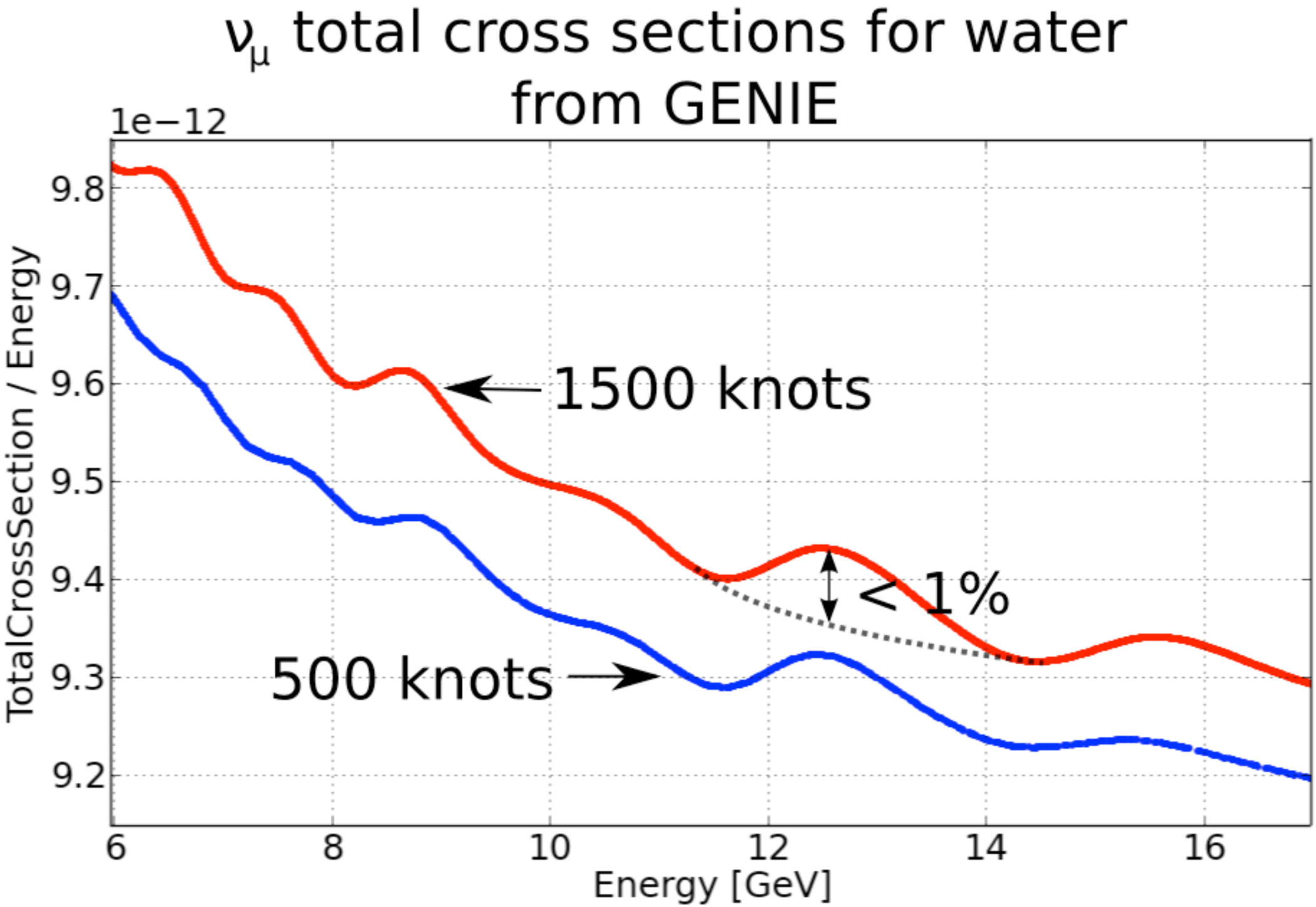
IceCube Generators

- Current cross-section models available in IceCube Monte Carlo simulation



CSS - Cooper-Sarkar, Mertsch & Sarkar
JHEP 1108 (2011) 042

GENIE


ν_μ total cross sections for water from GENIE
1e−12
9.8
9.7
9.6
9.5
9.4
9.3
9.2
TotalCrossSection / Energy
1500 knots
500 knots
< 1%
6
8
10
12
14
16
Energy [GeV]

Atmospheric ν_e

- First observation of neutrino induced cascades in IceCube was completed using a DeepCore data selection
- Background subtraction (mis-ID'd numu CC, atm. muons and all NC) provides a atm. nue flux