Atmospheric neutrino science with the IceCube Neutrino Observatory

Neutrino 2026
University of California, Irvine
Irvine, CA
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Dr. Spencer N. Axani
saxani@udel.edu
Assistant Professor
The University of Delaware
203 Sharp Lab
104 The Green, Newark, DE 19716
(608) 572-8426

Presenting on results published after Neutrino 2024 on behalf of the IceCube Collaboration

IceCube Neutrino Observatory

NSF

University of Delaware Bartol Research Institute

University of Delaware

ICECUBE
NEUTRINO OBSERVATORY
IC78
A CUBIC KILOMETER OF CLEAR ANTARCTIC ICE INSTRUMENTED TO DETECT NEUTRINOS
ICETOP
Water Čerenkov surface array
324 DOMs
ICECUBE LABORATORY (ICL)
STRINGS
Vertical holes drilled in the ice in a grid covering 1km²
In-Ice Optical Modules
DIGITAL OPTICAL MODULE (DOM)
Each DOM contains:
• 10” PMT
• Readout electronics
• Calibration LEDs
5,160 DOMs total
78 STRINGS
60 DOMs per string
17m vertical spacing
125m horizontal spacing
0m
50m
1450m
2450m
2850m
Bedrock
EMPIRE STATE
443m


ICECUBE
NEUTRINO OBSERVATORY
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ICETOP
Water Čerenkov surface array
324 DOMs
ICECUBE LABORATOR (ICL)
STRINGS
Vertical holes drilled in the ice in a grid covering 1km²
IC86
In-Ice Optical Modules
DIGITAL OPTICAL MODULE (DOM)
Each DOM contains:
• 10” PMT
• Readout electronics
• Calibration LEDs
5,160 DOMs total
0m
50m
1450m
2450m
2850m Bedrock
DEEPCORE Sub-Array
8 Optimized strings
60 DOMs per string
‣ 384 HQE DOMs
‣ 96 Standard QE DOMS
7m vertical spacing
40-70m horizontal spacing
EMPIRE STATE
443m

ICECUBE
NEUTRINO OBSERVATORY
IC91
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DIGITAL OPTICAL MODULE (DOM)
Each DOM contains:
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5,160 DOMs total
ICECUBE UPGRADE (ICU)
5 Specialized Strings
~100 OMs per string
+ calibration devices
2.4m vertical spacing
0m
50m
1450m
2450m
2850m
Bedrock
EMPIRE STATE
443m


IceCube
Neutrino Observatory
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288 mDOMs total
ICECUBE UPGRADE (ICU)
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4


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DUAL SENSORS IN AN ELLIPSOID GLASS FOR GEN2 (D-Egg)
Each D-Egg contains:
• Two 8” HQE PMT
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200 D-Eggs total

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ν_μ ($\sim$ 1 TeV)
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ν_μ ($\sim$ 100 GeV)
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CASCADES
Neutral Current ν Interaction
ν
ν
Z^0
q
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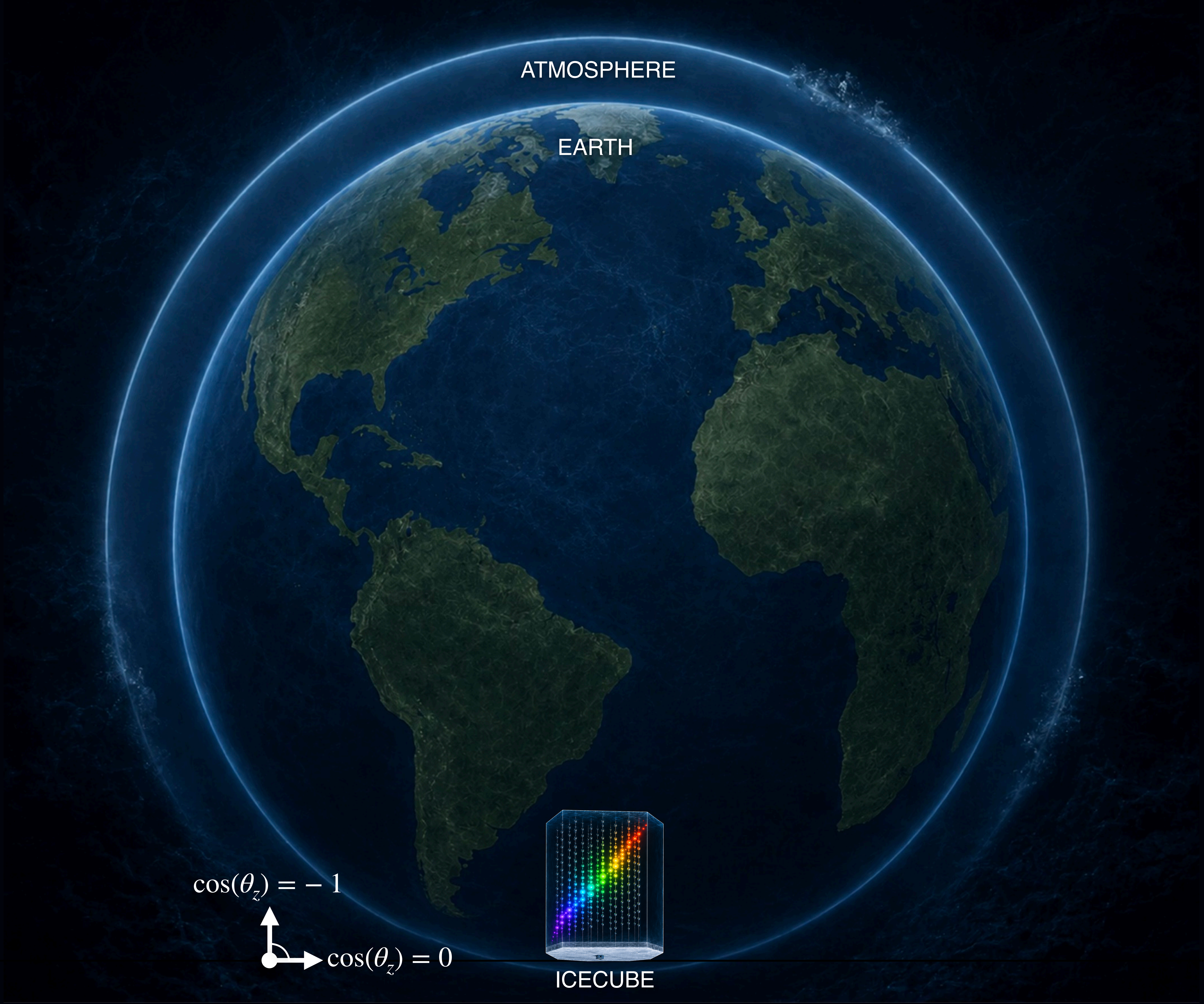
ATMOSPHERE
EARTH
$\cos(\theta_z) = -1$
$\cos(\theta_z) = 0$
ICECUBE


ATMOSPHERE
EARTH
COSMIC RAY
MESONS
ν
μ
ATMOSPHERIC NEUTRINOS
Event rate in IceCube: ~mHz
Composition at source: $1\nu_e : 2\nu_\mu : 0\nu_\tau$
Primary channels: kaon, pion, D-mesons
$\cos(\theta_z) = -1$
$\cos(\theta_z) = 0$
ICECUBE
SPL all direction average
ν_μ
$\bar{\nu}_\mu$
ν_e
$\bar{\nu}_e$
$\phi_\nu \times E_\nu^3$ (m^{-2} s^{-1} sr^{-1} GeV^2)
E_ν (GeV)
HKKM: Phys. Rev. D92, 023004 (2015)

ATMOSPHERE
EARTH
COSMIC RAY
ν
ASTROPHYSICAL NEUTRINOS
Event rate in IceCube: ~10μHz
Composition at source: still unknown
Dominant neutrino flux above 100TeV
MESONS
ν
ATMOSPHERIC NEUTRINOS
Event rate in IceCube: ~mHz
Composition at source: $1\nu_e : 2\nu_\mu : 0\nu_\tau$
Primary channels: kaon, pion, D-mesons
μ
SPL all direction average
ν_μ
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$\bar{\nu}_e$
$\phi_\nu \times E_\nu^3\ (\mathrm{m^{-2}\,s^{-1}\,sr^{-1}\,GeV^2})$
E_ν (GeV)
10^{-1} 10^0 10^1 10^2 10^3 10^4
10^0 10^1 10^2 10^3
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$\cos(\theta_z) = -1$
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Event rate in IceCube: ~10μHz
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SEE PROF.
ALI KHEIRANDISH'S
TALK ON WEDNESDAY
10:15AM
MESONS
ν
ATMOSPHERIC NEUTRINOS
Event rate in IceCube: ~mHz
Composition at source: $1\nu_e : 2\nu_\mu : 0\nu_\tau$
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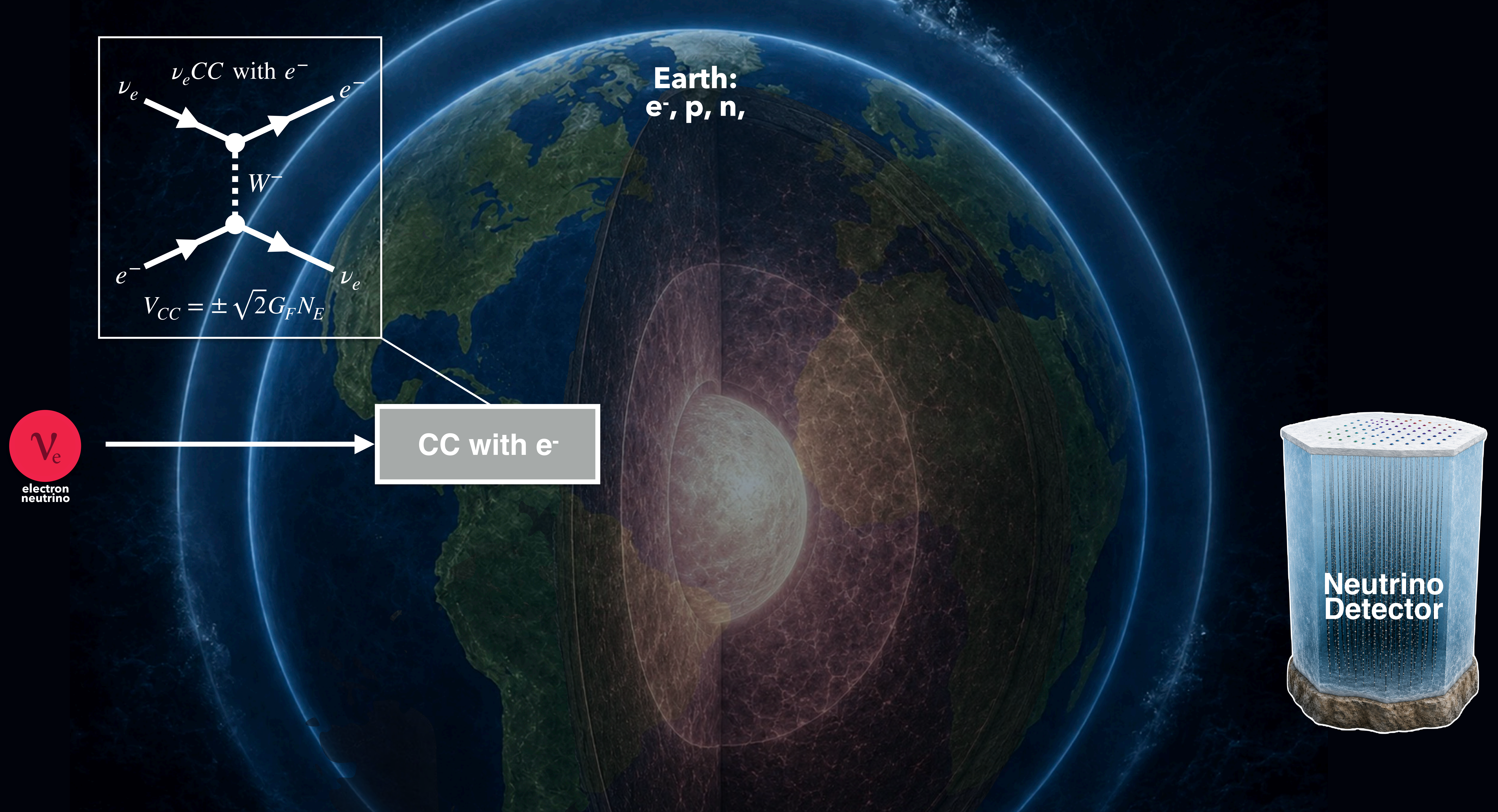
Earth-Transiting Neutrino Oscillations

The presence of matter affects vacuum neutrino oscillations through coherent forward scattering of electron neutrinos or antineutrinos.

Earth-Transiting Neutrino Oscillations



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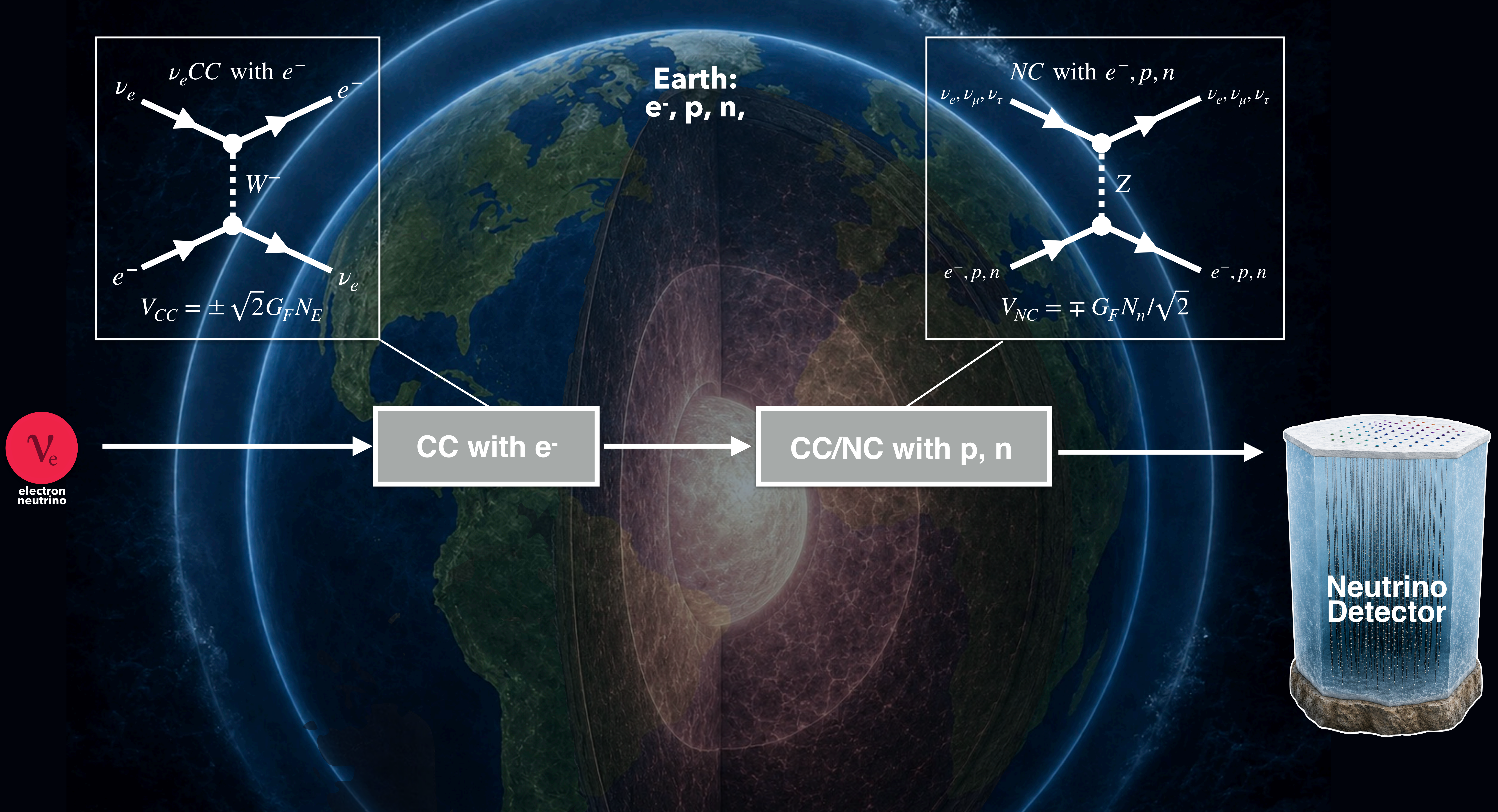

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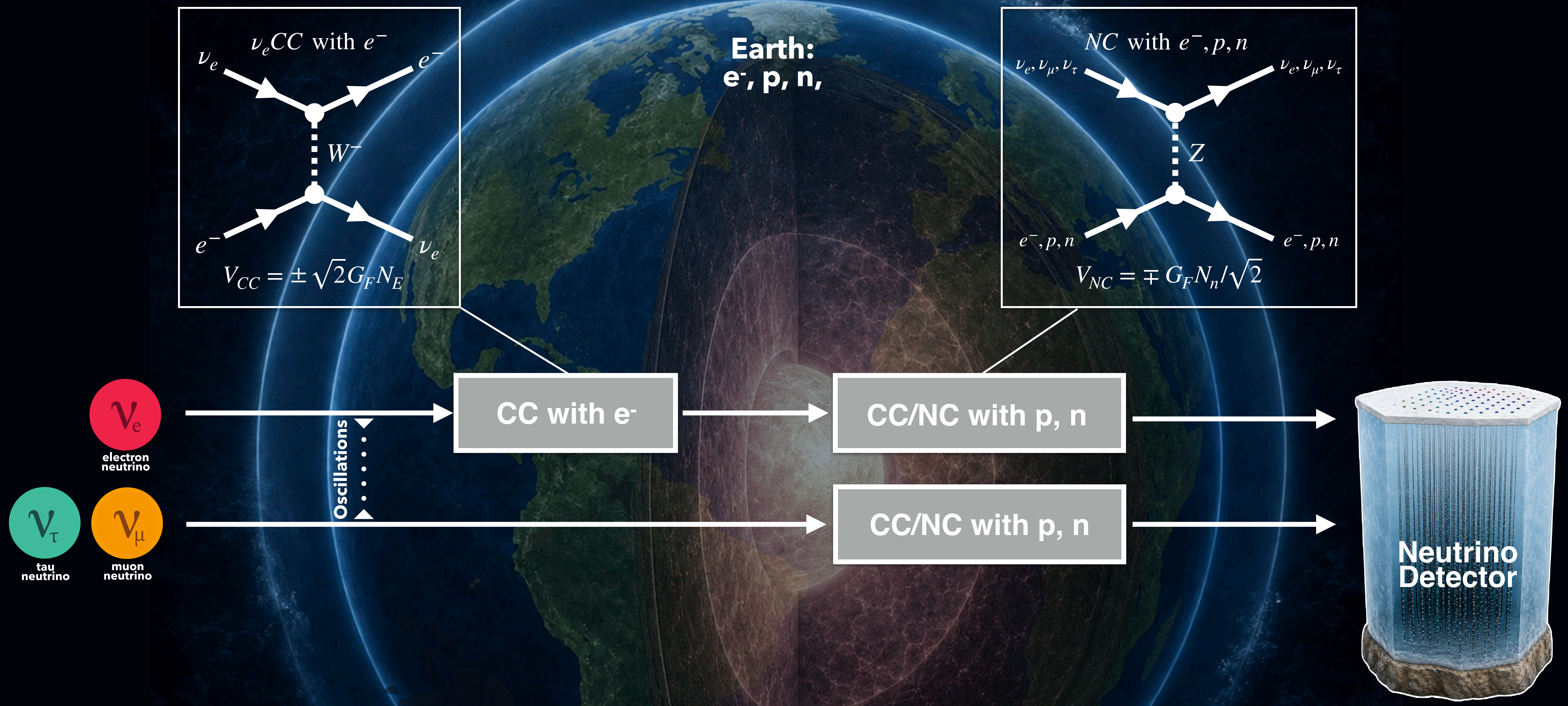
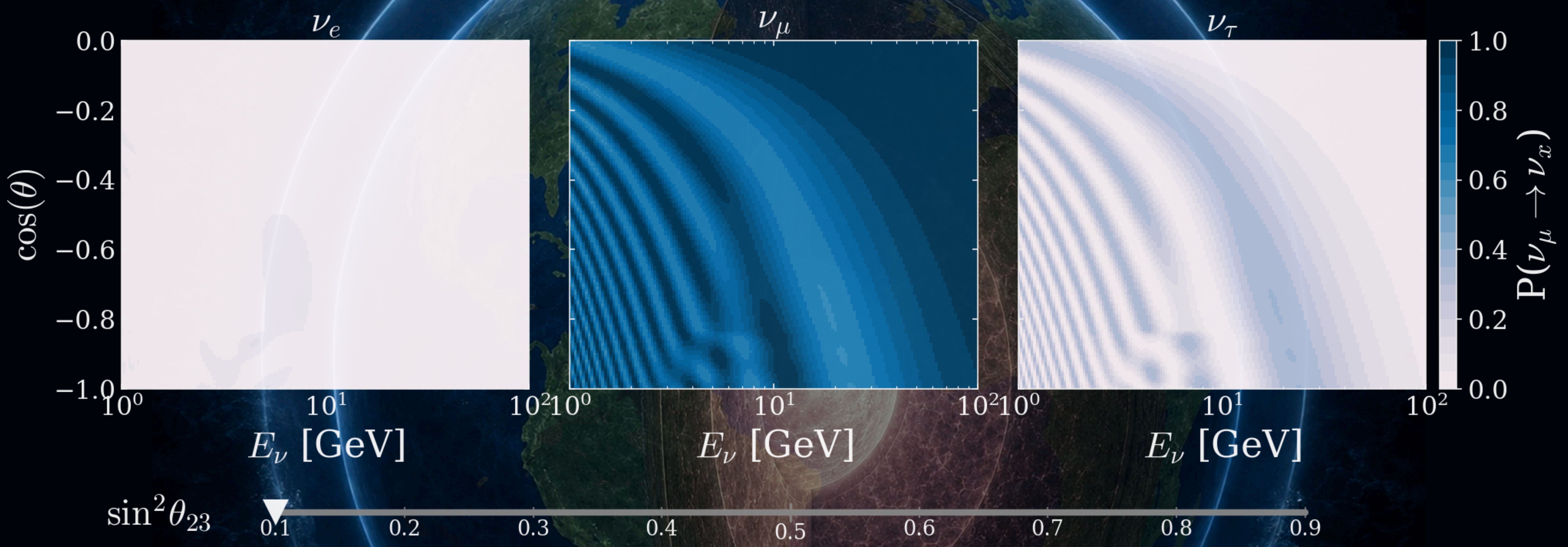


The presence of matter affects vacuum neutrino oscillations through coherent forward scattering of electron neutrinos or antineutrinos.

Earth-Transiting Neutrino Oscillations Signature

P($\nu_\mu \rightarrow \nu_x$) oscillogram passing through earth, assuming Normal Ordering (NO): $\mathrm{m}_3 > \mathrm{m}_2 > \mathrm{m}_1$.



nuSQuIDS: arXiv:2112.13804

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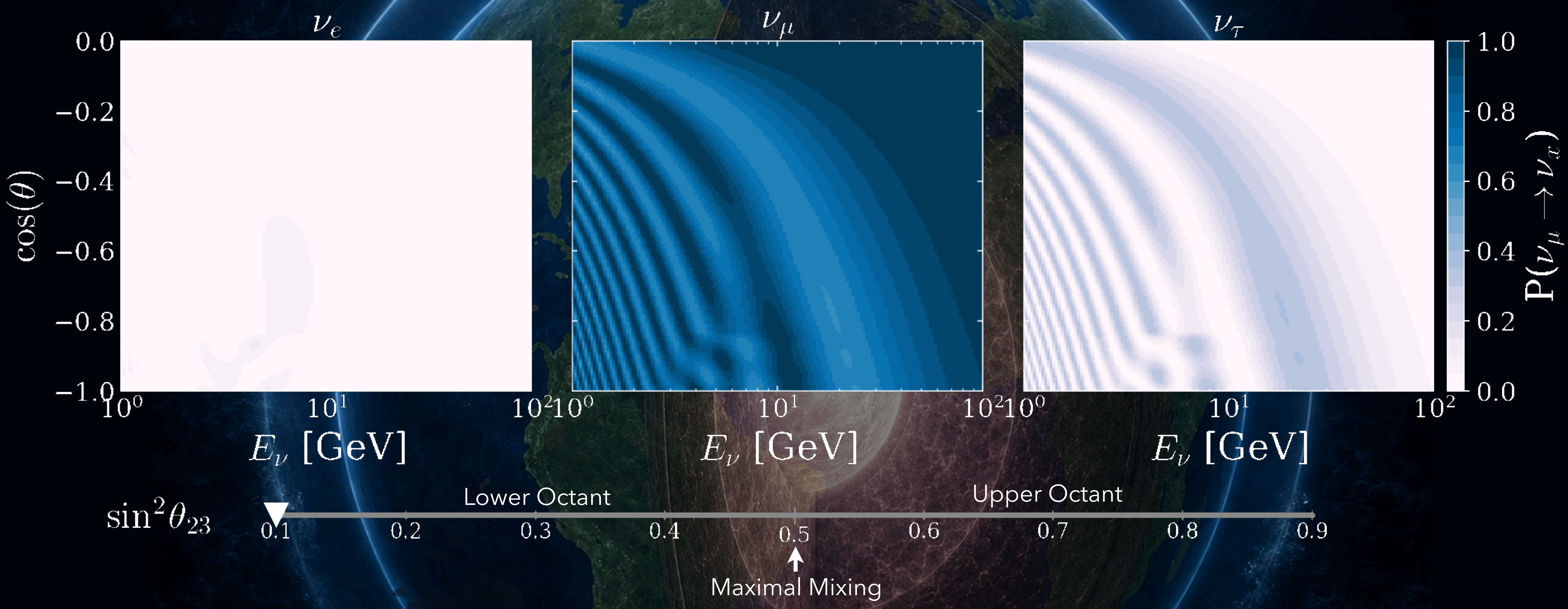

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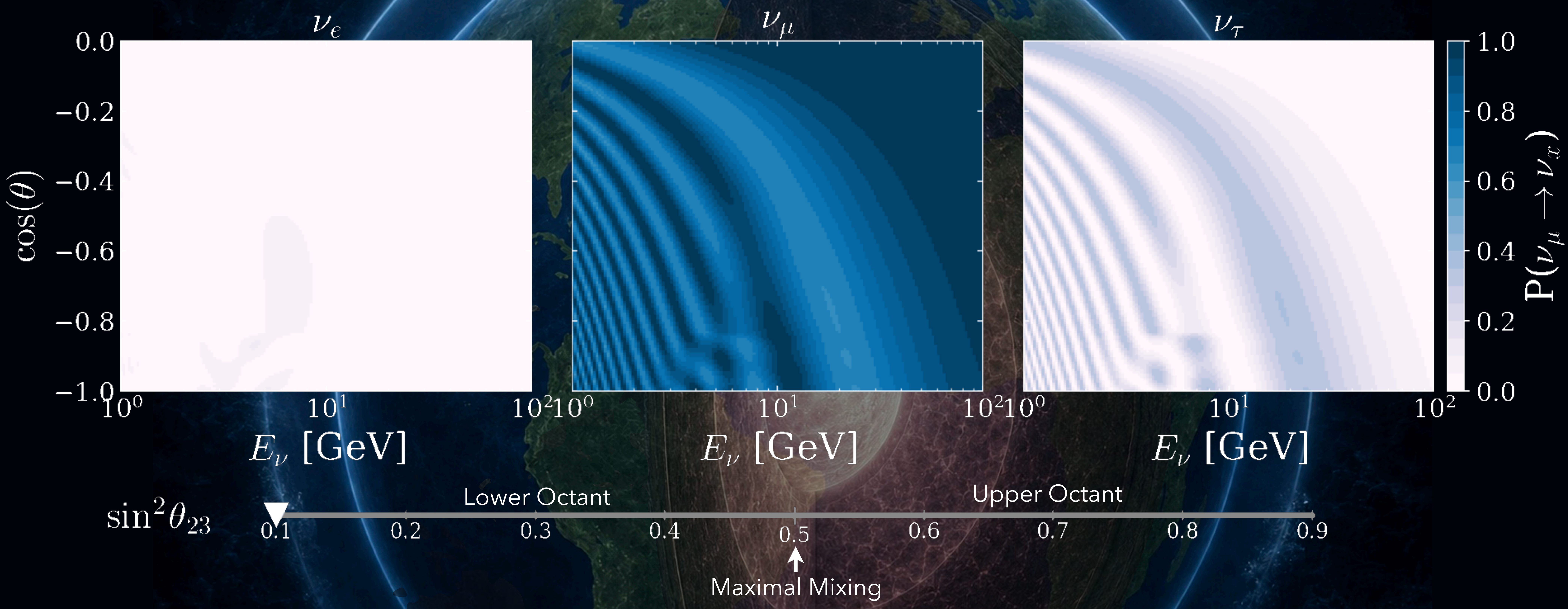

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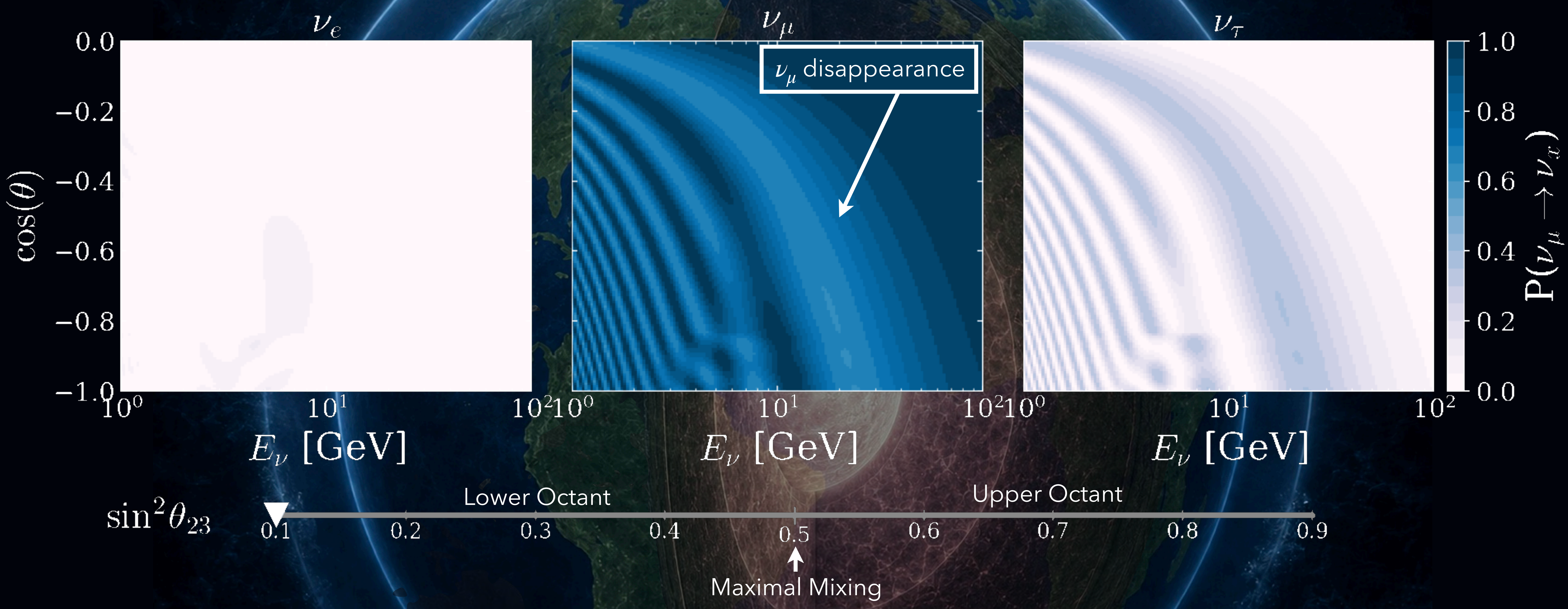

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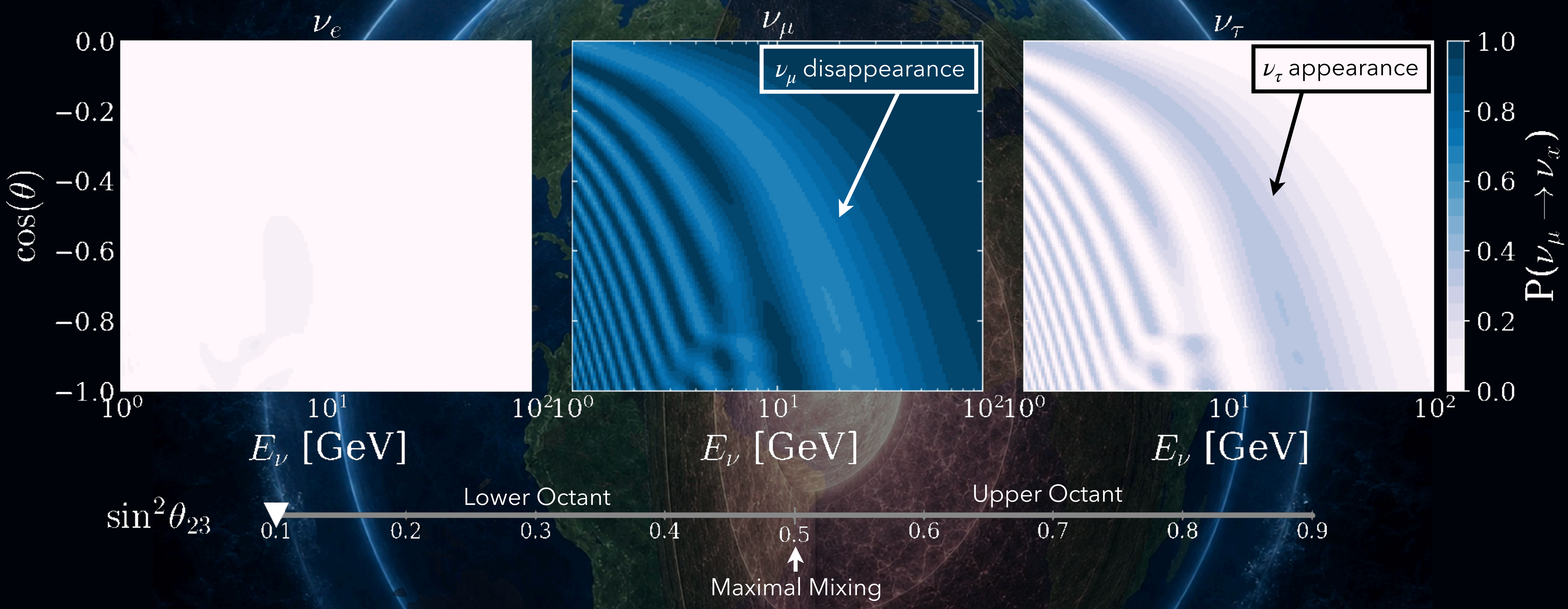
Earth-Transiting Neutrino Oscillations Signature

P($\nu_\mu \rightarrow \nu_x$) oscillogram passing through earth, assuming Normal Ordering (NO): $m_3 > m_2 > m_1$.



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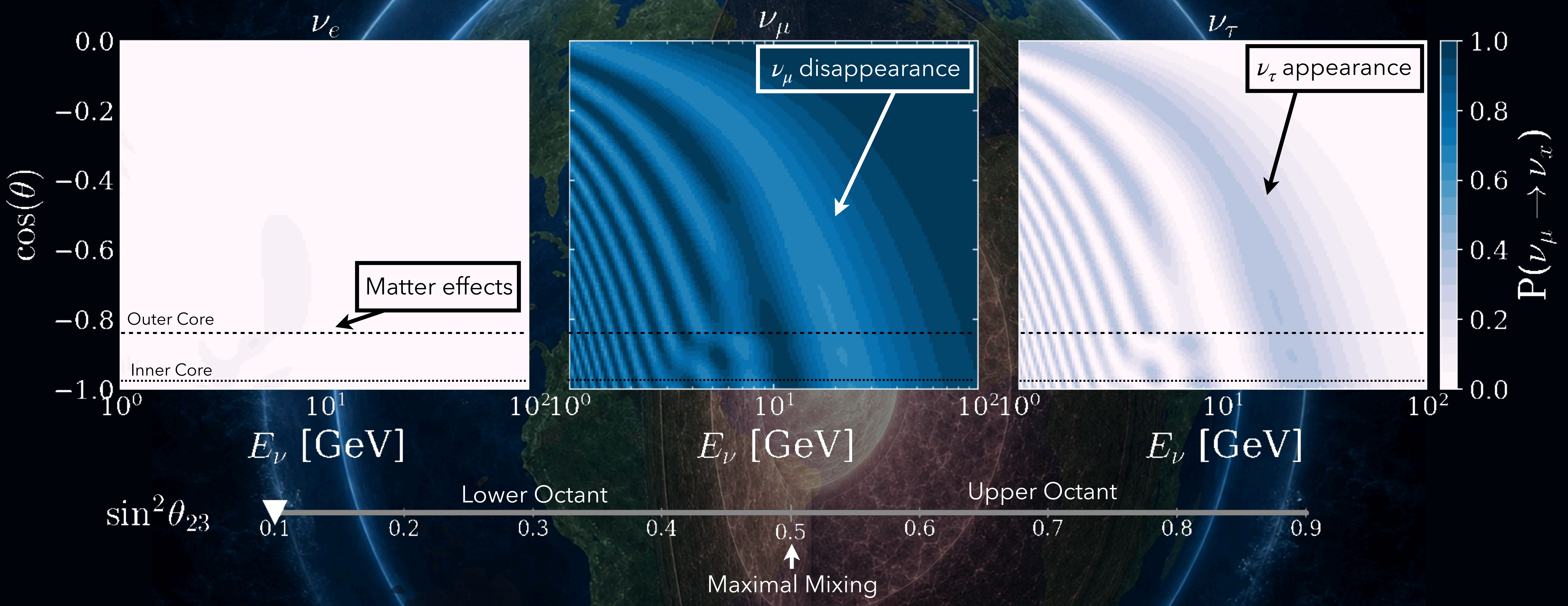

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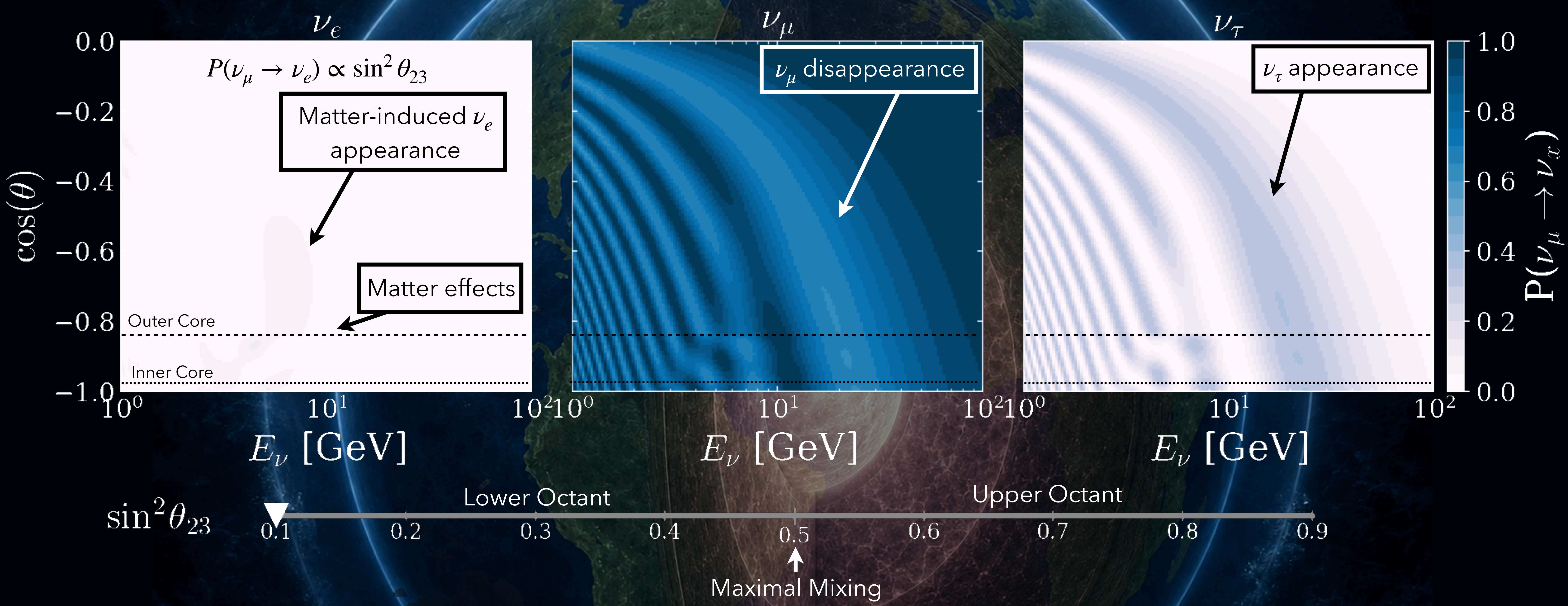

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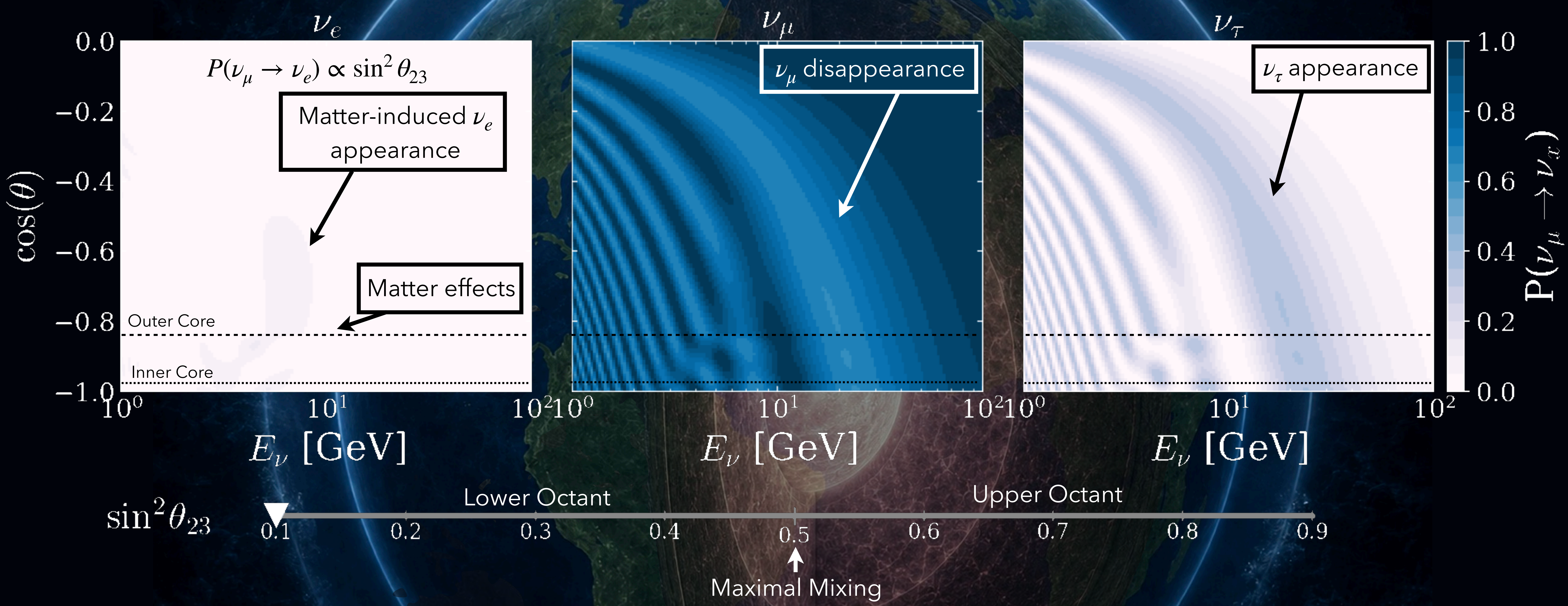

- For Inverting Ordering (IO): $m_3 < m_2 < m_1$, the matter effect moves into the antineutrino flux.

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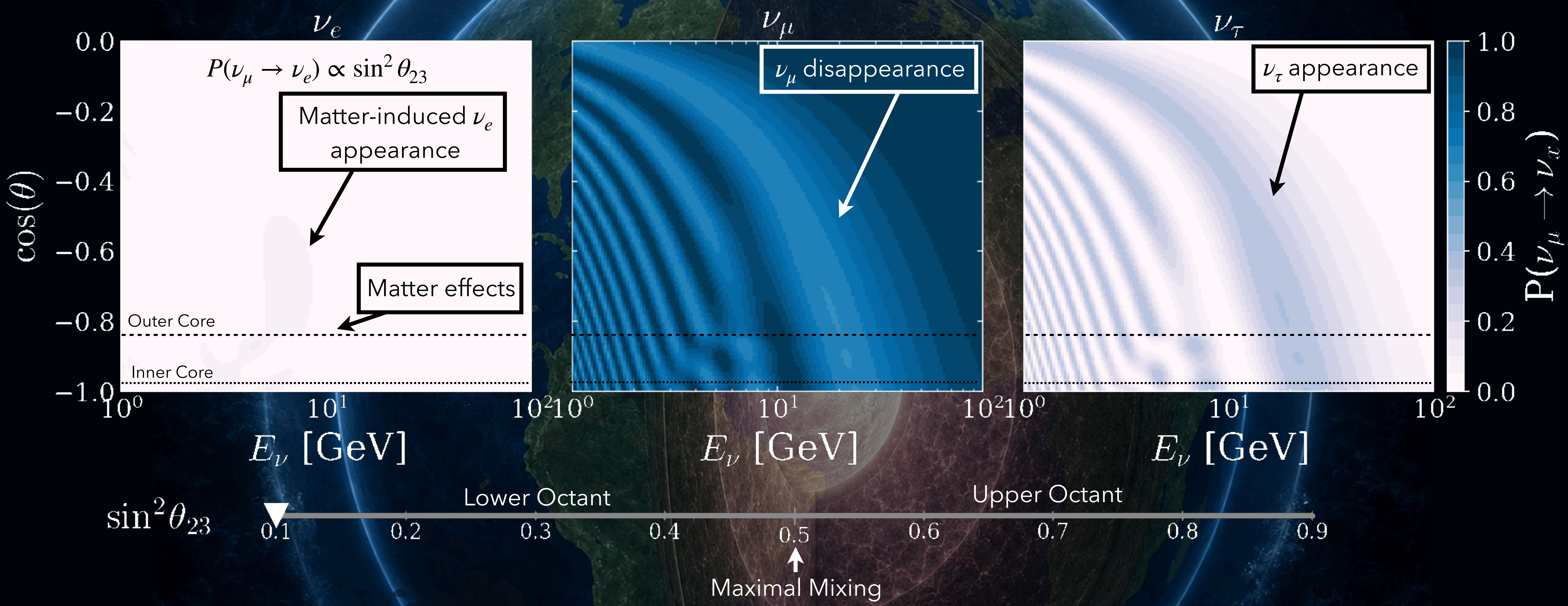

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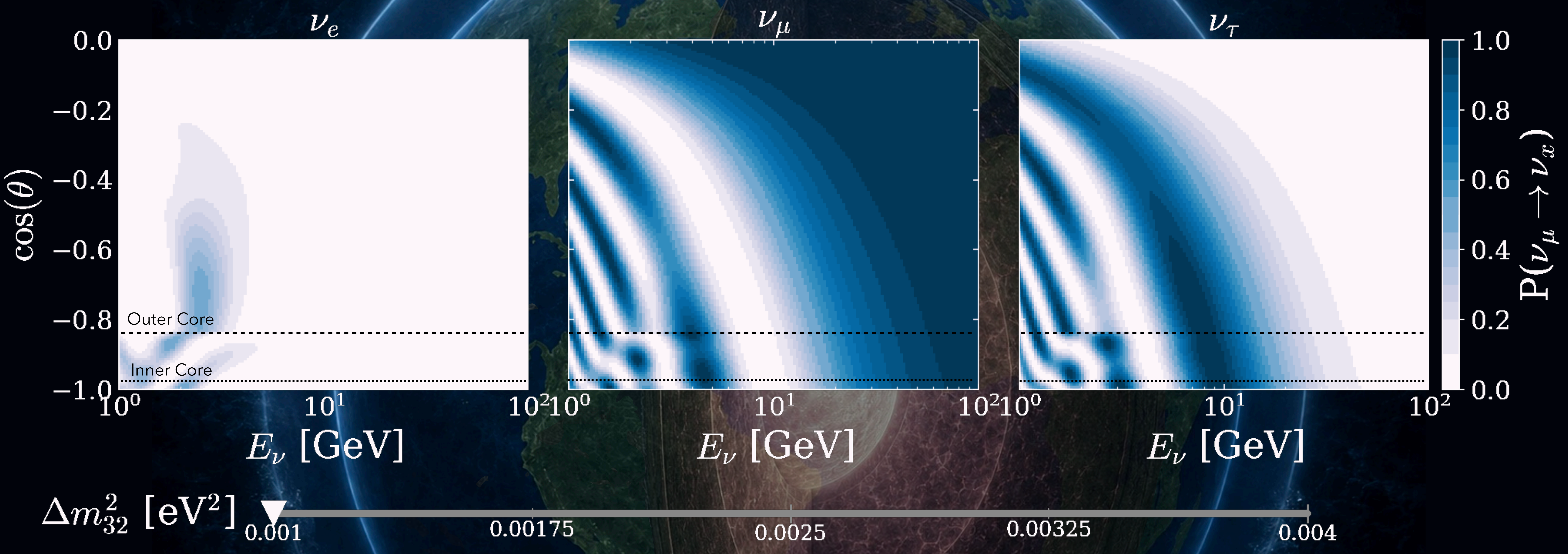

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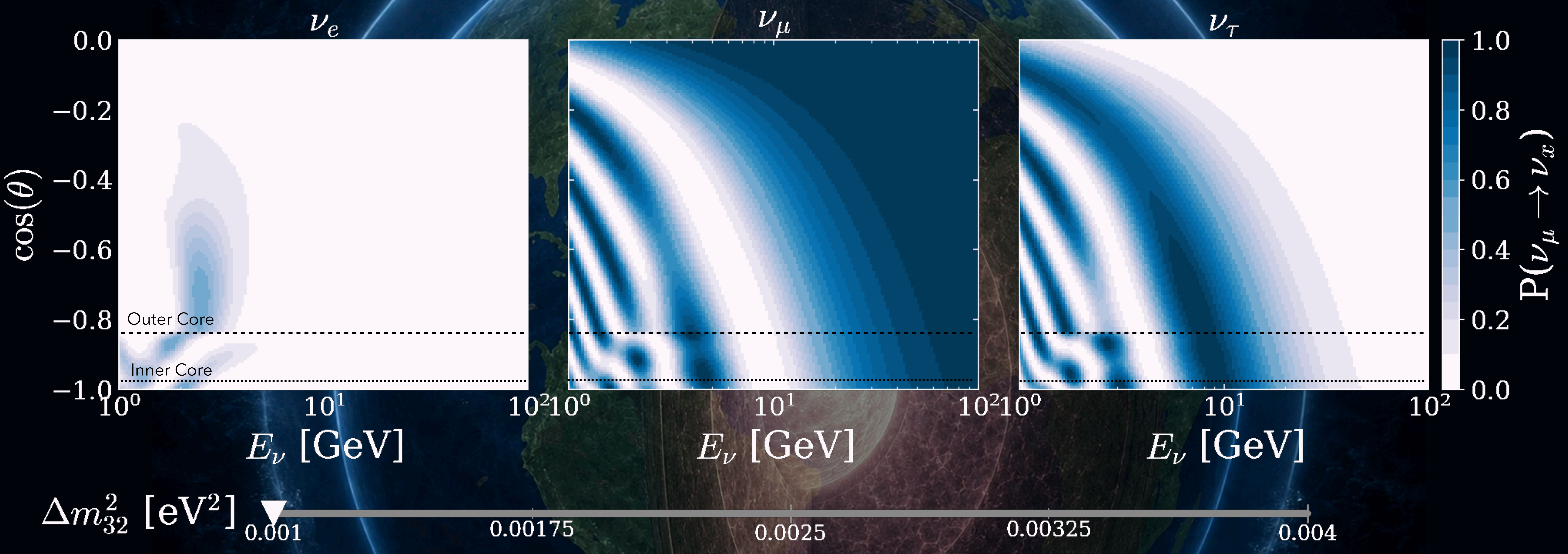

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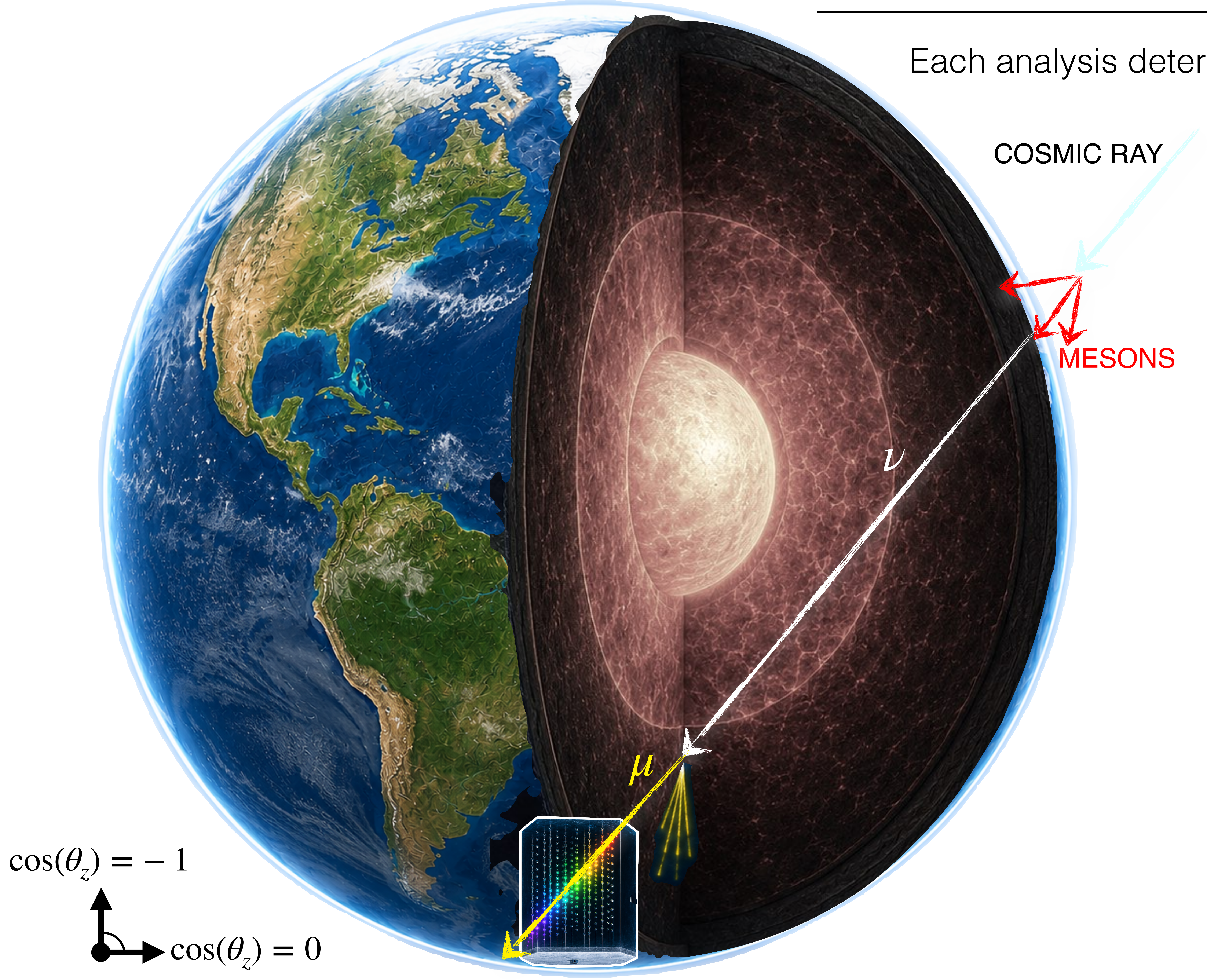
Overview of systematic uncertainties

Each analysis determines how sensitive it is to:



Conventional ν flux uncertainties

- ν production rates from pions and kaons (DAEMONFLUX [1], BARR)
- Atmospheric density (new IC seasonal variations result in [2])

Careful systematic control through probing multiple baselines (L/E).

[2] Seasonal Variations of the Atmospheric Muon Neutrino: Eur. Phys. J. C 85, 1368 (2025)
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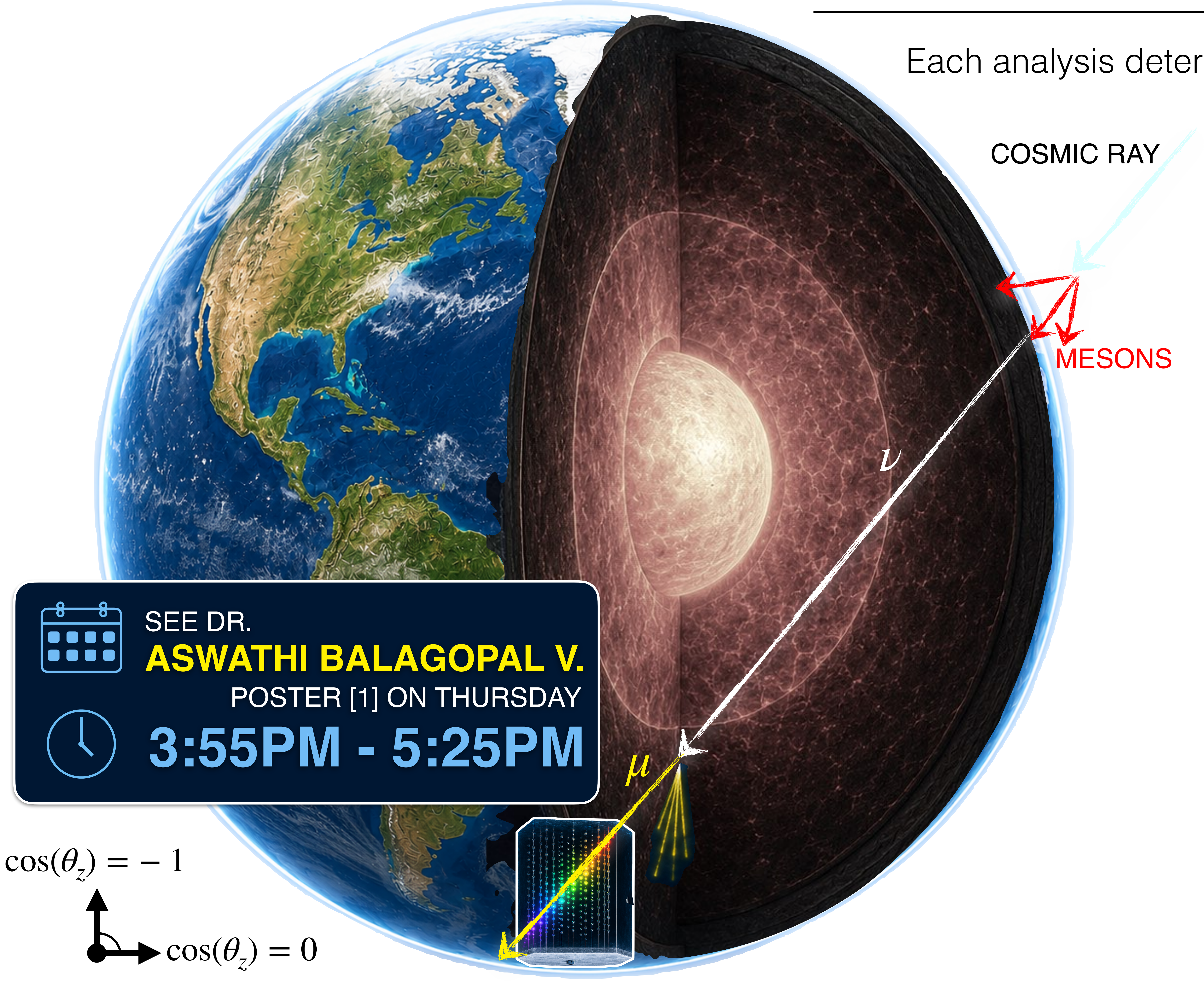

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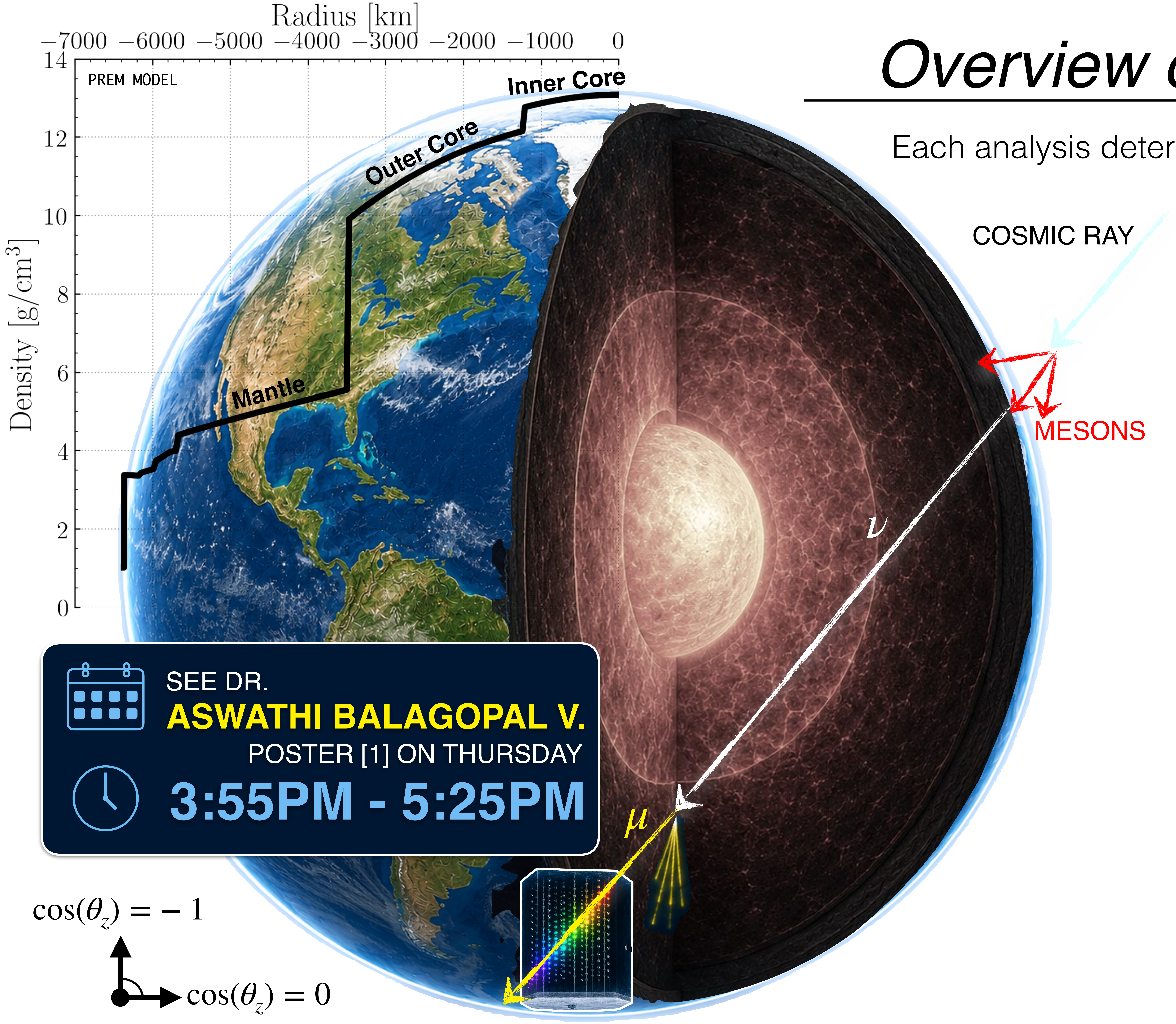

SEE DR.
ASWATHI BALAGOPAL V.
POSTER [1] ON THURSDAY
3:55PM - 5:25PM

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- Kaon energy loss in matter (re-interaction rates)
- ν-nucleon cross sections
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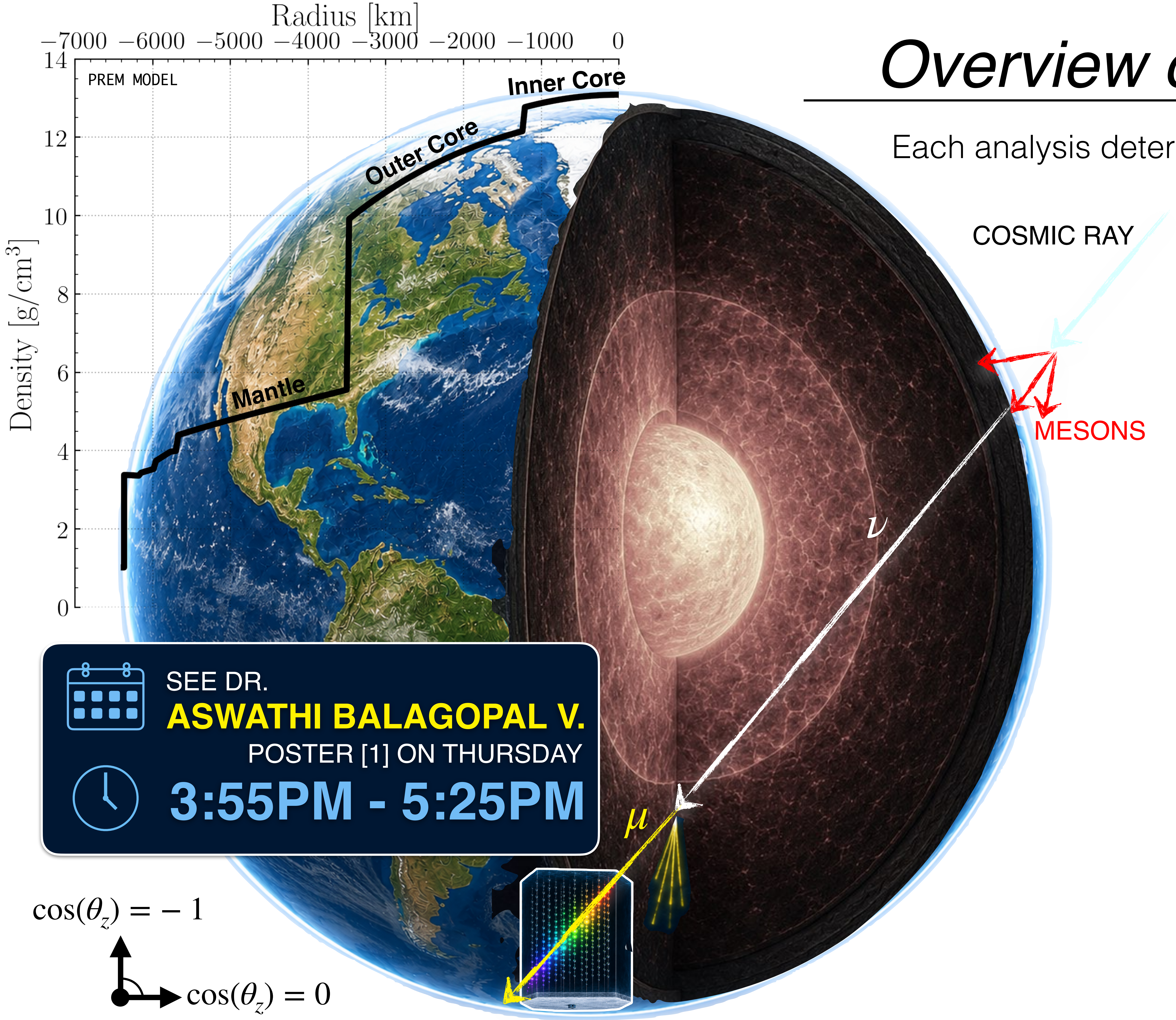

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- Global optical efficiency of the detector
- Photon scattering and absorption in bulk ice and dust
- The optical angular efficiency introduced by the hole ice

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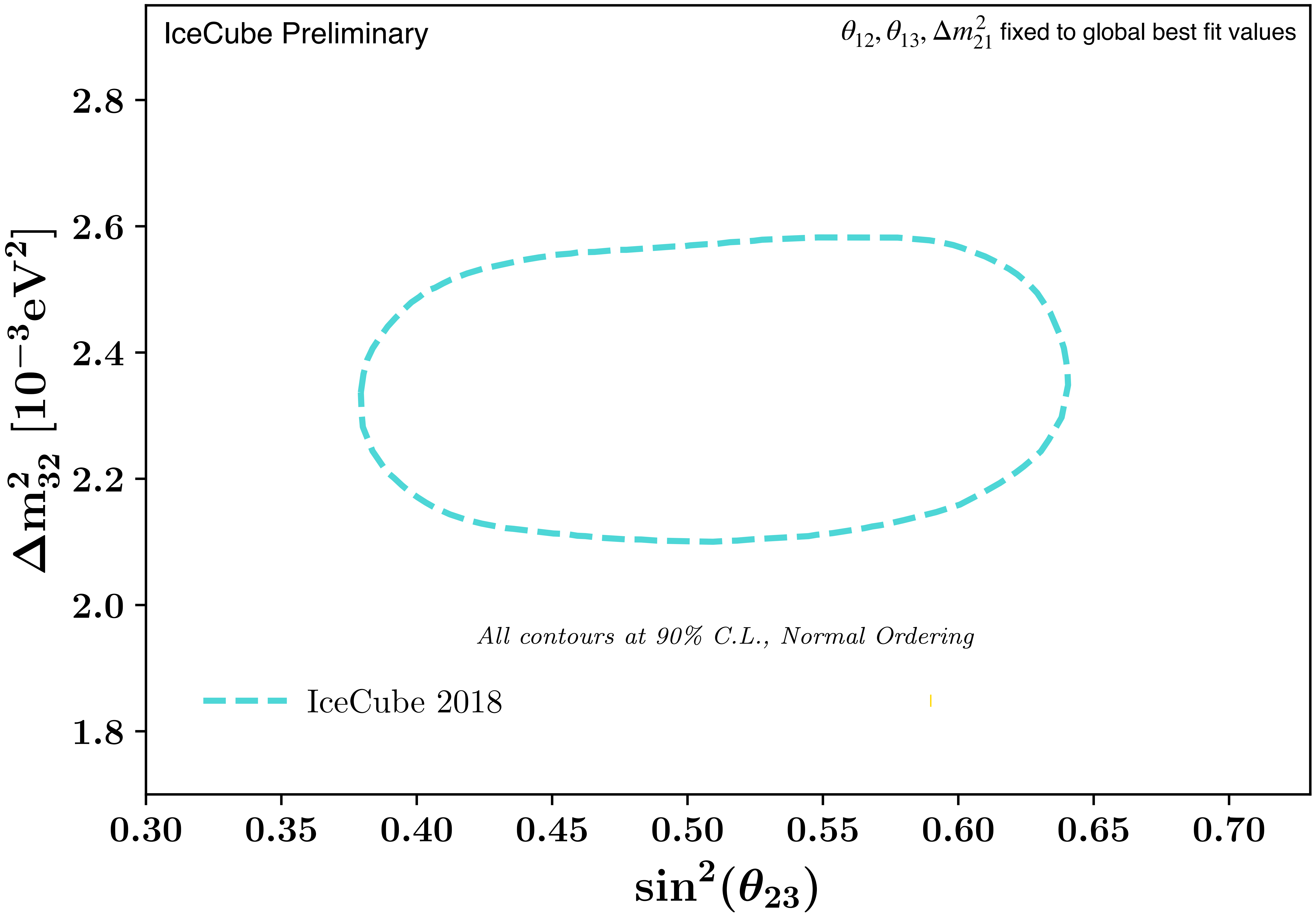
IceCube's ν_μ-disappearance DeepCore results



IC 2018 (3y): Physical review letters 120.7 (2018): 071801; IC 2019 (3y): Physical Review D 99.3 (2019): 032007.; IC 2023 (8y) Physical Review D 108.1 (2023) 012014; IC 2025 (9.3y): Physical review letters 134.9 (2025): 091801.

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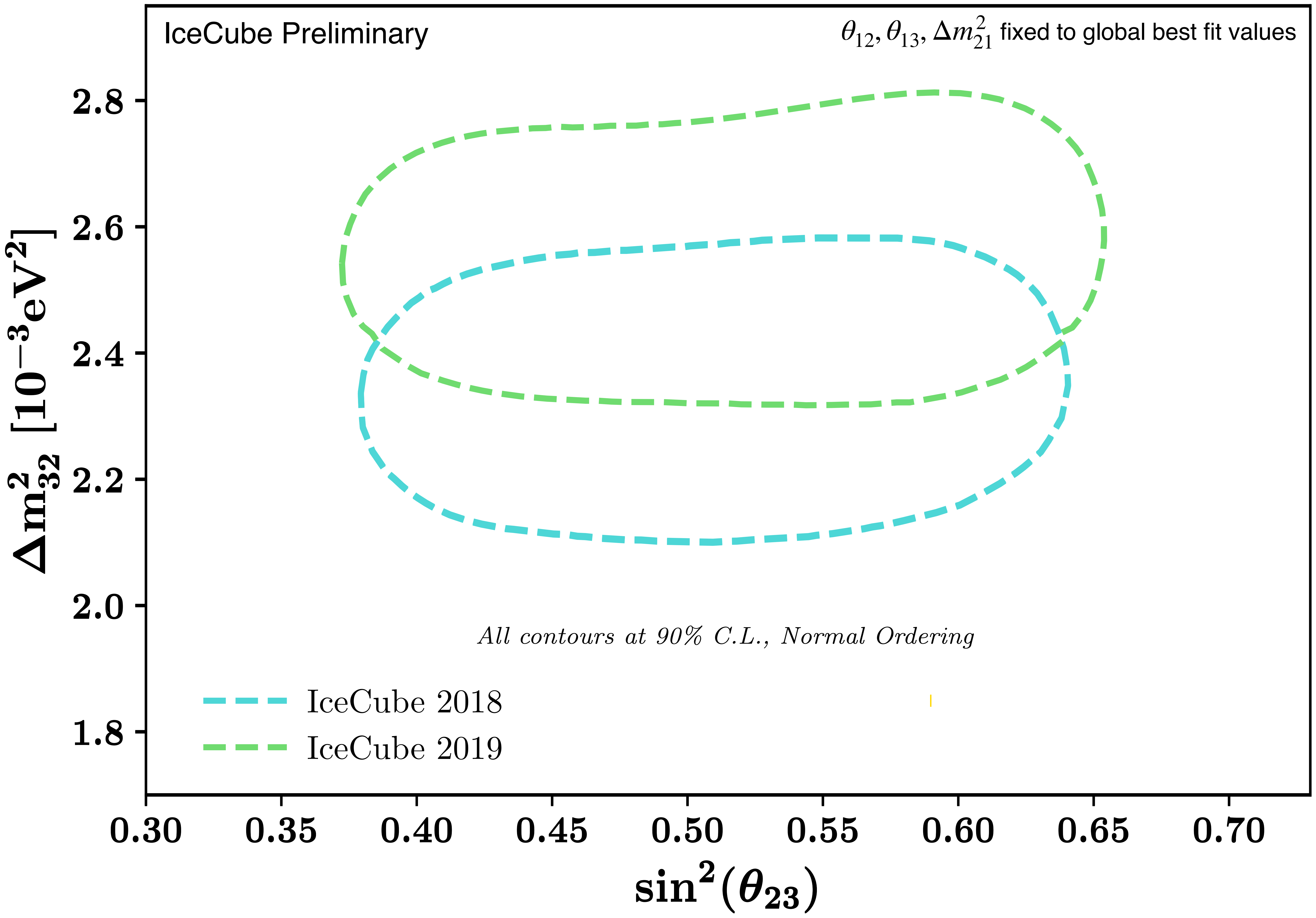

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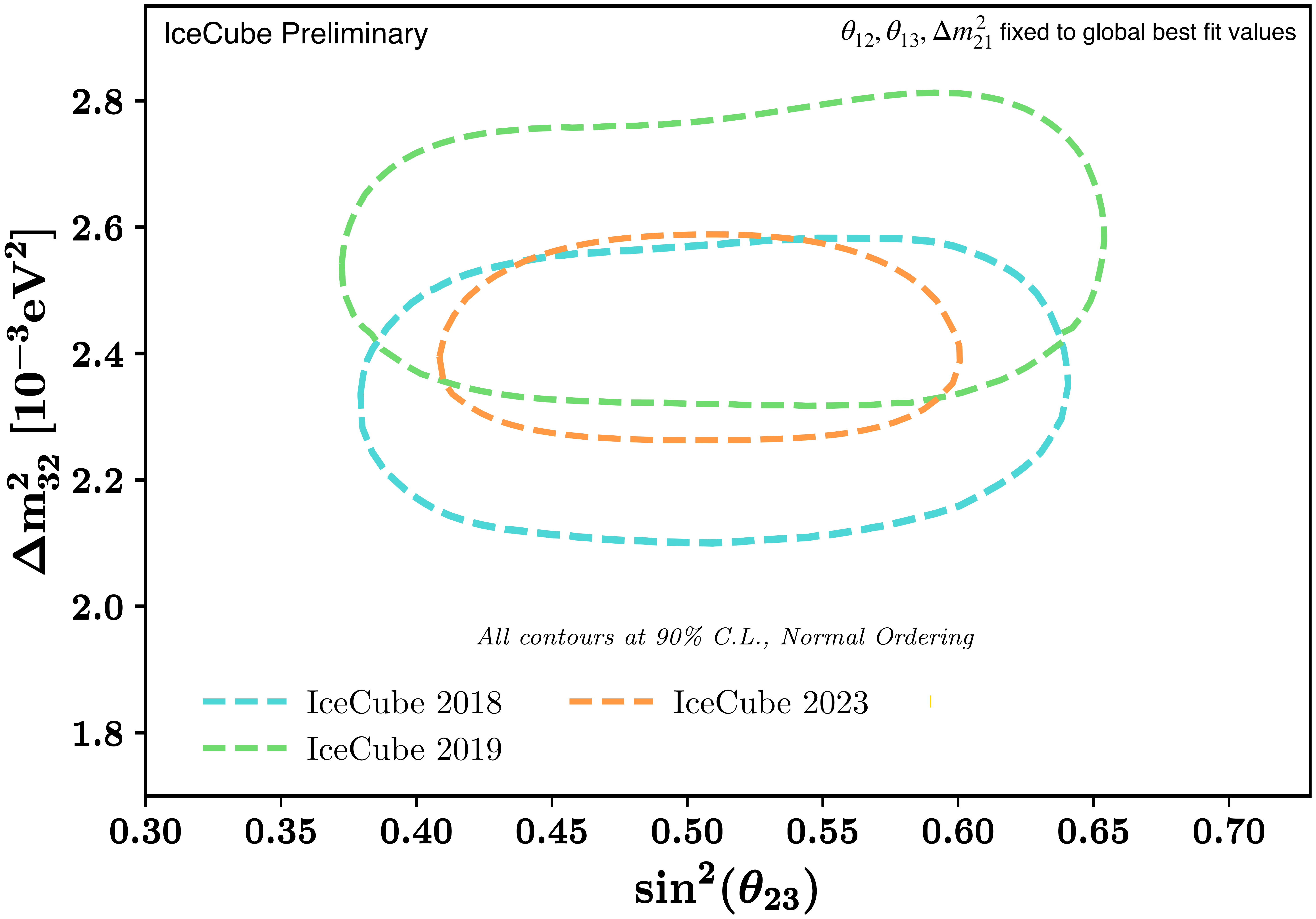

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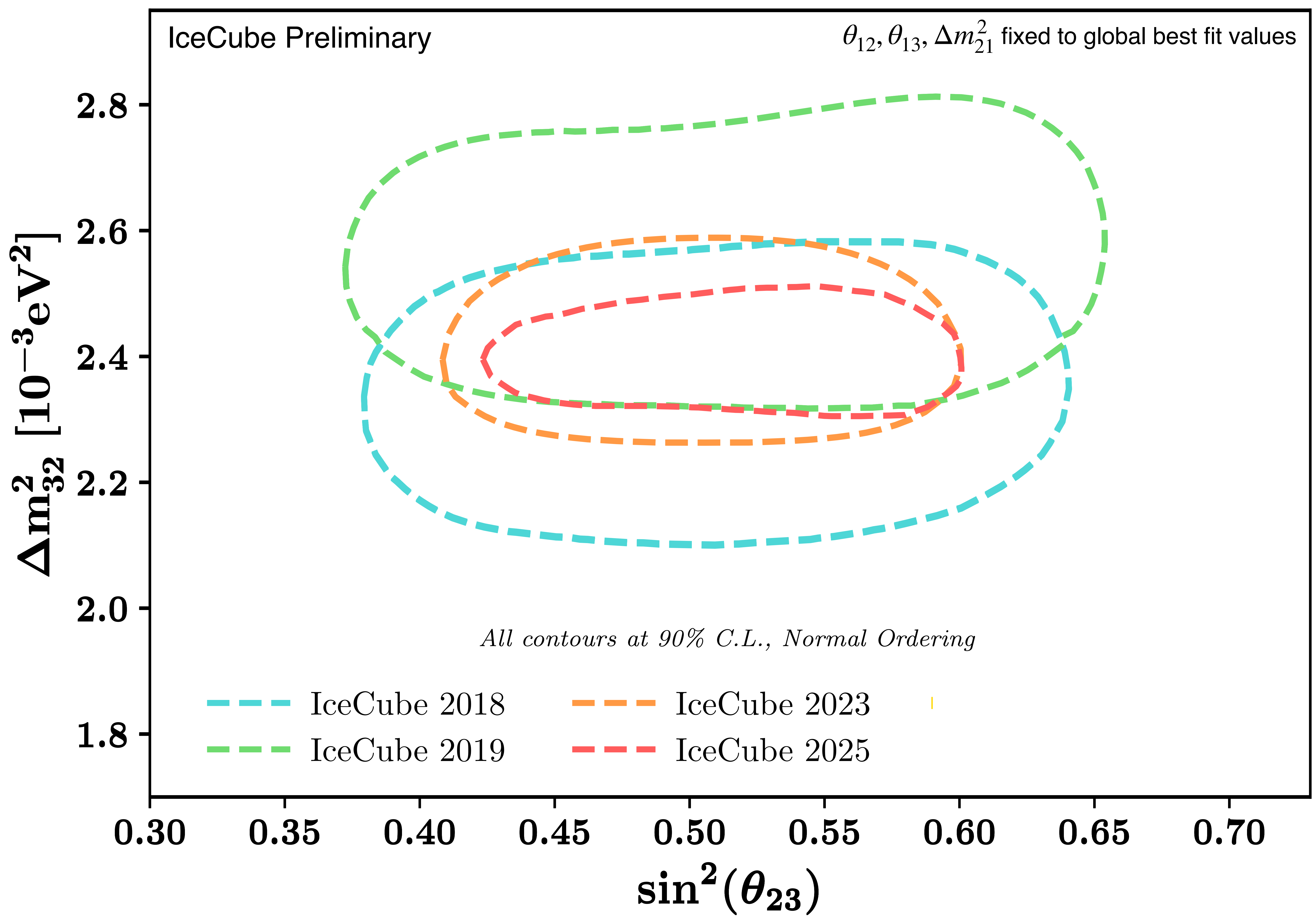

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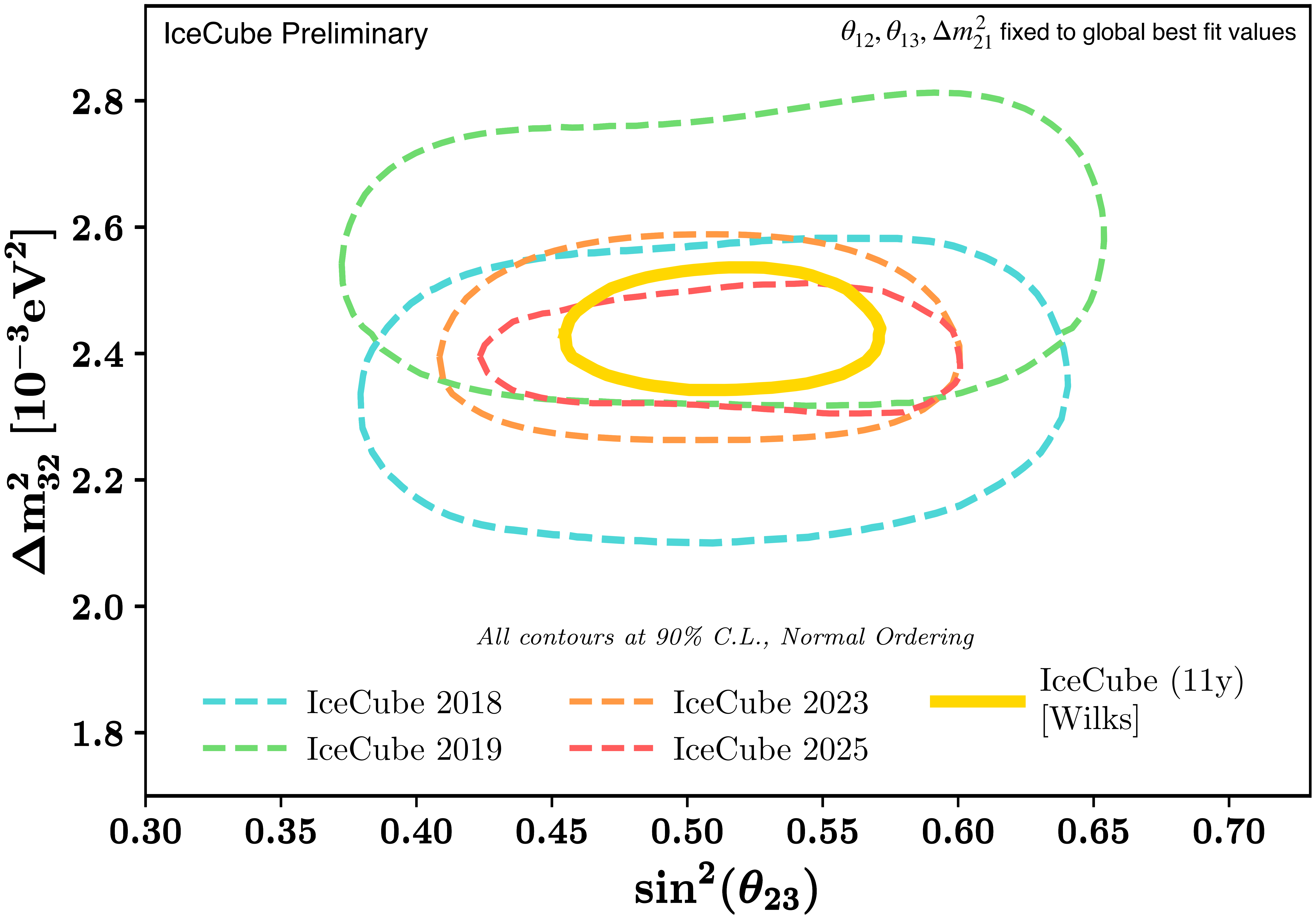

New Result (11y):

State-of-the-art GraphNet-based classification and reconstruction with robust classifier extreme gradient boosted decision tree (BDT):

- 11.1 years of data
- Excellent data MC agreement
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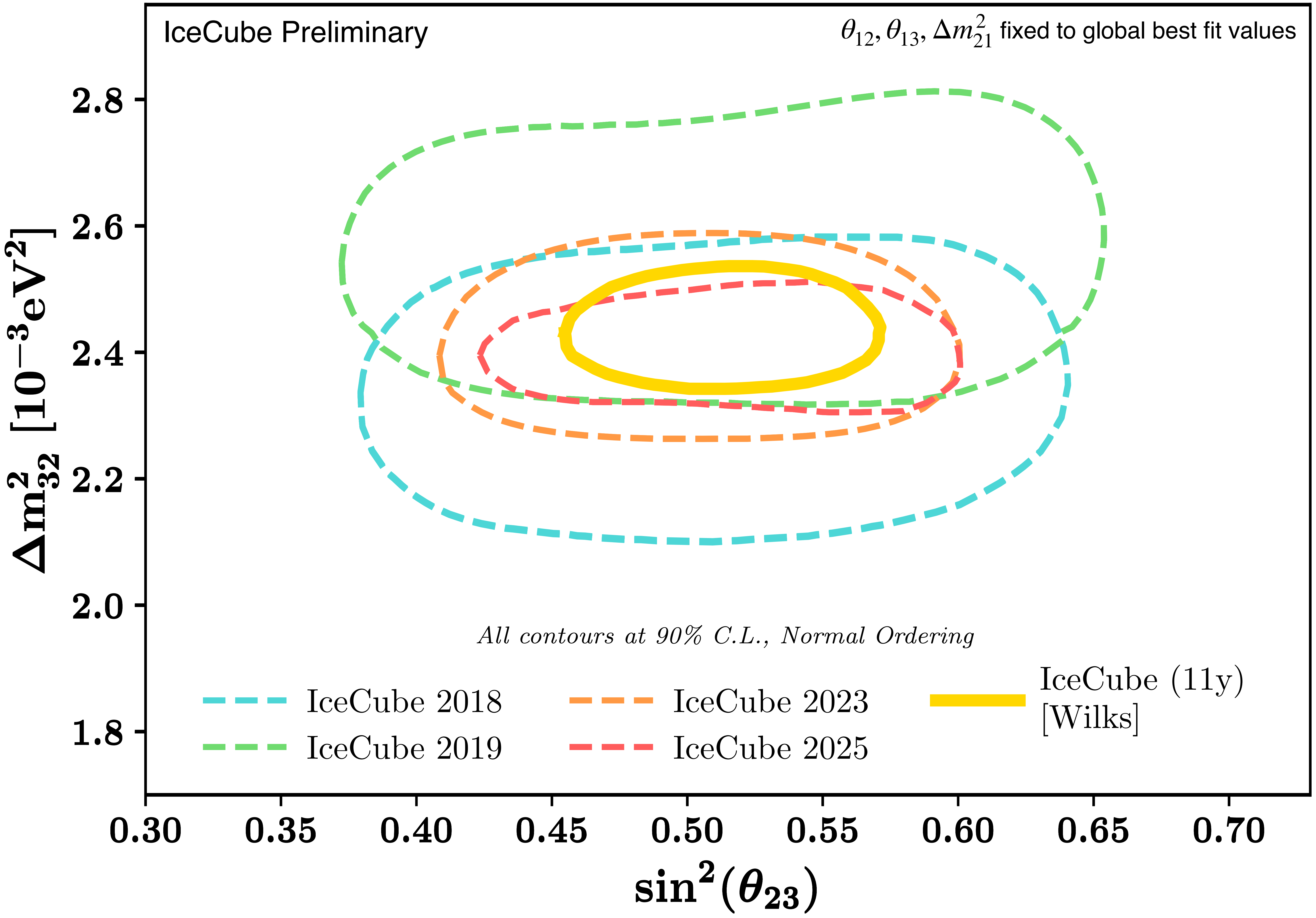

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ν_eCC	71	24,822 ± 56	22.8
ν_μCC	187	65,665 ± 97	60.4
ν_τCC	16	5,629 ± 21	5.2
ν NC	34	11,912 ± 39	11.0
μ_{atm}	2	754 ± 46	0.7
Total	311	108,784 ± 129	100

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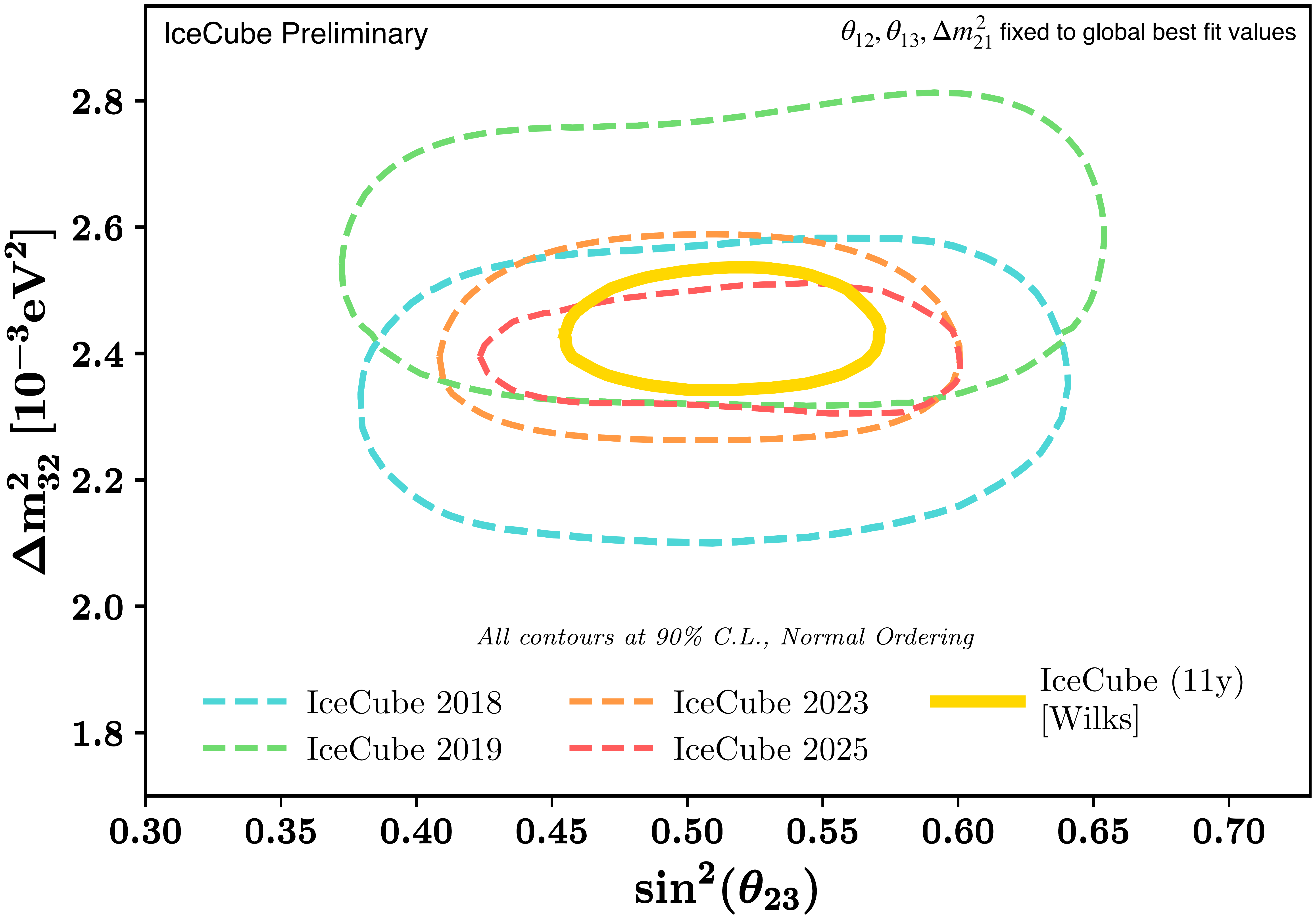

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Result consistent with previous IceCube results.

Feldman Cousins corrections and paper in preparation.

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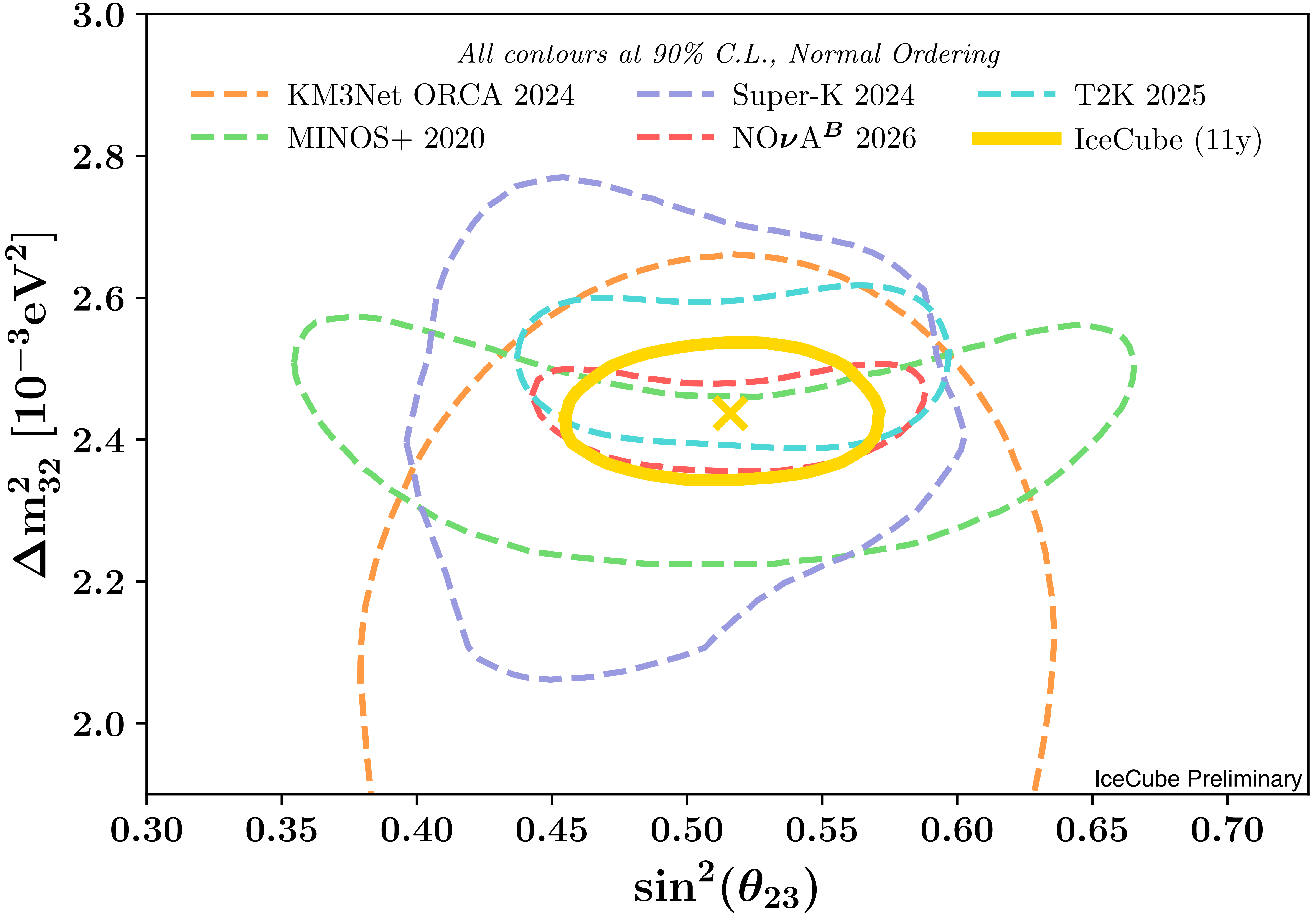
The ν_μ-disappearance result in context



Best Fit:

$$\Delta m^2_{32} = 2.437^{+0.043}_{-0.048} \times 10^{-3}\,\text{eV}^2$$

$$\sin^2(\theta_{23}) = 0.516^{+0.024}_{-0.035}$$

KM3Net-ORCA6 (2024): JHEP10(2024)206; MINOS+ (2020): Phys. Rev. Lett. 125, 131802; Super-K (2024): Phys. Rev. D 109, 072014; NOνA^B (2026): Phys. Rev. Lett. 136, 011802; T2K (2025): Phys. Rev. Lett. 135.26: 261801

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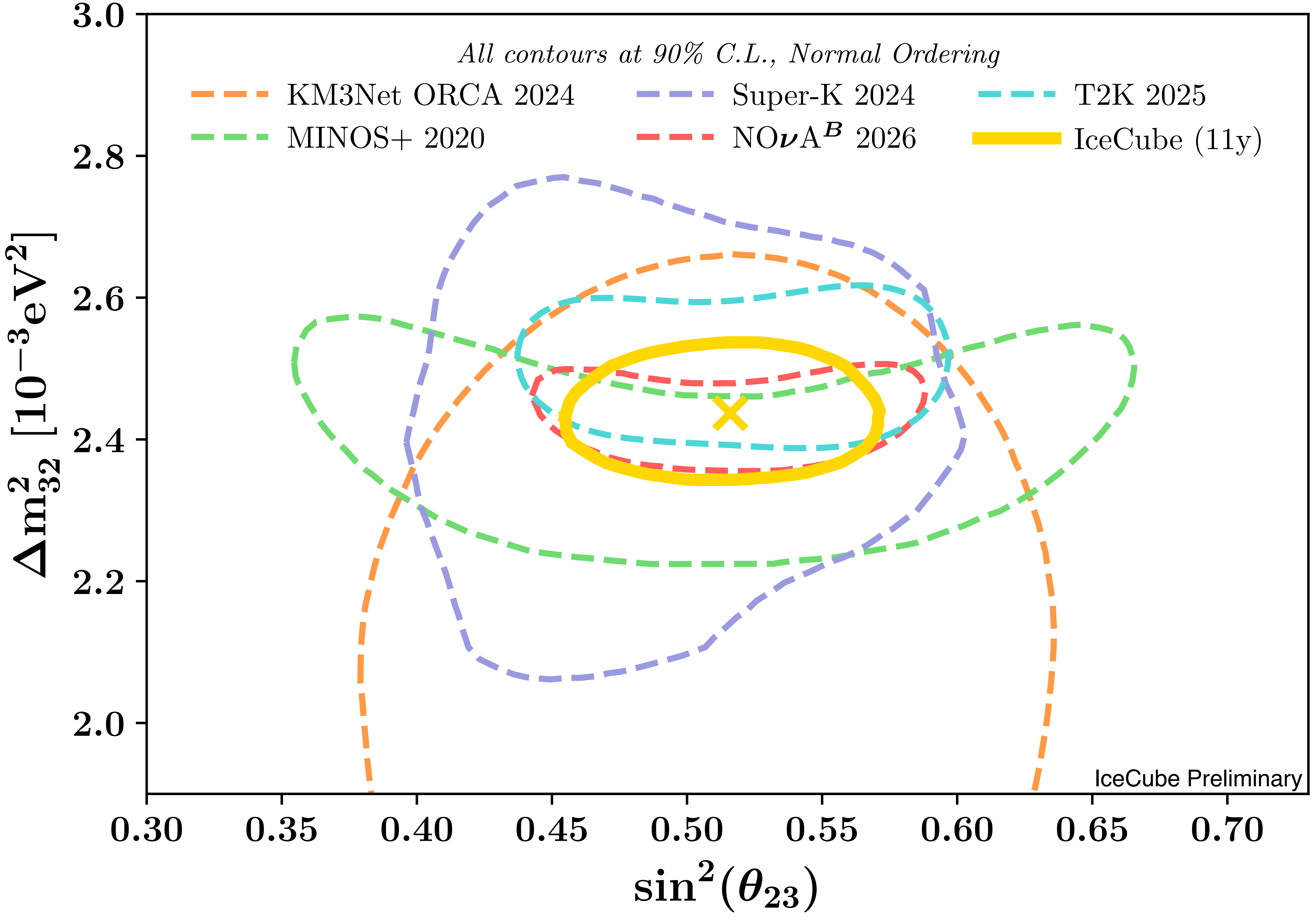

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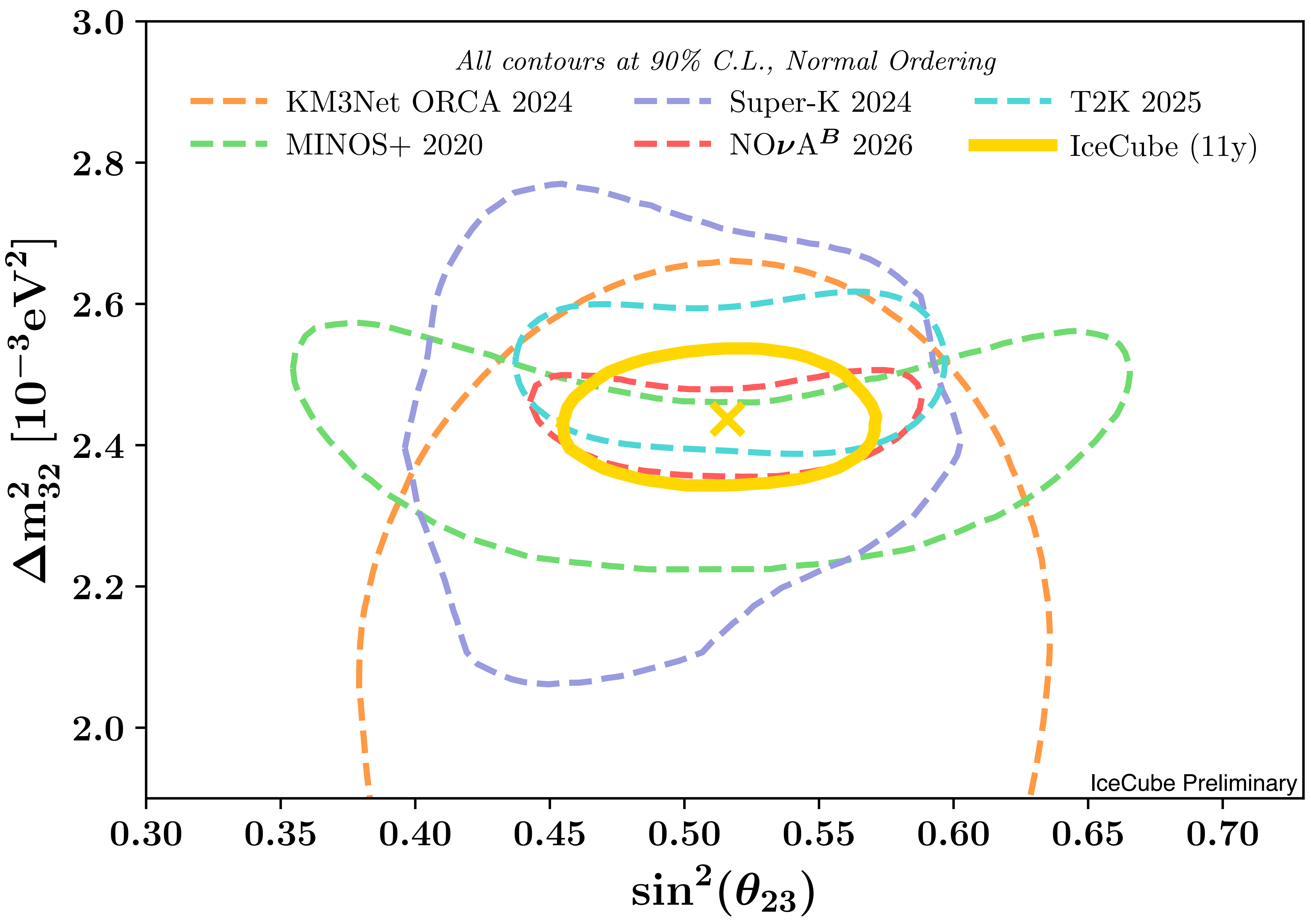

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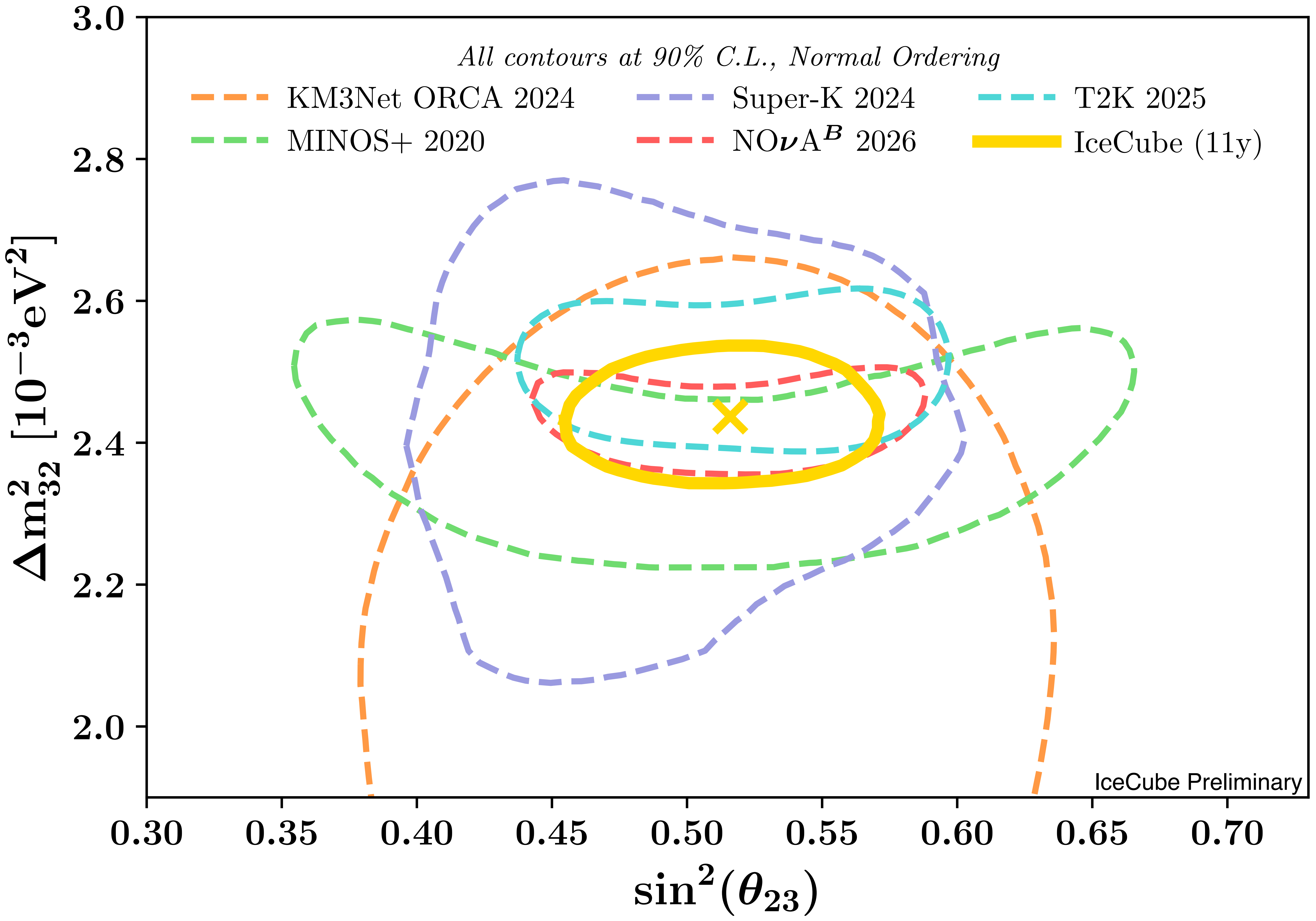

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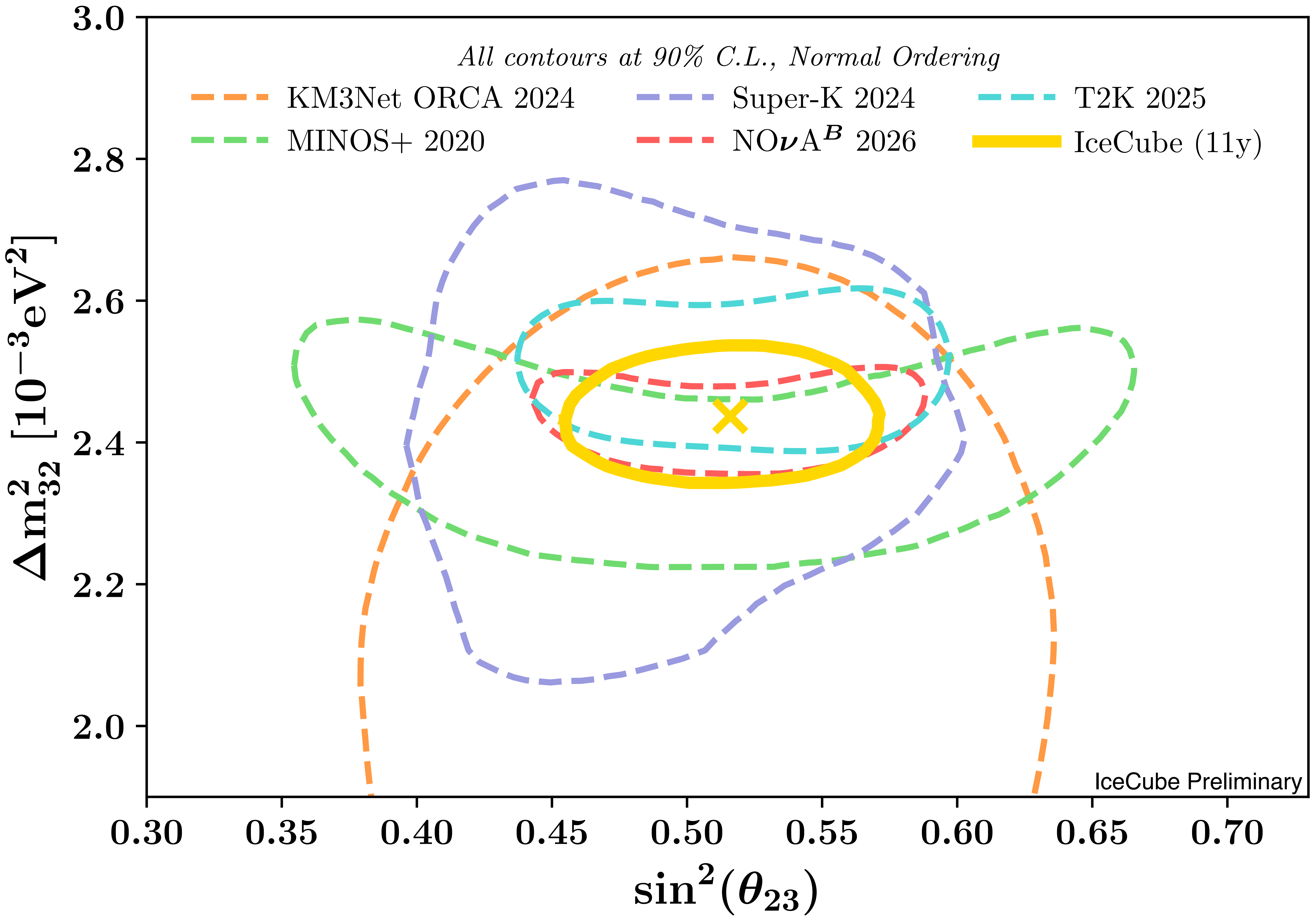

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- Globally competitive results for both mixing angle and mass squared splitting.

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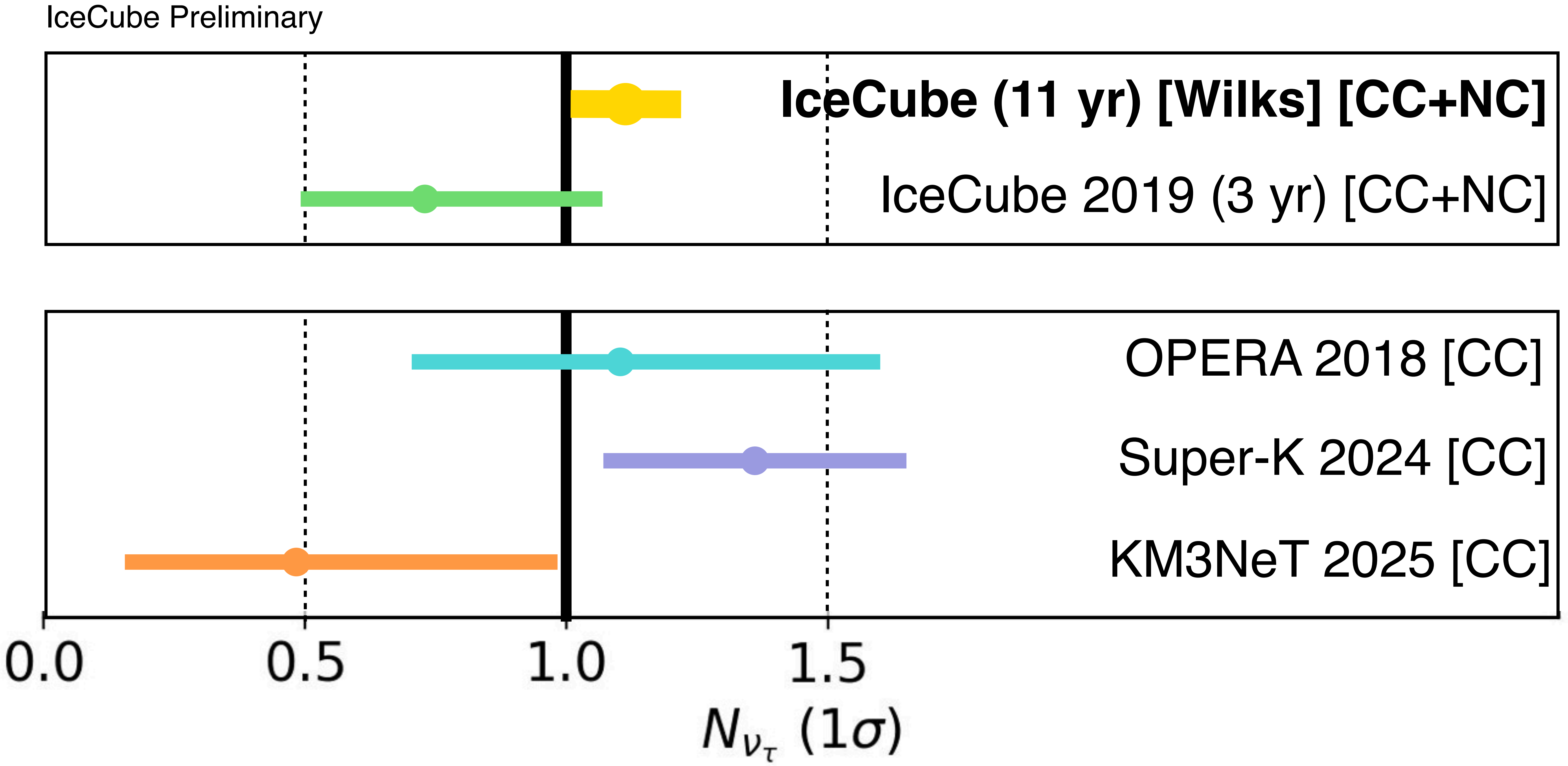
The ν_τ-appearance result

At low energies, this analysis searches statistically excess of cascades, at specific energies and zenith angles, indicating ν_τ appearance.



Tau neutrino normalization parameter:

$$N_{\nu_\tau} = \frac{\text{Measured } \nu_\tau \text{ flux}}{\text{SM Expected } \nu_\tau \text{ flux}}$$

- $N_{\nu_\tau} = 1$: Standard Model (SM) 3-flavor oscillations
- $N_{\nu_\tau} = 0$: no tau appearance
- $N_{\nu_\tau} > 1$: Excess ν_τ appearance

Simultaneous fit oscillations and systematic parameters to the binned energy-zenith distribution.

Best Fit:

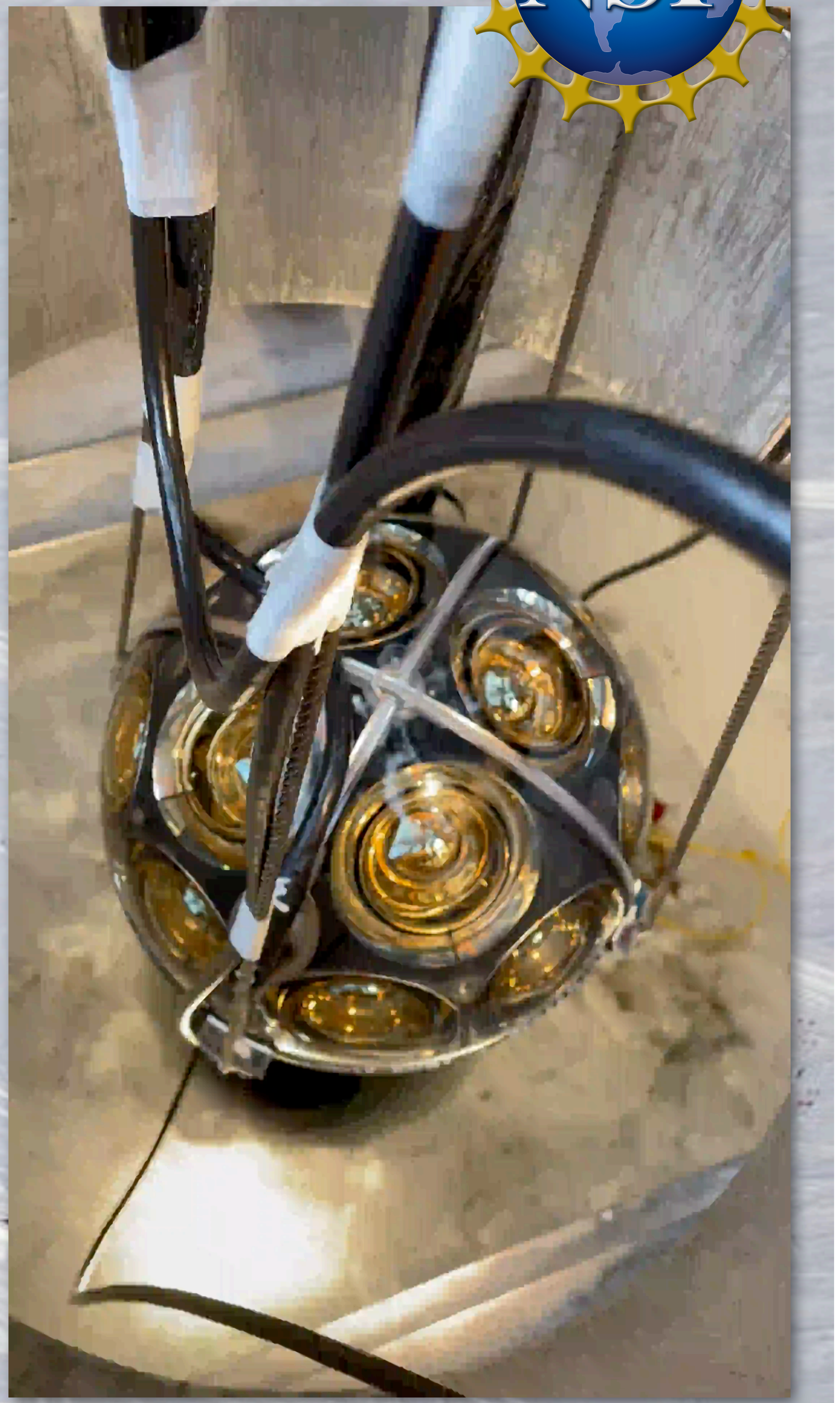
$$N_{\nu_\tau} = 1.11^{+0.11}_{-0.10} (+9.5\,\% / -9.4\%)$$

- ☑ Tau polarization
- ☑ Resonant production
- ☑ Geant4 branching ratio fix

Consistent with Standard Model 3-flavor oscillation at ~1σ

DIS Cross-section:Physical Review D 111.9 (2025): 093009.

Where do we go from here? IceCube got an Upgrade!



We have 5 new strings installed in the 2025/2026 season!

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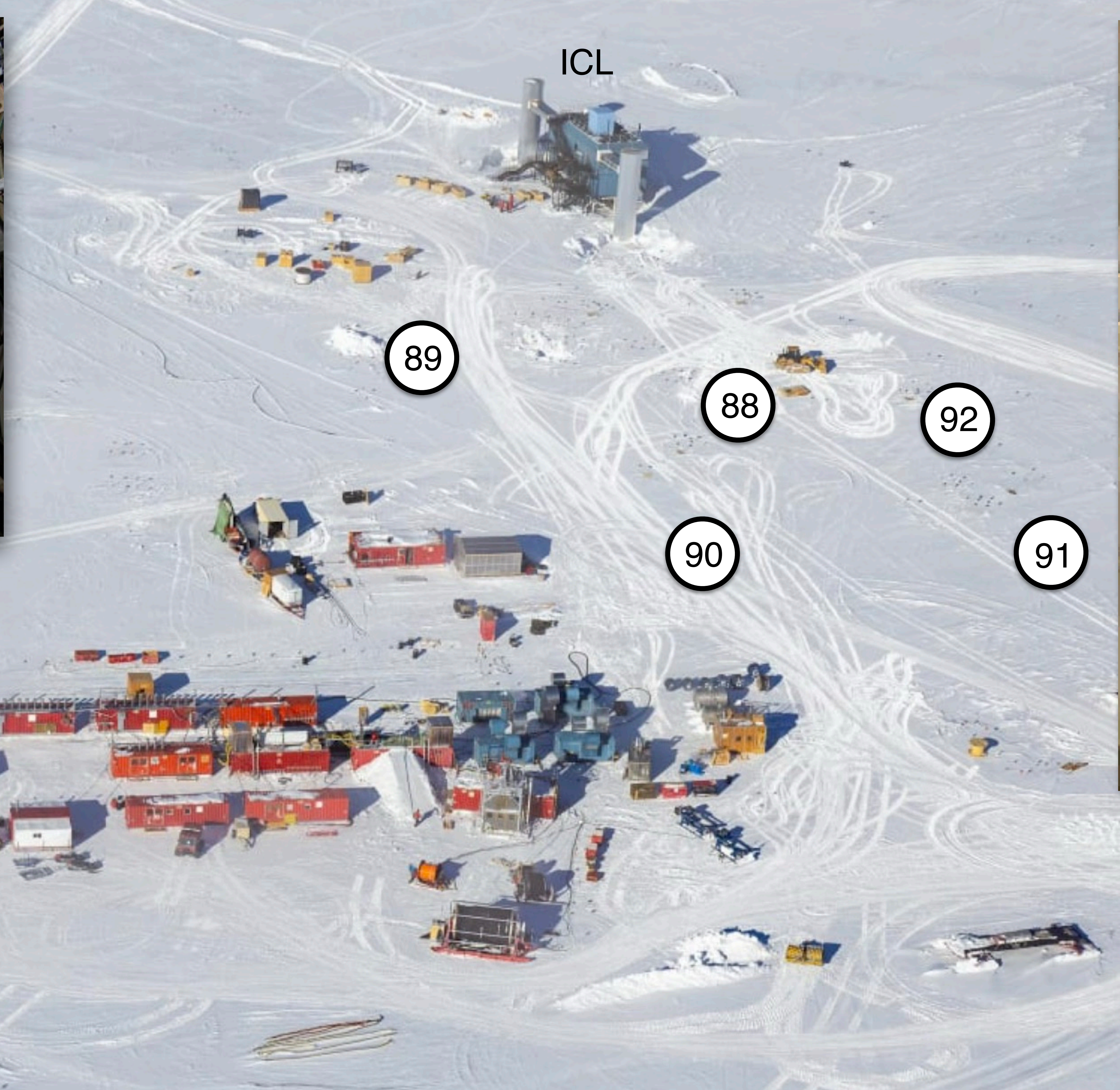

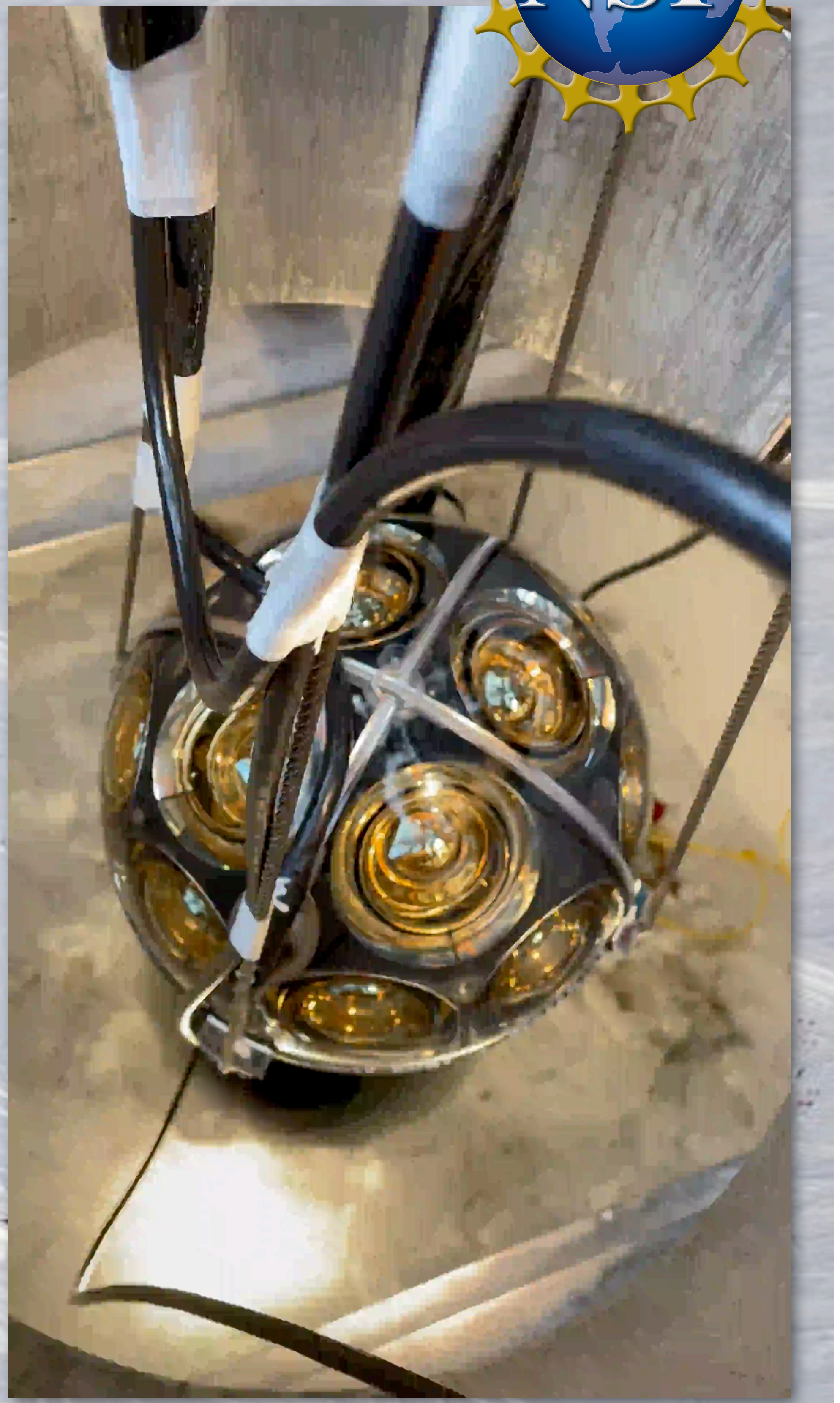

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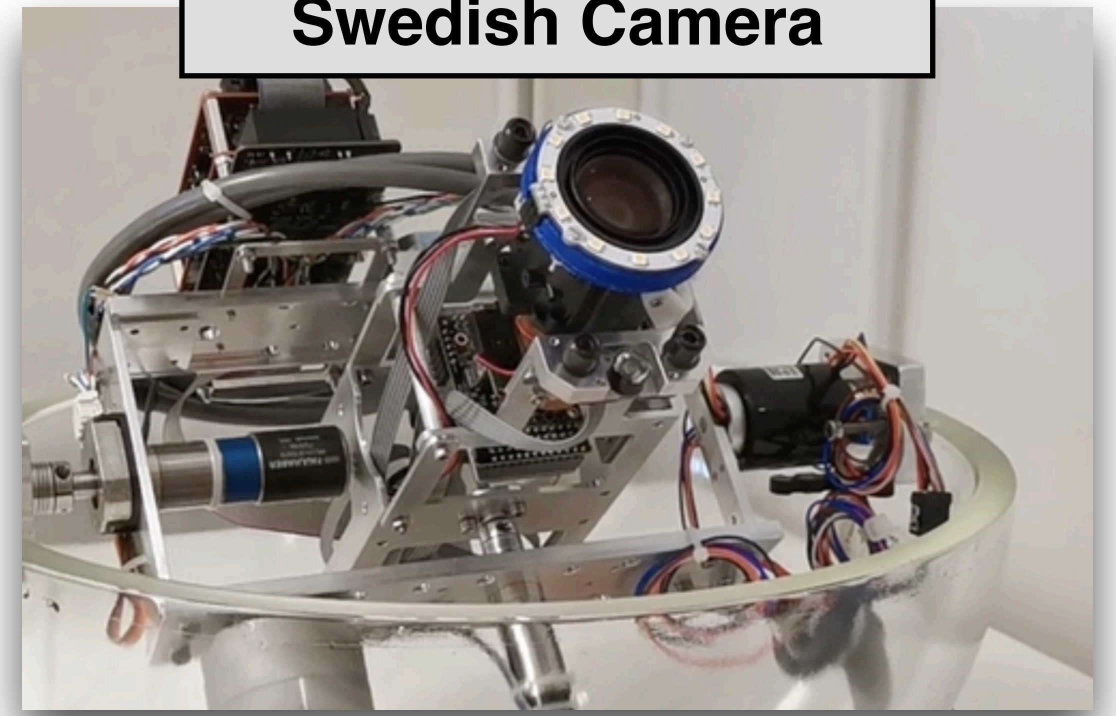
IceCube Upgrade (ICU) new calibration devices

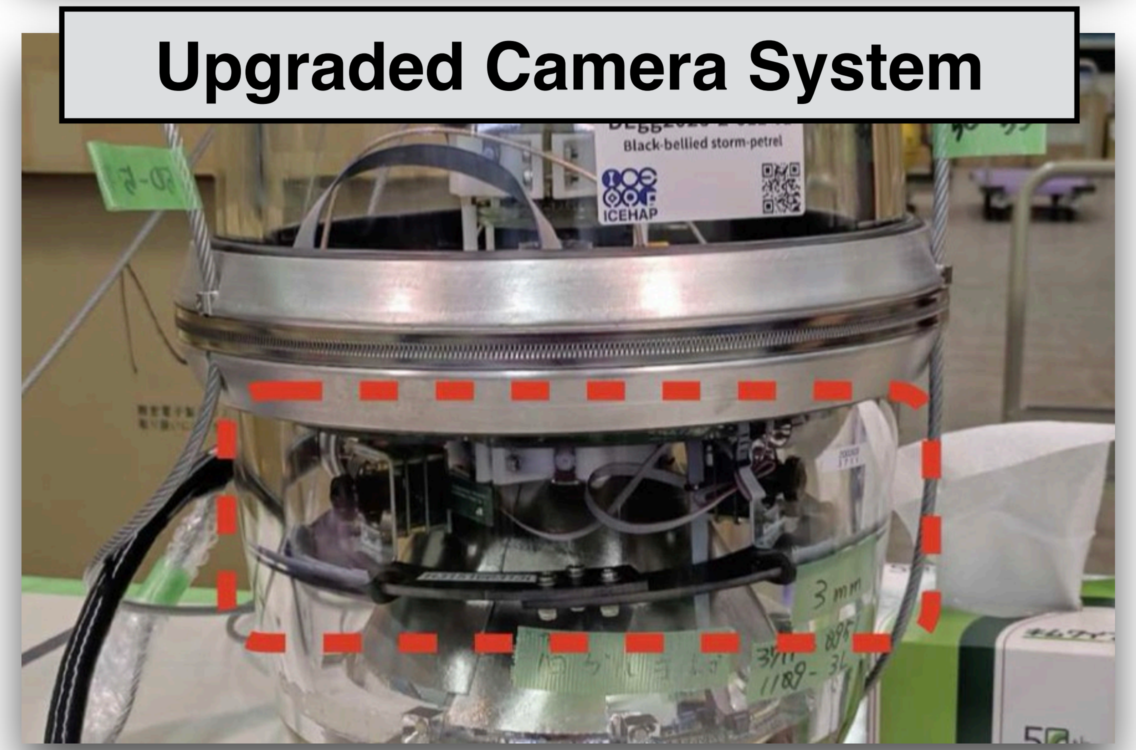
New calibration devices will improve our understanding of the Antarctic ice, **enabling IceCube to reanalyze more than 12 years of data** with enhanced detector modeling, reduced systematic uncertainties, and improved physics sensitivity.


POCAM

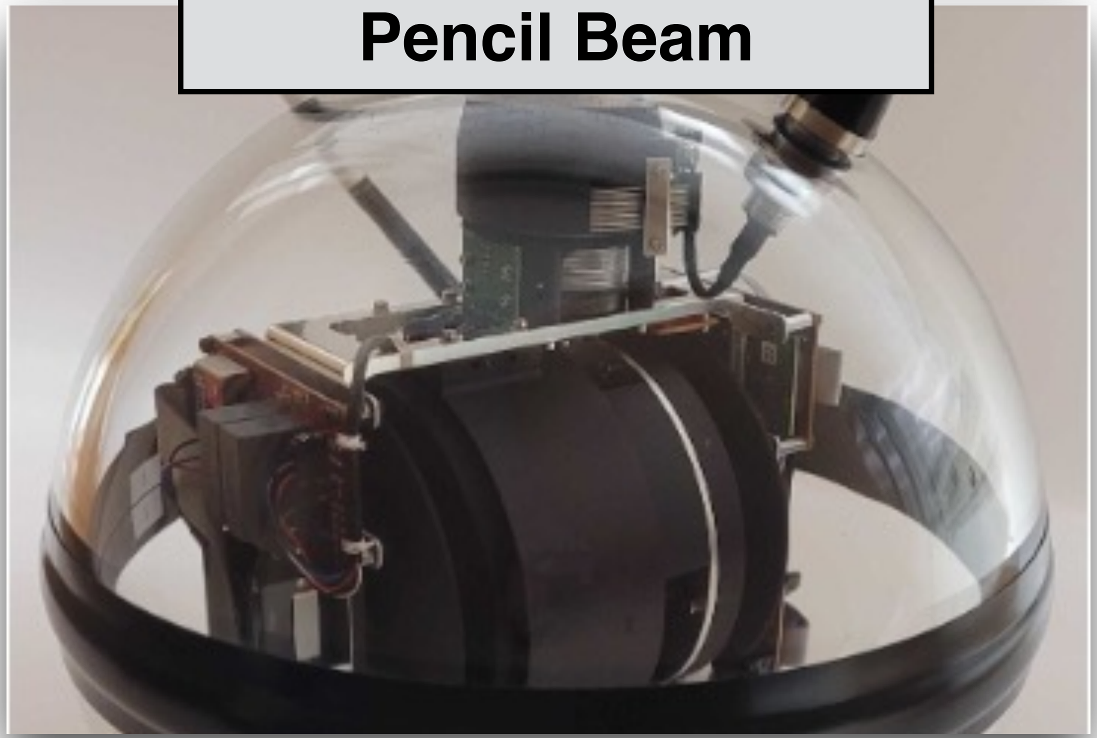

Swedish Camera


Seismometers


LOM Logger


Upgraded Camera System


Acoustic Modules


Pencil Beam

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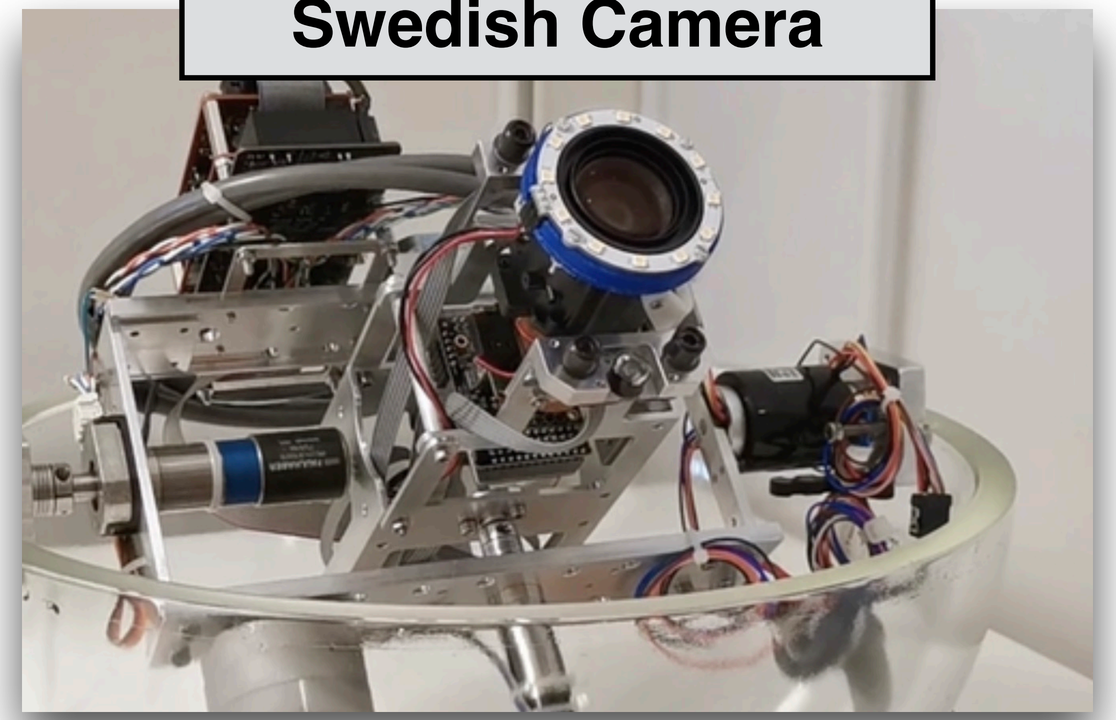

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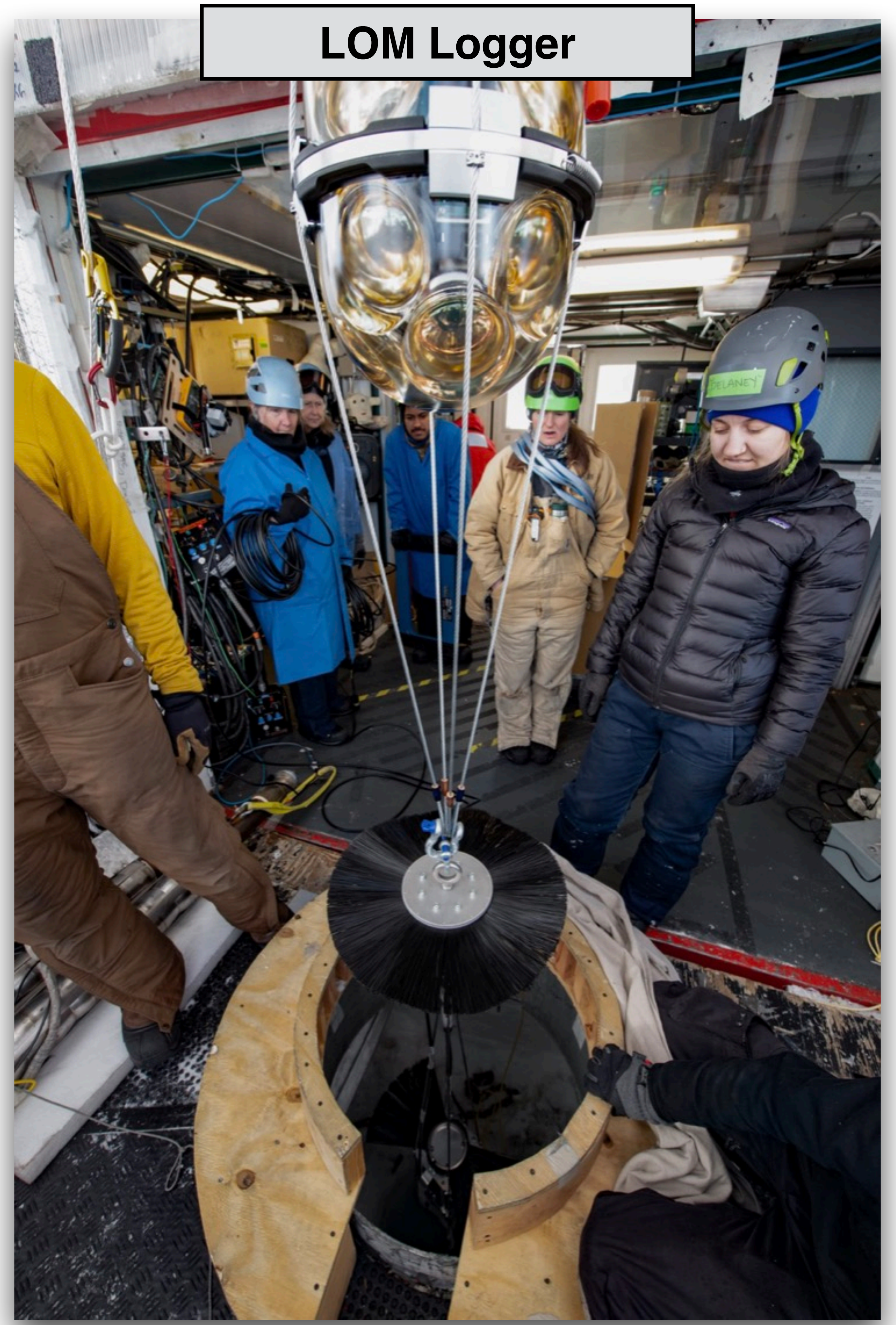

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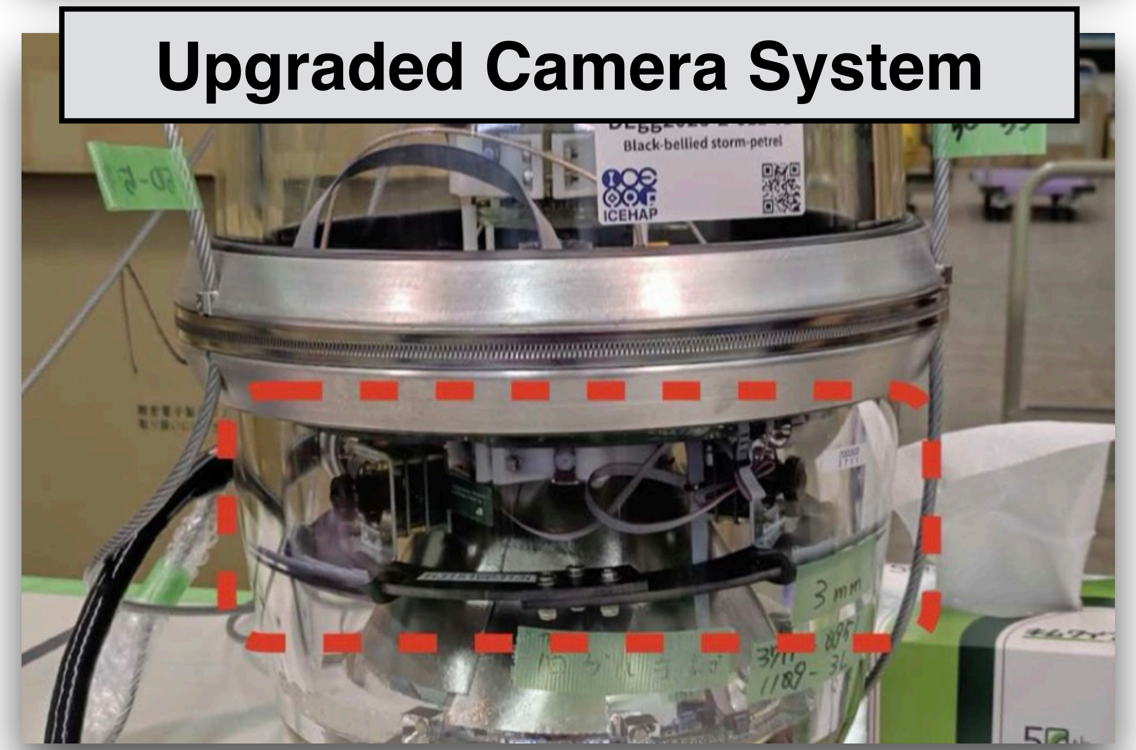

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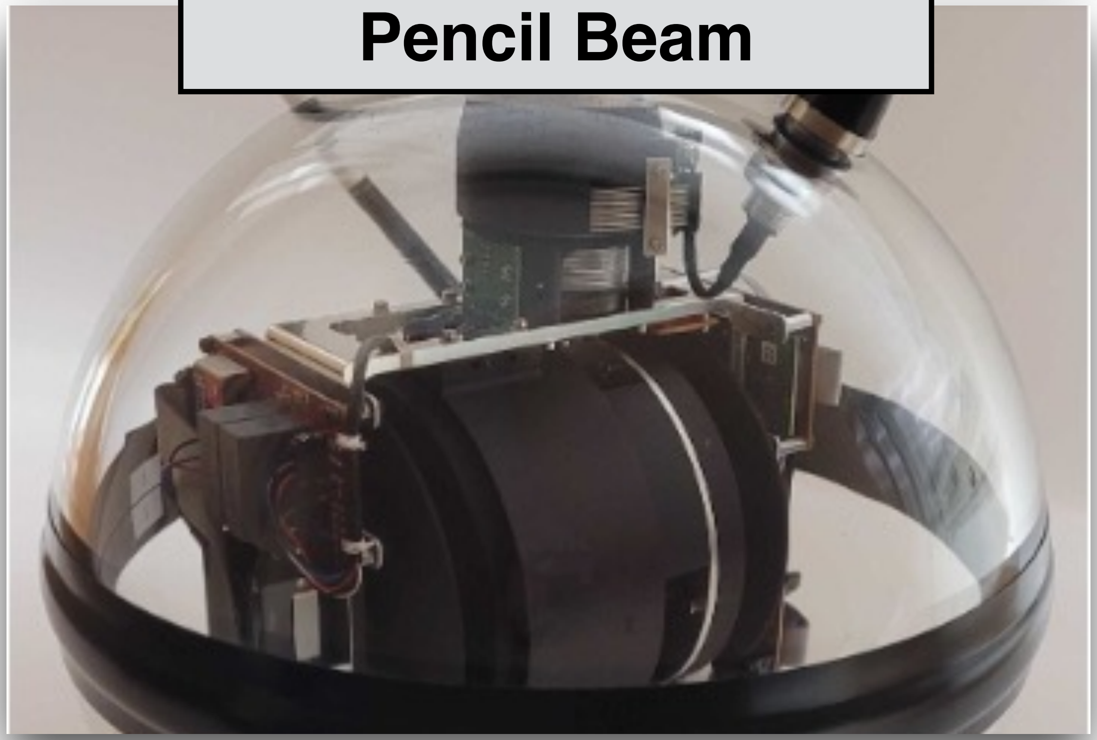

SEE PROF.
CARSTEN ROTT
POSTER ON TUESDAY
4:10PM - 5-40PM

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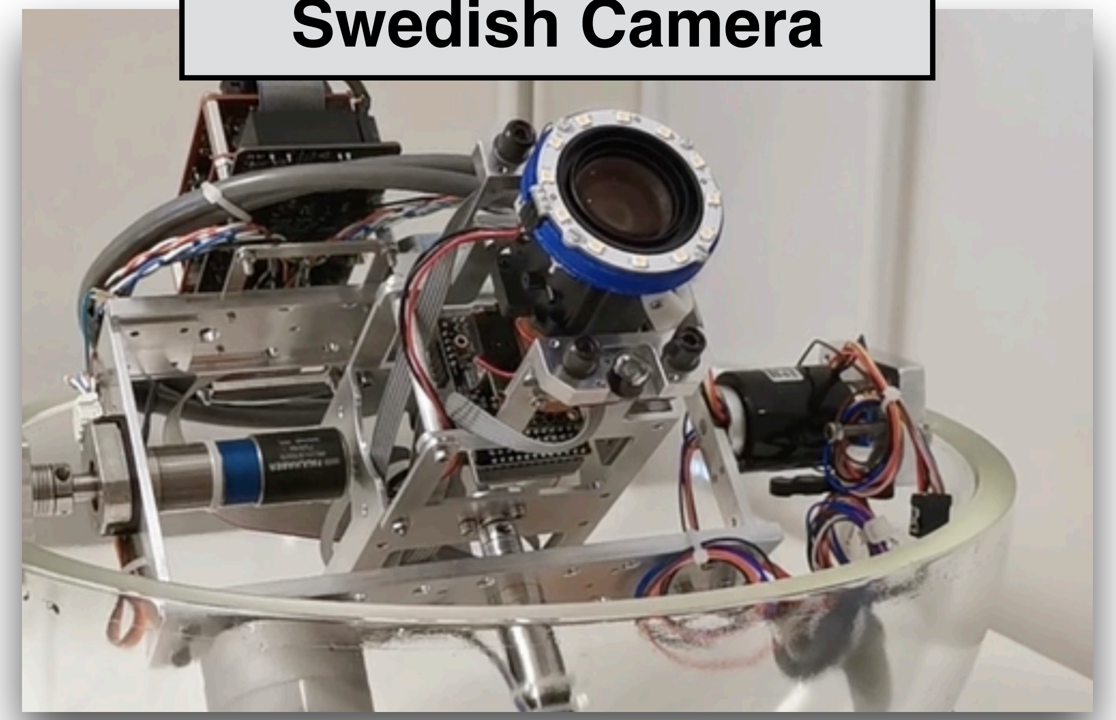
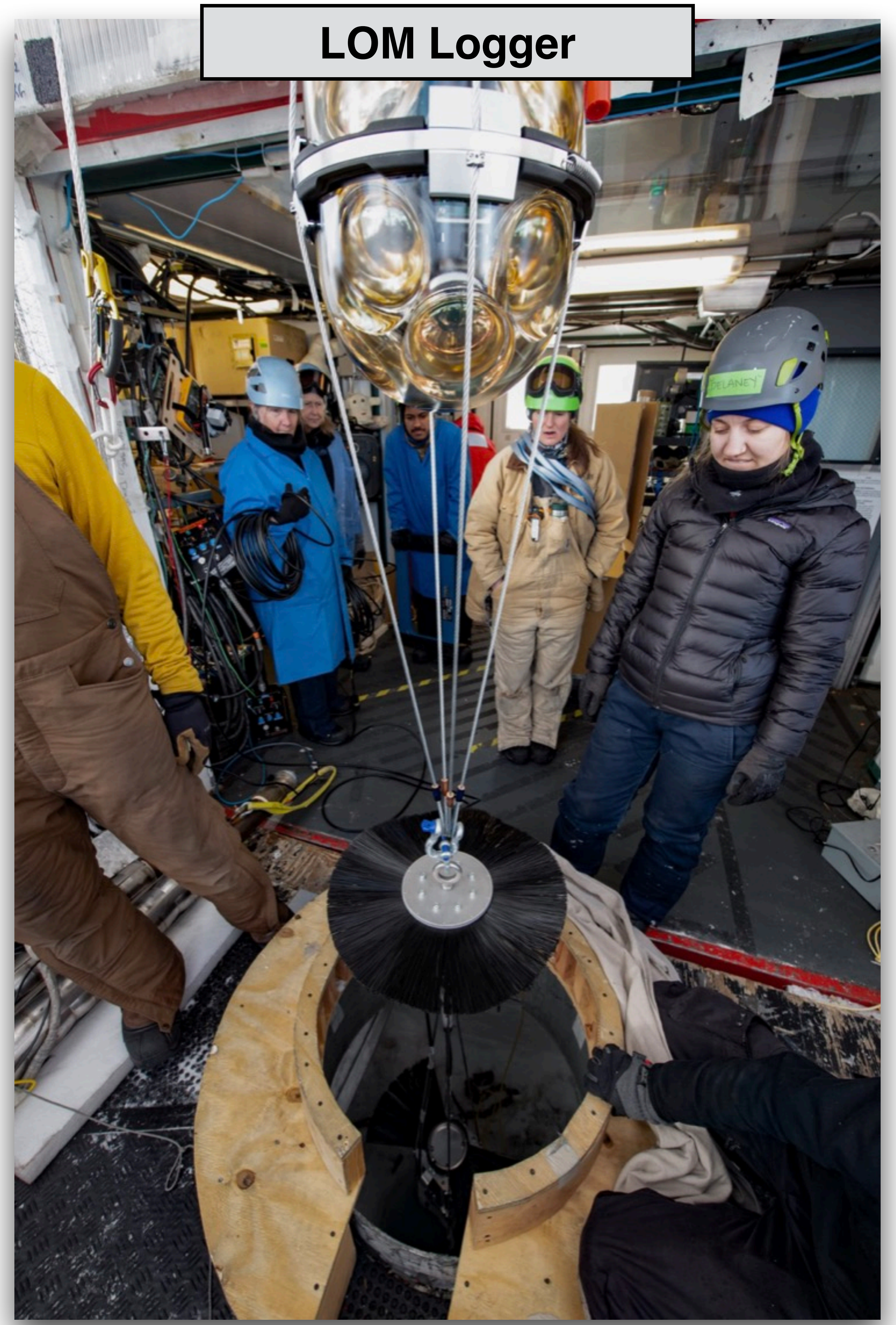
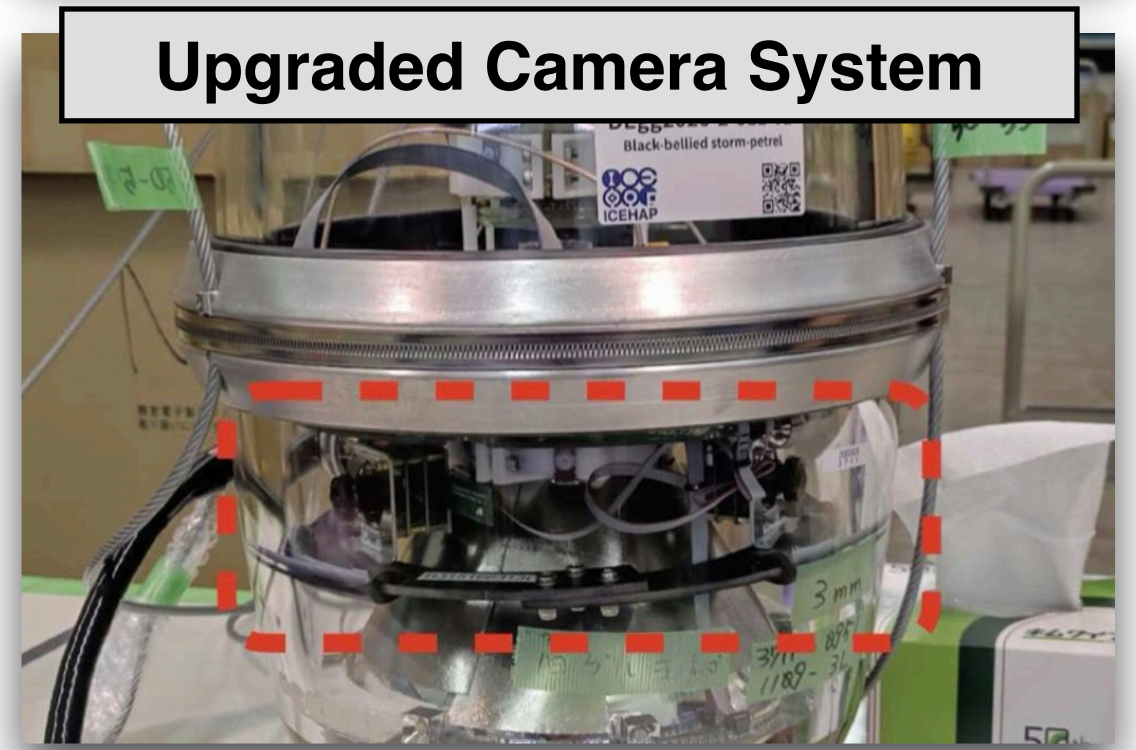


Seismometers

LOM Logger

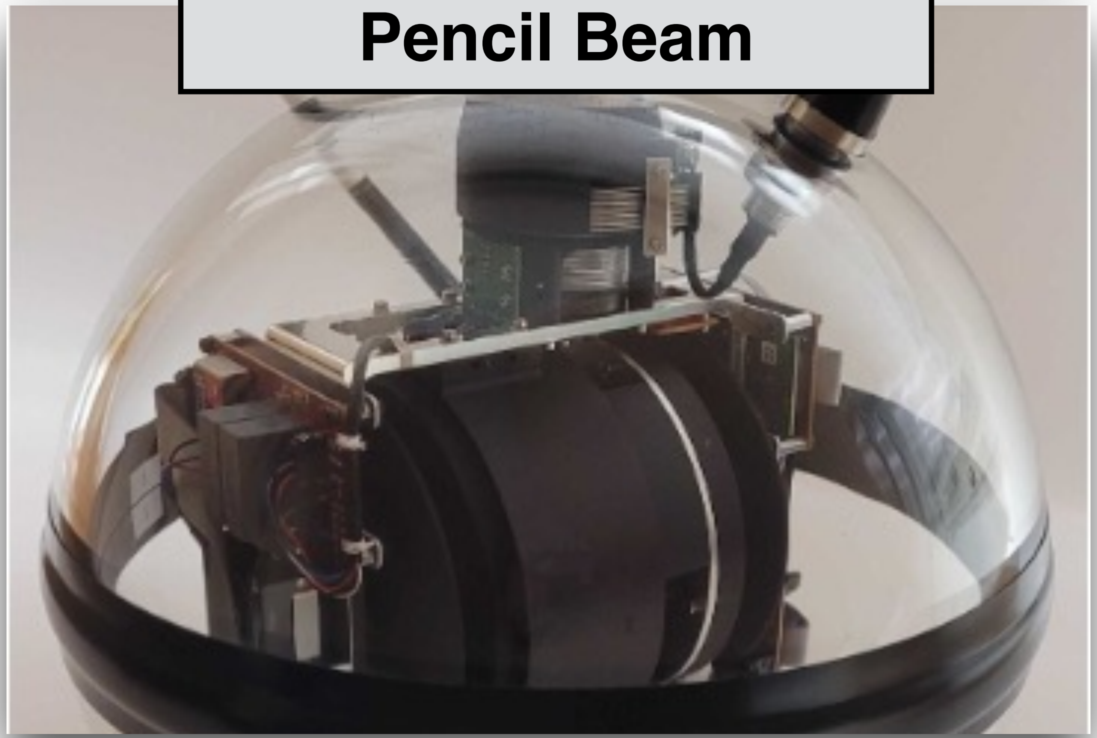


Upgraded Camera System



Acoustic Modules

Pencil Beam

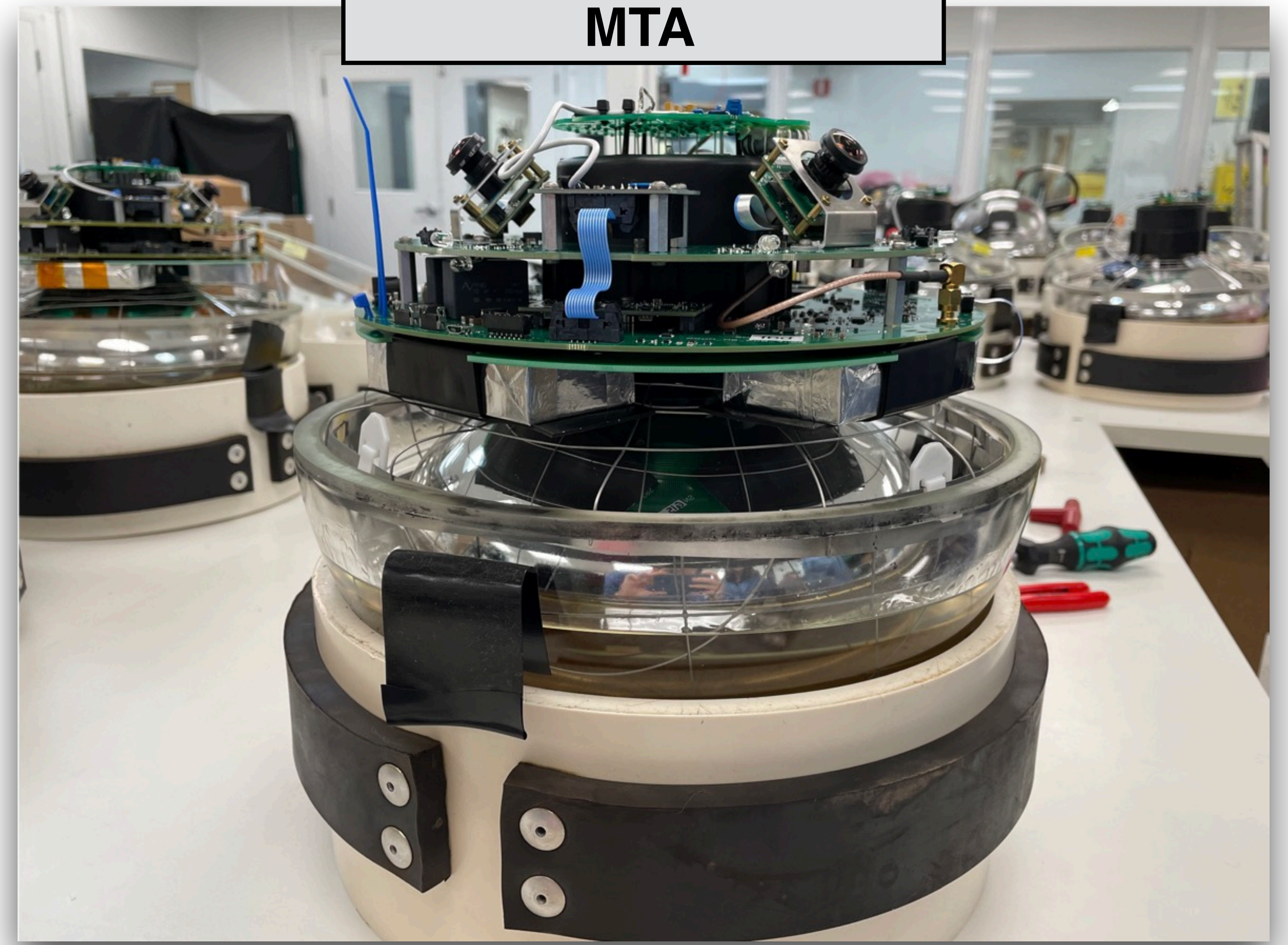


SEE PROF.
CARSTEN ROTT
POSTER ON TUESDAY
4:10PM - 5-40PM

SEE DR.
JORGE TORRES
POSTER ON TUESDAY
4:10PM - 5-40PM

IceCube Upgrade (ICU) specialty optical devices

MTA



LOM

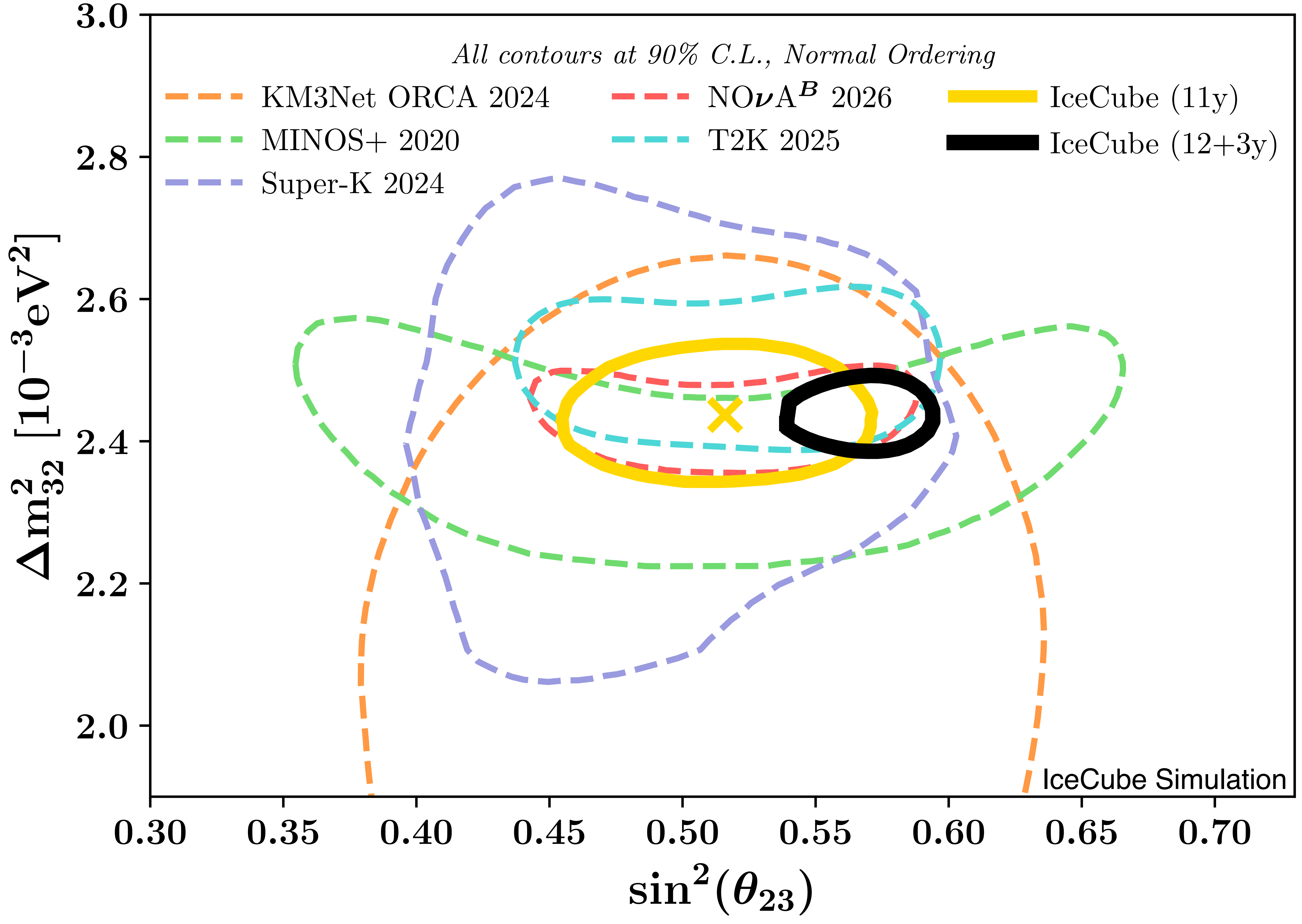
We've also deployed various new types of photon collection devices as prototypes for IceCube Gen2.

PDOM/FOM

WOM

The IceCube Upgrade: Sensitivities

Significant improvement to sensitivity to Δm^2_{32} and θ_{23}, and θ_{23} octant.



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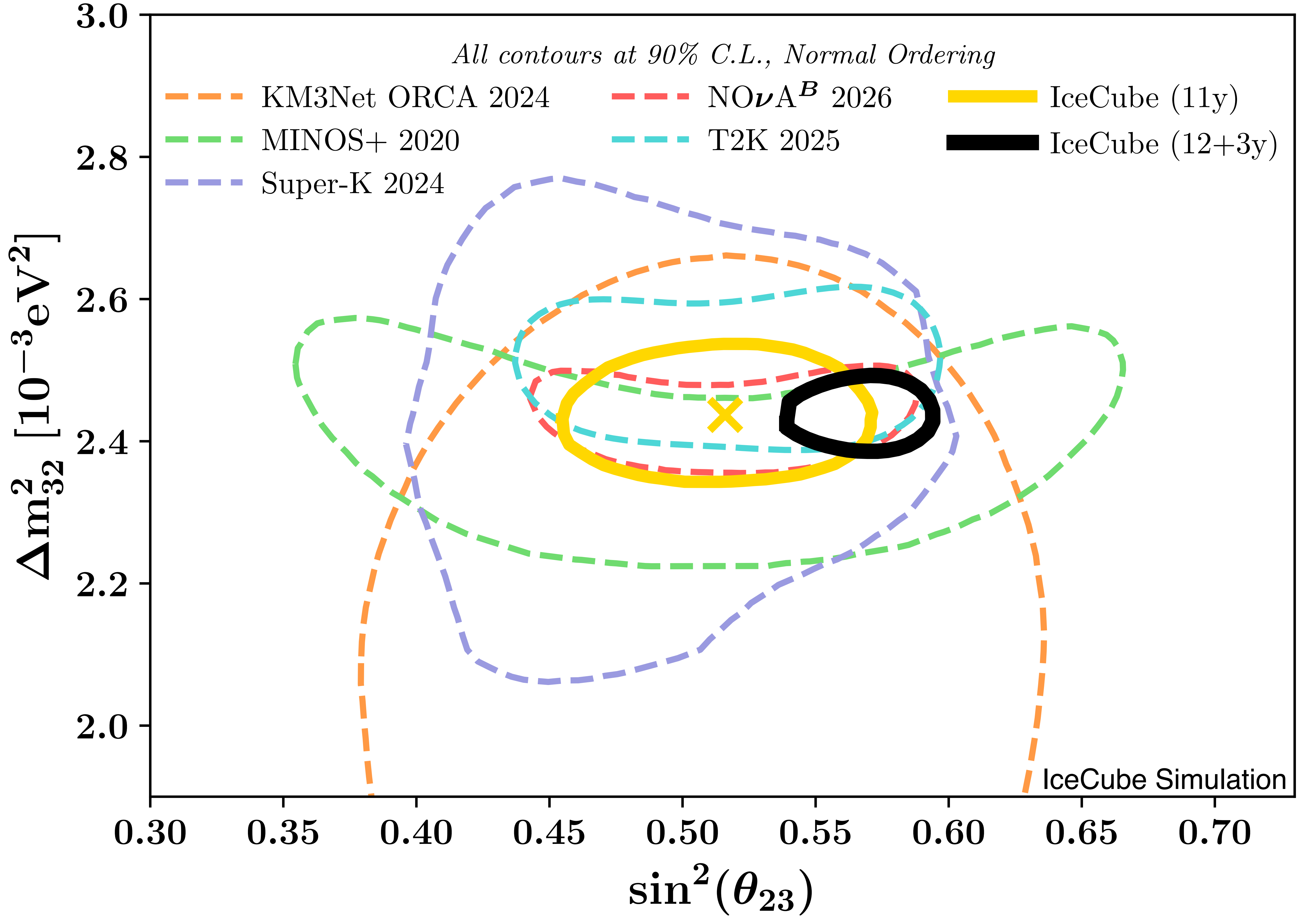
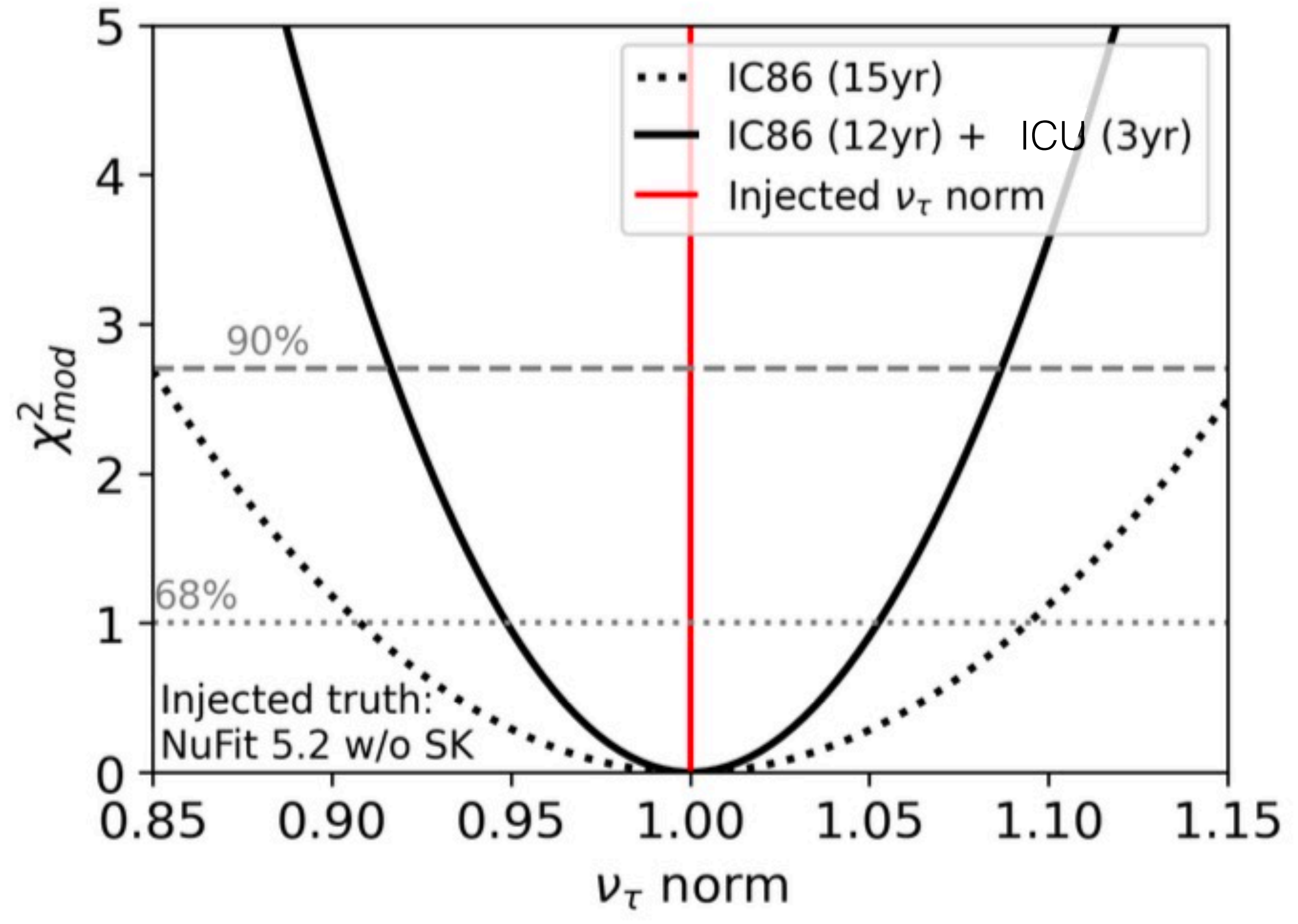


± 5 % precision on ν_τ normalization after 3 years.



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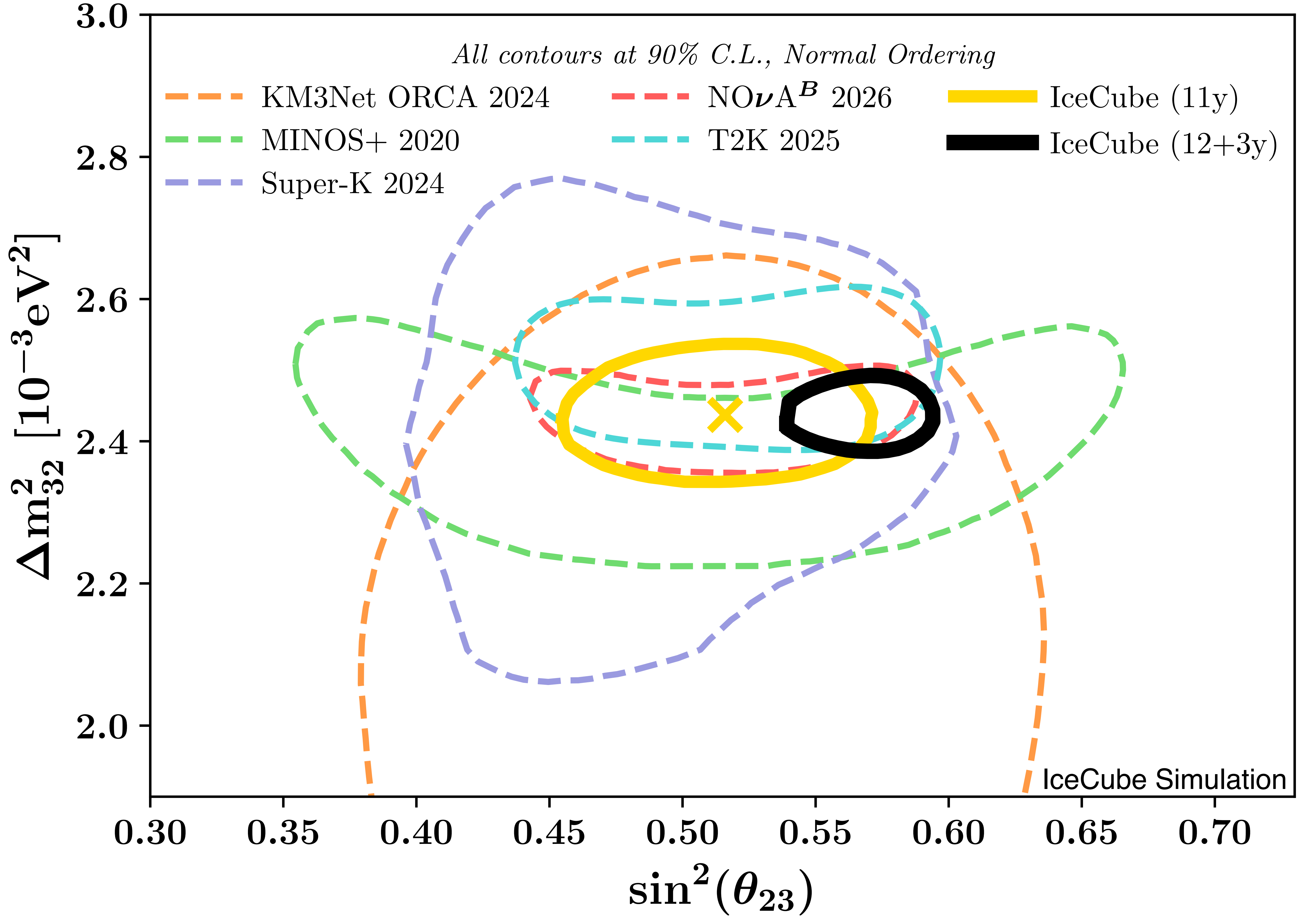

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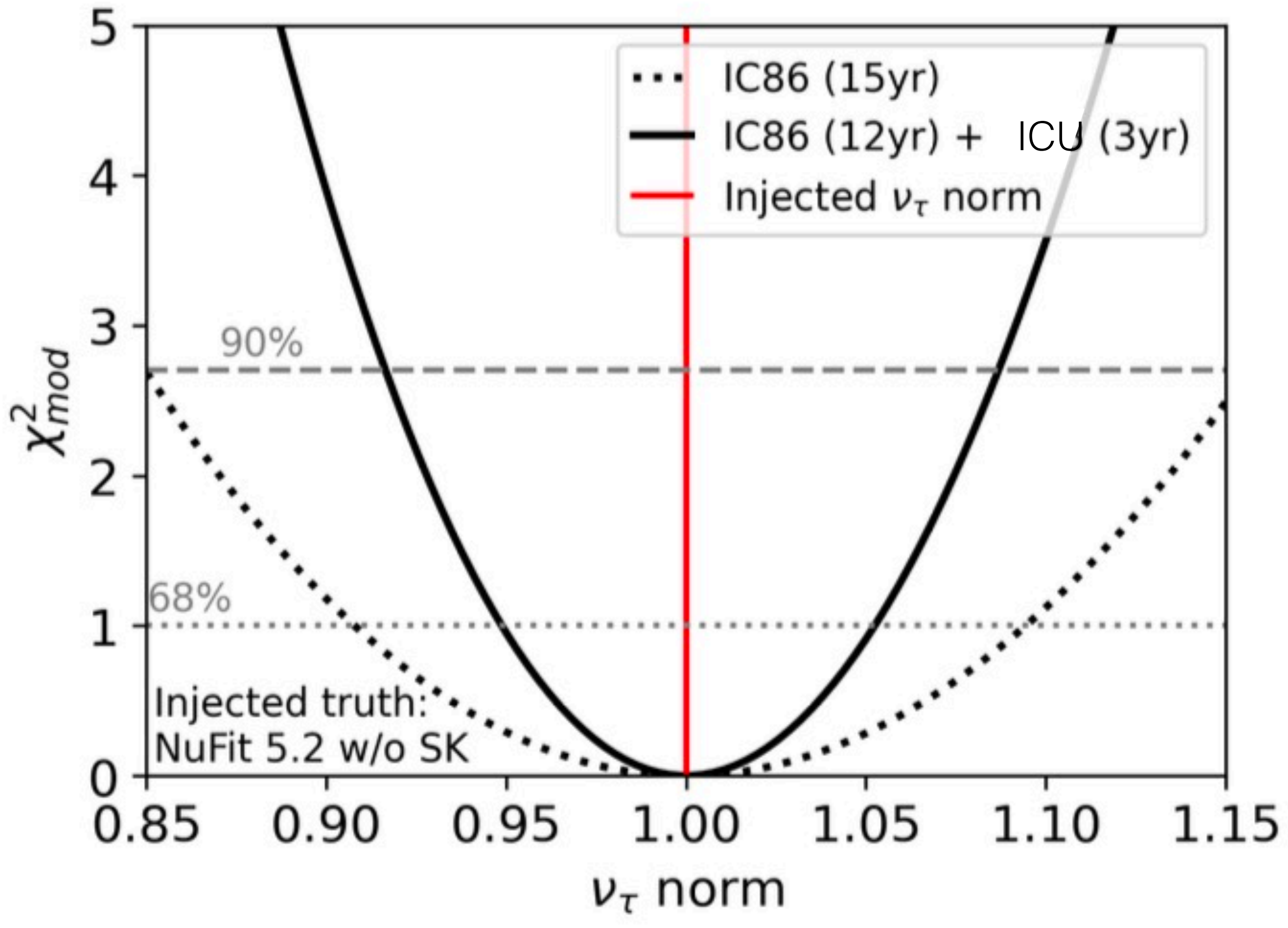
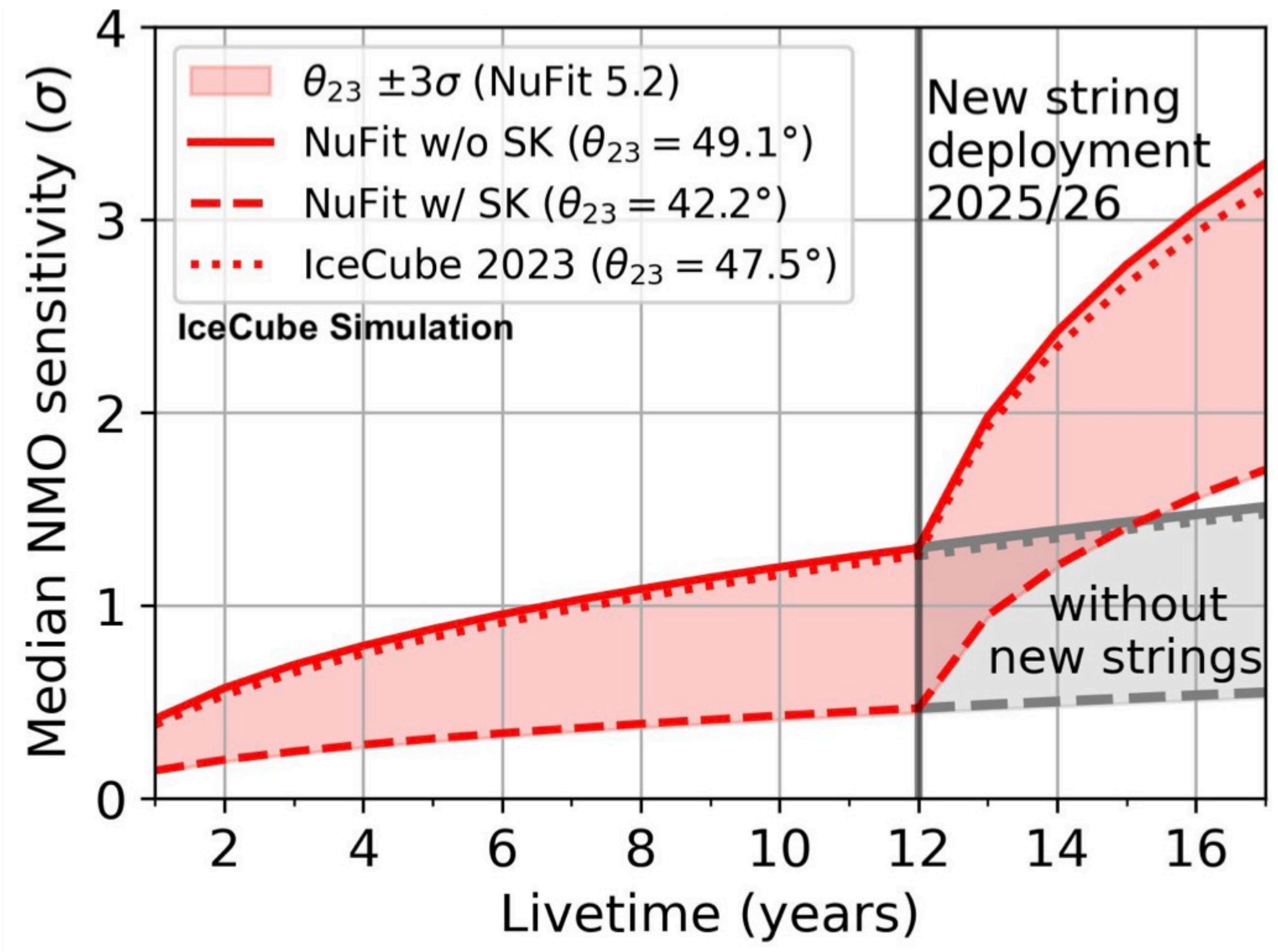


~1.5-2.5σ sensitivity to neutrino mass ordering after 3 years.



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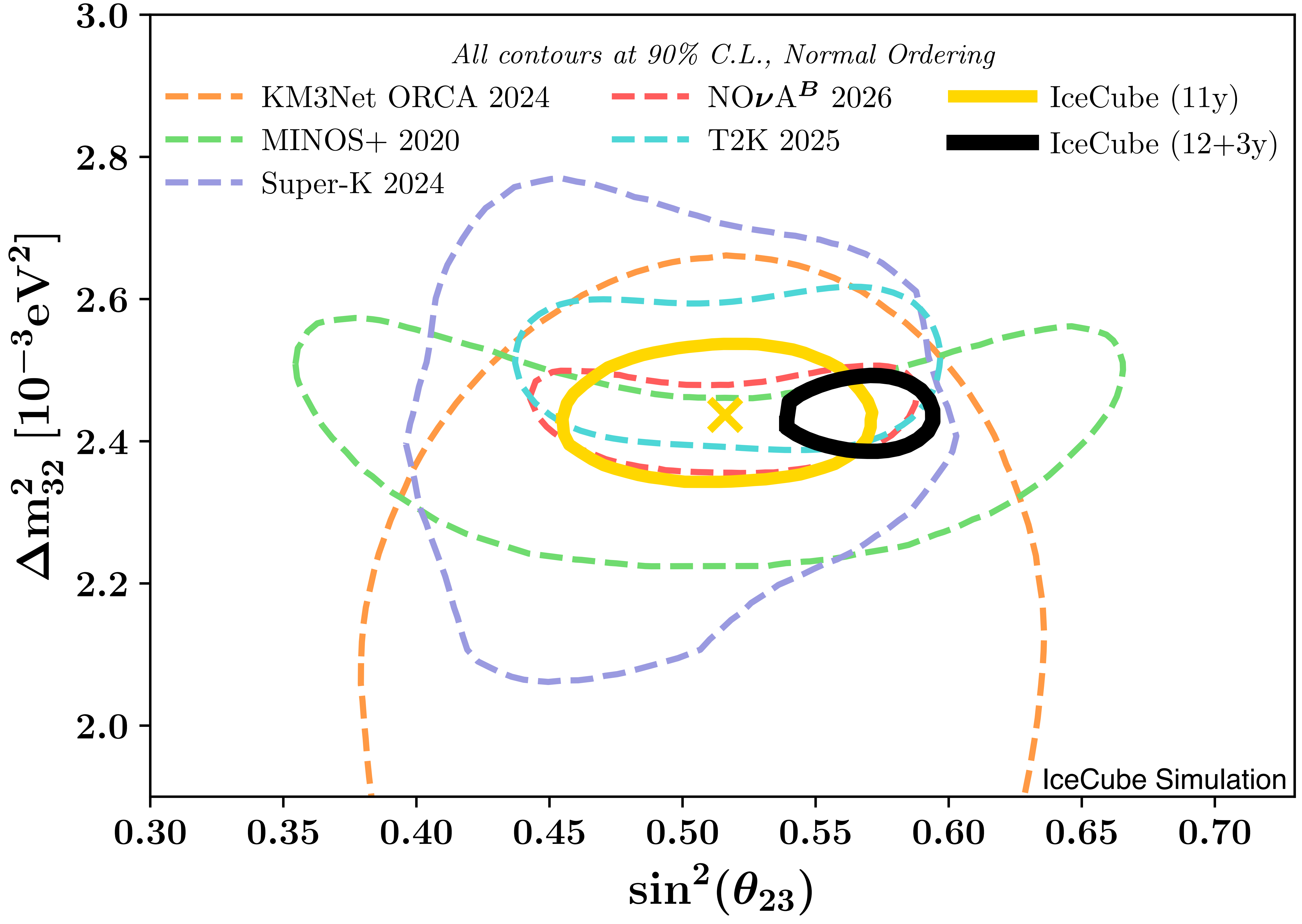

In addition to expanding our understanding of the ice to help with multi-messenger astrophysics.

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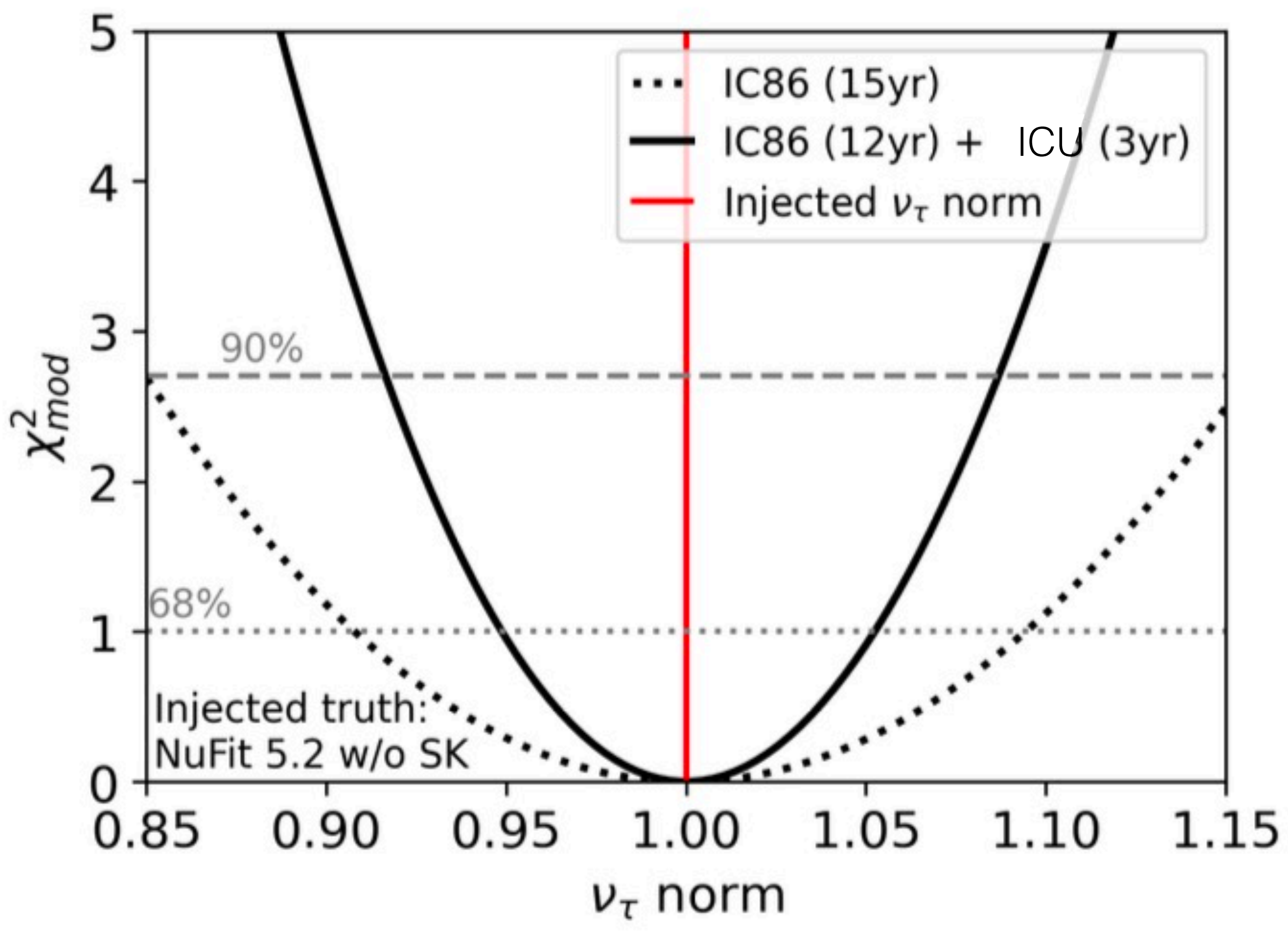

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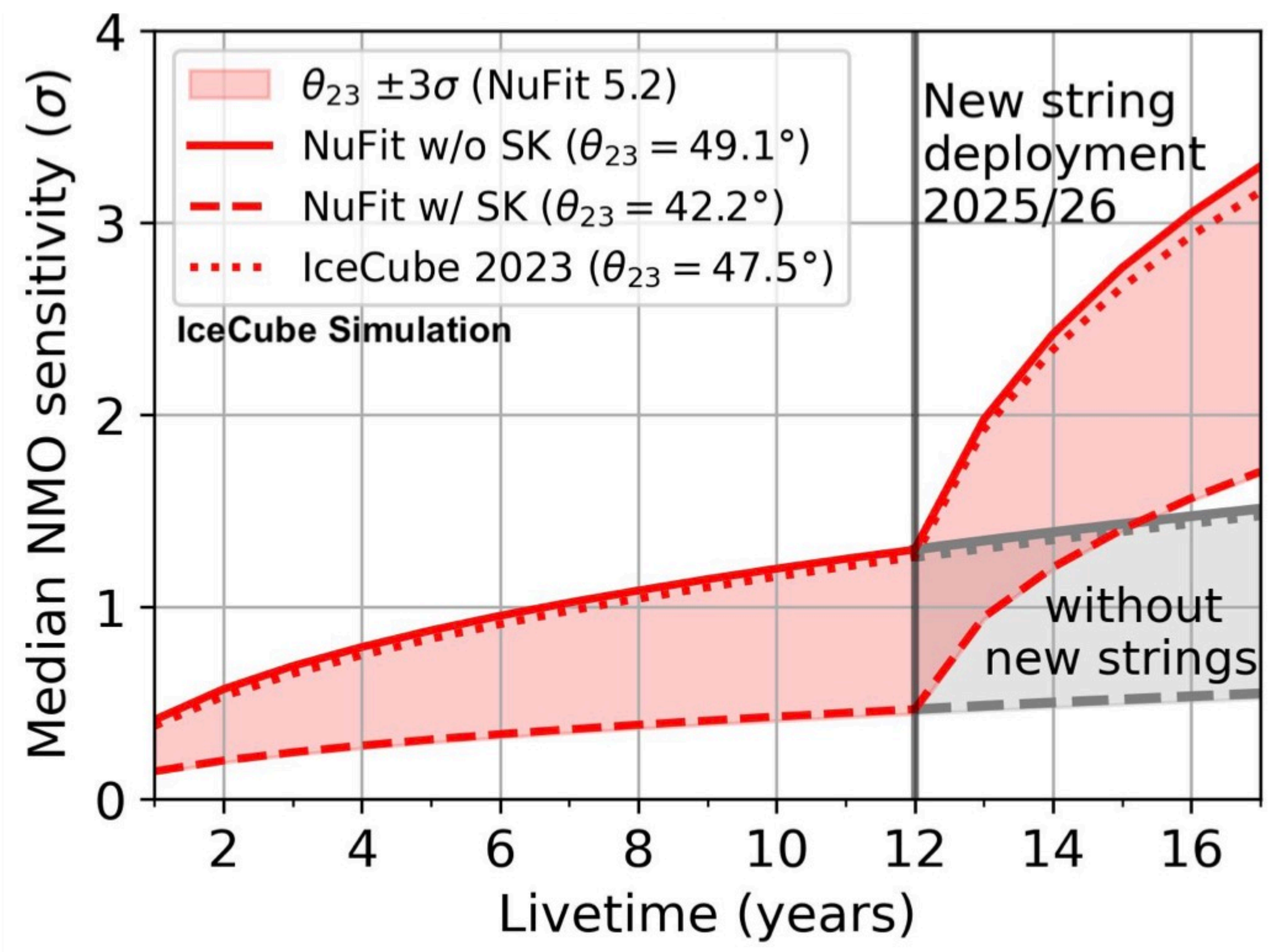

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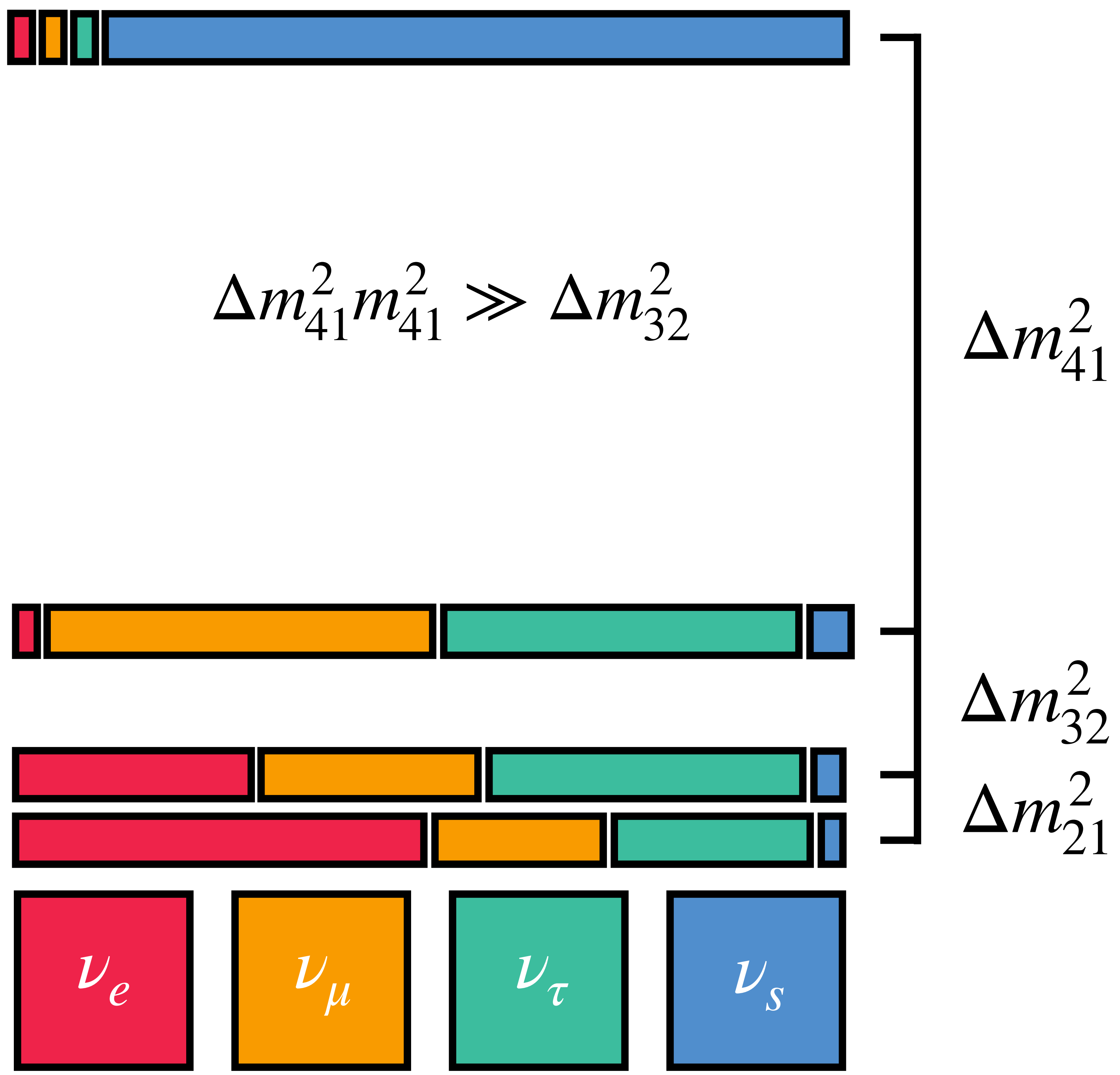
Moving into the TeV: the 3+1 sterile neutrinos model

Anomalies observed in ν_e-appearance and -disappearance experiments have motivated the introduction of an additional eV-scale neutrino state. IceCube probes sterile neutrino oscillations using fundamentally different systematic uncertainties, baselines, and energy ranges than short-baseline experiments, providing a highly complementary test of sterile neutrino models.



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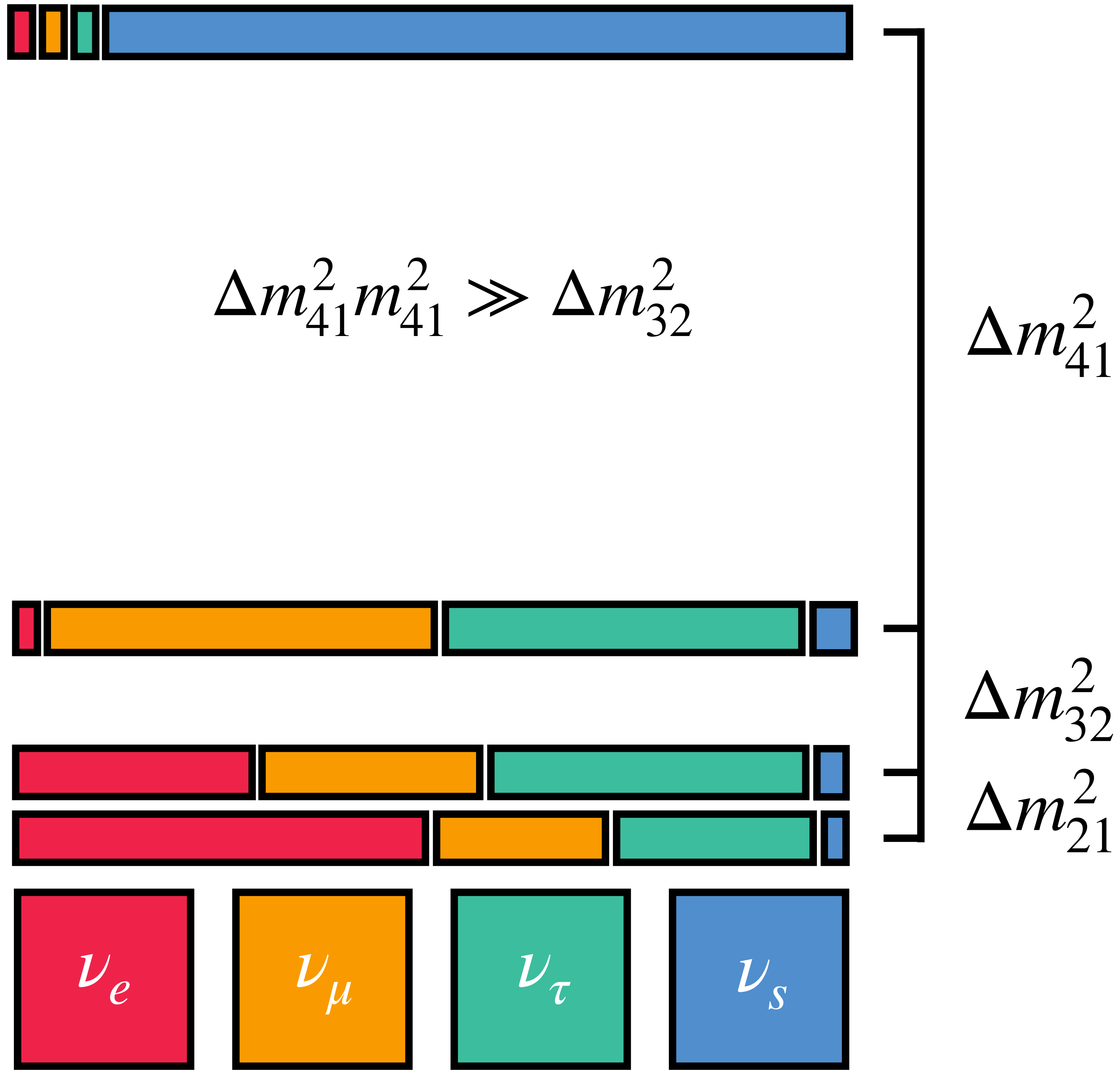
Flavor states — U_{3+1} — Mass states

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \\ \nu_s \end{pmatrix} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} & U_{e4} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} & U_{\mu 4} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} & U_{\tau 4} \\ U_{s1} & U_{s2} & U_{s3} & U_{s4} \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \\ \nu_4 \end{pmatrix}$$



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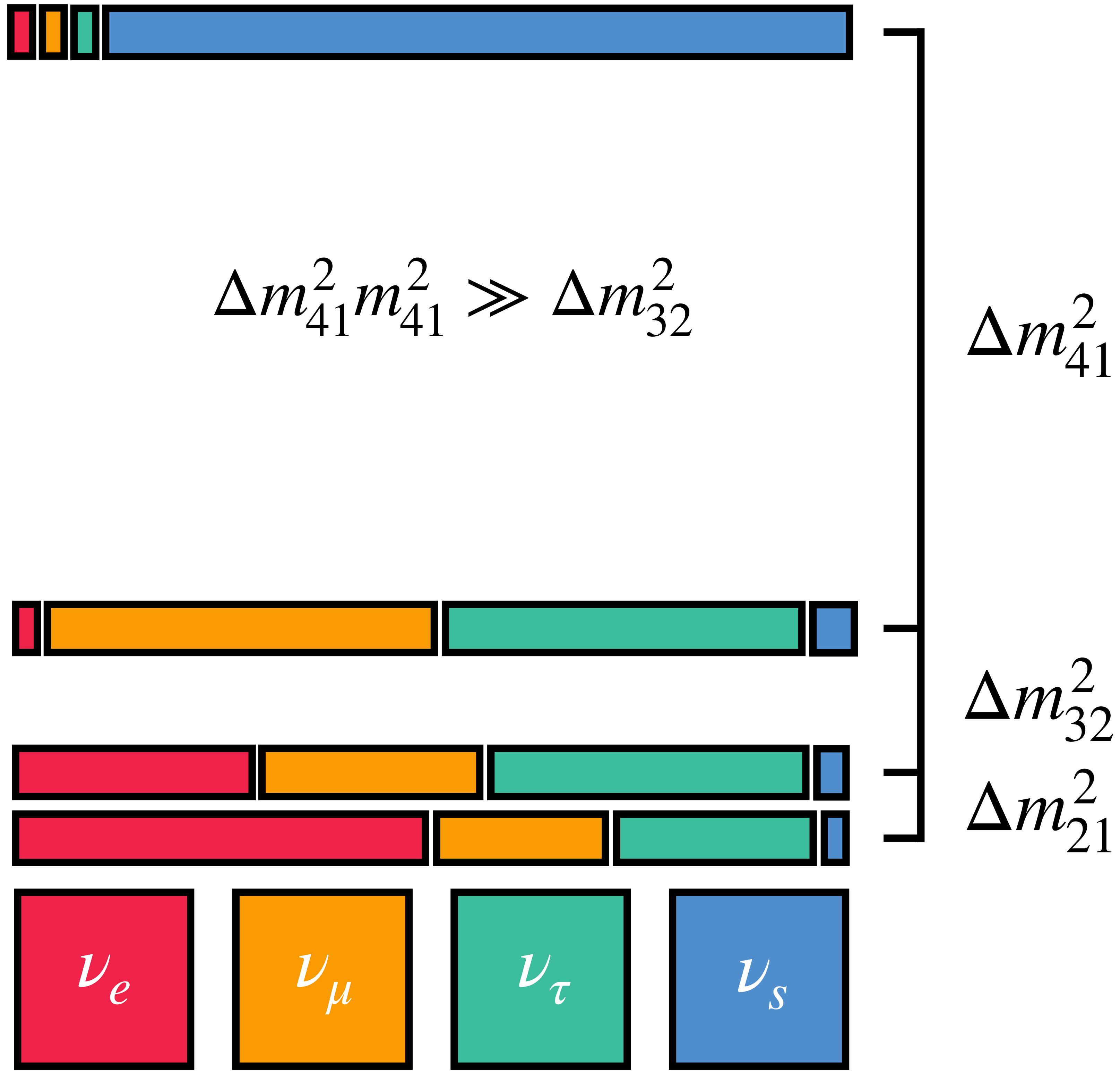

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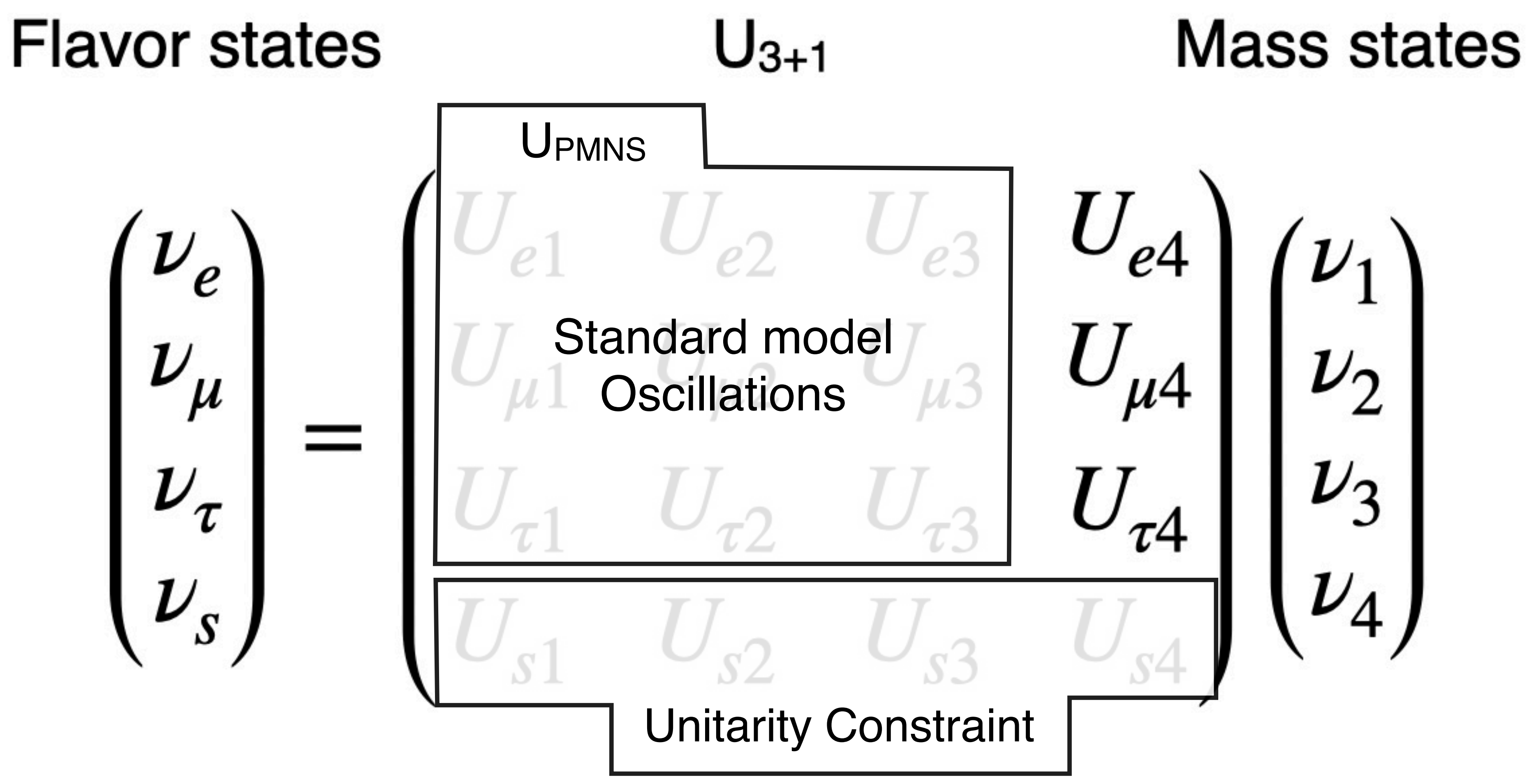

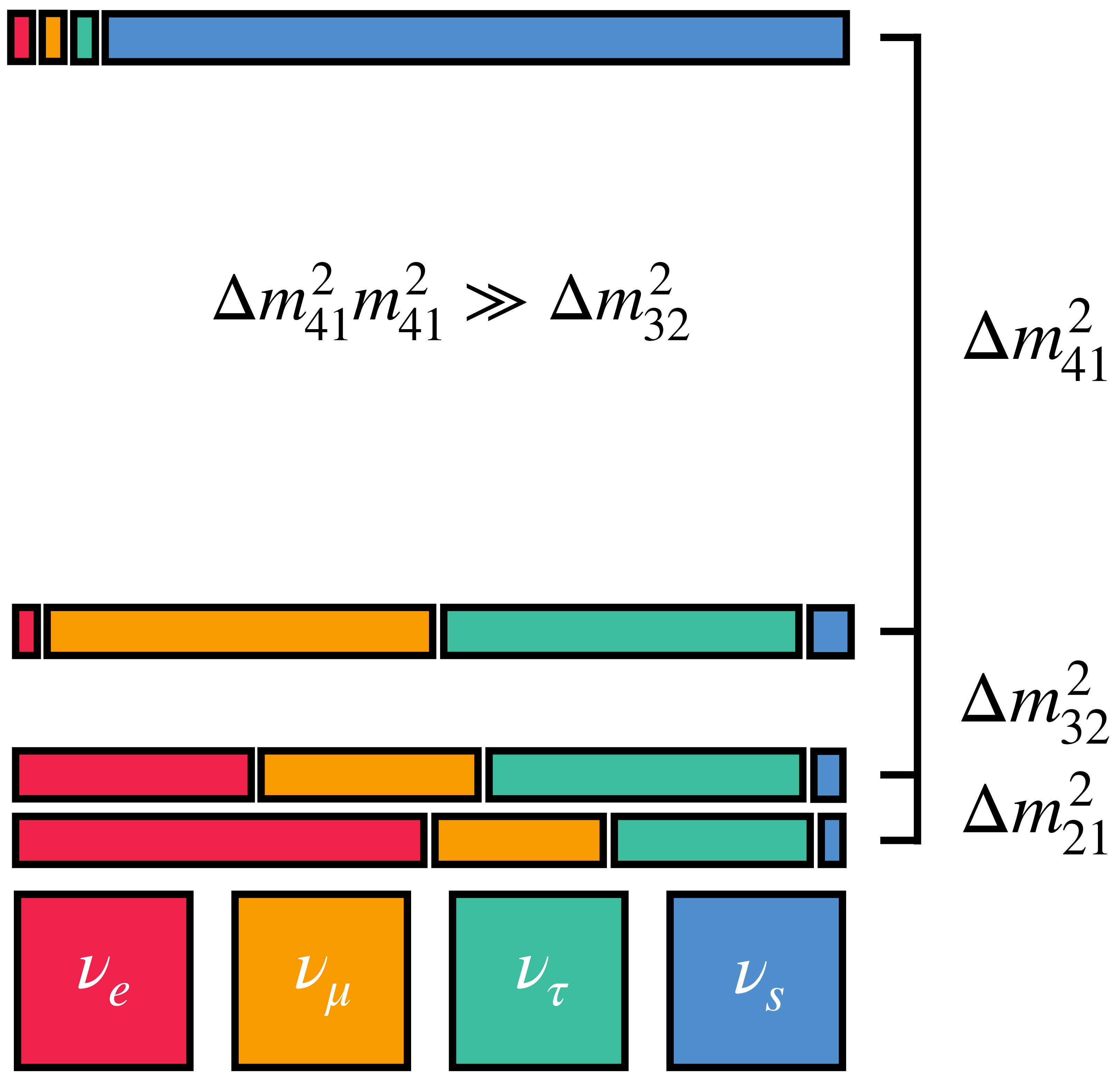

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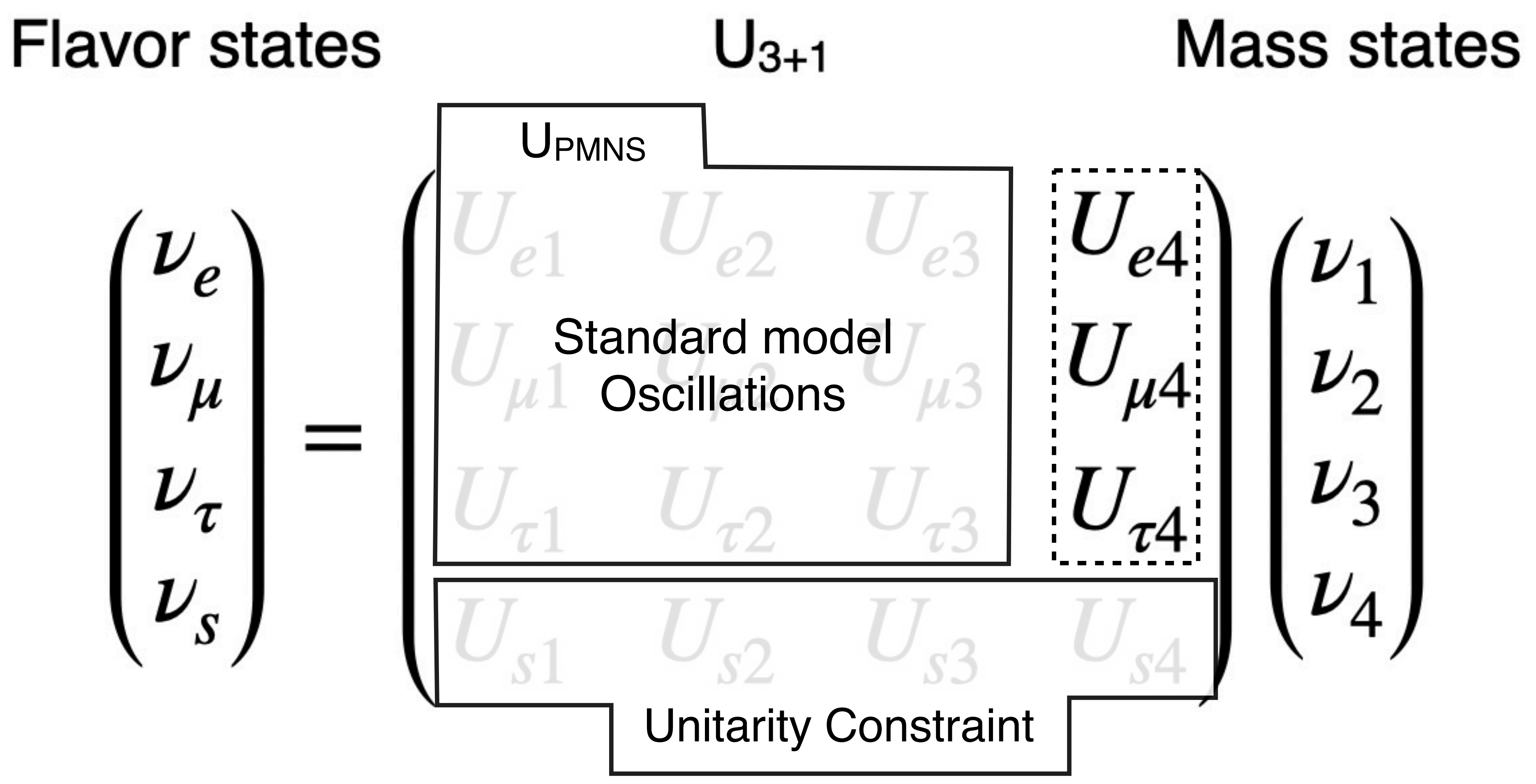

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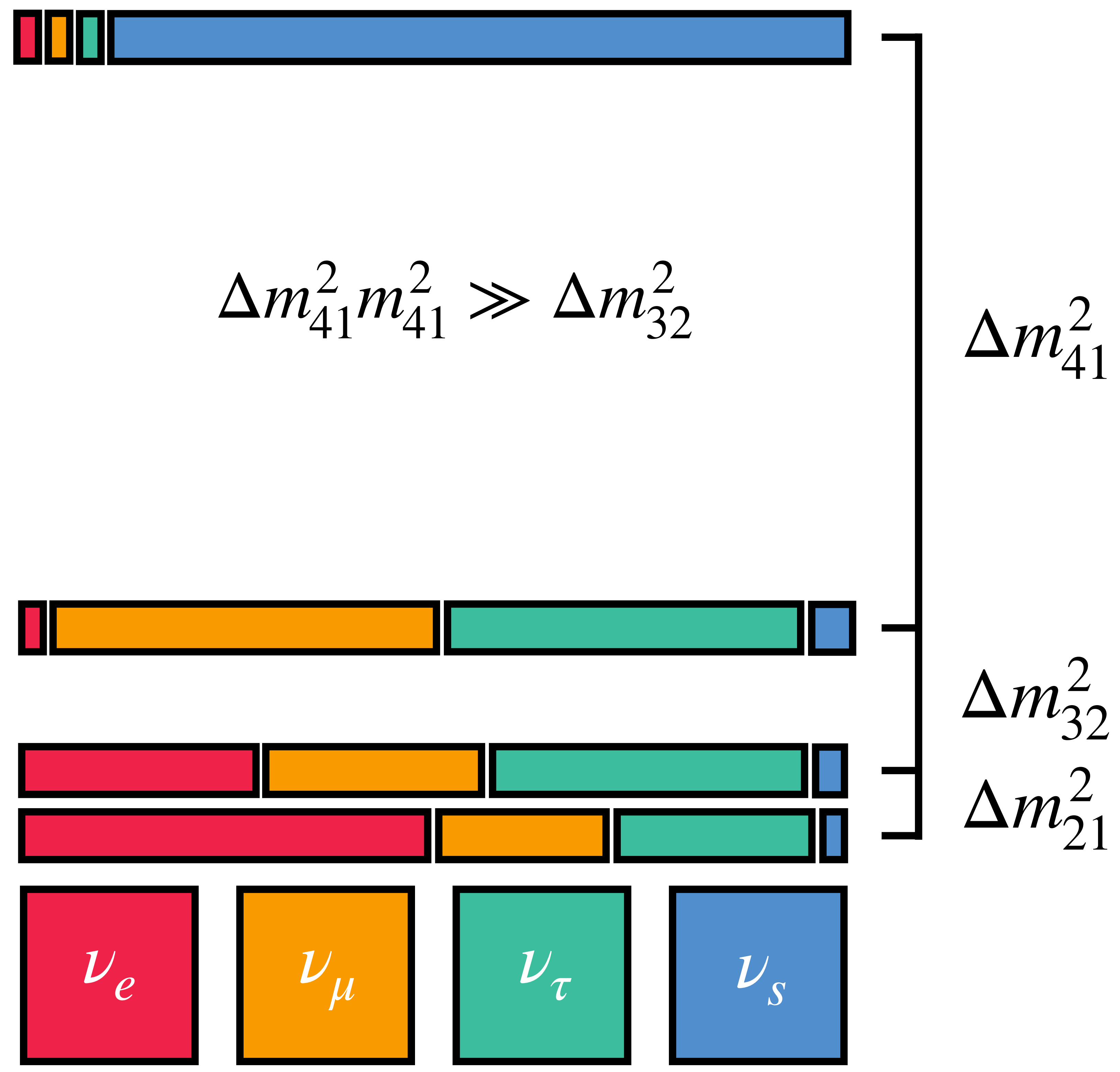

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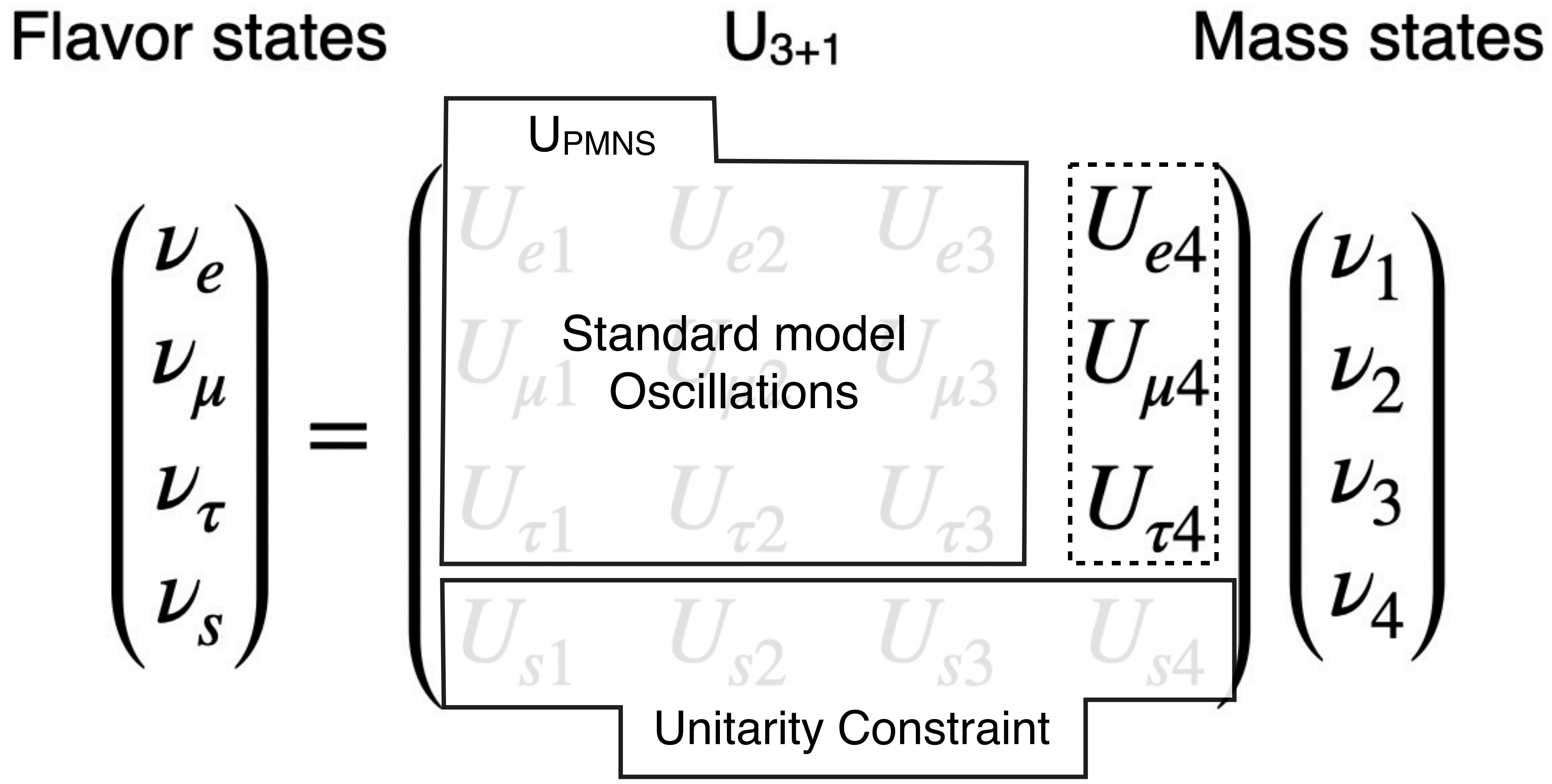

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Small θ_{14}, removes dependence on electron flavor mixing.

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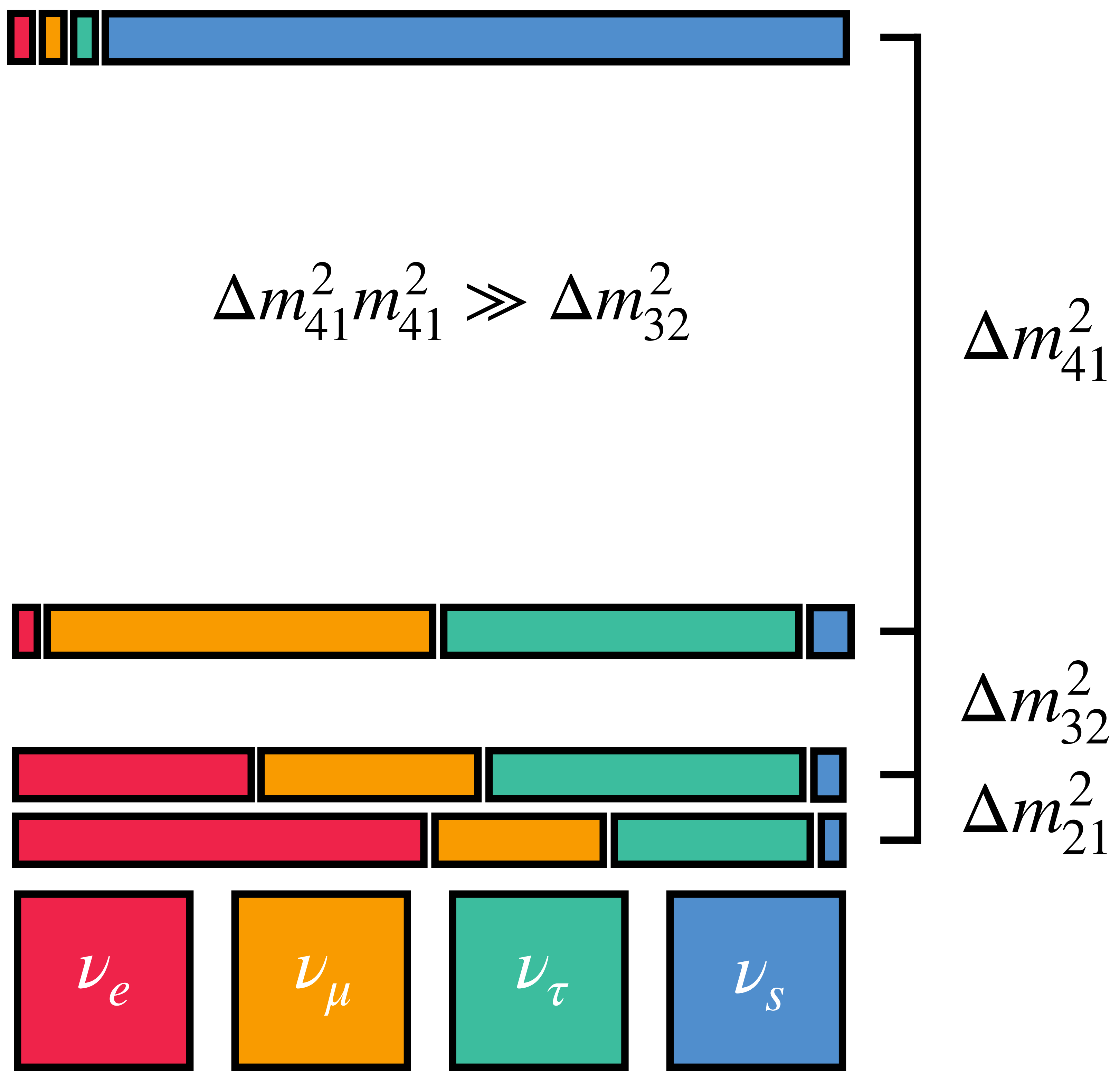

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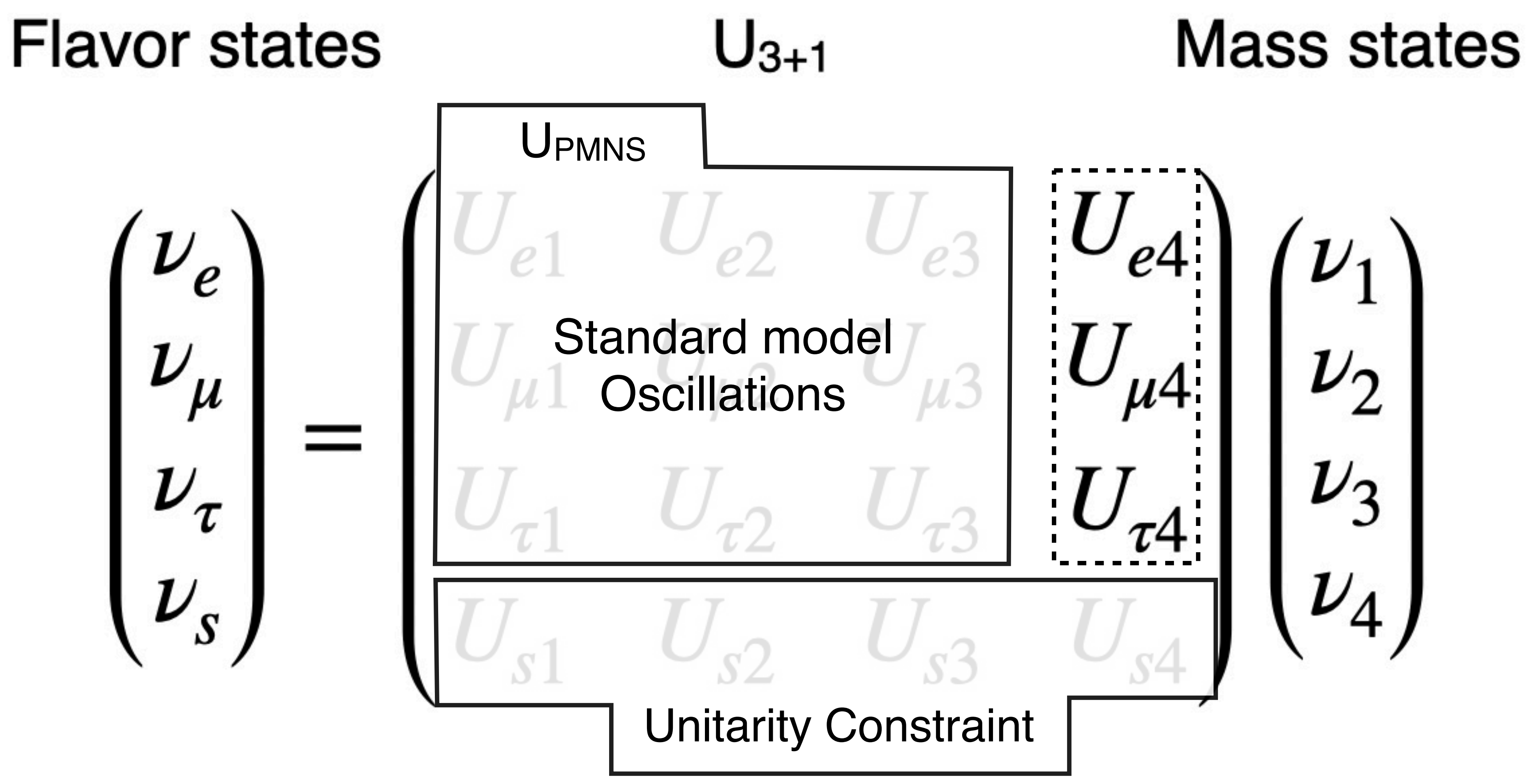

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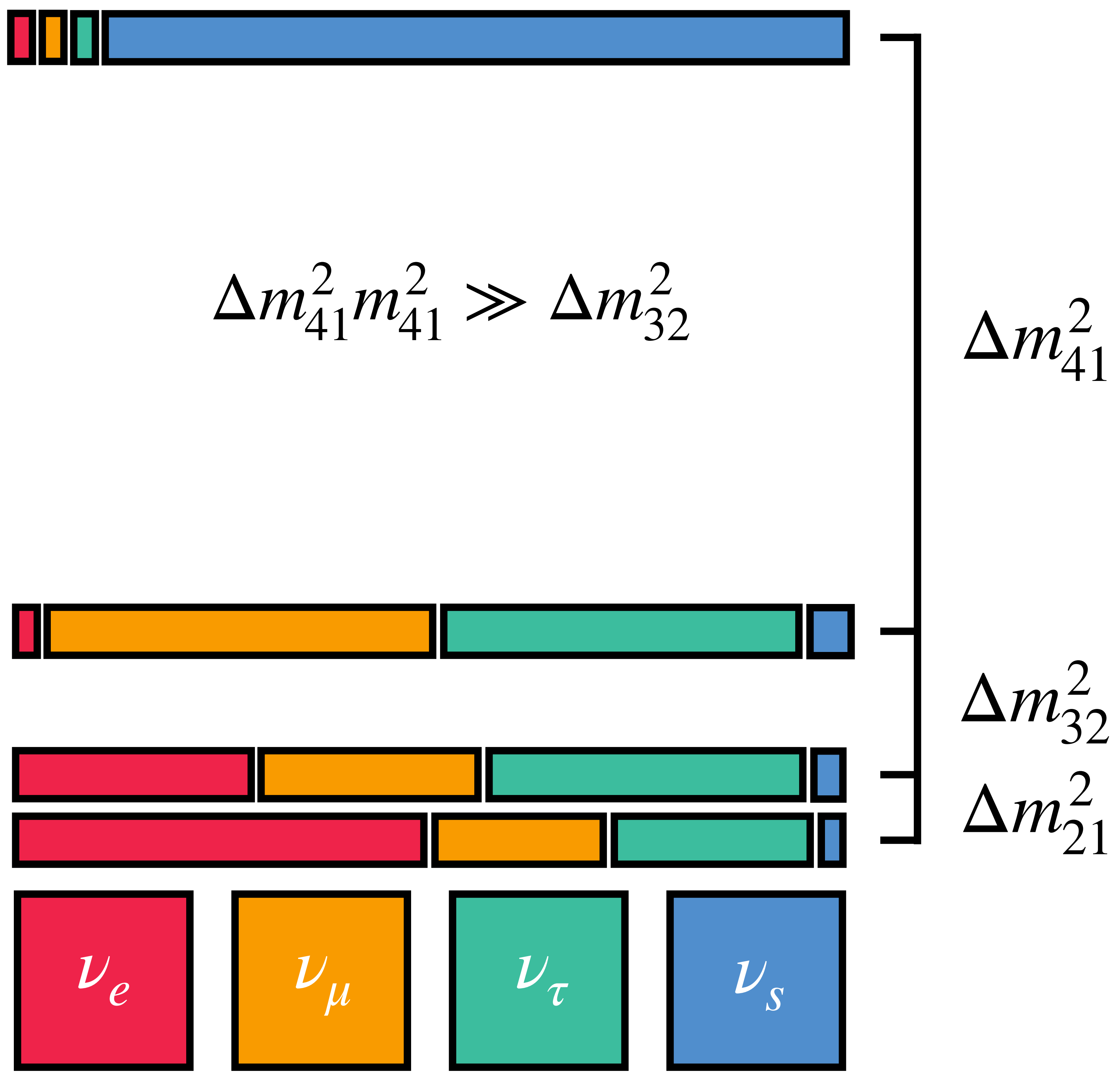

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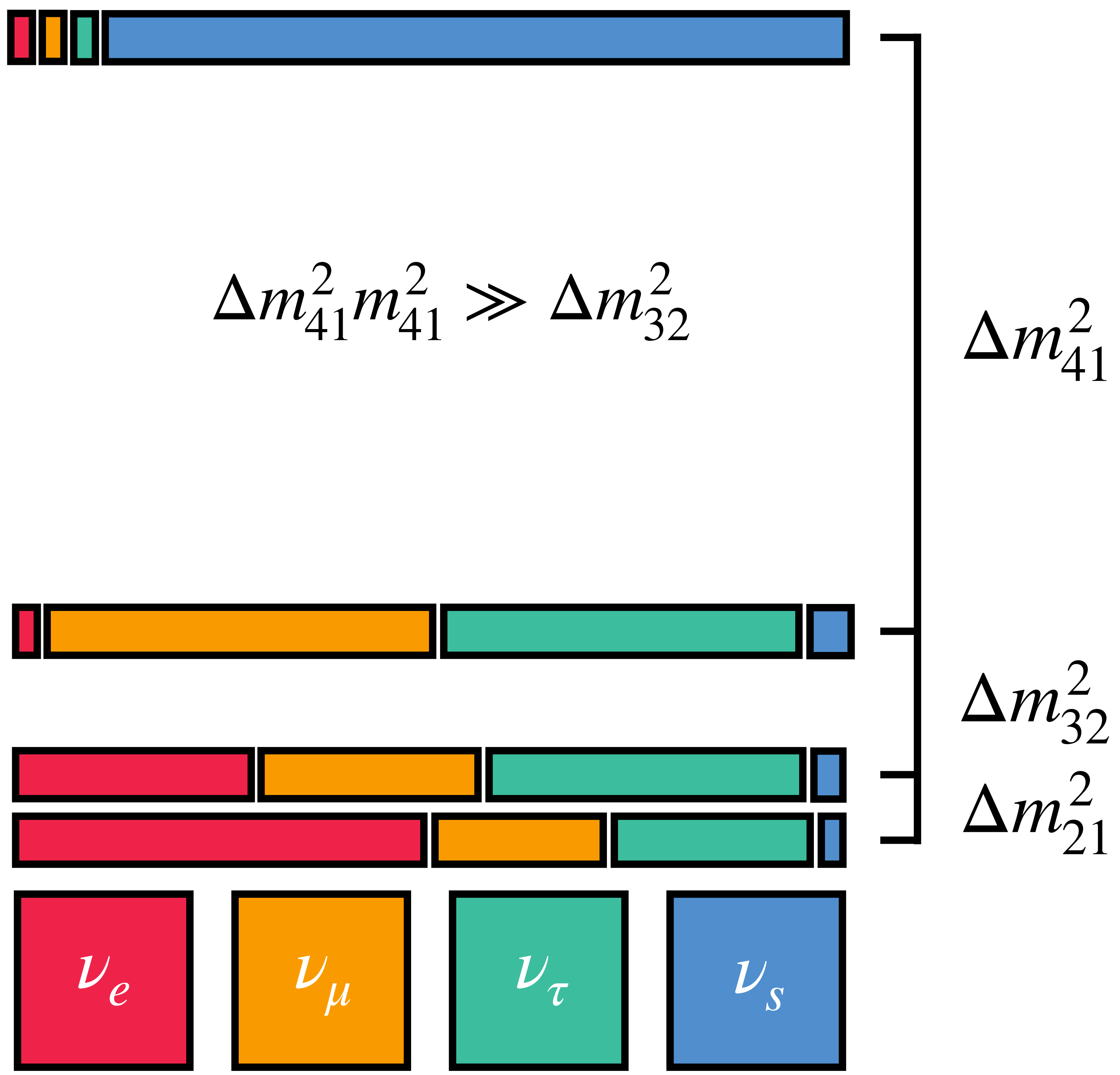

Parameters of interest: $\Delta m^2_{41}, \theta_{24}, \theta_{34}$

CP-violating phases are either marginalized over, or fixed to zero.

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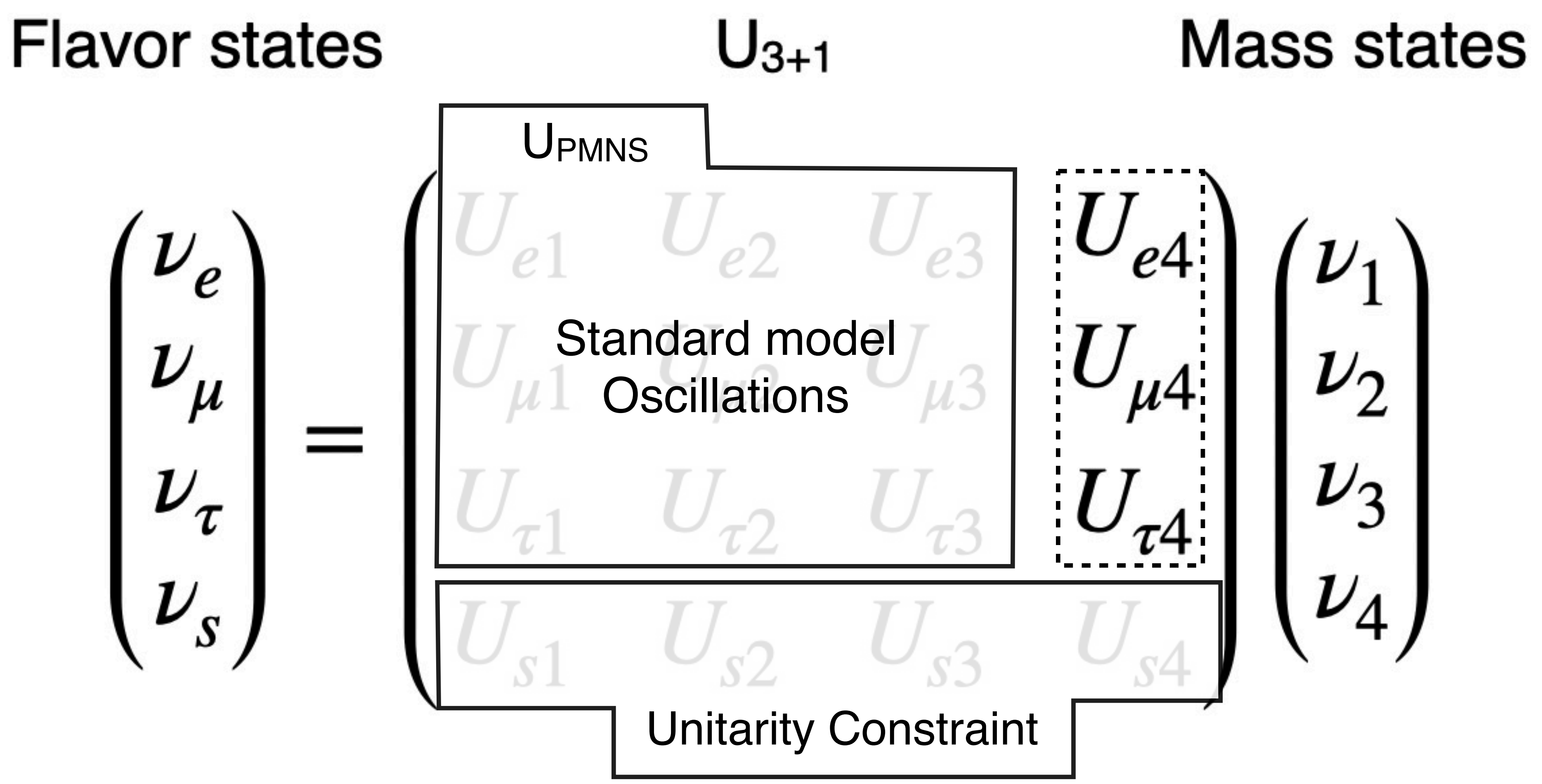

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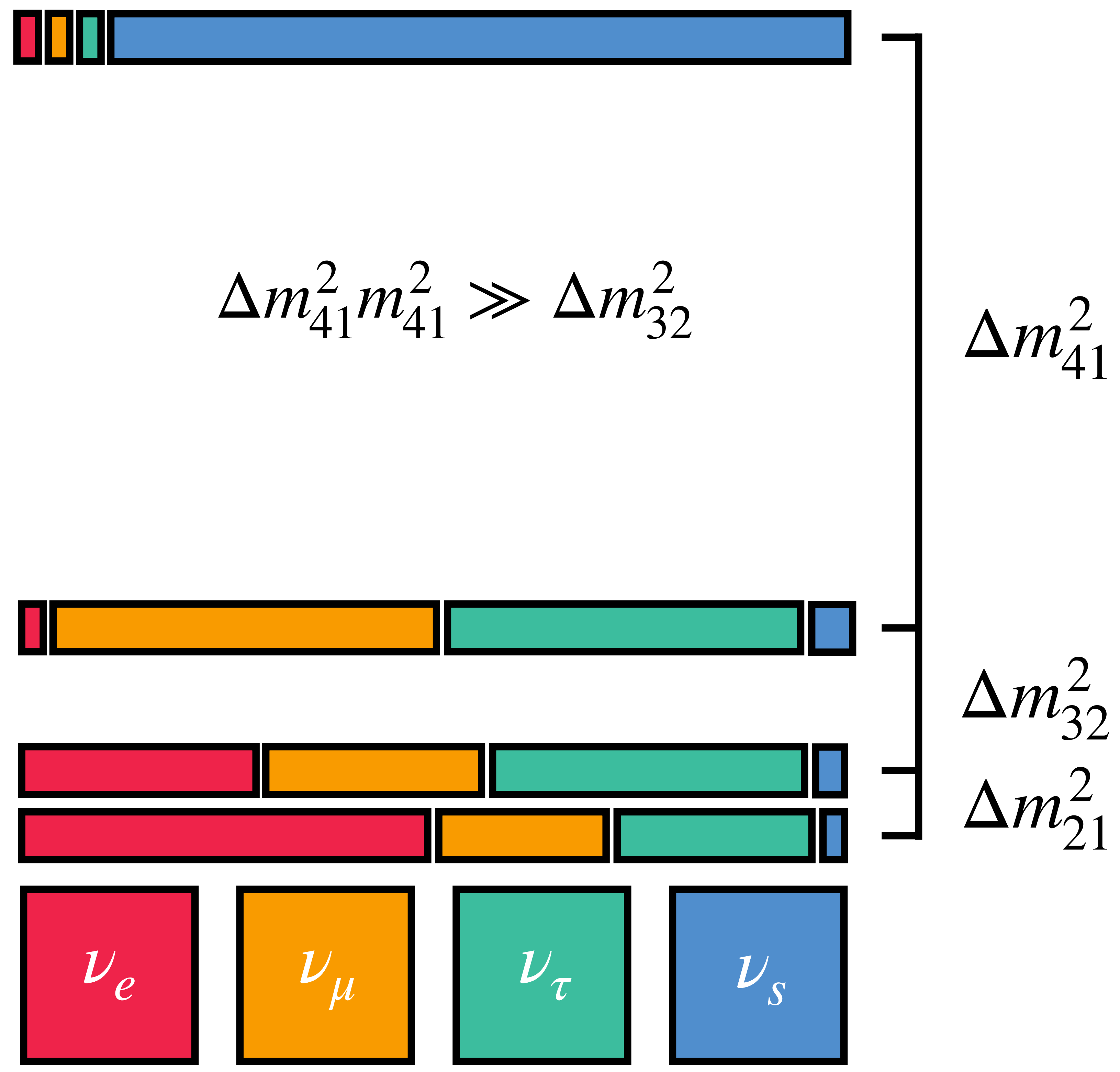

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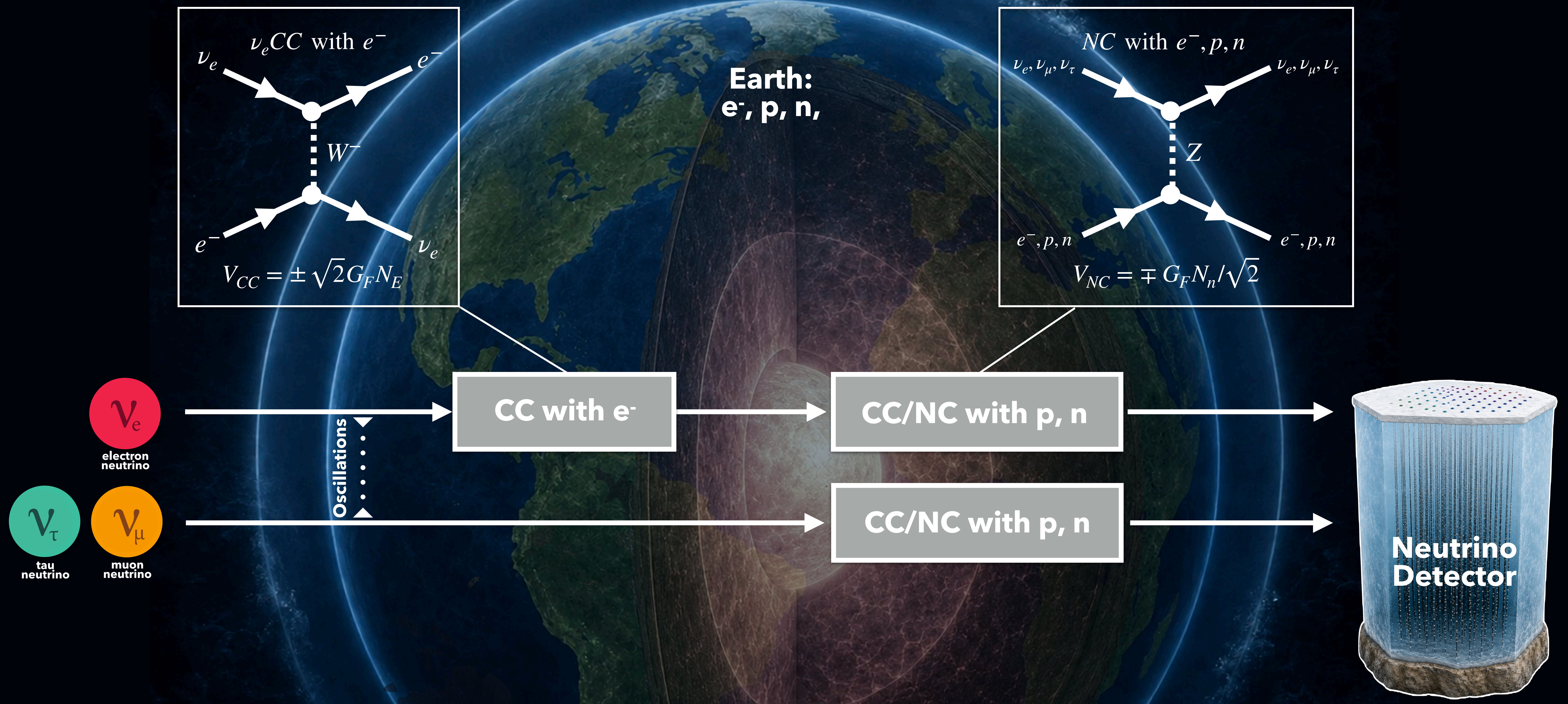
Earth-transiting neutrino oscillations with the ν_s state



Presence of matter modifies neutrino oscillations.

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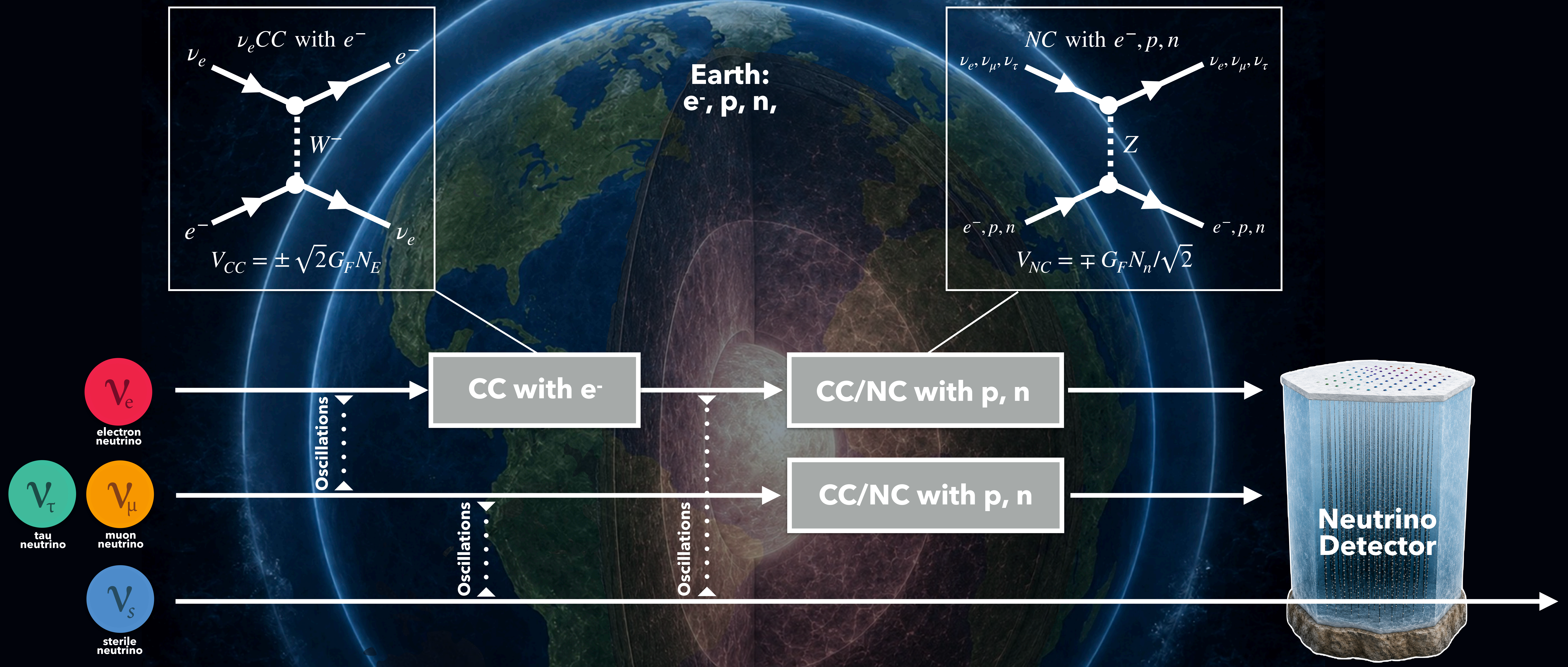

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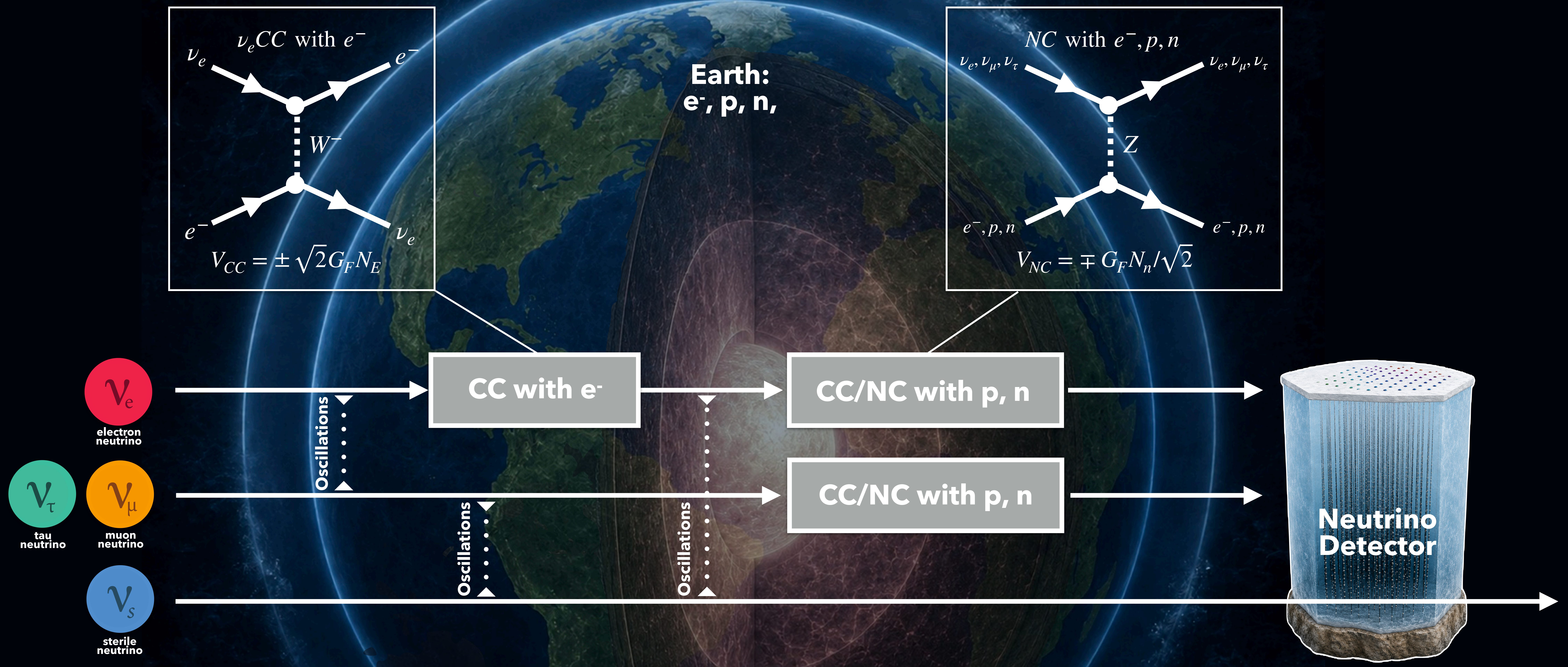

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Given the right conditions (E_ν, ρ), this can lead to resonant transformation into the ν_s state.

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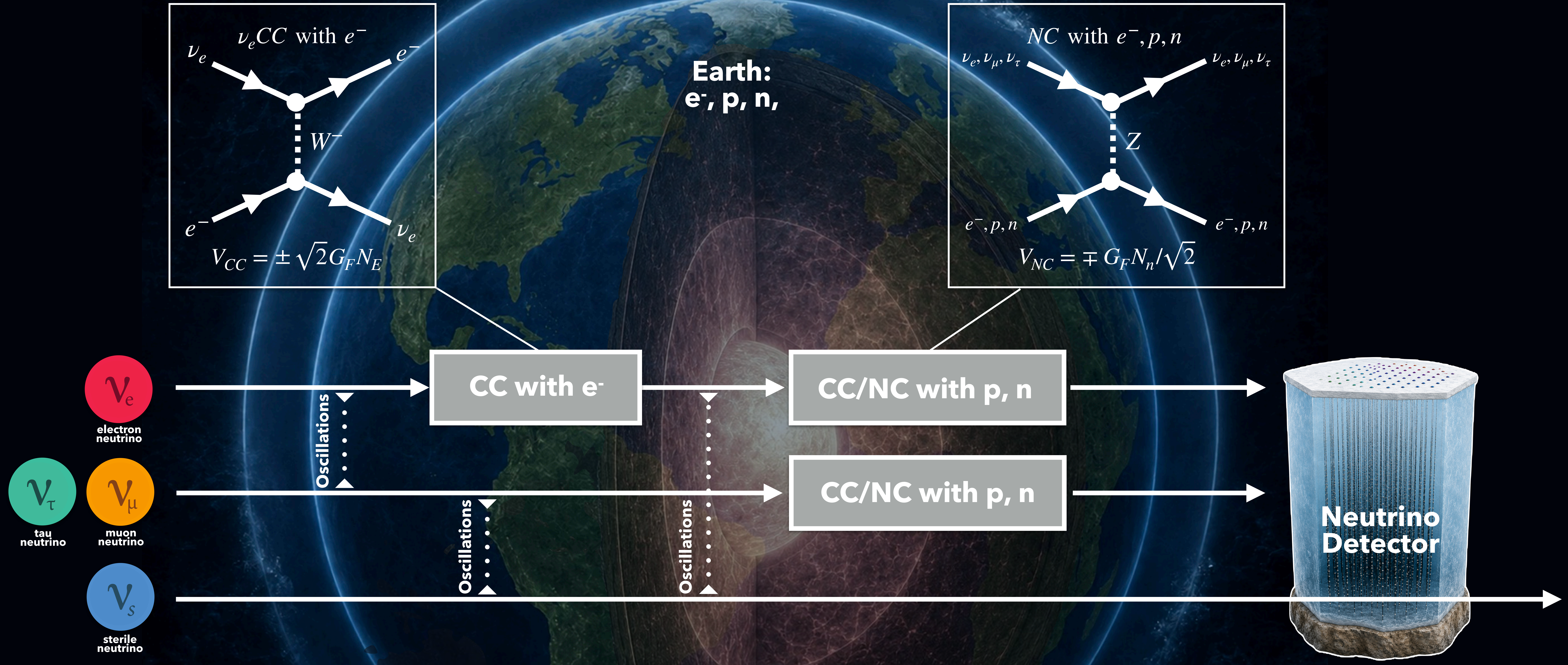

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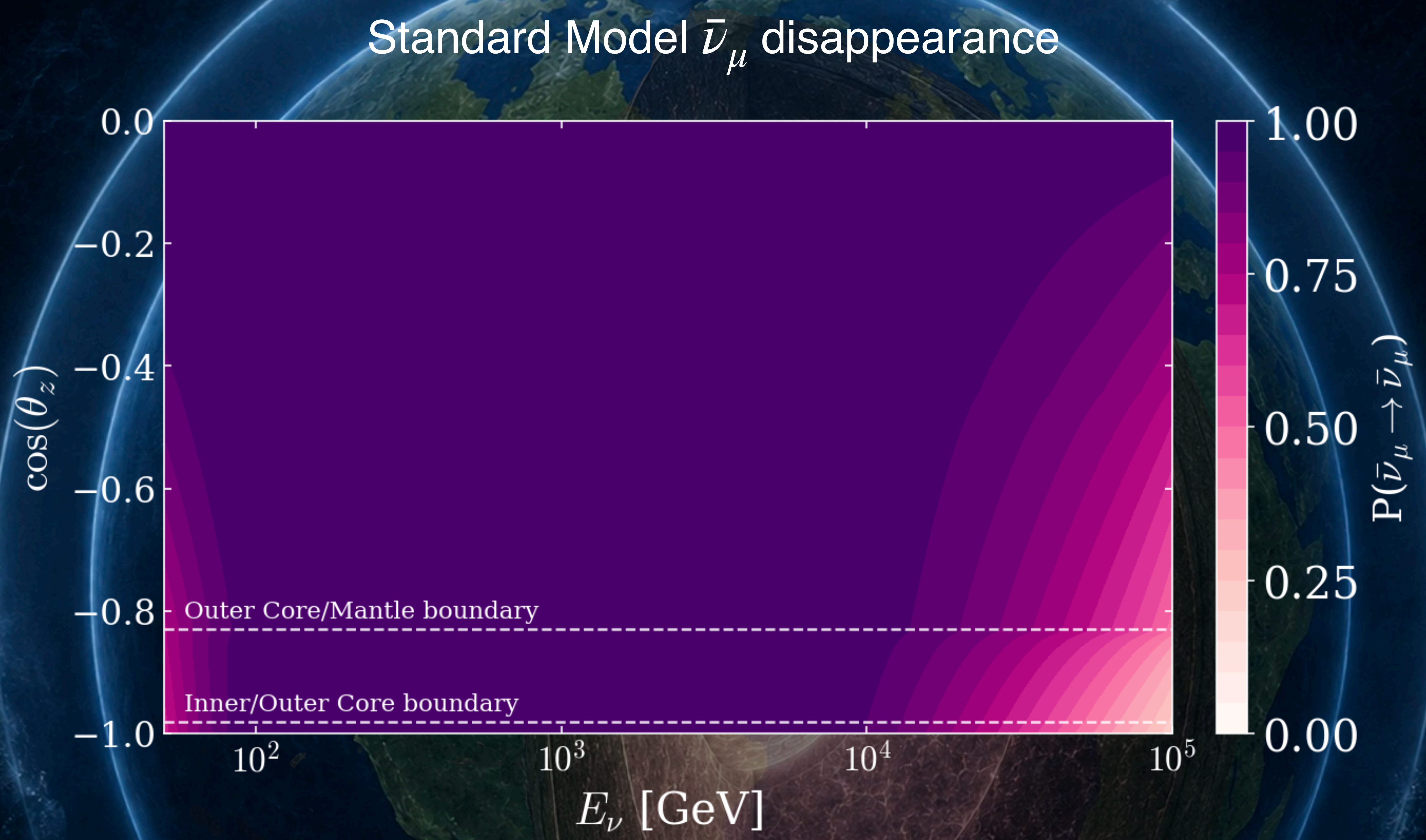
$$E_\nu^{res} = \pm \frac{\cos(2\theta)\cdot \Delta m^2}{\sqrt{2}G_F N_{nuc}}$$

3+1 Sterile Neutrino oscillatory signatures



nuSQuIDS: arXiv:2112.13804

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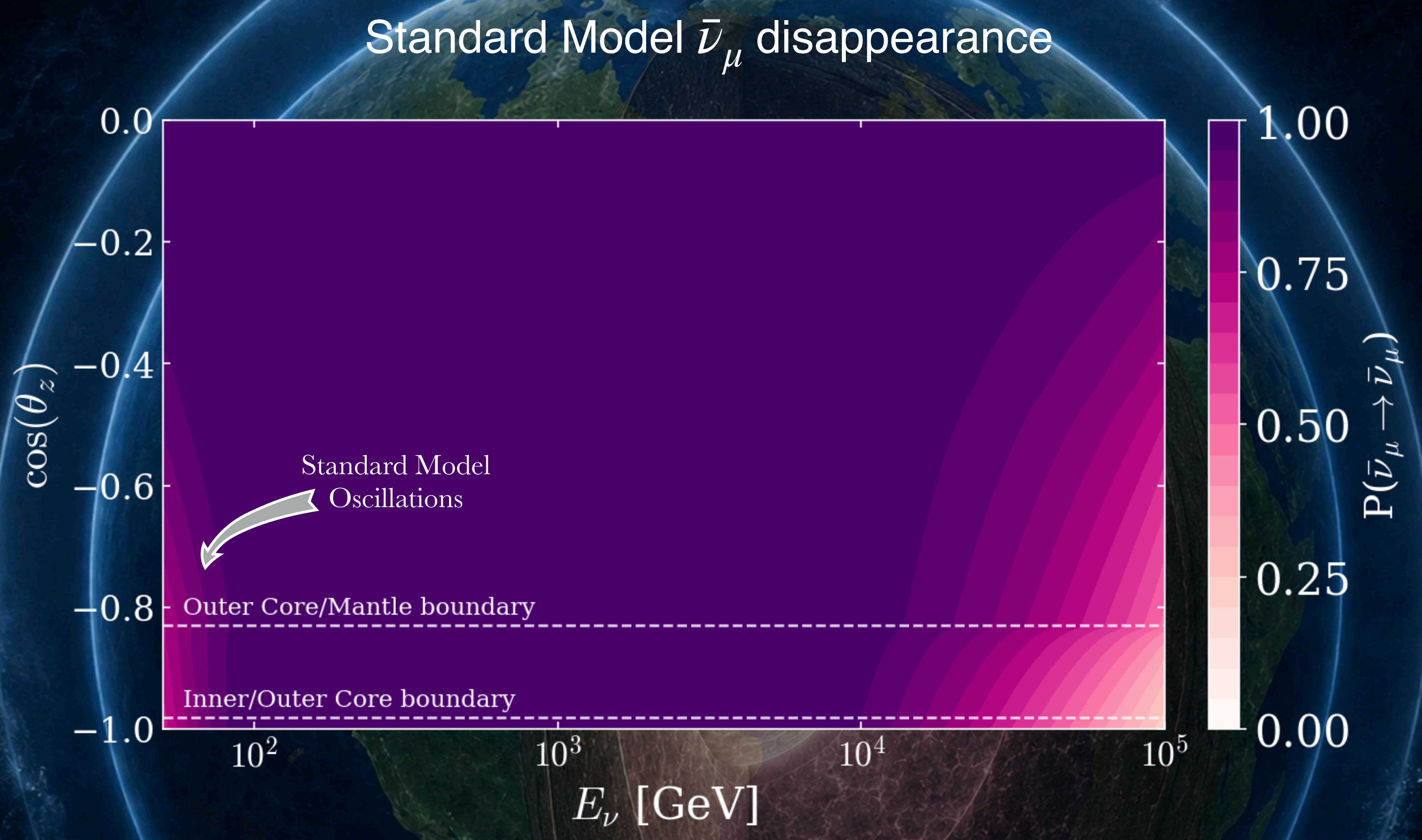

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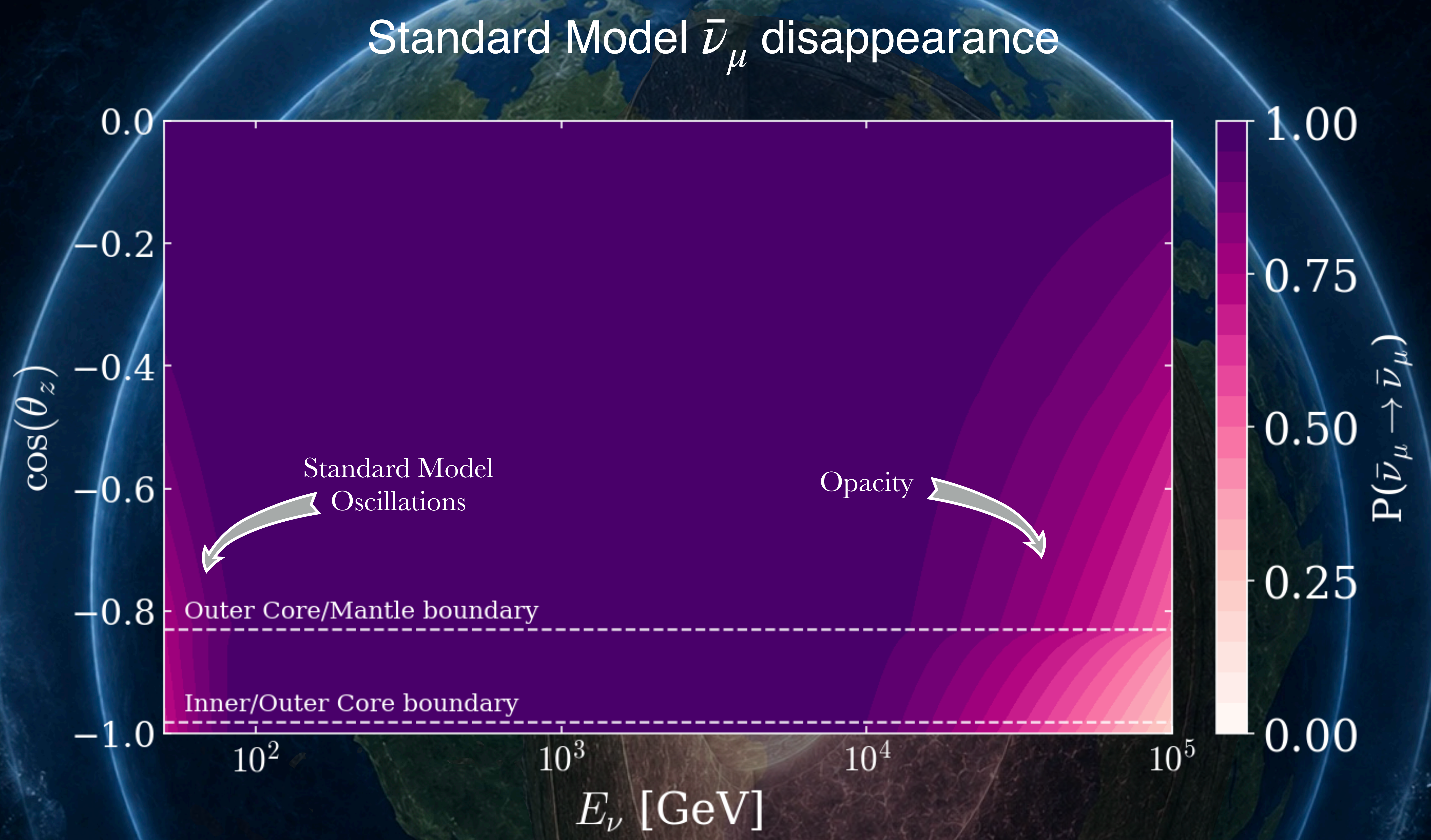

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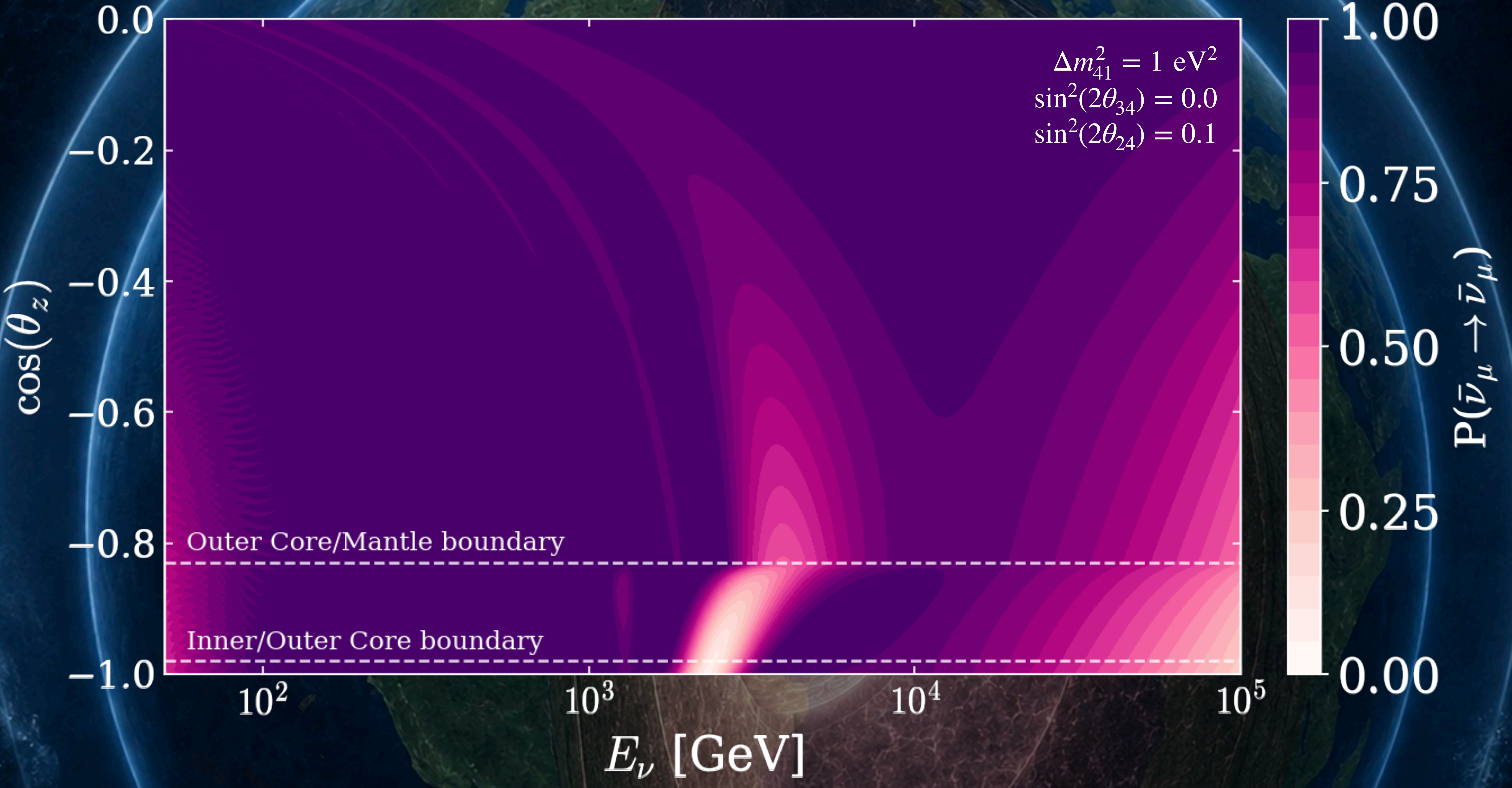
3+1 Sterile Neutrino oscillatory signatures

$P(\bar{\nu}_\mu \rightarrow \bar{\nu}_\mu)$ resonant disappearance at TeV energies with 3+1 sterile model.



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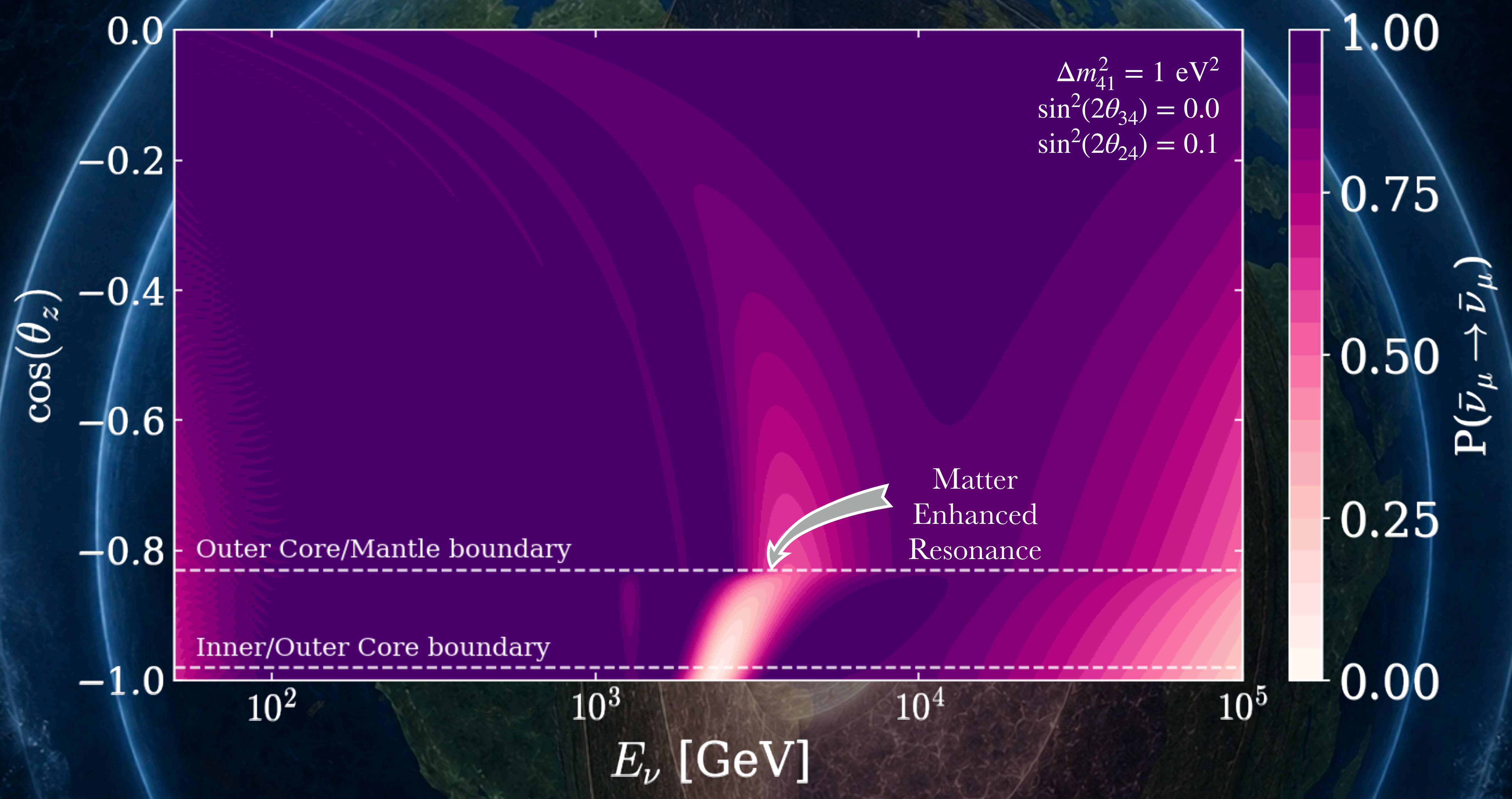

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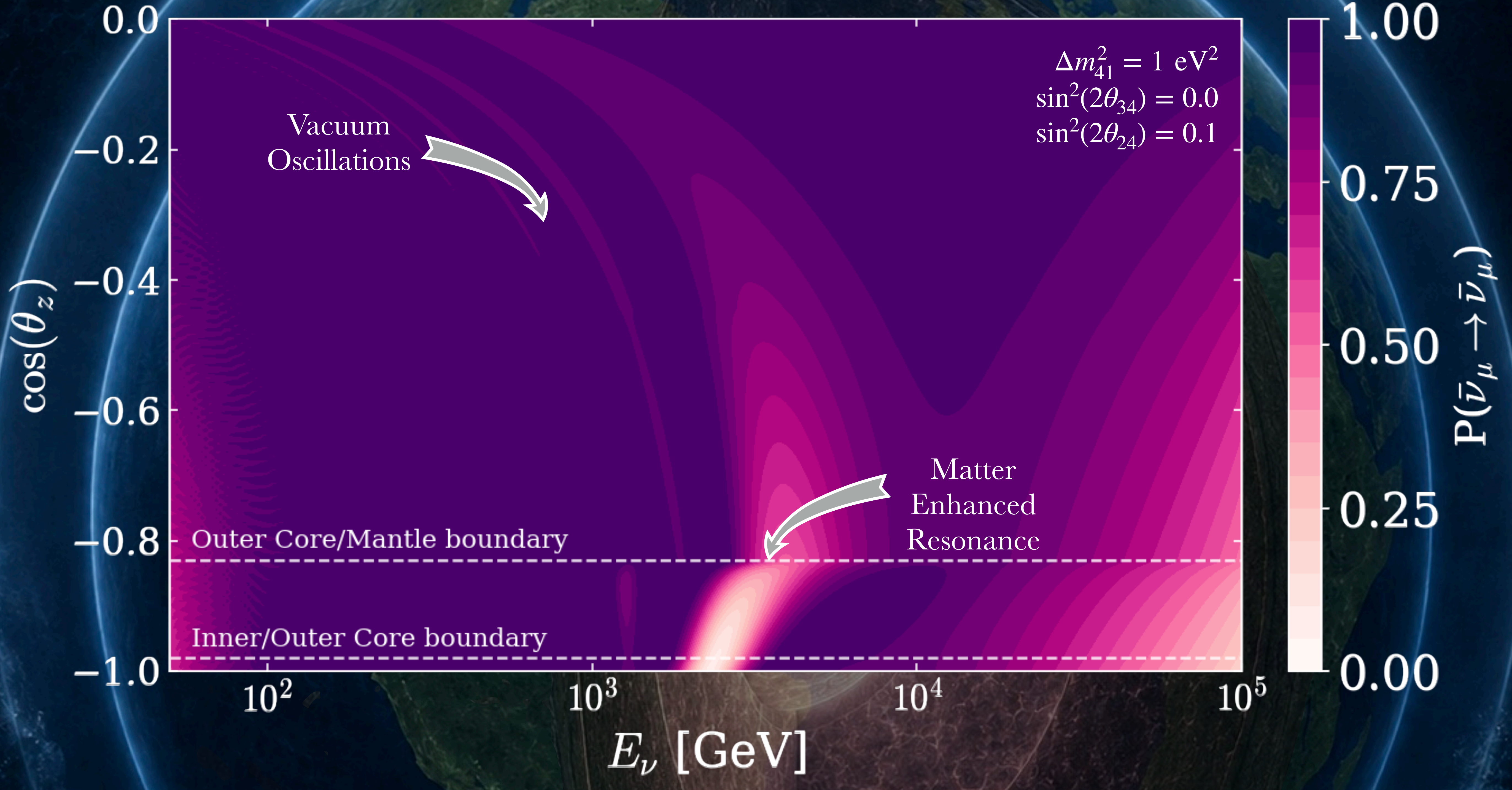

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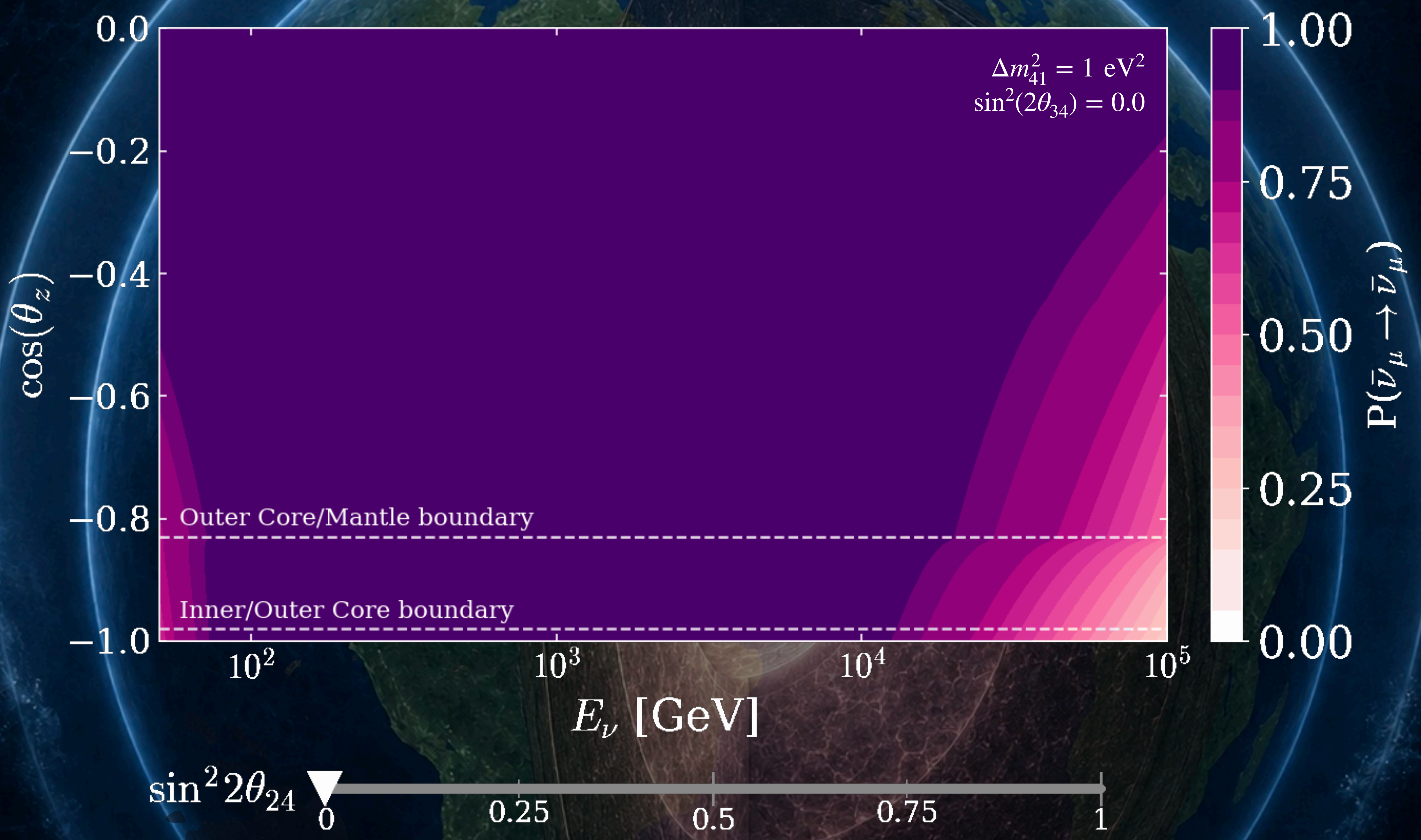

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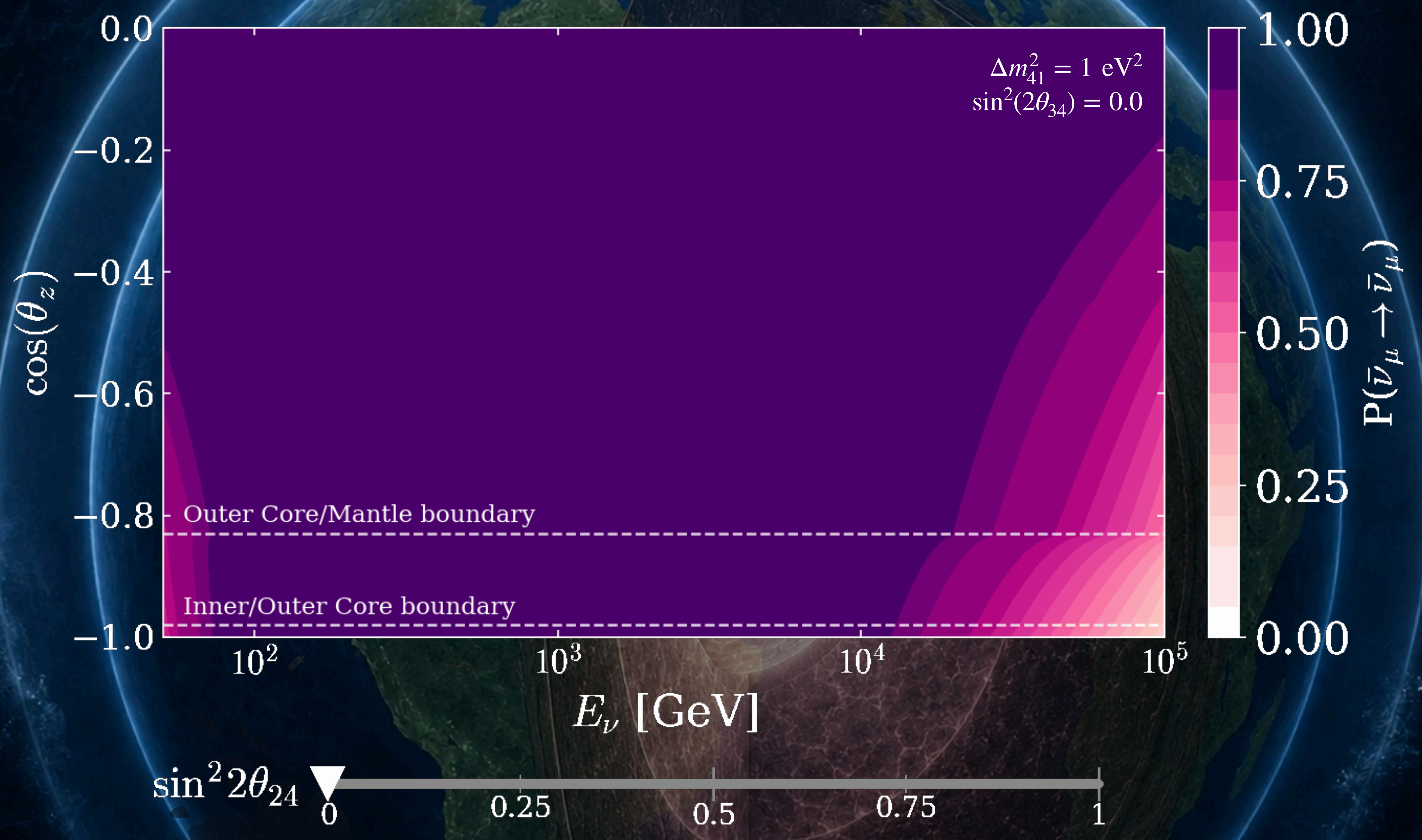

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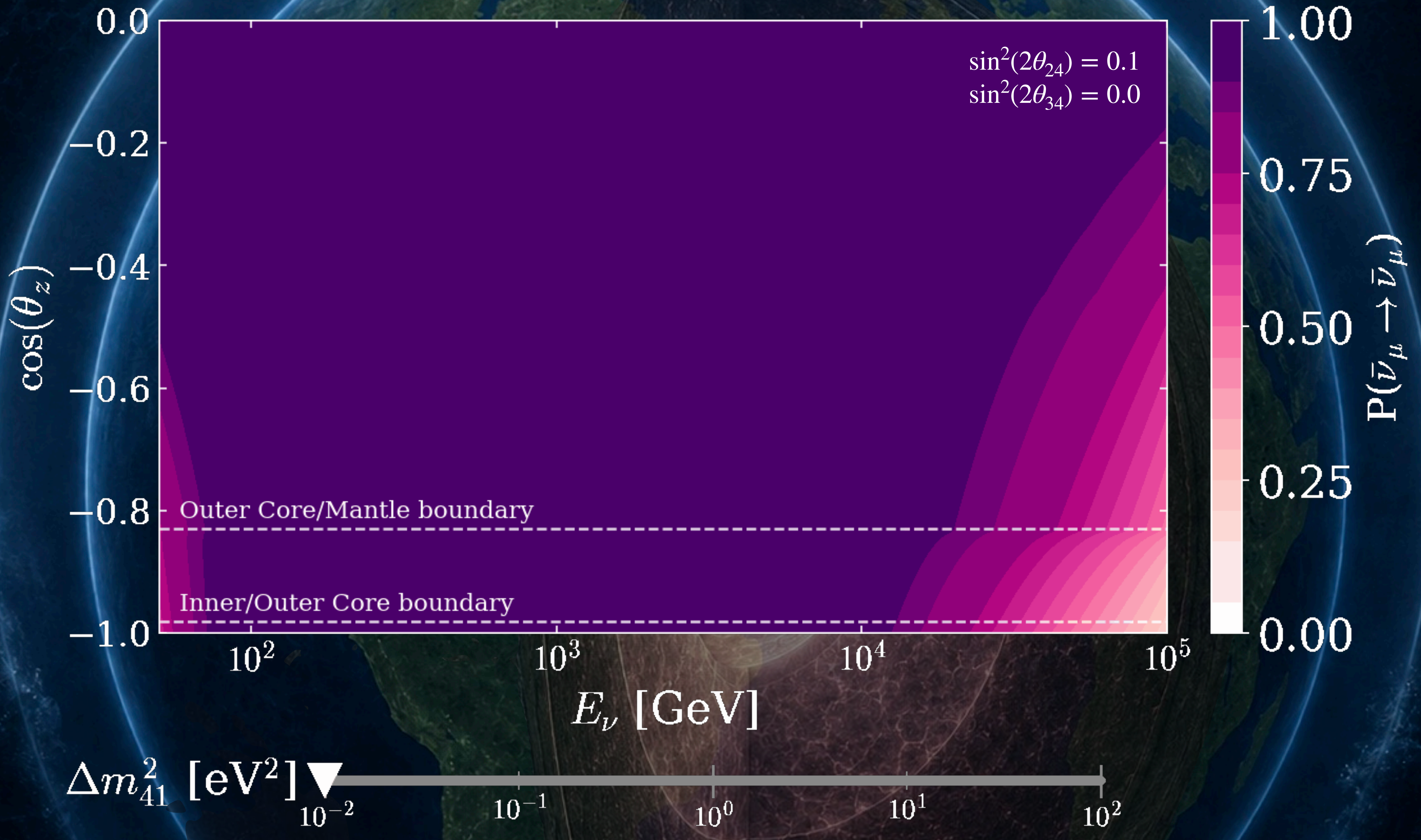

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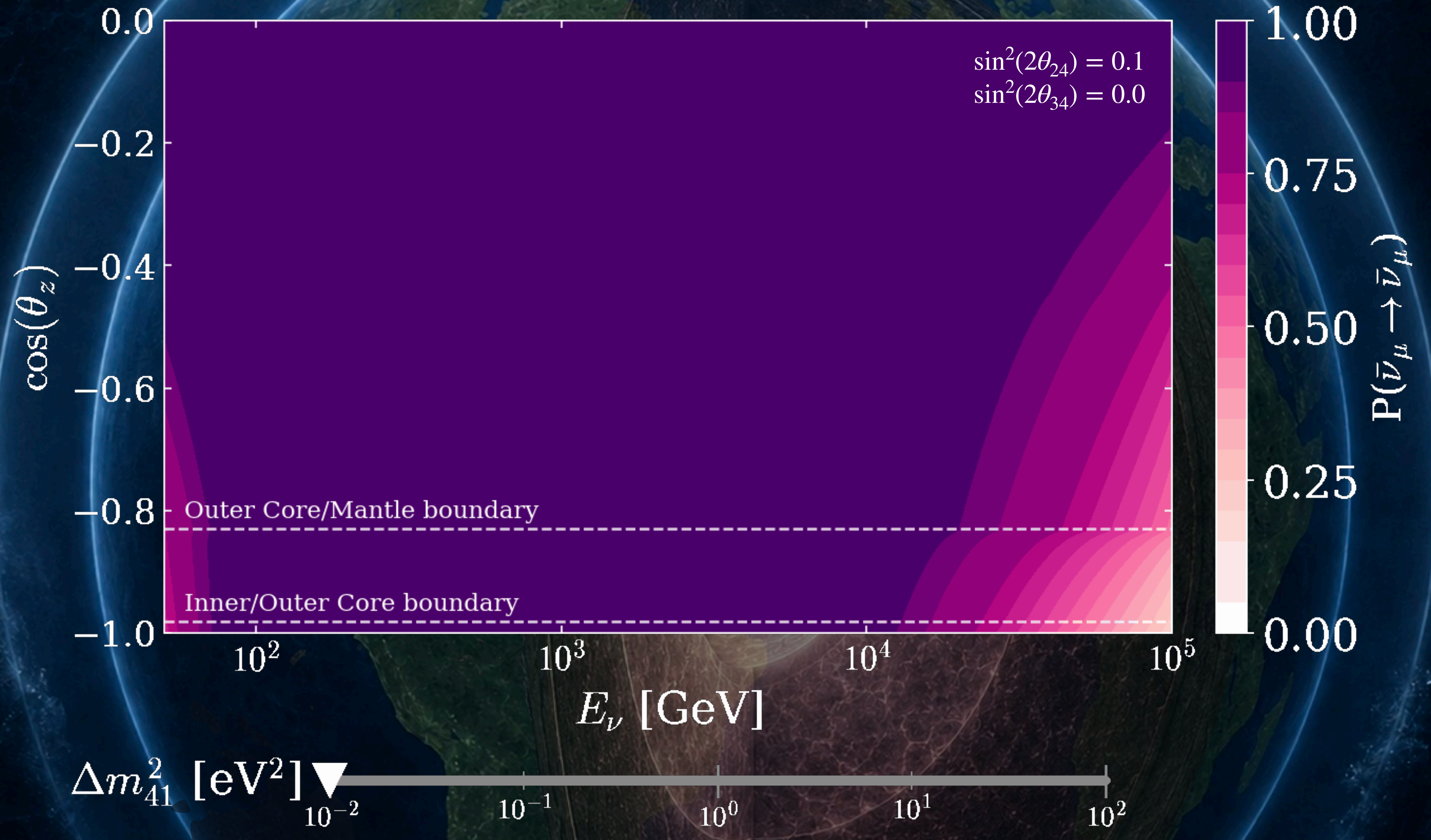

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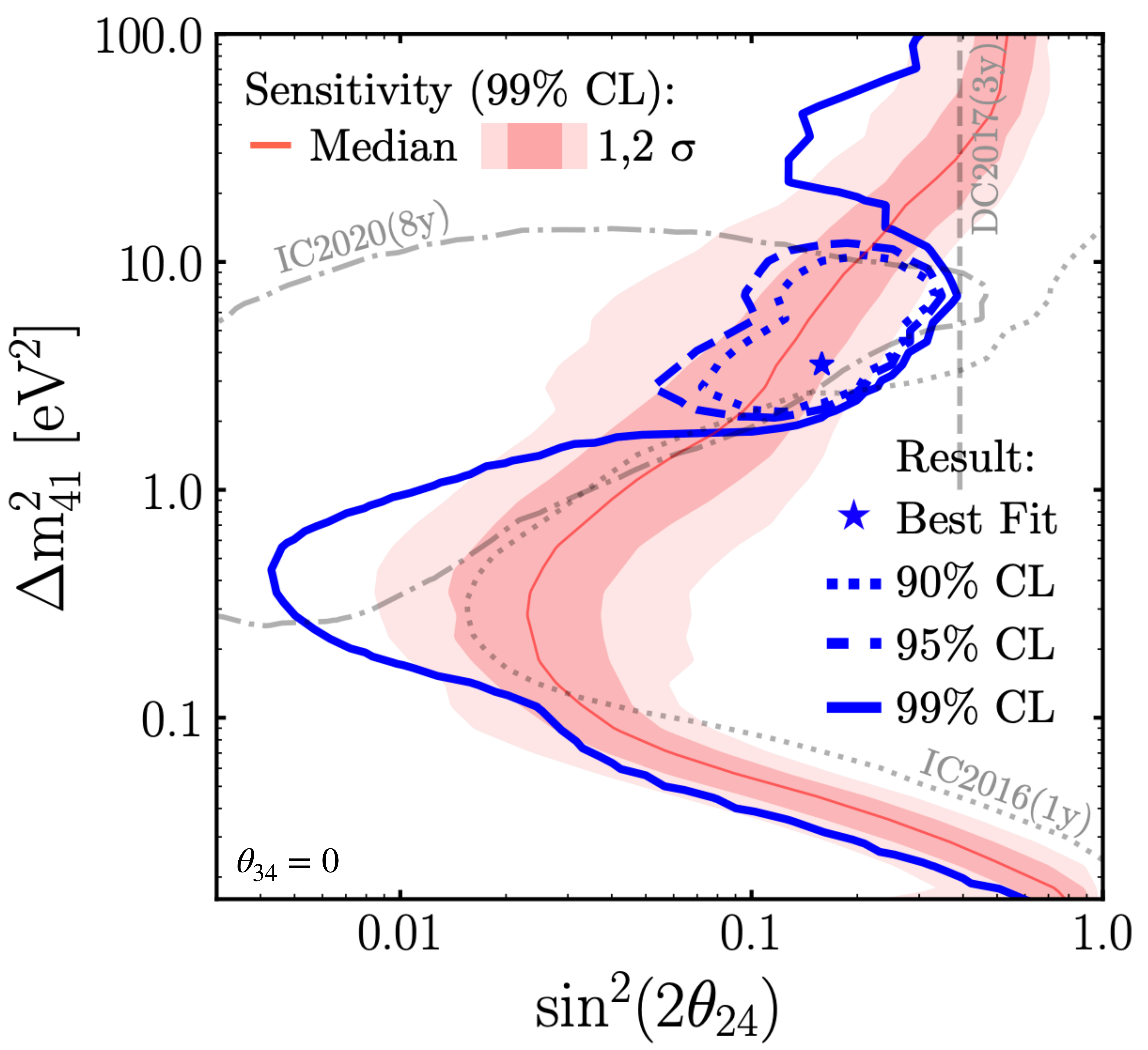
The high-energy 3+1 sterile neutrino result

Dataset consists of 10.7 years of data, resulting in 368,071 events (>99.9% ν_μCC starting and through-going tracks). Energy range between 0.5 and 100 TeV. BDT event selection with DNN ML reconstruction.



Best Fit:
$\Delta m^2_{41} = 3.5$ eV^2
$\sin^2(2\theta_{24}) = 0.16$

[1] 3+1 IceCube: Phys. Rev. lett. 133.20 (2024): 201804

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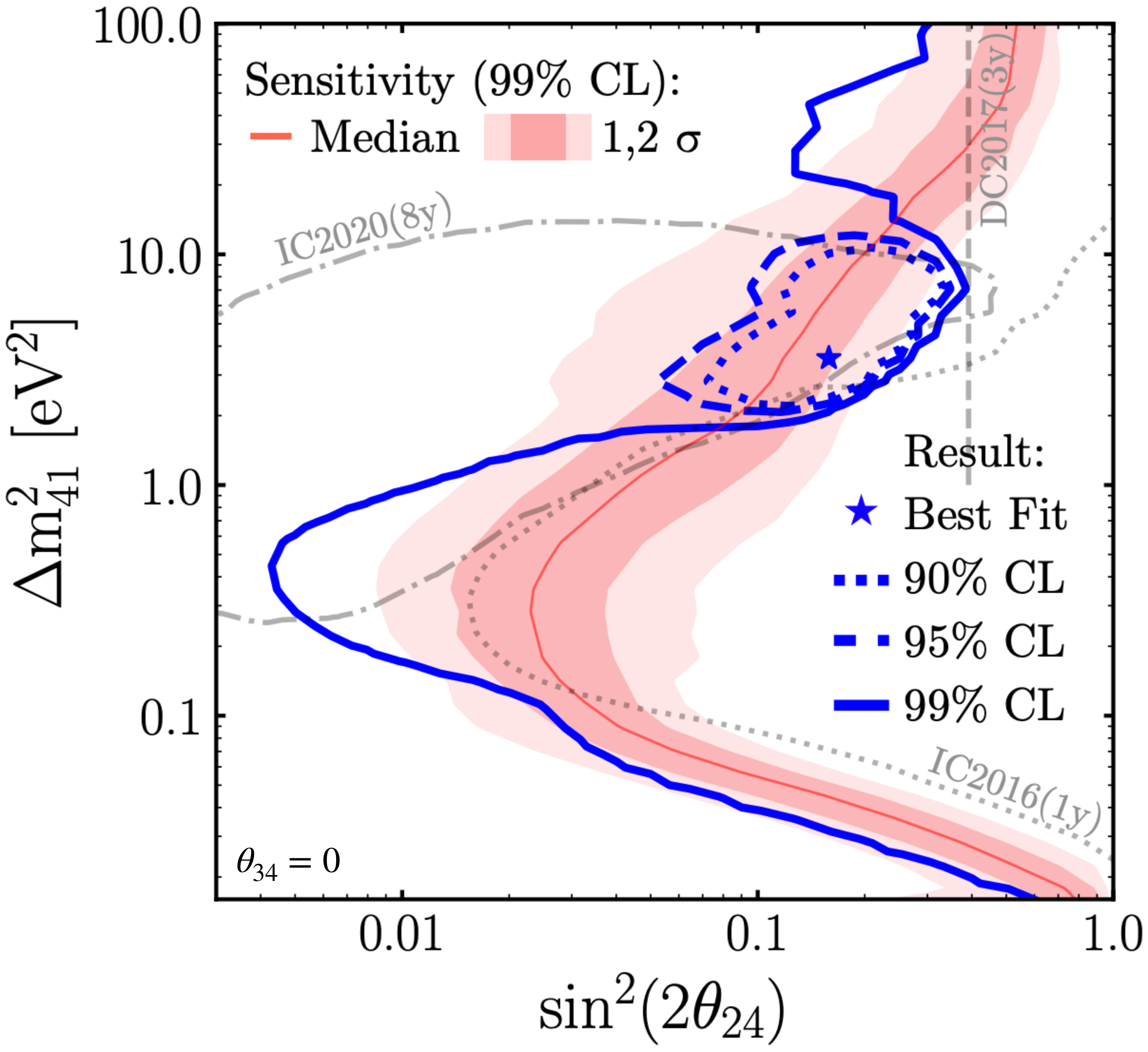

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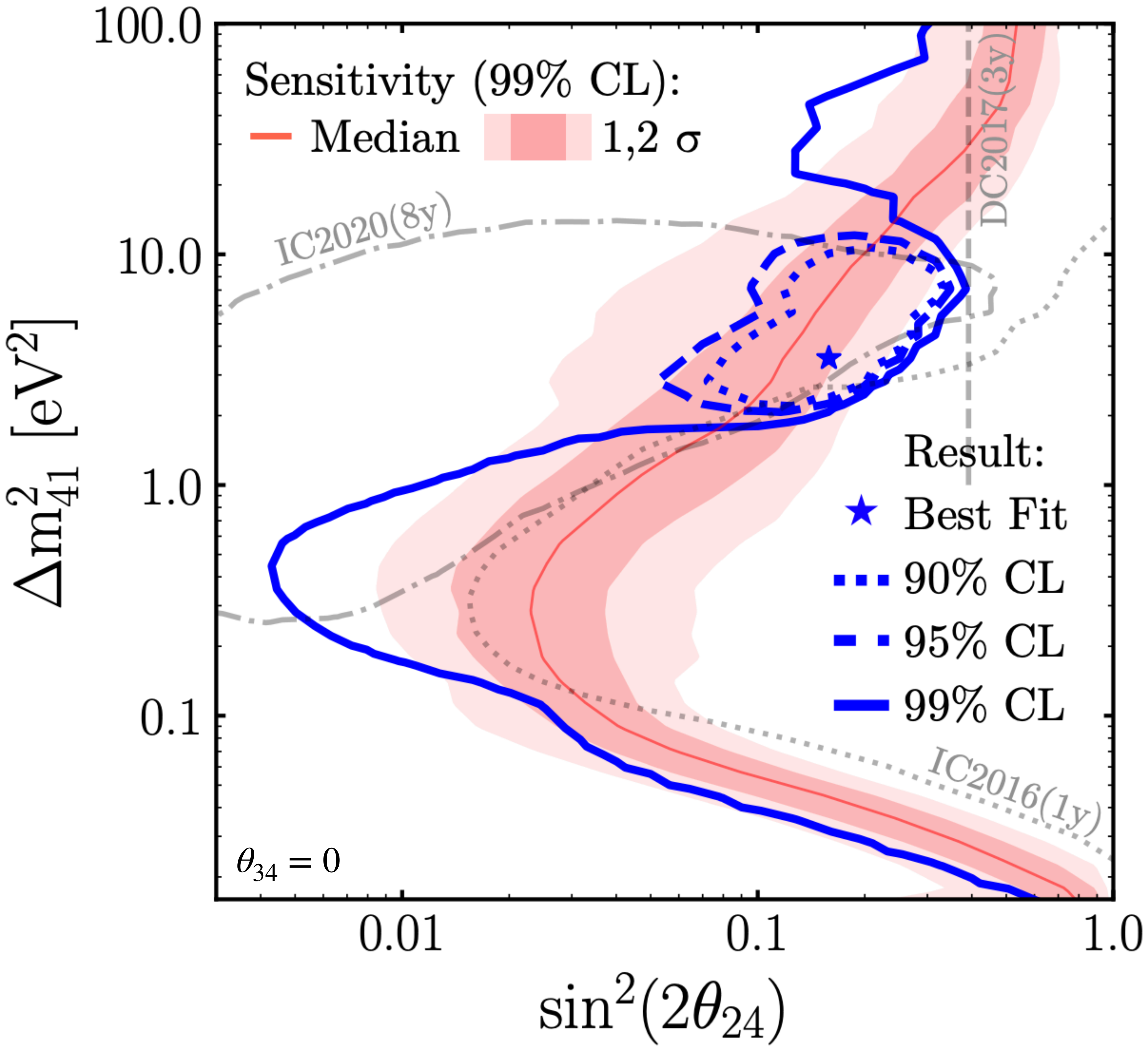

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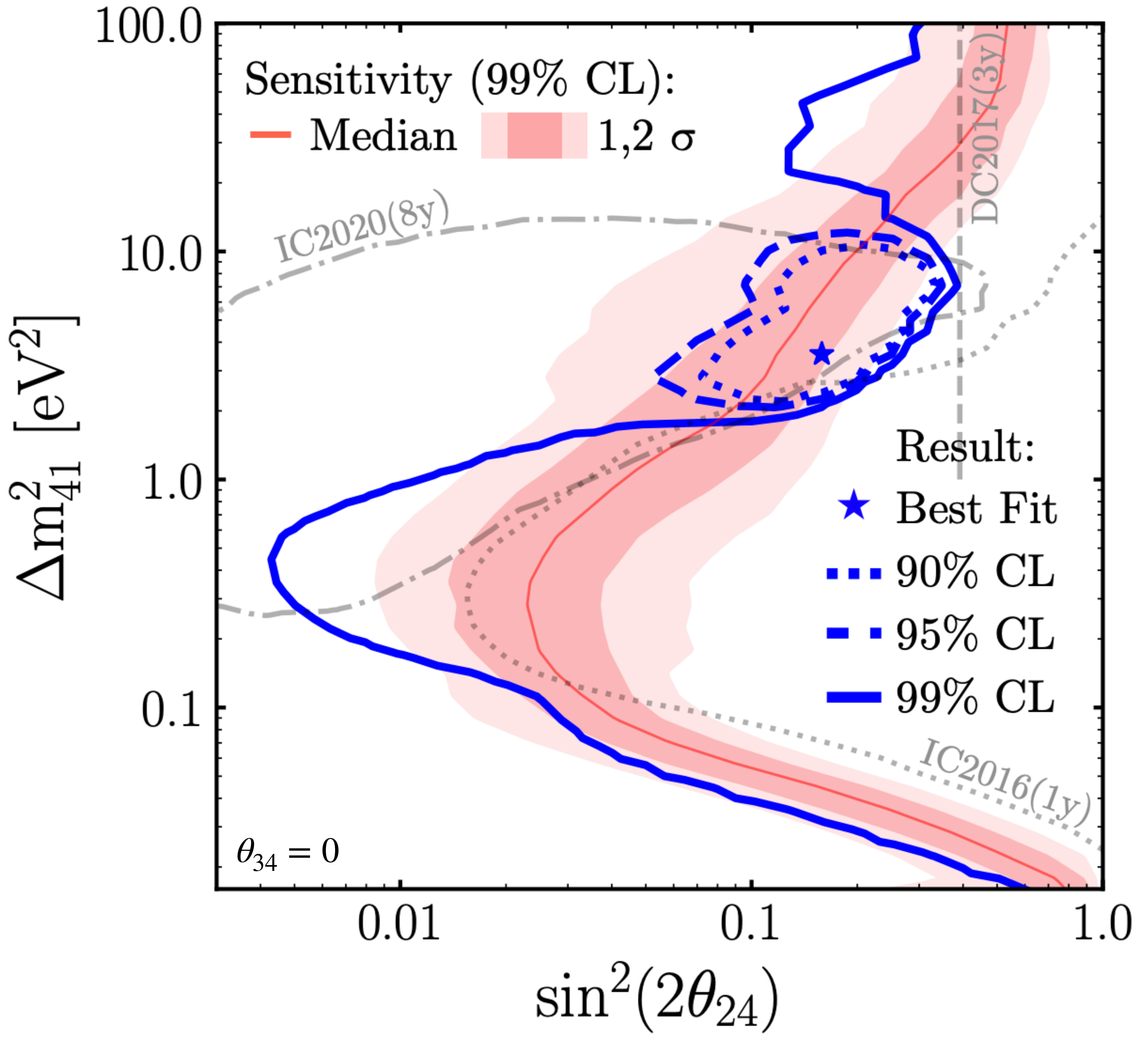

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SEE
MILES GARCIA'S
POSTER ON TUESDAY
4:10PM - 5:40PM

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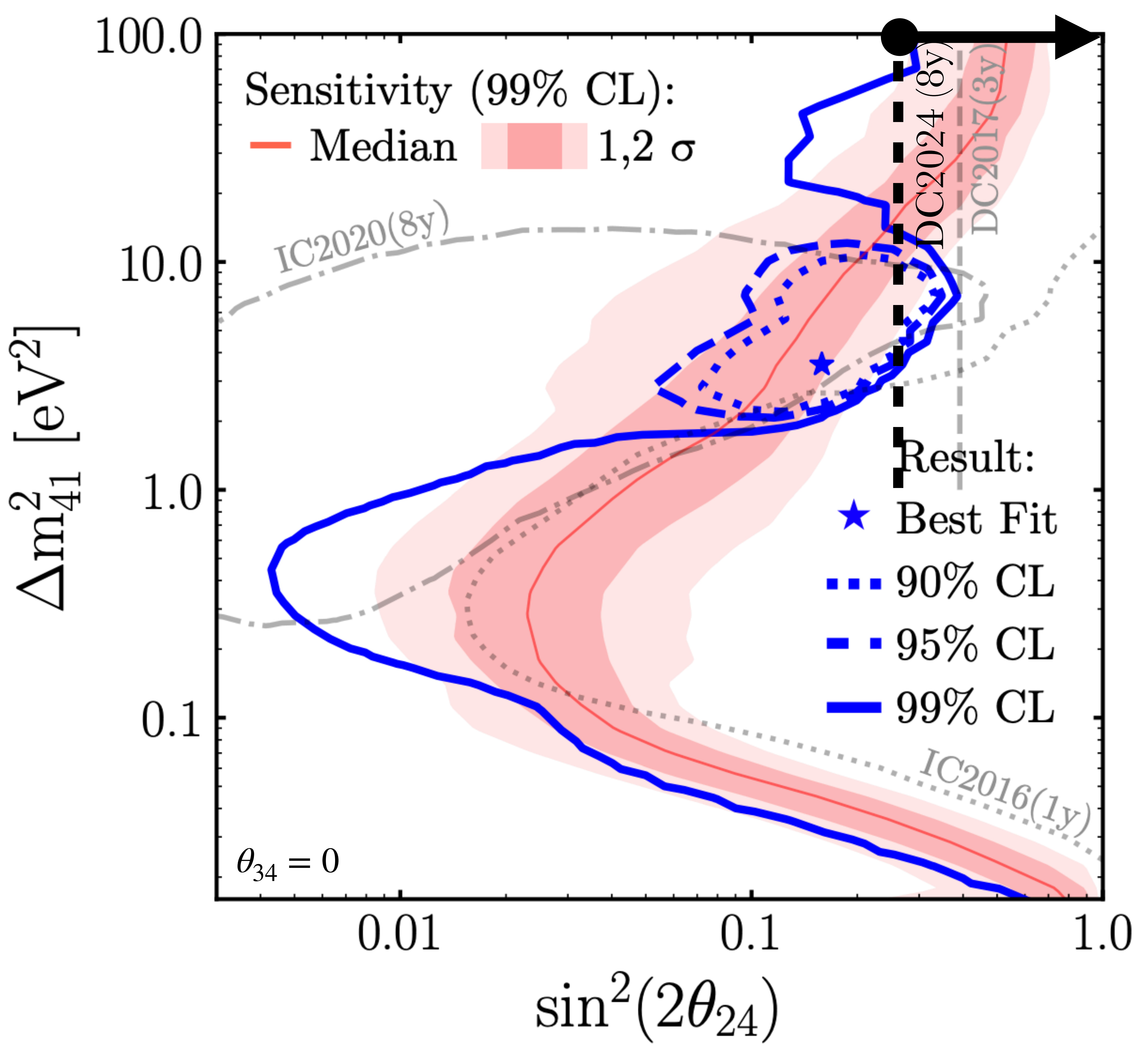

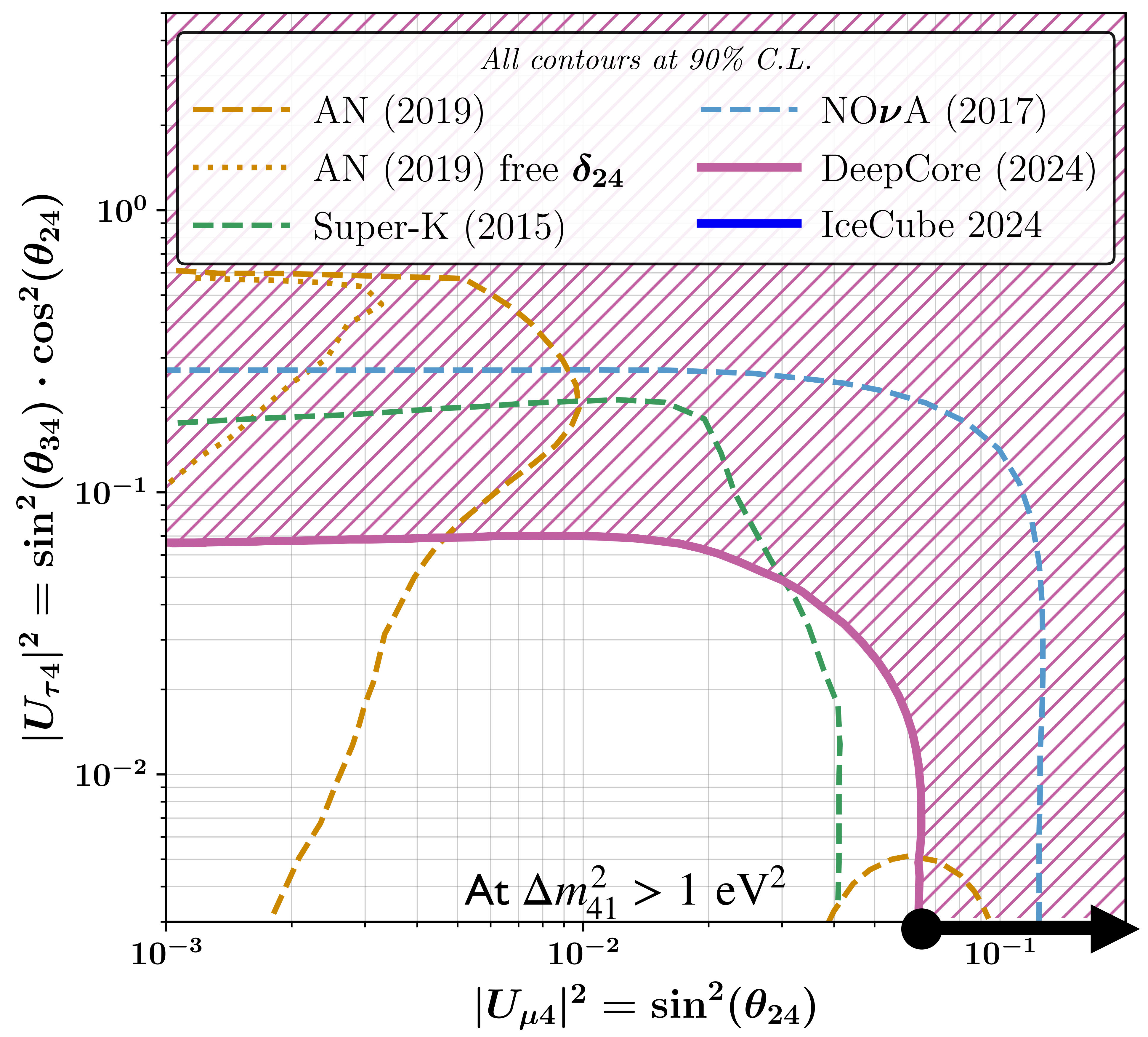

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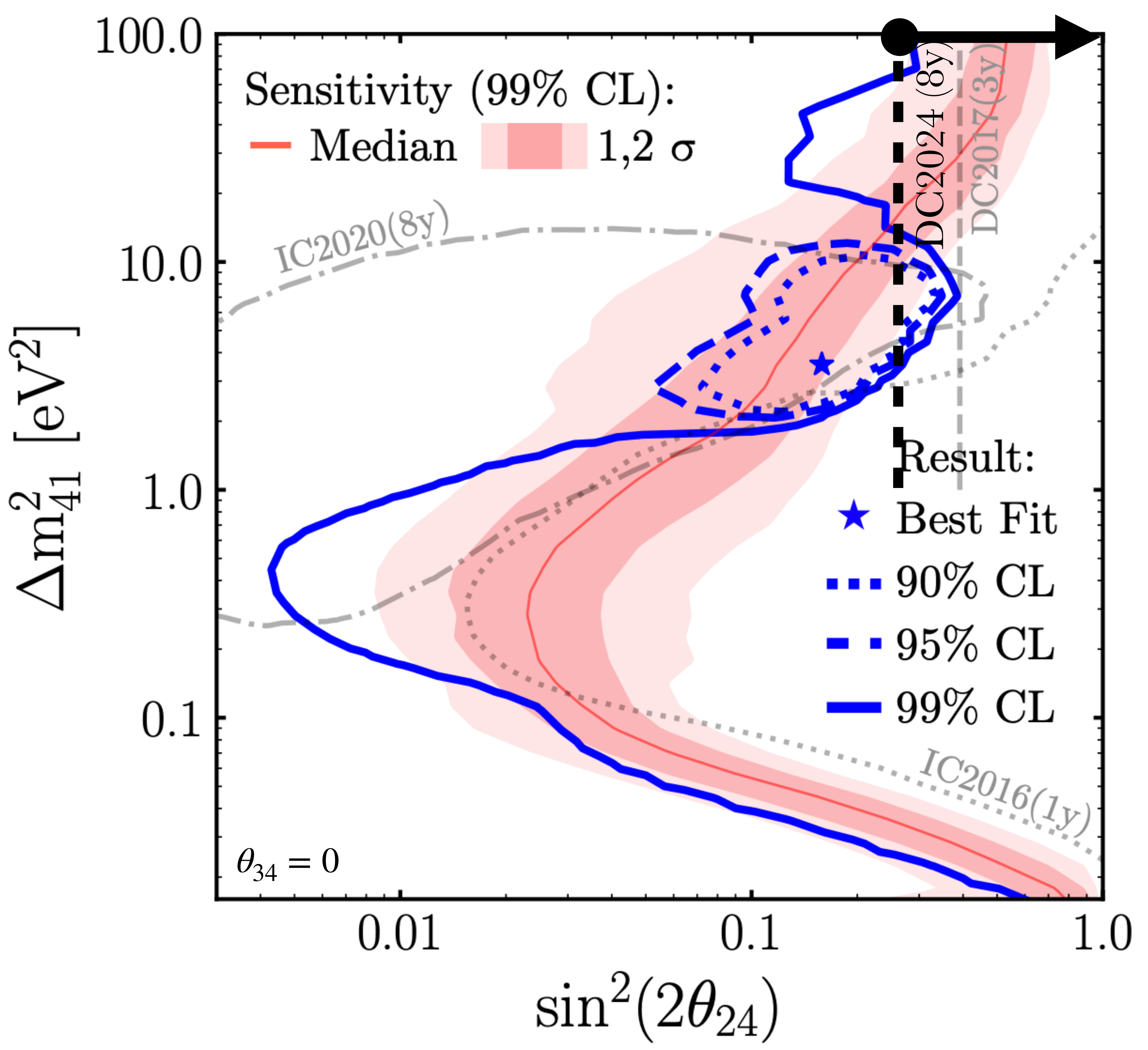

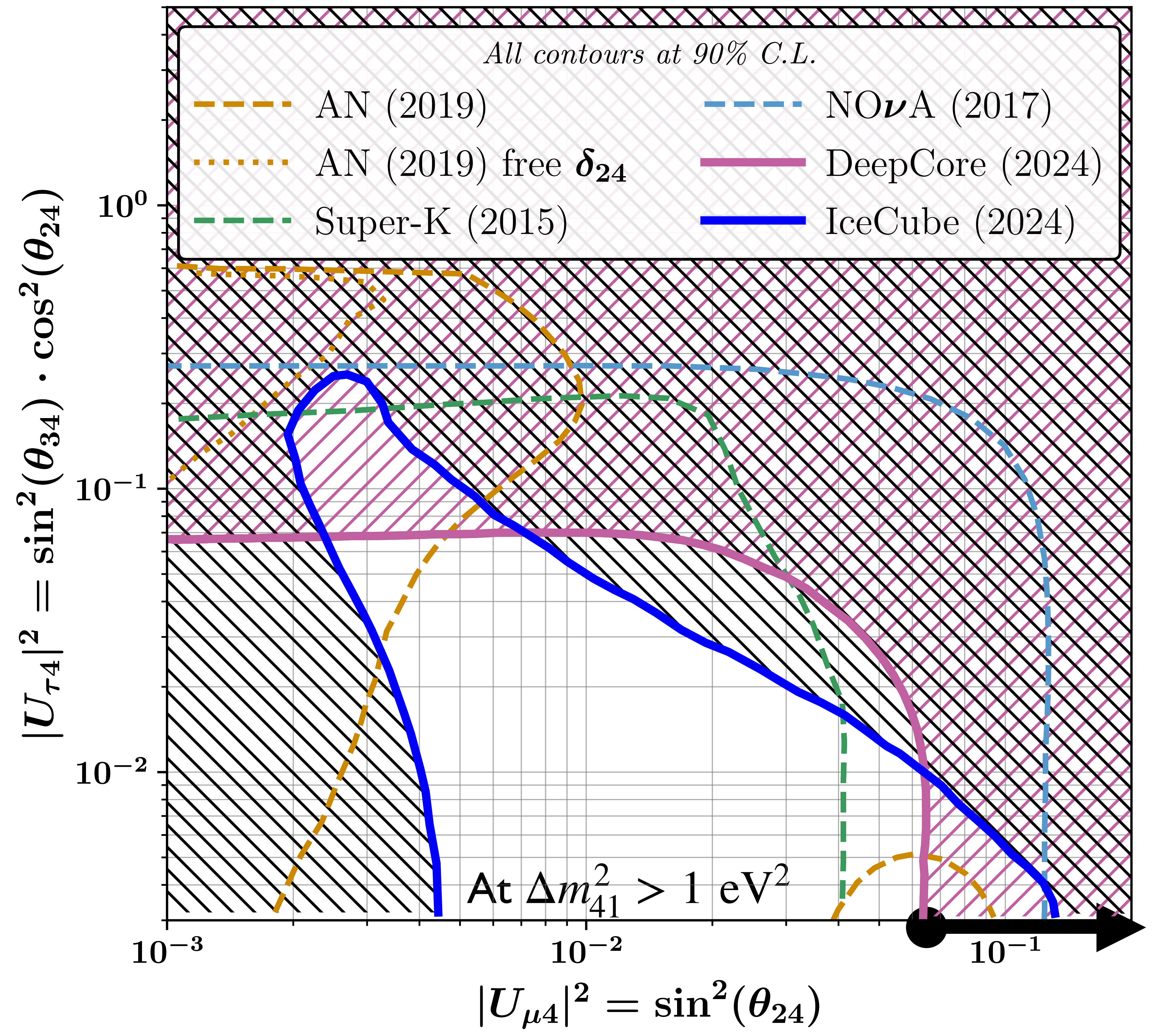

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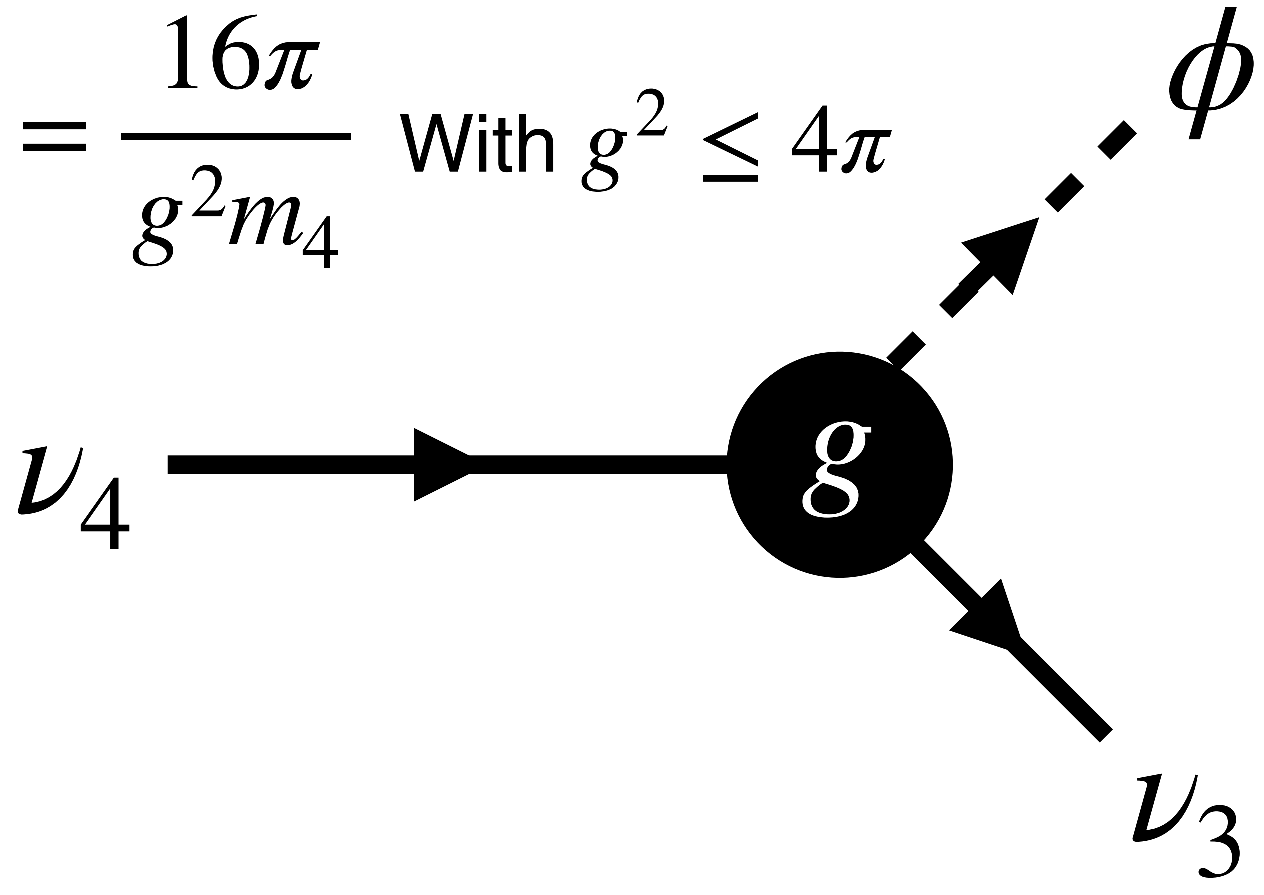

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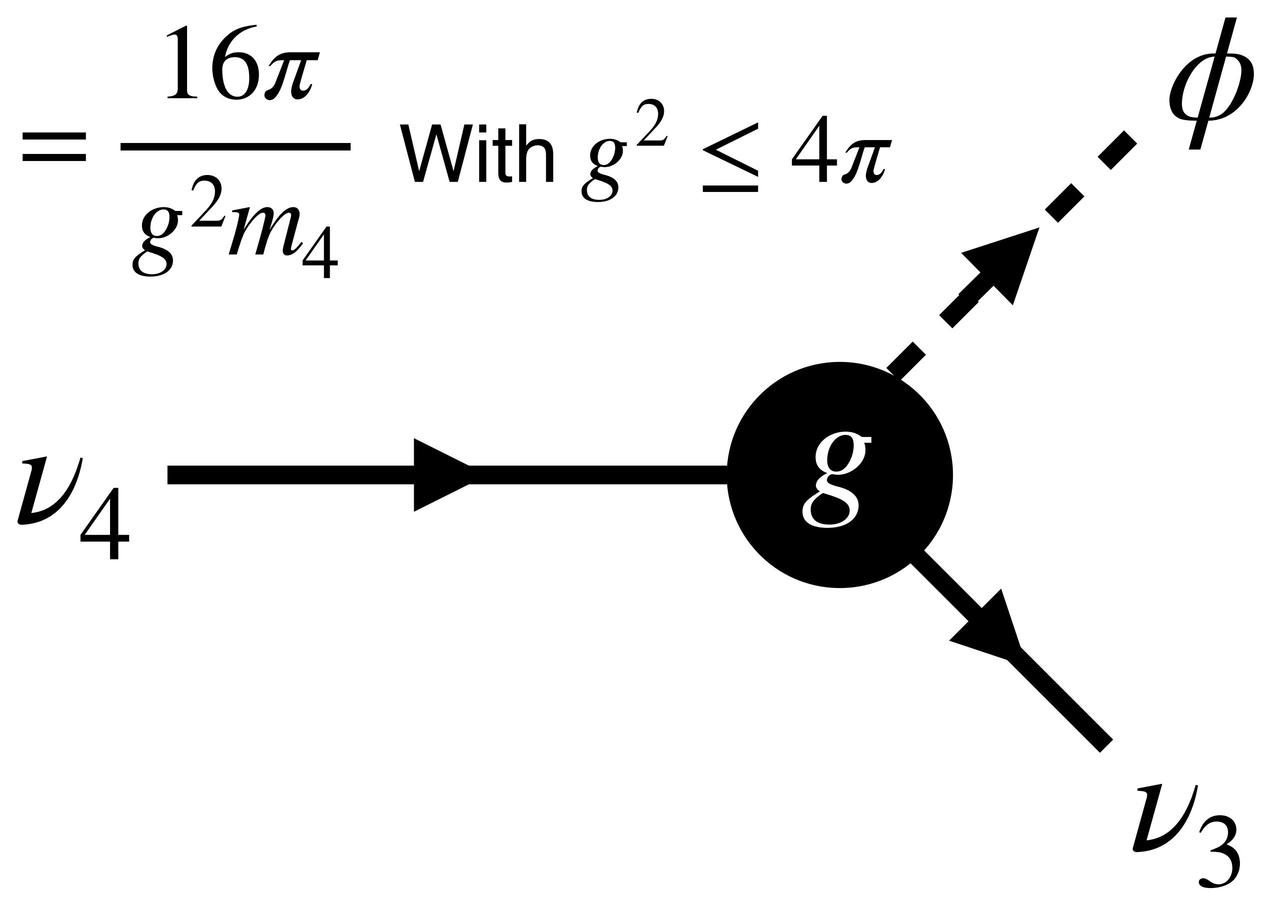

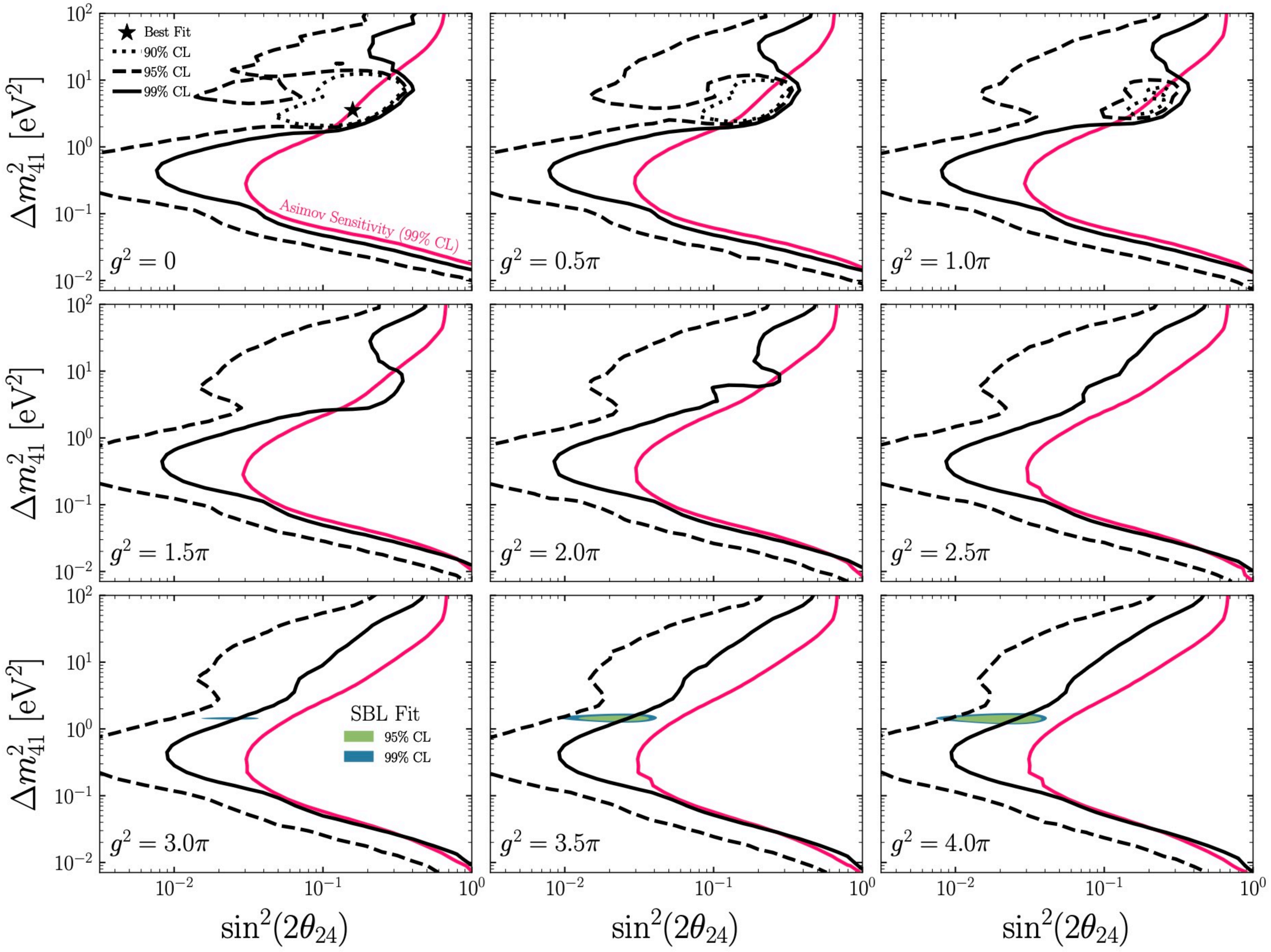

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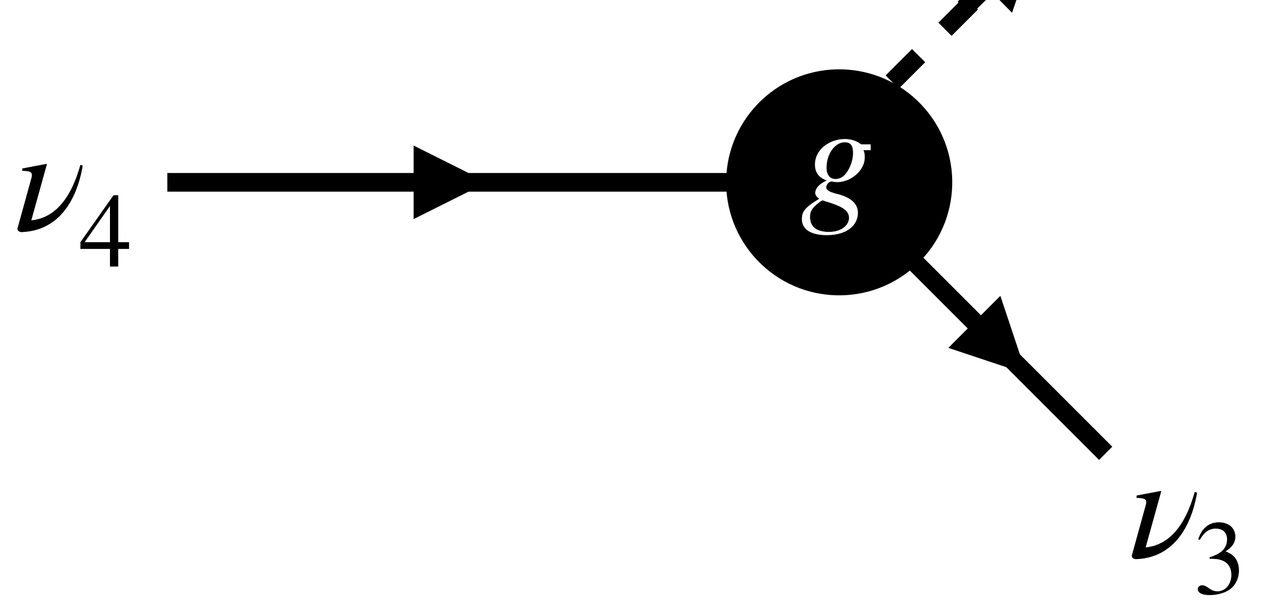
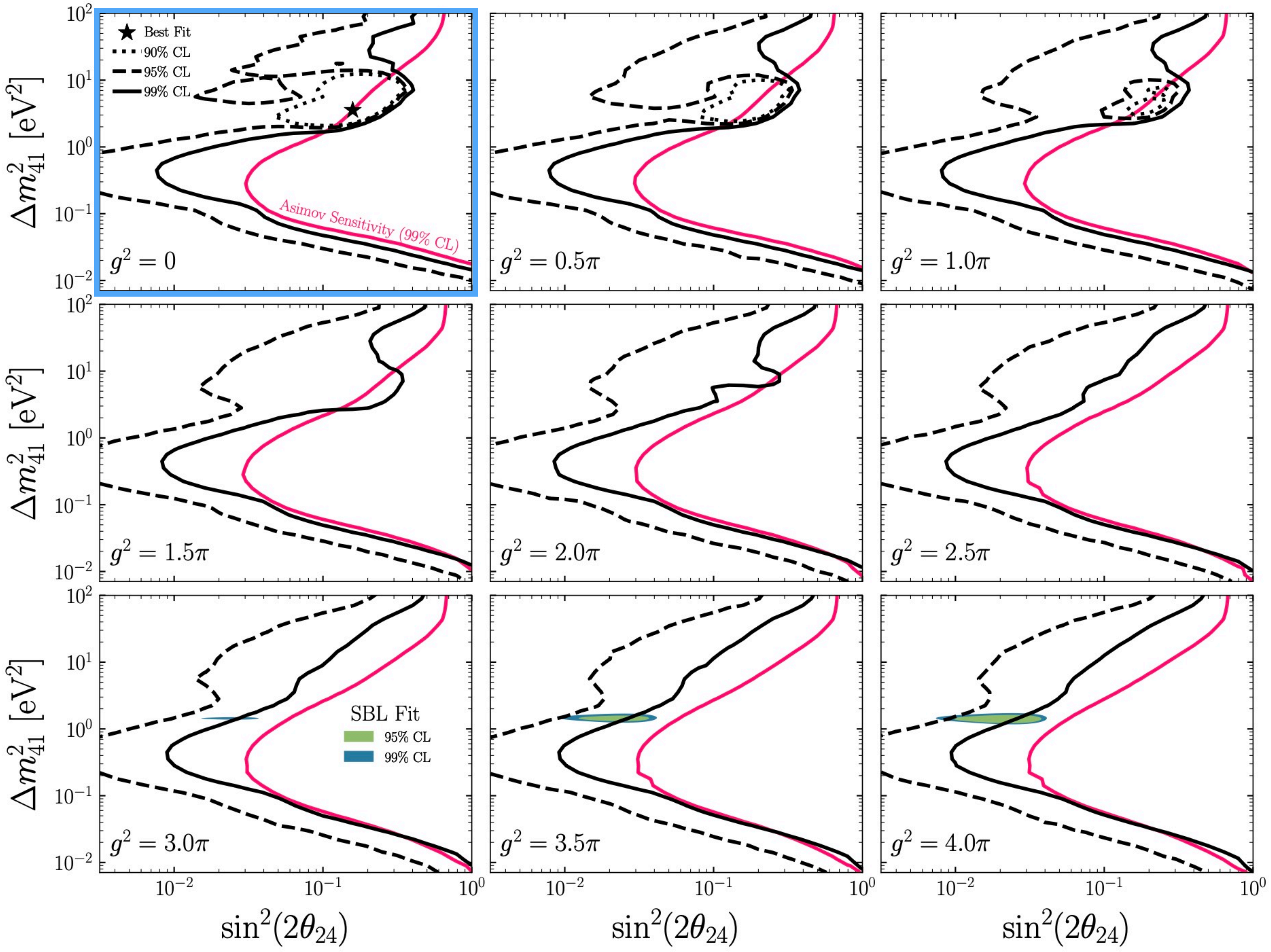


This analysis significantly reduces the remaining allowed parameter space for 3+1+decay.
Exclude for $g^2 > \pi$ at the 95% CL.

Result: Best Fit found $g^2 = 0$.



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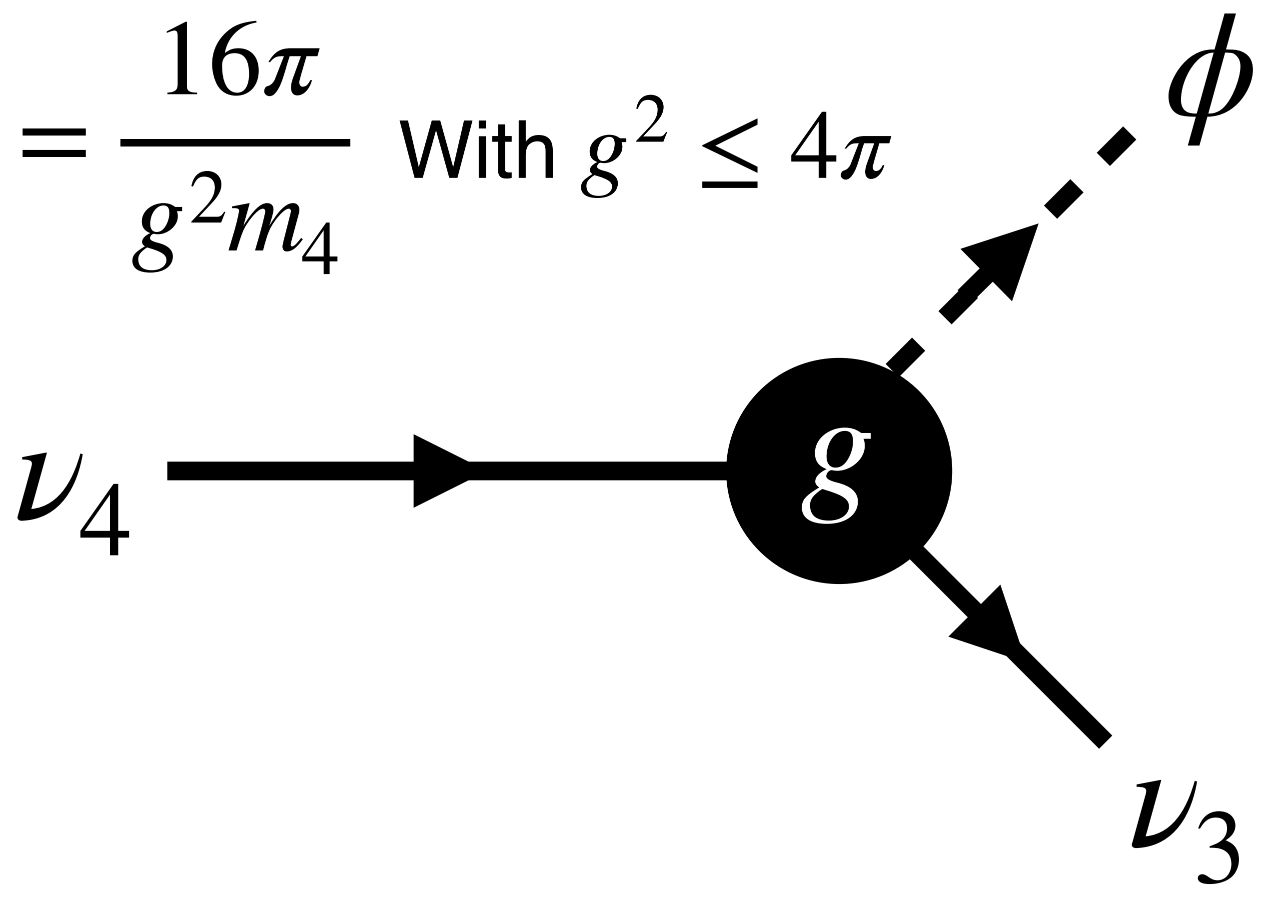

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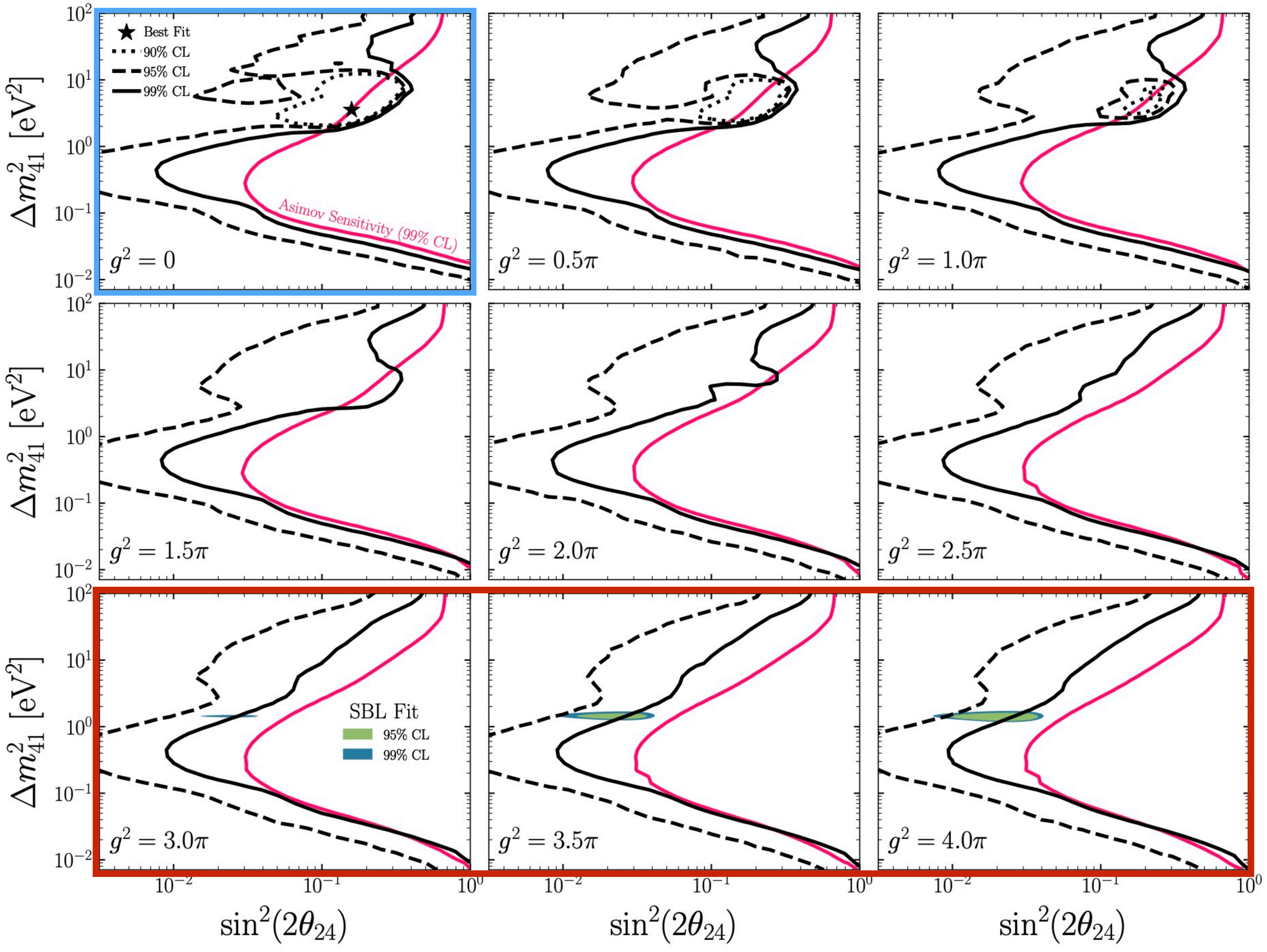

[1] Where are we with light sterile neutrinos? *Physics Reports* 884 (2020): 1-59

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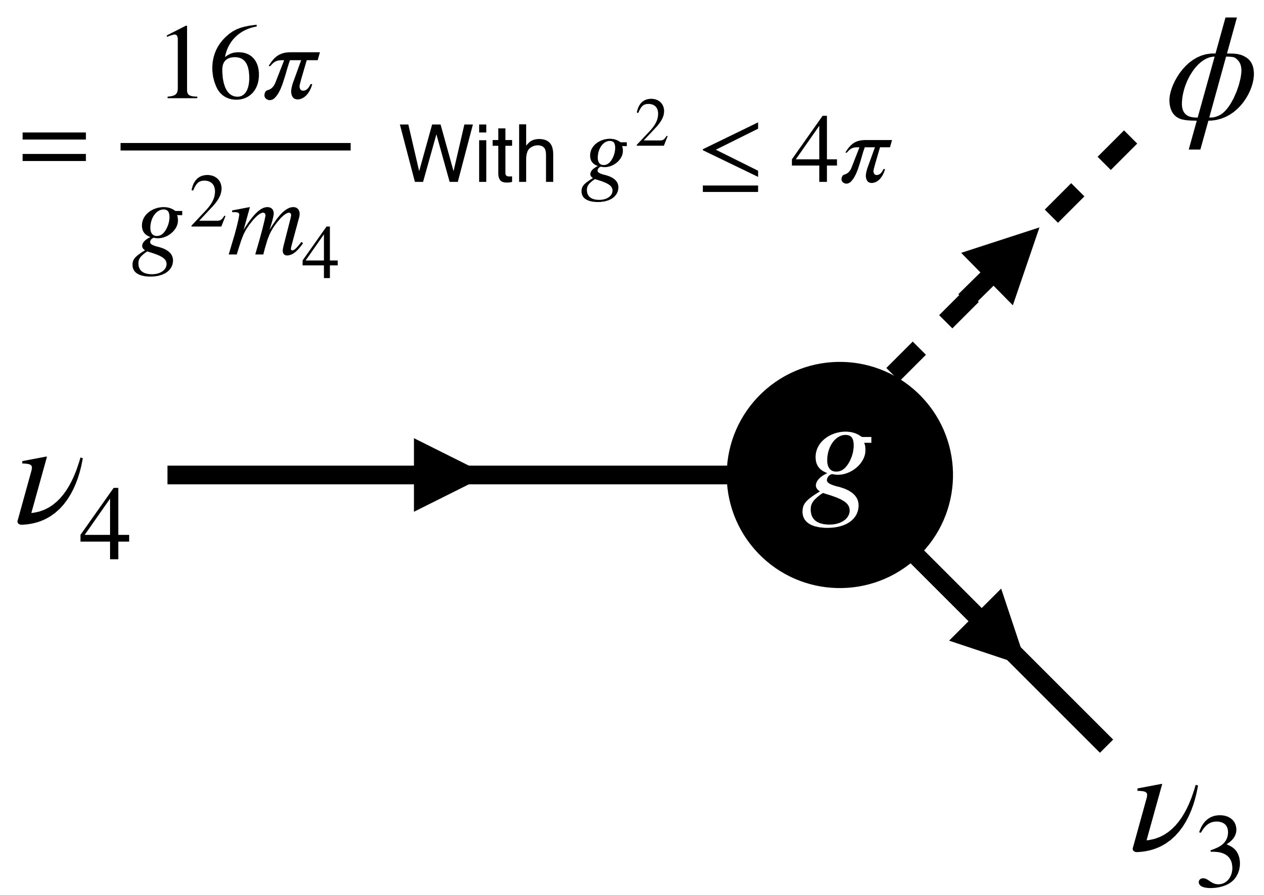

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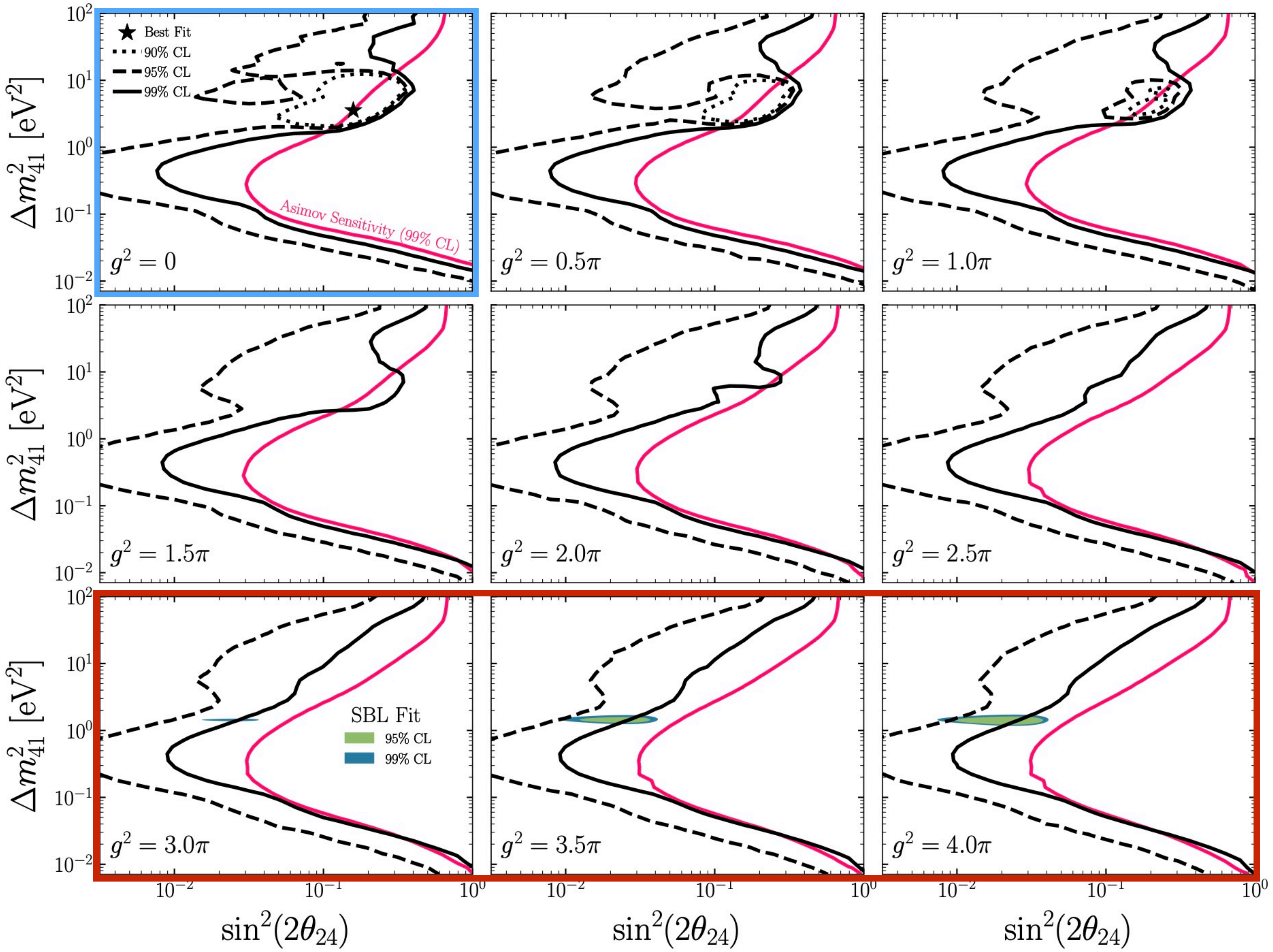

3+1+decay: Phys. Rev. Lett. - Accepted **(2026)**

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Neutrino tomography: mapping the Earth's interior

High energy (>TeV) neutrino attenuation can be used to map the Earth’s interior density profile

<u>Goal</u>: Observe macroscopic object using the weak force: the “weak mass.”

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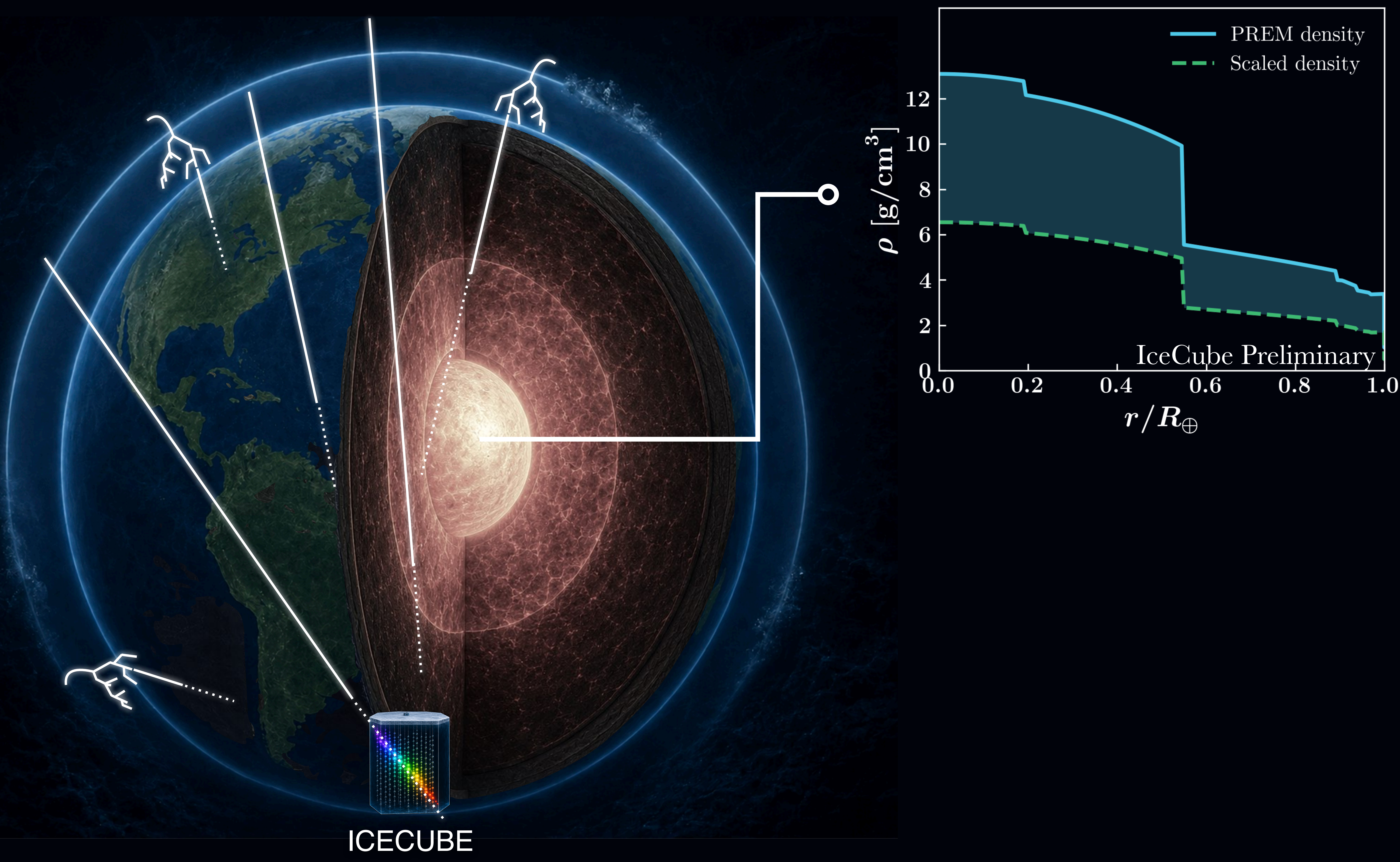
Measures total mass, not how it is distributed.

SEISMIC WAVES
Sensitive to elastic properties, not density alone.

GEOMAGNETISM
Probes core dynamics, not static structure.



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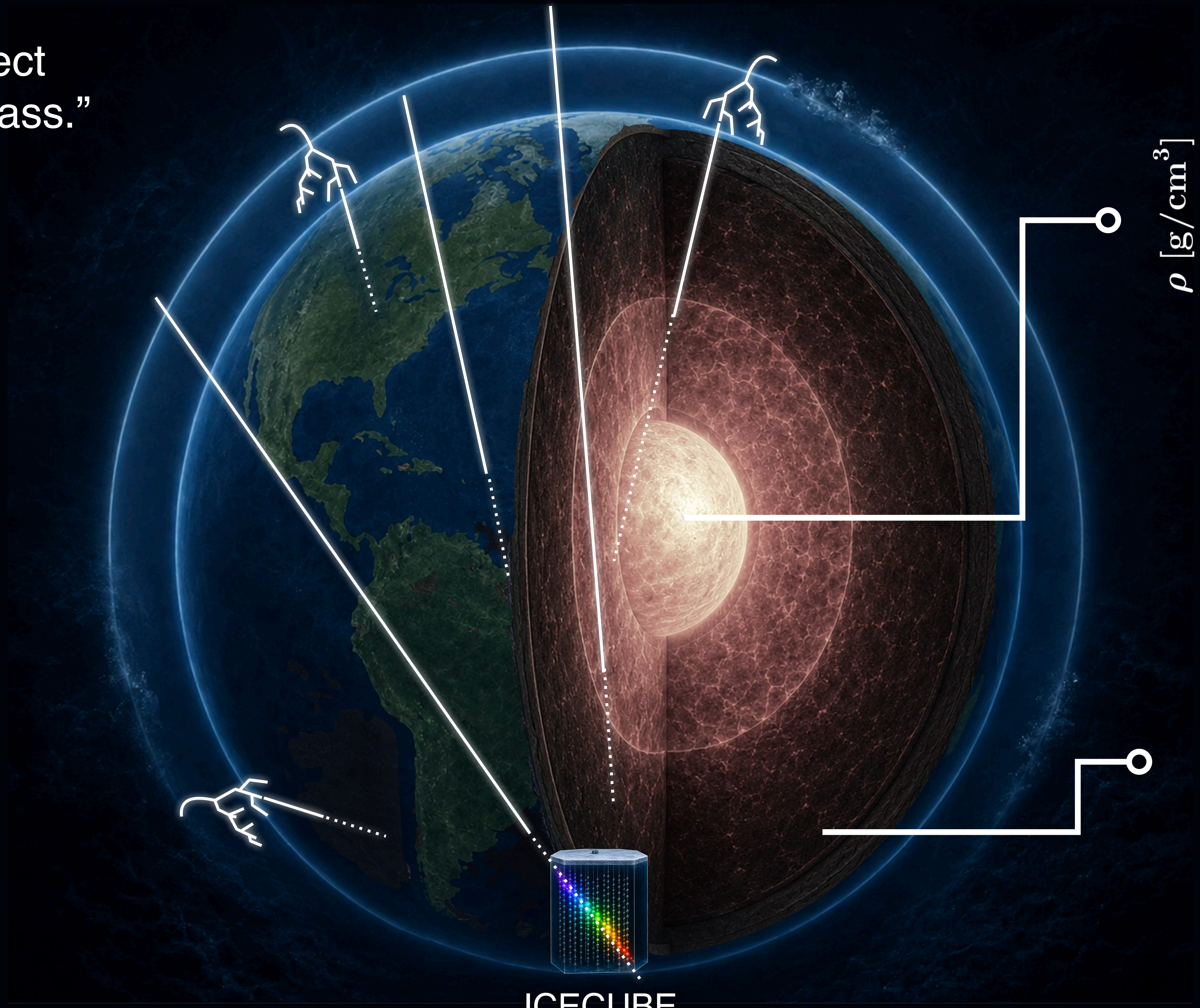

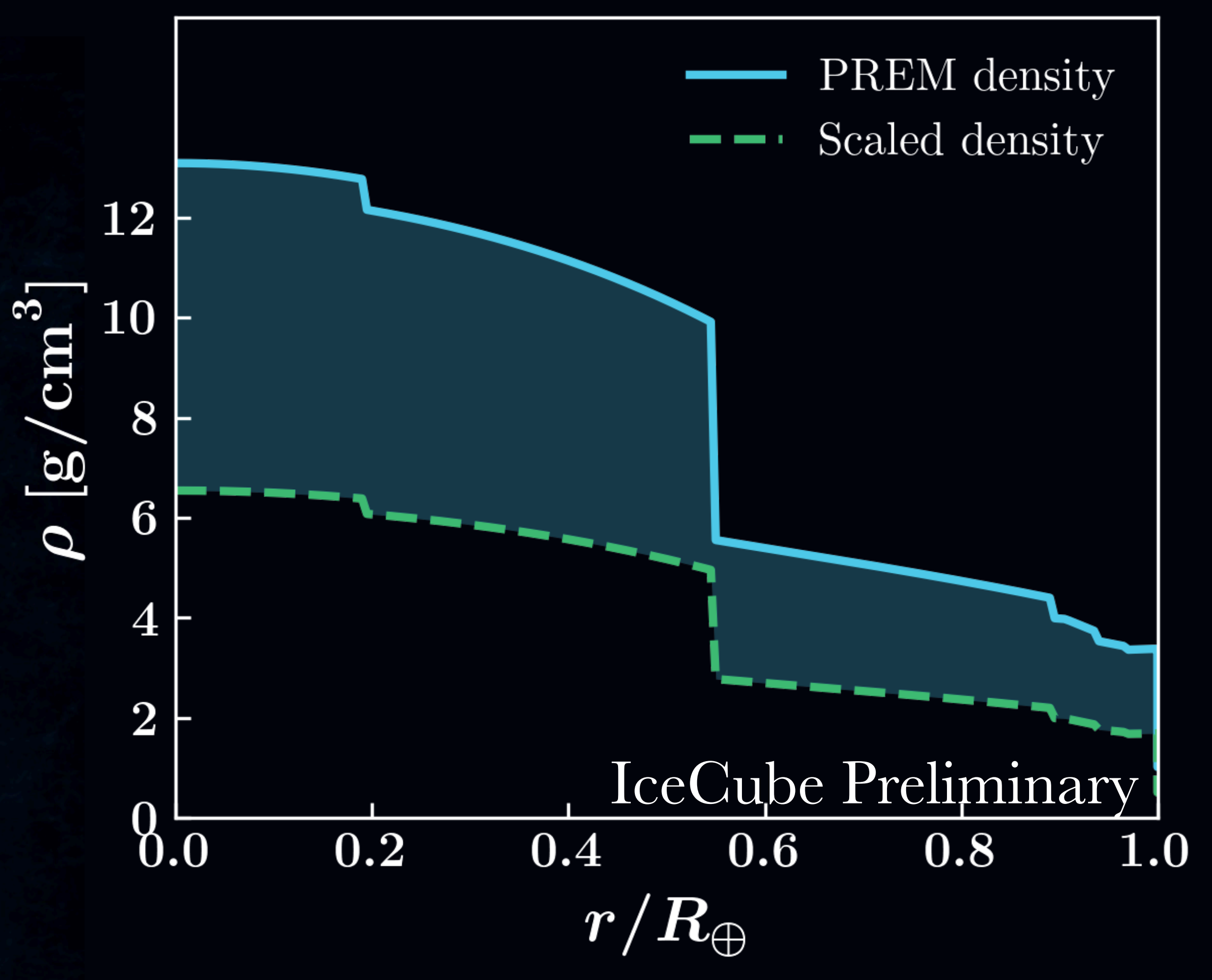

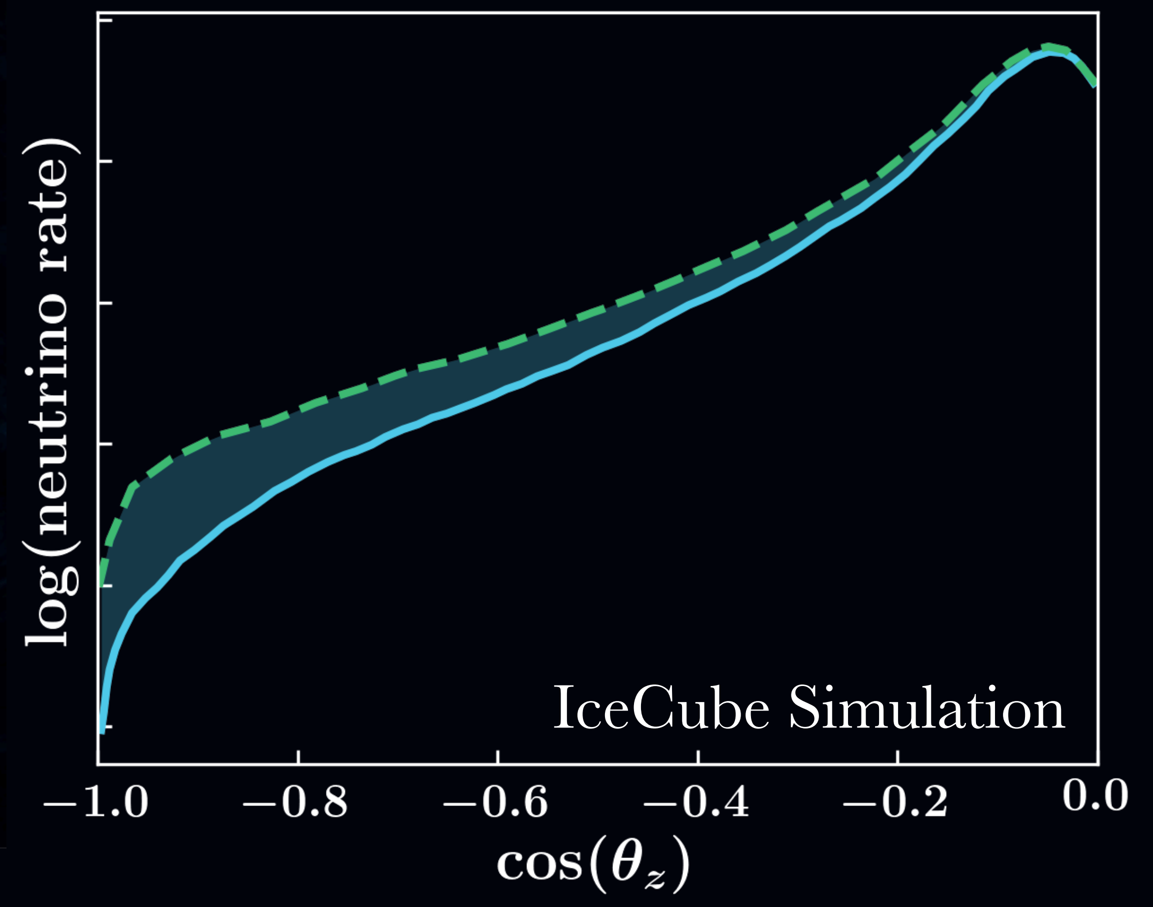

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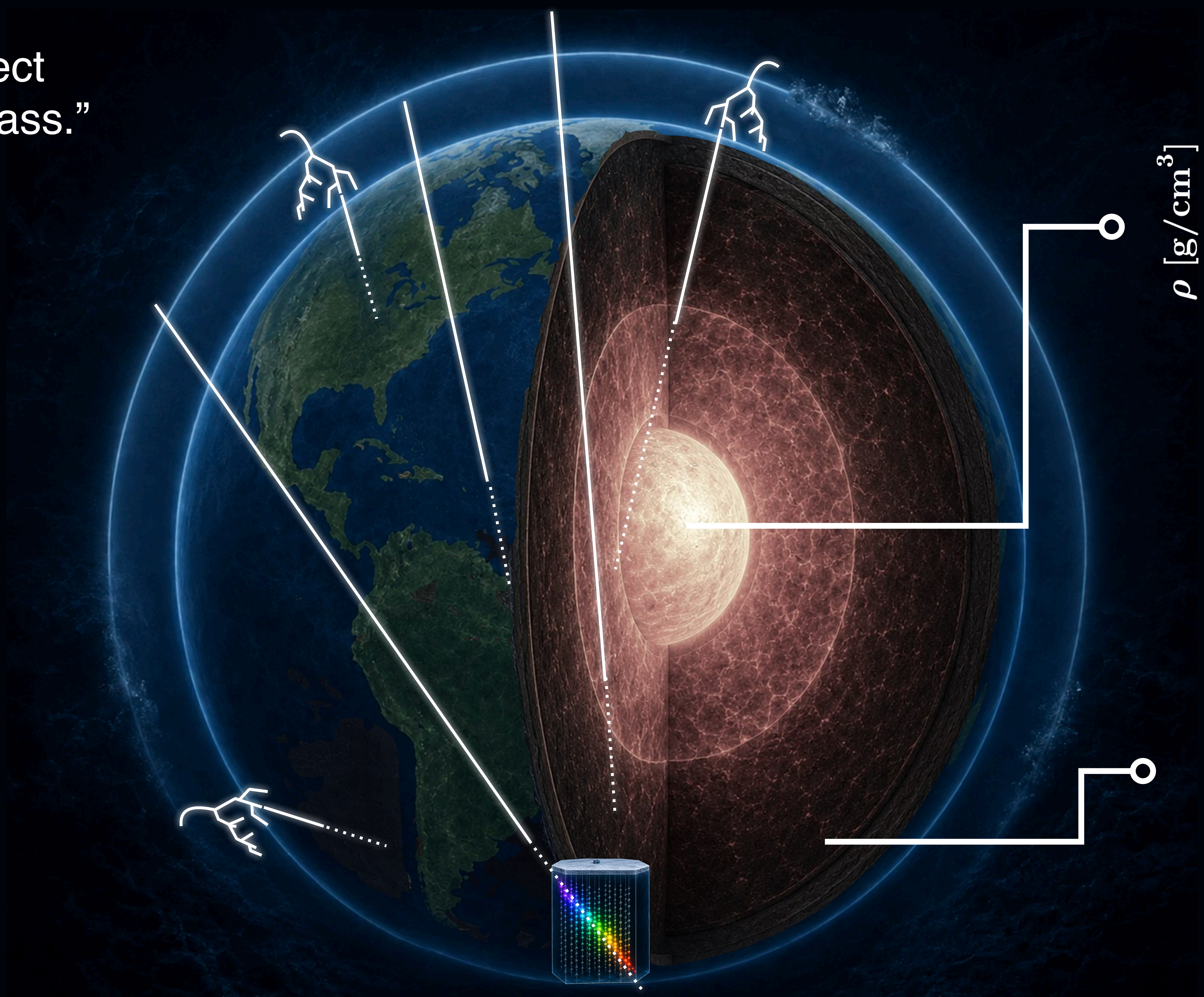

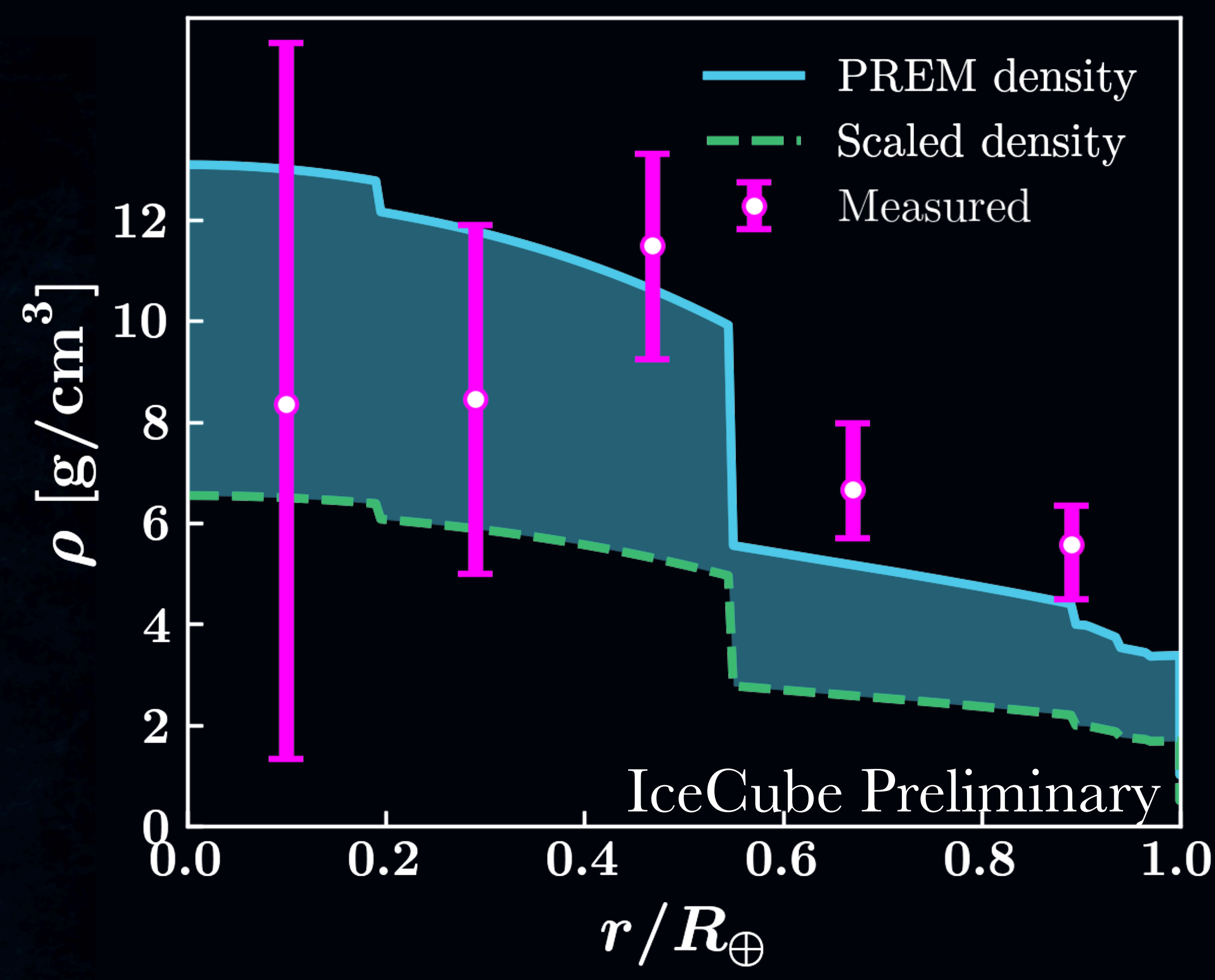

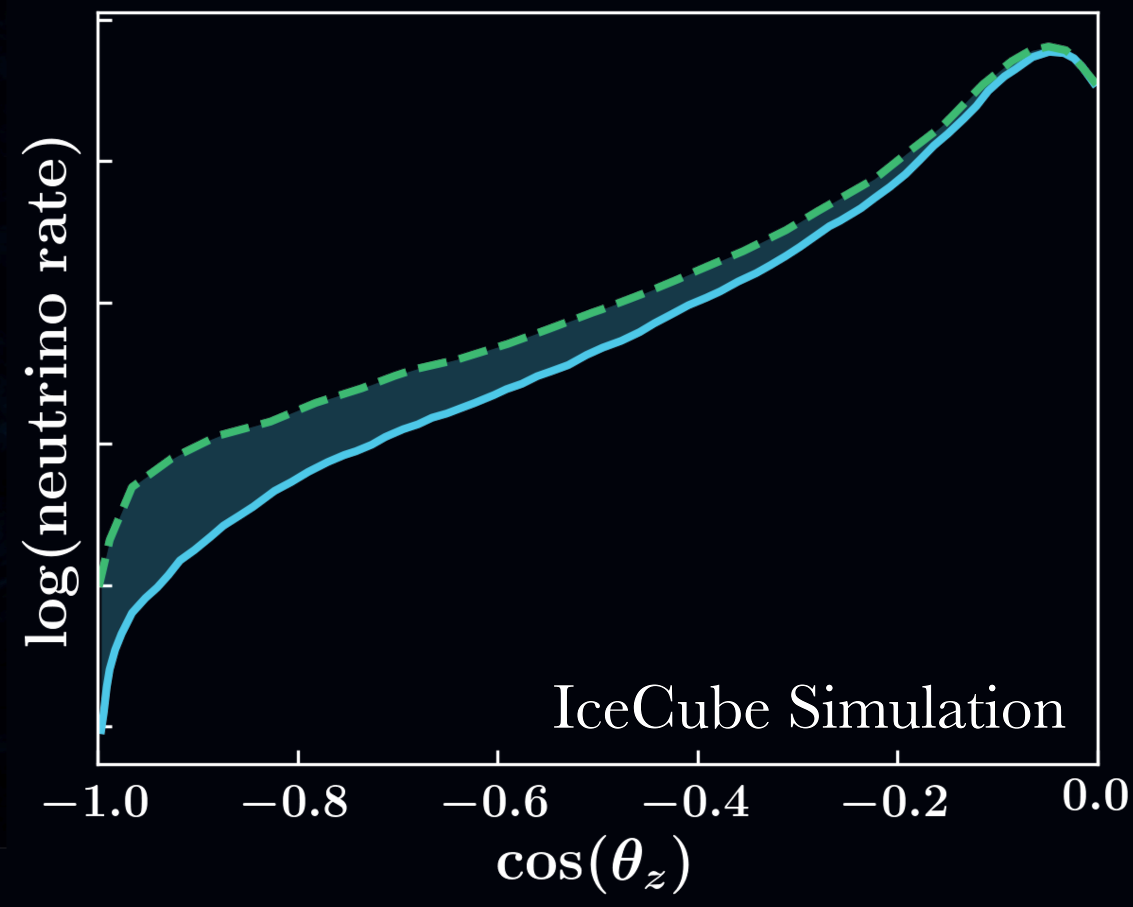

From the resulting density posteriors, we derive the Earth’s mass and polar moment of inertia, found to be consistent with PREM and gravitational determination. Paper under collaboration review.

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Summary and Outlook

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Thanks for your attention!

IceCube Neutrino Observatory
NSF
University of Delaware
Bartol Research Institute
University of Delaware


ICECUBE
NEUTRINO OBSERVATORY
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meV
eV
keV
MeV
GeV
TeV
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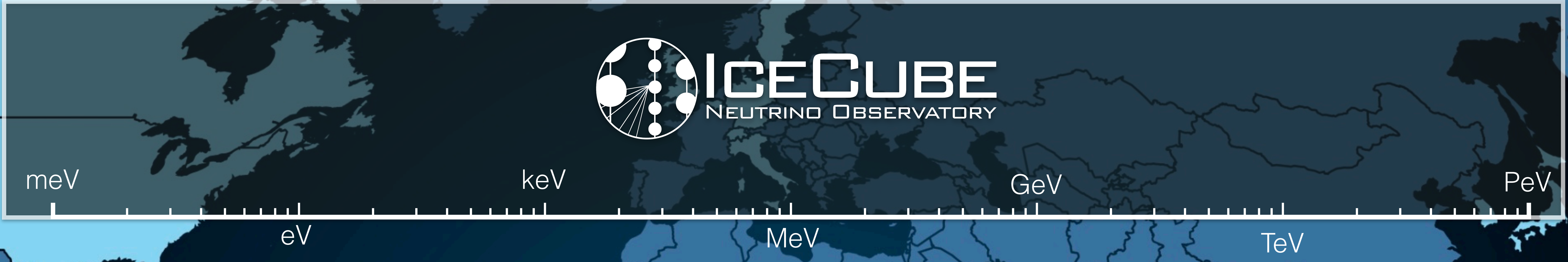

THE ICECUBE COLLABORATION

AUSTRALIA
University of Adelaide

BELGIUM
UCLouvain
Université libre de Bruxelles
Universiteit Gent
Vrije Universiteit Brussel

CANADA
Queen's University
Simon Fraser University
University of Alberta–Edmonton

DENMARK
University of Copenhagen

GERMANY
Deutsches Elektronen-Synchrotron
ECAP, Universität Erlangen-Nürnberg
Humboldt–Universität zu Berlin
Karlsruhe Institute of Technology
Ruhr-Universität Bochum
RWTH Aachen University
Technische Universität Dortmund
Technische Universität München
Universität Mainz
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Universität Wuppertal

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SWEDEN
Stockholms universitet
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University of Alabama
University of Alaska Anchorage
University of California, Berkeley
University of California, Irvine
University of Delaware
University of Kansas
University of Maryland
University of Nevada, Las Vegas
University of Rochester
University of Utah
University of Wisconsin–Madison
University of Wisconsin–River Falls
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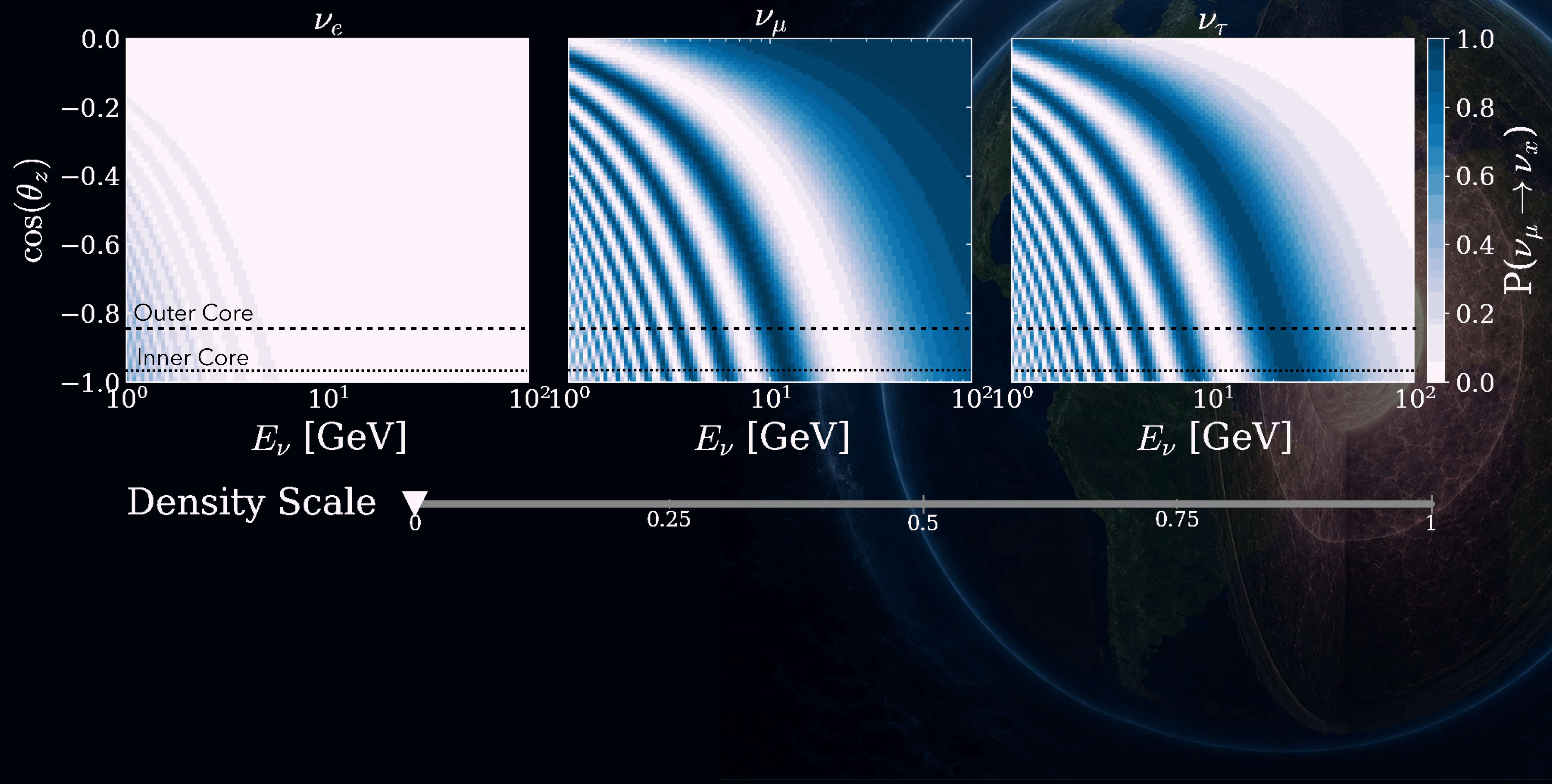

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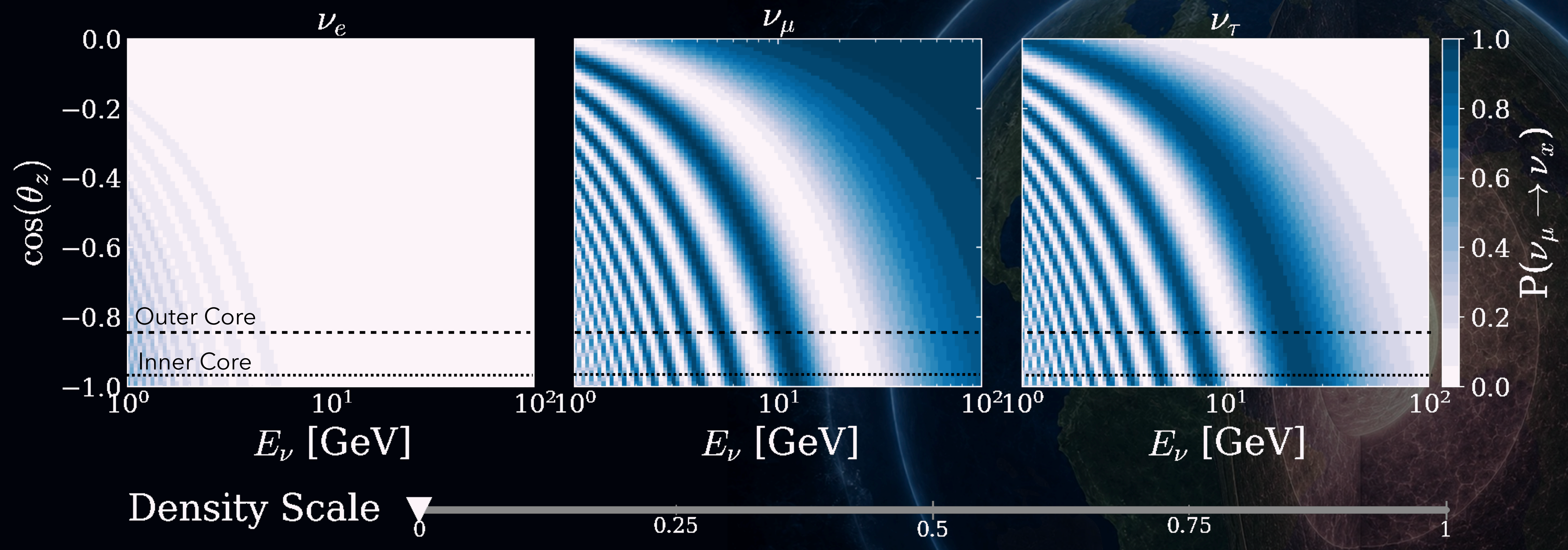

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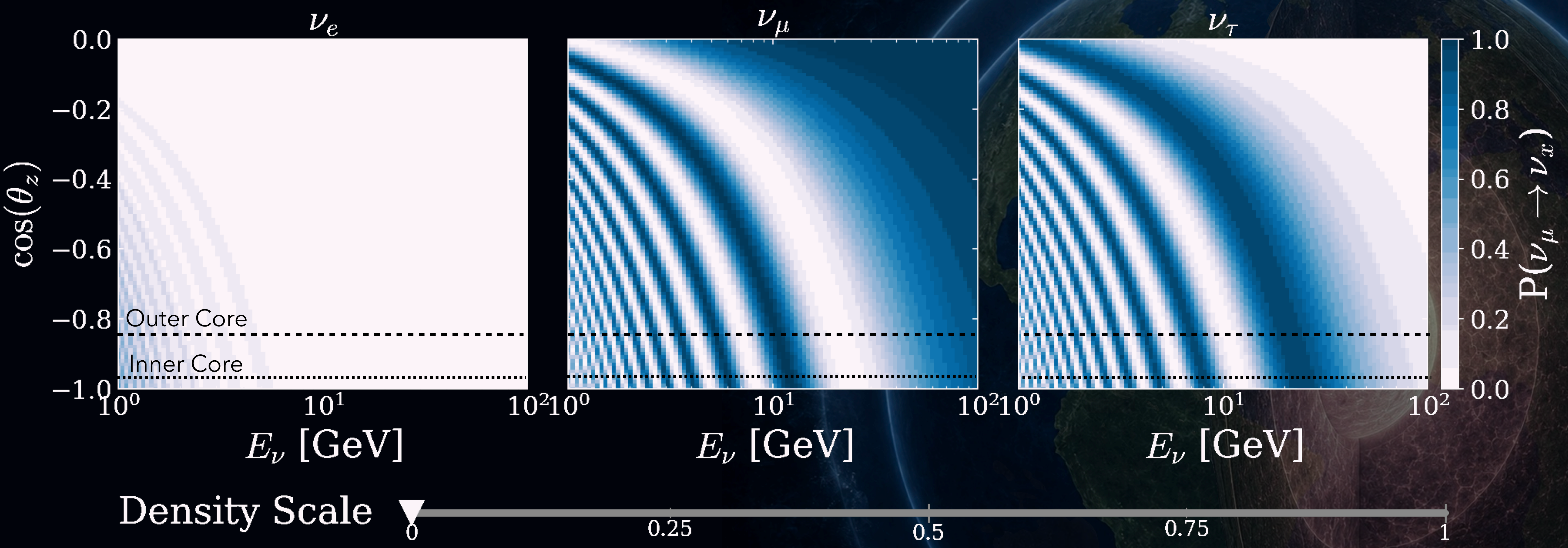

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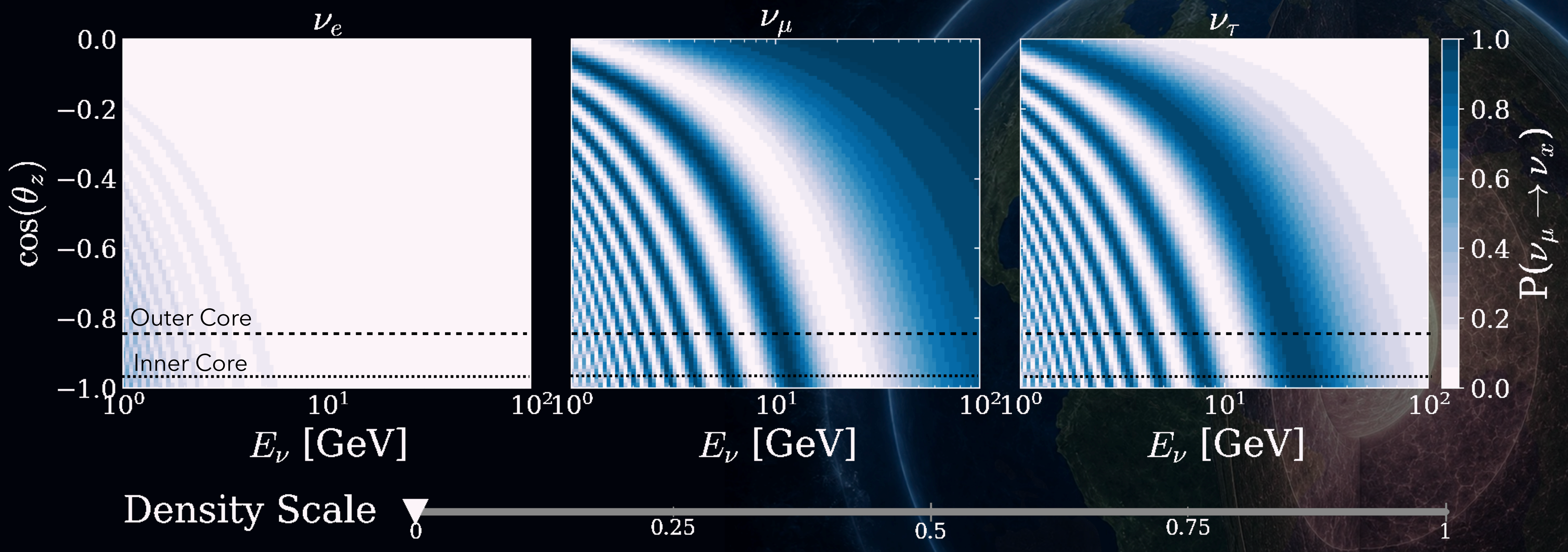

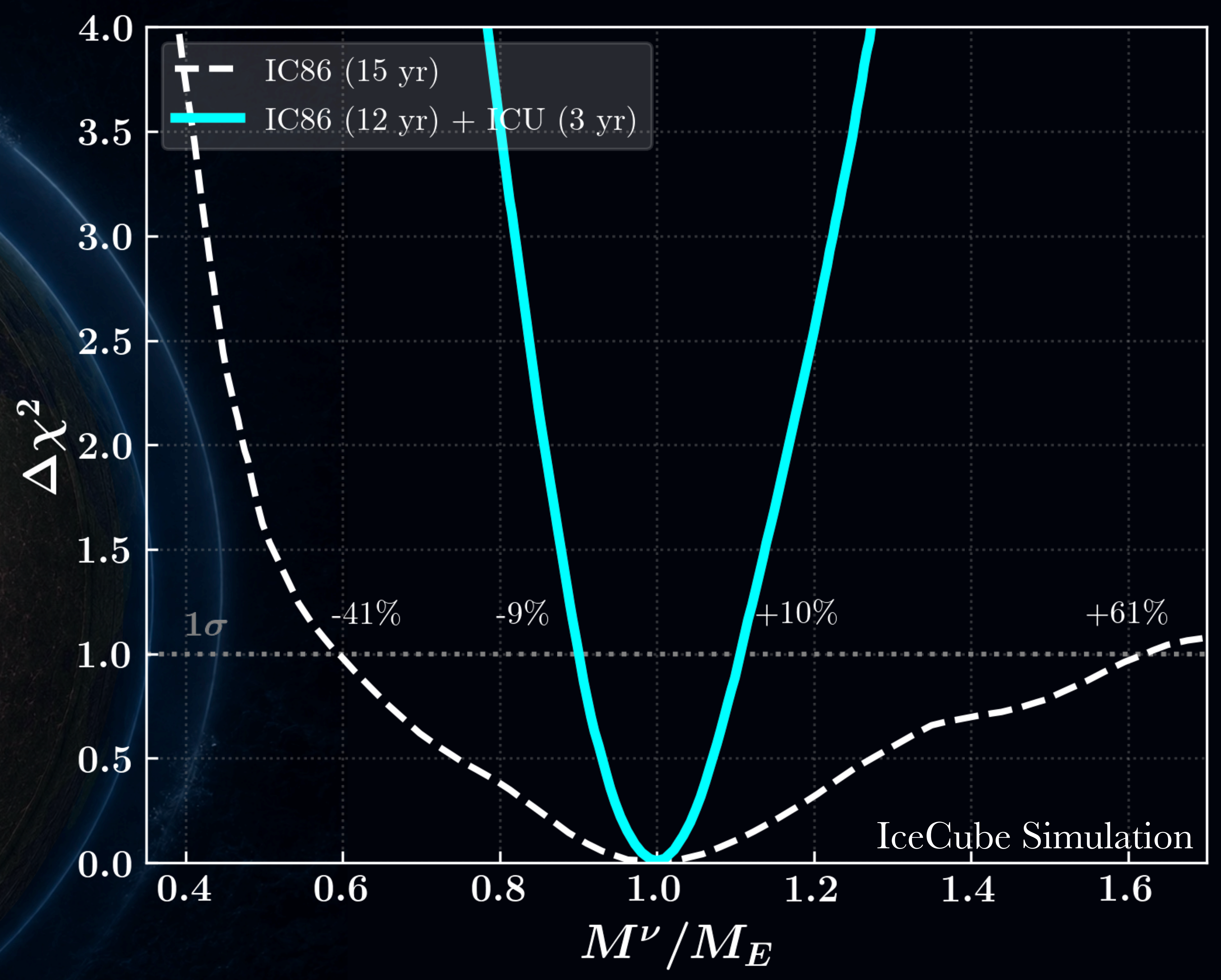

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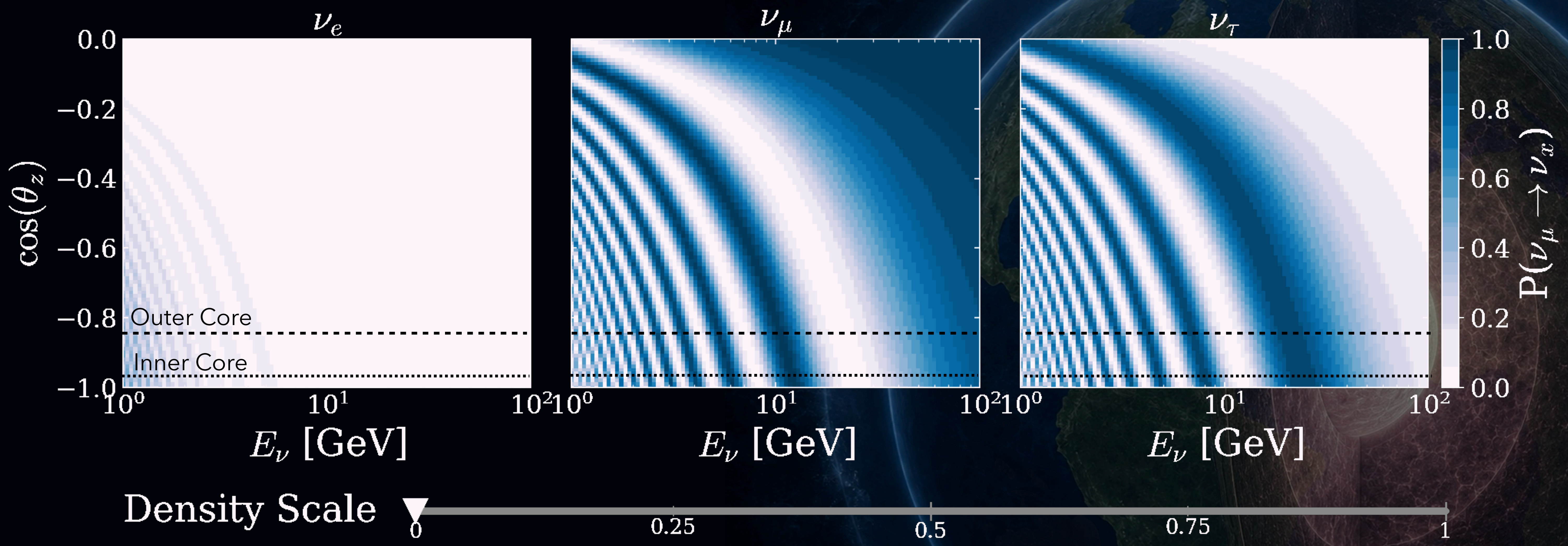

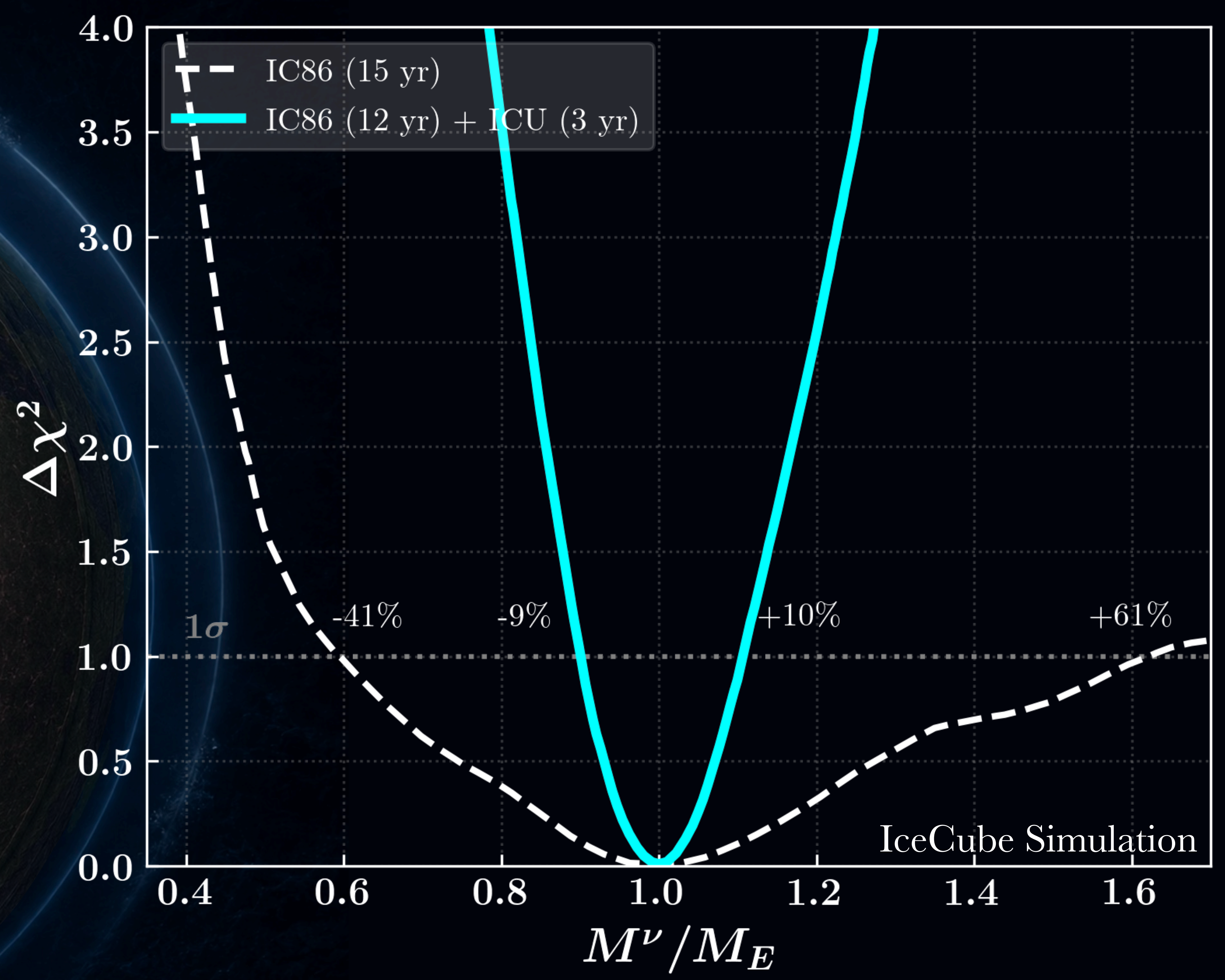

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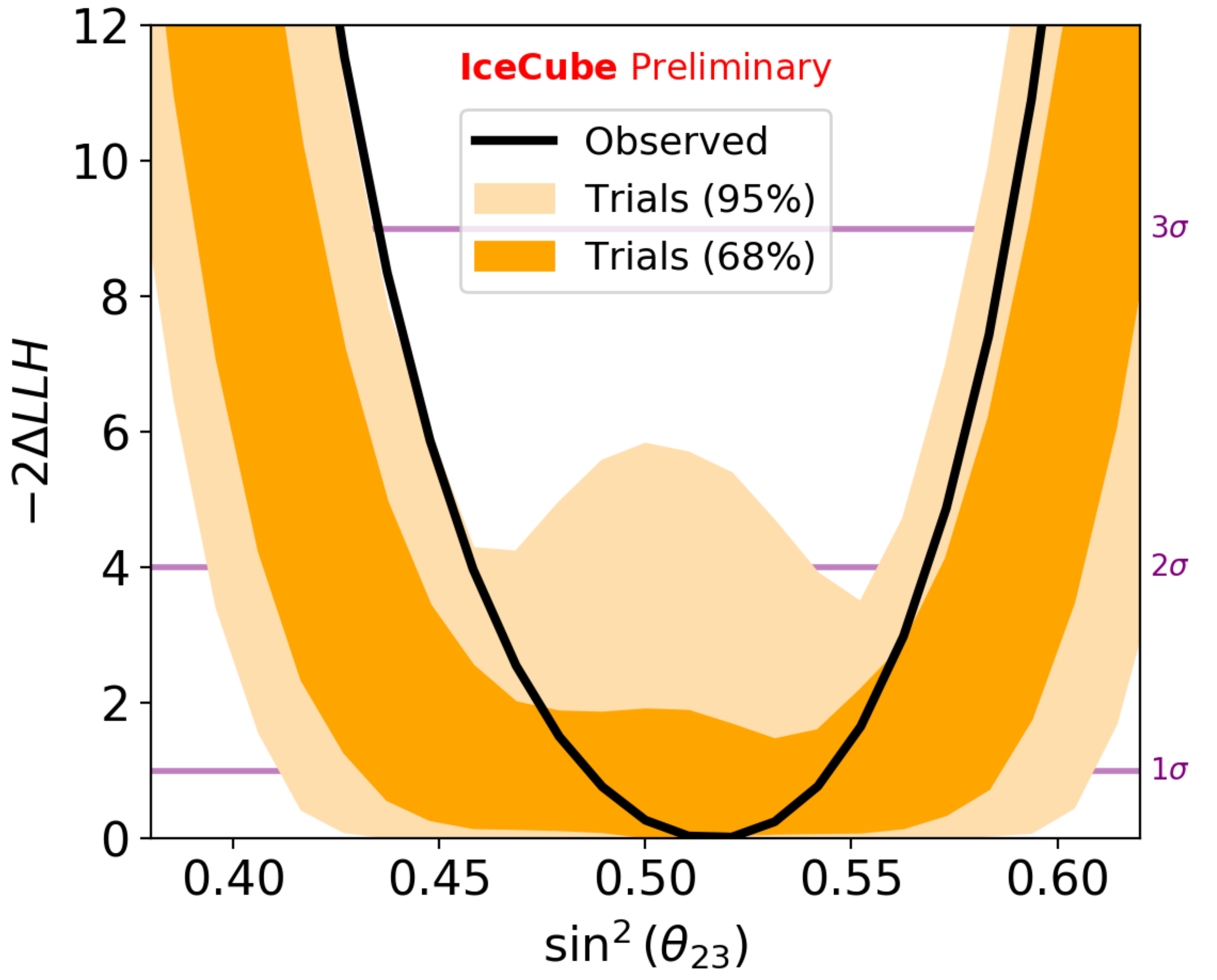
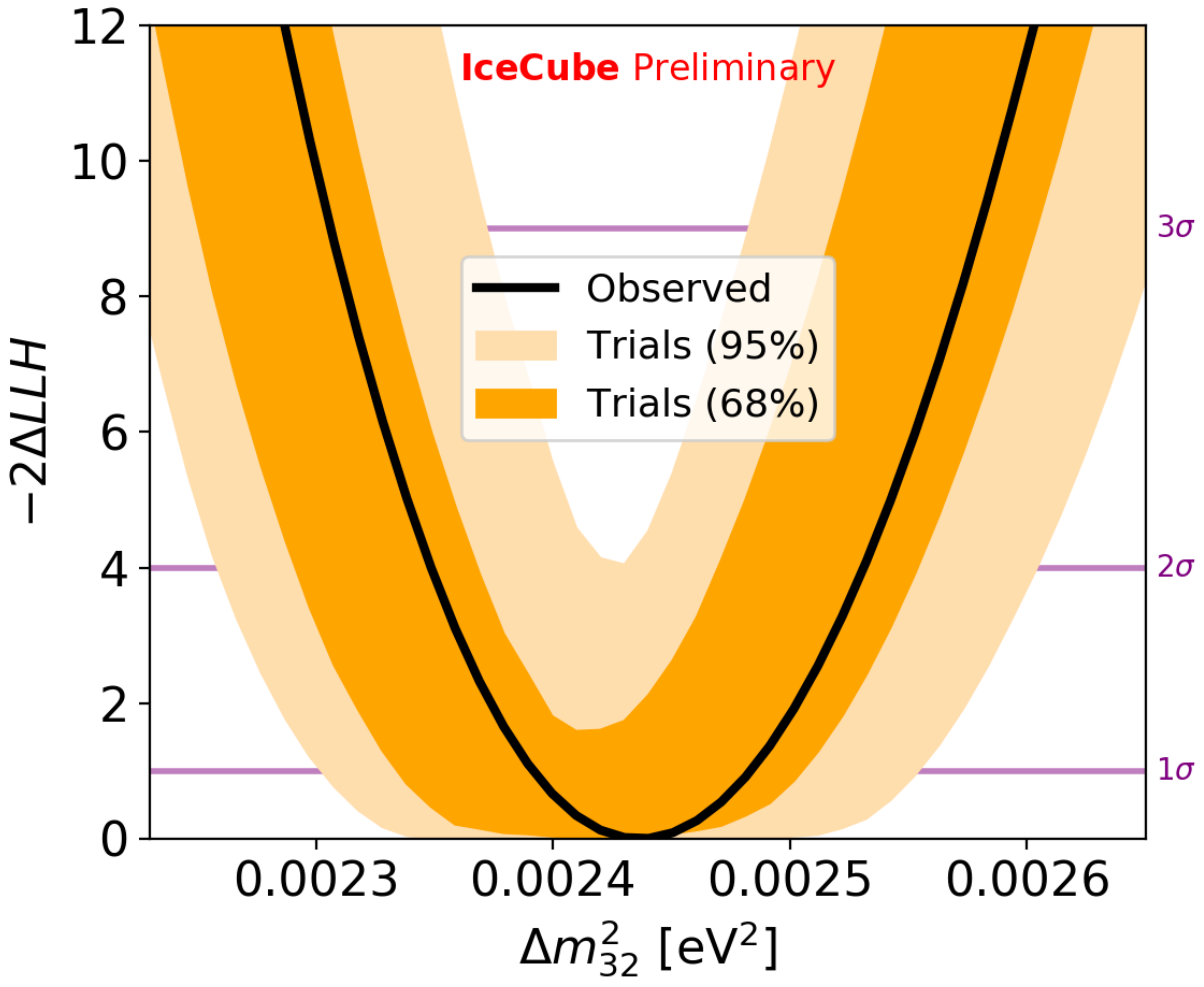
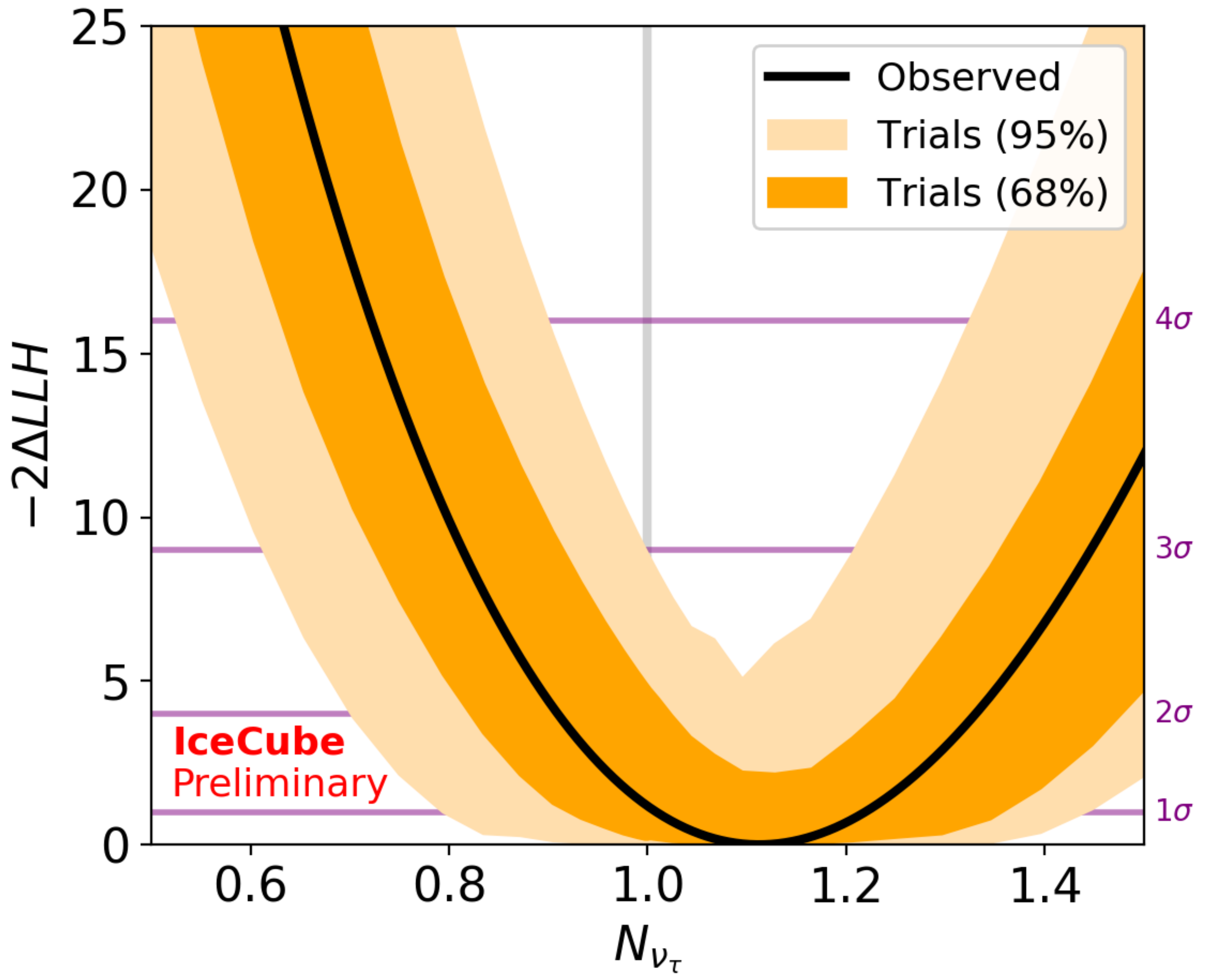




Test stat profile for the mixing angle (from a 1D scan), a subset of the numu disappearance result. The Brazil band (generated from pseudodata trials at the best fit point) is included for comparison.

11y ν_τ-appearance Brazil Bands



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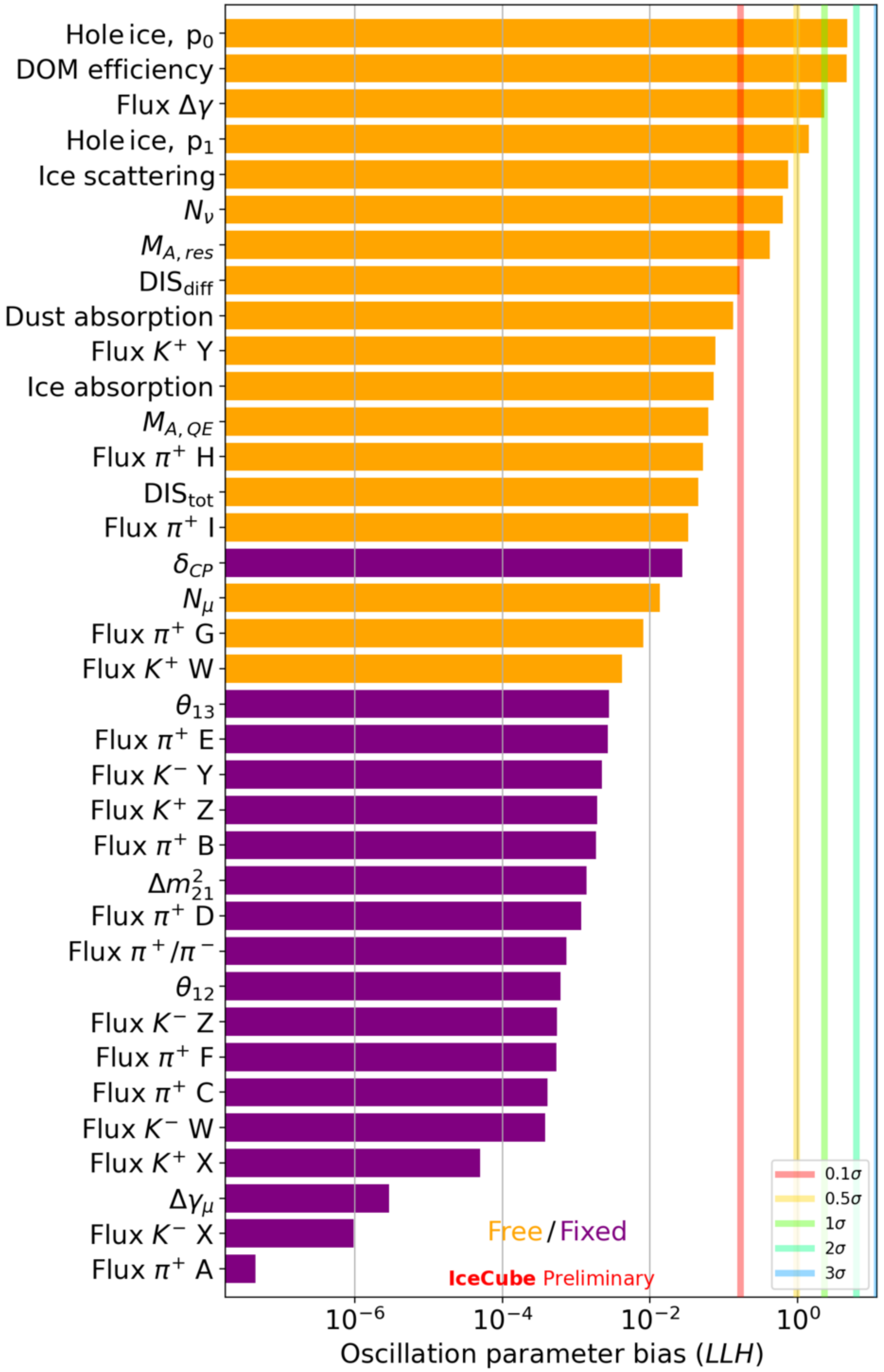
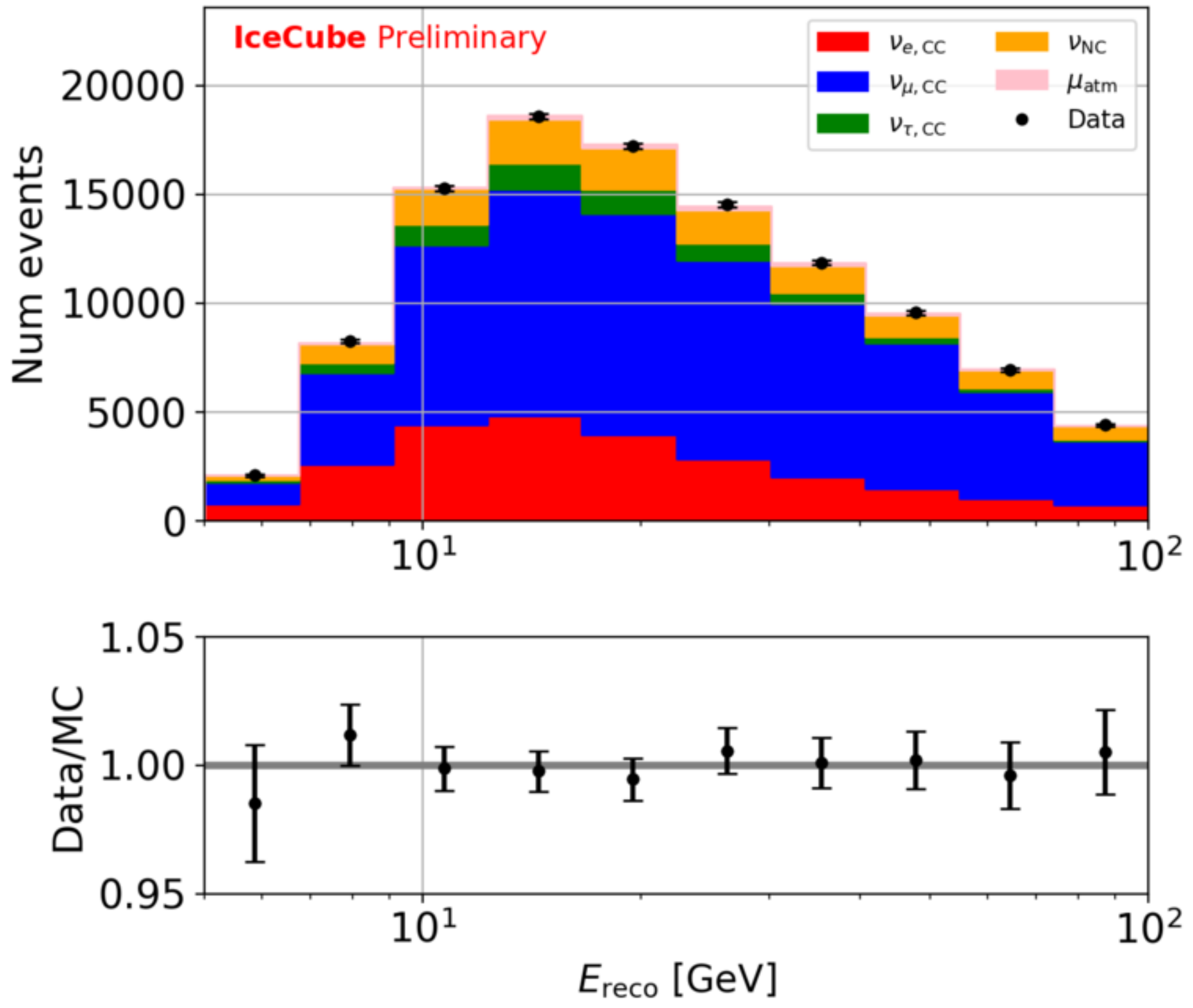
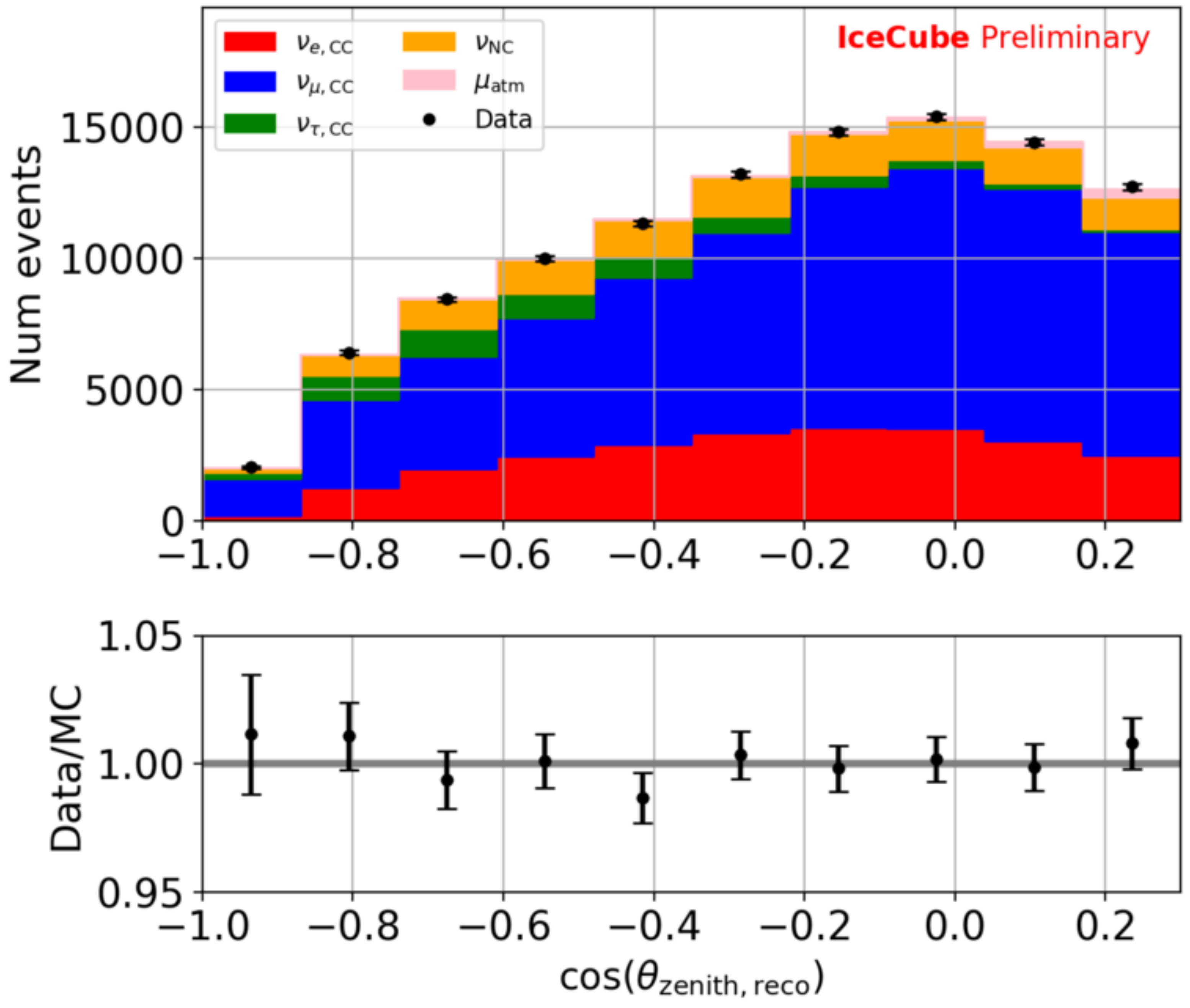


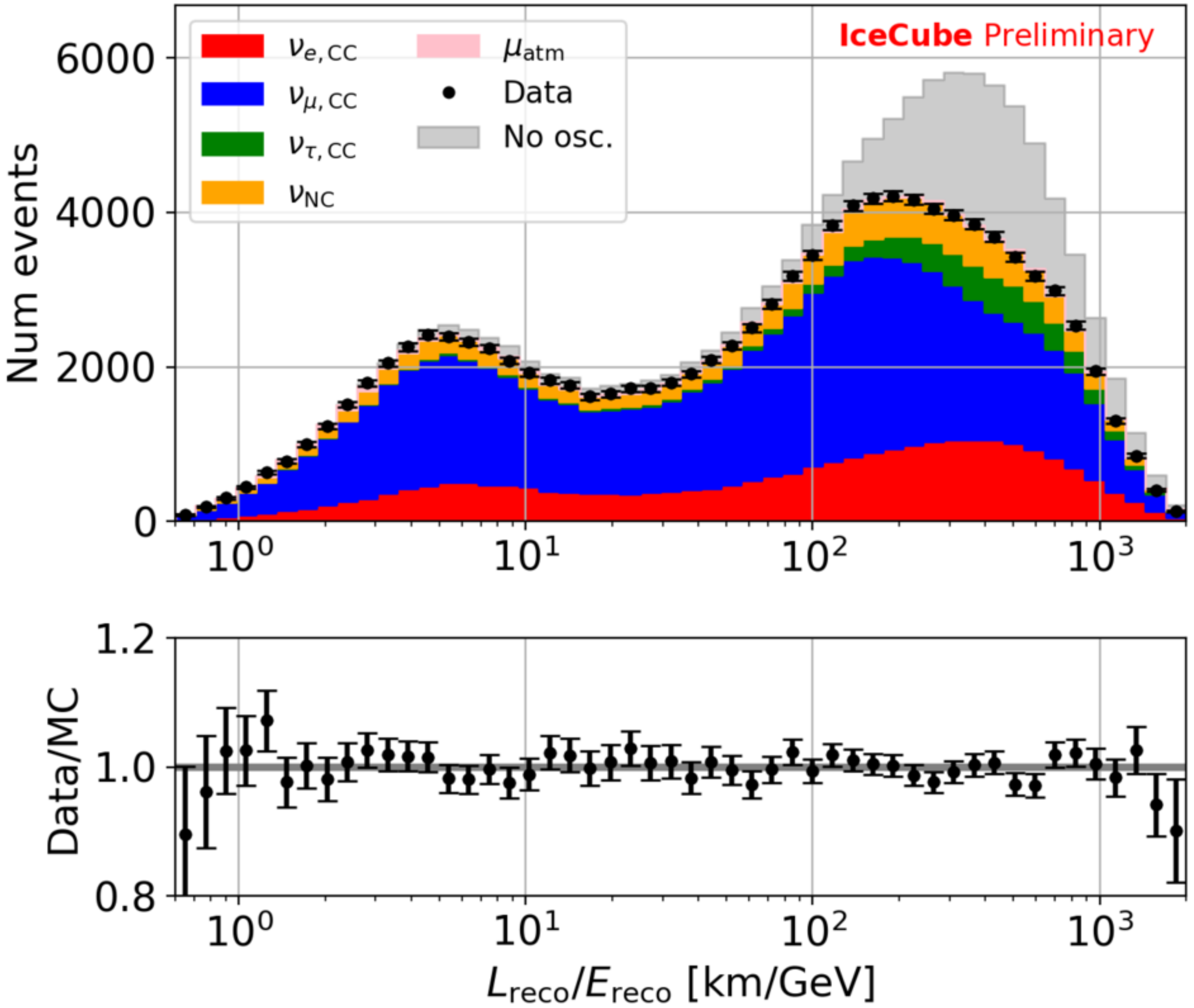


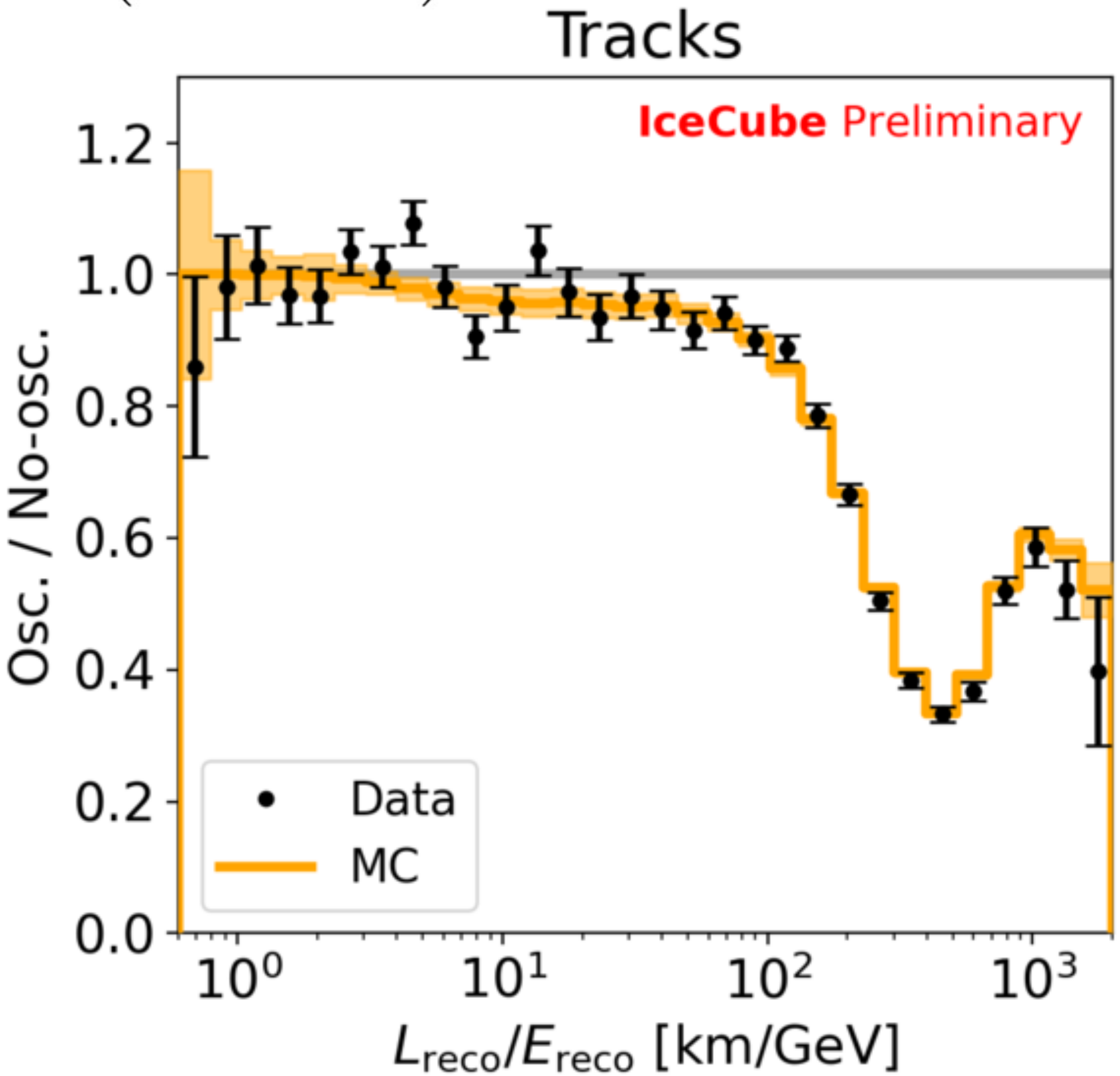


Good data/MC agreement over full space.

11y dataset

$$P(\nu_\mu \to \nu_\mu) \approx 1 - \sin^2(2\theta_{23})\sin^2\left(1.27\frac{\Delta m^2_{32} L}{E}\right)$$





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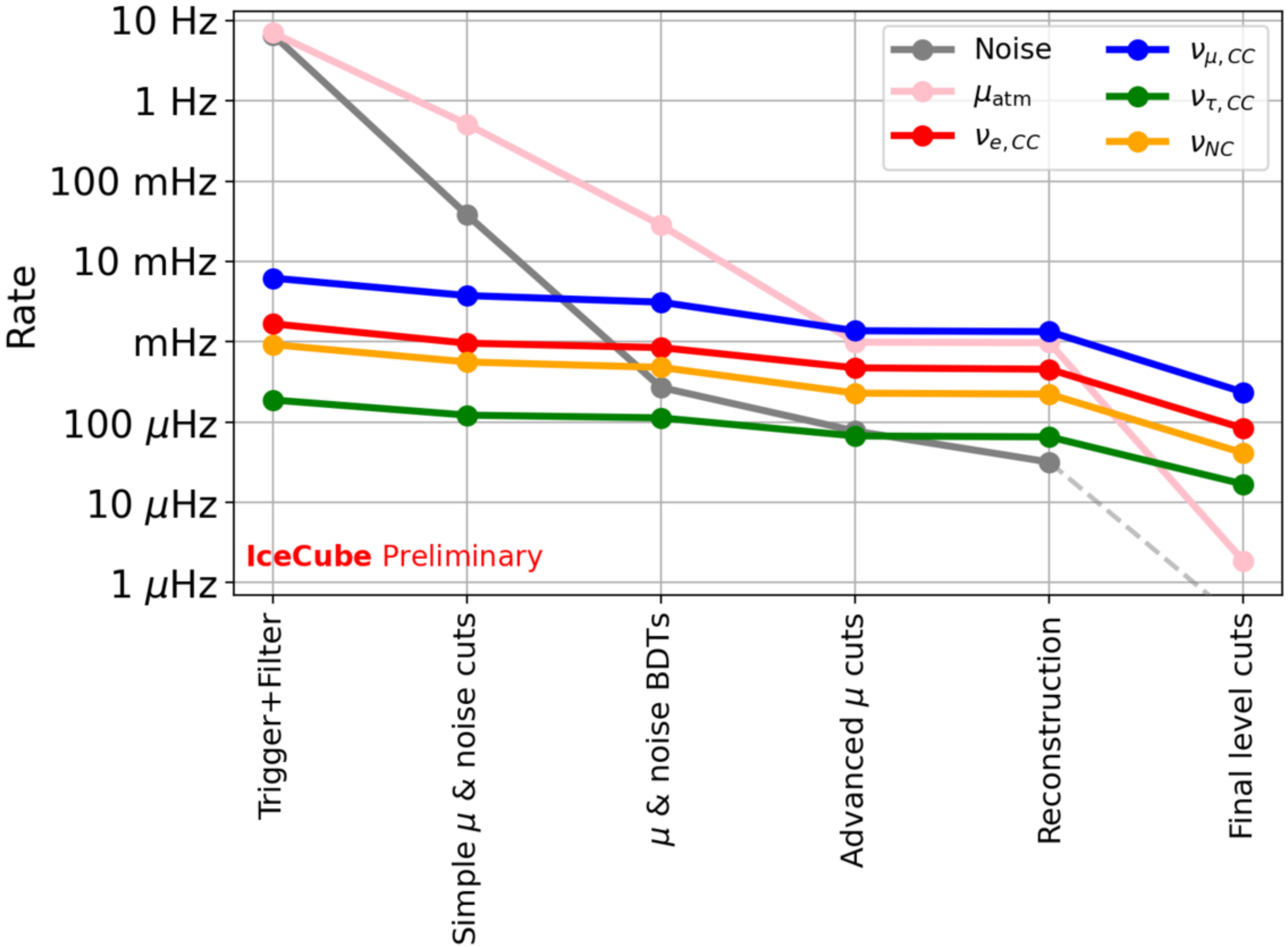
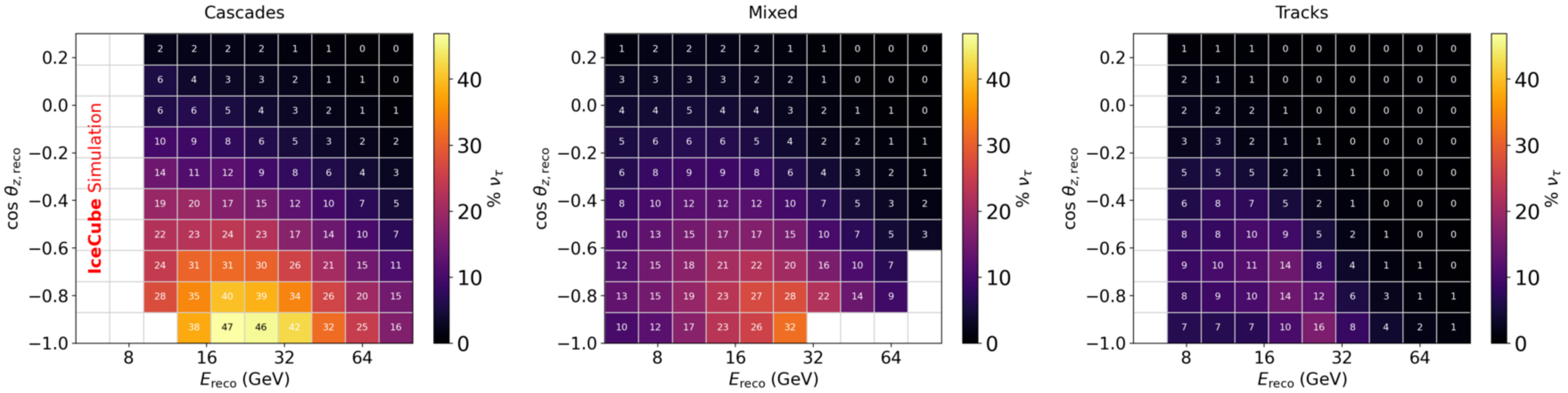


Event rate vs processing level. The dashed line for the final level for noise events indicates that this last stage only represents an estimate of the upper limit, since no MC events remain.

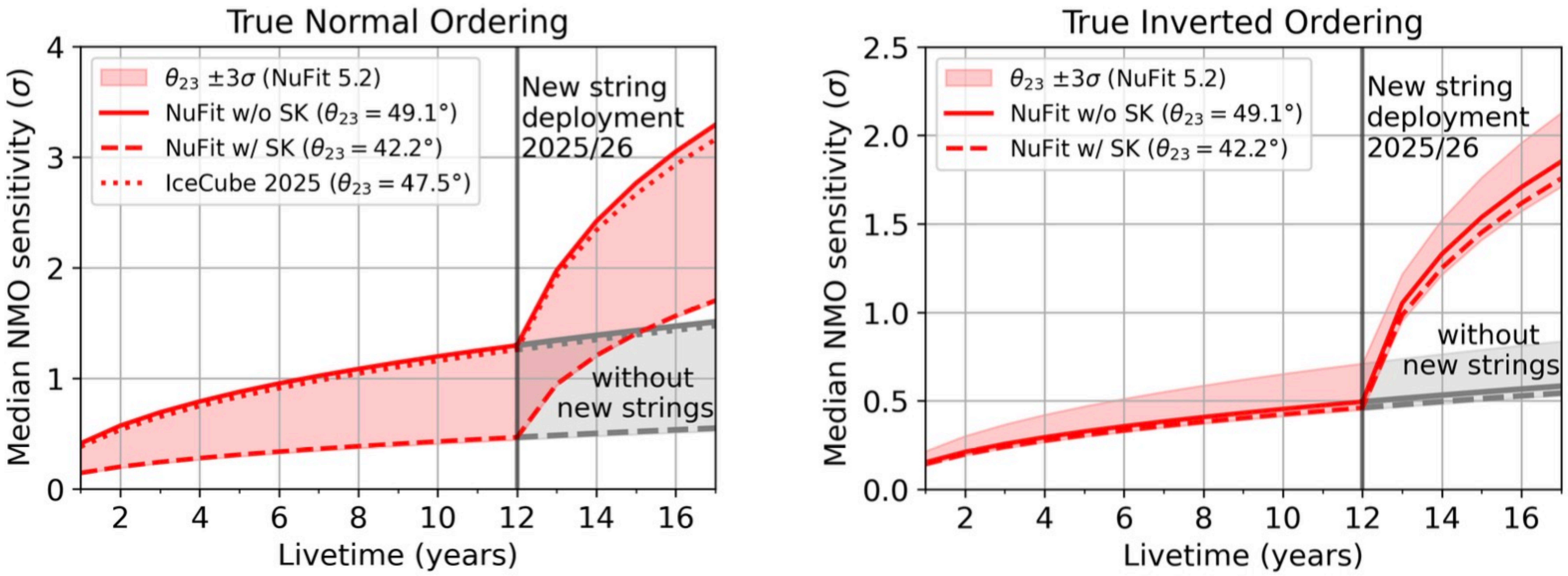
Overall, approx 5% of neutrino events are retained by final level, with the rest being removed by quality cuts or as false positives in background cuts.

11y ν_τ-appearance expectation

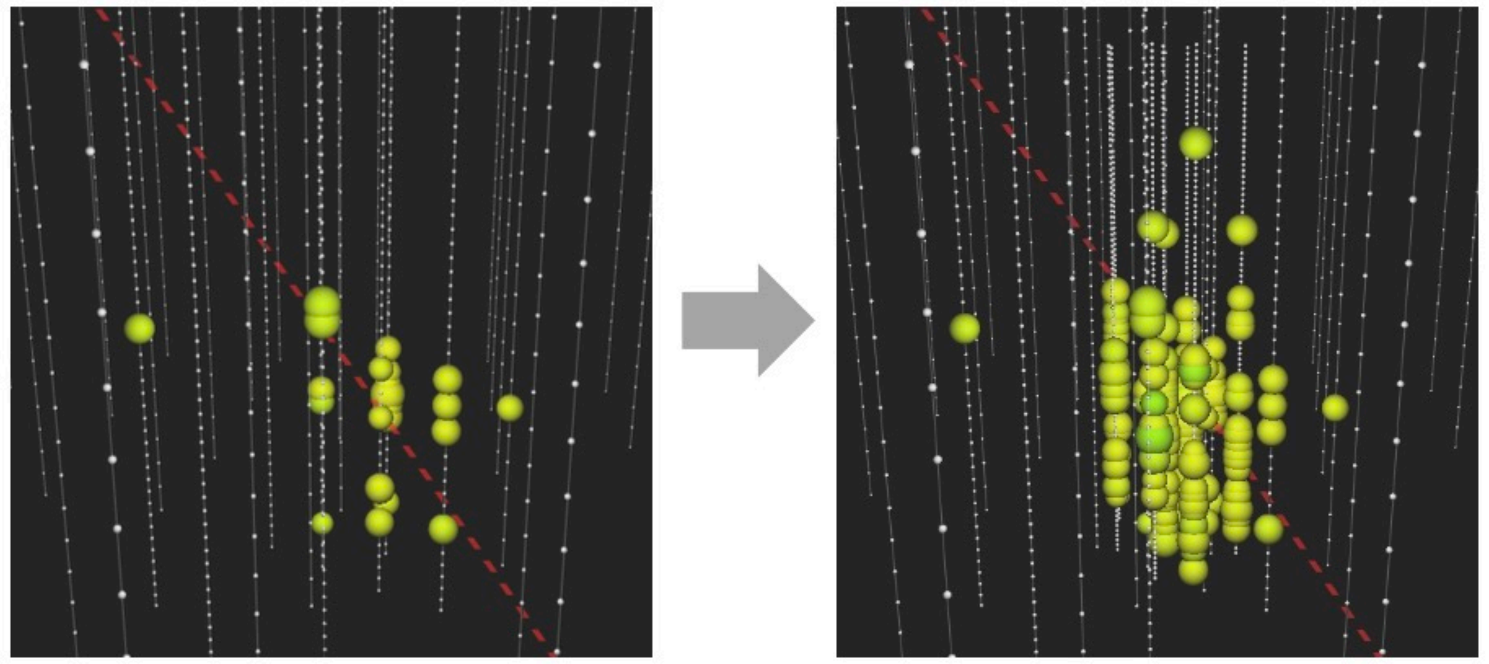


nutau appearance oscillation signal in the analysis binning, showing the nutau percentage of each bin (at the best fit point of the analysis). The signal is strongest in the cascade bin.

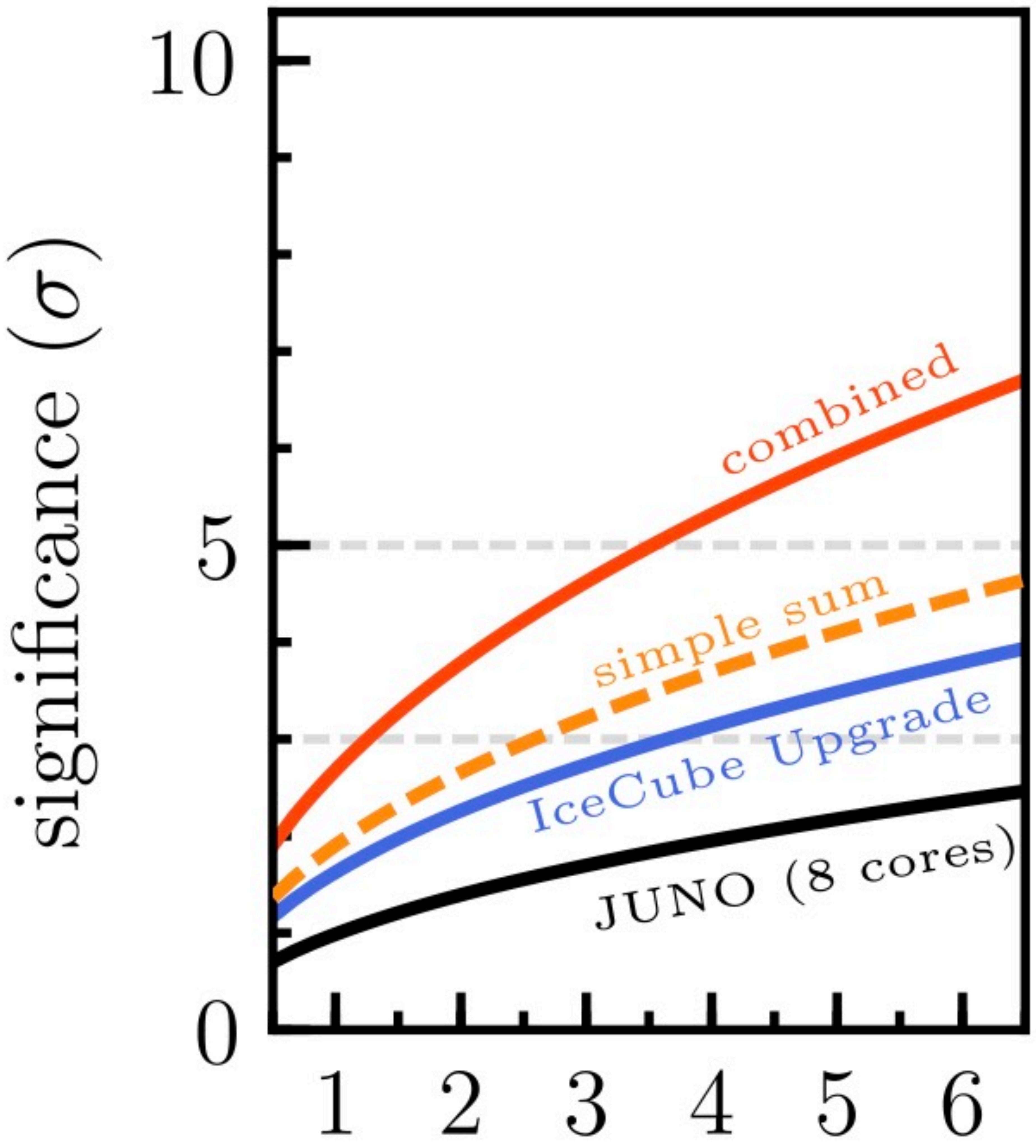
ICU mass ordering sensitivity



Sensitivity to Mass Ordering depends strongly on θ_{23}



ICU + JUNO combined mass ordering sensitivity

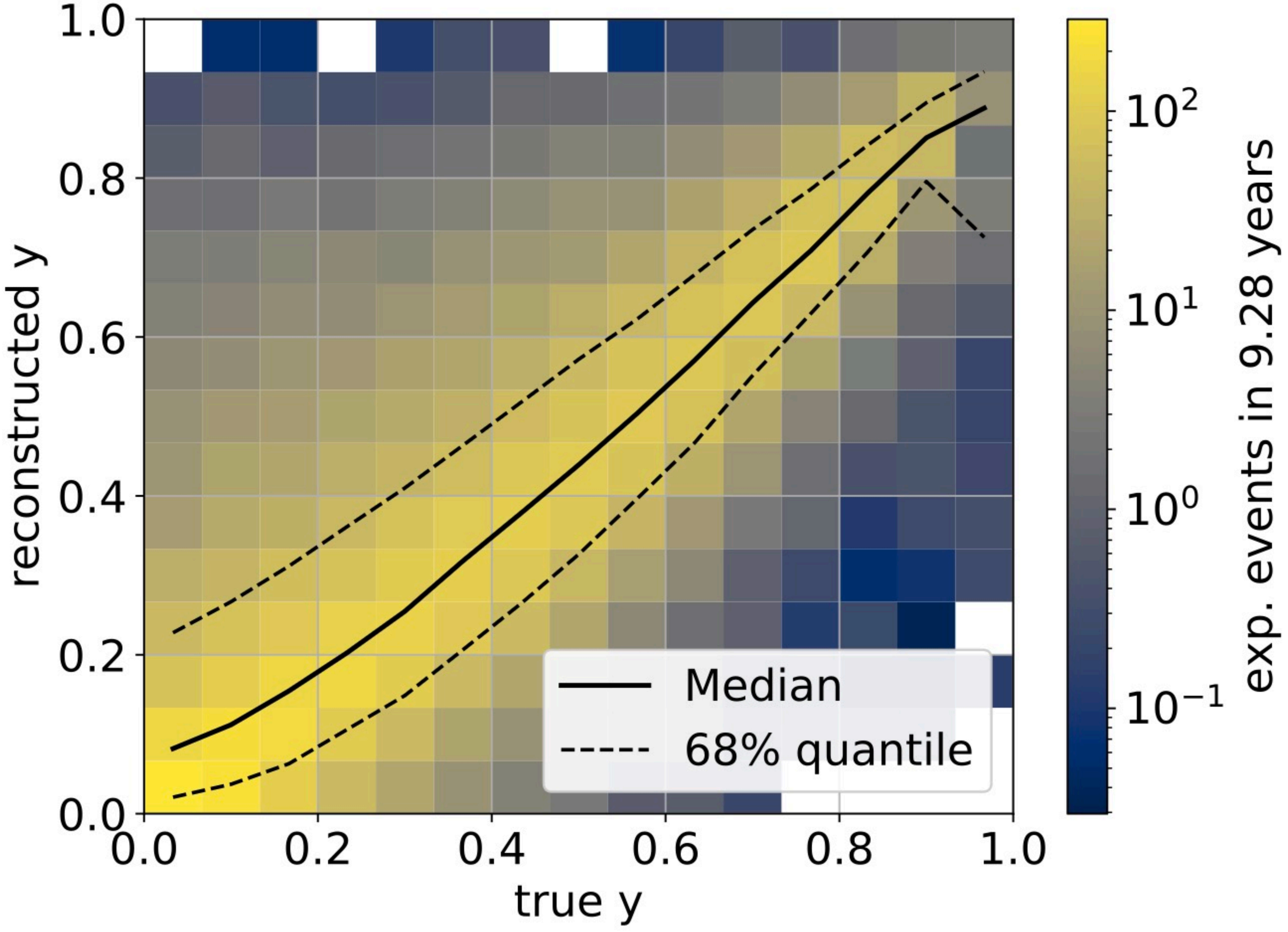


Synergy from combined ICU + JUNO, is expected to hit 5sigma.

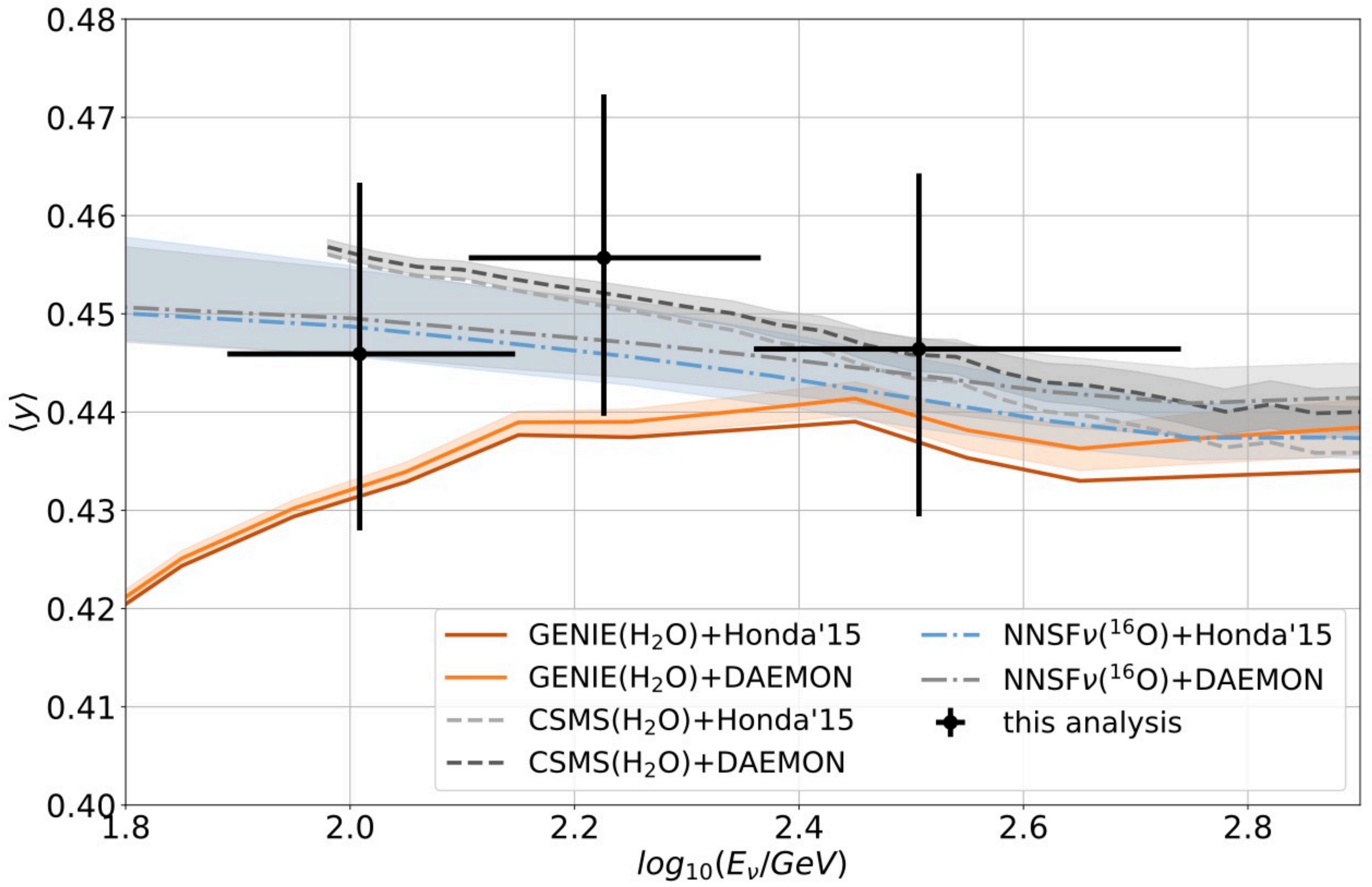
PHYS. REV. D 101, 032006 (2020)

The combined fit works because JUNO and IceCube prefer different values of the effective atmospheric mass splitting when forced into the wrong ordering. The resulting inconsistency creates a strong ΔX^2 synergy that greatly enhances mass-ordering sensitivity.

Inelasticity measurement of $\nu_\mu CC$ events

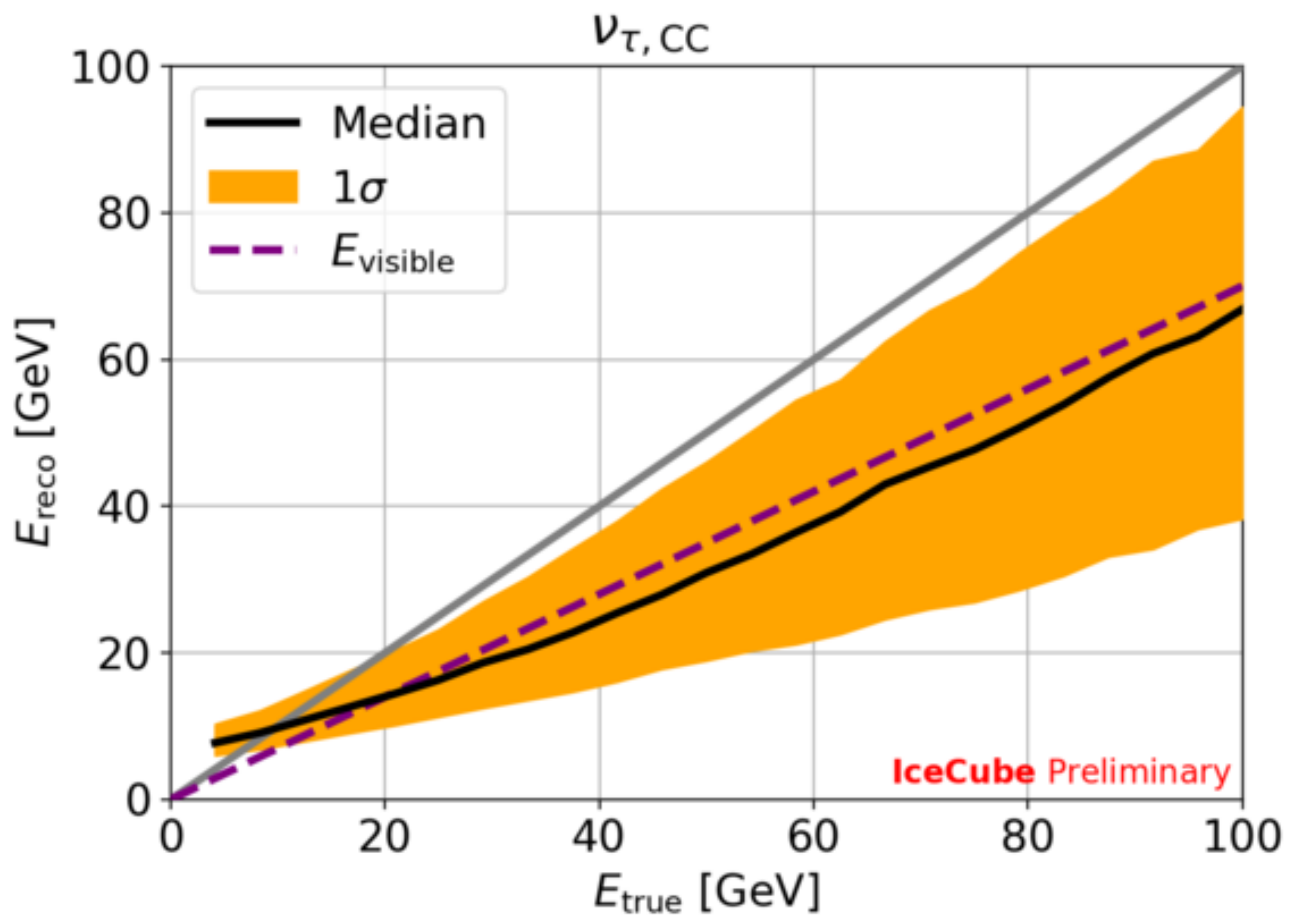


80 - 560 GeV, 9.28 year sample of neutrinos.
Good fit global fit p-value 9.5%.



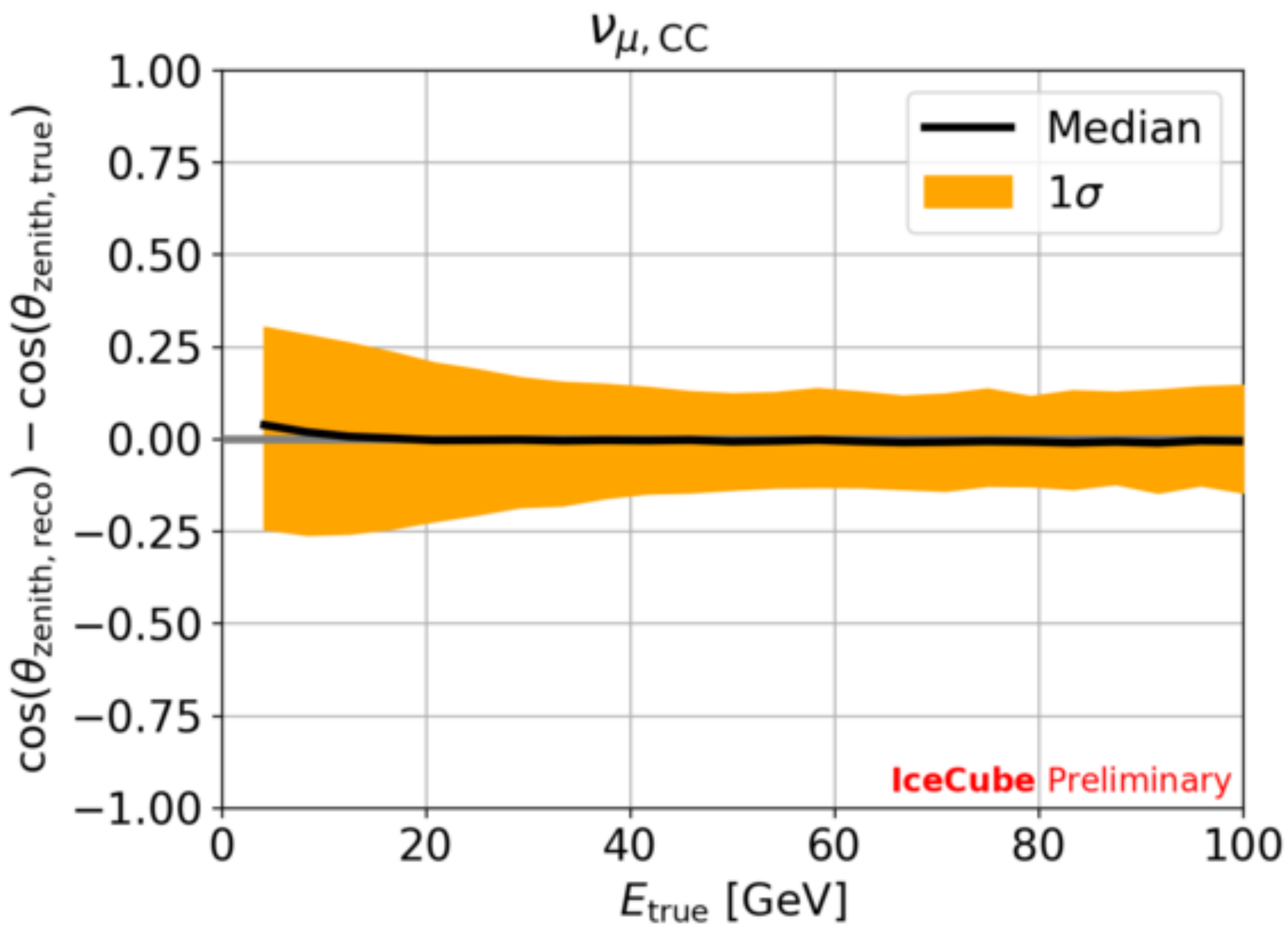
Measurement of inelasticity: PRD 111, 112001 (2025)

11y ν_τ-appearance expectation



Energy reconstruction resolution for contained nutau CC events. The average expected visible energy is also shown (differs from true energy due to final state neutrinos).s

11y ν_τ-appearance expectation



cos(zenith) reconstruction resolution for contained numu CC events.

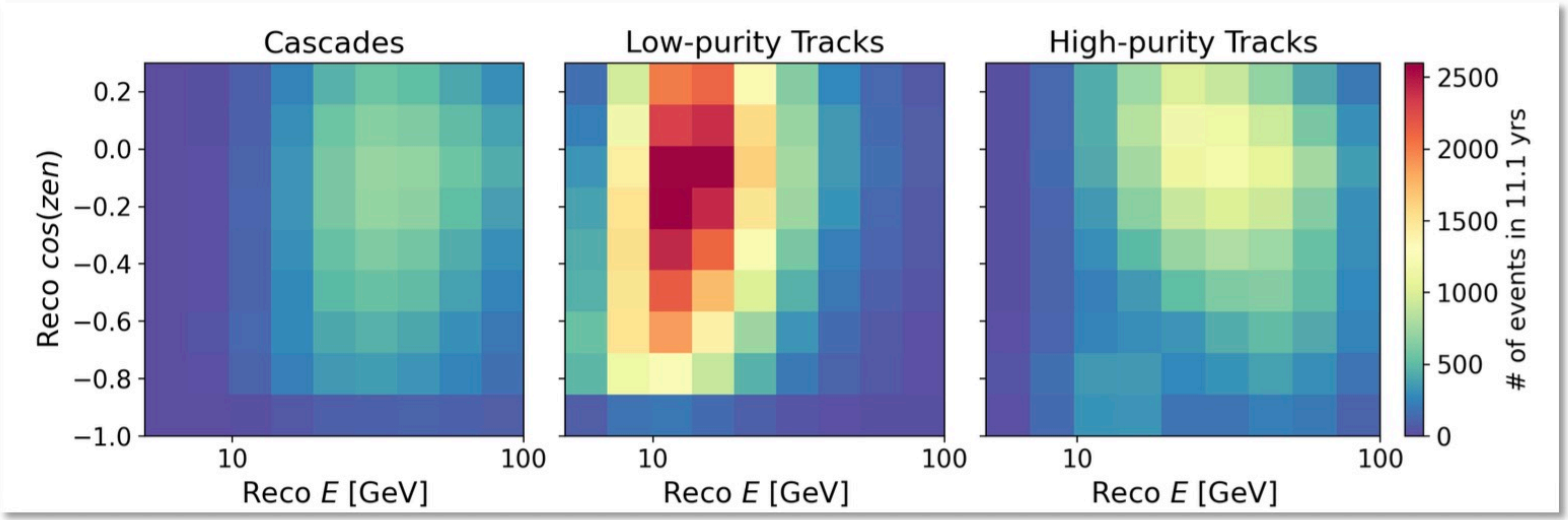
11y expectation

>100,000 events and >99% neutrino purity

• Reconstructed energies: 5-100 GeV

• Events are binned in energy, cos(zenith), and PID (particle/flavor identification)

• Parameters are varied in simulation to change the shapes of these templates



Event selection and Monte Carlo expectation

Event selection conceptual description:

1) Collaboration filtering and data calibration/cleaning
2) Cosmic-ray background reduction by six orders of magnitude (Boosted decision tree (BDT) or straight cuts)
3) Classification (differentiation between cascades, mixed, tracks)
4) reconstruct (energy, zenith, interaction point, inelasticity (see new IC result in [1]))

Plots from Maria Veronica Prado Rodriguez Thesis

[1] Inelasticity measurement: Physical Review D 111.11 (2025): 112001

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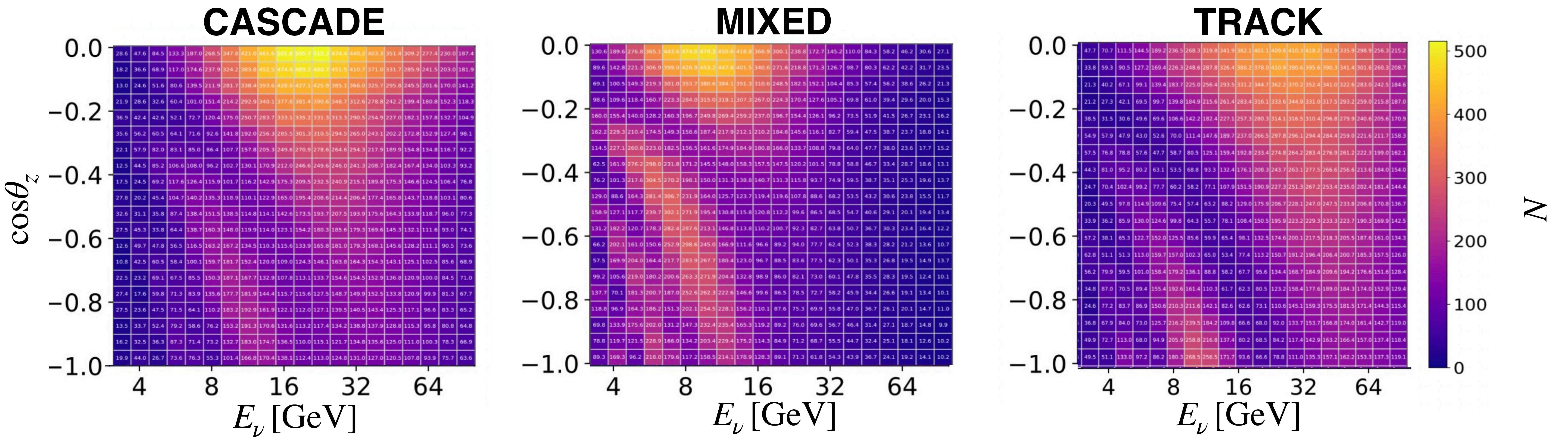
Truth



Plots from Maria Veronica Prado Rodriguez Thesis

[1] Inelasticity measurement: Physical Review D 111.11 (2025): 112001

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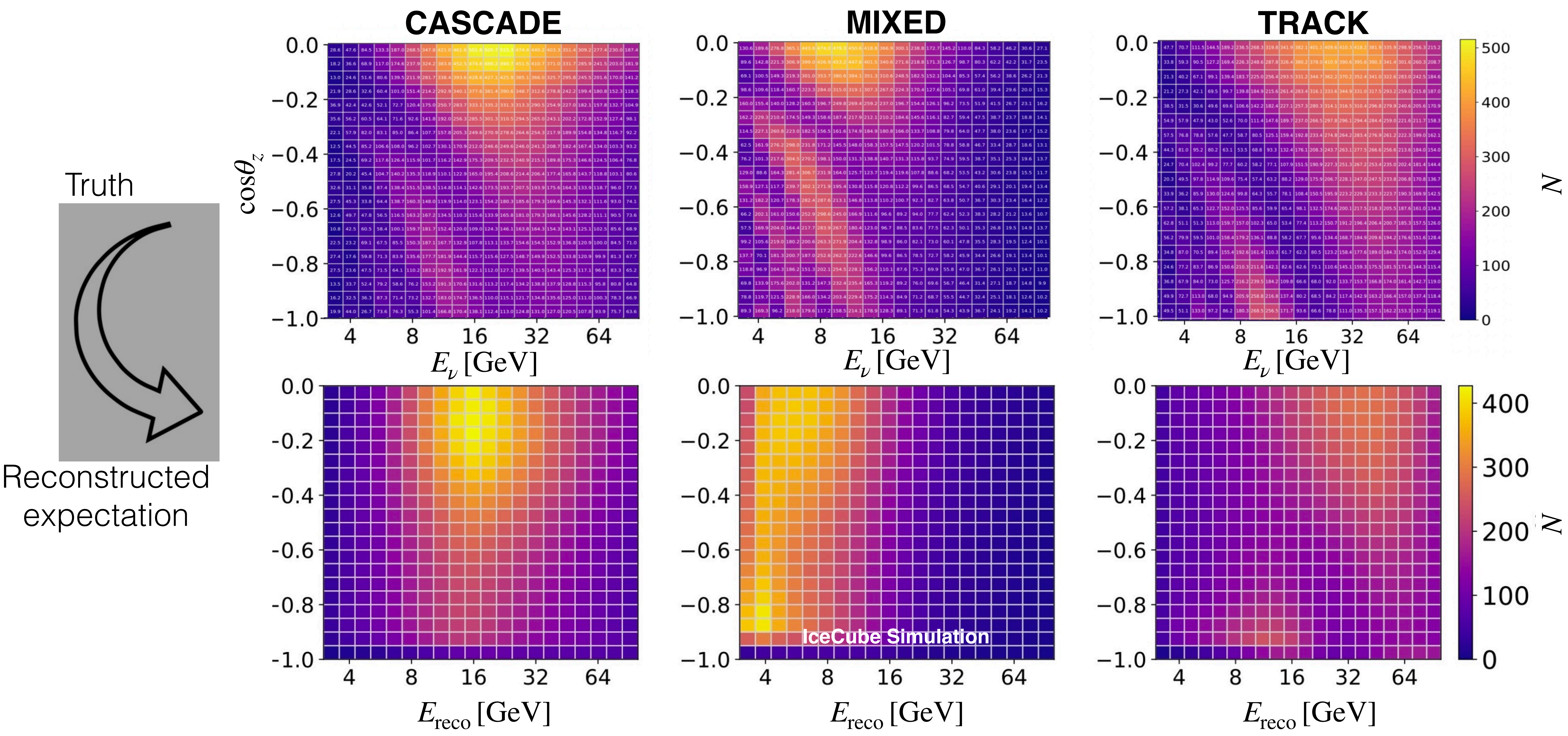

Plots from Maria Veronica Prado Rodriguez Thesis

[1] Inelasticity measurement: Physical Review D 111.11 (2025): 112001

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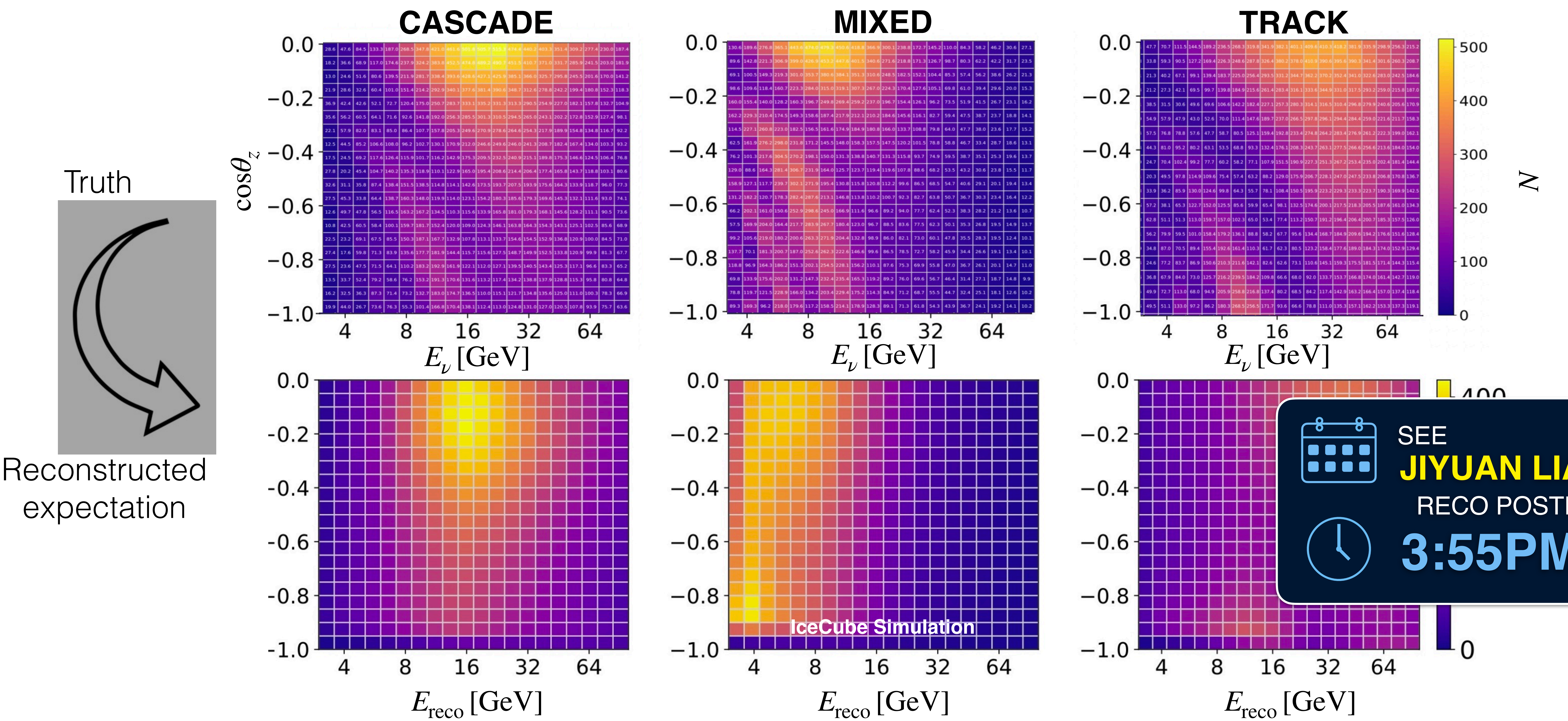


SEE
JIYUAN LIAO'S
RECO POSTER ON THURSDAY
3:55PM - 5:25PM

Plots from Maria Veronica Prado Rodriguez Thesis

[1] Inelasticity measurement: Physical Review D 111.11 (2025): 112001

The fitting procedure

- Binned Poisson Log Likelihood (LLH) calculated for physics hypothesis point ($\vec{\Theta}$), while profiling over nuisance parameters.
- Compare LLH at each hypothesis point to best fit point.
- Nuisance parameters implemented as 3D splines with gaussian or flat priors introduced in the LLH as a penalization term.
- Confidence intervals generated using Wilks' theorem.
    - Feldman-Cousins spot checks to ensure coverage, or full correction calculation after unblinding.

Computer physics communications (2026): 110195

Nucl.Instrum.Meth.A 977 (2020) 164332)

$$LLH_{\vec{\Theta}} = \sum_{i \in \text{bins}} \text{Log}_{10}\left(\frac{n_i^{n_o} e^{-n_i}}{n_o!}\right) + \frac{1}{2}\sum_{j \in \text{syst}} \frac{(\hat{s}_j - s_j)^2}{\sigma_j^2}$$

Observation (n_o); MC Expectation (n_i); Prior central value ($\hat{s}_j$); Prior width (σ_j)

Binned Poisson Likelihood

Gaussian Priors for continuous nuisance parameters

Test statistic may incorporate finite MC statistics (Journal of High Energy Physics 2019.6 (2019): 30)

$$TS := 2\Delta LLH = 2(LLH_{\vec{\Theta}} - LLH_{BF})$$

The high-energy sterile neutrino search

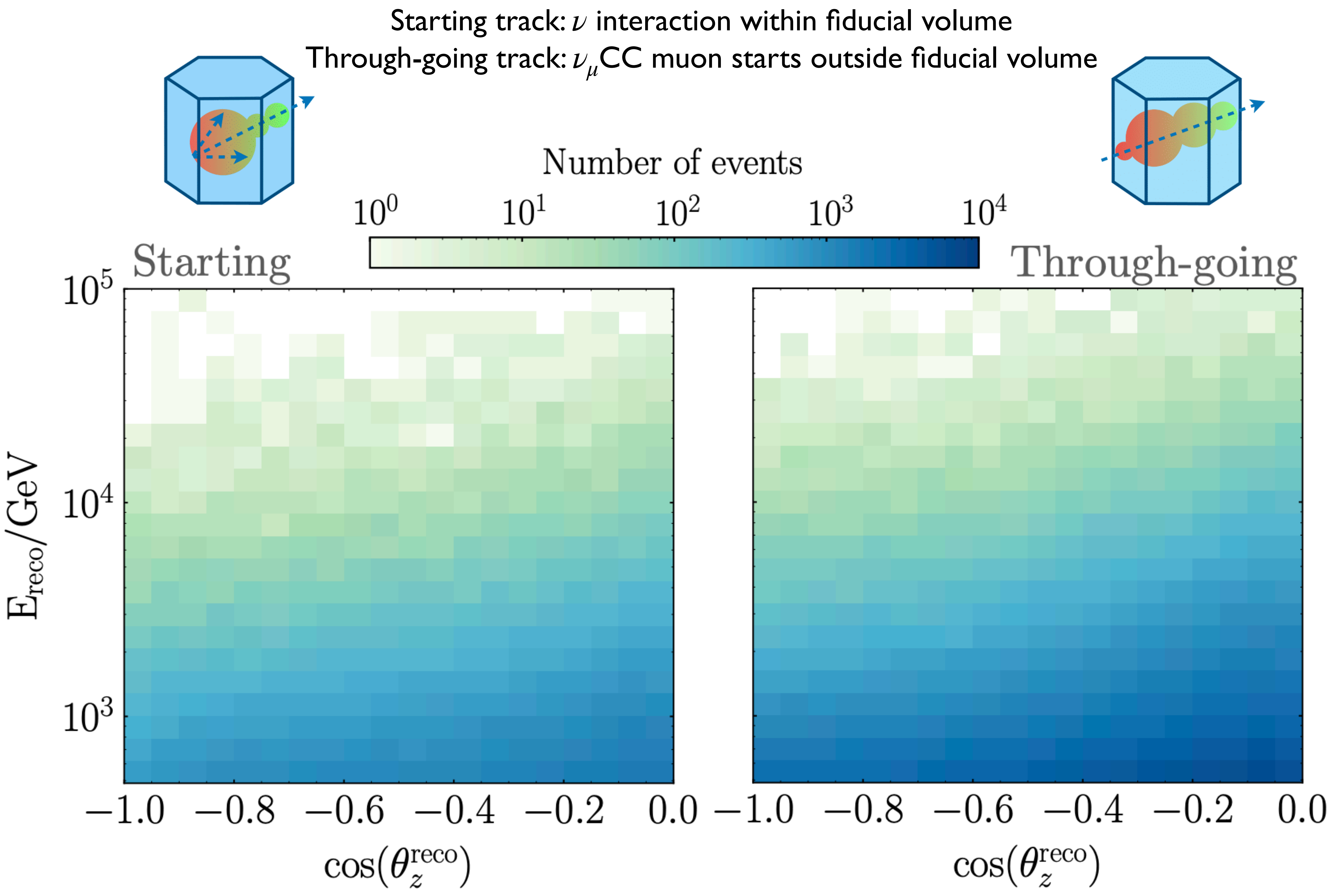
- Use dataset of up-going ν_μ tracks. High purity, high statistics, improved directional reconstruction

Component	Starting	Through-going
Conv. ν_μCC	90,757.1	260,692.9
Non-conv. ν_μCC	709.8	4,000.2
All ν_e	0.5	0.2
All ν	60.0	258.0
μ_{atm}	2.3	4.2
Total MC	91,529.7	264,955.5
Data	93,762	274,309

- Most recent dataset consists of 368,071 events 10.7 years of data, with neutrinos between 0.5 and 100 TeV

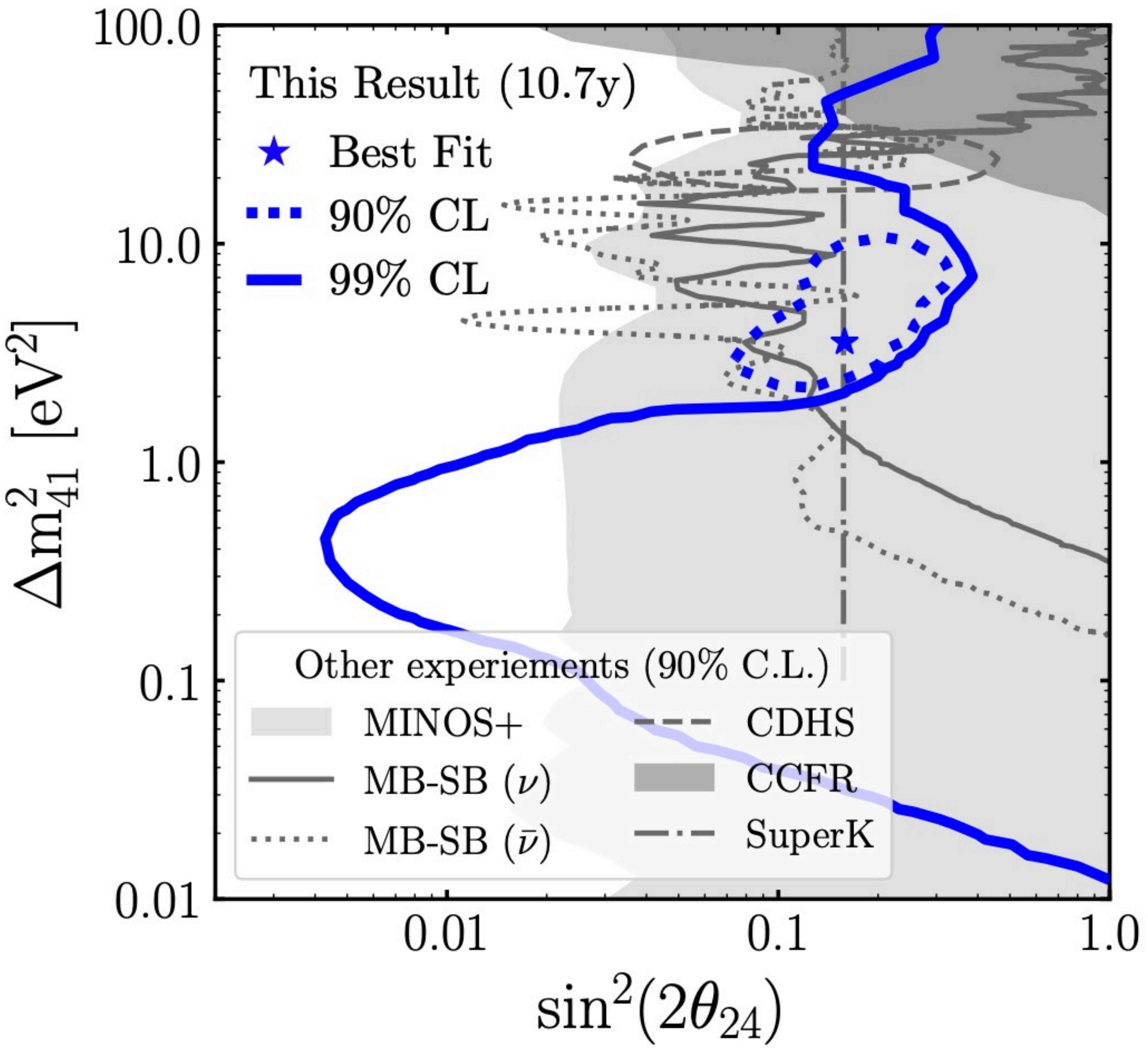
- Machine learning used to improve energy resolution as well as remove background (skimming muons, cascades), leading to 99.9% purity.

- SnowStorm ice model systematic treatment[2]



[1] Phys. Rev. lett. 133.20 (2024): 201804
[2] Journal of Cosmology and Astroparticle Physics 2019.10 (2019): 048-048

The high-energy 3+1 sterile neutrino result



- World leading exclusion at the 99% C.L. between:

$$0.1\text{eV}^2 < \Delta m^2_{41} < 1.0\text{eV}^2$$

- Best fit point and closed 90% C.L. contour is disfavored by other ν_μ-disappearance experiments.

(**SciBooNE, MiniBooNE**) Phys.Rev. D 85, 032007 (2012),
(**MINOS+**) Phys. Rev. Lett. 122, 091803(2019),
(**MiniBooNE, SciBooNE**) Phys. Rev. D 86, 052009 (2012),
(**Super-Kamiokande**) Phys. Rev. D 91, 052019 (2015),
(**CCFR**) Phys. Rept. 884, 1 (2020))

Neutrino - Antineutrino ratio

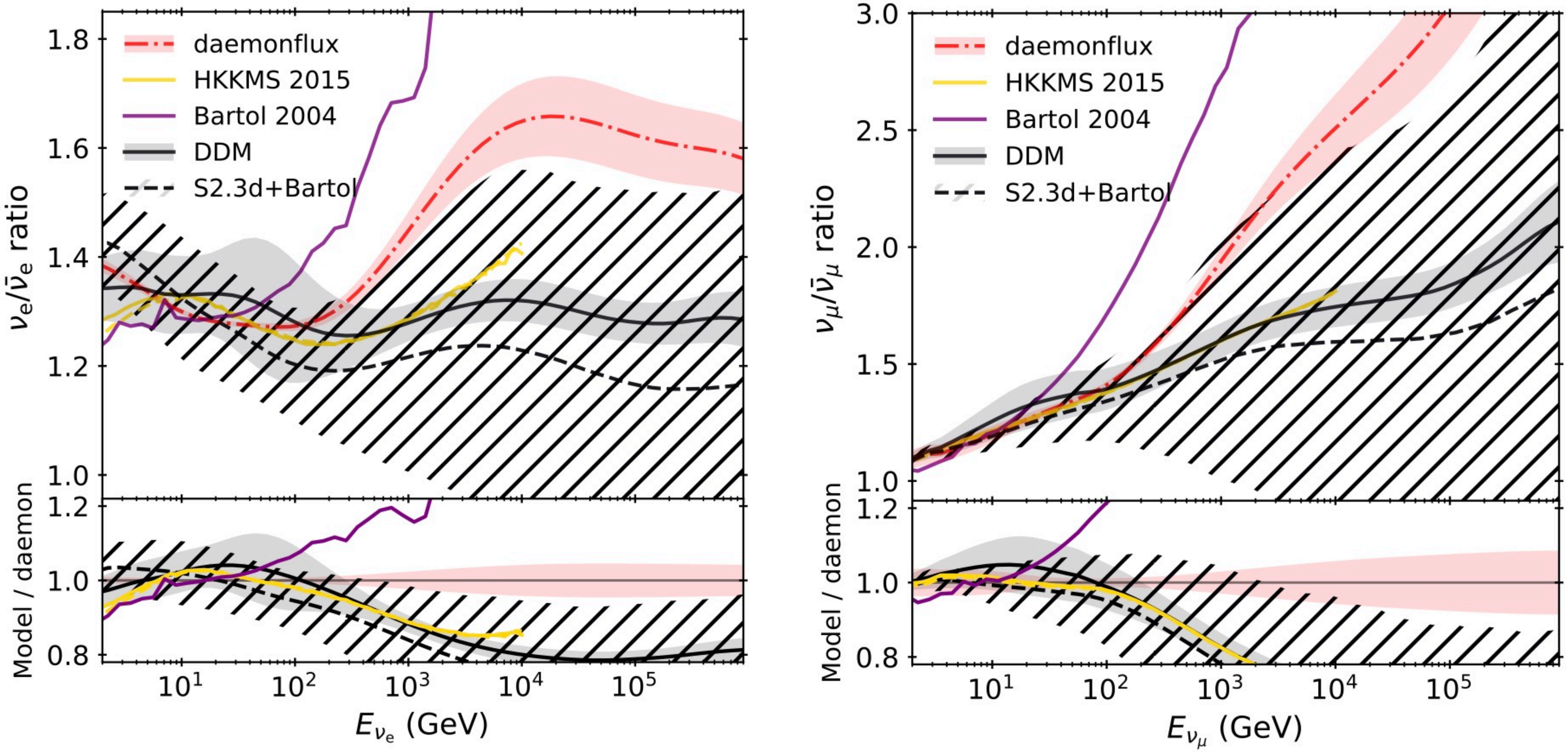
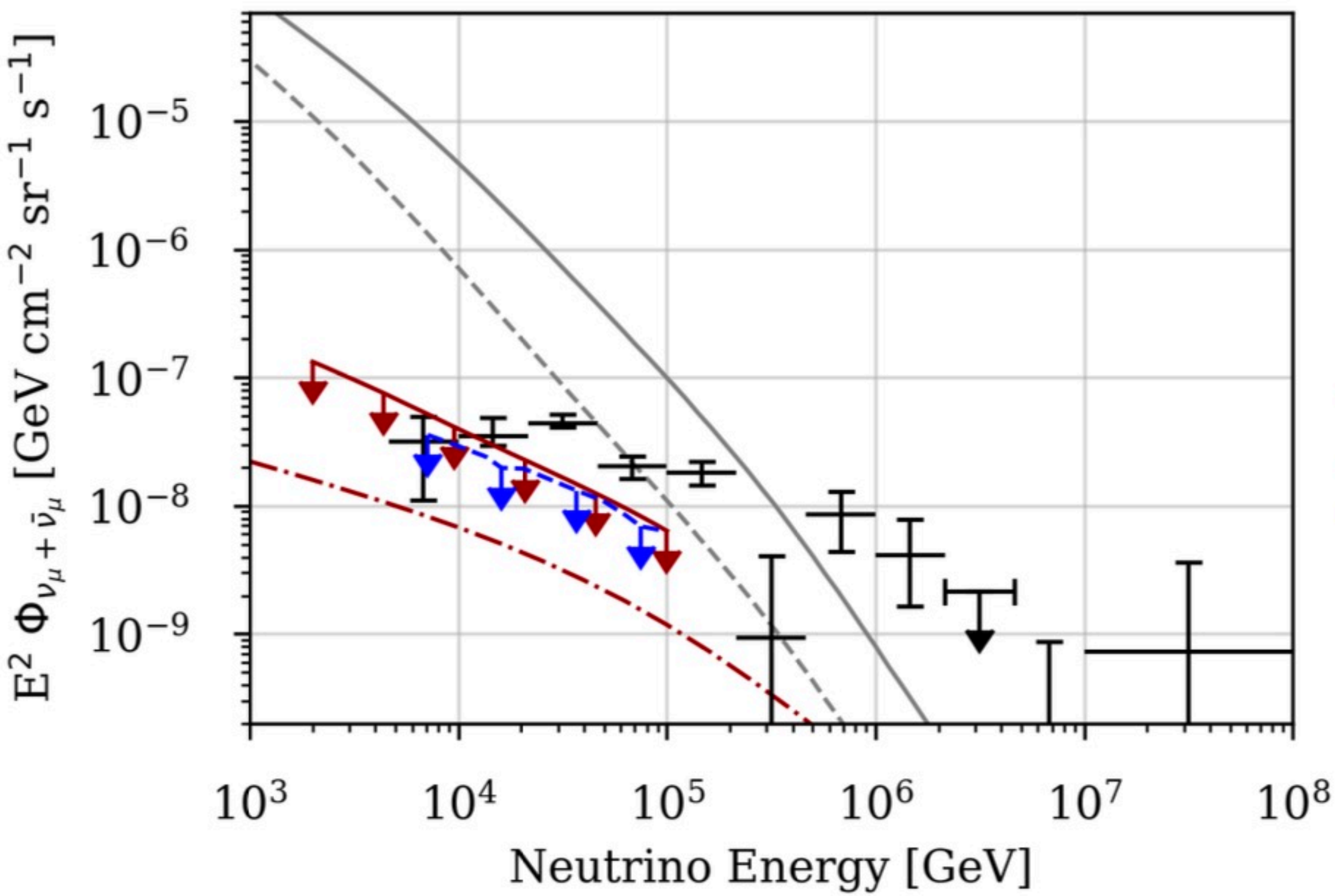


FIG. 16. Neutrino-antineutrino ratios for the conventional, zenith-averaged atmospheric neutrino flux. The uncertainties are computed as described in [24].

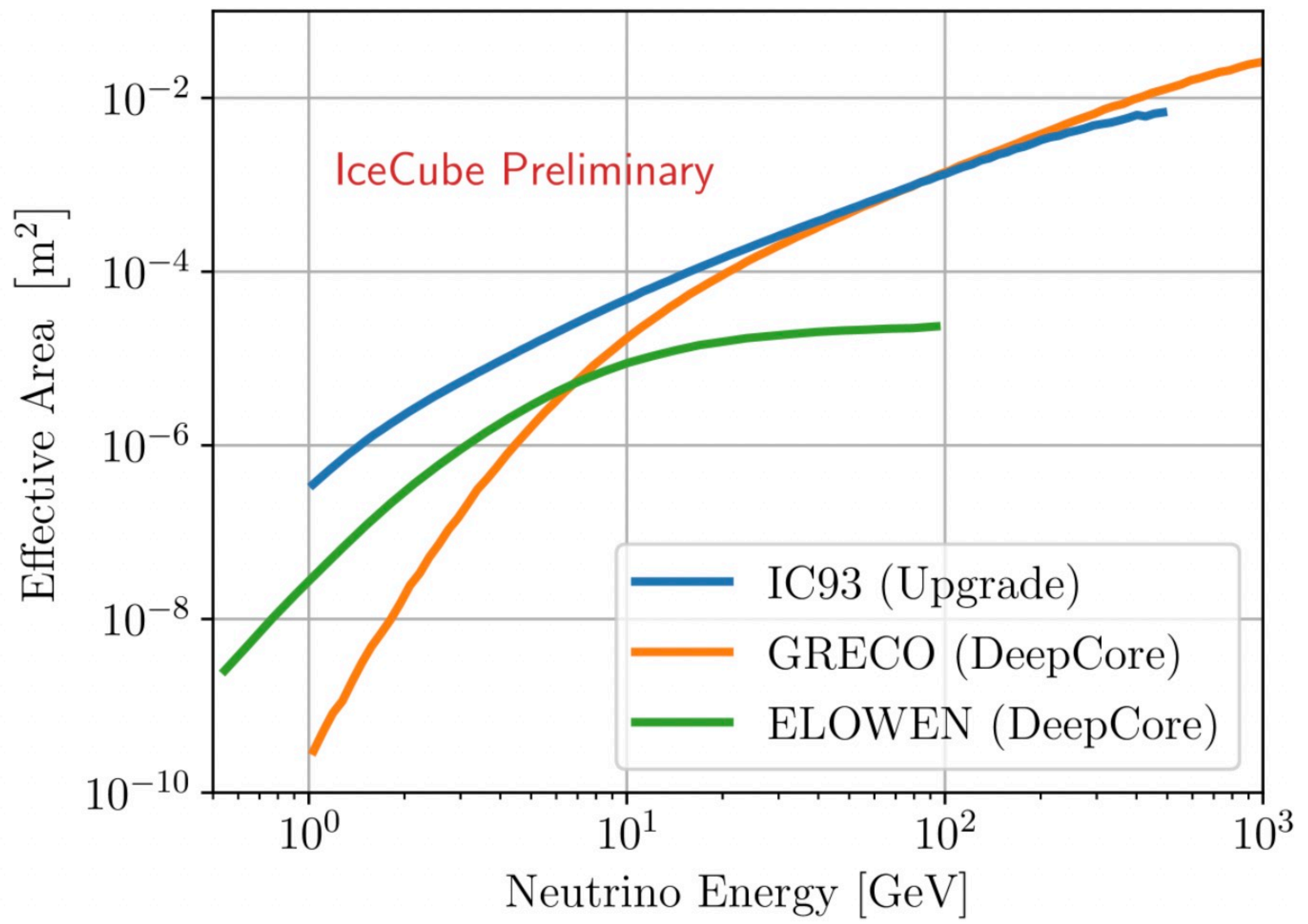
Physical Review D 107.12 (2023): 123037.

Prompt neutrino component, new results



The limit on the prompt atmospheric neutrino flux (in dark red) compared to the previous 6-year NT-limit (blue dashed line). The best-fit prompt flux is also shown, the fitted segmented astrophysical flux in black, and the conventional atmospheric neutrino flux as a gray line.

Prompt neutrino component, new results



Sky-averaged, all flavor, effective area of the IC93 sample in comparison to the existing DeepCore event selections.

arXiv preprint arXiv:2507.16050 (2025)