Earth Tomography with Atmospheric Neutrino Absorption at TRIDENT

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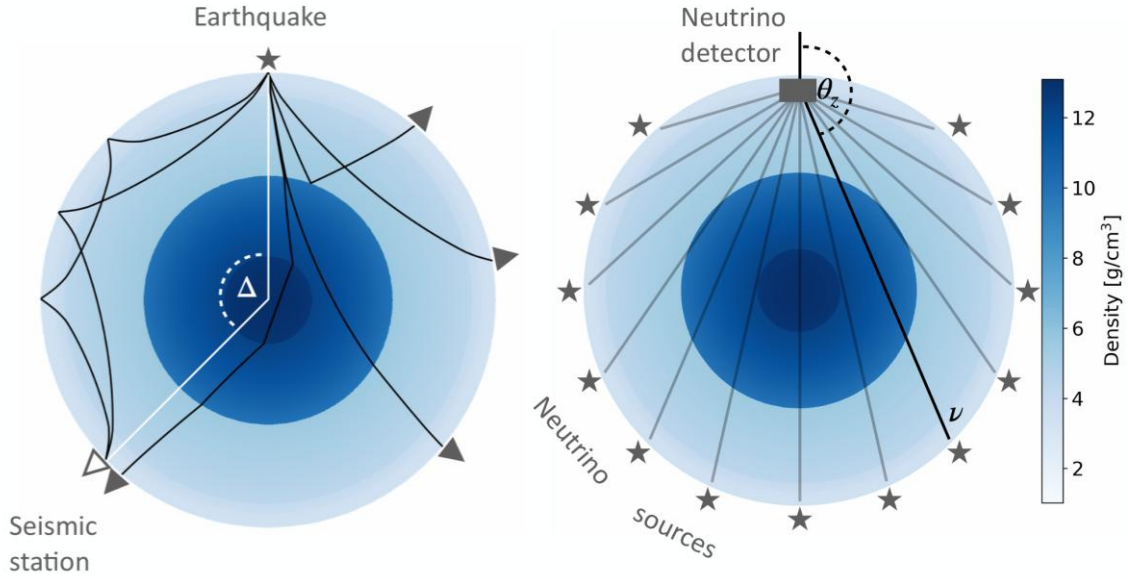
2026.08.31 @ TeVPA 2026

Introduction: Earth tomography

Earth tomography: Using through-going neutrinos to probe the Earth’s interior

Why?

- Earth's density profile constrains its internal composition and evolution
- The conventional method (seismology) constrains density indirectly through wave velocities, which are also affected by T, P, and composition.
- We can probe the Earth's density profile by measuring the energy and angular distributions of neutrinos propagating through the Earth



seismic tomography neutrino tomography

Image Credit: Isabel Goos @ Neutrino Geoscience 2025

Introduction: Earth tomography

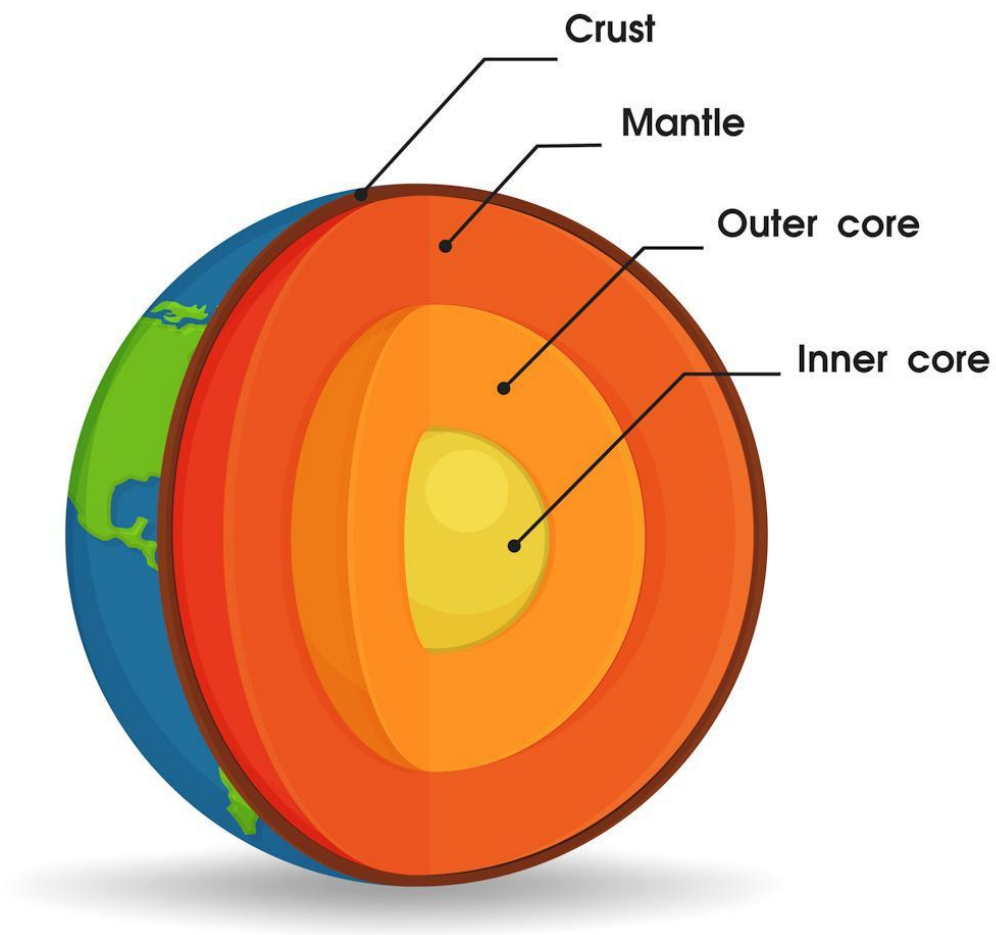


Image credit: VRVector / Shutterstock, via Carleton University

- Main idea: use up-going atmospheric neutrinos that traverse the Earth
- Two modes:

  1) Absorption tomography (TeV-PeV)

$$\Phi(E,\theta) = \Phi_0(E,\theta) \cdot \exp[-\sigma(E) \cdot N_A \cdot \int \rho(r)\, dl\,]$$

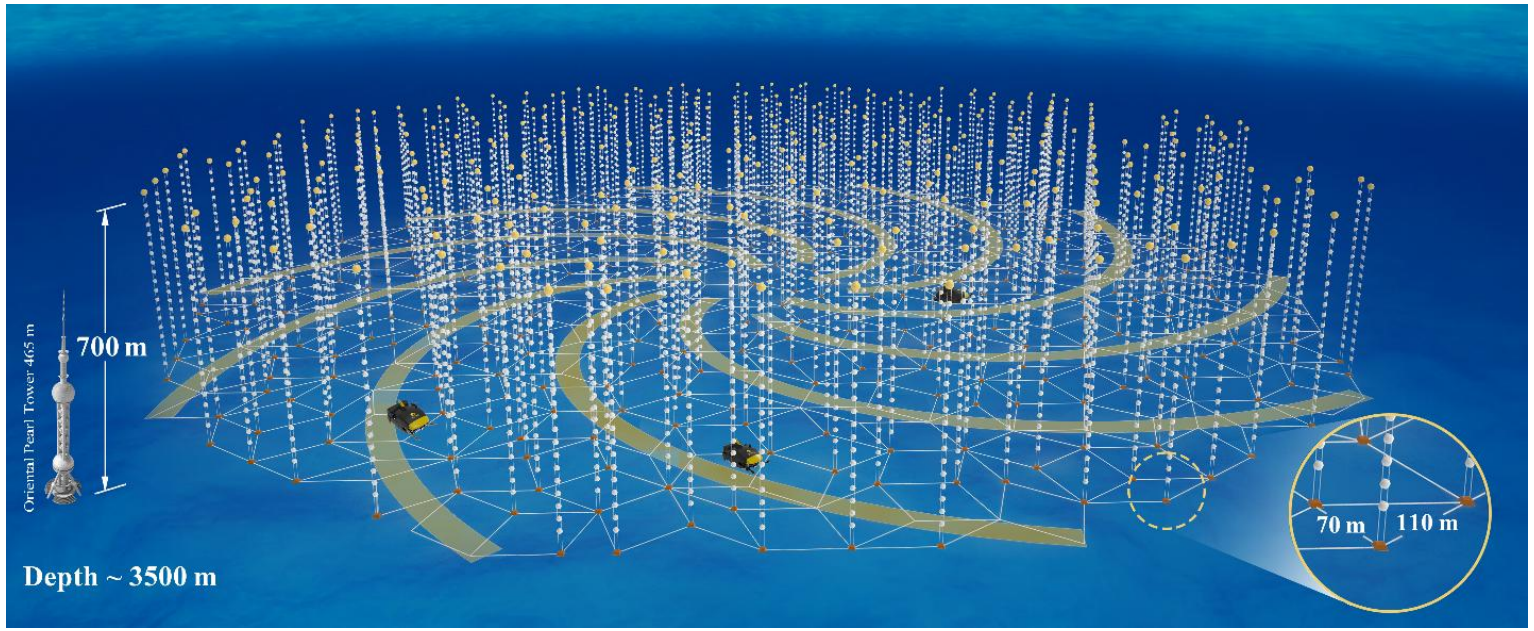
  2) Oscillation tomography (MeV-GeV)

$$n_e = \frac{N_A}{m_n}\,\rho\,\frac{Z}{A}$$

- Expected result: Map a 1D radial density profile:

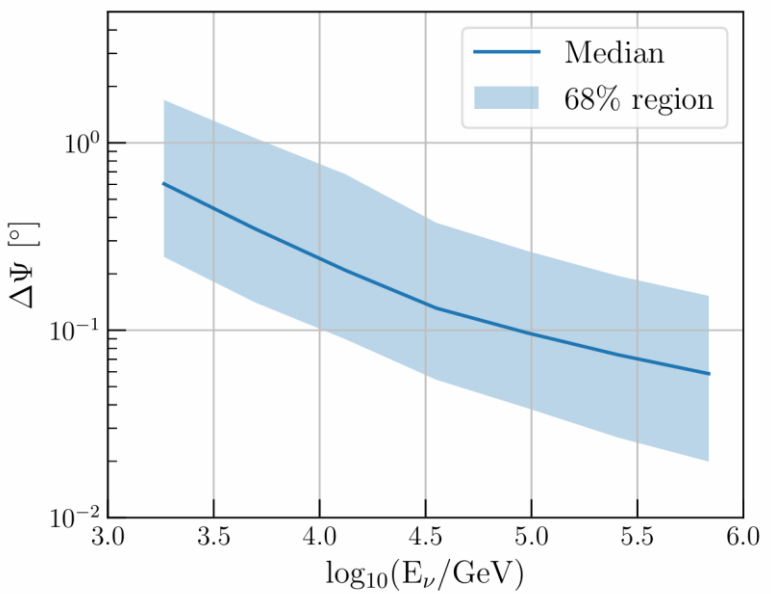
$$\rho(r)$$

Introduction: TRIDENT



Ye Z.P et al.. Nat Astro 7, 1497 – 1505 (2023).

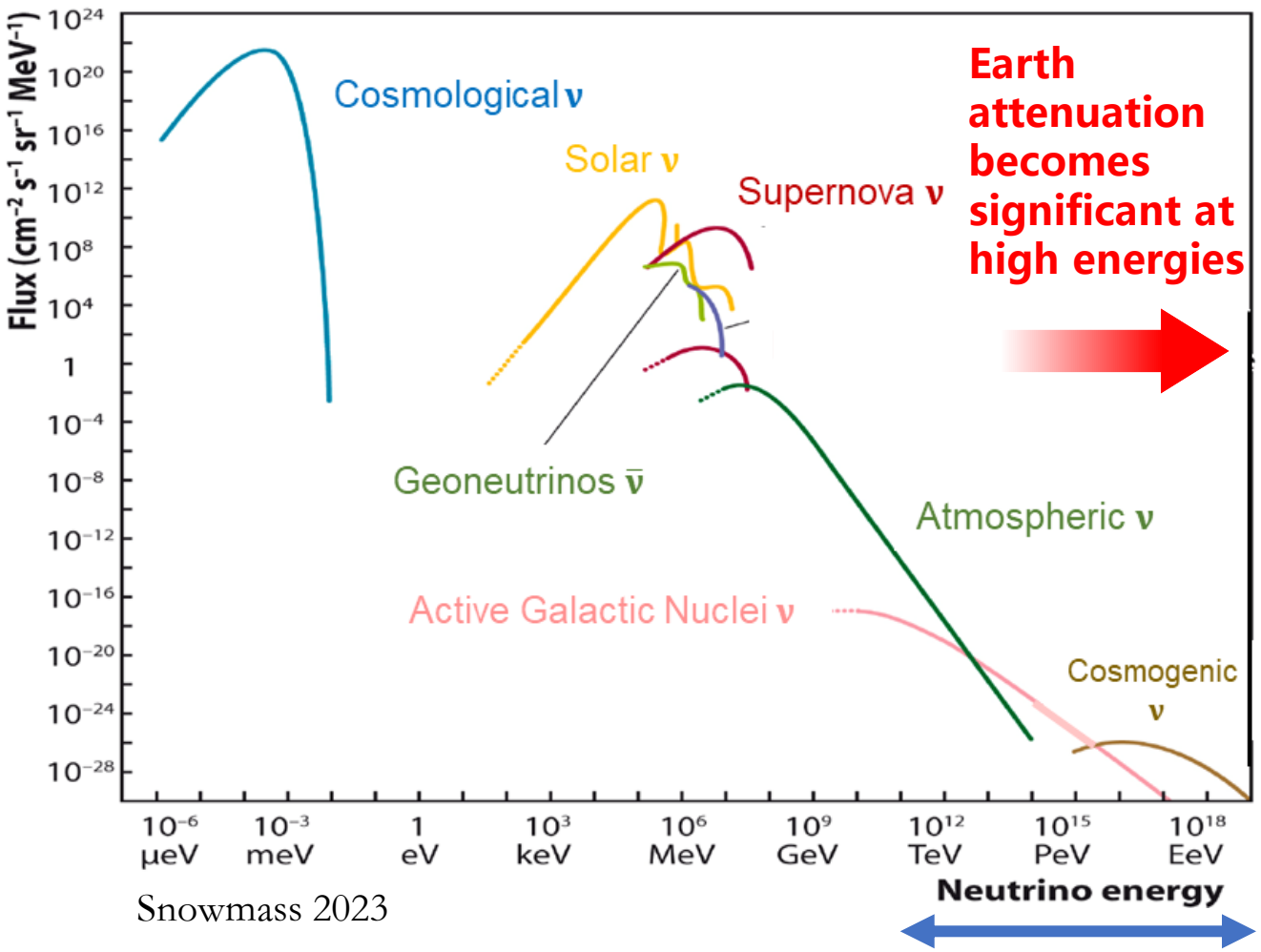
Angular resolution for ν_μ track events



I. Morton-Blake et al.. Phys. Rev. D 113, 043030 (2026)

- An up-coming next-gen neutrino telescope
- Including ~1000 strings with 20 hDOMs (hybrid digital optical modules) per string
- Size: ~8 km³
- Broad neutrino sensitivity from sub-TeV to EeV energies

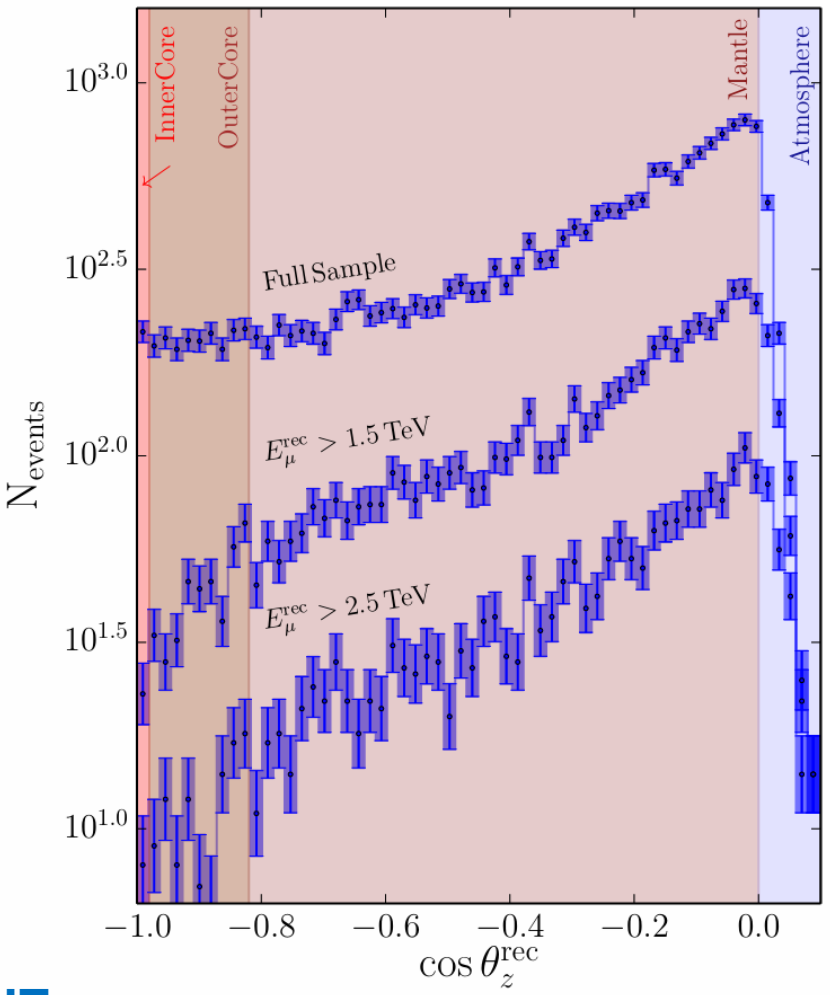
Introduction: TRIDENT



Snowmass 2023

Sensitive region of TRIDENT

IceCube 1yr events

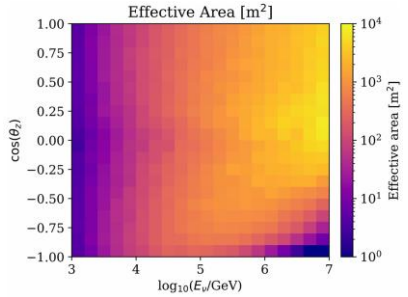


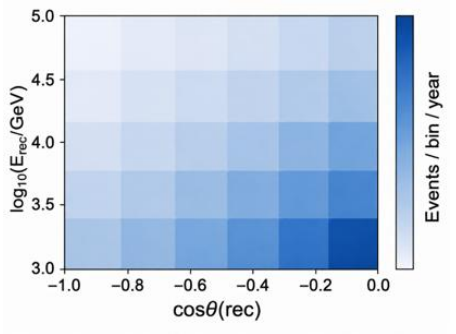
Donini, A. Nature Phys **15**, 37 – 40 (2019).

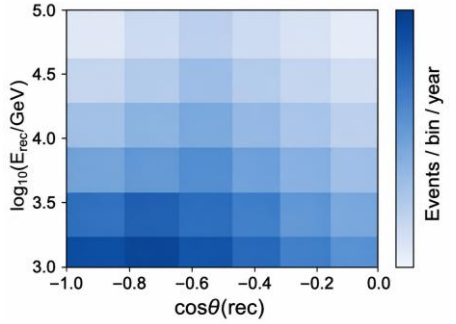
Methodology

Φ_0 → Earth → Φ → N^{data}

Daemonflux[1] → Φ_0' → Propagate by **nuSQuIDS**[2] → **Assumed density profile** → Φ' → $\times A_{eff}$ [3] → $N^{expected}$







$$\ln \mathcal{L}(\boldsymbol{\rho}, \boldsymbol{\eta}) = \sum_{i \in bins} \left(N_i^{data} \ln N_i^{expected}(\boldsymbol{\rho}, \boldsymbol{\eta}) - N_i^{expected}(\boldsymbol{\rho}, \boldsymbol{\eta}) \right) - \sum_j \frac{\left(\eta_j - \eta_j^0\right)^2}{2\sigma_j^2}$$

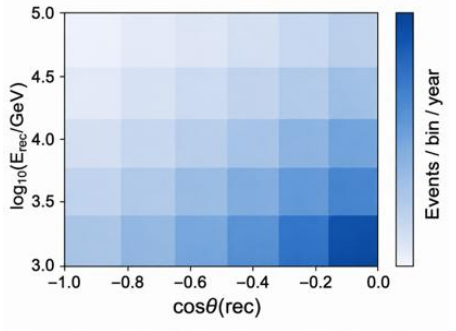
[1] Juan Pablo Yañez, Anatoli Fedynitch. Phys. Rev. D 107, 123037, 2023
[2] Carlos A. Argüelles, et al.. Comput. Phys. Commun. 277, 108346, 2022.
[3] Z. P. Ye et al., Nat. Astron. 7, 1497 – 1505, 2023.

Methodology

PREM
(Preliminary Reference Earth Model)

Φ

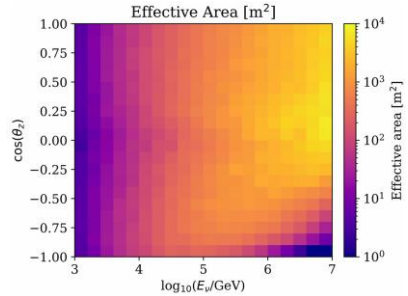
$\times A_{\mathrm{eff}}$ [3]



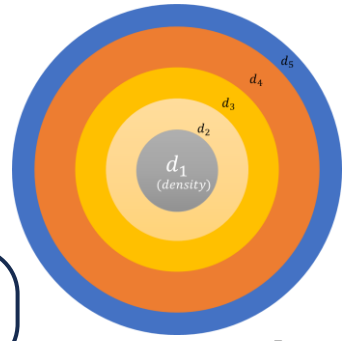
N^{asimov}

Daemonflux[1]

Φ_0'



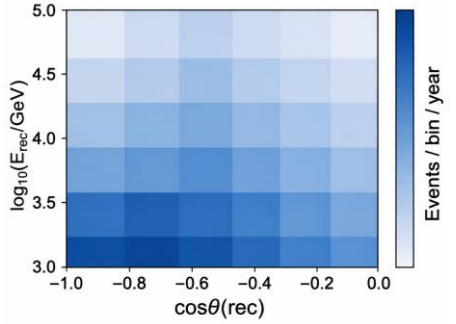
Propagate by **nuSQuIDS**[2]



Assumed density profile

Φ'

$\times A_{\mathrm{eff}}$ [3]



$N^{expected}$

$$\ln \mathcal{L}(\boldsymbol{\rho}, \boldsymbol{\eta}) = \sum_{i \in bins} \left(N_i^{asimov} \ln N_i^{expected}(\boldsymbol{\rho}, \boldsymbol{\eta}) - N_i^{expected}(\boldsymbol{\rho}, \boldsymbol{\eta}) \right) - \sum_j \frac{\left(\eta_j - \eta_j^0\right)^2}{2\sigma_j^2}$$

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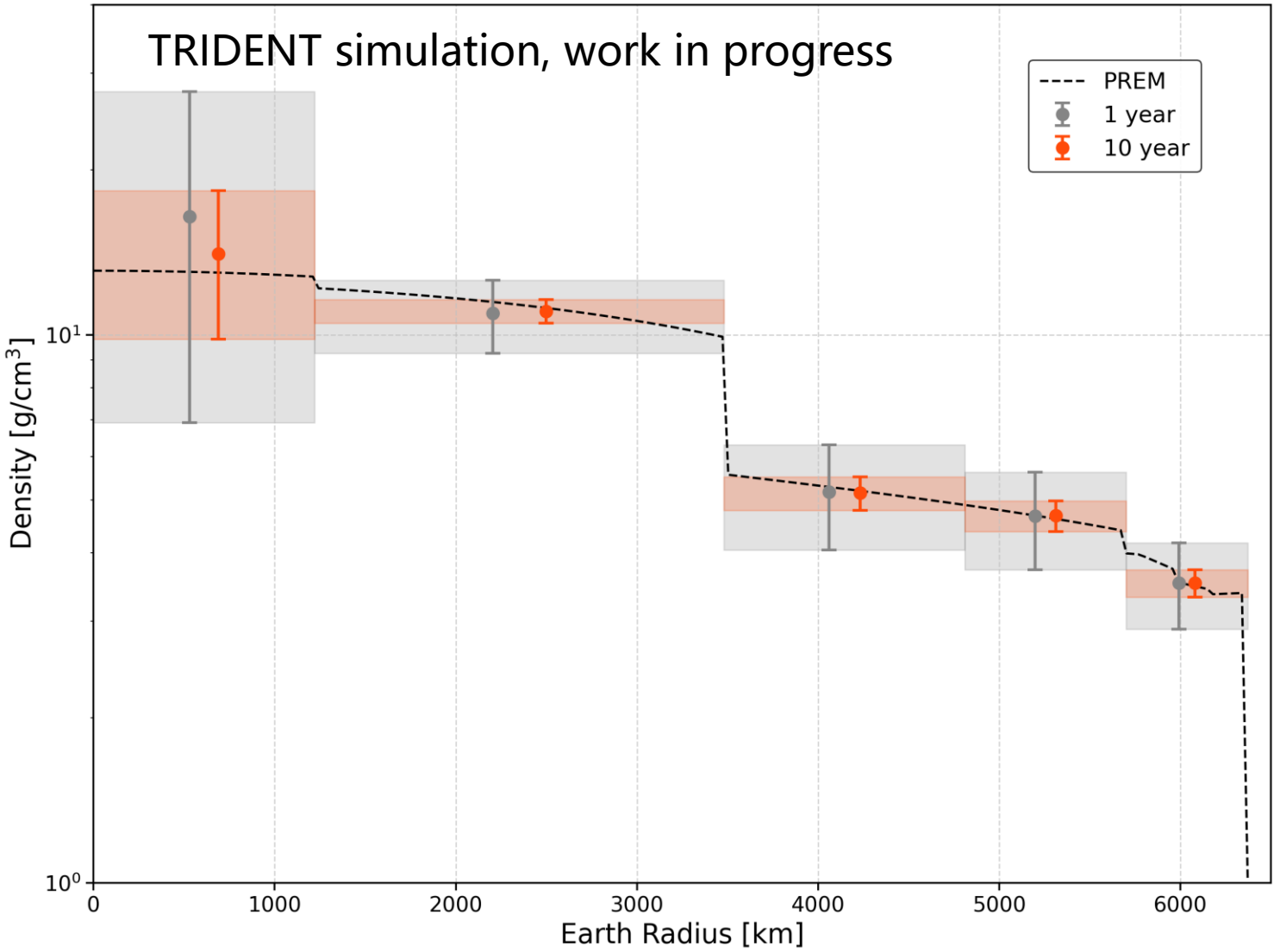
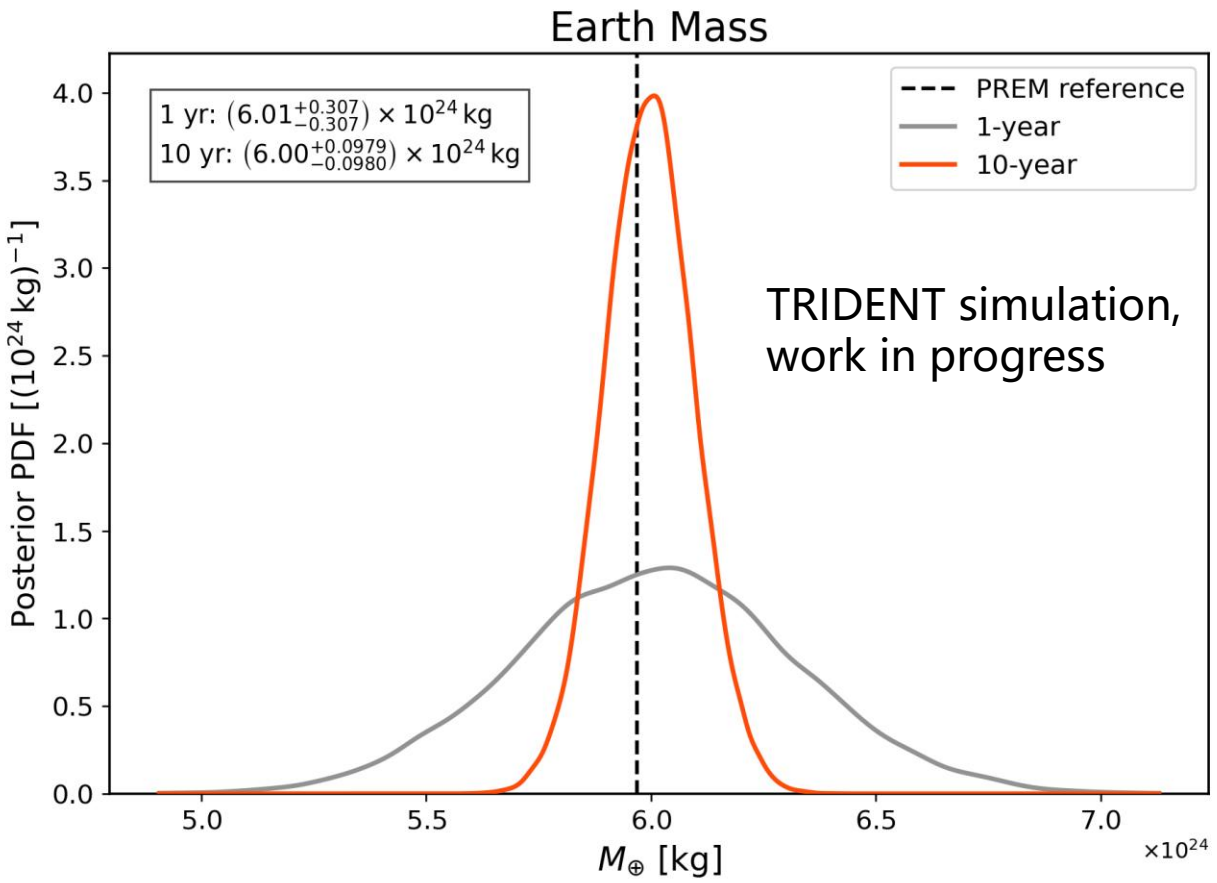
Results

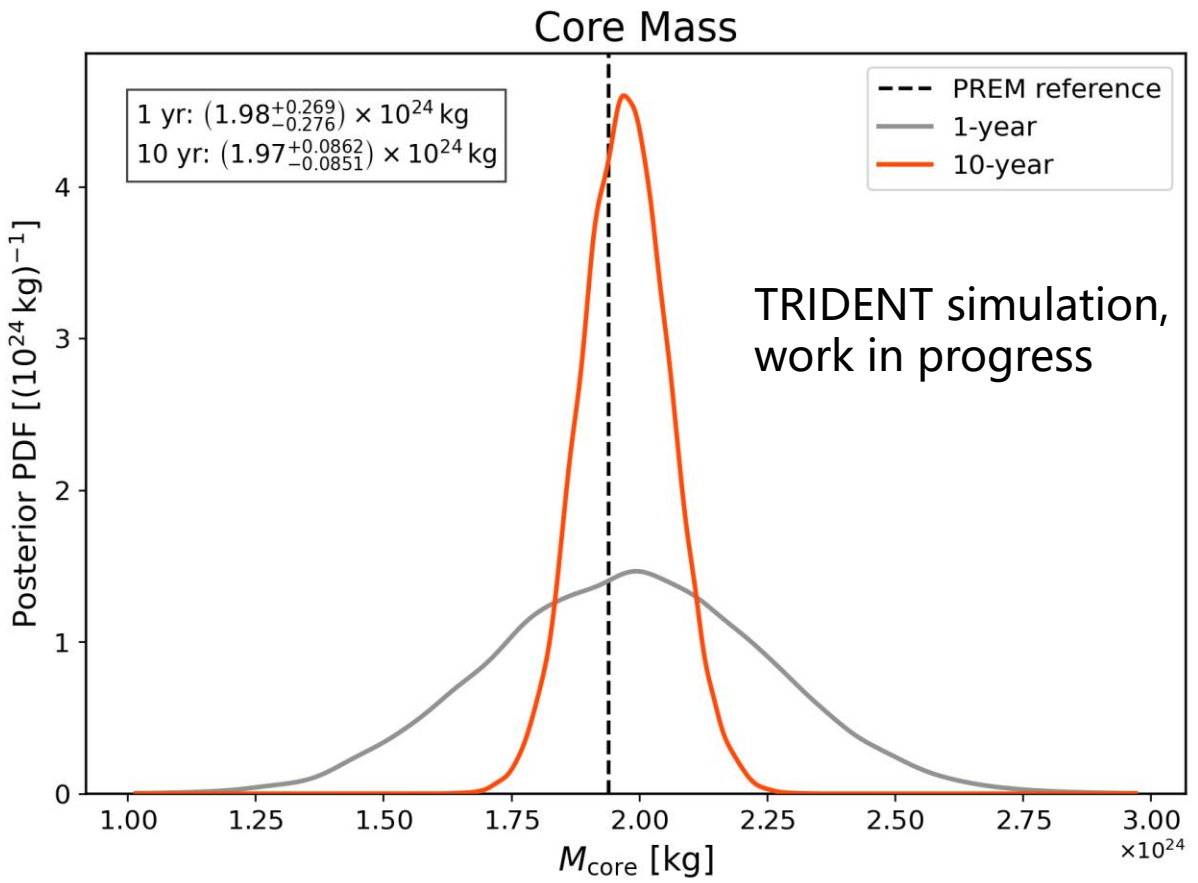


- **With enough statistics TRIDENT expects to reconstruct a multi-layer Earth density profile.**
- **Most Earth layers can be well constrained, while the innermost region remains the most challenging.**
- **Neutrino absorption enables layer-by-layer constraints on the Earth's internal density.**

Results

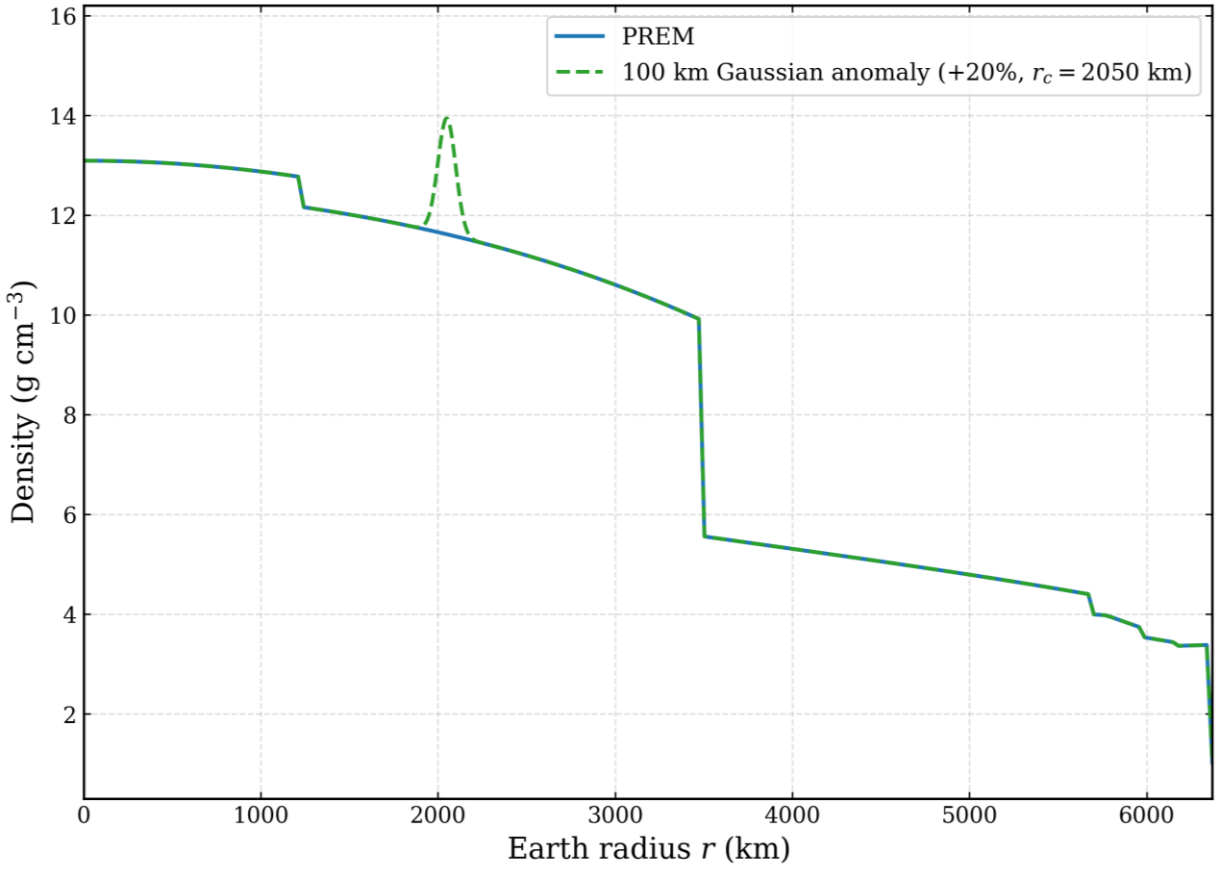
Neutrino tomography also provides an independent measurement of the Earth and core masses



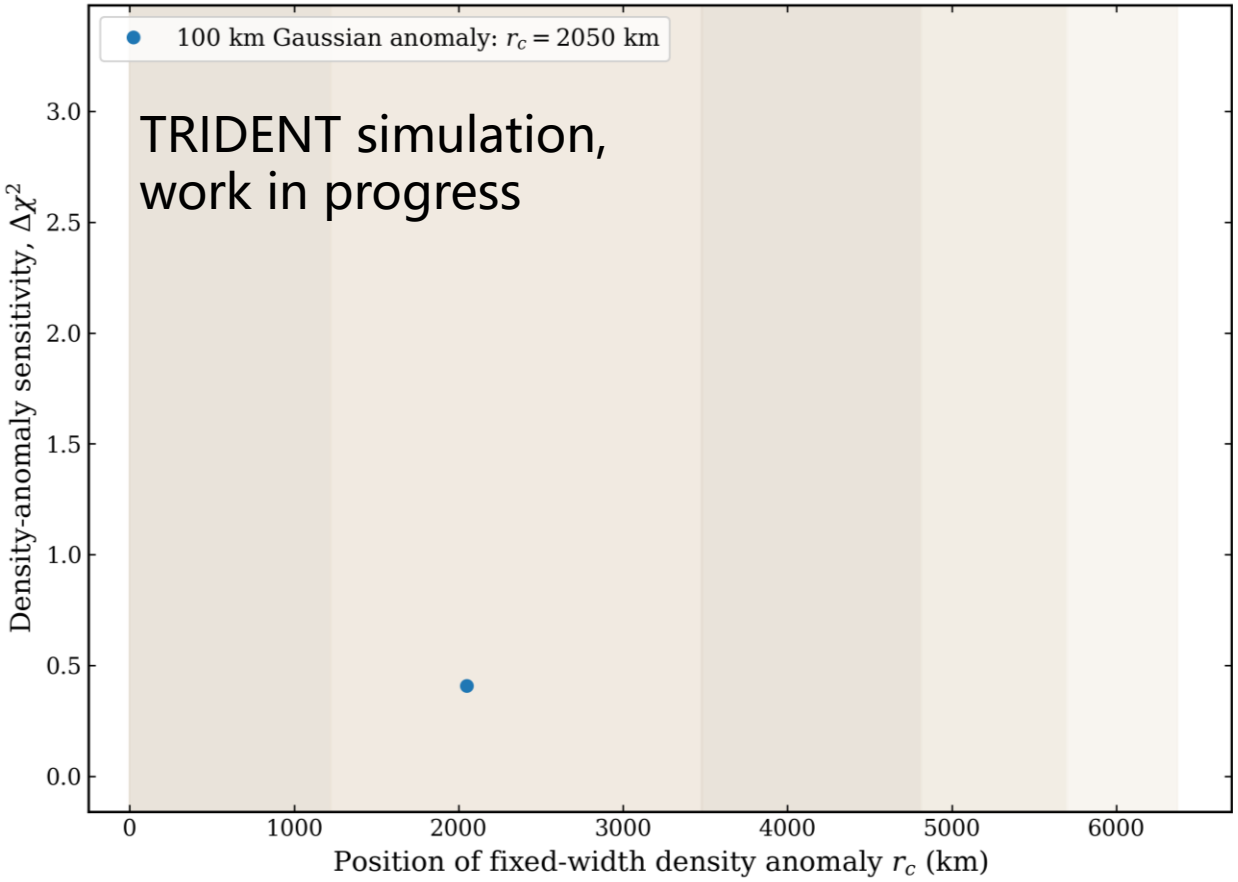


Sensitivity to Density Anomalies

What if the Earth contains a localized density anomaly?



Sensitivity for TRIDENT-10y to localized density anomalies



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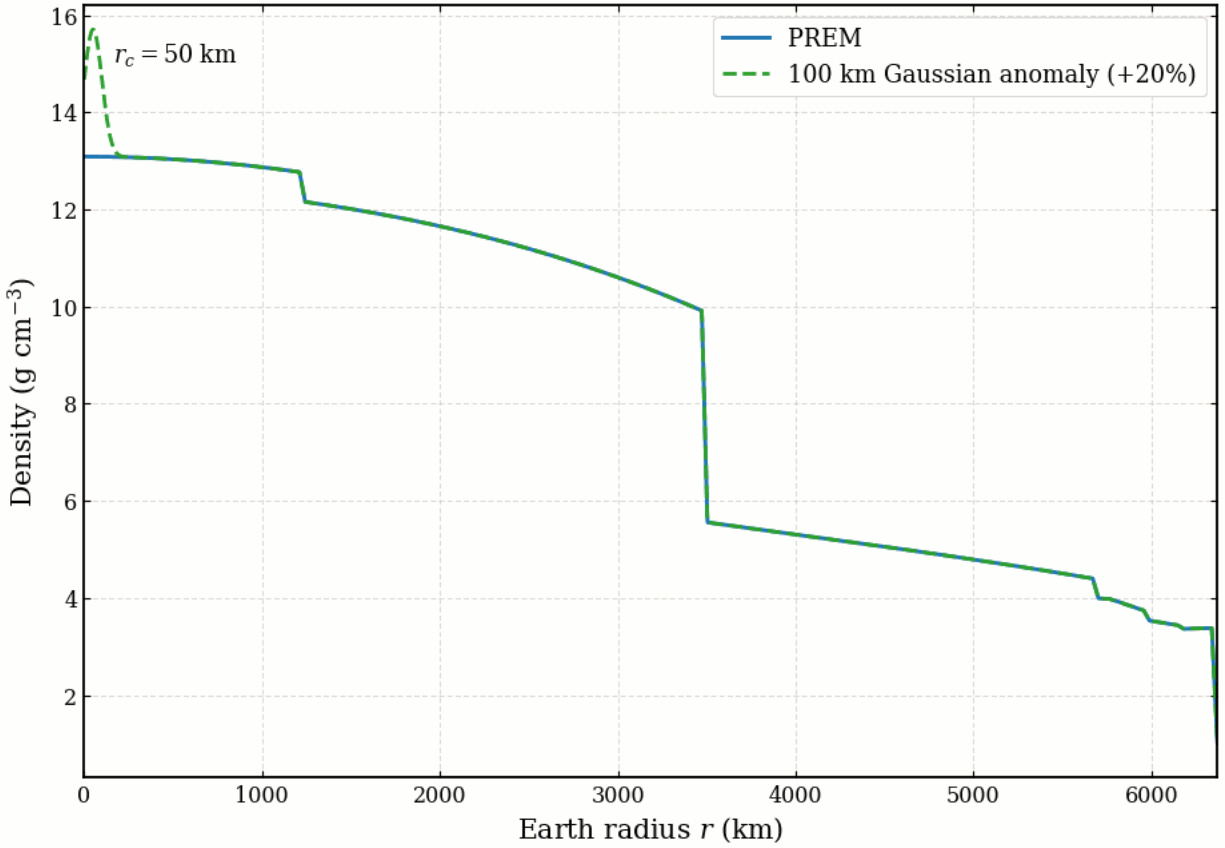

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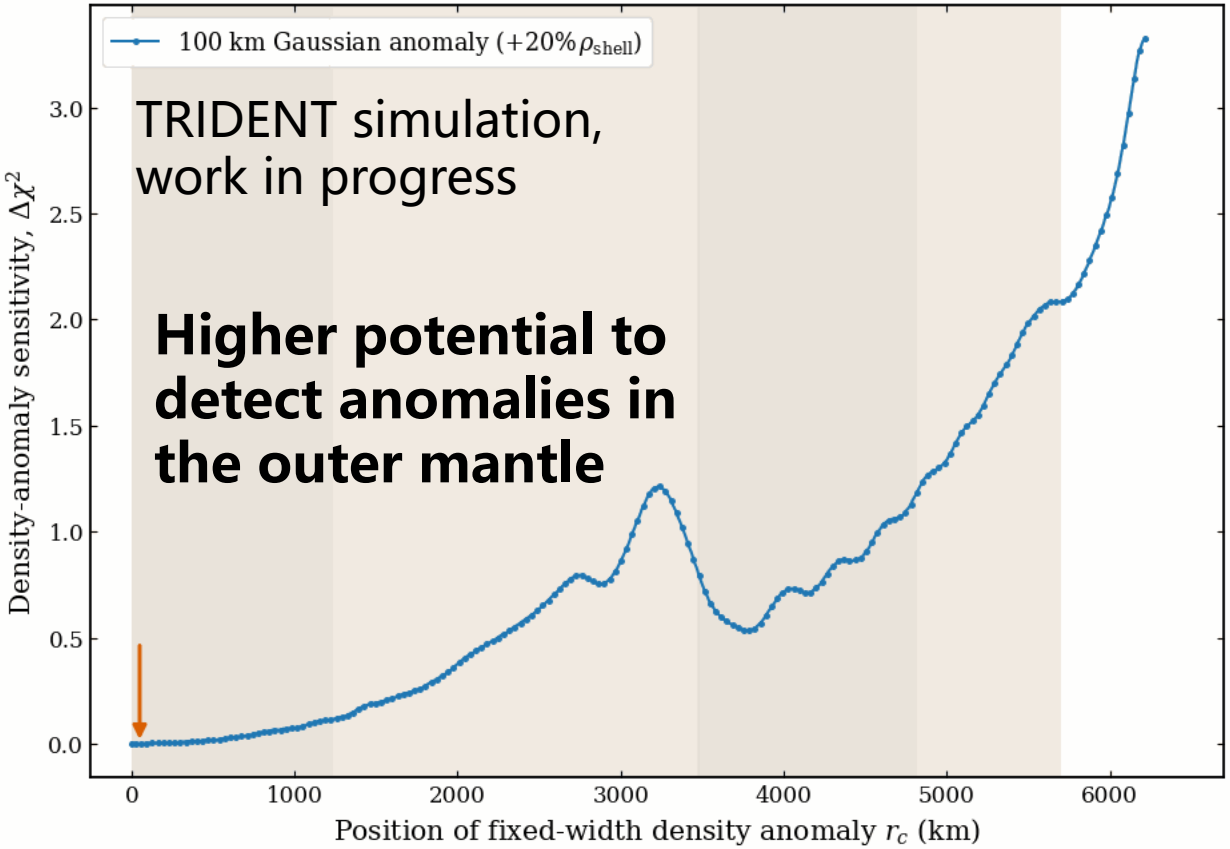


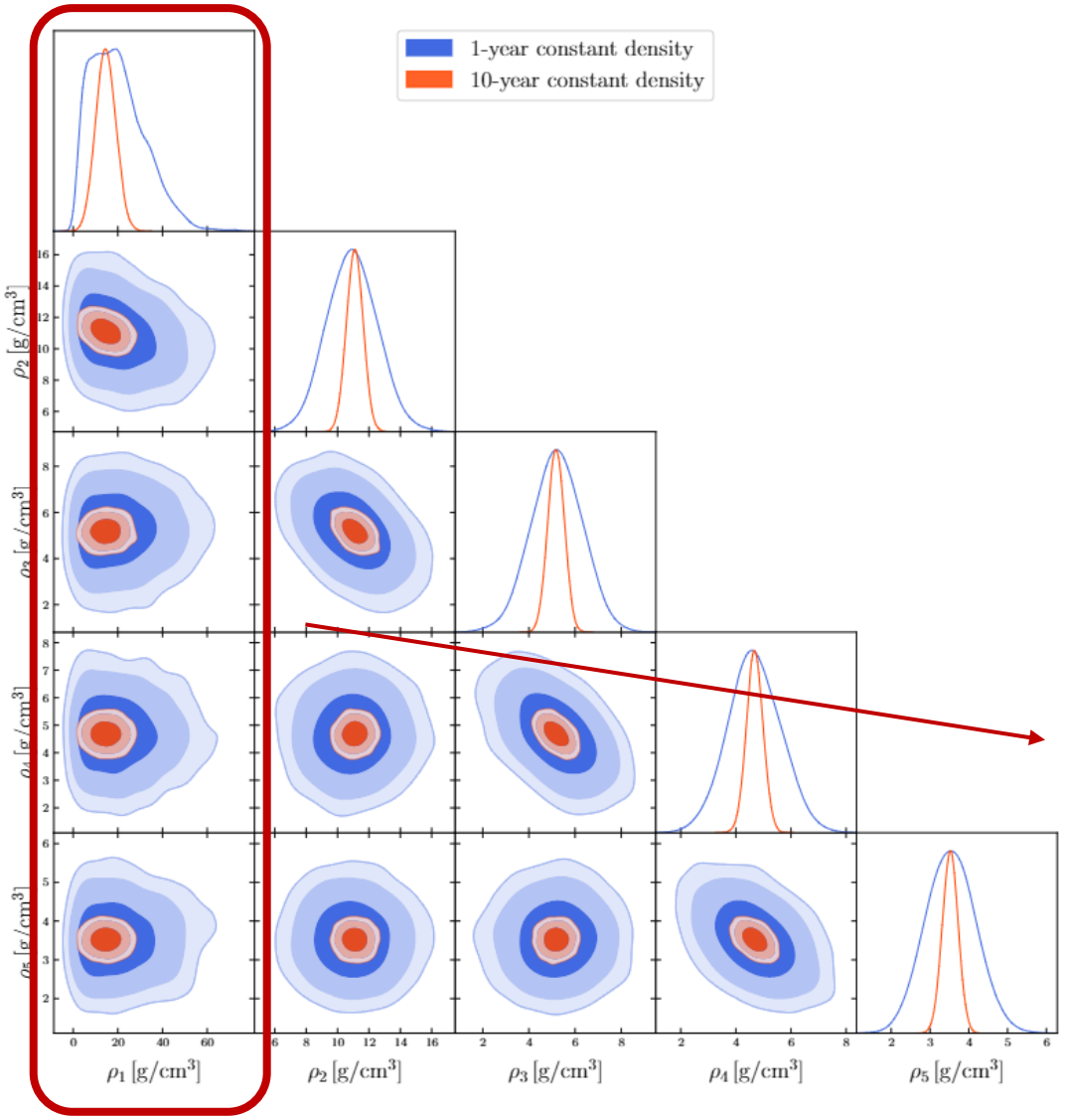
Summary

- Neutrino attenuation **directly probes matter density** through the weak interaction, independently of conventional geophysical observables.
- TRIDENT can **constrain multiple radial density layers**, with precision improving continuously as exposure accumulates.
- The same framework can independently constrain global Earth properties and probe localized density anomalies.

Thank you!

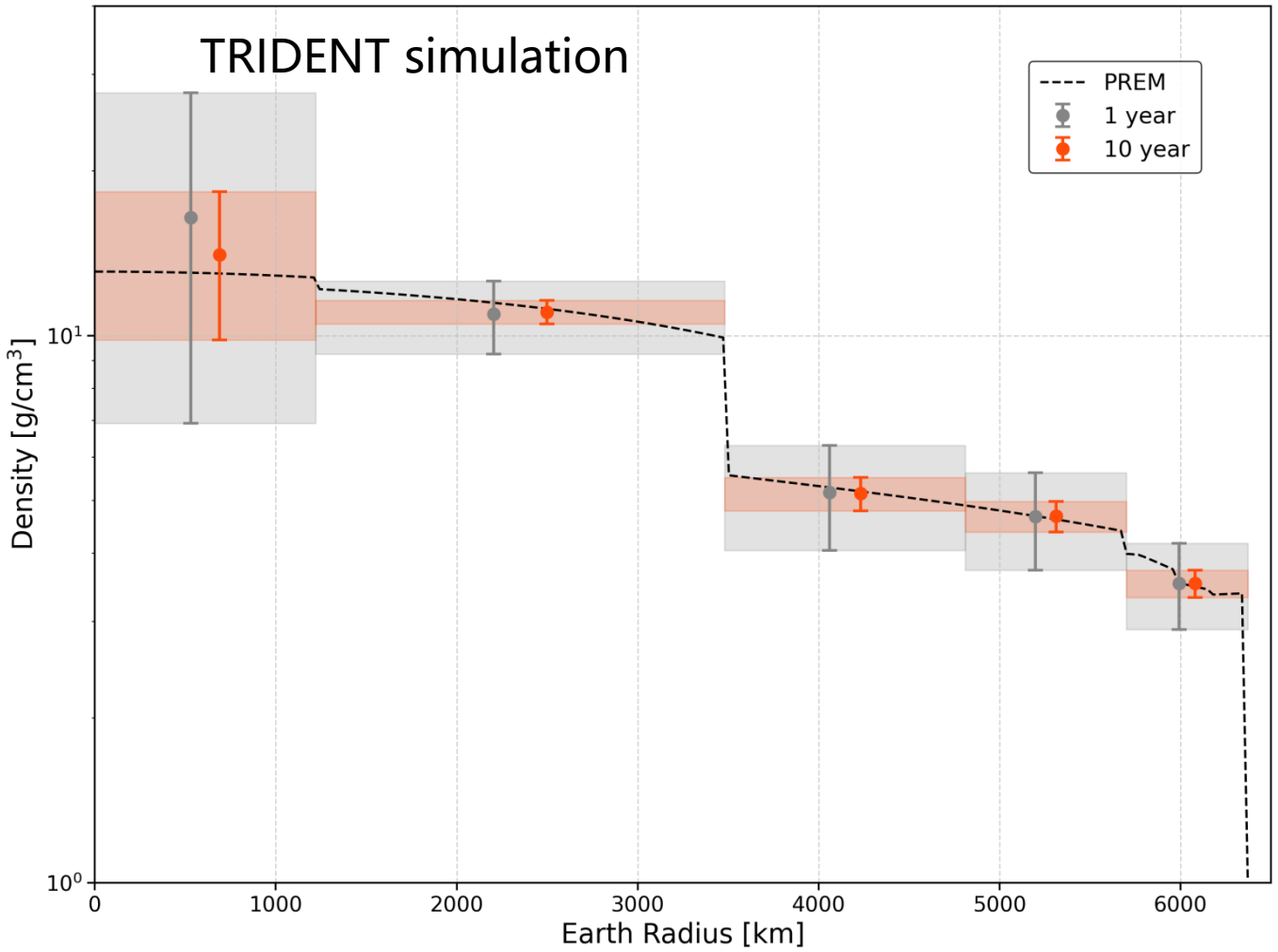
Backup

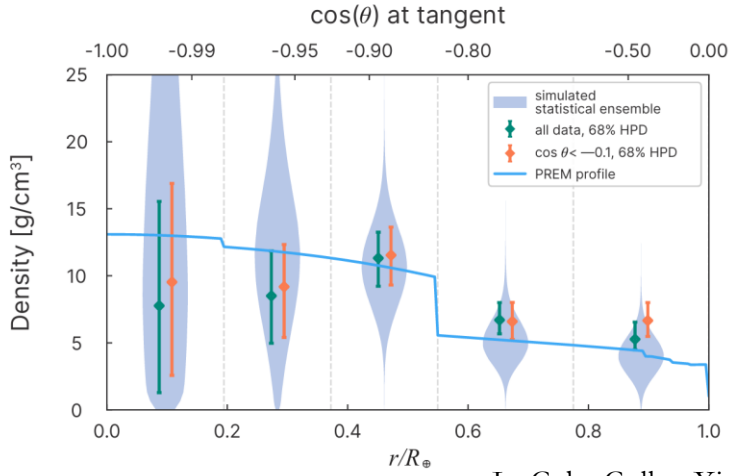
Results from Multinest



- Posterior distributions of the five constant-density layers for 1-year and 10-year exposures.
- Diagonal panels show **marginalized 1D posteriors**; off-diagonal panels show correlations between layer densities.
- The 10-year exposure significantly narrows the allowed parameter space, especially for the outer layers.
- The innermost density remains the least constrained, while clear inter-layer correlations persist.
- **The innermost density is biased high due to the asymmetric prior range**: the large uncertainty extends toward low densities but is truncated at the physical boundary $\rho > 0$

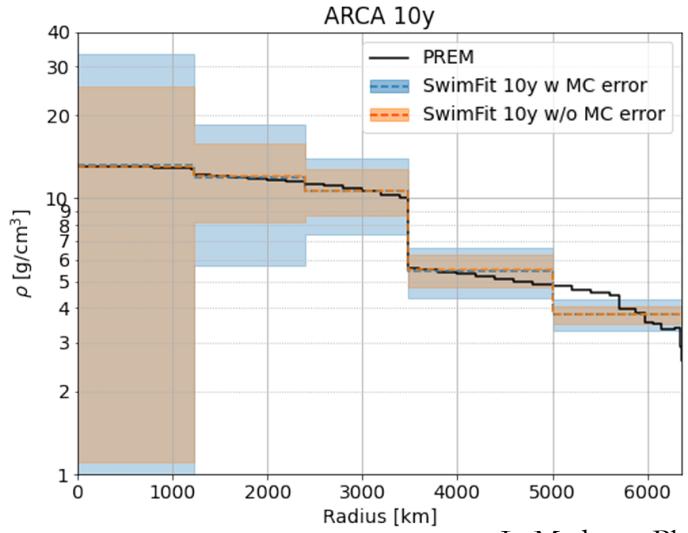
Results Comparing





IceCube results

IceCube Coll. arXiv:2607.02644



KM3NeT results

L. Maderer, Ph. D thesis