Chi-squared Analysis of Solar Neutrino Parameters at DUNE

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Introduction

- **Neutrinos** are the most abundant massive particles in the universe. Trillions pass through us every second but interact so rarely we don't notice. Studying them helps us answer big questions in physics, like why the universe is dominated by matter over antimatter.
- The Deep Underground Neutrino Experiment[1] (**DUNE**) will send a neutrino beam 1300 km from Fermilab to Sanford Lab to study neutrino oscillations.

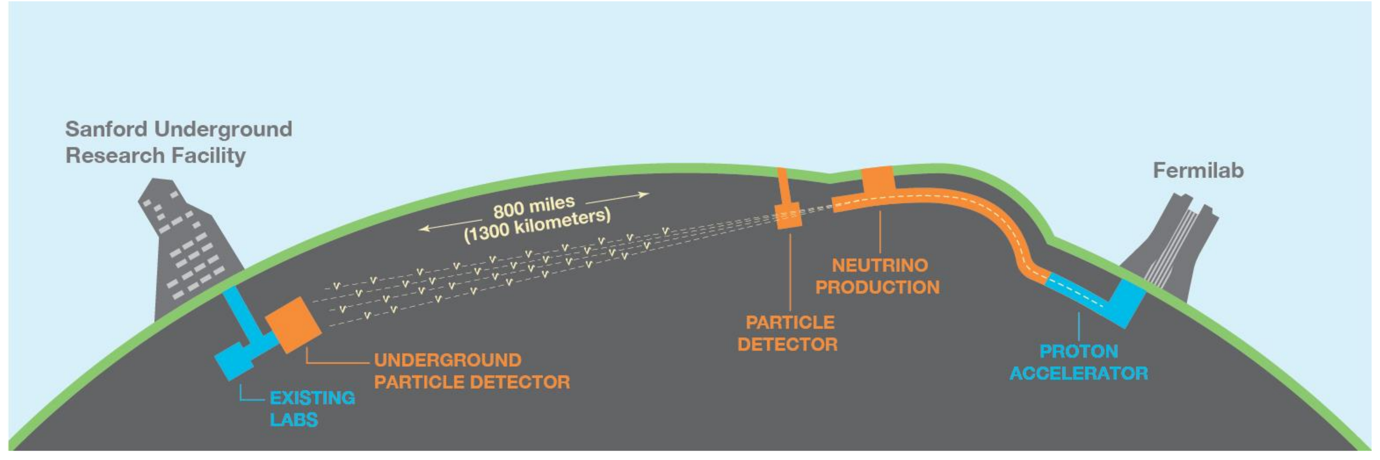


Image credit: DUNE collaboration[1]

- Neutrinos come in **three "flavors"** (electron, muon, tau) and can transform between them as they travel. This discovery provided the first conclusive evidence of physics beyond the Standard Model!
- DUNE is optimized to measure oscillation parameters linked to atmospheric neutrinos. In this project, we tested how sensitive it could also be to **solar neutrino parameters** (θ_{12}, Δm^2_{21}).
- We calculated the expected **number of detections** with different assumptions and compared them using a **chi-squared test.**
- By testing how solar parameters affect muon neutrino appearance at DUNE, we can **check whether DUNE's measurements are consistent with solar experiments**. If the data and theory disagree, it could mean there is new physics to discover.

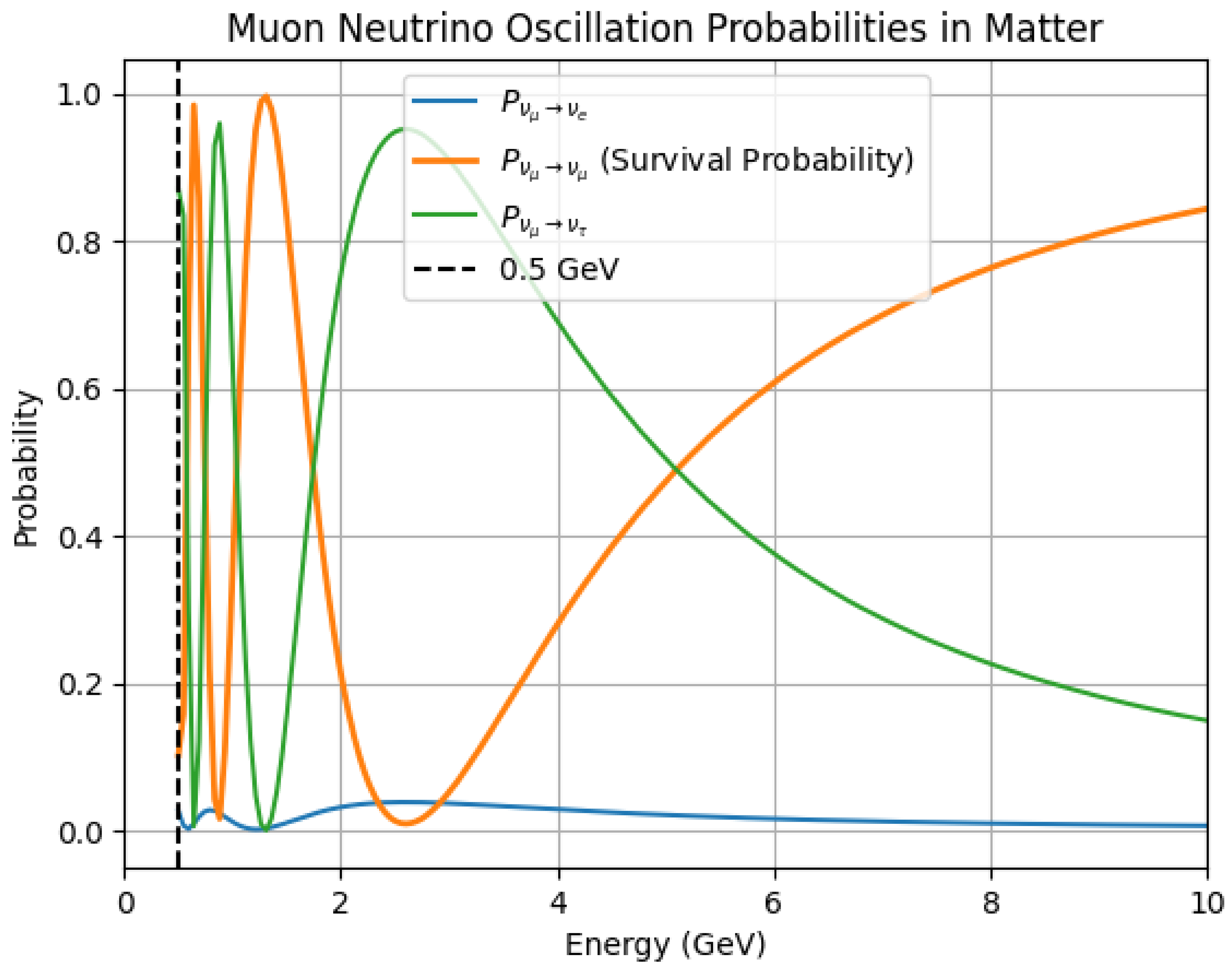
Background

To calculate the expected number of detections we first need to compute the **event spectrum**, Integrating over energy gives the predicted number of events that DUNE would observe:

$$\frac{dN}{dE} = \left(\frac{d\Phi_{\nu_\mu}}{dE} P_{\mu\to\mu} + \frac{d\Phi_{\nu_e}}{dE} P_{e\to\mu}\right)\sigma_\mu$$

- **Differential Neutrino Flux** $\frac{d\Phi_{\nu_\alpha}}{dE}$: The number of neutrinos per unit area, per unit energy.
- **Cross section** σ_μ: Probability of a muon neutrino interacting with the argon in the detector
- **Oscillation probability** $P_{\alpha\to\mu}$: Probability of a neutrino created in flavor α to be detected as a muon neutrino (μ)

Computing the oscillation probability is where we get to vary the parameters we care about. For DUNE, we care about the probability of detecting a muon neutrino after 1300 km of travel. The plot below shows how the **oscillation probability** changes with energy **for a neutrino that starts out as a muon neutrino** traveling 1300 km through the Earth's crust.



DUNE is optimized for atmospheric oscillations.

As expected, it shows **little sensitivity to solar parameters** but testing them provides a valuable consistency check with other experiments.

Future work will include accounting for detector effects like noise and energy resolution, we also want to explore the χ^2 dependence on θ_{12} in more detail.

Learn more

Acknowledgements and references

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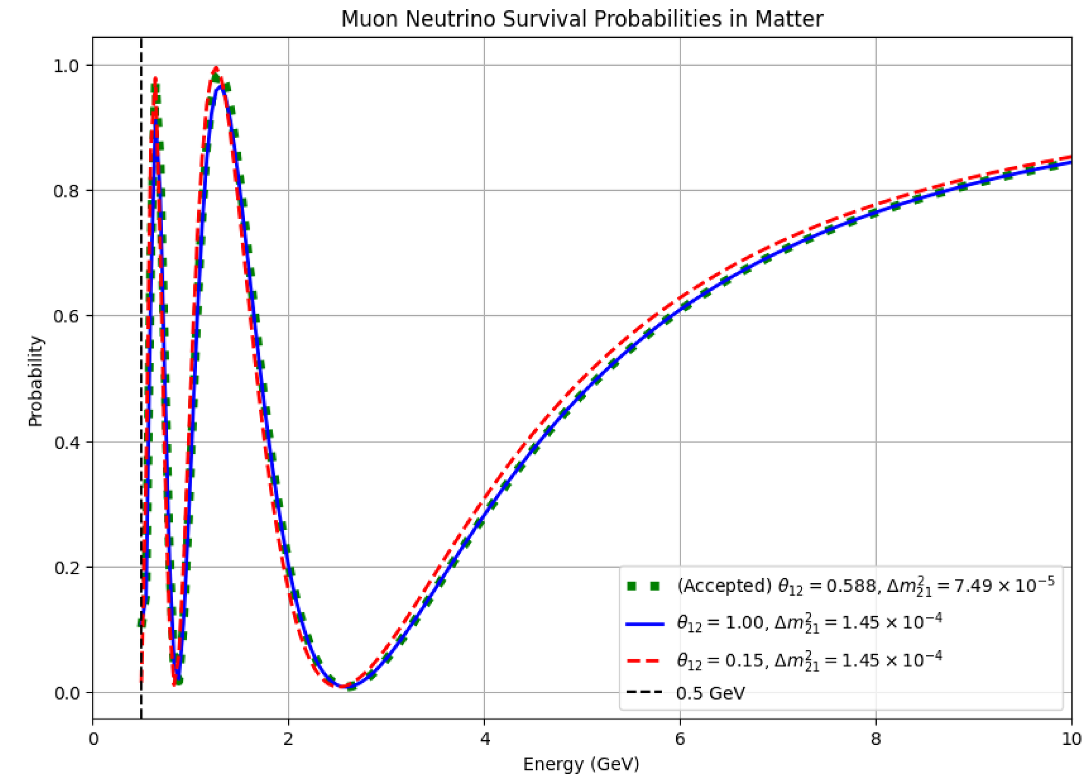
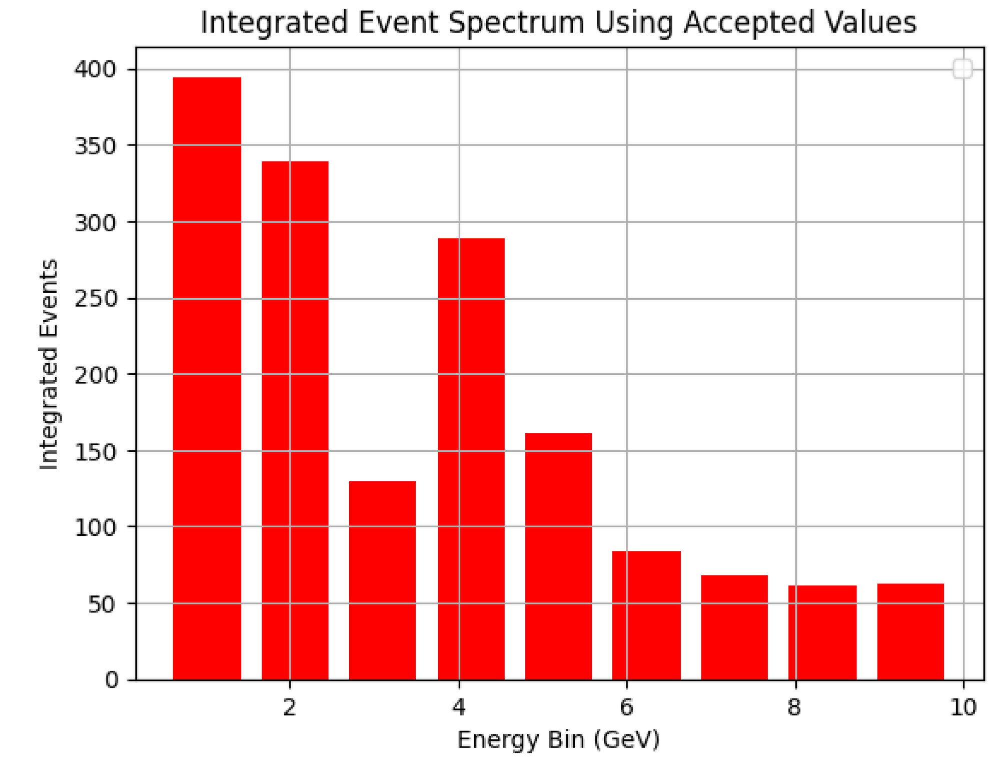
The plot below shows survival probabilities for a neutrino starting as a muon neutrino, **with different solar parameter values compared to the accepted ones**[2] (**θ_{12}** = 0.588 ± 0.013 [rad], **Δm^2_{21}** = (7.49 ± 0.19) × 10^{-5} eV^2).

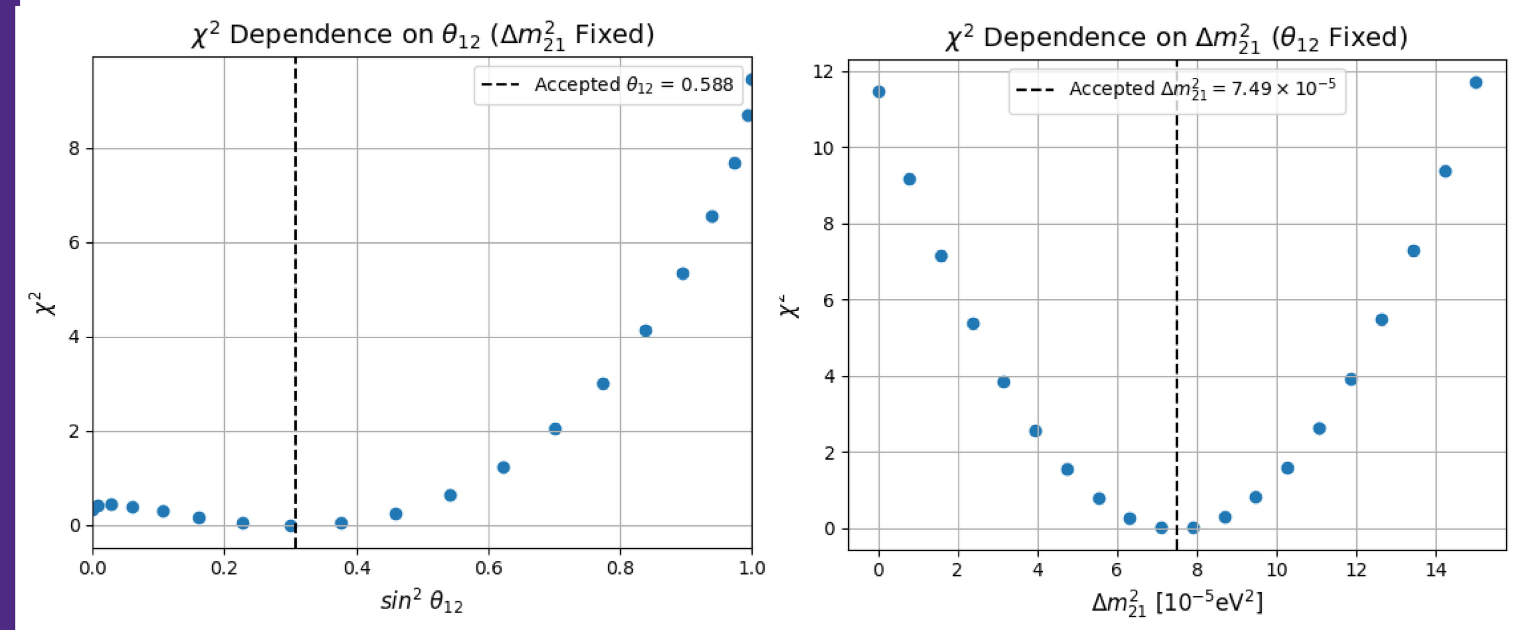


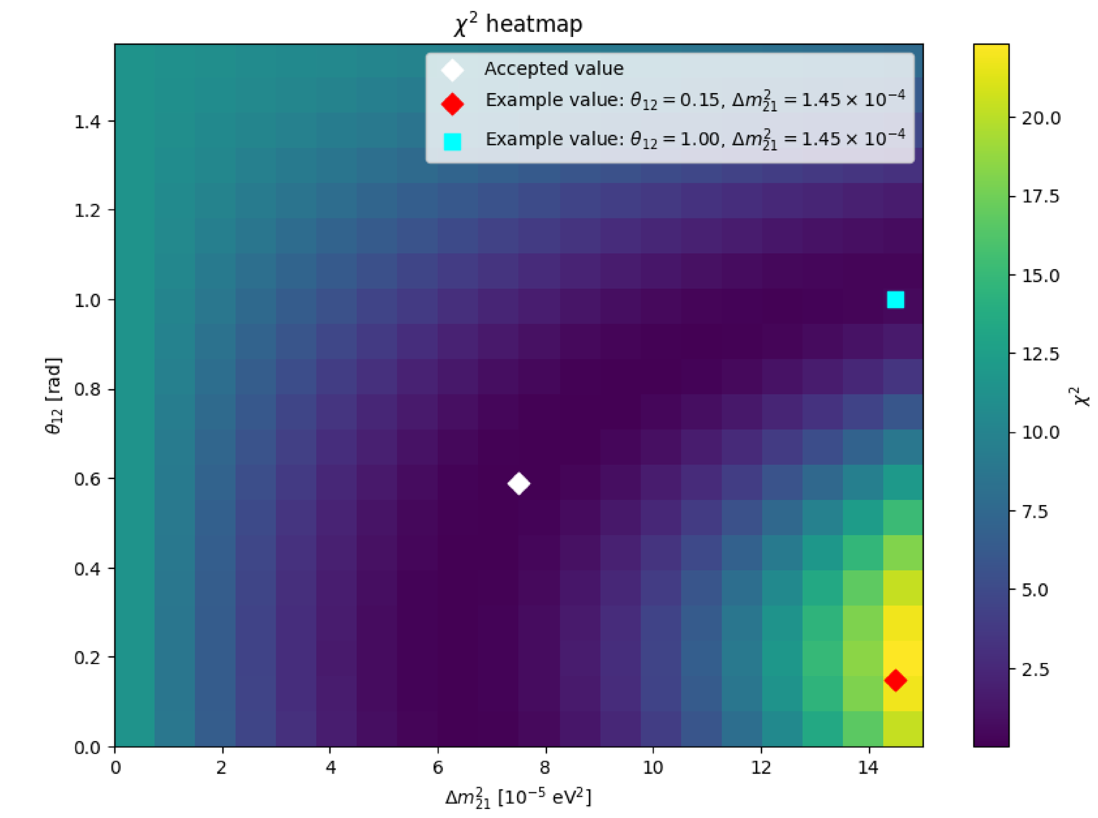
Methods

- **Flux:** Digitized, smoothed, and interpolated from DUNE simulation plots
- **Cross Section:** Taken from GLoBES[3,4] tables for muon neutrinos on argon, scaled by 40 kt detector size.
- **Oscillation Probability:** Computed numerically at 1300 km using SciPy ODE solver.
- **Event Spectrum:** Combined flux, cross section, and oscillation probability, then binned events for χ^2 analysis.



Preliminary Results





The **Chi-squared** analysis shows **weak sensitivity** of DUNE to solar parameters