

Long Baseline Project

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Problem Statement

- Design a long baseline neutrino experiment
- Limitations:
 - 2MW neutrino beam located at UCSB
 - Far detector must be on Earth
 - Only 1 near detector allowed
 - 10 years of runtime
 - Should be legally distinct from DUNE

Deep

Deep Underground

Deep

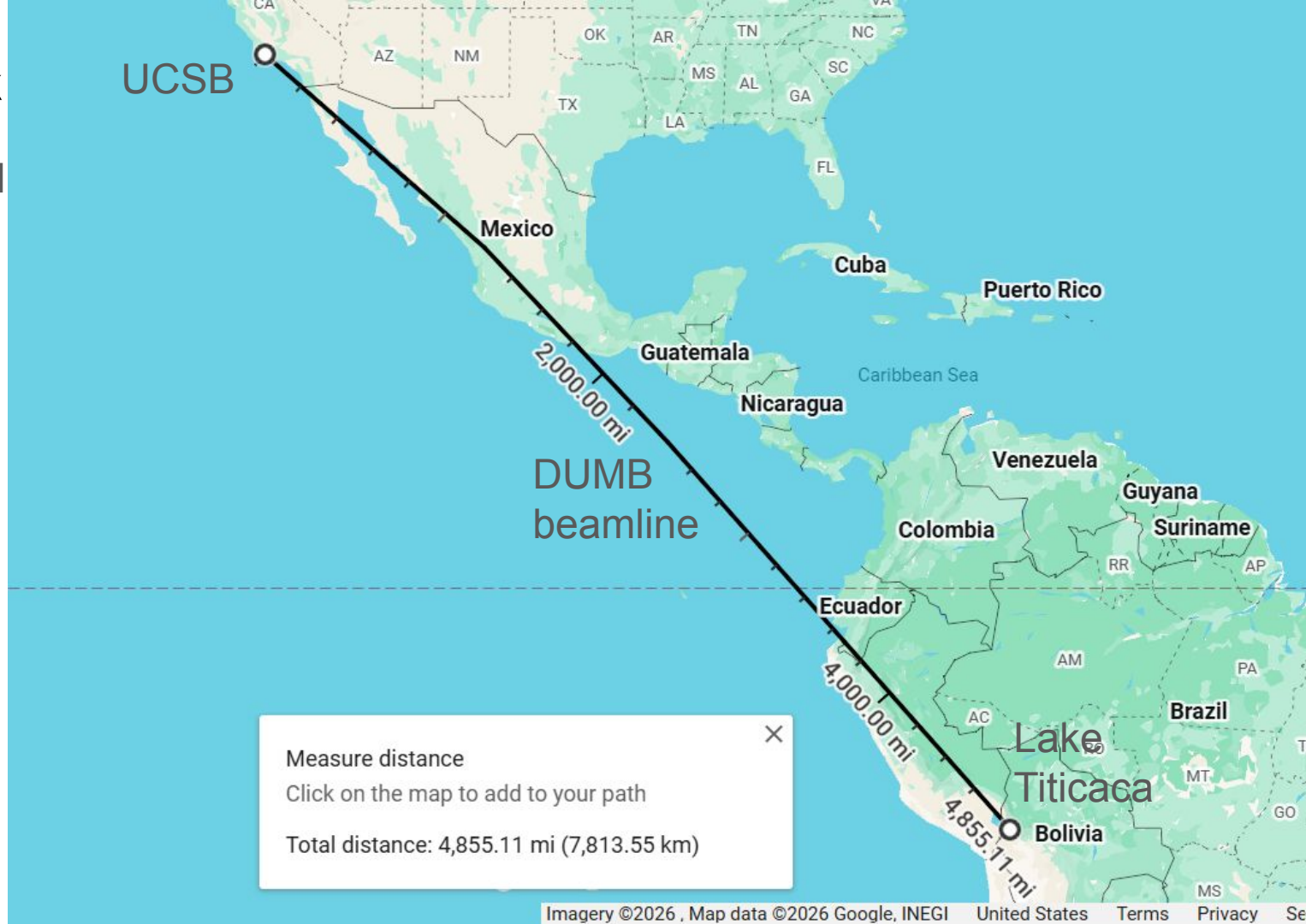
Underground

Mega

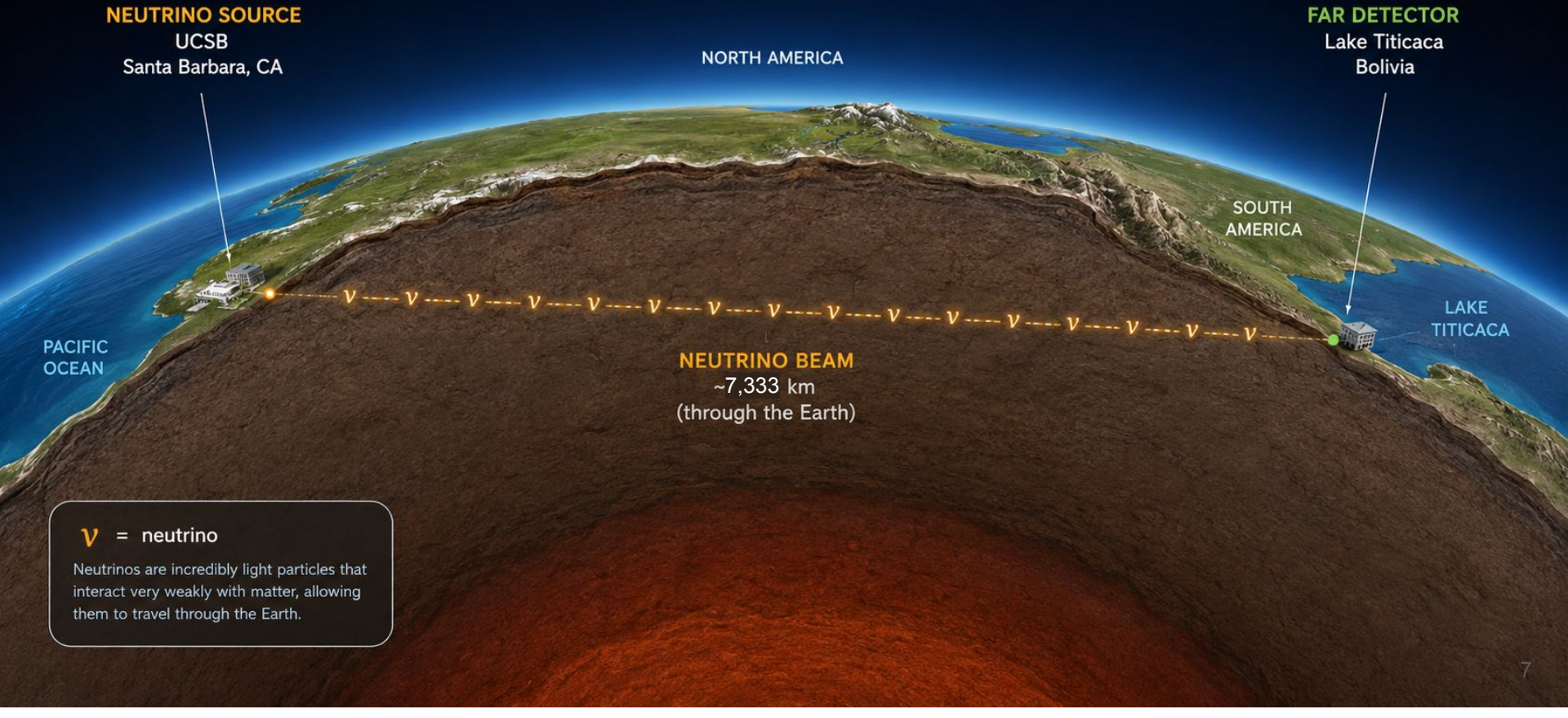
BOONE
BOONE

Click

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Deep Underground MegaBooNE (DUMB) UCSB (Santa Barbara, CA) to Lake Titicaca, Bolivia



Near Detector Facility:

- **A**bsurdly **RR**adioactive **A**ll **K**nowing **I**nstitute of **S**tudy
- Replace the current Charles T. Munger Physics Residence

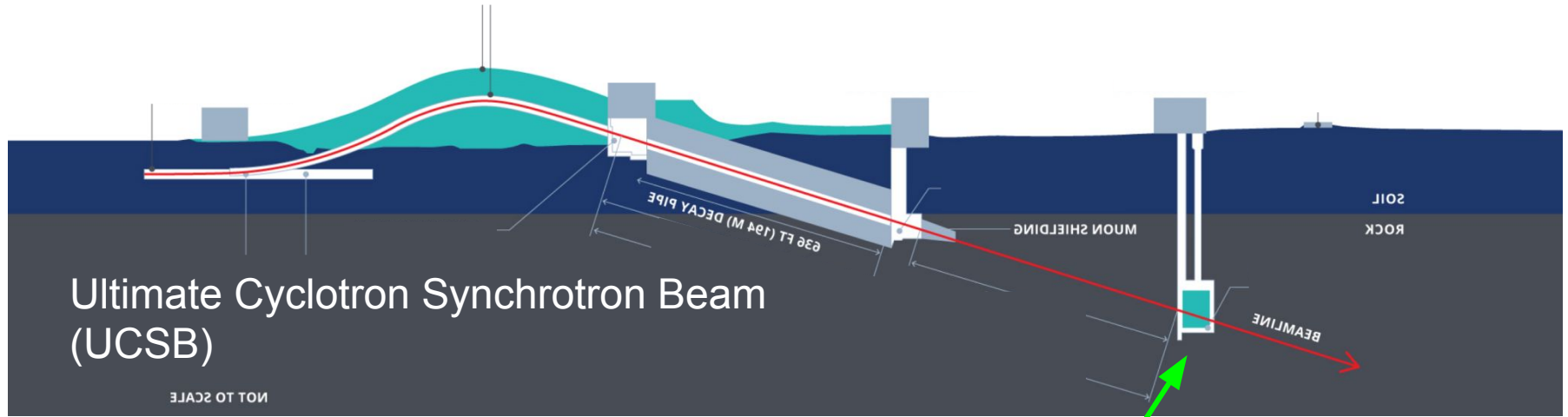


Near Detector Facility:

- Absurdly RRadioactive All KNowing IInstitute of SStudy
- Replace the current Charles T. Munger Physics Residence
- Physics Director:
 - David
 - And
 - Very
 - Into
 - Detectors



Absurdly RRadioactive All KNowing IInstitute of SStudy



Zero Energy Near Detector At Your Apartment (ZENDAYA)



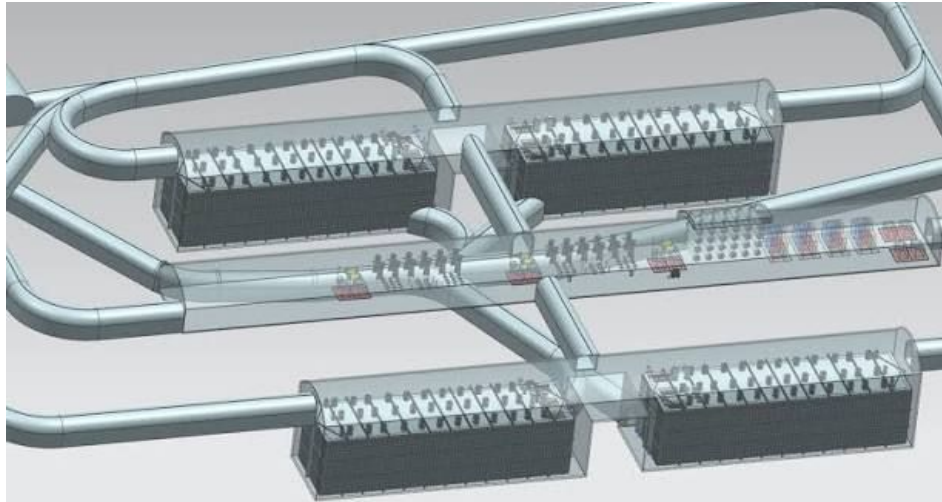
Far Detector Facility

- Placeholder Argon Underground Laboratory
- Located on the southern shore of Lake Titicaca, Bolivia
 - Near the town of Quehuaya



Far Detector Facility

- Placeholder Argon Underground Laboratory
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×60

Massive
Underground
Argon
Detector
'Deep
In
Basement
(MUAD'DIB)



Basic Facts

Beam power: 2 MW

2×10^{21} POT per year

10 year run time

Off-axis angle: 0.129 degrees

Peak neutrino energy: 12.9 GeV

Baseline: 7333 km

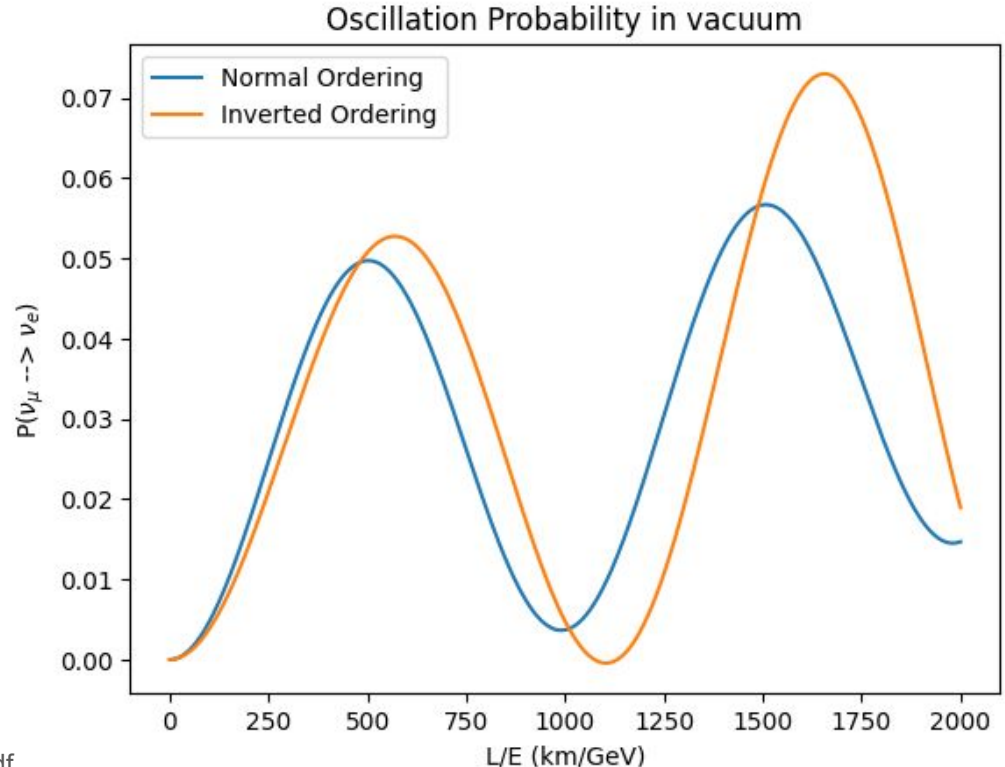


Oscillation probability in vacuum

$$\begin{aligned} P(\nu_\alpha \rightarrow \nu_\beta) = & -4\Re[U_{\alpha 1}U_{\beta 1}^*U_{\alpha 2}^*U_{\beta 2}] \sin^2\left(\frac{\Delta m_{21}^2 L}{4E}\right) \\ & -4\Re[U_{\alpha 1}U_{\beta 1}^*U_{\alpha 3}^*U_{\beta 3}] \sin^2\left(\frac{\Delta m_{31}^2 L}{4E}\right) \\ & -4\Re[U_{\alpha 2}U_{\beta 2}^*U_{\alpha 3}^*U_{\beta 3}] \sin^2\left(\frac{\Delta m_{32}^2 L}{4E}\right) \\ & +8\Im[U_{\alpha 1}U_{\beta 1}^*U_{\alpha 2}^*U_{\beta 2}] \sin\left(\frac{\Delta m_{21}^2 L}{4E}\right) \sin\left(\frac{\Delta m_{31}^2 L}{4E}\right) \sin\left(\frac{\Delta m_{32}^2 L}{4E}\right) \end{aligned}$$

First L/E maximum slightly above 500 km/GeV.

Parameters taken from central values reported in the PDG.



A varying neutrino spectrum

$$\frac{d^2 N}{dE_\nu d\cos\theta} \propto (E_p - E_\pi)^5 \frac{E_\pi E_\nu}{\cos\theta^*}$$

$$E_\pi \approx \frac{m_\pi E_\nu}{E_\nu^*(1 + \cos\theta^*)}$$

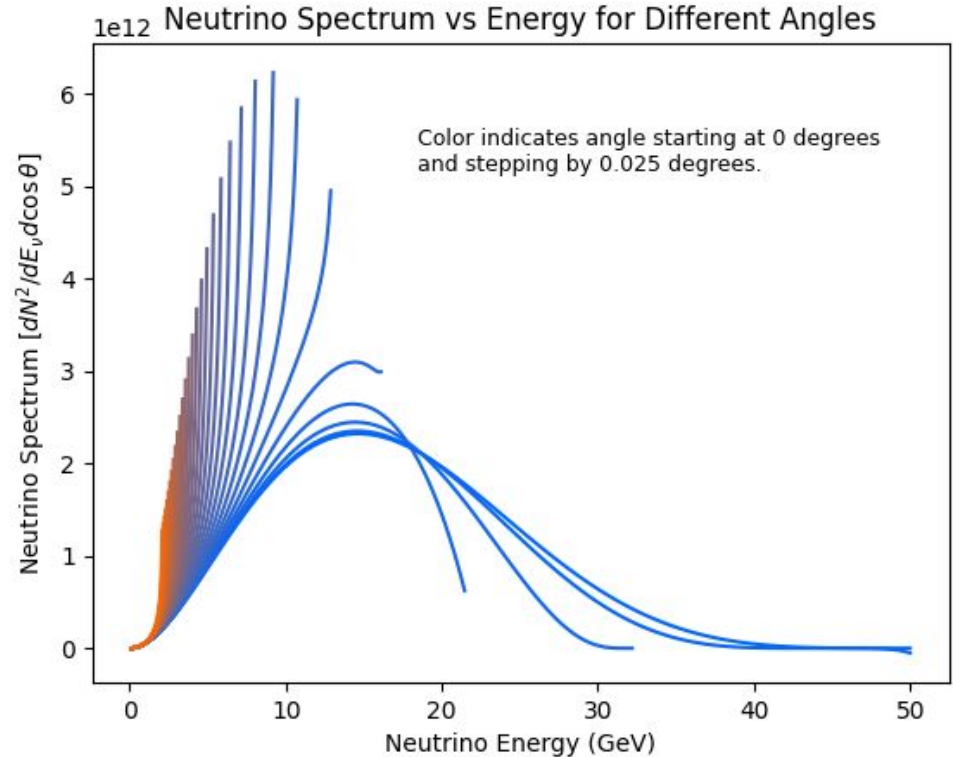
$$\cos\theta^* = \sqrt{1 - \frac{E_\nu^2}{E_\nu^{*2}} \left(\frac{1}{\cos^2\theta} - 1 \right)} \quad E_\nu^* = \frac{m_\pi^2 - m_\mu^2}{2m_\pi} = 29.8 \text{ MeV}$$

Formulas for calculating the neutrino spectrum as a function of the off-axis angle and the proton beam energy: <https://arxiv.org/pdf/hep-ex/0111033>

Off-axis spectra

Note: 2 MW beam corresponds to a proton energy of 196 GeV.

Picking off-axis angle corresponds to picking the peak neutrino energy!



Oscillation through matter

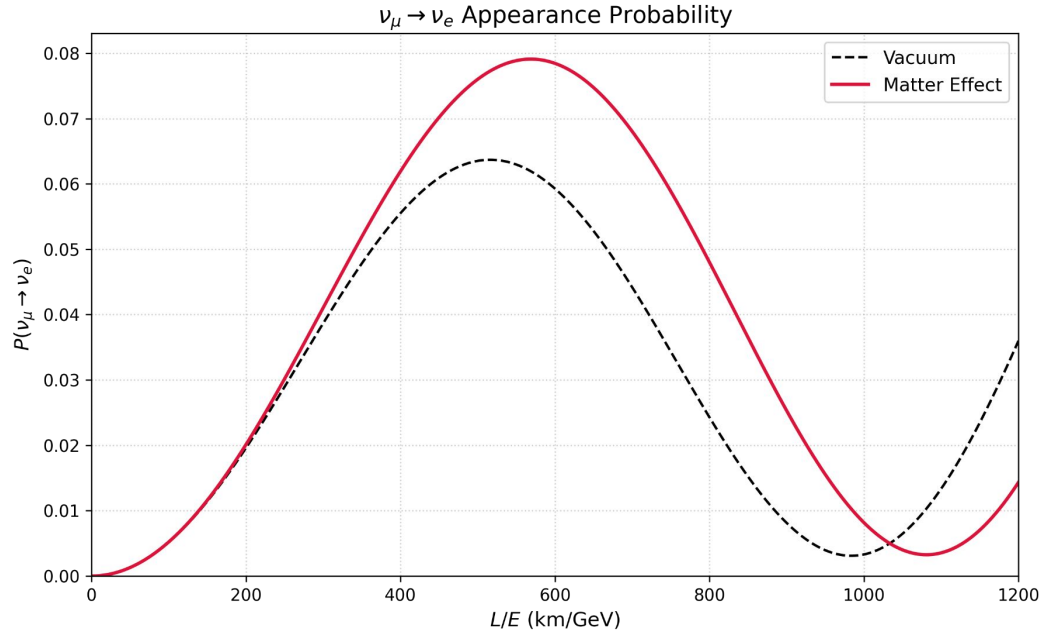
The appearance probability for neutrinos traveling through a reasonably uniform medium

$$\begin{aligned} P(\nu_\mu \rightarrow \nu_e) \simeq & \sin^2 \theta_{23} \sin^2 2\theta_{13} \frac{\sin^2(\Delta_{31} - aL)}{(\Delta_{31} - aL)^2} \Delta_{31}^2 \\ & + \sin 2\theta_{23} \sin 2\theta_{13} \sin 2\theta_{12} \frac{\sin(\Delta_{31} - aL)}{(\Delta_{31} - aL)} \Delta_{31} \frac{\sin(aL)}{(aL)} \Delta_{21} \cos(\Delta_{31} + \delta_{CP}) \\ & + \cos^2 \theta_{23} \sin^2 2\theta_{12} \frac{\sin^2(aL)}{(aL)^2} \Delta_{21}^2 \end{aligned}$$

where, $\Delta_{ij} = \Delta m_{ij}^2 L / 4E$ $a = G_F N_e / \sqrt{2}$

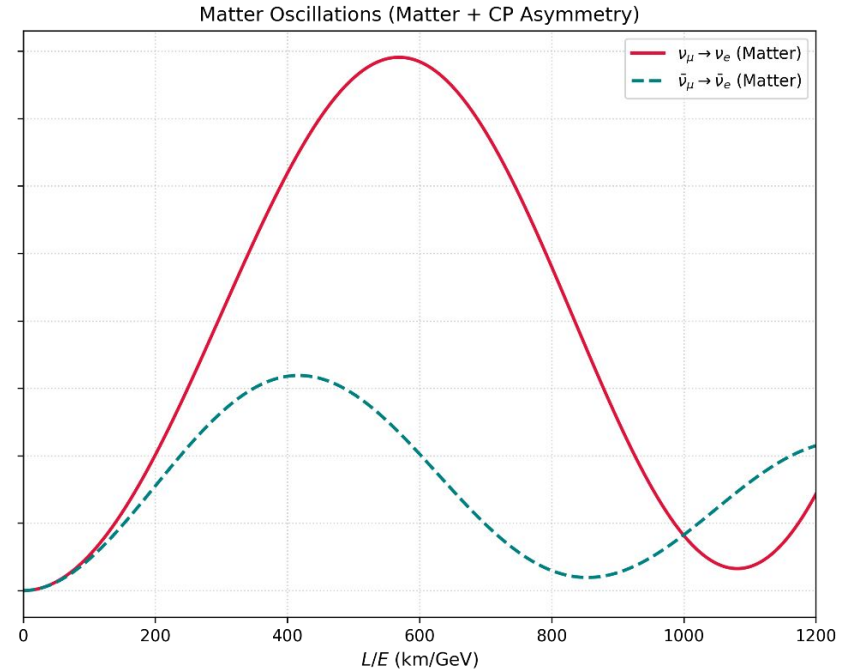
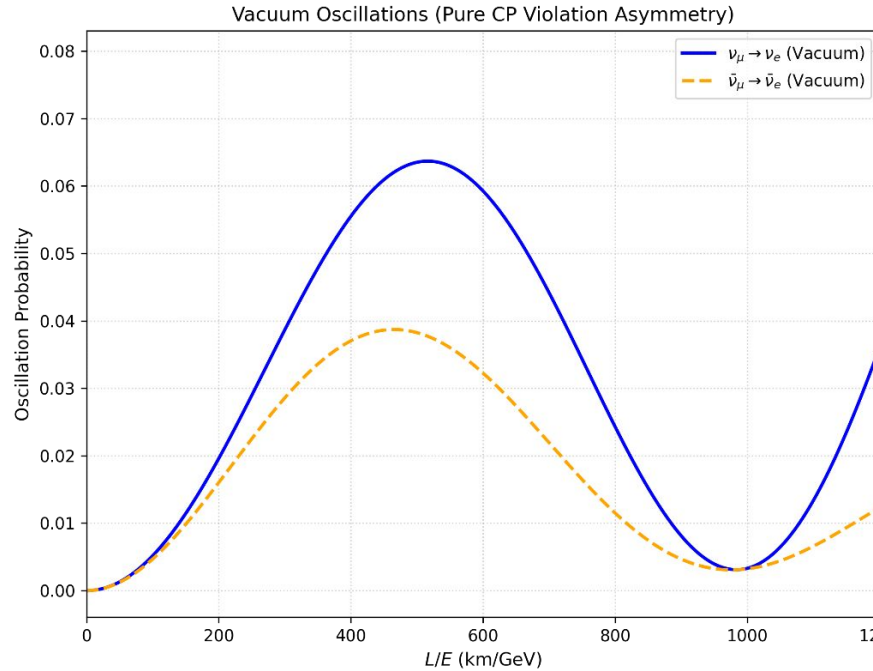
G_F is the Fermi constant
and N_e is the number
density of electrons in the
medium

Finding L/E of first maximum in matter



Matter effect shifts first oscillation maximum

Finding L/E of first maximum in matter

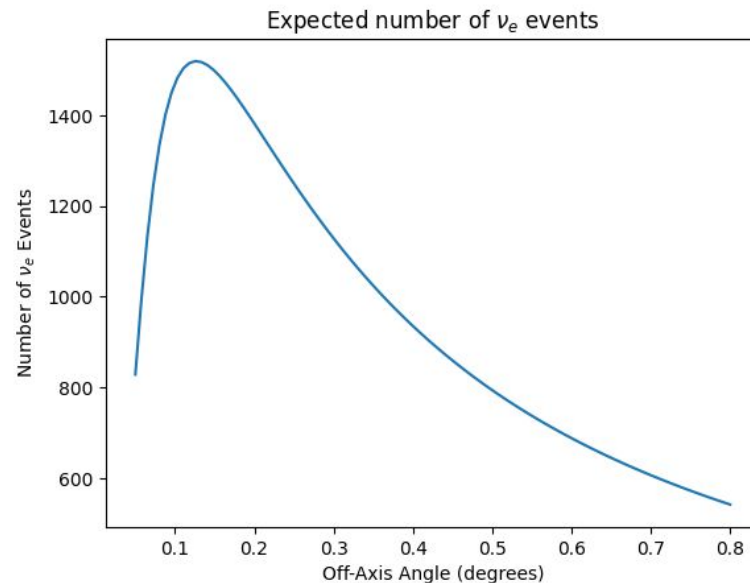


Expected number of events

DUNE expecting ~ 1400 ν_e events in 3.5 years [<https://cds.cern.ch/record/2709272/files/pdf.pdf>]

DUNE is on-axis, baseline $L=1300\text{km}$

Peaked at around $\theta = 0.126$ degrees



$$N_{\nu_e} = N_{\nu_e, D} \left(\frac{T}{T_D} \right) \left(\frac{\int d\tilde{E}_\nu \Phi(\theta, \tilde{E}_\nu)}{\int d\tilde{E}_\nu \Phi(\theta = 0^\circ, \tilde{E}_\nu)} \right) \left(\frac{M}{M_D} \right) \left(\frac{L_D}{\text{argmax}(\Phi(\theta, E_\nu)) \frac{L}{E}} \right)^2$$

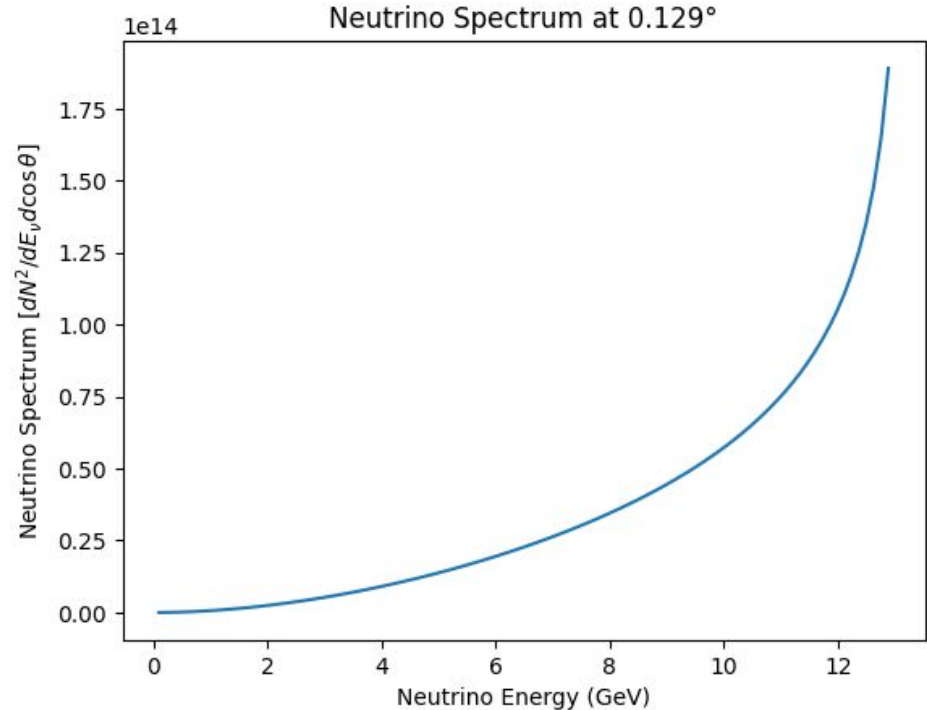
Off-axis angle $\theta = 0.129$ degrees

Neutrino energy peaks at 12.9 GeV

With first oscillation maximum at
568 km/GeV

→ Baseline ~ 7330 km

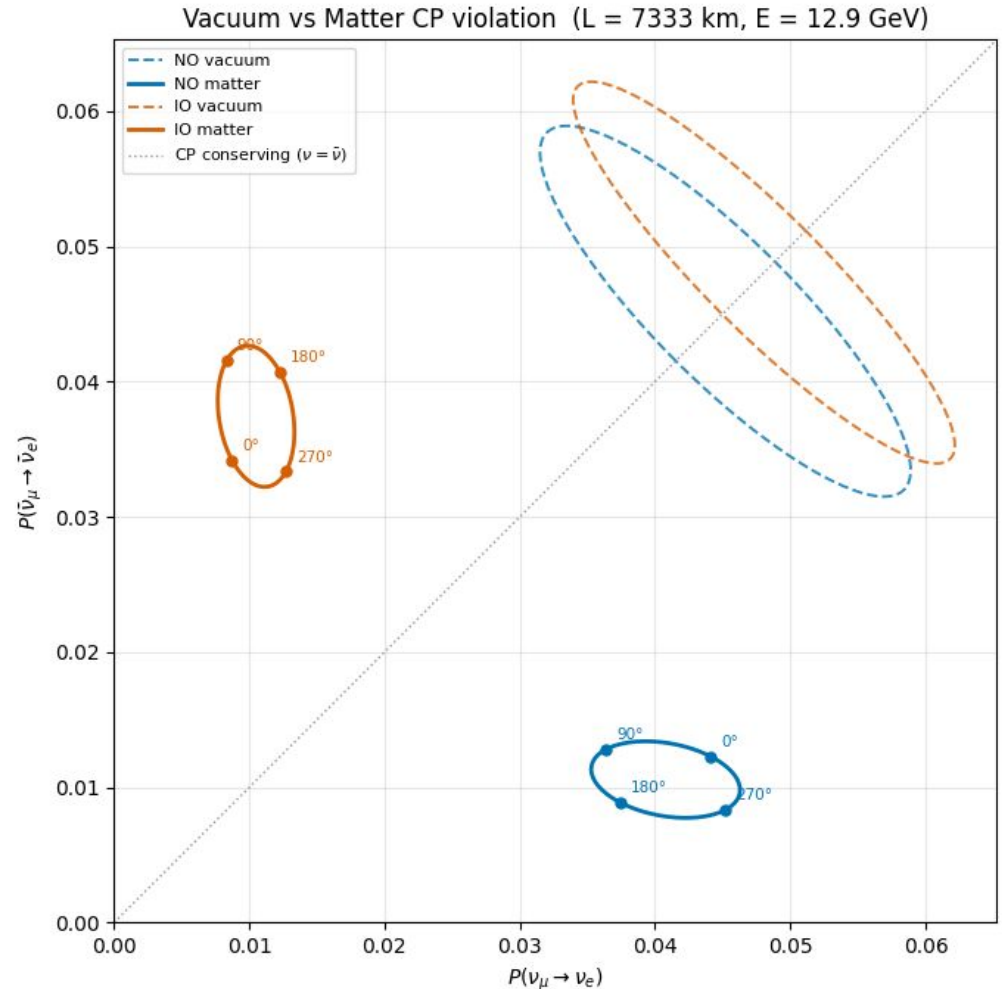
Expect ~ 1510 $\nu_e/\text{anti-}\nu_e$ events and
 ~ 6700 $\nu_\mu/\text{anti-}\nu_\mu$ events



Matter effect separates mass ordering!

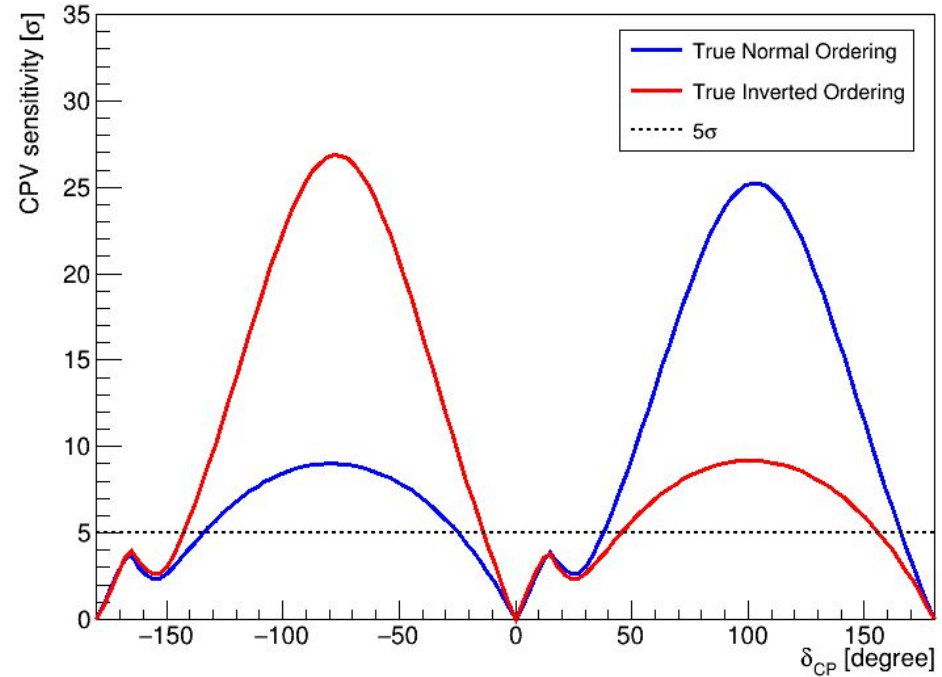
This means DUMB can establish the mass ordering.

Strong sensitivity to CP violation.



δ_{CP} sensitivity

We plan to run 2 years in neutrino mode and 8 years in anti-neutrino mode.



Conclusion

- DUMB is extremely sensitive to both CP violation and the mass ordering.

Specifications:

Beam power: 2 MW

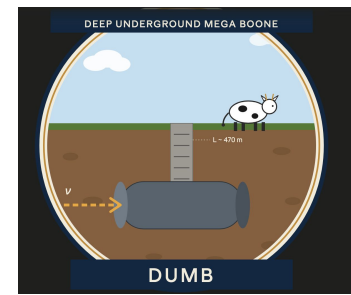
2×10^{21} POT per year

10 year run time

Off-axis angle: 0.129 degrees

Peak neutrino energy: 12.9 GeV

Baseline: 7333 km



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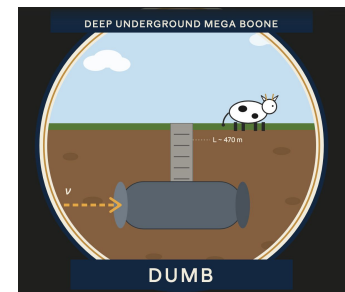
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Conclusion

- DUMB is extremely sensitive to both CP violation and the mass ordering.
- We had a lot of fun with acronyms (legally distinct from DUNE).
- This is probably not a good idea to build (need ~60 times DUNE's far detector).

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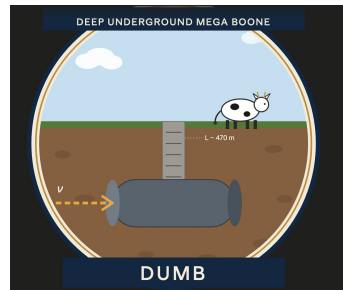
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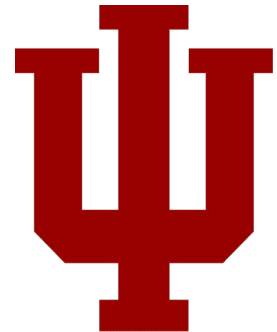
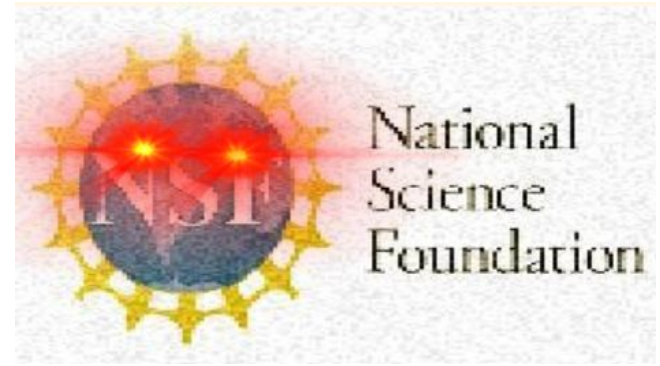
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Acknowledgements

- International Neutrino Summer School
 - David Caratelli
 - Zoya Vallari
- Our advisors
 - Mark Ross-Lonergan
 - Jon Urheim
 - Maria Brigida Brunetti
 -
- UCSB catering and cleaning staff



NEVIS LABORATORIES
COLUMBIA UNIVERSITY

Backup Slides



= Earth
Surface
???

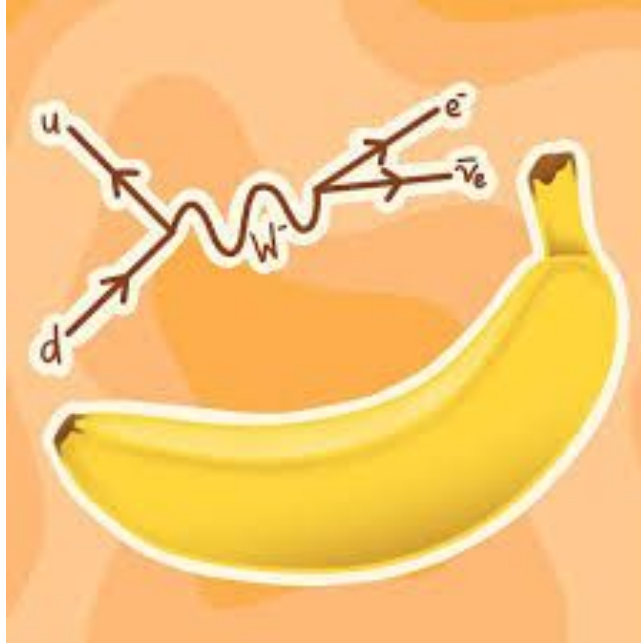




← How to get
around PAUL



Nissan al-gaib



x10000000000000000

Long Baseline Neutrino Experiment

Baseline: 7,333 km

UCSB
Santa Barbara, CA

Far Detector
Lake Titicaca, Bolivia

7,333 km

UCSB
Santa Barbara, CA

Far Detector
Lake Titicaca, Bolivia

Coast Ranges

Rocky Mountains

Great Plains

Central America

Andes Mountains

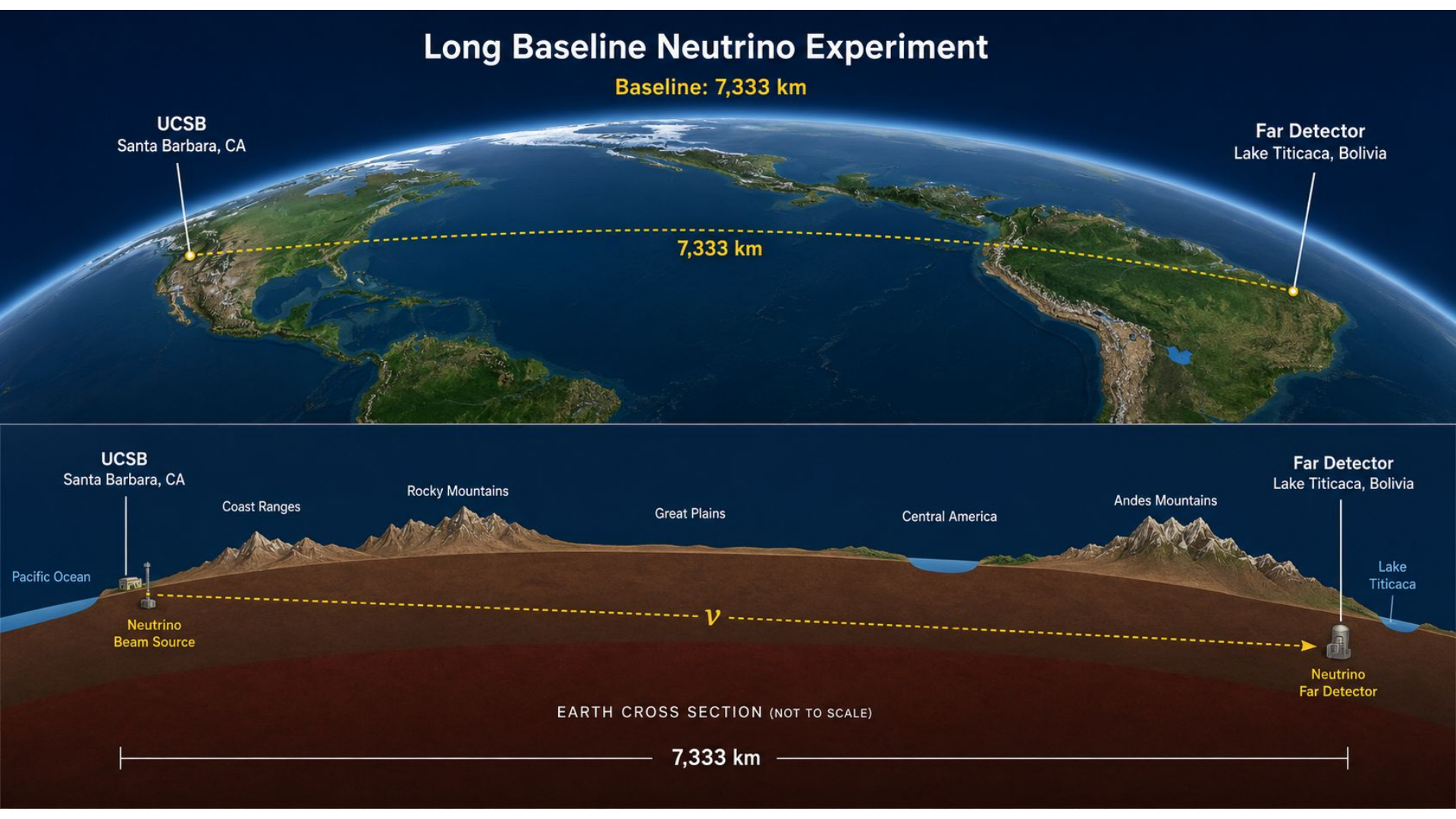
Lake
Titicaca

Neutrino
Beam Source

Neutrino
Far Detector

EARTH CROSS SECTION (NOT TO SCALE)

7,333 km



Declaration of Distinctiveness, Non-Affiliation, and Reservation of Rights Concerning the Deep Underground MegaBooNE ("DUMB") Initiative

WHEREAS, the undersigned proponents have conceived of a hypothetical scientific undertaking denominated the **Deep Underground MegaBooNE** ("DUMB"), solely for purposes of academic discussion, satire, and speculative scientific illustration;

WHEREAS, certain third parties have observed superficial similarities between DUMB and other long-baseline neutrino experiments, including but not limited to projects whose acronyms may coincidentally begin with the letter "D";

NOW, THEREFORE, the following declarations are hereby made:

1. **Separate Identity.** DUMB constitutes an independent nomenclatural, conceptual, and hypothetical enterprise possessing its own acronym, designation, linguistic character, branding, and overall commercial impression. Any resemblance to any existing experiment, acronym, collaboration, detector, facility, or federally funded scientific endeavor is expressly denied except to the extent that all long-baseline neutrino experiments necessarily involve neutrinos, long baselines, and, from time to time, underground detectors.
2. **No Affiliation.** DUMB is not sponsored by, endorsed by, authorized by, operated by, affiliated with, derived from, merged with, consolidated into, spun off from, spiritually descended from, reincarnated as, or otherwise juridically or metaphysically connected to any other experiment, including those whose names may evoke geological features, deserts, or large underground detector complexes.
3. **Independent Expression.** Any scientific concepts common to DUMB and other experiments—including but not limited to neutrino oscillations, charged-current interactions, neutral-current interactions, liquid argon time projection chambers, accelerator-produced neutrino beams, baseline optimization, matter effects, event reconstruction, statistical inference, χ^2 minimization, Bayesian analysis, detector calibration, or the Standard Model of particle physics—constitute unprotectable scientific principles, methods, facts, discoveries, or ideas, and not protectable expression. DUMB claims only such original expression as is independently created by its proponents.

4. **Trademark Distinctiveness.** The acronym "DUMB" is phonetically, orthographically, semantically, aesthetically, emotionally, and, most importantly, comedically distinguishable from any other acronym. No reasonably prudent, reasonably informed, reasonably caffeinated member of the international high-energy physics community would conclude that DUMB originates from, is sponsored by, or enjoys institutional continuity with any similarly capitalized four-letter acronym merely because both describe ambitious neutrino experiments.
5. **Absence of Consumer Confusion.** The likelihood of confusion is de minimis, negligible, remote, speculative, conjectural, hypothetical, attenuated, and otherwise insufficient under any recognizable multifactor test. The average physicist, grant reviewer, graduate student, or conference attendee exercising ordinary care is presumed capable of distinguishing between "DUMB" and any other acronym containing different letters arranged in a different order.
6. **Copyright Reservation.** DUMB neither reproduces nor appropriates any copyrighted text, figures, software, engineering drawings, detector designs, technical documentation, collaboration policies, proprietary data, nor any other copyrightable expression belonging to any third party. Any overlap in scientific subject matter reflects the immutable laws of nature rather than unlawful copying.
7. **Patent Neutrality.** Nothing herein shall be construed as practicing, inducing infringement of, contributing to the infringement of, or otherwise implicating any valid and enforceable patent claims. To the extent any hypothetical detector component accidentally wanders into patented territory, said wandering shall be deemed entirely coincidental and subject to redesign following consultation with persons substantially more knowledgeable than the authors.
8. **Academic Freedom.** The proponents respectfully invoke the long-standing traditions of academic inquiry, scientific discourse, parody, fair commentary, independent research, and the universal tendency of physicists to invent increasingly questionable acronyms.
9. **No Waiver.** Failure to capitalize every instance of "DUMB" shall not constitute a waiver, estoppel, admission, concession, acquiescence, abandonment, forfeiture, or other relinquishment of any rights, remedies, privileges, immunities, defenses, or opportunities for further acronym optimization.
10. **Entire Agreement.** This Declaration constitutes the entire understanding regarding the distinctiveness of DUMB and supersedes all prior discussions, drafts, whiteboard sketches, coffee-break conversations, napkin calculations, and hallway arguments concerning whether "this is basically DUNE."

THEREFORE, the undersigned respectfully submit that DUMB is, in all relevant legal, linguistic, conceptual, and comedic respects, manifestly not DUNE; that any similarity arises solely from the regrettable reality that there exist only so many concise names available for large-scale neutrino experiments; and that the laws of particle physics, unlike trademarks, remain in the public domain.



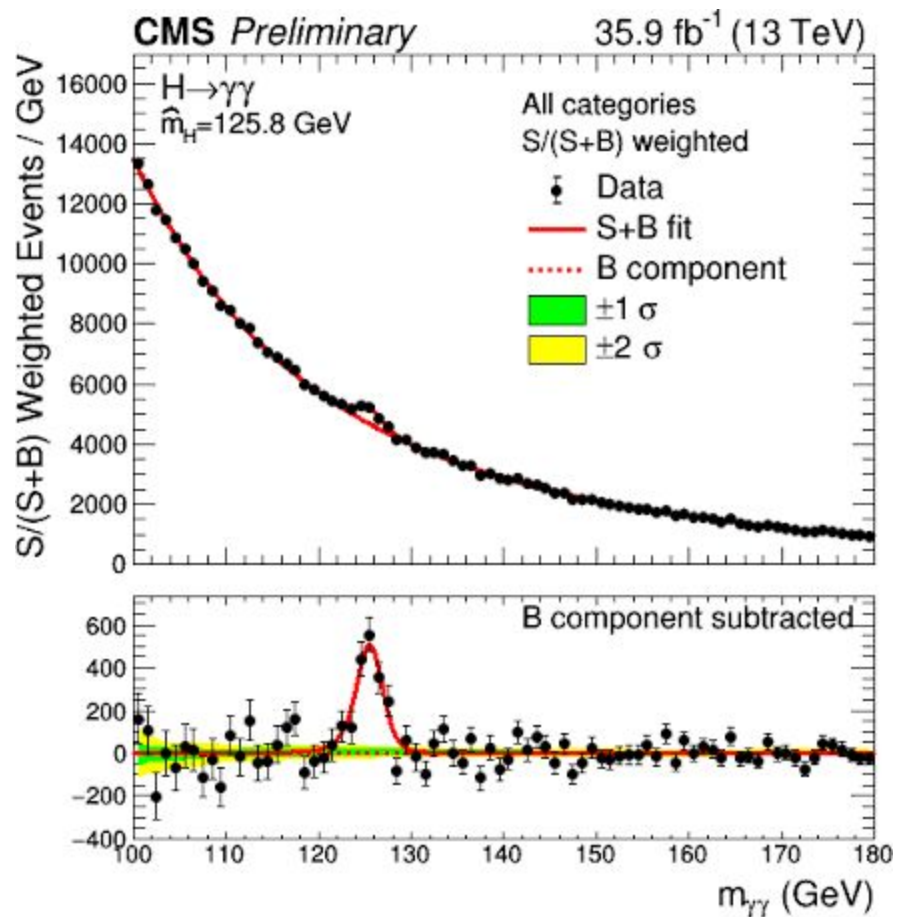
Why don't we take DUNE



and push it somewhere else

Far detector risks?





Cube with sidelength
1.4 football fields

(~14.5 basketball courts
or 1210 big macs)



Funding Plan

1. Install DAVID as dictator of the United States
- 2.

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2.

