

SEARCH FOR THE EV-SCALE STERILE NEUTRINO AT A VERY SHORT BASELINE

Alessandro Minotti – Università di Milano Bicocca

XVII International Conference on Topics in Astroparticle and Underground Physics 2023
28.08 – 01.09.2023 University of Vienna

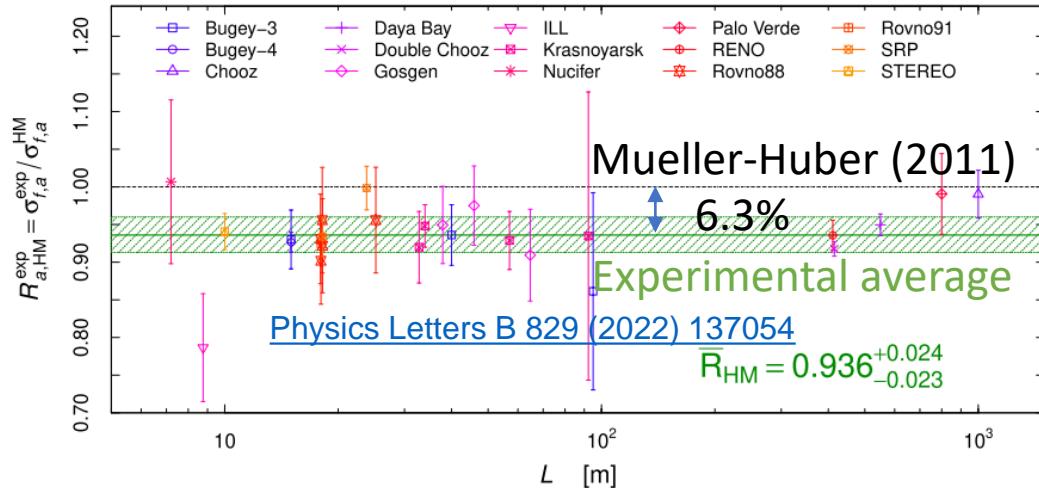
ANOMALIES



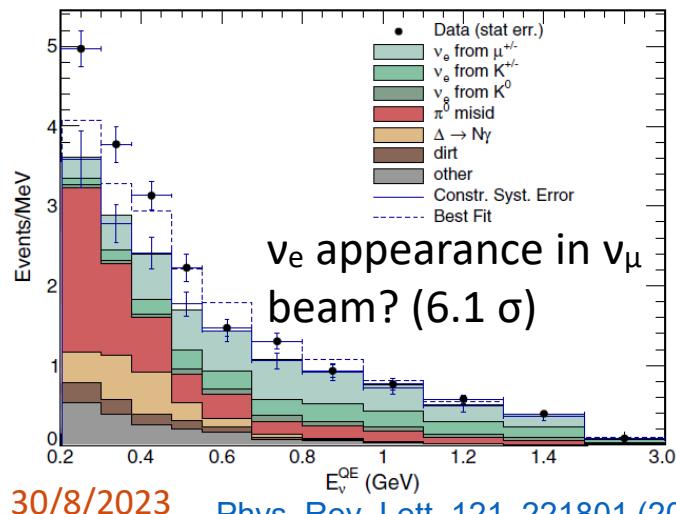
ANOMALIES EVERYWHERE

WHAT ANOMALIES

- Reactor Antineutrino Anomaly (RAA)



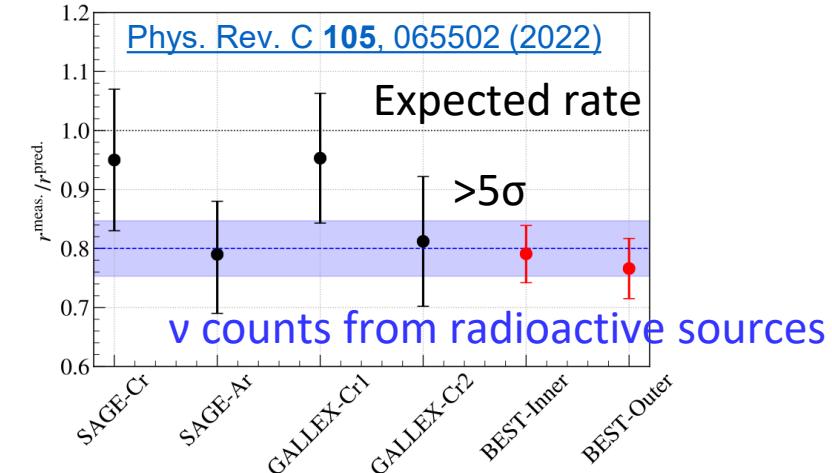
- LSND/MiniBooNE Anomaly



30/8/2023

[Phys. Rev. Lett. 121, 221801 \(2018\)](#)

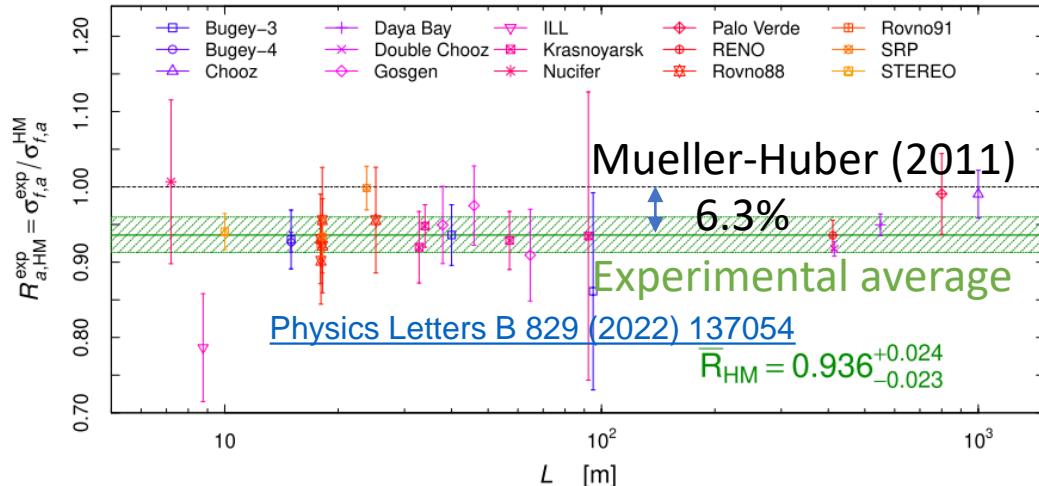
- Gallium Anomaly



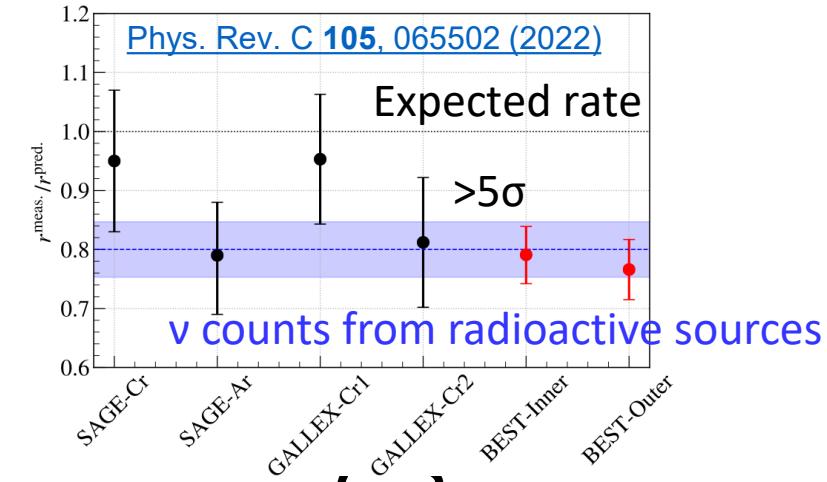
Search for eV-scale Sterile Neutrino @ TAUP 2023

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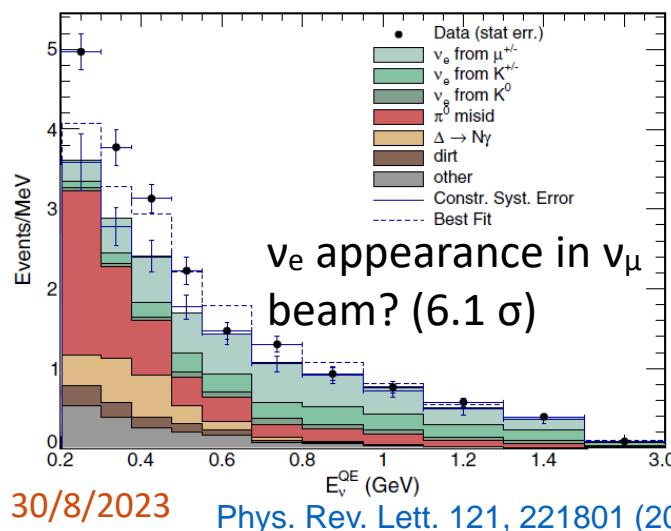
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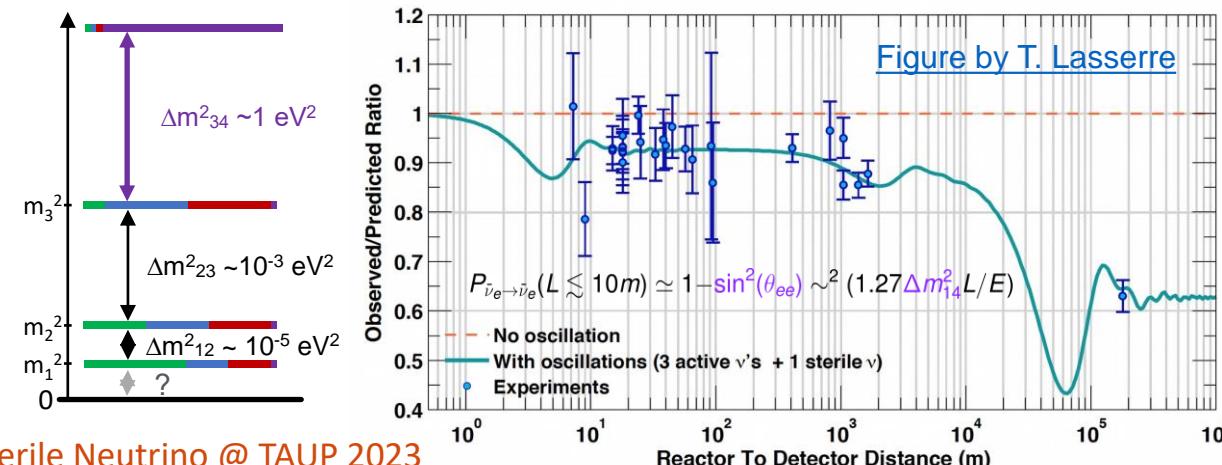
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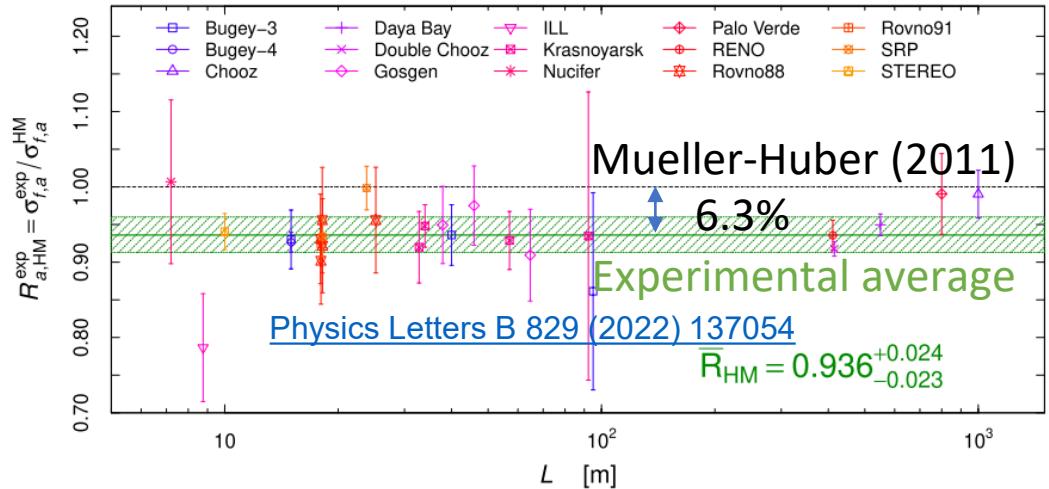


New 0.1-1 eV neutrino, consisting of a sterile flavor

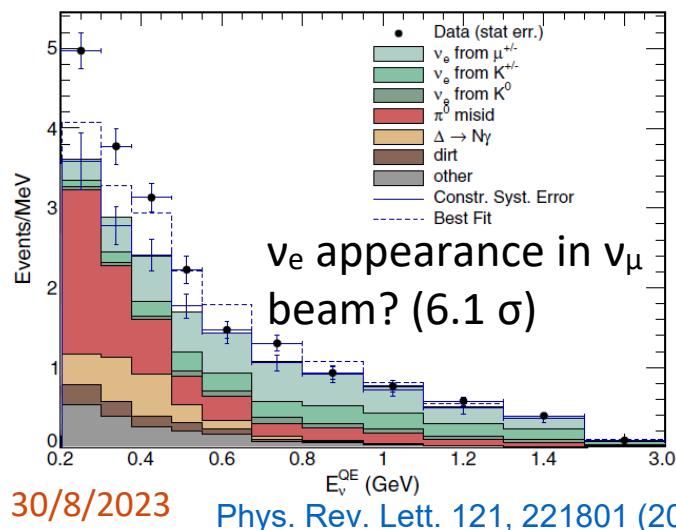


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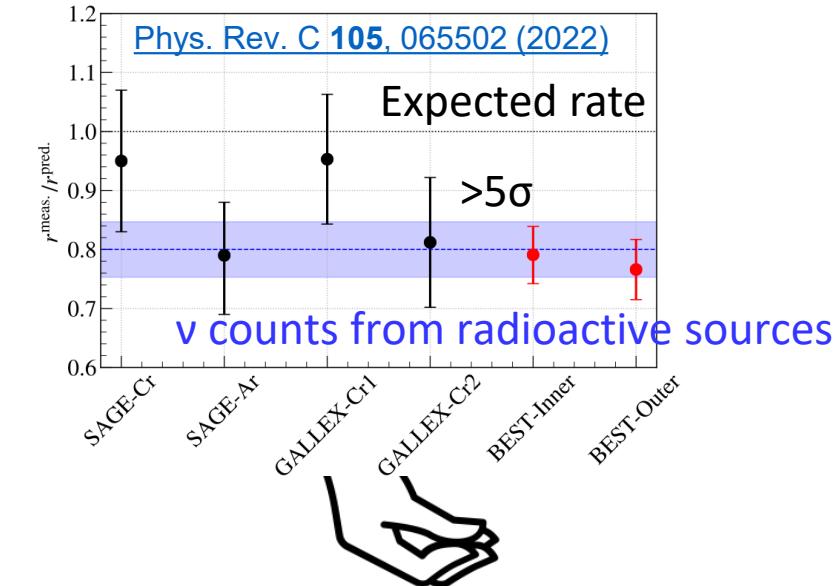


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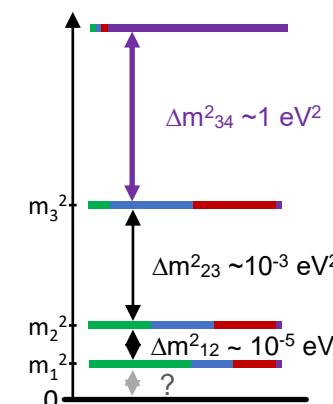


Do they really?

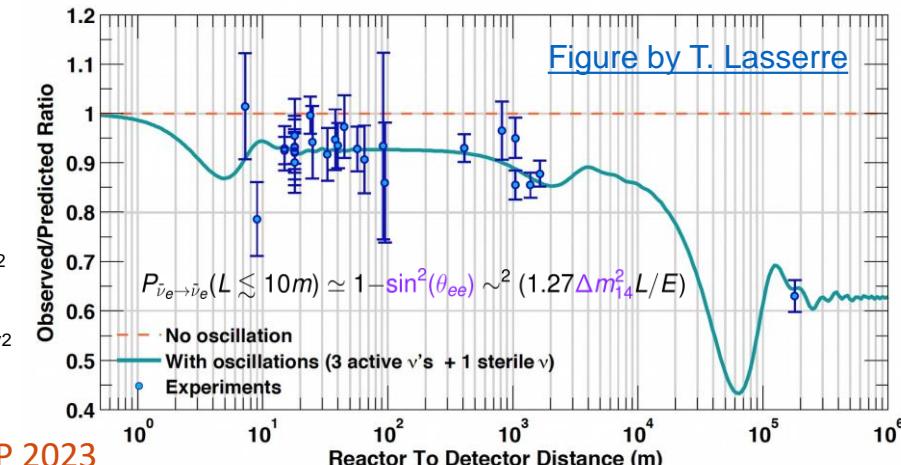
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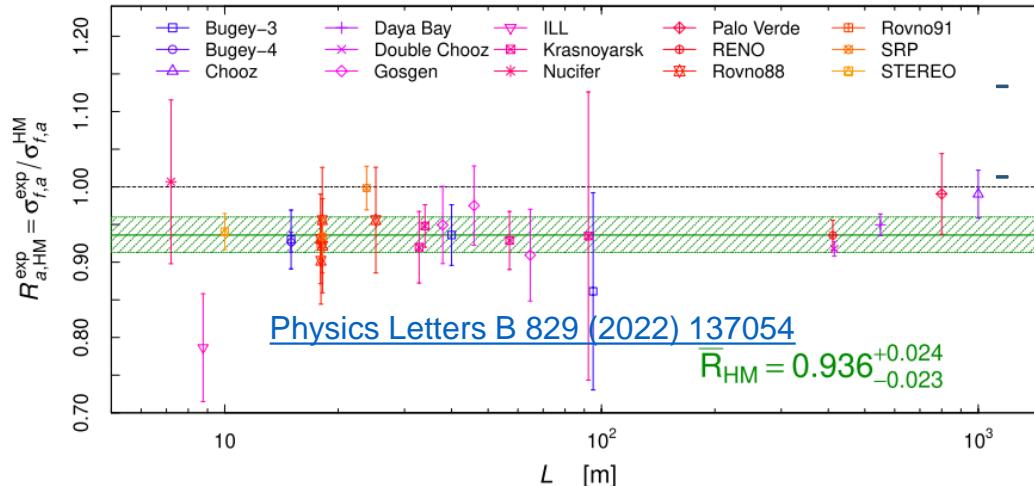


Search for eV-scale Sterile Neutrino @ TAUP 2023



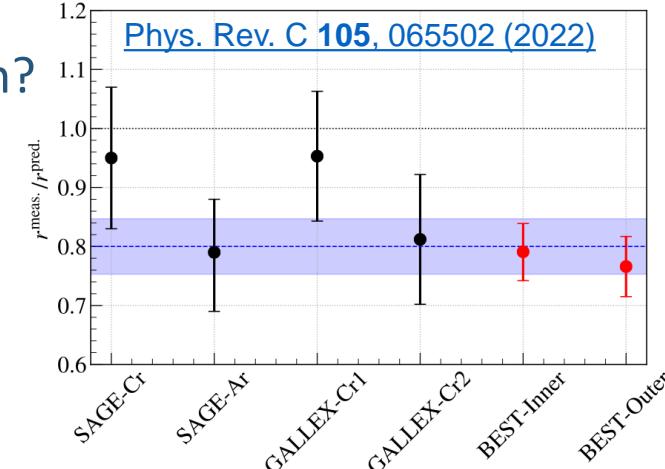
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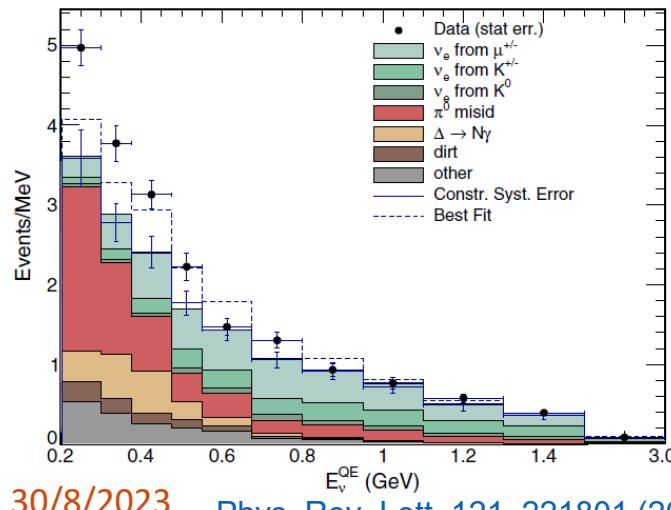
Rate prediction?
 β spectrum
normalization?

- Gallium Anomaly

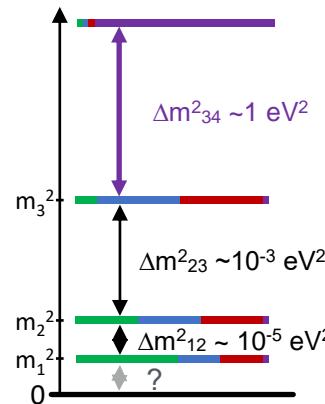


Capture cross-section?
Ge half-life?
Source calibration?

- LSND/MiniBooNE Anomaly



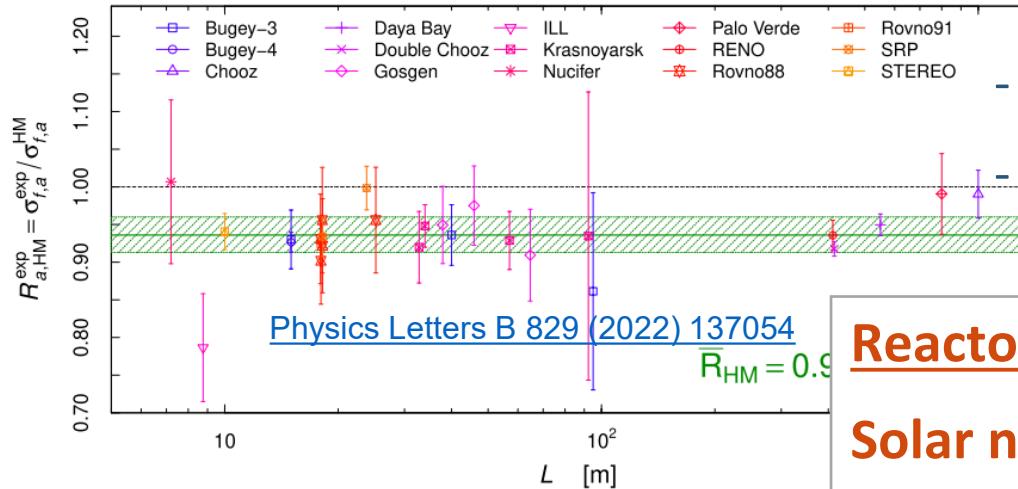
Highly disfavored by
disappearance results
and MicroBooNE data
Background?
Other BSM Physics?



$$U_{PMNS} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} & U_{e4} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} & U_{\mu 4} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} & U_{\tau 4} \\ U_{s1} & U_{s2} & U_{s3} & U_{s4} \end{pmatrix}$$

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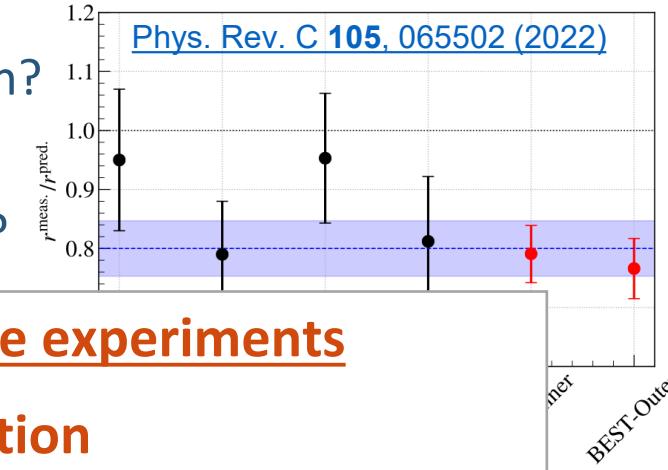
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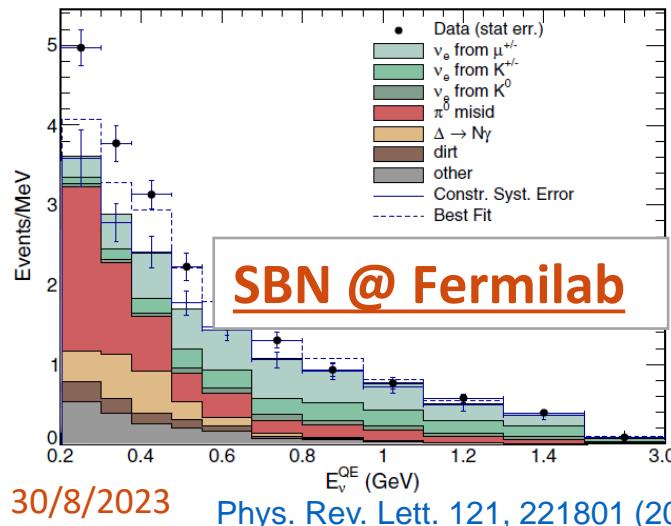
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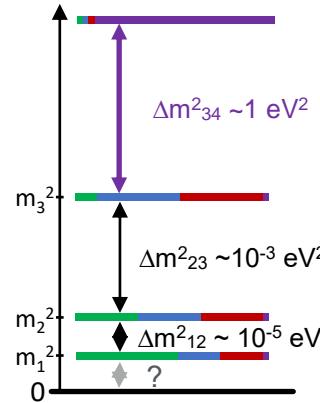
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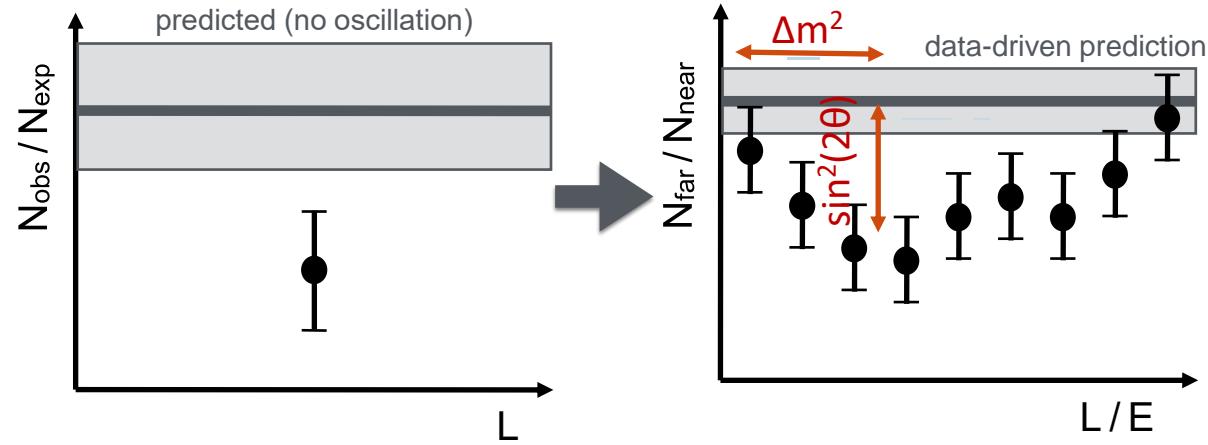
Other BSM Physics?



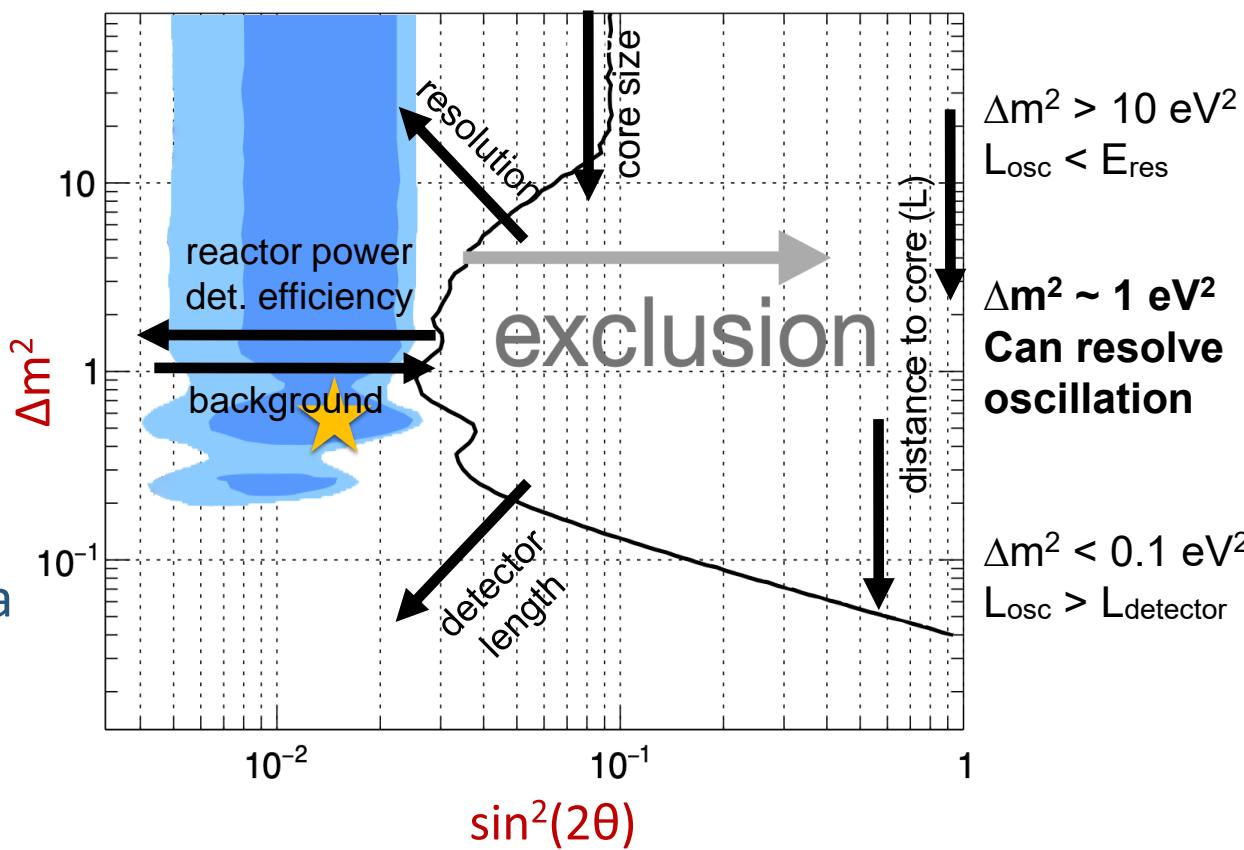
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HOW TO FIND THE SMOKING GUN

- Disentangle oscillation signature from absolute rate to overcome limitation of predictions

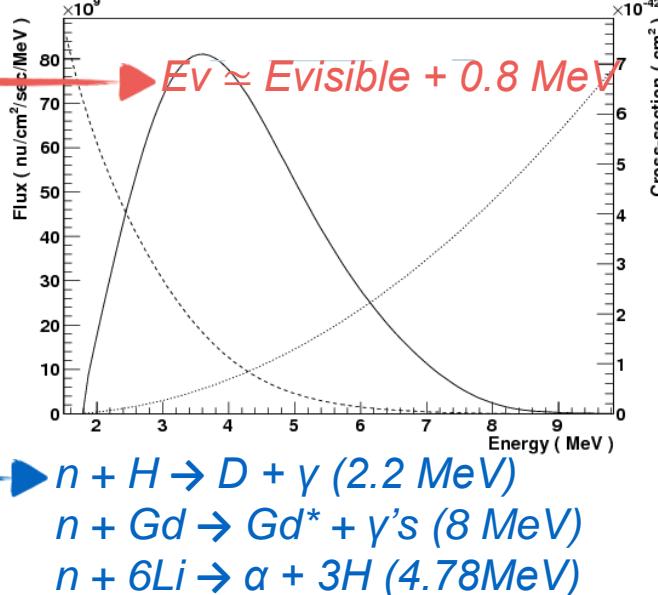
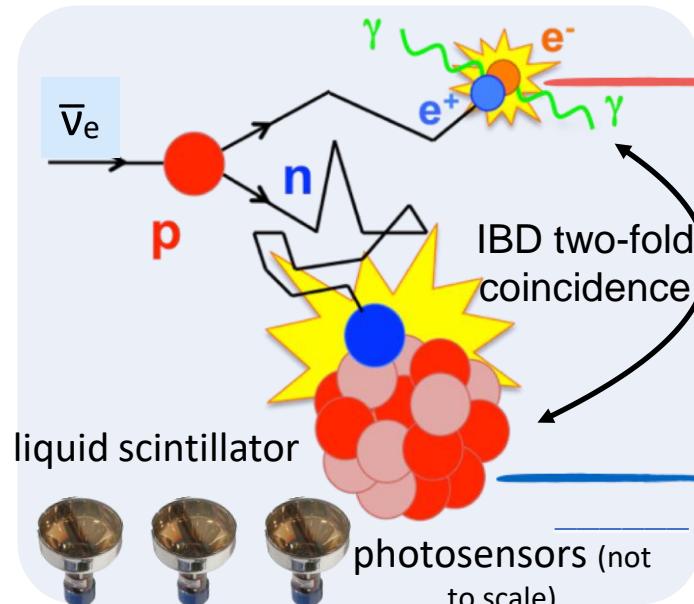


- Oscillation parameters (Δm^2 , θ) tested against data
 - Oscillation hypothesis \Rightarrow **contour plot (CL) + best fit**
 - Null hypothesis \Rightarrow **exclusion plot**



ANTINEUTRINO DETECTION AND CHALLENGES

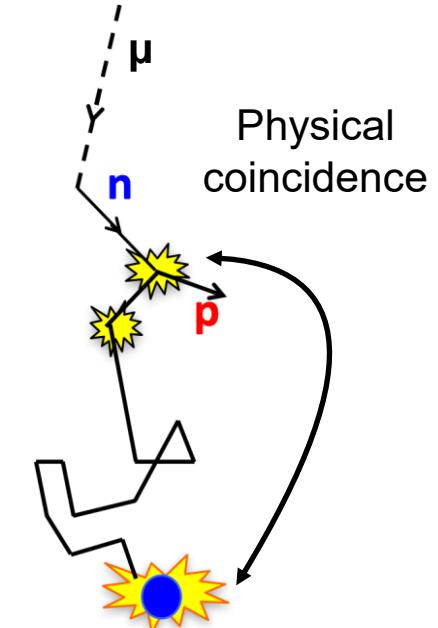
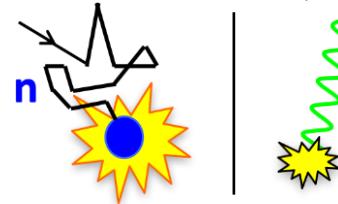
- Signal: Inverse Beta Decay in scintillating target



- Background

- Cosmic-induced
- Reactor-induced

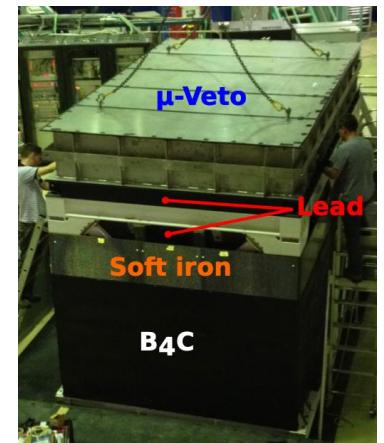
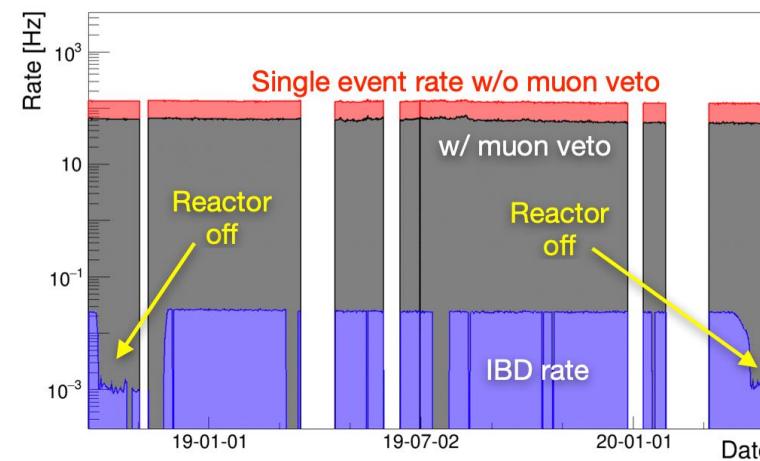
Accidental coincidence



- Signature: two-fold coincidence (E_{e^+} , E_n , Δt , $\Delta \vec{x}$)

- To mitigate background

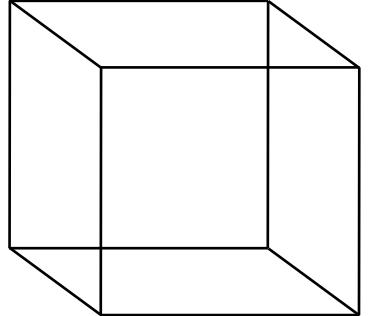
- Shielding & vetoes
- Pulse Shape Discrimination (PSD)
- Statistical subtraction of reactor-off spectrum



ANTINEUTRINO DETECTION AND CHALLENGES

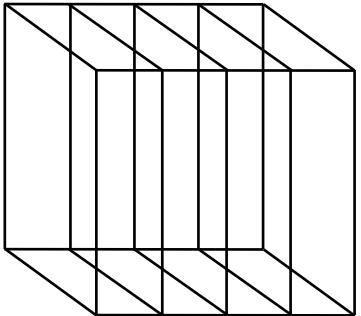
Detector segmentation

no-segmentation



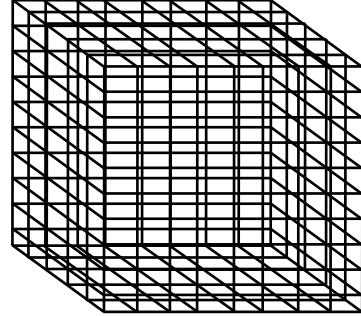
Compare $\bar{\nu}$ spectrum with predictions

coarse segmentation



Compare $\bar{\nu}$ spectra in different segments (model free)

fine segmentation



Compare $\bar{\nu}$ spectra in sections + background rejection w/ topology

Scintillator

plastic



Segmentation, detection efficiency

Large volumes

Reactor



research reactor (HEU)



Short L, compact core; no fuel evol. (^{235}U)



$\mathcal{O}10^2 \text{ MW}_{\text{th}}$, limited space, bkg from facility

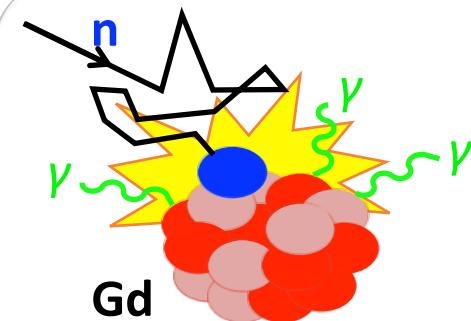


power reactor (LEU)

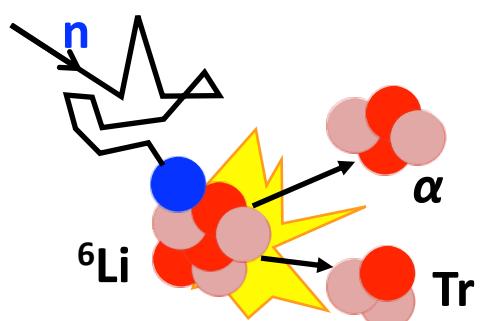
$\mathcal{O} \text{GW}_{\text{th}}$, some overburden

Lower sensitivity at low E_{ν} , burnup (U+Pu)

Neutron-capturing isotope



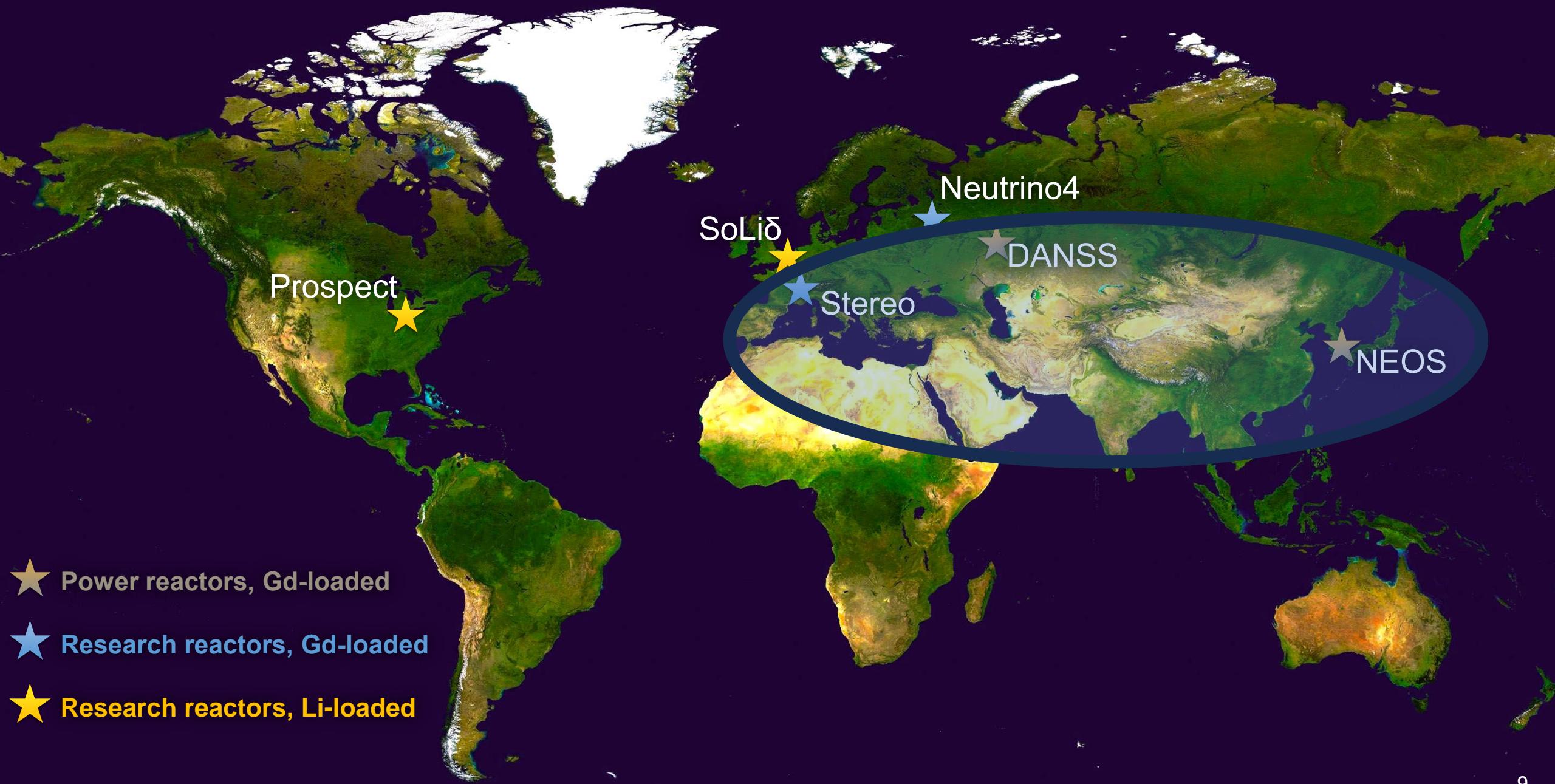
Well-established, high E_{dep} & σ_{capture}



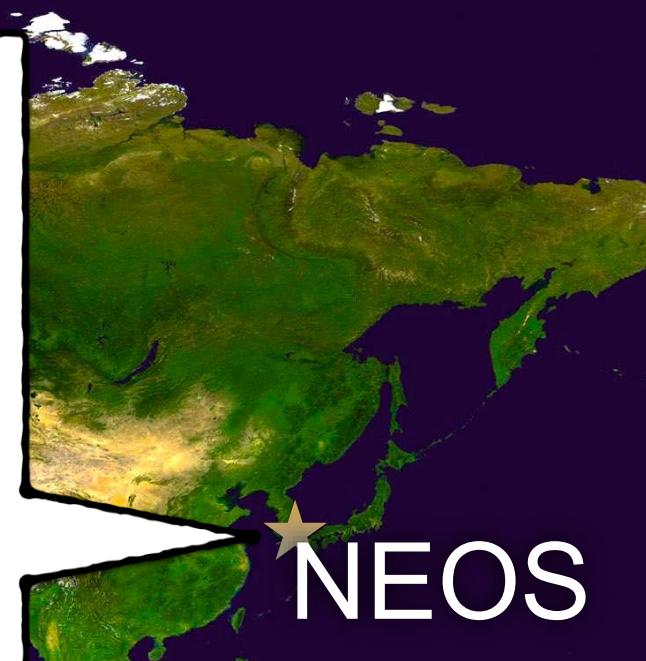
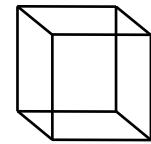
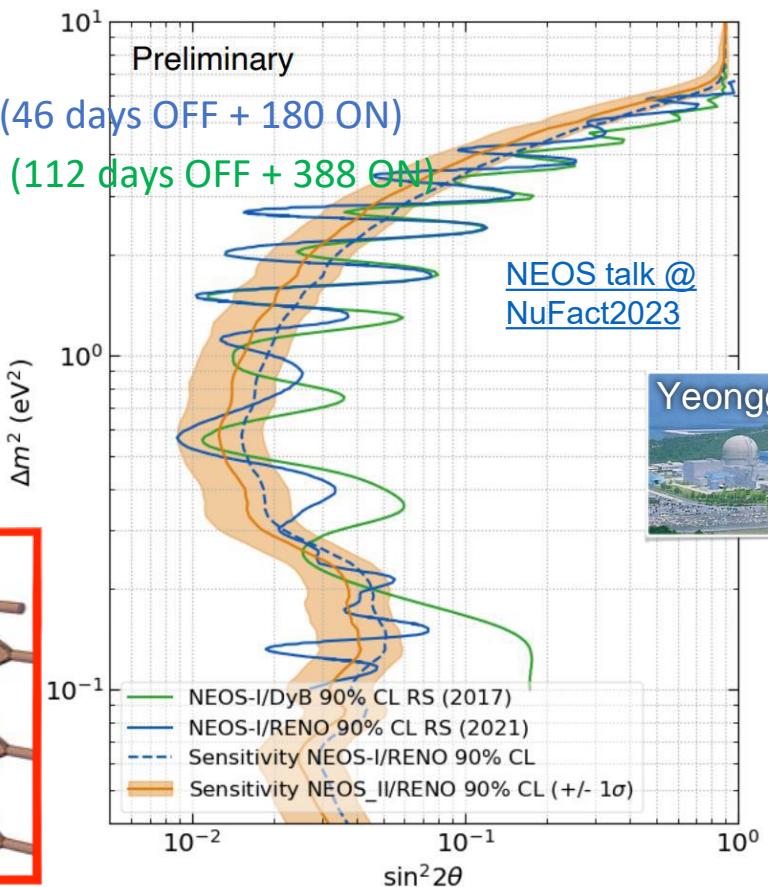
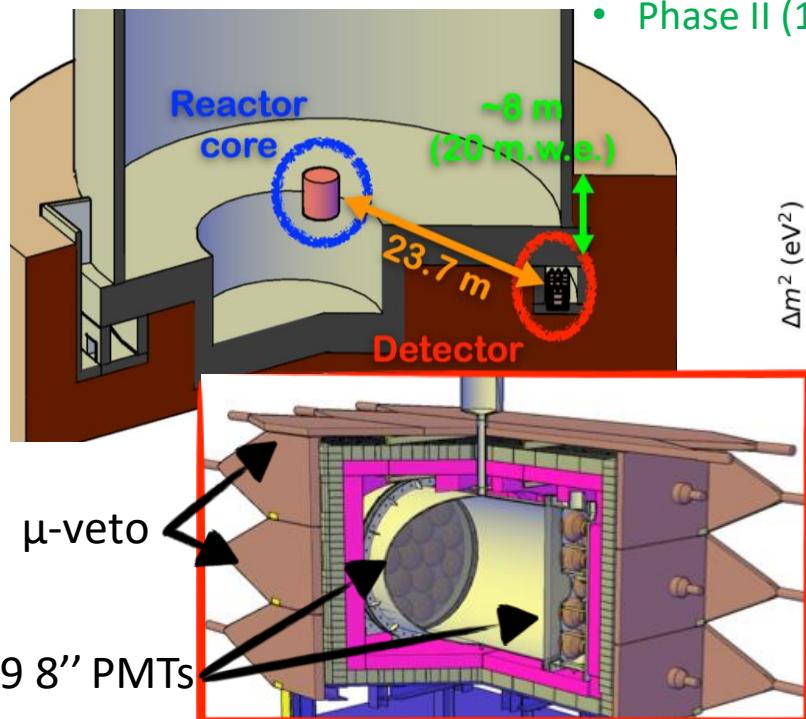
Localised E_{dep} : quenched but can select via PSD

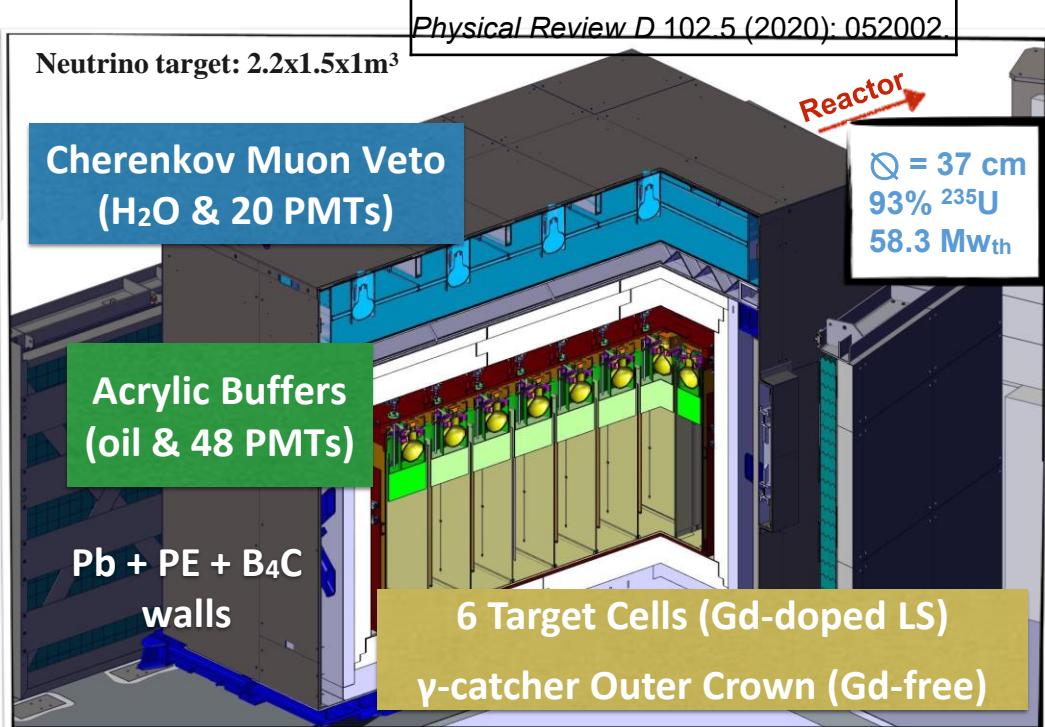
A detailed satellite map of the world, showing the outlines of all major continents and their terrain. The map uses a color palette ranging from dark blues for oceans to various shades of green, brown, and yellow for land, indicating vegetation and elevation. The text 'A WORLDWIDE HUNT' is overlaid in the center.

A WORLDWIDE HUNT

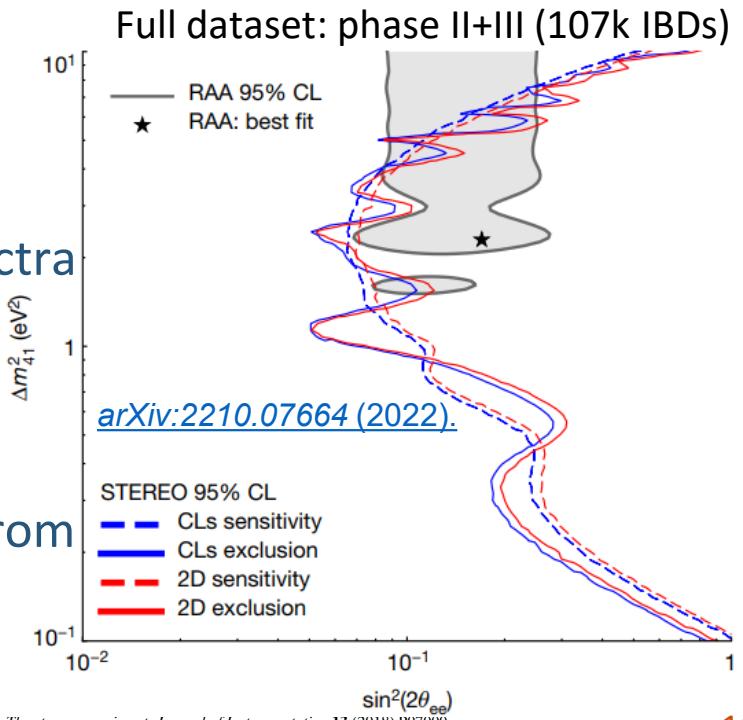
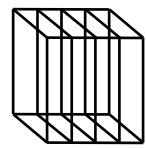


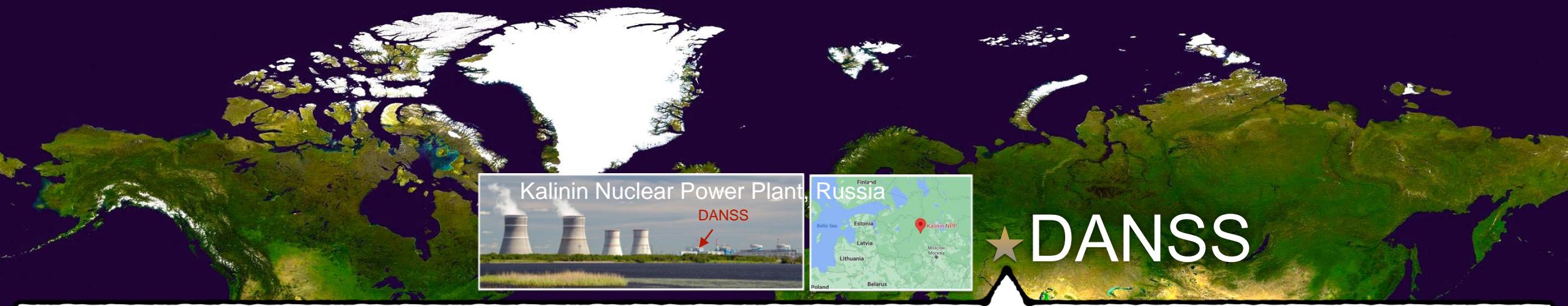
- 1008 L Gd-loaded (0.48%) liquid scintillator tank (spectrum compared with Data Bay / RENO)
- High statistics ($\approx 2k$ IBD/day) thanks to 2.8 GW commercial reactor
- Degradation of LY ($\approx 40\%$), λ_{att} , and σ_n in time
 - Phase I (46 days OFF + 180 ON)
 - Phase II (112 days OFF + 388 ON)





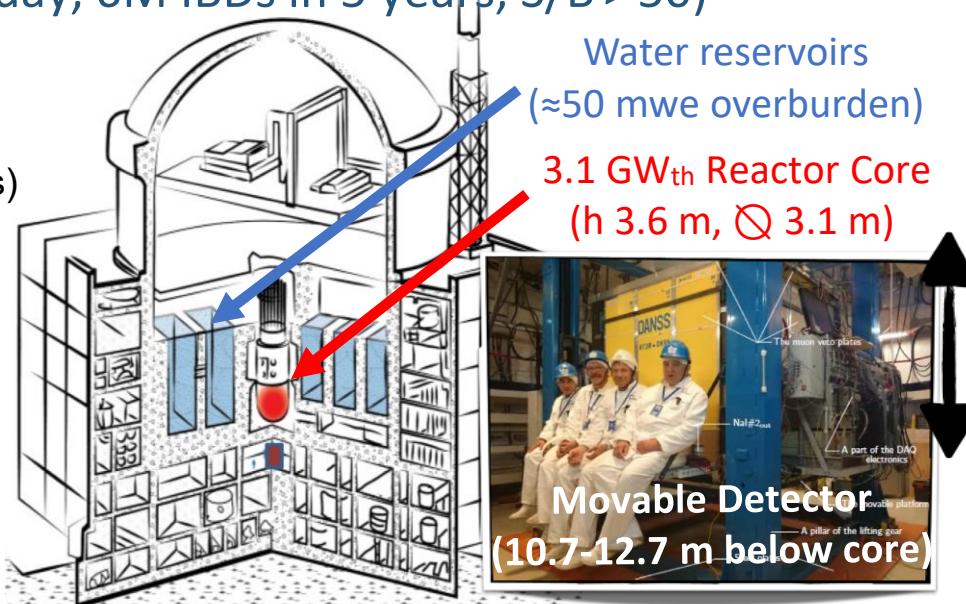
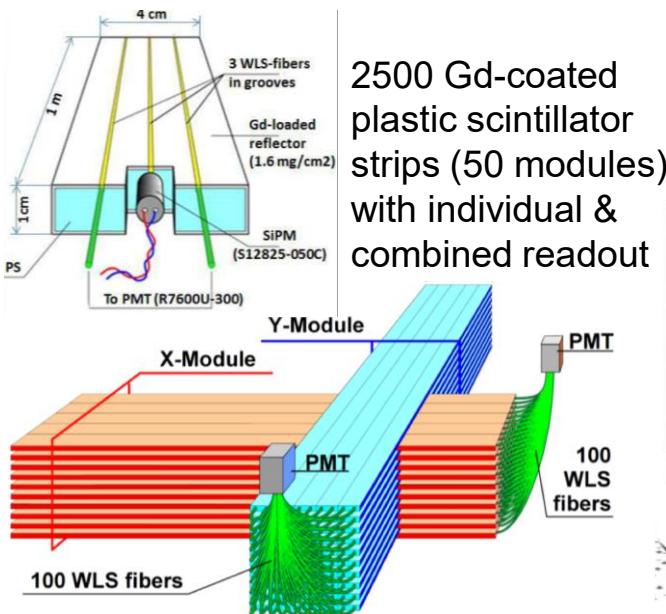
- Segmented design
→ cell-to-cell relative $\bar{\nu}$ spectra
- Compact HEU core & short baseline
- Little overburden & noise from reactor facility (S/B≈1)



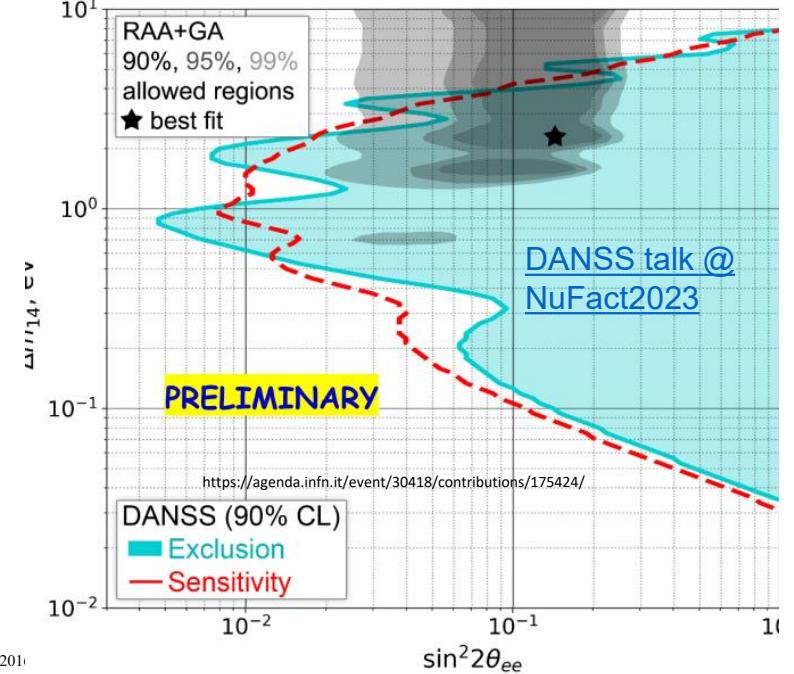


DANSS

- Highly-segmented ν spectrometer → quasi-3D reconstruction
- Excellent statistics (≈ 5 IBD/day, 6M IBDs in 5 years, S/B > 50)



- Phase-I (7.7 M IBD in 7 years) Phys.Lett.B787(2018)56
- Upgrade ongoing → halve E_{res}, increase V_{det}



**10
YEARS
Later**

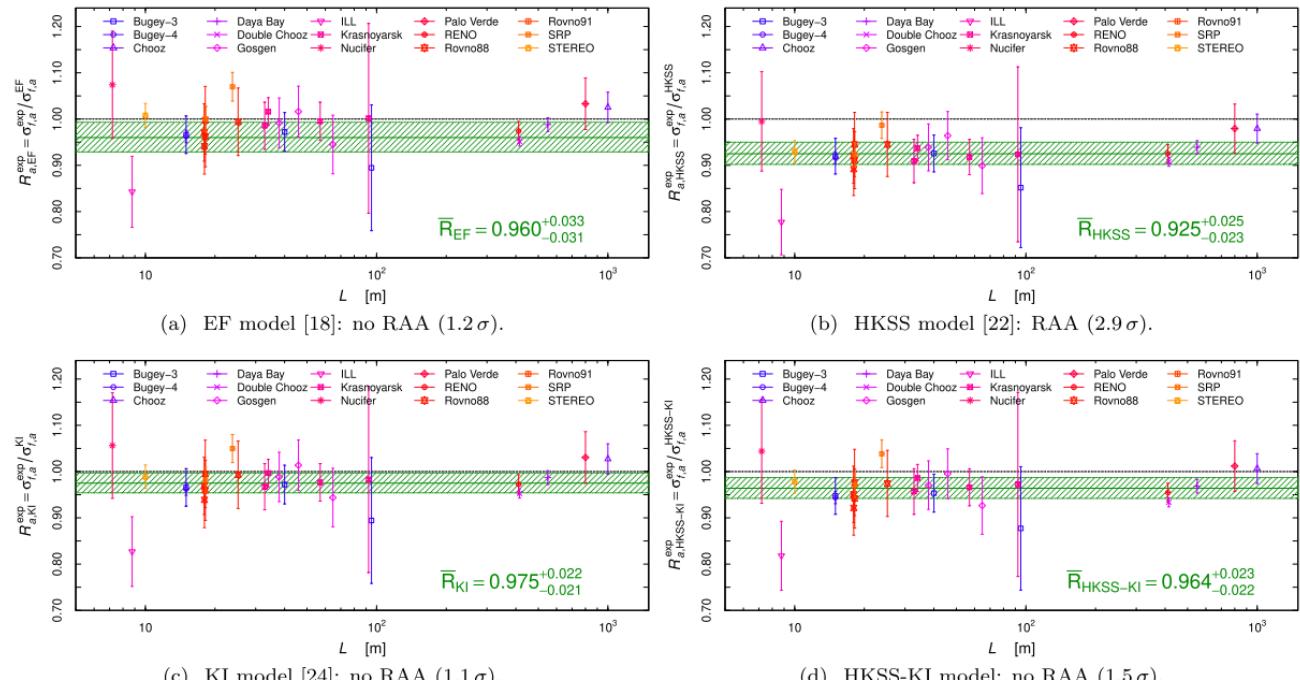
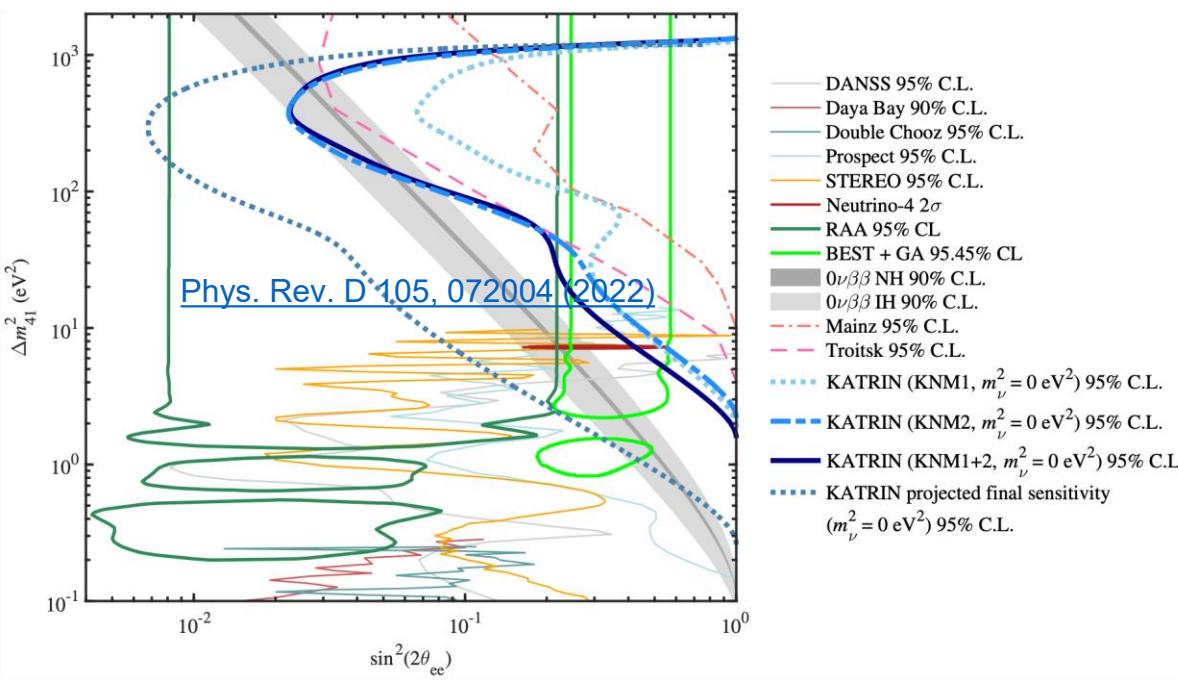
WHERE DO WE STAND

- DANSS, NEOS, STEREO, PROSPECT excluded large portions of the RAA mid-low Δm^2 region & best fit
- High Δm^2 s (in tension with cosmology) probed by KATRIN and solar neutrino data
- Individual spectra can still fit an oscillation: e.g. DANSS/RENO ratio, or the (criticized) Neutrino-4 result (2.8σ , $\Delta m^2 \approx 7.3\text{ eV}^2$)
- ...and meanwhile the rate discrepancy disappeared (but depends on who you ask)

[Physics Letters B 829 \(2022\) 137054](#)

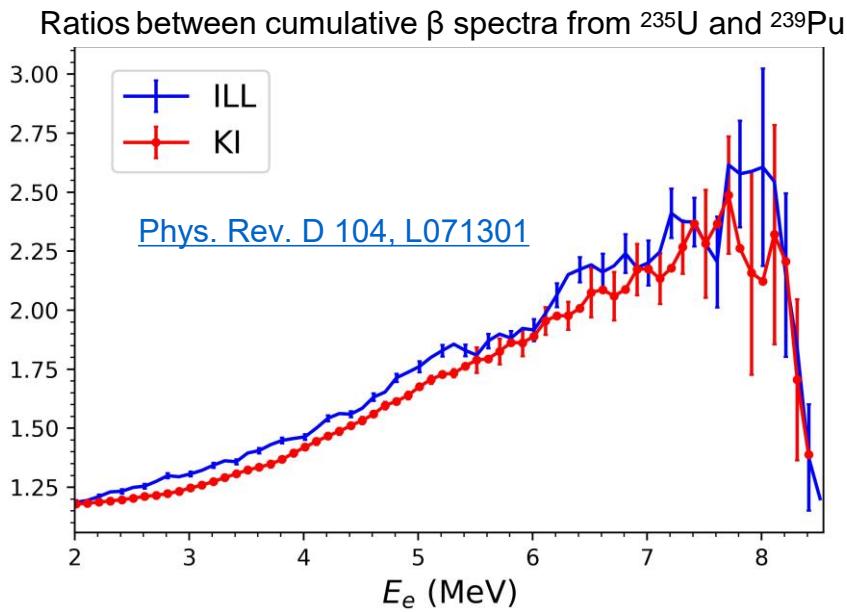
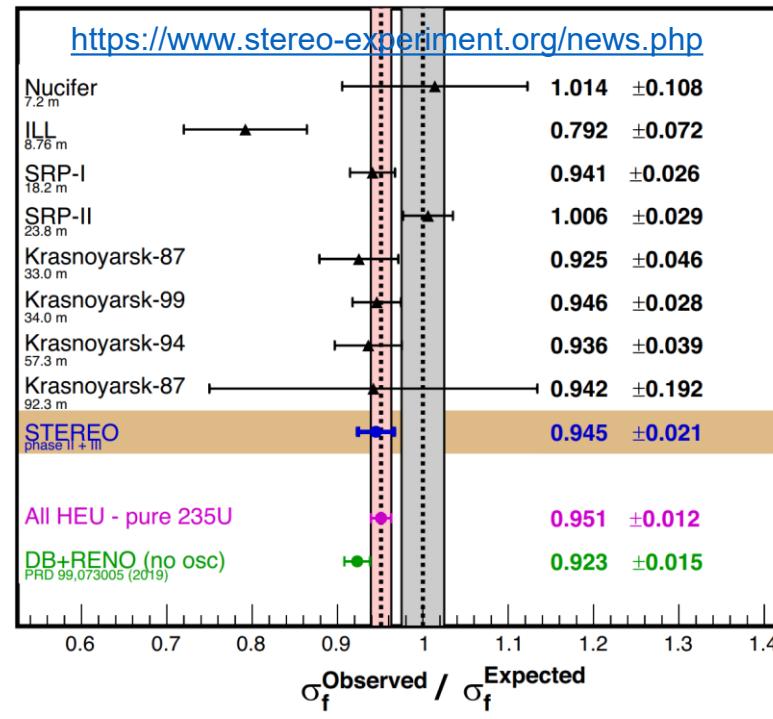
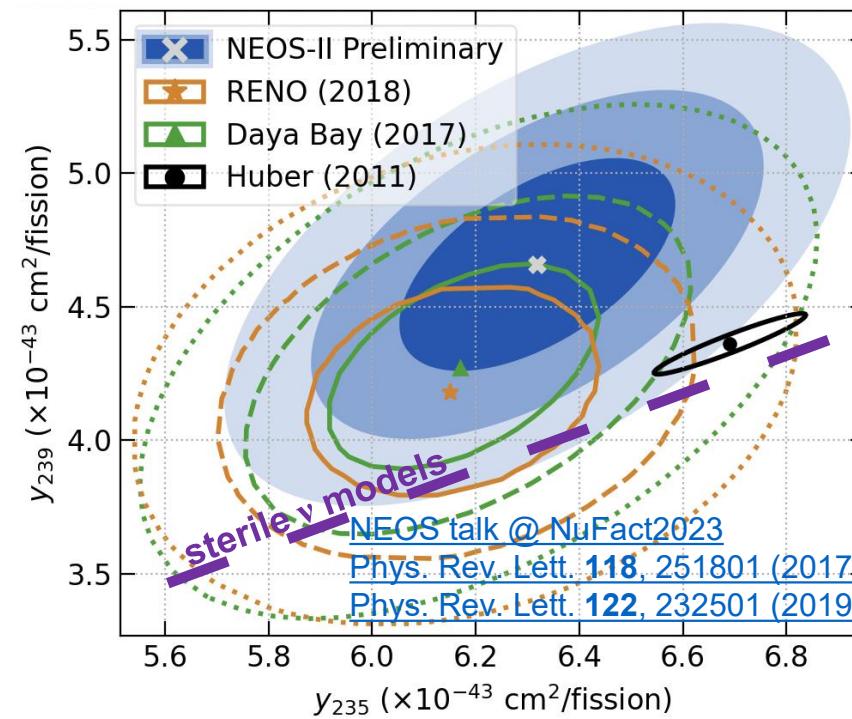
[Phys. Rev. D 104, 032003 \(2021\)](#)

[C. Giunti et al. Phys. Lett. B 816, 136214 \(2021\)](#)



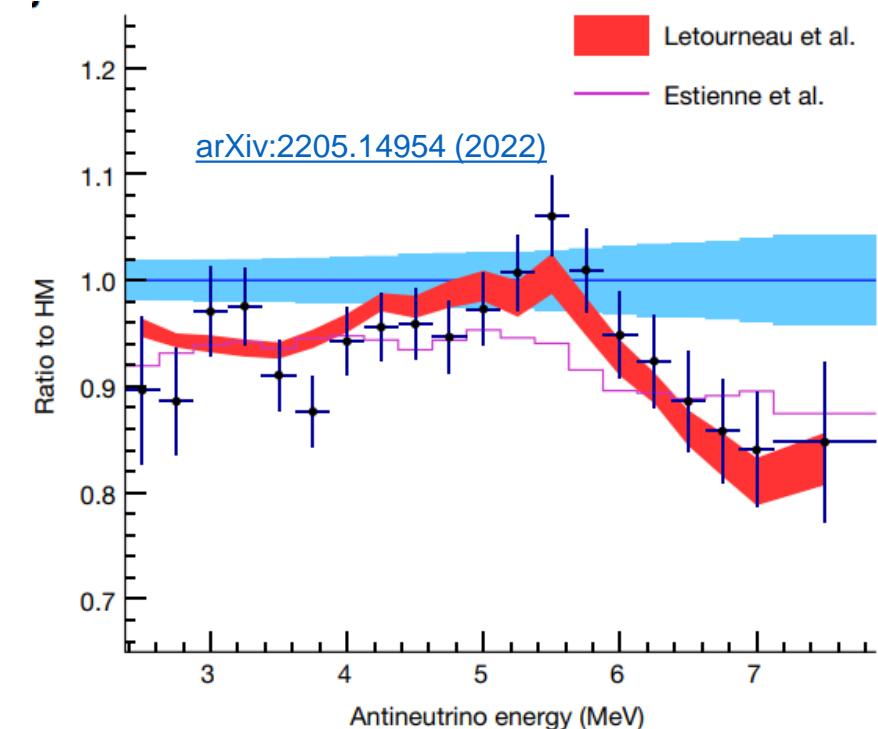
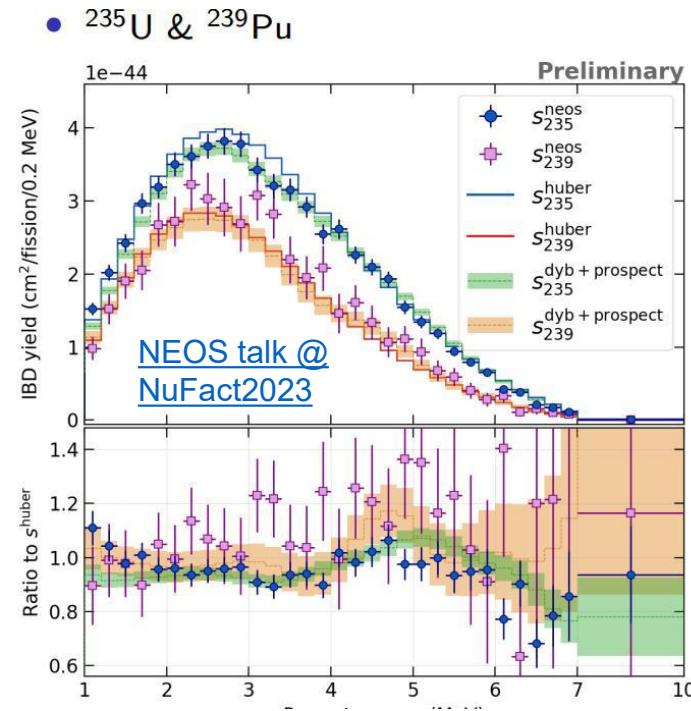
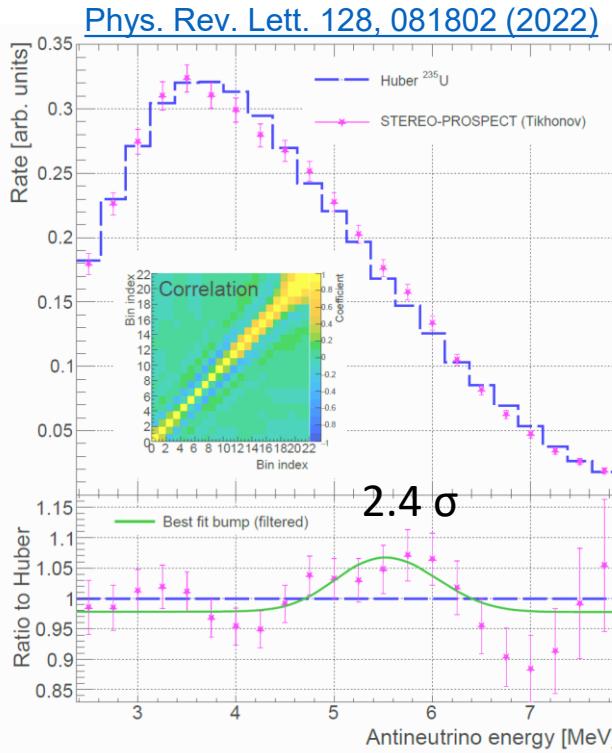
FISSION RATES AND THE RAA

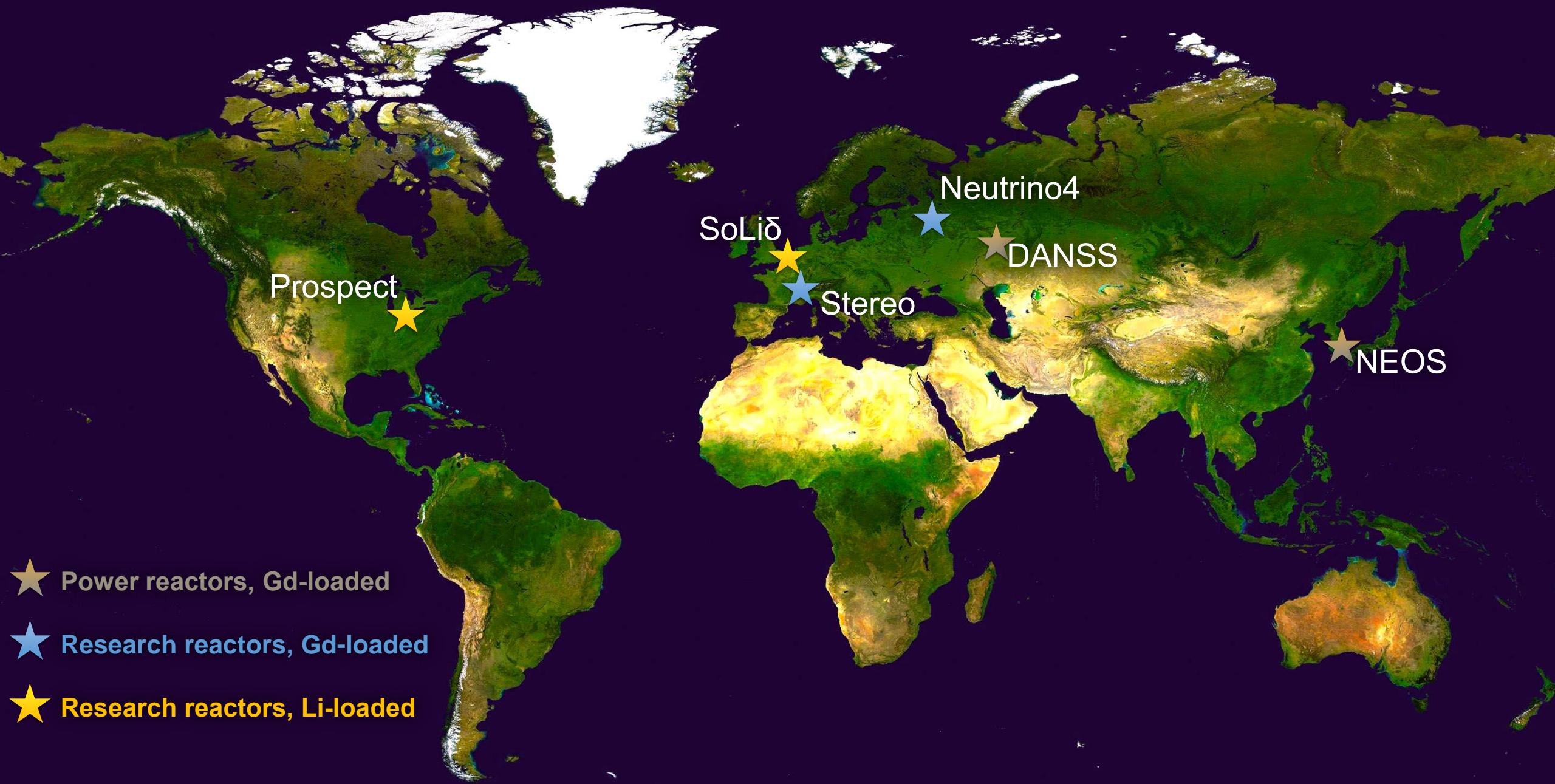
- Daya Bay, RENO, NEOS deconvolute ^{235}U and ^{239}Pu $\bar{\nu}_e$ yields → Rate deficit (~8%) mainly from ^{235}U ?
- STEREO's best estimation of pure ^{235}U $\bar{\nu}_e$ rate → overall $5.0 \pm 1.3\%$ deficit for HEU
- Recent re-evaluation of global β spectra → $\approx 5\%$ excess in ^{235}U to ^{2359}Pu ratio (compatible w/ RAA)



A SPECTRAL ANOMALY IN THE MIX

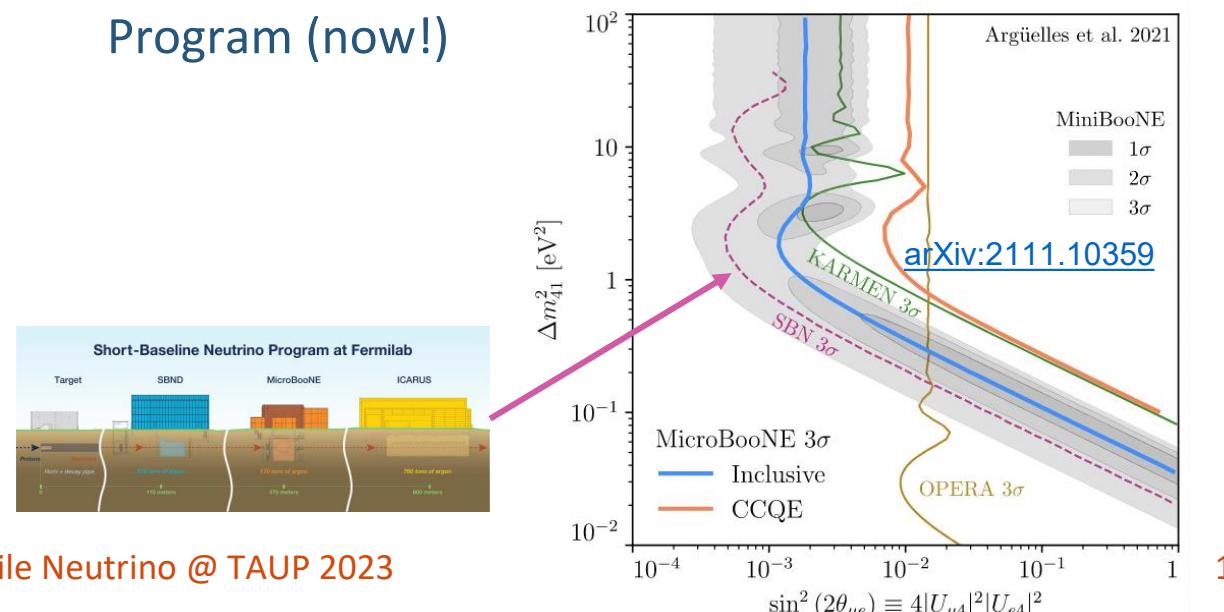
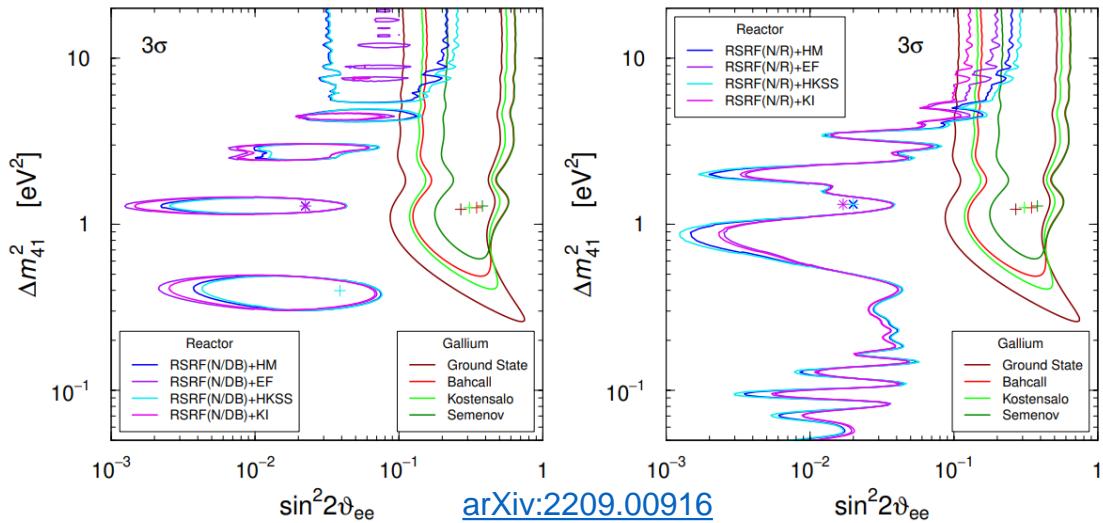
- Spectral distortion $E_\nu \approx 6$ MeV observed in θ_{13} -aimed reactor neutrino experiments in 2014
- STEREO+PROSPECT (^{235}U -only) and NEOS (U+Pu) confirmed ^{235}U alone can account for the distortion
- Modelled bias can reproduce the effect by benchmarking to most recent reactor neutrino data





WHAT ABOUT GALLIUM AND LSND/MINIBooNE

- Gallium anomaly
 - Strong tension w/ bounds from reactor, solar/KATRIN data
 - Usual suspects:
 - Cross-section → several calculations
 - $\text{Ge } \tau_{1/2} \rightarrow$ new meas. in agreement w/ older data
[arXiv:2307.05353](https://arxiv.org/abs/2307.05353)
 - Calibration of the source, Ge extraction efficiency
[arXiv:2303.05528](https://arxiv.org/abs/2303.05528)
 - Other (fine-tuned) BSM explanations possible
- LSND/MiniBooNE anomaly
 - Tension w/ disappearance results
 - Usual suspects:
 - Unknown background sources → severe constraints from MicroBooNE on photon interpretation
[arXiv:2209.00916](https://arxiv.org/abs/2209.00916)
 - Other systematic uncertainties
 - Several other BDM explanations possible
[arXiv:2308.02543](https://arxiv.org/abs/2308.02543)
 - Will be probed w/ the Fermilab Short Baseline Program (now!)



CONCLUSIONS

- **Is the RAA dead?**
- Probably, but we learned many things from it and explored a new physics frontier
- **How about Gallium and LSND/MiniBooNE?**
- Strong tension w/ other experimental data, but doesn't mean there is no new physics to be explored
- Overall, an intense experimental program and effort from theory has been spanning several fronts opened by the search for sterile neutrinos!

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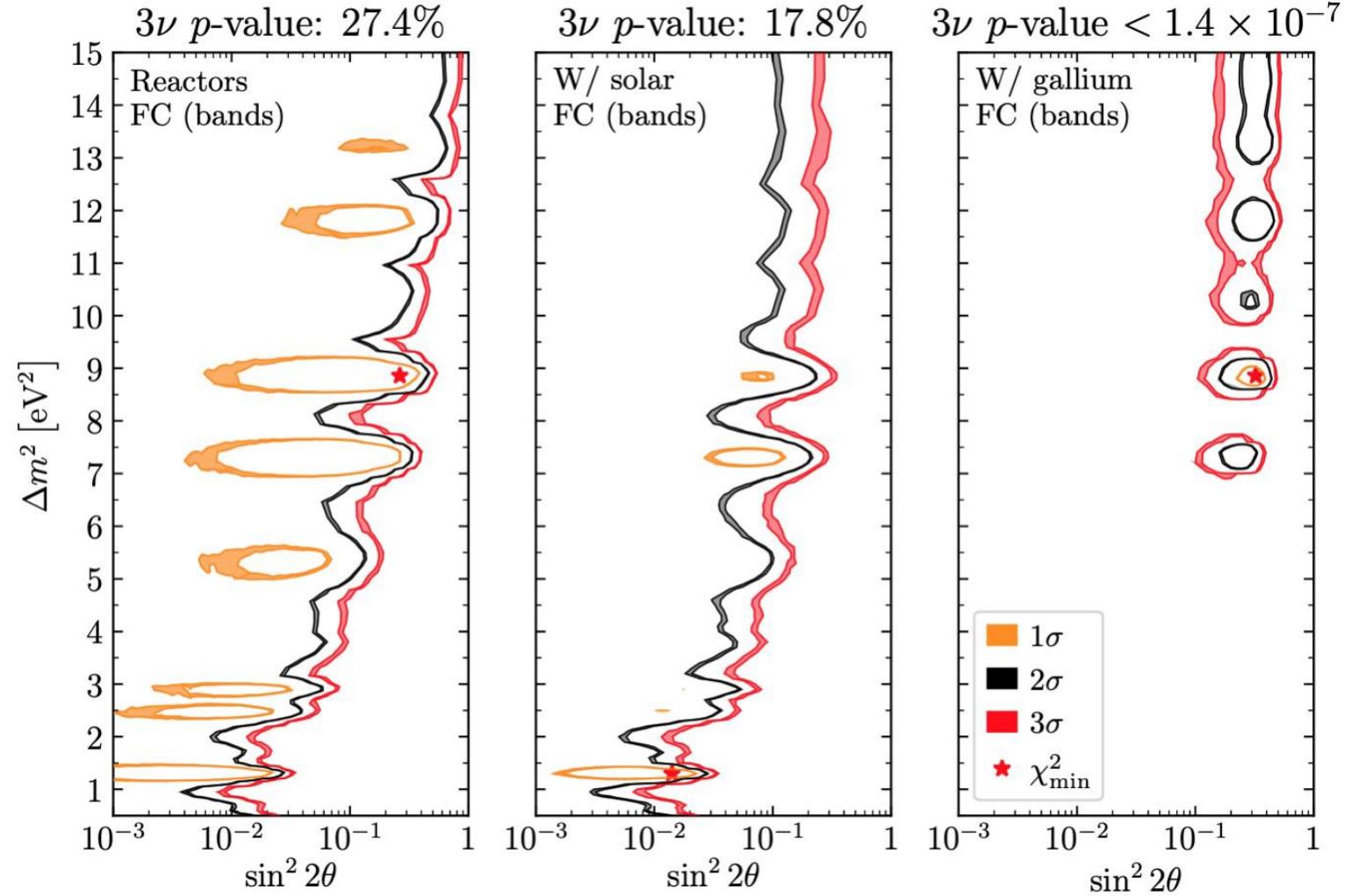
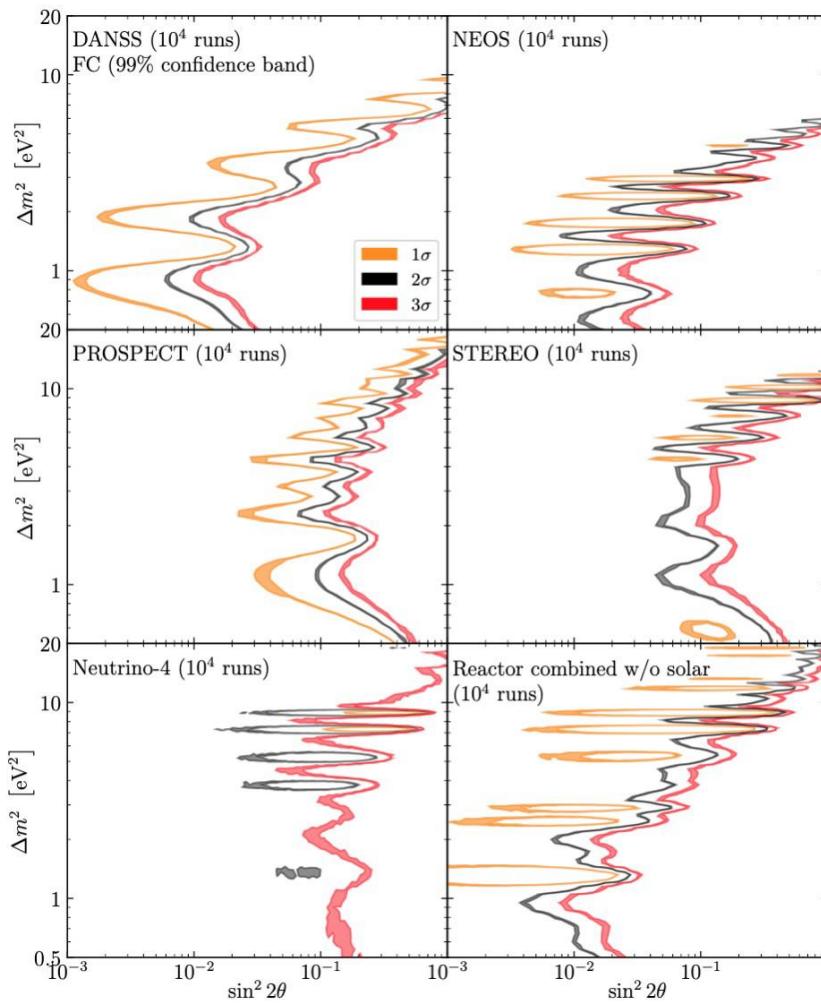
Thank You!

The background is a dense, intricate assembly of glowing blue mechanical components. It features numerous pipes, heat sinks, and structural supports, all bathed in a vibrant blue light that suggests either plasma or liquid helium. The perspective is from a low angle, looking up at the complex machinery.

EXTRAS

TRY TO PUT ALL TOGETHER?

[arXiv:2111.12530](https://arxiv.org/abs/2111.12530)



ANTINEUTRINO SPECTRUM ESTIMATION

- In LEU facilities four isotopes contribute to neutrino spectrum (^{235}U , ^{239}Pu , ^{238}U , ^{241}Pu), their fraction α_k evolves with time (burnup)
- Ab-initio (summation) methods
 - Single $\bar{\nu}$ spectra $S_k(E)$ unavailable, obtained from global β spectrum ($\mathcal{O}10^3$ branches)
 - Start with known branches from nuclear data table, and complement with effective decay branches

$$N_{IBD}(E_{\bar{\nu}_e}, t) = \frac{N_p \epsilon}{4\pi L^2} \times \frac{P_{th}(t)}{\langle E_f \rangle(t)} \times \langle \sigma_f \rangle(E_{\bar{\nu}_e}, t)$$

$$\langle E_f \rangle = \sum_k \alpha_k(t) \langle E_f \rangle_k$$

$$\langle \sigma_f \rangle_k = \int S_k(E) \sigma_{IBD}(E) dE$$

