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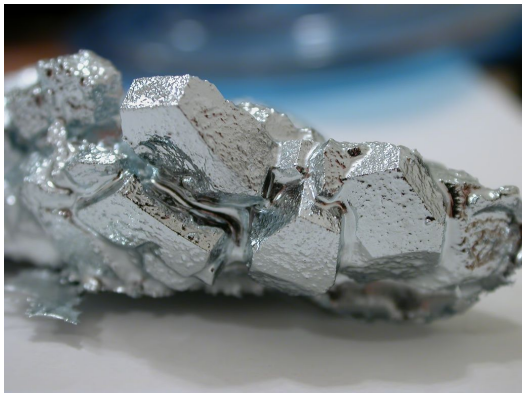


Liquidating the gallium anomaly

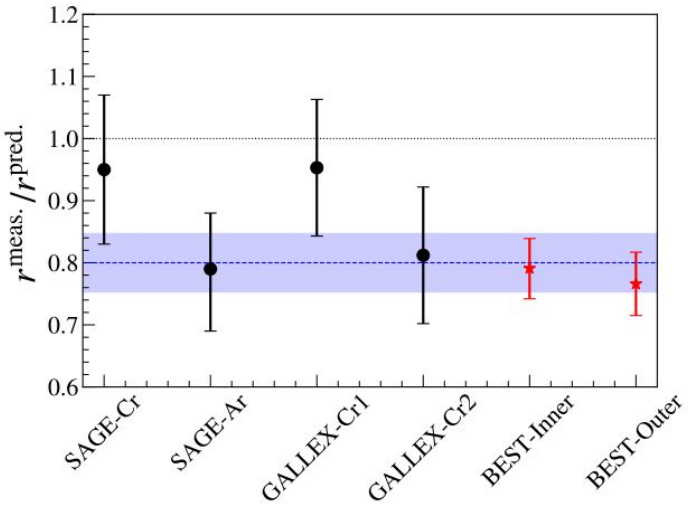
Phenomenology before and after the Standard Model
June 5, 2025 Pyle Center, Madison, WI

Garv Chauhan
Arizona State University
Patrick Huber
Center for Neutrino Physics at Virginia Tech

U.S. DEPARTMENT OF ENERGY | Office of Science

Gallium anomaly

$$\nu_e + {}^{71}\mathrm{Ga} \rightarrow e^- + {}^{71}\mathrm{Ge}$$



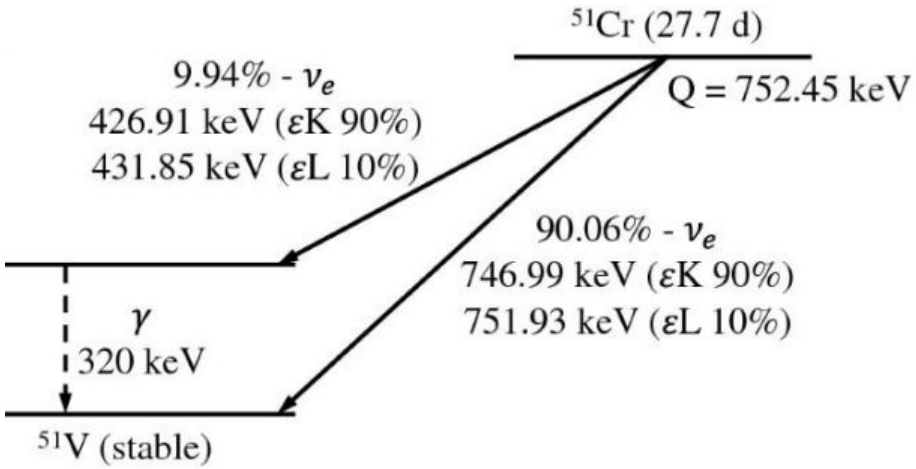
Elliott, Gavrin, Haxton, arXiv:2306.03299

No (simple) SM explanation

see e.g. Brdar, Gehrlein, Kopp arXiv: 2303.05528

arXiv:2207.10928

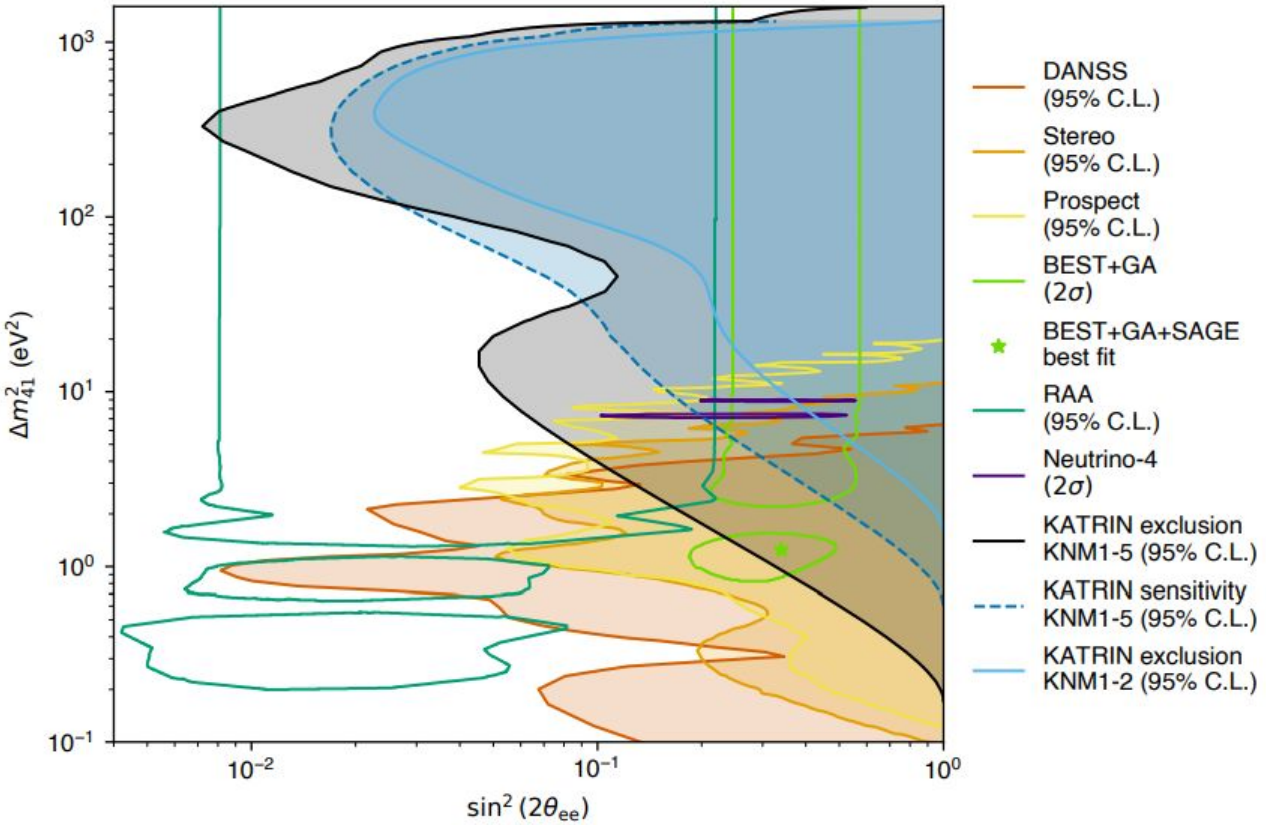
Chromium-51



- Can be made in multi--mega-Curie strength
- Can be calibrated to below 1%
- Two neutrino lines with known branching ratio: 427keV and 747keV

Sterile neutrino?

KATRIN, arXiv:2503.18667



Not shown: tension with solar neutrinos

eV-scale sterile neutrino

Score card (my own bias applied)

LSND & MiniBooNE 4-5σ	Why is there no muon neutrino disappearance?	Will be tested by the FNAL SBL program (and there maybe a SM explanation)
Reactor Antineutrino Anomaly 3σ	Went away with U235/Pu239 data from Kopeikin in 2021	RAA ~1000 citations Kopeikin ~100 citations
Neutrino-4 2σ	Tension with other reactor and KATRIN data	That experiment may simply be wrong
Gallium anomaly >5σ	Tension with solar data and KATRIN	It's NOT nuclear physics or chemistry (remember the solar neutrino anomaly?)

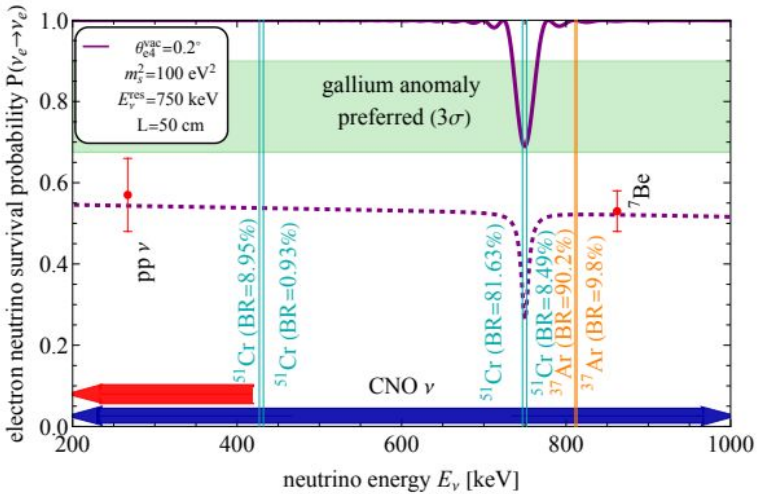
NB: Any new neutrino that contributes significantly to the energy density of the Universe either around BBN or today is in tension with vanilla cosmology – which is also in tension with itself.

BSM solutions that work (IMHO)

Brdar, Gehrlein and Kopp propose a MSW resonance by coupling neutrinos to something

- Small vacuum mixing angle (avoids KATRIN)
- Neutrino only (avoids reactors)
- Narrow resonance (avoids solar)

Brdar, Gehrlein, Kopp arXiv: 2303.05528

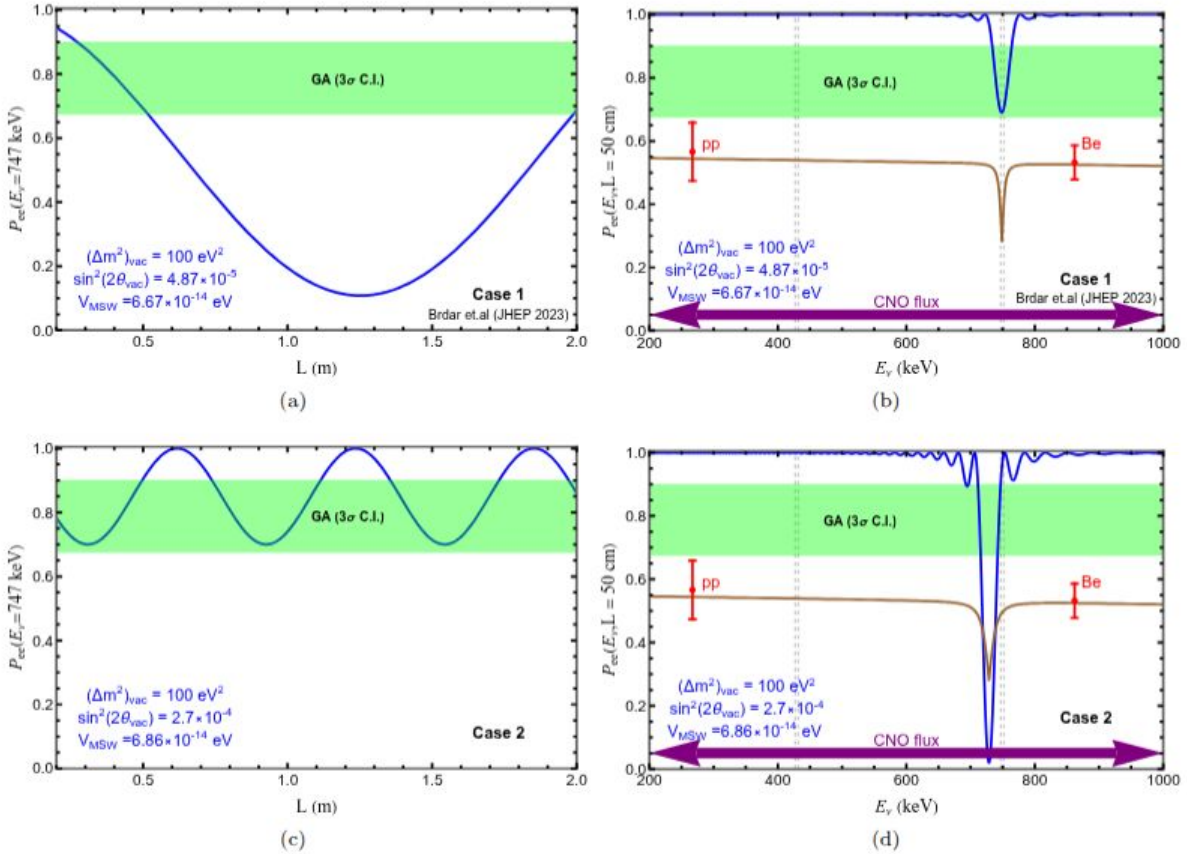


Davoudiasl & Denton (arXiv:2301.09651) propose a variant of mass-varying neutrinos by coupling neutrinos to a ultra-light scalar and thus avoid the solar & cosmological bounds, otherwise this looks like a regular sterile neutrino.

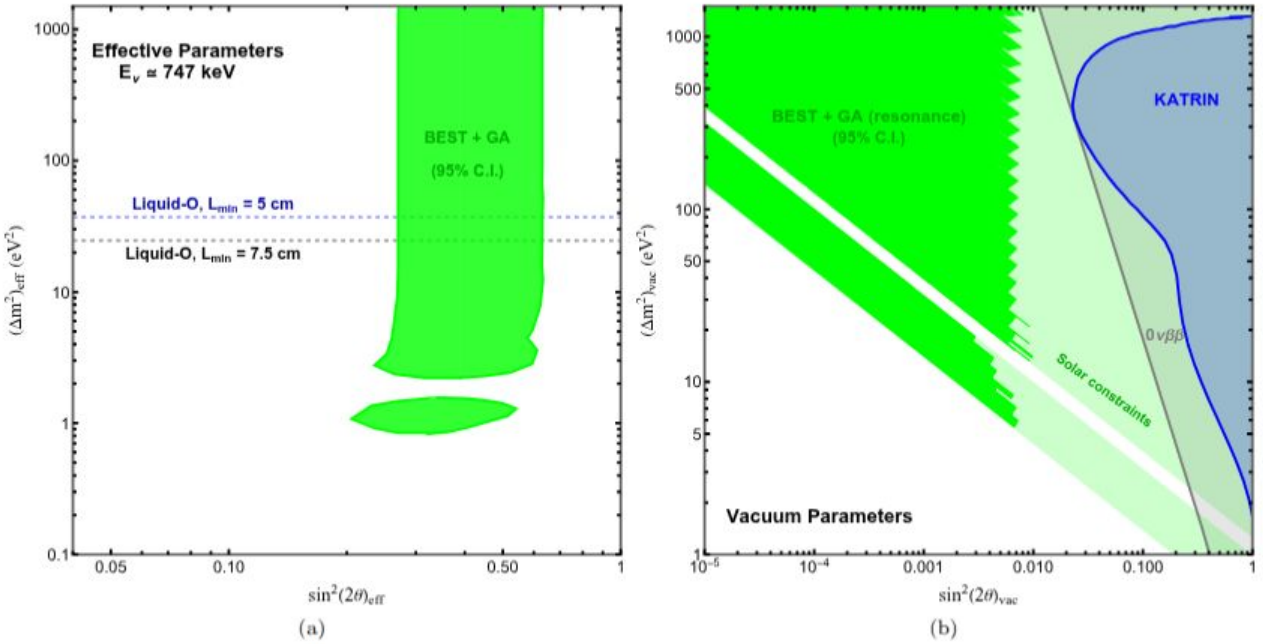
NB: Mass-varying neutrinos were one the first things I worked on here at UW Madison in 2005.

Baseline and energy dependence

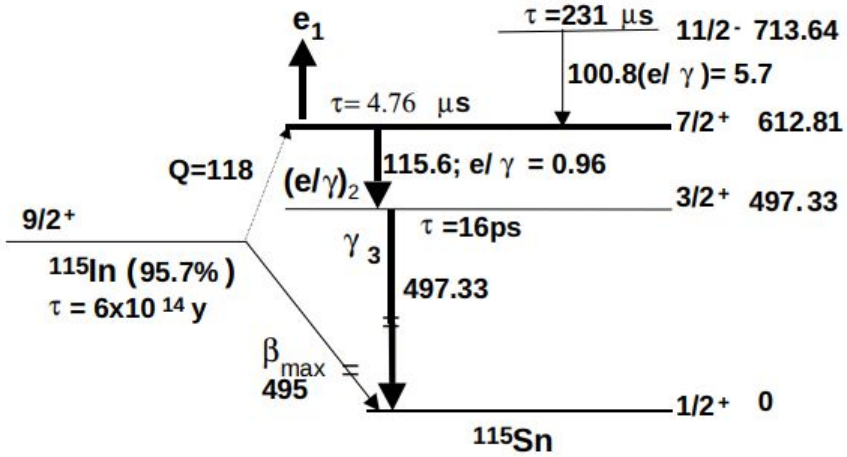
All previous gallium experiments are **insensitive** to neutrino energy and baseline



Effective and vacuum parameters



Measuring energy



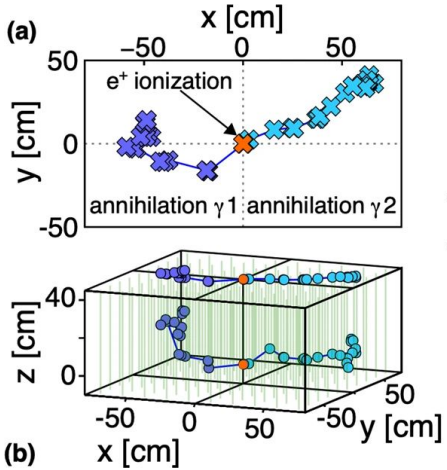
LENS proposal to use In-115 for low energy neutrino detection by R. Raghavan (1976)

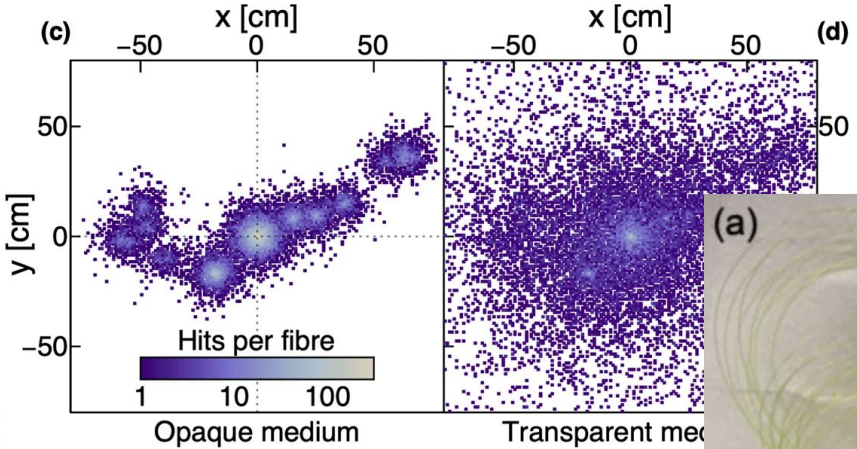
Triple coincidence to reject In-115 beta-decay background (and intrinsic radioactivity)

Requires high-efficiency detection of low-energy gammas at 115/497keV and position resolution

Energy resolution allows us to also use the low-energy Cr-51 line as intrinsic calibration (albeit with limited statistics)

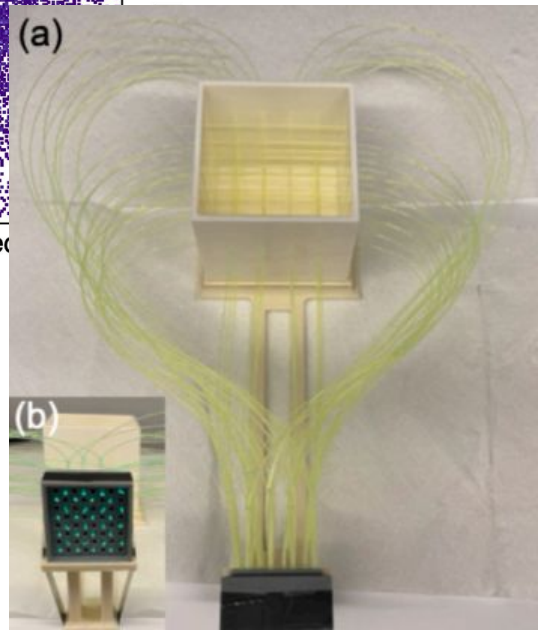
Measuring position & energy





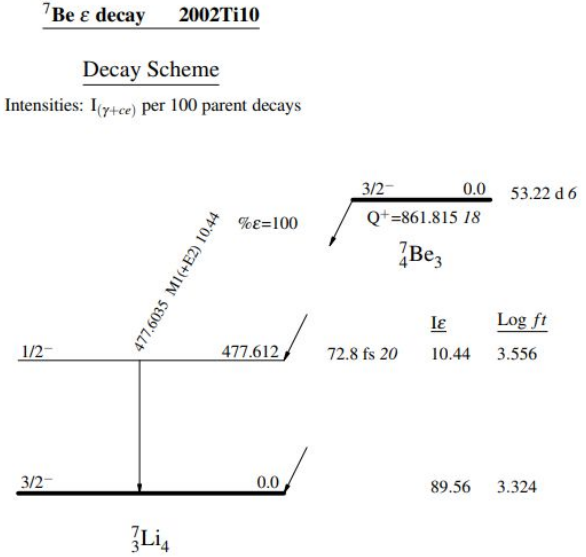
LiquidO 2021

LiquidO 2025

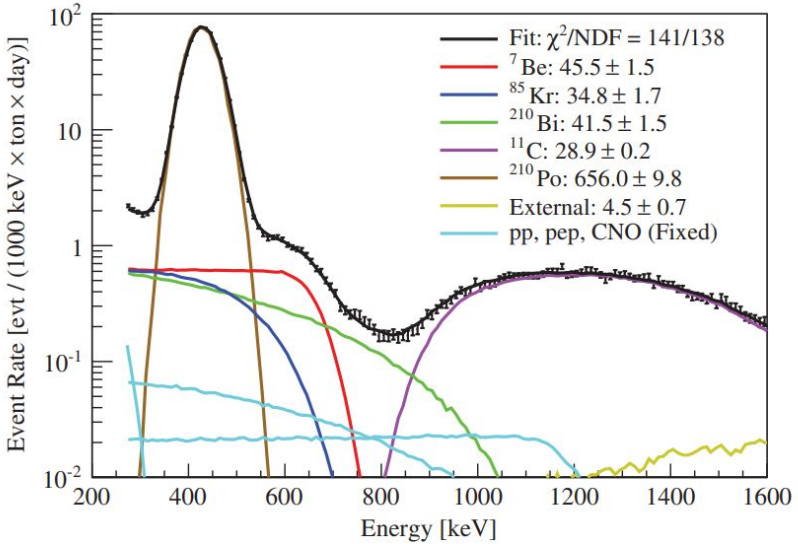


- Opaque scintillator provides excellent spatial and energy resolution.
- Up to 20% indium loading possible.
- Detector can be scaled to multi-ton size.
- Promising R&D results

Calibration using the Sun



PRL 107, 141302 (2011)

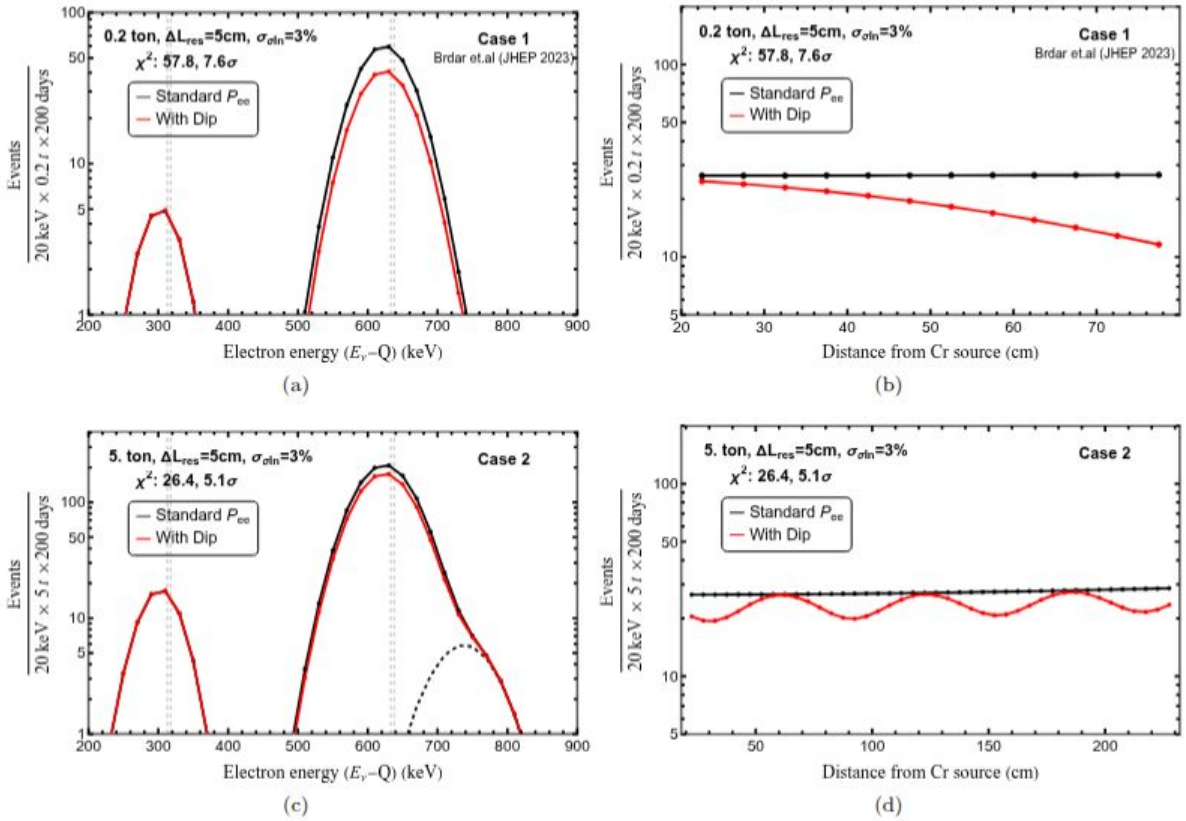


Be-7 has two neutrino lines at 862 and 384 keV and the Be-7 solar flux at Earth has been measured to 2.2% by Borexino using neutrino electron scattering, a purely leptonic process.

To match that precision we need about 100t indium and 10 years of data taking.

Baseline and energy measured

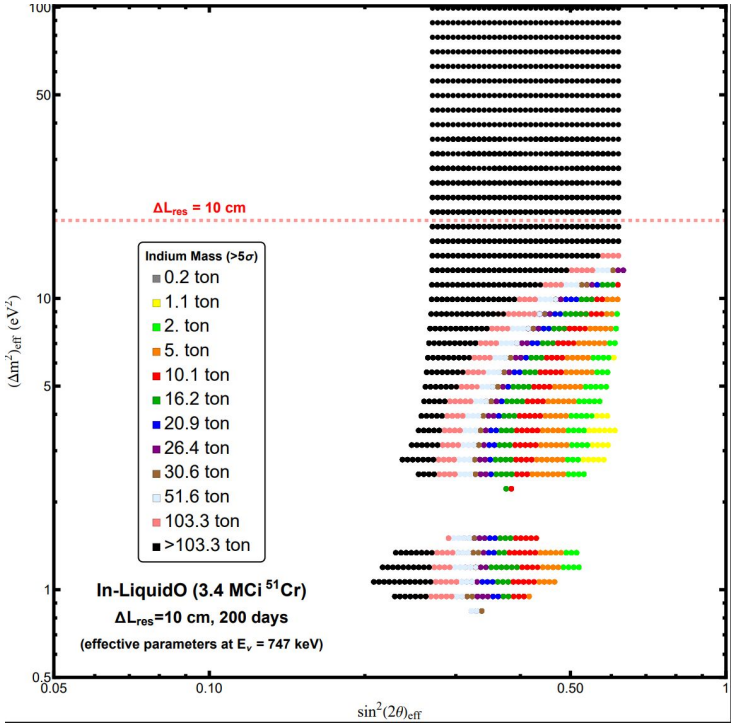
Low energy Cr-51 line and solar Be-7 lines serve as intrinsic, data-driven normalization of the In-115 cross section.



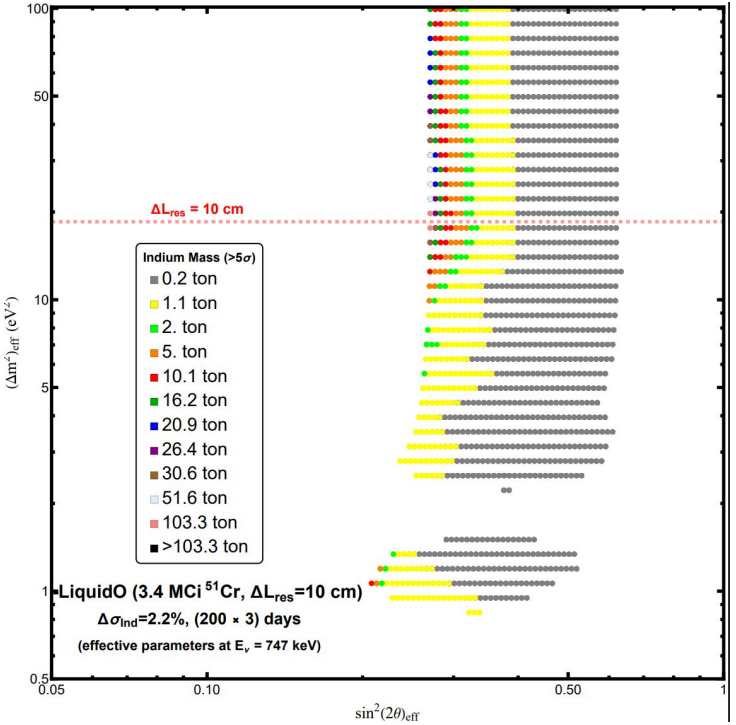
NB: the event rates for Cr-51 and Be-7 scale very differently with detector mass and exposure time.

How well does this work?

1 source, low-E Cr-51 calibration



3 sources, solar Be-7 calibration



Summary

The gallium anomaly is persistent and above 5**σ**. SM explanations like cross section, source strength, radio-chemistry etc. unlikely culprits.

We propose to use a real-time, position and energy sensitive experiment using In-115 as target and the LiquidO detector technology.

World annual indium production ~1000 tons and current price ~$750,000/ton.

Solar Be-7 can provide the necessary calibration of the indium cross section.

Already a one-source few-ton experiment can test non-trivial solutions and prove the technology – a 100t experiment can test **all (?) parameter space for plausible BSM solutions.**