AAP 2023, York
Introduction

John Gregory Learned

Physics, U. Hawaii

History of AAP Locations 2004-2023

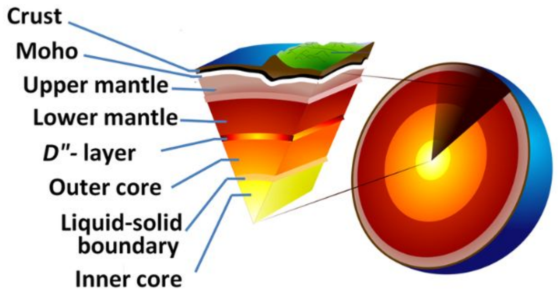
1 2004 Hawaii: http://www.phys.hawaii.edu/~jgl/nacw/agenda.html
2 2005 Hawaii http://www.phys.hawaii.edu/~sdye/hnsc.html, https://inspirehep.net/literature/1644476
3 2006 Livermore https://www.phys.hawaii.edu/aap/2006-livermore/
4 2007 Paris https://inis.iaea.org/collection/NCLCollectionStore/_Public/39/107/39107638.pdf
5 2009 Angra, http://www.cbpf.br/aap2009
6 2010 Sendai, http://www.awa.tohoku.ac.jp/cgi-bin/AAP2010/
7 2011 Vienna, https://apc.u-paris.fr/APC_CS/Conferences/AAP2011/Program.html
8 2012 Hawaii, http://www.phys.hawaii.edu/~jgl/AAP/AAP2012.html
9 2013 Seoul, https://indico.cern.ch/event/245969/
10 2014 Paris, http://aap2014.in2p3.fr/
11 2015 Virginia, https://arxiv.org/abs/1602.04759
12 2016 Liverpool, https://doi.org/10.1088/1742-6596/1216/1/011001
13 2017 BARC, Mumbai, India, http://www.aap.sympnp.org/
14 2018 Livermore, California, aap2018@llnl.gov
15 2019 Guangzhou, China, https://spe.sysu.edu.cn/aap2019
16 2023 York, UK https://indico.ph.liv.ac.uk/event/1195/

Genesis of this AAP series

- All started with 9/11/01 disaster and US Dep. Homeland Security contacting JGL asking what could neutrinos do for US defense.
- Note: was not long after the 1998 news about neutrino oscillations from SuperK & neutrinos were on people's minds, particularly at UH, hence UH president direction…
- First answer from John: "nothing, neutrinos are useless"
- Long history of detection of reactor neutrinos going back to Reines and Cowan in the '60s.
- Previously Russian, French and LLNL/Sandia physicists has started trying to do reactor neutrino monitoring from distances of ~5 – 24 m.
- We began to think about long range (many km) reactor monitoring and if now possible
- DHS offered small grant to write an assessment of what could be done if <u>no concern about costs</u>
- John wrote article suggesting that several gigaton low energy threshold detectors in the oceans could triangulate reactors around the world (except in some mid-Asia locations)
- Notion was scoffed at by old timers in nuclear weapons… "seismic, hydroacoustic, infrasound, air sampling and satellites good enough". However only neutrinos reveal a real nuke.
- Went before JASON committee and presented case… given hard time by such as Freeman Dyson and Richard Garwin, but in the end they conceded that it was possible. Garwin attended AAP2005.

Geoneutrinos Too

- Inspired by the KamLAND results of 2005, showing first detection of geoneutrinos, established contact with Nature commentator Geophysicist Bill McDonough.
- A number of geophysicist and geochemists joined the AAP2005
- Interesting exchanges between groups with different biases.
- Major geo question was/is where does the earth heat originate? Crust? Throughout mantle? Near CMB?
- KamLAND now starting to answer… probably very deep in the earth.
- Geoneutrinos now a growth area, own meetings…. (eg. 3/23 in HI)



0th-order goal: assay the entire Earth by looking at its "neutrino glow"

How much of Earth's heat is primordial (residual)?

How much heat is radiogenic?

Marl Chen, Snowmass 2023

Important Neutrino Questions in Geosciences

- what is the radiogenic contribution (U, Th, 40K) to heat flow and energetics in the deep Earth?
- →otherwise inaccessible, estimates between 9-36 TW
- " how much is mantle convection driven by radiogenic heat?” →1-28 TW
- geoneutrinos can say something about this (U and Th)
- are the fundamental ideas about Earth’s chemical composition and origin correct?

  →bulk Earth chemical composition based on chondrites correct?
- are the basic models of the composition of the crust correct?
- " geoneutrinos can test which models are consistent; →Th/U ratio (and K) important
  - distribution of reservoirs in the mantle?
  - " homogeneous or layered?
  - " lateral variability
- ? nature of the core-mantle boundary?
- ? radiogenic elements in the core?(in particular potassium)
- ? what is the planetary K/U ratio? if only we could detect 40K geoneutrinos

Marl Chen, Snowmass 2023

Other Concepts for Geoneutrino Detection

as mentioned in the Snowmass LOIs and elsewhere

- OBD – Ocean Bottom Detector (Hiroko Watanabe talk)
- THEIA – 50 kton WbLS
- 6Li doped liquid scintillator – good for IBD directionality
- coherent neutrino-nucleus scattering
  - CEvNS LOI (for geoneutrinos, see paper by G. Gelmini et al.)
  - CYGNUS LOI – gaseous detector for recoil direction
- LiquidO – low Ethres CC reaction based on single e+ signal ID
- electron scattering
  - • TPC – M. Leyton, S. Dye, J. Monroe paper
  - • Cherenkov-scintillation separation – Z. Wang and S. Chen paper

Technological Needs

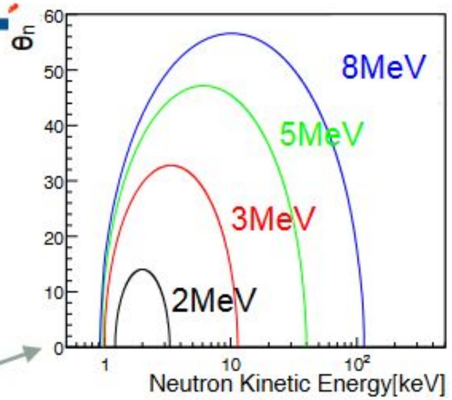
- New photodetectors (huge SiPMs, flexible organic photodetectors?…)
- Ongoing progress in electronics becoming cheaper: need local digitization and transmission, autonomous modules.
- Better cheaper scintillator or water dopants
- Eventually have to go to ocean…. for affordable size, depth, and portability
- Need demonstration experiment
- Hanohano long dormant, new initiative in Japan

AAP 2023 Introduction Summary

- Fruitful 20 yr series of meetings on low energy anti-electron neutrino detection, importance, techniques
- Excitement over RAA now past, back to focus on detectors, reactor monitoring and geoneutrino measurements
- Also unhappy revisions in expected relic neutrinos from SN, being more uniform in flavor content.
- New projects and techniques to be discussed here
- Looking forward to exciting meeting here in York
- Thanks to organizers, particularly Liz.

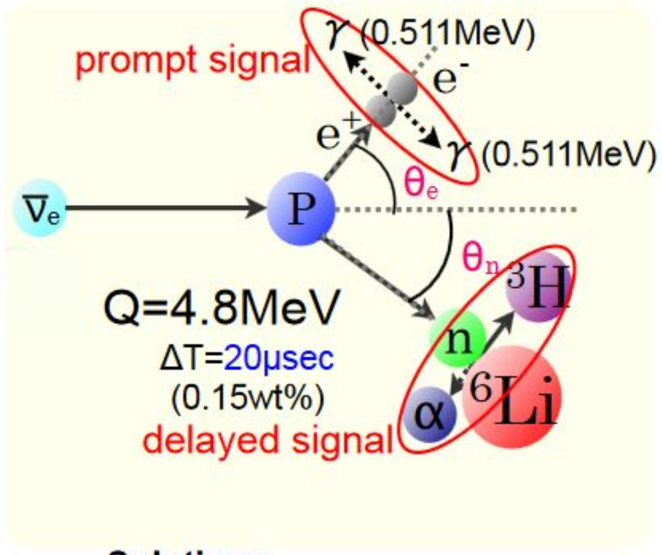
On the topic of directionality…

^{6}Li loaded LS development was an LOI (did not specifically mention geoneutrinos)



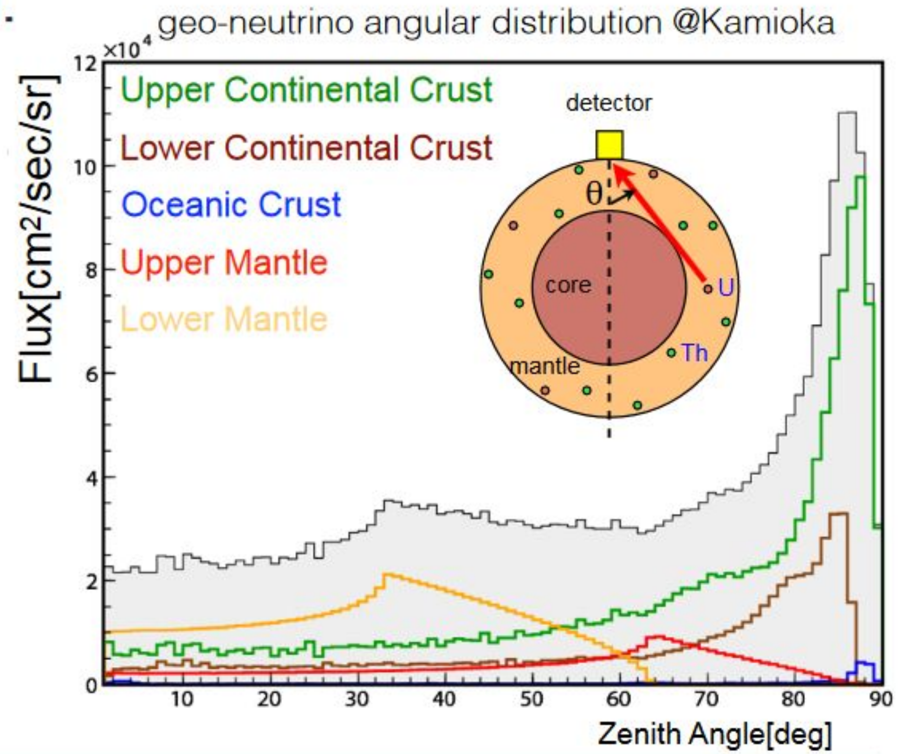
$E_{\bar{\nu}_e}$ <3MeV→θ_n<35°

There has been research into ^{6}Li IBD directionality for geoneutrinos by H. Watanabe et al.



Solutions

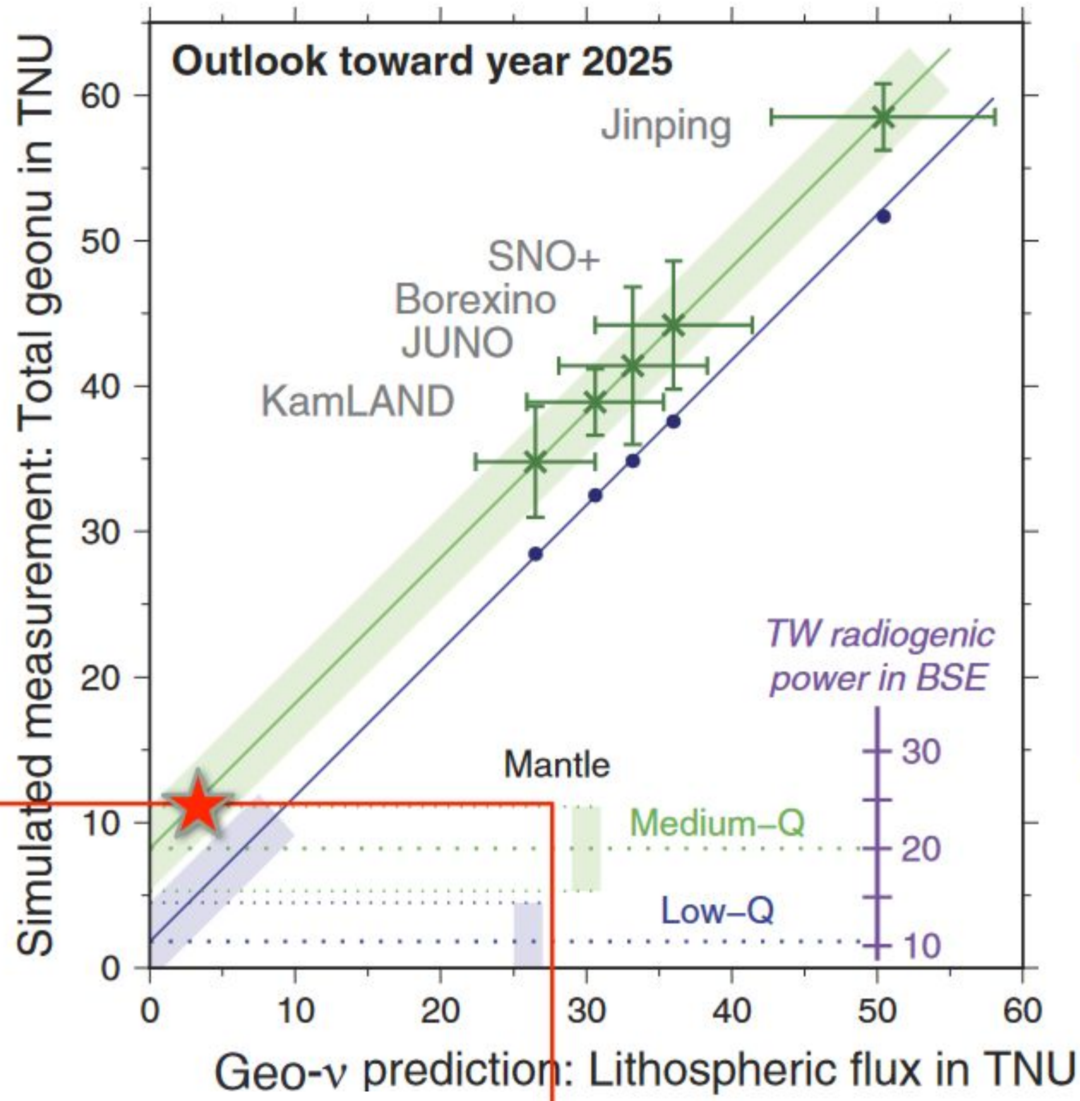
- large neutron capture cross section (^{6}Li 940 barns vs ^{1}H 0.3 barns)
- α does't travel far



directional info separates mantle from crust and rejects background events from reactors 20

Marl Chen & Hiroko Watanabe Snowmass 2023

Future Combined "Global" Analysis
with more experiments



An experiment in the ocean would measure predominantly the mantle component…see OBD

- each experiment needs local crust geology characterized
- combined analysis yields the common mantle component

or

- reveals hidden reservoirs = mantle lateral inhomogeneity

from O. Šrámek et al. Scientific Reports (2016)

^{40}K geoneutrino via charged-current reaction with lower threshold than IBD(p)

$$\bar{\nu}_e + X \rightarrow e^+ + Y$$

"*Probing Earth's missing potassium using the unique antimatter signature of geoneutrinos*"
paper to be submitted

Could a single positron signal be used for ^{40}K geoneutrino detection?
What possible nuclear targets? Which one is best?
What are possible single e^+ backgrounds? →fewer than single e^-

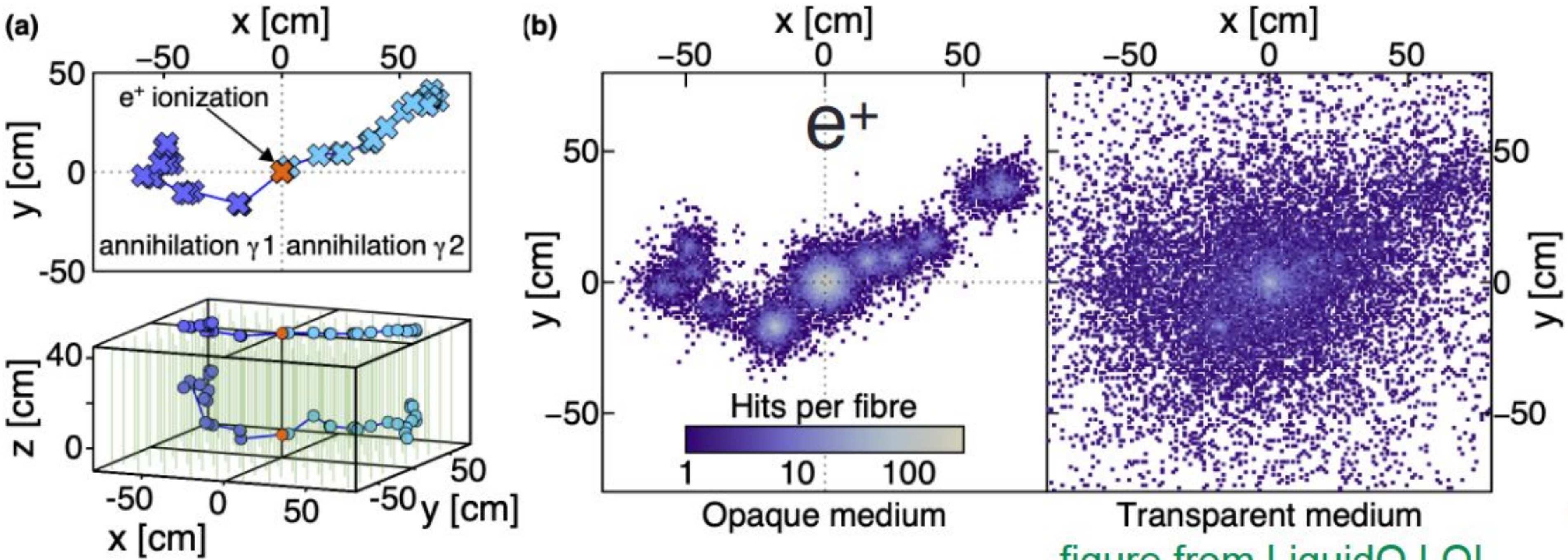
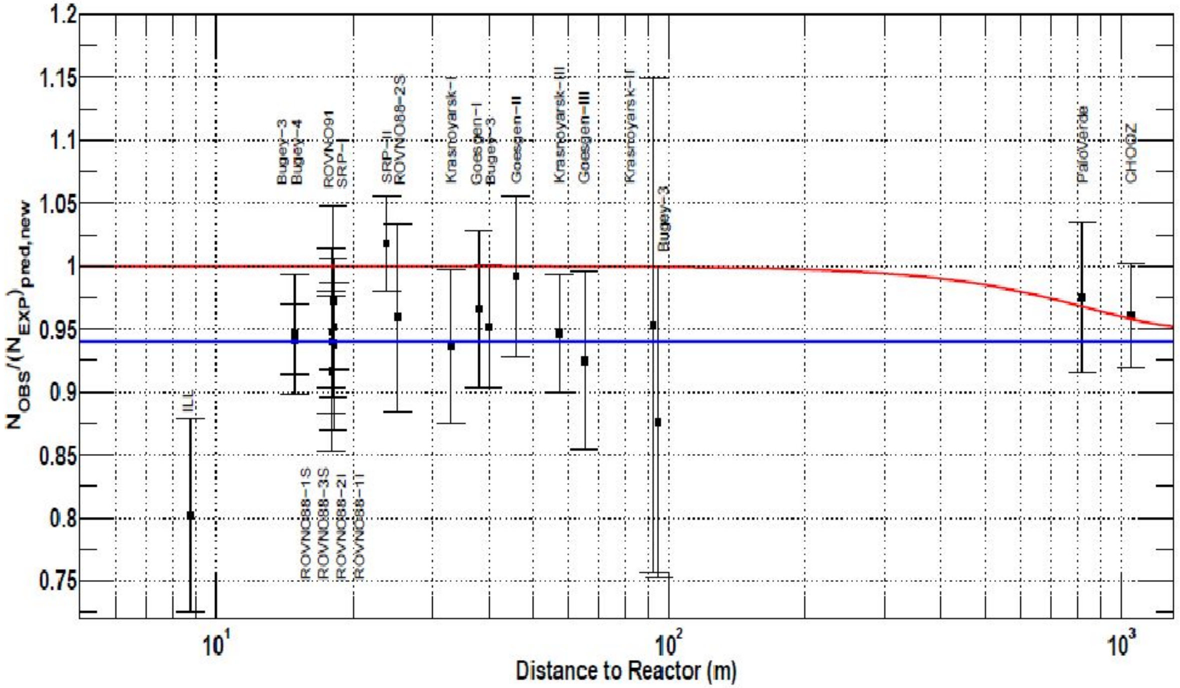


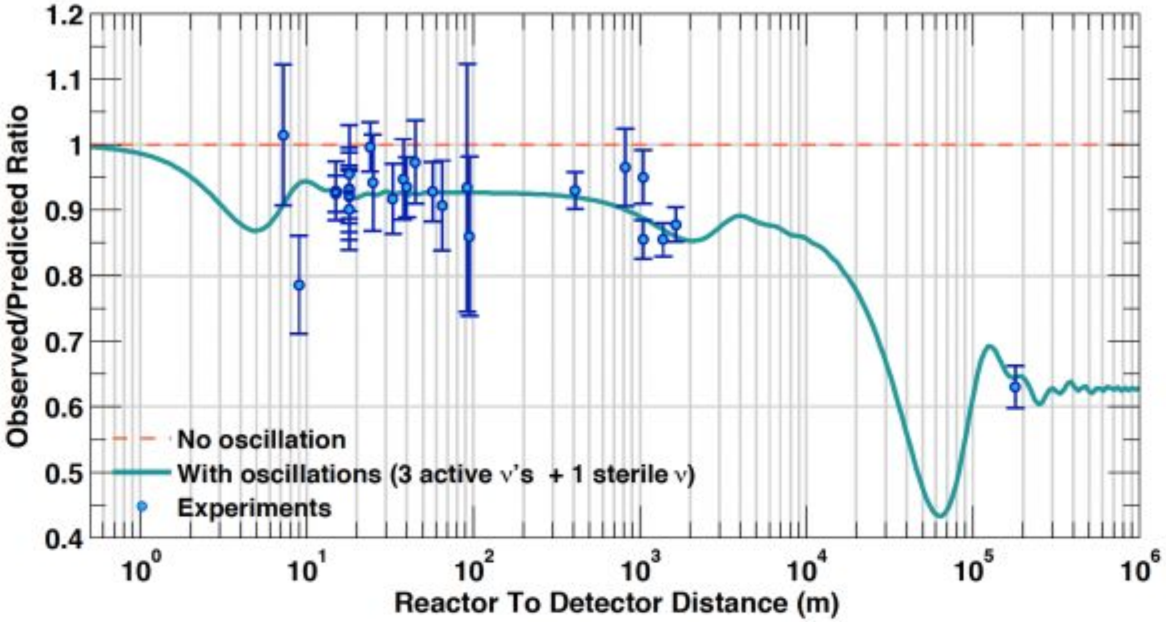
figure from LiquidO LOI

The RAA 2011

- French group proposes problem with nu observations from a few m out from reactors being slightly lower than expectations, G. Mention, *et al*, arXiv:1101.2755



. 5. Illustration of the short baseline reactor antineutrino anomaly. The experimental results are compared to the prediction out oscillation, taking into account the new antineutrino spectra, the corrections of the neutron mean lifetime, and the quilibrium effects. Published experimental errors and antineutrino spectra errors are added in quadrature. The mean aged ratio including possible correlations is 0.943 ± 0.023. The red line shows a possible 3 active neutrino mixing solution, $\sin^2(2\theta_{13}) = 0.06$. The blue line displays a solution including a new neutrino mass state, such as $|\Delta m^2_{\text{new,R}}| \gg 1$ eV^2 and $(2\theta_{\text{new,R}}) = 0.12$ (for illustration purpose only).



Problems with RAA…
now appearing to be gone or greatly reduced

- Two experimental problems (Russian Uranium beta decay measurement +?)
- Concern due to all earlier models normalizing to 1985 measurement of Schreckenbach, et al. PLB 160,325, October 1985
- STEREO Data (arXiv:2210.07664v2, 10/22) seems most damning.
- But 5 MeV bump remains a problem… probably beta decay rates?

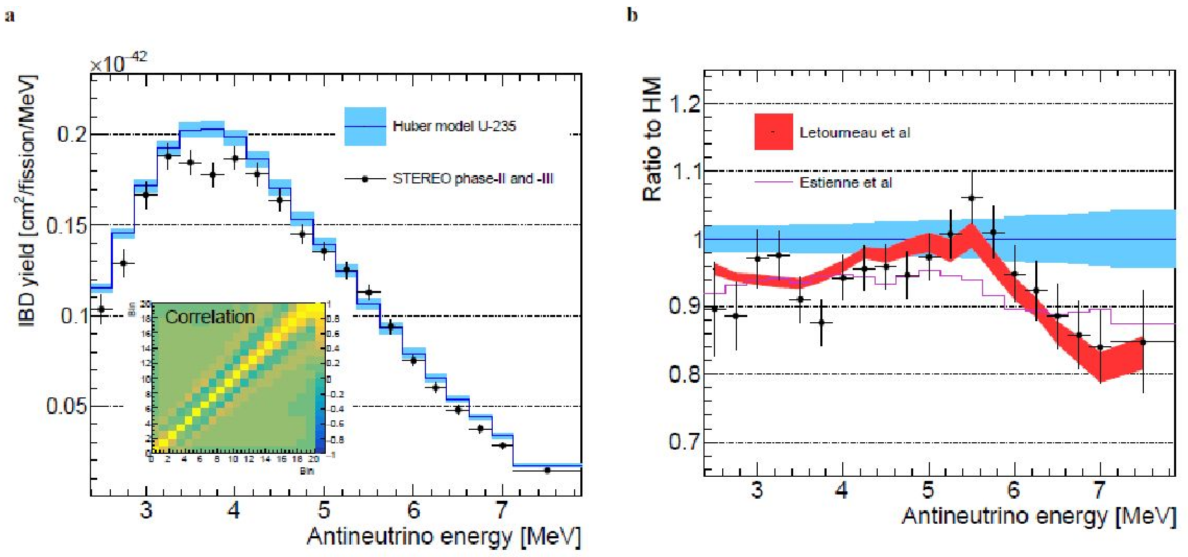


FIG. 3. **New reference ^{235}U antineutrino spectrum. a.** The unfolded antineutrino spectrum associated to the fission of ^{235}U (black points) is shown with the HM prediction (blue) in the true antineutrino energy space. The vertical bars and blue band represent the respective total uncertainties and the vertical axis provides the absolute IBD yield. To obtain the HM prediction the emitted spectrum was multiplied by the theoretical IBD cross section [40]. The matrix illustrates the bin-to-bin correlations. Since the STEREO measurement is statistically limited, the pattern of correlations observed around the diagonal is mainly induced by the unfolding process. **b.** Relative deviations (black points) to the HM prediction (blue), exhibiting significant discrepancies in norm and in shape. However a better agreement is obtained with two recent summation models. The prediction of M. Estienne et al. [9] (magenta) corrects the evaluated nuclear data by including the most recent measurements of the β-strengths of the main fission products. It is in good agreement with the mean deficit measured by STEREO and could indicate the beginning of a shape distortion at high energy. A complementary approach [10] (red band of uncertainties) generalises the correction of the β-spectra to all nuclei by completing the β-decay schemes of the ENSDF nuclear database [41] with a simple phenomenological Gamow-Teller β-decay strength model. Remarkable agreement with the STEREO spectrum is obtained both in normalisation and in shape.

Reevaluating reactor antineutrino spectra with new measurements of the ratio between 235U and 239Pu β spectra

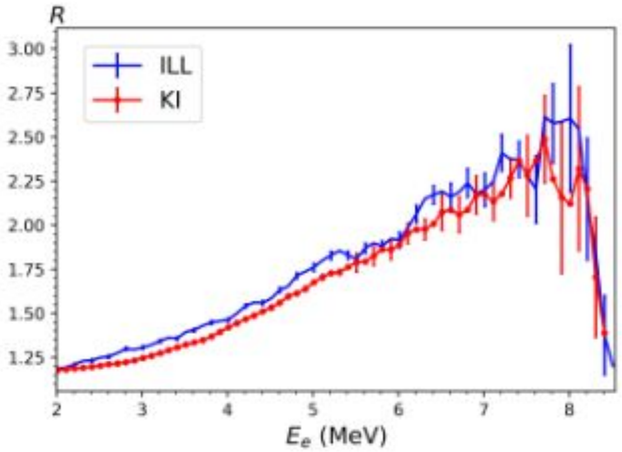


FIG. 1. Ratios $R = {}^eS_5/{}^eS_9$ between cumulative β spectra from ^{235}U and ^{239}Pu from ILL data [11] (the upper curve, blue) and KI data [10] (the lower curve, red). Total electron energies are given. Only statistical errors are shown.

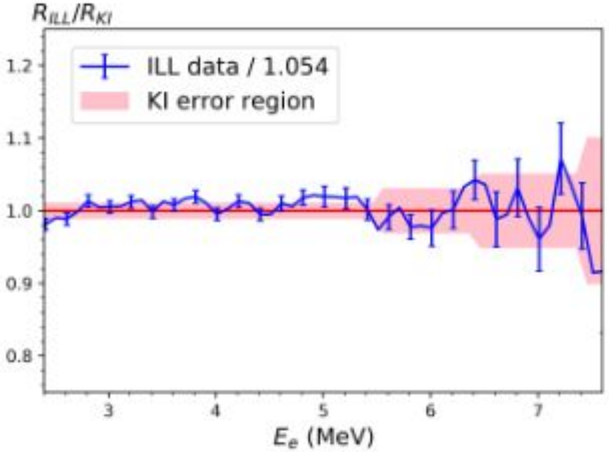


FIG. 2. Ratios R between cumulative β spectra from ^{235}U and ^{239}Pu, normalized to the KI data. Plotted ILL quantities were divided by 1.054, as explained in the text. The colored region shows KI uncertainties.

arXiv:2103.01684v2, Kopelin, et al. 5/2021

Gallium Results

- SAGE experiment, BEST

TABLE XIV. Results of all six Ga source experiments.

Experiment	R
SAGE-Cr [24]	0.95 ± 0.12
SAGE-Ar [25]	0.79 ± 0.095 (+0.09 / -0.10)
GALLEX-Cr1 [27]	0.953 ± 0.11
GALLEX-Cr2 [27]	0.812 ± 0.11
BEST-Inner	0.791 ± 0.05
BEST-Outer	0.766 ± 0.05

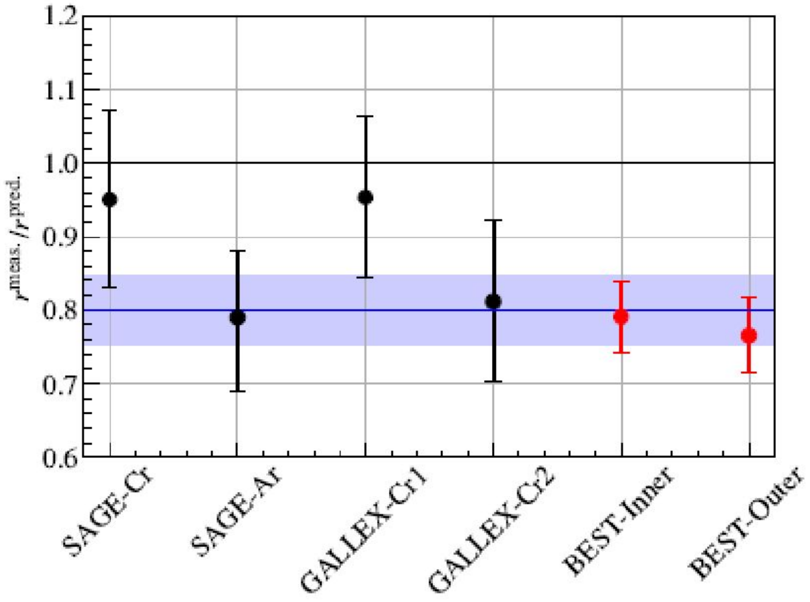
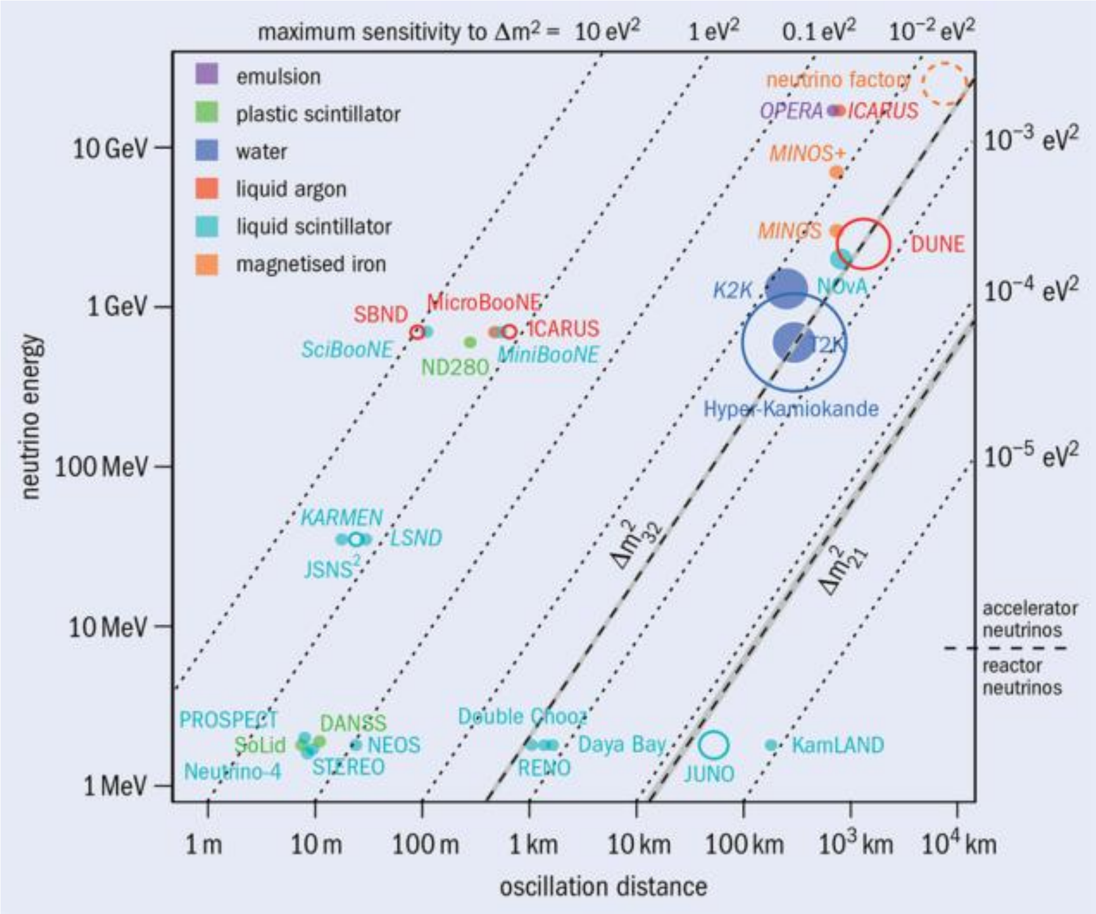


FIG. 12. Ratios of measured and predicted ^{71}Ge production rates in all Ga source experiments. The combined result is shown as a blue band.

arXiv:2201.07364v3, Barinov, et al, 7/22



https://cerncourier.com/a/tuning-in-to-neutrinos. 7/2020