PROCEEDINGS OF SCIENCE

Towards the Solutions for Reactor and Gallium Anomalies

Yu-Feng Li[a,b,*] **and Zhao Xin**[a,b]

[a] *Institute of High Energy Physics, Chinese Academy of Sciences, 19B Yuquan Road, Beijing, China*

[b] *School of Physical Sciences, University of Chinese Academy of Sciences, 19A Yuquan Road, Beijing, China*

E-mail: liyufeng@ihep.ac.cn

The reactor and gallium anomalies of the electron (anti)neutrino disappearance at short baselines have attracted intensive attentions and interests, but have to be resolved yet. In this work or proceeding, we will discuss the status of the reactor and gallium anomalies, both in the framework of 3+1 neutrino oscillation scheme and their possible nuclear-physics interpretations. Future prospect for testing the solution of these anomalies will also be discussed.

XVIII International Conference on Topics in Astroparticle and Underground Physics (TAUP2023)
28.08-1.09.2023
University of Vienna

[*] Speaker

PoS(TAUP2023)194

1. Introduction

The possible existence of light sterile neutrinos is a hot topic of high energy physics , which was motivated by anomalies found in short-baseline neutrino oscillation experiments: the Gallium Anomaly, the Reactor Antineutrino Anomaly, and the LSND and MiniBooNE anomalies (see the reviews in Refs. [1–6]). In this proceeding we discuss the status of reactor and gallium anomalies and compare the neutrino oscillation explanation of the Gallium Anomaly with the constraints from reactor neutrino experiments.

Reactor antineutrinos have been widely used to study the fundamental properties of neutrinos, which are mainly from beta decays of neutron-rich fission fragments generated by the heavy fissionable isotopes ^{235}U, ^{238}U, ^{239}Pu, and ^{241}Pu. In 2011, the improved calculations by Mueller *et al.* [7] and Huber [8] (HM model) predicted reactor antineutrino fluxes which are about 5% larger than the fluxes measured in several short-baseline reactor neutrino experiments. This discrepancy is known as the “reactor antineutrino anomaly” (RAA). In addition to the HM model, other conversion models: HKSS [9], KI (Kurchatov Institute measurement [10]) and HKSS-KI models, summation model: EF model (Estienne, Fallot *et al* [11]) are often considered to predict the reactor antineutrino spectra.

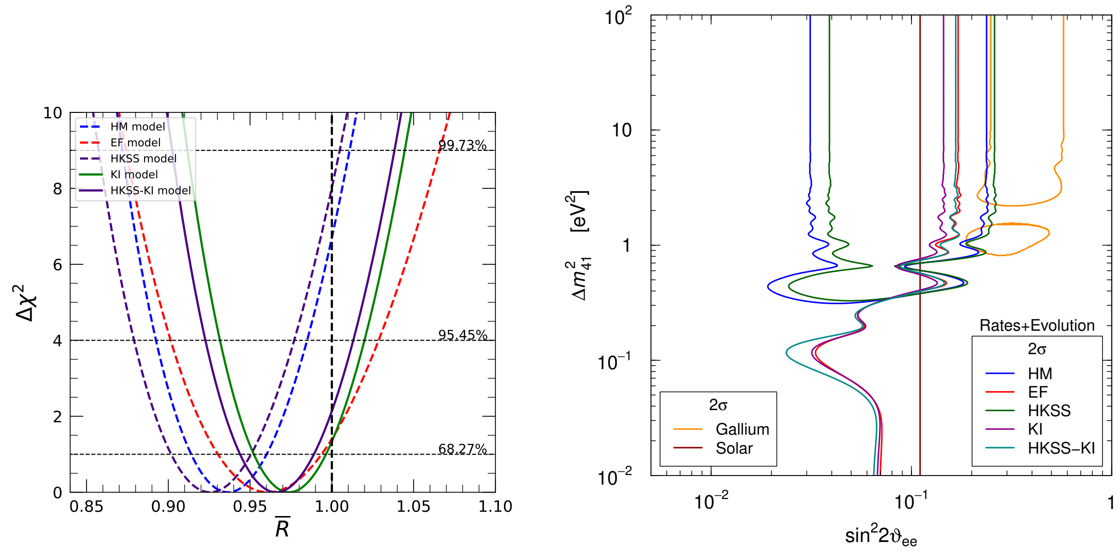
Currently, the Reactor Antineutrino Anomaly is regarded to be resolved or, at least, diminished with the new refinements of reactor flux models [12], but the Gallium Anomaly is reinforced by the new measurements of the BEST experiment [13, 14]. Therefore, it is desirable to pay special attention to the Gallium Anomaly, and look for possible viable solutions.

In Section 2, the possible solution to the reactor anomaly is presented. In Section 3, we show the results of the global fit of the ν_e and $\bar{\nu}_e$ disappearance data. And we close with a discussion and a summary of our results in Section 4.

2. Reactor anomaly

We performed the least-squares χ^2 function to evaluate RAA for these five models. Fig. 1(a) shows the average ratio $\overline{R}$ obtained in our least-squares analysis for these models. The averaged ratio of measured and expected rates for HM model is $\overline{R}_{\mathrm{HM}} = 0.936^{+0.024}_{-0.023}$, corresponding to a reactor antineutrino anomaly with a statistical significance of 2.5σ. From Fig. 1(a), only HM and HKSS conversion models give a reactor antineutrino anomaly [12]. We do not have a significant anomaly if we assume the EF reactor antineutrino fluxes. Also the KI reduction of the ^{235}U IBD yield obtained with the conversion method leads to the practical disappearance of the reactor antineutrino anomaly, especially without the HKSS corrections.

We also discuss the implications of the reactor neutrino flux models for the neutrino oscillation analysis of the short-baseline reactor neutrino data. Fig.1(b) shows the contours of the 2σ allowed regions in the $(\sin^2 2\theta_{ee}, \Delta m^2_{41})$ plane obtained from the neutrino oscillation fit of the reactor data. One can see that there is an indication in favor of neutrino oscillations only for the HM and HKSS models that give a significant reactor rate anomaly above 2σ, as shown in Fig. 1(a). Considering the EF, KI, and HKSS-KI models, for which the reactor rate anomaly is smaller than 2σ, we obtained the 2σ exclusion curves, that allow only small values of $\sin^2 2\theta_{ee}$, including $\sin^2 2\theta_{ee} = 0$, that corresponds to the absence of short-baseline oscillations.



(a) (b)

Figure 1: (a): $\Delta\chi^2 = \chi^2 - \chi^2_{\rm min}$ as a function of the average ratio $\overline{R}$ obtained in our least-squares analysis of short-baseline reactor rates considering the IBD yields of the HM, EF, HKSS, KI, and HKSS-KI models. (b): Contours of the allowed regions in the $(\sin^2 2\vartheta_{ee}, \Delta m^2_{41})$ plane obtained from the neutrino oscillation fit of the combined fit of the reactor rates and reactor evolution data.

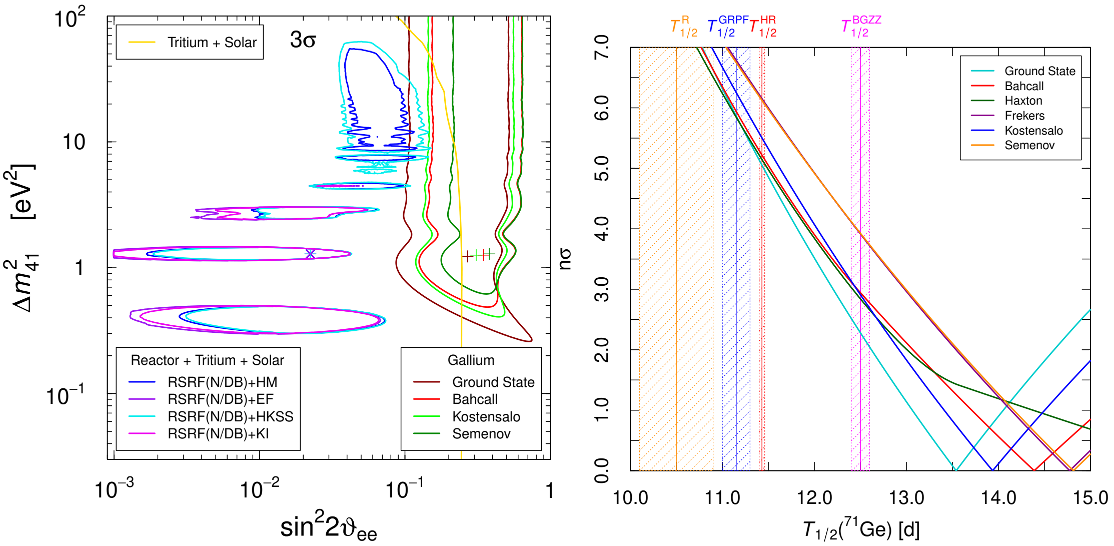
3. Gallium anomaly

We also present the results of the global analysis of the ν_e and $\bar{\nu}_e$ disappearance data in the framework of 3+1 active-sterile neutrino mixing. One can see the dramatic tension between the Gallium data and other experiments constraints in Fig. 2(a), which is also quantified in Ref. [15]. It is very likely that the Gallium Anomaly is not due to neutrino oscillations.

The measurement of $T_{1/2}(^{71}\mathrm{Ge})$ might be a possible explanation for Gallium Anomaly, which has a impact on the detection cross section [16]. The dependence on $T_{1/2}(^{71}\mathrm{Ge})$ of the size of the Gallium Anomaly is shown in Fig. 2(b) for the different cross section models. One can see that $T_{1/2}(^{71}\mathrm{Ge}) \gtrsim 13.5$d is necessary in order to reduce the Gallium Anomaly below about 2σ for all the cross section models.

4. Summary

In conclusion, we think that the Reactor Antineutrino Anomaly discovered in 2011, is practically resolved with a reduction of the ^{235}U flux. As for the Gallium Anomaly discovered in 2007, which is very likely not due to neutrino oscillations, and one of the possible explanations is the measurements of the ^{71}Ge half life.



(a) (b)

Figure 2: (a): Comparison of the contours surrounding the 3σ allowed regions in the $(\sin^2 2\theta_{ee}, \Delta m^2_{41})$ plane obtained from the combined analysis of the data of the reactor rate experiments with different flux models, the spectral ratio experiments, the Tritium experiments, and the solar bound with those obtained from the Gallium data with different cross sections. Also shown is the 3σ bound obtained from the combination of the Tritium and solar bounds.
(b): Size of the Gallium Anomaly as a function of $T_{1/2}(^{71}\mathrm{Ge})$ for different cross section models. The vertical bands show the measurements of $T_{1/2}(^{71}\mathrm{Ge})$.

References

[1] S. Gariazzo, C. Giunti, M. Laveder, Y.F. Li and E.M. Zavanin, *Light sterile neutrinos*, *J. Phys. G* **43** (2016) 033001 [1507.08204].

[2] M. Gonzalez-Garcia, M. Maltoni and T. Schwetz, *Global Analyses of Neutrino Oscillation Experiments*, *Nucl. Phys.* **B908** (2016) 199 [arXiv:1512.06856].

[3] C. Giunti and T. Lasserre, *eV-scale Sterile Neutrinos*, *Ann. Rev. Nucl. Part. Sci.* **69** (2019) 163 [arXiv:1901.08330].

[4] A. Diaz, C. Arguelles, G. Collin, J. Conrad and M. Shaevitz, *Where Are We With Light Sterile Neutrinos?*, *Phys.Rept.* **884** (2020) 1 [arXiv:1906.00045].

[5] S. Boser, C. Buck, C. Giunti, J. Lesgourgues, L. Ludhova, S. Mertens et al., *Status of Light Sterile Neutrino Searches*, *Prog.Part.Nucl.Phys.* **111** (2020) 103736 [arXiv:1906.01739].

[6] B. Dasgupta and J. Kopp, *Sterile Neutrinos*, *Phys.Rept.* **928** (2021) 63 [arXiv:2106.05913].

[7] T.A. Mueller et al., *Improved Predictions of Reactor Antineutrino Spectra*, *Phys. Rev.* **C83** (2011) 054615 [arXiv:1101.2663].

[8] P. Huber, *On the determination of anti-neutrino spectra from nuclear reactors*, *Phys. Rev.* **C84** (2011) 024617 [arXiv:1106.0687].

[9] L. Hayen, J. Kostensalo, N. Severijns and J. Suhonen, *First-forbidden transitions in the reactor anomaly*, *Phys.Rev.* **C100** (2019) 054323 [arXiv:1908.08302].

[10] V. Kopeikin, M. Skorokhvatov and O. Titov, *Reevaluating reactor antineutrino spectra with new measurements of the ratio between U235 and Pu239 β spectra*, *Phys. Rev. D* **104** (2021) L071301 [2103.01684].

[11] M. Estienne, M. Fallot et al., *Updated Summation Model: An Improved Agreement with the Daya Bay Antineutrino Fluxes*, *Phys. Rev. Lett.* **123** (2019) 022502 [arXiv:1904.09358].

[12] C. Giunti, Y.F. Li, C.A. Ternes and Z. Xin, *Reactor antineutrino anomaly in light of recent flux model refinements*, *Phys. Lett. B* **829** (2022) 137054 [2110.06820].

[13] V. Barinov et al., *Results from the Baksan Experiment on Sterile Transitions (BEST)*, arXiv:2109.11482.

[14] V.V. Barinov et al., *A Search for Electron Neutrino Transitions to Sterile States in the BEST Experiment*, 2201.07364.

[15] C. Giunti, Y.F. Li, C.A. Ternes, O. Tyagi and Z. Xin, *Gallium Anomaly: critical view from the global picture of ν_e and $\overline{\nu}_e$ disappearance*, *JHEP* **10** (2022) 164 [2209.00916].

[16] C. Giunti, Y.F. Li, C.A. Ternes and Z. Xin, *Inspection of the detection cross section dependence of the Gallium Anomaly*, *Phys. Lett. B* **842** (2023) 137983 [2212.09722].