PAPER • **OPEN ACCESS**

Neutrino scattering and the reactor antineutrino anomaly

To cite this article: Estela Garcés *et al* 2017 *J. Phys.: Conf. Ser.* **934** 012004

IOP Conf. Series: Journal of Physics: Conf. Series **934** (2017) 012004 doi:10.1088/1742-6596/934/1/012004

Neutrino scattering and the reactor antineutrino anomaly

Estela Garcés[1], Blanca Cañas[2], Omar Miranda[1] and Alexander Parada[2]

[1]Departamento de Física, Centro de Investigación y de Estudios Avanzados del IPN, Apdo. Postal 14-740, 07000 Ciudad de México, México

[2] Universidad Santiago de Cali, Campus Pampalinda, Calle 5 No. 6200, 760001, Santiago de Cali, Colombia

E-mail: egarces@fis.cinvestav.mx

Abstract.

Low energy threshold reactor experiments have the potential to give insight into the light sterile neutrino signal provided by the reactor antineutrino anomaly and the gallium anomaly. In this work we analyze short baseline reactor experiments that detect by elastic neutrino electron scattering in the context of a light sterile neutrino signal. We also analyze the sensitivity of experimental proposals of coherent elastic neutrino nucleus scattering (CENNS) detectors in order to exclude or confirm the sterile neutrino signal with reactor antineutrinos.

1. Introduction

The reactor antineutrino anomaly [1] and the so called gallium anomaly [2, 3] are around 3σ hints that could not be explained in the context of the standard 3 neutrino oscillation picture. On the other side experimental results of solar, atmospheric and accelerator neutrino experiments can be very well explained by the standard 3 neutrino oscillation scheme [4], however the tension produced by these anomalies could be solved by the existence of a sterile neutrino.

In this contribution we discuss our results on the analysis of reactor antineutrino electron scattering data, including a sterile neutrino. The Texono [5], MUNU [6], Rovno [7] and Krasnoyarsk [8] experiments provide the current measurement of antineutrino electron scattering cross sections at very short baselines.

With the recent discovery of CENNS by the COHERENT Collaboration [9], there is new interest in using CENNS experiments as a tool to probe the Standard Model, making possible the study of neutrino magnetic moment, neutrino non standard interactions, among other interesting neutrino properties, and as we propose in this work of sterile neutrinos.

We analyze the potential of the antineutrino neutrino electron scattering and CENNS at reactor experiments, as alternatives to the detection by inverse beta decay (IBD) where the rector anomaly has been reported. This work is mainly based on [10], the authors refer the reader to it for any further details and for updated versions.

IOP Conf. Series: Journal of Physics: Conf. Series **934** (2017) 012004 doi:10.1088/1742-6596/934/1/012004

2. The 3+1 neutrino oscillation scheme

The survival probability in the 3+1 neutrino oscillation scheme for short baseline $\bar{\nu}_e$ can be approximated as

$$P^{\text{SBL}}_{\bar{\nu}_e \to \bar{\nu}_e} = \sin^2 2\theta_{ee} \sin^2 \left(\frac{\Delta m^2_{41} L}{4E} \right), \tag{1}$$

where

$$\sin^2 2\theta_{ee} = 4|U_{e4}|^2(1 - |U_{e4}|^2), \tag{2}$$

the two oscillation parameters that can be studied in short baseline reactor neutrinos are $\sin^2 2\theta_{ee}$ and Δm^2_{41}.

3. Antineutrino electron scattering measurement

The differential cross section for the antineutrino scattering off electrons, at tree level can be written as [11]

$$\frac{d\sigma}{dT} = \frac{2G_F^2 m_e}{\pi} \left[g_R^2 + g_L^2 (1 - \frac{T}{E_\nu})^2 - g_L g_R m_e \frac{T}{E_\nu^2} \right], \tag{3}$$

m_e is the electron mass, G_F is the Fermi constant, and $g_L = 1/2 + \sin^2\theta_{\text{W}}$, $g_R = \sin^2\theta_{\text{W}}$ are the Standard Model couplings. When we perform a chi squared analysis of the current neutrino-electron data [5, 6, 7, 8], and using the most recent predictions for the reactor neutrino flux [12] we find that due to huge uncertainties the exclusion region in the 3+1 oscillation parameter space is not competitive with current global fits. However this is enough to constrain part of the region allowed by the gallium anomaly [2, 3] .

Future measurements from the GEMMA experiment[13] could be very useful to constrain the sterile signal using the antineutrino electron scattering as detection reaction.

4. Sensitivities of CENNS reactor experiments to sterile neutrinos

The coherent elastic neutrino nucleus scattering is a standard model prediction and was proposed in the early seventies by Freedman [14, 15]. In the last few decades several experimental collaborations have been in the quest towards its detection [16, 17, 18, 19], recently it was finally achieved by the first time by the COHERENT experiment using neutrinos from a spallation source.

Table 1. List of CENNS experiments analyzed, reactor composition, energy threshold and baseline.

	^{235}U	^{239}Pu	^{238}U	^{241}Pu	T_{thres}	Baseline
TEXONO(1kg) [16]	0.55	0.32	0.07	0.06	100 eV	28 m
RED100 [20]	0.54	0.33	0.07	0.06	500 eV	19 m
MINER [18]	1.0	-	-	-	10 eV	1-3 m
CONNIE [17]	$\simeq 1.0$	–	–	–	50 eV	30 m

The cross section for CENNS is given by

$$\left(\frac{d\sigma}{dT} \right)^{\text{coh}}_{\text{SM}} = \frac{G_F^2 M}{2\pi} \left[1 - \frac{MT}{E_\nu^2} + \left(1 - \frac{T}{E_\nu} \right)^2 \right] \left\{ [Z g_V^p + N g_V^n]^2 \right\}, \tag{4}$$

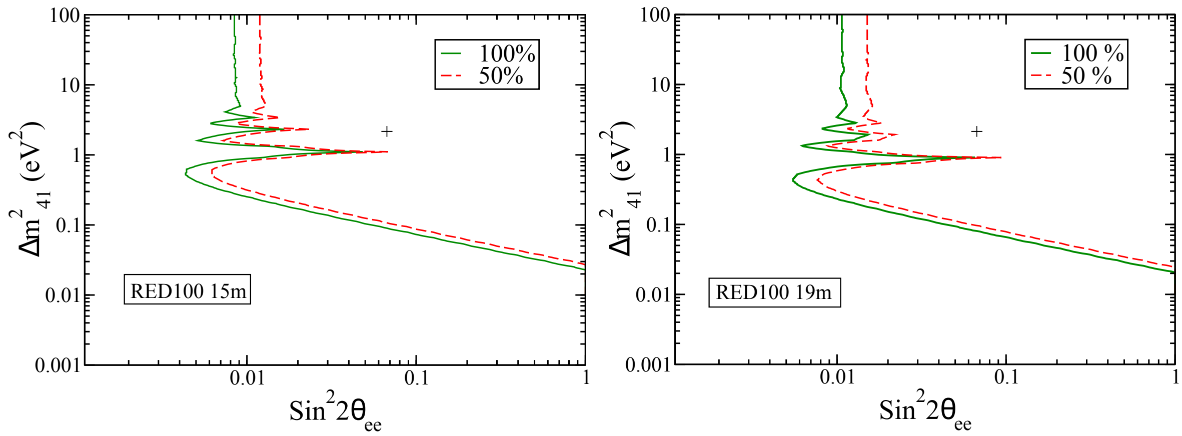

Figure 1. Exclusion regions for the RED100 proposal with a baseline of 15(19) m. The solid (green) line correspond to a detector with 100% efficiency and the dashed (red) lines a 50% efficiency. The current best fit point for the sterile analysis is shown as a reference [10].

G_F ins the Fermi constant, M is the nucleus mass, E_ν the antineutrino energy and T the recoil energy in the nucleus. The neutral current vector couplings are [21]

$$\begin{aligned} g_V^p &= \rho_{\nu N}^{NC}\left(\frac{1}{2} - 2\hat{\kappa}_{\nu N}\hat{s}_Z^2\right) + 2\lambda^{uL} + 2\lambda^{uR} + \lambda^{dL} + \lambda^{dR} \\ g_V^n &= -\frac{1}{2}\rho_{\nu N}^{NC} + \lambda^{uL} + \lambda^{uR} + 2\lambda^{dL} + 2\lambda^{dR}, \end{aligned} \tag{5}$$

where $\rho_{\nu N}^{NC} = 1.0082$, $\hat{s}_Z^2 = \sin^2\theta_W = 0.23126$, $\hat{\kappa}_{\nu N} = 0.9972$, $\lambda^{uL} = -0.0031$, $\lambda^{dL} = -0.0025$, and $\lambda^{dR} = 2\lambda^{uR} = 7.5\times 10^{-5}$ [22].

We calculate the number of expected events in each detector, by

$$N_{\rm events}^{\rm SM} = t\phi_0 \frac{M_{\rm detector}}{M}\int_{E_{\nu\rm min}}^{E_{\nu\rm max}} \lambda(E_\nu) P_{\nu_\alpha\to\nu_\alpha}^{\rm SBL} dE_\nu \int_{T_{\rm min}}^{T_{\rm max}(E_\nu)} \left(\frac{d\sigma}{dT}\right)_{\rm SM}^{\rm coh} dT, \tag{6}$$

in the above equation, $M_{\rm detector}$ is the detector mass, ϕ_0 the incoming neutrino flux and t period of time the experiment is working data recording, $\lambda(E_\nu)$ accounts for he neutrino spectrum, E_ν is the neutrino energy, and T recoil energy of the nucleus. $P_{\nu_\alpha\to\nu_\alpha}^{\rm SBL} = 1$ is the SM case and the $3+1$ oscillation is given by Eq. (1).

The nuclear recoil energy can have a maximum value depending on the neutrino energy and its mass

$$T_{\rm max}(E_\nu) = 2E_\nu^2/(M + 2E_\nu). \tag{7}$$

We will assume one year of data taking and compare statistically the case of no oscillations, $P_{\nu_\alpha\to\nu_\alpha}^{\rm SBL} = 1$ the one in Eq. (1). We will use the prescriptions for the experiments summarized in Table (1) with one year of data taking. We show in Fig. (1) the case of the RED100 experiment with two different baselines and two possible efficiencies. The expectative to improve current constraints sterile neutrino mixing is very promising.

In Fig(2) we compare the antineutrino rate measured if a 5% decrease in the ^{235}U is considered [23] (without sterile neutrino) versus the expected ratio assuming a sterile neutrino $\Delta m^2 = 1.7$ eV ^{2} and $\sin^2 2\theta_{ee} = 0.062$ [24]. It is illustrated how experiments with different baselines, thresholds, and fuel proportions can discriminate possible explanations of the reactor anomaly.

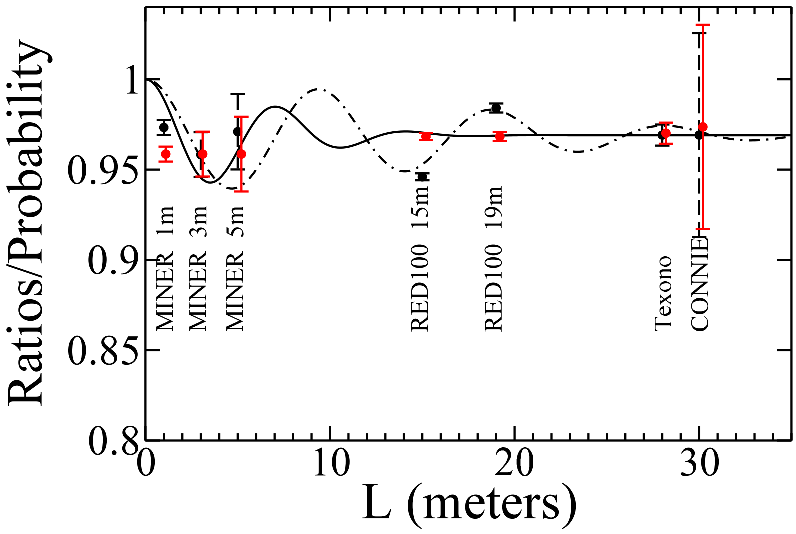

Figure 2. Ratios R of predicted to expected rates for different proposed CENNS experiments. Black dots show the expected ratio for the case of a sterile neutrino with $\sin^2\theta_{ee} = 0.062$ and $\Delta m^2 = 1.7$ eV. The blue dots give the ratio for the case of a decrease in the ^{235}U of 5% [23]. The black and dotted lines represent the average probabilities for a mean energies of 4 MeV, and 6.5 MeV and $\sigma = 15\%$ of resolution. The error bars take into account the statistical errors.

5. Conclusions

In this contribution we obtain an exclusion region to the mixing of a sterile neutrino from reactor antineutrino electron scattering data. We analyze the TEXONO, Rovno, MUNU and Krasnoyarsk experiments taking into account the most recent theoretical prediction of the reactor neutrino flux. We find that given the poor statistics the limit is not competitive with the current best fit point of sterile neutrinos but it is possible to exclude part of the region allowed by the gallium anomaly. We also study the future sensitivity of some CENNS experiments, using reactor neutrinos and we find that CENNS experiments could provide a way to finally discover or rule out the existence of a sterile neutrino.

5.1. Acknowledgments

The authors thank Dmitri Akimov and Alexis Aguilar-Arevalo for useful discussions; E.A.G. would like to thank Gabriel Lopez-Castro and Red temática de Altas Energía (RED FAE) for support to attend the ICPPA 2017 conference. This work has been supported by CONACyT. E. A. G. thanks CONACYT Project No. FOINS-296-2016 (Fronteras de la Ciencia).

References

[1] Mention G, Fechner M, Lasserre T, Mueller T A, Lhuillier D, Cribier M and Letourneau A 2011 *Phys. Rev.* D **83** 073006
[2] Laveder M 2007 *Nucl. Phys. Proc. Suppl.* **168** 344 doi:10.1016/j.nuclphysbps.2007.02.037
[3] Giunti C and Laveder M 2011 *Phys. Rev.* C **83** 065504 doi:10.1103/PhysRevC.83.065504 (*Preprint* 1006.3244)
[4] de Salas P F, Forero D V, Ternes C A, Tortola M and Valle J W F 2017 Status of neutrino oscillations 2017 *Preprint* 1708.01186
[5] Deniz M *et al.* [TEXONO Collaboration] 2010 *Phys. Rev.* D **81** 072001
[6] Amsler C *et al.* [MUNU Collaboration] 1997 *Nucl. Instrum. Meth.* A **396** 115
[7] Derbin A I, Chernyi A V, Popeko L A, Muratova V N,Shishkina G A and Bakhlanov S I 1993 *J. Exp. Theor. Phys Lett.* **57** 768, *Pisma Zh. Eksp. Teor. Fiz.* **57** 755

[8] Vidyakin G S, Vyrodov V N, Gurevich I I, Kozlov Y V, Martemyanov V P, Sukhotin S V, Tarasenkov V G and Turbin E V *et al.* 1992 *J. Exp. Theor. Phys Lett.* **55** 206, *Pisma Zh. Eksp. Teor. Fiz.* **55** 212
[9] Akimov D *et al.* 2017 *Science* 357 (6356) 1123-1126
[10] Cañas B C, Garcés E A, Miranda O G and Parada A 2017 The reactor antineutrino anomaly and low energy threshold neutrino experiments *Preprint* 1708.09518
[11] Vogel P and Engel J 1989 *Phys. Rev.* D **39** 3378
[12] Mueller T A, Lhuillier D, Fallot M, Letourneau A, Cormon S, Fechner M, Giot L and Lasserre T *et al.* 2011 *Phys. Rev.* C **83** 054615
[13] Beda A G, Brudanin V B, Egorov V G, Medvedev D V, Pogosov V S, Shirchenko M V and Starostin A S 2012 *Adv. High Energy Phys.* **2012** 350150
[14] Freedman D Z 1974 *Phys. Rev.* D **9** 1389
[15] Drukier A and Stodolsky L 1984 *Phys. Rev.* D **30** 2295
[16] Wong H T 2008 *Mod. Phys. Lett.* A **23** 1431
[17] Aguilar-Arevalo A *et al.* [CONNIE Collaboration] 2016 *J. Instrum.* **11** 07024
[18] Dutta B, Mahapatra R, Strigari L E and Walker J W 2016 *Phys. Rev.* D **93** 013015
[19] Collar J I, Fields N E, Hai M, Hossbach T W, Orrell J L, Overman C T, Perumpilly G and Scholz B 2015 *Nucl. Instrum. Meth.* A **773** 56
[20] Akimov D Y *et al.* [RED Collaboration] 2013 *J. Instrum.* **8** 10023
[21] Barranco J, Miranda O G and Rashba T I 2005 *J. High Energy Phys.* **0512** 021
[22] Beringer J *et al.* [Particle Data Group Collaboration] 2012 *Phys. Rev.* D **86** 010001
[23] Giunti C 2017 *Phys. Lett.* B **764** 145
[24] Gariazzo S, Giunti C, Laveder M and Li Y F 2017 *J. High Energy Phys.* **1706** 135