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Omnibus experiment: CPT and CP violation with sterile neutrinos

Omnibus experiment: CPT and CP violation with sterile neutrinos

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Abstract. The verification of the sterile neutrino hypothesis and, if confirmed, the determination of the relevant oscillation parameters is one of the goals of the neutrino physics in near future. We propose to search for the sterile neutrinos with a high statistics measurement utilizing the radioactive sources and oscillometric approach with large liquid scintillator detector like LENA, JUNO, or RENO-50. Our calculations indicate that such an experiment is realistic and could be performed in parallel to the main research plan for JUNO, LENA, or RENO-50. Assuming as the starting point the values of the oscillation parameters indicated by the current global fit (in 3 + 1 scenario) and requiring at least 5σ confidence level, we estimate that we would be able to detect differences in the mass squared differences Δm^2_{41} of electron neutrinos and electron antineutrinos of the order of 1% or larger. That would allow to probe the CPT symmetry with neutrinos with an unprecedented accuracy.

1. Introduction

The existence of sterile neutrinos have been proposed as an explanation of anomalies in short baseline accelerator experiments: LSND [1], and MiniBooNE [2] as well as in gallium-based solar neutrino experiments: GALLEX [3], and SAGE [4]. Anomalies were also reported in the reactor neutrino spectra at short distances [5]. There is still no solid evidence for the existence of sterile neutrinos. The global fit [6] indicates that the parameters governing the ν_e - ν_{sterile} oscillation are of the order of $\Delta m^2_{41} \approx 1$ eV^2 and $\sin^2 2\theta_{ee} \approx 0.1$. By conducting a high significance measurement of the oscillation parameters of both neutrinos and antineutrinos the conservation of CPT and CP symmetries can be probed.

2. Neutrino oscillometry and sterile neutrinos

In oscillometric measurement the substantial part of the oscillation probability curve is measured within the dimensions of the single detector. This approach has been explained in details in our previous publications [7, 8, 9, 10]. In the case of electron neutrinos the imprint of the sterile neutrinos will be the oscillatory behavior of deficit of the neutrino events with respect to the distance from the neutrino source. By assuming the $\Delta m^2_{41} \sim 1$ eV^2, the oscillometric measurement requires neutrino energies below few MeV.

3. Proposed experiment

We propose to use of ^{51}Cr [11] as a source of electron neutrinos previously used in for example in GALLEX. The ^{51}Cr decays with $T_{1/2} = 27.7$ days via electron capture emitting ∼750 keV (mono-energetic) neutrinos. The expected activity at the start is of the order of 300 PBq [11]. For an low-energy electron antineutrinos mono-energetic sources do not exist. In addition, the 1.8 MeV detection threshold of the inverse beta decay sets the lower limit to the required neutrino energy. In this case the choice [12] is the ^{144}Ce-^{144}Pr mother-daughter combination providing detectable neutrinos with energies in the 1.8-3 MeV energy range. The half-life of the source is determined by ^{144}Ce with $T_{1/2} = 258$ days. The daughter nucleus decays with $T_{1/2} = 17$ min. The expected activity at the start of the measurement is around 4.6 PBq. For the measurement, we have considered two scenarios: (i) placing of a strong radioactive source in the center of JUNO-like spherical detector [13] and (ii) placing of a source on the top of LENA-like cylindrical detector[14] . From the point of view of the detection efficiency and symmetry the first option provides the ultimate scenario, while the second one is considerably easier to realize, as the integrity of the LS tank does not have to be compromised.

4. Simulation results

The proposed experiment will be sensitive to two of the new oscillation parameters associated with the sterile neutrinos: θ_{ee} and Δm^2_{41}. The former governs the oscillation amplitude of the deficit of the neutrino events. The later determines the oscillation length. The accuracy of the parameter extraction is limited by several factors including the uncertainty in the determination of the source activity (normalization), the position and energy determination capability of the detector and the background level. Due to normalization the accuracy of the extraction of θ_{ee} relatively poor. In this analysis we focus only on the extraction of Δm^2_{41}. The Monte Carlo method is used to generate the measurement and to take into account the uncertainties and background sources. The parameter extraction is based on dividing the observed, background rejected events, with the expected non-oscillation scenario and fitting the probability function to that. The simulations were done for two radioactive sources with the initial activities described above and with the exposures of 55 days with ^{51}Cr and 300 days with ^{144}Ce-^{144}Pr. The background for ^{51}Cr is induced by the solar neutrinos and the gamma-rays. The electron antineutrino measurement is essentially background-free as the event rate from reactor neutrinos and geoneutrinos are at the level of sub-permille compared to event rate from the source. The energy dependent performance of the energy and position reconstruction of JUNO and LENA are taken into account and were taken from the specifications provided by JUNO and LENA publications. Fig. 1 illustrates the outcome of the simulations. It shows the sensitivity to extract Δm^2_{41} value at the 5 confidence level as a function of the Δm^2_{41}. For the $\sin^2 2\theta_{ee}$ we have used two values: 0.1 and 0.05. The calculations were made for two detector geometries: a sphere (JUNO) with the source in the center (left panels), and a cylinder (LENA) with the source on the top (right panels). The top panels summarize the results with ^{144}Ce-^{144}Pr source and the two bottom panels show the outcome of the simulations for the ^{51}Cr source.

5. Conclusions

If the sterile neutrinos do exist, the experimental scenario we propose would be of a fundamental importance to the study of their properties and to the physics behind them. The experiment would not compromise the main research goals proposed for the new large-scale liquid scintillator detectors. For that reason, even if Borexino SOX would yield a negative result, it would be still worthwhile to perform the oscillometric measurements on a large scale using detectors like JUNO, LENA, or RENO-50. Our results show that in a favorable case (^{51}Cr) one may expect sensitivity of a few per-mille in the determination of Δm^2_{41}. In the case of ^{144}Ce-^{144}Pr source the sensitivity is just over one percent. It may not be sufficient to detect subtle effects but it

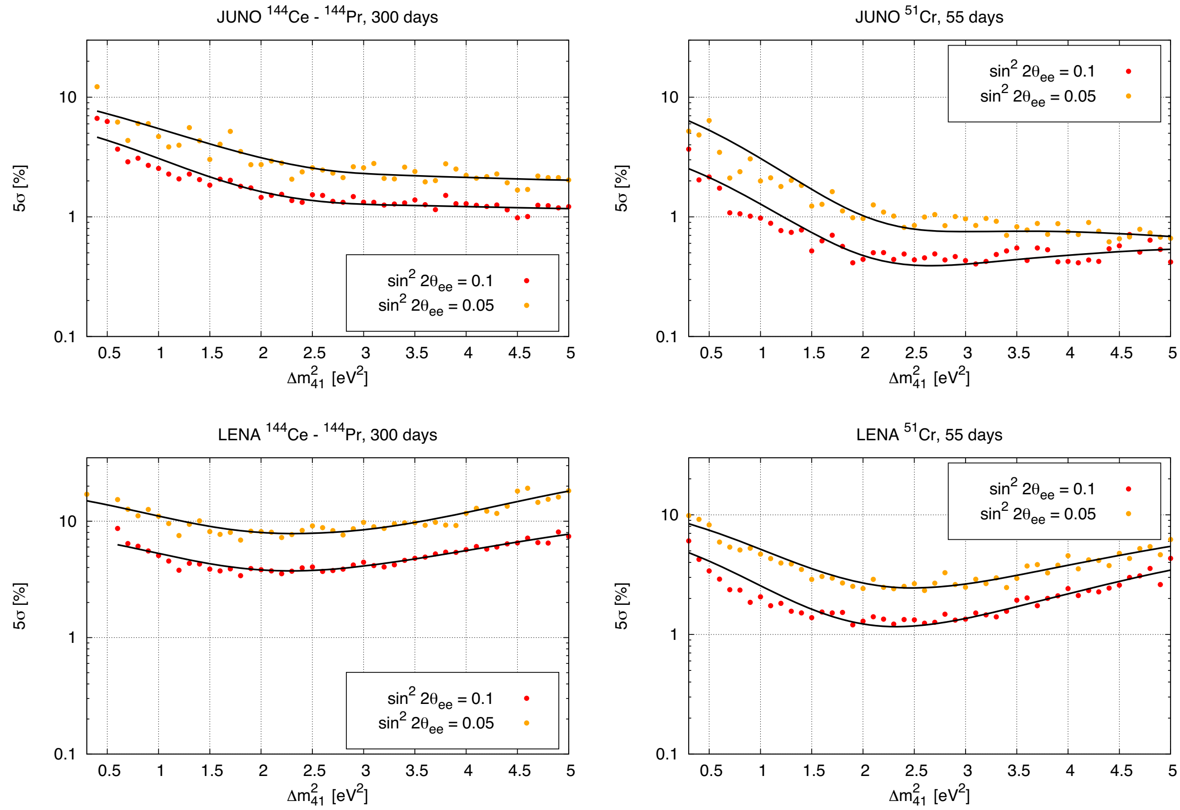

Figure 1. Outcome of the simulations showing the sensitivity to extract m^2_{41} at 5σ confidence level with respect to the true value of the Δm^2_{14} and two values of $\sin^2 2\theta_{ee}$.

would provide an independent probe in the search for the symmetry violations in the leptonic sector.

References

[1] Aguilar-Arevalo A *et al.* (LSND) 2001 *Phys. Rev.* **D64** 112007 (*Preprint* `hep-ex/0104049`)
[2] Aguilar-Arevalo A A *et al.* (MiniBooNE) 2013 *Phys. Rev. Lett.* **110** 161801 (*Preprint* `1207.4809`)
[3] Kaether F, Hampel W, Heusser G, Kiko J and Kirsten T 2010 *Phys. Lett.* **B685** 47–54 (*Preprint* `1001.2731`)
[4] Abdurashitov D *et al.* 1994 *Phys. Lett.* **B328** 234–248
[5] Mention G, Fechner M, Lasserre T, Mueller T A, Lhuillier D, Cribier M and Letourneau A 2011 *Phys. Rev.* **D83** 073006 (*Preprint* `1101.2755`)
[6] Giunti C and Laveder M 2011 *Phys. Rev.* **D84** 073008 (*Preprint* `1107.1452`)
[7] Novikov Yu N *et al.* 2011 (*Preprint* `1110.2983`)
[8] Vergados J D, Giomataris Y and Novikov Yu N 2012 *Nucl. Phys.* **B854** 54–66 (*Preprint* `1103.5307`)
[9] Loo K, Enqvist T, Hissa J, Nesterenko D, Novikov Yu N, Trzaska W H, Vergados J and Wurm M 2012 *J. Phys. Conf. Ser.* **375** 042053
[10] Smirnov M V, Loo K K, Novikov Y N, Trzaska W H and Wurm M 2015 *Nucl. Phys.* **B900** 104–114 (*Preprint* `1505.02550`)
[11] Cribier M *et al.* 1996 *Nucl. Instrum. Meth.* **A378** 233–250
[12] Cribier M, Fechner M, Lasserre T, Letourneau A, Lhuillier D, Mention G, Franco D, Kornoukhov V and Schonert S 2011 *Phys. Rev. Lett.* **107** 201801 (*Preprint* `1107.2335`)
[13] An F *et al.* (JUNO) 2015 (*Preprint* `1507.05613`)
[14] Wurm M *et al.* (LENA) 2012 *Astropart. Phys.* **35** 685–732 (*Preprint* `1104.5620`)