Ga source experiment for detection of short baseline neutrino oscillations

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Abstract. The status of the feasibility studies for a proposed Ga source experiment to search for possible electron neutrino transitions into sterile states is presented. The advantages of the proposed technique are considered. The experiment has the potential to detect neutrino oscillation transitions with mass-squared difference \( \Delta m^2 > 0.5 \text{ eV}^2 \) with a sensitivity to disappearance of electron neutrinos of a few percent.

1. Introduction

Interpretation of the LSND results by oscillations with large value of \( \Delta m^2 (\sim 1 \text{ eV}^2) \) [1] can be applied also to results of a number of other experiments. Indications for existence of short baseline neutrino oscillations (L/E \~{} 1 m/MeV) have been obtained in the accelerator experiment MiniBooNE [2], gallium experiments with artificial neutrino sources SAGE and GALLEX [3], and the measurements of electron antineutrino fluxes (after corrections) from nuclear reactors such Bugey, Goesgen and a number of others with baselines less than 100 m [4].

Because of low data statistics and the complexity of the experiments, one cannot exclude interpretations that do not include oscillations. A proposed experiment with an intense artificial neutrino source on Ga target of SAGE detector [5] would have sensitivity to short baseline oscillations with an amplitude of about several percent and should also impose tight constraints on oscillation parameters..

Measurements with artificial neutrino sources have been carried out on Ga solar neutrino detectors SAGE and GALLEX to verify the efficiency of their experimental procedures. In those experiments, a compact intense source of monochromatic neutrinos was placed in center of Ga targets. The number of neutrino interactions was determined by the production of \(^{71}\text{Ge}\) atoms in reaction of inverse \( \beta \)-decay on \(^{71}\text{Ga}\) nuclei.

Ratio of the average neutrino capture rate from sources in four calibration experiments to the expected rate was \( R = 0.87 \pm 0.05 \) [3]. The obtained result can be explained with existence of short baseline oscillations. Probability of electron neutrino disappearance by oscillations with large \( \Delta m^2 \)
value can be described as $P_{ee} = 1 - \sin^2(2\theta) \cdot \sin^2\left(\frac{1.27 \Delta m^2 (eV^2) L(m)}{E_\nu (MeV)}\right)$. If the obtained small capture rate in Ga source experiments is determined by oscillations only, the best fit oscillation parameters are $\Delta m^2 = 2.15 \text{ eV}^2$ and $\sin^2 2\theta = 0.24$ [5].

2. Proposed experiment

The hypothesis of short baseline oscillations can be verified with high statistics in new Ga neutrino source experiment. The $^{51}$Cr and $^{37}$Ar sources used in Ga experiments emit monochromatic neutrinos. Therefore, the dependence of neutrino capture rate from a compact source placed into the center of target on distance repeats the correspondent dependence of survival probability $P_{ee}(L)$. The positional sensitivity of the detector, which is necessary for determination of oscillations parameters, can be accomplished in Ga measurements by dividing the target into spherical zones. It is technically difficult to realize the dividing to a set of zones, and in addition the statistics in each zone turns out to be limited. However, by dividing the target into 2 zones with the same neutrino path length, it is possible to obtain stringent limits for neutrino oscillation parameters.

In the proposed experiment, the target will consist of 50 t of liquid metal Ga from the SAGE detector. Two zones of the target will be divided by thin spherical shell with center in the place where the neutrino source will be situated. Ga masses in the internal and in the external zones will be 8 t and 42 t; the average path length in both zones will be about 55 cm. The external zone will be bounded with cylindrical shell with a diameter equal to its height. Compared to a spherical form of the target, the capture rate in a target with cylindrical form turns out to be only 2% less. Figure 1 shows capture rates in two zones dependent on the $\Delta m^2$ value for the $^{51}$Cr source. Oscillations will be discovered in the experiment if one obtains a large difference in the capture rate in the two zones, or if one observes a suppression of capture rates in both zones.

![Figure 1](image_url)

**Figure 1.** Ratio of measured capture rate to predicted rate in the inner zone (red), ratio of measured capture rate to predicted rate in the outer zone (blue) and ratio of the rates (black) versus $\Delta m^2$ for the case of $\sin^2(2\theta)=0.30$.

We intend to use in the experiment a $^{51}$Cr source ($T_{1/2} = 27.7 \text{ d}$) with activity 3 MCi. Neutrinos from the source have an energy 0.75 MeV (90%) and 0.43 MeV (10%). Contribution of the capture rate from neutrinos with lower energy is less than 5%. The expected neutrino capture rate from the source should be about 65 per day in the beginning of the first exposure in each target zone. We intend to carry out 10 exposures with 9 days for each. The produced $^{71}$Ge will be extracted from target after each exposure within one day as a standard procedure. Simultaneously, the measurement of activity of the source will be performed using a calorimetric procedure.

The total number of events from decay of $^{71}$Ge atoms extracted from the target should be about 870 in each zone. The statistical uncertainty is expected to be 3.7% in each zone and 2.6% in the whole target. The only source of background in the experiment arises from solar neutrinos. Characteristics of this background reliably investigated for the 20-year period of Ga solar measurements: $^{71}$Ge
production rate from solar neutrinos is 0.02 atom per day in 1 t of Ga. In all exposures the average ratio of a number of neutrino captures from source and from the Sun should be about 140 in the internal zone of target and 27 – in the external zone.

Systematic uncertainties of the experiment have been carefully studied in solar measurements and in two previous source experiments. The total systematic uncertainty is expected to be ±2.6% and includes the uncertainty from the efficiency of the extraction procedures and counting of the produced $^71$Ge, the masses of target and Ge-carrier, the background processes, and the measurements of the source activity.

An additional source of uncertainty is the uncertainty of cross section of capture of neutrino from Cr source on Ga. For the evaluation of cross sections, we use data from Reference [6], where the uncertainty of cross section is +3.6/-2.8%. The expected uncertainty obtained in quadratic summarizing of statistical and systematic uncertainties, as well as the uncertainty of cross section, should be about 5.5% for each zone of the target and 4.8% for the total target.

3. Conclusion
Possible results on limits of regions for allowed oscillation parameters which can be obtained in the proposed 2-zone experiment are shown in figure 2. The measured capture rates in two zones denoted

![Figure 2](image-url)
as $R_1$ and $R_2$ are shown as ratios of the values expected in the internal and external zones, correspondingly. One can see that at the 90% confidence level the oscillation parameters $\Delta m^2$ as well as $\sin^2 2\theta$ can be significantly localized by difference of capture rates in two zones of 15-20%. Furthermore, unlike to other short baseline experiments, large values of $\Delta m^2 (>5\text{-}8 \text{ eV}^2)$ can be excluded at the 95-99% confidence level.

In the proposed $^{51}$Cr source experiment on SAGE target with 50 t of metal Ga, a hypothesis of short baseline neutrino oscillations will be verified. The experiment has a number of features which allow not only the discovery of oscillations, but under definite conditions significantly localize their parameters. Independent measurements of the disappearance of pure monoenergetic neutrinos from a compact source on two different baselines will be carried out. The experiment should be sensitive to oscillations with parameter $\Delta m^2 > 0.5 \text{ eV}^2$ with amplitude of several percent.

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