Search for sterile neutrinos on the Gallium Germanium Neutrino Telescope with artificial neutrino sources in the BEST experiment

V N Gavrin\textsuperscript{1,3}, B T Cleveland\textsuperscript{2}, V V Gorbachev\textsuperscript{1}, T V Ibragimova\textsuperscript{1}, A V Kalikhov\textsuperscript{1}, Yu P Kozlova\textsuperscript{1}, Yu A Malyshkin, I N Mirmov\textsuperscript{1}, A A Shikhin\textsuperscript{1} and E P Veretenkin\textsuperscript{1}

\textsuperscript{1}Institute for Nuclear Research, Russian Academy of Sciences, prospekt 60-letiya Oktyabrya 7a, Moscow, 117312, Russia
\textsuperscript{2}SNOLAB, 1039 Regional Road 24 Lively ON, P3Y 1N2, Canada
E-mail: gavrin@inr.ru

Abstract. The possibility of the BEST experiment on electron neutrino disappearance with intense artificial sources of electron neutrino $^{51}\text{Cr}$ is considered. BEST has the great potential to search for transitions of active neutrinos to sterile states with $\Delta m^2 \sim 1\text{ eV}^2$ and to set the limits on short baseline electron neutrino disappearance oscillation parameters. The possibility of the further constraints the oscillation parameters region with using $^{65}\text{Zn}$ source is discussed.

1. Introduction
The oscillation effects in the entire energy spectrum of solar neutrinos were first observed in the gallium measurements of SAGE and GALLEX. The good agreement between the results of the two independent experiments, which used gallium target in a different chemical form, confirms the reliability of the obtained results. We have excellent agreement between theory and experiment for the gallium experiment [1]. Gallium experiments are also unique in having been directly tested for efficiency of neutrino detection with a radioactive sources, $^{51}\text{Cr}$ and $^{37}\text{Ar}$.

2. Gallium experiments with artificial neutrino sources
Two independent experiments with artificial sources of electron neutrinos with activity close to 1 MCi were performed on each of the detectors. SAGE used $^{51}\text{Cr}$ [2] and $^{37}\text{Ar}$ [3] sources and GALLEX twice used a $^{51}\text{Cr}$ source [4, 5]. The weighted-average result of these experiments, expressed as the ratio $R$ of the measured neutrino capture rate to the expected rate, based on the known neutrino capture cross section [6], gave $R = 0.87 \pm 0.05$, more than two standard deviations less than unity, named the Gallium anomaly [7]. Possible explanations of such a low result are considered in detail in [1].

From recent measurements [8] precise value of contribution from excited states is $7.2\% \pm 2.0\%$, which exceeds the $5.1\%$ value previously used in [6]. With new cross section value average

\textsuperscript{3} To whom any correspondence should be addressed.
ratio is \( R = 0.84 \pm 0.05 \), which indicates a deficit with a significance 2.9 \( \sigma \). The Gallium anomaly can be explained as \( \nu_e \) oscillations into sterile states at very short baselines with \( \Delta m^2 \) about 1 eV\(^2\) [9]. The region of allowable oscillation parameters, obtained from the results of all four gallium source experiments is shown in figure 1.

![Figure 1. Region of allowed mixing parameters inferred from gallium source experiments assuming oscillations to a sterile neutrino at 90%, 95% and 99% C.L.. The plus sign at \( \Delta m^2 = 2.15 \) eV\(^2\) and \( \sin^2 2\theta = 0.24 \) indicates the best-fit point.](image)

3. Experiment BEST

The search for sterile neutrinos is now a field of very active investigation. We propose the BEST experiment to search for the disappearance of electron neutrinos at short baselines from a radioactive source [10]-[12]. An intense 3 MCi \(^{51}\)Cr source will be placed at the center of a 50-t target of liquid Ga metal that is divided into independent inner and outer zones and the neutrino capture rates in each zone are measured simultaneously. The geometry of the tanks ensures that the average neutrino path length through the two Ga zones is equal, and has the value \( \langle L \rangle \sim 550 \) mm. Both zones will be irradiated simultaneously, and in the absence of oscillations the predicted number of \(^{71}\)Ge atoms generated in each zone will be the same. With chosen irradiation schedule expected systematic uncertainty is of \( \pm 2.6\% \), and a total uncertainty, statistical plus systematic, is of \( \pm 4.5\% \) for each zone and of \( \pm 3.7\% \) for the total target.

4. Sensitivity and prospects

In a model with just the electron neutrino and one sterile neutrino, the probability that neutrino with energy \( E \) will survive after passing the distance \( L \) from the source, is described by the expression:

\[
P_{ee} = 1 - \sin^2(2\theta) \sin^2[1.27\Delta m^2(eV^2)\frac{L(m)}{E_{\nu e}(MeV)}],
\]

where \( \Delta m^2 \) is the squared mass difference of neutrino eigenstates and \( \theta \) is the mixing angle.

The probability of interaction of the neutrinos in each zone, for the specific case of \( \sin^2 2\theta = 0.3 \), is shown in figure 2 together with the ratio of event rates.
Figure 2. Ratio of measured capture rate to predicted rate in the inner ($R_1$) and outer ($R_2$) zones and their ratio $R_2/R_1$ as a function of $\Delta m^2$ for mixing angle $\sin^2 2\theta = 0.3$.

A statistically significant deviation of either of the rates, $R_1$ or $R_2$, or their ratio, would provide direct evidence of non-standard properties of the neutrino.

Additional we consider the next step of the BEST experiment evolution with using of 0.5 MCi $^{65}$Zn electron neutrino source. $^{65}$Zn disintegrates by electron capture to $^{65}$Cu with half life 244.1 days. The 48.35% branch decays directly to the ground state of $^{65}$Cu, and the 50.23% branch decays to the excited level with the emission of 1115.5 keV gamma ray to the ground state. The source will radiate neutrinos with energies 236.5 keV (50.23%) and 1352.1 keV (48.35%). Since the radiochemical gallium experiments threshold is of 233 keV the source also can be considered as monochromatic. In figure 3 is shown the regions derived from combination results of the BEST experiments with sources $^{51}$Cr and $^{65}$Zn and with previous four source experiments in case of the Gallium anomaly confirmation.

5. Conclusion
The BEST experiment on electron neutrino disappearance with intense artificial sources of electron neutrino and optimized geometry of Ga target has the great potential to search for transitions of active neutrinos to sterile states with $\Delta m^2$ about 1 eV$^2$ and to set the limits on short baseline electron neutrino disappearance oscillation parameters. The use of $^{65}$Zn source along with the $^{51}$Cr source can lead to the further constraints the oscillation parameters region.

References
[1] Abdurashitov J N et al. (SAGE Collaboration) 2009 Phys. Rev. C 80 015807
[2] Abdurashitov J N et al. (SAGE Collaboration) 1999 Phys. Rev. C 59(4) 2246
[3] Abdurashitov J N et al. (SAGE Collaboration) 2006 Phys. Rev. C 73 045805
[4] Anselmann P et al. (Gallex Collaboration) 1995 Phys. Lett. B 342 440
Figure 3. Region of mixing parameters for combined result of the BEST experiment with 3 MCI $^{51}$Cr and 0.5 MCI $^{65}$Zn source at 90%, 95% and 99% C.L. in case of the Gallium anomaly confirmation. $R_1$ and $R_2$ are the ratios of the measured rate to the predicted rate in the inner and outer zones, respectively. The plus sign at $\Delta m^2 = 2.15$ eV$^2$ and $\sin^2 2\theta = 0.24$ indicates the best-fit point.

[5] Hampel W et al. (Gallex Collaboration) 1995 Phys. Lett. B 420 114
[6] Bahcall John N 1997 Phys. Rev. C 56 3391
[7] Giunti C and Laveder M 2007 Mod. Phys. Lett A 22 2499
[8] Frekers D et al. 2011 Phys. Lett. B 706 134
[9] Gariazzo S et al. 2015 arXiv:1507.08204
[10] Abazajian K N et al. 2012 arXiv:1204.5379
[11] Gavrin V et al. 2010 arXiv:1006.2103
[12] Gavrin V et al. 2015 Physics of Particles and Nuclei 46(2) 131