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# Search for sterile neutrinos with the SOX experiment

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**Summary.** — In the recent years, the Borexino detector has proven its outstanding performances in detecting neutrinos and antineutrinos in the low energy regime. Consequently, it is an ideal tool to investigate the existence of sterile neutrinos, whose presence has been suggested by several anomalies over the past two decades. The SOX (*Short distance neutrino Oscillations with boreXino*) project will investigate the presence of sterile neutrinos placing a neutrino and an antineutrino sources in a location under the detector foreseen for this purpose since the construction of Borexino. Interacting in the detector active volume, each beam would create a well detectable spatial wave pattern in case of oscillation of neutrino or antineutrino in a sterile state. Otherwise, the experiment will set a very stringent limit on the existence of a sterile state.

## 1. – Introduction

Although the collected neutrino experimental data well fit into the three-flavor oscillation model, several short-baseline neutrino experiments have reported anomalies which significantly deviates from the three active neutrino pictures. Previous indications for sterile neutrino oscillations came from the LSND and Miniboone neutrino accelerator experiments [1, 2]. Other indications are given by the re-evaluation of the reactor antineutrino flux [3, 4] and from the calibration of the Gallex and SAGE solar neutrino experiments [5]. The latter experiments have calibrated their detectors using neutrino and antineutrino sources and have measured a flux smaller than expected. The SOX project aims to use the Borexino detector to investigate the existence of sterile neutrinos in the $\Delta m^2_{14}$ region of $\sim 1\,\mathrm{eV}^2$ [6].

## 2. – Borexino

Borexino is a 300 t liquid scintillator detector designed for the real time solar neutrinos detection. It is located underground, in the hall C, of the LNGS laboratories in Italy [7]. Borexino is able to detect both neutrinos (it has measured different components of solar neutrinos [8-10]) and antineutrinos (geoneutrino measurements [11]). The detector is depicted in fig. 1. Its design is based on the principle of graded shielding, with the inner scintillating core at the center of a set of concentric shells of decreasing radiopurity from inside to outside. The scintillator is a solution of PPO (2,5-diphenyloxazole) in pseudocumene (PC, 1,2,4-trimethylbenzene) at concentration of 1.5 g/l. The scintillator is contained in a $125\,\mu$m thick spherical nylon vessel (IV) with 4.25 m radius. A 6.85 m radius unsegmented stainless steel sphere (SSS) encloses the central part of the detector and serves also as support structure for the 2212 8 in. PMTs. The space between the IV and the SSS is filled with a passive shield composed by PC and a small quantity of DMP (dimethylphthalate), a material that quenches the residual scintillation of PC, so that scintillation arises dominantly from the IV. The SSS is contained within a high domed Water Thank (WT) of 18 m diameter and 16.9 m height filled with ultrapure water and instrumented with 208 PMTs to detect the muon(1) Cherenkov light. The WT represents also a shield against the external radiation [12]. The light yield is about 500 photoelectrons/MeV with a threshold of about 60 keV. Since scintillation light coming from nuclear decays inside the IV is indistinguishable from the neutrino elastic scattering off electrons, an extreme radiopurity level must be maintained. Thanks to several purification campaigns an unprecedented level of several $10^{-19}$ grams of $^{238}$U and $^{232}$Th per gram of scintillator is reached. The spatial resolution of the detector is about 10 cm at 1 MeV while the energy resolution is about 5% [8].

## 3. – The SOX project

The SOX project [6] aims at a complete confirmation or at a clear disproof of the so-called neutrino anomalies. If successful, SOX will demonstrate the existence of the first particle beyond the Standard Electroweak Model and would have profound implications in our understanding of the Universe and of fundamental particle physics. In

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(1) The Gran Sasso d'Italia mountains, under which the LNGS are located, provide a 3600 meters of equivalent water shielding against cosmic rays.

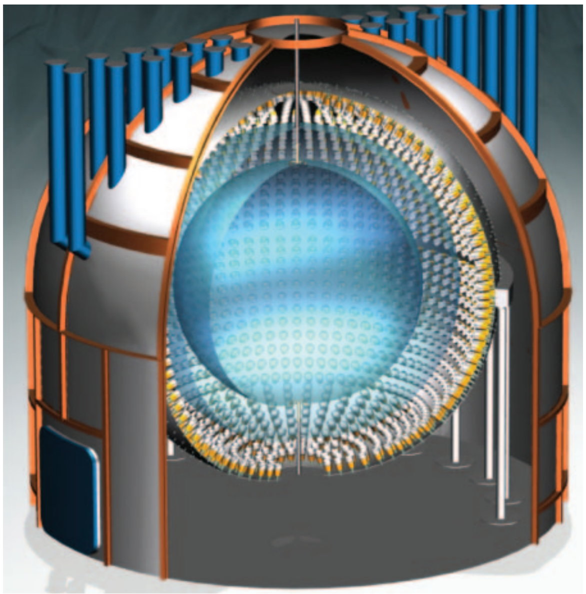

Fig. 1. – Schematic view of the Borexino detector.

case of a negative result, the experiment will close the long-standing debate on the presence of neutrino anomaly and new physics in the low-energy neutrino interaction. The first part of the experiment will consist in deploying a $\sim$ 1050 kCi $^{144}$Ce-$^{144}$Pr $\overline{\nu}_e$ source in the pit under the detector (8.25 m from the detector's center). The second part of the project will consist in deploying a $^{51}$Cr $\nu_e$ source in the same position. The following of the paper is focused in the $\overline{\nu}_e$ source scenario since it is the first to happen.

**3**˙1. $^{144}$Ce-$^{144}$Pr *anti-neutrino source*. – Anti-neutrinos are detected in Borexino by means of inverse beta decay (IBD, 1.8 MeV threshold) on protons. This process automatically offers a clear tag thanks to the space-time coincidence between the prompt $e^+$ signal and the subsequent neutron capture ($\tau = 254\,\mu$s [11]) event. Consequently, accidental background is almost zero. The $^{144}$Ce-$^{144}$Pr source has been identified as a suitable $\overline{\nu}_e$ emitter having a long enough half-life to allow the source production and the transportation to LNGS. The $^{144}$Ce source $\beta$-decays to $^{144}$Pr ($t_{1/2} = 296$ days) which rapidly ($t_{1/2} = 17$ min) $\beta$-decays to $^{144}$Nd emitting $\overline{\nu}_e$ above IBD threshold (the endpoint of the $^{144}$Pr decay is about 3 MeV).

**3**˙2. *Calorimetry and data analysis*. – The source with the proper shielding will be placed in two independent calorimeters to measure the activity. It will happen before the insertion under the detector and at the end of the data-taking, when the source will be removed from the pit. Both calorimeters are mostly finalized and under test using resistive heaters.

The analysis of short baseline neutrino oscillations in Borexino can be performed in two ways. The standard disappearance procedure is a rate analysis: if oscillations occur, the number of interaction in the detector will be lower than the expected in case of no oscillations. This technique relies on a precise knowledge of the source activity. The

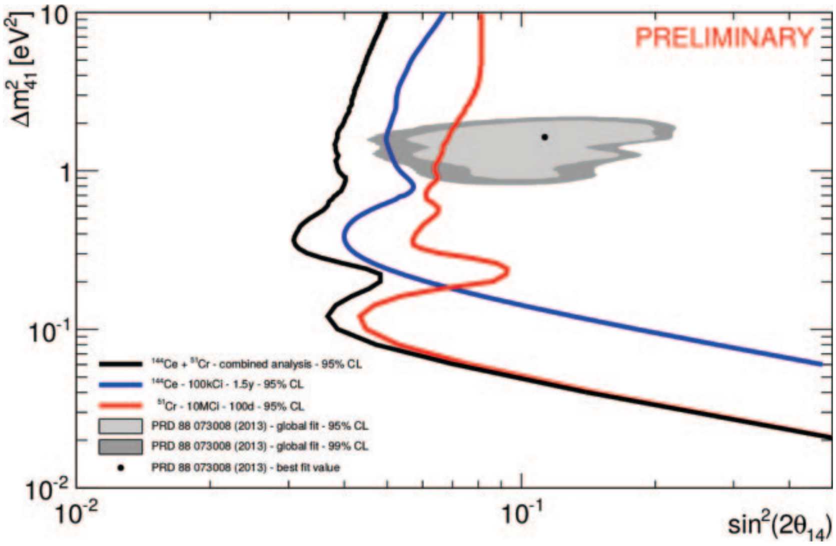

Fig. 2. – Allowed parameter space region accordingly to one of the latest review of global fit and region of space covered by SOX in case of neutrino and antineutrino sources.

second technique is based on an oscillometry measurement within the detector volume. If $\Delta m^2_{14} \approx 1\,\text{eV}^2$ and the $\overline{\nu}$ energy is of the order of 1 MeV, the typical oscillation length is of the order of 1 m. Consequently the typical oscillation waves can be directly seen in Borexino [6]. This technique allows to directly measure both $\Delta m^2_{14}$ and $\theta_{14}$, investigating most of the anomaly region (fig. 2).

## 4. – Conclusions

Borexino is the ideal detector to perform a short-baseline experiment. Thanks to the high radiopurity and the low energy threshold, it is possible to test the existence of sterile neutrinos. The SOX data taking will start in the second part of 2016 and first results are expected by mid 2017.

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