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The SOX experiment in the neutrino physics

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Summary. — SOX (Short distance neutrino Oscillations with BoreXino) is a new experiment that takes place at the Laboratori Nazionali del Gran Sasso (LNGS) and it exploits the Borexino detector to study the neutrino oscillations at short distance. In different phases, by using two artificial sources ^{51}Cr and ^{144}Ce–^{144}Pr, neutrino and antineutrino fluxes of measured intensity will be detected by Borexino in order to observe possible neutrino oscillations in the sterile state. In this paper an overview of the experiment is given and one of the two calorimeters that will be used to measure the source activity is described. At the end the expected sensitivity to determine the neutrino sterile mass is shown.

PACS `28.20.Pr` – Neutron imaging; neutron tomography.
PACS `14.60.Pq` – Neutrino mass and mixing.
PACS `95.55.Vj` – Neutrino, muon, pion, and other elementary particle detectors; cosmic ray detectors.

1. – The SOX experiment

Despite the fact that the standard three-flavor neutrino oscillation paradigm is in agreement with many experimental results, the possibility of the existence of at least one additional sterile state as suggested by a small subset of data, that calls for physics beyond the standard model, is still open. Among these, some disappearance experiments have shown a small deficit of neutrinos coming from nuclear reactors (known as reactor anomalies) [1, 2] or from ^{51}Cr and ^{37}Ar sources as in the GALLEX and SAGE

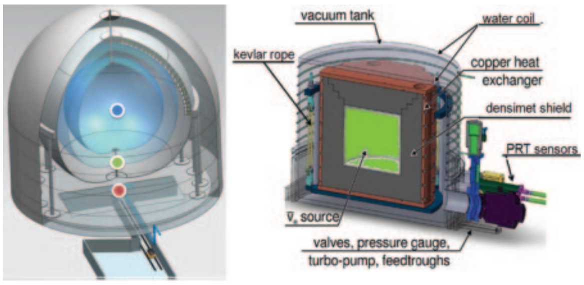

Fig. 1. – Left: Layout of the Borexino detector and the locations of the neutrino and antineutrino sources during the phases A (red), B (green) and C (blue). Right: Scheme of the Ce-Cr calorimeter designed to measure the source activity with 1% of accuracy.

experiments [3]. In addition, also appearance evidences were observed by the LSND experiment, where electron antineutrinos were found in a pure muon antineutrino beam [4], or by miniBooNE experiment, which also saw appearance of electron neutrino in a muon neutrino beam (known as accelerator anomaly) [5]. All the anomalies may be explained by oscillations into one or more sterile components with a mass squared difference Δm^2 of about $1\,\mathrm{eV}^2$ but this hypothesis has to be confirmed by better and more sensitive results.

In order to perform a new measurement with a more intense ν_e (or $\bar{\nu}_e$) sources and a larger and lower background detector, the SOX experiment was proposed [6] and it is now under construction. It is based on the ultra-low background Borexino detector at LNGS that will detect the neutrino/antineutrino fluxes emitted by artificial sources placed in three different positions. In the first phase (Phase A) a ^{144}Ce–^{144}Pr ($\bar{\nu}_e$) of 5 PBq of activity and a ^{51}Cr(ν_e) source of 200–400 PBq activity, will be deployed at different times at 8.25 m from the detector center. More, in possible second and third phases (Phase B and C) a similar ^{144}Ce–^{144}Pr ($\bar{\nu}_e$) source with 2–4 PBq activity will be deployed at 7.15 m from the detector center and right in the center of the liquid scintillator volume (see fig. 1). In the Phase A the activity of the sources will be measured at 1% of precision by two precisely calibrated isothermal calorimeters, one of which will be used to measure only the Ce activity, while the second one will be used also to measure the Cr activity and as a transport and cooling system of the Cr and Ce sources inside the pit just below the Borexino vessel. Since the Ce source has a longer lifetime the activity measurement will be carried out by both calorimeters separately in few days before the insertion in the pit, while for the Cr source, since the lifetime is 40 days, the measurement will be performed only by the Ce-Cr calorimeter inside the pit during the Borexino data taking.

2. – The Ce-Cr calorimeter

The Ce-Cr calorimeter was conceived to measure the activity through a very precise knowledge of the heat released by the source and absorbed by a water flow. As is shown in fig. 1 the source is placed within a tick densimet-alloy shield, in contact with a copper heat exchanger, where a water coil is embedded. By measuring the mass flow $\dot{m}$ thanks to a Coriolis flowmeter with 0.1% of accuracy and by knowing the difference of temperature ΔT between the entering water and the outgoing water through two Platinum Resistance Thermometers (PRT) with high accuracy ($\delta T < 5\,\mathrm{mK}$), the power P emitted by the source can be obtained by the relation

$$P = c\dot{m}\Delta T + P_{lost}, \tag{1}$$

where c is the specific heat of the water, and P_{lost} is the heat that is not adsorbed by the water. In the apparatus P_{lost} can be neglected because the conduction, convection and irradiation losses are minimized by keeping the source suspended through kevlar ropes (see fig. 1), by placing the source inside a vacuum chamber with a pressure of 10^{-4} mbar and by using some copper shields and superinsulator material between the source and the external chamber, respectively. In such a way P_{lost} was estimated to be less than few watts if the initial Ce power is around 1200 W and, with a flow of 10 g/s, a ΔT of around 29° has to be measured to obtain the activity of the source with a good level of accuracy ($\sim 1\%$).

3. – The expected data and the future results

The Borexino detector can observe either the neutrino (by elastic scattering with the electron of the scintillator) or the antineutrino (in the beta inverse decay) and for each event the interaction position, with a spatial resolution of 10 cm and the energy, with a resolution of 5% at 1 MeV, can be reconstructed [7, 8]. These data will be useful to investigate the effect of short distance neutrino oscillation in two different ways. Firstly, as in a standard disappearance technique, the total count rate can be compared with that expected from the measured activity and the reactor anomaly could be confirmed with high precision; secondly the neutrino oscillation might be directly observed. In fact, since the function of the two-flavor oscillation formula,

$$P_{ee} = 1 - \sin^2(2\theta_{14}) \sin^2\left(1.27 \frac{\Delta m^2_{14}(eV^2) L(m)}{E(MeV)}\right), \tag{2}$$

(where θ_{14} is the mixing angle of the ν_e (or $\bar{\nu_e}$) into sterile component, Δm^2_{14} is the corresponding squared mass difference, L is the distance of the source to the detection point, and E is the neutrino energy) has been presumed also for the oscillation in a fourth sterile state, a typical oscillations length of few meters can result. In this case the oscillations waves can be directly seen with a large detector like Borexino and a plot of the oscillometry pattern as a function of the reconstructed (positron) energy, as shown in fig. 2(a), might be obtained [9]. From this plot Δm_{14} and θ_{14} can be reconstructed and the SOX sensitivity to this parameters, as resulted by a Monte Carlo simulation, is visible in fig. 2(b), where it is evident that the reactor anomaly region [10] is mostly covered.

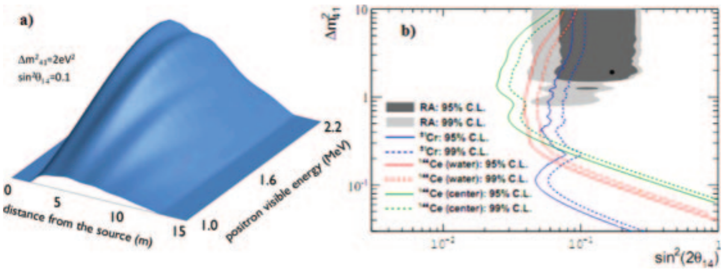

Fig. 2. – a) The oscillometry pattern as a function of the reconstructed (positron) visible energy for the Phase B experiment if $\sin^2(\theta_{14}) = 0.1$ and $\Delta m^2_{14} = 2\,\mathrm{eV}^2$. b) Sensitivity of the Phase A (^{51}Cr in blue), Phase B (in red) and Phase C (in green). The grey area is the one indicated by the reactor anomaly, if interpreted as oscillations to sterile neutrinos [11].

As further results also the measurements of the Weinberg angle at energy of MeV and of the neutrino magnetic moment might be performed [12].

In conclusion the SOX experiment will give important accurate data in the neutrino physics and in the sterile neutrino scenario. The calorimeters construction together with the procedure for the production and transportation of the Ce source have already started and the target data for the arrival of the source at LNGS is set on September 2016.

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