Improvements in the simulation code of the SOX experiment

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Improvements in the simulation code of the SOX experiment

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Abstract. The aim of the SOX experiment is to test the hypothesis of existence of light sterile neutrinos trough a short baseline experiment. Electron antineutrinos will be produced by an high activity source and detected in the Borexino experiment. Both an oscillometry approach and a conventional disappearance analysis will be performed and, if combined, SOX will be able to investigate most of the anomaly region at 95% c.l. This paper focuses on the improvements performed on the simulation code and on the techniques (calibrations) used to validate the results.

1. Introduction

The SOX experiment aims to investigate the existence of light sterile neutrinos by testing the Gallex and reactor anomalies with a short baseline oscillation experiment [1, 2]. The successful detection of a signal incompatible with the Standard Model prediction could imply the existence of at least one sterile neutrino and consequently it could be a breakthrough in the search for new physics.

The SOX project consists in deploying a high activity ^{144}Ce-^{144}Pr antineutrino source below the Borexino detector, exploiting the well proven capability of Borexino of detecting antineutrinos via inverse beta decay [3, 4, 5]. We will study the eventual disappearance of antineutrino through both the comparison of the measured and expected antineutrino fluxes and with an oscillometric analysis. The disappearance analysis will rely on the measurement of source activity that will be done using two independent calorimeters [6].

2. Calibration and data analysis

A reliable simulation algorithm of the experiment is fundamental for the data analysis, both for sensitivity studies and for the calculation of the efficiency in detecting the inverse beta decay in the peripheral regions, close to the vessel surrounding the innermost active zone. The Borexino simulation code, which was already used in solar analysis [7], has been extended, in order to be ready for the SOX data analysis. Finally, a novel efficient method for simulating external background events surviving the Borexino passive shield has been developed. It is based on Geant4 toolkit [8]. This technique allows to reliably predict the effect of the external contaminations and can be very useful for the next generation of liquid scintillator experiments. It has been verified comparing the simulations with data acquired with a ^{232}Th source placed in the peripheral part of the detector. The expected source induced background has been evaluated with this method and the result has been compared to those reported in [9], showing good agreement. In the last years, Borexino has been calibrated deploying several vials containing γ sources of different energies in different positions inside the scintillator. These sources have been used to test the accuracy of the simulations in reproducing the collected scintillation light. Moreover, a $^{241}Am - ^{9}Be$ neutron source have been deployed to characterize neutron capture processes which are of fundamental importance for geoneutrino and SOX analyses [10]. A new extensive calibration campaign is foreseen in 2017 before the SOX source arrival.

3. Conclusions

The Borexino detector is an ideal tool to search for sterile neutrinos. It is possible to test the existence of sterile neutrinos using an antineutrino source with almost negligible background. Figure 1 shows the expected SOX sensitivity obtained using the simulations. Uncertainties on the shape factor (σ_b, in units of electron mass) of the beta decay and on the source activity (σ_h) are taken into account. SOX will cover most of the anomaly region (90% confidence level) with the combined analysis (at 95% confidence level). The start of data taking is foreseen in 2017.

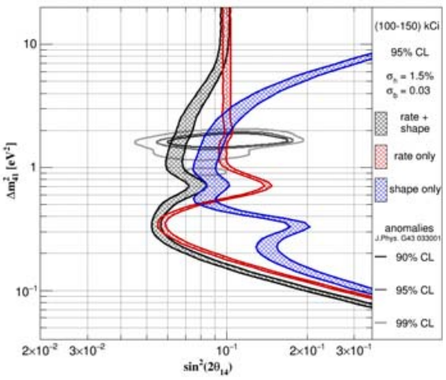

Figure 1. Anomaly region superimposed to the expected SOX sensitivity: rate only (red), shape only (blue) and combined (black).

References

[1] Mention G *et al.*, 2011, *Phys. Rev.* D **83** 073006
[2] Giunti C. and Laveder M., 2011, *Phys. Rev.* C **83** 065504
[3] Bellini G *et al.*, 2013, *JHEP* **38** 1308
[4] A. Caminata *et al.*, 2016, *Il Nuovo Cimento* C **39** 236
[5] Agostini M *et al.*, 2015, *Phys. Rev.* D **92** 031101
[6] L. Papp *et al.*, 2016, *Nuclear Instruments and Methods in Physics Research A* **824** 699700
[7] Bellini G *et al.*, 2014 *Phys. Rev.* D **89** 112007
[8] Geant4 Collaboration, Physics Reference Manual
[9] Gaffiot J. *et al.*, 2015, *Phys. Rev.*D **91** 072005
[10] Bellini G *et al.*, 2012, *Journal of Instrumentation* **7** 10018