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Understanding the detector behavior through Montecarlo and calibration studies in view of the SOX measurement

A Caminata[1], M Agostini[2], K Altenmüller[2], S Appel[2], G Bellini[3], J Benziger[4], N Berton[5], D Bick[6], G Bonfini[7], D Bravo[8], B Caccianiga[3], F Calaprice[9], P Cavalcante[7], A Chepurnov[10], K Choi[11], M Cribier[5], D D'Angelo[3], S Davini[12], A Derbin[13], L Di Noto[1], I Drachnev[12], M Durero[5], A Empl[14], A Etenko[15], S Farinon[1], V Fischer[5], K Fomenko[16], D Franco[17], F Gabriele[7], J Gaffiot[5], C Galbiati[9], C Ghiano[1], M Giammarchi[3], M Goeger-Neff[2], A Goretti[9], M Gromov[10], C Hagner[6], T Houdy[5], E Hungerford[14], Aldo Ianni[7], Andrea Ianni[9], N Jonquères[18], K Jedrzejczak[19], M Kaiser[6], V Kobychev[20], D Korablev[16], G Korga[7], V Kornoukhov[30], D Kryn[17], T Lachenmaier[21], T Lasserre[5], M Laubenstein[7], B Lehnert[22], J Link[8], E Litvinovich[15,23], F Lombardi[7], P Lombardi[3], L Ludhova[3], G Lukyanchenko[15,23], I Machulin[15,23], S Manecki[8], W Maneschg[24], S Marcocci[12], J Maricic[11], G Mention[5], E Meroni[3], M Meyer[6], L Miramonti[3], M Misiaszek[19,7], M Montuschi[25], P Mosteiro[9], V Muratova[13], R Musenich[1], B Neumair[2], L Oberauer[2], M Obolensky[17], F Ortica[26], M Pallavicini[1], L Papp[2], L Perasso[1], A Pocar[27], G Ranucci[3], A Razeto[7], A Re[3], A Romani[26], R Roncin[7,17], N Rossi[7], S Schönert[2], L Scola[5], D Semenov[13], H Simgen[24], M Skorokhvatov[15,23], O Smirnov[16], A Sotnikov[16], S Sukhotin[15], Y Suvorov[28,15], R Tartaglia[7], G Testera[1], J Thurn[22], M Toropova[15], E Unzhakov[13], C Veyssière[5], A Vishneva[16], M Vivier[5], R B Vogelaar[8], F von Feilitzsch[2], H Wang[28], S Weinz[29], J Winter[29], M Wojcik[19], M Wurm[29], Z Yokley[8], O Zaimidoroga[16], S Zavatarelli[1], K Zuber[22] and G Zuzel[19]

[1] Dipartimento di Fisica, Università degli Studi e INFN, 16146 Genova, Italy
[2] Physik-Department and Excellence Cluster Universe, Technische Universität München, 85748 Garching, Germany
[3] Dipartimento di Fisica, Università degli Studi e INFN, 20133 Milano, Italy
[4] Chemical Engineering Department, Princeton University, Princeton, NJ 08544, USA
[5] Commissariat à l'Énergie Atomique et aux Énergies Alternatives, Centre de Saclay, IRFU, 91191 Gif-sur-Yvette, France
[6] Institut für Experimentalphysik, Universität, 22761 Hamburg, Germany
[7] INFN Laboratori Nazionali del Gran Sasso, 67010 Assergi (AQ), Italy
[8] Physics Department, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061, USA
[9] Physics Department, Princeton University, Princeton, NJ 08544, USA
[10] Lomonosov Moscow State University Skobeltsyn Institute of Nuclear Physics, 119234 Moscow, Russia
[11] Department of Physics and Astronomy, University of Hawai'i, Honolulu, HI 96822, USA

[12] Gran Sasso Science Institute (INFN), 67100 L'Aquila, Italy
[13] St. Petersburg Nuclear Physics Institute NRC Kurchatov Institute, 188350 Gatchina, Russia
[14] Department of Physics, University of Houston, Houston, TX 77204, USA
[15] NRC Kurchatov Institute, 123182 Moscow, Russia
[16] Joint Institute for Nuclear Research, 141980 Dubna, Russia
[17] AstroParticule et Cosmologie, Université Paris Diderot, CNRS/IN2P3, CEA/IRFU, Observatoire de Paris, Sorbonne Paris Cité, 75205 Paris Cedex 13, France
[18] Commissariat à l'Énergie Atomique et aux Énergies Alternatives, Centre de Saclay, DEN/DM2S/ SEMT/BCCR, 91191 Gif-sur-Yvette, France
[19] M. Smoluchowski Institute of Physics, Jagiellonian University, 30059 Krakow, Poland
[20] Kiev Institute for Nuclear Research, 06380 Kiev, Ukraine
[21] Kepler Center for Astro and Particle Physics, Universität Tübingen, 72076 Tübingen, Germany
[22] Department of Physics, Technische Universität Dresden, 01062 Dresden, Germany
[23] National Research Nuclear University MEPhI (Moscow Engineering Physics Institute), Kashirskoe highway 31, Moscow, 115409, Russia
[24] Max-Planck-Institut für Kernphysik, 69117 Heidelberg, Germany
[25] Dipartimento di Fisica e Scienze della Terra Università degli Studi di Ferrara e INFN, Via Saragat 1-44122, Ferrara, Italy
[26] Dipartimento di Chimica, Biologia e Biotecnologie, Universita' degli Studi e INFN, 06123 Perugia, Italy
[27] Amherst Center for Fundamental Interactions and Physics Department, University of Massachusetts, Amherst, MA 01003, USA
[28] Physics and Astronomy Department, University of California Los Angeles (UCLA), Los Angeles, California 90095, USA
[29]Institute of Physics and Excellence Cluster PRISMA, Johannes Gutenberg Universität Mainz, 55099 Mainz, Germany
[30]Institute for Theoretical and Experimental Physics, 117218 Moscow, Russia

E-mail: `alessio.caminata@ge.infn.it`

Abstract. Borexino is an unsegmented neutrino detector operating at LNGS in central Italy. The experiment has shown its performances through its unprecedented accomplishments in the solar and geoneutrino detection. These performances make it an ideal tool to accomplish a state-of-the-art experiment able to test the existence of sterile neutrinos (SOX experiment). For both the solar and the SOX analysis, a good understanding of the detector response is fundamental. Consequently, calibration campaigns with radioactive sources have been performed over the years. The calibration data are of extreme importance to develop an accurate Monte Carlo code. This code is used in all the neutrino analyses. The Borexino-SOX calibration techniques and program and the advances on the detector simulation code in view of the start of the SOX data taking are presented.

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 ([1, 2, 3, 4]). The SOX project aims to use the Borexino detector to investigate the existence of sterile neutrinos in the Δm^2_{14} region of $\sim 1\ eV^2$ [5]. The first part of the project consists in deploying a 150 kCi $^{144}Ce-^{144}Pr\ \overline{\nu}_e$ source in a dedicated pit located 8.25 m below the detector's center. Antineutrinos are detected in Borexino by means of inverse beta decay (IBD, 1.8 MeV threshold) on protons. IBD events are clearly tagged using the space-time coincidence between the prompt e^+ signal and the subsequent neutron capture ($\tau = 254\ \mu s$ [6]) event. Consequently, accidental background is almost negligible. The $^{144}Ce-^{144}Pr$ source has been identified as a suitable $\overline{\nu}_e$ emitter having a long enough half-life

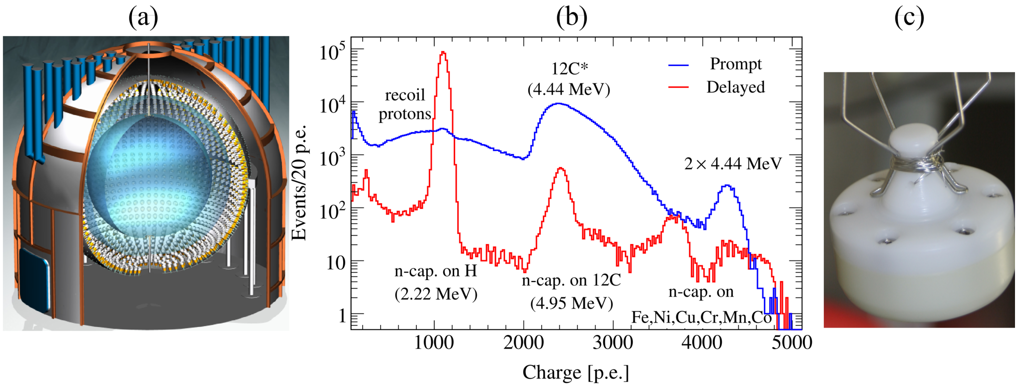

Figure 1. a) schematic view of the Borexino detector. b) Energy spectrum (variable photoelectrons) of the ^{241}Am^{9}Be source. The spectrum is subdivided in prompt (blue) and delayed (red) signals. c) Picture of the AmBe neutron source.

to allow the source production and the transportation to LNGS. The ^{144}Ce source β-decays to ^{144}Pr ($t_{1/2} = 296$ days) which rapidly ($t_{1/2} = 17$ min) β-decays to ^{144}Nd emitting $\overline{\nu}_e$ above IBD threshold (the endpoint of the ^{144}Pr decay is about 3 MeV).

One of the key requirement for the success of the SOX project is a good knowledge of the detector's response. The large dimensions of the detector require a careful mapping of its energy response in different positions within the scintillating volume. Since the energy of the incoming antineutrino is reconstructed from the positron energy, the knowledge of the energy scale is mandatory. Borexino has been calibrated several times in the past (2008 and 2009 calibration campaigns [7]). These data are extremely useful in view of the SOX experiment. Since the SOX and geoneutrino signals have the same features, calibration data acquired for the geoneutrino analysis can be used also for SOX. Nevertheless, a new calibration campaign is foreseen before the arrival of the SOX antineutrino source. These calibration data are of extreme importance in understanding the detector behavior and to increase the reliability of the SOX Monte Carlo simulation code. Since the SOX analysis, the cut efficiency and the sensitivity studies are performed analyzing the output of the simulations, having an accurate simulation code is crucial for a proper data analysis.

2. Detector calibration with gamma and neutron sources

Calibration sources are deployed into the desired location within the scintillator using a series of interconnecting hollow rods, assembled into an arm that can be bent up to 90° once inside the detector. The system is deployed through a pipe connecting the scintillator to the top of the detector (figure 1). To determine the source reference position, seven consumer grade digital cameras are fixed to the stainless steal sphere. The true location of a source is determined in the following way: a laser-illuminated diffuser ball, attached close to the source, is flashed while the CCD cameras take pictures simultaneously. During the 2008 and 2009 calibration campaigns, several sources of different types (α, β, γ, neutron) were inserted into Borexino to test the response to different particle types and to cover the energy region of interest for Borexino (which is larger than the SOX one). A detailed description of all the inserted sources can be found in [7]. Gamma sources cover the energy range between 0.1 MeV and 1.5 MeV. They are placed not only in the detector's center, but also in several positions within the scintillating volume to create a map of the energy response. The sources were dissolved in water and sealed in a quartz vial. A well understanding of the detector response to the gamma sources is necessary for SOX since the energy deposit of the prompt event is due to positron interaction with matter and to the signal due to the two 511 keV annihilation gammas. The ^{241}Am^{9}Be neutron source calibration was performed for Borexino ^{8}B neutrino and geoneutrino analyses. However, those data are of fundamental importance for SOX, since the delayed event is due to neutron capture. Neutrons are produced associated with de-excitation γ rays with a total energy of 4.44 MeV. These γ rays, together with the recoil protons from neutron scattering in the medium, are responsible for a prompt scintillator signal (figure 1). Afterwards, neutrons thermalize in the hydrogen-rich organic scintillator and are captured either on protons or carbon nuclei, emitting characteristic 2.22 MeV and 4.95 MeV γ rays (figure 1). These γ rays produce a delayed signal according to the neutron capture time of $\sim$254 μs.

3. Monte Carlo simulation code and the physics modeling the detector response

Particles depositing energy in the scintillator produce scintillation and Cherenkov light which propagates inside the detector and it is detected by the 2212 PMTs. For each event, the number of photon measured and the charge collected by each PMT and the time of arrival of each photon are measured. From these quantities, the energy of the event, its position and, in some cases, the particle type can be extracted. A precise knowledge of the detector response to different particle types and energies is fundamental for properly connecting physical and measurable quantities. The method of evaluation of the detector response function is based on a Monte Carlo simulation that models and predicts the expected shapes of the signal and background. It is an *ab initio* simulation of all the processes influencing the energy deposits in the materials building the detector. The scintillation and Cherenkov light emission, light propagation and detection processes are fully simulated as well as the read-out electronics. The Monte Carlo code produces a set of raw data with the same format of the real raw data, allowing an identical data processing [8]. Previously measured parameters are used as input values of the Monte Carlo code. The energy deposit and all physical processes of the light (from propagation to detection in the PMTs) are simulated using the standard GEANT4 [9] package while a custom C++ code simulates the electronic response. In view of the Borexino phase II solar neutrino analysis and the SOX measurement, the Monte Carlo code has been reviewed. Particular attention have been devoted in developing generators for sterile neutrino signal as well as in improving the reliability of the light collection and the detector's response for events far away from the center.

4. Conclusions

A complete knowledge of the detector response is fundamental for the forthcoming SOX analysis. Calibration campaigns with radioactive sources have been performed over the years. A new one is foreseen in the first months of 2016. The Borexino-SOX Monte Carlo code have been refined to increase the reliability of the simulations especially for events that interacts far from the detector's center. The new calibration data will be extremely useful for a final tuning of the parameters used in the detector simulation.

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