PROCEEDINGS OF SCIENCE

Neutron calibration of the SoLid detector

Valentin Pestel[*†]
LPC Caen
E-mail: pestel@lpccaen.in2p3.fr

SoLid is a reactor neutrino experiment, located at BR2@SCK • CEN (Mol, Belgium), searching for very-short baseline neutrino oscillation (< 10 m). Its main objectives are to confirm the so-called Reactor Antineutrino Anomaly (RAA), and to test *in-fine* the existence of light sterile neutrino(s). This experiment is based on a new kind of neutrino detector specially designed against background. The fiducial volume is made of composite solid scintillators (polyvinyl-toluene or PVT and ^{6}Li screens), which is compact and highly segmented (8000 voxels/m^3). As most of reactor neutrino experiments, neutrinos are detected through Inverse Beta Decay reaction (IBD), which produces a positron and a neutron. To perform a sensitive oscillation analysis, one of the most important requirement is to control perfectly the detection efficiency, which is in IBD case directly driven by the neutron detection efficiency. Regarding the SoLid setup, the challenge arises from the very large number of cells (12800). This proceeding will present the calibration strategy adopted by the collaboration to determine the neutron efficiency at percent level, by the use of two automated systems : CALIPSO and CROSS. Those last were designed in order to irradiate each 12800 cells, with well-calibrated neutron sources (AmBe and ^{252}Cf). This proceedings also present the Monte-Carlo (GEANT4) simulation used on one hand to estimate the geometrical efficiency effects, and on the other hand to study the systematic errors arising from the neutron transport calculation.

The European Physical Society Conference on High Energy Physics
5-12 July
Venice, Italy

*Speaker.
†on behalf of the SoLid Collaboration

© Copyright owned by the author(s) under the terms of the Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License (CC BY-NC-ND 4.0).

PoS(EPS-HEP2017)642

1. Introduction

The "reactor anti-neutrino anomaly" emerged few years ago, after a recalculation of the flux emitted by nuclear core and an update of the Inverse Beta Decay (IBD) cross section [1]. It consists of a 2.5σ deficit in the measured flux by all reactor experiments with baselines shorter than 100 m. It could be explained by the existence of light sterile(s) (*i.e.* flavourless) neutrino, mixing with the 3 known flavored neutrinos. The "favored" parameters for this oscillation are $\Delta m^2 \approx 1\,\mathrm{eV}^2$ and $\sin^2(2\theta) \approx 0.1$. The purpose of the SoLid experiment is to add new measurement at very-short baseline (<10 m) with a new technology. It will be located on the BR2 experimental nuclear reactor, at the SCK • CEN in Mol, Belgium. The oscillation can be signed by looking at the flux variation and the energy spectrum distortion in function of the baseline (6.2 to 9.7 m). To succeed, SoLid detector needs a good segmentation and energetic resolution. As we operate at a low overburden and near the reactor core, an efficient background rejection is also needed.

2. SoLid detector

SoLid used a composite scintillator technology : its detection cell is made of $5 \times 5 \times 5\,\mathrm{cm}^3$ plastic scintillator cube (PVT) covered on two faces with thin LiF:ZnS layers. Each detection cells are optically isolated with a thin Tyvek coating. The light is collected through 4 wavelength shifting optical fibers (2 in 2 directions, see figure 1) [2]. The PVT plays the role of the target for the inverse beta decay $\bar{\nu}_e + p \to n + e^+$ (IBD). The positron is directly detected and tagged as the prompt signal. The plastic scintillator will also act as a moderator for the neutron that will be captured after thermalization on the ^{6}Li contained in the LiF:ZnS layer. The breakup reaction $n + ^6Li \to t + \alpha$, releasing 4.77 MeV, generate scintillation light in the ZnS. The two particle, due to different scintillation decay time in the two scintillators ($\tau_{\mathrm{PVT}} \sim 20\,\mathrm{ns}$ versus $\tau_{\mathrm{ZnS}} \sim 10\,\mu\mathrm{s}$), are distinguishable thanks to a Pulse Shape Discrimination (PSD). Associated with a time coincidence, this is a powerful signature of the IBD interaction.

These compact fundamental cells, arranged in detection plane of 16×16 cubes read out by 64 fiber coupled to SiPM, allows a bi-dimensional positioning of any signals. With the 50 detection planes and 8000 voxels/m^3, SoLid detector is able to perform a topological reconstruction of events, and is capable to separate IBD events from background.

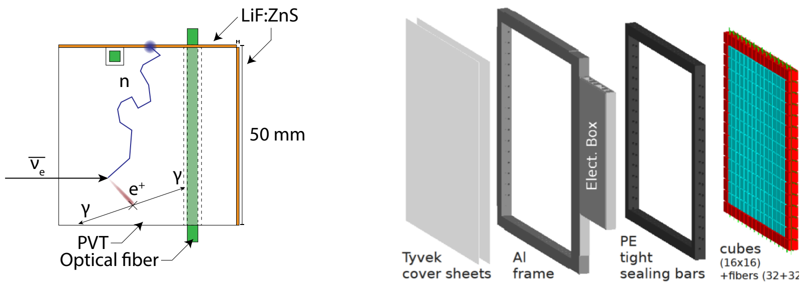

Figure 1: Left : Schematic view of the detection cell. Right : 3D model of a detection plane, with 64 channels (SiPM+fiber+reflector) and 256 detection cells.

PoS(EPS-HEP2017)642

3. Neutron calibration challenge

For an IBD based neutrino experiment, as the positron is directly detected in the plastic scintillator, the key for an accurate flux or spectrum measurement is a high and a well-known neutron efficiency. The detector is composed of 12 800 detection cells and 3200 readout channels. This granularity is a challenge for the calibration. It requires optimized and dedicated procedures. First of all, there was a rigorous follow-up of every component during the construction steps. Each PVT cube and LiF:ZnS layer, as well as the overall wrapped detection cell were weighted. It's a mandatory prerequisite to compute the total number of hydrogen target in the detector. All these informations are stored in a Database with their production batch identification. Every technical specifications about SiPM are also stored. It enables to recover the properties of each component of each of the 50 detection planes. Once the construction of cubes and assembly of plane are completed, dedicated measurements are performed in order to characterize properly the physics performance, in particular the neutron efficiency and the energy resolution. In the following, we will focus on the neutron calibration.

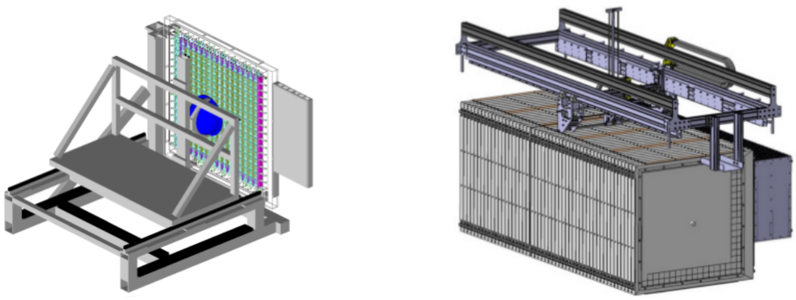

Figure 2: Left : Monte-Carlo representation (GEANT4) of CALIPSO with a detection plane and neutron collimator (blue). Right : 3D view of the 5 modules detector and the CROSS system.

3.1 Plane quality assurance process

The initial specification for these process was to collect about 5 000 neutron events for each of the 12 800 detection cells, with the aim of reaching statistics uncertatinties below 2 %. To achieve this objective, without increasing the workforce and time requirements, a first automated system was developed : CALIPSO (CALIbration for Plane in SOlid). This system was designed in order to position neutron source, but also gamma and positron radioactive sources, in front of every cube of a plane, following a predefined temporal and spatial pattern.

Firstly, a dedicated Monte-Carlo model (GEANT4 based [4]), including CALIPSO and its direct room environment, was developed in order to optimize the setup and the QA procedure (see picture 2). The first study was to size a neutron collimator, used to reduce environnement contributions (neutron diffusion) and increase the number of neutron interaction in the detector. The final geometry consists on a half sphere of polyethylene with 12.5 cm radius. As a result, the neutron detection rate is increased by a factor of 1.4, and the environnement effect (neutron entering the detector after diffusion in the room) is decreased by a factor of 5 to 10, depending of the position of the source.

PoS(EPS-HEP2017)642

Secondly, this Geant 4 model was used to optimize the duration and the number of measurement points. The definitive selected pattern consists of a 5×5 points scan (see figure 3.1). Two kind of neutron sources have been choosen (AmBe and ^{252}Cf) as presented in table 3.2. The CALIPSO system runned succesfully. It enables to qualify and characterize properly the neutron response of each plane in less than 4 hours of data taking. At the present time, more than 30 plans have already been checked and qualified with this sytem. These QA process phase will be completed before the end of October 2017.

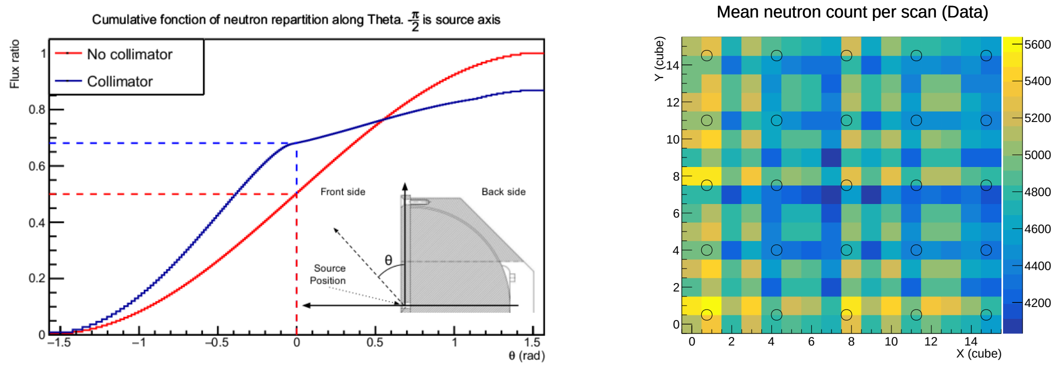

Figure 3: Left : Neutron flux cumulative function ($-\frac{\pi}{2}$ is the detector direction). Right : typical measured hitmap with CALIPSO and a ^{252}Cf neutron source. The black dot are the different source positions (25 measurement steps).

3.2 Calibration process

As the physic data taking will took place at BR2 during 3 years minimum, a second system was developed to calibrate and monitor over time the neutron response as well as the energy resolution. For pratical reasons the detector is divided in 5 modules, each made of 10 planes. During the data taking, all the modules will be in direct contact, in order to minimize border effect and to make a uniform and homogenous fiducial mass ($16 \times 16 \times 50$ detection cells). Also, the overall detector will be located in a cooled closed container, itself shielded by 50 cm water walls. Taking into account this mechanical and environnemental constraints, the 5 modules are installed on moving trays coupled with actuators. It enables to create 3 cm air gap between 2 adjacent modules. Besides, a second automated system, CROSS (CalibRation On-Site Solid), has been built in order to insert different radioactive sources (neutron, gamma, positron) on a moving arm from outside of the water shielding. It enables to carry the source between modules and to perform scans *à la* CALIPSO. As it was done for CALIPSO, a detailed Geant4 model of the experimental setup at BR2 was developed (plane, module, services, container and shielding). One important systematic effect could occur from the neutron transport. Indeed, there is a slight difference between the energy spectrum from the available radioactive sources (AmBe and ^{252}Cf) and the IBD spectrum, as shown on table 3.2. As a result, the IBD neutron detection efficiency must be extrapolated from measurements coming from the two chosen sources and by using the Monte-Carlo simulation. As SoLid is made of a very large amount of voxels, each measurement points will provide many different capture rates according to the distance to the source. In complement, some correlation between multiple

PoS(EPS-HEP2017)642

neutrons emitted by ^{252}Cf or between gamma and neutron coming from AmBe will also be taken into account. By using all these informations, the Monte-Carlo simulation will be tuned and the systematic errors determined at the percent level.

Source	AmBe	^{252}Cf	IBD
Activity (n.s^{-1})	1794 ± 35	3763 ± 44	-
E_{max}	11 MeV	15 MeV	70 keV
$< E >$	4.2 MeV	2.1 MeV	29 keV

Figure 4: Summary table for the activity and the energy of neutron coming from the two radioactive sources and the IBD process. Activity presented here are measured at the National Physical Laboratory (UK).

4. Conlusion

SoLid detector calibration, in view of the large amount of cells and channels, is quite challenging. In answer, SoLid collaboration has developed dedicated systems, allowing a time efficient and accurate determination of the neutron efficiency. The same works, based on the same devices but not presented here, is done for the energy scale of the detector. The quality assurance step is finishing now and the detector installation at BR2 will be completed this year [3]. The data taking is planned for 3 coming years.

References

[1] K. N. Abazajian et al., *Light sterile neutrinos: A white paper*, arXiv:1204.5379 (2012).

[2] Y. Abreu et al., *A novel segmented-scintillator antineutrino detector*, JINST 12(04):P04024 (2017).

[3] F. Yermia, *A Search for Sterile Neutrinos with SoLid*, these proceedings.

[4] The Geant4 Collaboration, *Geant4 a simulation toolkit, Nuclear Instruments and Methods in Physics*, 185 Research A 506 (2003) 250-303.

[5]

PoS(EPS-HEP2017)642