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SoLid: Search for oscillations with a ^{6}Li detector

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Several anomalies in the neutrino sector are pointing towards the existence of a new (sterile) neutrino state with a mass around 1 eV. The SoLid experiment is located at the SCK•CEN BR2 research reactor in Belgium and will investigate this possibility. Using the large flux of antineutrinos generated in the reactor, it will collect a high statistics sample of Inverse Beta Decay (IBD) events. These will be used to study the energy and distance dependence of the neutrino flux, which in turn will provide unambiguous support or reject the evidence of sterile neutrinos being the cause of these anomalies.
The measurement is challenging as one has to operate a detector very close to the high radiation environment of a nuclear reactor and on the surface with little overburden to shield against cosmic rays. SoLid is employing a new technology combining PVT (cubes of $5 \times 5 \times 5$ cm^3) and ^{6}LiF:ZnS(Ag) scintillators (sheets $\sim$250 μm thickness) to face these challenges. The highly segmented detector is read out by a network of wavelength shifting fibers and SiPMs, which allows for a precise localization of the IBD reaction products. Neutrons captured in the ^{6}Li can be easily separated from electromagnetic particles (e^+, γ) which are absorbed in the PVT, due to the different response of the respective scintillators.

The 1.6 tons detector was installed towards the end of 2017 and is taking date since early 2018.

We will describe the detector design, the experimental setup at BR2 and the detection principle.

This will be followed by a first look at the data.

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1. Introduction

The recent observation of the *Reactor Antineutrino Anomaly* has revived the interest in short-baseline experiments probing the disappearance of electron neutrinos and antineutrinos [1, 2]. The SoLid experiment is a short-baseline reactor project, that aims to resolve the anomaly using a novel detector design. The SoLid detector is installed at a distance of $\sim$ 6.0 - 9.0 m from the BR2 research reactor core at SCK•CEN (Mol, Belguim) and it will be able to scan the allowed parameter region through the detection of low-energy $\bar{\nu}_e$. The detector design allows for an efficient background reduction. This an important aspect for experiments at surface and near a nuclear reactor. SoLid has started taking data with the Phase I detector in early 2018 and it will run in this configuration for several years.

BR2 is a nuclear reactor that is used for scientific research and the production of radioactive isotopes for medical applications. It is highly enriched in ^{235}U and it operates for approximately 150 days per year at a nominal thermal power of $\sim$ 60 MW. Due to the beta decays of neutron-rich fission fragments inside its core, a high-intensity flux of low-energy $\bar{\nu}_e$ is provided by BR2. Its compact dimensions (diameter of the core smaller than $\sim$ 0.5 m) ensure that the neutrino oscillations, those predicted by the reactor anomaly, are not washed out by the spatial extension of the source. Furthermore, the SoLid site is ideal for performing such an experiment, since the background from the reactor is small compared to other locations.

SoLid employs a long detector that covers a wide baseline range between $\sim$ 6.0 to 9.0 m. In this way, it will be able to probe neutrino oscillations as a function of the visible energy in the detector (E_{vis}) and distance from the reactor center (L). Due to the close distance from the reactor, a high statistics $\bar{\nu}_e$ sample is expected in the SoLid detector. Nonetheless, for the purpose of the analysis a very good understanding of the detector systematics is necessary. In particular, the detector will need to have good energy and spatial resolutions.

2. Detector concept

SoLid employs a finely segmented detector made of 5×5×5 cm^3 polyvinyl-toluene (PVT) plastic scintillator cubes, Fig. 1 (left). The cubes are optically separated through Tyvek wrappings and they are aggregated in 16×16 planes through the use of an aluminum frame. Squared wavelength shifting fibers are threaded through grooves on the cubes, in two orthogonal directions, allowing light to be detected by silicon photomultipliers (SiPMs) attached at the end of the fibers, Fig. 1 (right). With this design one can have precise spatial and calorimetric information of the neutrino interactions happening in the detector.

In the SoLid experiment, reactor antineutrinos are detected through *Inverse Beta Decay* (IBD) interactions on free protons in PVT, $\bar{\nu}_e + p \rightarrow e^+ + \ n$. This is a channel that has a rather high cross-section but energy threshold at 1.8 MeV. Following an IBD interaction, a prompt signal is first seen in the detector from the combined positron thermalization and annihilation. Subsequently, a secondary (delayed) signal is then observed from the capture of the neutron inside the detector, after the neutron thermalization. We should emphasize that these two signals are highly correlated in space (a few cubes distance) and time (time coincidence of about $\sim$100 μs).

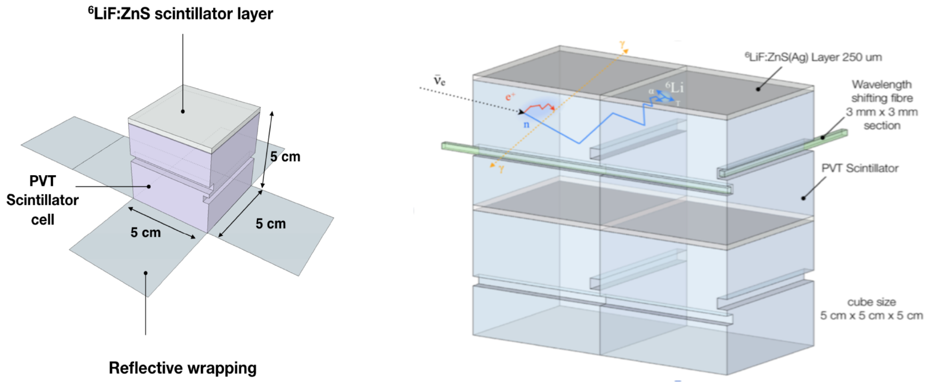

Figure 1: Simple schematics of the PVT cubes (left) and the detector design concept (right).

In general, the neutron can capture on several materials inside the detector. To tag the neutron, the SoLid technology is based on the use of ^{6}LiF:ZnS sheets interleaved between the PVT cubes and the Tyvek covers, Fig. 1 (left). The neutron capture cross-section on ^{6}Li is high and the delayed signal, $n + {}^6\text{Li} \rightarrow {}^3\text{He} + \alpha + 4.78$ MeV, can be identified with *pulse shape discrimination* (PSD) since the properties of the ^{6}LiF:ZnS inorganic scintillator provide a very specific signal shape with respect to a signal in PVT. This particular feature becomes important in separating neutrons from background signals. More details about the SoLid detector technology can be found in Ref. [3]. First results with a full-scale prototype have biin reported in Ref. [4].

3. Phase I detector

The construction of the Phase I detector started in late 2016, and it was fully assembled and commissioned by February 2018; since then it takes data in stable conditions. Phase I is a large detector of 1.6 tons active volume and it is an instrument capable of performing high-precision physics measurements. It consists of 5 detector submodules of 10 planes of 16×16 cubes each. Stated differently, it is made of 50 planes totally and 12800 PVT cubes.

The detector is placed inside a container, where the temperature is controlled to a very precise level, ensuring low SiPM dark rates and a better detector stability. Additionally, a wall of water bricks and a polyethylene ceiling, surround the container to provide shielding from cosmic rays. To improve the neutron detection efficiency, every cube was equipped with two ^{6}LiF:ZnS sheets, increasing the capture efficiency on ^{6}LiF:ZnS in about 30%. Moreover, each cube is read out by two optical fibers in each direction, with a SiPM attached at one end and a mirror at the other end. This choice improves significantly the light collection, increasing the energy resolution to about $\sim 14\ \%/\sqrt{E_{vis}}$ (See Ref. [5]).

One of the major highlights of Phase I is the so-called *neutron trigger*, implemented at the level of the read out [6]. More specifically, in order to reduce the event rate, an online trigger was designed and implemented at the data acquisition. According to this design, the detector triggers on neutron waveforms (using online PSD algorithms) and stores only short time-intervals, ~ 1 ms, before and after that trigger. Other trigger configurations are available that register crossing muons (needed for calibration) and random triggers. The quality and performance of all detector planes

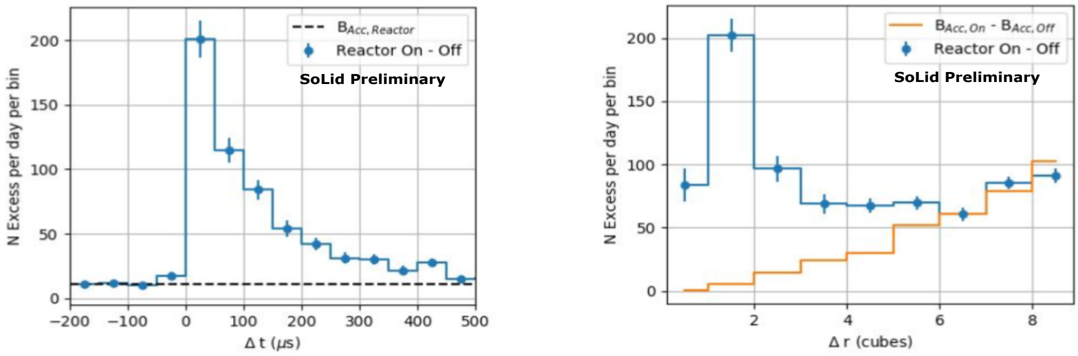

Figure 2: Time (left) and space (right) correlation of IBD candidates from May data sample.

were tested with an offsite calibration system (CALIPSO, Ref. [7]), and the detector is taking stable data in *physics mode* since February 2018.

4. First results

SoLid has recorded a large amount of physics data both with BR2 on and off. We should note that reactor off data are extremely important since they will be used for background estimation and subtraction. Additionally an intense calibration campaign has been performed with e/γ and neutron emitters using an *in situ* calibration system (a short of an articulated arm that can deploy radioactive sources in the detector). Furthermore, cosmic samples with crossing muons, Michel electrons, spallation neutrons, etc, have been selected. All data show that Phase I detector operates smoothly, as it was expected, with uniform energy response and high neutron efficiency.

A preliminary analysis, using basic cuts, with data from May indicates a clear excess of events when the reactor operates. These candidate signals are high correlated in space and time, Fig 2, as one expects from antineutrino interactions in the detector. The rate of accidental coincidences is also very low. The object reconstruction and IBD selection criteria are currently under development and SoLid aims to publish first results in 2019.

References

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