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SoLid: why and how we search for sterile neutrinos

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Although neutrino oscillations were discovered more than 10 years ago, some anomalies, such as the reactor antineutrino anomaly, still remain in the neutrino oscillation data [1]. The existence of a light sterile neutrino could explain these anomalies [2]. The SoLid experiment aims to resolve the inconsistencies in the neutrino oscillation sector and to test the sterile neutrino hypothesis. To be able to perform this sensitive measurement a novel detector technology is used, based on the combination of solid scintillator PVT cubes in combination with ^{6}LiF:ZnS screens. Compared to standard liquid scintillators + Gd detectors this technology will allow for a better background rejection capability, neutron identification and localization of the inverse beta decay. During the past 2 years the SoLid collaboration has build 2 prototype detectors and it is now in the process of building a full scale 1.5 ton detector. This poster covers the novel technology used in the SoLid experiment and discusses the improvements made on the design and electronics for the construction of the full SoLid detector.

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1. The reactor antineutrino anomaly

Due to the observations of the Z boson decay, it is known that there are exactly 3 weakly interacting neutrinos. The Super-Kamiokande detector and the Sudbury Neutrino Observatory showed that these 3 neutrinos can oscillate into each other and that they therefore have mass. In 2015 these findings were awarded with the Nobel Prize in Physics [3]. Today the framework of 3 oscillating neutrinos is very well known, except for some anomalies: the LSND and MiniBooNE appearance results [4], the Gallium anomaly from re-analysis of SAGE and Gallex runs [5] and the reactor antineutrino anomaly [6].

According to the theory of neutrino oscillations $\bar{\nu}_e$ from reactors are not expected to oscillate at distances smaller than 100 m, therefore one would expect the number of created antineutrinos to be the same as the amount reaching the detector at a small baseline. However a recent re-evaluation of the antineutrino spectra from reactors shows that there is a deficit in the amount of observed $\bar{\nu}_e$ [7]. This observed deficit is called the reactor antineutrino anomaly and it is especially visible in short baseline regions [9].

Possible explanations for this anomaly include the many uncertainties on the reactor $\bar{\nu}_e$ flux calculations, problems on the detector side or the existence of one or more light sterile neutrinos. Because of the Z boson decay observations we know that this neutrino can not be weakly interacting and therefore it is dubbed “sterile".

The SoLid experiment, located at the SCK•CEN institute in Belgium, will investigate the reactor antineutrino anomaly by performing an oscillometry analysis in distance versus energy. It will also measure the ^{235}U spectrum precisely to help understand the 5MeV distortion seen by Daya-Bay, Double Chooz [8] and Reno.

2. The SoLid experiment

SoLid is short for Search for Oscillation with a ^{6}Li Detector. The experiment is conducted at the BR2 research reactor in Belgium which is the ideal place to perform a sensitive oscillation search. The small core diameter allows for a point like behavior, a rate of 450 $\bar{\nu}_e$/tonne/day is expected and the background conditions are excellent compared to power plants. The distance between the detector and the core of the reactor can be as small as 5.5m and goes up to 10m.

The $\bar{\nu}_e$ is detected via the inverse beta decay (IBD) in which the antineutrino interacts with a proton from the SoLid detector giving rise to a neutron and a positron. A sketch of this interaction can be seen in figure 1. The positron of the IBD will interact in the 5cm × 5cm × 5cm PVT scintillator cubes that make up the detector and a direct, sharp scintillation pulse will be generated. The neutron will thermalize first and will then be captured by ^{6}LiF:ZnS screens, that are placed on every cube especially for this purpose. This reaction will generate an ^{3}H and an α which will in turn excite the ZnS of the screens. This will be followed by a slow de-excitation signal. The scintillation pulses will be transported via wavelength shifting fibers to the MPPC (Multi Pixel Photon Counter) at the end of the fibre. The combination of this prompt sharp peak followed by a slowly decaying signal allows us to identify an IBD event as can be seen in figure 2.

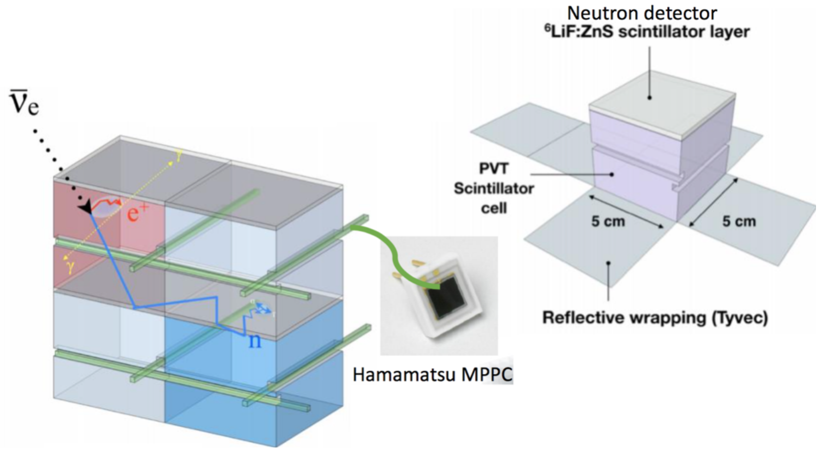

Figure 1: Sketch of the SoLid detector cubes and an IBD interaction.

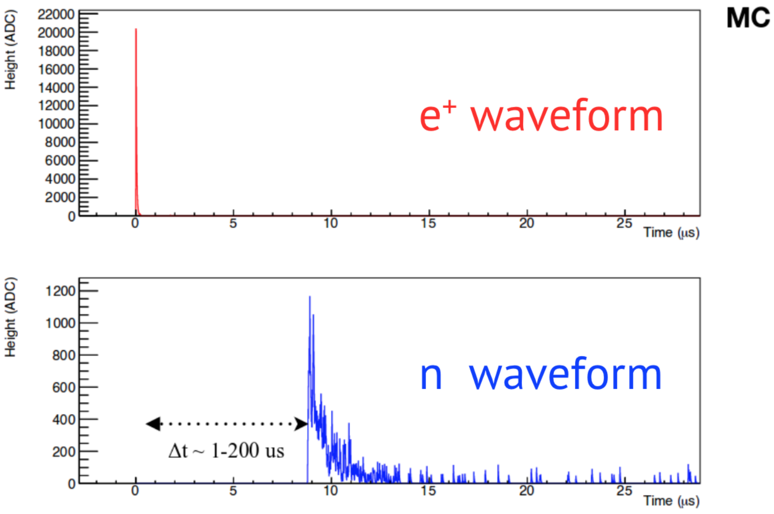

Figure 2: Monte Carlo generated positron and neutron waveforms form an IBD event detected in the SoLid readout system.

3. SubModule 1 prototype and the full SoLid detector

To demonstrate the large scale use of the detector technology a large prototype SubModule 1 (SM1) was constructed. This module consisted of 9 planes, each of 16 × 16 cubes, giving a total of 2304 PVT cubes and a weight of 288kg. This prototype was successfully calibrated and commissioned at the BR2 reactor and data taking was performed under realistic conditioned. Some results can be found in the proceedings of I. Michiels [10]. The data taking has proven the stability and our understanding of the detector performance. The experience gained with SM1 was used to improve on the design for the full SoLid detector construction.

The full SoLid detector will consist of 5 modules of 10 planes each with a total detector mass of 1.6 tonnes. The amount of fibers and ^{6}LiF:ZnS screens are doubled compared to the SM1 prototype to improve the light output. A cooled container will provide a reduced thermal noise and water shielding around it reduce the neutron background. A sketch can be found in figure 3. Construction is ongoing and data taking should start in spring 2017.

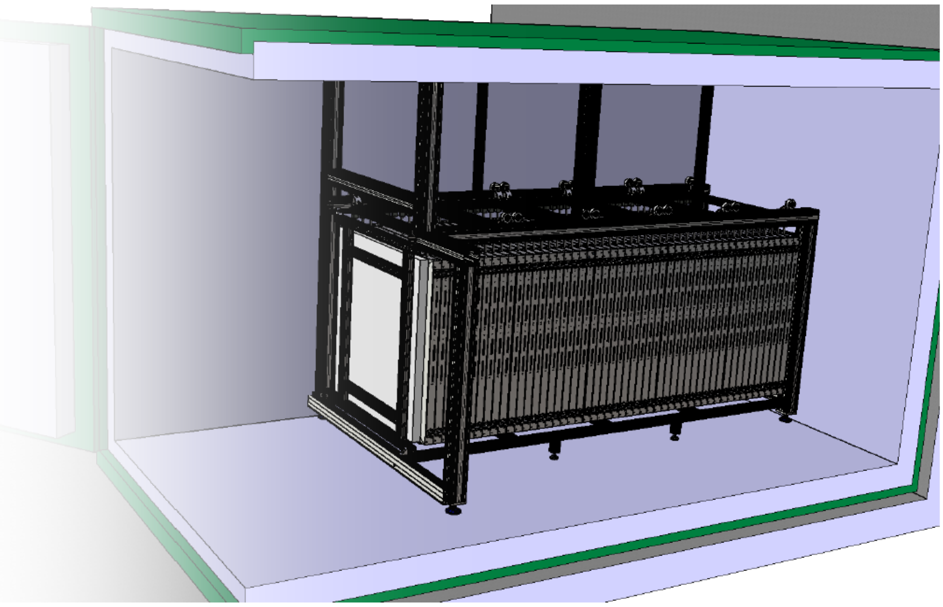

Figure 3: Sketch of the full SoLid detector in a cooled container.

4. Outlook

With a target mass of 1.6 tonnes, an average reactor power of 60MW, an IBD efficiency of 30%, a S/B of 3/1 and an energy resolution of $14\%/\sqrt{E_\nu}$ the SoLid collaboration will have a sensitivity as shown in figure 4. With a reactor running 150 days per year SoLid expects to provide an answer to the reactor antineutrino anomaly after only a few years of operation.

References

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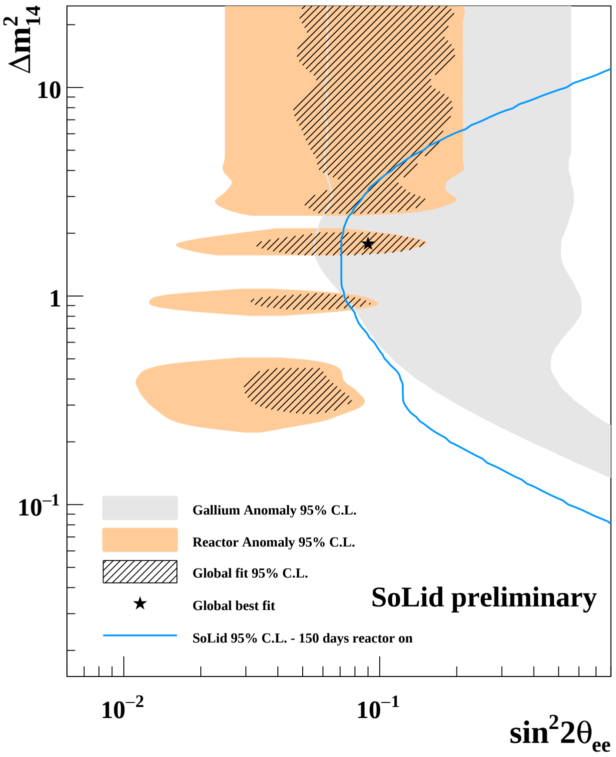

Figure 4: Sensitivity plot of the SoLid experiment.

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