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SoLid: Search for Oscillations with Lithium-6 Detector at the SCK-CEN BR2 reactor

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Abstract

Sterile neutrinos have been considered as a possible explanation for the recent reactor and Gallium anomalies arising from reanalysis of reactor flux and calibration data of previous neutrino experiments. A way to test this hypothesis is to look for distortions of the anti-neutrino energy caused by oscillation from active to sterile neutrino at close stand-off (~ 6-8m) of a compact reactor core. Due to the low rate of anti-neutrino interactions the main challenge in such measurement is to control the high level of gamma rays and neutron background.

The SoLid experiment is a proposal to search for active-to-sterile anti-neutrino oscillation at very short baseline of the SCK•CEN BR2 research reactor.

This experiment uses a novel approach to detect anti-neutrino with a highly segmented detector based on Lithium-6. With the combination of high granularity, high neutron-gamma discrimination using 6LiF:ZnS(Ag) and precise localization of the Inverse Beta Decay products, a better experimental sensitivity can be achieved compared to other state-of-the-art technology. This compact system requires minimum passive shielding allowing for very close stand off to the reactor. The experimental set up of the SoLid experiment and the BR2 reactor will be presented. The new principle of neutrino detection and the detector design with expected performance will be described. The expected sensitivity to new oscillations of the SoLid detector as well as the first measurements made with the 8 kg prototype detector deployed at the BR2 reactor in 2013-2014 will be reported.

Keywords: Reactor anomaly; sterile neutrino; innovative detector; research reactor

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1. Physics case

In the last few decades a vast number of experimental results established that neutrino oscillation occurs between three neutrino flavours and is a result of quantum effects arising from the tiny difference in their mass.

A few anomalies at a similar L/E have emerged in oscillation data at 2-3σ level: The LSND and MiniBooNE appearance results [1-2], the so-called "reactor anomaly" [3] after a recent re-evaluation of anti-neutrino spectra [4,5] and the Gallium anomaly from re-analysis of SAGE and Gallex calibration runs [6].

When combined, the last two anomalies (electron neutrinos) disfavour the no-oscillation hypothesis at 99.97% (3.6σ). It means, an oscillation into a sterile neutrino at short distance could explain these rate deficits consistently (if the sterile neutrino has a mass of ~1 eV).

This situation calls for new experimental data, in order to cross-check previous short baseline results with better control of the systematic uncertainties and test sterile neutrino hypothesis. The sensitivity to small oscillations can be maximized by the use of a compact source (research reactor) coupled to a highly segmented detector with good energy reconstruction.

2. The SCK-CEN BR2 research reactor

SoLid aims to search unambiguously for short distance oscillations from 5.5m to 12m away from the SCK-CEN BR2 reactor in Mol, Belgium. This compact reactor has an exceptionally low level of backgrounds. BR2 is operational 150 days/year at a nominal power between 60 and 100 MW, ensuring a large exposure time with high enrichment uranium fuel elements. The Solid detector will be located on-axis starting at 5.5 m distance from the core center (see Fig. 1). The detector site is free from other experiments having also a very effective shielding assuring excellent background conditions.

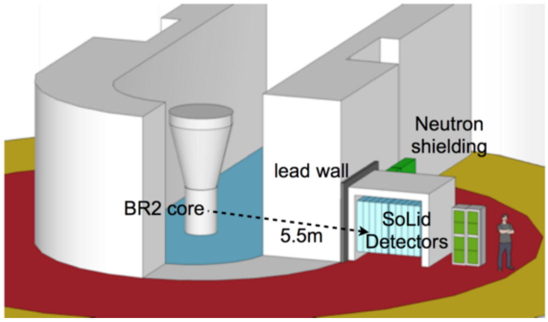

Fig. 1. Solid experiment at SCK-CEN BR2

3. The SoLid experiment

The SoLid detector is a segmented detector (2.88t) divided in 10 modules (1,2m x 1,2m x 0,2m). Each module consists of 4 planes of 576 plastic scintillation PolyVinylToluene (PVT) cubes of size of (5×5×5) cm^3, each cube being covered with one layer highly sensitive to thermal neutrons ($^6LiF:ZnS(Ag)$). The detector is read in (X,Y) by optical fibers coupled to Multi-Pixel Photon Counter MPPC. As shown in Fig. 2, anti-neutrino interacts with protons in the PVT cubes producing a positron and a neutron through the Inverse Beta Decay reaction (IBD):

$$\nu_e + p \rightarrow n + e^+ \quad (E\nu > 1.805\text{MeV}) \quad (1)$$

A neutrino event is then defined by the time-coincidence detection of a neutron and a positron. The outgoing neutron, after thermalisation, is absorbed few centimeters away on a layer rich in ^{6}Li, generally in a other cube, between a few hundreds of nanoseconds to few hundreds of microseconds, through the reaction:

$$n + {}^6\text{Li} \rightarrow {}^3\text{H} + \alpha + 4.78\text{MeV} \quad (3)$$

The outgoing nuclei have sufficient kinetic energy to escape a few tens of microns in the mixture and excite the surrounding grains of

ZnS, one of the brightest inorganic scintillator. Then a neutron converting in the layer produces 160 000 photons per neutron. Due to the large ionisation density created by the tritium and alpha particle, neutron signals have long decay constants, of the order of ten microseconds. The signature from a neutron event is, therefore, very different from that of an EM signals in PVT (e^+, γ, μ) (see Fig. 3).

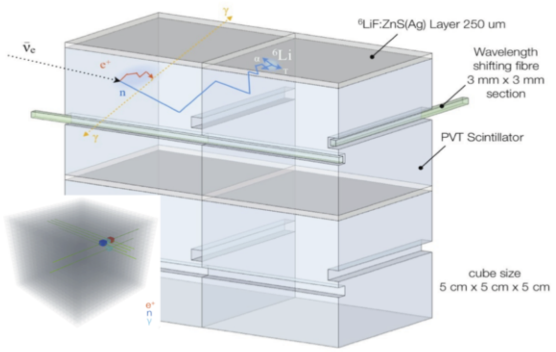

Fig. 2. IBD interaction in the detection elements and deposited energy due to an IBD event in the SoLid detector

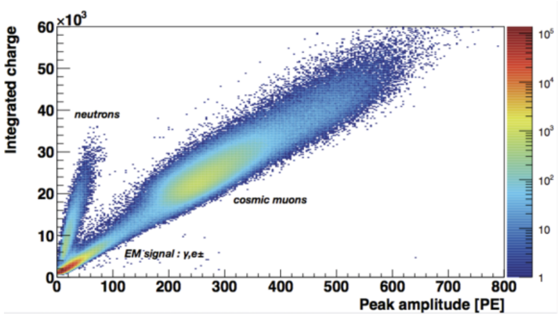

Fig. 3 EM / neutron /muon Discrimination, Integrated charge vs peak amplitude for signals collected by fiber-MMPC (1PE=80keV).

It provides a very effective discrimination between the two event types. The second and most significant novelty in neutrino detection is the segmentation of the design. It allows a precise reconstruction of events topology, then the study of background. Its rate is dramatically reduced with the temporal and spatial cuts used in the analysis. As a result, without the need for a large mass of passive shielding, a signal to background ratio of 6 can be achieved. The achievable energy resolution is ~17% at 1 MeV. The SoLid situation remains very competitive in terms

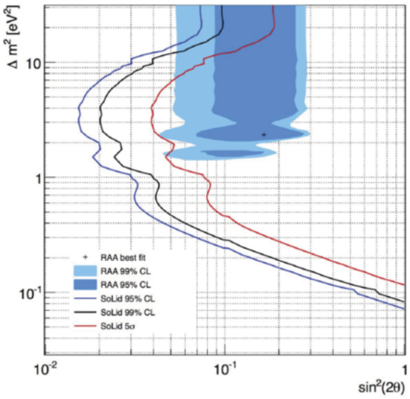

Fig. 4. shows the reactor and Gallium anomalies allowed region (blue shades) and the expected SoLiD exclusion area (3 and 5 σ).

of data accumulation within 300 days, to cover most of the reactor anomalies allowed region at 99% CL or if hints of oscillations are found to make a 5σ measurement over the same range (Fig. 4).

4. Current status

A 8kg SoLid prototype was installed at BR2 and has demonstrated the expected detector response (Fig. 2). The SoLid phase I is ongoing with the installation of the first SoLid Module (SM1), early November 2014, at 5.5 m from BR2 for 2 cycles data taking in order to perform a measurement with less than 5% total uncertainty.

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