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Detector of the reactor AntiNeutrino based on Solid-state plastic Scintillator (DANSS). Status and first results.

I Alekseev[1,2,3], V Belov[4], V Brudanin[4], M Danilov[2,3,5], V Egorov[4,6], D Filosofov[4], M Fomina[4], Z Hons[4,7], S Kazartsev[4,6], A Kobyakin[1,3], A Kuznetsov[4], I Machikhiliyan[1], D Medvedev[4], V Nesterov[1], A Olshevsky[4], D Ponomarev[4], I Rozova[4], N Rumyantseva[4], V Rusinov[1], A Salamatin[4], Ye Shevchik[4], M Shirchenko[4], Yu Shitov[4,8], N Skrobova[1,3], A Starostin[1], D Svirida[1], E Tarkovsky[1], I Tikhomirov[1], J Vlášek[4,9], I Zhitnikov[4], D Zinatulina[4]

[1] Alikhanov Institute for Theoretical and Experimental Physics, B. Cheremushkinskaya 25, Moscow, 117218, Russia
[2] National Research Nuclear University MEPhI (Moscow Engineering Physics Institute), Kashirskoe highway 31, Moscow, 115409, Russia
[3] Moscow Institute of Physics and Technology, 9 Institutskiy per., Dolgoprudny, Moscow Region, 141701, Russia
[4] Joint Institute for Nuclear Research, Joliot-Curie 6, Dubna, Moscow region, 141980, Russia
[5] Lebedev Physical Institute of the Russian Academy of Sciences, 53 Leninskiy Prospekt, Moscow, 119991, Russia
[6] Dubna State University, Universitetskaya 19, Dubna, Moscow Region, 141982, Russia
[7] Nuclear Physics Institute, Řež 130, 250 68 Řež, Cz, Czech Republic
[8] Imperial College London, South Kensington Campus, SW7 2AZ, London, United Kingdom
[9] Czech Technical University in Prague, Zikova 1903/4, 166 36 Prague 6, Czech Republic

E-mail: `igor.alekseev@itep.ru`

Abstract. A detector of the reactor antineutrino based on a cubic meter of plastic scintillator is installed below 3.1 GW industrial reactor. The detector is placed on a movable platform which allows to change the distance to the reactor core center in the range 10.7-12.7 m. 2500 scintillator strips are read out individually by SiPMs and in groups of 50 by PMTs. In addition to the overburden by the reactor (50 m w.e.) the detector has multilayer passive shielding and active muon veto.

Inverse beta-decay count rate of about 5000 events per day in the fiducial volume (78% of the detector) with about 5% of cosmic background has been reached. DANSS is sensitive to sterile neutrino in the most interesting region of mixing parameter space.

The article covers the detector status and performance, as well as the first results.

1. Introduction

Neutrino oscillation experiments had a tremendous progress in the last 20 years. The picture of three usual neutrino flavors oscillation looks to be established, though neutrino mass hierarchy is not set yet [1]. Nevertheless neutrino study and in particular experiments with reactor antineutrino could be a way to search for a new physics [2]. For example, averaging of the world reactor neutrino results done by G. Mention et al. [3] showed that the picture is inconsistent — reactor anomaly. The paper [3] proposed a new non-standard neutrino state which didn't interact weakly and could be observed through oscillations only. The proposed oscillation parameters ($\Delta m^2_{new} > 1.5$ eV^2 and $\sin^2(2\theta_{new}) = 0.14 \pm 0.08$) assume relatively short oscillation range. The ideal place for direct search of such an oscillations would be around ten meters from the reactor core. But placement of the detector so close to the core implies additional requirements, non-flammability being the most important. This requirement makes impossible utilization of the standard liquid scintillator technology. We use solid state scintillator to eliminate this problem, which allowed us to place the detector just below the core shielding of 3.1 GW industrial reactor.

Details of the DANSS detector could be found elsewhere [4, 5, 6, 7]. The main advantages of the detector are:

- its position below the reactor, providing high neutrino flux and an overburden of about 50 m w.e., protecting from cosmic muons and fast neutrons;
- fine granularity, helping in the event reconstruction and background suppression;
- a movable platform, which allow to move the detector for nearly 2 m, which allows to measure neutrino spectrum at various distances with the same detector.

The proof-of-principle experiment [8] was carried out with 1/25 of the whole detector. It demonstrated that the idea of the experiment was correct and allowed to optimize the passive shielding.

The idea of the reactor antineutrino detection by Inverse Beta-Decay (IBD) was proposed more than 80 years ago [9]:

$$\overline{\nu}_e + p \to e^+ + n \tag{1}$$

The IBD process produces two time separated signals. One signal, usually called "prompt", comes from positron, and the other, "delayed", from neutron capture. The prompt signal is produced immediately and consists of the positron track ionization and Compton scattering of the two γ-quanta, coming from the annihilation of stopped positron. The neutron undergoes moderation and then it is captured by gadolinium, which is included in the strip coating. This capture produces a flash of γ-rays with the total energy of about 8 MeV. The time difference between the prompt and the delayed signal is in the tens of microseconds range, which produces a very good reaction signature. For reactor neutrino energy of the positron produced is to a good precision equal to that of the original neutrino energy with the subtraction of the reaction threshold energy of 1.804 MeV.

2. Detector performance

Cosmic muons together with SiPM intrinsic noise provide continuous detector calibration and monitoring. A schematic view of the cosmic muon passing the detector is shown in figure 1. The two projections of the spectrometer are seen. Small rectangles show single strips read by individual SiPMs, while large squares present detector modules of 50 strips each read by PMTs. Rectangles on the edges and the top side correspond to veto system. Another check of the detector performance was done using ^{248}Cm neutron source inserted into detector via Teflon tubes running through the detector body. ^{248}Cm undergoes nuclear fission with release of about 200 MeV of energy together with several neutrons. The energy distribution of the delayed events corresponding to the neutron capture is shown in figure 2. Two peaks are seen corresponding to the neutron capture by proton (near 2 MeV) and by gadolinium (near 7 MeV). This is slightly lower than one would expect due to γ escape from the detector.

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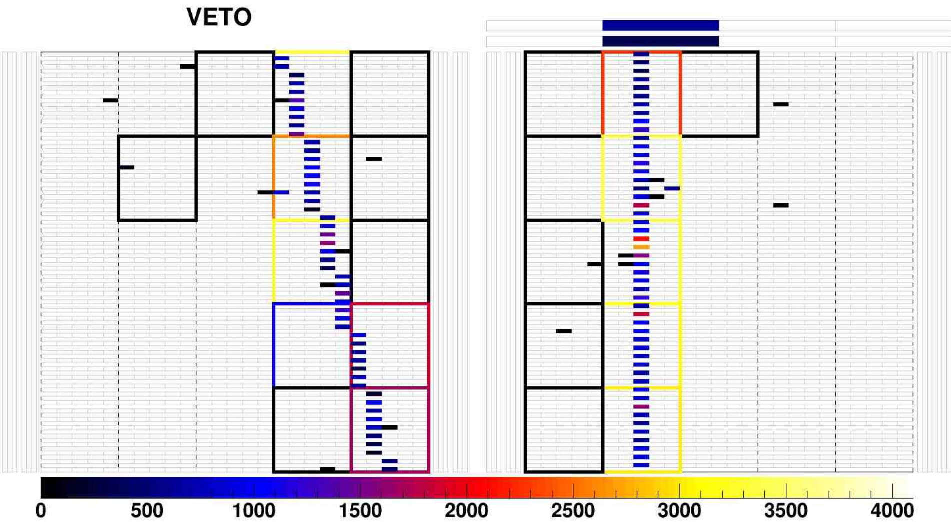

Figure 1. A schematic view of cosmic muon event.

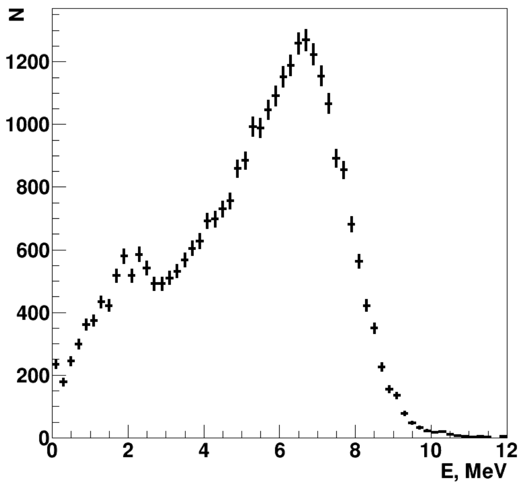

Figure 2. DANSS energy distribution of the delayed events from ^{248}Cm neutron source.

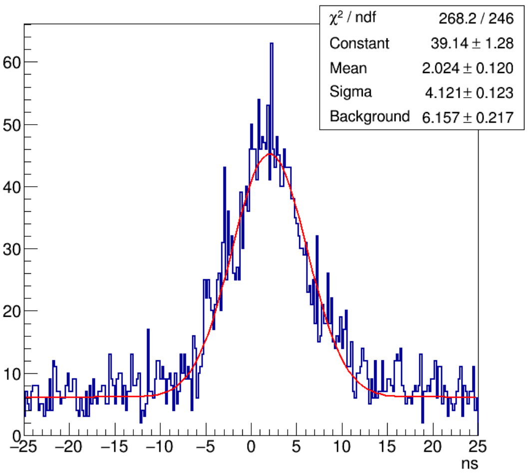

Figure 3. Distribution of the hit time difference from the event average time.

3. Analysis and the first results

Trigger of the experiment is produced when digital sum of all PMT signals is above 0.5 MeV or when the veto system is hit. As a consequence an IBD event exists in the data as two distinct events. The data analysis is performed in a few stages. The first is the noise cleanup. At this step average event time is calculated and all hits more than 15 ns away are rejected. Time distribution of a single strip is shown in figure 3. Then single pixel SiPM hits which don't have confirmation by corresponding PMT are also rejected. After these two steps less than 0.01 noise hit per event survive out of about 40 in the original sample. On the next stage various characteristics of the event such as total energy, number of hits and so on are calculated. At this stage we also look for a continuous cluster and calculate its energy. The next step is search for time-correlated pairs of prompt-delayed events. We start with finding of the event with more than 3 MeV energy deposit. This is a delayed event candidate unless it has too large energy deposit or veto scintillators hit. Then we look backward in time searching for prompt event with more than 1 MeV in positron cluster. The pair is considered found if the time difference between the events is less than 50 μs. For valid pair we also require no veto event within 100 μs before and no any event 50 μs before and up to 100 μs after, counting from the prompt event. The events found form a signal sample. Similar to the signal sample an accidental coincidence sample is formed by looking for prompt signal in 16 regions 50, 100, 150 etc. ms before the neutron candidate. Two distributions of signal events (blue lines), accidental background (red lines) and their difference (green points) are presented in figures 4 and 5. The left figure shows distance between positron and neutron clusters. The distribution is contributed by the neutron travel in the detector core and uncertainty of neutron capture vertex reconstruction from the γ-flash observed. Distribution of the neutron capture time from the positron production is presented in the right figure. These two figures also illustrate the method used to get physical distributions: the parameter is plotted for experimental data set and accidental background data set using the same selection criteria, then physical distribution is obtained as a difference of these distributions.

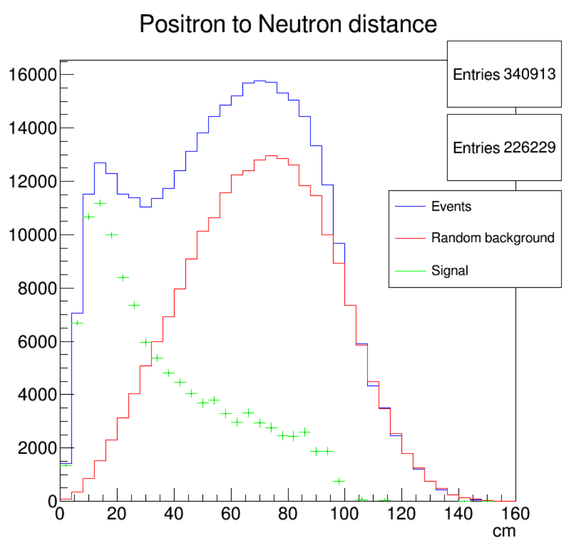

Figure 4. Distance between positron and neutron clusters.

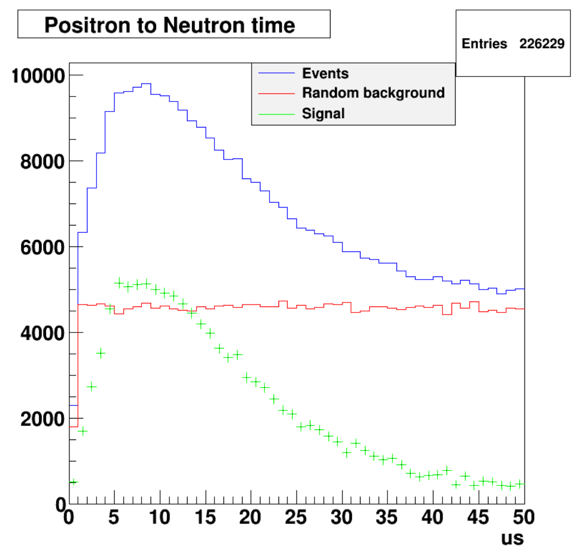

Figure 5. Time between prompt and delayed signals.

Preliminary energy spectra of positron cluster is shown in figure 6 with statistical errors only. The muon-induced background is shown at the bottom of the figure and is subtracted from the spectra. The data was collected at three different detector positions: top, 10.7 m from the reactor center, 7 days exposure, red points; middle, 11.6 m, 15 days, green points, and bottom, 12.7 m, 5 days, blue points. The muon-induced background estimate is based on the amount of muons missing veto counters but producing large energy deposit in the core detector (5%) and spectrum of neutrino like events, accompanied by veto.

The DANSS experiment reached counting rate of 5200 neutrino events per day in the position closest to the reactor. Data taking is in progress.

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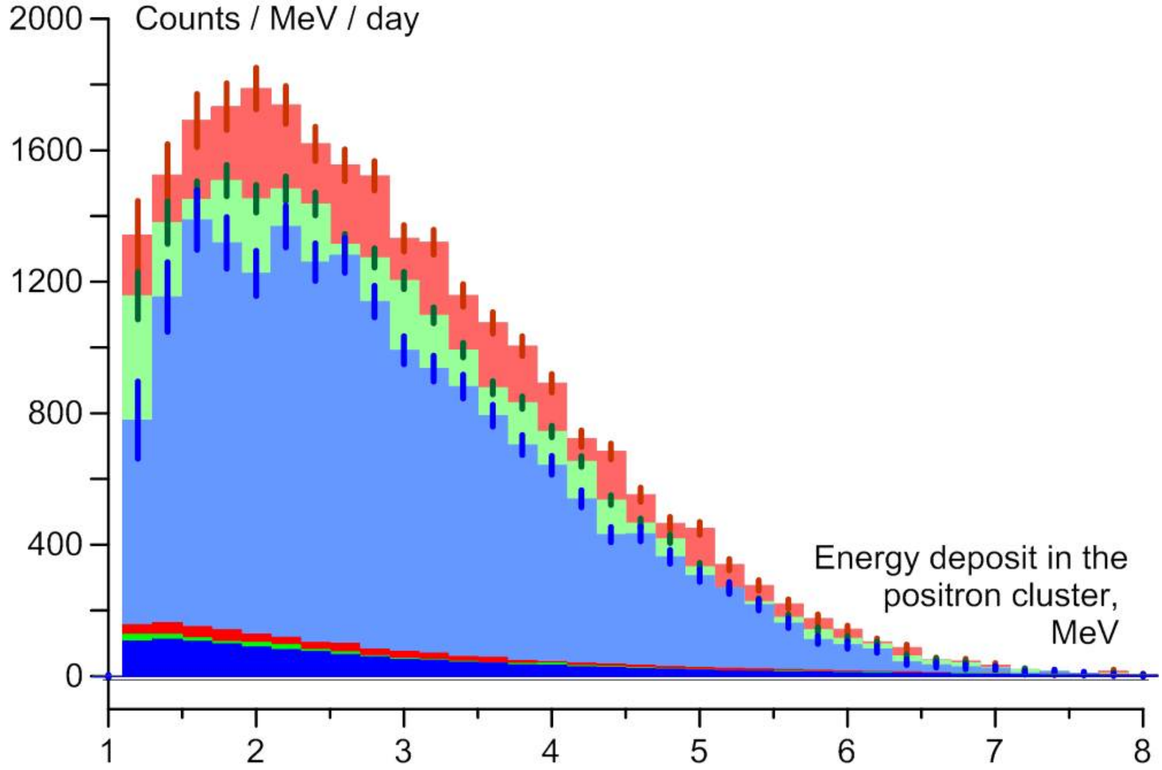

Figure 6. Energy spectra of positron cluster measured at different detector positions. Statistical errors only. Preliminary.

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