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Upgrade of the DANSS detector of reactor antineutrino

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The experiment DANSS is located on a movable platform under the 3.1 GW industrial reactor of the Kalininskaya NPP. The detector is a solid state scintillator spectrometer collecting up to 5000 neutrino events per day with the background of 2% only. The experiment has been running for 6 years and more than 6 million inverse beta-decay events have been already collected. DANSS already explored a large portion of the possible parameter space of the sterile neutrino oscillations. No statistically significant signal of sterile neutrino was found so far and important part of the sterile neutrino parameters have been excluded. The strongest limit is set around $\Delta m^2_{41} \sim 1\text{eV}^2$ with $\sin^2 2\theta_{ee}$= 0.008.

The main drawback of the detector is a moderate energy resolution of 34% at 1 MeV. This limits its sensitivity especially in the region of large Δm^2_{41}. The aim of the upgrade is to reach the energy resolution of 12% at 1 MeV. We also plan to use SiPM only readout and increase the sensitive volume by 70% keeping the same passive shielding and the platform. The main idea of the upgrade is in a new design of the scintillator strips providing larger light output with much better uniformity. The strips will be read out from both edges which will allow to reconstruct all three coordinates even if only a single strip is hit.

The paper covers the detector design and expected sensitivity, as well as the beam test of the new strip prototypes with the pion beam of the PNPI synchrocyclotron. The new strips demonstrated more than twice higher light output together with fairly flat detector response uniformity. For the better time response of the new strips we are going to use newer wavelength shifting (WLS) fiber YS-2 by Kuraray. For the new Kuraray WLS YS-2 the light output and attenuation length are as good as of Y-11. The decay time of YS-2 is nearly two times shorter.

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1. The DANSS detector

DANSS [1] is a highly segmented plastic scintillator detector which consists of 2500 scintillator strips ($1 \times 4 \times 100$ cm^3) with a thin ($\sim$ 0.2 mm) Gd-containing reflective surface coating. The strips are arranged in 100 layers. The strips in the adjacent layers are orthogonal. Light from the scintillator strip is collected with three wavelength-shifting fibers glued into grooves along the strip. The central fiber is read out with a Silicon PhotoMultiplier (SiPM). The side fibers from 50 parallel strips are bundled together and read out with a compact PhotoMultiplier tube (PMT).The sensitive area is surrounded with a composite shielding to suppress backgrounds. DANSS is placed on a movable platform under the core of the 3.1 GW$_{\text{th}}$ industrial power reactor at the Kalinin Nuclear Power Plant (KNPP) in Russia. The detector distance to the reactor core center is changed from 10.9 m to 11.9 m, and 12.9 m 2-3 times a week. The very good suppression of the cosmic background and the high granularity of the detector allow DANSS to achieve a very high signal/background (S/B) ratio of more than 50 (at 10.9 m from the reactor, after model independent subtraction of the accidental background). The size of the reactor core is quite big (3.7 m in height and 3.2 m in diameter) which leads to smearing of the oscillation pattern. This drawback is compensated by a high $\tilde{\nu}_e$ flux which allows DANSS to detect more than 5 thousand $\tilde{\nu}_e$ per day at a distance of 10.9 m. The energy resolution of the DANSS detector is very modest ($\sigma_E/E \sim 34\%$ at $E = 1$ MeV). This leads to additional smearing of the oscillation pattern, comparable with the smearing due to the large reactor core size. The main goal of the upgrade is to achieve a better energy resolution.

2. The upgrade

For the upgraded detector we plan to use the same passive shielding as in the current design. We plan to abandon the PMT readout and to use the SiPM readout on the both sides of the scintillator strip. Free space that appeared after the abandonment of the PMTs allows to increase the sensitive volume. Dimensions of the new scintillator strips are $2 \times 5 \times 120$ cm^3. There will be 60 layers with 24 strips in each layer. Therefore, the new DANSS will have 1.7 times larger sensitive volume. Strips are machined from a block of a bulk polystyrene by IPTP (Dubna, Russia). Unlike the current design there will be no large dead layer with titanium and gadolinium. New strips have chemical whitening of the surface. Gadolinium will be contained in films between the strip layers. Strip cross section is presented in figure 1, left. There are 8 grooves for 8 WLS fibers. Currently we consider two different possibilities. The first one is to use 8 SiPMs for one strip. In this case 4 of them (A0-A3 in the figure) will be placed on one side of the strip and another 4 SiPMs (B0-B3 in the figure) will be placed in another side. Another possibility is to use 16 SiPM for one single strip. Such approach will require more accurate SiPM board positioning. We are now testing this design. Figure 1, right shows the possible connection of the SiPM board to the strip. In any case signals will be measured using both sides of the strip. Therefore, we will be able to use time-of-flight measurements in order to reconstruct longitudinal coordinate in each strip. Distribution of time difference between the two sides of the strip is presented in figure 2. These results were obtained with 8 SiPMs per strip during the strip tests with a pion beam of the PNPI synchrocyclotron. During the tests the uniformity of the strip response was also measured. Results for longitudinal and transverse responses are presented in figure 2 (center and right). The test results are very promising. We expect to achieve resolution of 12% at 1 MeV after the upgrade.

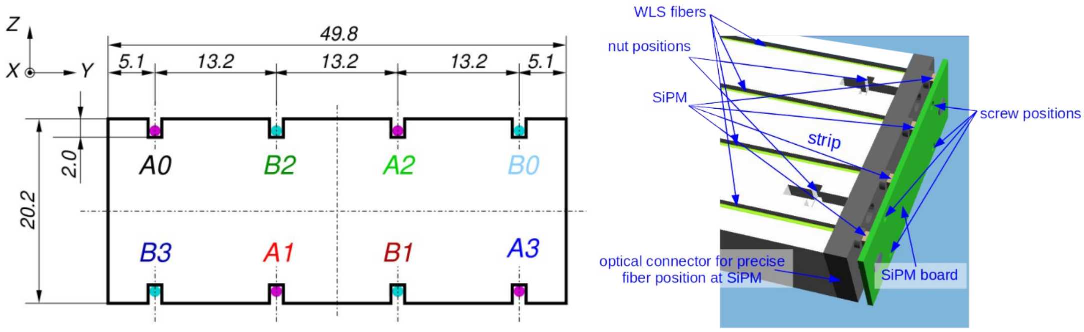

Figure 1: Left: new strip cross section. In case of 8 SiPM read-out A0-A3 markers correspond to SiPMs from one side and B0-B3 correspond to SiPMs from the other side. Right: 3D scheme of SiPM board mounting to the strip.

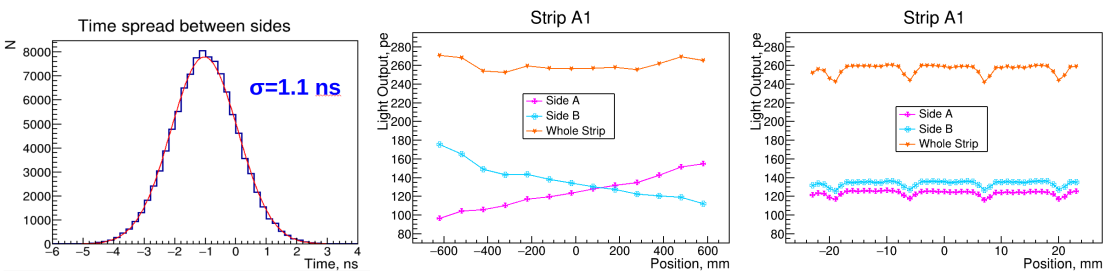

Figure 2: Results of the strip tests with the pion beam of the PNPI synchrocyclotron. There were 8 SiPMs per strip. Left: distribution of the time difference between the two sides of the strip. Center: the longitudinal light yield profiles for the signal sums at each side and for the whole strip. Right: Transverse light yield profiles for the signal sums at each side and for the whole strip. More details are presented in [2]

For the better time response of the new strips we are going to use newer wavelength shifting (WLS) fiber YS-2 by Kuraray. A dedicated study of this fiber with a 360 nm picosecond laser pulses demonstrated nearly twice shorter decay time (4.0 ns) in comparison with a mature Y-11 fiber [3]. Light output of YS-2 and Y-11 fibers was also compared using ^{90}Sr source and cosmic rays and the new fiber turned out to be at least as good as the mature one.

Expected sensitivity area in sterile neutrino parameter space is presented in figure 3. With improved energy resolution we hope to cover the area with larger Δm^2_{41} values where some indication in favour of sterile neutrino oscillations from BEST [4] and Neutrino-4 [5] experiments are present.

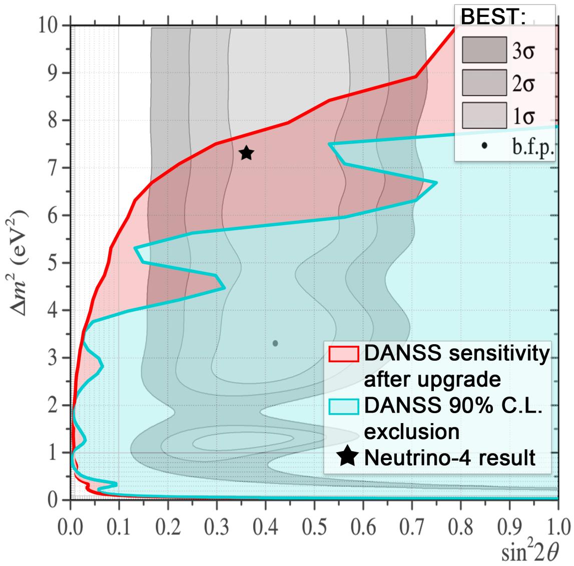

Figure 3: Expected sensitivity area to the oscillations in sterile neutrino state after two years of data taking (red). Current exclusion area based on 6 million IBD events (cyan).

References

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