PROCEEDINGS OF SCIENCE

Calibration of the DANSS detector with stopped atmospheric muons and their decays

Petr Gorovtsov [a,b,*] **and Nataliya Skrobova** [c,d]

for the DANSS collaboration

[a] *DFA, University of Padua*
via Marzolo, 8, Padua, Italy

[b] *Moscow Institute of Physics and Technologies*
Institutskiy pereulok, 9, Dolgoprudnyy, Russia

[c] *National Research Center "Kurchatov Institute",*
Akademik Kurchatov square 1, Moscow, 123182, Russia

[d] *Lebedev Physical Institute of the Russian Academy of Sciences,*
Leninskiy avenue 53, Moscow, 119991, Russia

E-mail: gorovtsov.pa@phystech.edu

The DANSS detector is placed under the reactor core of the Kalinin NPP and collects up to 5000 $\bar{\nu}$ events per day. The experiment is aimed to scrutinize the sterile neutrino hypothesis, and the obtained limits exclude practically all sterile neutrino parameters preferred by the BEST experiment. The main goal of the energy calibration is the determination of energy scale coefficient K_E. However, the Birks and Cherenkov effects are also investigated. The report covers calibration with atmospheric muons (μ) stopped inside the sensitive volume of the detector including their decays. Muons were selected by applying geometrical constraints and searching for subsequent e^- or e^+. The spectrum of the Michel e^-/e^+ is used for K_E determination. The time stability of the energy scale calibration with the Michel spectra is better than 0.4% over a period of 4 years. Bragg's curve built using μ energy release along its track is sensitive not only to K_E but also to nonlinear effects: the Birks effect, and Cherenkov radiation. This calibration complements the results of the calibration via radioactive sources and ^{12}B β-decays and results coincide with each other within $\sim 2\sigma$

42nd International Conference on High Energy Physics
17-24 July, 2024
Prague Conference Center, Prague, Czech Republic

[*] Speaker

PoS(ICHEP2024)205

1. Introduction

One of the main goals of the DANSS (**D**etector of **A**nti**N**eutrino based on **S**olid **S**cintillator) experiment is to test the sterile neutrino hypothesis. The DANSS detector is located near the nuclear reactor at the Kalinin Nuclear Power Plant (KNPP). Antineutrinos are detected via the Inverse Beta Decay (IBD) reaction: $\bar{\nu} + p \rightarrow e^{+} + n$ and their energies are determined from the positron energies. A precise energy calibration is needed for the investigation of the sterile neutrino hypothesis [2]. The DANSS energy scale is determined using beta decays of ^{12}B produced by muons. Radioactive sources (^{22}Na, ^{60}Co, ^{248}Cm) are also used for cross-checks. We developed another type of calibration using atmospheric muons that stopped inside the sensitive volume of the detector. The main feature of this method is its sensitivity not only to energy scale but also to non-linear effects: the Birks effect and Cherenkov radiation.

The DANSS sensitive volume is made of 2500 one-meter-long strips - plastic scintillator blocks. They are covered with a light-reflective substance which also contains Gd needed to capture neutrons from IBDs. Strips are laid down in 100 layers of 25 strips each. The sensitive volume is surrounded with a passive shielding made of copper, lead and borated polyethylene, and a veto system [1]. In adjacent layers, strips are oriented along perpendicular directions. This allows to reconstruct 3D-image of an event from the two 2D projections called XZ and YZ.

2. Calibration

The dependence of energy losses on the distance to the muon stop point (the Bragg curve) allows to simultaneously evaluate the Birks effect and Cherenkov light intensity using one calibration source. Geometrical constraints select nearly vertical ($\theta < 10^{\circ}$) tracks that start in the upper layer of the sensitive volume and stop above the three lower layers. Another important requirement is the presence of a muon decay event in the 1-7 μs window after the muon event in the same place where the muon stopped. This requirement guarantees that the subsequent muon decays or captures do not overlap with signals from the stopped muons. The Bragg curve is built using median losses at different distances from the muon stop point.

K_E is a proportionality coefficient between signals in experimental data and GEANT 4 Monte Carlo (MC) so $E_{MC} = K_E \cdot E_{Data}$. The Birks effect is parametrized with the coefficient K_B:

$$\left.\frac{dE}{dx}\right|_{detected} = \frac{\left.\frac{dE}{dx}\right|_{true}}{1 + K_B \cdot \left.\frac{dE}{dx}\right|_{true}} \tag{1}$$

For the K_B determination 3 MC datasets with different K_B were generated and 3 Bragg curves were obtained. This allowed us to calculate numerical derivatives over K_B. The Cherenkov constant variation was performed by adding equivalent Cherenkov light contribution given by expression (2) to the Bragg curve. Since the MC model includes the Cherenkov light contribution with the initial non-zero value of K_{Ch}, the formula describes the Cherenkov light losses caused by the change of this coefficient.

$$\Delta\left.\frac{dE}{dx}\right|_{Ch} = \Delta K_{Ch} e^2 \left(1 - \frac{E^2}{n^2(E^2 - m_\mu^2)}\right) \tag{2}$$

The fit of the MC Bragg curve with the Birks coefficient and Cherenkov light contribution fixed to the experimental data resulted in the following optimal coefficient: $K_E = 1.021 \pm 0.003_{stat} \pm 0.011_{syst}$ where the systematic error includes instability in time, variations of K_E for different regions of the muon stop points in the detector and comparison with the fit where K_B was a free parameter. The optimal Bragg curve is compared with the data in Fig. 1 a).

Michel e^-/e^+ events are also selected during the search for stopped muons. The GEANT4 MC predictions of Michel spectra were fit to the data multiplied by different K_E values in the range 15 − 56MeV. The lower energies are not used in the fit because of the pollution from μ^- captures which are not well described by GEANT4. At higher energies, radiative corrections could be large. The fit results in the optimum value of $K_E = 1.023 \pm 0.002_{stat} \pm 0.009_{syst}$. Spectra of Michel electrons or positrons are shown in fig 1 b).

The time instability is only 0.4% over a period of 4 years.

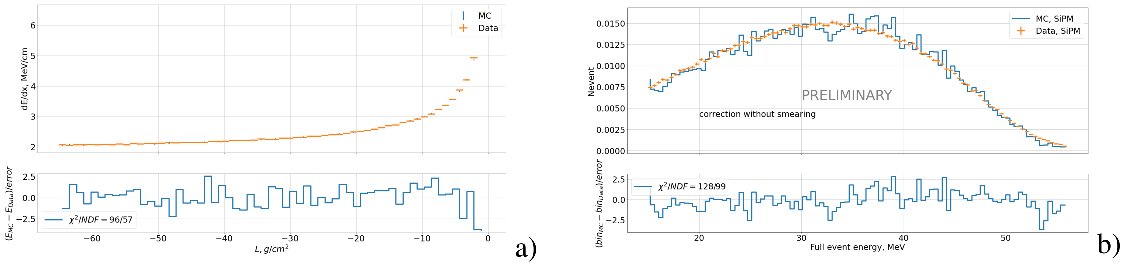

Figure 1: Calibration results: a) - corrected Bragg curves and b) - corrected Michel spectra

3. Conslusion

A novel method of segmented calorimeter energy scale calibration was developed for the DANSS detector. It is sensitive to the Birks effect and Cherenkov light contribution. Used event selection criteria also allow to select muon decay events and use the Michel e^+/e^- energy spectrum for the calibration of the detector energy scale. The time stability of the energy calibration with Michele e-/e+ is better than 0.4% over a period of 4 years. The obtained results on the energy scale from the two methods agree with each other within errors. They also agree within 2% (which is about 2σ) with the energy scale determined using ^{12}B beta decays. The difference can be partially due to non-perfect description of μ decays in orbit in the GEANT4 MC. We plan to improve it. We also plan to provide the Bragg curve fit with three free parameters: K_E, K_B, K_{Ch}

References

[1] I. Alekseev et al. DANSS: Detector of the reactor AntiNeutrino based on Solid Scintillator. *JINST*, 11(11):P11011, 2016.

[2] I. G. Alekseev. The DANSS Experiment: Recent Results and Perspective. *Bull. Lebedev Phys. Inst.*, 51(1):8–15, 2024.