EPJ Web of Conferences **191**, 03004 (2018) https://doi.org/10.1051/epjconf/201819103004
QUARKS-2018

Possible explanation of the neutrino signal from SN1987A detected with the LSD

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Abstract. On February 23 1987 in 2:52 UT the neutrino telescope LSD under Mont Blanc detected neutrino signal, which could not be explained within the framework of the standard collapse model. We show that the LSD signal could be a consequence of the detection of gamma-quanta emitted from neutron-capture reactions on by iron nuclei contained in the composition of the experimental setup. Neutrons are produced in neutrino-nuclei reactions in the surrounding granite rock and steel structures of the detector.

1 Introduction

The type II supernova SN1987A exploded in the Large Magellanic cloud On February 23, 1987. Astronomers discovered it in the optical range on the night of February 23-24 [1]. The liquid scintillation detector (LSD) detected the neutrino signal on February 23 at 2:52 am universal time (UT). Information about the LSD signal characteristics was sent to the International Astronomical Union on February 28 [2], [3]. The IMB [4] and Kamiokande II [5] collaborations have published their data on detected events 10 days later. BUST [6] announced data 3 weeks later. Time of neutrino detection for these detectors was about 5 hours later, at 7:35 UT. The LSD detector also had two pulses at 7:35 UT [3].

2 Neutrino interaction

In the framework of the standard collapse model, the main reaction of antineutrino detection is the inverse beta decay (IBD reaction). As a result of this reaction, two signals appear in the scintillator: the first signal is caused by a positron (visible energy E_{vis} = E_{ν_e} - 1.8 MeV + 2 $m_e c^2$), following the neutron capture (E_γ = 2.2 MeV, average capture time of about 185 μs). Protons and alpha particles in $\nu_e(\bar{\nu}_e)$Fe and ν_iFe reactions from excited nuclei Co* , Mn* and Fe* are not detectable due to the quenching effect in scintillator. Until now, the reactions of neutron production ($^{A}X(\nu_e, e^- n)^{A-1}X$, $^{A}X(\bar{\nu}_e, e^+ n)^{A-1}X$) have not been given much importance due to their small cross section. In a recent work [7] it was shown that the LSD signal can be explained by gamma quanta from nFe-captures. Neutrons are produced by νA-interactions in the rock and in steel structures of the detector.

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3 LSD description in underground hall

The Liquid Scintillation Detector (LSD) placed under Mont Blanc operated in the continuous rate from January 1985 to March 1999 [8]. The detector was in a garage inside a 12 km long motorway tunnel between Italy and France, passing at an altitude of 1400 m from the southeast to the northwest. The thickness of the rock about 2 km above the detector suppressed the cosmic-ray muon flux by 6 orders of magnitude. The detector consisted of 72 scintillation counters each with a volume of 1.5 m^3 and a liquid scintillator mass of 1.2 t. The counters were placed in iron containers with a wall thickness of about 20 mm. The thickness of the stainless steel walls of the case of a counter was 4 mm. The total mass of iron was $\sim$ 200 tons and more than twice the mass of the liquid scintillator (86.4 ± 0.5 tons). Each counter was equipped with three PMT-49B photomultipliers and had a detection system determining the amplitude and time of a trigger pulse with energies higher than 5 MeV in 16 inner counters and about 7 MeV in 56 external counters. During 500 μs after the trigger pulse, the thresholds were lowered so that all pulses with an amplitude larger than 0.8 MeV were detected including np- or nFe-captured γ-quanta in the case of the neutron appearance in the material of the detector at the time of the trigger. The LSD detects neutrons by γ-quanta from radiative capture of thermal neutrons by protons of scintillator ($E_\gamma = 2.2$ MeV, $\tau \approx 180$ μs), and iron nuclei in the LSD support structure ($< E_\gamma > \approx 7$ MeV, $\tau \approx 100$ μs).

4 MC Simulation of neutron interaction with iron and granite rock

Simulation of the neutrino interaction is a difficult task because only limited amount of experimental [9] and calculated data is available on the cross sections for the interaction of neutrinos with nuclei contained in the Mont Blanc rock composition. With good accuracy, the cross sections for neutrino-iron interaction were obtained in [10] paper.

The massif of the Mont Blanc mountain is composed of granite, which consists mainly of silicon dioxide (SiO2). The content of uranium and thorium in granite is higher than, for example, in sedimentary rocks by a factor of 10−100. Therefore, at the first stage of the GEANT4 simulation [11], we investigated the ability of neutrons produced in the rock to reach the LSD setup and be captured by the iron nuclei of the detector.

We simulated the propagation of neutrons in the Mont Blanc granite to obtain the neutron survival function prior to their capture by nuclei. It was found that the maximum thickness of the rock layer that a neutron can pass before being captured is little over 1 meter, and this thickness does not depend on the initial neutron energy. The calculated mass of granite surrounding the LSD is about 1000 tons for a thickness of 1 m.

We performed two sets of Monte-Carlo calculations. In the first series, we simulate 10^4 neutrons generated in 1-meter layer of granite, and in the second - 10^4 neutrons generated in steel structures of the detector. The LSD setup with realistic geometry and correct masses of materials was used in our simulations. The detector response to generated neutrons was obtained. The energy distributions of pulses with initial neutron energy $E_n = 2$ MeV from nFe-captures are shown in the Fig. 1 and Fig. 2. Numbers of detected pulses from neutrons produced in steel structures of LSD detector are presented on Fig. 1. Numbers of detected pulses from nFe-captures of neutrons produced in granite nuclei with different energies are presented on Fig. 2. We took into account the pulses from gamma quanta with energy higher than 5 MeV threshold. Under the abscissa axis of figuries, the vertical lines indicate the energies of the five (5) SN1987A events detected with LSD.

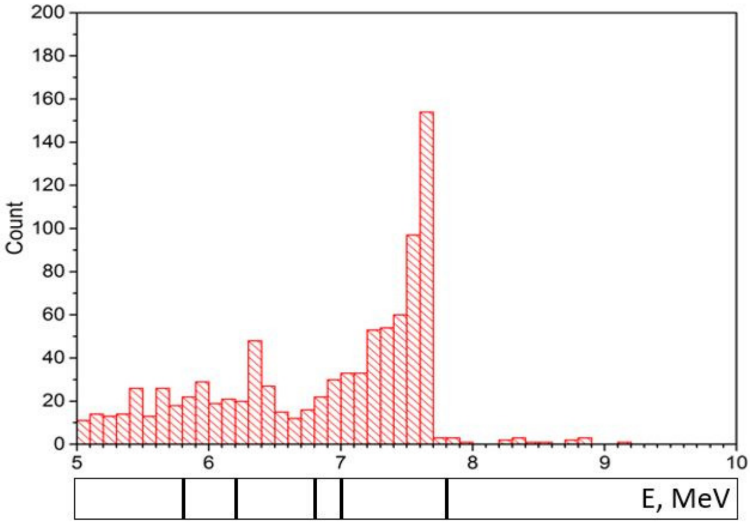

Figure 1. A histogram of events in LSD counters for neutrons with an initial energy of 2 MeV produced in steel structures of the LSD

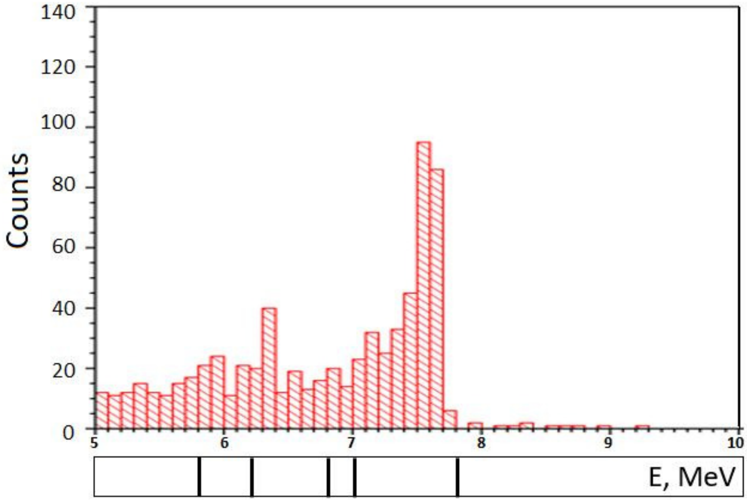

Figure 2. A histogram of events in LSD counters for neutrons with an initial energy of 2 MeV produced in the granite surrounding the LSD

5 Discussion and conclusion

If the detected events in the LSD were attributed to antineutrinos, then the pulse spectrum should be wider (up to ~ 30 MeV) and each pulse should be accompanied by a 2.2 MeV pulses from neutron capture. Neither of which were observed in the experiment. A possible explanation for the LSD signal is the detection of neutrinos, within the Imshennik's Rotating Collapsar Model [12]. In [13], [14], reactions with gamma quanta emitted from excited ^{12}C, ^{56}Co, ^{56}Mn, ^{56}Fe nuclei were considered, where the central role is played by electron neutrinos having an energy $E(\nu_e)$ of about 40 MeV. In this paper, we discuss possible channels for detecting neutrinos in LSD, inaccessible to other detectors, within the framework of a standard collapse. We show that taking into account neutron production by neutrino and antineutrino makes it possible to increase the effective mass of the target and can explain the LSD signal similar to distribution of γ-quanta from nFe-captures. In this paper, we do not discuss the relationship of the LSD signal to the IMB, KII, and BUST signals at 7:35 UT. We can only mention that there are many articles with models of two-stage core collapses [15], [16], [17].

6 Acknowledgments

This work was partially supported by the Russian Foundation for Basic Research, project N 18-02-00064-a; and the joint program of investigations of the Presidium of Russian Academy of Sciences "Physics of Fundamental Interactions and Nuclear Technologies".

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