The search for rare events using Large Volume Detector

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Abstract. The results of the searching for rare events in the Large Volume Detector (LVD) are presented. The rare events could be caused by neutrino interactions in the experimental setup. In the work, the experimental data for 2006-2017 are analyzed. A stability of LVD background counting rate during the specified period is shown. Candidates on neutrino bursts from collapsing stars in the sequence of the LVD events are not found.

1. Introduction
Correct background estimations are very important in the underground physics experiments. The main goals of the experiments are the search for neutrino bursts from collapsing stars, double beta-decay, proton decay, dark matter particles and other extremely rare phenomena. The search for neutrino bursts from gravitational collapses of stars is a long-term experiment. Within the work, research of background events in the LVD setup is done to estimate parameters of real neutrino events. At the moment, only the neutrino burst from SN1987A in the Large Magellanic Cloud has been registered.

The basic scheme of the experiment to search for a neutrino burst is very simple. A cluster of events in detector that could be caused by neutrino interactions is being looked for. The main problem of the neutrino interaction detection is determination of background events. The event due to neutrino burst detection is selected using characteristics of a cluster (duration and multiplicity) depending on the counting rate of background events. The event caused by the detection of a neutrino burst by the detector is selected. The neutrino burst detection will allow to check theoretical gravitational star collapse models.

2. LVD detector
The LVD detector [1] is located at the LNGS underground laboratory (the Laboratori Nazionali del Gran Sasso, Italy) at a depth of 3620 m.w.e. The LVD detector is an underground iron-scintillator calorimeter with a total mass of 2 kt (1 kt of liquid scintillator and 1 kt of iron). The detector contains 840 independent scintillation counters. The modular structure of LVD is presented in figure 1. The structure contains 3 towers. 5 columns are arranged in each tower, each column consists of 7 portatank levels. Each portatank contains 8 counters (tanks). Modular structure of the LVD setup allows use external counters as an active shield from muons and other background events. Scintillator in tanks is based on white spirit. In addition to its extremely low cost, the parameters of this scintillator remain unchanged during long time under operating conditions [3].

Each counter is viewed by 3 photomultipliers tubes (PMT). The PMTs have different high voltage
values, so the background from PMT after-pulses is minimized. Energy threshold of LVD detector is 5 MeV. Coincidence of signals from 3 PMT during event detection reduces effect of the PMT dark current. Trigger opens time gate for a period of 1 ms with an energy threshold of 1 MeV. It thus becomes possible to detect both positrons and gamma-quanta produced by the capture of neutrons generated in the reaction of the inverse beta decay.

Figure 1. The modular structure of the LVD detector.

3. Events selection
The purpose of experimental data selection is the selection of events that could be caused by the neutrino interactions in the LVD detector. At the first stage, events caused by muon interactions in the detector are excluded. Such events are characterized by the response of two or more counters in a time window of less than 175 ns. Also external counters are excluded from the analysis, i.e. counters bordering on the surrounding volume of the LVD detector. In figure 1, these are counters that form an external rectangular parallelepiped. This limitation is caused by the different counting rate of background events in the counters. The counting rate of background events in external counters is several times higher than in internal ones. After excluding muon events and events in external counters, counters whose average counting rate exceeds the expected value are also excluded from the analysis.

Background events are random events. It means that time between them has an exponential distribution. In figure 2, the event time distributions in the LVD detector are presented. We can see that the time between events is distributed exponentially and experimental results do not contradict the calculations. Pseudorandom number generator described in the article of Marsaglia and Tsang [3] is used in the calculations. Average counting rate in the LVD detector is about 0.04 events per second.
4. Searching for clusters in the LVD detector

Probability of detecting the cluster with multiplicity $N$ and duration $T$ has the form:

$$ p_N = \frac{(\lambda T)^N}{N!} \cdot \exp(-\lambda T). $$

This is Poisson distribution, $N$ is cluster multiplicity, $T$ is cluster duration and $\lambda$ is counting rate of background events. Counting rate of occurrence of events with cluster multiplicity $N$ and duration $T$ has the form:

$$ \lambda_N = \lambda \frac{(\lambda T)^{N-1}}{(N-1)!} \cdot \exp(-\lambda T). $$

In that way, the average occurrence time of the cluster with multiplicity $N$ and duration can be written as:

$$ T_N = \frac{1}{\lambda_N}. $$

If we can estimate average occurrence time of the cluster, we can calculate its statistical significance. For example, we can select the cluster at its occurrence time. The search for clusters in the LVD detector was carried out as follows. The maximal cluster multiplicity is 30. So, it was done for all clusters with multiplicity no more than 30 and with duration less than 100 seconds. For each cluster, average time of its detecting and duration was calculated. Clusters of events from collapsing stars have not been detected in the LVD detector.
In future, it is planned to include in the analysis the experimental data from the external counters. Clusters will be searched in the same way as in the internal counters. The difference consists in the quantitative estimate of the average time of a cluster generation by background events. When calculating the average time, another value of the average rate of the background events will be used, it is lower than that in the internal counters. Therefore, the average time that the background event cluster generates in the internal counters is always greater than the average time that a similar cluster forms in the external counters. Furthermore, each counter in the LVD detector is an independent detection element, so the data from the external and internal counters can be considered as data from two independent detectors. The number of external and internal counters in the LVD detector is approximately the same. So when registering a neutrino burst, clusters of events with similar parameters (multiplicity and duration) in the external and internal counters should be simultaneously detected. After cluster obtaining in the internal and external counters, their coincidences will be searched for. The average time of formation of two background clusters at the same time will be calculated. This will enable clusters with lower multiplicity and longer duration to be included in the analysis.

5. Conclusion
In the article, a stable long-term (for about 11 years) functioning of the LVD detector is presented. The counting rate in the LVD detector is about 0.04 events per second. The practical invariability of the counting rate for background events enhances significantly the probability for identifying a neutrino burst. The experimental results do not contradict the calculations. In accordance with LVD data, the clusters of events from collapsing stars have not been detected. In future, the analysis will include data from the external counters of the LVD detector, which will reduce the requirements for the selection of clusters.

Acknowledgments
This work was partially supported by the Russian Foundation for Basic Research, projects ## 18-02-00064-a, 19-02-00262-a, and the joint program of investigations of the Presidium of the Russian Academy of Sciences "Physics of Fundamental Interactions and Nuclear Technologies".

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