Joint analysis of experimental data on the search for neutrino bursts using the BUST and LVD detectors

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Abstract Preliminary results of joint analysis of data of the INR's Baksan Underground Scintillation Telescope (BUST) and the Gran Sasso Large Volume Detector (LVD) are presented. The results can be explained by random pulse coincidences in the BUST and LVD detectors.

Keywords: Supernova, Neutrino Bursts

1. Introduction

The neutrino burst from a supernova (SN) is a very rare and transient event. To record it, several long-time experiments with a high percent of live time are needed.

A joint analysis of data of different facilities, operating in the search for neutrino bursts regime, will allow us to make the search with a greater sensitivity and increase reliability of detected neutrino signals. For the task of supernovae search, this is especially important in cases when the observation of SN is performed under "uncomfortable" conditions, for example, a shading of optical flare by galactic dust or in the case of non-canonical optical luminosity of an SN.

With that end in view, we attempt to carry out a joint analysis of data of the BUST and LVD detectors. In this paper we use the data of both facilities over the period of 2012 - 2014.

Section 2 is a brief description of the BUST and LVD detectors. Section 3 is devoted to the method of neutrino burst detection. In Section 4 the algorithm of the search for temporal coincidences of "single events" clusters in both facilities is presented. Section 5 is the conclusion.

2. The BUST and LVD detectors

The Baksan Underground Scintillation Telescope (BUST) is located in the Northern Caucasus (Russia) in the underground laboratory at the effective depth $8.5 \cdot 10^4$ g$\cdot$cm^{-2} (850 m of w.e.) [1]. The facility has the size $17\times17\times11$ m^3 and consists of four horizontal scintillation planes and four vertical ones (Fig. 1).

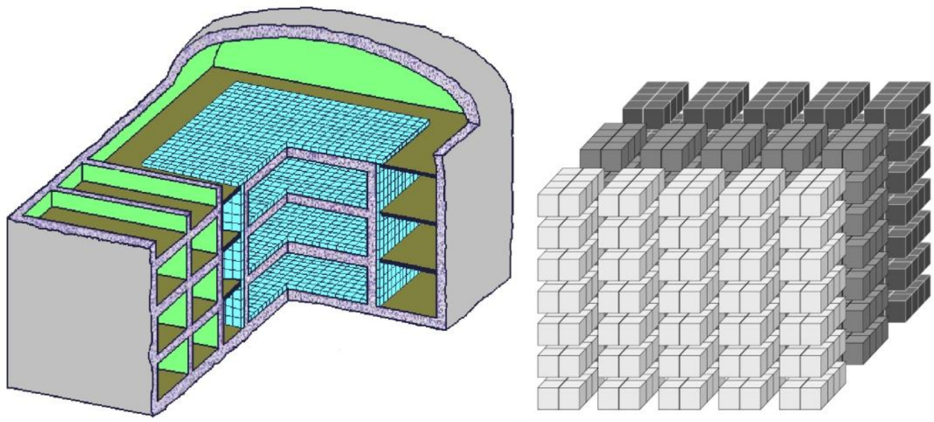

Fig1. *Left – the Baksan Underground Scintillation Telescope, Right –the Large Volume Detector (schematic views)*

Five planes of them are external planes and three lower horizontal planes are internal ones. The upper horizontal plane consists of 576 (24×24) liquid scintillator counters of the standard type, three lower planes have 400 (20×20) counters each. The vertical planes have (15×24) and (15×22) counters. Each counter is 0.7×0.7×0.3 m^3 in size, filled with the organic C_nH_{2n+2} ($n \approx 9$) scintillator, and viewed by one photomultiplier (FEU 49B) with a photocathode diameter of 15 cm. The distance between neighboring horizontal scintillation layers is 3.6 m. The angular resolution of the facility is 2^o, the time resolution is 5 ns.

Information from each counter is transmitted over three channels: an anode channel (which serves for triggering formation and amplitude measurements up to 2.5 GeV), a pulse channel with the operation threshold 8 MeV and 10 MeV for the horizontal and vertical planes, respectively (at first this threshold was equal to 12.5 MeV; the most probable energy deposition of a muon in a counter is 50 MeV ≡ 1 relativistic particle) and a logarithmic channel with the threshold $s_o = 0.5$ GeV. A signal from the fifth dynode of PM tube FEU-49 goes to the logarithmic channel where it is converted into a pulse whose length *t* is proportional to logarithm of the signal amplitude.

The BUST is a multipurpose detector. One of the current tasks is the search for neutrino bursts. The facility has been operating almost continuously under the program of search for neutrino bursts since the mid-1980. The total time of Galactic observation accounts for 90% of the calendar time.

The Large Volume Detector (LVD) is located at the LNGS underground laboratory (the Laboratori Nazionali del Gran Sasso, Italy) at a depth of 3600 m w.e.[2]. 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). LVD consists of an array of 840 scintillator counters (Fig. 1). The whole array is divided into three identical towers with independent high voltage power supply, trigger and data acquisition. In turn, each tower consists of 35 modules hosting a cluster of 8 counters. Each counter (1.5×1×1 m^3 in size) is filled with liquid scintillator having a mass of 1200 kg, and is monitored by three FEU 49B or FEU 125 photomultipliers. The operating threshold of the counter is 5 MeV. The total time of Galactic observation accounts for ≈ 99% of the calendar time [3].

Identical hydrocarbon-based scintillators are used in the BUST and LVD detectors.

3. The method of neutrino burst detection

The BUST consists of 3184 standard autonomous counters. The total scintillator mass is 330 t, and the mass enclosed in three lower horizontal layers (1200 standard counters) is 130 tons. The majority of events recorded with the Baksan telescope from a supernova explosion will be produced in inverse beta decay reactions

$$\bar{\nu}_e + p \rightarrow n + e^+ \tag{1}$$

If the mean antineutrino energy is around 15 MeV [4], [5], the pass of e^+ (produced in reaction (1) will be included, as a rule, in the volume of one counter. In such a case the signal from a supernova explosion will appear as a series of events from singly triggered counters (a single counter of 3184 operates; below we call such an event “the single event” or “1 from 3200”) during a neutrino burst.

Background events are radioactivity and cosmic ray muons if only one counter from 3184 hit. The total count rate from background events is f = 0.02 s^{-1} in internal planes (three lower horizontal layers) and ≈ 1.5 s^{-1} in external ones. Therefore three lower horizontal layers are used as a target. The trigger is an operation of any counter pulse channel (with the threshold 8 MeV).

In Fig.2 we show how the counter operation threshold changed with time (12.5 → 10 → 8 MeV) and the corresponding total count rate of single events in the three internal planes (1200 counters, the target mass is 130t).

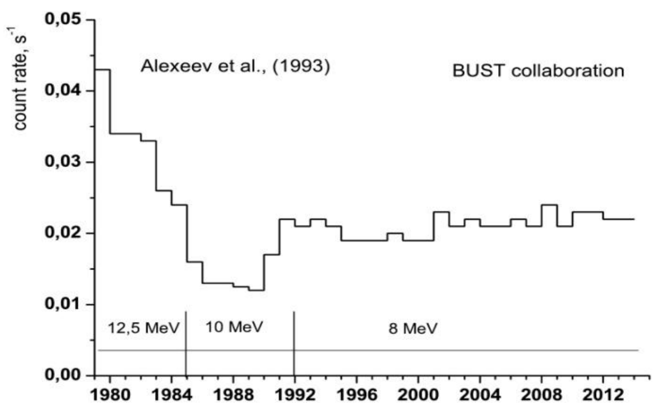

Fig2. *The mean count rate of single events in the three telescope internal planes (1200 counters) vs the counter operation threshold.*

Background events can imitate the expected signal (k single events within sliding time interval τ) with a count rate [6]

$$p(k) = f \times \exp\left(-f\tau\right) \frac{(f\tau)^{k-1}}{(k-1)!} \tag{2}$$

The processing of experimental data (background events over a period 2001 - 2014 y; T_{actual} = 11. 98 years) is shown by squares in Fig.4 in comparison with the expected distribution according to expression (2) calculated at f = 0.02 s^{-1}. Note there is no normalization in Fig.3.

Background events are to create clusters with k = 8 with the rate = 0,138 y^{-1} (and =6.9*10^{-3} y^{-1} if k = 9). The expected number of clusters with k = 8 during the time interval T_{actual} = 11.98 y is 1.65 what we observe in the experiment (2 events). Clusters with k ≥ 9 should be considered as a neutrino burst signal.

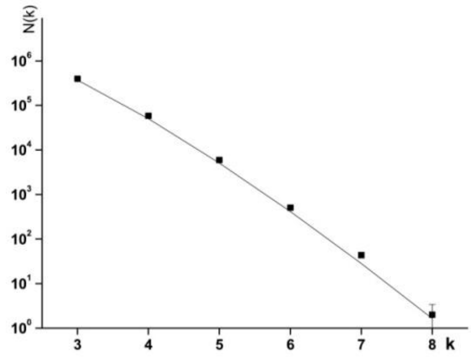

Fig3. *The BUST; the number of bunches with k single events within time interval of τ = 20s. Squares are experimental data, the curve is the expected number according to the expression (2)*

The search for a neutrino burst in the LVD detector consists also in the recording of a single- event cluster within a time interval of τ = 20 s (in the case of the LVD detector, "the single event" is "1 from 840" event).In order to reduce the count rate from background events, the counters of internal part of the facility were selected. A total of 360 counters in the LVD detector were selected for further analysis. The count rate of single events in the array of 360 counters selected for analysis in the LVD is 0.4 s^{-1}. It is shown in Fig.4.

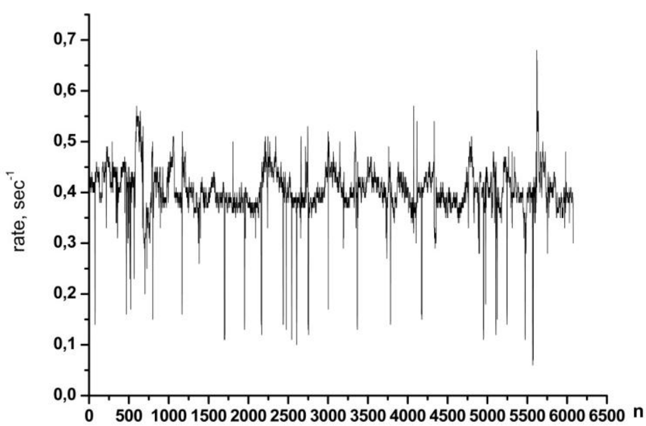

Fig4. *The LVD; the count rate of single events in the array of 360 counters vs the RUN number; (data of 2012 – 2014 years, the number of RUNs 6074)*

4. The joint analysis of the BUST and LVD data

We carried out a search for coincidence of clusters of single events in both facilities (BUST and LVD). It should be noticed, we treat background events certainly and the present analysis is of methodical character. The search for the clusters coincidence has been performed for two variants:

1) search for clusters in LVD, which coincide with clusters in the BUST and the "inverse" task
2) search for clusters in BUST, which coincide with clusters in the LVD.

In the first variant we proceed from the fact that, for a real neutrino burst, an LVD cluster begins earlier than that at the BUST. It is related with a larger target mass in the LVD (430 t instead of 130 t in the BUST) and a smaller value of the detection threshold (5 MeV instead of 8 MeV at the BUST). It will lead to that the number of recorded neutrino events in LVD, k_{LVD}, will be 4-5 times greater than the event number in BUST:

$$k_{LVD} \approx (4 - 5) * k_{BUST} \quad (3)$$

Therefore the search algorithm was the following.

For each cluster in BUST, which has a fixed number of events, k_{BUST}, and starts at t_{BUST}, we search (20 s) for clusters in LVD which start in the interval from (t_{BUST} – 10 s) up to t_{BUST}. Among the latter the cluster with the maximal multiplicity k_{LVD} is compared with the one in BUST at t_{BUST}. As a result of such processing, the distributions of LVD clusters on the multiplicity, k_{LVD}, were obtained for a given number of events in the cluster in BUST (Fig.5). Some parameters of these distributions are shown in Table1.

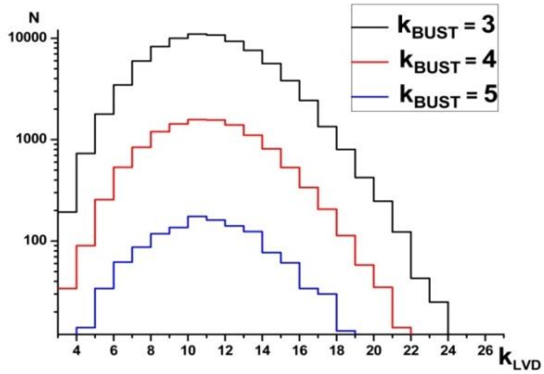

Fig5. *Distributions of LVD clusters on the multiplicity, k_{LVD}, for the fixed number of events in the BUST cluster*

As one can see from the table, the mean and most probable number of events in the LVD clusters does not change when the multiplicity of BUST clusters grows, as it would be if the events in the clusters are background events. It is clear also that the value of $\overline{k}$ does not practically change at the occurrence of even several of real neutrino bursts. I.e. the parameter $\overline{k}$ is not sensitive to presence of neutrino bursts, however it is an indicator of stable operation of the facility.

Table1. *$N(k_{BUST})$ - the number of clusters registered for BUST; $\overline{k}_{LVD}$ - the mean number of events in LVD clusters; k_{peak} - the number of events at which the peak in the distribution is observed (due to poor statistics, no peak is observed at k_{BUST} = 6 and 7)*

$\mathbf{k_{BUST}}$	$\mathbf{N(k_{BUST})}$	$\overline{k}_{\mathbf{LVD}}$	k_{peak}
3	83909pt	9.71	10
4	12126	9.70	10
5	1273	9.63	10
6	90	9.08	
7	8	8.63	

It should be noted that although the cluster in the LVD, in case of a real neutrino signal, always starts earlier cluster in BUST, this advance does not certainly exceed of 10 seconds. Therefore, the proposed algorithm provides a search for correlations for all models of the collapse of the star core.

The “inverse” task consisted in the search for clusters in the BUST that began less than 10 s later than the LVD clusters. Such coincidences were sought in three ranges of LVD cluster multiplicity: 6–8, 12–14 and 18–20 events in a cluster. The obtained multiplicity distributions of BUST clusters are presented in Table 2. As in the former case, the mean number of events in BUST clusters, k, remains the same as the multiplicity of LVD clusters grows. This indicates to stable operation of BUST.

Table2. *Multiplicity distributions of the BUST clusters that coincided in time with LVD clusters with fixed multiplicity*

k_{LVD}	2	3	4	5	6	$\bar{k}_{BUST}$
6 - 8	89912	6440	329	8	0	2.07
12 - 14	58848	4055	201	8	0	2.07
18 - 20	2178	168	11	0	0	2.08

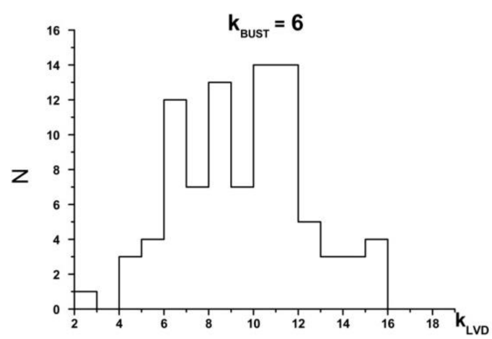

Fig6*. The multiplicity distribution of LVD clusters which coincide with BUST clusters at $k_{BUST} = 6$*

In Fig.6, the multiplicity distribution of LVD clusters which coincide with BUST clusters at $k_{BUST} = 6$ is shown. If we assume that any of 90 BUST clusters with $k_{BUST} = 6$ (see Table 1) is the signal from a real neutrino burst (from some distant source) then the corresponding cluster in LVD must have (according to estimation (3)) ≈ 25 - 30 events. The distribution in Fig.A3 terminates at the multiplicity $k_{LVD} = 15$. It does imply that none of 90 BUST clusters with $k_{BUST} = 6$ can be considered as a candidate for the neutrino burst signal.

5. Conclusion

We have presented the first results of the joint analysis of the BUST and LVD data on the search for neutrino bursts.

We have performed the search for coincidence of clusters of single events in the BUST and LVD detectors over the period of 2012 – 2014. The obtained results point out to the stable operation of the facilities and can be explained by random coincidences of background events.

The joint analysis of data of different facilities can be especially useful for the recording of neutrino bursts from distant sources (e.g. in Magellanic Clouds).

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