The search for rare events using Large Volume Detector


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Motivation

- coincidence of events clusters in LVD and BUST detectors allows increase volume of experimental data in the analysis

- thanks to estimate of the random coincidences frequency between the background events in the LVD and BUST detectors perhaps to refine the searching parameters of rare events, for example, neutrino bursts from collapsing stars

- thanks to long-term stable work of detectors we can refine estimation of gravitational stellar collapses frequency
LVD Detector

- Length $\times$ Width $\times$ Height: 22.7 m $\times$ 13.2 m $\times$ 10 m
- Iron mass: 1020 t
- Scintillator mass: 1008 t
- Amount of counters: 840
- Amount of PMTs: 2520
- Average depth (min): 3620 m w.e., 3000 m w.e.
- Average muon energy: 280 GeV
- $E_\mu$ at see lev. (min.): 1.3 TeV
- Muon rate (per 1 tower): $\sim 120$ h$^{-1}$
- $\varepsilon_{th}$ threshold –inner: 4 MeV, 7 MeV

Main goal – neutrino burst search from collapsing star
The BUST detector is located in the North Caucasus, on the slope of Mount Andyrchi at an effective depth of 850 mwe. It is $17 \times 17 \times 11$ m$^3$ in size and consists of four horizontal and four vertical plates with scintillation counters. Five plates are external, while the three lower horizontal planes are internal. The counter size is $0.7 \times 0.7 \times 0.3$ m$^3$. Total number of counters is 3184 and an overall scintillator mass of around 0.3 kt.
### Main neutrino interaction reactions

| Reaction | 
|----------|---|
| $\nu_e + p \rightarrow e^+ + n$ | $E_{\text{th}} = 1.8 \text{ MeV}$ |
| $n + p \rightarrow d + \gamma$ | $E_{\gamma} = 2.2 \text{ MeV}$ |
| $n + \text{Fe} \rightarrow \text{Fe} + \Sigma \gamma.$ | $\langle E_{\gamma} \rangle \approx 7 \text{ MeV}$ |
| $\nu_e + ^{12}\text{C} \rightarrow e^- + ^{12}\text{N}$ | $E_{\text{th}} = 17.3 \text{ MeV}$ |
| $^{12}\text{N} \rightarrow ^{12}\text{C} + e^+ + \nu_e$ | |
| $\nu_e + ^{12}\text{C} \rightarrow e^+ + ^{12}\text{B}$ | $E_{\text{th}} = 14.4 \text{ MeV}$ |
| $^{12}\text{B} \rightarrow ^{12}\text{C} + e^- + \bar{\nu}_e$ | |
| $\nu_i + ^{12}\text{C} \rightarrow \nu_i + ^{12}\text{C}^*$ | $E_{\text{th}} = 15.1 \text{ MeV}$ |
| $^{12}\text{C}^* \rightarrow ^{12}\text{C} + \gamma$ | $E_{\gamma} = 15.1 \text{ MeV}$ |
| $^{12}\text{C}^* \rightarrow ^{11}\text{C} + n$ | $E_n = 8 - 9 \text{ MeV}$ |
| $^{12}\text{C}^* \rightarrow ^{11}\text{B} + p$ | $E_p = 8 - 9 \text{ MeV}$ |
| $\nu_i + e^- \rightarrow \nu_i + e^-$ | - |
| $\nu_e + ^{56}\text{Fe} \rightarrow e^- + ^{56}\text{Co}^*$ | $E_{\text{th}} = 10 \text{ MeV}$ |
| $^{56}\text{Co}^* \rightarrow ^{56}\text{Co} + \Sigma \gamma$ | $E_{\gamma} = 7-11 \text{ MeV}$ |
| $^{56}\text{Co}^* \rightarrow ^{55}\text{Co} + n$ | |
| $^{56}\text{Co}^* \rightarrow ^{55}\text{Fe} + p$ | |
| $\nu_e + ^{56}\text{Fe} \rightarrow e^+ + ^{56}\text{Mn}^*$ | $E_{\text{th}} = 12.5 \text{ MeV}$ |
| $^{56}\text{Mn}^* \rightarrow ^{56}\text{Mn} + \gamma$ | |
| $^{56}\text{Mn}^* \rightarrow ^{55}\text{Mn} + n$ | |
| $^{56}\text{Mn}^* \rightarrow ^{55}\text{Cr} + p$ | |
| $\nu_i + ^{56}\text{Fe} \rightarrow \nu_i + ^{56}\text{Fe}^*$ | $E_{\text{th}} = 15.0 \text{ MeV}$ |
| $^{56}\text{Fe}^* \rightarrow ^{56}\text{Fe} + \gamma$ | $E_{\gamma} \approx 7.6 \text{ MeV}$ |
| $^{56}\text{Fe}^* \rightarrow ^{55}\text{Fe} + n$ | |
| $^{56}\text{Fe}^* \rightarrow ^{55}\text{Mn} + p$ | |
Events selection

• Using data only from the internal counters of the LVD detector

• Using events consist of only 1 response of internal BUST detector counters

• Energy threshold in the LVD detector is 5 MeV

• Energy threshold in the BUST detector is 10 MeV

• Events energy less than 50 MeV

• Exception of “muon” events

• Experimental data for 2006-2017 years in the analysis are used
Time distribution of events in LVD and BUST detectors

Experimental results do not contradict the calculations.

0.04 ev/sec

LVD

0.01 ev/sec

BUST

Experimental results do not contradict the calculations.
Searching for clusters in the LVD and BUST detectors

Clusters of events from collapsing stars are not detected in the detectors

\[ p_N = \frac{(\lambda T)^N}{N!} \cdot e^{-\lambda T} \]

\[ \lambda_N = \lambda \frac{(\lambda T)^{N-1}}{(N-1)!} e^{-\lambda T} \]

\[ T_N = \frac{1}{\lambda_N} \]

multiplicity no more than 30 events

duration less 100 sec

Clusters of events from collapsing stars are not detected in the detectors
Searching for coincidences

• time between events from LVD and BUST detectors less than 1s

• non-overlapping time intervals were used

• energy threshold in the LVD detector is 5 MeV

• energy threshold in the BUST detector is 10 MeV

• events energy less than 50 MeV

• exception of “muon” events

• experimental data for 2006-2017 years in the analysis are used
Main results of searching for coincidences

Distributions of the numbers of coincidences of events per hour (left histogram) and per day (right histogram) in LVD and BUST detectors.

- 3 coin/hour
- 70 coin/day
Conclusion

• counting rate in the LVD detector is about 0.04 ev/sec

• counting rate in the BUST detector is about 0.01 ev/sec

• stable long-term operation of LVD and BUST detectors is shown

• experimental results do not contradict the calculations

• in accordance with LVD and BUST data, clusters of events from collapsing stars are not detected
Thank you for your attention
As showed the diagram, near the 02:52 UT, the most amount of events registered by LSD detector. Later on it was carried out the search for coincidences in the time window of one second between the single pulses of different pairs of detectors.