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The 1 kton LVD neutrino observatory

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Abstract. The Large Volume Detector (LVD) in the Gran Sasso Underground Laboratory, Italy, is a neutrino observatory mainly devoted to detect low energy ν from gravitational collapses of galactic objects.
The experiment, which at the present time has an active mass $M = 1000$ tons, has been taking data, under ever increasing mass configurations, since 1992, with a sensitivity high enough to cover the Galaxy. Results of the monitoring, based on ever larger statistics, have already been reported: no candidates for supernova ν bursts have been found.
We update here the analysis up to December 2000, presenting the results of the search based on the sets of data taken in 1999 and 2000 (592 days of live-time). The new upper limit (based on 2691 days of observation) on the rate of stellar collapses in the Milky Way is 0.3 event per year.

1 Introduction

The Large Volume Detector (LVD) in the Gran Sasso Underground Laboratory, Italy, consists of an array of 840 scintillator counters, 1.5 m^3 each, interleaved by streamer tubes, arranged in a compact and modular geometry (see Aglietta et al., 1992, for a more detailed description), with an active scintillator mass $M = 1000$ tons. Concerning the energy threshold, $E_{\rm th}$, counters can be considered as divided into two subsets: external, i.e. those directly exposed to the rock radioactivity, which operate at $E_{\rm th} \simeq 7$ MeV, and inner (core), operating at $E_{\rm th} \simeq 4$ MeV.
The main purpose of the telescope is the detection of neutrinos from gravitational stellar collapses in the Galaxy, through the absorption interaction $\bar{\nu}_e{\rm p}, {\rm e}^+{\rm n}$, charged and neutral current reactions on ^{12}C, and neutrino-electron scattering. The principal reaction[1] is however the inverse β decay on pro-

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[1]An evaluation of expected number of inverse β decay neutrino interactions in LVD, from the gravitational collapse of a star at a distance D, gives:

$$N_{\bar{\nu}_e} \sim 200 \cdot \frac{M}{1\,kton} \cdot \frac{T_{\bar{\nu}_e}}{3.5 MeV} \cdot (\frac{D}{10kpc})^{-2} \qquad (1)$$

where the linear dependence on the average temperature of the $\bar{\nu}_e$-sphere and the conservative value of $< T_{\bar{\nu}_e} >= 3.5\ MeV$ (corresponding to $< E_{\bar{\nu}_e} >\sim 11\ MeV$ (Burrows, Klein and Gandhi , 1992)) are essential elements.
With respect to the contribution due to β decay, the one due to reactions on ^{12}C increases faster with the temperature of the relative

tons, which is observed in LVD counters through two detectable signals: the prompt signal due to the e^+ (detectable energy $E_d \simeq E_{\bar{\nu}_e} - 1.8$ MeV $+2m_ec^2$), followed, with a mean delay $\Delta t \simeq 200\ \mu$s, by the signal from the $np, d\gamma$ capture ($E_\gamma = 2.2$ MeV).
The experiment has been taking data, under different larger configurations, since 1992 with a sensitivity high enough to cover the Galaxy. Results of the monitoring, based on ever larger statistics, have already been reported ((LVD Coll. , 1993),(LVD Coll. , 1995),(LVD Coll. , 1997),(LVD Coll. , 1999)): no candidates for supernova ν bursts have been found.
We update here the analysis up to December 2000, presenting the results of the search based on the sets of data taken in 1999 and 2000 (592 days of live-time).

2 Analysis and results

In the LVD experiment, the scintillator counting rate is continuously monitored, in order to extract neutrino candidate signals. No cuts on pulse energy are applied at this level. For each selected event, absolute time, counter location and energy value are recorded. At the end of each LVD run, some preliminary cuts are applied to candidate events:

– using the global LVD Data Base information, continuously upgraded by the complete analysis of previous runs, the rejection of bad counters pulses is performed.

– pulse energy is required to belong to the $7 \div 100$ MeV range, in order to avoid fluctuations at the threshold, problems due to electronic noise and, finally, to reject single counter muon signals.

A subsequent algorithm, *the Supernova On-line Monitor SOM*, examines all the events on the basis of their time sequence, in order to identify significant clusters of pulses having an imitation frequency less than a predefined threshold, which represent candidate alarms.
The LVD neutrino burst candidate selection (widely discussed in (Fulgione, Mengotti and Panaro , 1996)) basically consists of a process which analyzes all possible clusters of events initiated by each single pulse belonging to the events sequence. For a selected cluster, of multiplicity m and duration $\Delta t \leq 200\ s$, the imitation frequency *FIM* is calculated. FIM is therefore a function of m, Δt and f, the mean rate of background events. After the statistical selection, a complete analysis of selected clusters tests their consistency with a neutrino burst, based on:

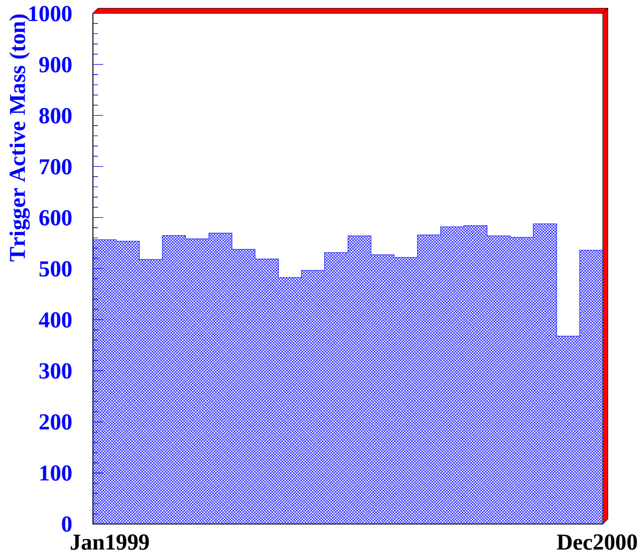

Fig. 1. Monthly active mass of the LVD detector for the analyzed period.

(1) the study of topological distribution of pulses inside the detector (a uniform distribution is expected for a real burst while background pulses are more frequent in the surface counters);

(2) the energy spectrum of the events in the cluster;

(3) the time distribution of delayed low energy pulses (due to neutron capture following the $\bar{\nu}_e$ interaction).

All related informations, mainly duration and multiplicity, are stored, in order to be reprocessed for the off-line, long term analysis.
Here we present the results of this analysis, performed on neutrinos data since March 16^{th} 1999 to December 11^{th} 2000, made by using the above described clustering technique, and taking into account information concerning the data quality and the operational condition of each counter, run by run, (LVD Global Data Base File). Figure 1 shows the monthly averaged active mass of the experiment, since January 1999, which is the result of a complete off-line analysis excluding counters showing malfunction problems.
The analysis regards 4278282 events detected during 592 days, corresponding to an average frequency $\bar{f} = 0.084\ \mathrm{s}^{-1}$. Clusters have been scanned searching for candidate with low imitation frequency. The multiplicity distributions of clusters are shown in figure 2, compared to the expectations from Poissonian fluctuations of the background: the agreement between data and expectations is quite good.
The sensitivity of the telescope (at the level of 1 imitation event every 100 years) is shown in figure 3, where each detected cluster is represented by its multiplicity m and dura-

neutrinospheres, due to the higher energy threshold of the latter. Nevertheless, even for very high values of $T_{\bar{\nu}}$, the maximum contribution of ^{12}C interactions is of the order of 30%, (while that from the scattering $\nu_i e^-$, $e^-\nu_i$ is always less than 3%).

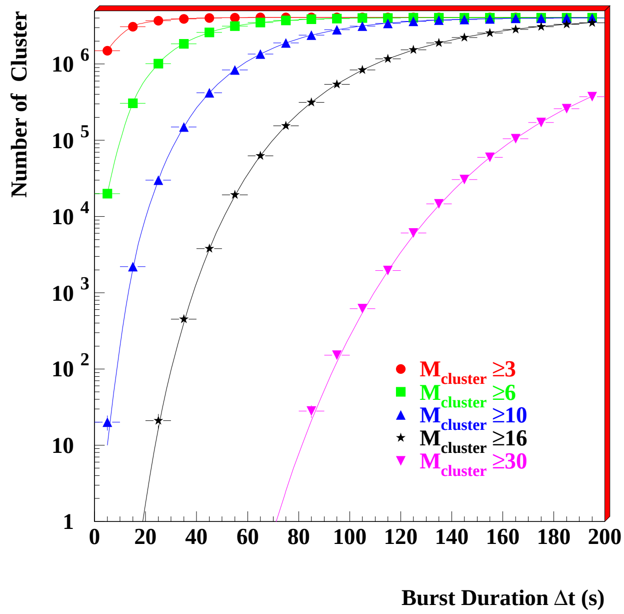

Fig. 2. Number of clusters of certain multiplicity (m) and duration (Δt). Curves are calculated on the basis of Poissonian fluctuations of the background.

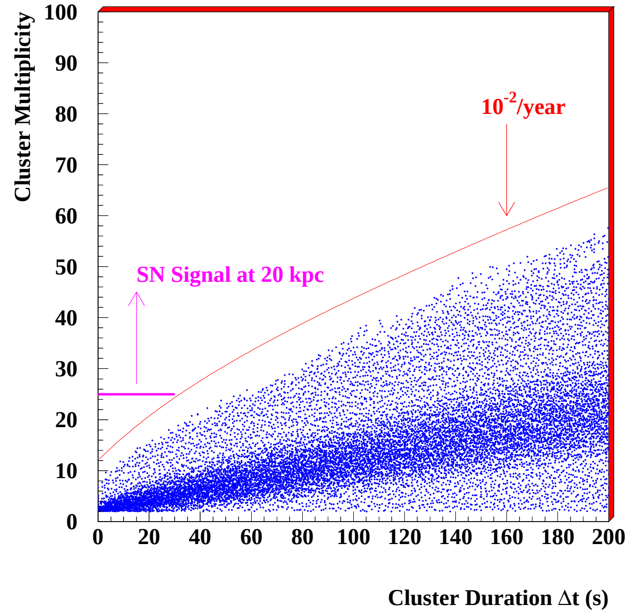

Fig. 3. Scatter plot ($m, \Delta t$) of clusters detected during the period under study. Solid line limits the area in which the cluster frequency produced by background is $< 10^{-2}$ per year.

tion Δt.
From equation (1), and taking into account the average active mass of the telescope during the period under study, we can say that even in the case of a gravitational collapse at $D = 20\,\mathrm{kpc}$ and $T_{\bar{\nu}_e}$ as low as $3.5\mathrm{MeV}$, we expect a number of interaction greater than 25 clusterized in a time window of duration $\sim 10\ s$, well inside the sensitivity limits of the telescope. Therefore, we can conclude that no ν signal from gravitational stellar collapse in the Galaxy has been detected during the period under study. Taking into account the previously reported results ((LVD Coll. , 1993),(LVD Coll. , 1995),(LVD Coll. , 1997), (LVD Coll. , 1999)), the new upper limit at 90% c.l. to the rate of Gravitational Stellar Collapse in our Galaxy is $0.3\ \mathrm{event} \cdot \mathrm{year}^{-1}$.

3 LVD 1 kton: status and prospects

Since January 2001, LVD is in operation in its final configuration with a sensitive mass $M = 1\mathrm{kton}$.
A complete upgrade of the DAQ system has been realized during 2000: particular care has been taken in the design of the new system, in order to ensure both high modularity of the DAQ configuration and the possibility to insert/remove counters from the read-out, in case of maintenance, without interruption of data taking. This upgrade will increase furtherly the duty cycle, which is already better than 98% (averaged over the last four years).
An additional Fe shielding has been mounted on the top layer of the telescope, which causes a lowering of the background counting rate of the upper counters of the telescope by a factor > 2.
Moreover, LVD goes on with the participation to the SuperNova Early Warning project (SNEWS), which involves an international collaboration of experiments representing current supernova neutrino detectors (SuperKamiokande and SNO) (SNEWS , 1998). Since the neutrino signal emerges promptly from a supernova's core, whereas it may take hours for the first photons to be visible, the detection of the neutrino burst from the next Galactic supernova can provide an early warning for astronomers.

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