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ScienceDirect
Astroparticle Physics 28 (2008) 516–522
Astroparticle Physics
www.elsevier.com/locate/astropart

On-line recognition of supernova neutrino bursts in the LVD

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Received 27 June 2007; received in revised form 26 August 2007; accepted 17 September 2007
Available online 1 October 2007

Abstract

In this paper we show the capabilities of the Large Volume Detector (INFN Gran Sasso National Laboratory) to identify a neutrino burst associated with a supernova explosion, in the absence of an "external trigger", e.g., an optical observation. We describe how the detector trigger and event selection have been optimized for this purpose, and we detail the algorithm used for the on-line burst recognition. The on-line sensitivity of the detector is defined and discussed in terms of supernova distance and $\bar{\nu}_e$ intensity at the source.

PACS: 95.55.Vj; 97.60.Bw; 13.15.+g; 29.40.Mc

Keywords: LVD; Neutrino detection; Supernova core collapse; Burst identification

1. Introduction

The detection of neutrinos from SN1987A marked the beginning of a new phase of neutrino astrophysics [1–4]. In spite of the lack of a firmly established theory of core collapse supernova explosion, the correlated neutrino emission appears to be well established. However, since this first ν observation was guided by the optical one, the detector capabilities of identifying a ν burst in the absence of an "external trigger" should be demonstrated very carefully. In the presence of an electromagnetic counterpart, on the other hand, the prompt identification of the neutrino signal could alert the worldwide network of observatories allowing study of all aspects of the rare event from its onset.

The Large Volume Detector (LVD), in the INFN Gran Sasso National Laboratory (Italy), at the depth of 3600 m w.e., is a 1 kt liquid scintillator detector whose major purpose is monitoring the Galaxy to study neutrino bursts from gravitational stellar collapses [5]. Besides interactions with protons and carbon nuclei in the liquid scintillator,

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doi:10.1016/j.astropartphys.2007.09.005

LVD is also sensitive to interactions with the iron nuclei of the support structure whose total mass is 0.9 kt [6]. The experiment has been taking data, under different configurations, since 1992, reaching in 2001 its present and final configuration. Its modularity and rock overburden, together with the trigger strategy, make this detector particularly suited to disentangle on-line a cluster of neutrino signals from the background.

We will discuss in this paper the LVD performances from the point of view of the on-line identification of a neutrino burst: we will describe in Section 2 the trigger of the detector, the event selection and the on-line burst recognition. In Section 3 we will define and discuss the detector sensitivity to neutrino bursts which, as we will show in Section 4, can be expressed in terms of supernova distance or neutrino intensity at the source.

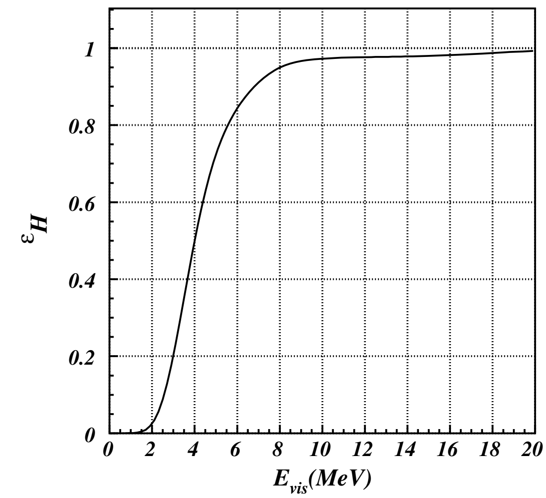

Fig. 2. Trigger efficiency, averaged over all the scintillator counters, for the H coincidence versus visible energy E_{vis}.

2. The LVD event selection chain

2.1. The trigger

LVD consists of an array of 840 scintillator counters, 1.5 m^3 each. The whole array is divided in three identical "towers" with independent high voltage power supply, trigger and data acquisition (see Fig. 1). In turn, each tower consists of 35 "modules" hosting a cluster of eight counters. Each counter is viewed from the top by three 15 cm photomultiplier tubes (PMTs) FEU49b or FEU125. The charge of the summed PMT signals is digitized by a 12 bit ADC (conversion time = 1 μs) and the arrival time is measured with a relative accuracy of 12.5 ns and an absolute one of 100 ns [7].

The main neutrino reaction in LVD is $\bar{\nu}_e p \to e^+ n$, which gives two detectable signals: the prompt one due to the e^+ (visible energy $E_{\mathrm{vis}} \simeq E_{\bar{\nu}_e} - 1.8\ \mathrm{MeV} + 2\ m_e c^2$) followed by the signal from the $np \to d\gamma$ capture ($E_\gamma = 2.2$ MeV, mean capture time $\simeq$185 μs). The trigger logic is optimized for the detection of both products of the inverse beta decay and is based on the three-fold coincidence of the PMTs of a single counter. Each PMT is discriminated at two different thresholds resulting in two possible levels of coincidence between a counter's PMTs: H and L, corresponding to $\mathscr{E}_H \simeq 4$ MeV and $\mathscr{E}_L \simeq 1$ MeV. The H coincidence in any counter represents the trigger condition for the array. Once a trigger has been identified, the charge and time of the three summed PMTs' signals are stored in a memory buffer. All signals satisfying the L coincidences in the same module of the trigger counter are also stored, if they occur within 1 ms. The average efficiency of the H trigger (for electrons) is shown in Fig. 2 as a function of the visible energy E_{vis}. The average neutron detection efficiency, ϵ_n, amounts to about 50% for neutrons detected in the same counter where the positron has been detected [8].

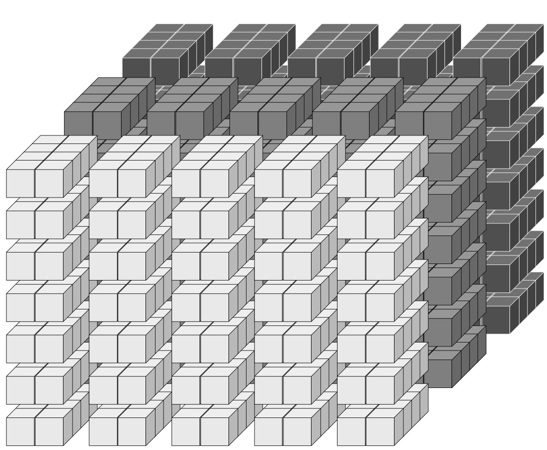

Fig. 1. LVD schematic view: the building block is a module of eight scintillator counters, 35 modules form a tower.

One millisecond after the occurrence of a trigger, the memory buffers,[1] containing the charge and time information of both H and L signals, are read out. This is performed independently on the three towers, without introducing any dead time. The tower event fragments, if present, are then sent to a central processor which provides event-building requiring time coincidence of the first pulse registered in each tower within 10 μs. The whole duration of one event can extend up to 1 ms.

2.2. Event selection criteria

The basis of the search for neutrino bursts is the identification of clusters of signals in fixed time windows. A preliminary step consists in the selection of good signals detected by good counters; we thus apply to the events

[1] Each memory buffer, one per module, is able to store up to 512 signals, corresponding to 50,000 signals in the whole apparatus.