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On the Event Observed in the Mont Blanc Underground Neutrino Observatory During the Occurrence of Supernova 1987*a*.

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Abstract. – We discuss here the characteristics of the event detected in the Mont Blanc Underground Neutrino Observatory on February 23, 1987, consisting of 5 interactions recorded during 7 s. The measured energies of the 5 pulses, the duration of the burst, and the advance of the detection time in comparison with the first optical observations give evidence that the event can be explained in terms of detection of neutrinos emitted during the stellar collapse in the Large Magellanic Cloud.

1. Introduction

An Underground Neutrino Observatory (UNO) has been built [1] by our two institutes with the main aim to search for bursts of low-energy neutrinos from stellar collapses. The UNO has been running [2] since October 1984 in the Mont Blanc Laboratory, at a depth of 5200 hg/cm^2 of standard rock underground. The very large coverage of rock and an additional shielding allow us to operate the UNO at a very low energy threshold.

An event, considered as a candidate for a neutrino burst, was recorded (1) on February 23.12, 1987 (2 h 52 m 36s UT). Shelton in Las Campanas Observatory (Chile) reported the

(1) We distributed [3] the announcement of this detection on February 28, and the first discussion of this event was given [4] on March 2 during the «Rencontres de Physique de la Vallée d'Aoste», La Thuile.

observation [5] made in February 24.23 of an optical supernova (SN Shelton 1987) in the Large Magellanic Cloud (LMC), 52 kpc far away. Optical data indicate that no star brighter than magnitude 12 was present at February 23.08, and that the supernova was of magnitude 6.1 at February 23.44.

The characteristics of the event which we observed in UNO are described here.

2. The Mont Blanc Underground Neutrino Observatory

The neutrino telescope (see fig. 1) is a 90 ton liquid scintillation detector (LSD) consisting of 72 counters ($(1.0 \times 1.5 \times 1.0)\ \mathrm{m}^3$ each) in 3 layers, arranged in a parallelepiped shape with $(6 \times 7)\mathrm{m}^2$ area and 4.5 m height. The low-energy local radioactivity background, discussed in detail elsewhere [6], from the surrounding rock is reduced by shielding each counter and the whole detector with more than 200 tons of Fe slabs. The cosmic-ray muon background is very low at the depth of the Mont Blanc Laboratory: after several months of running time we measured on the average 3.5 muons per hour in the whole LSD detector.

The liquid scintillator is watched form the top of each counter by 3 photomultipliers (15 cm diameter), and the total signal of the photomultipliers is recorded if they are in 3-fold coincidence within 150 ns. Our calibrations [1], both from muons and with a ^{252}Cf source, show that a 1 MeV energy loss yields on the average 15 photoelectrons in 1 scintillation counter.

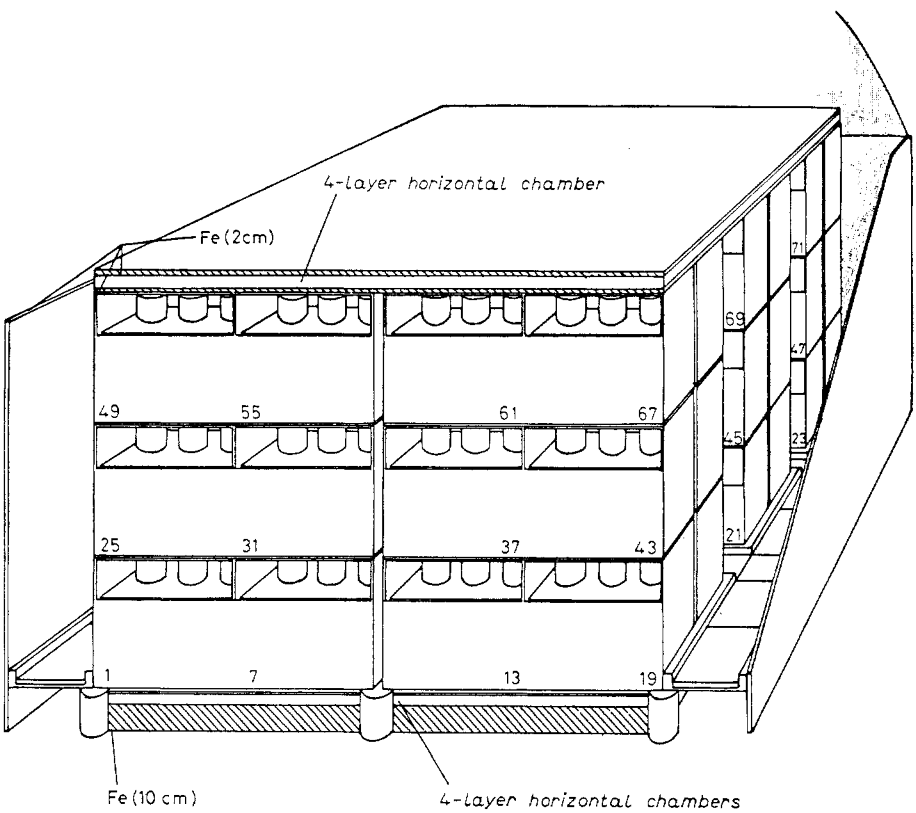

Fig. 1. – The 90 ton liquid scintillation detector (LDS) running in the Mont Blanc Underground Neutrino Observatory (UNO).

The electronic system consists of 2 levels of discriminators for each scintillation counter. A high-level discriminator for pulses above the energy threshold $\sim(6\div7)$ MeV for the 56 surface counters, and ~ 5 MeV for the 16 internal ones, with a total trigger rate 0.012 Hz. A low-level discriminator for pulses above the energy threshold 0.8 MeV, active only during a 500 μs wide gate, opened for all the 72 counters by the main high-level trigger. The average counting rate of the low-level discriminator is 0.05 per gate for the internal counters, and 0.57 per gate for the external ones.

Two ADCs per counter measure the energy deposition in the scintillator, in 2 overlapping energy ranges: from 4 to 800 MeV sensitive to high-energy pulses, and from 0.8 to 50 MeV sensitive to the low-energy ones. A TDC, automatically tested every 7 min, gives the time with a resolution of 100 ns.

Three memory buffers, 16 words deep, for the 2 ADCs and the TDC of each scintillation counter, allow us to record all pulses without dead time. On-line software prints any burst of pulses satisfying our operational definition of a neutrino burst, namely a cluster of pulses above a given multiplicity in a given time.

This recording system allows us to detected both products of $\bar{\nu}_e$ interactions, with protons (namely positrons with energy above the high-level discriminator, and gammas, with energy above the low-level one, in a delayed coincidence within 500 μs), and of electrons from elastic scattering of neutrinos of other species with the electrons of the scintillator. For positron detection the pulse amplitude is given by the sum of the positron kinetic energy and the annihilation energy (~ 1 MeV) of gammas. The efficiency to detct γ's from the (np, dγ) capture reaction, in the same counter where the neutron was produced, measured by using a ^{252}Cf source as a neutron source, is $\varepsilon \geqslant 60\%$ when the Cf source is inserted in the central positron of a scintillation counter, and $\varepsilon \sim 40\%$ on the average.

The absolute time in the LSD is recorded by using the signal broadcast by the Italian Standard Time Service (IEN). The accuracy on the absolute time is better than 2 ms.

The expected [2] neutrino burst, from a standard stellar collapse at the distance of the Large Magellanic Cloud, is made of 2-3 interactions during the burst duration in the LSD experiment.

3. The neutrino bursted detected on February 23rd, 1987.

Since January 1, 1986, the LSD experiment has been running with an average efficiency of 90% (and almost 99%, since October 1986). Recently, the detector shielding has been partly increased (for testing purposes) with paraffin and lead in order to further decrease the low-energy background from the surrounding rock.

Trigger pulses are analysed in order to have a long-term statistics and to search for bursts. The experimental time distributions of these pulses, grouped in bursts above a given multiplicity, are plotted in fig. 2 as a function of their duration Δt. The distributions of fig. 2 refer to a data-taking period of 143.6 days (from September 28, 1986, to March 4, 1987). The smooth behaviour as well as the agreement with the predicted Poisson distributions (represented by the continuous curves) show that the trigger counting rate is stable and the detector is properly working during this time.

The detector counting rate is also checked on line every 100 triggers. The analysis of the data taken several days before and after the event connected with the supernova 1987*a* shows that the apparatus was running properly throughout the entire period.

On February 23.12, 1987 (2h 52m 36s UT), an event, consisting of a burst of 5 pulses and printed in real time at the occurrence, was recorded in 5 different counters (3 of them internal) during 7 seconds. Table I gives the event number, the absolute universal time

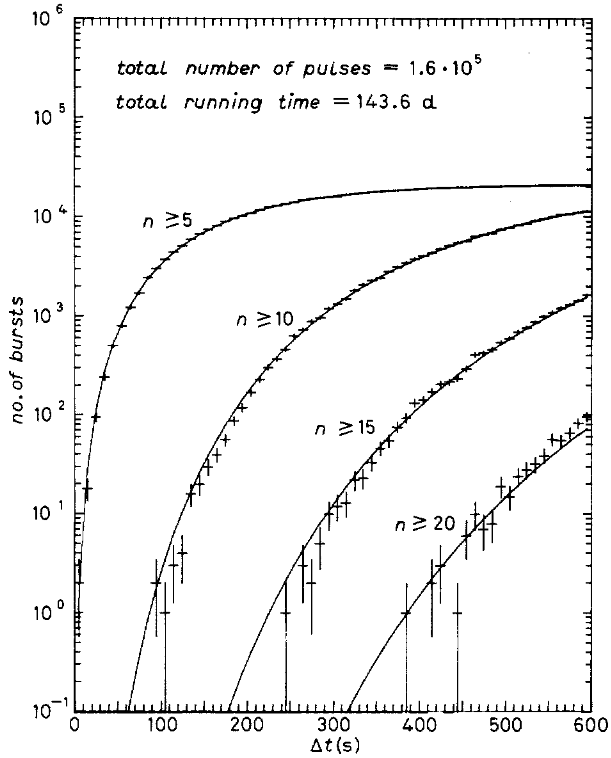

Fig. 2. – Experimental distributions of bursts of pulses with multiplicity $n \geq 5$, $n \geq 10$, $n \geq 15$, and $n \geq 20$, as a function of their duration Δt (in s), with a binning of 10 s, measured during 143.6 days (from September 28, 1986, to March 4, 1987). The full lines are the corresponding expected distributions, assuming randomness (Poisson distribution) of the background.

TABLE I – *Event number, time* (UT), *and preliminary visible energy* (MeV) *of the pulses in the burst detected on February 23rd, 1987.*

Event No.	Time (UT)	E_v (MeV)
994	2 h 52 m 36 s.79	7
995	40.65	8
996	41.01	11
997	42.70	7
998	43.80	9

(with an accuracy better than 2 ms) and the preliminary estimate value (with an accuracy better than 20%) of the visible energy of the detected pulses. A new calibration of the 72 scintillation counters at different energies is in progress. The more accurate values of the visible energies of the detected pulses seem to be lower ($\sim 10\%$), and will be reported in a forthcoming paper. A low-energy pulse, with $E = 1.2$ MeV, accompanying the 3rd interaction, was detected 278 μs after the main pulse in the same scintillation counter. From the quoted efficiency to detect γ's from neutron capture, we expect on the average 2 such pulses in the 5 counters involved in the burst. We evaluate that $\sim 40\%$ of neutrons can escape from the counter where they are produced, and could possibly be detected in the surrounding counters.

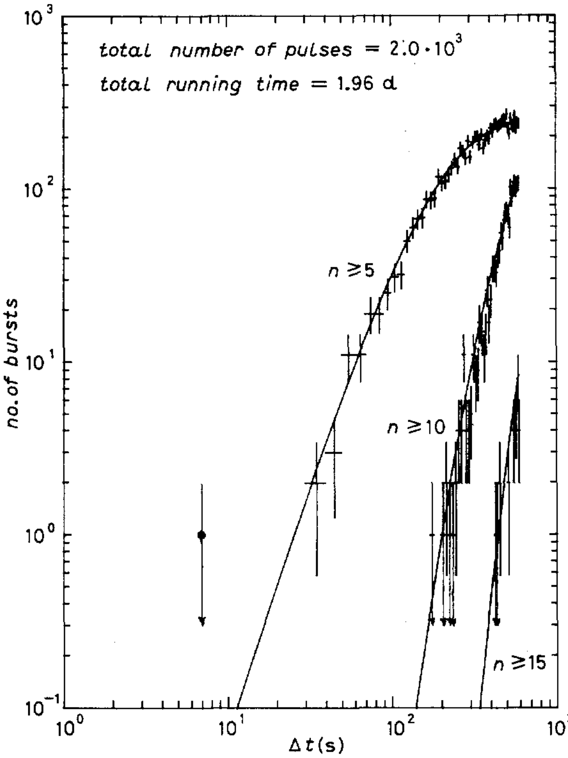

Fig. 3. – The same as for fig. 1, but for the run (of duration 1.96 days) including the event of February 23, 1987, shown by a large dot.

Figure 3 shows the distribution of the number of bursts with multiplicity $n \geqslant 5$, $n \geqslant 10$, and $n \geqslant 15$, relative to 1.96 days of data taking encompassing the event. The full lines are computed according to a Poisson distribution of the trigger counting rate, with a binning of 10 s and mean value given by our average trigger rate, which has the value of 0.012 Hz during this run.

Excellent agreement between the expected and measured distributions is found, except for the point at $t = 7$ s, which has been added just to show the event considered here. The imitation rate from the background is 0.7 per year for this burst, or $\sim 4 \cdot 10^{-4}$ in the time interval corresponding to the uncertainty of the instant of collapse (~ 5 hours), as suggested by the first optical observation [5].

Finally, a close coincidence in time was observed [7] between our event and data from the gravitational-wave antenna operating in Rome. The detection time in the LSD is delayed of 1.4 s in comparison with the data of the gravitational detector, within a time uncertainty of ± 0.5 s from the antenna data. If our event is due to $\bar{\nu}_e$, and assuming that the antenna signal is due to gravitational waves, from the previous arrival time values one would obtain a neutrino rest mass $m_\nu c^2 = (7.2 \pm 1.3)$ eV assuming simultaneous emission of the two bursts of particles.

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