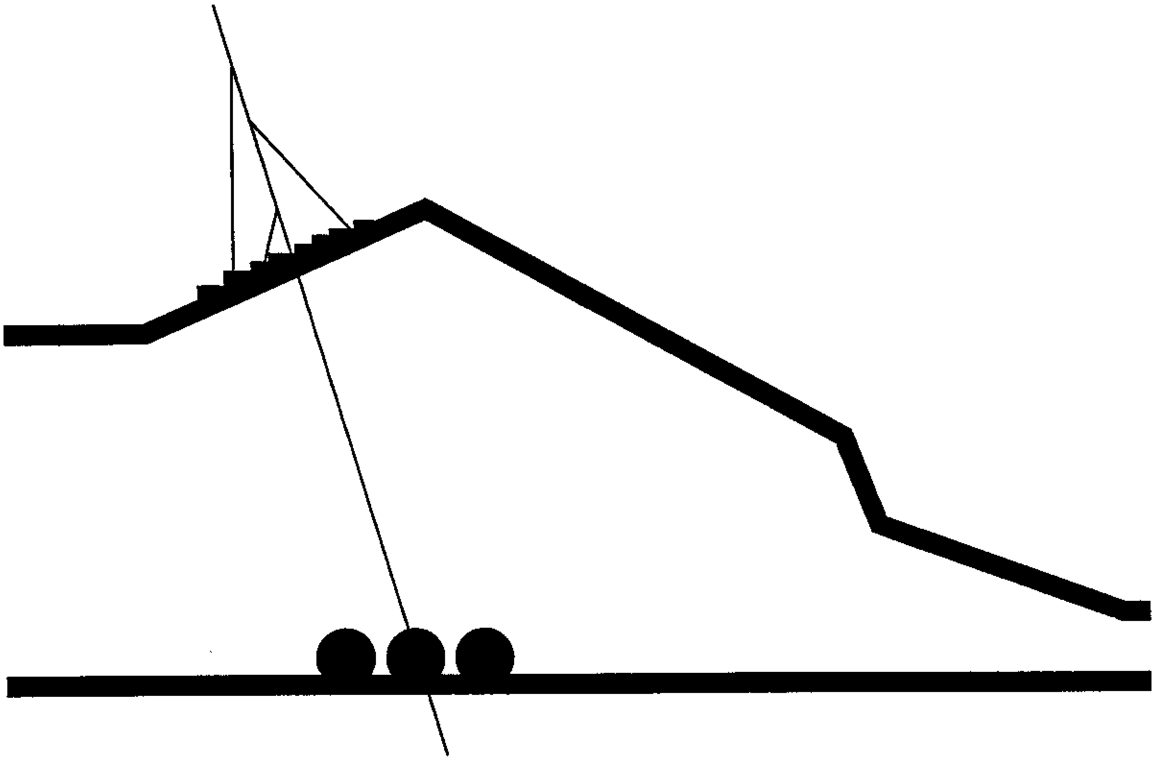
INFN/AE-99/19
3 Settembre 1999



GRB990705: a detectable neutrino source?

The LVD collaboration

CERN LIBRARIES, GENEVA
SCAN-0003060

INFN - Laboratori Nazionali del Gran Sasso

ClibPDF - www.fastio.com

INFN - Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali del Gran Sasso

INFN/AE-99/19
3 Settembre 1999

GRB990705: a detectable neutrino source?

Abstract

The detection of the Gamma Ray Burst GRB990705 on July 5^{th} 1999, pointing to the Large Magellanic Clouds, suggested the search for the possible existence of a neutrino signal, either in coincidence or preceding the photon burst. We investigated this possibility by the LVD neutrino telescope at the Gran Sasso Underground Laboratories. No evidence of a ν signal either simultaneous or preceding the GRB has been found, hence we set upper limits on the $\bar{\nu}_e$ flux $\cdot$ cross-section product.

Assuming thermal $\bar{\nu}_e$ spectra, the results are expressed in terms of limits on the $\bar{\nu}_e$ flux for different spectral temperatures.

ClibPDF - www.fastio.com

1 Introduction

On July 5th 1999, 16:01:25 UT, a Gamma Ray Burst (GRB990705) has been detected by BeppoSAX (mail 99/16 and 99/17) from the direction of the outskirts of the Large Magellanic Clouds. The corresponding GCN circular n.368 [1] quoted the following:

"If the burst is indeed located in the LMC or its halo, a search for a neutrino signal coincident with, or just prior to the GRB event would be most interesting. ...... If the GRB event was in the LMC or even closer, it may even represent a new type of a GRB phenomenon."

At that time the LVD neutrino telescope (located in the Gran Sasso Underground Laboratory) was regularly taking data, (with active scintillator mass $M = 573$ ton), the run being active continuously since June 22nd 1999. The detector duty cycle averaged on the last 2 years is 97% [2].

The detector characteristics are described in [3]. We only remind here that the telescope consists of an array of 840 1.5 m^3 scintillator counters arranged in a compact geometry. The main purpose of the telescope is the detection of neutrinos from gravitational stellar collapses in the Galaxy, mainly through the absorbtion interaction: $\bar{\nu}_e p, e^+ n$.

On July 19th 1999, the result of a preliminary analysis of the data recorded on July 5th was reported by the LVD collaboration in the GCN circular n.390 [5]. The absence of a neutrino signal, as expected from a gravitational stellar collapse in the Galaxy, correlated to the GRB990705 was established and the searching for weaker signals preceding the GRB was started.

We report here the final results of this analysis. In section 2 we describe the results of the search for a $\bar{\nu}_e$ signal in time coincidence with the photon signal. In section 3 the 24 hours interval preceding the GRB990705 has been scanned searching for any not statistical fluctuation of the background . For sake of completeness, a 10 days interval has been also scanned. Finally, results are discussed in terms of upper limits on the $\bar{\nu}_e$ flux associated to the GRB in the hypothesis of thermal neutrino energy spectra.

2 Analysis in coincidence with GRB990705

The reaction $\bar{\nu}_e p, e^+ n$ is observed in the LVD counters by two detectable signals: the prompt signal due to the e^+ (detectable energy $E_d \simeq E_{\bar{\nu}_e} - 1.8 MeV + 2m_e c^2$) followed, with a mean delay $\delta t \simeq 200\ \mu s$, by the signal from the $np, d\gamma$ capture reaction ($E_\gamma = 2.2 MeV$).

The LVD counters can be divided into two subsets: external counters, which are directly exposed to the rock radioactivity and operate at the energy threshold $E_{th} \simeq 7 MeV$, and inner core counters which operate at $E_{th} \simeq 4 MeV$.

In the search for antineutrino interactions ($\bar{\nu}_e p, e^+ n$), raw data are processed in order to reject muons, and filtered on the basis of the prompt pulse (e^+) energy release and of the presence of delayed, low energy signals (n capture).

We define 3 classes of data:

- class A: pulses with $E_d \geq 7 MeV$ ($M = 573\ ton$);

ClibPDF - www.fastio.com

- class B: pulses with $E_d \geq 7MeV$ followed by at least one delayed low energy pulse in the same counter ($M = 573$ *ton*);

- class C: pulses detected by core scintillators ($E_d \geq 4MeV$) followed by at least one delayed low energy pulse in the same counter ($M = 256$ *ton*).

The detector average efficiency for n-capture is $\epsilon_n \simeq 60\%$ for the core and $\epsilon_n \simeq 50\%$ for the whole detector.

The search for a signal in time coincidence with GRB990705 has been made in the three different classes of events by comparing the number of observed signals (N_d) inside time windows of different duration Δt centered on the GRB time, with the number of signals expected from the background (N_{bk}).

In order to evaluate N_{bk}, a 24 hours interval starting $15'$ after the GRB990705 has been used. Errors on N_{bk} are always less then 3%. The stability of the detector counting rate during the 48 hours around the GRB for the three event classes is shown in Fig.1 where the origin of the abscissa corresponds to July 5^{th}, 1999, 16:01:25 UT.

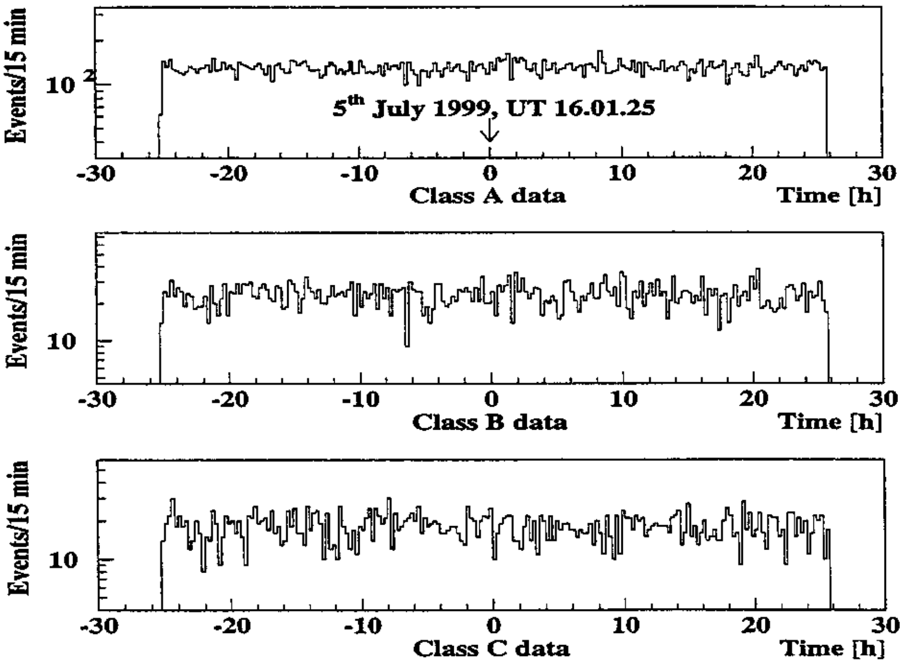


Figure 1: Counting rates in the 48 hours window centered on the GRB990705 time.

The results are summarized in Table 1, for time windows of duration $\Delta t = 1, 5, 10, 20, 50$ and 100 s. Differences between detected number of pulses and expectations from the background for all the event classes are well within statistical fluctuations.

ClibPDF - www.fastio.com

Δt [s]	class A		class B		class C	
	N_{bk}	N_d	N_{bk}	N_d	N_{bk}	N_d
1	0.15	0	0.03	0	0.02	0
5	0.73	0	0.13	0	0.10	0
10	1.46	0	0.26	0	0.20	0
20	2.91	1	0.53	0	0.40	0
50	7.28	7	1.32	0	0.99	0
100	14.56	12	2.64	0	1.98	1

Tab.1: Analysis of the coincidences.

No evidence for a $\bar{\nu}_e$ signal coincident with the GRB990705 appears from this analysis.

3 Analysis of the 24 hours preceding the GRB990705

There is no strong argument to predict the neutrino emission just in coincidence with the GRB; therefore the period preceding the photon emission has been searched for a possible $\bar{\nu}_e$ signal. In addition one has to take into account a possible non zero ν mass. A finite ν mass would cause a neutrino signal time spreading. In this case the delay τ of arrival times depends on the ν energy and mass as:

$$\tau \approx 5.15 \cdot \frac{D}{10\ kpc} \cdot \left(\frac{m_\nu c^2}{1eV}\right)^2 \left(\frac{E_\nu}{10MeV}\right)^{-2} msec \qquad (1)$$

In the cosmologically allowed mass region ($m_\nu \leq 100\ eV$) and for a source in the LMC ($D \sim 50\ kpc$), the maximum delay for the ν signal should be: $\tau^{max} \simeq 250s$. For this reason the search has been extended since 24 hours before the GRB time to 10 minutes after, for a total time $T = 1450\ min$.

The interval of interest has been divided into $N_{\Delta t} = 2 \cdot \frac{T}{\Delta t}$ intervals of duration Δt, each one starting at the middle of the previous one. The distribution of event multiplicity within each interval has been studied and shown in Fig.2, Fig.3 and Fig.4 for the three classes of data and for $\Delta t = 1, 5, 10, 20, 50$ and 100 seconds. The dashed curves represent the expectation from pure Poissonian fluctuations of the background as calculated by using the average event rate in 24 hours.

The agreement between data and expectations confirms the detector stability, allowing to state that there is no evidence for a detectable ν signal during this period.

For sake of completeness the same analysis has been applied on the data collected during 240 hours preceding the GRB. In this case too, the data are in total agreement with expectation from background statistical fluctuations.

ClibPDF - www.fastio.com

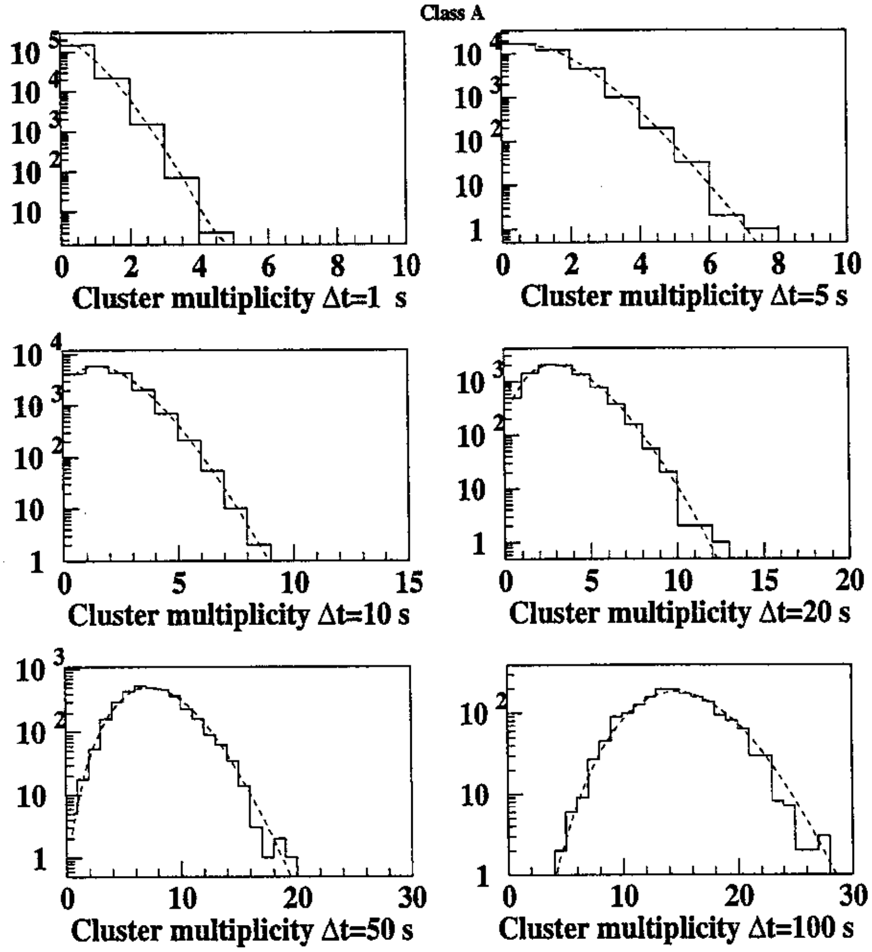


Figure 2: Distribution of cluster multiplicity for events of class A and $\Delta t = 1, 5, 10, 20, 50$ and 100 s, in the scanned time interval T.

ClibPDF - www.fastio.com

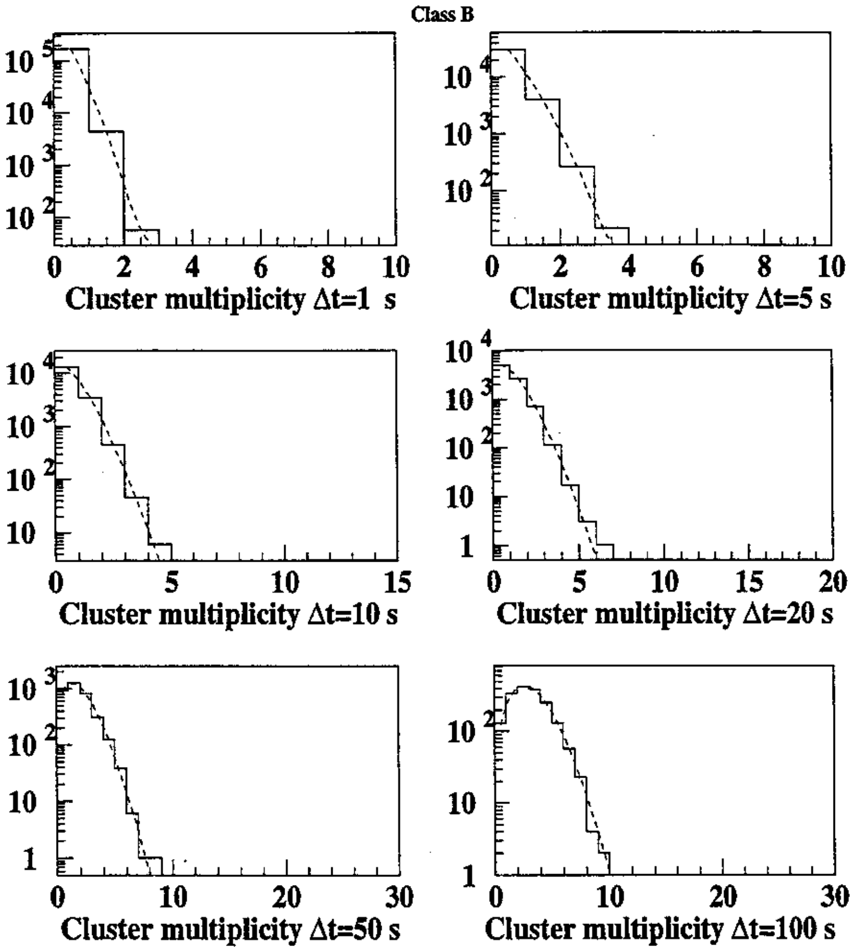


Figure 3: Distribution of cluster multiplicity for events of class B and $\Delta t = 1, 5, 10, 20, 50$ and 100 s, in the scanned time interval T.

ClibPDF - www.fastio.com

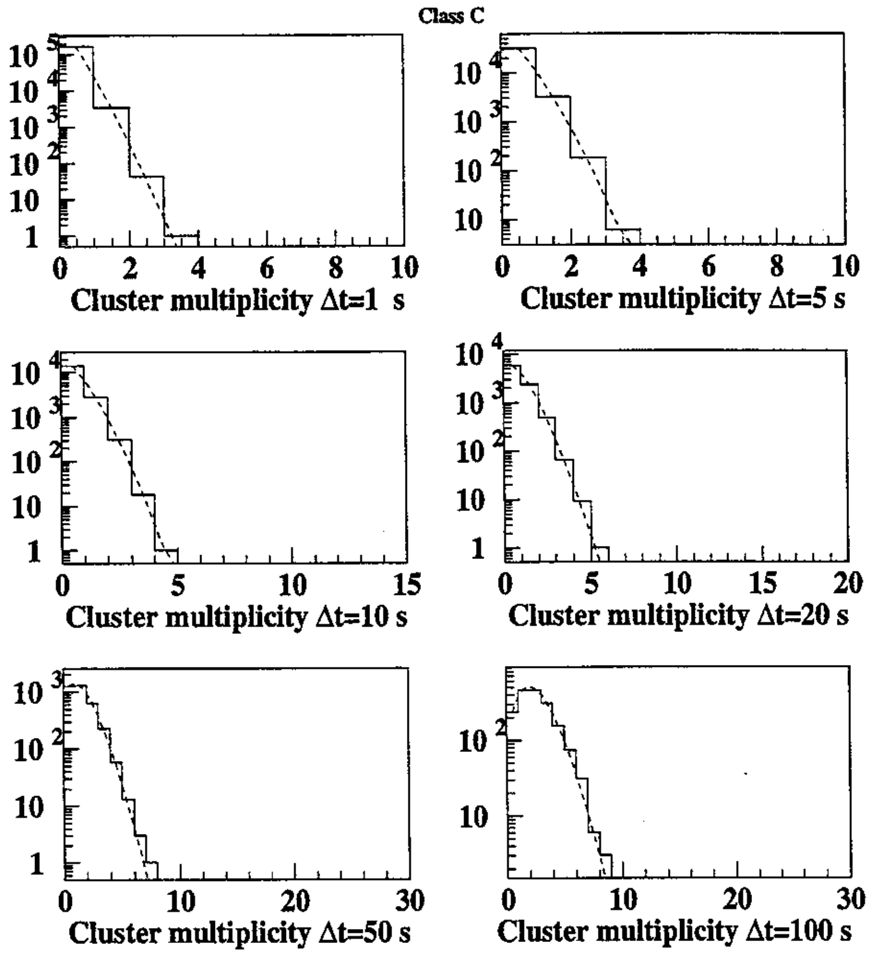


Figure 4: Distribution of cluster multiplicity for events of class C and $\Delta t = 1, 5, 10, 20, 50$ and 100 s, in the scanned time interval T.

ClibPDF - www.fastio.com

Δt [s]	coincidence		24 hour preceding	
	$\int_0^{\Delta t} dt \int_5^\infty \frac{d^2\phi_\nu}{dEdt}\sigma(E)dE$	$\int_0^{\Delta t} dt \int_8^\infty \frac{d^2\phi_\nu}{dEdt}\sigma(E)dE$	$\int_0^{\Delta t} dt \int_5^\infty \frac{d^2\phi_\nu}{dEdt}\sigma(E)dE$	$\int_0^{\Delta t} dt \int_8^\infty \frac{d^2\phi_\nu}{dEdt}\sigma(E)dE$
1	$1.7 \cdot 10^{-31}$	$4.3 \cdot 10^{-32}$	$5.9 \cdot 10^{-31}$	$1.9 \cdot 10^{-31}$
5	$1.7 \cdot 10^{-31}$	$4.3 \cdot 10^{-32}$	$5.9 \cdot 10^{-31}$	$2.4 \cdot 10^{-31}$
10	$1.7 \cdot 10^{-31}$	$4.3 \cdot 10^{-32}$	$7.4 \cdot 10^{-31}$	$2.8 \cdot 10^{-31}$
20	$1.7 \cdot 10^{-31}$	$7.5 \cdot 10^{-32}$	$8.1 \cdot 10^{-31}$	$3.5 \cdot 10^{-31}$
50	$1.7 \cdot 10^{-31}$	$8.6 \cdot 10^{-32}$	$9.6 \cdot 10^{-31}$	$5.2 \cdot 10^{-31}$
100	$2.9 \cdot 10^{-31}$	$8.6 \cdot 10^{-32}$	$1.1 \cdot 10^{-30}$	$6.0 \cdot 10^{-31}$

Tab.2: Limits on the $\bar{\nu}_e$ time integrated flux-cross-section product.

4 Results and Discussion

The number of $\bar{\nu}_e$ interactions in a time interval Δt due to a pulsed $\bar{\nu}_e$ emission is defined by the following expression:

$$N_{ev} = M \cdot N_p \cdot N_A \cdot \epsilon \int_0^{\Delta t} dt \int_{E_{min}}^{\infty} \frac{d^2\phi_{\bar{\nu}_e}}{dE_{\bar{\nu}_e} dt} \sigma(E_{\bar{\nu}_e}) dE_{\bar{\nu}_e} \tag{2}$$

where ϵ is the detector efficiency, $M[ton]$ the active scintillator mass, N_A the Avogadro constant, N_p the number of protons per 1 scintillator ton, $\sigma(E_{\bar{\nu}_e})$ the neutrino interaction cross section [6] and $\frac{d^2\phi_{\bar{\nu}_e}}{dE_{\bar{\nu}_e} dt}$ the differential neutrino flux at the Earth.
In the case of $\bar{\nu}_e$ detection for the LVD we have: $N_p = 1.55 \; 10^5 [ton^{-1}]$ and $E_{min} = E_{th} + 0.8 \; [MeV]$.

In the absence of any information regarding the distance of the source and the emission spectra, we can express the results of the search in terms of upper limits to the time integrated flux · cross-section product at the Earth.
These limits, reported in Table 2 at 90% c.l. for various Δt, are expressed in total number of interactions per target proton.

An hypothesis on the $\bar{\nu}_e$ spectrum leads to a limit to the time integrated $\bar{\nu}_e$ flux at the Earth. Assuming a thermal spectrum for $\bar{\nu}_e$ emission at the source, i.e.:

$$\frac{dN_{\bar{\nu}_e}}{dE_{\bar{\nu}_e}} \propto \frac{(\frac{E_{\bar{\nu}_e}}{T})^2}{1 + exp(\frac{E_{\bar{\nu}_e}}{T})} \tag{3}$$

and a burst duration $\Delta t \leq 10 \; s$, the time integrated $\bar{\nu}_e$ flux is obtained as a function of the emission temperature $T[MeV]$. The corresponding 90% *c.l.* upper limits are shown in figures 5 and 6.

In addition, by assuming the source to be in the LMC or even closer ($D \leq 50 \; kpc$), we can give upper limits to the maximum emitted energy $E_{\bar{\nu}_e}$ which are shown in figures 7 and 8, at 90% c.l. for $\Delta t \leq 10 \; s$, as a function of the spectral temperature T. This

ClibPDF - www.fastio.com

results can be compared with the model expectation on the $\bar{\nu}_e$ total energy emission from Gravitational Stellar Collapses [7], i.e. $E_{\bar{\nu}_e} \approx 5 \cdot 10^{52} erg$ in a time scale of the order of 10 seconds at a spectral temperature of $3 \div 4 MeV$.

5 Acknowledgements

We would like to acknowledge the Gran Sasso Laboratory Staff for the continuous and valuable support.

References

[1] http://lheawww.gsfc.nasa.gov/docs/gamcosray/legr/bacodine/ gcn3/368.gcn3

[2] LVD Coll. Proc XXVI ICRC (1999) **HE.4.2.08**

[3] M.Aglietta et al., Il Nuovo Cimento **A105** (1992) 1793.

[4] W.Fulgione, N.Mengotti-Silva and L.Panaro, NIM **A368** (1996) 512.

[5] http://lheawww.gsfc.nasa.gov/docs/gamcosray/legr/bacodine/ gcn3/390.gcn3

[6] Vogel P., Phys. Rev. **D29** (1984) 1918

[7] Burrows, Klein and Gandhi Phys.Rev. **D45** (1992) 3361.

ClibPDF - www.fastio.com

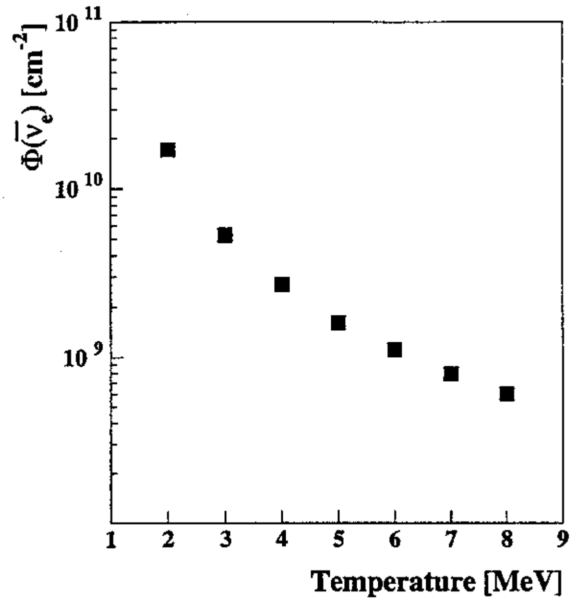


Figure 5: Upper limits to the time integrated $\bar{\nu}_e$ flux coincident with the GRB990705 event as a function of the $\bar{\nu}$ emission temperature, for $\Delta t \leq 10s$.

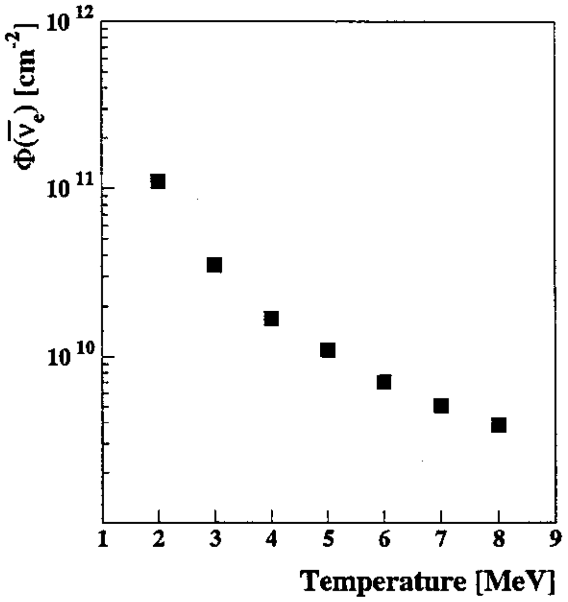


Figure 6: Upper limits to the time integrated $\bar{\nu}_e$ flux, in the 24 hours preceding the GRB990705 event, as a function of the $\bar{\nu}$ emission temperature, for $\Delta t \leq 10s$.

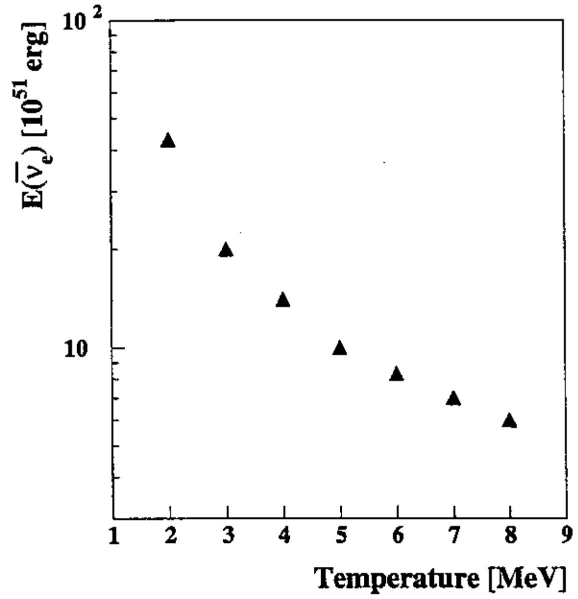


Figure 7: Upper limits to the $\bar{\nu}_e$ energy emission, as a function of the spectral temperature and for $\Delta t \leq 10$ s for a source distance $D \leq 50$ kpc.

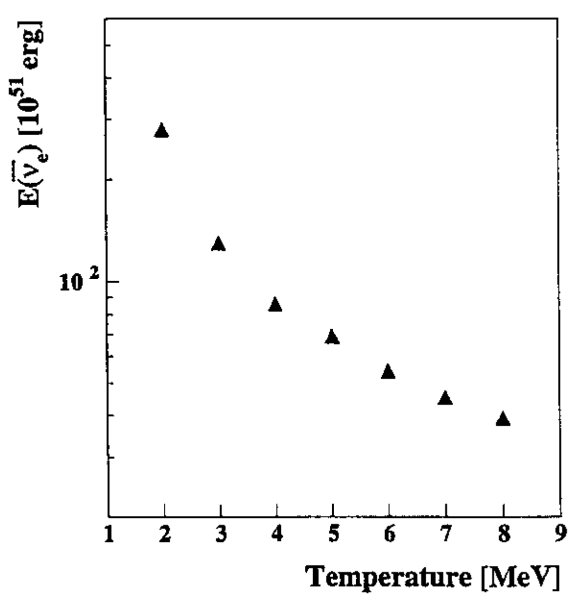


Figure 8: Upper limits to the $\bar{\nu}_e$ energy emission, as a function of the spectral temperature and for $\Delta t \leq 10$ s for a source distance $D \leq 50$ kpc.

ClibPDF - www.fastio.com