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A search for neutrino bursts from gravitational collapse of stars at Baksan Underground Scintillation Telescope.

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Abstract: Current status and results of the experiment on recording neutrino bursts are presented. The observation time (since 1980) is 22.6 years. The upper bound of collapse frequency in our Galaxy is 0.10 y^{-1} (90% CL).

Introduction

One of the current task of the Baksan Underground Scintillation Telescope (BUST) is the search for neutrino bursts from gravitational collapse of stars.

BUST is located in the Northern Caucasus in the underground laboratory at the effective depth of $8.5 \times 10^4\ g \cdot cm^{-2}$ (850 m of w.e.) [1]. The facility has dimensions $17 \times 17 \times 11$ m^3 and consists of four horizontal scintillation planes and four vertical ones (Fig. 1). Six planes of them are external planes and two planes are internal ones. The upper horizontal plane consists of 576 (24×24) liquid scintillator detectors of the standard type, three lower planes have 400 (20×20) detectors each. The vertical planes have 15×24 and 15×22 detectors. The detector sizes are $0.7 \times 0.7 \times 0.3\ m^3$. The distance between neighboring horizontal scintillation layers is 3.6 m. The angular resolution of the facility is 2^o, time resolution is 5 ns.

The information from each detector is transmitted over three channels: an anode channel (which serves for trigger formation and amplitude measurements up to 2.5 GeV), a pulse channel with operation threshold 12 MeV (since 1991 this threshold = 9 MeV; the most probable energy deposition of a muon in a detector is 50 MeV $\equiv$ 1 relativistic particle) and a logarithmic channel with a threshold $s_o = 0.5$ GeV. The signal from the fifth dynode

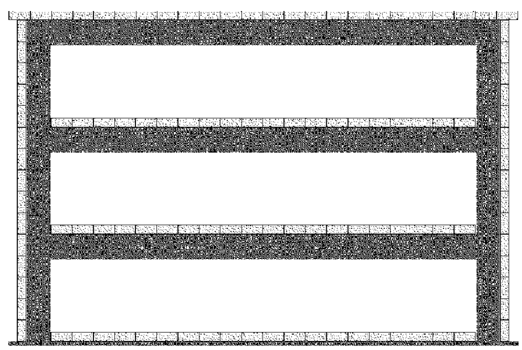

Figure 1: General view of the Baksan underground scintillation telescope.

of PM tube FEU-49 goes to a logarithmic channel (LC) where it is converted into a pulse whose length t is proportional to the logarithm of the amplitude of the signal [2].

The method of neutrino burst detection

BUST consists of 3156 standard autonomous detectors. Each detector is filled with an organic scintillator C_nH_{2n+2}, ($n \simeq 9$) and is viewed by one photomultiplier with a photocathode diameter of 15 cm. The total scintillator mass is 330 t, and the mass enclosed in three lower horizontal layers (1200 standard detectors) is 130 t. The neutrino signal from a supernova explosion is recorded with a help of a reaction

$$\overline{\nu}_e + p \rightarrow n + e^+ \qquad (1)$$

If the mean antineutrino energy is $E_{\nu_e} = 12 - 15$ MeV [3, 4, 5] the pass of e^+ (produced in reaction (1)) will be included, as a rule, in the volume of one detector. In such case the signal from a supernova explosion will appear as a series of events from singly triggered detectors (one and only one detector from 3156) during the neutrino burst. The search for a neutrino burst consists in recording of single events bunch within time interval of τ = 20 s.

If one assumes the distance from the star is 10 kpc and the total energy irradiated in neutrinos is

$$\varepsilon_{tot} = 3 \times 10^{53}\ erg \qquad (2)$$

the expected number of single events from reaction (1) (we assume the total energy of the $\overline{\nu}_e$ flux is equal to $1/6 \times \varepsilon_{tot}$) will be

$$N^H_{ev} \simeq 38 \times \eta_1, \qquad (3)$$

where $\eta_1 \approx 0.6$ denotes the detection efficiency of e^+ in reaction (1).

Background events are radioactivity, spurious signals from detectors and cosmic ray muons if only one detector from 3150 hit. The total count rate from background events is n = 0.019 s^{-1} in internal planes (three lower horizontal layers) and 1 s^{-1} in external ones. Therefore three lower horizontal layers are used as a target.

Background events can imitate the expected signal (k single events within sliding time interval τ) with a count rate

$$p(k) = n \times exp(-n\tau) \sum_{l=k-1}^{\infty} \frac{(n\tau)^l}{l!} \qquad (4)$$

The treatment of experimental data (over a period 2001 - mid-2006 y; T = 172850 RUNs, RUN = 900 s) is shown by squares in Fig.2 in comparison with the expected distribution according to the expression (4).

If the scenario of 2-stage collapse [6] is realized in Nature and the mean neutrino energy (during the first stage) is $\overline{E}_{\nu_e} = 30 - 40$ MeV, the following reactions begin to work:

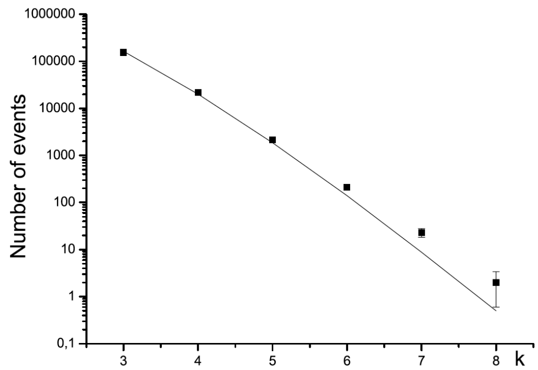

Figure 2: The number of bunches with k single events within time interval of τ = 20 s. Squares are experimental data, the curve is the expected number according to the expression (4).

$$\nu_i + {}^{12}C \rightarrow {}^{12}C^* + \nu_i,\ E_{th} = 15.1\ MeV,\ i = e, \mu, \tau \qquad (5)$$
$${}^{12}C^* \rightarrow {}^{12}C + \gamma, \quad E_\gamma = 15.1\ MeV$$

$$\nu_e + {}^{12}C \rightarrow {}^{12}N + e^-, \quad E_{th} = 17.34\ MeV, \qquad (6)$$
$${}^{12}N \rightarrow {}^{12}C + e^+ + \nu_e, \quad \tau = 15.9\ ms,$$

In such case the expected number of events can be estimated (under conditions (2)) by formulas

$$N^C_{ev4} = 16 \times \kappa_\gamma(15\ MeV), \qquad (7)$$

$$N^C_{ev5} = 30 \times \eta_5^{C \rightarrow N}(30\ MeV), \qquad (8)$$

The total energy of $e^+ + \nu_e$ in reaction (6) is 17.3 MeV therefore $\eta_5^{C \rightarrow N} \approx 0.3$ is small enough.

The low part of the overlap between horizontal scintillation planes is the 8 mm iron layer. This can be used as the target in the reaction

$$\nu_e + {}^{56}Fe \rightarrow {}^{56}Co^* + e^-, \ \ E_{th} = 4.056\ MeV, \qquad (9)$$

Under conditions (2) the expected number of events from reaction (9) (neutrinos arrive from above) is

$$N^{Fe}_{ev} = 6.3 \times \eta_{Fe}(26\ MeV), \qquad (10)$$

$\eta_{Fe}(26\ MeV) \approx 0.4$ is the detection efficiency of e^- with the energy 26 MeV produced into the 8 mm iron layer.

It should be noticed, if $\overline{E}_{\nu_e} = 30 - 40$ MeV a high percentage of neutrino reactions (9) will cause triggering two detectors.

Results

So, if the scenario of 2-stage collapse [6] is realized in Nature the signal from collapse (the number of events in a bunch) is increased $\approx 30 - 40\%$.

The facility has been operating under the program of search for collapse neutrinos since the mid-1980. The observation time is $T =$ 22.6 years. Let f_{col} be the mean frequency of collapses. The probability of collapse absence during the time interval T is (according to the Poisson law) $\exp(-f_{col}T)$. An upper bound on the mean frequency of gravitational collapses in the Galaxy at 90% CL can be obtained with the help of the expression

$$\exp(-f_{col}T) = 0.1 \qquad (11)$$

Thus

$$f_{col} < 0.102y^{-1}, \quad 90\%\,CL \qquad (12)$$

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