Monitoring for the Core-Collapse Supernova in Baksan Underground Scintillation Telescope

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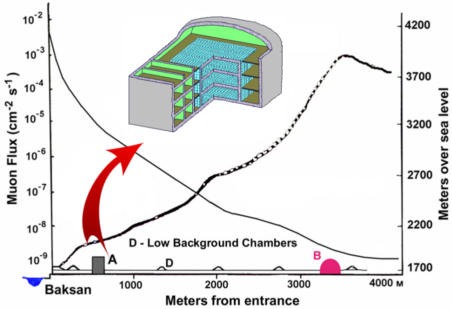
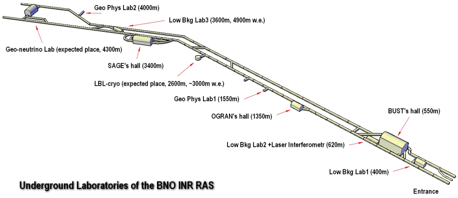
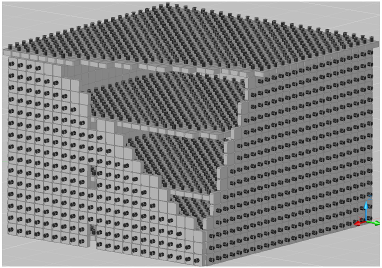
Baksan Neutrino Observatory



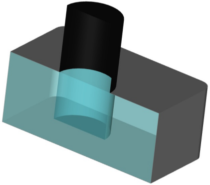


The general view of BUST



- dimensions 16.5x16.5x11.5 m3
- number of counters 3184
- tank size - 70x70x30 cm3
- the scintillator CnH2n+2 (n 9)
- the total mass of scintillator is 330 t (3180 tanks)
- three lower horizontal layers -130 t (1200 tanks)

Standard scintillation counter



The standard counter is an aluminum tank 0.70.70.3m^3 in size, filled with an organic CnH2n+2 (n 9) scintillator. The scintillator volume is viewed by one FEU-49 photomultiplier (PM) with a photocathode diameter of 15 cm through a 10-cm-thick organic glass window.

The information from each counter is transferred through three channels concurrently:

- The signal from the PM anode is used to measure the plane trigger time and the energy deposition up to 2.5 GeV.
- The signal from the 12th dynode is fed to the input of a discriminator (the so-called pulse channel) with a trigger threshold of 8 and 10 MeV for the horizontal and vertical planes, respectively.
- a logarithmic channel from 5th dinode with the energy threshold 500 MeV is fed to the input of a logarithmic converter, where it is converted into a pulse whose length is proportional to the logarithm of the signal amplitude

The method of neutrino burst detection

The BUST consists of 3184 standard autonomous counters. The total scintillator mass is 330 t, and the mass enclosed in three lower horizontal layers (1200 standard counters) is 130 tons. The majority of the events recorded with the Baksan telescope from a supernova explosion will be produced in inverse beta decay (IBD) reactions:

$$\tilde{\nu} + p \to n + e^+$$
$$E_{e^+} = E_{\neq_e} - 1.3\ MeV$$
$$\sigma(\nu_e P) \simeq 9.3 E_e^{+2} \cdot 10^{-44}\ cm^2$$

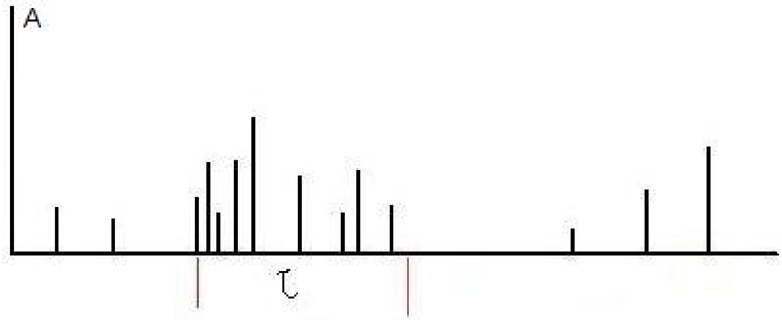
Hillebrandt W., Hoflish P. // Rep. Prog. Phys. v.52, p. 1421 (1989) G. G. Raffelt, "Stars as laboratories for fundamental physics"

If the mean antineutrino energy is $E_{\nu_e} = 12 - 15\ MeV$ the path of e^+ (produced in IBD reaction will be confined in the volume of one counter. In such case the signal from a supernova explosion will appear as a series of events from singly triggered counters (one and only one counter from 3184 operates.

From the theory of the Standard collapse it follows that the total energy, carried out by all flavors of neutrinos.

The method of neutrino burst detection

If the mean antineutrino energy is $12 - -15\ MeV$ the range of e^+ will be included, as a rule, in the volume of one detector.

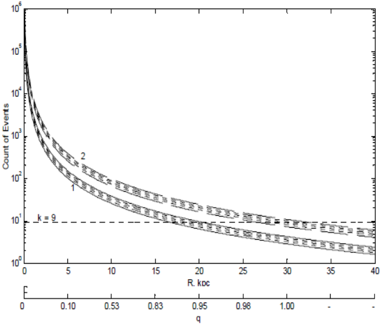


$$E_{e^+} = E_{\nu_e} - 1.3\ MeV$$
$$E_e^+ \geq 8\ MeV$$

The search for a neutrino burst consists in recording a bunch of single events within time interval of $\tau = 20\ s$

The expected number of neutrino interactions

The dependence of expected number of neutrino events on a distance to the star.



Curve 1 is for 130 tons, curve 2 is for 330 tons of scintillator. q is the percentage of stars in the Galaxy within a distance R.

$$N = N_p \cdot \int_0^{\Delta t} dt \int_0^{\infty} dE \cdot F(E,t) \cdot \sigma(E) \cdot \eta(E)$$

here N_p is the number of free protons, $F(E,t)$ is the flux of electron antineutrinos, $\sigma(E)$ - the IBD cross section[astroph302055], and $\eta(E)$ is the detection efficiency. In calculatingused the Fermi-Dirac spectrum for the ν_e energy spectrum integrated over time (with the antineutrino temperature $k_B T = 3.5\ MeV$.

For an SN at a distance of 10 kpc, a total energy radiated into neutrinos of $\epsilon_{tot} = 3 \cdot 10^{53}\ erg$, and a target mass of 130 t (the three lower horizontal planes, we obtain (we assume the e flux is equal to $\frac{1}{6}\epsilon_{tot}$)

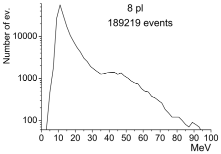
$$N \simeq 38 \text{ (no oscillations)}$$

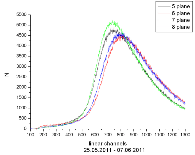
Reactions used in search for bursts from SN

Reaction	detection efficiency	N of event
$\tilde{\nu} + p \to n + e^+$	$0.5 - 0.9$	$19 - 35$
$\nu_i +^{12} C \to \nu_i +^{12} C$	0.2	3.2
$\nu_e +^{12} C \to^{12} N + e^-$	0.5-0.7	15 - 21
$\nu_e +^{56} Fe \to^{56} Co + e^-$	0.4	2.5

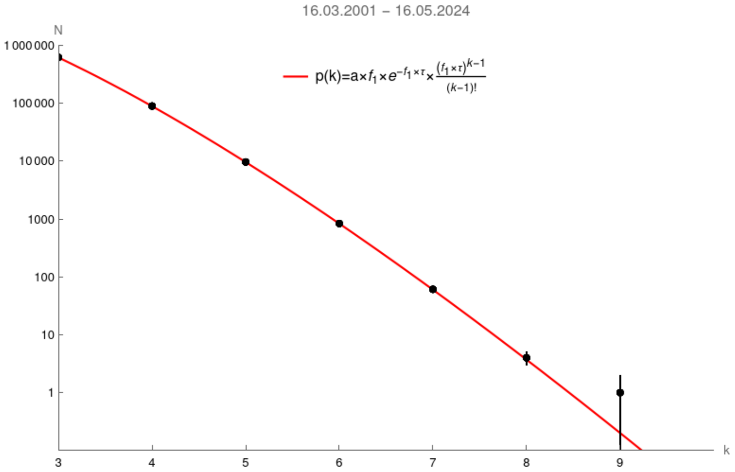
Background events

- radioactivity: Inelastic muon interaction with the matter of the detector. Some part of the background events can be connected with inelastic muon interactions which can produce unstable nuclei whose disintegration brings into operation only one detector;
- ghost signals from detectors;
- cosmic ray muons:a single muon is registered by one detector due to spatial gaps between modules of the telescope, and also in the case of one muon energy release ¡ 8 MeV;





Clusters



The number of clusters with k single events within time interval of$\tau = 20\ s$. Squares are experimental data, the curve is the expected number according to the expression p(k)

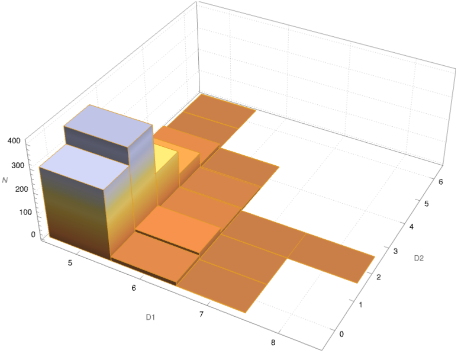
Two independent detectors

To increase the number of detected neutrino events and to increase the "sensitivity radius" of the BUST, we use those parts of external scintillator layers that have relatively low count rate of background events. The total number of counters in these parts is 1030, the scintillator mass is 110 tons. We call this array the D2 detector, it has the count rate of single events $f_2 = 0.12\ s_1$. The joint use of D1 and D2 detectors allows us to increase the number ofdetected neutrino events and the detection reliability of a neutrino burst. We use the following algorithm: in case of a cluster detection with k1 6 in the D1, we check the number of single events, k2, in the 10-second time frame in the D2 detector. The start of the frame coincides with the start of the cluster in D1. Mass ratio of D2 and D1 detectors $1030/1200 = 0.858$ implies that for the mean value of neutrino events k1 = 6 in D1, the mean number of neutrino events in D2 will be $k2 = 6 \cdot 0.858 \cdot 0.8 = 4.12$ (factor 0.8 takes into account that the frame duration in D2 is 10 seconds instead of 20 seconds in D1). Since the background adds f2 $\times$10 s = 1.2 events, we obtain finally k2(k1 = 6) = 4.12+1.2 = 5.32. So the expected total number of detected neutrino events in IBD reactions:

$$N = N(D1) + N(D2) \simeq 67$$

The D1 and D2 detectors are independent, therefore the imitation probability of clusters with multiplicities k1 in D1 and k2 in D2 by background events is the product of appropriate probabilities. Therefore the events with k1 6, k2 6 should be considered as candidates for a neutrino burst detection (since mean values of k1 and k2 are significantly exceeded in two independent detectors simultaneously and the imitation probability of such events by background is very small).

Two independent detectors



Clusters in D1D1 detector. The experimental data includes 2022-2024 y.

Thank you for attention!