Measurement of the characteristics of a neutrino flux from a supernova at the Baksan Underground Scintillation Telescope

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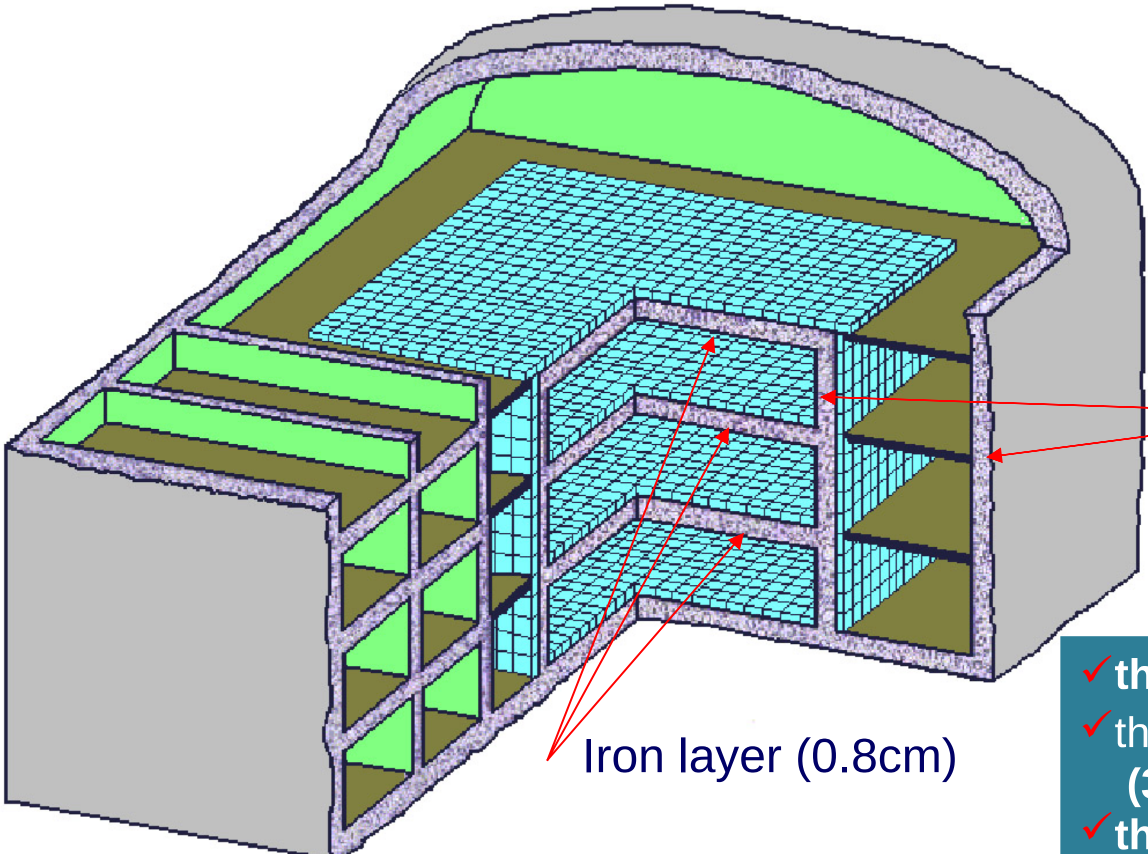
for BUST Collaboration

BUST – the general view

(the effective depth 850 m of w.e.)

- ✓ **dimensions 17•17•11 m^3**
- ✓ **number of counters 3180**
- ✓ **tank size - 70•70•30 cm^3**

Angular resolution – 2^o



- ✓ **the scintillator C_nH_{2n+2} (n ≈9)**
- ✓ the total mass of scintillator is 330 t **(3180 counters)**
- ✓ **three lower horizontal layers (the interior) -130 t ,1200 counters**

ИЯИ РАН

BUST – the facility of real time
A local clock with a self–contained power provides 0.2 ms accuracy of determining the absolute time (GPS)

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

1) **an anodic channel –** measures amplitude (6 MeV - 2 GeV) and operation time of a scintillator layer
2) **a pulse channel** from 12th dynode (12.5 MeV, 10 MeV, 8 MeV- since 1992 year; 1 r.p. = 50 MeV)
3) a **log channel** from 5th dynode has the energy threshold 500 MeV

a counter has a broad **range of measurement – (8 MeV – 800 GeV)**

Since March 2001 data collection is realized without exception.

Standard model of collapse

ε, erg	$\bar{E}_{\bar{\nu}_e}$, MeV	$\bar{E}_{\nu_e}$, MeV	$\bar{E}_{\nu_{\mu,\tau}}$, MeV	τ, s
(2-4)•10^53	12-14	11	20	5-20

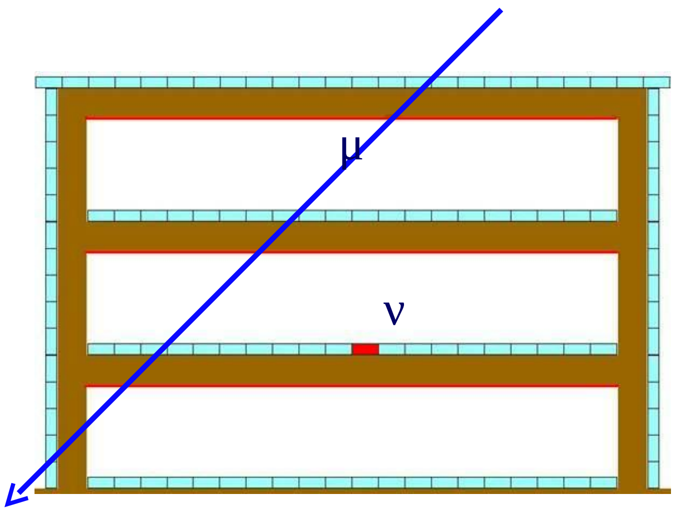
$$\bar{\nu}_e + p \rightarrow n + e^+; \quad E_{e^+} = E_{\bar{\nu}_e} - 1{,}3\,MeV, \; E_{e^+} \geq 8\,MeV$$

The search for a neutrino burst at the BUST

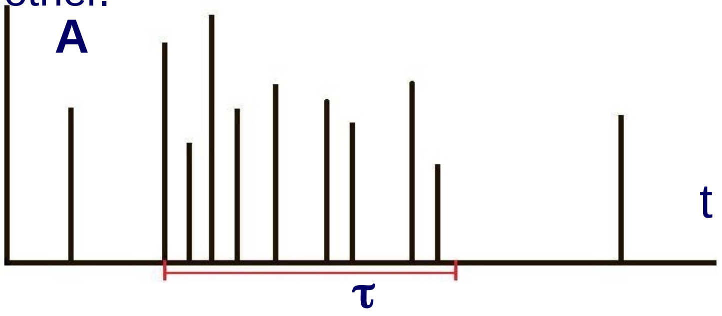
The radiation length for our scintillator is 47 g/cm² (tank size - 70•70•30 cm³)

If the mean antineutrino energy $\bar{E}_{\bar{\nu}_e}$ = 12-14 MeV the track of e^+ will be included, as a rule, in the volume of the only tank.

a neutrino event → an event at the BUST with the only counter = the single event



The search for a neutrino burst consists in recording a cluster of single events within time interval of τ. We use a sliding time window – from one single event to the other.



Background events (1)

i) cosmogeneous isotopes ($^{12}B, ^{12}N, ^{8}B, ^{8}Li$ etc.)

ii) cosmic ray muons if only one counter from 3180 is hit

The total count rate from background events is

f1 = 0.02 s^{-1} in the internal planes (three lower horizontal layers)

and ≈ 1.5 s^{-1} in the external layers

Therefore, the three lower horizontal layers are used as a target

130 tons (1200 counters)

The method of detection of neutrino burst

$$\bar{\nu}_e + p \rightarrow n + e^+; \; E_{e^+} = E_{\bar{\nu}_e} - 1{,}3\,MeV, E_{e^+} \geq 8 MeV$$

The number of interactions detected during an interval of duration Δt from the beginning of the collapse can be expressed as:

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

N_p - number of free protons, F(E,t) - the flux of electron antineutrinos, σ(E) - the IBD cross section, η(E) - the detection efficiency

The Baksan experiment

- ✓the scintillator C_nH_{2n+2} (n ≈9)
- ✓the total mass of scintillator is 330 t
  three lower horizontal layers -130 t ,
  1200 counters, -- detector D1

The Baksan experiment

- the scintillator C_nH_{2n+2} (n ≈9)
- the total mass of scintillator is 330 t
- three lower horizontal layers (the interior) -130 t , 1200 counters

1) the distance to the star is 10 kpc

2) the energy radiated in neutrinos

$$E_{tot} = 3 \cdot 10^{53}\, erg$$

$$E_{\bar{\nu}_e} = \left(\tfrac{1}{6}\right) \cdot E_{tot}$$

$$N_{ev}^{H}(D1) \simeq 35 \quad \left(T_{\bar{\nu}_e} = 4.5\, MeV\right)$$ no oscillations

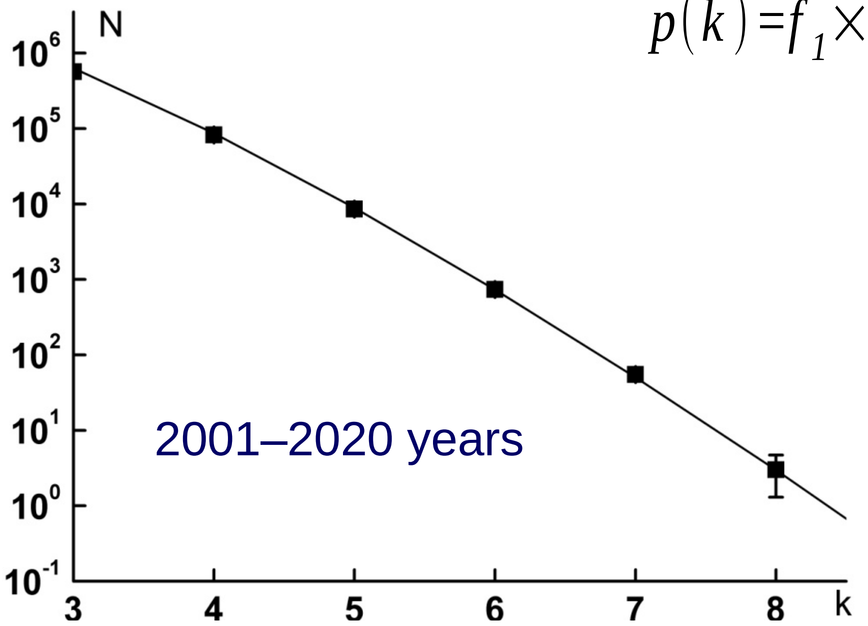
MSW effect, $\left(T_{\nu_x} = 6\, MeV\right)$

$$N_{ev}^{H}(D1) \simeq 39$$ normal hierarchy

$$N_{ev}^{H}(D1) \simeq 48$$ inverted hierarchy

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

$$p(k) = f_1 \times \exp(-f_1 \tau) \frac{(f_1 \tau)^{k-1}}{(k-1)!} \quad (1)$$



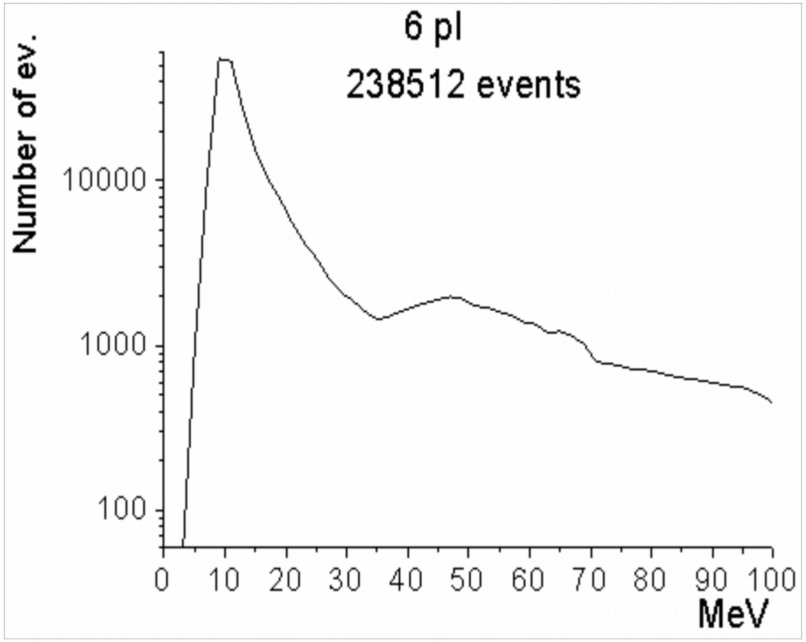
multiplicity	cluster's frequency
k =6	≈1/10 day
k =7	≈1/152 day
k =8	≈1/7.27 year
k =9	≈1/145 year

The number of clusters 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 (1)

Background events (2)

i) cosmogeneous isotopes ($^{12}B, ^{12}N, ^{8}B, ^{8}Li$ etc.)

ii) cosmic ray muons if only one counter from 3180 is hit



The exposure time is 322 days (2 MeV/bin)

The peak in the region of 10-15 MeV is due to decays of cosmogenic isotopes

Two independent detectors

To increase the number of detected neutrino events
and the detection reliability of a neutrino burst
we use those parts of external scintillator layers that have
a relatively low count rate of background events (D2).

D1 detector – 1200 counters (130 tons), $0.02\ s^{-1}$

D2 detector – 1030 counters (110 tons), $0.12\ s^{-1}$

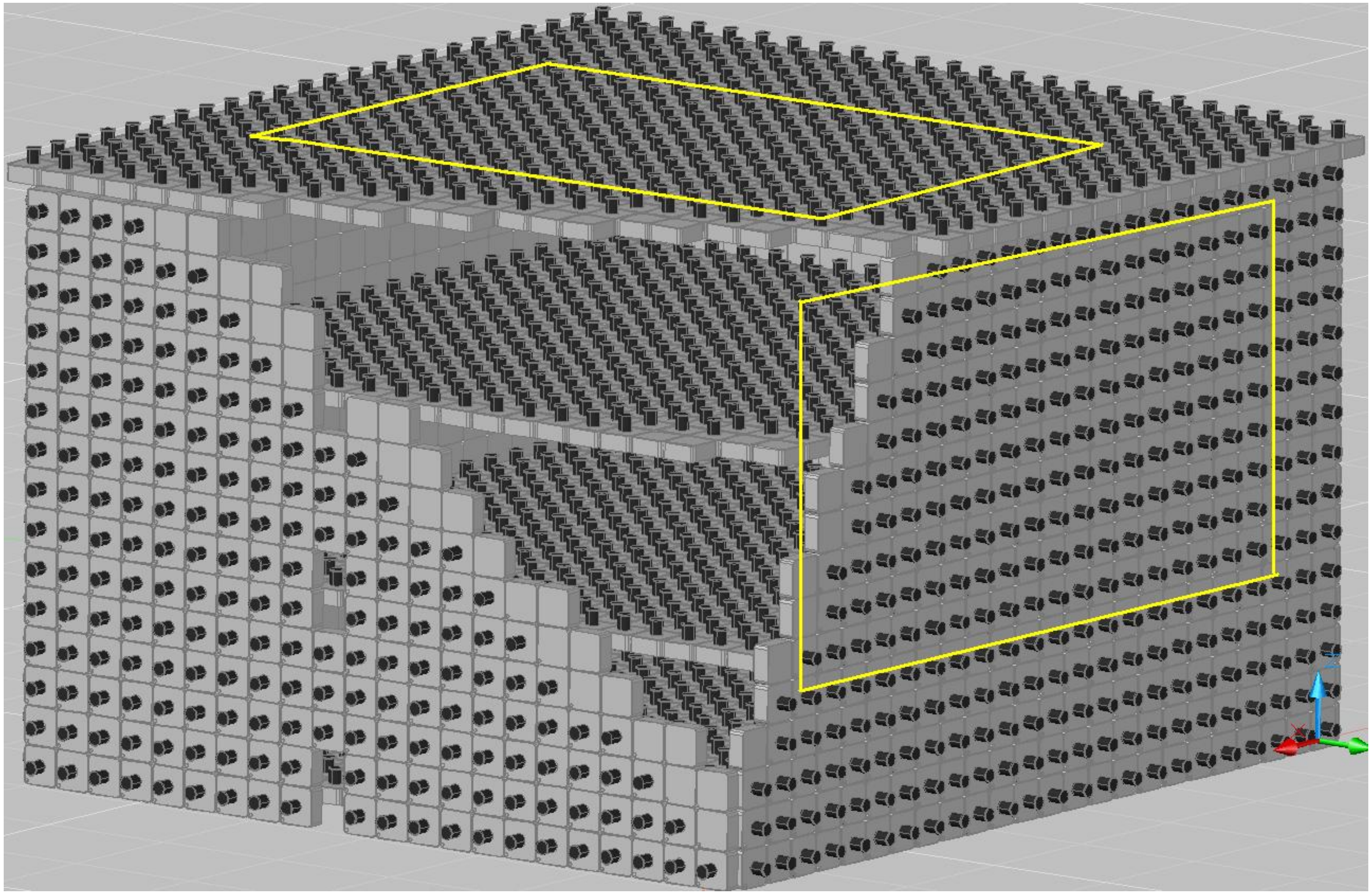
We use the following algorithm: in case of a cluster detection
with $k1 \geq 6$ in the D1, we check the number of single events, k2,
in the 10-second time frame in the D2 detector.

$$P(k1, k2) = P1(k1) \times P2(k2)$$

$$P(6,5) = 0.23\ y^{-1}$$

$$P(6,6) = 0.045\ y^{-1}$$

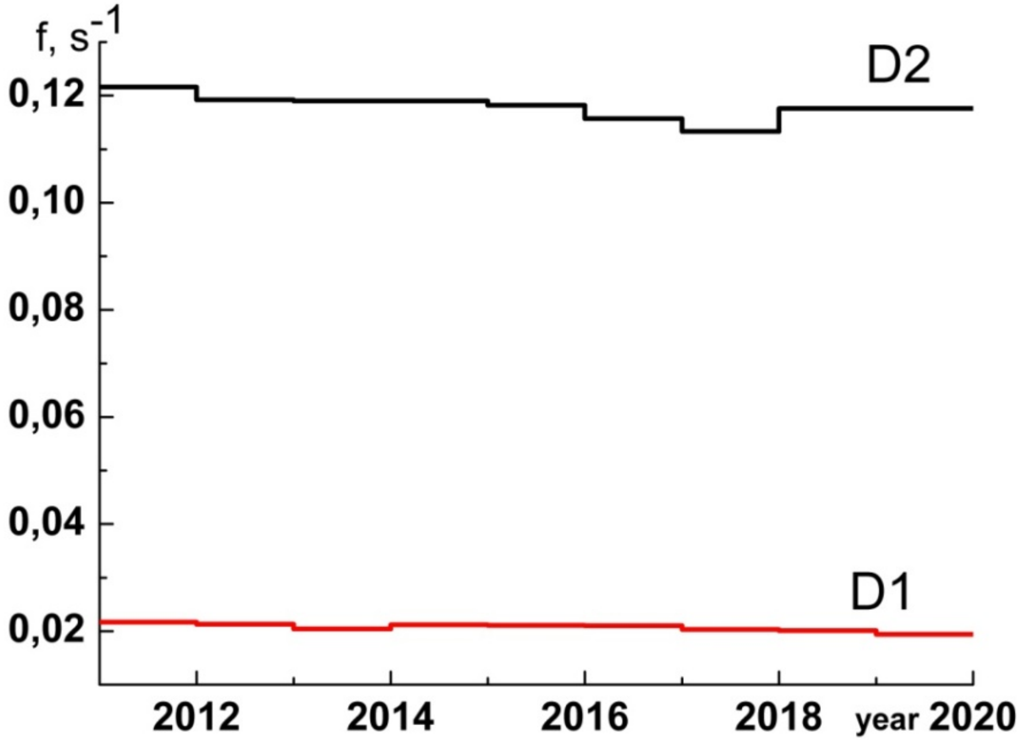
Two independent detectors



1,2,3,4,5 planes – 1980 counters, 1.5 s^{-1}

the D2 - 1030 counters (110 tons), 0.12 s^{-1}

6,7,8 planes, the D1 - 1200 counters (130 tons), 0.02 s^{-1}



The count rates of single events in the D1 and the D2 detectors.

The expected total number of detected neutrino events (in IBD reactions)

$$N_{ev} = N_{ev}(D1) + N_{ev}(D2) \simeq 63$$

no oscillations

MSW effect, $\left(T_{\nu_x} = 6\, MeV\right)$

$$N_{ev}(NH) \simeq 71$$

normal hierarchy

$$N_{ev}(IH) \simeq 88$$

inverted hierarchy

In the case of a very close SN, for example at the distance of 0.2 kpc, the total number of events from IBD reactions will be ≈ 250 000.

In the first seconds (after a core bounce), we should expect ≈ $(20-30)\times 10^3$ events per second.

All events recorded by the BUST (with all 3180 counters, the scintillator mass is 330 tons) during this time period will be neutrino events.

The frame processing time is ≈ 1 ms, therefore we will record ≈ 1000 events per second.

CONCLUSIONS

- As a target, we use two parts of the BUST (the D1 and D2 detectors) with a total mass of 240 tons. The joint use of D1 and D2 detectors increases the number of detected neutrino events and the detection reliability of a neutrino burst.
- Background events are (1) decays of cosmogeneous isotopes and (2) cosmic ray muons if only one counter from 3180 hit.
- We expect ≈ 10 neutrino interactions from a most distant SN (≈ 25 kpc) of our Galaxy.

- No burst candidate for the core collapse has been detected during the observation period of June 30, 1980, to June 30, 2020. The actual observation time is 34.4 years. This is the longest observation time of our Galaxy with neutrinos in the same facility.

The upper limit for the mean frequency of collapses in the Milky Way

$$\mathbf{f_{col} < 0.067\ year^{-1}\ (90\%\ C.L.)}$$