Search for neutrino bursts from core collapse supernovae at the Baksan Underground Scintillation Telescope (BUST)

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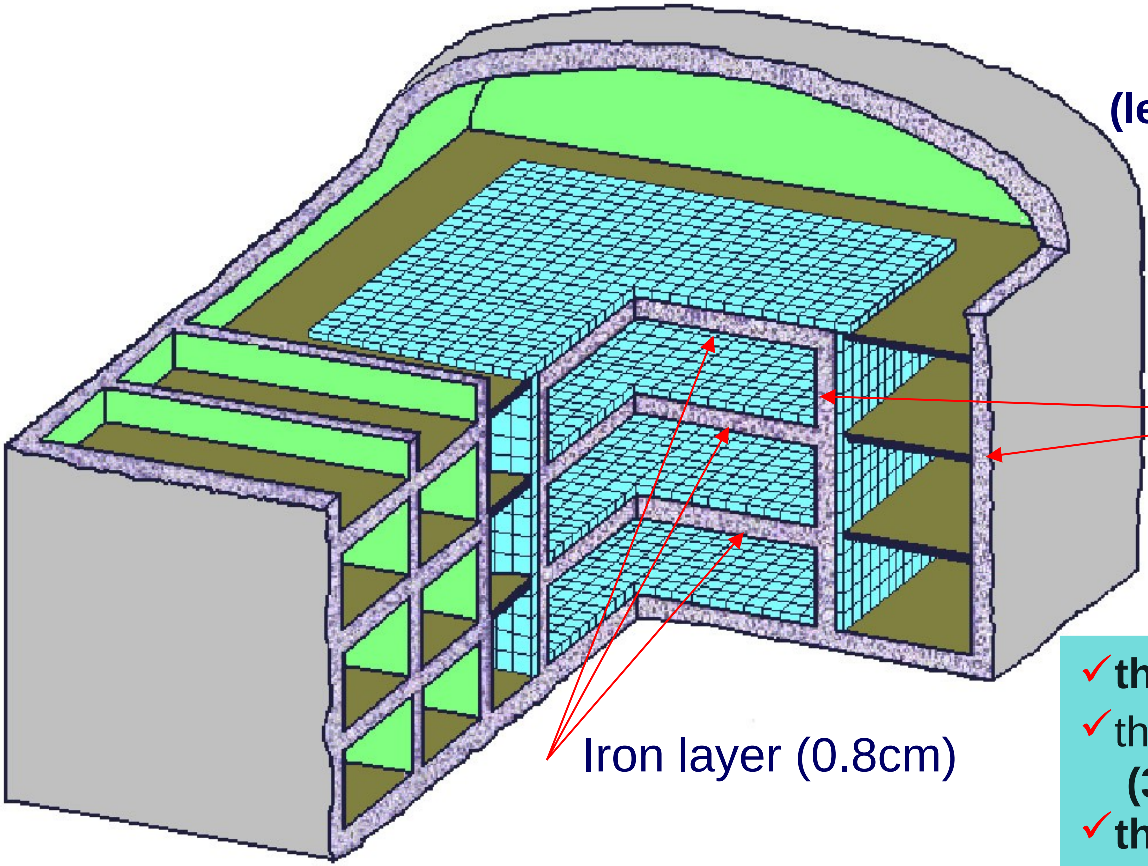
BUST – the general view

(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 – 2.5°
(length of muon paths ≥ 8m)



- ✓ **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**

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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 (direction-of-arrival location)
2) **a pulse channel** from 12th dynode (12.5 MeV, 10 MeV, 8 MeV- since 1992 year)
3) a **channel** from 5th dynode has the energy threshold 500 MeV

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

The last essential change: 2000 - 2001 ys, modification of DAQ system

How is it possible to detect neutrino signal?

Standard model of collapse

ε, erg	$\overline{E}_{\bar{\nu}_e}, MeV$	$\overline{E}_{\nu_e}, MeV$	$\overline{E}_{\nu_{\mu,\tau}}, MeV$	τ, s
$(2\text{-}4)\bullet 10^{53}$	12-13	11	25	5-20

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

Charged current on carbon

Neutral current on carbon

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The Baksan experiment

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

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

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

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 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 total energy is $E_{total} = 3 \bullet 10^{53} erg$

energy radiated in $\bar{\nu}_e$ **is** $E_{\bar{\nu}_e} = (1/6) \bullet E_{tot}$

(equally distributed among all flavors)

3) we leave out a possible influence of oscillations

$$N^H_{ev1} \cong 38 * \eta_1$$ - for three internal planes, 130 t

E (MeV)	η_1
10	0.7
20	0.9

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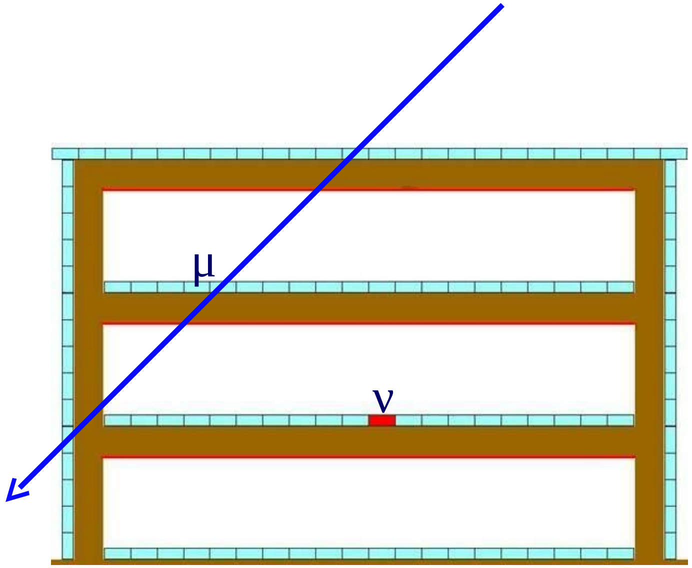
The search for a neutrino burst at the BUST

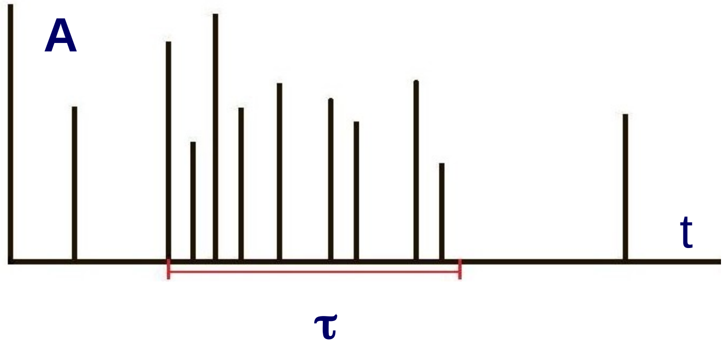
If the mean antineutrino energy $\overline{E}_{\overline{\nu}_e}$ =12 - 13 MeV the range of e^+ will be included, as a rule, in the volume of the only counter.

The radiation length for our scintillator is 47 g/cm^2 (tank size - 70•70•30 cm^3)

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 event to the other (the clusters overlap).



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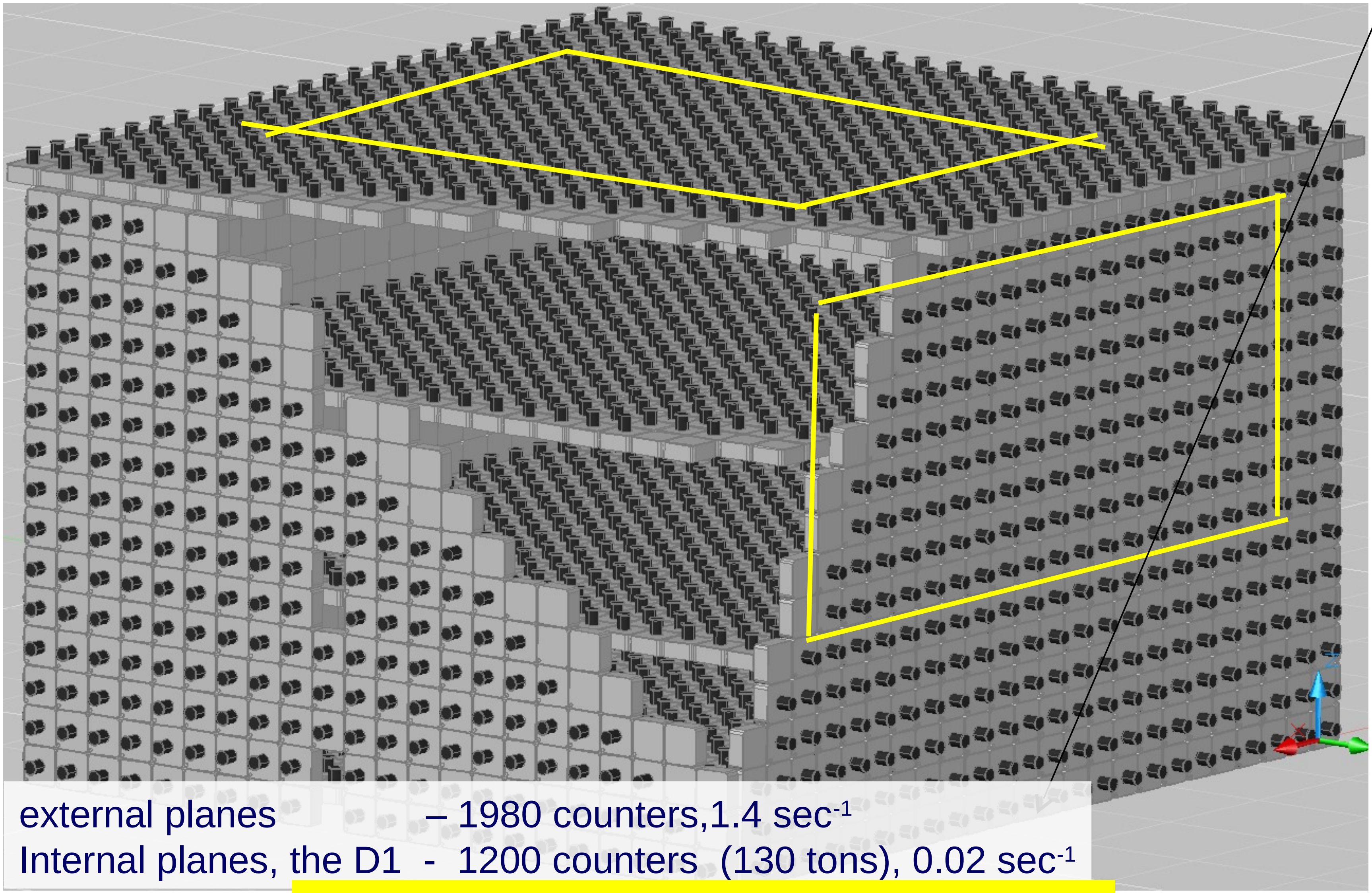
Two parts of the BUST – two independent detectors

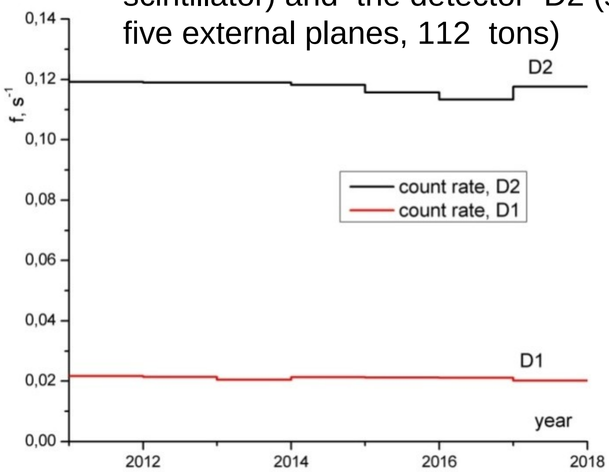


external planes – 1980 counters,1.4 sec^{-1}

Internal planes, the D1 - 1200 counters (130 tons), 0.02 sec^{-1}

the D2 - 1030 counters (112 tons), 0.12 sec^{-1}

BUST, single events, mean annual trigger count rate for the detector D1 (three internal planes,130 tons of scintillator) and the detector D2 (selection counters from five external planes, 112 tons)



The D1, rate of background $f1=0.02\ sec^{-1}$	cluster's frequency
k1=6	≈1/10 day
k1=7	≈1/152 day
k1=8	≈1/7.27 year
k1=9	≈1/145 year

Three lower horizontal planes (the Detector 1) - the main trigger target

Use of the two detectors - increasing of dependability of the signal and increasing the radius of sensitivity for registration of collapsing stars

If we registered the cluster in the main target, one is checked the time frame in the detector D2. The beginning of this frame for the D2 coincides with the beginning of the cluster in the D1.

Estimation of number of neutrino events in the D2:

D1, $k1_\nu$ =6 → D2, $k2_{\nu+b}$ = 5 or 6

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Background events

1.ghost signals from module (noises)

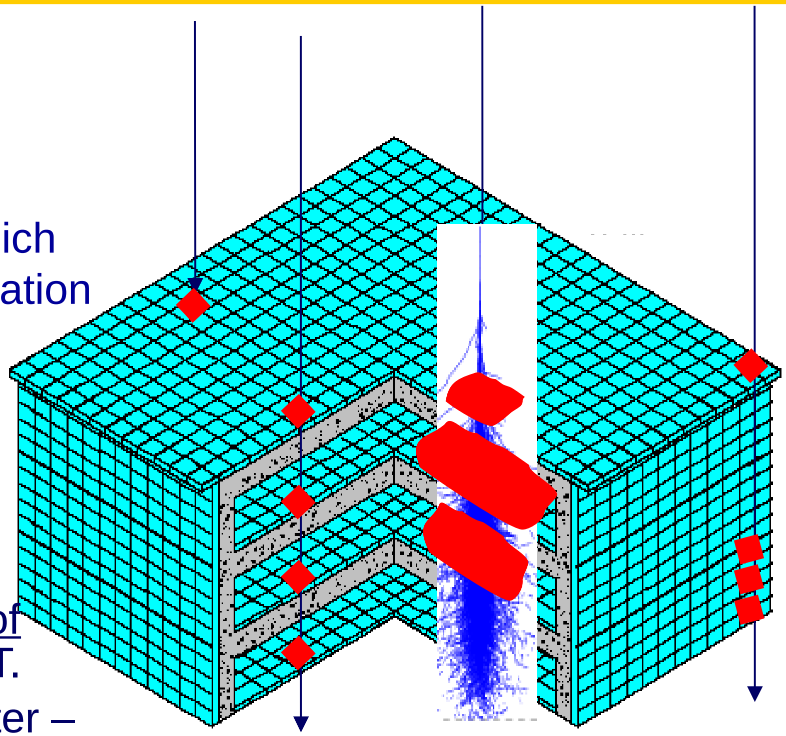
2.cosmic ray muons:

- **a single muon is registered by one counter due to spatial gaps between tanks of the telescope**
- **a muon energy release < 8 MeV**

3. radioactivity:

- natural radioactivity

Muon group + cascade



- Some part of the background events can be connected with inelastic muon interactions which can produce unstable nuclei whose disintegration brings into operation the only counter

$$^{12}C + \pi^{-} \rightarrow {}^{12}B + \pi^{0}$$

$$^{12}B \rightarrow {}^{12}C + e^{-} + \bar{\nu}_e, \quad E_e = 13.37\ \mathrm{MeV}$$

Searching for <u>a train of events - the cluster of single events after the cascade</u> at the BUST.

It is the standard procedure for each cluster – to check its prehistory.

Two clusters with large multiplicity over 17 years: one cluster with 5 events, and one cluster with 9 events.

Clusters - imitation by background

Detectors D1 and D2 are independent. Then probability of imitation by background such event, when the D1 with the cluster k1, and the D2 with the cluster k2, is equal to product of probabilities of occurrence clusters k1 and k2 in detectors D1 and D2 accordingly.

$P(6;5)=P1(6)*P2(5)$

Estimation of number of neutrino events in the D2: D1, $k1_{\nu}$ =6 → D2, $k2_{\nu+b}$ = 5 or 6

the D1	N (18 years)
k1=5	7801
k1=6	668
k1=7	54
k1=8	2

2001-2018 years, Tcalen=501547906 sec			
calculation=P(m1)*P(m2)*Tcalen			
rate of single events at the D2 =0,1242 per sec			
rate of single events at the D1 =0,0206 per sec			
k1	k2	N_exp	calculation
5	6	23	12.10
5	7	2	2.15
5	8	0	0.33
6	5	3	4.81
6	6	0	1.00
6	7	0	0.18
7	5	0	0.33

fake a SN neutrino burst

One of the assets of use of two parts is that the facility has the potential to see a supernova independently from other detectors.

Since early 2017, information about researching for neutrino bursts is added to data from other facilities of the Baksan observatory in the online mode.

CONCLUSIONS

- We have shown a long-term stability of the BUST operation.
- Using all set of the BUST's data allow us to know background in great depth.
- Two independent detectors the D1 (the inside, 130 t) and the D2 (the outside, 112 t) increase dependability of neutrino signal and the radius of sensitivity of the BUST. The facility has the potential to see a supernova independently from other detectors.

year	live time (years)	upper bound (90% cl)
1983	2,2	0,33/yr
1993	11,0	0,21/yr
2000	17,6	0,13/yr
31.12.2018	33,02	0,070/yr

- No burst candidate for the core collapse has been detected during the observation period of June 30, 1980, to December 31, 2018. The actual observation time T= 33.02 years. This is the longest observation time of our Galaxy with neutrinos in the same facility.

An upper bound on the mean frequency of gravitational collapses in the Galaxy can be obtained from the observing time -

$$\exp(-f_{col} \times T) < 0.1$$

The limit on the mean frequency of collapses in the Milky Way

$f_{col} \leq 7.0$ per century (90% C.L.)