Institute for Nuclear Research
Russian Academy of Sciences
Baksan Neutrino Observatory

The search for neutrino bursts from supernovae with the Baksan Underground Scintillation Telescope (BUST)

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50th anniversary of the Baksan Neutrino Observatory

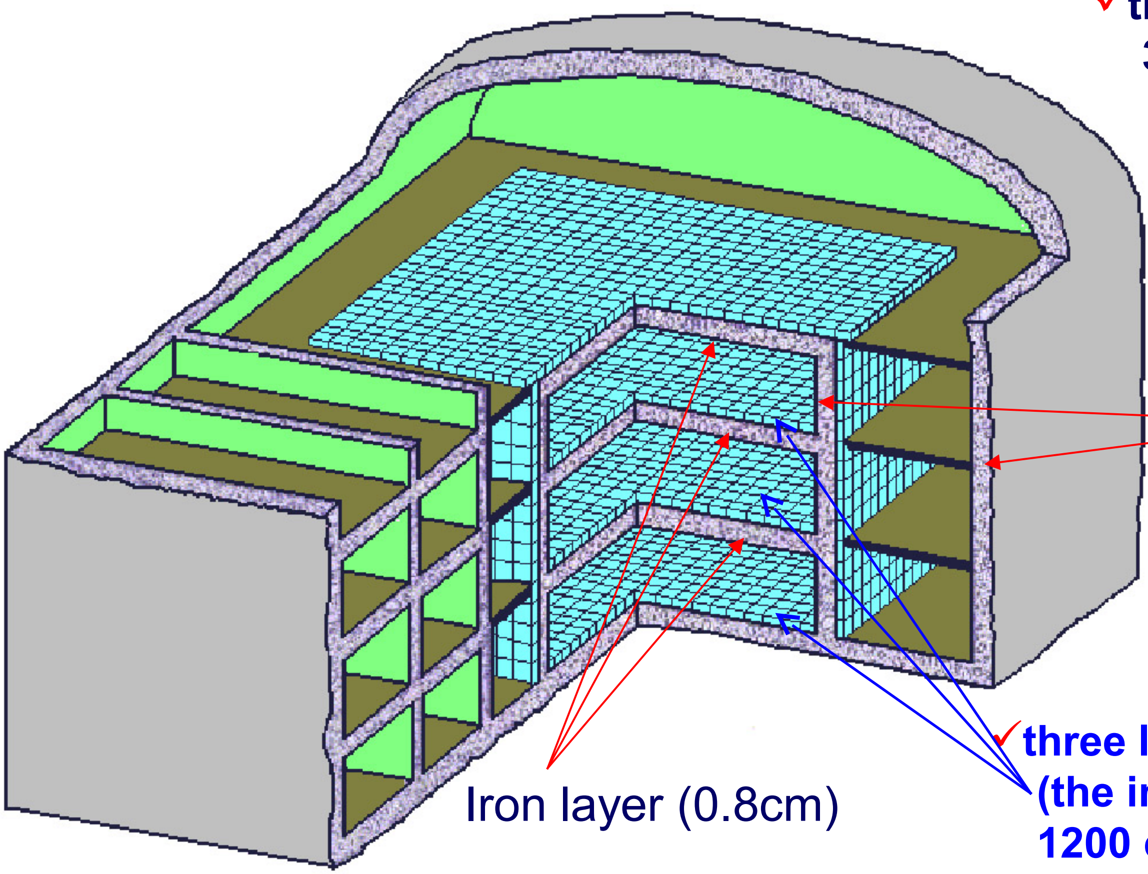
BUST – the general view

(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

- ✓**the scintillator C_nH_{2n+2} (n ≈9)**
- ✓**the total mass of scintillator – 330 t (3180 counters)**

A clock with a self–contained power provides 0.2 ms accuracy of determining the absolute time.



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BUST: the upper plane
24*24 counters

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

an anodic channel – measures of amplitude and operation time of a scintillator layer (6 MeV - 2 GeV)

2) **a pulse channel** from 12th dynode (12.5 MeV, 10 MeV, 8 MeV)

3) a **channel** from 5th dynode has the energy threshold 500 MeV

a counter has a broad **range of measurement – (8 MeV – 600 GeV)**

The last essential change - the condition of event's selection at the facility.

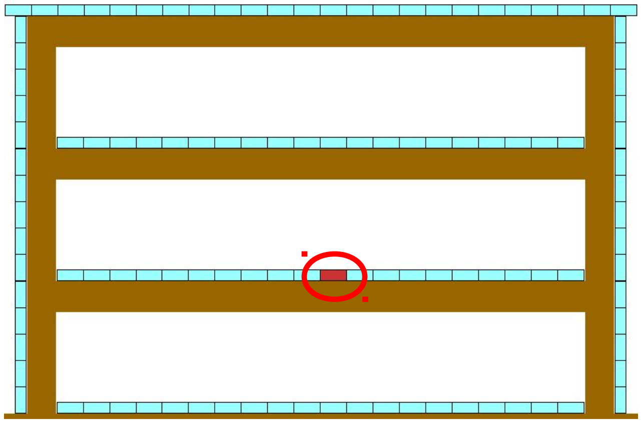
Since March 2001 data recording is realized without exception.

The Baksan experiment: the method

$$\bar{\nu}_e + p \rightarrow n + e^+$$

$$E_{e^+} = E_{\bar{\nu}_e} - 1,3\ MeV$$

$$E_{e^+} \geq 8\ \mathrm{MeV}$$

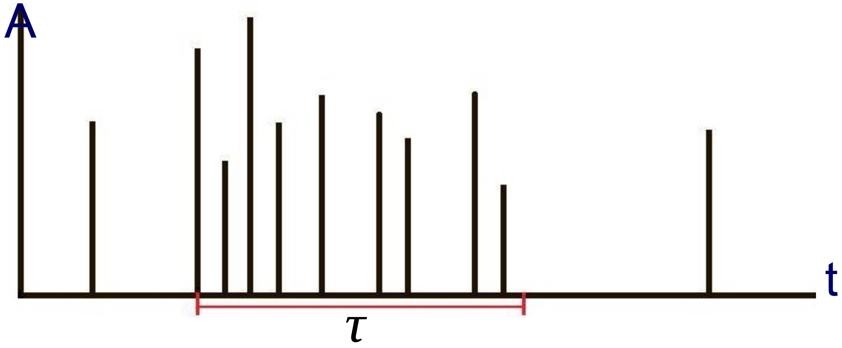


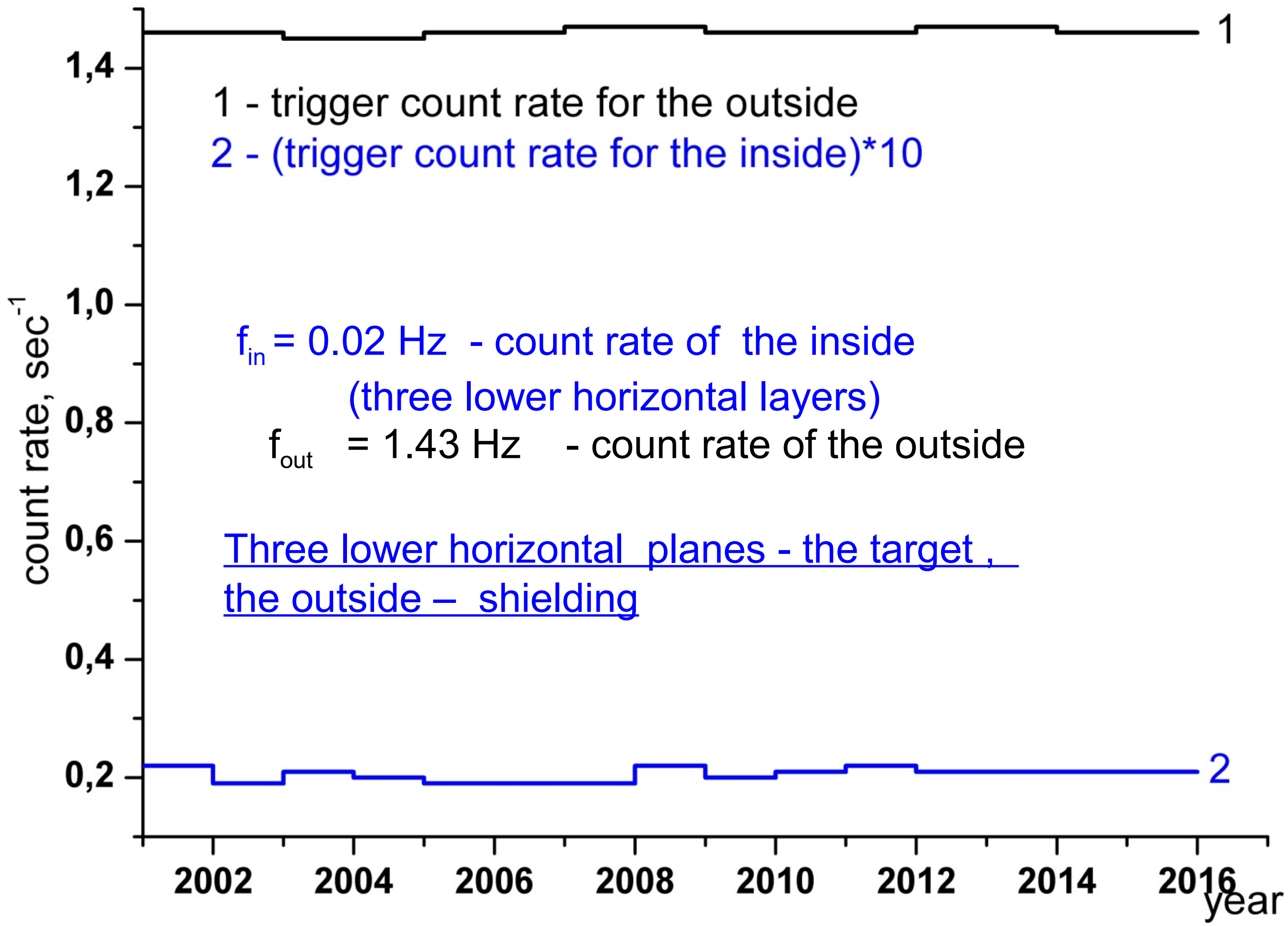
If the mean antineutrino energy

$$\bar{E}_{\bar{\nu}_e} = 11 - 17\ MeV$$

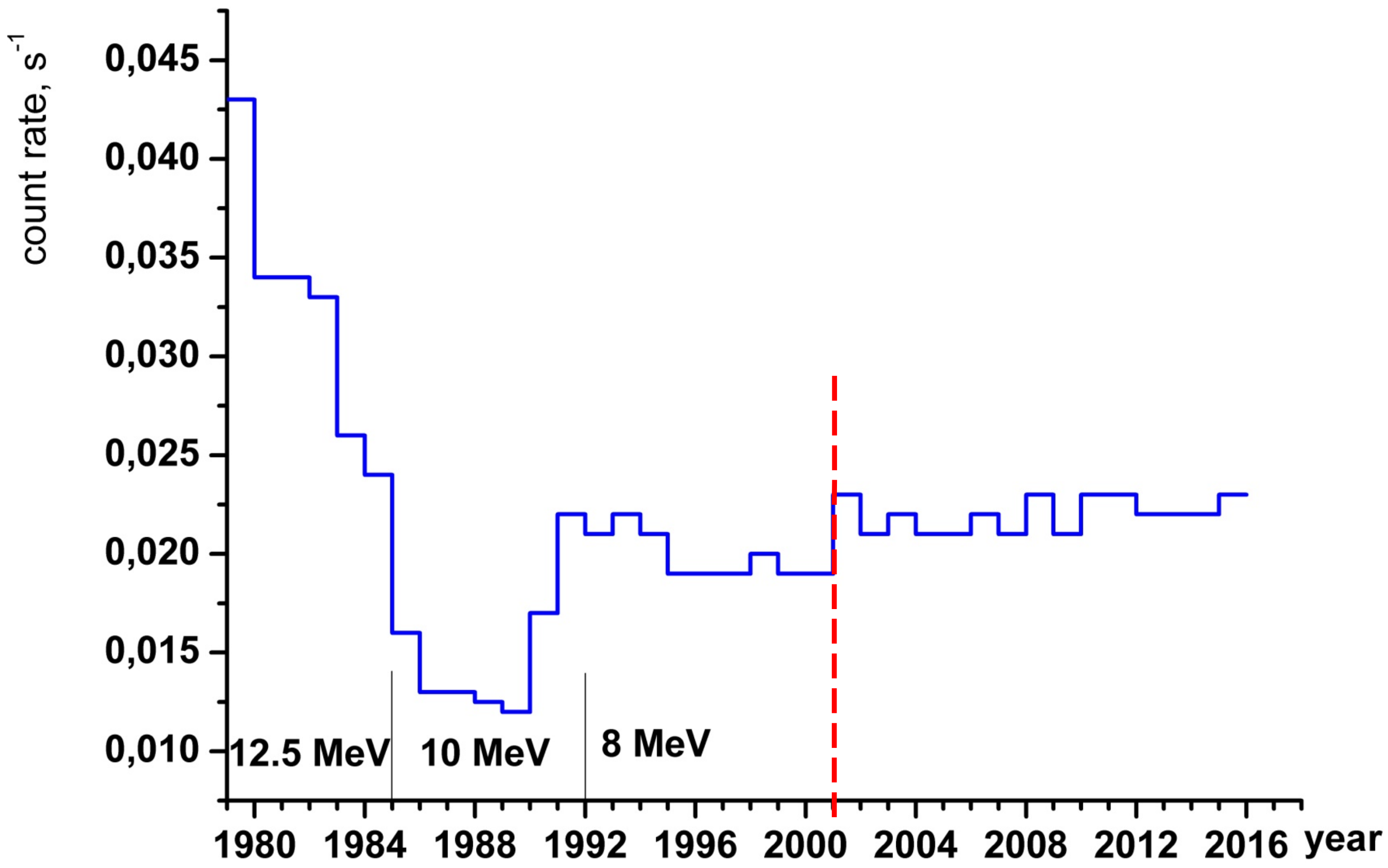
the range of e^+ will be included, as a rule, in the volume of one counter. (The radiation length for our scintillator is 47 g/cm^2)

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).





BUST, mean annual trigger count rate for **three internal planes** (**130 tons of scintillator)** and **five external planes (200 tons)**



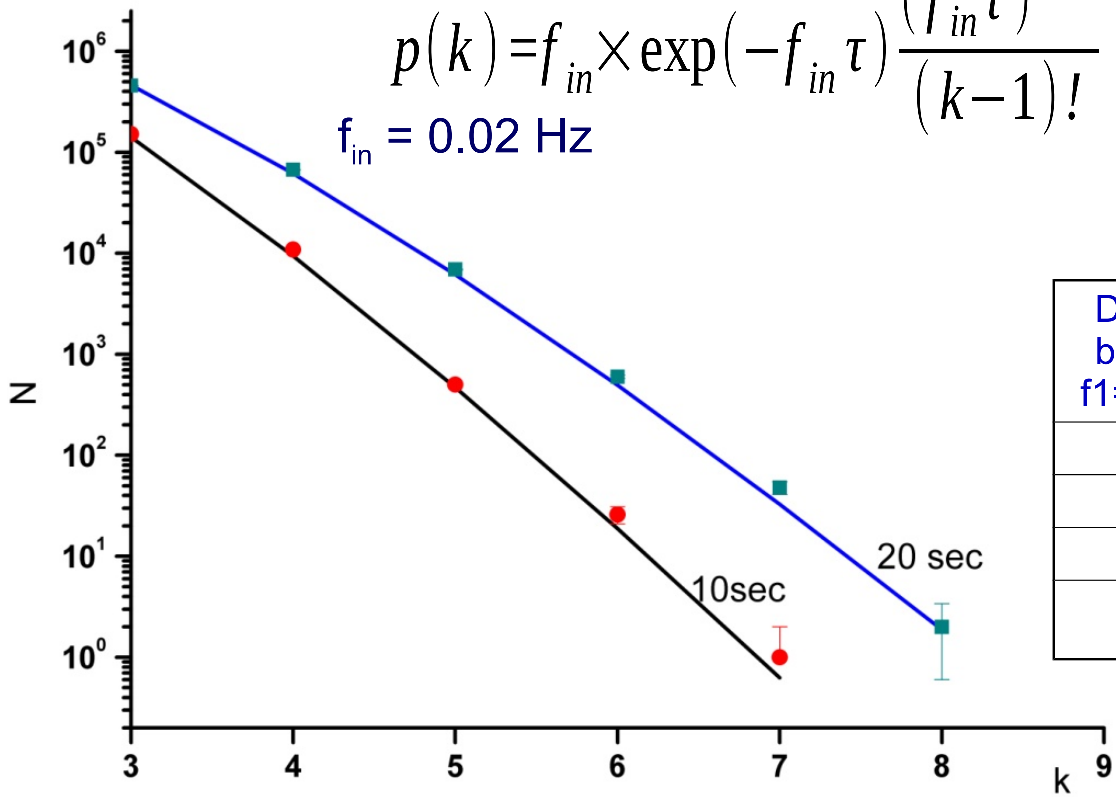
Mean annual trigger count rate for three internal planes of the BUST (single events, target mass 130 tons of scintillator)

March 2001 - data recording without exception

Background events can mimic expected signal accordingly (1)

$$p(k) = f_{in} \times \exp(-f_{in}\tau) \frac{(f_{in}\tau)^{k-1}}{(k-1)!} \qquad (1)$$

f_{in} = 0.02 Hz



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

The number of clusters with *k* single events within time interval of τ

■ and ● - experimental data, the curves are the expected number according to the expression (1) (sliding time window), actual T = 13.67 yr (2001 – 2016 years)

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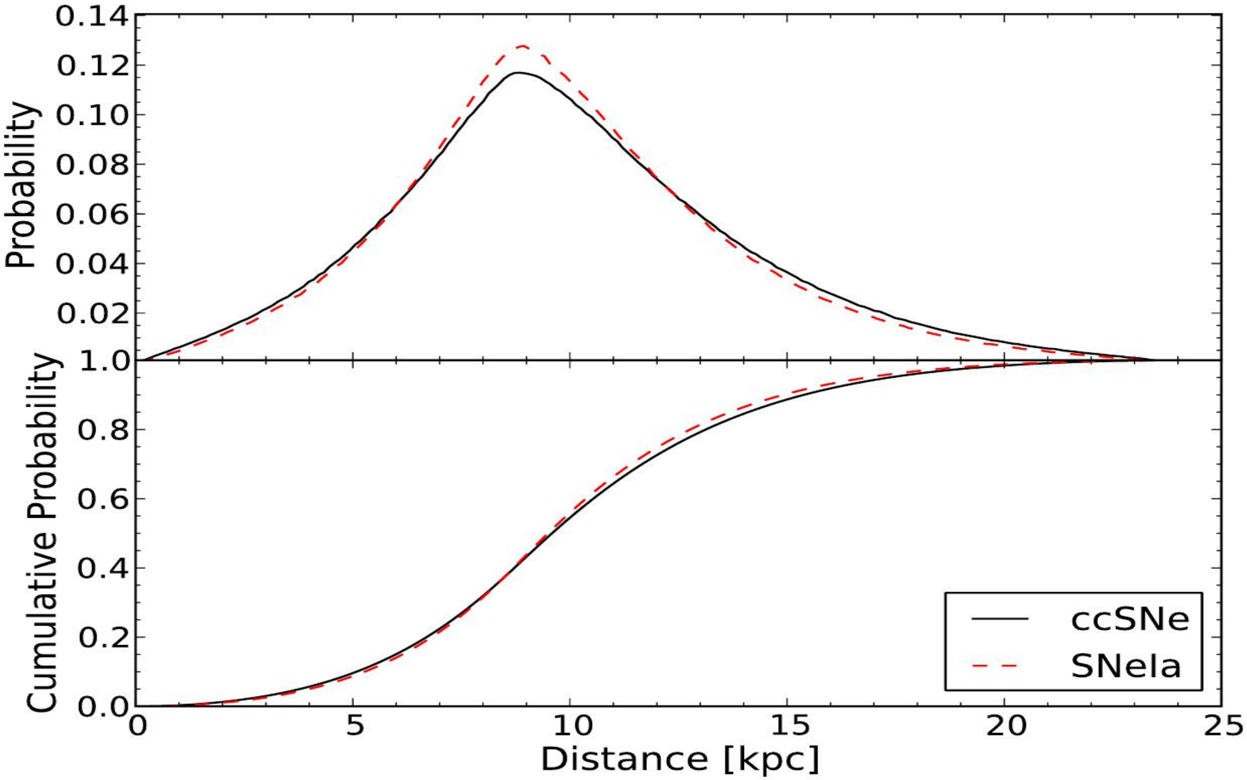

Figure 2. Differential (top) and cumulative (bottom) distance distributions of Galactic SNe from the Sun. Reasonable changes in the distance distributions have little effect on the visibility, so we only present the fiducial case. In particular, three-dimensional structure, such as spiral arms, would produce features in this figure but would have little consequence for the magnitude distribution of SNe, as discussed in Section 2.2.

R_{SN} – a distance from the core collapse Supernova
k_ν – mean value of number of neutrino events in the target (130 t)

k_ν	R_{SN}
1	56.6
2	40.0
3	32.7
4	28.3
5	25.3
6	23.1
7	21.4
8	20.0
9	18.9

D1, rate of background f1=0.02 sec^{-1}	frequency
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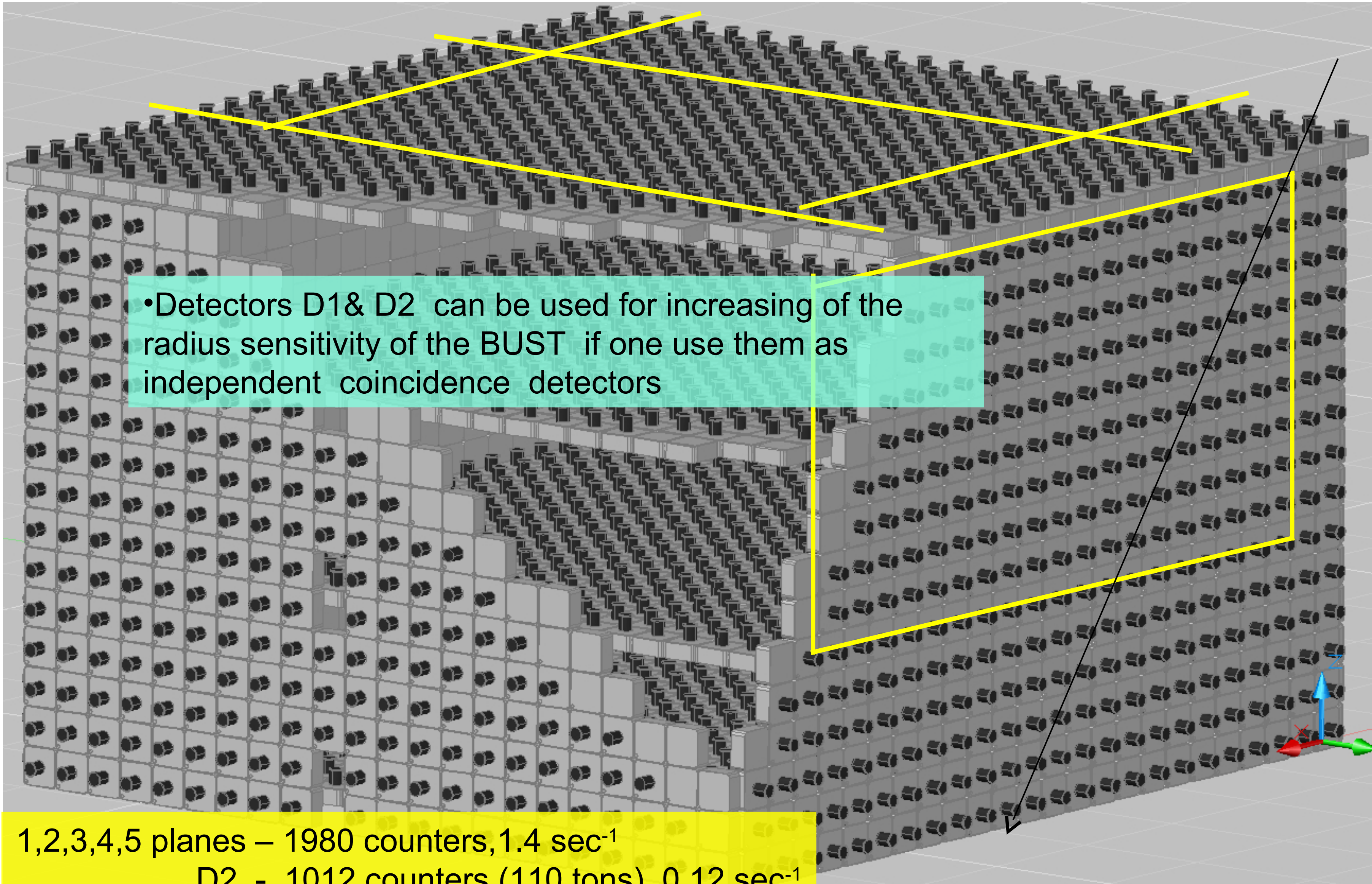
To increase the radius of sensitivity of the BUST in the experiment of registration neutrino bursts from Supernova we have allocated an array of 1012 counters on external planes. This array from 1012 counters (weight of 110 tons) can be used as the second independent detector for registration neutrino events (Detector D2).

$$R'_{SN} = \sqrt{\frac{M1 + M2}{M1}} \times R_{SN}$$



- Detectors D1& D2 can be used for increasing of the radius sensitivity of the BUST if one use them as independent coincidence detectors

1,2,3,4,5 planes – 1980 counters,1.4 sec^{-1}

D2 - 1012 counters (110 tons) ,0.12 sec^{-1}

The algorithm of event selection - a candidate for neutrino burst:

1.Registration in detector D1 in the sliding 20-sec window a cluster with large multiplicity $k1_v$.
2. It is checked the 10-sec window in detector D2.
The beginning of the 10-sec window in D2 coincides with the beginning of cluster in D1, duration is reduced in 2 times (20 sec:2) to reduce number of the background events

Estimation of number of neutrino events in D2:
the relation of weights 110/130 = 0.846
If an average value $k1_v$=6 in D1,
an average value of neutrino events in D2 $k2_v$ = 6*0.846***0.8** = 4.06.

Event from background in D2 - 0.12*10= 1.2 event → $k2_{v+b} = k2_v + 1.2 = 5.25$
D1, $k1_v$=6 → D2, $k2_{v+b}$ = 5 or 6

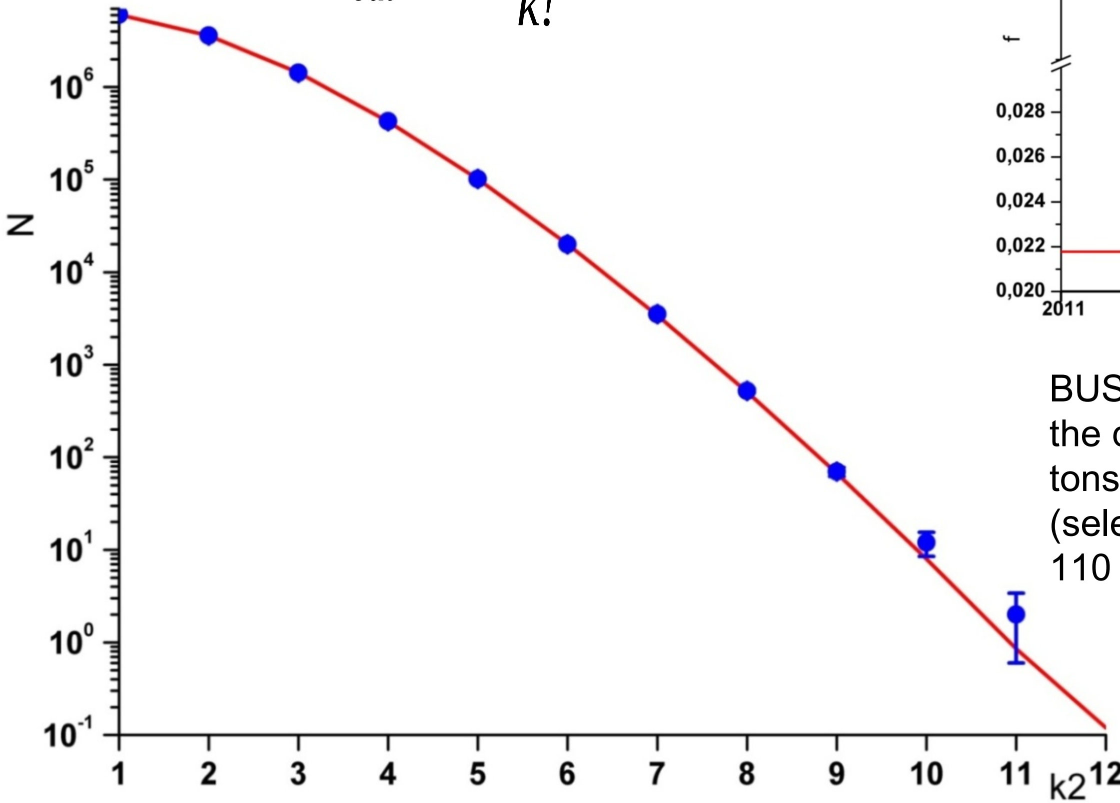
$f1= 0.02\ sec^{-1}$, $f2=0.123\ sec^{-1}$, T=1 year

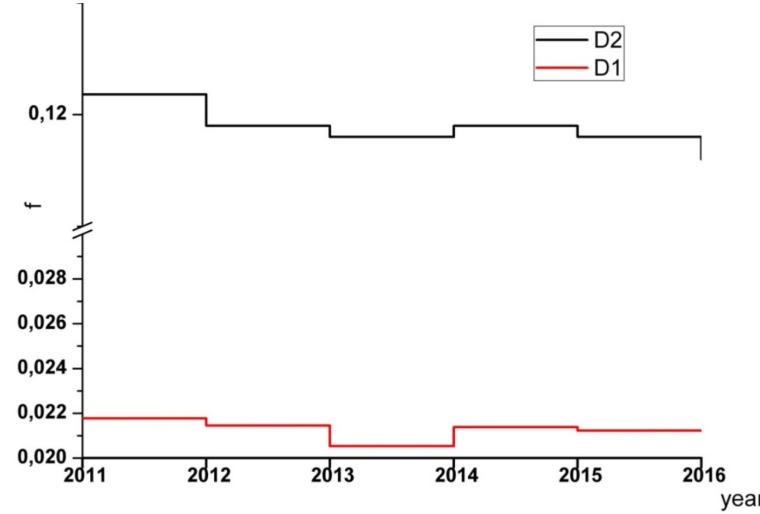
Clusters - imitation by background
Detectors D1 and D2 are completely independent.
Then probability of imitation by background such event, when D1 with cluster k1, and D2- cluster k2, is equal to product of probabilities of occurrence clusters k1 and k2 detectors D1 and D2 accordingly.

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

D1 \ D2	k2=5	k2=6
k1=5	3,121	0,641
k1=6	0,250	0,051
k1=7	0,017	0,003
k1=8	0,001	0,000

$$p(k) = \exp(-f_{out}\tau)\frac{(f_{out}\tau)^k}{k!} \qquad (P)$$





BUST, 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, 110 tons)

Distribution of 10-sec clusters in D2 on multiplicity k2, (the clusters follow each other and do not overlap)

● - experimental data, the detector D2; the curve is the expected number according to the expression (P) , actual T = 5.3 yr (2011 – 2016 years)

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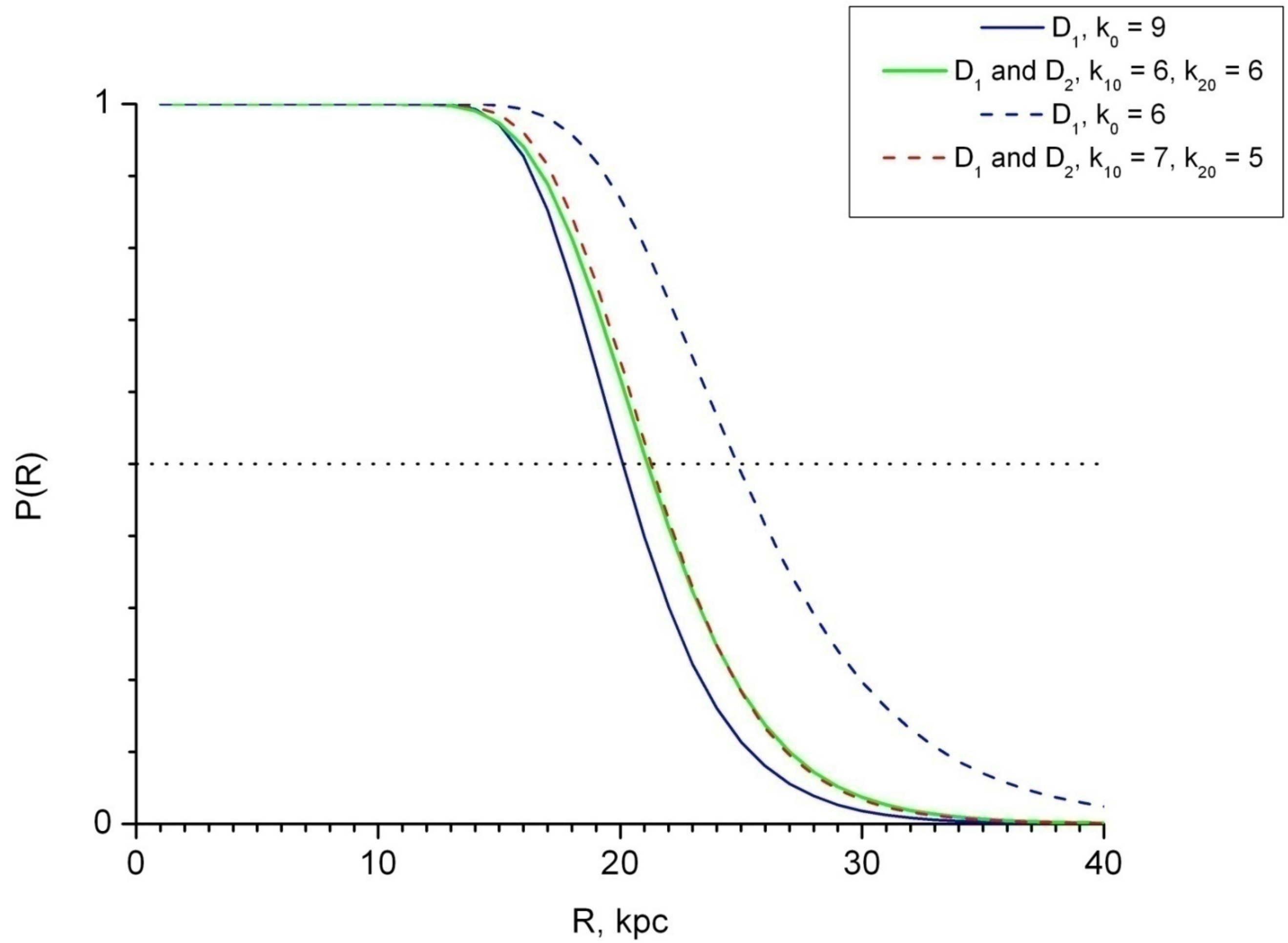
N1= 3561976 events
N2=19904427 events

D1 / D2	k1=4 ,N=27513		k1=5,N=2960		k1=6,N=249		k1=7, N=15	
	exp	calc	exp	calc	exp	calc	exp	calc
k2=2	5815	5302	595	530	53	42	3	3
k2=3	2325	2179	239	218	30	17	1	1,2
k2=4	742	672	77	67	7	5,4	2	0,4
k2=5	186	166	15	17	2	1,3	0	0,1
k2=6	27	34	9	3,5	0	0,3	0	0,02
k2=7	5	6	1	0,6	0	0,05		

In the table experimental data for 2011-2016 years are resulted:
number of clusters with k1 in D1 which are accompanied by not less than two events in D2; the calculation number of events for T=5.3 yr is shown.



Detection probability of clusters from neutrino burst with different multiplicity

CONCLUSIONS

- We have shown a long-term stability of the BUST operation.
- To increase the sensitivity radius of the BUST, we use two independent detectors D1 (the inside) and D2 (the outside) and carried out a search for clusters in both parts of the facility – 1200 counters (130 t) and 1012 counters (110 t).
- The radius of sensitivity of the BUST (the target 240 tons) is ≈24 kpc - in using mean value of number of neutrino events, ≈21,5 kpc - in using detection probability of clusters from neutrino burst with definite multiplicity.

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
2014	29,8	0,077/yr
31.12.2016	31,3	0,074/yr

- No burst candidate for the core collapse has been detected during the observation period of June 30, 1980, to December 31, 2016. The actual observation time is 31.27 years. This is the longest observation time of our Galaxy with neutrinos in the same facility.

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

$f_{col} < 0.074\ year^{-1}$ (90% C.L.)