The Baikal-GVD neutrino telescope: search for cascade events

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on behalf of the Baikal collaboration,

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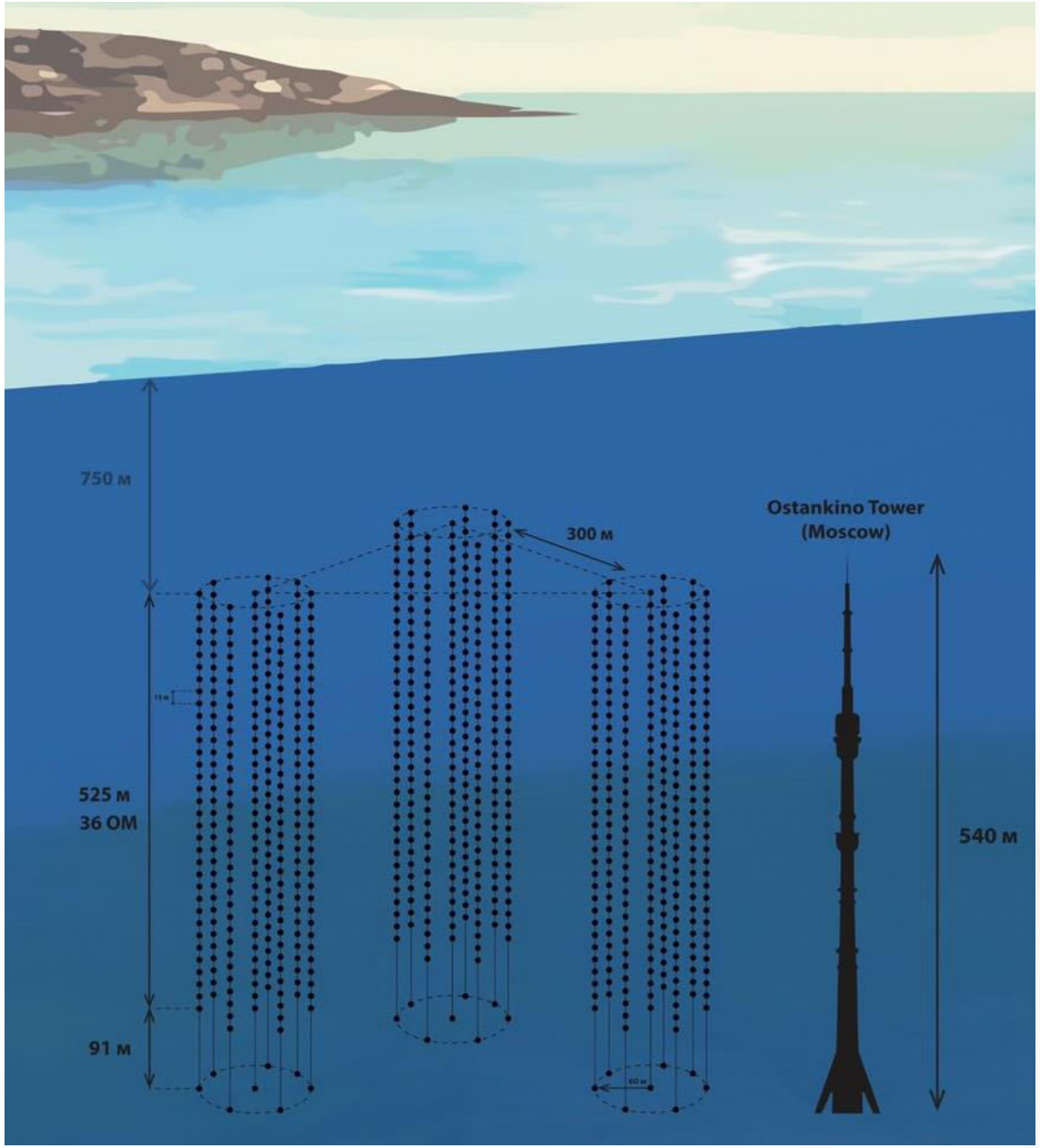
Comenius University, Bratislava, Slovakia

Collaboration: 9 institutions

1. Institute for Nuclear Research, Moscow, Russia.
2. Joint Institute for Nuclear Research, Dubna, Russia.
3. Irkutsk State University, Irkutsk, Russia.
4. Skobeltsyn Institute of Nuclear Physics MSU, Moscow, Russia.
5. Nizhny Novgorod State Technical University, Russia.
6. St.Petersburg State Marine University, Russia.
7. EvoLogics Gmbh., Berlin, Germany.
8. ITEP, Czech Technical University, Prague, Czech Republic.
9. Comenius University, Bratislava, Slovakia.

Status-2018 of the Baikal-GVD project



- Cluster 1 since 2016
- Cluster 2 since 2017
- Cluster 3 since 2018
- Powerful isotropic laser source

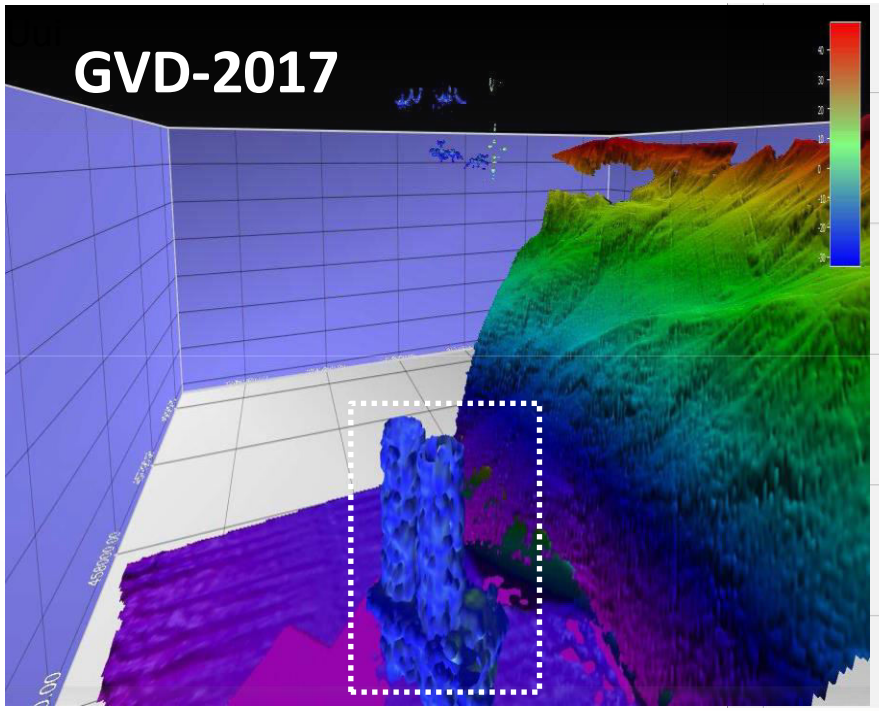
Data transmission

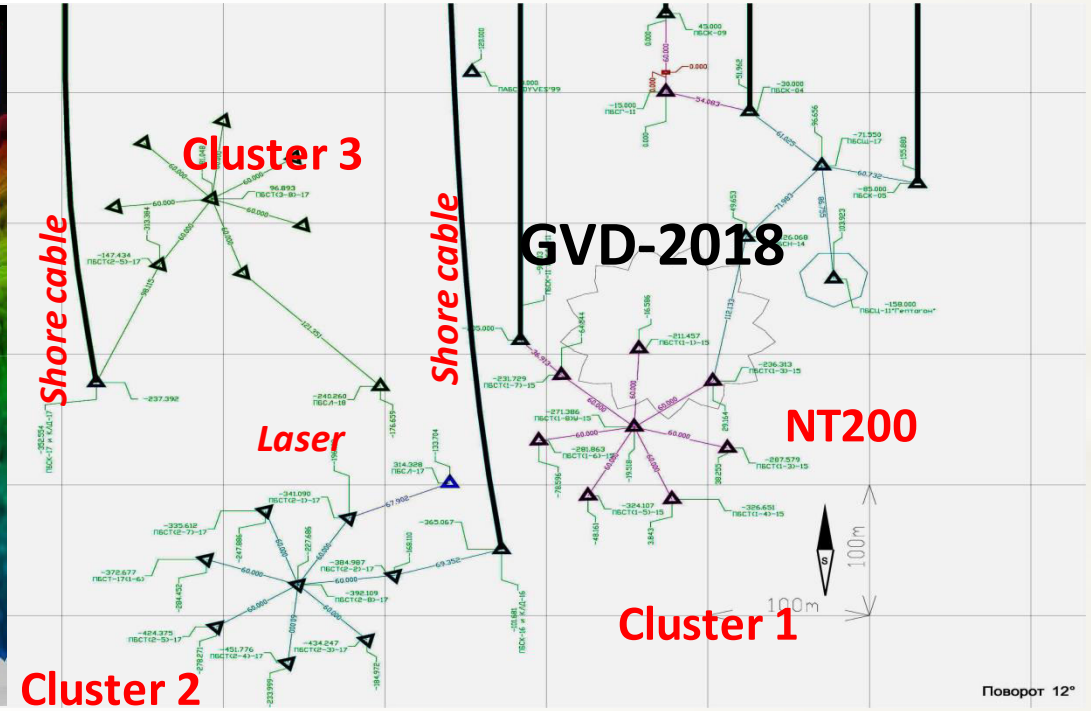
- 40 Gb per cluster per day to shore
- 5 Mb/s 40 km radio channel to Baikalsk
- Raw data transferred to storage in Dubna facility through internet

For recent - 2019
see talk by F. Šimkovic
July 29, 14:00 - NU7c

Stages of the deployment of the GVD-1

Configuration	2016	2017	2018	2019
The number of OMs	288 (8str×36)	576	864	1 440
Geometric sizes	∅120m×525m	2×∅120m×525m	3×∅120m×525m	5×∅120m×525m
Eff. Vol. (E > 100TeV)	0.05 km^3	0.1 km^3	0.15 km^3	0.25 km^3





(image: echo location from boat, bathymetry)

Data analysis is based on reconstruction of cascade parameters and applying cuts on observables

Reconstruction of cascade position

$$\chi_t^2 = \frac{1}{N_{hit}-4}\sum_{i=1}^{N_{hit}}\frac{\left(T_i\left(\vec{r}_{sh},t_0\right)-t_i\right)^2}{\sigma_{ti}^2}$$

Iterative procedure - OMs with residual δt > 15 ns are excluded and reconstruction is repeated

$\chi_t^2 < 2 \div 5$

Reconstruction of cascade direction and energy

$$L_A = -\sum_{i=1}^{N_{hit}} \ln P_i\left(A_i, E_{sh}, \vec{\Omega}_{sh}(\vartheta,\varphi)\right),$$

$L_a < 10 \div 20$

where P_i is calculated with respect of tabulated $n_{pe}(\rho,z,\theta,\varphi,\tau)$

$$P_i = \sum P\left(n/\bar{n}\right)\int_{A_i-\alpha/2}^{A_i+\alpha/2}\xi_i\left(A,n\right)dA, \qquad \bar{n} = 10^8 \times \left(E/TeV\right) n_{pe}\left(\rho,z,\vartheta,\varphi,\tau\right)$$

Analysis strategy:

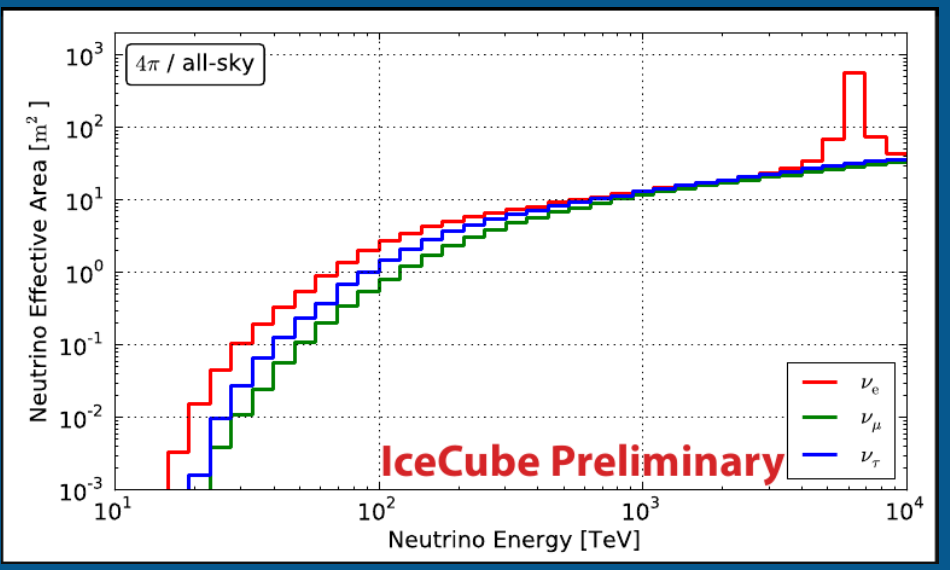
- Pre-selection of hits – rejection of noise hits: causality cuts, stronger trigger conditions
- Reconstruction of cascade vertex: cuts on χ_t^2, OMs residual times, allowed values of reconstructed coordinates
- Energy and direction reconstruction: cut on L_a, analysis of **hit/nonhit probability**, cut on a value of reconstructed energy and hit OMs multiplicity

$$\eta = l_{\max}^{100} - l^{ev} > 0,$$

$$l^{ev} = -\left(\sum_{i=1}^{N_{hit}} \ln P_i^+ + \sum_{j}^{N_{tot}-N_{hit}} \ln(1 - P_j^+) \right)$$

P^+ – OM hit probability

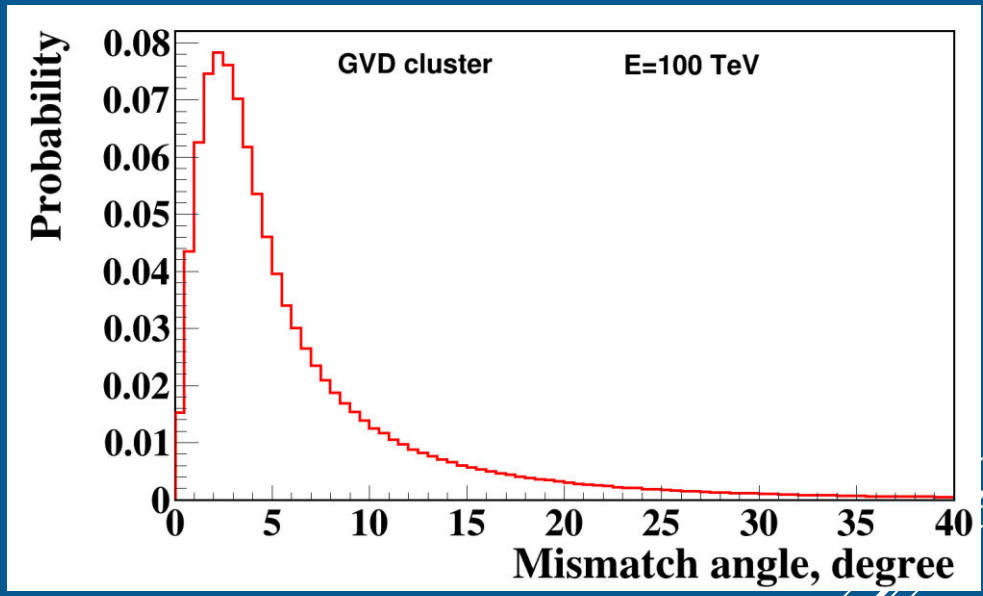
Neutrino Effective Area
IceCube HESE



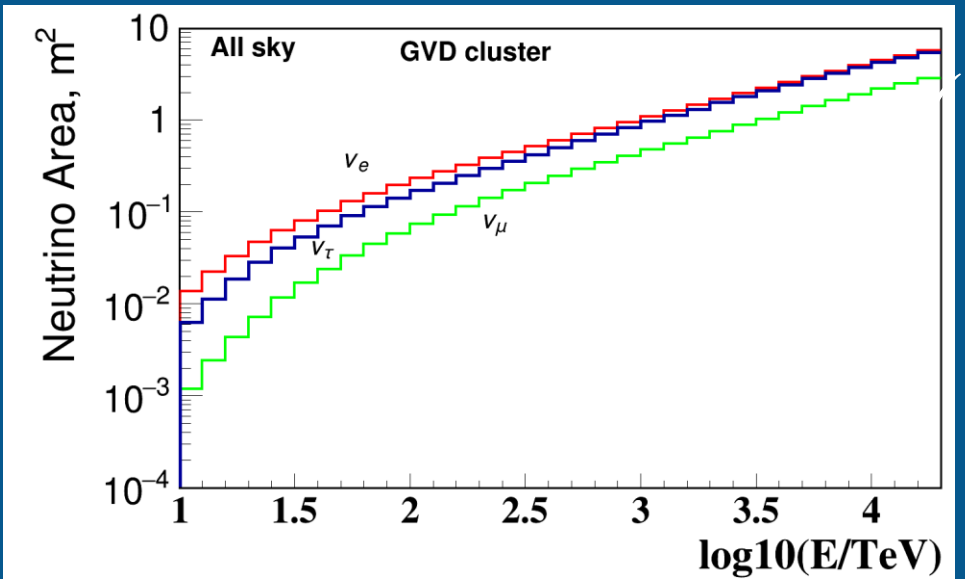
Directional resolution for cascades:

~ 3°- 4° - median value of mismatch angles

Distribution of mismatch angles



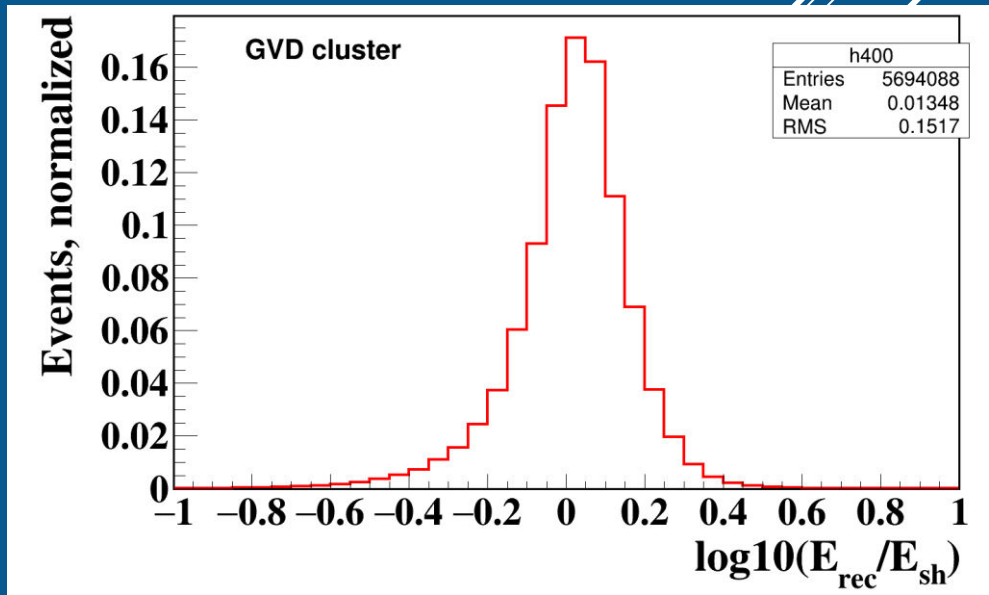
Baseline GVD Cluster S_{cl} ~ (0.05 - 0.1) S_{IC}



Energy resolution :

$\delta E/E$ ~ 30%

averaged by E^{-2} ν_e spectrum



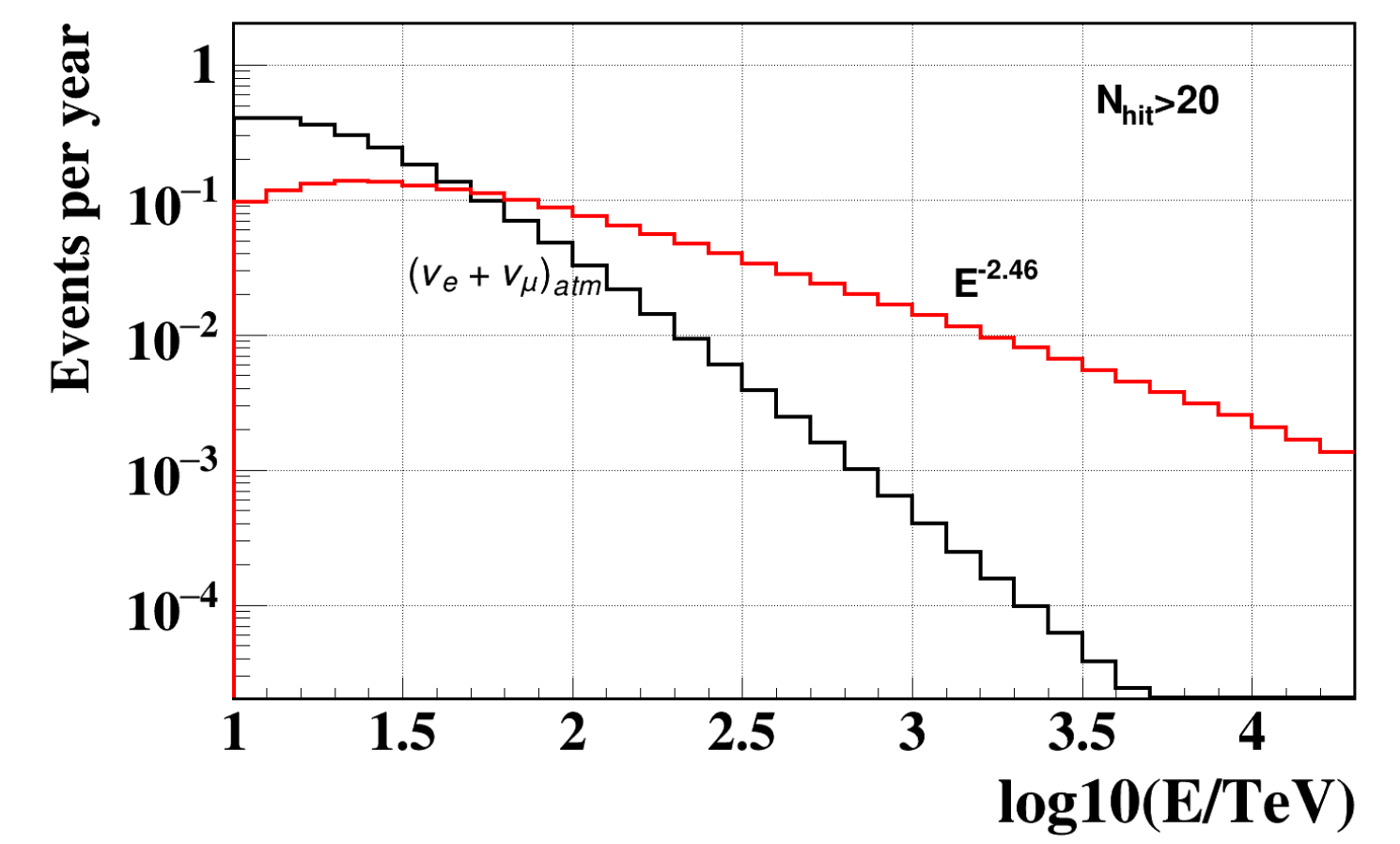
Energy spectrum of astrophysical neutrinos measured by IceCube:

$4.1 \cdot 10^{-6}\ E^{-2.46}\ GeV^{-1}\ cm^{-2}\ s^{-1}\ sr^{-1}$

Event selection criteria (E_{sh} >100 TeV, N_{hit} >20):

~0.6 events/yr are expected

Expected number of detected events in GVD Cluster from astrophysical neutrinos for 1 yr. observation



A search for cascades induced in GVD: 2016, 2018 (*Preliminary*)

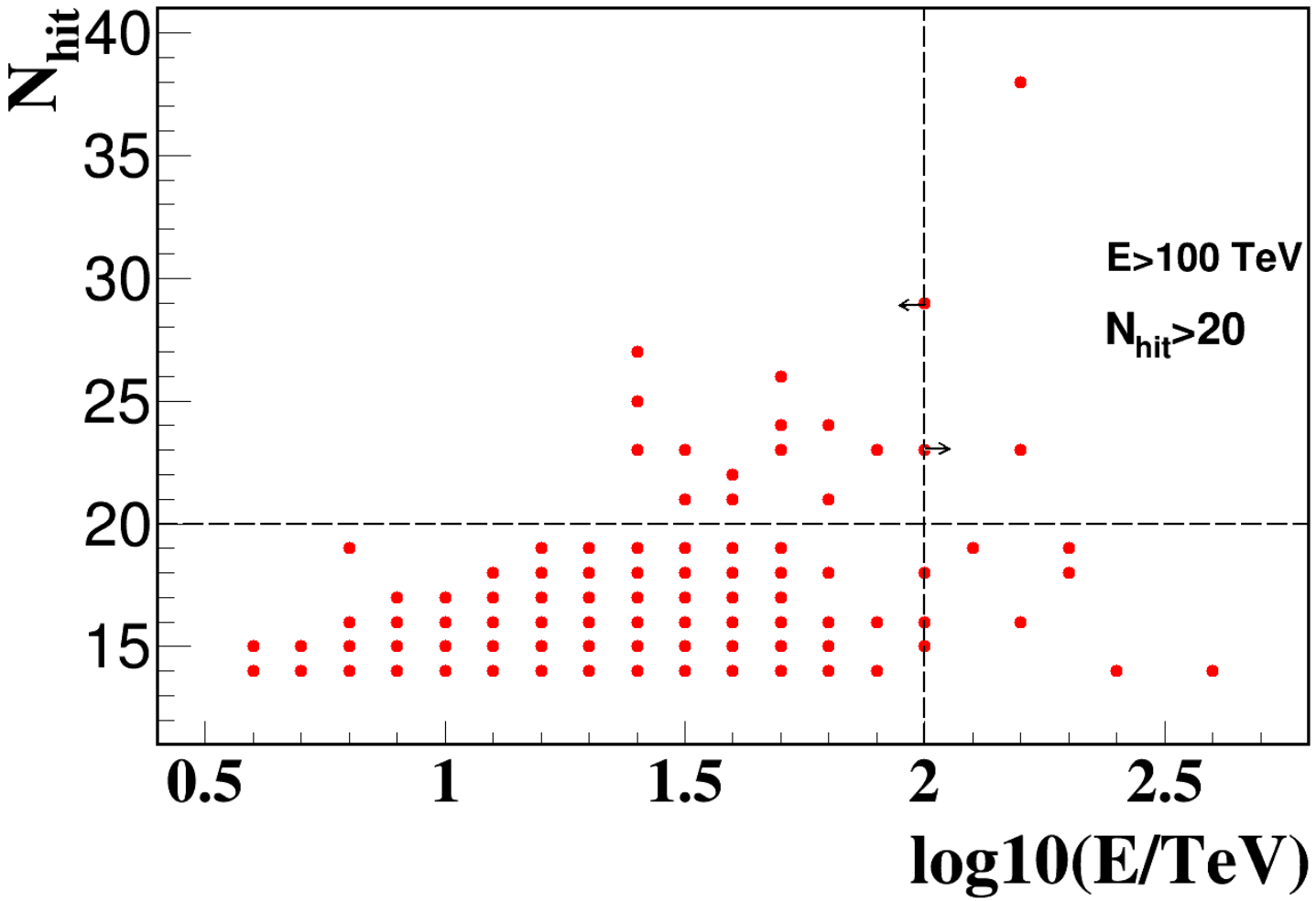
Statistics of data recording in 2016 and 2018

	Number of events	Live time, days
Cluster #1 (2018)	969427196	223
Cluster #2 (2018)	993527274	208
Cluster #3 (2018)	1178496960	259
Cluster #1 (2016)	685523932	182
Total	3826975362	872

For 1 year exposition 0.6 events are expected in one GVD Cluster from astrophysical neutrino flux

In 2016, 2018 data (2.4 year×cluster) the following number of cascade events have been selected:

(N_{hit} > 13 & E > 1 TeV) - 417 events
(N_{hit} > 20 & E > 1 TeV) – 18 events
(N_{hit} > 20 & E > 100 TeV) – 3 events

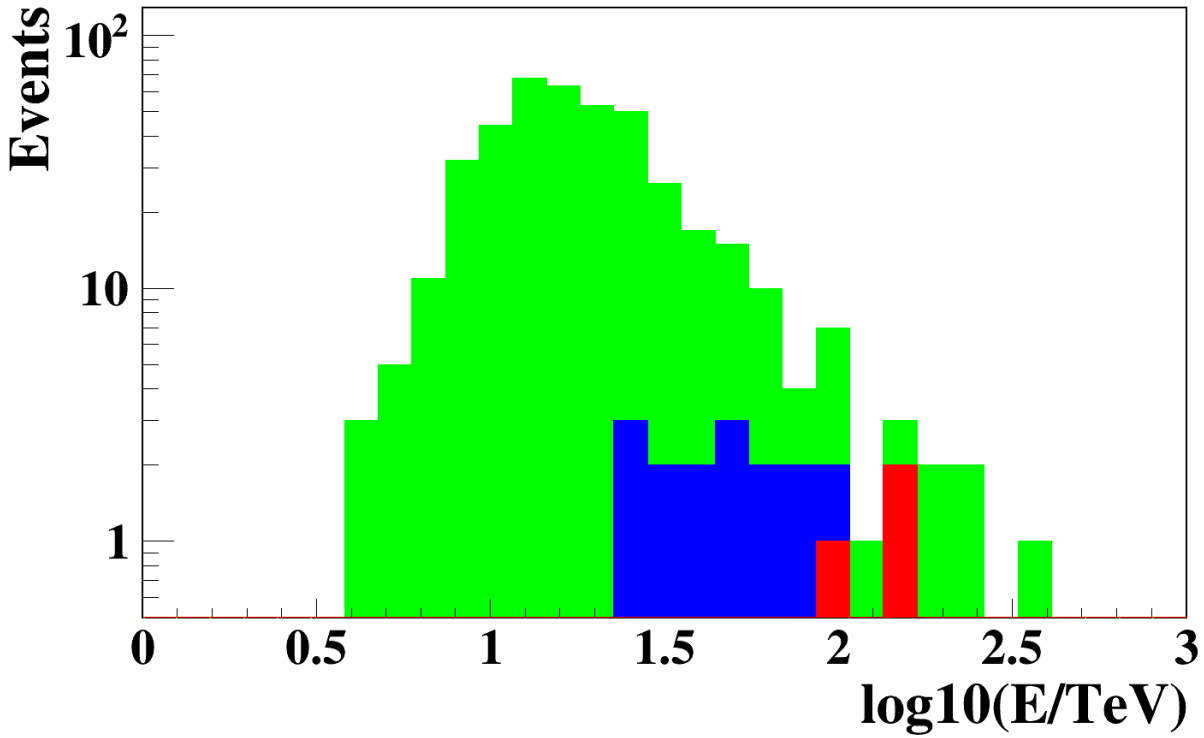


Green - 417 events with N_{hit} >13 & E>1 TeV have been selected

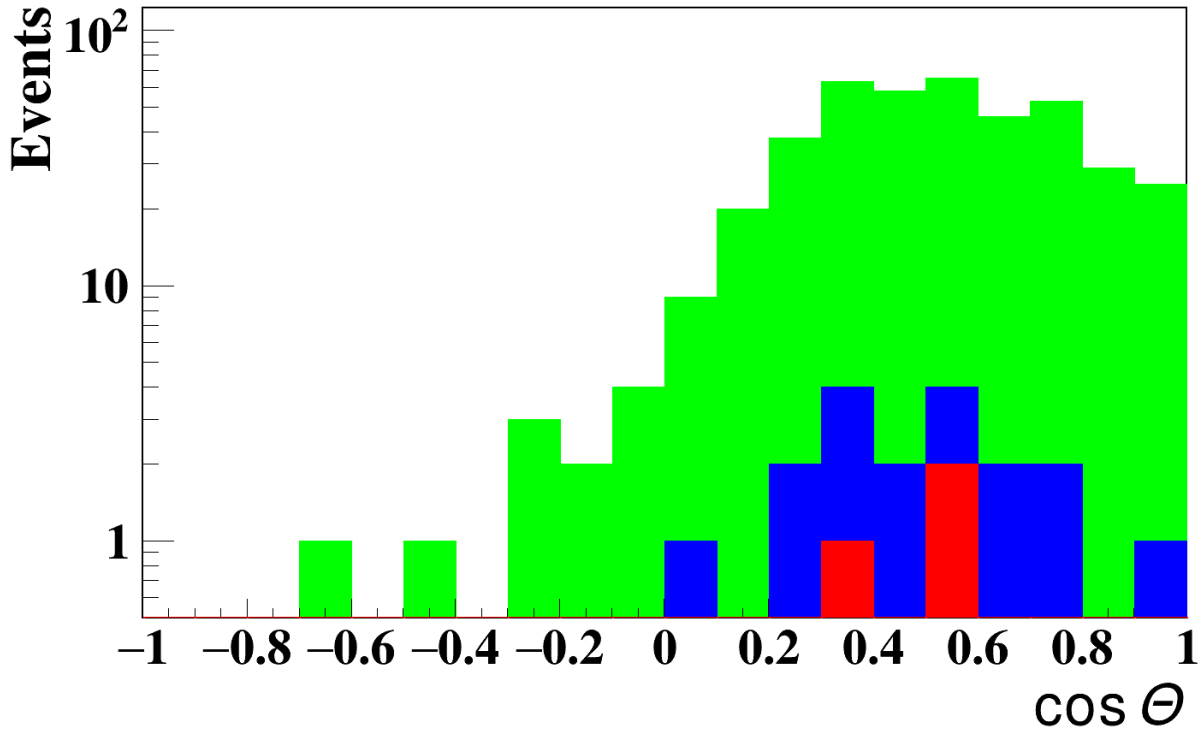
Blue - 18 events with N_{hit} >20

Red - 3 events with N_{hit} >20 & E >100 TeV (1.4 events are expected for 872 life days from astrophys. flux)

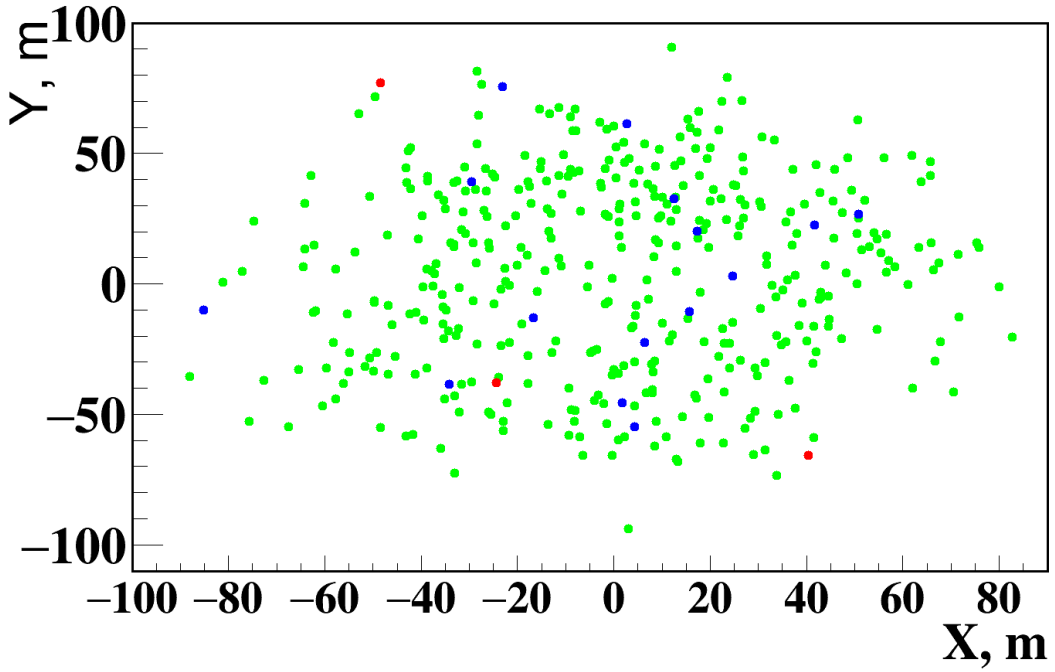
Energy distribution

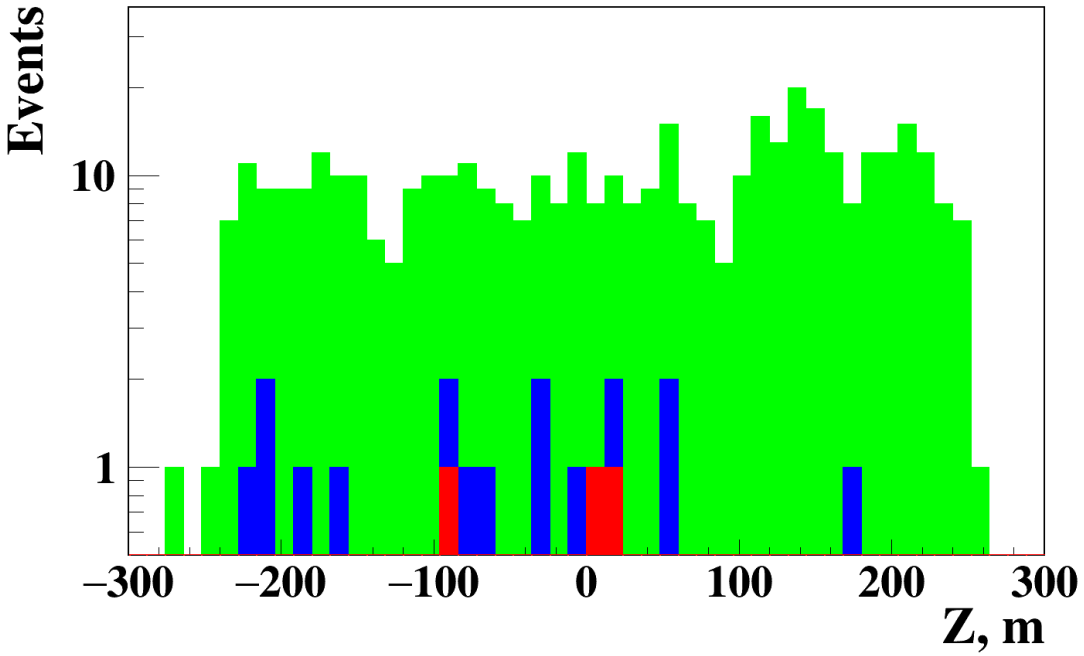


Zenith angle distribution

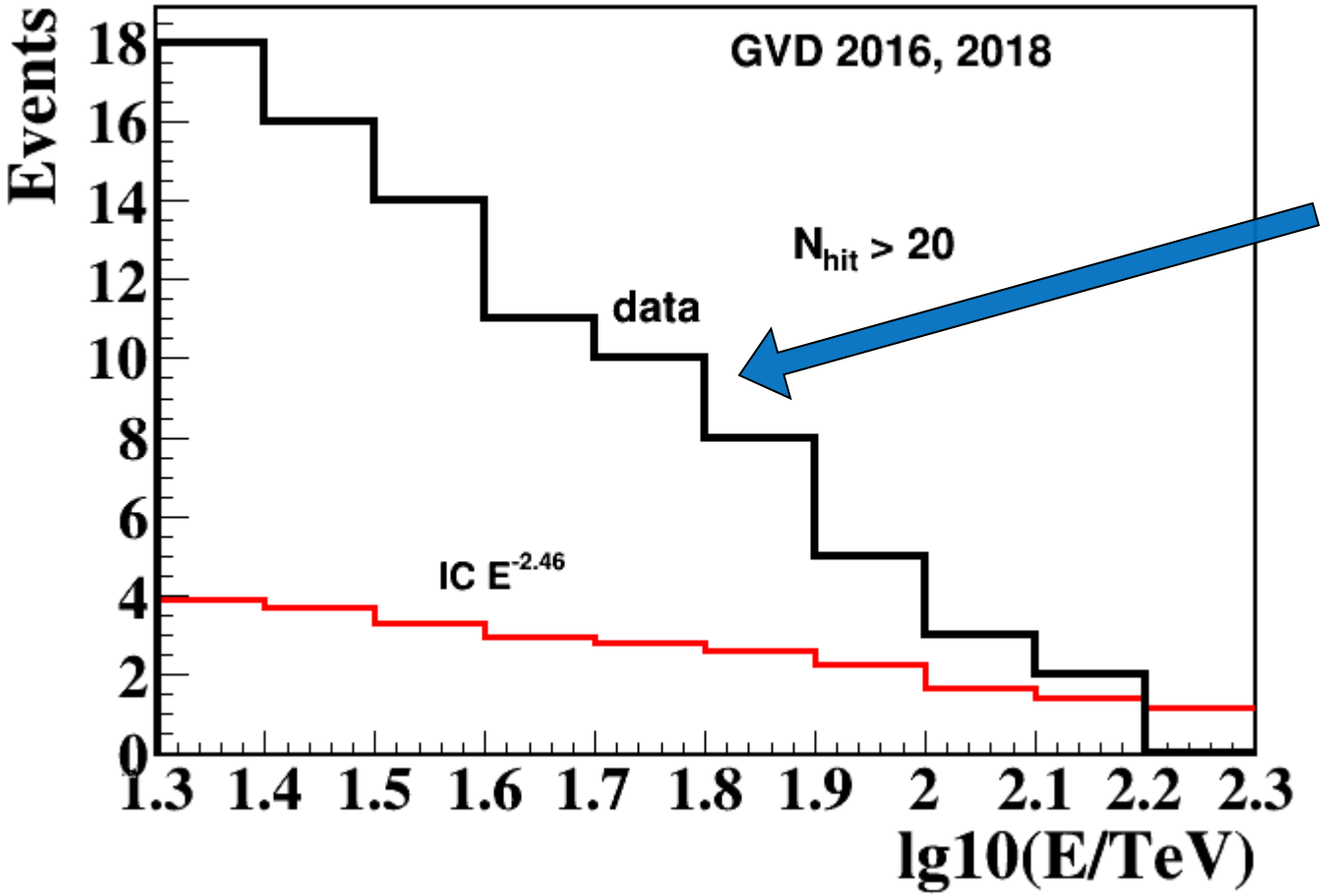


Reconstructed cascades coordinates





Cumulative number of expected astrophysical events and data

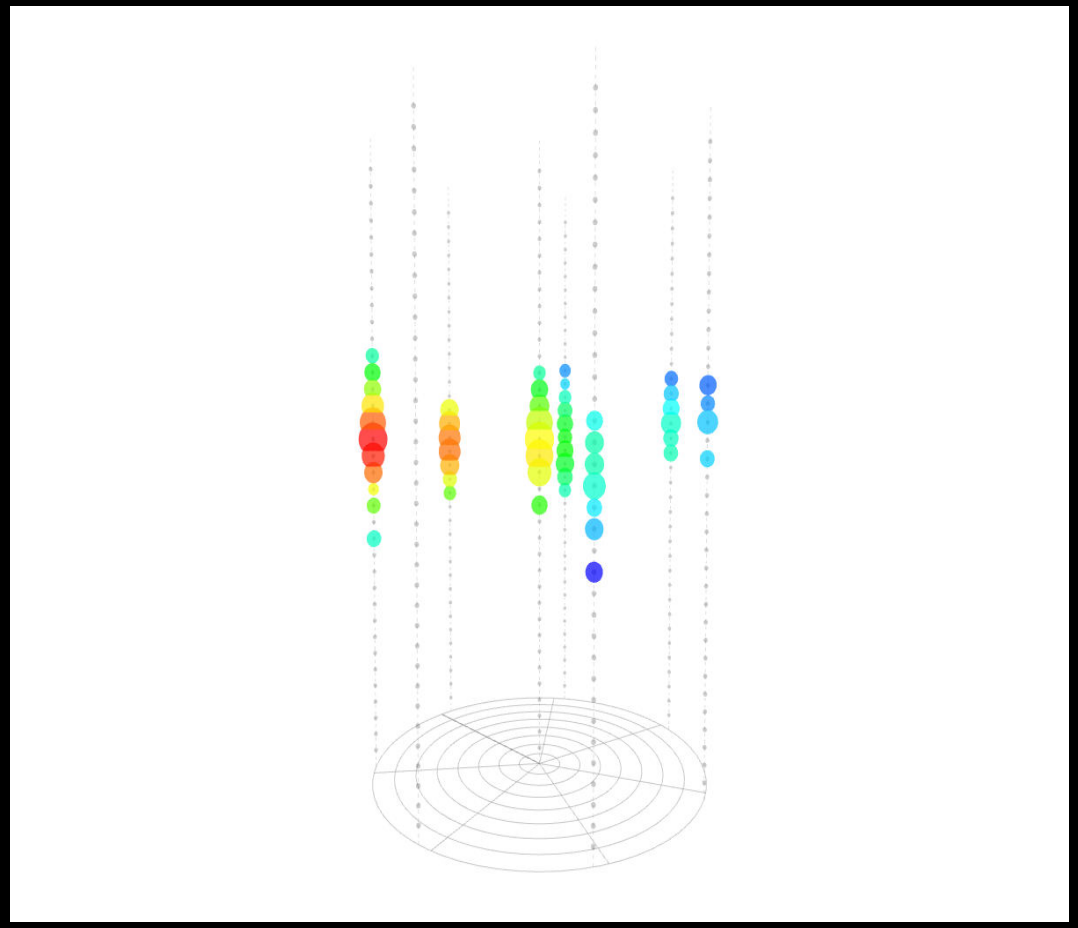


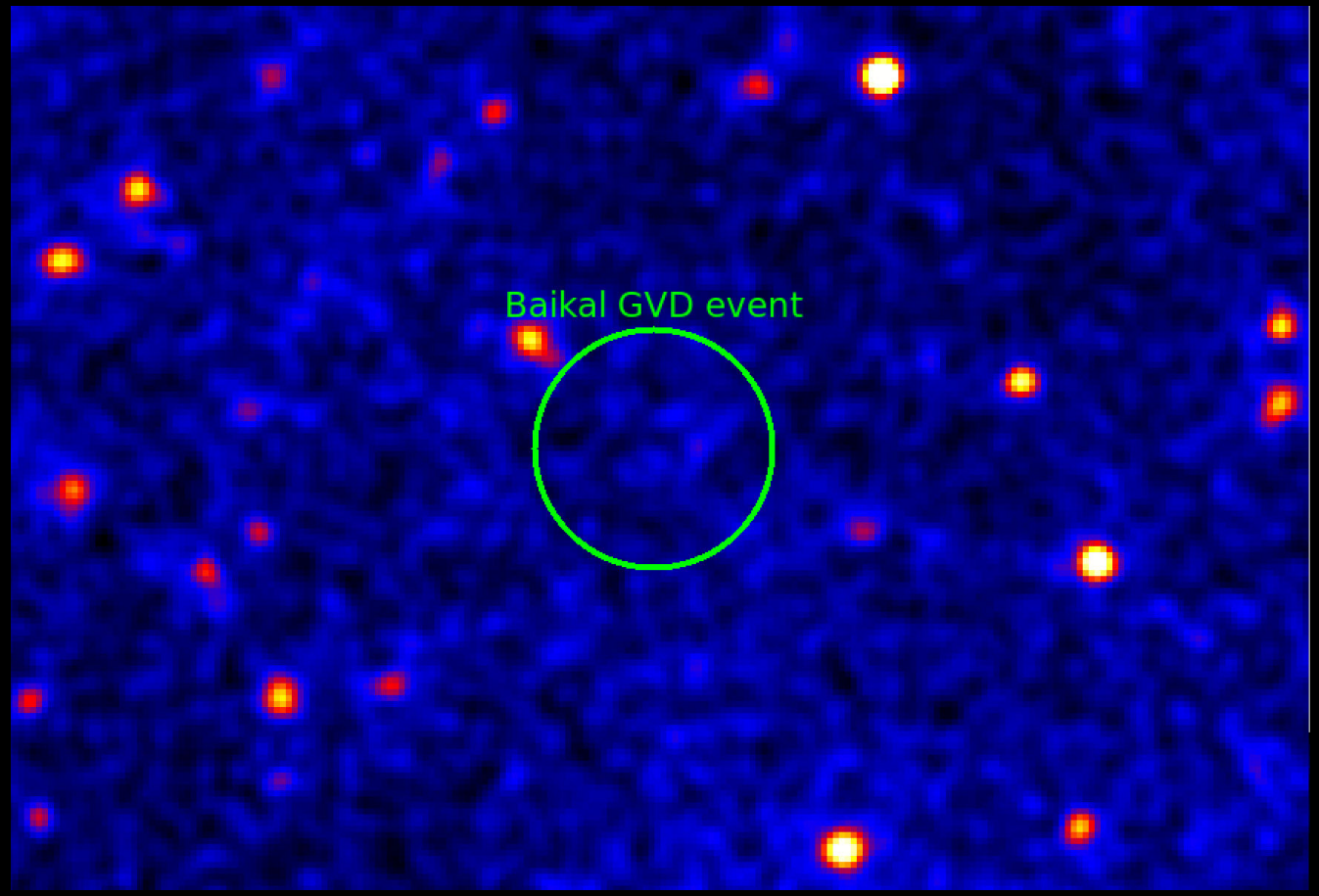
Work in progress:
background from muon bundles
- see talk by L. Fajt
July 31, 16:45 – NU11b

Event 2016: E=157 TeV, θ = 57°, φ = 249°
x=-25m, y=-37m, z=11m, ρ=44m

Selected hits (53 hits)

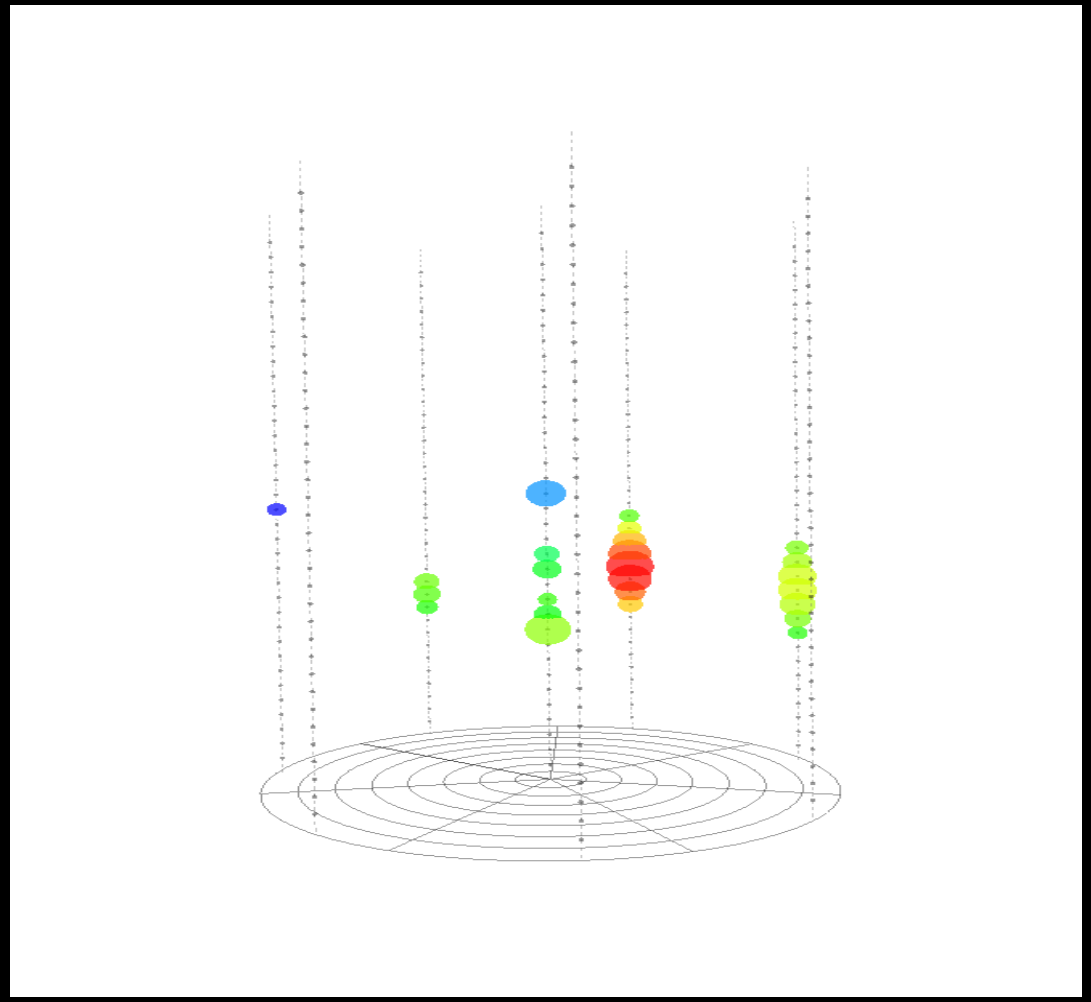
MJD 0.575074357292E+05 RA 173.4° Dec 13.95°

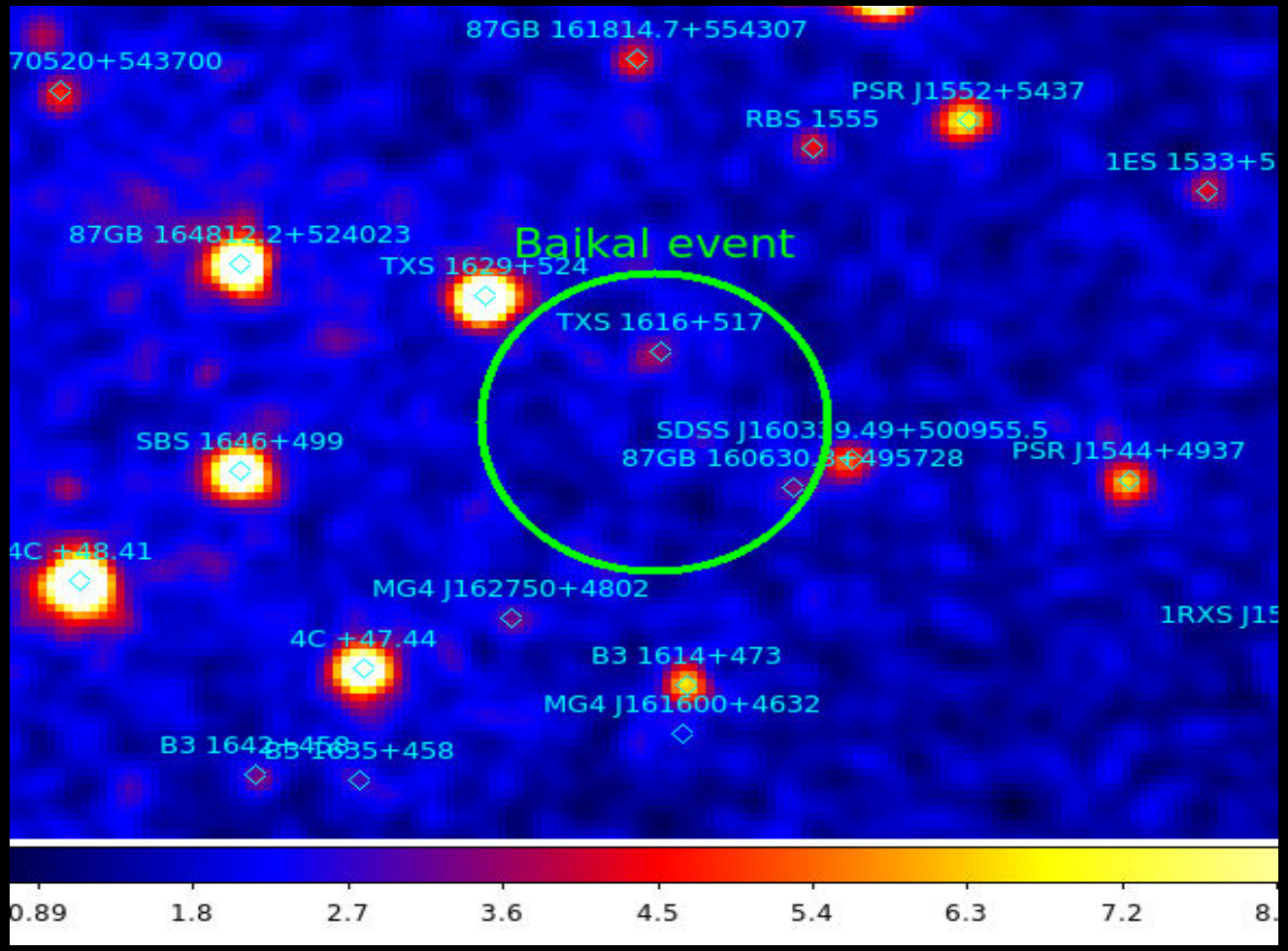




Event 2018: E=153 TeV, θ = 49°, φ = 57°
x=40 m, y=-65 m, z=-94 m, ρ=76 m

Selected hits (25 hits)





Upper limit on diffuse neutrino flux with power low energy spectrum $E^{-2.46}$

Feldman & Cousins approach:

Selection: N_{hit} >20 and E > 100 TeV;

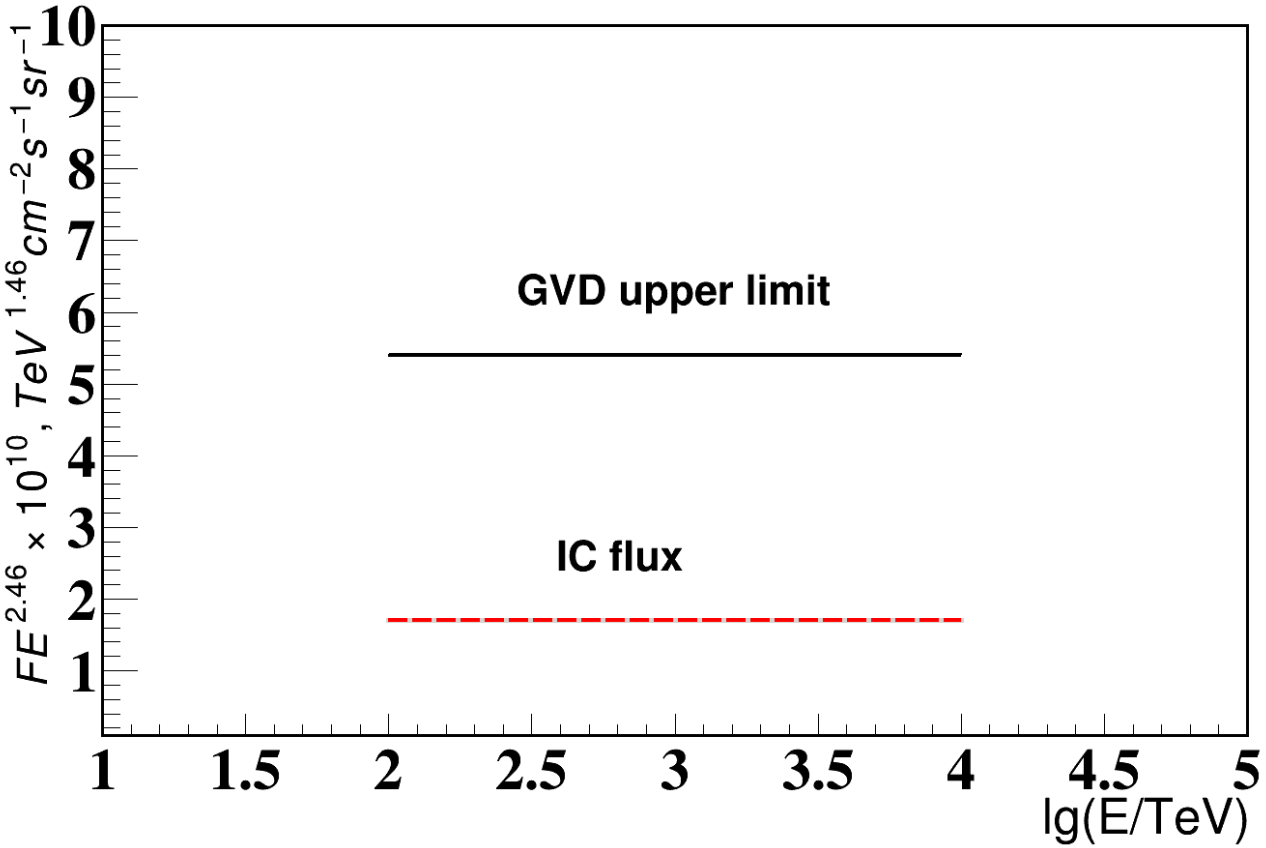
Three events have been selected;

$n_{90\%} = 4.42$ (for $n_{bg} = 3$, most stringent limit) ;

$F_{90\%} = 5.4 \times 10^{-10}$ (TeV cm^2 s sr)$^{-1}$

$F_{IC} = 1.7 \times 10^{-10}$ (TeV cm^2 s sr)$^{-1}$

Upper limit consistent with IC results!



Thank You for your attention

http://baikalgvd.jinr.ru