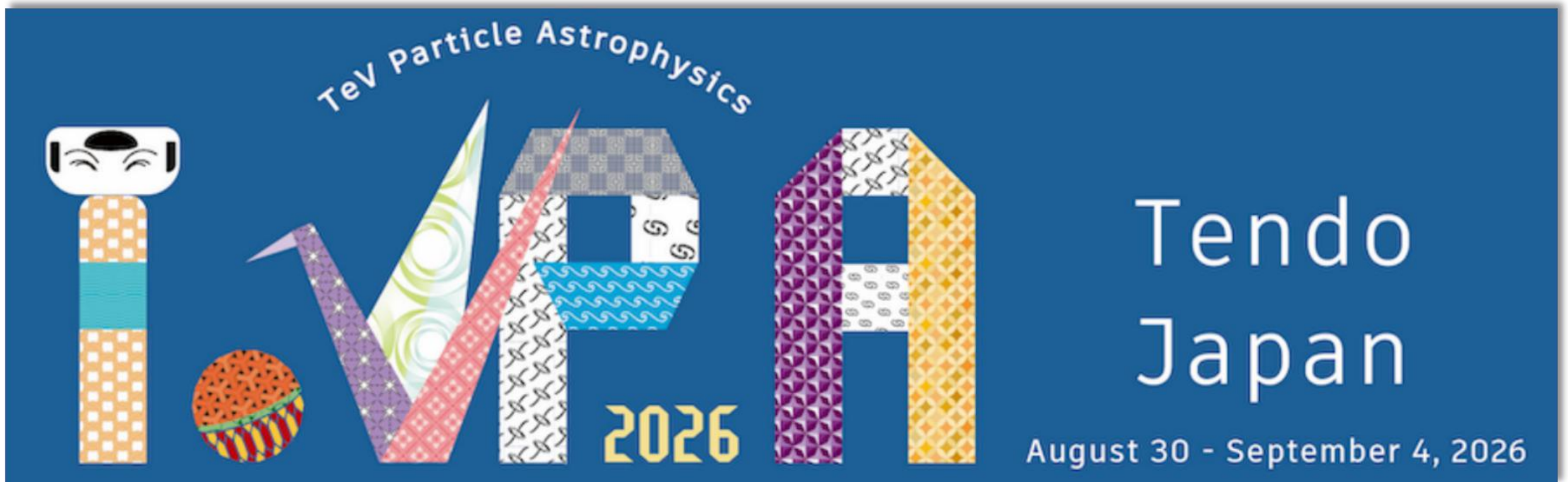
Baikal-GVD

JINR

The Baikal-GVD neutrino telescope: status and recent results

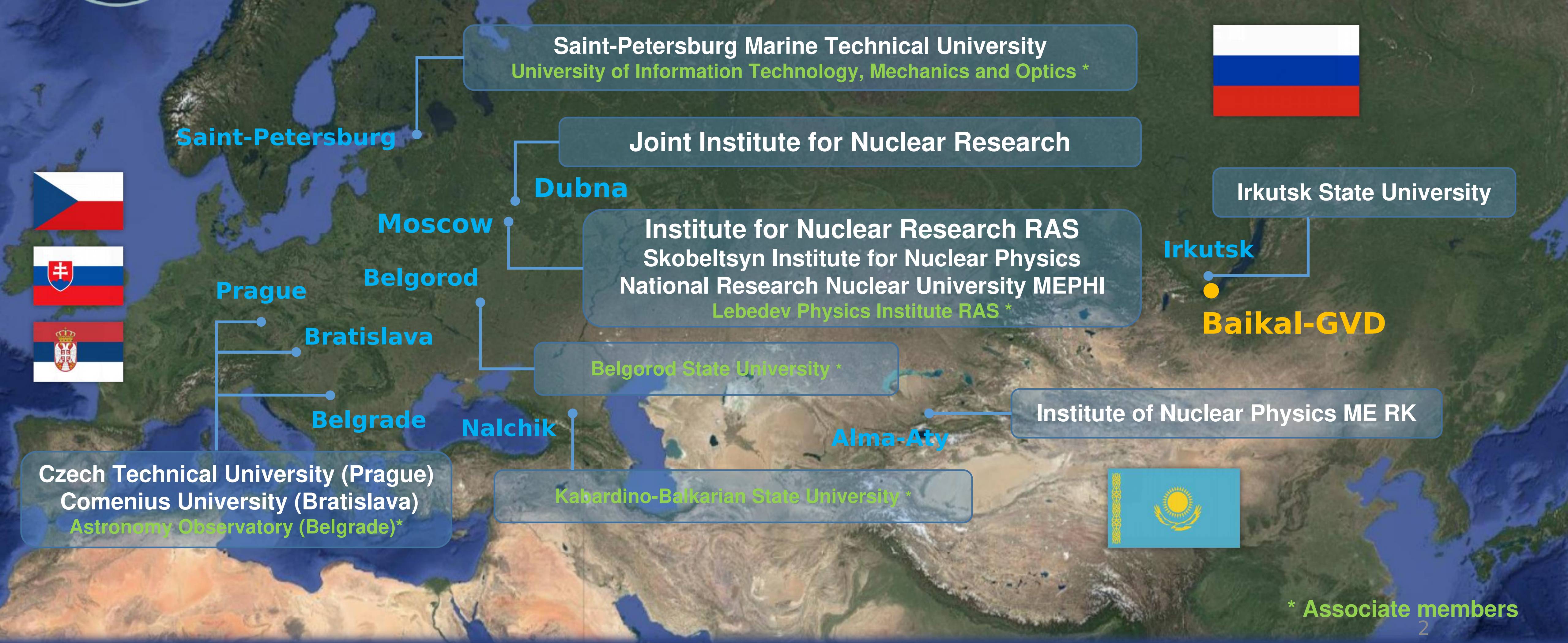
Grigory Safronov (INR RAS, JINR)
for the Baikal-GVD collaboration



The Baikal-GVD experiment

The Baikal-GVD is a 1 km^3 - scale neutrino telescope being built in Lake Baikal

Collaboration consists of 15 institutions and ~85 scientists

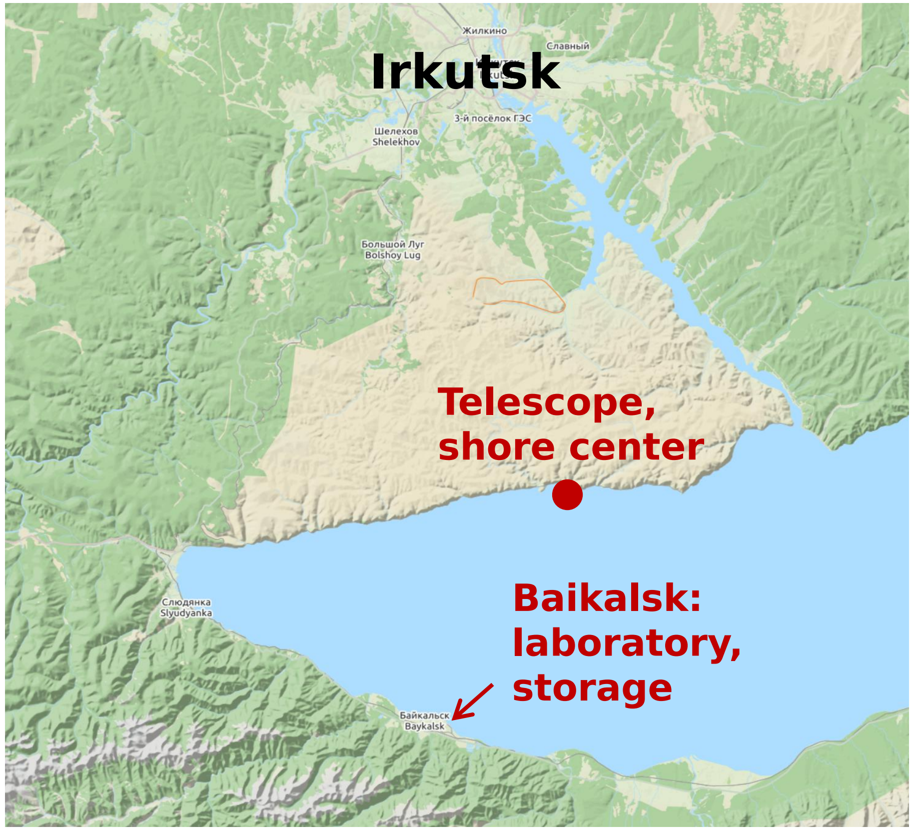


* Associate members

The detector site

Southern part of Lake Baikal

Platform “Ivanovka” of Circum-Baikal railway
Telescope is located 3.6 km away from shore



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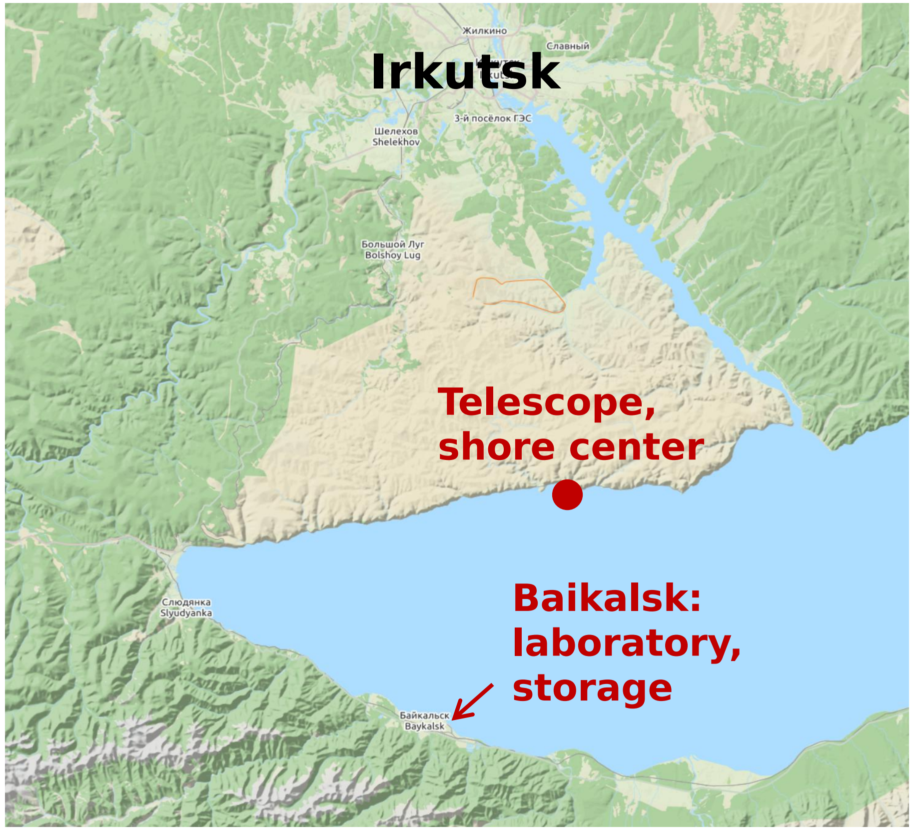
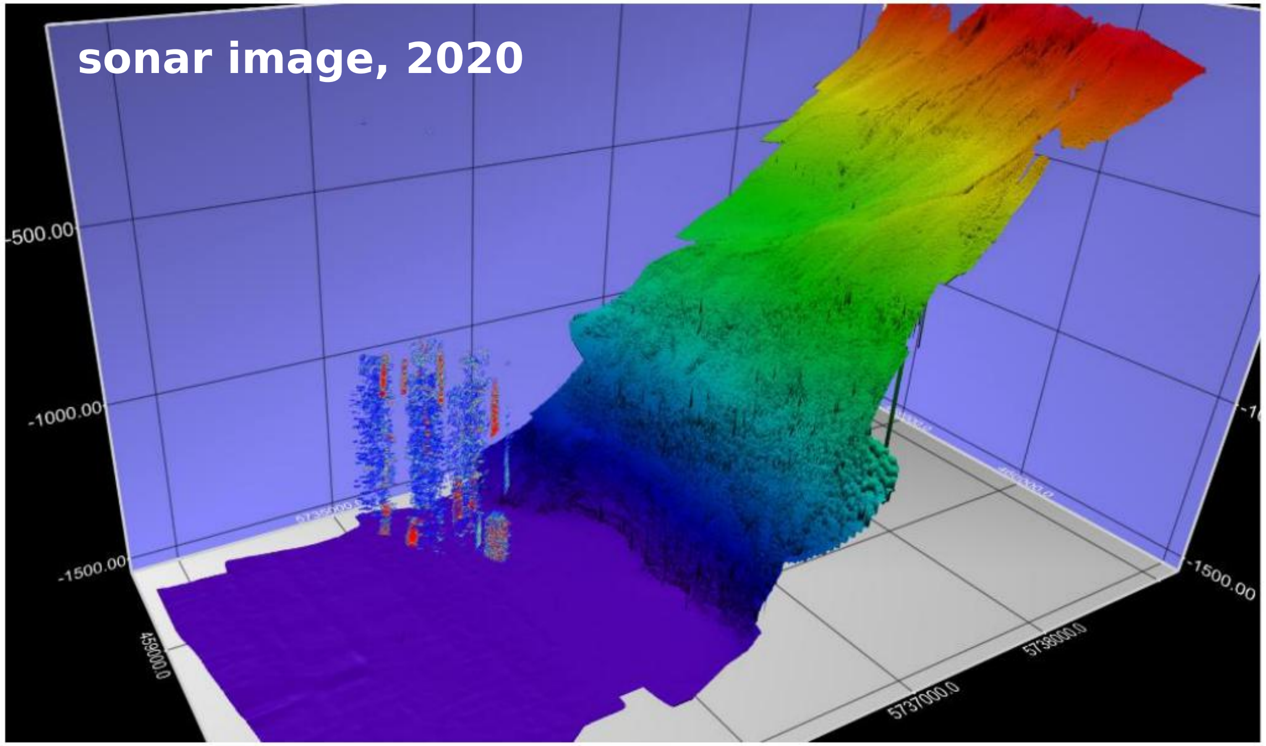


Constant lake depth: ~1360 m

Water transparency:

- Peak absorption length: 22 m
- Scattering length: 60 - 80 m

Stable ice cover over 7 - 8 weeks in February - April:
→ detector deployment and maintenance

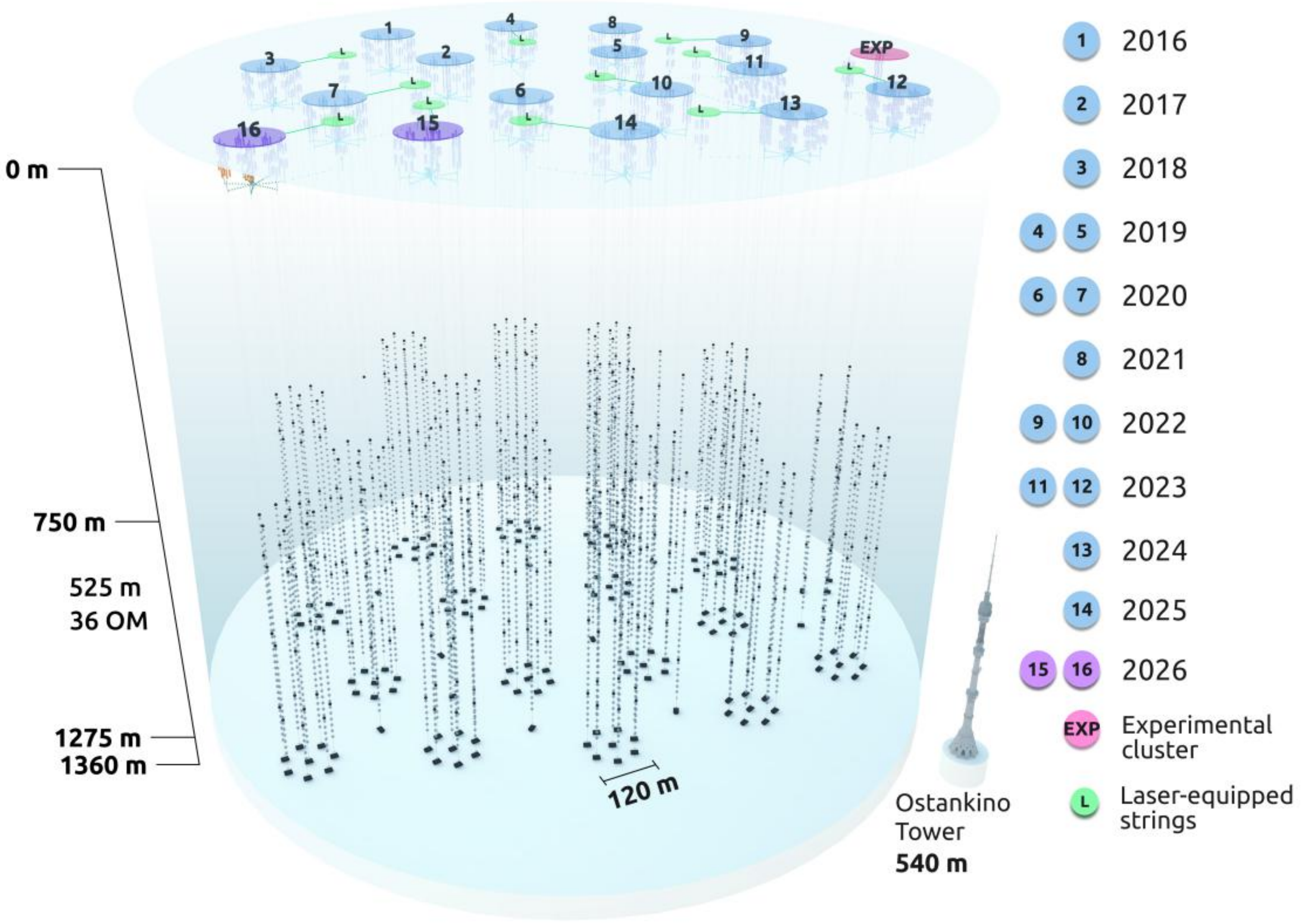


The detector status

After the 2026 deployment campaign:

- 135 vertical strings arranged into 16 independent detectors - **clusters**
- 4896 optical modules (OM) in total
- 0.8 km^3 detection volume (1 PeV cascades)

In the next 2-3 years it is planned to expand the detector to ~1 km^3 detector volume employing ~6000 OMs

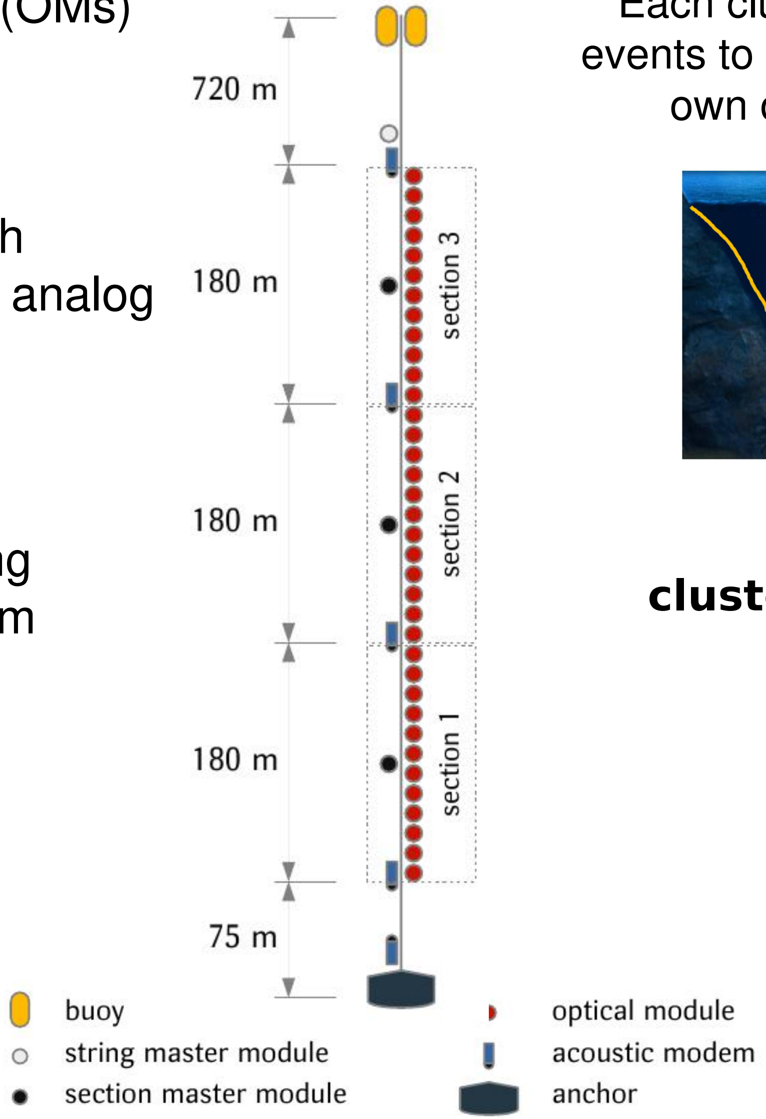


Key components

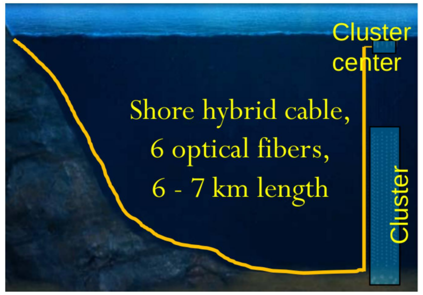
String: carries 36 optical modules (OMs)
- 10-inch high-quant.-eff. PMT
- 15 m vertical spacing
- OM facing the lake bottom
- 3 readout sections, 12 OMs each
- Section master module digitizes analog signals from each of 12 OMs

Positioning system
- Acoustic modems on each string
- OM positioning precision ~20 cm

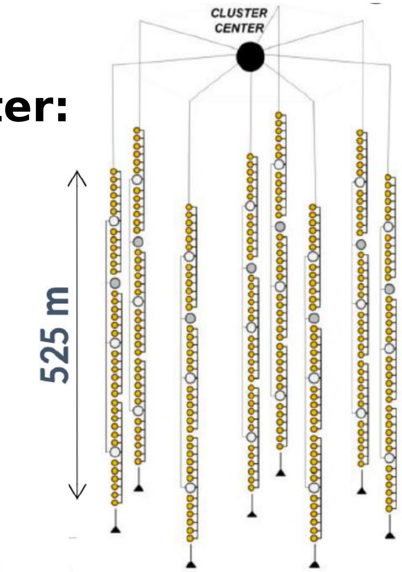
Time calibration systems
- LED in each OM
- LED beacons
- Isotropic lasers between clusters
- Calibration precision ~2 ns



Each cluster sends triggered events to the shore center via its own opto-electric cable



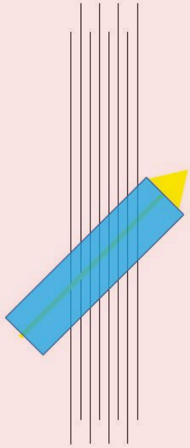
cluster:



Event reconstruction pipelines

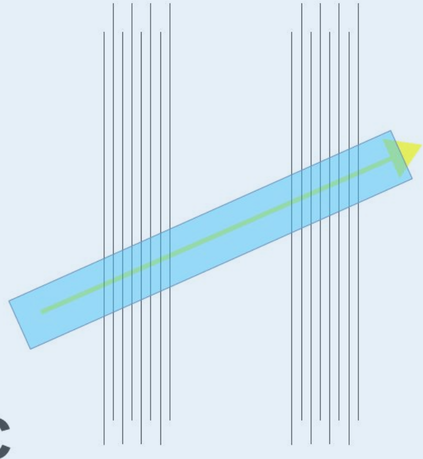
In this report

Single-cluster tracks



- Low energy threshold
- Optimal sensitivity to nearly vertical tracks
- 90% of recorded track events

Multi-cluster tracks



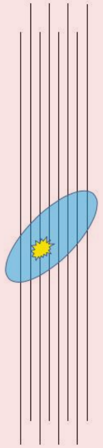
- Moderately low energy threshold
- Optimal sensitivity to inclined tracks
- Best angular resolution

in development

ν_μ CC

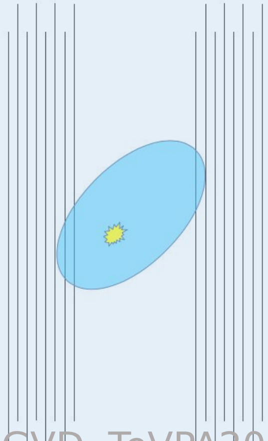
NC, ν_e ν_τ CC

Single-cluster cascades



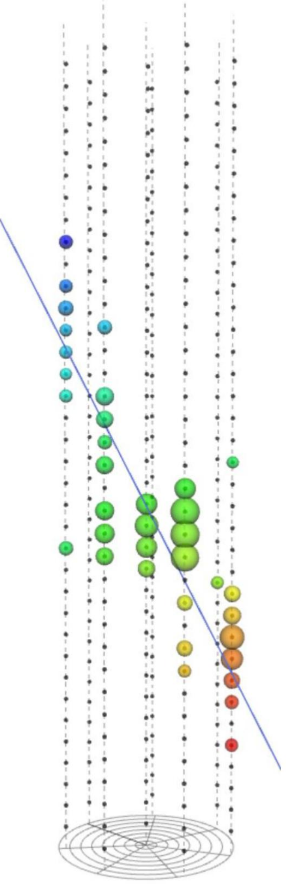
- High energy threshold
- Good energy resolution
- Relatively rare events

Multi-cluster cascades



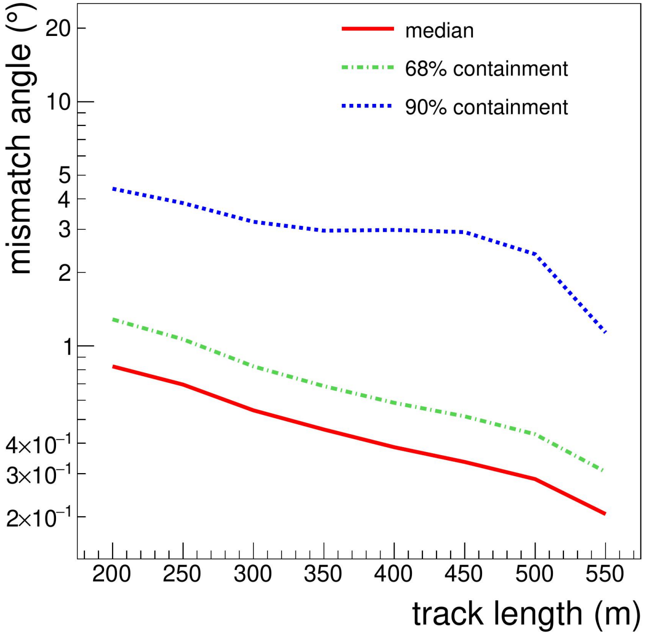
- Very high energy threshold
- Excellent energy resolution
- Very rare events

Single-cluster reconstruction precision

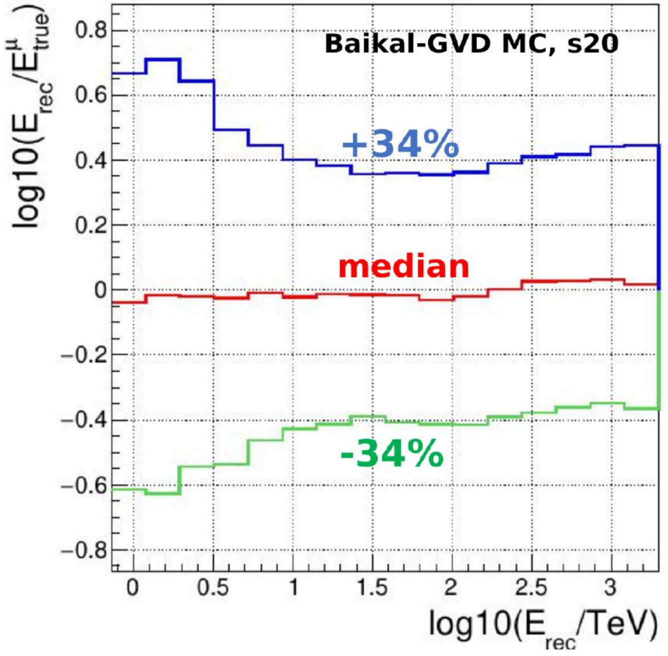


track-like,
data 2019

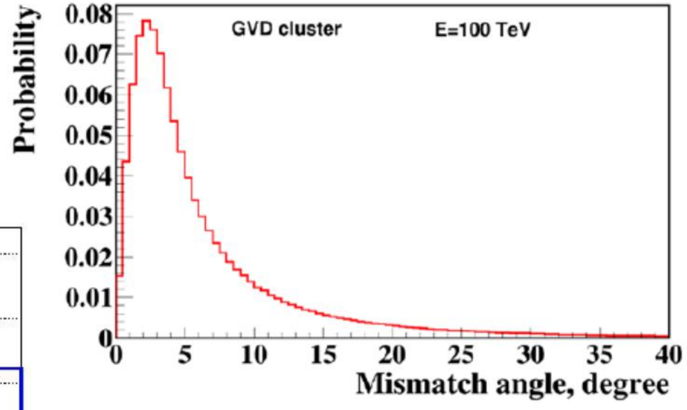
Track angular resolution:
~0.8° - ~0.2° for tracks
longer than 200 m



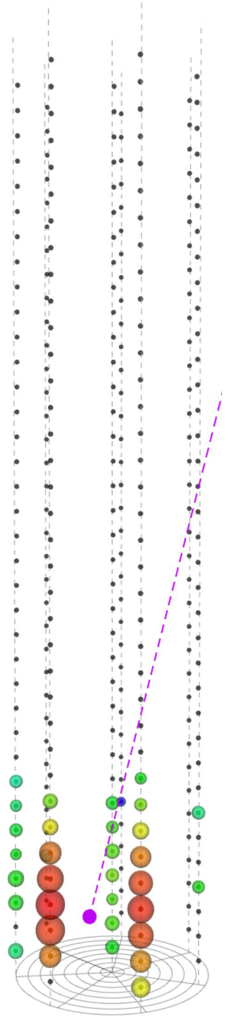
Muon energy resolution:
factor 2.5
for E^{μ} > ~10 TeV



Cascade angular resolution:
~2-5° depending on energy and
cascade location



Cascade energy
resolution 10-20%



cascade-like,
data 2022

Results with cascade events

Diffuse astrophysical neutrino flux

Analysis of the 6-year data, April 2018 - March 2024

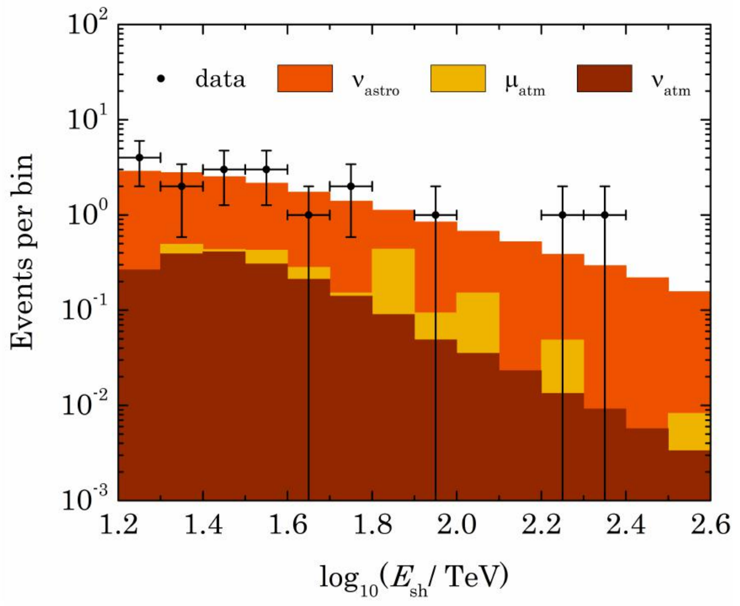
- Upgoing cascade events: lower atmospheric background
- Main selection requirements:

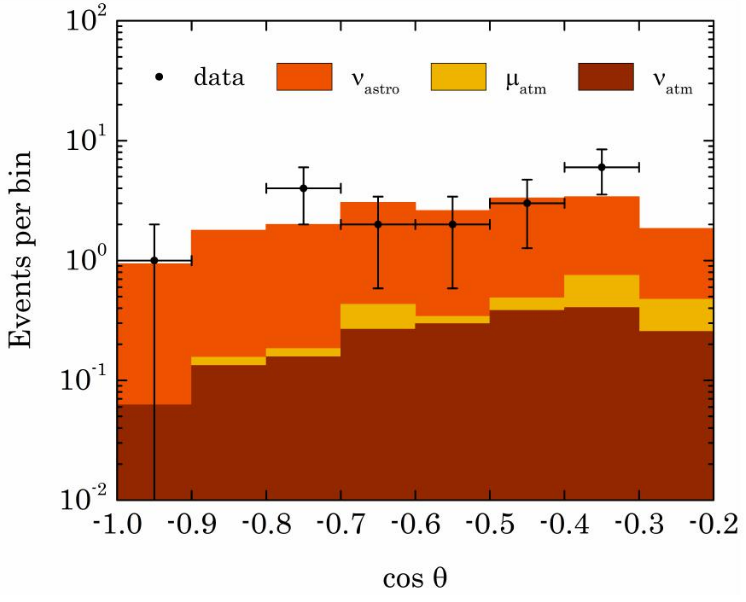
  $\mathbf{E_{sh} > 15\ TeV}$ && $N_{hit} > 11$ && $\cos\theta < -0.25$
  && downgoing muon veto

N_{data}	N_{bg}	P-value	Significance (no syst.)	Significance (stat.&syst.)
18	2.8	2.1×10^{-7}	6.24	**5.10**

https://arxiv.org/abs/2507.01893

Previous version of analysis (4-year dataset):
Phys.Rev.D 107 (2023) 4, 042005





Diffuse astrophysical neutrino flux

Extraction of one-flavour single-power-law flux:

$$\Phi^{\nu+\bar{\nu}}_{astro} = \phi_{astro}\left(\frac{E_\nu}{100\mathrm{TeV}}\right)^{-\gamma_{astro}}$$

Best-fit parameters:

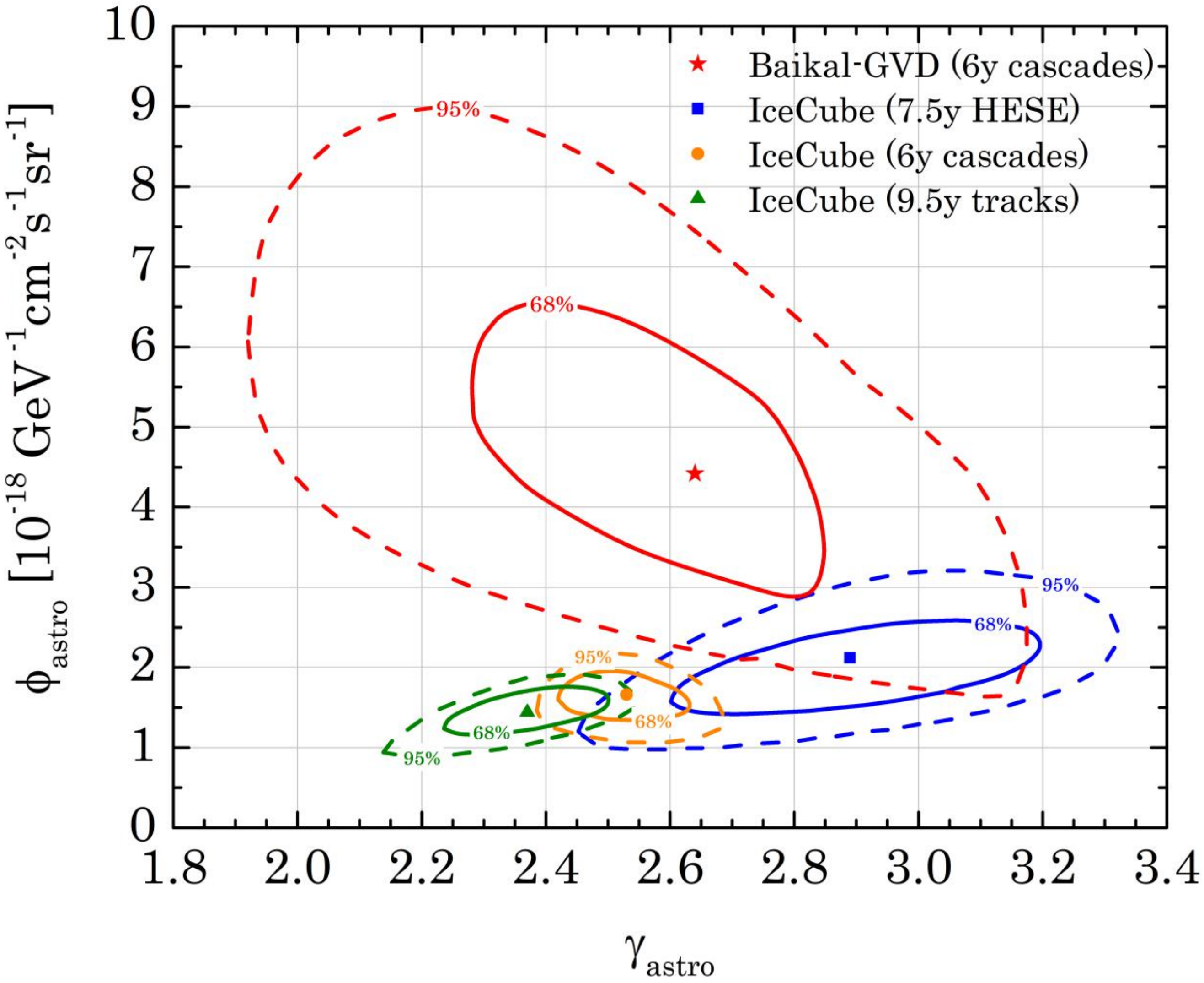
$$\gamma_{astro} = 2.64^{+0.09}_{-0.11}$$

$$\phi_{astro} = 4.42^{+2.31}_{-1.29}\ (10^{-18}\mathrm{GeV}^{-1}\mathrm{cm}^{-2}\mathrm{s}^{-1}\mathrm{sr}^{-1})$$

The spectral index is in agreement with IceCube measurements

Spectrum normalisation is in general larger than IceCube

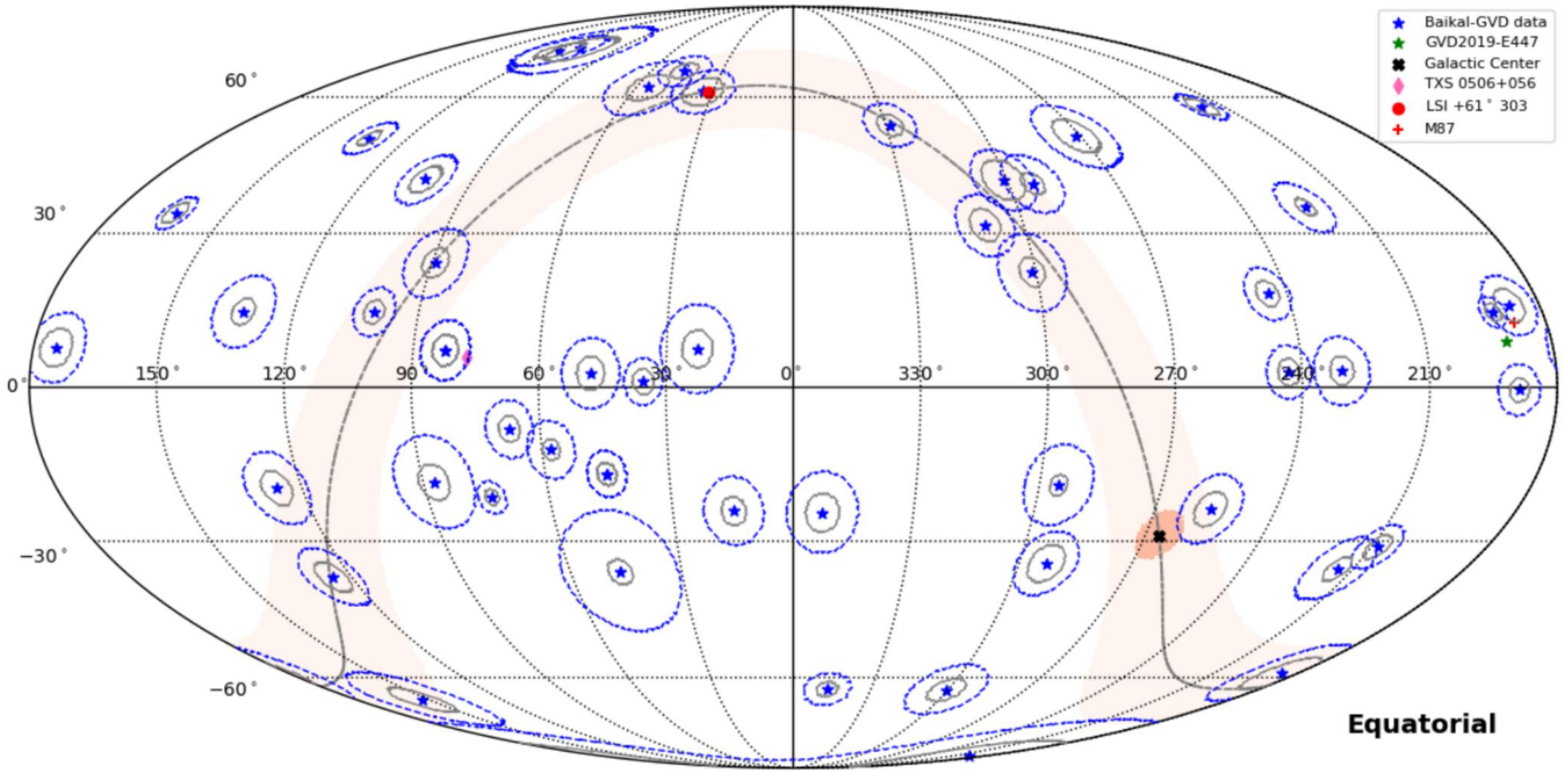
https://arxiv.org/abs/2507.01893



Neutrino source searches

Search for neutrino association using 4-year cascade data [MNRAS 526, 942 (2023)]

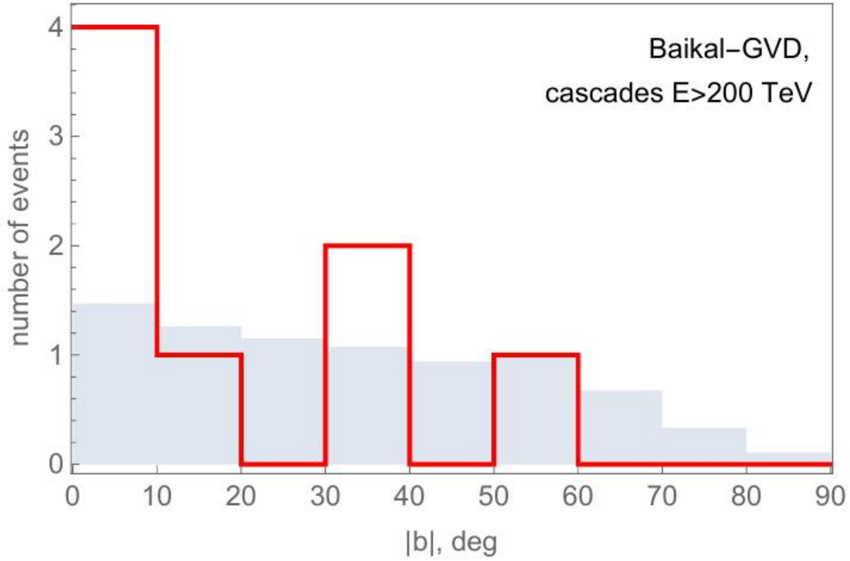
- Catalogue of VLBI-bright blazars
- Examination of promising coincident sources: galactic and extragalactic
- Largely no conclusive results

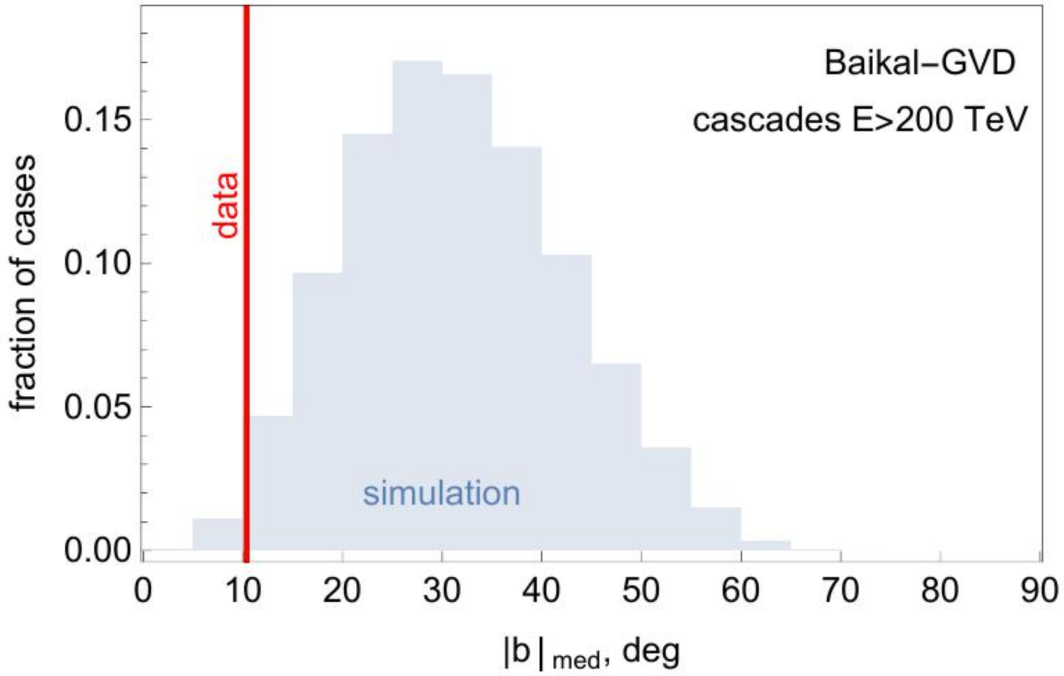


High-energy cascade events from the 6-year dataset (Apr 2018 - March 2024)

Cascade association with galactic plane

- Analysis is inspired by independent analysis of public IC data in **ApJL 940, L41 (2022)**
- High-energy cascades April 2018 - March 2024 (6 years)
- Test the Galactic excess for cascades with $\mathbf{E_{sh}}$**>200 TeV**
- Used the sample of 8 events, 64% of astrophysical origin
- Simple model-independent test using median of galactic latitude $|b|_{med}$
- Null hypothesis is excluded with a significance of 2.5σ





Baikal-GVD data was combined with IceCube producing stronger hint for event association with the galaxy

Sample	$\lvert b\rvert_{\rm med}$ observed	$\langle\lvert b\rvert_{\rm med}\rangle$ expected	p
Baikal-GVD cascades	10.4°	31.4°	$1.4\cdot10^{-2}$ (2.5σ)
IceCube cascades	12.4°	31.9°	$8.7\cdot10^{-3}$ (2.6σ)
combined cascades	12.4°	31.5°	$1.7\cdot10^{-3}$ (3.1σ)
IceCube tracks	24.7°	36.0°	$1.8\cdot10^{-3}$ (3.1σ)
all cascades+tracks	23.4°	35.0°	$3.4\cdot10^{-4}$ (3.6σ)

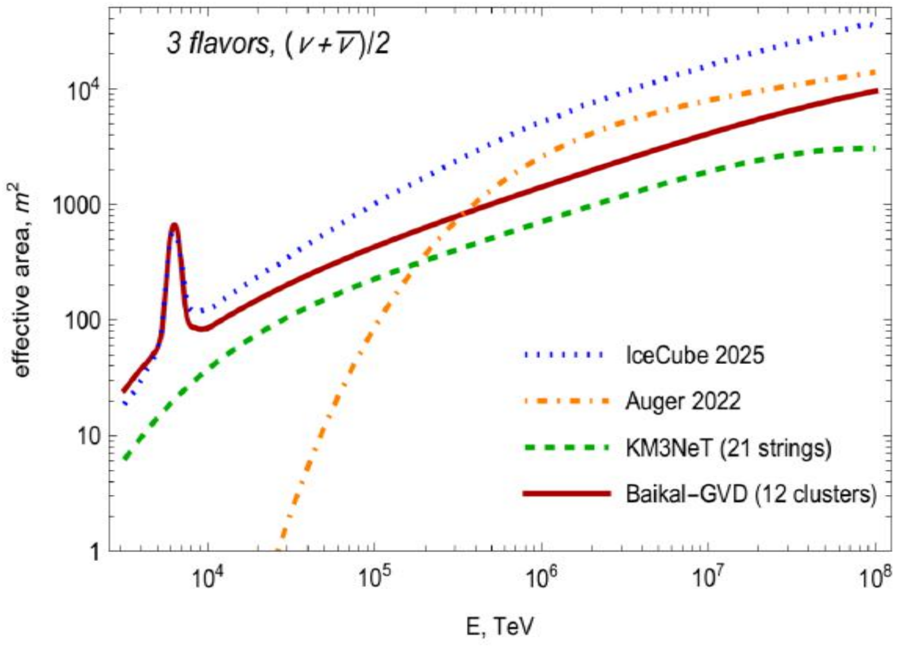
ApJ 982:73 (6pp), 2025

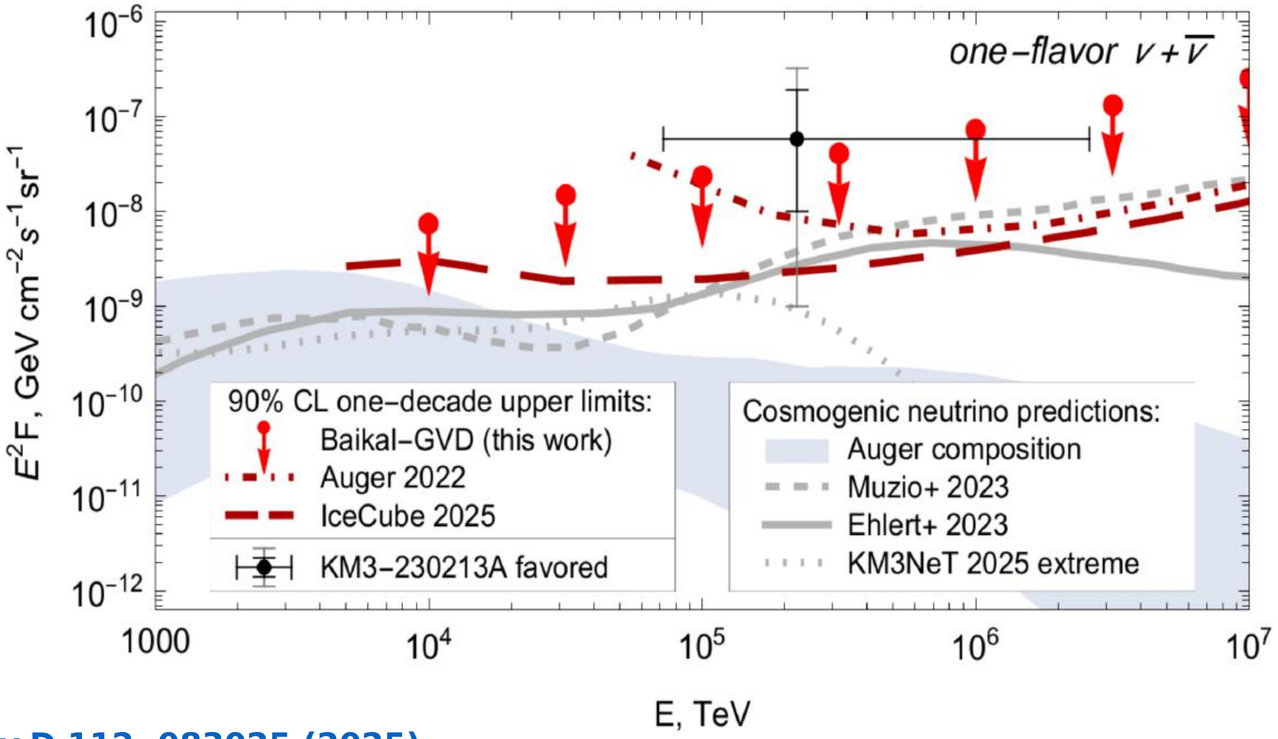
Multi-PeV neutrino flux limits

6-year cascade dataset:
- All-sky selection largest cascade energy - 1.2 PeV
- Non detection above this energy can be used to constrain flux of Multi-PeV neutrino

Confront recent Multi-PeV neutrino detection by KM3NeT: KM3-230213A
- Exposure: 26.8 years of one cluster operation
- Constraints are weaker than ones from the IceCube due to smaller exposure
- Our constraint do not contradict KM3-230213A flux estimate

Effective area in cascade channel





Phys.Rev.D 112, 083025 (2025)

Track results

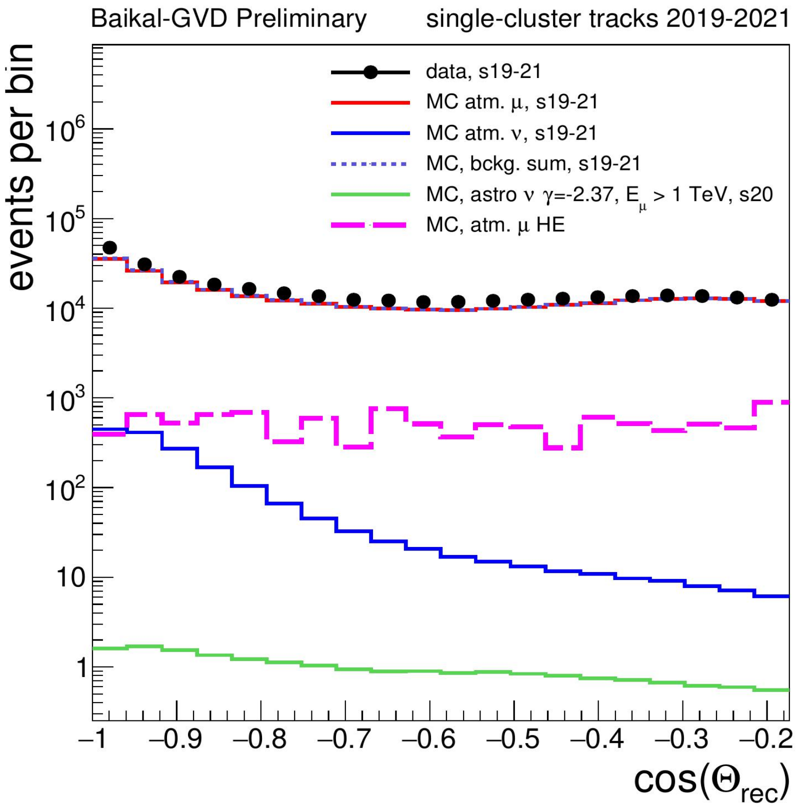
The 5-year track dataset

The data from Apr 2019 to March 2024 were processed with track reconstruction algorithms in single-cluster regime
- Equivalent of 30 yr. of one cluster operation

The 5-year dataset allowed to perform first probe for diffuse flux and point source search (later in the talk)

Analyses with this dataset are restricted to upgoing tracks

Cosine zenith angle before the neutrino selection



Dominated by muon bundles

PoS(ICRC2025)1162

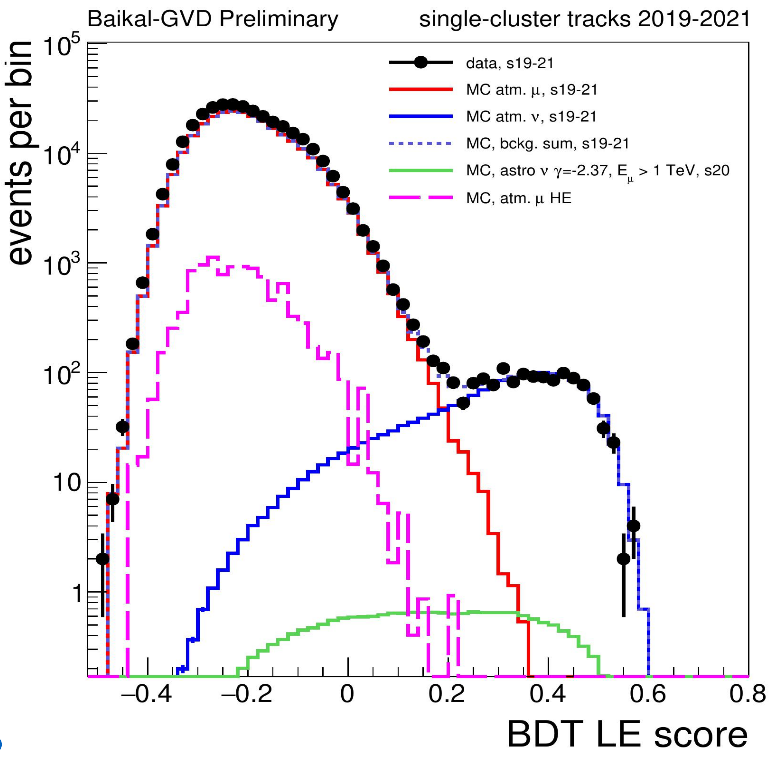
The 5-year track dataset

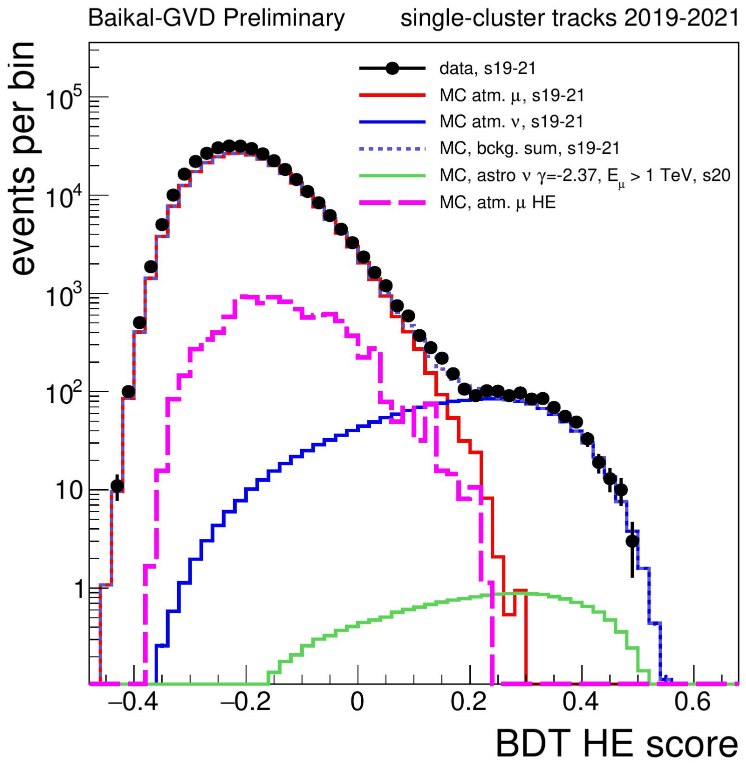
Misreconstructed atmospheric muon bundle events are suppressed with BDTs

Low-energy BDT (E_μ < 10TeV) and high-energy BDT (E_μ > 10 TeV)

To strengthen the background suppression training samples were enriched with high-energy muon bundles with leading muon energy E^μ > 100 TeV

BDTs evaluated over the sample of upgoing tracks before selection:

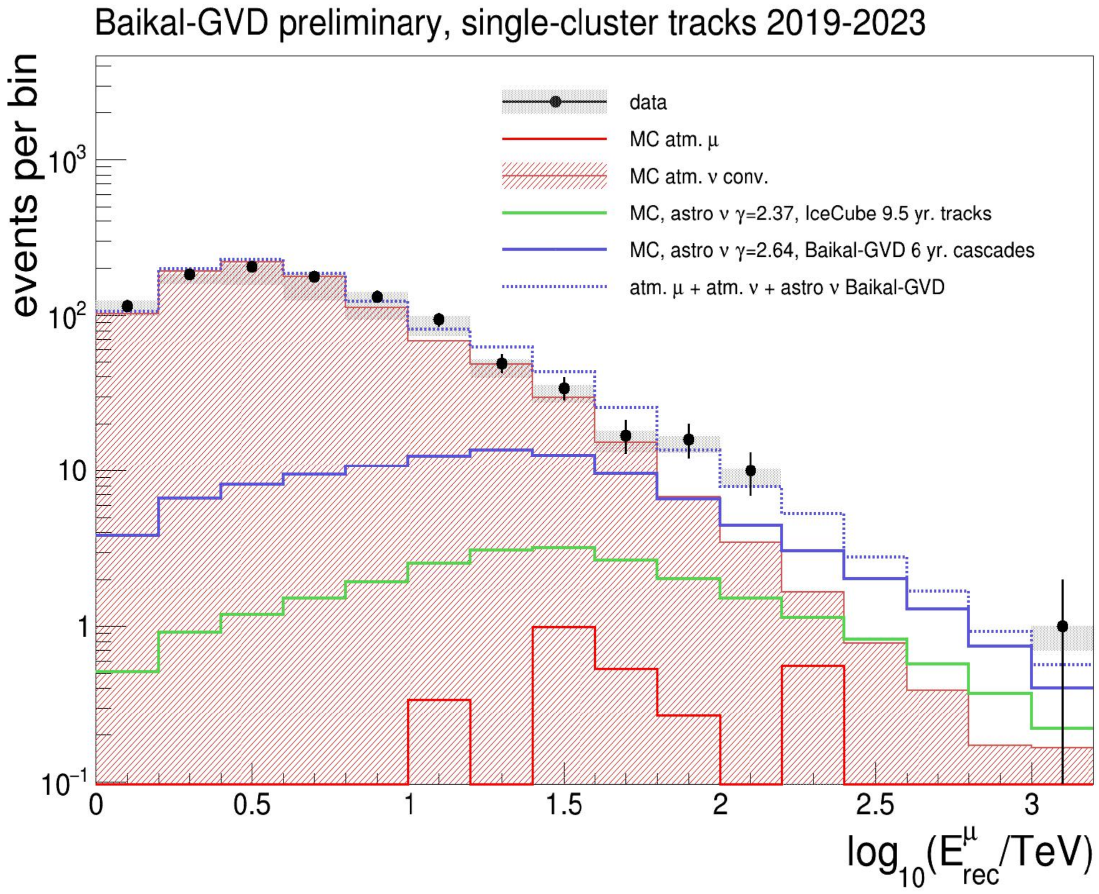




[PoS(ICRC2025)1162]

Probe for diffuse fux

Energy distribution for tracks passing the selection



PoS(ICRC2025)1162

Probe for the diffuse flux with cut-based event-counting analysis

Cuts are optimized for spectrum γ=2.37
optimization result: **E^{μ}_{rec} > 45 TeV, BDT_HE > 0.26**

Event counts:

MC atm. μ	1.4
MC atm. ν	23.5
Observed	38

P-value of the excess: 0.0087, significance: 2.39σ,
no systematics is taken into account yet

The 90% CL one-flavour flux limits for γ=2.37:
$0.59 < \varphi_0 < 3.95$ (10^{-18} GeV^{-1} cm^{-2} s^{-1}sr^{-1})
do not contradict IC and cascade Baikal-GVD results

Likelihood-based analysis is in development

Point source search

Guided search over a list of 92 objects

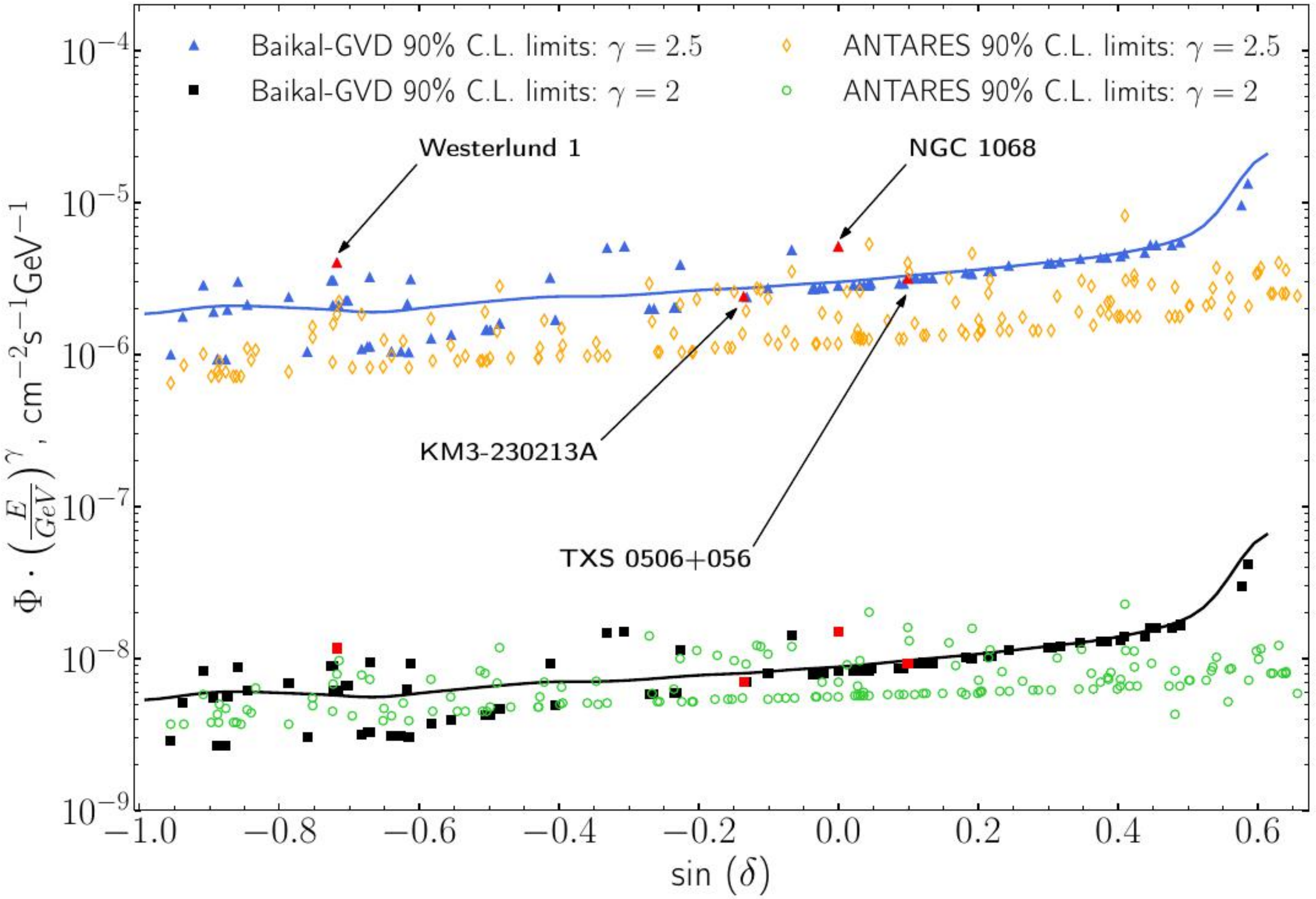
Cut-based: BDT cut was optimised for the best sensitivity to E^{-2} spectrum

Background was estimated using scrambling of data events in right ascension

Count events in 2° cone around each object, estimate excess over the background

The object with most coincidences: potential galactic PeVatron **Westerlund 1** with three coincidences, background expectation - 0.98 events, pre-trial significance - 2.7σ

https://arxiv.org/abs/2603.21261



Multimessenger analyses

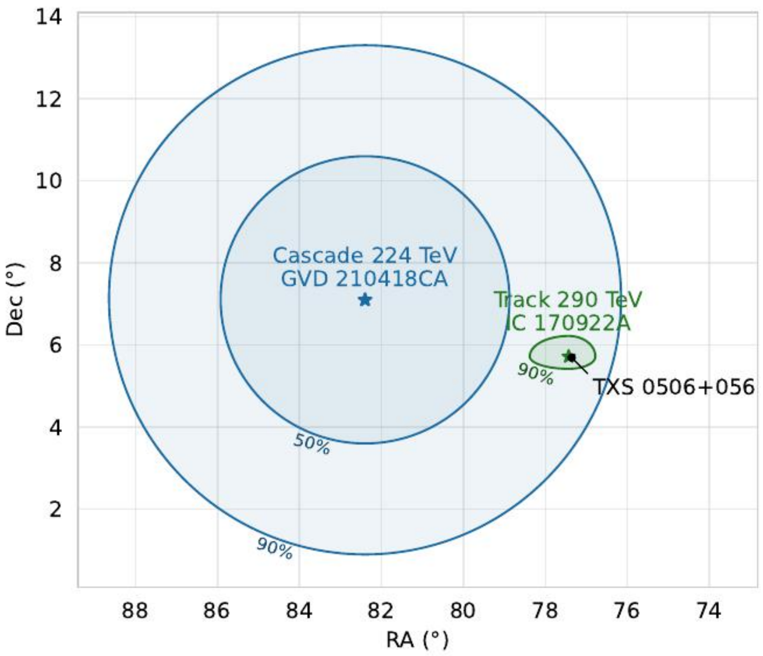
Cascade from TXS0506+056 direction

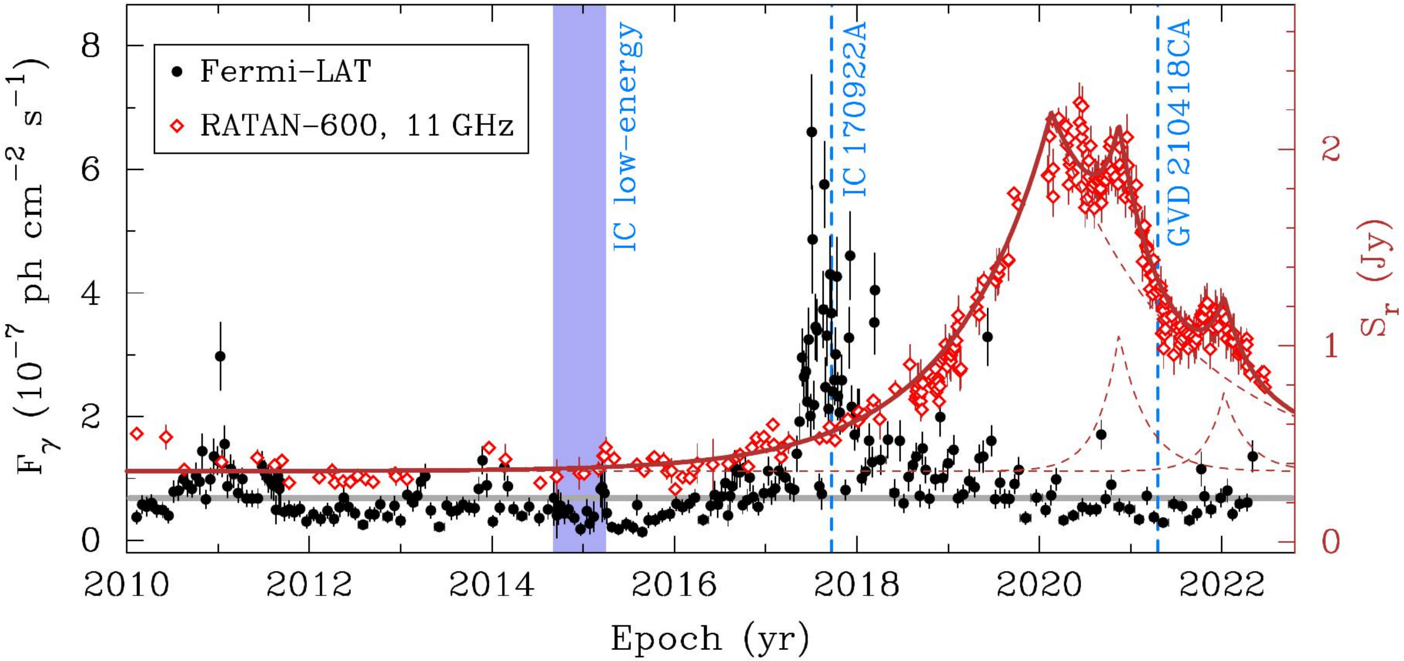
Upgoing cascade analysis,
highest energy event GVD210418CA:
224 TeV, 24 hits, 97.1% astro origin

IceCube neutrino source candidate TXS 0506+056 is within 90% containment circle

Analysis of RATAN-600 [[https://rat.sao.ru/en/]](https://rat.sao.ru/en/)
radiotelescope data indicated increased activity at the time of event

- IC event registered during γ flare
- Baikal event during radio flare
- Consistency with IC observations: 8% or 13% depending on ν spectrum assumption



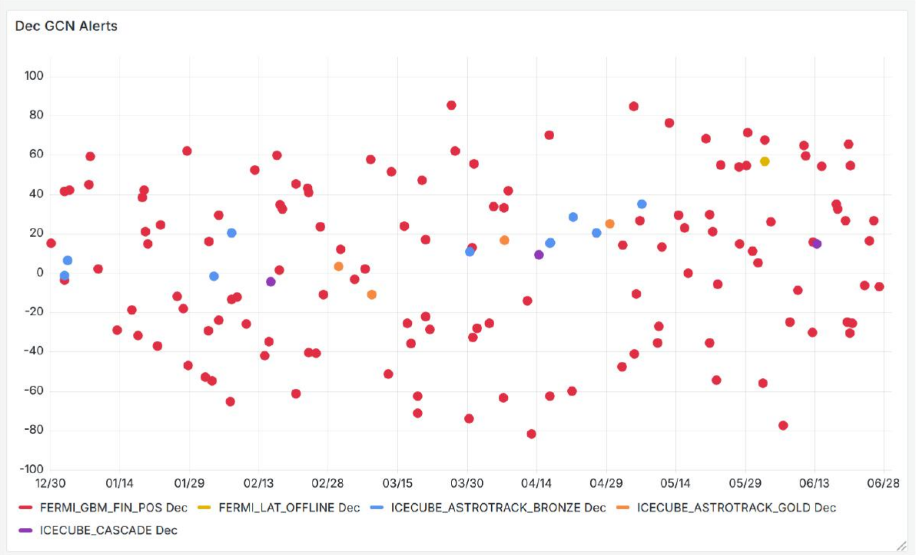


[MNRAS 527, 8784 (2024)]

Multimessenger alert follow-up

Follow-up through GCN

- IceCube neutrino alerts, 180 since 2020
- LIGO-Virgo-KAGRA, 350 alerts in run O4
- Fermi GRB, 300 alerts since Nov. 2024



No significant coincidences
with IC alerts

Multimessenger alert follow-up

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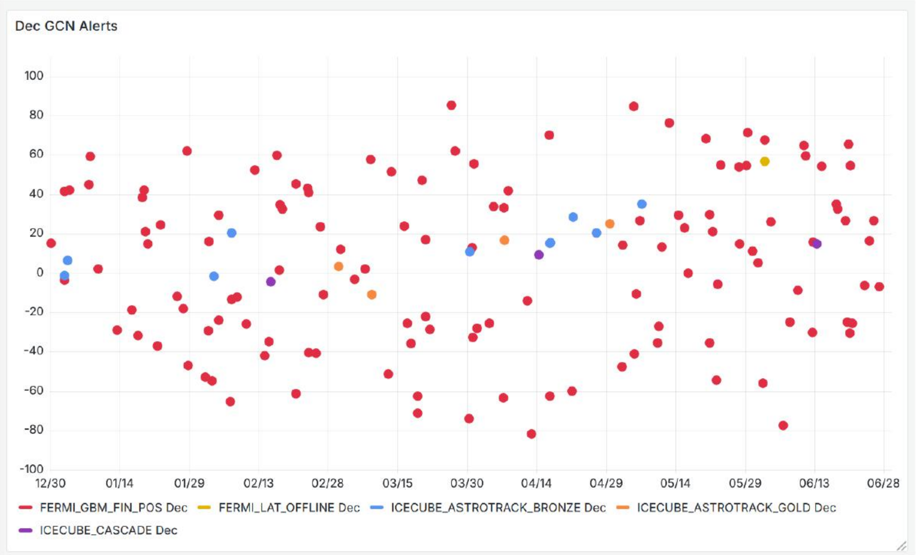
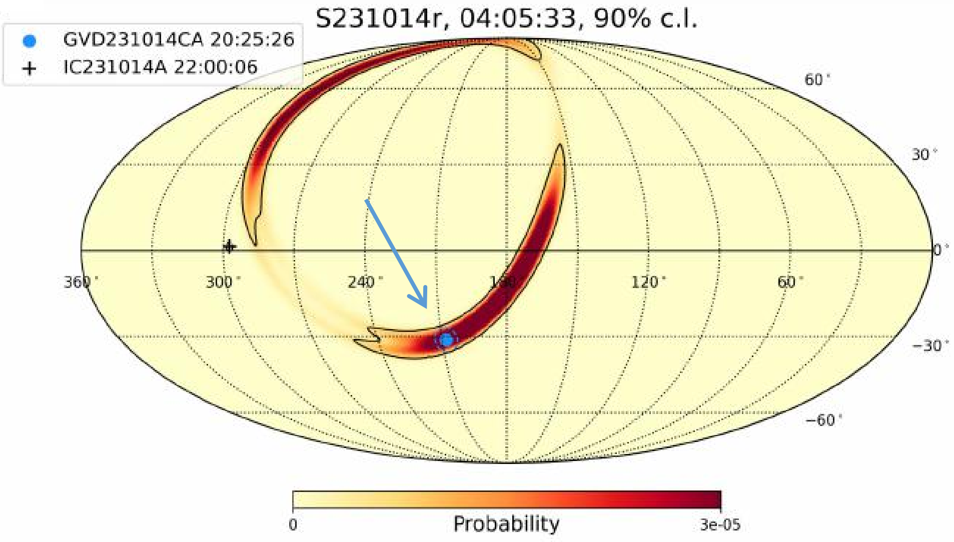


No significant coincidences with IC alerts

GW: LIGO S231014r, BH merger event

GVD231014CA: upgoing cascade with E ~ 35 TeV 16 h later than the alert

90% circle of GVD231014CA is 5.5% of 90% region of S231014r



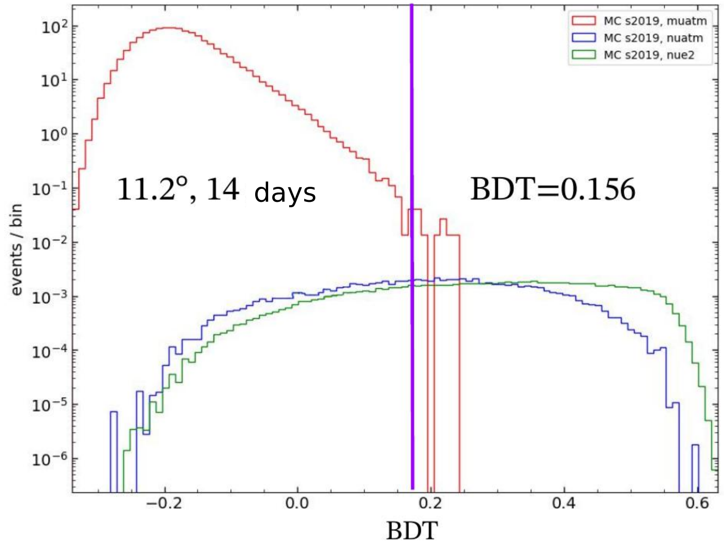
Significance: 0.77σ

[Phys. Atom. Nuclei 88, 859-870 (2025)]

Multimessenger alert follow-up

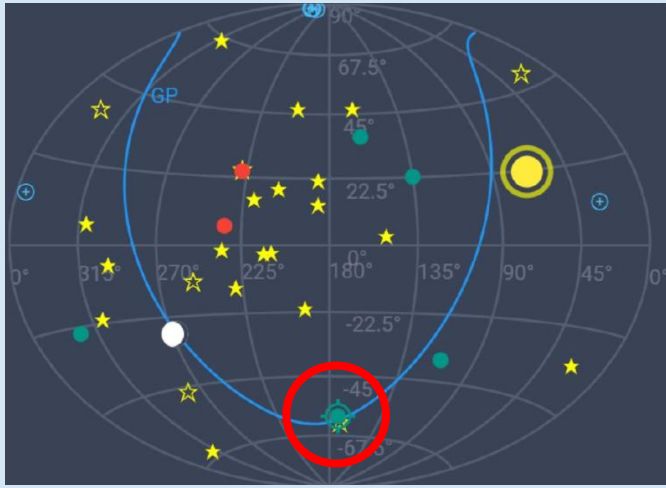
Track selection optimization,
ON/OFF bckg. estimation

R_{on},°	time interval	BDT
0.7	+/- 1 d	- 0.022
5	0, +1 d	0.017
11.2	0, + 14 d	0.156



Fermi-GBM coincidence

GRB 260516C
2026-05-16, 19:34:38 UTC,
RA=172.57°, Dec = -59.89°, Err=3.19°
[Southern sky]



Upgoing track-like event

- E = 4 TeV
- δ = 2.8° to GRB 260516C (within 90% containment),
- **9.5 hours after the GRB**

selection	N_{bckg} (01-05.26)	significance (pre-trial)
BDT > 0.017 (Poisson)	$9.8 \cdot 10^{-3}$	2.34σ
BDT > 0.15 (Gauss)	$5.2 \cdot 10^{-4}$	3.27σ

work in progress

V. Dik, RCRC 2026

Summary

After the 2026 deployment campaign the Baikal-GVD neutrino telescope incorporates 16 clusters including 135 strings instrumented with 4896 optical modules

In the next two-three years it is planned to reach the detector volume of ~1 km^3 and total instrumentation of 6000 OM

The 6-year cascade dataset
- The diffuse astrophysical neutrino flux observation in cascade channel
- The hint on substantial galactic component in high-energy cascades

The 5-year track dataset
- First hints on the diffuse flux in track channel
- First point source search competitive with full ANTARES dataset

Routine follow-up of multimessenger alerts was commissioned

Thank you!

This work is supported in the framework of the State project “Science” by the Ministry of Science and Higher Education of the Russian Federation under the contract 075-15-2024-541

BACKUP