Joint Institute for Nuclear Research

SCIENCE BRINGS NATIONS TOGETHER

BAIKAL-GVD

Baikal-GVD Deep-Underwater Neutrino Telescope: Status and Recent Results and JINR neutrino program

India-JINR Workshop on Particle, Nuclear, Neutrino Physics and Astrophysics

Bair Shaibonov, NISER, Bhubaneswar, 11.11.2025

Outline

- Introduction
- Baikal-GVD Telescope Description and Status
- Recent Results:
  - Characterization of diffuse astrophysical flux of high-energy neutrino
  - Search for astrophysical neutrino point sources
  - Search for extended neutrino source: Galactic plane
  - Follow-up activities
- Brief introduction to JINR neutrino program

M.Markov, **1960**:

„We propose to install detectors deep in a lake or in the sea and to determine the direction of charged particles with the help of Cherenkov radiation“ Proc. 1960 ICHEP, Rochester, p. 578.

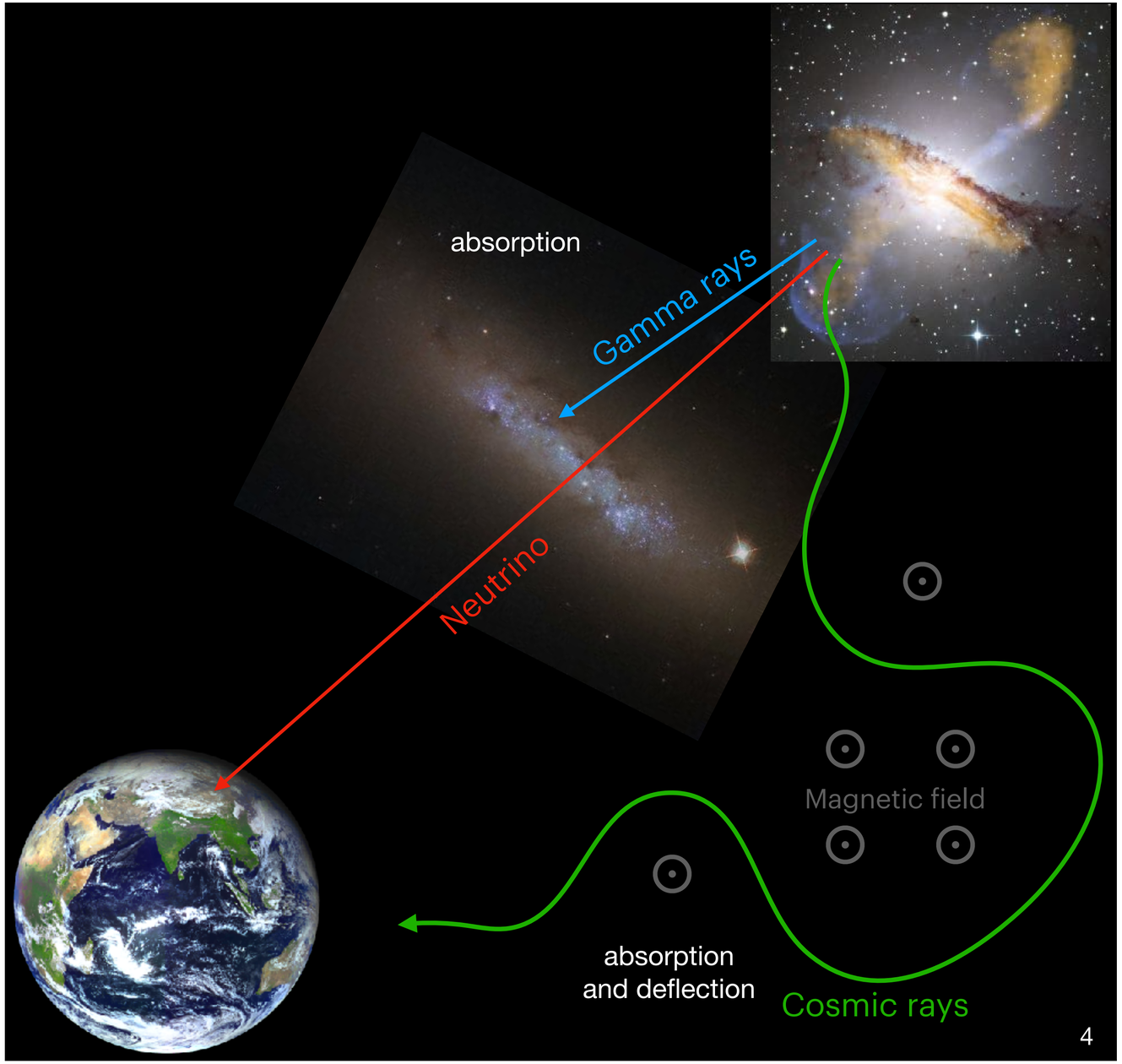
High-Energy Neutrino (>10 GeV) as an Astrophysical Messenger

- Neutrino is a neutral stable light elementary particle weakly interacting with matter
- Abundantly born in hadronic processes in space accelerators (active galactic nuclei, supernova remnants, microquasars, gamma-ray bursts, tidal disruption events etc.)
- Unlike high-energy gamma rays:
  - freely escape from the source
  - freely distributed in the Universe
- Unlike cosmic rays (high-energy p, He, etc.):
  - not deflected by magnetic fields
  - trace production and acceleration sites of neutrino and thus cosmic rays

$$p + p, \quad p + \gamma \rightarrow \pi^{\pm} + \ldots$$

$$\pi^{\mp} \rightarrow \mu^{\mp} + \nu_{\mu}(\bar{\nu}_{\mu})$$

$$\mu \rightarrow e + \nu_{\mu} + \nu_{e}$$

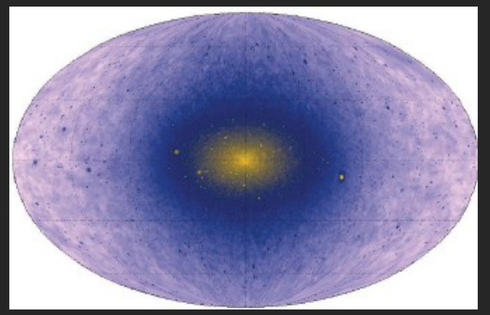


Prominent Source Candidates

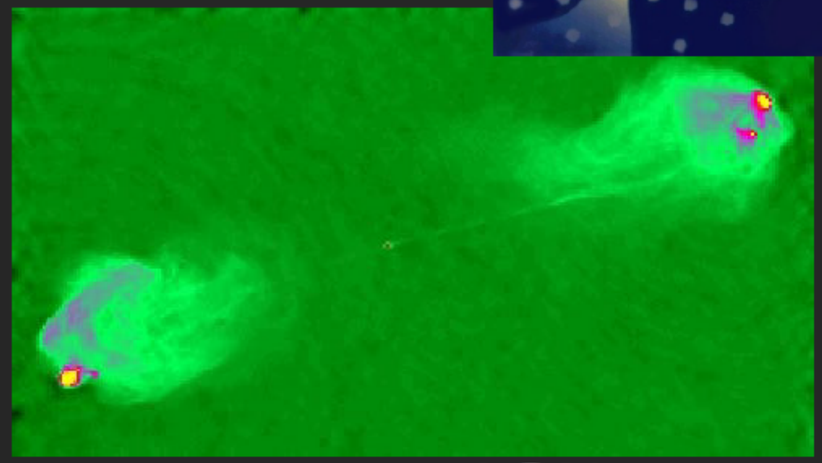
Galactic

SNR
Microquasars
Young SN shells
Pulsars

Extra-Galactic

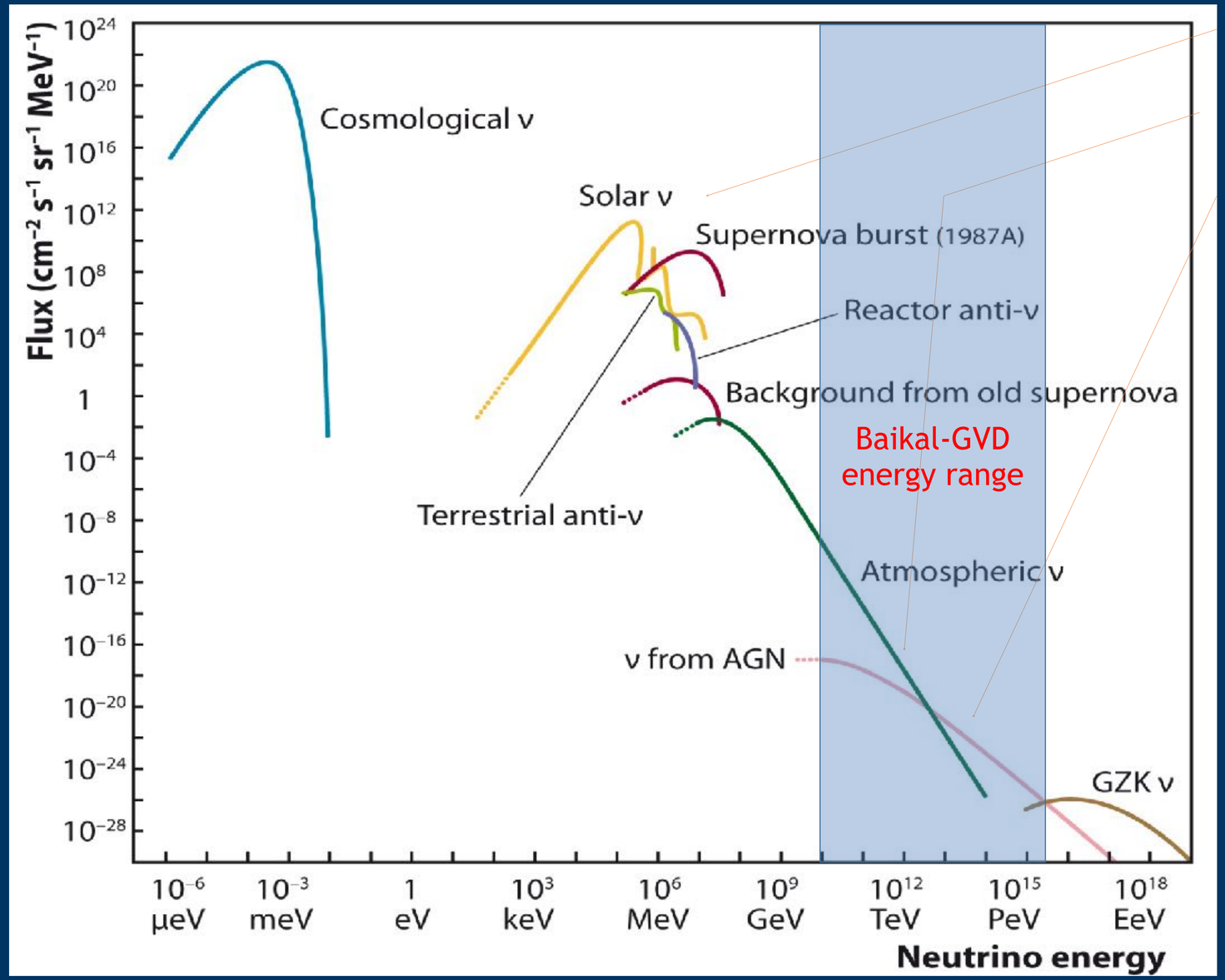


Dark Matter



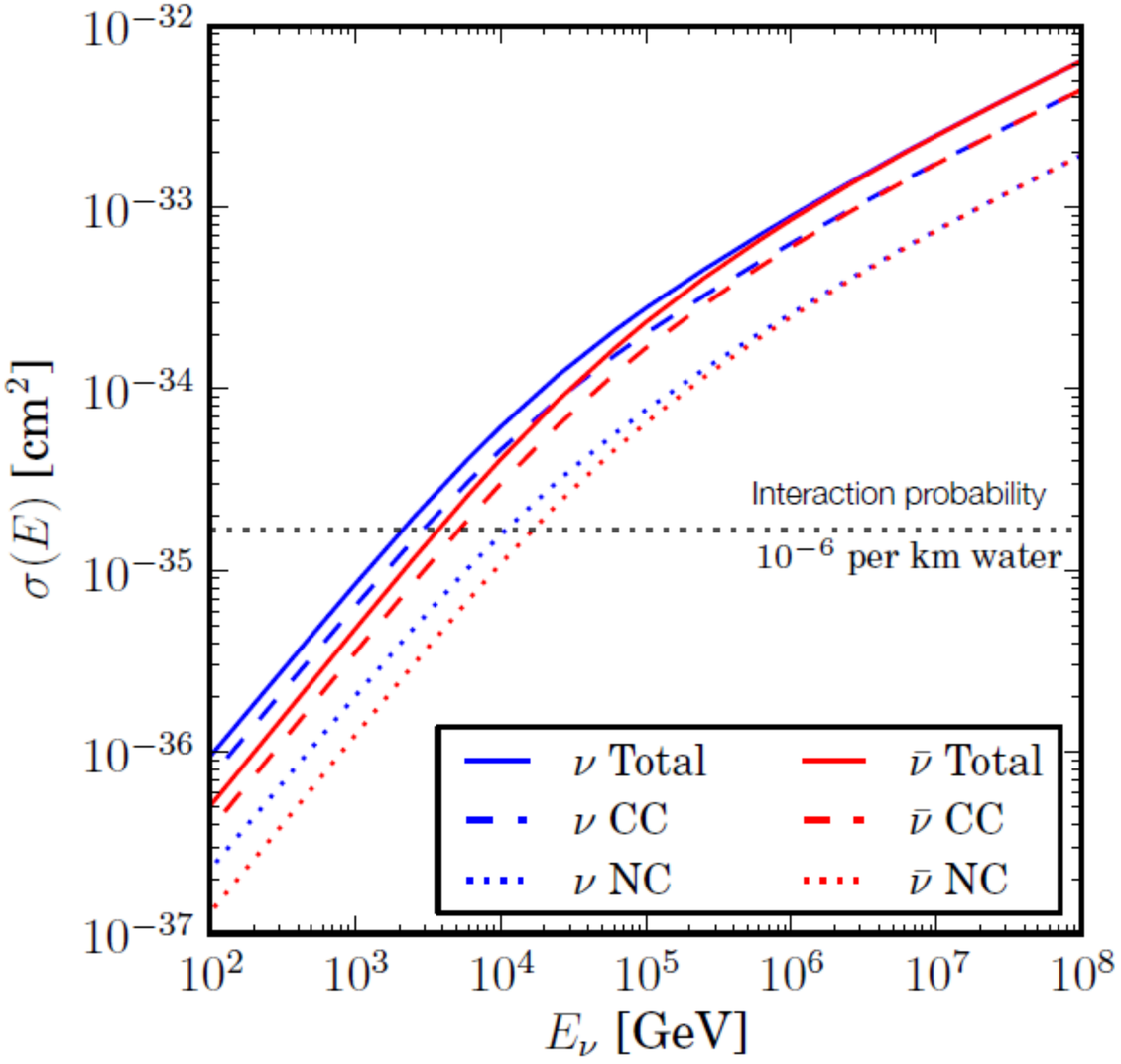
AGN
Starburst Galaxies
Galaxy Clusters
GRB

Neutrino Sources and Energy Scale



Favorable Features of High-Energy Neutrino

- The cross-section of the interaction of neutrinos with matter increases with increasing energy (~1 nb at 10^{15} eV)
- High–energy events are much easier to register - there is more energy release in the installation. Fewer detector recording elements are required. The ability to use large volumes of natural transparent media

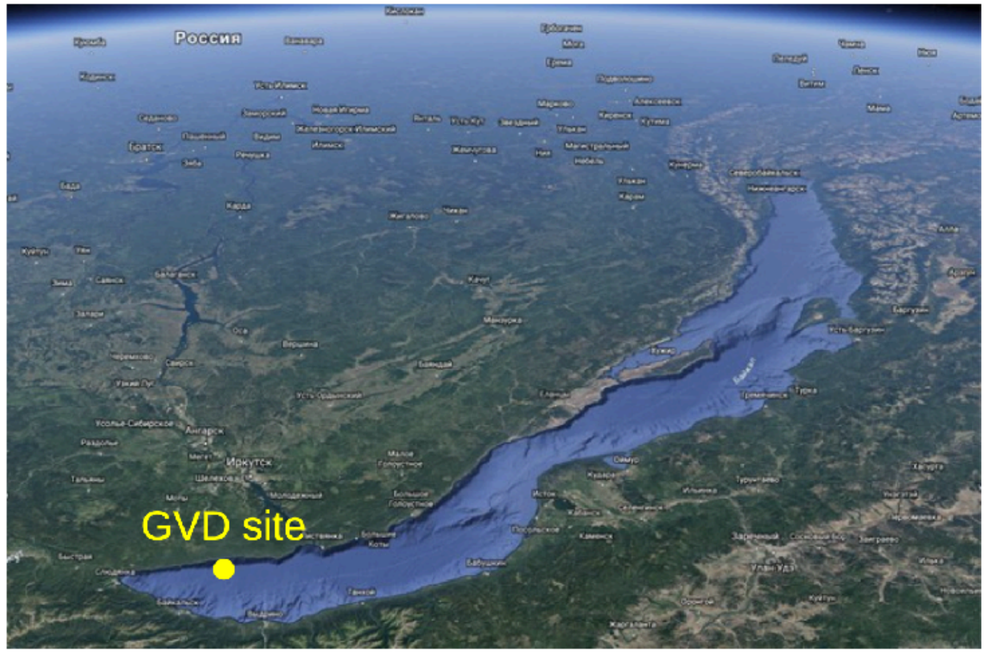


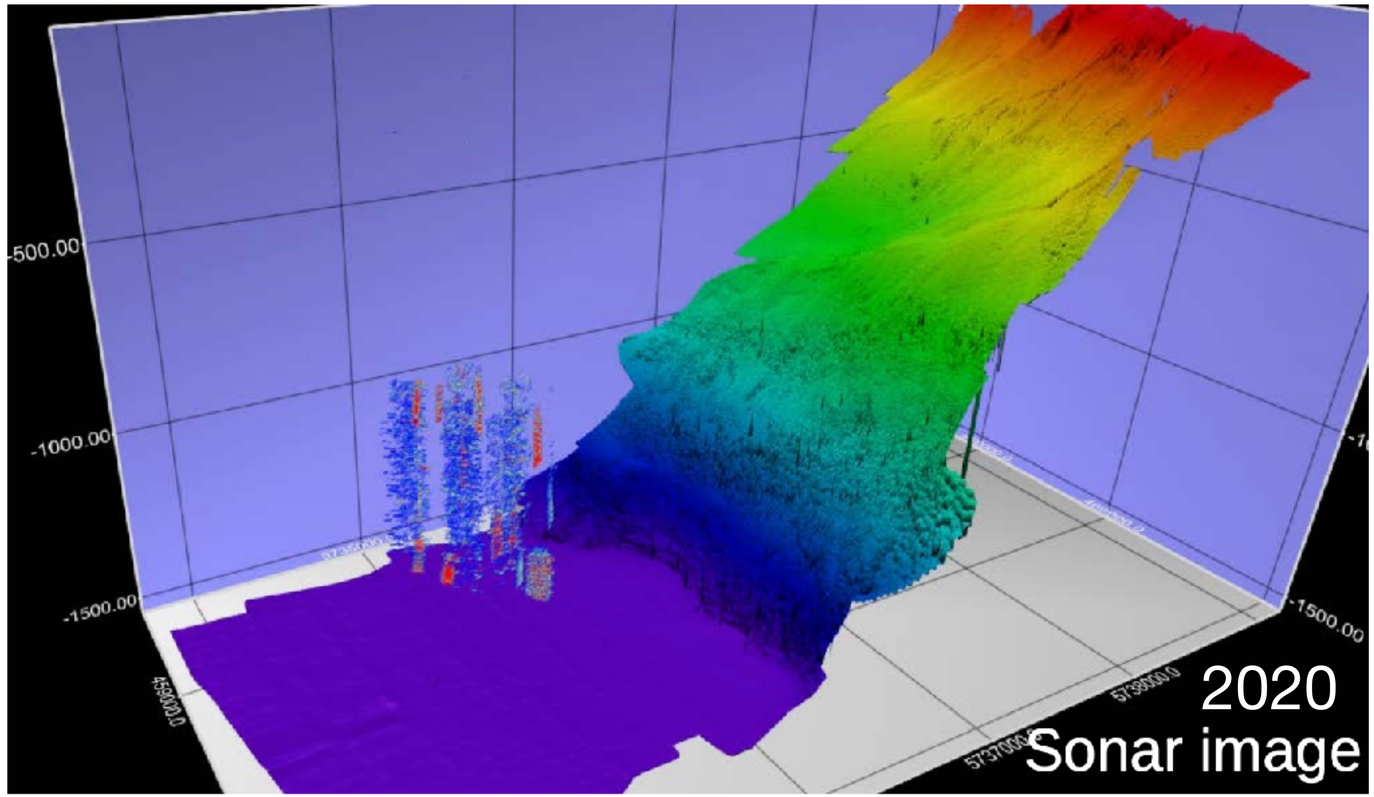
Baikal-GVD Collaboration

- Joint Institute for Nuclear Research, Russia
- Institute for Nuclear Research of the Russian Academy of Sciences, Russia
- Comenius University, Slovakia
- Czech Technical University in Prague, Czech Republic
- Irkutsk State University, Russia
- Skobeltsyn Research Institute of Nuclear Physics, Russia
- Institute of Nuclear Physics ME RK, Kazakhstan
- AO ‘LATENA’ (Joint Stock Company), Russia
- St. Petersburg State Marine Technical University, Russia

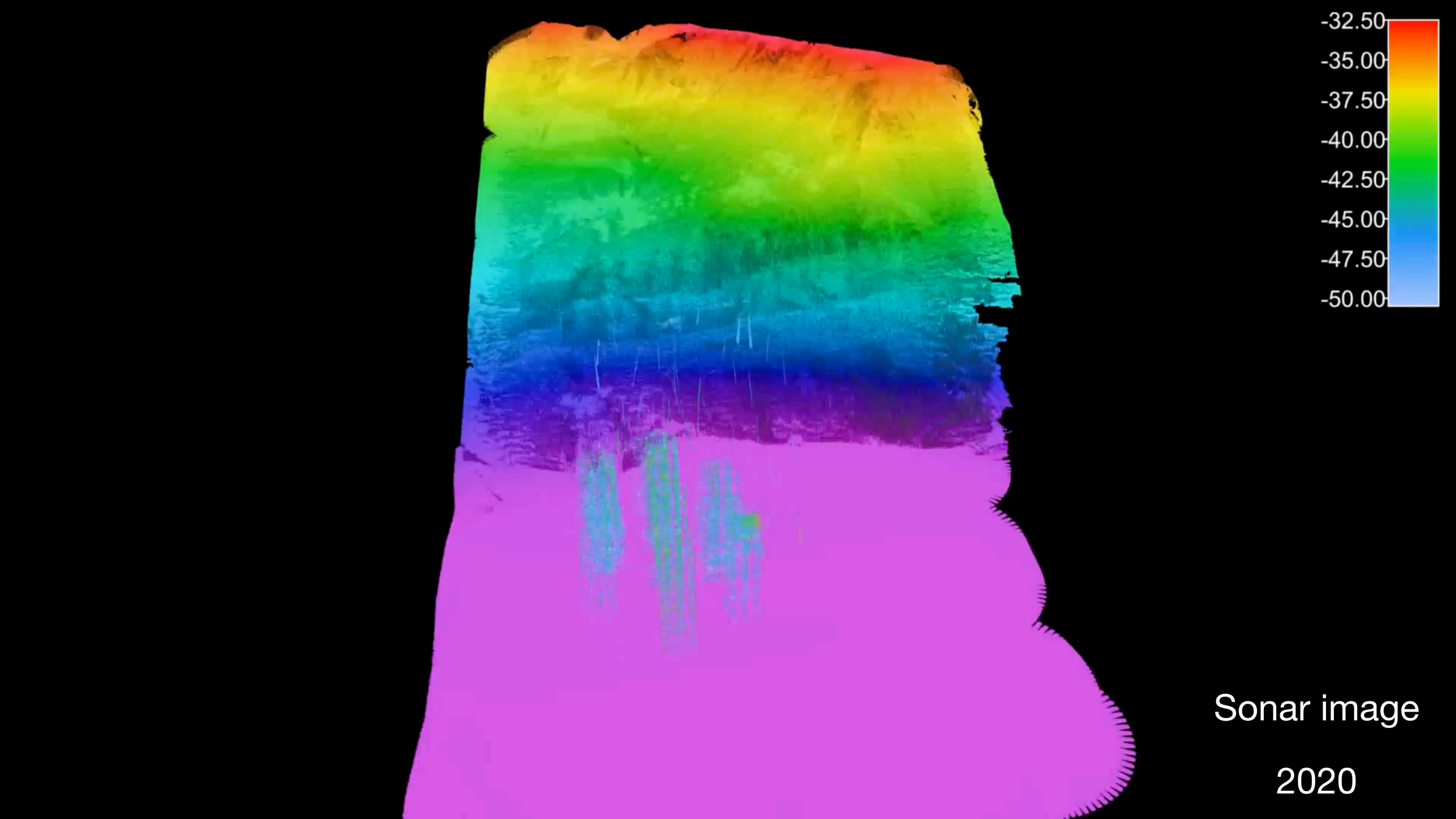
~ 65 physicists and engineers

Baikal-GVD Site



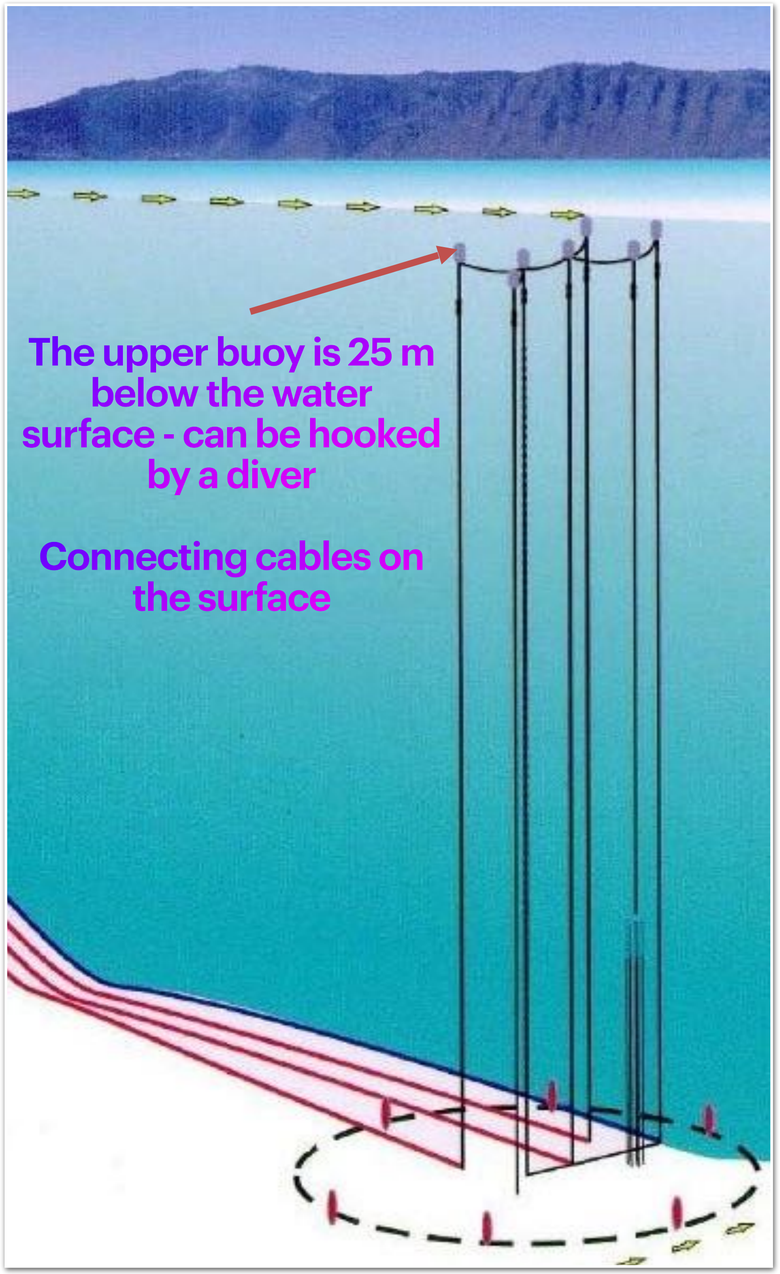


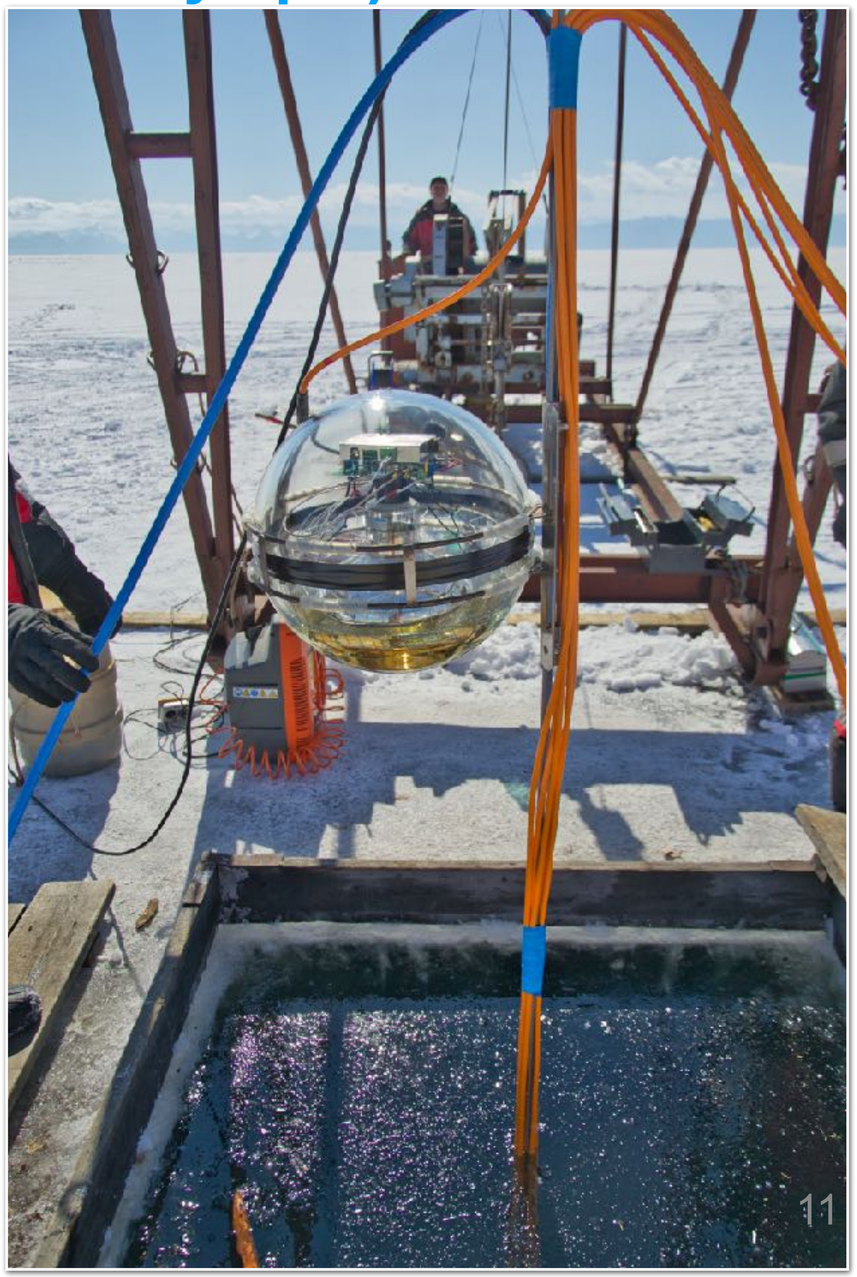
- Southern basin of the lake
- ~3.6 km offshore
- Flat area at depths 1366–1367 m
- High water transparency:
  - Absorption length: 22 m
  - Effective scattering length: 480 m
- Moderately low optical background: 15–50 kHz
- Deployment from the ice cover of the lake


-32.50
-35.00
-37.50
-40.00
-42.50
-45.00
-47.50
-50.00
Sonar image
2020

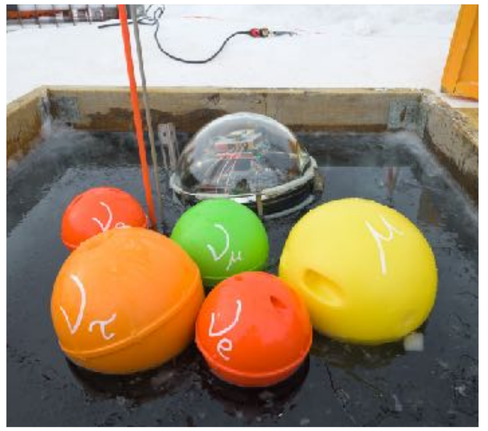
Telescope Deployment

From the ice cover of the lake (mid-February - early April)





Winter Expedition



Bottom Cable Laying

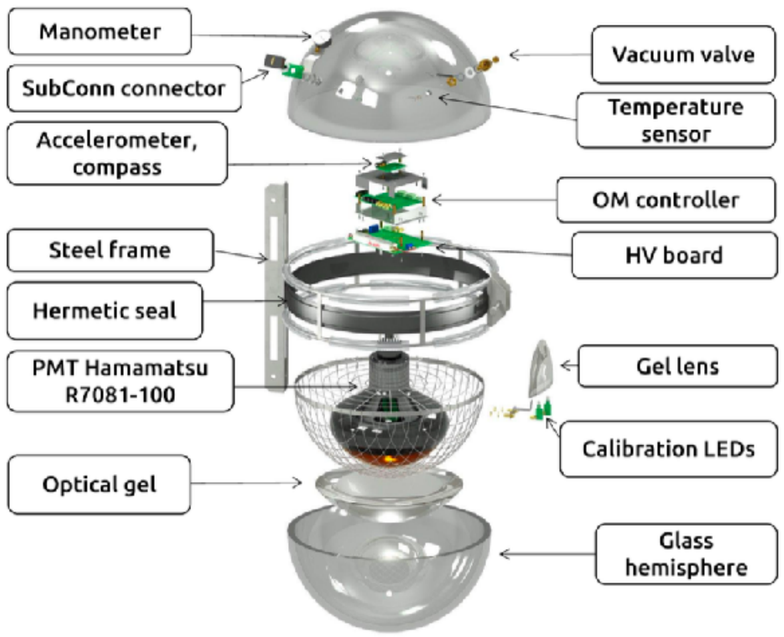
Optical Module - Basic Element of the Telescope

17 inches sphere
(42 cm)

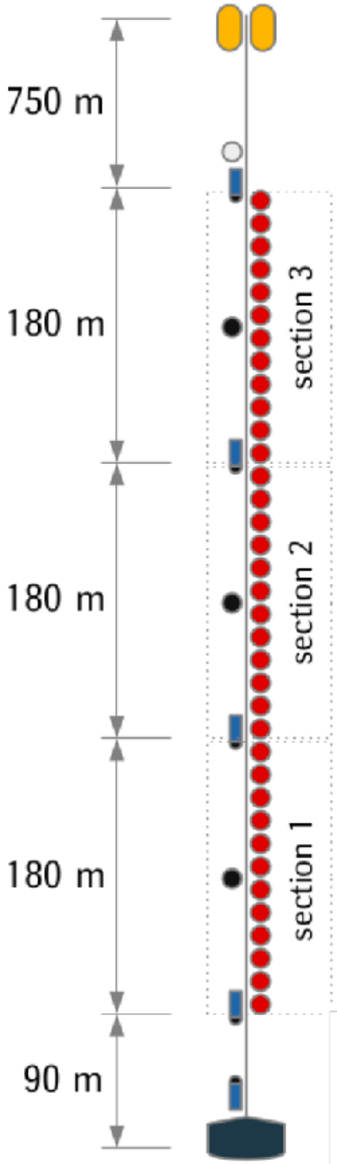
10 inch Hamamatsu PMT
R7081-100

Baikal-GVD technology

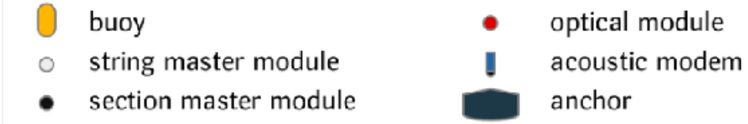
Optical module



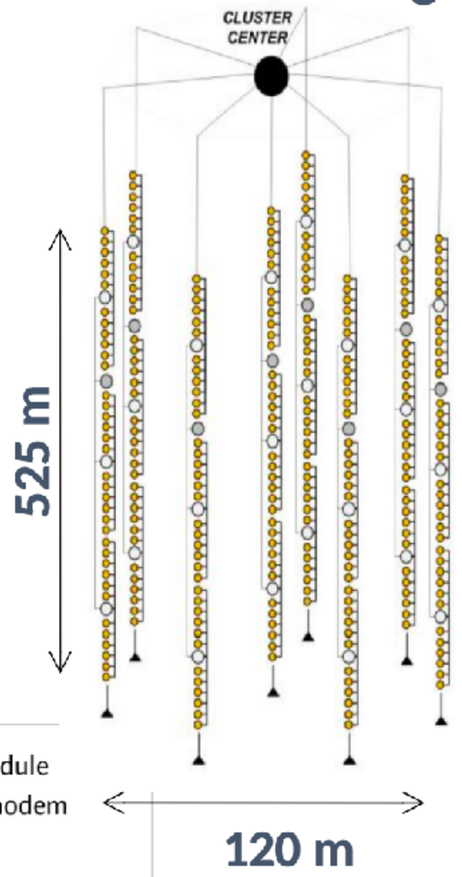
string



- **36 OMs** (10” high QE PMT, 15 m spacing, all PMTs look downward)
- **4 acoustic modems** of the positioning system
- **Section modules** digitize OM signals and send data to shore via shDSL/Ethernet
- Depths 750 m to 1275 m



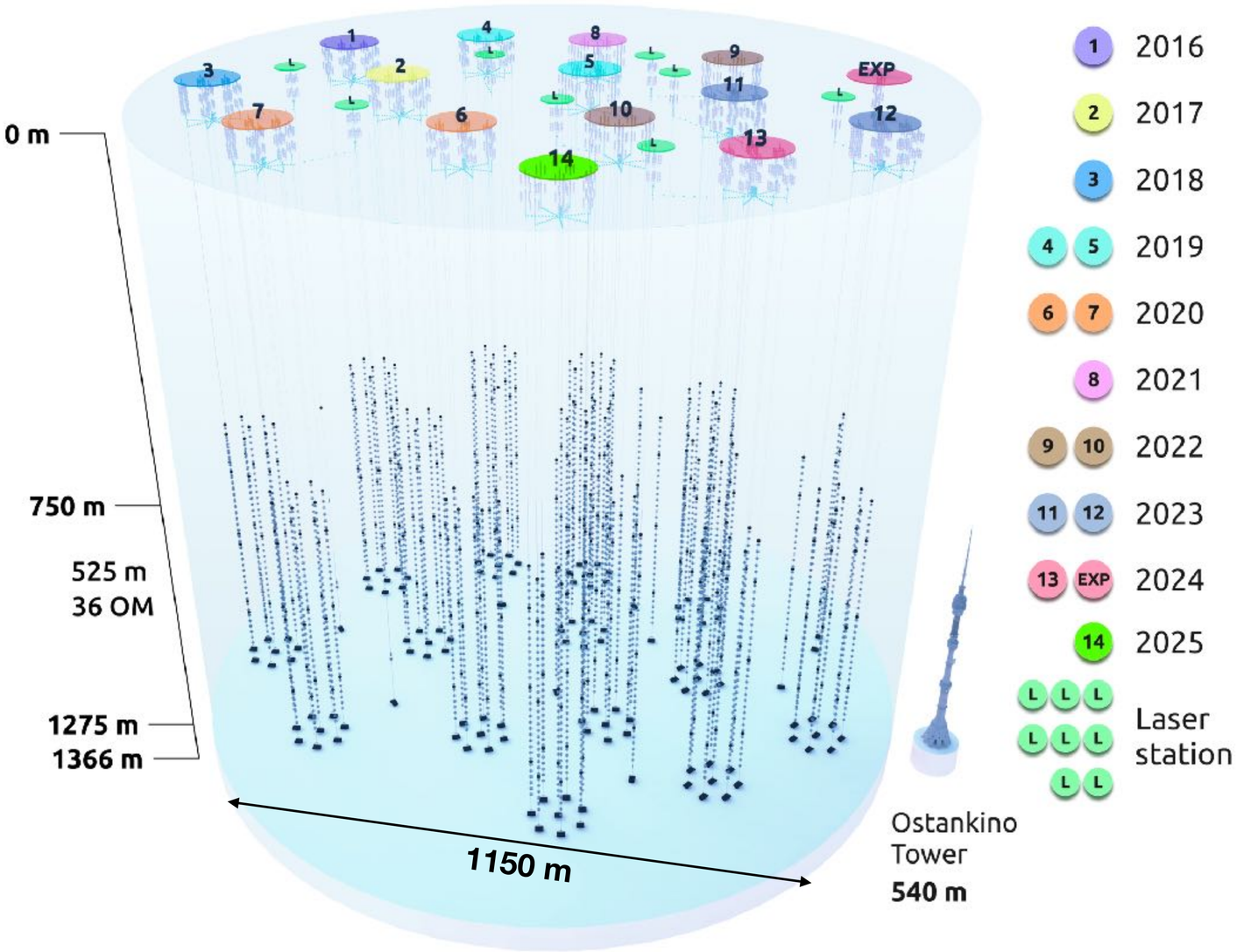
Cluster: 8 strings



Baikal-GVD Status

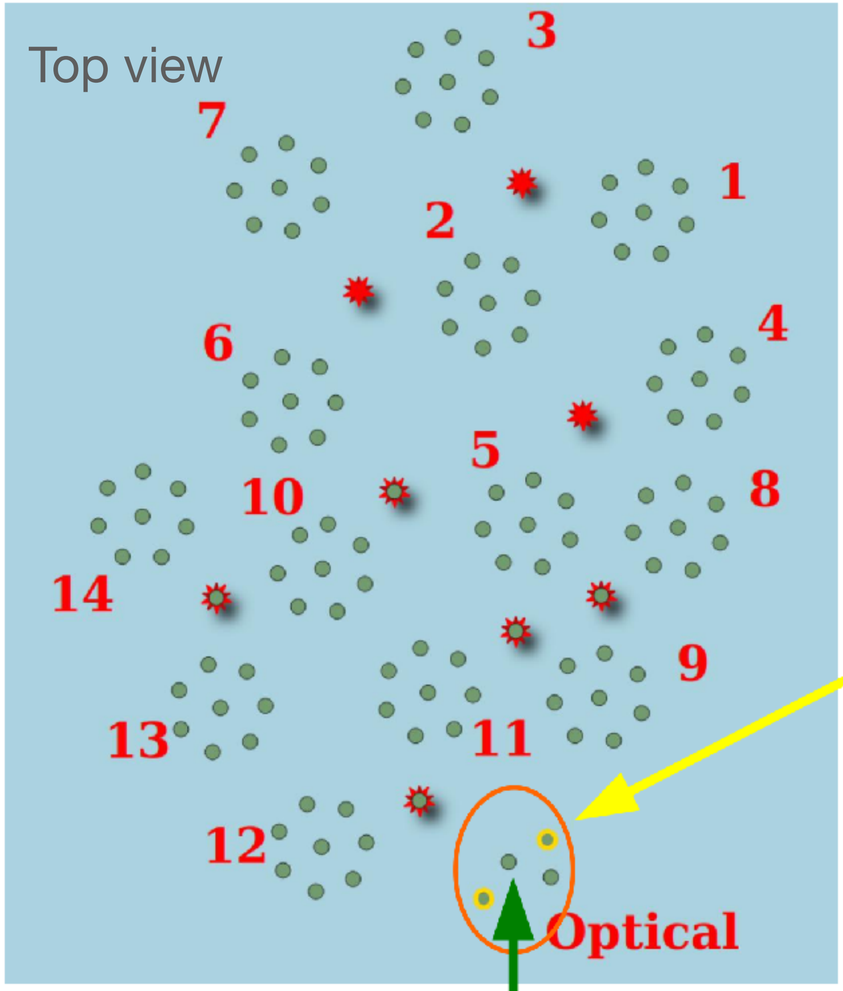
April 2025

- 4212 Optical modules on 117 strings (14 clusters)
- 8 strings form a cluster - independent array of optical modules
- 36 optical modules per string
- 60 m between strings in a cluster, 250-300 m between clusters
- More than 0.7 km^3 of water volume
- 8 laser stations/inter-cluster strings
- More than 400 acoustic modules for positioning
- LED beacons and powerful laser sources for calibration
- 4 experimental strings with the fibre-optic DAQ for testing of new equipment
- Prototype strings for the next-generation telescope



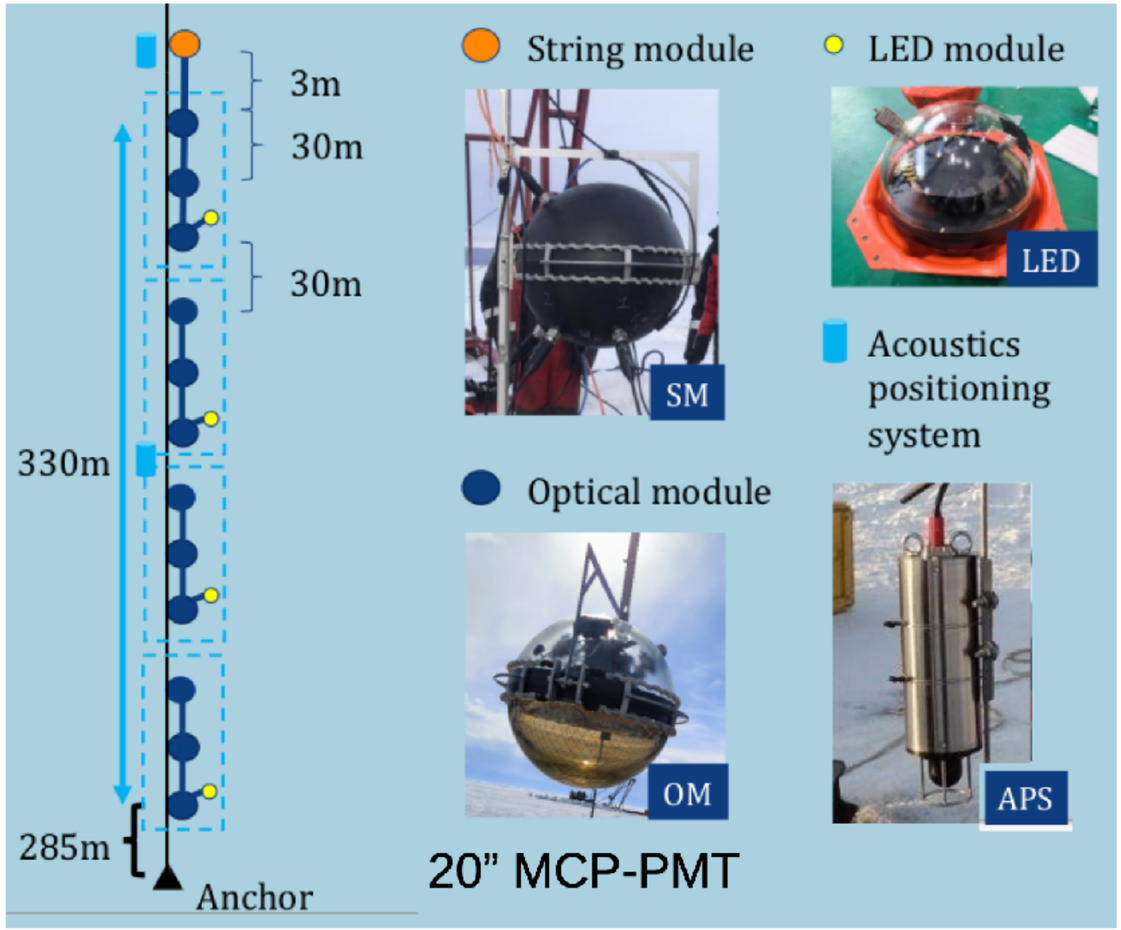
Plan for 1 km^3 and 6000 OMs in 3 years

Technological prototype strings (2025)



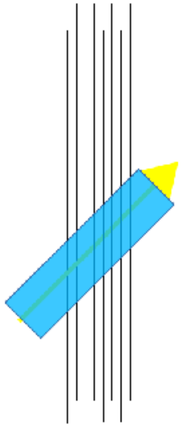
2 “experimental” strings using fiber optic technology for data transmission and standard Baikal-GVD OMs

Two HUNT prototype strings deployed in 2024 & 2025
36 OMs in total
IHEP (Beijing) & Baikal-GVD joint effort



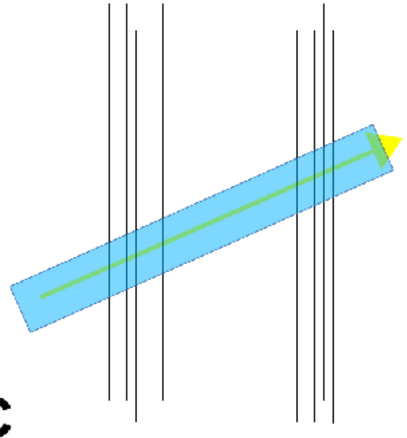
Event Topologies

Single-cluster tracks



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

Multi-cluster tracks

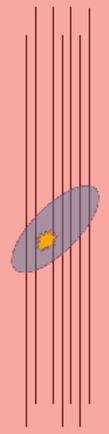


- Moderately low energy threshold
- Optimal sensitivity to inclined tracks
- Best angular resolution

ν_μ CC

NC, ν_e ν_τ CC

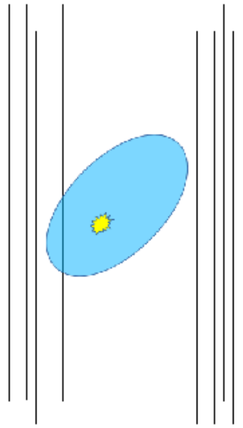
Single-cluster cascades



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

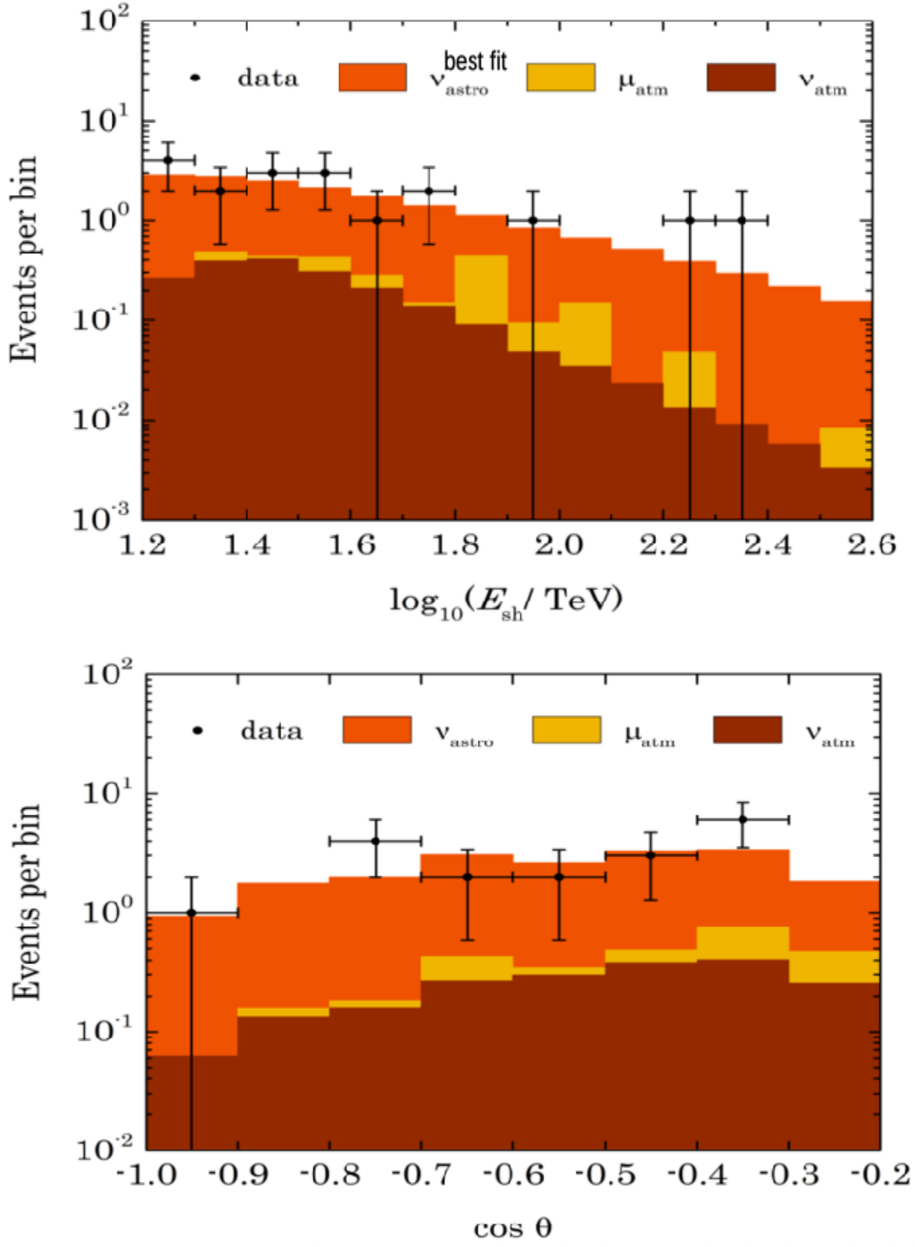
Main results for today

Multi-cluster cascades



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

Astrophysical Diffuse Neutrino Flux: Upward-Going Events



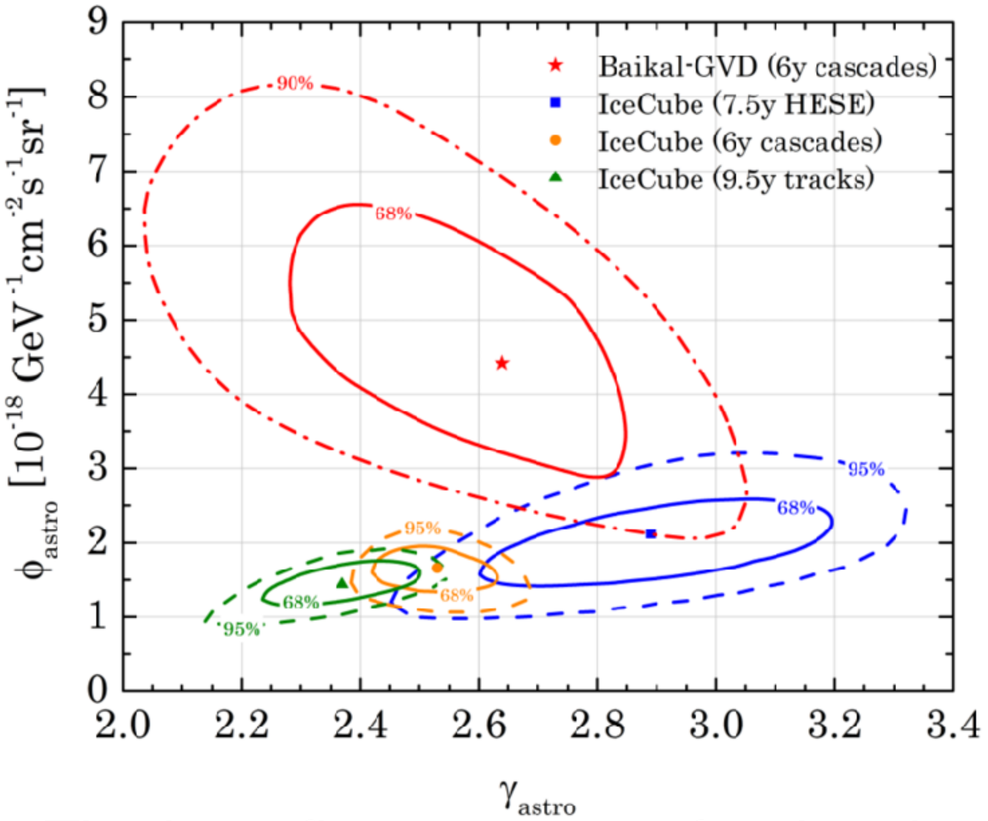
- Data analysed April 2018 - March 2024 (6 years)
- Less background from below:
  - Improving purity and lower energies
- Event selection: Cascade energy >15 TeV & Nhit >11 & cosθ < -0.25 & downgoing muon veto cuts

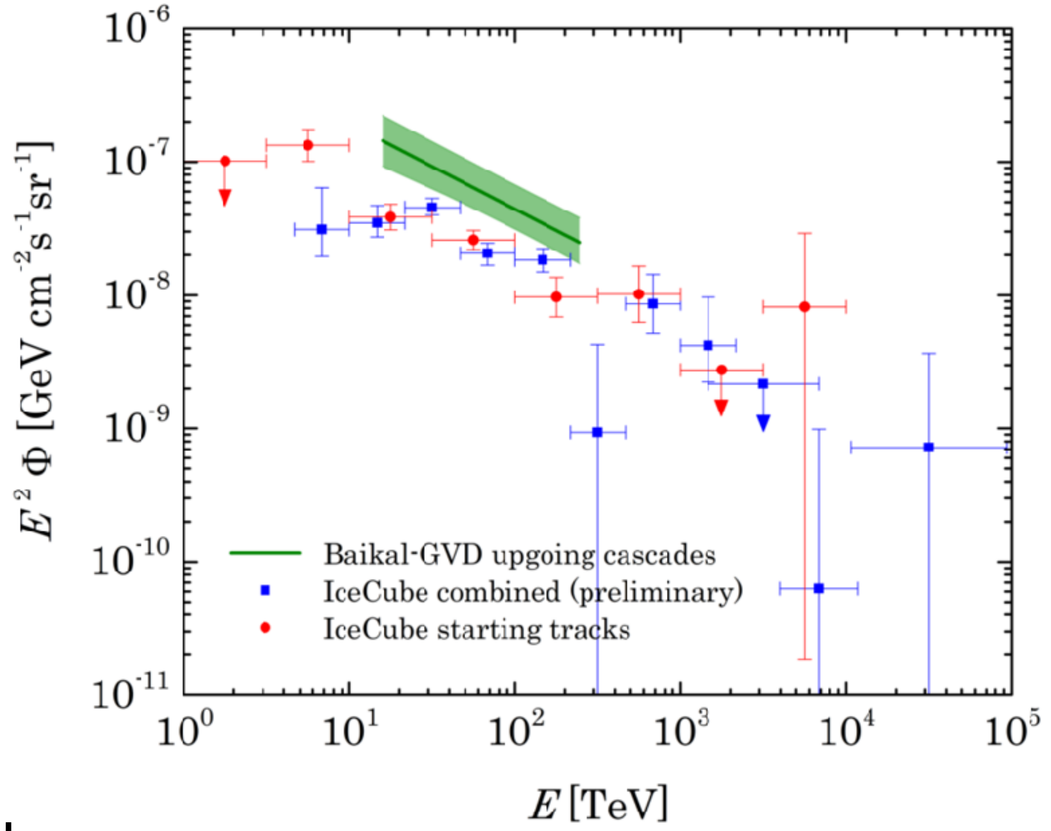
	Events
Atm. muons MC	0.9
Atm. neutrino MC	1.9
Data	18

Excess over the atmospheric background:
5.1σ (stat. & syst.)

[arXiv:2507.01893]
Older version: Phys. Rev. D **107**, 042005, February 2023

Single Power-Law Model of Astrophysical Flux





The best fit parameters for the single power law model:

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

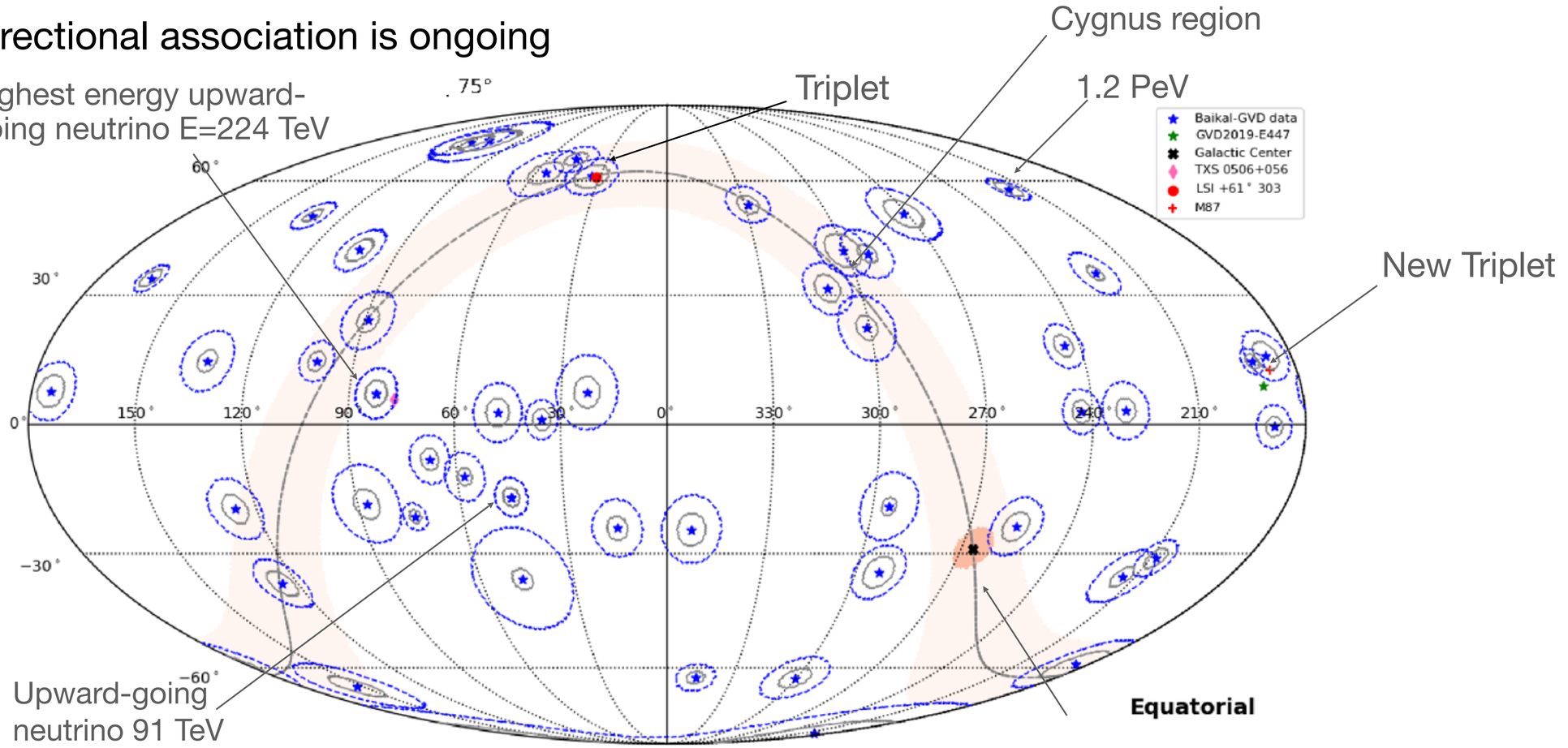
$$\phi_{\rm astro} = 4.42^{+2.31}_{-1.29} \times 10^{-18}{\rm GeV}^{-1}{\rm cm}^{-2}{\rm s}^{-1}{\rm sr}^{-1}$$

$$\Phi^{\nu+\bar{\nu}}_{astro} = 3 \times 10^{-18} \phi_{astro} \left(\frac{E_\nu}{E_0}\right)^{-\gamma_{astro}} {\rm GeV}^{-1}\ {\rm cm}^{-2}\,{\rm s}^{-1}\,{\rm sr}^{-1}$$

High-Energy Cascade Sky Map

Data from April 2022 to March 2024 double the statistics:

- Excess over the atmospheric background is 5.1σ.
- Search for directional association is ongoing



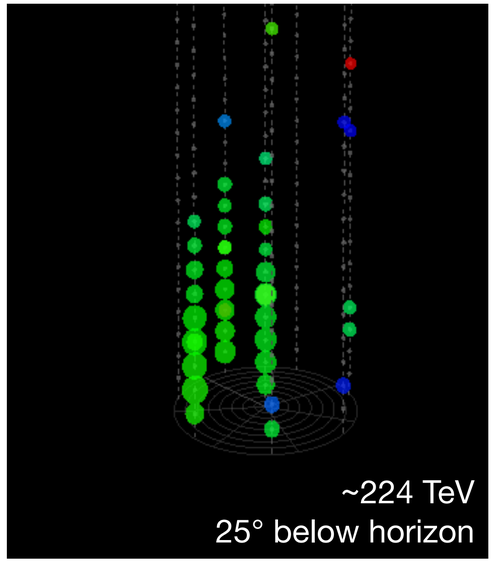
Best fit positions and 90% angular uncertainty regions

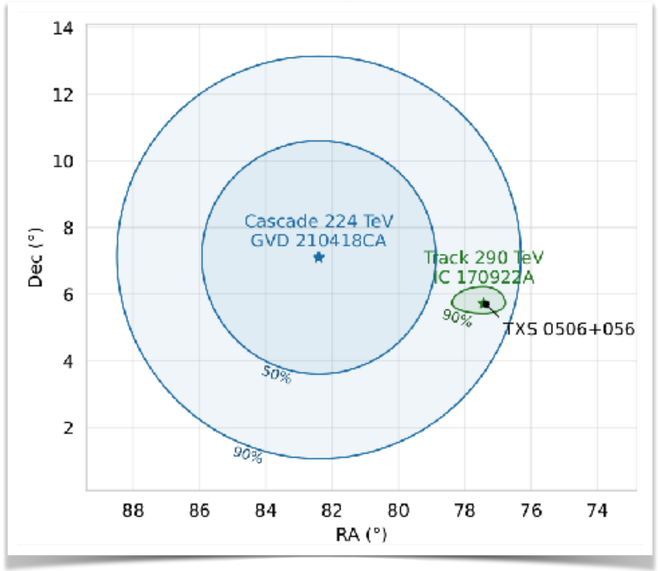
About half of the events are background from atmospheric muons and neutrinos

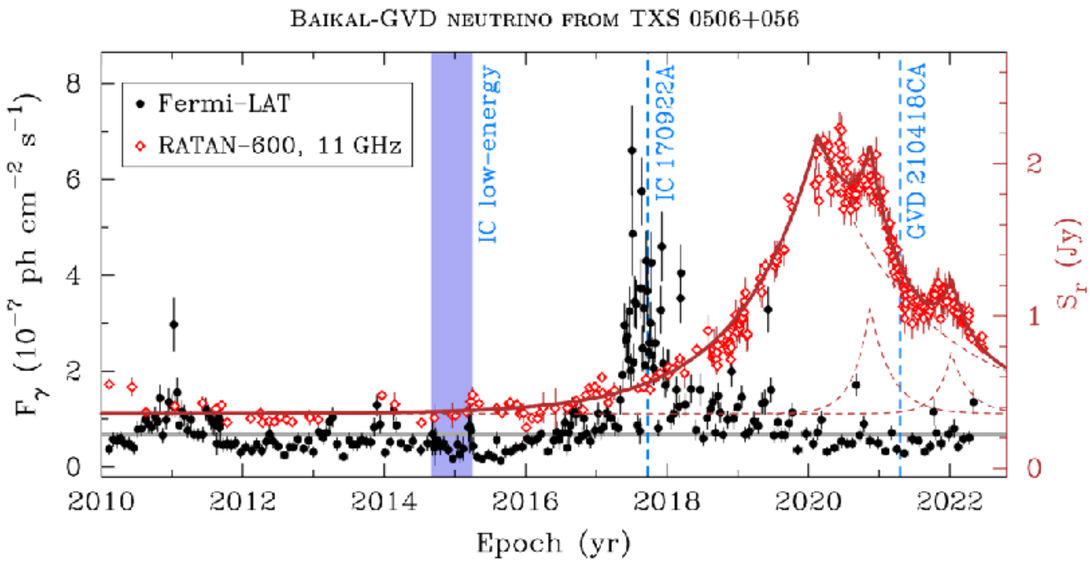
For a search for associations with VLBI blazars using a subset of this sample see MNRAS 526, 942–951 (2023)

Most energetic upgoing cascade event

Best candidate for neutrino events of astrophysical origin







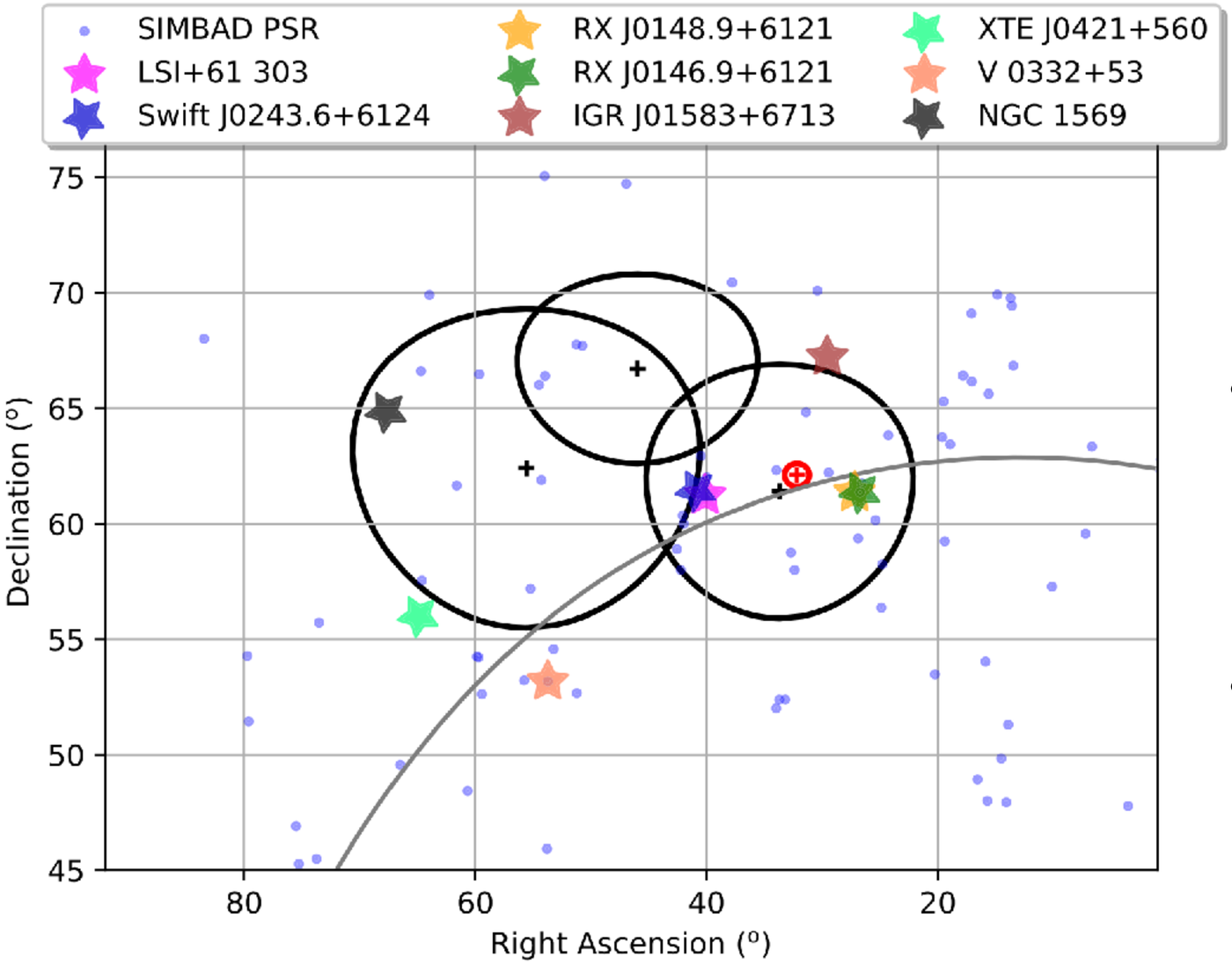
Closest sources (in 6 degrees):

- TXS 0506+056 Blazar (BL Lac) at z= 0.34 (5.7 Gly) is IceCube neutrino source observed at 3.7σ
- This event is probably of astrophysical origin (signalness = 97%).
- Chance probability of coincidence p=0.0074 (2.7σ)

Monthly Notices of the Royal Astronomical Society, Volume 527, Issue 3, January 2024, Pages 8784–8792

Event Triplet near Galactic Plane

Intriguing events



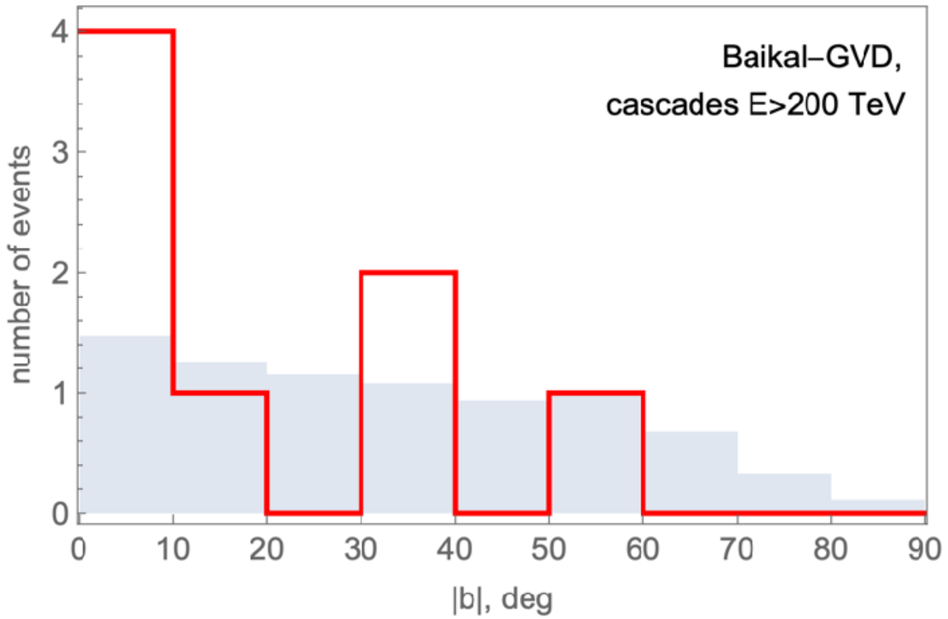
Chance probability to observe such a triplet was estimated as 0.024 (2.3 σ)

- γ-ray microquasar LS I +61 303 (very well known high energy Galactic source, only 2.6 kpc away) and the two Baikal-GVD events with 3.1° and 7.4° from the source (both are downgoing events)
- Highest significance IceCube persistent Northern hot spot (red plus and circle)

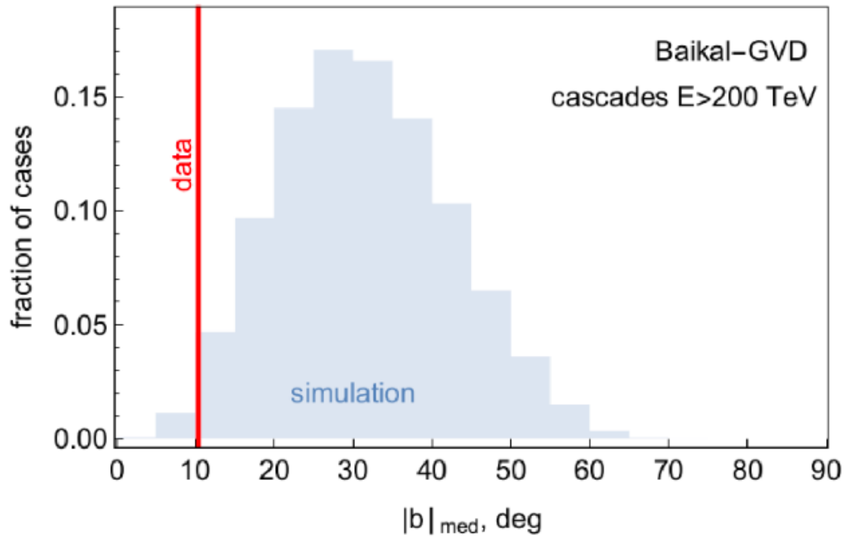
Monthly Notices of the Royal Astronomical Society, Volume 526, Issue 1, November 2023, Pages 942–951

Galactic Neutrinos with the Highest Energies

- High-energy cascades April 2018- March 2024 (6 years of operation)
- Test the Galactic excess at E>200 TeV (8 events, 64% of astrophysical origin)
- Simplest model-independent test using median of galactic latitude $|b|_{med}$
- Galactic component is visible with a significance of 2.5σ
- IceCube cascades and tracks also demonstrate the Galactic excess
- Fraction of Galactic events reaches several tens of percent at E>200 TeV disagreeing many theoretical predictions



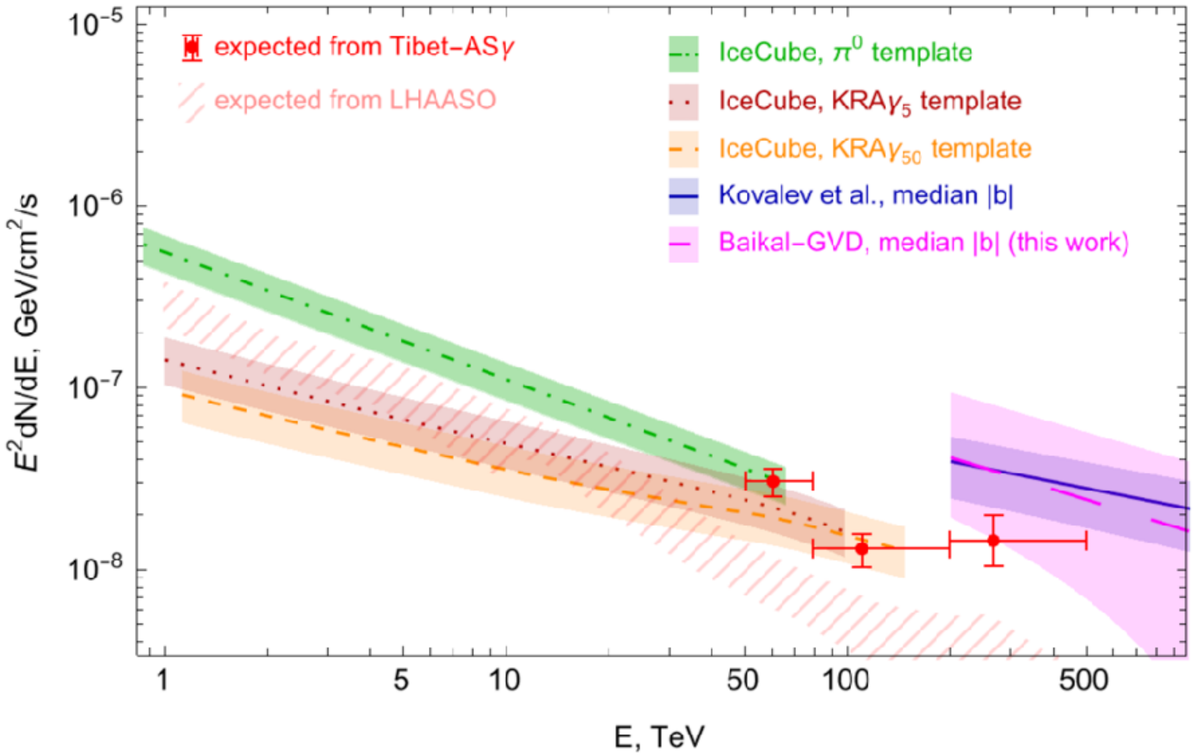
Sample	$\|b\|_{\rm med}$ observed	$\langle\|b\|_{\rm med}\rangle$ expected	p
Baikal-GVD cascades	10.4°	31.4°	$1.4 \cdot 10^{-2}$ (2.5σ)
IceCube cascades	12.4°	31.9°	$8.7 \cdot 10^{-3}$ (2.6σ)
combined cascades	12.4°	31.5°	$1.7 \cdot 10^{-3}$ (3.1σ)
IceCube tracks	24.7°	36.0°	$1.8 \cdot 10^{-3}$ (3.1σ)
all cascades+tracks	23.4°	35.0°	$3.4 \cdot 10^{-4}$ (3.6σ)

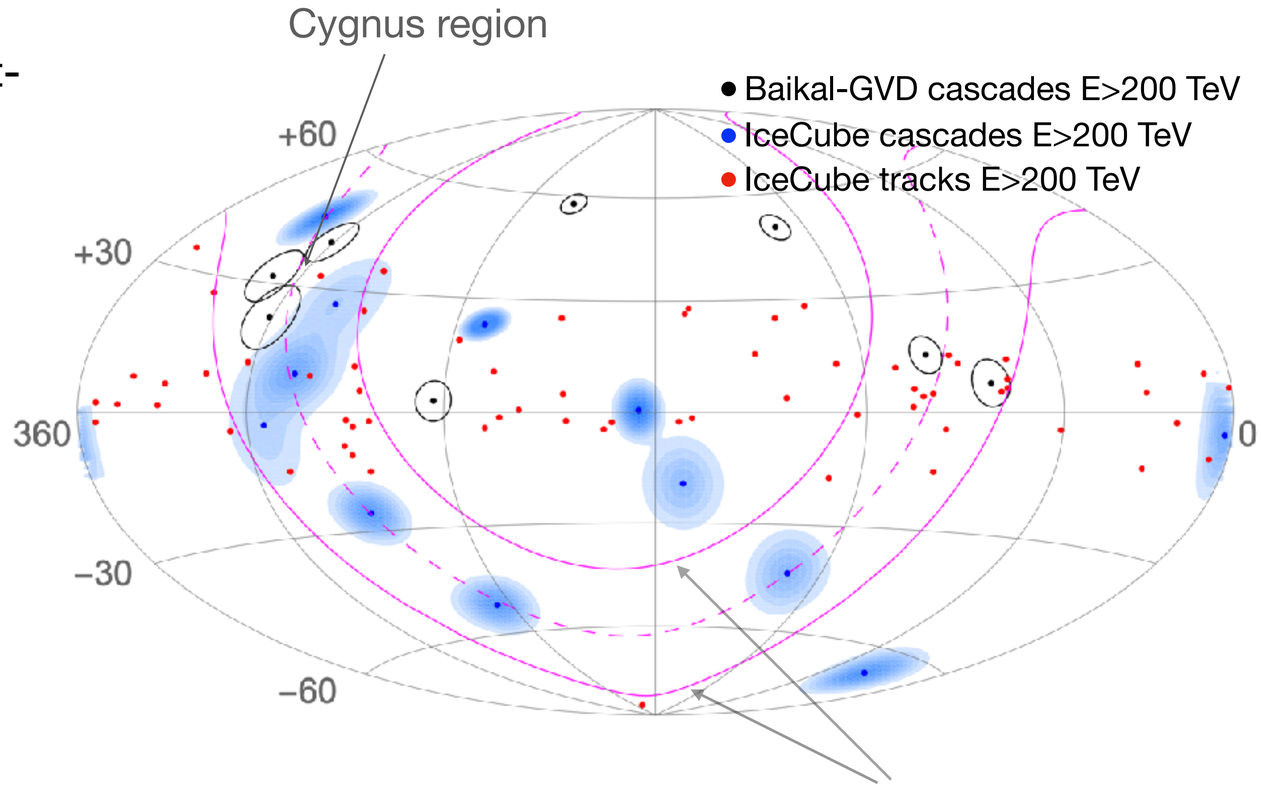


ApJ 982 (2025) 73 (arXiv:2411.05608)

Galactic Neutrinos with the Highest Energies

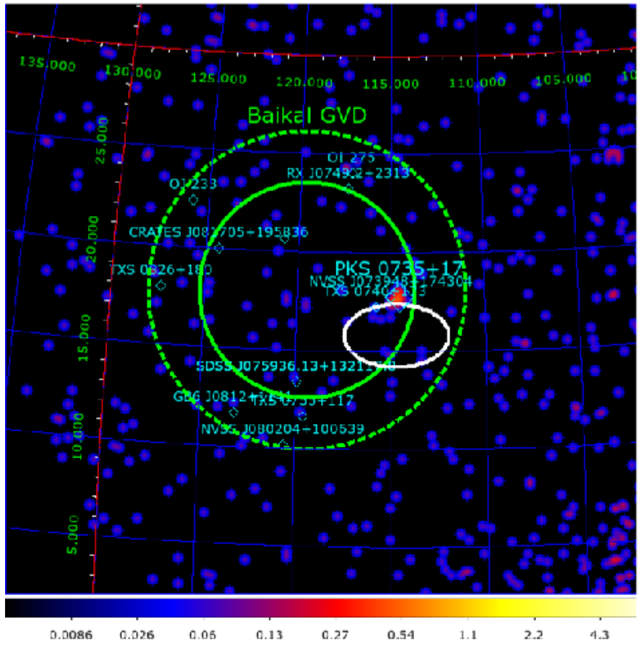
- Very rough estimate of the Galactic neutrino flux is obtained
- Agrees with Galactic gamma-ray diffuse emission by Tibet-ASy
- Some event clustering towards the Cygnus region





Baikal-GVD Follow-up of IceCube-211208A / PKS 0735+17

- Fast processing system for transient sources has been working since 2021
- Dec 8, 2021 20:02: IceCube “Astrotrack Bronze” neutrino event in the vicinity of the bright blazar PKS 0735+17
- Active state of PKS 0735+17 reported in optical (MASTER), HE gamma-rays (Fermi LAT), X-rays (Swift XRT) and radio
- Baikal-GVD found a downward-going (30° above horizon) cascade-like event 4 hours after the IceCube alert and in 5.3° from it and 4.7° from PKS 0735+17
  - E ≈ 43 TeV
  - PSF 50% (68%) containment radius = 5.5 deg (8.1 deg)
  - Pre-trial p-value = 0.0044 (2.85 σ) [24 hr, 5.5 deg cone]
  - Trial factor ~ 40 (total number of IceCube alerts analysed)



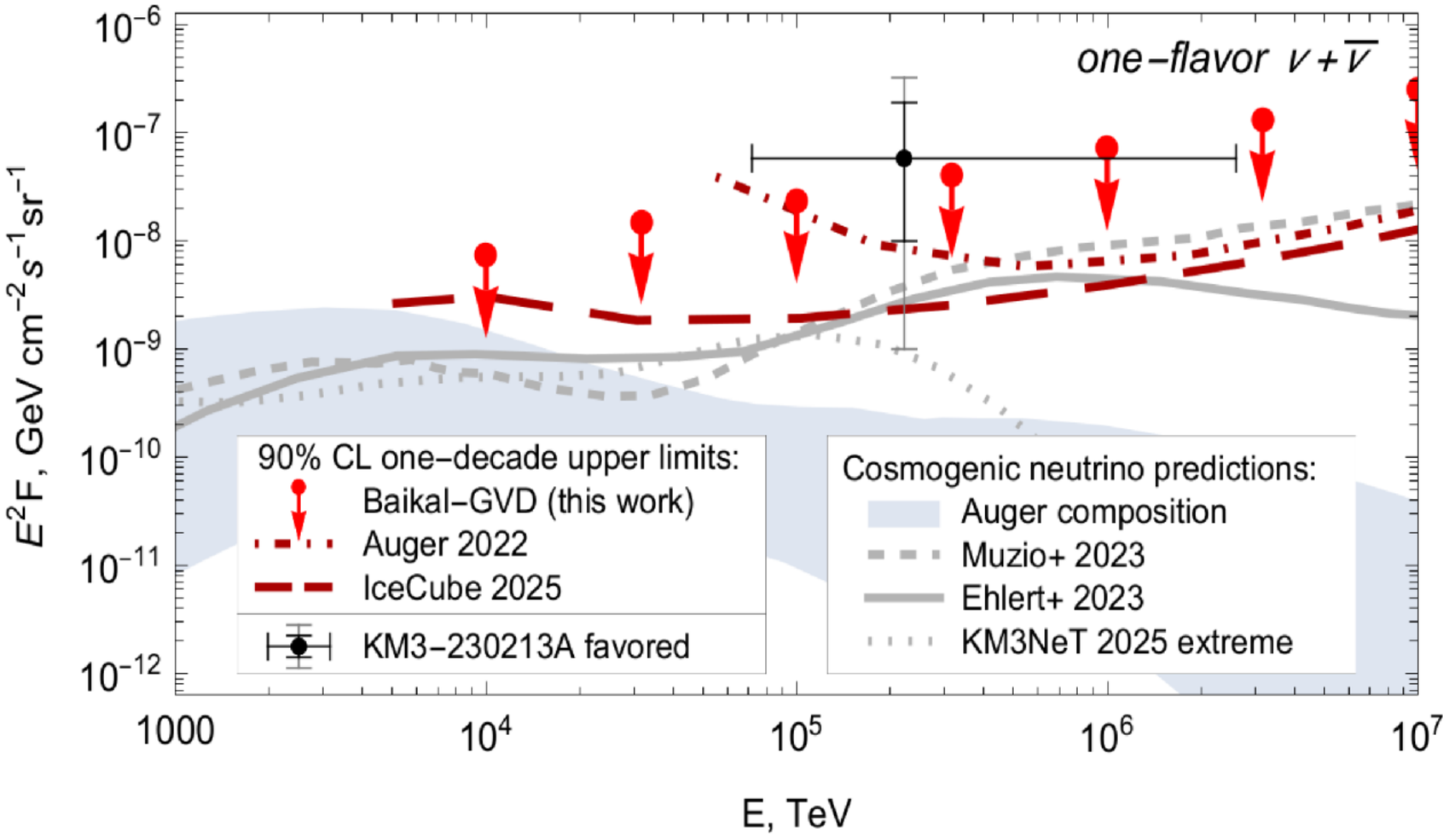
Astronomy telegram ATeL 15112 was sent

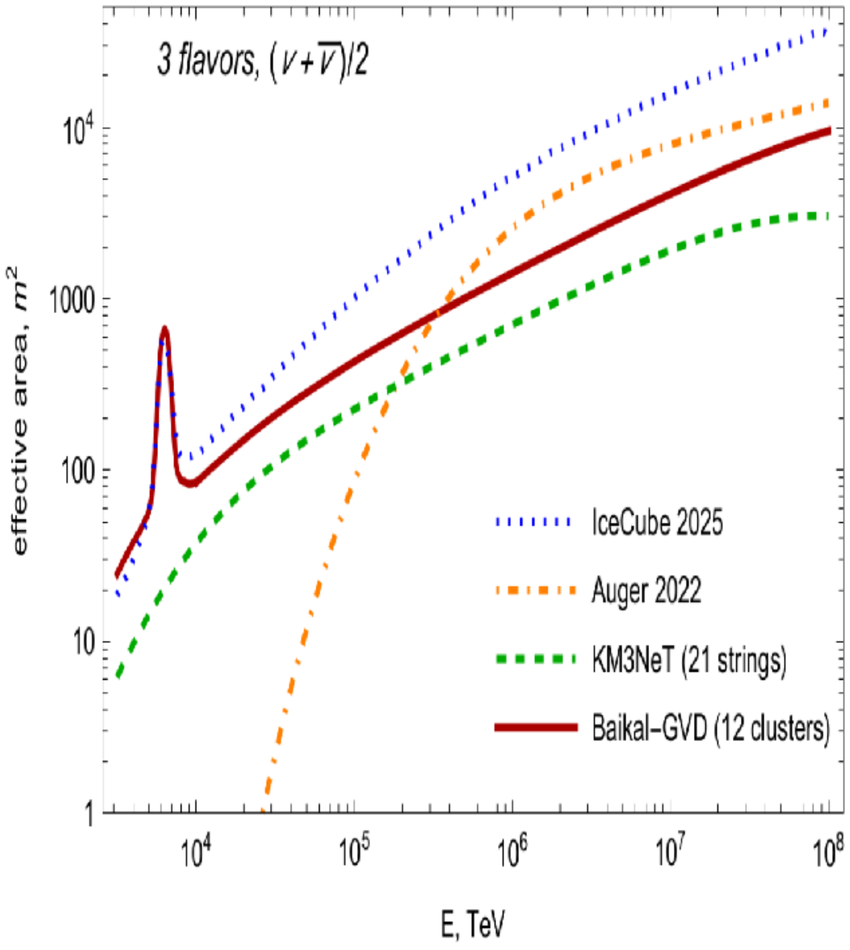
Related

- 15290 Search for neutrino counterpart to the blazar PKS0735+178 potentially associated with IceCube-211208A and Baikal-GVD-211208A with the KM3NeT neutrino detectors.
- 15148 NIR followup of the Blazar PKS 0735+178
- 15143 Baksan Underground Scintillation Telescope observation of a GeV neutrino candidate event at the time of a gamma-ray flare of the blazar PKS 0735+17, a possible source of coinciding IceCube and Baikal high-energy neutrinos
- 15136 Optical and near-infrared observations of PKS 0735+178
- 15132 Optical view of neutrino emitter candidate PKS 0735 +178
- 15130 Re-brightening of the BL Lac object PKS 0735+178 observed by Swift
- 15129 Fermi-LAT observations of flaring activity from PKS 0346-27 and PKS 0735+17
- 15113 NuSTAR observations of the blazar PKS 0735+178
- 15112 Baikal-GVD observation of a high-energy neutrino candidate event from the blazar PKS 0735+17 at the day of the IceCube-211208A neutrino alert from the same direction
- 15109 Swift monitoring of the BL Lac object PKS 0735+178 during a bright state
- 15108 SRG/eROSITA observation of PKS 0735+17
- 15106 Search for counterpart to IceCube-211208A with ANTARES
- 15105 TELAMON, Metsahovi, Medicina, OVRO and RATAN-600 programs find a long-term radio flare in PKS0735+17 coincident with IceCube-211208A
- 15102 Swift-XRT observations of the blazar PKS 0735+178 in a flaring state
- 15100 Significant optical decay and brightening in blazar PKS 0735+17 coincident with IceCube-211208A
- 15099 Fermi-LAT Gamma-ray Observations of IceCube-211208A
- 15098 MASTER OT J073807.40+174219.2 brightening during IceCube-211208A observations
- 15021 BL Lac object PKS 0735+17 is bright in optical

Constraints on Multi-PeV neutrinos

Using non-observation of cascade-like events above $10^{3.5}$ TeV

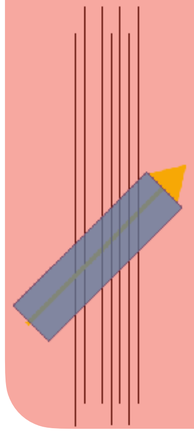




[arXiv:2507.05769]

Event Topologies

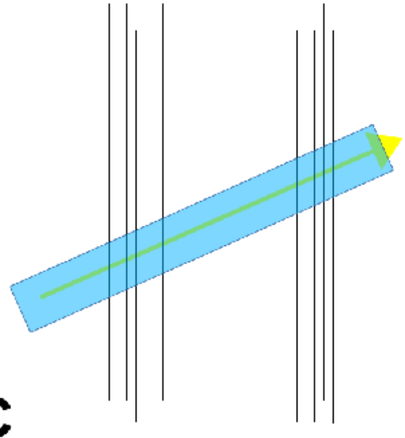
Single-cluster tracks



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

Results are coming

Multi-cluster tracks

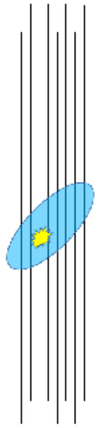


- Moderately low energy threshold
- Optimal sensitivity to inclined tracks
- Best angular resolution

ν_μ CC

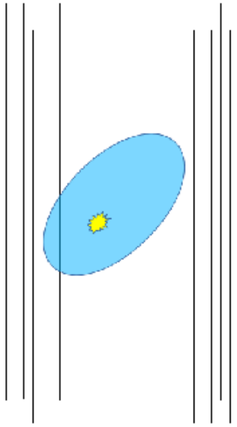
NC, ν_e ν_τ CC

Single-cluster cascades



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

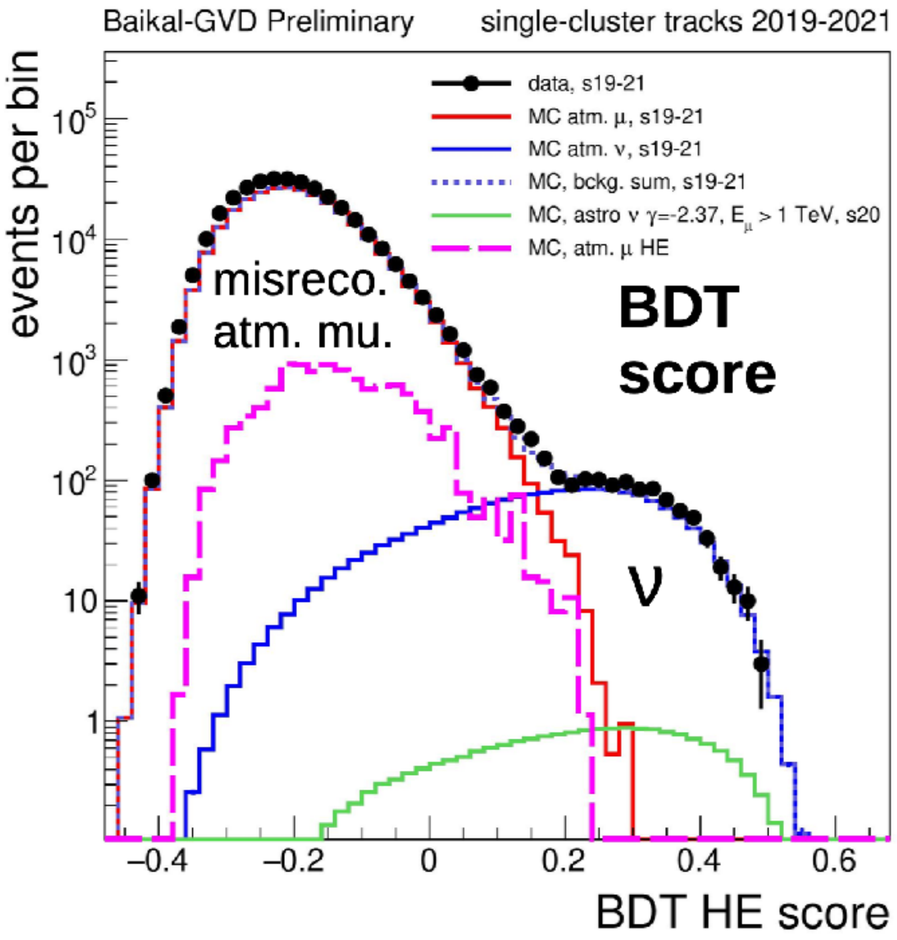
Multi-cluster cascades

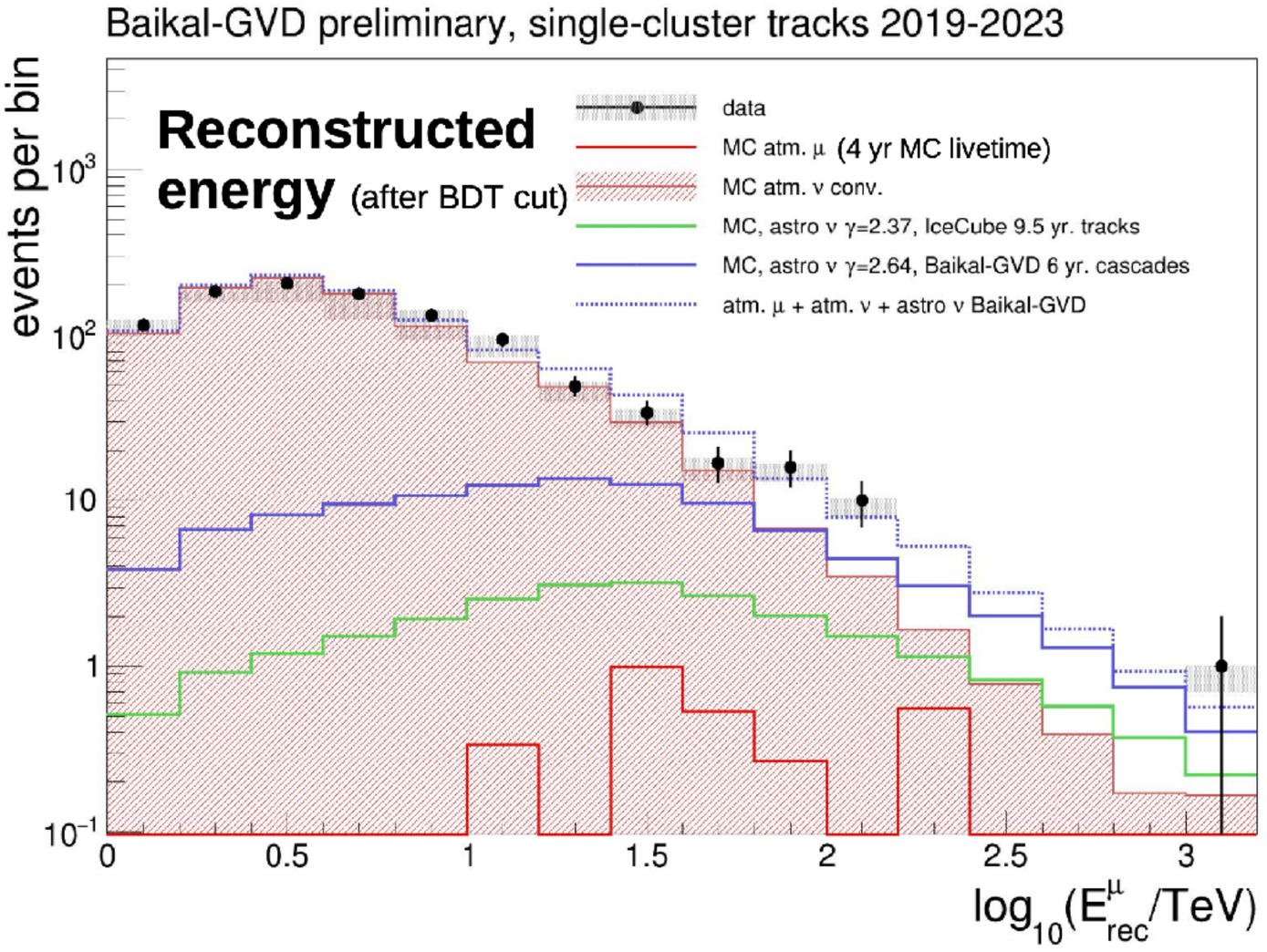


- Very high energy threshold
- Excellent energy resolution
- Very rare events

Towards diffuse flux with tracks

"Upgoing" events only





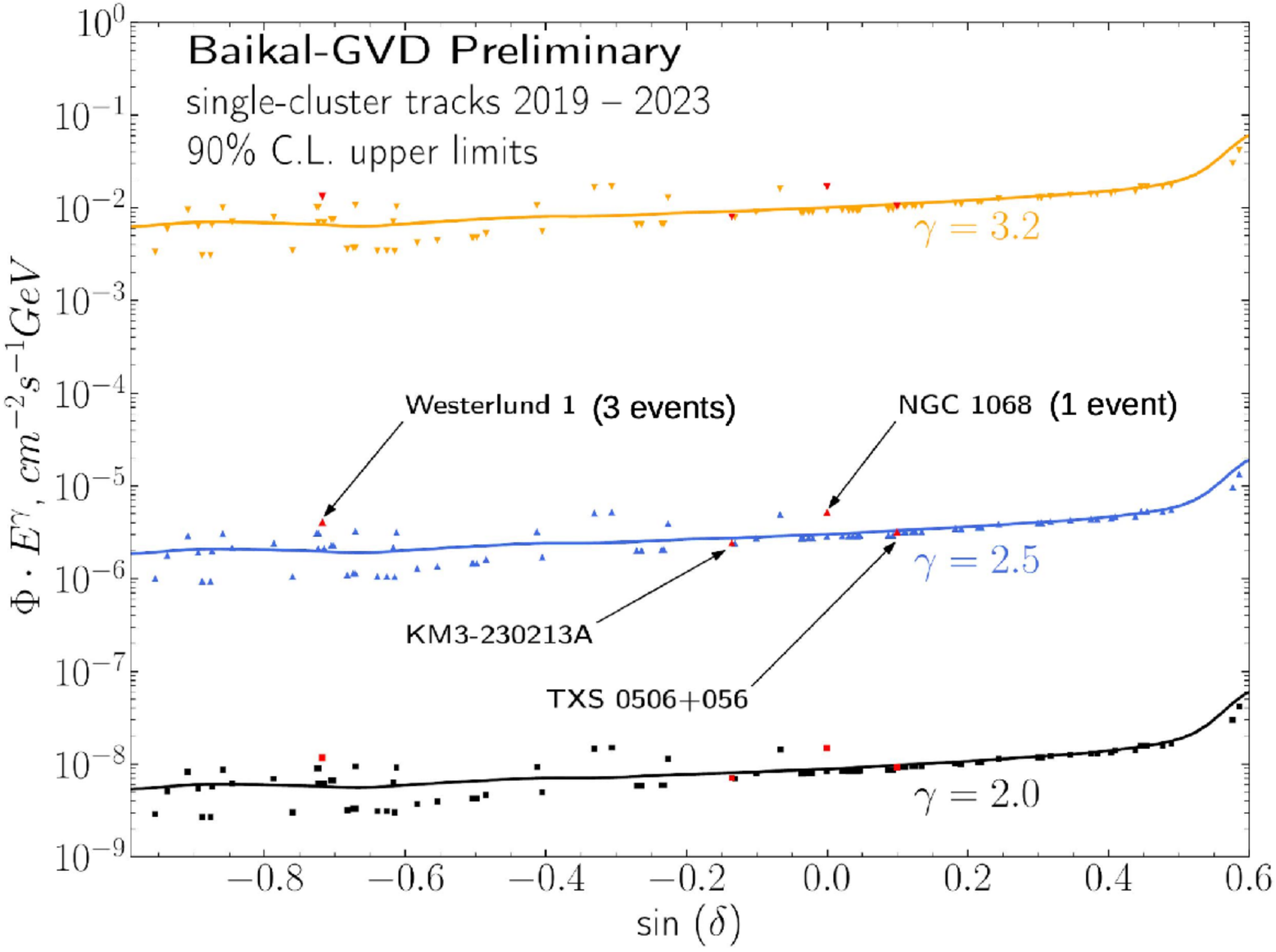
[G. Safronov et al, PoS (ICRC2025) 1162]

$BDT_{HE} > 0.26$, $E^{\mu}_{rec} > 45$ TeV

→ 38 events observed while 25 events expected from background

Error bars for MC not shown

Point-like source search with tracks



Guided search over a list of 112 objects using a simple cut & count analysis

5-year dataset: Apr 2019 - Mar 2024

The cuts on BDT and angular distance were optimized for best sensitivity to E^{-2} spectrum

The sensitivity is similar the level of ANTARES 15 yr (and will be further improved)

The object with most events in the search cone (3) is Westerlund 1 (bkg=0.3; 2.89 σ pre-trial)

G. Safronov et al, PoS (ICRC2025) 1162

JINR neutrino program

the largest neutrino program conducted at a single institute

- Neutrino interactions:
  νGeN, Ricochet, DsTau, FASER
- Three-flavor neutrino oscillations:
  JUNO, NOvA, T2K
- Sterile neutrinos, monitoring of the nuclear reactor:
  DANSS
- Neutrinoless double β-decay:
  LEGEND, SuperNEMO, MONUMENT, Zr-BNO, Se-LSM, TGV
- Theoretical support from JINR Laboratory of theoretical physics

Joint Institute for Nuclear Research

SCIENCE BRINGS NATIONS TOGETHER

JINR neutrino program

the largest neutrino program conducted at a single institute

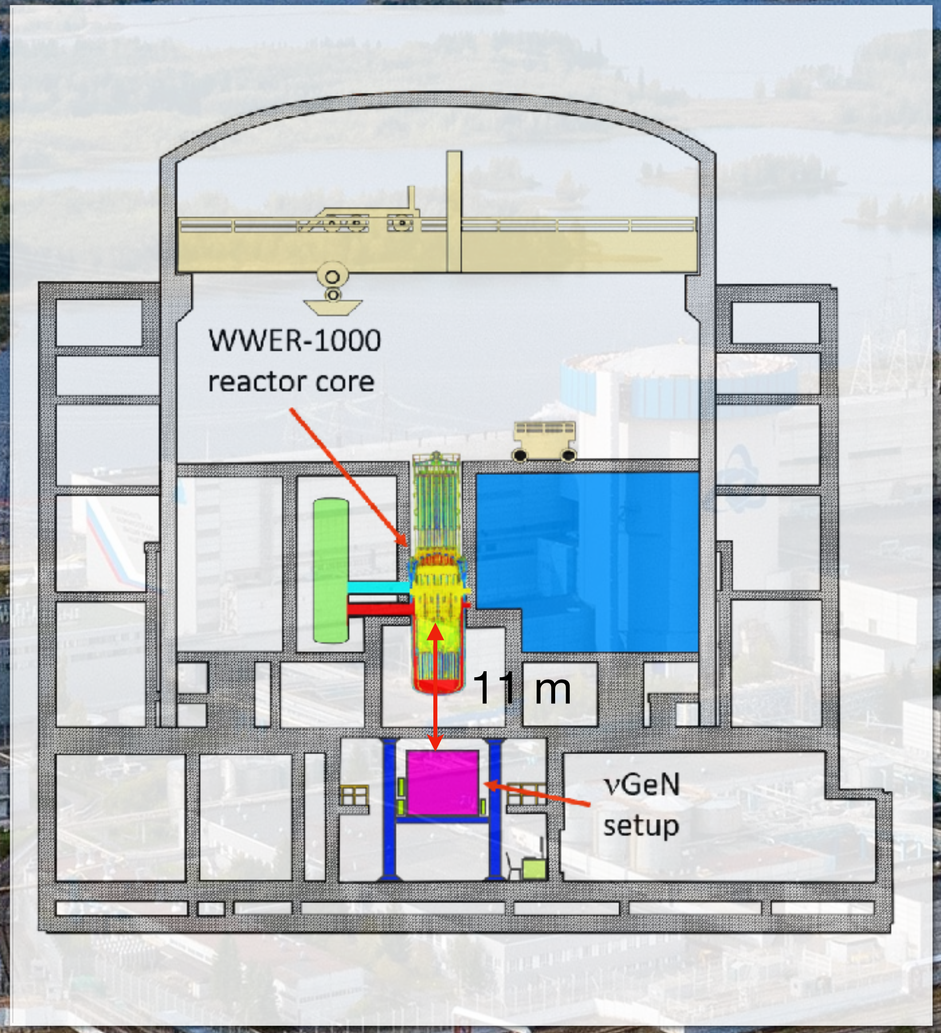
- Neutrino interactions:
  ν**GeN, Ricochet, DsTau, FASER**
- Three-flavor neutrino oscillations:
  JUNO, NOvA, T2K
- Sterile neutrinos, monitoring of the nuclear reactor:
  DANSS
- Neutrinoless double β-decay:
  LEGEND, SuperNEMO, MONUMENT, Zr-BNO, Se-LSM, TGV
- Theoretical support

Joint Institute for Nuclear Research

SCIENCE BRINGS NATIONS TOGETHER

Neutrino experiments at Kalinin Nuclear Power Plant

285 km from JINR



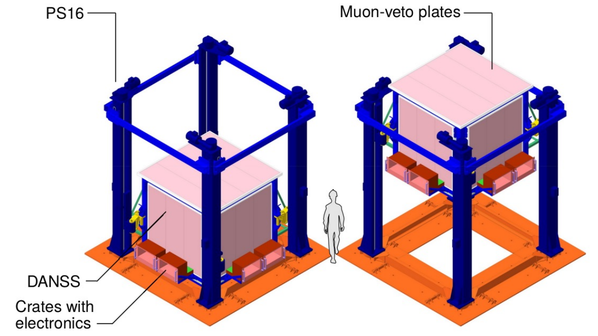
νGeN

DANSS

DANSS experiment at Kalinin Nuclear Power Plant

Search for short-range active-sterile neutrino oscillations and remote monitoring of the reactor.

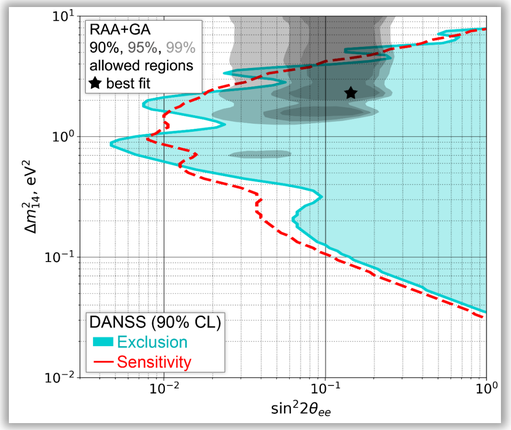
- ✓ DANSS started in April 2016 and is still running.
- ✓ DANSS records more than **5k antineutrino events per day (world record)**. More than **7.7M IBD events** collected. **Signal to background ratio is > 50**.
- ✓ Precision reactor monitoring: **1.5% accuracy** / in two days
- ✓ DANSS **excludes a large portion of the short based active-sterile oscillations** parameter space. Recent analysis provides even stronger exclusion of the parameters of **Reactor Antineutrino Anomaly + Gallium Anomaly** best fit (**5σ exclusion** was obtained with one-year data analysis.)
- ✓ **DANSS upgrade** is in progress. New calorimeter with **improved energy** resolution $(34\%/\sqrt{E} \rightarrow 12\%/\sqrt{E})$ and **1.7 times larger fiducial volume is partly ready.** The aim is to reach **a sensitivity to** check **Neutrino–4 and BEST** results in a model independent way.



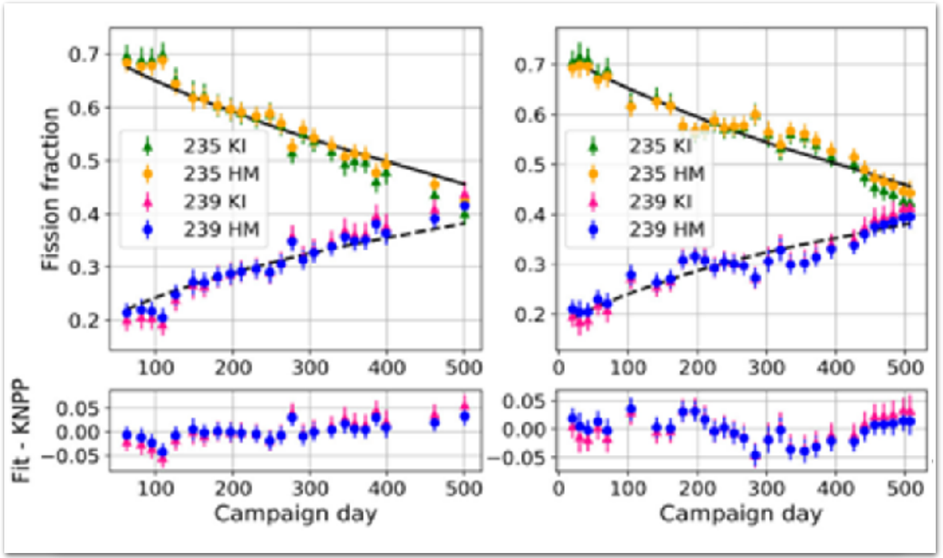
2500 scintillation counters with Gd-doped coating (0.35%wt) = 1 m³ of sensitive volume

$\bar{\nu}_e \rightarrow \nu_s$

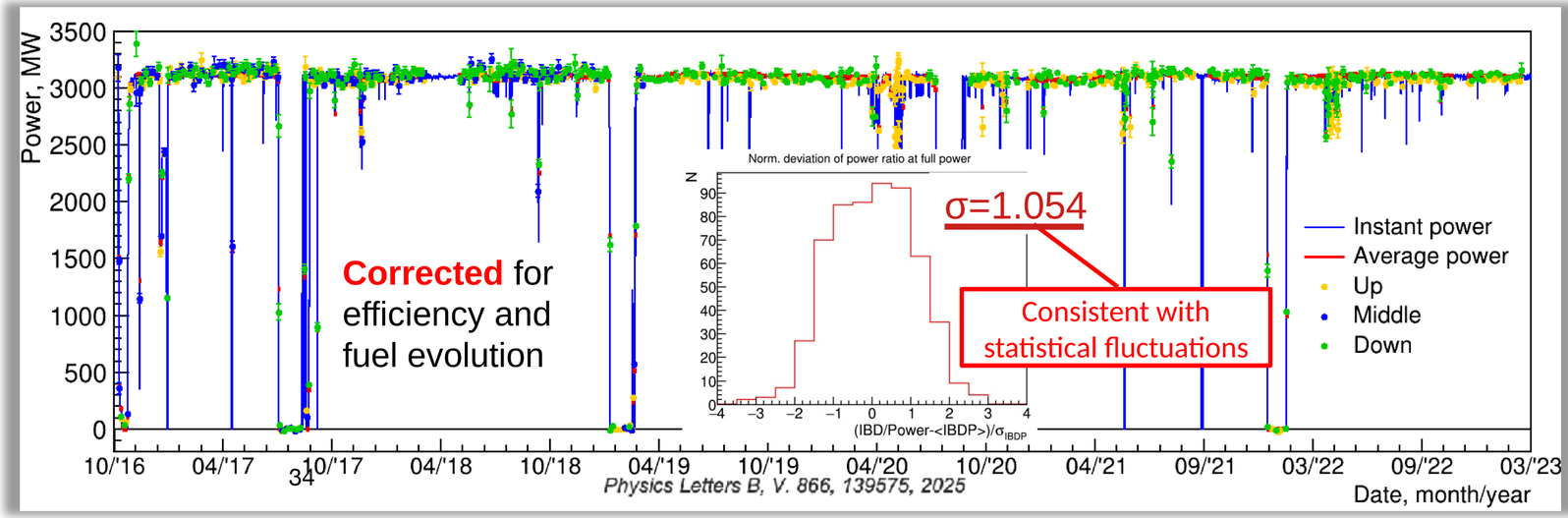
disappearance search



First extracted ^{239}Pu and ^{235}U fission fractions evolution using antineutrinos

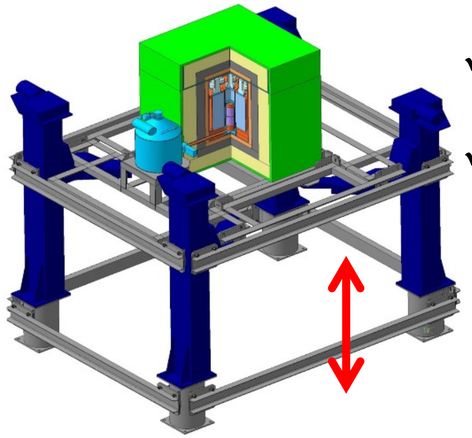


Power monitoring



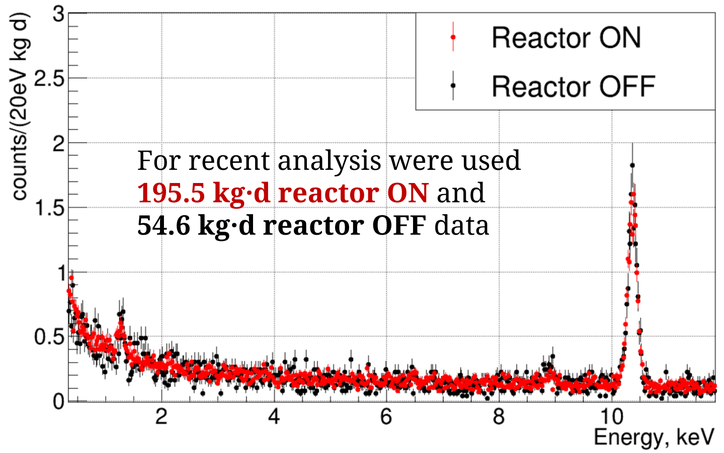
νGeN experiment at Kalinin Nuclear Power Plant

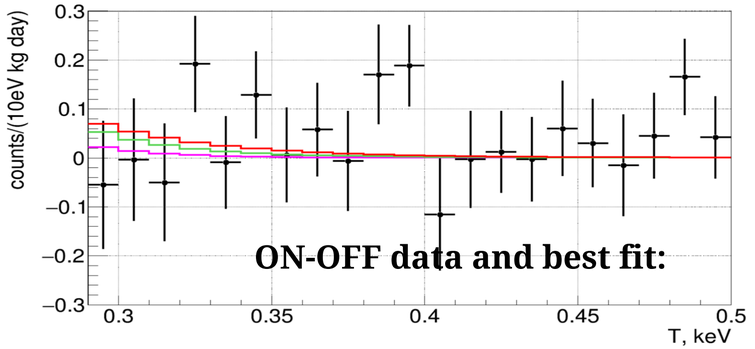
Aims: Coherent elastic neutrino-nucleus scattering (CEνNS), the search for the magnetic moment of neutrino (MMN), search for New Physics beyond the SM, and many other applications, including reactor monitoring.



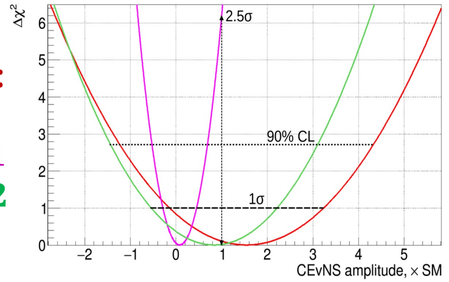
- ✓ Low-threshold, low-background HPGe detector.
- ✓ Detector with a mass of 1.4 kg. Good performance and stability were observed during measurements. No significant difference between regimes with reactor ON and OFF due to CEvNS has been observed so far. The new limit on the CEvNS is obtained depending at quenching model was used.

- ✓ Accumulated more than 1470/160 kg·d of ON/OFF data so far. Measurements with the νGeN spectrometer are ongoing. More results are coming soon.
- ✓ An upgrade of the setup is planned at 2025: new active veto, electronics with pulse shape discrimination, better shielding, new detectors…





Quenching models:
CONUS - C
Dresden-II Fef – D1
Dresden-II Ybe – D2



QF	$A_{best} \pm \sigma_A$, ×SM	χ^2_{best} (ndf=10)	S,×SM	L,×SM
C	1.5 ± 1.7	13.6	3.8	4.3
D1	0.1 ± 0.4	14.4	1.6	0.7
D2	0.8 ± 1.4	14.1	3.3	3.1

Conclusion

- Baikal-GVD is the largest neutrino telescope in the Northern hemisphere:
  - Volume approaching 0.7 km^3 for high-energy cascades
  - Angular resolution better than 1° for tracks
  - Field of view complementary to IceCube
  - Installation of 1-2 new clusters every year
- Partially installed telescope produces astrophysical results:
  - Diffuse neutrino flux is confirmed with $> 5\sigma$ significance
  - Hints of Galactic and extragalactic neutrino sources are accumulating
- The completion of work on the creation of 1 km^3 Baikal-GVD detector with ~6000 OM is planned in 2028
- JINR neutrino program is the largest neutrino program conducted at a single institute.

Thank you for attention!

Welcome to join us!