STATUS AND PERSPECTIVES OF THE BAIKAL-GVD PROJECT

Bair Shaybonov on behalf of the Baikal Collaboration,

Colloquium Towards CP violation in neutrino Physics, Prague, 25.10.19

BAIKAL COLLABORATION

9 institutions, 55 members

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. Saint Petersburg State Marine University, Russia
7. Institute of Experimental and Applied Physics, Czech Technical University, Prague, Czech Republic
8. Comenius University, Bratislava, Slovakia
9. EvoLogics, Berlin, Germany
10. Krakow Institute for Nuclear Research, Poland (associated member)

M.Markov, **1960**: 4 years after ν discovery

„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.

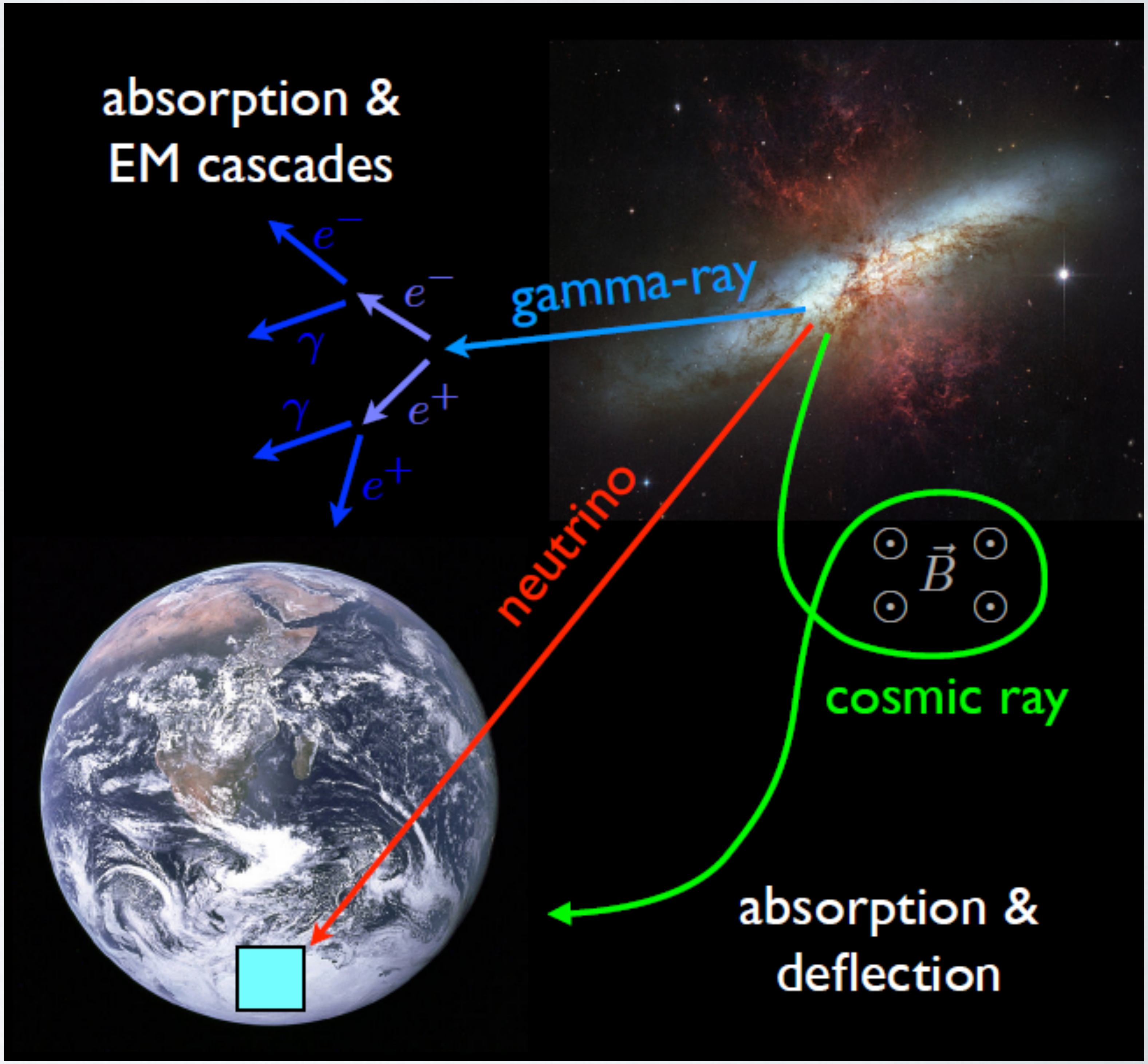
HIGH-ENERGY NEUTRINO ASTROPHYSICS

The main goal of the experiment

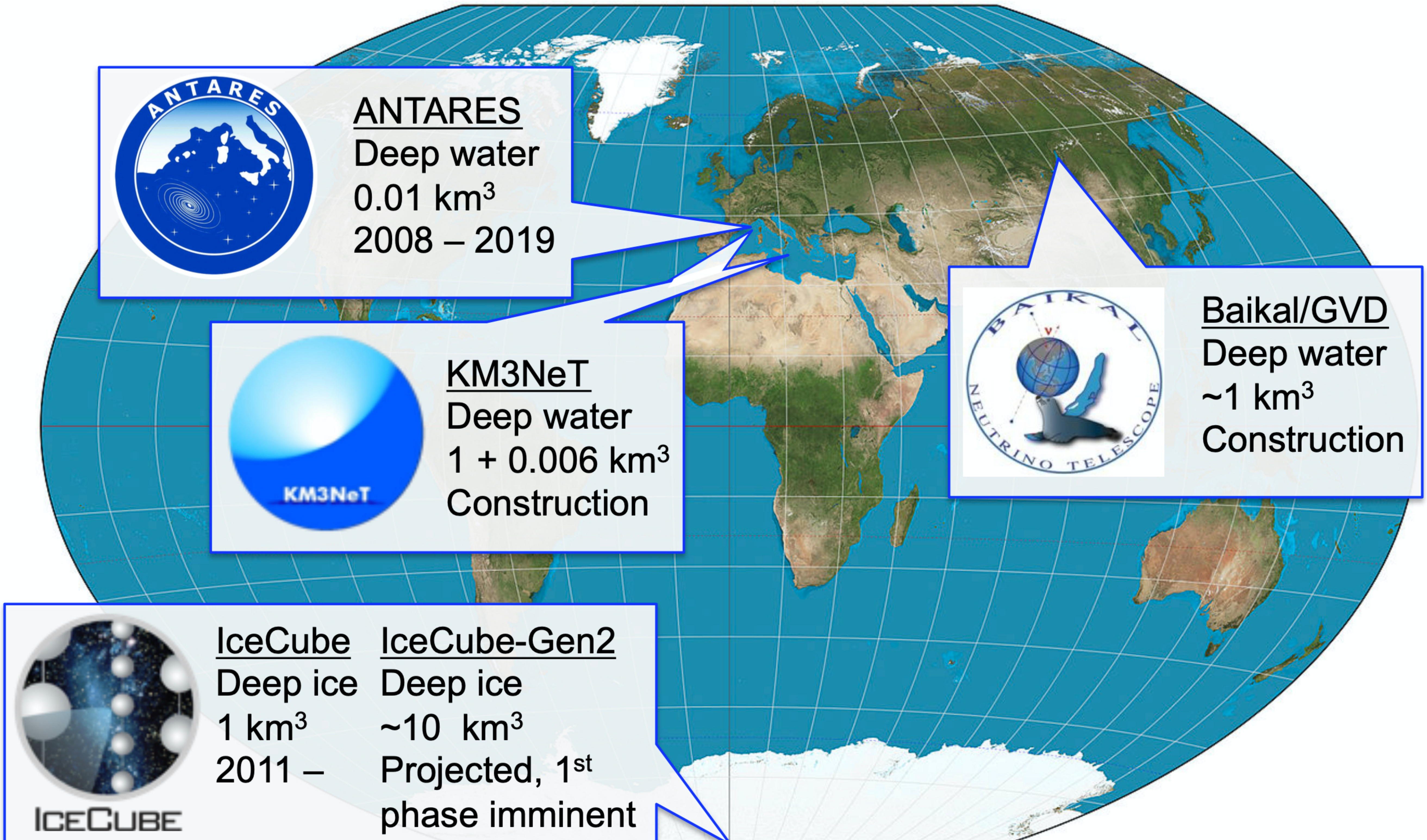
$$p+p, \quad p+\gamma \rightarrow \pi^{\pm} + \ldots$$

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

- Easily born:
  - in space accelerators
  - in cosmic rays interactions with interstellar media
- Unlike high-energy photons:
  - freely fly out of the area of birth
  - the Universe is transparent to neutrinos
- Unlike cosmic rays:
  - not deflected by magnetic fields
  - we can measure the direction of arrival → cosmic neutrino sources
- Disadvantage:
  - hard to detect → we have to build a huge detector

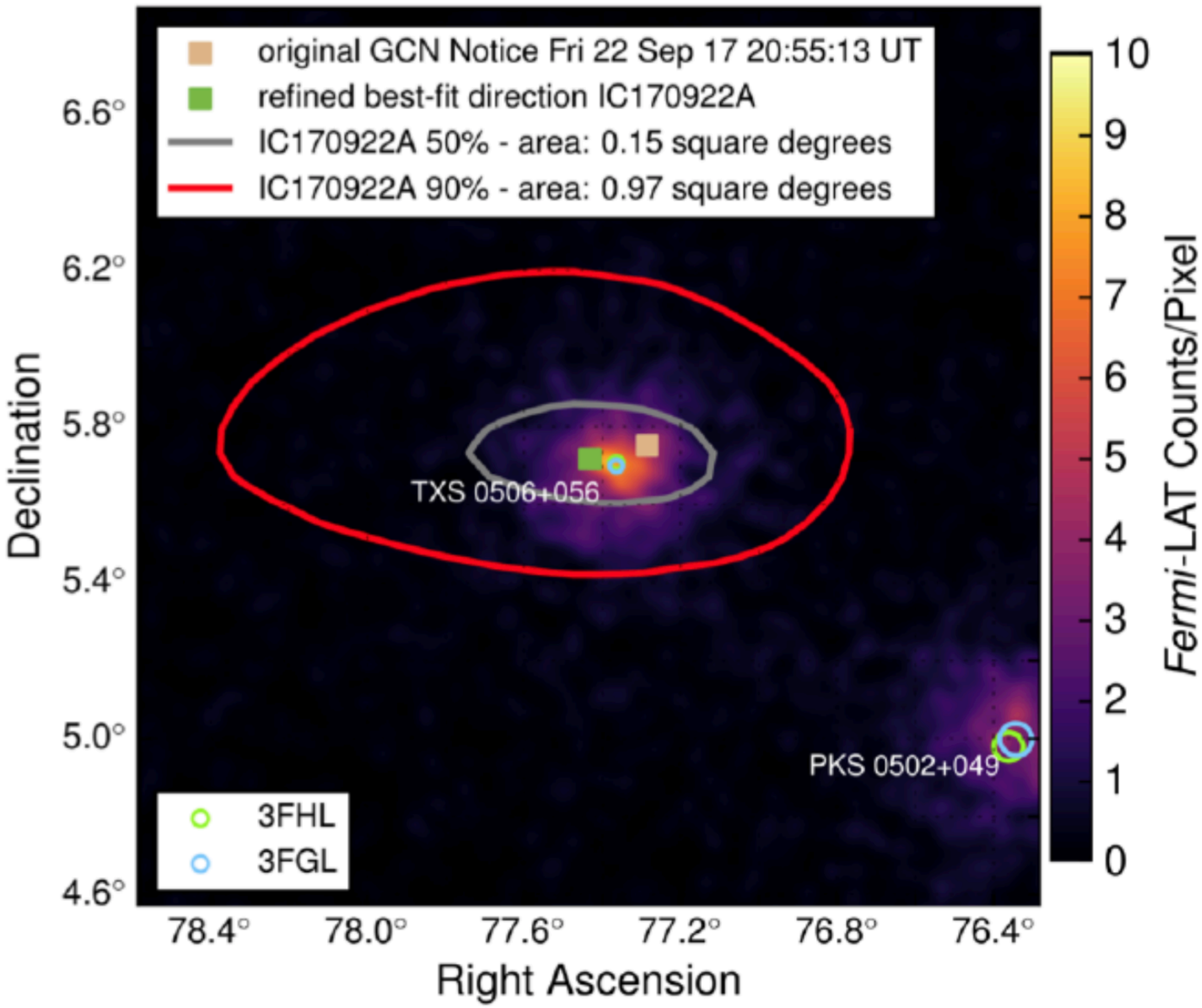


Ice/water Cherenkov neutrino telescopes - global view



103 astrophysical neutrinos detected

TXS 0506+056: First evidence of a ν source



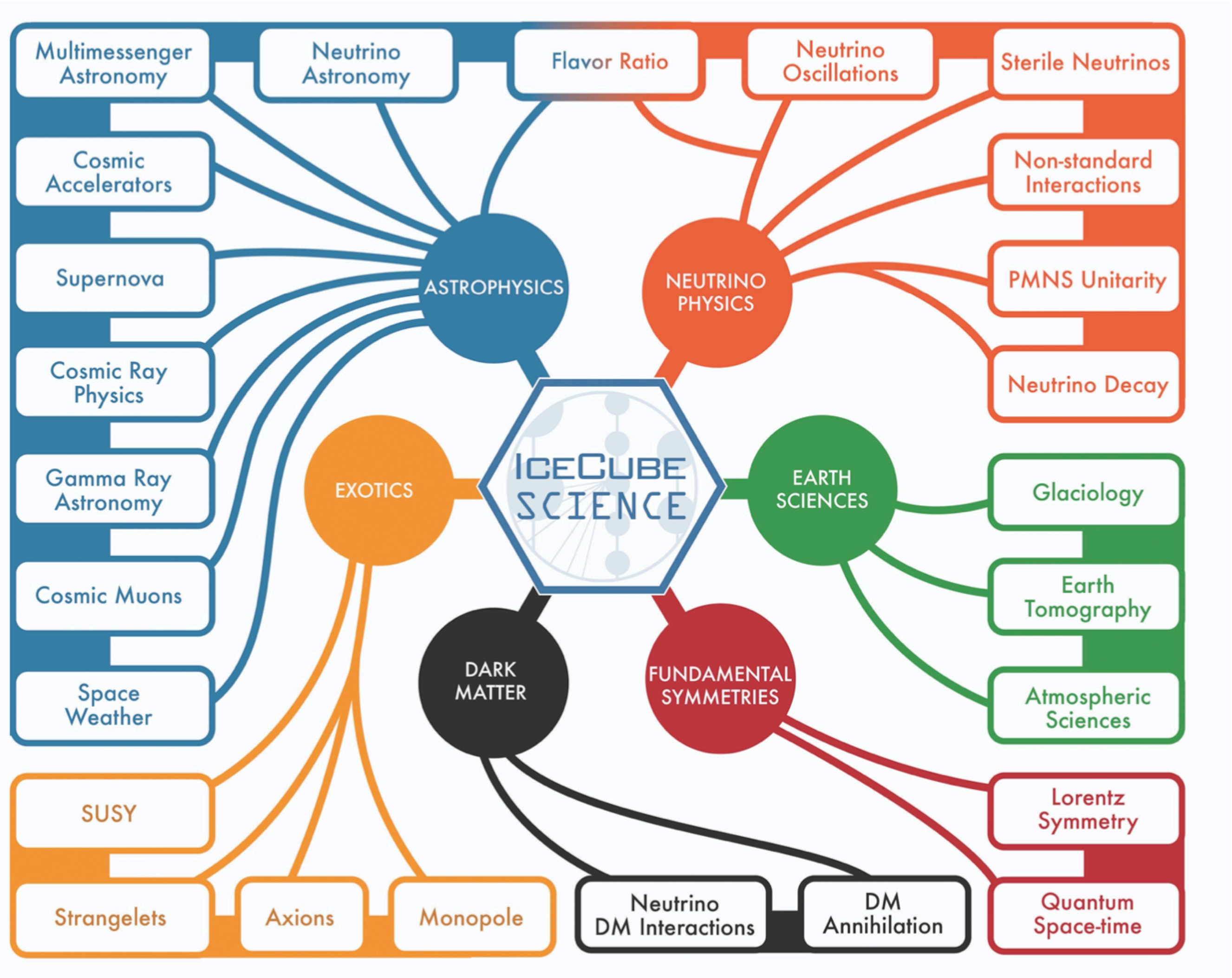
See Talks by:
- A. Franckowiak
- C. Finley (today)
- T. Glauch (HE 1)
- C. Raab (HE 1)

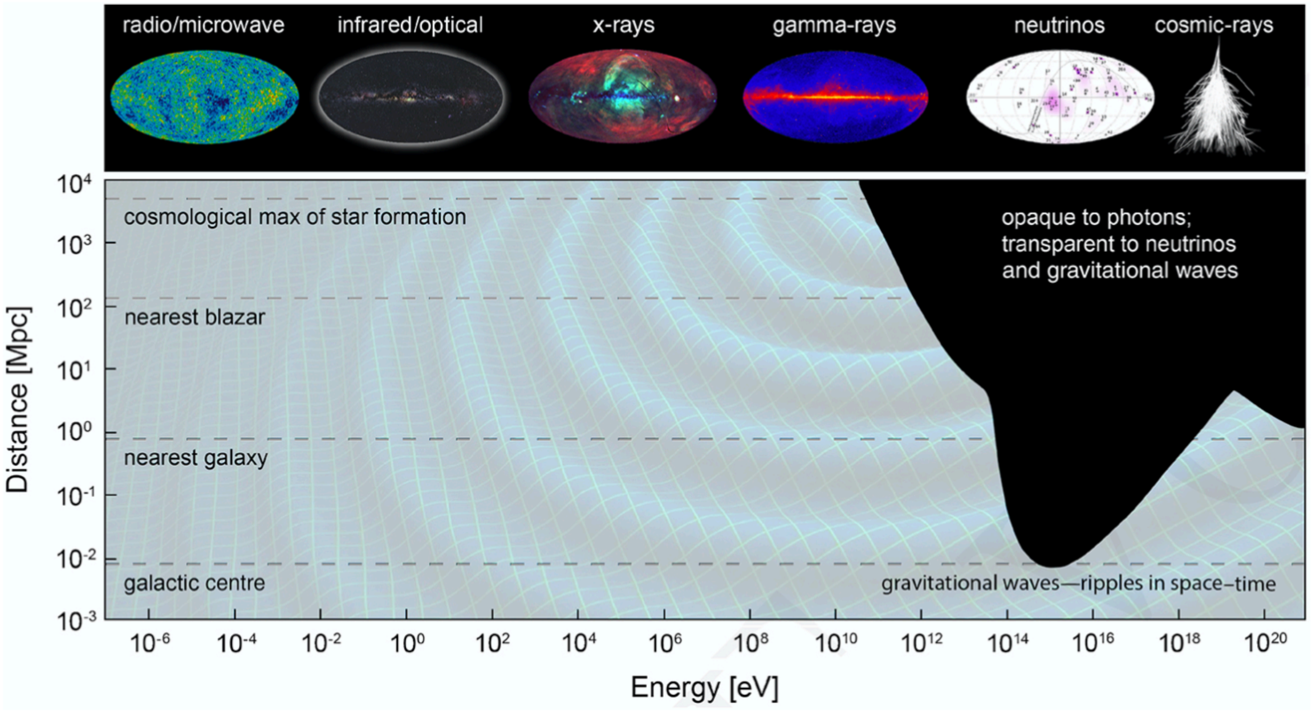
Science 361 (2018) eaat1378
Science 361 (2018) 147-151

IceCube-170922: a neutrino alert issued by IceCube
Fermi and MAGIC identify a spatially coincident flaring blazar (TXS 0506+056)
A ν-flare was found in archival IceCube data (10/2014 – 03/2015)

IceCube Science

2 Highlight Talks (D. Soldin and D. Williams)
36 parallel talks
43 posters



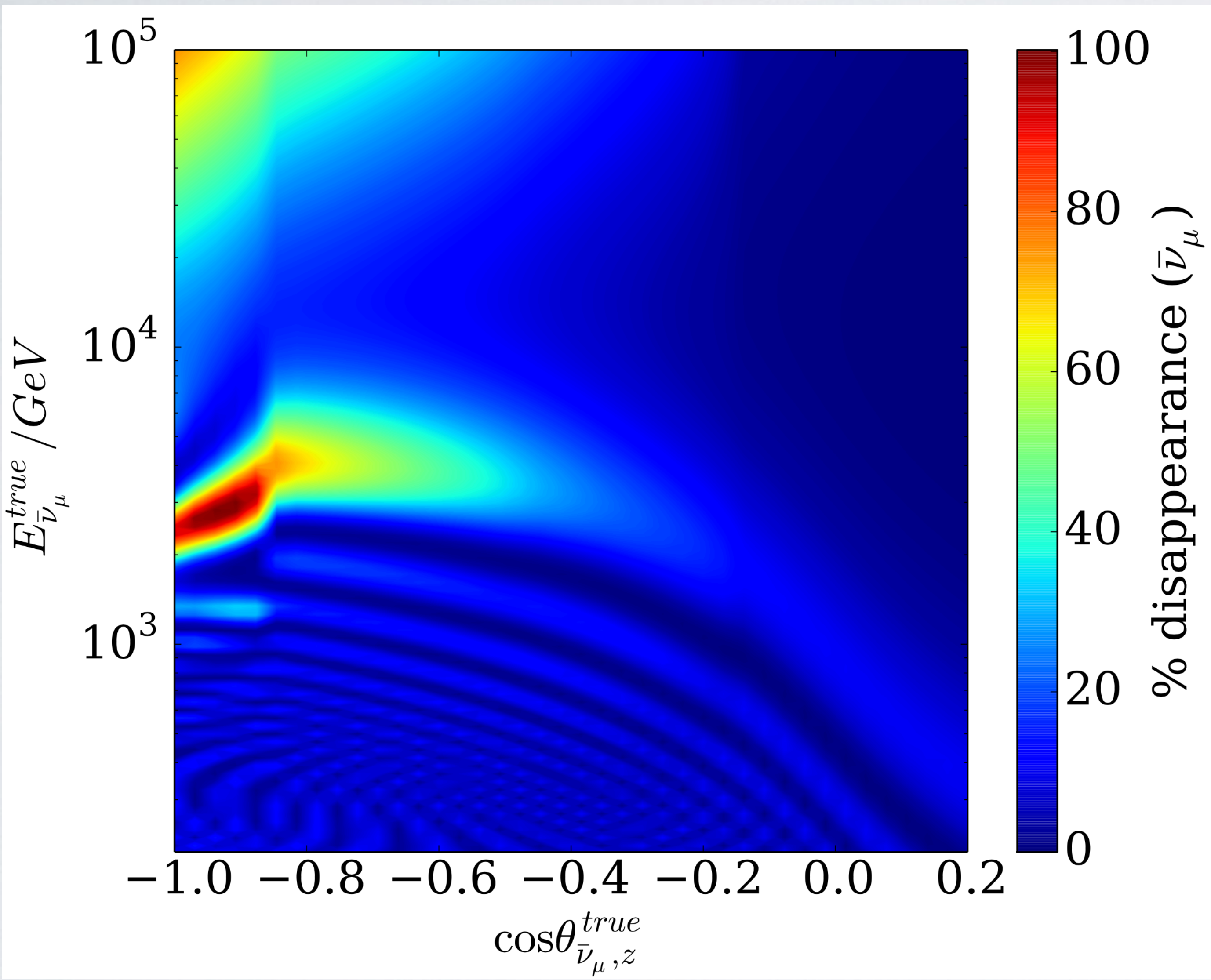


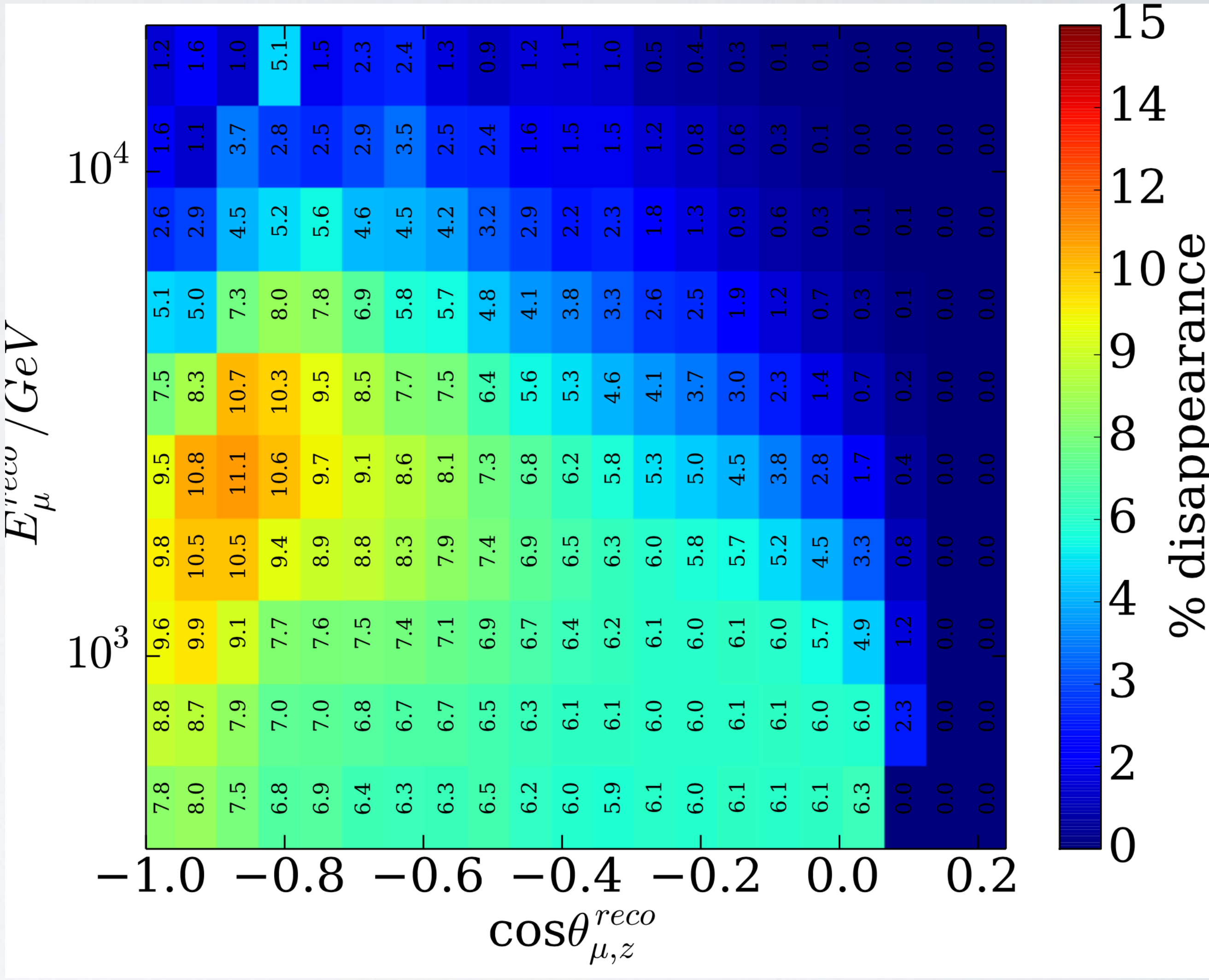
Bartos and Kowalski 2017

SEARCH FOR STERILE NEUTRINOS

IceCube papers:

- EPJ Web of Conferences **207**, 04005 (2019)
- M.G. Aartsen et al. (IceCube), Phys. Rev. Lett. 117, 071801 (2016), 1605.01990





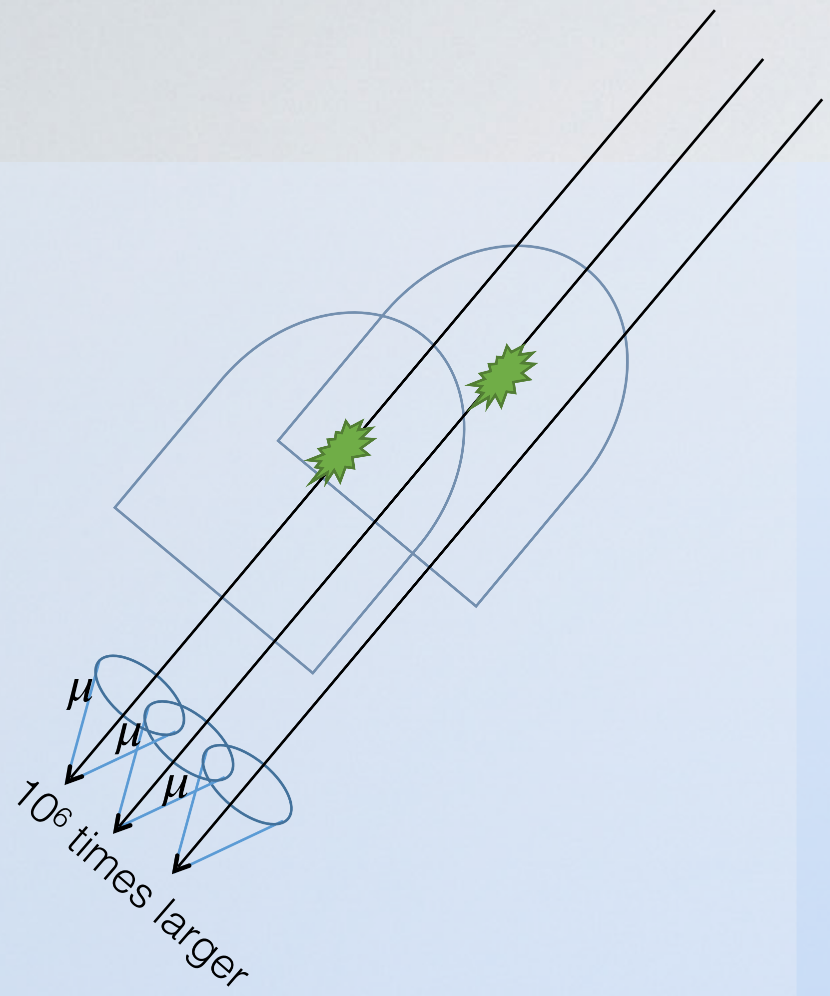
Resonant matter effects for TeV scale atmospheric neutrinos, assuming

$$\Delta m_{41}^2 \approx 1 eV^2$$

NEUTRINO DETECTION PRINCIPLE

Deep Underwater

NEUTRINO DETECTION PRINCIPLE

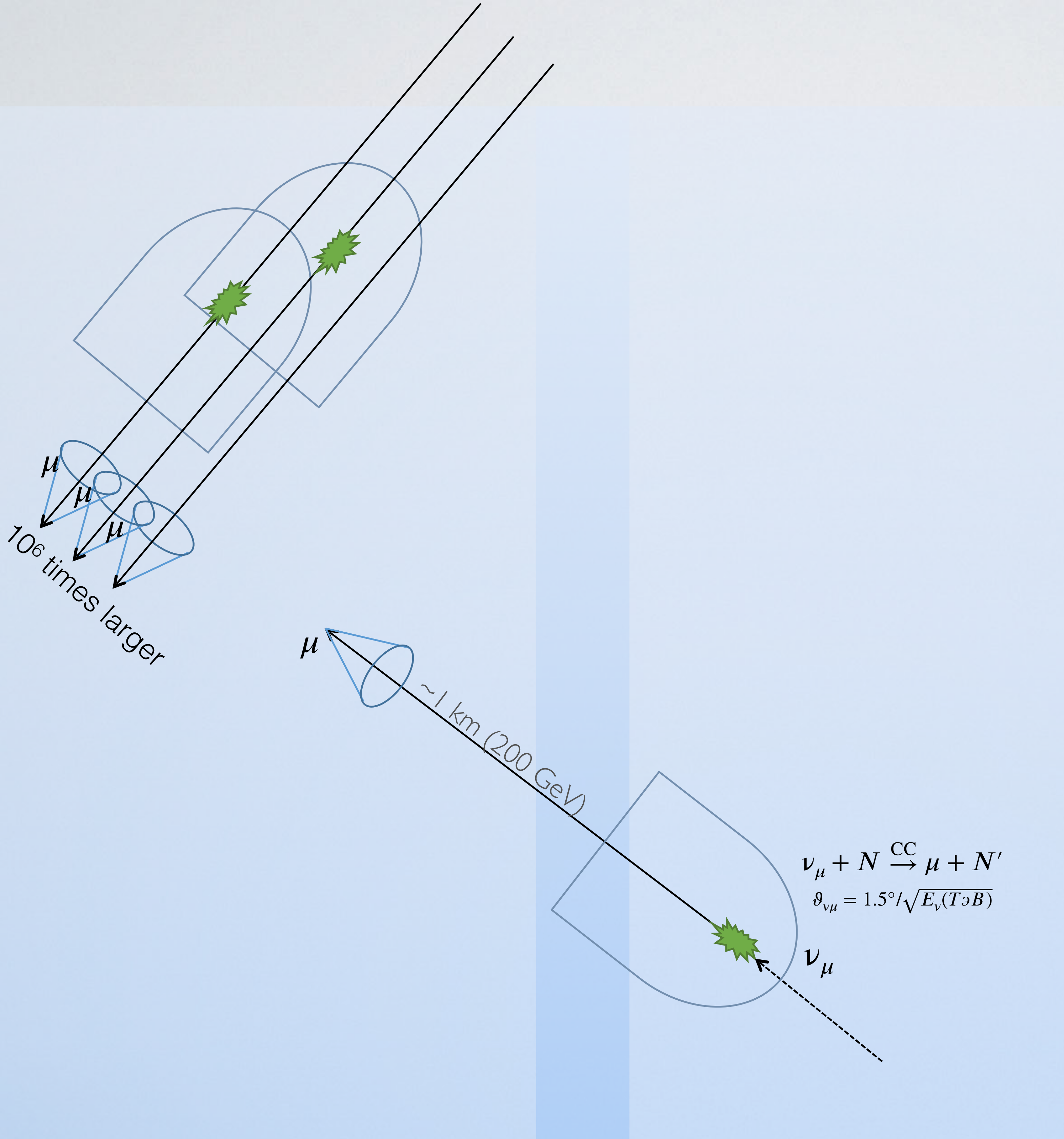


Deep Underwater

Atmospheric muons

- Factor of 10^6 more abundant than atm. neutrino
- Very complex signature -> mimic neutrino events

NEUTRINO DETECTION PRINCIPLE



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Neutrino induced muons

- Long track in the detector: dE/dX (< 1 TeV) ≈ 2 MeV/cm
- 230 photons/cm in 350-600 nm → $10^7 phot/500m$ (<1 TeV)
- Good angular resolution < 1°
- Neutrino interaction vertex can be located at several km from the detector → large detection volume

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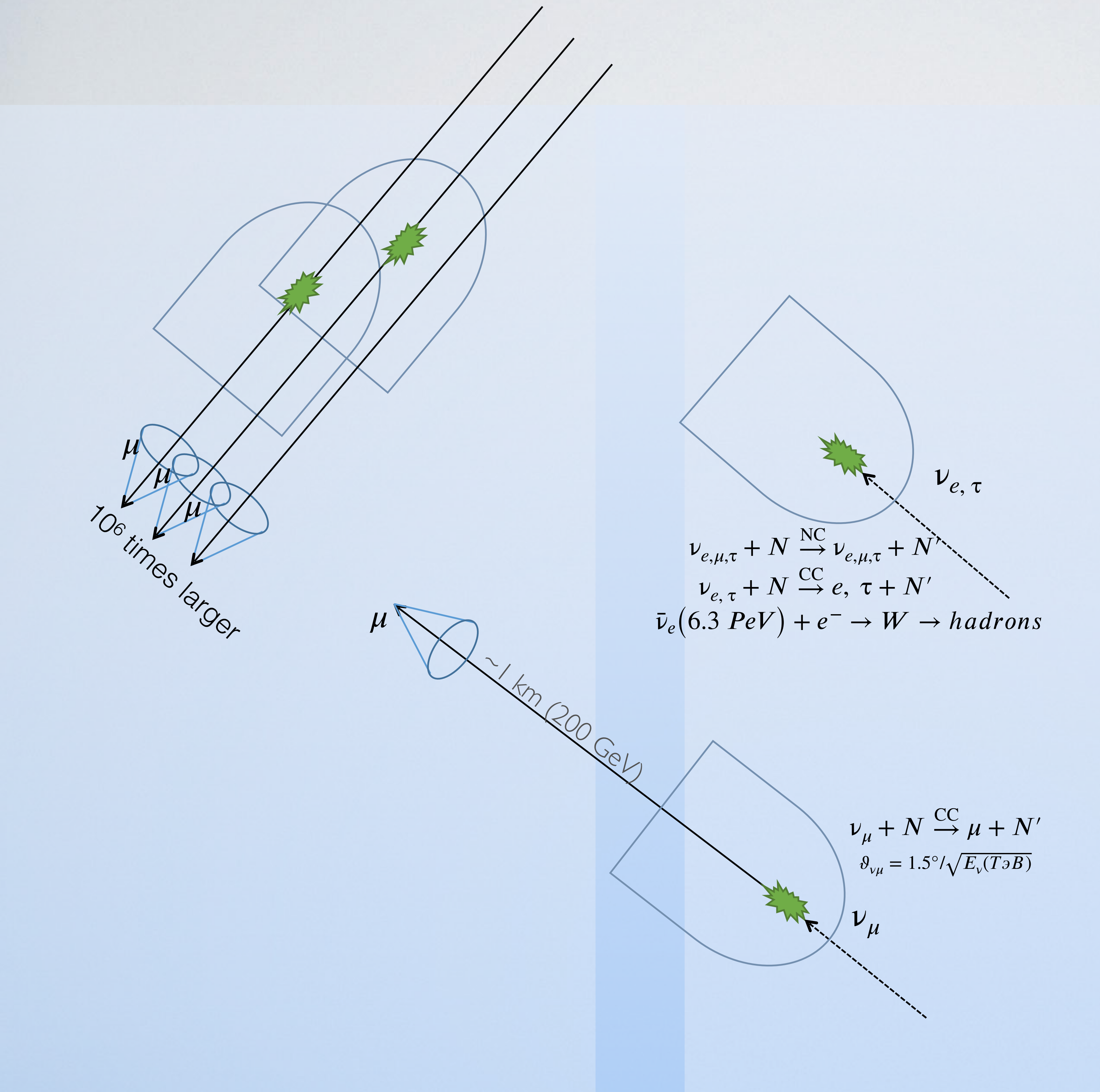

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Neutrino induced showers

- Showers are produced in all neutrino interaction channels and by all neutrino flavors
- Bright anisotropic point-like source of Cherenkov light
- Moderate angular resolution in water
- Good energy resolution $N_{photons} \approx 10^8$ E (TeV)

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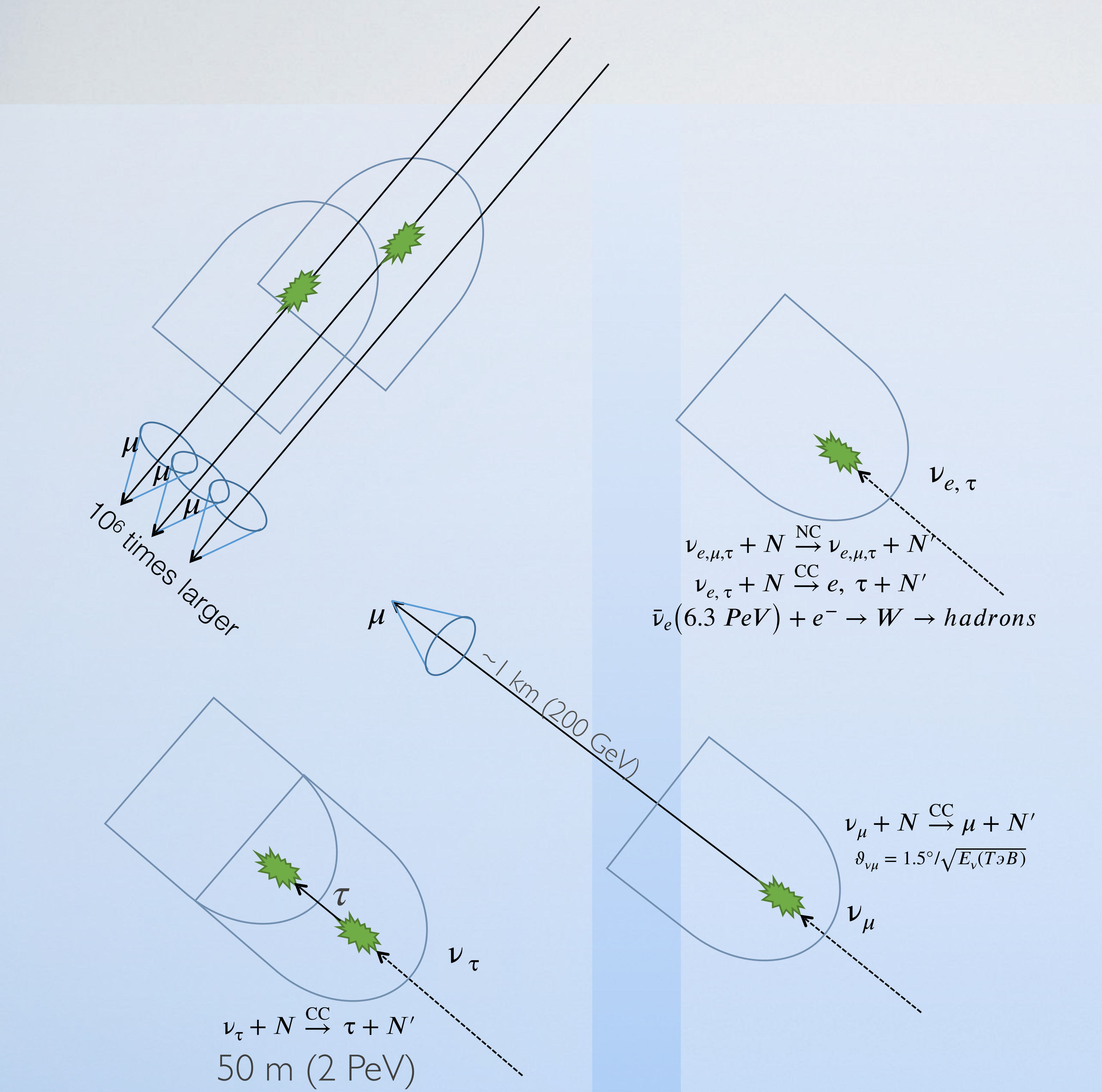

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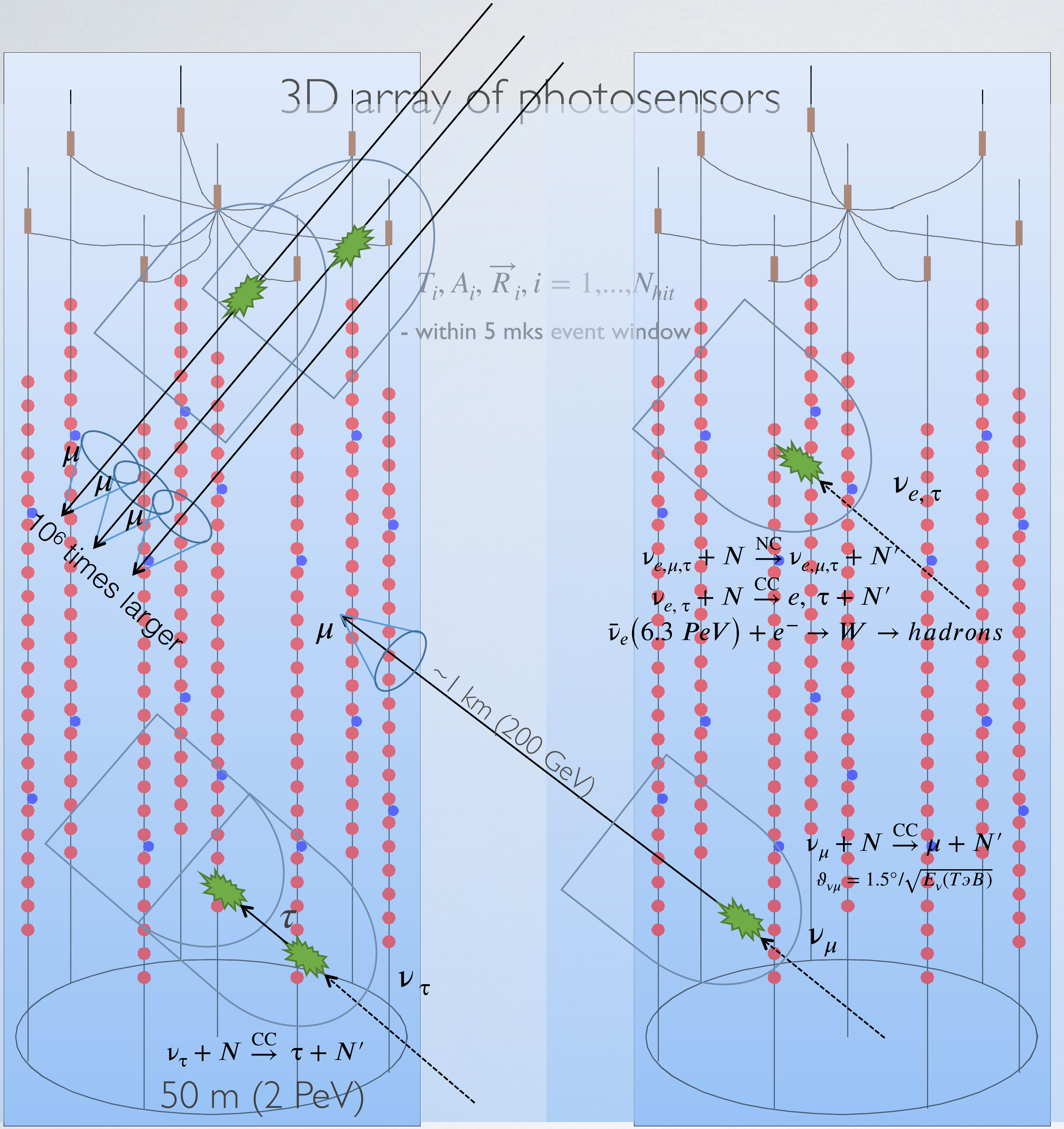

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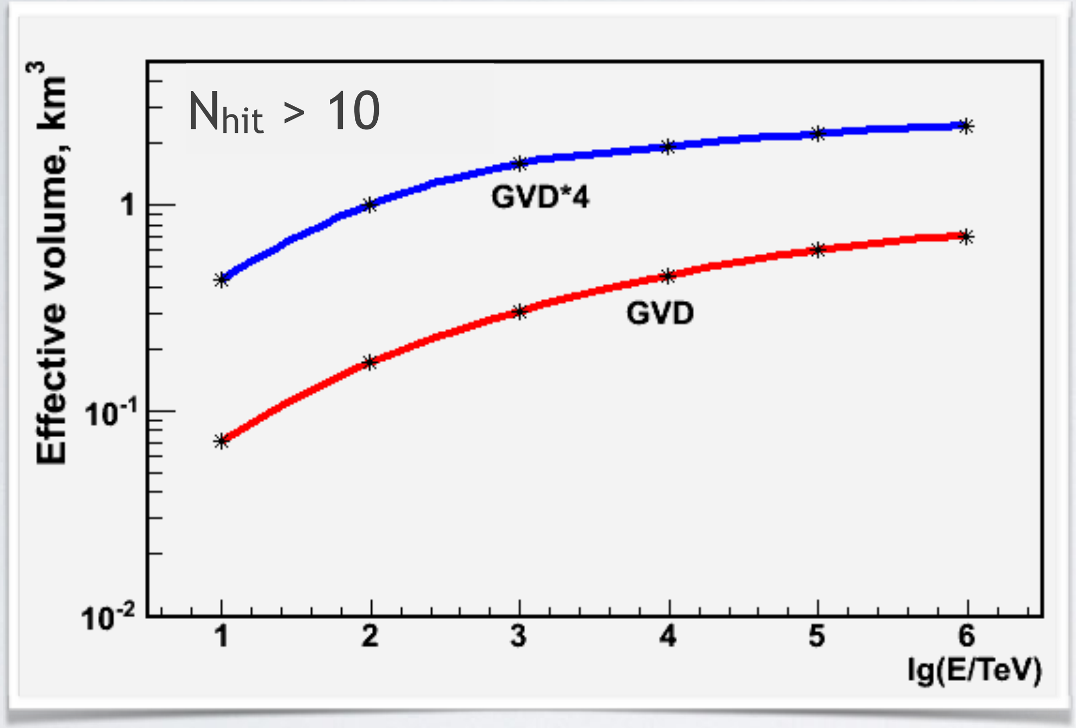
Deep Underwater
+ Lake Noise Background

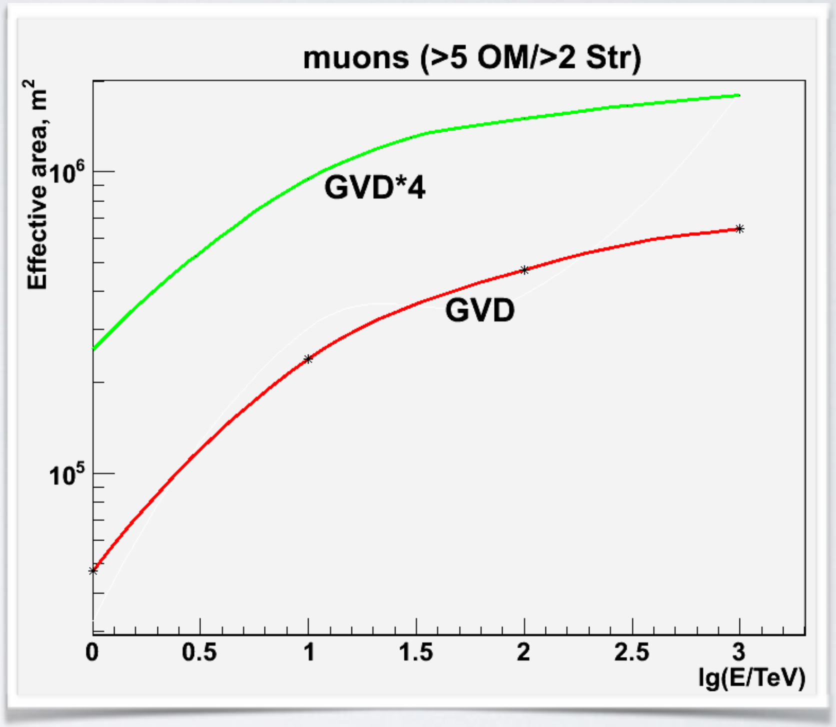
BAIKAL-GVD PERFORMANCE

A gigaton scale neutrino telescope

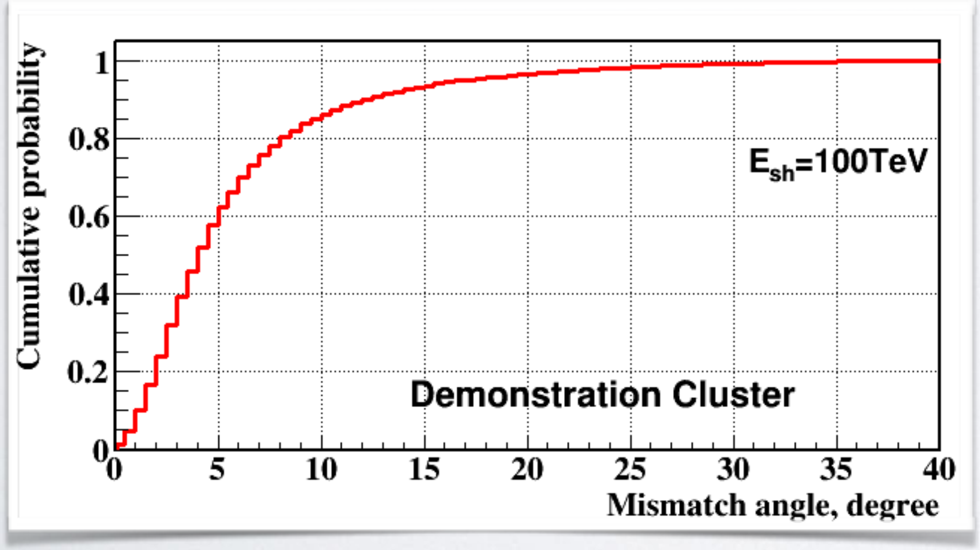
Eff. volume for cascades with E > 100 TeV: 0.1 - 0.6 km^3



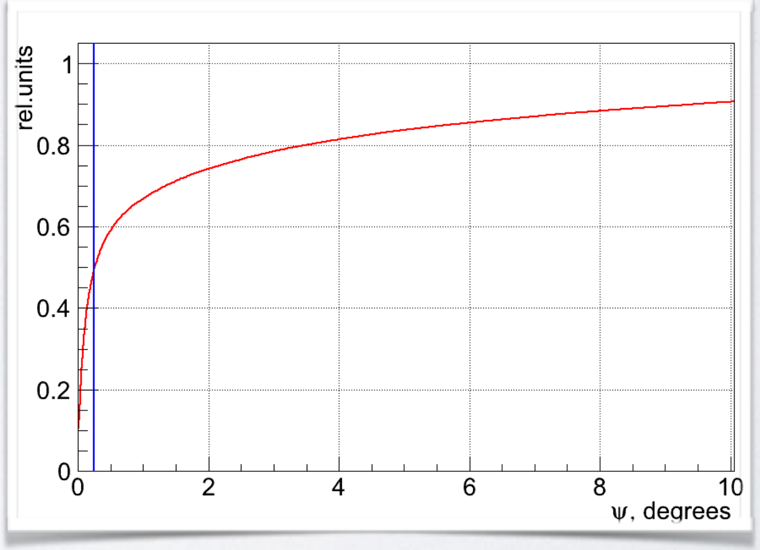
Eff. area for muons E > 10 TeV: 0.2 - 0.6 km^2



Angular resolution for cascades: 3.5 - 5.5°



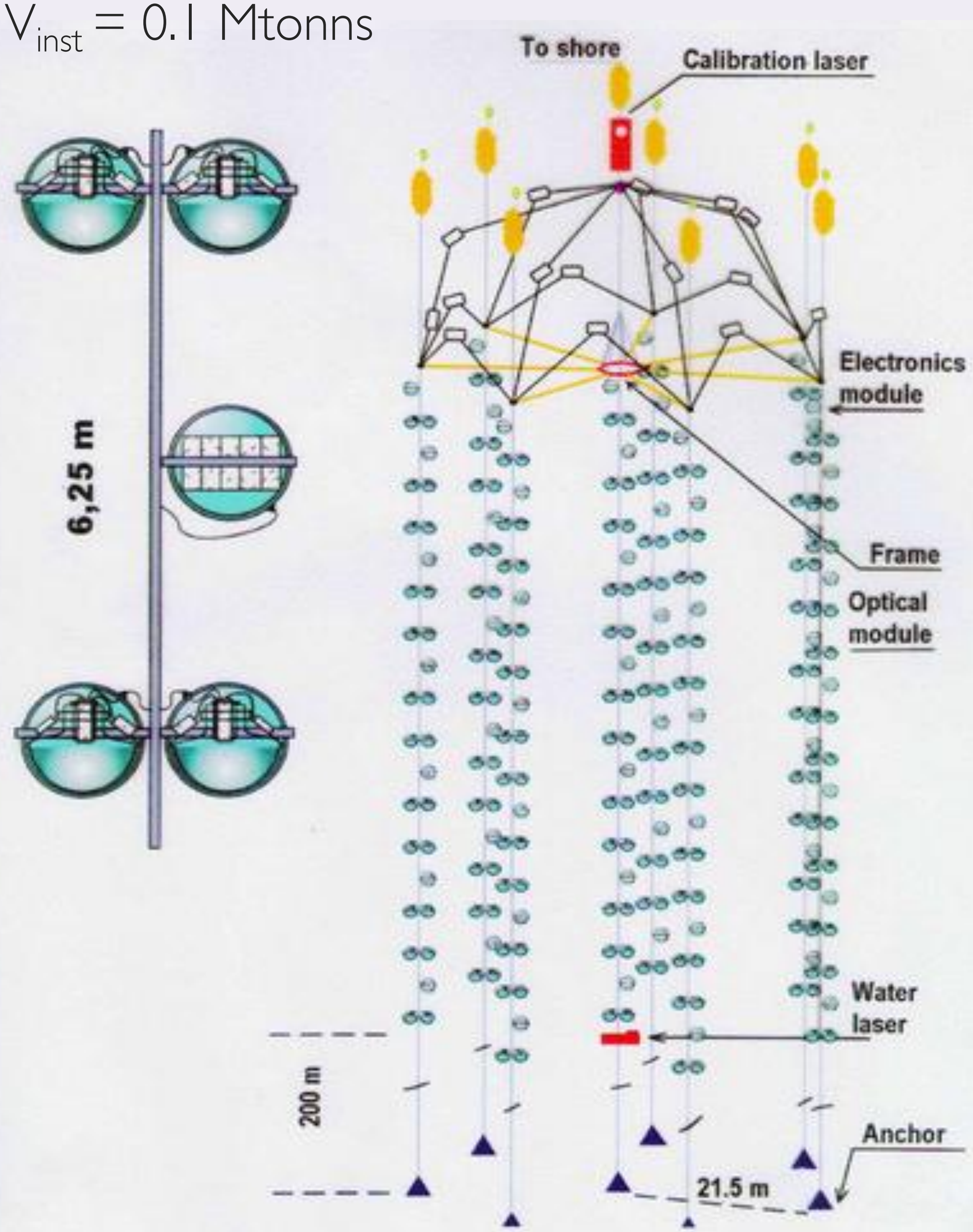
Angular resolution for muons: 0.25°



NT-200 NEUTRINO TELESCOPE(1998)

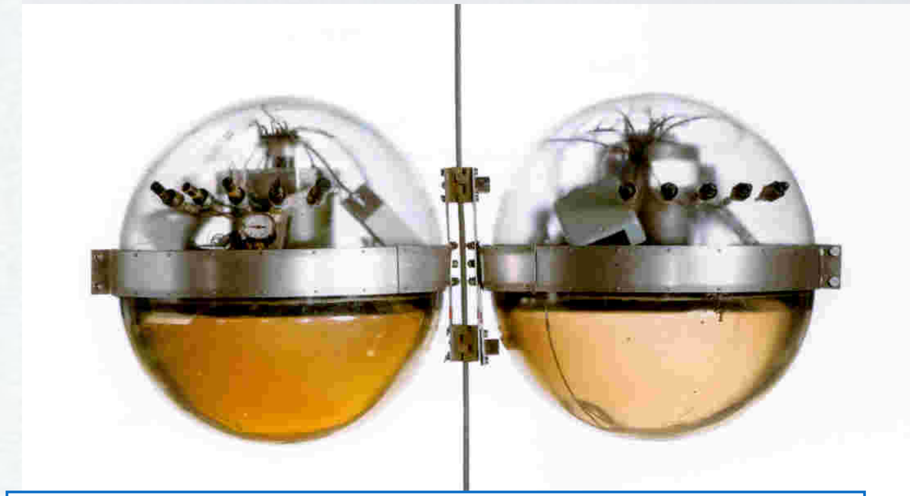
Proof of the concept

1. NT-200: Height= 70 m, Diameter = 42 m
V_{inst} = 0.1 Mtonns

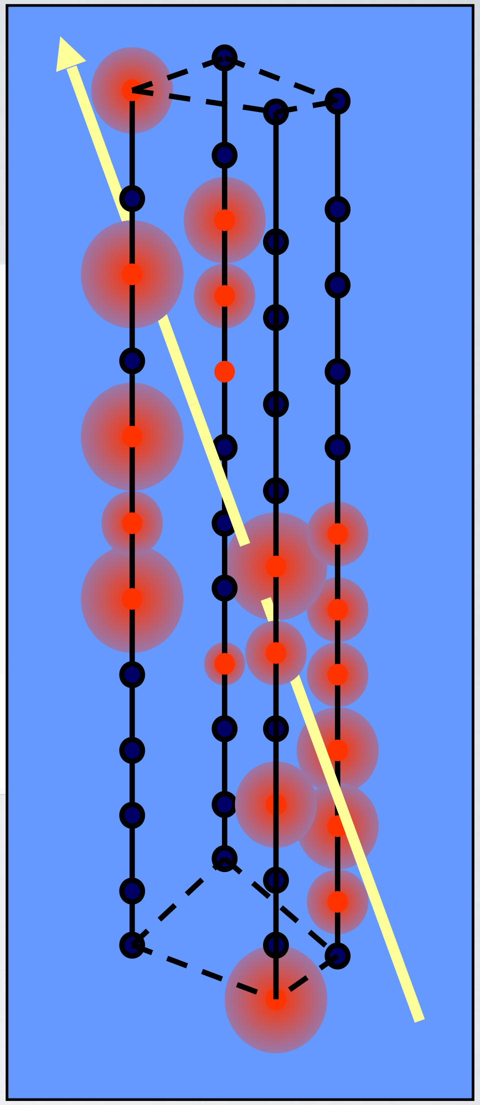


Dense installation

«Quasar» PMT: 37 cm (14.6")



- 8 strings
- 192 optical modules
- σ_T ~ 1 ns

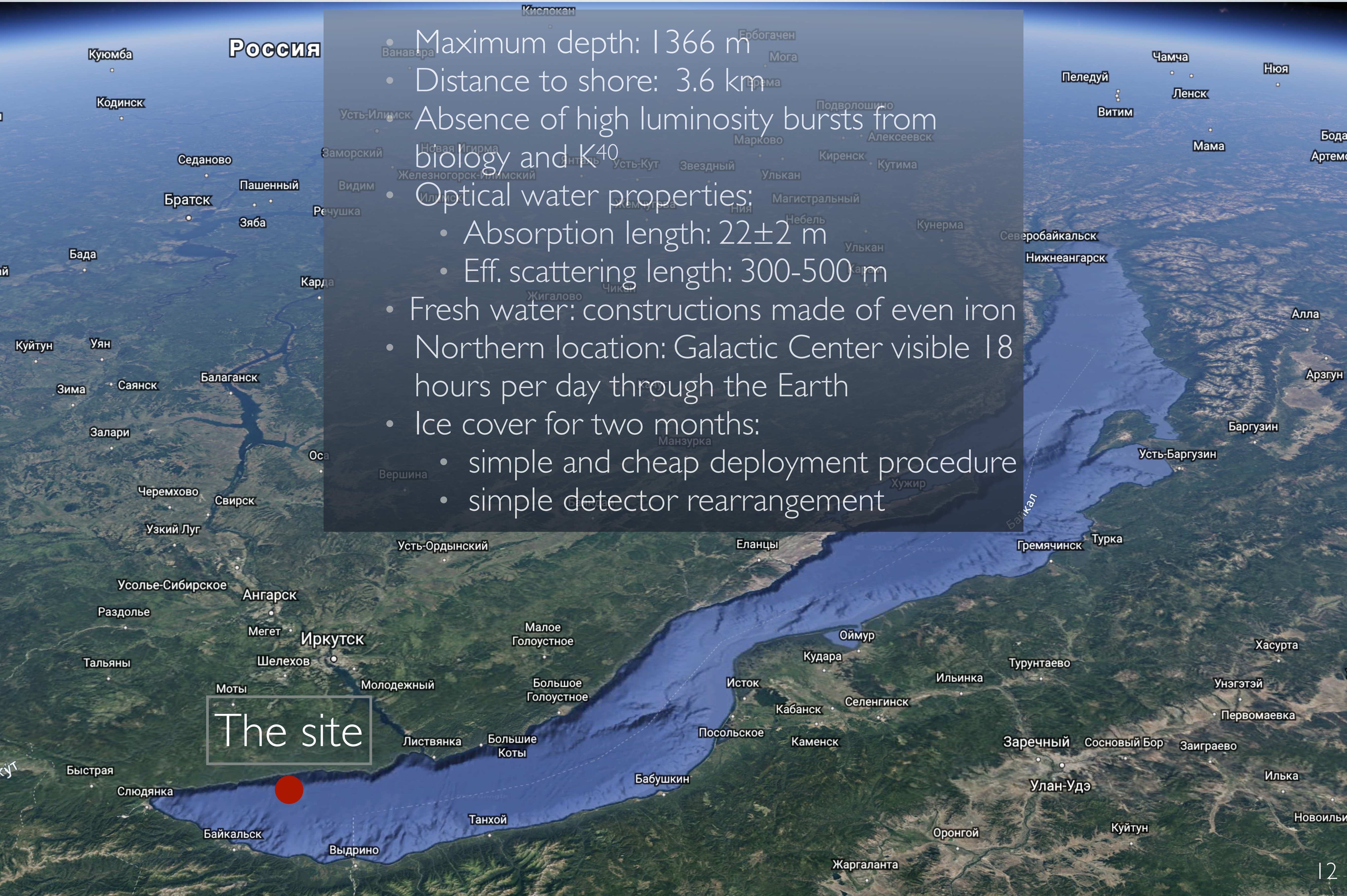


First neutrino event

Energy threshold: ~ 15 GeV
Eff. area: ~ 2000 m² (1 TeV)
Eff. volume: ~ 0.2 Mt (10 TeV)
~ 1 Mt (1 PeV)

BAIKAL SITE

- Maximum depth: 1366 m
- Distance to shore: 3.6 km
- Absence of high luminosity bursts from biology and K^{40}
- Optical water properties:
  - Absorption length: 22±2 m
  - Eff. scattering length: 300-500 m
- Fresh water: constructions made of even iron
- Northern location: Galactic Center visible 18 hours per day through the Earth
- Ice cover for two months:
  - simple and cheap deployment procedure
  - simple detector rearrangement




976

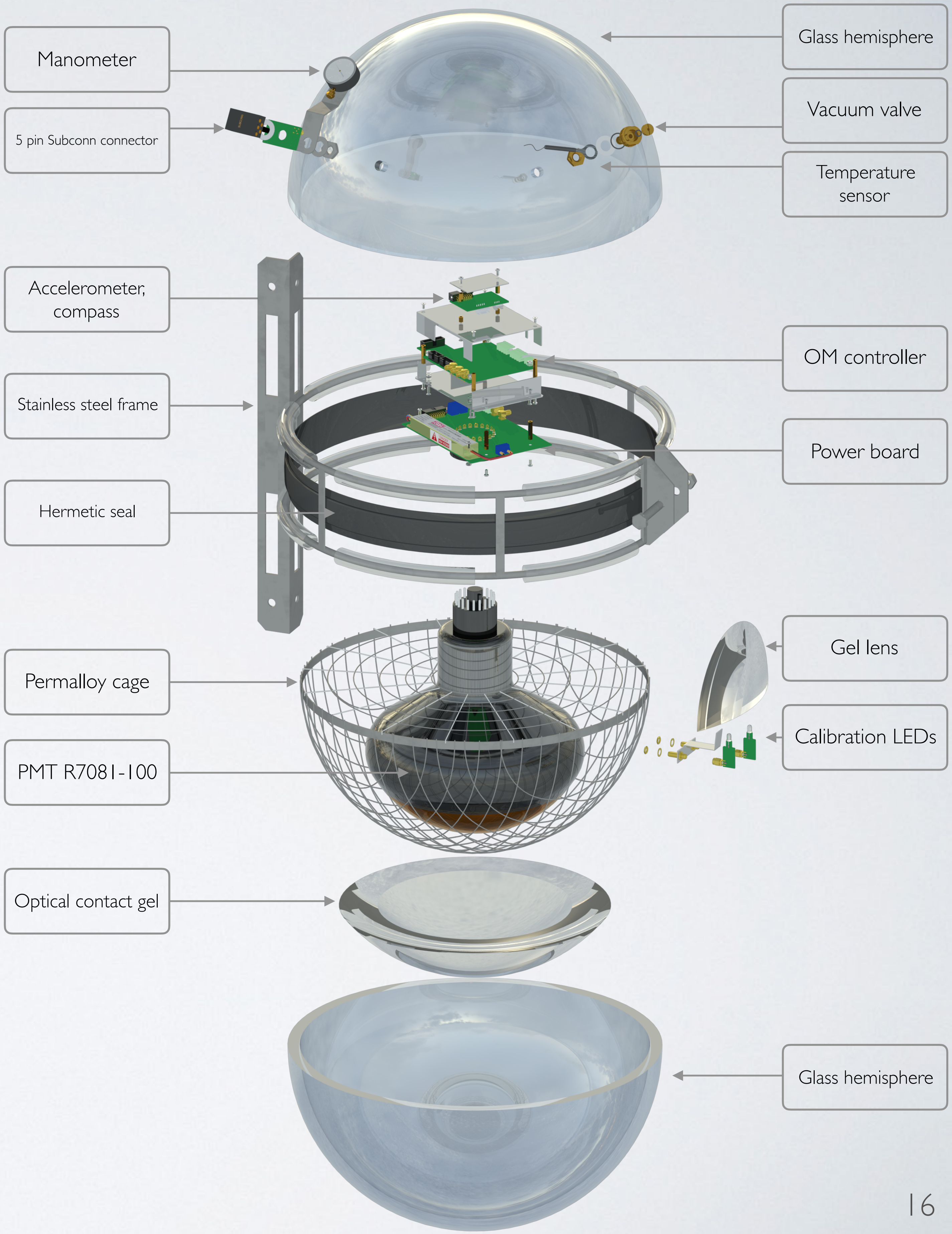

Bair Shoyb


44


1002
959

OPTICAL MODULE

- 10" Hamamatsu PMT R7081HQE, $Q_{eff} \approx 0.35$
- 17" Glass pressure-resistant sphere VITROVEX
- Underwater 5-pin industrial SubConn connector
- OM electronics: amplifier, HV DC-DC, controller
- 2 on-board LED flashers for calibration: 10^8 p.e., 430 nm, 5 ns
- Mu-metal cage



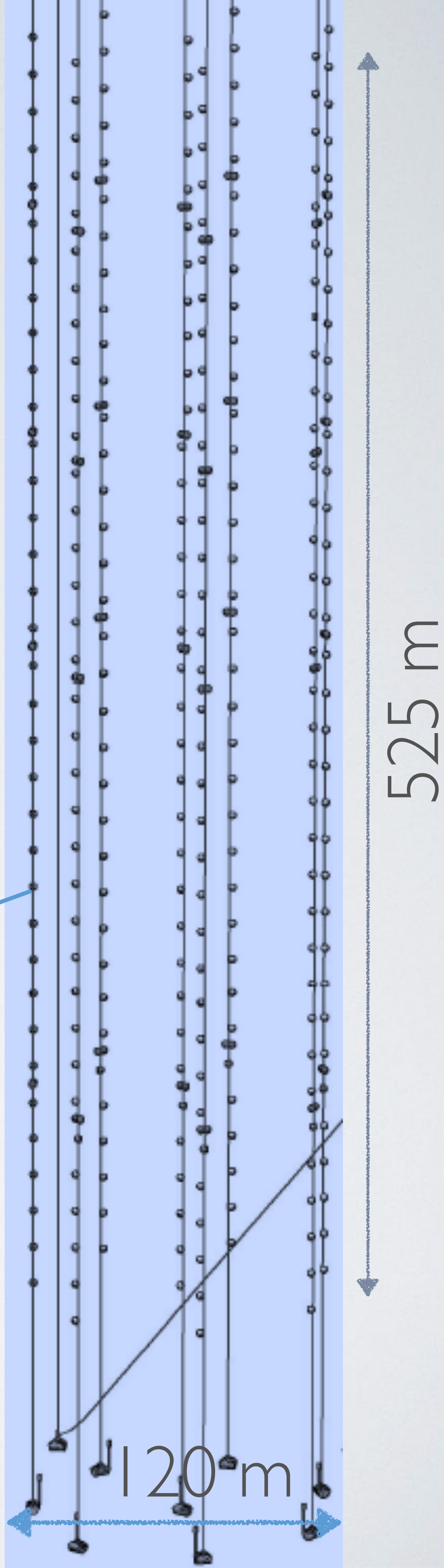
INFRASTRUCTURE

OM production line in JINR (Dubna) (600 OMs/year)

The control center at the Baikal shore The local lab and OM storage in the Baikalsk

THE CLUSTER OF STRINGS

- 288 OMs at 8 strings
  - 36 OMs per string, 15 m spacing
  - depth 750 - 1275 m
  - 60 m between strings
  - Instrumented volume is 6 Mt
- Cluster DAQ center (30 m below surface)
  - Trigger, power, data transfer systems of the cluster
- Electro-optical cable to shore
- Acoustic positioning system (4 beacons on each string)
- 3 calibration light beacons (matrix of LEDs)
  - Interstring time calibration



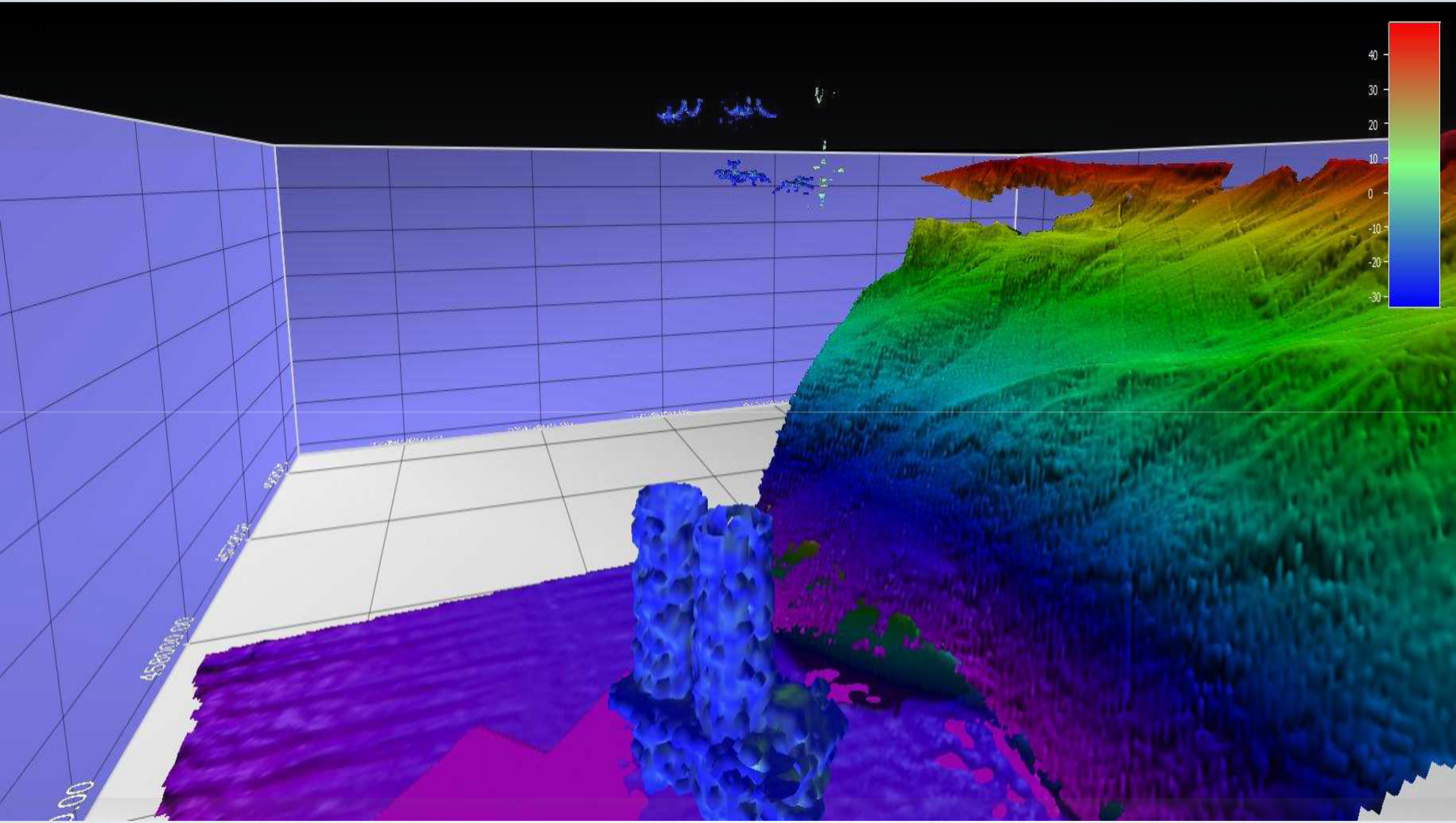
TIMELINE BAIKAL-GVD PHASE 1

Cumulative number of clusters vs. year

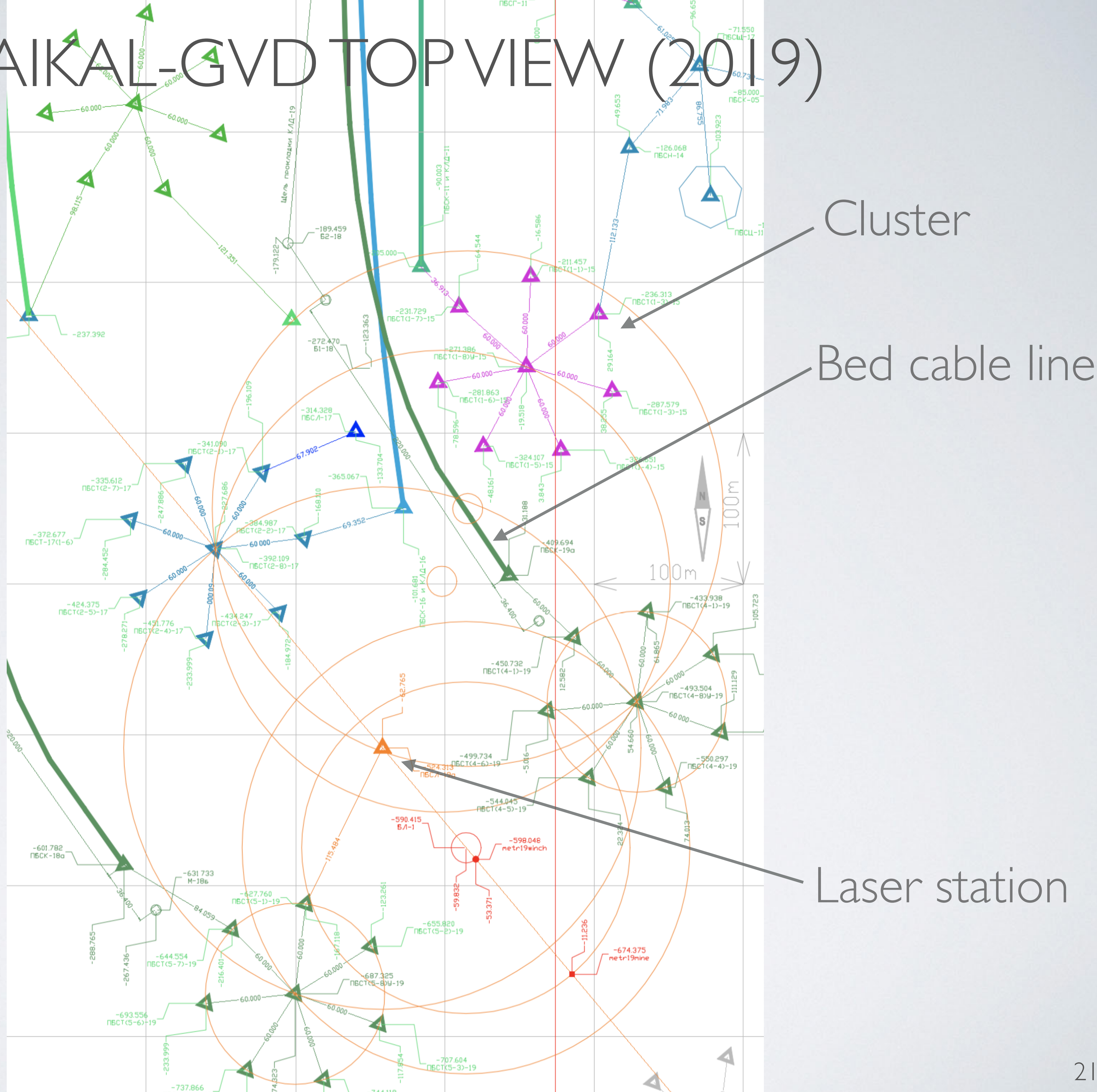
Year	2016	2017	2018	2019	2020	2021
Number of clusters	1	2	3	5	7	9
Number of OMs	288	576	864	1440	2016	2592

Fully funded

REAL SONAR IMAGE (2017)

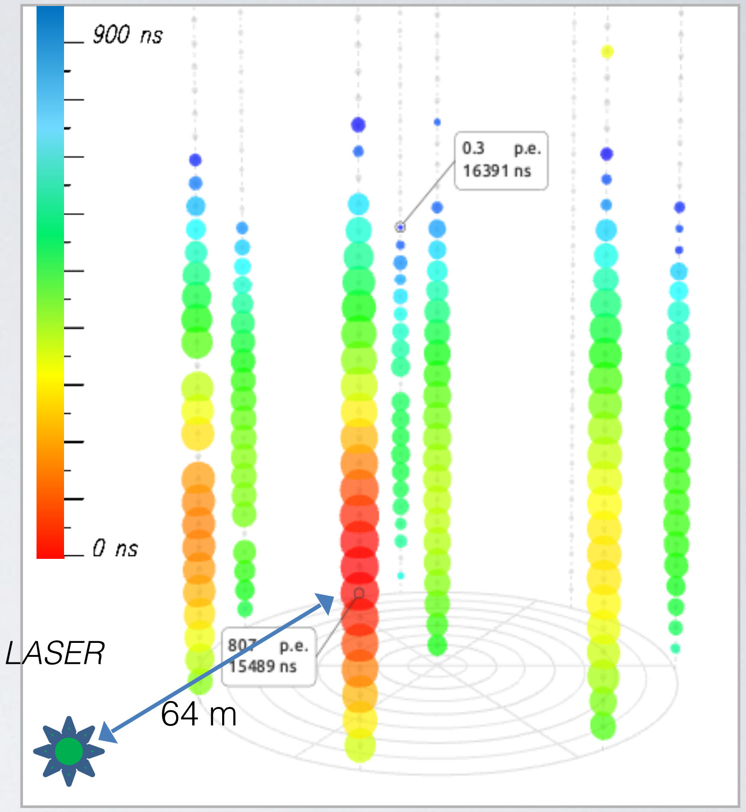


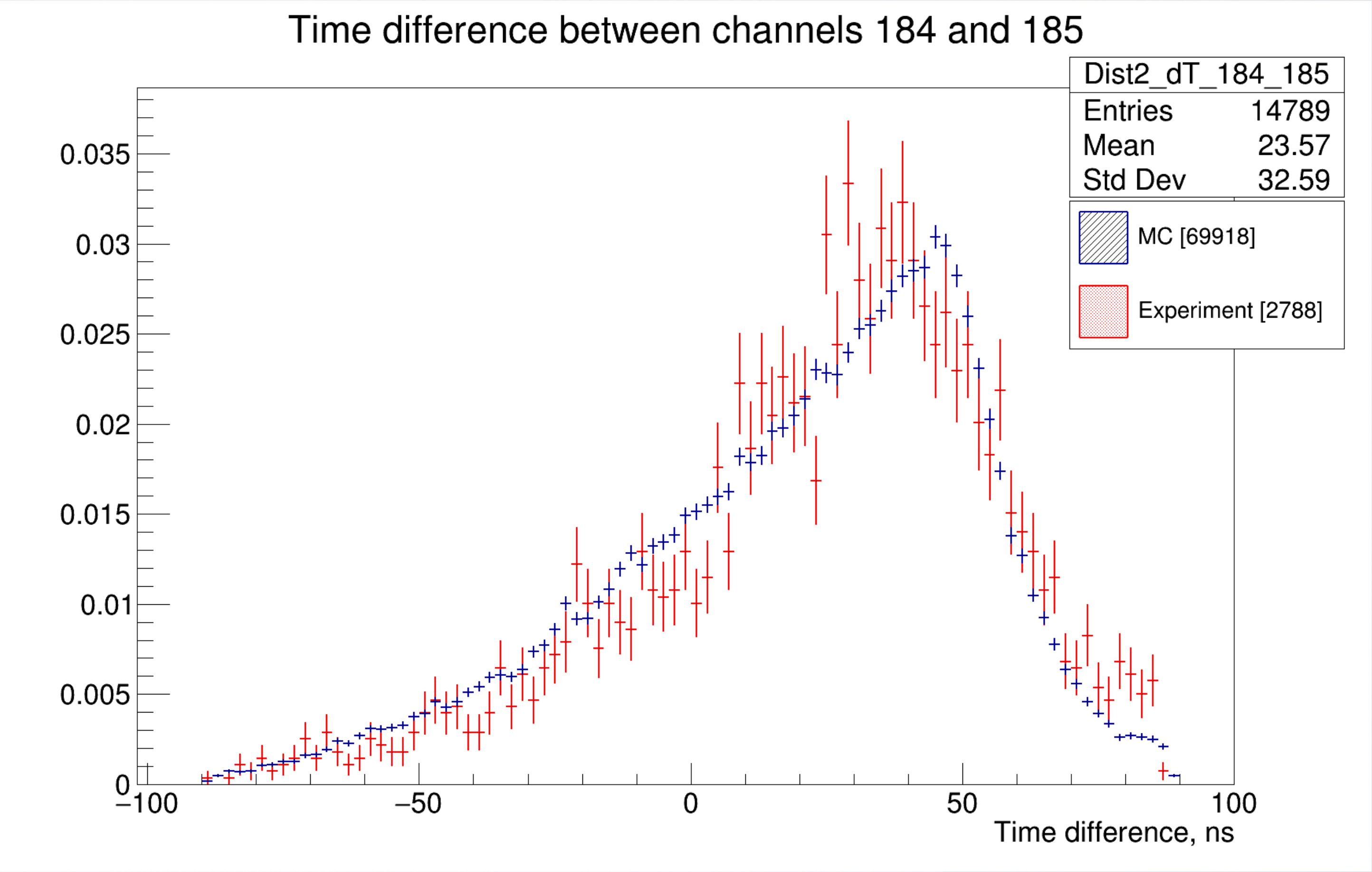
BAIKAL-GVD TOP VIEW (2019)



TIME CALIBRATION

- Artificial light sources:
  - OM's built-in LEDs (delays between OMs in the same string)
  - LED matrixes (delays between OMs in different strings)
  - Powerful laser source (delays between OMs in different clusters)
- Natural light source:
  - Atmospheric muons

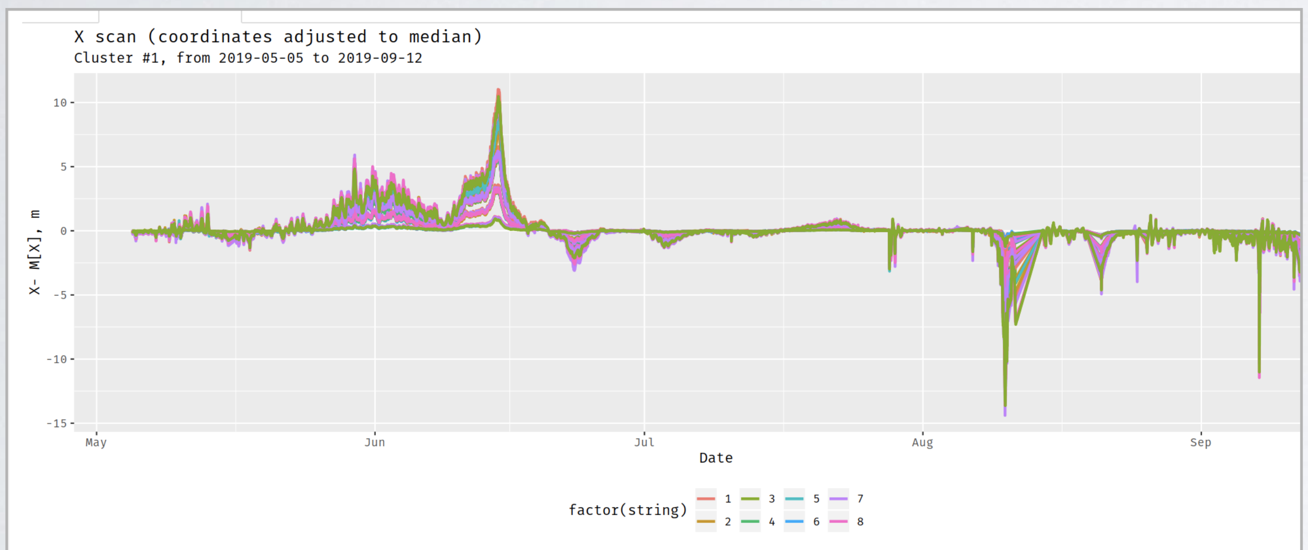


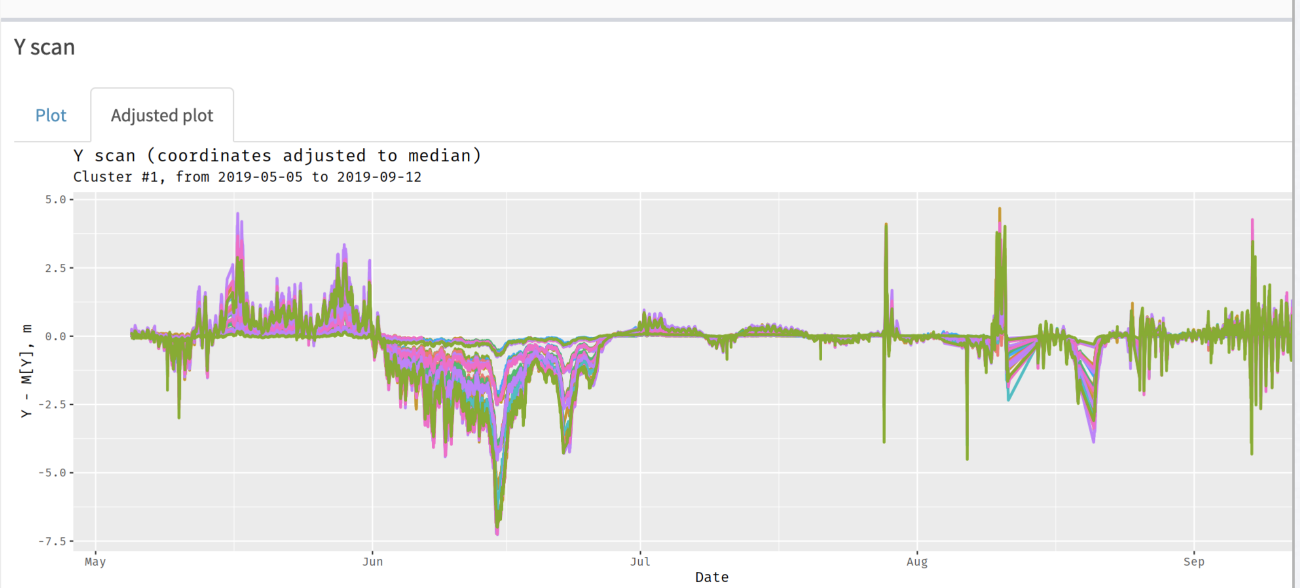


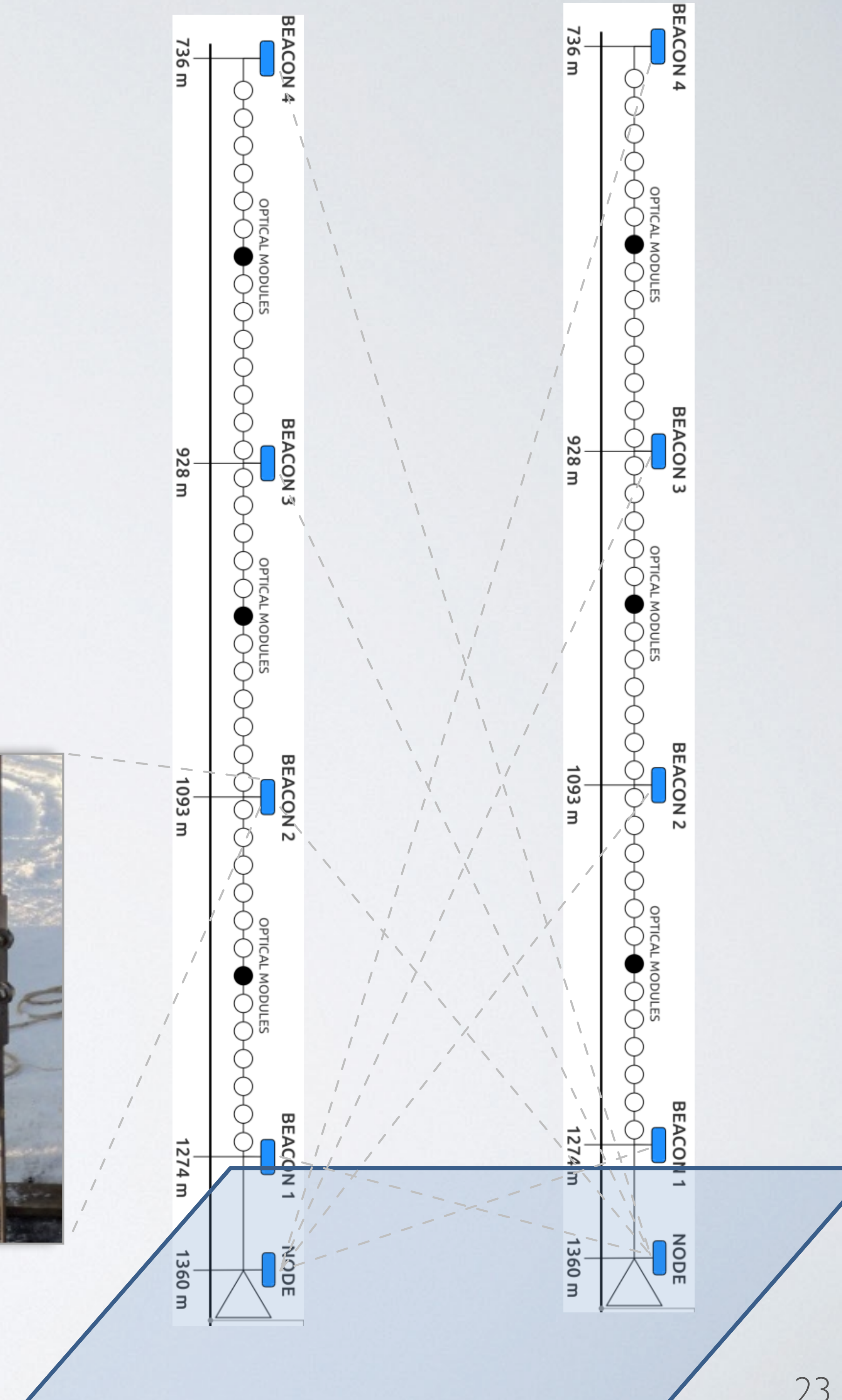
GEOMETRY CALIBRATION

Acoustic positioning system:

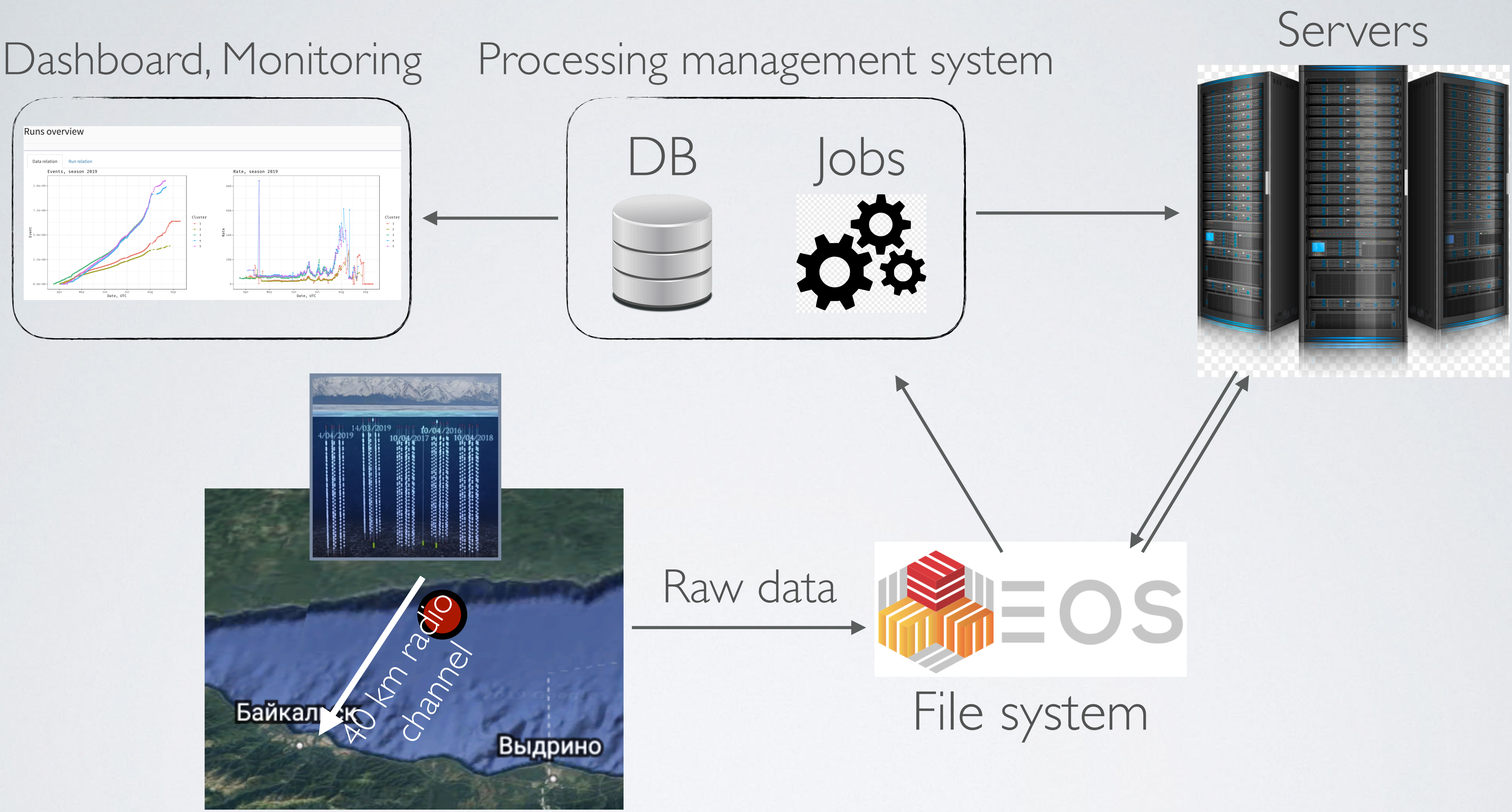
- 5 acoustic modules (AMs) on each string (4 AMs in 2016)
- One module is fixed to anchor (node), the rest are along the string (beacons)
- Acoustic signal delays between node and beacons are measured every 5 min
- Relative positions of the AMs are obtained by triangulation
- Monitor pictures are obtained automatically with a delay about 7 minutes







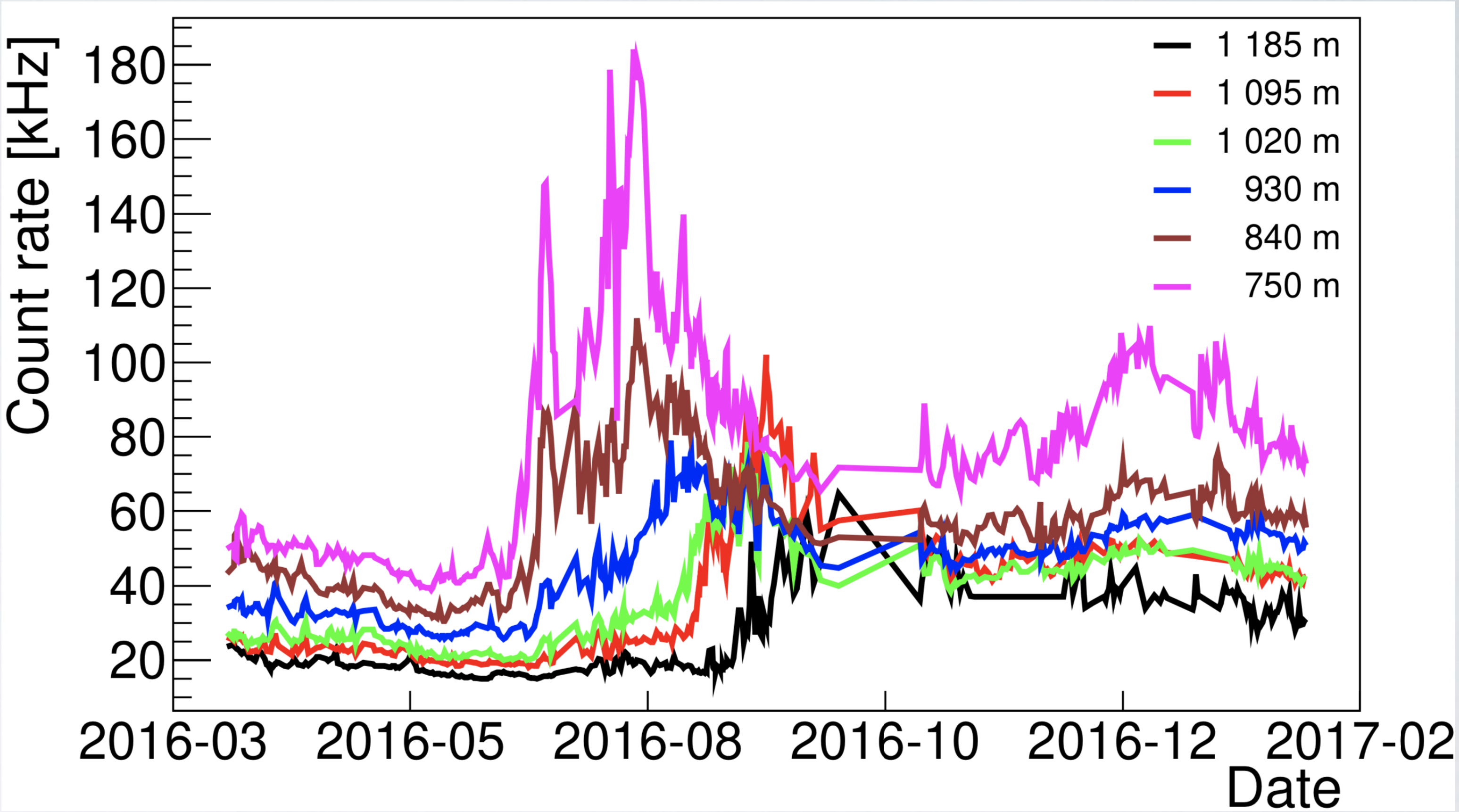
ONLINE DATA PROCESSING SYSTEM

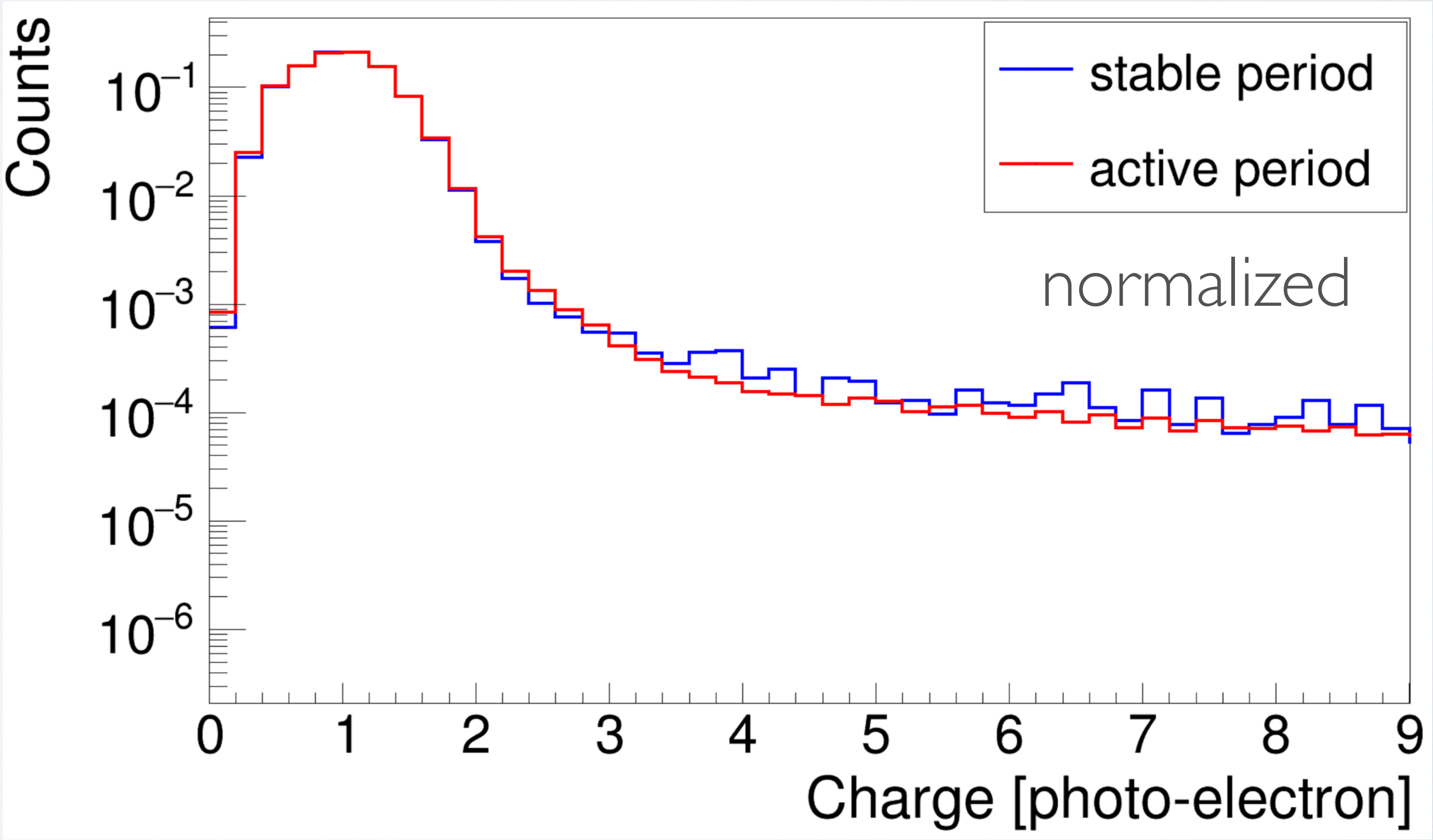


- ≈6 min exposition file comes to the Computing Center in Dubna (+30 sec delay)
- Primary data processing jobs start immediately (+5 min delay)
- → Alert system (≈15-20 min delay)

LAKE BACKGROUND NOISE

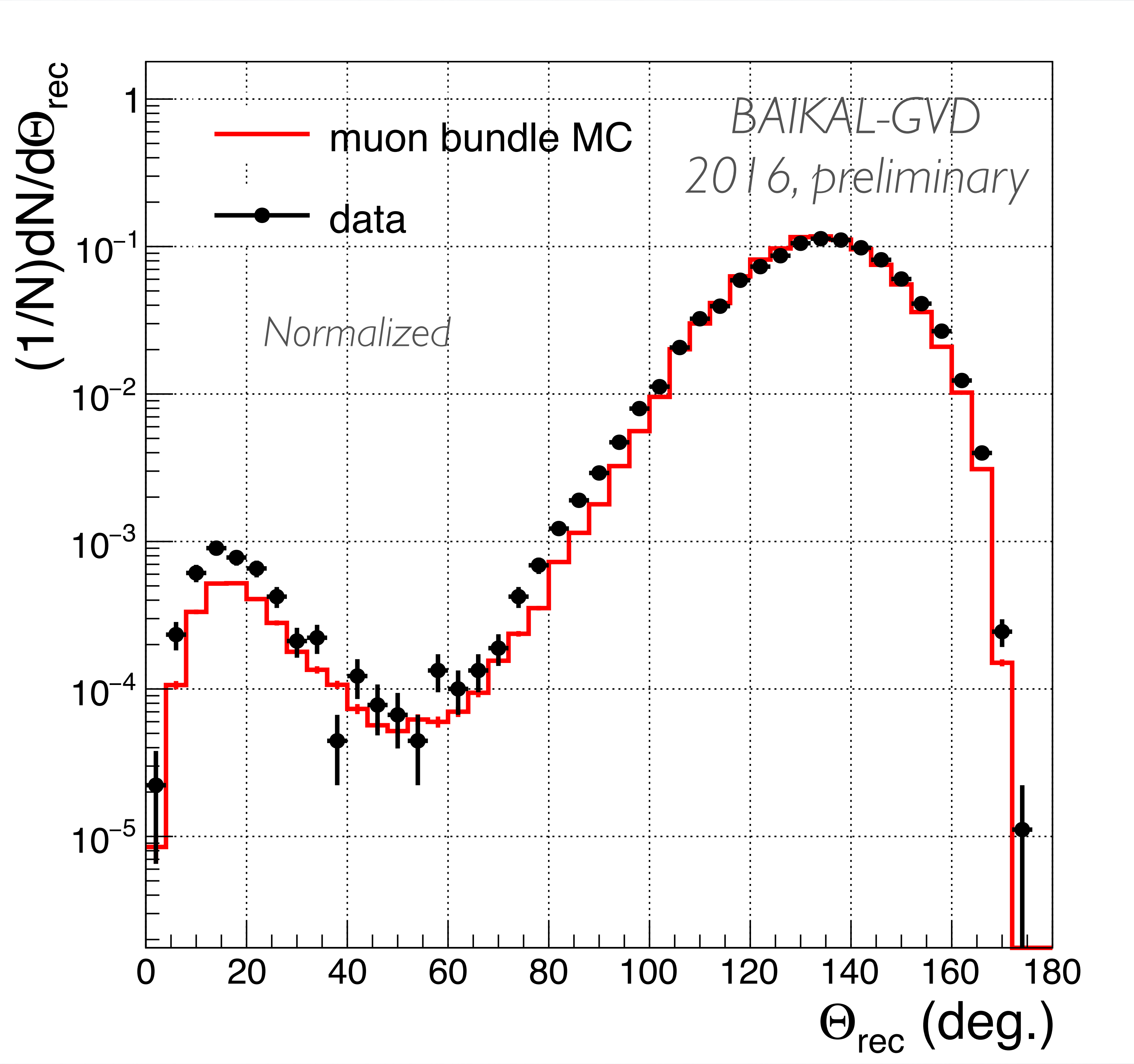
- Lake chemiluminescence level varies during a year
- It has one-p.e. nature
- 20-40 kHz for "low noise" period
- The shallower the OM the higher the noise level
- The same charge distributions for low noise and active periods





NOISE SUPPRESSION AND TRACK RECONSTRUCTION

- The noise suppression method:
  - Surviving true hits: 94%
  - Admixture of noise hits: 5%
- Track reconstruction (one cluster):
  - Mismatch angle ≈ 1° median

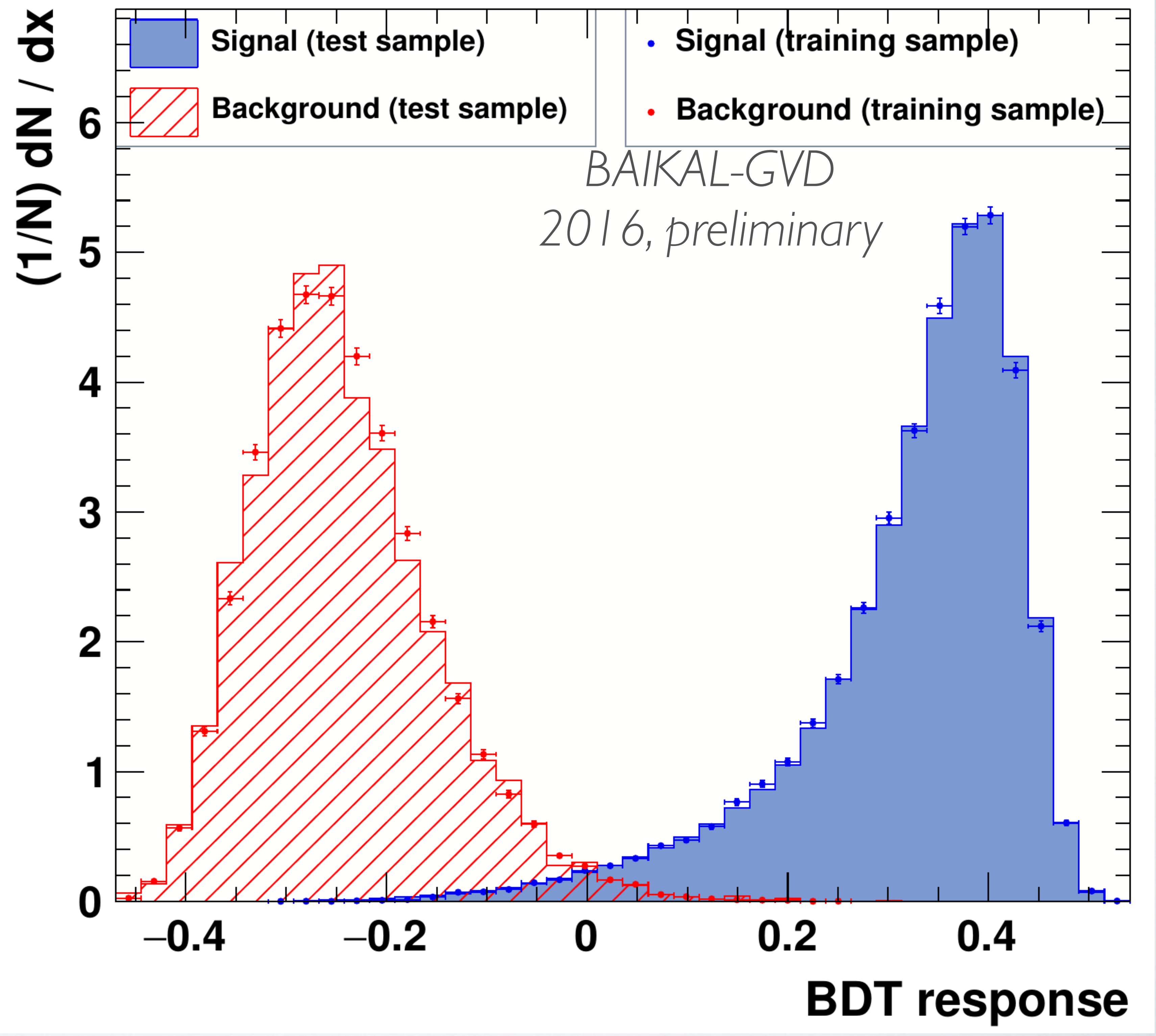


Experimental data agree well with MC expectations

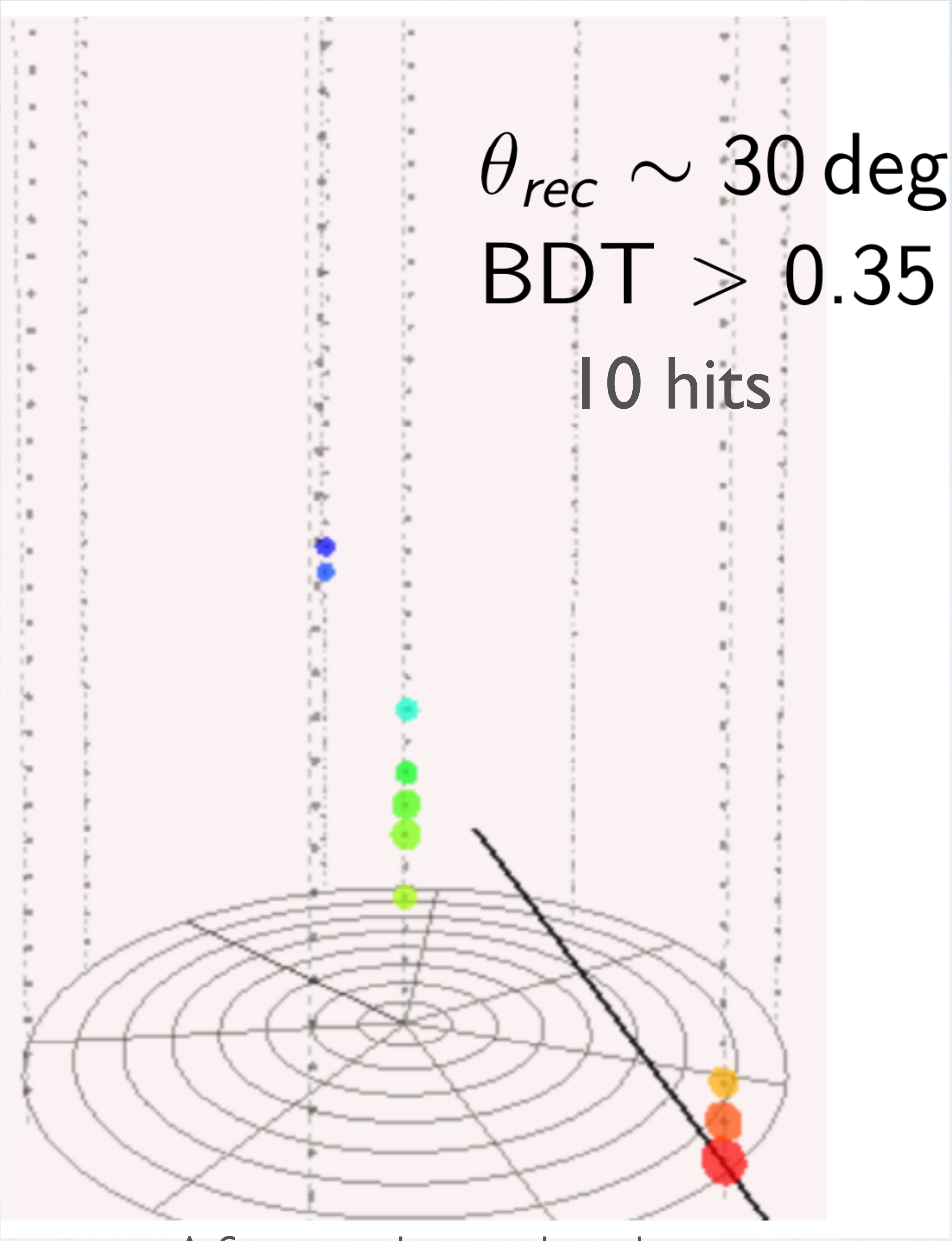
NEUTRINO EVENT SELECTION

- A set of 15 quality variables was used as input for BDT

- Atm muon background is suppressed at the level of 10^5, maintaining signal efficiency at the level of ~80 % (BDT response > 0.25)



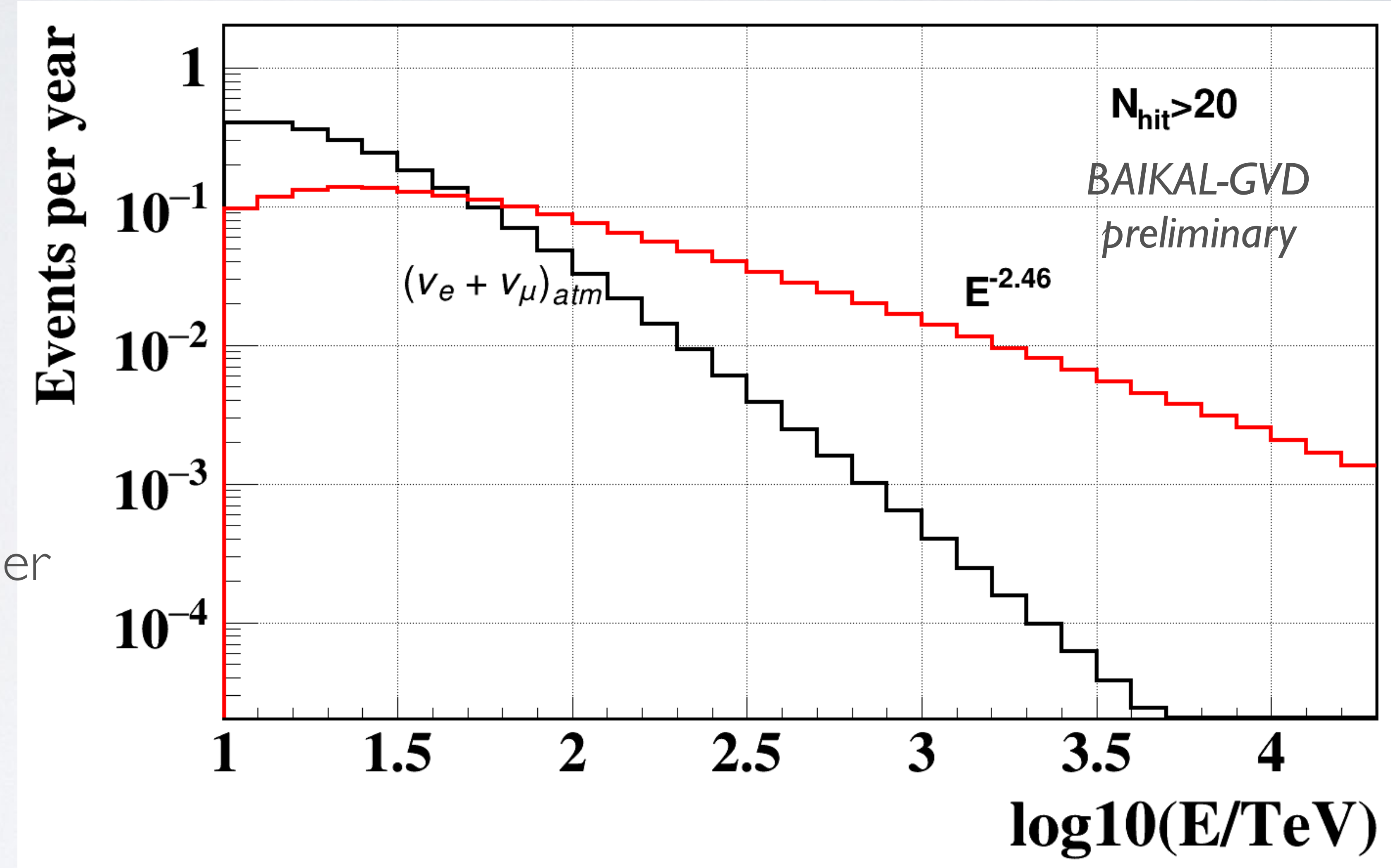
UPWARD GOING NEUTRINO EVENT



After noise rejection

SEARCH FOR CASCADE EVENTS

- Directional resolution: ~ 3°- 4° (median)
- Energy resolution: δE/E ~ 30%
- 872 live days data were selected from 2016, 2018 (≈2.4 clusters per year)

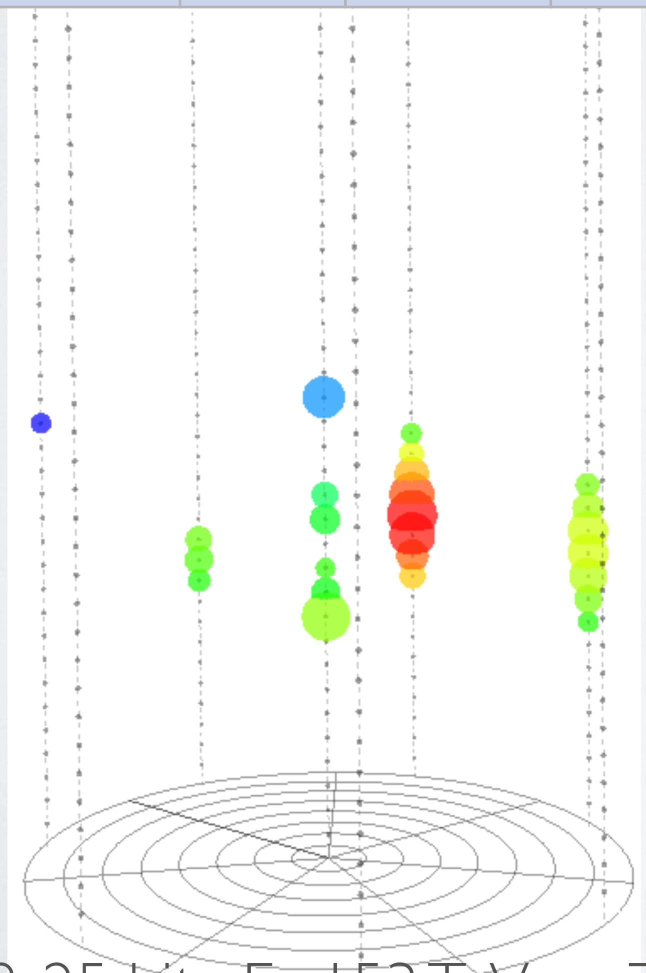


CASCADE EVENTS

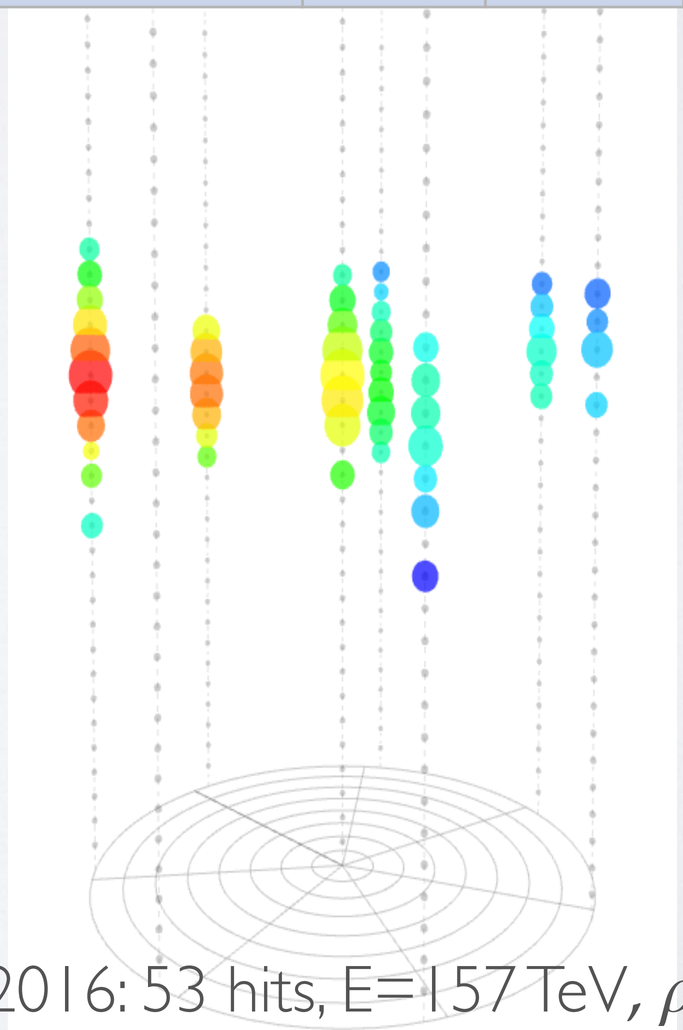
Preliminary

5 events were selected with E > 100 TeV
Background is under study

Date	E, TeV	Zenith degree	Azimuth degree	RA	Dec	T_{UNIX}	x, m	y, m	z, m
16.11.2015	107	56	131	139.5	5.6	1447637711	-50.2	49.7	-60.7
29.04.2016	157	57	249	173.4	14.0	1461925647	-25.1	-37.0	11.4
21.08.2018	153	49	57	231.7	49.1	1534868736	40.4	-65.7	-93.8
24.10.2018	107	69	112	41.3	0.7	1540416000	79.8	61.6	151.0
15.02.2019	339	67	350	68.4	61.9	1550278144	-48.0	75.7	4.3



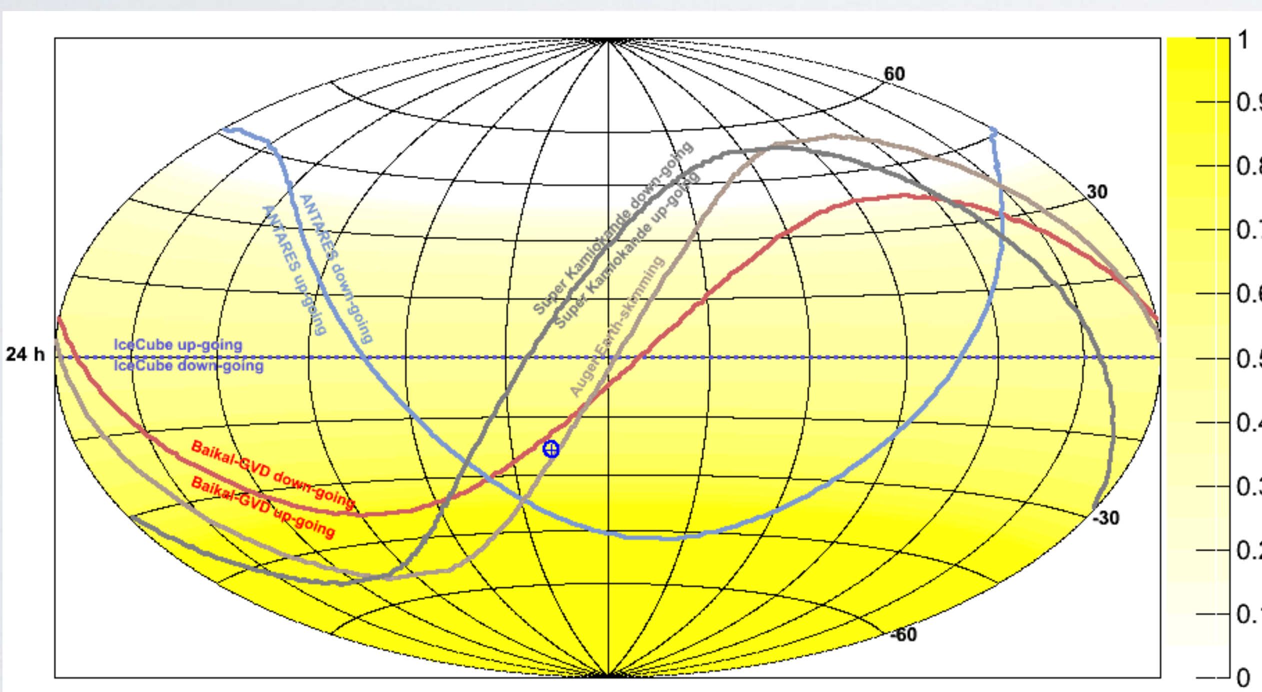
2018: 25 hits, E=153 TeV, ρ=76 m

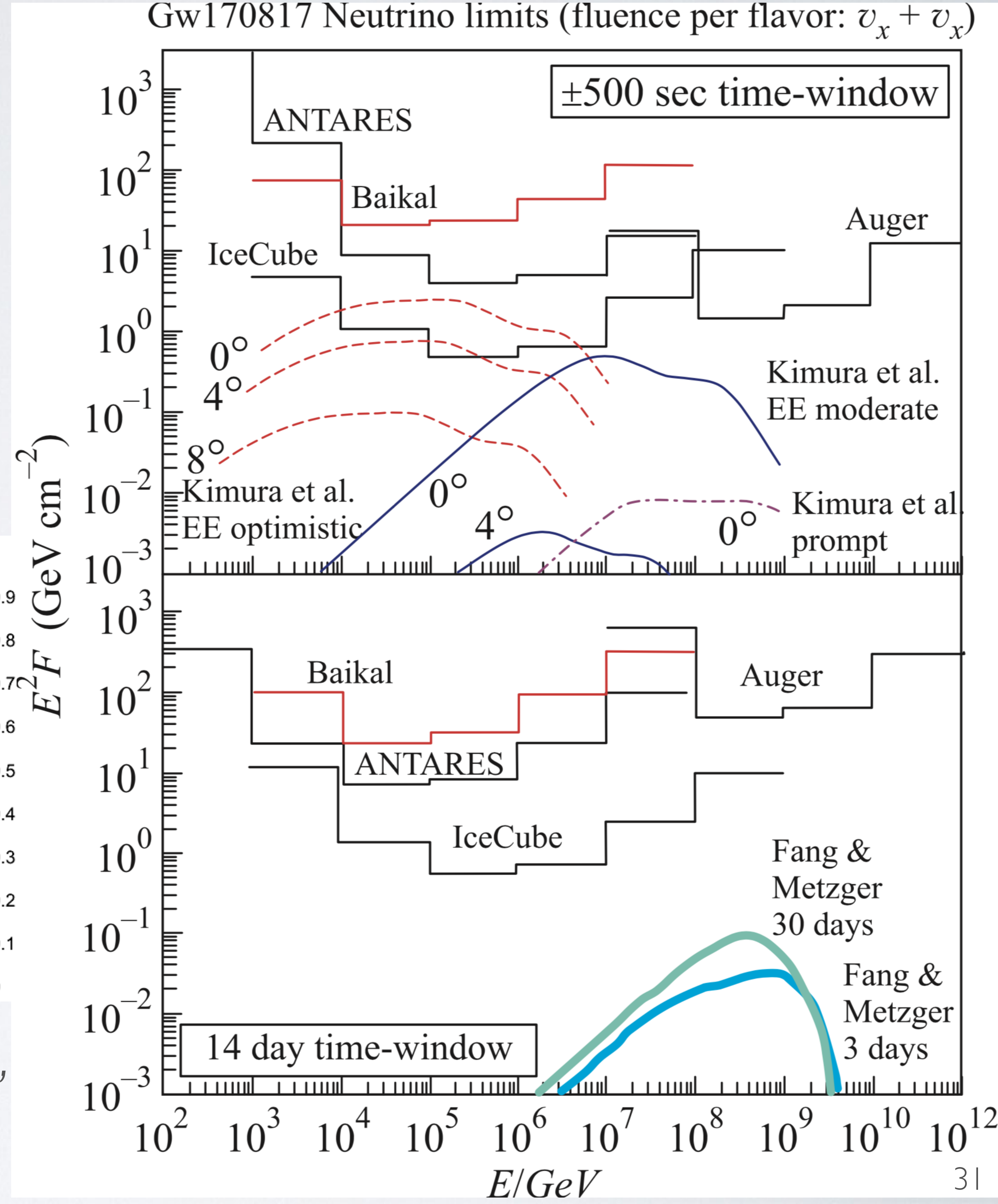


2016: 53 hits, E=157 TeV, ρ=44m

SEARCH FOR HIGH-ENERGY NEUTRINO INDUCED CASCADES ASSOCIATED WITH GW170817

- The source was under horizon at registration time: 93.3°
- No neutrino events associated with GW170817 using cascade mode within both ± 500 sec and 14 days
- Assuming E^{-2} spectral behavior and equal fluence in all flavors upper limits at 90% C.L. are obtained on the neutrino fluence from GW170817 for each energy decade





ISSN 0021-3640, JETP Letters, 2018, Vol. 108, No. 12, pp. 787–790.

SUMMARY AND OUTLOOK

- Baikal-GVD neutrino telescope is under construction now
- Five clusters of the Baikal-GVD commissioned in April 2019
- Phase 1 will be finished in 2021 with construction of 9 clusters (≈2600 OMs)
- A numerous low-level stuff were done or almost ready:
  - Time, amplitude, geometry calibrations
  - Data processing system with "alert" feature
  - Advanced noise suppression method
  - Muon track and cascade reconstruction
- Reconstructed atmospheric muon tracks are in good agreement with the expectation.
- Preliminary cascade analysis yields 5 events passing all criteria.
- Baikal-GVD is the biggest neutrino installation in the Northern hemisphere. We have already 3.5 years of data.
- Welcome to join us!!

106 km of the Circum-Baikal railway

Thank you for attention!