

Scope of Baikal-GVD lectures

Lecture 1 (G. Safronov)

- Motivation for Large-Volume neutrino telescopes
- History of neutrino telescope projects at Lake Baikal

Lecture 2 (A. Avrorin)

- The Baikal-GVD detector and its environment
- Data acquisition and triggering
- Background noise suppression

Lecture 3 (G. Safronov)

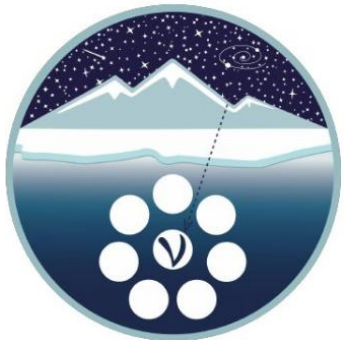
- Event reconstruction

Lecture 4 (A. Avrorin)

- Detector calibration and positioning

Lecture 5 (G. Safronov)

- Baikal-GVD physics results



Baikal-GVD



Development of neutrino astronomy at Lake Baikal

Grigory Safronov (INR RAS, JINR)

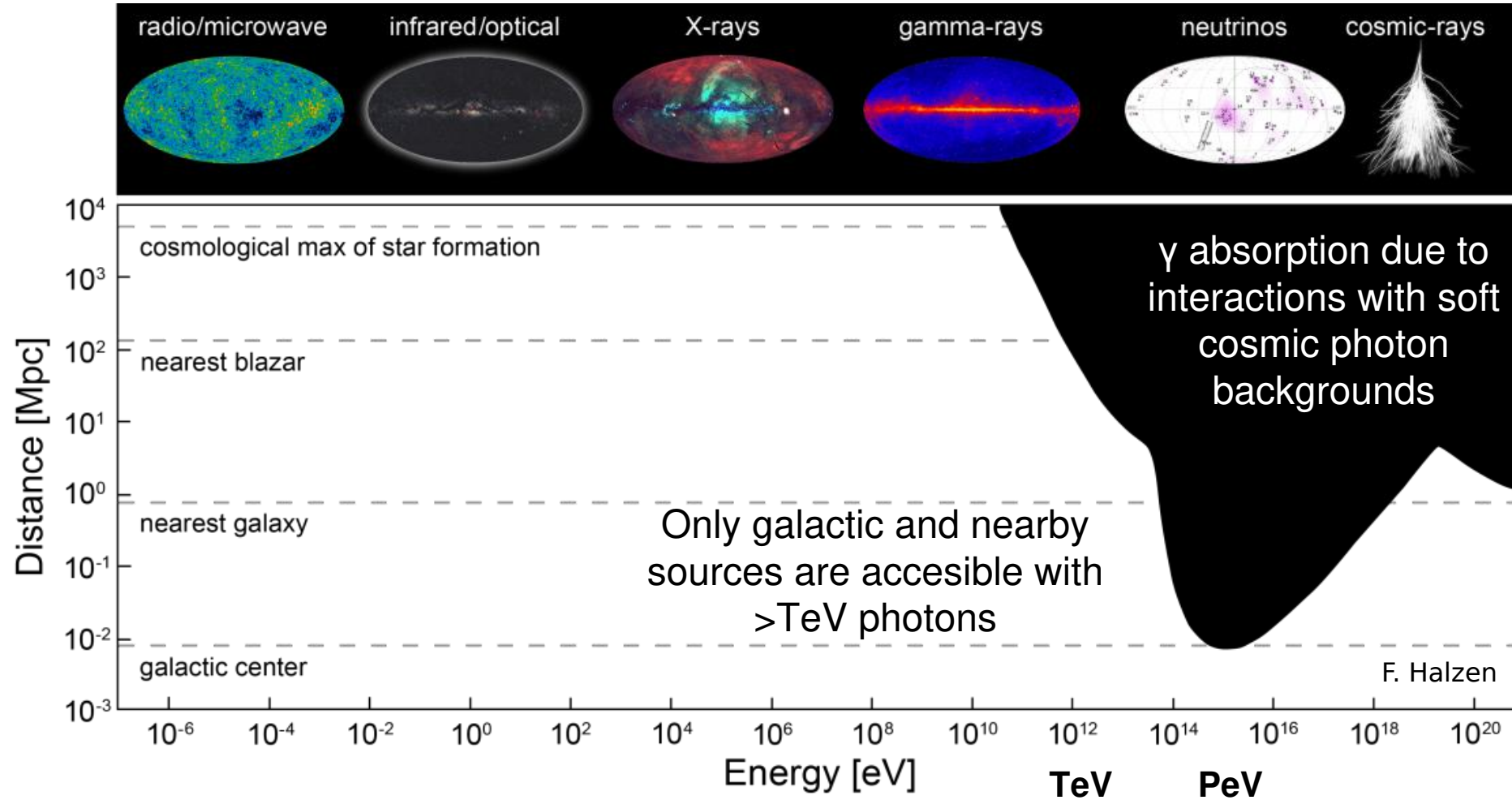


**The First China-Europe Neutrino
Astronomy Summer School**

Chengdu, September 14-23, 2026

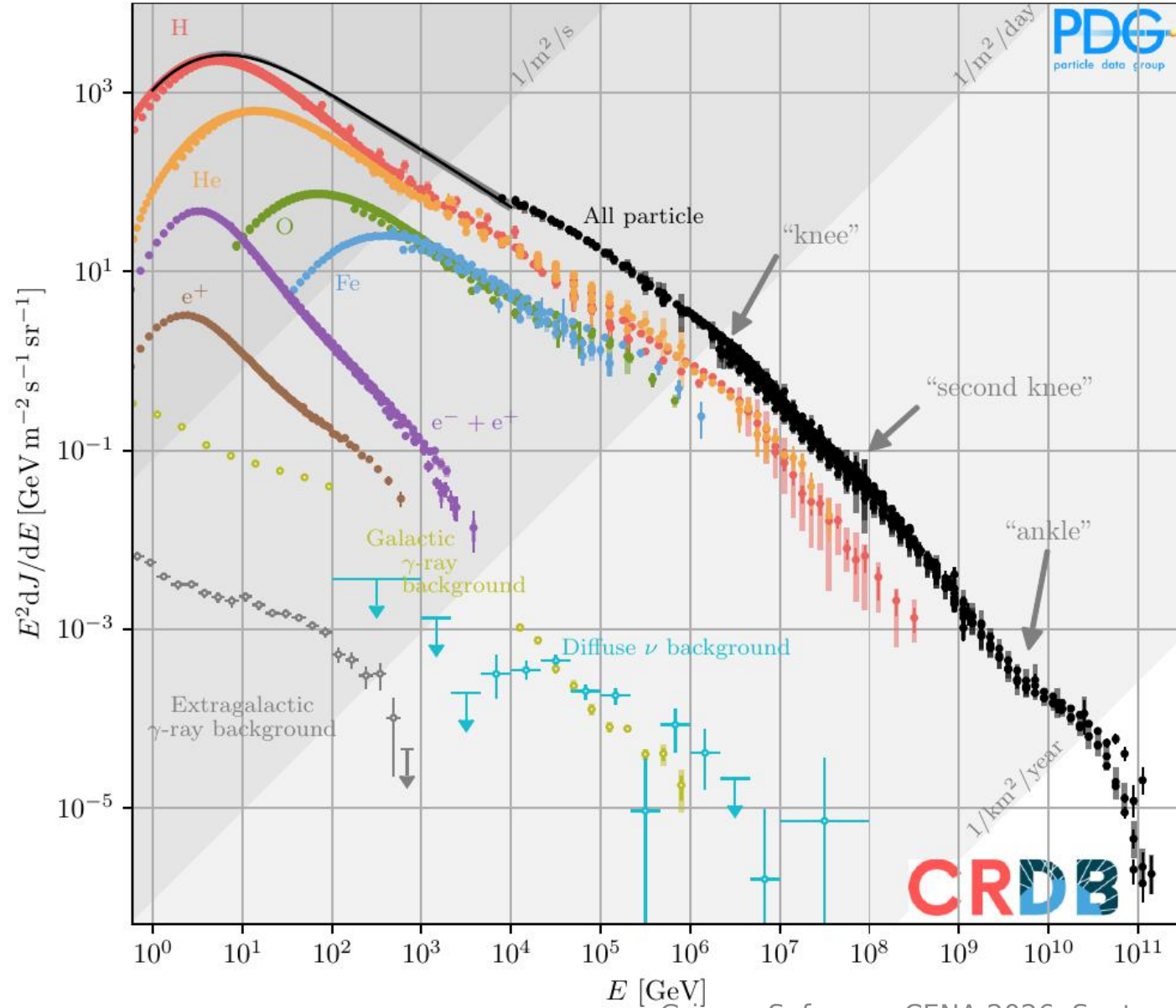
Physics motivation for LVNT

Vast majority of information about the Universe is obtained via the electromagnetic spectrum



Universe is opaque for highest energy photons and is fully transparent for neutrinos

Physics motivation for LVNT



From cosmic ray (CR) spectrum we know that extremely powerful particle accelerators exist in the universe

The range of observed CR particle energies extends up to 10^{11} GeV [10^{20} eV]

Experimental evidence for origin of such energetic particles remain vague

Neutrino properties suggest it as a good tool for unlocking this problem

High-energy neutrino production

Astrophysical neutrinos are produced in pion decays
in interactions of energetic CR with cosmic environment

Production modes

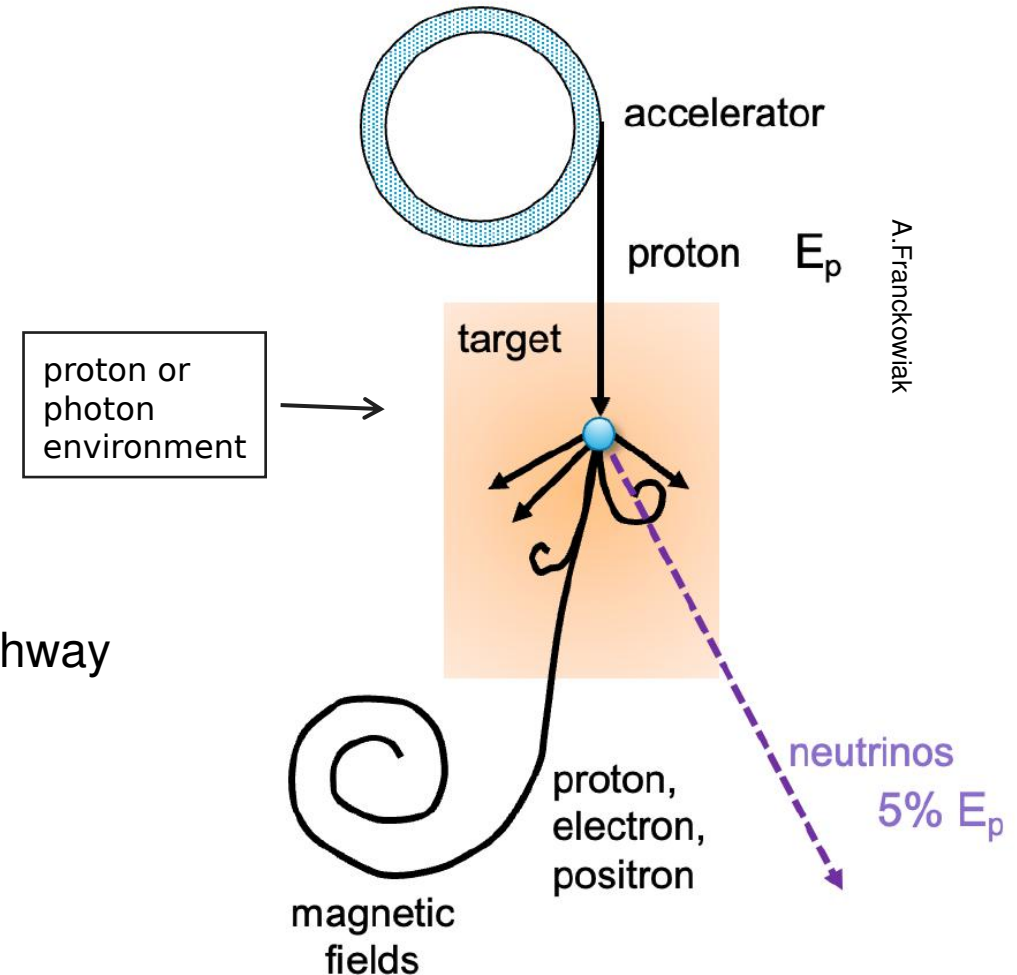
photon-rich environment: $p\gamma \rightarrow \pi$

proton-rich environment: $pp \rightarrow \pi$

Neutrino energy: $E_\nu \sim E_p/20$

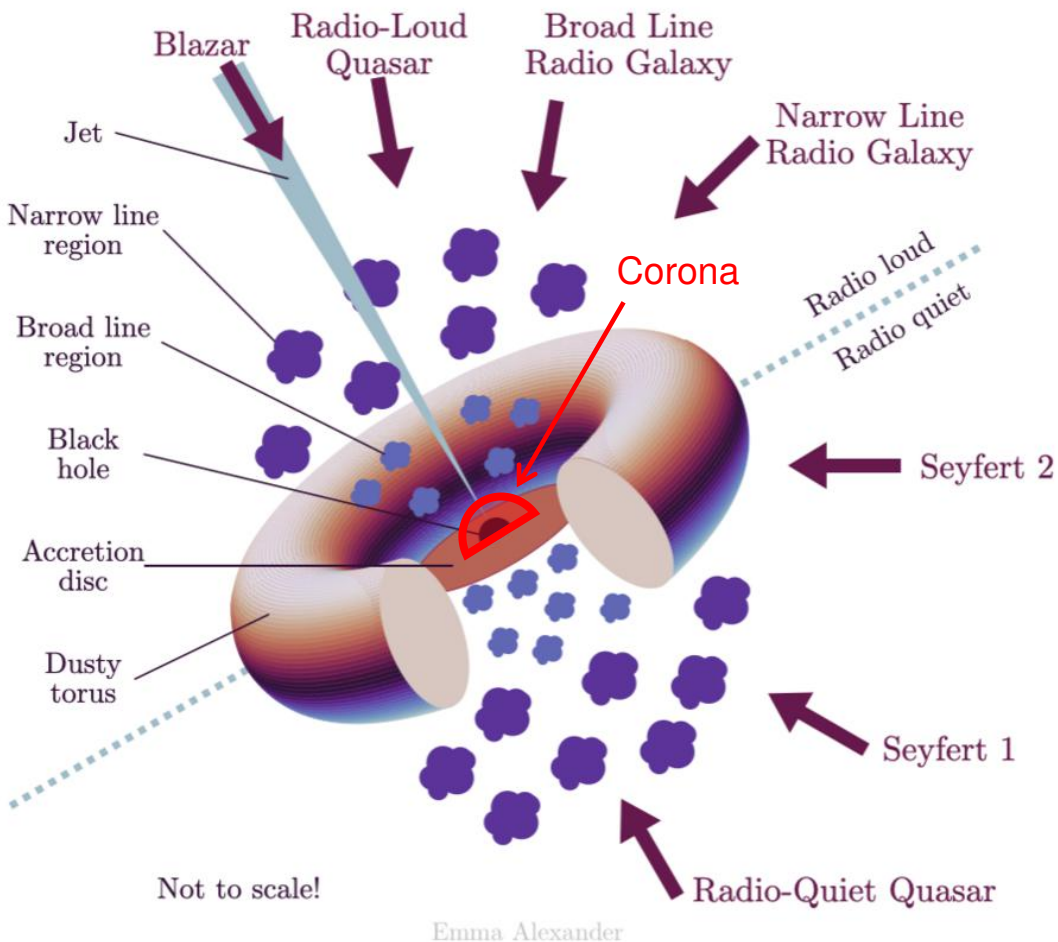
In general target environment can be anywhere on the CR pathway

- Near the high-energy CR source
- Dense environments on its path
- Soft photon backgrounds
- Earth atmosphere



Neutrino points to its origin and probes the energy scale of hadronic processes at the source

High-energy neutrino sources



An example of $p\gamma$ -dominated source

Active galactic nuclei (AGN)

Suggested ν production mechanism

- Protons are accelerated in shock-waves or black hole magnetosphere
- Interact with low-energy EM radiation of the accretion disk
- Interact with X-ray radiation of corona

AGN class depends on observer angle wrt the rotation axis

High-energy neutrino sources

An example of pp mechanism -dominated source:

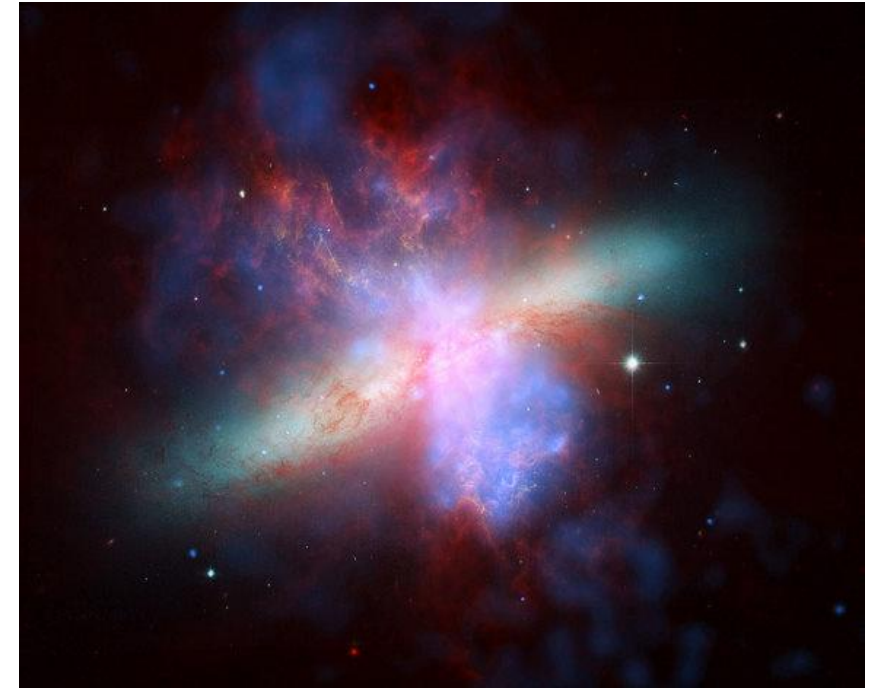
Cosmic ray reservoirs, e.g.:

- Starburst galaxies
- Supernovae remnants (SNR)

High-energy protons are accelerated and
confined with the reservoir

Interact with each other

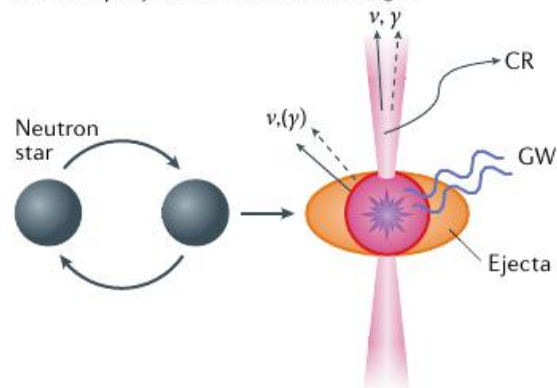
Reference starburst galaxy: M82
dist.: 3.7 Mpc



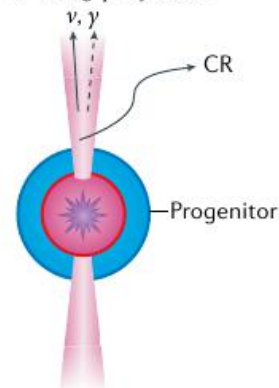
Transient neutrino sources

Transient: lasting for only a short time; temporary [Cambridge Dictionary]

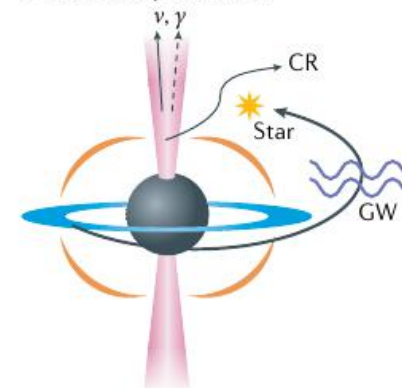
a Short γ -ray burst neutron star merger



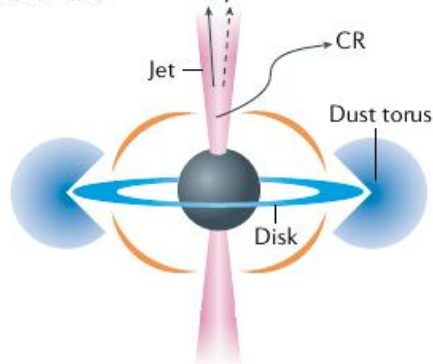
b Long γ -ray burst



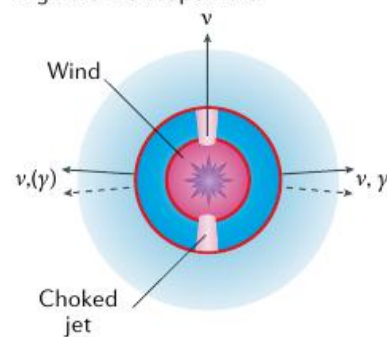
c Tidal disruption event



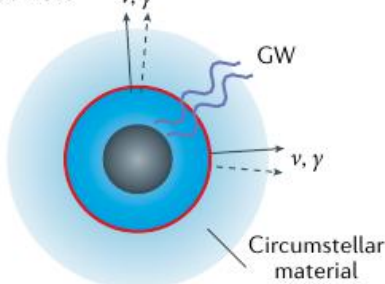
d Blazar flare



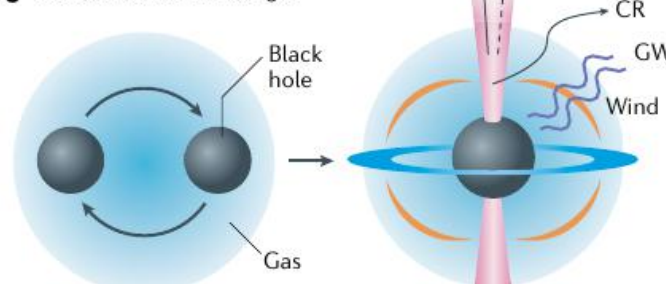
e Engine-driven supernova



f Supernova



g Double black hole merger



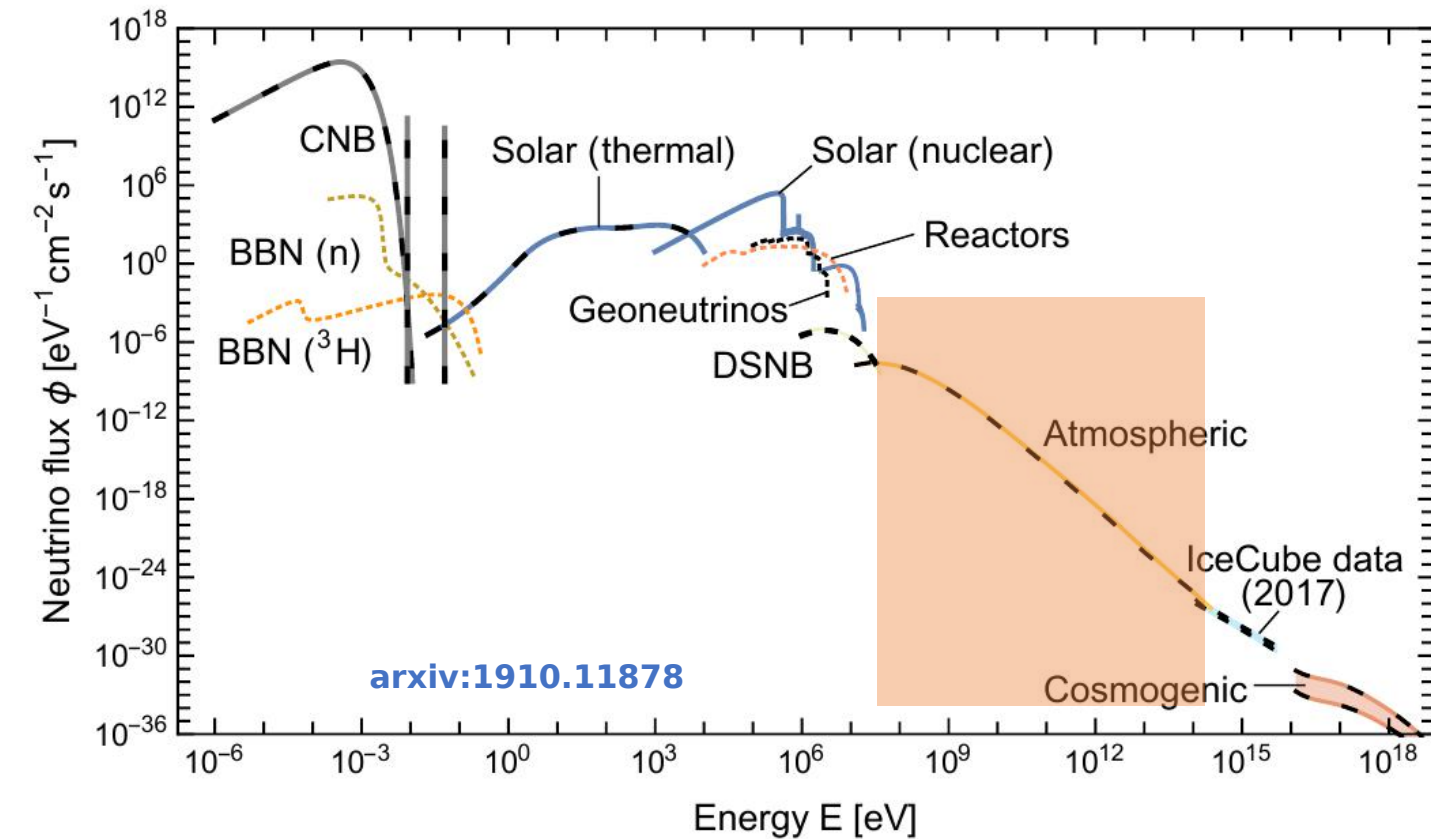
Many more possible sources
P. Meszaros
[arXiv:1708.03577](https://arxiv.org/abs/1708.03577) (2017)

More useful reading:
S. Troitsky
[arXiv:2311.00281](https://arxiv.org/abs/2311.00281) (2024)

High-energy neutrino fluxes

Flux of neutrino at Earth spans over large energy range

Full-sky neutrino flux at Earth differential in energy

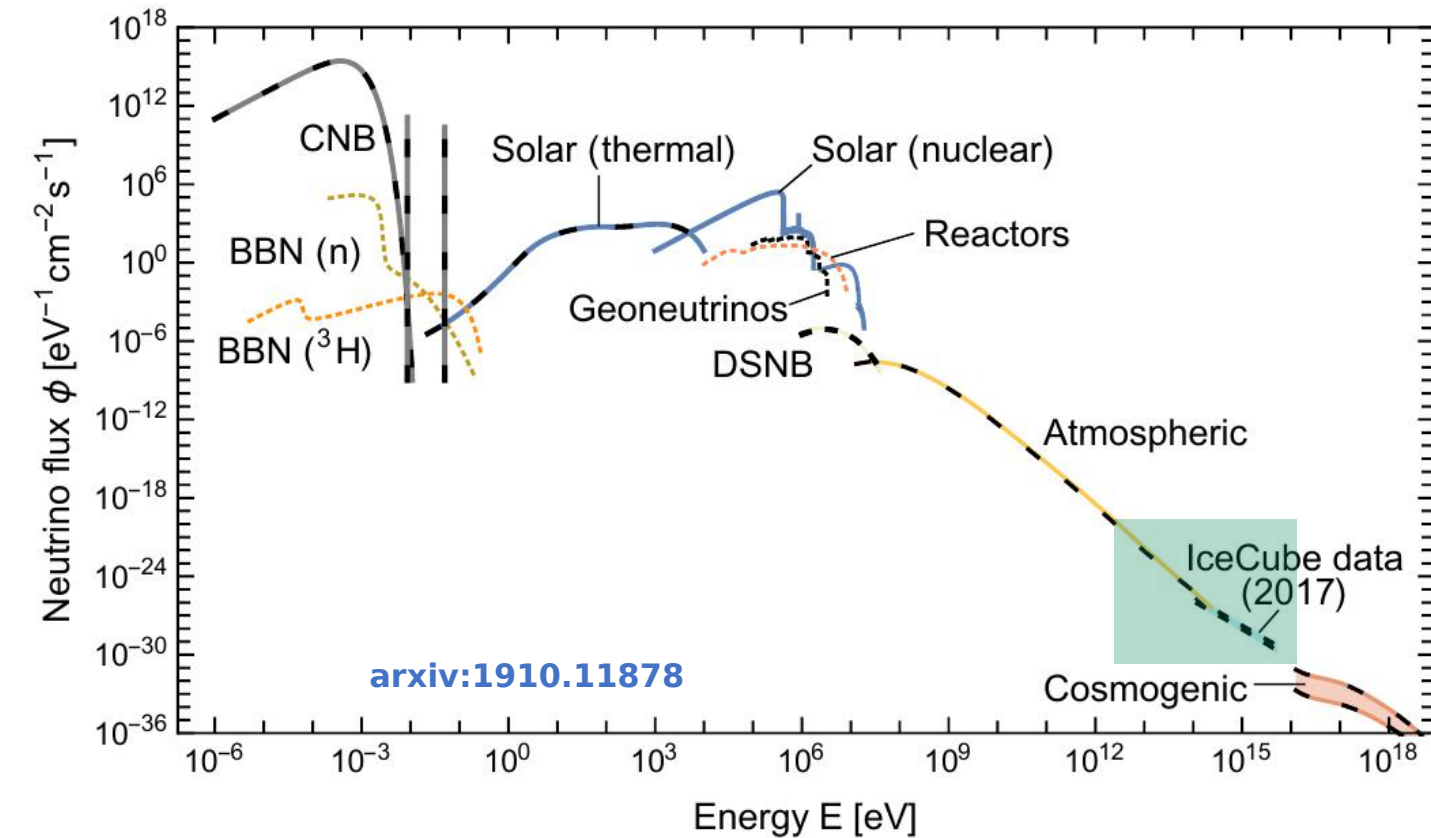


~ GeV - TeV ν energy:
Atmospheric neutrino flux from CR
hitting the atmosphere

High-energy neutrino fluxes

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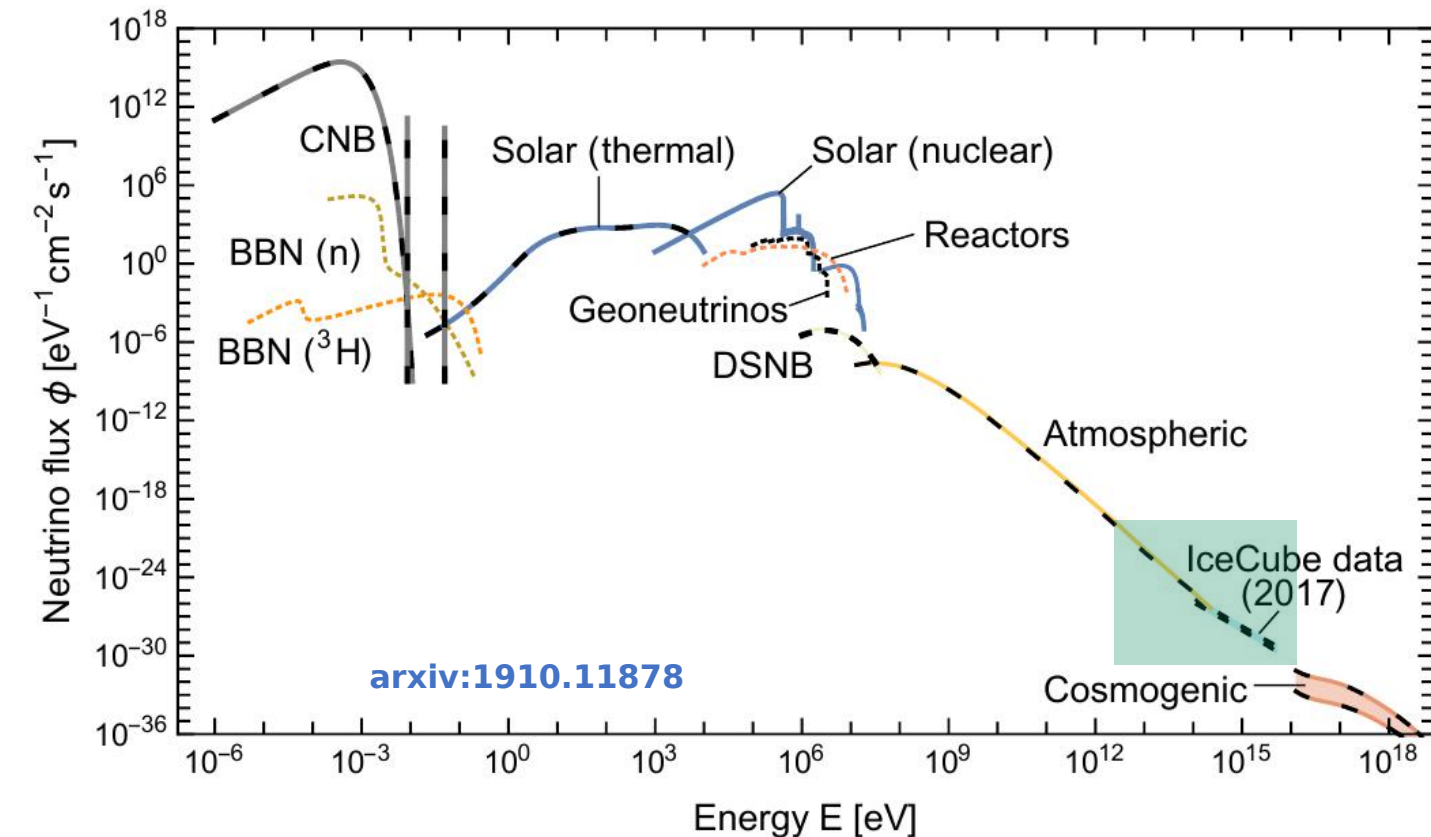


TeV-PeV ν energies:
astrophysical neutrino flux emerges

High-energy neutrino fluxes

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Full-sky neutrino flux at Earth differential in energy

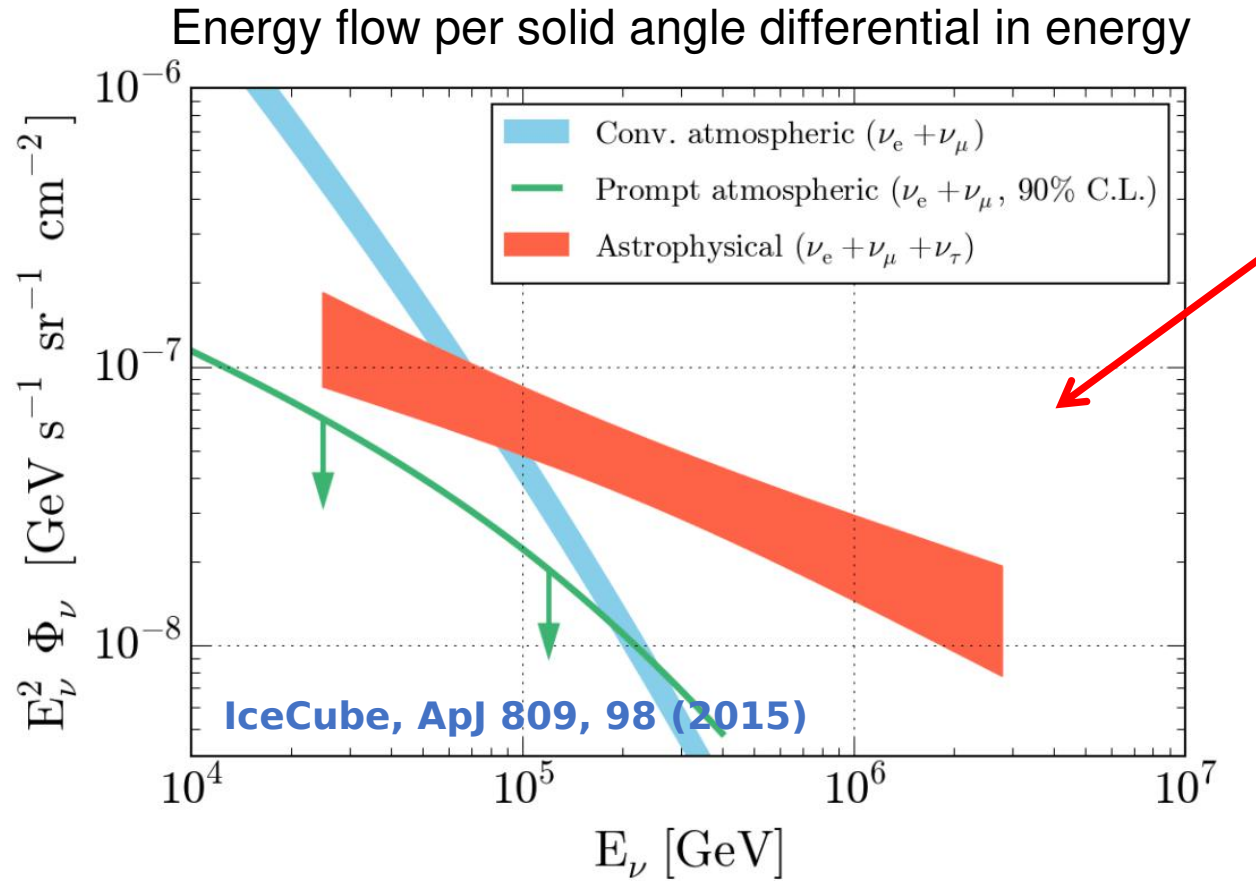


TeV-PeV ν energies:
astrophysical neutrino flux emerges

**Let's zoom into our region of interest
and quantify the event rate**

High-energy neutrino fluxes

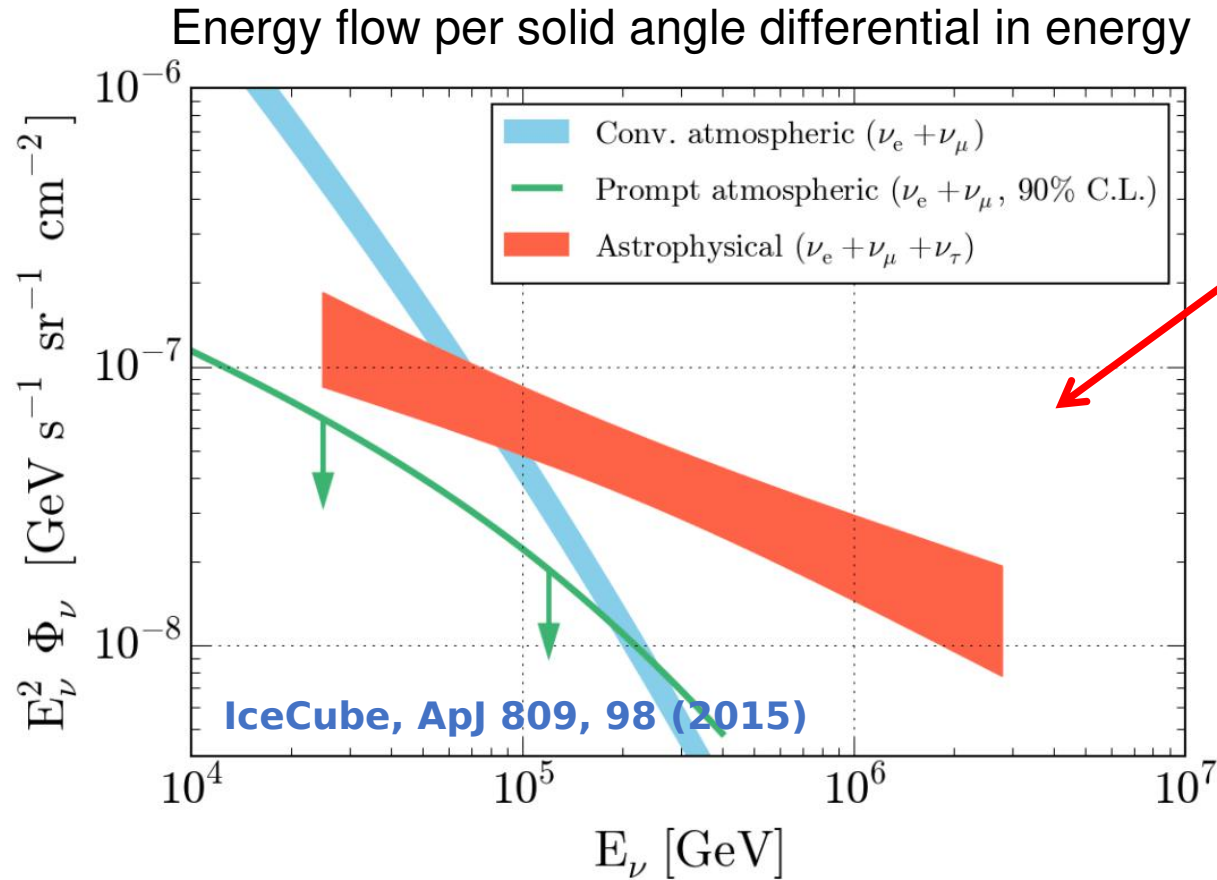
Astrophysical neutrino flux overcome atmospheric neutrino background around 50-100 TeV



Diffuse all-flavour astrophysical flux:
average flux from the whole sky
disregarding potential sources

High-energy neutrino fluxes

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Diffuse all-flavour astrophysical flux:
average flux from the whole sky
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Measured ν fluxes are often discussed as a
single power-law with spectral index γ and
normalisation ϕ_0

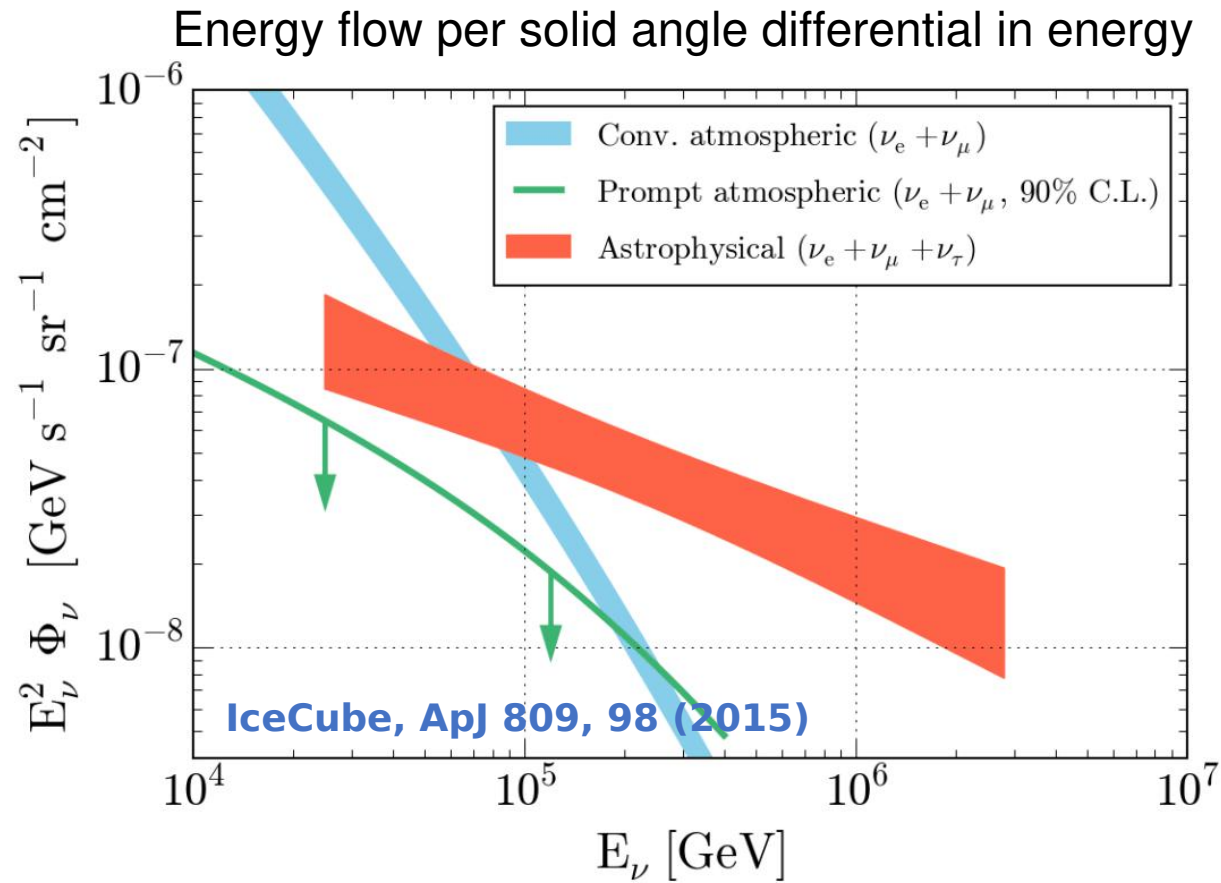
$$\frac{d\Phi_\nu}{dE_\nu}(E_\nu) = \phi_0 \left(\frac{E_\nu}{E_0} \right)^{-\gamma}$$

Atmospheric neutrino, “soft” spectrum: $\gamma \sim 3.7$
Astrophysical neutrino, “hard” spectrum: $\gamma \sim 2.5$

E_0 - normalisation point

High-energy neutrino fluxes

Usual normalisation point: $E_0 = 100 \text{ TeV}$



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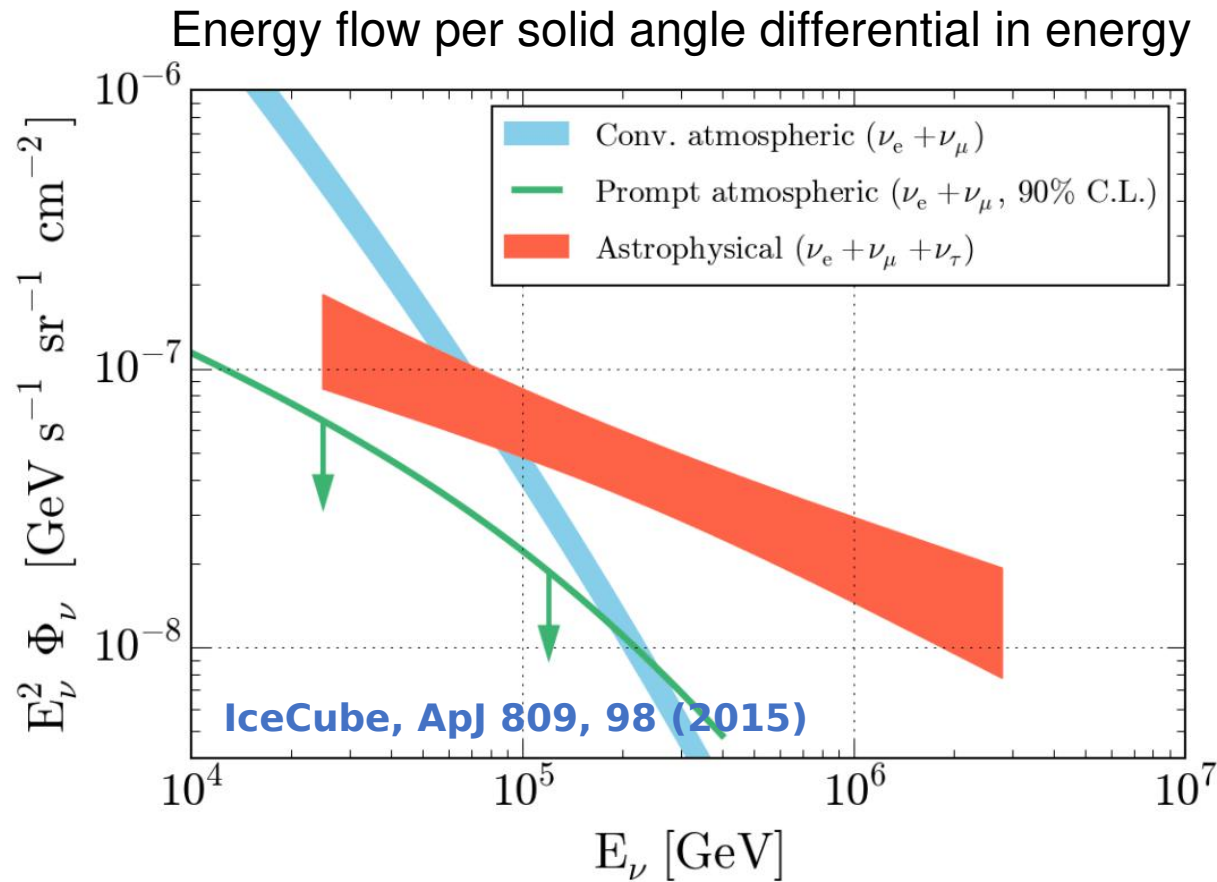
$$\frac{d\Phi_\nu}{dE_\nu}(E_\nu) = \phi_0 \left(\frac{E_\nu}{100 \text{ TeV}} \right)^{-\gamma}$$

Selected diffuse flux measurement:

IceCube 9.5 yr. track-like events spectrum fit

$$\phi_0 = 1.44 \cdot 10^{-18} \text{ (GeV}^{-1} \text{ cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}\text{)}, \quad \gamma = 2.37$$

R. Abbasi et al 2022 ApJ 928 50



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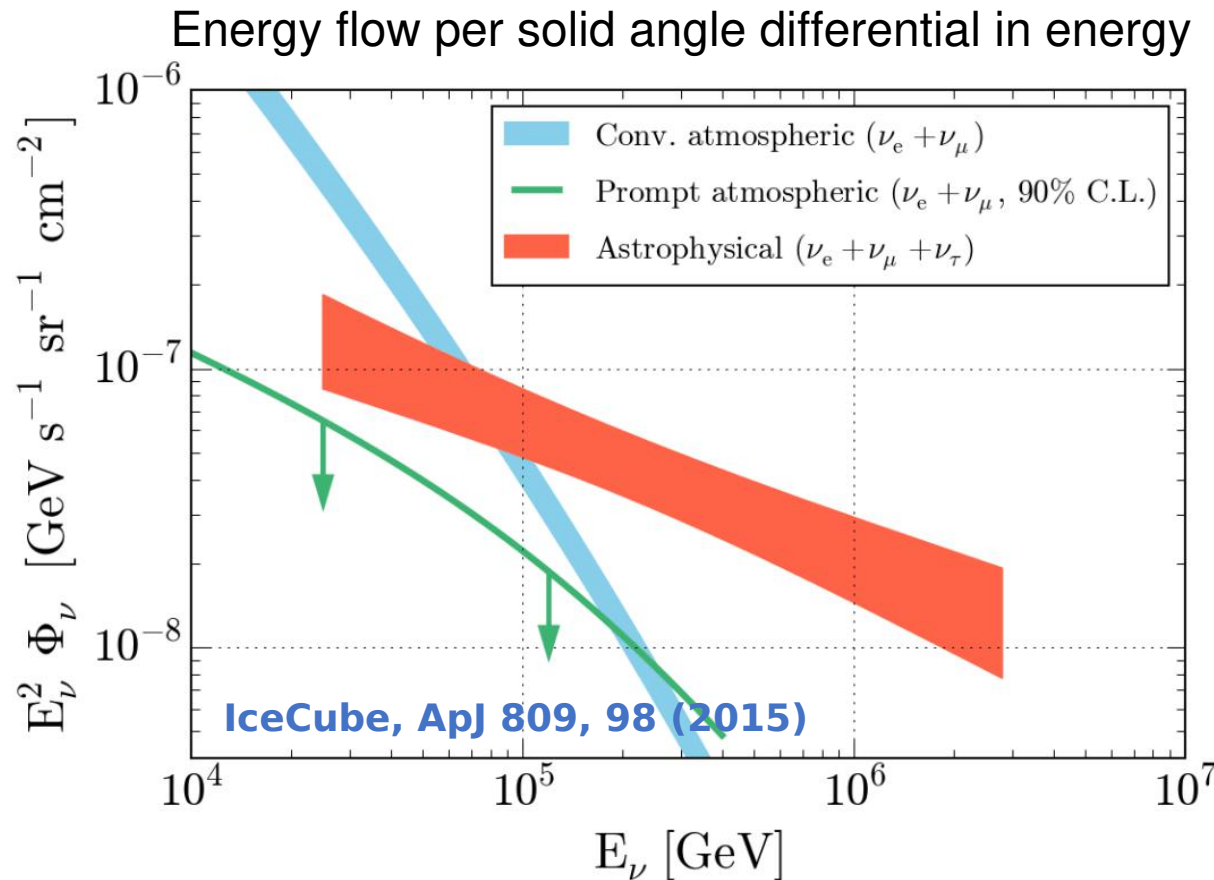
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R. Abbasi et al 2022 ApJ 928 50

The corresponding integrated flux of astro. neutrino with $E > 1 \text{ TeV}$ is: **$\sim 230 \text{ per m}^2 \text{ per year}$**



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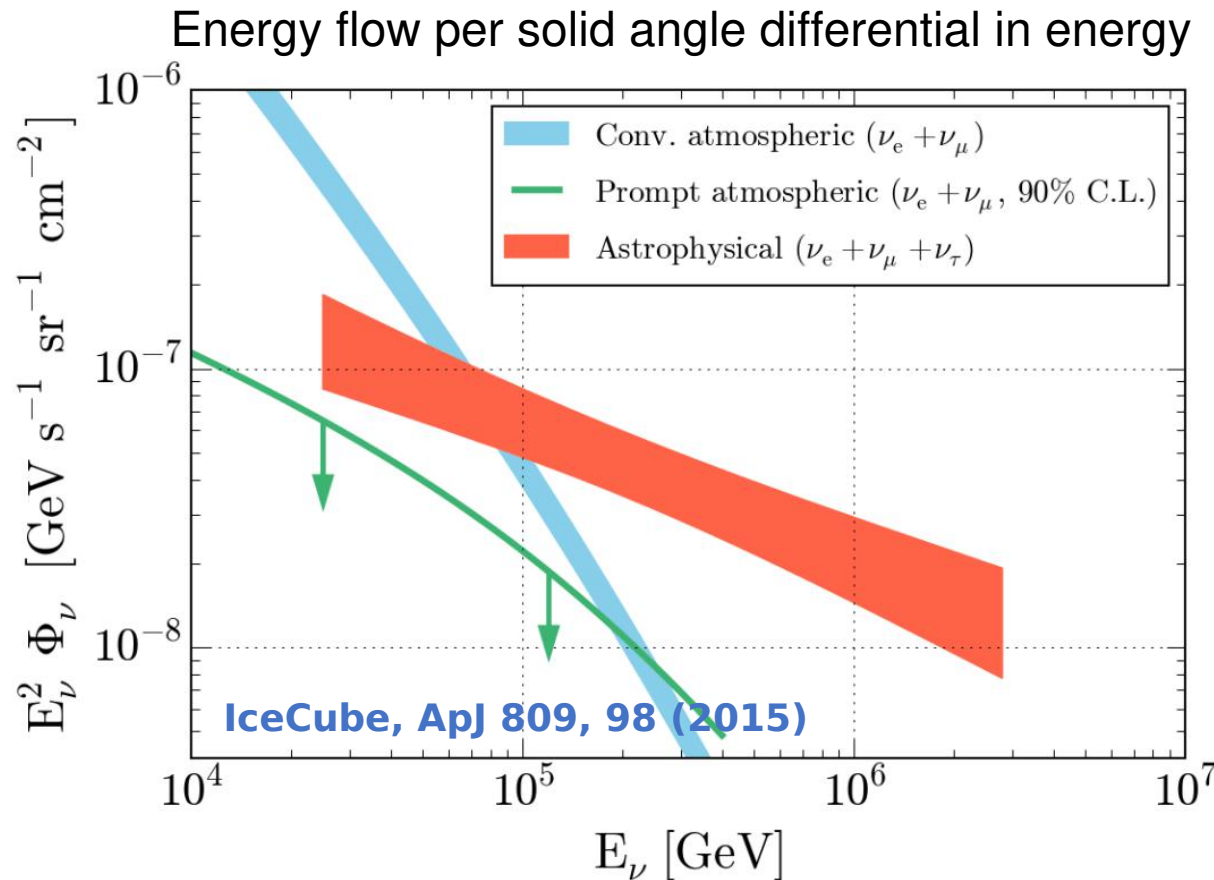
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R. Abbasi et al 2022 ApJ 928 50

The corresponding integrated flux of astro. neutrino with $E > 1$ TeV is: **~ 230 per m^2 per year**



How do we detect such a low neutrino flux?

Let's estimate rate of neutrino interactions in our detector volume

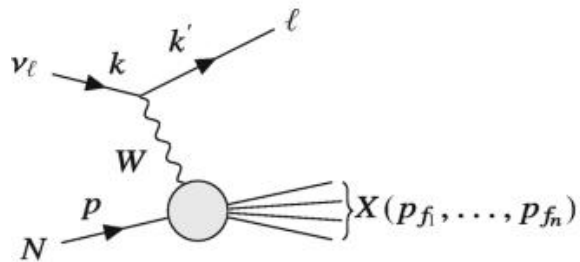
High-energy neutrino interactions

Interaction cross-section: $\text{rate}(\text{s}^{-1}) = \boxed{\sigma(\text{cm}^2)} \times \text{flux}(\text{cm}^{-2}\text{s}^{-1})$

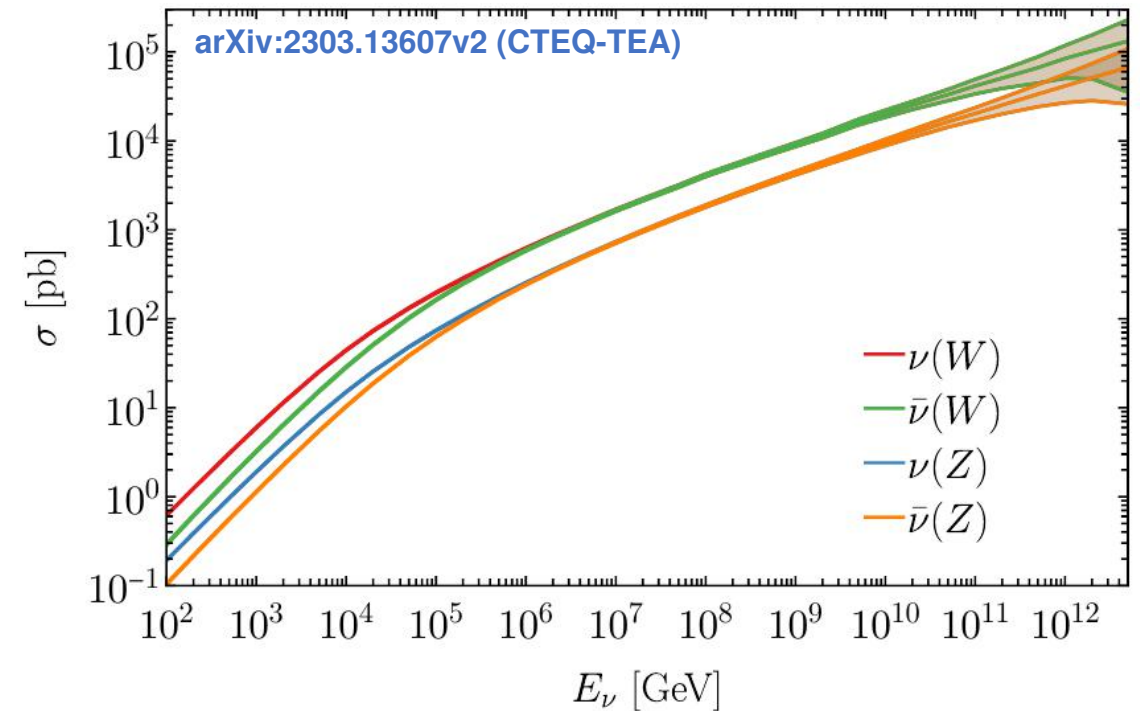
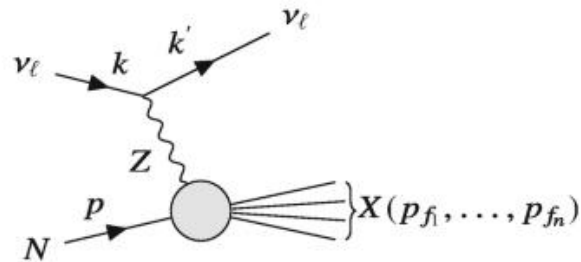
Neutrinos interact with nucleons of the target detector volume

Above $E_\nu \sim 1 - 10 \text{ GeV}$ νN interaction goes via Deep Inelastic Scattering (DIS)

Charged Current (CC) interaction
($W^\pm$ bosons)



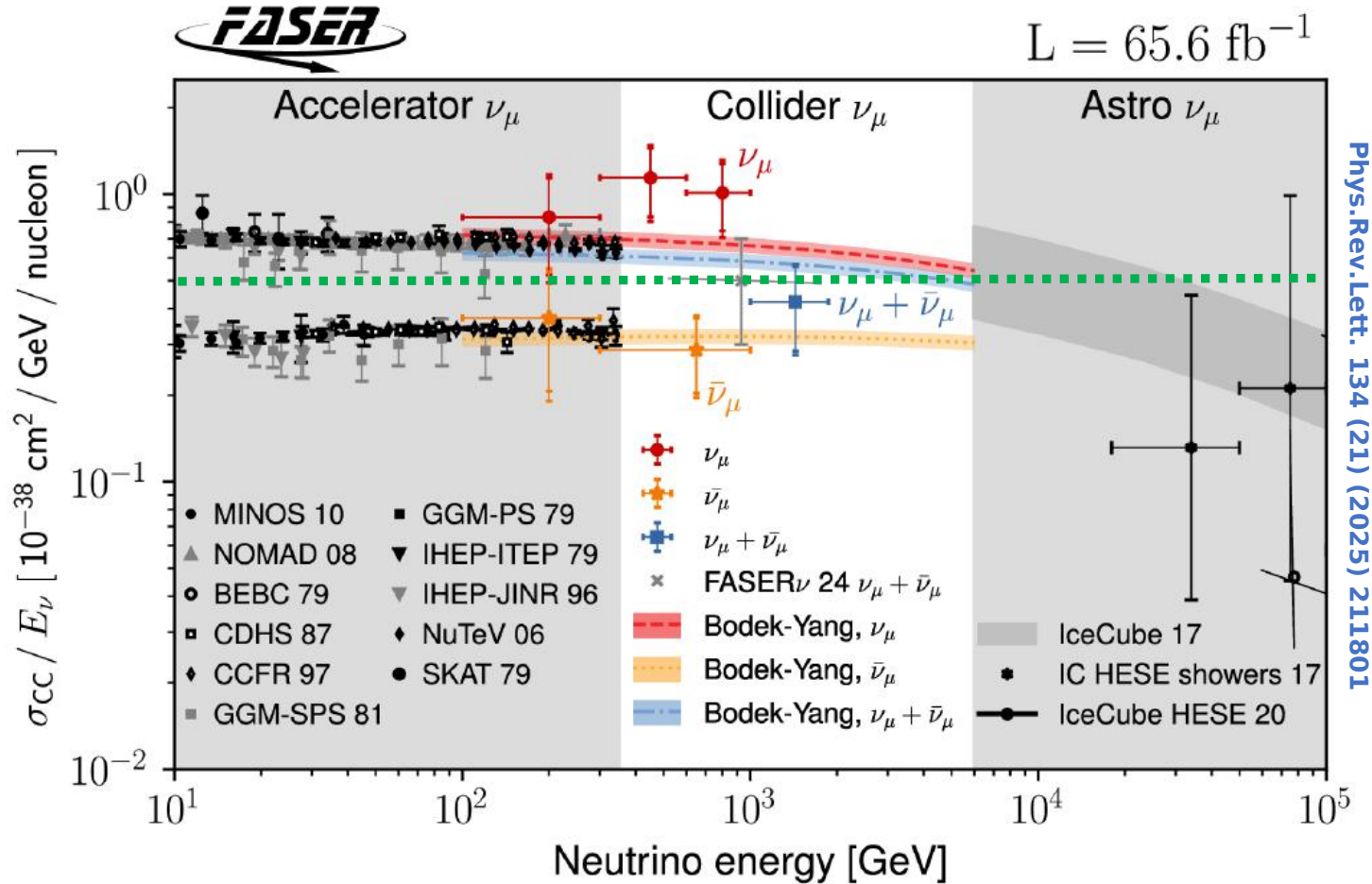
Neutral current (NC) interaction
(Z boson)



NC cross-section is ~ 3 times smaller than CC

Neutrino interaction cross-section

Neutrino cross-section measurements



Neutrino interaction cross-section scales as $\sim E_\nu$ for TeV energies

Assume $\nu + \bar{\nu}$ CC cross-section:

$$\sigma_{\nu+\bar{\nu}} = E_\nu(\text{GeV}) \times 5 \times 10^{-39} (\text{cm}^2/\text{GeV})$$

Neutrino interaction rate

To calculate number of interactions per some volume one has to integrate the total flux with the cross-section

full-sky flux convoluted with
cross-section - rate of interactions per nucleon

Rate of events per s in volume V :

$$R = \left(\frac{\rho V}{\mu} N_A \right) I$$

where:

$$I = \sum_{\nu} \int_{E_{min}}^{E_{max}} \left(\frac{d\Phi}{dE_{\nu}} (E_{\nu}) \right) \sigma_{\nu+\bar{\nu}} (E_{\nu}) dE_{\nu}$$

number of nucleons per V

sum over ν flavours

full-sky flux

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full-sky flux convoluted with cross-section - rate of interactions per nucleon

number of nucleons per V

sum over ν flavours

full-sky flux

Let's calculate **rate of all-flavour CC interactions within 1 m³ or 1 tonne of water for $E_{\nu} > 1$ TeV**

Consider IceCube track flux: $\phi_0 = 1.44 \cdot 10^{-18} \text{ (GeV}^{-1}\text{cm}^{-2}\text{s}^{-1}\text{sr}^{-1}\text{)}$, $\gamma = 2.37$

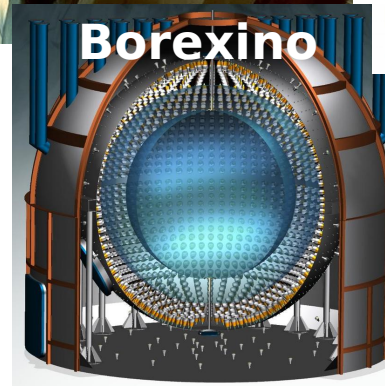
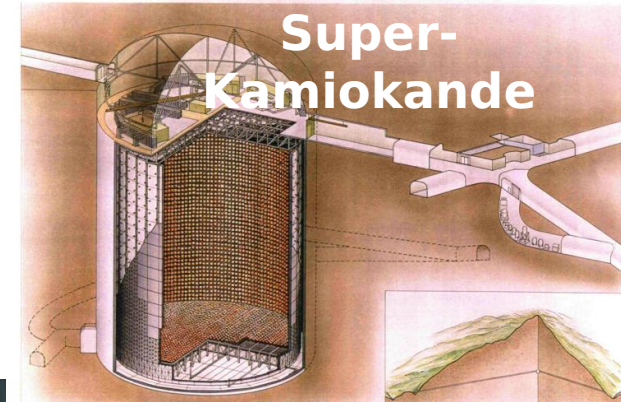
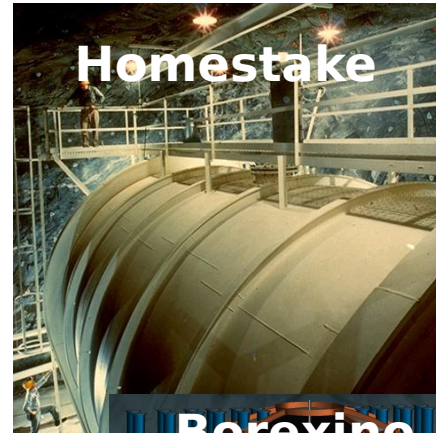
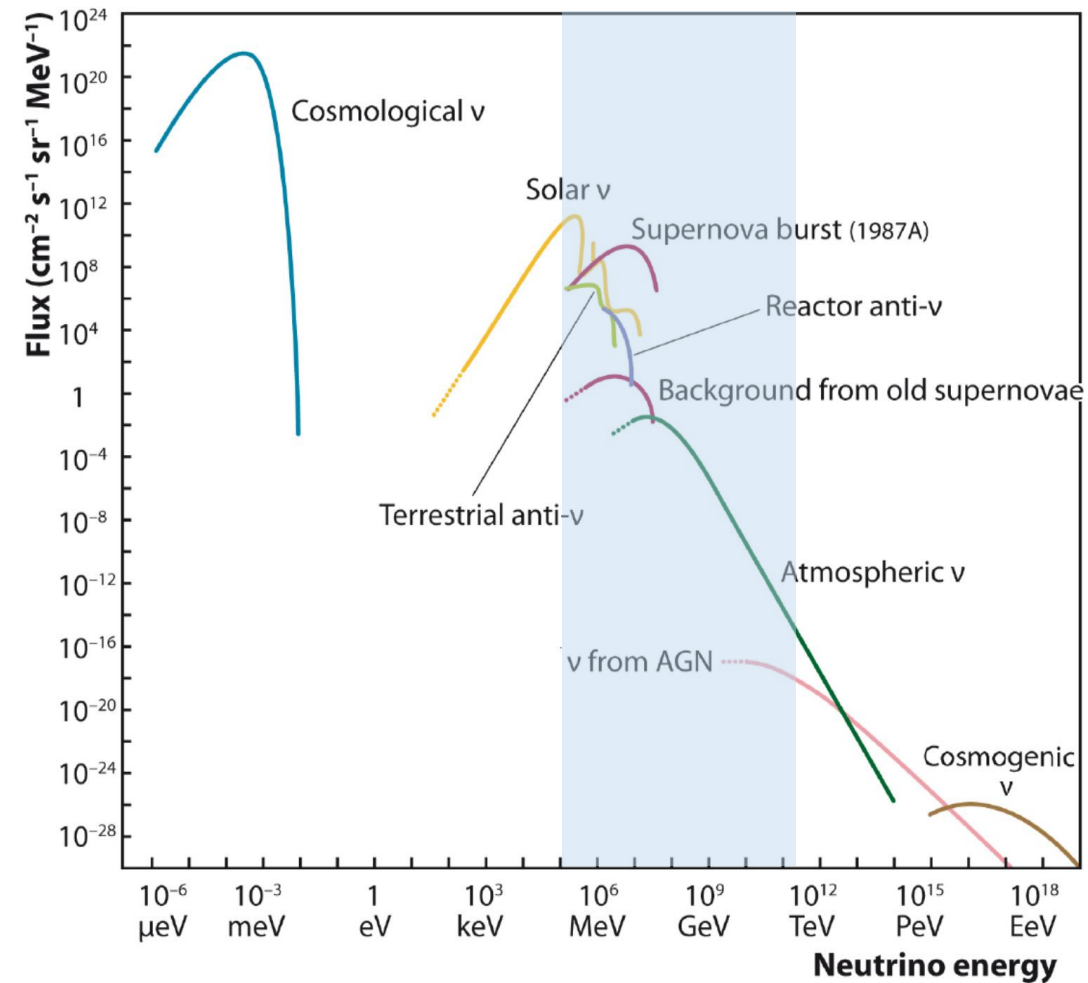
Interaction rate: $\sim 7.6 \cdot 10^{-7}$ per tonne per year

Underground neutrino detectors

Neutrino physics, solar neutrino, atmospheric neutrino

Great variety of exciting experimental techniques

Sensitive volume mass: **10's tons -10's kilotons**



and many-many others

Underground neutrino detectors

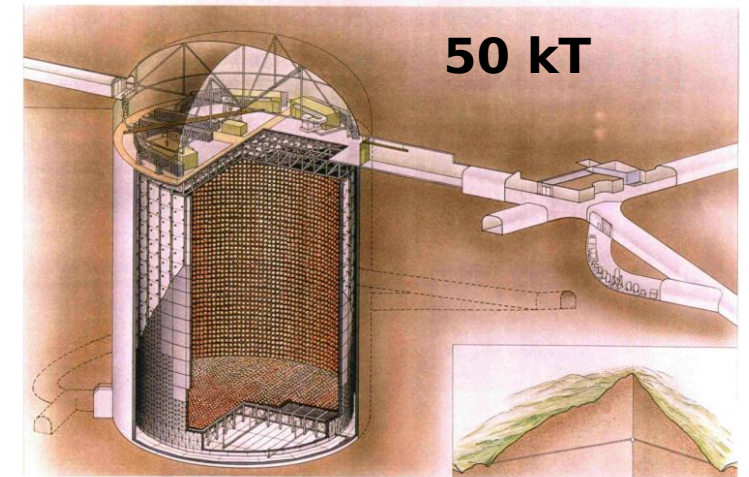
Largest underground neutrino experiments: water-tank detectors

Super-Kamiokande detector, 1980

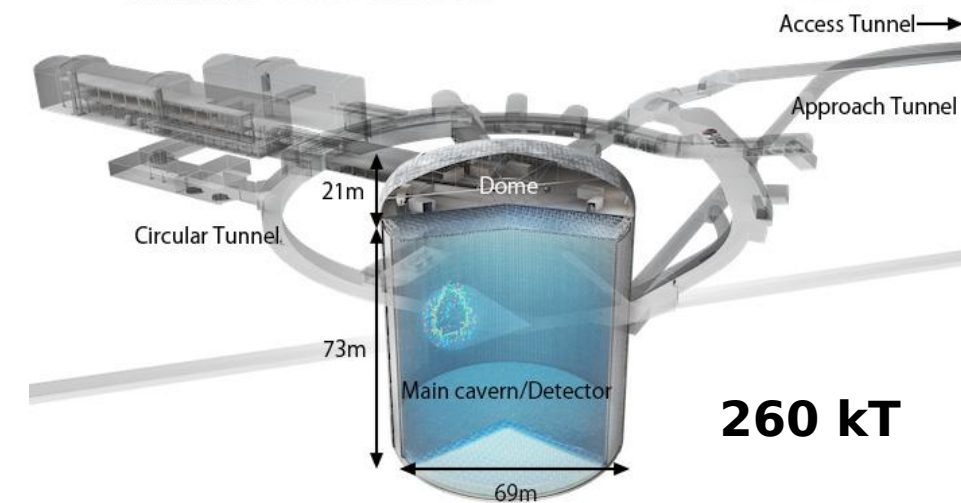
50 kT of water $\rightarrow$ would undergo just ~ 0.04 interactions per year for astro. ν with $E_\nu > 10$ TeV

Hyper-Kamiokande, to be launched soon

260 kT of water $\rightarrow$ would undergo ~ 0.2 such interactions per year



SUPERKAMIOKANDE INSTITUTE FOR COSMIC RAY RESEARCH UNIVERSITY OF TOKYO



For the studies of astro neutrino flux we need different detection techniques

The concept of very-large volume neutrino telescopes

The concept was suggested by Moisey A. Markov at 1960 ICHEP conference



“We propose to install detectors deep in a lake or in the ocean and to determine the direction of charged particles with the help of **Cherenkov radiation**”

artist impression

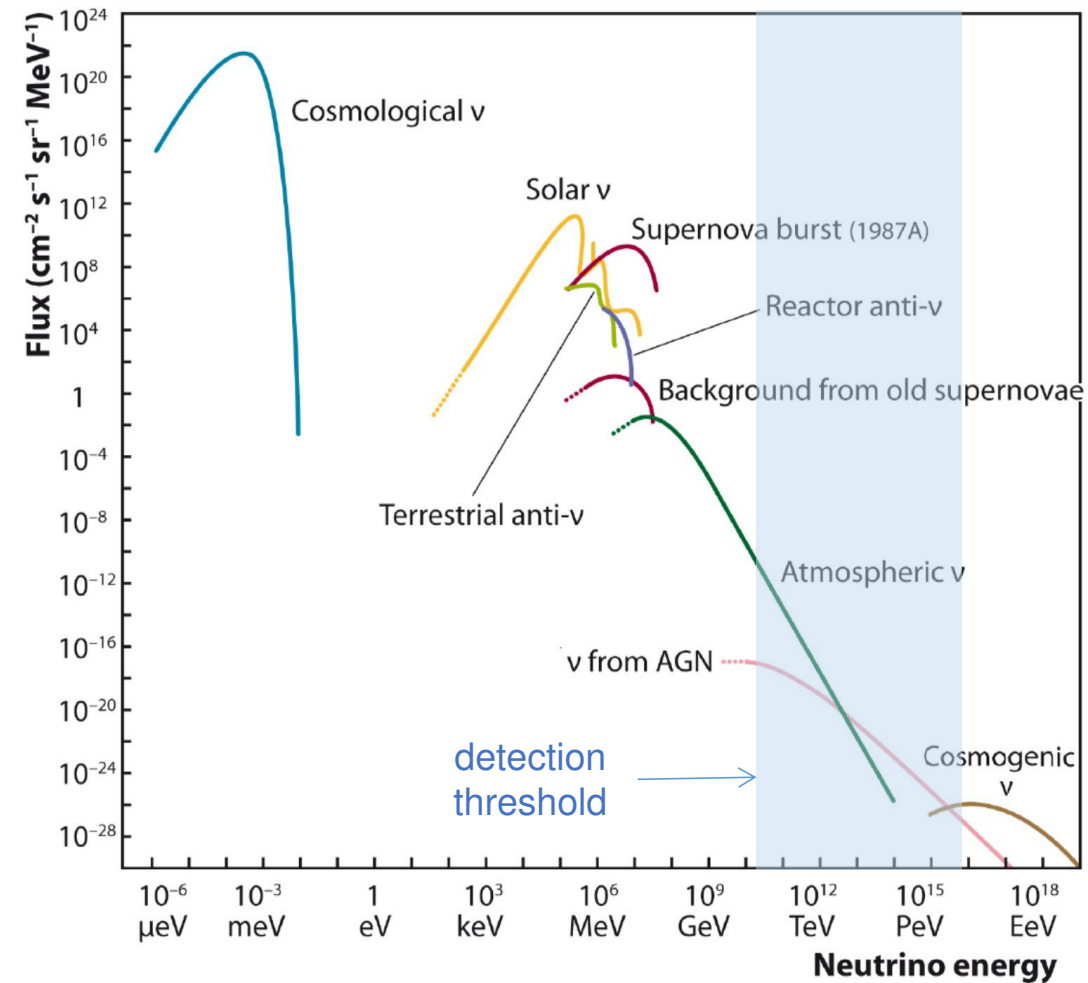
Chengdu ICHEP 2026, September 14-23, Chengdu

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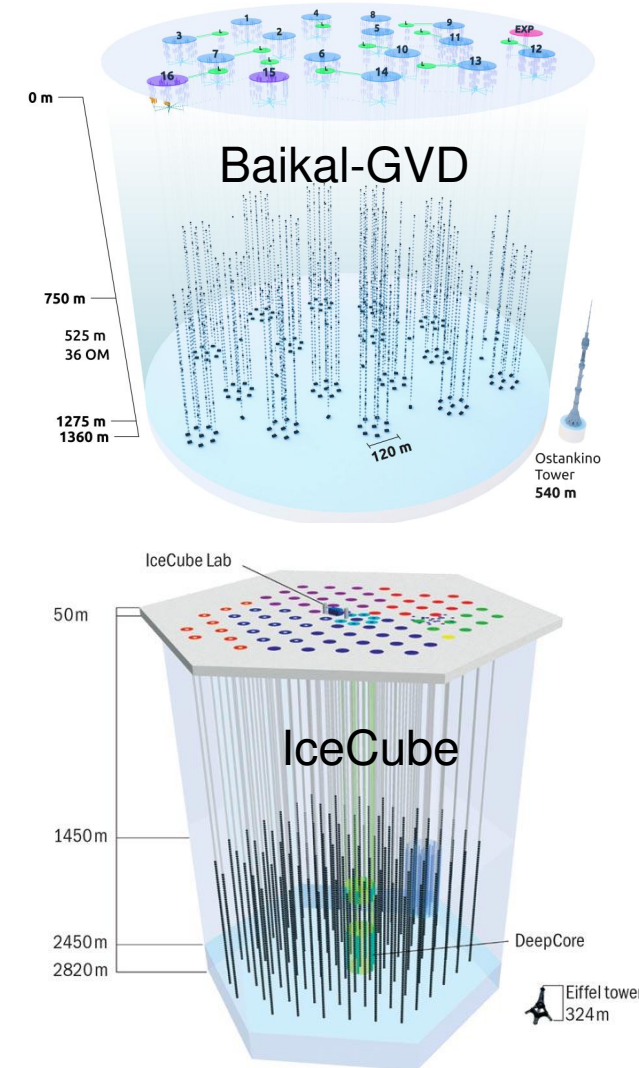
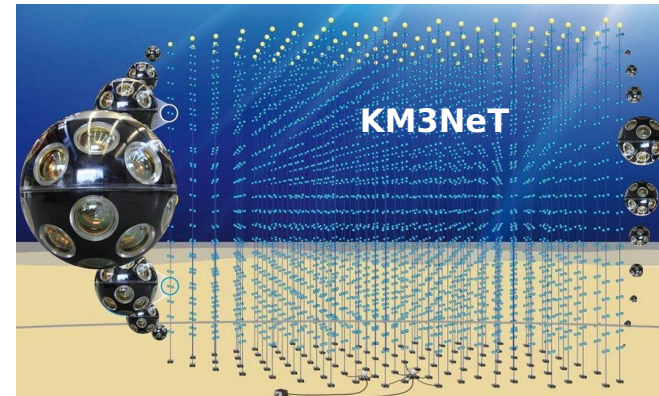
Large-volume neutrino telescopes

Present generation: **Gigaton mass scale**



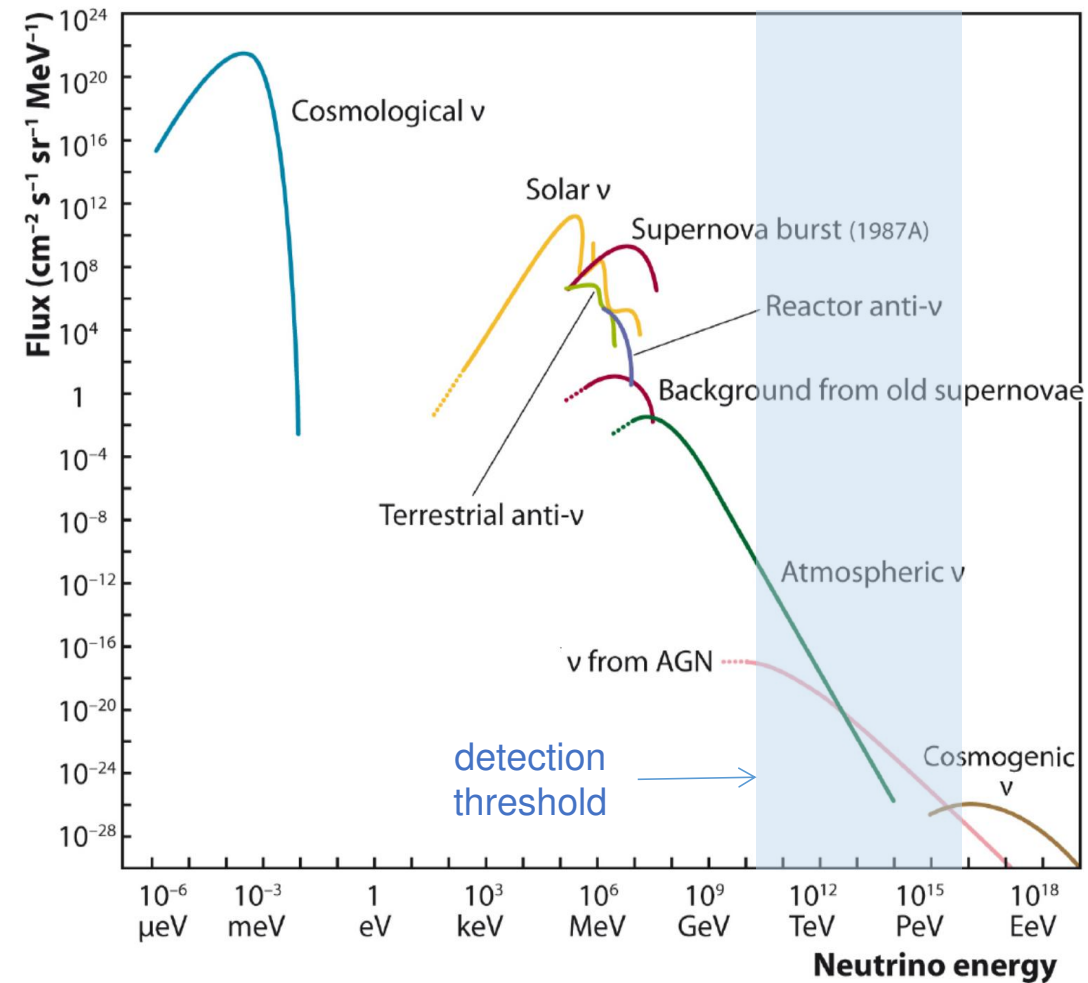
Energy range:
10's GeV - multi-PeV

- Atmospheric neutrino
- Astrophysical neutrino (galactic, extragalactic)
- ~ cosmogenic neutrino



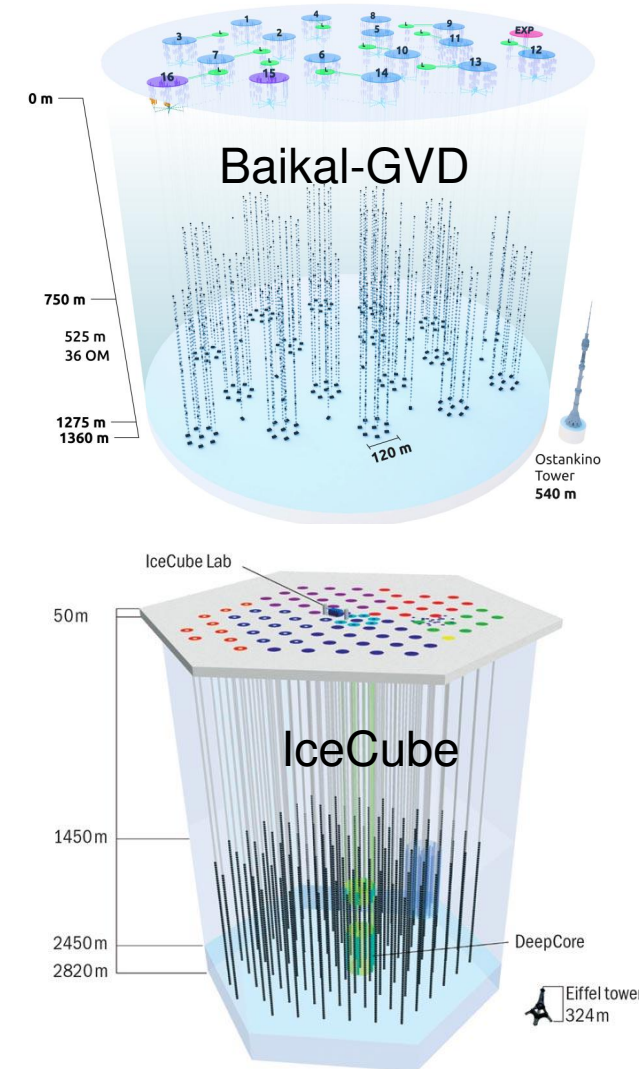
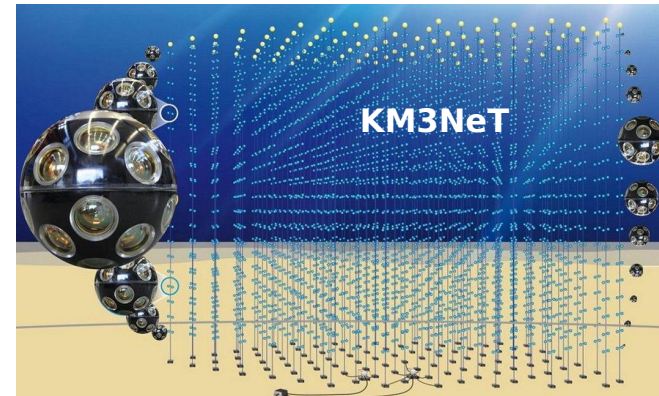
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~760 interactions per year for 1 Gt of water for $E_\nu > 1$ TeV

Towards large-volume neutrino telescope in Lake Baikal

DUMAND

Back in 1970s neutrino astronomy thought to be much closer than it turned to be

DUMAND (Deep Underwater Muon And Neutrino Detector)

- Suggested and discussed in the second half of 1970s

Very challenging initial detector project

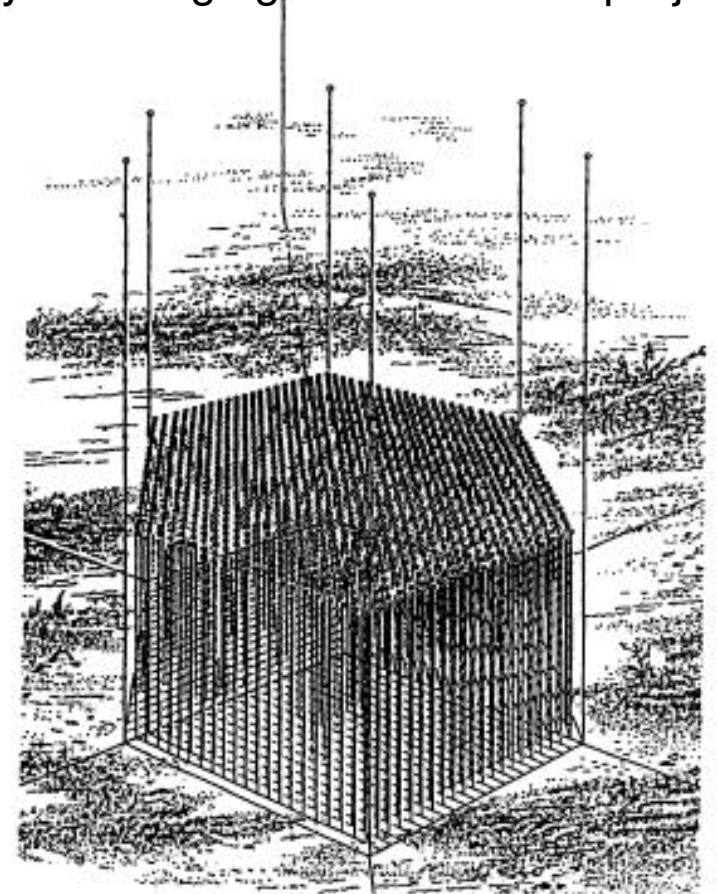


FIG. 9. The first DUMAND array: DUMAND G, the 1978 model. See text for details (Roberts and Wilkins, 1978).

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Very optimistic expectations for the neutrino flux:

The most liberal estimates of the overall cosmic background of active galactic nuclei imply a count rate in a 10^9 ton detector averaging up to $\sim 2 \times 10^2$ counts per day at $E_\nu \gtrsim 10^{12}$ eV.

SOME BRIGHT GALACTIC NUCLEI

Star	Flux at $10 \mu\text{m}$ ($\text{eV cm}^{-2} \text{s}^{-1}$)	Total Flux	Count Rate (yr^{-1}) ^a
NGC 1068.....	5.0×10^{3c}	1.9×10^{4e}	3×10^3
NGC 253.....	1.2×10^{3c}	3.0×10^{4e}	4×10^3
NGC 3077.....	6.6×10^{2c}	2×10^{3b}	3×10^2
NGC 3034 (M82).....	5.4×10^{3c}	2×10^{4b}	3×10^3
NGC 1614.....	1.8×10^{2c}	8×10^{2b}	1×10^2
NGC 7469.....	1.6×10^{2c}	6×10^{2b}	1×10^2
Markarian 231.....	2.8×10^{2c}	1×10^{3b}	1×10^2

Eichler, D. **High-energy neutrino astronomy: a probe of galactic nuclei?**, ApJ 1979, 232, 106-112. <https://doi.org/10.1086/157269>.

Very challenging initial detector project

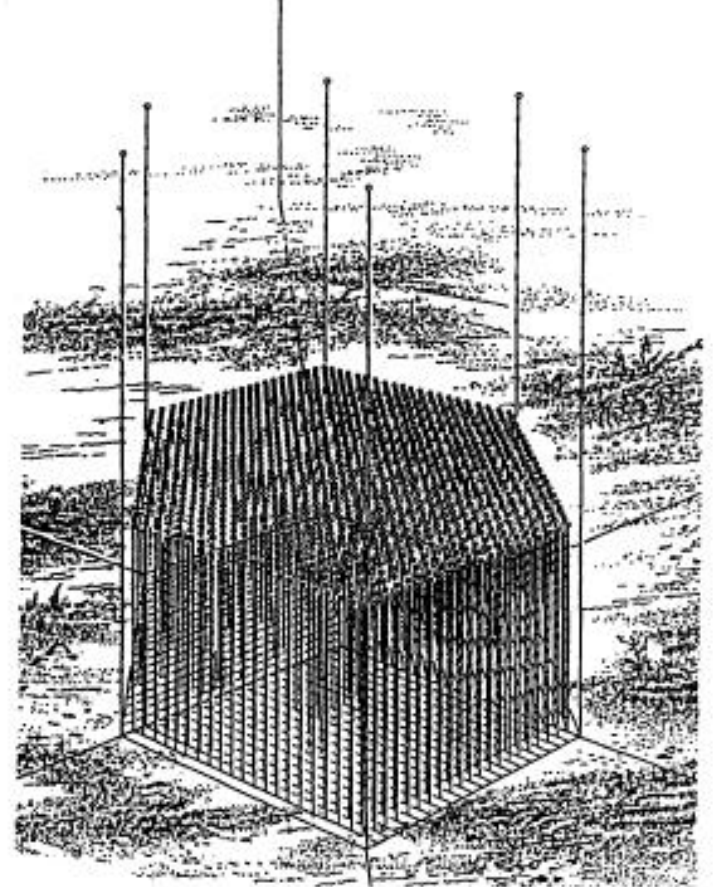


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IceCube:

79 v in 9 years

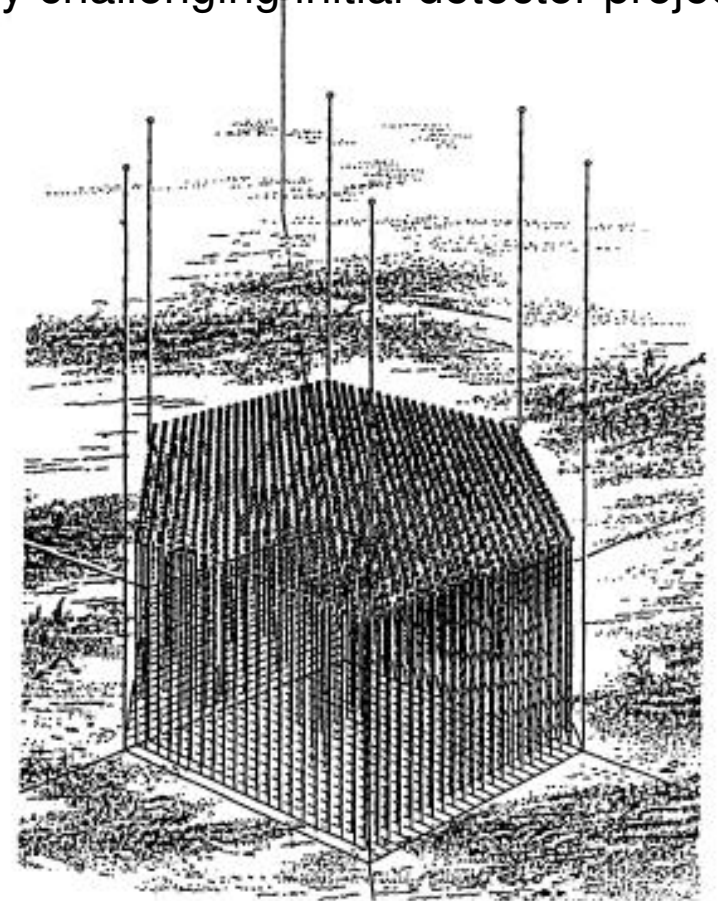
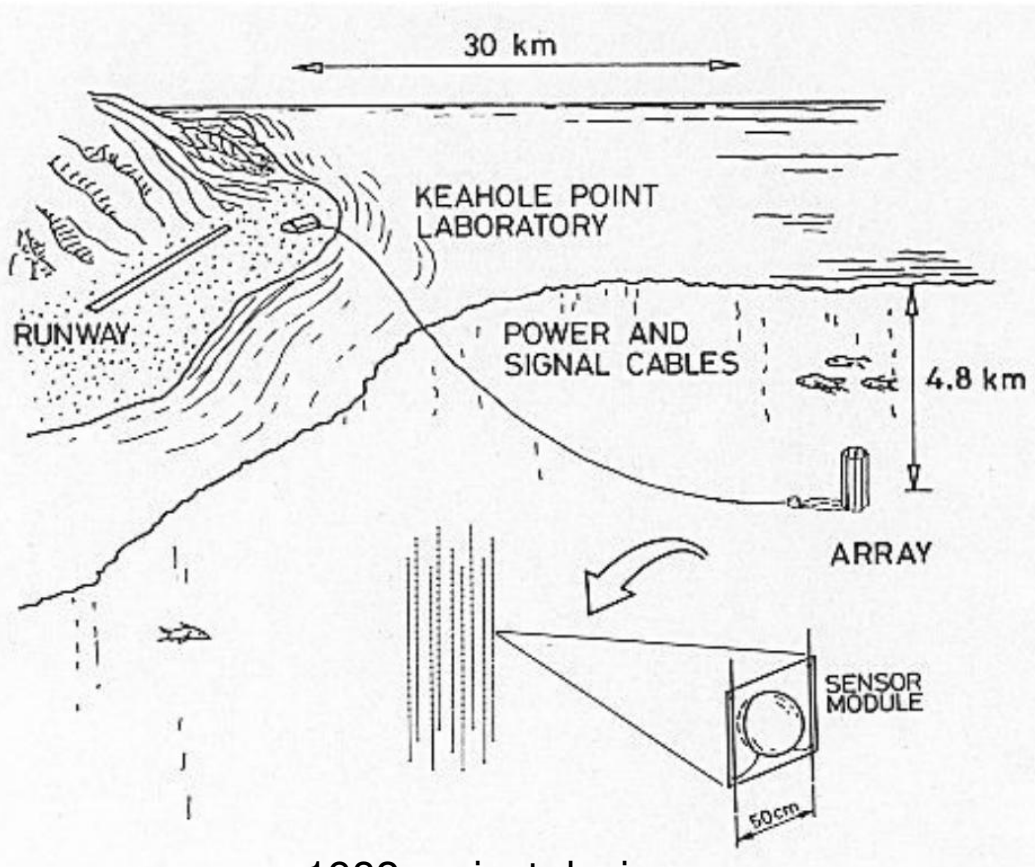


FIG. 9. The first DUMAND array: DUMAND G, the 1978 model. See text for details (Roberts and Wilkins, 1978).

DUMAND

4800 m depth at Hawaii shore



1982 project design

Gradual reduction of the project scale

1978: 1.26 km³ 22,698 OM*s*

1980: 0.60 km³ 6,615 OM*s*

1982: 0.015 km³ 756 OM*s*

Successful prototype test in 1987
→ Atm. muon flux observed

Project terminated in 1995



useful reading: [A. Roberts "The birth of high-energy astronomy: A personal history of the DUMAND Project", Rev. Mod. Phys. 64, 259 \(1992\)](#)

Soviet participation in DUMAND

Active Soviet participation in DUMAND:

- Scientific program for DUMAND: Berezinskii V. S., Zatsepin G. T., **Possible experiments with very high energy cosmic neutrinos: the Dumand project**, Sov. Phys. Usp. 20 361–380 (1977)



Veniamin
Berezinsky

1977 г. Май Том 122, вып. 1(500)

УСПЕХИ ФИЗИЧЕСКИХ НАУК

530.123

ВОЗМОЖНОСТИ ЭКСПЕРИМЕНТОВ С КОСМИЧЕСКИМИ НЕЙТРИНО ОЧЕНЬ ВЫСОКИХ ЭНЕРГИЙ: ПРОЕКТ ДЮМАНД

В. С. Березинский, Г. Т. Зацепин

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1. ВВЕДЕНИЕ

Нейтрино с энергиями выше 10 Тэв *) по-прежнему остаются монополией природы: пока специалисты работают над проектами ускорителей с энергией 10 Тэв, где-то в глубинах галактик с неведомой для нас целью работают гигантские естественные ускорители, сообщающие частицам энергии, превышающие $1 \cdot 10^{20}$ эв. При взаимодействии этих частиц с межзвездным и межгалактическим веществом и при соударениях в атмосфере нашей Земли рождаются нейтрино очень высоких энергий.

Интерес к этим космическим нейтрино двойной.

Во-первых, с их помощью можно изучать взаимодействие нейтрино с веществом при энергиях, недоступных ускорителям планируемого будущего, — от 10^{13} до 10^{15} — 10^{16} эв.

Во-вторых, метagalacticкие нейтрино высоких энергий представляют собой, по выражению В. Л. Гинзбурга, новый канал связи по Все-

*) 1 Тэв = 10^{12} эв.

© Главная редакция физико-математической литературы издательства «Наука», «Успехи физических наук», 1977 г.



Georgy
Zatsepin

Neutrino experiment in Lake Baikal

An alternative project
in Russia was suggested
in the end of 1970s



Alexander Chudakov

Pilot array in Lake Baikal

- Deployment from the ice cover
- Components to be produced within USSR

Neutrino experiment in Lake Baikal

An alternative project
in Russia was suggested
in the end of 1970s



Alexander Chudakov

Pilot array in Lake Baikal

- Deployment from the ice cover
- Components to be produced within USSR

1980 – Start of the Baikal Project in USSR

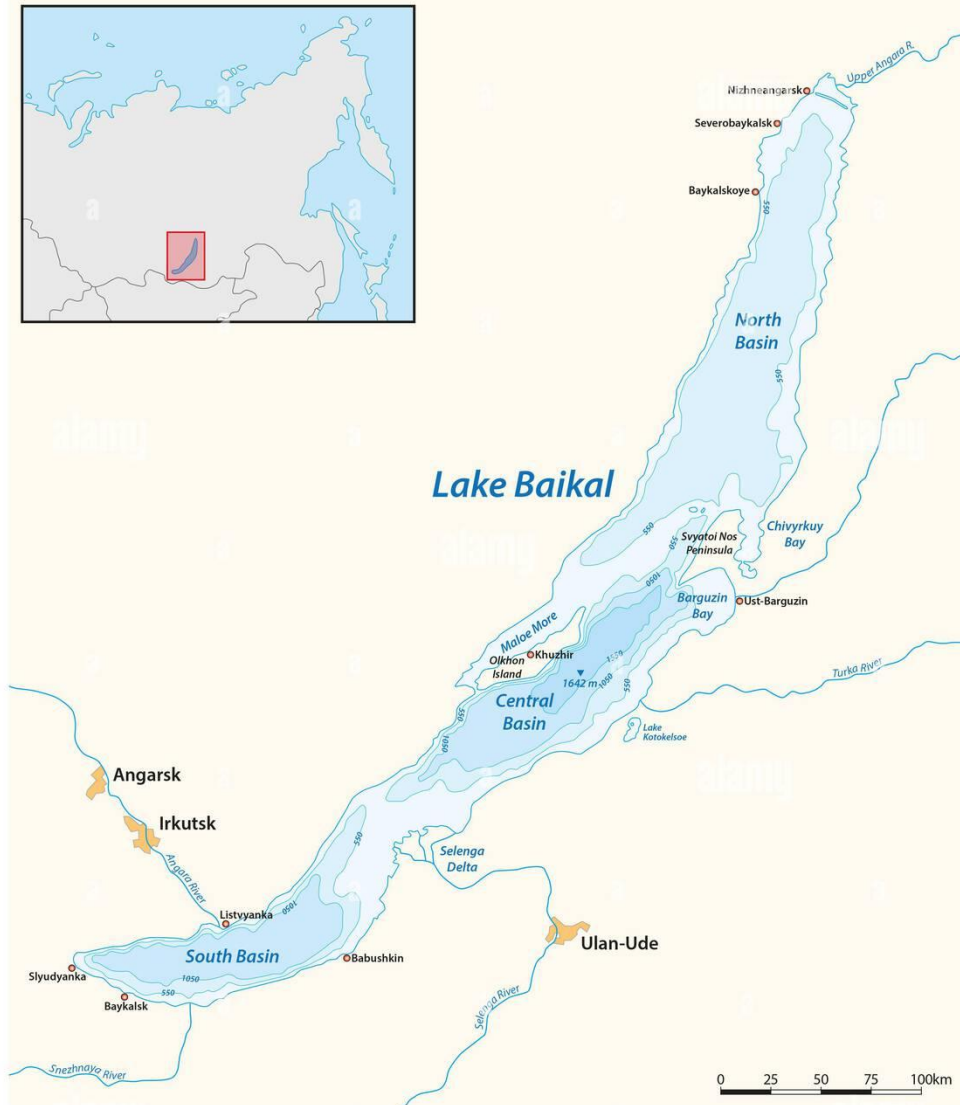


Grigory Domogatsky

Head of the Laboratory of High Energy
Astrophysics (INR) (1980 – 2024)

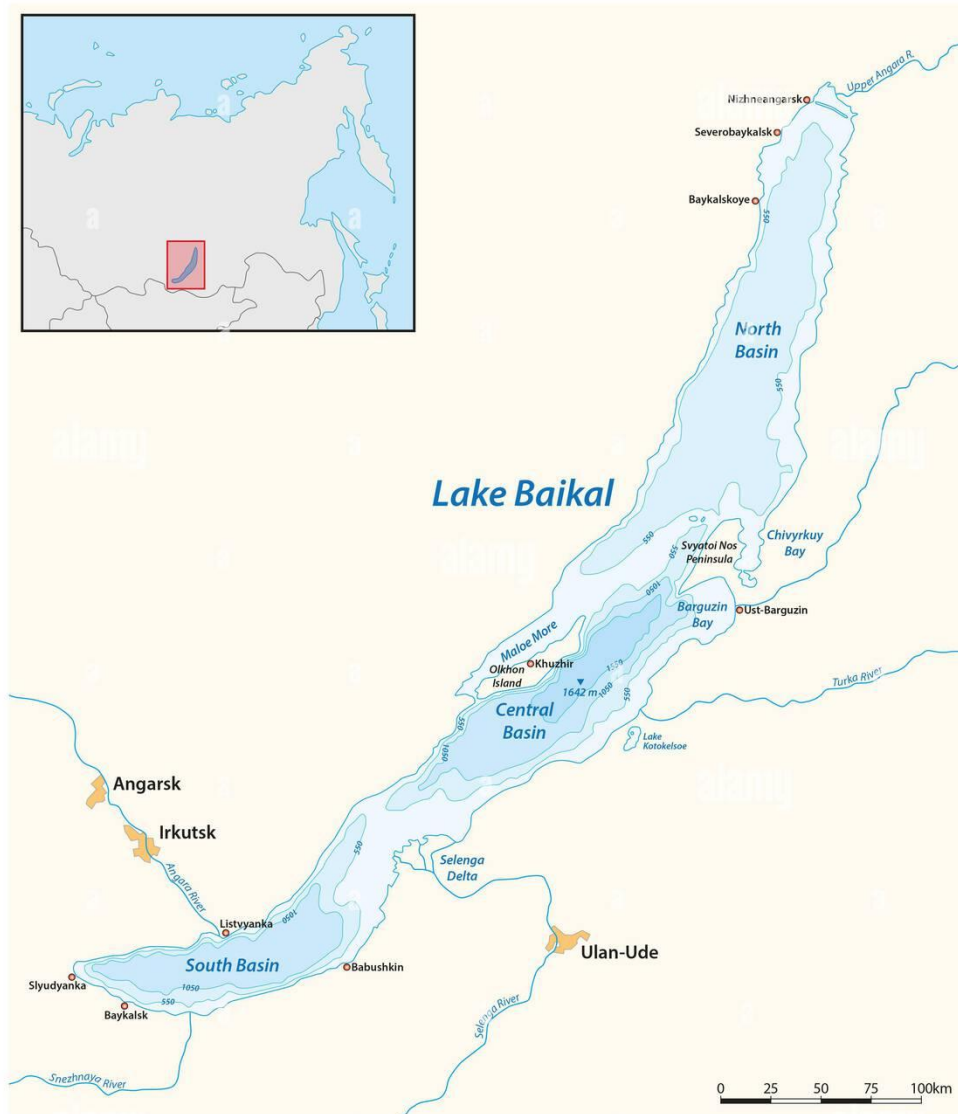
Baikal neutrino telescope site

Lake Baikal: the deepest
fresh water lake in the world



Baikal neutrino telescope site

Lake Baikal: the deepest
fresh water lake in the world

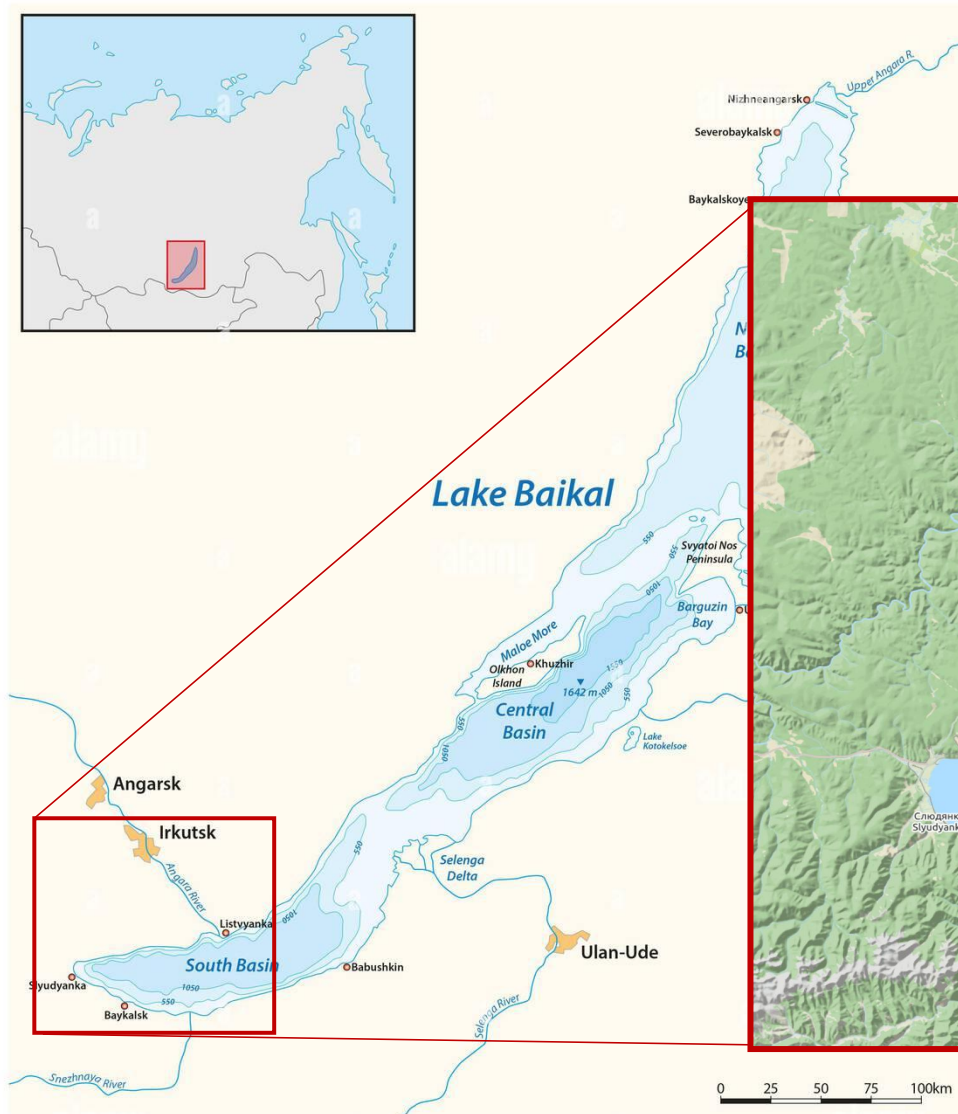


Conservative approach to deepwater telescope project:

- Much shallower depth than DUMAND
- Thick ice cover in winter provides stable platform for the instrumentation testing and deployment
- Deployed instrumentation can be repaired

Baikal neutrino telescope site

Lake Baikal: the deepest fresh water lake in the world

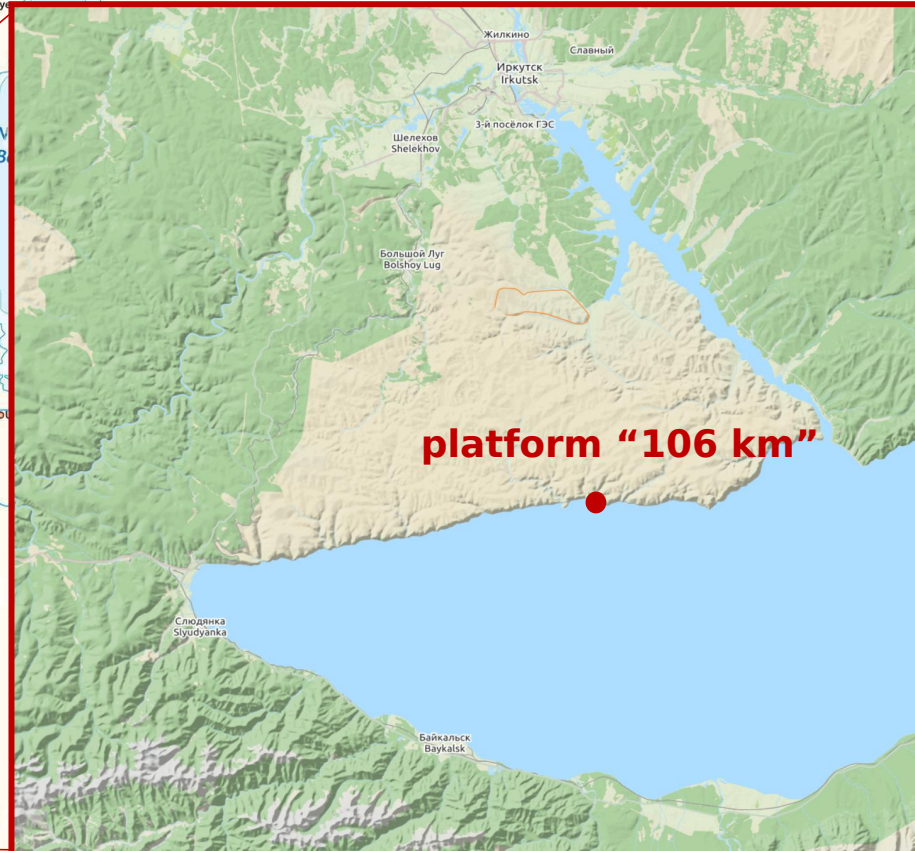


Conservative approach to deepwater telescope project:

- Much shallower depth than DUMAND
- Thick ice cover in winter provides stable platform for the instrumentation testing and deployment
- Deployed instrumentation can be repaired

Convenient transportation infrastructure in the southern part of the Lake:
Circum-Baikal Railway (CBR)

Chosen site:
platform “106 km” of CBR



Baikal neutrino telescope site

The Lake properties near the site

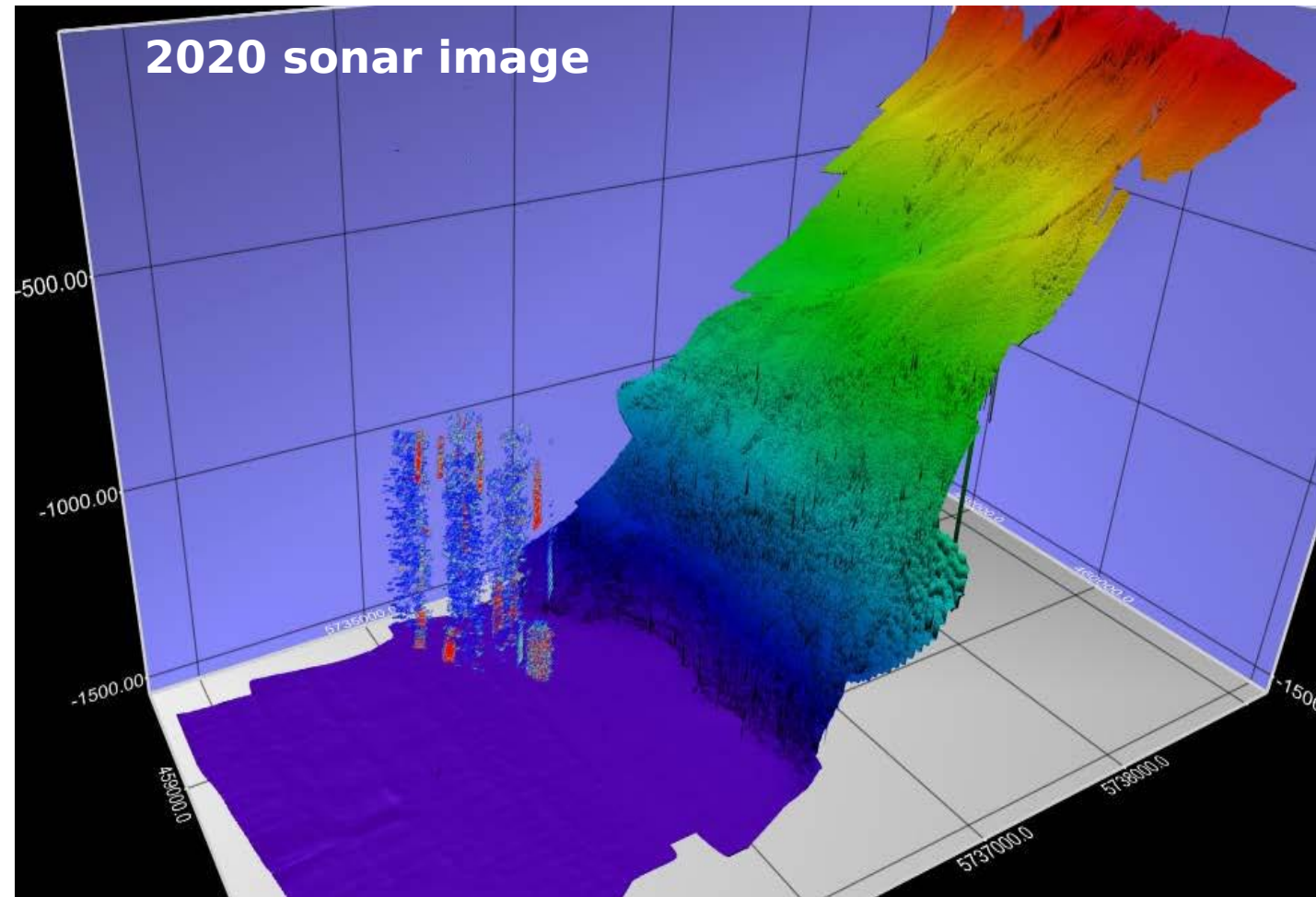
Deepwater plains at ~ 1360 m depth
extending to tens of kilometers

Peak absorption length: 22-24 m

Effective scattering length: 300-400m

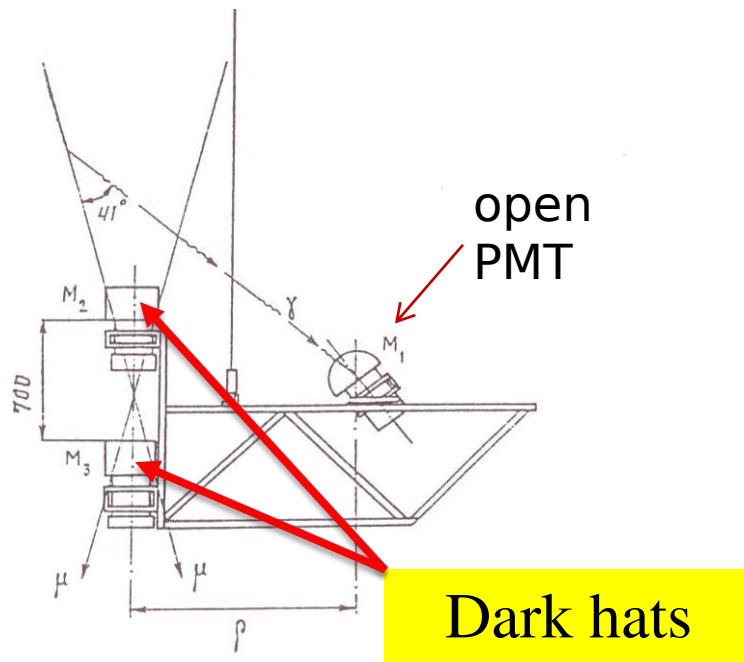
No ^{40}K decay and no bioluminescence
like in sea environments

Moderate noise from chemiluminiscense



First expedition at lake Baikal 1981

Device for the registration of muon and its Cerenkov radiation was deployed

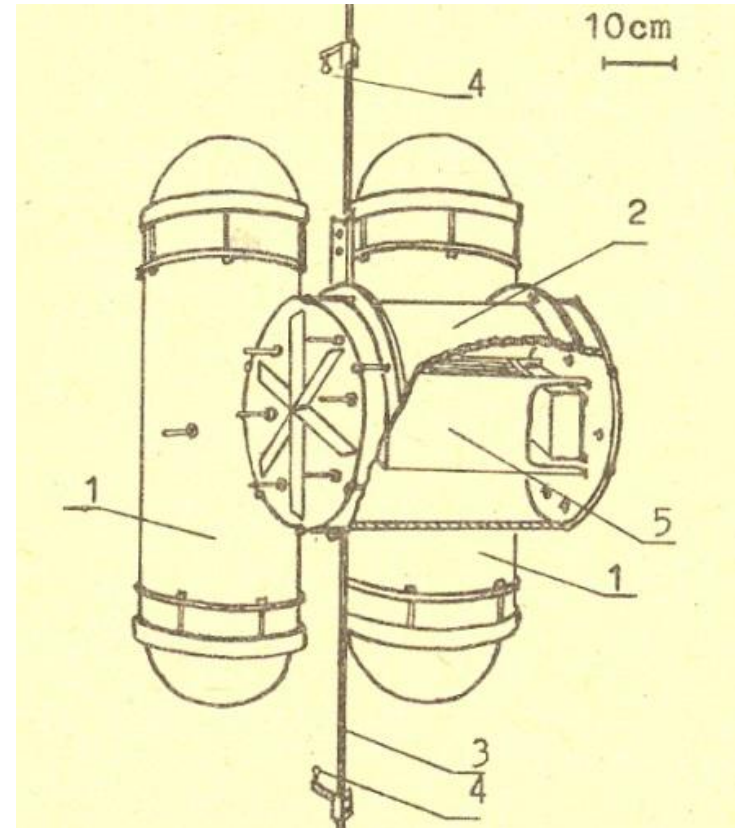


First stationary string: GIRLYANDA

1984: first shore cable deployed



First optical modules:
4 PMTs in hermetic containers



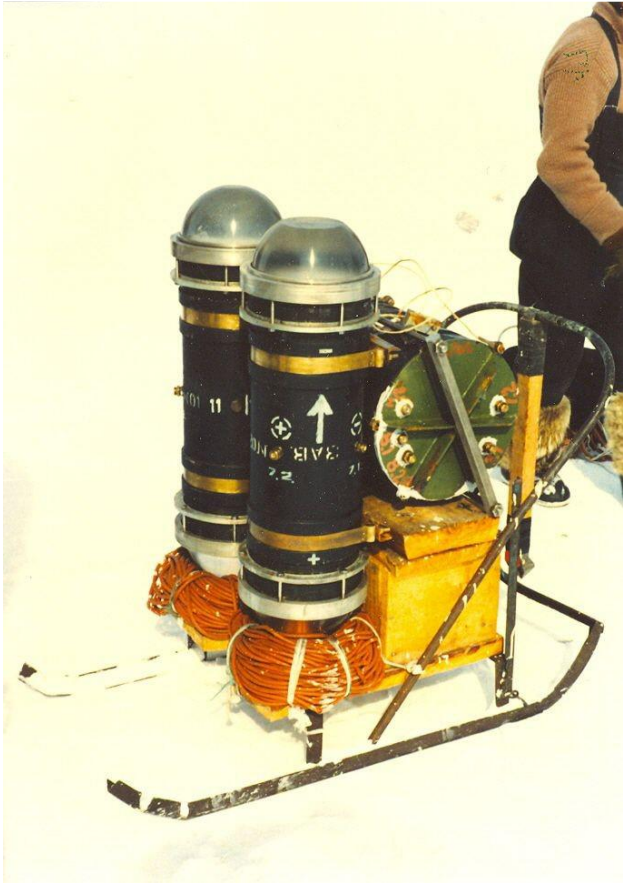
Soviet -made
PMT-49
(ФЭУ-49)



15 cm
photocathode

First stationary string: GIRLYANDA

G. Domogatsky and G. Zatsepin



Grigory Safronov, GEVA 2026, September 14-23, Chengdu

First stationary string: GIRLYANDA

GIRLYANDA 84

GIRLYANDA 86

1984: first stationary string, GIRLYANDA 84

- Muon flux measurement

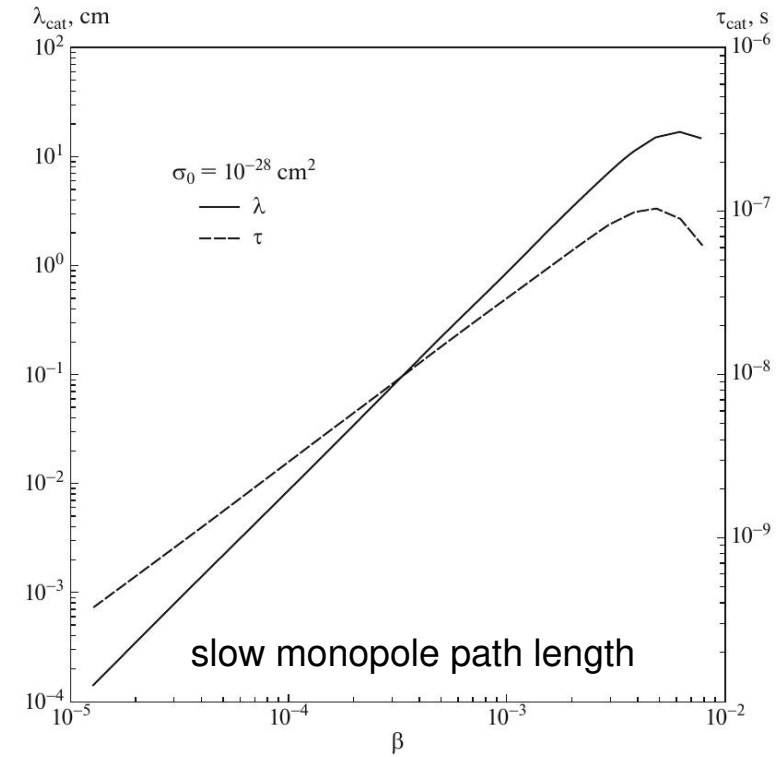
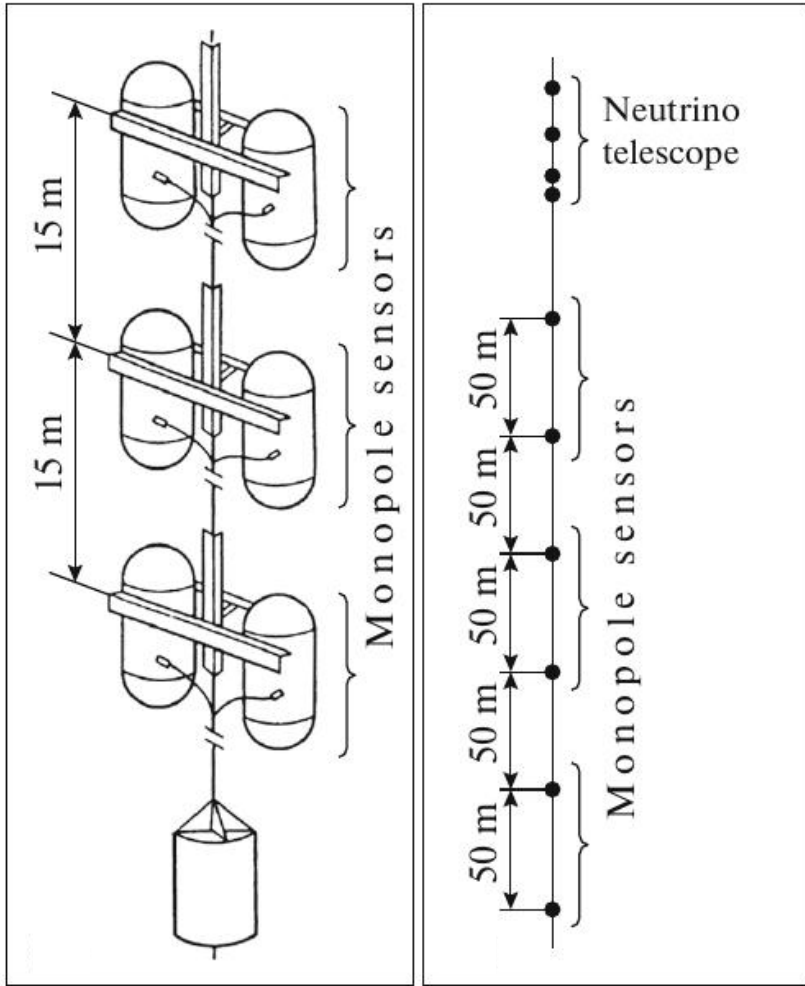
1986: second stationary string, GIRLYANDA 86

- Limits on GUT magnetic monopoles flux

Great Unification Theory (GUT)
magnetic monopoles:

- Nonzero magnetic charge
- Mass: $10^8 - 10^{21}$ GeV
- Catalysis of baryon decay

$$\sigma_c = 0.17 \cdot \sigma_o / \beta^2$$



Towards first deepwater neutrino telescope

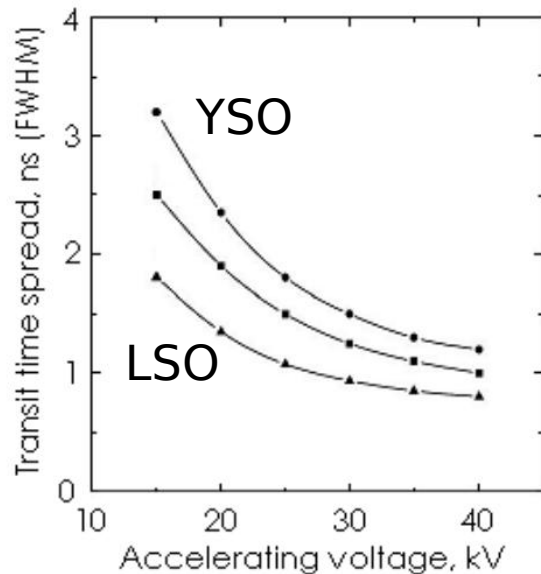
Beginning of 1980s: large hybrid PMTs for DUMAND: PHILIPS XP2600

Start of the development of Quasar-370 PMTs in 1980s

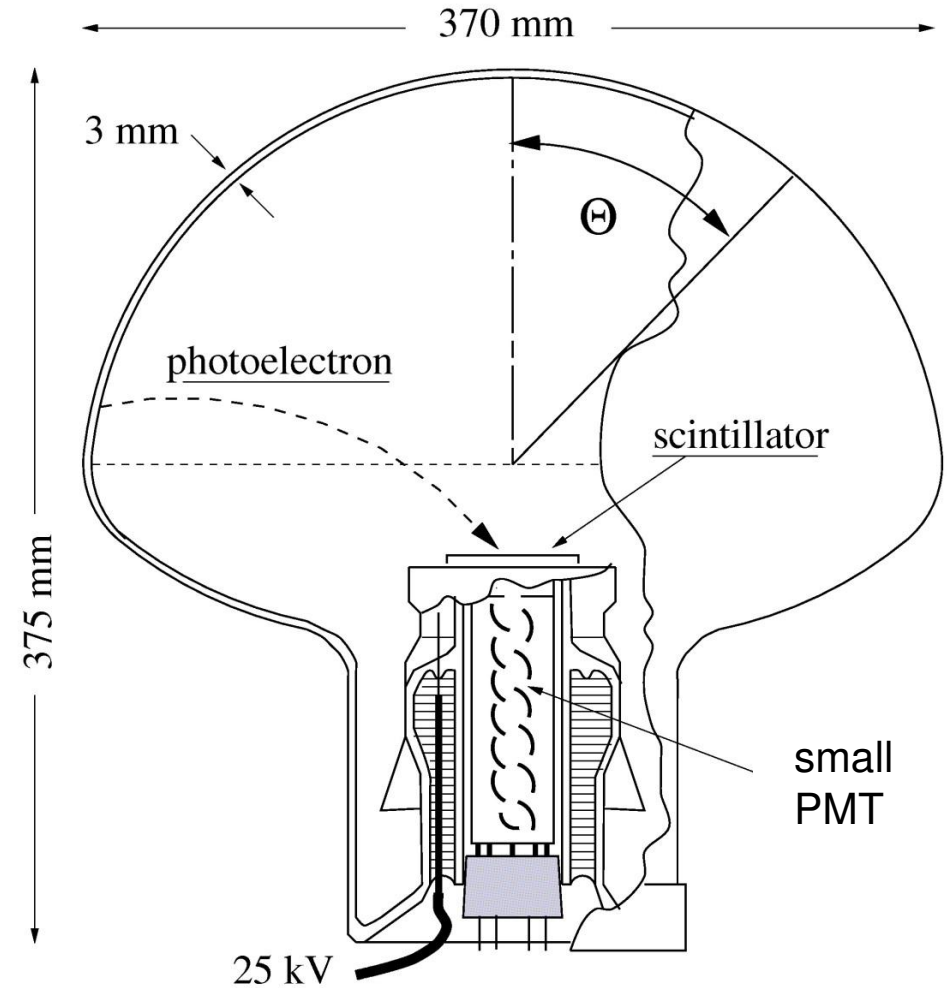
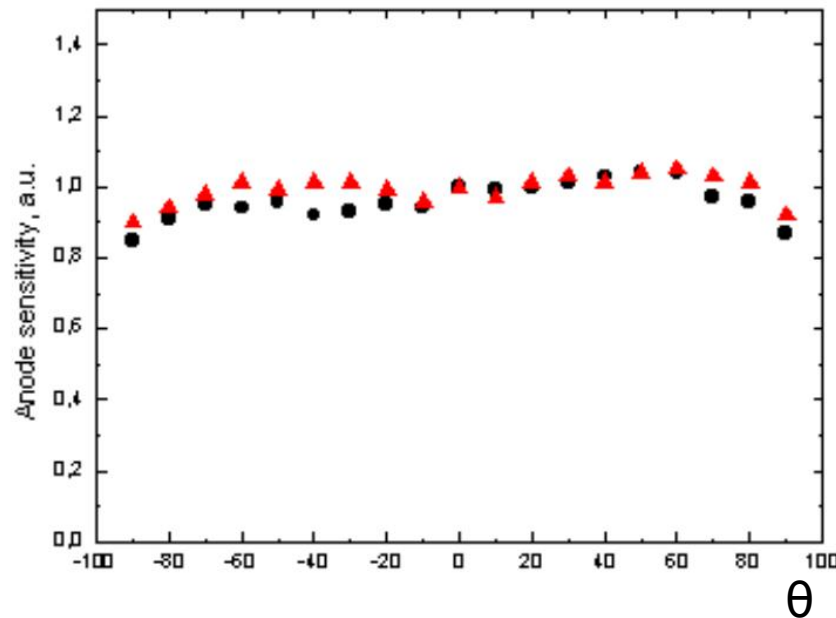
- Bialkali photocathode
- Scintillator plate coupled to small 3-inch PMT
- Accelerating voltage applied between photocathode and scintillator



Transit time spread depends on scintillator type



Very uniform angular sensitivity

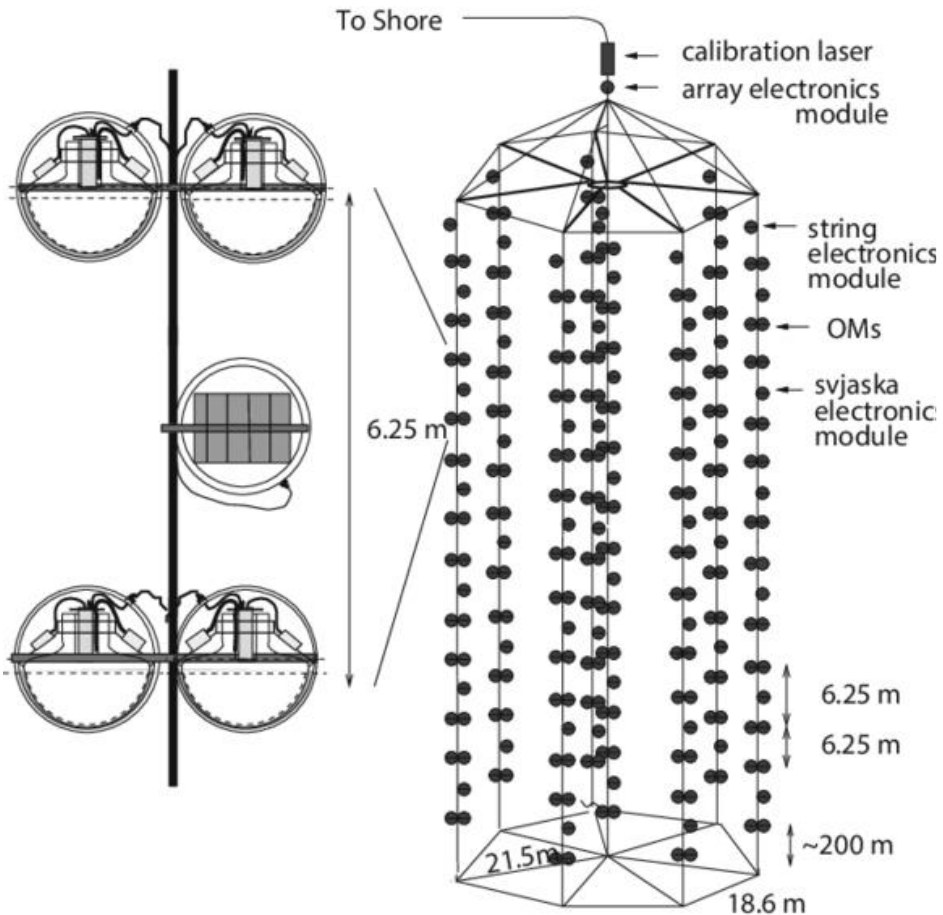


<https://arxiv.org/abs/0910.5588>

NT-200 telescope

NT-200: first full-scale large-volume neutrino telescope deployed throughout 1993-1998

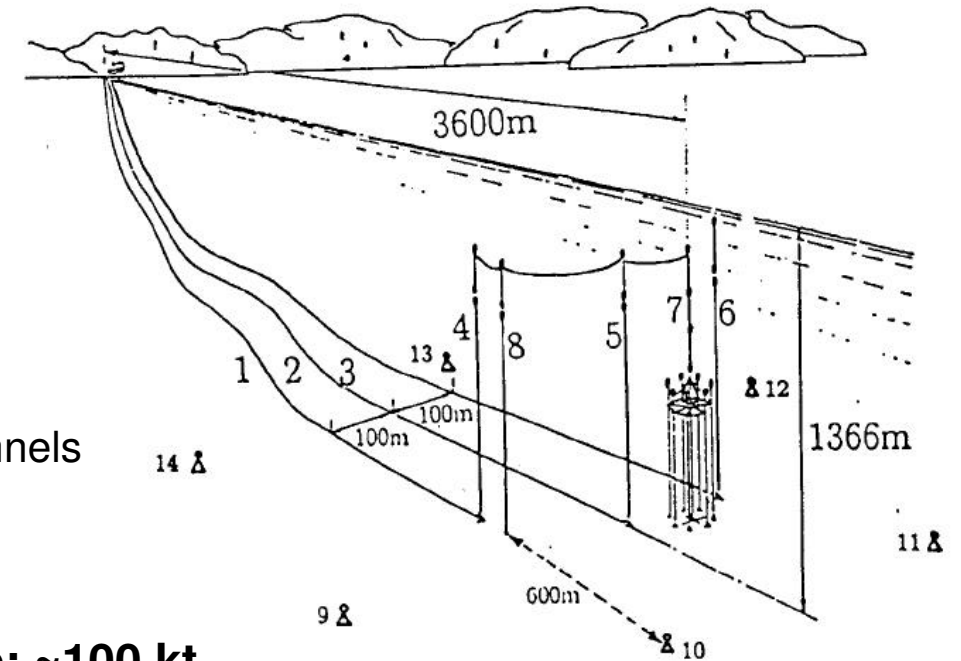
OMs enclose the Quasar-370 PMTs, two OMs per storey



Rather small detector

- Height: 72m
- Diameter: 43m
- 8 strings:
- 192 Optical Modules
- 96 measurement channels
- Calibration - N-laser

Instrumented volume: ~100 kt



<https://arxiv.org/abs/astro-ph/0609711>



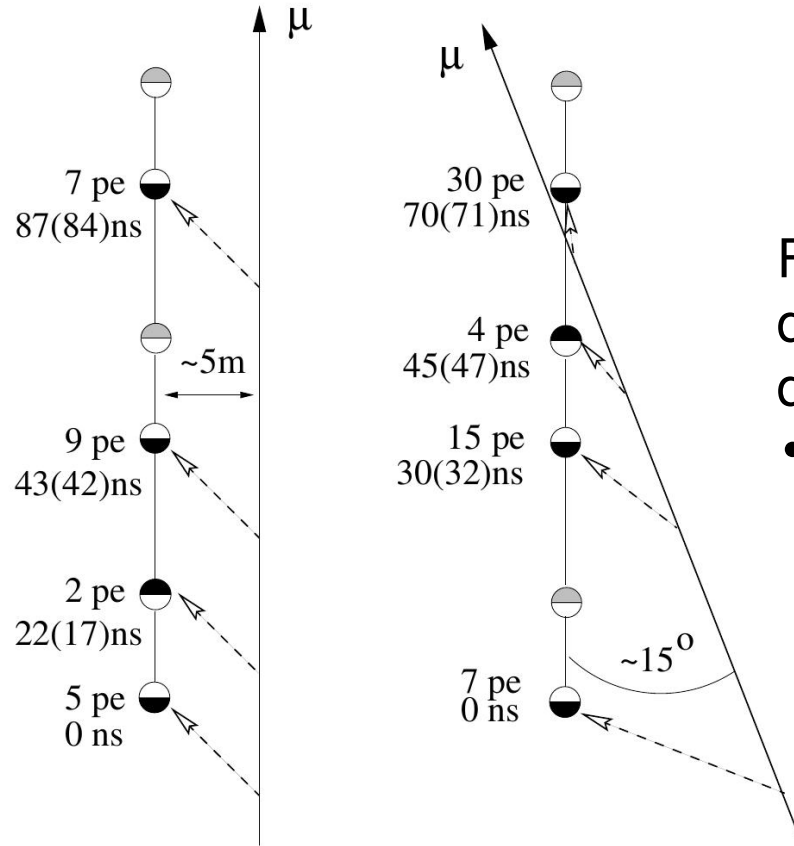
A photograph of two men, Christian Spiering and Grigory Domogatsky, working on a large, rusted metal structure in a snowy, mountainous landscape. Christian Spiering, on the left, is wearing a green jacket, a green bucket hat, and sunglasses. Grigory Domogatsky, on the right, is wearing a dark jacket and a brown fur hat. They are both focused on their work, with Grigory using a long metal rod to adjust a part of the structure. The background shows a vast, snow-covered field and distant mountains under a clear blue sky.

**Invaluable contribution to NT-200 from
DESY-Zeuthen group**

Christian Spiering

Grigory Domogatsky

NT200: first neutrino candidates



First-ever upgoing muon events
detected by unaccomplished
detector in mid-1990s (NT-36, 96)

- Successful proof of principle

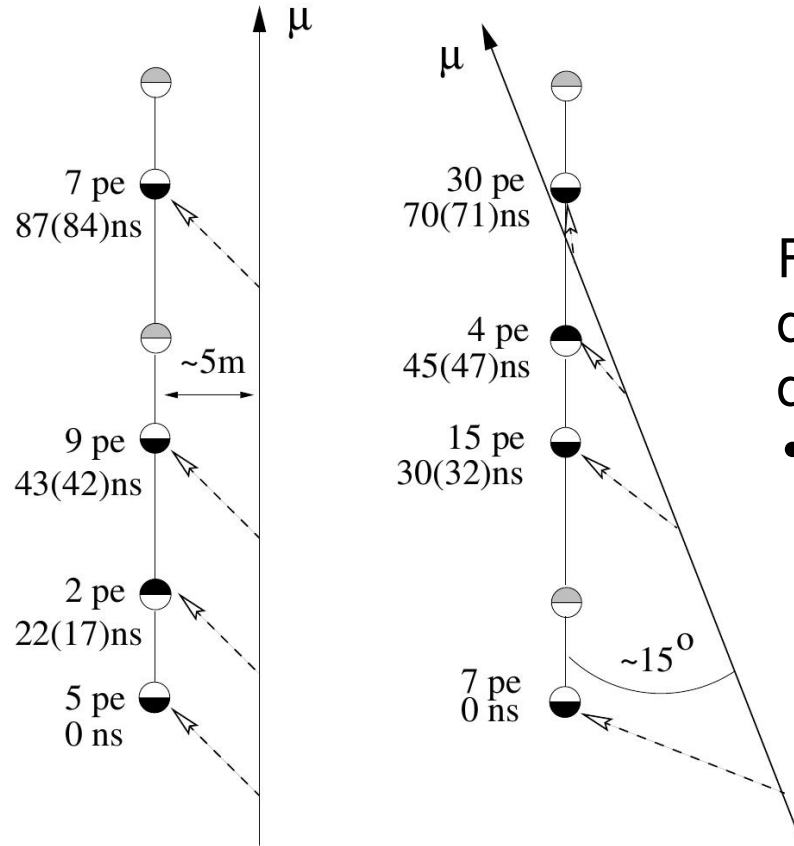
First LVNT neutrino candidates, 1994

[arXiv:astro-ph/9601161v3](https://arxiv.org/abs/astro-ph/9601161v3)

presented by Zh.Djilkibaev

to the 2nd Workshop on "Dark Side of the Universe:
Experimental efforts and theoretical
framework", Rome, Italy,
November 13-14 1995

NT200: first neutrino candidates



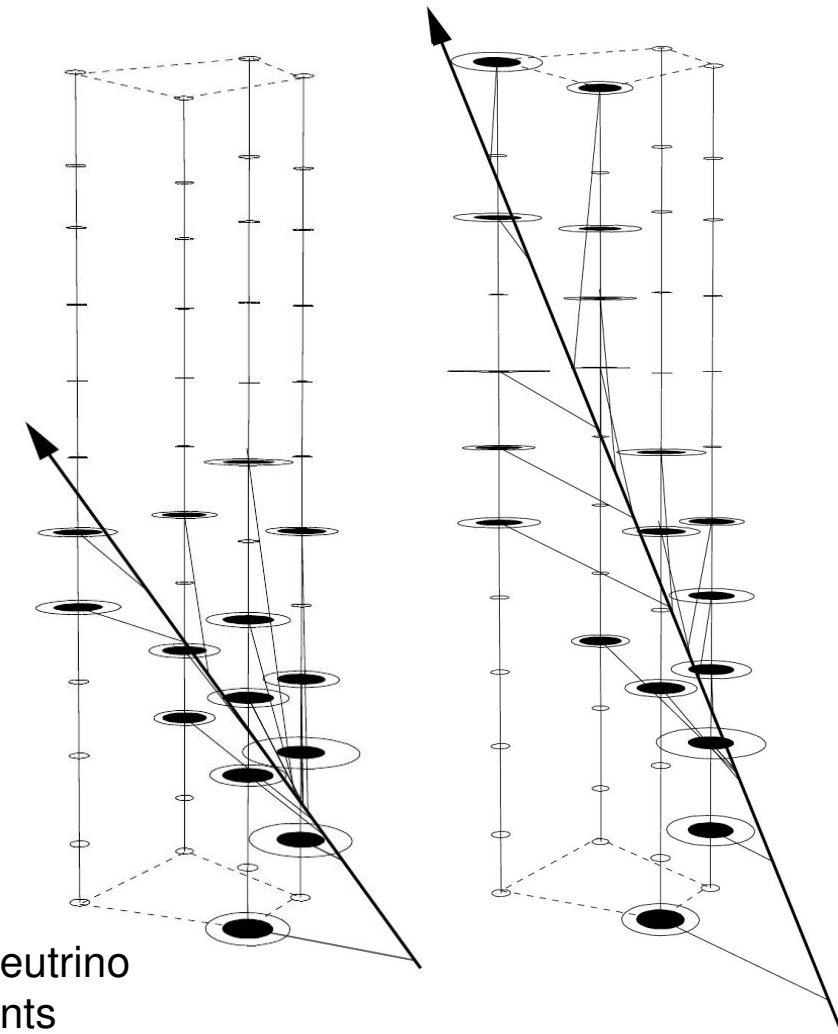
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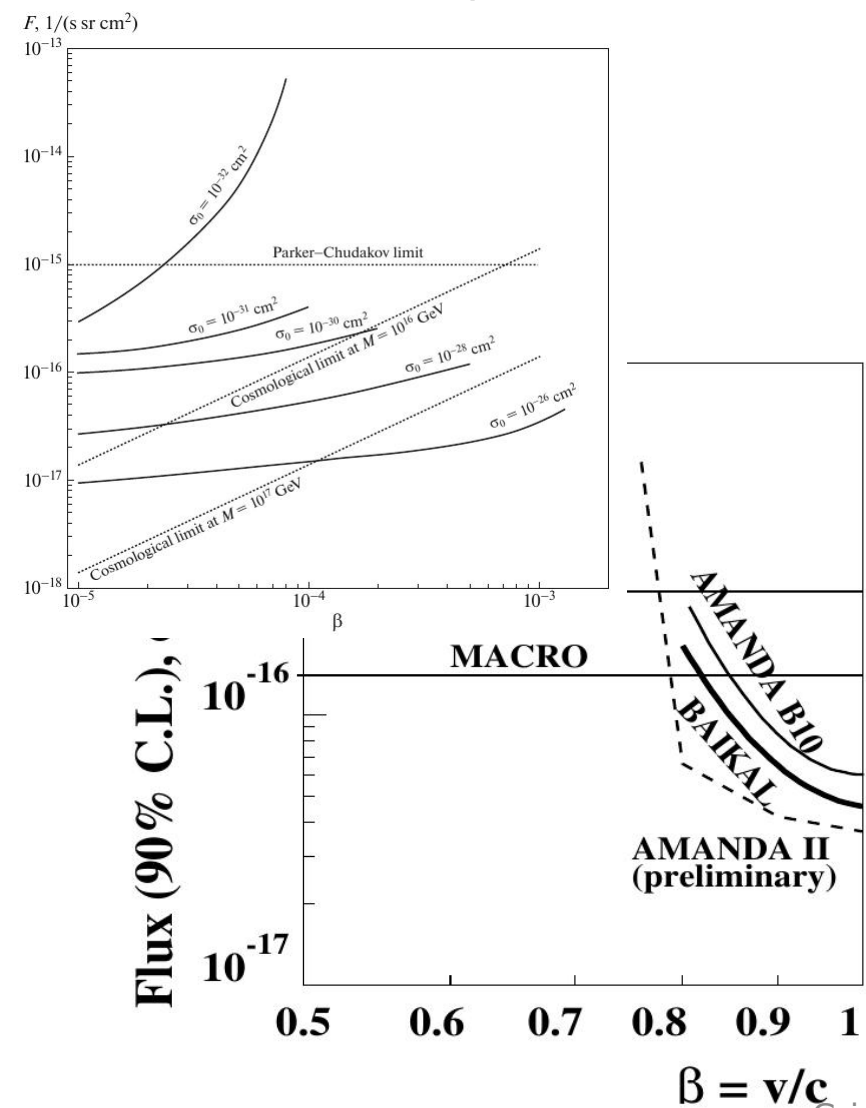


First multi-string neutrino
candidate events
NT-96, 1996

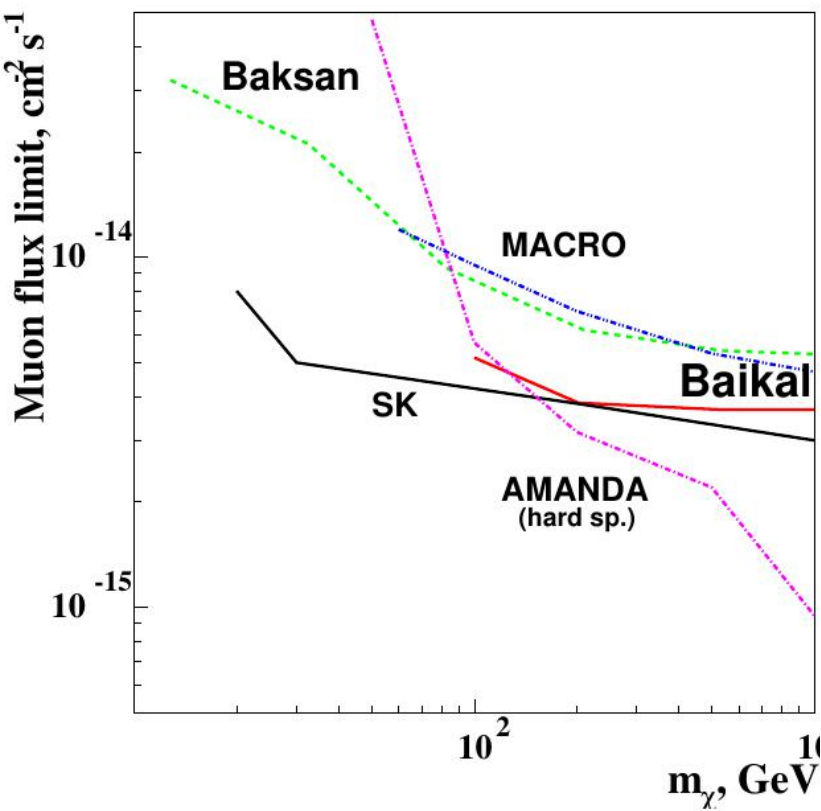
[\[arXiv:astro-ph/9705244\]](https://arxiv.org/abs/astro-ph/9705244)

NT-200 physics results

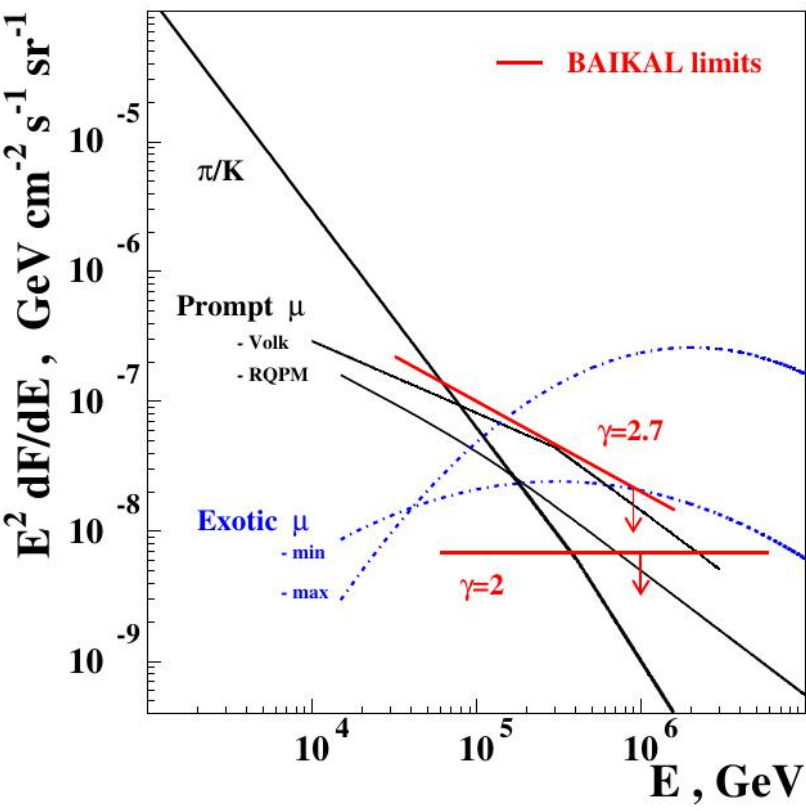
Limits on fast and slow GUT monopoles



Limits on WIMP annihilation in Earth



Limits on prompt muon flux



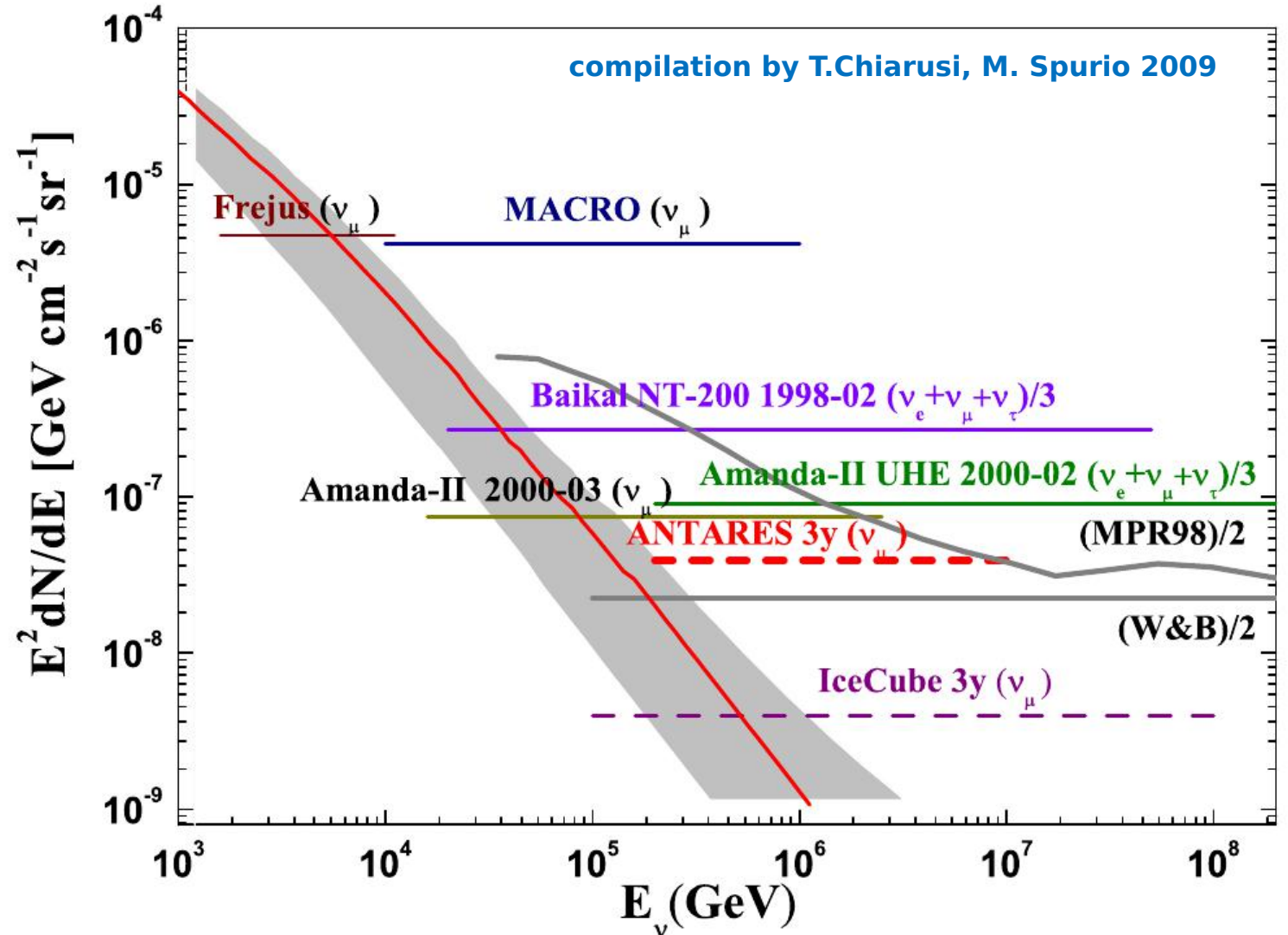
<https://arxiv.org/abs/astro-ph/0609711>

Approaching the diffuse astrophysical neutrino flux

First diffuse flux constraints

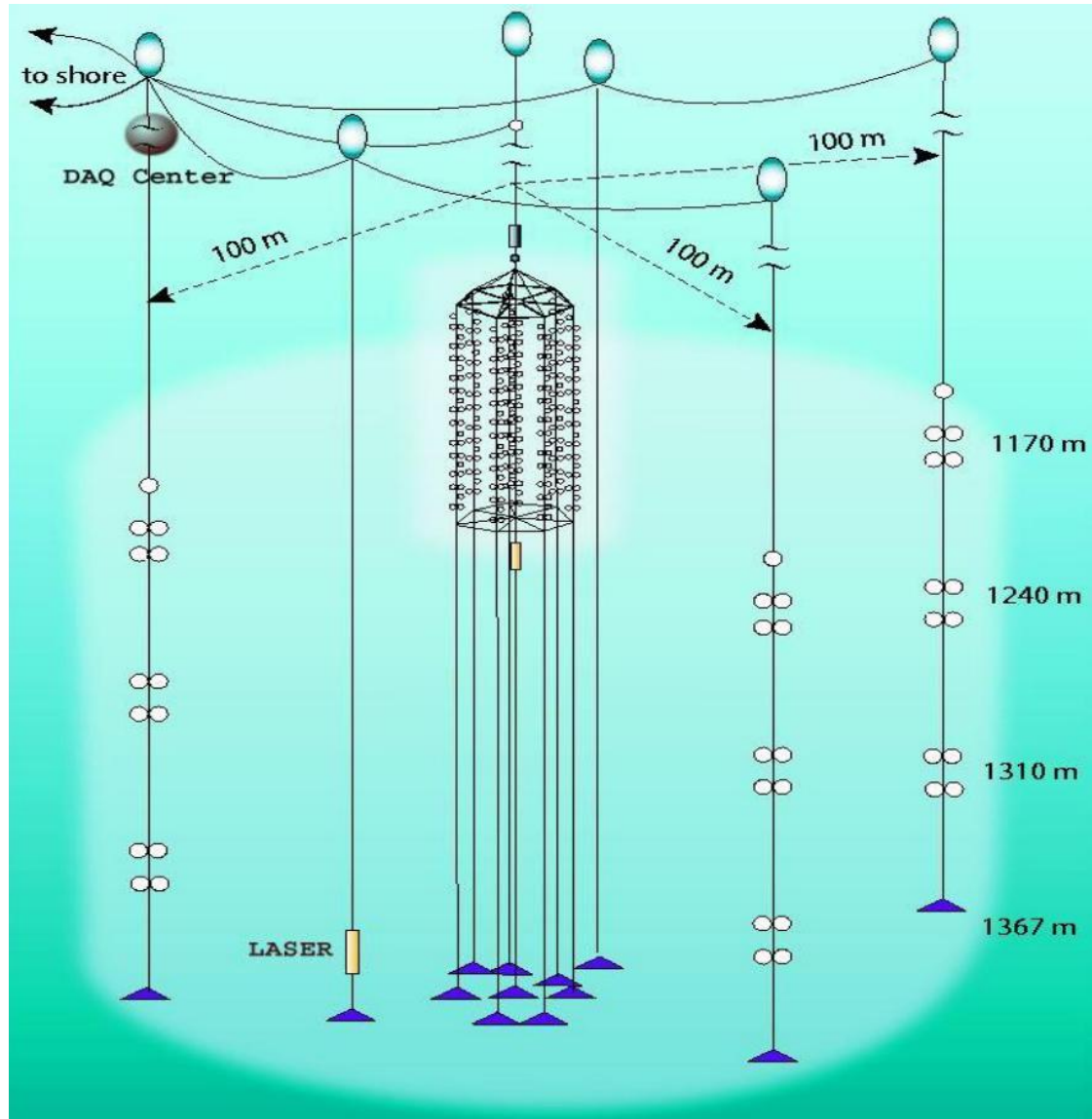
First constraints on the diffuse flux:

- NT-200 (1998)
- AMANDA (2000)



Sensitivities from ANTARES and IceCube are shown in dashed lines

2003-2006 upgrade: NT-200



Deployment of 3 additional
peripheral strings

The next step towards
 km^3 -scale NT in Lake Baikal

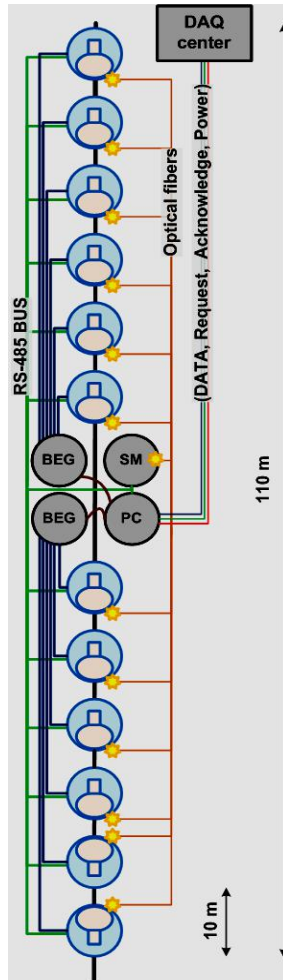
The Baikal-GVD project

2007-2011: Baikal-GVD components testing and development

Prototype string
2009

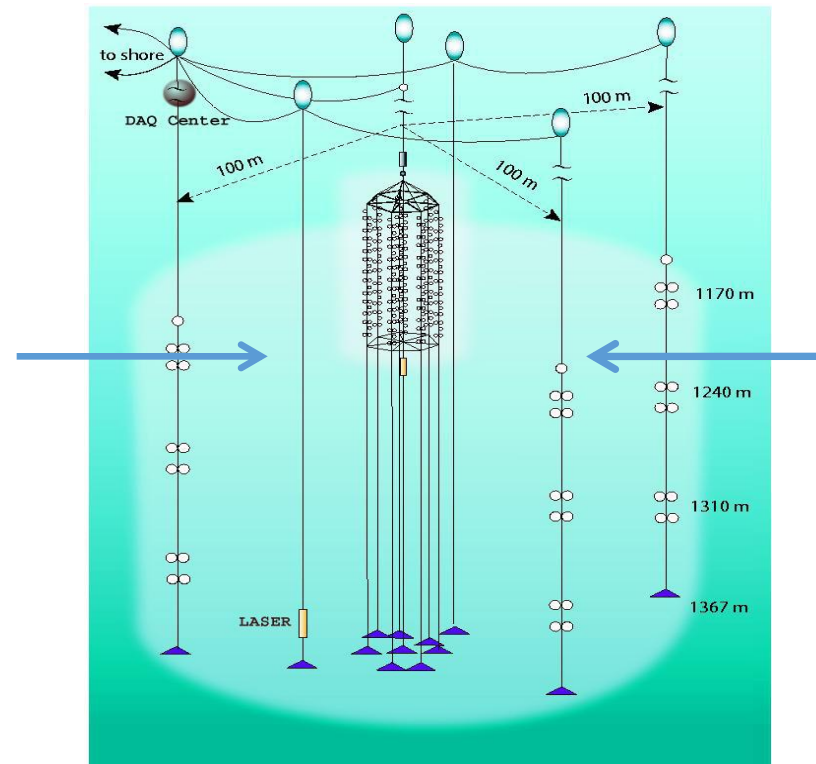
PMT:
Photonis
XP1807
6 OMs

Hamamatsu
R8055
6 OMs



In-situ tests of basic elements of GVD
with prototype strings 2009 and 2010

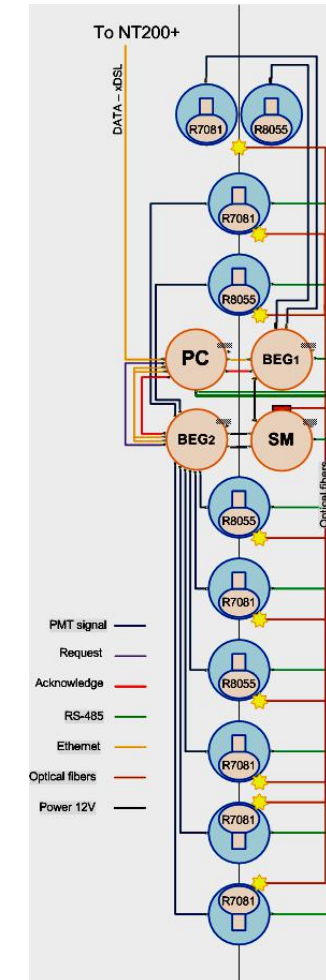
Investigation and tests of new optical
modules, DAQ system, cabling
system, triggering approaches



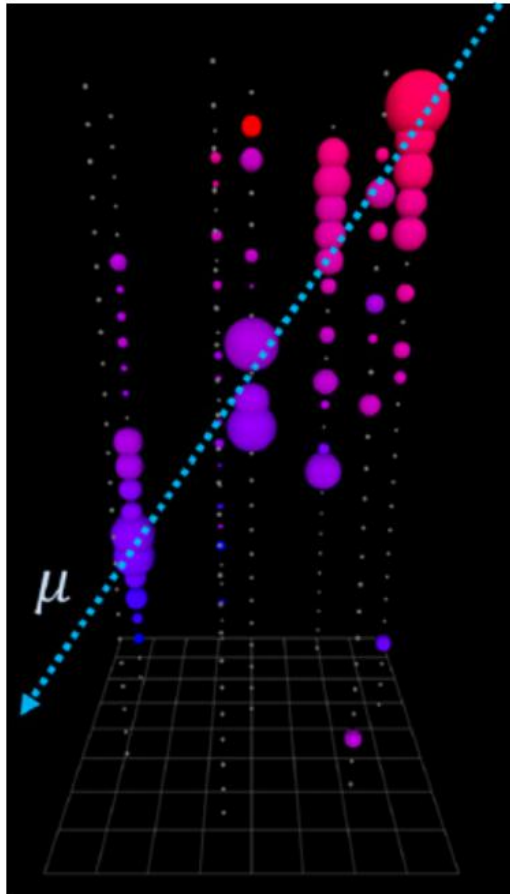
Prototype string
2010

Hamamatsu
R7081HQE
7 OMs

Hamamatsu
R8055
3 OMs



Baikal-GVD demonstration cluster

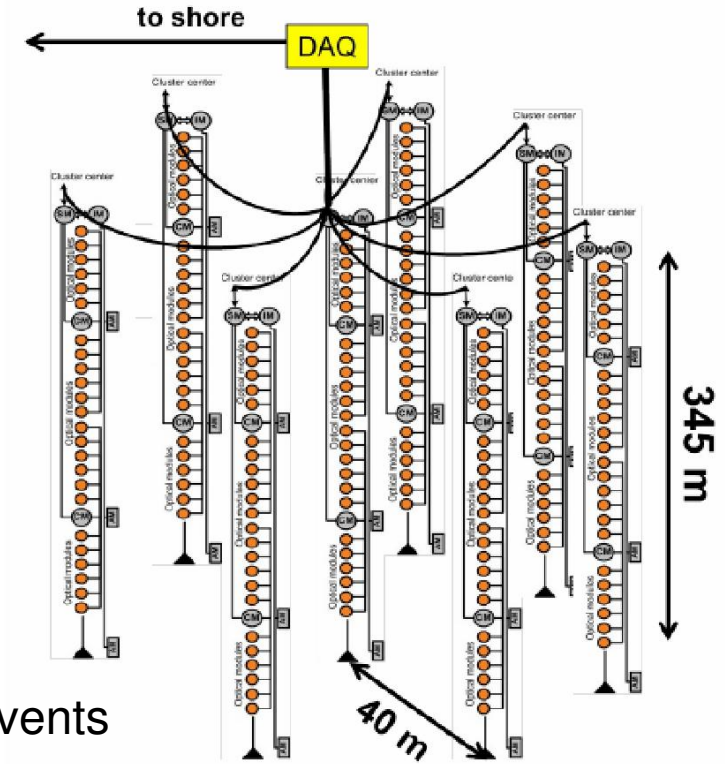


reference

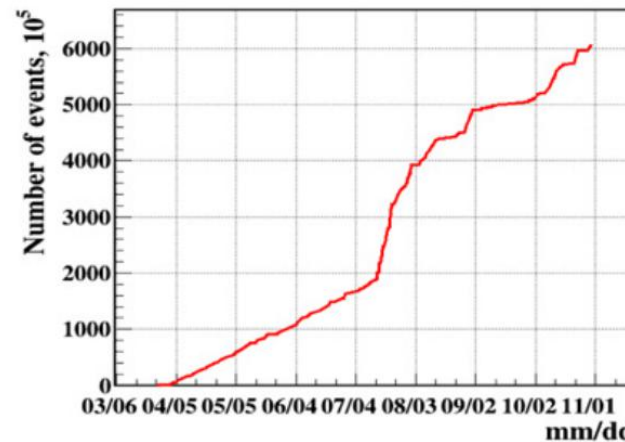
2015: demonstration cluster, “Dubna”

First multi-string muons

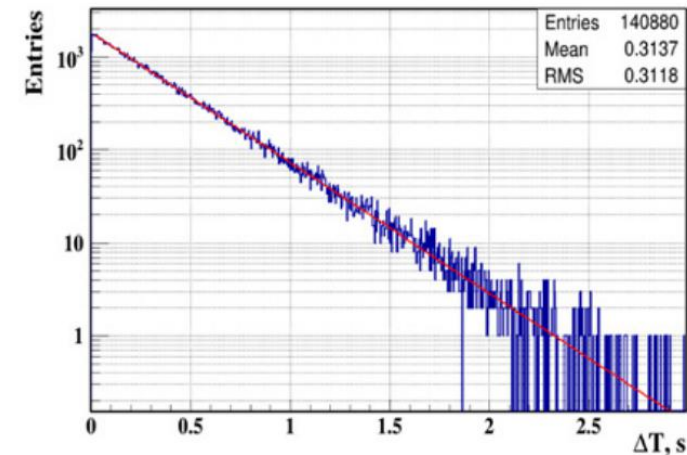
Validation of trigger and readout architecture



Accumulated events



dT between events



Baikal-GVD experiment today



Collaboration consists of 15 institutions and ~85 scientists

Saint-Petersburg

Saint-Petersburg Marine Technical University
University of Information Technology, Mechanics and Optics *



Joint Institute for Nuclear Research

Dubna

Institute for Nuclear Research RAS
Skobeltsyn Institute for Nuclear Physics
National Research Nuclear University MEPhI
Lebedev Physics Institute RAS *

Irkutsk State University

Irkutsk

Baikal-GVD

Moscow

Belgorod

Belgorod State University *

Prague

Bratislava

Belgrade

Czech Technical University (Prague)
Comenius University (Bratislava)
Astronomy Observatory (Belgrade) *

Nalchik

Kabardino-Balkarian State University *

Alma-Aty

Institute of Nuclear Physics ME RK



* Associate members

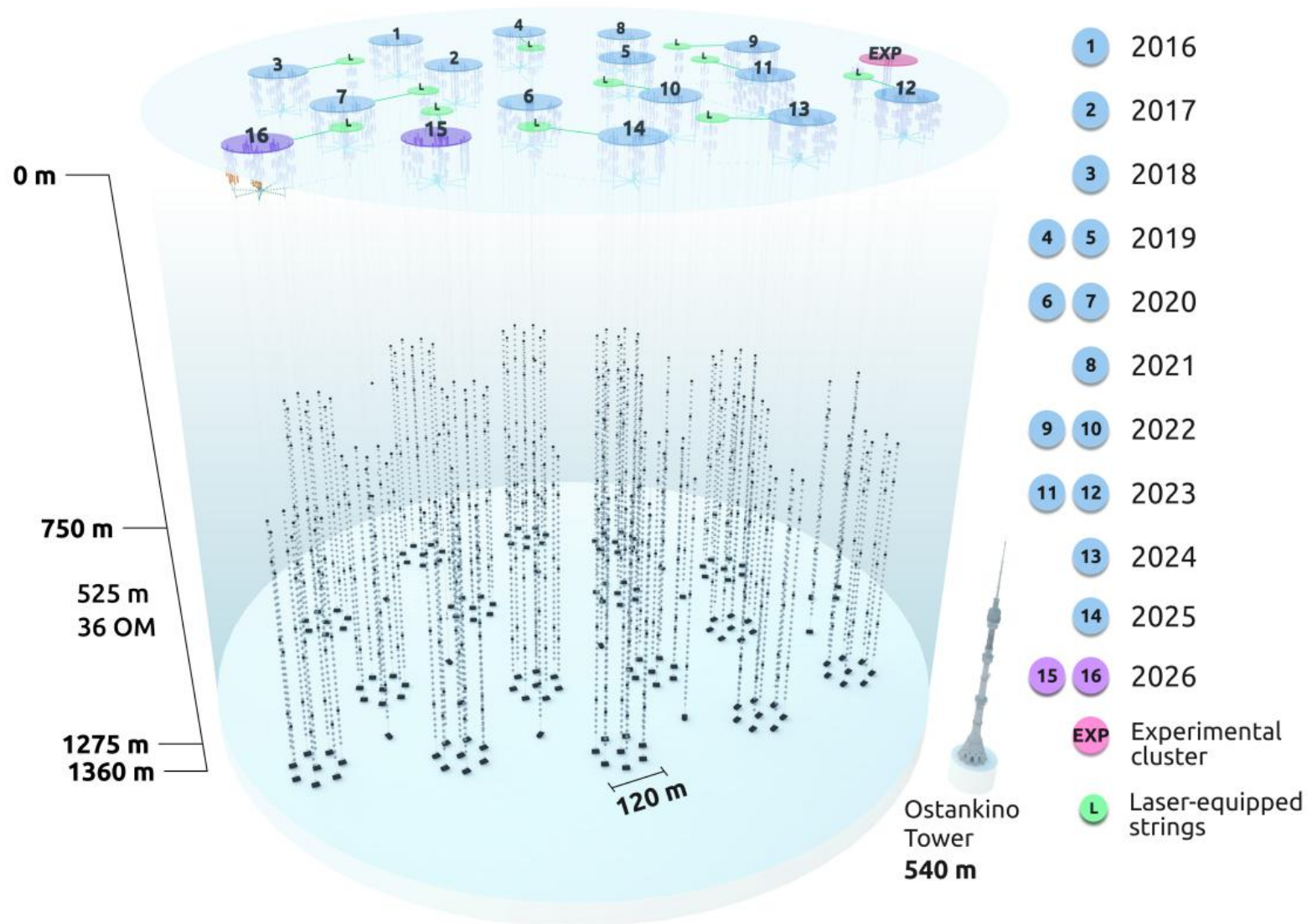


The detector status

After the 2026 deployment campaign:

- 135 vertical strings arranged into 16 independent detectors - **clusters**
- 4896 optical modules (OM) in total
- 0.8 km³ detection volume (1 PeV cascades)
- Largest neutrino telescope in the Northern hemisphere

In the next 2-3 years it is planned to expand the detector to ~1 km³ detector volume employing ~6000 OMs



Detector deployment process



People at work



Thank you!



Grigory Safronov, CENA 2026, September 14-23, Chengdu

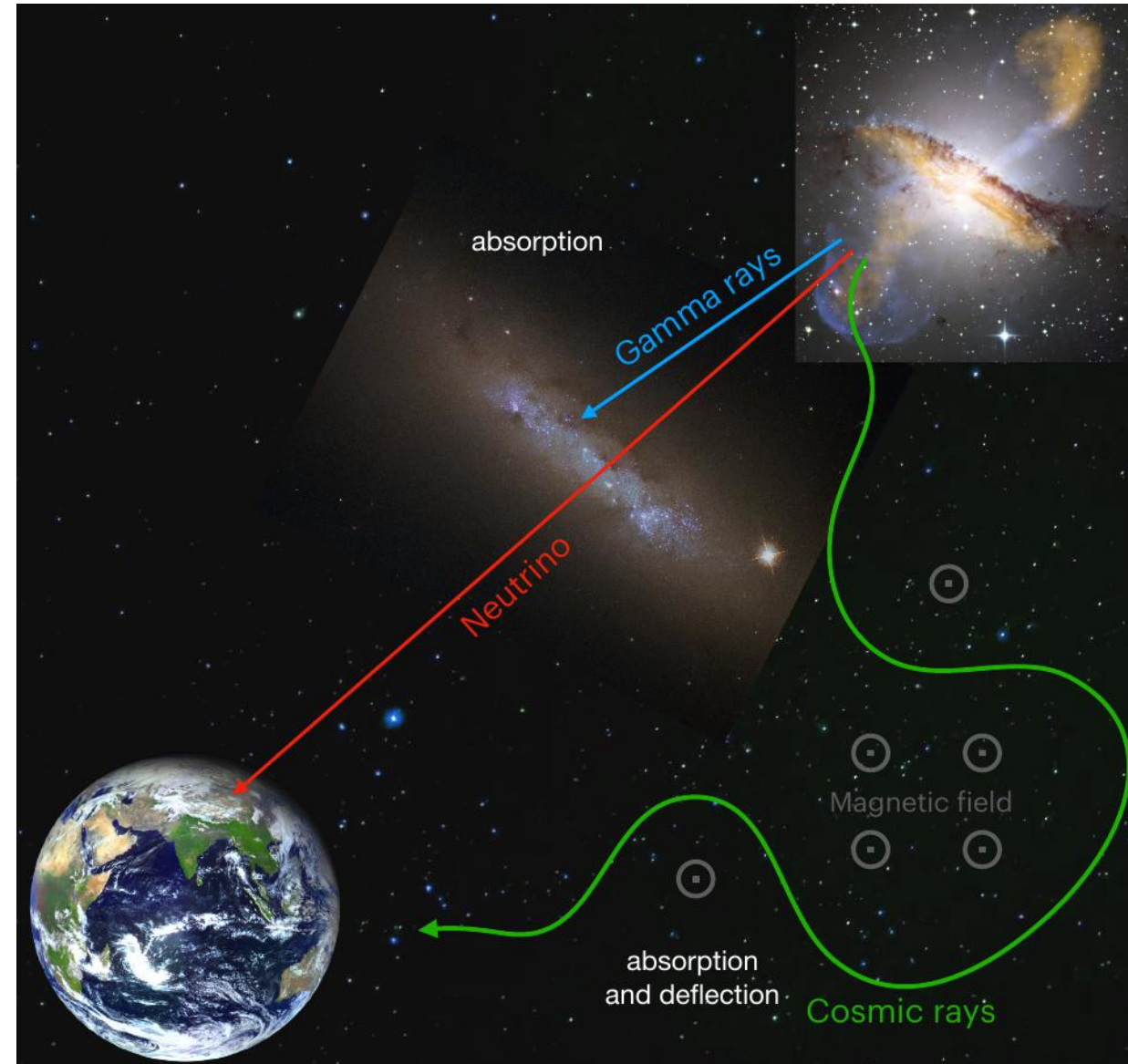
BACKUP

Physics motivation for LVNT

Neutrino is not absorbed

It does not lose energy

Does not lose the direction to source



Expected neutrino fluxes

Main contributions to astrophysical neutrino flux expected:

Neutrinos from AGN

GZK neutrinos

Eichler

The most liberal estimates of the overall cosmic background of active galactic nuclei imply a count rate in a 10^9 ton detector averaging up to $\sim 2 \times 10^2$ counts per day at $E_\nu \gtrsim 10^{12}$ eV.

Berezinskii V. S., Zatsepin G. T., **Possible experiments with very high energy cosmic neutrinos: the Dumand project**, Sov. Phys. Usp. 20 361-380 (1977)

Eichler, D. **High-energy neutrino astronomy: a probe of galactic nuclei?**, ApJ 1979, 232, 106-112. <https://doi.org/10.1086/157269>.

Berezinskii, V.S.; Ginzburg, V.L. **On high-energy neutrino radiation of quasars and active galactic nuclei**, MNRAS 1981, 194, 3-14. <https://doi.org/10.1093/mnras/194.1.3>.

Stecker, F.W.; Done, C.; Salamon, M.H.; Sommers, P. **High-energy neutrinos from active galactic nuclei**, Phys. Rev. Lett. 1991, 66, 2697-2700. <https://doi.org/10.1103/PhysRevLett.66.2697>.

SOME BRIGHT GALACTIC NUCLEI

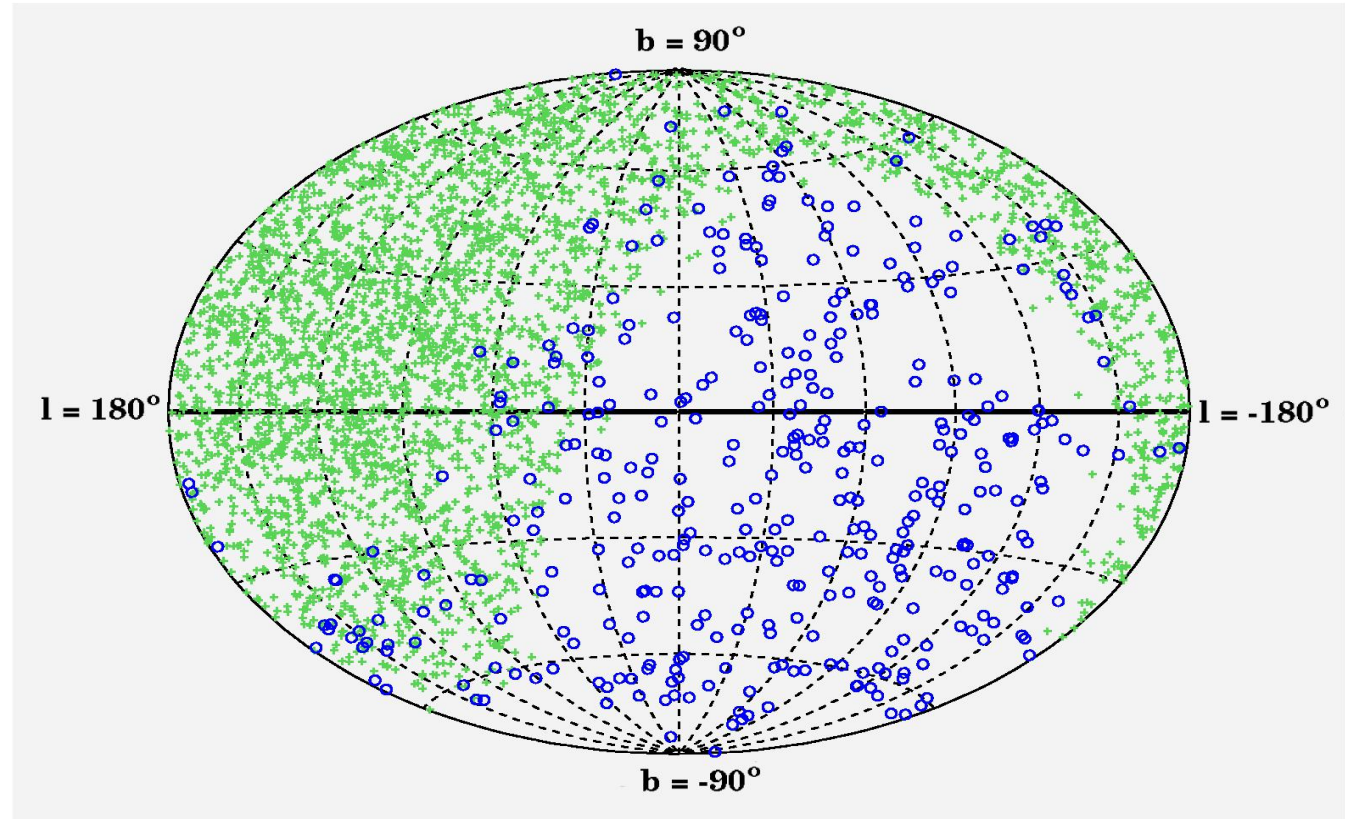
Star	Flux at $10 \mu\text{m}$ ($\text{eV cm}^{-2} \text{s}^{-1}$)	Total Flux	Count Rate (yr^{-1}) ^a
NGC 1068.....	5.0×10^{3c}	1.9×10^{4e}	3×10^3
NGC 253.....	1.2×10^{3c}	3.0×10^{4e}	4×10^3
NGC 3077.....	6.6×10^{2c}	2×10^{3b}	3×10^2
NGC 3034 (M82).....	5.4×10^{3c}	2×10^{4b}	3×10^3
NGC 1614.....	1.8×10^{2c}	8×10^{2b}	1×10^2
NGC 7469.....	1.6×10^{2c}	6×10^{2b}	1×10^2
Markarian 231.....	2.8×10^{2c}	1×10^{3b}	1×10^2
I Zw 1.....	8×10^c	3×10^{2b}	6×10
NGC 1275.....	2.0×10^{2c}	2.0×10^{2e}	4×10
NGC 4151.....	2.4×10^{2c}	$\leq 2.4 \times 10^2$	5×10
3C 273.....	6×10^c	$\leq 6 \times 10$	10
NGC 5128 (Cen A).....	1×10^{3d}	1×10^{3e}	1×10^2

NT-200 results

Tracks

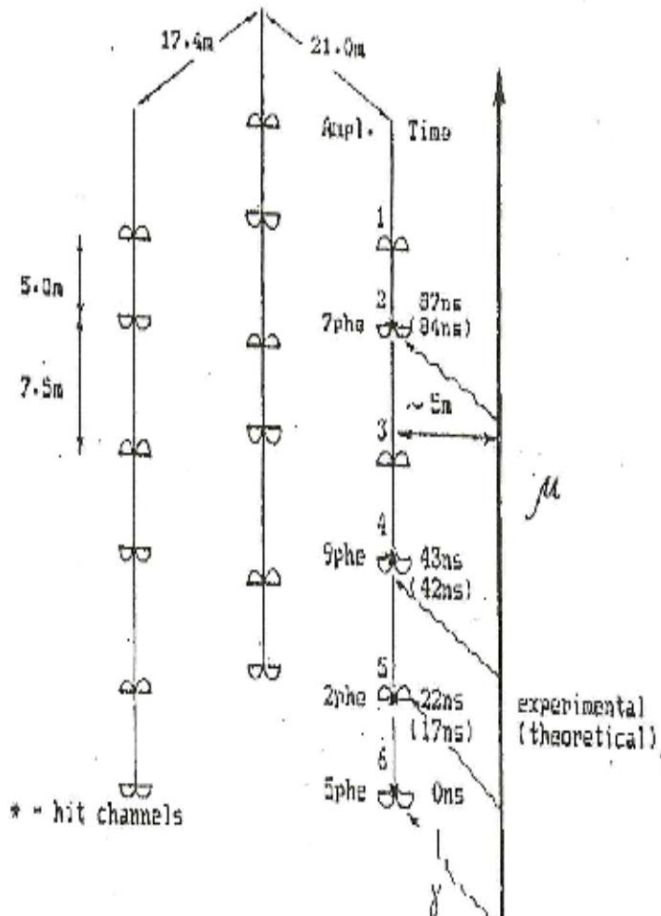
AMANDA 4 years

NT-200 5 years

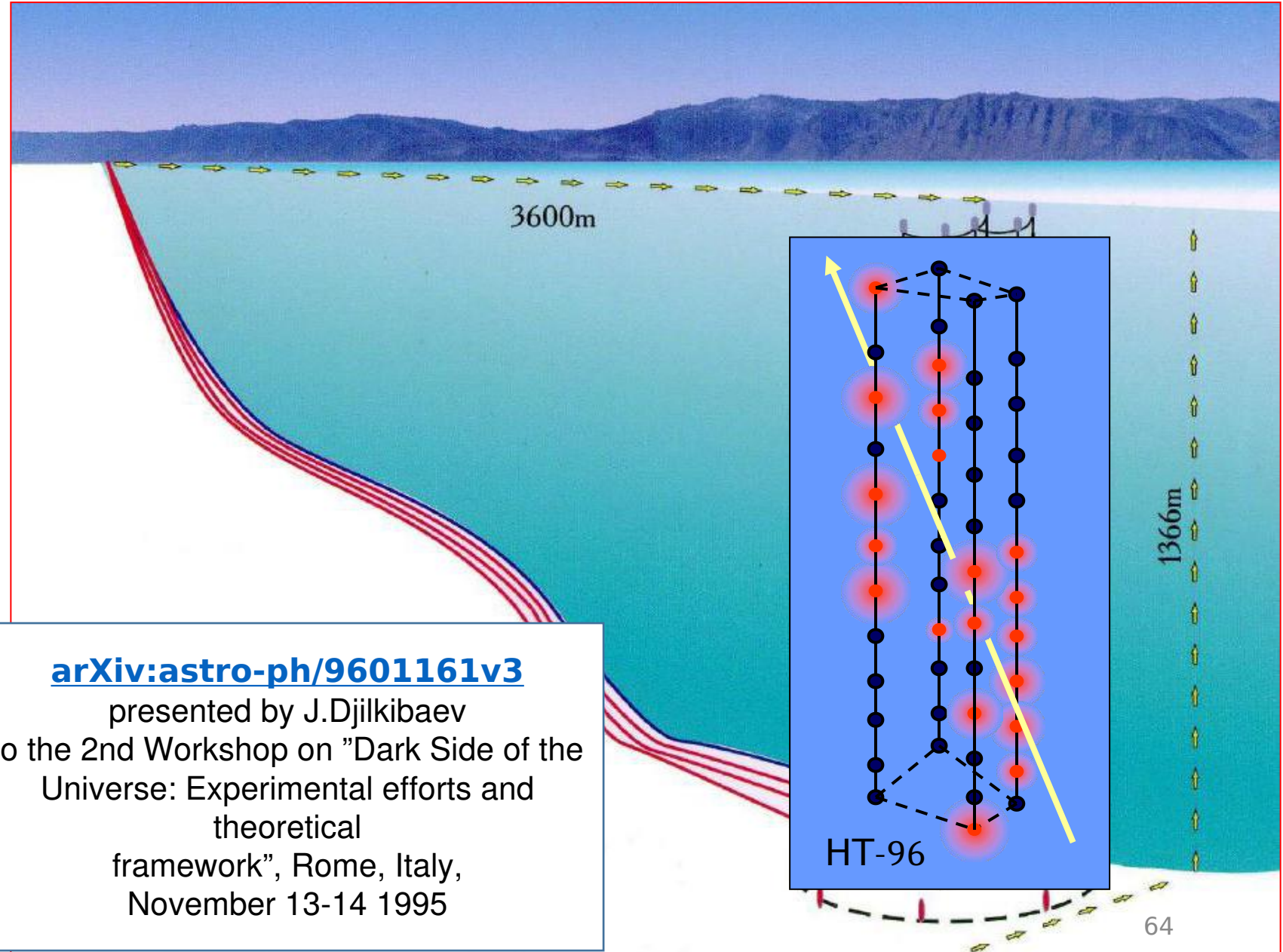


First underwater neutrinos

1994

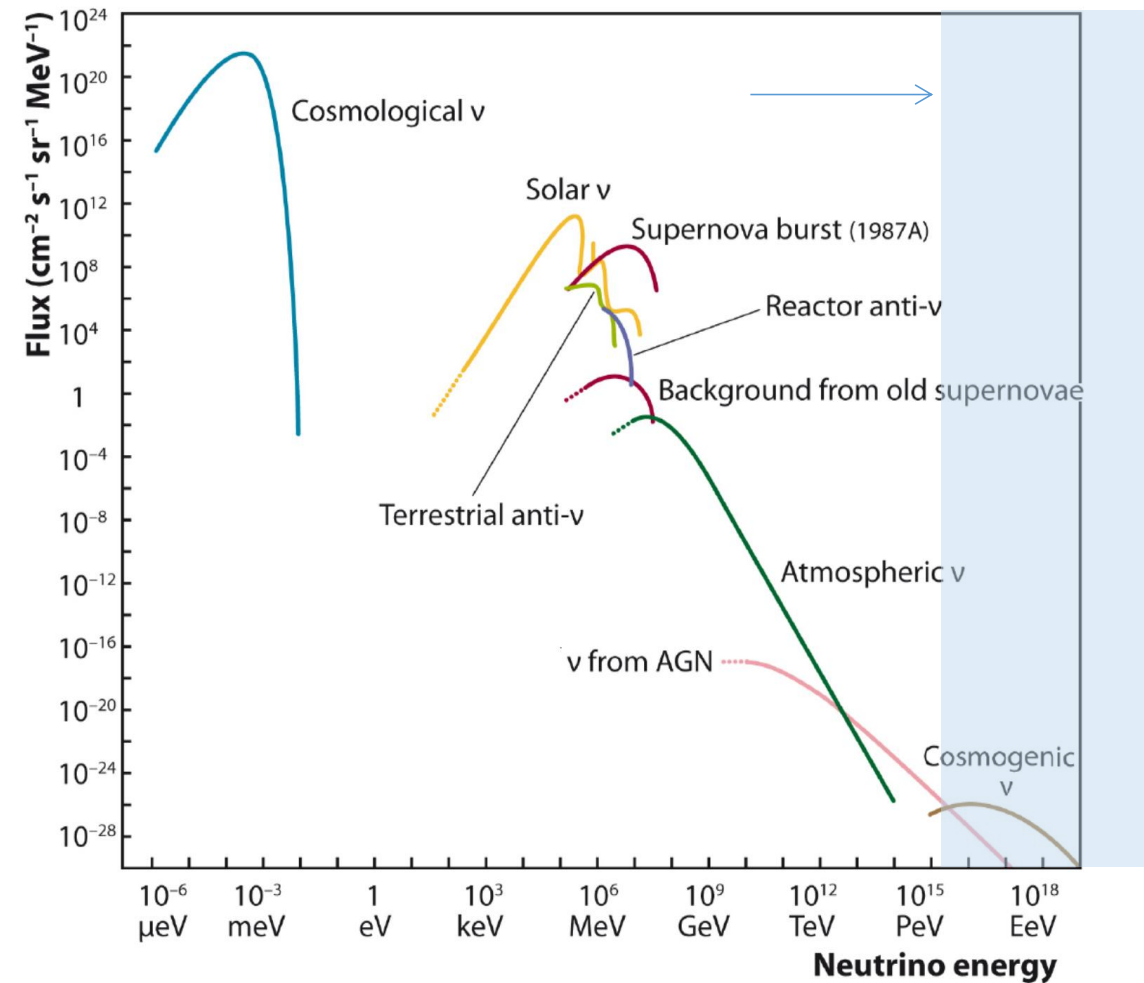


[arXiv:astro-ph/9601161v3](https://arxiv.org/abs/astro-ph/9601161v3)
presented by J.Djilkibaev
to the 2nd Workshop on "Dark Side of the
Universe: Experimental efforts and
theoretical
framework", Rome, Italy,
November 13-14 1995



Ultra high-energy neutrino detectors

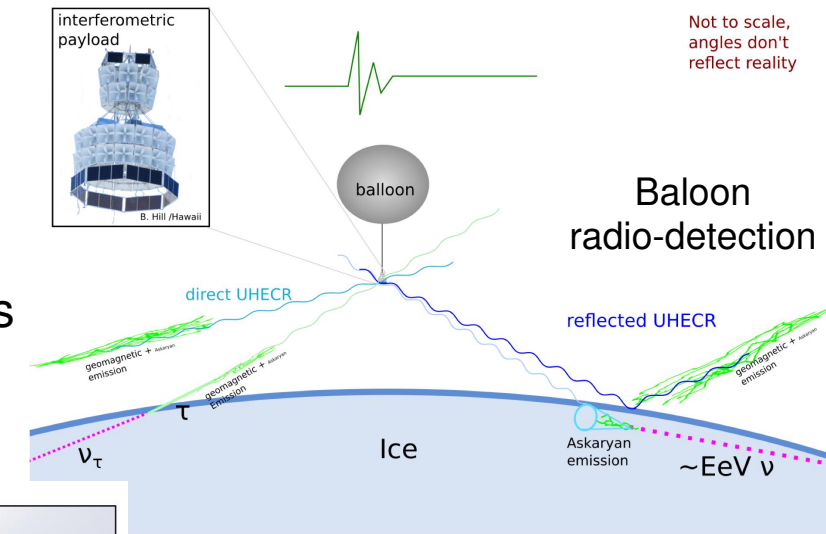
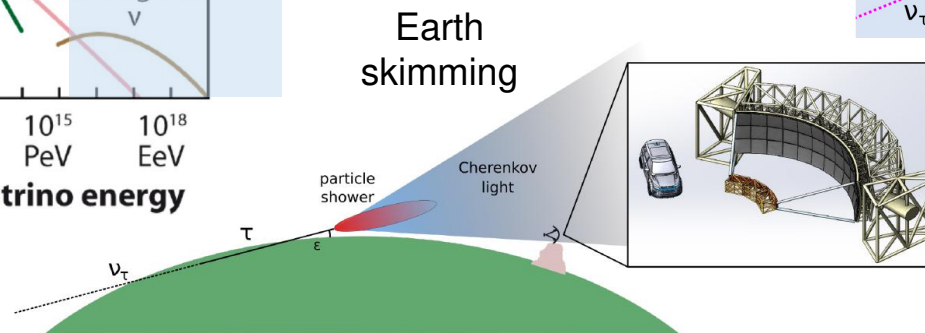
Very sparse instrumentation, **enormous sensitive volume: $O(100\text{km}^3)$ and more**



Multi-PeV neutrinos and beyond

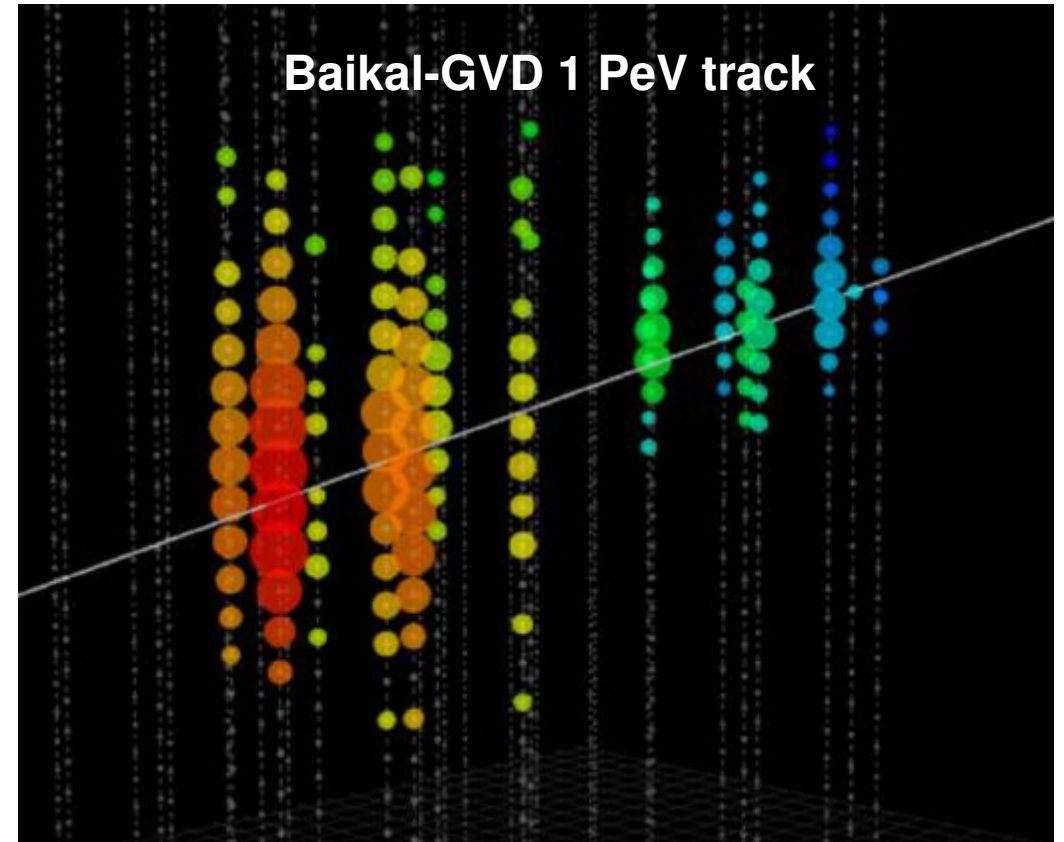
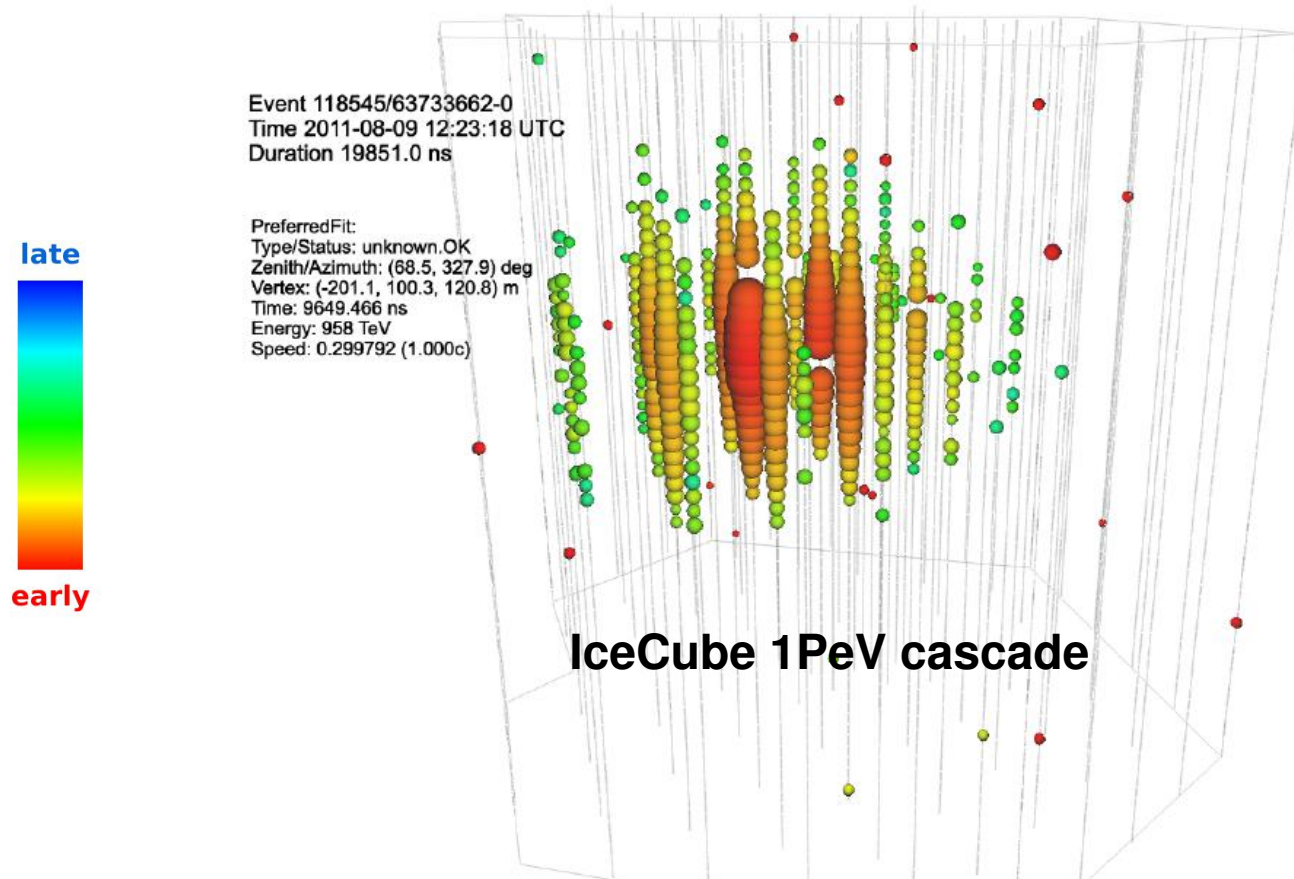
- Earth skimming
- Radio-detection
- Acoustic detection

Lots of impressive projects and concepts



Not in this lecture :(

Event examples



Baikal-GVD detector

