Baikal
GVD experiment

Rastislav Dvornický
on behalf of the Baikal collaboration,
DLNP, JINR, Dubna, Russia & Comenius University, Bratislava, Slovakia

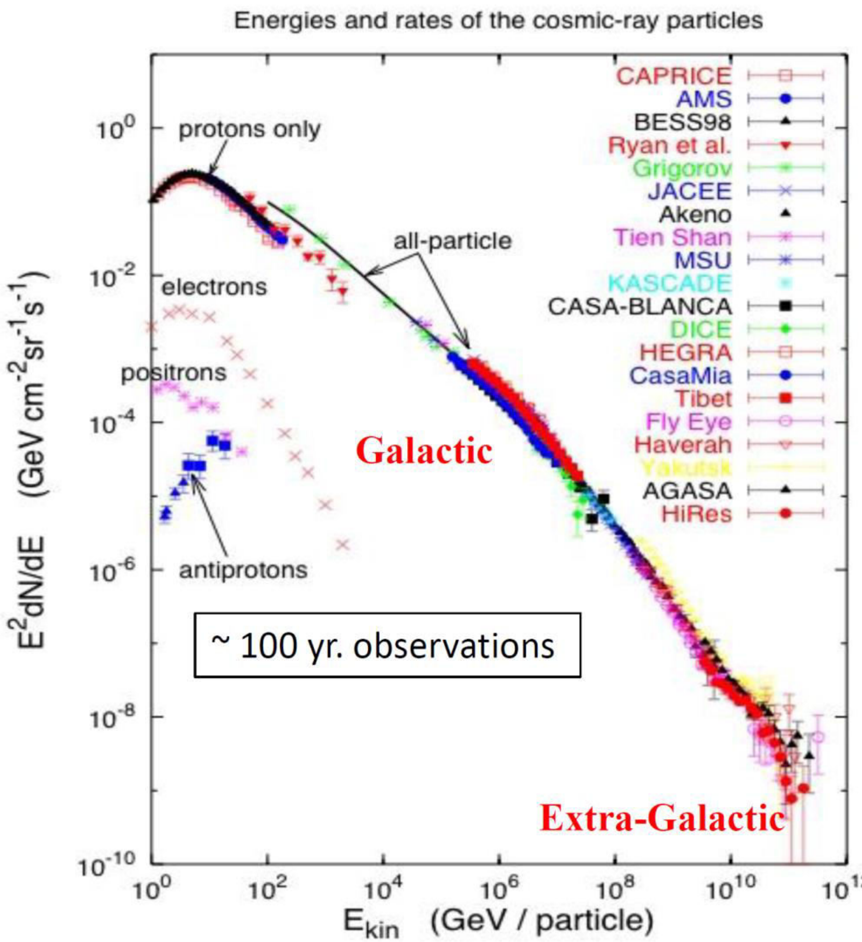
Collaboration: 9 institutions

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

Other associated institutions:

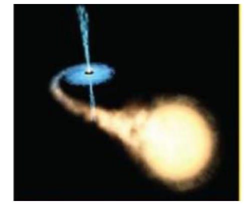
•Krakow University, Poland
•University of Bucharest, Romania

Cosmic rays:



Galactic sources: TeV – EeV ?

SNR, micro-quasars, pulsars



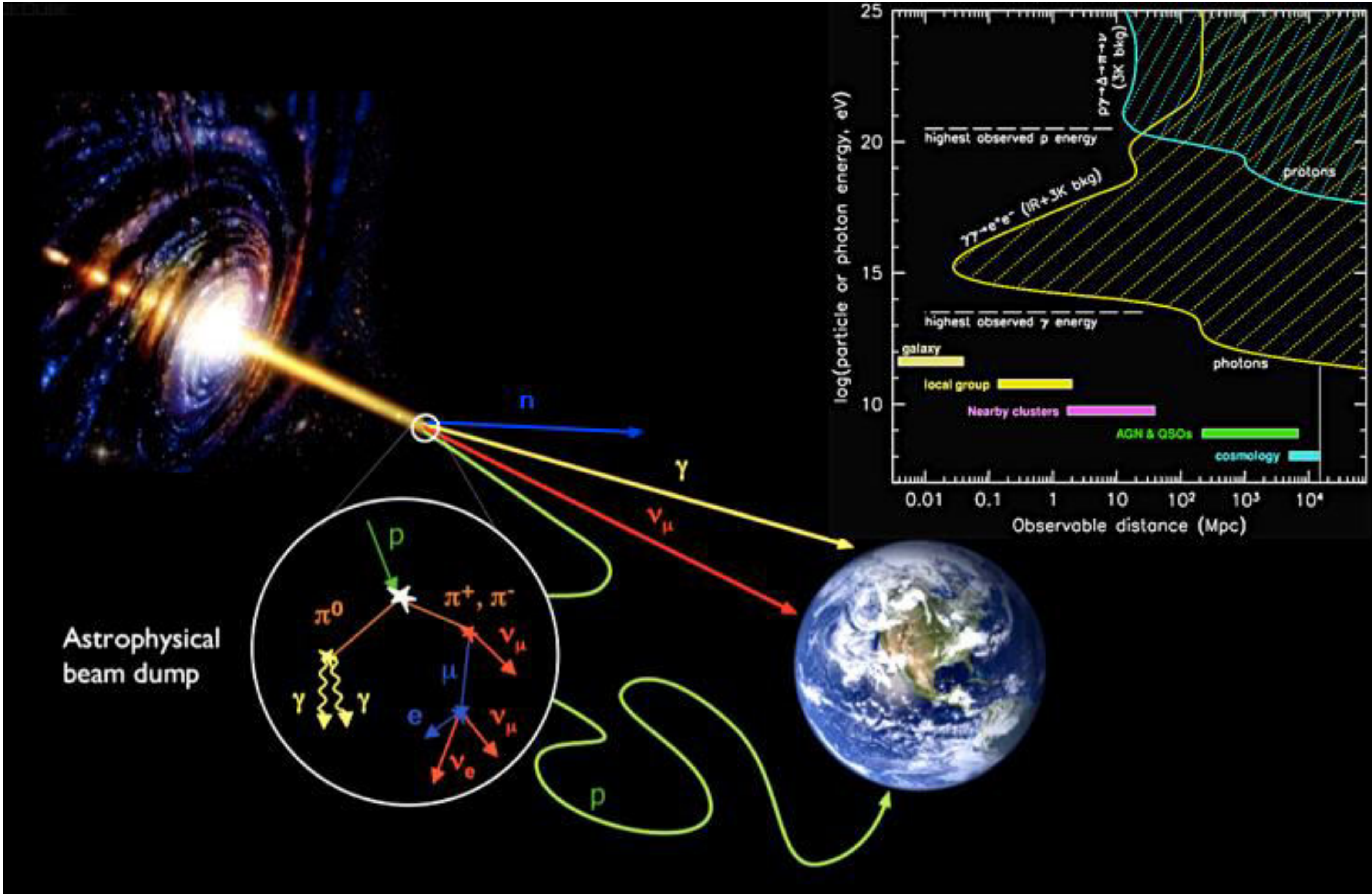
Extra-Galactic sources: EeV–PeV…

AGN, GRB,…

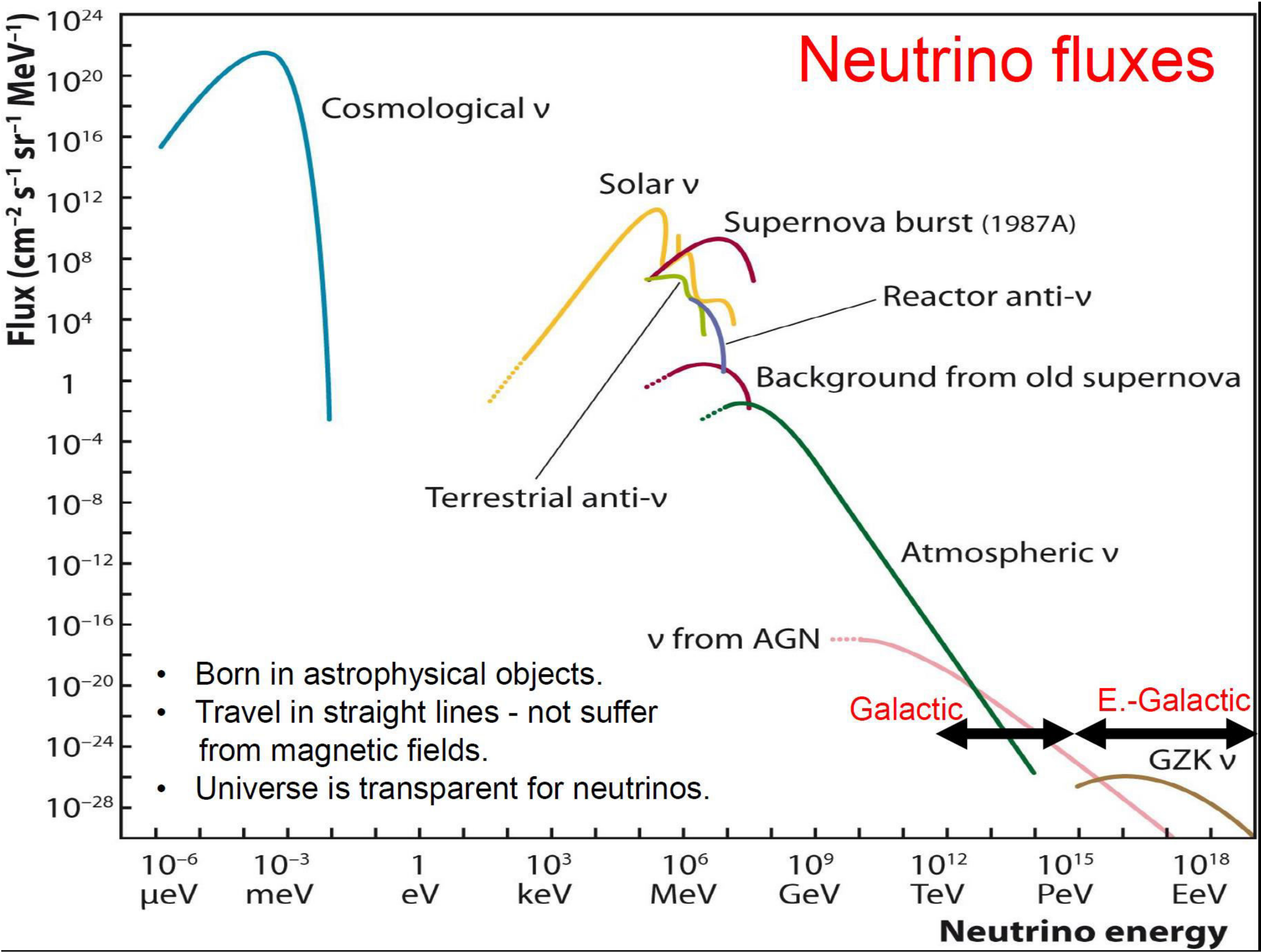
Energy spectrum and mass composition ☺

Sources location ?

Charged cosmic rays vs. γ rays vs. neutrinos

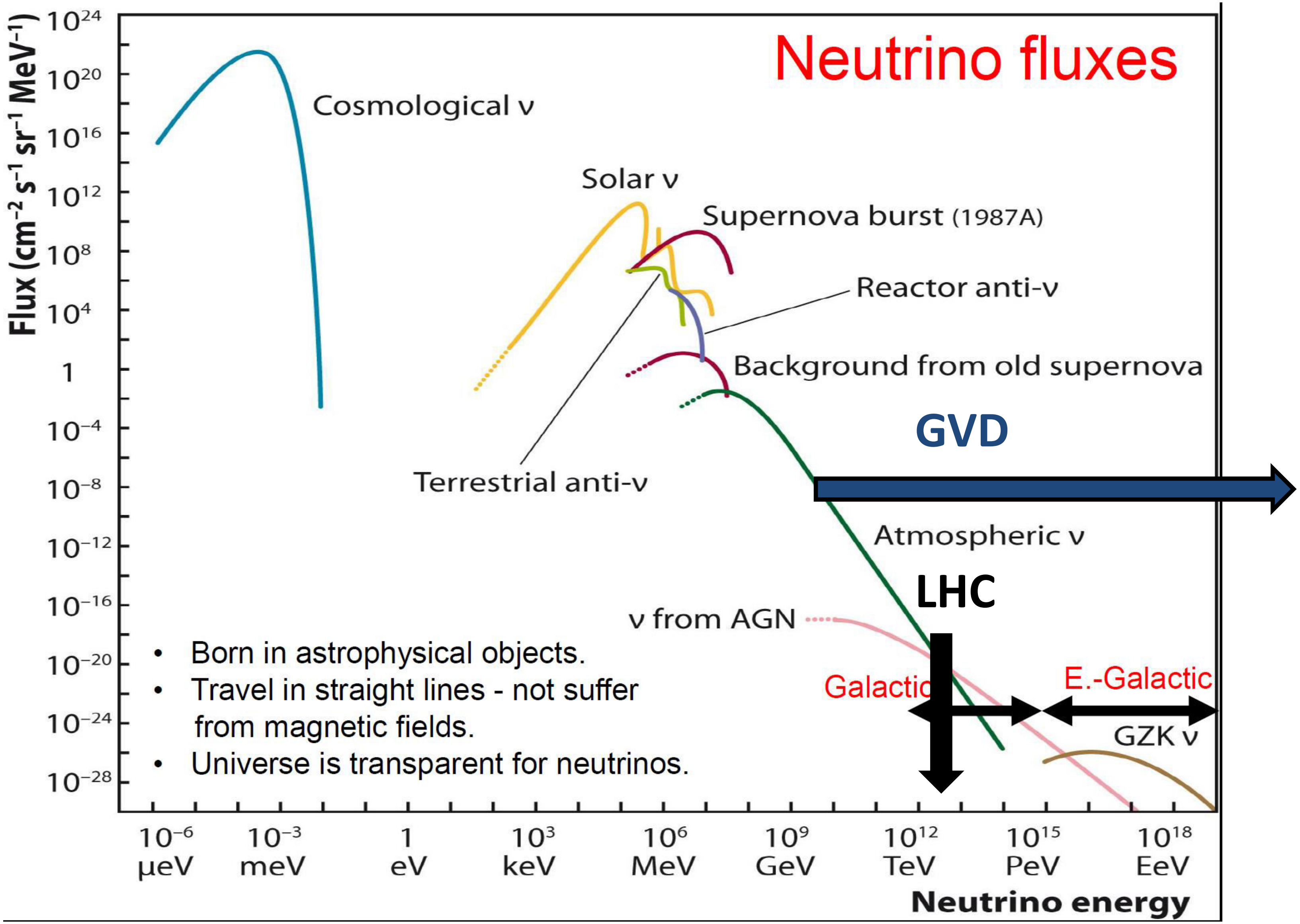


Neutrinos – one of the 3 messengers



- Born in astrophysical objects.
- Travel in straight lines - not suffer from magnetic fields.
- Universe is transparent for neutrinos.

Neutrinos – one of the 3 messengers



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.

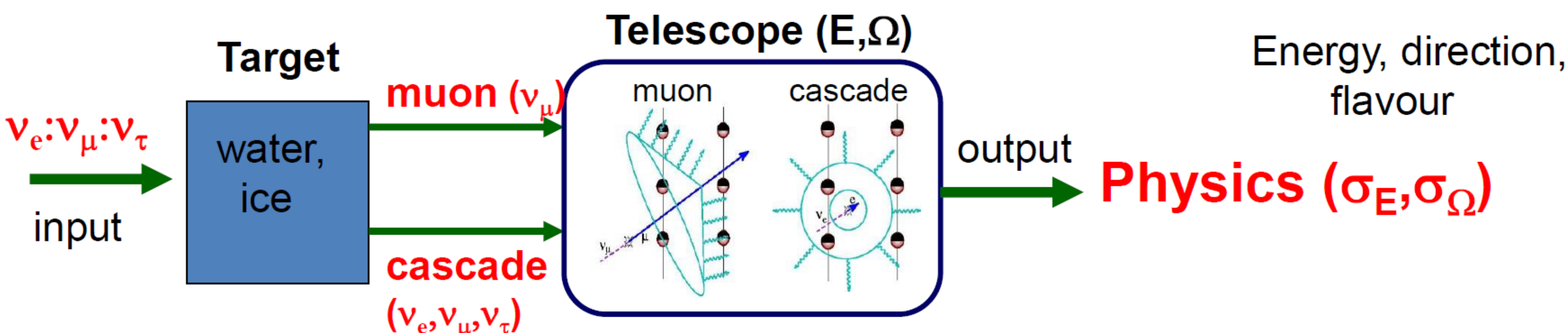
Detection Principle – M. Markov 1960

Flux
From local sources, diffuse flux

Detection modes
muons, cascades

Environment properties
absorption, scattering, light background – K^{40}, bioluminescence

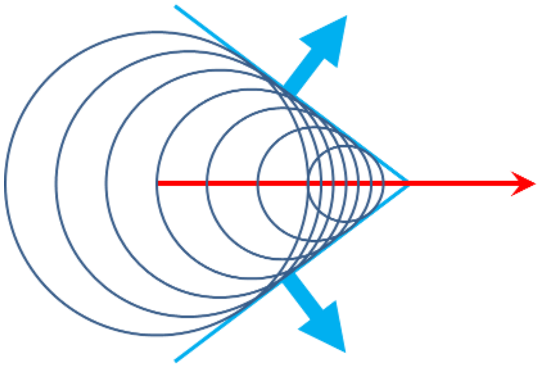
Background
downward going atm. muons, atm. neutrinos



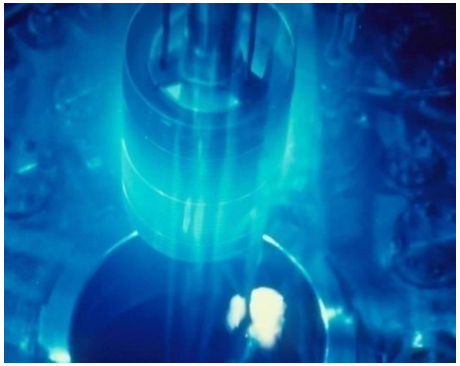
Arrival times & amplitudes,
PMTs arrangement and orientation

Cherenkov light

•Charged particle travelling faster than the speed of light in a particular environment radiates Cherenkov light



• Pale blue light



• Effect known for ultrasonic airplanes

• Cherenkov radiation

➢ Intensity: $$\frac{dN_c}{d\lambda} = 2\pi\alpha\left(1 - \frac{1}{\beta^2 n^2}\right)\frac{1}{\lambda^2},$$

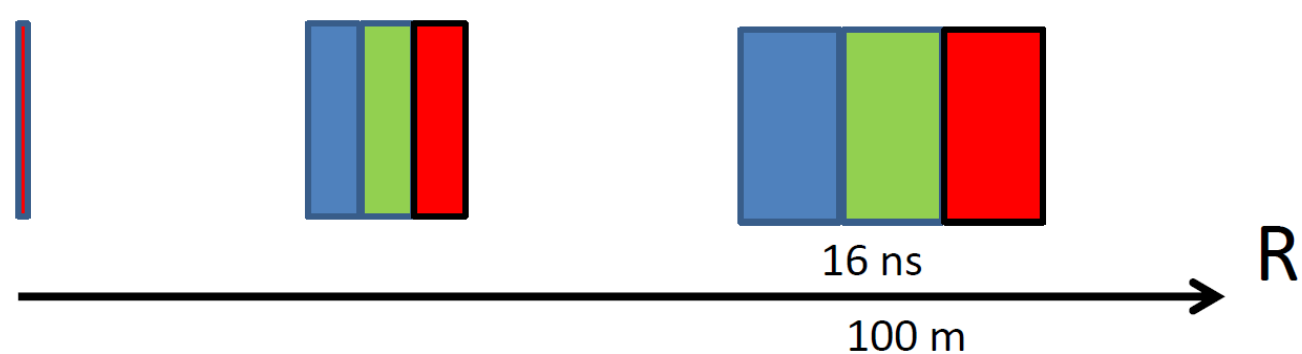
$N_c = 230\ \gamma/cm$ (350 – 600 nm, water)

➢ Cherenkov angle: $\cos\theta_c = 1/(\beta n)$, $\theta_c = 42^{\circ}\ water$

➢ Light velocity: $v_c = \frac{c}{n_g(\lambda)}$, $n_g(\lambda) = n(\lambda) - \lambda\frac{dn}{d\lambda}$

$$n(470nm) = 1.33 \rightarrow n_g(470nm) = 1.37$$

Light velocity dispersion leads to time dispersion of signal



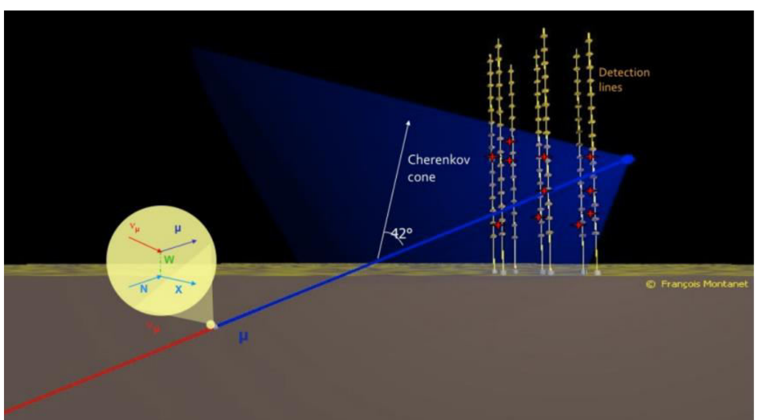
Detection principle

$$\nu_l + N \xrightarrow{CC} \begin{cases} e^- + X \rightarrow cascades \\ \tau^- + X \rightarrow cascades \\ \mu^- + X \rightarrow track + cascades \end{cases}$$

•Cherenkov radiation is detected by an array of photo-sensors

$$\nu_l + N \xrightarrow{NC} \nu_l + cascade$$

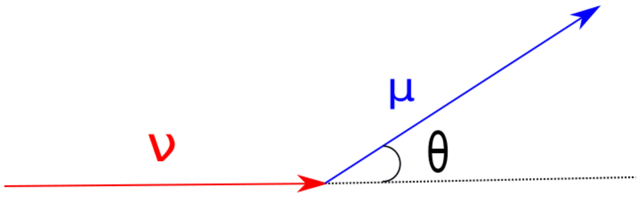
• Optical Module

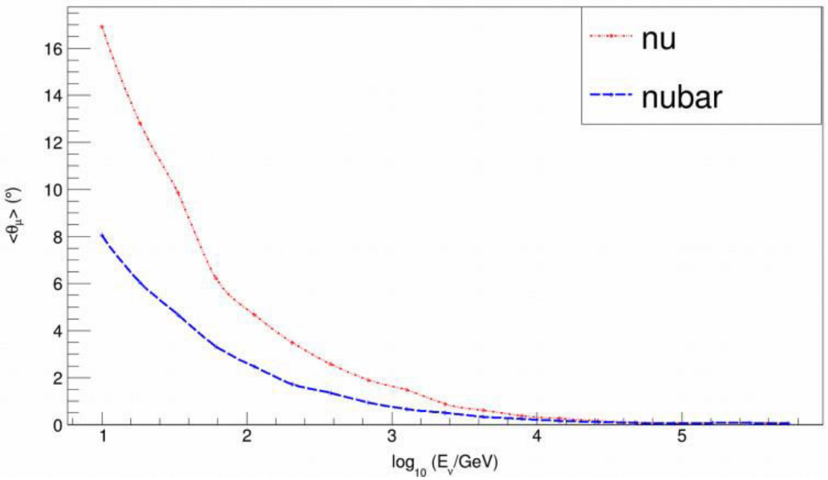


•μ / cascades ≈ 1 / 3
•cascades – point-like
•muons – large effective volume

Detection principle

The angle between the incoming neutrino and outgoing muon



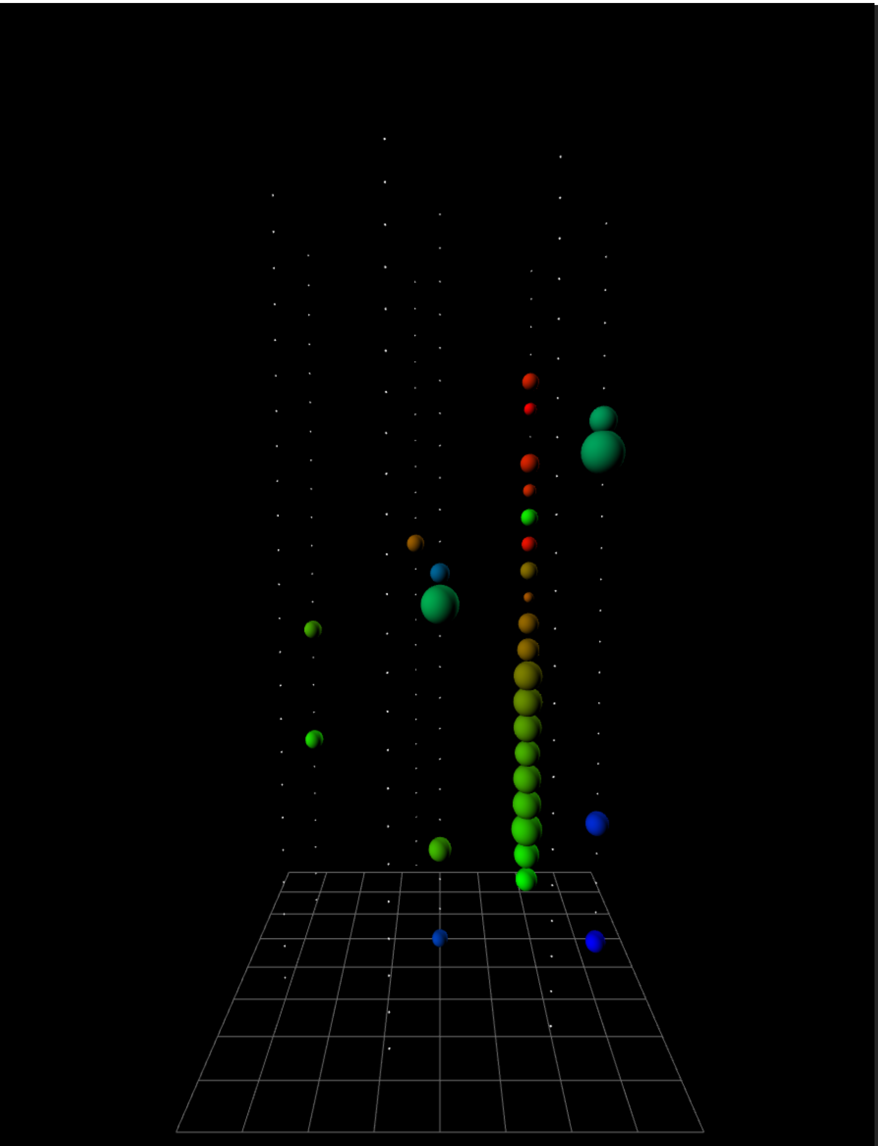


Charge calibration

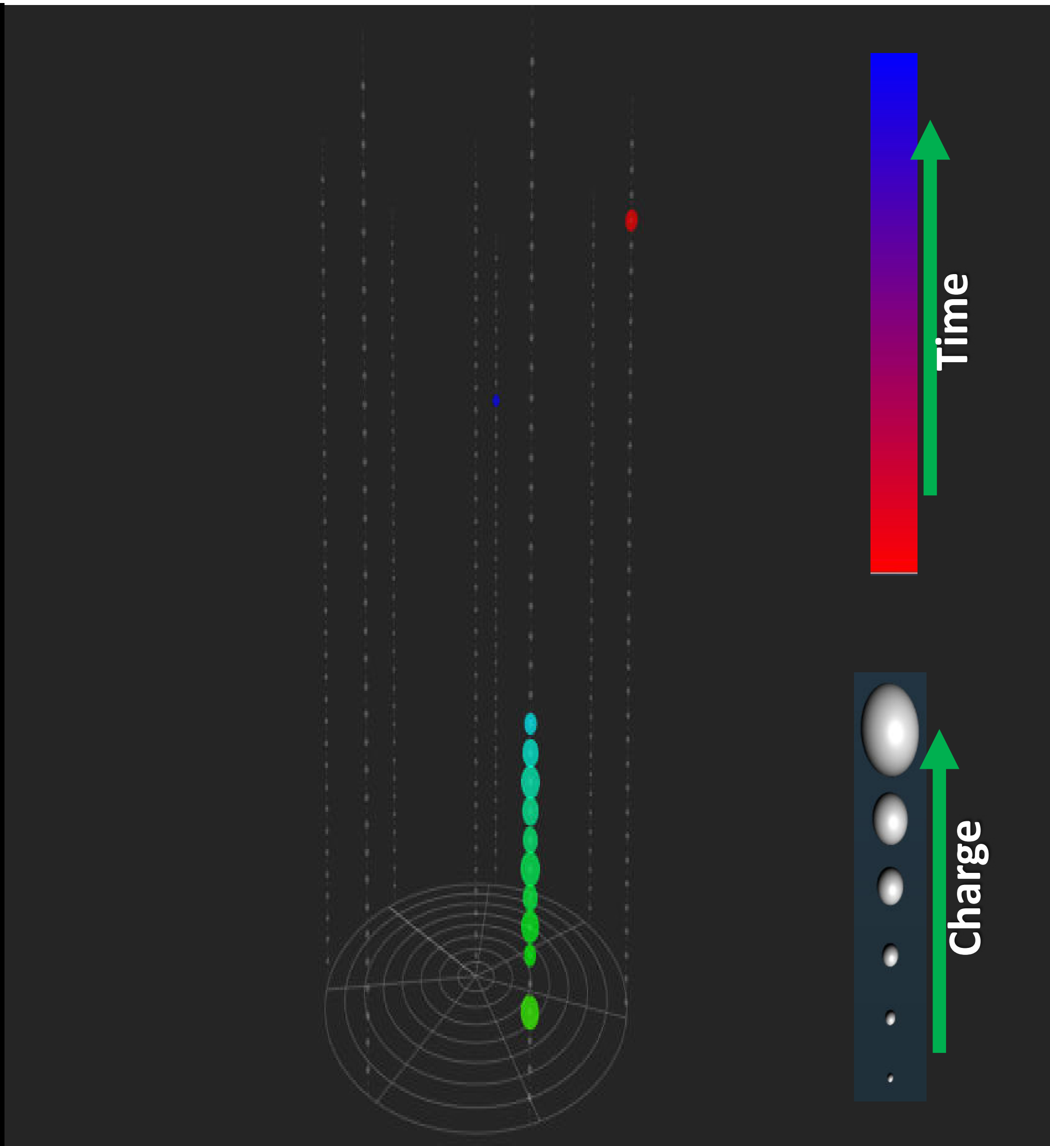
- Light is registered with Optical Module
- Yield is given in FADC = channels
- Channels → photons
- Task: a single photon corresponds to 1photo-electron = ? FADC

a photon →  → signal in FADC

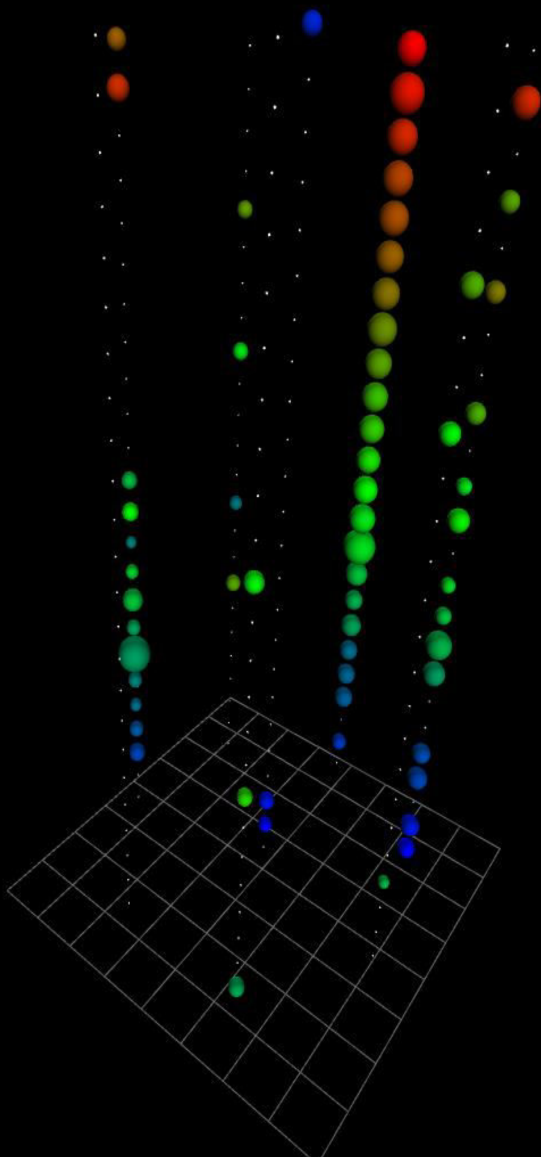
Downward going muon



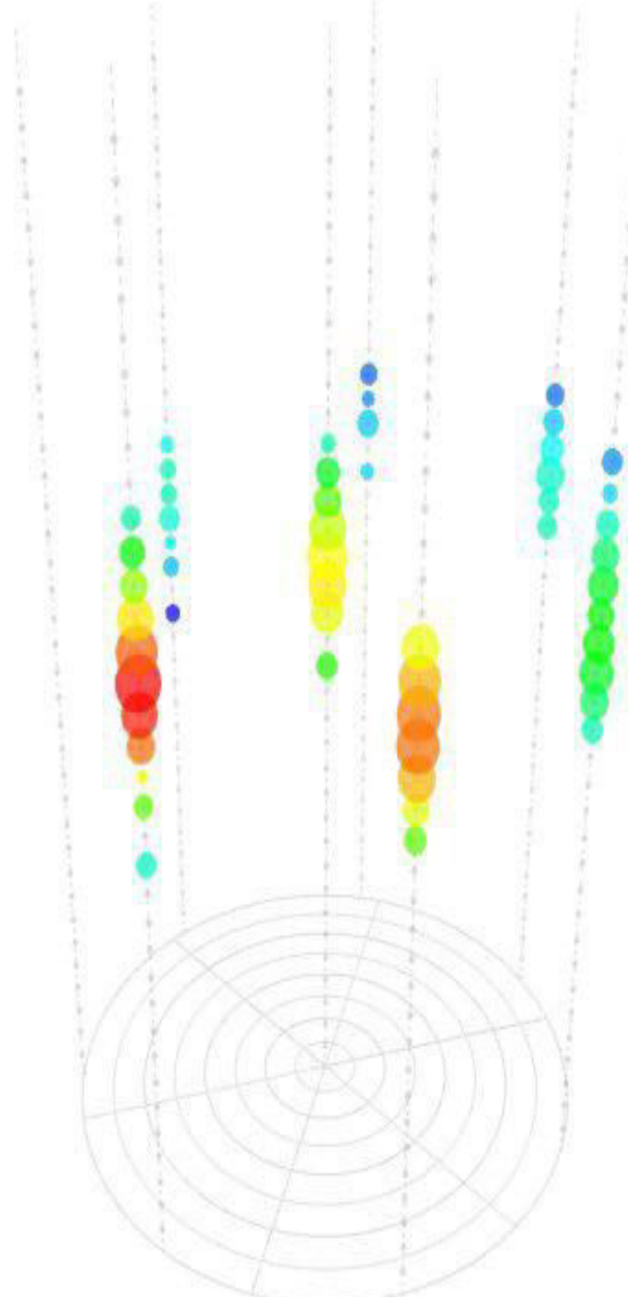
Upward going neutrino



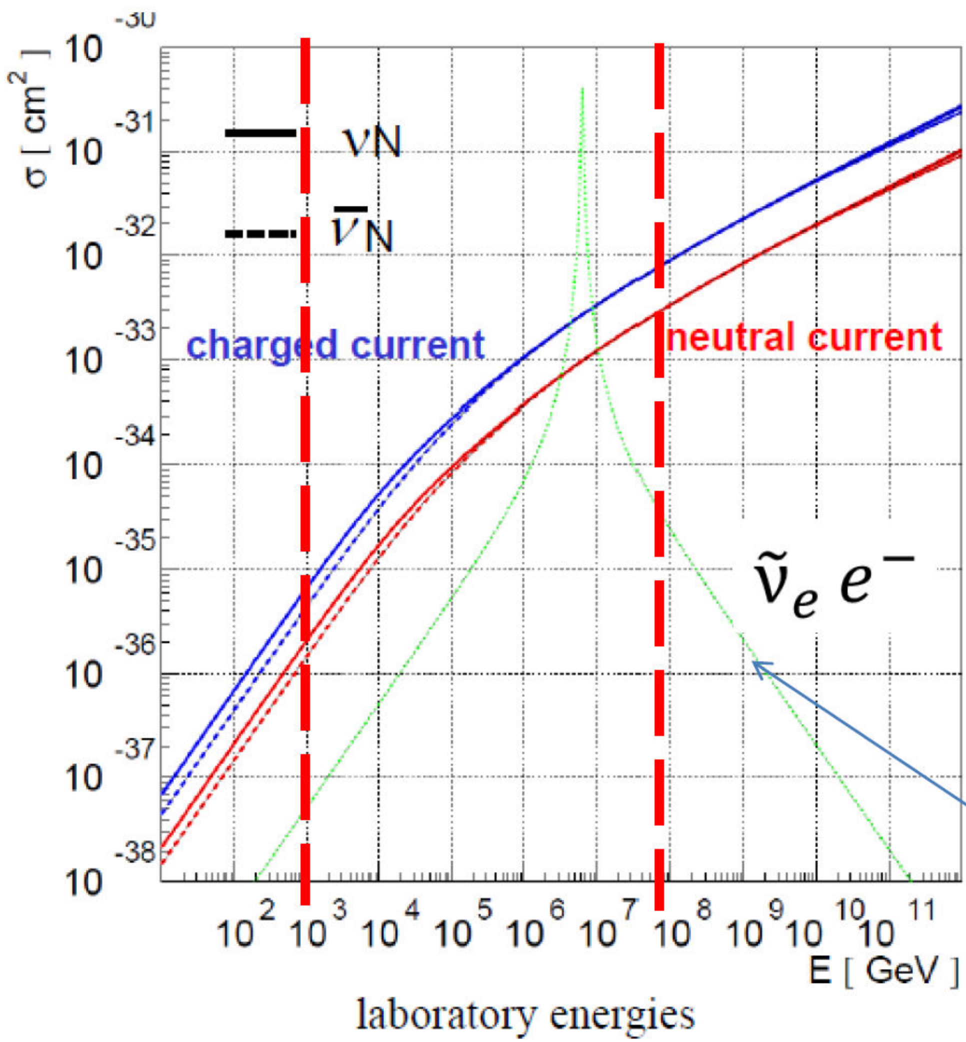
Background muon bundle

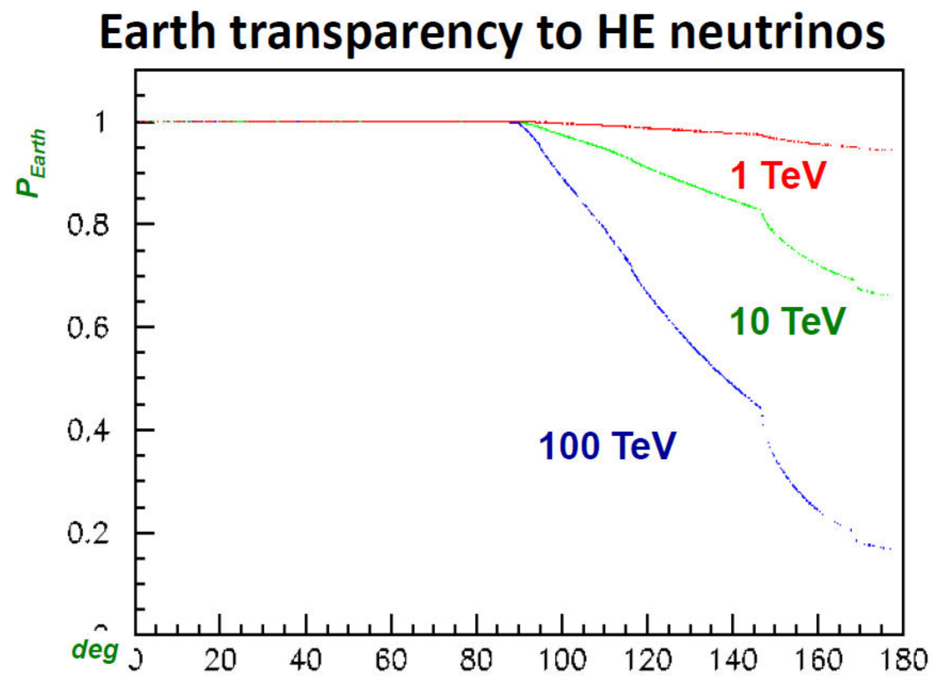


High-energy cascade



• Neutrino cross sections

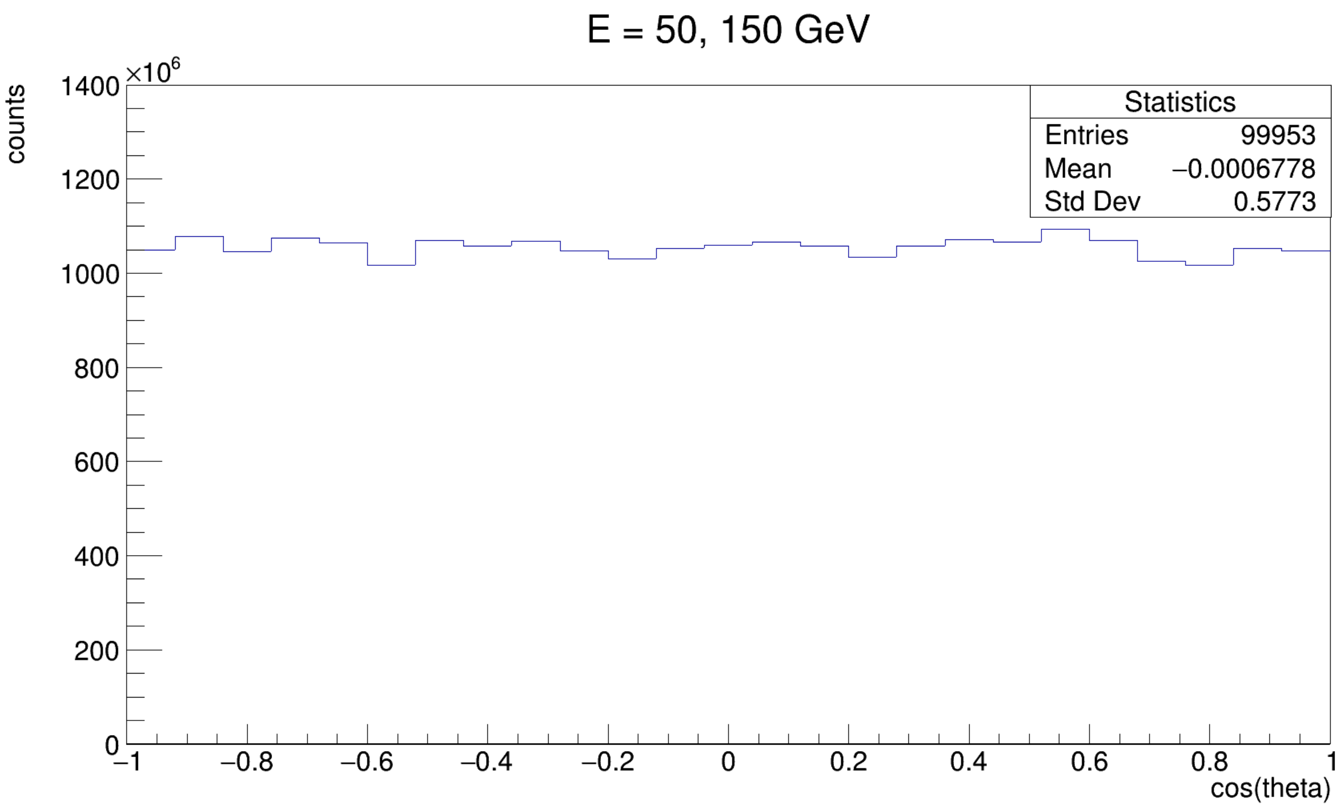




"Glashow resonance"
neutrino energy: $6.3\cdot10^{15}$ eV,
resonance width: ±130 TeV,
peak cross section: $5\cdot10^{-31}$ cm^2

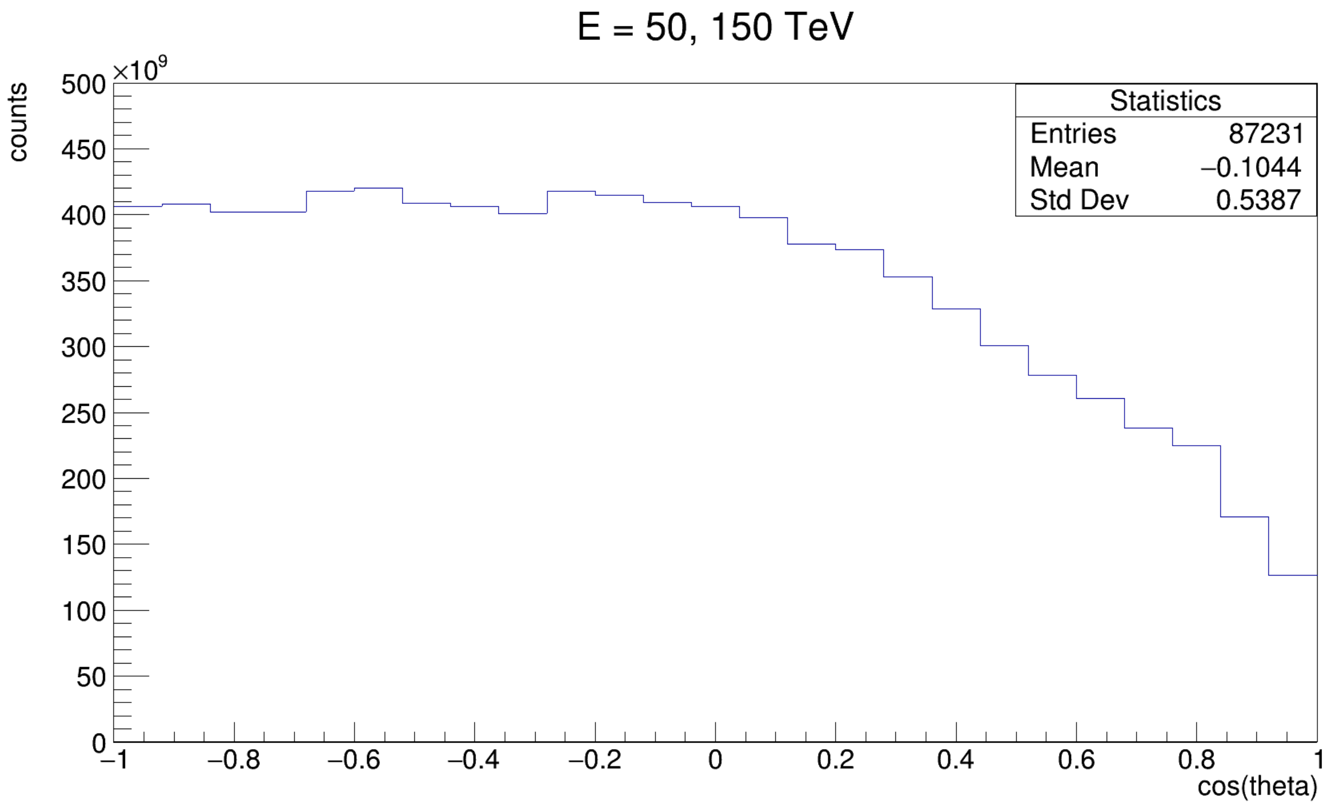
MC - ANIS

The Earth's transparency to neutrinos



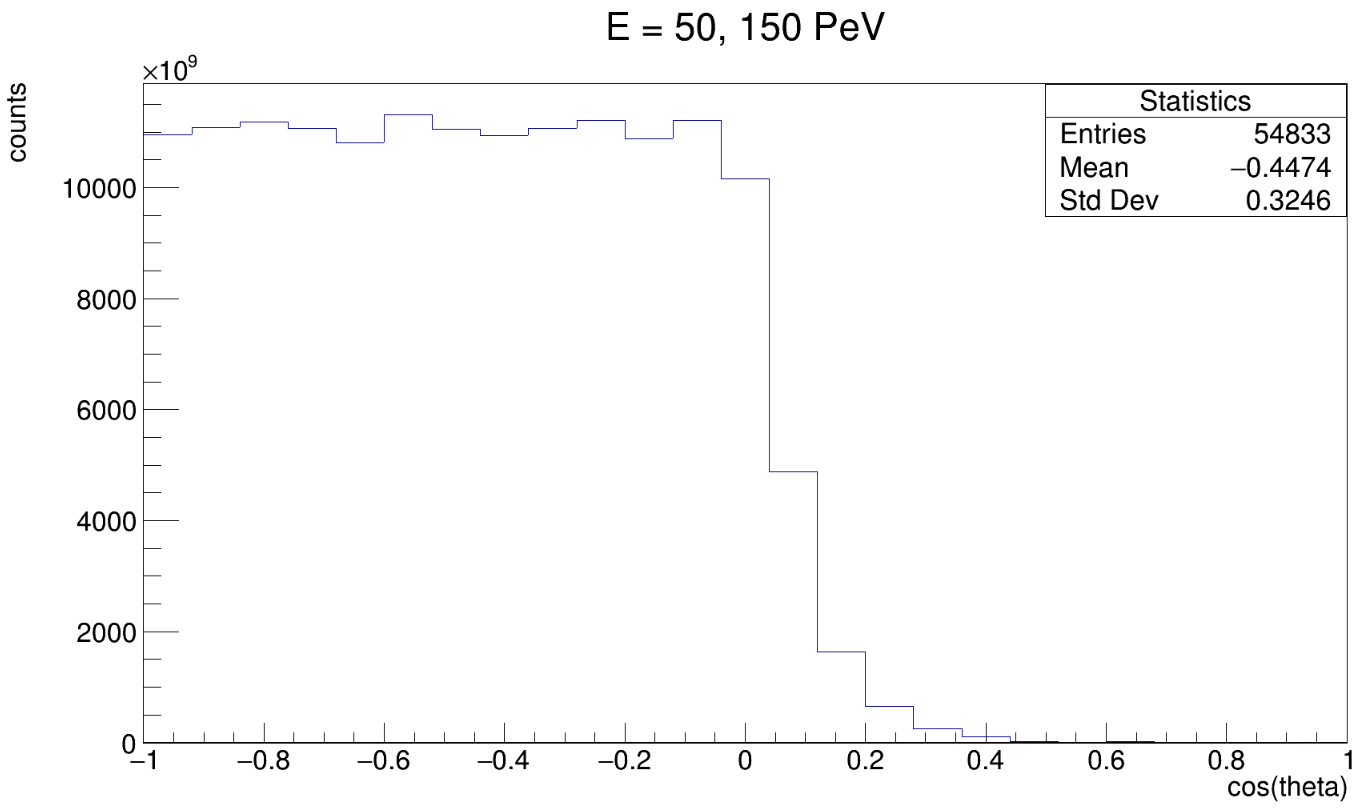
MC - ANIS

The Earth's transparency to neutrinos

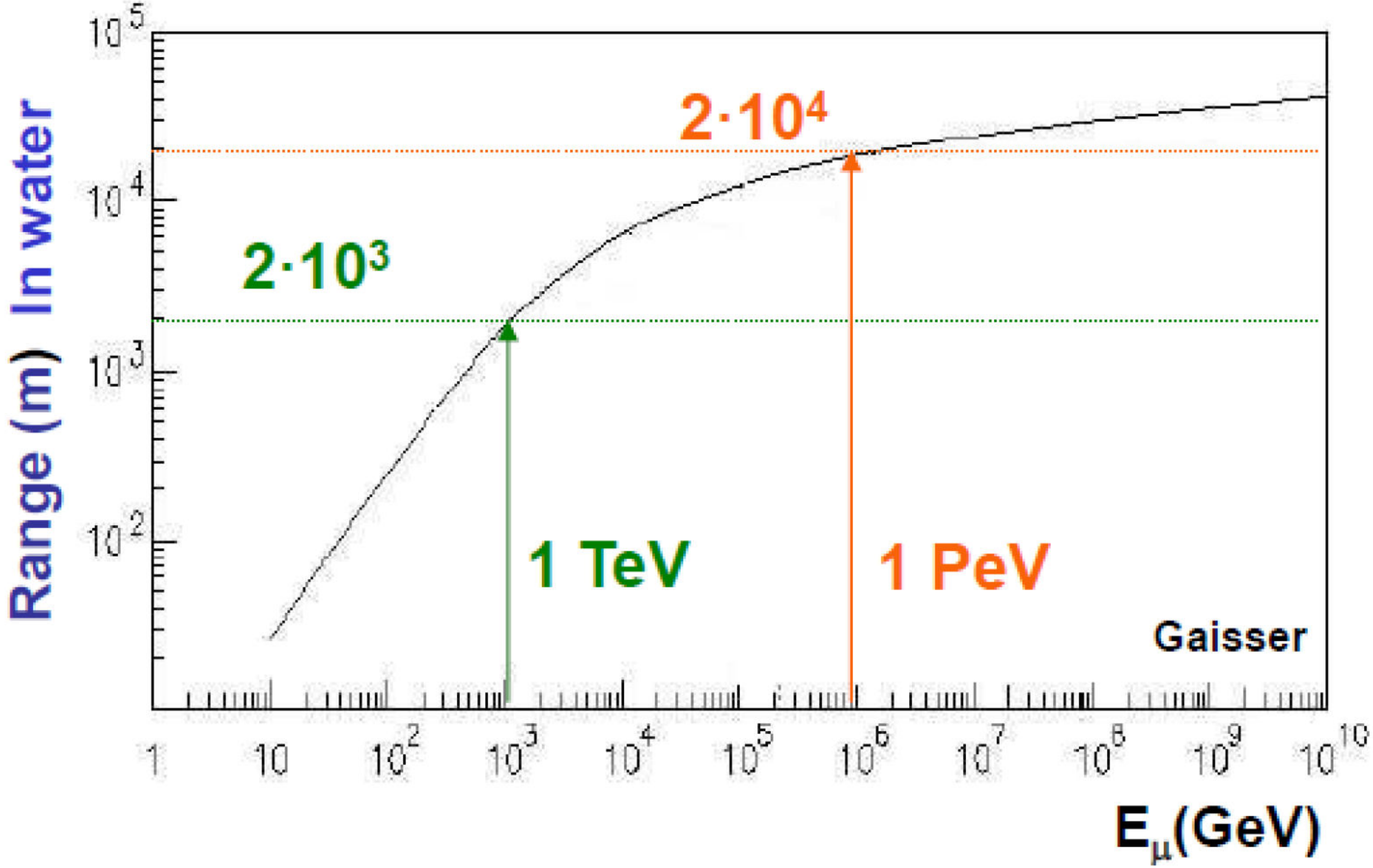


MC - ANIS

The Earth's transparency to neutrinos

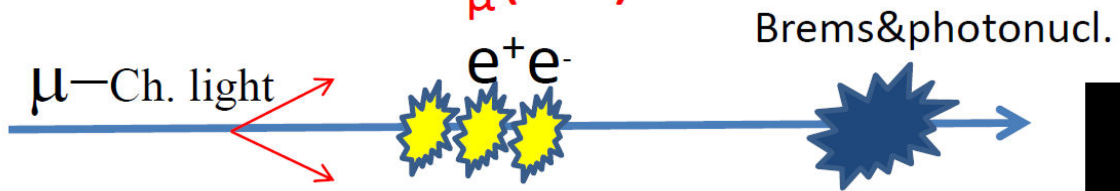


Muon energy loss and range in water

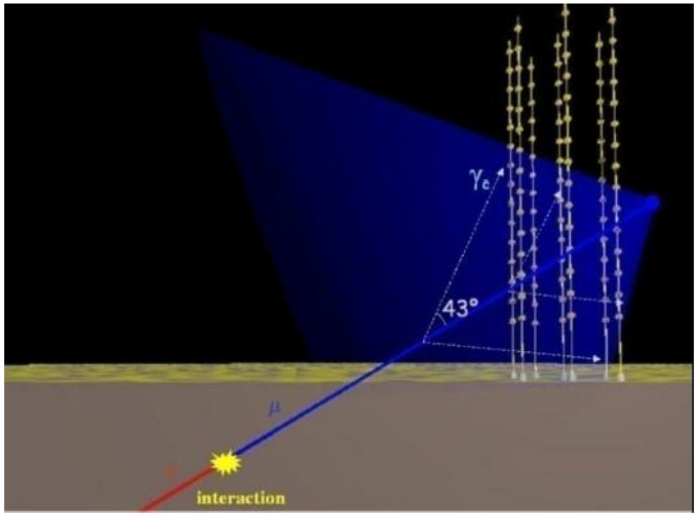


• Muon Detection Mode

✓Muons from ν_μ(CC):

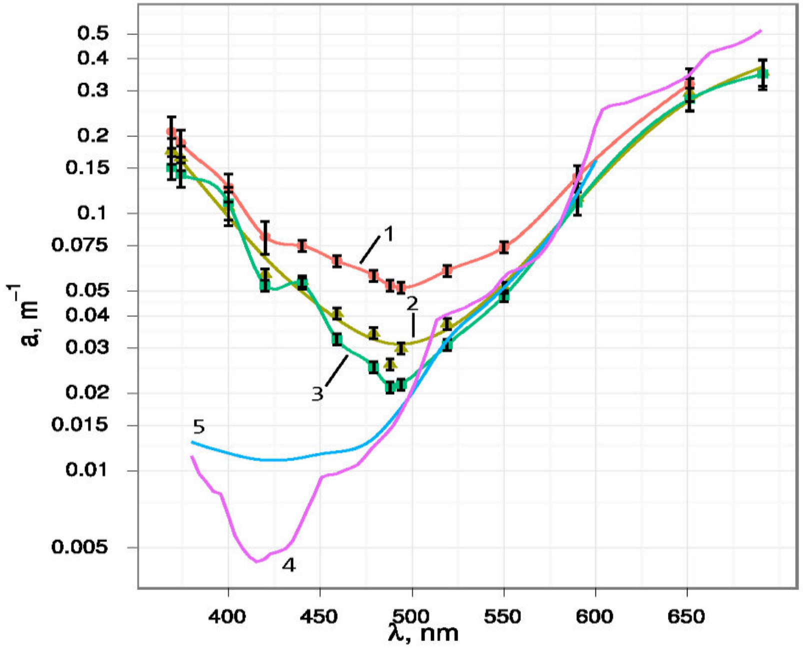


$$N_{ch} = n_\mu(1 + 0.6E(TeV))$$

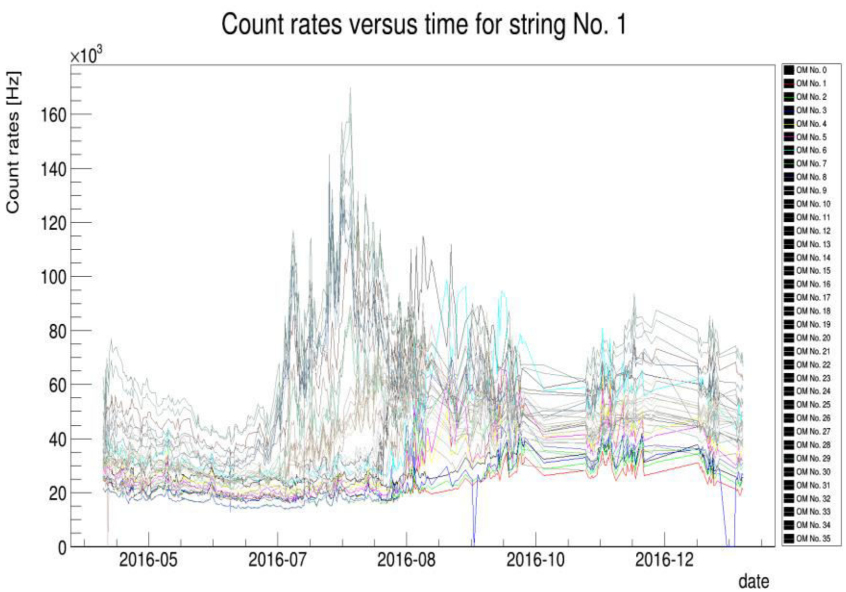


- High angular resolution ~0.1°- 1°
  (depends on visible track length)
- Enlarged effective volume
  (water/ice & bedrock for up-going ν_μ)
- Emits strongly in the Cherenkov angle

Water properties



- **Absorption length: ~ 22-24 m**
- **Scattering length: L_s ~ 30-50 m**
  $L_{eff} = L_s /(1- <\cos\theta>)$ ~ 300-500 m
- **Strongly anisotropic phase function:**
  $<\cos\theta>$ ~ 0.9



- **Moderately low background in fresh water:**

  15 – 40 kHz (R7081HQE)
  absence of high luminosity bursts from biology and K^{40} background.

Baikal GVD -
Gigaton Volume Detector

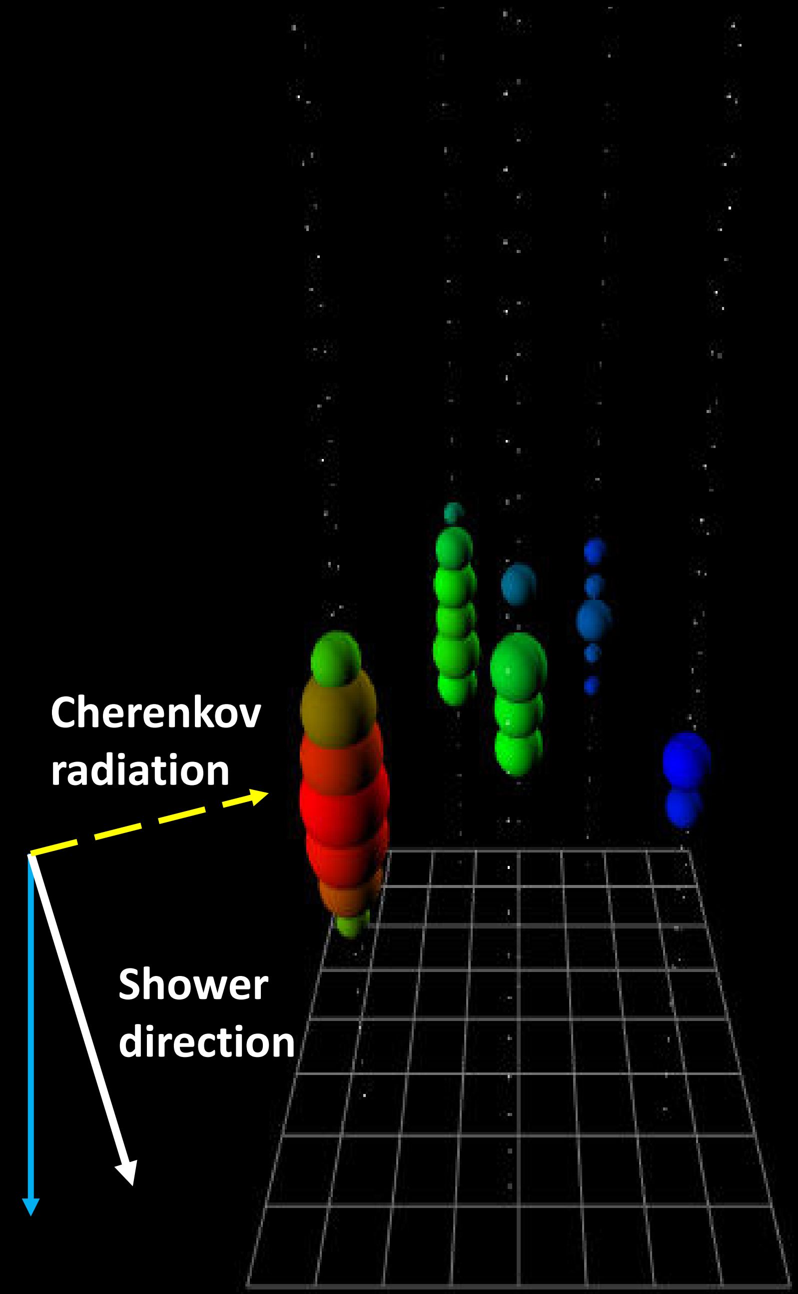
Objectives:

- km3-scale 3D-array of photo sensors
- flexible structure allowing an upgrade and/or a rearrangement of the main building blocks (clusters)
- high sensitivity and resolution of neutrino energy, direction and flavor content

Central Physics Goals:

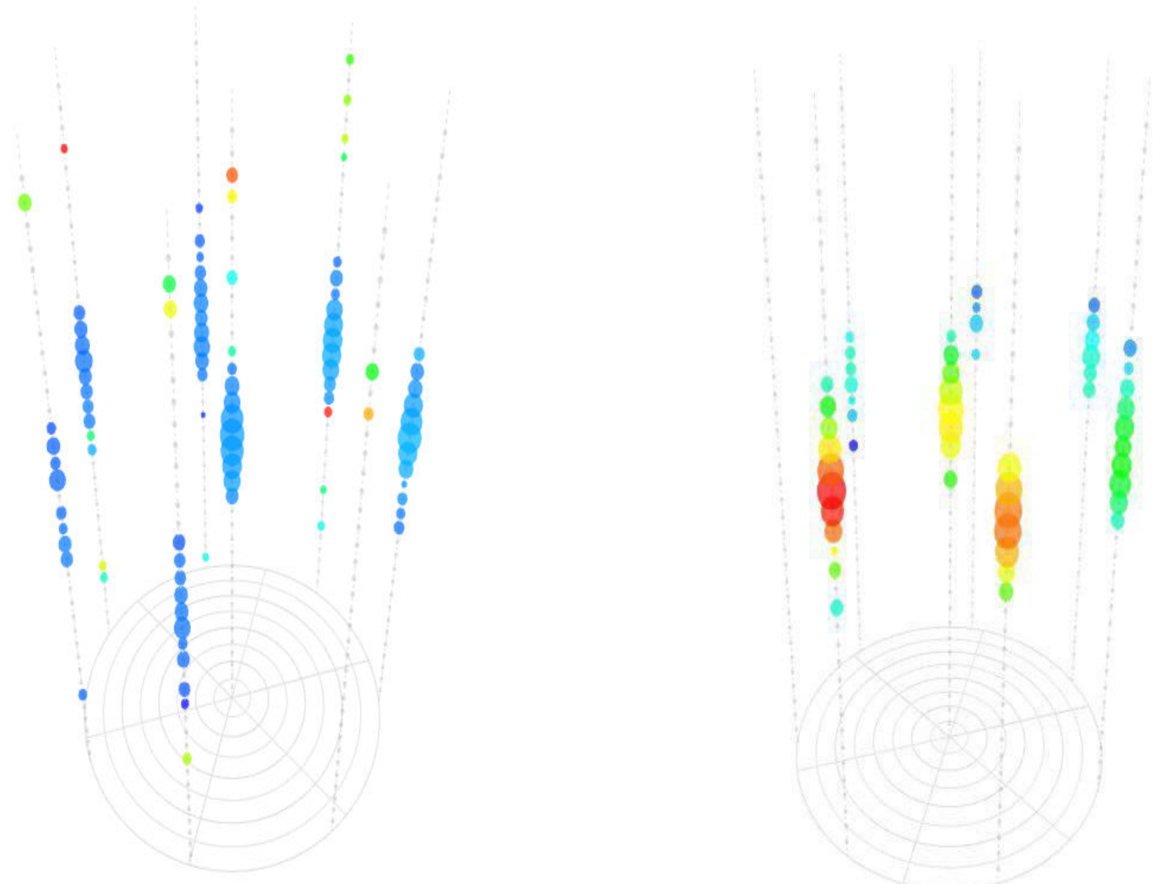
- Investigate Galactic and Extragalactic neutrino "point sources" in energy range E > TeV
- Diffuse neutrino flux – energy spectrum, local and global anisotropy, flavor content
- Transient sources (GRB, …)
- Dark matter – indirect search
- Exotic particles – monopoles, Q-balls, …

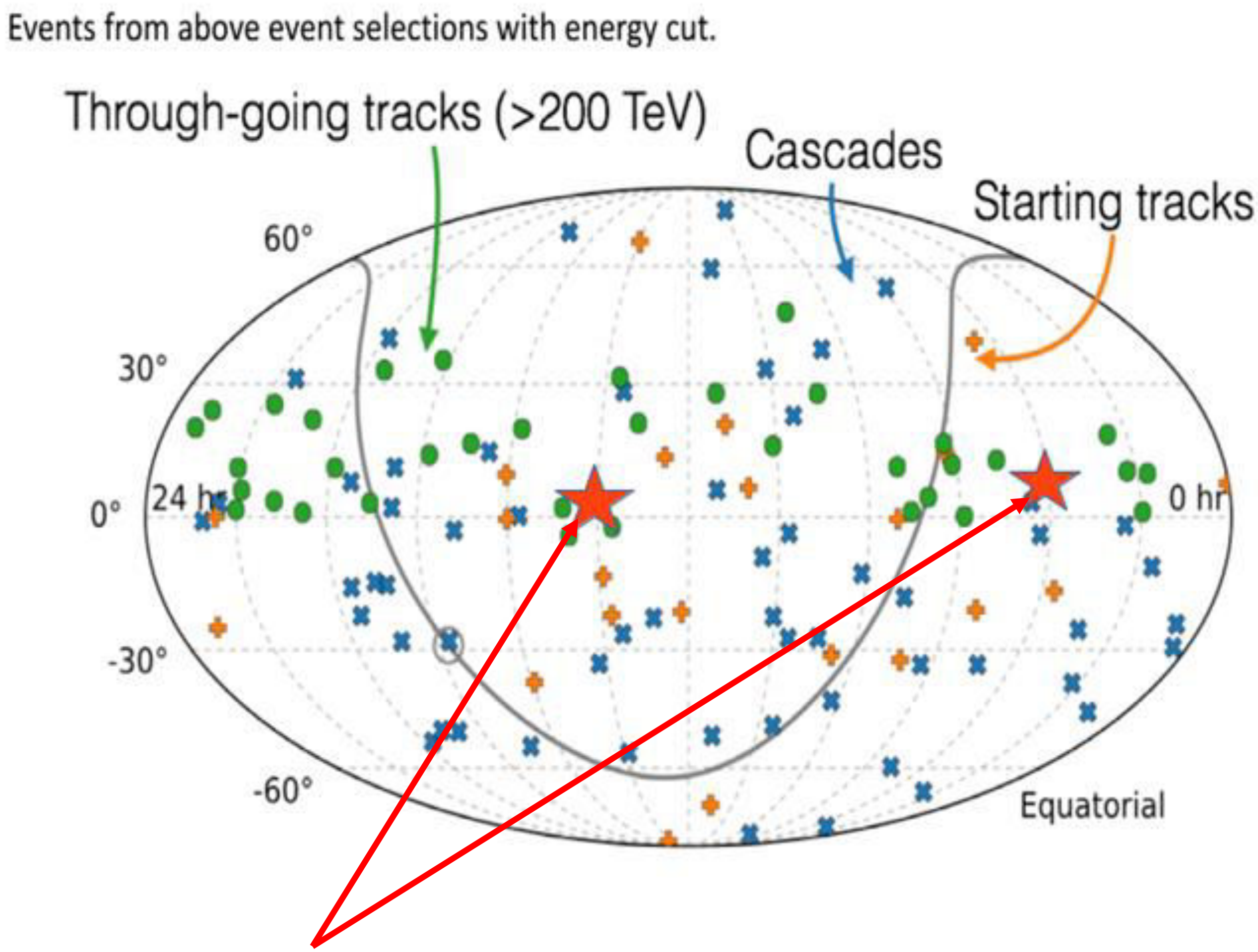
E = 107 TeV, θ = 56.6°, ρ = 68 m, z = -59 m



Cascade: E=157 TeV, θ = 57°, φ = 249°

x=-25m, y=-37m, z=11m, ρ=44m

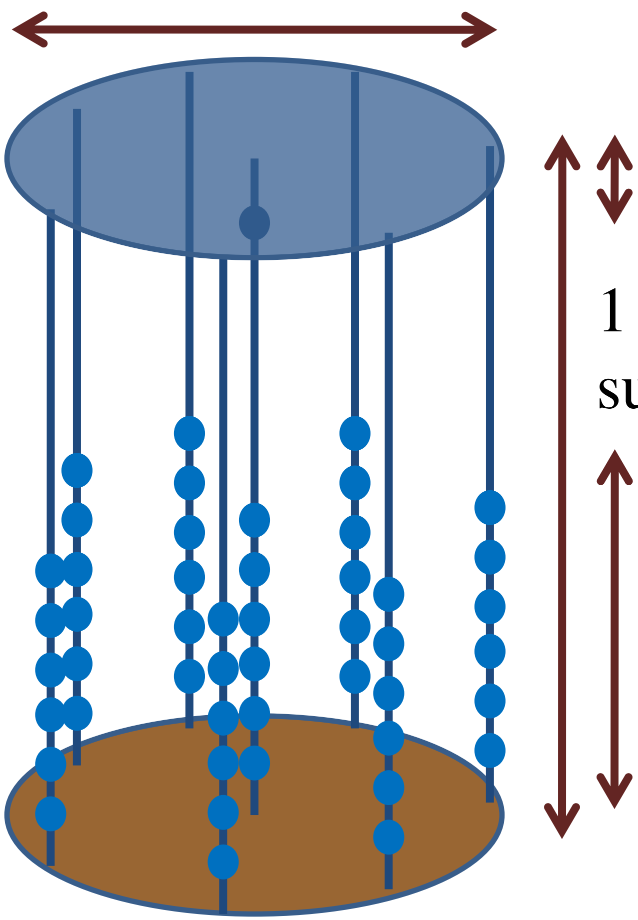



Events from above event selections with energy cut.
Through-going tracks (>200 TeV)
Cascades
Starting tracks
60°
30°
0°
-30°
-60°
24 hr
0 hr
Equatorial

GVD events

Site properties – 106 km КБЖД

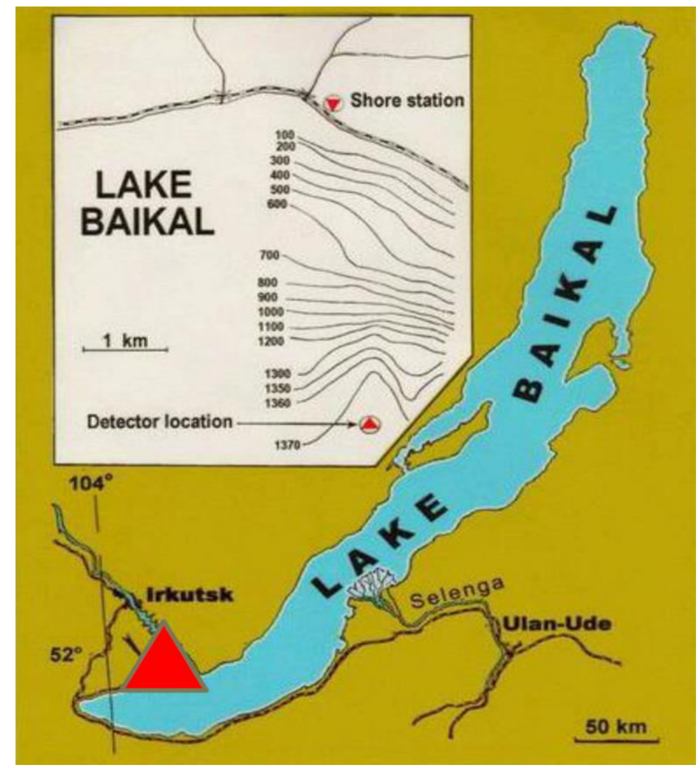
120 m



15 m–DAQ center

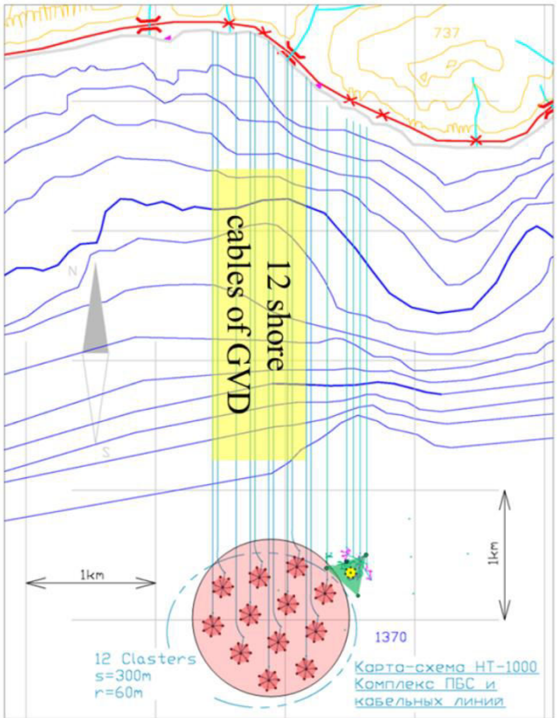
1 366 m – from surface to bottom

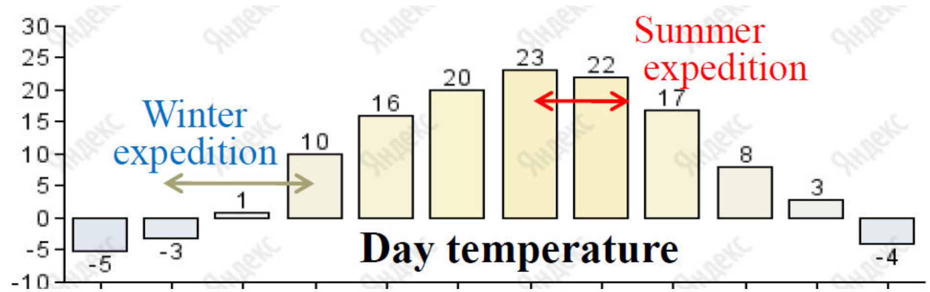
525 m - height

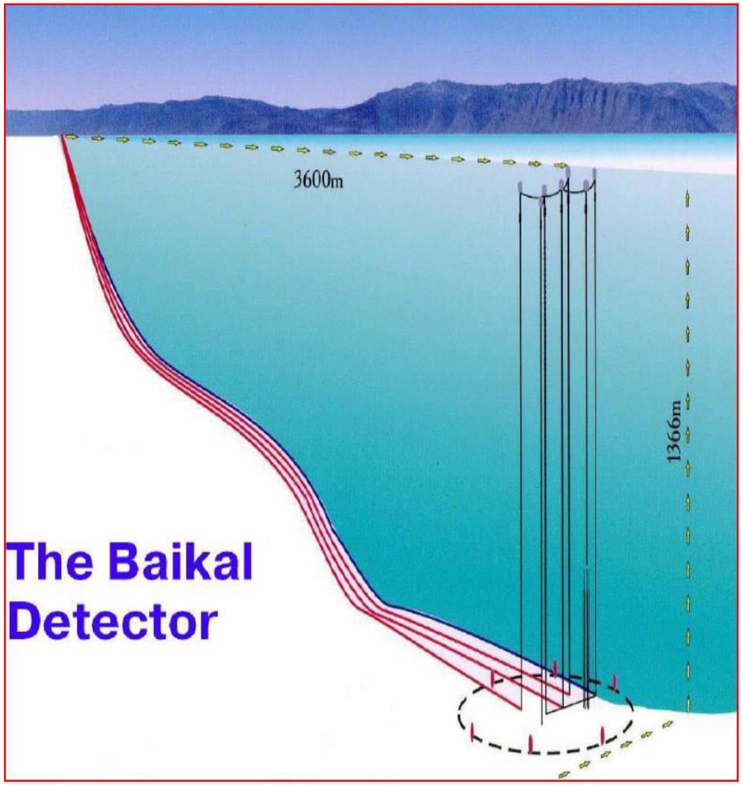


Location: 104°25’ E, 51°46’ N

Site properties – 106 km КБЖД







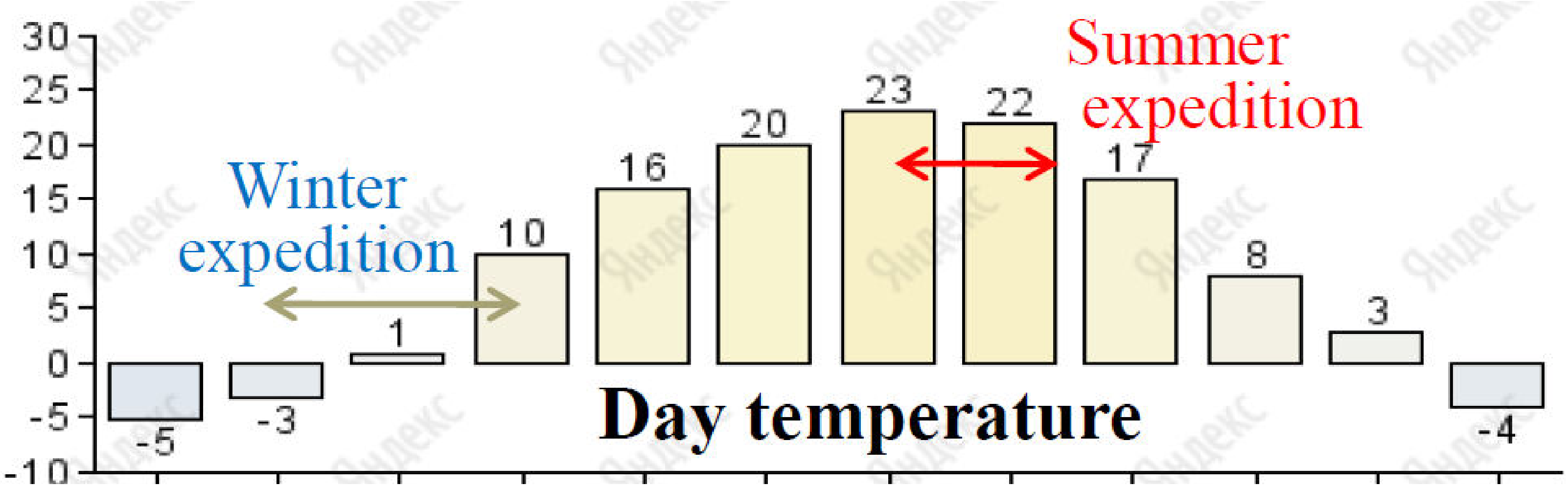
Depth – 1360 m; Flat the lake bed at >3 km from the shore – allows > 250 km3 Instrumented Water Volume!

Distance is shorter during the winter period

- Infrastructure

Upgrade: control center in a new cabin

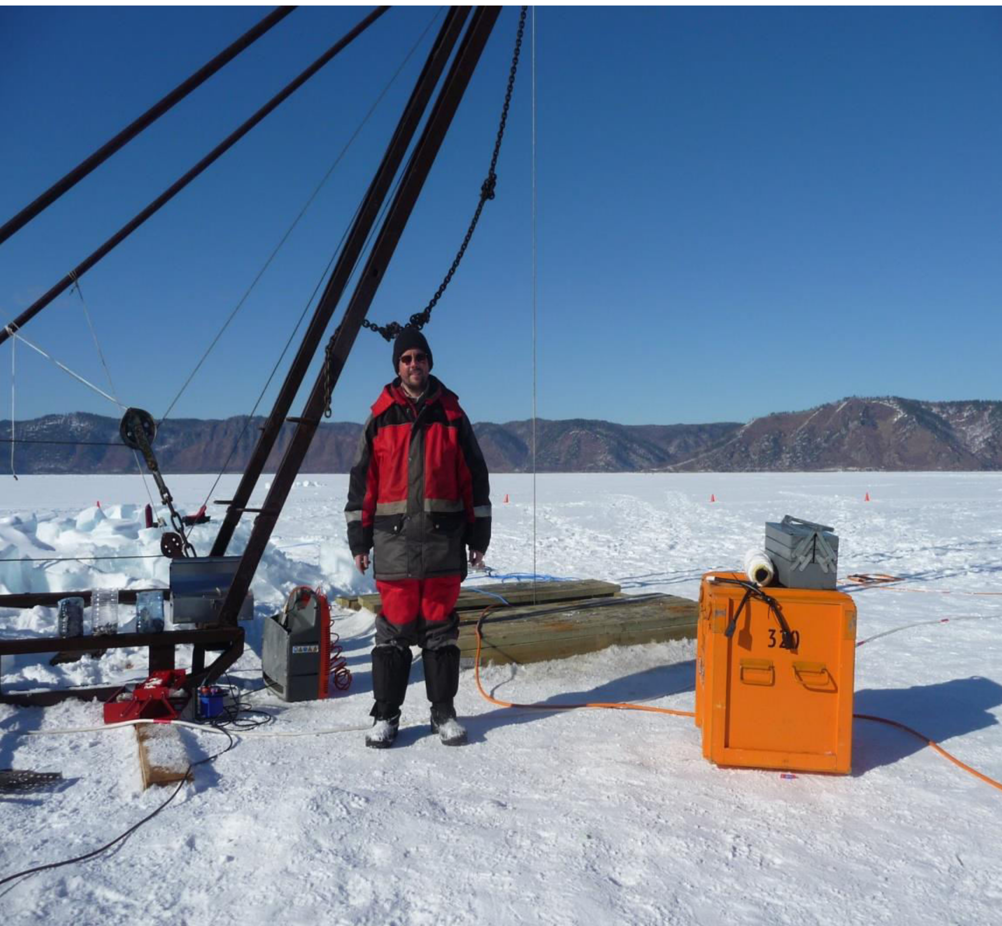
Winter expedition

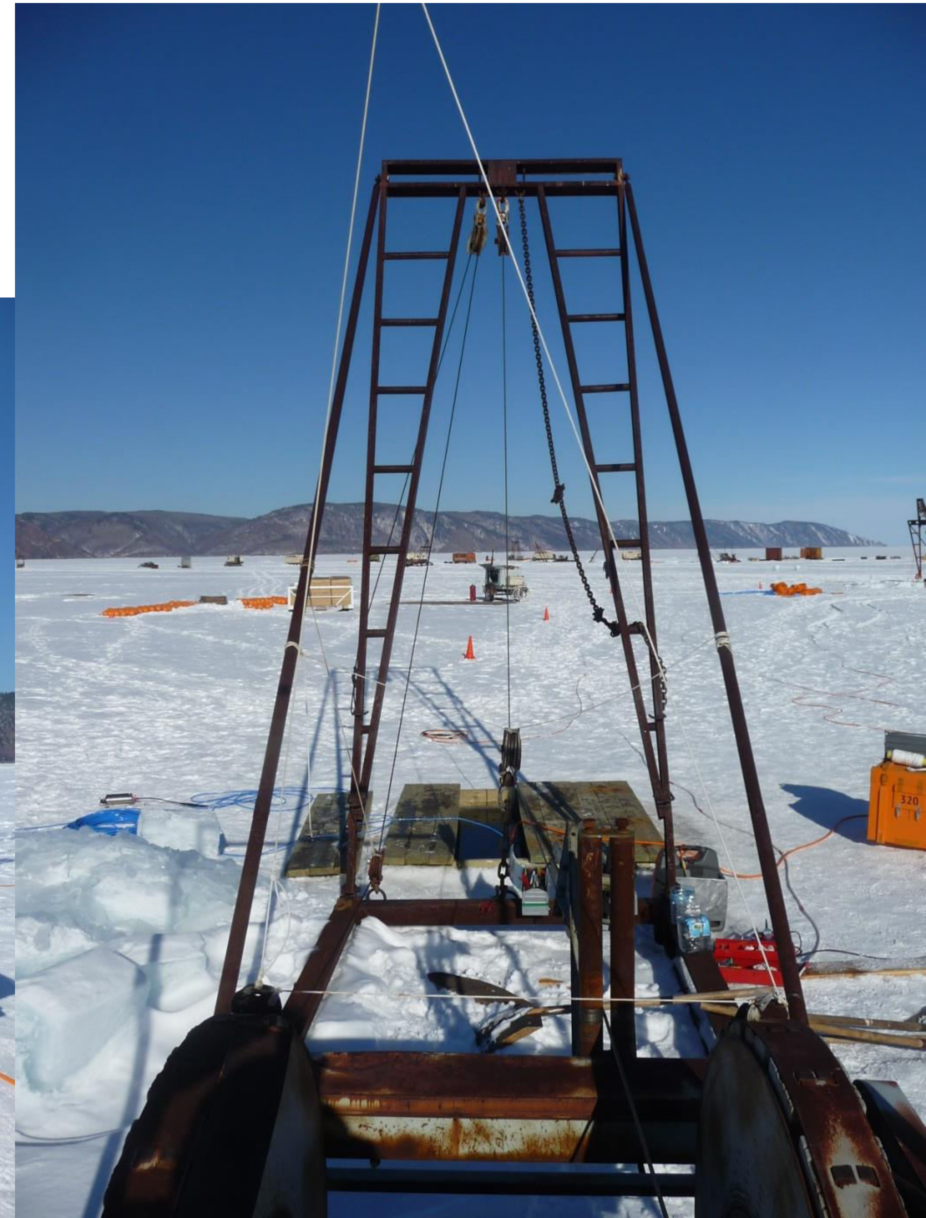


Making ice holes

Dismantling the string

String attachment





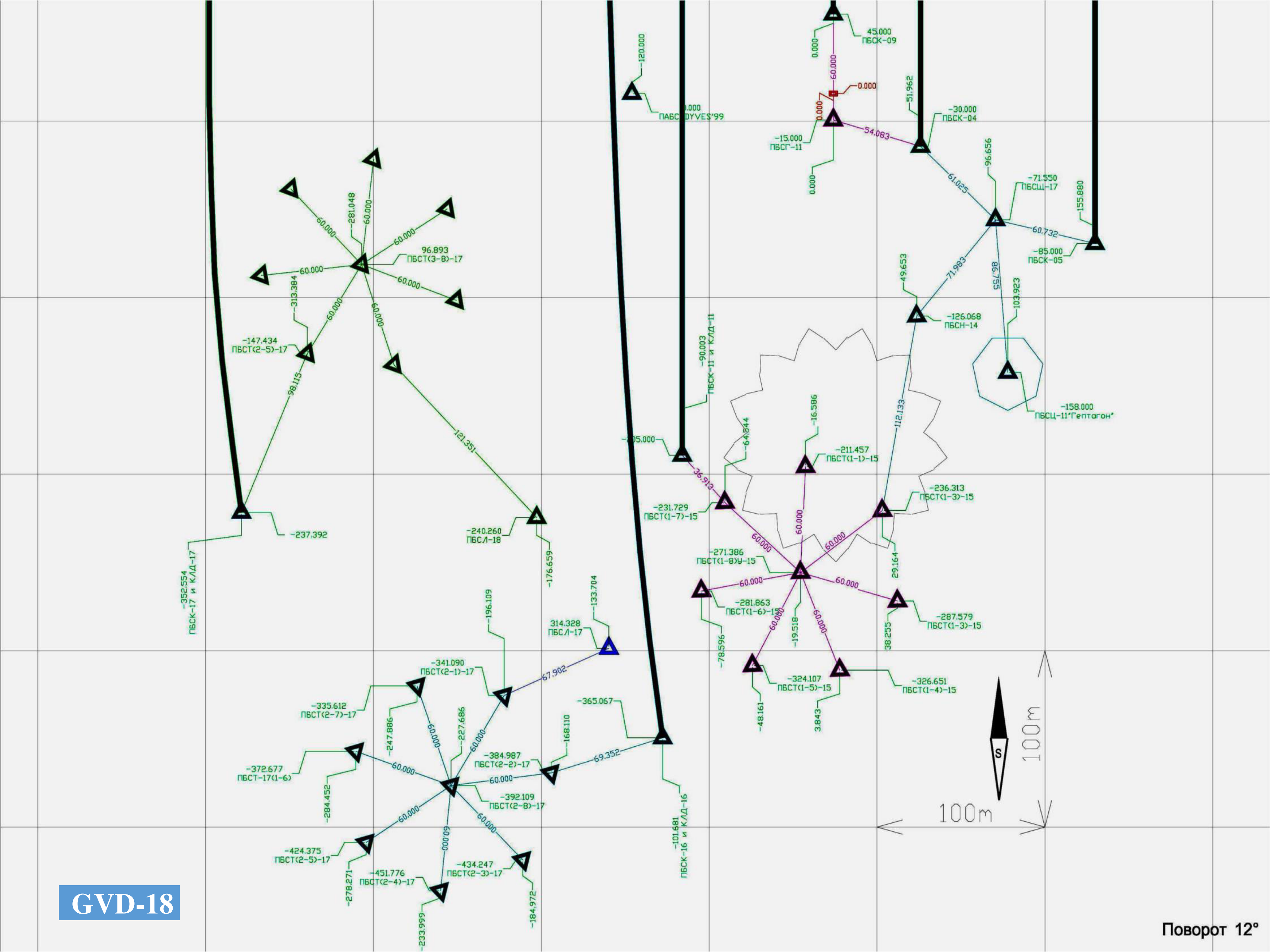
Deployment of the string

Tea break to warm up a little bit

Cables to the shore station

The end of the winter expedition

The end of the winter expedition


45.000
ПБСК-09
60.000
0.000
120.000
ПАБС DYVES'99
51.962
-30.000
ПБСК-04
-15.000
ПБСГ-11
54.083
61.025
96.656
-71.550
ПБСЩ-17
155.880
60.732
-85.000
ПБСК-05
49.653
71.983
86.755
103.923
-126.068
ПБСН-14
-158.000
ПБСЦ-11"Гептагон"
-90.003
ПБСК-11 и КЛД-11
112.133
-16.586
-211.457
ПБСТ(1-1)-15
-64.544
36.913
-231.729
ПБСТ(1-7)-15
-236.313
ПБСТ(1-3)-15
29.164
-271.386
ПБСТ(1-8)У-15
-281.863
ПБСТ(1-6)-15
-78.596
-19.518
-287.579
ПБСТ(1-3)-15
38.255
-324.107
ПБСТ(1-5)-15
-48.161
3.843
-326.651
ПБСТ(1-4)-15
96.893
ПБСТ(3-8)-17
281.048
313.384
-147.434
ПБСТ(2-5)-17
98.115
121.351
-237.392
-352.554
ПБСК-17 и КЛД-17
-240.260
ПБСЛ-18
-176.659
314.328
ПБСЛ-17
-133.704
67.902
196.109
-341.090
ПБСТ(2-1)-17
-335.612
ПБСТ(2-7)-17
-247.886
227.686
-365.067
-384.987
ПБСТ(2-2)-17
168.110
69.352
-372.677
ПБСТ-17(1-6)
-284.452
-392.109
ПБСТ(2-8)-17
-101.681
ПБСК-16 и КЛД-16
-424.375
ПБСТ(2-5)-17
-278.271
-451.776
ПБСТ(2-4)-17
-233.999
-434.247
ПБСТ(2-3)-17
-184.972
S
100m
100m
GVD-18
Поворот 12°

Old NT200:
volume ~ 0.0001 km³

Now clearly bypassed ANTARES

No. PMTs:

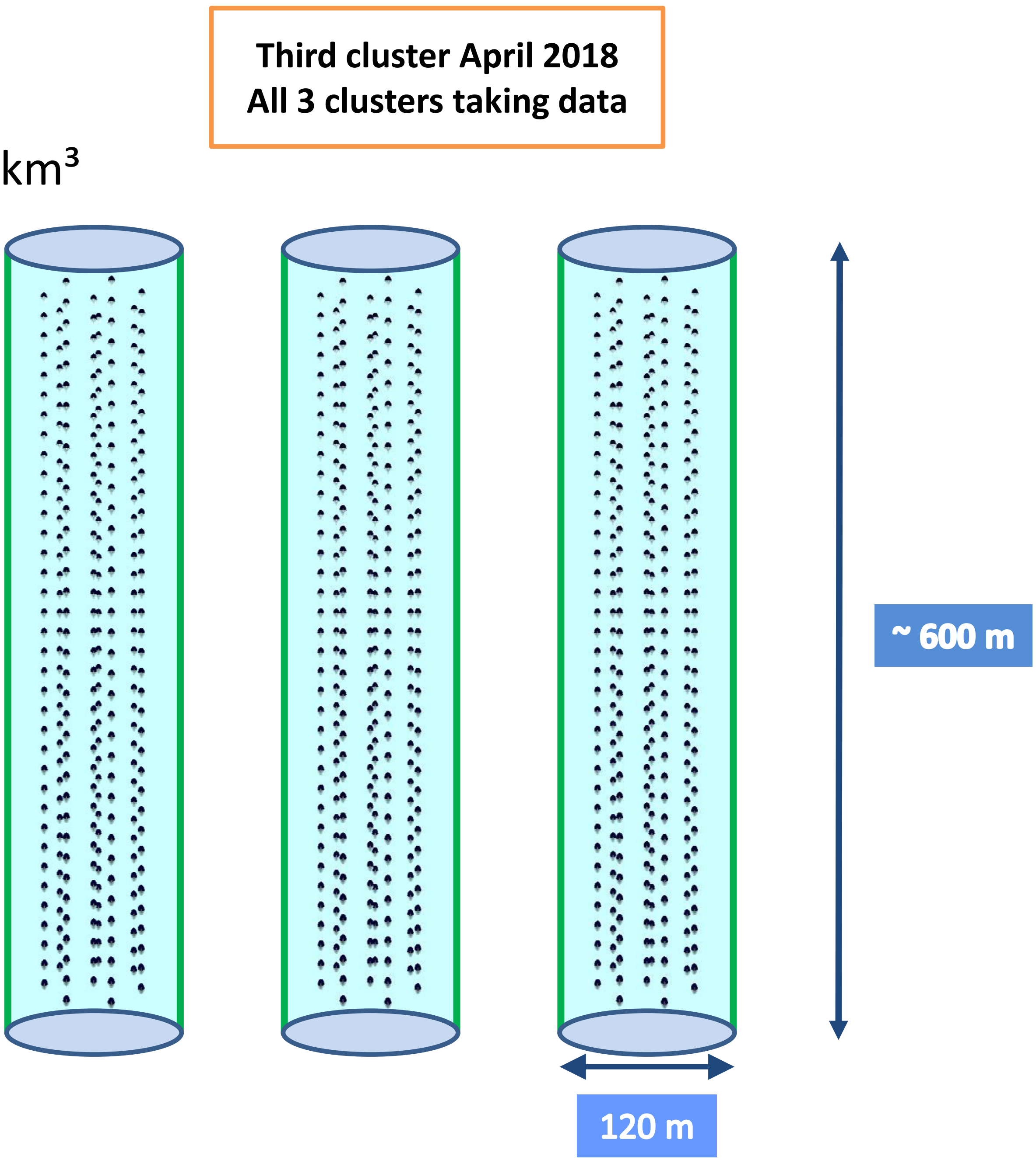
ANTARES: 885

GVD 2018: 864

No. space points:

ANTARES: 295

GVD 2018: 864



Stages of deployment of the Baikal-GVD

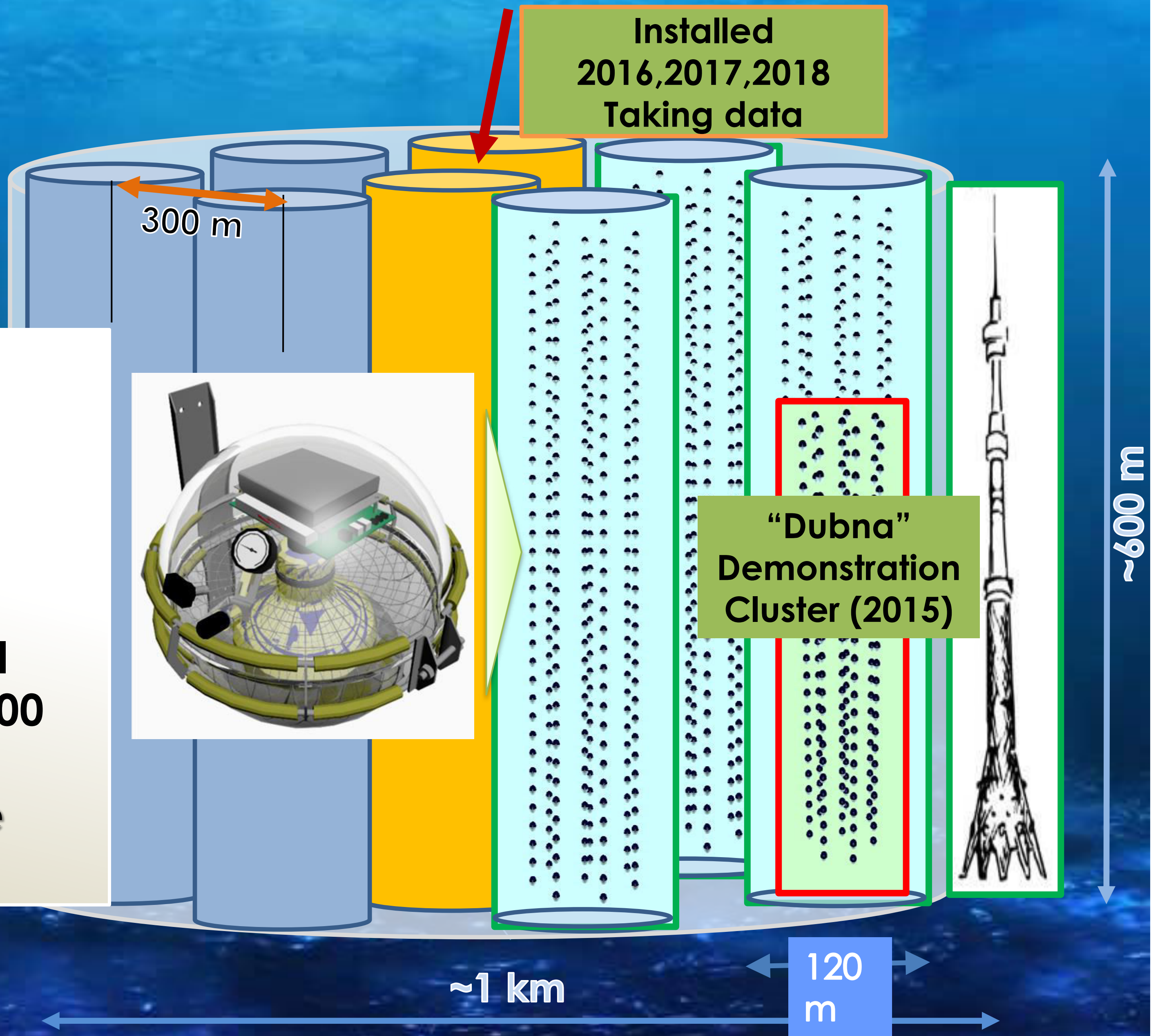
Configuration	2015	2016	2017	2018
The number of OMs	192 (8str×24)	288 (8str×36)	576	864
Geometric sizes	∅80m×345m	∅120m×525m	2×∅120m×525m	3×∅120m×525m
Eff. Vol. (E > 100TeV)	0.03 km^3	0.05 km^3	0.1 km^3	0.15 km^3

Timeline GVD 1

Cumulative number of clusters vs. year

Year	2016	2017	2018	2019	2020	2021
No. of clusters	***1***	***2***	***4***	***6***	***8***	***10***
No. of OM	***288***	***576***	***1152***	***1728***	***2304***	***2592***
Recent numbers →			**3**	**5**	**7**	**9**

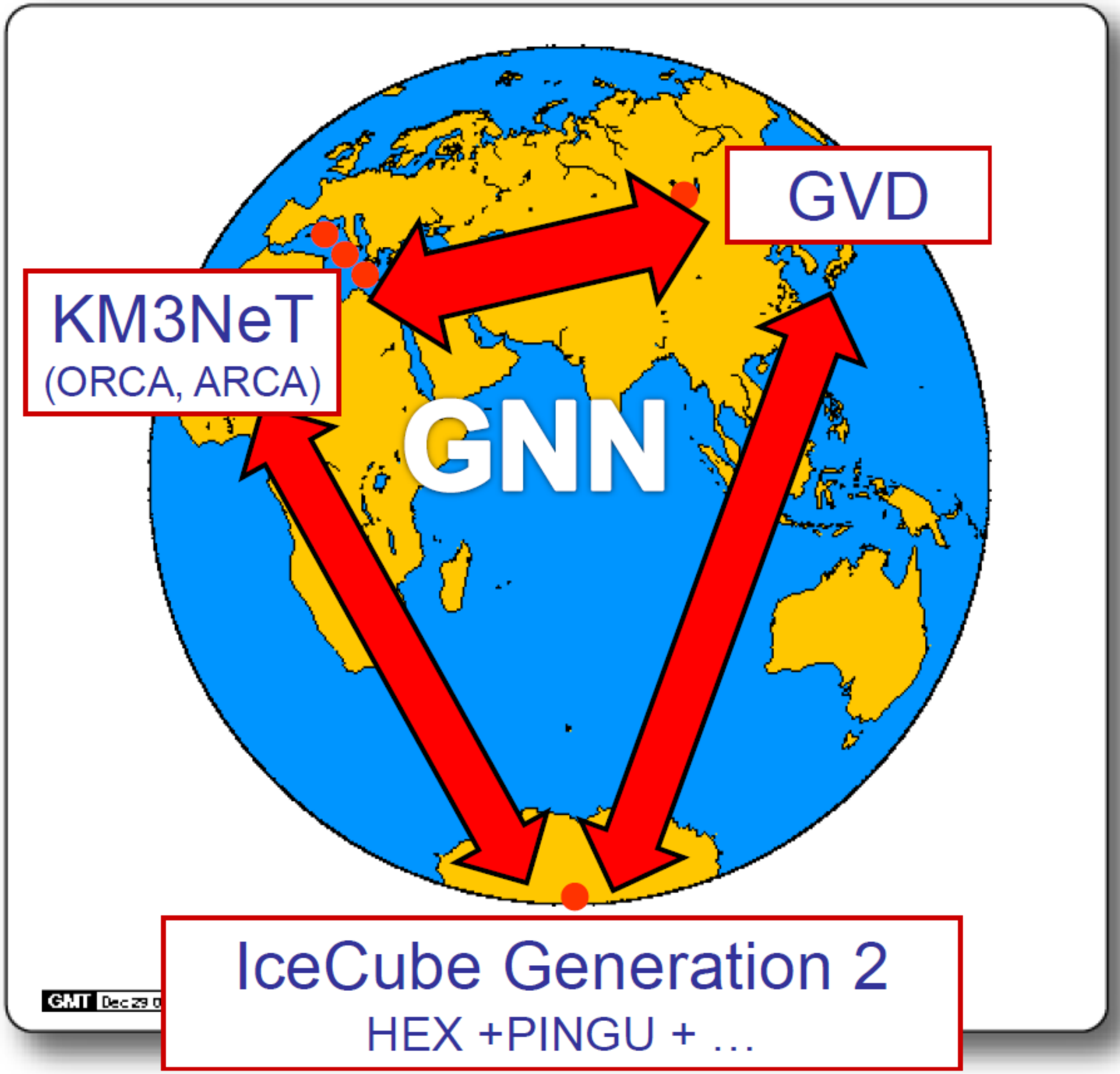
Deployment plan for expedition 2019



BAIKAL
GVD-1

2304 light sensors combined in 8 clusters of vertical strings at 750 – 1300 m depths.
Detection volume 0.4km^3

Baikal, Mediterranean Sea, South Pole



Thank You for your attention