Geo-neutrino Program at Baksan Neutrino Observatory

Yu.M. Malyshkin[1,4], A.N. Fazilakhmetov[1], A.M. Gangapshev[1,3], V.N. Gavrin[1], T.V. Ibragimova[1], M.M. Kochkarov[1], V.V. Kazalov[1], D.Yu. Kudrin[1], V.V. Kuzminov[1,3], B.K. Lubsandorzhiev[1], Yu.M. Malyshkin[1,4], G.Ya. Novikova[1], A.A. Shikhin[1], A.Yu. Sidorenkov[1], N.A. Ushakov[1], E.P. Veretenkin[1], D.M. Voronin[1],E.A. Yanovich[1]

[1]Institute for Nuclear Research of RAS, Moscow, Russia
[2]Institute of Astronomy of RAS, Moscow, Russia
[3]Kabardino-Balkarian State University, Nalchik, Russia
[4]National Institute of Nuclear Physics, Rome, Italy

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Introduction

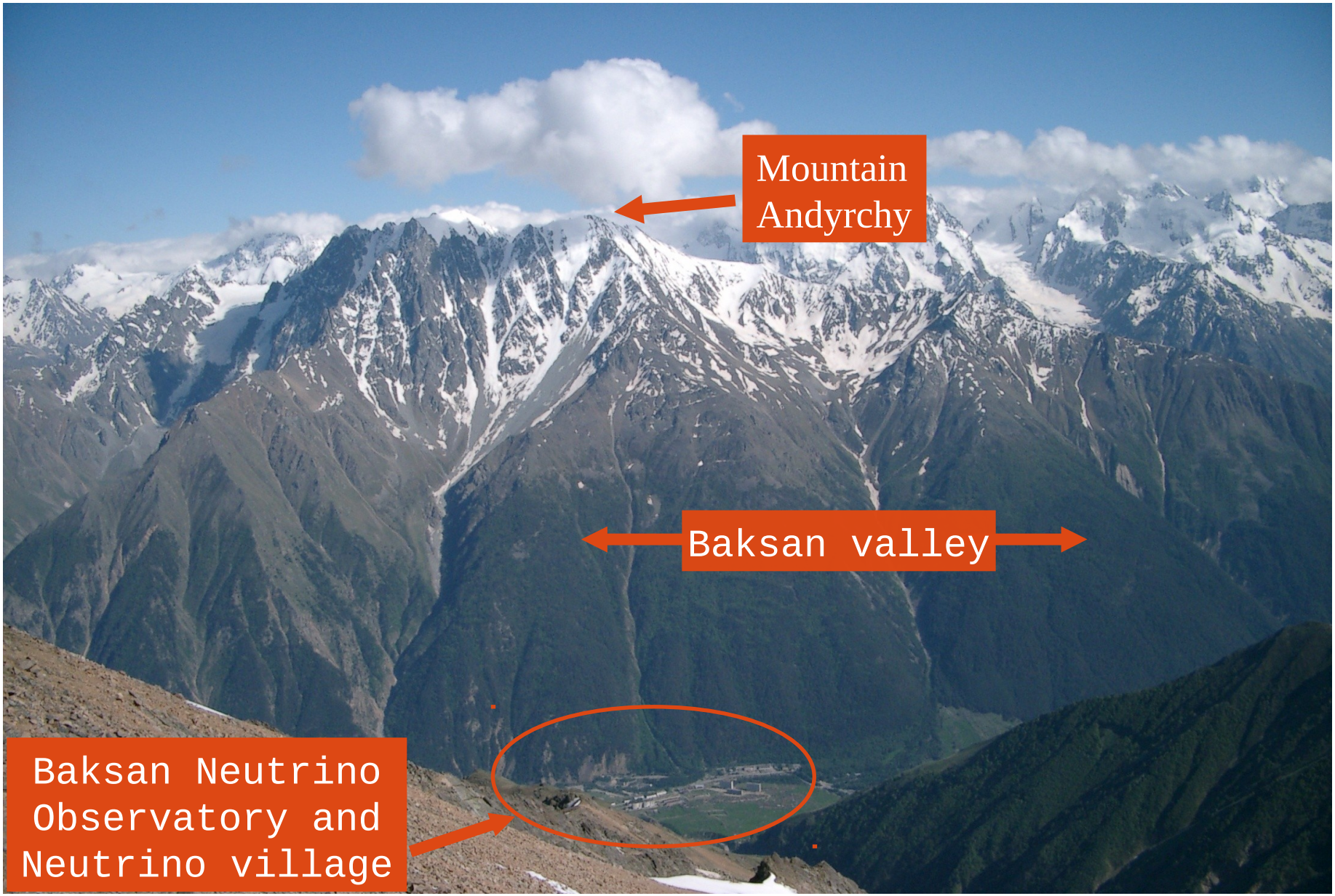
Construction of a large volume scintillator detector has been discussed for a long time. The works aimed to its preparation has been resumed recently.

We will discuss:

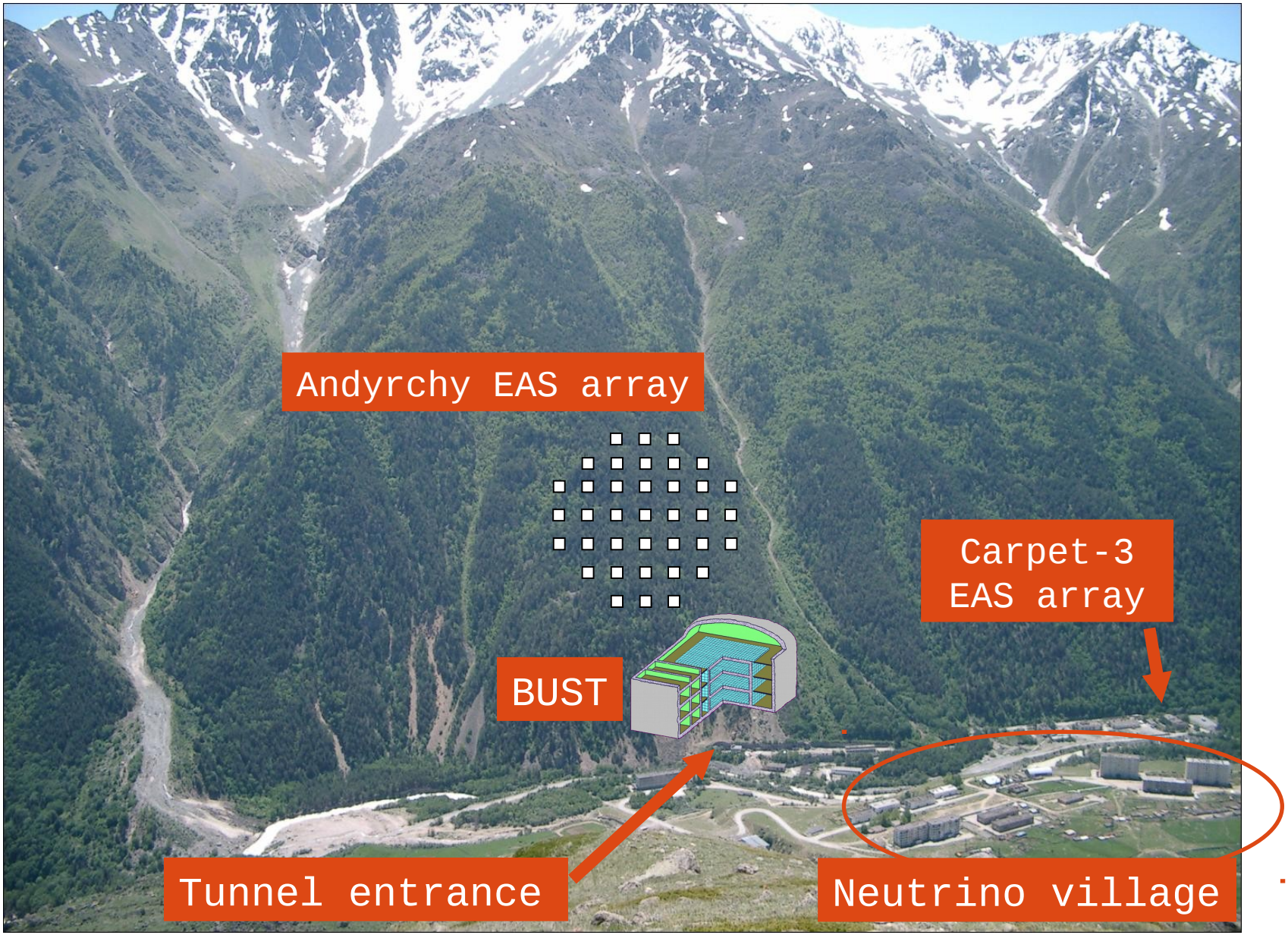
- Benefits of its location at Baksan Neutrino Observatory
- Its potential for geo-neutrino studies
- Current progress

BNO Location

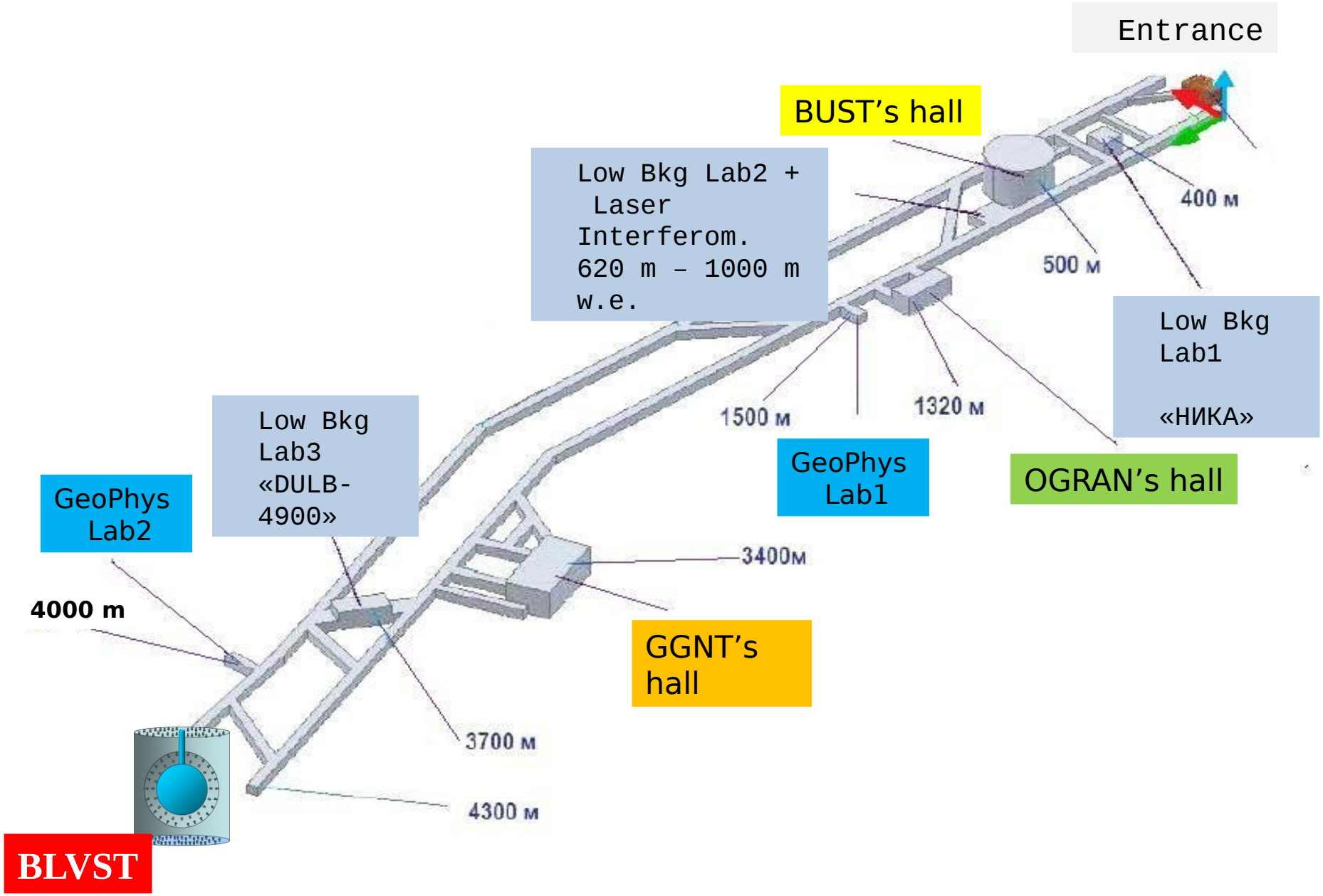
Baksan Valley



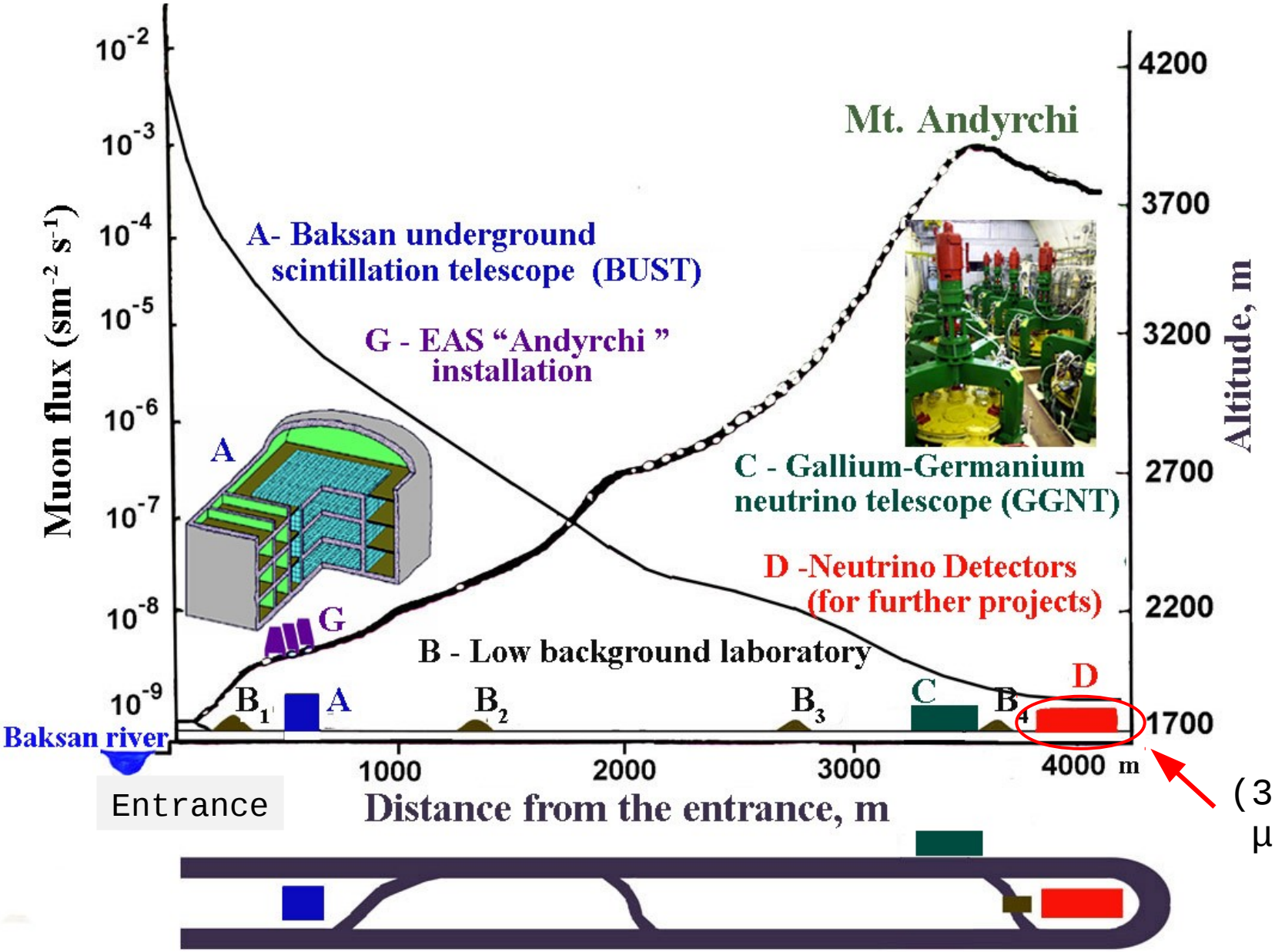
BNO Facilities and Neutrino village



Underground labs of BNO



Muon shielding



$(3.0\pm0.15)\cdot10^{-9}$ μ/cm²/s

Detector Layout

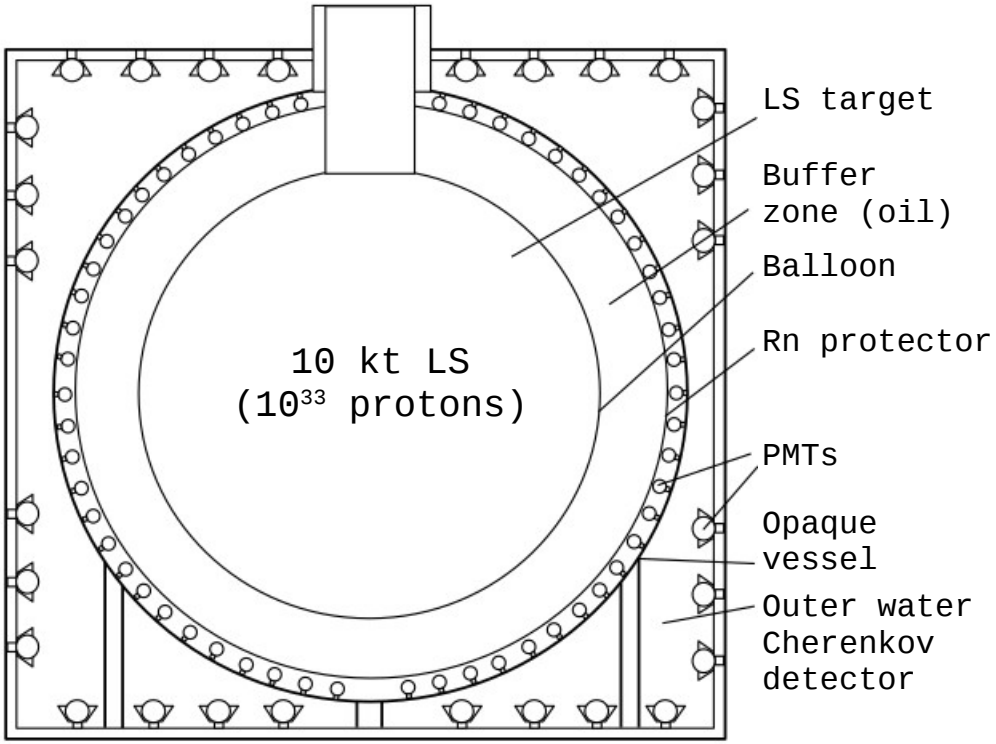
The future neutrino detector at Baksan will have a standard layout, similar to KamLAND and Borexino, but with larger mass and deeper underground.

Neutrino interaction channel:

$$\bar{\nu}_e + e^- \rightarrow e^+ + n$$

Signal signature:
prompt (e^+) +
delayed (n capture)

Deposited energy is converted to visible light and then detected by photo-sensors.



BLVST Scientific Program

Probing Earth's interior:
- Geo-neutrino flux
- Th/U ratio
- 40K abundance
- Georeactor

Probing solar interior:
- Solar neutrino
- Neutrinos from CNO cycle

Monitoring Nuclear Power Plants

Testing Supernova Explosion Models:
- Neutrinos right from SN explosions
- Relic SN flux

Signal / Background flux

	Total reactor neutrino *R* (TNU)	Reactor neutrino within geo-neutrino window R_G (TNU)	Geo-nuetrino *G* (TNU)	R_G/G	Ref.
Baksan	38.24	14.37	52.6	**0.3**	[1]
Gran Sasso	94.15	35.35	39.8	**0.9**	[1]
Sudbury	190.74	72.85	49.9	**1.4**	[1]
Pyhasalmi	72.97	27.61	52.9	**0.5**	[1]
Hawaii	3.44	1.29	15.3	**0.1**	[1]
Kamioka	27.79	10.30	31.7	**0.3**	[1]
Jinping	27.8	6.8	59.4	**0.1**	[2]

[1] I.R. Barabanov et al., Large-Volume Detector at the Baksan Neutrino Observatory for Studies of Natural Neutrino Fluxes for Purposes of Geo- and Astrophysics. Phys. of Atom. Nucl. 80 (30), 446–454 (2017)

[2] L. Wan et al., Geoneutrinos at Jinping: Flux prediction and oscillation analysis. Phys. Rev. D 95, 053001 (2017)

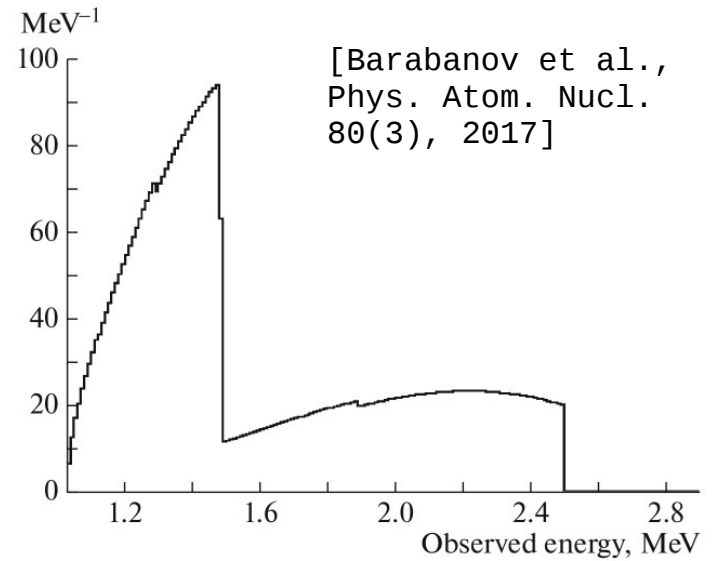
More on geo-neutrino studies

1a. Determination of ^{238}U + ^{232}Th flux at a mountainous location (larger contribution from the crust) – to complement world-wide measurements.

1b. Measurement of Th/U ratio. The precision is expected to be ~10%.

Channel: $\bar{\upsilon}_e + p \rightarrow e^+ + n$

Requirements: low reactor flux,
low radioactive background

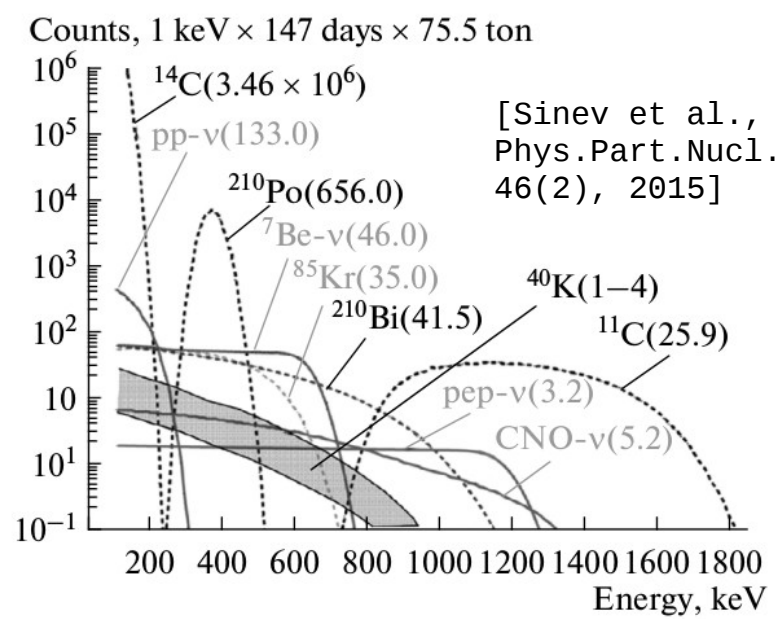


[Barabanov et al., Phys. Atom. Nucl. 80(3), 2017]

2. Detection of ^{40}K neutrinos – to determine its contribution to the radiogenic heat production. May vary depending on whether it is present in mantle or not.

Channel: $\bar{\upsilon}_e + e \rightarrow \bar{\upsilon}_e' + e'$

Requirements: low ^{14}C contamination



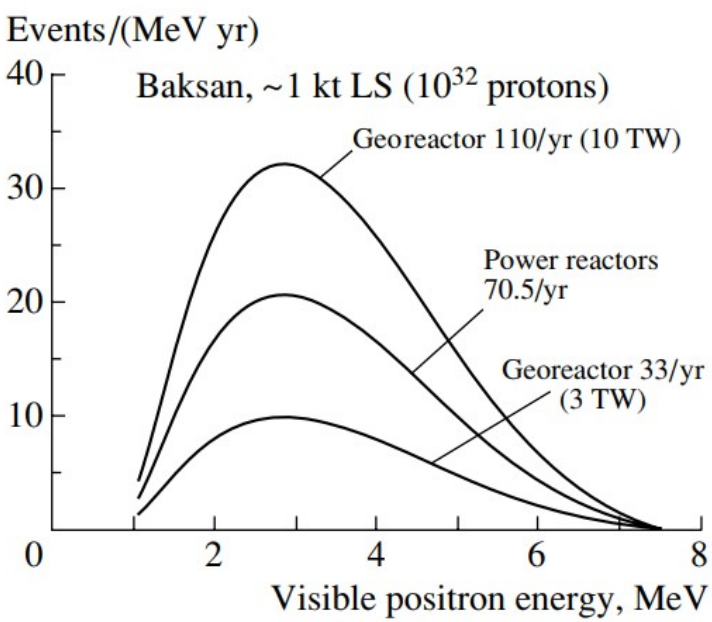
[Sinev et al., Phys.Part.Nucl. 46(2), 2015]

Georeactor

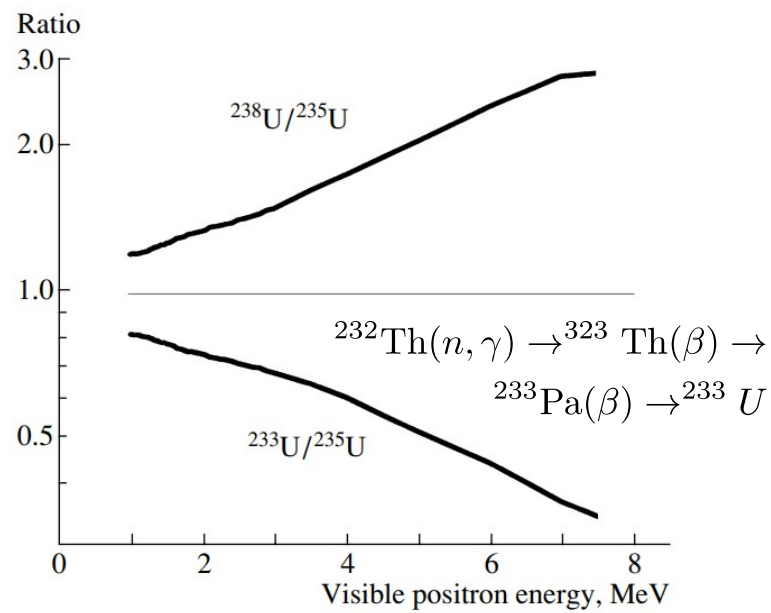
– hypothetical chain reaction taking place in the Earth's centre. It explains the (unknown) changing force sustaining the magnetic field of Earth.

EXPECTED RATES (events/year):
for 3-10 TW georeactor, no oscillations, 10 kton target, 100% efficiency

Georeactor: ~(300 – 1000)
Power reactors: ~700
Intrinsic background: ~10



Georeactor fuel composition can be determined by the spectrum shape.



[G.V. Domogatsky, Neutrino Geophysics at Baksan I: Possible Detection of Georeactor Antineutrinos. *Phys. Atom. Nucl. 68(1), pp.70-73, 2005*]

Liquid Scintillator

LAB (linear alkyl benzene) is the standard choice:

- low-cost
- high light yield (~10^4 photons/MeV)
- high transparency
- compatible with structure materials
- flash point ~140°C

Liquid Scintillator Studies

Samples from KINEF (Kirishi, Russia) are currently under examinations using chromato-mass-spectroscopy analysis:

Transparency

Attenuation length for wavelengths of 420, 430 and 440 nm.

	L_{440}, m	L_{430}, m	L_{420}, m
Crude LAB	25.6	18.1	14.0
Refined LAB	72.5	48.3	39.5
Refined LAB after 1 year	25.6	18.1	14.5

The decrease of light attenuation length is the result of interaction of hydrocarbons with oxygen and the formation of primary oxidation products
→ Possible solution: blowdown of the LAB storage tank with an inert gas or introduce antioxidants.

[N.I. Bakulina et al. Linear alkyl benzene (LAB): chemical composition, stability and oxidation by air oxygen in the presence of cobalt stearate. *Chemical Industry Today, 2018, #3, p.38 (in Russian)*]

Natural radioactivity

For LAB-based liquid organic scintillator containing 2 g/l of BPO scintillation addition:

^{232}Th : $6.2 \cdot 10^{-12}$ g/g

^{238}U : $1.8 \cdot 10^{-11}$ g/g

Low concentration of ^{14}C is also of great importance for lowering detection threshold:

(e.g. for measuring solar CNO neutrinos in the elastic electron scattering).

$^{14}C/^{12}C$: $(3.3 \pm 0.5) \cdot 10^{-17}$

[I.R. Barabanov et al. Measurement of the ^{14}C Content in Liquid Scintillators by Means of a Small-Volume Detector in the Low-Background Chamber of the Baksan Neutrino Observatory. *Phys. Atom. Nucl., 80, p.1146, 2017*]

TO BE IMPROVED

Prototyping first

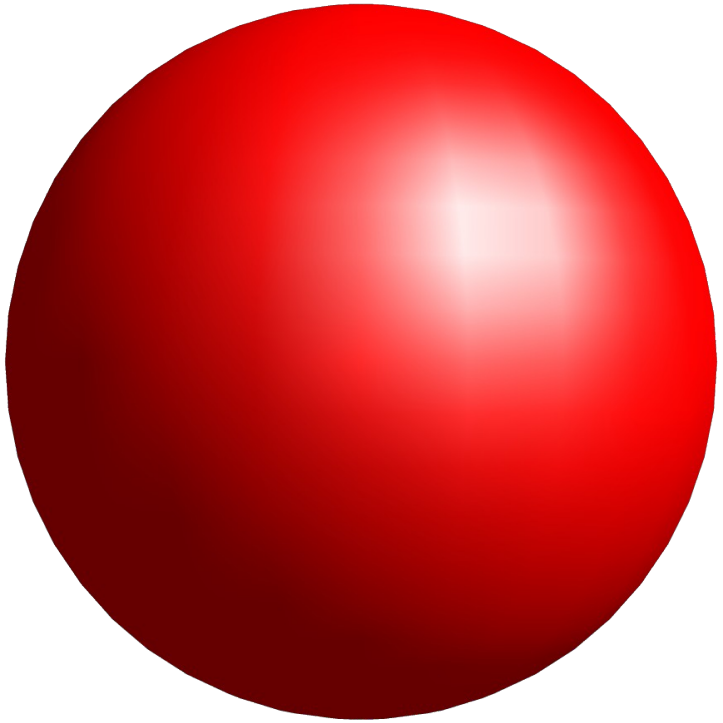
0.5 t

2019
(fully funded)

5 t

2020-…
(funding is under negotiation)

10 kt



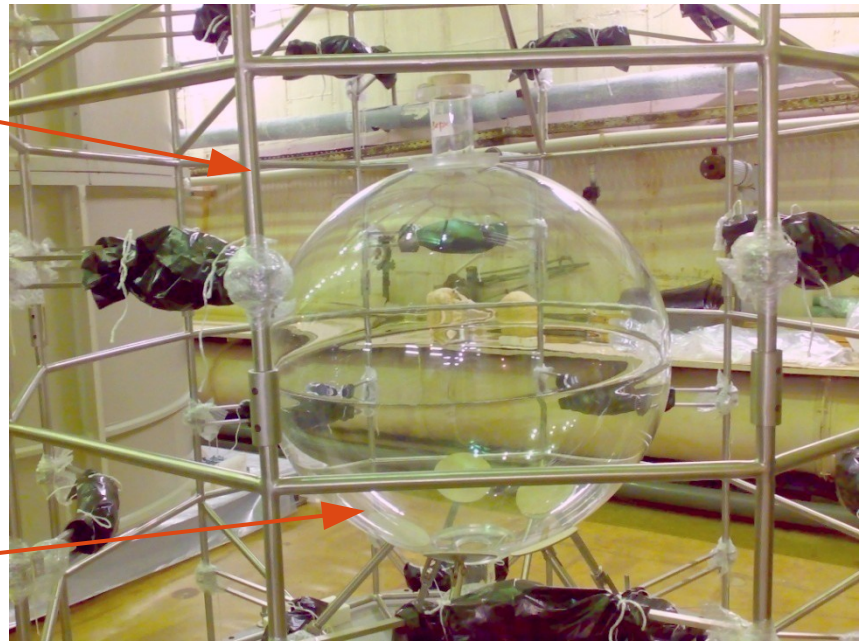
First prototype

0.5 ton of liquid scintillator (LAB)

20 PMTs (10-inch Hamamatsu R7081-100)

Supporting structure

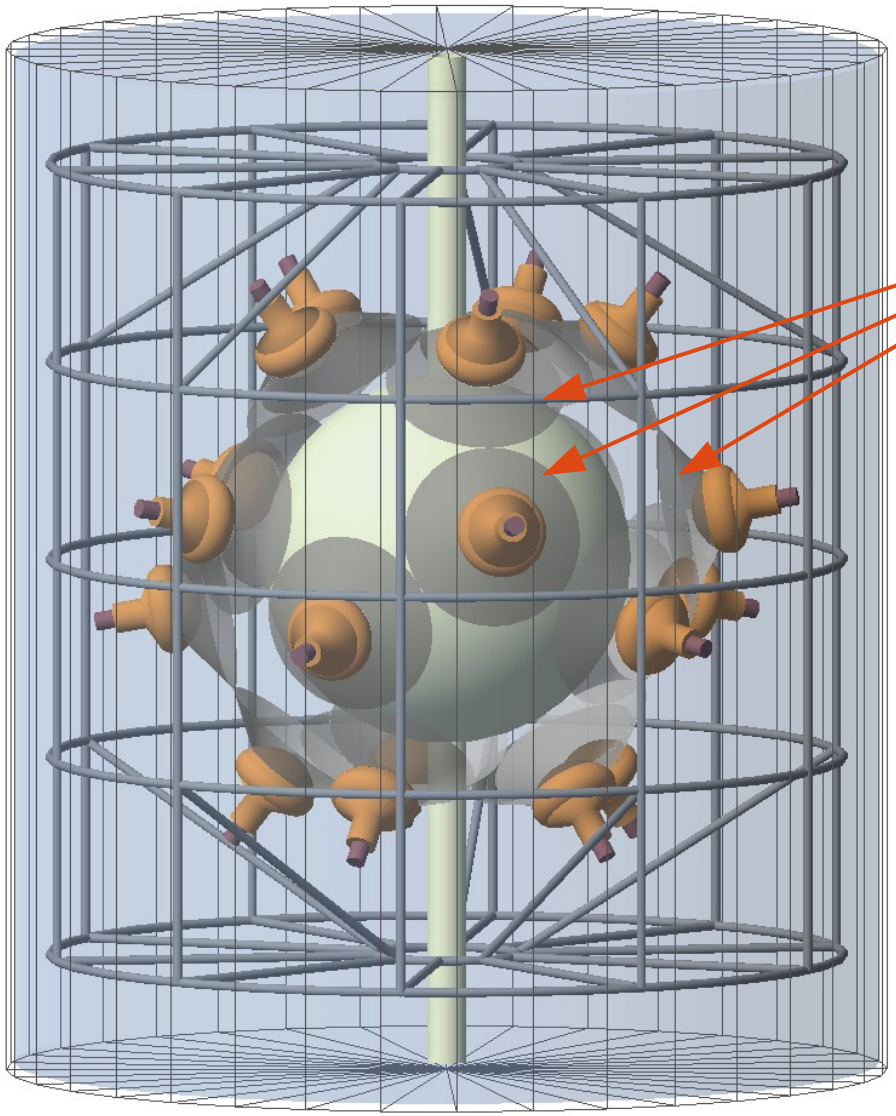
Acrylic vessel (R=50 cm) for liquid scintillator



Setup assembling

Outer vessel filled with water

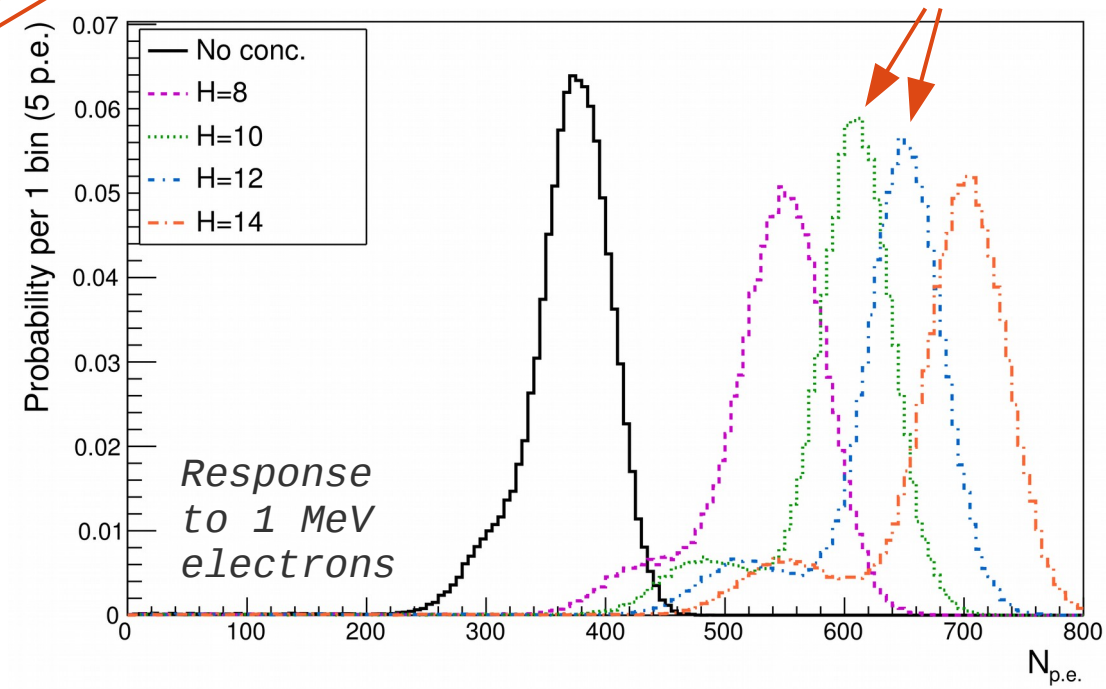
Modeling of First Prototype



The shape of light concentrators has been optimized via detector modeling with LSMC package.

Light concentrators

~optimal



[Yu. Malshkin et al., Modeling of a MeV-scale Particle Detector Based on Organic Liquid Scintillator, arXiv:1909.03229 (2019), subm. to NIM-A]

Summary

- Baksan is a good location for geo-neutrino studies:
  - Far from power reactors
  - Low muon flux
  - Well studied backgrounds
  - At mountainous region (thick crust) – complementary to other experiments
- The work has started:
  - Examination of liquid scintillator
  - Assembling of the first prototype

BACKUP SLIDES

Neutrino detection

Geo-neutrinos can be detected via inverse beta-decay (IBD) reaction:

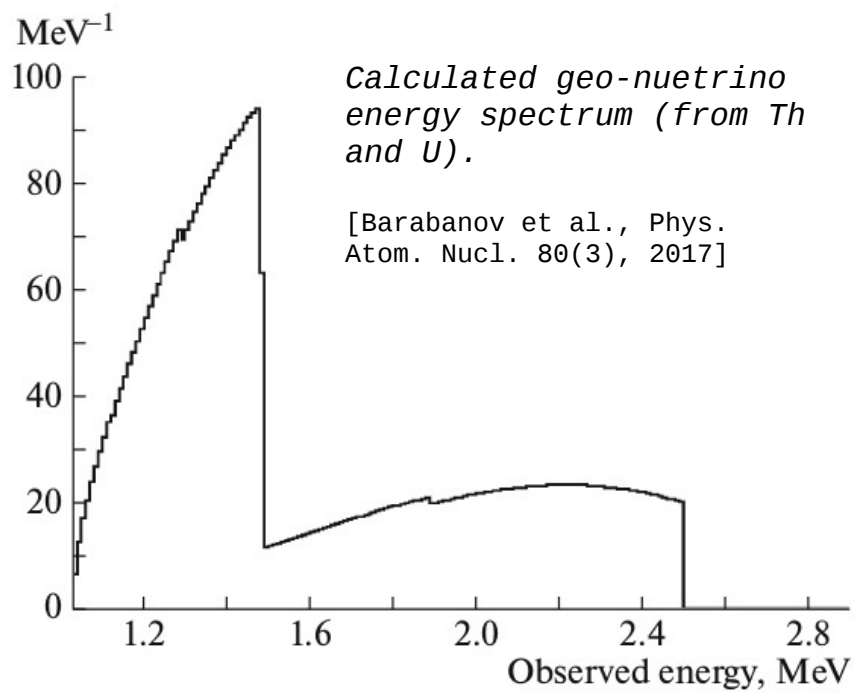
$$\bar{\nu}_e + e^- \rightarrow e^+ + n$$

prompt signal – brings the information about the neutrino energy: $E_\upsilon \approx E_{e+} + 1.3$ MeV

delayed signal – neutron capture provides a coincidence marker.

On H: 2.2 MeV after ~200 μsec.

On Gd: 8.1 MeV after 30-50 μsec.



Calculated geo-nuetrino energy spectrum (from Th and U).

[Barabanov et al., Phys. Atom. Nucl. 80(3), 2017]

IBD cross section is given by:

$$\sigma_{\mathrm{IBD}} = 9.55 \cdot 10^{-44} pE(1+\delta)$$

where p and E are the positron momentum and energy, and δ is a correction for nuclear recoil and weak magnetism.