Baksan Neutrino Observatory as a complex of underground laboratories. Deep underground low background laboratory for SAGE experiment

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Brief history of BNO INR RAS

1958 — Academician Moisey Markov proposed to study the weak interaction in underground experiments using neutrino from cosmic rays.

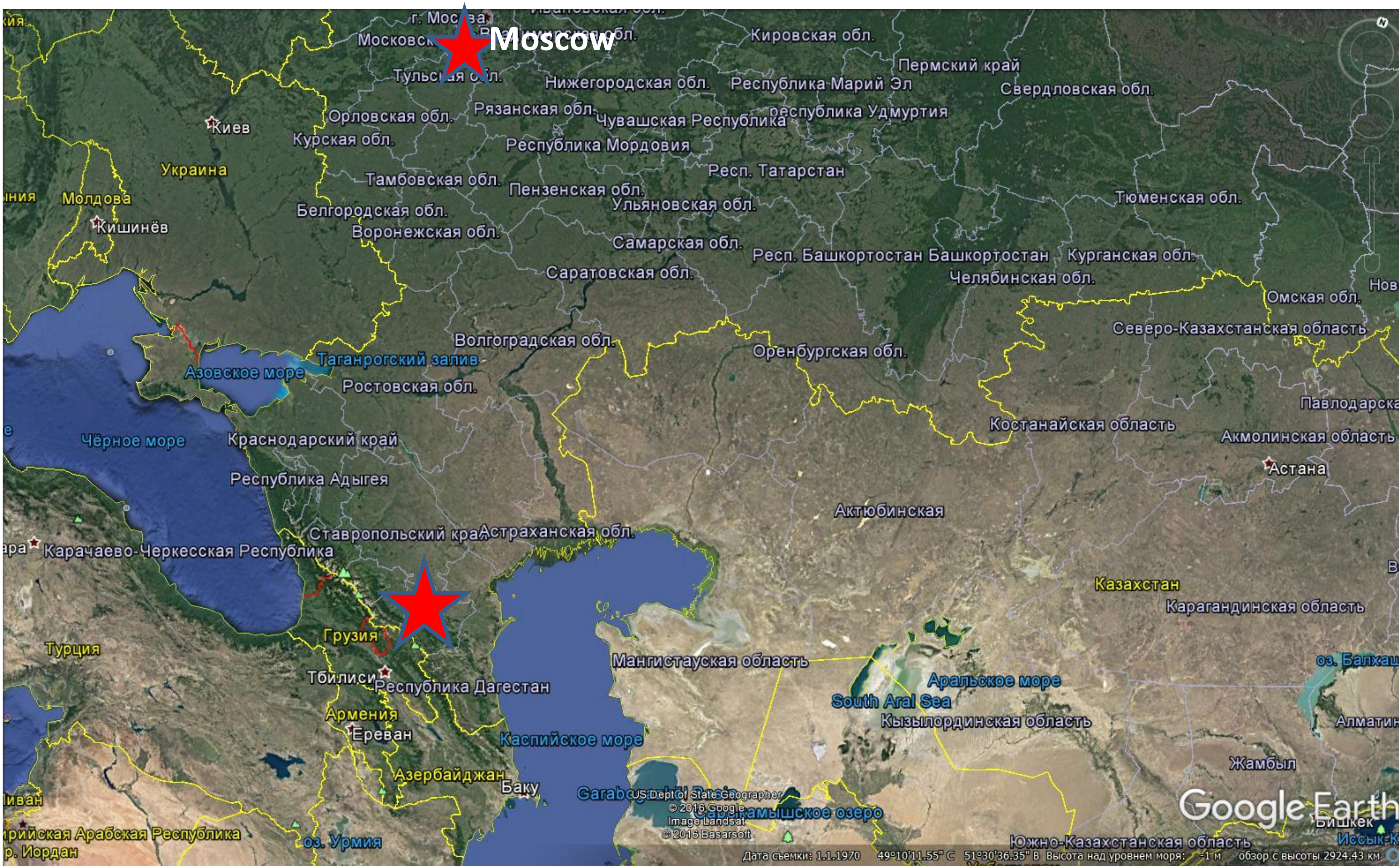
The suggested technique was based on the registration of muons generated in the interactions of neutrinos with nucleons of the matter in the depths of the Earth.

1962 — a group of Soviet physicists (M.A. Markov, G. T. Zatsepin, I.M. Zheleznikh, and V.A. Kuz'min) published a number of articles regarding realization of Markov's idea: in particular, investigation of the neutrino-nucleon cross-section as a function of neutrino energy, a mass of intermediate boson etc.

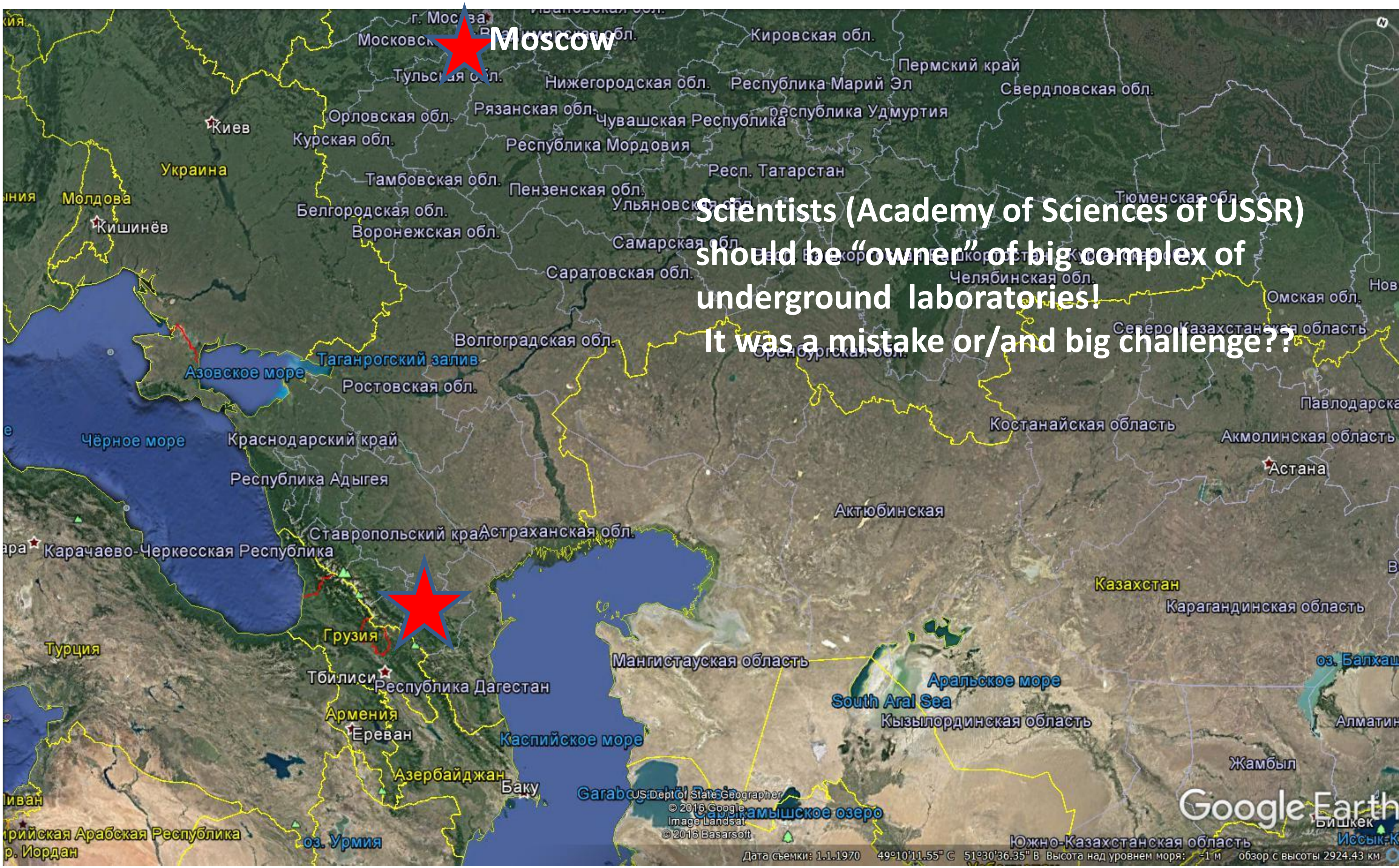
1963 — G.T. Zatsepin proposed new scheme of a facility (neutrino telescope). To avoid influence of different components of the cosmic rays (as the main background for registration of neutrinos), a facility should be placed deep underground. Another direction of underground research was to develop methods for detecting and measuring the flux of neutrinos coming from the Sun.

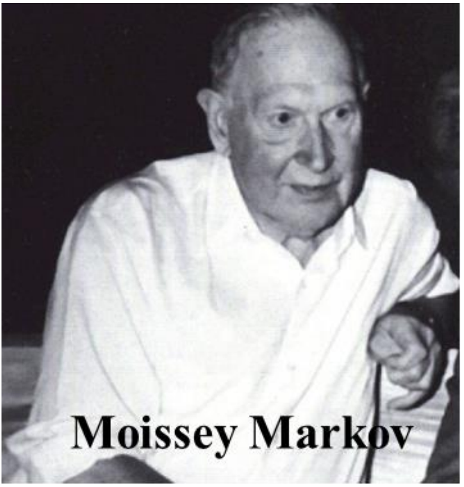
The site of the Baksan Neutrino Observatory of Institute of Nuclear Research RAS (BNO INR RAS) was chosen because of the steep slopes of Mount Andyrchi and its relatively high elevation above the base (2300 m). These favorable characteristics of the mountain make it possible to set up deep-laid chambers (cavities) with a relatively short (~ 4000 m) horizontal adit (tunnel). The minimal thickness of rock above these cavities is ~ 2000 m.

Baksan Neutrino Observatory INR RAS

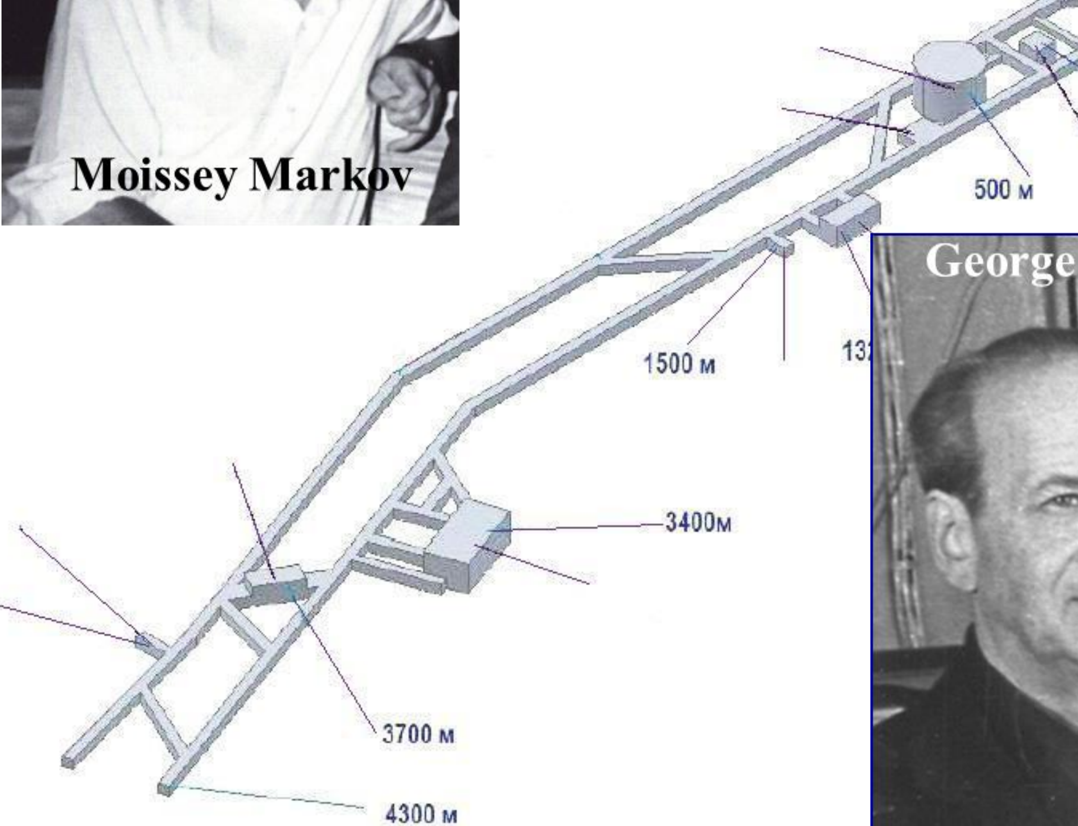


Baksan Neutrino Observatory INR RAS

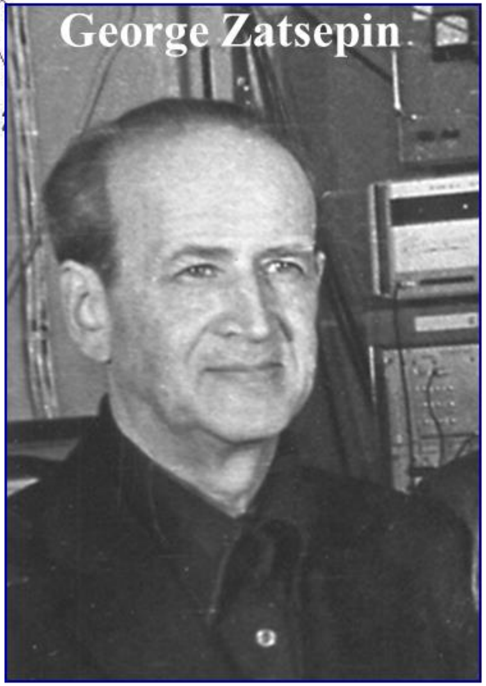




1966. Under the action of M. Markov, Head of the Physics Division, the Academy of Sciences of the USSR obtains a Decree of the Soviet Government for the construction of the underground and surface facilities (Neutrino village)



Scientific activity started under the leadership of

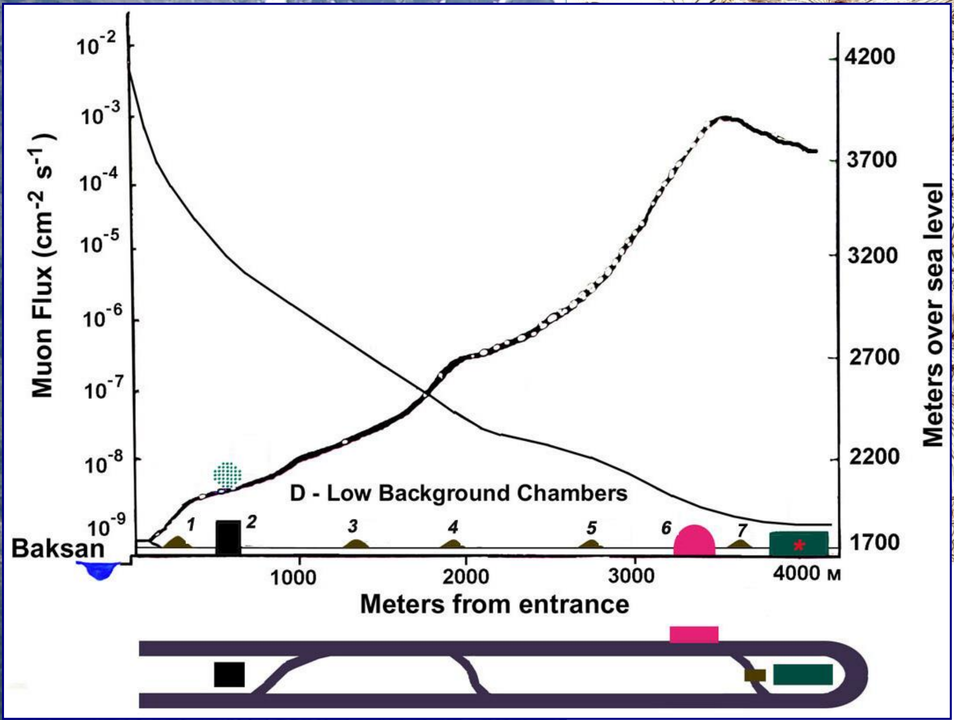


and

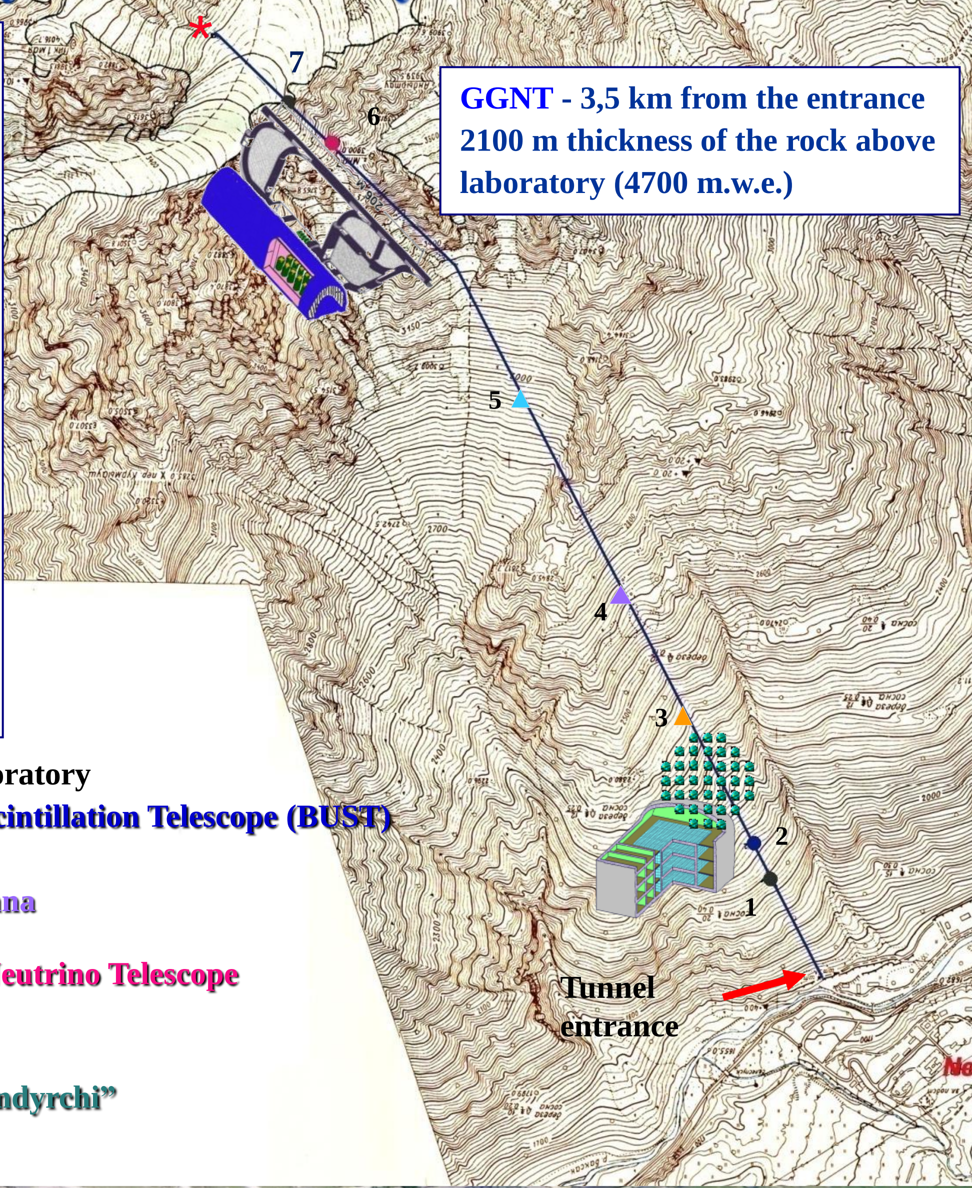
Laboratories at BNO INR RAS (as 2016)

Gallium-Germanium Neutrino Telescope (GGNT)	**Low Background Laboratory**	**Baksan Underground Scintillation Telescope (BUST)**
Measurement of the Solar Neutrino Flux (> 233 keV)	- *The study of rare Processes (Double β-decay, 2K-capture, Search for Dark Matter)* - *HPGe measurements*	*Study of Cosmic Rays*

Baksan Valley and Mt. Andyrchi



GGNT - 3,5 km from the entrance
2100 m thickness of the rock above laboratory (4700 m.w.e.)



1, 7 – Low Background laboratory

2 - Baksan Underground Scintillation Telescope (BUST)

3 - Laser interferometer

4 - Gravitation wave antenna

5 - Geophysics laboratory

6 - Gallium-Germanium Neutrino Telescope (SAGE)

* - For future experiments

- Air shower facility "Andyrchi"

Baksan Valley and Mt. Andyrchi

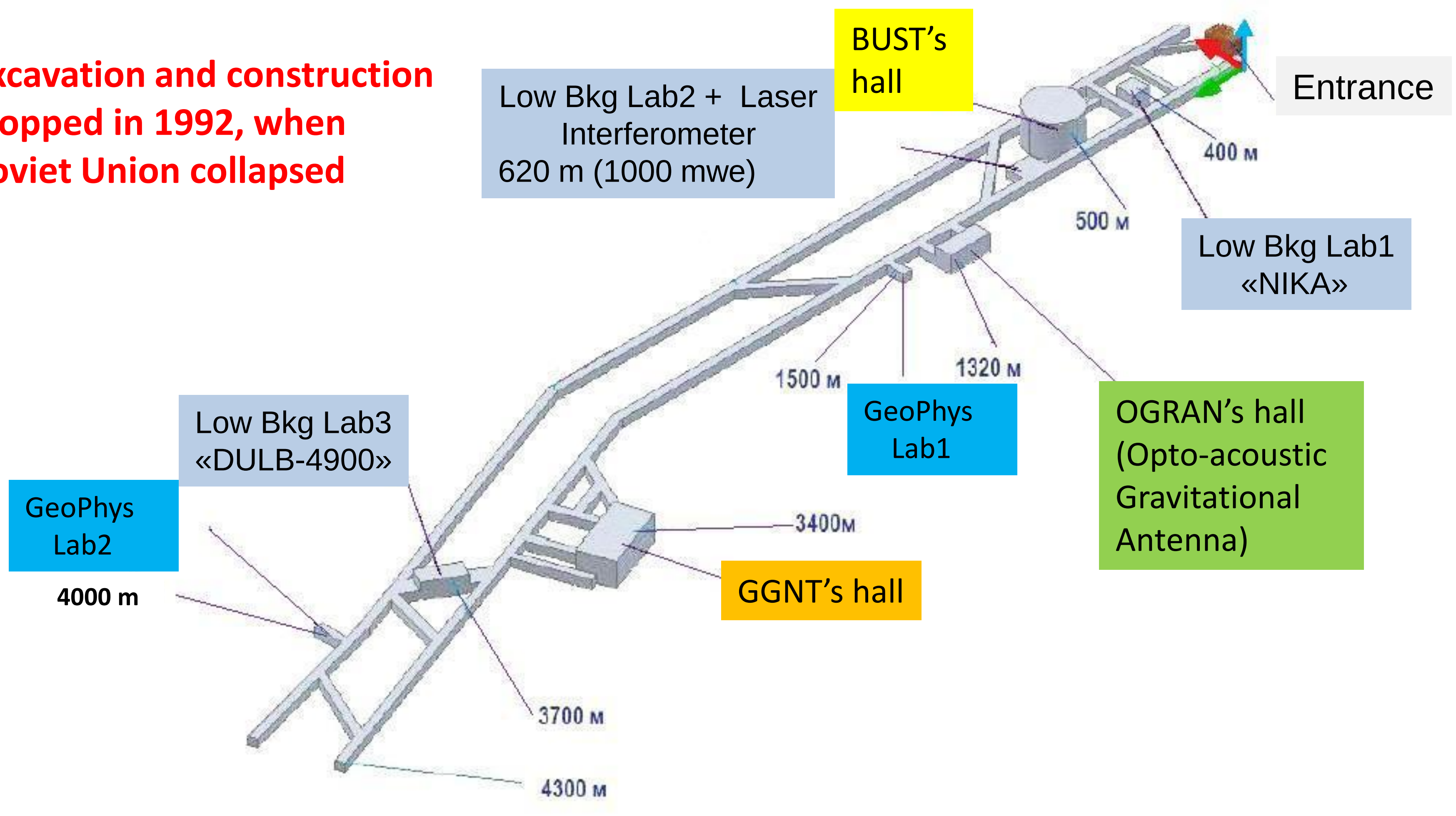
Above-ground facilities

Underground Laboratories of the BNO INR RAS

Total volume ≈ 40 000 m^3

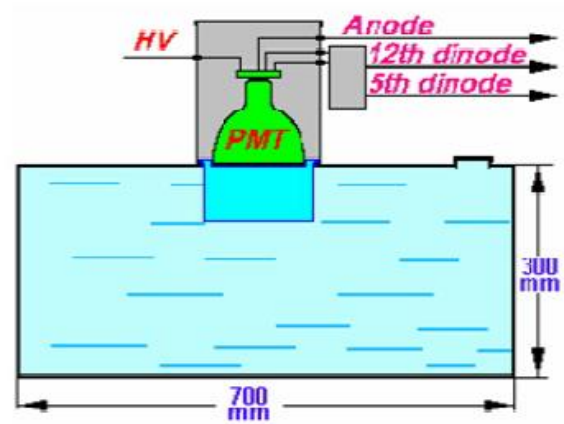
Largest hall, 15 000 m^3,

Excavation and construction stopped in 1992, when Soviet Union collapsed

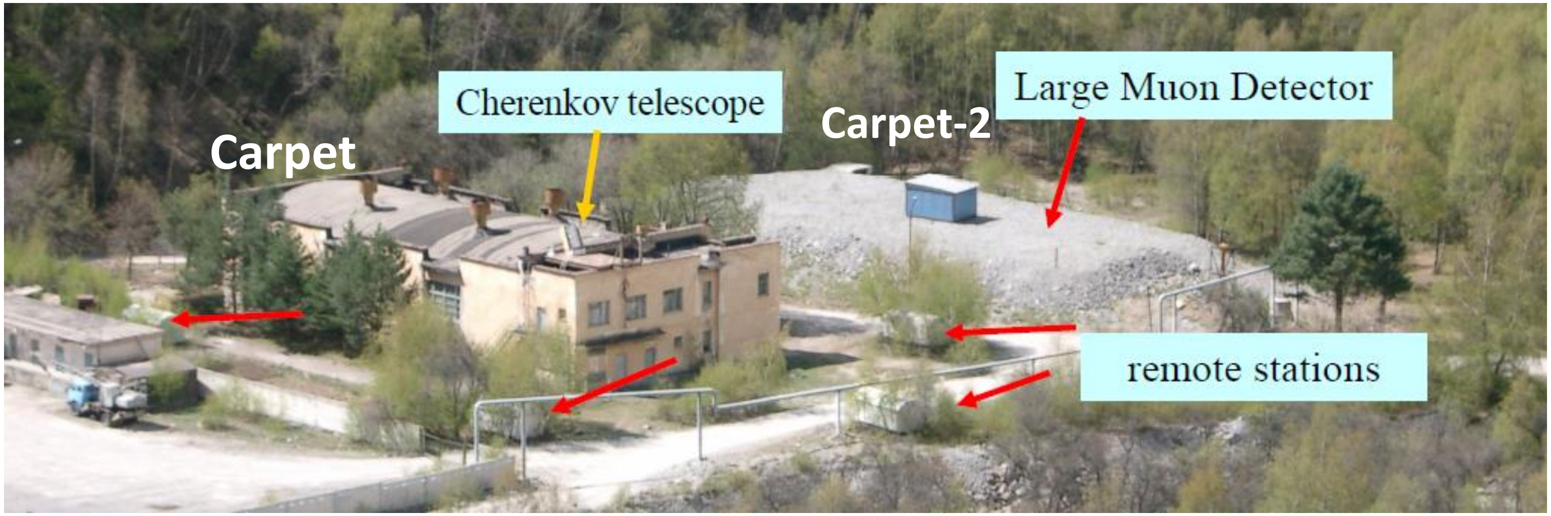


The ground-based detection facility “CARPET” (since 1973)

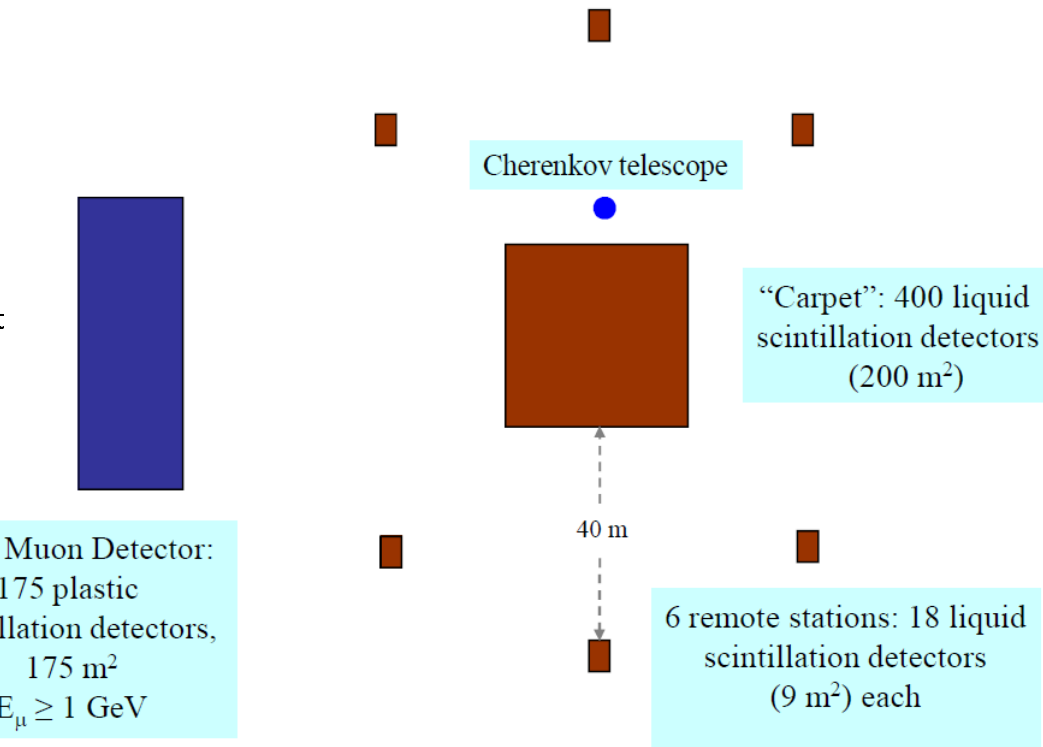
400 standard scintillation detectors a rectangular aluminum tank (70 cm × 70 cm × 30 cm) filled with a liquid scintillator on the base of ***white spirit*** (a high-purity kerosene fraction of petroleum). A 200 m^2 is an replica of the one of the eight layers of the Baksan Underground Scintillation Telescope that came into operation later. The Carpet facility was targeted to study primary cosmic rays of $5.7 \cdot 10^9$–10^{16} eV, mechanisms and characteristics of their interaction with particles of the atmosphere by registering a single secondary component together with EAS generated in such interactions.



CARPET-2 EAS Array (since 1998)



Under a 2 m ground layer
(5 mwe), which absorbs
the soft cosmic rays component

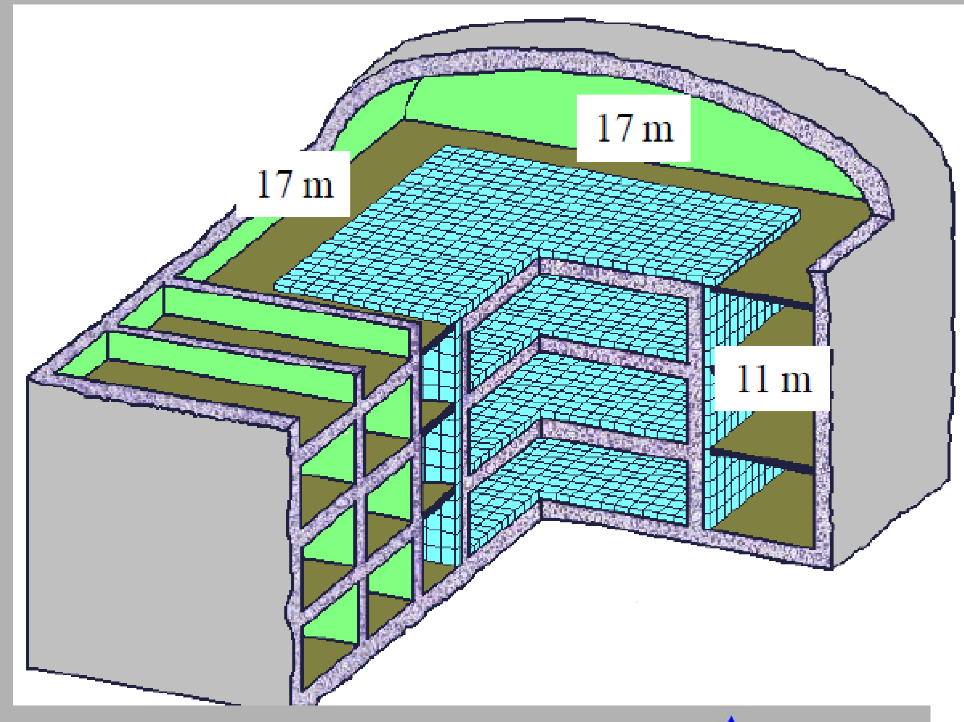


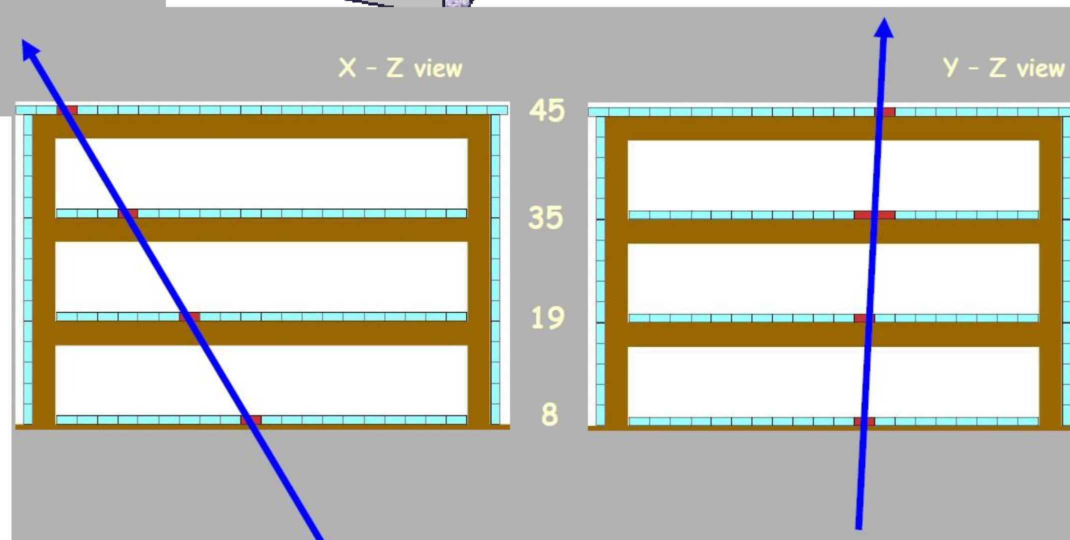
Baksan Underground Scintillation Telescope (BUST, since 1977)

- Depth: 850hg/cm^2
- Size: 17m×17m×11m
- Number of tanks: 3185
- Tank size:

70cm×70cm×30cm

- Angular resolution: 2^0
- Time resolution: 5 ns
- Trigger: 10Mev in any plane
- Rate: 17 Hz
- upward/downward: 10^{-7}





First upward-going muon observed 13/12/1978

The Baksan Underground Scintillation Telescope (BUST)
Horizontal wall (plane)

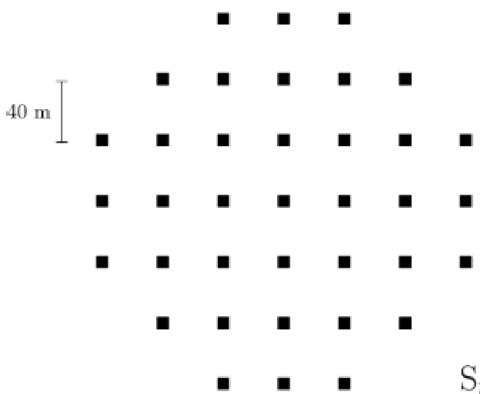
The Baksan Underground Scintillation Telescope: a vertical wall (plane)

Study of Cosmic Rays

- *The origin of cosmic rays.*
  1. *Galactic cosmic rays:*($10^{13} – 10^{17}$) *eV – spectrum, cosmic ray composition, anisotropy.*
  2. *The problem of the break in the spectrum of the EAS.*
- *Interaction of cosmic rays. Search for new particles.*
- *The study of variations in the intensity of cosmic rays.*
- *Neutrino physics and astrophysics.*
- *Gamma-ray astronomy* **(E_γ : 10 GeV – 100 TeV).**

Andyrchi EAS Array (since 1995)

BUST + "Andyrchi" EAS Array: simultaneous operation (since 1995)



The projection on to horizontal plane

$S_{tot} = 4.4 \cdot 10^4\ m^2$

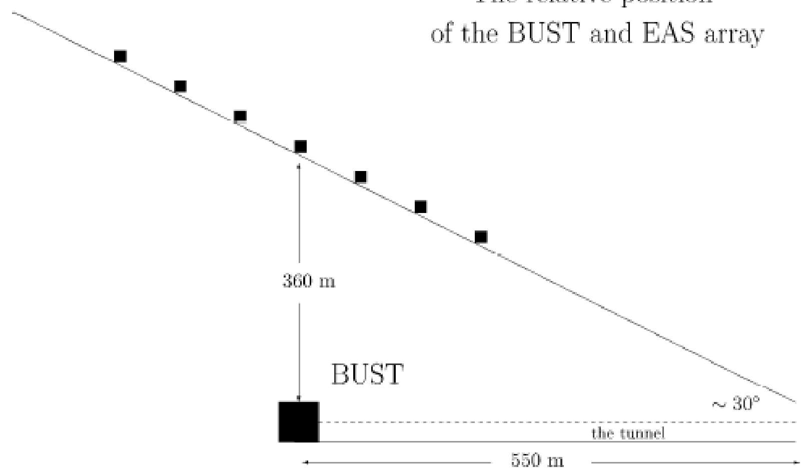
37 plastic scintillation detectors

(1 m × 1 m × 0.05 m)

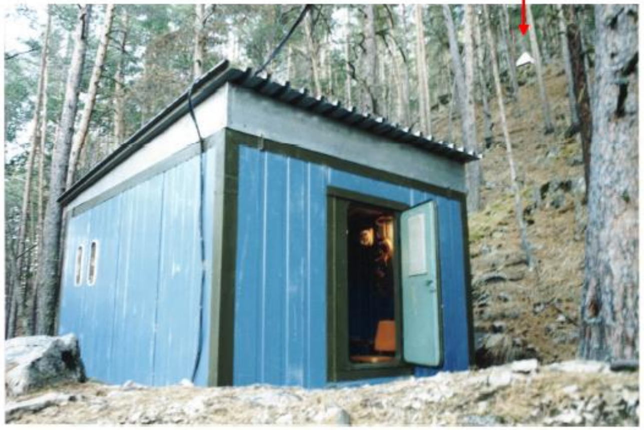
Shower trigger: ≥ 4 fired detectors

Trigger rate ≈ 9 $\sec^{-1}$

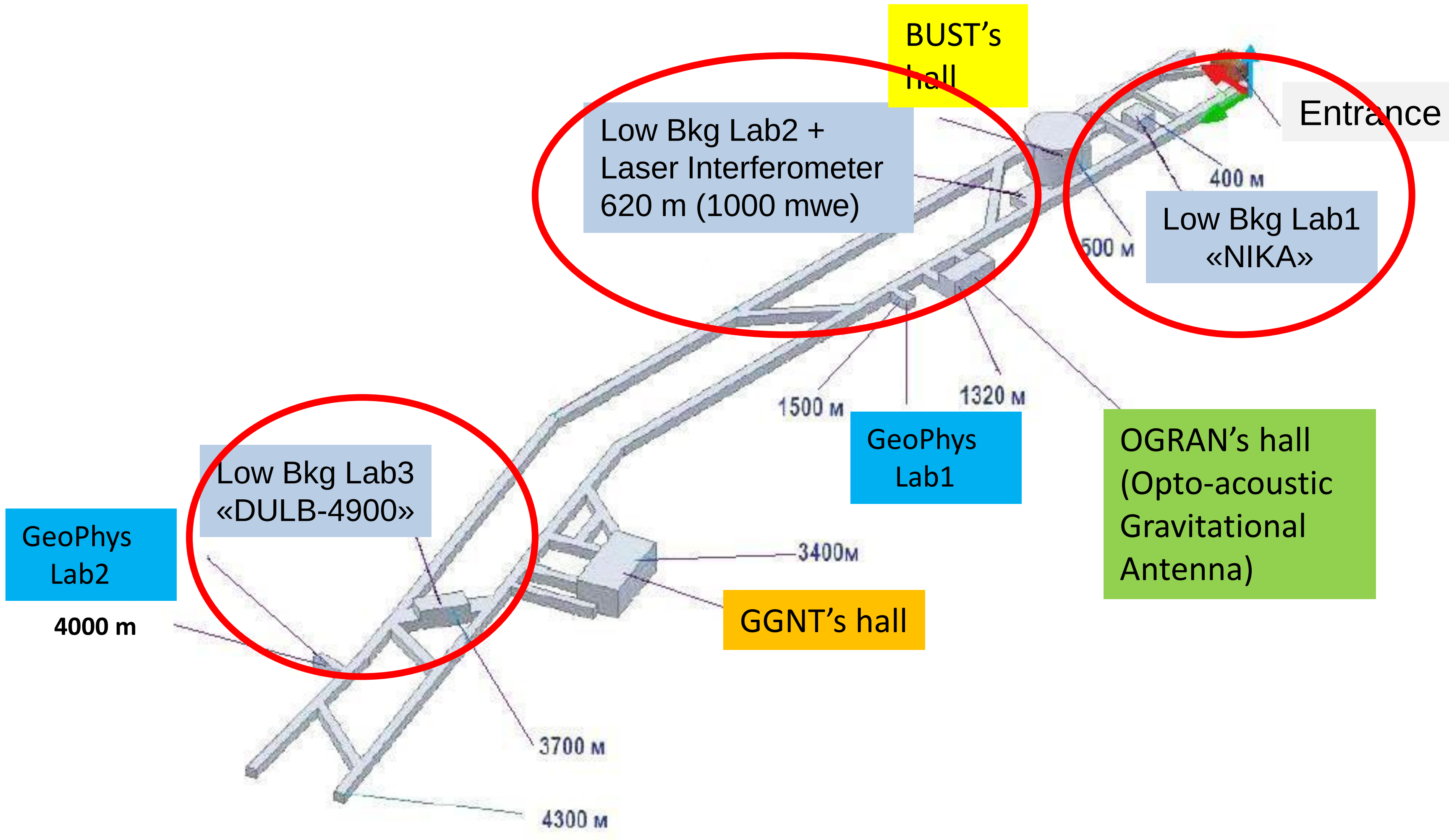
The relative position of the BUST and EAS array



Coincidence rate BUST + "Andyrchy" ≈ 0.1 $\sec^{-1}$

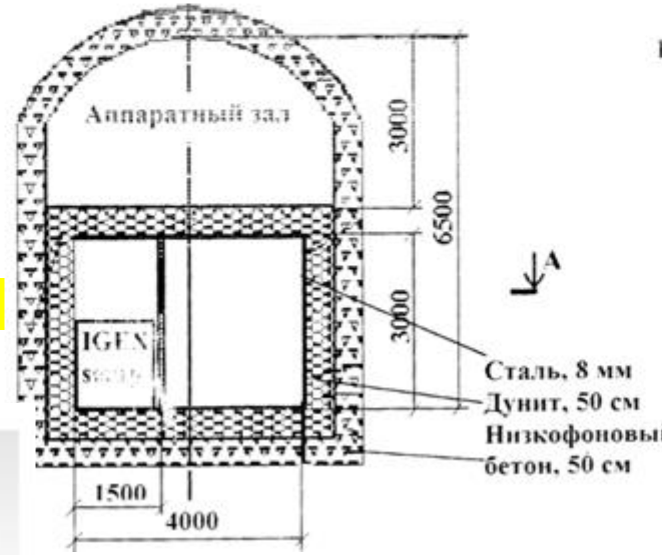


Low background Laboratories of the BNO INR RAS

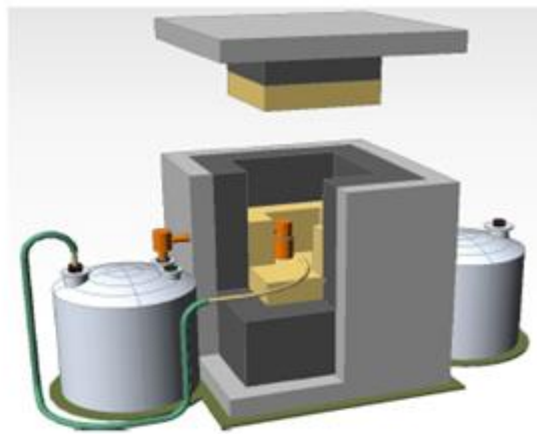


Characteristics of LBL «NIKA» (Lab 1)

Low-background laboratory at a depth of 660 m w.e,
400 m from the entrance to the tunnel,
useful area of 100 m^2, put into operation in 1974



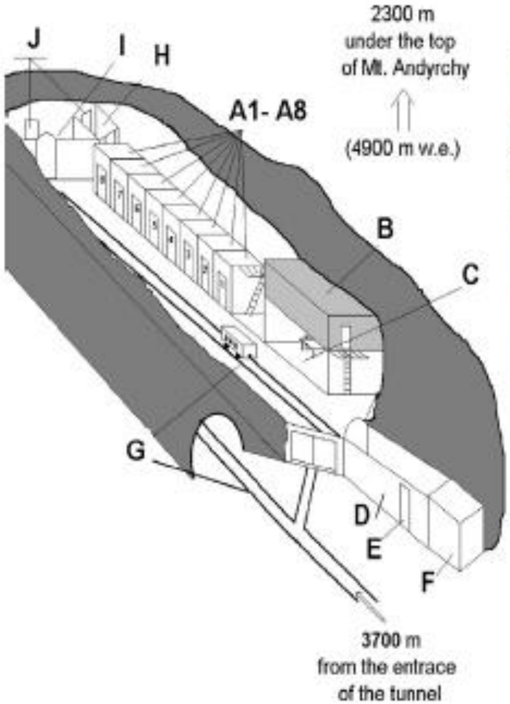
The detector is made of high-purity germanium of natural content (7,76% of ^{76}Ge). Effective mass of detector is 980 g.



Low-background shield is consists of: 80 mm of borated polyethylene, 230 mm of lead (Pb) and 120 mm of copper (Cu)

Working characteristics of the Low-Background Laboratory DULB-4900

The laboratory is located at a distance of 3700 m from the main entrance of the observatory tunnel in the hall with dimensions $\sim 6 \times 6 \times 40$ m^3. Thickness of the mountain rock over DULB corresponds to 4900 m w.e. and this deep location provides the cosmic ray flux reduction with the factor of about 10^7.



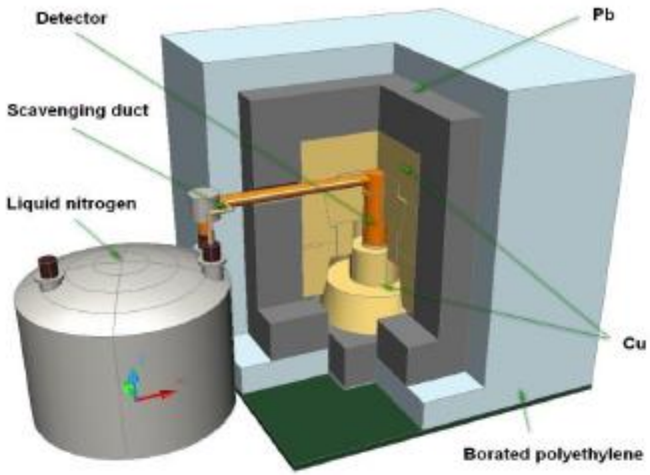
Schematic view of DULB-4900: **A1-A8** - counting chambers; **B** - air condition equipment; **C** - engineering and processing facility; **D** - buffer area; **E** - entrance; **F** - bathroom; **G** - electric-driven wagon railway; **H** - fire-fighting equipment; **I** - electrical and process equipment; **J** - emergency exits.

Ju.M. Gavriljuk, A.M. Gangapshev, A.M. Gezhaev, V.V. Kazalov, V.V. Kuzminov, S.I. Panasenko, S.S. Ratkevich, A.A. Smolnikov, S.P. Yakimenko "Working characteristics of the New Low-Background Laboratory (DULB-4900)". Nuclear Instruments and Methods in Physics Research A 729 (2013) pp.576-580

General view of auxiliary and low-background boxes.

Interior view of the low-background box with the door opened.

Ultra-low background germanium gamma-spectrometer (SNEG)



The detector is made of high-purity germanium enriched by ^{76}Ge isotope up to 87%. Effective mass of detetector is 630 g.

Low-background shield is consists of: 80 mm of borated polyethylene, 1 mm of cadmium (Cd), 150 mm of lead (Pb) and 180 mm of copper (Cu)

Low background laboratories

Nuclear physics:

- *search for Superdence Nuclei and Electron Stability*
- *double beta decay search (Nd-150, Mo-100, Xe-136...)*
- *search for 2k-capture (^{78}Kr u ^{124}Xe)*

2β-decay ^{136}Xe: $T_{1/2}(2\beta 2\nu) \geq 8,5 \cdot 10^{21}$ year (90% C.L.) 2005 y.

$T_{1/2}(2\beta 0\nu) \geq 3,1 \cdot 10^{23}$ year (90% C.L.)

2k-capture ^{78}Kr: $T_{1/2}(0\nu+2\nu,2K) \geq 3,4 \cdot 10^{21}$ year (95% C.L.) 2010 y.

Astrophysics:

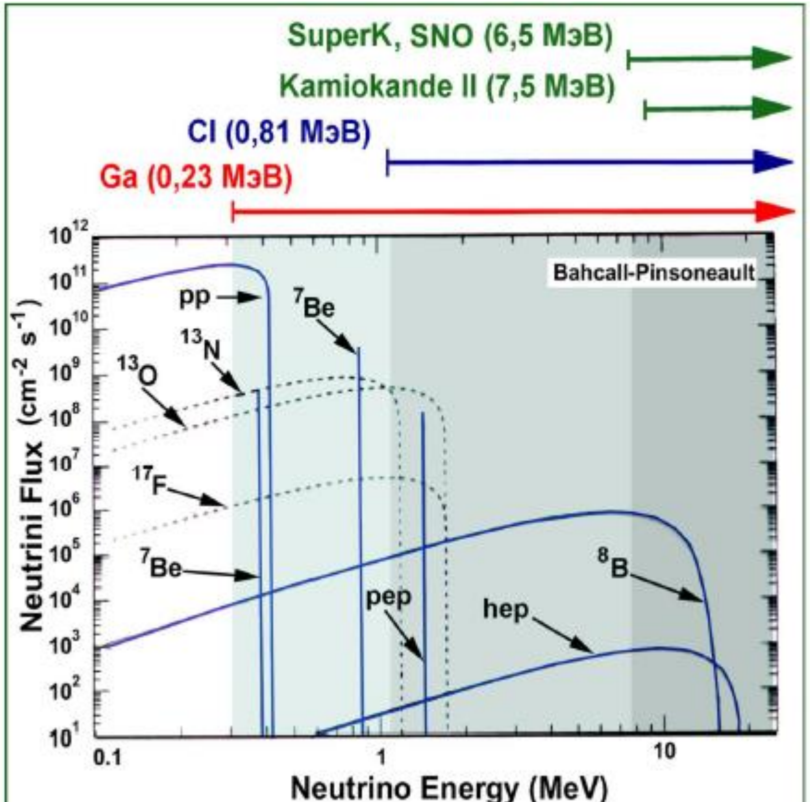
search for Dark Matter particles

(WIMP – Weekly Interaction Massive Particle)

HPGe measurement of different samples
Sensitivity (Bi214, Tl208) = 2-3 mBq/kg if 0,5 kg&500 hours
(AMoRE experiment)

GGNT laboratory & SAGE experiment (since 1988)

To resolve Solar Neutrino Puzzle: Cl-Ar, Li-Be and **Ga-Ge**



- 1 SNU = 1 interaction/sec in a target that contains 10^{36} atoms of the neutrino absorbing isotope.

$$^{71}Ga + \nu \rightarrow {}^{71}Ge + e^-$$

Kouzmine, 1965

LOW THRESHOLD:

233 keV

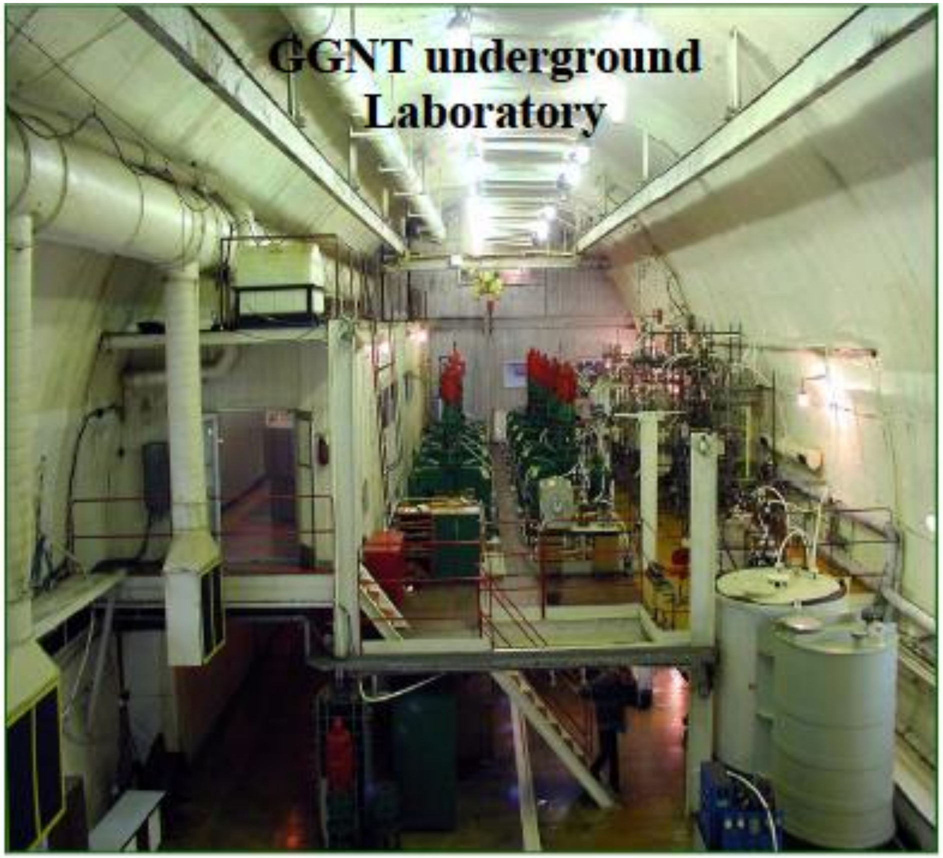
SENSITIVE TO
DOMINANT p-p NEUTRINOS

SSM PREDICTIONS:
BAHCALL-PINSONNEAULT:
128 +9 / -7 SNU (1σ)

p-p NEUTRINOS CONTRIBUTE
70 SNU (54%) OF THE RATE

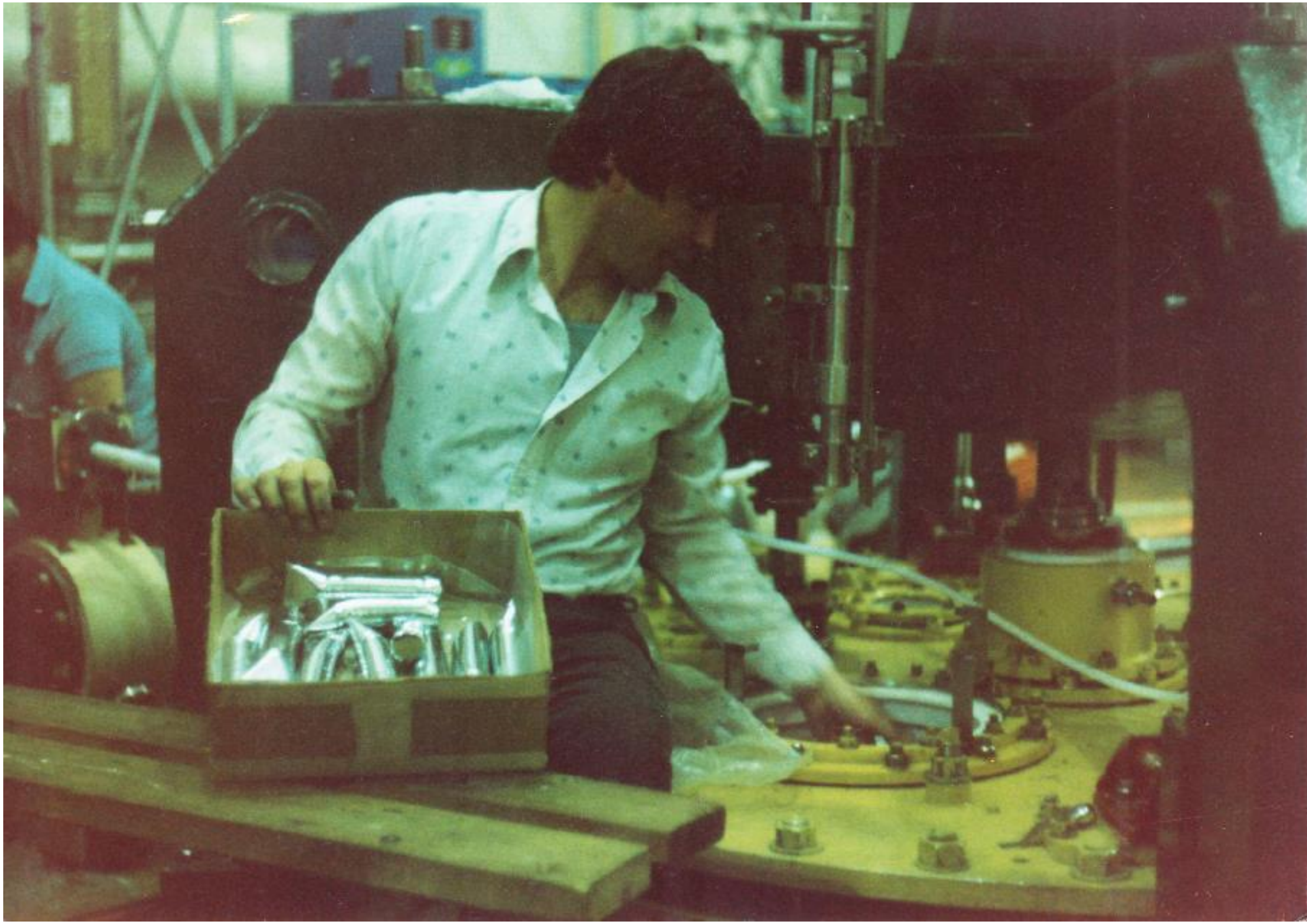
General view of GGNT laboratory - 1

General view of GGNT laboratory - 2

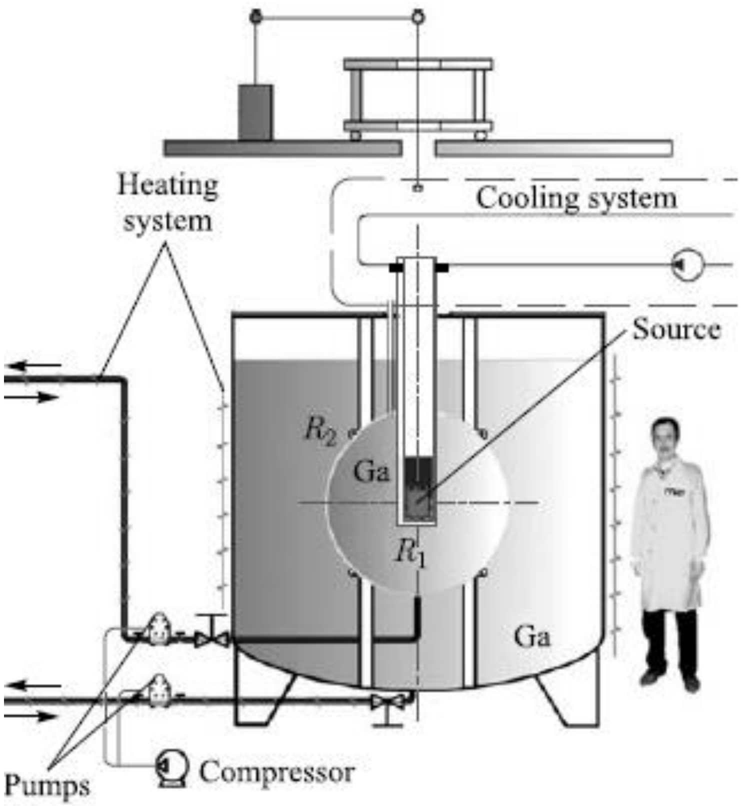


- *Depth – 4700 m.w.e* $((3.03\pm0.10)\cdot10^{-9}\ \mu\ cm^{-2}\cdot s^{-1})$
- *Size – 60m×10m×12m*

Ga metal bars are loaded into chemical reactor (1988)



Experiment BEST in GGNT Hall: a search for sterile neutrino using two-zone Ga target and Cr-51 neutrino source



Background of **radiochemical** detectors (Li-Be, Cl-Ar and Ga-Ge)

The main source of ^{71}Ge in the detector other than from solar neutrinos is from ***fast protons*** arising as secondary particles produced by:

i) External neutrons;

ii) internal radioactivity;

iii) Cosmic ray muons.

$^{71}Ga(p,n)^{71}Ge^{*}$

The only way to be sure that these Ge-71 atoms are produced by solar neutrinos is to substantially decrease and well-controlled any possible channels of background events.

- The goal is to substantially decrease fast neutrons flux from surrounded shale rock. **Very low background components of the concrete** (crushed stone, sand, and cement) with ultra-low content of U, Th and Ra have been specially chosen and then delivered to BNO from different areas of Soviet Union during construction works.
- **Deep underground laboratory** situated in 3500 m far from the entrance (4715 mwe)

Characteristics of Baksan rock (shale)

Element	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O	CO_2	SO_3
Content, %	65,73	0,35	13,35	3,68	4,5	2,3	2,52	0,79	3,28	1,7	0,85	0,6

	238U	232Th	40K
Content, g/g	$(1{,}5 \div 3{,}3) \cdot 10^{-6}$	$(1{,}9 \div 2{,}5) \cdot 10^{-5}$	$3{,}4 \cdot 10^{-6}$
Gamma-activity of the rock, gamma/sec/gr	3,17E+4	1,17E+4	3,25 (natural)
	~ 0,47		
Unscattered gamma-flux	3,94 gamma/cm^2/sec 3,4*10^5 gamma/cm^2/day		

Neutron activity: 21,2*10^{-3} neutrons/gr/day
Radon: ~ 10^{-12} Ci/L

Characteristics of Low background concrete based on dunite, quartz sand and selected Portland cement

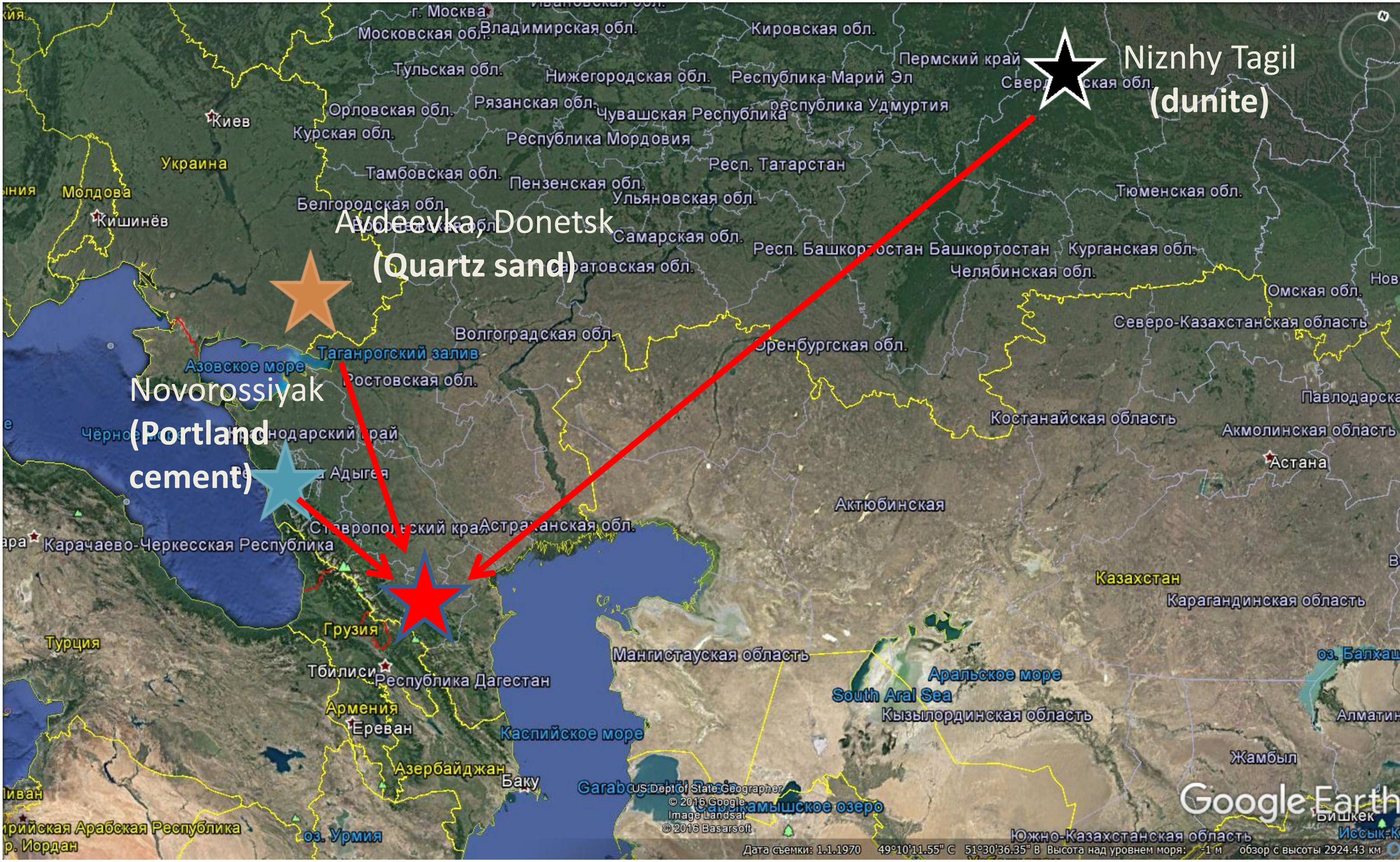
Composition	Mass content, %	^{238}U, g/g	^{232}Th, g/g	^{40}K, g/g
Dunite crushed stone/rock (5÷20 mm)	1115 kg (48,5%)	$< 3*10^{-9}$	$2,5*10^{-8}$	$7,7*10^{-9}$
Quartz sand (white inwash)	665 kg (28%)	$9,5*10^{-8}$	$4,0*10^{-7}$	$2,2*10^{-9}$
Portland cement (M-400)	370 kg (15,5%)	$1,5*10^{-6}$	$2,7*10^{-6}$	$1,33*10^{-7}$
Water	189 kg (8%)			
Sulfite waste liquor	additive	$< 3,1*10^{-8}$	$< 1,3*10^{-8}$	-
Plasticizing agent	additive	$< 6,5*10^{-9}$	$< 3,1*10^{-8}$	-

Neutron activity: $0,64*10^{-3}$ neutrons/gr/day

Low-background concrete at GGNT laboratory

- **Low-radioactive concrete is a key and unique feature of GGNT underground lab**: it serves as radiation shielding and structural reinforcement of rocks (at such a depth it is a prerequisite).
- Total volume of low background concrete is 2200 m^3, the thickness is 70 cm, total weight of frameworks made of steel siding is 370 t.
- Neutron flux is $3,8 \cdot 10^{-6}$ neutrons/cm^2/sec
- Gamma flux (0,2 – 3,2 MeV) is 15÷16 times less compare with the standard rock

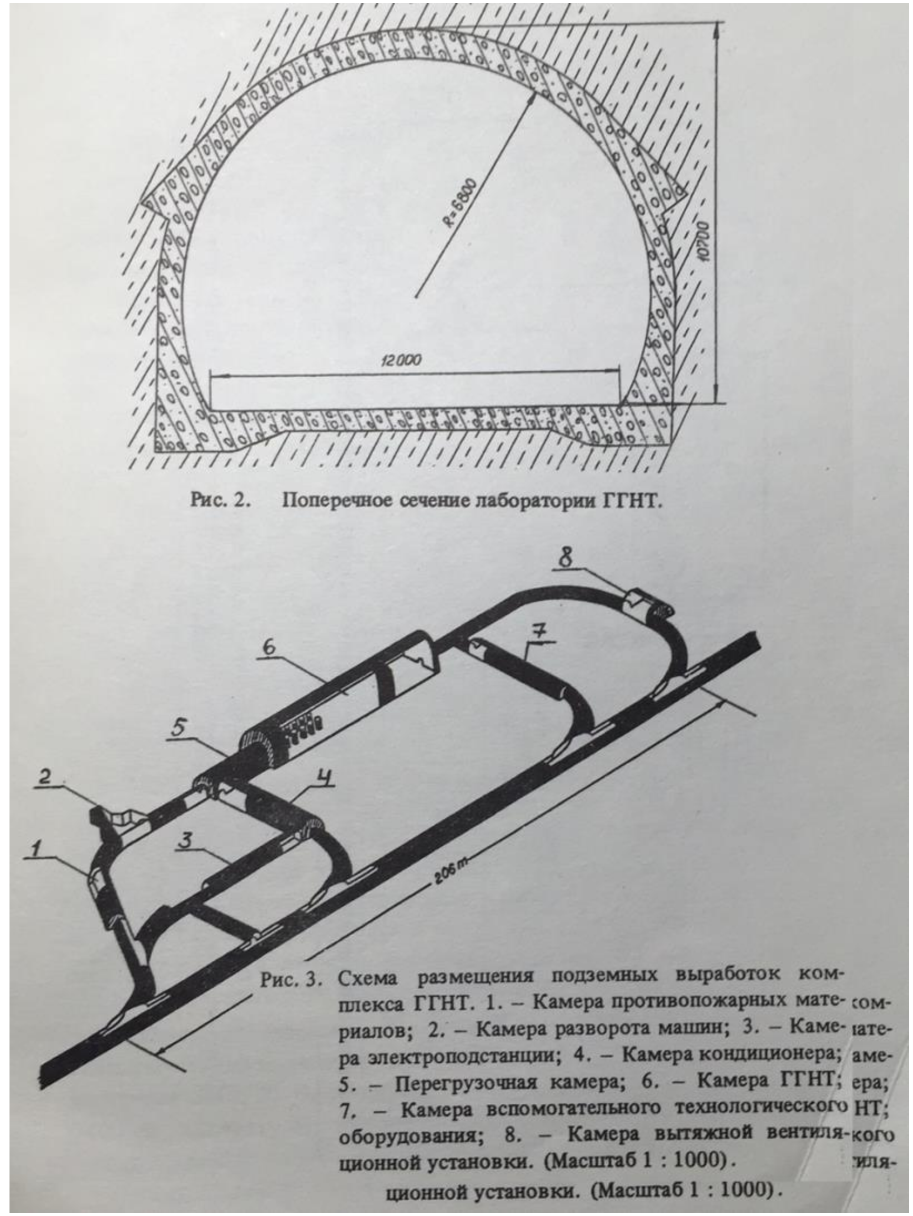
Supply of components of Low-radioactive concrete



Sketch of GGNT laboratory (scale 1:1000)

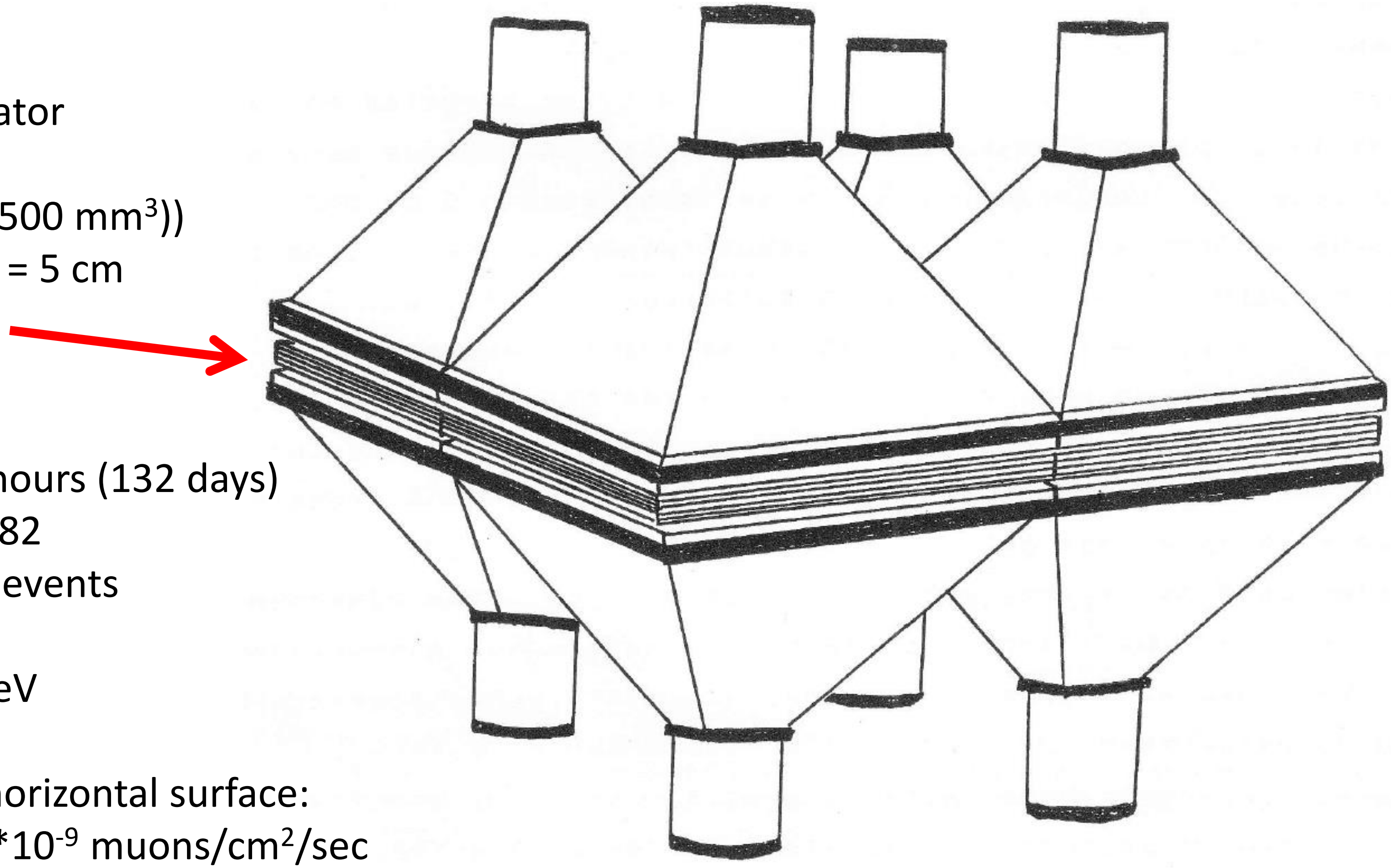
Main hall of 7 200 m^3 lined with 70 cm of low background concrete
Overburden: 2000 m (4.8 km w.e.)
Radon: 40 Bq/m^3
F_n (>1 MeV) = $1.4 \times 10^{-3}\ m^{-2}s^{-1}$
F_n (>3 MeV) = $6.28 \pm 2.2 \times 10^{-4}\ m^{-2}s^{-1}$

1- Chamber of firefighting materials and equipment
2- Chamber of a car U-turn
3- Chamber of electric substation
4- Chamber of Air conditioning
5- Reload chamber
6- Main hall
7- Chamber of technical equipment
8- Chamber of exhaust ventilation
- Emergency chamber (10 persons x 2 weeks)



Measurements of muon flux at GGNT laboratory (4715 mwe)

Plastic scintillator
S_{tot} = 1 m^2
(4*(500x500x500 mm^3))
The thickness = 5 cm
Lead = 5 cm
Steel = 1 cm



$T_{meas.}$ = 3172 hours (132 days)
N events = 1182
$N_{selected}$ = 913 events

<Eμ> = 381 GeV

Intensity via horizontal surface:
(2,23+/-0,07)*10^{-9} muons/cm^2/sec

Global intensity:
I_{glob}= (3,03+/-0.10)*10^{-9} muons/cm^2/sec

Measurements of fast neutrons flux at GGNT laboratory lined low-radioactivity concrete and steel

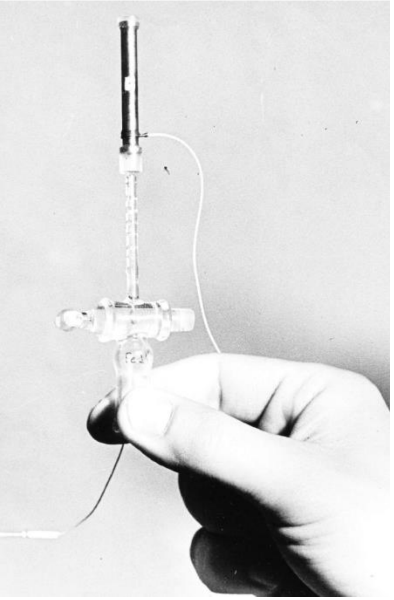
- Vacuum-tight tank with 187 kg of dry Ca_2CO_4 powder
- Reaction $^{40}Ca(n,\alpha)^{37}Ar$ (if $E_n > 2,5$ MeV)
- Extraction of ^{37}Ar on the charcoal trap under LN_2-temperature after 5 hours ($\varepsilon = 98\%$)
- F(E>3 MeV) = (6,28+/-2,20)*10^{-8} neutrons/cm^2/sec

  = (4,56+/-1,62)*10^{-3} neutrons/cm^2/day

(syst. uncertainty : the cross-section&Monte-Carlo)

- R(^{71}Ge) < 2,7*10^{-4} at/day/56 tons

  < 0,016 SNU



Excavation and construction of BNO tunnel and cavities (chambers)

Explosion drilling method

- Precise marking of position of bore-holes
- Drilling of bore-holes of different depth to form proper distribution of explosive
- Blasting of explosive
- Ventilation of tunnel/cavity
- Hauling of rocks with tubs

Explosion drilling method: main disadvantage

Rock after blast is broken → effect of "bounce/ bump"

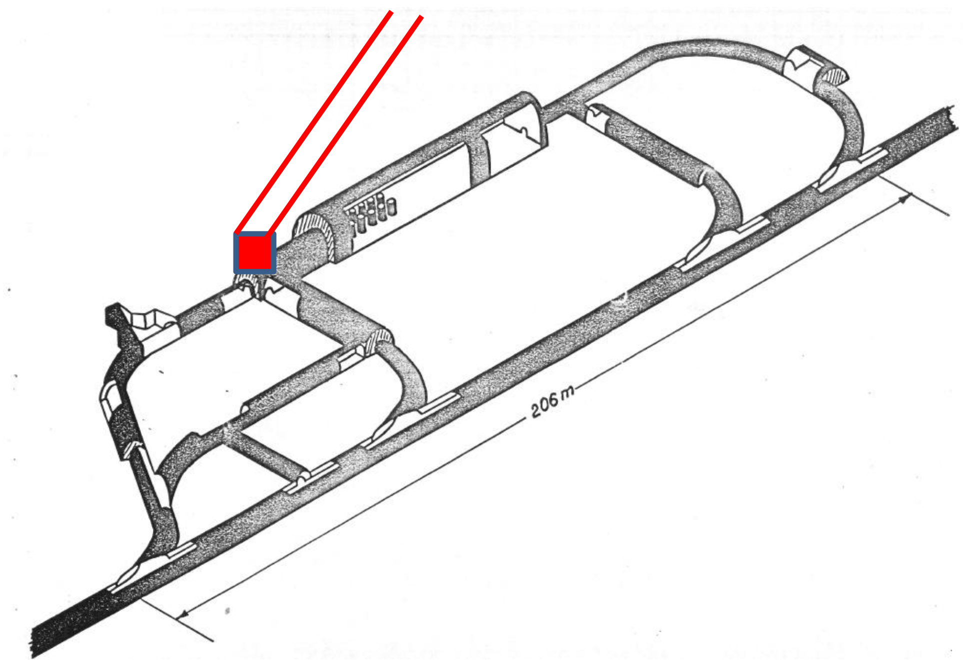
Special procedure to strengthen it after blasting:

- Special anchors with different length (~ 4,5 m) equipped with slit for wedge on one side and threading for washer (metal plater) from another side (850 mm between anchors)
- Net screen to catch small pieces of rock after possible bumping.
- Cover with shotcrete

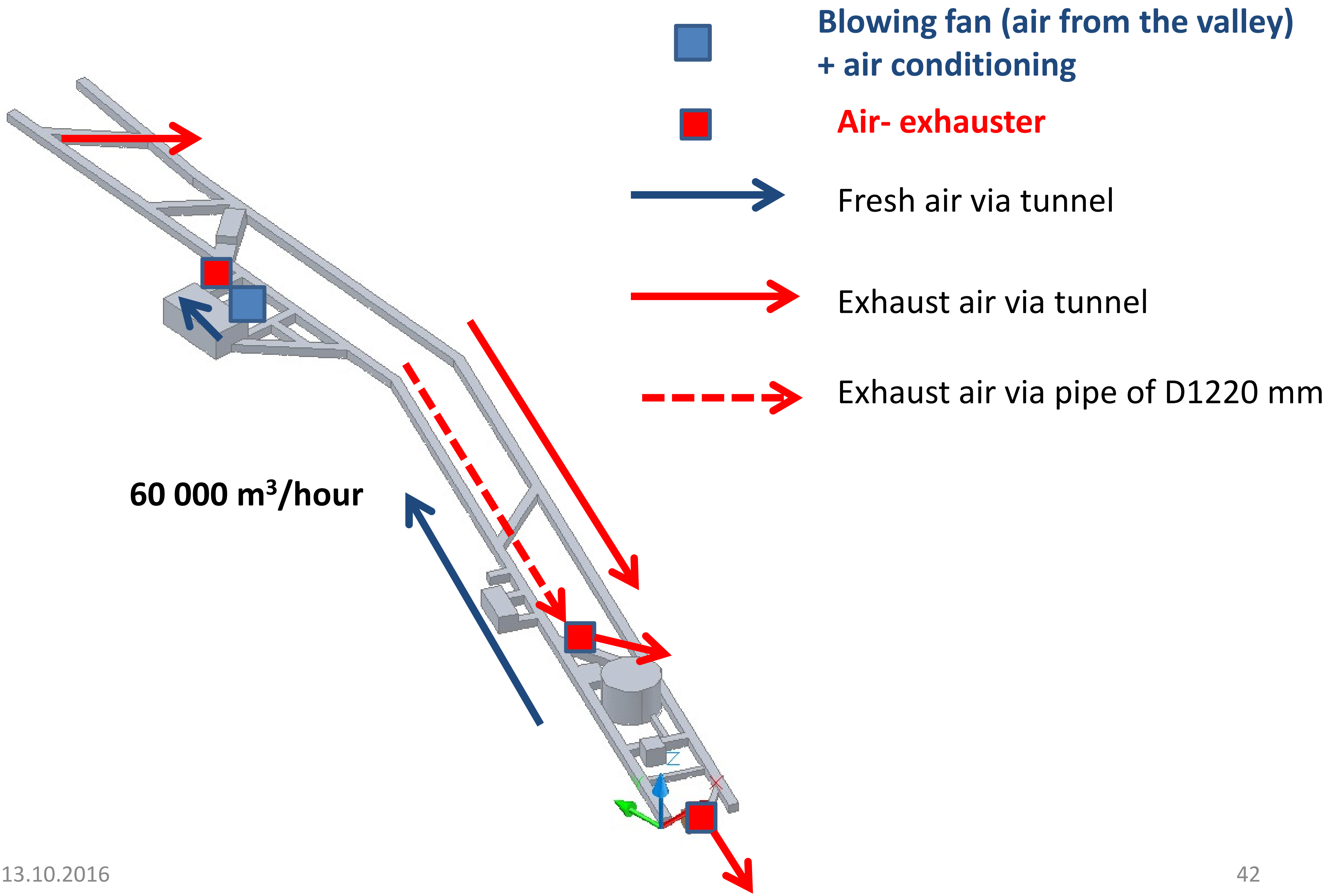
Photo made yesterday in A-5 tunnel (YangYang)
no net screen, no shotcrete

Underground Rock Water around cavity of the laboratory

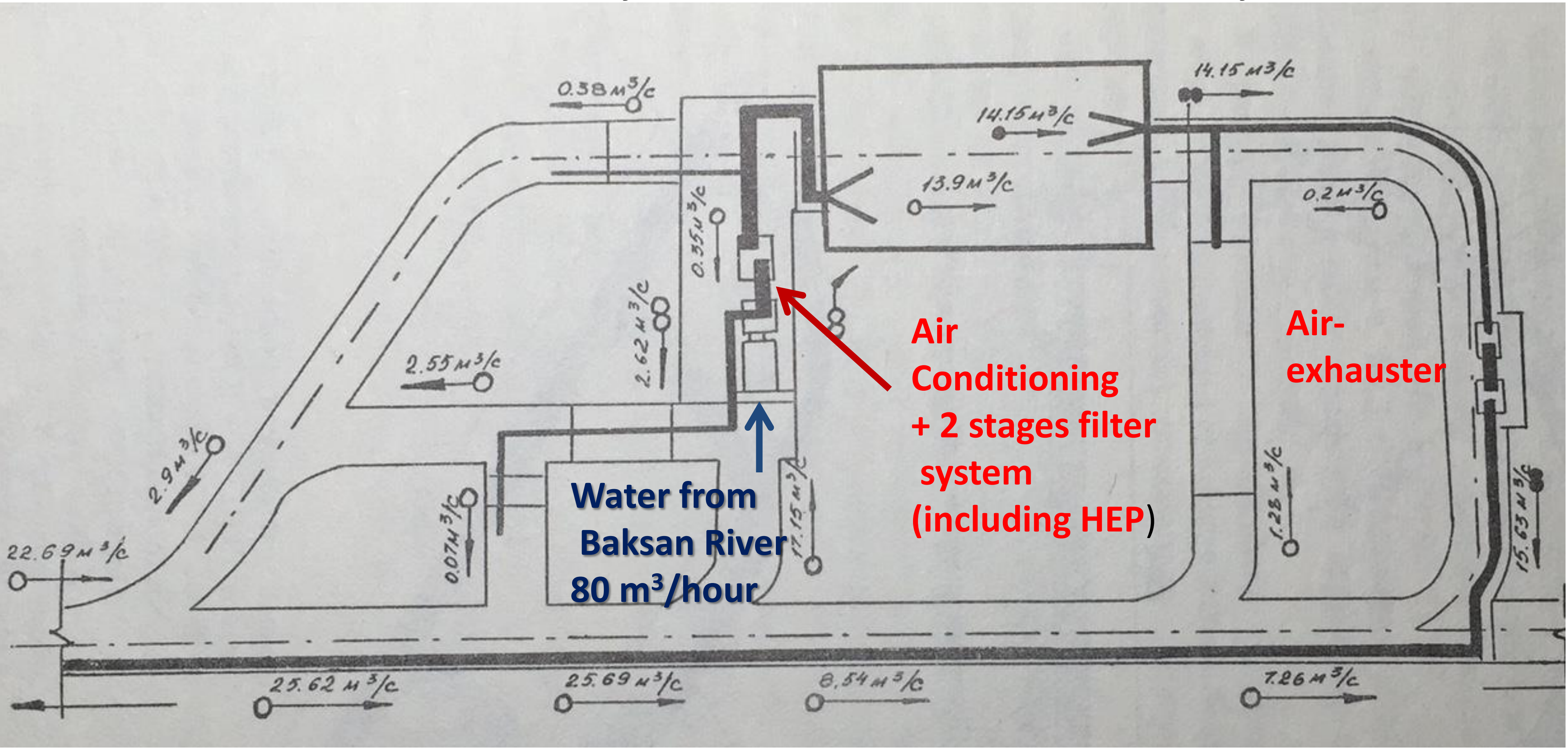
- Water "intercepting" (catching) above cavity to decrease the pressure inside rock of the vault of the cavity.
- We drilled a "sheaf" of bore-holes with length of 20 ÷ 50 m from a special chamber which is situated just near a main hall of GGNT. These bore-holes are above a main hall.
- Periodically we "clean" these bore-holes with drilling machine



Ventilation of GGNT laboratory (general view)



Ventilation system of GGNT laboratory



Fresh air flows to the laboratory from the valley through tunnel and after are pumped through steel tube with the diameter of 1220 mm back. This air is cooled down into conditioner and purified from dust and aerosols (including the products of Th and U decay) with the filters. Rate of fresh air is 60000 m^3/hour.

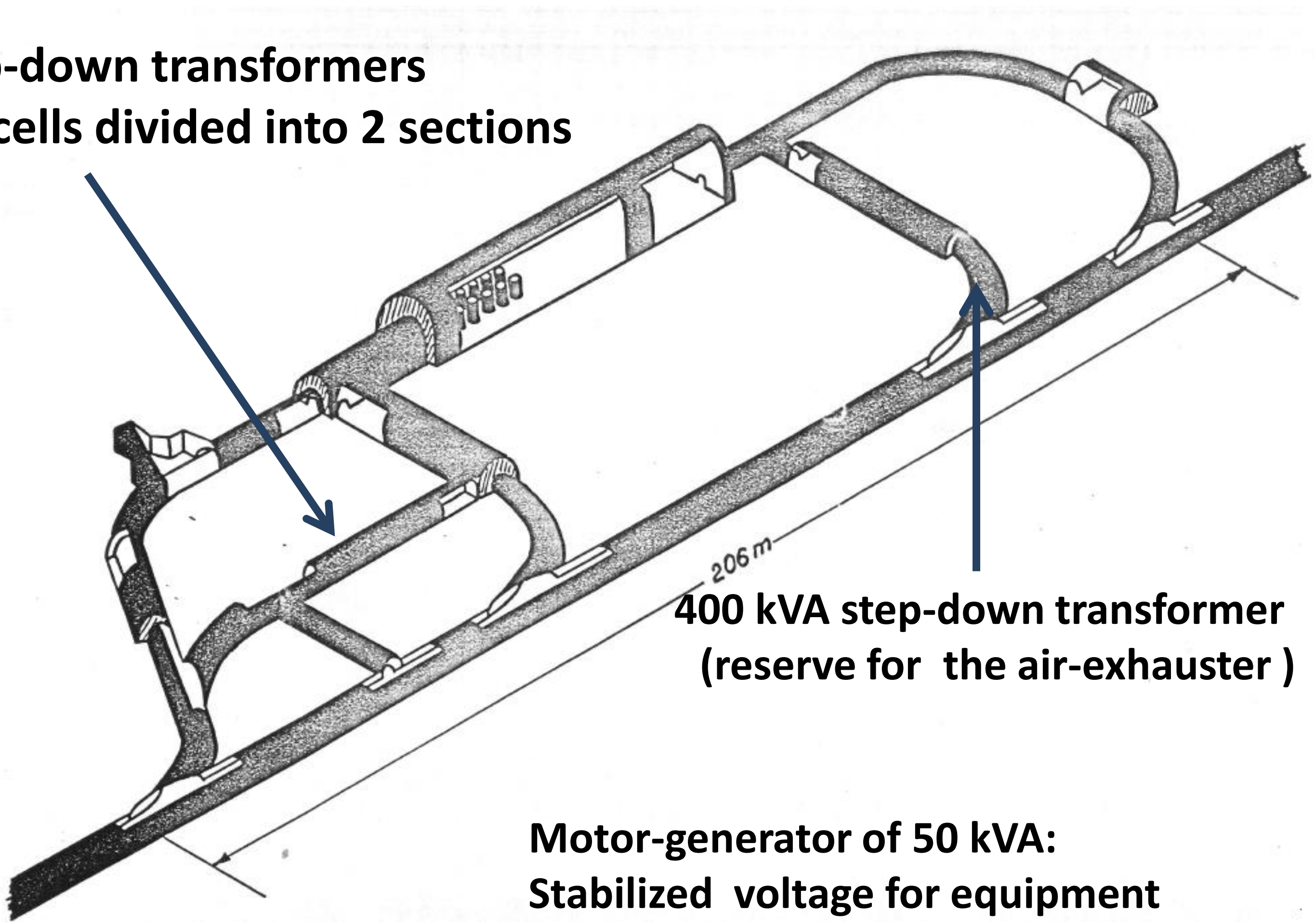
The air exchange multiplicity is 7 $hour^{-1}$. Radon: 40 Bq/m^3

GGNT Power supply

3 x 400 kVA step-down transformers
10 high voltage cells divided into 2 sections

Above-ground step-down substation 110 kV/6 kV

2 x 6 kV cables



400 kVA step-down transformer (reserve for the air-exhauster)

Motor-generator of 50 kVA:
Stabilized voltage for equipment

There are two excesses to GGNT and DULB 4900: via main tunnel and auxiliary tunnel (train transport)

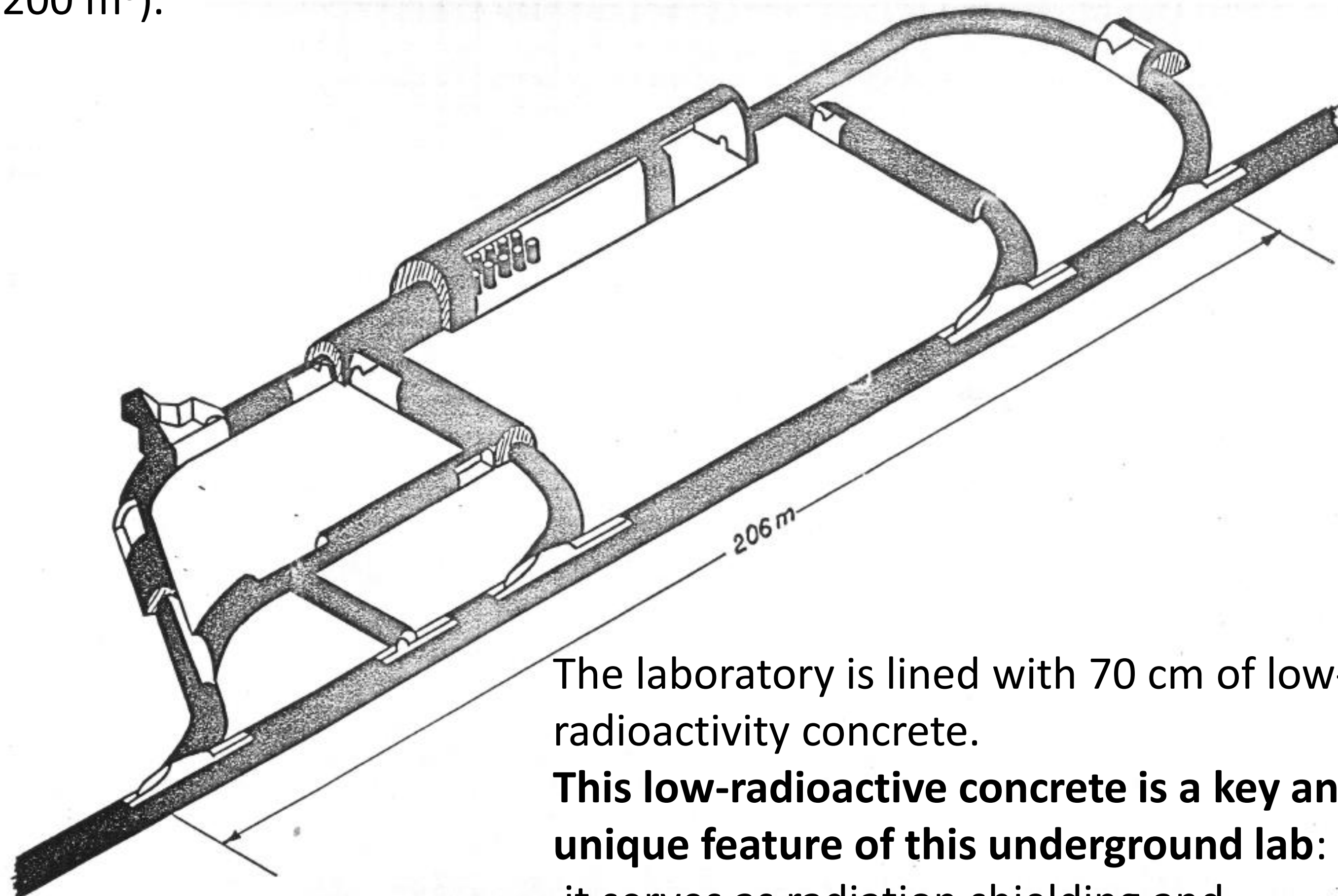
FUTURE of Baksan Neutrino Observatory (?)

Thank you for your attention !

Back up slides

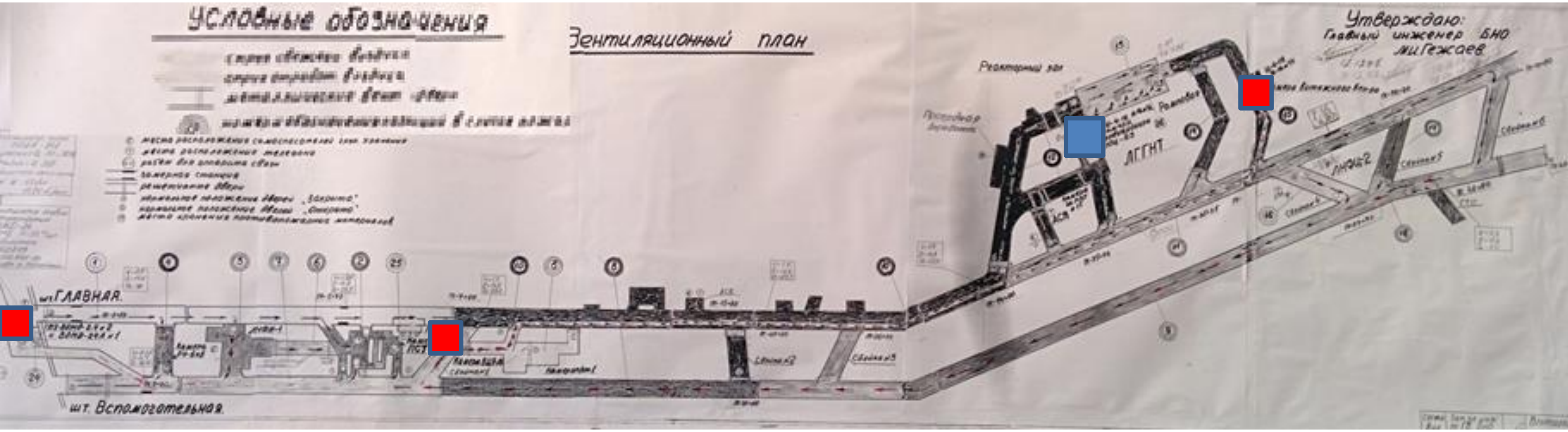
Sketch of GGNT laboratory (scale 1:1000)

The main chamber is 60 m long, 10 m wide and 12 m high (V ~ 7200 m^3).

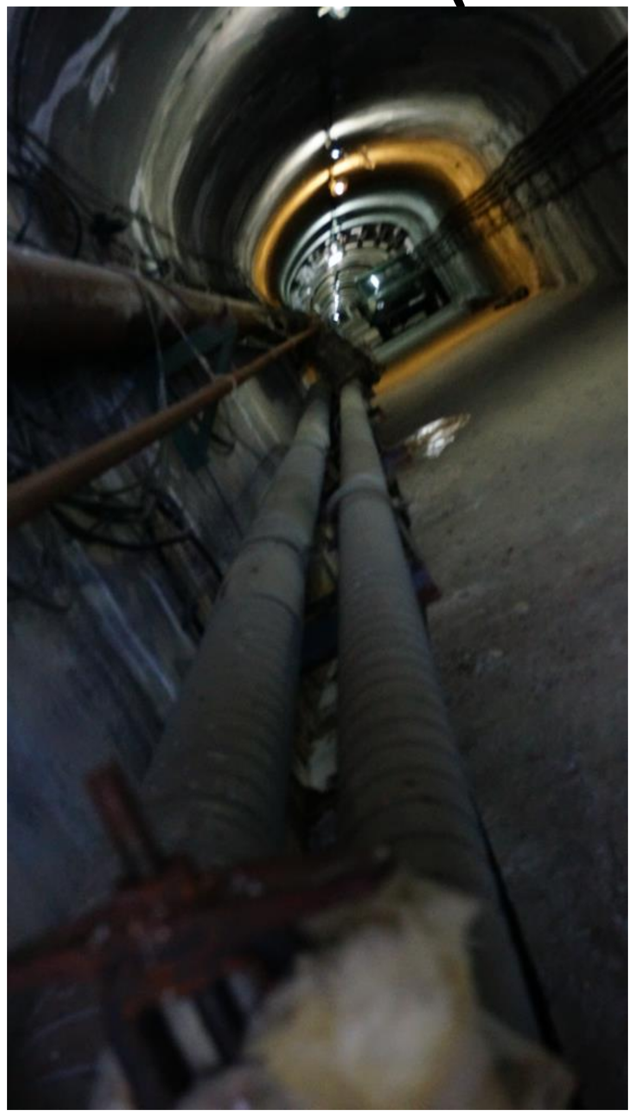


The laboratory is lined with 70 cm of low-radioactivity concrete.

This low-radioactive concrete is a key and unique feature of this underground lab:
it serves as radiation shielding and structural reinforcement of rocks (at such a depth it is a prerequisite).


Условные обозначения
Вентиляционный план
Утверждаю:
Главный инженер БНО
М.И.Гежаев
шт. ГЛАВНАЯ
шт. Вспомогательная
Реакторный зал
АГГНТ

Main tunnel (to BUST)



Cables of power supply (main tunnel)

Baksan neutrino observatory

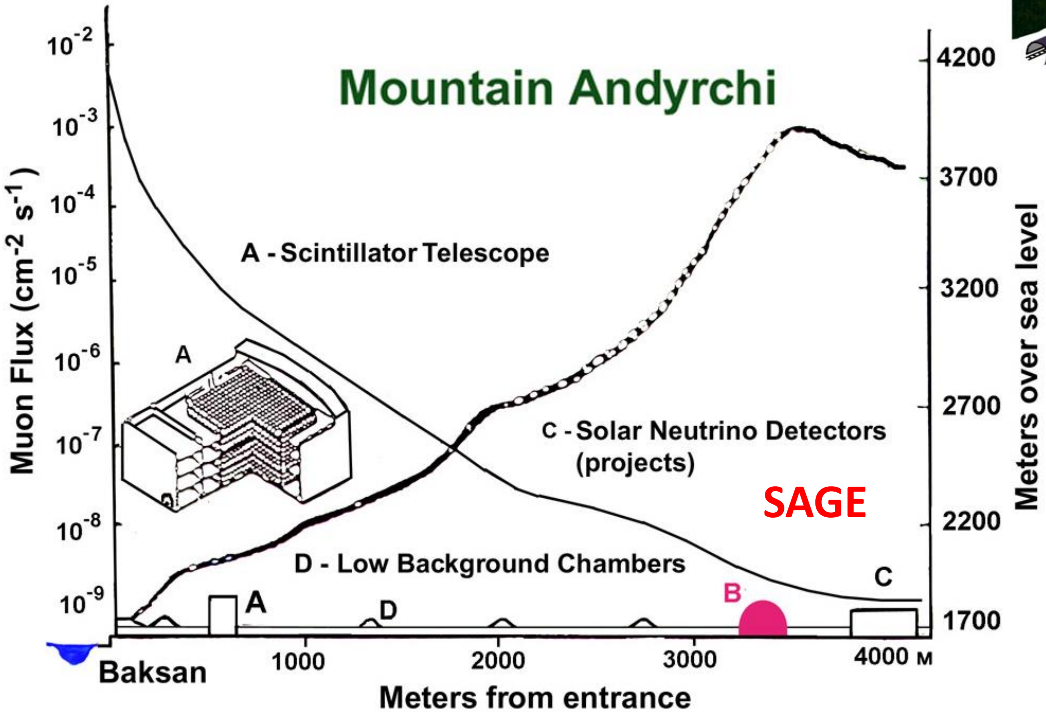
Institute for Nuclear Research RAS

Total volume ≈ 40 000 m^3

Largest hall, 40 000 m^3, construction stopped in 1992, when SU collapsed

BUST. Since 1978 1st large LS neutrino telescope ready for SN explosion (smaller one @ Artemovsk since 1977)

Exclude SN in Galaxy last 30 yr



@ SAGE site ≈ 7 200 m^3 lined with 60 cm of low background concrete

- Overburden: 2000 m ≈ 4.8 km w.e.
- μ flux: ϕ_μ = 3.03±0.19 x 10^{-5} $m^{-2}s^{-1}$
- Ventilation: 60 000 m^3/h
- Radon: 40 Bq/m^3
- ϕ_n (>1 MeV) = 1.4 x 10^{-3} $m^{-2}s^{-1}$
- ϕ_n (>3 MeV) = 6.28±2.2 x 10^{-4} $m^{-2}s^{-1}$
- Dedicated horizontal access (4 km)

Two tunnels, train transportation