# Scientific program of the Baksan Neutrino Observatory

V.V. Kuzminov

P&C-2019 (Terskol, April 10-18 , 2019)

# Laboratories

**L. of Baksan Underground Scintillation Telescope (BUST)**

Investigations of cosmic rays

**L. of Gallium-Germanium Neutrino Telescope (GGNT)**

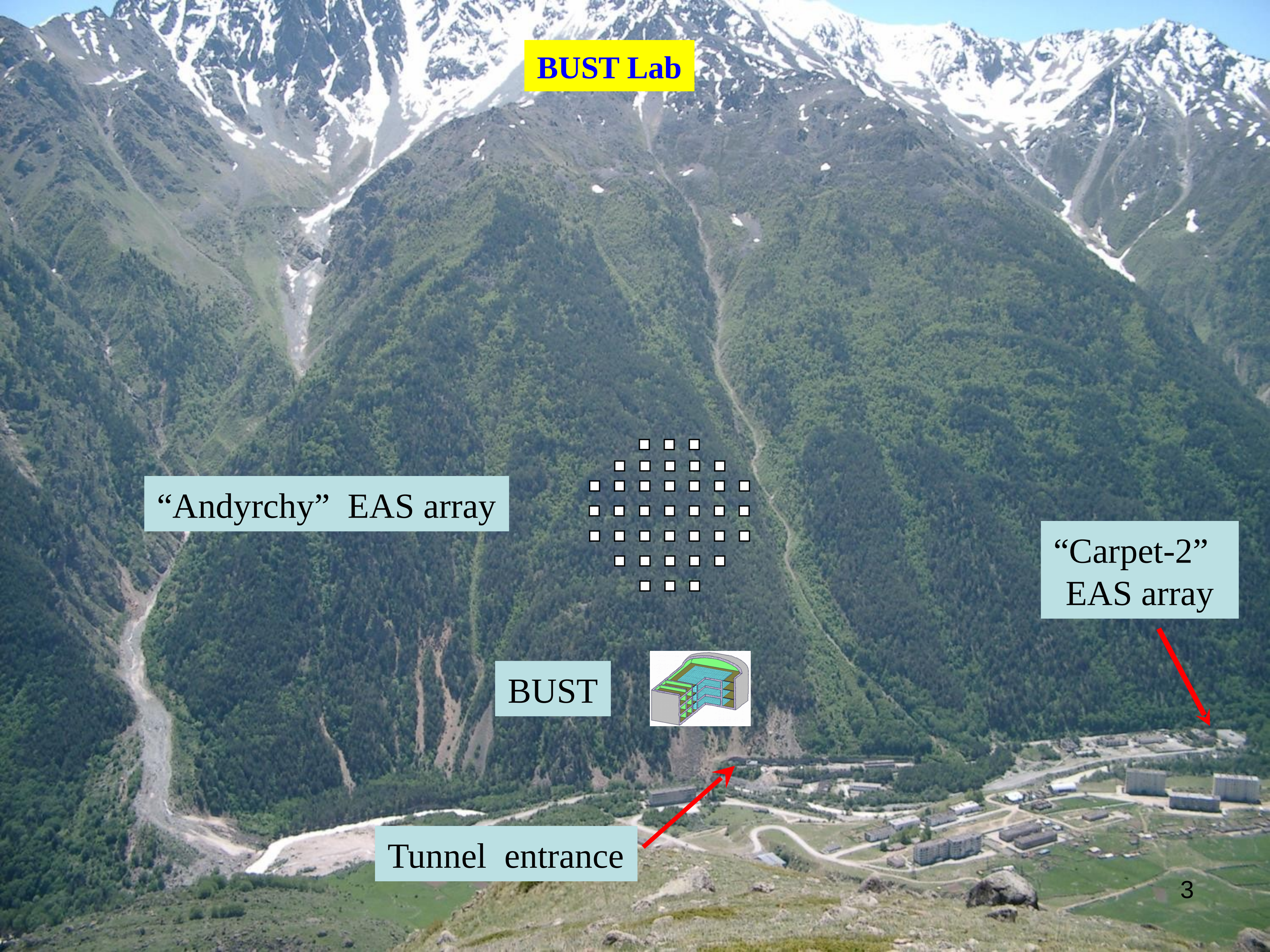
Measurement of Solar neutrino flux

**L. of Low Background Researches (LBR)**

Investigations of rare decay processes (double β-decay, dark matter search)

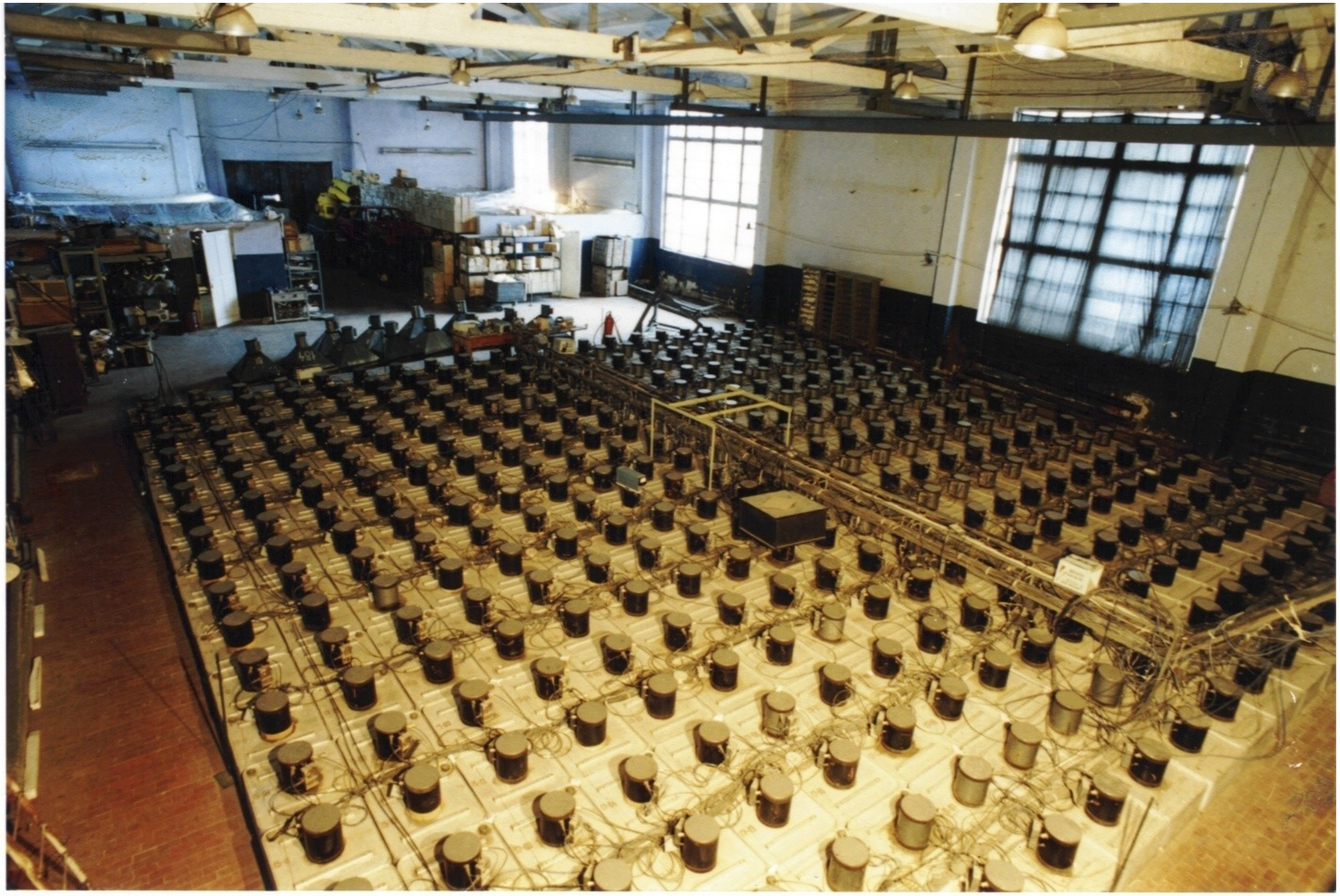
**L. of Geophysics and Gravity (LGG)**

Investigations of process in the Earth and search for GV in the Galaxy


BUST Lab
"Andyrchy" EAS array
"Carpet-2" EAS array
BUST
Tunnel entrance

# “Carpet-2” EAS Array

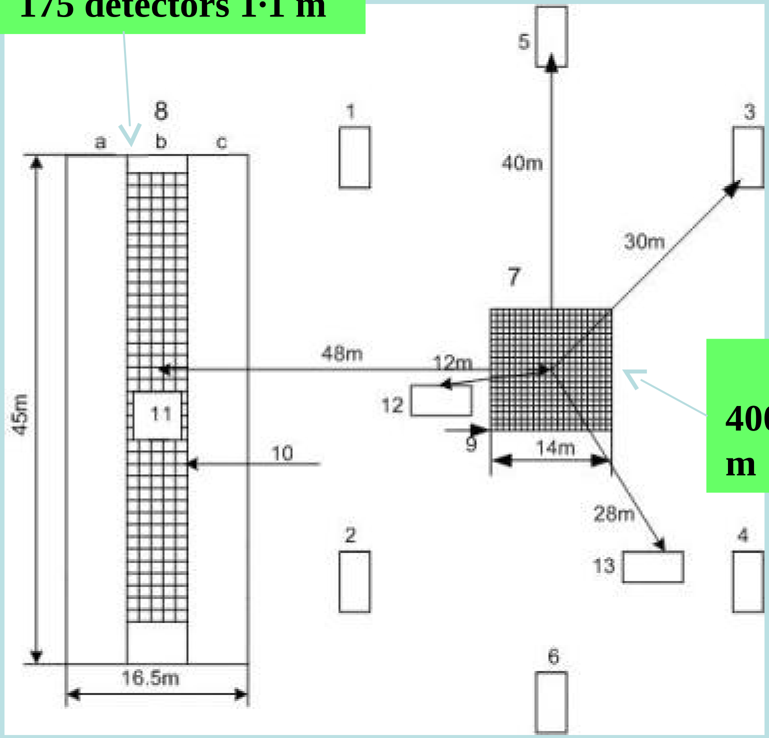
# “Carpet-2” EAS Array



View of the “Carpet-1”

# “Carpet-2” EAS Array

Large Muon Detector
175 detectors 1·1 m




“Carpet-1”
400 detectors 0.7·0.7 ·0.3 m

**Scheme of the “Carpet-2”**

# “Carpet-2” EAS Array → “Carpet-3”

1) 61 scintillator detectors (1 $m^2$) around the Carpet;
2) increase of the μ-detector area up to 615 $m^2$;
3) increase of the n-detector area from 5 $m^2$ up to 13 $m^2$.


View of the Muon Detector (section “C”)

# “Carpet-2” EAS Array

**The main task of the Carpet-2 Air Shower array is to study primary cosmic rays (c.r.) in the energy region of $5.7 \cdot 10^{9}$-$1 \cdot 10^{16}$ eV.**

**Basic researches carried out at the Carpet-2:**

1. **Study of structure of the EAS central part;**
2. **Study of cosmic ray variation;**
3. **Study of c.r. anisotropy;**
4. **Gamma-ray astronomy of ultrahigh energies;**
5. **Study of atmospheric neutron flux variation;**
6. **Study of muon component in EAS;**
7. **Study of chemical composition of primary c.r. of $E \geq 10^{14}$ eV.**

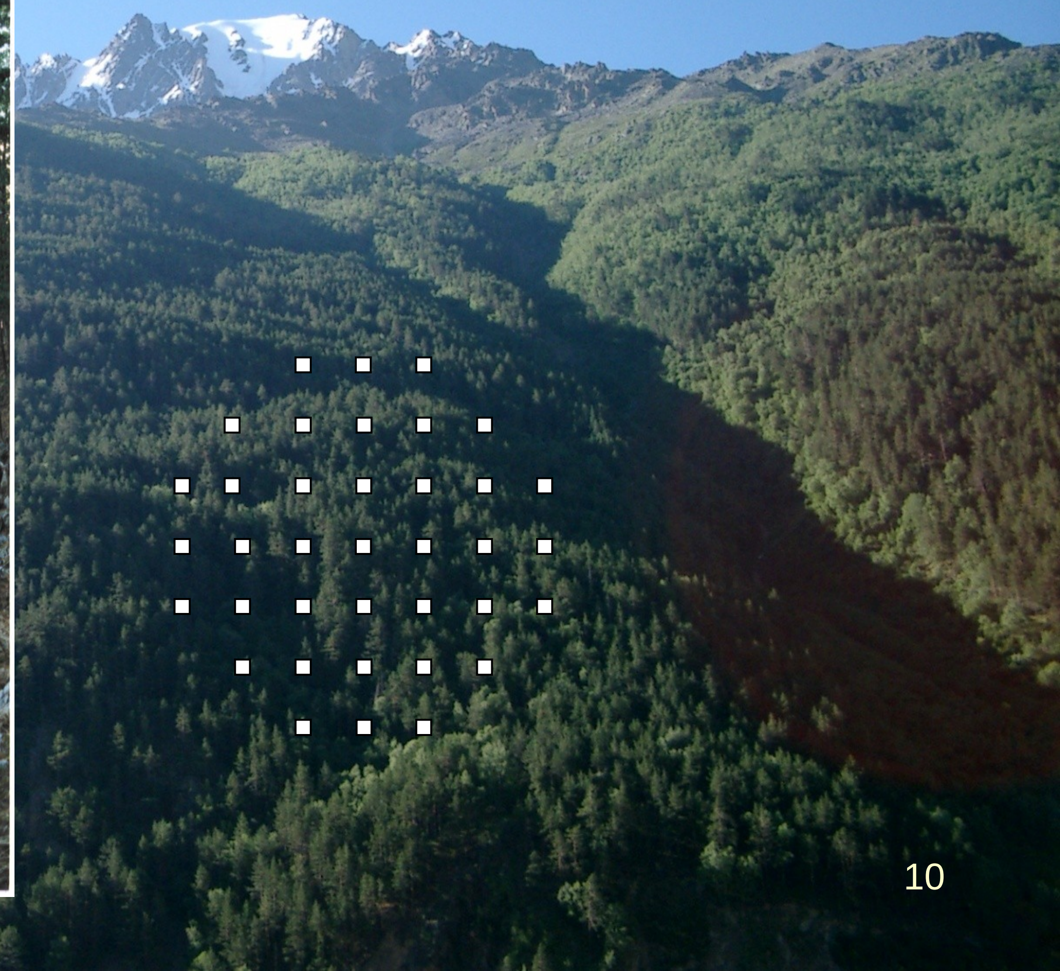
# “Carpet-2” EAS Array

## Some results

1. The first evaluation of a cross section of generation of particles with large transversal momentum in hadron-hadron interactions with c.m. system energy of $\sqrt{S} \sim 500$ GeV.
2. High-precision evaluation of c.r. intensity dependence on meteoeffects.
3. Pioneer observations of particles with energy of $\sim 10^{10}$ eV generated in solar flares.
4. Discovery of anisotropy (0.057 ± 0,005) in cosmic rays with $\sim 10^{13}$ eV.
5. Pioneer registration of Crab Nebula burst on February 23, 1989.

………..

# “Andyrchy” EAS array



# “Andyrchy” EAS array

**The Andyrchy EAS array consists of 37 scintillation detectors, 1 $m^2$ each, evenly spaced (40 m) over the area of ~ $4.5 \cdot 10^4$ $m^2$. The Andyrchy EAS array is aimed to register air showers of energy > $10^{14}$ eV independently and in coincidence with the BUST.**

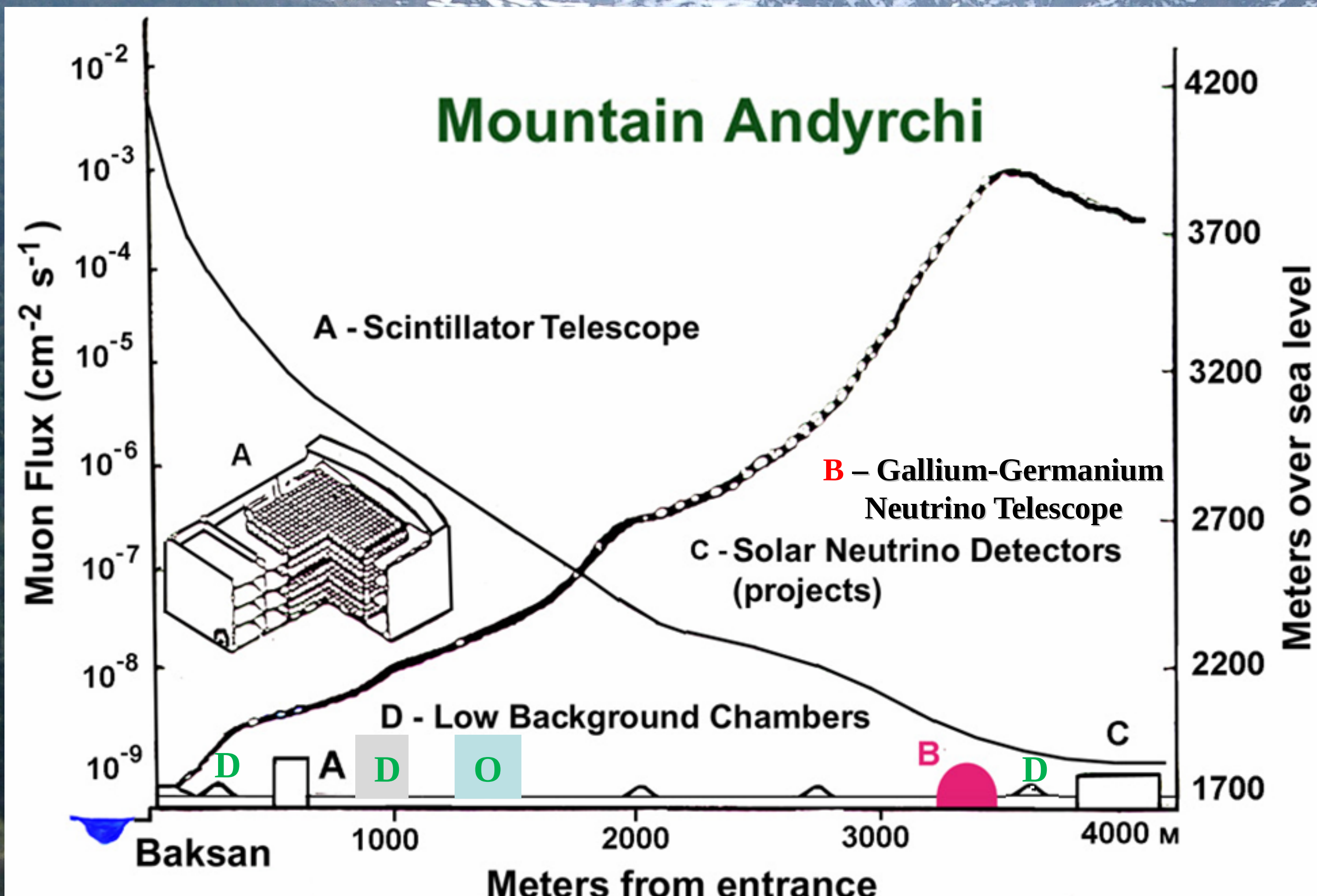
## Researches carried out at the Andyrchy EAS array

**1. Ultrahigh energy gamma astronomy.**

**2. Anisotropy of primary cosmic rays in the energy region of $10^{14}$-$10^{17}$ eV.**

**3. Gamma ray bursts of hard spectrum:**

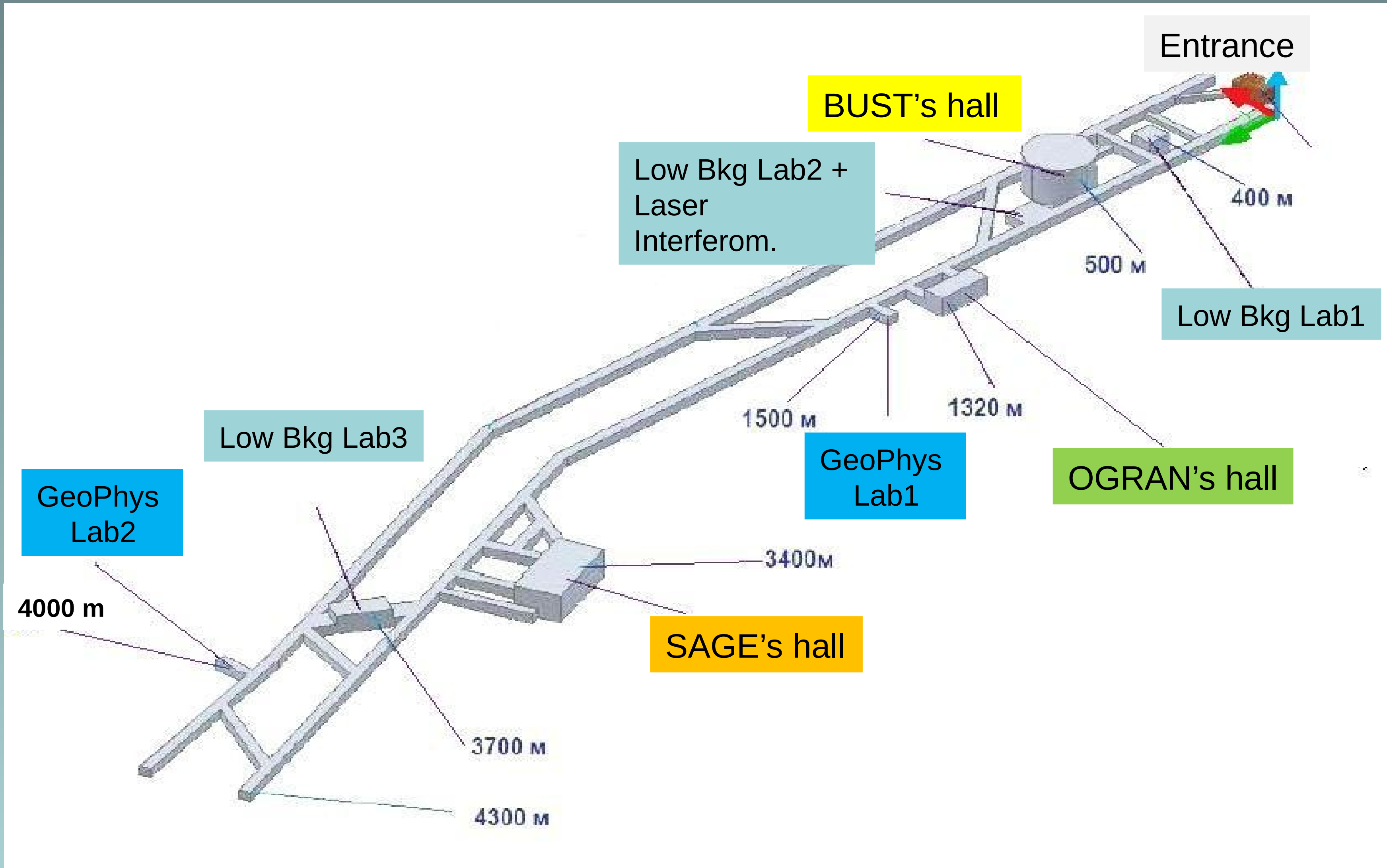
**- data analysis for short gamma ray bursts for a period of 1996-2006 yrs yielded the excess of 24 s duration (in 5 s after the start of the event) over the background. Such an excess could be explained by extended gamma radiation of high energy.**




Global Intensity of muons

$(3{,}0 \pm 0{,}15) \cdot 10^{-9}$ μ $cm^{-2} \cdot s^{-1}$

~ 4800 m.w.e.

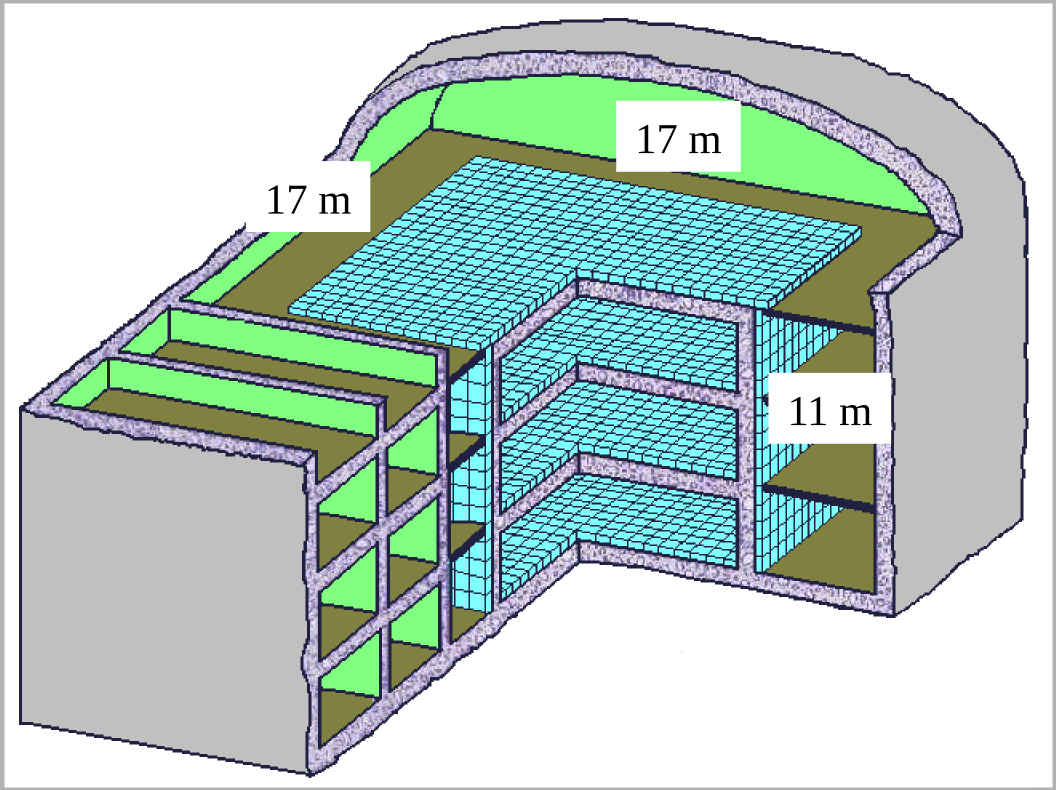



Underground Laboratories of the BNO INR RAS

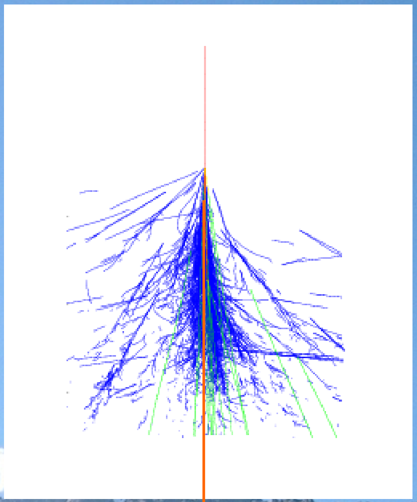
# Baksan Underground Scintillation Telescop

## ➢ Telescope construction completed 1977

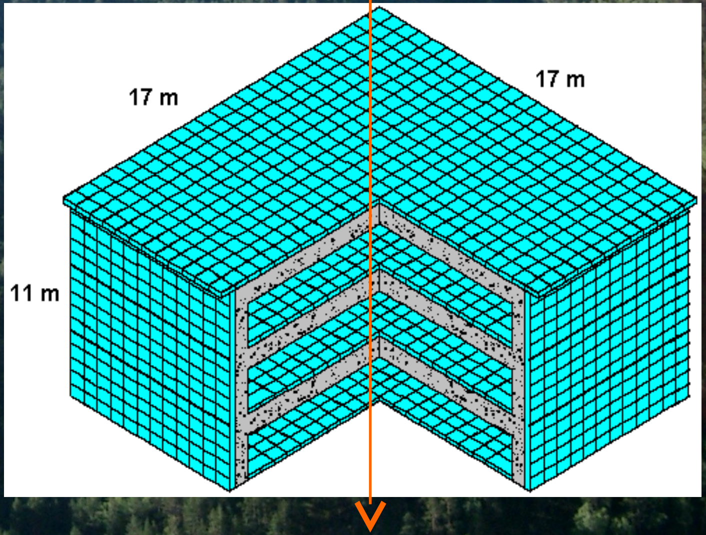
- Depth: 850hg/cm$^2$
- Size: 17m×17m×11m
- Number of tanks: 3185
- Tank size: 70cm×70cm×30cm
- Angular resolution: $2^0$
- Time resolution: 5 ns
- Trigger: 10Mev in any plane
- Rate: 17 Hz
- upward/downward: $10^{-7}$



$$E_\mu \geq E_{th}(x)$$
$$x = x(\theta,\varphi)$$



$$(E_{th})_{eff} = 0.22\ \text{TeV}$$



# The Baksan Underground Scintillation Telescope

## Researches carried out at the BUST

1. Measurement of muon flux generated by high-energy neutrinos.
2. Search for neutrino bursts from the galactic star collapses.
3. Search for anisotropy of c.r. ($>10^{12}$ eV).
4. Study of chemical composition of c.r. ($10^{12}$ - $10^{16}$ eV).
5. Study of muons interactions ($>10^{12}$ eV).

………..

# The Baksan Underground Scintillation Telescope

## Some results

1. Limit obtained for the high energy neutrino flux due to local sources in the galactic plane [ $F_\nu \leq 4 \cdot 10^{-14}$ $cm^{-2} sec^{-1} cp^{-1}$].
2. Amplitude [$(12.3 \pm 2.0) \cdot 10^{-4}$] and phase [$1.6 \pm 0.8$] measured for the first harmonic of anisotropy in sidereal time.
3. Search carried out for 32 years for neutrino burst from the gravitational collapse of the stars in the Galaxy.
4……..

# The Baksan Underground Scintillation Telescope

An upper bound on the mean frequency of gravitational collapses in the Galaxy for BUST's data (at 90% CL)

| year | LIVE TIME (years) | UPPER BOUND (90%CL) |
|---|---|---|
| **1983** | **2.2** | **0.33/year** |
| **1993** | **11.0** | **0.21/year** |
| **2000** | **17.6** | **0.13/year** |
| **2011** | **26.2** | **0.088/year** |
| **2014** | **29.8** | **0.077/year** |
| **2018** | **32.1** | **0.072/year** |

# BUST + “Andyrchy” EAS array: simultaneous operation

**BUST – “Andyrchy” joint research**

1. **Study of composition spectrum and anisotropy of galactic c.r. of ($10^{13}$ – $10^{17}$) eV**
2. **Study of EAS spectra in the knee region.**
3. **Study of c.r. interactions with matter. Search for new particles.**
4. **Study of c.r. intensity variations.**
5. **Gamma-ray astronomy ($E_\gamma$ = 10 GeV – 100 TeV).**

# The SAGE Collaboration

## Measurement of the Solar Neutrino Capture Rate with gallium metal

**J.N.Abdurashitov, V.N.Gavrin*, S.V.Girin, V.V.Gorbachev, P.P.Gurkina, T.V.Ibragimova, A.V.Kalikhov, N.G.Khairnasov, T.V. Knodel, I.N.Mirmov, A.A.Shikhin, E.P.Veretenkin, V.M.Vermul, V.E.Yants, and G.T.Zatsepin***

*Institute for Nuclear Research, Russian Academy of Sciences, 117312 Moscow, Russia*

**M.L.Cherry**

*Louisiana State University, Baton Rouge, Louisiana 70803*

**T.J.Bowles*, W.A.Teasdale and D.L.Wark**

*Los Alamos National Laboratory, Los Alamos, New Mexico 87545, USA*

**J.S.Nico**

*National Institute of Standards and Technology, Stop 8461, Gaithersburg, Maryland 20899, USA*

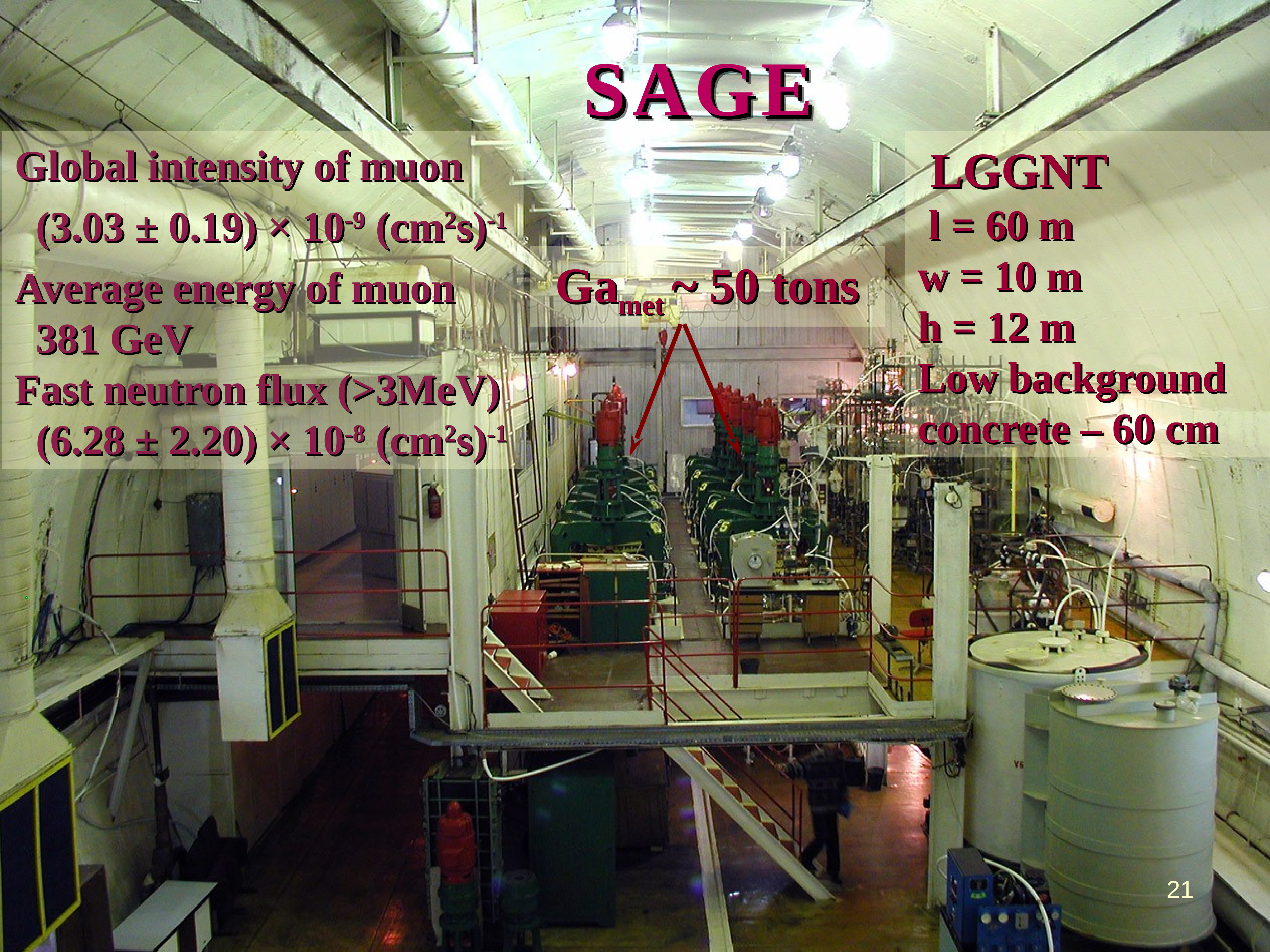
**B.T.Cleveland, S.R.Elliott, and J.F.Wilkerson***

*University of Washington, Seattle, Washington 98195, USA*

**K.Lande, R.Davis, Jr., P.Wildenhain**

*Department of Physics and Astronomy, University of Pennsylvania*
*Philadelphia, PA, 19104, USA*

* - Principal Investigators


SAGE
Global intensity of muon
$(3.03 \pm 0.19) \times 10^{-9}$ $(cm^2 s)^{-1}$
Average energy of muon
381 GeV
Fast neutron flux (>3MeV)
$(6.28 \pm 2.20) \times 10^{-8}$ $(cm^2 s)^{-1}$
$Ga_{met}$ ~ 50 tons
LGGNT
l = 60 m
w = 10 m
h = 12 m
Low background
concrete – 60 cm

# Ga solar neutrino measurements

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

**Threshold 233 keV,**

**$T_{1/2}$ of ${}^{71}Ge$ = 11.43 d**

**${}^{71}Ga$: 40% in natural Ga**

**50 t of Ga = $1.7 \cdot 10^{29}$ atoms of ${}^{71}Ga$**

**Capture rate on Ga (SSM)~130 SNU**

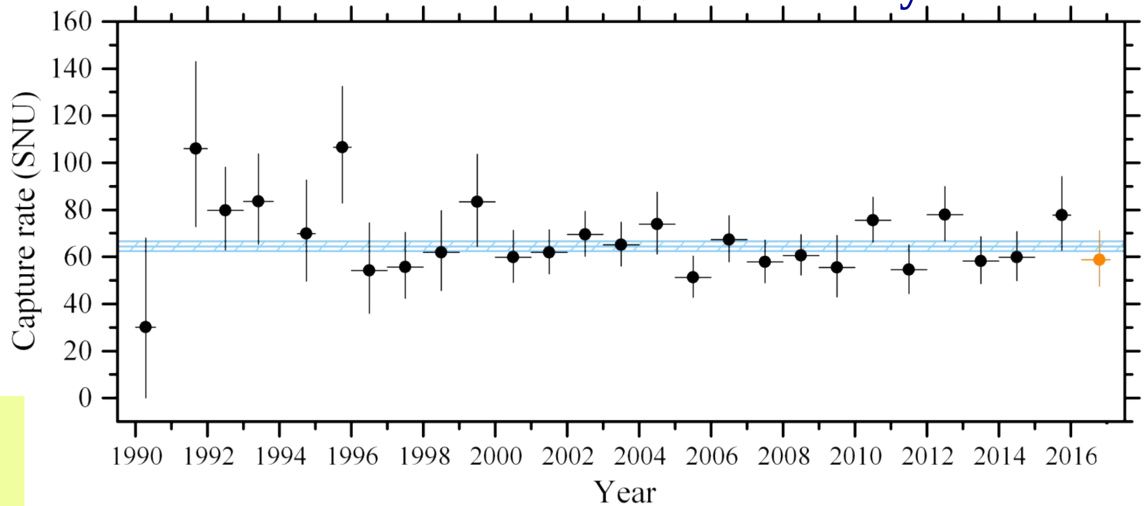
- **1.9 captures/day**
- **26 atoms of ${}^{71}Ge$/month**

**Efficiencies: (extraction, chemical, counting) ~50%,**

**one run – ≈13 decays of ${}^{71}Ge$ atoms**

**Counting time of each run ~ 150 days**

## Combined results for each year



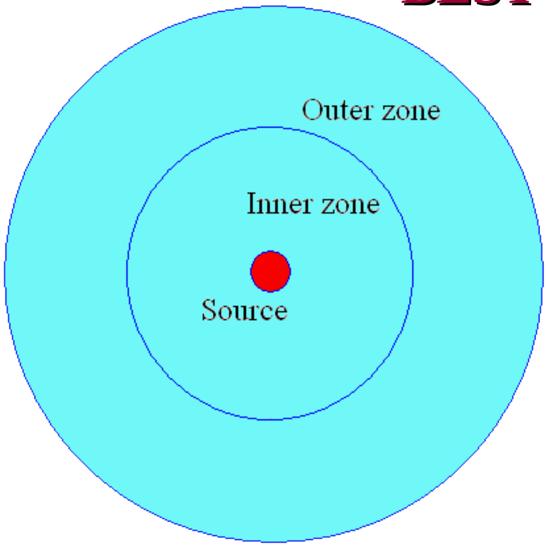

$$\text{Result}: 64.7 \pm 2.4(\text{stat.}) \, {}^{+2.6}_{-2.8} (\text{syst.}) \; SNU$$

$$\downarrow \quad 64.7 \, {}^{+3.5}_{-3.7} \; SNU$$

**[*pp*|Ga] = 39.9 ± 5.2 SNU**

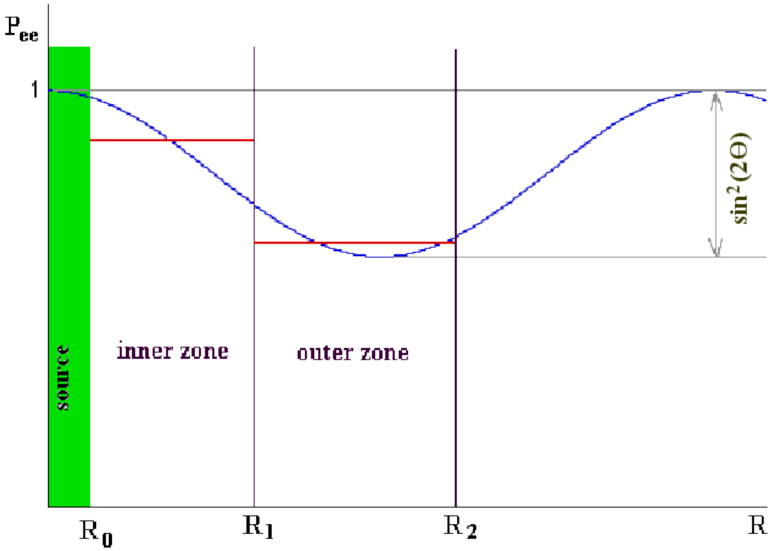
**(1 SNU = 1 interaction/s in a target that contains $10^{36}$ atoms of the neutrino absorbing isotope).**

## New Ga source experiment
## "BEST"– Baksan Experiment on Sterile Transitions




**In a new Ga experiment we will increase the sensitivity to oscillations by separating the target in two independent zones**
**- include space sensitivity, two different baselines**

**Features:**
- **(Almost) monochromatic pure $\nu_e$ (0.75 MeV)**
- **Known neutrino flux**
- **Small size of source (several cm)**
- **Negligible backgrounds**
- **High density of $\nu_e$ interactions in Ga metal**

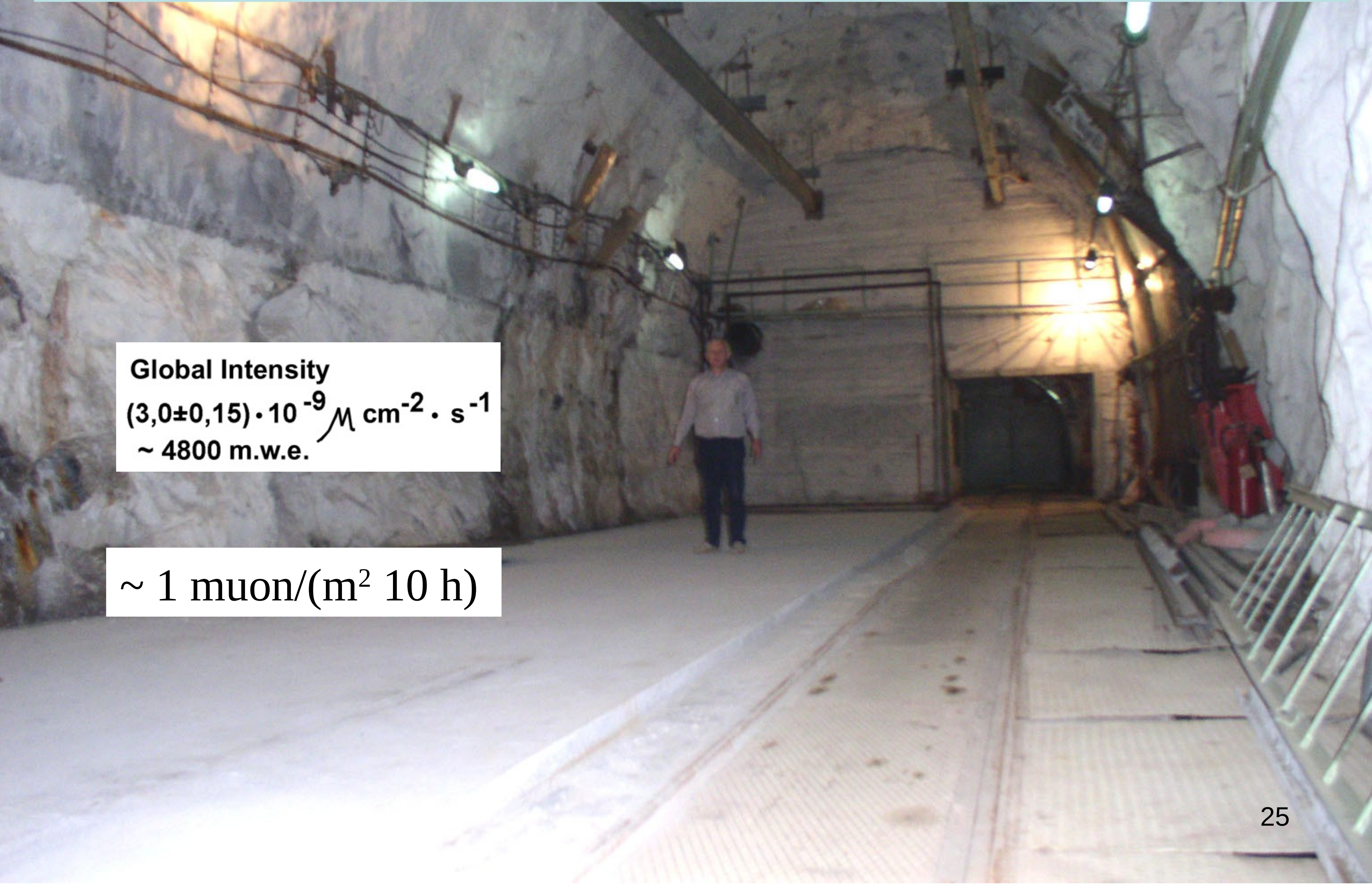


# Work stages on creation of a two-zone reactor for Ga target

1. To complete modernization of GGNT and begin to use 2-zone tank for Ga target as well as the new registration system with 8 counting channels for solar neutrino measurement – **2014**

2. Seeking funding for enrichment of 3.5 kg $^{50}$Cr & producing of 3 MCi $^{51}$Cr source – **2015 ?**

# Deep Underground Low-background Chamber



Global Intensity

$(3{,}0 \pm 0{,}15) \cdot 10^{-9} \mu\ cm^{-2} \cdot s^{-1}$

~ 4800 m.w.e.

~ 1 muon/($m^2$ 10 h)

# Deep Underground Low-background Chamber

The wall 25 cm polyethylene + 0.1 cm Cd + 15 cm Pb

# Low-background Deep-laid Chamber

# Results of low background experiments

I. Nd-150: $T_{1/2}(2□)=(1.9^{+0.7}_{-0.4})*10^{20}$ y,

$T_{1/2}(0□) \geq 1.7*10^{21}$ y

Ge-76: $T_{1/2}(2□)=(9.0 \pm 1.0)*10^{20}$ y,

$T_{1/2}(0□) \geq 1.6*10^{25}$ y

Xe-136: $T_{1/2}(2□)= (5.5^{+4.6}_{-1.7}) \cdot 10^{21}$ y (year 2011)

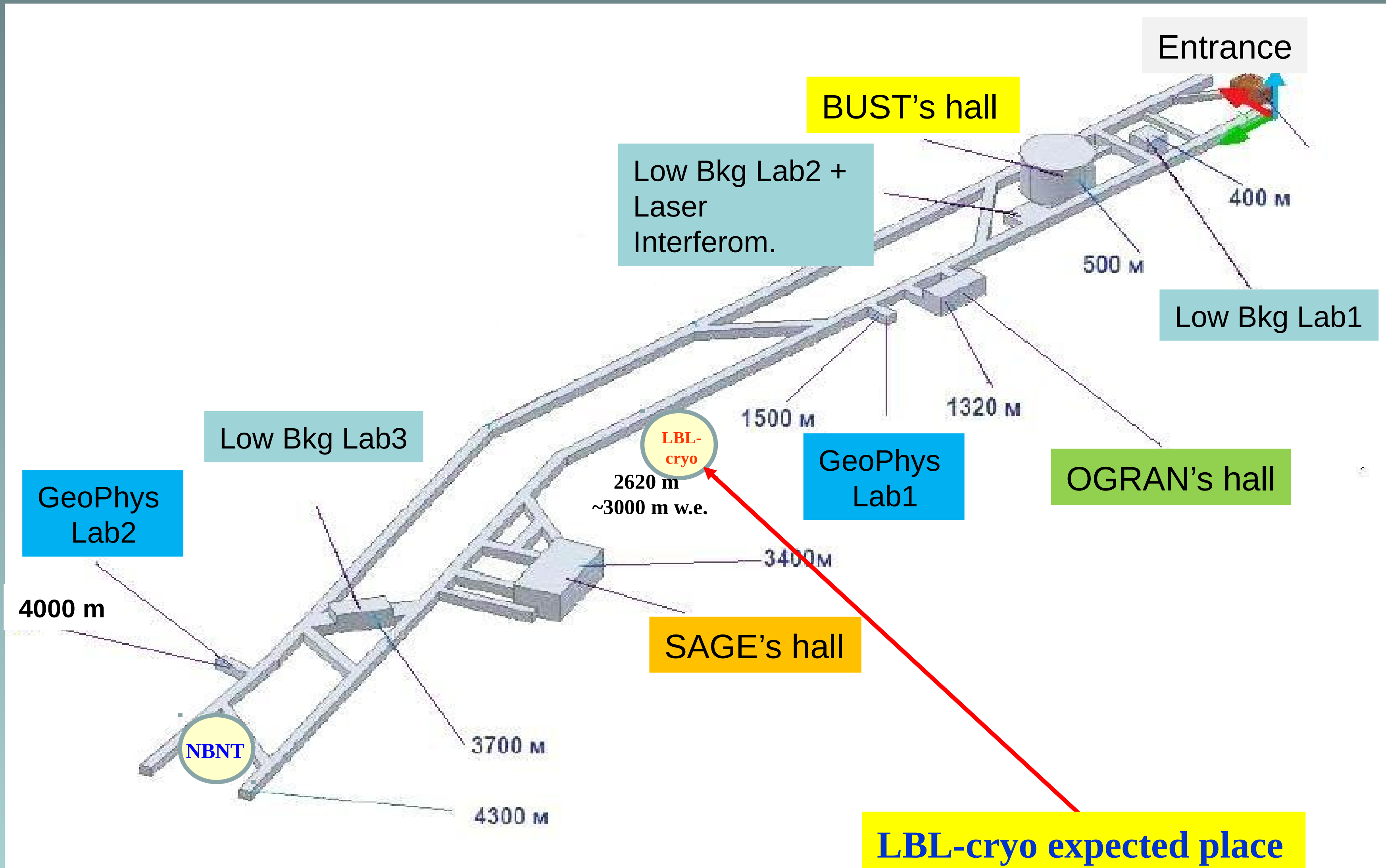
Kr-78 (2K-capture): $T_{1/2}$(2K, 2v+0v)=$(1.4^{+2.2}_{-0.7}) \cdot 10^{22}$ y (90% c.l.) (2011)

Xe-124 (2K-capture): $T_{1/2}$(2K, 2v+0v) $\geq 2.0 \cdot 10^{21}$ y (90% c.l.) (2015)

II. Limit on solar hadronic axion mass: $m_A \leq 65$ eV (95% c.l.)

III. Variation of $^{214}$Po, $^{213}$Po and $^{212}$Po half-lives: $\Delta\tau/\tau \sim (4\text{-}8) \cdot 10^{-4}$

**Participation in GERDA and AMoRE**

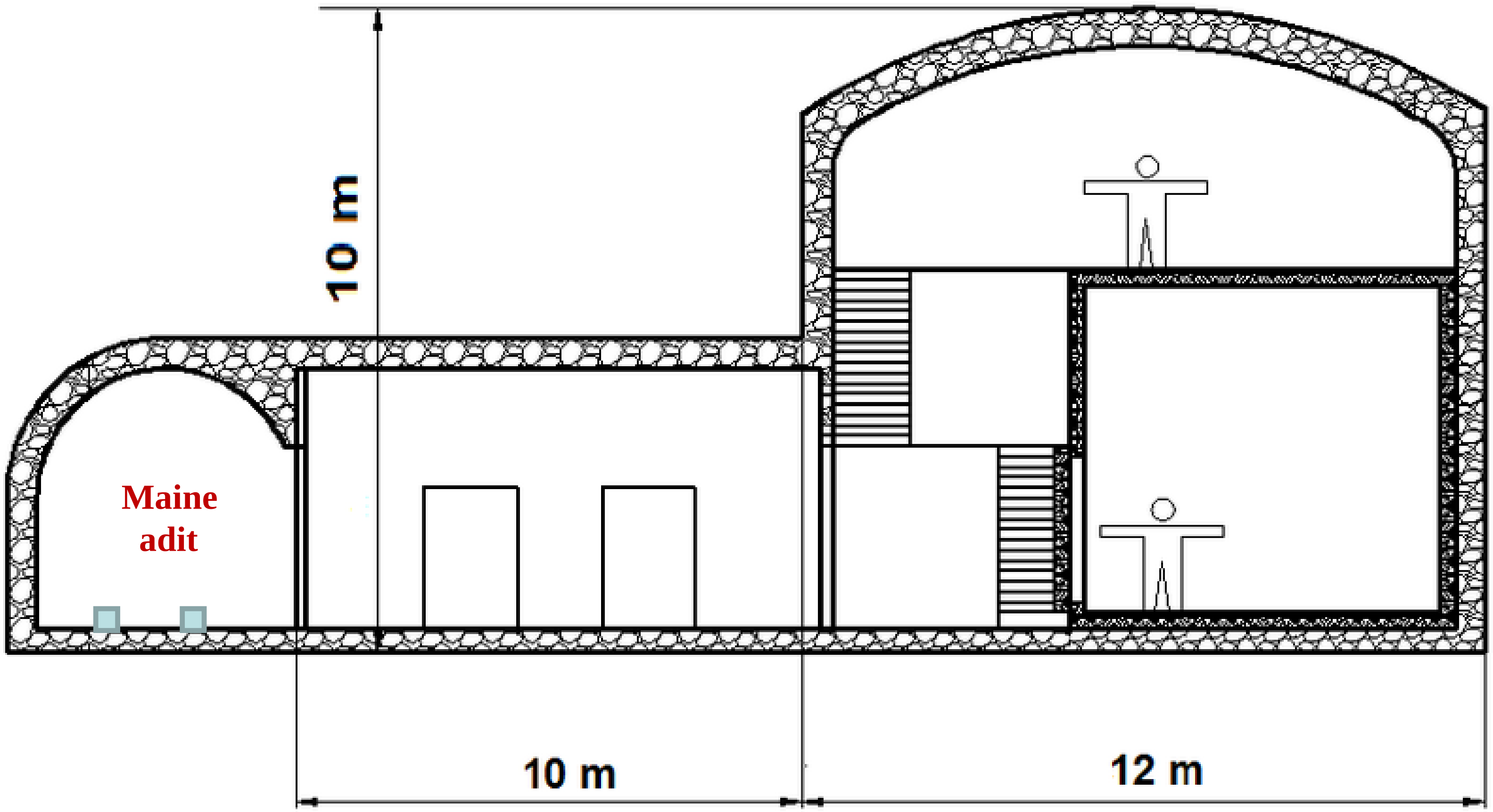



Underground Laboratories of the BNO INR RAS

# LBL-cryo expected place

**2620 м, ~ 3000 м в.э.**

# LBL-cryo expected place




Example :

$^{40}Ca^{100}MoO_4$ cryogenic scintillator detector, T~ 40 mK,

m~300 g, R=0.3-0.4% at 3000 keV

(AMoRE - collaboration)

# Laboratory of Geophysics and Gravity

1. **Laser Interferometer - MSU**
2. **Geo Physical Laboratories I and II - IEP RAS + GS RAS + KBSU**
3. **Optical–Acoustic Gravitation Antenna with cryogenic sensitivity – INR RAS+MSU+ILPh SD RAS**

**Researches carried out at the LGG**

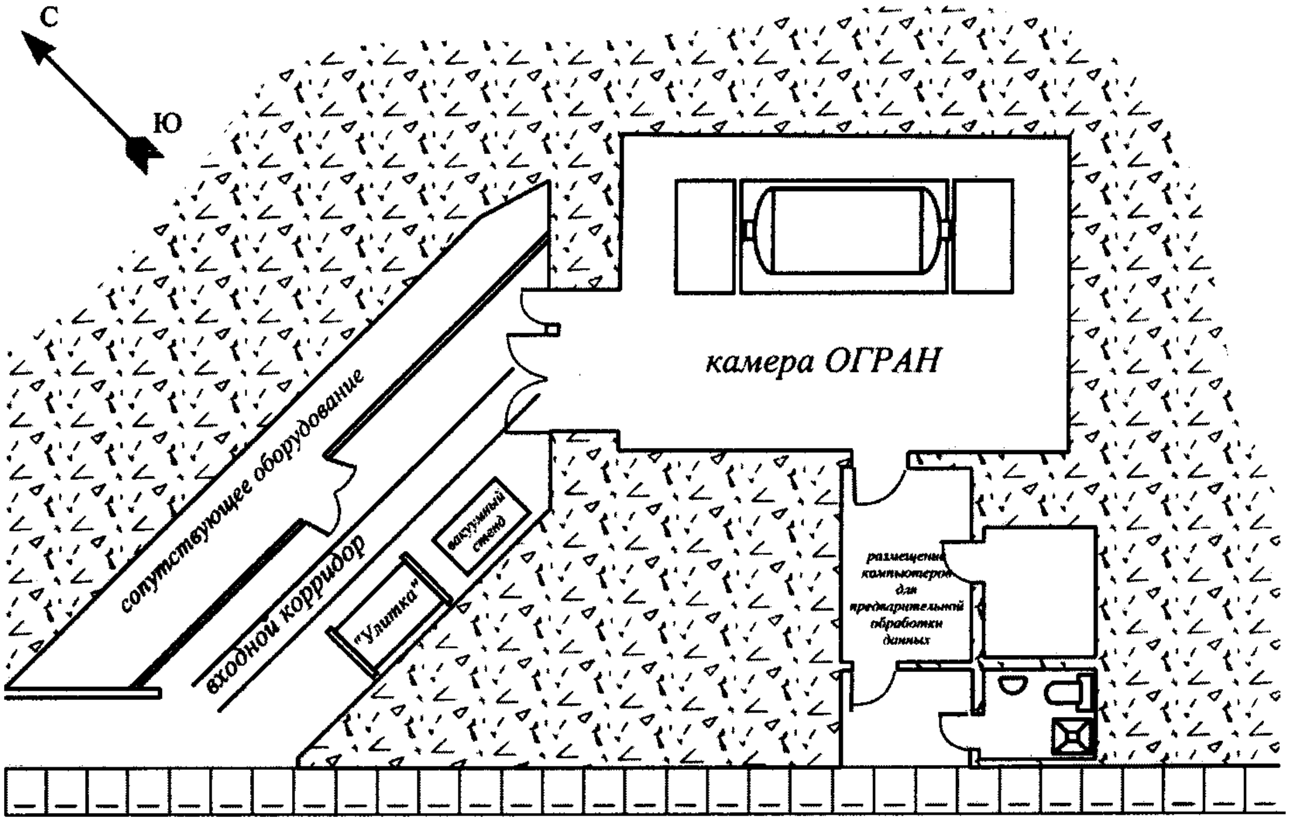
1. **Monitoring of the Earth magnetic field.**
2. **Monitoring of a drift of lithosphere plate.**
3. **Seismic monitoring.**
4. **Preparation of the OGRAN.**

# Geophysics and Gravity

View of the GeoPhys Lab1

**View of the GeoPhys Lab2 at 4000 m**

**Distant geophysical complex have tilt indicators, magnetometers, gravimeters, thermometers and earthquake detection stations.**
**Low level of noise and stable temperature (+38$^{o}$C) give good conditions for the long time measurements.**




главная штольня БНО

**At a distance of 1350 m from the entrance to the main tunnel, the new laboratory is created to accommodate the Optoacoustic GRavitational ANtenna (OGRAN).**

L = 2 m
$S_h \sim 10^{-18}$

**The OGRAN facility has been constructed using principles of solid-state and laser interferometer gravitational antennae. Acoustic vibrations of solid-state detector (manufactured in the form of cylindrical aluminum bar with a central axial tunnel) induced by gravity wave are registered by optical resonator Fabri-Perro, whose mirrors are mounted on the far ends of the detector. Low noise of such an optical read-out system allows sensitivity of relative deformation to be of $10^{-18}$ for the detector of 2.5 t without any cooling procedure. This sensitivity is good enough to detect bursts of gravity wave radiation generated in relativistic cataclysms in the center of our Galaxy (~10 kpc) and its close vicinity (up to 100 kpc) according to optimistic scenarios.**

# MULTYGOAL NEUTRINO OBSERVATORY

**>MeV**

- CNO solar neutrinos
- geoneutrinos
- relic supernova

  neutrino background
- supernova bursts
- interdisciplinary tasks

**New Baksan Neutrino Telescope (NBNT)**

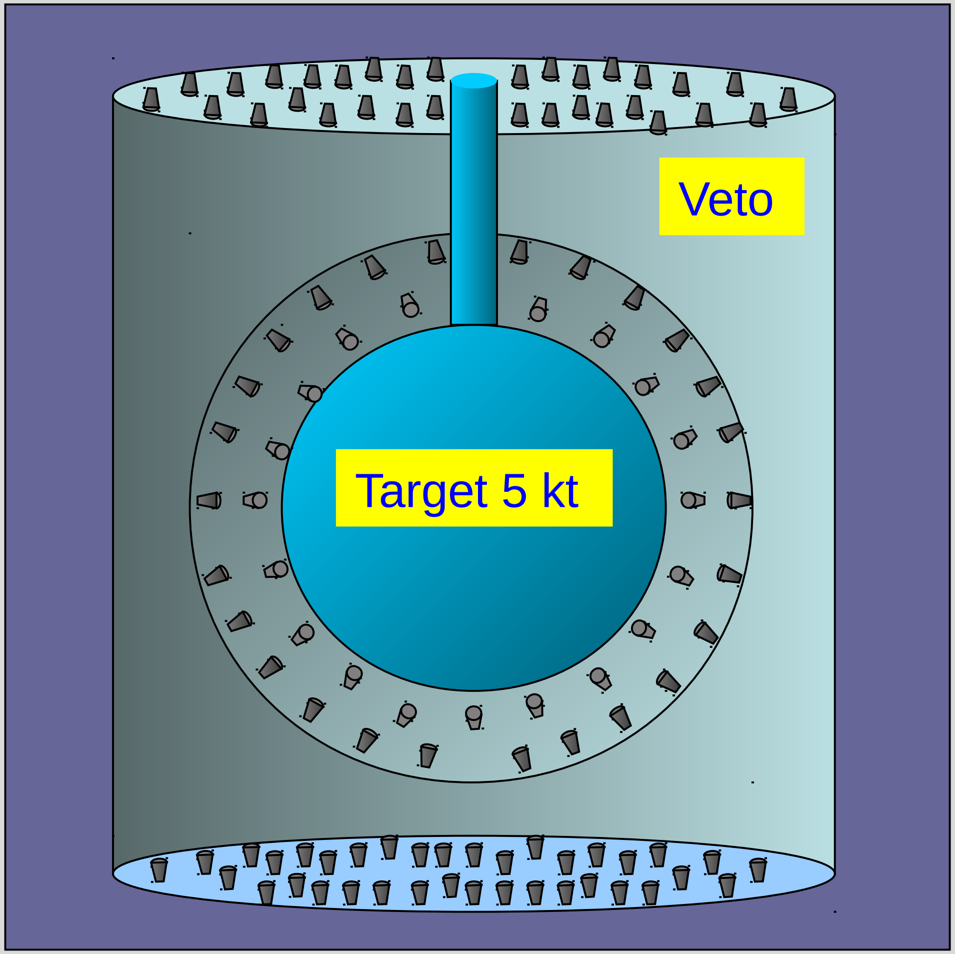
**>TeV**

- high energy astro-physics neutrinos
- cosmic rays origin
- multimessenger astrophysics
- interdisciplinary tasks

**Deep Underwater Neutrino Telescope (Baical-GVD+)**

# A large volume Baksan scintillation detector for GEO-neutrino proposed in 2006

**G. Domogatsky, V. Kopeikin, L. Mikaelyan and V. Sinev, Phys. of At. Nucl., 69, iss. 11,(2006) 1894.**



## A large volume Baksan scintillation detector for GEO-neutrino proposed in 2006

### Neutrino fluxes

**- Geoneutrinos** – study of neutrino/antineutrino fluxes from the decays of $^{40}K$, $^{238}U$, $^{232}Th$ in the Earth; georeactor (if exist)

**- Antineutrinos and neutrinos from SN burst**

**- Relic neutrinos as remnants of SN explosions in the past** (~2 events/year in 1 kT)

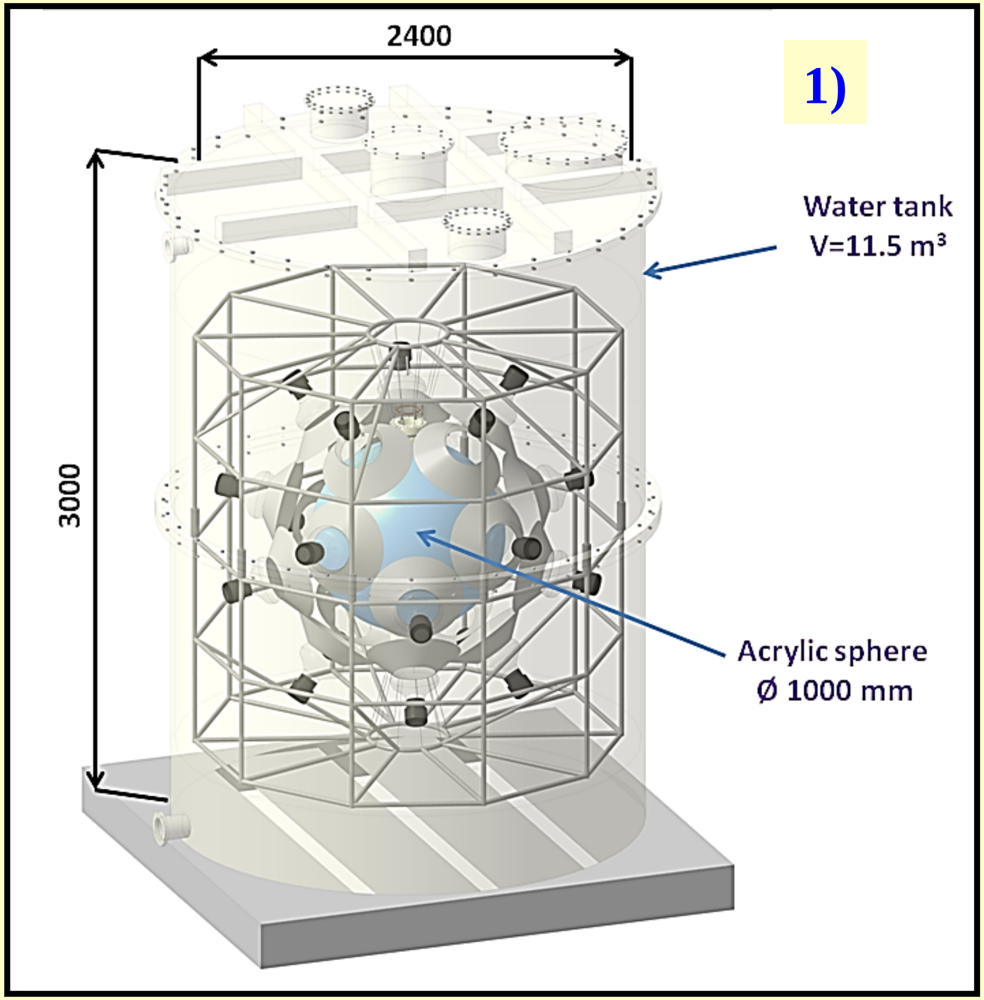
**- Solar neutrinos**

**- Reactor antineutrinos**

# Geoneutrino effect (1/year) in 1 kt ($10^{32}$ H) at known sites and its ratio to Nuclear reactors background

| Site | Mantovani et al, 2004 | Enomoto 2005 | Sinev et al., 2009 | With the core | $R=N_{geo}/N_{reactor}$ |
|---|---|---|---|---|---|
| Hawaii | **12.5** | **13.4** | **15.99** | **20.8** | **10** |
| Kamioka | **34.8** | **36.5** | **33.2** | **38.2** | **0.15** |
| Gran Sasso | **40.5** | **43.1** | **41.7** | **47.1** | **1.1** |
| Sudbury | **49.6** | **50.4** | **52.2** | **57.5** | **0.9** |
| Pyhäsalmi | **52.4** | **52.4** | **55.4** | **60.5** | **2.0** |
| Baksan | **51.9** | **55.0** | **55.1** | **61.8** | **5.0** |
| Himalaya | **60.0** | **-** | **72.8** | **83.2** | **-** |

# NBNT Prototypes

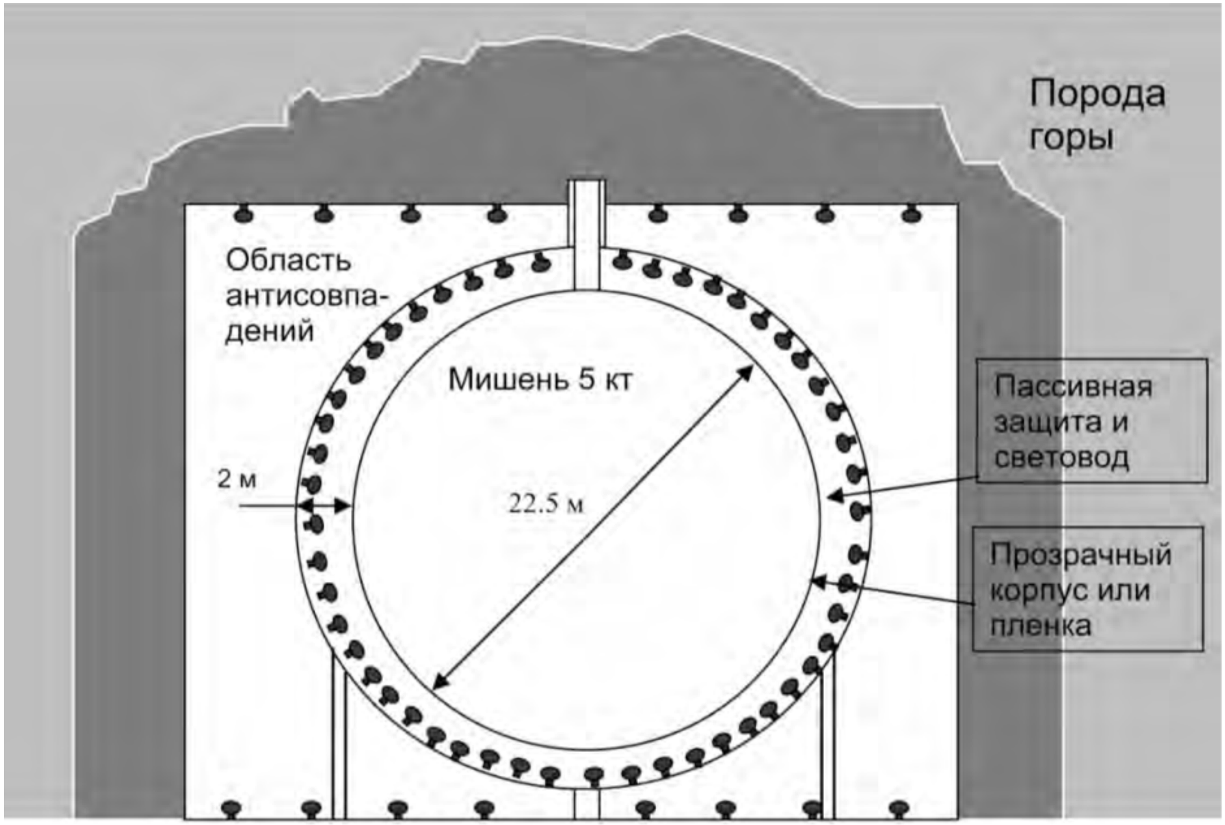



2)

- 100 t LS
- R&D
- sterile neutrino

- 0.5-1.0 t Liquid Scintillator
- 20 PMTs
- Grant РНФ 2017-2019
- Realize

# NBNT scheme




- 5-10 kt LS
- ~5200 m.w.e.
- low background
- ~1 MeV threshold
- overall configuration
- all programs

# New Baksan Neutrino Telescope (NBNT)