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Development of calibration system for a project of a new Baksan Large Neutrino Telescope

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We present results of the development of a calibration system for a project of a new Baksan Large Neutrino Telescope. The calibration system is based on fast blue and UV InGaN and AlGaN ultra bright and high power light emitting diodes (LEDs), a diffusing ball and fiber optics. Special fast electronic drivers for such LEDs were developed. The drivers are based on fast complementary pair of transistors and avalanche transistors. The diffusing ball is designed to provide uniform isotropic illumination of all photomultipliers of the detector. Thorough studies of timing and light yield parameters are done. Special emphasis is done on careful studies of compatibility of calibration system parts with liquid scintillator and ultra pure water.

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1. Introduction

A project of a new Large Baksan Neutrino Telescope (LBNT) is being presently under development [1]. The LBNT will be located at the Baksan Neutrino Observatory of INR RAS in the North Caucasus. The aim of the project is to build a large 1-10 kt liquid scintillator detector with high energy resolution. Among the main scientific goals of the project are the following:

- high precision measurements of solar neutrino fluxes, in particular ^{8}B neutrino fluxes;
- monitoring supernovae explosions in our Galaxy and its satellites;
- measurement of diffuse flux of neutrinos from supernovae explosions;
- studies of geoneutrino flux;
- measurements with powerful artificial neutrino sources
- measurements of proton decay with high sensitivity;
- dark matter searches;
- searches for magnetic monopoles, Q-balls, nuclearites and other exotics;
- geophysics studies;
- etc.

High precision measurements of ^{8}B solar neutrino flux are of utmost importance. Such measurements will solve unequivocally and ultimately the problem of solar metalicity and neutrino mass eigenstates m_1 and m_2 hierarchy. To do so one need to have a large volume liquid scintillator detector with energy resolution better than 3%/MeV, or even of order 1%/MeV, if it will be feasible at al. The latter is undoubtedly experimental challenge for the project. Measurements of geoneutrino fluxes are another experimental challenge too.

Strictly speaking every physics motivation points listed above put very strong requirements on the detector parameters. To withstand such challenges the detector should have high energy resolution, in fact as higher as possible, excellent time resolution and high stability of parameters over the years, at least for a decade.

To have high energy resolution better than 3%/MeV or even ~ 1%/MeV for 1kt-10kt detector liquid scintillator should have high transparency (better that 30 m attenuation length) and high light yield, more than 80% (or higher, ideally – 100%) covering of the detector area by photocathodes. To reach so high value of photocathode covering of the detector area is possible using large area photomultipliers and Winston cones. On the other hand it is possible to exploit high quantum efficiency photocathodes with 40% or more quantum efficiency at their maximum of sensitivity. To get liquid scintillator with higher light yield (~ 20kγ/MeV) is also possible as it was shown in [2]. All this factors will help to reach high energy resolution as high as 1%/MeV!

Presently searches for new scintillator materials, organic solvents and fluors, resulting in new high quality liquid scintillator detectors are being underway with promising results. Photomultipliers with high quantum efficiency of 40% and even higher photocathode are also available. So, we believe that perspectives for large-scale liquid scintillator experiments are bright.

The last but not least point is to have high precision, reliable and robust calibration system – photon calibration system for the detector's photomultipliers gain and sensitivity and controlling and monitoring liquid scintilator transparency.

2. Detector project and prototypes

The detector project envisages several stages. The first stage is the development of a half ton (0.5-t) liquid scintillator detector to test all elements of the project: liquid scintillator, its transparency, light yield; engineering system for storing, filling, removing, safety issues connected with liquid scintillator; photomultipliers, evaluation of their performance (sensitivity, single photoelectron response, timing etc.), their encapsulations, water proofing, material compatibility etc.; detector electronics and DAQ system, data storage etc. It is also important to measure the level of radioactivity in the underground laboratory and screen all the detector materials for radioactivity and to test capabilities of veto (passive and active) systems.

The first 0.5-t prototype of the project before filling by liquid scintillator and immersing into the water tank is shown in Fig.1.

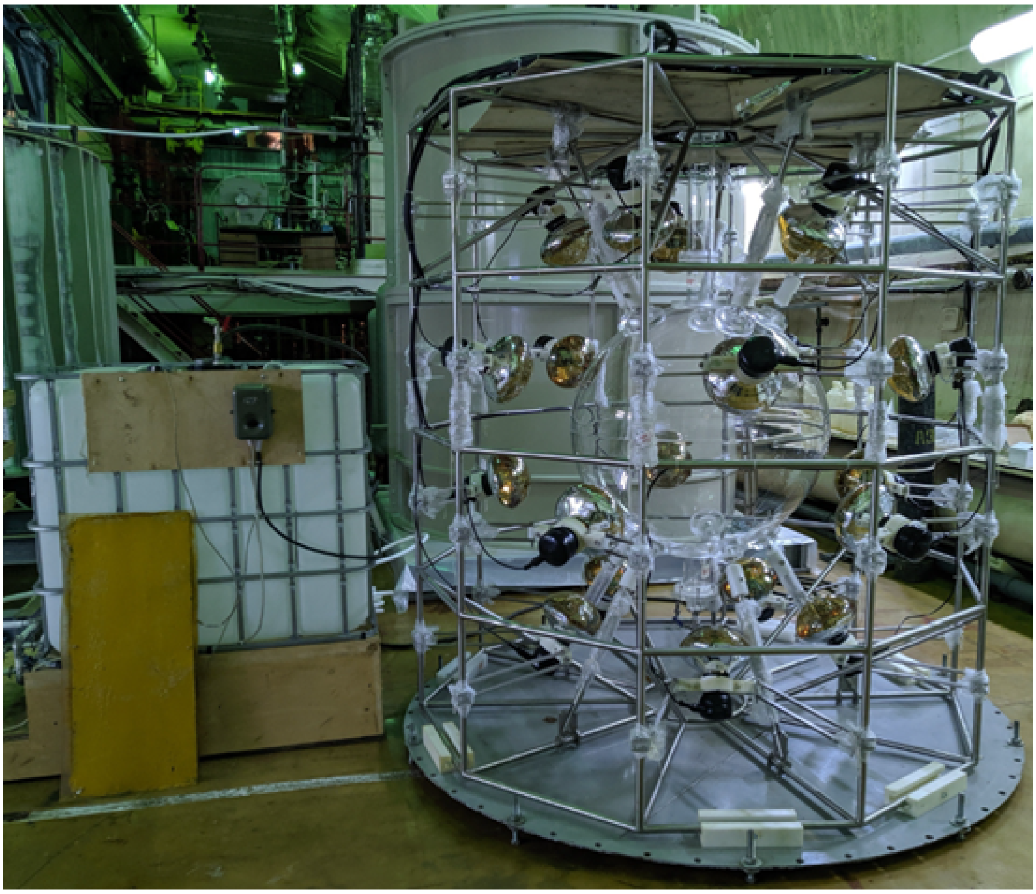


Figure 1: The first 0.5-t prototype of the Large Baksan Neutrino Telescope project. The prototype is shown at the stage when all parts are assembled and fixed right before filling by 0.5 t liquid scintillator and immersing into water tank, seen behind the PMT array.

Acrylic sphere, ∼ 100 cm in diameter, for ∼ 0.5 t liquid scintillator is clearly seen in the centre of the PMTs array. Twenty PMTs are fixed at the stain steel scaffolding. PMTs are 10-inch Hamamatsu R7081-100 WA-S70 high quantum efficiency water proof photomultiplier assemblies; one can see black water proof covering of PMTs voltage dividers and signal cables coming out of coverings. High voltage is delivered to PMT by the same cable as signals. The whole array are put into water tank, 240 cm in diameter and 280 cm high.

There is a chimney in the acrylic sphere for mostly liquid scintillator filling, Fig.1. Through this chimney it is also possible to put down calibration source: calibration light pulses diffuser in case of photon calibration system or a container with radioactive source in case of calibration system based on a radioactive source (γ-quanta or neutron source).

The second stage will be a 5-t prototype [3], shown in Fig.2.

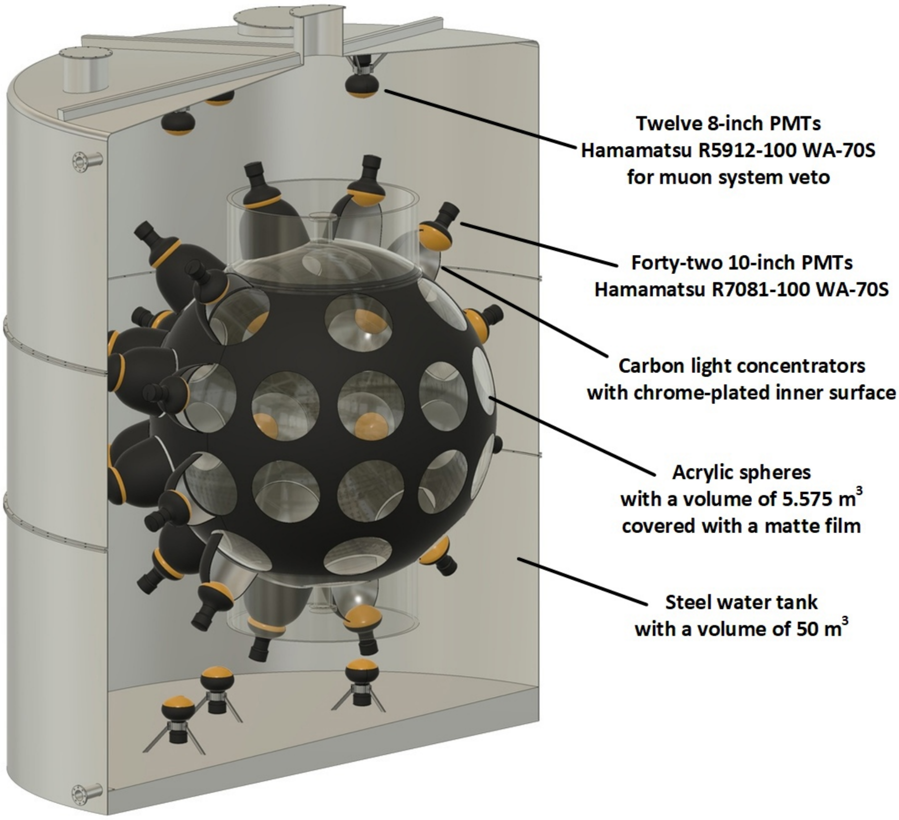


Figure 2: The second 5-t prototype of the Large Baksan Neutrino Telescope project. The prototype is shown at the stage when all parts are assembled and fixed right before filling by 5 t liquid scintillator and immersing into water tank, seen behind the PMT array.

At this stage 5 t of liquid scintillator in acrylic sphere will be viewed by forty-two 10-inch Hamamatsu R7081-100 WA-S70 PMTs. Each PMT of the array will be equipped by a Winston cone to increase light yield of the detector. All areas of the acrylic sphere just outside of the Winston cones will be covered by non-transparent foil separating optically scintillator volume. The array will be surrounded by a stainless steel tank which will be filled with ultra pure water and equipped by twelve 8-inch Hamamatsu R5912-100WA water proof photomultiplier assembles.

There are also chimneys and outlets to insert fibers, light diffusers and containers with radioactive source for calibration purposes.

We plan to have a third stage – 100-t prototype of the project after completing the second one. After this stage the final project will start.

3. Light source, LED drivers

Ultra bright light emitting diodes (LEDs) with InGaN/GaN single or multi-quantum well structures provide very convenient and useful, high quality and reliable and robust base for development of very fast powerful light source in wide region of wavelengths spanning from UV to green regions of light spectrum.

For the 0.5-t first stage of the project we developed photon calibration system based on a fast light pulses source and a plastic fiber system and a light pulses diffuser. The fast light pulses source is based on ultra bright InGaN/GaN blue LEDs and a fast LED driver.

The light emission kinetics of LED based light sources depends mainly on both LED itself and driver's property. One should select thoroughly LED with the fastest emission kinetics and to build its driver would suit its kinetics. So, after a wide campaign of searching for the fastest LED we chose violet GNL3014VC with λ_{max}~405 nm and blue GNL3014BC with λ_{max}~470 nm. Their brightness (light yield) is at the acceptable level. It should be noted that there are faster and brighter LEDs [4, 5], but unfortunately they are not produced any more and available from stores.

The fast driver for theses LEDs are based on the fast discharge of a small capacitor via a fast complementary pair of RF transistors with 6 GHz bandwidth. We refer for all details of the driver to [5–7]. The electrical scheme of the driver is shown in Fig.3. T1 and T2 – BFT92 and BFR92P correspondingly; C1 - 47 pF; C2 – 100 pF discharging capacitor; R1 - 100 kΩ; R2 – 2.2 kΩ; R3 – 10 kΩ; L – 100nH; LED – GNL3014VC or GNL3014BC.

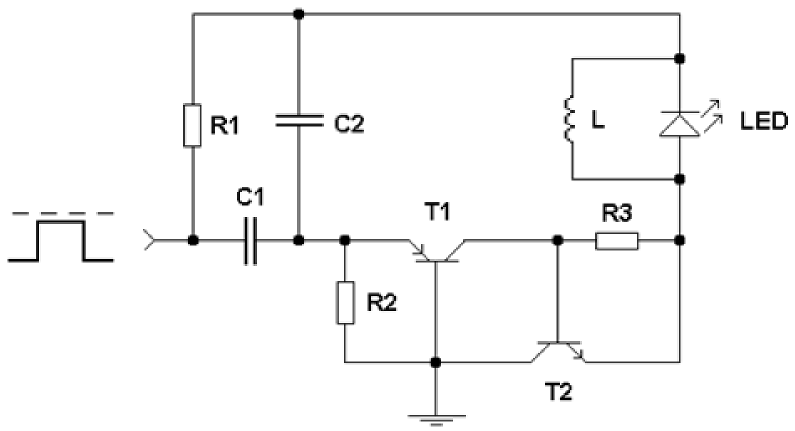
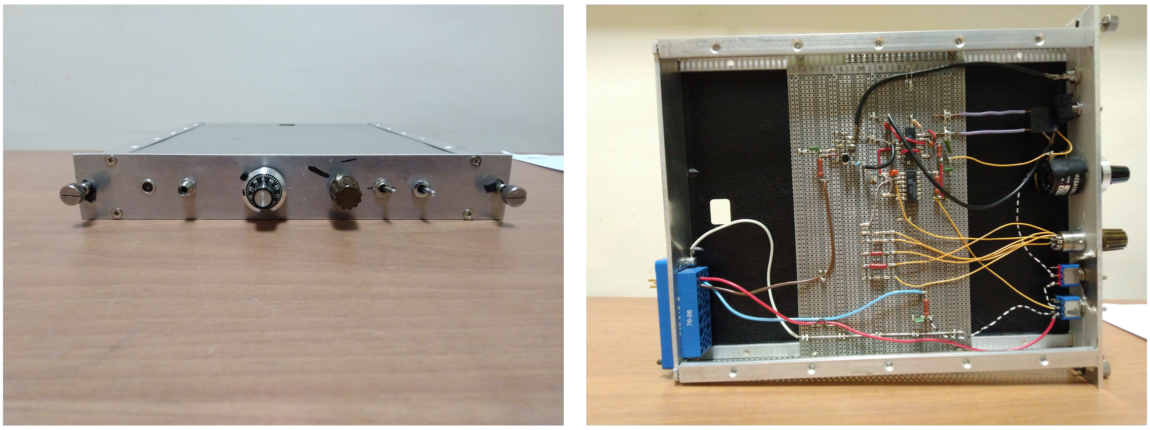


Figure 3: Electrical scheme of the fast LED driver [5, 7]. LED – GNL3014VC or GNL3014BC; T1 – BFT92; T2 – BFR92P; C1 – 47 pF; C2 – 100 pF; R1 – 100 kΩ; R2 – 2.2 kΩ; and R3 – 10 kΩ; L – 100 nH.

The driver is built on separate small PC board which is in turn incorporated into a NIM single wide module together with generator triggering pulses for the driver and synchronization pulses with a jitter less than 100 ps. The fast LED is fixed directly into fibers optical connector right on the front panel of the module. The light pulses and their intensity are driven manually from the front panel of the module. The light pulses light yield is adjusted in a wide range of 0-10^8 γ/pulse with $\sim$ 1 ns width (FWHM) and with repetition rate of 0-100 kHz.

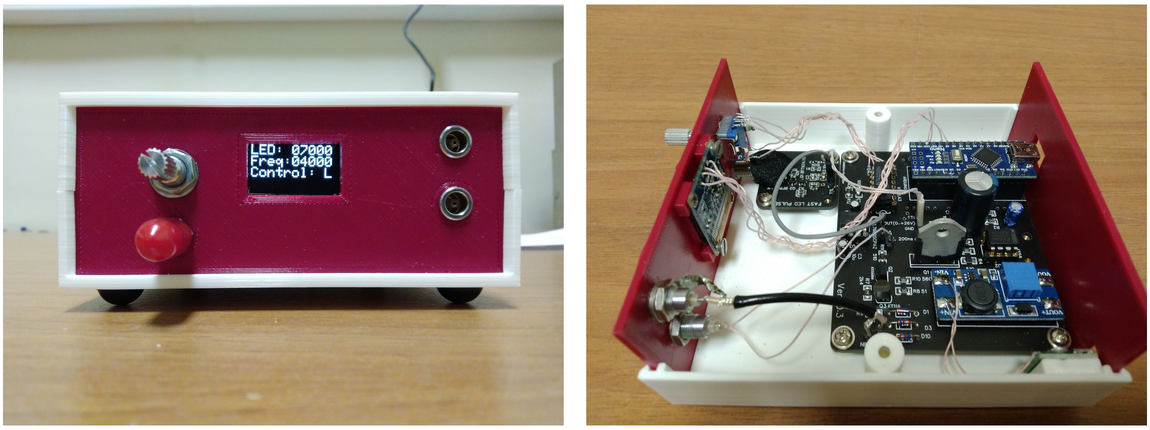
This NIM module is presented in Fig.4(a, b).



a) b)

Figure 4: NIM module of fast light pulses source for calibration of the 0.5-t prototype of the Large Baksan Neutrino Telescope project: a) front view; b – without cover.

Along with the NIM module a stand-alone desktop module was developed too. This module, Fig.5(a, b) incorporates the fast LED driver PV board and specially designed system based on Arduino Nano v3 plate with 8-bit microcontroller AVR ATmega328P (Atmel).



a) b)

Figure 5: Stand-alone desktop module of fast light pulses source for calibration of the 0.5-t prototype of the Large Baksan Neutrino Telescope project: a) – front view; b) – without cover.

Optical connector is capped by a red plug. The module is driven by a computer via USB connector. There is an opportunity to drive it manually from the front panel.

4. Fibers, Diffuser, Compatibility studies

Comar FS 04 plastic optical cable with 1 mm PMMA core and black clad from PVC is used to deliver light pulses from the light source to a specially designed diffusing ball. The diffusing ball is shown in Fig.6.

Figure 6: Diffusing ball.

The diffusing ball is made of a glass sphere with 5 cm in diameter and 1 mm thickness. The sphere is filled with a special mixture prepared in advance. The mixture is made of SilGel Wacker 612A silicone gel and S32 glass microspheres powder. The end cap of the fiber is fixed at the point of 5 mm above the geometrical center of the glass sphere and gel mixture is poured into the sphere. The diffuser does not deteriorate the light pulses width. The light level intensity is still enough to illuminate the whole array of photomultipliers in the wide dynamic range.

The outer clad of the fiber should be compatible with linear alkylbenzene. To test it we have been carrying a dedicated long-term measurements with the fiber sample immersed into linear alkylbenzene. After almost two years we did not observe any deterioration of the cable.

Recently we are developed also containers for encapsulation of radioactive source of γ-quanta for energy calibrations of the project prototypes. The radioactive calibration sources will be tested in the nearest future.

5. Conclusion

We developed calibration system for 0.5-t and 5-t prototypes of the Large Baksan Neutrino Telescope project. The system performance is adequate for the requirements of the project prototypes. The system can be served as a prototype of a calibration system of the whole project.

6. Acknowledgments

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References

[1] N. Ushakov et al., *New large-volume detector at the Baksan Neutrino Observatory: Detector prototype*, *Journal of Physics: Conference Series* **1787** (2021) 012037.

[2] S. Lubsandorzhiev et al., *Development of new liquid scintillators for neutrino experiments of next generation*, *PoS* **ICRC2019** (2020) 946.

[3] N. Ushakov et al., *A new Baksan Large Neutrino Telescope: the project's status*, *PoS, ID:1188* **ICRC2021** (2021) .

[4] J. Kapustinsky et al., *A fast timing light pulser for scintillation detectors*, *Nuclear Instruments & Methods in Physics Research Section A-accelerators Spectrometers Detectors and Associated Equipment* **241** (1985) 612.

[5] B. Lubsandorzhiev and Y. Vyatchin, *Studies of 'Kapustinsky's' light pulser timing characteristics*, *JINST* **1** (2006) T06001 [physics/0410281].

[6] Y. Vyatchin, *PhD. Thesis (in Russian)*, 2006.

[7] B. Shaibonov, *PhD. Thesis (in Russian)*, 2010.