PAPER • OPEN ACCESS

Development of scintillation detectors with light collection via wavelength shifting light guides for TAIGA experiment

To cite this article: E Kravchenko *et al* 2022 *J. Phys.: Conf. Ser.* **2374** 012042

Development of scintillation detectors with light collection via wavelength shifting light guides for TAIGA experiment

E Kravchenko[11,12], J E Alizzi[11], I Astapov[9], P Bezyazeekov[2], A Borodin[10], M Brueckner[8], N Budnev[2], A Chiavassa[4], A Dyachok[2], A Gafarov[2], A Garmash[11,12], V Grebenyuk[10,14], O Gress[2], T Gress[2], A Grinyuk[10], O Grishin[2], D Horns[6], A Igoshin[1], A Ivanova[2,11], N Kalmykov[1], V Kindin[9], S Kiryuhin[2], R Kokoulin[9], K Kompaniets[9], E Korosteleva[1], V Kozhin[1], A Kryukov[1], L Kuzmichev[1,2], A Lagutin[15], M Lavrova[10], Y Lemeshev[2], B Lubsandorzhiev[3,1], N Lubsandorzhiev[1], D Lukyantsev[9], S Malakhov[9], I Mamaev[11], R Monkhoev[2], R Mirgazov[2], R Mirzoyan[5,1], E Osipova[1], A Pakhorukov[2], A Pan[10], L Panasenko[11], L Pankov[2], A Petrukhin[9], I Poddubnyi[9], V Poleschuk[2], V Ponomareva[9], M Popesku[13], E Popova[1], A Porelli[8], E Postnikov[1], V Prosin[1], V Ptuskin[7], A Pushnin[2], R Raikin[15], G Rubtsov[3], E Ryabov[2], Y Sagan[10,14], V Samoliga[2], A Silaev[1], A Sidorenkov[3], A Skurikhin[1], V Slunecka[10], A Sokolov[11,12], Y Suvorkin[2], L Sveshnikova[1], V Tabolenko[2], B Tarashchansky[2], L Tkachev[10,14], M Tluczykont[6], A Tanaev[2], M Ternovoy[2], R Togoo[17], N Ushakov[3], A Vaidyanathan[11], P Volchugov[1], D Voronin[3], R Wischnewski[8,10], A Zagorodnikov[2], D Zhurov[2,16] and I Yashin[9]

[1] Skobeltsyn Institute of Nuclear Physics MSU, Moscow, Russia
[2] Institute of Applied Physics ISU, Irkutsk, Russia
[3] Institute for Nuclear Research RAS, Moscow, Russia
[4] Dipartimento di Fisica Generale Universiteta di Torino and INFN, Torino, Italy
[5] Max-Planck-Institute for Physics, Munich, Germany
[6] Institute for Experimental Physics, University of Hamburg, Germany
[7] IZMIRAN, Moscow, Russia
[8] DESY, Zeuthen, Germany
[9] National Research Nuclear University MEPhI (Moscow Engineering Physics Institute), Moscow, Russia
[10] Joint Institute for Nuclear Research, Dubna, Russia
[11] Novosibirsk State University, NSU, Novosibirsk, Russia
[12] Budker Institute of Nuclear Physics SB RAS, Novosibirsk, Russia
[13] ISS, Bucharest, Romania
[14] Dubna State University, Dubna, Russia
[15] Altai State University, Barnaul, Russia
[16] Irkutsk National Research Technical University, Irkutsk, Russia
[17] Institute of Physics and Technology Mongolian Academy of Sciences, Ulaanbaatar, Mongolia

E-mail: e.kravchenko@nsu.ru

Abstract.
The TAIGA gamma observatory is continuing its deployment at the Tunka valley, close to lake Baikal. The new, original detectors, able to work under severe conditions of Siberia, were developed to increase the TAIGA sensitivity for the study of gamma-quanta at energies about 1 PeV and above. The distinguishing feature of the detectors is the use of the wavelength shifting light guides for scintillation light collection on a photodetector. Several designs of the counters have been tested: equipped with PMT or SiPM photo-detectors, acrylic or polystyrene based scintillators with thickness from 1 to 5 cm and detecting area from 0.75 to 1.0 m^2. The data on the amplitude of the signal from cosmic muons measured in different points within the counter are presented. The first 48 counters were produced and deployed in 2019 at the TAIGA experiment. They form 3 stations each with 8 surface detectors and 8 underground detectors buried at the depth of 1.7 m. After two winters, all counters are working.

1. TAIGA-Muon scintillation array
The TAIGA-Muon scintillation detector array, which is a network of surface and underground detectors for the detection of charged particles of EAS, began to be deployed at the TAIGA experiment area, in addition to the existing Tunka-Grande scintillation array. It is assumed that in the future the total area of the installation will be about 2000 m^2 and it will search for cosmic gamma-rays in the energy range from 50 TeV together with the Cherenkov experiments of the TAIGA gamma-ray Observatory[1]. By the autumn 2019, the first three TAIGA-Muon clusters were installed. They consist of 8 surface and 8 underground scintillation detectors of the base design respectively. Surface and underground detectors in clusters are located in pairs, surface detectors are strictly above the underground ones buried at a depth of 1.7 m, along the perimeter of the square with a side length of 5 m. In addition to the detectors, each cluster has a thermally insulated container (electronic box), which contains electronics designed for collecting and transmitting the experimental data. Since December 2019, the first TAIGA-Muon cluster has started operation in a test mode.

2. Development of scintillation detectors
The use of scintillation counters for the detection of EAS secondary particles at the ground level at TAIGA experiment imposes special conditions on their design:

- large area (about 1 m^2 or more),
- ability to work in a wide temperature range (-40^o C to +40^o C),
- sealed design (to withstand groundwater),
- reliability
- low cost.

To satisfy the above requirements it was suggested to use a design with the wavelength shifting light quides (shifters) like in the ASHIPH aerogel counters of the KEDR detector [2]. This helped us to minimize the thickness of the scintillator to 1-2 cm and use PMT with a small photocathode diameter, thus minimizing the total cost of the detector.

2.1. Base design
The base design of scintillation counters was developed by the Novosibirsk State University and Budker Institute of Nuclear Physics (Fig. 1)[3]. There are two stages of the scintillation light collection on the PMT. The part of the emitted scintillation light ($\lambda = 415$ nm) is captured into the angle of the total internal reflection and transported to the ends of the scintillation plates. This light hits the shifters, where it is absorbed and reemitted ($\lambda = 500$ nm). Again the part

of this reemitted light is captured into the angle of the total internal reflection and transported to the end of the shifters where it hits the PMT photo cathode. The far end of the shifter is painted with special reflecting paint to double the light collection. The main features of the base design are:

- polystyrene based scintillator (central plates - 1 cm thickness, external - 2 plates of 1 cm thickness)
- detection area 0.94 m^2,
- 4 wavelength shifting light guides with 5x20 mm cross section and the length up to 860 mm,
- FEU-85-4 with the photocathode diameter of 25 mm is used for the light detection,
- stainless steel case.

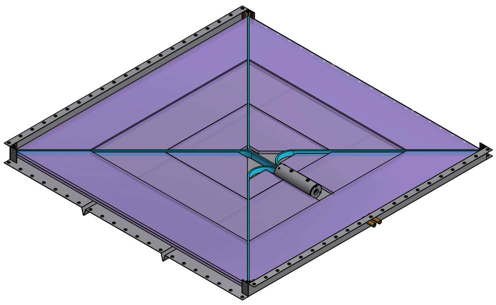

Figure 1. The base design of the scintillation counter.

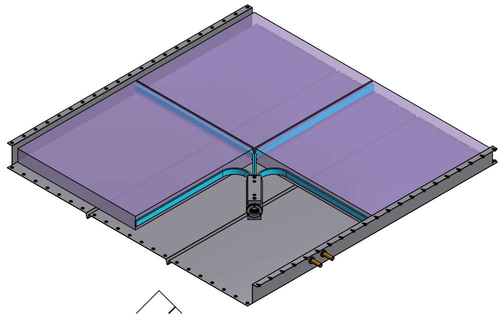

Figure 2. The design of the counter with 5 cm thick scintillation plates.

After assembly the counters were tested with single cosmic muons. Special small trigger counters (100x100 mm) localize muons in different locations within the counter area. The mean number of photoelectrons within the counter area and the RMS of amplitude variation were calculated (Table 1).

Table 1. The mean number of photoelectrons from a single muon, RMS of the amplitude variation and the detection area for the counters of different design.

	$\mathbf{A}_{mean}$,$\mathbf{N}_{pe}$	**RMS**,%	S_{det},m^2
Base design	31	20	0.94
SiPM design	90	20	0.94
Design with 5 cm plate	130	14	0.75

2.2. Alternative designs

Two alternative designs of the scintillation detectors were successfully tested:

Special design was developed to utilize large scintillation plates (500x500x50 mm) based on PMMA which are currently available for the TAIGA collaboration for detector construction from earlier projects. 3 plates are used in one counter with the total detection area of 0.75 m^2, the shifters and the PMT assembly were taken from the base design (Fig. 2). Tests with single muons showed the mean amplitude of 130 photoelectrons and smaller amplitude variation (Table 1, Design with 5 cm plate). The increase in amplitude comparing with the base design is explained by better light collection of scintillation light on the shifters due to the larger thickness of scintillatation plates, much better quality of their surface smoothness and smaller length of shifters.

FEU-85-4 was replaced by 3x3 matrix of Hamamatsu S13360-6050VE (6x6 mm) SiPMs (Fig. 3).These led to threefold increase in the amplitude up to 90 photoelectrons from a single particle (Table 1, SiPM design).

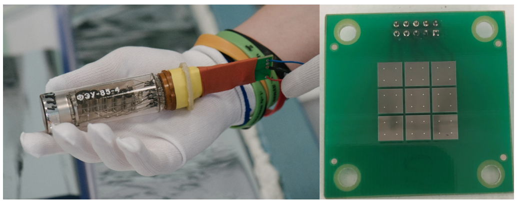

Figure 3. FEU-85-4 with HV divider and SiPM matrix.

3. Status and conclusion

In January 2021 counters of the first TAIGA-Muon cluster have been tested to check the stability of parameters after two winter seasons of operation. The coincidence rates of 8 pairs of counters (top+underground) were measured. The variation of rates fits into ± 5%. This number could be explained by the difference in the detection areas of counters and the variation of thresholds in electronics. The measured rates are presented in the Table 2.

Table 2. The coincidence rates in pairs of counters – top+underground, s^{-1}.

1-9(1)	**2-9(2)**	**3-10(1)**	**4-10(2)**	**5-11(1)**	**6-11(2)**	**7-12(1)**	**8-12(2)**
18.6	18.7	18.5	17.0	18.4	17.4	17.4	17.5

The tests carried out in the lab and under the real experimental conditions revealed the efficiency of the proposed design based on the wavelength shifting light guides. The production of the counters and the deployment of the new TAIGA-Muon stations will be continued.

Acknowledgments

The reported study was funded by the Russian Federation Ministry of Science and High Education FSUS-2020-0039. The work was performed at the UNU "Astrophysical Complex of MSU-IS" and supported by Russian Foundation for Basic Research (grant 19-52-44002).

References

[1] Budnev N et al. (TAIGA Collaboration) 2017 *Nucl. Instrum. Methods A* **845** 330-333
[2] Barnyakov M Yu et al. 1998 *Nucl. Instrum. Methods A* **419** 584-589
[3] Astapov I et al. (TAIGA Collaboration) 2019 *Nucl. Instrum. Methods A* **936** 254–256
[4] Gress O et al. (TAIGA Collaboration) 2017 *Nucl. Instrum. Methods A* **845** 367-372