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Implementation of silicon photomultipliers in scintillation detector systems of the GAMMA-400 space gamma-ray telescope

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The scintillation detectors characteristics of GAMMA-400 gamma-ray space telescope constructed with the implementation of silicon photomultipliers manufactured by different manufacturers are reported. The measurements were carried out at the technological model of the gamma-ray telescope. The efficiency, amplitude ant timing properties of fast plastic large area scintillators were investigated. The detectors characteristics matching to the requirements for the systems of gamma-ray telescope is shown.

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1.Introduction

The International Collaboration GAMMA-400 develops gamma-ray telescope for the energy range from 200 MeV up to 3000 GeV with very high angular and energy resolution on board of the satellite at very high apogee orbit (up to 300 000 km). Charged particles would also be detected.

The device will investigate point gamma-ray sources and peculiarities in the energy spectrum of diffuse gamma-radiation that can be attributed to annihilation of dark matter particles.

The gamma-ray telescope [1-2], shown in fig. 1, has the total area of 1 m^2 and consists of fast plastic scintillator anticoincidence detector AC forbidding the charged particle detection, multilayer (tungsten + silicon strip detectors) converter C for gammas conversion to the electron-positron pair and for their trajectories visualization. Time-of-flight (TOF) system (S1 and S2 fast plastic scintillator counters with 50 cm base) generates the trigger signal for particles moving up-to-down after the conversion. Two sections of heavy CsI(Tl) calorimeter (CC1 and CC2) are interleaved by one more fast scintillator (S3), indicating the level of shower development. S4 leakage detector and the neutron detector ND for electron-proton discrimination are placed under the calorimeter.

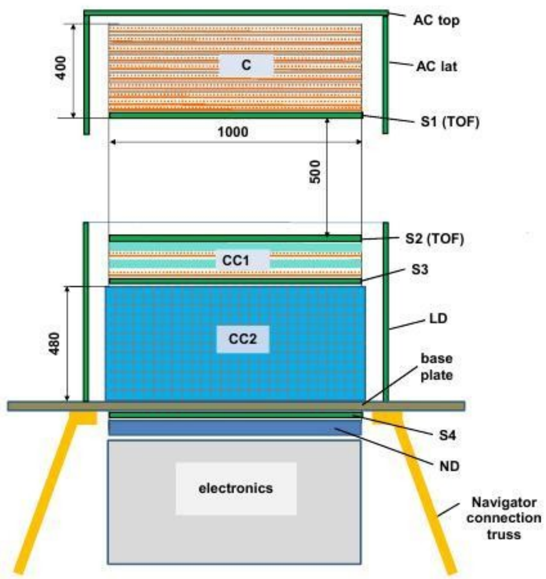

Fig. 1. The layout of the gamma-ray telescope GAMMA-400.

2.SiPM implementation in fast scintillation detectors

AC, S1, S2, S3 and S4 detectors, developed by our group, are based each on two layers of 10 mm thick Bicron-408 fast plastic scintillators with silicon photomultipliers readout. We aim on reaching high detection efficiency for these detectors and high time resolution for TOF detectors (what is obvious) and for AC detectors, since we are intended to measure time-of-flight between AC and S1 to distinguish events, when the so-called “back-splash current” of soft gammas and electrons (up to 1 MeV each) is presented at high energies (over 50 GeV) moving up from the calorimeter. These particles, falling at AC, imitate primary charged particle, but come later and we can distinguish such events by means of time-of-light.

To diminish back-splash effect we divide the detectors area on strip sections 10 cm wide.

During the present investigation we tested different modifications of Bicron-408 scintillators 1 meter long with 10 x 1 cm^2 cross-section with silicon photomultiplier light sensors (SiPM) sized 6 x 6 mm^2 by SensL (MICRO FB-6035-SMT) [3] and KETEK (PM6660-B66T99S-Q3) [4] manufacturers. In the first set of measurements shown in fig. 2 [5] these SiPM types with standard cathode outputs were used simultaneously at the opposite ends of scintillator strip.

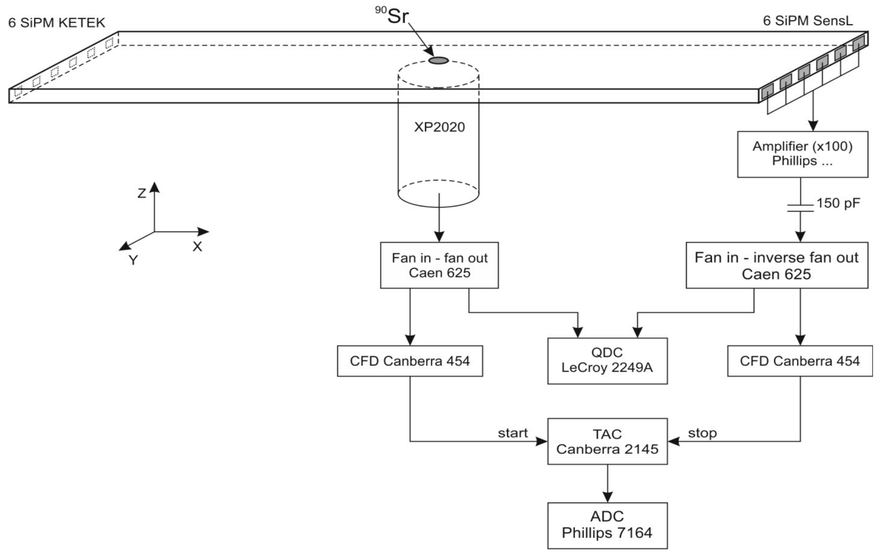

Fig. 2. Test setup for the detector's time and amplitude characteristics study (SiPM with standard output).

The irradiation was made by the Strontium-90 beta-source with the boundary energy 2.3 MeV. The selection of events with the energy deposit in the scintillator more than 2.0 MeV was done by XP2020 photomultiplier.

First we compared signal-to-noise ratio for one SiPM, shown in fig. 3, with the same pictures for attenuated signal of 6 SiPMs, connected in parallel, shown in fig. 4.

We can see the better distinction of signal and noise spectra for the latter case since the average amplitude of useful signals is proportional to the number of light sensors, while maximal amplitude of noise spectrum is practically equal as for single SiPM, and for six electronically interconnected units (because of random time distribution of dark signals). After that we used in all cases 6 SiPMs at each end of the scintillator.

3. The experimental results.

We also tried to use the fast output, which is present in MICRO FB-6035-SMT. Standard and fast biasing schemes are shown in fig. 5 [3].

For the measurements six SensL MICRO FB-6035-SMT SiPMs with fast outputs connected in parallel were located at the opposite ends of Bicron-408 1-meter long scintillator strip. The selection of detection point in this case was provided by the pair of additional scintillation detectors with vacuum photomultipliers connected in coincidence.

The measurements of time resolution, energy deposition and detection efficiency for the different distances from the SiPMs at one end of the detector were carried out.

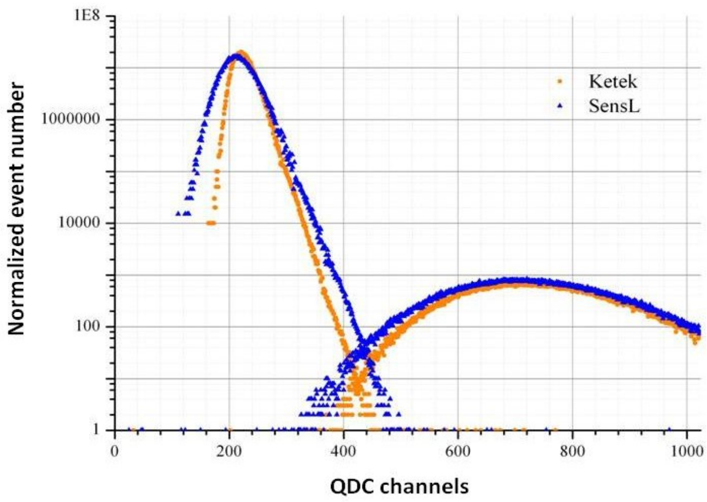

Fig.3. Overlapping of particle and noise signals of one SiPM [6x6 mm^2] by Ketek and SensL

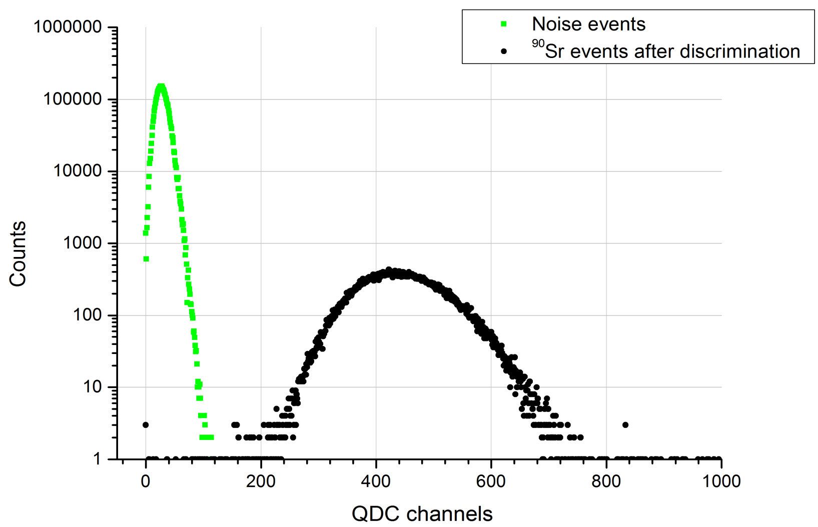

Fig.4. Overlapping of 1 m.i.p. signal and noise spectra measured by 6 SensL SiPMs [6x6 mm^2].

The time resolution that is defined by flight bases of the counters of TOF and AC must be better than 1 ns. The time resolution measurements results for the different distances from one end of the detector are shown in fig. 6. For the fast output time resolution was measured between opposite ends of the scintillator strip, but for the measurements with the standard output "start" signal was taken from the XP2020 photomultiplier as shown in fig. 2. In all investigated configurations the time resolution satisfy the requirements, taking into account that in the case of preliminary results for fast output the selection of charged particles is much softer than in the case of standard output measurements. For the gamma-rays the time resolution will be square root of two better because of double energy deposit from electron-positron pair.

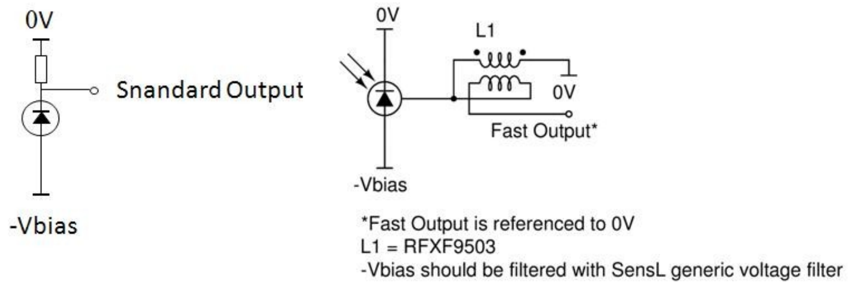

Fig. 5. SensL SiPM biasing schemes.

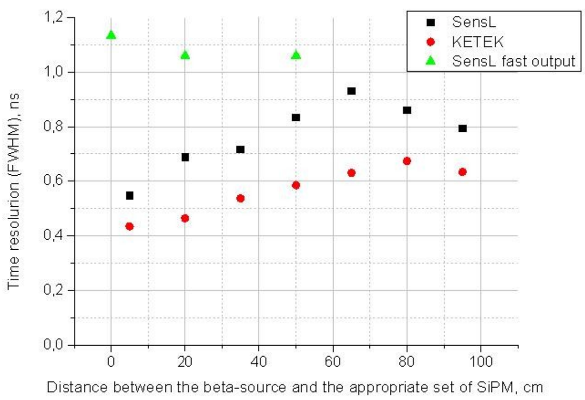

Fig. 6. Time resolution for the tested scintillation detector as a function of the distance between the beta-source and the appropriate set of SiPM.

The normalized results for the amplitude decrease along the scintillator strip are almost the same for all configurations used and give the "e" times attenuation length equal to 160 cm (passport data are 210 cm for 20 cm wide strip).

The detection efficiency, shown in fig. 7 is over 0.9995, in the case of the slow KETEK SiPM output in all the measurements for using only one end of detector.

Preliminary results for the fast output give the efficiency higher than 0.99, but for precise measurements in the presence of natural radioactivity of surrounding materials the additional triggering conditions are needed.

4. Conclusion.

The preliminary results of the time resolution and detection efficiency measurements of the fast scintillation counters with implementation of SensL SiPMs showed the possibility of their usage in the GAMMA-400 gamma-ray telescope.

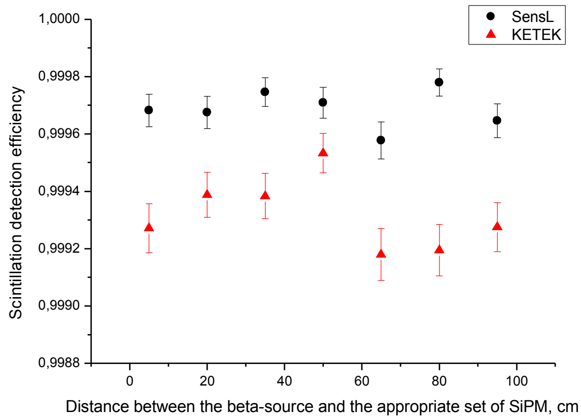

Fig 7. The dependence of the scintillation detection efficiency for the tested scintillation detector on the distance between the beta-source and the detecting set of SiPM.

References

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[4] *KETEK Silicon Photomultiplier Sensors, User Manual*.

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