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2016 J. Phys.: Conf. Ser. 675 032017

(http://iopscience.iop.org/1742-6596/675/3/032017)

Investigation of the dynamic range of calorimeter scintillation detector for space gamma-ray telescope

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Abstract. An arrangement of the GAMMA-400 space gamma-ray telescope that currently is under the ground testing, suggests implementation of fast two-layer calorimeter scintillation detector system S3 with large dynamic range for electromagnetic showers detection in the main operation mode of the device. The S3 constructive features are demonstrated. The experimental method and basic diagram of the ground prototype dynamic range investigation are described.

1. Introduction

The international project GAMMA-400 includes the gamma-ray telescope for the energy range from 10^2 MeV up to 3×10^3 GeV onboard of the space satellite. This device will investigate the point gamma-ray sources and the peculiarities in the energy spectrum of diffuse gamma emission including one might be produced by the annihilation of so-called "dark matter" particles [1].

The gamma-ray telescope [1] layout is shown in the figure 1.

It has the sensitive area of about 1 m^2 and consists of fast plastic scintillation anticoincidence detector AC to forbid the charged particle detection due special algorithms used in the system of counting and triggers signals formation [2], multilayer (tungsten + silicon strip detectors) converter C for the conversion of gammas to the electron-positron pair and for their trajectories visualization. The time-of-flight system (S1 and S2 fast plastic scintillator counters with 50 cm flight base) generates the signal for up-to-down moving charged particles. Two sections of heavy CsI(Tl) calorimeter (CC1 and CC2) are interleaved by two-layer fast scintillation detector S3 indicating the stage of shower development (the main mode for the S3 detector implementation in the telescope system). The system of the particle's leakage detector S4 and the neutron detector ND for clear electron-proton discrimination are located below the calorimeter.

The electronic box is located under the last detector to exclude any matter on the particle trajectory.

All of gamma-telescope components will be mounted on the base plate and installed at the space platform named NAVIGATOR.

We are considering here the prototype version for gamma-telescope described in [3].

During the converting of high-energy gamma-quanta in the converter C and interaction process in calorimeter, electromagnetic cascade develops, so the number of charged particles in the scintillation detector system S3 considerably increases. This requires a large dynamic range of the S3 detector system.

So, first of all, for the S3 dynamic range increasing the detector system consists of two layers of plastic scintillator Bircon-408, has total sensitive area of 1 m^2 and layer thickness of 10 mm. For better light collection the S3 layers are subdivided into modules of 100 mm wide. Light is detected by basic group of 6 silicon photomultipliers (SIPM) [4] located on the both ends of the scintillator module. SIPM SensL MicroFB-60035-SMT was selected. This type of fast SIPM device has the package dimensions 7.0 x 7.0 mm, signal amplification factor is about 3×10^6, and signal rise time is about 1 ns. SIPM can operate at low voltage (less than 30 V) and can be exploited in extended temperature range satisfied to hard implementation conditions.

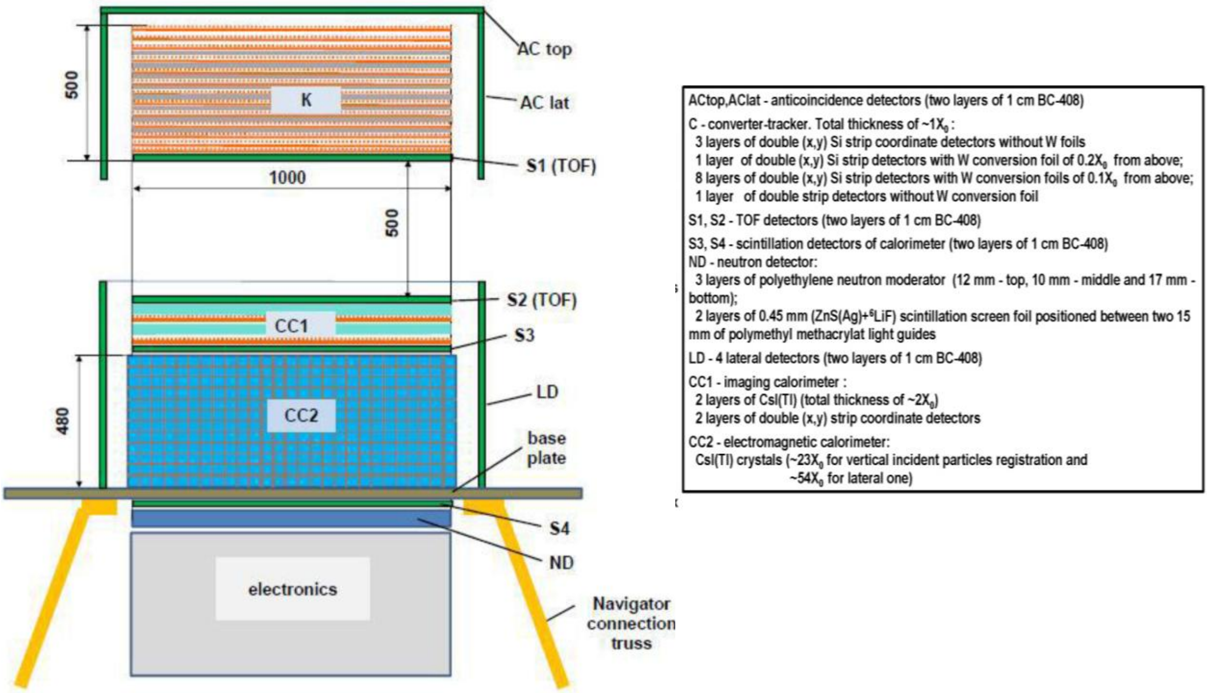

Figure 1**. Layout of the gamma-ray telescope GAMMA-400.**

The modern SIPMs are good photosensors for compact detector devices in space applications. But it has a limited signal dynamic range connected with so-called saturation effect and, so, the range investigation for real experimental conditions must be carried out.

2. Measurement of the S3 dynamic range

Preliminary, Monte-Carlo simulation was done using a program we developed especially to compute the physical characteristics of the GAMMA-400 telescope by simulating the passage of particles through device matter on the base of Geant4 simulation toolkit [5]. The simulation shows that for gammas with the energy 1000 GeV the maximum energy deposition in the S3 detector corresponds to about 1000 minimum ionizing particles (MIP). It should be noted what the average energy deposition in whole thickness of S3 detector system from the single charged relativistic particle is about 4 MeV.

We especially have chosen the SIPM with maximum number of cells to increase the dynamic range. Next, we suggest to use an additional registration channel to expand the dynamic range. This channel will collect signals from the group of two SiPMs that are located on the each end of scintillator. For this group we use optical filters for the attenuation of the light signal.

In the figure 2 the simplified diagram of the S3 detector dynamic range measurements is shown.

This experimental method has the two purposes. First of all we obtain the mean value of energy deposition from one particle in one layer of detector (1 MIP) to use it for the energy scale calibration.

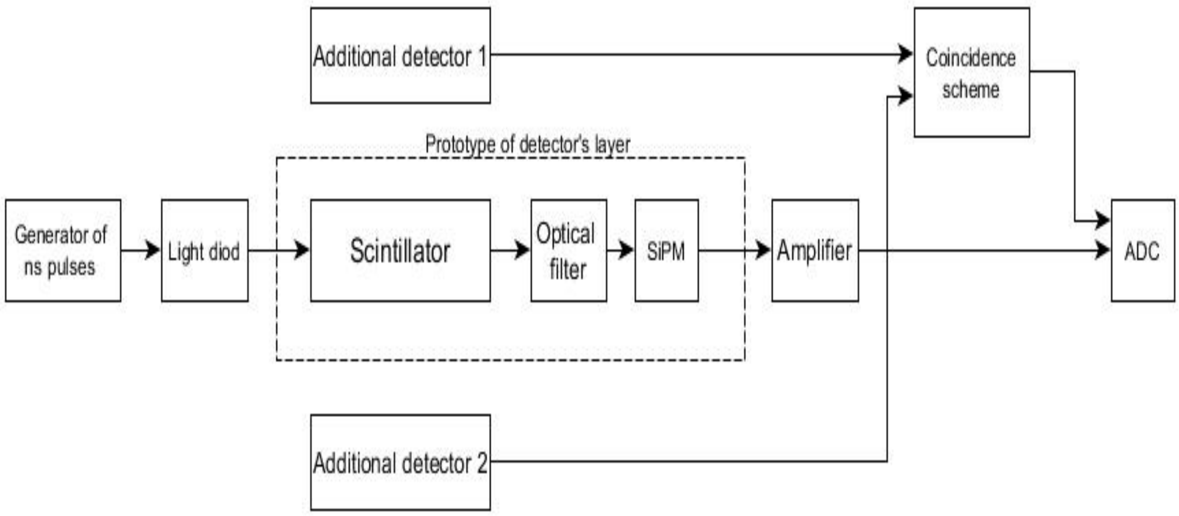

Figure 2. Diagram of the measurement setup.

The second purpose is the measurement of SiPM amplitude dependence from the light splash intensity (see below).

The set of optical filters were used for attenuation of light splash intensity. Thus, we can simulate the particle registration process with higher energy (for example, above 1000 GeV).

In the figure 3 we illustrate the results of the dynamic range measurements for the S3 one layer detector system.

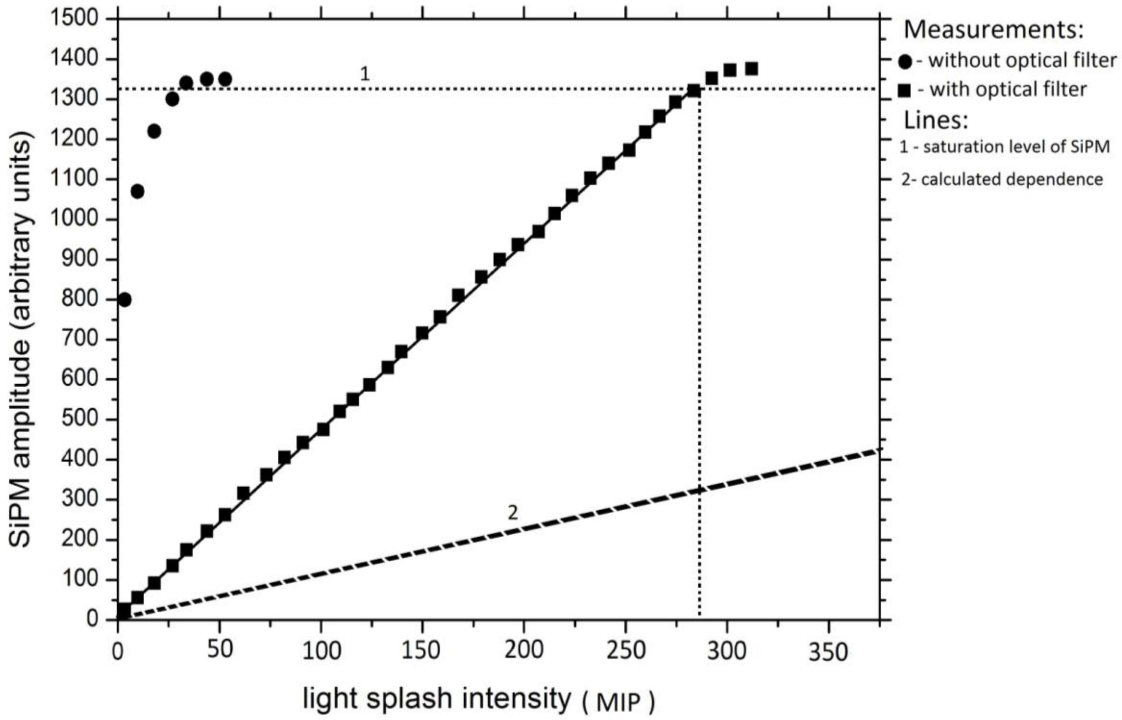

Figure 3. Results of the S3 one layer detector dynamic range measurements.

The brightening of photodetectors was implemented with ultraviolet light-emitting diode triggered by nanosecond pulse signal generator. Dotted plot shows the dependence of signal amplitude from

SiPM without optical filter, rectangles show the same dependence with optical filter. Initial coefficient of attenuation equals 100. But we can do it more if needed (see below).

Measurements without optical filter allow us to achieve saturation level of SiPM amplitude. It is about 1200 arbitrary units (in the units of 15 bit ADC channels). Strait horizontal line 1 corresponds to the SiPM saturation level and it is the upper limit for dynamic range at the current experimental conditions.

The ground S3 detector calibration in MIP units was carried out with the use of atmospheric cosmic rays fluxes (muon particles mainly). The calibration scale of the pulse generator was obtained with the help of photomultiplier Planacon XP85012 with high quality of amplification linearity and large signal dynamic range. So, we obtained the linear dependence on scintillator illumination with optical filter (see squared line in the figure 3) in MIP units.

We achieved the dynamic range of the S3 one layer detector equal to 280 MIP (see vertical line in the figure 3). From the figure 3 it can be seen also, if we shall increase the attenuation of filter to about 4 times, the S3 one layer dynamic range can expand up to 1000 MIP. This is the value that we can calculate for the 1000 GeV gamma quanta detection (see line 2 in the figure 3) and we shall have some reserve before SIPM saturation. So, we can increase the optical filter attenuation to the value corresponding to gamma-quanta energy more than 1000 GeV.

3. Conclusion

The preliminary measurements of the S3 one layer prototype dynamic range are presented. The resulting range for the charged particle shower detection from 1 to 1000 MIP might be obtained that corresponds to the design requirements.

Acknowledgements

This work was performed within the framework of the Fundamental Research and Particle Physics Center supported by MEPhI Academic Excellence Project (contract N 02.a03.21.0005, 27.08.2013).

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