The anticoincidence system of space based gamma ray telescope GAMMA-400, test beam studies of anticoincidence detector prototype with SiPM readout

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I. INTRODUCTION

Scientific project GAMMA-400 [1, 2] is one of the new generation of space observatories intended for an indirect search for signatures of dark matter in the cosmic-ray skies, precision investigation of characteristics of diffuse gamma ray emission and gamma-rays from the Sun during periods of solar activity, gamma-ray bursts, extended and point gamma-ray sources in the wide energy range from several tens of MeV up to the TeV region, electron/proton and cosmic-ray nuclei fluxes with energies up to $10^{19}$ eV by means of the GAMMA-400 gamma-ray telescope (Fig 1) represents the core of the scientific complex. For gamma-rays with the energy $>100$ GeV expected angular and energy resolution are $<0.5^\circ$ and $<1\%$ respectively and electron/proton rejection factor is $>5\times10^3$. The GAMMA-400 space observatory will be launched on the Navigator service platform [3] designed by Lavochkin Association on the elliptical orbit with following initial parameters: an apogee ~30000 km, a perigee ~500 km, a rotation period ~7 days, and inclination of 51.4°. The GAMMA-400 observatory is expected to operate more than 5 years, reaching an unprecedented sensitivity in the indirect search of dark matter signatures and in the study of the unresolved and unidentified so far gamma-ray sources. The planned scientific complex main technical parameters are: weight ~2500 kg, power consumption ~2000 W, total downlink transmission up to 100 Gbit/day

The space based gamma ray telescope must effectively separate photons from charged particles of instrumental background and cosmic rays. The anticoincidence system (ACS) of gamma ray telescopes is suffered from the self-veto (backslash) effect when the products of the high energy photon interactions in the instrument's calorimeter, mainly low-energy electromagnetic shower particles moving in the direction opposite to the direction of the detected photons, cause a veto signal in the ACS, resulting in the degradation of the efficiency for high energy $>$15 GeV gamma rays. One method of this self-veto effect reduction is segmenting the ACS into tiles and vetoing an event only if the pulse appears in the tile through which the reconstructed event trajectory passes [4]. Further improvement is time-based backslash rejection technique [5] based on the use of the veto signal in time within the time interval in which backslash particles hit the ACS. This time interval start moment and duration depend on the detector geometry and for the GAMMA-400 telescope averages out from 3 to 12 ns after TOFS triggering. It requires the intrinsic time resolution of TOFS and ACS segments better than $500\text{ps}$ for effective self-vetoing suppression. In this case the proton impurity is selected gamma rays and the loss of useful events do not exceed $10^3$ and $10^2$ respectively [6].

II. THE EXPERIMENTAL SETUP

The tested detector presents two strips of polyvinyltoluene scintillator BC-408 with dimensions of $1200\times100\times100$ mm$^3$, wrapped with one layer of Tyvek reflective material and placed into 1.5 mm thick aluminum alloy optical interstage adapters. At galleying and from photo blocks consisting of four 6x6 mm$^2$ silicon photomultipliers (SiPM) of the type Semp, MicroFC-60035-SMT counters, connected to front and-end electronics. Only "slow" SiPM outputs were used in this prototype variant. The amplified and shaped signals from both sides of the detector are split into two paths: the first signal goes directly to the LeCroy WaveRunner 62I digital oscilloscope directly, for amplitude and charge analysis, and the second signals passes through constant fraction discriminator (CFD) ORTEC Model 910A for timing analysis. Threshold of CFD was set at about 25% of the most probable energy deposited by minimum-ionizing particles crossing the whole thickness of scintillator (10 mm). The bias voltage for SiPMs was set at 29.5 V level (~5 V above SiPM breakdown voltage). The primary beam of the synchrotron C-25P "PAKHRA" of Lebedev Physical Institute (Fig. 2) consists of 300-850 MeV particles with electron intensity up to $2\times10^{13}$ e$^-$/s and repetition frequency of 50 Hz. Bremstrahlung photon beam is formed by interaction of accelerated electrons with an intensity target with the help of the magnet inside the accelerator vacuum chamber. This beam is used to create a secondary position beam by et pair production on copper converter with 0.15 mm thickness. Secondary protons with particle momentum of 300 MeV/c and intensity up to $3\times10^{11}$ cm$^{-2}$s$^{-1}$ are selected using dipole magnet. The studied detector was installed on a remote controlling platform which allows horizontally and vertically moves the detector with respect to the beam position in the range of $\pm 40$ cm with accuracy of 1 mm (Fig. 3). A beam monitor (Fig.4) for secondary protons selection installed behind 10 mm diameter lead collimator consists of four $15\times15\times5$ mm$^3$ polyethylene (BIEP_SC-301) scintillation counters M1-M4 wrapped with aluminized mylar film and coupled with silicon grade BC-630 from one side with 2.5x3 mm$^2$ MicroBI-3005X51 SiPMs connected in parallel. These counters are installed on high-precision horizontal and vertical shim positioners for finely positioning of monitors counters with respect to position beam (range $\pm 6.5$ mm with 10um accuracy). The signals from each SiPM pair are amplified by two-stage broad-band shape-amplifiers with pulse-zero cancellation circuit on based fast AD8900 operational amplifiers, produced output signals with rise-time of ~3.5 ns and width of $T_{c}=10$ ns. The amplified and shaped signals are fed into four-channel CFD (ORTEC Model 915). The CFD outputs are connected through the set of delay lines (CRAIN Model N100) to coincidence logic unit (CAEN Model N405) which generate the reference start pulse for the positrons registration. Two quad scalers are used for counting M1-M4 and M pulses. The beam monitor time resolution was measured as 1040±2 ps. To characterize the prototype detector, the measurements of the following parameters defined its time resolution were carried out: attenuation length, photostatic, effective light velocity and intrinsic time resolution. The statistics at each data point is about 10$^3$ for all results presented. The measurements of absolute detection efficiency require much greater beam intensity to reach suitable accuracy in a reasonable accelerator time than secondary positron beam used and are in preparation now at primary beam of the synchrotron C-25P "PAKHRA".

REFERENCES

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