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 fluxes, 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/positron and cosmic-ray nuclei fluxes with energies up to ~10^{15} 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 ~0.01° and ~1-2% respectively and electron/protons rejection factor is ~$5\cdot10^5$. 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 ~300000, a perigee ~500 km, a rotation period ~7 days, and inclination of 51.4º. 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 GByte/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 (backsplash) 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 (>5 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 backsplash rejection technique [5] based on ignoring of the veto signals in appropriate segments of ACS within the time interval in which backsplash 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 ns to 12 ns after TOFS triggering. It requires the intrinsic time resolution of TOFS and ACS segments better than 500 ps for effective self-vetoing suppression. In this case the proton impurity in selected gamma rays and the loss of useful events do not exceed 10^{-5} and 10% respectively [6].

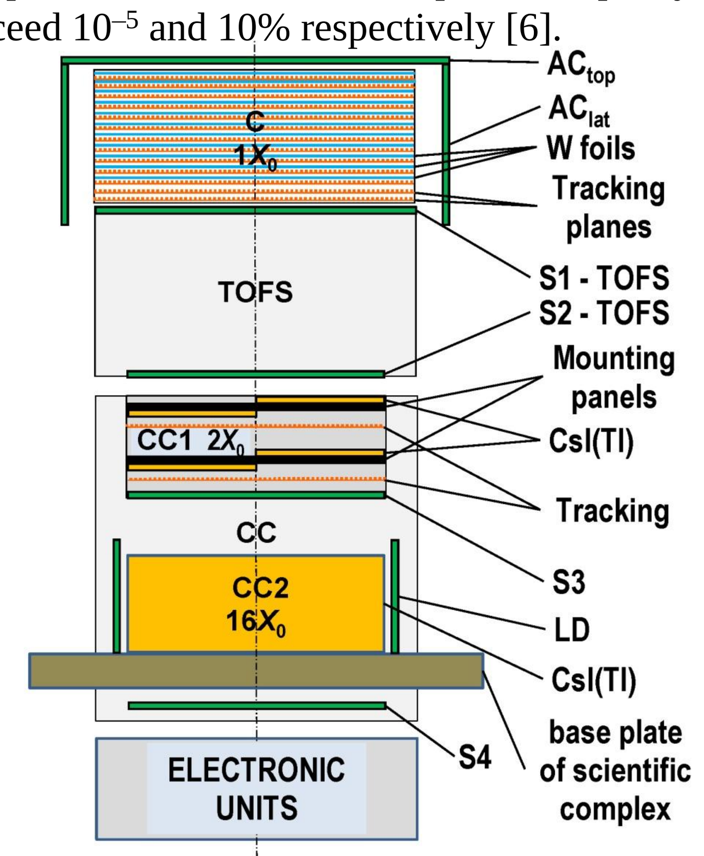

Fig. 1. The sketch of the GAMMA-400 gamma-ray telescope

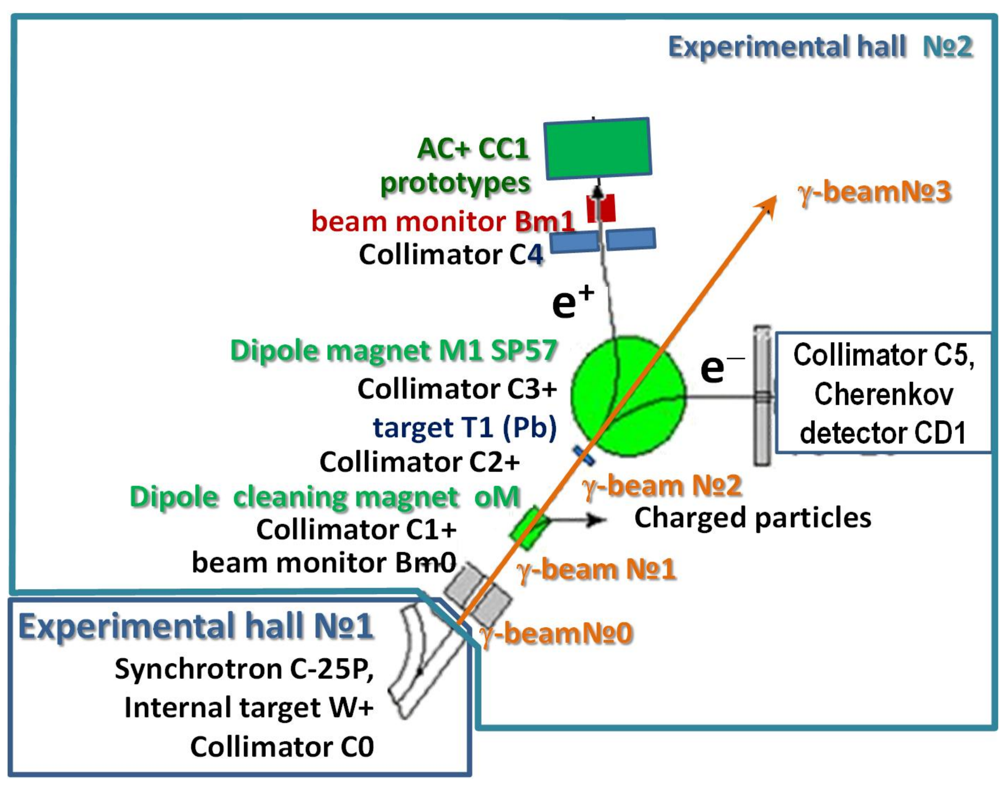

Fig. 2. The beam formation setup and apparatus installation at C−25P synchrotron "PAKHRA"

II. THE EXPERIMENTAL SETUP

The tested detector presents two strips of polyvinyltoluene scintillator BC-408 with dimensions of 1280×100×10 mm³, wrapped with one layer of Tyvek reflective material and placed into 1.5 mm thick aluminum cover. At the middle of each strip the FC-type fiber optic adapters are situated for optic cables connection from laser monitoring system. Each strip is viewed at opposite shortest ends by two photo sensor blocks which consist of four 6×6 mm² silicon photomultipliers (SiPM) of the type SensL MicroFC-60035-SMT connected in parallel and front-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 6Zi digital oscilloscope directly, for amplitude and charge analysis, and the second signal goes through constant fraction discriminator (CFD) ORTEC Model 935 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 electrons with particle intensity up to $2\cdot10^{12}$ s^{-1} and repetition frequency of 50 Hz. Bremsstrahlung photon beam is formed by interaction of accelerated electrons with an internal tungsten target with a thickness of $0.22X_0$ (X_0 - radiation length) placed inside the accelerator vacuum chamber. This beam is used to create a secondary positron beam by e± pair production on copper converter with 0.1-5 mm thickness. Secondary positrons with particle momentum of 300 MeV/c and intensity up to ~100 s^{-1}cm^{-2} 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 ±40 cm with accuracy of 1 mm (Fig. 3). A beam monitor (Fig.4) for secondary positrons selection installed behind 10 mm diameter lead collimator consists of four 15×15×3 mm³ polystyrene (IHEP_SC-301) scintillation counters $M1$-$M4$ wrapped with aluminized mylar film and coupled with silicon grease BC-630 from one side with two 3×3 mm² SensL MicroSB-30035-X13 SiPMs connected in parallel. These counters are installed on high-precision horizontal and vertical slide positioners for finely positioning of monitor counters with respect to positron beam (range ±6.5 mm with 10μm accuracy). The signals from each SiPM pair are amplified by two-stage broad-band shaper-amplifiers with pole-zero cancellation circuits based on fast AD8000 operational amplifiers, produced output signals with rise-time of ~3.5 ns and width of T_{90}~10 ns. The amplified and shaped signals are fed into four-channel CFD (ORTEC Model 935). The CFD outputs are connected through the set of delay lines (CAEN Model N108) to coincidence logic unit (CAEN Model N405) which generate the reference start time 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 104±2 ps. To characterize the prototype detector, the measurements of the following parameters defined its time resolution were carried out: attenuation length, photostatistics, effective light velocity and intrinsic time resolution. The statistics at each data point is about 10^4 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».

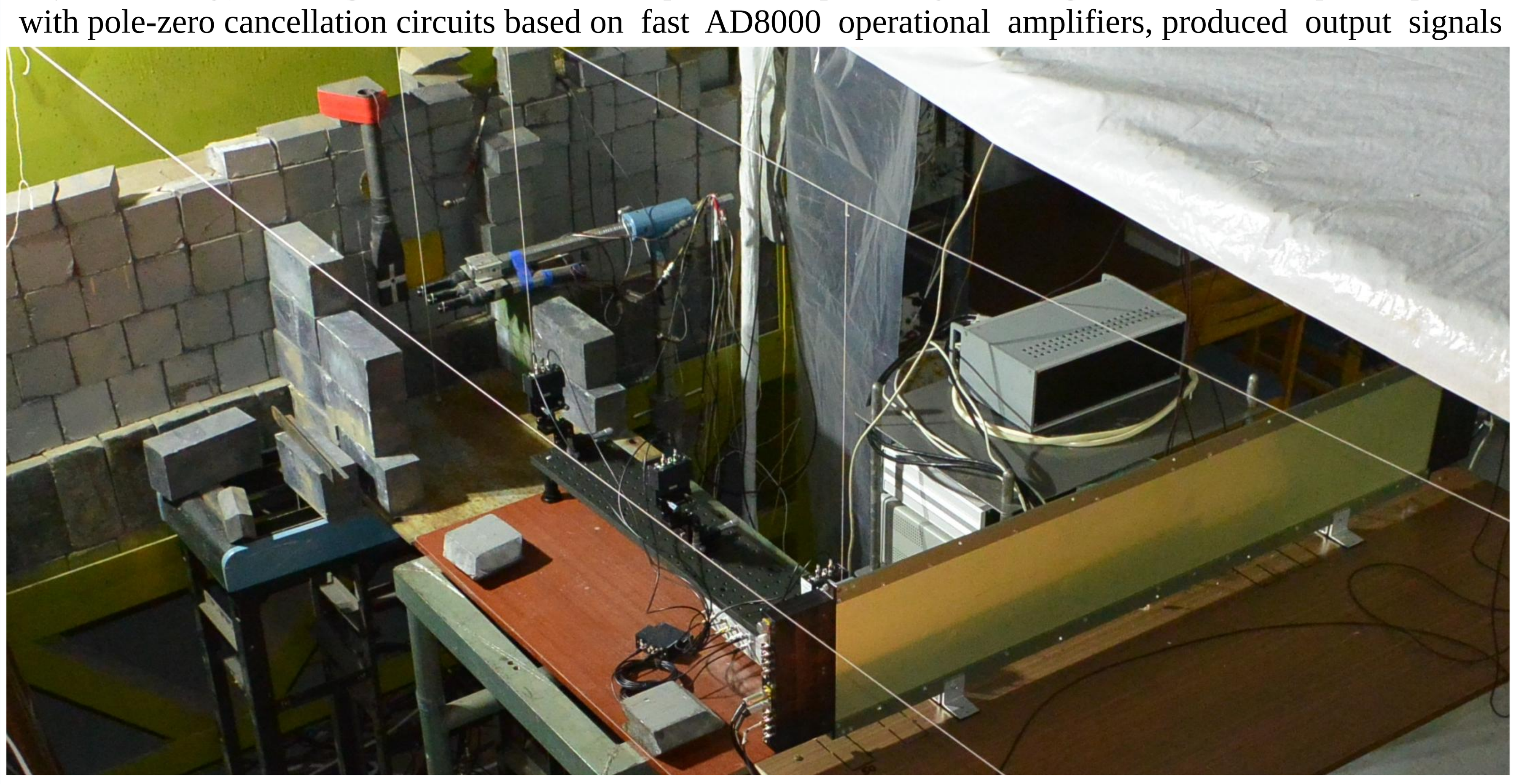

Fig. 3. The prototype detector and beam monitor at the experimental hall №2 of synchrotron C-25P "PAKHRA"

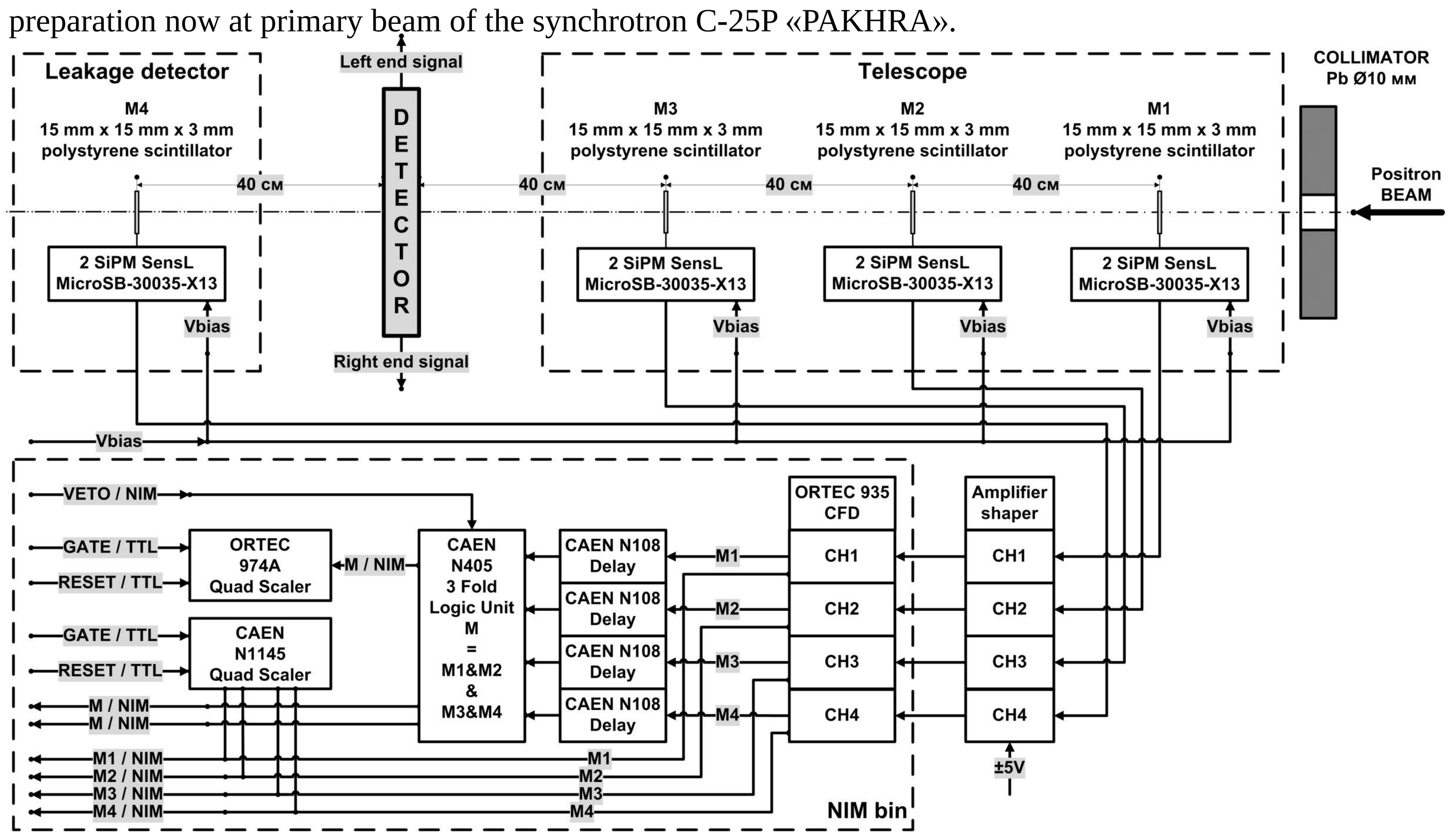

Fig. 4. Experimental setup, including beam monitor. The dash-dotted line represents the beam line

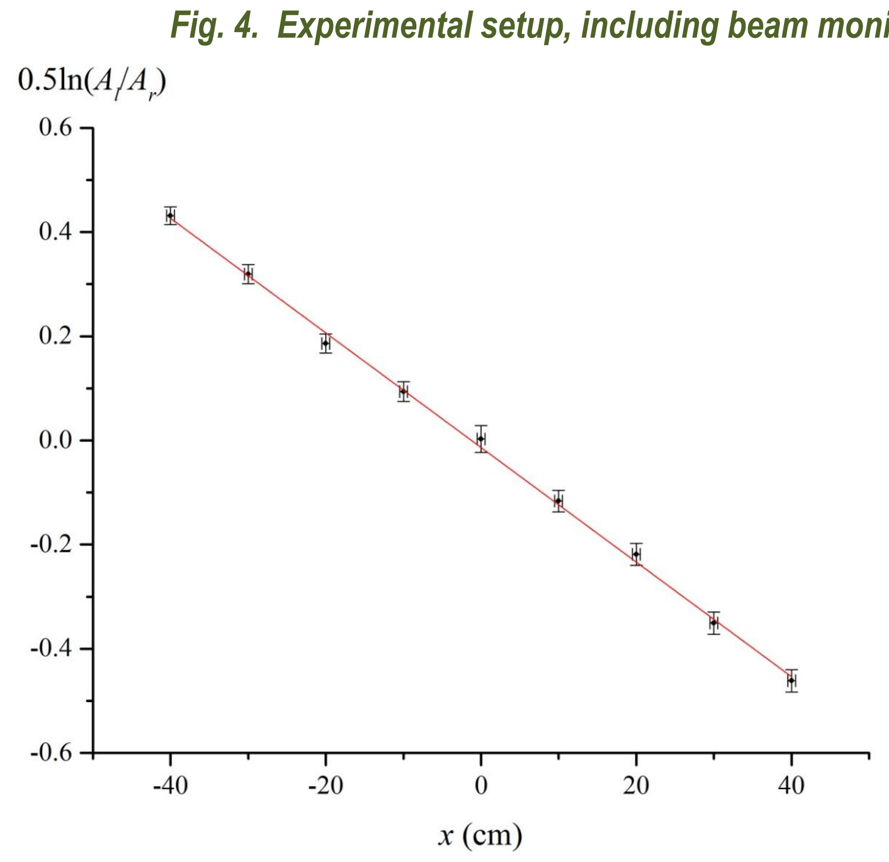

Fig. 5. Logarithmic ratio of amplitude of signals from the left and right ends of prototype detector. The inverse slope of the linear fit indicates the attenuation length λ=91±1 cm of scintillation light in the scintillator strip

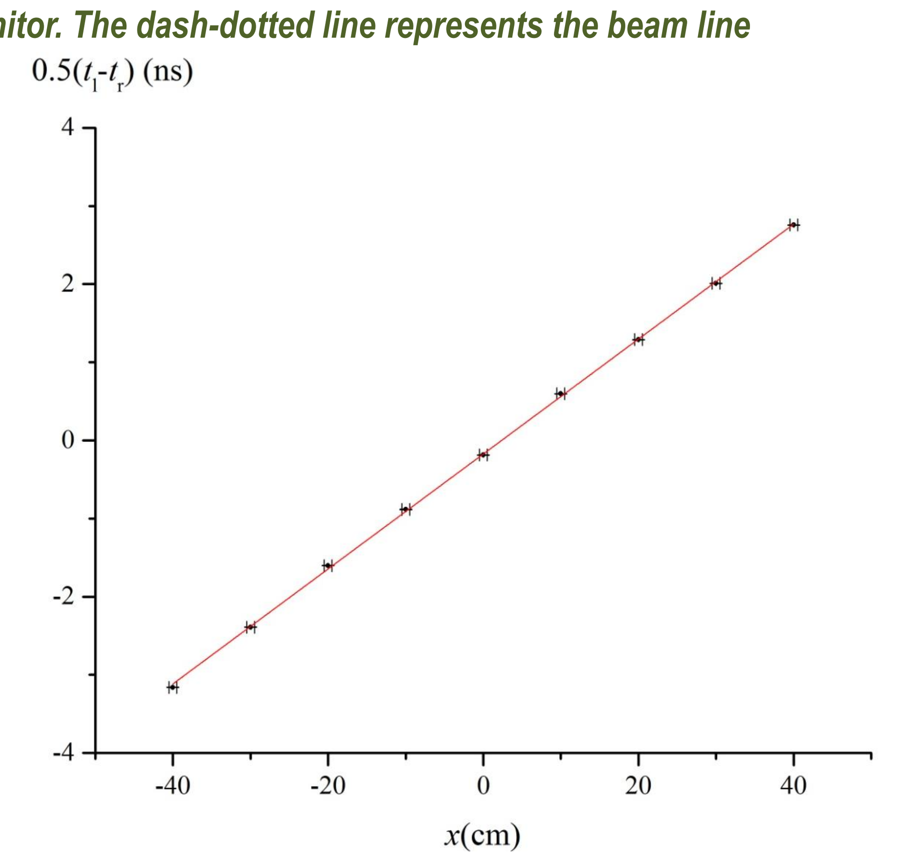

Fig. 6. Straight line fit to the semi difference of time of scintillation light arriving at strip ends at different beam positions relative to the detector centre. The inverse slope of the fit gives the effective scintillation light velocity 13.1±0.1 cm/ns in the scintillator strip

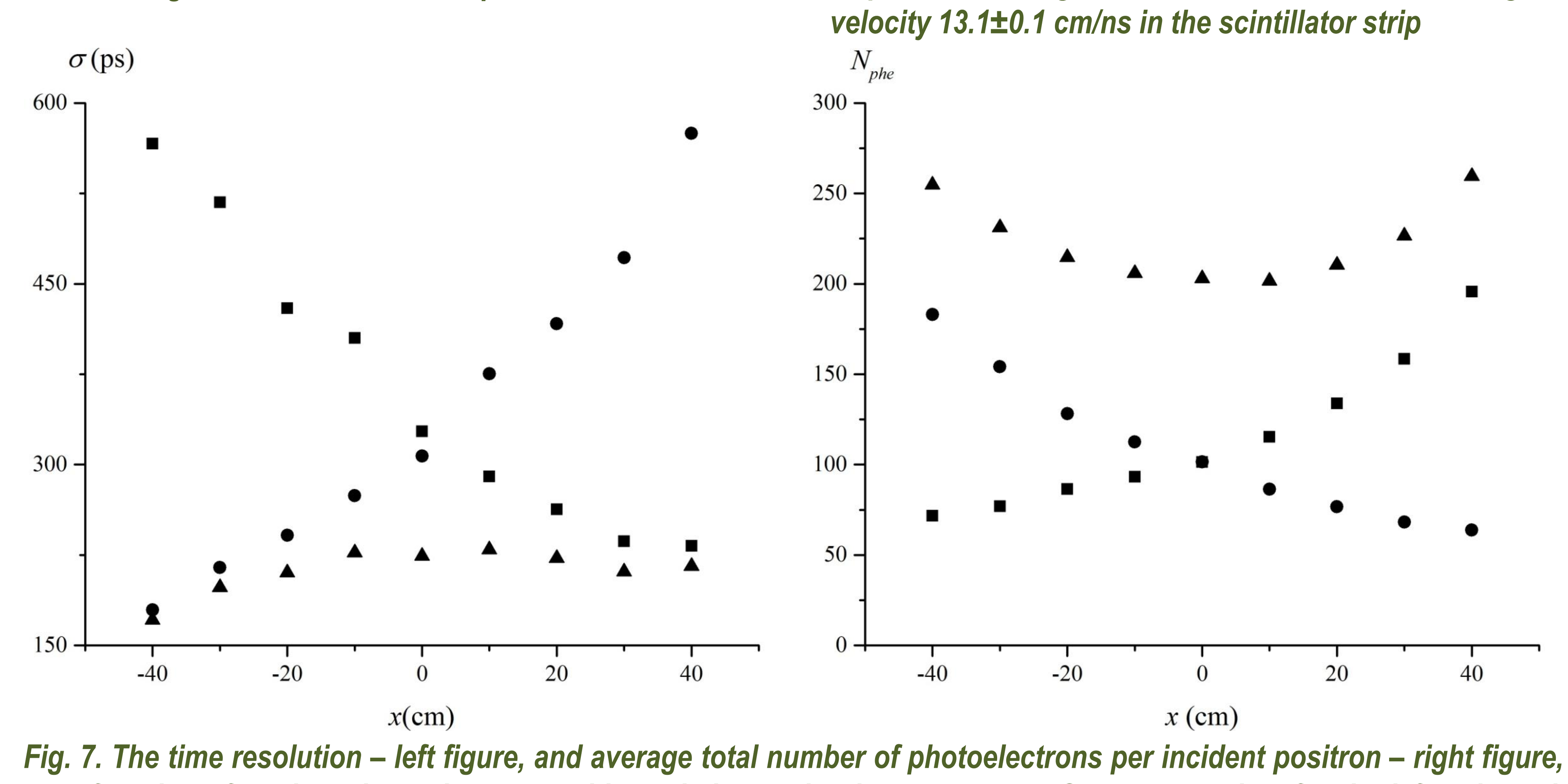

Fig. 7. The time resolution – left figure, and average total number of photoelectrons per incident positron – right figure, as a function of positron beam impact position relative to the detector centre. Squares are data for the left strip end, circles – for the right end, triangles – for left and right ends sum. Error bars are smaller than the points on the plot

III. CONCLUSION

The prototype detector on the base of 1280×100×10 mm³ BC-408 polyvinyltoluene scintillator strips with readout at both ends by photo sensor blocks consisting of four SiPMs of the type SensL MicroFC-60035-SMT was developed for carrying out a series of experiments in order to study amplitude, triggering and timing characteristics of the anticoincidence system of the GAMMA-400 gamma ray telescope. The properties of the prototype are measured using 300 MeV/c secondary positron beam of the synchrotron C-25P «PAKHRA» of Lebedev Physical Institute. The measured attenuation length is 91±1 cm, which is one quarter of the corresponding length of a bulk scintillator. (Fig. 5). The measured effective scintillation light velocity is 13.1±0.1 cm/ns (Fig. 6). The intrinsic time resolution of the prototype detector (Fig. 7) is found to be not worse than 230 ps which is enough for reliable suppression of the backsplash events. For further improvement of the prototype parameters the number of SiPMs at each detector end was increased up to 8 instead of currently used 4 SiPMs and the new type of silicon photomultipliers SensL MicroFJ-60035-TSV with enhanced photon detection efficiency and lower dark count rate were employed for obtaining the better photoelectron statistics and time resolution. In the new version of the prototype detector the "fast" SiPM outputs will be used as a source of signal for timing measurements.

REFERENCES

1. N. P. Topchiev, A. M. Galper, V. Bonvicini, et al., Bull. Russ. Acad. Sci. Phys. **79(3)**, 417 (2015)
2. A. M. Galper, N. P. Topchiev and Yu. T. Yurkin, Astronomy Reports. **62(12)**, 882 (2018)
3. A. S. Syrov, V. V. Smirnov, V. N. Sokolov, , et al., Cosmonautics and Rocket Engineering. **3**, 58 (2015)
4. A. A. Moiseev, R. C. Hartman, J. F. Ormes, , et al., Astropart. Phys. **27**, 339 (2007)
5. M. D. Kheymits, A. M. Galper, I. V. Arkhangelskaja, et al., Instrum. Exp. Tech. **59(4)**, 508 (2016)
6. I. V. Arkhangelskaja, A. I. Arkhangelskiy, A. M. Galper,et al.,J. of Phys.: Conf. Ser. **675(3)**, 032015 (2016)

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