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Gamma-quanta and charged particles recognition by the counting and triggers signals formation system of GAMMA-400 space gamma-telescope

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Abstract. Registered events identification procedures details in three apertures of gammatelescope GAMMA-400 are discussed in the presented article for gammas, electrons/positrons and protons both in low and high energy bands. Gamma-telescope GAMMA-400 consists of the converter-tracker (C) surrounded by anticoincidence system, time-of-flight system (2 sections S1 and S2) and calorimeter. Anticoincidence system will make of top and lateral sections - ACtop and AClat, time-of-flight system TOF contain 2 segments S1 and S2. Calorimeter consists of position-sensitive calorimeter CC1 makes of 2 strips layers and 2 layers of CsI(Tl) detectors and electromagnetic calorimeter CC2 composed of CsI(Tl) crystals surrounded by plastic lateral detectors LD. Scintillation detectors of the calorimeter S3 and S4 placed correspondingly between CC1 and CC2 and after electromagnetic calorimeter. All segments of detector systems ACtop, AClat, S1-S4, LD composed of two BC-408 based sensitive layers thickness of 1 cm each. Events registration both from upper and lateral directions provides due three apertures: main, additional and lateral. GAMMA-400 parameters are optimized for detection of gammaquanta with the energy $\sim 100 \text{ GeV}$ in the main aperture. Gammas, electrons/positrons and protons recognition in main aperture provides due energy deposition analysis in individual detectors of ACtop, AClat, S1-S3 and CC1 individual scintillator detectors discriminators. Particles identification in the additional aperture supplied by study of energy deposition in the individual detectors S2, S3 and position-sensitive calorimeter individual scintillator detectors discriminators. In the lateral aperture low energy (0.2 - 100 MeV) photons classified by using simple anticoincidence signals from the individual detectors of LD and CC2. Higher energies γ quanta (E>100 MeV) recognized using energy deposition analysis in the individual detectors of S3, S4, LD and CC2.

1. GAMMA-400 apertures short description

Events registration both from upper and lateral directions by gamma-telescope GAMMA-400 provides due three apertures: main, additional and lateral [1]. GAMMA-400 (Gamma Astronomical Multifunctional Modular Apparatus) parameters are optimized for detection of γ -quanta with the energy ~ 1.0×10^2 GeV in the main aperture [2-4]: the angular resolution ~0.01°, the energy resolution

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~1%, and the proton rejection factor ~5×10⁵. The physical scheme of the under consideration variant of gamma-telescope construction and GAMMA-400 apertures is shown at figure 1. Gamma-telescope GAMMA-400 consists of the converter-tracker (C) surrounded by anticoincidence system, time-of-flight system (two sections S1 and S2) and calorimeter [2]. The converter-tracker (C) makes from double (x, y)silicon strip coordinate detectors (pitch of 0.08 mm) interleaved by tungsten conversion foils with total thickness is $\sim 1 X_0$, but final two layers are without tungsten. Anticoincidence system will make of top and lateral segments - ACtop and AClat, time-of-flight system TOF contain 2 sections S1 and S2. Calorimeter consists of position-sensitive calorimeter CC1 makes of 2 strips layers and 2 layers of CsI(Tl) detectors and electromagnetic calorimeter CC2 composed of CsI(Tl) crystals surrounded by plastic lateral detectors LD. The thickness of CC1 is 2 X₀, the total calorimeter thickness is ~21 X₀ or ~1.0 λ_0 for vertically moved particles. Scintillation detectors of the calorimeter S3 and S4 placed correspondingly between CC1 and CC2



Figure 1. The physical scheme of the GAMMA-400 and its apertures.

and after electromagnetic calorimeter [3]. All segments of detector systems ACtop, AClat, S1-S4, LD composed of two BC-408 based sensitive layers thickness of 1 cm each [1, 3-4].

The main aperture created firstly due converter-tracker (C): gammas converted in tungsten conversion foils are registered. In the main aperture triggers will be formed using information about particle direction provided by TOF system and presence of charged particle or backsplash [1, 5]. The angular resolution provided by strip layers in the C and CC1, energy resolution approved due AC, CC1, CC2, LD and S1 - S4. Low energy threshold (~20 MeV for γ -quanta [2]) for this aperture approved due particles energy absorption in conversional foils of converter-tracker and supports elements. Events recognition in main aperture provides due energy deposition analysis in individual detectors of ACtop, AClat, S1-S3 and CC1 individual scintillator detectors discriminators. The examples for individual detectors of AC energy deposition analysis are described in section 2.

The additional aperture provides to observe particles passes out of converter-tracker: no any signal from TOF system for such events, but S2 will be anticoincidence detector together with LD and S4 instead of AC top and lateral sections. Up-down particle direction in the additional aperture indicates due fast signals from detectors CC1 and S3. The angular resolution provided by strip layers in the CC1, energy resolution approved due CC1, CC2 and S2 - S4. Particles identification in the additional aperture supplied by study of energy deposition in the individual detectors S2, S3 and position-sensitive calorimeter individual scintillator detectors discriminators. The examples for individual detectors of S2 energy deposition analysis described in section 2.

The lateral aperture allows to register γ -quanta, electrons/positrons and light nuclei with energy E>10 GeV. Also it provides detecting of gammas in the energy ranges of 0.2 - 10 MeV and 10 MeV – 10 GeV. One side of calorimeter will be solar oriented to support solar panels functioning and cooling radiator located from its other three sides. It gives lower limit for γ -quanta detection: ~0.2MeV from solar side (given due particles energy absorption in LD) and several MeV (refined value depends on cooling radiator final construction) for other three ones provides by particles energy absorption in LD and cooling radiator constructive elements. The total calorimeter thickness is ~43 X₀ or ~2.0 λ_0 when detecting laterally incident particles allows extending the energy range up to several TeV for γ -quanta in the lateral aperture. Angular resolution in this aperture obtained due individual detectors of CC2 count rate analysis (~5°) only for non-stationary events (GRB, solar flares and so on) in energy range

0.2 - 10 MeV. The applied method looks like BATSE (Burst And Transient Source Experiment) detector onboard Compton Gamma Rays Observatory algorithm for transient sources but differ from occultation analysis technique using in this experiment too - see [7] and references therein.

Cooling radiator construction also will affect to lower threshold in the additional aperture: this value will be several MeV too and it will caused by particles energy absorption in S2 and cooling radiator constructive elements.

GAMMA-400 main scientific objectives are [2 - 4]: indirect dark matter investigation due the methods of gamma-ray astronomy, γ -emission observations both from discrete astrophysical sources and diffuse background, high energy component of gamma-ray bursts emission studying, research of high energy light nuclei and e-e+ fluxes and so on. Moreover, GAMMA-400 lateral aperture allows to analyze hard x-ray and γ -emission from solar flares because of it's one side will solar oriented as was mentioned above.

2. Events onboard recognition in different apertures

Events types distinguish provide by the system of counting and triggers signals formation [1, 6]. Two pulses types used in it for signals formation:



Figure 2. Results of backsplash effect simulation for 7500 gammas with $E\gamma = 3$ GeV in ACtop: (a) energy deposition in upper layer from backsplash formed lower one; (b) energy deposition distribution in lower and upper layers for backsplash formed in conversion foils

slow (t \leq 10 µs) from inorganic scintillation detectors and fast (t \leq 10 ns) from plastic ones. Also this system information processing includes fast pulses from amplitude discriminators of CsI(Tl)-based individual detectors of calorimeters CC1 and CC2. These signals combinations analysis allows onboard recognition of several event types (for example gamma-quanta and charged particles) correspondingly to various energy and amplitude thresholds subsets. For particle recognition only signals from each detectors system or section individual detecting units without any summation are analysed. Two types of information generated by the counting and triggers signals formation system: triggers itself (pulses with characterised arriving time ~250 ns to open detectors systems sampling) and trigger markers (32 bites codes described registered events by means of all detectors thresholds both for slow and fast signals).

Figure 1 illustrates incident gammas passing through all GAMMA-400 apertures. It is seen backsplash effect (marked by orange color) where low-energy gammas and charged particles moved backward relatively to incident particle due to produced in their interaction with detectors and constructive materials secondary particles reverse scattering. Because of this effect the γ -quantum could be identified as charged particle.

Most part of backsplash in the main aperture produced in conversion foils and calorimeter. Also at some situations backsplash formation region from incident gammas is located in ACtop lower layer just below of upper layer individual detector on which particle is impinged. Results of modelling shows the energy deposition in ACtop upper layer from such kind of events is less than 0.9 MeV – see figure 2a. 234 γ -quanta from 7500 modeled events with $E\gamma = 3$ GeV produced backsplash just in ACtop lower layer, but only for 17 gammas energy deposition $E_{ACtop_up} > 0.2$ MIP~0.4 MeV while such value is one of typical thresholds (the lowest one) for anticoincidence systems. Distribution of

energy deposition in ACtop lower and upper layers for backsplash formed in conversion foils from incident gammas is presented at figure 2b. However, part of backsplash particles absorbed in conversion foils and detectors' supports. Taking into account this fact, 211 γ -quanta from 7500 modeled events with E γ = 3 GeV produced backsplash in conversion foils but only for 32 particles energy deposition exceed 0.2 MIP value in ACtop lower layer and for 4 events energy deposition sufficient for 0.2 MIP threshold overcoming for registration both in ACtop lower and upper layers.



Figure 3. Energy deposition distributions in ACtop simulation results for three subsets of 7500 particles each with E = 3 GeV: for gammas (backsplash produced in calorimeter (a) and direct γ -quanta interactions in plastics (b)); for electrons and protons direct interactions in plastics (marked by black and red colors at panel (c) correspondingly).

Figure 3a illustrates similar figure 2b distribution for backsplash produced in calorimeter. Sufficient portion of backsplash particles tracks are outside ACtop detector system due to long distance between ACtop and calorimeter. Usually backsplash particles delayed at individual time Δt _BS correspondingly twice distance between ACtop and place of backsplash production. For GAMMA-400 this time is ~4 ns for most particles. Taking into account backsplash particles partial absorption in conversion foils, detectors' supports and TOF system, energy deposition in ACtop lower layer for 196 events sufficient for 0.2 MIP threshold overcoming, but only for 17 particles energy deposition exceed 0.2 MIP value both in ACtop lower and upper layers and only 4 events (less than 0.1%) overcoming threshold for charged particles shown at figure 3c and possible could identified as protons or electrons. Thus temporal analysis using in anticoincidence system allow rejecting backsplash with accuracy better than 0.1%.

Distribution of energy deposition in ACtop lower and upper layers from direct γ -quanta interactions in plastics due pair production and Compton effect is shown at figure 3b. 273 gammas from 7500 modeled energy deposition exceed 0.2 MIP value in ACtop upper layer and for these entire events 0.2 MIP threshold overcoming in ACtop lower layer, but only 216 events (less than 3%) could be wrongly recognized as protons or electrons because of its energy deposition exceed threshold for charged particles.

Unfortunately in additional and lateral apertures temporal analysis of energy deposition is very difficult to realize because of small distance between backsplash production place and anticoincidence detectors. Only total energy deposition in each individual detector of all layers of system used as anticoincidence should be taking into account. S2 and LD used instead ACtop in additional and lateral apertures correspondingly. Backsplash in these apertures formed in CC1 and CC2 and it is possible suppose such processes similar in the first approximation without loss of generality. From 7500 modeled gammas energy deposition for 342 particles exceed 0.2 MIP value in S2 upper layer and for all of these events 0.2 MIP threshold overcoming in S2 lower one. But only 243 (~3%) events exceed 2 MeV threshold modeled for charged particles – see figure 4. For one layer anticoincidence detector

amount of gammas exceed 2 MeV threshold will be 346 particles (\sim 5%). Low energy gammas (E<100 MeV) do not give backsplash and such photons classified by using simple anticoincidence signals from the individual detectors of LD and CC2.



Figure 4. Total energy deposition distributions in S2 simulation results for three subsets of 7500 particles each with E = 3 GeV: for gammas (a); for electrons and protons (marked by black and red colors at panel (b) correspondingly).

3. Conclusion

Events registration both from upper and lateral directions provides due three apertures of gammatelescope GAMMA-400: main, additional and lateral. Gammas, electrons/positrons and protons recognition in main aperture provides due energy deposition analysis in individual detectors of ACtop, AClat, S1-S3 and CC1. Temporal analysis using in anticoincidence system allow rejecting backsplash with accuracy better than 0.1%.

Particles identification in the additional aperture supplied by study of energy deposition in the individual detectors S2, S3 and position-sensitive calorimeter individual scintillator detectors discriminators. In the lateral aperture low energy (0.2 - 100 MeV) photons classified by using simple anticoincidence signals from the individual detectors of LD and CC2. Higher energies γ -quanta (E>100 MeV) recognized using energy deposition analysis in the individual detectors of S3, S4, LD and CC2. Less than 3% gammas could wrongly recognize as charged particles for two layer anticoincidence detectors and more than 5% for single layer one.

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