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2016 J. Phys.: Conf. Ser. 675 032011

(http://iopscience.iop.org/1742-6596/675/3/032011)

Method to select gamma rays with energy above 50 GeV against a charge-particle background in the GAMMA-400 space telescope

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Abstract. Studying high-energy (>50 GeV) cosmic gamma radiation raises a problem of selection of neutral gamma rays from a background of charged particles. The problem is embarrassed by the *backsplash* effect. The backsplash consists, in the main, of low-energy (1 MeV) secondary photons moving backwards and is produced by any high-energy gamma quantum. A charged-particle rejection method using the anticoïncidence and time-of-flight systems is proposed. Charged-particle events are distinguished from those being triggered by high-energy gamma-rays producing backsplash. The method is based on the time separation of signals. It allows us to keep the gamma-ray detection efficiency high up to high energies.

1. Introduction

Modern status of fundamental research in cosmology, astronomy, high-energy physics, and cosmic-ray acceleration and propagation raises series of problems unsolvable without involving results of extraterrestrial high-energy γ-ray astronomy. The problem of dark matter origin is a representative example.

Typical gamma-ray telescope (such as GAMMA-1 [1], AGILE [2], EGRET [3], Fermi/LAT [4]) for tens of MeV – hundreds of GeV range is a pair-production telescope with three main components: a tracker to determine the direction of each incident particle, a calorimeter to determine its energy, and an anticoïncidence detector surrounding the tracker to distinguish gamma-ray events from the much more numerous charged-particle events. Tracker has high-Z foils (typically tungsten) for pair conversion interleaved with position-sensitive detectors (silicon strip detector planes) for the direction determination. Tracker provides highly efficient trigger for low energy

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Journal of Physics: Conference Series **675** (2016) 032011 doi:10.1088/1742-6596/675/3/032011

gammas, but raise problem of charged-particle rejection. To retain the rejection at high energies one can use trigger generated by much faster scintillation detectors.

A high-energy gamma-ray particle produces an electromagnetic shower in the telescope. Its major part develops inside the calorimeter. The more energetic the γ-ray particle being detected is, the more particles are produced in the shower, including the ones moving upwards, anti-parallel to the incident direction, and being referred to as the *backsplash*. It consists mainly of γ-ray photons with energy ∼ 1 MeV. This soft-spectrum flux 'soils' upper detectors and imitate a detection of a charged particle. Backsplash may dramatically reduce efficiency above tens of GeV. Triggering of AC caused by backsplash prevents detection of high-energy γ-radiation and makes detector efficiency vanish at high energy. To solve the problem, a new method of charged-particle rejection by measuring AC triggering time is being proposed.

In this work, a scheme of gamma-ray telescope's time-of-flight (ToF) and anticoïncidence (AC) systems is proposed. It provides measurement of time of particle's flight via AC and ToF detectors. The proposed procedure of event time selection keeps high-energy gamma-ray detection efficiency high.

This method is used for the GAMMA-400 instrument [5–7], nevertheless it still can be applied to most γ-ray telescopes with time-sensitive AC and ToF systems.

2. Anticoïncidence and time-of-flight systems

GAMMA-400 anticoïncidence (AC) system covers converter on top and on each lateral side. Its time-of-flight (ToF) system consists of two detectors — S1 and S2 — with the same design. Each detector of AC and ToF is composed of two layers, each consisting of a number of scintillation paddles. Paddles of the two layers are shifted across, so that gaps between those of one layer overlap gaps in another. This overlapping provides utterly high detector efficiency. Each one is made of polystyrene-based scintillating material. Scintillation light is detected with photosensors placed on opposite edges.

Photosensors' outputs are connected to a *time-coördinate compensation circuit* (TCC), which allows time of particle's interaction with scintillator material to be determined via compensation of dependency of flash detection time on place of its origin [8].

In this paper, the upper horizontal plane of AC is considered.

3. Time-selection method

Consider the following event. A gamma-ray photon goes down with no interaction in AC and produces an e^-e^+-pair in C. The pair continues its motion down. Being charged particles,

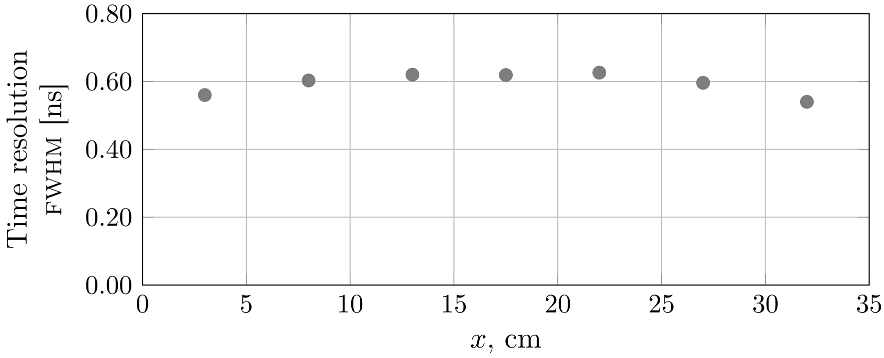

Figure 1: Time resolution vs. source position

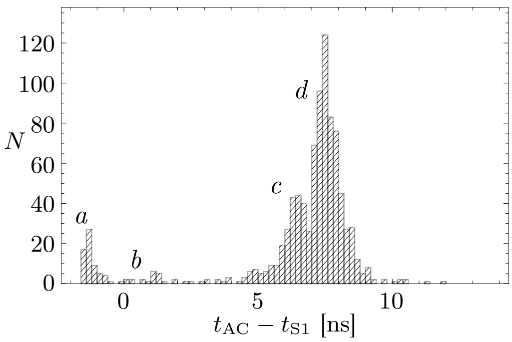

Figure 2: Distribution of the difference between AC and S1 triggerings when detecting gamma rays; a: conversion in AC, b: backsplash from C, c: from CC1, d: from CC2,

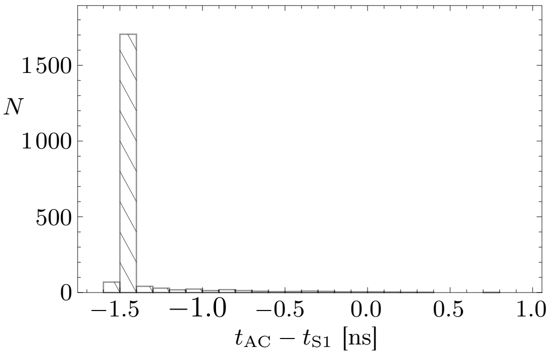

Figure 3: Distribution of the difference between AC and S1 when detecting protons (note expanded horizontal scale)

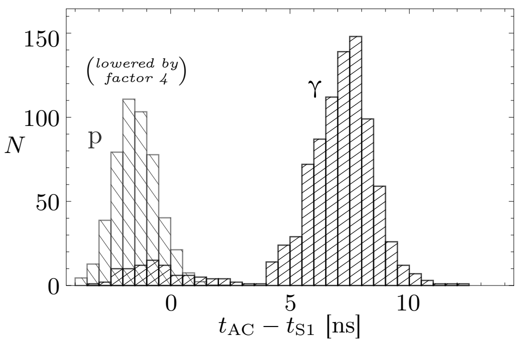

Figure 4: Normally blurred distribution of the difference between AC and S1 triggerings when detecting gamma rays and protons. Standard deviation of the blur is a pythagorean sum of AC and S1 time resolutions. For convenience of comparison, heights of columns on proton histogram are lowered fourfold.

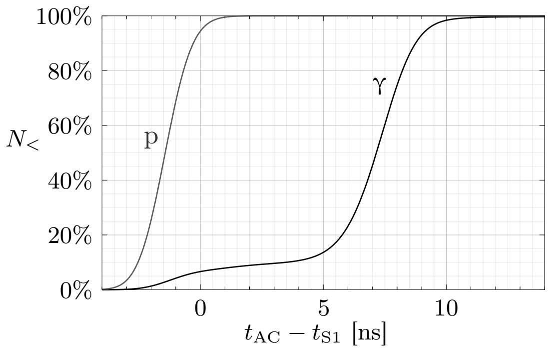

Figure 5: Cumulative distribution functions of S1-to-AC lag. Value of $N_<$ at abscissa t refers to fraction of events where the lag is less than t. Both gamma rays and protons are plotted.

e^- and e^+ (or their products) give a signal in S1, then in S2, come in the calorimeter, and develop a shower. The latter produces backsplash, whose particles trigger a signal in AC.

Since both AC–S1 and S1–CC1 distances are about half-meter long, time to move particles from S1 to CC1, to form a shower, and to bring a backsplash back to AC amounts to several nanoseconds, whereas in case of detection of a primary charged particle by the instrument (in the same direction), AC is triggered as soon as this particle enters it. Thus, time lags till AC is triggered, from the moment a primary charged particle enters the telescope and from the moment a primary gamma-ray particle does, differ. After the charged particle gets into the instrument, signal in AC appears with a small delay only determined by light propagation in the scintillator, whereas an interval until signal in AC appears after the gamma enters is composed of the time of backslash particles to be produced and to move up to AC and equals to several nanoseconds.

Thus, a signal in AC appears several nanoseconds later that in the case of flight of a charged particle in the same direction.

Detectors of AC and ToF systems are proved to have time resolution $\delta t \approx 0.6$ ns (see fig. 1).

The 100 GeV gamma-ray detection by the instrument has been simulated using Monte-Carlo method. Detector triggering time is defined as the earliest triggering time of all the constituent paddles, which in turn are defined by TCC mathematical model.

Events are selected by the set of detector signals indicating the presence of conversion in C. The distribution of difference between AC triggering time and S1 triggering time is plotted in fig. 2. Four peaks can be seen in the histogram: *a*) the left one (-1.5 to 0 ns) corresponds to gamma's interaction inside AC; *b*) the next low peak (0 to 3 ns) corresponds to the backsplash from the converter; *c*) (4 to 7 ns) and *d*) (7 to 10 ns) are the backsplash from the two parts of the calorimeter — CC1 and CC2, respectively.

The leftmost peak is the only one in the case of a charged particle since it always triggers AC first. It is shown by proton-event simulation in fig. 3. Tails appear due to the case of several interactions in AC (early backsplash or δ-electron). In these instances, TCC technique undervalues time: $\hat{t}_0 < t_0$.

The histograms mentioned above leave out of account inherent time resolution of AC and S1 detectors. If we blur the lag normally (Gaussianly) by $\delta t \times \sqrt{2} \approx 0.85$ ns we get histograms shown in fig. 4. It is the case to be expected in real instrument. The events of the two types are seen to be separated fairly enough even though being blurred.

Cumulative plots (see fig. 5) show that excluding AC from anticoïncidence scheme $t_{\mathrm{th}} \approx 3$ ns past S1 triggering leads to sure identification and classification of γ-ray events even in case of backsplash. Calculation yields that t_{th} being at least 2.9 ns leads to protons' admixture to gammas selected not more than 10^{-5}, while gamma-ray loss being 10%.

4. Conclusion

The proposed procedure of using time-sensitive detectors to distinguish events of charged-particle detection and γ-ray particles that produced backsplash triggered AC makes possible to effectively reject charged particles — primarily, protons — without significant loss of γ-ray detection efficiency. In the GAMMA-400 γ-ray telescope, this efficiency is at least 90% for high-energy gammas. Implementation of the technique using scintillation detectors, with SiPMs, is shown to be possible.

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