Gamma-ray Scintillator Fiber Tracker

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Abstract

We plan to develop and implement a novel ultralight tracker based on scintillating fibers with a spatial resolution below 100 μm, also able to perform precise timing and charge measurements. The fibers will be arranged in a 3D geometry, read-out by silicon photomultiplier (SiPM) arrays and equipped with a dedicated integrated fast front-end electronics followed by a pre-processing circuit. Although in the past the technology of scintillating fibers has been already used in high-energy physics, we plan to exploit its potential as a possible high-performance alternative to the classical technology of silicon strip detectors (SSDs), which is widely used in the current generation of space-borne experiments. Scintillating fibers allow a cost-effective instrumentation of large detector areas without the need of complex and potentially failure-prone wire bonding procedures required when using SSDs. In addition, a fiber-based tracking system can easily guarantee the implementation of several geometries, even different from simple planar layouts, that can be very useful in very specific applications. This tracker configuration could be implemented in future space-borne experiments aimed at the detection of sub-GeV gamma rays. Gamma-ray detection in this energy range is indeed very challenging, as photons interact with matter mainly through Compton scattering. This proposal aims to develop a detector based on scintillating fibers that will be able to detect photons via Compton scattering or pair production.

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The present generation of space-borne detectors for charged cosmic rays and gamma rays has greatly improved our understanding of many astrophysical phenomena and, at the same time, have opened new opportunities for the investigation of the Universe. A promising window for new explorations is the study of gamma rays in the MeV-GeV energy band, which was only approached in the 90s with the Energetic Gamma-Ray Experiment Telescope (EGRET) on board of the Compton Gamma-Ray Observer (CGRO) satellite and in the last decade with the Large Area Telescope (LAT) on board of the Fermi satellite. A large part of the astrophysical community is therefore focusing its efforts in the development of a new generation gamma-ray telescope for low-energy photons down to the MeV, more than an order of magnitude below the lower energy bound of the Fermi LAT.

In the last decade, many telescopes have been proposed to observe the Universe in the energy range from 0.3 MeV to 10 GeV. These proposals include MEGA [1, 2], GAMMA-LIGHT [3], PANGU [4], GAMMA-400 [5], ASTROGAM [6, 7] and AMEGO [8]. The designs of these telescopes are mainly based on those of the Agile [9] and Fermi LAT instruments [10], consisting of a silicon tracker in which gamma rays can interact either via Compton scattering or pair conversion, and a calorimeter to measure the energy of the secondary particles. In these telescopes, the proposed tracking system is based on the technology of double-sided silicon strip detectors (DSSDs), which allow a full 3D reconstruction of the interaction vertices with excellent spatial and energy resolution. The angular resolution, or equivalently defined point spread function (PSF), is therefore strongly determined by the tracker design. A tracking system based on the technology of DSSDs should provide a full 3D reconstruction of the interaction vertices with excellent spatial and energy resolution. The typical layout consists of an array of identical towers, each equipped with 40-80 layers of 10 cm side DSSD wafers, 500 µm thick, arranged in 4×4 or 5×5 horizontal planes. However, the mechanical assembly of these planes is not trivial, as bonding machines should be able to work on large area silicon planes and on both sides. The signals from the DSSD sensors should be processed with a charge readout providing an excellent spectral resolution, in order to accurately measure the low-energy deposits produced by Compton events. Therefore a ultralow-noise front-end electronics is needed, which should be coupled to the large input capacitance of 40-50 cm long silicon strips. The length of the strips is indeed limited by the electronic noise introduced by the large capacitance. With the evolution of the sensor technologies, scintillating fiber trackers equipped with SiPMs now represent a valid alternative to silicon detectors. Recent experimental results from LHCb [11], Mu3e [12] and from the balloon experiment PEBS [13] have demonstrated that spatial resolutions below 100 µm can be achieved in large area detectors equipped with fiber trackers.

A scintillating fiber tracker has several advantages with respect to a standard silicon tracker. First of all, the costs required to instrument a large detector area with fibers are significantly smaller than those required when using silicon detectors, as scintillating fibers are much cheaper than silicon detectors. In addition, a silicon tracker requires a high degree of segmentation, since silicon detectors usually must be assembled to form ladders, with an overall length that cannot exceed a few tens of cm, while single scintillating fibers with lengths up to 1-2 m can be used without suffering of significant light attenuation. Further advantages of a scintillating fiber tracker with respect to a standard silicon tracker are given by the relative ease of the detector assembly and by the possibility of implementing different geometries with respect to the simple planar configuration.

The achievable spatial resolution is correlated with the fiber diameter, and can be improved with staggered multi-layer fiber configurations. In addition, since the typical radiation length of a plastic scintillator (40 cm) is larger than that of silicon (9.5cm), for a given detector thickness the multiple scattering angle is reduced by about a factor 2. Figure 1 shows a possible layout of a stack (tower) equipped with four planes of scintillating fibers. The fibers in each plane are arranged in ladders, with the fibers of two consecutive ladders oriented along the X and Y axes alternatively. The scintillation light at both ends of each fiber is collected by a SiPM array consisting of 64-128 channels, with a pitch of 250-500 µm.

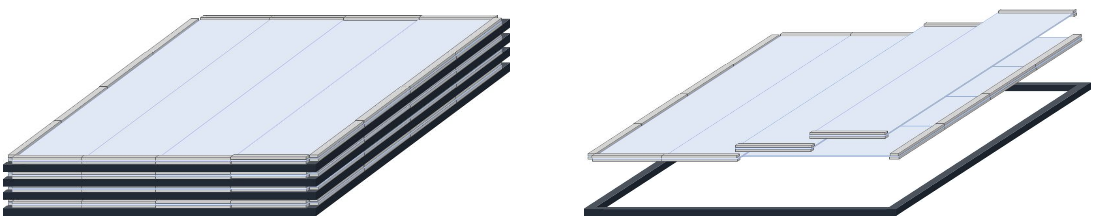

Figure 1: Left panel: Stack of four X-Y trays of scintillating fibers; Right panel: Exploded view of a X-Y tray.

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