Prospects of silicon photomultipliers for ground-based cosmic ray experiments

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An established technique to study ultra-high-energy cosmic rays is the detection of extensive air showers induced in the atmosphere of the earth. Thereby, cascades of secondary particles are produced consisting of a hadronic, an electromagnetic and a muonic component. Especially the determination of the number of muons and the amount of fluorescence light produced during the shower development allows to draw conclusions on the mass and energy of the primary particle. Thus, these are important observables for air shower experiments like for instance the Pierre Auger Observatory in Argentina, and its AugerPrime upgrade in progress.
The steady development of semiconductor devices in the last years resulted in highly improved photon sensors, e.g. silicon photomultipliers (SiPMs). The small package and moderate bias voltage (<100 Volts) of these silicon devices allow for compact and robust designs. Detailed detector simulations, the development of dedicated front-end electronics, as well as construction and investigation of detector prototypes, are needed to study the applicability of SiPMs for cosmic ray experiments.
We present our findings for two different detector techniques: First, we present the fluorescence telescope, FAMOUS. Its basic principle is based on a Fresnel lens focusing the incoming light onto a camera instrumented with 61 pixels. Secondly, the benefit of the application of SiPMs is studied for scintillator detectors designed for an improved determination of the muonic component in air showers of current experiments.

KEYWORDS: cosmic rays, UHECRs, muonic component, fluorescence telescope, silicon photomultipliers

1. Introduction

For the determination of the chemical composition of ultra-high-energy cosmic rays (UHECRs), a detailed understanding of the air shower development is indispensable [1]. A combined analysis by means of complementary detection methods is thereby a common technique to study these showers. For example, at the Pierre Auger Observatory [2], water-Cherenkov detector (WCD) stations [3] determine the distribution of charged particles on the ground, i.e. the electromagnetic and muonic component, while fluorescence telescopes [4] overlook the atmosphere above the array. For an improved discrimination between the electromagnetic and muonic components, an additional detector has been proposed: an array of scintillator-based stations. Located at the same position as the WCD stations, both detector arrays measure the same air showers, but with different response to their components. These Surface Scintillator Detectors (SSD), to be read out with standard photomultiplier tubes, are one main part of the on-going upgrade AugerPrime [5] of the Pierre Auger Observatory.
Nowadays, for many of these applications, silicon photomultipliers (SiPMs) promise a high potential as an excellent choice as photosensors [6, 7]. The working principle of SiPMs will be introduced in section 2. We present in section 3 the prototype fluorescence telescope FAMOUS [8] based on a re-