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Towards AugerPrime: the upgrade of the Pierre Auger Observatory

G. Cataldi[a], for the Pierre Auger Collaboration[b]

[a] *INFN, sezione di Lecce, Italy*
[b] *http://www.auger.org/archive/authors_2016_06.html*

Abstract

The Pierre Auger Observatory has begun a major Upgrade (AugerPrime), with an emphasis on improved mass composition determination using the surface detectors of the Observatory. AugerPrime will include new 4 m^2 plastic scintillator detectors on top of all the 1660 water-Cherenkov detectors, a faster and more powerful electronics, a large array of buried muon detectors, and an extended dynamic range. After introducing the physics motivation of AugerPrime, the planned detector upgrade is presented and the expected performance and improved physics sensitivity of the Observatory are discussed.

Keywords: air showers, cosmic rays, UHECRs, detector, AUGER, AugerPrime, upgrade

1. Introduction

The data taken with the Pierre Auger Observatory[1] contributed to a number of steps forward in the field of ultra-high energy cosmic rays (UHECRs). The measurements confirmed with high precision the suppression of the primary cosmic ray energy spectrum at energies above 5×10^{19} eV[2]. This reduction is compatible with the Greisen-Zatsepin-Kuzmin (GZK) effect, but the level of its impact to the cut-off remains unclear. The measured photon and neutrino fluxes limits at ultrahigh energy[3] indicate that top-down mechanisms such as the decay of super-heavy particles cannot be the main producer of the observed particle flux. The distributions of the depth of shower maximum (X_{max}) evaluated for different energy intervals have been used to determine the UHECR composition on Earth, surprisingly evidencing the presence of a large fraction of protons in the energy range of the spectral ankle. At the same time, according to the Auger data, the anisotropy of the arrival directions of these protons cannot be larger than a few percent. Moreover the proton component disappears just below 10^{19} eV where a helium component appears. These transitions indicate that we do not have enough composition-sensitive data to obtain the composition at energies higher than a few times 10^{19} eV.

In order to extend the composition sensitivity of the Auger Observatory into the flux suppression region, an upgrade of the Auger Observatory (named AugerPrime [4, 5]) has been planned. The main aim of AugerPrime is to provide additional measurements of composition-sensitive observables, allowing to determine the primary mass of the highest energy cosmic rays on a shower-by-shower basis. The study of the origin of the flux suppression will provide fundamental constraints on the astrophysical sources and will allow us to determine more precise estimates of gamma-ray and neutrino fluxes at ultra-high energy. The measurement of the flux contribution of protons will elucidate the physics potential of existing and future cosmic ray, neutrino, and gamma-ray detectors. In order to do so, the aim of AugerPrime is to reach a sensitivity as small as 10% in the flux contribution of protons in the suppression region. The determination of the primary mass composition of ultra-high energy cosmic rays is deeply related to our understanding of extensive air showers and hadronic interactions. In the Auger data, there is a disagreement between the observed and expected muon numbers, therefore it is of fundamental importance to study the hadronic multiparticle production in extensive air showers.

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2. The Detector Upgrade

Taking data until the end of 2024 will double the present surface detector (SD) event statistics and reduce the total statistical uncertainty at the highest energies. With the planned upgraded detector running for 7 years we can expect about 700 events above $3x10^{19}$ eV and more than 60 above $6x10^{19}$ eV for zenith angles less than 60°. "Horizontal air showers"will add about 30% to the exposure and thus to the number of expected events. Accounting for a detector resolution of 15% or better in determining the number of muons, this would allow a separation of a fraction as small as 10% of protons from intermediate and heavy primaries. The key question is whether we can use additional information on the separation between the electromagnetic and muonic shower components for improving the estimate of the mass of the primary particles adding an extra measurement of the particles in the EAS independent of the measurements made with the water-Cherenkov detectors (WCD). To achieve the maximum advantage from this additional measurement, the shower should be sampled in the position of the WCD with a detector that has a different response to the basic components of the EAS. Moreover, the additional detector has to be reliable, easy to realize and install, and has to have minimal maintenance. Overall, the expectations from air shower simulations strongly indicate the feasibility of composition determination at the highest energies. It can be expected that, if the detector resolution in determining the number of muons and the X_{max} is smaller or of the order of the shower fluctuations, the primary mass can be inferred on an event-by-event basis. The different parts of the upgrade are explained in the following subsections:

2.1. The Scintillator Surface Detector (SSD)

A thin scintillation detector, which is mounted above and triggered by the larger WCD detector below it, provides a robust and well-understood way of particle detection that is sufficiently complementary to obtain a good measurement of the density of muons.

An SSD unit consists of a box of 3.8m×1.3m, containing two scintillator sub-modules, each composed of extruded polystyrene scintillator bars of about 1.6m length, 5cm width and 1cm thickness.The 4m^2 scintillator planes are housed in light-tight, weatherproof enclosures, attached to the existing WCD with a strong support frame (see Figure 1). The scintillator light will be read out with wavelength-shifting fibres inserted into straight extruded holes in the scintillator planes, which are bundled and attached to a single photomultiplier tube. Figure 2 shows how the green wavelength-shifting fibres emerge from the scintillator planes and are grouped into bundles. As photodetector, the 8-stage, 38mm diameter photomultiplier Hamamatsu R9420 has been selected as baseline design due to its high linearity of up to 200 mA peak anode current, but other solutions are under investigation as well.

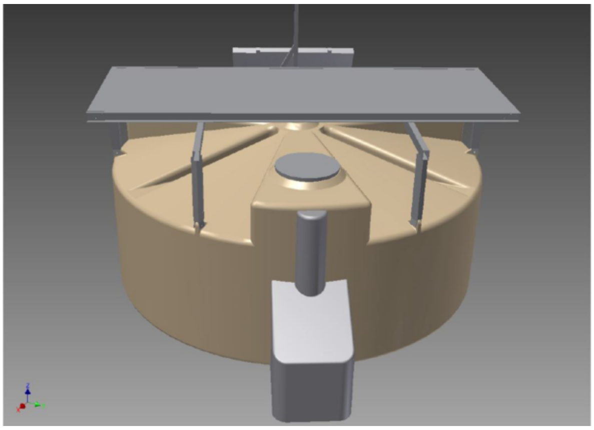

Figure 1: 3D drawing of an AugerPrime SSD station with the scintillator plane housed in a weatherproof enclosure above a WCD.

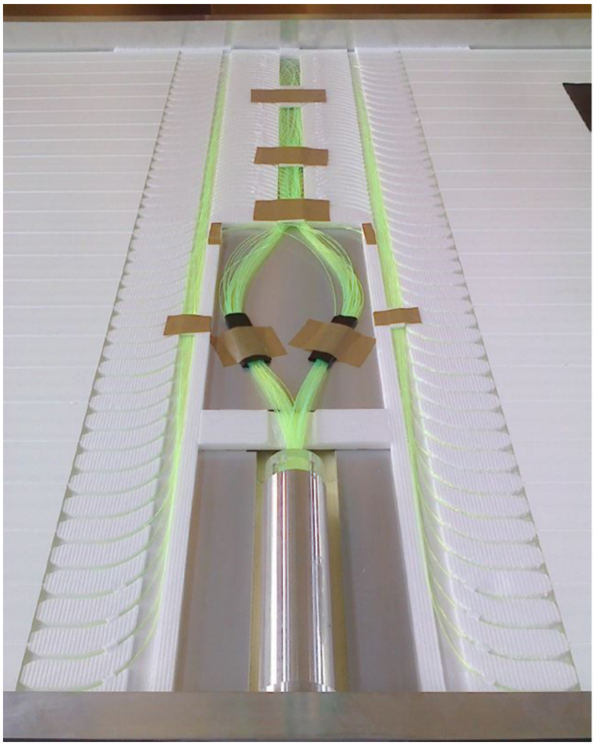

Figure 2: Photo of the inner part of a SSD detector with green wavelenght-shifting fibers routed from scintillators and guided in two bundles to the photomultiplier tube, housed in the aluminum support.