Journal of Physics: Conference Series

Composition studies using the surface detector of the Pierre Auger observatory

Composition Studies using the Surface Detector of the Pierre Auger Observatory

Karen Salomé Caballero Mora[1], Markus Roth[1], Ioana C. Mariş[1] and Talianna Schmidt[1]

[1] Universität and Forschungszentrum Karlsruhe, Karlsruhe Germany

E-mail: Karen.Mora@ik.fzk.de

Abstract. The Pierre Auger Observarory measures ultrahigh-energy cosmic rays combining two kinds of detectors namely Fluorescence telescopes and water Cherenkov tanks. This characteristic gives the capability to obtain more accurate measurements for estimating the meaningful parameters of the air shower produced by the primary particle. The mass of the primary particle is one of the most relevant characteristics, which gives information about its nature. The number of muons and the signal risetime of showers detected by the surface detector are explored to reveal the nature of the primary particle.

1. Introduction

Located in the City of Malargüe in western Argentina, the Pierre Auger Observatory is called a "hybrid detector" because it uses two independent methods to detect and study high-energy cosmic rays. One of the methods uses 1600 12-tons water tanks (Surface Detector (SD))on a surface of 3000 km^2, separated 1.5 km from each other. Each tank measures the Cherenkov light emited by charged particles traveling through the tank and recorded as FADC traces. At the moment there are already around 1300 tanks running.(See Fig. 1) The second method uses 4 telescope buildings with 6 fluorescence telescopes (Fluorescence Detector (FD)) per site, those telescopes measure the ultraviolet light emitted by charged particles in an air shower, which interact with atmospheric nitrogen.

1.1. The Muon Content of a shower

Meassured air showers are at ground level a mixture of photon and electrons, the electromagnetic component (EM,) and muons, the muonic component. The relative contribution of the EM and muonic components of an air shower at a given development stage and at a fixed radial distance is different for showers induced by different primaries, an iron primary may induce up to about 40 % more muons than a proton primary of the same energy. The muon content of a shower could therefore help to identify the mass of the primary particle [1].

1.2. The risetime

The risetime ($t_{1/2}$) defined as the time taken for the integrated signal in a tank to rise from 10% to 50% of the final value (See Fig. 2), is also a sensitive parameter to the mass composition of cosmic rays because particles which arrive at the SD from different primary particles result also in a different risetime. Air showers which have more content of muons (like those produced by heavy primary cosmic rays) have a smaller distribution in arrival times than showers with large fractions of electromagnetic particles (like those produced by light primaries). That is because muons travel in straight line through the atmosphere with hardly any interaction. Furthermore a shower maximum (maximum number of produced particles) which is closer to the detector (light primaries) will have particles which have a greater time spread when they reach a detector than that of a shower with maximum further from the detector (heavy primaries).

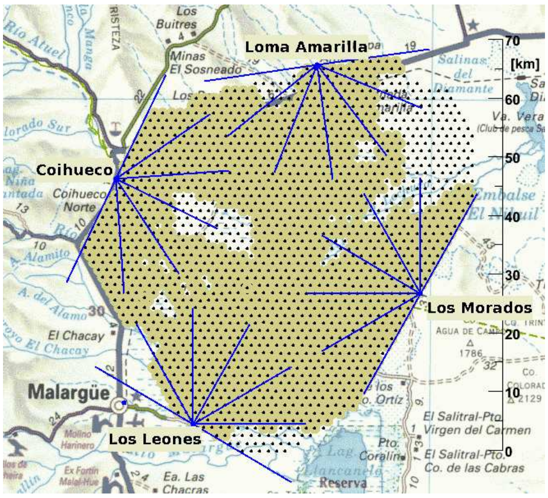

Figure 1. Current status of the Pierre Auger Observatory. The dots are the SD array and the "semi-asterisks" are the fluorescence telescopes.

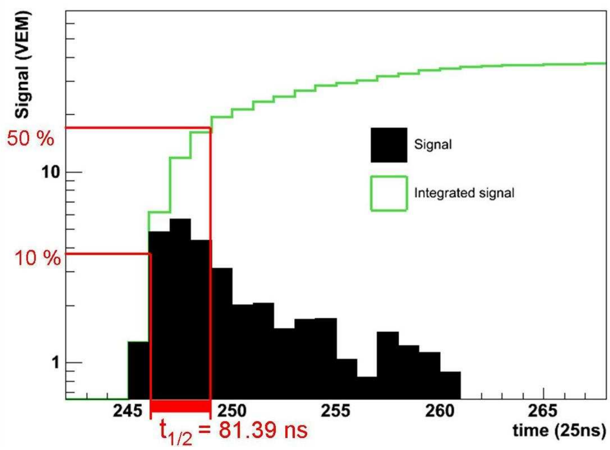

Figure 2. Risetime of a simulated signal.

2. The Muon Filter

The excellent timing resolution ($\sim 10\ ns$) of the SD may allow to identify the signal from different particles. The SD is especially sensitive to muons, which we might be able to count in detectors that are located faraway from the shower core. These remote tanks have a smaller contribution of electromagnetic particles (e/γ) and single muon traces can be isolated (See Fig. 3).

A linear filter [2, 3] applied on muonic FADC traces of simulated showers is used to find the number of muons counting the resulting peaks. This filter works as following:

- An idealized signal of the following form is considered:
$$\{...00C_0C_1...C_n...\}$$
where $C_n = \alpha^n C_0$, $\alpha = exp(-\Delta t/\tau)$, $\Delta t = 25\ ns$ and $\tau \approx 80\ ns$ is the signal decay time for the used simulations.
- The new signal will be calculated by
$$C'_k = \frac{C_k - \alpha C_{k-1}}{1-\alpha}$$
which is the form of the filter applied. Imposing some quality cuts the new signal is
$$\{...00C_00...\}$$
where the peak C_0 corresponds to a muon signal.

The approximation with the real number of muons already known from the simulated traces, is better for small number of muons and for stations located far from the shower core (See Fig.4).

Once the number of muons is approximated, an expresion for the lateral distribution function (LDF), that describes the decreasing of the signals in the water tanks as a function of distance [4] during the development of an air shower, for muons could be obtained (See Fig.5).

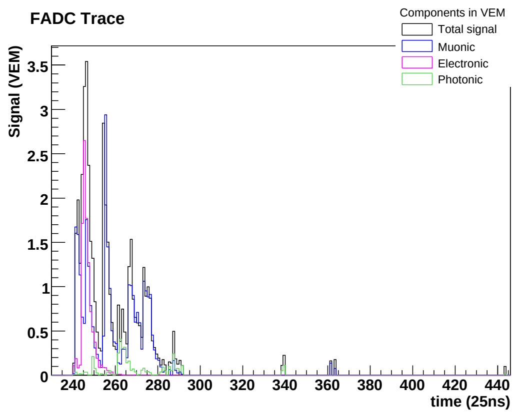

Figure 3. FADC trace of a simulated event with energy of 10^{20} eV.

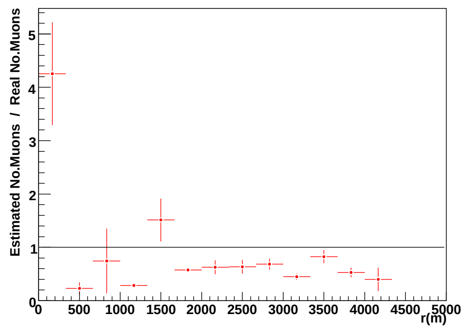

Figure 4. Ratio of number of "peaks" and known number of muons.

3. Risetime $t_{1/2}$

The risetime shows an asymmetry with respect to the azimuth angle for different intervals of distance to the core and zenith angle. This asymmetry is due to the attenuation of the electromagnetic component. Particles in the downstream region travel a longer path to the tanks than those at the upstream side. This induces a larger risetime measured on the upstream side because the electromagnetic component is less attenuated with respect to the downstream side (See Figs.6 and 7). There is also a geometrical effect on the SD signals due to the characteristics of the tanks. Tanks with a larger effective "top" than "side wall" area with respect to the longitudinal evolution of the shower, register more particles in the upstream region, while the tanks with a larger effective "side wall" area register more particles in the downstream region [5].

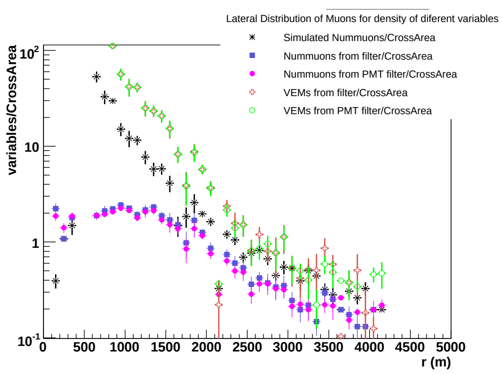

Figure 5. Lateral distribution of muons density in the tank for simulated showers.

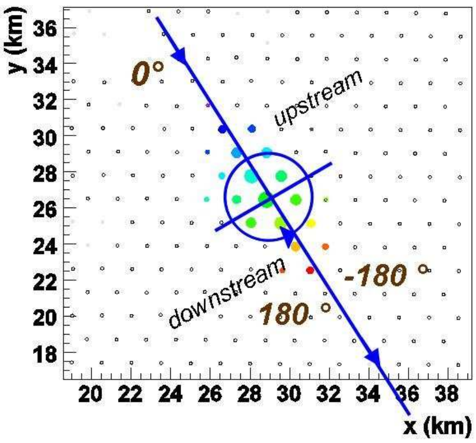

Figure 6. Asymmetry of the risetime with respect to the azimuth angle seen on the SD array for a real event.

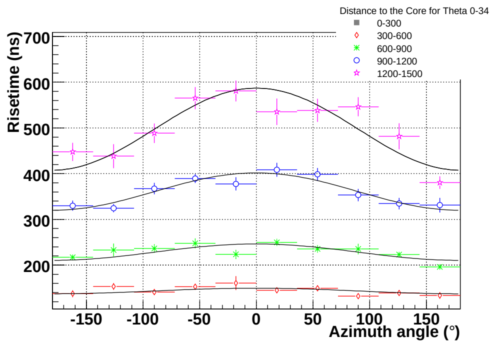

Figure 7. Asymmetry of the risetime for tanks at different distance to the core.

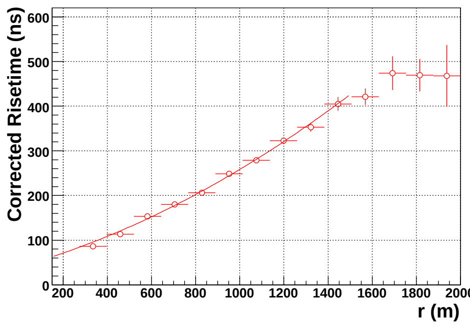

Figure 8. Corrected risetime as function of the distance to the core.

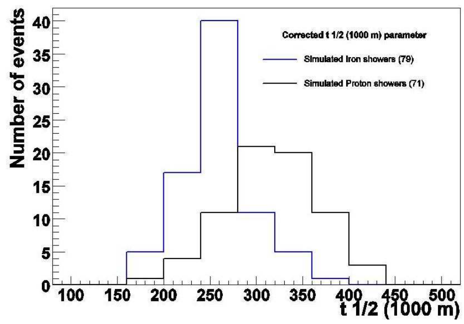

Figure 9. $t_{1/2}(1000)$ parameter from corrected risetime for simulated events.

To correct this asymmetry the parameterization of the risetime as a function of the distance to the core and as a funciton of the azimuth angle was considered as following

- Risetime with respect to the distance to the core: $t_{1/2}(r,\theta)$=$40 + b \cdot r + c \cdot r^2\ ns$ [6]
- Risetime with respect to the azimuth angle: $t_{1/2}(r,\theta,\phi) = f + g \cdot cos(\phi)$
- The correction will be done by :

$$t'_{1/2}(r,\theta,\phi) = t_{1/2}(r,\theta,\phi) - g \cdot cos(\phi)$$

With $g = \delta(\theta)r$ and δ the correction parameter (See Fig.8)

After correcting the asymmetry we are able to utilize another parameter, which characterize the risetime of each event, this parameter is the risetime for a detector which would be located at 1000 m from the core $t_{1/2}(1000)$ for making studies on mass composition (See Fig.9).

For more information about Composition Studies see [7].

4. Acknowledgments
I would like to thank Forschungszentrum Karlsruhe and CONACyT-Mexico for the financial support.

References
[1] X. Garrido *et al.*. Measurement of the number of muons in Auger tanks by the FADC jump counting method. *GAP-Notes 2007*
[2] P. Billoir. Peak Searching in Surface Detector FADC Traces: A Linear Filtering Method. *GAP-Notes 2002-076*
[3] P. Billoir. The Muon Hump in the Real Shower Data from the Surface Detector. *GAP-Notes 2005-004*
[4] D.Barnhill *et al.* for the Pierre Auger Collaboration. Measurement of the Lateral Distribution Function of UHECR Air Showers with the Pierre Auger Observatory. *29th International Cosmic Ray Conference Pune(2005)*
[5] X. Bertou *et al.*. Checking the Origin of the Asymmetry of the Surface Detector Signals. *GAP-2002-074*.
[6] A. Smialkowski, J. Knapp, M. Zha. Signal Rise-Time and Mass Sensitivity around 10 EeV with the Auger SD. *GAP-Notes 2005-051*
[7] J. Abraham *et al.* for the Pierre Auger Collaboration. *Submitted to Astrop. Phys.*