Study of the correlation of the UHECR detected by The Pierre Auger Observatory with Active Galactic Nuclei

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The astrophysical sites of origin of ultra high-energy cosmic rays (UHECRs) remain elusive after almost a half century since a cosmic ray (CR) with energy around 10^{20} eV was first reported [1]. Anisotropy in the arrival directions of UHECRs is expected to provide significant clues for identifying their sources. Protons and nuclei with these energies interact with the cosmic microwave background (CMB), either by pion photoproduction or by nuclear photodisintegration. This interaction limits the distance from which a source can contribute significantly to the flux on Earth [2]. For instance, most of the observed flux above 60 EeV (1 EeV = 10^{18} eV) should come from sources within a "GZK horizon" which is approximately 200 Mpc. Processes that could accelerate particles up to such energies require special astrophysical conditions [3]. Few classes of astrophysical objects, such as active galactic nuclei, radiogalaxy lobes and sources of gamma-ray bursts, meet these requirements. Inhomogeneities in their spatial distribution within the GZK horizon may imprint a detectable anisotropy in the UHECR arrival directions. Comparing the arrival directions with the celestial positions of different types of astronomical objects is a useful tool for identifying the sources provided intervening magnetic fields do not deflect the cosmic ray trajectories through large angles.

A knowledge of CR composition is important for deciding which of several source scenarios is more likely. The trajectories of highly charged nuclei are expected to undergo large deflections due to the Galaxy's magnetic fields. While a correlation of arrival directions with nearby matter on small angular scales is plausible for protons above 55 EeV, it is puzzling if the CRs are heavy nuclei.

We have investigated the relationship between a wide class of mass composition sensitive parameters obtained with the surface detector and the degree of correlation of the events above ~ 55 EeV (1 EeV $\equiv 10^{18}$ eV) with the active galactic nuclei (AGN), within 75 Mpc (redshift $z \leq 0.018$), of the 12^{th} Véron-Cetty and Véron catalogue.

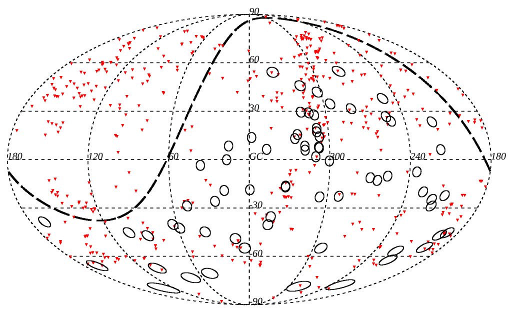

Figure 1. Sky map in galactic coordinates of arrival directions of cosmic rays with energies above ~ 55 EeV and the position of AGN with redshift $z \leq 0.018$.

Figure 1 shows the obtained sky map in galactic coordinates. The detected cosmic rays events are plotted as a circle of 3.1° radius while the AGN are shown as triangles.

To analyze the correlation signal of the events of highest energies with the AGNs of the VCV catalogue we have also used the method proposed by Hillas [4]. To estimate the level of correlation this method uses the average angular distance $< d >$ between the cosmic rays arrival direction and the position of the nearest AGN. A chance probability is assigned to this value and it is defined as the frequency to obtain a mean angular distance equal or lower than the observed one from a set of isotropically distribuited cosmic rays arrival directions (weighted by the detector exposure to each part of sky). The mean angular distance $< d >$ for the events used in the correlation analysis is $\sim 5.25°$ while the mean value of $< d >$ for an isotropic distributions of arrival directions is $\sim 6.18°$. The chance probability to obtain this value from an isotropic expectation is $P(< d >) \sim 10^{-2}$ (see black dot in the Figure 2).

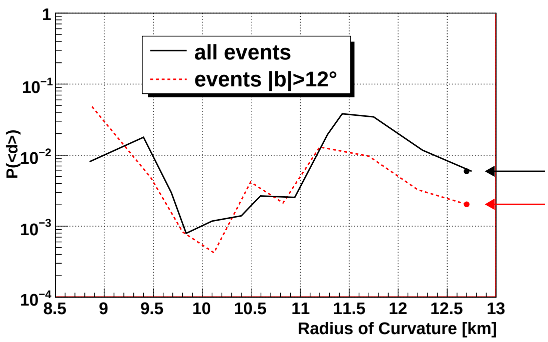

Figure 2. Hillas estimator as a function of one of the mass parameter analized. The black full lines refer to the evolution of the probability $P(< d >)$ for different cuts in the mass parameters going towards an increasingly lighter composition. The red dotted lines refer to the same evolution considering only the events outside the galactic plane. The dots are the $P(< d >)$ values without mass selection.

We study the evolution of this probability for different cut in the mass parameters value trying to go towards a lighter composition. In the Figure 2 there is the probability $P(< d >)$ as a function of each mass parameter, the black full line refer to the evolution of this probability whereas the red dotted line refer to the same probability evolution considering only the events outside the galactic plane. From the Figure 2 it can be seen that the probability $P(< d >)$ does not increase significantly as function of the mass parameters used.

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