The Pierre Auger Observatory Angular Resolution

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1. Introduction

For anisotropy studies and search for point sources of cosmic rays an accurate determination of the arrival direction is a key issue. The Angular Resolution (AR) is defined as the space angle that contains 68% of the cosmic rays coming from a given direction. For hybrid events the angular resolution is calculated from simulations and corresponds to the angle at 68% of the cumulative distribution function of the space angle between reconstructed and true axes. Hybrid events with at least 3 hitted stations of the surface detector can be reconstructed independently by both the surface and the fluorescence detectors giving the chance to point out systematics between different methods and compare simulations with data. Figure 1 shows the hybrid angular resolution as a function of energy for a class of well reconstructed events [1]. At energy larger than $10^{17.5}$ eV the angular resolution is less than 1 deg and at energy above $10^{18.5}$ eV is about 0.5 degs. A check with time dependent simulations has proven that these results don't degrade if the realistic detector configuration is used.

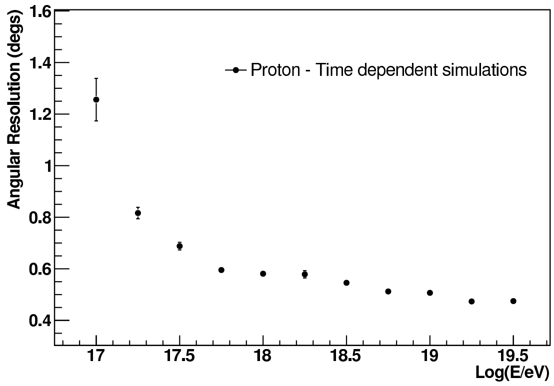

Figure 1. Angular resolution of hybrid events determined from simulations as a function of the energy [1].

2. Angular resolution with many-fold events from simulations and data

Events triggering multiple FD detectors (namely "stereo" or "many-fold") offer the chance to observe an incoming shower from different sides. An independent hybrid reconstruction can be performed for each triggered FD site. For this category of events, a space angle $\eta_{Hy1-Hy2}$ between two independent hybrid reconstructed axes can be defined both in simulation and data. Alternatively, the geometry of the shower may be reconstructed in "*stereo*" mode by intersecting the SDPs of the triggered FD-sites without using the time information of the station. Only events with E$\sim 10^{19}$ eV are selected as this corresponds to the mean energy of multiple-FD events in data. As a first approximation, an estimate of the mean $< AR_{Hy} >$ can be calculated as:

$$< AR_{Hy} >= AR_{Hy1-Hy2}/\sqrt{2} \quad (1)$$

where $AR_{Hy1-Hy2}$ is the AR from the space angle between the axes reconstructed by the FD sites 1 and 2. This is correct only when the ARs in both FD sites are similar. Actually, in many-fold events one of the two FD sites may have a short track length giving a poor geometrical reconstruction. To avoid not-equalized configurations, many-fold events with similar angular tracks and approximately equidistant to FD sites (within a tolerance of about 5 degs and 3 km respectively) are further selected. The mean angular resolution derived in this case is about (0.68±0.08) degs.

In a more general case, assuming that $AR^{narrow}_{Hy} = \alpha\, AR^{wide}_{Hy}$ ($\alpha > 1$), the AR between the two reconstructed axes can be written as:

$$AR^{wide}_{Hy} = \frac{AR_{Hy1-Hy2}}{\sqrt{1+\alpha^2}} \quad (2)$$

Given a many fold event, for each FD counterpart, the expected mean value of AR_{Hy} at the corresponding track length and core distance is taken from simulations and used to compute α. The AR is derived from data collected between January 2006 and March 2009 using eq. 1 and eq. 2. Table 1 summarizes the results obtained from time dependent simulations and from data. The main source of systematic uncertainties for the AR measurement is related to the time synchronization between SD and FD. The instrumental timing offset between the two detectors has been measured for each FD building using laser shots from CLF and golden hybrid data [2]. An uncertainty on the estimate of this quantity may influence the time fit for the axis determination. Moreover the assumption on the shape of the shower front propagates into a delay of the SD station trigger time with respect to a planar approximation. This time delay increases with the station distance from the axis and it is less than ∼50-100 ns for vertical events with the station at about 600 m. Since the instrumental SD/FD time offset is known within 100 ns [2], a systematic shift (± 50 ns and ± 100 ns) has been artificially introduced and a reconstruction assuming a planar shower front has been performed. In fig. 2, the angular resolution is shown as a function of the core distance to FD-site, for simulated events at 10^{19} eV (black dots) selected in the range of angular track lengths between 23 and 30 degs, as it occurs for many-fold hybrid data surviving the selection criteria imposed for this study. The maximum interval of variability due to the discussed sources of systematics is delimited by the shaded area. The AR from data (red star) and from time dependent simulations (blue square) are also displayed using the most conservative value between the ones provided by eq. 1 and eq. 2. Due to the lack of statistics of real events, these points are placed in correspondence of the mean core distance from FD with the x-axis error bars giving the full range of observed distances.

Simulation 10^{19} eV	**AR (degs)**
$AR^{SIM}_{Hy1-Hy2}/\sqrt{1+\alpha^2}$	0.58 ± 0.02
$AR^{SIM,sel}_{Hy1-Hy2}/\sqrt{2}$	0.68 ± 0.03
Multi-eye Data	**AR (degs)**
$AR^{DATA}_{Hy1-Hy2}/\sqrt{1+\alpha^2}$	0.69 ± 0.04
$AR^{DATA,sel}_{Hy1-Hy2}/\sqrt{2}$	0.76 ± 0.08

Table 1
Summary table of the overall angular resolutions derived from simulated hybrid and many-fold events at E=10^{19} eV. AR from data are also shown.

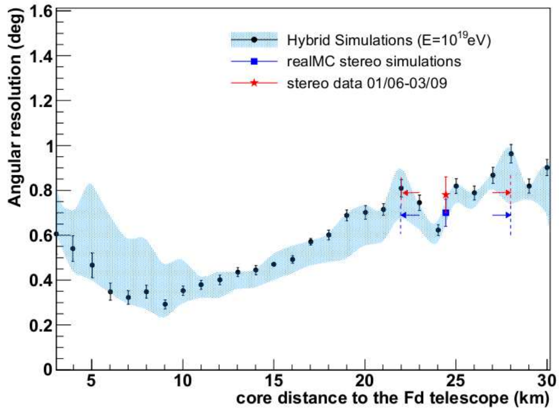

Figure 2. Angular resolution as a function of distance for proton simulations (black dots) at 10^{19} eV with an angular track length between 23° and 30° (see text). Error bars refer to statistical uncertainties only. The overall systematic uncertainty is shown as a shaded area. Results from many fold events in data (red star) and from time dependent simulations (blue square) are derived as in eq. 1. Given the poor statistics, only one point is displayed with arrows indicating the maximum interval of average distances observed.

REFERENCES

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