

Abstract

In order to investigate the effects of the fluorescence energy error distributions on the determination of the ultra high energy cosmic ray (UHECR) spectrum we developed a Monte Carlo simulation of fluorescence telescopes using the HiRes and Auger telescopes as examples. We show that the energy error distribution (EED) for this kind of detector cannot be adequately represented by Gaussian or Lognormal distributions. We then compare the expected UHECR with one convolved using the determined EEDs. We conclude that the convolved energy spectrum will be smeared but not enough to affect the GZK cutoff detection. We also investigate the effects of possible systematic errors on Fluorescence yield (FY) measurements on the UHECR spectrum and conclude that a FY error between 10% and 30% can match the flux measured by the HiRes and AGASA collaborations.

1 Introduction

In this analysis [1], we determine EEDs for fluorescence telescopes and convolve the expected UHECR spectrum with them. We show that the average energy error and the shape of the EED are energy dependent and investigate its impact on the convolved spectrum.

2 Simulation

We developed a Monte Carlo simulation using the CORSIKA package [2] and QGSJET01 [3]. Fluorescence telescopes and reconstruction procedures were simulated in detail using HiRes-II and Auger telescope parameters (see [1] for more details).

Using the simulated shower energy deposition, fluorescence photons are generated [4] and propagated to the telescope taking Rayleigh and Mie scattering into account. The signal in each PMT of the telescope was then simulated and the shower geometry reconstructed. These signals are then transformed back into energy deposited in the atmosphere, taking into account the new reconstructed shower direction. This reconstructed energy deposition is then fit by a Gaisser-Hillas function and the primary energy determined by adding the missing energy correction [5] to the integration of the fitted function. Quality cuts [6, 7] were then applied.

Figure 1 shows the EEDs for 10^{19} and 10^{20} eV proton showers after our simulation of both HiRes-II and Auger fluorescence telescopes, including energy reconstruction and quality cuts. It can be seen that the EED's shape, including the asymmetric tail, is different for each energy. In [1] we investigate this energy dependence in detail.

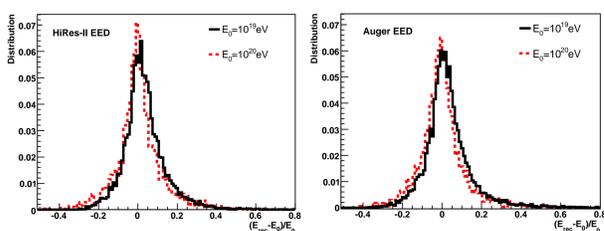


Figure 1: Energy error distributions from simulated FD energy reconstruction using HiRes-II parameters (left) and Auger parameters (right).

3 UHECR Energy Spectrum

The UHECR energy spectrum at the Earth was determined following the analysis described in [8]. We took this spectrum as the true spectrum and convolved it using a Monte Carlo procedure with the EEDs determined from our simulation. To take into account the EED energy dependency, the convolution was divided in four energy ranges. For each range we used a different EED, each obtained using showers with a different primary energy. Figure 2 shows the UHECR convolved spectrum and figure 3 shows the percentage excess of events for each studied EED in relation to the number of expected events above 10^{19} eV from our "true" spectrum. As can be seen, the excess of events is still significant around the expected GZK energy. Although fluorescence measurements errors will not erase the GZK cutoff from the spectrum they might shift its position.

3.1 Uncertainties on the FY

We also studied the effect of possible errors in the FY measurements in the spectrum by introducing an arbitrary FY systematic error (10, 30 or 50%) when the energy deposited in the atmosphere was transformed in fluorescence photons, i.e. the number of photons produced in our simulation following [4] (FY_K) was either increased or decreased by an arbitrary percentage. In the

reconstruction procedure the original FY_K [4] was used.

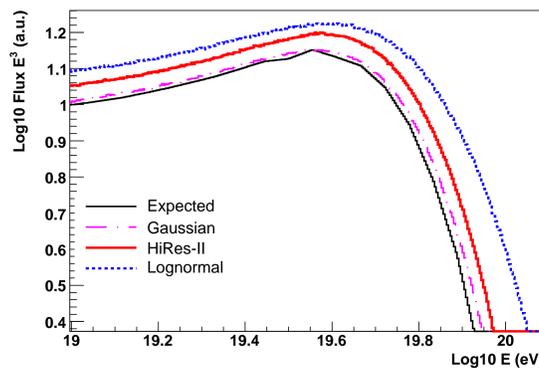


Figure 2: Energy spectrum as expected from theoretical prediction and convolved with various EEDs ($\sigma_G = 0.1E$ and $\sigma_{\log_{10}} = 0.1$).

As a result the distribution of reconstructed energies was not only shifted to either larger or smaller energies but the shape of the EED was also modified. The mean of the EED will shift by approximately the same percentage as the FY. So a shift on the FY is not equivalent to a simple shift on the shower energy. Figure 4 shows the UHECR spectrum convolved with the fluorescence EED taking FY errors into account, and figure 5 shows the percentage excess of events. As can be seen the flux times the third power of energy shifts significantly. It shifts to larger values when the FY error is positive and vice-versa. The GZK cutoff is also smeared but not enough to be absent from the spectrum.

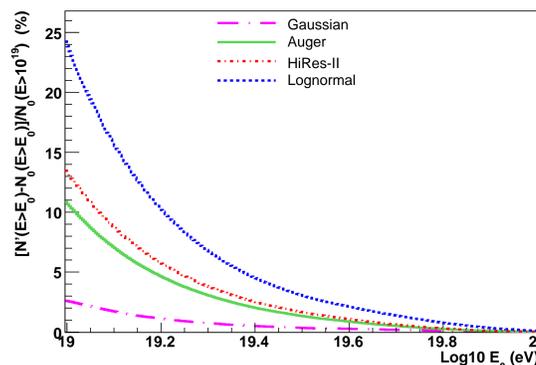


Figure 3: Percentage excess of events due to the smearing of the UHECR spectrum with several EEDs. N' is the number of events above E_0 calculated for each distribution, N_0 is the number of events above E_0 calculated with the theoretical GZK spectrum.

It is clear that an error on the FY will influence the determination of the GZK cutoff energy as well as the flux. Figure 6 shows the spectra measured by AGASA and HiRes-II experiments. We also show our calculation of the GZK theoretical spectrum convolved with the HiRes-II EED. We have considered three values of the fluorescence yield in this analysis: FY_K (green solid line), $FY_K+10\%$ and $FY_K+30\%$. It can be seen that a FY systematic error between 10% and 30% would be enough to match HiRes and AGASA fluxes but would not smear the GZK cutoff in an important way.

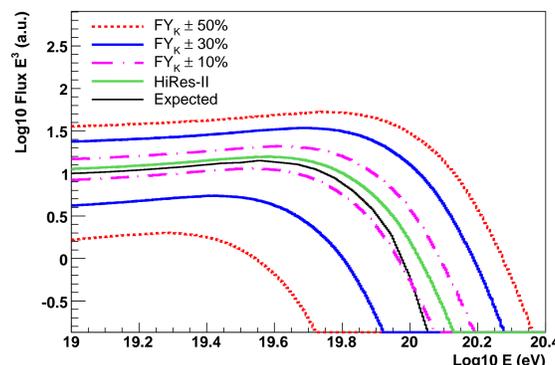


Figure 4: expected UHECR spectrum and its convolution with EEDs from our simulation of the HiRes-II fluorescence telescope with and without FY systematic errors.

4 Discussion and conclusions

We convolved the UHECR spectrum with EEDs determined by simulating either the HiRes-II or the Auger telescopes. Similar results were obtained for both telescopes despite the different parameters and quality cuts applied. Figure 3 shows that this effect on the spectrum can result in 5% more events above $10^{19.2}$ eV. We also showed that fluorescence EED's shape is energy dependent.

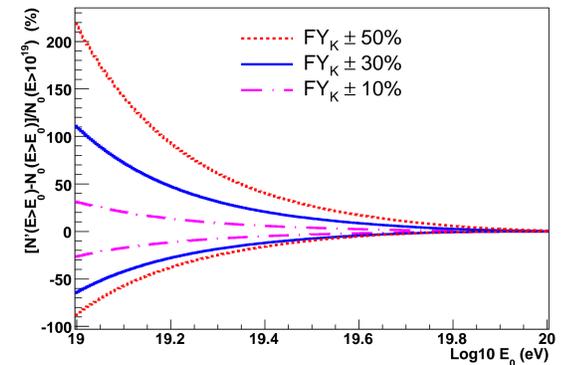


Figure 5: Percentage excess of events with an EED determined from our simulation of the HiRes-II fluorescence telescope including FY systematic errors.

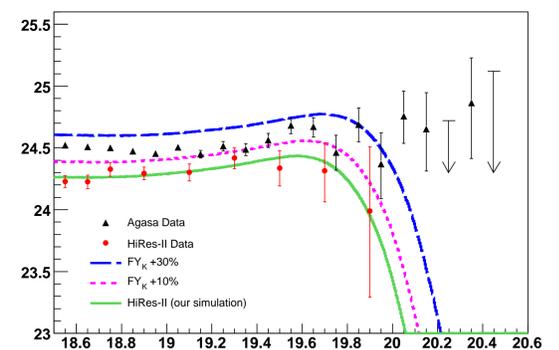


Figure 6: Energy spectrum measured by AGASA and HiRes-II experiments compared to a theoretical GZK spectrum convolved with EED corresponding to simulations with the FY measured by Kakimoto et. al and arbitrary shifts of 10% and 30%.

We have analyzed the influence of a systematic error in the FY on the energy spectrum and showed that shifting the FY is not equivalent to an automatic shift in the reconstructed energy. Not only the average reconstructed energy shifts systematically by the same FY error factor but the EED has its shape modified as well. Also, the effects of positive FY errors are not symmetric in relation to negative ones. We also conclude that although the GZK cutoff position might shift significantly it will not be erased. The measured flux is also directly proportional to the FY error. A error between 10% and 30% of the FY is enough to match the flux measured by the HiRes and the AGASA collaborations.

Finally, we conclude that the energy error distributions of fluorescence telescopes including shower fluctuations, detection and reconstruction uncertainties and fluorescence yield errors will significantly smear the UHECR energy spectrum. The GZK cutoff position in the spectrum might shift significantly but not enough to erase the GZK cutoff.

5 Acknowledgments

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