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Effects of the energy error distribution of fluorescence telescopes on the UHECR energy spectrum

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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 Log-normal ditributions. We then compare the expected UHECR with one convolved using the determided 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) mesurements 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.

Introduction

Here we summarize the analysis [1] of the influence of fluorescence EEDs in the UHECR spectrum. The goal is to understand how this spectrum is affected by uncertainties on the fluorescence reconstructed energy. We also analyze the influence of possible FY errors on these energy measurements.

Simulation

Our simulation can be divided into three parts: extensive air showers (EAS) simulation, fluorescence detector (FD) simulation and reconstruction simulation. Our Monte Carlo EAS simulation was performed using the CORSIKA package [2] and QGSJET01 [3]. Fluorescence telescopes and reconstruction procedures were simulated in detail using HiRes-II and Auger telescope parameters.

Using the simulated shower energy deposition, fluorescence photons are generated using FY measurements [4] and propagated to the telescope, taking attenuation and geometric parameters into account. The signal in each PMT of the telescope is then simulated using all relevant FD parameters including among others FD efficiency, background and simplified trigger conditions. The shower geometry is then reconstructed and the PMT signals are transformed back into energy deposited in the atmosphere, taking into account reconstruction uncertainties. This reconstructed energy deposition profile is then fit by a Gaisser-Hillas function and the primary energy is determined by adding the missing energy correction [5] to the the fitted function integral. Quality cuts [6, 7] are then applied to the data set (see [1] for more details).

Figure 1 shows the EED for $10^{19.5}$ eV proton showers after our simulation of the HiRes-II telescope, reconstruction procedures and quality cuts. For comparison we fitted the central part of this EED using Gaussian and lognormal functions. It is clear that neither of these curves represent well the fluorescence EED.

Figure 2 shows the EED 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.

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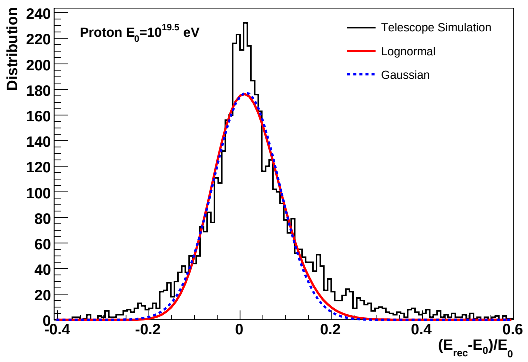

Figure 1: EED from simulated FD energy reconstruction using HiRes-II parameters.

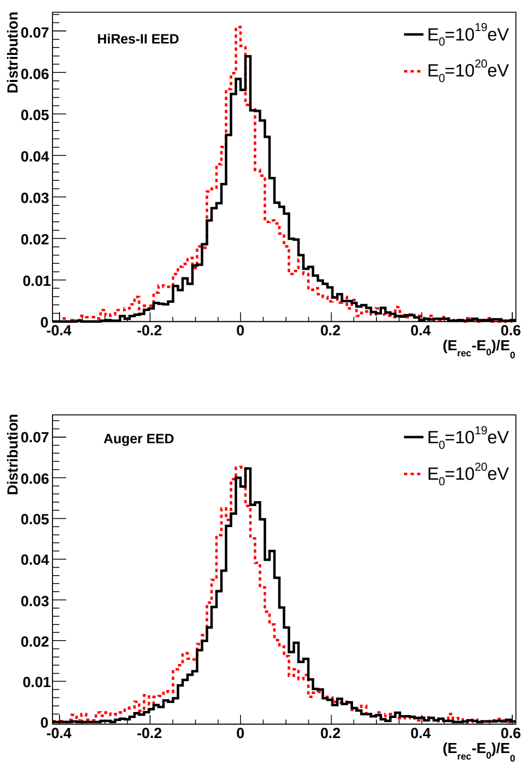

Figure 2: EEDs from simulated FD energy reconstruction using HiRes-II parameters (top) and Auger parameters (bottom).

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 3 shows the UHECR convolved spectrum and figure 4 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.

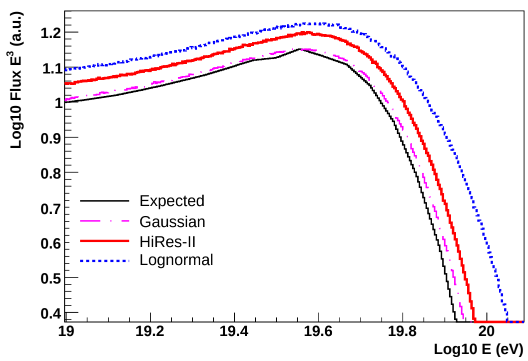

Figure 3: Energy spectrum as expected from theoretical prediction and convolved with various EEDs ($\sigma_G = 0.1E$ and $\sigma_{\log_{10}} = 0.1$).

Uncertainties on the Fluorescence Yield

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

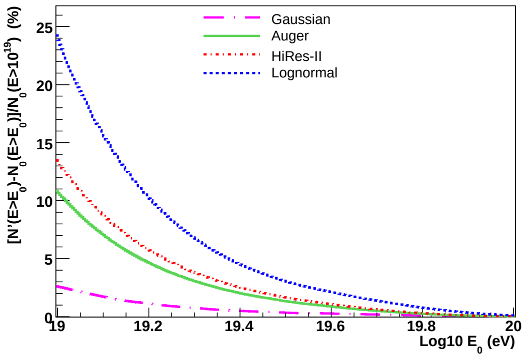

Figure 4: Percentage excess of events due to the smearing of the UHECR spectrum with several EEDs. N' is the number of events above E_0 calculated for each distribution, N_0 is the number of events above E_0 calculated with the theoretical GZK spectrum.

by an arbitrary percentage. In the reconstruction procedure the original FY_K [4] was used.

As a result, the mean of the distribution of reconstructed energies will shift by approximately the same percentage as the FY, but its shape will also be modified. Therefore a shift on the FY is not equivalent to a simple shift on the reconstructed shower energy. Figure 5 shows the UHECR spectrum convolved with the fluorescence EED taking FY errors into account, and figure 6 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.

It is clear that an error on the FY will influence the determination of the GZK cutoff energy as well as the flux. Figure 7 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

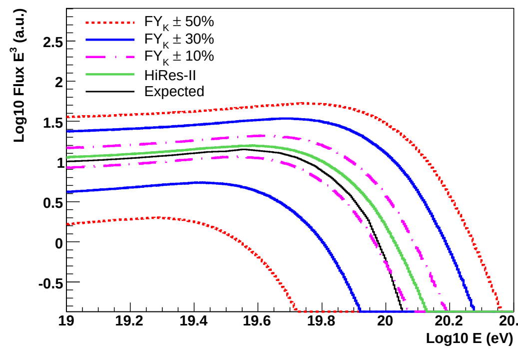

Figure 5: expected UHECR spectrum and its convolution with EEDs from our simulation of the HiRes-II fluorescence telescope with and without FY systematic errors.

to match HiRes and AGASA fluxes but would not smear the GZK cutoff in an important way.

Discussion and conclusions

We showed that fluorescence EEDs cannot be described by Gaussian or lognormal distributions and that its shape is energy dependent. 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 4 shows that this effect on the spectrum can result in 5% more events above $10^{19.2}$ eV.

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 simetric 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

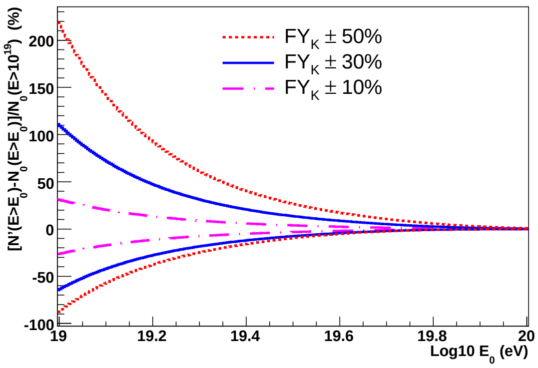

Figure 6: Percentage excess of events with an EED determined from our simulation of the HiRes-II fluorescence telescope including FY systematic errors.

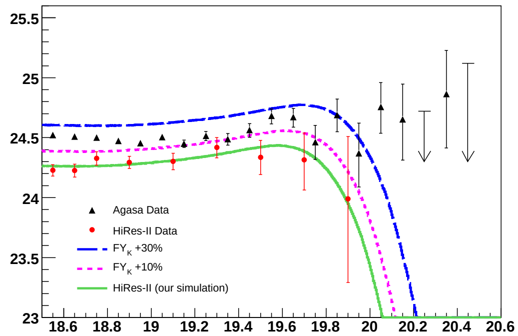

Figure 7: Energy spectrum measured by AGASA and HiRes-II experiments compared to a theoretical GZK spectrum convolved with EED corresponding to simulations with the FY measured by Kakimoto et. al and arbitrary shifts of 10% and 30%.

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.

Acknowledgments

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