Proceedings of the 30th International Cosmic Ray Conference
Rogelio Caballero, Juan Carlos D'Olivo, Gustavo Medina-Tanco,
Lukas Nellen, Federico A. Sánchez, José F. Valdés-Galicia (eds.)
Universidad Nacional Autónoma de México,
Mexico City, Mexico, 2008

Vol. 4 (HE part 1), pages 543–546

ID 975

30TH INTERNATIONAL COSMIC RAY CONFERENCE

ICRC'07 Mérida, México

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

WASHINGTON CARVALHO JR.
Instituto de Física, Universidade de São Paulo, Brasil
carvajr@if.usp.br

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 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

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

Simulation

Our Monte Carlo air shower 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 (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] are then applied.

Figure 1 shows the EED for $10^{19.5}$ eV proton showers after our simulation of the HiRes-II telescope, reconstruction procedure and quality cuts. For comparison we fitted the EED shown in Figure 1 with a Gaussian and a lognormal. 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.

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

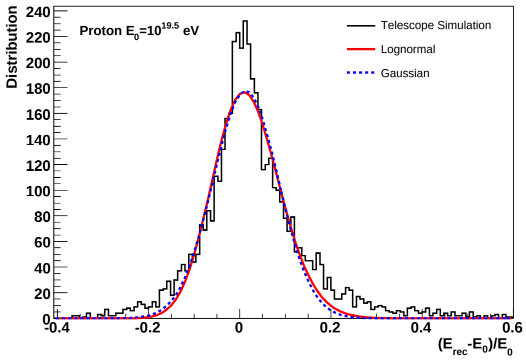

Figure 1: Energy error distribution from simulated fluorescence energy reconstruction using HiRes-II parameters. We fitted a Gaussian and a lognormal to the central part of the EED.

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.

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

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 mod-

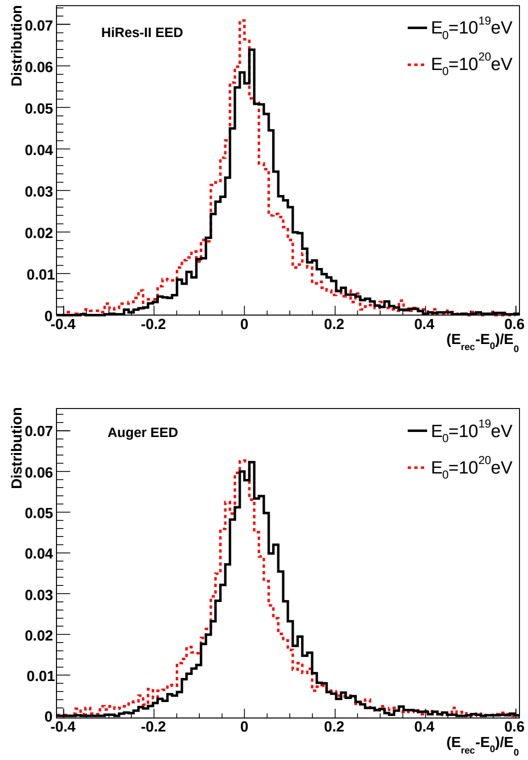

Figure 2: Energy error distributions from simulated fluorescence energy reconstruction using HiRes-II parameters (top) and Auger parameters (bottom).

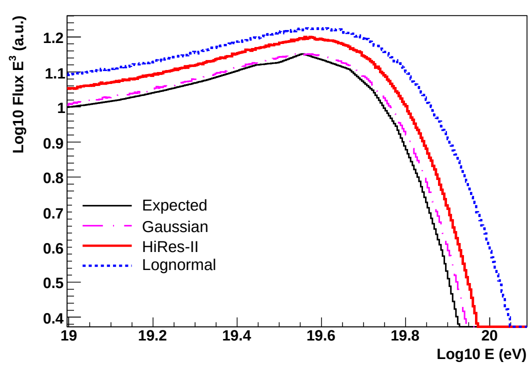

Figure 3: Energy spectrum as expected from theoretical prediction and convolved with various EEDs ($\sigma_G = 0.1E$ and $\sigma_{\log_{10}} = 0.1$).

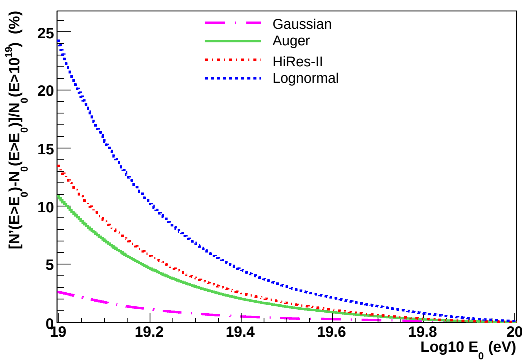

Figure 4: Percentage excess of events due to the smearing of the UHECR spectrum with several EEDs. N' is the number of events above E_0 calculated for each distribution, N_0 is the number of events above E_0 calculated with the theoretical GZK spectrum.

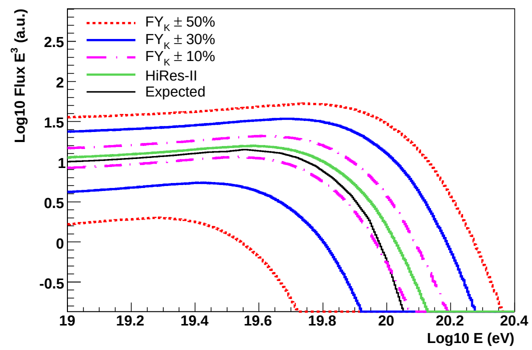

Figure 5: expected UHECR spectrum and its convolution with EEDs from our simulation of the HiRes-II fluorescence telescope with and without FY systematic errors.

ified. 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 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 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 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

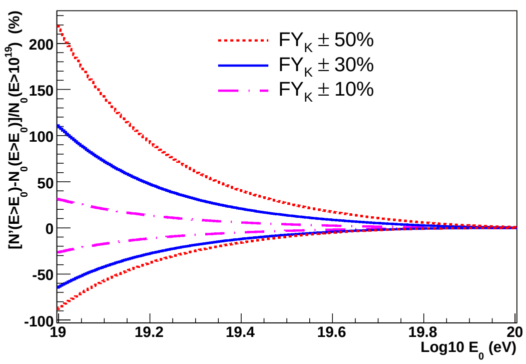

Figure 6: Percentage excess of events with an EED determined from our simulation of the HiRes-II fluorescence telescope including FY systematic errors.

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.

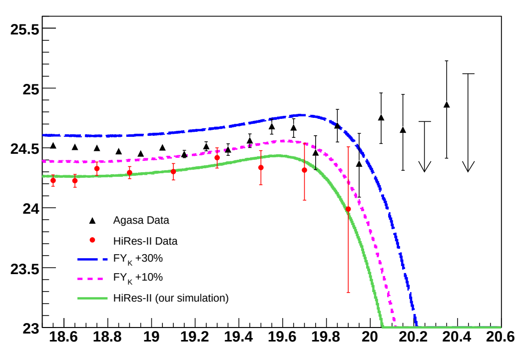

Figure 7: Energy spectrum measured by AGASA and HiRes-II experiments compared to a theoretical GZK spectrum convolved with EED corresponding to simulations with the FY measured by Kakimoto et. al and arbitrary shifts of 10% and 30%.

Acknowledgments

We thank Ivone F. M. Albuquerque and Vitor de Souza, with whom I developed this work. We also thank Bruce Dawson for his comments. This work was supported by the State of São Paulo Research Foundation (FAPESP).

References

[1] V. d. S. W. Carvalho Jr., Ivone F. M. Albuquerque, Effects of the energy error distribution of fluorescence telescopes on the uhecr energy spectrum (and references therein), Astroparticle PhysicsIn press doi:10.1016/j.astropartphys.2007.04.010, astro-ph/0702123.

[2] D. Heck, J. Knapp, J. Capdevielle, G. Schatz, T. Thouw., A monte-carlo code to simulate extensive air showers - report FZKA 6019, Tech. rep., Forschungszentrum Karlsruhe, www-ik.fzk.de/h̃eck/corsika (1998).

[3] N. N. Kalmykov, S. S. Ostapchenko, A. I. Pavlov, Nucl. Phys. B (Proc. Suppl.) 52B (1997) 17.

[4] F. Kakimoto, E. C. Loh, M. Nagano, H. Okuno, M. Teshima, S. Ueno, A measurement of the air fluorescence yield, Nucl. Instr. Meth. A (372) (1996) 527–533.

[5] H. Barbosa, et al., Astroparticle Physics 22 (2004) 159–166.

[6] T. P. A. Collaboration, First estimate of the primary cosmic ray energy spectrum above 3 EeV form the pierre auger observatory, in: 29^{th} Int. Cosmic Ray Conf., 2005, usa-sommers-P-abs1-he14-oral.

[7] R.U.Abbasi, et al., Measurement of the flux of ultrahigh energy cosmic ray from monocular observations by the High Resolution Fly's Eye Experiment, Physical Review Letter 92 (15) (2004) 151101–1.

[8] I. F. Albuquerque, G. F. Smoot, GZK cutoff distortion due to the energy error distribution shape, Astroparticle Physics 25 (2006) 375–379.