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Measurement of Cosmic Ray Electrons with H.E.S.S.

KATHRIN EGBERTS[1], CHRISTOPHER VAN ELDIK[1], JIM HINTON[2] FOR THE H.E.S.S. COLLABORATION
[1]*Max-Planck-Institut für Kernphysik, P.O. Box 103980, D 69029 Heidelberg, Germany*
[2]*School of Physics & Astronomy, University of Leeds, Leeds LS2 9JT, UK*
kathrin.egberts@mpi-hd.mpg.de

Abstract: Due to energy losses in the interstellar medium, cosmic ray electrons at TeV energies carry information on local (within a few hundred parsecs) accelerators. However, measurements of the spectrum of the cosmic ray electrons beyond 1 TeV are extremely difficult due to the rapidly declining flux and the much more numerous background of nucleonic cosmic rays. The very large collection area of Cherenkov telescope arrays makes them promising instruments with which to measure these high energy electrons. While Cherenkov telescopes solve the problem of low fluxes of cosmic ray electrons in the TeV range, they still have to deal with the problem of distinguishing electrons from the nucleonic background. Here we report on first results towards a measurement of the cosmic ray electron spectrum with the High Energy Stereoscopic System (H.E.S.S.). The improved background supression that is needed for such a measurement is achieved by an event classification with the "Random Forest" algorithm based on decision trees.

Introduction

Cosmic ray electrons are with about 1% of the flux in the GeV range a small but peculiar fraction of cosmic rays. In contrast to hadronic cosmic rays, they lose their energy rapidly via inverse Compton scattering and synchrotron radiation leading to a steep spectrum following a power law $dN/dE \propto E^{-\Gamma}$ with spectral index $\Gamma \approx 3.3$, which is observed in the GeV range by various balloon and satellite experiments as shown in Fig. 1. Furthermore, at high energies, the energy of the electron limits its lifetime, $t \propto 1/E$, and hence its propagation distance. Therefore, at TeV energies, distinct features of single nearby sources can be expected in the electron spectrum [1][2]. At these energies, however, no measurements exist, as the rapidly declining electron flux calls for larger detector areas than balloon and satellite experiments can provide. Thus, while interesting theoretical predictions for the TeV range of the spectrum exist, it has been impossible so far to measure.
J. Nishimura proposed an alternative approach using imaging atmospheric Cherenkov telescopes (IACTs) [8]. They use the earth's atmosphere as detector and therefore provide an order of 10^5 larger collection areas. Designed for the measurement of γ-rays, they can be used to study cosmic ray electrons, which, like γ-rays, produce electromagnetic showers. The High Energy Stereoscopic System (H.E.S.S.) is an array of four imaging atmospheric Cherenkov telescopes in the Khomas highlands in Namibia [9]. Its sensitivity and its large field of view make such a measurement of cosmic ray electrons in the TeV range now possible.

Measuring cosmic ray electrons with H.E.S.S.

For the analysis of cosmic ray electrons, all data that were taken by the complete four telescope array, targeting extragalactic fields to avoid contamination of diffuse γ-ray emission from the galactic plane, were used. Any known or potential γ-ray source was excluded.
While the big advantage of IACTs is their large collection area, the challenge that is posed by such a cosmic ray electron measurement is the discrimination of the electrons from the much more numerous hadronic background. Therefore, a sophis-

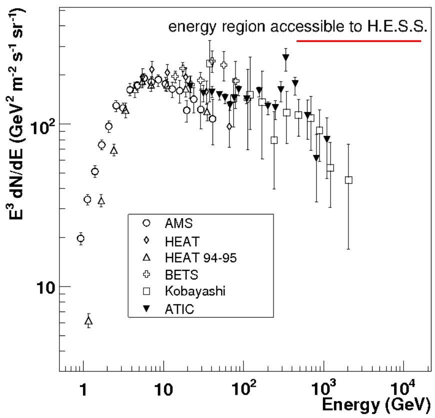

Figure 1: The electron spectrum measured with balloon and satellite experiments. Data are taken from [3][4][5][6][7]. The energy region accessible to H.E.S.S. with sufficient statistics, assuming a spectral index of 3.3, is indicated by the red bar. Systematic effects may limit the results.

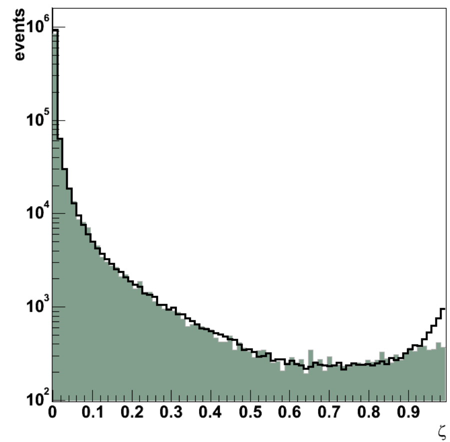

Figure 2: The distribution of the Random Forest output ζ for data with energy 0.4-1.0 TeV(solid line) and background simulation consisting of contributions from protons, helium, nitrogen, silicon and iron. A clear excess of electron events can be seen at higher values of ζ that cannot be explained by background simulations.

ticated machine learning algorithm was chosen to separate electron and hadron events. The "Random Forest" program [10][11] is based on decision trees and was trained using Monte Carlo simulations of electrons and off-source data. The input parameters for the training contain camera image information like the width and length of the elliptical image scaled to the expected width and length defined by simulations, and intensity information. Only those events are used that triggered all four telescopes in order to assure that only the best measured events are chosen for analysis. As the input parameters are partially energy dependent, an improved performance was achieved by training in five energy bands. The zenith angle dependence was taken into account by restricting the data set to zenith angles smaller than $28°$, thus approximately matching the simulations at $20°$.

The Random Forest converts the input parameters into an output ζ between zero and one, denoting the electron-likeness of the respective event. A large ζ represents an electron-like event, while $\zeta = 0$ stands for background events. The Random Forest method allows for an improved background rejection shown in Fig. 2. Only about $0.5 - 2.0\%$, depending on energy, of all proton events passing the four-telescope cut end up in the electron signal region of $\zeta > 0.6$. This large suppression of hadronic background events makes a measurement of cosmic ray electrons possible in the first place. In Fig. 2 the ζ distribution of data is shown together with a Monte Carlo simulation of the background, showing the good agreement at low values of ζ and a clear signal of an electromagnetic showers at $\zeta = 1$.

In order to estimate the remaining background and extract the number of electrons from the data, simulated electrons and protons are fitted to the data in the ζ distribution. The simulations are produced using CORSIKA [12] with SIBYLL as hadronic interaction model [13]. Modeling the background with simulated protons only is possible because heavier nuclei contained in the hadronic background show an even better classification power than protons and therefore, background in the signal region is completely dominated by protons. This method of fitting electron and proton simulations to the data is demonstrated in Fig. 3 exemplarily for the energy between 0.7 and 1.0 TeV. A good match between data and electron-proton combination is observed.

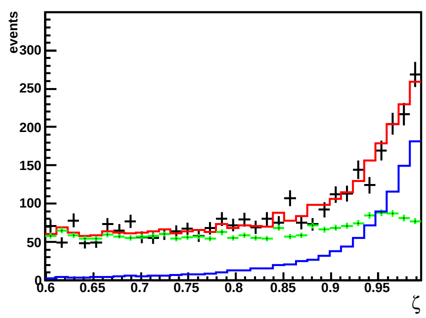

Figure 3: The distribution of ζ in the signal region of $\zeta > 0.6$ for data (black) with a reconstructed energy between 0.7 and 1 TeV and the fitted proton (green) and electron (blue) simulations in this energy range. The best fit model of electrons and protons is shown in red.

This method has the potential to extend the spectrum of cosmic ray electrons to energies of several TeV. While statistical errors are small compared to direct measurements, systematic effects have to be taken into account. Prime source of systematic uncertainties is the usage of proton simulations to model the data. To quantify this effect, two different hadronic interaction models, SIBYLL [13] and QGSJET [14] are compared. Additionally, confusion with γ-rays might occur as γ-rays and electrons produce very similar air showers in the atmosphere. They can be separated on a statistical basis by the height of their shower maximum X_{max}, which occurs half a radiation length higher in the atmosphere for electrons than for γ-rays. As X_{max} is not measured precisely enough, a contribution of extragalactic γ-rays can experimentally not be excluded. However, theoretical predictions for diffuse extragalactic γ-ray flux lie far below the electron flux [15].
Ongoing work concerns the in-depth study of systematic errors and model-dependence of the results with the goal to derive a reliable electron spectrum.

Conclusion

For the first time, cosmic ray electrons have been measured with IACTs. A clear signal of electrons can be seen in the H.E.S.S. data. Therefore, IACTs seem to be able to extend the measured spectrum of cosmic ray electrons into the TeV range, where the shape of the spectrum is completely unknown, but expected to give information on the existence of nearby cosmic ray accelerators.

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