Probing the ATIC peak in the cosmic-ray electron spectrum with H.E.S.S.

F. Aharonian[1,13], A.G. Akhperjanian[2], G. Anton[16], U. Barres de Almeida[8,*] A.R. Bazer-Bachi[3], Y. Becherini[12], B. Behera[14], K. Bernlöhr[1,5], A. Bochow[1], C. Boisson[6], J. Bolmont[19], V. Borrel[3], J. Brucker[16], F. Brun[19], P. Brun[7], R. Bühler[1], T. Bulik[24], I. Büsching[9], T. Boutelier[17], P.M. Chadwick[8], A. Charbonnier[19], R.C.G. Chaves[1], A. Cheesebrough[8], L.-M. Chounet[10], A.C. Clapson[1], G. Coignet[11], M. Dalton[5], M.K. Daniel[8], I.D. Davids[22,9], B. Degrange[10], C. Deil[1], H.J. Dickinson[8], A. Djannati-Ataï[12], W. Domainko[1], L.O'C. Drury[13], F. Dubois[11], G. Dubus[17], J. Dyks[24], M. Dyrda[28], K. Egberts[1,†] D. Emmanoulopoulos[14], P. Espigat[12], C. Farnier[15], F. Feinstein[15], A. Fiasson[11], A. Förster[1], G. Fontaine[10], M. Füßling[5], S. Gabici[13], Y.A. Gallant[15], L. Gérard[12], D. Gerbig[21], B. Giebels[10], J.F. Glicenstein[7], B. Glück[16], P. Goret[7], D. Göring[16], D. Hauser[14], M. Hauser[14], S. Heinz[16], G. Heinzelmann[4], G. Henri[17], G. Hermann[1], J.A. Hinton[25], A. Hoffmann[18], W. Hofmann[1,‡] M. Holleran[9], S. Hoppe[1], D. Horns[4], A. Jacholkowska[19], O.C. de Jager[9], C. Jahn[16], I. Jung[16], K. Katarzyński[27], U. Katz[16], S. Kaufmann[14], E. Kendziorra[18], M. Kerschhaggl[5], D. Khangulyan[1], B. Khélifi[10], D. Keogh[8], W. Kluźniak[24], T. Kneiske[4], Nu. Komin[15], K. Kosack[1], R. Kossakowski[11], G. Lamanna[11], J.-P. Lenain[6], T. Lohse[5], V. Marandon[12], J.M. Martin[6], O. Martineau-Huynh[19], A. Marcowith[15], J. Masbou[11], D. Maurin[19], T.J.L. McComb[8], M.C. Medina[6], R. Moderski[24], E. Moulin[7], M. Naumann-Godo[10], M. de Naurois[19], D. Nedbal[20], D. Nekrassov[1], B. Nicholas[26], J. Niemiec[28], S.J. Nolan[8], S. Ohm[1], J-F. Olive[3], E. de Oña Wilhelmi[1,12,29], K.J. Orford[8], M. Ostrowski[23], M. Panter[1], M. Paz Arribas[5], G. Pedaletti[14], G. Pelletier[17], P.-O. Petrucci[17], S. Pita[12], G. Pühlhofer[14], M. Punch[12], A. Quirrenbach[14], B.C. Raubenheimer[9], M. Raue[1,29], S.M. Rayner[8], O. Reimer[30], M. Renaud[1], F. Rieger[1,29], J. Ripken[4], L. Rob[20], S. Rosier-Lees[11], G. Rowell[26], B. Rudak[24], C.B. Rulten[8], J. Ruppel[21], V. Sahakian[2], A. Santangelo[18], R. Schlickeiser[21], F.M. Schöck[16], R. Schröder[21], U. Schwanke[5], S. Schwarzburg [18], S. Schwemmer[14], A. Shalchi[21], M. Sikora[24], J.L. Skilton[25], H. Sol[6], D. Spangler[8], Ł. Stawarz[23], R. Steenkamp[22], C. Stegmann[16], F. Stinzing[16], G. Superina[10], A. Szostek[23,17], P.H. Tam[14], J.-P. Tavernet[19], R. Terrier[12], O. Tibolla[1], M. Tluczykont[4], C. van Eldik[1], G. Vasileiadis[15], C. Venter[9], L. Venter[6], J.P. Vialle[11], P. Vincent[19], M. Vivier[7], H.J. Völk[1], F. Volpe[1], S.J. Wagner[14], M. Ward[8], A.A. Zdziarski[24], and A. Zech[6]

[1] *Max-Planck-Institut für Kernphysik, P.O. Box 103980, D 69029 Heidelberg, Germany*
[2] *Yerevan Physics Institute, 2 Alikhanian Brothers St., 375036 Yerevan, Armenia*
[3] *Centre d'Etude Spatiale des Rayonnements, CNRS/UPS, 9 av. du Colonel Roche, BP 4346, F-31029 Toulouse Cedex 4, France*
[4] *Universität Hamburg, Institut für Experimentalphysik, Luruper Chaussee 149, D 22761 Hamburg, Germany*
[5] *Institut für Physik, Humboldt-Universität zu Berlin, Newtonstr. 15, D 12489 Berlin, Germany*
[6] *LUTH, Observatoire de Paris, CNRS, Université Paris Diderot, 5 Place Jules Janssen, 92190 Meudon, France*
[7] *IRFU/DSM/CEA, CE Saclay, F-91191 Gif-sur-Yvette, Cedex, France*
[8] *University of Durham, Department of Physics, South Road, Durham DH1 3LE, U.K.*
[9] *Unit for Space Physics, North-West University, Potchefstroom 2520, South Africa*
[10] *Laboratoire Leprince-Ringuet, Ecole Polytechnique, CNRS/IN2P3, F-91128 Palaiseau, France*
[11] *Laboratoire d'Annecy-le-Vieux de Physique des Particules, Université de Savoie, CNRS/IN2P3, 9 Chemin de Bellevue - BP 110 F-74941 Annecy-le-Vieux Cedex, France*
[12] *Astroparticule et Cosmologie (APC), CNRS, Universite Paris 7 Denis Diderot, 10, rue Alice Domon et Leonie Duquet, F-75205 Paris Cedex 13, France* [§]
[13] *Dublin Institute for Advanced Studies, 5 Merrion Square, Dublin 2, Ireland*
[14] *Landessternwarte, Universität Heidelberg, Königstuhl, D 69117 Heidelberg, Germany*
[15] *Laboratoire de Physique Théorique et Astroparticules, Université Montpellier 2, CNRS/IN2P3, CC 70, Place Eugène Bataillon, F-34095 Montpellier Cedex 5, France*
[16] *Universität Erlangen-Nürnberg, Physikalisches Institut, Erwin-Rommel-Str. 1, D 91058 Erlangen, Germany*
[17] *Laboratoire d'Astrophysique de Grenoble, INSU/CNRS, Université Joseph Fourier, BP 53, F-38041 Grenoble Cedex 9, France*
[18] *Institut für Astronomie und Astrophysik, Universität Tübingen, Sand 1, D 72076 Tübingen, Germany*
[19] *LPNHE, Université Pierre et Marie Curie Paris 6, Université Denis Diderot Paris 7, CNRS/IN2P3, 4 Place Jussieu, F-75252, Paris Cedex 5, France*
[20] *Charles University, Faculty of Mathematics and Physics, Institute of Particle and Nuclear Physics, V Holešovičkách 2, 180 00 Prague 8, Czech Republic*
[21] *Institut für Theoretische Physik, Lehrstuhl IV: Weltraum und Astrophysik, Ruhr-Universität Bochum, D 44780 Bochum, Germany*
[22] *University of Namibia, Private Bag 13301, Windhoek, Namibia*
[23] *Obserwatorium Astronomiczne, Uniwersytet Jagielloński, Kraków, Poland*
[24] *Nicolaus Copernicus Astronomical Center, ul. Bartycka 18, 00-716 Warsaw, Poland*
[25] *School of Physics & Astronomy, University of Leeds, Leeds LS2 9JT, UK*
[26] *School of Chemistry & Physics, University of Adelaide, Adelaide 5005, Australia*
[27] *Toruń Centre for Astronomy, Nicolaus Copernicus University, ul. Gagarina 11, 87-100 Toruń, Poland*
[28] *Instytut Fizyki Jądrowej PAN, ul. Radzikowskiego 152, 31-342 Kraków, Poland*
[29] *European Associated Laboratory for Gamma-Ray Astronomy, jointly supported by CNRS and MPG and*

arXiv:0905.0105v1 [astro-ph.HE] 1 May 2009

[30] *Stanford University, HEPL & KIPAC, Stanford, CA 94305-4085, USA*

The measurement of an excess in the cosmic-ray electron spectrum between 300 and 800 GeV by the ATIC experiment has - together with the PAMELA detection of a rise in the positron fraction up to ≈ 100 GeV - motivated many interpretations in terms of dark matter scenarios; alternative explanations assume a nearby electron source like a pulsar or supernova remnant. Here we present a measurement of the cosmic-ray electron spectrum with H.E.S.S. starting at 340 GeV. The H.E.S.S. data with their lower statistical errors show no indication of a structure in the electron spectrum, but rather a power-law spectrum with spectral index of $3.0 \pm 0.1(\text{stat.}) \pm 0.3(\text{syst.})$ which steepens at about 1 TeV.

PACS numbers: 95.85.Ry

Cosmic-ray electrons[1] above a few GeV lose their energy rapidly via inverse Compton scattering and synchrotron radiation resulting in short cooling time and hence range. Therefore, they must come from a few nearby sources [1, 2, 3]. Recently, the ATIC collaboration reported the measurement of an excess in the electron spectrum [4]. The excess appears as a peak in $E^3\ \Phi(E)$ where Φ is the differential electron flux; it can be approximated as a component with a power law index around 2 and a sharp cutoff around 620 GeV. Combined with the excess in the positron fraction measured by PAMELA [5], the peak feature of the ATIC measurement has been interpreted in terms of a dark matter signal or a contribution of a nearby pulsar (e.g. [6] and references given there). In the case of dark matter, the structure in the electron spectrum can be explained as caused by dark matter annihilation into low multiplicity final states, while in the case of a pulsar scenario the structure arises from a competition between energy loss processes of pulsar electrons (which impose an energy cutoff depending on pulsar age) and energy-dependent diffusion (which favors high-energy particles in case of more distant pulsars).

The possibility to distinguish between a nearby electron source and a dark matter explanation with imaging atmospheric Cherenkov telescopes has been discussed by Hall and Hooper [7]. Imaging atmospheric Cherenkov telescopes (IACTs) have five orders of magnitude larger collection areas than balloon and satellite experiments and can therefore measure TeV electrons with excellent statistics. Hall and Hooper assume that a structure in the electron spectrum should be visible even in the presence of a strong background of misidentified nucleonic cosmic rays. However, the assumption of a smooth background is oversimplified; in typical analyses the background rejection varies strongly with energy and without reliable control or better subtraction of the background, decisive results are difficult to achieve. In a recent publication, the High Energy Stereoscopic System (H.E.S.S.) Collaboration has shown that such a subtraction is indeed possible, reporting a measurement of the electron spectrum in the range of 700 GeV to 5 TeV [8].

Here an extension of this measurement towards lower energies is presented, partially covering the range of the reported ATIC excess. H.E.S.S. [9] is a system of four imaging atmospheric Cherenkov telescopes in Namibia. While designed for the measurement of γ-ray initiated air-showers, it can be used to measure cosmic-ray electrons as well. The basic properties of the analysis of cosmic-ray electrons with H.E.S.S. have been presented in [8]. For the analysis, data from extragalactic fields (with a minimum of 7° above or below the Galactic plane) are used excluding any known or potential γ-ray source in order to avoid an almost indistinguishable γ-ray contribution to the electron signal. As the diffuse extragalactic γ-ray background is strongly suppressed by pair creation on cosmic radiation fields [10], its contribution to the measured flux is commonly assumed to be negligible. For an improved rejection of the hadronic background a Random Forest algorithm [11] is used. The algorithm uses image information to estimate the *electron likeness* ζ of each event. To derive an electron spectrum, a cut on ζ of $\zeta > 0.6$ is applied and the number of electrons is determined in independent energy bands by a fit of the distribution in ζ with contributions of simulated electrons and protons. The contribution of heavier nuclei is sufficiently suppressed for $\zeta > 0.6$ as not to play a role. For an extension of the spectrum towards lower energies, the analysis has been modified to improve the sensitivity at low energies. In the event selection cuts, the minimum image amplitude has been reduced from 200 to 80 photo electrons to allow for lower energy events. In order to guarantee good shower reconstruction, only events with a reconstructed distance from the projected core position on the ground to the array center of less than 100 m are included. Additionally, only data taken between 2004 and 2005 are used. The reason is that the H.E.S.S. mirror reflectivity degrades over time and a reduced light yield corresponds to an increased energy threshold. The new data and event selection

[1] The term *electrons* is used generically in the following to refer to both electrons and positrons since most experiments do not discriminate between particle and antiparticle.

reduces the event statistics but enables to lower the analysis threshold to 340 GeV. The effective collection area at 340 GeV is $\approx 4 \times 10^4$ m^2. With a live-time of 77 hours of good quality data, a total effective exposure of $\approx 2.2 \times 10^7$ m^2 sr s is achieved at 340 GeV. Owing to the steepness of the electron spectrum, the measurement at lower energies is facilitated by the comparatively higher fluxes. The ζ distribution in the energy range of 340 to 700 GeV is shown in Fig. 1.

The low-energy electron spectrum resulting from

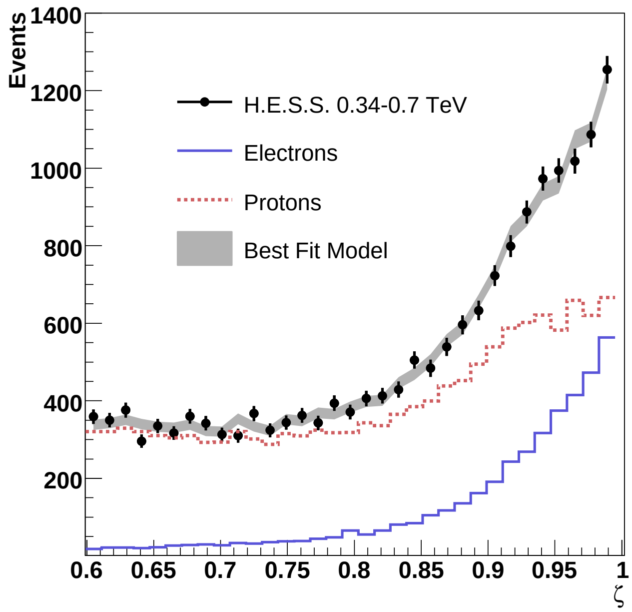

FIG. 1: The measured distribution of the parameter ζ, compared with distributions for simulated protons and electrons, for showers with reconstructed energy between 0.34 and 0.7 TeV (the energy range of the extension towards lower energies compared to the analysis presented in [8]). The best fit model combination of electrons and protons is shown as a shaded band. The proton simulations use the SIBYLL hadronic interaction model. Distributions differ from the ones presented in Fig. 1 of [8] because of the energy dependence of the ζ parameter.

this analysis is shown in Fig. 2 together with previous data of H.E.S.S. and balloon experiments. The spectrum is well described by a broken power law $dN/dE = k \cdot (E/E_\mathrm{b})^{-\Gamma_1} \cdot (1 + (E/E_\mathrm{b})^{1/\alpha})^{-(\Gamma_2-\Gamma_1)\alpha}$ (χ^2/d.o.f. $= 5.6/4$, $p = 0.23$) with a normalization $k = (1.5 \pm 0.1) \times 10^{-4}$ TeV^{-1} m^{-2} sr^{-1} s^{-1}, and a break energy $E_\mathrm{b} = 0.9 \pm 0.1$ TeV, where the transition between the two spectral indices $\Gamma_1 = 3.0 \pm 0.1$ and $\Gamma_2 = 4.1 \pm 0.3$ occurs. The parameter α denotes the sharpness of the transition, the fit prefers a sharp transition, $\alpha < 0.3$. The shaded band indicates the uncertainties in the flux normalization that arise from uncertainties in the modeling of hadronic interactions and in the atmospheric model, and are derived in the same fashion as in the initial paper [8]. The band is centered around the broken

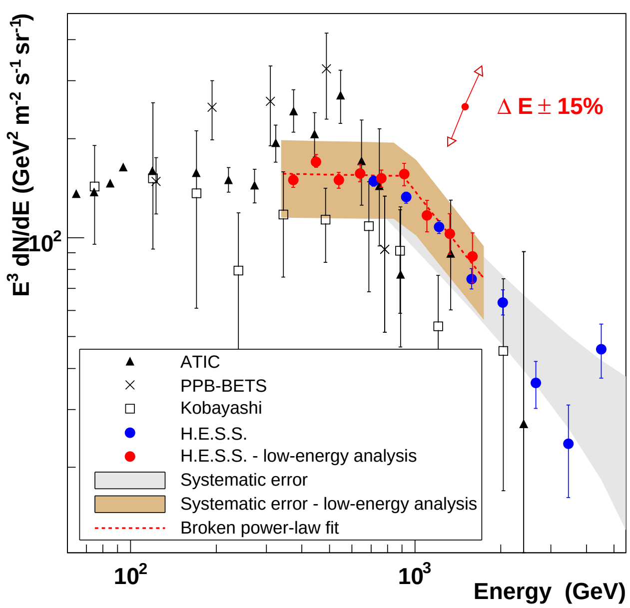

FIG. 2: The energy spectrum E^3 dN/dE of cosmic-ray electrons as measured by ATIC [4], PPB-BETS [12], emulsion chamber experiments [3] and H.E.S.S. Previous H.E.S.S. data [8] are shown as blue points, the result of the low-energy analysis presented here as red points. The shaded bands indicate the approximate systematic error arising from uncertainties in the modeling of hadronic interactions and in the atmospheric model in the two analyses. The double arrow indicates the effect of an energy scale shift of 15%, the approximate systematic uncertainty on the H.E.S.S. energy scale. The fit function is described in the text.

power law fit. The systematic error on the spectral indices Γ_1, Γ_2 is $\Delta\Gamma(\mathrm{syst.}) \lesssim 0.3$. The H.E.S.S. energy scale uncertainty of 15% is visualized by the double arrow.

The H.E.S.S. data show no indication of an excess and sharp cutoff in the electron spectrum as reported by ATIC. Since H.E.S.S. measures the electron spectrum only above 340 GeV, one cannot test the rising section of the ATIC-reported excess. Although different in shape, an overall consistency of the ATIC spectrum with the H.E.S.S. result can be obtained within the uncertainty of the H.E.S.S. energy scale of about 15 %. The deviation between the ATIC and the H.E.S.S data is minimal at the 20 % confidence level (assuming Gaussian errors for the systematic uncertainty dominating the H.E.S.S. measurement) when applying an upward shift of 10 % in energy to the H.E.S.S. data. The shift is well within the uncertainty of the H.E.S.S. energy scale. In this case the H.E.S.S. data overshoot the measurement of balloon experiments above 800 GeV, but are consistent given the large statistical errors from balloon experiments at these energies. A model calculation of how a Kaluza-Klein (KK) signature with a mass of 620 GeV [4] and a flux approximated to fit the ATIC data would appear in the H.E.S.S. data is shown in Fig. 3. Due to the limited

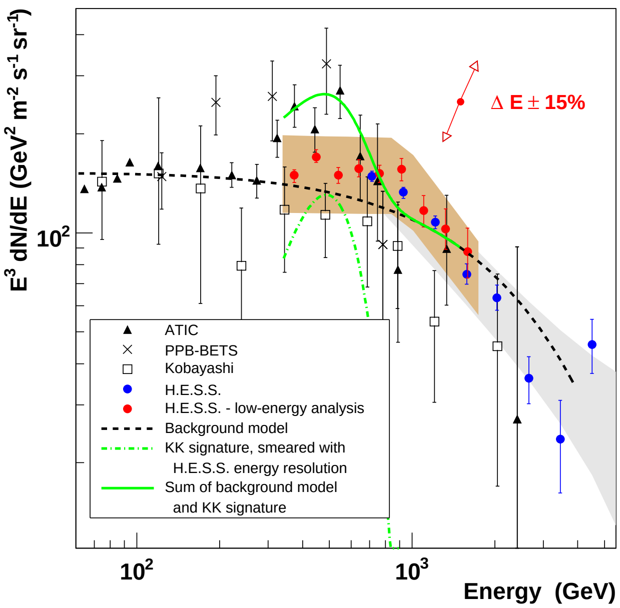

FIG. 3: The energy spectrum E^3 dN/dE of cosmic-ray electrons measured by H.E.S.S. and balloon experiments. Also shown are calculations for a Kaluza-Klein signature in the H.E.S.S. data with a mass of 620 GeV and a flux as determined from the ATIC data (dashed-dotted line), the background model fitted to low-energy ATIC and high-energy H.E.S.S. data (dashed line) and the sum of the two contributions (solid line). The shaded regions represent the approximate systematic error as in Fig. 2.

energy resolution of about 15%, a sharp cutoff at the energy of the KK mass would have been smeared out. The background spectrum of non-dark matter origin is here modeled by a power law with exponential cutoff, which is fitted to the low-energy ATIC data ($E < 300$ GeV) and the high-energy H.E.S.S. data ($E > 700$ GeV). The sum of the two contributions is shown as solid curve in Fig. 3. The shape of the predicted spectrum for the case of a KK signal is not compatible with the H.E.S.S. data at the 99% confidence level.

Despite superior statistics, the H.E.S.S. data does not rule out the existence of the ATIC-reported excess owing to a possible energy scale shift inherent to the presented measurement. However, there is no indication of a sharp drop in the cosmic-ray electron spectrum as expected in a KK dark matter scenario; the spectrum rather experiences a steepening towards higher energies and is therefore compatible with conventional electron populations of astrophysical origin within the uncertainties related to the injection spectra and propagation effects.

An improved measurement of the electron spectrum over a wide range of energies from 10 GeV to 1 TeV can be expected from FERMI [13].

The support of the Namibian authorities and of the University of Namibia in facilitating the construction and operation of H.E.S.S. is gratefully acknowledged, as is the support by the German Ministry for Education and Research (BMBF), the Max Planck Society, the French Ministry for Research, the CNRS-IN2P3 and the Astroparticle Interdisciplinary Programme of the CNRS, the U.K. Science and Technology Facilities Council (STFC), the IPNP of the Charles University, the Polish Ministry of Science and Higher Education, the South African Department of Science and Technology and National Research Foundation, and by the University of Namibia. We appreciate the excellent work of the technical support staff in Berlin, Durham, Hamburg, Heidelberg, Palaiseau, Paris, Saclay, and in Namibia in the construction and operation of the equipment.

* supported by CAPES Foundation, Ministry of Education of Brazil
† Electronic address: Kathrin.Egberts@mpi-hd.mpg.de
‡ Electronic address: Werner.Hofmann@mpi-hd.mpg.de
§ UMR 7164 (CNRS, Université Paris VII, CEA, Observatoire de Paris)

[1] C. S. Shen, Astrophys. J. Lett., **162**, L181, (1970).
[2] F. A. Aharonian, A. M. Atoyan, H. J. Völk, Astron. & Astrophys., **294**, L41 (1995).
[3] T. Kobayashi *et al.*, Astrophys. J., **601**, 340 (2004).
[4] J. Chang *et al.*, Nature, **456**, 362-365 (2008).
[5] O. Adriani, arXiv:0810.4995 [astro-ph](2008).
[6] D. Malyshev, I. Cholis, J. Gelfand arXiv:0903.1310v1 [astro-ph.HE] (2009).
[7] J. Hall, D. Hooper, arXiv:0811.3362 [astro-ph] (2008).
[8] F. A. Aharonian *et al.*, Phys. Rev. Lett. **101**, 261104 (2008).
[9] J. A. Hinton (*H.E.S.S. Collaboration*), New Astron. Rev. **48**, 331 (2004).
[10] P.S. Coppi & F. A. Aharonian, Astrophys. J., **487**, L9 (1997).
[11] L. Breiman & A. Cutler, http://www.stat.berkeley.edu/users/breiman/RandomForests/
[12] S. Torii *et al.*, arXiv:0809.0760 [astro-ph] (2008).
[13] J. F. Ormes & A. A. Moiseev, The First GLAST Symposium, Ed. S.Ritz, P.Michelson, C.Meegan, AIP Conf. Proc. 921, 494 (2007).