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Cosmic Ray Electron and Positron Spectrum with the PAMELA Experiment

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The PAMELA magnetic spectrometer, located on board the Resurs-DK1 satellite on Earth polar orbit with altitude of 350-600 km, measured the fluxes of cosmic ray particles and antiparticles in a wide energy range from 50 MeV to several TeVs. In this paper new results on the "all-electron" (sum electrons and positrons) spectrum are presented. New improved analysis on the full data set from 2006 to 2016 allows a significant increase in statistic compared to previously published results and an extension of energy interval up to 1 TeV.

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1. Introduction

Measurements of the ratio of positrons flux to the total flux of cosmic ray electrons and positrons in the PAMELA [1, 2], FERMI-LAT [3], and AMS-02 [4] experiments showed that positron fraction increases with energy, starting from $\sim$ 5 GeV that contradicts to the standard diffusion model of cosmic rays propagation. This increase of the positron fraction results from a positron spectrum harder than the electron one above 10 GeV [4, 2] and it may be a signature of primary sources of positrons either astrophysical, e.g. pulsars, or more exotic ones like annihilation or decay of dark matter particles. However, more mundane explanation related to the propagation of cosmic rays in the Galaxy are not excluded [5]. To clarify the situation it is necessary to have more data on the electron and positron spectra in the TeV energy range. A huge experimental efforts were undertaken to precisely measure the cosmic ray electron and positron energy spectrum over the last few years. Measurements of the all electron spectrum up have been performed by orbital experiments located onboard satellites like Fermi-LAT [7] and DAMPE [8] and on the International Space Station like AMS02 [6] and CALET [9]. A spectral suppression above 1 TeV was observed by HESS ground based Cherenkov telescope and then has been confirmed by two space born experiments CALET [9] and DAMPE [8]. Very recently AMS02 has provided new very high precision data on positron and electron spectra [10]. The data cover energy range from 1 GeV to 1 TeV. This measurement shows that the positron spectrum softens above $\sim$ 400 GeV. Positron fraction also has a suppression at these energies.

The magnetic spectrometer PAMELA was launched onboard the Resurs-DK1 satellite on the 15^{th} of June 2006 and it was continuously gathering data during almost 3200 days till 24 January 2016. The satellite had an initial quasi-polar (70^0 inclination) elliptical orbit at an altitudes between 350 and 600 km. The main goal of the experiment was to study the energy spectra of cosmic ray antiparticles in a wide energy range from tens of MeV up to hundreds GeV. While geometric factor of the PAMELA instrument was small compared to other instruments, total lifetime was long, almost 10 years. The apparatus was equipped with redundant detector that allowed cross checks of data obtained by different methods. E.g. particle energy may be inferred from rigidity in magnetic spectrometer or from energy deposit in calorimeter. Results of the PAMELA observation of electron and positron fluxes near the Earth, which were made in first three years of the flight, were reported in papers [2]. Separate measurement of electrons and positrons needs very strong requirements for track reconstruction to avoid spillover that leads to efficiency suppression at high energy.

New analysis of high energy electrons and positrons was performed to obtain all-electron spectrum above 40 GeV with increased statistical accuracy. This paper presents preliminary results obtained by processing PAMELA experiment using data collected from June 2006 to January 2016.

2. PAMELA spectrometer

The instrument consists of a Time-of-Flight system (ToF), an anticoincidence system, a magnetic spectrometer, an electromagnetic calorimeter, a shower tail scintillator and a neutron detector [11, 2]. The ToF system provides the main trigger for particle acquisition, measures the absolute value of the particle charge and its flight time while crossing the apparatus (the accuracy is about

350 psec). Particle rigidity is determined by the magnetic spectrometer, composed by a permanent magnet with a magnetic field intensity 0.4 T and a set of six double micro-strip silicon planes to measure X and Y coordinates of particles tracks. The spatial resolution of the tracker system of the spectrometer was observed to be about $\sim$4 μm, corresponding to a maximum detectable rigidity (MDR) exceeding 1 TV. The tracker also provides measurements of ionization energy losses *dE/dx* in silicon planes. The high energy electron and positron identification is provided mainly by the electromagnetic imaging calorimeter. The calorimeter consists of 44 layers with silicon detectors interleaved by 22 tungsten planes. Total thickness is 16.3 radiation and 0.6 nuclear interaction lengths. Particles not cleanly entering the PAMELA acceptance are rejected by the anticoincidence system. Neutron detector and shower scintillator improve particle identification. The main axis of the PAMELA instrument was pointed mainly to zenith during the flight, so any atmospheric effects could not affect results of observations. The acceptance is about 21.6 cm^{2}sr [2].

3. Data analysis

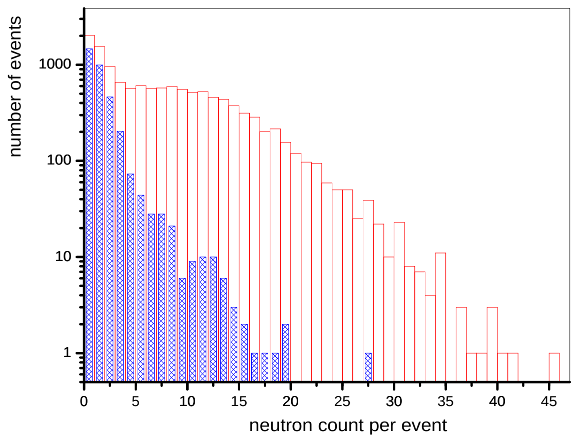

Figure 1: Distributions of neutrons for pre-selected events with *Etot* $>$ 40 GeV (open columns) and for identified electrons and positrons (filled columns).

The analysis was based on last reduction of the PAMELA experiment data. Using this data the number of tracks and energy losses in the magnetic spectrometer planes, rigidity, the time of flight, energy deposit in calorimeter strips and variables dealing with point of interaction were obtained for each registered event, transversal and longitudinal profiles were plotted for better particle identification and energy determination. On first step of analysis only events which interact in first 4 layers of calorimeter ($\sim$3 Xo) with total energy *Etot* above 40 GeV were selected. Electrons and positrons were selected requiring to have *dE/dx* energy losses in the spectrometer planes and ToF detectors corresponding to charge *Z*=1 and particle velocity $\beta > 0.8$. For this analysis on high-energy electrons and positrons no requirement were placed on the signals from the anticoincidence system. Moreover, because of back scattering of secondary particles from calorimeter, multiple hits were allowed in detectors of ToF. To reduce background from wrongly reconstructed tracks a consistency check of selected tracks was performed between tracker, calorimeter and time-of-flight data. In this analysis, also events with rigidities higher than the MDR were used. However, above ∼200 GeV the energy of tracks is not reliable. The energy of electrons and positrons was determined by fitting and integrating the shower profile in the calorimeter. For this reason only track fully contained inside the calorimeter were considered (shower axis intersects last calorimeter X and Y planes). Set of calorimeter variables was used for final electron and positron identification.

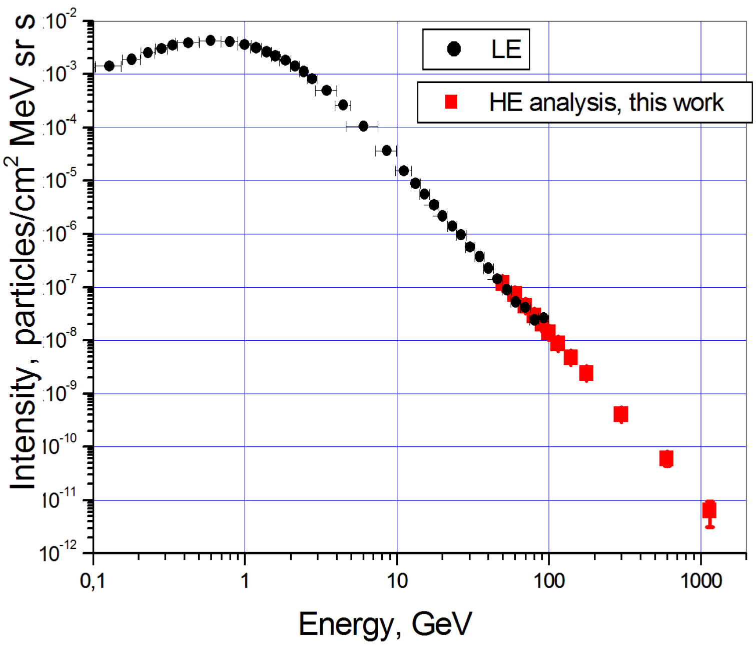

Figure 2: Differential energy spectra of total flux of electrons and positrons flux with PAMELA. Red points show preliminary results of new analysis.

Figure 1 shows neuron detector distributions for all pre-selected interacting events with *Etot* > 40 GeV and for identified events only. Electrons produce a few neutrons in photonuclear interactions in calorimeter whereas practically all interacting protons produce neutrons in inelastic ireactions. Difference of two distributions demonstrates the effect of selection. Proton rejection power is about 10^3 - 10^4, estimated on base of Monte-Carlo simulation with PAMELA Collaboration software [2]. Electron efficiency is 55 - 65% over practically all high energy range above 40 GeV till ∼1 TeV. The flight efficiency of the instrument was estimated from experimental data by using different combination of information from imaging calorimeter, magnetic spectrometer and time of flight system.

4. Results

The differential energy spectrum of the total flux of electrons and positrons of galactic cosmic rays is shown in figure 2 with comparison with low energy data from previous analysis. Despite the fact that the PAMELA magnetic spectrometer has a relatively small geometrical factor, small amount of material inside the instrument and powerful identification capabilities, resulting from the redundant information of the various detectors, allowed to measure the all electron spectrum over a wide energy range from approx 50 MeV up to more than 1 TeV. These new results are consistent with AMS-02 measurements [10] up to $\sim$ 1 TeV, while at higher energies a residual proton contamination of the order of ten percent cannot be excluded. Total number of selected electrons and positron is about 10^3 above 100 GeV that is several times more than in previous analysis.

5. Summary

A new, higher efficiency selection was developped and applied to the whole set of PAMELA data to obtain all electrons and positrons spectrum above 40 GeVs. The increase in efficiency allows to extend measurements till 1 TeV.

6. Acknowlegments

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References

[1] O.Adriani, G.C.Barbarino, G.A.Bazilevskaya et al. Nature **458**, 607 (2009) .

[2] O.Adriani, G.C.Barbarino, G.A.Bazilevskaya et al. Phys. Rep. **544**, 323 (2014).

[3] A. Abdo, M. Ackermann, M. Arimoto et al. Phys.Rev. Lett. **102**, 181101 (2009).

[4] L.Accardo, M. Aguilar, D.Aisa, et al. Phys. Rev. Lett. **113**, 121101 (2014).

[5] P.Lipari. Phys.Rev. Lett. **122**, 271101 (2019).

[6] M. Aguilar, D.Aisa, B.Alpat, et al. Phys. Rev. Lett. **113**, 221102 (2014).

[7] S.Abdollahi, M. Ackermann, M.Ajello, et al. Phys. Rev. D. **95**, 082007 (2017).

[8] Ambrosi, G Asfandiyarov, R Azzarello, et al. Nature **552**, 63 (2017).

[9] O.Adriani, Y. Akaike, K. Asano, et al. Phys. Rev. Lett. **120**, 261102 (2018).

[10] M. Aguilar, L. Ali Cavasonza, B. Alpart, et al. Phys. Rev. Lett.,**122**, 101101 (2019).

[11] P. Picozza ,A.M. Galper, G. Castellini et al.,Astropart. Phys., **v.27**, 296-315 (2007).