International Journal of Modern Physics A
Vol. 20, No. 29 (2005) 6745–6748

World Scientific
www.worldscientific.com

ABOUT SEPARATION OF HADRON AND ELECTROMAGNETIC CASCADES IN THE PAMELA CALORIMETER

YURI I. STOZHKOV

P. N. Lebedev Physical Institute, RAS, Leninsky Prospekt 53, Moscow, RU-119991 Russia
stozhkov@fian.fiandns.mipt.ru

(for the PAMELA COLLABORATION)

A. BASILI,[a] R. BENCARDINO,[a] M. CASOLINO,[a] M. P. DE PASCALE,[a] G. FURANO,[a] A. MENICUCCI,[a] M. MINORI,[a] A. MORSELLI,[a] P. PICOZZA,[a] R. SPARVOLI,[a] R. WISCHNEWSKI,[a] A. BAKALDIN,[b] A. M. GALPER,[b] S. V. KOLDASHOV,[b] M. G. KOROTKOV,[b] V. V. MIKHAILOV,[b] S. A. VORONOV,[b] Y. T. YURKIN,[b] O. ADRIANI,[c] L. BONECHI,[c] M. BONGI,[c] P. PAPINI,[c] S. B. RICCIARINI,[c] P. SPILLANTINI,[c] S. STRAULINO,[c] F. TACCETTI,[c] E. VANNUCCINI,[c] G. CASTELLINI,[d] M. BOEZIO,[e] M. BONVICINI,[e] E. MOCCHIUTTI,[e] P. SCHIAVON,[e] A. VACCHI,[e] G. ZAMPA,[e] N. ZAMPA,[e] P. CARLSON,[f] J. LUND,[f] J. LUNDQUIST,[f] S. ORSI,[f] M. PEARCE,[f] G. C. BARBARINO,[g] D. CAMPANA,[g] G. OSTERIA,[g] G. ROSSI,[g] S. RUSSO,[g] M. BOSCHERINI,[h] W. MENNH,[h] M. SIMONH,[h] L. BONGIORNO,[i] M. RICCI,[i] M. AMBRIOLA,[j] R. BELLOTTI,[j] F. CAFAGNA,[j] M. CIRCELLA,[j] C. DE MARZO,[j] N. GIGLIETTO,[j] N. MIRIZZI,[j] M. ROMITA,[j] P. SPINELLI,[j] E. BOGOMOLOV,[k] S. KRUTKOV,[k] G. VASILJEV,[k] G. A. BAZILEVSKAYA,[l] A. N. KVASHNIN,[l] V. I. LOGACHEV,[l] V. S. MAKHMUTOV,[l] O. S. MAKSUMOV,[l] YU. I. STOZHKOV,[l] J. W. MITCHELL,[m] R. E. STREITMATTER[m] and S. J. STOCHAJ[n]

[a]*INFN, Structure of Rome II and Physics Department of University of Rome "Tor Vergata", Via della Ricerca Scientica 1, Rome, I-00133 Italy*
[b]*Moscow Engineering and Physics Institute, Kashirskoe Shosse 31, Moscow, RU-115409 Russia*
[c]*INFN, Structure of Florence and Physics Department of University of Florence, Viale Sansone 1, Sesto Fiorentino, Florence, I-50019 Italy*
[d]*Istituto di Fisica Applicata "Nello Carrara", Via Panciatichi 64, Florence, I-50127 Italy*
[e]*INFN, Structure of Trieste and Physics Department of University of Trieste, Via A. Valerio 2, Trieste, I-34147 Italy*
[f]*Royal Institute of Technology (KTH), Albanova University Centre, Stockholm, SE-10691 Sweden*
[g]*INFN, Structure of Naples and Physics Department of University of Naples "Federico II", Via Cintia, Naples, I-80126 Italy*
[h]*Universitat Siegen, Siegen, D-57068 Germany*
[i]*INFN, Laboratori Nazionali di Frascati, Via Enrico Fermi 40, Frascati, I-00044 Italy*
[j]*INFN, Structure of Bari and Physics Department of University of Bari, Via Amendola 173, Bari, I-70126 Italy*
[k]*A. F. Ioffe Physical-Technical Institute, Polytekhnicheskaya 26, St. Petersburg, RU-194021 Russia*
[l]*P. N. Lebedev Physical Institute, Leninsky Prospekt 53, Moscow, RU-119991 Russia*
[m]*NASA/Goddard Space Flight Center, Greenbelt, MD 20771 USA*
[n]*New Mexico State University, Las Cruces, NM 88003-8001 USA*

Received 25 October 2004
Revised 20 June 2005

Results of calibration of the PAMELA instrument at the CERN facilities are discussed. In September, 2003, the calibration of the Neutron Detector together with the Calorimeter was performed with the CERN beams of electrons and protons with energies of $20 - 180$ GeV. The implementation of the

Neutron Detector increases a rejection factor of hadrons from electrons about ten times. The results of calibration are in agreement with calculations.

Keywords: cosmic rays; hadron and electromagnetic cascades.

1. Introduction

Among the scientific goals of the orbital spectrometer PAMELA is investigation of cosmic ray energy spectrum in the range of $10^{11} - 5 \times 10^{12}$ eV. Up to now the spectrum in the TeV energy range is under discussion concerning the existence of “a knee” in the proton spectrum around the energy of protons $E_p = (1-3)$ TeV.[1–4]

Another goal is measurements of primary electron spectrum in the TeV energy range. The detection of such electrons would mean that there is a source of electrons at the distances of less than ~ 200 pc from the solar system. This point is very important for the problem of cosmic ray origin.

These tasks can be solved with the use of the calorimeter and the neutron detector, which are the components of the PAMELA instrument.[5] Energy of incident particle is determined from a cascade recorded in the calorimeter. However, separation of hadronic and electromagnetic cascades is a complicated problem because the cascades initiated by electrons and hadrons are rather similar. In addition, the electron flux in this energy range is about 10^{-3} of the total flux of primary particles. Since the number of neutrons generated in the electromagnetic cascade is much less than that in the hadronic cascade, the neutron detection essentially improves separation of electrons from protons and nuclei.

Calculations of the neutron yield in the PAMELA calorimeter were performed in Ref. 6, 7. Experimental verification of the calculation was carried out with the high-energy particle beam at CERN in September 2003. The neutron yield as determined by the neutron detector during the CERN calibration is discussed below.

2. Outline of the experiment

Two devices of the PAMELA spectrometer were used in the experiment: the calorimeter and the neutron detector. The calorimeter is composed of layers of tungsten absorber and silicon detectors planes. The total depth is about 16.3 radiation lengths and about 0.6 interaction length. The neutron detector is placed under the calorimeter. It contains 36 He^3-counters surrounded by the polyethylene moderator ~ 9 cm thick. The He^3 tubes detect the thermal neutrons with high efficiency ($\sigma \approx 6000$ b). To suppress the outside thermal neutron background, the neutron detector is shielded by the thin Cd layer from the bottom and side directions.

When a high-energy hadron interacts inside the calorimeter, the neutrons from the decay of excited nucleus are produced. Afterward, a part of these neutrons is thermalized by the polyethylene moderator and recorded by the He^3-counters. If a primary particle is a lepton, only a small number of neutrons is generated in the photonuclear interactions. The main contribution comes from the giant resonance. The number of neutrons generated in the electromagnetic cascade is much less than that in the hadronic cascade.

The calorimeter was exposed to a beam of electrons and protons with energy in the range of $(20 - 180)$ GeV. The features of the beam were the following: the bunch and spill durations were ~ 2 s and ~ 12 s, respectively; the number of particles per bunch was $(10^4 - 10^5)$. After the acquisition system of the PAMELA spectrometer was triggered the neutron detector recorded the number of neutrons during 200 sec, the time needed for majority of neutrons to be thermalized.

3. The results

The main results of the calculations and the experiment are presented in Figs. 1 and 2. The Monte-Carlo simulation of the particle interaction in the calorimeter and the detection of neutrons was performed with the GEANT 3.21 and GCALOR.[8,9] The neutrons were traced until their energy became lower than 10^{-2} eV. The neutron yield from photonuclear interactions was taken from Ref. 10. The processes of a neutron thermalization and consequent detection were also simulated. As an example, the distribution of events over

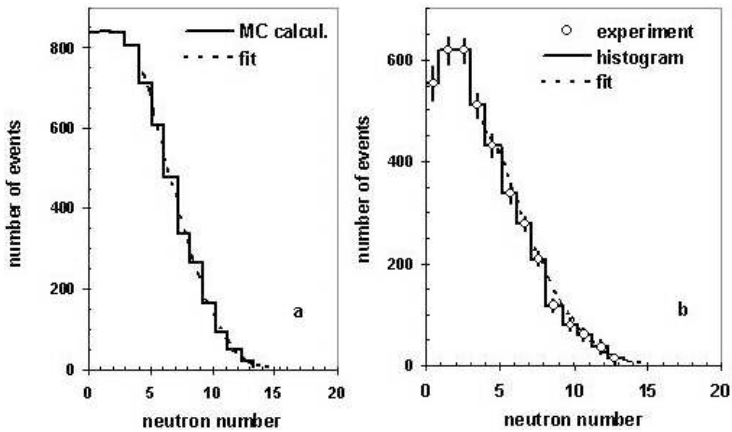

Fig. 1. The distributions of events over the number of detected neutrons produced by the 150 GeV proton interactions in the calorimeter: a – results of simulations, histogram; b – experimental results, open points with error bars. The dashed curves are the results of Gaussian fitting with the mean value M = 2.7, RMS = 4.0.

detected neutron number obtained from simulations of 150 GeV proton interactions in the calorimeter is shown in Fig. 1 a. In Fig. 1 b are given the results of the CERN experiment. Both results are well fitted by the Gaussian law with the mean M = 2.7 and RMS = 4.0. Similar results for electrons with energy 180 GeV are presented in Figs. 2 a, b. The fitting Gaussian law has parameters M = 0.6 and RMS = 1.6.

A good agreement between the experimental data and results of simulations is obtained. It means that the simulation parameters were chosen adequately and argues for validity of the results of calculation made earlier for particles with energy up to 10^{13} eV. During this experiment and calculations, protons were assumed to interact at any point of the calorimeter. It is known that electrons always interact in the first 3 radiation units. Therefore, only

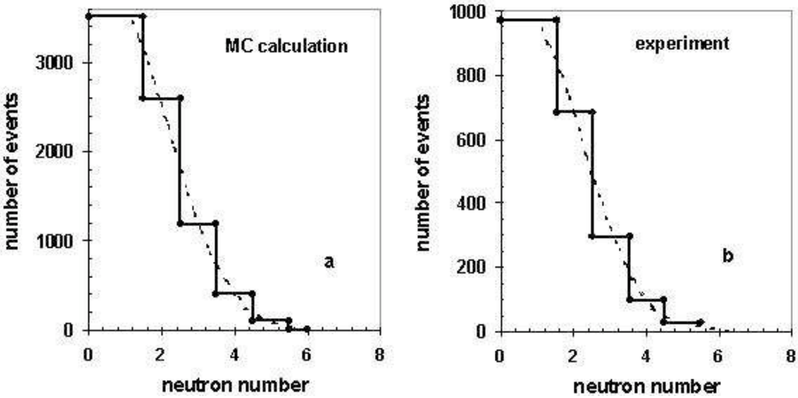

Fig. 2. The distribution of events over the number of detected neutrons produced by the 180 GeV electron interactions in the calorimeter: a – results of simulations, b – experimental results (histograms). The dashed curves are the results of Gaussian fitting with the mean value M = 0.6, RMS = 1.6.

protons interacted in the first 3 radiation units could imitate the electrons. Being taken into account this factor would lead to increase in M and decrease in RMS values (Figs. 1 a, b). Neutron detecting allows us to increase a proton rejection factor significantly.[7]

4. Conclusion

The calibration of the PAMELA spectrometer was performed with $(20 - 180)$ GeV electrons and protons at CERN and the neutron distributions generated in the calorimeter were obtained. They are in a good agreement with the results of Monte-Carlo simulations. It demonstrates high efficiency of the separation of hadron and electromagnetic cascades (that is the primary hadrons and electrons) in the calorimeter of the PAMELA experiment.

References

1. J. P. Wefel (for the ATIC Collaboration), in *Proc. 27th Int. Cosmic Ray Conf., Hamburg* **3**, 2111 (2001).
2. J. P. Wefel (for the ATIC Collaboration), in *Proc. 28th Int. Cosmic Ray Conf., Tsukuba* **4**, 1849 (2003).
3. H. S. Ahn *et al.* (ATIC Collaboration), in *Proc. 28th Int. Cosmic Ray Conf., Tsukuba* **4**, 1853 (2003).
4. Y. I. Stozhkov and N. L. Grigorov, *Bulletin of the Lebedev Physics Institute (Russian Academy of Sciences)* **No. 5**, 3 (2004).
5. M. Bongi (for the PAMELA Collaboration), *IEEE Trans. Nucl. Sci.* **51** (No. 3), 854 (2004).
6. International PAMELA collaboration, *Bulletin of the Lebedev Physics Institute (Russian Academy of Sciences)* **No. 8**, 10 (2003).
7. G. A. Bazilevskaya, S. A. Voronov, A. M. Galper, V. G. Zverev, A. N. Kvashnin, O. S. Maksumov, Y. I. Stozhkov and Y. T. Yurkin, *Izv. Ross. Akad. Nauk Ser. Fiz.*, **69(3)**, 312 (2005) (in Russian).
8. R. Brun and F. Carminati, *CERN Program Library* **W5013**, 427 (1993).
9. C. Zeitnitz and T. A. Gabriel, *Nucl. Instrum. Meth.* **A349**, 106 (1994).
10. B. L. Berman, *Atom. Data Nucl. Data Tabl.* **15** (No. 4), 398 (1975).