YU ISSN 0015—3206
FZKAAA 18 (1) 113 (1986)

ALL PARTICLE PRIMARY NUCLEON SPECTRUM DERIVED FROM THE LATEST JACEE RESULTS AND THE PREVIOUS SPECTRA

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Received 3 September 1985

UDC 539.12

Original scientific paper

The all particle primary nucleon spectrum estimated from the recent JACEE data has been compared with the earlier survey of Wolfendale group. The sea level proton spectrum calculated from the primary nucleon spectrum agrees with the measured data of Cowan and Matthews, and also with the data of Baruch, Brooke and Kellermann for proton energies up to 2 TeV.

The latest primary nuclei spectra measured by the Japanese American Co-operative Emulsion Experiments have been analysed in a recent investigation[1]. It is found that the integral spectra of protons, helium and a mixture of heavier nuclei have been found to follow the power law fit of the form

$$N(>E) = A_i \, E^{-\gamma_i} \tag{1}$$

where A_i and γ_i are the spectral amplitudes and indices of the primary cosmic ray particles.

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The power law fit to the JACEE data[2] follows

$$N_p(>E) = (0.8720 \pm 0.03)\, E^{-(1.7\pm 0.04)} \tag{2}$$

$$N_{He}(>E) = (0.6340 \pm 0.003)\, E^{-(1.7\pm 0.04)} \tag{3}$$

$$N_{CNO}(>E) = 0.2940\, E^{-1.7} \tag{4}$$

$$N_{Ne,\,Mg,\,Si}(>E) = 0.2539\, E^{-1.7} \tag{5}$$

$$N_{Fe}(>E) = 0.1518\, E^{-1.7}. \tag{6}$$

For simplicity the CNO, MH and H nuclei groups have been assumed to have the average atomic numbers of 14, 28 and 56, respectively. It is assumed that the cosmic ray nuclei break up in the upper atmosphere and from the consequences of superposition model one can relate the primary differential flux for each species by the following relations

$$N_p(E)\,\mathrm{d}E = (1.4824 \pm 0.051)\, E^{-(2.70\pm 0.04)}\,\mathrm{d}E \tag{7}$$

$$N_{He}(E)\,\mathrm{d}E = (0.1020 \pm 0.0051)\, E^{-(2.70\pm 0.04)}\,\mathrm{d}E \tag{8}$$

$$N_{CNO}(E)\,\mathrm{d}E = 0.00569\, E^{-2.7}\,\mathrm{d}E \tag{9}$$

$$N_{Ne,\,Mg,\,Si}(E)\,\mathrm{d}E = 0.0015\, E^{-2.7}\,\mathrm{d}E \tag{10}$$

$$N_{Fe}(E)\,\mathrm{d}E = 0.000275\, E^{-2.7}\,\mathrm{d}E. \tag{11}$$

The derived all particle integral primary nucleon spectrum follows the form

$$I(>E) = (1.1918 \pm 0.0418)\, E^{-(1.70\pm 0.04)} \tag{12}$$

where E is the nucleon energy in GeV and $I(>E)$ is in $(\mathrm{cm}^2\ \mathrm{s\ sr})^{-1}$. This spectrum has been compared in Fig. 1 with earlier important observations by Barrett et al.[3], Kaplon and Ritson[4], Lal[5] and the predicted spectrum from EAS results by Linsley et al.[6] and also with the derived result from ground level muon spectrum by Wolfendale group[7] which is based on Cocconi, Koester and Perkins[8] model. It is evident from the figure that the latest primary spectrum based on directly measured balloon flight emulsion chamber results by JACEE groups[2] is in accord with the calculated result of Wolfendale group[7] in the energy range $10^2 - 10^4$ GeV. This result is also in agreement with the recent primary spectrum estimated by Yodh et al.[9] from EAS results.

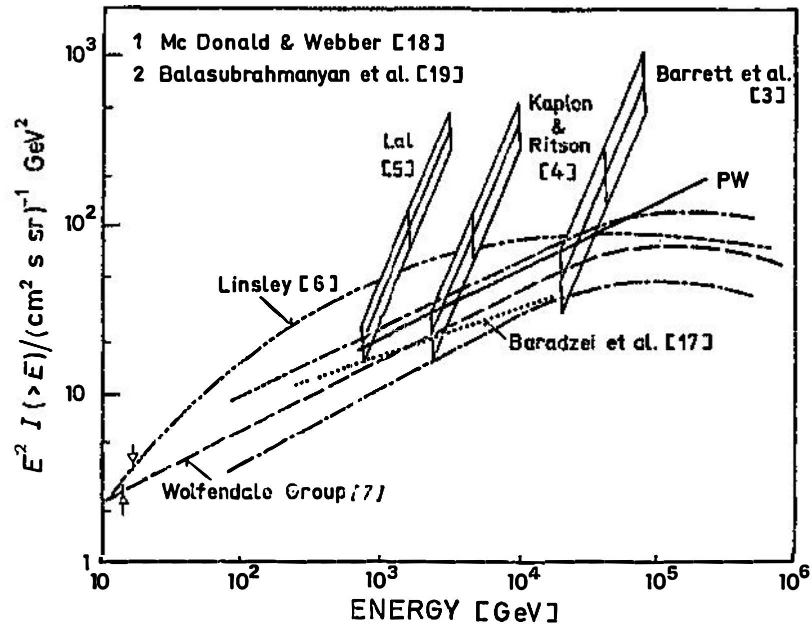

Fig. 1. Comparsion of the present estimate of the all particle primary nucleon spectrum from the earlier survey after Wolfendale group[7]:
Full line is the result from the latest JACEE data[2]; — — — — — Wolfendale group[7] whose error limits are indicated by chain curves; —·—·—·—. Linsley et al.[6];. ········ Baradzei et al.[17]; ⊞ Barrett et al.[3], ⊞ Lal[5], ⊞ Kaplon and Ritson[4]; ∇ Mc Donald and Webber[18]; △ Balasubrahmanyan et al.[19].

Calculation of sea level proton spectrum from the latest primary nucleon spectrum has been done by following the procedure described in our earlier work[10]. The differential primary nucleon flux incident at the top of the atmosphere follows

$$N(E)\,\mathrm{d}E = (p_0 + n_0)\,E^{-(\gamma+1)}\,\mathrm{d}E \cong N_p(E, y = 0)\,\mathrm{d}E + N_n(E, y = 0)\,\mathrm{d}E. \quad (13)$$

The $N_p(E,y)$ and $N_n(E,y)$ represent the differential intensities of protons and neutrons of energy E at an atmospheric depth y g · cm^{-2}. The diffusion equation for the propagation of these particles follows

$$\frac{\partial N_p(E,y)}{\partial y} = \frac{N_n(E,y)}{\lambda_N} Z_{np} - \frac{N_p(E,y)}{\lambda_N} + \frac{N_p(E,y)}{\lambda_N} Z_{pp} \quad (14)$$

where λ_N is the interaction length for nucleons in air. The usual solution to above equation yields the differential proton spectrum at an atmospheric depth y g · cm^{-2} follows the form

$$N_p(E,y)\,\mathrm{d}E = \frac{1}{2}\left[(p_0 + n_0)\,\mathrm{e}^{-y/\Lambda_N} + (p_0 - n_0)\,\mathrm{e}^{-y/\Lambda'_N}\right] E^{-(\gamma+1)}\,\mathrm{d}E \quad (15)$$

where

$$1/\Lambda_N = (1 - Z_{pp} - Z_{pn})/\lambda_N$$

and

$$1/\Lambda'_N = (1 - Z_{pp} + Z_{pn})/\lambda_N.$$

Using the parton recombination model which governs large x and small p_T a quark parton model supplemented by coherent tube model after Berlard et al.[11], Minorikawa and Mitsui[12] have estimated the fractional hadronic energy moments Z_{pp} and Z_{pn} for p-air collisions and the result follows:

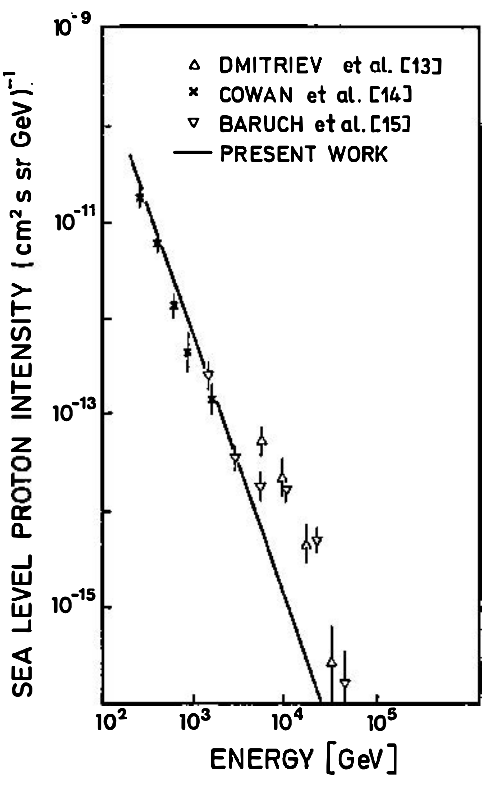

Fig. 2. Energy spectrum of sea level protons: Experimental data, Δ — Dmitriev et al.[13], X — Cowan and Matthews[14]; ∇ — Baruch et al.[15]. Full line is the present calculated proton spectrum derived from the primary nucleon spectrum[1] based on the latest JACEE data[2].

$Z_{pp} = 0.1911$, $Z_{pn} = 0.0644$ which yield $\Lambda_N = 107.45 \text{ g} \cdot \text{cm}^{-2}$, $\Lambda'_N = 91.61$ $\text{g} \cdot \text{cm}^{-2}$, respectively. The derived sea level proton spectrum follows the form

$$N(E, 1033 \text{ g-cm}^{-2} \text{ air}) \, dE = 7.6935 \cdot 10^{-5} E^{-2.7} \, dE \, (\text{cm}^2 \text{ s sr GeV})^{-1}. \quad (16)$$

The estimated sea level proton spectrum has been compared with the measured proton intensity data after Dmitriev et al.[13], Cowan and Matthews[14] and Baruch et al. [15]. For the burst sizes corresponding to nucleon energy above 2 TeV the change of the burst size spectrum observed by Baruch et al.[15] appears to be confirmed by the measurements of Dmitriev et al.[13] in that there is an agreement with the enhanced intensities found for the large burst sizes. Brooke[16] has also pointed out that there is a systematic error in the absolute energy calibration of the apparatus used by Dmitriev et al.[13] and any conclusion related to the behaviour of the burst spectrum in this region must be tentative until direct measurements are made of the neutral to charged hadron ratio. Our calculated sea level proton spectrum is in accord with the measurements of Cowan and Matthews[14] and Baruch et al.[15] for proton energies up to 2 TeV. We have used the calculated value of proton-hadron flux at sea level after Grigorov[20] which is $\approx$ 0.1 for the conversion of hadron flux data[13–15] to proton flux.

Acknowledgments

The authors are grateful to Prof. Dr. O. C. Allkofer, Director, Institut für Reine und Angewandte Kernphysik, Universität Kiel for his interest in the work. One of us (DPB) is thankful to Dr. M. Samorski and Dr. W. Stamm for hospitality. He is thankful to Alexander von Humbolt Foundation for the award of a fellowship.

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TOTALNI SPEKTAR PRIMARNOG NUKLEONA NA OSNOVI POSLJEDNJIH JACEE REZULTATA I RANIJIH SPEKTARA

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UDK 539.12

Originalni znanstveni rad

Totalni spektar primarnog nukleona koji je procijenjen na osnovi nedavnih JACEE podataka uspoređen je s ranijim pregledom Wolfendaleove grupe. Spektar protona na morskoj površini, računan pomoću primarnog nukleonskog spektra slaže se s mjerenjima Cowana i Matthewsa, kao i s mjerenjima Barucha, Brookea i Kellermanna za energije protona do 2 TeV.