THE COSMIC RAY PROTON AND HELIUM SPECTRA ABOVE 50 GeV

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## Abstract

The primary cosmic ray proton and He spectra from 50 GeV to 2000 GeV have been measured by an ionization spectrometer flown on a balloon at an altitude of $6 \mathrm{gm} \mathrm{cm}^{-2}$ for 16 hours. The geometrical factor of the instrument was 300 $\mathrm{cm}^{2}$ sterad and more than 5,000 events were observed. At low energies, the energies of individual events can be determined to within $\pm 30 \%$. At higher energies, the cascade is not fully contained within the four mean free path thick spectrometer and the problems of estimating the energies of these events will be discussed. The proton spectrum continues with constant exponent $=-2.7 \pm 0.1$ up to energies greater than $1,000 \mathrm{GeV}$. This spectrum is in agreement with the results of Pinkau et al. (1969) at the low energies. However, there is no evidence for the spectral break at about $1,000 \mathrm{GeV}$ as reported by Grigorov et a1. (1969).

## 1. Introduction

In this paper we report measurements of the proton and helium energy spectra obtained at balloon altitudes using an ionization spectrometer of depth $4 \mathrm{~m} . f . \mathrm{p}$. and $2,500 \mathrm{~cm}^{2}$ cross sectional area. An outline of the arrangement of the detectors is shown in Fig. 1. The major part of the spectrometer is the 7 iron modules each 0.5 proton m.f.p. '(5 radiation lengths) thick. Notice that there are 3 plastic scintillators in each module so that an observed detector output of $N$ particles is actually an average of the three sampling scintillators. This averaging helps to reduce fluctuations of the nuclear cascades but allowances must be made for this averaging when reconstructing shower curves in regions of rapid development.

Above the iron section are 12 tungsten modules each 1 radiation length thick, making a total of 0.48 proton $m$.f.p. of tungsten. An incident primary particle is identified in the charge module section which contains 2 plastic scintillators, a Cerenkov counter and a CsI scintillator. A wire grid spark chamber containing $4 \mathrm{X}-\mathrm{Y}$ planes defines the particle trajectory and is helpful in rejecting background events.

A11 detector outputs are normalized to a single particle output defined as the mean energy loss of a single muon which passes through the entire spectram eter. In the proton mode the spectrometer is triggered by an energy release $>50 \mathrm{GeV}$ in the first five iron modules. Fig. 2 shows 4 events obtained during the balloon flight. The frequent independent sampling of this spectrometer allows a good estimate of the first interaction point of the incoming particles. For protons an interaction is defined to have occurred in the first detector whose output is greater than 3 particles provided that the following 2 detectors have outputs greater than 5 particles. For He nuclei the corresponding particle numbers are 7,10 , and 10 . Basically the definition requires that a neutral pion of energy $>0.5 \mathrm{GeV}$ be produced at that point.
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The ability to specify the first interaction point removes a major source of fluctuation in shower development, but the remaining fluctuations in nuclear disintegration energy and in cascade development limit the estimation of the energy of individual events to $\pm 25 \%$. A more serious problem is that for large energy primaries the nuclear cascade is not contained within the $4 \mathrm{~m} . f . \mathrm{p}$. depth of the spectrometer and some energy escapes out the bottom as suggested by curves 2 and 4 of Fig. 2.

## 2. Calibration and Energy Estimation

The spectrometer was calibrated with 10,15 and 20 GeV protons from A.G.S. at the Brookhaven National Laboratory. The total calorimeter output formed by summing the seven iron modules was found to be directly proportional to the incident proton energy. The excellent energy resolution obtainable with this type of instrument is shown in Fig. 3. The observed output implies that at these low energies $60 \%$ of the incident energy is being sampled by the scintillators. However, these energies are lower than those of the cosmic rays of interest and so a similar instrument will be calibrated at the National Accelerator Laboratory later this year. This should provide accurate calibration up to proton energies of 500 GeV . Theoretical and Monte Carlo calculations (1), (2) show that the total output of an infinitely deep absorber will be directly proportional to the incident energy up to energies of at least $10^{4} \mathrm{GeV}$. To estimate the energy escaping out the bottom of our finite depth instrument we have extrapolated the mean shower curves shown in Fig. 4.

The lowest curve is that obtained with $17.6 \mathrm{GeV} / \mathrm{c}$ protons at Brookhaven. The flight data curves are constructed for events which interacted in the first iron module and penetrated the bottom of the spectrometer. They are grouped according to the sum over seven modules. The extrapolated curves indicate that the fraction of energy escaping increases from $3 \%$ at 40 GeV to $22 \%$ at 40 GeV . The correction for high energy events has been estimated from

$$
\begin{equation*}
\mathrm{C}=8.31 \mathrm{n} E_{7}-28 \tag{1}
\end{equation*}
$$

where $\mathrm{E}_{7}$ is the energy obtained by summing over all 7 modules.
In order to increase the effective geometry factor, we have also used those events which exited after 5 iron modules i.e., $3 \mathrm{~m} . f . \mathrm{p}$. To estimate the energies of these events we have used a weighted mean of modules 4 and 5 and extrapolated assuming that the showers are exponentially absorbed with an attenuation length of $240 \mathrm{gm} \mathrm{cm}^{-2}(3)$. A cross check of this method has been made using those events which exited beyond the 7th module, and it is found that the energy estimates using 5 and 7 modules are in good agreement.

We have also investigated using the number of particles at shower maximum as an energy estimator but the dispersion within groups of events is much larger. The number at maximum increases as $\mathrm{E}^{0.8}$. Similar corrections have been estimated for He at the same energy/nucleon.

## 4. Energy Spectra

Using the corrections outlined above, we obtain the primary energy spectra shown in Fig. 5. We have included data from 12 hours of flight at an altitude of $6 \mathrm{gm} \mathrm{cm}^{-2}$. The sensitive live time was $68 \%$ and the geometrical factor was
$330 \mathrm{~cm}^{2}$ ster. The fluxes shown have been corrected to the top of the atmosphere ( x 1.15 ), for particles which interact beyond module 3 ( x 1.30 ) for spark chamber inefficiency ( x 1.2) and for backscattering ( x 1.25). These corrections will be discussed in detail in a paper to be published.

The spectra show that the ratio of protons to the nuclei remains constant up to total energies of $3,000 \mathrm{GeV}$. We have checked the influence of backscatter $(<25 \%$ at $17.6 \mathrm{GeV} / \mathrm{c})$ on our spectra by observing that the spectrum has the same slope for the groups of events which interact in the first, second, and third modules. The loss of events due to backscattering of multiple particles into the charge module from a depth of $1.5 \mathrm{~m} . f . \mathrm{p}$. should be small due to the large thicknesses of material and the small solid angle (. 60 sterad) into which high energy products would have to be backscattered.

Our measurements do not give any evidence for the change in slope of the proton spectrum observed by Grigorov in the region of $1,000 \mathrm{GeV}$. If the proton spectrum continues with constant exponent to above $10^{13} \mathrm{eV}$ then the observed spectra at mountain altitudes suggest that there is a change in the proton air nuclei cross section at those energies. It is hoped that these discrepancies will be resolved by the spectrometer similar to the one described above, which is being designed for the High Energy Astronomy Satellite.

## 5. References

Grigorov, N.L., V.E. Nestorov, I.D. Rapoport, I.A. Savenko, G.A. Skuridin, 1969,
Proc. XI Int. Conf. on Cosmic Rays, $1,518$.
Jones, W.V., 1969, Phys. Rev. 187, 1868.
Jones, W.V., 1969, Proc. XIth Int. Conf. on Cosmic Rays.
Jones, L.W., et al., 1970, "Properties of Proton-Proton Interactions between
70 to $600 \mathrm{GeV}^{\prime \prime}$, Proceedings of the XI Interamerican Seminar on Cosmic Rays,
La Paz, Bolivia (to be published).
Kamata, K., et al., 1969, Proc. XIth Int. Conf. on Cosmic Rays, 3, 49.
Murzin, V.S., 1967, Progress in Elementary Particles and Cosmic Ray Physics, 9,
North Holland Publishing Co., Amsterdam.
Pinkau, K., U. Pollvogt, W.K.H. Schmidt and R.W. Huggett, 1969, Proc. XIth
Conf. on Cosmic Rays, $3,291$.


## IONIZATION SPECTROMETER

Figure 1


Figure 2


Figure 3


Figure 4


Figure 5

