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N^* PRODUCTION IN $\pi^\pm$-p AND p-p INTERACTIONS*†

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We have observed a peak in the pion momentum spectrum in inelastic $\pi^\pm$-p scattering corresponding to a recoiling baryon of mass 1.4 BeV. Previous investigations have demonstrated the existence of this peak in p-p collisions.[1-4] In the present investigation, production of this mass peak and the 1.24-, 1.52-, and 1.69-BeV isobars have been observed in $\pi^\pm$-p as well as p-p interactions in the range of four-momentum transfer $0.01 < |t| < 0.2$ (BeV/c)^2 at incident lab momenta from 10 to 26 BeV/c.

The apparatus has been described previously,[5] and consisted of a magnetic spectrometer of scintillation-counter hodoscopes. The average momentum resolution was ~0.4 %.

Figure 1 shows typical momentum spectra $d^2\sigma/dpdt$ at various angles and incident momenta. The dominant feature of the data at small angles is the large peak corresponding to a missing mass of 1.4 BeV. In order to extract production cross sections, the data were fitted with Briet-Wigner line shapes broadened by the resolution (deduced from the width of the elastic peak) plus various simple forms for the unknown background. The tail of the elastic peak was fitted by a Gaussian. The mass which best fitted the 1.4 peak was 1.40 ± 0.03 BeV, in good agreement with 1.405 ± 0.015 BeV from Anderson et al.,[2] and 1.410 ± 0.015 BeV from Blair et al.[4] Within the error, the mass observed was independent of incident energy, four-momentum transfer, and incident particle. The other isobar masses used in the fit were fixed at 1.24, 1.52, 1.69, and 1.92 BeV.[6] The spectra did not include measurements corresponding to masses greater than 2 BeV. The widths of the isobars were chosen as 0.12 BeV for the 1.24-, 1.52-, 1.69-, and 1.92-BeV isobars and 0.15 BeV for the 1.4-BeV isobar. Various background shapes were tried including flat (independent of P/P_{el}) and polynomial in P/P_{el} up to the fourth power, with the background vanishing at the elastic peak. However, since the more complex functions did

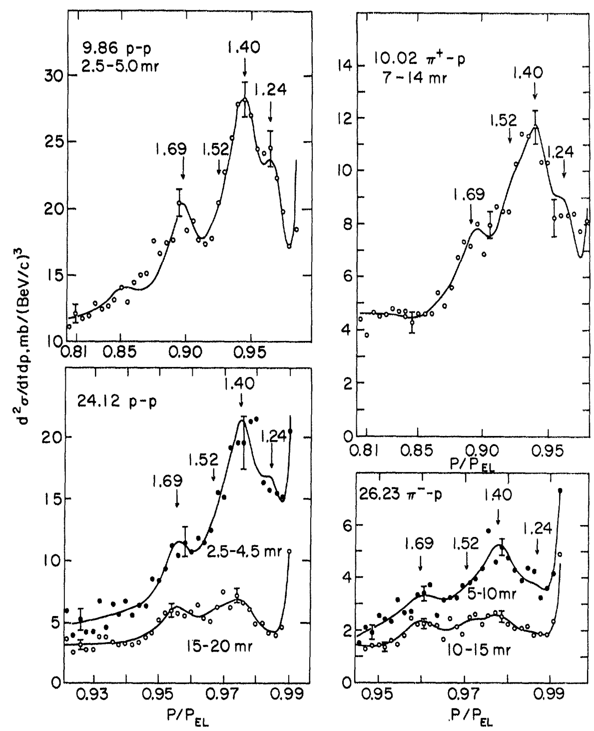

FIG. 1. Typical inelastic momentum spectra $d^2\sigma/dpdt$ plotted versus the ratio of particle momentum to that of elastically scattered particles at the same angle. The arrows show the expected locations of the isobars. The solid lines are least-squares fits described in the text.

not significantly improve the fit, the simplest (flat) background assumption was used to deduce cross sections.

Figure 2 shows the production cross sections $d\sigma/dt$ for the 1.4- and 1.69-BeV isobars plotted versus t. The errors shown are counting statistics. In addition, there is an over-all systematic error of ±40%, largely of a scale nature, due to uncertainty in the background shape and isobar widths. The p-p results are in agreement with previous measurements.[2]

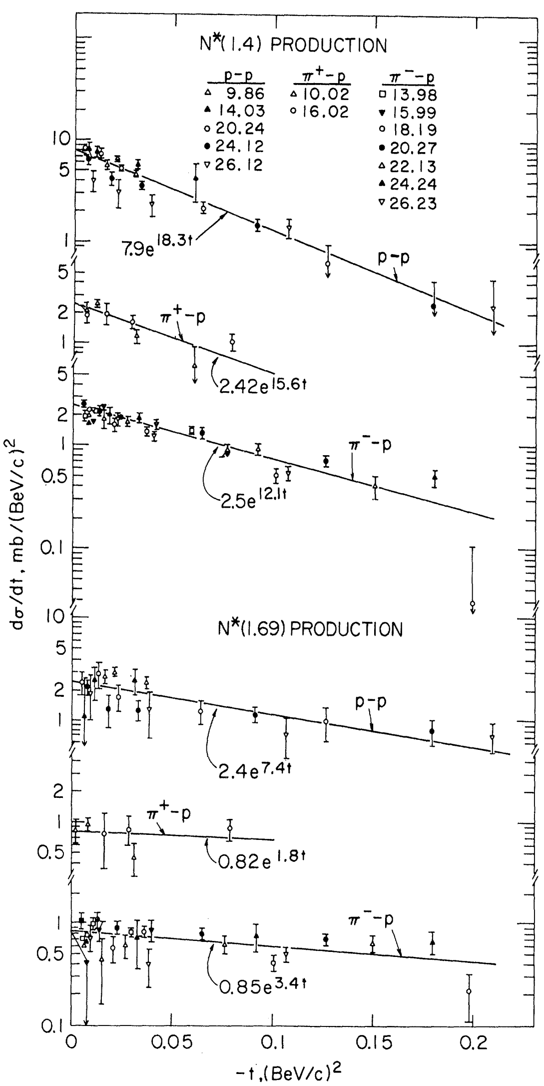

FIG. 2. The cross section $d\sigma/dt$ plotted versus four-momentum transfer for $N^*(1.4)$ and $N^*(1.69)$ production. The various symbols represent the different incident lab momenta. The lines are least-squares fit to the data. The representative errors shown are statistical. In addition, there is a systematic uncertainty of ±40%, mainly of a scale nature.

There is no significant evidence in the present experiment for an energy dependence within the s and t range probed, and so the cross sections were fitted by a single exponential in t, independent of energy. The results of the least-squares fits are shown in Fig. 2. The values of B in the fit function Ae^{Bt} are given in Table I with the estimated systematic errors. The exponential slope of the 1.4-BeV–isobar production cross section is larger than the average value for the elastic diffraction scattering peak, while that of the 1.69-BeV–isobar cross section is smaller. There is some indication that in each case the production cross section falls off more rapidly with increasing $|t|$ for p-p than for π-p, but considering the systematic errors, this difference may not be significant. Because of the proximity to the large 1.4-BeV peak and the uncertainty in the background shape, the 1.24- and 1.52-BeV–isobar production cross sections are not well determined, although the 1.24-BeV isobar appears clearly at low $|t|$ and the 1.52-BeV isobar at large $|t|$. There is no significant evidence in our data for production of an isobar at a mass of 1.92 BeV.

An interesting observation is that the momentum spectra at a given t appear to have about the same shape for all three channels ($\pi^\pm$-p and p-p) relatively independent of incident energy, and the ratio of cross sections for isobar production by incident pions compared with that for incident protons is essentially the same as the ratio of the elastic cross sections.

It has been suggested that the peak seen at 1.4 BeV is not an isobar.[3] However, the fact that three different incident probes ($\pi^\pm$ and p) show a well-defined peak at the same mass independent of the energy and four-momentum transfer enhances the conclusion that this peak represents a recoiling isobar rather than a kinematical effect. Of course, this is not a rigorous demonstration of the existence of an

Table I. Values of the exponential slopes for 1.4- and 1.69-BeV isobar production as obtained from least-squares fits. The errors include statistics and an estimate of the systematic errors.

	$N^*(1.4)$	$N^*(1.69)$
p-p	18±2	7±2
π^+-p	16±4	2±5
π^--p	12±2	3±2

isobar, but the conclusion is further supported by evidence from phase-shift analysis of π-p elastic scattering.[7] An article describing this investigation in more detail is in preparation.

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ENERGY SPECTRUM AND THE ORIGIN OF COSMIC-RAY ELECTRONS ABOVE 12 BeV

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Recent measurements by Daniel and Stephens[1] on high-energy cosmic-ray electrons indicate that (i) the energy spectrum between 12 and 350 BeV can be represented by a power law with spectral index of 2.1 ± 0.2, which is in contradiction with the expected steepening predicted by previous papers,[2,3] and (ii) there is a positron excess in the energy range $E > 12$ BeV as opposed to the negatron excess in the lower energy range.[4] Several suggestions have been put forward to explain these discrepancies. Daniel and Stephens[1] themselves conclude that either the 3°K blackbody radiation does not exist or there exists a second component to the electron spectrum with spectral index of $\alpha \cong 1.1$ in the energy range below 10 BeV. O'Connell[5] and Cowsik et al.[6] suggested that the leakage lifetime of cosmic-ray electrons should be less than 10^7 y. Ramaty and Lingenfelter[7] proposed that the observed spectrum results from the fact that the lifetime of cosmic-ray electrons in the galactic disk is shorter than the radiative lifetime of these electrons. While these suggestions may take care of the flatness of energy spectrum, they do not explain the observed positron excess.

We wish to point out that in the high-energy range where the radiative lifetime of an electron is shorter than its leakage lifetime, the equilibrium energy spectrum of electrons at Earth depends strongly on the spatial distribution of their sources. Thus, assuming the existence of the 3°K blackbody radiation and a leakage lifetime of 10^8 y for both cosmic-ray nuclei and electrons, the electron spectrum above 10 BeV will provide us a tool to determine the origin of cosmic-ray electrons.

The general diffusion equation for a steady-state electron flux is[8]

$$(\partial/\partial E)[B(E)N(E,\vec{r})]-\nabla\cdot[D(\vec{r})\nabla N(E,\vec{r})]=Q(E,\vec{r}). \quad (1)$$

The term on the right-hand side of Eq. (1) is the source term which describes the generation of electrons. The first term on the left side represents the energy loss suffered by electrons propagating the interstellar space. In the range above 5 BeV this is mainly due to the Compton and synchrotron processes, and

$$B(E) = -bE^2, \quad (2)$$

where, including the 3°K blackbody radiation, we have $b \cong 6\times10^{-17}$ BeV^{-1} sec^{-1}. The second term on the left side describes the spatial diffusion of particles. The diffusion coefficient D depends on the strength and size of magnet-