Since in the case of carbon a large part of the scattering might be inelastic, especially at large Θ, it is important to investigate e not only as a function of Θ but also of the energy of the protons detected. We have started this investigation by taking measurements with various energy cutoff values by inserting various absorber thicknesses in our counter telescope at $\Theta=15°$ and $9°$. In each case the lowest energy group of scattered protons (0 to 210 Mev) shows no observable asymmetry. For $\Theta=15°$ the intermediate energy group (210 to 280 Mev, quasielastic scattering) gives large asymmetry with $e=0.37\pm0.04$, and the elastically scattered protons (290 Mev) indicate $e=0.45\pm0.04$. For $\Theta=9°$, the elastically scattered protons show $e=0.43\pm0.02$.

If the beam polarization P were known, we could determine the polarization in scattering by hydrogen P_{H} from the relation $e_{\mathrm{H}}=P\,P_{\mathrm{H}}$. If we tentatively assume that $e_{\mathrm{C}}=P^2$ (even though the carbon scattering is not elastic) then we obtain from the data for $\Psi=\Theta=20°$ the result $P=0.5$, and $P_{\mathrm{H}}=2e_{\mathrm{H}}$. This allows a provisional interpretation of the data of Fig. 2. Quite aside from the absolute value of P_{H}, its angular distribution is given in Fig. 2 and this indicates a more complex dependence than the $\sin(2\vartheta)$ dependence obtained by considering only s and p waves.

* This work was done under the auspices of the U. S. Atomic Energy Commission.
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Polarization by p-p Collision at 310 Mev*

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THE discovery of polarized protons at 240 Mev by Oxley and co-workers[1] led us to look for similar phenomena at 320 to 430 Mev. For angles and energies consistent with quasi-free nucleon scattering inside the beryllium nucleus from 25° to 35°, we have reported an unsuccessful search.[2] We are grateful to Segrè for telling us of preliminary results at Berkeley indicating production of a polarized 340-Mev proton beam by small-angle scattering from carbon. Following this lead, we have obtained a polarized proton beam of about 310 Mev by scattering of 322-Mev average energy protons at 14° to the right from a beryllium target inside the cyclotron. The polarization has been demonstrated by a second scattering on a beryllium target outside the cyclotron giving asymmetries as high as 80 percent. The polarization increases as shown in Fig. 1 with thickness of absorber as if the main polarized component were the elastic scattering. We estimate a rough value of the amount of polarization of the beam as $(\frac{1}{2}\text{ asymmetry})^{\frac{1}{2}}$ (see definitions in reference 1), where the asymmetry is measured at 14° excluding the nucleon-scattered component, these conditions being true for both first and second scatterings. Our beam therefore is believed to be ~60 percent polarized.

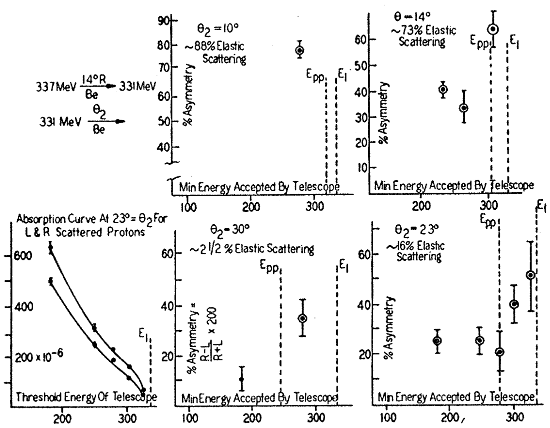

FIG. 1. Dependence of polarization of beryllium-scattered protons on scattering angle θ_2 and on energy of scattered protons. E_1 is the energy of protons incident on the second beryllium target. E_{pp} is the energy a proton would have if scattered by a free nucleon. The high absorption curve at $23°=\theta_2$ is for right-scattered protons, the lower for left. The percent elastic scattering is estimated by using the elastic scattering cross sections measured by Moyer *et al.* (see reference 4) at 340 Mev.

Liquid hydrogen was substituted for the second beryllium target, and the asymmetry of scattering was measured as shown in Fig. 2. The polarization due to hydrogen, P_{H}, is obtained from the data of Fig. 2 according to the relation $0.6\,P_{\mathrm{H}}=\frac{1}{2}$ asymmetry. A phase shift analysis indicates that the asymmetric part of the p-p scattering should vary as $\sin\theta\cos\theta$, where θ is the barycentric angle if only ^3P states act, but if ^3P and ^3F states both are important, the asymmetry should vary as $\sin\theta\cos\theta(a+b\cos^2\theta+c\cos^4\theta)$. The singlet states do not give asymmetric terms. The data of Fig. 2 indicate large values of b and c and a small value of a. We are investigating the effect of this result on the phase shifts.

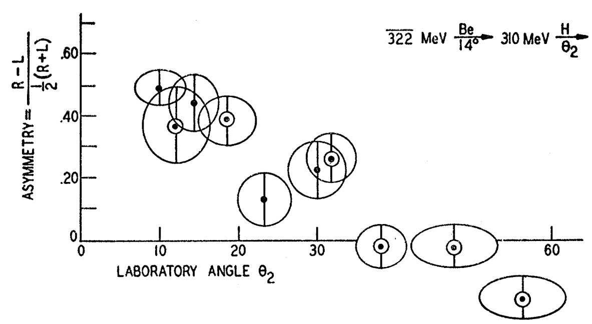

FIG. 2. Asymmetry produced by second scattering from liquid hydrogen of estimated 60 percent polarized 310-Mev proton beam.

The values of p-p differential scattering cross section previously reported by us[3] were for a beam scattered first to the right at a small angle and scattered externally always to the left. The evidence of Fig. 1 is that a similar beam at 310 Mev is polarized. The evidence of Fig. 2 is that cross sections measured to the left will be lower than the cross sections for a nonpolarized beam. Consequently our cross sections at 420 Mev may have been low at small angles. This point is under further investigation.

* Research supported by a joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
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Energy Spectrum of Negative Pions Produced in Beryllium by 2.3-Bev Protons*

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THE study of pion production by nucleon-nucleon and nucleon-nucleus collisions is of considerable basic interest, and a number of experiments have been performed[1] both at comparatively low-incident nucleon energies (up to 440 Mev) with particles produced by particle accelerators and at extremely relativistic energies with cosmic-ray particles. The existing experimental data have shed considerable light on the nature of the π meson and its interaction with nucleons. Since the Brookhaven Cosmotron produces protons of energies up to about 2.3 Bev and

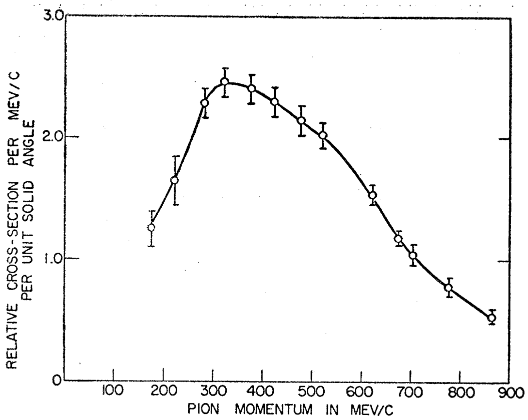

FIG. 1. The relative momentum spectrum of negative pions produced in beryllium by 2.3-Bev protons at 32° in the laboratory system. The momentum resolution was approximately 10 percent (total width).

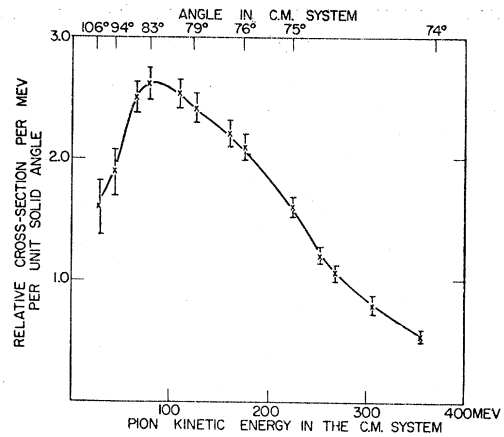

FIG. 2. The relative energy spectrum of negative pions, transformed to the proton-nucleon center-of-mass system (assuming that the pions are produced effectively by proton-nucleon interaction in beryllium.

it is relatively easy to vary the energy[2] from the top of the FM cyclotron range (400 Mev) to 2.3 Bev, we have begun an investigation of charged-pion production processes at these energies. It would be especially interesting to compare the data in this near-relativistic region with the predictions obtained from Fermi's statistical theory[3] for multiple production of pions, which seems to explain satisfactorily the data obtained on extremely high-energy production processes observed in cosmic-ray experiments. Also one could perhaps expect to see some evidence of the "apparent" pion-nucleon resonance interactions[4] in the production processes.

We have obtained preliminary results for the energy spectrum of negative pions emitted at 32° (laboratory angle) from a 2×2×6 inch beryllium target when bombarded by 2.3-Bev protons. The experimental arrangement was similar to that previously described.[4] A 3-inch collimator looked directly at the beryllium target (in a straight section outside the magnet quadrant) at an angle of 32° from the incident beam direction. A double-coincidence counter telescope defined and monitored the incident beam. An analyzing magnet followed by a third counter, displaced by 30°, in triple coincidence measured the relative fraction of negative particles of a particular momentum range. By varying the magnet current, the relative momentum spectrum of the negative particles issuing from the target was determined. The percentage of pions at each momentum was determined by range-curve analysis of the beam as previously described.[4] A correction for the π-μ decay in flight was applied to the data. The relative momentum spectrum deduced for negative pions in the laboratory system at 32° is shown in Fig. 1. The momentum resolution was approximately constant and about 10 percent (total width) for all points.

If one makes the assumption that beryllium is a light enough nucleus so that one is essentially observing the elementary proton-nucleon production of mesons, without appreciable subsequent scattering and reabsorption of the mesons produced, one can transform the observed spectrum in the laboratory system back to the proton-nucleon center-of-mass system. This has been done in Fig. 2, neglecting the Fermi momentum distribution of the nucleons involved. An analysis of the effect of the Fermi motion demonstrates that the energy transformation back to the c.m. system is affected only slightly (a few percent) by the Fermi motion.

The angular range seen in the c.m. system is rather narrow (between 74 and 80°) except for the lower-energy points where the angle rises rapidly to about 105° for the lowest-energy point observed. The effect of the Fermi motion is only to smear out the angular region observed by a few degrees. Hence one is essentially observing the energy spectrum in the region near 90° in the c.m. system. The most striking feature of the energy spectrum is the dominance of low-energy mesons and the existence of a well-defined peak in the region of 75–100 Mev. The total energy available in the c.m. system is 930 Mev. The mean total energy of the negative pions is ~300 Mev. Therefore, if one assumes that all of the available energy in the c.m. system went into meson production and that the π^+ and π^0 spectra are similar to the π^- spectrum, we might expect a mean multiplicity of ~3. However, the nucleons carry away some kinetic energy, and therefore the mean multiplicity probably is less than three.

The general shape of the energy spectrum as shown in Fig. 2 suggests a comparison with the Fermi statistical type of meson production process. Christian and Yang[5] have calculated the spectra for one-, two-, and three-meson production processes according to the Fermi theory.[3] Our results appear to be consistent with a mixture of mostly double and some (~10 percent) triple meson production.[6] Christian and Yang[5] have recalculated the relative weights of the various multiplicities predicted by the Fermi theory using more exact statistical weight expressions and taking into account the rest mass of the meson. They concluded that one-meson production should be highly dominant. The predicted spectrum would then favor a peak at much higher energies in the c.m. system and hence be in disagreement with our results.

If one assumes that the spectra for the different multiplicities predicted by the Fermi theory are correct, one concludes that double and triple production are favored for some other reason than the simple statistical factors considered. Of course, some other effect could distort the expected spectra. The strong pion-nucleon interaction observed in the scattering data at the "apparent" low-energy resonance is one possible explanation. In fact one might assume that the pion-nucleon cross section, as a function of energy (relative to the nucleons), be considered a multiplying factor in the final state weight for these processes and thereby enhance those modes of meson production which yield low-energy mesons.

The continuing investigations of the dependence of positive and negative pion production on angular distribution and incident proton energy should further clarify these effects.

We would like to thank Dr. E. O. Salant for his interest in and helpful discussions of this experiment.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

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5 R. Christian and C. N. Yang (private communication).
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