the expected energy should bring a neat proof of the isospin nature of the splitting. The relative contribution of the dipole part may become too small to consider other multipoles as corrections and then evaluate total muon capture rate as FW did; however, comparison of results with experimental total-capture-rate data for several nuclei can bring some interesting information on the shell-model estimates of other multipole contributions; this aspect, as well as several points only touched upon in this note, shall be investigated in a forthcoming publication.

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Measurements of Polarization in $\pi^- p$ Elastic Scattering at Large Angles*

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We have made measurements of polarization in $\pi^- p$ elastic scattering, with emphasis over the backward region, at 1.60 to 2.28 GeV/c. The results indicate the absence of u-channel dominance in the backward region, as was observed in the case of $\pi^+ p$ scattering. Comparisons have been made with predictions of various phase-shift analyses which show that the agreement is generally very poor in the backward region.

Recent polarization measurements[1,2] of $\pi^+ p$ elastic scattering at large angles in the region of pion incident momenta below 2.75 GeV/c revealed the following interesting phenomena: (1) large changes in the sign of polarization, with respect to incident momenta, in the backward region, (2) a dip[2] in the polarization at constant $u \sim -0.65$ $(\text{GeV}/c)^2$, and (3) poor agreement in the backward region with predictions of the existing phase-shift analyses.[3]

In order to continue our study of these problems, we have measured polarization in $\pi^- p$ elastic scattering in the energy range between 1.60 and 2.28 GeV/c, with emphasis on the backward region. Previous measurements[4-6] in a similar energy range have covered mainly the forward region.

The experiment was carried out at the Argonne zero-gradient synchrotron with a polarized-proton target. Beam pion intensities ranged from 4×10^5 to 8×10^5 π^-'s per pulse, with a momentum spread of $\Delta p/p = \pm 2.0\%$, resulting from 2×10^{11} protons per pulse striking a 3-in.-long Cu production target. Both final-state particles were detected in counter hodoscopes in a setup similar to the one used in the previous experiments.[1] For the backward scattering, a spherical Fitch-type Cherenkov counter[7] was used to detect the forward-going proton while rejecting pions. The use of this counter sometimes reduced the statistical error on the polarization by as much as a factor of 2 or 3.

The polarized target material was ethylene glycol which produced a target polarization of 45 to 50%.

The measured polarization parameters at 1.60, 1.70, 1.88, 2.07, and 2.28 GeV/c plotted versus the momentum transfers t and u in $(\mathrm{GeV}/c)^2$ are shown in Fig. 1. The errors shown are statistical only. There is an additional systematic error of $\pm 7\%$ due to uncertainty in the target polarization. We have compared our data with those of previous experiments[4-6] in the forward region and have found no evidence of inconsistency.

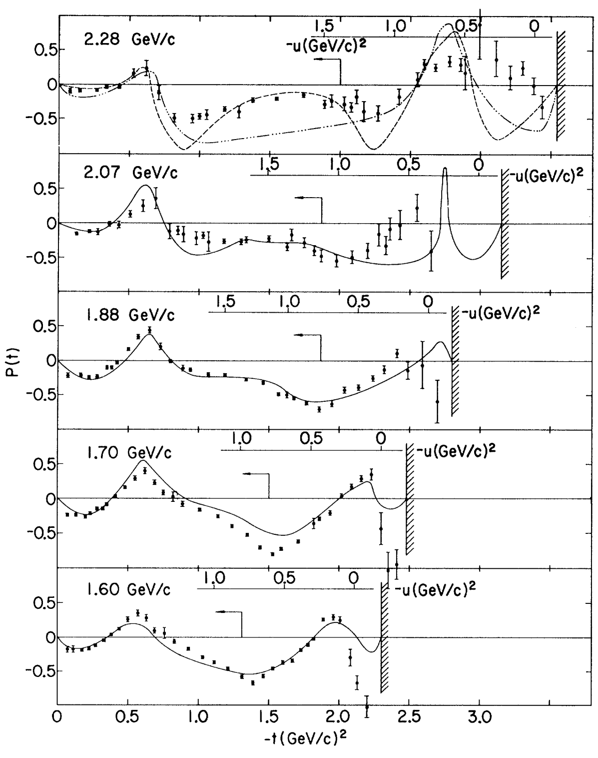

FIG. 1. Polarization parameter as a function of momentum transfer $|t|$ and $|u|$ in $(\mathrm{GeV}/c)^2$ for beam momenta of 1.60, 1.70, 1.88, 2.07, and 2.28 GeV/c. The Regge-pole prediction shown by the dot-dashed curve is based on Ref. 9. The CERN and ANL-Chicago phase-shift predictions are shown by solid and dashed curves, respectively.

Our data at 2.28 GeV/c cover the regions of the dip in the π^-p differential cross section at $t \simeq -2.8$ $(\mathrm{GeV}/c)^2$. The polarization exhibits a fairly large positive maximum in the region of this dip, crossing zero to negative values both above and below this point. Recent data from CERN[8] at 2.74 GeV/c also show this feature. This behavior is qualitatively consistent with predictions of the t-channel Regge-pole model of Barger and Phillips,[9] as shown by the curve in Fig. 1.

A large negative polarization (consistent with 100%) is found at the very backward region, particularly at 1.60 and 1.70 GeV/c. If we assume $P = -100\%$ at $u \approx 0$, then $f = ig$ or $F_{++} = iF_{+-}$, where $d\sigma/dt = |f|^2 + |g|^2 = |F_{++}|^2 + |F_{+-}|^2$ and $P d\sigma/dt = -2\,\mathrm{Im}(fg^*) = -2\,\mathrm{Im}(F_{++}F_{+-}^*)$ with f and g being the spin-nonflip and spin-flip amplitudes, respectively, and F_{++} and F_{+-} being the s-channel helicity-nonflip and helicity-flip amplitudes. It is interesting that we observe a 90° phase difference between the nonflip and flip amplitudes in a region where a one-baryon-exchange process, which gives the same phase between these amplitudes in a simple Regge model, might be expected.

There are two general features of the data that have a simple systematic behavior. One is the well-known forward maximum at $t \simeq -0.6$ $(\mathrm{GeV}/c)^2$. Another, that has not been discussed before, is the minimum at negative values of P that is found at large angles. As shown in Fig. 2, this

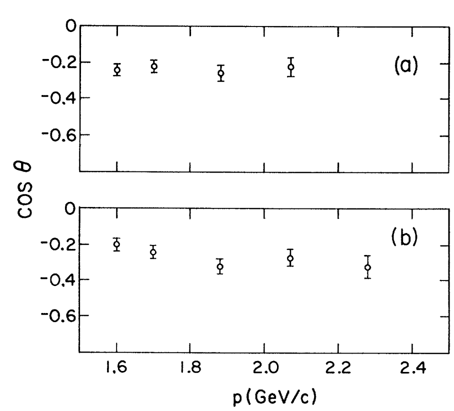

FIG. 2. (a) Position in $\cos\theta_{\mathrm{c.m.}}$ of the minimum in $P d\sigma/d\Omega$ plotted as a function of incident momentum. (b) Position in $\cos\theta_{\mathrm{c.m.}}$ of the minimum in P plotted as a function of incident momentum. The positions of the minima and the errors were estimated by eye.

TABLE I. Values of χ^2 for fits of various phase-shift solutions to our data.

Incident momenta (GeV/c)	Number of data points	CERN[a]	Saclay[b]	χ^2 ANL-Chicago[c]	Durham[d]	Berkeley[a]
1.60	33	489	3259	...	2354	5016
1.70	33	1273	1676	3091	1122	1234
1.88	32	328	912	870	1315	...
2.07	29	120	253	213	1661	...
2.28	37	...	1052	474	980	...

[a]Ref. 3.
[b]Ref. 14.
[c]Ref. 4.
[d]Ref. 15.

seems to occur at a fairly constant value of $\cos\theta_{c.m.} \simeq -0.25$. (But we also find that it seems to occur at an even more constant value of the variable t/s^2.) When these data are combined with the cross-section data of Aplin *et al.*[10] to make curves of $Pd\sigma/d\Omega$, we find that they also exhibit a relative minimum at a constant $\cos\theta_{c.m.} \simeq -0.2$; this is also shown in Fig. 2. This minimum can be seen in previous data[5,6] also, but there appear to be systematic differences in its position as seen in the two data sets. Measurements of π^-p cross sections[11] have also found a feature at constant $\cos\theta_{c.m.}$ (a dip at $\cos\theta_{c.m.} \simeq -0.7$), but others[10] have interpreted it to be at constant $u \simeq -0.6$ (GeV/c)^2, as well as a broad maximum in the cross section[12] at about the same value of u. Regularities of this type in this energy region have been discussed by Odorico[13] in terms of the Veneziano model.

We have compared our results with predictions of the Berkeley,[3] CERN,[3] Saclay,[14] Argonne National Laboratory (ANL)-Chicago,[4] and Durham[15] phase-shift analyses. An arrow in Fig. 1 indicates the angular region of the data that were available at the time of these analyses. All the predictions are poor in the backward region. Table I shows values of χ^2 for each solution, compared with our new data. Partial waves included in these fits are $l = 0$ to 5, with the exception of that of Durham, in which partial waves up to $l = 6$ are included. Predictions of the CERN and ANL-Chicago phase-shift analyses are shown in Fig. 1.

A new phase-shift analysis using current data is in progress, using a new method with accelerated convergence.[16]

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