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A PHENOMENOLOGICAL ANALYSIS OF π^+ AND π^o PHOTOPRODUCTION AT BACKWARD ANGLES†

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ABSTRACT

The new π^+ and π^o backward photoproduction data is analyzed in terms of three Regge trajectories. A satisfactory solution is found with the nucleon trajectories almost degenerate. Several experimental checks of the model are proposed.

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The early photoproduction data in the backward direction and at high energies[1] had several distinct features with strong implications for the contributions of certain trajectories[2]. Recent data on π^+ and π^o photoproduction[3] impose greater constraints on the exchanges and they permit a more accurate description of the situation. Three features of the new data are important and we discuss them in detail.

1) The nucleon trajectory has a nonsense wrong-signature zero at $u \approx -0.15\ (\mathrm{BeV/c})^2$, which appears in all four helicity amplitudes. There is no evidence of such a zero in the new π^+ and π^o data. This eliminates the dominance of the N_α trajectory.

2) At the position of the dip, the nucleon contribution is zero and there remains only the Δ trajectory (in a simple model of $\Delta + N_\alpha$). A pure Δ contribution involves only the isovector part of the photon and it implies:

$$\left(\frac{d\sigma}{du}\right)_{\gamma p \to p\pi^o} = 2\left(\frac{d\sigma}{du}\right)_{\gamma p \to \pi^+ n} . \tag{1}$$

The recent data show that the two cross sections are almost equal for $-0.3 \leq u \leq 0.0$. Therefore, there must necessarily exist an $I = \frac{1}{2}$ contribution, which does not vanish at $u \approx -0.15\ (\mathrm{BeV/c})^2$.

3) From the $\pi^- p \to p\rho^-$ data[4] and isospin we can obtain the contribution of the $I = 3/2$ trajectories to $\pi^- p \to n\rho^o$. Furthermore, using vector meson dominance and the maximum value of the density matrix element $\rho_{11}(u) = \frac{1}{2}$, we obtain an upper bound for the contribution of the $I = 3/2$ trajectories to π^o and π^+ photoproduction. Columns two and three in Table 1 give upper bounds for the contributions of the $I = 3/2$ trajectories to π^o and π^+ cross sections

using $g_\rho^2/4\pi = 0.5$. Comparing these bounds with the experimental values in columns four and five, we conclude that the contribution of the Δ trajectory could be large enough to account for almost all the observed π^0 cross section for $-0.5 < u$, while its maximum contribution to π^+ can be at most half the observed cross section. We conclude that the $I = 3/2$ contributions can be sizable contrary to the conclusion arrived at by G. Kane[5] using the total backward $\pi^- p \rightarrow p\rho^-$ cross sections.

From the above we conclude that a simple explanation in terms of $N_\alpha + \Delta$, with the Δ dominating the π^+ photoproduction[2], cannot account for the new data. Another $I = \frac{1}{2}$ contribution must be introduced. The best candidate is the $N_\gamma(3/2^-, 7/2^-, \ldots)$ whose trajectory is slightly lower than the N_α trajectory. We estimated the residues $\gamma_\alpha(w)$, defined below, using the isobaric model of Gourdin and Salin[6] and we found that the N_γ has a residue considerably larger than the N_α and Δ residues.

We investigate in this Letter a model in terms of three Regge trajectories and we propose experiments which can check different aspects of the model.

The Reggeized Chew-Goldberger-Low-Nambu amplitudes are given by

$$F_2(w, z_u) = \frac{u - m^2}{\pi^{\frac{1}{2}} u} \left[(w-m)^2 - \mu^2\right]^{\frac{1}{2}} \sum \gamma_2^\alpha(w) \left[1 + \eta_i e^{-i\pi(\alpha - \frac{1}{2})}\right] \Gamma(\tfrac{1}{2} - \alpha)(s/s_0)^{\alpha - \frac{1}{2}}$$

$$F_4(w, z_u) = q\, \frac{u - m^2}{\pi^{\frac{1}{2}} u} \left[(w-m)^2 - \mu^2\right]^{\frac{1}{2}} \sum \gamma_4^\alpha(w) \left[1 + \eta_i e^{-i\pi(\alpha - \frac{1}{2})}\right] \Gamma(\tfrac{3}{2} - \alpha)(s/s_0)^{\alpha - \frac{3}{2}} \tag{2}$$

The contribution of the other two amplitudes are obtained by the MacDowell symmetry

$$F_2(w, z_u) = F_1(-w, z_u), \qquad F_3(w, z_u) = F_4(-w, z_u) \tag{3}$$

The residues are free of kinematic singularities. They contain only the dynamic information of the vertices.

The N_α and Δ trajectories have already been determined by the $\pi^+ p \to p\pi^+$, $\pi^- p \to p\pi^-$ and $\pi^- p \to p\rho^-$ data[7]. The trajectories used in this work are:

$$\begin{aligned} N_\alpha \;:\; \alpha &= -0.34 + 0.093\, w + 1.15\, w^2 \\ \Delta \;:\; \alpha &= 0.05 + 0.25\, w + 0.75\, w^2 \end{aligned} \tag{4}$$

We prefer a non-linear Δ trajectory, because a w term may be necessary to explain the πp polarization data. The N_γ trajectory is constrained to pass through the $3/2^-$ (1520) and $7/2^-$ (2190) resonances:

$$N_\gamma \;:\; \alpha = x - (0.385 + 1.105\, x)\, w + (0.88 + 0.278\, x)\, w^2 \tag{5}$$

where x is a free parameter to be determined by the photoproduction data. The isospin dependence of the u-channel amplitudes is given in the standard form:

$$\begin{aligned} F(\gamma p \to p\pi^o) &= \sqrt{2}\, F^\Delta + (F_V^{\frac{1}{2}} - F_S^{\frac{1}{2}}) \\ F(\gamma p \to n\pi^+) &= F^\Delta - \sqrt{2}\, (F_V^{\frac{1}{2}} + F_S^{\frac{1}{2}}) \end{aligned} \tag{6}$$

where S and V denote the isoscalar and isovector contributions of the $I = \frac{1}{2}$ trajectories. The residues were parametrized as follows:

$$\gamma_2^{\alpha}(w) = A_{\alpha}(1 + \frac{S}{V})(1 + b_{\alpha} w)$$

$$\gamma_4^{\alpha}(w) = C_{\alpha}(1 \pm \frac{S}{V})(1 + d_{\alpha} w)\, e^{hu} \qquad (7)$$

The ratio of the isoscalar to the isovector part S/V is zero for the Δ trajectory. For the $I = \frac{1}{2}$ trajectories it is a constant. The same constant was used for both of the $I = \frac{1}{2}$ and also for both of the helicity amplitudes. The ± signs follow from Eqs. (6). A search was made by varying the residues, x and s_0. The best solution found is shown in Figs. 1 and 2. Comparable solutions were obtained when the N_{α} trajectory was replaced by the nucleon trajectory given in Ref. 7b. The values of the parameters corresponding to our best solution are:

$$N_{\alpha}: \quad A = -3.5 \times 10^{-4}/\mathrm{BeV}^2, \qquad C = 2.53 \times 10^{-3}/\mathrm{BeV}^3$$
$$b = 8.88/\mathrm{BeV}, \qquad d = -22.87/\mathrm{BeV}$$

$$N_{\gamma}: \quad A = 2.02 \times 10^{-2}/\mathrm{BeV}^2, \qquad C = 2.46 \times 10^{-2}/\mathrm{BeV}^2$$
$$b = 0.194/\mathrm{BeV}, \qquad d = -0.332/\mathrm{BeV}$$

$$\Delta: \quad A = -1.41 \times 10^{-3}/\mathrm{BeV}^2, \qquad C = 1.27 \times 10^{-2}/\mathrm{BeV}^3$$
$$b = 7.16/\mathrm{BeV}, \qquad d = 1.982/\mathrm{BeV}$$

with

$$s_0 = 4.4\ \mathrm{BeV}^2, \quad S/V = -0.353, \quad h = 4.405/\mathrm{BeV}^2 \ \text{and} \ x = -0.517,$$

resulting in

$$\alpha_{N_{\gamma}}(w) = -0.517 + 0.19\, w + 0.735\, w^2$$

and a $\chi^2 = 108.5$.

There are several conclusions that can be drawn from this model.

1) The contribution of the N_γ trajectory is essential in the position of the dip. In fact, in the region $-0.5 < u < 0.0\ (\mathrm{BeV/c})^2$ it is almost degenerate to the N_α trajectory. We can check this exchange degeneracy by comparing $pp \to \mathrm{Deuteron}\ \pi^+$ scattering to the crossing symmetric processes $\pi^- p \to \bar{p}\,\mathrm{Deuteron}$. Both of these processes are dominated by the same $I = \frac{1}{2}$ trajectories of the u-channel. For exchange degenerate N_α and N_γ trajectories the interference terms do not contribute and the two cross sections must satisfy[8]

$$\frac{d\sigma}{du}(\pi^- p \to \bar{p} D) = 2\left(\frac{q_s}{q_t}\right)^2 \frac{d\sigma}{du}(pp \to D\pi^+)$$

at high energies. Furthermore, according to this model at the position of the nucleon dip both of the contributing trajectories are of the same signature. We therefore expect π^+ photoproduction to be related to (within known phase space factors) the crossing symmetric process $\bar{p}n \to \pi^- \gamma$ in this region of u.

2) The Δ contribution is sizable and in some places dominant. This is indicated by the numbers in the last two columns of the table. We note that the Δ-contribution is within the upper bounds for $-0.3\ (\mathrm{BeV/c})^2 < u$. In the large u region, where the N_γ has a minimum, this model predicts a dominant Δ-trajectory. It will be of great interest to extend the $\pi^- p \to p\rho^-$ data to the large u-region and check whether or not the Δ contribution of the model drastically violates the upper bounds. A drastic violation of the bounds will imply that simple Regge pole models cannot account for the data and that Regge cuts must be taken into account.

3) The small minimum at 180° is a kinematic effect, coming from

the facts that the diffraction peak is not very steep and three of the s-channel helicity amplitudes go to zero by angular momentum conservation[2].

4) The reaction $\gamma n \rightarrow \pi^- p$ can be predicted in this model and the data will be very useful.

5) Our solutions at 180^o extrapolated to low energies pass through the mean of the differential cross sections.

References

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Table Caption

Comparison of upper bounds for $I = 3/2$ exchanges with the data and calculated cross sections. The second and third columns give the upper bounds for the contribution of the $I = 3/2$ exchanges to the cross sections. Columns four and five give the interpolated π^o and π^+ experimental cross sections. Columns two and five are subject to 10-15% errors. Columns six and seven give the percent contribution of the Δ to the calculated cross sections. Large entries imply large destructive inteference.

Figure Captions

Figure 1 - The fit to π^+ photoproduction. The photon momentum varies somewhat about the indicated average. The theoretical points are calculated using the photon momentum of each point. The data are from Reference 3.

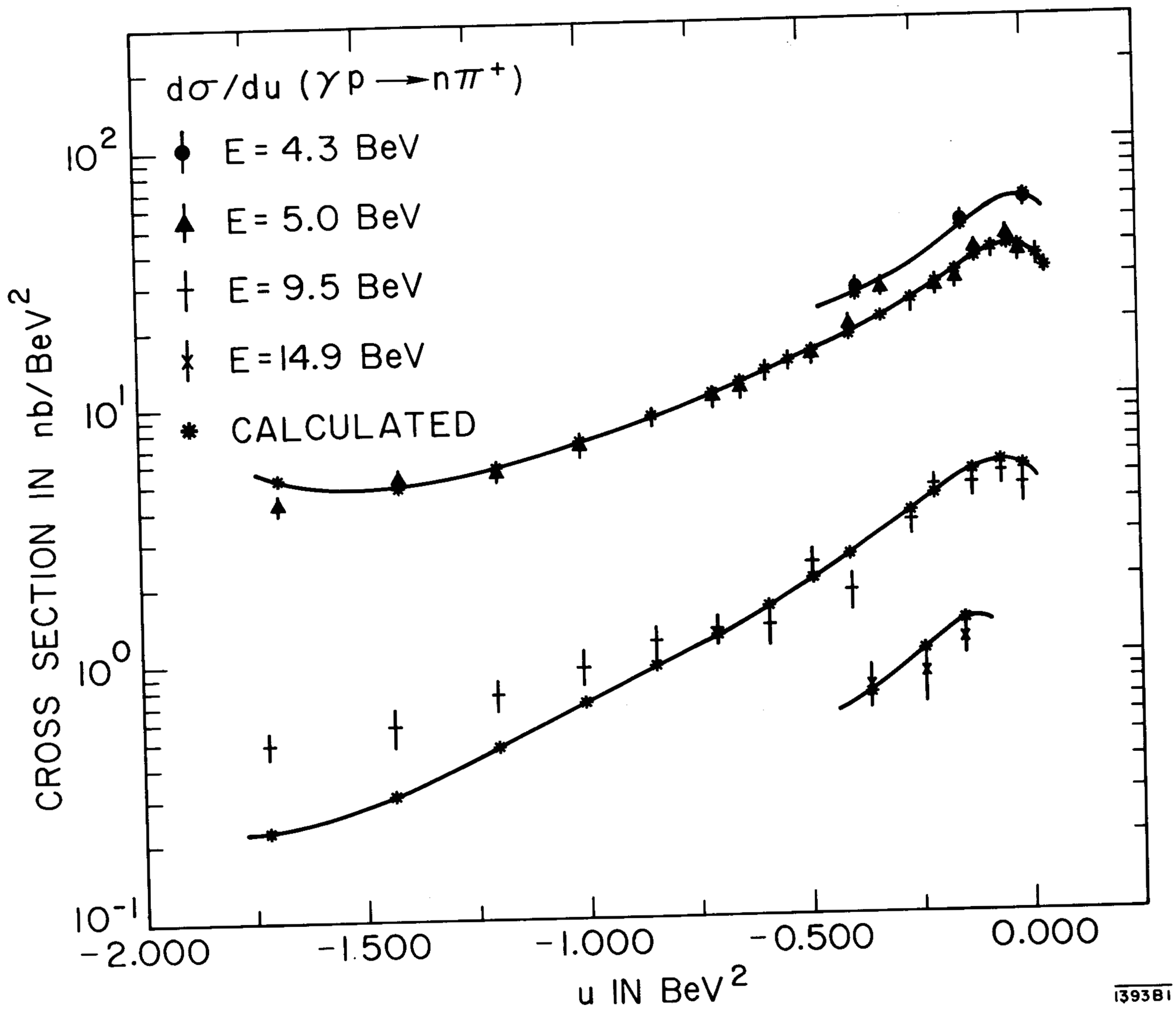
Figure 2 - The fit to π^o photoproduction data of Reference 3.

E = 8 BeV

u BeV^2	Upper Bound for π^o nb/BeV^2	Upper Bound for π^+ nb/BeV^2	$d\sigma/du(\pi^o)$ nb/BeV^2	$d\sigma/du(\pi^+)$ nb/BeV^2	Calculated $\%\Delta$ to π^o	Calculated $\%\Delta$ to π^+
-0.02	5.48	2.74	6.7	5.6	27	12
-0.06	4.56	2.28	6.2	6.3	35	16
-0.13	3.36	1.68	5.0	6.1	55	20
-0.18	2.04	1.02	3.8	5.8	75	23
-0.24	1.40	0.70	2.7	4.5	—	30
-0.32	0.96	0.48	2.2	3.0	104	34

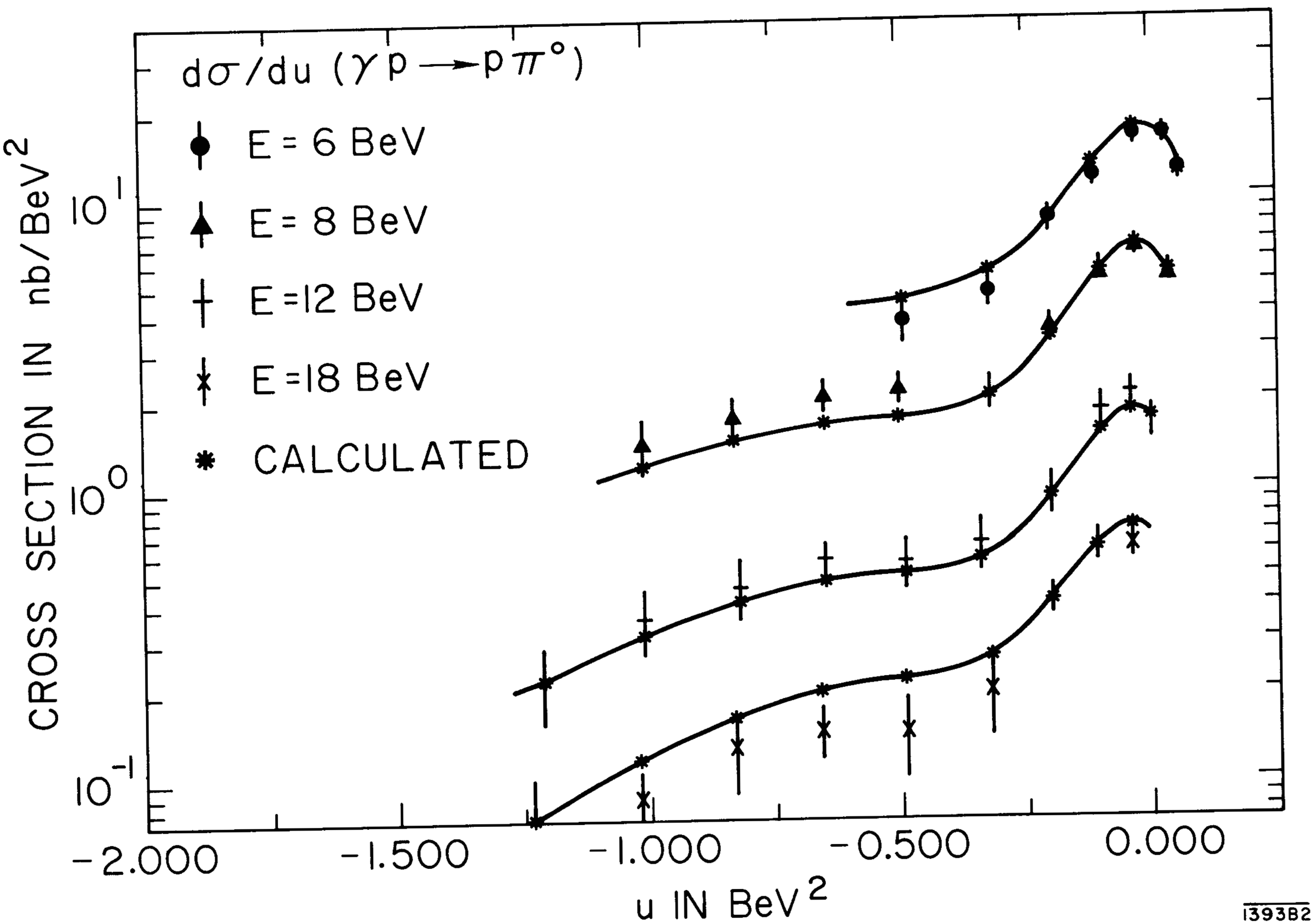
E = 16 BeV

-0.10	0.56	0.28	0.87	—	92	—
-0.14	0.60	0.30	0.79	0.78	—	29
-0.20	0.48	0.24	0.59	—	134	—
-0.26	0.36	0.18	0.40	0.61	—	32
-0.33	0.24	0.12	0.27	0.57	164	36
-0.43	0.16	0.08	0.22	—	150	—
-0.57	0.096	0.048	0.13	—	136	—



dσ/du (γp ⟶ nπ⁺)
E = 4.3 BeV
E = 5.0 BeV
E = 9.5 BeV
E = 14.9 BeV
CALCULATED
CROSS SECTION IN nb/BeV²
10²
10¹
10⁰
10⁻¹
-2.000
-1.500
-1.000
-0.500
0.000
u IN BeV²
1393B1

Fig. 1



dσ/du (γp → pπ°)
E = 6 BeV
E = 8 BeV
E = 12 BeV
E = 18 BeV
CALCULATED
CROSS SECTION IN nb/BeV^2
10^1
10^0
10^{-1}
−2.000
−1.500
−1.000
−0.500
0.000
u IN BeV^2
1393B2

Fig. 2