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INTERFERENCE OF t AND u CHANNEL AMPLITUDES
IN PION NUCLEON SCATTERING

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A B S T R A C T

We propose a Regge model for the full angular distribution in πN scattering. The pronounced dip near $t = -2.8(\text{GeV}/c)^2$ is explained as a t - u channel exchange interference effect.

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A rather remarkable dip is present in both the $\pi^\pm$ -p elastic scattering differential cross-sections near invariant momentum transfer $t = -2.8 (\text{GeV}/c)^2$. This dip is very prominent in the few GeV/c region (pion laboratory momentum), appearing to degenerate into a shoulder at around 10 GeV/c, although the data ¹⁾ are not too plentiful at momentum transfers in this range at higher energies. Recently an experiment ²⁾ has been done scattering 5 GeV/c π^+ mesons from protons and measuring the differential cross-section from 0° to 180° . The main features of the angular distribution shown in Fig. 1 are the strong forward peak, the broad shoulder starting near $t = -0.8(\text{GeV}/c)^2$, the strong dip near $t = -2.8(\text{GeV}/c)^2$, a relatively flat region from $t = -3$ to $-6(\text{GeV}/c)^2$ followed by a dip-peak structure near the backward direction ($u \approx 0$).

We propose the following picture to explain these features. The forward peak and shoulder are taken to be the result of multi-Pomeron exchange ³⁾. The contribution of lower trajectories will be considered in a subsequent paper. The backward peak-dip structure and subsequent flat distribution are the result of u channel baryon exchanges corresponding to the Δ and N_α trajectories. Extreme flatness following the peak-dip structure is obtained here following the work of Halzen et al. ⁴⁾, who obtain a fixed cut ⁵⁾ in baryon exchange amplitudes as the result of removing parity doublets. This model not only fits the near backward data but also gives an excellent extrapolation to the large u region ^{*}). The deep dip near $t = -2.8(\text{GeV}/c)^2$ then results from interference of the t channel and u channel exchange amplitudes added together.

^{*}) The model for the backward amplitude is based on the work of Carlitz and Kisslinger ⁵⁾. Without modification this model faces some difficulties ⁴⁾ with unitarity and extrapolation to particle poles. It is unclear how to extrapolate this model to baryon poles. However, the essential feature for our work is that it gives a good fit to the whole backward scattering region.

We shall study the above features of the scattering cross-section in terms of an s channel non-helicity flip amplitude for the t channel contribution. Our reasons for this are a) recent work on photoproduction of ρ^0 mesons⁶⁾ on hydrogen indicates that diffractive processes are of this character and b) within the framework of the model used here⁴⁾, fits to backward scattering impose this condition on the u channel exchange amplitudes away from the extreme backward direction. Other recent work⁷⁾ indicates that Pomeron exchange may retain this s channel non-helicity flip character even in the resonance region of πN scattering. For the t channel exchange amplitude we form

$$f_F(s,t) = \frac{i}{2k} \sum (2l+1) (1 - e^{2i\delta_l}) P_l(\cos\theta)$$

$$\delta_l = \frac{k}{4\pi} \int A_{pole}(s,t) P_l(\cos\theta) d\Omega$$

where $A_{pole}(s,t)$ is the Regge pole amplitude corresponding to a straight line Pomeron trajectory with non-zero slope³⁾. The s channel helicity non-flip and flip amplitudes are of the form⁸⁾

$$f_{++} = (f_1 + f_2) \cos \theta/2$$

$$f_{+-} = (f_1 - f_2) \sin \theta/2$$

In this model we take $f_1 = f_2 = \frac{1}{2} f_F(s,t)$. For the u channel baryon exchange amplitude we use the amplitude of Ref. 4) which we call $f_B(s,u)$. Note that we use the whole amplitude of Ref. 4) which contains both helicity non-flip and helicity flip amplitudes in the s channel. We have used the same parameters in $f_B(s,u)$ as in Ref. 4). The parameters for $f_F(s,t)$ are almost the same as in Ref. 3). The Regge slope in $A_{pole}(s,t)$ has been moved slightly to $\alpha'_P = 1(\text{GeV}/c)^{-2}$. We can expect improvement in the fit by including lower trajectories. The large slope used here, $\alpha'_P = 1(\text{GeV}/c)^{-2}$, is a feature of the one-effective trajectory approximation to the forward scattering amplitude. It is not clear how the Pomeron slope will come out when lower trajectories are included.

It is clear from estimates we have made that the similar dip observed in $\pi^- p$ scattering at $t \simeq -2.8(\text{GeV}/c)^2$ will be reproduced

by the same type of interfering t and u channel amplitude superposition. In fact we expect such strong dips to appear in many cases where there are strong backward scattering amplitudes. In this connection we note that this phenomenon is known in nuclear physics. The scattering of protons by ^4He at energies of the order of 100 MeV shows a strong dip which has been interpreted as interference between direct and exchange scattering amplitudes ⁹⁾.

It is perhaps of interest to have a qualitative explanation of the phenomenon of t and u channel interference producing a dip, whose position varies very slowly with momentum transfer, $\underline{t}$. The t channel exchange multiple scattering series has been summed approximately ¹⁰⁾ and has a form

$$|f_F(s, t)|^2 \approx \left(\frac{1}{s}\right) e^{-\sqrt{-at \ln s/s_0}}$$

The backward amplitude in its flat region decreases as

$$|f_B(s, u)|^2 \approx \frac{1}{s^4}$$

It follows that if the two amplitudes interfere destructively, the value of $\underline{t}$ at the minimum will move only logarithmically with $\underline{s}$. In fact, as is seen in Fig. 2, the shrinkage of the forward multiple scattering amplitude and that of the u channel background conspire to keep the dip at an almost constant value of $\underline{t}$. That the destructive interference is almost bound to happen follows from the rapid variation in phase of $f_F(s, t)$ as a function of $\underline{t}$ and the very slow variation in phase of $f_B(s, u)$ in the model above.

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FIGURE CAPTIONS

Figure 1 :

Differential cross-section for π^+p elastic scattering at 5(GeV/c). The data shown are from Ref. 2). The solid line is the prediction of our model with the diffraction amplitude taken to be pure s channel helicity non-flip. The dashed line, shown for comparison, is the prediction obtained if the s channel diffraction amplitude is taken to be pure spin non-flip.

Figure 2 :

Predictions of our model for the π^+p differential cross-section at 5, 6, 7.5 and 10 GeV/c. The curves are computed with an s channel non-helicity flip diffraction amplitude and show that the dip at $t = -2.8(\text{GeV/c})^2$ remains approximately stationary in $\underline{t}$ but degenerates into a shoulder by 10(GeV/c).

FIG.1

FIG.2