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Extraction of off-mass-shell $\pi\pi$ and $K\pi$ interactions

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Abstract

Inclusive Δ^{++} production is studied in pp, K^+p, π^+p, and π^-p at 147 GeV/c in terms of a one-meson exchange model. We measure the effective trajectory exchanged at the target p vertex and find it to be consistent with that of a pion up to t = 1 $(GeV/c)^2$ in all four reactions. Using a Chew-Low extrapolation method modified by Durr-Pilkuhn, we extract $\pi^-_E p$, $\pi^-_E K^+$, $\pi^-_E \pi^+$, and $\pi^-_E \pi^-$ cross sections. The ratios of these cross sections are in agreement with that expected from a naive quark model.

Reactions in which Δ^{++} is produced and which are shown to be dominated by one-pion-exchange can be used to extract the interaction of the off-mass-shell pion, π_E, with the beam (see fig. 1). This has been done for some exclusive pp reactions at low energies [1] to measure $\pi_E p$ interaction properties, the results of which have been shown to agree well with that of the on-mass-shell πp interactions. Using the Chew-Low extrapolation method [2] as modified by Durr-Pilkuhn [3], results have been obtained also for $\pi_E \pi$ scattering [4]. In a $K^- p$ experiment [5] and in a $K^+ p$ one [6], both at 8.2 GeV/c, information was obtained about the total $K^- \pi^-_E$ and $K^+ \pi^-_E$ for $(K\pi)$ cm energies up to 1.8 GeV. The average charged multiplicity $\langle n \rangle$ of $\pi_E \pi$ interactions has been extracted at 15 GeV/c [7] and at 100 GeV/c [8] $\langle n \rangle$ was given also for $K_E \pi$ interactions. We have used our measurements at 147 GeV/c [9, 10] to extract the total cross sections of $\pi^-_E p$, $\pi^-_E K^+$, $\pi^-_E \pi^+$, and $\pi^-_E \pi^-$ interactions.

In a recent analysis [10], we have studied the reactions

$$pp \rightarrow \Delta^{++} X^0 \tag{1}$$

$$K^+ p \rightarrow \Delta^{++} X^0 \tag{2}$$

$$\pi^+ p \rightarrow \Delta^{++} X^0 \tag{3}$$

$$\pi^- p \rightarrow \Delta^{++} X^{--} \tag{4}$$

at 147 GeV/c. These reactions come from the exposure of the 30-inch hybrid spectrometer system at Fermilab to a tagged positive and negative beam. The 210,000 pictures analyzed of the positive beam contained 11,513 pp events, 12,561 $\pi^+ p$ events, and 1,701 $K^+ p$ events. The 105,000 pictures taken with a negative beam contained 6,974 $\pi^- p$ events. We have shown [10] that all four reactions (1) - (4) are dominated by one-pion exchange. We have obtained [10] the density

matrix elements for the Δ^{++} decay, which gave results in good agreement with that of a Reggeized π-exchange model with absorption [11]. We have studied the Δ^{++} recoil system using a triple-Regge analysis. We have measured the effective trajectory of the exchange at the $p\Delta^{++}$ vertex and found for all four reactions that it is in good agreement with a pion trajectory [10].

In the present paper we report a study of the four reactions $a\,p \to \Delta^{++}X$, in which we interpret X as being the production of an off-mass-shell $\pi^-_E a$ interaction, where a stands for p, K^+, π^+, and π^- beam particles. We restrict our study of reactions (1) - (4) to those events satisfying the cuts $1.12 < M\,(p\pi^+) < 1.32$ GeV and $|t| < 1\,(\mathrm{GeV}/c)^2$, where t is the four momentum transfer squared between the $(p\pi^+)$ and the target proton. The analysis of reaction (1) is restricted to the backward hemisphere only.

The differential cross section for the process depicted in fig. 1 is, according to the simple OPE model,

$$\frac{d^3\sigma}{dt\,dm\,dM} = \frac{1}{4\pi^3 p^2 s} M^2 Q_t(M)\, \sigma_{\pi^+ p}(M,t) * \frac{1}{(t-\mu^2)^2} m^2 q_t(m)\, \sigma_{\pi^-_E a}(m,t) \qquad (5)$$

where p is the incident momentum in the center-of-mass frame, $\sqrt{s}$ the total energy, and μ the pion mass. Q_t and q_t represent the momentum of the exchanged pion in the $p\pi^+$ and X rest systems, respectively. M and m are the $p\pi^+$ and X effective masses and $\sigma_{p\pi^+}$, $\sigma_{\pi^-_E a}$ are the corresponding off-shell cross sections. We have used the Chew-Low extrapolation method [2] with the modification of Durr-Pilkuhn [3] to extract the physical $\pi^-_E a$ cross sections, $\sigma_{\pi^-_E a}(m)$, from the measured off-shell cross sections, $\sigma_{\pi^-_E a}(m, t)$, where a stands for the incident beam particle. The off-shell $\pi^+ p$ cross sections are related to their on-shell values by

$$Q_t(M)\,\sigma_{p\pi^+}(M,t) \longrightarrow Q(M)\,\sigma_{p\pi^+}(M)\left[\frac{Q_t(M)}{Q(M)}\right]^2 *$$

$$* \left[\frac{(M+m_p)^2 - t}{(M+m_p)^2 - \mu}\right]\left[\frac{1 + R_\Delta^2\, Q^2(M)}{1 + R_\Delta^2\, Q_t^2(M)}\right] \tag{6}$$

where m_p is the proton mass and R_Δ has the value of 4 $(\mathrm{GeV/c})^{-1}$, taken from Wolf [12]. Q(M) is the outgoing momentum in the $p\pi^+$ rest frame. Following Durr-Pilkuhn, we set q_t (m) in (5) equal to q(m), the outgoing momentum in the X rest frame. We also introduced into (5) the weakly t-dependent form factor

$$G^2(t) = \left[\frac{c - \mu^2}{c - t}\right]^2 \tag{7}$$

where c = 2.3 $(\mathrm{GeV/c})^2$, proposed by Wolf [12] in order to obtain a better description of experimental differential cross sections at high t.

There are several different extrapolation methods [6] and therefore the results are somewhat model dependent. However, by using the same procedure on all four reactions (1) - (4), we may study the ratios of the extrapolated cross sections, ratios which are model independent. We use the conventional method in which we evaluate the quantity

$$F(m,t) = \frac{\sigma_{exp}}{\sigma_{OPE}} \tag{8}$$

σ_{exp} is the experimental cross section and σ_{OPE} is the cross section obtained from the form (5) with the modification of (6), setting $\sigma_{\pi_E^- a}$ (m, t) equal to 1 mb. The π^+p cross sections, integrated over the range of M = 1.12 - 1.32 GeV, are taken from Carter et al. [13]. Data were used in the range m = 5-10 GeV. The population of events for some intervals of t and m is affected by the kinematical constraints imposed by a t, m, M boundary surface. Therefore, bins with a population too strongly affected by the Chew-Low cut were not used in the analysis.

Figure 2 shows the experimental points of F(m, t) with a linear fit of the form a + bt. Points below t = 0.2 $(GeV/c)^2$ were not included in the fit due to the strong kinematic Chew-Low cuts. The physical cross sections, obtained by extrapolation to the pion pole, are $\sigma_1 \equiv \sigma_{\pi^- p} = 23.7 \pm 2.5$ mb, $\sigma_2 \equiv \sigma_{\pi_E^- K^+} = 13.4 \pm 2.5$ mb, $\sigma_3 \equiv \sigma_{\pi_E^- \pi^+} = 19.0 \pm 2.5$ mb, and $\sigma_4 \equiv \sigma_{\pi_E^- \pi^-} = 15.0 \pm 2.5$ mb. It is interesting to note that the measured $\pi^- p$ total cross section, which is ~ 27 mb in the energy range of 5-10 GeV, is consistent with our extrapolated value. Nevertheless, the absolute values of the extrapolated cross sections should be regarded with caution since they are model dependent. We will therefore discuss their ratios relative to each other. The measured values $\sigma_1/\sigma_3 = 1.3 \pm 0.2$ and $\sigma_1/\sigma_4 = 1.6 \pm 0.3$ are both consistent with 1.5, which is the value one expects from a naive quark model. Such a model would predict the ratio σ_3/σ_4 to be one, which is not inconsistent with our value of 1.3 ± 0.3. However, since the $\pi_E^- \pi^-$ has exotic quantum numbers, one in fact would expect σ_3 to be somewhat higher than σ_4 at these energies. This phenomena is also the reason why σ_T $(K^- p)$ is higher than σ_T $(K^+ p)$ in the energy range below 10 GeV. The naive quark model would expect σ_3/σ_2 and σ_4/σ_2 to be the same as the ratio between the total πp to total Kp cross section at high energies, which is about 1.2. Our experimental ratios are consistent with that expectation.

In summary, we find that the extrapolated total cross sections $\pi_E^- p$, $\pi_E^- K^+$, $\pi_E^- \pi^+$, and $\pi_E^- \pi^-$ relate to each other in ratios consistent with those expected from a naive quark model.

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Figure Captions

Figure 1 One-pion exchange diagram for the inclusive reaction $a + p \rightarrow \Delta^{++} + X$.

Figure 2 Data used for extrapolation to pion pole to extract (a) $\sigma_{\pi^- p}$, (b) $\sigma_{\pi^- K^+}$, (c) $\sigma_{\pi^- \pi^+}$, and (d) $\sigma_{\pi^- \pi^-}$. The solid lines are linear fits to the form $a + b\,|t|$.

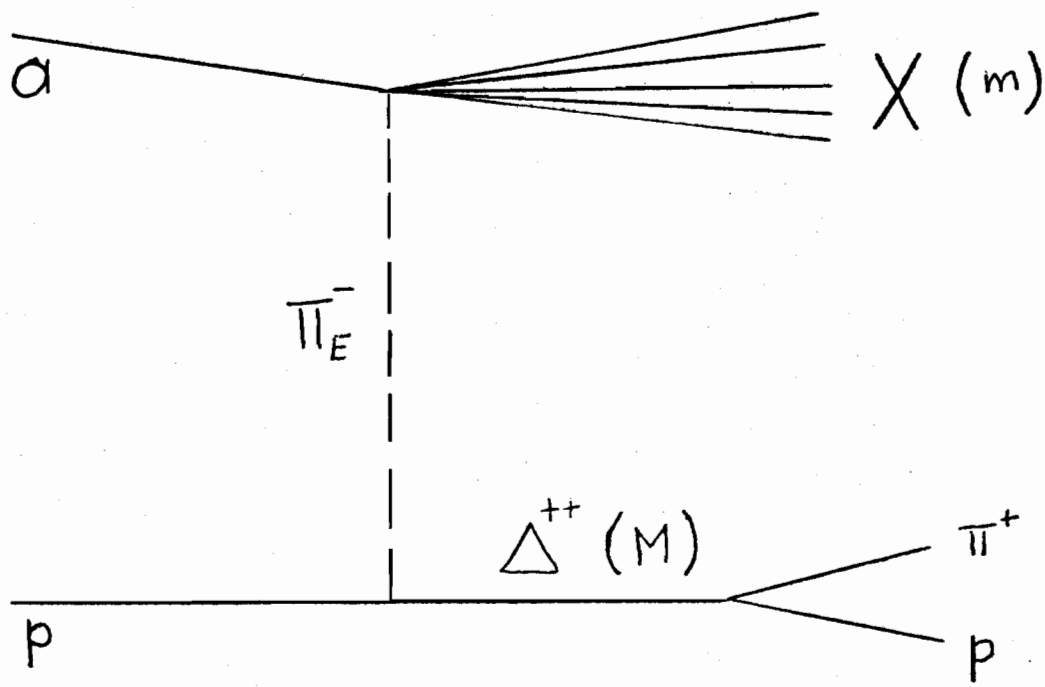

Figure 1

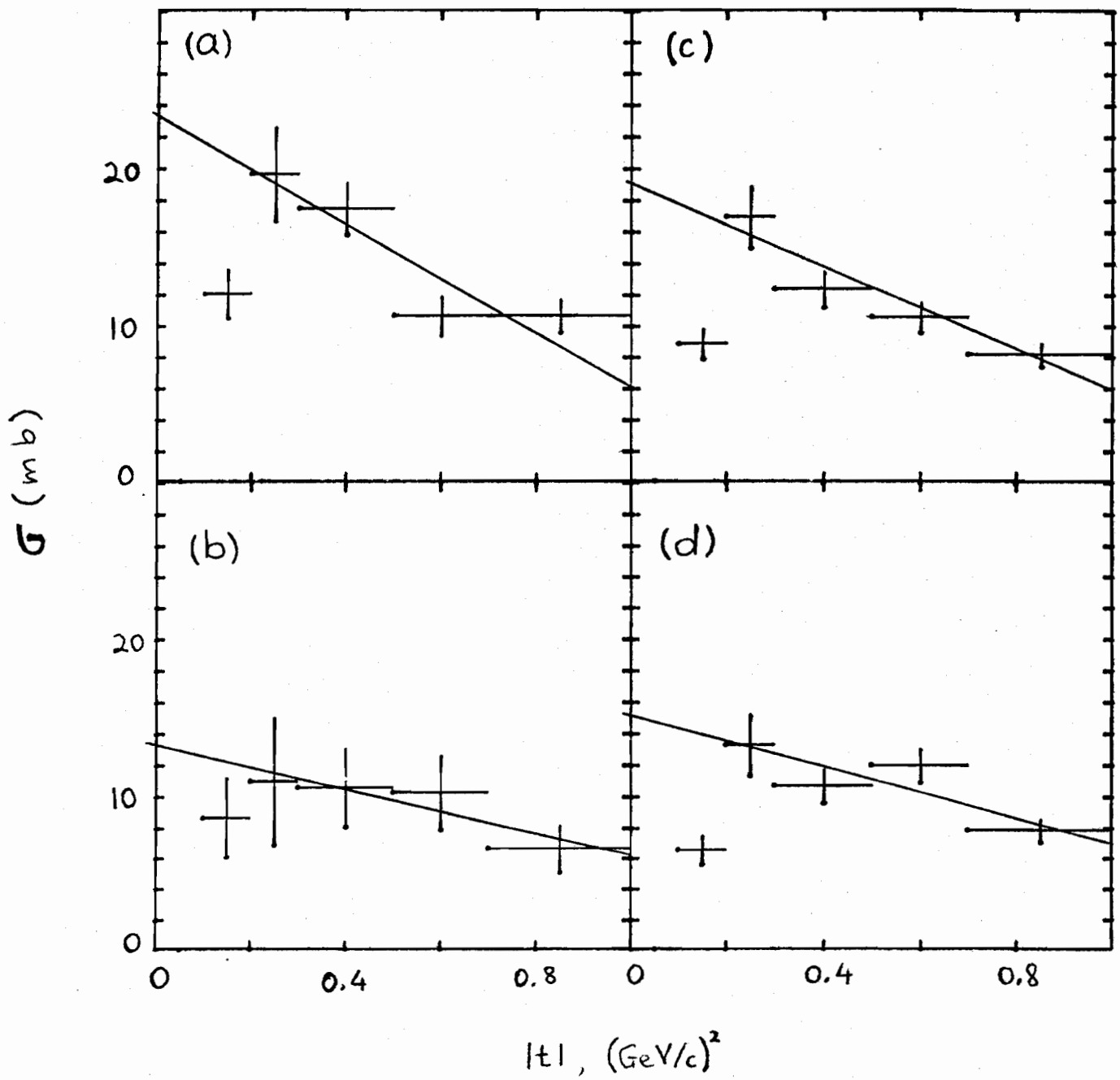

Figure 2