MASTER

Production of K^+K^- and $p\bar{p}$ pairs
in Four-body reactions at 13.1 GeV/c.*

J. A. Gaidos, T. A. Mulera, C. R. Ezell,

J. W. Lamea, R. B. Willmann

Purdue University

West Lafayette, Indiana 47907

Abstract: Data in the channels $\pi^+p \rightarrow \pi^+p K^+K^-$
and $\pi^+p \rightarrow \pi^+p\bar{p}p$ at 13.1 GeV/c are presented;
the $\Delta^{++} K^+K^-$ and $p K^+K^*(890)$ subsamples are
discussed in terms of a double-Regge model. No
resonance structure at $M(p\bar{p}) = 3.755$ GeV is
observed.

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A. Introduction

We have extended an analysis of the four-constraint four-prong π^+p interactions at 13.1 GeV/c to include K^+K^- and $p\bar{p}$ pairs. The data derives from an ~ 9 event/ μb equivalent exposure obtained in the SLAC 82" hydrogen bubble chamber.

The K^+K^- and $p\bar{p}$ candidates were selected from some 70,000 events which were not in the $\pi^+p\pi^+\pi^-$ fitted sample ($\sim 11,000$ events were accepted as $\pi^+p\pi^+\pi^-$ [1]) and for which the unbalance of measured momenta was less than 2 GeV/c. By varying the beam until momentum was conserved, the mass, $M(+)$, in $\pi^+p \rightarrow \pi^+p + \pi^+\pi^-$ was determined from energy conservation; the method was suggested by Enrich et al. [2]. This procedure was complicated in many cases by the inability to uniquely identify π^+ , p , and K^+ components of the three positively charged tracks produced; for these events, permutations of identity were included. The mass spectrum of the assumed particle-antiparticle pairs thus obtained contained large peaks at the K and p mass values. Those combinations for which the $(\text{mass})^2$ determined was greater than the M_{π}^2 were processed in the usual manner by the SQUAW fitting routines with $\pi^+p K^+K^-$ and $\pi^+p p\bar{p}$ hypotheses. Each event with a satisfactory fit was examined on the scanning table to ascertain whether the ionizations were consistent with particle assignments of the fitted hypotheses; only consistent events were accepted; A $P(\chi^2) < .1\%$ cut was also imposed. The initial $M(+)$ distribution of those events finally accepted is shown in fig. 1. Good separation of K^+K^- and $p\bar{p}$ events is evident. This selection yielded 343 $\pi^+p K^+K^-$ and 125 $\pi^+p p\bar{p}$ events, corresponding to cross sections of $39 \pm 8 \mu\text{b}$ and $14 \pm 5 \mu\text{b}$ respectively. The ratios $\pi^+p K^+K^-/\pi^+p\pi^+\pi^-$ and $\pi^+p p\bar{p}/\pi^+p\pi^+\pi^-$ are $\approx 1/30$ and $\approx 1/85$ respectively at 13.1 GeV/c. If we define

$$r(A) = \sigma(\pi^+p \rightarrow \pi^+p\bar{A}A, 8 \text{ GeV/c}) / \sigma(\pi^+p \rightarrow \pi^+p\bar{A}A, 13.1 \text{ GeV/c}), \quad [3]$$

the data yields $r(\pi^+) : r(K^+) : r(p) = 1.6 : 1.8 : 1.1$ which can be compared with $(P_{\text{Lab}} = 8.0 / P_{\text{Lab}} = 13.1)^{-.6} = 1.3$.

B. $\pi^+p K^+K^-$

A Scatterplot of $M(K^+\pi^+)$ vs $M(\pi^+p)$ is given in fig. 2, with a projection on the $M(\pi^+p)$ axis showing a conspicuous Δ^{++} signal of ~ 99 events within the mass band $M(\Delta) = 1.24 \pm 0.1 \text{ GeV}$. Events in the $K^+(890) - \Delta^{++}$ overlap region were taken

as Δ 's, resulting in an improper inclusion of ~ 7 events. The projection on the $M(K^-\pi^+)$ axis is given in fig. 3-a, where the shaded portion corresponds to a removal of Δ^{++} events. There are ~ 106 events in the $K^*(890)$ region defined by $M(K^*) = 0.89 \pm 0.1$ GeV and in addition, there is some indication of a $K^*(1420)$ signal. Removing the $K^*(890)$ points yields the shaded area in the $M(\pi^+p)$ distribution of fig. 2. The marginal enhancement at $M(\pi^+p) \sim 1.6$ GeV is also observed in the $\pi^+p\pi^+\pi^-$ data where again it is more suggestive than indicative. Within the present data, the Δ^{++} decay is described approximately by $(1 + 3 \cos^2 \theta_J)$ where θ_J is the Jackson angle of the proton in the π^+p c.m.s.; the $M(\pi^+p) \sim 1.6$ GeV region is flat in $\cos \theta_J$ and beyond $M(\pi^+p) \sim 1.7$ the events are almost wholly within $\cos \theta_J > .8$.

The $M(K^+K^-)$ spectrum is given in fig. 3-b, where the hatched area indicates removal of $K^*(890)$ events and the double hatched portion shows the $M(K^+K^-)$ distribution produced with the Δ . There is, perhaps, an indication of a shoulder in the ϕ or S^* band and a modest f^0 and/or A_2^0 signal. Selecting on the Δ does not sharpen the f^0/A_2^0 signal, a result evidently different from the 8 GeV data [3]. The $M(K^-\bar{p})$ spectrum suggests no clear resonance formation.

A low mass enhancement is evident in the $M(K^+K^-\pi^+)$ distribution in fig. 4. The hatched area remains after removal of Δ^{++} events and the double-hatched part is left following the further subtraction of $K^*(890)$ events. An explanation of the $M(K^+K)$ threshold enhancement will be given in the following section.

C. K^*Kp

The K^*Kp subsample of the data is characterized by low four-momentum transfers $t(\pi K^*)$, $t(\pi K)$ and $t(pp)$ in addition to a tendency towards low values of $M(K^*K)$; these features are reminiscent of the (ρ, π) behaviour through the A_1 enhancement region and suggest that a similar interpretation in terms of a double-exchange peripheral amplitude may be appropriate [1]. By requiring $-t(\pi K^*)$ and $-t(\pi K) < 2.0$ (GeV/c)² and $-t(pp) < 0.5$ (GeV/c)² a peripheral set of 60 events is obtained which has the t -distributions shown in fig. 5, also pictured is the double-Begge diagram assumed.

The amplitude was taken as

$$A(K^*, Pom) = \frac{i\frac{1}{2}\pi\alpha'_{K^*}(0) e^{-i\frac{1}{2}\pi\alpha_{K^*}}}{\Gamma(\alpha_{K^*} + 1) \cos(\frac{1}{2}\pi\alpha_{K^*})} \left(\frac{S_{KK^*}}{S_0}\right)^{\alpha_{K^*}} e^{4t_{PP}} \left(\frac{S_{K^*P}}{S_0}\right)^{\alpha_{Pom}},$$

with

$\alpha_{K^*} = 1 - \alpha'_{K^*}(0) [M_{K^*}^2 - t_{\pi K}]$ and where the values $\alpha'_{K^*}(0) = 1(\text{GeV}/c)^2$ and $S_0 = 1(\text{GeV})^2$ are used throughout. The Pomernanchuk exchange assumes a constant trajectory, $\alpha_{Pom}=1$ and an exponential residue function determined from elastic scattering. The predictions are normalized to the data and comparisons to the t -spectra and mass distributions are shown in fig. 5 and fig. 6 respectively. Evidently there is no necessity to include a diagram involving K exchange (K^* and K positions interchanged).

Duality arguments would suggest that the observed $M(KK^*)$ threshold enhancement corresponds to the existence of a resonance in the KK^* system at a low mass value; in fact, there is a reported abnormal (spin-parity) state decaying into the KK^* channel with a mass of ~ 1.54 GeV, listed as the $F_1[3]$

D $K^+K^-\Delta^{++}$

A description of the $K^+K^-\Delta$ channel was attempted in terms of the double-exchange diagram given in fig. 7. There are 49 events within the kinematical region defined by $-t_{\pi K^+} < 1.0 (\text{GeV}/c)^2$ and $-t_{p\Delta} < 0.5 (\text{GeV}/c)^2$. The double-Regge amplitude assumed to describe this data is taken as

$$A(K^*, \pi) = \frac{i\frac{1}{2}\pi\alpha'_{K^*}(0) e^{-i\frac{1}{2}\pi\alpha_{K^*}}}{\Gamma(\alpha_{K^*} + 1) \cos(\frac{1}{2}\pi\alpha_{K^*})} \left(\frac{S_{K^+K^-}}{S_0}\right)^{\alpha_{K^*}} \frac{i\frac{1}{2}\pi\alpha'_{\pi}(0) e^{-i\frac{1}{2}\pi\alpha_{\pi}}}{\Gamma(\alpha_{\pi} + 1) \sin(\frac{1}{2}\pi\alpha_{\pi})} \left(\frac{S_{K^-\Delta}}{S_0}\right)^{\alpha_{\pi}}$$

with $\alpha_{\pi} = -\alpha'_{\pi}(0) [M_{\pi}^2 - t_{p\Delta}]$, and $\alpha'_{\pi}(0) = 1(\text{GeV}/c)^{-2}$; the K^* is the same as in section C. The t distributions and mass spectra are given in fig. 7 and fig. 8 respectively along with curves obtained from the amplitude $A(K^*, \pi)$. Within the limited statistics, the data is well described by the double-Regge exchange.

E. $\pi^+ p \bar{p} p$

Both combinations of $M(\pi^+ p)$ are shown in fig. 9-a where Δ production is clearly evident, with approximately 30% of the reaction involving a Δ . The curve in fig. 9-a is the prediction of phase space. There is no suggestion of a resonant state at 3.755 GeV in the $M(p \bar{p} p)$ distribution shown in fig 9-b; the only deviation from phase space is the high mass peaking which reflects Δ formation in $M(\pi^+ p)$. [3] The $M(p \bar{p})$ spectrum is given in fig. 10; the two small enhancements in the low mass range may correspond to production of $N\bar{N}(2190)$ and $\rho(2290)$ respectively [5].

F. Conclusion:

The reaction $\pi^+ p \rightarrow \pi^+ p K^+ K^-$ occurs with a frequency of $\frac{1}{30}$ th of that of the $\pi^+ p \pi^+ \pi^-$ channel and is dominated by $K^*(890)$ and Δ^{++} production, each of which contributes $\approx 30\%$. A double-Regge model involving $K^*/\text{Pomeranchuk}$ exchanges provides a good description of the $p K^+ K^+$ final state and a similar model with K^*/π exchanges gives a good picture of the $\Delta^{++} K^+ K^-$ channel. The $\pi^+ p \rightarrow \pi^+ p \bar{p} p$ reaction is 2.8 times less frequent than the $\pi^+ p K^+ K^-$ state. Formation of Δ^{++} occurs in $\approx 30\%$ of these events, the remainder evidently following phase space. A resonance at $M(p \bar{p} p) = 3.755$ GeV, reported by Ehrlich et al. [2], was not observed.

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- [5] Reviews of Particle Properties, Phys. Letters 33B (1970).

FIGURE CAPTIONS

- Fig. 1. Distribution in $M(+)^2$ for the reaction $\pi^+p \rightarrow \pi^+p \pi^+\pi^-$ at 13.1 GeV/c for events satisfying $M(+)^2 = K^+K^-$ or $p\bar{p}$ acceptance criteria.
- Fig. 2. Scatterplot of $M(K^-\pi^+)$ vs. $M(\pi^+p)$ axis. An event with $|M(\pi^+p)-1.236| < 0.1$ GeV was accepted as a Δ^{++} ; the hatched area corresponds to the removal of $K^*(890)$ points.
- Fig. 3. (a) Distribution in $M(K^-\pi^+)$; the hatched portion remains after Δ^{++} subtraction.
(b) Distribution in $M(K^+K^-)$; removal of $K^*(890)$ events yields the hatched area and selecting on the Δ^{++} gives the cross-hatched spectrum.
- Fig. 4. Distribution in $M(K^+K^-\pi^+)$; removing Δ^{++} events gives the hatched spectrum; further removal of $K^*(890)$ data yields the cross-hatched area.
- Fig. 5. Four-momentum transfer distributions in the process $\pi^+p \rightarrow pK^+K^*(890)$; the curves represent the prediction of the double-exchange diagram shown.
- Fig. 6. Invariant mass distributions in the reaction $\pi^+p \rightarrow pK^+K^*(890)$; the curves are from the double-Regge model.
- Fig. 7. Four-momentum transfer distributions in the process $\pi^+p \rightarrow \Delta^{++} K^+K^-$; the curves represent the predictions of the double-exchange diagram shown.
- Fig. 8. Invariant mass distributions in the reaction $\pi^+p \rightarrow \Delta^{++} K^+K^-$; the curves are from the double-Regge model.
- Fig. 9. (a) Distribution in $M(\pi^+p)$ of the reaction $\pi^+p \rightarrow \pi^+p\bar{p}p$ at 13.1 GeV/c.
(b) Distribution in $M(p\bar{p}p)$ of the reaction $\pi^+p \rightarrow \pi^+p\bar{p}p$ at 13.1 GeV/c.
- Fig. 10. Distribution in $M(p\bar{p})$ of the reaction $\pi^+p \rightarrow \pi^+p\bar{p}p$ at 13.1 GeV/c.

24
5.1
1

1
5.1
1.1

π
 K^*
 K^*
 p

EVENTS / 0.2 $(\text{GeV}/c)^2$

EVENTS / 0.05 $(\text{GeV}/c)^2$