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PHOTOPRODUCTION OF K^+K^- PAIRS ON HYDROGEN AT
PHOTON ENERGIES OF 20 to 36 GeV

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ABSTRACT

The reaction $\gamma p \rightarrow K^+ K^- p$ has been investigated with photons in the energy range of $20 < E_\gamma < 36$ GeV and with $K^+ K^-$ pairs in the mass range of $M_{K^+ K^-} < 2.0$ GeV. The production of the $\phi(1019)$ contributes with a cross section $\sigma(\gamma p \rightarrow \phi p) \times \text{BR}(\phi \rightarrow K^+ K^-) = 240 \pm 6$ nb with an additional systematic error of ± 20 nb. In the higher mass range of $1.05 < M_{K^+ K^-} < 2.0$ GeV the production of $K^+ K^-$ pairs yields a cross section $\sigma(\gamma p \rightarrow K^+ K^- p) = 160 \pm 8$ nb with an additional systematic error of $^{+40}_{-30}$ nb.

1. INTRODUCTION

In this paper results are presented from a measurement of 2525 K^+K^- pairs which were photoproduced in the reaction

$$\gamma p \rightarrow K^+ K^- p \quad (1)$$

by photons in the energy range of $20 < E_\gamma < 36$ GeV. This reaction has been studied previously at lower energies⁽¹⁾ and first results exist from measurements at higher energies⁽²⁾.

The data have been taken in an experiment performed at CERN with the OMEGA Spectrometer using a tagged photon beam generated by bremsstrahlung of 81.5 GeV/c electrons in tungsten. The tagged photons had energies in the range 20 to 70 GeV.

2. EXPERIMENTAL SET UP AND TRIGGER CONDITIONS

The set up of the OMEGA Spectrometer is shown in Fig. 1. A full description of the whole apparatus is given elsewhere⁽³⁾.

The trigger on K^+K^- pairs required a signal from the photon tagging logic and a multiplicity of two charged particles produced in the forward direction. These particles were required to give no light in a Cerenkov counter that had thresholds of 5.9, 19 and 36 GeV/c for pions, kaons and $p/\bar{p}$, respectively. Thus the trigger selected charged kaon pairs with both momenta in the range of $5.9 < |\vec{P}| < 19$ GeV/c, and, in addition, $p\bar{p}$ pairs in the range of $5.9 < |\vec{P}| < 36$ GeV/c.

To suppress e^+e^- pairs a veto on $e^\pm$ showers was required. Such a veto signal was obtained with sufficient efficiency ($> 99.0\%$) by means of detectors located in the horizontal median plane behind the magnet; these were the lead glass blocks in the median plane of the photon detector PD and the two lead scintillation shower counters EV1 and EV2 on both sides of PD⁽⁴⁾. Finally a veto on non-interacting photons and on secondary bremsstrahlung above 3 GeV was required from a shower counter BV in the photon beam line downstream of the detection apparatus^(4,5).

3. DATA SELECTION

From the interaction of $5 \cdot 10^{10}$ photons in the tagging range, incident on $\sim 3 \cdot 10^{24}$ p/cm² of the hydrogen target, a total of $3 \cdot 10^5$ triggers on K^+K^- (and $p\bar{p}$) pairs was recorded corresponding to a trigger cross section of $\sim 2 \mu\text{b}$. The raw data were processed through a program chain consisting of a program for pattern recognition and event reconstruction⁽⁶⁾ and a program for analysing the tagging system and the downstream devices.

By selecting events with two charged particles (total charge zero) and with three charged particles (total charge + 1) originating from a vertex inside the hydrogen target we obtained a sample of 10^5 candidates for reaction (1). In order to remove background from hadronic reactions competing with reaction (1) we accepted from this sample only those events having a) a positive and a negative track without light in the Cerenkov counter where both momenta were in the range of $5.9 < |\vec{P}| < 18$ GeV/c, and b) no signal from the photon detector (set with an energy threshold of 2 GeV). Additionally we required the sum of the energies of charged particles to be at least 20 GeV.

In the remaining sample, comprising about 3000 candidates for reaction (1), all events containing a slow positive particle whose direction was inconsistent with that of a recoil proton corresponding to this reaction were removed.

As the final sample for the analysis, we obtained 1666 events with two charged particles (2-prong events) and 859 events with three charged particles (3-prong events). For 2-prong events the recoil proton does not leave the target or is not reconstructed.

Figs. 2a) and 2b) show for 2-prong and 3-prong events in the ϕ mass region the distribution of the balance in the longitudinal momentum, i.e. the difference between the momentum of the incoming photon and the sum of the outgoing particles due to reaction (1). The expected peak at zero is

observed; however there is, in addition to the spread due to the experimental resolution, a tail towards positive values which indicates mainly multiple bremsstrahlung processes of the primary electron in the radiator target. The shaded distributions correspond to subsamples of events with a high probability for single bremsstrahlung; for these events we required no radiation losses in the area of the tagging system and no signal for double bremsstrahlung in the downstream photon beam veto counter (BV in Fig. 1). The remaining background from inelastic channels, where one or more neutral particles are missing, is small ($\sim 10\%$ for the ϕ mass range and $\sim 20\%$ for the K^+K^- masses above the ϕ mass region). This observation is confirmed by Fig. 2c which shows the missing mass squared distribution for $\gamma p \rightarrow K^+K^-$ (missing mass) calculated from the four-momenta of the K^+K^- pair and the photon.

Since, in the momentum range where charged kaons give no light in the Cerenkov counter, events of the type^{*)}

$$\gamma p \rightarrow \bar{p} p \quad (2)$$

are indistinguishable from K^+K^- , we have a background due to this channel. Fig. 3 shows the 3-prong events distributed as a function of Δ^2 , where

$$\Delta^2 = (P_\gamma - \text{missing } P)^2 = (\sum_{K^+K^-} P - P_{\text{target}})^2.$$

P 's are four-momenta and reaction (1) is assumed. The peaks at $\Delta^2 = \text{zero}$ are due to K^+K^-p events, whereas the peak observed in Fig. 3b at negative Δ^2 is identified with a contamination from reaction (2) in the K^+K^- mass region above that of the ϕ meson. This $\bar{p}p$ peak sits on a shoulder representing the remaining background from inelastic channels. From this plot we estimate the background of $\bar{p}p$ events in our final sample at $17 \pm 5\%$.

*) This reaction was studied in the same experiment for $\bar{p}/p$ momenta in a range from 19 to 36 GeV/c where $\bar{p}/p$ are uniquely identified⁽⁷⁾.

4. EXPERIMENTAL RESULTS

The distribution of the invariant K^+K^- masses is shown in Fig. 4a) and b) together with a curve showing the mass dependent geometrical acceptance of the experimental setup (full line). The acceptance was calculated by simulating events of reaction (1) for various mass values of the K^+K^- system (on the basis of a Monte Carlo method) and tracking the particles through the experimental setup. The input parameters of the simulation were: a photon energy spectrum $\sim 1/E$ and in the range $20 < E_\gamma < 36$ GeV; a production cross section independent of the photon energy with a dependence on the four-momentum transfer squared $t \sim \exp(-5.0|t|)$; s-channel helicity conservation, i.e. the $J^P = 1^-$ decay angular distributions of the K^+K^- system in the s-channel helicity frame, $W(\cos\theta) \sim \sin^2\theta$. These assumptions are supported by previous experiments⁽¹⁾.

The mass spectrum exhibits a clear $\phi(1019)$ signal; the FWHM of this signal, fitted with a Breit-Wigner distribution, is 8.5 ± 2 MeV and compatible with the experimental resolution⁽⁸⁾.

In addition to the ϕ , K^+K^- pairs are produced with masses up to ~ 2.0 GeV (see Fig. 4b). Estimates of background contributions are shown: first, there is the background from $\bar{p}p$ pair production in reaction (2), which was already discussed in section 3; second, there is background from misidentified $\pi^+\pi^-$ pairs produced in the reaction

$$\gamma p \rightarrow \pi^+\pi^- p \quad (3)$$

which contributes at the level of about 5% due to $1.3 \pm 0.4\%$ ^{*)} inefficiency of the Cerenkov counter for pions. A possible background from misidentified e^+e^- pairs (in the 2-prong events) was found to be negligible over the whole mass range.

Distributions of photon energy (E_γ) for reaction (1) are compared with the total bremsstrahlung spectrum in Figs. 5a) and b) showing that the data in the ϕ mass range as well as in the range of higher K^+K^- masses are consistent with energy independent production mechanisms.

*) This number was determined from studying 3.10^4 events of reaction (3) in this experiment.

The $\cos\theta$ distributions of the K^+ polar decay angle θ in the K^+K^- system (s-channel helicity frame) are shown in Figs. 6a) and b). The dashed lines indicate the angular dependence of the geometrical acceptance; the solid lines represent the prediction of $d\sigma/d(\cos\theta) \sim \sin^2\theta$ (folded with the acceptance curve), which is expected for the decay of a $J^P = 1^-$ resonance into a pair of 0^- mesons with conservation of s-channel helicity in the production process.

Both the energy independence of the cross section (Figs. 5a, b) as well as the s-channel helicity conservation (Figs. 6a, b) favour a diffraction-like production of the K^+K^- pairs at the ϕ mass and above.

The distributions of the differential cross section with respect to t (from target p to recoil p) are shown for 3-prong events in Fig. 7, for the ϕ mass range in Fig. 7a and for the K^+K^- mass range above the ϕ in Fig. 7b. These distributions have been fitted in the t range of $0.10 < |t| < 0.60 \text{ GeV}^2$, where the variation of the geometrical acceptance with t is negligible, with an ansatz of the form $d\sigma/d|t| \sim \exp(-b|t|)$, yielding

$$b = 4.9 \pm 0.9 \text{ GeV}^{-2} \text{ for } M_{K^+K^-} < 1.05 \text{ GeV}$$

$$\text{and } b = 4.5 \pm 1.0 \text{ GeV}^{-2} \text{ for } 1.05 < M_{K^+K^-} < 2 \text{ GeV}.$$

The total ϕ production cross section multiplied by the branching ratio for decay into K^+K^- has been determined to be

$$\sigma(\gamma p \rightarrow \phi p) \times \text{BR}(\phi \rightarrow K^+K^-) = 240 \pm 6 \text{ nb}$$

from the sums of the 2- and 3-prong data, averaged over the photon energy range $20 < E_\gamma < 36 \text{ GeV}$. The additional systematic error is estimated to be $\pm 20 \text{ nb}$. The cross section value includes corrections for the background from reactions (2) and (3), and also for some inelastic channels where K^+K^- production is estimated from the events removed by the recoil angle cut (see sect. 3).

The cross section of K^+K^- production above the mass region of the ϕ , integrated over the mass range $1.05 < M_{K^+K^-} < 2.0 \text{ GeV}$ and averaged over the photon energy range of $20 < E_\gamma < 36 \text{ GeV}$, is $\sigma(\gamma p \rightarrow K^+K^- p) = 160 \pm 8 \text{ nb}$. The calculation of this cross section was based on the assumption that the decay angular distributions of the K^+K^- system have at the high masses essentially

the same structure as in the ϕ mass range, as is suggested by the compatibility of the corresponding experimental distributions (see Figs. 5 and 6). If other processes were contributing to the production of high mass K^+K^- pairs, the angular distribution could deviate appreciably from $W(\cos\theta) \sim \sin^2\theta$. For instance, an admixture of 30% of an isotropic angular distribution would increase the calculated cross section by ~ 20 nb. We took this additional uncertainty into account by estimating a total systematic error of $^{+40}_{-30}$ nb.

Figures 8a) and b) show a comparison of the present data with previous measurements of $\sigma(\gamma p \rightarrow \phi p)$, and of the slope parameter b for the ϕ mass range. The agreement with other experiments is seen to be good.

5. CONCLUSIONS

In a study of the reactions $\gamma p \rightarrow K^+K^-p$ with tagged photons in the energy range of $20 < E_\gamma < 36$ GeV we observe the production of the $\phi(1019) \rightarrow K^+K^-$ with a cross section $\sigma(\gamma p \rightarrow \phi p) \times \text{BR}(\phi \rightarrow K^+K^-) = 240 \pm 6$ nb and an additional systematic error of ± 20 nb. The K^+K^- pair production above the ϕ mass range ($1.05 < M_{K^+K^-} < 2.0$ GeV) contributes with a cross section $\sigma(\gamma p \rightarrow K^+K^-p) = 160 \pm 8$ nb with $^{+40}_{-30}$ nb systematic error. Low mass (ϕ region) and high mass data are consistent with a diffraction-like production process.

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FIGURE CAPTIONS

Fig. 1: Layout of the OMEGA Spectrometer for this experiment.

Fig. 2: Balance in longitudinal momentum, and missing mass squared, for $\gamma p \rightarrow K^+ K^- p$ in the ϕ mass range ($1.0 < M_{K^+ K^-} < 1.05$ GeV). The shaded distributions correspond to the events with photons produced by single bremsstrahlung (see text); these numbers are multiplied by a factor 3.

a) Balance $\Delta P_L = P_L(\gamma) - \Sigma_{K^+ K^-} P_L$ for 2-prongs.

b) Balance $\Delta P_L = P_L(\gamma) - \Sigma_{K^+ K^-} P_{out} P_L$ for 3-prongs.

c) (Missing mass)² distribution for $\gamma p \rightarrow K^+ K^- +$ (missing mass).

Fig. 3: Distribution of 3-prong events as a function of

$$\Delta^2 = (\Sigma_{K^+ K^-} P_{out} P - P_{pin})^2$$

where the P's are four-vectors.

a) $M_{K^+ K^-} < 1.05$ GeV

b) $1.05 < M_{K^+ K^-} < 2.0$ GeV

Fig. 4: $K^+ K^-$ mass spectrum of reaction (1).

a) total $K^+ K^-$ mass spectrum ($M_{K^+ K^-} < 2.0$ GeV).

The insert shows the ϕ mass range for a 2 MeV bin width together with a curve obtained in a fit assuming a Gaussian distribution.

b) $K^+ K^-$ mass spectrum for $1.05 < M_{K^+ K^-} < 2.0$ GeV.

These data are the same as in the corresponding mass range of a). The background estimates indicated belong to reactions (2) and (3).

Fig. 5: Distribution of photon energy (E_γ) of the events of reaction (1). The curves show the prediction $W(E_\gamma) \sim 1/E_\gamma$ folded with the geometrical acceptance of the apparatus.

- a) $M_{K^+K^-} < 1.05 \text{ GeV}$
- b) $1.05 < M_{K^+K^-} < 2 \text{ GeV}$

Fig. 6: Distribution of $\cos\theta$, where θ is the K^+ polar angle in the K^+K^- s-channel helicity frame of reaction (1). The solid curves show the prediction $W(\cos\theta) \sim \sin^2\theta$ folded with the geometrical acceptance of the apparatus.

- a) $M_{K^+K^-} < 1.05 \text{ GeV}$
- b) $1.05 < M_{K^+K^-} < 2.0 \text{ GeV}$

Fig. 7: Four-momentum transfer distributions ($t_p \rightarrow p$) for 3-prongs in reaction (1), fully corrected for the losses (including those by geometrical acceptance) in the range $|t| > 0.1 \text{ GeV}^2$. The straight lines correspond to the fit described in the text.

- a) $M_{K^+K^-} < 1.05 \text{ GeV}$
- b) $1.05 < M_{K^+K^-} < 2.0 \text{ GeV}$.

Fig. 8: Comparisons with other experiments;
 $\diamond$ ref. (9), $\blacksquare$ ref. (10), $\triangle$ ref. (11), $\circ$ ref. (12), $\square$ ref. (13),
 ∇ ref. (14), $\bullet$ ref. (2), $\otimes$ ref. (15), $\blacktriangle$ ref. (16),
 and $\times$ this experiment.

- a) The cross section $\sigma(\gamma p \rightarrow \phi p)$ as a function of the photon energy.

The result of this experiment was calculated assuming
 $BR(\phi \rightarrow K^+K^-) = 0.486 \pm 0.012$.

- b) The slope parameter $b(\gamma p \rightarrow \phi p)$ as a function of the photon energy.

FIG. 1

Fig. 2a

Fig. 2b

Fig. 2c

Fig. 3a

Fig. 3b

Fig. 4a

$M_{K^*K^-} [\text{GeV}]$

Fig. 4 b

Fig. 6b

$$\gamma p \rightarrow \phi p$$

Fig. 8a

Fig. 8b