

Kaon pair production in proton-proton collisions at COSY-ANKE

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Abstract. The near-threshold production of kaon-pairs has been investigated in proton-proton collisions at Cooler Synchrotron (COSY) at Forschungszentrum Jülich. In the $pp \rightarrow ppK^+K^-$ reaction, the invariant mass distributions of K^-p , K^-pp , and K^+K^- indicate the presence of both K^-p and K^+K^- final state interactions. Total cross sections for $pp \rightarrow pp\phi$ reaction have been determined at excess energies ε of 18.5, 34.5, and 76 MeV. The differential spectra at an excess energy of 18.5 MeV exhibit a clear s -wave dominance, while the high statistics data at an excess energy of 76 MeV shows that higher partial waves represent the majority of the $pp \rightarrow pp\phi$ total cross section, whose energy dependence would then seem to require some s -wave ϕp enhancement near threshold.

1 Introduction

Extensive measurements of kaon-pair and ϕ -meson production in proton-proton collisions have been performed at COSY facilities. The $pp \rightarrow ppK^+K^-$ reaction has been studied by the COSY-11 and COSY-ANKE collaboration for excess energies ranging from 3 to 108 MeV [1–4]. The study of KN system can provide valuable information about the scattering length of kaon-nucleon interaction, and potentially, about intermediate hyperon states such as $\Lambda(1405)$ [5]. In all the $pp \rightarrow ppK^+K^-$ data the K^-p and K^-pp invariant mass distributions display a strong preference for lower invariant masses, which may reflect an attraction between the K^- and one or both of the protons. The effects can be described by assuming factorized pair-wise final state interactions (FSI) in the K^-pp systems [4]. However, the uncertainty on the effective scattering length for K^-p interaction was very large. High statistics data are required in order to study the K^-p FSI and the interaction between two kaons in detail.

Another prominent feature of the $pp \rightarrow ppK^+K^-$ data is the production of ϕ (1020) meson which shows up as a clear peak in the K^+K^- invariant mass distribution. The near threshold ϕ production could provide a clean way of investigating the production mechanism of the ϕ meson and possible violations of the Okubo-Zweig-Iizuka (OZI) rule [6]. Besides the data collected by DISTO at an excess energy of 83 MeV [7], we have previously measured the $pp \rightarrow pp\phi$ reaction at excess energies of 18.5, 34.5 and 76 MeV at COSY-ANKE [3]. The total cross section for the ϕ production as a function of excess energy can be described by a calculation of three-body phase modified by the effects of pp FSI. The differential cross section at the lowest energy of the ANKE data shows a clear S wave dominance and strong pp final state interaction. While the work of the DISTO collaboration shows the importance of higher partial waves, they did not see any indication of pp FSI in the proton-proton momentum spectrum. The lower statistics ANKE data at the two higher energies were sufficient to

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exact total cross sections but it was hard to draw firm conclusions from the differential spectra. High statistic data are required to understand the ϕ production mechanism.

2 Kaon-pair and ϕ meson production

We present more precise data for the $pp \rightarrow ppK^+K^-$ reaction at a beam energy of $T_p=2.83$ GeV ($\varepsilon = 76$ MeV) obtained using the COSY-ANKE spectrometer. The experimental data were divided into two samples, a ϕ -rich region where $1.01 \text{ GeV}/c^2 < \text{IM}_{K^+K^-} < 1.03 \text{ GeV}/c^2$ and a non- ϕ (the rest) region.

The main feature of the non- ϕ data is the strong distortion of both the K^-p and K^-pp invariant mass distributions. The effects are more explicit if one forms the ratios of the differential cross section in terms of the invariant masses, as shown in Fig. 1. If the K^+p and K^-p final state interactions were identical, then the ratios would be constant and equal to unity. However, both R_{Kp} and R_{Kpp} display a strong preferences for lower invariant masses. The results are well reproduced by a simple factorized ansatz:

$$F = F_{pp}(q_{pp}) \times F_{Kp}(q_{Kp_1}) \times F_{Kp}(q_{Kp_2}) \quad (1)$$

where q_{pp} , q_{Kp_1} and q_{Kp_2} are the magnitudes of the relative momenta in the pp and the two K^-p systems, respectively. The pp FSI was calculated using Jost function [4].

It is surprising that the distortions produced by the constant effective scattering length, $a = (0 + 1.5i)$ fm, used at $\varepsilon_{KK} = 51$ MeV [4] still describes the data well even at an excess energy with respect to the K^+K^- threshold as high as 108 MeV. This parametrization also describes well the ANKE data at different energies and also the COSY-11 results in the vicinity of threshold. However, this simple ansatz underestimates the cross section for low K^+K^- masses, *i.e.*, in the interval between the K^+K^- and $K^0\bar{K}^0$ thresholds at 987.4 and 995.3 MeV/ c^2 . Although the enhancement can be due to K^+K^- final state interactions, a combined analysis of ANKE data suggests that the effect can be understood in terms of an elastic $K + K^-$ rescattering plus a contribution coming from the production of a $K^0\bar{K}^0$ pair followed by a charge-exchange rescattering. The inclusion of these contributions led to a better description of the K^+K^- invariant mass distribution and the energy dependence of the total cross section with respect to the excess energy. High statistics data have been collected at an excess energy of 25 MeV for further investigations. The data are currently under analysis.

Having a good understanding of the background under the ϕ peak, it is possible to extract the invariant mass and angular distributions for the $pp \rightarrow pp\phi$ reaction. A truncated partial wave decomposition of the $pp\phi$ reaction has been proposed to fit the experimental data. The model includes only typical partial waves, where the spin-averaged squared transition matrix element is written as [8]:

$$\begin{aligned} \overline{|M|^2} = & A_{S_s} (\hat{k} \times \hat{K})^2 + A_{P_s} \mathbf{p}^2 + A_{P_p} (\mathbf{q} \cdot \mathbf{p})^2 \\ & + A_{S_p} [3(\mathbf{q} \cdot \hat{K})^2 - \mathbf{q}^2]. \end{aligned} \quad (2)$$

The momenta of the beam proton and the ϕ meson in the overall c.m. system are denoted by \mathbf{K} and \mathbf{q} , respectively, \mathbf{k} represents the momentum of decay kaons in the ϕ reference frame, and \mathbf{p} is the relative momentum in the final pp system. The A_{S_s} and A_{S_p} contributions were multiplied by an enhancement factor calculated by the Jost function which accounts for pp FSI.

Monte Carlo simulations based on GEANT4, which took into account the detector efficiency, resolution and kaon decay probability, have been applied to perform acceptance corrections. The luminosity used for the analysis was determined on the basis of the pp elastic scattering data. The acceptance corrected angular distributions for the $pp \rightarrow pp\phi$ reaction measured in this experiment and that of DISTO are shown in Fig. 2. Systematic uncertainties arise from the background subtraction, tracking efficiency, and the model dependent acceptance corrections. In the near-threshold region where the S final state dominates the ϕ meson spin must lie along the beam direction. The polar angular distribution of the decay kaons in the ϕ meson rest frame should then display a $\sin^2 \theta_\phi^K$ distribution, where θ_ϕ^K is the angle of a daughter kaon from the ϕ decay in the ϕ rest frame. Our measurement shown in Fig. 2a is consistent with DISTO result within the statistical uncertainties, which shows that the higher

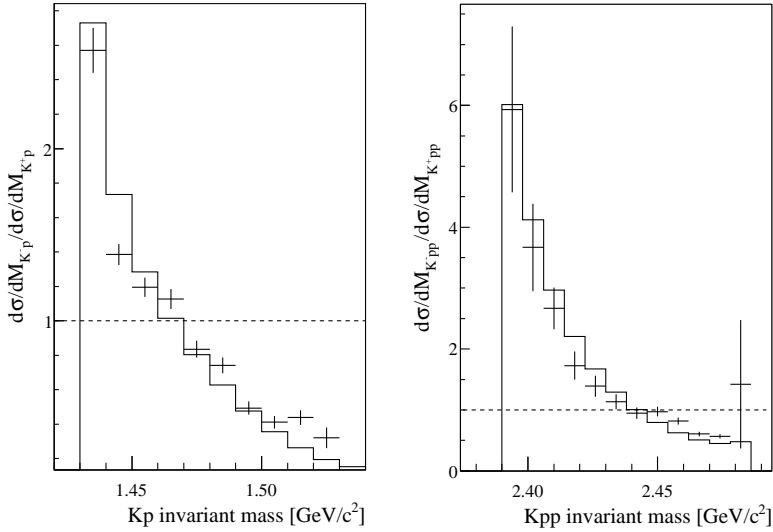


Fig. 1. Ratio of the differential cross section for the $pp \rightarrow ppK^+K^-$ reaction in terms of the K^+p (left) and K^+pp (right) invariant masses. The dashed lines represent the four-body phase-space simulations, whereas the solid ones represent the theoretical calculations taking into account the pp and K^-p final state interactions.

partial waves are important at even relatively modest excess energies. The angular distribution of the ϕ meson in the overall c.m. frame shown in Fig. 2b is symmetric within experimental uncertainties. The angular distribution is expected to be isotropic when the mesonic current is dominant, whereas the nucleonic current leads to a $\cos^2\theta$ distribution. The angular distribution might therefore provide some information on the $NN\phi$ coupling constant [9, 10]. The distribution in the proton polar angle measured in the pp reference frame relative to the beam direction is nearly isotropic, as shown in Fig. 2c. On the other hand, the analogous observable relative to the ϕ direction shown in Fig. 2d has some anisotropy. This feature, which was also seen in the DISTO data [7], is evidence for a contribution from a Pp final wave. The dominance of P waves in the final pp system can explain why the 1S_0 pp FSI, which is so important at $\varepsilon_\phi = 18.5$ MeV [3], is not observed at 76 MeV.

If the coefficients A_{LL} were constant, then they could be used to predict the energy dependence of the total cross section. However, the truncated model underestimates the total cross section at low energies, which might be due to the energy dependence of the fitting parameters. The simplest way out of the total cross section dilemma would be to assume a $\phi - p$ near threshold enhancement. Nevertheless, the phenomenological parametrization is sufficient for acceptance correction and it describes most of the differential distributions quite well.

Although some theoretical models have been able to describe the total cross sections for ϕ production, calculations of differential distributions are rather limited to be compared with our experimental data. Describing total cross sections is insufficient and more theoretical work is therefore required.

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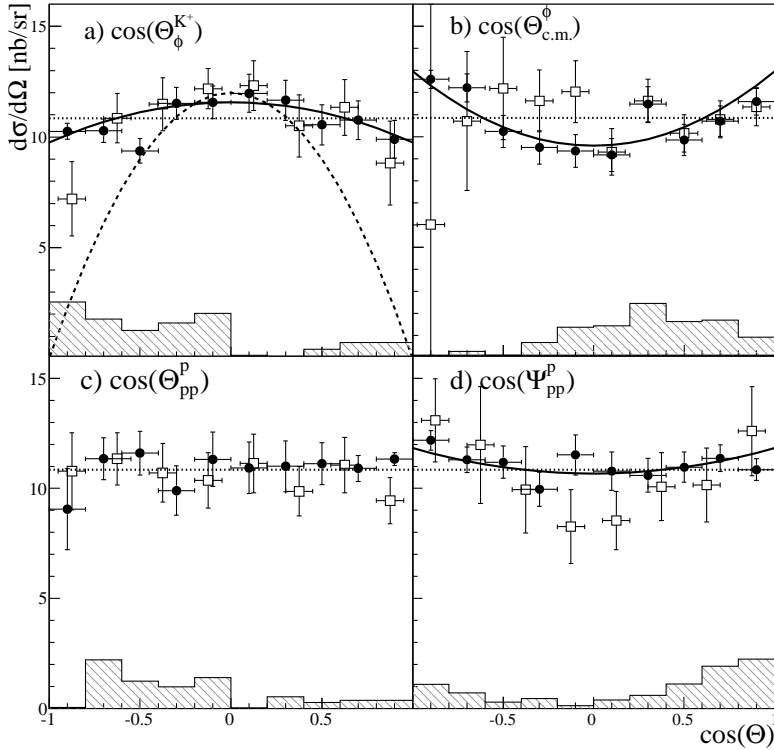


Fig. 2. Angular distributions of the $pp \rightarrow pp\phi$ reaction obtained in this experiment (solid circles), where the systematic uncertainties are shown by the hatched histograms, compared with the scaled DISTO data (open squares) [7]. The dotted curves represent isotropic distributions whereas the solid ones show fits to the ANKE results. (a) The distribution with respect to the cosine of the K^+ polar angle in the ϕ rest frame (Decay angle). The dashed curve demonstrates a $\sin^2 \theta_\phi^K$ behavior. (b) The distribution in the ϕ polar angle in the overall c.m. system. (c) The distribution of the proton polar angle in the pp reference frame relative to the incident proton direction (Jackson angle). (d) The distribution of the proton polar angle in the pp reference frame relative to the ϕ direction (Helicity angle).

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