STUDY OF THE PROCESS $e^+e^- \rightarrow K^+K^-\pi^+\pi^-$ WITH THE CMD-3 DETECTOR AT THE VEPP-2000 e^+e^- COLLIDER

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We report preliminary results on the measurement of the cross section of the process $e^+e^- \rightarrow K^+K^-\pi^+\pi^-$ in the c.m. energy range from 1.5 GeV to 2 GeV. It is shown that the cross section is dominated by the contributions of several intermediate states $K^+K^-\rho$, $K^*K\pi$, $\phi\pi^+\pi^-$ and K^*K^* .

Keywords: Luminosity; e^+e^- colliders; hadrons; detectors.

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1. Introduction

It is well known that precise data on the cross sections of $e^+e^- \rightarrow \text{hadrons}$ are required to evaluate the anomalous magnetic moment (AMM) of muon $a_\mu = (g-2)_\mu/2$. In the case of a_μ^{had} , the VEPP-2000 energy range gives the major contribution ($\sim 92\%$) both to the value of the hadronic vacuum polarization itself and to its uncertainty.¹ Although some processes with kaons in the final state have been measured with BaBar,^{2,3} other channels are not yet studied up to now. To calculate their contribution to AMM, isospin relations are applied. If these relations are broken, it will be crucial for the accuracy of the AMM calculation. Therefore direct measurements are required. Here we report the measurement of the cross section of the process $e^+e^- \rightarrow K^+K^-\pi^+\pi^-$ based on 22 pb^{-1} of data collected with the CMD-3 detector⁴ at the VEPP-2000 collider⁵ in the c.m. energy range from 1.5 to 2.0 GeV.

2. Energy scan and Luminosity determination

The c.m. energy range from 1 to 2 GeV was scanned up and down with a step of 50 MeV. At each energy an integrated luminosity of about 500 nb^{-1} was collected. The energy points were shifted by 25 MeV in the “up” and “down” scans. The beam energy was monitored with accuracy of 0.5 MeV by NMR measurements of the magnetic field in dipole magnets. The average trigger counting rate was 200–400 Hz and strongly depended on the beam optics tuning.

The accuracy of the luminosity measurement is one of the key ingredients in a study of the hadronic cross sections. Sometimes a systematic uncertainty of the luminosity determination is one of the largest sources of uncertainty and can cause significant reduction of the measurement accuracy. Therefore it is very important to use several well-known QED processes $e^+e^- \rightarrow e^+e^-$, $\mu^+\mu^-$, $\gamma\gamma$ to determine the luminosity. Their combined treatment helps to understand and estimate the real accuracy of the luminosity measurement better.

Information about the energy deposition in the CMD-3 calorimeters with a requirement of back-to-back clusters in the barrel and tracks in the drift chamber (DC) was used to separate Bhabha and $\gamma\gamma$ events. The process $e^+e^- \rightarrow \gamma\gamma$ has essential advantages for luminosity determination^{6,7} with respect to the Bhabha scattering. It is free of difficulties related to radiation of the final state particles and their Coulomb interaction. It is also important that corresponding Feynman graphs do not contain photon propagators affected by the vacuum polarization effects. These reasons are the main motivation to explore this process as an independent tool for luminosity measurement. Currently we estimate the accuracy of luminosity determination as $\sim 1\%$.⁸

3. Selection of $e^+e^- \rightarrow K^+K^-\pi^+\pi^-$ events

Candidates for the process under study are required to have 3 or 4 tracks in DC coming from the interaction region. Reconstructed momenta and angles of these

Fig. 1. Scatter plot of the difference between the total energy and c.m. energy (ΔE_4) versus the total momentum for four-track events. The upper cluster of dots represent $\pi^+\pi^-\pi^+\pi^-$ while the lower one $K^+K^-\pi^+\pi^-$ events.

Fig. 2. Pion and kaon ionization losses in DC vs particle momentum.

particles were used for further selection. First, energy-momentum conservation is used to select $K^+K^-\pi^+\pi^-$ candidates. For these events the total energy is calculated assuming that all tracks belong to pions:

$$E_{\text{tot}} = \sum_{i=1}^4 \sqrt{p_i^2 + m_\pi^2}, \quad P_{\text{tot}} = \left| \sum_{i=1}^4 \vec{p}_i \right|.$$

Figure 1 shows a scatter plot of the difference between the total energy and c.m. energy $\Delta E_4 = E_{\text{tot}} - E_{\text{c.m.}}$ vs the total momentum for such candidates. A clear signal of four-pion events is seen as a cluster of dots near zero on the vertical axis. The second cluster of dots with a zero total momentum, seen shifted down the vertical axis, is a domain of signal events.

Further particle identification is based on the analysis of the likelihood function using information about ionization losses (dE/dx) in DC. The probability density functions (PDF) are built with the following parameters: momentum and dE/dx for kaons $f_K(p, dE/dx)$ and pions $f_\pi(p, dE/dx)$. The ionization losses versus particle momentum are plotted in Fig. 2. The example of PDF is shown in Fig. 3 as a smooth curve for momenta 400 - 450 MeV/c. The PDF is the sum of the normal and logarithmic Gaussian functions with the relative weights which depend on momentum.

The likelihood function ($L_{KK\pi\pi}$) for the four-track events is defined as:

$$L_{KK\pi\pi} = \text{Log} \left(\frac{\prod f_\alpha^i(p, dE/dx)}{\prod [f_\pi^i(p, dE/dx) + f_K^i(p, dE/dx)]} \right),$$

where i - track index, α - type of the particle. The most probable combination of particle types is achieved when this function has a maximum. The values of $L_{KK\pi\pi}$ for experimental data are shown in Fig. 4. The open histogram corresponds to all four-track events. The hatched histogram corresponds to $\pi^+\pi^-\pi^+\pi^-$ events, the shaded one corresponds to $K^+K^-\pi^+\pi^-$ events. The condition for the $L_{KK\pi\pi}$ value larger than -2 was chosen as an optimal compromise, which allows to suppress background by a factor of 20 and pertaining more than 99% of useful events.

Fig. 3. PDF represents pion and kaon ionization losses in DC for the momentum interval from 400 to 450 MeV/c.

Fig. 4. Distribution of the likelihood function ($L_{KK\pi\pi}$) for the four-track events. The open histogram corresponds to all four-track events, the hatched one - $\pi^+\pi^-\pi^+\pi^-$ events and the shaded one - $K^+K^-\pi^+\pi^-$ events.

Energy deficit should be correlated with the total (missing) momentum for the candidates of the data sample with three-track events. The track losses are caused by the DC reconstruction inefficiency and limited DC acceptance. Using the total momentum of three-track candidates, the energy of a missing particle is calculated and added to the energy of three detected particles. The difference between the obtained energy ΔE_{3+1} and c.m. energy is shown in Fig. 5.

A signal due to events under study is clearly seen. To obtain the number of $K^+K^-\pi^+\pi^-$ events from a three-track sample, the histogram was fitted with a sum of the two Gaussian distributions for a signal peak and a quadratic polynomial for background. A variation of the polynomial fit parameters for the experimental and MC simulated background leads to about 3% uncertainty in the number of signal events. As a result, we find ~ 13300 four-track events and ~ 16000 three-track events from all scans. To obtain a detection efficiency, the $K^+K^-\pi^+\pi^-$ events were simulated with a primary generator, passed through the CMD-3 detector using the GEANT4 package and then reconstructed with the same software as experimental data. A few production mechanisms with the $K^+K^-\rho$, $K^*K\pi$, $\phi\pi^+\pi^-$ and K^*K^* intermediate states were considered, sufficient to describe angular and invariant

Fig. 5. The histogram of the difference between the calculated energy of the four particles, when one is lost, ΔE_{3+1} and c.m. energy.

Fig. 6. The $e^+e^- \rightarrow K^+K^-\pi^+\pi^-$ cross section measured with the CMD-3 detector (dots). The BaBar results are shown by open circles. The vertical line shows the $p\bar{p}$ threshold.

mass distributions of the experimental data. A phase space model was also considered and excluded from further consideration because it contradicted all studied distributions.

4. Cross section calculation and Summary

At each energy point the cross section is calculated as

$$\sigma = \frac{N_{4\text{tr}} + N_{3\text{tr}}}{L \cdot \epsilon \cdot (1 + \delta)},$$

where L is the integrated luminosity, ϵ is the detection efficiency, and $(1 + \delta)$ is the radiative correction calculated according to Ref. 9, 10. The cross section as a function of energy is presented in Fig. 6. The peak value ~ 4.5 nb is observed at ~ 1.85 GeV, some structure near $p\bar{p}$ threshold is possible. Systematic errors are under study and are currently estimated as 7%. The obtained cross section agrees with the previous measurement performed by the BaBar Collaboration³ presented by open circles.

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