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Study of the processes $e^+e^- \rightarrow K^+K^-\pi^+\pi^-$, $\phi\eta$ with the CMD-3 detector at the e^+e^- collider VEPP-2000

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Abstract. We report preliminary results on the measurement of the cross sections of the processes $e^+e^- \rightarrow K^+K^-\pi^+\pi^-$ and $e^+e^- \rightarrow \phi\eta$ in the c.m.energy range from 1.5 GeV to 2 GeV with the CMD-3 detector. The cross sections of these processes agree with BaBar results and have better accuracy.

1 Introduction

It is known that the accuracy of the calculations of the hadronic contribution to the anomalous magnetic moment of the muon is driven in part by the process $e^+e^- \rightarrow$ *hadrons* with kaons in the final state. Studies of the hadronic cross sections allow us to determine parameters of light vector mesons and their excitations.

The process $e^+e^- \rightarrow K^+K^-\pi^+\pi^-$ has been studied at DM1 [1], DM2 [2] and with much larger effective integrated luminosity at the BaBar by ISR [3, 4]. Study of production dynamics with BaBar exhibited complex resonant substructures ($K^+K^-\rho$, $K^*K\pi$, $\phi\pi^+\pi^-$, K_1K etc.). Part of such intermediate states were studied by the Babar collaboration, but with CMD-3 [5] it is possible to make a more detailed analysis of this dynamics.

BABAR measured the $e^+e^- \rightarrow K^+K^-\eta$ cross section in the c.m. energy range from 1.56 to 3.48 GeV in the $\eta \rightarrow \gamma\gamma$ decay channel [6], and (with lower accuracy) in the energy range from 1.56

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to 2.64 GeV in the $\eta \to \pi^+\pi^-\pi^0$ decay channel [7]. They also found that the major intermediate mechanism in this process is $\phi\eta$, and the $NON - \phi$ cross section part amounts to about 3 – 15 percent. The collected statistics were not enough to analyse the intermediate states in the $NON - \phi$ part.

The results on the $e^+e^- \to K^+K^-\pi^+\pi^-$ and $e^+e^- \to \phi\eta$ cross sections presented here are based on 22 pb^{-1} of data collected with the CMD-3 detector at the VEPP-2000 collider [8] in the c.m. energy range from 1.5 to 2.0 GeV. The luminosity is measured using events of Bhabha scattering at large angles [9].

2 Cross section measurement of the process $e^+e^- \to K^+K^-\pi^+\pi^-$

Candidates for the process under study are required to have three or four tracks in the Drift Chamber coming from the interaction region. Momentum of charged particle $\vec{p}_i$ is determined from the track curvature and angles reconstructed in DC. As one can see in Fig. 1, the ionization losses of pions and kaons in the Drift Chamber are significantly different. This difference is used for K/π-separation.

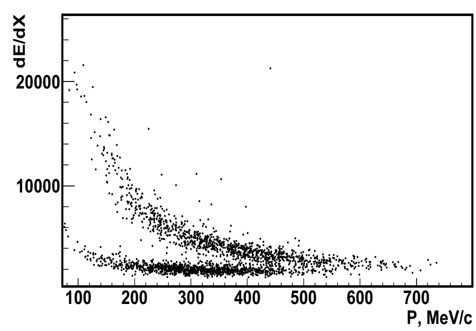

Figure 1. Pion and kaon ionization losses in DC vs particle momentum.

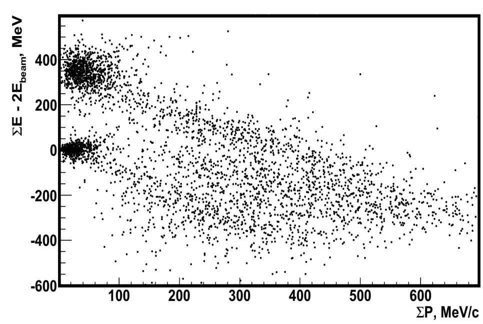

Figure 2. Scatter plot of the difference between the total energy and c.m. energy (ΔE_4) versus the total momentum for four-track events. The upper cluster of dots represents $\pi^+\pi^-\pi^+\pi^-$ while the lower one - $K^+K^-\pi^+\pi^-$ events.

The total energy E_{tot} and total momentum P_{tot} could be used for selection of four-track $e^+e^- \to K^+K^-\pi^+\pi^-$ events. They are defined as:

$$E_{tot} = \sum_{i=1}^{4} \sqrt{p_i^2 + m_i^2}, \qquad P_{tot} = |\sum_{i=1}^{4} \vec{p}_i|.$$

Figure 2 shows a scatter plot of the difference between the measured total energy and c.m. energy $\Delta E_4 = E_{tot} - E_{c.m.}$ vs the total momentum for events with four tracks. The signal events locate near zero in the vertical axis and near zero in the horisontal axis. Another cluster of events with a zero total momentum but shifted up the vertical axis, corresponds to $\pi^+\pi^-\pi^+\pi^-$ events. The conditions on ΔE_4 and P_{tot} for the signal events were chosen as:

$$-100\,\mathrm{MeV} < \Delta \mathrm{E}_4 < 100\,\mathrm{MeV}, \quad \mathrm{P_{tot}} < 100\,\mathrm{MeV}/c.$$

Energy deficit should correlate with the total (missing) momentum for the three-track candidates. The track loss can be caused by the DC reconstruction inefficiency or limited DC acceptance. Using the total momentum of three-track candidates, the energy of a missing particle was 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. 3. Signal events are clearly seen near zero. To obtain the number of $K^+K^-\pi^+\pi^-$ events from a three-track sample, the histogram was fitted with a sum of two Gaussian distributions for a signal peak and a quadratic polynomial for background in the range from −200 MeV to 200 MeV. Variation of fitting functions for the peak and background leads to about 3% uncertainty in the number of signal events.

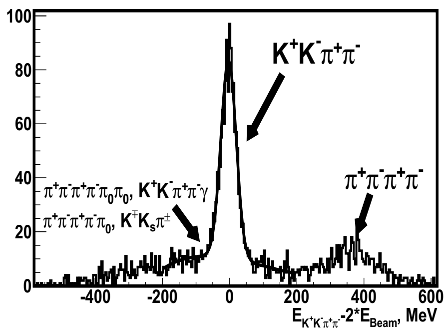

Figure 3. The histogram of the difference between the calculated energy of the four particles ΔE_{3+1} and c.m. energy.

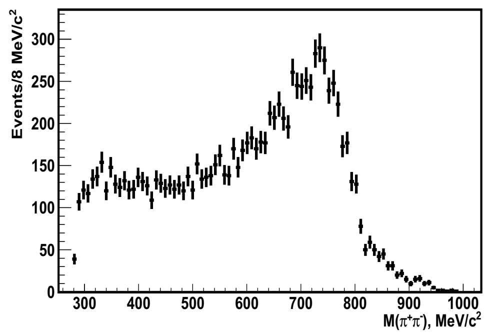

Figure 4. The $\pi^+\pi^-$ invariant mass.

To obtain a detection efficiency, the $K^+K^-\pi^+\pi^-$ events were simulated with a primary generator using the GEANT4 package and then reconstructed with the same software as experimental data. The $\pi^+\pi^-$ invariant mass, $K^\pm\pi^\mp$ invariant mass, and the K^+K^- invariant mass for the selected events are shown in Fig. 4, Fig. 5 and Fig. 6, respectively. Presence of ρ in the $\pi^+\pi^-$ combination, K^* in $K^\pm\pi^\mp$ and ϕ in K^+K^- is seen. Production mechanisms with the $K^+K^-\rho$, $K_1K \to K^*\pi K$, $\phi\pi^+\pi^-$ and K^*K^* interfering intermediate states are used for the primary generator to describe angular and invariant mass distributions of the experimental data. The total detection efficiency takes into account the contributions of different intermediate states based on the approximation of the experimental angular and momentum distributions. A phase space model was also considered and excluded from further consideration because it contradicted to all studied distributions.

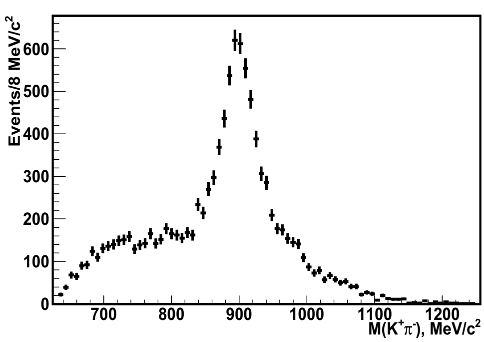

Figure 5. The $K^\pm\pi^\mp$ invariant mass.

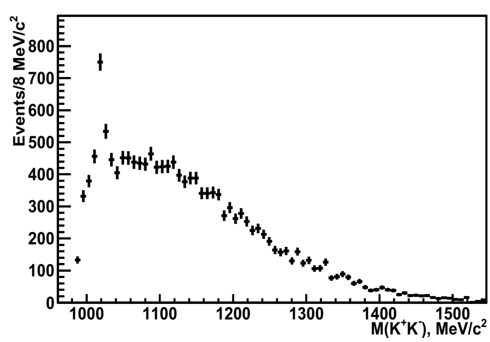

Figure 6. The K^+K^- invariant mass.

At each energy point the cross section is calculated as

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

where L is the integrated luminosity, ϵ is the detection efficiency, and $(1+\delta)$ is the radiative correction calculated according to [10, 11]. The detection efficiency is about 50-60 % and is basically determined by detector acceptance. The radiative correction smoothly increases from 0.8 to 0.98 in the studied energy range. The cross section as a function of energy is presented in Fig. 7. The cross section maximum value is ~ 4.5 nb. Systematic errors are under study and are currently estimated as 7%. The main uncertainty is due to model dependence of the detection efficiency. The obtained cross section agrees with the previous measurement by the BaBar Collaboration [4] presented by open circles.

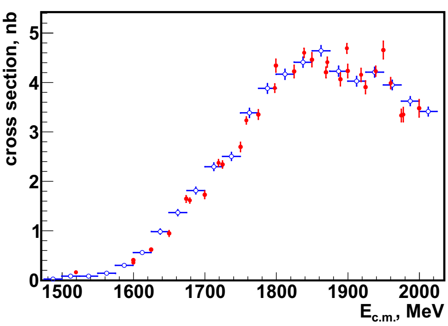

Figure 7. Dots show the ee $e^+e^- \rightarrow K^+K^-\pi^+\pi^-$ cross section measured with the CMD-3 detector. The BaBar results are shown by open circles.

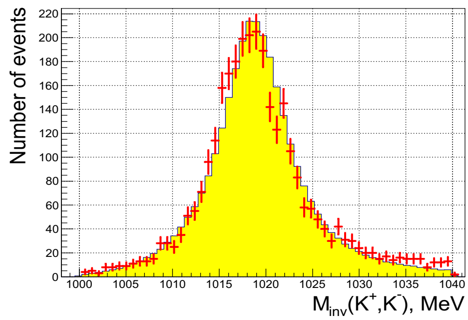

Figure 8. Distribution of the invariant mass of two kaons.The hatched histogram corresponds to MC and dots correspond to data. The number of events in the MC-histogram is normalized to the number of events in the experimental one.

3 Measurement of the Cross section for the process $e^+e^- \rightarrow \phi\eta$

To select candidates for two kaons from ϕ decay, we apply the following set of selection criteria to all pairs of charged particles in the DC (the optimal values of cuts are determined using MC of signal and background processes): 1) Total charge of the pair should be zero; 2) Both tracks have a minimal distance ρ to the beams axis of less than 0.5 cm; 3) The distances of tracks from the beam interaction point along the z-axis $|z_{1,2}|$ is less than 12 cm; 4) The absolute difference of the distances of tracks from the beam interaction point along the z-axis $|z_1 - z_2|$ is less than 4 cm; 5) Particles passed more than a 19 cm of the DC in the transverse direction: $r_\perp > 19$ cm; 6) The energy losses dE/dx are typical for the charged kaons with corresponding momenta; 7) The invariant mass of particles, if they are kaons, should come from ϕ decay: $M_{\text{inv}} \in (1000\,\text{MeV}; 1040\,\text{MeV})$; 8) Angle between kaons and their momenta are inside certain limits taken from simulation for ϕ decay at a given energy.

If a pair of charged particles satisfies the above conditions, we consider them to be kaons from ϕ decay and calculate the parameter $E_{\text{total}} - 2E_{\text{beam}}$:

$$E_{\text{total}} - 2E_{\text{beam}} = \sqrt{\vec{p}^{\,2}_{K^+} + m_K^2} + \sqrt{\vec{p}^{\,2}_{K^-} + m_K^2} + \sqrt{(-\vec{p}_{K^+} - \vec{p}_{K^-})^2 + m_\eta^2} - 2\cdot E_{\text{beam}},$$

which represents the total energy of the final particles minus twice beam energy assuming that the missing particle is an η-meson. The distribution of this parameter has a peak around zero for any energy point and is used for determining the number of selected signal events N_{exp}.

The invariant mass distributions $M_{\text{inv}}(K^+, K^-)$ for experimental and simulated events are presented in Fig. 8. Figure 9 shows the experimental distribution of the missing mass of two kaons together with an indication of background processes.

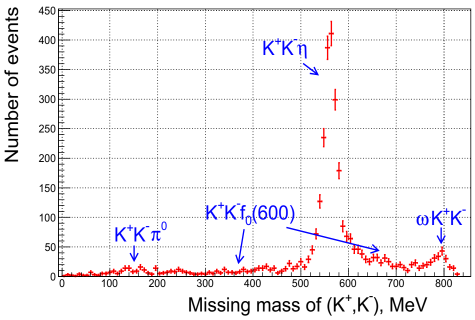

Figure 9. Distribution of the missing mass of the K^+-K^- pair for experimental data. The events of signal and $K^+K^-\pi^0$, $\phi f_0(600)$, $K^+K^-\omega$ background processes are seen.

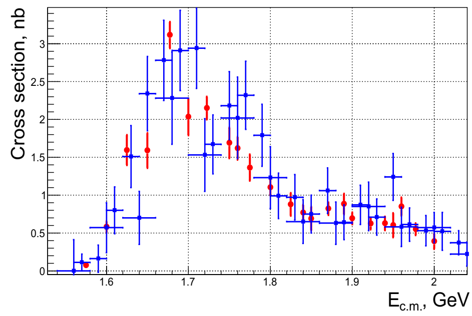

Figure 10. Circles show the $e^+e^- \to \phi\eta$cross section measured with the CMD-3 detector. The BaBar results are shown by squares.

The cross section of the process $e^+e^- \to \phi\eta$ at the c.m. energy $E_{\text{c.m.}}$ is given by the expression:

$$\sigma_{e^+e^-\to\phi\eta} = \frac{N_{\text{exp}}\cdot Corr}{L\cdot\varepsilon\cdot(1+\delta_{\text{rad}})\cdot\mathcal{B}(\phi\to K^+K^-)},$$

where L - the collected luminosity at the fixed energy point, N_{exp} - the number of signal events determined at this energy point, ε - the efficiency, $Corr$ - the correction to the efficiency of detecting charged particles taken from MC. The determined cross section is presented in Fig. 10 along with the BABAR data.

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References

[1] A. Cordier *et al.*, Phys. Lett. B **110**, 335 (1982).
[2] D. Bisello *et al.*, Nucl.Phys.Proc.Suppl. **21**, 111 (1991).
M.R. Whalley, J. Phys. G **29**, A1 (2003).
[3] B. Aubert *et al.*, Phys. Rev. D **77**, 092002 (2008).
[4] J.P. Lees *et al.*, Phys. Rev. D **86**, 012008 (2012).
[5] B.I. Khazin *et al.*, Nucl. Phys. B (Proc. Suppl.) **181-182**, 376 (2008).
[6] B. Aubert *et al.*, Physical Review D **77**, (2008).
[7] B. Aubert *et al.*, Physical Review D **76**, (2007).
[8] D.E. Berkaev *et al.*, JETP **113**, 213 (2011).
[9] R.R. Akhmetshin *et al.*, Nucl. Phys. B (Proc. Suppl.) **225-227**, 69 (2012).
[10] E.A. Kuraev and V.S. Fadin, Sov. J. Nucl. Phys. **41**, 466 (1985).
[11] S. Actis *et al.*, Eur. Phys. J. C **66**, 585 (2010).