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Results from the e^+e^- colliders in Novosibirsk

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Abstract. Two e^+e^- colliders, VEPP-4M and VEPP2000, are taking data at the Budker INP in Novosibirsk, Russia. KEDR detector at the VEPP-4M collider continues deliver precision measurements of the charmonium family. Results of the $\psi(2S)$ and $\psi(3770)$ study are presented. Two energy scans of a center-of-mass energy range from 1 GeV to 2 GeV has been performed by the VEPP2000 collider with an integrated luminosity of about 35 pb^{-1}, collected by each of the CMD-3 and SND detectors. This paper reports the latest results from VEPP-2000 obtained by the CMD-3 collaboration.

1 Introduction

Production of the hadrons in the low energy e^+e^- collisions remains an interesting experimental area due to its important contribution to the Standard Model (SM) calculations of the muon anomalous magnetic moment and $\alpha(s)$ [1], and application to the hadron spectroscopy.

The VEPP-4M e^+e^- collider [2] with unique feature of precise energy measurement, continues study the ψ family with KEDR [3] detector. In latest publications [4], also presented in this Proceedings [5], KEDR Collaboration presents precision measurements of the electron width and mass of $\psi(2S)$ and parameters of $\psi(3770)$.

The e^+e^- collider of the next generation, VEPP-2000 [6], has been constructed and started regular data taking at Budker INP, Novosibirsk, Russia. It is designed to cover a center-of-mass ($E_{c.m.}$) energy from hadron production threshold up to 2 GeV.

Two detectors [7], SND and CMD-3, have been prepared for the rich physics program at the VEPP-2000 collider. During next few years we plan to scan the available energy range to measure the hadron production cross sections with a percent or better accuracy level, including $e^+e^- \to \pi^+\pi^-$ channel, and a study of the production dynamics for the multi-hadron channels.

At the Conference the results from two energy scans of the 1-2 GeV center-of-mass energy range is presented by both SND and CMD-3 detector, collected about $35pb^{-1}$ integrated luminosity each. Re-

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sults from SND detector are discussed in the talk by L.Kardapoltsev [8], presented in this Proceedings. In this paper we present results obtained with the CMD-3 detector.

2 The VEPP-2000 collider, CMD-3 detector and experiments

The VEPP-2000 collider is described elsewhere [6]. A special feature of the machine is the solenoidal focusing for the interaction regions, what allows to suppress beam-beam effects and store larger currents. During the energy scan, reported here, a maximum luminosity of $2{\cdot}10^{31}$ cm^{-2}sec^{-1} has been achieved, limited by the positron current. With a new positron source, currently under construction, the design luminosity of 10^{32} cm^{-2}sec^{-1} should be reached.

The CMD-3 detector is described elsewhere [7]. It is a general-purpose magnetic detector, providing good spatial and momentum resolution for charged particles [9], and excellent (about 1-2 mm) spatial resolution for photons in the LXe calorimeter [10], as well as good photon energy measurement. The detector performance is demonstrated in Fig. 1, where the DC and calorimeter responses for the collinear events at $E_{c.m.}$=1.975 GeV are shown.

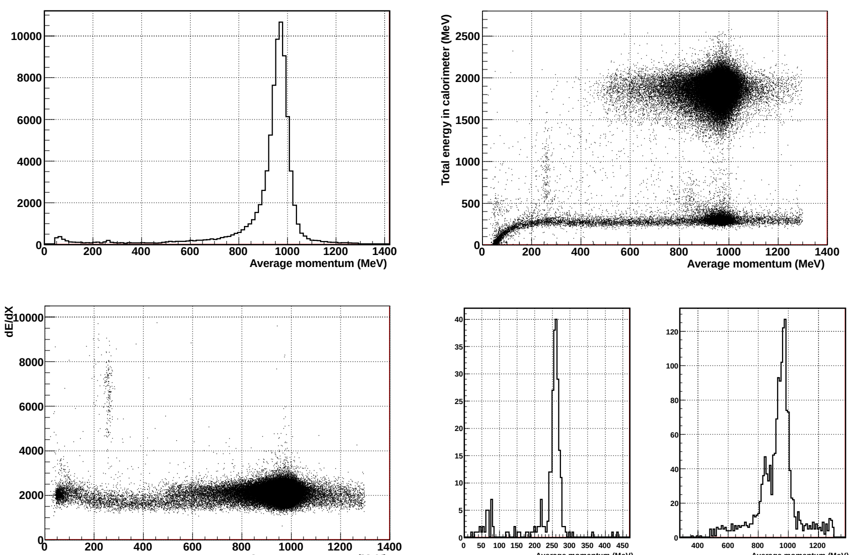

Fig. 1. The CMD-3 detector performance at $E_{c.m}$=1.975 GeV for the collinear events: (top left) the average momentum of two tracks. Major peak is for the Bhabha events; (bottom left) the dEdX DC measurement versus average momentum; (top right) the total energy deposition in the calorimeter versus average momentum; (bottom right) the $e^+e^- \to p\bar{p}$ signal from dEdX>3000 selection and $e^+e^- \to K^+K^-$ and $e^+e^- \to \pi^+\pi^-$ signals from calorimeter energy deposition selection.

A relatively clean selection of the processes $e^+e^- \to e^+e^-$, $p\bar{p}$, K^+K^-, $\pi^+\pi^-$ can be performed using detector subsystems.

We have performed three energy scans of the 1-2 GeV energy range collecting data at 56 energy points with about 0.5-1.0 pb^{-1} integrated luminosity per point. This luminosity corresponds from 200000 to 50000 events of Bhabha events per point used for the luminosity measurements and from a few hundreds to a few thousands of multi-hadron events like $\pi^+\pi^-\pi^0$, $2(\pi^+\pi^-)$, $2(\pi^+\pi^-)\pi^0$, $K^+K^-\pi^+\pi^-$, 6π etc.

3 Preliminary physics results

3.1 $e^+e^- \to p\bar{p}$

As shown in Fig. 1(bottom), a simple requirement of dEdX>3000 gives a very clean signal of the $e^+e^- \to p\bar{p}$ process with about 200-300 events per energy point. We estimate the cross section for these energy points above the threshold and show in Fig. 2 the results, compared with other measurements. At two energy points, just above the threshold, the protons and anti-protons stop inside the vacuum beam pipe and are detected by selecting multi-track "stars" from anti-proton annihilation.

We use angular distribution of detected proton-anti-proton pairs to extract electric (GE) and magnetic (GM) form factors contribution. We fit experimental distribution with a function, describing mixture of GE and GM distributions as shown in Fig. 3 (top), combining our data into two energy intervals. The GE/GM ratio for these intervals are shown in Fig. 3 (bottom) in comparison with other measurements.

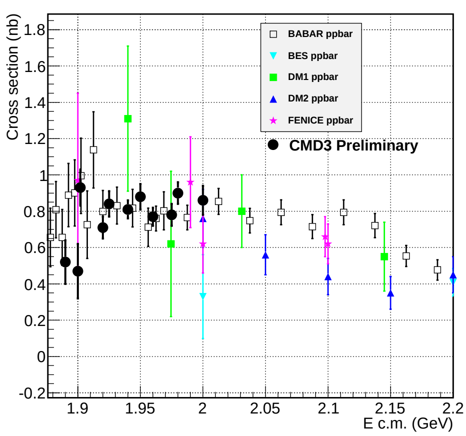

Fig. 2. Cross section of the $e^+e^- \to p\bar{p}$ process measured with CMD-3 detector in comparison with other measurements.

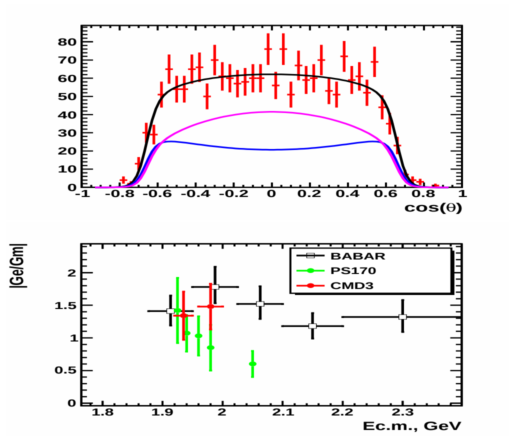

Fig. 3. Angular distribution with fit function describing mixture of GE and GM distributions (top); The GE/GM ratio in comparison with other measurements (bottom).

3.2 $e^+e^- \to 2(\pi^+\pi^-), \pi^+\pi^-\pi^0\pi^0$

By selecting events with four tracks in DC with a zero total charge, we obtain candidates for the $e^+e^- \to 2(\pi^+\pi^-)$, $2(\pi^+\pi^-)\pi^0$, $K^+K^-\pi^+\pi^-$, $2(\pi^+\pi^-)2\pi^0$ and other multi-hadron processes. Figure 4 shows a difference between the total energy and the center-of-mass energy for four (left) and for three (right) tracks (assuming pions), versus total momentum. A clear signal of the dominating $e^+e^- \to 2(\pi^+\pi^-)$ process is seen in both plots. Selecting these events and normalizing to the integrated luminosity at each energy point we obtain the cross section for this process shown in Fig. 5 in comparison with the recent most precise measurement by BaBar [11]. The agreement is good and we estimate our systematic errors at the level 3-5% at the moment. We confirm the $a_1(1260)\pi$ dominance in this reaction, but in the invariant masses of two and three pions we observe a small admixture of the $\rho(770) f_0(600)$, $\rho(770) f_0(980)$ and $a_2(1320)\pi$ reactions.

A four-pion final state with two neutral pions has a more complicated internal structure. We look for two pairs of photons with π^0 mass each in addition to two charged tracks satisfying energy-momentum conservation. The $e^+e^- \to \pi^+\pi^-\pi^0\pi^0$ reaction is dominated by the $\omega\pi^0$ intermediate state.

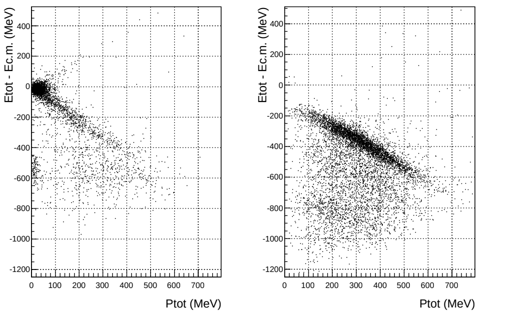

Fig. 4. The $e^+e^- \to 2(\pi^+\pi^-)$ process: (left) the difference between the total energy of four charged tracks (assuming pions) and E$_{c.m.}$ versus total momentum; (right) the difference of the total energy of three charged tracks (assuming pions) and E$_{c.m.}$ versus total momentum.

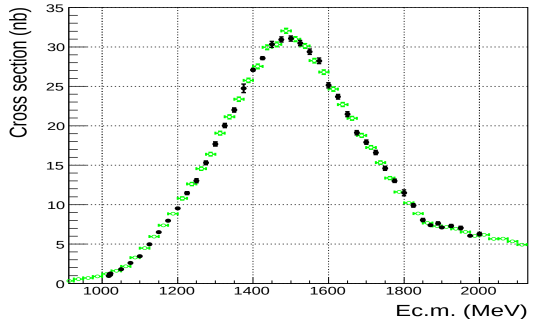

Fig. 5. Cross section of the $e^+e^- \to 2(\pi^+\pi^-)$ process at CMD-3 (dots) in comparison with the BaBar measurement (open circles).

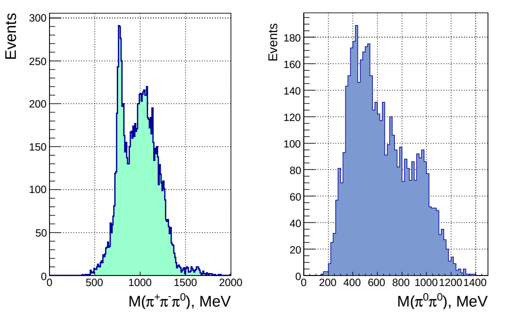

Fig. 6. The $e^+e^- \to \pi^+\pi^-\pi^0\pi^0$ process: (left) invariant mass of three pions; (right) invariant mass of two π^0 when two charged tracks form $\rho(770)$.

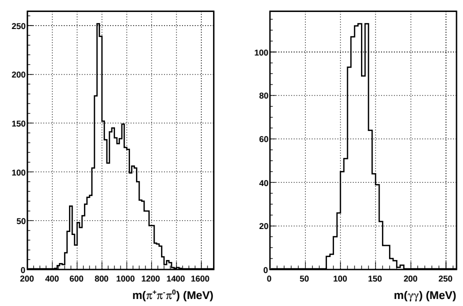

Fig. 7. The $e^+e^- \to 2(\pi^+\pi^-)\pi^0$ process: (left) invariant mass of three pions; (right) invariant mass of two photons when four charged tracks are found.

Figure 6 (left) shows $m(\pi^+\pi^-\pi^0)$ invariant mass distribution (two entries per event) for selected events. Very clear $\omega(782)$ peak is seen. The rest is dominated by the $a_1(1260)\pi$ intermediate state, but in two-pion combinations we also observe contributions from $\rho(770)^+\rho(770)^-$ and $\rho(770)^0 f_0(980)$. For example, Fig. 6 (right) shows $m(\pi^0\pi^0)$ invariant mass distribution for events, when $m(\pi^+\pi^-)$ invariant mass is within ±100 MeV from the nominal $\rho(770)$ mass. A bump around $m(\pi^0\pi^0)$=980 MeV is corresponding to $\rho(770)^0 f_0(980)$ contribution. All these reactions should be included into simulation for correct estimate of the acceptance. Work is in progress.

3.3 $e^+e^- \to 2(\pi^+\pi^-)\pi^0$

Looking for two photons detected in the calorimeter with the invariant mass corresponding to π^0, we select events of the $e^+e^- \to 2(\pi^+\pi^-)\pi^0$ reaction.

Figure 7(left) shows $\pi^+\pi^-\pi^0$ invariant masses for selected events when the π^0 is found in the best two-gamma combination shown in Fig. 7(right). Signals from $e^+e^- \to \eta\pi^+\pi^-$ and $e^+e^- \to \omega\pi^+\pi^-$ reactions are clearly seen. For events corresponding to the η and ω peaks, we plot two-pion mass distributions and observe contributions from the $\omega f_0(980)$ and $\eta\rho(770)$ final states. The π^0 detection efficiency is under study right now.

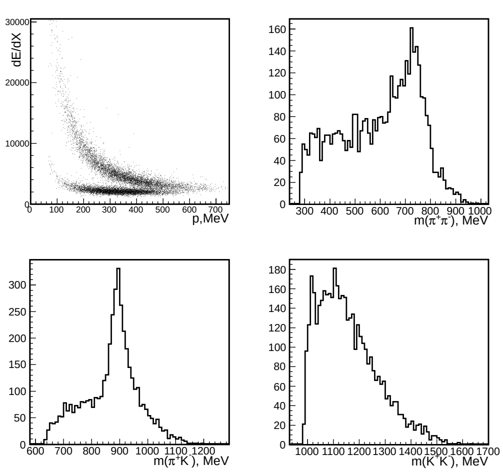

Fig. 8. The $e^+e^- \to K^+K^-\pi^+\pi^-$ process: The dE/dX measurement for the tracks in DC (top, left), The $\pi^+\pi^-$ invariant mass (top, right), the $K^\pm\pi^\mp$ invariant mass (bottom, left), and the K^+K^- invariant mass (bottom, right) for the selected events.

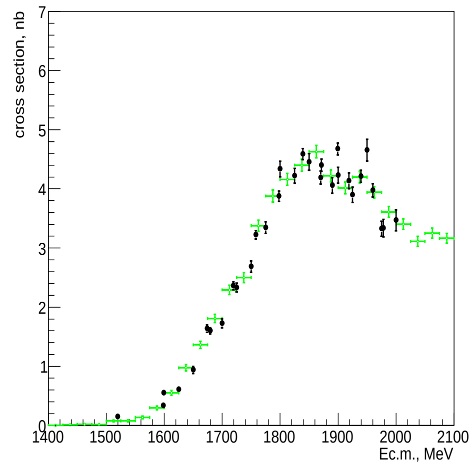

Fig. 9. The $e^+e^- \to K^+K^-\pi^+\pi^-$ cross section measured by the CMD-3 detector (dots) in comparison with the BaBar data (open circles).

3.4 $e^+e^- \to K^+K^-\pi^+\pi^-$

The four-charged-track events with a zero total momentum and Etot-Ec.m around -550 MeV (assuming all tracks to be pions, see Fig. 4) are taken as candidates for the $e^+e^- \to K^+K^-\pi^+\pi^-$ reaction. The dEdX information from the DC, shown in Fig. 8 (left,top), helps to identify kaons in this reaction and allows to select $K^+K^-\pi^+\pi^-$ events when one track is missing.

Figure 8 (left,bottom) confirms dominance of the $K^*(892)^0$ intermediate state, when plots on the right show presence of $\rho(770)$ in $\pi^+\pi^-$ combinations (top) and presence of $\phi(1020)$ in K^+K^-. Fig. 9 (right) shows the $e^+e^- \to K^+K^-\pi^+\pi^-$ cross section in comparison with recent BaBar data [12].

3.5 $e^+e^- \to 3(\pi^+\pi^-)$, $2(\pi^+\pi^-)2\pi^0$

We detect five and six charged tracks and using the total energy for six tracks and total energy for five tracks, assuming missing track to be pion, we select candidates for the $e^+e^- \to 3(\pi^+\pi^-)$ reaction with almost no background as shown in Fig. 10 (left). Our cross section measurement is shown in Fig. 10 (right) in comparison with recent BaBar data [13].

By looking for four photons in the calorimeters forming two π^0s (see Fig. 11 (left), matching energy-momentum conservation with four detected charged tracks, we select events of the $e^+e^- \to 2(\pi^+\pi^-)2\pi^0$ reaction. Figure 11 (right) shows the obtained cross section in comparison with the most precise measurement performed by the BaBar Collaboration [13].

We confirm a very sharp dip at the $p\bar{p}$ threshold, first observed by DM2 Collaboration [14]. The dynamics of these reactions are under study.

4 Summary

The CMD-3 detector has collected data at the VEPP-2000 e^+e^- collider in the 1-2 GeV energy range. The detector parameters allow to study all multi-hadron reactions in this energy region with high precision. Many intermediate states are demonstrated in this paper. First preliminary measurements of the cross sections for some reactions are presented.

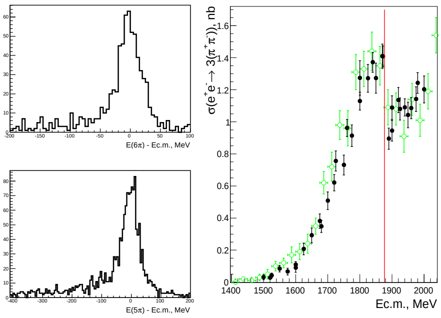

Fig. 10. The $e^+e^- \rightarrow 3(\pi^+\pi^-)$ process: (left) the difference between the total energy of 6 pions and $E_{c.m.}$ (top) and this difference for 5 tracks, assuming missing track to be pion (bottom); (right) the $e^+e^- \rightarrow 3(\pi^+\pi^-)$ cross section measured by the CMD-3 detector (dots) in comparison with the BaBar data (open circles). Line shows the $p\bar{p}$ threshold.

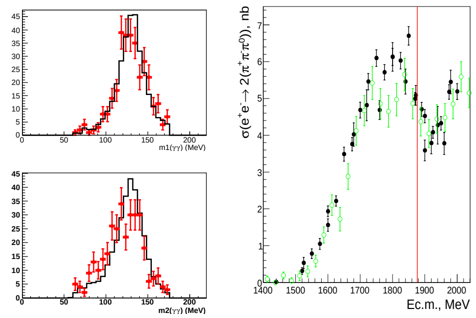

Fig. 11. The $e^+e^- \rightarrow 2(\pi^+\pi^-)2\pi^0$ process: (left) two-photon invariant masses for the first, highest momentum, (top) and second (bottom) π^0 for data (points) and simulation (histogram); (right) the $e^+e^- \rightarrow 2(\pi^+\pi^-)2\pi^0$ cross section in comparison with the BaBar data (open circles). Line shows the $p\bar{p}$ threshold.

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