PROCEEDINGS OF SCIENCE

Measurement of hadronic cross sections at CMD-3

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This paper reports a current status of the measurements of the hadronic cross sections in the c.m. energy range from 0.32 to 2.0 GeV with the CMD-3 detector at the VEPP-2000 electron-positron collider. The overall size of the data, acquired by the CMD-3 in the runs of 2010-2013 and 2017-2018 years, is about 160 pb^{-1}. The results of data analysis for various exclusive modes of $e^+e^- \to hadrons$ are described.

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1. Introduction

The CMD-3 detector [1] at the VEPP-2000 collider [2] in Novosibirsk carries out a comprehensive study of the exclusive cross-sections of $e^+e^- \to hadrons$ in the c.m. energy range from 0.32 up to 2 GeV. The CMD-3 results provide an important input for calculation of the hadronic contribution to the muon anomalous magnetic moment (AMM). The VEPP-2000 energy range gives the major hadronic contribution to AMM, both to the hadronic vacuum polarization itself ($\sim 92\%$) and to its uncertainty [3]. In this report we present the overview of the results of CMD-3 data analysis, including various modes of electron-positron annihilation with up to six pions or two kaons and pions in the final state.

Up to now, the CMD-3 collected about 160 pb^{-1} of data in the runs of 2010-2013 and 2017-208 years, with $\sim$70 pb^{-1} at $\sqrt{s} < 1.0$ GeV (including $\omega(782)$ region scan); $\sim$8.4 pb^{-1} at $\phi(1020)$ meson region; $\sim$85 pb^{-1} at $\sqrt{s} > 1.04$ GeV, including 14 pb^{-1} of data at nucleon-antinucleon production threshold region. Starting from 2013 the beam energy was determined using the Compton backscattering technique with accuracy $\sim$ 50 keV [4]. The peak collider luminosity was $\sim 3 \cdot 10^{31}$ cm^{-2}s^{-1}. The integral luminosity was determined with 1% systematic uncertainty using the events of Bhabha scattering, and, for cross-check, the $e^+e^- \to \gamma\gamma$ events [5].

2. Pion Form Factor Measurement

One of the main goals of the CMD-3 is to reduce a systematic uncertainty of the cross section of two-pion production to the level smaller than 0.5%, which corresponds to $\sim$0.35 ppm uncertainty in the AMM. The data sample, collected by CMD-3 in 2011-2013 at $\sqrt{s} < 1.0$ GeV is at the level of BaBar, KLOE and BES statistics, whereas 2-3 times more data have been collected in this region in 2017-2018. To control the systematic uncertainty, the $\pi^+\pi^-$ events selection is performed using two independet methods - using particles momenta or their energy deposition in the calorimeter. In both cases 2-dimensional binned likelyhood function maximization is performed to obtain the ratio of numbers of $\pi^+\pi^-$ and e^+e^- events. Currently the systematic uncertainty for pion form factor is estimated to be 0.4-0.9% (momentum-based approach) and 1.5% (energy-based).

3. Study of the Process $e^+e^- \to 3(\pi^+\pi^-)$

Production of six pions in e^+e^- annihilation was studied at DM2 [6] and BaBar [7]. The DM2 experiment observed a “sharp behavior” of the cross section of this process near nucleon-antinucleon threshold, confirmed later by the BaBar. The origin of this phenomenon remains unclear, see theoretical papers [8], [9], [10]. The cross section, measured with the CMD-3, is shown in Fig. 1. The final results for the data of 2011-2012 years were published in [11].

4. Study of the Process $e^+e^- \to \pi^+\pi^-\pi^0\eta$

CMD-3 performed the first measurement of $e^+e^- \to \pi^+\pi^-\pi^0\eta$ process cross section in the c.m. energy range from 1.394 to 2.005 GeV. The $\eta \to \gamma\gamma$ decay mode is used, and the total number of selected events was found to be 2769±95. The obtained Born cross section is shown in Fig. 2.

The systematic uncertainty was estimated as 15%. The main intermediate states for the studied process were found to be $\omega(782)\eta$, $\phi(1020)\eta$, and $a_0(980)\rho(770)$, the cross sections of their production also were extracted, final results are published in [12].

5. Study of the Process $e^+e^-\to K^+K^-\pi^+\pi^-$

We observed several intermediate mechanisms of $K^+K^-\pi^+\pi^-$ production ($f_0(500)\phi(1020)$, $f_0(980)\phi(1020)$, $\rho(770)KK$, $K_1(1270,1400)K\to K^*(892)\pi K$, $K_1(1400)K\to\rho(770)KK$), and unbinned fit was used to adjust the simulation to the data. The final results for the cross section measurement on the base of 2011-2012 statistics were published in [14]. However, the 3 times larger data sample, collected in 2017, revealed the indication on the drop of the process cross section at the nucleon-antinucleon threshold, see Fig. 3, similar to that in the $3(\pi^+\pi^-)$ final state.

6. Study of the Prosess $e^+e^-\to p\bar{p}$

The results for the $e^+e^-\to p\bar{p}$ cross section and G_E/G_M ratio near threshold on the base of 2011-2012 years were published in [15]. In 2017 a thorough $p\bar{p}$ production threshold scan was performed, see the preliminary results for $p\bar{p}$ production cross section in Fig. 4. The fitting curve, taken from the theoretical works [9] and [10], shows a good agreement with data.

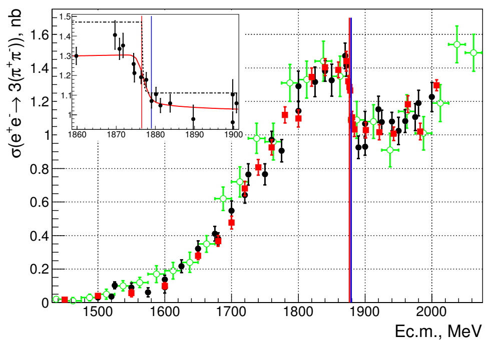

Figure 1: The $e^+e^-\to 3(\pi^+\pi^-)$ cross section, measured by the CMD-3 in the 2017 runs (red), in 2011-2012 (black), and by BaBar (green). The inset shows the visible cross section with the fit. The lines show nucleon-antinucleon thresholds.

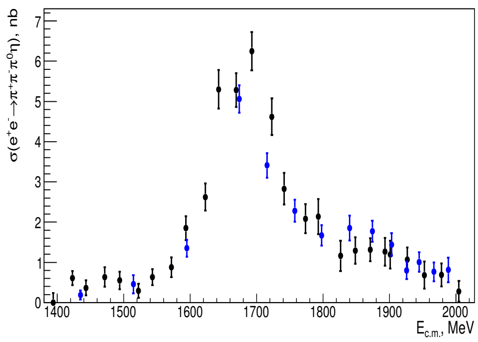

Figure 2: The $e^+e^-\to\pi^+\pi^-\pi^0\eta$ cross section, measured by CMD-3 (black -2011 runs, blue - 2012 runs).

7. Summary and Conclusion

The VEPP-2000 e^+e^- collider, CMD-3 and SND detectors successfully operate to collect $\sim 1\ fb^{-1}$ of data in the next 5-10 years. The collected data sample of 160 pb^{-1} is enough to provide the results with competitive precision compared to previous experiments.

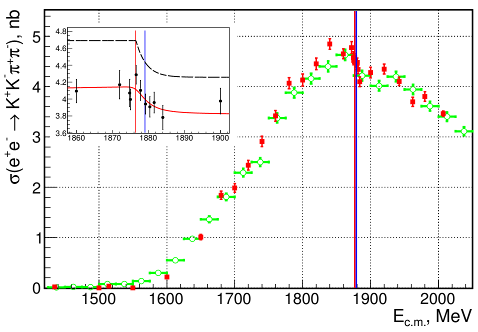

Figure 3: The $e^+e^-\to K^+K^-\pi^+\pi^-$ cross section, measured by the CMD-3 in the 2017 runs (red), and by BaBar (greeb). The inset shows the visible cross section with the fit. The lines show nucleon-antinucleon thresholds.

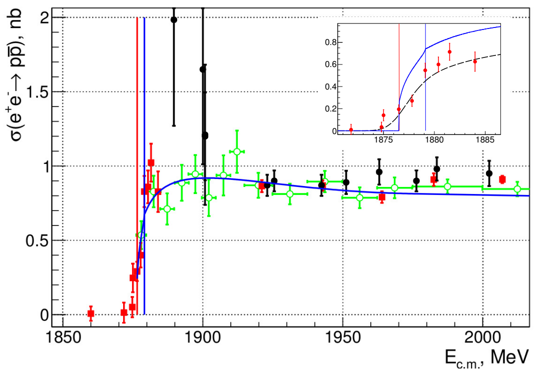

Figure 4: The $e^+e^-\to p\bar{p}$ cross section, measured by the CMD-3 in the 2017 runs (red, preliminary), in 2011-2012 (black), and by BaBar (green). The inset shows the visible cross section (CMD-3, 2017) with the fit. The lines show nucleon-antinucleon thresholds.

8. Acknowledgements

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