MEASUREMENT OF THE $e^+e^- \rightarrow p\bar{p}$ CROSS SECTION WITH THE CMD-3 DETECTOR AT VEPP-2000

R. R. AKHMETSHIN*, A. V. ANISENKOV*, V. M. AULCHENKO*,[†], V. S. BANZAROV*,
 L. M. BARKOV*, N. S. BASHTOVOY*, D. E. BERKAEV*,[†], A. V. BRAGIN*,
 S. I. EIDELMAN*,[†], D. A. EPIFANOV*,[§], L. B. EPSHTEYN*,[‡], A. L. EROFEEV*,
 G. V. FEDOTOVICH*,[†], S. E. GAYAZOV*,[†], A. A. GREBENUK*,[†], D. N. GRIGORIEV*,^{†,‡},
 E. M. GROMOV*, F. V. IGNATOV*, S. V. KARPOV*, V. F. KAZANIN*,[†],
 B. I. KHAZIN*,[†], A. N. KIRPOTIN*, I. A. KOOP*,[†], O. A. KOVALENKO*,[†],
 A. N. KOZYREV*, E. A. KOZYREV*,[†], P. P. KROKOVNY*,[†], A. E. KUZMENKO*,[‡],
 A. S. KUZMIN*, I. B. LOGASHENKO*,[†], P. A. LUKIN*,[†], A. P. LYSENKO*,
 K. Yu. MIKHAILOV*,[†], V. S. OKHAPKIN*, Yu. N. PESTOV*,
 E. A. PEREVEDENTSEV*,[†], A. S. POPOV*,[¶], Yu. S. POPOV*, G. P. RAZUVAEV*,[†],
 Yu. A. ROGOVSKY*, A. L. ROMANOV*, A. A. RUBAN*, N. M. RYSKULOV*,
 A. E. RYZHENENKOV*,[†], V. E. SHEBALIN*, D. N. SHEMYAKIN*,[†], B. A. SHWARTZ*,[†],
 D. B. SHWARTZ*,[†], A. L. SIBIDANOV*,^{||}, P. Yu. SHATUNOV*, Yu. M. SHATUNOV*,
 E. P. SOLODOV*,[†], V. M. TITOV*, A. A. TALYSHEV*,[†], A. I. VOROBIOV*,
 Yu. V. YUDIN* and Yu. M. ZHARINOV*

*Budker Institute of Nuclear Physics, SB RAS, Novosibirsk, 630090, Russia

[†]Novosibirsk State University, Novosibirsk, 630090, Russia

[‡]Novosibirsk State Technical University, Novosibirsk, 630092, Russia

^{||}University of Sydney, School of Physics, Falkiner High Energy Physics,
 NSW 2006, Sydney, Australia

[§]University of Tokyo, Department of Physics,
 7-3-1 Hongo Bunkyo-ku Tokyo, 113-0033, Japan

[¶]Corresponding author: al.s.popov@inp.nsk.su

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We report preliminary results on the measurement of the $e^+e^- \rightarrow p\bar{p}$ cross section with the CMD-3 detector at the VEPP-2000 electron-positron collider based on 4.5 pb^{-1} of integrated luminosity collected in the c.m. energy range 1.92 - 2.0 GeV. Event selection using information from the Drift Chamber and Calorimeters provides a clean sample of $p\bar{p}$ events. The obtained results are in good agreement with the previous measurements.

The lowest-order Feynman diagram of the process $e^+e^- \rightarrow p\bar{p}$ including final-state interaction is shown in Fig. 1.

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Fig. 1. Feynman diagram of $p\bar{p}$ production with final state interaction .

Fig. 2. $e^+e^- \rightarrow (3\pi^+3\pi^-)$ cross section

The Born cross section can be written as

$$\sigma_{p\bar{p}}(E) = \frac{4\pi\alpha^2\beta C}{3E^2} \left[|G_M(E)|^2 + \frac{2m_p^2}{E^2} |G_E(E)|^2 \right], \quad (1)$$

where E is the c.m. energy, m_p is the proton mass, $\beta = \sqrt{1 - 4m_p^2/E^2}$, and $C = y/(1 - e^{-y})$ with $y = \pi\alpha/\beta$ is the Sommerfeld correction factor (see, for example, Ref. 1), describing Coulomb interaction in the final state. This interaction results in a nonzero value of the cross section at the threshold. In our case the leading contribution to the final state interaction comes from strong interactions. The "strong" exchange depends on the relative velocity of p and $\bar{p}$ and has complicated behavior in the narrow energy region near threshold. The parameter that governs the intensity and dynamics of this interaction is a wave length of the relative $p\bar{p}$ motion. Up to $\lambda \geq 1$ fm corresponding to proton energies less than 1050 MeV, the interaction is high.

Additional interest to this energy region is related to the energy dependence of the cross section of the reaction $e^+e^- \rightarrow 3(\pi^+\pi^-)^2$ showing a dip near threshold of $p\bar{p}$, see Fig. 2. The origin of this dip can be explained in two different ways. The first one is the interference between the diagram of the direct $3(\pi^+\pi^-)$ production and $p\bar{p}$ loop diagram of Fig. 3, which has a large imaginary part at the threshold.³ It is clear that this effect should start revealing itself below threshold. Another reason for quick decrease of 6π production above the $p\bar{p}$ threshold can be the opening $p\bar{p}$ channel. In other words, the amplitude of $q\bar{q}$ pair production is governed by the short range of e^+e^- annihilation ($R_{annihilation} = 1/E = 1/2000$ MeV⁻¹) and is independent of the quark hadronization at rather long distances ($R_{hadronization} = \lambda_{QCD} = 1/300$ MeV⁻¹). When the $p\bar{p}$ channel opens, the probability of 6π production falls down. So it can be just the effect of probability normalization which can occur only above the $p\bar{p}$ threshold. At the present time the experimental accuracy could not discriminate one of these hypotheses.

$p\bar{p}$ loop in 6π production

Direct 6π production

Fig. 3. Possible mechanisms of 6π production.

1. CMD-3 Detector

The Cryogenic Magnetic Detector (CMD-3)^{4,5} is installed in the interaction region of the electron-positron collider VEPP-2000⁶ that operates at Budker Institute of Nuclear Physics. The collider has been designed to provide luminosity up to $10^{32}\text{cm}^{-2}\text{s}^{-1}$ at the maximum center-of-mass energy $\sqrt{s} = 2\text{ GeV}$. The Drift Chamber of CMD-3 is placed inside the superconducting solenoid with a magnetic field of 1.3 T and has momentum resolution 1.5-5% at 160-1000 MeV/c. The angular resolution is $\sigma_\phi = 9\text{ mrad}$ and $\sigma_\theta = 15\text{ mrad}$. The energy resolution of the electromagnetic calorimeter is about 4-8%⁷ depending on the energy deposition. The physics program⁸ includes high-precision measurements of the $e^+e^- \rightarrow \text{hadrons}$ cross sections in the wide energy range up to 2 GeV, studies of known and search for new vector mesons, studies of $n\bar{n}$ and $p\bar{p}$ production cross sections in the vicinity of the threshold and search for exotic hadrons.

2. Event selection

The analyzed c.m. energy region is 1920 to 2000 MeV. The corresponding nucleon kinetic energies vary from 22 to 62 MeV and allow $p(\bar{p})$ to cross the material of the vacuum tube and sensitive volume of DC. Antiprotons mostly annihilate in the DC outer shell with production of many hadrons, which have high energy deposition in the calorimeter. Due to low velocity β of the nucleons, the specific ionization losses in DC are very high. According to these signatures the following selection criteria were chosen. The candidate event should have two or more tracks (two of them being

Fig. 4. $p\bar{p}$ mean momentum

Fig. 5. $e^+e^- \rightarrow p\bar{p}$ cross section

collinear) originating from the common vertex close to the beam axis and having opposite charges. The collinear tracks should satisfy the following requirements:

- Collinearity: $\delta\phi < 0.15$ rad, $\delta\theta < 0.25$ rad.
- Vertex position: $R_{\perp} < 0.5$ cm, $|Z| < 10$ cm.
- Small momentum difference: $\frac{P_+ - P_-}{P_- + P_+} < 0.15$
- $dE/dX > 5000$ arbitrary units.
- Number of hits > 9 .
- Energy of the cluster linked to the proton track $E_p < 50$ MeV.
- Total energy deposition in the calorimeter $E_{\text{tot}} > 100$ MeV.

The total efficiency of these selections for a $p\bar{p}$ pair is about 55%. The number of $p\bar{p}$ events is determined from the fit of the mean momentum distribution for collinear tracks. An example of the $p\bar{p}$ mean momentum distribution for MC and data is shown in Fig. 4. For thus selected events the background is negligibly small and MC simulation is in good agreement with the experiment. The left tail of the distribution is due to events where tracks are directed at small angles relative to the beam axis, when charged nucleons have a longer path and higher ionization losses in the vacuum tube. About 200 events were selected at each energy point.

3. Results and conclusion

The Born cross section was determined from

$$\sigma_{\text{Born}} = \frac{N_{p\bar{p}}}{L\epsilon(1-\delta)},$$

where L-integrated luminosity, ϵ -detection efficiency, $(1-\delta)$ radiative corrections calculated according to Refs. 9, 10. The results are shown in Fig. 5. It is seen that they are in good agreement with BaBar data and have comparable precision. At present the analysis of events at lower energies, when the kinetic energy of

protons and antiprotons does not allow them to penetrate the vacuum tube is in progress. After the new positron injection complex will be commissioned, a factor of 10 improvement of luminosity is expected. The corresponding increase of statistics will allow for a precise determination of the cross section and dynamics of final state interaction in the c.m. energy range from threshold up to 2000 MeV. Estimations show that with 3000–4000 events at each point the G_E/G_M ratio could be determined with a 10% accuracy.

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