Reanalysis of Hadronic Cross Section Measurements at CMD-2

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Abstract

The updated results of the precise measurements of the processes $e^+e^- \to \rho \to \pi^+\pi^-$, $e^+e^- \to \omega \to \pi^+\pi^-\pi^0$ and $e^+e^- \to \phi \to K^0_L K^0_S$ performed by the CMD-2 collaboration are presented. The update appeared necessary due an overestimate of the integrated luminosity in previous analyses.

1 Introduction

Precise measurement of the $e^+e^- \to$ hadrons cross section at low energy is important for numerous applications in particle physics. The widely discussed one is the evaluation of the hadronic contribu-

[1] deceased

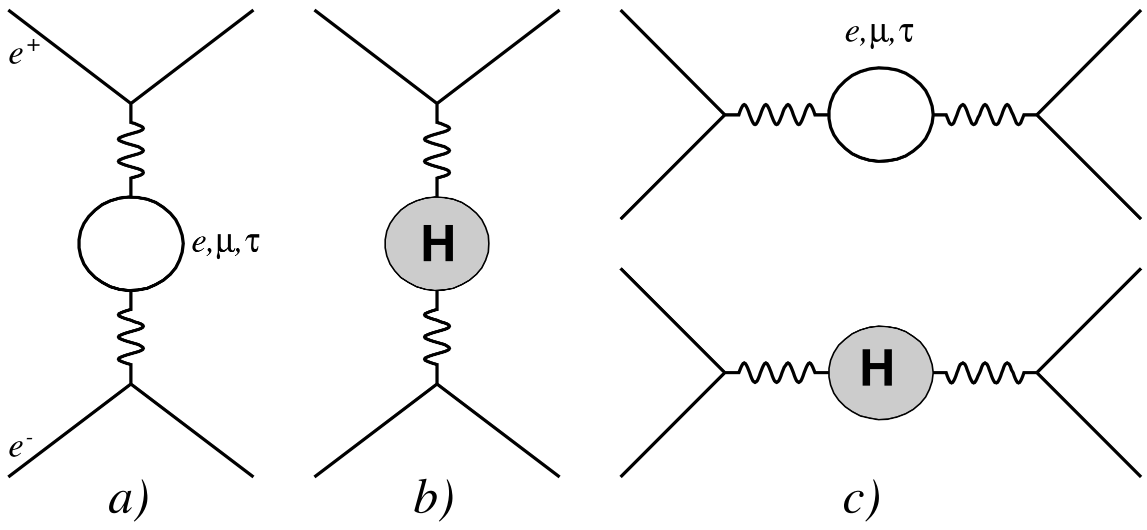

Fig. 1. Diagrams of the vacuum polarization contribution to the $e^+e^- \to e^+e^-$ cross section: a) t-channel (leptons), b) t-channel (hadrons), c) s-channel (leptons and hadrons).

tion to the muon anomalous magnetic moment. Recent publications hint at a possible discrepancy between the measurement [1] and the Standard Model prediction of a_μ [2,3]. Analysis in Ref. [2] also shows inconsistency between the cross sections of $e^+e^- \to$ hadrons and the spectral functions of $\tau \to \nu_\tau$ + hadrons related to the former via conservation of vector current (CVC).

Since data taking started in 1992, the CMD-2 collaboration measured various cross sections of $e^+e^- \to$ hadrons in the c.m. energy range 0.36-1.4 GeV and updated parameters of the $\rho(770)$, $\omega(782)$ and $\phi(1020)$ resonances. All these results are based on luminosity determined using large angle Bhabha scattering: $L = N_{e^+e^-}/\tilde{\sigma}_{e^+e^-}$, where $N_{e^+e^-}$ is the number of $e^+e^- \to e^+e^-$ detected events and $\tilde{\sigma}_{e^+e^-}$ is the cross section of the process $e^+e^- \to e^+e^-$ in the solid angle of the detector with radiative corrections taken into account according to [4]. These radiative corrections include all effects of initial and final state radiation and their interference as well as leptonic and hadronic vacuum polarization.

Recently we found out that the contribution from the leptonic loop in the t-channel (Fig. 1a) was omitted in the computer code calculating the radiative corrections for the cross section $\tilde{\sigma}_{e^+e^-}$. All other loop contributions (Figs. 1b,c) were taken into account. As a result, the cross-section $e^+e^- \to e^+e^-$ was underestimated and the luminosity L was overestimated by $2\% \div 3\%$ depending on energy.

After fixing the above error, the total cross section and various angular and energy distributions calculated in our code were compared to the well known program BHWIDE for high precision Monte Carlo generation of the Bhabha scattering [5]. Agreement at the level of 0.1% was found. Since the mistake was found in the computer code rather than in the approach based on Ref. [4], which was once again independently checked and shown to be valid, the systematic error of the calculated $e^+e^- \to e^+e^-$ cross section is estimated to be 0.2% as discussed in [4]. We have also performed a cross-check of our calculations for the $e^+e^- \to \mu^+\mu^-$ and $e^+e^- \to \pi^+\pi^-$ cross sections with independent computer codes [6,7] and found reasonable agreement within the accuracy claimed by their authors. The details of the comparison will be discussed in a separate paper.

Most of the measurements performed with CMD-2 and published by now [8–11] have systematic uncertainties significantly larger than 2% and it is therefore unreasonable to take into account the effect above in these papers before their complete reanalysis is done [2].

Below we present the results of the reanalysis of our high precision measurements at the ρ [13], ω [14] and ϕ [15] resonances. Following our paper [13], throughout this work we present two types of the cross section – σ and σ^0. While the former, σ, is the measured or "dressed" cross section, which includes all vacuum polarization effects and should be used in the approximation of the energy dependence with resonances, the latter, σ^0, is the "bare" cross section for various applications including calculations of the hadronic contribution to the muon anomalous magnetic moment.

2 Measurement of the pion form factor

The data analysis in the pion form factor experiment [13] was repeated. The corrected luminosity is 317.3 nb^{-1} or 2.4% lower than that quoted in the previous publication, corresponding to a data sample of 114000 $\pi^+\pi^-$ events. The resulting correction is slightly larger than the luminosity correction discussed above due to the correlation between the number of e^+e^- and $\pi^+\pi^-$ pairs introduced by the event separation procedure. Table 1 in [13] should be replaced by Table 1 of this work. We remind that the cross section $\sigma^0_{\pi\pi(\gamma)}$ shown in the last column of the Table is the "bare" cross section which also includes the effect of final state radiation. The systematic error of the cross section is estimated to be 0.6%.

The ρ-meson parameters listed in the Conclusion of [13], should be replaced with the following values obtained with the Gounaris-Sakurai parameterization of the reanalysed data:

$$
\begin{aligned}
\mathrm{M}_\rho \quad & = (775.65 \pm 0.64 \pm 0.50)\ \mathrm{MeV}, \\
\Gamma_\rho \quad & = (143.85 \pm 1.33 \pm 0.80)\ \mathrm{MeV}, \\
\Gamma(\rho \to e^+e^-) & = (7.06 \pm 0.11 \pm 0.05)\ \mathrm{keV}, \\
\mathcal{B}(\omega \to \pi^+\pi^-) & = (1.30 \pm 0.24 \pm 0.05)\%, \\
\arg\delta \quad & = 13.3^\circ \pm 3.7^\circ \pm 0.2^\circ.
\end{aligned}
$$

Compared to the previous analysis [13], the mass and total width become smaller by 0.54σ and 0.39σ, respectively. The branching fraction $\mathcal{B}(\omega \to \pi^+\pi^-)$ and the quantity $\arg\delta$ vary only slightly. Finally, the leptonic width becomes larger by 2.9% (1.7 standard deviations).

The hadronic contribution to the muon anomalous magnetic moment from the $\pi^+\pi^-$ channel in the energy range covered by present analysis is estimated to be $(378.7 \pm 2.7 \pm 2.3) \times 10^{-10}$ or 10.6×10^{-10} higher than in our previous estimate.

[2] Our recent result on the investigation of the process $e^+e^- \to \omega\pi^0 \to \pi^0\pi^0\gamma$ [12] is already based on the corrected luminosity value and should not be updated.

Table 1
The measured value of the pion form factor and "bare" cross section $e^+e^- \to \pi^+\pi^-(\gamma)$. Only statistical errors are shown. The systematic error is estimated to be 0.6%.

$E_{c.m.}$, MeV	$\lvert F_\pi\rvert^2$	$\sigma^0_{\pi\pi(\gamma)}$, nb	$E_{c.m.}$, MeV	$\lvert F_\pi\rvert^2$	$\sigma^0_{\pi\pi(\gamma)}$, nb
610.50	8.18 ± 1.15	335.3 ± 47.2	784.24	35.24 ± 1.00	961.5 ± 27.3
620.50	9.95 ± 0.74	400.3 ± 29.7	786.04	30.92 ± 1.10	835.2 ± 29.7
630.50	11.12 ± 0.74	438.8 ± 29.1	790.10	33.03 ± 1.14	889.5 ± 30.8
640.51	11.30 ± 0.73	437.4 ± 28.3	794.14	30.90 ± 0.87	829.7 ± 23.4
650.49	13.02 ± 0.85	494.1 ± 32.4	800.02	30.25 ± 0.73	805.7 ± 19.6
660.50	13.77 ± 0.77	512.3 ± 28.7	810.14	26.33 ± 0.56	689.2 ± 14.8
670.50	15.79 ± 0.84	576.2 ± 30.7	820.02	24.78 ± 0.79	636.8 ± 20.4
680.59	20.02 ± 0.93	716.3 ± 33.2	829.97	21.15 ± 0.76	533.5 ± 19.0
690.43	21.03 ± 0.74	737.6 ± 26.1	839.10	17.29 ± 0.72	428.8 ± 17.9
700.52	24.46 ± 0.64	840.5 ± 22.1	849.24	14.57 ± 0.72	354.8 ± 17.5
710.47	28.37 ± 1.01	955.1 ± 34.1	859.60	14.91 ± 0.70	356.2 ± 16.6
720.25	32.74 ± 0.85	1079.5 ± 27.9	869.50	11.41 ± 0.47	267.8 ± 11.0
730.24	35.29 ± 1.21	1138.1 ± 39.1	879.84	10.47 ± 0.81	241.3 ± 18.6
740.20	38.81 ± 1.20	1223.3 ± 37.9	889.72	8.69 ± 0.35	196.9 ± 7.9
750.28	43.52 ± 1.17	1339.8 ± 35.9	900.04	8.04 ± 0.30	178.8 ± 6.7
760.18	44.71 ± 1.19	1345.1 ± 35.7	910.02	7.05 ± 0.32	154.0 ± 7.0
764.17	44.48 ± 1.05	1327.0 ± 31.5	919.56	6.23 ± 0.31	133.9 ± 6.7
770.11	45.48 ± 1.17	1342.0 ± 34.5	930.11	5.91 ± 0.37	124.8 ± 7.9
774.38	44.29 ± 1.17	1299.4 ± 34.4	942.19	5.35 ± 0.25	110.8 ± 5.3
778.17	46.68 ± 1.33	1361.3 ± 38.8	951.84	4.72 ± 0.24	96.2 ± 4.9
780.17	44.04 ± 1.22	1269.9 ± 35.2	961.52	4.44 ± 0.23	89.1 ± 4.7
782.23	37.55 ± 0.68	1053.3 ± 19.0			

3 Measurement of the $\omega(782)$ meson parameters in the $\omega \to \pi^+\pi^-\pi^0$ mode

In the reanalysis of our ω meson experiment the selection procedure described in Ref. [14] can be left unchanged. Although small, the background cross section is not negligible, therefore we have to refit the data.

The corrected integrated luminosity is 119.6 nb^{-1}, i.e. 2.4% smaller than before. The results of the fit based on a data sample of about 11200 events are presented below:

$$\begin{aligned}
M_\omega &= (782.68 \pm 0.09 \pm 0.04)\ \text{MeV}, \\
\Gamma_\omega &= (8.68 \pm 0.23 \pm 0.10)\ \text{MeV}, \\
\sigma_0 &= (1495.6 \pm 25.5 \pm 19.4)\ \text{nb}, \\
\sigma_{bg} &= (12.2 \pm 4.5)\ \text{nb}.
\end{aligned}$$

Comparison with the previous publication shows that the values of the total width and background cross section remain the same while the value of the mass becomes 0.03 MeV smaller. The value of the cross section at the peak is 2.6% higher than previously.

From the value of the cross section at the peak, σ_0, one can calculate the following product of the branching ratios:

$$\mathcal{B}(\omega \to e^+e^-)\mathcal{B}(\omega \to \pi^+\pi^-\pi^0) = (6.24 \pm 0.11 \pm 0.08) \times 10^{-5}.$$

Finally, in Table 2 we present the measured and "bare" cross sections as a function of c.m. energy. The systematic error of the cross section is estimated to be 1.3%.

Table 2
The measured and "bare" cross section of the process $\omega \to \pi^+\pi^-\pi^0$. Only statistical errors are shown. The systematic error is estimated to be 1.3%.

$E_{c.m.}$, MeV	σ, nb	σ^0, nb
760.18	69.0 ± 11.0	68.0 ± 10.8
764.17	71.0 ± 8.0	70.0 ± 7.9
770.11	179.0 ± 15.0	176.6 ± 14.8
774.38	279.0 ± 22.0	275.9 ± 21.8
778.17	790.0 ± 41.0	781.8 ± 40.6
780.17	1193.0 ± 51.0	1149.1 ± 50.5
782.23	1490.0 ± 31.0	1427.8 ± 29.7
784.24	1338.0 ± 45.0	1254.8 ± 42.2
786.04	903.0 ± 44.0	842.8 ± 41.1
790.09	417.0 ± 19.0	391.4 ± 17.8
794.14	197.0 ± 11.0	185.9 ± 10.4
800.00	127.0 ± 8.0	120.3 ± 7.6
810.14	56.0 ± 4.0	53.2 ± 3.8

4 Measurement of the ϕ(1020) meson parameters in the $\phi \to K_L^0 K_S^0$ mode

The changes in the results of our ϕ(1020) meson study in the $\phi \to K_L^0 K_S^0$ mode [15] are straightforward. The corrected integrated luminosity is 1924 nb^{-1} or 2.7% smaller than previously. The corresponding data sample contains 2.72×10^5 $K_L^0 K_S^0$ events obtained in the analysis of four independent scans.

The reanalysis showed that the peak cross section, $\sigma_0(\phi \to K_L^0 K_S^0)$, as well as the values of the product of the branching fractions $\mathcal{B}_{e^+e^-}\mathcal{B}_{K_L^0 K_S^0}$ become higher by the same amount of 2.7%. The values of the ϕ mass and total width remain unchanged. The new values of ϕ(1020) parameters in four scans of our experiment are presented in Table 3.

Table 3
ϕ meson parameters obtained in this analysis

Scan	σ_0, nb	m_ϕ, MeV/c^2	$\mathcal{B}_{e^+e^-}\mathcal{B}_{K_L^0 K_S^0}$, 10^{-4}
1	$1402 \pm 14 \pm 24$	$1019.506 \pm 0.030 \pm 0.020$	$0.993 \pm 0.010 \pm 0.016$
2	$1378 \pm 13 \pm 24$	$1019.512 \pm 0.023 \pm 0.045$	$0.976 \pm 0.009 \pm 0.016$
3	$1434 \pm 12 \pm 25$	$1019.363 \pm 0.017 \pm 0.080$	$1.016 \pm 0.008 \pm 0.017$
4	$1431 \pm 12 \pm 25$	$1019.316 \pm 0.021 \pm 0.122$	$1.013 \pm 0.008 \pm 0.017$
Average	$1413 \pm 6 \pm 24$	$1019.483 \pm 0.011 \pm 0.025$	$1.001 \pm 0.004 \pm 0.017$

The value of the ϕ meson total width is the same as before:

$$\Gamma_\phi = (4.280 \pm 0.033 \pm 0.025) \text{ MeV}.$$

The measured and "bare" cross sections of the process $\phi \to K_L^0 K_S^0$ as a function of c.m. energy are presented in Table 4. The systematic error of the cross section is estimated to be 1.7%.

5 Conclusion

We performed a reanalysis of the high precision measurements of the processes $e^+e^- \to \rho \to \pi^+\pi^-$ [13], $e^+e^- \to \omega \to \pi^+\pi^-\pi^0$ [14] and $e^+e^- \to \phi \to K_L^0 K_S^0$ [15] at the CMD-2 detector. The corrected values of the ρ, ω and ϕ meson parameters are presented together with the detailed tables of the corresponding hadronic cross sections.

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Table 4
The measured and "bare" cross section of the process $\phi \to K_L^0 K_S^0$ for all scans. Only statistical errors are shown. The systematic error is estimated to be 1.7% for all four scans.

$E_{c.m.}$, MeV	σ, nb	σ^0, nb	$E_{c.m.}$, MeV	σ, nb	σ^0, nb
	1 Scan			2 Scan	
1010.27±0.03	42.21±5.16	42.89±5.24	1004.25±0.17	18.51± 9.85	18.40±9.79
1017.09±0.02	602.85±14.91	658.31±16.28	1010.86±0.13	52.96± 7.53	53.97± 7.67
1018.14±0.02	999.68±34.84	1069.66±37.28	1016.37±0.08	399.54±35.28	433.50± 38.28
1018.96±0.02	1278.75±32.27	1277.47±32.24	1017.19±0.08	600.22±45.78	655.44±49.99
1019.21±0.02	1328.94±38.80	1291.73±37.71	1018.06±0.08	930.66±51.35	999.53±55.15
1019.99±0.02	1325.08±28.63	1189.92±25.71	1019.00±0.08	1329.00±25.08	1322.36±24.95
1020.13±0.02	1342.71±41.89	1193.67±37.24	1020.00±0.08	1282.51±50.32	1150.41±45.14
1021.85±0.02	622.82±33.88	536.87±29.20	1020.96±0.08	941.38±46.99	811.47±40.51
1023.97±0.02	292.26±14.91	258.07±13.17	1021.88±0.09	620.70±40.29	535.04±34.73
			1027.70±0.11	126.74±10.35	115.46±9.43
			1033.63±0.17	66.33±8.57	61.69±7.97
			1039.48±0.17	37.92± 6.23	35.61±5.85
	3 Scan			4 Scan	
1004.64±0.17	13.58± 4.59	13.51±4.57	1004.19±0.17	12.39±1.77	12.32±1.76
1011.30±0.09	52.97± 3.48	54.14±3.56	1011.30±0.10	56.62±6.87	57.87±7.02
1015.99±0.08	350.79±28.31	378.50±30.55	1015.91±0.08	343.95±26.62	370.78±28.70
1016.93±0.08	560.58±42.85	611.59±46.75	1016.94±0.08	601.65±45.64	656.40±49.79
1017.91±0.08	931.61±49.23	1006.14±53.17	1017.92±0.08	998.50±51.38	1078.38±55.49
1019.04±0.07	1354.29±25.21	1342.10±24.98	1018.76±0.08	1317.09±23.21	1344.75±23.70
1019.95±0.07	1251.84±49.67	1127.91±44.75	1019.68±0.07	1321.09±45.42	1219.37±41.92
1020.86±0.08	891.48±45.54	770.24±39.35	1020.68±0.08	999.30±49.45	866.39±42.87
1021.74±0.08	606.96±37.01	522.59±31.87	1021.60±0.08	648.54±36.18	558.39±31.15
1022.67±0.09	419.31±30.91	364.38±26.86	1022.59±0.08	428.05±27.35	371.98±23.77
1028.36±0.12	102.38± 9.75	93.58±8.91	1028.41±0.10	102.57±8.42	93.75±7.70
1034.06±0.17	54.04± 7.78	50.31±7.24			

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