PROCEEDINGS

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Measurement of hadronic cross-sections in e^+e^- collisions below 1.4 GeV at CMD-2

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CMD-2 COLLABORATION

Abstract: In 1992-2000, new $e^+e^- \to hadrons$ data were collected in the energy range $0.36 < \sqrt{s} < 1.4$ GeV with the CMD-2 and SND detectors at the VEPP-2M collider in Novosibirsk. The status of the R(s) measurement by the CMD-2 group is presented.

1. Introduction

Precise knowledge of $R(s) = \sigma(e^+e^- \to hadrons)/\sigma(e^+e^- \to \mu^+\mu^-)$ is important in a variety of problems in particle physics. Particularly, its knowledge at low s is vital for interpretation of the recent measurement of the muon's anomalous magnetic moment [1]. The announced 2.6σ difference between the new experimental value of the muon's (g-2)

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and its theoretical value calculated within the Standard Model may indicate the presence of physics beyond the Standard Model. The uncertainty of the theoretical calculation is mainly driven by the uncertainty of R(s), especially at low s, which is used for evaluation of the hadronic contribution [2]. While at high energies R(s) can be calculated within the framework of QCD, at low energies it has to be measured in experiment. The existing e^+e^- data at low s ($\sqrt{s} < 1.4$ GeV), taken in the late 70s-early 80s, have a systematic error of 2% to 15% [3]. Another set of data, based on analysis of hadronic tau decays [4], became available last decade. Although these data, when included in the calculations, reduce the error of the hadronic contribution to the 1% level, the non-trivial theoretical assumptions required to link τ-lepton data with $R(s)$ are not fully understood [5].

In 1992-2000, new $e^+e^- \to hadrons$ data were collected in the energy range $0.36 < \sqrt{s} < 1.4$ GeV with the CMD-2 and SND detectors at the VEPP-2M collider in Novosibirsk [6, 7]. The status of the analysis of CMD-2 data is reviewed in this paper.

The exclusive approach is used for measuring $R(s)$ — the cross-section of each separate $e^+e^- \to hadrons$ channel is measured independently. Such an approach is natural for low energies, since the number of modes and the multiplicity are small, and a high precision of measurement is required. For the energy range under study, the dominant contribution comes from $e^+e^- \to \pi^+\pi^-$ (or ρ-meson). At energies above the φ-meson, the contribution from $e^+e^- \to 4\pi$ becomes important (and dominant above ≈ 1.2 GeV). Other modes, such as 3π, K_SK_L, K^+K^- etc., give important contributions around the narrow ω- and φ-resonances.

Measurement of $R(s)$		
Date	C.m. energy, GeV	L, 1/pb
02/94 – 02/94	$0.970 \div 0.810$	0.15
11/94 – 06/95	$0.810 \div 0.600$	0.16
09/96 – 10/96	$0.512 \div 0.370$	0.1
01/97 – 06/97	$1.040 \div 1.370$	5.93
03/98 – 06/98	$0.970 \div 0.360$	3.5
01/99 – 05/99	$1.080 \div 1.250$	2.5
11/99 – 06/00	$0.600 \div 0.980$	4.5
Study of $\varphi(1020)$ decays		
Date	C.m. energy, GeV	L, 1/pb
02/93 – 07/93	$0.994 \div 1.040$	1.43
01/94 – 02/94	$1.019 \div 0.980$	0.05
11/94 – 11/94	$1.018 \div 1.024$	0.16
04/96 – 07/96	$0.984 \div 1.034$	2.18
10/97 – 03/98	$0.984 \div 1.060$	11.93

Table 1: CMD-2 data taking history.

The general purpose detector CMD-2 is described in detail elsewhere [8]. The tracking system consists of a drift chamber with 250 μm resolution in the plane transverse to the beam axis, and a multiwire proportional Z-chamber with 0.5 mm resolution in the direction along the beam (z-) axis. The tracking system is located inside a thin 0.38 X_0 superconducting solenoid with a field of 1 T. The barrel calorimeter is placed outside the solenoid and consists of 892 CsI crystals, 8 X_0 thick. The endcap calorimeter consists of 680 BGO crystals, 13 X_0 thick. The muon range system consists of two double layers of streamer tubes, separated by the iron yoke.

The CMD-2 detector started to take data in 1992. A total of about 30 pb^{-1} integrated luminosity was collected, including about $2 \cdot 10^7$ φ-meson decays, $3 \cdot 10^6$ ω-meson decays, $5 \cdot 10^6$ 2π events and $3 \cdot 10^5$ multi hadron events. The list of CMD-2 data taking runs is shown in Table 1.

2. Cross-section $e^+e^- \to \pi^+\pi^-$

A total of about 2 million $e^+e^- \to \pi^+\pi^-$ events were collected for the cross-section measurement. Since this is the dominant mode, a high measurement precision, better than 1%, is required. The design of the detector, featuring the simultaneous measurement of particle momentum and energy, a thin beam pipe and precise determination of fiducial volume with the Z-chamber, allowed for a factor 2-3 reduction in systematic error compared with previous experiments.

Events with two collinear back-to-back tracks were selected for analysis. The sample consists of $e^+e^- \to e^+e^-$, $e^+e^- \to \mu^+\mu^-$, $e^+e^- \to \pi^+\pi^-$ events and the cosmic background. The spatial distribution of the vertex was used to separate the background events from the others. The e^+e^-, $\mu^+\mu^-$ and $\pi^+\pi^-$ final states were separated using either the information about energy deposition of the particles (at c.m. energies above 0.6 GeV) or the information about particle momenta (at c.m. energies below 0.6 GeV). Since muons and pions cannot be separated by their energy deposition, at energies above 0.6 GeV the ratio $N(\mu^+\mu^-)/N(e^+e^-)$ was fixed according to QED calculations with detector acceptance taken into account. Large angle Bhabha scattering $e^+e^- \to e^+e^-$ was used as the monitoring process. Since selection criteria were the same for $e^+e^- \to e^+e^-$ and $e^+e^- \to \pi^+\pi^-$, the effects of detector acceptance effectively cancel out, allowing one to measure $\sigma_{e^+e^-\to\pi^+\pi^-}$ with better precision than that of the luminosity. Details of the analysis can be found in [6, 9].

The radiative corrections were calculated according to [10, 11] with an estimated accuracy of 0.4%. It should be mentioned that the radiative correction to $e^+e^- \to \pi^+\pi^-$ does include effects of initial (ISR) and final (FSR) state radiation, thus excluding them from the cross-section, and does not include the effect of vacuum polarization, which is considered an intrinsic part of the hadronic cross-section. On the contrary, for the purpose of measuring $R(s)$, the FSR should be considered as part of the hadronic cross-section and the effect of vacuum polarization should be excluded from the cross-section. Therefore, the modified cross-section $\sigma^0_{\pi\pi(\gamma)}$ should be used for calculation of $R(s)$:

$$\sigma^0_{\pi\pi(\gamma)} = \sigma_{e^+e^-\to\pi^+\pi^-} \cdot (1 + \delta^{FSR}_{\pi\pi}(s)) \cdot |1 - \Pi(s)|^2,$$

where the factor $|1-\Pi(s)|^2$ with a polarization operator $\Pi(s)$ excludes the effect of leptonic and hadronic vacuum polarization, and the term $\delta^{FSR}_{\pi\pi}(s)$ describes the final state radiation. Similar modifications should be made for all other modes $e^+e^- \to hadrons$.

The 94-95 data taking run was dedicated to measurement of the $e^+e^- \to \pi^+\pi^-$ cross-section — the energy range 0.6–1.0 GeV was scanned in small energy steps with energy measurement by resonance depolarization at every point. These data have been analyzed and the cross-section has been measured with 0.6% systematic error. Results, expressed in terms of the pion formfactor, are shown in Fig. 1. The rest of the data is still under analysis. We expect to obtain a somewhat larger systematic error of 1-2% at energies below 0.6 GeV due to a more complicated separation procedure, and of 1-5% for energies above 1 GeV due to larger background.

3. Cross-section $e^+e^- \to 4\pi$

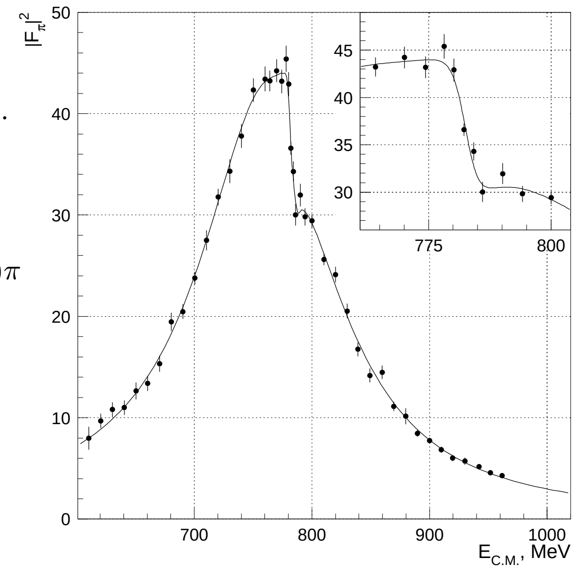

Figure 1: Pion formactor in the rho-meson energy range

The cross-section $e^+e^- \to 4\pi$ becomes important for energies above the φ-meson. This cross-section was measured based on the data collected in 1997.

It was shown that the $e^+e^- \to 4\pi$ process is dominated by $\omega\pi^0$ and $a_1(1260)\pi$ intermediate states [12]. That knowledge allowed for a more precise calculation of detector acceptance and efficiencies compared with previous measurements.

The radiative corrections for this and other modes, described below, were calculated according to [13]. Unlike the calculation used in the case of $e^+e^- \to 2\pi$, this approach is not based on Monte-Carlo integration of the full differential cross-section. Therefore, the modification of the geometry of the final state is not taken into account. As a result, the estimated precision of the calculations depends on the energy dependence and the angular structure of the measured cross-section and typically is about 1%.

The total estimated systematic error of the $e^+e^- \to 4\pi$ cross-section measurement is about 7%, dominated by the knowledge of the detector acceptance. It should be mentioned, that the cross-section measured by the SND detector [14] is systematically higher than the one measured by CMD-2. That might indicate the existence of unaccounted contributions to the systematic error.

4. Other modes

The cross-section $e^+e^- \to \pi^+\pi^-\pi^0$ was precisely measured around the ω and φ mesons with a systematic error of about 2-4% [15, 16]. The excitation curve of the φ-meson was measured in all major modes (K_SK_L, K^+K^-, $\pi^+\pi^-\pi^0$, $\eta\gamma$) [17]. The estimated systematic error for the K_SK_L mode is 2%, dominated by the knowledge of the detection efficiency. The estimated systematic error for the K^+K^- mode is about 4%. The larger error is explained by the fact that one of the charged kaons had to decay inside the drift chamber in order to trigger the detector, which significantly reduce the statistics and complicate the analysis.

The $e^+e^- \to K^+K^-$ and $e^+e^- \to K_SK_L$ cross-sections at energies above the φ-meson were measured based on data collected in 1997. The current systematic error for the $e^+e^- \to K^+K^-$ mode is estimated to be about 5%, and a smaller error seems to be in reach. The systematic error for the $e^+e^- \to K_SK_L$ mode is estimated to be 2-8% for the energy range 1.04-1.4 GeV. The increase in systematic error for higher energies reflects the increase in the background contribution.

The $e^+e^- \to \pi^+\pi^-\pi^+\pi^-\pi^0$ cross-section was measured by CMD-2 in the c.m. energy range 1.28-1.38 GeV [18]. The VEPP-2M energy range allows us to measure this cross-section only near threshold, and the main bulk of the $e^+e^- \to 5\pi$ production appears at higher energies. The systematic error of the measurement is estimated at 15%.

The current status of the hadronic cross-sections measured by CMD-2 is shown in Fig. 2. When the data analysis is completed, an overall improvement by a factor 2÷3 of the precision of $R(s)$ in the VEPP-2M energy range is expected.

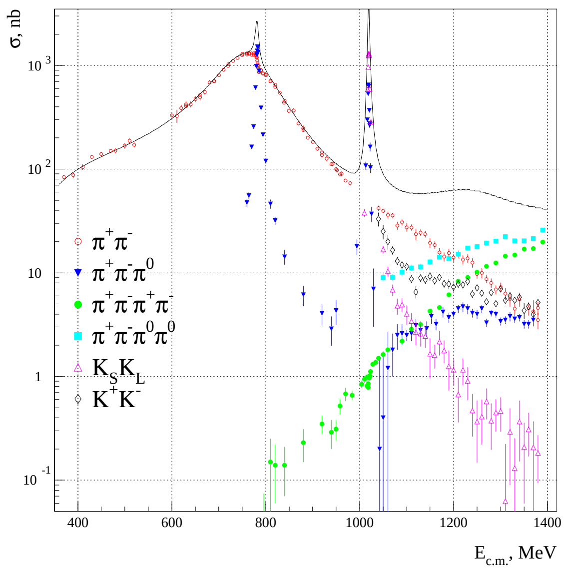

Figure 2: Hadronic cross-sections, measured by CMD-2. The line shows the total cross-section $e^+e^- \to hadrons$.

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