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Measurement of R_{uds} and R between 3.12 and 3.72 GeV at the KEDR detector

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ABSTRACT

Using the KEDR detector at the VEPP-4M e^+e^- collider, we have measured the values of R_{uds} and R at seven points of the center-of-mass energy between 3.12 and 3.72 GeV. The total achieved accuracy is about or better than 3.3% at most of energy points with a systematic uncertainty of about 2.1%. At the moment it is the most accurate measurement of $R(s)$ in this energy range.

1. Introduction

The quantity R is defined as the ratio of the radiatively corrected total hadronic cross section in electron–positron annihilation to the lowest-order QED cross section of the muon pair production. The precise $R(s)$ measurements are critical for determination of the value of the strong coupling constant $\alpha_s(s)$ and heavy quark masses [1], the anomalous magnetic moment of the muon $(g-2)_\mu$ and the value of the electromagnetic fine structure constant at the Z^0 peak $\alpha(M_Z^2)$ [2,3].

Several experiments contributed to the $R(s)$ measurement in the energy range between 3.12 and 3.72 GeV [4–12]. The precision of these measurements does not exceed 5% for all experiments except BES-II [12], in which the accuracy of about 3.3% was reached at 3.07 and 3.65 GeV, but that is not enough for reliable calculation of the dispersion integrals in the whole energy range. It should be

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noted that systematic uncertainties dominate in all $R(s)$ measurements, thus there is good motivation for new experiments on the precise determination of $R(s)$ in this energy range, particularly important for $\alpha(M_Z^2)$.

In 2011 the region of the J/ψ and $\psi(2S)$ resonances was scanned in the KEDR [13] experiment with an integrated luminosity of about 1.4 pb^{-1}. In the data analysis presented below we tried to minimize correlations of systematic uncertainties with those in similar experiments by BES.

2. VEPP-4M collider and KEDR detector

The e^+e^- collider VEPP-4M [14] was designed to operate in the wide range of the beam energy 1–5.5 GeV in the 2 × 2 bunches mode. The peak luminosity of VEPP-4M is about 2×10^{30} $\text{cm}^{-2}\,\text{s}^{-1}$ in the vicinity of $\psi(2S)$.

The collider is well equipped for a precise beam energy determination. The beam energy in dedicated calibration runs is measured using the resonant depolarization method (RDM) [15, 16] with the relative accuracy of about 10^{-6}. The results of RDM calibrations can be interpolated to determine the energy during data taking with the accuracy of about 10 keV [17,18]. Continuous energy monitoring is performed using the infrared light Compton backscattering [19] with the accuracy ∼60 keV. The Compton backscattering also allows for the beam energy spread determination with the accuracy about 5%.

The KEDR detector is described in Ref. [13]. The detector consists of the vertex detector (VD), drift chamber (DC), time-of-flight (TOF) system of scintillation counters, particle identification system based on the aerogel Cherenkov counters, electromagnetic calorimeter (liquid krypton in the barrel part and CsI crystals in the endcaps), superconducting solenoid and muon system inside the magnet yoke. The superconducting solenoid provides a longitudinal magnetic field of 0.6 T. The detector is equipped with a tagging system of scattered electrons for two-photon studies. The on-line luminosity measurement is provided by two independent single bremsstrahlung monitors.

The trigger has two hardware levels: the primary (PT) and the secondary one (ST) [20]. The PT operates using signals from the TOF counters and fast signals from the CsI and LKr calorimeters, whereas the ST uses optimally shaped calorimeter signals and the information from VD, DC and the TOF system.

3. Experiment

The goal of the experiment was a measurement of the total hadronic cross section at seven equidistant points between 3.12 and 3.72 GeV. Two scans of the region were performed. The actual energies determined using the Compton backscattering method and the integrated luminosity at the points are presented in Table 1. The table also presents the relative contributions of the J/ψ and $\psi(2S)$ in the observed cross section dominated by their radiative tails. To determine them without external data, the additional data samples of about 0.4 pb^{-1} were collected at ten points in the peak regions. The data points and the resonance fits are shown in Fig. 1.

The energies of the points in two scans are not the same because of the inaccuracy of the collider energy setting, but they are close enough to allow for summation of data samples.

4. Data analysis

4.1. Analysis procedure

The observed hadronic annihilation cross section was determined from

Table 1
Center-of-mass energy $\sqrt{s}$, integrated luminosity $\int \mathcal{L}dt$ and relative contribution of the J/ψ and $\psi(2S)$ resonances to the observed multihadronic cross section.

Point	$\sqrt{s}$, MeV	$\int \mathcal{L}dt$, nb^{-1}	$\frac{\sigma_{J/\psi}}{\sigma_{\text{obs}}}$, %	$\frac{\sigma_{\psi(2S)}}{\sigma_{\text{obs}}}$, %
Scan 1				
1	3119.8 ± 0.2	64.31 ± 0.72	59.6	
2	3222.4 ± 0.2	74.79 ± 0.80	22.9	
3	3315.2 ± 0.2	83.25 ± 0.87	14.8	
4	3418.1 ± 0.2	95.68 ± 0.97	10.9	
5	3521.0 ± 0.2	112.36 ± 1.08	8.3	
6	3619.7 ± 0.2	34.72 ± 0.61	5.6	
7	3720.4 ± 0.2	55.57 ± 0.80	3.6	29.7
Scan 2				
1	3120.1 ± 0.2	54.46 ± 0.63	58.3	
2	3223.6 ± 0.2	65.77 ± 0.88	23.0	
3	3313.9 ± 0.2	50.93 ± 0.61	14.9	
4	3418.4 ± 0.2	66.88 ± 0.88	10.4	
5	3520.3 ± 0.2	59.33 ± 0.67	7.9	
6	3617.6 ± 0.2	83.35 ± 0.95	5.6	
7	3718.9 ± 0.2	103.66 ± 1.05	3.5	30.5

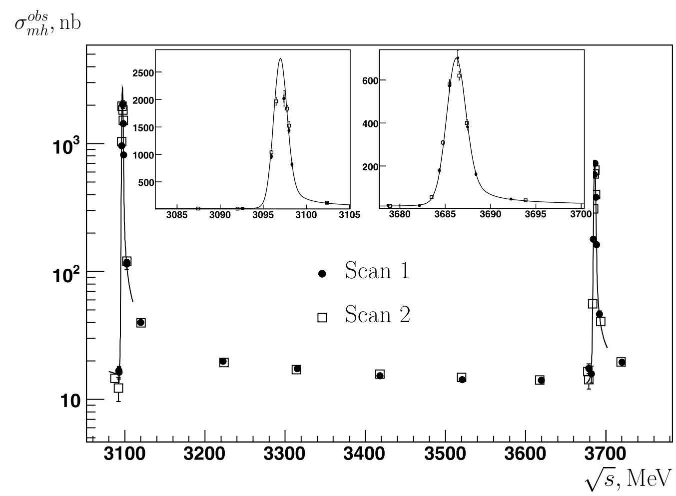

Fig. 1. The observed multihadronic cross section as a function of the c.m. energy for the two scans. The curves are the result of the fits of the narrow resonances. The inserts show closeup of the J/ψ and $\psi(2S)$ regions.

$$\sigma_{\text{obs}}(s) = \frac{N_{\text{mh}} - N_{\text{res.bg.}}}{\int \mathcal{L}dt}, \tag{1}$$

where N_{mh} is the number of events that pass hadronic selection criteria, $N_{\text{res.bg.}}$ is the residual machine background evaluated as discussed in Sec. 4.6, and $\int \mathcal{L}dt$ is the integrated luminosity.

For the given observed cross section the R value was calculated as follows:

$$R = \frac{\sigma_{\text{obs}}(s) - \sum \varepsilon_{\text{bg}}(s)\,\sigma_{\text{bg}}(s) - \sum \varepsilon_{\psi}(s)\,\sigma_{\psi}(s)}{\varepsilon(s)\,(1+\delta(s))\,\sigma^0_{\mu\mu}(s)}, \tag{2}$$

where $\sigma^0_{\mu\mu}(s)$ is the Born cross section for $e^+e^- \to \mu^+\mu^-$ and $\varepsilon(s)$ is the detection efficiency for the single photon annihilation to hadrons. The second term in the numerator corresponds to the physical background from e^+e^-, $\mu^+\mu^-$ production, $\tau^+\tau^-$ production above threshold and two-photon processes. The third term represents a contribution of the J/ψ and $\psi(2S)$. Unlike Refs. [9–12], we considered them explicitly instead of including in the radiation correction $\delta(s)$.

The detection efficiencies ε and ε_{bg} were determined from simulation. The efficiencies ε_ψ were found by fitting the resonance regions. The resonances were fitted separately in each scan, the free parameters were the detection efficiency at the world average values of the leptonic width Γ_{ee} and its product by the hadronic