NEW R VALUES IN 2-5 GeV FROM THE BEIJING SPECTROMETER

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The values of $R = \sigma(e^+e^- \to \text{hadrons})/\sigma(e^+e^- \to \mu^+\mu^-)$ for 85 center-of-mass energies between 2 and 5 GeV were measured with the upgraded Beijing Spectrometer at the Beijing Electron-Positron Collider, with an average uncertainty of $\sim 7\%$.

1 Introduction

The QED running coupling constant evaluated at the Z pole, $\alpha(M_Z^2)$, and the anomalous magnetic moment of the muon, $a_\mu = (g-2)/2$, are two fundamental quantities that are used to test the Standard Model (SM) [1]. The dominant uncertainties in both $\alpha(M_Z^2)$ and a_μ^{SM} are due to the effects of hadronic vacuum polarization, which cannot be reliably calculated. Instead, with the application of dispersion relations, experimentally measured R values are used to determine the vacuum polarization [1], where R is the lowest order cross section for $e^+e^- \to \gamma^* \to$ hadrons in units of the lowest-order QED cross section for $e^+e^- \to \mu^+\mu^-$, namely $R = \sigma(e^+e^- \to \text{hadrons})/\sigma(e^+e^- \to \mu^+\mu^-)$, where $\sigma(e^+e^- \to \mu^+\mu^-) = \sigma^0_{\mu\mu} = 4\pi\alpha^2(0)/3s$.

The uncertainties in $\alpha(M_Z^2)$ and a_μ^{SM} are dominated by the errors in the values of R in the center of mass (cm) energy range below 5 GeV. These were measured about 20 years ago with a precision of about $15 \sim 20\%$. Thus, new measurements of R in the energy region between 2 and 5 GeV with significantly improved precision are very important [1]. In this paper, we report measurements of R at 85 cm energies between 2 and 5 GeV, with an average precision of 6.6%.

2 R scan with BESII at BEPC

The measurements were carried out using the upgraded Beijing Spectrometer (BESII) [2] at the Beijing Electron Positron Collider (BEPC). BESII is a conventional collider detector based on a large solenoid magnet with a central field of 0.4 T.

Following a preliminary scan that measured R at six energy points between 2.6 and 5 GeV [3], we performed a finer R scan with 85 energy points covering the energy region between 2 and 4.8 GeV [4]. In order to understand beam-associated backgrounds, separated beam data were accumulated at 24 different energies and single beam runs for both e^- and e^+ were done at 7 energies interspersed throughout the entire energy range. Special runs were taken at the J/ψ resonance to determine the trigger efficiency. The J/ψ and $\psi(2S)$ resonances were scanned at the beginning and end of the R scan to calibrate the cm energy.

3 Data Analysis

Experimentally, the value of R is determined from the number of observed hadronic events, N_{had}^{obs}, by the relation

$$R = \frac{N_{had}^{obs} - N_{bg} - \sum_l N_{ll} - N_{\gamma\gamma}}{\sigma_{\mu\mu}^0 \cdot L \cdot \epsilon_{had} \cdot \epsilon_{trg} \cdot (1+\delta)}, \tag{1}$$

where N_{bg} is the number of beam-associated background events; $\sum_l N_{ll},\ (l = e, \mu, \tau)$ are the numbers of lepton-pair events from one-photon processes and $N_{\gamma\gamma}$ the number of two-photon process events that are misidentified as hadronic events; L is the integrated luminosity; δ is the radiative correction; ϵ_{had} is the detection efficiency for hadronic events; and ϵ_{trg} is the trigger efficiency.

The trigger efficiencies, measured by comparing the responses to different trigger requirements in special runs taken at the J/ψ resonance, are determined to be 99.96%, 99.33% and 99.76% for Bhabha, dimuon and hadronic events, respectively, with an error of 0.5% [3].

We developed a set of requirements on fiducial regions, vertex positions, track fit quality, maximum and minimum BSC energy deposition, track momenta and time-of-flight hits that preferentially distinguish one-photon multi-hadron production from all possible contamination mechanisms. Residual background contributions are due to cosmic rays, lepton pair production, two-photon interactions and single-beam-related processes. Additional requirements are imposed on two-prong events, for which cosmic ray and lepton pair backgrounds are especially severe [3].

The number of hadronic events and the beam-associated background level are determined by fitting the distribution of event vertices along the beam direction with a Gaussian for real hadronic events and a polynomial of degree two for the background, which can also be subtracted by applying the same hadronic event selection criteria to separated-beam data [3]. The differences in R values with these two methods range between 0.3 and 2.3%, depending on the energy.

The integrated luminosity is determined from the number of large-angle Bhabha events selected using only the BSC energy deposition.

JETSET, the commonly used event generator for $e^+e^- \to$ hadrons, was not intended to be applicable to the low energy region, especially that below 3 GeV. A new generator, LUARLW, was developed by the Lund group and the BES collaboration. The generator uses a formalism based on the Lund Model Area Law, but without the extreme-high-energy approximations used in JETSET's string fragmentation algorithm [5]. The final states simulated in LUARLW are exclusive in contrast to JETSET, where they are inclusive. Above 3.77 GeV, the production of charmed mesons is included in the generator according to the Eichten Model [6,7].

The parameters in LUARLW are tuned to reproduce the observed multiplicity, sphericity, angular and momentum distributions, etc., over the entire energy region covered by the scan. The uncertainty of detection efficiency is 2%, estimated by varying the parameters in LUARLW. The detection efficiencies were also determined using JETSET74 for the energies above 3 GeV. The difference between the JETSET74 and LUARLW results is about 1%, and is also taken into account in estimating the systematic uncertainty.

Different schemes for the radiative corrections were compared [8,9,10,11]. The schemes of Refs. [10] and [11] take into account vacuum polarization not only for electrons and muons, but also taus and hadrons. The correction factors calculated with these two approaches are consistent within 0.5% in the continuum and differ by less than 1% in the charm resonance region. The formalism of Ref. [11] is used in our calculation, and differences with the schemes described in Ref. [10] are included in the systematic errors. In the calculation of the radiative correction above charm threshold, where the resonances are broad and where the total width of the resonance is energy-dependent, we take the interference between resonances into account.

4 The Results

Table 1 lists the R values measured by BES in this experiment. They are displayed in Fig. 1, together with BESII values from Ref. [3] and those measured by MarkI, $\gamma\gamma 2$, and Pluto [12,13,14]. The R values from BESII have an average uncertainty of about 6.6%, which represents a factor of two to three improvement in precision in the 2 to 5 GeV energy region. These improved measurements should have a significant impact on the global fit to the electroweak data and the determination of the SM prediction for the mass of the Higgs particle. In addition, they are expected to provide an improvement in the precision of the calculated value of a_μ^{SM} [15,16].

Table 1: The measured R values obtained in this experiment; the first error is statistical, the second systematic.

E_{cm} (GeV)	R	E_{cm} (GeV)	R	E_{cm} (GeV)	R	E_{cm} (GeV)	R
2.000	$2.18 \pm 0.07 \pm 0.18$	3.890	$2.64 \pm 0.11 \pm 0.15$	4.120	$4.11 \pm 0.24 \pm 0.23$	4.340	$3.27 \pm 0.15 \pm 0.18$
2.200	$2.38 \pm 0.07 \pm 0.17$	3.930	$3.18 \pm 0.14 \pm 0.17$	4.130	$3.99 \pm 0.15 \pm 0.17$	4.350	$3.49 \pm 0.14 \pm 0.14$
2.400	$2.38 \pm 0.07 \pm 0.14$	3.940	$2.94 \pm 0.13 \pm 0.19$	4.140	$3.83 \pm 0.15 \pm 0.18$	4.360	$3.47 \pm 0.13 \pm 0.18$
2.500	$2.39 \pm 0.08 \pm 0.15$	3.950	$2.97 \pm 0.13 \pm 0.17$	4.150	$4.21 \pm 0.18 \pm 0.19$	4.380	$3.50 \pm 0.15 \pm 0.17$
2.600	$2.38 \pm 0.06 \pm 0.15$	3.960	$2.79 \pm 0.12 \pm 0.17$	4.160	$4.12 \pm 0.15 \pm 0.16$	4.390	$3.48 \pm 0.16 \pm 0.16$
2.700	$2.30 \pm 0.07 \pm 0.13$	3.970	$3.29 \pm 0.13 \pm 0.13$	4.170	$4.12 \pm 0.15 \pm 0.19$	4.400	$3.91 \pm 0.16 \pm 0.19$
2.800	$2.17 \pm 0.06 \pm 0.14$	3.980	$3.13 \pm 0.14 \pm 0.16$	4.180	$4.18 \pm 0.17 \pm 0.18$	4.410	$3.79 \pm 0.15 \pm 0.20$
2.900	$2.22 \pm 0.07 \pm 0.13$	3.990	$3.06 \pm 0.15 \pm 0.18$	4.190	$4.01 \pm 0.14 \pm 0.14$	4.420	$3.68 \pm 0.14 \pm 0.17$
3.000	$2.21 \pm 0.05 \pm 0.11$	4.000	$3.16 \pm 0.14 \pm 0.15$	4.200	$3.87 \pm 0.16 \pm 0.16$	4.430	$4.02 \pm 0.16 \pm 0.20$
3.700	$2.23 \pm 0.08 \pm 0.08$	4.010	$3.53 \pm 0.16 \pm 0.20$	4.210	$3.20 \pm 0.16 \pm 0.17$	4.440	$3.85 \pm 0.17 \pm 0.17$
3.730	$2.10 \pm 0.08 \pm 0.14$	4.020	$4.43 \pm 0.16 \pm 0.21$	4.220	$3.62 \pm 0.15 \pm 0.20$	4.450	$3.75 \pm 0.15 \pm 0.17$
3.750	$2.47 \pm 0.09 \pm 0.12$	4.027	$4.58 \pm 0.18 \pm 0.21$	4.230	$3.21 \pm 0.13 \pm 0.15$	4.460	$3.66 \pm 0.17 \pm 0.16$
3.760	$2.77 \pm 0.11 \pm 0.13$	4.030	$4.58 \pm 0.20 \pm 0.23$	4.240	$3.24 \pm 0.12 \pm 0.15$	4.480	$3.54 \pm 0.17 \pm 0.18$
3.764	$3.29 \pm 0.27 \pm 0.29$	4.033	$4.32 \pm 0.17 \pm 0.22$	4.245	$2.97 \pm 0.11 \pm 0.14$	4.500	$3.49 \pm 0.14 \pm 0.15$
3.768	$3.80 \pm 0.33 \pm 0.25$	4.040	$4.40 \pm 0.17 \pm 0.19$	4.250	$2.71 \pm 0.12 \pm 0.13$	4.520	$3.25 \pm 0.13 \pm 0.15$
3.770	$3.55 \pm 0.14 \pm 0.19$	4.050	$4.23 \pm 0.17 \pm 0.22$	4.255	$2.88 \pm 0.11 \pm 0.14$	4.540	$3.23 \pm 0.14 \pm 0.18$
3.772	$3.12 \pm 0.24 \pm 0.23$	4.060	$4.65 \pm 0.19 \pm 0.19$	4.260	$2.97 \pm 0.11 \pm 0.14$	4.560	$3.62 \pm 0.13 \pm 0.16$
3.776	$3.26 \pm 0.26 \pm 0.19$	4.070	$4.14 \pm 0.20 \pm 0.19$	4.265	$3.04 \pm 0.13 \pm 0.14$	4.600	$3.31 \pm 0.11 \pm 0.16$
3.780	$3.28 \pm 0.12 \pm 0.12$	4.080	$4.24 \pm 0.21 \pm 0.18$	4.270	$3.26 \pm 0.12 \pm 0.16$	4.800	$3.66 \pm 0.14 \pm 0.19$
3.790	$2.62 \pm 0.11 \pm 0.10$	4.090	$4.06 \pm 0.17 \pm 0.18$	4.280	$3.08 \pm 0.12 \pm 0.15$		
3.810	$2.38 \pm 0.10 \pm 0.12$	4.100	$3.97 \pm 0.16 \pm 0.18$	4.300	$3.11 \pm 0.12 \pm 0.12$		
3.850	$2.47 \pm 0.11 \pm 0.13$	4.110	$3.92 \pm 0.16 \pm 0.19$	4.320	$2.96 \pm 0.12 \pm 0.14$		

Further improvements in the accuracy of R measurements at BEPC will require higher machine luminosity, especially for energies below 3.0 GeV, and better detector performance, particularly in the area of calorimetry. Increased precision in the areas of hadronic event simulation and the calculation of the radiative correction are also required.

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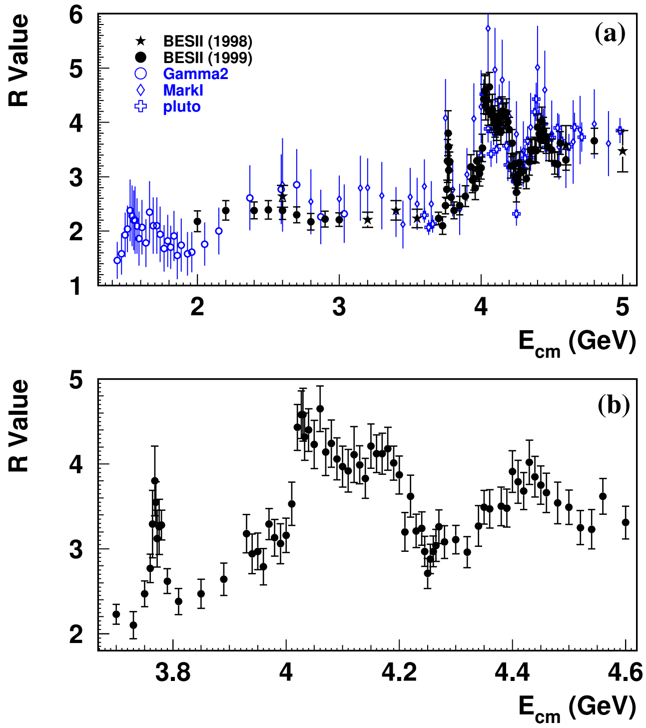

Figure 1: (a) A compilation of measurements of R in the cm energy range from 1.4 to 5 GeV. (b) R values from this experiment in the resonance region between 3.75 and 4.6 GeV.

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