Measurement of R Between 2-5 GeV

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We have obtained measurements of the total cross section for e^+e^- annihilation into hadronic final states for 6 energy points (2.6, 3.2, 2.4, 3.55, 4.6, and 5.0 GeV) with the upgraded Beijing Spectrometer (BESII). We report preliminary values from this data and outline future plans for a finer scan in the 2-5 GeV energy range.

1 Introduction

Two topics that depend on measurements in the center of mass (CM) energy range of a few GeV are of current interest. One is the precision of the QED coupling constant evaluated at the mass of the Z boson, $\alpha(M_Z^2)$, and the other is the anomalous magnetic moment of the muon, a_μ. Both are accessible via a measurement of the lowest order cross-section for $e^+e^- \to \gamma^* \to$ hadrons, which is usually parameterized in terms of the ratio R, defined as

$$R \equiv \frac{\sigma(e^+e^- \to \text{hadrons})}{\sigma(e^+e^- \to \mu^+\mu^-)}, \tag{1}$$

where the denominator is the lowest-order QED cross section and equals $4\pi\alpha^2/3s$.

The R ratio has been measured by many experiments over a large CM energy range from the hadron production threshold to the Z^0 mass [1]. Experimentally determined R values are, in general, consistent with theoretical predictions, and provide an impressive confirmation of the hypothesis of three color degrees of freedom for quarks.

The current values for R below 5 GeV have experimental uncertainties on the order of 15% [2,3,4,5]. These uncertainties limit the precision of $\alpha(M_Z^2)^{-1}$ [9] and a_μ and in turn the determination of the Higgs mass from radiative corrections in the standard model [6,7,8].

The BES collaboration has started a program of R measurements over the 2-5 GeV energy range with the goal of reducing the present uncertainties by a factor of two or more. The measurements were carried out with the upgraded BES detector (BESII), which is a conventional solenoidal detector that is described in some detail in Ref. 10.

2 Data Analysis

A first scan of R measurements was performed in the spring of 1998 with data samples of about 1000-2000 hadronic events collected each at 2.6, 3.2, 3.4, 3.55, 4.6 and 5.0 GeV. To understand beam-associated backgrounds, separated beam data were taken at each energy point, and single beam data were accumulated at 3.55 GeV. Additionally, data were taken at the J/ψ and ψ' resonances to provide a precise energy calibration as well as to determine the trigger efficiencies for the Bhabha, dimuon and hadronic events measured in the R scan. The 3.4 GeV point was remeasured after a time interval of about two weeks to test the stability of the detector.

The value of R is determined from the number of observed hadronic events (N_{had}^{obs}) by the relation

$$R = \frac{\sigma^0(e^+e^- \to \text{hadrons})}{\sigma^0(e^+e^- \to \mu^+\mu^-)} = \frac{N_{had}^{obs} - N_{bg} - \sum_l N_{ll} - N_{\gamma\gamma}}{\sigma_{\mu\mu}^0 \cdot L \cdot \epsilon_{had} \cdot \epsilon_{trg} \cdot (1+\delta)}, \tag{2}$$

where σ^0 is the tree-level cross-section of the particular process, N_{bg} is the number of beam associated background events; $\sum_l N_{ll}$, $(l = e, \mu, \tau)$ and $N_{\gamma\gamma}$ are the numbers of misidentified lepton-pair and two-photon processes events; L is the integrated luminosity; δ is the correction for initial state radiation; and ϵ_{had} and ϵ_{trg} represent the detection and trigger efficiencies for the hadronic events.

2.1 Hadronic Event Selection and Background subtraction

The dE/dx information, plus polar angle, energy, momentum and TOF cuts were used to identify a good track. After the track-level selection, a further event-level selection, based on the angle between tracks and their energy, was used to distinguish good events from cosmic rays and lepton pair events. Tau pair production and residual two-photon processes, were subtracted out statistically via a Monte Carlo simulation. Most beam gas and beam-wall background events were rejected by a vertex cut. The same hadronic event selection criteria were applied to the separated-beam data, and the number of the beam associated background events N_{bg} in the corresponding hadronic event sample was obtained as a function of the number of separated-beam events N_{sep}, the pressure P at the collision region, and the integrated beam current I.

The performance of the event selection routines were checked by hand scans, which were carried out for both the selected and rejected hadronic events, the separated-beam data, and the Monte Carlo events. We determined the error associated with the hadronic selection criteria from changes in the event yield caused by varying the selection requirements and from the results of the hand scan.

2.2 Luminosity, Hadronic Detection Efficiency and Initial State Radiation

The integrated luminosity was determined using large-angle Bhabha events with selection criteria based on the energy and the angular distribution of two clusters in the BSC. A cross check using only MDC information (dE/dx) was generally consistent with the BSC measurement; the difference was taken into account in the systematic error.

The detection efficiency for hadronic events was determined via a Monte Carlo simulation using the JETSET7.4 event generator [11]. Parameters in the JETSET7.4 generator were tuned using more than 40,000 hadronic events selected from the tau mass measurement data sample [12]. The parameters of the generator were adjusted to reproduce distributions of kinematic variables such as multiplicity, sphericity, transverse momentum, etc. Figure 1 shows the charge multiplicity, the sphericity, the aplanarity and the transverse momentum distributions for the real and simulated event samples.

The effect of radiative corrections on the measured cross-section was examined in detail. Four different schemes were examined: Berends and Kleiss [13], Kuraev and Fadin [14], Bonneau and Martin [15], and a method used by the Crystal Ball [16]. Radiative corrections calculated by all these methods were consistent to within 1% for off-resonance points, but could differ by 1-3% in resonance regions.

We used the approach of Bonneau and Martin, with the differences from the other schemes included in the systematic error.

2.3 Trigger

A two-level trigger system retained good events while rejecting background [10]. Event candidates fulfilling the two-level criteria were accepted.

The trigger efficiencies were measured using data taken in special runs made at the J/ψ resonance, by comparing the responses to different trigger requirements. Trigger efficiencies were respectively 99.5% for Bhabha events, 98.2% for dimuon type events and 99.2% for hadronic events.

2.4 Preliminary Results and Future Plans

The preliminary R values obtained at the six energy points are shown in Table 1 and graphically displayed in Figure 2. A further breakdown of contributions to the systematic errors is given in Table 2. In 1999, BES-II will carry out a finer scan from 2 to 5 GeV. Our goal is to reduce the present uncertainties of R by at least a factor of two over this entire energy region.

Table 1: Summary of R data and values.

E_{cm}	N_{had}^{obs}	N_{bg}	L (nb^{-1})	$\epsilon_{had}(\%)$	$(1+\delta)$	$\sigma_{\mu\mu}^{0}$	R value	Syst. err.	Stat. err.
2.60	5617	8	292.9	0.5482	1.009	12.840	2.61	6.59%	1.36%
3.20	2051	10	109.3	0.6430	1.447	8.477	2.25	5.65%	2.27%
3.40	2149	46	135.3	0.6961	1.173	7.509	2.36	6.80%	2.26%
3.55	2672	50	200.2	0.6840	1.125	6.888	2.29	7.17%	2.03%
4.60	1497	48	87.7	0.8227	1.079	4.102	3.53	8.93%	2.98%
5.00	1648	26	102.3	0.8453	1.068	3.472	3.42	10.27%	3.02%

Table 2: Contributions to systematic errors. All errors are in percentages (%).

E_{cm}	Had. select	Background	L	τ-pair	Bhabhas	ϵ_{had}	Trigger	Rad. corr
2.60	5.25	0.06	2.12	0.00	0.04	2.60	0.50	2.6
3.20	4.03	0.15	2.83	0.00	0.04	1.90	0.50	2.2
3.40	5.06	0.27	2.83	0.00	0.04	2.90	0.50	3.0
3.55	6.05	0.27	2.32	0.00	0.04	2.30	0.50	2.4
4.60	7.58	0.75	2.16	0.32	0.00	3.60	0.50	4.1
5.00	9.00	1.26	2.81	0.32	0.00	3.20	0.50	3.8

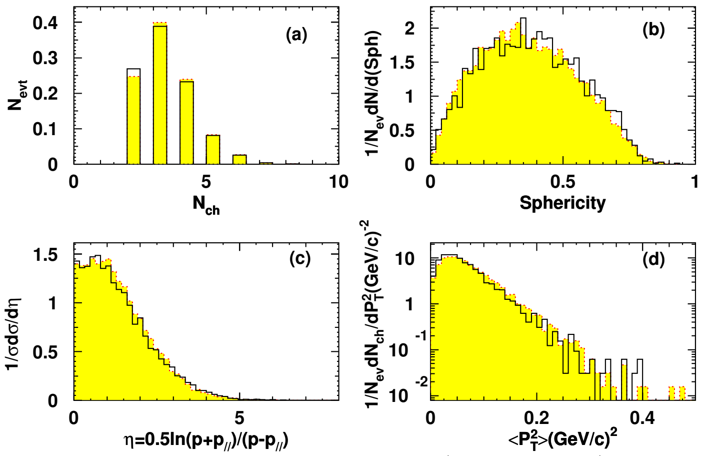

Figure 1: Comparison of hadronic event shapes between data (shaded region) and Monte Carlo (histogram). (a) Multiplicity; (b) Sphericity; (c) Rapidity; (d) Transverse momentum.

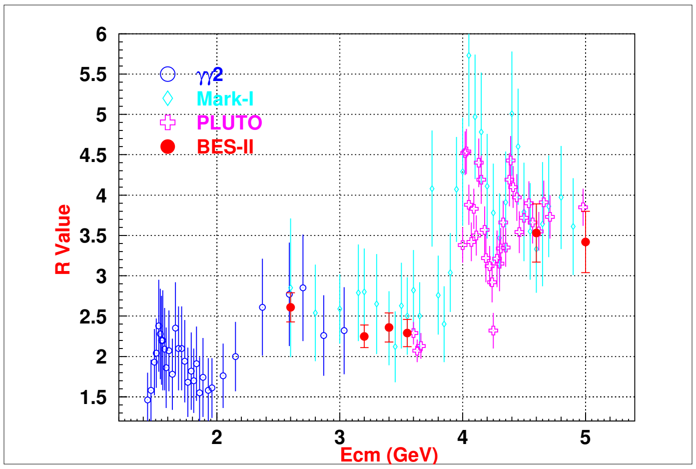

Figure 2: Plot of R values at the 6 data points vs E_{cm}.

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