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R-value measurements at BESIII

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Summary. — The R-value, defined as the ratio of inclusive hadronic cross section over dimuon cross section from electron-positron annihilation, is an important quantity that contributes to the SM prediction of the muon anomalous magnetic moment, and in the determination of the QED running coupling constant evaluated at the Z-pole. At BESIII, the R-value is measured with a total of 14 data points with the corresponding c.m. energy going from 2.2324 to 3.6710 GeV. The statistical uncertainty of the measured R is less than 0.6%. Two different simulation models, the LUARLW and a new hybrid generator, are used and give consistent detection and initial-state radiation corrections. An accuracy of better than 2.6% below 3.1 GeV and 3.0% above is achieved in the R-value measurements.

1. – Introduction

The R-value is defined as the leading-order production cross section ratio of hadrons and muon pairs in electron-positron annihilation,

$$R_{had} = \frac{\sigma^0(e^+e^- \to Hadrons)}{\sigma^0(e^+e^- \to \mu^+\mu^-)}. \tag{1}$$

The running QED coupling constant at the Z-pole $\alpha_{QED}(M_Z^2)$ and the anomalous magnetic moment of the muon $a_\mu = (g_\mu - 2)/2$ provide important precision tests of the Standard Model. Moreover, up to date the muon anomaly a_μ is determined at less than 0.5 ppm accuracy in both experiment [1] and theory [2], with a 4.2σ discrepancy which can be a hint of physics beyond the Standard Model. Precise experimental R-value measurements are fundamental to determine both the running QED coupling constant at the Z-pole, $\alpha_{QED}(M_Z^2)$, and the muon anomaly, $a_\mu^{SM} = (g-2)_\mu/2$. For both, the

(*) On behalf of the BESIII Collaboration.

dominant theoretical uncertainties are due to the hadronic vacuum polarization (HVP), which cannot be reliably calculated in the low-energy region. Indeed it is determined by dispersion integral, thanks to optical theorem, using the experimental R-value as input.

About 20 experiments contribute to R measurements, ~ 10 in the lower-energy region, with a precision around 6.6% from 2 to 5 GeV [3-5]. In this energy range the best accuracy, about 3.3%, was achieved by BESII and KEDR at a few energy points [4, 5]. The BESIII experiment at the e^+e^- collider BEPCII in Beijing has collected data at 130 different energies between 2.0 GeV and 4.6 GeV with the purpose to measure R-value with more than 10^5 events for each point.

2. – R experimental measurement

The measurement, that we have recently published [6] is an inclusive R-value measurement. The R-value is measured at 14 center-of-mass (c.m.) energies from 2.2324 to 3.6710 GeV, with data sets collected with the BESIII detector [7] at Beijing Electron-Positron Collider II. In experiment, R-value is determined by

$$R = \frac{N_{had} - N_{bkg}}{\sigma^0(e^+e^- \to \mu^+\mu^-) \cdot L \cdot \epsilon_{had} \cdot \epsilon_{trig} \cdot (1+\delta)}\,, \tag{2}$$

where N_{had} is the number of observed hadronic events, N_{bkg} is the number of background events, L is integrated luminosity, determined by Large Angle BhaBha, ϵ_{had} is the hadronic event selection efficiency, determined by hadronic event MC sample, $(1+\delta)$ is the initial state radiation (ISR) correction factor, and $\sigma^0(e^+e^- \to \mu^+\mu^-) = 4\pi\alpha^2(0)/3s$ is the leading-order cross section of $e^+e^- \to \mu^+\mu^-$, where s is the square of the center-of-mass (c.m.) energy. The trigger efficiency ϵ_{trig} for hadronic event at BESIII is very close to 100%.

The signal events are the hadronic events. They must have at least two good charged tracks with additional requirements to suppress background in two-prong and three-prong events. All the details can be found in ref. [6]. Events with more than three prongs are directly counted as hadronic events without any additional requirement.

After these selections the dominant backgrounds are beam-associated and QED events, like dilepton or digamma processes. The residual QED background can be accurately simulated, allowing its subtraction from data.

Furthermore the beam-associated background contribution can be estimated with side band method and subtracted.

A crucial and challenging task is the hadronic detection efficiency determination. For low-energy experiments, the ISR effects and event generators are comprehensively reviewed in ref. [8]. Monte Carlo samples generated by the LUARLW model, developed to simulate inclusive hadronic events [9] are used for this task.

The LUARLW generator has been used in the R-value measurements by BESII and KEDR experiment. Based on the Lund area law, it can simulate hadronic production in e^+e^- annihilation and decays of the continuumn and resonant states from $2m_{\pi^0}$ to 5 GeV. A fine tuning has been performed on its parameters controlling the sampling of flavors, multiplicities, and kinematic quantities of generated initial hadrons by extensive comparisons between simulation and data. After this tuning, the agreement is shown in fig. 1, where the distributions of some crucial observables are shown comparing signal.

MC sample and data. Figure 2 shows the R-value measurements obtained in this analysis as a function of the $\sqrt{s}$, together with previous measurements [3-5]. A theoretical

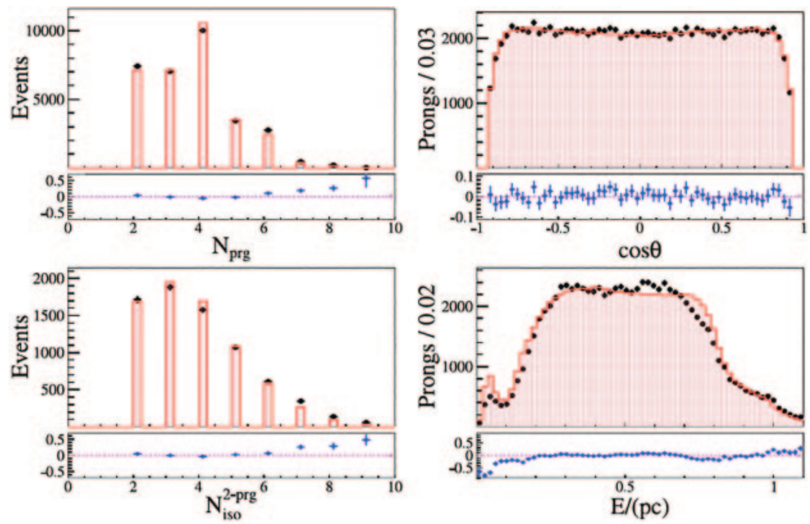

Fig. 1. – Comparison between data (black dots) and simulation, based on LUARLAW generator (red histogram) at $\sqrt{s} = 3.4000\,\mathrm{GeV}$. In these distributions N_{prong} is the number of charged tracks, $N_{iso}^{2-prong}$ the number of isolated photons in two-prong events and the others are track level variables: the polar angle of the track (θ) and the ratio of the energy deposited in the electromagnetic calorimeter (E) over the momentum (p) measured in the tracking system.

expectation obtained by combining the perturbative QCD prediction [10] and the contributions from involved narrow resonances is also shown by dotted purple line.

Average R-values are larger than the pQCD prediction by 2.7 σ, higher than KEDR [5] by 1.7 σ between 3.4 and 3.6 GeV. The achieved accuracy is better than 2.6% below 3.1 GeV and 3.0% above, dominated by systematic uncertainties.

The dominant sources of systematic uncertainties can be found in the simulation of the inclusive hadronic events and the calculation of the ISR correction factors. To estimate these uncertainties, a composite generator ("hybrid") [11] has been developed and

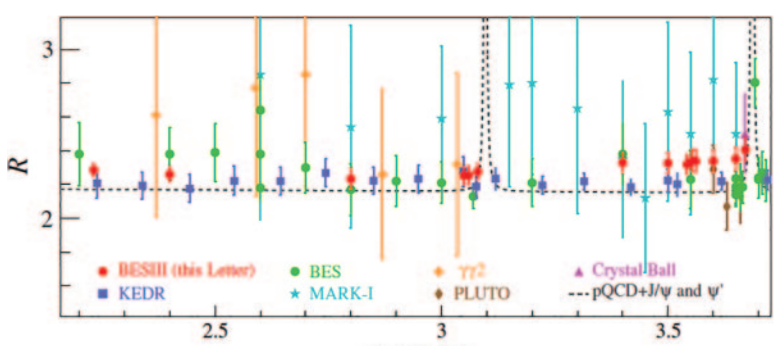

Fig. 2. – R-values in the c.m. energy region from 2.2 to 3.7 GeV are reported. The red dots are the recent BESIII measurements and the other colours and symbols denote the previous experiments as detailed in the legend.

widely studied. The idea was to use as much experimental information as possible. The hybrid generator combines three generators: CONEXC [12] with about 50 channels with cross sections measured in experiment, PHOKHARA [13] with 10 exclusive channels in which hadronic models are tuned to experiment and LUARLW for the other processes. Up-to-date experimental knowledge is implemented. Alternative ISR and vacuum polarization correction schemes from the nominal ones are adopted. The maximum difference of the calculated ISR correction factor between HYBRID and LUARLW simulations is 1.4%, mainly due to the different parametrization schemes of the ISR process. Being the hadronic detection efficiency related with the ISR correction, the deviations of the resulting R-values between these two simulation schemes is assigned as systematic uncertainty and is less than 2.3%.

3. – Conclusions and outlook

R-value measurements in the complete data sets is on-going in BESIII and the full program will cover the range between 2.0 and 4.96 GeV. R measurement both in the continuum and open-charm regions with high accuracy would have significant impact on precision tests of the Standard Model. In BESIII different approches for R measurement are being investigated. In particular ISR method can exploit large available charmonia data and can allow the comparison between inclusive and exclusive measurements below 2 GeV, not accessible by scan data.

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