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Recent results from the KEDR detector at the VEPP-4M

TODYSHEV K. Yu. [1,2] (for the KEDR collaboration)

(1. *Budker Institute of Nuclear Physics*, *Novosibirsk* 630090, *Russia*;
2. *Novosibirsk State University*, *Novosibirsk* 630090, *Russia*)

Abstract: The result is presented of precise measurement the values of $R_{\rm uds}$ and R at seven points of the center-of-mass energy between 3.12 and 3.72 GeV based on the data collected with the KEDR detector at the VEPP-4M e^+e^- collider in Novosibirsk. Also present is the preliminary result of determination of the product of the electron partial width by the branching fraction into hadrons of J/ψ resonance.

Key words: R measurement; J/ψ resonance; charmonium

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VEPP-4M 对撞机上 KEDR 探测器的最新结果

TODYSHEV K. Yu. [1,2] (KEDR 合作组)

(1. 布德克尔核物理研究所，新西伯利亚 630090，俄罗斯；2. 新西伯利亚州立大学，新西伯利亚 630090，俄罗斯)

摘要：基于新西伯利亚 VEPP-4M 正负电子对撞机的 KEDR 探测器采集的数据，报道了质心能量在 3.12～3.72 GeV 之间 7 个能量点的 $R_{\rm uds}$和 R 值的精确测量结果. 同时报道了 J/ψ 共振态衰变的电子和强子的联合分宽度.

关键词：R 值测量；J/ψ 共振态；粲偶素

0 Introduction

One of the most important quantities measured in e^+e^- annihilation is R, 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 crucial to testing QCD predictions and allow one to determine the value of the strong coupling constant $\alpha_s(s)$, the anomalous magnetic moment of the muon $(g-2)_\mu$ and the value of the electromagnetic fine structure constant at the Z^0 peak $\alpha(M_Z^2)$. Note that the systematic errors dominate in all experiments to measure the R value in the energy region between the J/ψ and $\psi(2S)$. That is a good motivation for new experiments on the precise measurement of R in this energy range.

The knowledge of the narrow resonance parameters allows us to calculate analytically their

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Biography: TODYSHEV K. Yu., male, born in 1977, PhD. Research field: high energy physics. E-mail: todyshev@inp.nsk.su

contribution in R. The product of the dielectronic width of the J/ψ resonance and the branching fraction for its decay to hadrons, $\Gamma_{ee}\boldsymbol{B}_{\mathrm{hadr}}$ was measured in the KEDR experiment, and the preliminary result is reported in the present article.

1 R measurement

1.1 Analysis

The following principles are used in our analysis. We subtract tails of the J/ψ and $\psi(2S)$ resonances from the observed cross section taking into account contributions from physical processes. The vacuum polarization is calculated without the contribution of narrow resonances.

The R value was calculated as follows:

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

where $\sigma_{\mathrm{obs}}(s)=\dfrac{N_{\mathrm{mh}}-N_{\mathrm{res.\,bg.}}}{\int \boldsymbol{L}\mathrm{d}t}$ is observed hadronic annihilation cross section, N_{mh} represents all events that pass hadronic selection criteria, $N_{\mathrm{res.\,bg.}}$ represents the residual machine background. $\sigma^{0}_{\mu\mu}(s)$ 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 $\psi(2S)$.

The detection efficiencies ε and $\varepsilon_{\mathrm{bg}}$ 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 branching fraction $\boldsymbol{B}_{\mathrm{hadr}}$, the machine energy spread and the observed continuum cross section magnitude in the reference point below the resonance. The procedures of a narrow resonance cross section calculation and fitting are described in more detail in Refs. [1-2].

In our approach the radiative correction factor can be written as

$$1+\delta(s)=\int\frac{\mathrm{d}x}{1-x}\,\frac{\boldsymbol{F}(s,x)}{|1-\widetilde{\Pi}((1-x)s)|^{2}}\cdot\frac{\widetilde{R}((1-x)s)\varepsilon((1-x)s)}{R(s)\varepsilon(s)} \tag{2}$$

where $\boldsymbol{F}(s,x)$ is the radiative correction kernel[3]. The vacuum polarizations $\widetilde{\Pi}$ and $\widetilde{R}$ do not include the J/ψ and $\psi(2S)$ resonances.

It should be mentioned that, using the way described above we get the R_{uds} value. To obtain the quantity R, it is necessary to take into account the contribution of narrow resonances.

1.2 Experiment description and results

In 2011 the region of the J/ψ and $\psi(2S)$ resonances was scanned in the KEDR experiment with an integrated luminosity of about 1 pb^{-1} at seven energy points. To determine the relative contributions of the J/ψ and $\psi(2S)$ in the observed cross section 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 following sources of systematic uncertainty have been considered for the R measurement at each energy point: luminosity, radiative correction, systematic uncertainties related to the detection efficiency of hadronic events, detector response, background from physical processes and residual machine background from the accelerator.

The major sources of the systematic uncertainty on the R_{uds} value are listed in Tab. 1. The uncertainties vary depending on the energy points.

During data collection at a given energy point the relative beam energy variation was less than 10^{-3} allowing us to neglect this source of uncertainty.

The obtained R_{uds} and R values and luminosity-weighted average center-of-mass energies are presented in Tab. 2. The results and analysis presented above are discussed in more detail in Ref. [4].

Tab. 1 R_{uds} systematic uncertainties

Source	Uncertainty/%
Continuum simulation	1.4～2.1
Luminosity measurement	1.1
Radiative correction	0.4～0.6
J/ψ and $\psi(2S)$ contribution	0.1～2.8
e^+e^-X contribution	0.1～0.2
l^+l^- contribution	0.1～0.2
Trigger efficiency	0.2
Nuclear interaction	0.2
Cuts variation	0.6
Machine background	0.5～1.1
Sum in quadrature	2.1～3.6

Tab. 2 Measured values of $R_{\text{uds}}(s)$ and $R(s)$ with statistical and systematic uncertainties

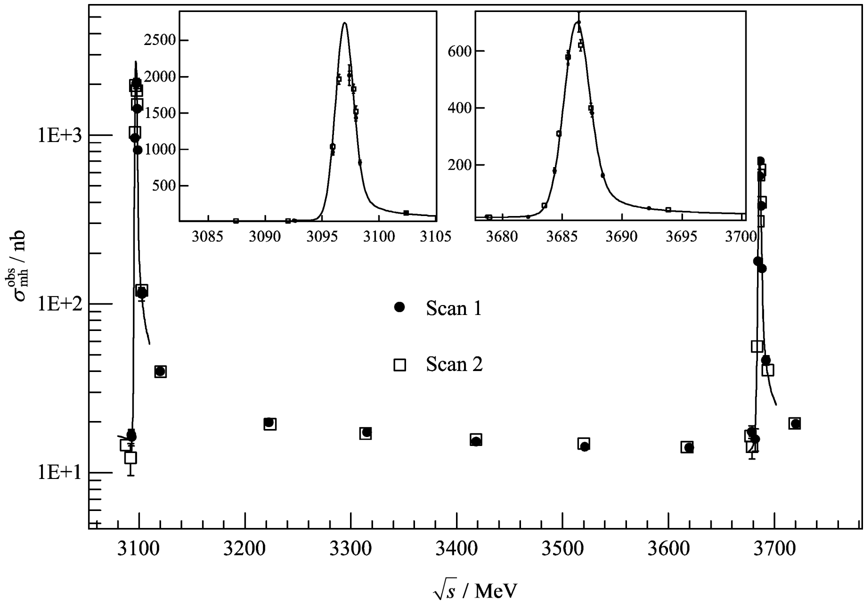
$\sqrt{s}$/MeV	$R_{\text{uds}}(s)\{R(s)\}$
3119.9±0.2	2.215{2.237}±0.089±0.066
3223.0±0.6	2.172{2.173}±0.057±0.045
3314.7±0.7	2.200{2.200}±0.056±0.043
3418.2±0.2	2.168{2.168}±0.050±0.042
3520.8±0.4	2.200{2.201}±0.050±0.044
3618.2±1.0	2.201{2.207}±0.059±0.044
3719.4±0.7	2.187{2.211}±0.068±0.060

2 $\Gamma_{e^+e^-}(J/\psi)\cdot \boldsymbol{B}(J/\psi\to\text{hadrons})$ analysis

The product of the dielectronic width of the J/ψ resonance and branching fraction for its decay to hadrons, $\Gamma_{e^+e^-}\times \boldsymbol{B}_{\text{hadr}}$, was measured in experiment with KEDR detector performed during energy scan at the VEPP-4M e^+e^- collider in 2005. In that experiment, the integrated luminosity 230 nb^{-1} was collected, which corresponds to about 250 thousand J/ψ mesons.

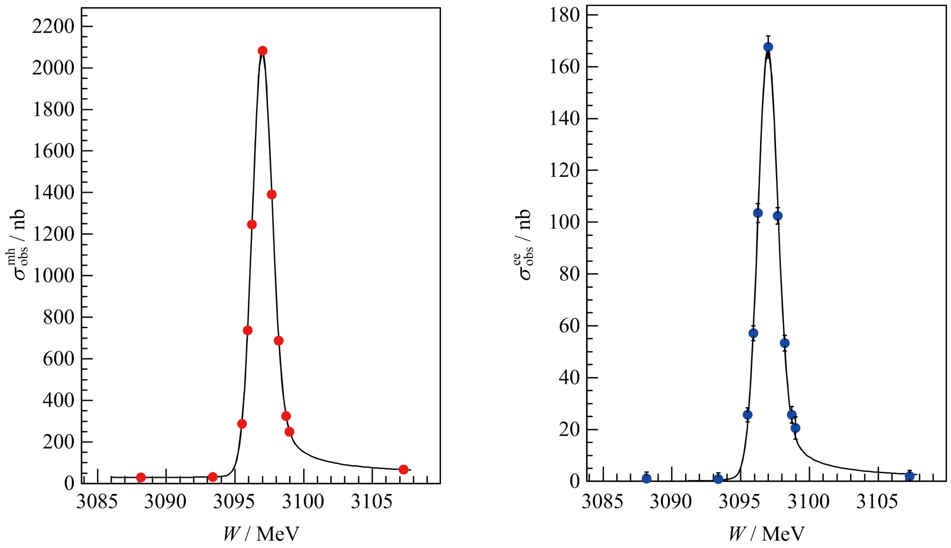
Analytical expression for the e^+e^- annihilation cross section near a narrow resonance in the soft photon approximation was first obtained in Ref. [5] forty years ago. With up-to-date modifications the procedures of a narrow resonance cross section calculation can be found in Refs. [1-2]. The hadronic cross section includes a resonant part and interference which are proportional to leptonic and hadronic widths. The observed multihadron and e^+e^- production cross sections as a function of the center of mass energy near J/ψ resonance are presented in Fig. 2.

The fitting of the resonance cross section allows us to determine the product dielectronic



The curves are the result of the fits of the narrow resonances. The inserts show the closeup of the J/ψ and $\psi(2S)$ regions.

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 combined fit. All data are corrected for the efficiency.

Fig. 2　The observed multihadron cross section as a function of the c. m. energy (left figure) and cross section of the process $J/\psi \to e^+e^-$ (right figure)

width and hadronic branching fraction. The preliminary result is $\Gamma_{ee} \times \boldsymbol{B}_{hadr} = (4.88 \pm 0.07 \pm 0.15)$ keV. The main sources of systematic uncertainties are listed in Tab. 3.

Tab. 3　Main systematic uncertainties in the measurements $\Gamma_{ee} \times \boldsymbol{B}_{hadr}$ of J/ψ

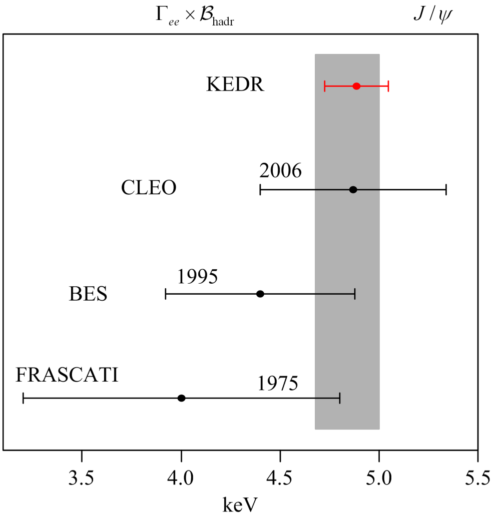
Source	Uncertainty/%
J/ψ decay simulation	2.0
Luminosity measurement	1.5
Detector response	1.5
Energy determination	0.5
Other	0.5
Sum in quadrature	3.0

Our preliminary result agrees with those of other measurements and has a better precision, as shown in Fig. 3.

3　Conclusion

We have measured the R ratio at seven points with the center-of-mass energy between 3.12 and 3.72 GeV. The achieved accuracy is about or better than 3.3% at most of energy points at the systematic uncertainty of about 2.1%.

The products of the dielectron width of the J/ψ meson and the branching fraction of its decays to the hadrons were preliminarily measured with an accuracy of 3.4%.



The gray band corresponds to the world-average value[6] with allowance for the uncertainty in it.

Fig. 3　Results of experiments aimed at measuring the product of the dielectronic-decay width of the J/ψ meson and the branching ratio for its decay to hadrons

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