Measurement of $\Gamma_{ee}(J/\psi)\cdot\mathcal{B}_{hadrons}(J/\psi)$ with KEDR detector

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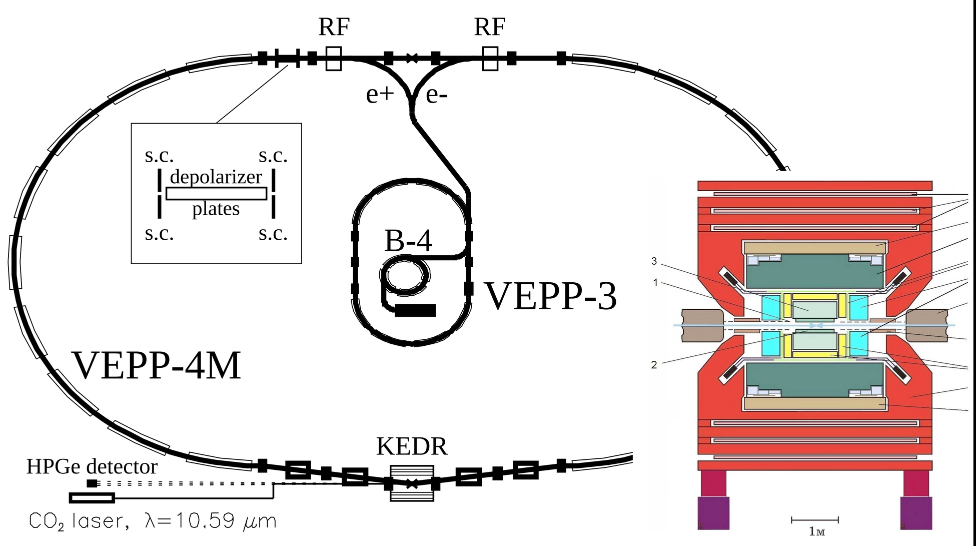
Abstract

We measure the product of the electron width of the J/ψ meson and the branching fraction of its decay to hadrons using KEDR detector at the VEPP-4M e^+e^- collider. The scan was performed at 11 energy points with the total luminosity $230\ nb^{-1}$. The obtained value is

$$\Gamma_{ee}(J/\psi)\cdot\mathcal{B}_{\text{hadrons}}(J/\psi) = 4.839 \pm 0.046 \pm 0.082\ keV,$$

and the uncertainties shown are statistical and systematical, respectively. Using the result presented and the world average values of the electron and hadron branching fractions, one obtains the electron partial width and the total width of the J/ψ meson. All results are consistent with the previous experiments.

1. VEPP-4M collider and KEDR detector



VEPP-4M/KEDR complex with the resonant depolarization and the infrared light Compton backscattering facilities.

- Beam energy from 1 to 5 GeV
- Luminosity 10^{30} cm$^{-2}c^{-1}$ at J/ψ, $3\cdot10^{31}$ cm$^{-2}c^{-1}$ at $\Upsilon(1S)$
- Energy measurement:
  - Resonant depolarization, accuracy of interpolation 10-30 keV
  - Compton backscattering, accuracy $\sim$ 100 keV

2. Theoretical e^+e^- cross section

The cross section for the annihilation process $e^+e^-\to$ hadrons in vicinity of a narrow resonance can be presented in the form:

$$\sigma^{hadr}_{n.r.}(W) = \frac{12\pi}{W^2}\left\{\left(1+\delta_{\text{sf}}\right)\left[\frac{\Gamma_{ee}\tilde{\Gamma}_{\text{h}}}{\Gamma M}\,\text{Im}\,f(W) - \frac{2\alpha\sqrt{R\,\Gamma_{ee}\tilde{\Gamma}_{\text{h}}}}{3W}\,\lambda\,\text{Re}\,\frac{f^*(W)}{1-\Pi_0}\right]\right.$$
$$\left.-\frac{\beta\,\Gamma_{ee}\tilde{\Gamma}_{\text{h}}}{2\Gamma M}\left[\left(1+\frac{M^2}{W^2}\right)\arctan\frac{\Gamma W^2}{M(M^2-W^2+\Gamma^2)} - \frac{\Gamma M}{2W^2}\ln\frac{\left(\frac{M^2}{W^2}\right)^2+\left(\frac{\Gamma M}{W^2}\right)^2}{\left(1-\frac{M^2}{W^2}\right)^2+\left(\frac{\Gamma M}{W^2}\right)^2}\right]\right\}.$$

The correction δ_{sf} follows from the structure function approach from E. A. Kuraev and V. S. Fadin, Sov. J. Nucl. Phys. **41** (1985) 466:

$$\delta_{\text{sf}} = \frac{3}{4}\beta + \frac{\alpha}{\pi}\left(\frac{\pi^2}{3}-\frac{1}{2}\right) + \beta^2\left(\frac{37}{96}-\frac{\pi^2}{12}-\frac{1}{36}\ln\frac{W}{m_e}\right).$$

The function f is defined as

$$f(W) = \frac{\pi\beta}{\sin\pi\beta}\left(\frac{W^2}{M^2-W^2-iM\Gamma}\right)^{1-\beta},\quad \beta = \frac{4\alpha}{\pi}\left(\ln\frac{W}{m_e}-\frac{1}{2}\right).$$

Due to the resonance – continuum interference the effective hadron width $\tilde{\Gamma}_{\text{h}}$ can differ from the true hadron partial width $\Gamma_{\text{h}} = \sum\limits_m \Gamma_m$:

$$\tilde{\Gamma}_{\text{h}} = \Gamma_h \times \left(1 + \frac{2\alpha}{3(1-\text{Re}\,\Pi_0)\mathcal{B}_h}\sqrt{\frac{R}{\mathcal{B}_{ee}}}\sum_m\sqrt{b_m\mathcal{B}^{(s)}_m}\,\langle\sin\phi_m\rangle_\Theta\right)$$

The interference parameter λ can be written as

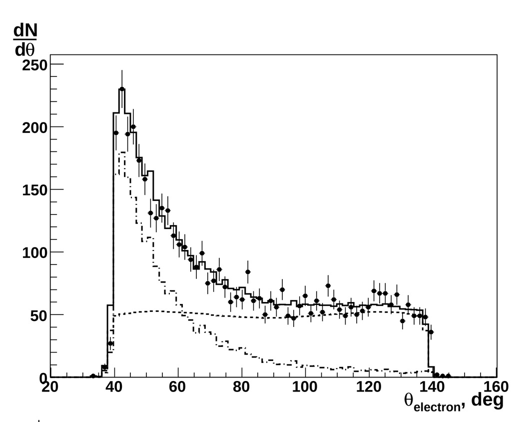
$$\lambda = \sqrt{\frac{R\mathcal{B}_{\text{ee}}}{\mathcal{B}_{\text{h}}}} + \sqrt{\frac{1}{\mathcal{B}_{\text{h}}}}\sum_m\sqrt{b_m\mathcal{B}^{(s)}_m}\,\langle\cos\phi_m\rangle_\Theta\,.$$

Here $\langle\cos\phi_m\rangle_\Theta$ is the cosine of the relative phase of the strong and electromagnetic amplitudes for the mode m averaged over the phase space of the products

3. Luminosity determination

The Bhabha events were selected as two most energetic collinear clusters in the LKr calorimeter.

The contribution of J/ψ decays into the $e^+e^-\to e^+e^-$ scattering was taken into account. Distribution of selected e^+e^- events with respect to the electron scattering angle is shown on the plot.



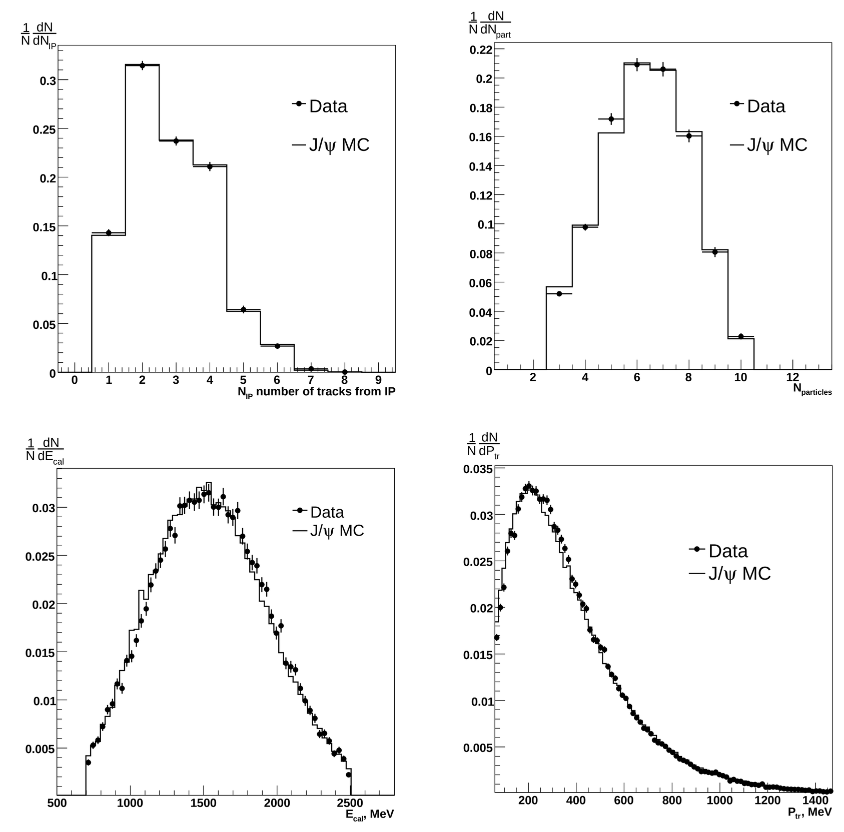
The differential $e^+e^-\to e^+e^-$ cross section is calculated with

$$\left(\frac{d\sigma}{d\Omega}\right)^{ee\to ee} = \left(\frac{d\sigma}{d\Omega}\right)^{ee\to ee}_{\text{QED}} + \frac{1}{W^2}(1+\delta_{sf})\left\{\frac{9}{4}\frac{\Gamma^2_{ee}}{\Gamma M}(1+\cos^2\theta)\,\text{Im}\,f - \frac{3\alpha}{2}\frac{\Gamma_{ee}}{M}\left[(1+\cos^2\theta)\,\text{Re}\,\frac{f^*}{1-\Pi_0(s)} - \frac{(1+\cos\theta)^2}{(1-\cos\theta)}\,\text{Re}\,\frac{f^*}{1-\Pi_0(t)}\right]\right\}.$$

4. Hadrons event selection

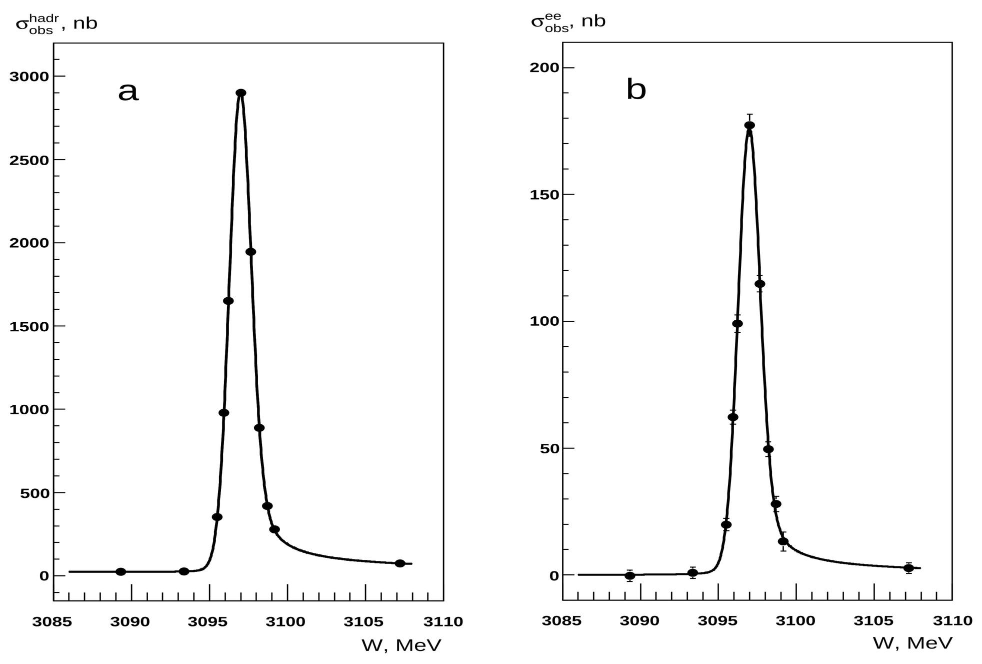
- total energy deposition in the calorimeter $700 < E_{cal} < 2500$ MeV;
- more than 15% of total energy is deposited in the barel LKr calorimeter $E_{LKr}/E_{cal} > 0.15$;
- at least one track coming from interaction point;
- at least three particles in the detector;
- Fox-Wolfram moments $H_2/H_0 < 0.9$.

The comparison between the most important event characteristics obtained in the experiment and in the simulation:



5. Analysis procedure

To minimize systematic uncertainties we performed combined fit of hadrons and e^+e^- production cross sections in the energy range of J/ψ resonance.



Numbers of hadronic N_i and leptonic n_i events observed at each energy point were fitted simultaneously as a function of collision energy with minimizing function

$$\chi^2 = \sum_i\frac{(N^{exp}_i - N^{theor}_i)^2}{N^{exp}_i} + \sum_i\frac{(n^{exp}_i - n^{theor}_i)^2}{n^{exp}_i},$$

where $N^{exp/theor}_i$ and $n^{exp/theor}_i$ are measured experimentally and theoretically calculated numbers of hadronic and Bhabha events, respectively.

$$N^{theor}_i = L_i\cdot\sigma^{hadr}(W_i),\quad n^{theor}_i = L_i\cdot\sigma^{ee}(W_i),$$

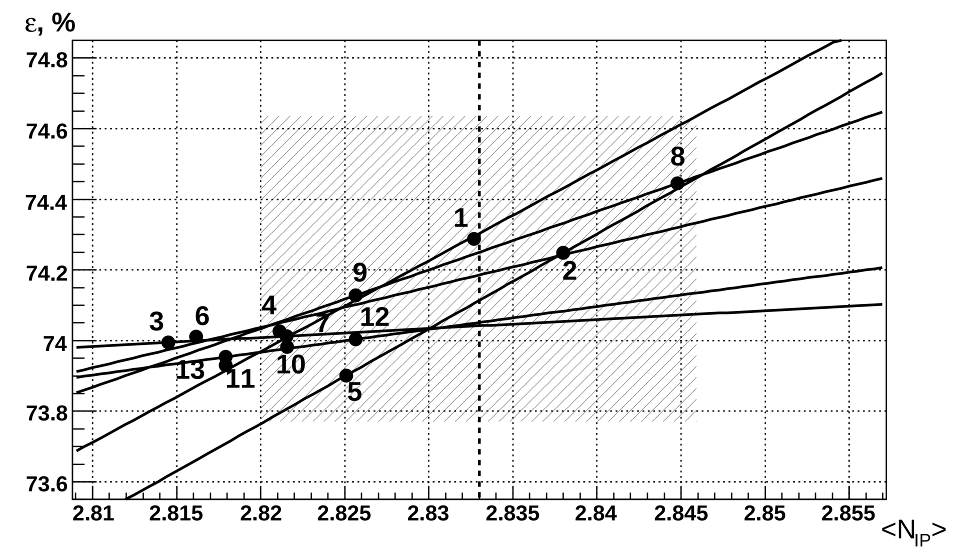
Theoretical cross sections were convoluted with Gaussian distribution with energy spread σ_W.

$\Gamma_{ee}(J/\psi)\cdot\mathcal{B}_{\text{hadrons}}(J/\psi)$ value, resonance mass shift from the PDG value, σ_W and continuum contribution were treated as fit parameters. $\Gamma_{ee}(J/\psi)\cdot\mathcal{B}_{\text{ee}}(J/\psi)$ and $\mathcal{B}_{\text{ee}}(J/\psi)$ values were fixed at their measured values from PDG.

6. Detection efficiency

To estimate detection efficiency and its uncertainty a number of independent event samples was generated with different simulation parameters. We iterated as follow:

- vary one of PYTHIA/JETSET parameter;
- modify complementary parameter to achieve good agreement in observed charged multiplicity $< N_{IP} >$,
- obtaine detection efficiencies dependence on $< N_{IP} >$ as shown on the plot with MC versions 1-13:



The dotted line corresponds to the experimental measured charged multiplicity and the shadow box shows its statistical error. Multihadron efficiency was averaged over efficiencies corresponding to experimentally measured $< N_{IP} >$ and equals to 74.16%. Efficiency uncertainty was estimated as bound positions within $< N_{IP} >$ statistical errors.

7. Systematical uncertainties

The summary of dominating systematic uncertainties in the $\Gamma_{ee}(J/\psi)\cdot\mathcal{B}_{\text{hadrons}}(J/\psi)$ product are listed in the table:

Source	%
Luminosity measurement: Calorimeter alignment and calibration, $e^+e^-\to e^+e^-$ cross section calculation, effi ciency $\varepsilon_e(\theta)$ determination, e^+e^- cuts variation	1.2
Detector related effects: Trigger ineffi ciency, nuclear interaction, track resolution calibration, hadron cuts variation	0.8
Simulation of J/ψ decays: $J/\psi\to hadrons$ generator tuning, selection of MC samples for tuning, track reconstruction effi ciency	0.7
Accelerator related effects: Energy interpolation, collider background, non-Gaussian energy distribution	0.4
Other uncertainties: $\Gamma_{ee}(J/\psi)\cdot\mathcal{B}_{\text{ee}}(J/\psi)$ variation, interference parameter, resonance term determination, accuracy of radiative correction calculation	0.2
Sum in quadrature	**1.7**

8. Results and conclusion

The parameters of J/ψ meson have been measured using the data collected with the KEDR detector at the VEPP-4M e^+e^- collider. Our result is

$$\Gamma_{ee}(J/\psi)\cdot\mathcal{B}_{\text{hadrons}}(J/\psi) = 4.839 \pm 0.046 \pm 0.082\ \text{keV}.$$

Obtained $\Gamma_{ee}(J/\psi)\cdot\mathcal{B}_{\text{hadrons}}(J/\psi)$ value is consistent with and one order of magnitude more precise than previous direct measurements.

Usually the composition $\Gamma_{ee}(J/\psi)\cdot\mathcal{B}_{\text{hadrons}}(J/\psi)$ is converted to the electron width value using the hadron branching fraction $\mathcal{B}_{\text{hadrons}}$. Taking into account $\mathcal{B}_{\text{hadrons}}(J/\psi) = 0.877\pm0.005$ and $\mathcal{B}_{\text{ee}}(J/\psi) = (5.971\pm0.032)\cdot10^{-2}$ from PDG we determined electron and total widths of J/ψ meson:

$$\Gamma_{ee} = 5.52\pm0.11\,\text{keV},$$
$$\Gamma = 92.4\pm1.9\,\text{keV}.$$

The lepton and full widths of the J/ψ meson Γ_{ee} are known from BESIII, CLEO and BaBar experiments. The values were calculated from $\Gamma_{ee}(J/\psi)\cdot\mathcal{B}_{\mu\mu}(J/\psi)$ measured in the radiation process $e^+e^-\to\mu^+\mu^-\gamma$ with J/ψ meson decaying to muon pair.