Measurement of $\Gamma_{ee}(J/\psi)\cdot\mathcal{B}(J/\psi\to e^+e^-)$ and $\Gamma_{ee}(J/\psi)\cdot\mathcal{B}(J/\psi\to\mu^+\mu^-)$

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Abstract

The products of the electron width of the J/ψ meson and the branching fraction of its decays to the lepton pairs were measured using data from the KEDR experiment at the VEPP-4M electron-positron collider. The results are

$\Gamma_{ee}\times\Gamma_{ee}/\Gamma = 0.3323\pm0.0064$ (stat.) ±0.0048 (syst.) keV,
$\Gamma_{ee}\times\Gamma_{\mu\mu}/\Gamma = 0.3318\pm0.0052$ (stat.) ±0.0063 (syst.) keV,
$\Gamma_{ee}\times(\Gamma_{ee}+\Gamma_{\mu\mu})/\Gamma = 0.6641\pm0.0082$ (stat.) ±0.0100 (syst.) keV,
$\Gamma_{ee}/\Gamma_{\mu\mu} = 1.002\pm0.021$ (stat.) ±0.013 (syst.)

and can be used to improve the accuracy of the leptonic and full widths and test leptonic universality. Assuming $e\mu$ universality and using the world average value of the leptonic branching fraction, we also determine the leptonic $\Gamma_{\ell\ell}=5.59\pm0.12$ keV and total $\Gamma=94.1\pm2.7$ keV widths of the J/ψ meson. V. V. Anashin, et al., Phys. Lett. B **685**, 134 (2010), **arXiv:0912.1082**.

1. VEPP-4M collider and KEDR detector

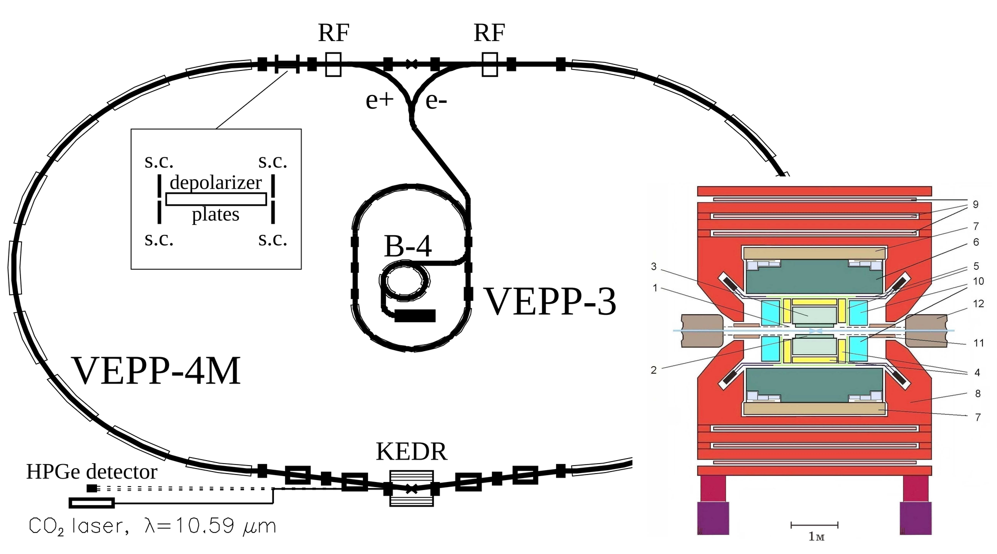

Figure 1: *VEPP-4M/KEDR complex with the resonant depolarization and the infrared light Compton backscattering facilities.*

One of the main features of the VEPP-4M is a possibility of precise energy determination. Between calibrations the energy interpolation in the J/ψ energy range has the accuracy of $6\cdot10^{-6}$ ($\simeq$10 keV).

2. Experiment description

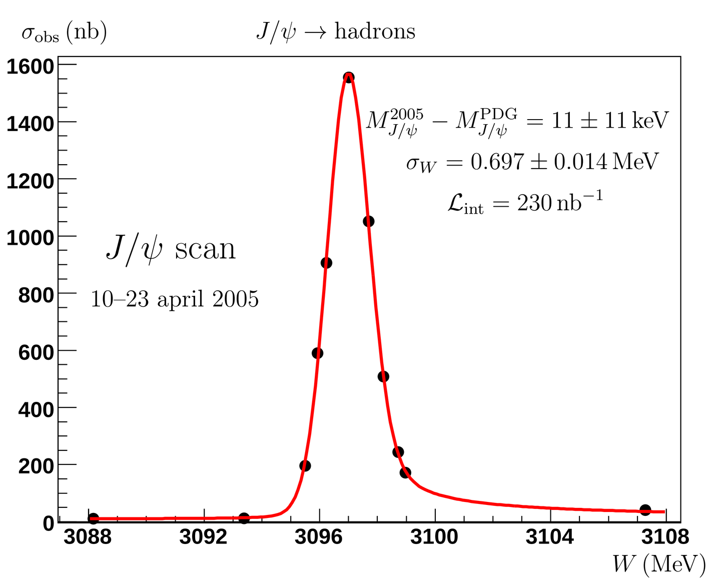

Figure 2: *Observed cross section of $e^+e^-\to$ hadrons.*

A data sample used for this analysis comprises 230 nb^{-1} collected at 11 energy points in the J/ψ energy range. This corresponds to approximately 15000 $J/\psi\to e^+e^-$ decays. During this scan, 26 calibrations of the beam energy have been done using resonant depolarization.

3. Theoretical $e^+e^-\to\ell^+\ell^-$ cross section

The analytical expressions for the cross section of the process $e^+e^-\to\ell^+\ell^-$ with radiative corrections taken into account in the soft photon approximation were first derived by Ya. A. Azimov *et al.*, JETP Lett. **21**, 172 (1975). With some up-today modifications one obtains in the vicinity of a narrow resonance:

$$\left(\frac{d\sigma}{d\Omega}\right)^{ee\to ee}\approx\frac{1}{M^2}\left\{\frac{9}{4}\frac{\Gamma_{ee}^2}{\Gamma M}(1+\cos^2\theta)\,(1+\delta_{\mathrm{sf}})\ \mathrm{Im}\,\mathcal{F}-\frac{3\alpha}{2}\frac{\Gamma_{ee}}{M}\left[(1+\cos^2\theta)-\frac{(1+\cos\theta)^2}{(1-\cos\theta)}\right]\mathrm{Re}\,\mathcal{F}\right\}+\left(\frac{d\sigma}{d\Omega}\right)^{ee}_{\mathrm{QED}},$$

$$\left(\frac{d\sigma}{d\Omega}\right)^{ee\to\mu\mu}\approx\frac{3}{4M^2}(1+\delta_{\mathrm{sf}})\left(1+\cos^2\theta\right)\times\left\{\frac{3\Gamma_{ee}\Gamma_{\mu\mu}}{\Gamma M}\mathrm{Im}\,\mathcal{F}-\frac{2\alpha\sqrt{\Gamma_{ee}\Gamma_{\mu\mu}}}{M}\mathrm{Re}\,\frac{\mathcal{F}}{1-\Pi_0}\right\}+\left(\frac{d\sigma}{d\Omega}\right)^{\mu\mu}_{\mathrm{QED}},$$

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

$$\mathcal{F}=\frac{\pi\beta}{\sin\pi\beta}\left(\frac{M/2}{-W+M-i\Gamma/2}\right)^{1-\beta},\quad \beta=\frac{4\alpha}{\pi}\left(\ln\frac{W}{m_e}-\frac{1}{2}\right)$$

4. Data analysis

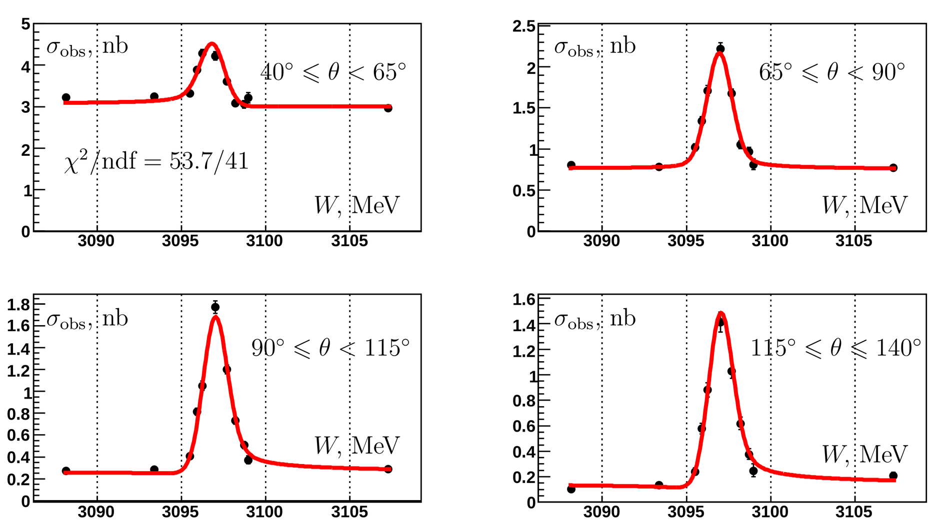

Figure 3: *Fits to experimental data for $e^+e^-\to e^+e^-$.*

At the i-th energy point E_i and the j-th angular interval θ_j, the expected number of $e^+e^-\to e^+e^-$ events was parameterized as

$$N_{\mathrm{exp}}(E_i,\theta_j)=\mathcal{R}_{\mathcal{L}}\times\mathcal{L}(E_i)\times\Big(\sigma^{\mathrm{theor}}_{\mathrm{res}}(E_i,\theta_j)\cdot\varepsilon^{\mathrm{sim}}_{\mathrm{res}}(E_i,\theta_j)+\sigma^{\mathrm{theor}}_{\mathrm{inter}}(E_i,\theta_j)\cdot\varepsilon^{\mathrm{sim}}_{\mathrm{inter}}(E_i,\theta_j)+\sigma^{\mathrm{sim}}_{\mathrm{Bhabha}}(E_i,\theta_j)\cdot\varepsilon^{\mathrm{sim}}_{\mathrm{Bhabha}}(E_i,\theta_j)\Big).$$

where $\mathcal{L}(E_i)$ — the integrated luminosity measured by the luminosity monitor at the i-th energy point; σ^{theor} — the theoretical cross sections for resonance, interference and Bhabha contributions, $\varepsilon^{\mathrm{sim}}$ — the detector efficiencies obtained from simulation.
In this formula the following free parameters were used: the product $\Gamma_{ee}\times\Gamma_{ee}/\Gamma$, which determines the magnitude of the resonance signal; the electron width Γ_{ee}, which specifies the amplitude of the interference wave; the coefficient $\mathcal{R}_{\mathcal{L}}$, which provides the absolute calibration of the luminosity monitor.
The dominant uncertainty of the $\Gamma_{ee}\times\Gamma_{ee}/\Gamma$ result is associated with the luminosity monitor instability.

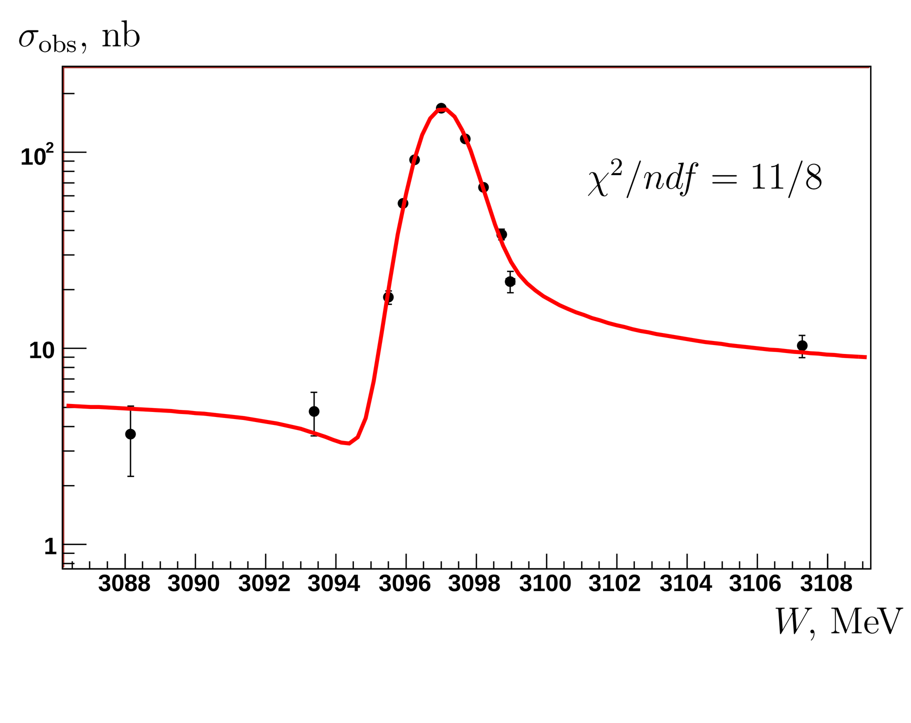

Figure 4: *Fit to experimental data for $e^+e^-\to\mu^+\mu^-$.*

The expected number of $e^+e^-\to\mu^+\mu^-$ events was parameterized in the form:

$$N_{\mathrm{exp}}(E_i)=\mathcal{R}_{\mathcal{L}}\times\mathcal{L}(E_i)\times\Big(\sigma^{\mathrm{theor}}_{\mathrm{res}}(E_i)\cdot\varepsilon^{\mathrm{sim}}_{\mathrm{res}}(E_i)+\sigma^{\mathrm{theor}}_{\mathrm{inter}}(E_i)\cdot\varepsilon^{\mathrm{sim}}_{\mathrm{inter}}(E_i)+\sigma^{\mathrm{theor}}_{\mathrm{bg}}(E_i)\cdot\varepsilon^{\mathrm{sim}}_{\mathrm{bg}}(E_i)\Big)+F_{\mathrm{cosmic}}\times T_i,$$

with the same meaning of $\mathcal{R}_{\mathcal{L}}$ and $\mathcal{L}(E_i)$ as for $e^+e^-\to e^+e^-$. $\mathcal{R}_{\mathcal{L}}$ was fixed from the $e^+e^-\to e^+e^-$ fit and T_i is the live data taking time.
The following free parameters were used: the product $\Gamma_{ee}\times\Gamma_{\mu\mu}/\Gamma$, which determines the magnitude of the resonance signal; the square root of electron and muon widths $\sqrt{\Gamma_{ee}\Gamma_{\mu\mu}}$, which specifies the amplitude of the interference wave; the rate of cosmic events, F_{cosmic}, that passed the selection criteria for the $e^+e^-\to\mu^+\mu^-$ events.
The dominant uncertainty of the $\Gamma_{ee}\times\Gamma_{\mu\mu}/\Gamma$ result is associated with the absolute luminosity calibration done in the e^+e^--channel.

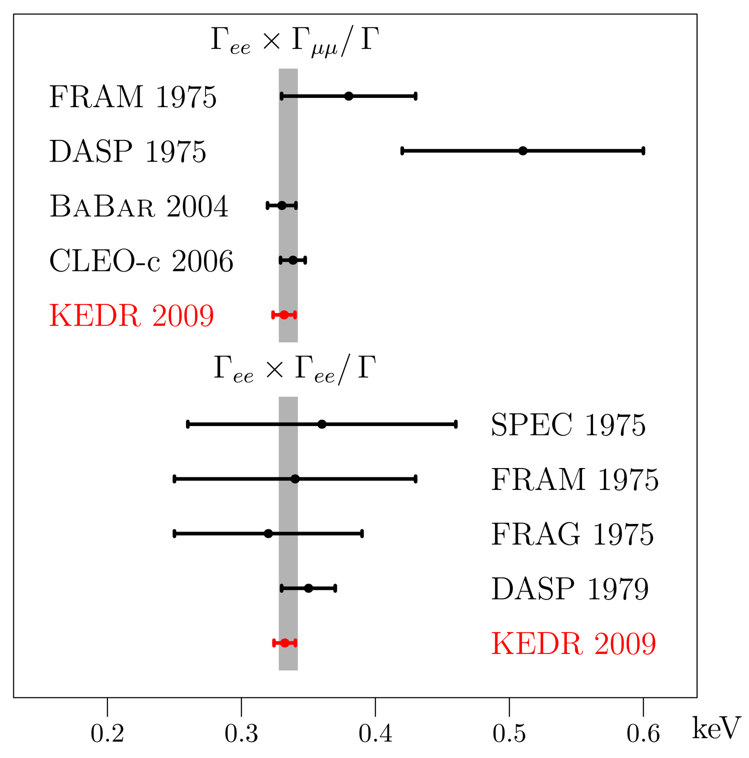

Figure 5: $\Gamma_{ee}\times\Gamma_{ee}/\Gamma$ *and* $\Gamma_{ee}\times\Gamma_{\mu\mu}/\Gamma$ *comparison*

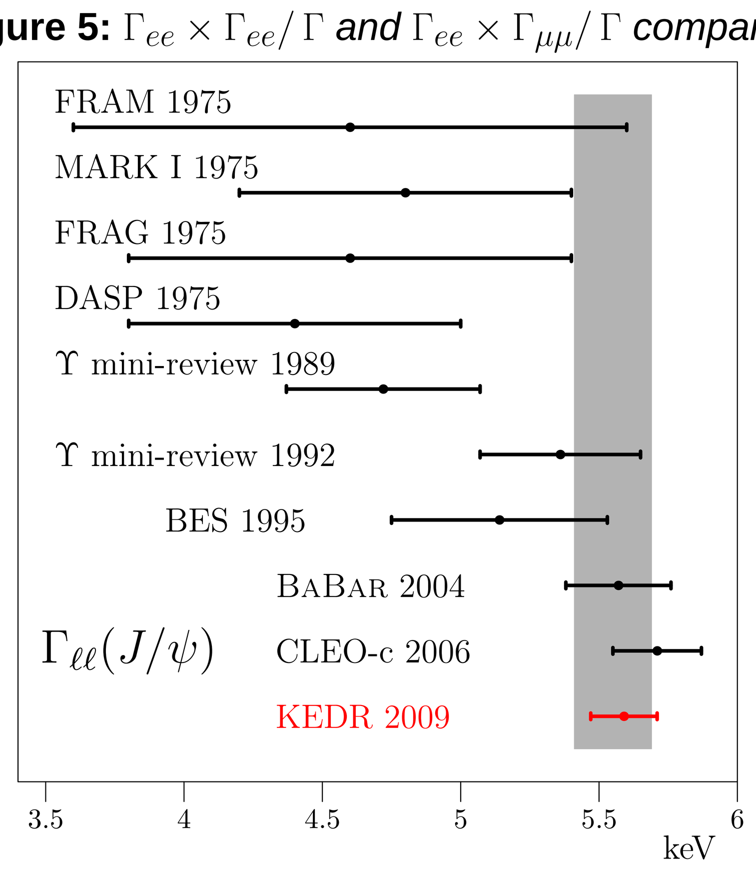

Figure 6: $\Gamma_{\ell\ell}$ *comparison*

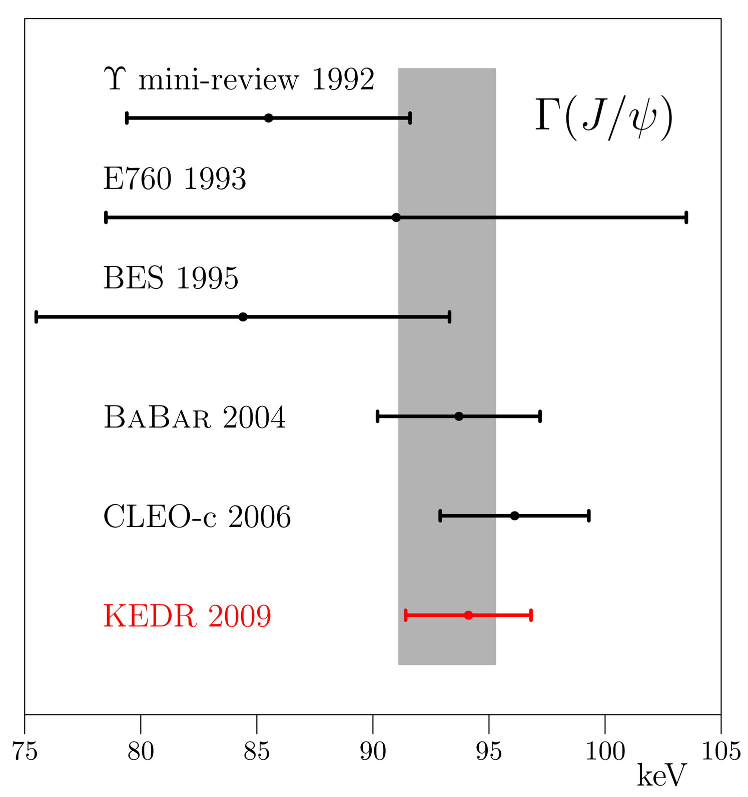

Figure 7: Γ *comparison*

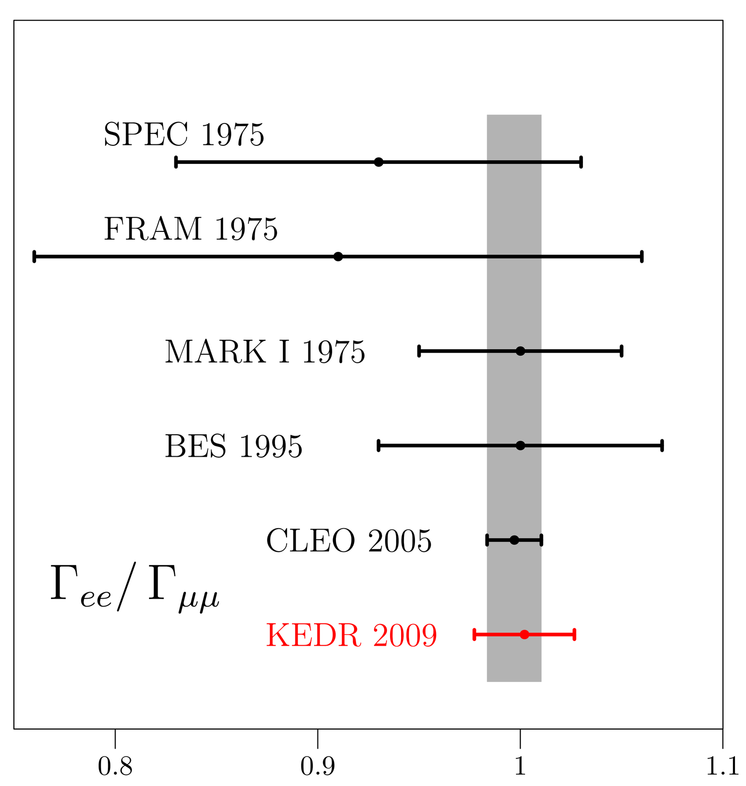

Figure 8: $\Gamma_{ee}/\Gamma_{\mu\mu}$ *comparison*