Measurements of the J/ψ and ψ(2S) leptonic widths with KEDR detector

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Outline

- Introduction
- VEPP-4M / KEDR
- Latest result on J/ψ leptonic width
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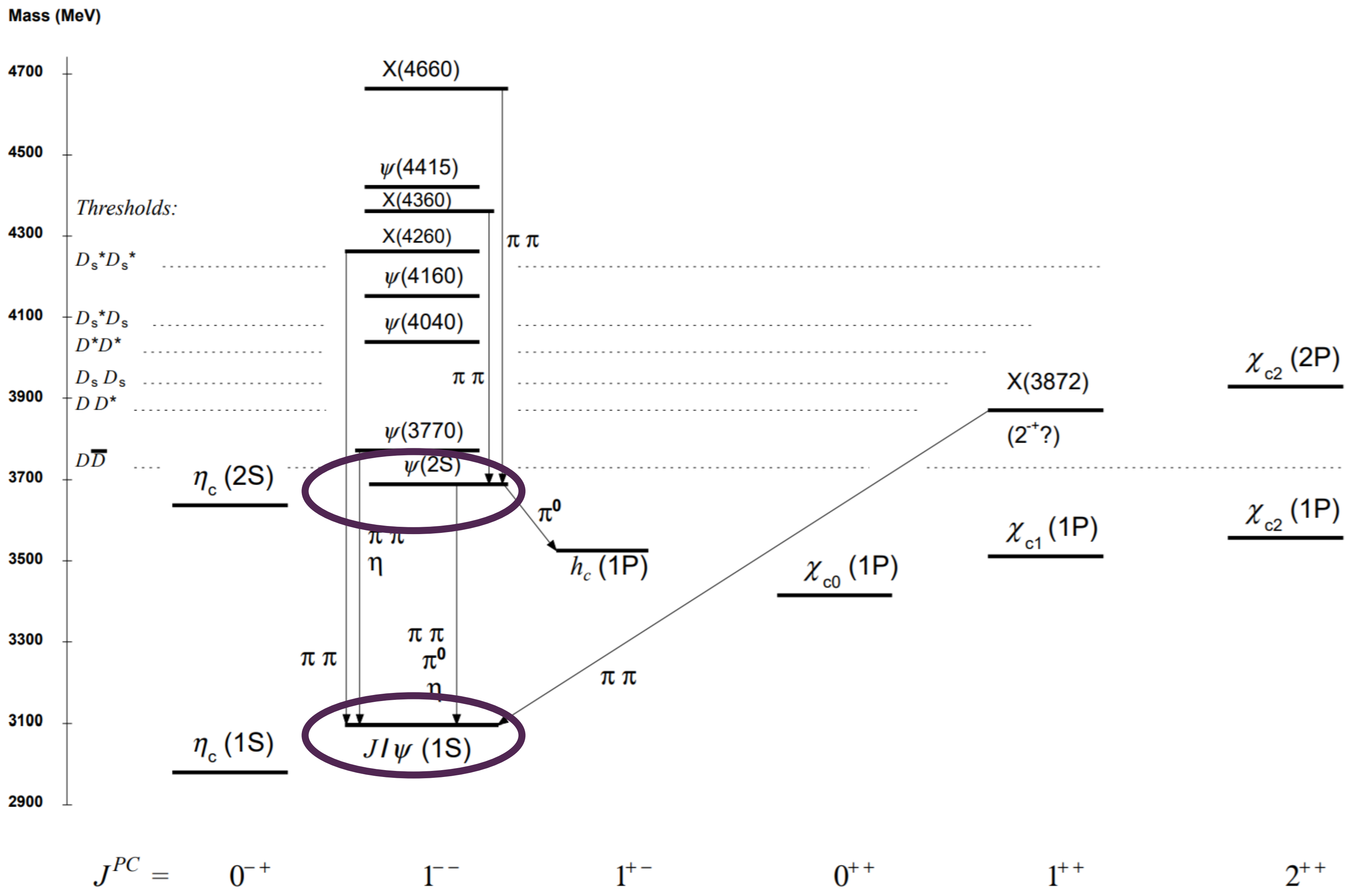
Charmonium system



J/ψ and ψ(2S) leptonic and total widths

J/ψ widths measurements

	Γ_{ee} , keV	Γ , keV	Comments
BaBar 04	5.61±0.21	94.7±4.4	$e^+e^-\to\mu^+\mu^-\gamma$ ISR
CLEO 06	5.71±0.16	96.1±3.2	$e^+e^-\to\mu^+\mu^-\gamma$ ISR
KEDR 10	5.51±0.12	94.1±2.7	$e^+e^-\to e^+e^-$
BES3 16	5.58±0.09	-	$e^+e^-\to\mu^+\mu^-\gamma$ ISR
PDG	5.55±0.14±0.02	92.9±2.8	
KEDR 18	5.55±0.11	92.9±1.8	$e^+e^-\to$hadrons $e^+e^-\to e^+e^-$

ψ(2s) widths measurements

	Γ_{ee} , keV	Γ , keV	Comments
BES2 02	2.44±0.21	264±27	e^+e^-
BES2 06	2.33±0.12	331±58	$e^+e^-\to$hadrons
BES2 08	2.34±0.10	358±88	$e^+e^-\to$hadrons
BES3 15	2.23±0.10	-	$e^+e^-\to\gamma\pi^+\pi^-J/\psi$
PDG	2.29±0.06	286±16	average
KEDR 18	2.28±0.04	-	e^+e^-

$e^+e^- \to l^+l^-$ cross section nearby the narrow resonance

The cross section nearby the narrow resonance is described by the sum of 3 contributions: QED process, resonance production and their interference

$$\left(\frac{d\sigma}{d\Omega}\right)^{ee\to ee} = \left(\frac{d\sigma}{d\Omega}\right)^{ee\to ee}_{\mathrm{QED}} + \frac{1}{W^2}(1+\delta_{sf})\left\{\frac{9}{4}\frac{\Gamma^2_{ee}}{\Gamma M}(1+\cos^2\theta)\,\mathrm{Im}\,f - \right.$$

$$\left.\frac{3\alpha}{2}\frac{\Gamma_{ee}}{M}\left[(1+\cos^2\theta)\,\mathrm{Re}\,\frac{f^*}{1-\Pi_0(s)} - \frac{(1+\cos\theta)^2}{(1-\cos\theta)}\,\mathrm{Re}\,\frac{f^*}{1-\Pi_0(t)}\right]\right\}$$

$$\left(\frac{d\sigma}{d\Omega}\right)^{ee\to\mu\mu} = \left(\frac{d\sigma}{d\Omega}\right)^{ee\to\mu\mu}_{\mathrm{QED}} + \frac{3}{4W^2}(1+\delta_{sf})(1+\cos^2\theta)\times$$

$$\left\{\frac{3\Gamma_{ee}\Gamma_{\mu\mu}}{\Gamma M}\,\mathrm{Im}\,f - \frac{2\alpha\sqrt{\Gamma_{ee}\Gamma_{\mu\mu}}}{M}\,\mathrm{Re}\,\frac{f^*}{1-\Pi_0(t)}\right\}$$

(in the soft photon approximation)

$e^+e^-\to$hadrons cross section nearby the narrow resonance

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

$$\left. - \frac{\beta\,\Gamma_{ee}\Gamma_{\text{h}}}{2\Gamma M}\left[\left(1+\frac{M^2}{W^2}\right)\arctan\frac{\Gamma W^2}{M(M^2-W^2+\Gamma^2)} - \frac{\Gamma M}{2W^2}\ln\frac{\left(\frac{M^2}{W^2}\right)^2+\left(\frac{\Gamma M}{W^2}\right)^2}{\left(1-\frac{M^2}{W^2}\right)^2+\left(\frac{\Gamma M}{W^2}\right)^2}\right]\right\}$$

[Phys. Lett. B 711(2012) 280]

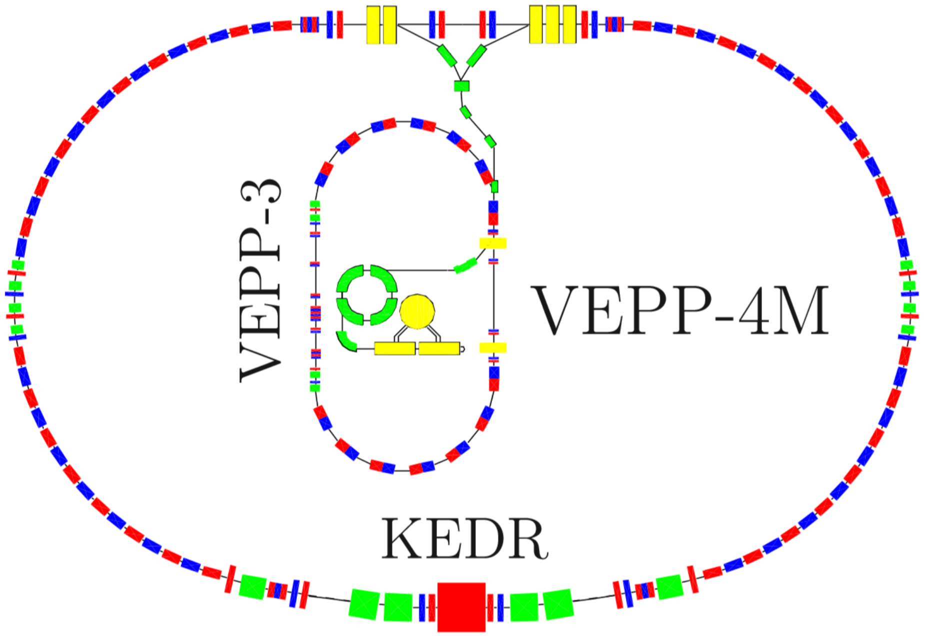
The radiative correction from the structure function approach:

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

Function *f* definition: $$f(W) = \frac{\pi\beta}{\sin\pi\beta}\left(\frac{W^2}{M^2-W^2-iM\Gamma}\right)^{1-\beta}$$

To fit resonance the numerical convolution of the analytical cross sections with the energy spread is used

Collider VEPP-4M

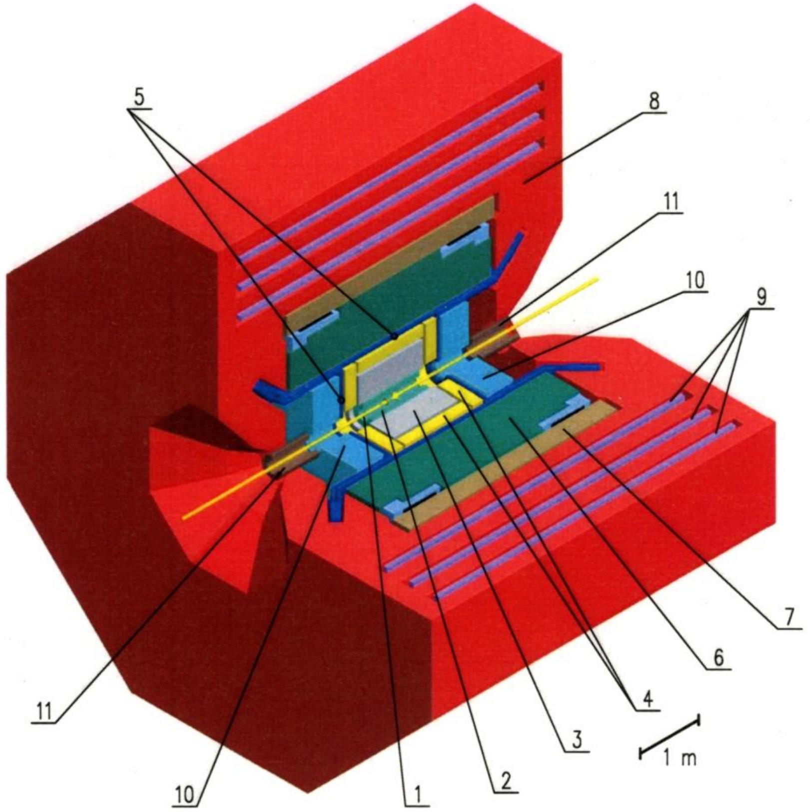


Circumference	366 m
Beam energy	1 – 5 GeV
Number of bunches	2 x 2
Luminosity at 1.5 GeV	$2\cdot10^{30}$ cm^{-2} s^{-1}
Luminosity at 5.0 GeV	$2\cdot10^{31}$ cm^{-2} s^{-1}

Beam energy measurement:

- Resonant depolarization method
  - Instant measurement accuracy $\sim1\cdot10^{-6}$
  - Energy interpolation accuracy $(5 – 15)\cdot10^{-6}$ (10-30 keV)
- Infrared light Compton backscattering
  - Monitoring with accuracy < 100 keV

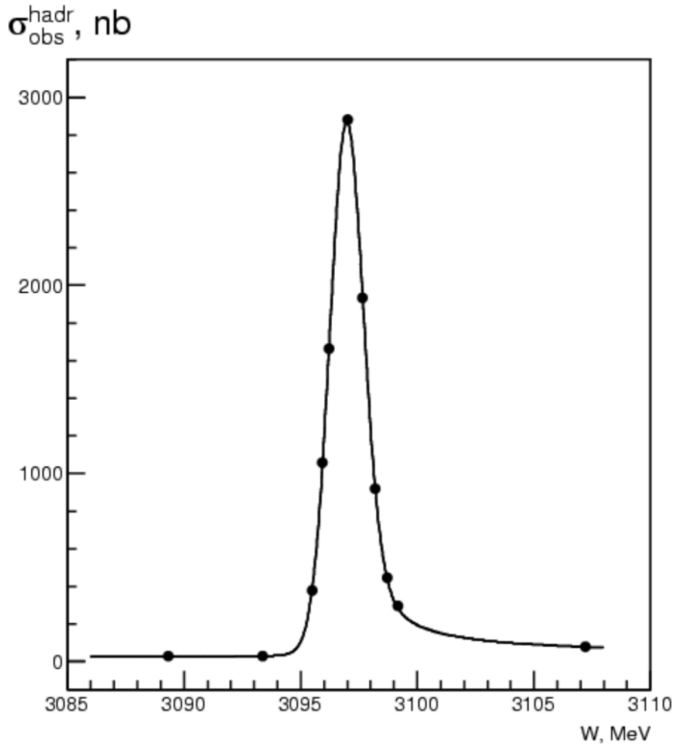
Detector KEDR

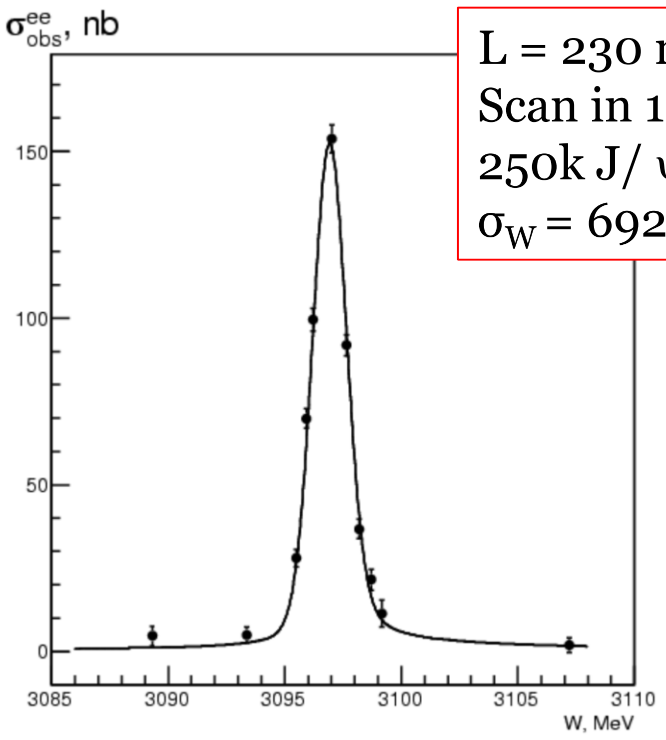


1. Vacuum chamber
2. Vertex detector
3. Drift chamber
4. Threshold aerogel counters
5. ToF counters
6. Liquid krypton calorimeter
7. Superconducting coil
8. Magnet yoke
9. Muon tubes
10. CsI calorimeter
11. Compensating s/c solenoid

Measurement of $\Gamma_{ee} \cdot B_h(J/\psi)$ and $\Gamma_{ee}(J/\psi)$

- Combined fit of hadronic and leptonic events
- Free parameters: $\Gamma_{ee} \cdot B_{ee}(J/\psi)$, $\Gamma_{ee} \cdot B_h(J/\psi)$ or $\Gamma_{ee}(J/\psi)$,
- and also : $m(J/\psi)$, R_L, σ_W, σ_o



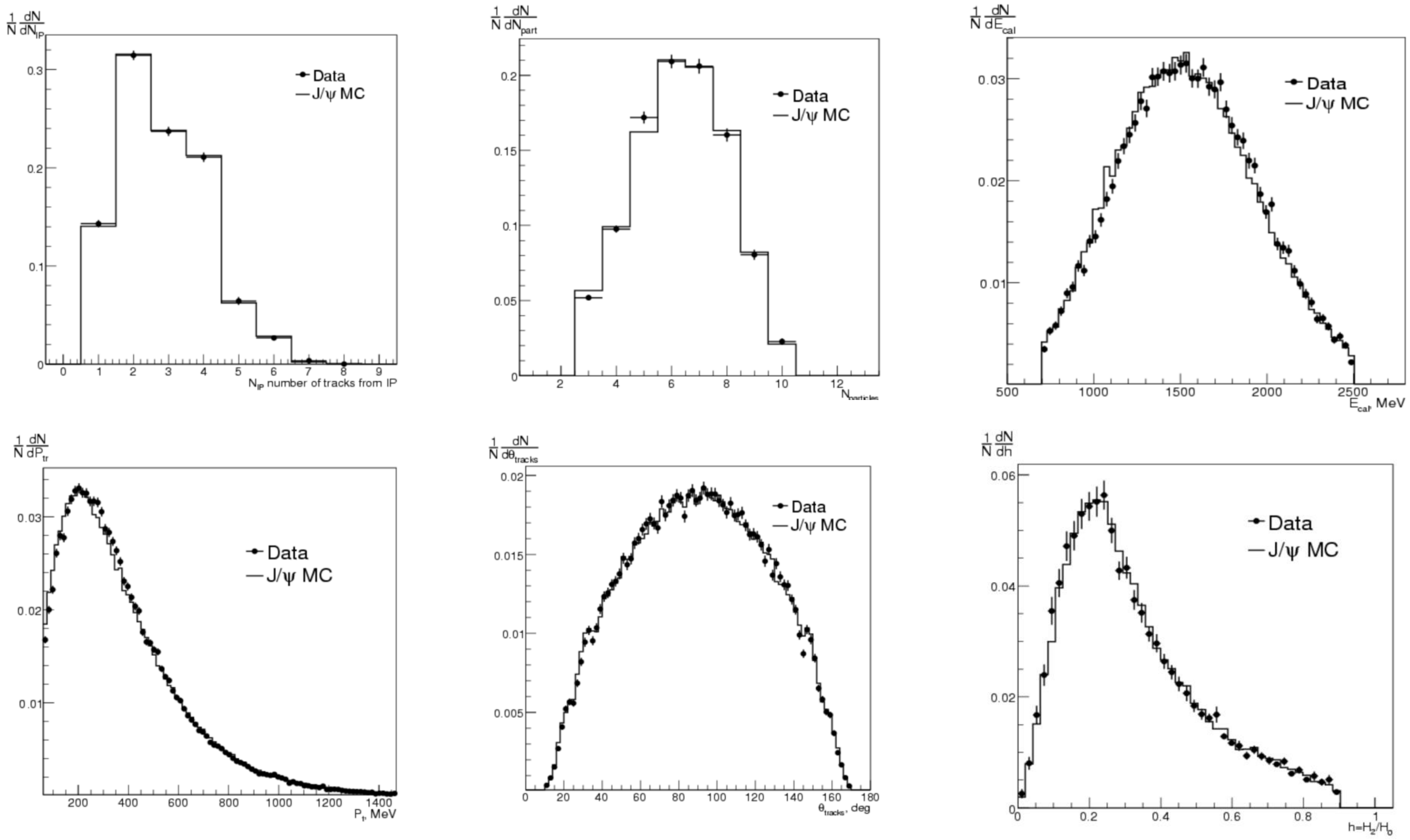


$L = 230\ nb^{-1}$
Scan in 11 points
250k J/ψ mesons
$\sigma_W = 692 \pm 4$ keV

$$\Gamma_{e^+e^-}/\Gamma_{\mu^+\mu^-}(J/\psi) = 1.0022 \pm 0.0065$$

was fixed from KEDR result Phys. Lett. B 731(2014) 227

Simulation of J/ψ decays

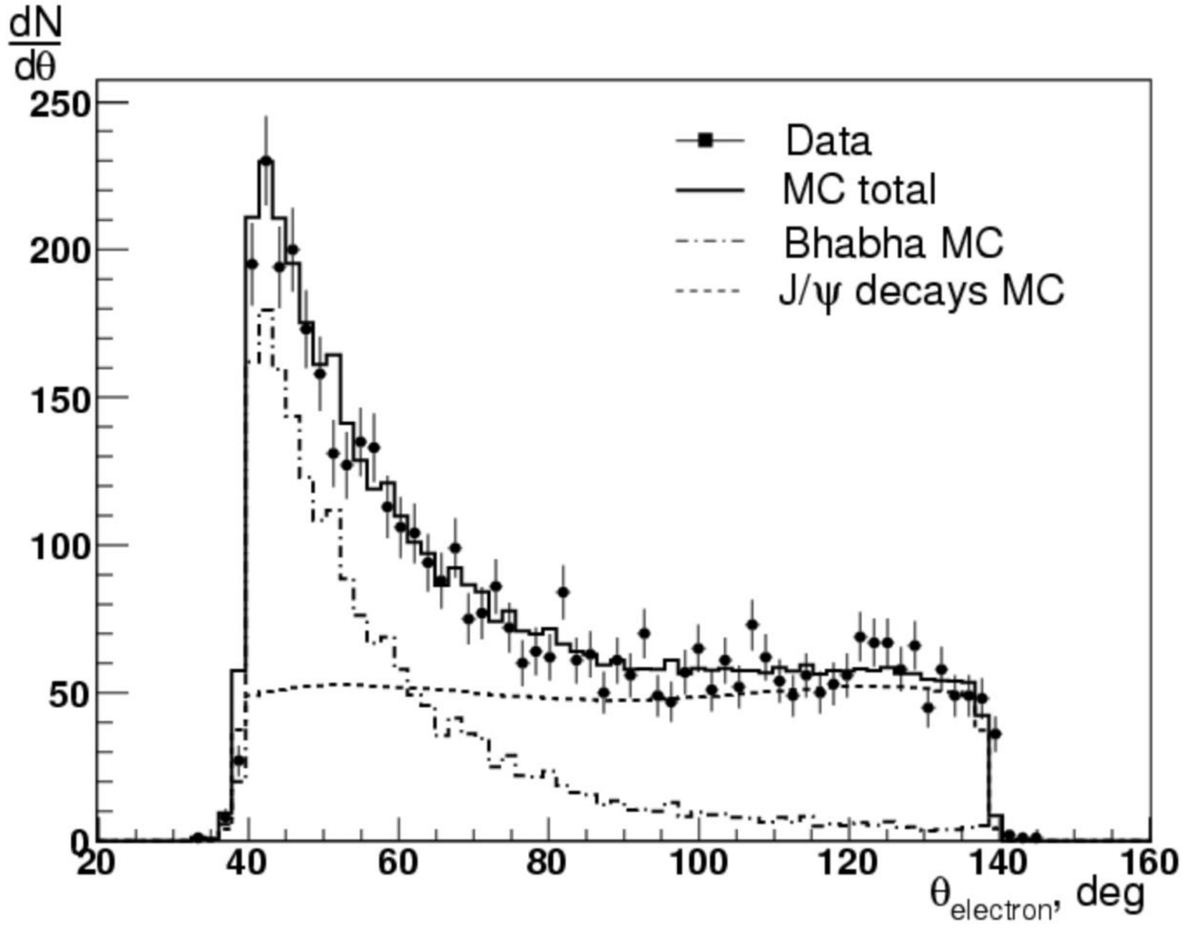


Main properties of hadronic events:

- the number of tracks from the IP,
- the total number of particles,
- energy deposited in the calorimeter
- inclusive P_t and θ distributions,
- the ratio of Fox-Wolfram moments H_2/H_0

Fair agreement between MC simulation and data

Measurement of $\Gamma_{ee} \cdot B_h(J/\psi)$ and $\Gamma_{ee}(J/\psi)$

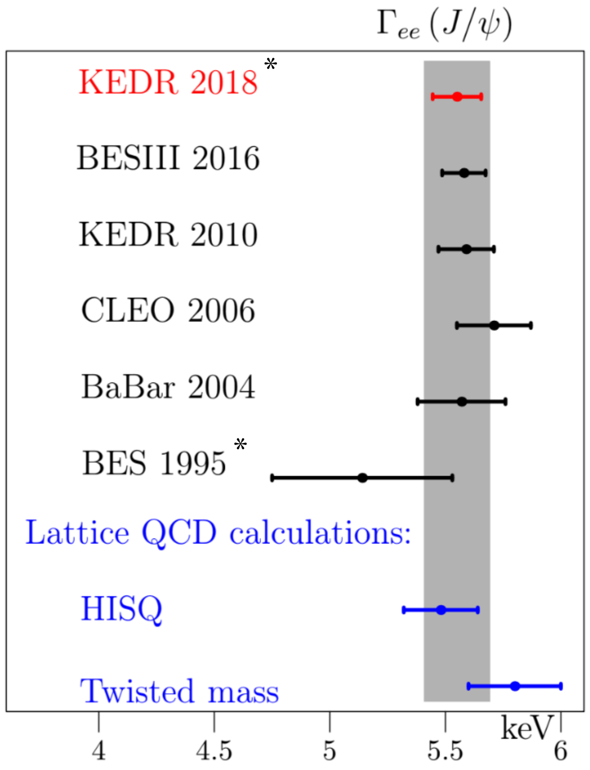


- The relative luminosity was measured by bremsstrahlung luminosity monitor
- The absolute luminosity factor was calculated using e^+e^- events

Systematic uncertainties for $\Gamma_{ee}(J/\psi)$

Source	Uncertainty, %		
	Γ_{ee}	$\Gamma_{ee} \cdot \mathcal{B}_{\text{hadrons}}$	$\Gamma_{ee} \cdot \mathcal{B}_{ee}$
Luminosity	1.0	1.0	1.0
Simulation of J/ψ decays	0.7	0.7	–
Detector response	0.8	0.8	0.4
Accelerator-related effects	0.4	0.4	0.4
Theoretical uncertainties	0.4	0.4	0.2
Total	1.6	1.6	1.2

Measurement of Γ_{ee} (J/ψ)



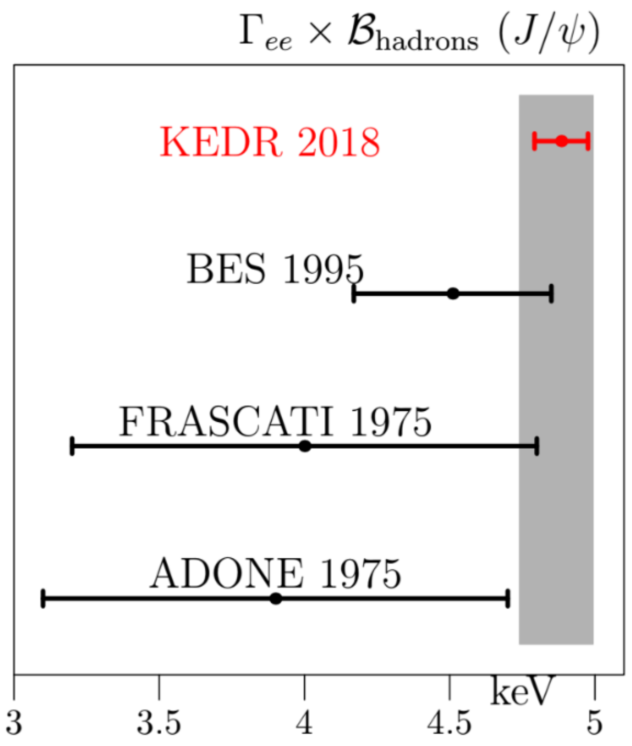
* Measured directly in e^+e^- collisions

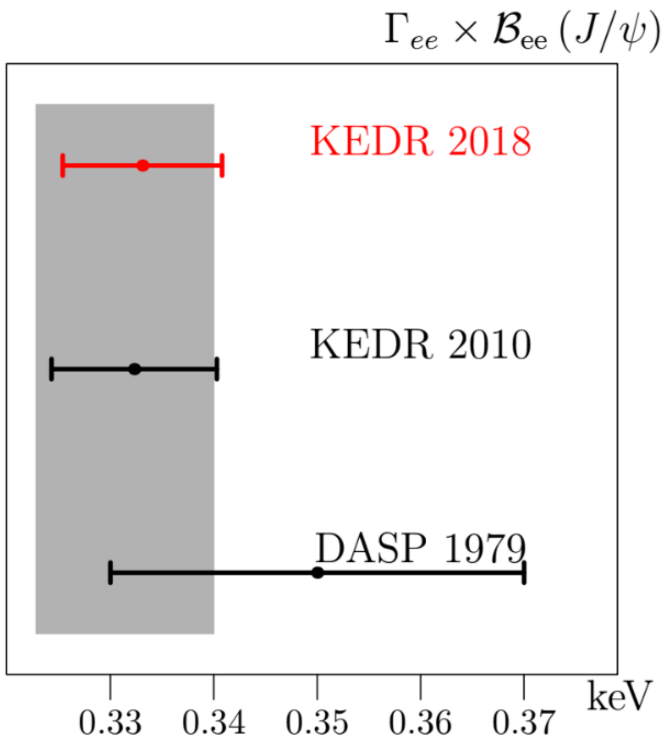
$$\Gamma_{ee}(J/\psi) = 5.550 \pm 0.056 \pm 0.089\,\mathrm{keV}$$

J. High Energ. Phys. (2018) 2018: 119

Agreement in Γ_{ee} (J/ψ) obtained from hadronic and leptonic decays confirms the assumption, that interference phases are not correlated

Measurement of $\Gamma_{ee} \cdot B_h$ and $\Gamma_{ee} \cdot B_{ee}(J/\psi)$





$$\Gamma_{ee}(J/\psi) \cdot \mathcal{B}_{\text{hadrons}}(J/\psi) = 4.884 \pm 0.048 \pm 0.078\,\text{keV}$$

$$\Gamma_{ee}(J/\psi) \cdot \mathcal{B}_{ee}(J/\psi) = 0.3331 \pm 0.0066 \pm 0.0040\,\text{keV}$$

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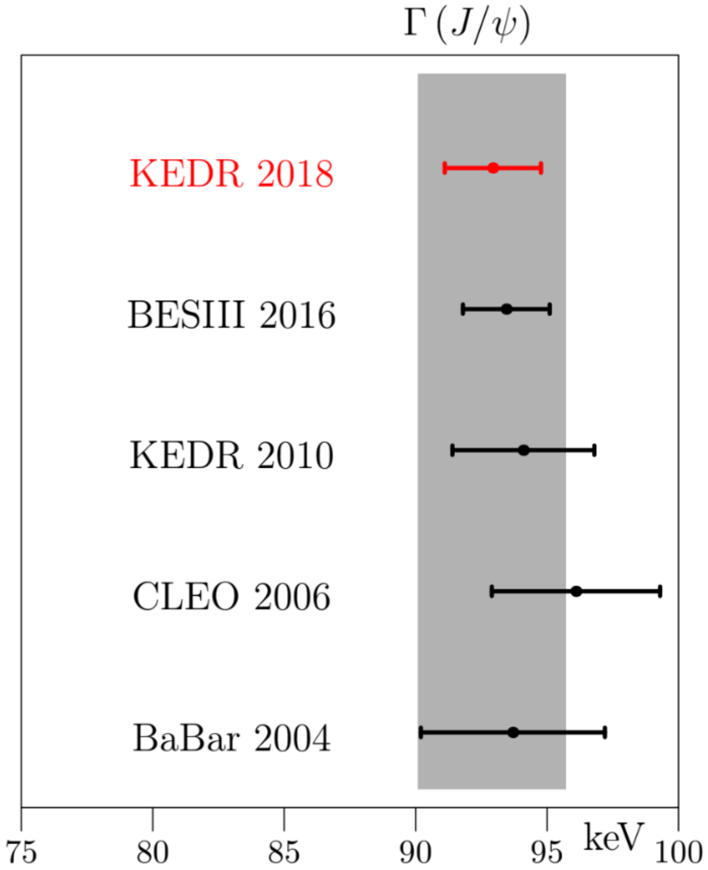
Determination of Γ(J/ψ)



$$\text{Taking into account } \mathcal{B}_{ee}(J/\psi) = (5.971 \pm 0.032)\% \text{ from PDG}:$$

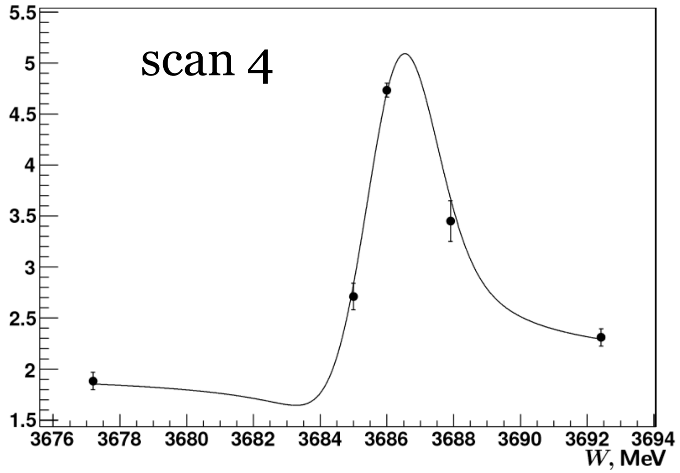
$$\Gamma = 92.94 \pm 1.83\,\mathrm{keV}$$

$\Gamma_{ee} \cdot B_{\mu\mu}(\psi(2S))$ measurement

Experimental Statistics

Data set	Period	$\int L\,dt$, nb^{-1}	σ_W, MeV
Peak/cont. 1	January 2005	358	1.08
Peak/cont. 2	Autumn 2005	222	0.99
Scan 1	Spring 2006	255	0.99
Peak/cont. 3	Spring 2006	631	0.99
Peak/cont. 4	Autumn 2006	701	0.99
Peak/cont. 5	Autumn 2007	1081	1.01
Scan 2	End 2007	967	1.01
Scan 3	Summer 2010	379	1.00
Scan 4	End 2010	2005	0.98

Total luminosity is about 6.5 pb^{-1}
4×10^6 $\psi(2S)$ mesons
Combined fit of e^+e^- and $\mu^+\mu^-$ events



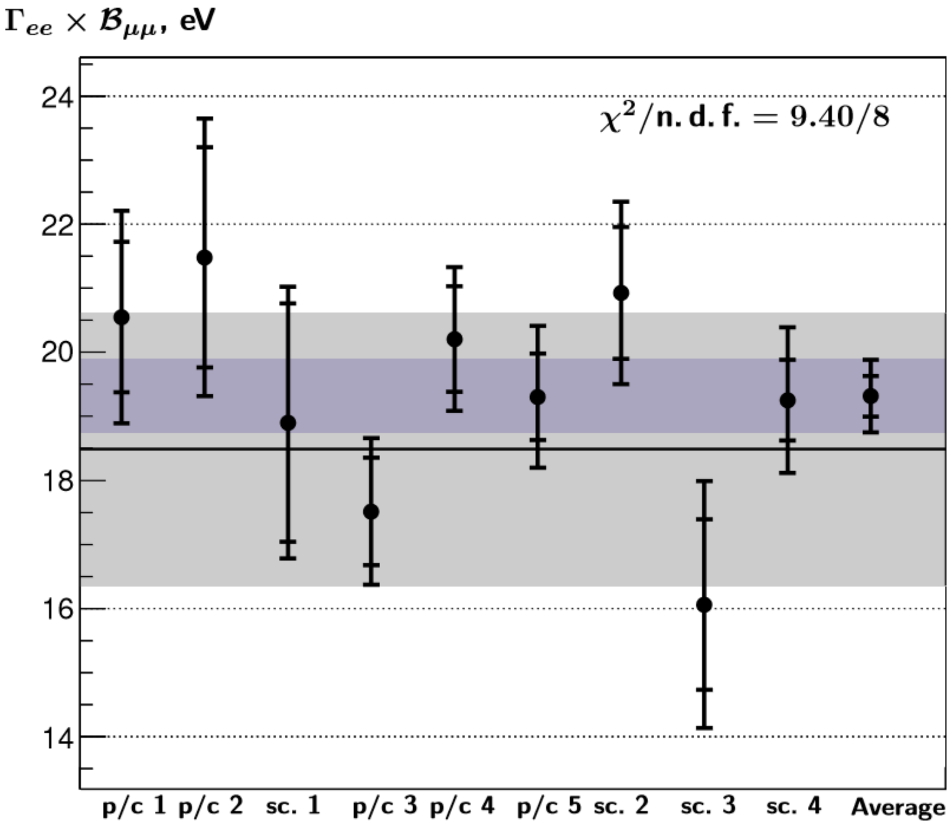
Main Background Sources

Bg mode	m, %	Efficiency, %	Correction, %
$J/\psi\pi^+\pi^-$	34.49	$0.03 \div 0.09$	$2.29 \div 8.94$
$J/\psi\pi^0\pi^0$	18.16	$0.01 \div 0.02$	$0.38 \div 0.92$
$\gamma\chi_{c0}(1P)$	9.99	< 0.01	$0.00 \div 0.05$
$\gamma\chi_{c1}(1P)$	9.55	$0.03 \div 0.03$	$0.47 \div 0.92$
$\gamma\chi_{c2}(1P)$	9.11	$0.02 \div 0.03$	$0.44 \div 0.69$
$J/\psi\eta$	3.36	$0.02 \div 0.05$	$0.17 \div 0.46$
e^+e^-	0.79	< 0.01	< 0.01
$\eta_c\gamma$	0.34	< 0.01	< 0.01
$\tau^+\tau^-$	0.31	$0.05 \div 0.08$	$0.05 \div 0.07$
$J/\psi\pi^0$	0.13	$0.10 \div 0.15$	$0.03 \div 0.05$
$p\bar{p}$	0.03	$0.01 \div 0.03$	< 0.01

Systematic uncertainties for $\Gamma_{ee}\cdot B_{\mu\mu}(\psi(2S))$

Systematic uncertainty source		p/c 1	p/c 2	sc. 1	p/c 3	p/c 4	p/c 5	sc. 2	sc. 3	sc. 4	σ_{syst}^{corr}
1	C. m. energy distribution	1.9	2.7	1.1	2.9	2.2	2.6	1.1	2.9	1.7	0
2	Fixed values of $M_{\psi(2S)}$, $\Gamma_{\psi(2S)}$	0.7	0.6	0.1	0.3	0.7	0.7	0.5	0.2	0.9	0.1
3	Energy measurement	3.1	0.6	<0.1	1.7	0.3	0.5	0.2	3.8	2.7	<0.1
4	Bhabha simulation	1.4	1.4	2.2	1.7	1.1	2.1	1.6	2.6	0.9	0.9
5	$\mu^+\mu^-$ scattering simulation	0.2	0.2	0.3	0.2	0.2	0.2	0.2	0.3	0.3	0.2
6	Collinearity cuts	0.8	2.8	2.4	0.8	2.1	1.4	1.5	5.4	1.6	0.8
7	e^+e^- polar angle range	1.1	2.0	1.8	1.0	1.0	1.2	1.6	2.1	1.3	1.0
8	Charge determination	0.6	0.3	0.8	0.6	0.2	1.9	0.1	1.0	0.4	0.1
9	Detector asymmetry	0.9	0.2	0.5	0.9	0.1	0.1	0.2	0.4	0.2	0.1
10	Extra energy deposit cut	1.4	1.2	2.2	0.5	1.0	0.6	2.2	1.7	1.6	0.5
11	Muon system cut	2.5	2.7	2.2	0.6	0.3	0.5	0.6	0.7	<0.1	0
12	ABG thresholds	0.3	0.7	0.5	0.1	0.3	–	–	–	–	0.1
13	Calo trigger thresholds	0.1	0.1	0.2	0.1	<0.1	0.4	0.5	0.4	0.2	<0.1
14	RND trigger application	0.2	0.1	<0.1	<0.1	<0.1	0.3	0.1	0.9	0.3	<0.1
15	FSR accounting	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3
16	e^+e^- events θ binning	0.6	0.2	0.6	0.5	0.5	0.3	0.1	0.4	0.3	0.1
17	ToF measurement efficiency	1.9	2.5	1.5	1.2	0.8	0.9	2.8	2.7	2.3	0.8
18	Trigger efficiency	0.9	<0.1	0.2	0.1	0.1	0.1	0.2	0.1	0.1	<0.1
19	Theoretical accuracy	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Sum in quadrature		5.7	6.2	5.4	4.4	3.7	4.5	4.7	8.7	4.9	1.9

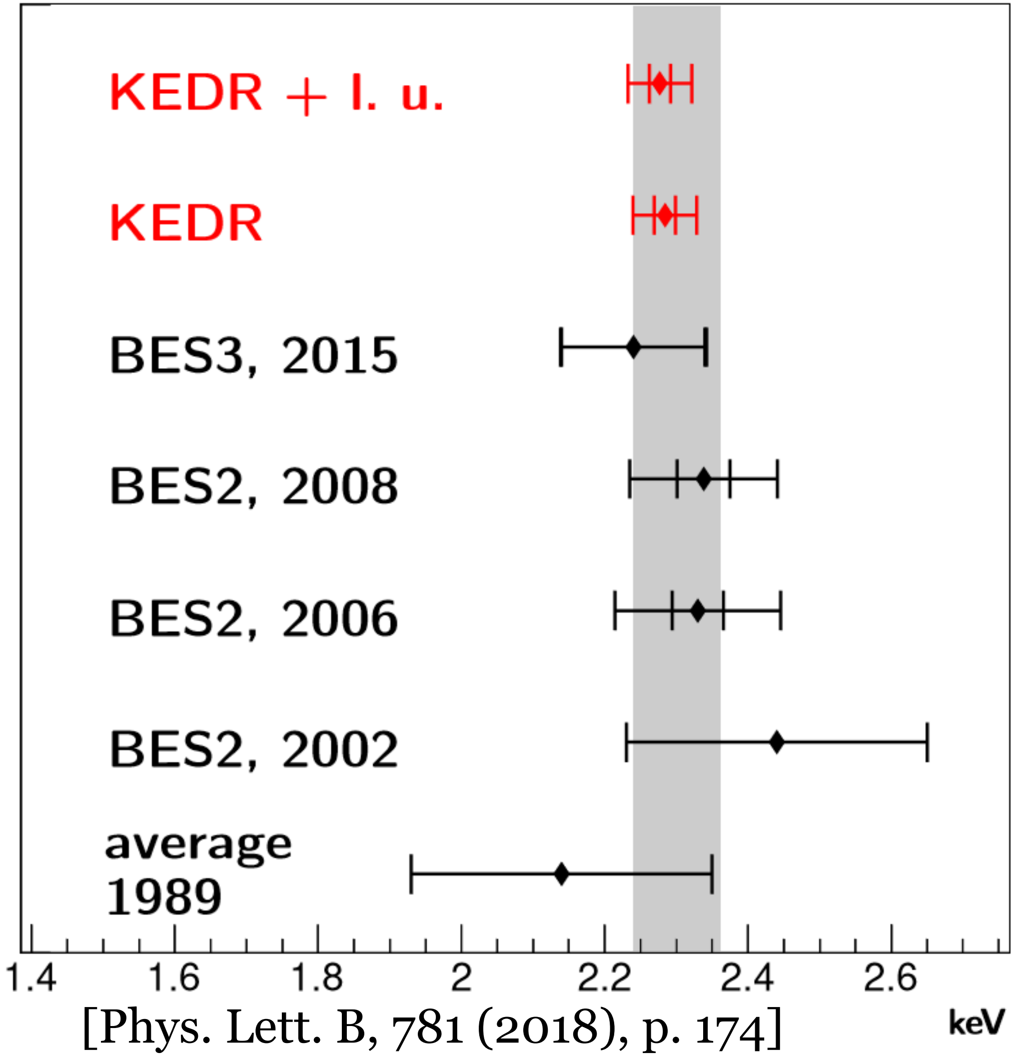
$\Gamma_{ee} \cdot B_{\mu\mu}(\psi(2S))$ measurement



$$\Gamma_{ee} \cdot \mathcal{B}_{\mu\mu} = 19.3 \pm 0.3 \pm 0.5 \text{ eV}$$

World average taking Γ_{ee} and $B_{\mu\mu}(\psi(2S))$ from PDG: $\Gamma_{ee} \cdot \mathcal{B}_{\mu\mu} = 18.5 \pm 2.1$ eV

Γ_{ee} ($\psi(2S)$) measurement



[Phys. Lett. B, 781 (2018), p. 174]

- With lepton universality and KEDR result on hadronic channel

$$\Gamma_{ee} \cdot \mathcal{B}_{\text{hadrons}} = 2.233 \pm 0.015 \pm 0.042 \text{ keV}$$

[Phys. Lett. B, 711 (2012), p. 280]

$$\boxed{\Gamma_{ee} = 2.279 \pm 0.015 \pm 0.042 \text{ keV}}$$

- Summing up hadronic and 3 leptonic channels from KEDR:

$$\Gamma_{ee} \cdot \mathcal{B}_{ee} = 21.2 \pm 0.7 \pm 1.2 \text{ eV}$$

[Phys. Lett. B V. 781 (2018) pp. 174]

$$\Gamma_{ee} \cdot \mathcal{B}_{\tau\tau} = 9.0 \pm 2.6 \text{ eV}$$

[JETP Lett., 85 (2007), p. 347]

$$\boxed{\Gamma_{ee} = 2.282 \pm 0.015 \pm 0.042 \text{ keV}}$$

Summary

- KEDR performed new precise measurements of J/ψ and $\psi(2S)$ leptonic widths:
- J/ψ leptonic width was measured in processes $e^+e^- \to$ hadrons and $e^+e^- \to e^+e^-$ with accuracy less than 2%.
- $\psi(2S)$ leptonic width was obtained in process $e^+e^- \to \mu^+\mu^-$ process with the world best accuracy about 3%.