Charmonium at KEDR

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9th International workshop on Charm Physics
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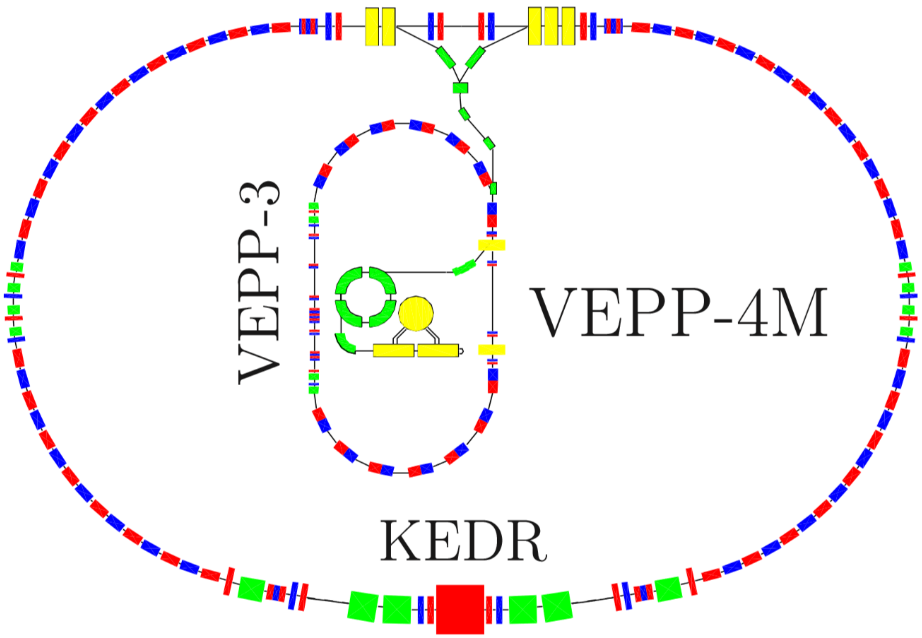
Outline

- VEPP-4M / KEDR
- New results on J/ψ leptonic width
- New result on $\psi(2S)$ leptonic width
- New R measurement
- Summary

Collider VEPP-4M

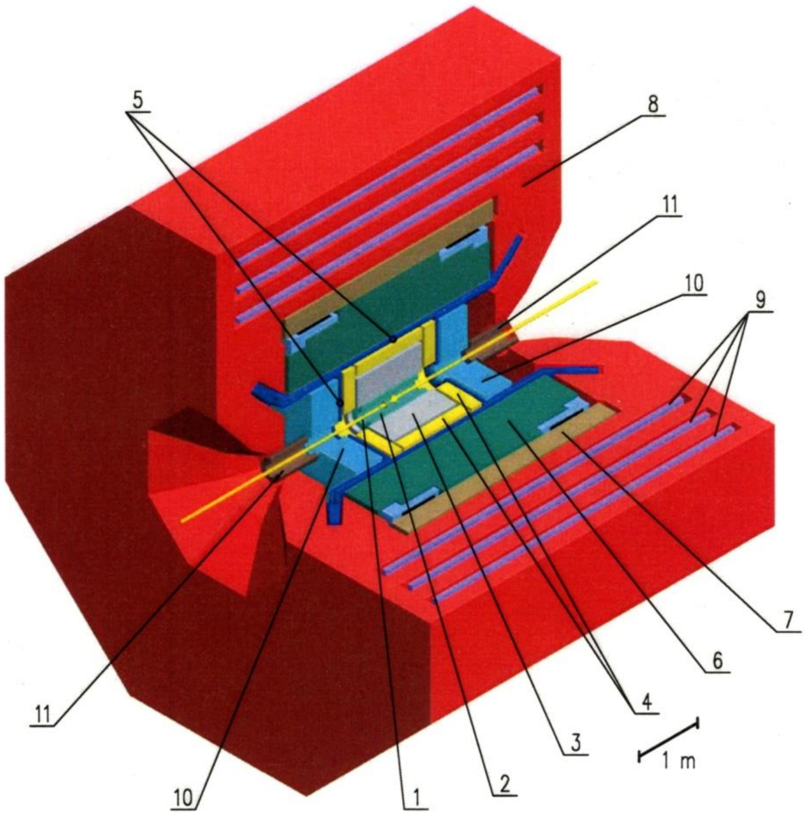


Circumference	366 m
Beam energy	1 – 5 GeV
Number of bunches	2 x 2
Luminosity at 1.5 GeV	$2\cdot10^{30}$ cm^{-2} s^{-1}
Luminosity at 5.0 GeV	$2\cdot10^{31}$ cm^{-2} s^{-1}

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

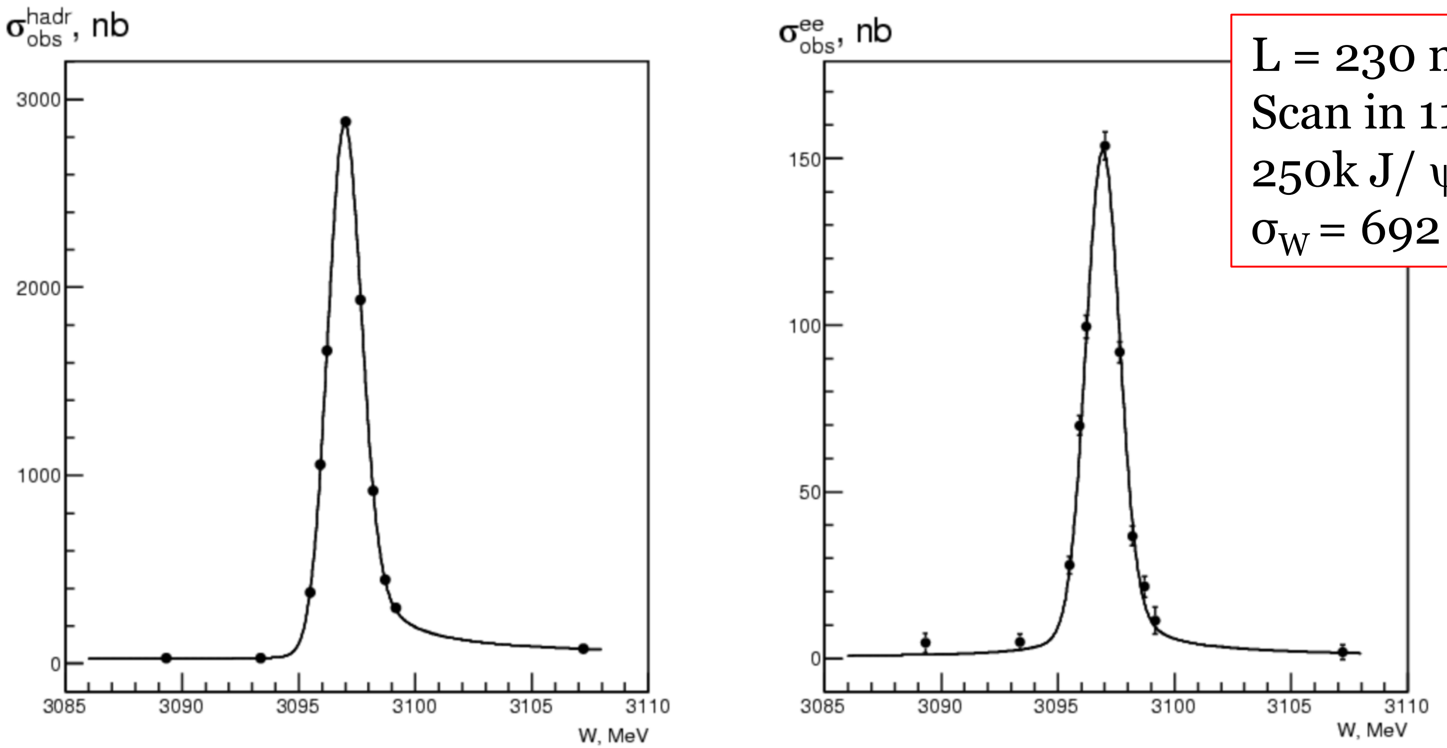
Detector KEDR



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

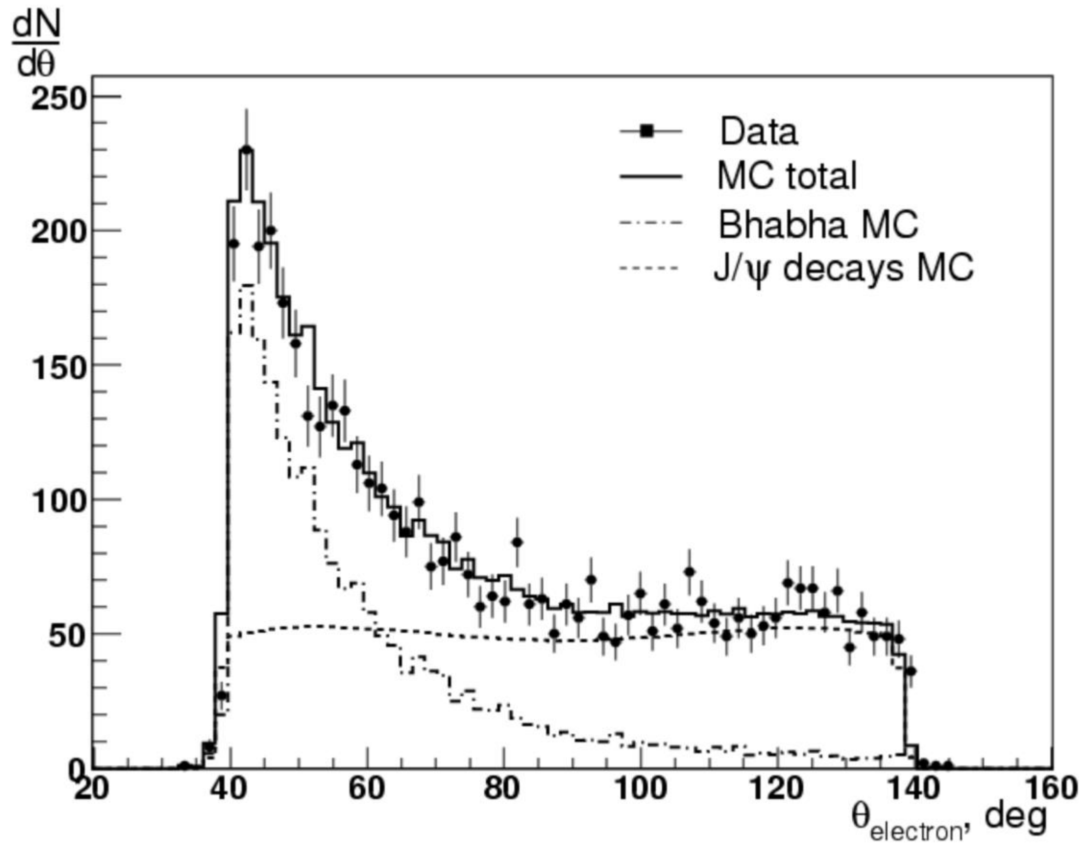


L = 230 nb^{-1}
Scan in 11 points
250k J/ ψ mesons
$\sigma_W = 692 \pm 4$ keV

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

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

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

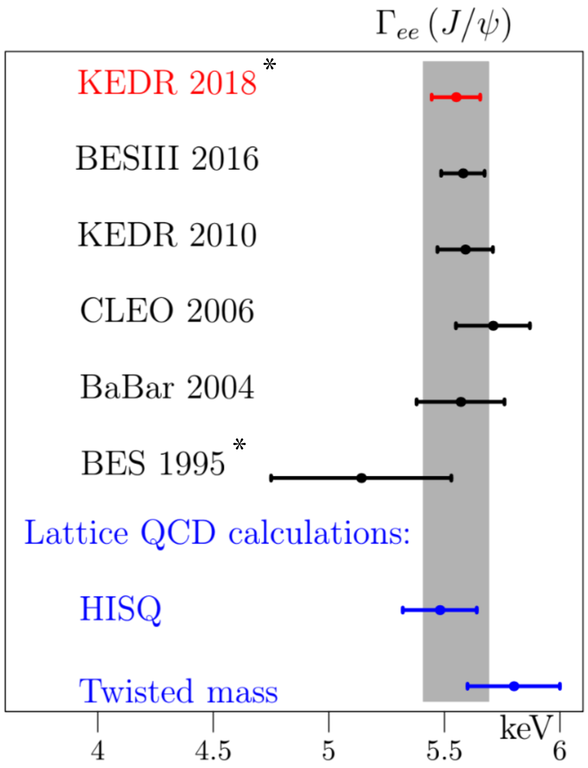


- The relative luminosity was measured by bremsstrahlung luminosity monitor
- The absolute luminosity was calculated using e^+e^- events in the barrel LKr calorimeter

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)

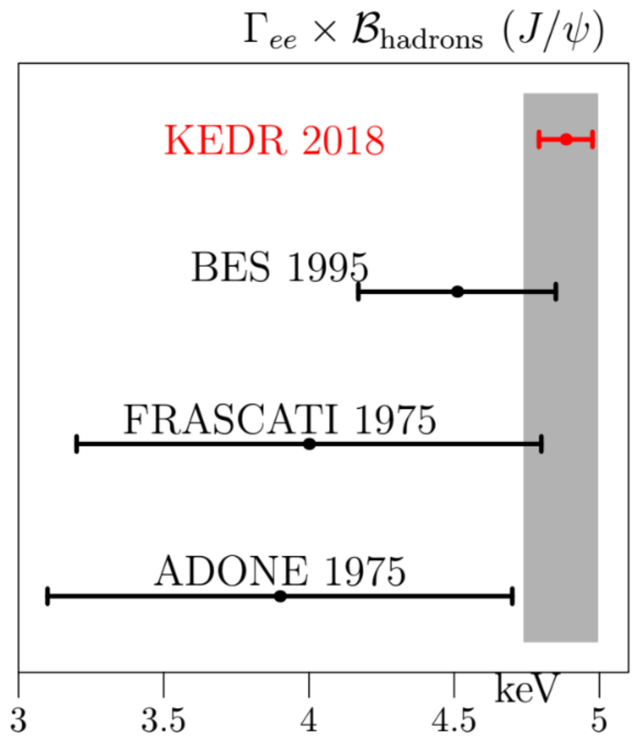


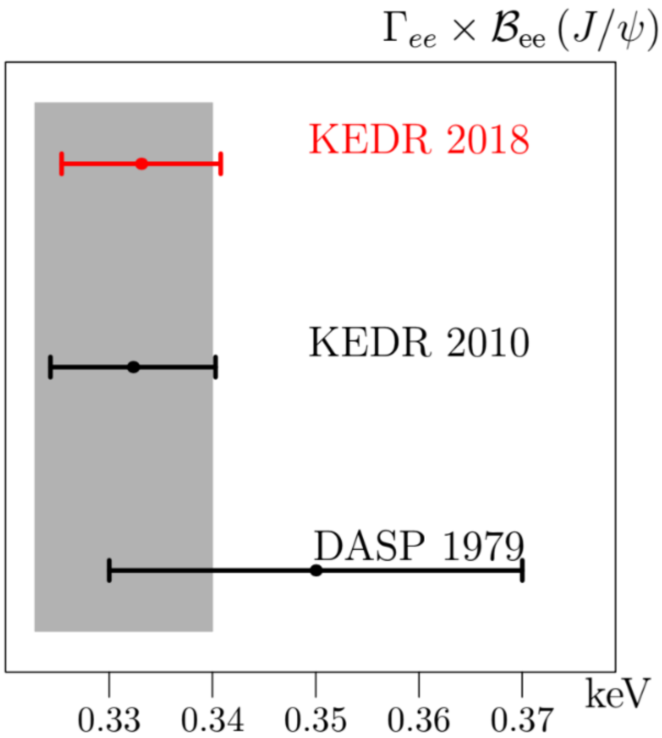
$$\Gamma_{ee}(J/\psi) = 5.550 \pm 0.056 \pm 0.089\,\mathrm{keV}$$

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

To note: Agreement in Γ_{ee} (J/ψ) obtained from hadronic and leptonic decays confirm 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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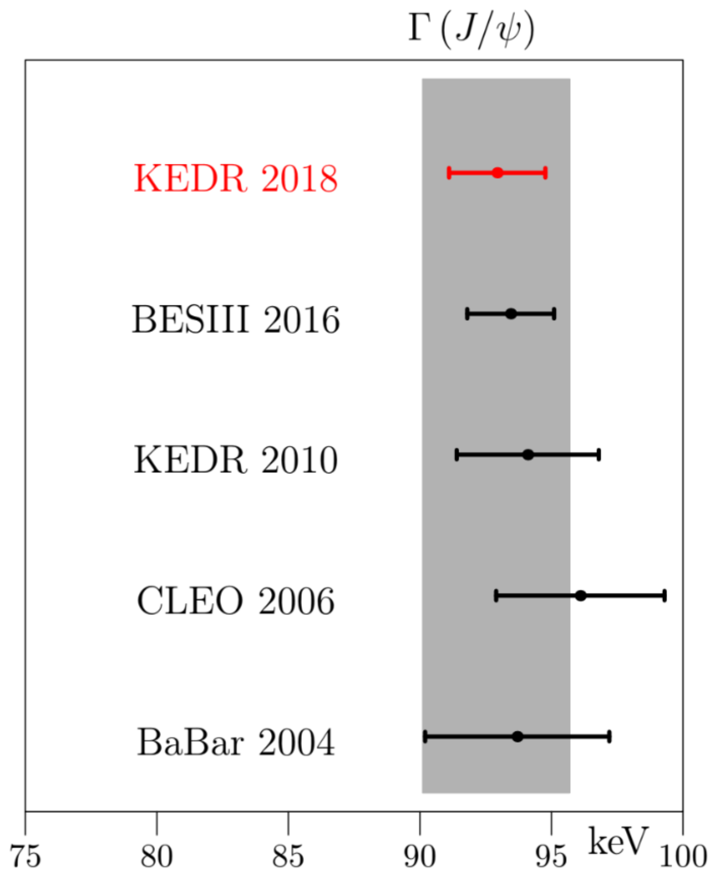
Determination of Γ(J/ψ)



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

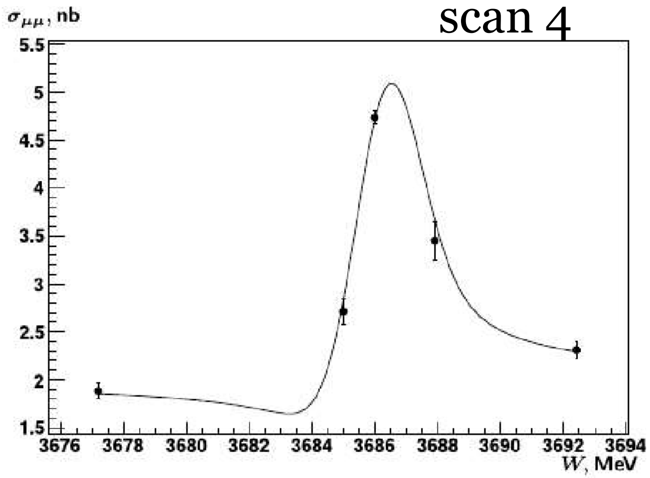
$$\Gamma = 92.94 \pm 1.83\,\text{keV}$$

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

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

scan 4



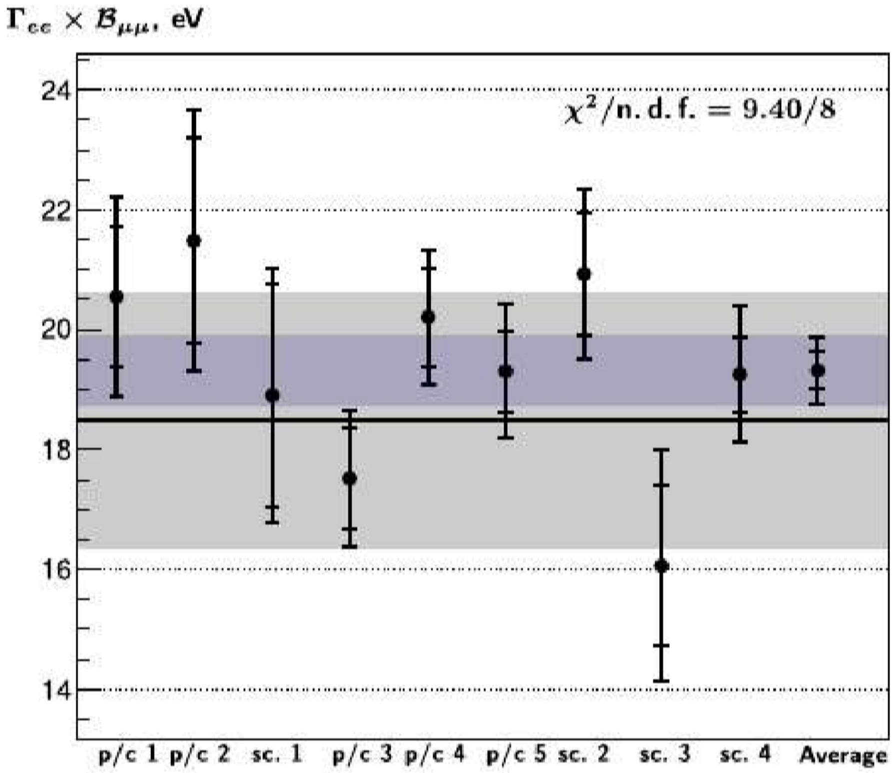
B

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

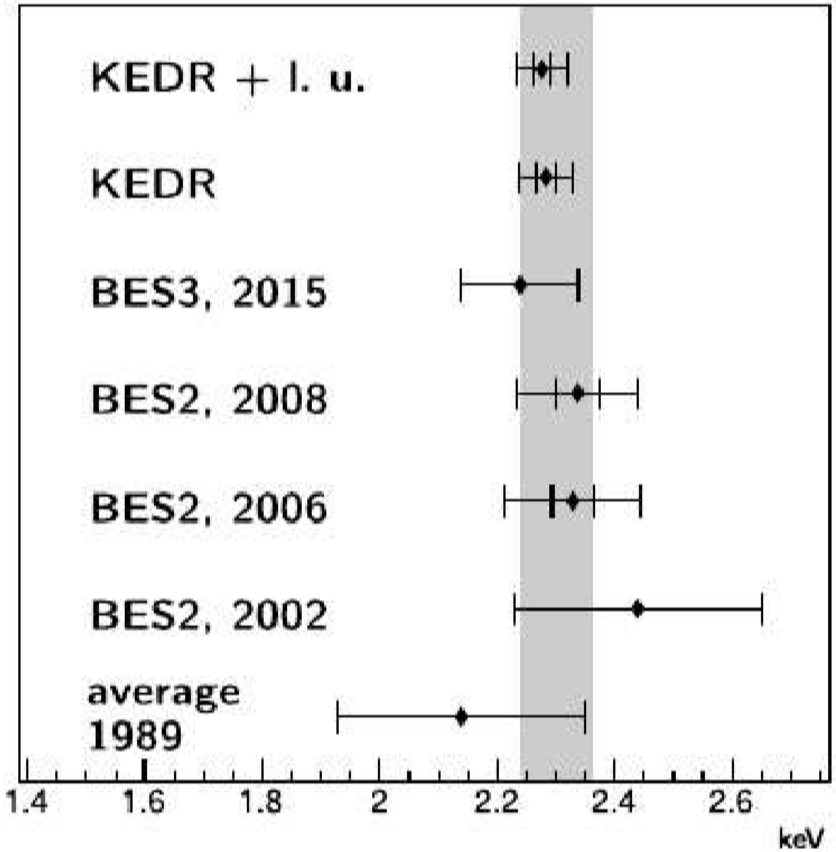


$$\Gamma_{ee} \times \mathcal{B}_{\mu\mu} = 19.3 \pm 0.3 \pm 0.5 \text{ eV}$$

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

Phys. Lett. B V. 781, 10 June 2018, pp. 174-181

Γ_{ee} (ψ(2S)) measurement



- With lepton universality and KEDR result on hadronic channel

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

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

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

- Summing up hadronic and 3 leptonic channels from KEDR:

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

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

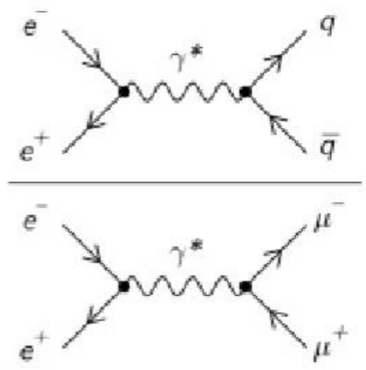
$$\Gamma_{ee} \times \mathcal{B}_{\tau\tau} = 9.0 \pm 2.6 \text{ eV}$$

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

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

R measurement

$$R = \frac{\sigma(e^-e^+ \to \text{hadrons})}{\sigma(e^-e^+ \to \mu^-\mu^+)} \approx$$



Precise R measurement at low energies is important in calculation of fundamental values:

- $\alpha_s(s)$
- $(g_\mu-2)/2$
- $\alpha(M_Z^2)$
- Heavy quark masses

At first approximation:

$$R(s) \simeq 3 \sum e_q^2$$

R measurement at KEDR

3.12 – 3.72 GeV, data 2011, L = 1.4 pb-1
Phys. Lett. B 753 (2016) 533
1.84 – 3.05 GeV, data 2010, L = 0.65 pb-1
Phys. Lett. B 770 (2017) 174

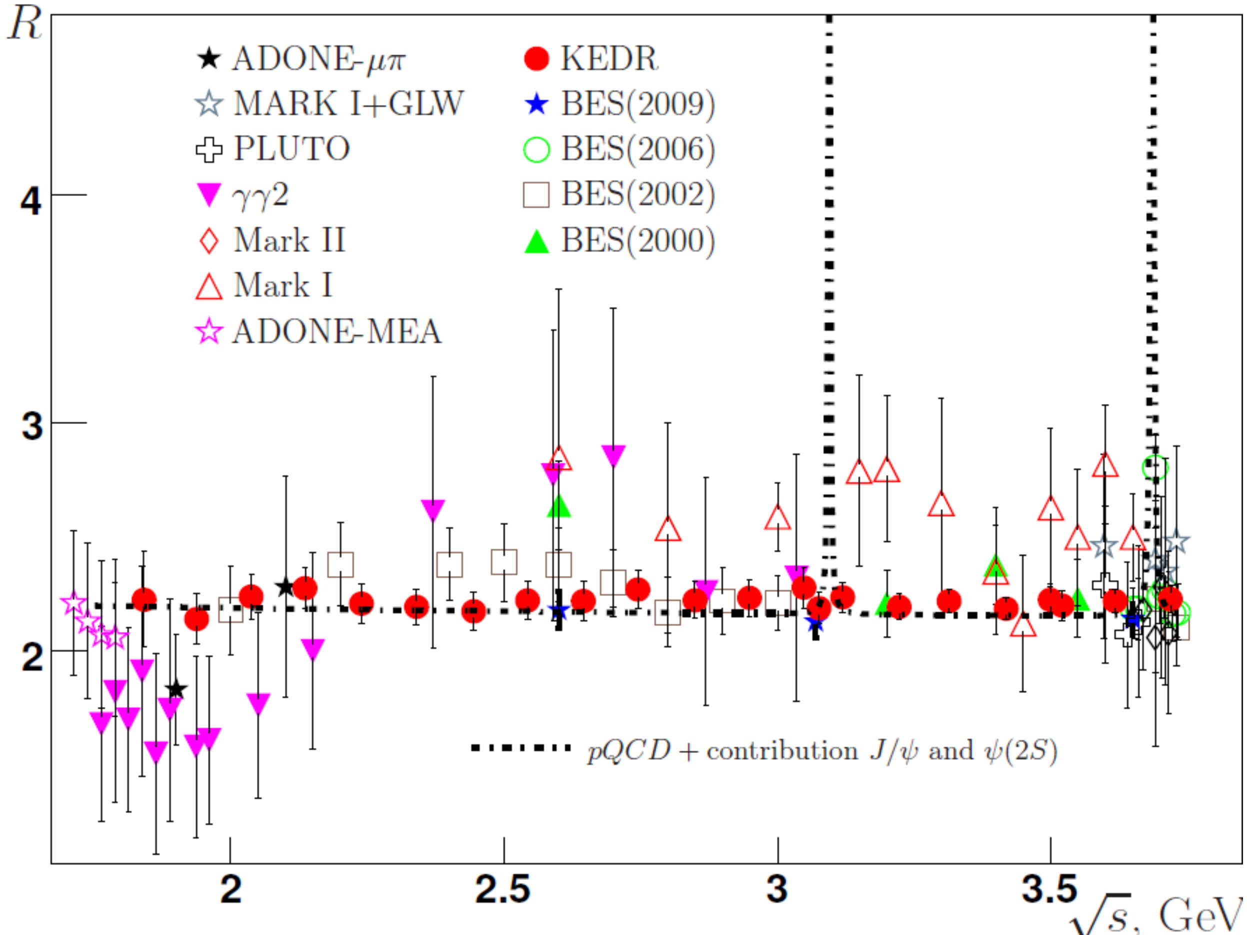
New measurement:
3.08 – 3.72 GeV, data 2014-15 (after detector repair), 8 points, L = 1.3 pb^{-1}
Submitted to Phys. Lett. B [arXiv:1805.06235]

Data 2011 [15]		Data 2014		Combination	
$\sqrt{s}$, MeV	$R_{uds}(s)$	$\sqrt{s}$, MeV	$R_{uds}(s)$	$\sqrt{s}$, MeV	$R_{uds}(s)\{R(s)\}$
-	-	3076.7 ± 0.2	2.188 ± 0.056 ± 0.042	3076.7 ± 0.2	2.188 ± 0.056 ± 0.042
3119.9 ± 0.2	2.215 ± 0.089 ± 0.066	3119.2 ± 0.2	2.211 ± 0.046 ± 0.060	3119.6 ± 0.4	2.212{2.235} ± 0.042 ± 0.050
3223.0 ± 0.6	2.172 ± 0.057 ± 0.045	3221.8 ± 0.2	2.214 ± 0.055 ± 0.042	3222.5 ± 0.8	2.194{2.195} ± 0.040 ± 0.037
3314.7 ± 0.7	2.200 ± 0.056 ± 0.043	3314.7 ± 0.4	2.233 ± 0.044 ± 0.042	3314.7 ± 0.6	2.220{2.220} ± 0.035 ± 0.036
3418.2 ± 0.2	2.168 ± 0.050 ± 0.042	3418.3 ± 0.4	2.197 ± 0.047 ± 0.040	3418.3 ± 0.3	2.186{2.186} ± 0.032 ± 0.036
-	-	3499.6 ± 0.4	2.224 ± 0.054 ± 0.040	3499.6 ± 0.4	2.224{2.224} ± 0.054 ± 0.040
3520.8 ± 0.4	2.200 ± 0.050 ± 0.044	-	-	3520.8 ± 0.4	2.200{2.201} ± 0.050 ± 0.044
3618.2 ± 1.0	2.201 ± 0.059 ± 0.044	3618.1 ± 0.4	2.220 ± 0.049 ± 0.042	3618.2 ± 0.7	2.212{2.218} ± 0.038 ± 0.037
3719.4 ± 0.7	2.187 ± 0.068 ± 0.060	3719.6 ± 0.2	2.213 ± 0.047 ± 0.049	3719.5 ± 0.5	2.204{2.228} ± 0.039 ± 0.043

Systematical errors for R measurement

	1	2	3	4	5	6	7	8
Luminosity	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Radiative correction	0.8	0.8	0.5	0.7	0.6	0.5	0.7	0.5
Continuum simulation	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
Track reconstruction	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
e^+e^-X contribution	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
l^+l^- contribution	0.4	0.4	0.4	0.3	0.3	0.3	0.4	0.4
Trigger efficiency	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Nuclear interaction	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Cuts variation	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
J/ψ and $\psi(2S)$	0.1	1.8	0.4	0.2	0.1	0.1	0.1	1.1
Machine background	0.4	0.8	0.5	0.6	0.5	0.4	0.4	0.6
Sum in quadrature	1.9	2.7	1.9	1.9	1.8	1.8	1.9	2.2

R measurement from p-antip to D-antiD threshold energy region

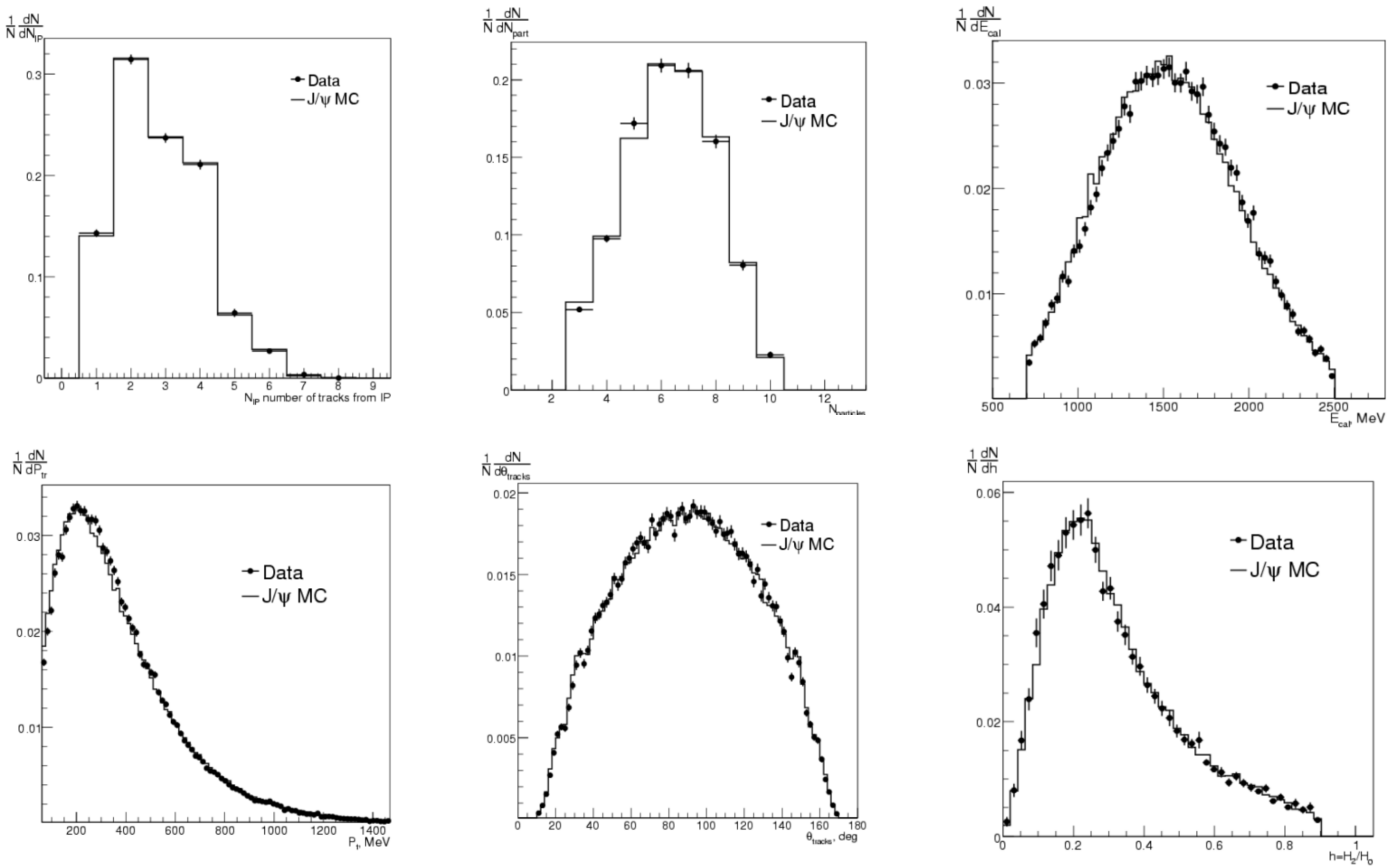


- R is measured at 22 points between 1.84 and 3.72 GeV
- Between 3.08 and 3.72 GeV syst. error 1.9%, total 2.6%

Summary

- New precise measurement of J/ψ leptonic width
- New precise measurement of $\Gamma_{ee} \cdot B_{\mu\mu}(\psi(2S))$
- New R measurement at 8 points between 3.08 and 3.72 GeV with accuracy up to 2.6%

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



- Comparison between data and MC in hadronic properties: the number of tracks from the IP, the total number of particles, energy deposited in the calorimeter, inclusive P_t and θ distributions and the ratio of Fox-Wolfram moments H_2/H_0