Results on J/ψ, $\psi(2S)$, $\psi(3770)$ from KEDR

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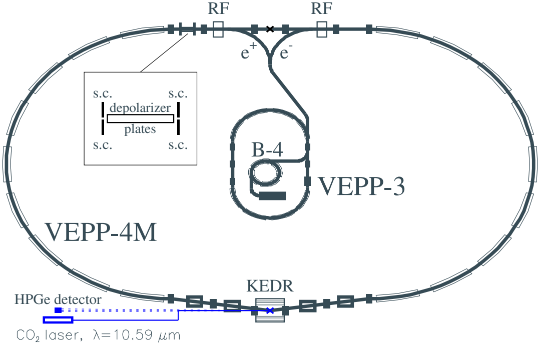
Introduction

- VEPP–4M colider and KEDR detector
- J/ψ and $\psi(2S)$ mass measurements
- $\psi(3770)$ mass measurement
- D-mesons mass measurements
- Meson width determination
  - $\Gamma_{e^+e^-} \times \Gamma_{e^+e^-}/\Gamma$ for J/ψ
  - $\Gamma_{e^+e^-} \times \Gamma_{\mu^+\mu^-}/\Gamma$ for $\psi(2S)$

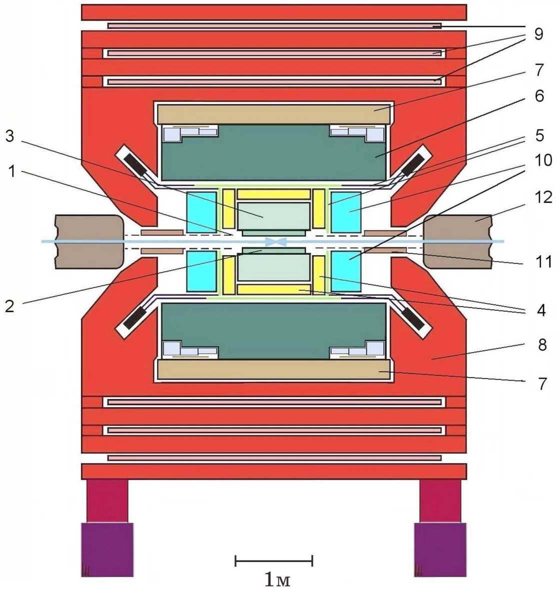
VEPP–4M collider



Circumference	366 m
Magnetic radius	34.5 m
Beam energy	$1 \div 6$ GeV
Number of bunches	2×2
Vertical beta-function	5 cm
Luminosity, $E = 1.5$ GeV	2×10^{30}
Beam current, $E = 1.5$ GeV	2 mA
Luminosity, $E = 5.0$ GeV	2×10^{31}
Beam current, $E = 5.0$ GeV	10 mA
RF frequency	181.8 MHz
Revolution period	1.2 μs

- Resonant depolarization technique:
  Instant measurement accuracy $\simeq 1 \times 10^{-6}$
  Energy interpolation accuracy $(5 \div 15) \times 10^{-6}$ $(10 \div 30$ keV$)$
- Infra-red light Compton backscattering (2005):
  Statistical accuracy $\simeq 5 \times 10^{-5}$ / 30 minutes
  Systematic uncertainty $\simeq 3 \times 10^{-5}$ $(50 \div 70$ keV$)$

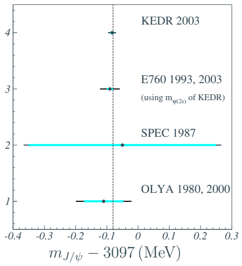
KEDR detector



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. Compensation solenoid
12. VEPP–4M quadrupole

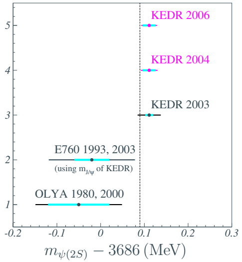
J/ψ MASS

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
3096.916±0.011 OUR AVERAGE					
3096.917±0.010±0.007		AULCHENKO	03	KEDR	$e^+e^- \to$ hadrons
3096.89 ±0.09	502	[1] ARTAMONOV	00	OLYA	$e^+e^- \to$ hadrons
3096.91 ±0.03 ±0.01		[2] ARMSTRONG	93B	E760	$\overline{p}p \to e^+e^-$
3096.95 ±0.1 ±0.3	193	BAGLIN	87	SPEC	$\overline{p}p \to e^+e^-X$



$\psi(2S)$ MASS

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
3686.09 ±0.04 OUR FIT	Error includes scale factor of 1.6.				
3686.093±0.034 OUR AVERAGE	Error includes scale factor of 1.4. See the ideogram below.				
3686.111±0.025±0.009		AULCHENKO	03	KEDR	$e^+e^- \to$ hadrons
3685.95 ±0.10	413	[1] ARTAMONOV	00	OLYA	$e^+e^- \to$ hadrons
3685.98 ±0.09 ±0.04		[2] ARMSTRONG	93B	E760	$\overline{p}p \to e^+e^-$

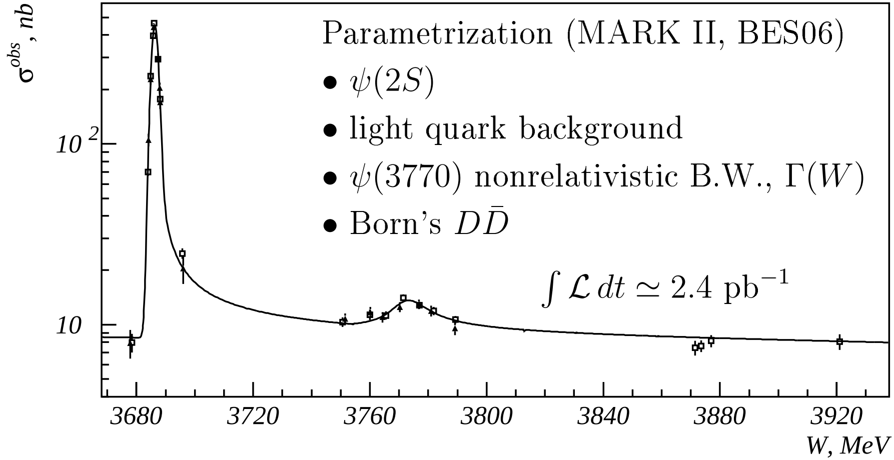


$$m^{2004}_{\psi(2S)} = 3686.117 \pm 0.012 \pm 0.015\,\mathrm{MeV}/c^2$$

$$m^{2006}_{\psi(2S)} = 3686.125 \pm 0.010 \pm 0.015\,\mathrm{MeV}/c^2$$

(preliminary)

$\psi(3770)$ mass measurement

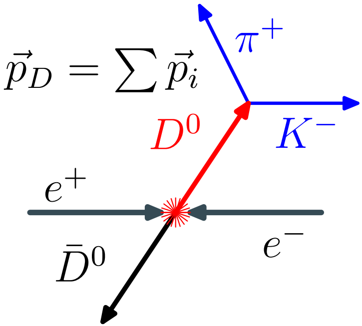


$$m_{\psi(3770)} = 3772.9 \pm 0.6 \pm 0.8\ \mathrm{MeV}/c^2$$ (preliminary)

Dominant systematic error: detector instabilities.

D-mesons produced in $e^+e^- \to \psi(3770) \to D\overline{D}$ process are used.

$$\int \mathcal{L}\,dt \simeq 0.9\,\mathrm{pb}^{-1}$$



One of D is reconstructed:

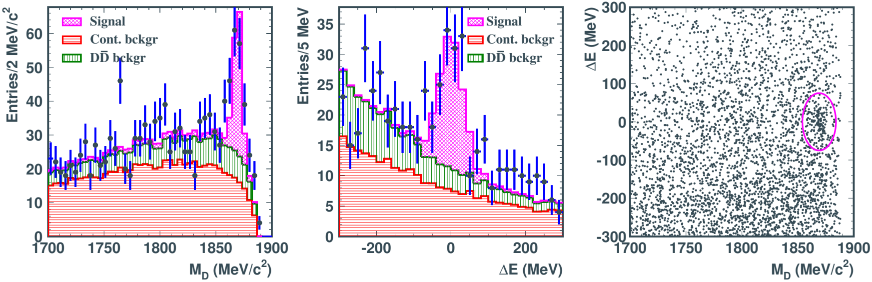
$$D^0 \to K^-\pi^+ \qquad \mathcal{B} = 3.8 \pm 0.1\%$$
$$D^+ \to K^-\pi^+\pi^+ \qquad \mathcal{B} = 9.2 \pm 0.6\%$$

Variables for signal selection:

$$M_D = \sqrt{E_{beam}^2 - p_D^2}$$
$$\Delta E = \sum_i \sqrt{p_i^2 + m_i^2} - E_{beam}$$

Perform a 2D fit in $(M_D, \Delta E)$ to obtain D meson mass.

$D^{\pm}$ mass measurement



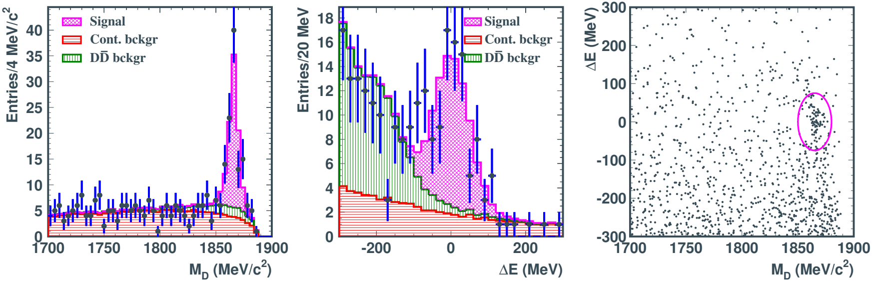
Number of $D^+ \to K^-\pi^+\pi^+$ events — 110 ± 14.

$$m_{D^{\pm}} = 1869.39 \pm 0.45 \pm 0.29\ \mathrm{MeV}/c^2$$ (preliminary)

Dominant systematic errors:

- Signal and background shapes (0.22 MeV)
- ISR corrections (0.17 MeV)
- Momentum calibration (0.10 MeV)

D^0 mass measurement



Number of $D^0 \to K^-\pi^+$ events — 92 ± 11.

$$m_{D^0} = 1865.43 \pm 0.60 \pm 0.38\ \mathrm{MeV}/c^2$$ (preliminary)

Dominant systematic errors:

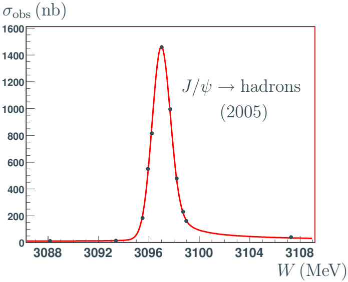
- Signal and background shapes (0.29 MeV)
- ISR corrections (0.17 MeV)
- Momentum calibration (0.17 MeV)

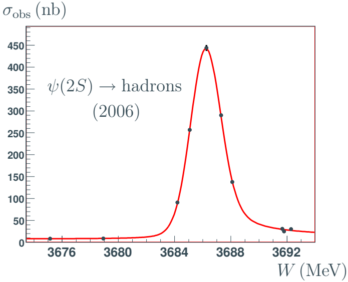
The results of precise scans can be used for obtaining leptonic and total width.

At the moment we present the following results:

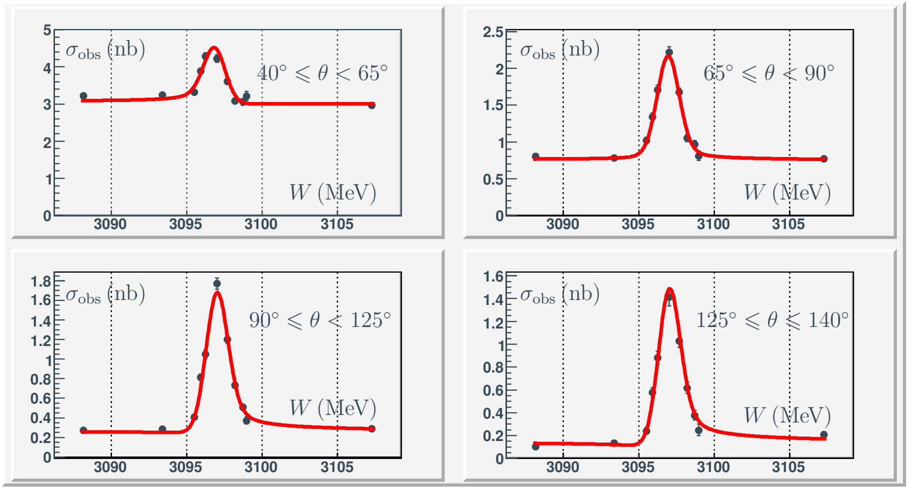
- $\Gamma_{e^+e^-} \times \Gamma_{e^+e^-}/\Gamma$ for J/ψ,
- $\Gamma_{e^+e^-} \times \Gamma_{\mu^+\mu^-}/\Gamma$ for $\psi(2S)$.

Unlike $\Gamma_{e^+e^-}/\Gamma$ to obtain these combinations one needs precise knowledge of the beam energy spread.



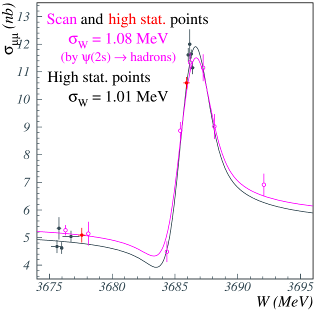


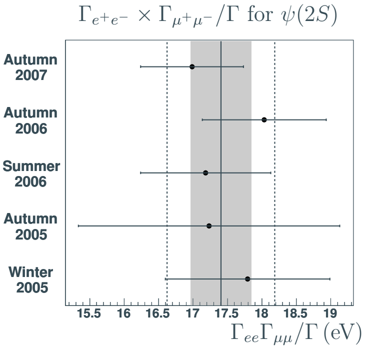
$e^+e^- \to e^+e^-$ cross section



$$\Gamma_{e^+e^-} \times \Gamma_{e^+e^-}/\,\Gamma_{\text{total}} = 339.2 \pm 6.8 \pm 6.3\,\text{eV}$$

$\Gamma_{e^+e^-} \times \Gamma_{\mu^+\mu^-}/\Gamma$ for $\psi(2S)$





$$\Gamma_{e^+e^-} \times \Gamma_{\mu^+\mu^-} / \Gamma_{\text{total}} = 17.40 \pm 0.44 \pm 0.64 \text{ eV}$$ (preliminary)

Dominant systematic errors:

- Absolute luminosity calibration (0.38 eV)
- Beam energy spread determination in $\psi(2S)$ scans (0.35 eV)

Summary

- $m_{\psi(2S)} = 3686.122 \pm 0.008 \pm 0.012\,\mathrm{MeV}/c^2$ (preliminary)
- $m_{\psi(3770)} = 3772.9 \pm 0.6 \pm 0.8\,\mathrm{MeV}/c^2$ (preliminary)

- $m_{D^\pm} = 1869.39 \pm 0.45 \pm 0.29\,\mathrm{MeV}/c^2$ (preliminary)
- $m_{D^0} = 1865.43 \pm 0.60 \pm 0.38\,\mathrm{MeV}/c^2$ (preliminary)

- J/ψ $\Gamma_{e^+e^-} \times \Gamma_{e^+e^-}/\Gamma = 339.2 \pm 6.8 \pm 6.3\,\mathrm{eV}$
- $\psi(2S)$ $\Gamma_{e^+e^-} \times \Gamma_{\mu^+\mu^-}/\Gamma = 17.40 \pm 0.44 \pm 0.64\,\mathrm{eV}$ (preliminary)

Summary

- $m_{\psi(2S)} = 3686.122 \pm 0.008 \pm 0.012\,\text{MeV}/c^2$ (preliminary)
  - $3686.09 \pm 0.04\,\text{MeV}/c^2$ (PDG fit, scale factor 1.6)
- $m_{\psi(3770)} = 3772.9 \pm 0.6 \pm 0.8\,\text{MeV}/c^2$ (preliminary)
  - $3772.4 \pm 1.1\,\text{MeV}/c^2$ (PDG, scale factor 1.8)

- $m_{D^\pm} = 1869.39 \pm 0.45 \pm 0.29\,\text{MeV}/c^2$ (preliminary)
  - $1869.5 \pm 0.5\,\text{MeV}/c^2$ (PDG)
- $m_{D^0} = 1865.43 \pm 0.60 \pm 0.38\,\text{MeV}/c^2$ (preliminary)
  - $1864.84 \pm 0.18\,\text{MeV}/c^2$ (PDG)

- J/ψ $\Gamma_{e^+e^-} \times \Gamma_{e^+e^-}/\Gamma = 339.2 \pm 6.8 \pm 6.3\,\text{eV}$
- $\psi(2S)$ $\Gamma_{e^+e^-} \times \Gamma_{\mu^+\mu^-}/\Gamma = 17.40 \pm 0.44 \pm 0.64\,\text{eV}$ (preliminary)

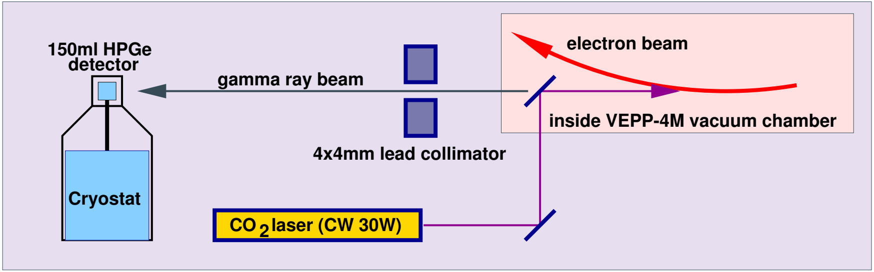
Summary

- $m_{\psi(2S)} = 3686.122 \pm 0.008 \pm 0.012\,\text{MeV}/c^2$ (preliminary)
  - $3686.09 \pm 0.04\,\text{MeV}/c^2$ (PDG fit, scale factor 1.6)
- $m_{\psi(3770)} = 3772.9 \pm 0.6 \pm 0.8\,\text{MeV}/c^2$ (preliminary)
  - $3772.4 \pm 1.1\,\text{MeV}/c^2$ (PDG, scale factor 1.8)
  - $m_{\psi(3770)} - m_{\psi(2S)} = 86.7 \pm 0.7\,\text{MeV}/c^2$ (BES, 2006)
  - $m_{\psi(3770)} = 3771.4 \pm 1.8\,\text{MeV}/c^2$ (BES, PLB 660 [2008] 315)
- $m_{D^\pm} = 1869.39 \pm 0.45 \pm 0.29\,\text{MeV}/c^2$ (preliminary)
  - $1869.5 \pm 0.5\,\text{MeV}/c^2$ (PDG)
- $m_{D^0} = 1865.43 \pm 0.60 \pm 0.38\,\text{MeV}/c^2$ (preliminary)
  - $1864.84 \pm 0.18\,\text{MeV}/c^2$ (PDG)
  - $1864.847 \pm 0.150 \pm 0.095$ (CLEO, 2007)
- J/ψ $\Gamma_{e^+e^-} \times \Gamma_{e^+e^-}/\Gamma = 339.2 \pm 6.8 \pm 6.3\,\text{eV}$
- $\psi(2S)$ $\Gamma_{e^+e^-} \times \Gamma_{\mu^+\mu^-}/\Gamma = 17.40 \pm 0.44 \pm 0.64\,\text{eV}$ (preliminary)

Conclusion

- New measurements of $\psi(2S)$, $\psi(3770)$ and D meson masses were presented.
- The results of precise scans were used for determination of $\Gamma_{e^+e^-} \times \Gamma_{e^+e^-}/\Gamma$ for J/ψ and $\Gamma_{e^+e^-} \times \Gamma_{\mu^+\mu^-}/\Gamma$ for $\psi(2S)$.
- We are working on analysis for obtaining lepton and total width and some decays probabilities for ψ meson family.

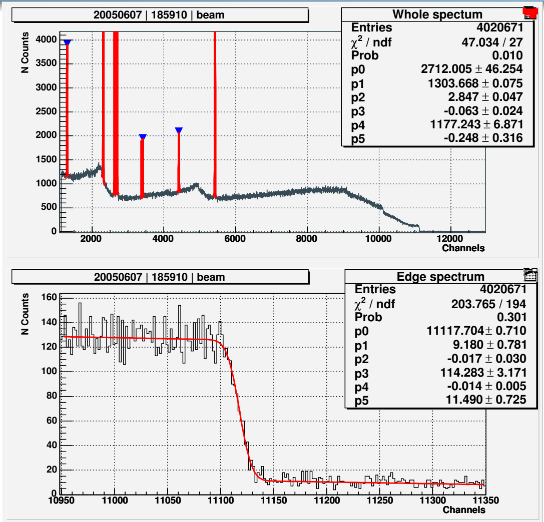
- R. Klein et al., NIM A384 (1997) 293: BESSY–I, 800 MeV
- R. Klein et al., NIM A486 (2002) 545: BESSY–II, 1700 MeV



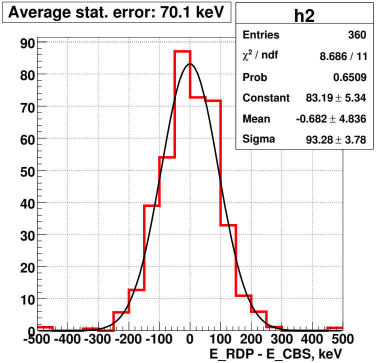
$$\omega'_{max} = \frac{E^2}{E + m^2/4\omega_{laser}}$$

- CO_2 – laser ($\lambda = 10.591\ \mu$m, $\omega_{laser} = 0.12$ eV, $\omega'_{max} \simeq 6$ MeV)

Compton backscattering spectrum

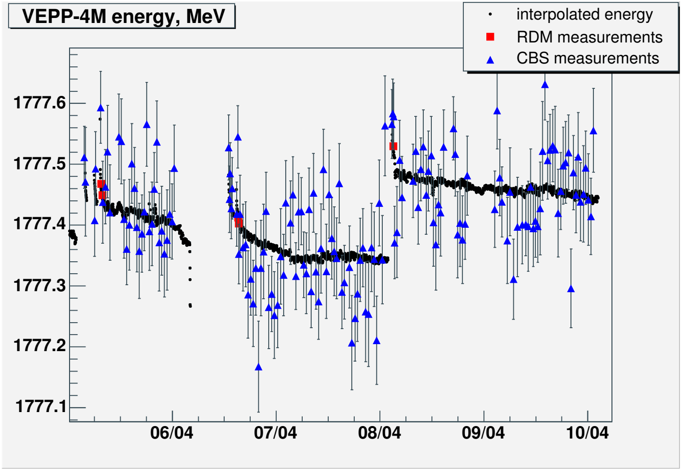


⇐ unlike to BESSY–II, only standard isotopes are used for the detector calibration



- Final CBS calibration with resonant depolarization ⇑
- Energy determination accuracy: 50÷100 keV (stat), 60 keV (syst)
- Energy spread determination accuracy $\simeq$ 15%

- April 2006:



- Energy drop of about 0.1 MeV in 1.5 hours after the magnetization cycle (no data taking at that time, resonant depolarization delay of 1 hour)

$(\Delta m/m) \cdot 10^6$ (PDG avg.)

particle	$\frac{\Delta m}{m} \cdot 10^6$ (PDG avg.)
p	0.1
n	0.1
e	0.1
μ	0.1
$\pi^{\pm}$	2.5
J/ψ	3.5
π^0	4.5
$\psi(2S)$	9.2

Systematic errors of the meson masses (keV)

Error source		J/ψ	ψ'
Energy spread variation		3.0	2.0
Energy assignment:	statistical uncertainty	2.5	3.5
	prediction function choice	2.7	1.7
	radial betatron oscillations	<1.5	<1.8
	beam separation in additional I.P.	0.4*	0.4*
Beam misalignment in the interaction point		1.8	5.1
e^+-, e^--energy difference		<2.0	<2.0
Non-gaussian collision energy distribution		<1.5	<2.0
β-function chromaticity		2.0*	2.5*
Beam potential		1.0*	1.0*
Single energy calibration		0.6*	0.8*
Detection efficiency instability		2.3	2.0
Luminosity measurements		2.2	3.0
Interference in the hadronic channel		1.3	0.8
Residual machine background		<1.0	<1.0
Sum in quadrature		≈ 7.3	≈ 8.9

* — correction uncertainty

Cross section $e^+e^- \to e^+e^-$ in soft photon approximation

$$\left(\frac{d\sigma}{d\Omega}\right)_{th} = \frac{1}{M^2}\left\{\frac{9}{4}\frac{\Gamma^2_{e^+e^-}}{\Gamma M}\left(1+\frac{3}{4}\beta\right)\left(1+\cos^2\theta\right)\operatorname{Im} f\right.$$

$$\left. - \frac{3\alpha}{2}\frac{\Gamma_{e^+e^-}}{M}\left[(1+\cos^2\theta) - \frac{(1+\cos^2\theta)^2}{(1-\cos\theta)}\right]\operatorname{Re} f\right\} + \left(\frac{d\sigma}{d\Omega}\right)_{QED},$$

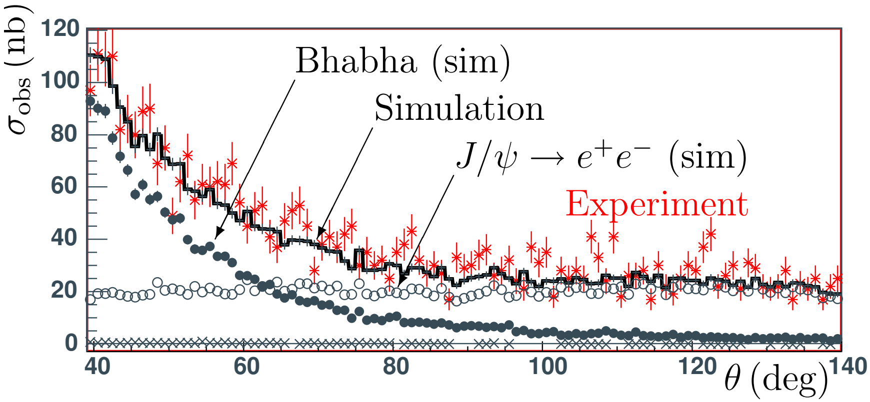
where $\quad f = \left(\dfrac{\frac{M}{2}}{-W+M-\frac{i\Gamma}{2}}\right)^{1-\beta}, \quad \beta = \dfrac{4\alpha}{\pi}\left(\ln\dfrac{W}{m_e} - \dfrac{1}{2}\right) \simeq 0.077$

[Asimov at el. Pis'ma Zh. Eksper. Fiz. 21, (1975) 172 (in English).]

Taking into account c.m.s. energy spread σ_W:

$$\sigma(W) = \frac{1}{\sqrt{2\pi}\sigma_W}\int \sigma_{th}(W')e^{\left\{-\frac{(W-W')^2}{2\sigma_W^2}\right\}}dW'$$

$\Gamma_{e^+e^-}\Gamma_{e^+e^-}/\Gamma$ for J/ψ



$$N_{\text{exp}}(E_i,\theta) = \mathcal{R}_{\mathcal{L}} \times \mathcal{L}(E_i) \times \Big(\sigma^{\text{th}}_{\text{peak}}(E_i,\theta)\cdot\varepsilon^{\text{sim}}_{\text{peak}}(E_i,\theta) +$$

$$+\sigma^{\text{th}}_{\text{inter}}(E_i,\theta)\cdot\varepsilon^{\text{sim}}_{\text{inter}}(E_i,\theta) + \sigma^{\text{sim}}_{\text{Bhabha}}(E_i,\theta)\cdot\varepsilon^{\text{sim}}_{\text{Bhabha}}(E_i,\theta)\Big),$$

where $\sigma^{\text{th}}_{\text{peak}}(E_i,\theta) \sim \Gamma_{e^+e^-} \times \Gamma_{e^+e^-}/\Gamma$

Systematic errors for $\Gamma_{e^+e^-}\Gamma_{e^+e^-}/\Gamma$ for J/ψ

• Energy and energy spread determination	
• Peak position	0.1%
• Energy spread	0.2%
• Energy measurement in point (better then 10–30 keV)	0.3%
• Luminosity (relative)	0.6%
• Background from $J/\psi \to$ hadrons	0.2%
• Bhabha generator	0.4%
• PHOTOS precision	0.4%
• Interference calculation	0.2%
• Selection conditions	
• Energy cuts	1.2%
• Angle cuts	0.4%
• 2 tracks from interaction point requirements	0.5%
• Trigger efficiency	0.8%
• Fit procedure	0.2%