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

#### Evgeny Baldin for KEDR/VEPP-4M

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- VEPP-4M colider and KEDR detector
- $J/\psi$  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  $J/\psi$   
•  $\Gamma_{e^+e^-} \times \Gamma_{\mu^+\mu^-}/\Gamma$  for  $\psi(2S)$ 

### VEPP-4M collider



• Resonant depolarization technique: Instant measurement accuracy  $\simeq 1 \times 10^{-6}$ Energy interpolation accuracy  $(5 \div 15) \times 10^{-6} (10 \div 30 \text{ keV})$ 

• Infra-red light Compton backscattering (2005): Statistical accuracy  $\simeq 5 \times 10^{-5}$  / 30 minutes Systematic uncertainty  $\simeq 3 \times 10^{-5}$  (50 ÷ 70 keV)

### KEDR detector



- Vacuum chamber
- 2 Vertex detector
- 3 Drift chamber
- Threshold aerogel counters
- 5 ToF-counters
- Liquid krypton calorimeter
- Superconducting coil
- 8 Magnet yoke
- Muon tubes
- Osl-calorimeter
- Compensation solenoid
- VEPP-4M quadrupole

### $J/\psi$ and $\psi(2S)$ mass measurements

 $J/\psi$  MASS

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

 $\psi(2S)$  MASS

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

$$m_{\psi(2S)}^{2004} = 3686.117 \pm 0.012 \pm 0.015 \,\mathrm{MeV}/c^2$$
  
 $m_{\psi(2S)}^{2006} = 3686.125 \pm 0.010 \pm 0.015 \,\mathrm{MeV}/c^2$ 

(preliminary)





### $\psi(3770)$ mass measurement



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

Dominant systematic error: detector instabilities.

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



One of D is reconstructed:

$$egin{array}{lll} D^0 & o \ K^- \pi^+ & \mathcal{B} = 3.8 \pm 0.1\% \ D^+ & o \ K^- \pi^+ \pi^+ & \mathcal{B} = 9.2 \pm 0.6\% \end{array}$$

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  $D^+ \rightarrow K^- \pi^+ \pi^+$  events — 110 ± 14.

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

Dominant systematic errors:

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

### D<sup>0</sup> mass measurement



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

 $m_{D^0} = 1865.43 \pm 0.60 \pm 0.38 \; {
m MeV}/c^2$ 

(preliminary)

Dominant systematic errors:

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

### Meson width determination

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

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



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





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

Evgeny Baldin for KEDR/VEPP-4M

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



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

Dominant systematic errors:

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

• 
$$m_{\psi(25)} = 3686.122 \pm 0.008 \pm 0.012 \text{ MeV}/c^2$$
 (preliminary)  
•  $m_{\psi(3770)} = 3772.9 \pm 0.6 \pm 0.8 \text{ MeV}/c^2$  (preliminary)  
•  $m_{D^{\pm}} = 1869.39 \pm 0.45 \pm 0.29 \text{ MeV}/c^2$  (preliminary)  
•  $m_{D^0} = 1865.43 \pm 0.60 \pm 0.38 \text{ MeV}/c^2$  (preliminary)  
•  $J/\psi$   $\Gamma_{e^+e^-} \times \Gamma_{e^+e^-}/\Gamma = 339.2 \pm 6.8 \pm 6.3 \text{ eV}$ 

•  $\psi(2S) \ \Gamma_{e^+e^-} \times \Gamma_{\mu^+\mu^-} / \Gamma = 17.40 \pm 0.44 \pm 0.64 \,\mathrm{eV}$  (preliminar

### Summary

•  $m_{\psi(2S)} = 3686.122 \pm 0.008 \pm 0.012 \,\mathrm{MeV}/c^2$ •  $3686.09 \pm 0.04 \,\mathrm{MeV}/c^2$  (PDG fit, scale factor 1.6) •  $m_{\psi(3770)} = 3772.9 \pm 0.6 \pm 0.8 \,\mathrm{MeV}/c^2$ •  $3772.4 \pm 1.1 \,\text{MeV}/c^2$  (PDG, scale factor 1.8) •  $m_{D^{\pm}} = 1869.39 \pm 0.45 \pm 0.29 \,\mathrm{MeV}/c^2$ •  $1869.5 \pm 0.5 \,\mathrm{MeV}/c^2$  (PDG) •  $m_{D^0} = 1865.43 \pm 0.60 \pm 0.38 \,\mathrm{MeV}/c^2$ •  $1864.84 \pm 0.18 \,\mathrm{MeV}/c^2$  (PDG) •  $J/\psi$   $\Gamma_{e^+e^-} \times \Gamma_{e^+e^-}/\Gamma = 339.2 \pm 6.8 \pm 6.3 \text{ eV}$ •  $\psi(2S) \Gamma_{e^+e^-} \times \Gamma_{\mu^+\mu^-} / \Gamma = 17.40 \pm 0.44 \pm 0.64 \,\mathrm{eV}$ 

### Summary

•	$m_{\psi(2S)} = 3686.122 \pm 0.008 \pm 0.012  { m MeV}/c^2$	(preliminary)
	• $3686.09 \pm 0.04 \mathrm{MeV}/c^2$ (PDG fit, scale factor 1.6)	
٠	$m_{\psi(3770)}=3772.9\pm0.6\pm0.8{ m MeV}/c^2$	(preliminary)
	• $3772.4 \pm 1.1  { m MeV}/c^2$ (PDG, scale factor 1.8)	
	• $m_{\psi(3770)} - m_{\psi(2S)} = 86.7 \pm 0.7  { m MeV}/c^2$ (BES, 2006)	
	• $m_{\psi(3770)} = 3771.4 \pm 1.8  { m MeV}/c^2$ (BES, PLB 660 [2008]	315)
٠	$m_{D^\pm} = 1869.39 \pm 0.45 \pm 0.29  { m MeV}/c^2$	(preliminary)
	• $1869.5\pm0.5\mathrm{MeV}/c^2~\mathrm{(PDG)}$	
٠	$m_{D^0} = 1865.43 \pm 0.60 \pm 0.38{ m MeV}/c^2$	(preliminary)
	• $1864.84 \pm 0.18 \mathrm{MeV}/c^2$ (PDG)	
	<ul> <li>1864.847 ± 0.150 ± 0.095 (CLEO, 2007)</li> </ul>	
٠	$J/\psi ~~\Gamma_{e^+e^-}  imes \Gamma_{e^+e^-}/\Gamma = 339.2 \pm 6.8 \pm 6.3  {\rm eV}$	
٩	$\psi(2S) \ \Gamma_{e^+e^-}  imes \Gamma_{\mu^+\mu^-} / \Gamma = 17.40 \pm 0.44 \pm 0.64  \mathrm{eV}$	(preliminary)

- 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  $J/\psi$  and  $\Gamma_{e^+e^-} \times \Gamma_{\mu^+\mu^-}/\Gamma$  for  $\psi(2S)$ .
- $\bullet$  We are working on analysis for obtaining lepton and total width and some decays probabilities for  $\psi$  meson family.



#### VEPP-4M collider

- 3 KEDR detector
- (3)  $J/\psi$  and  $\psi(2S)$  mass measurements
- (4)  $\psi$ (3770) mass measurement
  - 5 Measurements of *D*-meson masses
- 6 Meson width determination •  $\Gamma_{e^+e^-} \times \Gamma_{e^+e^-}/\Gamma$  for  $J/\psi$ •  $\Gamma_{e^+e^-} \times \Gamma_{\mu^+\mu^-}/\Gamma$  for  $\psi(2S)$ 
  - 🕽 Summary

#### Conclusion

## Energy monitoring using IR-light Compton backscattering

- 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<sub>2</sub> – laser ( $\lambda = 10.591 \ \mu$ m,  $\omega_{laser} = 0.12 \ \text{eV}$ ,  $\omega'_{max} \simeq 6 \ \text{MeV}$ )

### Compton backscattering spectrum

20050607 | 185910 | beam Whole spectum 4020671 Entries 4000 4 Counts  $\gamma^2$  / ndf  $\Leftarrow$  unlike to BESSY–II, only 47,034 / 27 Prob 0.010 3500 2712.005 + 46.254 standard isotopes are used p0 3000 p1  $1303.668 \pm 0.075$ . p2  $2.847 \pm 0.047$ for the detector calibration 2500 p3 -0.063 ± 0.024 . p4 1177.243 ± 6.871 2000  $-0.248 \pm 0.316$ 'n5 1500 Average stat. error: 70.1 keV h2 1000 Entries 360 90f 500  $\gamma^2$  / ndf 8.686 / 11 80 0.6509 Prob 12000 Channels Constant 83.19 ± 5.34 70 20050607 | 185910 | beam Edge spectrum Mean -0.682 + 4.836Entries 402067 60 Sigma  $93.28 \pm 3.78$ **V** Counts  $\gamma^2 / \mathbf{ndf}$ 203.765 / 194 Prob 0.301 50 11117.704± 0.710 p0 p1  $9.180 \pm 0.781$ . p2 -0.017 ± 0.030 40F 10 p3 114.283 + 3.171 $-0.014 \pm 0.005$ p4 30 p5  $11490 \pm 0725$ 20 10F 20 -500 -400 -300 -200 -100 0 100 200 300 400 500 11000 11050 11100 11150 11200 1135 E RDP - E CBS, keV Final CBS calibration with resonant depolarization Energy determination accuracy:  $50 \div 100$  keV (stat), 60 keV (syst)

ullet Energy spread determination accuracy  $\simeq 15\%$ 

## Example of VEPP-4M energy behavior

• 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)

particle	$\frac{\Delta m}{m} \cdot 10^6 \text{ (PDG avg.)}$
р	0.1
п	0.1
е	0.1
$\mu$	0.1
$\pi^{\pm}$	2.5
$J/\psi$	3.5
$\pi^0$	4.5
$\psi(2S)$	9.2

Systematic errors of the meson masses (keV)

$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	Error source	$J/\psi$	$\psi'$
Energy assignment: statistical uncertainty prediction function choice radial betatron oscillations beam separation in additional I.P.2.5 2.7 1.7 1.8 0.4*3.5 1.7 0.4*Beam misalignment in the interaction point $e^+$ -, $e^-$ -energy difference Non-gaussian collision energy distribution $\beta$ -function chromaticity Beam potential Single energy calibration Detection efficiency instability Luminosity measurements $2.5$ $2.7$ $2.7$ $1.7$ $2.7$ $1.8$ $2.18$ $0.4*$ $2.0$ $2.0$ $2.0*$ $2.5*$ $1.0*$ $1.0*$ $2.3$ $2.0$ $2.3$ $2.0$ $2.3$ $2.0$ $2.2$ $2.3$ $2.0$ $2.2$ $2.3$ $2.0$ $2.2$ $2$	Energy spread variation	3.0	2.0
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 $<1.5$ $<2.0$ $\beta$ -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 $2.2$ $3.0$	Energy assignment: statistical uncertainty	2.5	3.5
radial betatron oscillations beam separation in additional I.P.<1.5 $0.4^*$ <1.8 $0.4^*$ Beam misalignment in the interaction point $e^+$ -, $e^-$ -energy difference<2.0 $<2.0$ <2.0 $<2.0$ Non-gaussian collision energy distribution $\beta$ -function chromaticity<1.5 $2.0^*$ <2.0 $2.5^*$ Beam potential Single energy calibration Detection efficiency instability Luminosity measurements0.6^* $2.2$ 0.8^* $2.2$	prediction function choice	2.7	1.7
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 $<1.5$ $<2.0$ $\beta$ -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 $2.2$ $3.0$	radial betatron oscillations	< 1.5	< 1.8
Beam misalignment in the interaction point1.85.1 $e^+$ -, $e^-$ -energy difference $< 2.0$ $< 2.0$ Non-gaussian collision energy distribution $< 1.5$ $< 2.0$ $\beta$ -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 $2.2$ $3.0$	beam separation in additional I.P.	0.4*	0.4*
$e^+$ -, $e^-$ -energy difference< 2.0	Beam misalignment in the interaction point	1.8	5.1
Non-gaussian collision energy distribution< 1.5< 2.0 $\beta$ -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 $2.2$ $3.0$	e <sup>+</sup> -, e <sup>-</sup> -energy difference	< 2.0	< 2.0
Beam potential $2.0^{\circ}$ $2.5^{\circ}$ Beam potential $1.0^{*}$ $1.0^{*}$ Single energy calibration $0.6^{*}$ $0.8^{*}$ Detection efficiency instability $2.3$ $2.0$ Luminosity measurements $2.2$ $3.0$	Non-gaussian collision energy distribution	< 1.5	< 2.0
Beam potential1.01.0Single energy calibration0.6*0.8*Detection efficiency instability2.32.0Luminosity measurements2.23.0	$\beta$ -function chromaticity	2.0*	2.5*
Single energy calibration0.00.8Detection efficiency instability2.32.0Luminosity measurements2.23.0	Beam potential	1.0	1.0
Luminosity measurements 2.2 3.0	Single energy calibration	0.0	0.8
Luminosity measurements 2.2 3.0	Detection efficiency instability	2.3	2.0
I = I = I = I = I = I = I = I = I = I =	Luminosity measurements	2.Z 1 2	5.0
Residual machine background $1.5$ 0.0 (1.0)	Residual machine background	< 1.0	< 1.0
Sum in quadrature $\approx 7.3$ $\approx 8.9$	Sum in quadrature	$\approx$ 7.3	$\approx 8.9$

\* — correction uncertainty

## $\Gamma_{e^+e^-}\Gamma_{e^+e^-}/\Gamma$ for $J/\psi$ theory

Cross section  $e^+e^- 
ightarrow e^+e^-$  in soft photon approximation

$$\begin{pmatrix} \frac{d\sigma}{d\Omega} \end{pmatrix}_{th} = \frac{1}{M^2} \left\{ \frac{9}{4} \frac{\Gamma_{e^+e^-}^2}{\Gamma M} \left( 1 + \frac{3}{4}\beta \right) \left( 1 + \cos^2 \theta \right) \operatorname{Im} f \right. \\ \left. - \frac{3\alpha}{2} \frac{\Gamma_{e^+e^-}}{M} \left[ \left( 1 + \cos^2 \theta \right) - \frac{\left( 1 + \cos^2 \theta \right)^2}{\left( 1 - \cos \theta \right)} \right] \operatorname{Re} f \right\} + \left( \frac{d\sigma}{d\Omega} \right)_{\text{QED}},$$

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

[Asimov at el. Pis'ma Zh. Eksper. Fiz. 21, (1975) 172 (in English).] Taking into account c.m.s. energy spread  $\sigma_W$ :

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



$$\begin{split} N_{\text{exp}}(E_{i},\theta) &= \mathcal{R}_{\mathcal{L}} \times \mathcal{L}(E_{i}) \times \left( \sigma_{\text{peak}}^{\text{th}}(E_{i},\theta) \cdot \varepsilon_{\text{peak}}^{\text{sim}}(E_{i},\theta) + \right. \\ &+ \sigma_{\text{inter}}^{\text{th}}(E_{i},\theta) \cdot \varepsilon_{\text{inter}}^{\text{sim}}(E_{i},\theta) + \sigma_{\text{Bhabha}}^{\text{sim}}(E_{i},\theta) \cdot \varepsilon_{\text{Bhabha}}^{\text{sim}}(E_{i},\theta) \right), \\ \\ \text{where } \sigma_{\text{peak}}^{\text{th}}(E_{i},\theta) \sim \Gamma_{e^{+}e^{-}} \times \Gamma_{e^{+}e^{-}} / \Gamma \end{split}$$

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

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