Measurement of J/ψ, $\psi(2S)$, τ masses with KEDR detector at VEPP-4M collider.

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Abstract

We present the combined analyses of J/ψ and $\psi(2S)$ scans performed at VEPP-4M in 2002–2006. The results obtained supersede the mass values published in 2003. The result of the τ-lepton mass measurements is also presented.

$M_{J/\psi} = 3096.913 \pm 0.006 \pm 0.009$ MeV, $M_{\psi(2S)} = 3686.123 \pm 0.008 \pm 0.012$ MeV, $m_\tau = 1776.69^{+0.17}_{-0.19} \pm 0.15$ MeV.

1. VEPP-4M collider and KEDR detector

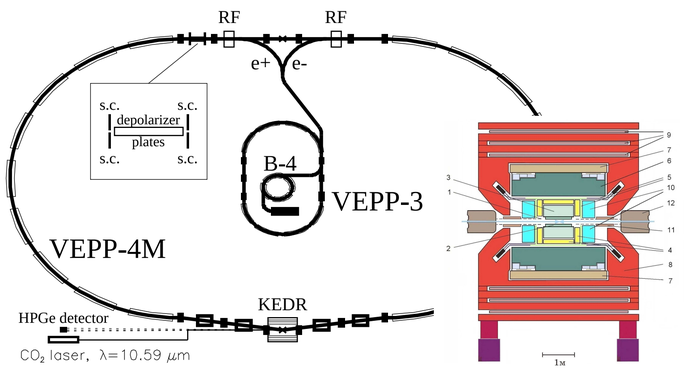

Figure 1: *VEPP-4M/KEDR complex with the resonant depolarization and the infrared light Compton backscattering facilities.*

Beam energy determination methods [NIM A598(2009)23]:

- Interpolation of results of resonant depolarization runs with accuracy of 8 ÷ 35 keV depending on collider operation mode.
- Infrared light Compton backscattering with systematic uncertainty 20 ÷100 keV and statistical accuracy of 100 keV for 15-45 minute measurements.

2. J / ψ mass

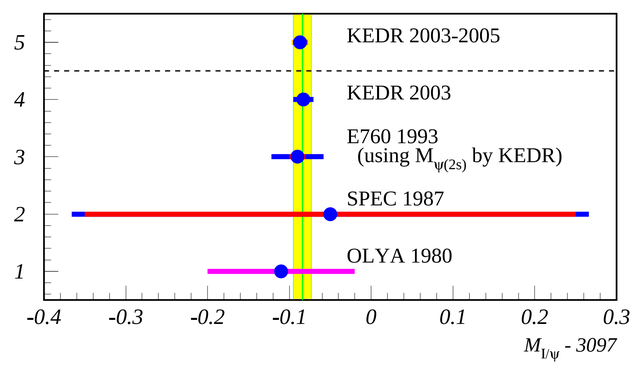

Figure 2: *Four PDG records on J/ψ mass and this work result. Red cores of error bars represent systematic uncertainties.*

All data are in good agreement, we use one additional scan to confirm the result published in [PL B573(2003)632003].

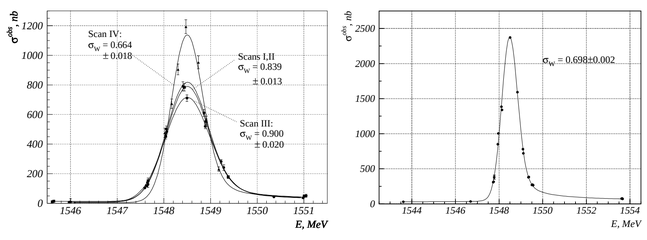

Figure 3: *J/ψ scans of 2002 (left) and 2005 (right).*

Correction to 2002 data:

- add $\delta M = 3.6 \pm 2.5$ keV for ψ-function chromaticity (was not applied earlier).

Mass values to be averaged (in MeV):

$$M^{2002}_{J/\psi} = 3096.921 \pm 0.010 \pm 0.008$$
$$M^{2005}_{J/\psi} = 3096.903 \pm 0.002 \pm 0.010$$

Mass weighting recipe keeping tracks of the statistical and systematic uncertainties separately:

$$M = \sum w_i \cdot M_i \qquad \sigma^2_{stat} = \sum w_i^2 \cdot \sigma^2_{stat,i}$$
$$\sigma^2_{syst} = \sum w_i^2 \cdot (\sigma^2_{syst,i} - \sigma^2_{syst,0}) + \sigma^2_{syst,0}$$
$$w_i \propto 1/(\sigma^2_{stat,i} + \sigma^2_{syst,i} - \sigma^2_{syst,0})$$

where weights w_i take into account statistical errors and uncorrelated parts of systematic error, $\sigma_{syst,0}$ is a common part of systematic uncertainties.

Table 1: *Systematic uncertainties in the J/ψ mass (keV) defined in* [PL B573(2003)632003].

Uncertainty source	2002	2005	common
Energy spread variation	3.0	1.	0.7
Energy assignment	3.8	11.	3.0
Beam misalignment in the I.P.	1.8	1.3	1.2
e^+-, e^--energy difference	<2.0	6.0	2.0
Symmetric dL/dE shape distortion	<1.5	<1.5	0.5
Asymmetric dL/dE shape distortion	3.2	3.5	2.0
Beam potential	1.0	1.5	1.0
Single energy calibration	0.6	0.5	0.5
Detection efficiency instability	2.3	2.3	
Luminosity measurements	2.2	2.4	
Interference in the hadronic channel	1.3	1.1	1.0
Residual machine background	<1.0	<0.3	
Sum in quadrature	≈ 7.6	≈ 13.8	≈ 4.6

Combined result

$$M^{KEDR}_{J/\psi} = 3096.913 \pm 0.006 \pm 0.009 \quad \text{MeV}.$$

The shift of -4 keV is inside the quoted errors of the previously published result. However, the accuracy improvement is small because of relatively large systematic uncertainty of the scan added. More accurate J/ψ scan could be considered.

3. $\psi(2S)$ mass

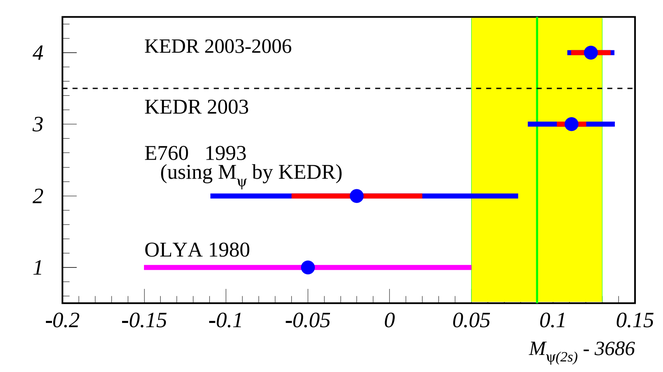

Figure 4: *Three PDG records on $\psi(2S)$ mass and this work result. Red cores of error bars represent systematic uncertainties.*

The combined results of the OLYA [PL B474(2000)427] and the E760 [PR D47(1993)772] experiments does not agree well with the KEDR results. The scale factor of 1.4 is applied by PDG.

We used three additional scans to confirm the published result and improve $\psi(2S)$ mass accuracy to that of J/ψ mass:

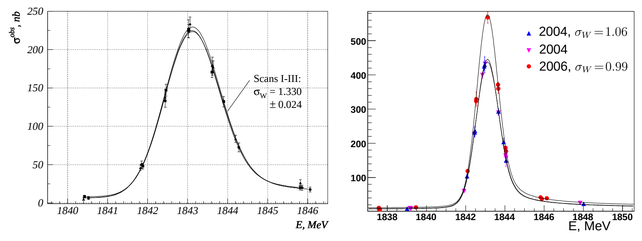

Figure 5: *J/ψ scans of 2002 (left) and 2004, 2006 (right).*

Corrections to 2002 data in addition to these mentioned in PL B573(2003)632003]:

- $\delta M = -5.0 \pm 3.5$ keV for ψ-function chromaticity (was not applied earlier).
- withdraw $\delta M = -4.0 \pm 0.4$ keV for switching off separation in the additional I.P. (actually it was switched on increasing the uncertainty due to the possible e^+- , e^-−energy difference).

Mass values to be averaged (in MeV):

$$M^{2002}_{\psi(2S)} = 3686.110 \pm 0.025 \pm 0.010$$
$$M^{2004}_{\psi(2S)} = 3686.128 \pm 0.010 \pm 0.010$$
$$M^{2006}_{\psi(2S)} = 3686.120 \pm 0.011 \pm 0.010$$

Table 2: *Systematic uncertainties in the $\psi(2S)$ mass (keV), defined in* [PL B573(2003)632003].

Error source	2002	2004	2006	common
Energy spread variation	2.0	1.8	1.7	0.7
Energy assignment	4.3	6.5	6.5	4.0
Beam misalignment in the I.P.	5.1	4.0	4.0	3.7
e^+-, e^--energy difference	9.0	7.0	7.0	6.0
Symmetric dL/dE shape distortion	<2.0	<1.8	<1.7	<1.2
Asymmetric dL/dE shape distortion	3.5	3.1	2.9	2.5
Beam potential	1.0	1.2	1.2	1.0
Single energy calibration	0.8	0.7	0.7	0.5
Detection efficiency instability	2.0	2.4	2.4	
Luminosity measurements	3.0	3.0	3.0	
Interference in the hadronic channel	0.8	0.7	0.6	0.6
Residual machine background	<1.0	<0.5	<0.5	
Sum in quadrature	≈ 12.7	≈ 11.9	≈ 11.8	≈ 8.7

Combined result

$$M^{KEDR}_{\psi(2S)} = 3686.123 \pm 0.008 \pm 0.012 \quad \text{MeV}$$

The accuracy improved by a factor of 1.9 to worse agreement with OLYA and E760.

4. τ mass

To determine m_τ from dependence of the $\tau^+\tau^-$ cross section on energy the integrated luminosity of 15.2 pb^{-1} was collected at nine data points in two scans [NP B189(2009)21].

The beam energy was measured using the resonant depolarization method and by the infrared light Compton backscattering.

The 2–prong events corresponding decay modes

$e^+e^- \to (\tau \to e\nu_\tau\bar{\nu}_e, \mu\nu_\tau\bar{\nu}_\mu, \pi\nu_\tau, K\nu_\tau, \rho\nu_\tau)^* + \text{c.c}$

were selected providing the detection efficiency of about 2.5%. 26 events were found at the points just above the threshold. No events were detected in the background 4 MeV below the threshold.

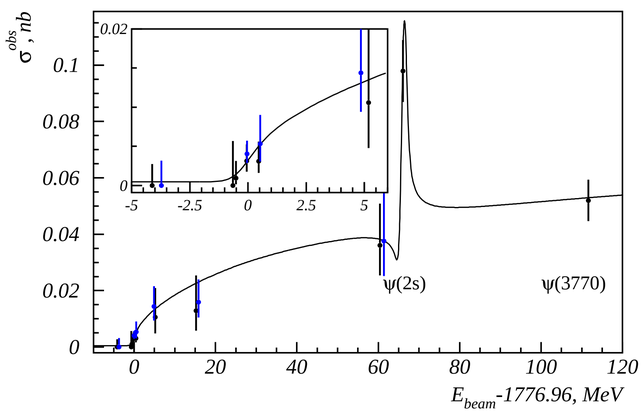

Figure 6: *Observed $\tau^+\tau^-$ cross section, the point color corresponds to the scan number.*

Current result

$$m^{KEDR}_\tau = 1776.69^{+0.17}_{-0.19} \pm 0.15 \quad \text{MeV}$$

The result is still preliminary, detector related uncertainties dominate in the systematic error but it is currently most precise.

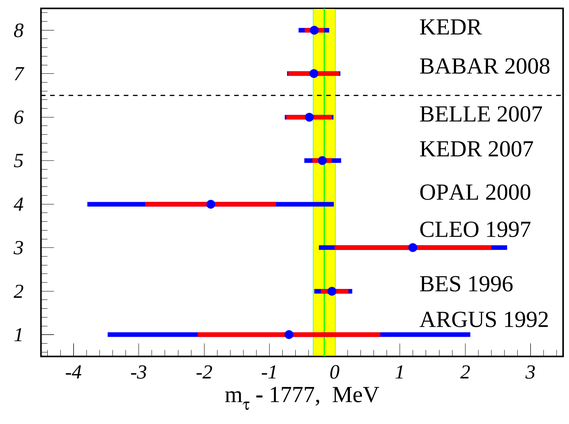

Figure 7: *PDG records on τ mass and recent results of BABAR and KEDR.*