PROCEEDINGS OF SCIENCE

Precision measurements of masses of charmonium states [†]

Korneliy Todyshev[‡] for KEDR collaboration

The Budker Institute of Nuclear Physics, Russia

E-mail: todyshev@inp.nsk.su

V.V. Anashin[*], V.M. Aulchenko[*], E.M. Baldin[*], A.K. Barladyan[*], A.Yu. Barnyakov[*], M.Yu. Barnyakov[*], S.E. Baru[*], I.V. Bedny[*], O.L. Beloborodova[*], A.E. Blinov[*], V.E. Blinov[*], A.V. Bobrov[*], V.S. Bobrovnikov[*], A.V. Bogomyagkov[*], A.E. Bondar[*], D.V. Bondarev[*], A.R. Buzykaev[*], S.I. Eidelman[*], S.E. Karnaev[*], G.V. Karpov[*], S.V. Karpov[*], V.A. Kiselev[*], S.A. Kononov[*], K.Yu. Kotov[*], E.A. Kravchenko[*], E.V. Kremyanskaya[*], V.F. Kulikov[*], E.A.Kuper[*], E.B. Levichev[*], V.M. Malyshev[*], A.L. Maslennikov[*], A.S. Medvedko[*], O.I. Meshkov[*], S.E. Mishnev[*], N.Yu. Muchnoi[*], D.A. Muravlyansky[*], A.I. Naumenkov[*], S.A. Nikitin[*], I.B. Nikolaev[*], A.P. Onuchin[*], S.B. Oreshkin[*], I.O. Orlov[*], S.V. Peleganchuk[*], S.S. Petrosyan[*], S.G. Pivovarov[*], A.O. Poluektov[*], G.E. Pospelov[*], V.G. Prisekin[*], A.A. Ruban[*], G.A. Savinov[*], A.G. Shamov[*], D.N. Shatilov[*], V.V. Smaluk[*], B.A. Shwartz[*], V.A. Sidorov[*], E.A. Simonov[*], Yu.I. Skovpen[*], A.N. Skrinsky[*], R.G. Snopkov[*], A.M. Soukharev[*], A.A. Talyshev[*], V.A. Tayursky[*], V.I. Telnov[*], Yu.A. Tikhonov[*], K.Yu. Todyshev[*], G.M. Tumaikin[*], Yu.V. Usov[*], A.I. Vorobiov[*], A.N. Yushkov[*], V.N. Zhilich[*]

The results of the high precision J/ψ and $\psi(2S)$ mass measurements carried out at the VEPP-4M collider in 2002 with the KEDR detector and the preliminary results of the $\psi(2S)$ and $\psi(3770)$ scans in 2004 have been presented. The resonant depolarization method was used to calibrate absolute beam energy. The mass determination accuracy is 12 keV for J/ψ and 20 keV for $\psi(2S)$. For the relatively broad $\psi(3770)$ state the accuracy of the mass measurement is approximately two times better than that of the current world average value.

International Europhysics Conference on High Energy Physics
July 21st - 27th 2005
Lisboa, Portugal

---

[*] KEDR collaboration, The Budker Institute of Nuclear Physics, 630090 Novosibirsk, Russia

[†] Partially supported by the Russian Foundation for Basic Research, Grant 05-02-16510-a.

[‡] Speaker.

1. Introduction

Precise measurements of the J/ψ and $\psi(2S)$ meson masses provide the energy scale in the range around 3 GeV which is a basis for accurate determination of masses for all charmed particles. These measurements are also important for the accurate determination of the τ-lepton mass.

The present work continues a series of experiments on precise measurement of the onium resonance masses, which exploit the resonant depolarization method suggested in the Budker Institute of Nuclear Physics [1]. The goals of the regular runs made in 2002 and 2004 at the VEPP-4M [2] collider with the detector KEDR [3] were to improve accuracy of the J/ψ, $\psi(2S)$ and $\psi(3770)$ meson masses and to develop the resonant depolarization technique at VEPP-4M for experiment of the forthcoming τ mass measurement [4].

2. Description of experiment

During 2002 four scans of J/ψ and three scans of $\psi(2S)$ were carried out with integrated luminosity $\int Ldt \approx 40$ and 76 nb^{-1} for J/ψ and $\psi(2S)$ regions, respectively [5]. To determine resonance mass, the data was collected at 7 points of the resonance excitation curve (Fig.1). Before data acquisition at point 1, the beam energy calibration was made to fix the current energy scale. At points 2—6 the energy calibrations were performed before and after data taking. The point 7 requires no energy calibration. The resonant depolarization method was used to calibrate the energy . The characteristic energy uncertainty of one beam energy calibration is 1.5 keV (for more detail see [6]).

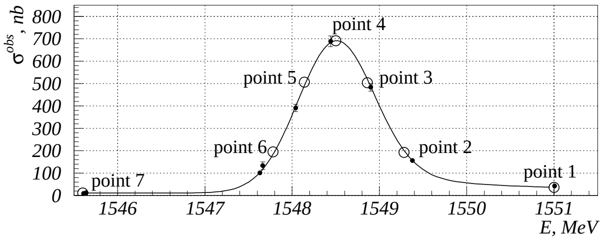

Figure 1: The data acquisition scenario for J/ψ (circles) and the actual points of the second scan (points with error bars). The solid line shows the second scan fit.

Relatively fast (the characteristic time of about a day) collider energy variations reaching 170 keV were observed. Such deviations did not allow us to use the mean energy of the two calibrations surrounding a data acquisition run as the beam energy for this run. Instead, energy interpolation functions have been suggested, which employ the results of the field measurements in some magnets by nuclear magnetic resonance. and the temperature measurements and include the explicit time dependence as a substitute of variables, which were not monitored (e.g., the effect of the tunnel wall temperature on the ring perimeter etc.) The result of the energy interpolation for runs in May 2002 is illustrated in Fig. 2. The accuracy of the energy interpolation varies from 6 to 8 keV during the whole experiment. The regions of $\psi(2S)$ and $\psi(3770)$ mesons have been scanned twice in 2004 ($\int Ldt \approx 650$ nb^{-1}). Scanning in the vicinity of the $\psi(2S)$ was performed according to the scenario described above. For the $\psi(3770)$ the data was collected at eleven center-of-mass energies over the range 3.75—3.92 GeV. At the points near the $\psi(3770)$ peak the energy calibrations were performed before and after data accumulation. The energy calibration was not required off the peak. The accuracy of the energy interpolation 30 keV was achieved.

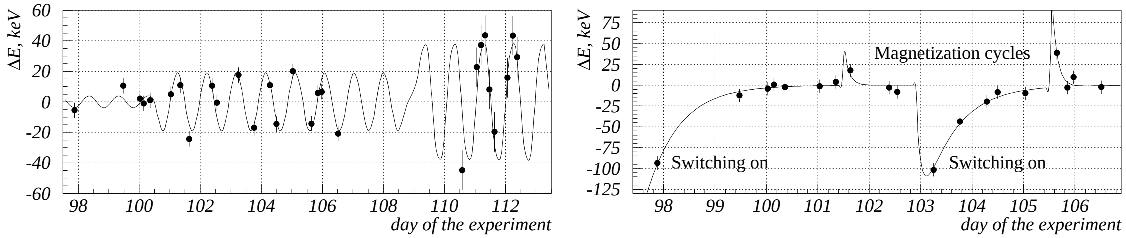

Figure 2: The difference between interpolated energy and the measured energy with all aperiodic dependences accounted (left). Aperiodic energy dependence on time due to switching on the storage ring and the magnetization cycles(right). The error bars show the mean deviation from the interpolation.

3. Detector conditions

The KEDR detector consists of the vertex detector, the drift chamber, the time-of-flight system of scintillation counters, the particle identification system based on the aerogel Cherenkov counters, the calorimeter (the liquid krypton in the barrel part and the CsI crystals in the end caps), the superconducting magnet system and the muon tube system inside the magnet yoke.

In 2002, the magnetic field was off and the liquid krypton calorimeter was out of operation. During season 2004 the magnetic field was 6.5 kGs and the liquid krypton calorimeter completely worked. The trigger efficiency was approximately 0.4 and 0.9 for 2002 and 2004 runs, respectively. Single bremsstrahlung monitors were installed in both e^+ and e^- directions for the operative VEPP-4M luminosity measurements. Their stability is not sufficient for the precise mass measurements, therefore, events of Bhabha scattering detected by the end-cap CsI calorimeter were employed.

4. Mass determination procedure and results

The observed cross-section for hadron production as a function of beam energy is shown in Fig. 3. The fit folded the Gaussian beam energy spread with radiative corrections [7] and Breit-Wigner cross-section. The $\psi(3770)$ resonance fitting function described the resonance shape and the dominant nonresonant hadronic backgrounds, and included radiative corrections for the resonance itself, nearby the $\psi(2S)$ and the continuum. The original $\psi(3770)$ resonance shape is parametrized as simple nonrelativistic p-wave Breit-Wigner, where the total width depends on energy [8]. The scans of J/ψ, $\psi(2S)$ were considered as independent experiments to obtain the resulting averaged mass values. The individual mass values of the scans were weighted using their statistical errors and ignoring the systematic ones. The specific systematic errors of the individual scans were weighted correspondingly. Then the systematic error common for all scans was taken into account. Such procedure overestimates the total error, but allows one to separate the statistical and systematic errors of the resulting value. The following mass values have been obtained in the experiment of 2002:

$$\begin{aligned} M_{J/\psi} &= 3096.917 \pm 0.010 \pm 0.007 \quad \text{MeV} \\ M_{\psi(2S)} &= 3686.111 \pm 0.025 \pm 0.009 \quad \text{MeV} \end{aligned}$$

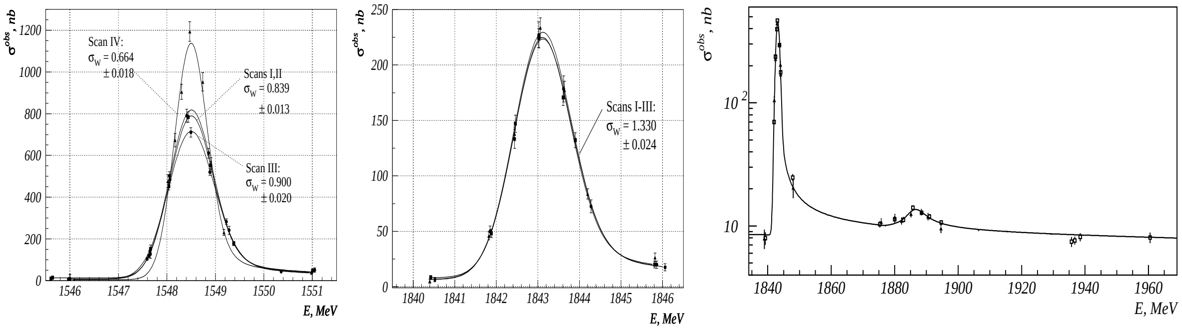

Figure 3: The visible cross-section for $e^+e^- \to hadrons$ versus beam energy. Four scans of J/ψ (left) and so on three scans $\psi(2S)$ (center) and two scans $\psi(2S)$ and $\psi(3770)$ together (right) are presented.

The analysis of the new data of 2004 is in progress, the preliminary values of the masses $\psi(2S)$ and $\psi(3770)$ are:

$$\begin{aligned} M_{\psi(2S)} &= 3686.117 \pm 0.012 \pm 0.015 \ \text{MeV} \\ M_{\psi(3770)} &= 3773.5 \pm 0.9 \pm 0.6 \ \text{MeV} \end{aligned}$$

5. Conclusion

New high precision measurements of the J/ψ, $\psi(2S)$ and $\psi(3770)$ meson masses were performed with the KEDR detector at the VEPP-4M collider in 2002-2004 . The relative measurement accuracy reached $4 \cdot 10^{-6}$ for J/ψ and $7 \cdot 10^{-6}$ for $\psi(2S)$ which is approximately 3 times better than that of the previous precise experiments. The accuracy of the mass measurement for $\psi(3770)$ is approximately two times better than that of the current world average value [9]. Further improvement of accuracy for the $\psi(2S)$ and $\psi(3770)$ masses is expected after the analysis completion.

References

[1] A. D. Bukin et al.,Proceed. of Vth Int Symp. on High Energy and Elem. Particle Physics, Warsaw (1975) 138.
Ya. S. Derbenev et al., Part. Acc. 10 (1980) 177.
A. N. Skrinsky and Yu. M. Shatunov, Sov. Phys. Usp., 32 (1989) 54.
More references see in
A. S. Artamonov et al., Phys. Lett. B 474 (2000) 427.

[2] V. V. Anashin et al., Proc. of the Eur. Part. Accel. Conf., Stockholm, 2005, 1 400.

[3] V. V. Anashin et al., Nucl. Instr. Meth. A 478 (2002) 420.

[4] A. G. Shamov et al., Nucl. Phys. B 144(2005) 113.

[5] V. M. Aulchenko et al., Phys. Lett. B 573 (2003) 63.

[6] V. E. Blinov et al., Proc. of the Eur. Part. Accel. Conf., Paris, 2002, p.1954.

[7] E. A. Kuraev and V. S. Fadin, Sov. J. Nucl. Phys. 41 (1985) 466.

[8] R. H. Schindler et al., Phys. Rev. D 21 (1980) 2716.

[9] S. I. Eidelman et al., Phys. Lett. B 592 (2004) 1.