ИЯФ

ИНСТИТУТ ЯДЕРНОЙ ФИЗИКИ СО АН СССР

S.E.Baru, A.E.Blinov, V.E.Blinov, A.E.Bondar, A.D.Bukin, V.R.Groshev, Yu.I.Eidelman, V.A.Kiselev, S.G.Klimenko, S.I.Mishnev, A.P.Onuchin, V.S.Panin, V.V.Petrov, I.Ya.Protopopov, A.G.Shamov, V.A.Sidorov, Yu.I.Skovpen, A.N.Skrinsky, V.A.Tayursky, V.I.Telnov, A.B.Temnykh, Yu.A.Tikhonov, G.M.Tumaikin, A.E.Undrus, A.I.Vorobiov, V.N.Zhilich, A.A.Zholents

NEW MEASUREMENT OF THE Υ-MESON MASS

PREPRINT 85-100

НОВОСИБИРСК

NEW MEASUREMENT OF THE Υ-MESON MASS*)

S.E.Baru, A.E.Blinov, V.E.Blinov,
A.E.Bondar, A.D.Bukin, V.R.Groshev,
Yu.I.Eidelman, V.A.Kiselev, S.G.Klimenko,
S.I.Mishnev, A.P.Onuchin, V.S.Panin,
V.V.Petrov, I.Ya.Protopopov, A.G.Shamov,
V.A.Sidorov, Yu.I.Skovpen, A.N.Skrinsky,
V.A.Tayursky, V.I.Telnov, A.B.Temnykh,
Yu.A.Tikhonov, G.M.Tumaikin, A.E.Undrus,
A.I.Vorobiov, V.N.Zhilich, A.A.Zholents

Institute of Nuclear Physics,
630090, Novosibirsk, U S S R

Abstract

The experiment on the precision measurement of Υ meson mass has been performed at VEPP-4 storage ring with the MD-1 detector. The absolute storage ring energy calibrations were carried out using the resonance depolarization method. The beam polarization was measured by the up-down asymmetry in the synchrotron radiation back-scattered on colliding electron (positron) beam. The Υ-meson mass has been determined from the energy dependence of hadron production cross section and is found to be $M_{\Upsilon} = 9460.59 \pm .12$ MeV.

---

*) Submitted to the International Symposium on lepton and photon Interactions at high energy, Kyoto, August 1985.

Introduction

In the paper the result of new measurement of the Υ-meson mass performed at VEPP-4 storage ring /1/ with the detector MD-1 /2/ in April 1984 is presented. The Υ-meson mass has been determined from the energy dependence of the hadronic cross section on the c.m. energy. The calibrations of the storage ring energy were carried out by the method of resonance beam depolarization. The method has been developed in our Institute in 1975 /3,4/ and was used, at VEPP-2M storage ring for measurements of the ϕ-meson /5/, charged /6/ and neutral /7/ kaon masses, and also at VEPP-4 storage ring for the mass measurements of the ψ, ψ' /8/, Υ /9,10/, Υ' /10/ and Υ''-mesons /10/. This method was used also for the energy calibration of CESR and DORIS storage rings in the mass measurements of Υ /11/ and Υ'-mesons /12/.

The energy calibration by the resonance beam depolarization method is based on the measurement of the electron spin precession frequency Ω around the guiding magnetic field of the storage ring.

The precession frequency /13/

$$\Omega = \omega_s\left(1 + \frac{\mu'}{\mu_0}\gamma\right), \qquad (1)$$

where ω_s - the beam revolution frequency,

μ'/μ_0 - the ratio of the anomalous and normal parts of the electron magnetic moment, γ - relativistic factor of electrons. The resonant influence of a weak high frequency electric field on the polarized beam is used for the measurement of the spin precession frequency. **The beam becomes depolarized** when the frequency of the external field coincides with that of the spin precession. Fixing the fact of depolarization and measuring the corresponding depolarizer frequency, one can thereby perform the absolute calibration energy of the storage ring.

The method allows to measure the average electron energy with an accuracy much better than the beam energy spread. It is provided by the fact that particles undergo many energy oscillations during the depolarization time, i.e. the depolarization time should be much longer than the period of the synchrotron oscillations.

Storage ring energy calibration

In the electron storage rings there exists the mechanism of the spontaneous beam polarization connected with the synchrotron radiation /14/. For a homogeneous magnetic field, the time dependence of the polarization degree $P(t)$ was calculated in the paper /15/:

$$P(t) = P_0\left[1 - \exp\left(-\frac{t}{\tau_p}\right)\right], \qquad (2)$$

$$P_0 = -\frac{8}{5\sqrt{3}} = -0.924\,, \qquad (3)$$

$$\frac{1}{\tau_p} = \frac{5\sqrt{3}}{8}\,\alpha\left(\frac{\lambda_e}{\rho}\right)^2 \gamma^5\,\omega_s\,, \qquad (4)$$

where α - the fine structure constant, λ_e - the Compton wavelength of an electron, ρ - the orbit radius, γ - the relativistic factor, ω_s - the revolution frequency, τ_p - the polarization time. For VEPP-4 storage ring the polarization time τ_p is about 50 minutes in the Υ -meson energy region.

Inhomogeneous storage ring fields have the depolarization influence on the beams. The degree of the equilibrium polarization P depends on the relative powers of the depolarizing and polarizing mechanisms τ_p/τ_d and is reached for the characteristic time τ /16/:

$$P(t) = P\left[1 - \exp\left(-\frac{t}{\tau}\right)\right], \qquad (5)$$

$$P = P_0\,\frac{\tau_d}{\tau_p + \tau_d} = P_0\,\frac{\left\langle (1/\rho^3)\,\vec{b}\,(\vec{n} - \vec{d})\right\rangle}{\left\langle (1/\rho^3)\left[1 - \frac{2}{9}(\vec{n}\vec{v})^2 + \frac{11}{18}d^2\right]\right\rangle} \qquad (6)$$

$$\tau = \tau_p\,\frac{\tau_d}{\tau_p + \tau_d}\,, \qquad (7)$$

where ρ - the orbit radius, $\vec{b}$ - the unit vector along the magnetic field, $\vec{v}$ - the unit vector along the particle velocity, $\vec{n}$ - the unit vector along the spin precession axis, $\vec{d}$ - the spin-orbit coupling vector. The averages are taken over the orbit circumference.

The main influence on the equilibrium beam polarization degree appears to be of the vertical orbit distortions and proximity of the spin precession frequency Ω to the resonance frequencies Ω_{res} /17/,

$$K\,\Omega_{res} = K_s\,\omega_s + K_x\,\omega_x + K_z\,\omega_z + K_\gamma\,\omega_\gamma\,, \qquad (8)$$

where ω_s - the revolution frequency; ω_x and ω_z - the radial and vertical betatron oscillations frequencies, ω_γ - - the synchrotron oscillation frequency, K_i - the integer numbers.

In the Υ energy region the spin precession frequency for the electrons in VEPP-4 storage ring is far from the resonance frequencies, and the degree of the equilibrium beam polarization depends only on the vertical orbit distortions. Using orbit corrections the mean square deviation of the orbit from the plane in VEPP-4 was decreased to the value of 1.3±5 mm, that provides the degree of the equilibrium beam polarization 0.6-0.7.

The resonance beam depolarization was performed by the alternating electric field of 10 V/cm amplitude, created between the pair of the vertically spaced plates of 1.3 m length. The external field changes the spectrum of the resonance frequencies,

$$K\,\Omega_{res} = K_s\,\omega_s + K_x\,\omega_x + K_z\,\omega_z + K_\gamma\,\omega_\gamma + K_d\,\omega_d \qquad (9)$$

where ω_d - the external field frequency (the field of depolarizer). The following resonance conditions were chosen for the measurements: $K = 1$, $K_s = -11$, $K_x = K_z = K_\gamma = 0$, $K_d = 1$, i.e.

$$\Omega_{res} = -11\,\omega_s + \omega_d \qquad (10)$$

At the frequency of ω_s = 818.78 kHz the frequency of the depolarizer field is in the region of $\omega_d \simeq 18.8$ MHz.

In order to test that $K_\gamma = 0$, the synchrotron oscillation frequency ω_γ was varied by means of changing the RF-voltage U_{RF} at the storage ring cavities ($\omega_\gamma \sim \sqrt{U_{RF}}$). The depolarization frequency did not change. The correctness of knowledge of the coefficients K_s, K_x and K_z was out of doubt.

In our experiment the depolarizing resonance width was determined by the frequency band of the generator creating the depolarizing field and was about 0.3 kHz. At the chosen value of the field the calculated depolarization time was about 0.5 second. The search for the depolarization frequency was performed by the slow variation of the external generator frequency (4 Hz for 1 second), and the generator frequency either increased or decreased.

The beam polarization in the storage ring was measured by the value of asymmetry in the angular distribution of the back-scattered circular-polarized photons. The cross section of the Compton scattering is /18/

$$\frac{d\sigma}{d\Omega} = \frac{d\sigma_0}{d\Omega} + \frac{d\sigma_1}{d\Omega}\,\xi\,|\vec{\zeta}|\sin\varphi, \qquad (11)$$

where $d\sigma_0/d\Omega$ - the cross section on the unpolarized electrons, ξ - the degree of the photon circular polarization, $\vec{\zeta}$ - - the vector of electron transverse polarization, φ - the angle between the scattering plane and the plane, perpendicular to the vector $\vec{\zeta}$. The sign of $d\sigma_1/d\Omega$ is opposite to the one of the value $\xi(\vec{K}\vec{\zeta})$, where $\vec{K}$ is a momentum of the scattered photon, and the value is maximum at $\varphi = \pm\frac{\pi}{2}$, i.e. when the vector $\vec{\zeta}$ lies in the scattering plane. Thus while the scattering of the circular polarized photons on the transverse polarized electrons the "up-down" asymmetry appears with respect to the plane, perpendicular to the vector $\vec{\zeta}$, i.e. with respect to the orbit plane. The asymmetry value A is given by the formula /18/

$$A = \frac{d\sigma_1}{d\sigma_0} = -\frac{2\lambda n(1+n^2)}{2\lambda^2(1+n^2)+(1+n^2+2\lambda)(1+n^4)}, \qquad (12)$$

where $\lambda = \frac{2\omega\varepsilon}{m_e^2}$, $n = \gamma\theta$, θ - the emission angle of the photon relative to the electron momentum $\vec{p}$, ω is the initial photon energy, ε is the electron energy.

The asymmetry value reaches its maximum $A_{max} \simeq -\frac{1}{3}$ at $\lambda = 1$ and $n = 1$, i.e. at the initial photon energy $\omega \simeq \frac{m_e^2}{2\varepsilon}$, that gives 25 eV at the electron energy ε = 5 GeV.

In this experiment the synchrotron radiation generated in the magnetic field of the detector by oppositely moving beam was used as a source of the circular polarized photons. Such a possibility is connected with a peculiarity of the MD-1 detector whose magnetic field is transverse to the orbit plane. In the interaction region the electrons collide with the synchrotron radiation photons generated by another beam. The synchrotron radiation is polarized, the polarization depends on the photon direction; in the orbit plane the photons are linearly polarized and out of it they have circular polarization with the opposite signs above and under the orbit. The degree of the circular polarization increases with increasing of the photon emission angle relative to the orbit plane. When the beams are separated in the vertical direction the collision of the circular polarized photons with the transversally polarized electrons and positrons is provided in the interaction region. The method allows to measure the polarization of both beams simultaneously. The asymmetry value in the synchrotron radiation scattering on the colliding beam is considerably greater than that in laser photons scattering. It is due to higher energies of the initial photons. The method of the measurement of the beam polarization by the synchrotron radiation photons scattering /19/ has been developed in our Institute and used in the mass measurements of the Υ, Υ' and Υ''-mesons /9,10/.

The equipment for the beam polarization measurement is shown in Fig. 1. It consisted of two identical parts situated from the both sides of the interaction region and intended for the polarization measurement of both beams. Backscattered photons were detected with two scintillation counters in front of which the lead plate of 13 mm thick was installed. One of the counters was placed above the orbit plane, and another one – under that plane. There was a gap of 1 mm between the counters. The asymmetry value was determined by the ratio

$$A = \frac{N_u - N_d}{N_u + N_d - N_{ud}} \tag{13}$$

where N_u and N_d are the counting rates of the upper and lower counters correspondingly, N_{ud} – the coincidence counting rate. At the same time it was required the detected photon energy to be higher than 0.5 GeV. The measurement of the photon energy was performed using the total absorption counter made of crystal NaJ(Tl).

For the stabilization of the vertical orbit position and the orbit angle in the vertical plane the ionization chambers were installed from the both sides of the interaction region which were measuring the "up-down" asymmetry of the straight synchrotron radiation of the beams. The results of the measurements were used for the continuous orbit correction in the interaction region that was carried out with the help of a computer controlling VEPP-4 storage ring.

While the polarization measurement the beams were separated vertically by 120 micrometers ($\sim 4\sigma_z$, where σ_z is the vertical size of the beams). For this separation the relative error of the asymmetry measurement is minimum.

For the beam polarization degree of 0.8 the asymmetry value is 5%. The statistical error in the asymmetry value equals 0.4% for the currents of 6 x 6 mA^2 and exposition time of 100 seconds. In Fig. 2 the results of one of the beams polarization measurements are shown. The electron and positron depolarization frequencies were obtained by the maximum likelihood method. The dependence of the beam polarization degree on time (and hence on the depolarization field frequency) was approximated by three straight line segments. The accuracy of the measurement of the beam depolarization frequency is determined by

the accuracy in the asymmetry measurement and by the size of asymmetry jump, i.e. depends on the beam currents and on beam polarization degree. In this experiment the typical statistical accuracy of the electron and positron energy measurements was about 60 keV. The errors were checked by the independent measurements of the electron and positron energies. Statistical agreement of 82 energy measurements of the electrons and positrons being done during the experiment was $P(\chi^2) \approx 20\%$. At the same time it turned out that in the VEPP-4 storage ring the average electron energy is greater than that of the positrons by 24±6 keV.

At the energy calibrations the average depolarization field frequency is measured in the moment of the beam depolarization. This value can differ from the spin precession frequency because of the finite width of the depolarizer frequency spectrum. The value of the shift depends on the depolarizer bandwidth, the rate of its frequency variation and on the depolarization time. By estimates in our experiment the shift is about 70 keV in one beam energy. For the experimental determination of this value the pairs of energy calibrations were used with the opposite scanning direction of the depolarizer frequency, being done with the same currents and with invariable conditions of the storage ring operation. From 11 measurement the shift value of 63±9 keV was obtained. The measured energy was correcected by this value.

In the experiment the data taking time with the same currents was about 3 hours. The energy calibrations were done either before or after data taking. For the determination of the storage ring energy instability the special measurements were performed in which several energy calibrations with the same currents were done with the time interval of about 40 minutes. Then calibrations for three currents were done. The VEPP-4 energy instability was obtained to be $\delta \approx 40$ keV. This value was added quadratically to the energy measurement error. No systematic variations of the storage ring energy during the data taking were found.

In the experiment about 35% of the statistics in the region of the Υ-meson peak were taken without energy calibrations. In these cases the energy was obtained from the magnetic field value in one of the bending magnets of the storage ring. The connection of the magnetic field with energy was taken from the two near-by calibrations. The accuracy of the energy determination by the magnetic field value appeared to be $\delta \approx 180$ keV and was obtained from the comparison of the energies obtained by the calibrations with those calculated from the magnetic field and two near-by calibrations.

Experiment

The experiment was carried out in April 1984. The VEPP-4 storage ring had the following parameters: the vertical beta-function in the interaction point was $\beta_z = 12$ cm, the maximum luminosity was about $5\cdot10^{30}$ sm^{-2} sec^{-1}, the beam life time was about 5 hours, the time of beam replacing in the storage ring was about 30 min.

The cross section of e^+e^- annihilation into hadrons was measured using the magnetic detector MD-1. In fig. 1 and 3 the central part of the detector, equipment for the luminosity and the beam polarization measurements are shown. The magnetic field of the detector is transverse to the orbit plane. The field strength in this experiment was 11.3 kGs. Starting from the interaction region the detector contains: coordinate system of 38 proportional chambers, 24 scintillation counters, 8 threshold gas Cerenkov counters, 14 blocks of the shower-range chambers. Every block of the shower-range chambers consists of 10 proportional chambers separated by the stainless steel plates of 13 mm thick. Muon chambers are placed beyond the magnet winding, inside and beyond the yoke. The scintillation counters, coordinate and shower-range chambers were used in the trigger. Some additional selection was carried out by the computer in "on-line" regime. According to the Monte Carlo simulation the detection efficiency for the process $e^+e^- \to \Upsilon \to$ had. was about 99%. With the currents of 7 x 7 mA^2 and the luminosity $4\cdot10^{30}$ cm^{-2} sec^{-1} the trigger counting rate was about 6 Hz, and the event recording rate to magnetic tape after the computer selection was about 2 Hz.

The luminosity measurement was carried out by the processes of single Bremsstrahlung and small angle elastic scattering. The photons of single Bremsstrahlung were detected from the both sides of the interaction region with the scintillation "sandwiches". The cross section of this process taking into account the impact parameter cut-off by the transverse size of the beam /20/ was $0.7\cdot10^{-25}$ cm^2, the background level did not exceed $2\cdot10^{-4}$ of the effect value. The ratio of the counting rates of the photons emitted in the electron and positron directions was constant during the experiment within ±0.5. The detection of the elastic scattering events in the angular range 15-35 mrad was carried out with the scintillation counters placed from the both sides of the interaction region above and below the orbit plane. The detection cross section of this process in the Υ energy region was $3.6\cdot10^{-29}$ cm^2. At the luminosity $4\cdot10^{30}$ cm^{-2} sec^{-1} the accidental coincidence background did not exceed 10% of the effect, the level of this background was continuously measured by the delayed coincidence method. The stability of the luminosity monitoring system by small angle scattering was checked by ratio of numbers of electrons scattered up and down, this ratio being constant within ±1.5%. The relative stability of two luminosity monitors during the experiment was within ±2%.

During the experiment the check-up of the detector elements was performed twice a day. The trigger electronics was checked, as a trigger the coincidence signals from couples of the coordinate chambers were used. The work of the chambers and counters was checked by the cosmic particles. The luminosity monitor systems were checked with the help of light diodes.

In the experiment 4 scanning of the Υ-meson region were carried out, the sequence of the energy values in each scanning was chosen accidentally. The integrated luminosity of 2.0 pb^{-1} was collected. The energy calibrations took about 15% of time, background events recording being done simultaneously since during the calibrations the beams were separated in the vertical direction in the interaction point. For the selection of the hadronic events the information from the coordinate and shower-range chambers was used. With the help of event reconstruction routine the number of charged particles, their emission angles and momenta were determined, as well as the number of photons and their emission angles. Firstly the presence in the event at least one charged particle coming from the interaction region was required. Subsequent selection took into account the emission points and angles of the charged particles from the interaction region, their momenta, the quantity and geometry of the tracks in the shower-range chambers. According to MC simulation the selection efficiency was about 80% for the events of the Υ -decay to hadrons and about 70% for nonresonance continuum. Background level in the continuum region did not exceed 5%.

Besides the hadronic events the events of large angle elastic scattering were selected. The detection cross section of such events was 40 nb with the background level less than 1%. The ratio of the number of elastic scattering events detected in the central part of the detector and in the counters at small angles was constant during the experiment within the statistical accuracy.

Experimental data processing

The observed cross section of the hadronic events vs. the summed energy of the electrons and positrons is shown in fig. 4. The visible dependence is determined by the storage ring luminosity distribution over the energy, by the resonance production cross section with the radiative effects taken into account and continuum level. For a determination of the Υ -meson parameters the observed cross section was approximated by the following formula:

$$\sigma_{vis}(W) = \varepsilon_{nr}\sigma_{nr} + \varepsilon_{res}\int_{-\infty}^{\infty}\sigma_{res}(W')\,L(W-W')\,dW', \qquad (14)$$

where ε_{nr} and ε_{res} are the detection efficiencies for continuum and resonance, σ_{nr} and σ_{res} - the production cross section of the hadronic events for continuum and resonance, $L(W-W')$ is the luminosity distribution over the energy,

W is the sum of the electron and positron energies. The function $L(W-W')$ is determined by the spread of the particle energy in the beams and was approximated as follows:

$$L(W-W') = \frac{L}{\sqrt{2\pi}\,\sigma_W}\exp\left[-\frac{(W-W')^2}{2\sigma_W^2}\right], \qquad (15)$$

where $\sigma_W=\sqrt{2}\,\sigma_E$, σ_E is the mean square spread of the particle energy in the beam. Usually for the fit of the data of the narrow resonance production as $\sigma_{res}(W)$ the formula is used from the paper by J.D.Jackson and D.L.Scharre /21/ claiming the accuracy about 1%. Recently E.A.Kuraev and V.S.Fadin derived the radiative corrections to the single photon annihilation process with an accuracy of about 0.1% /22/. They have shown that the formula for $\sigma_{res}(W)$ in /21/ is not correct and in particular for the ϕ -meson it gives an error in leptonic width about 2÷3%. In experimental data processing for $\sigma_{res}(W)$ we used the formula by E.A.Kuraev and V.S.Fadin keeping the terms taking into account only the soft photons radiation and rejecting the components of the order β^2, where

$$\beta = \frac{4\alpha}{\pi}\left(\ln\frac{W}{m_e} - \frac{1}{2}\right). \qquad (16)$$

The integration in the formula (14) was carried out similar to the procedure suggested in /21/, the Breit-Wigner curve for the resonance being replaced by delta-function with conservation of the resonance area S_{res},

$$S_{res} = \int_0^{\infty}\sigma_0\frac{M^2\Gamma^2\,dW}{M^2\Gamma^2+(M^2-W^2)^2}. \qquad (17)$$

Finally it was obtained:

$$\sigma_{vis}(W) = \varepsilon_{nr}\sigma_{nr} + \varepsilon_{res}S_{res}\,G(W-M)(1+\delta), \qquad (18)$$

$$G(x) = \left(\frac{2\sigma_w}{M}\right)^{\beta} \frac{\Gamma(1+\beta)}{\sqrt{2\pi}\,\sigma_w} \exp\left(-\frac{x^2}{4\sigma_w^2}\right) D_{-\beta}\left(-\frac{x}{\sigma_w}\right), \qquad (19)$$

$$\delta = \frac{\alpha}{\pi}\left(\frac{\pi^2}{3} - \frac{1}{2}\right) + \frac{3}{4}\beta, \qquad (20)$$

where M is the resonance mass, α is the fine structure constant, $\Gamma(1+\beta)$ is gamma-function, $D_{-\beta}$ is a Weber's parabolic cylinder function. Fitting of the experimental data was carried out by the maximum likelihood method, 4 parameters being free: the resonance mass M, energy spread σ_W, the continuum cross section $\varepsilon_{nr}\sigma_{nr}$ and the product $\varepsilon_{res} \cdot S_{res}$. As a result of the fit it was obtained:

$$M_{\Upsilon} = 9460.63 \pm 0.11 \text{ MeV}$$

$$\sigma_W = 4.40 \pm 0.12 \text{ MeV}$$

$$\varepsilon_{nr}\sigma_{nr} = 3.42 \pm 0.06 \text{ nb}$$

The statistical agreement of the experimental results with the approximating function was $P(\chi^2) \approx 12\%$. It should be noticed that using the formula from /21/ leads to the increase of the resonance mass value by 0.1 MeV and to the diminution of leptonic width by 9%.

In the experimental data fit only the statistical errors of the number of the detected hadronic events were taken into account, the energy W being considered fixed. The energy measurement errors were taken into account in the following way: the energies in every experimental point were shifted independently near the average value according to the Gaussian law with the standard deviation equal to the error in the value W at this point. For every set of the energy values the resonance mass was determined. The mean square spread of obtained mass values, equal to 0.03 MeV, was accepted as an error

of the resonance mass value due to the energy measurement errors. This value was quadratically added to the statistical error of the Υ-meson mass.

Systematic errors

There were considered different effects that could contribute the additional error to the Υ-meson mass value. The most essential of them are:

1. The spin precession frequency depends on $\gamma = E/m_e$ [Eq. (1)], the measured Υ mass is proportional to the electron mass. The uncertainty in the mass of electron /23/ contributes an error of about ±26 keV in the Υ mass.

2. The γ-factor was determined by the ratio of the depolarization and beam revolution frequencies, their uncertainties lead to the error in the Υ-meson mass value of about ±14 keV.

3. Vertical orbit distortions will perturb the value of the spin precession frequency because rotations about different axes do not commute. This effect increases quadratically with the size of the distortions, and we estimate the correction to the Υ mass to be about -9±7 keV for a 1.3±.5mm vertical rms distortion.

4. Actually the c.m. energy is not equal to sum of electron and positron energies due to the motion of produced system. For energy spread in VEPP-4 this fact leads to the shift of the mass value by - 4.1±0.2 keV. Similar effect caused by beam angular spread is negligible.

5. The electron and positron energies at the interaction point differ from average energy in the storage ring due to some effects: a) the interaction point is situated asymmetrically relative to the R.F. cavities (the shift value is $0.4 \cdot 10^{-2}$ of the circumference), b) since the synchrotron radiation intensity depends on the particle energy, the energy loss at the first half of the circumference is greater than at the second one. The mass shift value associated with these circumstances is negligible.

6. There is some chromaticity of the VEPP-4 at the inter-

action point. This means that the transverse beam size depends on the particle energy. The effect has been studied experimentally, and the data obtained agree with the calculations and give the following form of the luminosity distribution:

$$L(w-w') = \left(1 + a\,\frac{w-w'}{w}\right)\frac{L}{\sqrt{2\pi}\,\sigma_w}\exp\left[-\frac{(w-w')^2}{2\sigma_w^2}\right], \quad (21)$$

where $a = -12 \pm 5$. This effect leads to the shift of the mass value by -25 ± 10 keV.

7. The specific luminosity of VEPP-4 depends on the beam currents that means that there are some collision effects. Due to collision effects the transverse beam size may depend on the energy. To estimate the influence **of this effect to the** Υ mass we divided the experimental data in two parts. One part consisted of the data obtained at low specific luminosity, another part consisted of the data obtained at high specific luminosity. The independent fitting of two parts of data gave the mass

$$M_\Upsilon = 9460.54 \pm 0.15\ \mathrm{MeV} \quad (L_{sp} < \bar{L}_{sp}),$$

$$M_\Upsilon = 9460.69 \pm 0.16\ \mathrm{MeV} \quad (L_{sp} > \bar{L}_{sp}).$$

This result shows that the possible shift of the mass value is less than statistical error.

8. The beam energy spread may depend on the beam current. The results of separate fits of the data with low and high currents are

$$\sigma_w = 4.41 \pm 0.16\ \mathrm{MeV} \quad \left[(I_+ + I_-) < \overline{(I_+ + I_-)}\right],$$

$$\sigma_w = 4.62 \pm 0.17\ \mathrm{MeV} \quad \left[(I_+ + I_-) > \overline{(I_+ + I_-)}\right].$$

So, we did not reveal any dependence of the beam energy spread on the beam current.

9. In the experiment about 35% of the data in the peak region have been taken without energy calibration. In these cases the energy was obtained using the magnetic field value in one of the bending magnet. Separate processing of the data obtained with and without the energy calibrations gave the next Υ mass values:

$$M_\Upsilon = 9460.73 \pm 0.14\ \mathrm{MeV} \quad \text{(with energy calibration)},$$

$$M_\Upsilon = 9460.52 \pm 0.19\ \mathrm{MeV} \quad \text{(without energy calibration)}.$$

So, we did not reveal any evident systematic error in the energy measurements using the magnetic field.

10. Separate fits to the data of all 4 scannings the Υ-meson region agree within statistical errors:

$$M_\Upsilon = 9460.76 \pm 0.17\ \mathrm{MeV} \quad \text{(1 scan)},$$

$$M_\Upsilon = 9460.73 \pm 0.24\ \mathrm{MeV} \quad \text{(2 scan)},$$

$$M_\Upsilon = 9460.59 \pm 0.20\ \mathrm{MeV} \quad \text{(3 scan)},$$

$$M_\Upsilon = 9460.36 \pm 0.20\ \mathrm{MeV} \quad \text{(4 scan)}.$$

So, we did not reveal any instability of the detection efficiency during the experiment. We conclude that the total shift of the mass value due to all effects mentioned above is about -0.04 MeV and the systematic uncertainty is about ± 0.05 MeV. So the final Υ mass value obtained in this measurement is

$$M_\Upsilon = 9460.59 \pm 0.12\ \mathrm{MeV}.$$

This value is in agreement with our previous results of 1982 /9/ and of 1983 /10/:

$$M_\Upsilon = 9459.6 \pm 0.6\ \mathrm{MeV} \quad (1982),$$

$$M_\Upsilon = 9461.0 \pm 0.5\ \mathrm{MeV} \quad (1983).$$

At the same time our result differs from the CUSB one /11/ by 3.5 standart deviations:

$$M_\Upsilon = 9459.97 \pm 0.11 \pm 0.07 \ \mathrm{MeV} \qquad \text{(CUSB)}.$$

We would like to thank our Novosibirsk colleagues whose labor provided the possibility of performing the present experiment.

References

1. V.V.Anashin et al., Proc. National Conf. on Charged particle accelerators (Dubna, 1980).
2. S.E.Baru et al., Major detectors in elementary particle physics LBL-91 (Supplement, UC-37, 1983); Preprint INP 83-39 (Novosibirsk, 1983).
3. S.I.Serednyakov et al., Zh. Eksp. Teor. Fiz. 71(1976)2026.
4. Ya.S.Derbenev et al., Particle accelerators 10(1980)177.
5. A.D.Bukin et al., Yad. Fiz. 27(1978)976.
6. L.M.Barkov et al., Nucl. Phys. B148(1979)53.
7. L.M.Barkov et al., Preprint INP 83-85 (Novosibirsk, 1983).
8. A.A.Zholents et al., Phys. Lett. 96B(1980)214; Yad. Fiz. 34(1981)1471.
9. A.S.Artamonov et al., Phys. Lett. 118B(1982)225; Preprint INP 82-94 (Novosibirsk, 1982).
10. A.S.Artamonov et al., Phys. Lett. 137B(1984)272; Preprint INP 83-84 (Novosibirsk, 1983).
11. W.W.MacKay et al., Phys. Rev. D 29(1984)2483.
12. D.P.Barber et al., Phys. Lett. 135B(1984)498; Preprint DESY 83-067 (1983).
13. V.Bargmann, L.Michel, and V.L.Telegdi, Phys. Rev. Lett. 2 (1959)435.
14. I.M.Ternov, Yu.M.Loskutov, and K.L.Korovina, Zh. Eksp. Teor. Fiz. 41(1961)1294.
15. A.A.Sokolov and I.M.Ternov, Dokl. Akad. Nauk SSSR 153(1963) 1052.
16. Ya.S.Derbenev and A.M.Kondratenko, Dokl. Akad. Nauk SSSR 217(1974)311.
17. Ya.S.Derbenev, A.M.Kondratenko and A.N.Skrinsky, Preprint INP 77-60 (Novosibirsk, 1977).
18. V.N.Baier and V.A.Khoze, Yad. Fiz. 9(1969)409.

19. A.E.Blinov et al., Proc. National Conf. on Charged particle accelerators (Protvino, 1982) v. II, 268;
Proc. of the Third Intern. Conf. on Instrumentation for Colliding Beam Physics (INP, Novosibirsk, 1984) 233.
(To be published in Nucl. Instrum. Methods).

20. A.E.Blinov et al., Phys. Lett. 113B (1982) 423;
Preprint INP 82-15 (Novosibirsk, 1982).

21. J.D.Jackson and D.L.Scharre, Nucl. Instrum. Methods 128 (1975)13.

22. E.A.Kuraev and V.S.Fadin, Yad. Fis. 41 (1985) 733;
Preprint INP 84-44 (Novosibirsk, 1984).

23. Particle Data Group, Rev. of Modern. Phys. v. 56, No. 2, part 2 (1984).

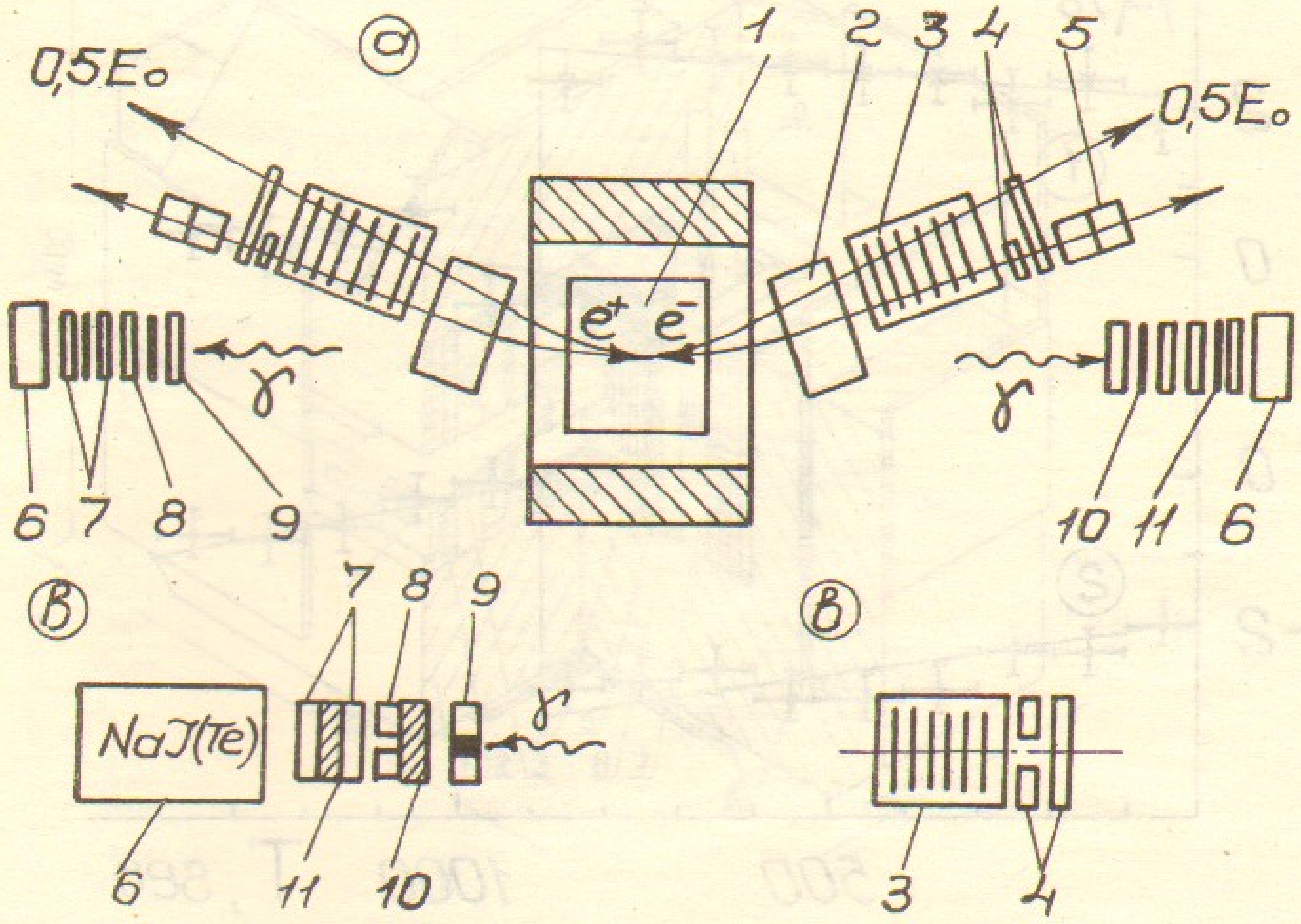

Fig.1. Layout of the detector MD-1
(a - upper view. b - section by vertical plane):
1 - central part; 2 - additional bending magnets;
3 - system for detection of scattered electrons;
4 - counters for luminosity monitoring by small angle elastic scattering; 5 - lenses; 6.8 - counters for polarization measurement by SR; 7- counters for luminosity monitoring by $e^+e^- \to e^+e^-\gamma$; 9-doubled ionization chambers; 10- lead plate of 13mm thickness; 11 - lead plate of 5 mm thickness.

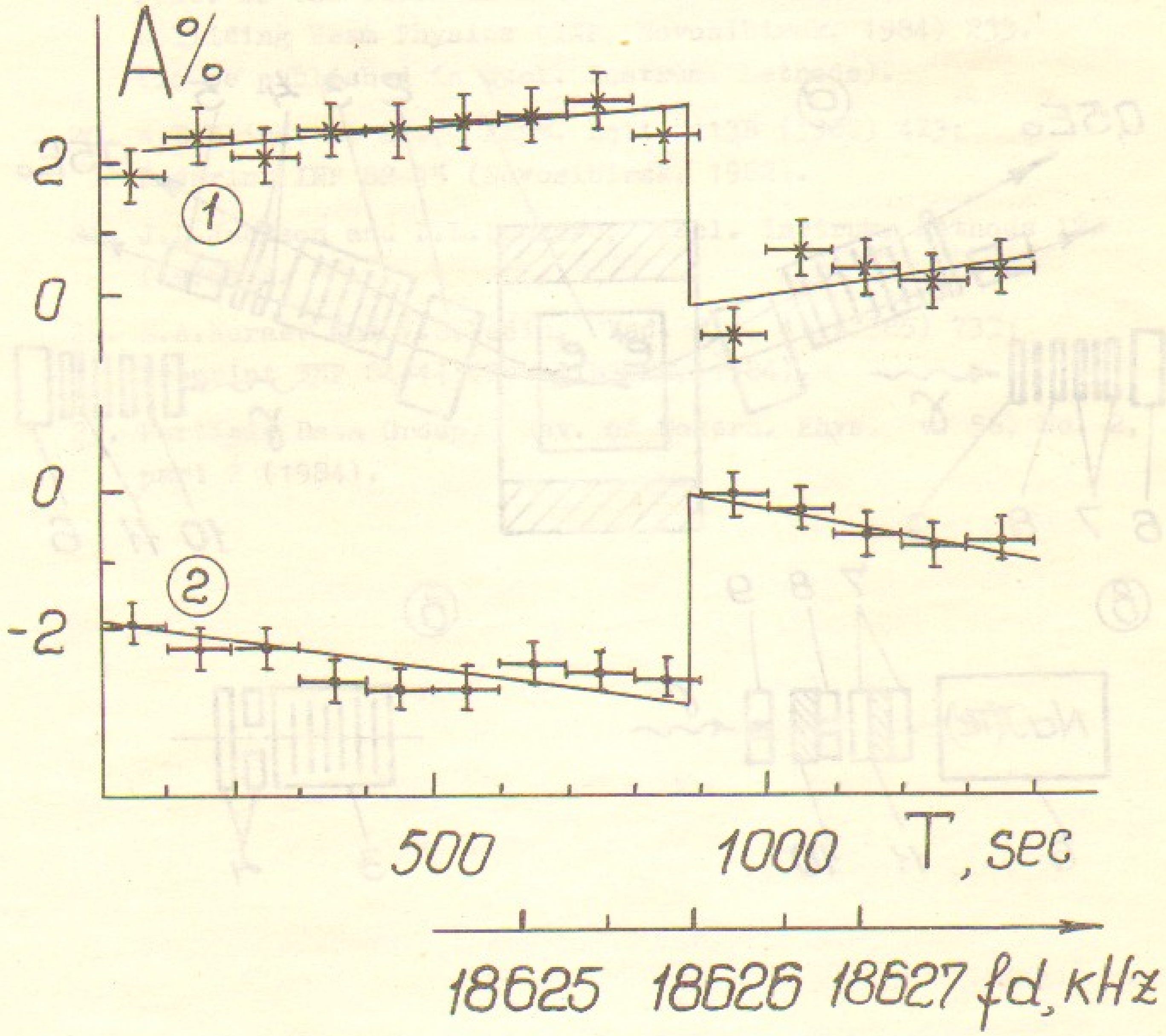

Fig. 2. Result of one of the depolarization frequency measurement.
1 and 2 - SR scattering on e^- and e^+ beams.
A = (up-down)/(up+down) is averaged over 100 sec.
Lower scale shows the depolarizer frequency f_d . Beam currents are $I_- = 5.8$ mA, $I_+ = 6.2$ mA.

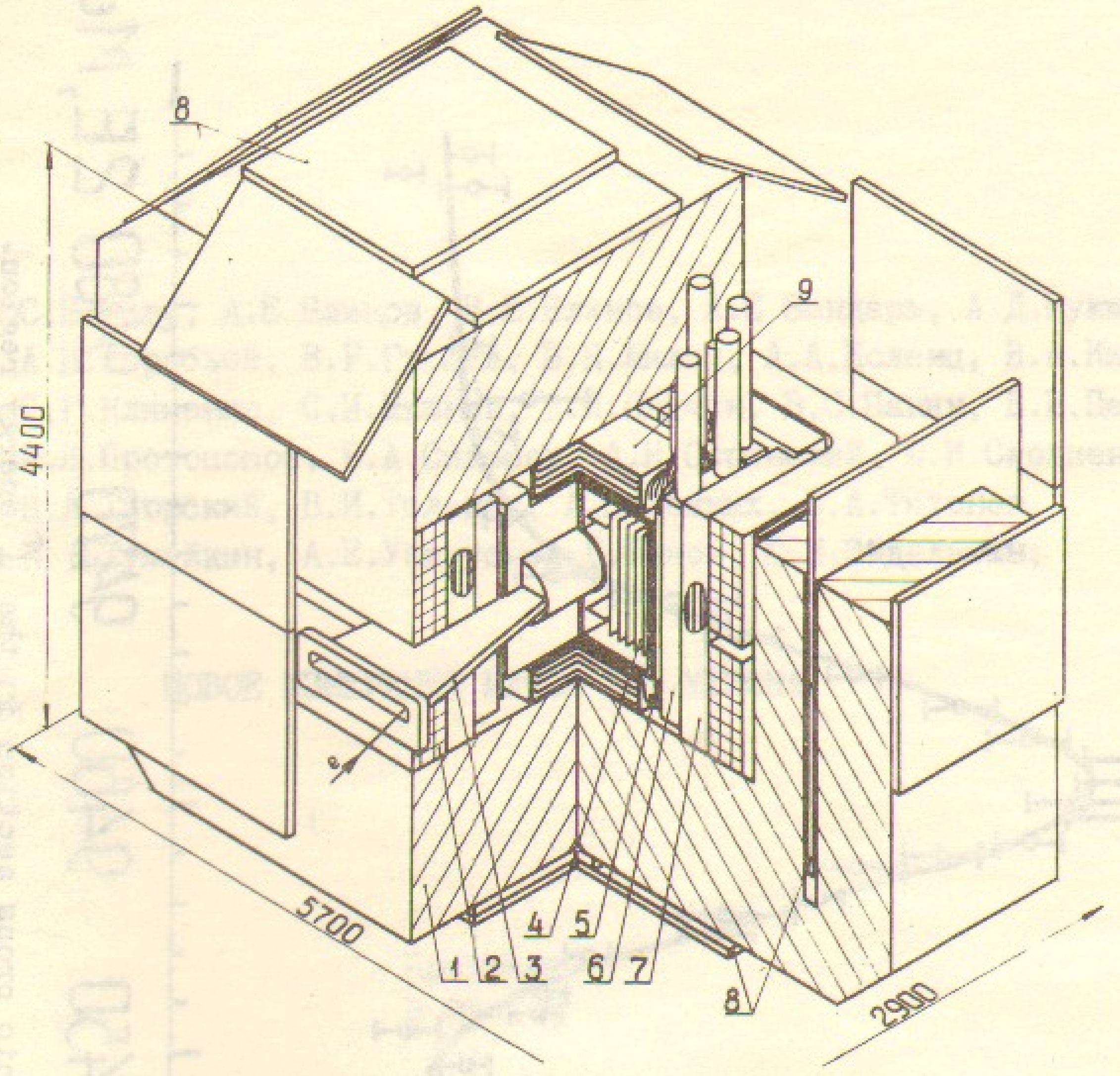

Fig. 3. Detector MD-1
1 - magnet yoke; 2 - copper winding; 3 - vacuum chamber; 4,8,10 - shower-range chambers; 5 - scintillation counters; 6 - coordinate chambers; 7 - gas Cerenkov counters; 9 - muon chambers.

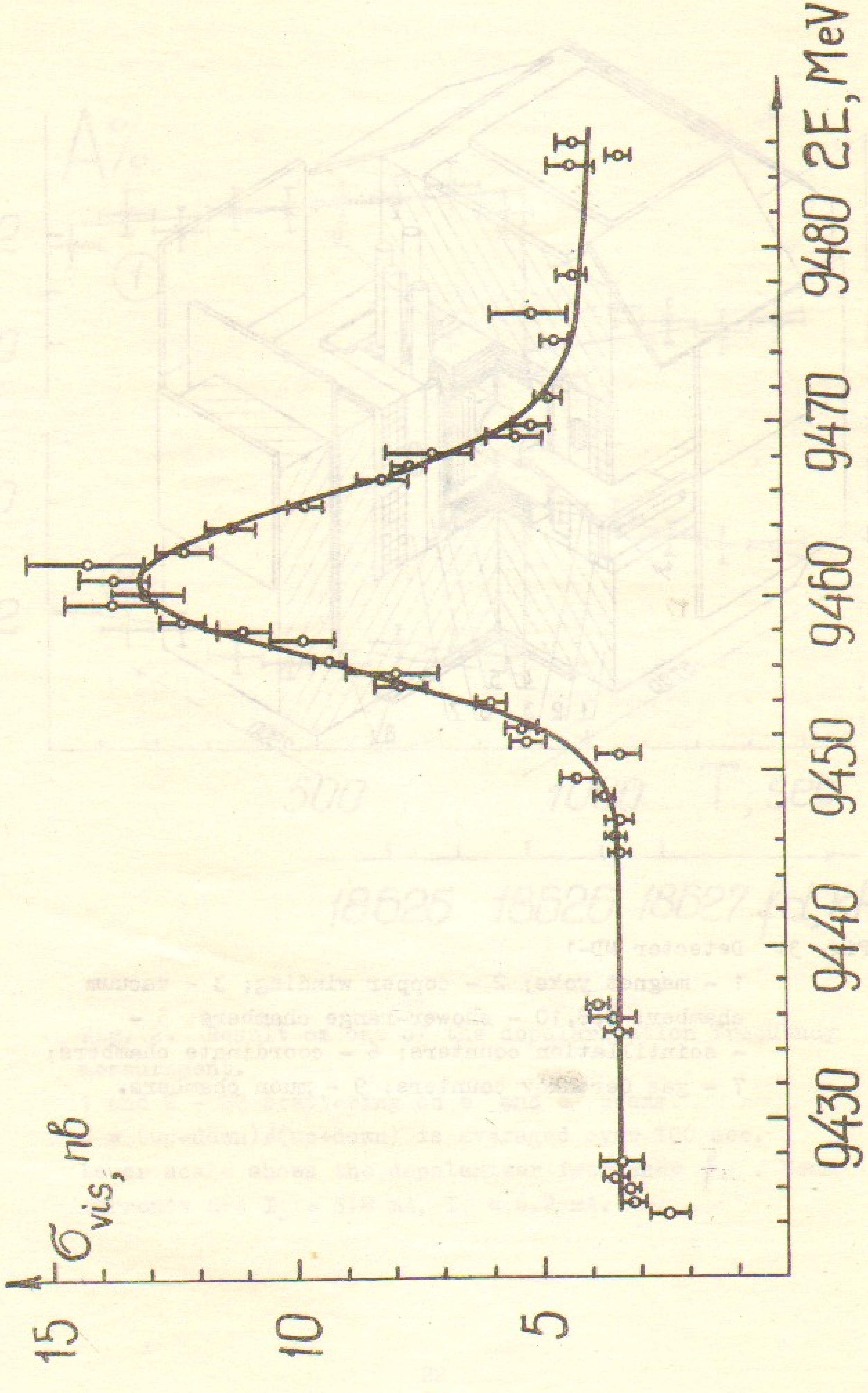

Fig. 4. Observed hadronic cross section in the Υ energy region.

С.Е.Бару, А.Е.Блинов, В.Е.Блинов, А.Е Бондарь, А.Д.Букин,
А.И.Воробьев, В.Р.Грошев, В.Н.Жилич, А.А.Жоленц, В.А.Киселев,
С,Г.Клименко, С.И.Мишнев, А.П.Онучин, В,С.Панин, В.В.Петров,
И.Я.Протопопов, В.А.Сидоров, А.Н.Скринский, Ю.И.Сковпень,
В.А.Таюрский, В.И.Тельнов, А.Б.Темных, Ю.А.Тихонов,
Г.М.Тумайкин, А.Е.Ундрус, А.Г.Шамов, Ю.И.Эйдельман,

НОВОЕ ИЗМЕРЕНИЕ МАССЫ Υ -МЕЗОНА

Препринт
№ 85-100

Работа поступила 30 июля 1985г.

Ответств.за выпуск - С.Г.Попов
Подписано к печати 6.08.85г. МН 06694
Формат бумаги 60х90 1/16 Усл.1,8 печ.л., 1,5 учетно-изд.л.
Тираж 290 экз. Бесплатно. Заказ №100

Ротапринт ИЯФ СО АН СССР, г.Новосибирск, 90