

NEW EXPERIMENTS WITH POLARIZED BEAMS AT VEPP-4M

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Abstract

Preparation for the new experiments in precise mass measurements of τ -lepton with the method of resonance depolarization is in progress. The new polarimeter was installed on the VEPP-4M storage ring and tested. We carried out the new precise mass measurements of J/ψ and ψ' mesons. As compared to the earlier measurements made in 1981, the accuracy was raised significantly. Careful analysis of possible sources of errors was performed.

1 INTRODUCTION

At present time, VEPP-4M [1] with the KEDR detector [2] is being prepared for the high precision measurement of the τ -lepton mass, which seems to be important for verification of universality of weak interaction. This experiment is planned to start lately in 2002 – early in 2003. A cycle of precision measurements of J/ψ and ψ' meson mass has been performed as preparation for the mentioned experiment. The gathered information is being treated now, however, it is already evident that the existing accuracy (experiments of 1981 at VEPP-4 [3,4]) can be made several times better. The accuracy of determination of the average beam energy by the method of resonance depolarization is now $\Delta E \approx \pm 2$ keV (the relative accuracy is $\approx \pm 1.3 \times 10^{-6}$), which more than 20 times exceeds the accuracy of the experiments in the 80s. Achievement of such accuracy and provision of high beam energy stability during statistic data collection made it necessary to take a number of technological and methodical decisions as well as to carry out a series of studies of factors influencing the beam energy value.

2 SCANNING SCENARIO

The average beam energy is measured by the well-known method of resonance beam depolarization. Initially, the electron beam is polarized in the booster storage ring of VEPP-3 (maximum energy up to 2 GeV) during $2\tau \approx 150$ min for J/ψ (1550 MeV) and during $2\tau \approx 40$ min for ψ' (1840 MeV). The difference of the IBS count rate for a polarized and non-polarized (reference) bunches in dependence on the frequency of the TEM wave of the depolarizator allows one to learn the beam energy with high accuracy [5].

The scanning scenario looks as follows. The resonance curve (defined by the beam energy spread) is

divided to a set of energy reference points and the required luminosity integral being measured in each of these points (for several hours). Statistic data collecting is preceded and followed by energy measurement. Direction of scanning of the depolarizator frequency is changed in each measurement. The up-down gap of the depolarization frequency defines actually the accuracy of energy measurement.

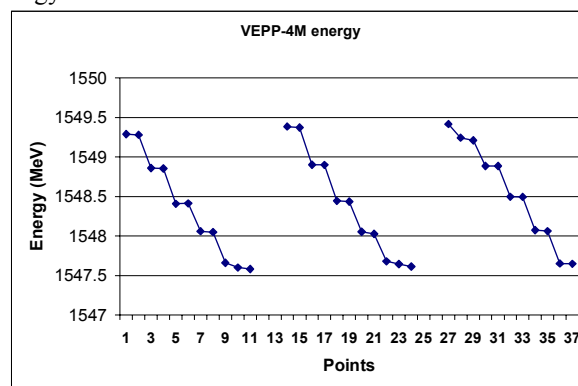


Fig.2.1 Three typical scans of J/ψ resonance.

The present small up-down gap of depolarization frequencies (about 5 Hz, which corresponds to $\Delta E \approx \pm 2$ keV) has been obtained via careful tuning of parameters of the depolarizator and reducing of the ripple level of the magnets' power supplies at frequencies of 50 and 100 Hz.

Fig.2.1 shows 3 typical scans for J/ψ meson mass measurement. Points in the plot show the energy measured by the method of resonance depolarization. The horizontal sections correspond to the periods of statistic data collection.

The main parameters of the collider are stored during scanning (once in several minutes): main magnets' field amplitude measured by NMR sensors, temperature of different points, ripple level of power supplies, revolution frequency, beam current, betatron frequencies, luminosity and so on. These data are used both for on-line analysis of current scanning situation and for subsequent treatment of the information gathered.

3 TECHNICAL ASPECTS OF ENERGY STABILITY

Serious attention is paid to stability of PS for the VEPP-4M magnets. The upgrade and tuning of the low-current PS for correction magnets made it possible to improve their long-term stability from 1% to 0.1%. Long-

term stability of the high-current PS for the main magnetic elements is now ± 5 ppm up to ± 20 ppm. The system for suppression of the current ripple ensures its relative level (measured) in the magnet field of the main elements to be about 3 ppm (50 Hz) and 0.8 ppm (600 Hz).

VEPP-4M is equipped with five NMR sensors to indicate the value of magnetic field of the magnet elements. Field of the main arcs bending magnets is measured by the NMR probe placed in a short reference magnet, which has the same cross-section as the regular one.

Fig.3.1 shows a plot of reference field measurement as well as beam energy having been obtained by resonance depolarization for 10 hours. As it was recognized, estimation of the beam energy from the NMR field measurement can differ from direct energy measurement by the technique of resonance depolarization.

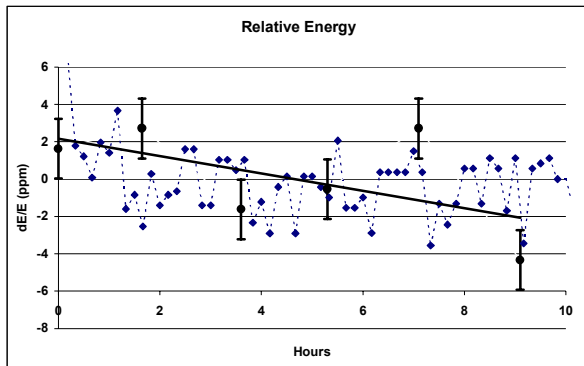


Fig.3.1 Reference magnetic field (curve) and energy calibration (points).

The difference can be as high as ~ 30 ppm. So, data on magnetic field were used mainly as an indicator of absence of any serious field variation during statistic data gathering. It was revealed that the discrepancy is caused by different temperature conditions for the main magnets and for the reference one.

Though special arrangements have been made to stabilize temperature of VEPP-4M and its elements and systems, the main factor influencing energy stability is temperature of air in the tunnel of the accelerator and cooling water temperature.

Fig.3.2 shows the electron beam energy oscillation reflecting day-to-night variation of temperature in the tunnel of the accelerator.

It was investigated how different VEPP-4M features able to influence the beam energy depend on the temperature [6]. Later on such dependencies were used to calibrate one or another parameter as to the temperature. Fig. 3.3 shows behavior of magnetic field of a magnet of the ring with and without temperature calibration.

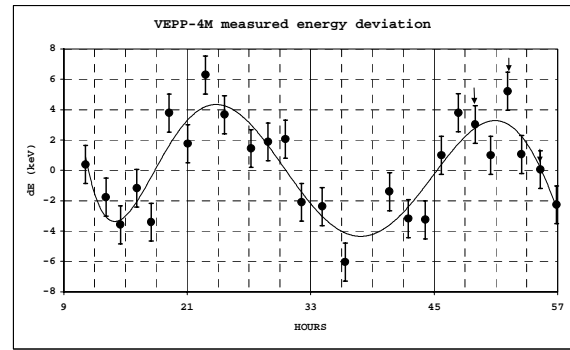


Fig.3.2 Beam energy oscillation due to the day-to-night temperature change.

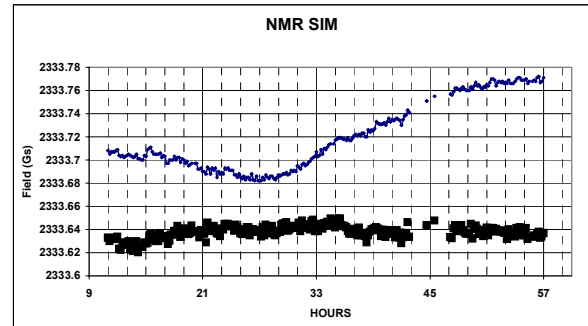


Fig.3.3 The VEPP-4M magnetic field with (the lower plot) and without the temperature factor.

Table 3.1 presents measured temperature factors for the VEPP-4M beam energy

Table.3.1 Dependency of the VEPP-4M beam energy on the temperature.

Temperature of magnets of half-rings	$-41 \text{ ppm}/^\circ\text{C}$
Temperature of magnets of inserts	$-7 \text{ ppm}/^\circ\text{C}$
Temperature of cooling water	$+1 \text{ ppm}/^\circ\text{C}$

4 ENERGY MEASUREMENT PRECISION

A detailed analysis and values of statistical, random and systematic errors of resonance mass measurement can be found in [7]. Below we will dwell on the main systematic errors due to different acceleration effects.

1. Difference in energy of the electron and positron beams. During the luminosity collection we calibrate the beam energy with the electron beam. However, due to the difference (though small) in trajectories of electrons and positrons, the average positrons energy can differ from the electrons one. Direct measurements showed that the difference in energy between the electrons and positrons is 2 ± 4 keV.

2. Electrons and positrons in parasitic IP are separated in the vertical direction with the help of electrostatic electrodes. Energy calibration is made with these electrodes switched-off (to get high efficiency of the

polarimeter IBS counters). However, the resonance scan is provided with the separation electrodes switched-on. To check the possible energy shift between calibration and experiment we have performed such measurements and found that it is less than 4 keV, i.e. it is negligible.

3. The requirement on stability of the horizontal orbit follows from estimation [7]

$$\sigma_E \sim \sigma_x \frac{2\sqrt{2} \sin \pi \nu_x \eta}{\alpha L \beta_x},$$

where σ_E is the rms error of the average beam energy due to rms distortion of the closed orbit σ_x , α is the compaction factor, L is the machine circumference, η and β_x – the average dispersion and betatron functions.

Estimations and direct measurements at VEPP-4M show that for $\sigma_E \sim 5 \times 10^{-6}$ the rms COD change during statistic data gathering should not exceed 100 μm .

4. If luminosity is an odd function of the energy, then there is a difference between the average energy extracted from the luminosity distribution and that measured directly by the method of resonance depolarization. This fact provides a systematic error of resonance mass measurement. The main source for such dependence is chromaticity of the betatron functions $\beta \approx \beta_0 + \beta_1 \cdot \delta$ and dispersion function $\eta \approx \eta_0 + \eta_1 \cdot \delta$ in the interaction point. Estimation shows that the asymmetry factor in the luminosity distribution as a function of the energy has the form

$$\frac{dL}{d\delta_i} \propto \frac{1}{\sqrt{\varepsilon_y (2\beta_{y0} + \beta_{y1} \delta_i)}} \frac{1}{\sqrt{\varepsilon_x (2\beta_{x0} + \beta_{x1} \delta_i) + 2\sigma_E^2 (\eta_0 + \eta_1 \delta_i)^2}},$$

where $\delta_i = (E_i - 2E_0)/E_0$, E_0 – the equilibrium energy, and E_i – the total energy of an electron and positron having collided.

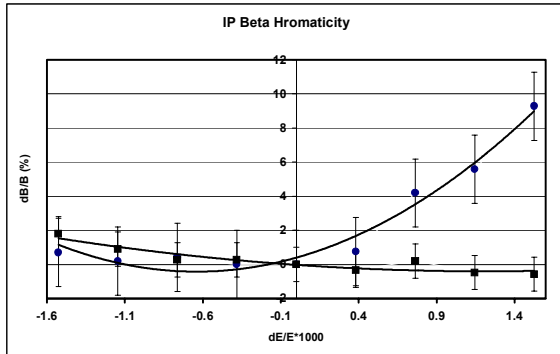


Fig.4.1 IP betatron function chromaticity. Beta-x – dots, beta-z – squares.

A chromaticity of the IP optical functions was investigated and optimized with the help of several families of sextupole lenses. Fig.4.1 shows the value of

the IP betatron function for different energy points. Fig.4.2 shows the specific luminosity as a function of revolution frequency before and after the optical function chromaticity correction.

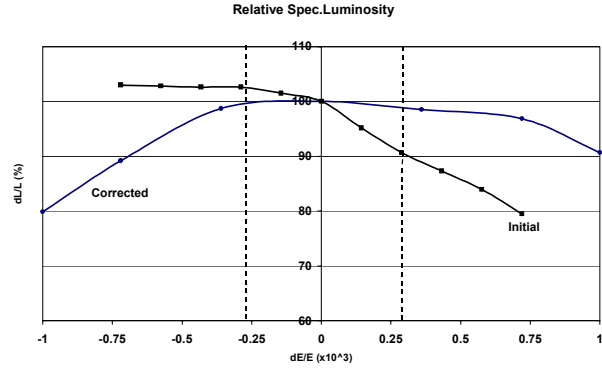


Fig.4.2 Specific luminosity vs. revolution frequency before and after IP chromaticity correction. Dashed line indicates VEPP-4M energy spread.

Evaluation shows that for optimized luminosity distribution the resonance mass systematic error due to the IP chromatic effects is about 5 keV.

5 CONCLUSIONS

During last experiments at the VEPP-4M collider equipped with the KEDR detector the $J/\psi(1S)$ and $\psi(2S)$ mass measurement was performed. The resonance curve was scanned by the collider energy and the average beam energy was calibrated just before and after luminosity collection. A statistical error of 10 keV and 20 keV was obtained for J/ψ and ψ' respectively.

6 REFERENCES

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