DIRECT COMPARISON OF THE METHODS OF BEAM ENERGY SPREAD DETERMINATION IN THE VEPP-4M COLLIDER

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Abstract

The VEPP-4M electron-positron collider is now operating with the KEDR detector for the experiment of precise measurement of tau-lepton mass [1]. The nearest experimental program of the accelerator also includes a scan of the energy area below J/ψ meson to search narrow resonances. The monitoring of beam energy spread is important to know the energy spread contribution into the total systematic error.

In this report we discuss the application of several diagnostics for beam energy spread measurement. The data obtained with Compton Back-Scattering (CBS) technique [2] are compared with the value of the spread derived from the betatron motion of the beam [3]. The measurements by all the methods were done at the same accelerator run, i.e. the different diagnostics can be compared directly. The value of the energy spread was determined for a set of collider operating modes, covering the energy area from 1200 MeV up to 1855 MeV……..

INTRODUCTION

Value of beam energy spread σ_E is directly included into accuracy of the mass measurement. Knowledge of exact value of the beam energy spread enables us to reduce significantly a systematical error in the experiment of $c-\tau$ lepton mass measurement. It is also an essential supplement to precision measurement of average beam energy.

The measurement of τ lepton mass with accuracy of ± 100 keV requires determination of beam energy spread with accuracy of ± 10%. In this case, the impact of energy spread on the systematical error of the τ lepton mass determination doesn't exceed ± 25 keV. Clear understanding of the effects of the parameters influencing the beam spread and the ability to control this value are important tasks for our experiments.

Compton Back-Scattering (CBS) is used at the VEPP-4M collider for permanent control of the electron beam energy during the run [2]. This diagnostics is able to measure the beam energy every 8-10 minutes with an accuracy of $\Delta\varepsilon = \pm 60$ кэВ.Period of the measurement is determined by the flow of the registered gamma quantum. Spectrum of scattered Compton quanta also contains information about the beam energy spread.

For a long time, spectrum processing method, as well as spectrum calibration, has been refined via comparison between the CBS data and the results of energy measurement by resonance depolarization technique [1]. Value of the beam energy spread averaged over a set of the collider runs is in a satisfactory agreement with a width of ψ' resonance determined by KEDR [4]. At the same time the successive measurements during the collider run do have a significant spread. This fact prompts us to compare the measurements from different diagnostics to elicit possible errors of the CBS method.

Correction of the systematical errors will allow us to control permanently the beam energy spread during the collider run. This is important for the future experiments at VEPP-4M in search of narrow resonances inside 0.9 – 1.5 GeV area. Perhaps, it will also cause the improvement of the accuracy in the beam energy measurement.

At the experiments, described above, beam energy of VEPP-4M (Fig. 1) was changed from 1100 GeV to 1855 GeV. The energy spread of the beam can be increased with the 3-pole snakes established in the experimental area (Fig.1). Snakes were applied only during the beam energy spread measurements described below.

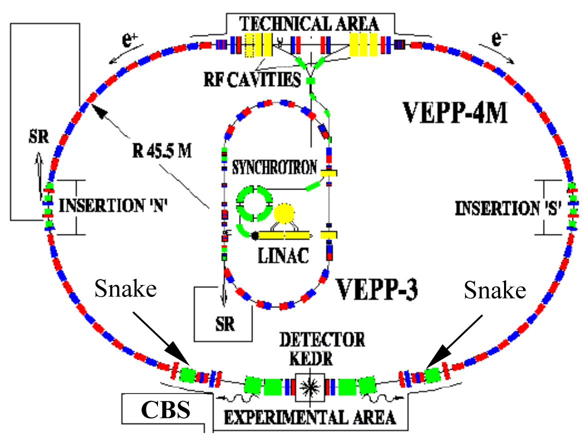

Figure 1. VEPP-4M general layout

APPLIED METHODS FOR BEAM ENERGY SPREAD MEASUREMENT

Compton Back - Scattering (I)

The VEPP-4M collider has a system of Compton Back-Scattering for permanent measurement of the average beam energy and the energy spread. [2], Fig.1.

When the monochromatic laser radiation with the photon energy w_0 interacts with the contrary relativistic electron beam with average particle energy E_0, the scattered photons with maximal energy $W_{\max}$ form a narrow edge in the spectrum. The value of $W_{\max}$ is strictly coupled with the average energy of the beam

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electrons by a simple relation: $W_{\max} \approx 4w_0 \cdot (E/m_e c^2)^2$. The width of the edge is mostly determined by the resolution of the photons detector and the energy spread of the electron beam. Thus, direct measurement of the energy spectrum of scattered photons allows us to measure both the electron beam average energy and the energy spread.

Chromaticity dependence of envelope of betatron oscillations (II)

It was shown [3] that envelope $A(t)$ of free coherent betatron oscillations excited by a kick with an amplitude $b >> \sigma_y$ b is described as

$$A(t) \propto \exp\left(-\frac{t^2}{2\tau^2}\right) \cdot \exp\left(-\left(\frac{\partial \omega_y}{\partial E}\frac{\sigma_E}{\omega_s}\right)^2 \cdot \left(1-\cos(\omega_s t)\right)\right)$$

$$\text{where } \tau = \left(2\frac{\partial \omega_y}{\partial a^2} b \cdot \sigma_y\right)^{-1}. \qquad (1)$$

Experimentally, the energy spread was determined comparing the measured beam betatron motion with the theoretical curve $A(t)$.

Bunch length dependence of energy spread (III)

The r.m.s of a bunch length σ_z is directly proportional to the r.m.s. of the energy spread:

$$\sigma_z = R\alpha \frac{\omega_s}{\omega_0}\frac{\sigma_E}{E_0} \qquad (2),$$

where R – the average radius of the ring, α - momentum compaction factor, E_0 - beam energy [4].

The φ-dissector [5] is used at VEPP-4M to measure the beam length σ_z. This device has a temporal resolution of about 30 ps (≈ 1 cm).

EXPERIMENTAL RESULTS

Measurements of the beam energy spread were carried out during two runs of VEPP-4M.

During the first run the collider energy was changed from 1855 MeV down to 1100 MeV with a step of about 100 MeV. Within the energy area of 1300 – 1855 MeV the measurements were performed by the three mentioned diagnostics together. The beam current was about $I_b \approx$ 80 – 100 mkA to neglect the collective effects. During the second run the accelerator energy was set to 1855 MeV and the snake current was varied from 0 up to 2000 A..

Spectra of the Compton Back-Scattering are shown in Fig. 2. The steepening of the spectrum edge with the beam energy spread increase can be easily seen.

For betatron frequency measurement we have applied an optical diagnostics based on the Multi-Anode Photomultiplier Tube R5900U-00-L16 HAMAMASU (MAPMT) [6]. To increase an accuracy, the digital filter was applied to the measured data. For envelope analysis, the oscillation is calculated by the inverse Fourier transform of spectrum of measured betatron oscillations, but only $\nu_y \pm m\nu_s$ harmonics are taken into account.

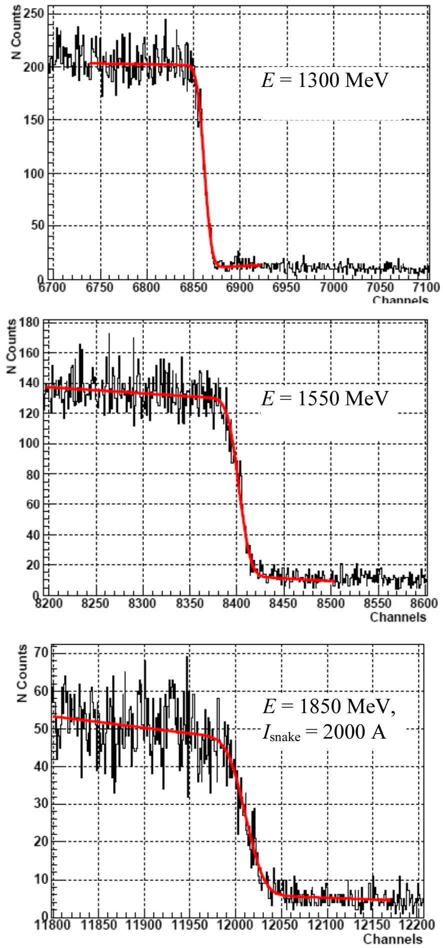

Figure 2: Compton Back-Scattering spectra for various values of the beam energy spread. Channel number is proportional to the γ-quantum energy.

The envelope of the derived betatron motion $En(t)$ was compared with (1). Energy spread δ_E was used as a fitting parameter. An example of filtered experimental envelope in comparison with theoretical curve $A(t)$ for 3 different values of energy spread σ_E is presented in Fig. 3.

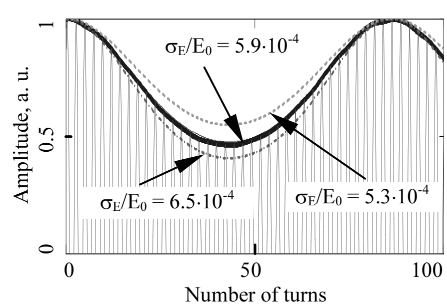

Figure 3: Measured betatron oscillation envelope in comparison with theoretical one.

The results of the measurements of beam energy spread are presented in Fig. 4.

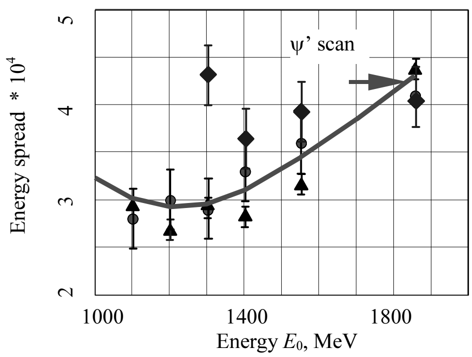

Figure 4: Variation of the beam energy spread depending on the beam energy.
◆ - CBS data;▲ - method (*III*) data;● - method (*II*) data; ▬ - simulation results. An arrow shows the data of KEDR.

Fig. 5. represents the variation of the beam energy spread with the snake current increase.

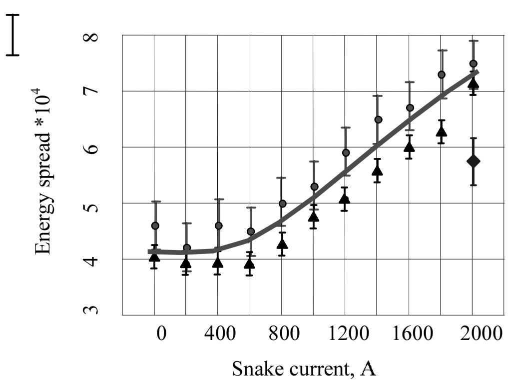

Figure 5: The beam energy spread depending on the snake current. $E_0 =$ 1855 MeV, the same symbols.

DISCUSSION

Determination of the beam energy spread by the measurement of a beam length been applied for a long time, therefore the data of this diagnostics look reliable.

Measurement accuracy of the described experiments is determined by the inherent noise of the dissector, which was rather high. The reasons of it are the small beam current and the reduced transparency of output window of vacuum chamber darkened under SR-influence during a 5-year run. Each point in Fig. 5 was obtained as a result of averaging out of 512 beam profiles registered by the dissector.

The main source for errors during derivation of the beam energy spread from an envelope of betatron oscillations (method *II*) is a noise of the Fourier spectrum. It influences the accuracy of the envelope restoration with the inverse Fourier transform.

The systematical discrepancy between (*II*) and (*III*) during the measurement of the beam energy spread depending on the snake current may be related to that.

An accuracy of the method (*II*) can be estimated as 10 percent (Fig. 3). The level of modulation depth of about 0.5 is necessary for a reliable reconstruction of the envelope. It creates some experimental inconveniences as it requires the increase of a vertical chromaticity up to $C_y \approx 13-18$, that exceeds significantly the nominal value.

Spectra of Compton Back-Scattering were got parallel with the measurements of two other diagnostics (Fig.6). In spite of an obvious sensitivity of CBS to the beam energy spread (Fig. 2), we have to recognize the discrepancy between the CBS data and the measurements of (*II*) and (*III*). This difference may be connected with the solid angle in which the CBS detector collects the scattered gamma quanta. Possibly, the “tails” of the scattered photons do not reach the detector that leads to distortion of the spectrum edge.

However, this hypothesis requires further investigation; and we plan to continue the experiments on comparison of the data of different methods for the beam energy spread measurement.

CONCLUSION

Experiments on the beam energy spread have been carried out at the VEPP-4M collider using three different diagnostics.

All three diagnostics have been used simultaneously during the same accelerator run.

The results of the measurements are in a satisfactory agreement, but further experiments to elicit the nature of systematical errors of CBS are necessary.

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