MEASUREMENTS OF ENERGY SPREAD AT VEPP-4M

V. M. Borin, V. L. Dorokhov, V. A. Kiselev, O. I. Meshkov[1], S. A. Nikitin, P. A. Piminov, S. V. Sinyatkin, Budker Institute of Nuclear Physics, Novosibirsk, Russia
A. V. Smirnov, General Physics Institute, Moscow, Russia
[1]also at Novosibirsk State University, Novosibirsk, Russia

Abstract

The unique feature of the VEPP-4M electron-positron collider is wide energy range (1 - 4.75 GeV) available for experiments in high-energy physics. Energy spread value of the beam is an important parameter in a choice of energy step during measurement of e+e- -> hadrons cross sections as well as it has a strong influence on the statistic collection time required for the scanning of narrow resonances like planned for the nearest future scan of Upsilon(2s) meson. Thus, it is important to control energy spread of the beam and measure it operatively and reliably. The paper presents measurements of the beam energy spread at the VEPP-4M electron-positron collider in its complete energy range. Energy spread was calculated from bunch length measured by PS-1/S1 streak camera with picosecond temporal resolution. In order to exclude the influence of collective effects on bunch length, we measured length of low-intensity bunch. Values of energy spread calculated from bunch length were cross-checked by the measurements of energy spread based on registration of a beam decoherence. The impact of the Touschek effect in the beam energy spread at low energy range (1.0 - 1.5 GeV) is discussed.

ENERGY SPREAD

Natural Energy Spread

Neglecting an influence of collective effects the energy spread in circular accelerator is determined by equlibrium between quantum excitation and radiation damping of synchrotron oscilations. The value of equlibrium energy spread is determined by an accelerator lattice and can be calculated using Eq. 1:

$$\left(\frac{\sigma_E}{E}\right)^2 \approx 0.9923\frac{\lambda_E <1/r_0^2>}{J_E <1/r_0^3>}\gamma^2, \qquad (1)$$

where σ_E is the energy spread, E is the bunch energy, λ_E is the Compton wavelength of the electron, J_E is the longitudinal damping partition number (Eq. 2), r_0 is the bending radius, γ is the Lorentz factor.

$$J_E = 2+\frac{\oint\left(\frac{1}{r_0^2}+\frac{2G}{H_0 r_0}\right)\frac{D}{r_0}\,\mathrm{d}s}{\oint\frac{\mathrm{d}s}{r_0^2}}, \qquad (2)$$

where G is a vertical magnetic field gradient, H_0 is a vertical magnetic field. Value of second term of Eq. 2 is limited by -2 and 1 by conditions of stable beam motion.

A presence of bending magnets with focusing sections at the lattice of VEPP-4M leads to values of second term of Eq. 2 out of its limits. In order to get the conditions of stable motion a special Robinson damping wigglers are installed at the VEPP-4M. Altering their strength, we can control the value of energy spread in a wide range. It is very important to know the value of energy spread during the scanning of narrow resonances, because the luminosity integral required for the measurements of the resonance cross section with certain precision is proportional to third degree of the energy spread of the beam.

Intrabeam Scattering

Another significant effect that we should consider during the operations of the VEPP-4M at the low energy range (below 1.5 GeV) is the intrabeam scattering (IBS of multiple Touscheck effect), which causes energy spread increase as the beam current increases. The effect is based on transferring of momentum from the transverse plane of motion to the longitudinal one, boosted by Lorentz factor [1,2].

The energy spread growth is not correlated with the quantum excitation. Thus, the total energy spread is determined by the quadratic sum of natural energy spread and the IBS term.

BEAM DIAGNOSTICS

Bunch Length Measurements

The main method we used to determine bunch energy spread is the measurements of its length:

$$\frac{\sigma_E}{E}=\frac{\sigma_s\omega_s}{\alpha c}, \qquad (3)$$

where σ_s is the bunch length, ω_s is the synchrotron revolution frequency, c is the speed of light, α is the momentum compaction factor.

For the measurements the PS-1/S1 streak camera was installed into optical diagnostics of the VEPP-4M [3, 4] The camera has a temporal resolution about 3 ps. The example of longitudinal profile of the bunch acquired by the camera is shown in the Fig. 1.

The method can be used only with low intensity beams. In case if beam is intense enough, then collective effects affect the relation between bunch length and energy spread [5]. In order to avoid it, all measurements were conducted with beam current about 0.2 mA at which all collective effects are negligible. Choice of current is based on studies of collective effects conducted earlier [6].

ISBN: 978-3-95450-197-7 doi:10.18429/JACoW-RUPAC2018-THPSC29

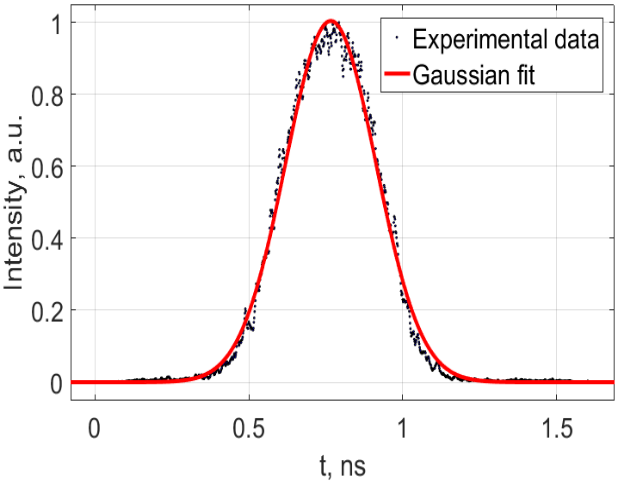

Figure 1: The longitudinal profile of the bunch acquired by the streak camera.

Envelope of the Betatron Oscillations

Another method was used to check results obtained from bunch length measurements. Method is based on a acquisition of transverse coherent beam oscillations after a short kick. Envelope of oscillations *A(t)* excited by a kick of amplitude *b* is described by Eq. 4,5.

$$A(t) \propto \exp\left(-\frac{t^2}{2\tau^2}\right)\exp\left(-\left(\frac{\partial\omega_y}{\partial E}\frac{\sigma_E}{\omega_s}\right)(1-\cos\omega_s t)\right), \quad (4)$$

$$\tau = \left(2\frac{\partial\omega_y}{\partial a^2}b\sigma_y\right)^{-1} \quad (5)$$

Where ω_y is the a vertical betatron frequency, σ_y is a vertical beam size.

Oscillations are acquired by BPM's. The obtained signal is Fourier filtered in order to increase a signal-to noise ratio and the accuracy of envelope fitting. Example of resulting signal with fitted envelope is shown in the Fig. 2.

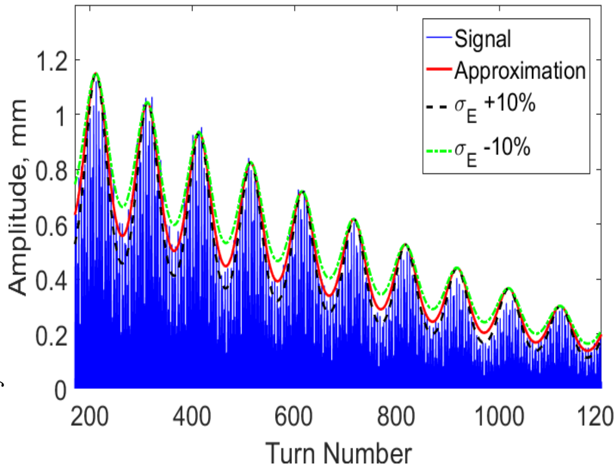

Figure 2: Envelope of coherent oscillations.

The accuracy of the method depends on the number of the acquired periods of oscillations. If beam intensity is low, then the limiting factor is the beam decoherence caused by lattice nonlinearities As the beam intensity increases, collective effects starting to damp a coherent mode of the oscillations.

EXPIREMENTS

Methods Comparisson

We have compared the both methods at the injection energy (about 1.9 GeV) with a series of simultaneous measurements of energy spread. By alrering current in the Robinson wigglers we changed the value of the beam energy spread. The experimental results of the both described methods are in a good agreement. The measurements with a bunch length are simpler and we are able to receive continuous stream of bunch length data with the optical dissector installed at the VEPP-4M optical diagnostics station. The value of the synchrotron frequency can be measured with a high precision from decoherence modulation during the measurements by the second method (Eq. 4, Fig.2). Meanwhile the second method needs in additional measurements and correction of a lattice chromacity in order to increase the depth of envelope modulation. And the measurements conducted only after a short beam kick, which takes some time. In addition, it takes more time to gather the value of energy spread from registered signal.

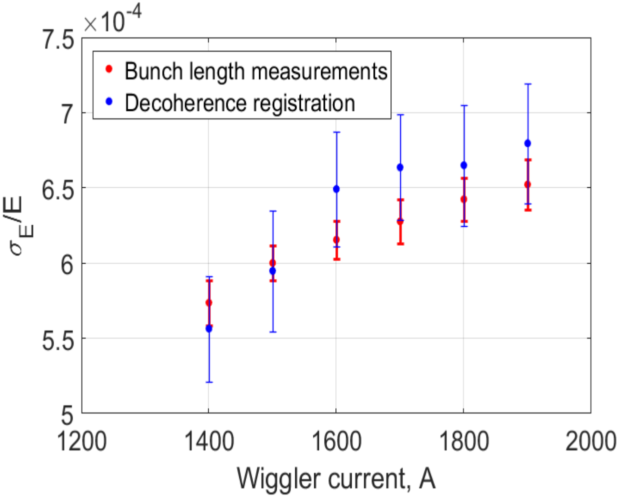

Figure 3: The comparison of the methods of measurements of a beam energy spread.

The second method is less affected by the influence of collective effects. Because of that we use the obtained data to check the results of the first method, despite thelower precision of this diagnostics (Fig. 3).

Overall Energy Spread data

Beam energy spread was measured at the VEPP-4M during the runs of 2016-2018 years (Fig. 4). The middle part of the plot wihin an energy range of 1.5-3.5 GeV has a linear dependence from beam energy as it was expected. The collider mode of operation were setup with constant value of the longitudinal partition damping number. At higher energies of the VEPP-4M (3.5-4.75 GeV) the Robinson wigglers are saturated and the value of longitudinal damping partition number is increasing. It leads to energy spread saturation as well. Further beam energy increase is limited by the beam stability.

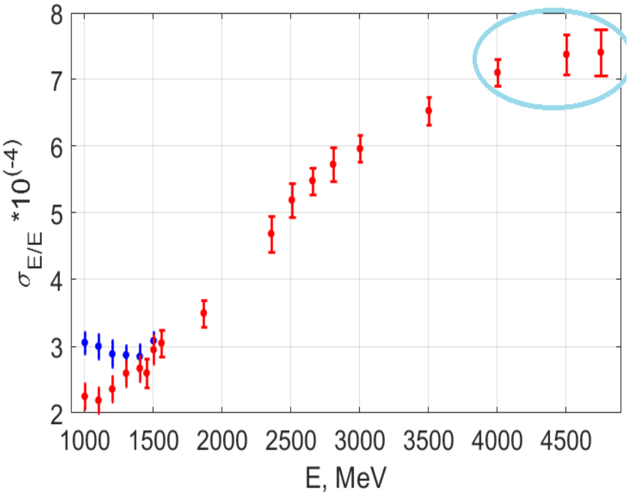

Figure 4: Measured energy spread.

IntraBeam Scattering

The influence of IBS results in non-linear dependence of the beam energy spread on the energy of the beam. It is clearly seen in the Fig. 4 at the beam energy lower 1200 MeV.. In order to observe a stronger deviation from the natural beam energy spread another series of the measurements were performed. The RF voltage was increased to compress the bunch Figure 5 shows the difference in the measured energy spread.

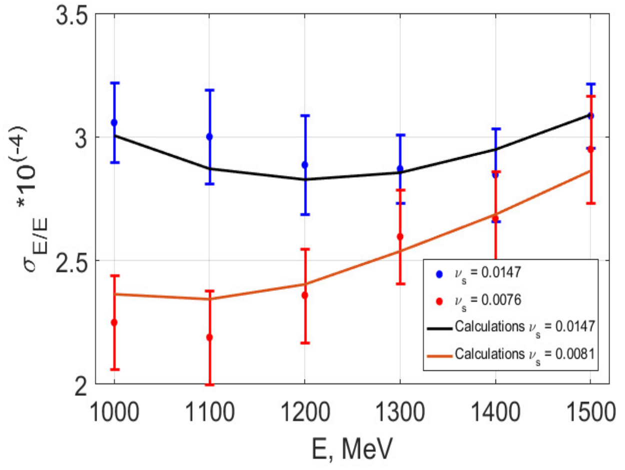

Figure 5: Comparison of the measured dependencies.

In the case of increased RF voltage (blue points)the energy with the minimal energy spread is near 1.2-1.4 GeV. The calculation for the energy spread with increased IBS power is in a good agreement with the experimental results.

CONCLUSION

The energy spread was measured in full operational range of VEPP-4M (1.0 – 4.75 GeV). The data obtained by two independent diagnostics are in a good agreement. IBS influence on the beam energy spread was studied at the energies lower than 1.5 GeV. The minimum of energy spread was acquired near 1.3 GeV. Calculations of the energy spread are in a good agreement with the measurements.

REFERENCES

[1] J. Le Duff, “Single and Multiple Touschek Effects” in *Proc. of CERN Accelerator School*, CERN 89-01, 1995.

[2] A. Piwinski, “Touscheck Effect and Intrabeam Scattering”, in *Handbook of Accelerator Physics and Engineering*, edited by A. Chao and M. Tigner, World Scientific, Singapore, 1999, pp. 125-127

[3] S.G. Garanin et al., “PS-1/S1 picosecond streak camera application for multichannel laser system diagnostics”, *Quantum Electron.*, vol. 44 no. 5, p. 798, 2014.

[4] O. I. Meshkov et al., “The upgraded optical diagnostics of the VEPP-4M collider”, in Proc. EPAC 2004, Lucerne, Switzerland, pp. 2739-2741.

[5] A. Chao, “Wake Fields and Impedances” in *Physics of Collective Beam Instabilities*. New York: Wiley, 1993.

[6] V. M. Borin et al., “The longitudinal broadband impedance and energy spread measurements at the VEPP-4M electron-positron collider”, in Proc. IPAC 2017, Copenhagen, Denmark, pp. 3117-3119.