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

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Abstract

The nearest experimental program of the VEPP-4M electron-positron collider and the KEDR detector includes scanning of the energy area below J/ψ meson to search for narrow resonances. The monitoring of the beam energy spread is important for these experiments.

In this report we discuss the application of several diagnostics for beam energy spread measurement. The data obtained with Compton Back-Scattering (CBS) technique are compared with the value of the spread derived from the betatron motion of the beam and the measurements of the beam length.

Similar experiments were carried out in 2006-07. They showed the necessity to improve the algorithm of energy spread derivation with CBS technique. New set of measurements was aimed at the examination of the improved algorithm.

INTRODUCTION

The beam energy spread, along with the beam energy, is a value, which is desirable to be controlled during the accelerator run. It is essential for the VEPP-4M collider because its experimental program includes precise measurements of the masses of elementary particles [1]. Knowledge of the beam energy spread with an accuracy below 10 percent enables reducing the systematical error significantly. We have no reliable method for «on the fly» measurement of a beam energy spread, whereas demands to accuracy of its (10^{-1}) are incommensurable with the demands to accuracy of the beam energy determination (10^{-6}). Until now we have to scan the narrow resonances (J/ψ, ψ' meson) for the beam energy spread determination that requires considerable resources and time. Therefore the development of the diagnostics, providing reliable data about the beam energy spread during collider run seems important. During VEPP-4M operation the continuous measurements with a frequency of 0.3-0.5 Hz of radial and longitudinal beam dimensions are carried out with CCD camera and φ-dissector [2]. Unfortunately, these data can't be applied directly for the beam energy spread derivation because of the dependence of beam dimensions on the beam current. Besides, the dispersion and beta functions can't be measured in the observation point with a necessary accuracy. The CBS diagnostics operates at the VEPP-4M as well, Fig 1. Spectrum of the backscattered photons enables the measurement of the beam energy with accuracy of 50 keV and contains information about the beam energy spread.

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COMPTON BACKSCATTERING MONITOR (CBS)

In case of the head-on collision of laser radiation with an electron beam the energy spectrum of Compton scattered photons has a sharp edge at maximal energy $\omega_{\max} \cong 4\gamma^2\omega_0$, where ω_0 is initial photon energy. One can obtain the absolute value of the electron energy E by measuring $\omega_{\max}$. If the beam has the energy spread of σ_E, the spectrum edge would get smeared to $\frac{\sigma(\omega)}{\omega} \approx \frac{2\sigma_E}{E}$.

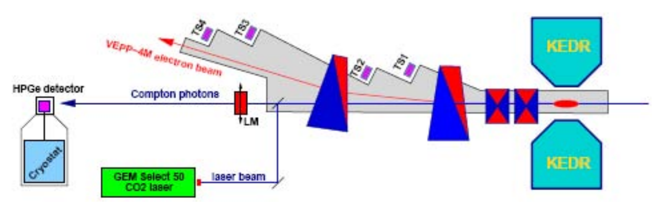

Figure 1: Experimental setup of CBS. The distance of the HPG detector from the interaction point is about 16 m.

Experimental Setup

The following equipment was used for CBS [3]:

- The CO_2 laser with $\omega_0 = 0.117$ eV provides $\omega_{\max}$ in the range of 4 – 7 MeV for the electron beam energy in the range of 1500 – 2000 MeV.
- The High Purity Germanium (HPGe) detector cooled with liquid nitrogen has the energy resolution of about 1.5 keV. Actually, the pile-up noise contributes additionally (1 - 3) keV. The expected spectrum edge width is about 3-5 keV. The HPGe scale and resolution are continuously calibrated with γ-sources in the range of 0.5 – 2.7 MeV. The extrapolation to $\omega_{\max}$ is necessary.

Measurement Procedure

The counting rate of Compton photons above 3 MeV threshold was 1 – 5 kHz. The higher rates cause the HPGe resolution degradation. The backscattered spectrum example is shown in Fig. 2 for $E \approx 1580$ MeV.

The resolution of the HPGe detector determined with the widths of calibration γ-peaks is about 2.1 keV for the edge of the spectrum at $E \approx 1800$ MeV. The edge of the

Compton spectrum and the on-line fit results are shown in Fig. 3.

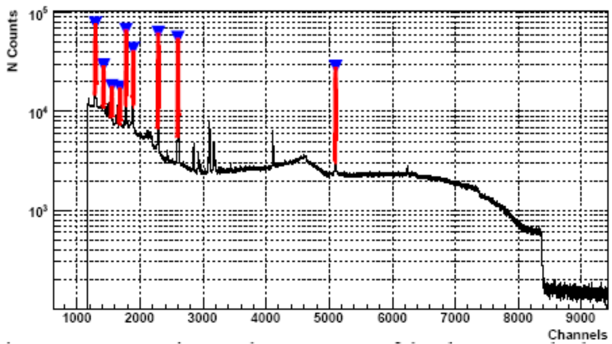

Figure 2: Experimental spectrum of backscattered photons with calibration lines. 1 channel = 0.512 keV. Collection time is about 3 hours. $E \approx 1580$ MeV

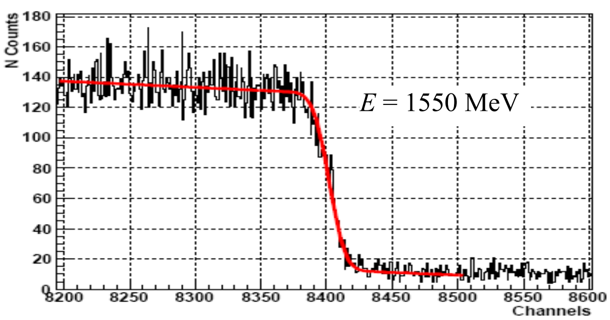

Figure 3: The edge of Compton Back-Scattering spectrum for the beam energy of 1550 MeV, $\omega_{\max}$ = 4.470 MeV. The edge width is 4.00 ± 0.15 keV.

The relative accuracy of the beam energy spread derived from the spectra is significantly worse than the beam energy determination. It relates to the obvious circumstance: the complete backscattered spectrum covers about 10^4 channels (bins) of the detector, whereas the statistical error for the spread value σ_E is proportional to the width of the edge of the spectra σ_{edge}: $\sigma_E \approx \sqrt{2}\sigma_{edge}$. This width has the extension of about 20 bins and energy resolution of the detector is about half of this value.

Spectra Fitting

For the on-line monitoring the collected spectra were fitted in the range ± 250 keV from the edge and approximated with the function with 6 free parameters. It includes the following components:

- The Compton spectra is $F_{Comp} = a + b(X - \omega_{\max})$ for $X < \omega_{\max}$ and $F_{comp} = 0$ for $X > \omega_{\max}$. Constant b is a free parameter due to strong energy dependence from the absorption coefficient.
- The Compton spectrum is convoluted with the detector resolution function. The Gaussian width σ_{edge} is mostly coupled with the beam energy spread.
- A smooth background, produced by a Single Bremsstrahlung is $F_{BG} = c + d(\omega_{\max}^{-1} - X^{-1})$.

It was found later that systematic errors for σ_{edge} are too large if we suppose the detector resolution function as the Gaussian. The fitted value for σ_{edge} was strongly dependent on the fitting range and the shift of σ_{edge} due to the upper limit variation was larger than the statistical error of this variable (Fig. 4, opened dots). Because of that the fitting function was modified in the following way:

- The additional term $e \cdot (X - \omega_{\max})^2$ for the Compton spectrum was added.
- The long exponential «tail» of $\lambda \cong 100$ keV f or the detector resolution function was added. The 8th free parameter is a fraction of the tail, which is proportional to the total rate of the detected γ's.

The modified fitting procedure became more stable (Fig. 4, black dots). The quality of the fit is controlled with the χ criterion.

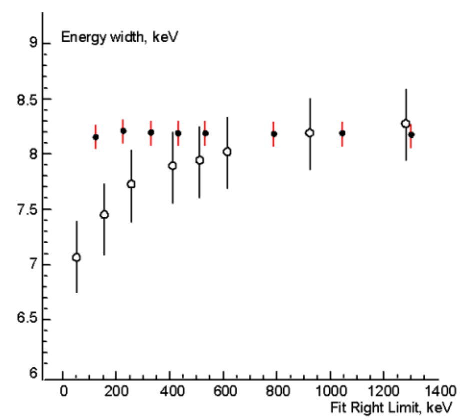

Figure 4: The variation of the fitted σ_{edge} for 6-parameter function (opened dots) and 8-parameter function (black dots). Error bars of the first plot are statistical. Error bars of the second plot illustrate the systematical error.

ACCURACY OF SPREAD MEASUREMENTS

The beam energy spread is $\sigma_E = \dfrac{\sqrt{\sigma_{edge}^2 - \sigma_{HRGe}^2}}{2\omega_{\max}} E$, where the detector resolution σ_{HPGe} is extrapolated from the calibration (Fig. 3). The error of the beam energy spread is determined by the following reasons:

- Statistical error for spectrum without background is $\sqrt{\dfrac{2\sigma_{edge} \cdot Bin}{a}}$ and provides about 5% of relative accuracy for collection time about one hour, *Bin* is an energy width of the detector channel.

- The extrapolation of detector resolution to ω_{edge} provides the uncertainty of 2-3% depending on extrapolation function.
- The detector resolution function is non-Gaussian and depends on the counting rate. The shift of σ_E with a big detector load can reach 10-15%.

Figure 5 represents the averaged data of the beam energy spread collected during a period of about few weeks.

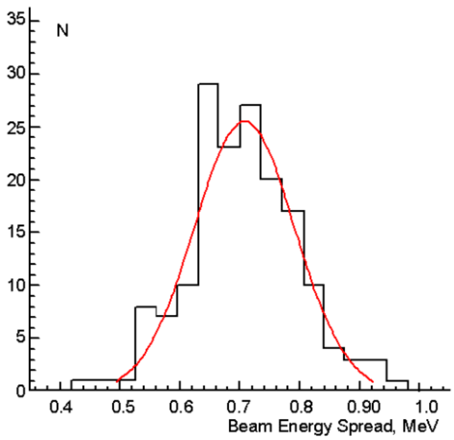

Figure 5: The averaged CBS data of the beam energy spread. E = 1845± 10 MeV. The data derived from ψ' meson scan are $\sigma_E = 0.71 \pm 0.03$ MeV. CBS data are $\sigma_E = 0.71 \pm 0.08$ MeV. The improved fitting procedure was applied.

EXPERIMENT

The improved fit was tested during special experiments. Previously, the beam energy spread was measured with three independent diagnostics simultaneously [4, 5] with the accelerator current reduced to 0.1 – 0.2 mA. In this paper we describe the prolongation of this experiments. Again, beam energy spread was determined with CBS (*I*), the method of the envelope of betatron oscillations (*II*), and with beam length measurement (*III*). Besides it, numerical simulation of the energy spread was performed. The combined data of the diagnostics and the simulation results are presented in Fig. 6a, b.

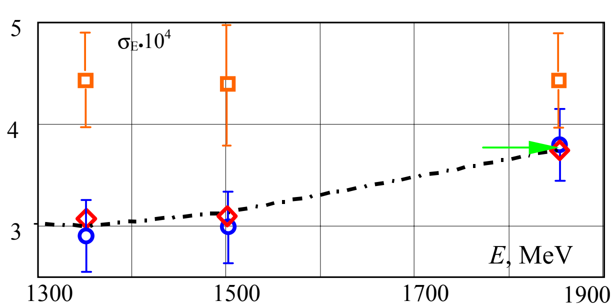

Figure 6a: Variation of the beam energy spread depending on the beam energy. - CBS data; - method (*II*) data; - method (*III*) data; - simulation results. An arrow shows the data of KEDR.

The beam energy spread was varied in two ways: the accelerator energy changed between 1350 MeV and 1852 MeV or the wiggler current changed from 0 to 2000 A.

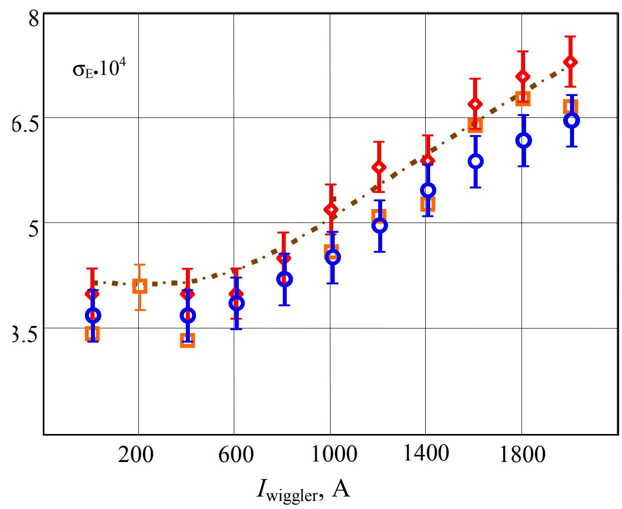

Figure 6b: The beam energy spread depending on the wiggler current. E_0 = 1852 MeV, the same symbols.

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, the fit of CBS data was improved in comparison with the previous version. Nevertheless, for the small beam energy spread the systematic error of CBS exceeds 10-15%. The detailed knowledge of the detector instrumental function is necessary. The study of the systematic errors is continued.

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