FAST AND PRECISE BEAM ENERGY MONITOR BASED ON THE COMPTON BACKSCATTERING AT THE VEPP-4M COLLIDER

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Abstract

Accurate knowledge of the colliding beam energies is essential for the current experiments with the KEDR [1] detector at the VEPP-4M collider. Now the experimental activity is focused on the new precise measurement of the τ-lepton mass by studying the behavior of the τ production cross-section near the reaction threshold. To achieve the desired quality of the experiment, an on-line beam energy monitoring by the Compton backscattering of laser light was performed. This approach is found to be a very good supplement to rare energy calibrations by the resonant depolarization technique, saving the beam time for luminosity runs. The method itself does not require electron beam polarization and additionally allows one to measure the electron beam energy spread. The achieved accuracy of the method in the beam energy range ε=1.7–1.9 GeV is $\Delta\varepsilon = 60$ keV.

INTRODUCTION

Compton scattering basics

The kinematics of Compton scattering is given by the four-momenta conservation:

$$p + k_0 = p' + k \,, \tag{1}$$

where $p = (\varepsilon, \vec{p})$ and $k_0 = (\omega_0, \vec{k_0})$ — four-momenta of the electron and photon before interaction, and $p' = (\varepsilon', \vec{p'})$ $k = (\omega, \vec{k})$ — after interaction. In relativistic case when $\varepsilon \gg m \gg \omega_0$ the scattered photons form a narrow cone along the initial electron momenta. This particular case is named inverse Compton scattering. For head-on collision the maximal energy of back-scattered photon is given by:

$$\omega_{max} = \frac{\varepsilon^2}{(\varepsilon + m^2/4\omega_0)} \,. \tag{2}$$

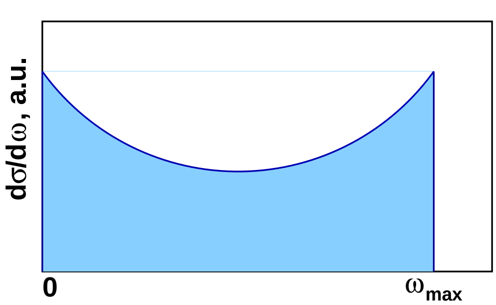

Figure 1: Energy spectrum of scattered photons

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The photons with maximal energy ω_{max} form a sharp edge in the energy spectrum, illustrated by Figure 1. In that way one can obtain the absolute value of the electron energy ε by measuring ω_{max}:

$$\varepsilon = \frac{\omega_{max}}{2}\left(1 + \sqrt{1 + \frac{m^2}{\omega_0 \omega_{max}}}\right) \tag{3}$$

The measurement accuracy is limited by the knowledge of the electron rest mass and initial photon energy. In practice the electron beam energy measurement is based on inverse Compton scattering of laser radiation with well-known energy.

Resonant spin depolarization technique

At the VEPP-4M collider an extremely precise measurement of the beam energy is performed by resonant spin depolarization technique (RDP) [3]. This technique provides an accuracy about 5-7 keV for the instant average beam energy value, but requires a special regime of collider and consumes about 1.5 – 2 hours to obtain polarized beam from the VEPP-3 booster ring. Moreover, various resonance effects in spin dynamics lead to very small beam polarization lifetime at some particular energy regions, one of those is very close to the τ-lepton production threshold.

EXPERIMENTAL SETUP

The design parameters of the Compton beam energy monitor at the VEPP-4M collider were based on the experimental demand to control the beam energy with absolute accuracy $\Delta\varepsilon/\varepsilon \simeq 5 \cdot 10^{-5}$ in the beam energy range 1.5 – 2.0 GeV. The following items were realized to fulfill these requirements:

- The carbon dioxide laser line 10P20 with wavelength $\lambda = 10.591035\mu$m and photon energy $\omega_0 = 0.11706522$ eV was chosen in order to have ω_{max} in the 4 – 7 MeV energy range.
- The High Purity Germanium (HPGe) detector with ultimate energy resolution was found to be the best calorimeter for measuring the energy spectrum of backscattered photons.
- Precise calibration of the HPGe detector absolute energy scale is possible due to well-known radioactive sources of γ-radiation in a few MeV energy range.

These approach was first realized experimentally at the BESSY-I and BESSY-II synchrotron radiation facilities [2].

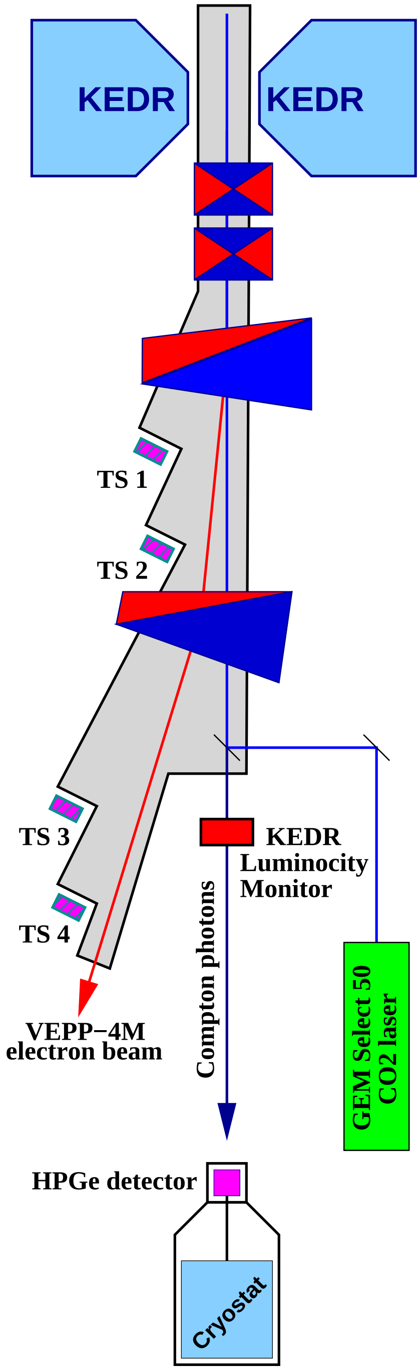

Figure 2: Experimental setup

The experiment layout is shown on Figure 2. Carbon dioxide laser GEM Select 50 by COHERENT Inc. is used as a source of photons. The average energy of laser photons could be treated as constant mentioned above at the level of $\Delta\omega_0/\omega_0 \simeq 10^{-8}$. The 25 to 50 W CW power laser radiation goes inside the VEPP-4M vacuum chamber through the system of mirrors, zooming telescope and input window made from ZnSe crystals. It interacts with the electron beam in the long straight section of the VEPP-4M collider, and backscattered high-energy photons go back and hit the HPGe detector (Canberra model GC2518 has 120 cm^3 active volume). The efficiency of total energy absorption in the detector is about 5% for 6 MeV photons.

Measurement procedure

During 2005-2006 VEPP-4M - KEDR experiment the Compton beam energy monitor was operating continuously. The calibration γ-sources (^{60}Co, ^{137}Cs, ^{24}Na, ^{228}Ac) were placed around the HPGe detector giving the counting rate about 1 KHz. The average counting rate of backscattered Compton photons was about 10 kHz. The detector was set to gather the photon spectra with about 5 million counts. As a result, each spectrum provides an information about the detector energy scale, Compton spectrum edge position and width. Data acquisition time for one spectrum was 5 – 30 min. The typical spectrum example is shown on Figure 3.

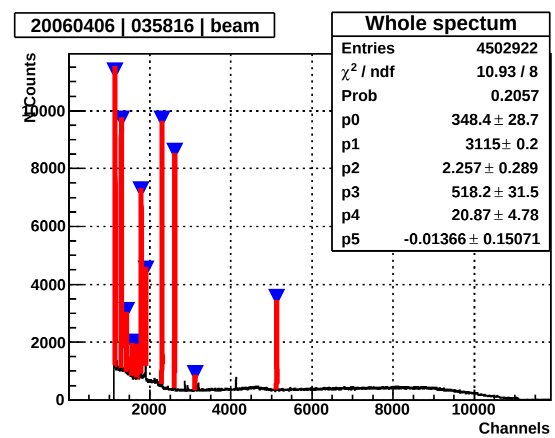

Figure 3: Experimental spectrum of backscattered photons with calibration lines

The energy scale and resolution of the detector is controlled by calibration peak positions and widths, the last one is shown on Figure 4:

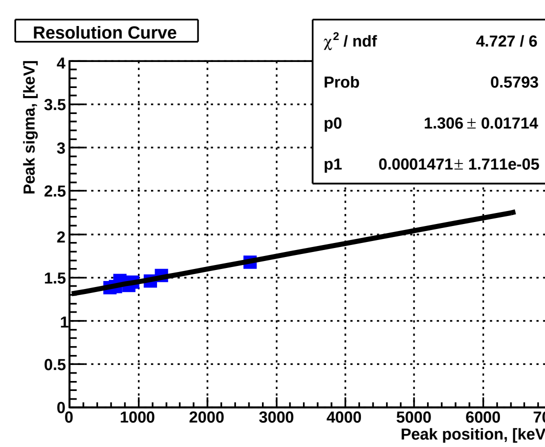

Figure 4: Detector energy resolution

The edge of the Compton spectrum is fitted by the six-parameter function:

$$g(x, p_{0\ldots5}) = \frac{1}{2}\left(p_2(x-p_0)+p_3\right)\cdot \mathrm{erfc}\left[\frac{x-p_0}{\sqrt{2}p_1}\right] - \\ -\frac{p_1 p_2}{\sqrt{2\pi}}\cdot \exp\left[-\frac{(x-p_0)^2}{2p_1^2}\right] + p_4(x-p_0)+p_5\ , \quad (4)$$

where the parameters are: p_0 – edge position; p_1 – edge width; p_2 – slope left; p_3 – edge amplitude; p_4 – slope right; p_5 – background. The p_0 parameter gives an information about the average electron beam energy during the data acquisition period, while p_1 is mostly coupled with the electron beam energy spread. The edge of the Compton spectrum of backscattered photons together with fit results is shown on Figure 5:

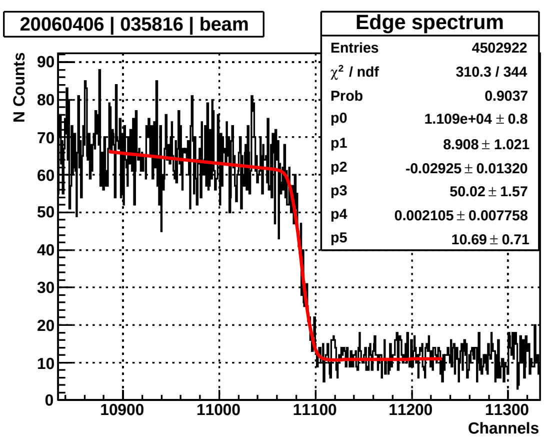

Figure 5: Spectrum fragment near ω_{max}

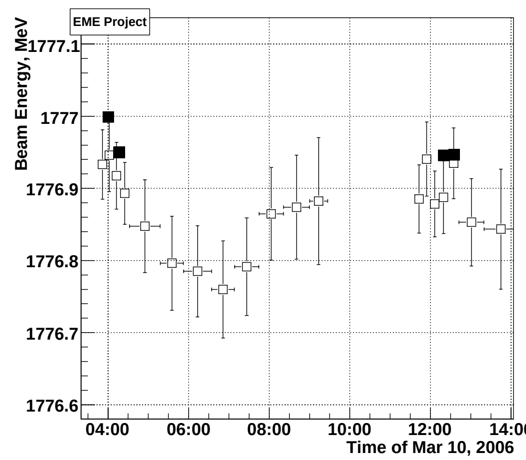

Figure 6: Beam energy vs time. Filled squares are obtained by RDP, empty squares by Compton energy monitor

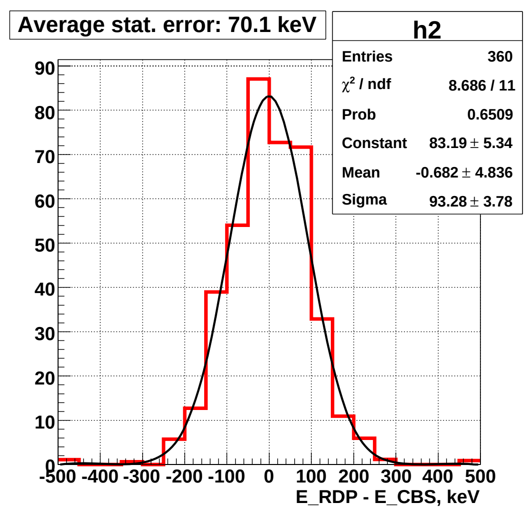

Figure 7: Accuracy check with RDP

RESULTS

The results of each energy measurement are available for on-line representation, and Figure 6 shows an example of the beam energy behaviour vs time. One can see the presence of beam energy drift after change of the accelerator guide field which is about 30 keV/hour.

The total amount of beam energy measurements by Compton backscattering is about 6000 for the period from June 2005 to June 2006. The absolute accuracy of the system was checked by comparison of its results with the RDP technique, at the moments when both measurements were done simultaneously. The histogram on Figure 7 shows the difference between RDP and Compton energy measurements in the beam energy range 1.7 — 1.9 GeV.

The excess of the histogram sigma over average statistical error in beam energy determination indicates a presence of systematical error with a value about 60 keV. The analysis of its sources is still continue.

CONCLUSION

The VEPP-4M electron beam energy monitor, based on inverse Compton scattering of laser radiation, allows to measure the energy with 90 keV error per one measurement in the energy range ε = 1.7 – 1.9 GeV. The overall accuracy of the method is $\Delta\varepsilon = 60$ keV, or $\Delta\varepsilon/\varepsilon \simeq 3\cdot 10^{-5}$ for the mentioned energy range.

REFERENCES

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