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Beam energy measurement system at BEPCⅡ *

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Abstract The beam energy measurement system at BEPCII is composed of there parts: laser source and optics system, laser-electron interaction system and High Purity Germanium (HPGe) detector system. The special components and construction of each part are introduced, especially about radiation background measurement in the storage ring, which is of great importance for the safe commissioning of HPGe detector.

Key words energy measurement, laser, electron, HPGe detector

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1 Introduction

The luminosity of 3×10^{32} cm^{-2} s^{-1} accessed at BEPCII on May, 2009, which is the highest luminosity in τ-charm energy region ever existed. The 100 M ψ′ and 200 M J/ψ data have been collected by BESⅢ [1], even more colossal data are to be collected in the forthcoming years, unprecedented statistical precision will be achieved in data analysis, hence many systematic factors and effects have to be considered seriously in order to obtain comparable correctness with precision. As pointed out in Ref. [2] the uncertainty of the beam energy plays an important role for BESⅢ physics analyses in many aspects. First of all, the detailed Monte Carlo simulation indicates [3, 4] that the uncertainty due to the beam energy will be bottleneck issue for the accuracy improvement of τ mass measurement. Secondly, such kind of uncertainty is the crucial part for the further high accurate measurement of resonance parameters at BESⅢ. Last, the small systematic uncertainty of the beam energy is also an independent factor for the improvement of branching ratio measurement aiming at the accuracy of 1%∼2%.

Therefore, based on Compton backscattering principle the beam energy measurement system is designed [5, 6] and being constructed at the north crossing point (NCP) of the BEPCⅡ [7].

The schematic plot of the beam energy measurement system is shown in Fig. 1, whose working principle can be recapitulated as follows [8]: first, the laser source provides the laser beam which will pass through an optics system. The optics system focus the laser beam and help it go into the storage ring, then the laser and electron beams make a head-on collision in the vacuum tube, after that the backscattering high energy photon or γ-ray will be detected by High Purity Germanium (HPGe) detector.

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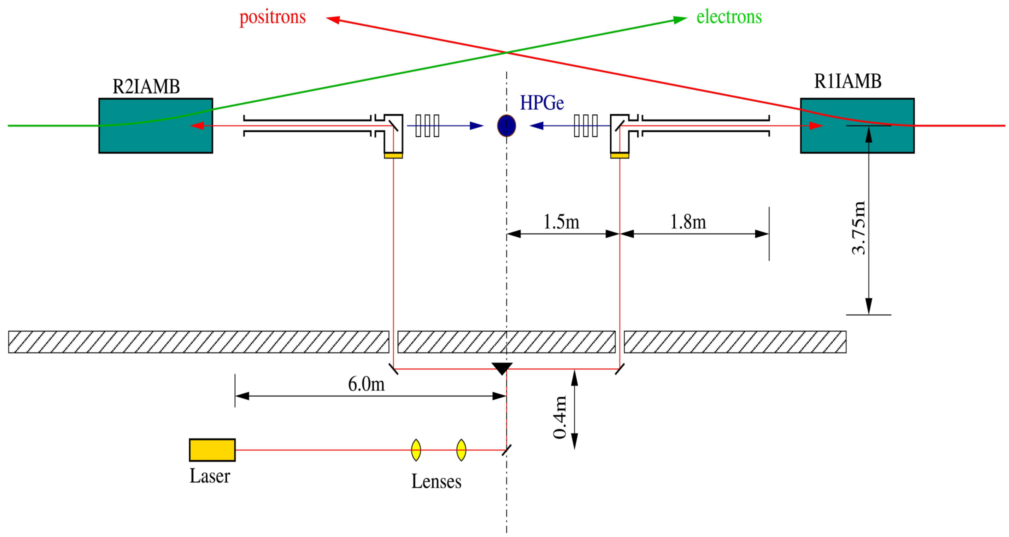


Fig. 1. Simplified schematic of the beam energy measurement system. The positron and electron beams are indicated. R1IAMB and R2IAMB are accelerator magnets, and the HPGe detector is represented by the dot at the center. The half-meter shielding wall of the beam tunnel is shown cross-hatched. The laser and optics system will be located outside the tunnel, where the optics system are composed of two lenses, few reflectors and one prism denoted by the inverted solid triangle.

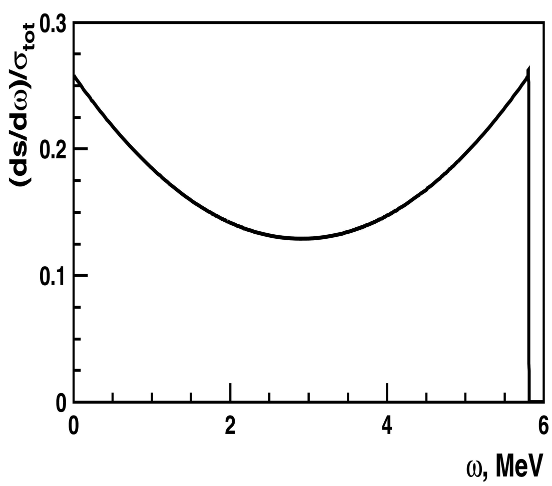


Fig. 2. Energy spectrum of backscattered Compton photons.

The great merit of such a process consists in two aspects: firstly, there is a sharp Compton edge as displayed in Fig. 2, which can be measured with fairly high accuracy by HPGe detector. Secondly, as indicated by the formula [9, 10]

$$E_{\rm e}=\frac{E_{\gamma}}{2}\left[1+\sqrt{1+\frac{m_{\rm e}^2}{\epsilon_{\gamma}E_{\gamma}}}\right] , \qquad (1)$$

there exists analytical relation between the energies of laser beam (ϵ_{γ}), electron beam ($E_{\rm e}$), and backscattering γ-ray (E_{γ}). Since energy of the laser beam (ϵ_{γ}) and electron mass ($m_{\rm e}$) are determined with the accuracy at the level of 10^{-8}, utilizing Eq. (1), $E_{\rm e}$ can be determined as accurate as E_{γ}, the accuracy of which is at the level of 10^{-5}.

For clearness of the following description, the whole system is subdivided into three parts according to their technique and engineering characters:

1) Laser source and optics system;

2) Interaction part where the laser beam collides with the electron or positron beam;

3) HPGe detector with related electronics to measur backscattering high energy γ-rays.

Besides, two personal computers are connected to build the data acquisition system for information processing and analyzing.

2 Laser and optics system

As a source of photons a continuous wave (CW) operation, high power, and single-line narrow-width laser is required. An excellent candidate is the GEM Selected 50$^{\rm TM}$ CO_2 laser from Coherent Inc [11]. It is compact, lightweight, with outstanding beam quality and stability, and accommodates ultra-stable frequency and amplitude output. It provides variable CW power and tunable wavelength.

A CO_2 laser can radiate photons spontaneously from several lines simultaneously. The width of a line is formed by Doppler and collision widening, resulting in about 100 MHz bandwidth ($\Delta\nu/\nu \simeq 3$ ppm). Averaging the radiation wavelength over longitudinal cavity modes yields average laser photon energy stability at the level of $\Delta\nu/\nu < 0.1$ ppm. Thus the single-line CO_2 laser is an excellent radiation source for the energy measurement system.

One of GEM Selected 50^{TM} lasers is used in the energy measurement system at the VEPP-4M collider in Novosibirsk since 2005 [12, 13]. During this period no degradation of its parameters was noticed.

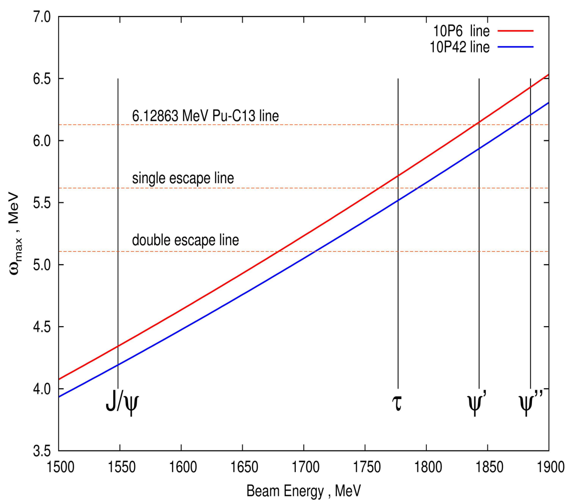


Fig. 3. The relation between beam energy and energy of backscattering Compton photons. Also shown are calibration energy lines due to Pu-C source.

For the system at BEPCII, in order to avoid any interference between calibration lines and the Compton edges of all interesting beam energy points in τ-charm energy region (refer to Fig. 3), the laser line 10P42 with wavelength $\lambda = 10.835$ μm (corresponding to laser energy $\epsilon_\gamma = 0.1144$ eV) is adopted.

By the end of December of 2009, from University of Hawaii, USA, transported to IHEP are all the laser-related equipments which include Coherent GEM select 50^{TM} CO_2 laser, Lytron Kodiak Recirculating Chiller (60 Hz), D600L RF Power Supply, and Agilent 6573 A DC Power Supply (2000 W).

The optical system was deployed at BEPCII in May, 2008. The following optical units are situated along the outside of the collider tunnel wall:

1) Two lenses with focal length 40 cm and aluminium supports;

2) A movable reflector prism which allows the laser beam to be directed towards the electron or positron beam pipe;

3) Two mirrors to reflect the right- or left-traveling laser beam into the beam tunnel. The mirrors are installed on special supports that allow precise vertical and horizontal angular alignment by the using of stepping motors (one step equals to 1.5×10^{-6} rad).

The total distance from the laser output aperture to the vacuum chamber window is about 18 m where the laser beam waist is around 2 ∼ 2.5 mm. The lenses should be placed 300 and 381.6 cm from the laser in order to provide this size.

3 Interaction part

In order to let laser beam go into vacuum tube, the previous vacuum chambers in the dipole magnets R1IAMB and R2IAMB (refer to Fig. 1) must be reformed. The entrance window at each new chamber with dimension 50 mm (horizontal) ×14 mm (vertical) is opened for laser beam. The reformed vacuum chamber is connected with the laser-to-vacuum insertion part [16], which is mainly composed of two chambers, the long one and the short one, as shown in Fig. 4. The long one is connected with the reformed vacuum chamber while the short one contains the reflector made of copper (viz. copper mirror). The laser beam is reflected through an angle of 90° by the copper mirror which is mounted with a good thermal contact on the massive copper support. This support can be tuned by bending the vacuum flexible bellow, so the angle between the mirror and the laser beam can be adjusted as necessary.

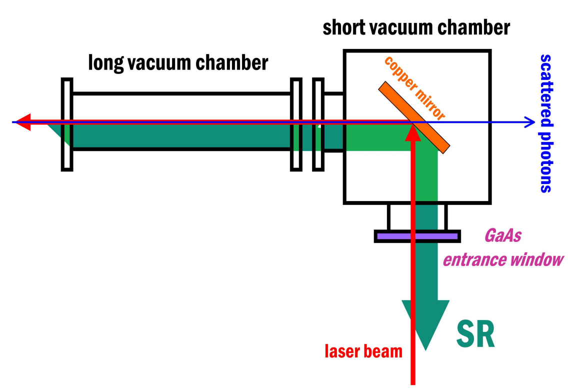


Fig. 4. Schematic plot of laser-to-vacuum insertion part.

The synchrotron radiation (SR) photons also fall on the mirror and heat it. In order to reduce the heating of the mirror, it is placed 1.8 m from the flange sandwiched between the long chamber and the reformed vacuum chamber. The SR power absorbed by the mirror approximately equal to 200 Watts. The extraction of heat will be provided by the water cooling system of BEPCII.

Here, especially attention should be paid for the material of the entrance window at the short chamber of the insertion part. This window must be transparent for laser light and transmissive for SR light, which is crucial for monitoring the laser beam and for aligning the optics system. After many tests, gallium arsenide is finally chosen as the material of the window.

The installation of the reformed chamber and insertion part is finished in September, 2009. After baking up to 180° centigrade, the vacuum accesses to $1.5\sim4.5\times10^{-10}$ mbar, which is at the same level of that of the vacuum tube at NCP.

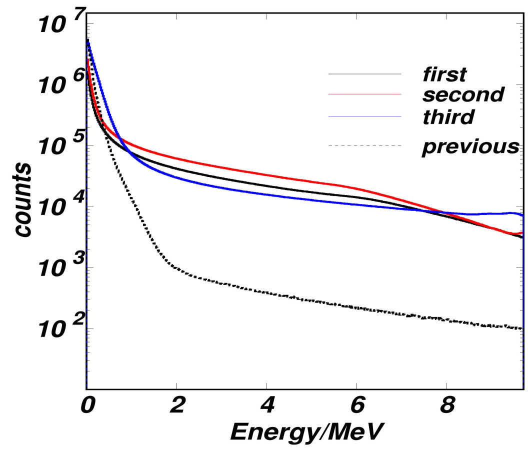
4 Detector system and radiation background

The most suitable HPGe detector for photon energy around 1 ∼10 MeV is the coaxial type detector. As far as BEPCⅡ energy measurement system is concerned, the coaxial HPGe detector manufactured by ORTEC (model GEM25P4-70) was chosen. It has diameter of 57.8 mm and height 52.7 mm with 31.2% relative efficiency at 1.33 MeV. The energy resolution for the 1.33 MeV line of ^{60}Co is 1.74 keV. The detector is connected to the spectrometric station, which transfers data using the USB port of the computer.

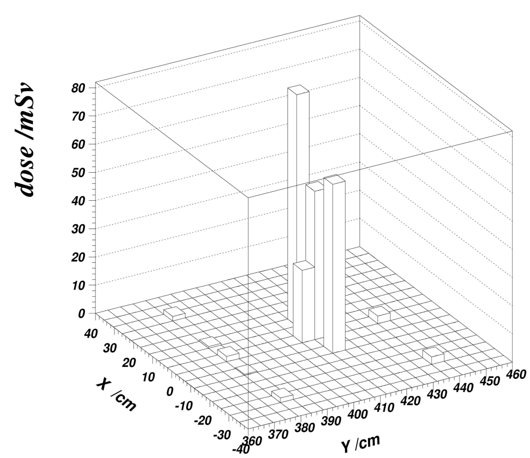
Unlike other systems where the HPGe detector is usually protected by radiation shielding wall [17, 18], the detector used at BEPCII has to be located near the vacuum tubes of the electron and positron beams in the storage ring tunnel. The irradiation field will definitely affect the proper performance of HPGe, one kind of high sensitive materials. Therefore, it is of paramount importance to measure the radiation dose at and around the position where the detector will be located.

Firstly, constructed is the NaI(Tl) detector, which is similar to an ordinary HPGe detector in detection efficiency of γ-rays. This γ-spectrometer system was consisted of the NaI(Tl) crystal (ϕ45 mm×40 mm), photomultiplier GDB50, and 8192 MCA, of which, the energy resolution is FWHM=9.5% for ^{137}Cs 662 keV γ-ray and the peak/valley ≈ 3:1 for ^{60}Co 1.33 MeV γ-ray, respectively. The γ background detection is carried on for 17 months (begin from February, 2008 to July, 2009). Some typical results are presented in Fig. 5 (a).

Besides, neutron background is also measured through IZ-type dosimeters[1)] accommodated by Landauer® incorporated company [19]. The energies detected by SSNTD ranges from 40 keV to 40 MeV for fast neutron and the corresponding measured dose are from 0.2 mSv to 250 mSv. Shown in Fig. 5 (b) is the measured dose distribution of neutron in the vicinity of the position where the HPGe detector will be located.



(a) results from NaI detector for photons



(b) results from dosimeters for neutrons

Fig. 5. Some typical results of radiation background measurement for photons by NaI(Tl) detector (a) and neutrons by IZ-type dosimeters (b). The details of measurement can be found in Refs. [14] and [15].

The analysis results indicate that the radiation shielding is needed in order to guarantee that the HPGe detector works without severe damage. Now

1)In fact, IZ-type dosimeter is composed of two types of probes: one is the optically stimulated luminescence detector (OSLD) [20, 21] made of carbon-doped aluminum oxide (Al_2O_3: C) which is mainly used for γ, β and X-ray detection, while the other is the solid state nuclear track detector (SSNTD) [22–24] made of allyl diglycol carbonate ($C_{12}H_{18}O_7$), shorten as CR-39 which is mainly used for neutron detection.

the table-like support for the detector has been manufactured to ensure the placement of shielding materials.

5 Work process and DAQ System

In the light of Fig. 1, the work process of the whole system is depicted as follows: the laser beam provided by Coherent GEM select 50^{TM} CO_2 laser, is focused by a doublet of lenses, reflected through an angle of 90° by a 45° mirror, and reflected either to light or right by means of a movable prism (denoted by the inverted triangle in Fig. 1). The beam is again reflected by 90° through a hole in the concrete wall of the beam tunnel and then incident on the GaAs window of the insertion part. The incident beam is reflected 90° by the copper mirror and focused at the flange sandwiched between the long chamber of insertion part and the reformed vacuum chamber of BEPCII storage ring. The incident laser beam and eletron/positron beam will interact in the straight region upstream the R1IAMB (for positron) or R2IAMB (for electron) bending magnet. The backscattering photons return to the mirror, pass through it, leave the chamber of the insertion part, and are detected by the HPGe detector (denoted by the dot in Fig. 1).

The processes that follows will be executed by data acquisition (DAQ) system as shown schematically in Fig. 6. This system is composed of multichannel analyzer (MCA), computer under control of Windows XP and computer under control of Ubuntu Linux OS [25]. The Windows computer transfers the control over MCA to the Linux-operated computer which responds for the overall control of all DAQ system. Three groups of software are prepared for the system running:

1) Data acquisition

(a) "Counter" is a Window program for spectra acquisition, which works on VirtualBox (one kind of virtual machines) installed on the Linux computer.

(b) "Get_statuts" is a program to acquire BEPC-II running parameters relevant to energy measurements system.

(c) "Deflecting_system" is a program for laser aiming, which can be realized manually or automatically.

2) Data processing and monitoring

(a) "Load_monitor", a program for watching online counting rates of HPGe detector;

(b) "SP_view", a program for spectra processing;

(c) "Show_status", a program for plotting BEPC-II parameters when spectra are being acquired.

3) Configuration of DAQ process.

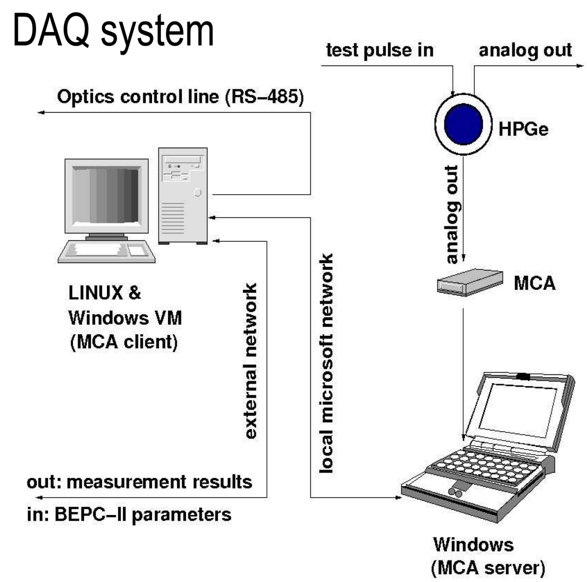


Fig. 6. Data acquision system for beam energy measurement at BEPCⅡ.

6 Conclusion

The completion of the whole energy measurement system is expected at the beginning of the next year (2010), then the preliminary alignment and adjustment will be performed afterwards. The commissioning of the energy measurement system will begin at the second half year of 2010.

As far as the relevant physics studies are concerned, the fine scans for J/ψ, ψ′, and τ mass measurement are planed to be preformed few years later.

References

1 BESIII collaboration. The BESIII Detector. IHEP-BEPCⅡ-SB-13, internal report. January, 2004
2 FU C D, MO X H. China Phys. C, 2008, **32**, 776–780
3 MO X H. Nucl. Phys. B (Proc. Suppl.), 2007, **169**: 132–139
4 WANG Y K et al. Nucl. Instr. Methods A, 2007, **583**: 479–484
5 MO X H. High accuracy energy measurement system for electron in storage ring. Fund application report. 2007
6 Achasov M N et al. BINP preprint 2008-4, 2008; arXiv: 0804.0159
7 Preliminary Design Report of accelerator BEPCII, (Second version, in Chinese; July, 2003) refer to http://acc-center.ihep.ac.cn/bepcii/bepcii.htm
8 MO X H et al. China Phys. C, 2008, **32**: 995–1002
9 Rullhusen P, Artru X, Dhez P. Novel Radiation Sources Using Relativistic Electrons. World Scientific Publishing. 1998
10 Landau L D, Lifshitz E M. Relativistic Quantum Mechanics. Pergamon. 1971
11 Refer to http://www.coherent.com/Lasers
12 Muchnoi N Yu et al. In Proc. of the EPAC, Scotland, Eidenbergh, June 26-30, 2006, EPAC 1181
13 Blinov V E et al. Nucl. Instr. Methods A, 2008, **598**: 23
14 MO X H et al. China Phys. C, 2009, **33**: 914–921
15 MO X H et al. Study of radiation background at the north crossing point of BEPCⅡ, paper in preparation
16 Achasov M N et al. Nucl. Phys. B (Proc. Suppl.), 2009, **189**: 366–370
17 Hsu I C, YU C I. Phys. Rev. E, 1996, **54**: 5657
18 Ohgaki H et al. Nucl. Instr. Methd. A, 2000, **455**: 54–59
19 Refer to http://www.landauerinc.com/
20 Yukihara E G et al. Radiation Meaurement, 2006, **41**: 1126–1135
21 McKeever S W S. Nucl. Instr. Methods B, 2001, **184**: 29–54
22 Amgaron K. Long-term measurements of Indoor Radon and its progeny in the presence of Thoron using nuclear track detectors: a novel approach. Ph.D. thesis. April, 2002
23 Durrani S A, Bull R K. Solid State Nuclear Track Detection. Pergamon Press, Heading Hill Hall. 1987
24 Leo W R. Techniques for nuclear and particle physics experiments. Berlin: Springer-Verlag. 1994
25 Refer to http://releases.ubuntu.com/