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FIRST RESULTS OF ENERGY MEASUREMENTS WITH A COMPACT COMPTON BACKSCATTERING SETUP AT ANKA*

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Abstract

An electron energy measurement setup based on the detection of Compton backscattered photons, generated by laser light scattered off the relativistic electron beam, has been proposed and developed for operation at the ANKA storage ring of the Karlsruhe Institute of Technology (KIT). In contrast to conventional methods based on head-on collisions, the setup at ANKA is, for the first time, realized in a transverse configuration where the laser beam hits the electron beam at an angle of ~90°. This makes it possible to achieve a relatively low-cost and very compact setup since it only requires a small side-port instead of a straight section. This development could benefit storage rings with restricted space or where no straight sections are available, for example due to interferences with existing beamlines. The setup and the first measurement results are presented in the paper.

MOTIVATION

The ANKA storage ring [1] is operated from 0.5 GeV to 2.5 GeV. In the short bunch operation mode, typically at 1.3 and 1.6 GeV, coherent THz synchrotron radiation is generated [2]. Previously, precise energy calibration at 2.5 GeV was successfully achieved by resonant spin depolarization [3]. For lower energies, however, this technique requires very long measurement times. Here Compton Back-Scattering (CBS) is more suitable as it does not require a polarized electron beam. So far, several facilities have reported energy measurements based on CBS using a head-on collision geometry ($\varphi=\pi$) with relative accuracies reaching 10^{-4} to a few 10^{-5} [4-9]. Compared to the traditional CBS method, we have for the first time developed and measured with a transverse configuration ($\varphi=\pi/2$). This setup has several advantages: It is very compact and can therefore also be used at rings with restricted space. Furthermore, the transverse setup reduces the energy of Compton edge photons by a factor of two, which either makes measurements and detector calibration much easier, or enlarges the measurable range of a specific setup considerably. The transverse configuration can in principle also be converted easily into a versatile laser wire diagnostics tool.

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METHOD PRINCIPLE

If monochromatic (laser) photons (energy E_L) scatter off of relativistic electrons (energy E_e), the scattered photons with energy E_s follow the kinematics illustrated in Eq. 1 and Fig. 1, where φ is the collision angle between the incoming laser and the electrons and θ is the scattering angle between the scattered photons and the initial electrons. The electron velocity divided by the speed of light is denoted by β:

$$E_s = \frac{E_L(1-\beta\cos\varphi)}{1-\beta\cos\theta + E_L / E_e[1-\cos(\theta-\varphi)]}. \quad (1)$$

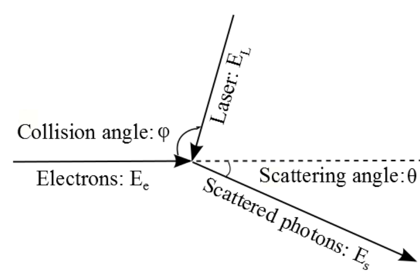

Figure 1: Scheme of CBS.

For $\theta=0$, the energy of the scattered photons reaches its maximum E_{max} and forms a sharp cut-off edge (Compton edge) in the energy spectrum.

For typical CBS measurements at storage rings we have $E_e \gg mc^2 \gg E_L$ (mc^2 is the electron rest energy) and $\varphi>0$. The electron beam energy E_e can then be determined from the known values of mc^2 and E_L, and the measured φ and E_{max} using

$$E_e \approx \frac{mc^2}{2\sin\frac{\phi}{2}}\sqrt{\frac{E_{max}}{E_L}}. \quad (2)$$

Its relative uncertainty can be calculated as

$$\frac{\sigma_{E_e}}{E_e} = \sqrt{[\frac{\sigma_{E_L}}{2E_L}]^2 + [\frac{\sigma_{\phi}}{2\tan(\phi/2)}]^2 + [\frac{\sigma_{E\max}}{2E_{\max}}]^2}. \quad (3)$$

Here σ_{E_L}/E_L is the relative uncertainty of the average laser photon energy.

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The angular deviation σ_φ comes from the drifts and measurement uncertainties of both electron beam and laser beam. For the transverse setup, this term has an impact on energy measurement accuracy [10].

The determination of the relative uncertainty of average E_{max} consists of two parts: systematic uncertainty comes from the energy calibration of the detector; statistical uncertainty is given by fitting the Compton edge.

SETUP AT ANKA

Figure 2 shows the transverse CBS setup for energy measurements currently implemented at ANKA. The interaction point is located at one long straight section. The gamma photons generated by CBS propagate in a narrow cone along the direction of the electron beam. The photons with energy E_{max} are concentrated on the propagation axis. We use a tungsten collimator in front of the detector to collect these photons and reduce the background level.

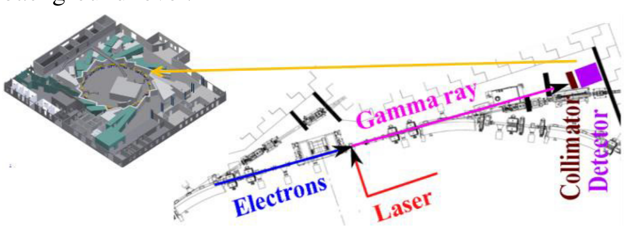

Figure 2: The compact CBS setup for energy measurement at ANKA.

The detector is a High Purity Germanium (HPGe) spectrometer (ORTEC GEM-M5970, nominal relative efficiency 38%), as shown in Fig. 3. Its crystal section is shielded by lead blocks in the experimental environment.

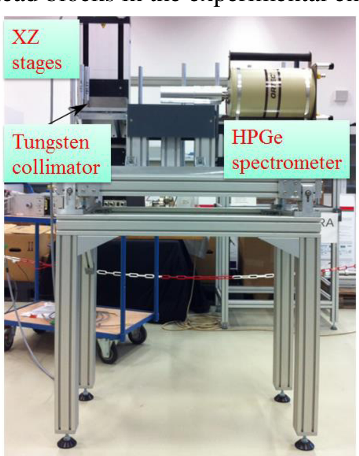

Figure 3: Gamma ray detection system.

As shown in Fig. 4, a monochromatic CO_2 laser, on loan from DLR (λ: 10.2 µm, ~20 W) covers the detectable range of our HPGe. Its frequency is specially stabilized through a PID loop and a Fabry-Perot interferometer to about 10^{-6} (σ_{EL}/E_L). The laser is tightly focused by a cylindrical lens to ~600 µm (4σ) vertically to match the electron beam and maximize the signal rate (Fig. 5). We take advantage of an ion pump port to couple in the laser, therefore it does not require any dedicated section of the storage ring.

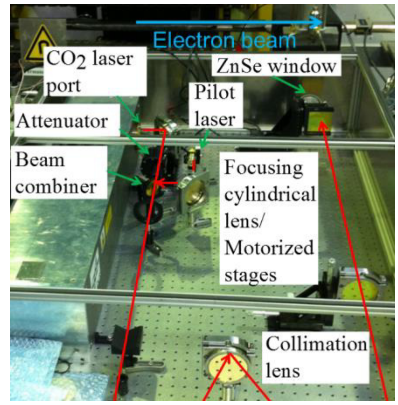

Figure 4: Laser and optical system of the CBS setup.

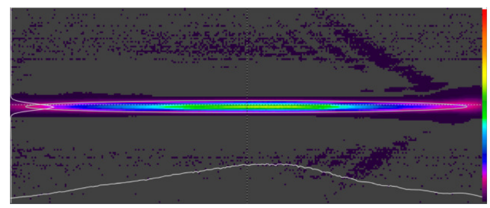

Figure 5: Laser profile at the focal plane with the vertical beam size much smaller than the horizontal one.

MEASUREMENT

Figure 6 shows a typical CBS spectrum with a distinct Compton edge compared to the radiation background. The signal to noise ratio is around 3, which agrees well with the design value [10].

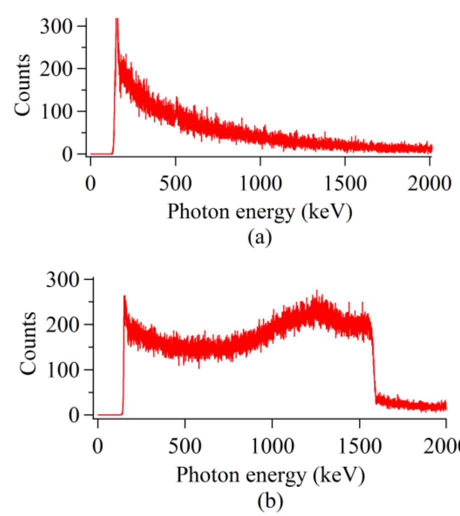

Figure 6: Spectrum at 1.3 GeV for over 120 seconds: (a) radiation background (laser off, e^- beam ~10.7 mA); (b) CBS signal + background (laser on, e^- beam ~9.3 mA).

Collision Angle

We use the mechanical centers of two quadrupoles as a Reference Line (RL) as shown in Fig. 7. We can measure

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the laser direction relative to the RL with a laser tracker (Leica Absolute Tracker AT401) and a camera (Spiricon Pyrocam IV). We also use Beam Position Monitors (BPMs) to monitor the electron orbit orientation relative to the RL. The collision angle φ can then be determined.

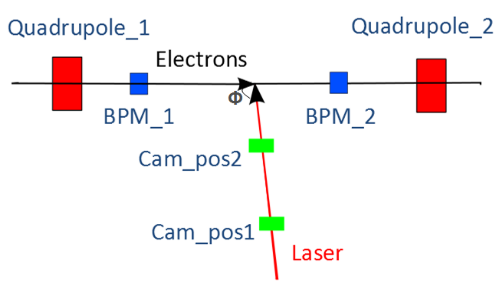

Figure 7: Determination of collision angle.

The main part of φ is between the RL and the vector set by the two camera positions. It is measured as 91.648° with the laser tracker. After consideration of the offset of the beam centroid centers shown in Table 1, the laser direction was determined to 91.630° relative to the RL.

Table 1: Centroid Measurement

	pos1	**pos2**
X center of 10000 samples (µm)	13901	14285
ΔX (4σ) (µm)	557.62	634.64
Distance between pos. 1 and 2 (m)	1.2010	

Since the laser tracker is very accurate (maximum permissible error: ±15 µm + 6 µm/m) compared to the beam centroid stability (ΔX in Table 1), its measurement uncertainty is negligible. If we assume the worst case that ΔX is solely caused by angular drift rather than parallel beam movement, the angular uncertainty of the laser direction can then be determined as 0.18 mrad = 0.010°. So the laser beam is 91.630 ° ± 0.010° relative to the RL.

According to the readings from BPM_1 and BPM_2, the electron beam orientation relative to the RL is -0.17 mrad = -0.010°. The uncertainty of this angle mainly comes from: mismatch between the magnetic and mechanical centers of the quadrupoles < 0.05 mrad; electron orbit drift during measurement < 0.01 mrad; calibration of BPM based on beam based alignment < 0.1 mrad/0.006°.

The collision angle φ is 91.620° ± 0.012°, which gives $\sigma_\varphi/\tan(\varphi/2) = 2.0 \times 10^{-4}$.

Edge Fitting

According to [7] and [9], the Compton edge curve can be fit by a six-parameter function (similar to a complementary error function, erfc) to determine the average value of E_{max}. For Fig.6 (b), the edge fitting gives E_{max} as 1580.44 keV ± 0.28 keV, as shown in Fig. 8. Given that the systematic uncertainty from the detector calibration should be smaller than 10^{-4}, then the statistical uncertainty dominates σ_{Emax}/E_{max}, which is 1.8×10^{-4}.

Preliminary Result

Using mc^2 = 0.5109989 MeV, E_L = 0.1211591 eV and the measured values φ = 91.620°, E_{max} = 1580.44 MeV, we can calculate E_e = 1286.95 MeV using Eq. 2. We can also get $\sigma_{Ee}/E_e = 1.3 \times 10^{-4}$ using Eq. 3. Subsequently, we can determine the energy we measured at 1.3 GeV is $E_e \pm \sigma_{Ee}$= 1287.0 MeV ± 0.2 MeV.

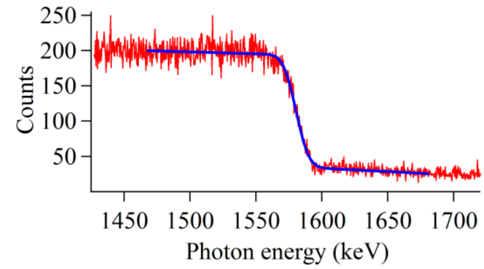

Figure 8: Zoom into Compton edge of Fig. 6 (b) and curve fitting at 1.3 GeV, χ^2/ndf = 524/555.

SUMMARY

Compared to the conventional CBS methods of energy measurement, we have for the first time developed a compact setup based on transverse scheme at ANKA. The signal to noise ratio agrees well with the designed value. Besides the result shown in the paper, measurements around 0.5 GeV, 1.6 GeV and 2.5 GeV also give promising initial results. Furthermore, longer accumulation time has shown the statistical uncertainty of determining E_{max} can be reduced down to a few 10^{-5}. Further studies need to be carried out to improve the deviation of the collision angle.

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REFERENCES

[1] D. Einfeld et al., WPPH094, PAC2001.
[2] A.-S. Müller et al., Beam Dynamics Newsletter 57, ICFA, p. 154, 2012.
[3] A.-S. Müller et al., THPKF022, EPAC2004.
[4] R. Klein et al., Nucl. Instrum. Methods Phys. Res., Sect. A 384, 293 (1997).
[5] R. Klein et al., Nucl. Instrum. Methods Phys. Res., Sect. A 486, 545 (2002).
[6] R. Klein et al., Phys. Rev. ST Accel. Beams 11, 110701 (2008).
[7] V.E. Blinov et al., Nucl. Instrum. Methods Phys. Res., Sect. A 598, 23 (2009).
[8] C. Sun et al., Phys. Rev. ST Accel. Beams 12, 062801 (2009).
[9] J.Y. Zhang et al., Nuclear Physics B Proceedings Supplement 00, 1-11 (2011).
[10] C. Chang et al., IPAC 2014, THPME112.