Beam Energy Measurement by Means of Compton Backscattering

N. Muchnoi[1], H.J. Schreiber[2] and M. Viti[2]*

1- Budker Institute for Nuclear Physics BINP
Novosibirsk 630090, Russian Federation

2- Deutsches Elektronen-Synchrotron DESY
15738 Zeuthen, Germany

A new non-destructive method to measure the beam energy based on Compton backscattering is suggested. In this paper a basic introduction is given with a short discussion on the results. A possible location in the Beam Delivery System is also presented. The apparatus is supposed to perform energy monitoring upstream of the IP complementary to a beam position monitor-based magnetic spectrometer, so that redundant measurements for cross checks are provided.

1 Basic Idea

In this note we will present a short overview on the method of beam energy measurements using Compton backscattering. More details can be found in [1] or [2]. Fig.1 shows the basic idea.

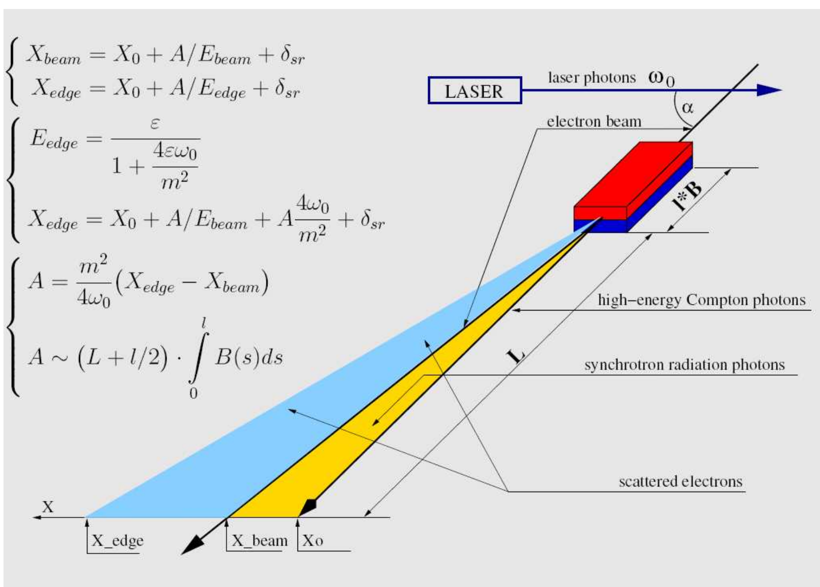

Figure 1: Basic scheme of measuring the beam energy by means of Compton backscattering

*michele.viti@desy.de

After the laser beam collides head-on with the electron/positron beam (actually the crossing angle α is very small), the backscattered photons and the electrons pass a spectrometer magnet. The magnet separates three particle types: the photons which travel undeflected through the magnet, the beam particles which are bent with a small angle of typically 1 mrad and the Compton scattered electrons with larger angles.

After traveling a distance L, the particles hit detectors to record their displacement. In Fig.1, X_{edge}, X_{beam} and X_0 represent the positions of the scattered electrons with minimum energy, the beam electrons and the center-of-gravity of the backscattered photons, respectively. With good approximation we can write the following relation between the X-position of the charged particles at the detector plane and their energy as

$$X = \frac{A}{E} + X_0,$$

where the quantity A is proportional to $(L + l/2) \int Bdl$, with l the length of the magnet, L the distance between magnet and detector and $\int Bdl$ the integrated B-field. From Fig.1 it is clear that

$$X_{edge} - X_{beam} = \frac{4\omega_0}{m_e^2} A,$$

where ω_0 is the laser frequency and m_e the electron mass. This formula is valid if $\int Bdl$ for edge electrons is the same as for beam electrons. We note that $X_{edge} - X_{beam}$ does not depend on the beam energy, a very important aspect of the method.

Finally, the beam energy can be calculated by

$$E_{beam} = \frac{m_e^2}{4\omega_0} \left(\frac{X_{edge} - X_{beam}}{X_{beam} - X_0} \right).$$

The term δ_{sr} in Fig.1 is a small correction due to emission of synchrotron radiation and will be neglected in the following.

Error propagation leads to an uncertainty of the beam energy:

$$\frac{\Delta E_{beam}}{E_{beam}} = \frac{X_{edge}}{X_{edge} - X_{beam}} \left(\frac{\Delta X_{edge}}{X_{edge}} \right) \oplus \frac{X_{edge}}{X_{edge} - X_{beam}} \left(\frac{\Delta X_{beam}}{X_{beam}} \right) \oplus \frac{\Delta X_0}{X_{beam}} .$$

Using the following input parameters

- 50 μm electron beam size in x and y
- 0.15% bunch energy spread
- 250 GeV beam energy
- $\int Bdl = 0.84\ T \cdot m$
- Distance magnet-detector of 25 m
- Accuracy on X_{beam} measurements, $\Delta X_{beam} = 500nm$
- Accuracy on X_0 measurements, $\Delta X_0 = 1\mu m$,

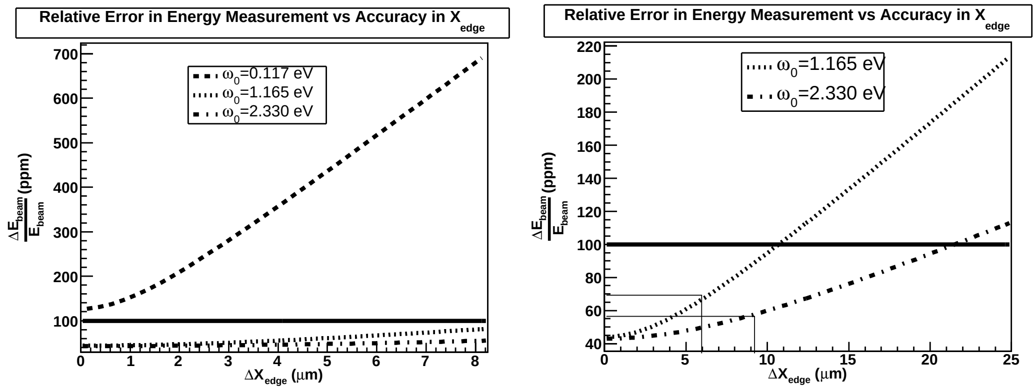

Figure 2: Left: $\frac{\Delta E_{beam}}{E_{beam}}$ as a function of ΔX_{edge} for three laser energies. Right: zoom of the left-hand figure for two laser energies. The horizontal line indicates the precision of 100 ppm (part per million) for the beam energy error.

$\frac{\Delta E_{beam}}{E_{beam}}$ values as a function of ΔX_{edge} for three different laser energies are shown in Fig.2. From this figure it is clear that a laser with short wavelength (in this case a green laser) provides higher sensitivity to beam energy changes.

From these results we draw the following conclusions:

- $X_{edge} - X_{beam}$ does not need to be measured bunch by bunch nor train by train, since this difference depends only on L, l and $\int Bdl$, which are expected to change slowly.
- A green laser is suitable for our purpose.
- Since $X_{edge} - X_{beam}$ is changing slowly we can collect this quantity over many electron bunches within a train, typically 10^3. For $10^3 - 10^4$ Compton scatters per bunch crossing, a total number of 10^6 scattered electrons can be collected which provides enough statistics for precise X_{edge} measurements.
- Once we have measured $X_{edge} - X_{beam}$ in a bunch train, the laser can be turned off for the next one and only X_{beam} and X_0 are measured. X_0 can be deduced from measuring the end points of the synchrotron radiation fan, while X_{beam} from a cavity BPM.

2 Possible Location of the Energy Spectrometer in the Beam Delivery System

According to the conclusions it seems possible to combine the upstream Compton polarimeter with the energy spectrometer proposed. A detailed description of the Compton polarimeter can be found in [3].

Using the same laser and laser-bunch IP and recording the scattered electrons, the backscattered photons and the unscattered beam particles, the basic requirements for the Compton energy spectrometer are fulfilled.

In order to measure the beam polarization the polarization of the laser is flipped (e.g. train by train). This modifies the profile of the spectrum of the scattered electrons/photons: in one case the electron spectrum shows a nice sharp peak, the edge energy, whereas in the other case the spectrum goes to zero when approaching the edge energy. This implies that in the latter case X_{edge} cannot be accessed properly. This is, however, not a problem, since we do not need to measure $X_{edge} - X_{beam}$ for every bunch nor for every train, but only when the correct laser polarization is applied.

3 Conclusions and Outlook

A short introduction to Compton backscattering as a mean for fast bunch-to-bunch energy recording upstream of the IP is given. Some basic results of simulation studies are reported. Finally, first preliminary considerations about the possibility to combine the upstream Compton polarimenter and the energy spectrometer are discussed. However, more detailed studies are needed and they will be presented in a forthcoming note.

References

[1] H.J. Schreiber, N. Muchnoi, M. Viti, "ILC Beam Energy Measurement by means of Laser Compton Backscattering," DESY preprint.

[2] H.J. Schreiber, N. Muchnoi, M. Viti, "ILC Beam Energy Measurement Using Compton Backscattering," Proceedings of the International Linear Collider Workshop, Hamburg, Germany, 28 May-01 June 2007.

[3] K.O. Eyser et al., Proceedings of the International Linear Collider Workshop, Hamburg, Germany, 28 May-01 June 2007.