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Worldwide Study of the Physics and Detectors for Future Linear e^+e^- Colliders
DESY

Compton Backscattering for Beam Energy Measurement: Introduction

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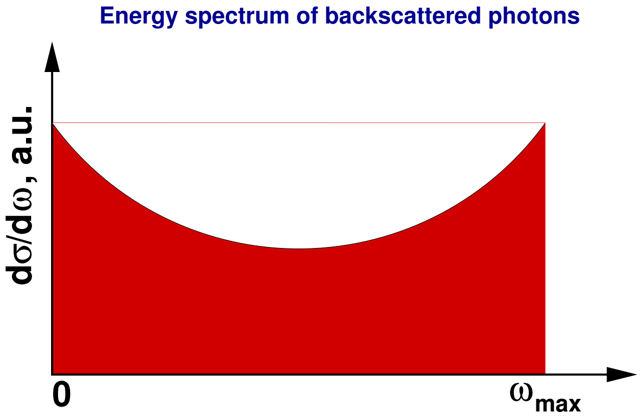
- Compton scattering & low energy experience
- ILC energy range & magnetic spectrometer basic concept
- adding laser to the setup
- Compton cross-section
- achievable statistical accuracy
- energy variation between bunches
- conclusion

Introduction

- The goal of this study was to suggest an independent complementary approach to measure the average bunch energy with accuracy better then 10^{-4}.

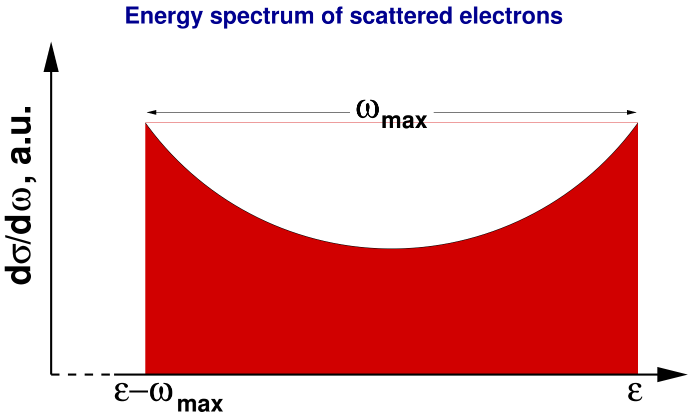
- The goal of this presentation is to introduce the main concepts of laser Compton backscattering application for precise ILC beam energy calibration.

Energy spectra of scattered photons/electrons



edge photons energy:

$$\omega_{max} = \frac{\varepsilon^2}{\varepsilon + \frac{m^2}{4\omega_0}}$$



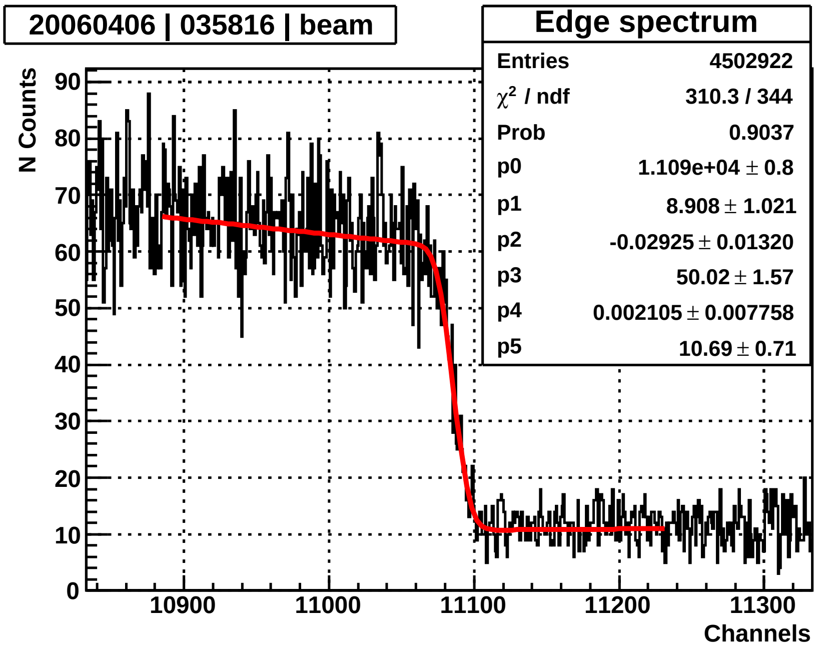
edge electrons energy:

$$E_{edge} \equiv \varepsilon - \omega_{max} = \frac{\varepsilon}{1 + \frac{4\varepsilon\omega_0}{m^2}}$$

▷ Both ω_{max} or E_{edge} could be used to measure the beam energy ε

Low energy experience

- BESSY-I (1997), BESSY-II (2002), VEPP-4M (2005)
- scattered photons are mesured by HPGe detector

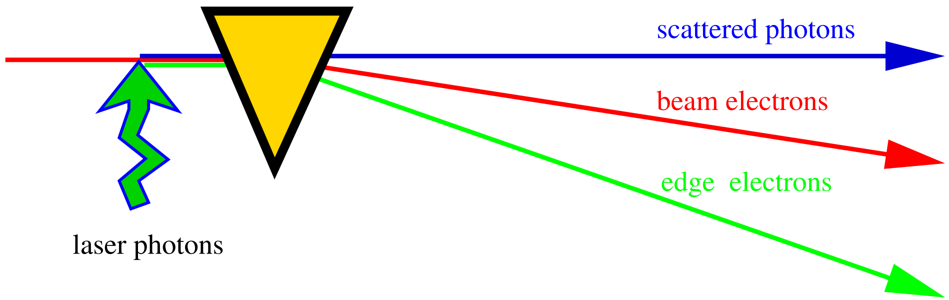


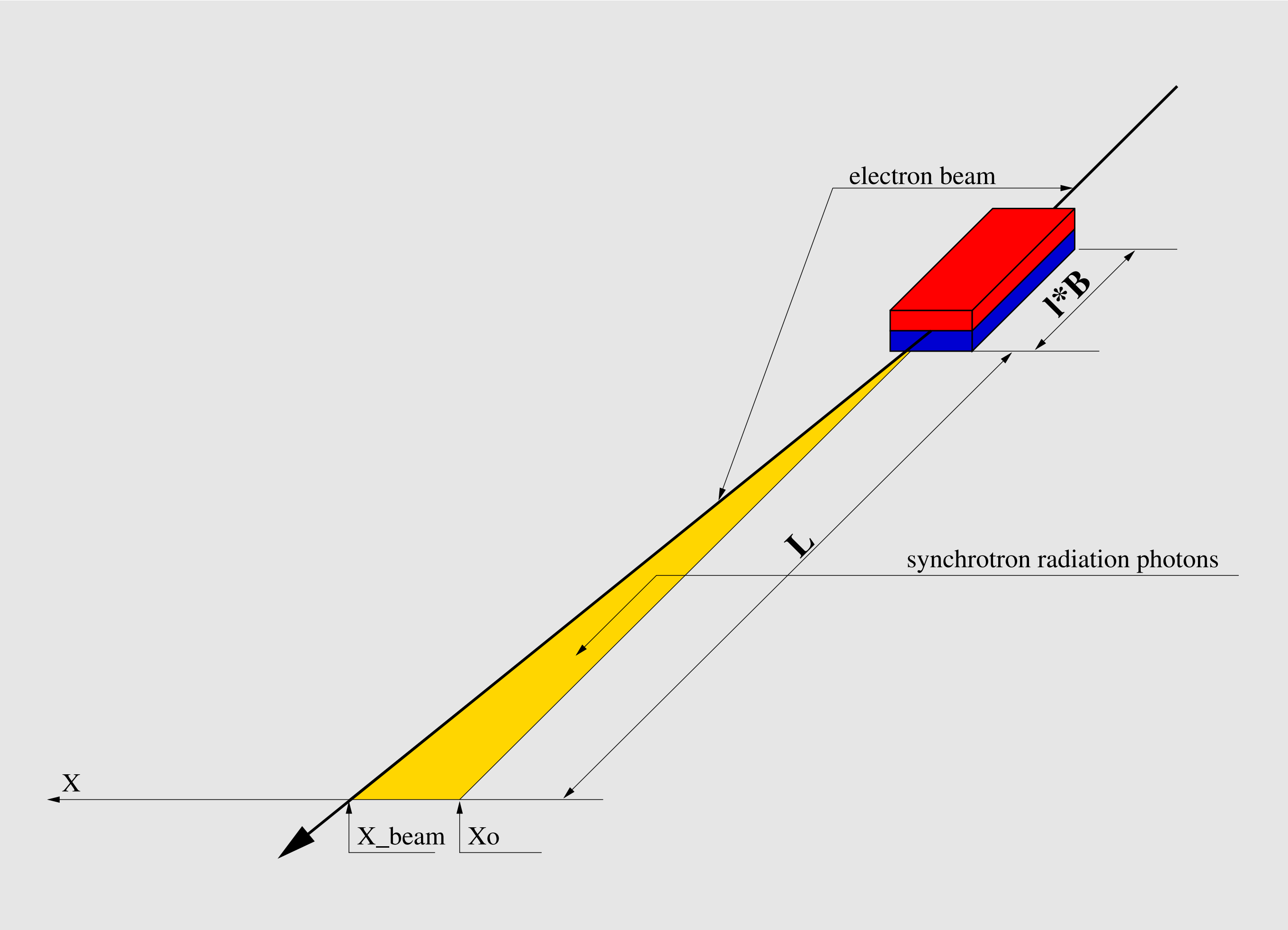
$\varepsilon \simeq 1 \div 2$ GeV; $\omega_0 = 0.117$ eV; $\omega_{max} \lesssim 10$ MeV; $\Delta\varepsilon/\varepsilon \simeq 2 \div 5 \cdot 10^{-5}$

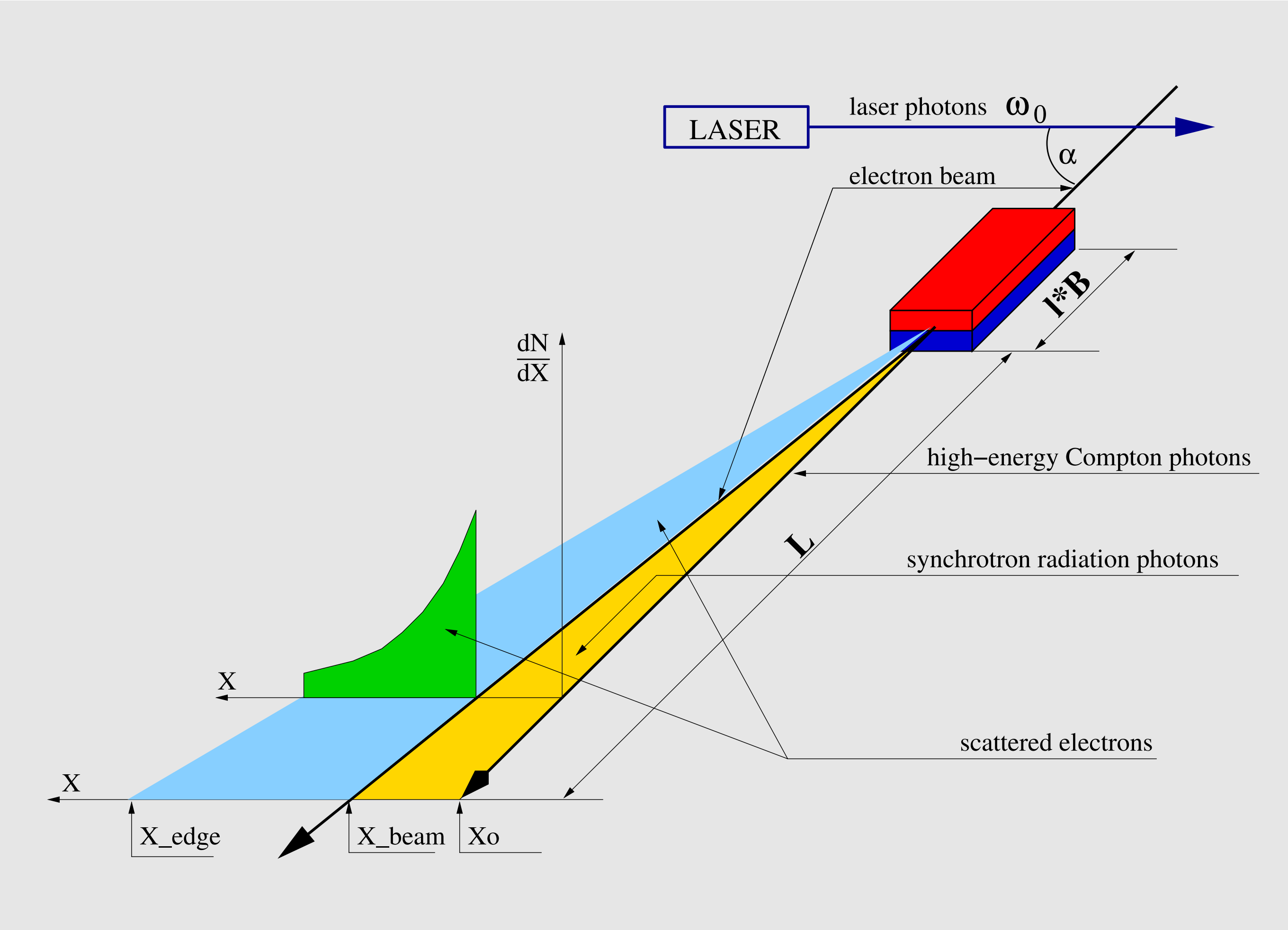
ILC energy range ($\varepsilon = 50 \div 500$ GeV)

- tens–hundreds GeV scattered photons or electrons
- energy of each bunch should be measured in a non-destructive way

That's why we can't use the low energy approach at the ILC, and a new scheme should be suggested:



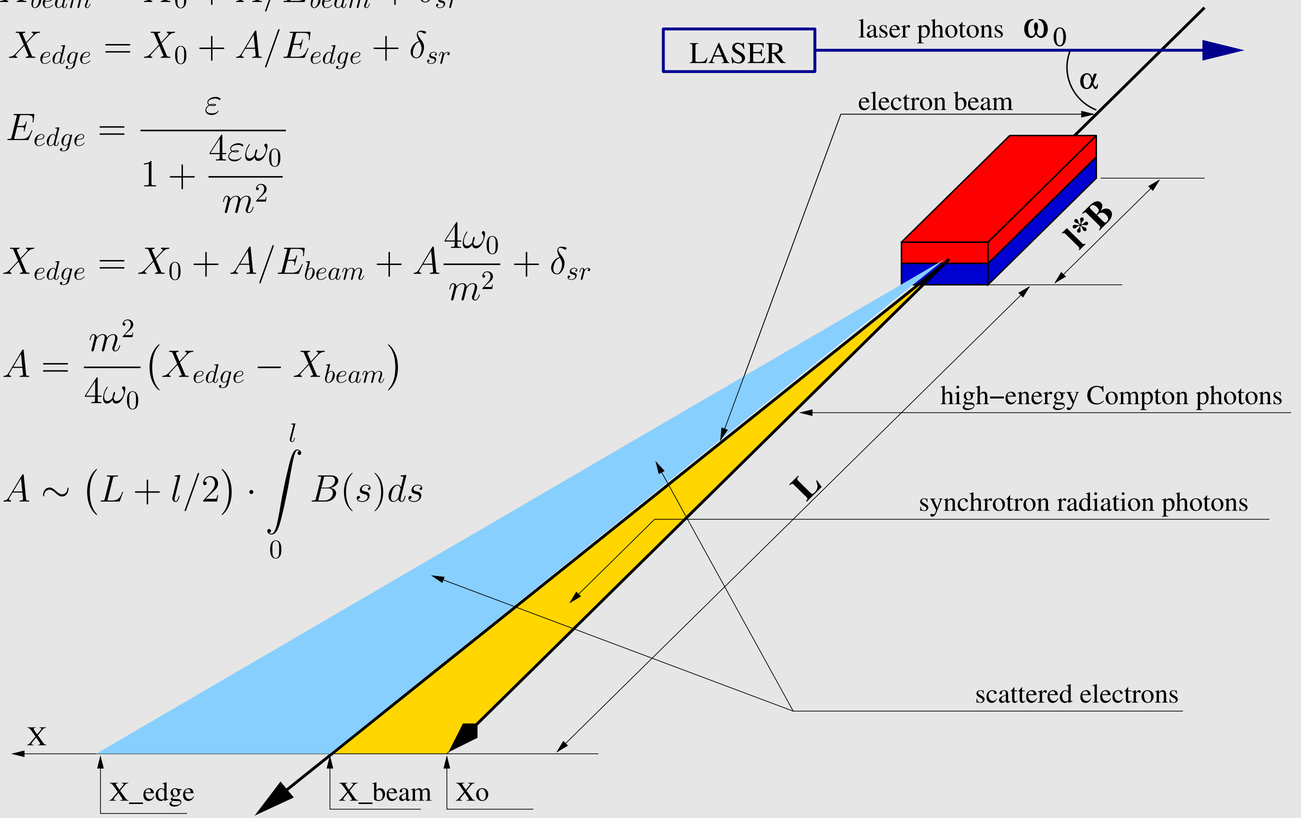

electron beam
I*B
L
synchrotron radiation photons
X
X_beam
Xo


LASER
laser photons ω_0
α
electron beam
I*B
dN/dX
high−energy Compton photons
L
synchrotron radiation photons
X
scattered electrons
X
X_edge
X_beam
Xo

$$\begin{cases} X_{beam} = X_0 + A/E_{beam} + \delta_{sr} \\ X_{edge} = X_0 + A/E_{edge} + \delta_{sr} \end{cases}$$

$$\begin{cases} E_{edge} = \dfrac{\varepsilon}{1 + \dfrac{4\varepsilon\omega_0}{m^2}} \\ X_{edge} = X_0 + A/E_{beam} + A\dfrac{4\omega_0}{m^2} + \delta_{sr} \end{cases}$$

$$\begin{cases} A = \dfrac{m^2}{4\omega_0}\left(X_{edge} - X_{beam}\right) \\ A \sim (L + l/2) \cdot \displaystyle\int_0^l B(s)ds \end{cases}$$



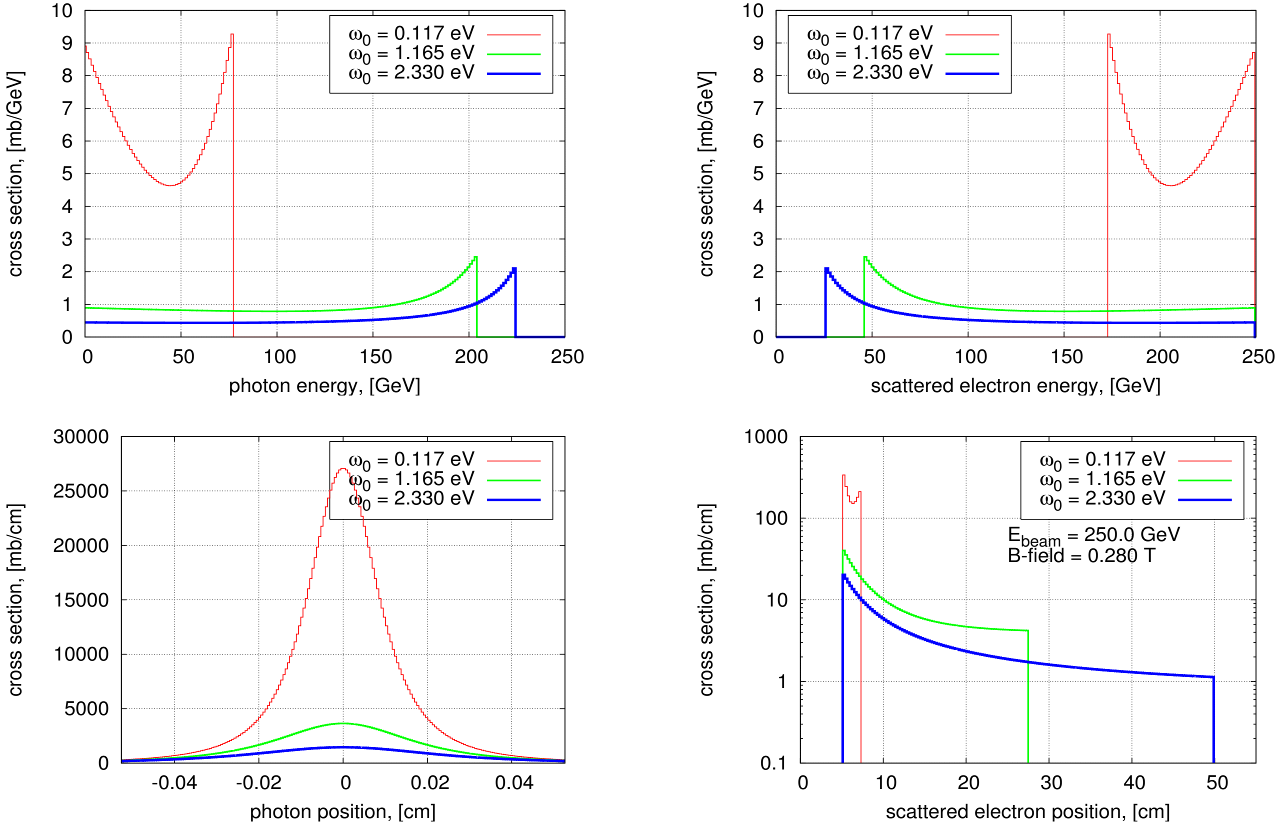
What do we have from laser backscattering?

- X_0 is the center of gravity in the space distribution of backscattered high-energy photons, it potentially could be measured by dedicated detector.
- X_{beam} is the beam position in the detection plane that could be measured by precise BPM.
- X_{edge} is the Compton edge position in the scattered electrons distribution over X. Also require dedicated detector.

One can measure the beam energy using X_0, X_{beam} and X_{edge} from three different space-sensitive detectors:

$$\boxed{E_{beam} = \frac{m^2}{4\omega_0}\left(\frac{X_{edge} - X_{beam}}{X_{beam} - X_0 - \delta_{sr}}\right)}$$

Compton cross section example



$B = 0.28$ T; $E_{beam} = 250$ GeV; $l = 3$ m; $L = 50$ m.

Accuracy

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

$\Downarrow$ $\Delta X_{edge} = \sqrt{\frac{2 \cdot \sigma_{X_{edge}}}{\frac{dN}{dx}(X_{edge})}}$

$\Downarrow$ BPM

$\Downarrow$ Photon detector

- dN/dX is defined by Compton cross section and luminosity, while $\sigma_{X_{edge}}$ is a convolution of the beam size at the detection plane with an influence from beam energy spread.
- Simple analytical predictions as well as Geant4 simulations, show that the accuracy $\Delta E/E \lesssim 10^{-4}$ is achievable with 10^6 scattered electrons.
- Systematic error source appears from B-field non-uniformity in the spectrometer magnet and L variations.

X_{Edge} smearing factors

reminding that

$$X_{edge} = X_0 + A/E + A\frac{4\omega_0}{m^2} + \delta_{sr}$$

one has:

$$\frac{dX_{Edge}}{dE} = -\frac{A}{E^2}$$

and beam energy spread influence the scattered electrons edge width:

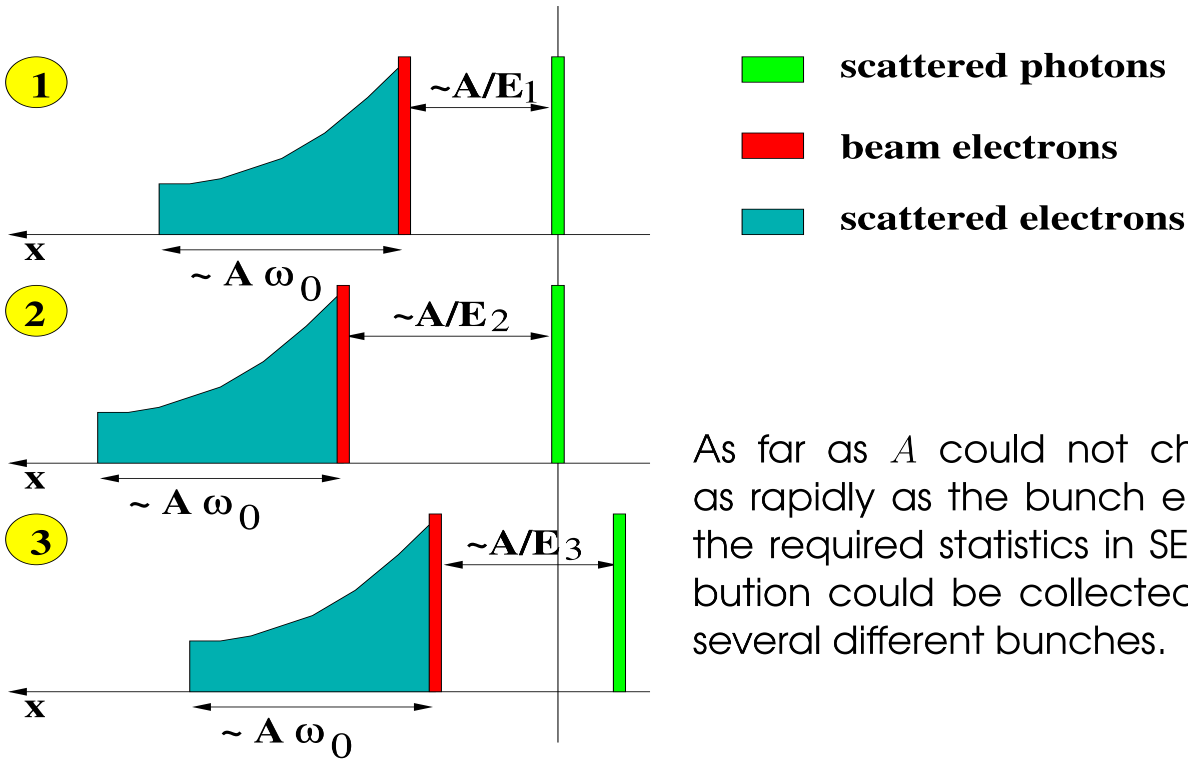
$$\sigma_{X_{Edge}} = (X_{beam} - X_0)\frac{\sigma_E}{E} \simeq \theta \cdot L \cdot \frac{\sigma_E}{E}$$

and don't forget about the beam size at the detection plane:

$$\sigma_{X_{Edge}} = \theta \cdot L \cdot \frac{\sigma_E}{E} \quad \oplus \quad \sigma_{X_{Beam}}(L)$$

ratio between these contributions are the subjects for optimization...

Bunch-to-bunch energy variations

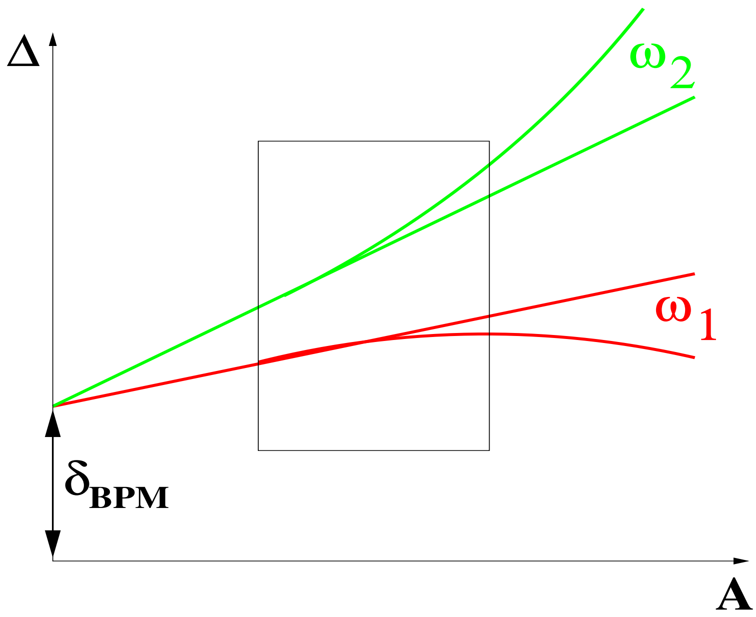


As far as A could not change as rapidly as the bunch energy, the required statistics in SE distribution could be collected from several different bunches.

Conclusions

- Compton backscattering in combination with magnetic spectrometer may provide a complementary approach to measure the beam energy: the absolute scale values of the spectrometer B-field and arc length do not impact on the measurement procedure.
- The statistical accuracy of the approach allows to hope that the systematic error sources will not cancel the idea
- The approach is flexible enough to work in the wide beam energy range, even at low-energy machines
- Why this setup couldn´t be used for polarimetry?
- Further studies are required to explore the influence of systematic error sources

P. S.
BPM "0" and B-field uniformity. Possible scenarios



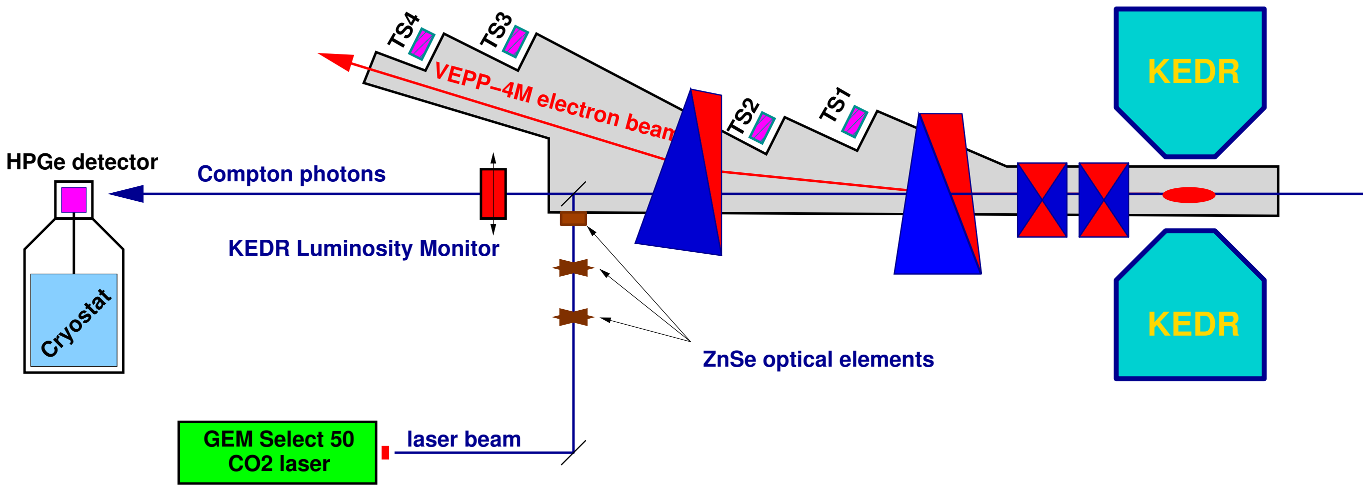
$$X_{beam} = X_0 + A/E_{beam} + \delta_{sr} + \delta_{BPM}$$

$$X_{edge} = X_0 + A/E_{beam} + \delta_{sr} + A'\frac{4\omega_0}{m^2}$$

$$\Downarrow$$

$$\Delta = X_{edge} - X_{beam} = A'\frac{4\omega_0}{m^2} - \delta_{BPM}$$

Appendix I.
Possible Test-Area at the ROKK-1M Facility VEPP-4M Collider, Novosibirsk



Appendix II.
Ultra relativistic electron in magnetic field

$$\theta(l, E) = \theta_0 \quad + \quad \frac{K_1}{E} \int_0^l B(s)ds \quad + \quad K_2 \int_0^l B^3(s)sds$$

$\Downarrow$ Lorentz force

$\Downarrow$ SR losses

Both K_1 and K_2 are just the combinations of fundamental constants $c, m, \hbar, \alpha$.

If the B-field integral is equal for electrons with different energies:

- Lorentz force bending is inverse proportional to the electron energy
- bending due to SR losses does not depend on the electron energy

In other words:

$$\theta(E) = \theta_0 + \frac{A}{E} + \delta_{sr}$$