FCC-ee Beam Energy Measurement Suggestion

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Talk outline

- Introduction: resonant depolarization
- Introduction: inverse Compton scattering
- Conventional spectrometer
- Spectrometer & laser calibration
- Discussion

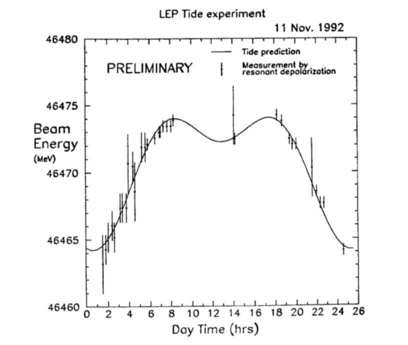
Resonant Depolarization (RD)

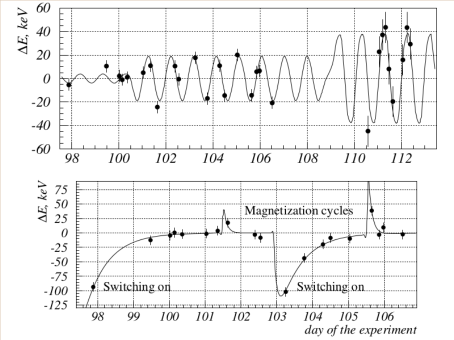
The energy scale in particle physics is established due to the resonant depolarization technique on e^+e^- colliders:

VEPP-2(M), SPEAR, DORIS, VEPP-4(M), CESR, LEP ...

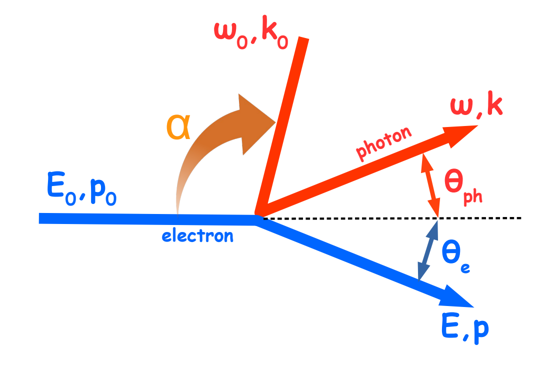
RD requires: a) polarization, b) polarimeter, c) depolarizer (?)

Allows to have $\Delta E/E \simeq 10^{-6}$!



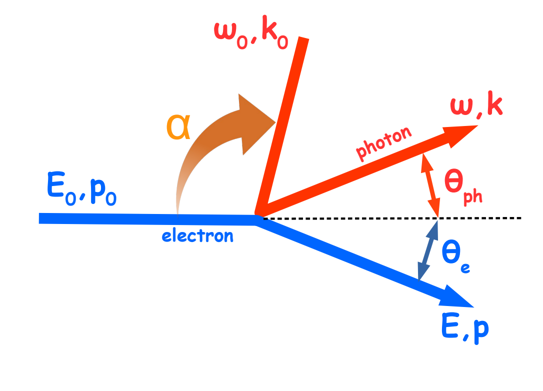


Compton Scattering



Compton Scattering

Inverse case: $\alpha = \pi,\ \theta_e = \theta_{ph} = 0$



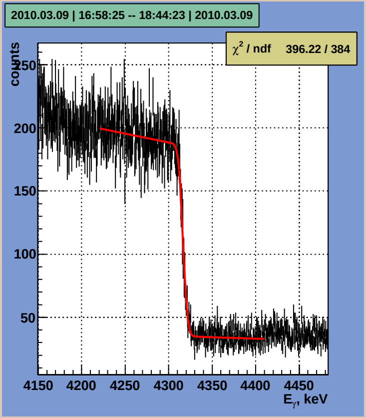
$$\boxed{\omega_{max} = E_0 \frac{\kappa}{1+\kappa}} \quad \kappa = \frac{4\omega_0 E_0}{m^2}$$

Laser for beam energy calibration at e^+e^- colliders

VEPP-4M$^{(2005)}$, BEPC-II$^{(2010)}$, VEPP-2000$^{(2012)}$

$$E_0 = \frac{\omega_{max}}{2}\left(1 + \sqrt{1 + \frac{m^2}{\omega_0 \omega_{max}}}\right)$$

$$\frac{\Delta E_0}{E_0} \gtrsim 3 \times 10^{-5} \quad \text{for } E_0 < 2 \text{ GeV}$$



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BES-III Collaboration

$$m_\tau = (1776.91 \pm 0.12^{+0.10}_{-0.13})\,\text{MeV/c}^2$$

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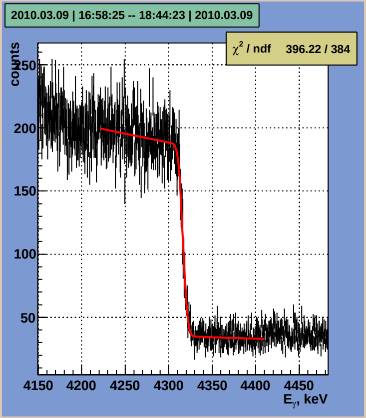
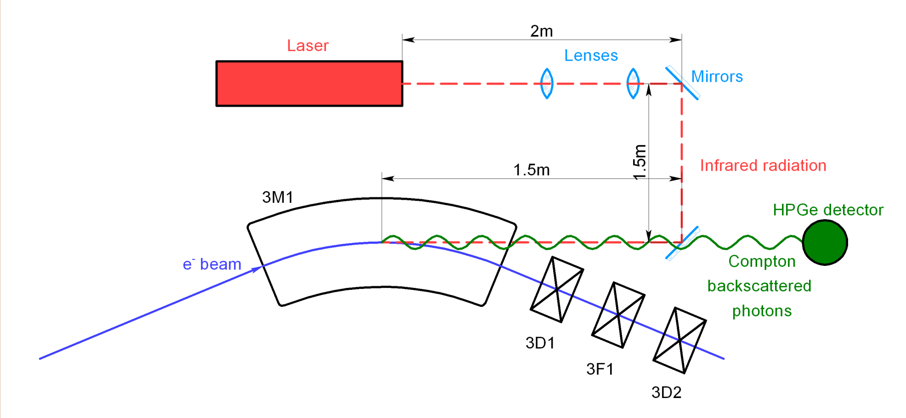
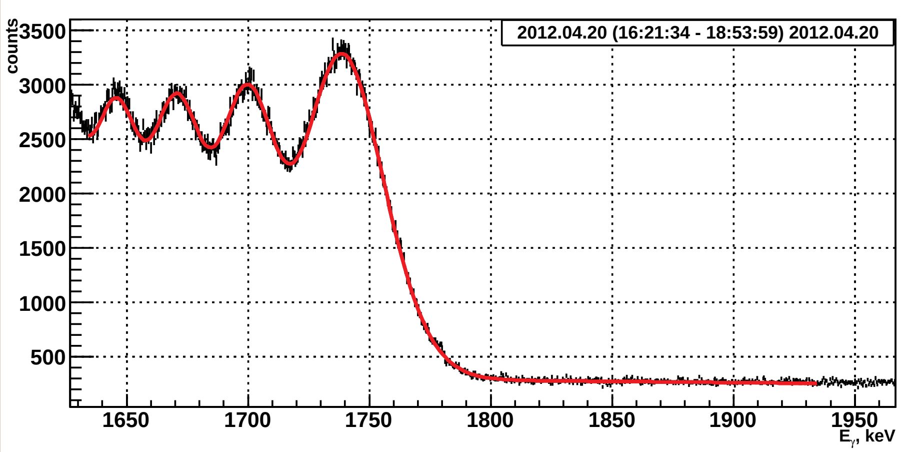


VEPP-2000

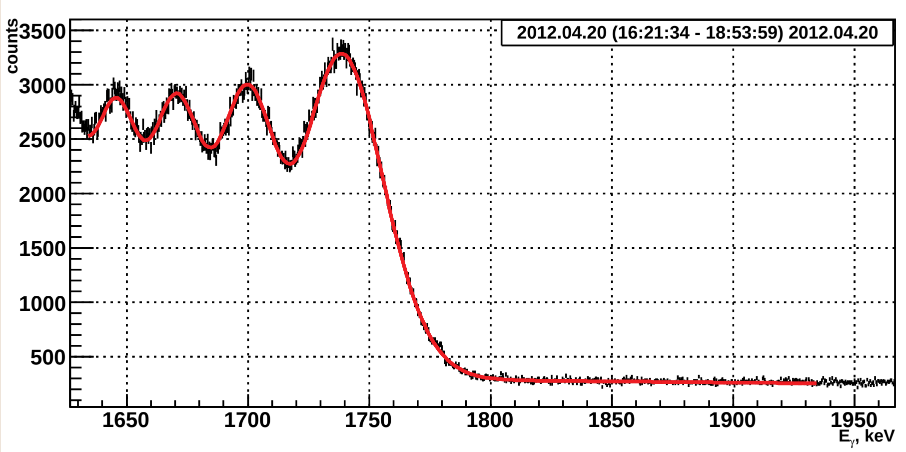


Beam orbit radius in the VEPP-2000 dipole $R = 140$ cm

VEPP-2000 puzzle



VEPP-2000 puzzle



$\chi^2/NDF = 773/745$, Prob. $= 0.23$,

$E = 993.662 \pm 0.016$ MeV, $B = 2.388 \pm 0.004$ T, $\sigma = 810 \pm 40$ ppm.

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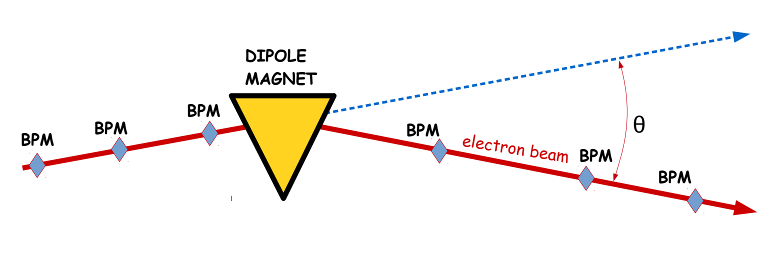
Conventional spectrometer

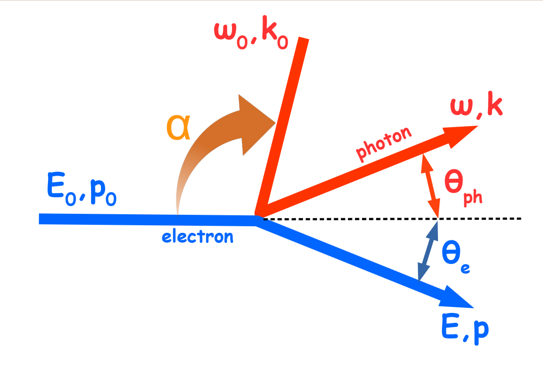
One of the complementary approaches for the beam energy determination at LEP – high energy runs.



Access to the beam energy: $E_0 = \dfrac{c \int B ds}{\theta}$

Compton Scattering

$$E_0 \gg m \gg \omega_0,\ \alpha = \pi,\ \theta_e = \theta_{ph} = 0$$



$$\boxed{\omega_{max} = E_0 \frac{\kappa}{1+\kappa}} \quad \kappa = \frac{4\omega_0 E_0}{m^2}$$

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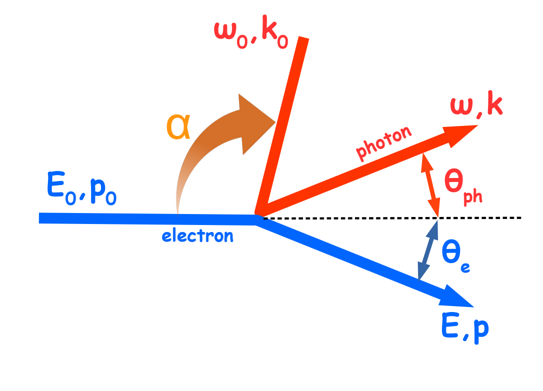
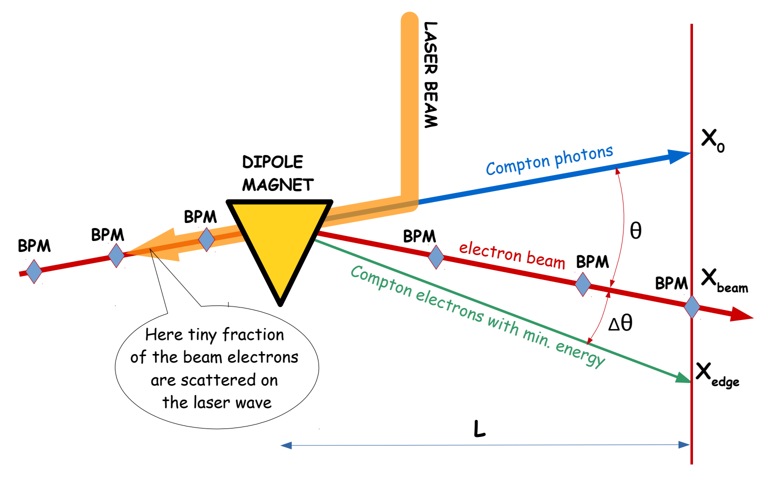


$$\boxed{\omega_{max} = E_0 \frac{\kappa}{1+\kappa}} \quad \kappa = \frac{4\omega_0 E_0}{m^2} \quad \boxed{E_{min} = E_0 - \omega_{max} = E_0 \frac{1}{1+\kappa}}$$

Spectrometer with laser calibration (suggestion)



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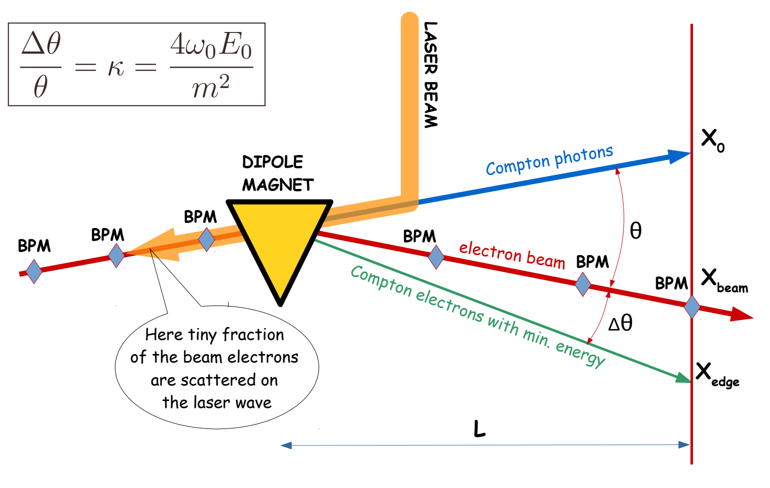

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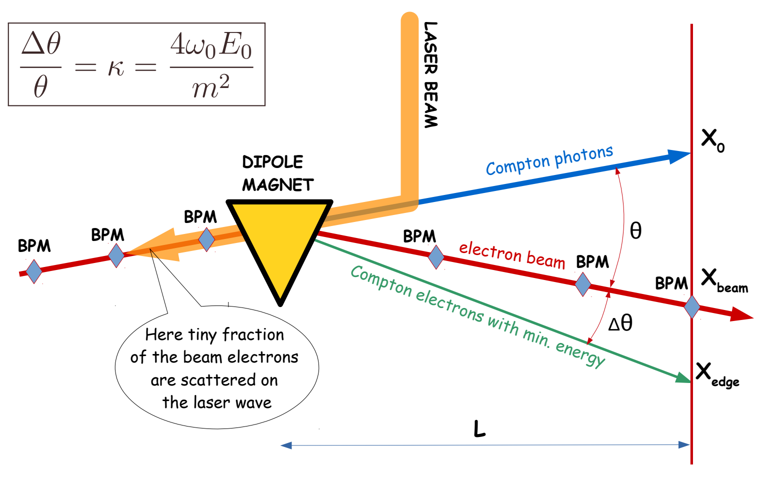
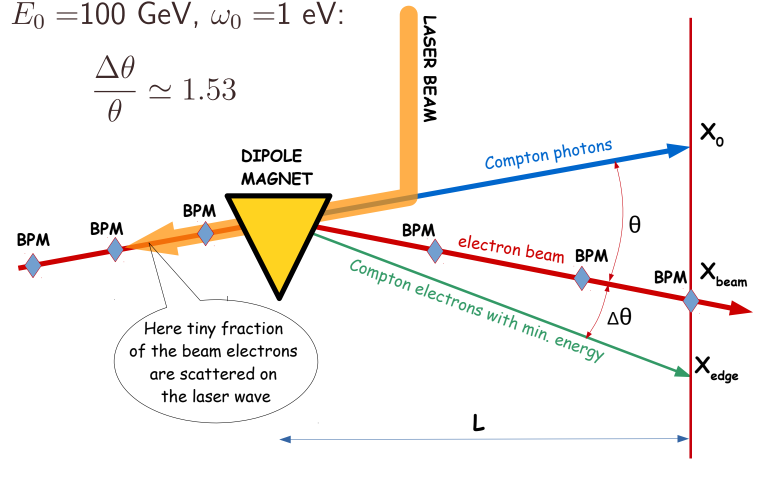


Access to the beam energy: $E_0 = \frac{\Delta\theta}{\theta} \times \frac{m^2}{4\omega_0}$

Spectrometer with laser calibration (suggestion)

E_0 =100 GeV, ω_0 =1 eV:

$$\frac{\Delta\theta}{\theta} \simeq 1.53$$



Access to the beam energy: $E_0 = \frac{\Delta\theta}{\theta} \times \frac{m^2}{4\omega_0}$

Rough accuracy estimation

- Assume 10 μm accuracy for $[X_{beam} - X_0]$ and $[X_{edge} - X_{beam}]$.
- For $\Delta E/E \simeq 10^{-5}$: $[X_{beam} - X_0] \simeq [X_{edge} - X_{beam}] \simeq$ 1 m.
- For example, this is $\theta \simeq 10$ mrad and $L \simeq 100$ m.

Discussion: the weaknesses of suggestion

- it is necessary to ensure equality of integrals of magnetic field for electrons with very different energies;
- the installation dimensions seems to be larger than one would like to have;
- three different types of coordinate detectors must work together to measure distances with high precision in absolute units.

Discussion: the strengths of suggestion

- it aims to measure the absolute energy of the electron beam and does not require measurement of bending field in absolute scale;
- backscattering of laser radiation is a proven tool for beam energy calibration at low energy machines;
- looks tempting the possibility to measure energy and polarization of the beam by the same apparatus;
- use of different laser wavelengths will definitely help to control some of possible systematic uncertainties;
- conventional spectrometer remains in service and provides *independent information* about the beam energy;
- the calibration procedure for coordinate-sensitive detectors does not directly depend on particles energies.

Acknowledgement

Thank you for your attention!