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ON ELECTRON BEAM DIAGNOSTICS AND CONTROL AT STORAGE RING WITH POLARIZED INTERNAL TARGET

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Abstract

The method for measurement of electron beam axis position and angular beam spread is developed for storage ring with internal target. The method is based on usage of elastic scattering of high energy electrons (positrons) circulating in storage ring on atomic electrons of target.

1 INTRODUCTION

The electron (positron) - electron scattering is widely used for luminosity measurement for both electron - positron colliders like the LEP and storage rings with internal target like the HERMES [1]. This work proposes a method for measurement of electron beam axis position and angular beam spread in a storage ring with internal target which is based on usage of elastic scattering of circulating high energy electrons (positrons) on atomic electrons of the target.

2 KINEMATICS OF ELECTRON-ELECTRON SCATTERING

The kinematics of scattering of high energy electron (positron) on electron at rest is defined by invariant $s = 2m(E_0 + m)$, where E_0 is initial electron energy, m - electron mass and by the scattering angle θ in the center mass frame (CM). In the CM frame the Møller cross section for high energy electrons is [2]

$$d\sigma = r_e^2 \frac{m^2}{s} \frac{(3+\cos^2\theta)^2}{\sin^4\theta} do \qquad (1)$$

where r_e is the classical electron radius. For positron - electron Bhabha scattering $d\sigma_{e^-e^+} = \cos^4(\theta/2) d\sigma_{e^-e^-}$. The electron energy in the CM frame is $E_{cm} = \sqrt{s}/2$.

2.1 Transformation to the laboratory frame

Transformation to the laboratory frame gives for the electrons' scattering angles

$$\tan\theta_{e1,e2} = \frac{\sin\theta}{(1\pm\cos\theta)\gamma_{cm}}, \qquad (2)$$

where $\gamma_{cm} = (E_0+m)/\sqrt{s}$ is the Lorentz factor of the CM in the lab frame. "Opening angle" θ_{e12} in the laboratory frame in a small angle approximation

$$\theta_{e12} = |\theta_{e1}| + |\theta_{e2}| = 2/(\sin\theta\gamma_{cm}) \qquad (3)$$

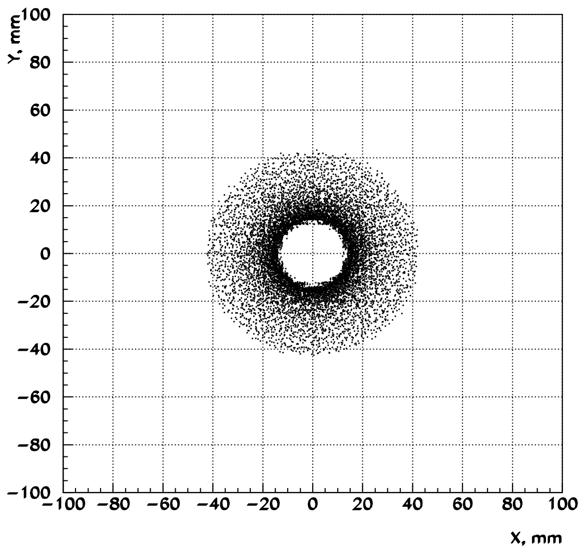

Figure 1: Transverse distribution of scattered electrons and positrons: ideal beam.

has a minimum at $\theta = \pi/2$, $\theta_{e12min} = 2/\gamma_{cm}$. It is possible to deduce a formula for the angle production

$$\theta_{e1}\theta_{e2} \approx \tan\theta_{e1}\tan\theta_{e2} = \theta_{ecr}^2 = 1/\gamma_{cm}^2, \qquad (4)$$

where θ_{ecr} is characteristic angle. For electrons energy we have

$$E_{1,2} = (E_0+m)/2 \pm (E_0-m)\cos\theta/2, \qquad (5)$$

for $E_1 > E_0/2$, $\theta_{e1} < \theta_{ecr}$, $E_2 \le E_0/2$, $\theta_{e2} \ge \theta_{ecr}$.

2.2 Polarization effects

In case of scattering of high energy electrons with helicity one has for cross sections' ratio for parallel and antiparallel spins [2]

$$\frac{d\sigma_{\uparrow\uparrow}}{d\sigma_{\uparrow\downarrow}} = \frac{1}{8}(1+6\cos^2\theta+\cos^4\theta). \qquad (6)$$

Dependence of this ratio on electrons' spin orientation can be used for determination of circulating beam spin if polarization of atomic electrons of the target is known.

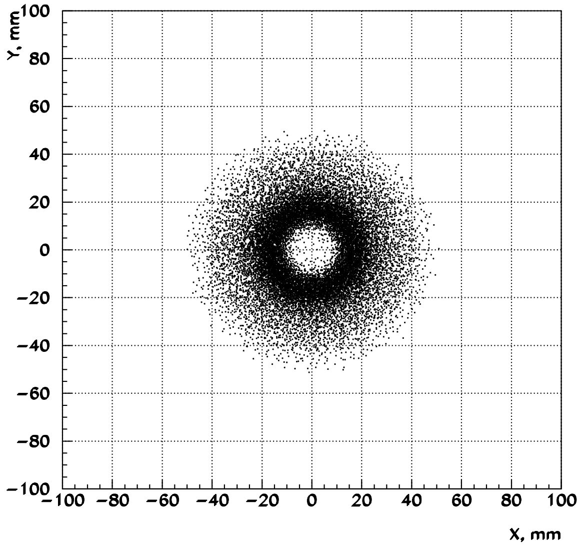

Figure 2: Transverse distribution of scattered electrons and positrons: beam with an angular spread.

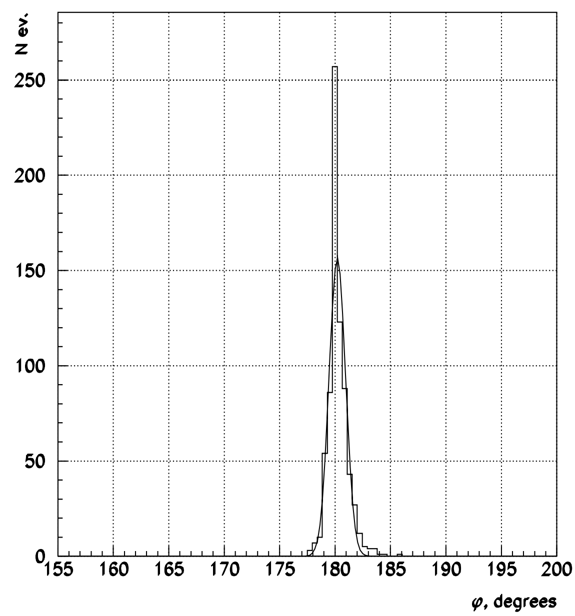

Figure 3: Azimuthal Bhabha scattered electron-positron distribution: for the positron beam with zero angular spread.

3 BASIC CONCEPTS

Obviously, in the CM frame scattered particles move in opposite directions ($\varphi_{cm} = 180^o$). In the lab frame polar angle between particle impulse projections on transverse to the beam axis plane taken from impact point of initial particle is also $\varphi = 180^o$. However, if

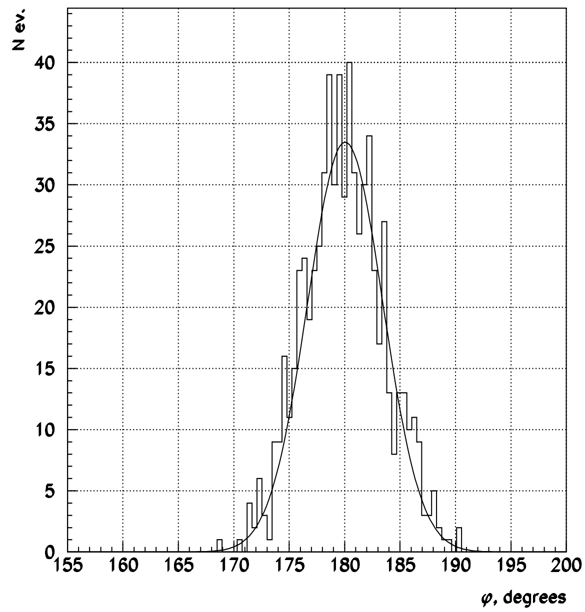

Figure 4: Azimuthal Bhabha scattered electron-positron distribution: for the positron beam angular dispersion $\sigma_\theta = 1.80 \times 10^{-4} rad$

the beam has a finite angular spread and the azimuth is taken from beam axis the picture looks different: we have an azimuth distribution with a width proportional to the beam's angular spread and a mean value depending on the magnitude of the displacement of the real storage ring close orbit position from the ideal one. Hence, from these values information about beam spread and close orbit position at the interaction point can be extracted.

4 ELECTRONS DETECTION

At the HERMES, for example, the luminosity is measured by detecting Bhabha scattering target electrons in coincidence with the scattered positrons in a pair of cherenkov electromagnetic calorimeters [3]. Each calorimeter consists of 12 separate modules with radiators of NBW crystals and PMT assembled in the form of a 3×4 array. The radiation length of NBW crystals is $X_0 = 1.03$ cm. The Møller radius is $R_m = 2.38$ cm. The radiator's longitudinal size $l = 200$ mm.
The radiator cross section is 22×22 mm [1], [4]. The distance of the calorimeter's front plane from the interaction point is $L = 720$ cm. The distance of the outward longitudinal calorimeter walls from storage ring orbit is $x_{cal} = 33$ mm.

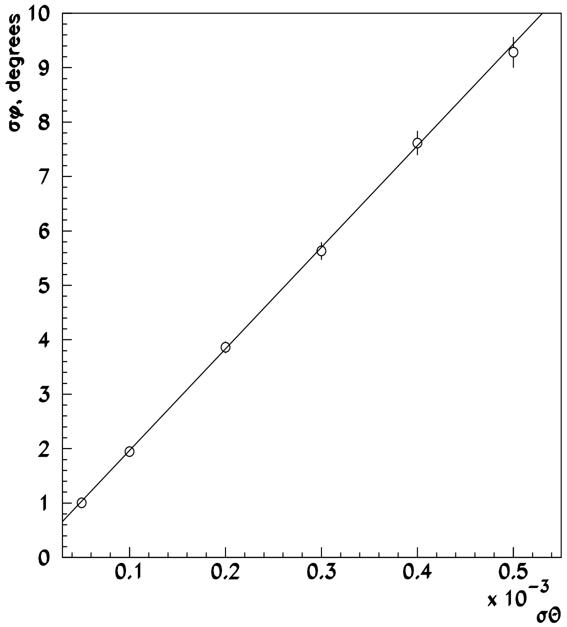

Figure 5: The width of φ-distribution as a function of positron beam angular spread.

5 MONTE CARLO SIMULATION

Figs.1-2 show spatial distribution of scattered positrons and electrons at the front calorimeter's plane for initial positron energy E_0 equal to 30.0 GeV typical for the electron-proton collider HERA [5]. The particles' energy is in the range $0.5E_0 < E < 0.95E_0$. Finite beam angular spread ($\sigma_\theta = 4.0 \times 10^{-4} rad$) gives rise to a smearing of the distribution of Fig. 2 in comparison with that of Fig. 1 for ideal beam ($\sigma_\theta = 0$) . The distribution of the azimuth angle between Bhabha scattering positron and electron is shown at Figs.3-4. Monte Carlo simulation was performed: a) for the positron beam with zero angular dispersion and the calorimeter spatial resolution $\delta x_{cal} = 2$ mm (Fig.3) and b) for perfect calorimeter ($\delta x_{cal} = 0$ mm) and the positron beam angular dispersion $\sigma_\theta = 1.80 \times 10^{-4} rad$ (Fig.4). The dispersion of this distribution $\sigma_\varphi = 3.41^o$ could be compared with experimental value. Displacement of the close orbit from the equilibrium position on $\Delta x = 4.5$ m-m brings the distribution mean value from $\varphi = 180^o$ to $\varphi = 177.9^o$.

The dependence of the width of azimuthal distribution on positron beam spread is shown in Fig.5

6 CONCLUSIONS

The consideration can be generalized by taking into account the positron beam and the target polarization and the final state radiation. Note that developed technique can be applied for particle beam parameters determination at electron-positron and proton-proton colliders.

7 ACKNOWLEDGEMENTS

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8 REFERENCES

[1] Hermes Technical Design Report, DESY-PRC 93/6, MPIH-V20-1993.

[2] V.B. Berestesky, E.M. Lifshitz, L.P. Pitaevsky, Relativistic quantum theory, M.: Nauka, 1968.

[3] K. Ackerstaff et al., HERMES collaboration, Measurement of the neutron spin structure-function $G(1)(N)$ with polarized $He-3$ internal target. Phys. Lett. B, 1997, v. 404, p. 383-389.

[4] T.Benisch, Diploma thesis, Universitet Erlangen-Nurenberg, 1994.

[5] B.H. Wiik, HERA Operation and Physics, Proc. 1993 IEEE Particle Accelerator Conference. v. 1, p. 1.