ON ELECTRON BEAM EMITTANCE MEASUREMENT AT STORAGE RING WITH INTERNAL TARGET

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Abstract

The method for measurement of electron beam axis position and angular beam spread is developed for a storage ring with internal target. The method is based on the usage of elastic scattering of high energy electrons (positrons) circulating in a storage ring on atomic electrons of the target. If the beam has a finite emittance and the azimuth is taken from the beam axis the distribution of the azimuth angle between Bhabha scattering positron and electron has a width proportional to the beam angular spread and a mean value depending on the magnitude of the displacement of the real storage ring close orbit position from ideal one. Monte Carlo simulation was made for the positron beam with a real angular dispersion for energy range typical for the electron-proton collider HERA. The consideration can be generalize by taking into account the positron beam and the target polarization and final state radiation. This method can be used also at electron-positron and proton-proton colliders.

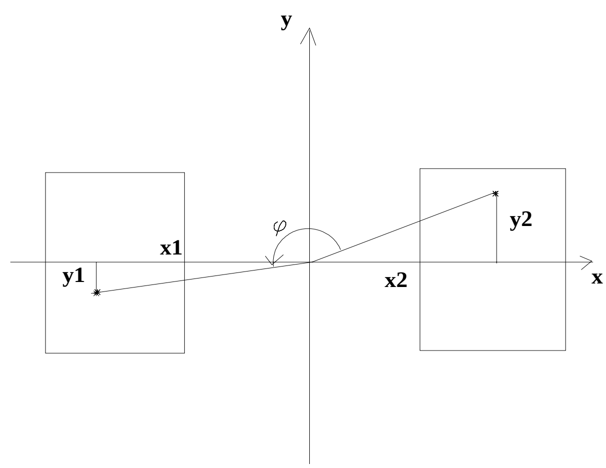

Figure 1: Electron - positron detectors layout.

1 INTRODUCTION

The electron (positron) - electron scattering is widely used for luminosity measurement for both electron - positron colliders like the LEP [1] and storage rings with internal target like the HERMES [2]. This work proposes a method for measurement of electron beam axis position and angular beam spread in 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 [3]

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

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

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

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

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

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

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

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

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

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

It is well known that atomic electrons of polarized internal gas target have high degree of polarization. In case of scattering of high energy electrons with helicity one has for cross sections ratio for parallel and antiparallel spins [3]

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

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

3 BASIC CONCEPTS

Obviously, in the CM frame scattered particles move into 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 also $\varphi = 180^o$. However if the beam has a finite angular spread and the azimuth is taken from beam axis the picture looks different: we have a azimuth distribution with a width proportional to the beam angular spread and mean value depending on magnitude of displacement of real storage ring close orbit position from ideal one. The angle φ can be written as follows (see Fig. 1):

$$\varphi = |\arctan(y_1/x_1) - \arctan(y_2/x_2)| \qquad (7)$$

where x_i, y_i are horizontal and vertical coordinates of the scattered particles taken from the detector axis. 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 [4]. Each calorimeter consists of 12 separate modules with radiators assembled in the form of a 3×4 array. The radiator cross section is 22×22 mm [2]. The distance of the calorimeter 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.

5 MONTE CARLO SIMULATION

Fig. 2 shows radial distribution of scattered positrons and electrons at the front calorimeters 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 2 in comparison with that (curve 1) for ideal beam ($\sigma_\theta = 0$). The distribution of the azimuth angle between Bhabha scattering positron and electron is shown at Fig.3. Monte Carlo simulation was performed: a) for the positron beam with zero angular dispersion and the calorimeter spatial resolution $\delta x_{cal} = 2$ mm 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. 3). Axial symmetric gaussian angle distribution of the circulating beam was used at the simulation. The dispersion of this distribution $\sigma_\varphi = 3.41^o$ could be compared with experimental value. It should be

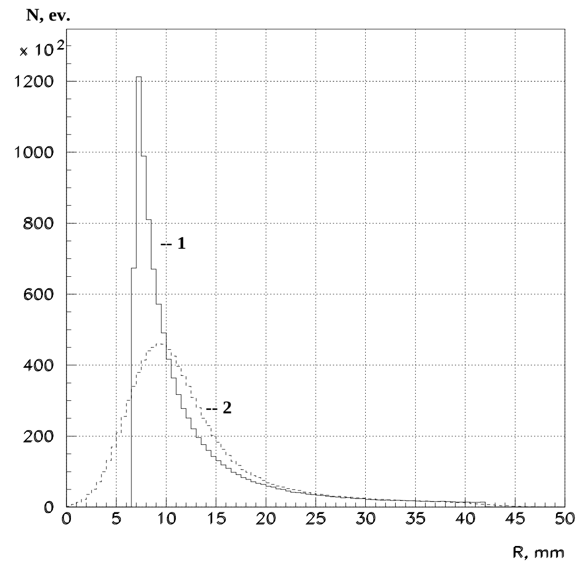

Figure 2: Radial distribution of scattered electrons and positrons: 1 - ideal beam, 2 - beam with an angular spread.

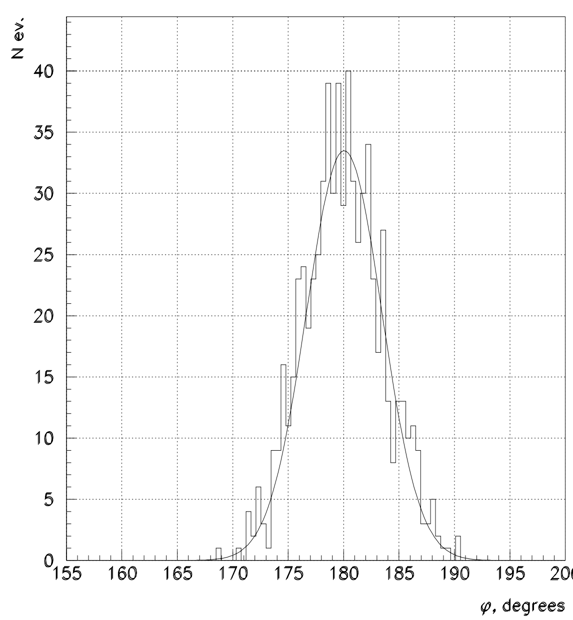

Figure 3: Azimuthal Bhabha scattered electron-positron distribution: for the positron beam angular dispersion $\sigma_\theta = 1.80 \times 10^{-4} rad$

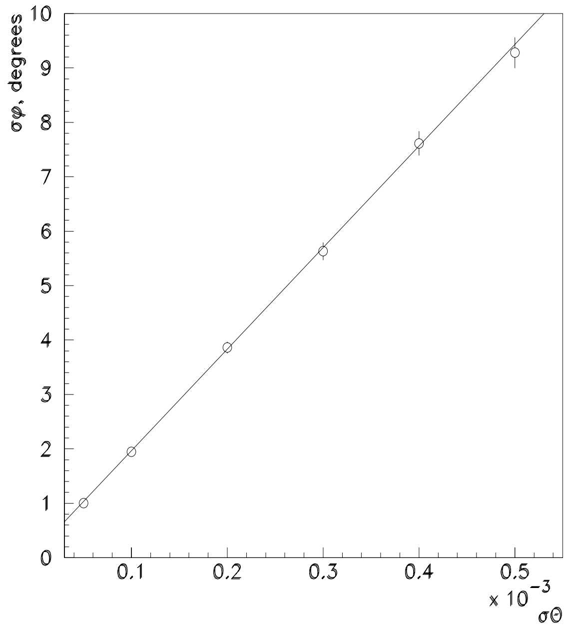

Figure 4: The width of φ-distribution as a function of positron beam angular spread.

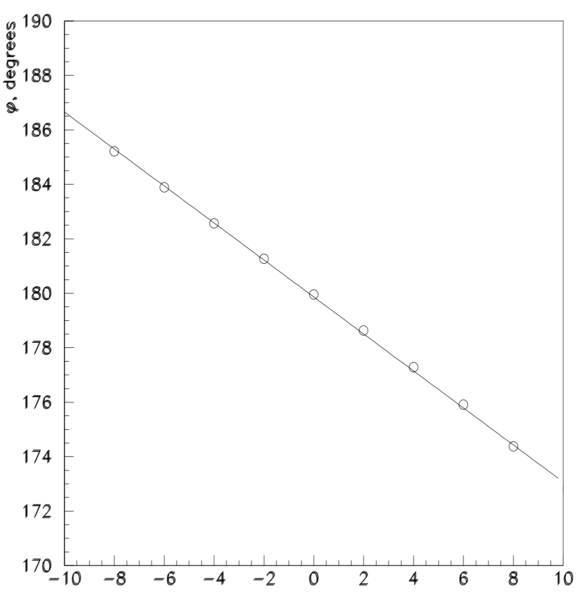

Figure 5: The dependence of mean φ value on horizontal close orbit position displacement.

noted that for the mention calorimeter resolution simulation gives rise to $\sigma_\varphi = 0.74^o$ for an ideal beam. The dependence of the width of azimuthal distribution on positron beam spread is shown in Fig. 4 The dependence of mean φ value on horizontal close orbit position displacement is shown in Fig. 5. For example displacement of the close orbit from the equilibrium position on $\Delta x = 4.5$ mm brings the distribution mean value from $\varphi = 180^o$ to $\varphi = 177.9^o$. Geometric acceptance of the detector was taken into account.

6 CONCLUSIONS

The consideration can be generalize by taking into account the positron beam and the target polarization and 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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