BACKGROUND FROM UNDULATOR IN THE PROPOSED EXPERIMENT WITH POLARIZED POSITRONS*

Yuri K. Batygin, SLAC, Stanford, CA 94309, USA

Abstract

In the proposed E-166 experiment [1], 50 GeV electrons pass through helical undulator, and produce circularly polarized photons, which interact with a tungsten target and generate longitudinally polarized positrons. The background is an issue for a considered experiment. GEANT3 simulations were performed to model production of secondary particles from high-energy electrons hitting an undulator. The energy density of generated photons at the target was analysed. Results of the simulations are presented and discussed.

INTRODUCTION

E-166 is the proposed experiment for the verification of polarized positron production for the Next Linear Collider [1]. According to the original suggestion of Ref. [2], high-energy electrons pass through a helical undulator and produce circularly polarized photons, which after interaction with tungsten target, generate longitudinally polarized positrons. In the E-166 experiment (see Fig. 1), the 50 GeV electron beam propagates inside 1 m long undulator followed by a drift space of 35 m. Polarized positrons generated in an undulator are analyzed by Si-W calorimeter which is placed along the axis. Polarized positrons are analyzed by a Cs-I calorimeter after reconversion of positrons to photons at the second target shifted by 45 cm from the axis. In this paper we discuss the effect of background particles generated by primary high-energy electrons hitting undulator tube.

SIMULATION SET-UP

Fig. 2 illustrates the simulation set-up of the Final Focus Test Beam (FFTB) line of SLAC linac. Beamline includes undulator (1), quadrupole magnet (2), bending magnets (3) and lead shields (4), (5). The undulator was substituted by a thin iron tube with length of 1 m and internal diameter of 0.88 mm. To prevent background, in front of the undulator a tungsten collimator with the length of 30 RL (10.5 cm) is used. Simulations were performed for two cases: illumination of the internal part of the undulator and illumination of collimator by halo electrons.

To define divergence of halo electrons, let us take into account that normalized rms beam emittance in FFTB line is $\gamma\varepsilon = 3\text{x}10^{-5}\ \pi$ m rad, and rms beam size is $\sigma = 40\cdot10^{-6}$ m. Therefore, rms beam divergence for beam energy of $\gamma = 10^5$ is

$$\left(\frac{dx}{dz}\right)_{rms} = \frac{\varepsilon}{\sigma} = 7.5\cdot10^{-6}. \qquad (1)$$

The internal undulator radius is approximately 10 times larger than the rms beam size. As soon as halo electrons are distributed in a phase space within a 10 times larger ellipse than the beam core, the divergence of the halo electrons was selected to be

$$\left(\frac{dx}{dz}\right)_{halo} = 10\cdot\left(\frac{dx}{dz}\right)_{rms} = 7.5\cdot10^{-5}. \qquad (2)$$

The generated secondary particles were collected and analyzed at the distance of 35 m from undulator.

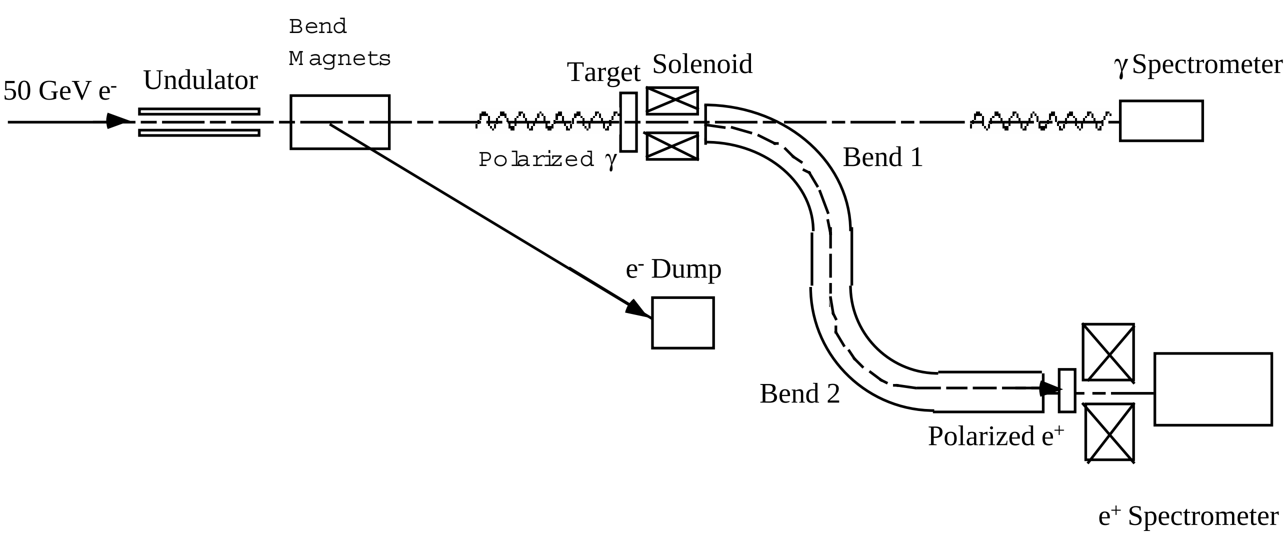

Figure 1: Layout of experiment.

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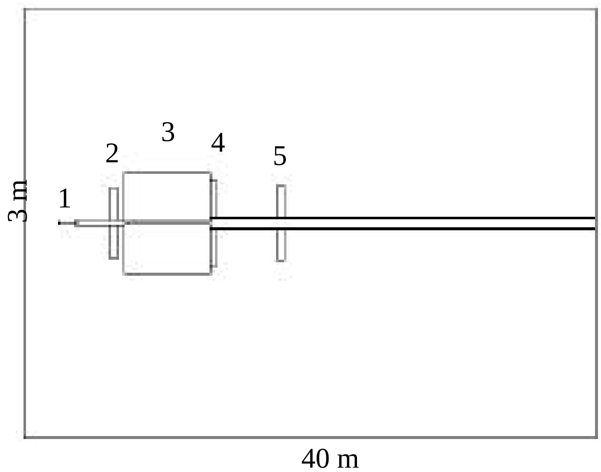

Figure 2: Simulation set-up: 1 –undulator, 2- quadrupole, 3- bending magnets, 4, 5- lead shield.

(a)

(b)

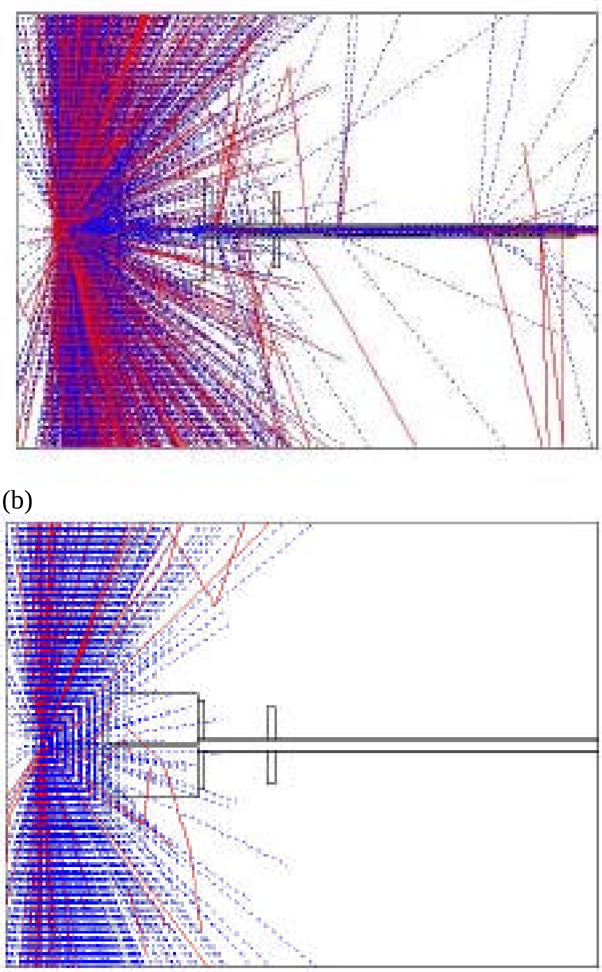

Figure 3: (a) Background from electrons hitting internal part of the undulator, (b) background from electrons hitting the collimator: blue – photons, red - electrons and positrons.

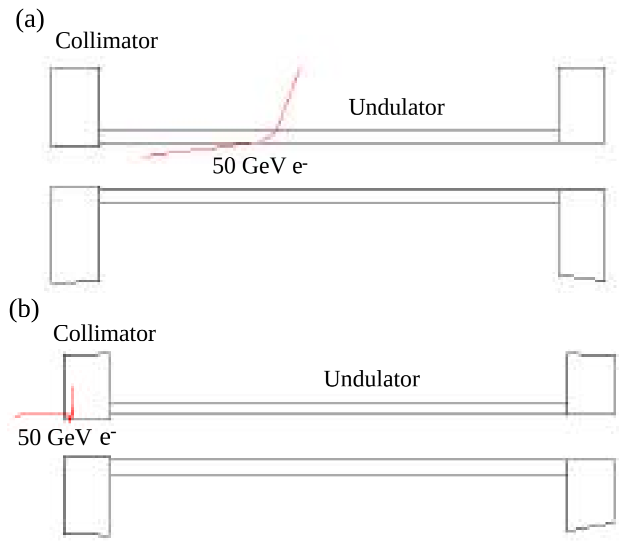

Figure 4: High energy electron hitting (a) internal part of undulator, (b) collimator.

BACKGROUND TREATMENT

Figs. 3, 4 illustrate illumination of the undulator by a single 50 GeV electron and the resulted background. Generated secondary particles contain mostly photons. Figs. 5, 6 illustrate energy density of photons, dE/dS, at the distance of 35 m from the undulator as a function of radial displacement:

$$\frac{dE}{dS}(r) = \frac{\sum_{i=1}^{N} E_i}{2\pi r dr}, \quad (3)$$

where E_i is an energy of an individual photon. The results are normalized by a single primary electron. From simulations, it follows that each primary electron hitting the internal part of the undulator generates around 22 photons, 2.4 electrons and 1.7 positrons which eventually reach the target area at the distance of 35 m. The distribution of photons has a peak at the axis (see Fig. 5a) and drops quickly with the radius (see Fig. 5b). Specific concern are photons within radial displacement of r < 0.15 cm which can affect Si-W detector, providing background noise. The average value of the energy of those photons is 0.2 GeV per primary electron.

To prevent background generation, a collimator in front of undulateor is used (see Fig. 4b). The internal diameter of the collimator of 0.73 mm was selected to be smaller than that of the undulator to ensure that halo electrons with divergence of 10^{-4} will not hit the internal part of the undulator. The results of the simulations are presented in Fig. 6. While the general shape of the background distribution as a function of the radius is close to that as in the case of background from the undulator, the level of background reduced by three orders of magnitude.

COULOMB ELASTIC SCATTTERING ON RESIDUAL GAS IN UNDULATOR

Because of the small diameter of the undulator, the vacuum in the undulator is supposed to be around 1 mTorr, which might be a reason for elastic scattering of primary electrons on residual gas in the undulator. To estimate the fraction of scattered electrons in the undulator, consider the cross section of elastic Coulomb scattering given by the Rutherford formula:

$$d\sigma(\theta) = \left(\frac{Z\, r_e}{\gamma\beta^2}\right)^2 \frac{d\Omega}{4\left(\sin\frac{\theta}{2}\right)^4}, \quad (4)$$

where r_e is the classical radius of the electron, Z is the charge of residual gas atoms, $d\Omega = 2\pi \sin\theta\, d\theta$ is the cone angle. The number of particles per volume, n, is given by the perfect gas equation:

$$n = \frac{N_A P}{R T}, \quad (5)$$

where $N_A = 6 \times 10^{23}$ mol^{-1} is the Avogadro's number, R = 8.31 J mol^{-1}K^{-1} is the ideal gas constant, P is the gas pressure (in Pa), and T is the absolute temperature. After passing through the gas of the length L, the fraction of particles scattered within the angle interval of [θ, θ +dθ] is

$$\frac{dN_\theta}{N} = n\, L\, d\sigma(\theta). \quad (6)$$

The probability of scattering of the particles within the angle interval [θ_{min}, θ_{max}] is obtained via integration of Eq. (6)

$$P_\theta = \int_{\theta_{min}}^{\theta_{max}} \frac{dN(\theta)}{N} = 4\pi n L \left(\frac{Z\, r_e}{\gamma\beta^2}\right)^2 \left(\frac{1}{\theta^2_{min}} - \frac{1}{\theta^2_{max}}\right). \quad (7)$$

For $\theta_{max} >> \theta_{min}$ the second term in Eq. (7) can be neglected. Finally, for the electron beam propagating in gas

$$P_\theta = \frac{4\pi n L}{\theta^2_{min}} \left(\frac{Z\, r_e}{\gamma\beta^2}\right)^2. \quad (8)$$

The value of θ_{min} can be estimated as a ratio of aperture of the undulator, R, to the length of the undulator, L:

$$\theta_{min} = \frac{R}{L} = 0.44 \times 10^{-3}. \quad (9)$$

Taking the E-166 parameters Z = 7, $\gamma = 10^5$, n = 3.2 x 10^{-19} m^{-3} (corresponds to pressure of 1 mTorr), the probability of a near-axis electron to be scattered for an angle sufficient to hit the undulator tube is

$$P_\theta = 0.79 \times 10^{-10}. \quad (10)$$

As far as the number of electrons per bunch in FFTB is 1 x 10^{10}, it is around 1 electron per bunch to hit the undulator tube due to the elastic Coulomb scattering.

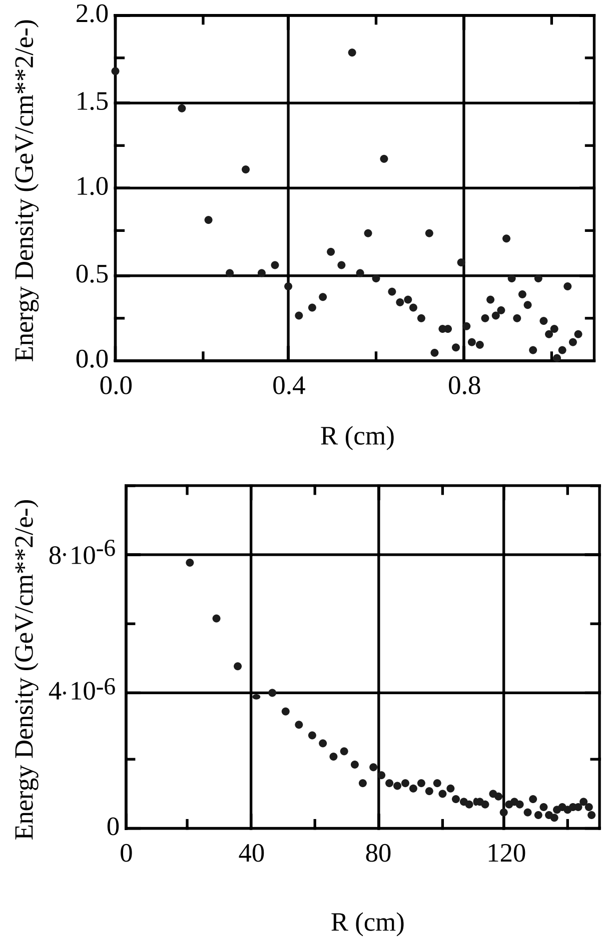

Figure 5: Photon background density from 50 GeV electron hitting internal part of undulator: (a) near axis, (b) far from axis.

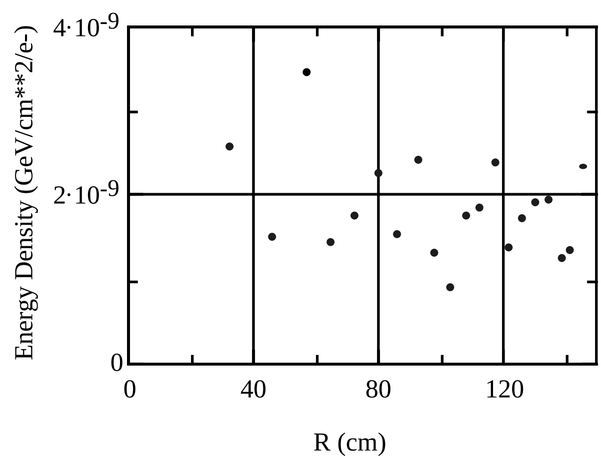

Figure 6: Photon background from 50 GeV electron hitting collimator.

REFERENCES

[1] "Undulator-based production of polarized positrons. A proposal for the 50-GeV beam in the FFTB", SLAC-NT-04-018, (20004), 67 pp.

[2] V.E.Balakin and A.A.Mikhailichenko, Preprint BINP 79-85 (1979).