Polarimeter for high energy photons

Bogdan Wojtsekhowski[#],
Branislav Vlahovic[*], and Samuel Danagulian[%]

 # Thomas Jefferson National Accelerator Facility, Newport News, VA
** NC Central University, Durham, NC*
% A&T State University, NC

Abstract. The physics program at TJNAF includes fundamental experiments with polarized photon beam in few GeV energy range. Development of the Polarimeter for use in Hall B experiments is the subject of present Technical Note. We have proposed to take advantage of the recent progress in silicon micro strip detectors for measurement of the geometry and angle correlation in electron positron pair production from an amorphous converter. A detailed analysis of the setup including MC simulation shows an experimental asymmetry $\sigma_{\parallel} / \sigma_{\perp} \sim 1.7$ in a wide range of the photon energies.

Introduction

The angle correlation in e^+e^- pair production by linear polarized photon was proposed for photon polarization measurements by Yang /1/ and Berlin & Madansky /2/. Accurate QED calculations with analysis of the possible experimental setup were done by L. Maximon and H. Olsen /3/. The effect was used succesfully for measurement of the beam polarization /4/. The limitation of the method at photon energy above 100 MeV arises from the small value of an angle between pair components. The realizations of the method /4,5/ were done by using a magnetic field for separation of the electrons and the positrons which caused considerable loss of analyzing power. Our proposal has the advantage of larger analyzing power and simplicity of setup.

The kinematics of the process is shown on Figure 1. The positron and electron have small angles ϑ_+, ϑ_- relatively to the direction of momentum of incident photon. The azimuth angles are φ_+, φ_-. They are the angles between photon polarization plane $(\vec{k}, \vec{x})$ and plane defined by momentum of the photon and momentum of outgoing particle (a positron or an electron). The opening angle between these planes is φ_{+-}. The angle $\omega_\pm$ between polarization plane and vector PN represents experimentally the most accessible parameter. Vector PN connects the crossing points of the positron and electron in the detector plane, which is perpendicular to the photon momentum.

available space for Polarimeter is about 1 meter, the distance e^+e^- is about a fraction of mm. It means that at the photon energies of our interest, up to 6 GeV, most of pairs have a distance e^+e^- larger then the micro strip detector limitation.

Analysis of the cross section formula

We used the following expression for the pair production cross section /5/:

$$\frac{\partial^3\sigma_e}{\partial E_-\partial\Omega_-\partial\Omega_+} = \frac{\overline{\Phi}}{4\pi^2}\cdot\frac{[1-F(q)]^2}{\delta\cdot q^4}\cdot X_e; \qquad (2)$$

where X_e is $X_\parallel$ or $X_\perp$, so that σ_e is the cross section for photon polarization vector $\vec{e}$ parallel or perpendicular to the direction of the axis x, which is indicated with suffixes $_\parallel$ and $_\perp$ respectively.

$$X_\parallel + X_\perp = \frac{4}{k\delta\Delta_+\Delta_-}\left\{\left(E_+^2+E_-^2\right)\times\left[(\xi_+ + \xi_-)^2 + (\eta_+ + \eta_-)^2\right] + 2E_+E_-\frac{(\Delta_+ - \Delta_-)^2}{\Delta_+\Delta_-}\right\}; \qquad (3)$$

$$X_\parallel - X_\perp = \frac{-4}{k\delta}2E_+E_-\left[\left(\frac{\xi_+}{\Delta_+}+\frac{\xi_-}{\Delta_-}\right)^2 - \left(\frac{\eta_+}{\Delta_+}+\frac{\eta_-}{\Delta_-}\right)^2\right]; \qquad (4)$$

where $\overline{\Phi} = \alpha r_0^2 Z^2$; k is the photon energy; E_+ and E_- are energies of the positron and the electron; $\partial\Omega_+$ and $\partial\Omega_-$ are the elements of solid angles for the direction of a positron and an electron; Z is the charge of the target nuclei; α is fine structure constant; r_0 is the electron classical radius; $F(q)$ is the atomic form factor, $F(q) = 1/\left[1+\left(111qZ^{-\frac{1}{3}}\right)^2\right]$;

δ is the minimum momentum transfer, $\delta = k/(2E_+E_-)$; q^2 is the square of momentum transfer to the nuclei,

$$q^2 = (\xi_+ + \xi_-)^2 + (\eta_+ + \eta_-)^2 + \delta^2\Delta_+\Delta_- + (\Delta_+ - \Delta_-)\left(\frac{\Delta_+}{4E_+^2} - \frac{\Delta_-}{4E_-^2}\right); \qquad (5)$$

where we used the combinations $\Delta_\pm = 1 + \xi_\pm^2 + \eta_\pm^2$; the reduced plane angles $\xi_\pm$ and $\eta_\pm$ are defined as: $\xi_\pm = E_\pm x_\pm / L$ and $\eta_\pm = E_\pm y_\pm / L$; $x_\pm$ is the x coordinates of the positron (electron) on the detector plane; $y_\pm$ is the y coordinates of the positron (electron) on the detector plane; L is the distance between the target and the detector. The rest mass of the electron is used as a unit of the energy and momentum in this formula.

When doing integration of σ_{asym} over φ_{+-}, we must use the expression of α from φ_{+-}. The α is an odd function of φ_{+-}. It is easy to see that the terms with $\sin 2\omega_{\pm}$ will not contribute to the result after integration over φ_{+-} because they are proportional to $\sin 2\alpha$, to $\sin 2(\alpha - \varphi_{+-})$, and to $\sin(2\alpha - \varphi_{+-})$. As result the σ_{asym} is proportional to the cos of angle $2\omega_{\pm}$ like it was for angle $2\varphi_{+}$. Numerical integration shows that the asymmetry in terms of $\omega_{\pm}$ is considerably larger than in terms of φ_{+}. It is also important to note that asymmetry does not depend on possible beam profile deformation.

Calculations of the cross section and asymmetry

For the analysis of the expected asymmetry we wrote a code which provides three dimensional integration of the cross section of Eq. 2-8 over electron and positron solid angles for fixed energy sharing between $e^{+}e^{-}$.

As the first test we used the code to reproduce the total cross section of the pair production. The results become correct after we fixed the wrong sign in article /5/ in the expression of the q^2 and in the expression for $X_{\parallel} - X_{\perp}$. In the second test we compared our results for the asymmetry with analytical calculation /3/. It was done for 2 GeV photons, equal energies positrons and electrons, for the case of complete screening of the copper nuclei ($Z = 29$), at φ_{+-} angle integrated between 0 and $\pi - 4 \cdot \beta$ or $\Delta\varphi / \beta = 4$ (see Fig. 4 in /3/). Maximon's result is $R = \dfrac{\sigma(\varphi_1 = 0)}{\sigma(\varphi_1 = \pi/2)} \approx 1.45$ (reading from Fig. 4 in /3/). Our result (in terms of φ_{+-} angle) for the same conditions is 1.443.

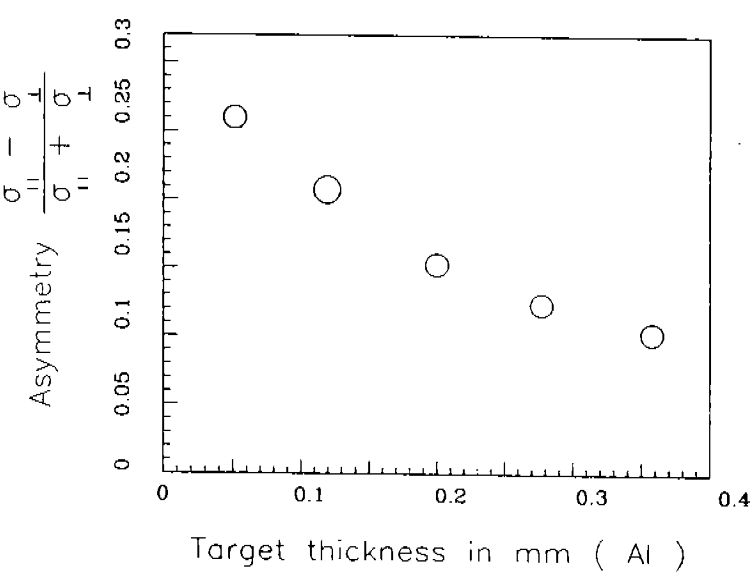

Figure 3. Effect of multiple scattering in the production target on polarization asymmetry.

Scheme of the Polarimeter

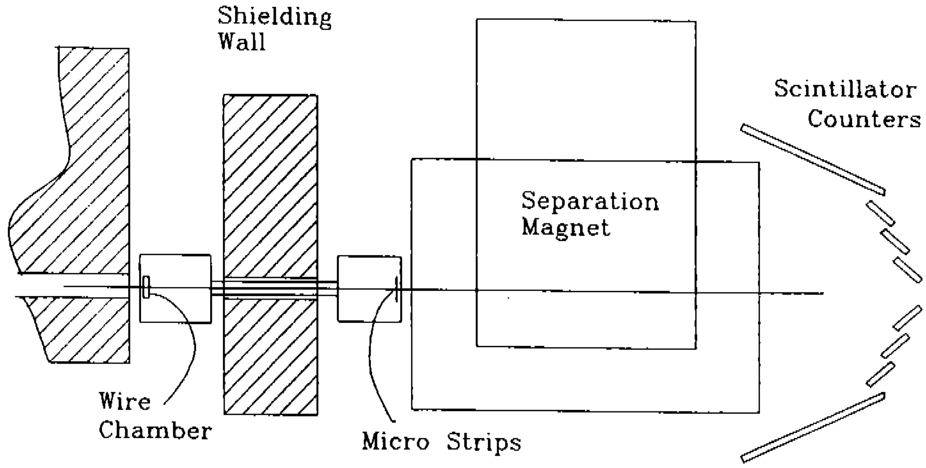

Figure 4. Layout of the photon Polarimeter

The Polarimeter needs a space of ~ 100 cm on the beam line. The distance from the conversion point of the photon to the detector of the electron/positron is about 80 cm.

The wire chamber is used as an active converter with a thickness of about 0.01% of the radiation length. It has an active area of about 20x20 mm. The gas windows are made from mylar film 5 microns thick. The field electrodes are located outside of an active area. The total thickness of the detector is 2 cm. The sensitive thickness will be about 1 cm of ethane gas at STP. The time resolution can be better than 50 nanoseconds.

The micro strip detectors have three layers for reconstruction of the coordinates of two particles. The size of the micro strip sensitive area is 10 x 10 mm. The inter strips distance is 50 microns which allows position resolution (sigma) of about 5 microns and two track separation of about 100 microns. The strips are connected to the flash ADC.

The μ metal shield between production target and the micro strip detectors protects pair components from the effect of the magnetic field.

The pair spectrometer used in our setup is an existing pair spectrometer located in the beam dump tunnel of Hall B.

Design considerations

The accuracy of the measurements of the angle correlation is limited by multiple scattering of the electron and positron in the pair production target. The opening angle between pair components is about $1/\gamma \sim 10^{-4}$. It requires us to keep the converter thickness ~ 0.01 % of the radiation length. This limitation is independent of the beam energy because multiple scattering is also inversely proportional to initial energy:

$$\theta_{+-} \approx \frac{mc^2}{E_\gamma} \quad \textit{must be} \gg \textit{than} \quad \theta_{mult} \sim \frac{14}{E_{+(-)}}\sqrt{t}\,; \qquad (9)$$

Conclusion

The proposed scheme of the photon Polarimeter provides a large analyzing power compact device which can work continuously during the experiment. The space on the beam line required is about 1 meter upstream of the CLAS pair spectrometer. The detectors used in proposed Polarimeter are well developed and can be constructed quickly. We also expressed asymmetry in terms of $\omega_{\pm}$, which has advantage that it does not depend on possible detector and beam asymmetries, and as was shown by numerical integration is larger than when it is expressed in terms of φ_{+}.

Additional analysis needs to be done on the intensity of the soft component of the photon spectra, which can give an increase of the detectors counting rate. The MC of the pair spectrometer acceptance needs to be done for more accurate calculation of the measurement time.

Acknowledgments

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