A POSSIBILITY TO MEASURE THE LINEAR POLARIZATION OF PHOTONS BY USING TRIPLET PHOTOPRODUCTION

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A review of currently available high-energy photon polarimeters, which use the effect of asymmetry of recoil electron yield during triplet photoproduction, is presented. The influence of both multiple scattering of electrons and δ-electron production in the target medium on the decrease of the experimentally observed asymmetry is considered. The graphs of effective asymmetry and the figure of merit versus target thickness are given.

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1. GENERAL CHARACTERISTICS OF THE METHOD

The possibility of measuring the linear photon-beam polarization by measuring the asymmetry of recoil electron yield in the process of triplet photoproduction $\gamma+e^- \to e^- + e^- + e^+$ has first been indicated by the KIPT group [1–4]. The cross section for the recoil electron yield has the form:

$$2\pi \frac{d\sigma}{d\varphi_1} = \sigma^{(t)} + P\sigma^{(l)} \cos 2\varphi_1 = \sigma^{(t)}(1 + P\Lambda \cos 2\varphi_1), \qquad (1)$$

where $\sigma^{(t)}$ is the total cross section for unpolarized photons, $\sigma^{(l)}$ is a part of cross section due to the photon polarization, P is the degree of linear photon-beam polarization, $\Lambda = \sigma^{(l)}/\sigma^{(t)}$ is the asymmetry of the yield of recoil electrons for $P=1$, φ_1 is the azimuthal angle.

The detailed analysis of this process and the development of a new method, which, in principle, allows measuring the linear photon-beam polarization in a wide range of photon energies from 25 MeV to several TeV, been performed in [5]. Possibilities of constructing tracking devices and high-speed counters for these measurements have been discussed.

About 90% of recoil electrons detectable at the experiment momentum $q \geq q_0 \approx 1mc$ have a polar angle $\Theta_1 \geq 20°$, that makes it possible to determine reliably their azimuthal angle φ_1. The values $\sigma^{(t)}$ and $\sigma^{(l)}$ increase, and the asymmetry Λ slightly decrease and tend to the asymptotical value with an increase in the photon energy ω. It is possible to choose such a region of kinematics' variables, where $\sigma^{(t)}$ and $\sigma^{(l)}$ are of the order of several mbn and the asymmetry is not less than $\Lambda \sim 0.11$.

2. THE USE OF THE TRACKING DEVICES

The tracking devices have a slow rate of statistics acquisition. To measure the photon-beam linear polarization by these devices, one should use all the range of allowed values for recoil electron moment with $q > q_0$..

The helium-filled streamer chamber SK–600 has been used in the course of a trial experiment [6] to measure the degree of linear polarization of a beam of coherent bremsstrahlung (CB) with an electron energy of 600 MeV in the LUE–2000 with a photon energy of 60 MeV at the coherent peak. The method developed was used in this experiment for the first time.

The photon polarization determined by means of the asymmetry method gives $P=0.68\pm0.94$.

For the determination of photon polarization by the least-squares method (LSM) and by the maximum likelihood method (MLM), two sets of events were used. The first one contained events with all θ_1 and the second contained events with $\theta_1 < 60°$. With these sets the following P values were obtained:

$P=0.53\pm0.45$ and $P=0.59\pm0.83$ (LSM),
$P=0.66\pm0.54$ and $P=0.66\pm1.18$ (MLM).

All five values for the degree of polarization, obtained by the method of asymmetry of recoil electrons of triplets, agree with $P=0.65\pm0.15$ determined on the basis of the coherent bremsstrahlung theory.

These results mean that the method under consideration can be used for measuring the photon-beam polarization. At the same time, it is clear that tracking devices cannot be effective monitors of the polarization of photon beams. For this purpose short-response time detectors should be used.

3. THE USE OF HIGH–SPEED COUNTERS

The polarimeters based on the method considered have been developed in Japan [7-8], Germany [9], and USA [10]. The scintillation counters with short response times were used for registration of both the recoil electrons and the e^+e^--pairs [7-8], [10]. Plastic plates of different thickness were used as targets. By the method under discussion the Tokyo group [11] measured the energy spectra of observed asymmetry (PΛ product) in the range of photon energies from 240 to 620 MeV with the use of a polarimeter, which was installed in the CB beam. This experiment has corroborated the validity of the method.

The mentioned experiments show that in the real case the observable asymmetry value of the yield of recoil electrons is less than the values predicted in [1-5]. Actually, the important effects which reduce the observable asymmetry of recoil electron yield in the polarimeter considered are the multiple scattering of slow electrons and the δ-ray production by fast particles of the e^+e^- pair produced in the medium of target, air, and counters.

The multiple scattering of charged particles in the matter is described by the Moliere theory [12]. According to this theory, for a rather thick layer of medium the

Gauss approximation to the angular distribution of particle deviation from the initial direction is valid

$$F(\Theta) = (\pi\Theta_0^2)^{-1/2} e^{-\Theta^2/\Theta_0^2}, \qquad (2)$$

where $\Theta_0 = \frac{15MeV}{E\beta^2}\sqrt{\frac{x}{X_0}}$, E is the particle energy in *MeV*, β is the particle velocity , X_0 is the radiation length, x is the particle path length in the matter.

After averaging the initial distribution (1) taking into account (2) we get

$$\begin{aligned} 2\pi\left\langle\frac{d\sigma}{d\varphi_1}\right\rangle &= \int d\varphi\, F(\varphi)(\sigma^{(t)} + P\sigma^{(l)}\cos 2(\varphi-\varphi_1)) \\ &= \sigma^{(t)}(1+P\Lambda e^{-\Theta_0^2}\cos 2\varphi_1). \end{aligned} \qquad (3)$$

The macroscopic cross section for the yield of recoil electrons produced by the photon at the point x after these electrons traversed the target layer of thickness *(L-x)*, is given by

$$\begin{aligned} \Sigma_{tr}(x,L) &= N_A\frac{\rho\,\bar{Z}}{\bar{A}}\int_x^L dx_1\sigma^{(t)}(1+P\Lambda e^{-b(L-x_1)}\cos 2\varphi_1) \\ &= N_A\frac{\rho\,\bar{Z}}{\bar{A}}\sigma^{(t)}\left((L-x)+P\Lambda\frac{1-e^{-(L-x)b}}{b}\cos 2\varphi_1\right). \end{aligned} \qquad (4)$$

Here $b = \left(\frac{15MeV}{E\beta^2}\right)^2\frac{1}{X_0}$, L is the target thickness in cm, $N_A\rho\,\bar{Z}/\bar{A}$ is the number of electrons in 1 cm^3 (ρ - density, N_A – Avogadro number, $\bar{Z},\bar{A}$ – averaged atomic number and atomic weight of medium, respectively). Considering that points of triplet production are uniformly distributed inside the target with the probability density $F_1(x) = \frac{1}{L}\Theta(x)\Theta(L-x)$, and averaging over the target thickness L, we shall obtain the following expression for the macroscopic cross section:

$$\begin{aligned} \Sigma_{tr}(L) &= \int F_1(x)\Sigma_{tr}(x,L)dx \\ &= N_A\rho\frac{\bar{Z}}{\bar{A}}\sigma^{(t)}\frac{L}{2}\left(1+P\Lambda\frac{2}{(Lb)^2}(e^{-Lb}+Lb-1)\cos 2\varphi_1\right). \end{aligned} \qquad (5)$$

As regards the production of δ-rays, they are mainly due to the Moliere and Bhabha scattering of fast particles from the e^+e^--pair by the electrons of the target. The total cross section for this process is given to an accuracy of $1/\gamma$[13,14] as

$$\sigma^{(ee)} = 2\pi r_0^2\frac{1}{t_{cut}\beta^2}, \qquad (6)$$

where r_0 is the classical radius of electron, m is the electron mass, $t_{cut} = E_{cut}/m - 1$;, $\beta^2 = 1-\gamma^{-2}$ $\gamma = E_1/m$, E_1 is the initial particle energy , E_{cut} is the minimal detectable energy of δ-electrons. The number of e^+e^- pairs which are produced at the point x of the target with an average charge $\bar{Z}$, is $\Sigma_{pair}(x) = xN_A\frac{\rho}{\bar{A}}\sigma^{(pair)}(\bar{Z})$. Each particle of the pair can produce the following number of δ–electrons in the remaining layer *(L-x)* of the target:: $\Sigma_\delta(x) = (L-x)N_A\rho\frac{\bar{Z}}{\bar{A}}\sigma^{(ee)}$. Taking into account that photons are producing e^+e^--pairs inside the target uniformly with the probability density $F_1(x)$, and averaging over x, we shall get the expression for the quantity of δ-electrons produced by each photon in the target of thickness L:

$$\begin{aligned} \bar{\Sigma}_\delta &= 2\int dxF_1(x)\Sigma_\delta(x)\Sigma_{pair}(x) \\ &= N_A\rho\frac{\bar{Z}}{\bar{A}}\sigma^{(ee)}N_A\frac{\rho}{\bar{A}}\sigma^{(pair)}(Z)\frac{L^2}{3}. \end{aligned} \qquad (7)$$

In the experiments considered, the events of triplet photoproduction and the events of e^+e^--pair photoproduction followed by δ-electron knocking-out cannot be distinguished. Therefore the effective macroscopic cross section will be equal to the sum of macroscopic cross sections of these two processes:

$$\Sigma_{eff} = \Sigma_{tr} + \bar{\Sigma}_\delta = \Sigma_{eff}^{(t)}\left(1+P\Lambda_{eff}\cos 2\varphi\right), \qquad (8)$$

where

$$\Sigma_{eff}^{(t)} = N_A\rho\frac{\bar{Z}}{\bar{A}}\sigma^{(t)}\frac{L}{2}\left(1+DL\right) \qquad (9)$$

and the effective azimuthal asymmetry equals

$$\Lambda_{eff} = \Lambda\frac{2}{(Lb)^2}\frac{e^{-Lb}+Lb-1}{1+DL} \qquad (10)$$

Here the parameter D is:

$$D = \frac{2}{3}\sigma^{(ee)}N_A\frac{\rho}{\bar{A}}\frac{\sigma^{(pair)}(\bar{Z})}{\sigma^{(t)}}. \qquad (11)$$

The parameters b and D entering into expressions (8)–(11) are strongly dependent on the minimal observable momentum of electron, q_0. For the following estimations it is reasonable to set E and E_{cut} entering, respectively, into (2) and (6), equal to $E = E_{cut} = \sqrt{q_0^2+m^2}$. In our numerical calculations we shall use the approximation from [14] for $\sigma^{(pair)}(Z)$ and the asymptotic expression from [4, 5] for $\sigma^{(t)}$. We assume that the target is a plastic plate (polystyrene, C_8H_8, ρ=1.032 g cm^{-3}, X_0=42.4 cm, $\bar{Z}/\bar{A} \approx 7/13$) of different thickness.

Fig. 1 shows the effective asymmetry Λ_{eff} (Eq. (10)) as a function of target thickness. Curves 1to 3 correspond to different minimal observable moments of the electron, q_0.. The dashed curves 1a to 3a correspond to the case, where the effect of δ-electron production (D=0) with the same q_0 values as for curves 1 to 3 was neglected. The difference between solid and dashed curves shows the importance of taking into account the δ-electron production effect. It can be seen that the selection of the events with a greater q_0 value is appears more effective for measuring the photon-beam polarization by the method under consideration.

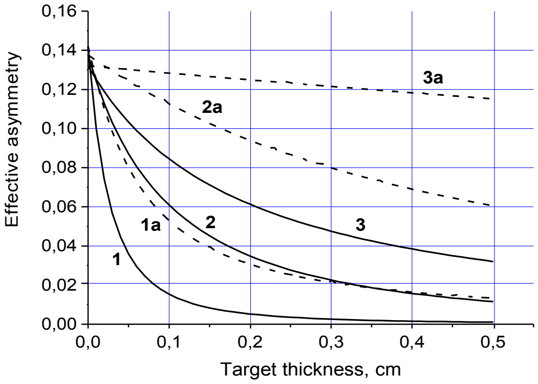

Fig. 1. *Effective asymmetry as a function of polystyrene target thickness. Curve* 1 *corresponds to* q_0=1 *MeV/c,* 2 *–* q_0=2 *MeV/c,* 3 *–* q_0=5 *MeV/c. The dashed curves (1a to 3a) correspond to the D=0 case with the same* q_0 *values as for curves 1 to 3*

An important characteristic of the experiment is the figure of merit, $F = \Lambda^2_{eff}\Sigma_{eff}$. It is well known that relative error of the measurements is minimal if the figure of merit is maximal.

Fig. 2 shows the figure of merit as a function of target thickness for different q_0 values. The units used are the number of recoil electrons and δ-electrons emerging from the target per initial photon. It is evident that for the most of experiments [7,8,11], where the scintillation counters of recoil electrons were tuned to register the events with q>1 MeV/c, it would be more effective to use the target with a thickness of about 1 mm.

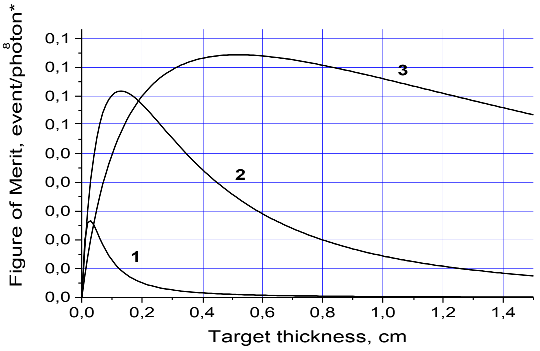

Fig. 2. *Figure of merit,* $\Sigma^{(tr)}_{eff}\Lambda^2_{eff}$*, as function of polystyrene target thickness. The curve* 1 *corresponds to* q_0=1 *MeV/c,* 2*–*q_0=2 *MeV/c,* 3*–*q_0=5 *MeV/c*

In conclusion, we would like to note that up till now no sequential analysis of the whole set of effects which are accompanying the measurements of photon-beam linear polarization by the method considered has not been performed. This task demands for numerous calculations to be done with the help of the GEANT code. So, the present work should be regarded as information on only preliminary results of the study.

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