COMPTON SCATTERING OF POLARIZED ELECTRON BEAM

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Compton scattering of polarized photon beam by polarized relativistic electron beam is considered in the report. The numerical comparison of Compton scattering intensity and polarization intensity has been carried out for different directions of initial photon and electron polarization. It was shown that the use of polarized beam leads to considerable increasing of Compton scattering intensity in the range of high photon energy for initial electron beam energy beginning from 5 GeV. The effect of initial polarization of photon and electron beams to final polarization of scattered photon beam was considered.

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1. INTRODUCTION

Intensive sources of short-pulse X-rays are in application in a very wide range of the modern science and technology. For few recent years a new generation of sources of hard X-rays based on interaction of electrons accumulated in a storage ring with an intensive laser beam - Laser Electrons Storage Rings (LESR) is begun to develop. One of the traits of these sources is a medium energy of the electron beam (40…400 *MeV*).

As it was shown in [1,2] in the process of γe - collisions the polarization effects have its own place. The following effects are important:

- with a modification of direction of initial beam polarization of both interacted beams an energy spectrum of scattered radiation can be varied essentially [2];
- a scattered beam of high-energy photons can have various polarization directions. Varying initial direction of polarization, it is possible to receive a photon beam with various directions of polarization [2];
- at interaction of unpolarized electrons and polarized photons beams the electron beam is polarized [3].

Until now all these effects were considered in application to the high-energy electron beam (10 *GeV* and more) used in linear accelerators ($\gamma\gamma$ - colliders). In the present work the influence of polarization effects on the spectrum of scattered radiation and generation of intense polarized X-rays in storage rings with the energy of an electronic beam in the range from 40 to 400 *MeV* is considered.

2. TASK SETTING

Let us consider interaction of relativistic electrons with energy E_0, moving along the axis Z in the laboratory coordinate system (LCS), with photons with energy ω_0, moving at an angle α to the axis Z.

Let θ and φ are resulted polar and azimuth scattering angles of scattered photon with a momentum k in LCS.

The polarization state of final photons is set by parameters of the Stokes ξ_i (i=1,2,3), determined relatively to LCS axes. Here ξ_2 is average helicity (degree of circular polarization), and $(\xi_1^2+\xi_3^2)^2$ is degree of linear polarization.

The polarization state of an initial photons is set by values P_c, P_t and γ, where P_c is the degree of circle polarization (equal to an average helicity), P_t is the degree of linear polarization, γ is the azimuthal angle of a direction of maximum linear polarization.

The polarization state of an initial electron is set by a vector of polarization ζ, the longitudinal component of this vector is $\zeta_{||} = 2\lambda_e$, where λ_e is the average helicity of an electron.

Let us estimate the effect of the initial polarization characteristics of interacting particles to such characteristics of dispelled radiation, as an energy and polarization spectrum.

3. SCATTERED RADIATION SPECTRUM

As was shown in [4], the differential cross section of a linear Compton scattering in LSC is given by:

$$\frac{d\sigma}{dy}=\frac{2\sigma_0}{x\sigma_c}[1-y+\frac{1}{1-y}-4r(1-r)+2\lambda_e P_c rx(1-2r)(2-y)] \quad (1)$$

where ω is the energy of scattered photons,

$$\sigma_c=\sigma_c^{np}+2\lambda_e P\sigma_1,$$

$$\sigma_c^{np}=\frac{2\sigma_0}{x}[\{1-\frac{4}{x}-\frac{8}{x^2}\}\ln(x+1)+\frac{1}{2}+\frac{8}{x}-\frac{1}{2(x+1)^2}],$$

$$\sigma_1=\frac{2\sigma_0}{x}[(1+\frac{2}{x})\ln(x+1)-\frac{5}{2}+\frac{1}{x+1}-\frac{1}{2(x+1)^2}],$$

$$x=\frac{4E\omega_0}{m_e^2c^4}\mathrm{Cos}^2\frac{\alpha}{2},\quad y=\frac{\omega}{E_0}\le y_m=\frac{\omega_m}{E_0}=\frac{x}{(x+1)},$$

$$r=\frac{y}{x(1-y)},\quad \sigma_0=\pi\left(\frac{e^2}{m_ec^2}\right)=2.5\cdot10^{-25}cm^2.$$

Cross section depends on the initial direction of polarization of electron and photon beams. This can result in the essential change of energy distribution of scattered radiation.

The energy of a scattered photon can be written via a scattering angle of the photon, using the law of conservation of energy, as follows:

$$y=\frac{y_m}{[1+(\theta/\theta_0)^2]}. \quad (2)$$

We obtain the differential cross section of Compton scattering depending on the scattering angle of a photon by substitution (2) in (1).

Writing a scattering angle of a photon θ as ω:

$$\theta(\omega)=\theta_0\sqrt{\frac{\omega_m}{\omega}-1} \quad (3)$$

we obtain the distribution of probability of a photon scattering with relativistic electron in a solid angle unit depending on the energy of scattered photons (spectral intensity of Compton scattering).

In Fig. 1, 2, 3 the spectral intensity obtained in such a way is depicted for different polarization states for initial energy of electrons $E_0 = 270$ *GeV*, $E_0 = 5$ *GeV*, and $E_0 = 100$ *MeV*.

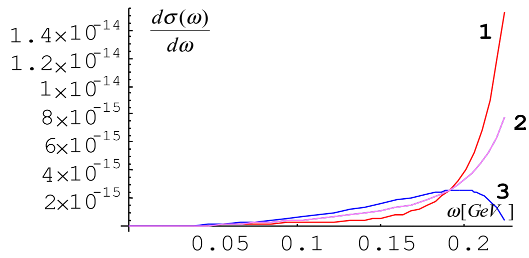

Fig.1. Spectral intensity versus the energy of a quantum, for the initial energy of electrons E_0 = 270 GeV. 1- λ_e = 0.5, P_c = -1; 2 - λ_e = 0. P_c= -1; 3- λ_e = -0.5, P_c = -1

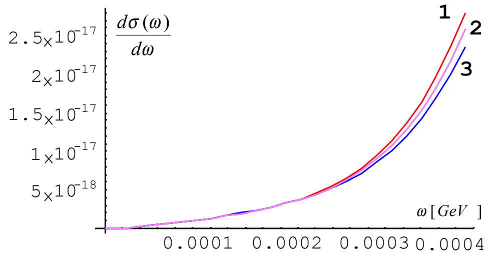

Fig.2. Spectral intensity versus the energy of a quantum, for the initial energy of electrons E_0 = 5 GeV

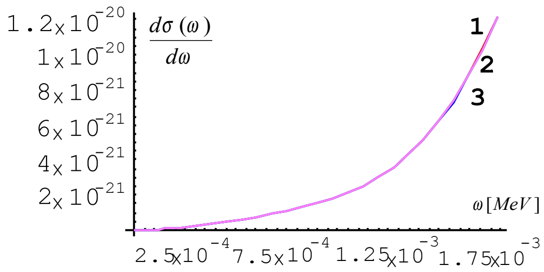

Fig.3. Spectral intensity depending on the energy of a quantum, for the initial energy of electrons E_0 = 100 MeV

It is clear from the figures that the influence of polarization effects to the differential cross section of Compton scattering becomes noticeable for initial energies of an electron beam E_0 of about 5 *GeV*. Thus application of polarized beams for change of a spectrum of scattered photons at energies of electrons E_0 less then 5 *GeV* is out of expediency.

4. *PRODUCTION OF POLARIZED HIGH ENERGY PHOTONS*

As it was already noted at usage of polarized beams during Compton scattering it is possible to produce intensive high-energy polarized photon beams. Let us consider this process in more detail.

The average degree of linear polarization of high-energy photons is set by expression [3]:

$$<\xi_3> = \frac{2r^2 P_t \mathrm{Cos}2\gamma}{1-y+\dfrac{1}{1-y}-4r(1-r)+2\lambda_e P_c rx(1-2r)(2-y)}.$$

The dependence $<\xi_3>$ on the energy is shown in Fig. 4,5 for different energies of an initial electron for initial photon energy ω_0 =1.17 *eV*.

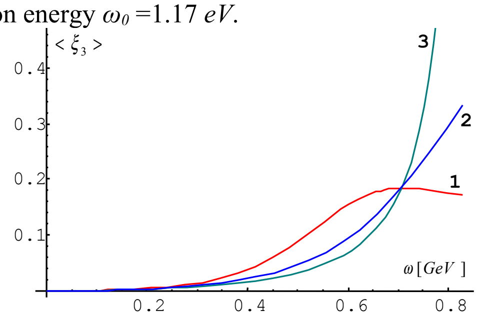

Fig.4. Average degree of linear polarization versus the photon energy, for initial energy of electrons E_0 = 270 GeV; P_t = 1; γ = 0; 1 - λ_e = 1/2. P_c = -1; 2 - λ_e = 0. P_c = -1; 3 - λ_e = -1/2. P_c= -1

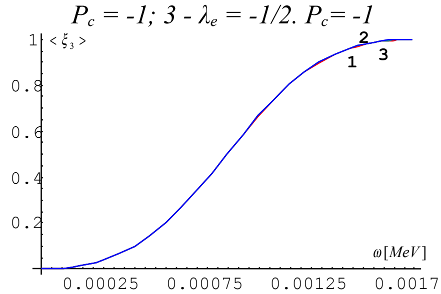

Fig.5. Average degree of linear polarization versus the energy of photons, for initial energy of electrons E_0 = 100 MeV

An average degree of circular polarization of a high-energy quantum is set by expression:

$$<\xi_2> = \frac{2\lambda_e rx[1+(1-y)(2r-1)^2 - P_c(2r-1)[(1-y)^{-1}+1-y]}{1-y+\dfrac{1}{1-y}-4r(1-r)+2\lambda_e P_c rx(1-2r)(2-y)}$$

The dependence of $<\xi_2>$ on the energy is represented in Fig. 6,7 for different energies of an initial electron.

Let us consider interaction of an electron beam with the energy E_0=100 *MeV* with laser photons with energy ω_0 = 1.17 *eV* (Nd:YAG laser) having different directions of polarization. Our purpose is to define a number of scattered photons with a determined direction of polarization i.e. polarization intensity of scattered photons. With dependence of a degree of linear ξ_3 and circular ξ_2 polarizations on the energy of scattered photons and also with dependence of a number of scattered photons on their energy ω (spectral intensity), we can find the dependence of probability of producing particular polarization photon states for linear ξ_3 and circular ξ_2 polarizations depending on their energy: $\frac{dN_{\gamma p}}{dP}$.

Assuming that photon and electron beams are cylindrical with equal radius, an angle of interaction equal to zero (head-on collision), we can write the expression for the polarization intensity of scattered radiation:

$$N_{\gamma p} = \frac{n_{ph} n_e c}{\pi C \sigma_{ph}^2} \frac{dN_{\gamma p}}{dp},$$

where n_{ph} is the number of photons in a laser flash, n_e is the number of electrons in the bunch, σ_{ph} is the radius of photon beam, c is the velocity of the light, C is the ring circumference.

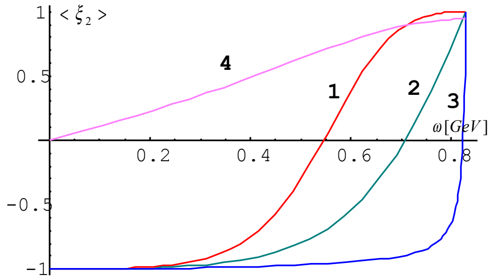

Fig.6. Average degree of circular polarization versus the energy of scattered photons, for the initial energy of electrons E=270 GeV; 1 - λ_e = ½, P_c = -1; 2 - λ_e = 0, P_c = -1, 3 - λ_e = -1/2, P_c = -1, 4 - λ_e = ½, P_c = 0

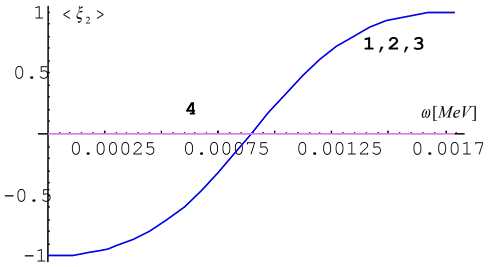

Fig.7. Average degree of circular polarization versus the energy of scattered photons, for the initial energy of electrons E=100 GeV

In a Fig. 8, 9 normalized polarization intensity of scattered photons are represented for a circular (Fig. 8) and linear (Fig. 9) polarizations, for initial energy of electrons E_0 = 100 *MeV*. Calculations have showed that the polarization spectrum for circular polarization does not depend on the initial polarization of the electron beam.

Thus, using the polarized initial photon beam, it is possible to produce intense polarized X-rays in the electron storage ring with medium energies of the beam.

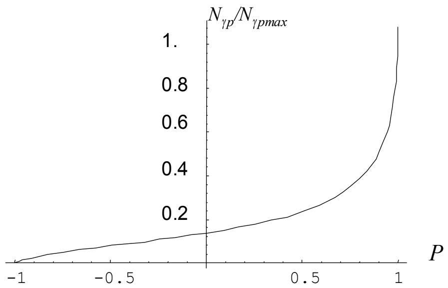

Fig.8. Numbers of scattered polarized photons with circular polarization for λ_e = 0, P_c = -1 and λ_e = ½, P_c = -1

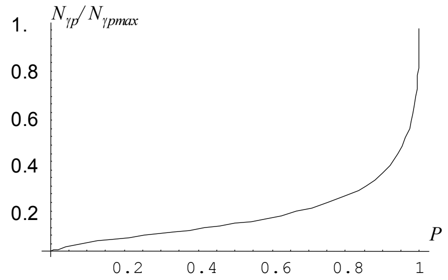

Fig.9. Numbers of scattered polarized photons with linear polarization for λ_e = ½, P_c = -1

5. CONCLUSION

Calculations showed that the influence of polarization effects on the differential cross section of Compton scattering becomes noticeable beginning from the initial electron beam energy E_0 of about 5 *GeV*. Thus, the use of polarized beam for changing of Compton spectra is out of sense for the electron beam energy E_0 is less then 5 *GeV*. It was shown, that with different initial direction of the laser beam polarization the production of intense X-rays with a high degree of polarization is possible.

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КОМПТОНОВСКОЕ РАССЕЯНИЕ ПОЛЯРИЗОВАННОГО ЭЛЕКТРОННОГО ПУЧКА

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Рассматривается комптоновское рассеяние поляризованного фотонного пучка на поляризованном релятивистском электроне. Рассмотрено дифференциальное сечение комптоновского рассеяния с учетом эффектов поляризации. Было сделано сравнение для различных поляризаций. Показано, что применение поляризованных пучков приводит к значительному увеличению спектральной интенсивности фотонов, в области высоких энергий, для начальной энергии электронного пучка от 5 ГэВ. Рассмотрено влияние поляризации начальных фотонов на поляризацию комптоновских фотонов.

КОМПТОНІВСЬКЕ РОЗСІЯННЯ ПОЛЯРИЗОВАННОГО ЕЛЕКТРОННОГО ПУЧКА

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Розглянуто комптонівське розсіяння фотонного пучка на поляризованому релятивістському електроні. Розглянуто диференційний перетин комптонівського розсіяння з урахуванням ефектів поляризації. Доведено, що застосування поляризованих пучків призводить до значного зросту спектральної інтенсивності фотонів, в області високих енергій для початкової енергії електронного пучка від 5 ГеВ. Розглянуто вплив поляризації початкових фотонів на поляризацію комптонівських фотонів.