VLEPP; THE CONVERSION SYSTEM FOR OBTAINING HIGHLY POLARIZED ELECTRONS AND POSITRONS

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Abstract

The conversion system which allows the obtaining of electrons and positrons with a degree of polarization of about 80-90% is considered.

The general idea of the method is that the circular polarized photons are converted into e^+, e^- on a target. Circular polarized photons are radiated by the particles in the helical ondulator. On the high boundary of the energy spectrum, e^+ and e^- from the pairs and Compton betas have polarization of photons.

Some technical details and parameters of the system are discussed.

Introduction

Experiments with polarized particles permit to study the more interesting details of the interaction than those with unpolarized ones. It is evident that such experiments will be interesting at a high energy because the cross-section of the weak interaction increases and becomes comparable with the cross-section of the electromagnetic interaction (according to contemporary ides, at ~100 GeV, VLEPP). It is important to use polarized particles for separation of the effects from the weak interaction of nonconservate parity and the electromagnetic interaction. The difficulties to obtain the polarized particles at a high energy are obvious. Though there are some proposals about the passage of spin resonance in cyclic accelerators. But the question on a high-intensity source of polarized particles, especially e^+, has still left open.

It is considered here the conversion system which enables one to obtain both polarized e^+, e^- with the conversion efficiency more than unity. Nonpolarized bunches of e^+, e^- can be used at the initial ones and after their passage through the conversion system they are not lost. The degree of polarization of the produced particles can be about 80-90%.

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As to the VLEPP, after acceleration the particles are injected into the storage ring where the bunch is cooled by synchrotron radiation. After cooling the necessary polarization is prepared and then the beam is ejected to VLEPP.

Below we discuss the quantitative characteristics of the method proposed and some technical details.

Interaction of polarized photons with substance

The more interesting property of the interaction of high energy polarized photons is the correlation between polarization of initial photons and final e^+, e^- from the pairs and Compton betas /1,2,3/. Just near the high boundary of energy of e^+, e^- the polarizations are equal. The behavior of polarization as a function of the particle energy is shown in Fig. 1 in Ref. /1/. The view of the graph is practically independent of the photon energy. That is why it is necessary to select the energy of final particles near the maximum of the energy spectrum. In Fig. 3 one can see the mean polarization as a function of the fractional energy from the maximum at $\hbar\omega / mc^2 = 10$. At highest $\hbar\omega / mc^2$ the mean degree of polarization, as seen in Fig. 2, is higher at the same fractional energy.

Really, there are

$$\frac{\int_{E_{max}}^{E} \xi(E) \frac{d\sigma}{dE} dE}{\int_{E_{max}}^{E} \frac{d\sigma}{dE} dE} \quad \text{and} \quad \frac{\int_{E_{max}}^{E} \frac{d\sigma}{dE} dE}{\int_{E_{max}}^{0} \frac{d\sigma}{dE} dE}$$

on the graphs.

An analogous graph can be plotted for Compton electrons which are being produced with the pairs /3/. The directions of polarizations of Compton betas and e^+, e^- from pairs are equal. One can see that at the Compton effect $E_{max} - mc^2 = \hbar\omega$ and for the electrons in pair $E_{max} - mc^2 = \hbar\omega - 2mc^2$ So for production of betas it is possible to collect the Compton electrons having the maximal energy by 1 MeV higher than the e^- energy from pairs. In the photons have the energy for which the Compton effect is negligible, one can collect betas from pairs.

The degree of polarization of e^+, e^- is limited by degree of polarization of the photons from the ondulator, so it is desirable to have it as high as possible. As we shall see, the ondulator radiation satisfies the requirements.

It is clear that the number of photons

radiated by each initial particle must be maximal for compensation of the non-full energy interval of collected particles and limited efficiency of conversion gammas into pairs.

Production of circular polarized photons

The properties of non-coherent ondulator radiation are considered in detail in /4/. Circularly polarized photons are produced in helical fields of minimal period. Much more interesting is to obtain such fields with the help of the usual helical static fields and the electromagnetic waves. It may well be that the method of gamma production in helical crystals can be useful in future.

The main parameters for production of ondulator radiation are:

$$\beta_\perp = \frac{eH_\perp \lambda_0}{2\pi mc^2 \gamma}, \quad \Omega = \frac{2\pi c}{\lambda_0}, K, L$$

where $H_\perp$ is the field in the ondulator, the period, $L = K\lambda_0$ the ondulator length, K the number of periods. The full radiation intensity of particles is $I = 2e^2\Omega^2(\beta_\perp\gamma)^2/3c$ The angular and spectral distributions of ondulator radiation at $K \gg 1$ can be found in /4/.

At the fields $H_\perp^{opt} = \frac{\pi\sqrt{2}\, mc^2}{e\lambda_0}$ the first harmonic of intensity reaches its maximum, at this field $\beta_\perp\gamma = 1/\sqrt{2}$. As shown in /4/, the degree of polarization can be about 95%. For $\lambda_0 = 1$ cm $H_\perp^{opt} \lesssim 10^4$ Oe for the magnetic strength and $1.5\cdot10^6$ V/cm for the electromagnetic-wave ondulator. Really for the best properties of ondulator radiation it is necessary to use the fields smaller than $H_\perp^{opt}$.

The number of radiated photons at the first harmonic is

$$N_q \simeq \frac{0.5\, I \frac{L}{c}}{\frac{4}{3}\hbar\Omega\gamma^2} = \frac{e^2\Omega L}{8\hbar c^2}$$

where $\frac{4}{3}\hbar\Omega\gamma^2$ is the photon energy.

Let us consider now the ondulator with the parameters: $\lambda_0 = 1$ cm, fields are optimal, $L = 300$ m, beam energy 100 GeV (VLEPP), then

$$N_q \approx 170$$

The peak width of radiation at the first harmonic is 15% frequency of maximum $\omega_m = \frac{4}{3}\Omega\gamma^2$. For monochromatization of the particle energy one can use the threshold effects of pair creation. Because it is necessary to generate a lot of quata the ondulator must be long ($H_\perp$ is limited by production of higher harmonics).

Coherent radiation

All this is right if radiation is noncoherent. In /5/ the authors studied the conditions which provide the coherent radiation by the particles in the ondulator. In this case the fluctuation of density becomes unstable, so that the coherent radiation becomes dominative after passage of some length /6/. To shorten this length the method suggested in /7/ can be used.

This effect is very useful to produce the ondulator of short length. It is necessary then to operate with the parameters of the ondulator for obtaining the number of quanta which does not vary from cycle to cycle.

Probably the utilization of helical crystals with a period of about 100 Å will enable one to generate circular polarized gammas with the necessary energy by a 1 GeV beam.

Target and collection of the particles

For the full utilization of gammas the target of maximal thickness must be taken. But all this contradicts the requirements of the minimum of the energy and angular dispersion. If the thickness of a target is t, the radiation length is X_0, the angular dispersion of multiscattering in the target is $\theta \sim \frac{21}{p\beta c}\sqrt{t/X_0}$. As one can see, the angle grows as $\sqrt{t}$, and the number of quanta as t. The energy spread is about $(2\rho\ell(\mathrm{cm}^2)t)/(\hbar\omega - 2mc^2)$. If there is the accelerating field next to the target, the energy and angular dispersions become smaller with an increase of the particle momenta. The accelerating field strength must be high because there are a lot of particles after the target, which have the high total charge and therefore the high field strength of about 100 kV/cm. It is possible now to achieve the field strength of about 1 MeV/cm /8/. One can make a few target and collect the particles from each of them.

To obtain the conversion coefficient k (for the particles) it is necessary to realize

$$N_q \eta_p \eta_E \eta_\varphi \geq k$$

where η_p is the efficiency of pair conversion $\sim t/X_0$, η_E some share of collected particles with the energy, η_φ the part of angular acceptance. After the target the particles have the angular spread of about $\bar{\theta}$.

The direction of the spin for each particle is determined by the process of creation ($\sim mc^2/\hbar\omega$) and multiscattering in the target. After acceleration the mean degree of polarization is determined by a degree of polarization for gammas from the ondulator. The multiscattering is not capable to make the degree of polarization to be lower.

Let us consider the scheme of conversion system like that in Fig. 4. The beam 1 after travelling through the ondulator 2 is corrected with a small field and goes away. Gammas from the ondulator creats e^+, e^- on a target 3. The lens 4 has axial symmetry and short focus. It makes the angular divergence lower. 6 is the accelerator which makes the same energy of the particles as that needed for storage ring 6. The particles after their passage through accelerator 6 have the longitudinal polarization. The storage ring has the equilibrium spin-orbit trajectory as it is shown in /8/. The injection occurs at the place where the particles have the longitudinal polarization. 5 is the energy selector (RF cavity).

After cooling in the storage ring by synchrotron radiation the necessary polarization is prepared and ejected to VLEPP. The short longitudinal size is prepared in the storage ring or after ejection, before VLEPP, with the system of magnets and the necessary energy head-tail spread, this spread being prepared with the additional radiofrequency cavity.

It is clear that one can prepare the rectangular polarization before the storage ring.

The temperature of the target can be made not high by enlarging the area of the spot on the target where the gammas are converted (for example, by the angular spread of the sections of the ondulator).

Of course, this scheme demonstrates the only method of realization of the general idea on the possibility of obtaining the polarized e^+e^- with circular gammas.

In conclusion we adduce some oriental figures for the VLEPP conversion system:

Energy	100 GeV
Length of the beam	1 cm
Number of particles	10^{12}
Field strength	$9 \cdot 10^3$ Oe
Period	1 cm
Length of ondulator	300 m
Number of quanta/particle	170
Energy of quanta	6 MeV
Thickness of the target	0.1 rad length
The mean degree of polarization	85%
Conversion coefficient	1

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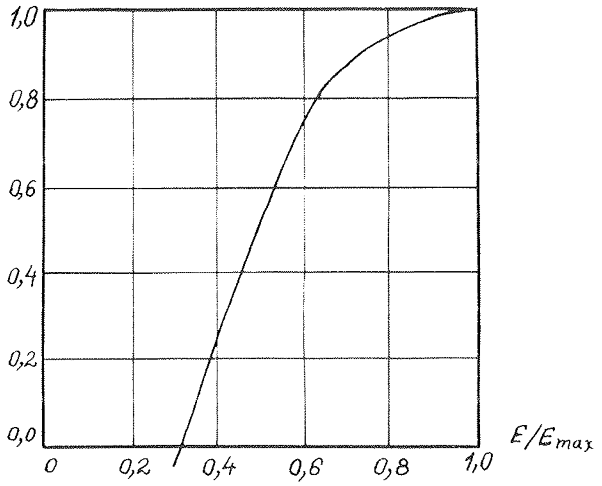

Fig.1. The longitudinal electron or positron polarization as a function of its energy /1/.

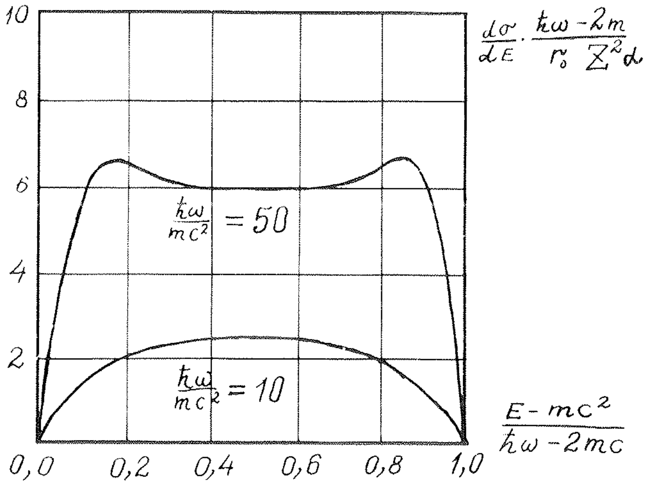

Fig.2. The differential cross-section of generated electrons and positrons /2/.

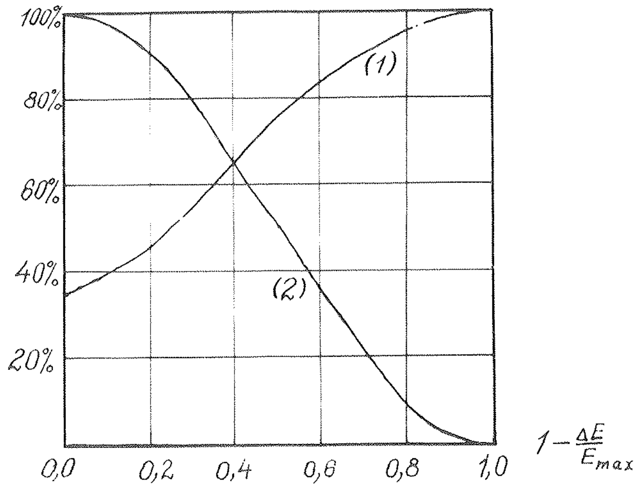

Fig.3. The mean polarization (1) and percentage of particles (2) as a function of the energy interval from the maximum particle energy.

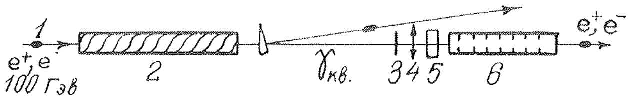

Fig.4. Testing conversion system (the comments are in the text).