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ИНСТИТУТ ЯДЕРНОЙ ФИЗИКИ
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ON POSSIBILITY TO OBTAIN COLLIDING $\gamma\gamma$ - AND γe - BEAMS WITH HIGH ENERGY AND LUMINOSITY USING ACCELERATORS OF VLEPP TYPE

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ABSTRACT

It is shown that, using the designed linear accelerators with high-energy colliding e^+e^- -beams, one can obtain, by laser-light scattering, the colliding $\gamma\gamma$ and γe beams with energy and luminosity of the same order as for e^+e^- -beams.

АННОТАЦИЯ

Показано, что на базе проектируемых линейных ускорителей со встречными e^+e^- -пучками с высокой энергией можно получить при рассеянии света лазера встречные $\gamma\gamma$ и γe пучки с энергией и светимостью того же порядка, что и для e^+e^- -пучков.

1. It is clear now that obtaining colliding e^+e^- beams with the energy $E=\sqrt{s}/2 \gtrsim$ 100 GeV is only perspective at linear accelerators. Such machines are being designed now in Novosibirsk (VLEPP, E = 100÷300 GeV [1]) and in the USA (SLAC Linear Collider (SLC), E = 50 GeV [2]). Below we show that it is possible on their ground to realize colliding $\gamma\gamma$ and γe beams with high energy and luminosity.

Physical problems which can be studied in $\gamma\gamma$ and γe collisions are no less interesting than in e^+e^- collision; they are important as an addition to the problems to be studied in pp, ep and e^+e^- collisions on accelerators of the next generation. In comparison with the two-photon physics in e^+e^- collisions the proposed version is much richer in its possibilities.

2. High energy photons can be obtained by Compton scattering of laser light on an electron beam. This method is well known [3] and has been realized at SLAC [4]. However, the conversion coefficient of electrons to photons k was small ($k \sim 10^{-7}$) and the number of photons obtained was only sufficient for experiments with a stationary target.

In this work we found out that at VLEPP and SLC it is possible to obtain photons with the energy $\omega \sim E$ and in amount close to a number of electrons at sufficiently good light focusing. It appears possible owing to a number of new properties of these beams:

a) the beams will only be used once and the rate of repetition will be low (10÷200 Hz);

b) very small beam size (length 0.1÷1 cm, square of beam's cross section $\sim 10^{-7}$ cm^2);

c) high energy of electrons (50 ÷ 300 GeV).

The suggested scheme is shown in Fig. 1: the light of a powerful laser is focused on an electron beam at some distance b from an interaction point O; the created energetic photons follow along initial electron trajectories

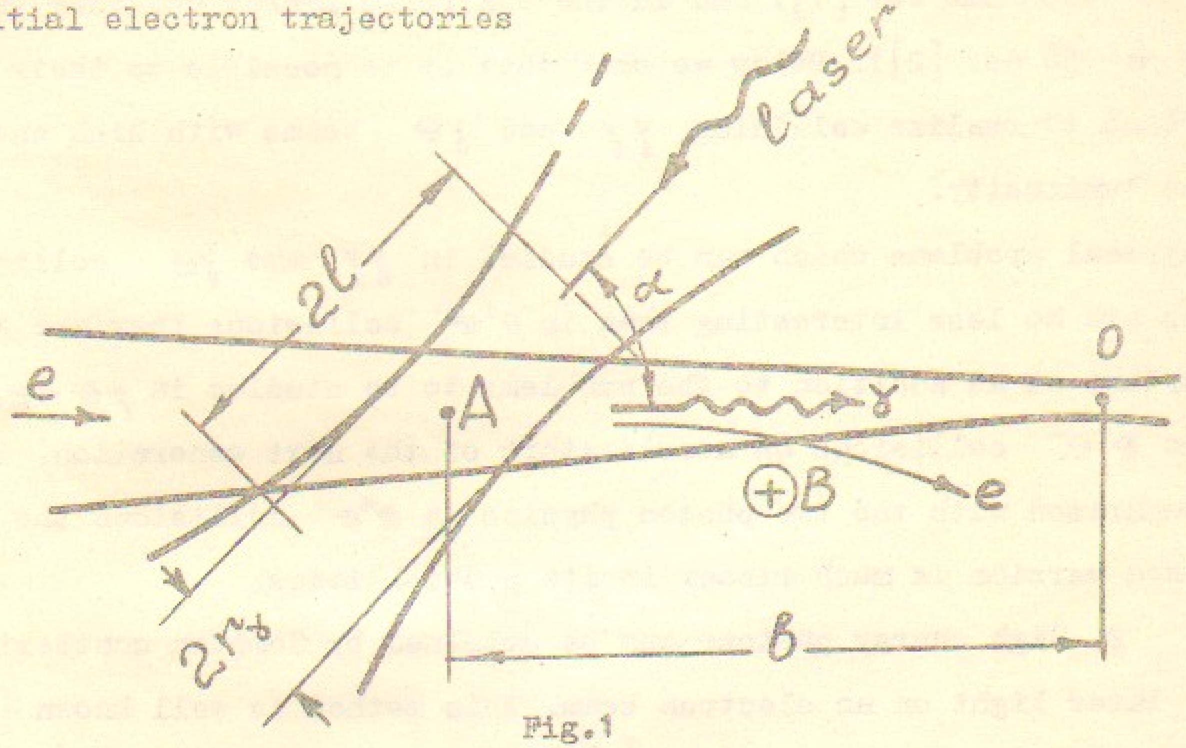

Fig.1

to the interaction point; electrons are bent by a magnetic field.

3. Below we present a few useful formulae for scattering a photon with the energy $\omega_0 \sim 1eV$ by an electron with the energy $E \sim$ 100 GeV at a collision angle $\alpha \ll 1$ [5,3]. The main fraction photons fly along electron trajectories at small angles $\theta \ll 1$. Their energy

$$\omega = \frac{\omega_m}{1+(\theta/\theta_0)^2}; \; \omega_m = \left(1-\frac{m_e^2}{W^2}\right)E; \; \theta_0 = \frac{W}{E}; \; W = \sqrt{4E\omega_0 \cos^2(\alpha/2) + m_e^2} \approx \approx (1.5 \div 2.5)\, m_e \qquad (1)$$

The energy distribution of scattered photons is defined by cross section (r_0 is a classical radius of an electron) (see Fig. 2)

$$\frac{d\sigma}{dy} = \frac{2\sigma_0}{x}\left[\frac{1}{1-y} + 1 - y - \frac{4y}{x(1-y)} + \frac{4y^2}{x^2(1-y)^2}\right], \; x = \frac{W^2}{m_e^2}, \; y = \frac{\omega}{E}, \; \sigma_0 = \pi r_0^2. \qquad (2)$$

The fraction of photons with the energy close to ω_m grows with E and ω_0 growth. The angular distribution for photons is

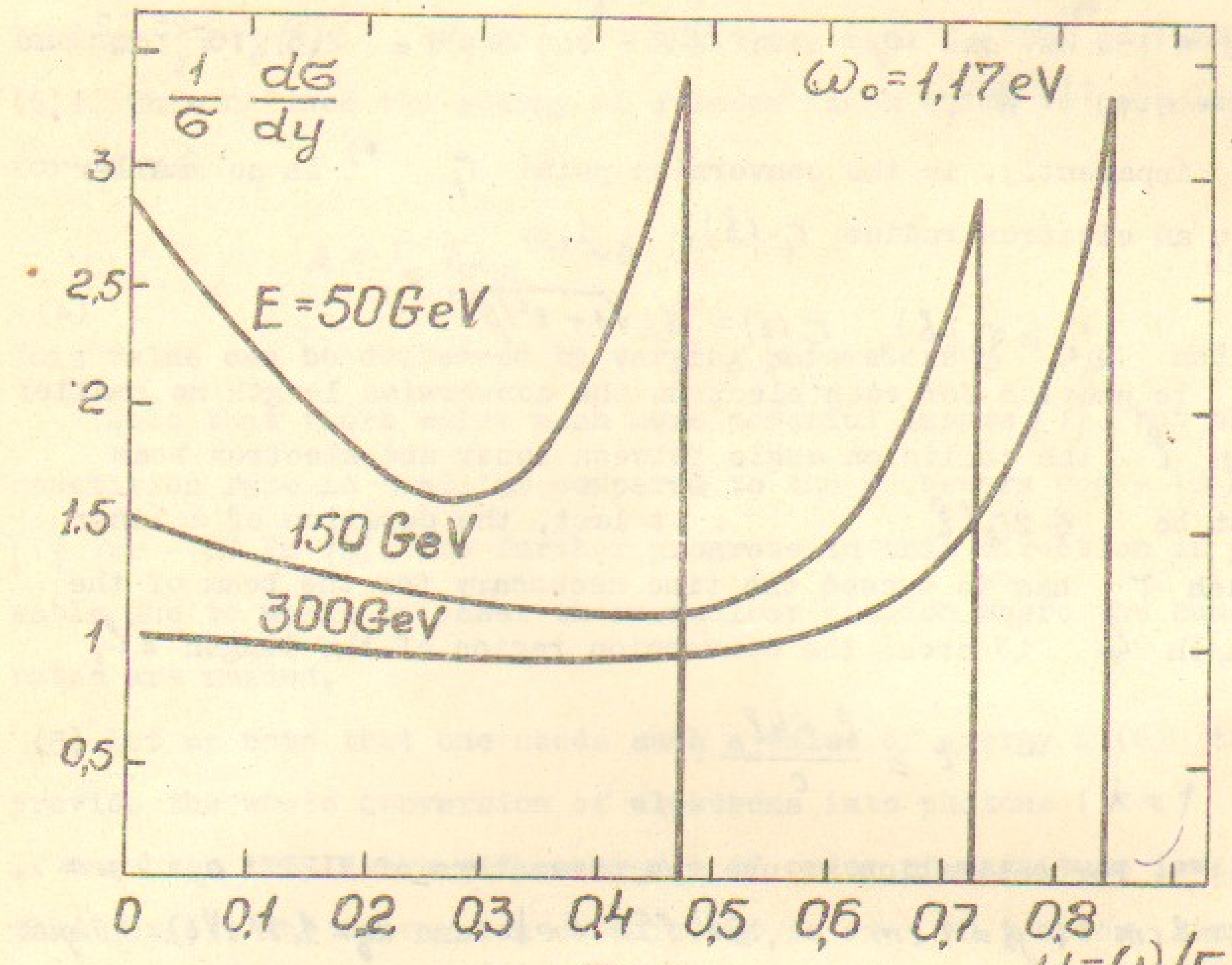

Fig.2 $y = \omega/E$

easy to obtain from (1) and (2). The region of $\theta \le \theta_0 \lesssim 10^{-5}\, rad$ (i.e. $\omega \gtrsim \omega_m/2$) gives approximately half of the cross section.

If the laser light or the electron beam are polarized, scattered photons have significant $(0.1 \div 1)$ polarization as well.

4. Let the electron fly the way ℓ in the region with the density of laser photons n_γ , then the conversion coefficient $k \approx 1 - exp(-2\sigma n_\gamma \ell) \approx 2\sigma n_\gamma \ell$. Expressing n_γ via laser power and a radius of laser beam r_γ one finds $k \approx (2\sigma P/\pi\omega_0 c)\cdot(\ell/r_\gamma^2)$ To obtain the maximum k the laser light has to be focused in the conversion region A (Fig. 1). Taking as ℓ the distance where the cross section of the laser beam grows by 2 one obtains for a Gaussian shape of the beam $\ell/r_\gamma^2 = 2\pi/\lambda$ [6]. Then

$$k \approx \frac{P}{P_0}, \quad P_0 = \frac{\pi \hbar c^2}{2\sigma}. \qquad (3)$$

At $E = 150$ GeV and $\omega_0 = 1.17$ eV one has $\sigma = 2.5 \cdot 10^{-25}\,cm^2$ and $P_0 = 6 \cdot 10^{11}$ W.

Apparently, in the conversion point r_γ *) is no smaller than an electron radius $r_e(b)$, i.e.

$$r_\gamma \geq r_e(b), \quad r_e(z) = a_e \sqrt{1 + z^2/\beta^2}. \qquad (4)$$

To provide for each electron the conversion length no smaller than ℓ the collision angle between laser and electron beam must be $\lesssim 2r_\gamma/\ell$. At last, the duration of a laser flash τ has to exceed the time necessary for the beam of the length ℓ_e to cross the conversion region of the length 2ℓ,

$$\tau \geq \frac{\ell_e + 4\ell}{c}. \qquad (5)$$

5. For estimation we use the parameters of VLEPP: $a_e = 2\,\mu m$, $\ell_e = 1\,cm$, $\beta = 1\,cm$, $E = 150$ GeV and $\omega_0 = 1.17\,eV$ ($\lambda = 1.06\,\mu m$-neodium glass laser).

After the conversion high energy photons move along electron trajectories and are focused in the collision point O. An additional broadening arises due to the angular spread of photons at the level $\lesssim \theta_0$. The conversion place has to be chosen far enough from the interaction point to bend electrons by a magnetic field B, on the other hand, the additional spread of the photon beam in the interaction point $\sim b\theta_0$ has to be smaller than a_e for keeping luminosity. At $b = 10\,cm$ both requirements are easily satisfied (for $B \sim 20$kG). Then, According to (4), $r_e(b) = 20\,\mu m$.

*) Radius of focal spot r_γ is defined by the distraction condition $r_\gamma \sim F \cdot \lambda / D$, where F is a focal distance of the lens, D is a beam diameter in the lens.

Taking $r_\gamma = r_e(b)$, we get $\ell = 0.25\,cm$, i.e. $\tau \geq 7 \cdot 10^{-11}\,s$ (see (5)). This defined the energy of a laser flash which is necessary for $k \approx 1$:

$$A = P_0 \tau_{min} = 40\ J. \qquad (6)$$

This value can be decreased by varying parameters b, β and ℓ_e.

Note that there exist much more powerful lasers [7], but their repetition rate is small as compared to the necessary one - 10 Hz [1] or 180 Hz [2]. The further progress in this direction is possible due to works on laser thermonuclear fussion where the same rates are needed.

Let us note that one needs such a value of energy A (6) to provide the whole conversion of electrons into photons ($k \approx 1$). If one uses the lasers with energy A of order of magnitude lower than in (6), the conversion coefficient is of 0.1 order. Even under such conditions the appearing possibilities to investigate the physics of $\gamma\gamma$ - and γe -collisions are very rich. In the first line, it is connected with the fact that the $\gamma\gamma \to$ hadrons cross section $(\sim \alpha^2/m_\pi^2)$ is larger by a factor $10^4 \div 10^5$ than the $e^+e^- \to$ hadrons cross section ($\sim \alpha^2/E^2$), to study which the accelerators with colliding e^+e^- -beams are being built.

6. At $b < a_e/\theta_0$ the luminosities of γe and $\gamma\gamma$ collisions are $L_{\gamma e} \approx k L_{ee}$, $L_{\gamma\gamma} \approx k^2 L_{ee}$ (L_{ee} is the luminosity of e^+e^- -collisions). (In principle, $L_{\gamma\gamma}$ can be larger than L_{ee} since there are no problems with the collision effects) In γe collision the luminosity distribution in $s_{\gamma e} = 4\omega E$ coincides with $d\sigma/d\omega$ (see Fig. 2). For $\gamma\gamma$ collision the luminosity distribution in $W_{\gamma\gamma} = \sqrt{4\omega_1\omega_2}$ is shown by the solid line in Fig. 3.

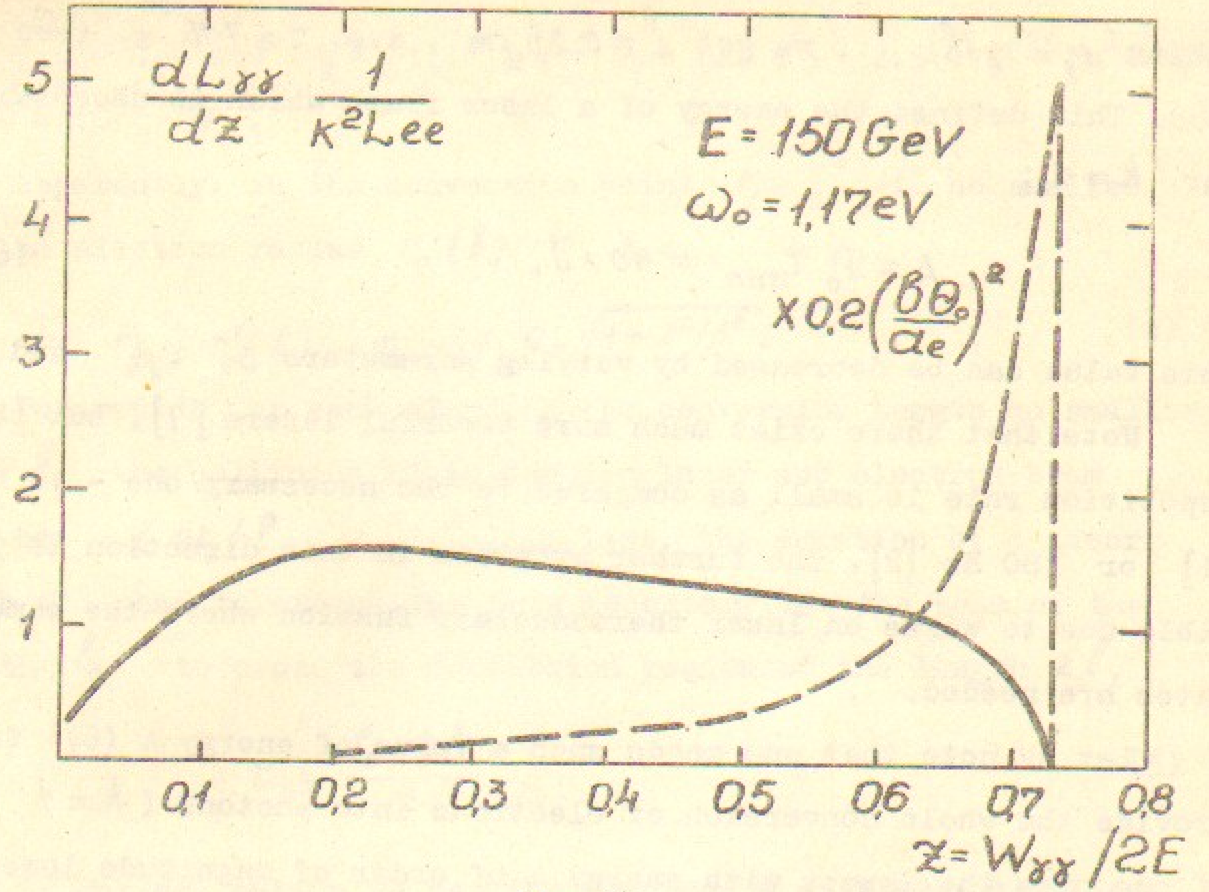

Fig.3

The notable monochromatization can be obtained by increasing the distance b (at the expense of luminosity decrease). In the γe case only photons with scattering angles $\theta \leq a_e/b$ take part in the collision with electrons, i.e. with an energy spread $\Delta\omega/\omega \sim$ $\sim (a_e/b\theta_0)^2$. The luminosity distribution over $W_{\gamma\gamma}$ for $\gamma\gamma$ collision in the case $(b\theta_0)^2 \gg a_e^2$ is shown in Fig. 3 (the dashed line)

7. In the suggested scheme of $\gamma\gamma$ collision the main background process $\gamma\gamma \to e^+e^-e^+e^-$ is not too dangerous unlike e^+e^- collisions where there are many backgrouns problems.

A more detailed consideration of the discussed problems, inclusing calibration and energy measurements, can be found elsewhere [8].

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