ИНСТИТУТ ЯДЕРНОЙ ФИЗИКИ СО АН СССР

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RADIATION FROM THE LENSES OF THE FOCUSING SYSTEM OF THE LINEAR COLLIDER AND UTILIZATION OF THIS RADIATION FOR ALIGNMENT

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ABSTRACTS

In this paper there is revised the phenomenon of radiation of the particles in the focusing tract of the Linear collider. There is pointed out, that such tract as the FODO type of quadrupole lenses, which is, in principle, *Quadrupole Wiggler*, provides radiation with well defined properties.

General idea of the method of alignment is to use this radiation from the focusing system of the Linear collider, where radiation depends of the beam size (which also defined by missalignment). Radiation from short additional *Dipole Wiggler*, where radiation does not depends of the beam size, is using for monitoring. Operating by small wirtual movements *of the axis of the lenses of the focusing* system, it is possible to minimize the radiation from the focusing system. Analyses of the polarization is the additional factor in this procedure.

There was made a proposal to test this method of alignment in SLAC linac also.

ИЗЛУЧЕНИЕ ИЗ ЛИНЗ ФОКУСИРУЮЩЕЙ СИСТЕМЫ ЛИНЕЙНОГО КОЛЛАЙДЕРА И ИСПОЛЬЗОВАНИЕ ЭТОГО ИЗЛУЧЕНИЯ ДЛЯ ВЫРАВНИВАНИЯ УСКОРИТЕЛЯ

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Аннотация

В этой работе рассмотрены эффекты излучения частиц в фокусирующем тракте линейного коллайдера. Отмечается, что в таком ФОДО тракте квадрупольных линз, который является, в принципе, *Квадрупольным Вигглером*, генерируется излучение с хорошо определенными свойствами.

Основная идея метода выравнивания состоит в использовании этого излучения из фокусирующей системы линейного коллайдера, в которой излучение зависит от размеров пучка, (проистекающих в том числе и от смещения линз). Излучение из дополнительного короткого *Дипольного Вигглера*, в котором излучение не зависит от размеров сгустка, используется для мониторирования. Производя небольшие виртуальные смещения магнитной оси линз, минимизируется излучение из системы фокусировки. Дополнительным фактором является анализ поляризации излучения.

Сделано предложение для тестирования этого метода выравнивания на линейном ускорителе SLAC.

INTRODUCTION

In [1] there was noticed, that radiation from the lenses of the focusing system of the Linear collider can provide limitation in accelerating gradient for high energy.

In [2] there were made a proposal to use Dipole Wigglers of one kilometer total length, displaced one by one in a sequence of the accelerating structures for damp of the transverse emittance and energy spread - Linear Damping system.

In [3] there is described the method of recycling of positrons. For realization of the method proposed it is necessary to use the Dipole Wiggler of few kilometers long.

Conversion system for obtaining polarized positrons and electrons [4] also contains two helical Wiggler (Undulator) of 150 meters each. In [5] also described conversion system with wiggler of 50 meters long.

We noticed here, that the mostly important part of any linear collider- focusing system is some kind of the Wiggler also. This is *Quadrupole Wiggler*. So, any linear collider contains *One* Wiggler - as minimum.

Radiation of a particle, moving in *any* wiggler with velosity $\vec{v}$ occurs at characteristic frequencies [6] which is equal

$$\omega_\gamma = \frac{k\,\Omega}{1 - (\vec{n}\,\vec{\beta})} \cong k\, 2\,\gamma^2\Omega\,, \qquad k = 1, 2, \ldots,$$

where $\Omega = 2\pi c/\lambda$ -is the angular frequency of transverse oscillations in the wiggler, $\vec{n}$ - unit vector in direction of observation, $\vec{\beta} = \vec{v}/c$, c - velocity of light. In dipole wiggler λ corresponds to period of the wiggler, for quadrupole wiggler λ corresponds to betatron wavelength in focusing systen of the wiggler. Spectrum depends of the strength of magnetic field on the trajectory of the particle, i.e. amplitude of oscillation. But mainly, it defined by *relation between length of the focusing quadrupole and distance* between lenses. In that case radiation presents fragmentary only from the places with magnetic field, cause the particle moves from lens to lens by straight line and does not radiate. In smooth approximation used down, trajectory of the particle looks like Sine. Exact solution with envelope function is much complex for this first demonstration of the possibilities of the method, described here.

I discuss here the possibility to use radiation from the focusing lenses for *alignment* of the linac. Importance of alignment was stressed a lot of times [7,8]. Seems, now it is possible to made *absolute* reference line, which goes through the centers of the quads of the linear collided. From the point of successful operation of the linear collider, it becomes possible to organize simple method of operation with displacement of the centers of the quads for minimization of emittance growth. Together with any method of alignment, which uses beam position monitors and feed-back system it is possible to satisfy the requirements for prevent emittance growth.

The experience of manipulations with beam position in damping ring with monitoring of undulator radiation was represented in [9]. Some kind of description of angular distribution and polarization of the radiation from the quadrupole wiggler is presented in [10].

When particle goes trough such long focusing system and radiates, the radiation *goes ahead* from the beam at the distance of the order of wavelength of the radiated photons multiplied by the number of oscillations, i.e. can achieve the distance, compatible the longitudinal beam size *ahead* of it. So, this radiation from both beams came first to the interaction point and can provide, in principle, the problem in collision point as Compton back-scattering. Fortunately, the developed projects of final focus has bending magnets for compensation of the chromaticity of the final lens. We'll see, that the number of radiated photons is compatible with the number of particles in each colliding beam, so it is necessary to shield the interaction point from this photons of the energy of tens eV range.

In the fin, there was made a proposal for SLAC linear collider to test this alignment method.

INTENSITY OF RADIATION

First we'll calculate the amount of energy, radiated by the beam, which is propagated along unperturbed line of FODO focusing system. Then we'll calculate energy, radiated in the same system, but when one lens is shifted off-axis. The difference of the radiated energy from this perturbed trajectory, and from unperturbed one will show us the sensitivity of the method of alignment. So, alignment will be connected with minimization of the radiation from Linac.

The amount of the energy, radiated by the charged particle in some time, can be expressed by formula [11]

$$\frac{d\varepsilon}{dt} = -\frac{2}{3}\frac{e^2}{c^3} w_\perp^2 \gamma^4 ,$$

where $w_\perp$ - is the transverse to velocity acceleration, e - charge of the particle. Notice here, that $(d\varepsilon/dt)$ is relativistic invariant.

Oscillation of the particle in transmission line described by well known functions [12]

$$a_x = (\varepsilon_x\beta_x)^{1/2} \operatorname{Cos} \int \frac{ds}{\beta x(s)} , \quad a = (\varepsilon_y\beta_y)^{1/2} \operatorname{Cos} \int \frac{ds}{\beta y(s)}$$

$\varepsilon_{x,y}$ - emittance for corresponding direction.
In smooth approximation, when $\beta_x \cong \beta_{0x} =$ const$_1$, $\beta_y \cong \beta_{0y} =$ const$_2$,

$$a_x = a_1 \operatorname{Cos}(\Omega_1 t + \alpha_1), \qquad a_y = a_2 \operatorname{Cos}(\Omega_2 t + \alpha_2),$$

$$\alpha_1, \alpha_2 \text{ -const}, \quad a_1 = (\varepsilon_x\beta_{0x})^{1/2}, \; a_2 = (\varepsilon_y\beta_{0y})^{1/2}$$

$$\Omega_1 = c/\beta_{0x}, \quad \Omega_2 = c/\beta_{0y}$$

we obtain for energy losses, averaged over period of oscillations

$$\frac{d\varepsilon}{dt} = -\frac{1}{3}\frac{e^2}{c^3}(a_1^2\,\Omega_1^4 + a_2^2\,\Omega_2^4)\,\gamma^4$$

Remembering, that radiated frequency is shifted by Doppler effect.

For Dipole Wiggler

$$a_i\Omega_i = c\,\frac{e\,H_i\,\lambda_i}{2\pi\, m_0 c^2 \gamma} = c\, P_{\perp i}/\gamma, \qquad i = 1,2$$

where $P_{\perp_1}$ - is so called factor of undulatority for the field of the strength H_1 and period λ_1, $\beta_\perp \approx P_\perp\gamma$. $P_\perp$ = .934 H [Tesla] λ [cm].

Notice here, that the amplitude of oscillation defined by the field strength itself and does not depend of initial amplitudes.

This yields the usual formula

$$\frac{d\varepsilon}{dt} = -\frac{1}{3}\, e^2\, c\, \gamma^2 \left\{ \frac{P_{\perp_1}^2}{\lambda_1^2} + \frac{P_{\perp_2}^2}{\lambda_2^2} \right\},$$

which gives

$$\frac{d\gamma}{ds} = \frac{1}{m_0 c^3}\frac{d\varepsilon}{dt} = -\frac{1}{3}\, r_0\, \gamma^2 \left\{ \frac{P_{\perp_1}^2}{\lambda_1^2} + \frac{P_{\perp_2}^2}{\lambda_2^2} \right\}.$$

Also important item for the method of alignment is that the intensity of radiation in Dipole Wiggler does not depend of the beam size, as it was mentioned before.

For Quadrupole Wiggler the amplitude of oscillation is not defined by the field, but by initial conditions. If we assume, that the quads of the *focusing system of the collider has longitudinal* length *l*, distance between them L, gradient of amount G_x and G_y, we can estimate betatron tune shift μ as

$$\cos \mu_{x,y} = 1 \mp \frac{L}{F_x} \pm \frac{L}{F_y} - \frac{L^2}{2F_xF_y}$$

where $F_{x,y} = \frac{(BR)}{G_{x,y} l} = \frac{m_0 c^2 \gamma}{e G_{x,y} l}$ is the focusing distance of the lens. Let us suppose for the simplicity, that $G_x \cong G_y$ and F»L. Putting $\cos\mu \cong 1 - \frac{\mu^2}{2} \cong 1 - \frac{1}{2}\frac{L^2}{F^2}$, which yields

$$\mu \cong L/F, \quad \beta_{0x} \cong \beta_{0y} \approx \beta_0 \cong \frac{L}{\pi\mu} = \frac{F}{\pi}$$

$$\Omega_1 = \Omega_2 = \Omega = \frac{c}{\beta_0} = c\,\frac{e\,G\,l}{m_0 c^2 \gamma}\,\pi = c\,\frac{G\,l}{B\,R}\,\pi\ ,$$

$$\beta_0 \cong (BR)/(Gl)/\pi = \frac{m_0 c^2 \gamma}{\pi e (Gl)},$$

where $(BR) = m_0 c^2 \gamma / e$. *So, we obtain for energy losses of the particle* in quadrupole wiggler

$$\frac{d\varepsilon}{dt} = -\frac{1}{3}\,\frac{e^2}{\beta_0^4}\, c\, \gamma^4 (a_1^2 + a_2^2) = -\frac{1}{3}\,\frac{e^2}{c^3}\left(\frac{e\,G\,l\,\pi}{m\,c}\right)^4 (a_1^2 + a_2^2),$$

If acceleration in Linac goes with constant envelope function β_0, then intensity has strong dependence of the energy. For realization of this regime it is necessary to have $(Gl) \cong \gamma$. But if $(Gl) \cong$ const, the intensity does not depend of the energy of the particle at all.

In addition, let us suppose for simplification, that amplitudes in both directions x and y are equal, so

$$\frac{d\varepsilon}{dt}_{tot} = -\frac{2}{3}\frac{e^2}{c^3} a^2 \Omega^4 \gamma^4 = -\frac{2}{3}\frac{e^2}{\beta_0^4} a^2 c\, \gamma^4 ,$$

$$\frac{d}{ds}\gamma = \frac{1}{m_0 c^3}\frac{d\varepsilon}{dt} = -\frac{2}{3}\frac{e^2}{m_0 c^2 \beta_0^4}\gamma^4 a^2 = -\frac{2}{3}\frac{r_0 a^2}{\beta_0^4}\gamma^4 = -k(s)\,\gamma^4 .$$

Sense of $\frac{d}{ds}\gamma$ here is the change of γ factor by losses of radiation by the particle which has energy $m_0c^2\gamma$.

Let us estimate the number of quants, radiated at first harmonic by one pass trough focusing system. Energy of the quanta is

$$E_\gamma \cong \hbar\, 2\gamma^2\Omega = 2\, m_0c^2\gamma^2 (\frac{\hbar c}{e^2})(r_0/\beta_0),$$

or

$$\gamma_q \cong (E_\gamma/m_0c^2) = 2\,\gamma^2 \frac{1}{\alpha}\,(r_0/\beta_0), \qquad \frac{1}{\alpha} = 137,$$

so,

$$\frac{dN_\gamma}{ds} \cong -\frac{1}{\gamma_q}\frac{d}{ds}\gamma = \frac{1}{3}\alpha\frac{a^2}{\beta_0^3}\gamma^2 = \frac{1}{3}\alpha\frac{\epsilon\gamma}{\beta_0^2}\gamma = \frac{1}{3}\alpha\frac{(\delta\theta)^2}{\beta_0}\gamma^2$$

where $\epsilon\gamma$ - invariant emittance of the beam, and $\delta\theta$ - angular spread in the beam.

From last equation it is clear, that total number of photons depends of the strategy of acceleration i.e. behavior of β function during acceleration. We will estimate, that $\beta_0 \cong$ const.

For obtain small amount of higher harmonics level it is necessary to have the bending angle ϕ in the lens, smaller, than $1/\gamma$. For typical values of the emittance $\epsilon \cong 10^{-8}$cm rad at the energy 10 GeV, and envelope function β_0 about 5 meters $a \cong (\epsilon\beta_0)^{1/2} \cong 20$ micrometer. For G = 50 kGs/cm this gives $H_\perp = G\, a = 50\ 20\ 10^{-4} \cong 10^{-1}$kGs. For the lens with length about 10 cm bending angle in the lens will be $\phi \cong$ $\cong H_{\perp} l/(BR) = Gal/(BR) \cong a/\pi\beta_0 \cong 3\ 10^{-5}$ and $1/\gamma \cong 5\ 10^{-5}$.

If we suppose that acceleration is going with constant field strength about 1 MV/cm, that gives $\gamma = \gamma(s) \cong 2\ [cm^{-1}]\ s\ [cm]$, and with $\beta_0 \cong$ const, we can integrate last equation, which yields

$$N_\gamma \cong \frac{1}{3}\,\alpha\,\frac{a^2}{\beta_0^3}\int_0^L \gamma^2 ds = \frac{1}{3}\,\alpha\,\frac{a^2}{\beta_0^3}\,\frac{4[cm^{-2}]}{3}\,L^3,$$

where $L = 2lK$ -is full length of accelerator, K- is the number of periods.

Taking for estimation $L = 10^4$ m, $\beta_0 = 5$ m, $a \cong 20\ 10^{-4}$cm, we obtain $N_\gamma \cong 100$ quants per unit particle. For example, $E_\gamma \cong 30$ eV for E = 10 GeV.

For obtain full intensity of the beam, it is necessary to summarize the intensities of each particle, i.e. average $(a_1^2 + a_2^2)$ over all particles, defines the beam size. Let N will be total number of the particles in the beam. Define $N\,\langle a^2\rangle = \sum_{n=1}^{N} a^2(n)$, where n nominates the particles. For uniform distribution of amplitudes in interval $(0\ ;\ a\ )$, where $a \cong (\ \varepsilon\ \beta_0)^{1/2}$, we obtain $N\,\langle a^2\rangle = \frac{1}{3}\,N\,a^2$. So, total number of quants $N_{\gamma t}$ will be

$$N_{\gamma t} \cong \frac{1}{9}\,N\,\alpha\,\frac{a^2}{\beta_0^3}\int_0^L \gamma^2 ds = \frac{1}{9}\,N\,\alpha\,\frac{a^2}{\beta_0^3}\,\frac{4[cm^{-2}]}{3}\,L^3$$

The accuracy of the relative measurement of the intensity defined by the number $1/\sqrt{N_{\gamma t}}$ i.e. accuracy of the measurement of a can be at least $(\delta a/a) \cong 1/2/(N_{\gamma t})^{1/2}$. Estimation of accuracy for $N = 10^{10}$ and $a \cong 20\ 10^{-4}$ cm, gives $(\delta a/a) \cong 0.5\ 10^{-5}$ and $\delta a \cong 1$ Å. Of cause, it is necessary to measure the number of electrons with the same accuracy ($1/10^5$).

Remember here, that the intensity of radiation in Dipole Wiggler does not depend of initial beam size. So, the best way to measure the total number of particles to use additional Dipole Wiggler. This Wiggler gives *reference* radiation, and it can be very short as if it has small period and high field.

Number of the quants, radiated by particles in Dipole Wiggler, described by the formula [10], which is similar to previous one

$$N_{\gamma t} \cong N\, 4\pi \frac{1}{137} \frac{L}{\lambda_0} (P_\perp/P_{opt})^2$$

where λ_0 is the period of the wiggler, and $P_{opt} = 1/\sqrt{2}$, which yields maximum of the first harmonic. Taking $P_\perp \cong 5$ and $\lambda_0 = 10$ cm, we obtain, that the wiggler with the length of $L \cong 250$ cm ≅ 2.5 meter gives the same number of the quanta, that the whole focusing system of 10 km long.

If one of the lenses at distance $s = s_0$ is shifted from ideal position of-axis with distance x_0, that provides magnetic field Gx_0 and central particle obtains angle kick $\delta x' \cong (Gx_0 l)/(BR)$ and *orbit began oscillate with amplitude* $b \cong \beta_0\ \delta x' \cong \beta_0 (Gx_0 l)/(BR)$. Remember, that $\beta_0 \cong (BR)/(Gl)/\pi$, so, $b \cong x_0/\pi$. Going through focusing system, beam size also increase its value by the same order due to energy spread in the beam and chromaticity of the focusing system.

This yields $\delta a \cong b$

$$(\delta a/a) \cong (x_0/\pi/a) \cong 1/2/(N_{\gamma t})^{1/2}\ ,$$

and minimal registered level of x_0 will be of order

$$x_0 \cong \pi a/2/(N_{\gamma t})^{1/2}\ ,$$

i.e. about 1.5 Å for previous figures.

Of cause, if the point s_0 is more and more close to the end of accelerator, resolution goes down proportional to number of quants. But influence of perturbation at the end of accelerator also goes down.

ALIGNMENT

General strategy is to minimize the level of photon flux from the focusing system of Linac. As the flux depends of the beam size, so any changing of gradient of the lens provides increase of the size, so it is necessary operate with position of the lens.

Let us considering the scheme, represented on Fig.1.

Here beam goes from the left side in Linac, which has accelerating structures and quads with additional coils, supplied by additional Power supply. This coils are placed on the hardware of the

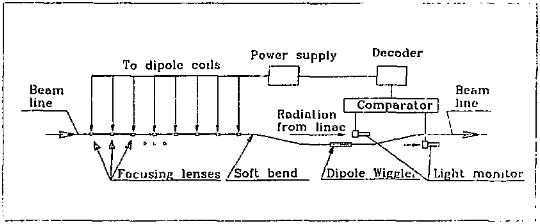

Fig.1. Principle scheme of the equipment.

lens and provides dipole field on the axis. Four additional coils can provide movements of the axis in two directions independently. *Manipulation with this field is necessary to recognize which lens is* shifted, see lower. Other details, represented on the Fig.1 is Dipole Wiggler and two Light monitors. One of the monitors are looking through the hole in the vacuum chamber to linac, and registrates radiation from the focusing system, second - registrates radiation from Dipole Wiggler. To prevent interference, Dipole Wiggler is placed in some bypass line with soft bend. Angular divergence of the radiation from quads of the order $\cong 1/\gamma$. As γ changes from the beginning of linac to the end, from initial value, say γ_0, to its *highest level, maximal sport size on the Light monitor will be of the* order ℓ/γ_0, where ℓ is length of the focusing system which gives the light. So, radiation from the beginning of the linac covers biggest area. This circumstance, seems not important, case only influence of this restriction is cutting gammas from the beginning of the linac. Missalignment at the beginning of the linac gives effect at all distance from s_0 to the end of accelerator and can be recognized.

First, suppose for example, that only one lens is shifted from its ideal axis. Simplest procedure which finds it, is to provide small wirtual movements of the axis of each lens step by step going to its initial position after one pulse of Linac. After each step it is necessary to recognize if total flux increase or decrease. If Linac operates with repetition rate f Hz and number of lenses is $L/L = 2K$, it is necessary to spend not more than $4\ 2K/f$ seconds. Additional factor of 4 reflects, that we used two steps in opposite directions in both transverse directions. For example, if one lens follows though one meter, so for 10 km Linac total number of the lenses is about 10^4, and if f = 200 Hz, maximal time will be 2 10^4/200 = 100 sec, or 1.6 minutes. So, this simplest algorithm is not slow enough. Possible improvement is to use independent modulation of displacement of each lens with its own law and use synchronous detection method. In this case f will be maximal frequency of modulation. The low of modulation must be not sinusoidal, but rectangle, which is used in sequence analysis [14]. In this case minimal frequency defined by permissive resolution of registration equipment.

So, comparator, represented of the Fig.1, makes monitoring for exclude dependence of number of particles. Decoder selects the frequency, if there used algorithm with different frequencies. After one circle, synchronized with operation of the linac, Power supply changes current in the coils, providing displacement.

We remember, that

$$E_\gamma = \hbar\ \omega_\gamma \cong \hbar\ 2\gamma^2\Omega = m_0c^2\ 2\ \gamma^2\ \frac{1}{\alpha}\ (r_0/\beta_0),$$

For β = 5 m, $a \cong 20\ 10^{-4}$cm, E = 10 GeV, $\gamma = 2\ 10^4$ we obtain, as mentioned, $E_\gamma \cong m_0c^2\ 2\ 4\ 10^8\ 137\ 2.8\ 10^{-13}/500 \cong m_0c^2\ 6\ 10^{-5} \cong 30$ eV. For E = 100 GeV, $\gamma = 2\ 10^5$ and $E_\gamma \cong 3$ keV.

For estimation of the length of radiation forming, for fixed longitudinal velocity $v_\parallel$ of the particle

$$\lambda_f \cong \frac{c}{\omega}\ \frac{1}{1-v_\parallel/c} = \lambda\!\!\!^{-}_\gamma\ \frac{1}{1-v_\parallel/c}\ ,$$

where $v_\parallel \cong v\ \sqrt{1-v_\perp^2/c^2} \cong c\ (1-\ a^2\Omega^2/c^2/2) = c\ (1\ -a^2/\beta^2_0/2)$. So, formally,

$$\lambda_f \cong \frac{\beta_0}{2\ \gamma^2}\ \frac{2\ \beta_0^2}{a^2} = \frac{\beta_0^3}{a^2\gamma^2},$$

which is much bigger, than the length of accelerator. It means, that the condition of forming is determined by changing the wavelength of radiated photon. So, in principle there is possible to distinguish place of radiation using spectral analysis of photons of High Ultraviolet.

Polarization is additional factor, which helps to determine removed lens. Angular and spectral properties and polarization, described by formulas of undulator radiation [3,6]. Polarization is defined by relation between a_1, Ω_1, a_2, Ω_2, α_1, α_2. For example, if lens is removed in one direction, that provides linear polarization of radiation, cause beam oscillates in the plane of removed lens.

We hope to discuss this more carefully in other place.

PROPOSAL FOR SLAC

Linear accelerator SLAC has the maximal energy about 50 GeV, number of particles $N \cong 5\ 10^{10}$, invariant emittance $\gamma\varepsilon \cong 3\ 10^{-3}$ rad cm. Till the energy 26 GeV betatron tune shift is constant with $\mu = \pi/2$. After 26 GeV the field strength in the lenses is constant with integral $Gdl \cong 100$ kGs. Quadrupole lenses are placed at the end of each 12.4 m linac girder [16].

Beta function β oscillates from 50 to 5 meters, so smooth approximation here in not precise, nevertheless let us estimate $\beta_0 \cdot$ 20 meters. This gives $a(\gamma) = (\varepsilon\gamma\beta_0/\gamma)^{1/2}$ and

$$N_{\gamma t} \cong \frac{1}{9} N \alpha \frac{(\varepsilon\gamma)}{\beta_0^2} \int_0^L \gamma\, ds = \frac{1}{9} N \alpha \frac{(\varepsilon\gamma)}{\beta_0^2} \frac{0.3[\mathrm{cm}^{-1}]}{2} L^2,$$

where supposed, that $\frac{d}{ds}\gamma$ corresponds to $\cong$150 kV/cm. Substitute here numerical values, and estimate $L \cong 3\ 10^5 \frac{26[\mathrm{GeV}]}{50[\mathrm{GeV}]} \cong 1.5\ 10^5$ cm, we obtain the number of photons, radiated from whole length 0÷1.5 km

$$N_{\gamma t} \cong \frac{1}{9} N \frac{1}{137} \frac{3\ 10^{-3}}{4\ 10^6} \frac{0.3[\mathrm{cm}^{-1}]}{2} 2.2\ 10^{10} \cong 2\ 10^{-3} N = 10^8$$

Formally, one particle radiates less, than one photon.

From 26 GeV to 50 GeV,

$$\beta_0 \cong (BR)/(Gl)/\pi = \frac{m_0c^2\gamma}{\pi e(Gl)},$$

and

$$N_{\gamma t} \cong \frac{1}{9}\, N\, \alpha\, (c\gamma)\, \frac{(\pi eGl)^2}{m_0^2c^4} \int_{L_1}^{L} \frac{1}{\gamma}\, ds \cong \frac{1}{9}\, N\, \alpha\, (\varepsilon\gamma)\, \frac{(\pi eGl)^2}{m_0^2c^4} \frac{1}{2[cm^{-1}]} ln(L/L_1),$$

where $L/L_1 \cong 2$, L_1 corresponds the energy 26 GeV, or, approximately, half of the total length. Rewrite last expression

$$N_{\gamma t} \cong \frac{1}{9}\, N\, \alpha\, (\varepsilon\gamma)\, \pi^2\, \gamma_f^2\, \frac{(Gl)^2}{(BR)_f^2}\, \frac{1}{2[cm^{-1}]}\, ln(L/L_1),$$

where $\gamma_f = 10^5$, $(BR)_f = 1.6\ 10^5$ kGs cm corresponds to final energy, i.e. 50 GeV, we obtain $N_{\gamma t} \cong 3\ 10^{-2}N \cong 1.5\ 10^9$.

Energy of quanta

$$E_\gamma \cong h\ 2\ \gamma^2\ \frac{c}{\beta} = m_0c^2r_0\ \frac{1}{\alpha}\ 2\ \gamma^2\ \frac{1}{\beta} = m_0c^2r_0\ \frac{1}{\alpha}\ 2\ \gamma^2\ \pi\ \frac{(Gl)}{(BR)}$$

is equal to 16 eV at 20 Gev, 150 eV at 30 GeV, 752 eV at 50 GeV. For a we can estimate $a = (c\gamma\beta_0/\gamma)^{1/2} \cong 300\ 10^{-4}$cm or 300 micrometer. So, resolution can achieve less than $\pi\ 300/2(10^8)^{1/2} \cong 1/20$ micrometers. For current monitoring here may be used Pick-up electrodes with precision analizator of total charge, passed in Linac (about $10^{-4.5}$).

CONCLUSION

Let us summarize here previous considerations.

First of all any particle in focusing system radiates only few quants, of soft energy, so influence of this radiation to beam dynamics, including energy spread and emittance is negligible. Second, the resolution of this method can be of order of tens Angstrom, which is enough for operation of Linear collider. Third, this method is chip and easy to test.

* * *

Of course this brief consideration demonstrates the method of alignment only and it is necessary to take into account a lot of details of the focusing strategy of the Linear collider.

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