Quantum Geometrical Phase Signal of NLC Bunch Cross Section Carried by Virtual Photons

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Abstract

Richter pointed out that the final focus for NLC pose a very difficult challege. The cross section of bunch at interaction point is about $\sigma_x\sigma_y = 60$ nm * 2nm. It is too small to measure by EEE methods. Hence, The new conceptions of beam — beam deflection and inverse Compton gamma modulation are developing respectly at SLAC and KEK in the scope of orthodox quantum mechanics. Here we pointed out that the cross section information of bunch can be carried by the quantum geometrical phase of a test beam across the bunch which is modulated by the virtual photons of bunch. It is beyond the orthodox quantum mechanics, standard of *IEC, ANSI, IEEE, GB* and presented by EM potential $[A, i\sqrt{\varepsilon_0\mu_0}\varphi]$ of bunch. The EM potential signals of unpolarized bunch signals have similar formula of $\sigma_x\sigma_y = a_i^2\exp[P_i\theta/N]$, where $P_i = -P_m = -8h/\mu_0 e^2 v$ is a magnetic constant for rarefied bunch, $P_i = P_e = 4\pi\varepsilon_0 hc/e^2$ is a electric constant for dense bunch. Since NLC beam is always polarized, the magnetic potential flux line of bunch spin are concentric circles surrounding the bunch axis. It can be measured remotely. Hence, $\sigma_x\sigma_y\sigma_z = SH^2N/\theta$, where $S = 3\mu_0 a\mu_B e/32h =$ Constant, σ_z is bunch length, H is the distance of detection beam, θ is quantum geometrical phase, N is partical number of a bunch. It can be measured by electron, neutron or atom beam interferometers, including superconductive ring interferometers.

I. Introduction

Richter pointed out in 1989 that the final focus system for the NLC (Next generation Linear Collider) pose a very difficult challenge. One of the most difficult problems is measuring the beam size at the interaction point. None now exists except for beam deflection system. [1, 2] Hitherto, physical methods of Beam—Beam Deflection and Inverse Compton Gamma Modulation have been developing at SLAC and KEK in the scope of orthodox quantum mechanics, [3—5] and standards of *IEC, ANSI, IEEE, GB*.

In the point of view of EEE technique, the bunch size measurement of NLC demands time — spatial resolution of fs and pm. It exceeds the recent technical ability of EEE. Therefore, it is a physical problem, which will promote the development of EEE.

II. Quantum Signal Dynamics

The particle distance in NLC is equal approximately to the radius of positronium. Hence, bunch signal of NLC is a special problem of QED field with geometric shape of bunch and boundary condition of beampipe. However, it is beyond orthodox QM.

Here we pointed out that the information of a bunch can be carried by the quantum geometrical phase of a test beam across the bunch side. It is an effect beyond orthodox quantum mechanics, and presented by EM potential A of a polarized bunch spin as well as $[A, i\sqrt{\varepsilon_0\mu_0}\varphi]$ of bunch.

To modulate and demodulate a QED signal of both real and virtual photons as well as electrons for the purpose of carrying NLC bunch size information, we have analyzed subtle discrimination in the four kinds of quantization theory. [6, 7] Therefore, we suggest that

(1) abendon the quantization of wave — particle unification which is the standard quantum conception of recent *ANSI/IEEE std 100 — 1988*, because it neglects virtual photons, which are the bunch signals actually;

(2) abendon the carnonical quantization of QED signal field, because it is not covariant though it is the standard form of orthodox QED theory;

(3) adopt quantization of path integral of gauge field;

(4) extend the quantization of path integral in state space from flat Hilbert space to a curved Riemann—Hilbert space to reform the basic conception of cybernetics, where the measurable and controllable problems of object like bunch is the first fundamental conception of all.

It is covariant, and deal with both virtual and real photons. Furthermore, the state transfer equation of bunch signal splits into two parts: the dynamic equation and the geometric phase equation. The late has not yet been used as a signal equation in *ANSI/IEEE std 100 — 1988, GB3100 — 86, IEC 50 (121) 1978, ISO 31—5: 1979, ISO 31—6: 1992,* but it carries the information of bunch size. Hence, It can be used to measure the bunch cross—section $\sigma_x\sigma_y$ of the NLC bunch.

III. Quantum Geometric Phase of Virtual Photon of Bunch

Let Φ_d is the state transfer matrix in an ordinary flat Hilbert space of orthodox quantum theory, then the extended state transfer matrix in a curved Riemann Hilbert space is Φ which equals Φ_d multiplied by Φ_θ. Hence, we have

$$\Phi = \Phi_\theta \cdot \Phi_d \qquad (3.1)$$

where the phase factor of state vector is

$$\Phi_\theta = \exp[-i\theta(x)] \qquad (3.2)$$

and the phase angle is

$$\begin{aligned}\theta(x) &= \frac{e}{h}\oint A_\mu(x)\mathrm{d}x \\ &= \frac{e}{h}\oint[A, i\sqrt{\varepsilon_0\mu_0}\varphi]\cdot\mathrm{d}[x, ict] \\ &= \frac{e}{h}\left[\oint A(x)\cdot\mathrm{d}x,\ -\sqrt{\varepsilon_0\mu_0}\int_A^B(\varphi_B-\varphi_A)\mathrm{d}l\right]\end{aligned}$$

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$$= \frac{e}{h}[F_{m}, - \frac{i}{c}Vl] \quad (3.3)$$

where

θ: the angle increament of a parallel displacement loop of a state vector in the curved state space, [0];

$A(x)$: the magnetic potential of bunch, [W/m];

F_m: the magnetic flux of bunch, [W];

φ_A, φ_B: the electrical potential of bunch at position A and B, [V];

l: the effective bunch length, [L].

IV. Bunch Cross Section Information Carried by Potential and Readout by Quantum Geometric Phase

A. *Flight Coaxial Cavity*

Approximately, the VLE virtual photon in wakefield looks like a inner conductor which extend the bunch[6]. It is π multiple longer than bunch length. Hence, the flight coaxial approximation of bunch — beampipe system of Wang — Leow [7] can be considered as a first order. If we choose $4\sigma_z$ of bunch to be the inner current then its actual length is $4\pi\sigma_z$, because the following wakefield of VLE mode is a displacement current which extends the bunch current length to

$$l = 4\pi\sigma_z \quad (4.1.1)$$

Thus, the mutual inductance L and capasitance C are approximately expressed by

$$L = 4\pi\sigma_z \frac{\mu_0}{4\pi}\ln \frac{a}{\sqrt{\sigma_x\sigma_y}} \quad (4.1.2)$$

$$C = 4\pi\sigma_z 2\pi\varepsilon_0/\ln(\frac{a_i}{\sqrt{\sigma_x\sigma_y}}) \quad (4.1.3)$$

and the bunch current as a δ function is

$$I_b = \frac{Nev}{4\sigma_z}\delta(t - t_0) \quad (4.1.4)$$

and its magnetic flux and electric potential difference

$$F_m = I_bL = NevL/4\sigma_z \quad (4.1.5)$$

$$\varphi_B - \varphi_A = V = Q/C = Ne/C \quad (4.1.6)$$

where

σ_x, σ_y, σ_z: standard deviation of bunch width, height, and length, [L];

N: the particle number in bunch, [0];

v: the bunch velosity, [LT^{-1}];

a: the radius of beampipe, [L];

a_i: the radial distances of potential detectors, [L].

B. *Magnetic Potential Signal of Unpolarized Bunch Cross Section*

From (4.1.2), we have

$$\sigma_x\sigma_y = a^2\exp[-\frac{2L}{\sigma_z\mu_0}] \quad (4.2.1)$$

Substitute (4.1.5), (3.3) into (4.2.1)

$$\sigma_x\sigma_y = a^2\exp[-P_m\theta/N] \quad (4.2.2)$$

$$P_m = \frac{8h}{\mu_0e^2v}, \quad [0] \quad (4.2.3)$$

$h = 1.05457266(63) \times 10^{-34}$Js

$e = 1.60217733(49) \times 10^{-19}$C

$\mu_0 = 4\pi 10^{-7}$H/m

$\varepsilon_0 = 8.854187817 \times 10^{-12}$F/m

$v = c = 299792458$m/s

$\therefore \quad P_m = 43.62$

$$\theta = \frac{N}{P_m}\ln\frac{a^2}{\sigma_x\sigma_y} \quad (4.2.4)$$

If $N = 10^2$, then $\theta \approx \pi$, that means it is suitable merely to the very rarefied bunch.

C. *Electric Potential Signal of Unpolarized Bunch Cross Section*

Substituting (4.1.3) and (3.3) into (4.1.6), we have

$$\sigma_x\sigma_y = a_i^2\exp[P_e\theta/N] \quad (4.3.1)$$

where

$$P_e = 16\pi^2\varepsilon_0hc\sigma_z/e^2l = 4\pi\varepsilon_0hc/e^2, \ [0] \quad (4.3.2)$$

$\therefore \quad P_e = 1.370 \times 10^{14}$

If N$=4.3\times10^{14}$ then $\theta=\pi$ that means it is good for very dense bunch.

D. *Polarized Signal of Bunch*

The magnetic induction on the bunch axis is

$$B_z^e = \mu_0M = \mu_0 \lim_{\triangle V\to 0}\frac{\sum_i m_i}{\triangle V} \quad (4.4.1)$$

$$\sum_i m_i = Na\mu_B \quad (4.4.2)$$

$$\triangle V = \frac{4}{3}\pi(2\sigma_x)(2\sigma_y)(2\sigma_z) \quad (4.4.3)$$

where

M is the magnetization of bunch, [A/m];

m_i is the magneton of bunch electron, [Am^2];

μ_B is Bohr magneton $=9.27401541\times10^{-23}$J/T

$=5.78838263\times10^{-11}$MeV/T

$\alpha=1.001145358\pm0.000000005$

Hence.

$$\sigma_x\sigma_y = \frac{3\mu_0a\mu_BN}{32\pi\sigma_zB_z^e} \quad (4.4.4)$$

Unfortunately, B_z^e is difficult to measure because it is at the bunch axis

However

$$\because \quad |B_z^e|\pi H^2 = |A_\varphi^e|2\pi H \quad (4.4.5)$$

$$\because \quad A_\varphi^e = \frac{h\theta}{e2\pi H} \quad (4.4.6)$$

$$\therefore \quad B_z^e = \frac{h\theta}{\pi eH^2}Z_0 \quad (4.4.7)$$

where, A_φ^e is concentric circles surrounding the bunch axis. It can be measured remotely like measuring the magnetic flux and electric potential, Z_0 is unit vector in direction of axis. H is the distance of detector from the bunch axis. Hence, substituting (4.4.7) into (4.4.4), we have

$$\sigma_x\sigma_y = \frac{3\mu_0a\mu_BNe}{32h\sigma_z\theta}H^2 \quad (4.4.8)$$

$$\sigma_x\sigma_y\sigma_z = SH^2N/\theta \quad (4.4.9)$$

$$S = \frac{3\mu_0a\mu_Be}{32h} = 1.659906733 \times 10^{-15}\text{ meter} \quad (4.4.10)$$

$$\theta = SN\frac{H^2}{\sigma_x\sigma_y\sigma_z} \quad (4.4.11)$$

If $N=10^{10}$, then $SN=1.66\times10^{-5}$

If $\sigma_x=60$nm, $\sigma_y=2$nm, $\sigma_z=60$nm, $H=36.9$nm, then $\theta=\pi$

That means, the distance between test beam and bunch is about 40nm, then $\theta=\pi$. It is available to carry out by atom interferometers for the intermediate density bunch.

E. Magnetic Field of Bunch Motion

The magnetic field strength of bunch motion is

$$H_\varphi = \frac{I_b}{2\pi H} = \frac{Nev}{4\sigma_z H}[\mathrm{A/m}] \qquad (4.5.1)$$
$$=1.71\times10^7[\mathrm{A/m}],$$

where $N=10^{10}$, $H=1.17$cm. It is equivalent to $B_\varphi = \mu_0 H_\varphi = 21.48$T

Hence, it is an extreme strong jamming for the electron interferometer, therefore, the neutron or atom interferometers may be used.

F. Wake Field Effect

The wakefield effect will reduce B_φ from 21T to about 7T. [6] Furthermore, If $\sigma_z=600\mu$m, then $B_\varphi=0.7$T, hence it is easy to be shielded by Meissner effect.

The wakefield effect also happens to A_φ^δ. It lengthen the interference time and benefits the mothod of interference. If the $\sigma_z=60\mu$m. then the interference time is lengthened from 0.8ps to 2.4ps.

Thus, we can obtain the bunch cross section by three ways of magnetic flux F_m, electric potential V, and polarizational potential A_φ^e. All of these three quantities can be measured remotely by the phase shifts θ of probe beam interferometers which are composed of electron beam, neutron beam, or atom beam etc.

V. Bunch Length Information

$\sigma_z\approx60$ micron, It is about $1-2\times10^2$ times long of the wave length of Cerenkov radiation in an optical fiber close to the bunch. Hence σ_z can be measured by waveguiding Cerenkov radiation[9] which is also in the response range of optical interferometers. [10] or by non — linear optical method. [11]

VI. Instrumentation

θ may be measured directly by electron or atom beam interferometer through EEE quantities of $[F_m, -\frac{i}{c}Vl]$ of A_φ^δ with SI unit of [Webb, $-i$Volt • sec].

The bunch length of NLC is desigened as 60 micron, Thus, the signal duration is 0.4—0.8ps. It is lengthened by wakefield to 2.4 ps and just in the response range of coherent technique of recent electron[12] and atom[13, 14] interferometers. We analyze subtle discrimination this subject as the bunch signal dynamics. [6, 7]

VII. Virtual Photons and Accelerator

Hitheto, the $[\boldsymbol{E}, c\boldsymbol{B}]$ is always used in accelerator physics to deal with accelerating, bending, focusing, observing, monitoring and measuring. It complys with standards of *IEC*, *ANSI*, *IEEE*, *GB* etc, but it loses some abilites of EM field. For example, [15]

$$\boldsymbol{E} = -\frac{q}{4\pi\varepsilon_{00}}\left[\frac{\boldsymbol{R}_0'}{R'^2} + \frac{R'}{c}\partial_t\left(\frac{\boldsymbol{R}_0'}{R'^2}\right) + \frac{1}{c^2}\partial_t^2\boldsymbol{R}_0'\right] \qquad (7.1)$$

to be the acceleration field, people used first term of static for van de Grooff, (1931) or Cokcroft—Walton (1932) accelerators. People used third term of real photon for Wideroe proton linac (1929), Hanson electron linac (1947), Lawrence cyclotron (1931), Kerst betatron (1941), and Veksler—McMillan Synchrotron (1945); and also modern colliders of e^+e^-, $p\bar{p}$, pp and ep. People usually forgot second term of virtual photon for accelerator. Here we used A_μ instead of $[\boldsymbol{E}, c\boldsymbol{B}]$ to research accerators. A_μ composed of virtual and real photons which include more properties. Some of new conceptual designs about detection and acceleration worked out by the author are in preparing. [16] The geometrical information of bunch is one of them.

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VIII. References

[1] B. Richter, "SLC Statuts and SLAC Future Plans" *SLAC—PUB—5075*, Aug. 1989(E/A).

[2] J. M. Paterson, "Next Generation Linear Collider", Address on Opening *Conference of Accelerator Physics Symposium of PASC*, IHEP, Beijing June 8, 1991.

[3] Yu—Chiu Chao and Pisin Chen "Higher Order Effects in Beam — Beam Deflection" *SLAC — PUB — 5221*, Jan. 1992. (A).

[4] R. D. Ruth, "The Development of NLC at SLAC", *SLAC—PUB—5729*, Feb. 1992(A).

[5] T. Shintake, "Laser—Comptor Spot Size Monitor, *Proc. of the 3rd Workshop on JLC*, *KEK Proc.* 92—13 Dec. 1992.

[6] Jing Shen, "Bunch Signal Dynamics I: Charge, and Virtual Photon Sources, Beampipe Responces, Coherent Beamstrahlung: VTA, VTEM, VTE, VTM, VLE, RTE, RTM Modes of Signal", *BIHEP—DE—92—02*, Jan. 1. 1992.

[7] Jing Shen, "Theoratical Base of NLC Bunch Size Measurement — Quantum Geometrical Information and General Relativistic Cybernetics, Bunch Signal Dynamics II", *BIHEP—DE—92—03*, April. 1. 1992.

[8] J. W. Wang and G. A. Leow, *SLAC—PUC—2830*, Oct. 1981(A).

[9] A. I. Akhiezer, *Nuovo Cim*, Series 10. 3, Suppl. (4). 591, (1956).

[10] R. C. Eckardt and C. H. Lee, *Appl. Phys. Lett.* 15, PP. 425—427, (1969).

[11] Jing Shen, "Ultra Short Bunch Length Measurement—Nonlinear Optical Effect of Bunch Virtual Photon", *BIHEP—DE—93*, in printing, 1993.

[12] R. A. Webb and S. Washburm, *Phys. Today*. 41. 12, PP. 44—53. Dec. 1988.

[13] D. W. Keith, C. R. Ekstrom, A. Turchette, and D. E. Pritchard, *Phys. Rev. Lett.* 66, 2693(1991).

[14] M. Kasevich, and S. Chu, *Phys. Rev. Lett.* 67, 181 (1991).

[15] E. J. N. Wilson, "Accelerators for the Twenty — First Century—A Review", *CERN90—05*. 1990.

[16] Jing Shen, "Virtual Photon Impulse of Bunch, Beampipe Response , Coherent RF Beamstrahlung; and BEPC Bunch Length, BES Jam, Virtual Acceleration", 1993 *IEEE—APS Particle Accelerator Conference*, Washington D. C. Mar. 1993.