Virtual Photon Impulse of Bunch, Beampipe Response, Coherent RF Beamstrahlung; and BEPC Bunch Length, BES Jam, Virtual Acceleration

Jing Shen

Institute of High Energy Physics, Academia Sinica.
19 Yu Quan Road, P. O. Box 918, Bin 6, Beijing 100039 P. R. C

Abstract:

A brief EEE view of signal QED is presented. The research has been concentrated on the virtual photon modes of ultra relativistic shock wave in a bunch—beampipe system, and real photon modes of Coherent RF Beamstrahlung CRFB. Physically, the virtual photons emitted by a bunch were treated as a travelling pseudo wave packet in a flight coaxial cavity constructed by bunch—wakefield core and beampipe. Mathematically, it is a boundary solution of shock wave excited by ultra relativistic impulse of bunch. The new modes of solution: VTA, VTEM, VTM, VLE are virtual photon packets and RTE, RTM, RTEM are real photon modes of CRFB. By these results we measured and corrected BEPC bunch length from signals of : (1) TOF reference of BES, (2) BPM of BEPC, (3) Colliding CRFB of BEPC—BES coupling signal, as well as (4) the ordinary method of Synchrotron Radiation. All results of the measured bunch lengthes are in accordance with the design length of BEPC, and were verified by the BES data of vertex reconstruction of hadron events. We also found that CRFB is the unknown jam source of BES electronics. VLE virtual photons can accelerate particles.

I. Specialities of Bunch Signal and Dynamics

The known physics of accelerator, microwave, laser, Synchrotron radiation and Beamstrahlung, QED[1—4] can not explain bunch signal perfectly. The main variations are A. Boundary QED, B. Source Guiding Wave, C. Guiding Relativistic Shockwave, D. Virtual and Real Photon signal, E. Special Gauge Choise. The equations and quantization are:

$$\Box^2 A_\mu = -\mu_0 J_\mu,\quad J_\mu = J^b_\mu + J^f_\mu \qquad (1.1.1)$$

$$\Box \cdot A_\mu = 0,\ \nabla \cdot A = 0,\ A_0 = 0,\ A_3 = 0 \qquad (1.1.2)$$

$$\Box \cdot J_\mu = 0,\ J_\mu = (v\rho, ic\rho),\ \rho = \langle \psi | \psi \rangle \qquad (1.1.3)$$

$$[\partial_t + \boldsymbol{u} \cdot \nabla + \boldsymbol{a} \cdot \nabla_u]\rho(R', u' + v, t') = 0 \qquad (1.1.4)$$

$$|\psi\rangle \rightarrow |\psi\rangle \exp[-\frac{i}{h}e\theta],\ A_\mu \rightarrow A_\mu + \partial_\mu\theta \qquad (1.1.5)$$

$$(1.1.1) \text{ is invariant, } \therefore\ p_\mu \rightarrow -ih\partial_\mu - eA_\mu \qquad (1.1.6)$$

II. Pseudo Waves of Virtual Photon

A. Virtual Photon Cloud in Bunch Beampipe System

A virtual photon of electron in bunch can travel at most a distance

$$\triangle R = c\triangle T = 2\pi c/\triangle\omega = 2\pi hc/\triangle E \qquad (2.1.1)$$

It carries the information of bunch shape, and can be absorbed by an electron in detector. The wave equations of a motional virtual photon package surrounding a bunch can be obtained by $\nabla \cdot A = 0$ gauge of (1.1.1).

$$\nabla_b^2 \Phi^V(\boldsymbol{R}, t) = -\frac{1}{\varepsilon_0}\rho(\boldsymbol{R}', t') \qquad (2.1.2)$$

$$\Box^2 \boldsymbol{A}^R(\boldsymbol{R}, t) = -\mu_0(\boldsymbol{J} + \varepsilon_0\partial_t\nabla\Phi^V) = -\mu_0\boldsymbol{J}_t \qquad (2.1.3)$$

(2.1.2) is a Coulomb field in the bunch coordinate. (2.1.3) is a transvers real photon wave resulted from the transverse impulse of the bunch $\boldsymbol{J}_t$.

B. Pseudo Transverse Electric Wave Packet — Bunch Field

In laboratory the Coulomb field Φ^V is travelling with the bunch by velosity $\boldsymbol{v}$ like a travelling wave package. ∇_b (2.1.1)

$$\nabla_b^2 \boldsymbol{E}^V(\boldsymbol{R}, t) = -\mu_0 c\nabla_b c\rho(\boldsymbol{R}' + \boldsymbol{v}t, t') \qquad (2.2.1)$$

Transform from bunch coordinate to laboratory coordinate by

$$c\nabla_b c\rho(\boldsymbol{R}' + \boldsymbol{v}t, t') \rightarrow [c\nabla + \beta\partial_t]c\rho(\boldsymbol{R}', t') \qquad (2.2.2)$$

$$\nabla_b^2 \rightarrow [\nabla^2 - \frac{1}{v^2}\partial_t^2]_L \equiv [\Box_V^2]_L \approx \Box^2,\quad (v \approx c) \qquad (2.3.3)$$

The right sides imply an image of the bunch at the origen to be the source of pseudo transverse wave.

$$\Box^2 \boldsymbol{E}^V(\boldsymbol{R}, t) = -\mu_0[\nabla + \beta\partial_t]c\rho^i(\boldsymbol{R}', t') \qquad (2.2.4)$$

C. Pseudo Magnetic Wave Packet—Wake Field

The impedance virtual photon package following the bunch can be obtained by the Hamilton gauge $A_0 = 0$ of (1.1.1).

$$\Box^2 \boldsymbol{A}^V(\boldsymbol{R}, t') = -\mu_0\boldsymbol{J}^V(\boldsymbol{R}', t') \qquad (2.3.1)$$

$$\Box^2 \boldsymbol{B}^V(\boldsymbol{R}, t') = -\mu_0\nabla \times \boldsymbol{J}^V(\boldsymbol{R}', t') \qquad (2.3.2)$$

D. Spin Potential Wave Equations of Bunch — Spin Field

The Third kind virtual photon is the Spin — Potential wave of polarized bunch in Axis gauge $A_3 = 0$ of (1.1.1).

$$\Box^2 \boldsymbol{A}^S(\boldsymbol{R}, t) = -\mu_0\boldsymbol{J}^S(\boldsymbol{R}', t') \qquad (2.4.1)$$

In cylindrical symmetry, $\boldsymbol{A}^S(\boldsymbol{R}, t)$ is in the direction of $\boldsymbol{v}_z$.

III. Virtual, Real Modes in Different Region

A. Sparating Virtual and Real Photons

By (2.2.4), (2.3.2), (2.4.1); (1.1.1) is decomposed into[5—8]

$$\Box^2 \boldsymbol{E}^V(\boldsymbol{R}, t) = -\mu_0 c\Box_\beta c\rho^i(\boldsymbol{R}', t') \equiv f^V \qquad (3.1.1)$$

$$\Box^2 c\boldsymbol{B}^V(\boldsymbol{R}, t) = -\mu_0 c\nabla \times \boldsymbol{v}\rho^i(\boldsymbol{R}', t') \qquad (3.1.2)$$

$$\Box^2 \boldsymbol{A}^S(\boldsymbol{R}, t) = -\mu_0\boldsymbol{J}^S(\boldsymbol{R}', t') \qquad (3.1.3)$$

$$\Box^2 \boldsymbol{E}^R(\boldsymbol{R}, t) = -\mu_0 c\Box_\beta c\rho(\boldsymbol{R}', t') \equiv f^R \qquad (3.1.4)$$

$$\Box^2 c\boldsymbol{B}^R(\boldsymbol{R}, t) = -\mu_0 c\nabla \times \boldsymbol{v}\rho(\boldsymbol{R}', t') \qquad (3.1.5)$$

B. Ahead Bunch Vacuum and Restard Wave Vacuum

The relativity makes field vanish ahead the bunch. The causality makes the front of bunchstrahlung retard the bunch top head at a distance z apart from

$$z = Htg\theta = Hcos\psi/2 \qquad (3.2.1)$$

z is beampipe axis. θ, ψ are the angles of (z, R_s), (z, R). H is distance of detector from z.

C. Bunch Field Region of Guiding Relativistic Shock

$$f^V = f_t H_0 + f_l z_0 \qquad (3.3.1)$$

In the region of flight bunch, $f_t \gg f_l$ if $H \ll 2\sigma_z$; the TEM, TE modes are superiority. $f_t \approx f_l$, if $H \gg 2\sigma_z$; the TEM, TE modes are equal to TM, LE modes. Thus, $H \ll 2\sigma_z$ is much better for getting single mode signal for bunch size measurement.

D. Wake Field Region of Impedance Effect

In the region behind the bunch, where $\psi > \pi/2$, and $f_l > f_t$, thus, VLE and VTM modes become the superiority. It leads to a region of wake fields with $4\pi\sigma_z$ in length when $H \leqslant 2\sigma_z$. VLE mode fields can accelerate or decelerate the tail of the bunch. Practically wake fields have both LE and LM modes, Hence, they make the tail of the bunch rotate, and conduct the wall currents which carry the bunch size information precisely.

E. Transformation Region of Reaction

The wake field is actually charged by the δ impulse of bunch and input to the bunch—beampipe cavity which is flying with bunch called Fight Coaxial Cavity FCC. Hence, transformation region is the discharging region.

F. Radiation Propagation Region of Collision

Following the transformation region, there is the radiation region, where the real photons of (3.1.4), (3.1.5) are radiated by interactions of bunch—bunch, bunch—field. The typical radiation is SR and CRFB. [8]

IV. Waveform of Real and Virtual Photon

A. VTEM Mode Signals of Relativitic EM Shock Wave

In the case of ultra relativistic case the electric fields observed in laboratory coordinate is $E^V(R, t) = E^{im} + E^f$, where

$$E^{im} = E_R R_0,\ E_\varphi = E_z = 0,\ i_d = \varepsilon_0 \pi \sigma_x \sigma_y E^{im} \qquad (4.1.1)$$

The relalivistic transvers impulse f_t^V solution of (3.1.1) with (3.3.1) is

$$E^{im}(R, t) = \frac{1}{2c}\int_{\tau=0}^{t} d\tau \int_{z-c(t-\tau)}^{z+c(t-\tau)} d\zeta f_t^V(\zeta, \tau) \qquad (4.1.2)$$

Hence, it looks like a TEM transvers photon, and

$$i_d(0, t) == -\frac{NeS}{\sqrt{2\pi}}\rho(x, y)\frac{v^2 t}{\sigma_z^2}\exp[-\frac{v^2 t^2}{2\sigma_z^2}] \qquad (4.1.3)$$

This is the waveform of BEPC bunch signal which we detected at TOF time reference electrode of BES[5—8]. After correction of the skin effect of the signal cable, the bunch length of BEPC is $\sigma_z = 5.4$cm. (See Fig. 1)

B. VLE VTM Mode Signals of Wall Current and Wake Field

Because FCC impedance retards $[E, cB]$ and

$$E_\varphi = B_z = 0 \qquad (4.2.1)$$

Thus, the impulse width is < the wake field length, then $\Box_\beta \approx \nabla$, $\Box^2 \approx \nabla^2$. Integrate (3.1.1), (3.1.2).

$$i_w(t) = \frac{Ne}{\sqrt{LC}}\exp[-\frac{R_{sb}}{2L}t]\sin\sqrt{\frac{1}{LC}}t \qquad (4.2.2)$$

$$R_{sb} = R_{sh}\cdot\frac{4\sigma_z}{2\pi H} = 3.26\times 10^{-7}\sqrt{f}\,\frac{2\sigma_z}{\pi H}\Omega \qquad (4.2.3)$$

Hence the risefront of $i_w(t)$ is resulted by bunch length

$$T_r = \frac{T}{4} = \frac{1}{4}\cdot\frac{2\pi}{\omega} = \frac{\pi}{2}\sqrt{LC} = 2\pi\sqrt{\varepsilon_0\mu_0}\sigma_z \qquad (4.2.4)$$

$$\sigma_z = cT_r/2\pi = 4.775T_r\,(\text{ns})\,\text{cm} \qquad (4.2.5)$$

The σ_z of BEPC obtained by (4.2.5) is 5.6cm. [5—8] (See Fig. 2)

C. Boundary Free Mode Signal of Synchrotron Radiation

The readout waveform $S(t)$ of SR is a cascade convolution of electronic responses of $f_i(t)$. [5—8] (See Fig. 3)

$$S(t) = f_0(t) * f_1(t) * .... * f_i(t).... \qquad (4.3.1)$$

$$t[FWHM]^S = gt[FWHM]^{f_0} \qquad (4.3.2)$$

We proved by the functional theroy in Banach space, that

$$g = g_1 g_2 .... g_i,\quad g_i = t[FWHM]^{f_i}/t[FWHM]^{f_0} \qquad (4.4.3)$$

Hence, $\sigma_z = 6.16cm$ with respect to $t[FWHM]^S = 800$ps.

D. RTEM Mode Signals of Coherent RF Beamstrahlung

When e^+ bunch travels in the wake field of e^- bunch after collision and *vice versa*, both radiate CRFB. In BEPC, it is a beat wave in beampipe. The wave length carries the information of bunch length. It has been observed by the readout electronics of sub—detectors of BES. $\sigma_z = 5.7$ cm. (See Fig. 4 and 5) All measured σ_z narrated above are proved by collision point reconstruction of BES event data. [9]

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V. References

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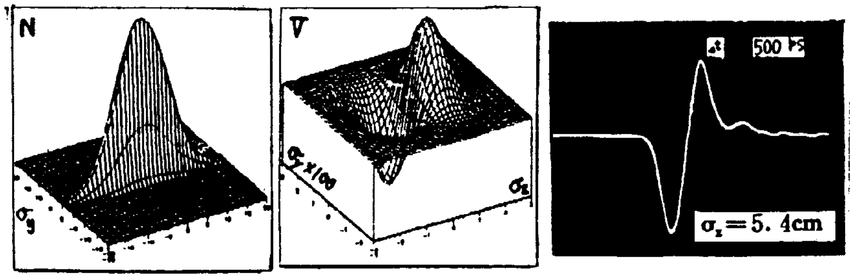


Fig1. VTEM Virtual Photon Signal of BEPC read out by TOF of BES

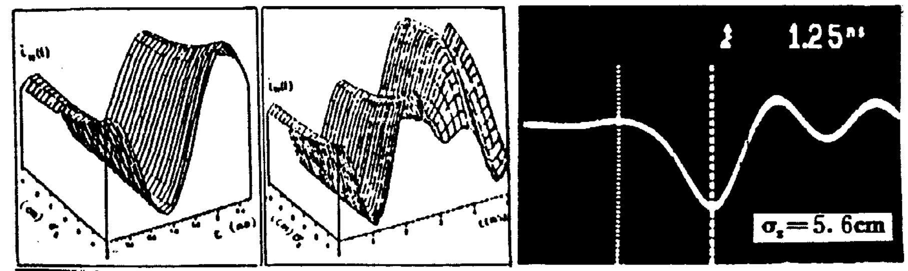
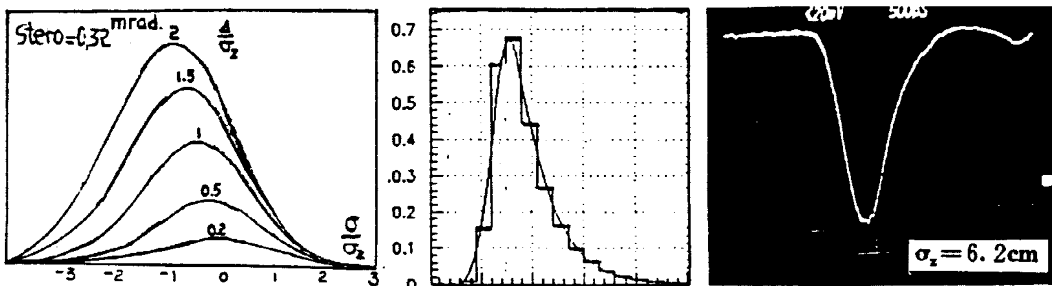


Fig. 2 VTM, VLE Virtual Phton Signal of BEPC read out by BPM



a. Window Effect of SR b. Convolution of SR signal with readout electronics c. Observed SR waveform

Fig. 3 Convolution Correction of RBF (Real Boundary Free) mode of Synchrotron Radiation Signal of BEPC

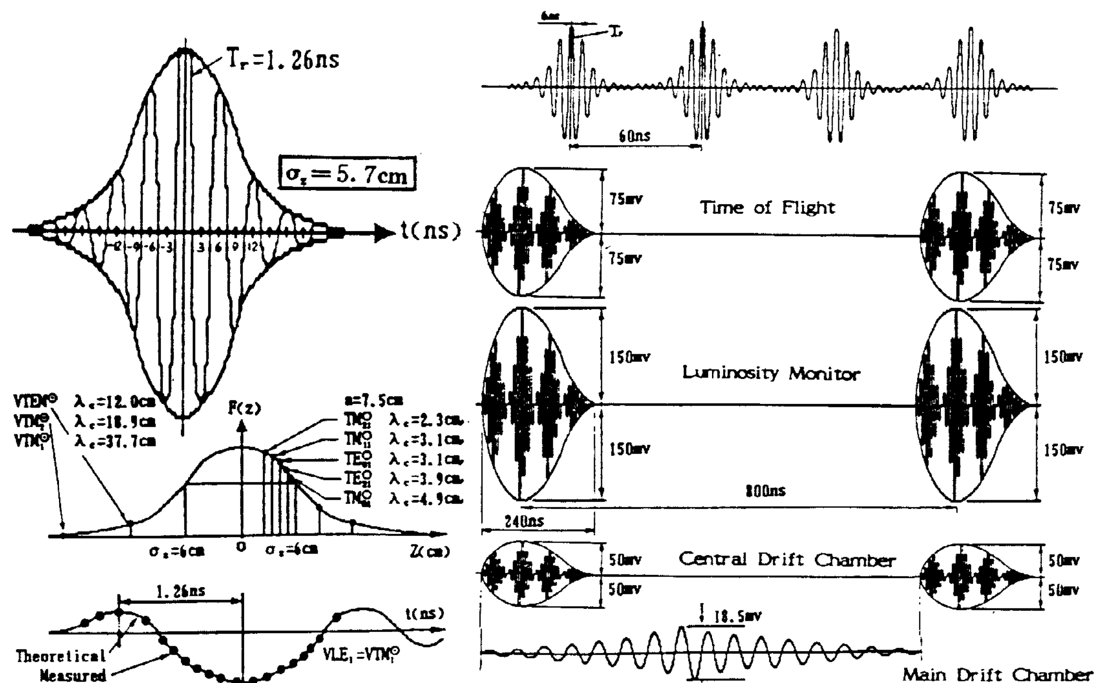


Fig. 4 RTEM model of Coherent Radio Frequency Beamstrahlung Signal of BEPC read out by Sub—detectors of BES

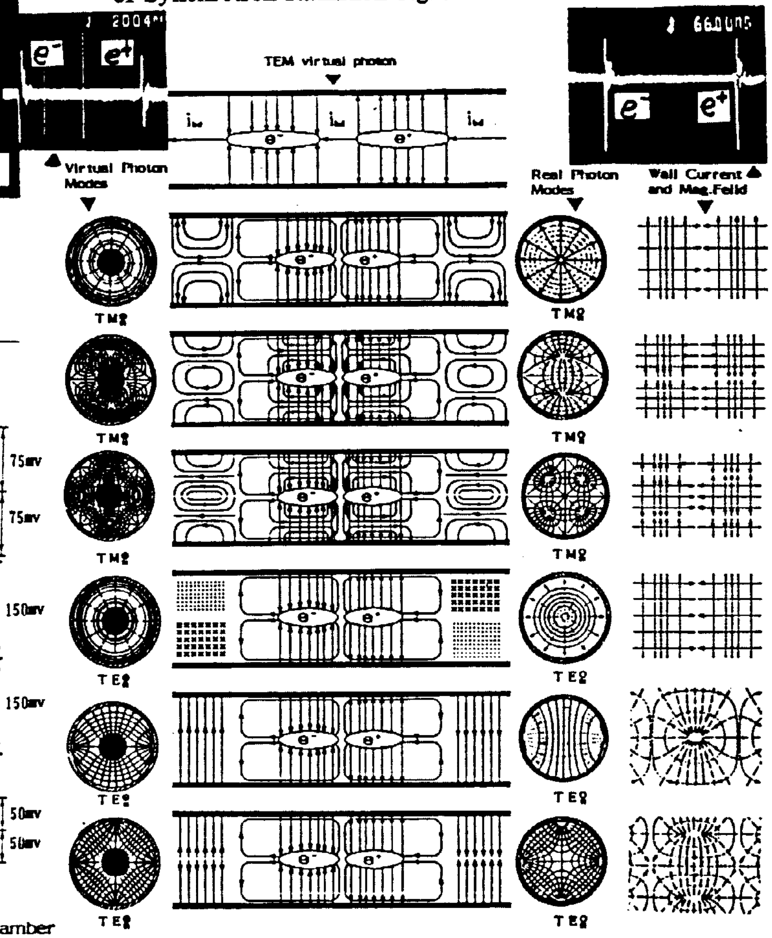


Fig. 5 Modes of Real and Virtual Photon