

PROPOSAL TO OBSERVE HALF-BARE ELECTRONS ON A 45-MeV LINAC*

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Abstract

The experimental investigation of the transition radiation (TR) generated by a “half-bare” electron having the proper field different from the Coulomb one is proposed. The electrons in half-bare state are intended to be obtained in the result of their crossing of a conducting screen. We propose to investigate the influence of the half-bare state of electron in this process upon TR generated by such electron on a downstream OTR screen situated on some distance along the direction of the electron beam from the upstream screen which “undresses” the particle. Calculations are presented for the case of a 45 MeV linac and the distance between the screens in the region between 100 mm and 300 mm. The proposed experiment is expected to reveal new features of TR signal in such process comparing to previous measurements.

INTRODUCTION

In normal conditions electrons are surrounded by a Coulomb field. When a relativistic electron interacts with matter or external fields it can lose part of its electric field and become “half-bare”. In such state the characteristics of its electromagnetic field are significantly modified and this can be observed when the particle interacts with matter again: the properties of the emitted radiation will be different. For example, in the case of relativistic electron multiple scattering in amorphous medium such modification results in the Landau-Pomeranchuk-Migdal and Ternovsky-Shul'ga-Fomin effects (see [1–3]) of the electron bremsstrahlung suppression.

Presently we propose to study the influence of the half-bare state of electron upon its transition radiation (TR). For the case when the electron becomes half-bare in the result of scattering or deflection in magnetic field the existence of such influence was theoretically predicted in [4]. In [5] it was shown that the electron also appears in the analogous state after crossing a conducting screen such as an optical transition radiation (OTR) screen. Such way of obtaining relativistic electrons in half-bare state provides certain advantages, from the experimental point of view, comparing to the case of electron deflection (e.g. unnecessary of the use

of bending magnets). Therefore it is such approach that we adopt in the present paper and discuss the TR produced by electron impinging upon a downstream screen after having traversed an upstream one.

Let us note that previously the experimental investigation of TR produced by electron beam crossing a system of two screens was reported in [6]. This experiment was made at three times higher energy (150 MeV) than the one provided at CLIO [7–9]. Here the increase of the TR signal at certain wavelengths with the increase of the distance between the screens was observed. In the present paper we show that the conditions available at the CLIO facility provide the possibility of investigating new features of half-bare electron TR, comparing to ones studied in [6]. The proposed investigation also aims at answering certain questions which the study [6] remained obscure. Particularly, it concerns the measurement of the ratio of TR signal from half-bare particle to the one from the particle having Coulomb field.

Let us also note that the example of direct experimental observation of gradual recovery of the Coulomb field of the electron after its traversal of the conducting screen (based on the measurement of the electric field spatial distribution) electron is presented in [10].

THEORY

Let us consider the traversal by an ultrarelativistic electron of a system of two conducting screens (figure 1). Presently we will consider the case of ideally conducting screens. Such approximation works well in the waveband applied in the proposed study. As follows from [5] (see also the discussion in [11]), the scalar potential of the electromagnetic field of the electron after its traversal at the moment of time $t = 0$ of the upstream (left) target can be approximately presented in the form:

$$\varphi(\mathbf{r}, t) = \frac{e}{\sqrt{\rho^2 \gamma^{-2} + (z - vt)^2}} \theta(ct - r), \quad (1)$$

where $\theta(x)$ is the θ -function, which equals unit for $x > 0$, and zero for $x < 0$. Here also $\mathbf{r} = (\rho, z)$ is the radius-vector of the observation point, e , v and γ are the electron charge, velocity and Lorenz-factor, c is the speed of light.

The expression (1) shows that after the electron traversal of an ideally conducting target its electromagnetic field is different from zero only inside the hemisphere of radius $r = ct$ with the center in the point of the electron emission from the target. Here it coincides with the Coulomb field of a relativistic charged particle. The part of the field outside

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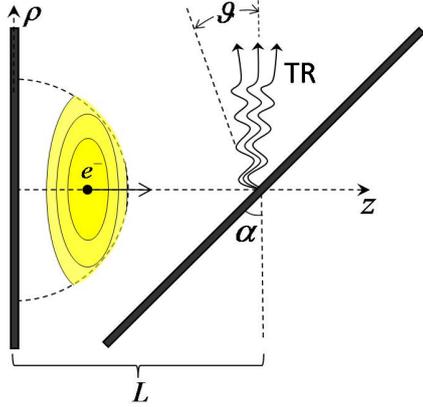


Figure 1: Incidence of the half-bare electron upon the downstream screen

the hemisphere is absent, which makes the electron half-bare. The radius of the hemisphere increases with the speed of light and the electron gradually restores its Coulomb field.

The strength of the electric field around the electron, which in ultrarelativistic case can be approximately considered as having just the component perpendicular to z -axis, can be defined as $E \approx -\partial\varphi/\partial\rho$. In the experiment it is more convenient to study the considered electromagnetic process in a narrow frequency range. A single-frequency component of the electric field strength around the half-bare electron can be derived from (1) in the following form:

$$E_{\omega}(\mathbf{r}) = \frac{2e}{v} e^{i\frac{\omega z}{v}} \int_0^{\infty} \frac{dx x^2 J_1(x\rho)}{x^2 + \omega^2/(v^2\gamma^2)} \times \quad (2)$$

$$(1 - \exp\{i\omega z[\gamma^{-2} + x^2 v^2/\omega^2]/(2v)\}),$$

where the first term in the parentheses is associated with the electron proper Coulomb field while the second one – with TR (which comes from taking $\partial/\partial\rho$ in (1) from the θ -function). Here $J_1(x)$ is the Bessel function. Expression (2) shows that the Fourier component with the frequency ω is suppressed in the field surrounding the electron at distances from the upstream screen $z \ll z_0 = 2\gamma^2 c/\omega \sim \gamma^2 \lambda$, where λ is the wavelength.

The simplest case of the considered problem corresponds to infinite screens and small value of the inclination angle α of the downstream one (see figure 1). In this case the spectral-angular density of TR produced by electron with the field (2) impinging on the downstream screen, registered in the far field (wave) zone, is defined by the following expression:

$$\frac{d^2 W}{d\omega d\vartheta} = \frac{e^2}{\pi^2 c} \frac{\vartheta^2}{(\vartheta^2 + \gamma^{-2})^2} 4 \sin^2 \left(\frac{\pi L(\vartheta^2 + \gamma^{-2})}{2\lambda} \right), \quad (3)$$

where ϑ is the observation angle (see figure 1). The interference term consisting of the sine squared, together with the coefficient 4 preceding it, differs this quantity from the corresponding distribution of TR generated by the electron with Coulomb field.

THE CLIO 45-MeV AND THE PROPOSED EXPERIMENT

To study the half-bare state we propose to use the linac of the CLIO Free Electron Laser at Orsay [7–9]. This linac can deliver pulses of up to 45 MeV and with a charge per beam of more than 0.5 nC. An experiment using a transition radiation screen has already been installed at the exit of the accelerating cavity [12] and is being upgraded.

We propose to use this experimental setup to insert two transition radiation screens at the same time as shown on figure 2. One of these screens will have a 45° angle with respect to the beam axis and will be imaged through a fused silica viewport. It will be used to measure the transition radiation. The second screen will be located slightly upstream and will have a shallow angle with respect to the beam. By moving this screen up or down the position at which it will be intersected by the beam will change and therefore the distance travelled by the beam between the two screens will also change.

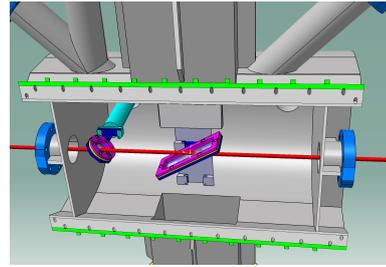


Figure 2: Conceptual view of the screens layout in the chamber for the half-bare electrons experiment. The beam comes from the right. The white screen is used to strip the electrons from their Coulomb field and the pink screen is used to measure the TR. The pink screen will move back and forth and the white screen up and down (actuators are not shown).

By completely removing the upstream screen it will be possible to measure the normal transition radiation whereas by inserting this screen it will be possible to measure the TR by electrons in half-bare state. By moving this screen up and down the distance travelled by these electrons will vary between 100 mm and 300 mm allowing to observe the partial recovery of their Coulomb field.

SIGNAL PREDICTION AT CLIO

In order to estimate the signal in the situation of the experiment proposed to be performed at CLIO several complicating factors (neglected by the expression (3)) should be taken into account. They are associated, particularly, with the fact that the measurement is proposed to be made with the use of a collecting parabolic mirror of finite size situated in the near-field (prewave) zone of the TR process. Further we present the numerical estimations of the expected results of TR characteristics measurements taking this into account.

Figure 3 represents the expected integrated yield of TR for a single electron in the wavelength range $1 \text{ mm} < \lambda < 5 \text{ mm}$.

It shows significant increase of the signal with the increase

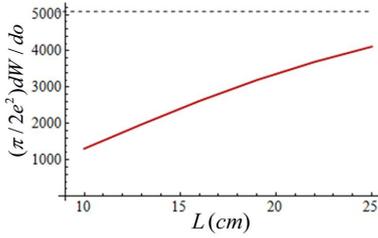


Figure 3: Half-bare electron TR yield (solid line) integrated over the wavelength region $1 \text{ mm} < \lambda < 5 \text{ mm}$. Dashed line – corresponding signal from the electron with Coulomb field

of the distance L between the screens in the available range $10 \text{ cm} < L < 25 \text{ cm}$. The TR signal is suppressed comparing to the corresponding signal from the electron with Coulomb field (dashed line).

Figure 4 demonstrates the calculated TR spectral-angular distribution for the wavelength $\lambda = 0.5 \pm 0.1 \text{ mm}$ (averaged over such interval) and 3° inclination β of the parabolic mirror axis with respect to the direction orthogonal to the beam. The figure shows the possibility of observation of

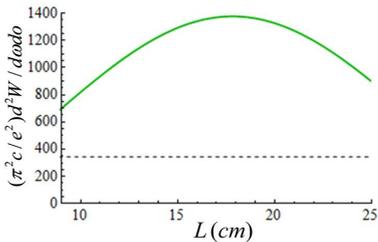


Figure 4: Half-bare electron TR yield for $\lambda = 0.5 \pm 0.1 \text{ mm}$ and parabolic mirror inclination $\beta = 3^\circ$. Dashed line – corresponding signal from the electron with Coulomb field

something like an antieffect in half-bare electron TR. It is the enhancement of the TR signal comparing to the one from the electron with Coulomb field and its further decrease with the increase of separation between the screens. Let us note that the presented calculations do not take into account the finiteness of the screens size and certain (45°) inclination of the downstream screen. The first factor may reduce radiation intensity in the long wavelength region. The second one should not lead to significant modification of the results at considered electron energies. Additionally the TR coherence considerably increases the bunch signal (up to 10^9 times).

DISCUSSION

Summarizing the discussion presented above, let us outline the main new features of the present experimental proposal and the half-bare electron TR properties which it deals with. Firstly, we propose to make the comparison of TR signals from half-bare electron and the one from the particle with Coulomb field. It could allow to judge of the magnitude of the influence of the half-bare state of electron upon its

TR and was not made in [6]. Secondly, calculations show that at parameters available at CLIO facility it is possible to observe the effect opposite to the one, reported in [6], which is the decrease of the TR signal with the increase of the distance between the screens. Thirdly, we propose to study the evolution of the integrated signal (with respect to wide waveband) with the change of L , which provides more complete information (comparing to narrow waveband study) about the process of the electron field regeneration after crossing the screen. Finally, under the discussed conditions the study of the prewave zone effect in half-bare electron TR could be performed as well by varying the detector aperture and its distance from the screen.

The proposed investigation is expected to reveal valuable for TR-based diagnostics information about TR properties in the case when interference effects in radiation are significant. It is also relevant for the TR-based diagnostics of extracted beams (with the use of bent crystal or magnetic field) which under certain conditions present the example of half-bare particle beams.

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