Longitudinal Profile Monitor Using Smith-Purcell Radiation: Recent Results from the E-203 Collaboration

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LONGITUDINAL PROFILE MONITOR USING SMITH-PURCELL RADIATION: RECENT RESULTS FROM THE E-203 COLLABORATION*

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Abstract

We report on recent measurements made at FACET by the E-203 collaboration to test a longitudinal bunch profile monitor based on Coherent Smith-Purcell radiation. The capacity of this monitor to resolve sub-picosecond bunches will be shown as well as a comparison of profile reconstructed for different data sets. We also present recent electromagnetic simulations of the interactions between the beam and the grating as well as the expected resolution of such monitor with a "notch collimator".

INTRODUCTION

Smith-Purcell radiation was first observed in 1953 by Smith and Purcell [1] in an experiment using a Van de Graaf linear accelerator which accelerated a continuous beam of electrons of 300 keV. With an optical grating they observed an emitted radiation on its surface, the color changing with the observation angle (see Fig. 1).

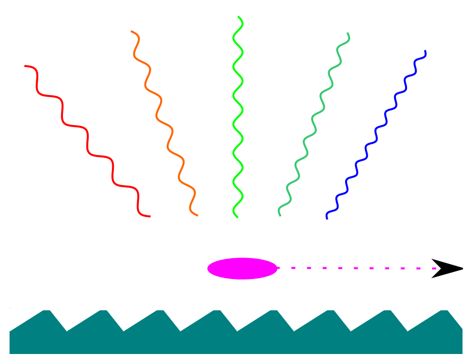

Figure 1: Smith-Purcell radiation is emitted when an electron beam passes near a grating.

Coherent Smith-Purcell radiation (CSPR) occurs when the length of the bunch is comparable to that of the emitted wavelength. In that case the radiation is emitted coherently and encodes the form factor (longitudinal profile) of the bunch (see equation 1):

$$\begin{aligned}
\left(\frac{dI}{d\Omega}\right)_{N_e} &= \left(\frac{dI}{d\Omega}\right)_1 \left(N_e S_{\text{incoh.}} + N_e^2 S_{\text{coh.}}\right) \\
S_{\text{coh.}} &\sim \left|\int_{-\infty}^{\infty} T e^{-i\omega t} dt\right|^2 G^2(\sigma_x, \sigma_y) \\
\left(\frac{dI}{d\Omega}\right)_{N_e} &\sim \left(\frac{dI}{d\Omega}\right)_1 N_e^2 \left|\int_{-\infty}^{\infty} T e^{-i\omega t} dt\right|^2
\end{aligned} \tag{1}$$

where $\left(\frac{dI}{d\Omega}\right)_{N_e}$ is the angular distribution of the radiation emitted by N_e electrons, $\left(\frac{dI}{d\Omega}\right)_1$ is the distribution for a single electron, $S_{\text{incoh.}}$ and $S_{\text{coh.}}$ are emission coefficients for the incoherent and coherent processes respectively, T and G are function describing the longitudinal and transverse profile respectively.

More details on CSPR can be found in [2, 3]. Past experiments have succesfully demonstrated that Smith-Purcell radiation can be used as a longitudinal profile monitor in the picosecond range [4, 5, 6].

The aim of the E-203 experiment at the FACET [7] User Facility at SLAC National Accelerator Laboratory is to extend this demonstration to the sub-picosecond regime. Early results and a description of the experiment can be found in [8].

In the E-203 experiment, an aluminum grating is approached from the beam. A carousel supporting gratings is used to changed them during data taking (this carousel is shown on Fig. 2). We use three gratings with different pitches ($50\mu m$, $250\mu m$, $1500\mu m$) and a further one without teeth for background subtraction. A motorized arm is used to insert and retract the carousel with the grating in the vacuum chamber. Pyroelectric detectors are used to measure the infrared radiation produced. They are placed around the interaction point over an angle of 100 degrees, from 40 to 140 degrees. The radiation is concentrated on our detectors by Winston cones. This arrangement is shown on Fig. 3. The wavelengths covered by our experiment go from 20 μm to about 2000 μm. Filters are used to select only the wavelength relevant for each detector and to reject background radiation.

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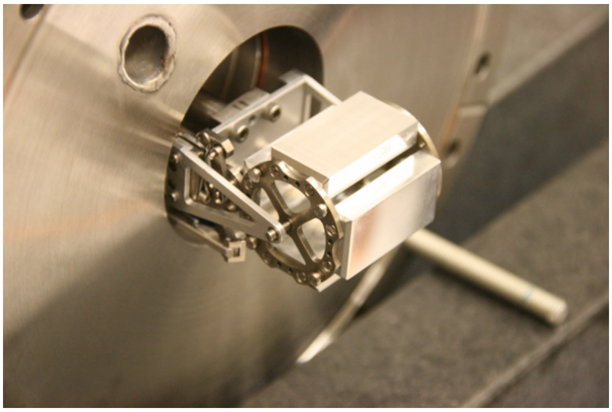

Figure 2: The carousel used to select the grating facing the beam.

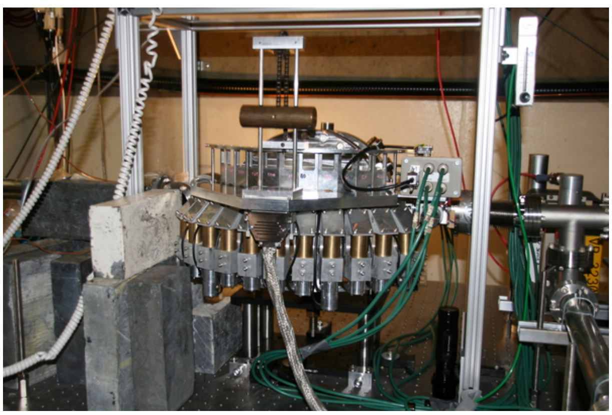

Figure 3: The carousel used to select the grating facing the beam.

RECONSTRUCTED PROFILES AND SHOT TO SHOT REPRODUCIBILITY

The signal produced by the pyroelectric detectors is acquired by ADCs. The measured value is then corrected to take into account the radiation losses between the gratings and the detectors. This value is further corrected to take into account the beam-grating coupling effects and grating efficiency. Once these corrections have been applied the resulting spectrum gives the form factor of the beam. Examples of such spectrum is shown on Fig. 4.

The measured form factor does not contain any phase information. To reconstruct the longitudinal profile, we need to recover the phase information. This is done using the Kramers-Kronig method [9]. Once this phase has been recovered the inverse Fourier transform of the measured form factor gives the longitudinal profile of the beam. Examples of such profiles are shown on Fig. 5.

At the moment a longitudinal profile reconstruction requires 6 measurements : first we measure the signal for each of our 3 gratings with corresponding filters and then we measure the background for each of the 3 sets of filters. For each of these measurements we record 200 samples to reduce the statistical errors on the data.

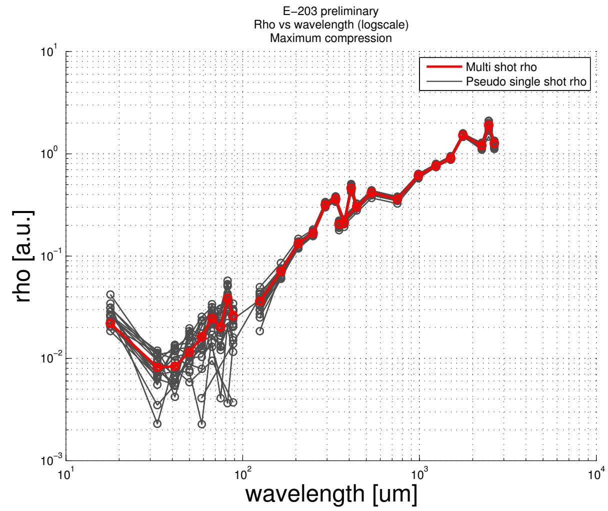

Figure 4: Measured form factor of the beam. The red curve corresponds to an average of 200 measurements whereas each gray curve corresponds to a pseudo-shot (details in text).

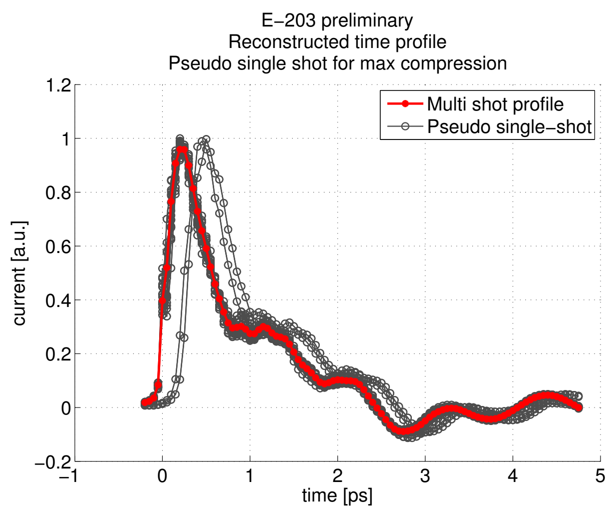

Figure 5: Reconstructed longitudinal profile using the form factors presented on Fig. 4. The red curve corresponds to an average of 200 measurements whereas each gray curve corresponds to a pseudo-shot (details in text).

As part of our recent studies, we investigated the shot to shot stability of the data taken. To do this we isolated one shot in each of the 6 measurements necessary for one reconstruction and we used the data from these shots to produce a spectrum and reconstruct the beam profile. On Fig. 4 and 5 the red line correspond to the spectrum and the profile reconstructed using 200 shots and the grey line correspond to 10 spectrums and profile reconstruction using only one shot from each of the 6 measurements. We can see that there is a good agreement between the two types of measures.

NOTCH COLLIMATOR LONGITUDINAL PROFILE MEASUREMENT SIMULATIONS

At FACET it is possible to insert a "notch collimator" that will create a special bunch longitudinal profile with two bunches separated by only a few hundreds femtoseconds. Although E-203 has not yet had the opportunity to take data in this configuration we have simulated what we expect to see with such bunch. Figure 6 shows the spectrum expected from such configuration and Fig. 7 compares the profile that could be reconstructed with the original profile. As we can see there is a rather good agreement between the original profile and the reconstructed profile.

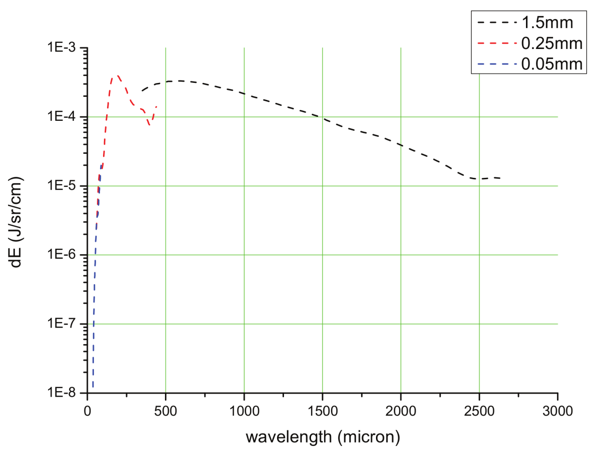

Figure 6: The expected Coherent Smith-Purcell radiation spectrum in a "notch collimator" configuration. Each color correspond to a different grating.

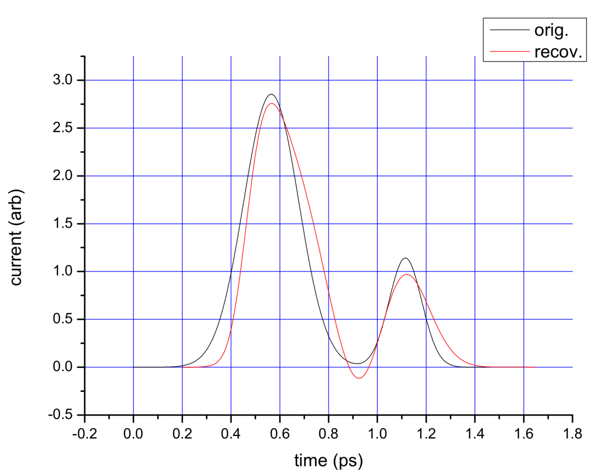

Figure 7: Comparison between the simulated profile of the "notch collimator" and what could be reconstructed using the simulated spectrum shown on figure 6.

OUTLOOK

The E-203 experiment has the capacity to measure the longitudinal profile of sub-picoseconds bunches and the analysis of the recent data taking campaign should be published soon [10]. Additional analysis of that the recent data set shows a good shot to shot stability. Recent simulations show the capacity of the current experimental setup to measure the FACET beam with a notch collimator inserted.

ACKNOWLEDGMENT

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