Longitudinal profile monitors using coherent Smith-Purcell radiation

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Single shot longitudinal profile monitors using Coherent Smith-Purcell radiation

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Abstract

Coherent Smith-Purcell radiation has the potential of providing information on the longitudinal profile of an electron bunch. The E-203 experiment at the FACET User Facility measures bunch profiles from the SLAC linac in the hundreds of femtoseconds range and the SPESO collaboration at Synchrotron SOLEIL is planning to make an accurate 2D map of the Coherent Smith-Purcell Radiation emission.

Keywords: Coherent Smith Purcell radiation, Longitudinal profile, single shot, bunch length, FACET, SOLEIL

1. Introduction: Coherent Smith-Purcell radiation

1.1. Coherent Smith-Purcell radiation as a bunch longitudinal profile diagnostic

Smith-Purcell radiation [1] is produced when an bunch passes near a grating as shown on figure 1. As for most radiative phenomena in accelerators if the radiating bunch is sufficiently short this radiation will be emitted coherently with an intensity proportional to the square of the bunch charge (N_e) and to its form factor. In the case of Smith-Purcell radiation this radiation is dispersed spectrally by the grating [2].

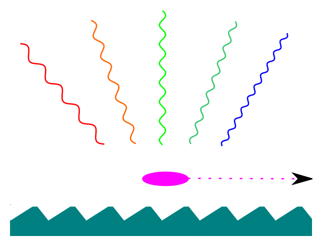

Figure 1: Smith-Purcell radiation is emitted when an electron beam passes near a grating.

The theory of the emission of coherent Smith-Purcell radiation is discussed in several papers [3, 4]. Several experiments have already investigated and validated Coherent Smith-Purcell radiation as a longitudinal bunch profile monitor in the picosecond regime [5, 6].

2. E-203: Smith-Purcell measurements at SLAC

The E-203 experiment started in 2011 at the FACET [7] User Facility at SLAC National Accelerator Laboratory and early results were published soon after [8]. FACET uses the first two thirds of the SLAC linac to deliver 20 GeV electrons (and later positrons) to experiments. The analysis of the data taken during the most recent data taking run is published elsewhere [9]. The experimental setup is shown on figure 2 and described in [9].

In this experiment, we bring gratings to within a millimeter of the electron beam. The coherent Smith-Purcell radiation from the electron bunch passing near the grating is measured simultaneously by 11 pyroelecric detectors. Filters are used to enhance the signal over noise ratio. The background is measured by substituting a flat piece of metal ("blank") for the grating. Three gratings with different periods are used in series to cover a wide spectral range. After processing this radiation can be converted into the bunch form factor and then the Kramers-Kronig relation [10] is used to reconstruct the original beam profile.

2.1. Effect of each grating

The 3 gratings used in the current experimental set-up give us a large wavelength coverage and therefore a more accurate reconstruction of the measured profile. However this comes at a cost of requiring consecutive acquisition for each grating. In our 2013 data set we have compared the profile reconstructed using the data from 3 gratings with the profile reconstructed

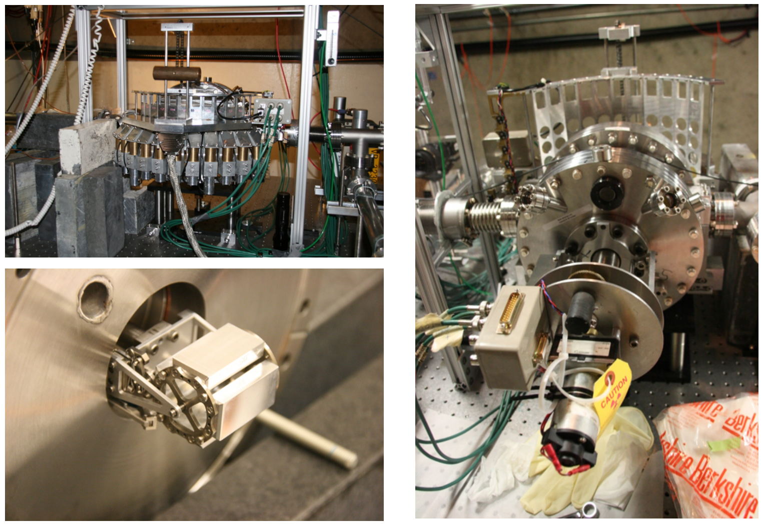

Figure 2: The E-203 experiment seen from the detectors side (top left), from the motors side (right) and the grating's carousel (bottom left).

using the data from a single grating. These reconstructed profiles for two different beam configuration are shown on figure 3.

For the shortest beam delivered by FACET during our acquisition (figures 3 a-c) we see that the profile reconstructed using the data acquired with the $250\mu m$ grating (figure 3 b) is very close from what is reconstructed using data coming from all the gratings. However with a longer beam (figures 3 d-f) this is no longer the case and the profile reconstructed using data from a grating with a longer pitch ($1500\mu m$) are closer from that reconstructed using the data from all the gratings.

This shows that for a given beam setting a single grating can give a good approximation of the overall beam profile. However one should keep in mind that such measurement would have a limited dynamic range and a change in beam settings affecting the bunch length would require a change of grating.

2.2. Measurements using one shot from each configuration sequentially

Although our current setup does not have the capability to be used to perform single shot measurements it is interesting to see how stable is the beam and a how close a pseudo single shot measurement would be from our current measurement. To build such pseudo single shot measurement we used six data files of 100 shots each, one file corresponding to each grating-filter

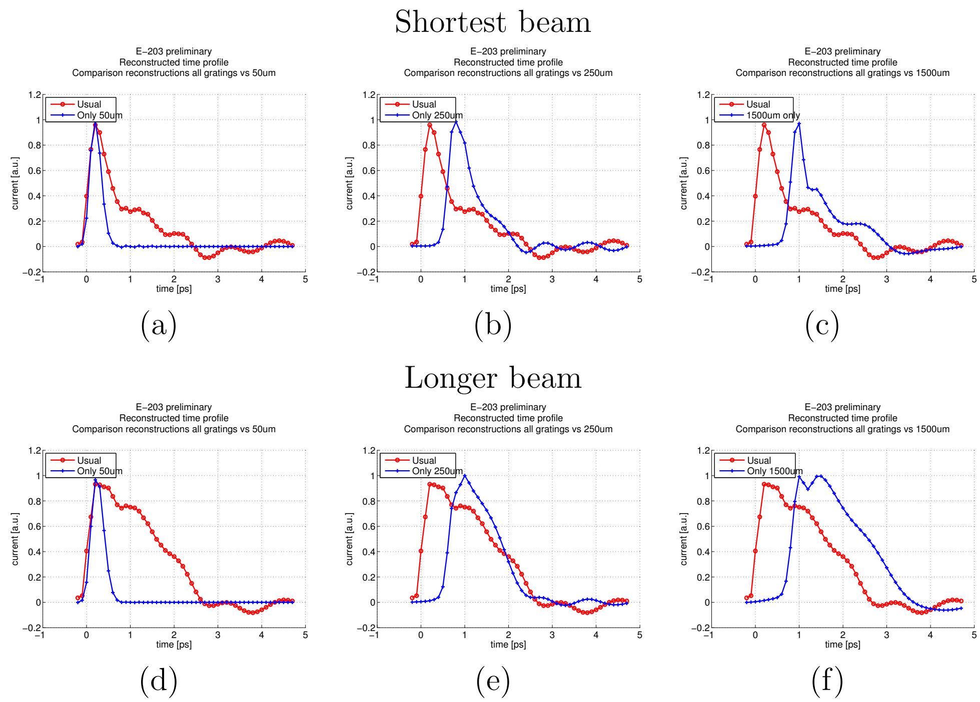

Figure 3: Comparison between the profile reconstructed with data from all the gratings (in red) and the one reconstructed with a single grating (in blue), from left to right, 50 μm pitch, 250 μm pitch and 1500 μm pitch. The top three plots are for the shortest beam settings, the bottom three plots are for a different beam settings leading to a longer beam. Note that the zero of the time axis is arbitrary and therefore the reconstructed profiles can be translated freely along that axis.

configuration (3 grating measurements with the associated filter and 3 times the blank with each filter set). Then one shot was extracted from each file and only this shot was processed through the usual analysis chain. Figure 4 shows the outcome of such analysis for several pseudo single shot (in grey), compared to the profile reconstructed in multishot mode (in red), as one can see in most cases there is a fairly good agreement.

3. SPESO: Smith-Purcell Experiment at SOLEIL

There are several theoretical models describing Smith-Purcell radiation (see for example [11]). Before building a single shot model that will rely on these theoretical models, it is important to compare them with experimental data. For this purpose a test stand called SPESO has been installed at the

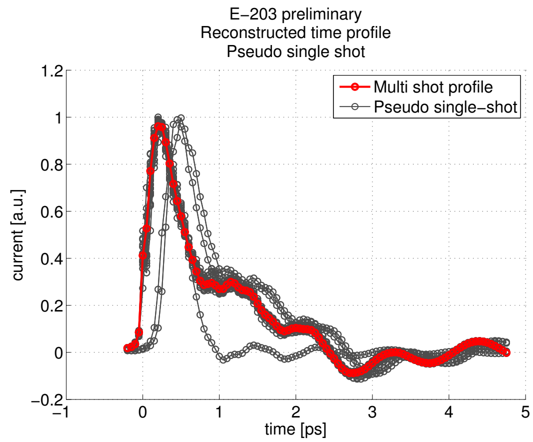

Figure 4: Comparison of the profile reconstructed by pseudo single host measurements (each grey line) and by the profile reconstructed using the full data sample (red line).

end of the linac of Synchrotron SOLEIL. The aim of SPESO is to allow a detailed study of Coherent Smith-Purcell radiation. One of the features of the test stand will be a 5-axis robot capable of mapping the emission of Coherent Smith-Purcell radiation in several direction, taking advantages of the linac high stability to accumulate a large statistical sample. At that location the electrons have an energy of 100 MeV.

The vacuum vessel of SPESO is made of a chamber and an antechamber (see figure 5). The antechamber can be sealed off from the linac vacuum by a UHV valve. A grating mounted on a movable arm can be brought from the antechamber to the chamber, close from the beam trajectory. This grating can be changed by retracting the arm to the antechamber, sealing the vacuum valve and then breaking the vacuum only in the antechamber. This will allow to test a large number of gratings (shapes, material, profile,...) relatively easily.

SPESO has been installed at SOLEIL in April 2013 and the first tests took place at the beginning of the summer. From a radioprotection point of view it has been confirmed that an interception of the beam by the grating does not generate unacceptable radiation levels. During high charge preliminary operations a signal was observed on some detectors, but not very strong. This may have been due to the small size of the infrared window used. This window has been replaced by a larger one during the latest SOLEIL shutdown and the detectors amplification will be improved.

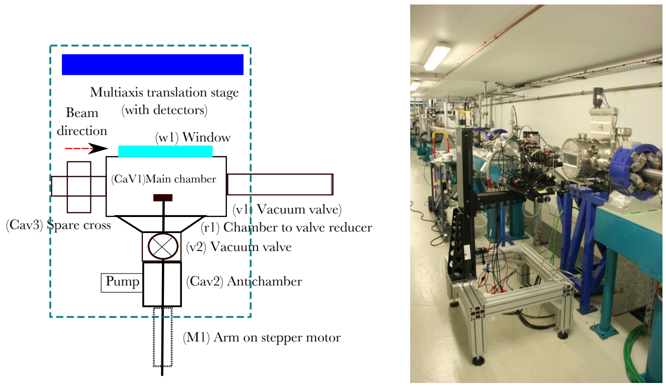

Figure 5: The experimental setup of SPESO at the end of the SOLEIL Linac.

4. Outlook

Coherent Smith-Purcell radiation has the potential of being used as a non interceptive diagnostic to measure bunch longitudinal profiles. Two experiments, E-203 at FACET and SPESO at SOLEIL, are currently working on validating this technique. Furthermore there is no theoretical requirement to use several shots to reconstruct such profile and thus this technique has the potential of being used as a single shot non interceptive bunch profile monitor.

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