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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].

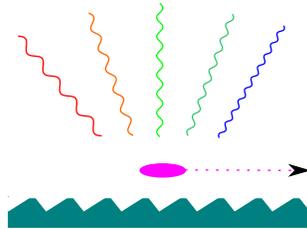


Figure 1: Smith-Purcell radiation is emitted when an electron beam passes near a grating.

10 The theory of the emission of coherent Smith-Purcell radiation is dis-
 11 cussed in several papers [3, 4]. Several experiments have already investigated
 12 and validated Coherent Smith-Purcell radiation as a longitudinal bunch pro-
 13 file monitor in the picosecond regime [5, 6].

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

15 The E-203 experiment started in 2011 at the FACET [7] User Facility
 16 at SLAC National Accelerator Laboratory and early results were published
 17 soon after [8]. FACET uses the first two thirds of the SLAC linac to deliver
 18 20 GeV electrons (and later positrons) to experiments. The analysis of the
 19 data taken during the most recent data taking run is published elsewhere [9].
 20 The experimental setup is shown on figure 2 and described in [9].

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

30 2.1. Effect of each grating

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

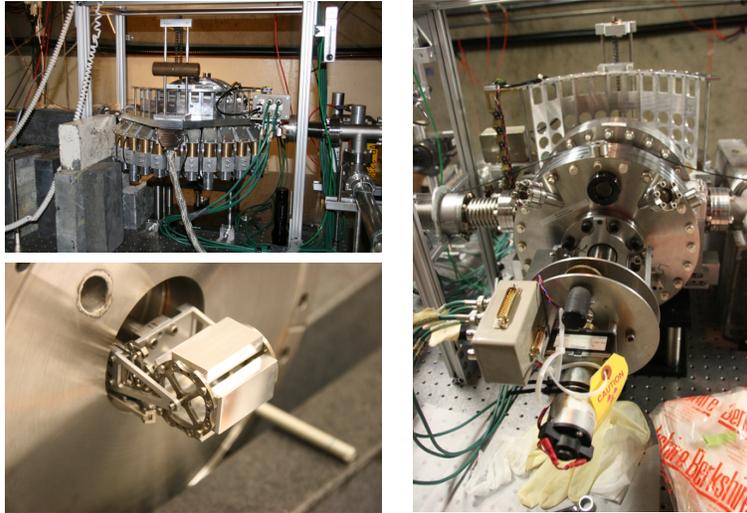


Figure 2: The E-203 experiment seen from the detectors side (top left), from the motors side (right) and the grating's carousel (bottom left).

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

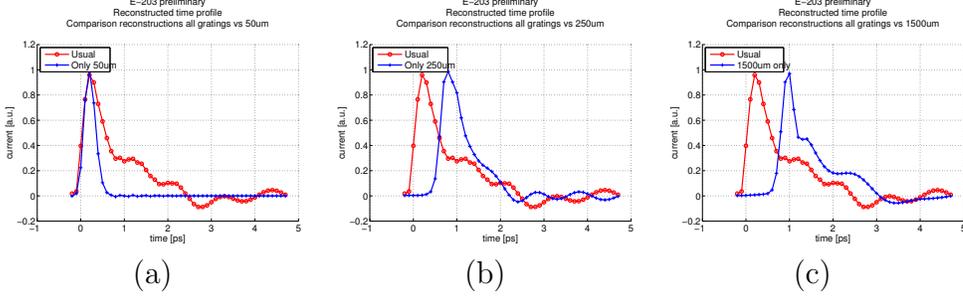
38 For the shortest beam delivered by FACET during our acquisition (figures
 39 3 a-c) we see that the profile reconstructed using the data acquired with the
 40 $250\mu m$ grating (figure 3 b) is very close from what is reconstructed using data
 41 coming from all the gratings. However with a longer beam (figures 3 d-f) this
 42 is no longer the case and the profile reconstructed using data from a grating
 43 with a longer pitch ($1500\mu m$) are closer from that reconstructed using the
 44 data from all the gratings.

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

49 *2.2. Measurements using one shot from each configuration sequentially*

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

Shortest beam



Longer beam

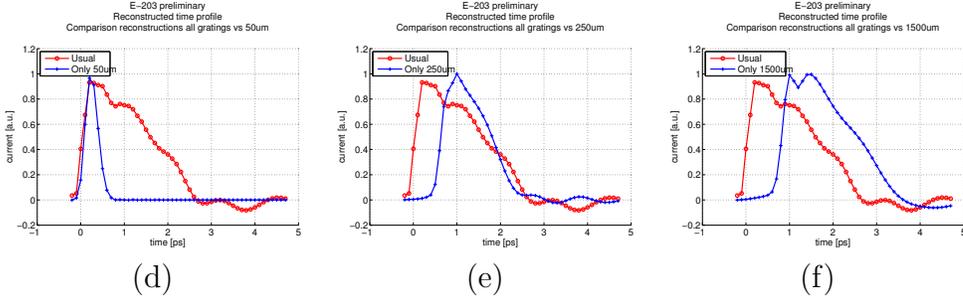


Figure 3: Comparison between the profile reconstructed with data from all the gratings (in red) and the one reconstructed with a single grating (in blue), from left to right, $50\ \mu\text{m}$ pitch, $250\ \mu\text{m}$ pitch and $1500\ \mu\text{m}$ pitch. The top three plots are for the shortest beam 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.

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

61 3. SPESO: Smith-Purcell Experiment at SOLEIL

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

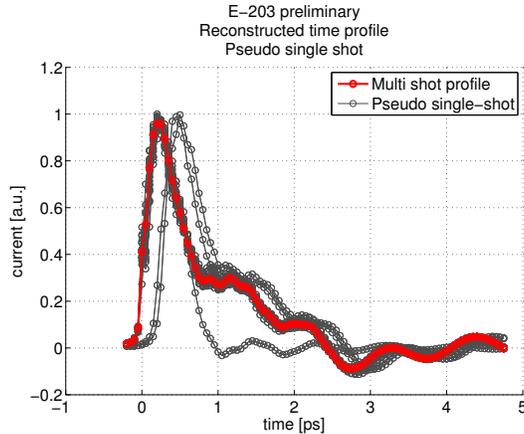


Figure 4: Comparison of the profile reconstructed by pseudo single host measurements (each grey line) and by the profile reconstructed using the full data sample (red line).

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

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

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

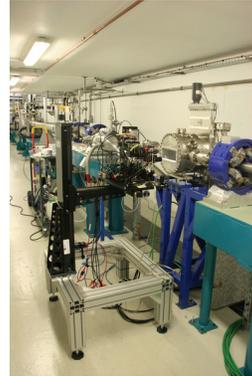
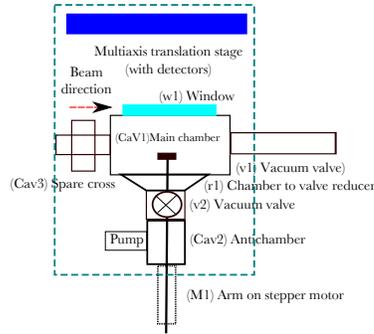


Figure 5: The experimental setup of SPESO at the end of the SOLEIL Linac.

88 4. Outlook

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

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