BUNCH LENGTH MEASUREMENTS USING COHERENT SMITH-PURCELL RADIATION WITH SEVERAL GRATINGS AT CLIO*

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Abstract

Coherent Smith Purcell radiation allows the measurement of a beam longitudinal profile through the study of the emission spectrum of the radiation emitted when a grating is brought close from the beam. In order to increase the dynamic range of our measurements we have used several gratings and we report on the measured bunch form factor using this technique. We report on these measurements and on the background rejection used.

INTRODUCTION AND EXPERIMENTAL SETUP

Coherent Smith Purcell Radiation (CSPR) is a radiative phenomena that encodes the bunch longitudinal profile. It occurs when a charged bunch of particles passes near a metallic grating. Coherent emission occurs at wavelength longer than the bunch length. It has been described in details in [1]. We have installed a CSPR monitor at the CLIO [2] Free Electron Laser in Orsay. This monitor and simulations of the expected signal are described in [3] and the first results have been reported in [4]. We report here on recent measurements done at CLIO with the CSPR monitor and on comparison between the predicted and observed signal. We also report preliminary results on the first multiple gratings measurements.

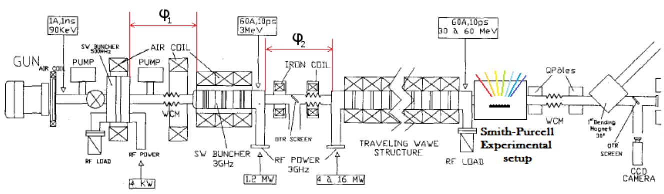

Figure 1: Layout of the CLIO accelerator, position of the experimental setup and indication of the relative phases that can be modified to change the bunch length. Image taken from [4] and adapted from [5]. ϕ_2 in this figure will later be referred to as ϕ_B.

In the measurements described below the CLIO Free Electron Laser was operated at an energy of 35 MeV to 45 MeV (depending on the beam configuration chosen) delivering electron bunches with a charge of approximately 0.5 nC and an expected bunch length of a few picoseconds.

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With such bunch length the wavelength at which coherent emission occurs is in the far infrared. A z-cut quartz window was used to get the signal out of the accelerator vacuum. Most of the measurements presented here were made with a grating with a pitch of 6 mm. Another grating with a pitch of 3 mm was used in the last section.

EXPONENTIAL DECAY FIT

One of our first measurements (partially reported in [4]) was the signal amplitude as function of the beam grating separation. The amplitude is expected to decay exponentially, following a parameter called the evanescent field length of the CSPR (see equation 7 in [1]). An example of such fit is shown in Figure 2.

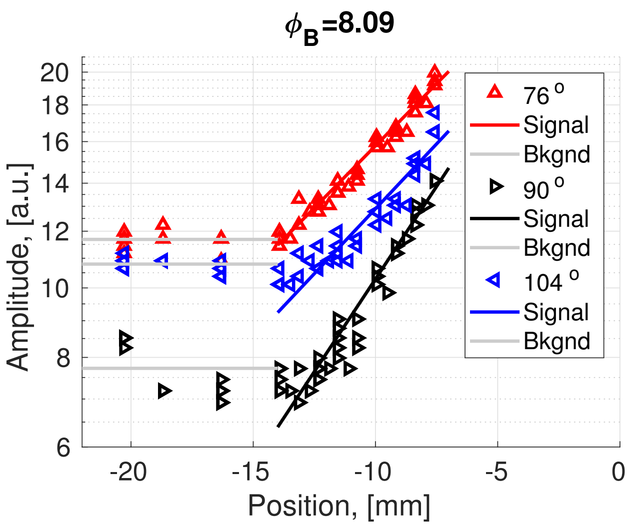

Figure 2: Signal amplitude as function of beam grating separation. As expected the exponential decay can clearly be seen.

However for this fit to be correct we previously reported in [4] that a tilt angle had to be introduced in the evanescent wavelength function. To check if this tilt had a physical meaning we took advantage of a maintenance week of the accelerator to move slightly the board holding the pyroelectric detectors. The evanescent wavelength fit before and after this extra tilt is shown in Figure 3. As we can see the board tilt went down by about one degree, confirming that we can use the evanescent wavelength fit to check the detectors alignement.

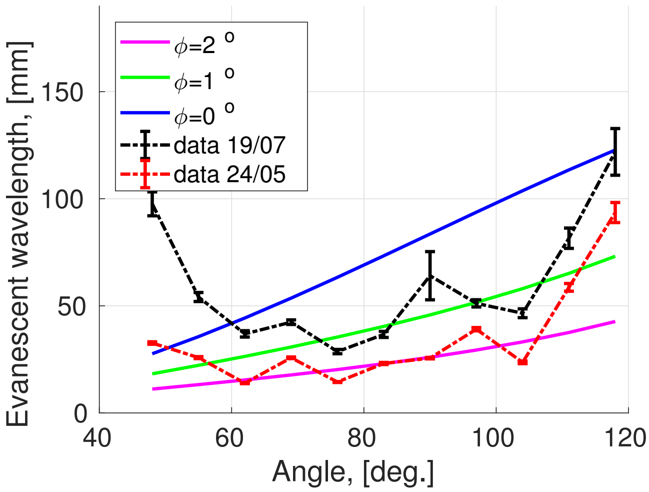

Figure 3: Evanescent wavelength as function of the detector angle. The data measured on 24th May are in red and those measured after moving the detectors board on 24th May are in black. The expected evanescent wavelength from the theory are in blue (for 0° tilt), green (for 1°) and pink (for 2°).

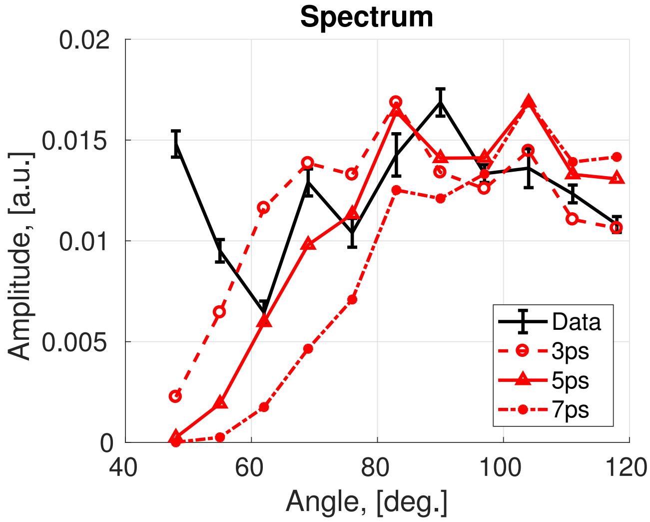

Figure 4: Example of measured spectrum as function of the detector angle. The measured data are in black and the three red lines give simulated spectrum for a bunch length of 3 ps FWHM (dashed line), 5 ps (plain line) and 7 ps (dot-dashed line).

SPECTRUM, FORM FACTOR AND PROFILE RECONSTRUCTION

In Figure 4 an example of spectrum measurement is shown and compared to the expected signal for different bunch length. As we can see in that configuration the signal is the closest from the predictions for a 5 ps (FWHM) bunch length with apparently two detectors (at 48° and 55° giving non-sensical readings [1]).

From the spectrum it is possible to compute the form factor of the electron bunch as described in [6]. We have repeated these measurements several times for different settings of the booster phase ϕ_B (see Figure 1) and the different bunch form factors reconstructed from these measurements are shown on Figure 5.

From this form factor and following the methods from [6] we can reconstruct the bunch profile. In Figure 6 examples of bunch profiles reconstructed for different booster phases are presented. As we can see, when the phase is changed a small tail will appear and this tail will grow when the booster is dephased even further.

COMPARISON WITH ASTRA PREDICTIONS

Prior to this experiment we had used Astra [7] to model this linac [3]. As the bunch lengthening is first characterized by the apparition of a low intensity tail, the FWHM is not immediately affected and another relevant variable is the FW0.1M (Full width at 0.1 of the maximum) and the FW0.9M (Full width at 0.9 of the maximum). The evolution of the FWHM and FW0.1M variables as function of the booster phase as simulated in Astra is shown in Figure 7. As one can see on that figure around the shortest possible bunch length ($\phi_B \simeq 300°$) the FW0.1M is much more sensitive to the booster phase than the FWHM.

Doing a similar plot for the data collected shows a similar behavior as can be seen on Figure 8.

[1] This is probably due to some background radiation hitting these detectors.

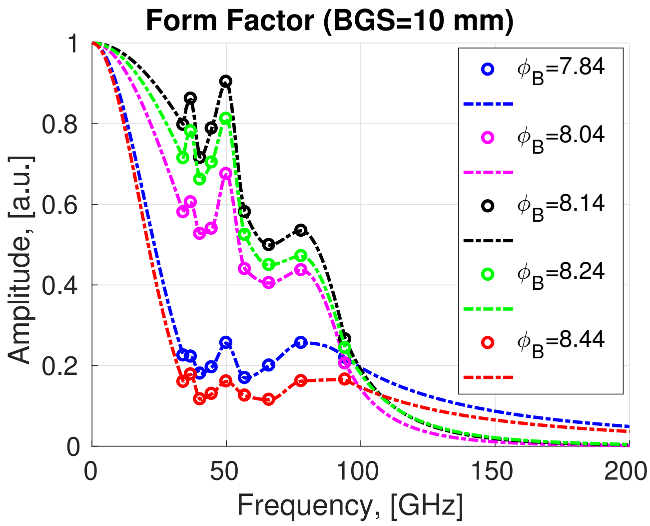

Figure 5: Form factors reconstructed for different settings of the booster phase ϕ_B. The two data points above 100 GHz have been excluded as non-sensical. The recorded signal is represented by the open circles and the dashed line correspond to the interpolations between these points and the extrapolations outside the sensitivity range as described in [6].

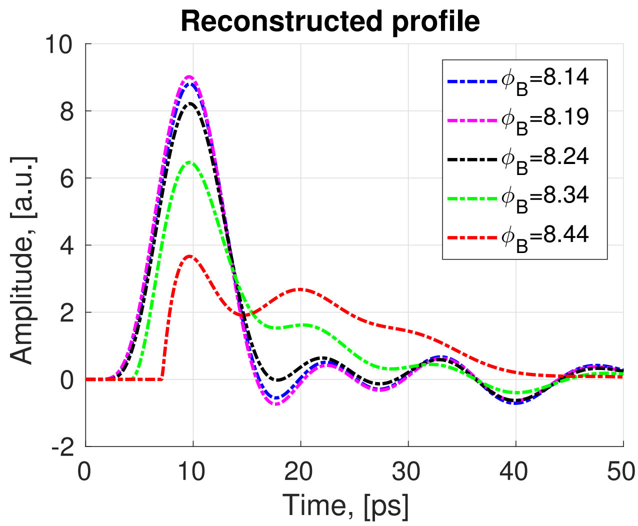

Figure 6: Examples of bunch profiles reconstructed for different booster phases. Going from the optimum phase to a different phase will spread the bunch over a longer tail. The oscillations near zeros come from the numerical approximations and are non physical.

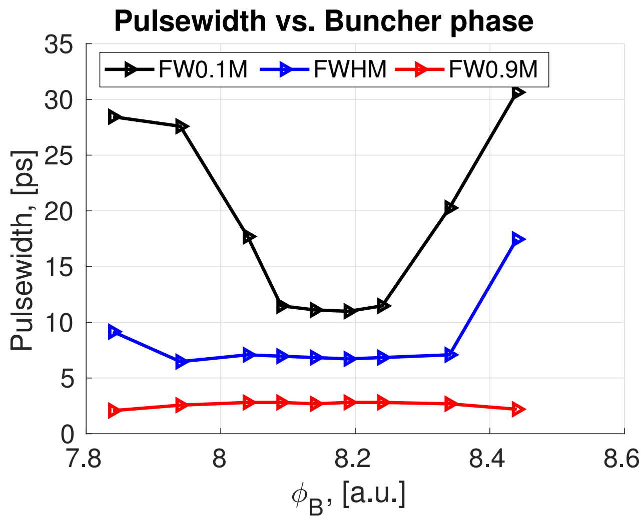

Figure 8: Examples of the bunch FWHM, FW0.1M and FW0.9M as function of the booster phase (note: the values given for the booster phase are arbitrary, only their variation has some physical meaning). As expected the FW0.1M is more sensitive to the booster phase as a booster detuning will results in the apparition of a small low intensity tail to the bunch.

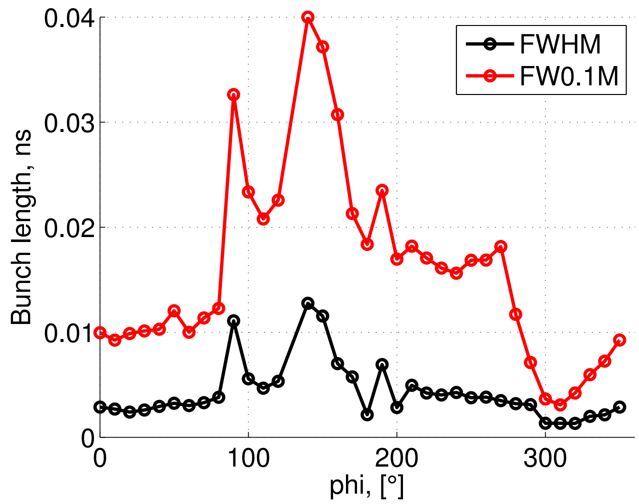

Figure 7: Predicted FWHM and FW0.1M bunch length using the Astra software [7]. In the simulations the shortest bunches are found around $\phi_B \simeq 300°$ and at that position the FW0.1M is much more sensitive to booster phase change than the FWHM.

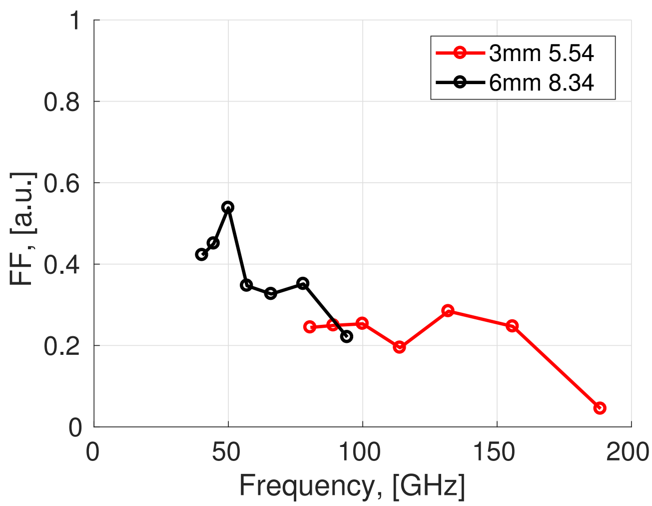

Figure 9: Form factors measured for two different gratings with different pitches.

MULTIPLE GRATINGS MEASUREMENTS

We took advantage of a maintenance week to change the grating in the setup to put another grating with a shorter pitch (3 mm instead of 6 mm). The form factors obtained for these two gratings can be seen in Figure 9. As the two measurements have been made several days apart they should be compared with care, but we can see that the data from the two gratings follow a similar and compatible trend.

OUTLOOK

Over the past year we have made significant progress in understanding the CSPR at CLIO. A new experimental setup is being designed with the possibility of using several gratings without breaking the accelerator vacuum. We hope to be able to report on these measurements next year.

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