STUDY OF A SMITH-PURCELL RADIATION-BASED LONGITUDINAL PROFILE MONITOR AT THE CLIO FREE ELECTRON LASER

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Abstract

We report on measurements of Coherent Smith-Purcell radiation at the CLIO Free Electron Laser. Smith-Purcell radiation is emitted when a grating is brought close from a bunch of relativistic particles. When the bunch is sufficiently short coherent radiation is emitted. This coherent radiation encodes the longitudinal form factor of the bunch and can therefore be used as a longitudinal profile monitor. With its short pulses and high charge the 45 MeV Linac of CLIO is a good location to test advanced longitudinal profile diagnostics. The results will be compared with measurements using the RF dephasing. induced energy dispersion.

INTRODUCTION

Smith-Purcell radiation (SPR) occurs when a charged particle move above a metallic periodic structure. Emitted radiation is spread in solid angle. The wavelength of the radiation for SPR depends on the observation angle Θ according to the following formula:

$$\lambda = \frac{l}{n}(\frac{1}{\beta} - cos\Theta) \tag{1}$$

where l is the grating period , n is the order of radiation, Θ is the observation angle and β is the relativistic velocity.

For one electron the emission spectrum (single electron yield [1]) is given by:

$$\frac{d^2 I_1}{d\omega d\Omega} = \frac{e^2 \omega^2 l^2}{4\pi^2 c^3} R^2 exp(-2x_0/\lambda_e) \tag{2}$$

where ω is the emission frequency, $d\Omega$ is the solid angle, e is the electron charge, c is the speed of light, R^2 is the "grating efficiency factor", x_0 is the beam-grating separation (BGS) and λ_e is the evanescent wavelength:

$$\lambda_e = \lambda \frac{\beta\gamma}{2\pi\sqrt{1 + (\beta\gamma \sin\Theta \sin\phi)^2}} \tag{3}$$

where β, γ are the relativistic parameters of the particles in the beam. The total spectrum is proportional to the single electron yield and contains incoherent and coherent components:

$$\frac{d^2 I}{d\omega d\Theta} = \frac{d^2 I_1}{d\omega d\Theta}[N + N(N-1)F(\omega)] \tag{4}$$

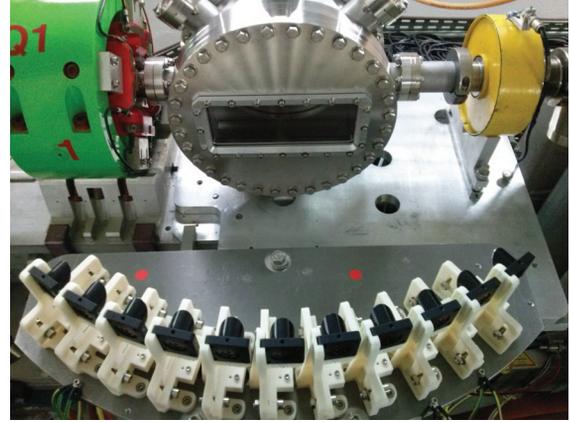* hodnevuc@lal.in2p3.fr
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Figure 1: Experimental setup for SPR measurements at CLIO: set of twelve pyrodetectors with off axis parabolic mirrors placed equidistantly with 7° separation and experimental chamber with the grating inside.

Where N is the number of electrons in the bunch and $F(\omega)$ is the form factor of the time profile of the bunch. Using the phase recovery methods, such as Kramers-Kronig or Hilbert [2], it is possible to recover the phase and then the time profile of the bunch.

So Smith-Purcell radiation can be used to monitor the longitudinal beam profile.

EXPERIMENTAL SETUP

The experimental setup is shown on Figure 1. It consist of 12 pyrodetectors placed from 48° to 125° with 7° separation. To collect the emitted radiation 25 mm diameter off-axis parabolic mirrors are used. The signal from the detectors is amplified and then digitized by a data 12 bits 1 MS/s acquisition system.

The experiment uses a 40×20 mm aluminium grating with 3 mm pitch. The beam-grating separation can be changed by a stepper motor.

CLIO

The CLIO free electron laser is an accelerator built in 1991. It is described in details in [3] and it is shown on Figure 2. The CLIO accelerator consist of a thermionic gun, a subharmonic buncher (SHB), a fundamental buncher (FB) and an accelerating cavity (AC). The gun produce bunches about 1.5 ns long at an energy of 90 keV. These bunch are then compressed by the subharmonic buncher to 200 ps or
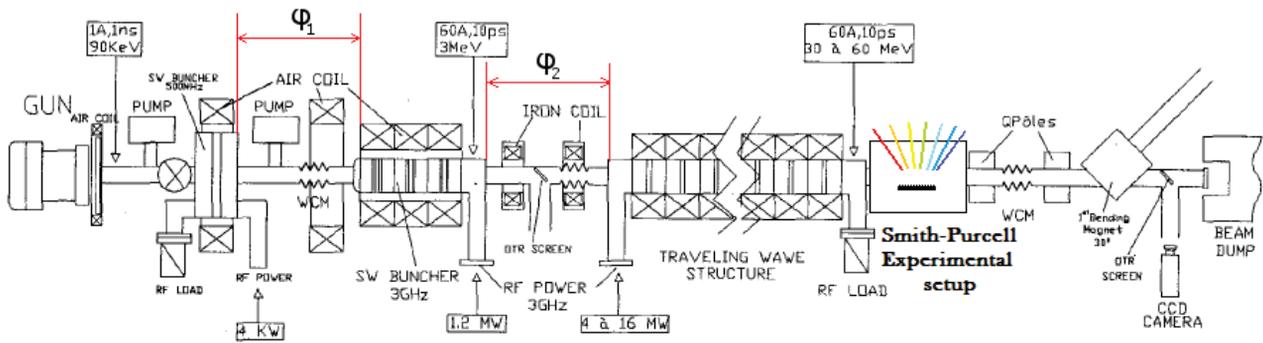
Figure 2: Layout of the CLIO accelerator and position of the experimental setup.

less to make it suitable for further compression with the fundamental buncher. This fundamental buncher further compresses the beam to a few ps and accelerates bunch to several MeV, making the electrons relativistic. The bunches are then further accelerated in the accelerating cavity to the operation energy (typically 10-45 MeV).

For bunch compression the most important parameters are the phases φ_1 (between SHB and FB) and φ_2 (between FB and AC). In our experiment we change bunch length by changing φ_1 and while keeping the beam energy constant at 44.3 MeV.

RESULTS

First we made a scan of the beam-grating separation and recorded the amplitude of the signal as function of the grating position. The result for three angles of measurement is presented on Figure 3. For beam-grating separation between 20 mm and 30 mm we observe a peak in signal intensity that we have not been able to explain yet. Closer to the beam we observe an exponential increase of the signal (see Figure 4) as predicted by the theory of SPR [1].
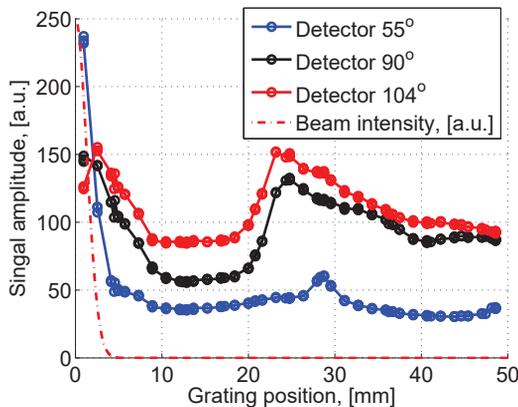

Figure 3: Preliminary results. Amplitude of the signal as function of BSG. FWHM of the beam is 3.1 mm. Zero point correspond to the center of beam.

The theory of Smith-Purcell radiation [1] predicts also the the signal intensity should decay as function the beam grating separation (see Eq. 2). The experimental data for 3
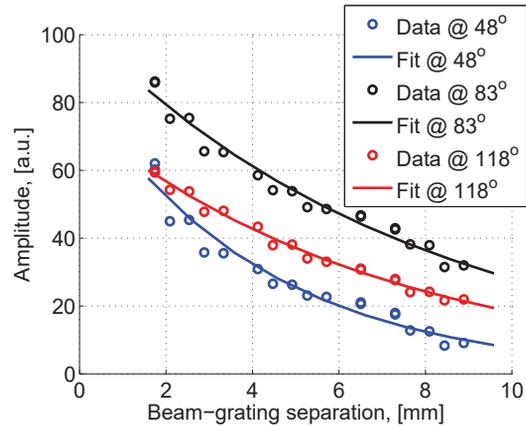

Figure 4: Preliminary results. Decay of the signal near beam: data (circles) and fit (solid line) for three angles and constant phase $\varphi_1 = 4.24$.
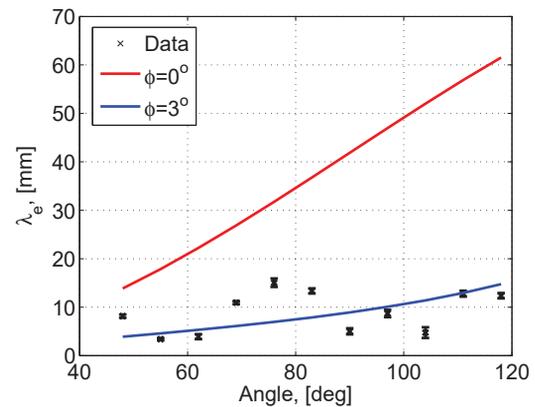

Figure 5: Preliminary results. The data is the decay length of the signal as function of the angle. The red line corresponds to polar angle $\phi = 0°$ and blue is for $\phi = 3°$.

angles (48°,83°,118°) and phase $\varphi_1 = 4.24$ as example are presented on Figure 4. We fit this curve with exponential and get a decay length, which is proportional to evanescent wavelength. The result of this fit for all angles and the average for all phases is presented on Figure 5. The error for the data on the plot correspond to fluctuation over phases,

but it is relatively small, so we confirm that this parameter is not dependent on the phase φ_1. On Figure 5 we also present two curves, which correspond to measurement polar angle $\phi = 0°$ and $\phi = 3°$ of evanescent wavelength. From this measurement we conclude that our setup is probably slightly titled (with respect to the grating position).

To be sure that the radiation measured is dependent on the bunch length, we change the phase φ_1 between the subharmonic and fundamental bunchers. During this operation beam intensity was stable with $\pm 10\%$. The result is presented on Figure 6 and 7.

As we can see from Figure 7 and 6, the spectrum changed during the phase scan and the observed peak at phase $\varphi_1 = 4.24$ (arbitrary units) corresponds also to the largest emission from the free electron laser i.e. the shortest bunch. The largest emission increase occurs for the longest wavelength, as expected for coherent emission.

CONCLUSIONS

We have observed at the CLIO Free Electron Laser a signal that is compatible with Coherent Smith-Purcell Radiation and that depends on the phase between the subharmonic and fundamental buncher. Our current setup does not allow a full reconstruction of the bunch length but an upgrade is underway. We also observe another radiative phenomena for w beam-grating separation of about 25 mm which is still under investigation.

REFERENCES

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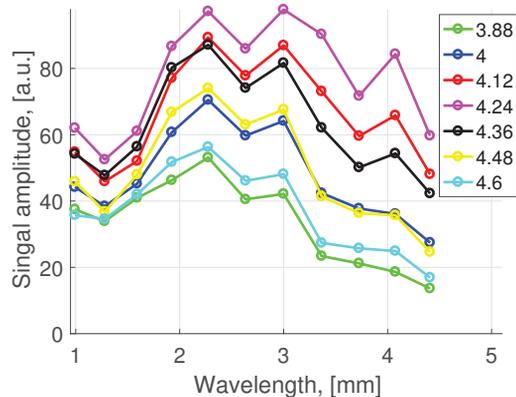
Figure 6: Preliminary results. Measured spectrum for different phase.
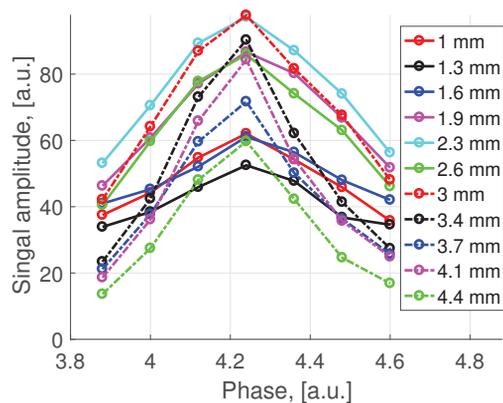
Figure 7: Preliminary results. Change of spectrum components as function of phase.