Coherent Diffraction Radiation as a tool for longitudinal beam profile diagnostics at CTF3

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Abstract

A setup for the investigation of Coherent Diffraction Radiation (CDR) from targets with various configurations as a tool for non-invasive longitudinal electron beam profile diagnostics has been designed and installed in the CRM line of the CLIC Test Facility 3(CTF3 at CERN). In this report we present the status of the experiment. Recently we have upgraded the system by installing the second target. In this report we shall also demonstrate the results on simulations of CDR spatial distribution from a two targets configuration.

Diffraction Radiation

Diffraction radiation (DR) arises when a charged beam passes by in the vicinity of a target, effect of the beam interaction with the target material is minimal and a smaller perturbation to the beam is produced compared with other diagnostics, such as transition radiation (TR) [1].

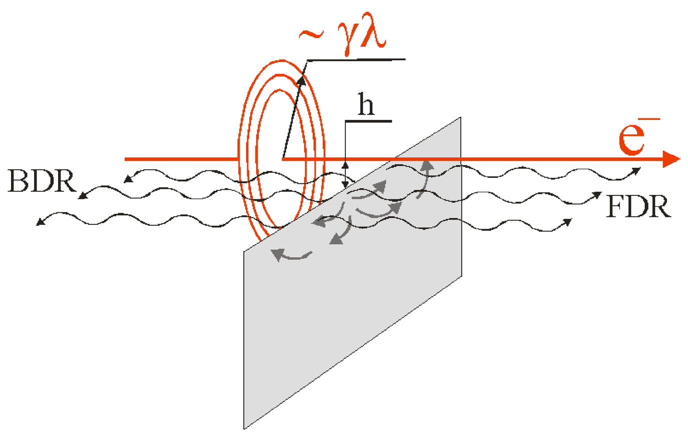

Figure 1: DR production mechanism.

DR was suggested as a mechanism for the coherent radiation generation (radiation wavelength is comparable to or longer then a bunch length) due to its non-invasive nature. It is utilized in this experiment.

- DR appears when a charged particle moves in the vicinity of a target with impact parameter $h \leq \frac{\gamma\lambda}{2\pi}$ (γ is the particle Lorentz factor, λ is an observation wavelength)
- DR is emitted in backward and forward direction.
- Used for transverse [2] and longitudinal [3] beam parameters monitoring.

CLIC Test Facility

A novel scheme for a drive beam generation has been proposed, in which a long bunch train with a low bunch repetition frequency is accelerated with a low RF frequency [4]. The main goals of the CTF3 are to test this new RF power generation scheme and to produce 12 GHz RF power at the nominal peak power and pulse length, such that all 12 GHz components for the Compact Linear ColLider (CLIC) can be tested at nominal parameters. The monitoring of a longitudinal bunch profile will be very important for the CLIC:

- During CDR running the electron beam had a train length of 150 ns to 300 ns, a bunch sequence frequency of 3 GHz, and a nominal current of 3.5 A.

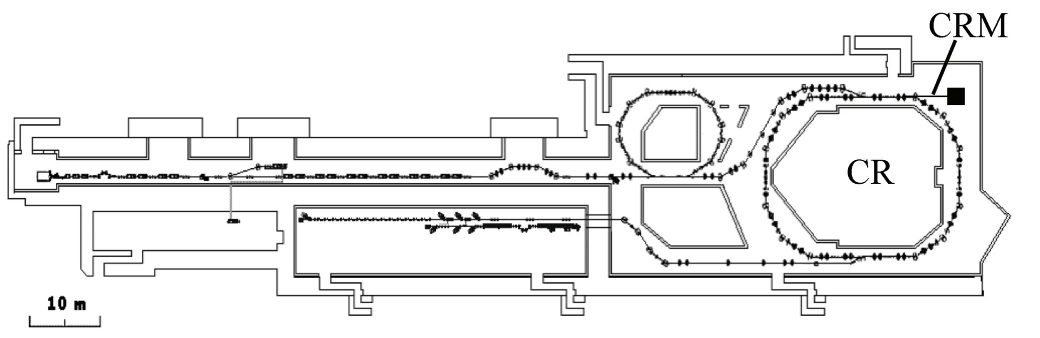

Figure 2: ClIC Test Facility (CTF3) with CRM line

Experimental setup

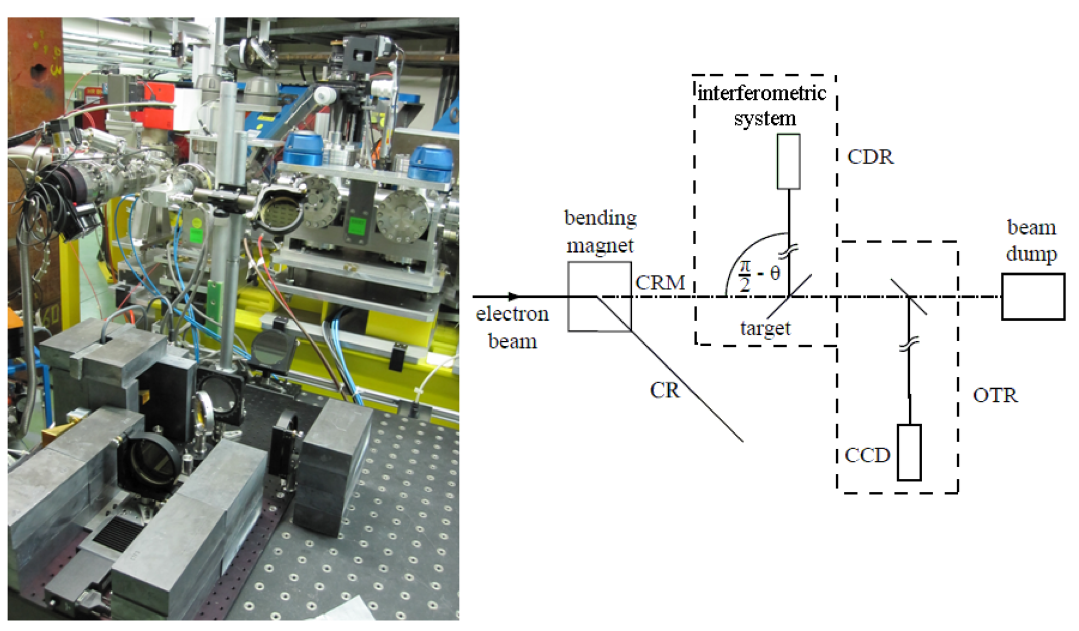

Figure 3: CRM line at CTF3

- Two UHV six-way crosses contain aluminum coated silicon targets (60 mm × 40 mm) to one side of the beam.
- Downstream target is attached to an UHV 4D manipulator, which is mounted on top of the downstream cross and provides precise remote control of rotational and vertical translation axes.
- Upstream target is attached to an UHV 1D manipulator, which provides translation in the vertical plane.
- The radiation originating from the targets is translated vertically by a periscope towards an interferometric system [6].

Simulations

Schematic layout of the targets configuration is shown in Fig.4.

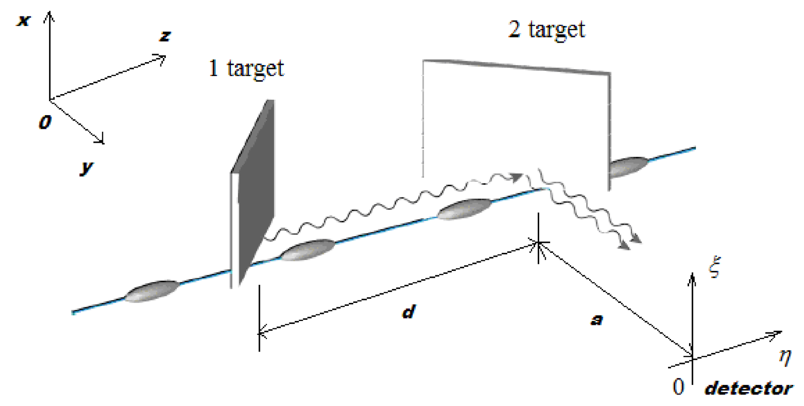

Figure 4: Schematic layout of two targets configuration.

For calculations we shall use a classical theory of Diffraction Radiation (DR), based on Huygens principle of plane wave diffraction. A particle field is introduced as a superposition of its pseudo-photons and when they are scattered off a target surface they are converted into real ones and propagate either in the direction of specular reflection (BDR) or along the particle trajectory (FDR).
Two polarization components of DR from a target at the distance **r** [1, 5]:

$$E_r = \frac{1}{4\pi^2}\iint E'(x_r, y_r)\frac{e^{i\phi}}{r}dx_r dy_r \qquad (1)$$

$E'(x_r, y_r)$ is an amplitude of an elementary radiation source positioned at (x_r, y_r), ϕ defines a phase advance of photons emitted by each elementary radiation source, r is the distance from a source of radiation at the target to an observation point.
In order to calculate the CDR spatial distribution from two targets the following formula is used:

$$\frac{d^2W}{d\omega d\Omega} = 4\pi^2k^2a^2\left[\left(ReE_1 - Re\left(E_2exp[-\frac{ikd}{\beta}]\right)\right)^2 + \left(ImE_1 - Im\left(E_2exp[-\frac{ikd}{\beta}]\right)\right)^2\right] \qquad (2)$$

where k is a wave number, a is the distance between the second target and the observation plane, d is the distance between the targets, β is an electric charge speed in terms of speed of light, E_1 is FDR from the first target, diffracted at the second one and E_2 is BDR from the second target.
Calculated CDR distributions for the following parameters: the targets dimensions 60 mm × 40 mm, the electron beam energy $\gamma = 235$, the impact parameters $h_{1targ} = h_{2targ} = 10mm$ in case when all targets are in and $h_{1targ} = 30mm, h_{2targ} = 10mm$ when the first target is out , the wavelength is $\lambda = 5mm$, the observation plain is at $a = 2m$, the distance between the targets $d = 0.25m$.

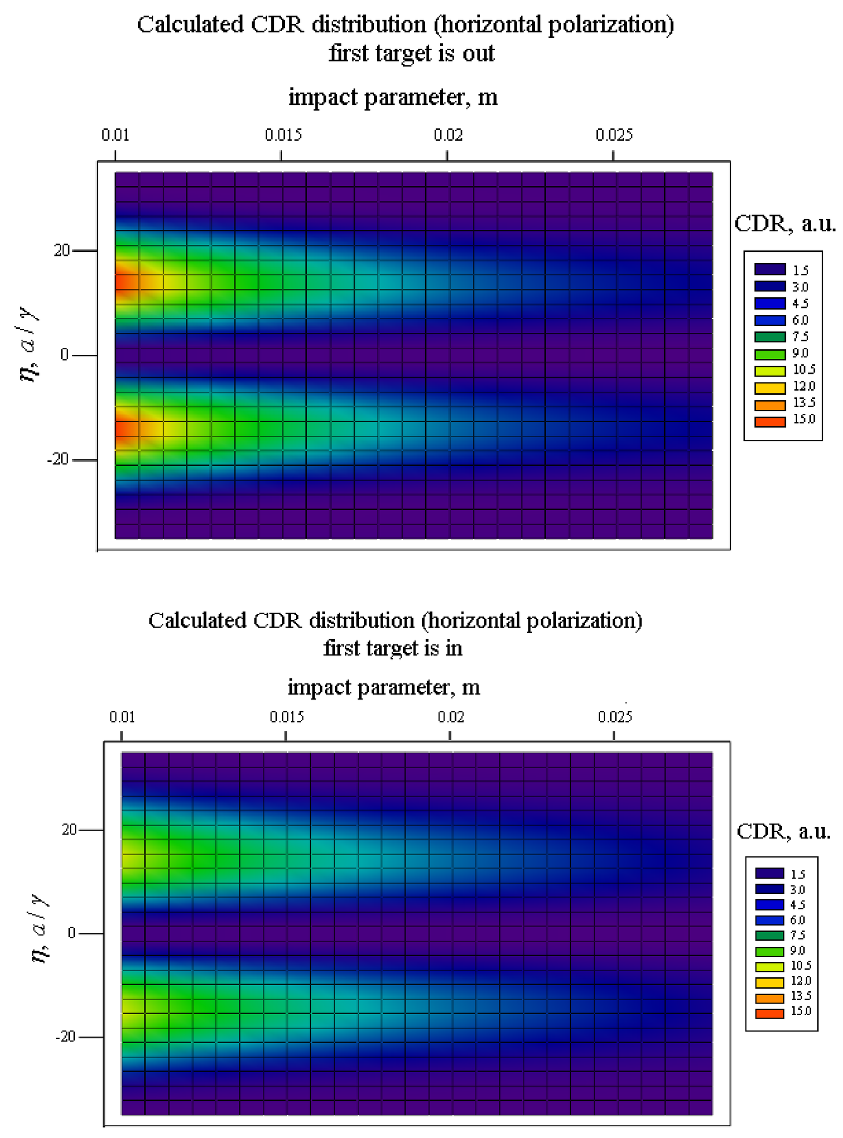

Figure 5: DR for different targets configurations.

Experimental results

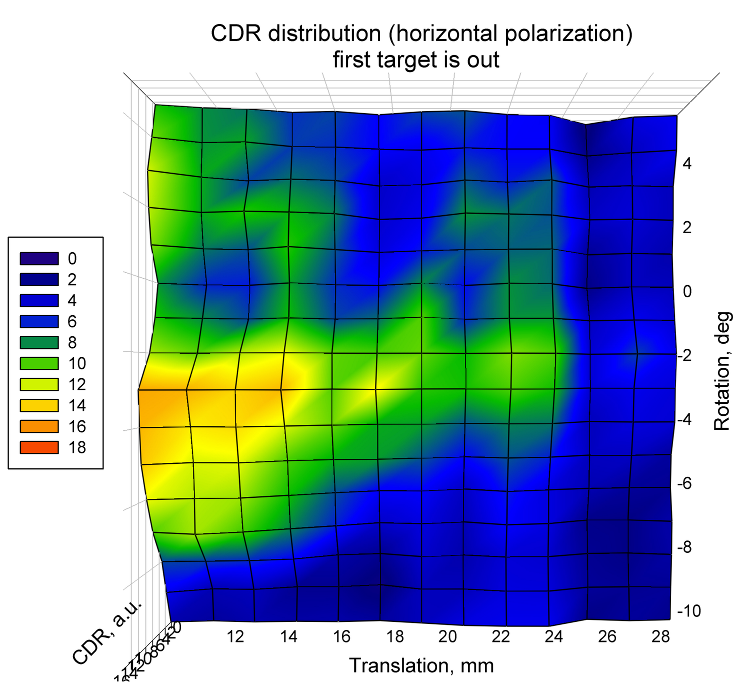

Figure 6: CDR distribution when the first target is out and the impact parameters are $h_{1targ} = 30mm, h_{2targ} = 10mm$.

Experimental results

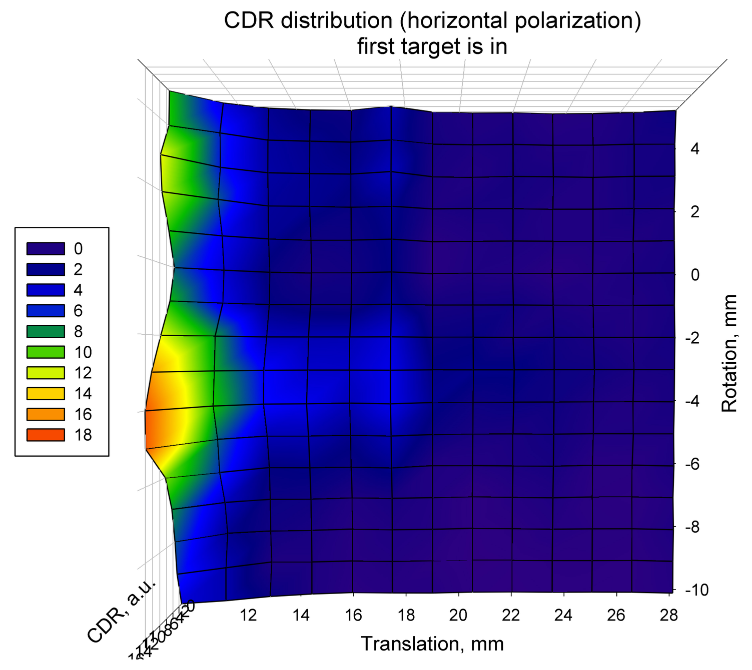

Figure 7: CDR distribution when both targets are in with the impact parameters $h_{1targ} = h_{2targ} = 10mm$.

2D scans for SBD detector DXP15 (50-75 GHz) over the second target orientation and translation of horizontal CDR polarization component.

In Fig. 6 and 7 distributions agree fairly well with the calculated CDR distributions, however distortions are observed which might be caused by backgrounds from the CRM line beam dump and also beam losses

Inequality of peaks intensities is still to be understood.

In Fig. 7 strong background suppression proves effectiveness of the two targets configuration.

Interferometric measurements

To reconstruct the longitudinal electron beam profile at CTF3, the coherent diffraction radiation spectrum has to be measured. It contains information about the longitudinal electron distribution:

$$S(\omega) = [N_e + N_e(N_e - 1)F(\omega)]S_e(\omega) \qquad (3)$$

$S(\omega)$ is the signal from the detector, N_e is the number of electrons in the bunch, $S_e(\omega)$ is the single electron radiation spectrum, and $F(\omega)$ is the longitudinal form factor, which has to be obtained experimentally.

A Michelson interferometer is installed to measure $S(\omega)$. In the interferometer a new broadband pyroelectric detector with broad wavelength response from x-ray to far infrared spectrum with a specially coated 1mm-diameter sensitive element was utilized.

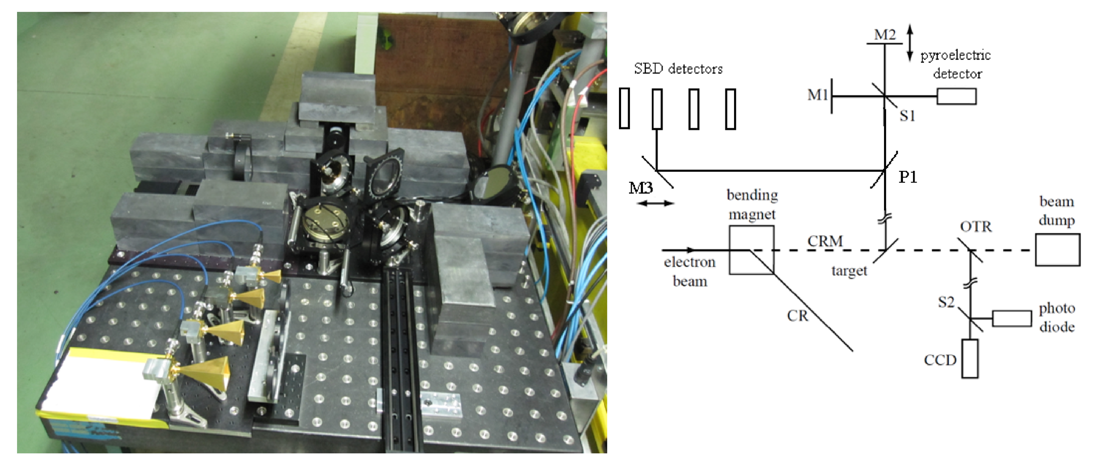

Figure 8: Upgraded interferometric system.

$S_e(\omega)$ can be calculated by integrating calculated radiation distributions (simulation section) at the observation plane over the detector aperture.

Along the OTR optical line a beam splitter S2 and fast photo diode are installed to measure incoherent OTR which is proportional to $\mathbf{N_e}$.

In order to calculate the longitudinal particle distribution in the bunch from experimentally obtained form factor a Kramers-Kronig relation is utilized [7].

Conclusions and Outlook

- 2D radiation distributions measurements have been performed for CDR and CSR.
- The upstream target is effectively blocking backgrounds coming from the upstream.
- Interferometric measurements haven't been finalized due to insufficient sensitivity of the pyroelectric detector and tough background conditions.
- New more sensitive pyroelectric detector will be installed in the near future.

References

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