Bunch profiling at CTF3 using Coherent Diffraction Radiation

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Abstract

A setup for the investigation of the 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 the simulations of the CDR spatial distribution from a two target configuration.

Diffraction Radiation

Diffraction radiation (DR) arises when a charged beam passes by in the vicinity of a target, the 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].

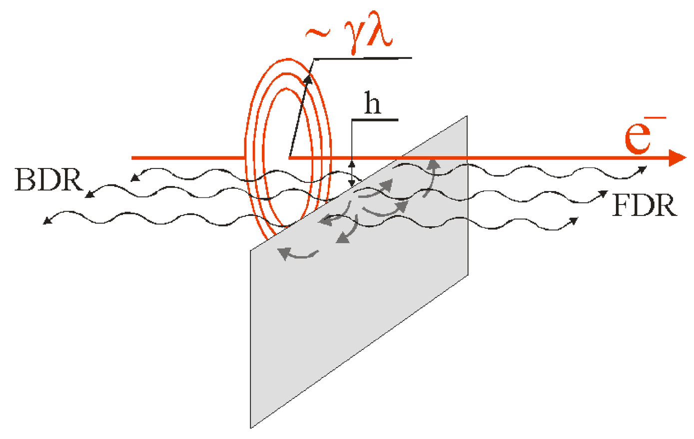

Figure 1: DR production mechanism.

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

Experimental setup

The experimental setup is positioned in the CRM line of the CTF3 [4], Fig.2.

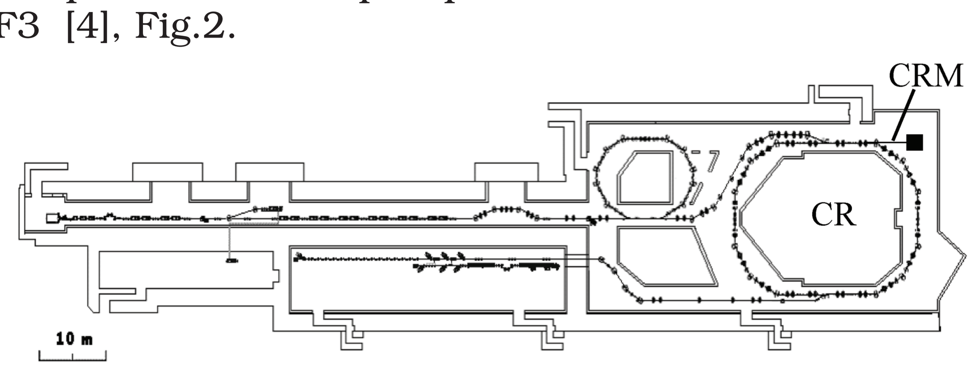

Figure 2: ClIC Test Facility (CTF3).

Table 1: CTF3 and CDR setup parameters.

Parameter	Value	Unit
Beam energy (γ)	235	
Bunch charge	2.3	nC
Bunch spacing frequency	1.5 or 3	GHz
Target dimensions (projected)	40x40	mm
Observation wavelength	5	mm
First target impact parameter, h_1 (upper pos.)	30	mm
First target impact parameter, h_1 (lower pos.)	10	mm
Second target impact parameter, h_2	10	mm
Distance between the targets, d	0.25	m
Distance from the second target to the observ. plane, a	2	m

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

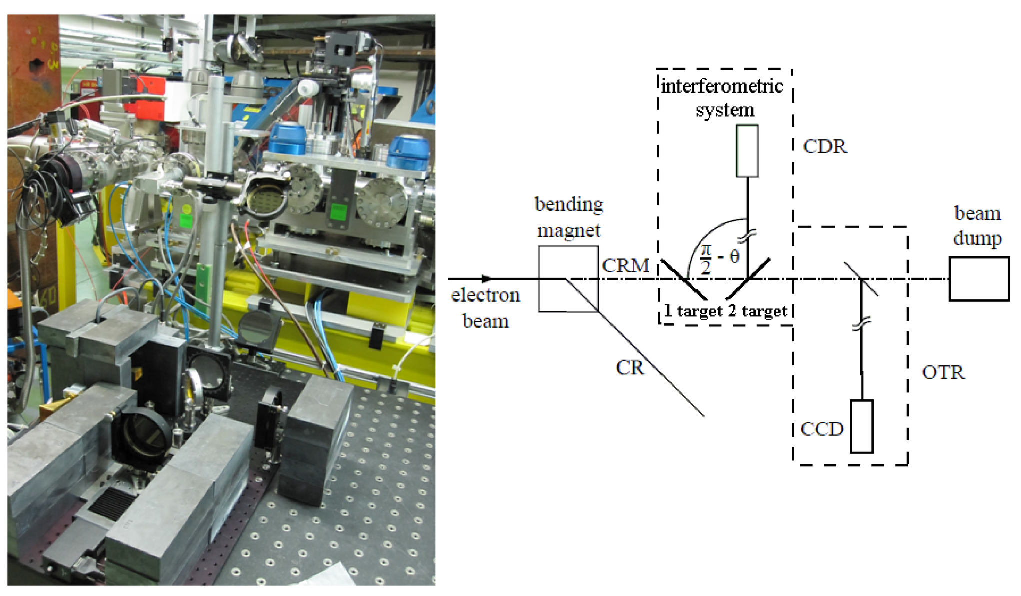

Figure 3: CRM line at CTF3

Simulations

For the calculations, we shall use a classical theory of Diffraction Radiation (DR) [1]. Each point of the target surface can be represented as an elementary source. Two polarization components of the DR from the two targets can be written as:

$$E_{\xi,\eta} = \frac{ik}{8\pi^3}\iint E_1(r_1)\frac{exp\left[i\left(\phi_1+\phi_2\right)\right]}{ad}dr_1dr_2 + \frac{1}{4\pi^2}\int E_2(r_2)\frac{exp\left[i\phi_2+\frac{ikd}{\beta}\right]}{a}dr_2. \quad (1)$$

In (1) r_1 and r_2 are the coordinates of the particle field at the first and at the second target correspondingly; E_1 and E_2 give amplitudes of the arbitrary elementary sources positioned at r_1 and r_2 on the targets; ϕ_1 defines the phase advance of the photons propagating from the first target to the second one; ϕ_2 defines the phase advance of the photons propagating from the second target to the observation plane, d is the distance between the targets, a is the distance from the second target to the observation plane (O,ξ,η). For more detailed information please refer to [5].
Once two radiation components in (1) are obtained, we are able to derive the DR distribution from the two targets:

$$\frac{d^2W}{d\omega d\Omega} = 4\pi^2k^2a^2\left[\left|ReE_{\xi,\eta}\right|^2 + \left|ImE_{\xi,\eta}\right|^2\right], \quad (2)$$

where $E_{\xi,\eta}$ defines the amplitude of the particle field interacted with the two target system.

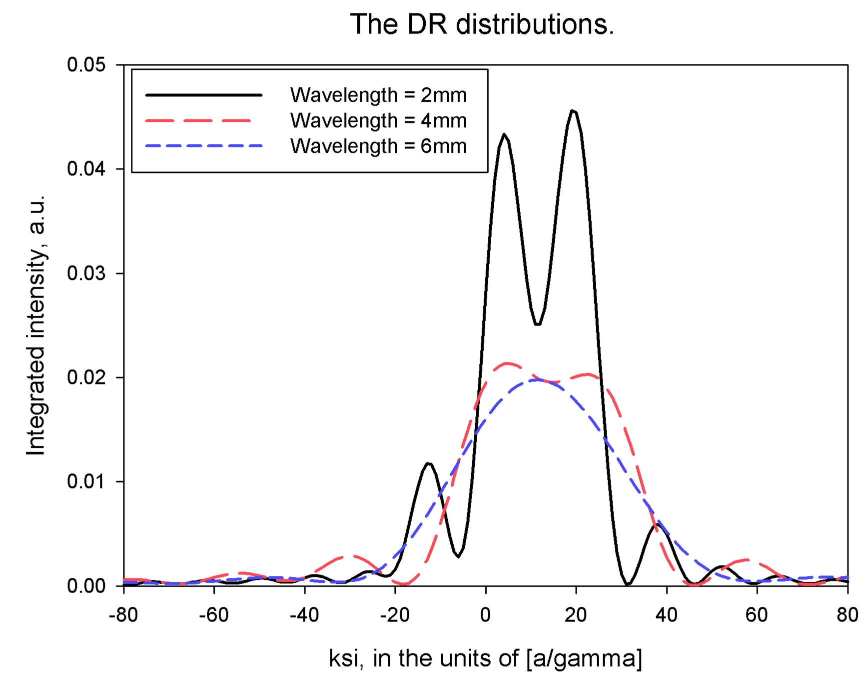

Figure 4: The DR distribution over ξ at the observation plane. The targets are positioned at 10mm from the beam.

In Fig.4 the DR distributions over ξ at the observation plane become broader and less intensive with the increase of the wavelength. The distortions of the distributions due to interference are clearly seen as well.
The calculations were done using the parameters listed in Table 1 (Experimental Setup section). By integrating the DR spatial distribution over a detector aperture (ξ,η), the single electron spectrum can be obtained, Fig. 5.

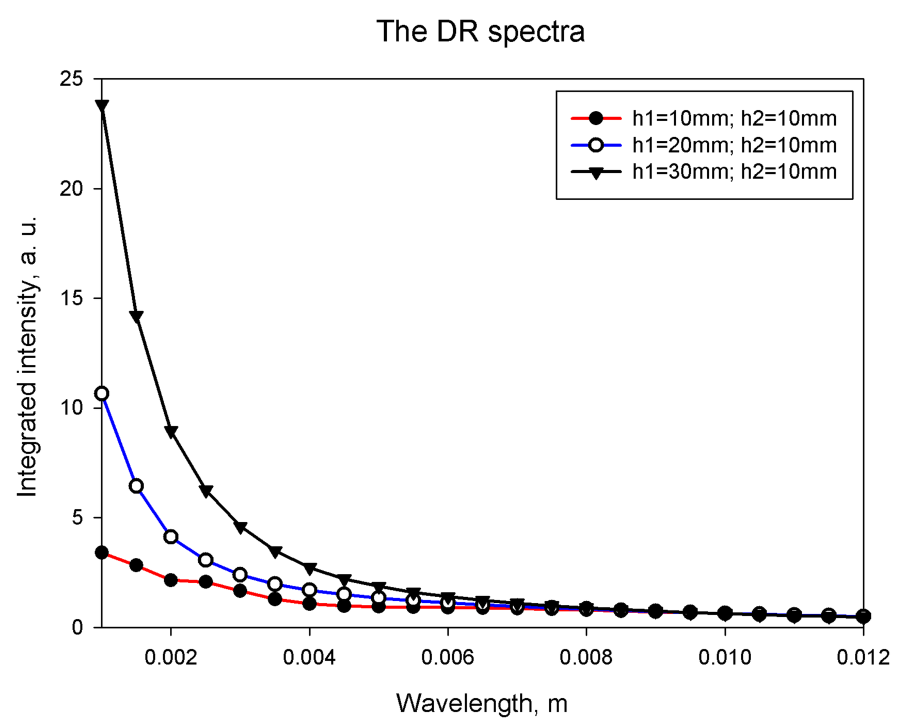

Figure 5: The DR spectra for three configurations of the experimental setup.

Fig. 5 shows the spectra for three different configurations of the system, when the upstream target is gradually lifted upwards and the DR spectrum converts itself while the influence of the second target becomes negligible.

Experimental results

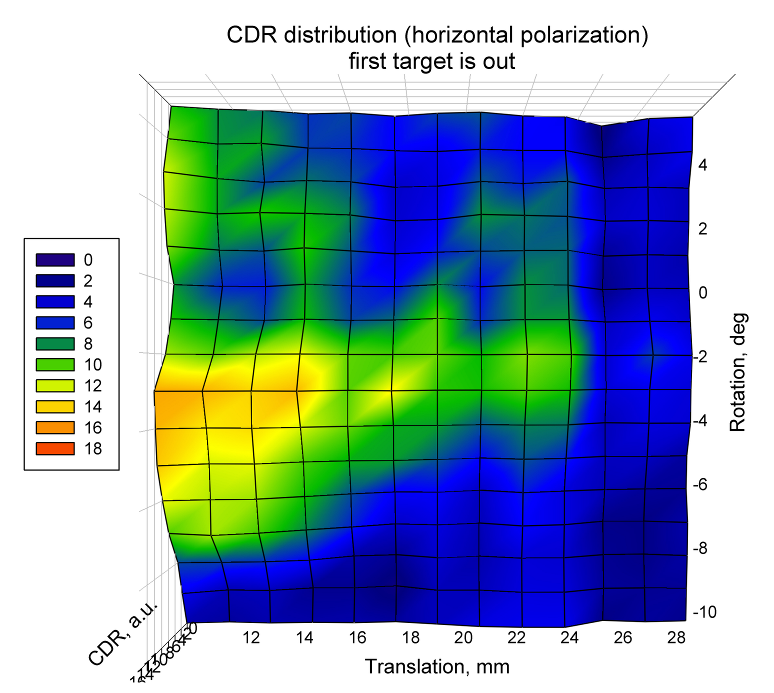

Figure 6: The CDR distribution when the first target is out and the impact parameters are $h_{1targ} = 30mm, h_{2targ} = 10mm$.

Experimental results

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

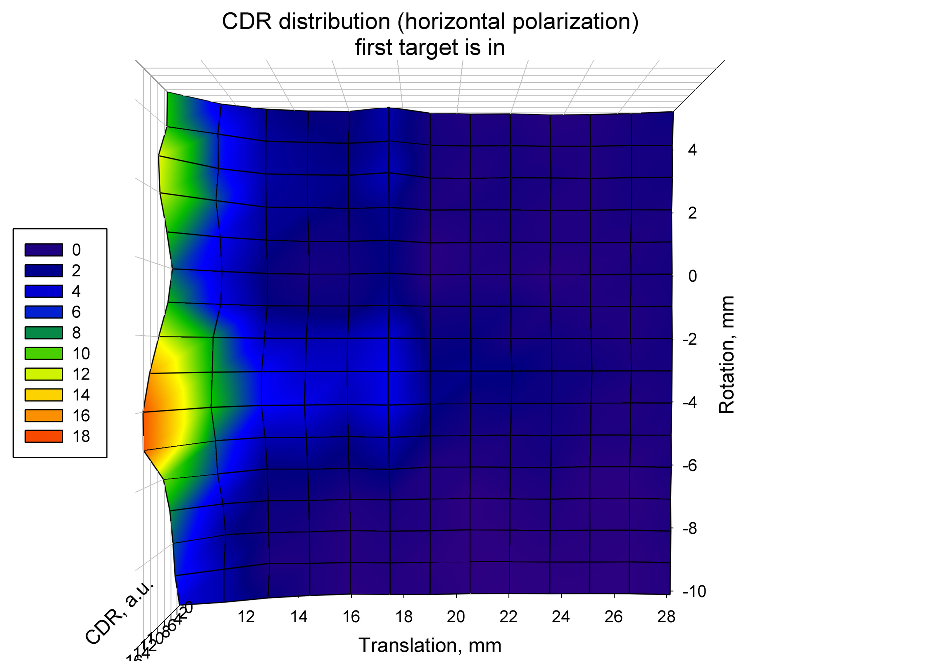

Figure 7: The CDR distribution when both targets are in with the impact parameters $h_{1targ} = h_{2targ} = 10mm$.

In Fig. 6 and 7 the distributions agree fairly well with the calculated CDR distributions, however the distortions are observed which might be caused by the backgrounds from the CRM line beam dump and also by the beam losses.
Inequality of the peaks intensities is still to be understood.
In Fig. 7 strong background suppression proves effectiveness of the two target configuration.

Recent upgrade

The CDR spectrum can be calculated as:

$$S(\omega) = \left[N_e + N_e\left(N_e-1\right)F(\omega)\right]S_e(\omega); \quad (3)$$

$S(\omega)$ 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.
Recent modifications of the setup included installation of the new pyroelectric detector based on $LiTaO_3$ crystal, which is designed to detect electromagnetic radiation in the millimeter and sub-millimeter wavelength range. The shielding was improved as well.

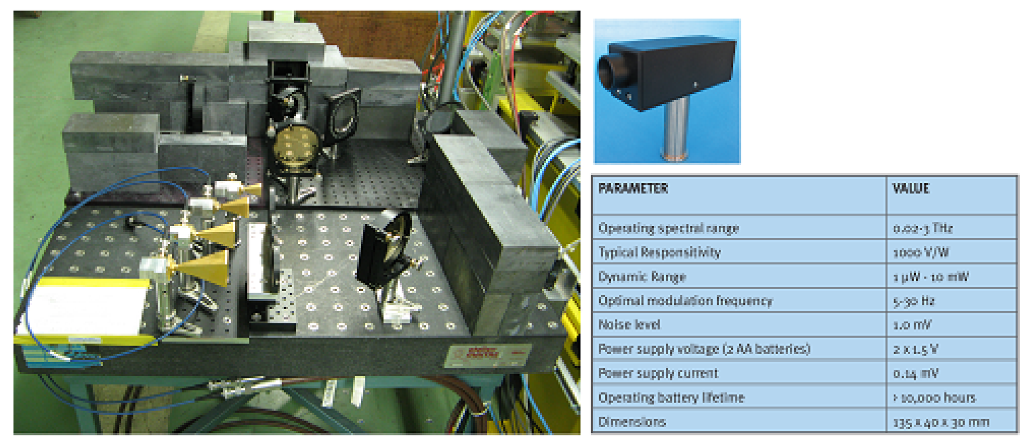

Figure 8: Upgraded interferometric system.

Along the Optical Transition Radiation (OTR) line the beam splitter and the fast photo diode are installed to measure incoherent OTR which is proportional to $\mathbf{N_e}$. The multimode fiber with operating wavelength range 500 - 1100 nm and bandwidth 20 MHz/km was installed at the OTR setup.

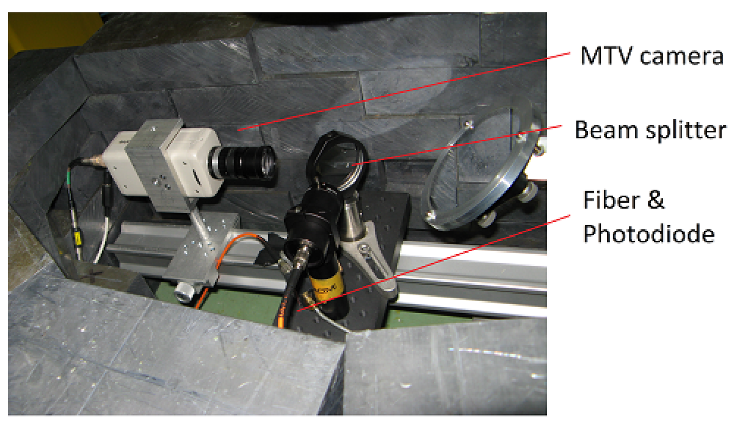

Figure 9: OTR setup.

Conclusions

- The radiation distribution measurements have been performed for CDR.
- It was proved that the second target is effectively blocking the backgrounds coming from the upstream.
- New pyroelectric detector was installed in the interferometric system; new multimode fiber was installed at the OTR setup.

References

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