Coherent Diffraction Radiation as a Tool for Non-invasive Bunch Length Diagnostics

Konstantin Lekomtsev, Grahame Blair, Gary Boorman, Pavel Karataev, Maximilian Micheler
John Adams Institute at Royal Holloway University of London

Roberto Corsini, Thibaut Lefevre
CERN

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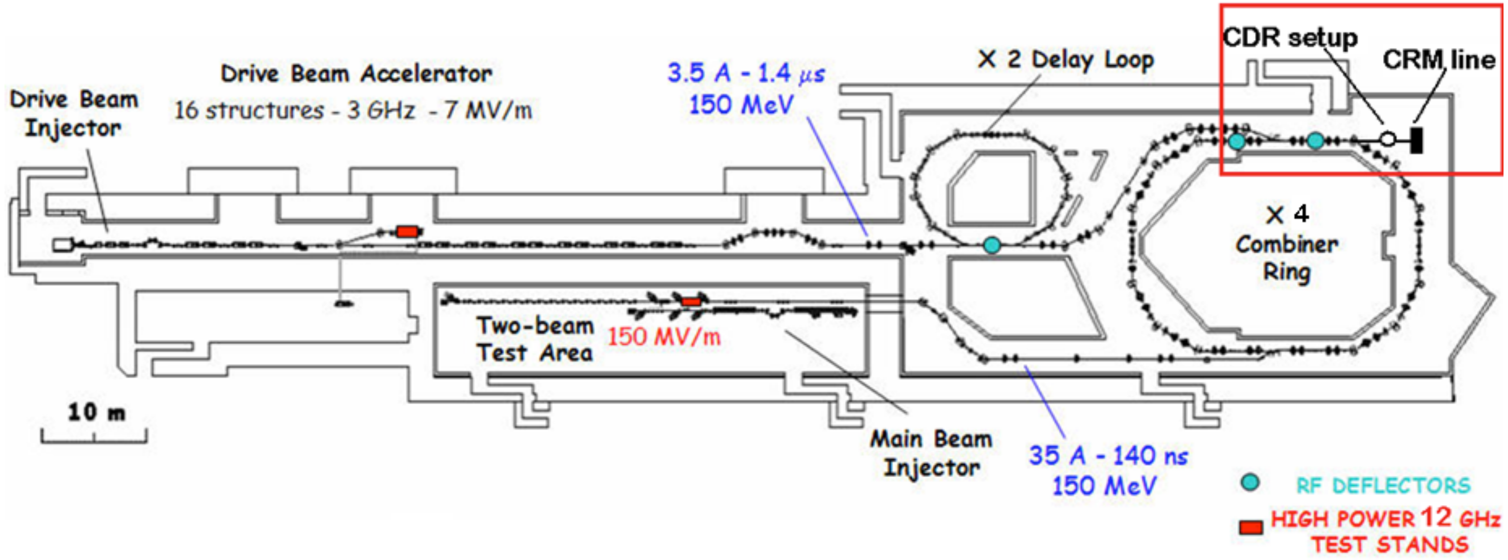
K.V.Lekomtsev@rhul.ac.uk

Introduction

1) CLIC Test Facility 3 and CDR experiment.
2) Simulations for one target configuration.
   - Virtual photon method.
   - Time – domain simulations.
5) Simulations for two target configuration.
6) Experimental setup and interferometric system.
7) Current status of the experiment.
8) Conclusions and outlook.

K.V.Lekomtsev@rhul.ac.uk

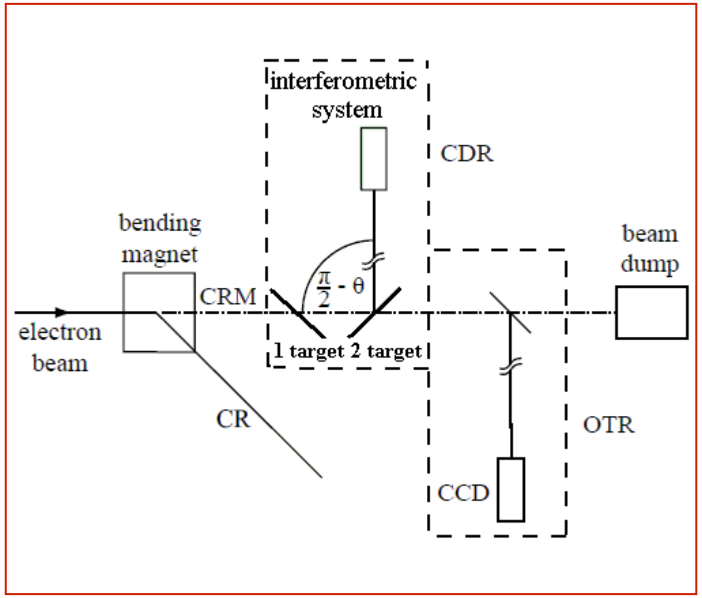
CLIC Test Facility 3 & CDR experiment



• Test accelerator at CERN is built to demonstrate the feasibility of two-beam acceleration scheme.

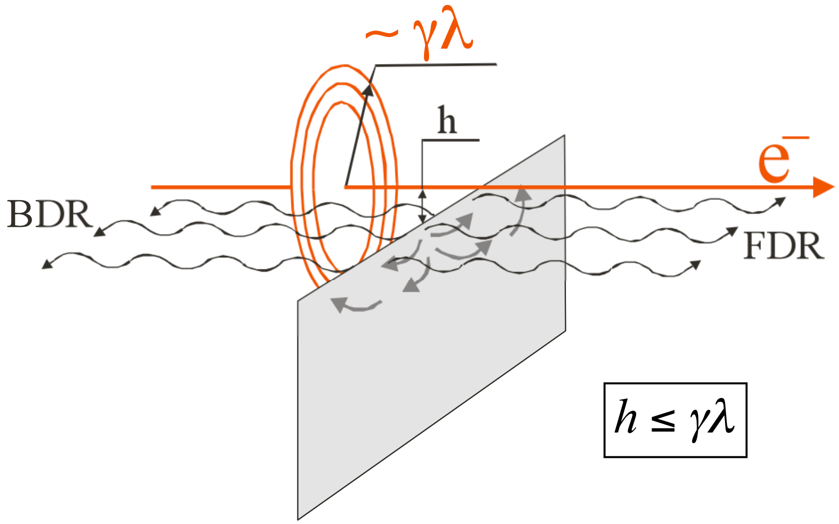
• High charge, high frequency electron bunch trains are generated by beam combination in the rings using transverse deflectors.

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



K.V.Lekomtsev@rhul.ac.uk

Coherent Diffraction Radiation phenomenon



Diffraction radiation appears when a charged particle moves in the vicinity of a medium.

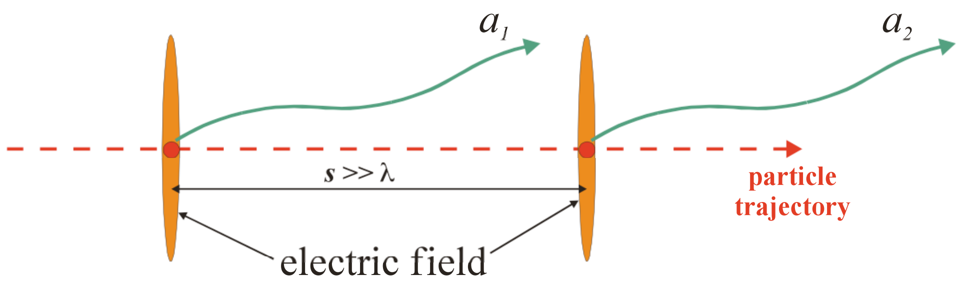
Impact parameter h – the shortest distance between a particle and a target.

λ – observation wavelength,

$\gamma = \dfrac{E}{mc^2}$ – Lorentz factor.

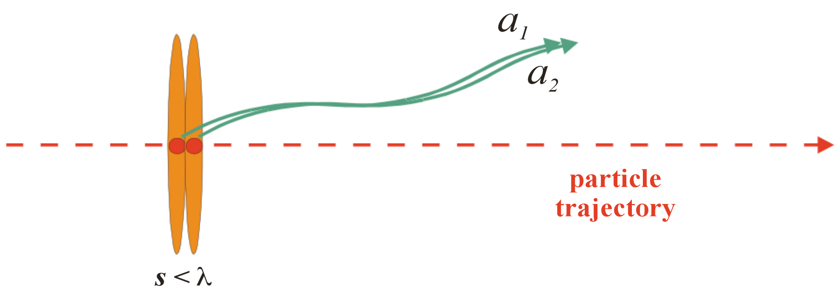
Incoherent radiation:

$$I = |a_1|^2 + |a_2|^2 = 2|a|^2 \rightarrow N|a|^2$$



Coherent radiation:

$$I = |a_1 + a_2|^2 = |2a|^2 = 4|a|^2 \rightarrow N^2|a|^2$$



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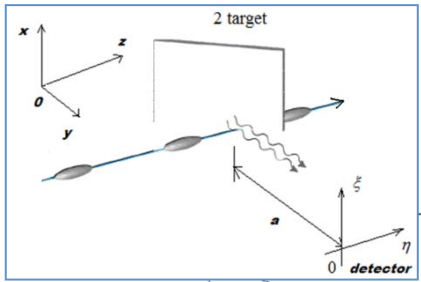
CDR from the single target

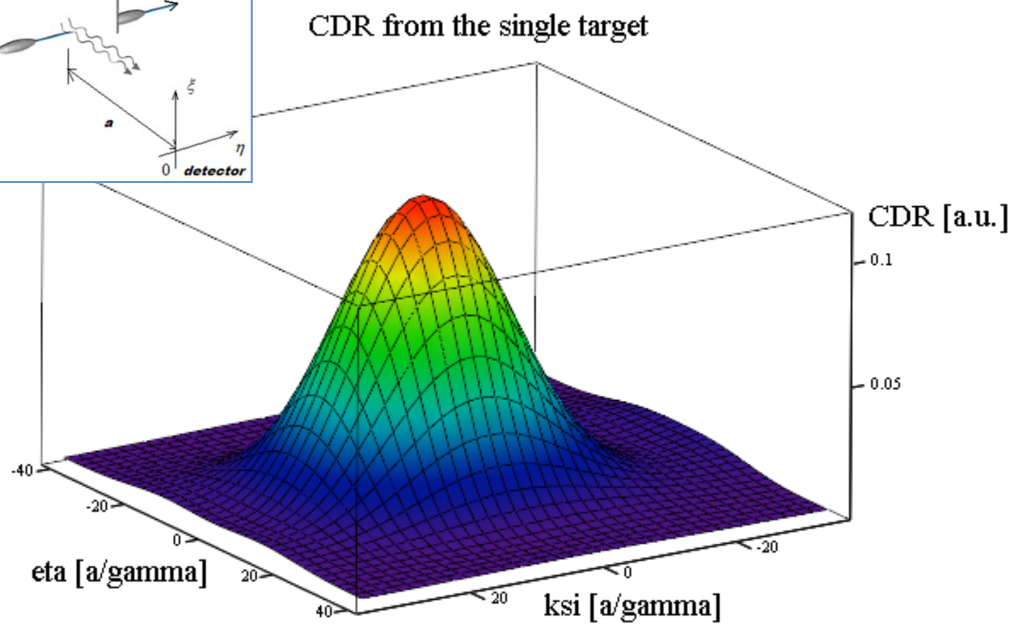
$$E_{x,y}=\frac{1}{4\pi^2}\frac{iek}{\pi\gamma}\frac{e^{ika}}{a}\iint\begin{pmatrix}\dfrac{x}{\sqrt{x^2+y^2}}\\ \dfrac{y}{\sqrt{x^2+y^2}}\end{pmatrix}K_1\left(\frac{k}{\gamma}\sqrt{x^2+y^2}\right)\exp\left[\frac{ik}{2a}\left((x-\xi)^2+(y-\eta)^2\right)\right]dx\,dy$$

x, y - the coordinates at the target surface. η, ξ - the coordinates at the observation plane.

a - the distance from the target to the observation plane. k - the wave number.

Target dimensions: $40mm \times 60mm$
Beam energy: $\gamma = 235$
Radiation wavelength: $\lambda = 5mm$
Impact parameter: $h = 10mm$

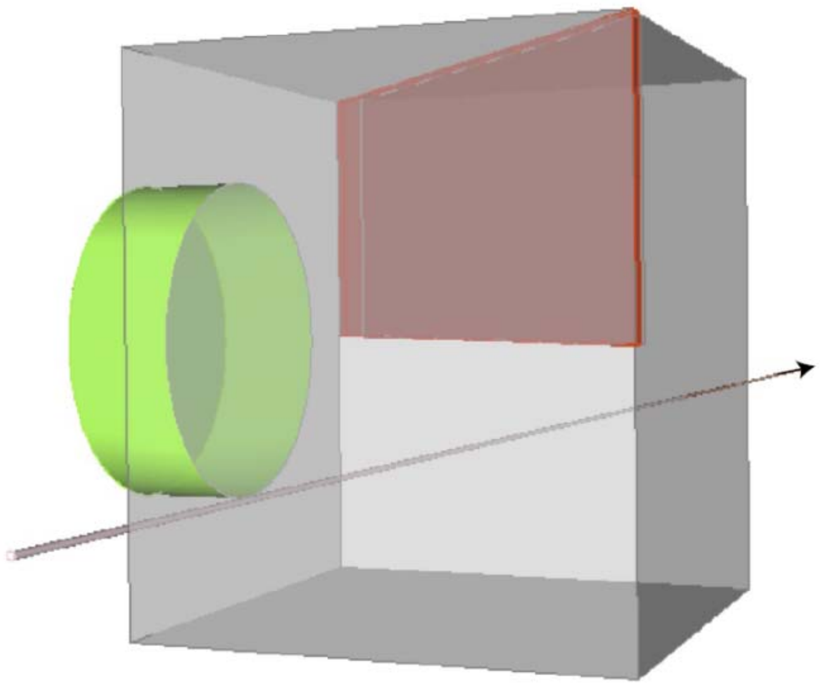




- The target is positioned in the vacuum in the infinite space.
- Ideal conductor approximation is utilized.
- Limited target dimensions.

K.V.Lekomtsev@rhul.ac.uk

Single target, model



Meshing properties:

Properties	Value
Volume numbers:	
Total no.	7506506
Edge length [mm]:	
Minimum	0.257
Maximum	1.040
Average	0.523
Std. dev.	0.095
Element volume [mm^3]:	
Minimum	1.67×10^{-3}
Maximum	5.49×10^{-2}
Average	1.33×10^{-2}
Std. dev.	3.75×10^{-3}

The model features:

- the target (red) with the dimensions in the projection perpendicular to the electron beam of 40x40 mm.
- the impact parameter of 15mm is chosen for the simulations.
- the viewport with diameter (green) 35mm.
- all surfaces except the viewport surface and the surfaces through which the beam enters and leaves the model were set to be a conductor (for modified model: the surfaces were set to be transparent).

K.V.Lekomtsev@rhul.ac.uk

Single target, time-domain simulations

SLAC's Advanced Computation Department suite of 3D parallel finite-element based electro-magnetic codes for accelerator modelling (ACE3P)*.

Time-domain solver to calculate the transient field response of an electromagnetic structure to imposed fields, and dipole or beam excitations (T3P)

The Gaussian electron beam with a bunch length of 2mm and a total bunch charge of 1pC were selected for the model.

A time discretisation of 2ps for an interval from 0 to 900 ps was chosen.

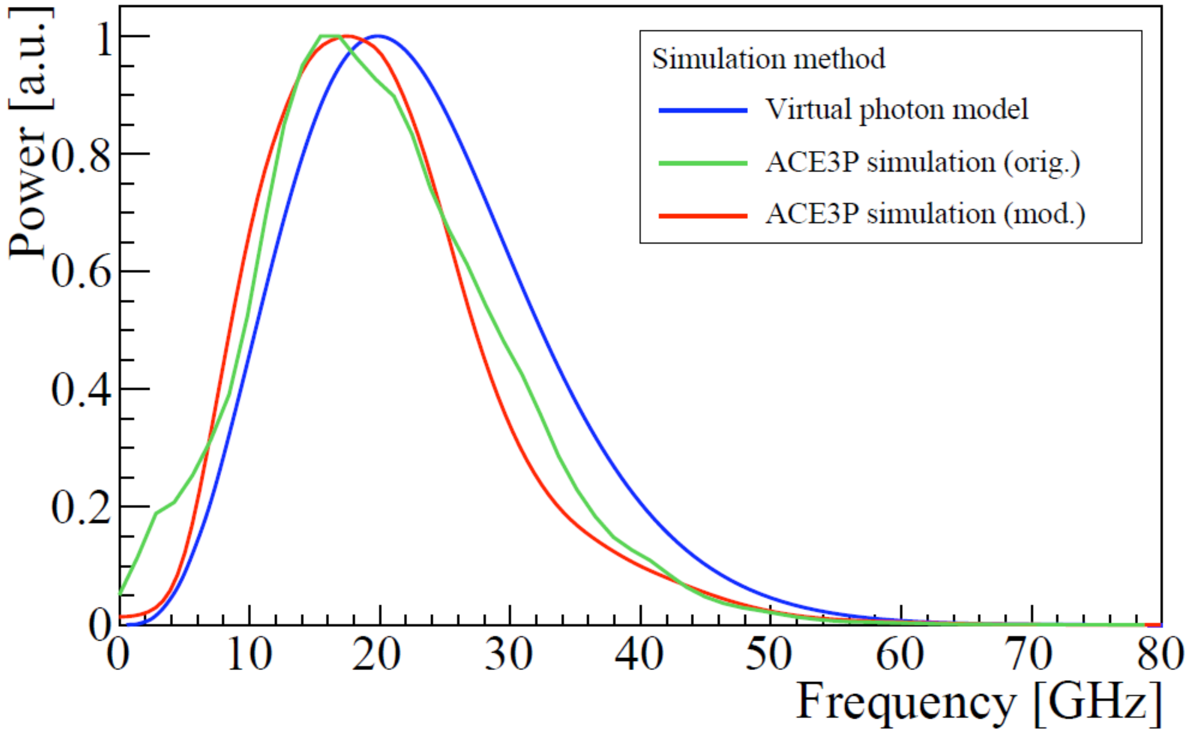
BDR propagates in the mirror reflection direction into the cylindrical viewport towards the left.

FDR propagates in the beam propagation direction.

*Advanced Computational Electromagnetics 3P (ACE3P) Website, http://www.slac.stanford.edu/grp/acd/ace3p.html.

K.V.Lekomtsev@rhul.ac.uk

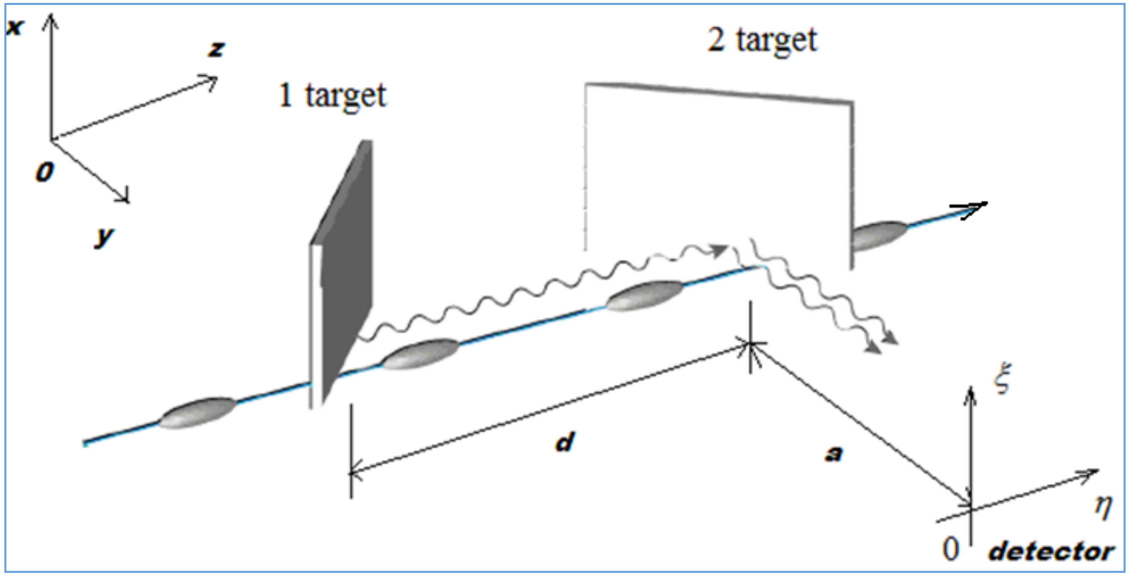
Models comparison

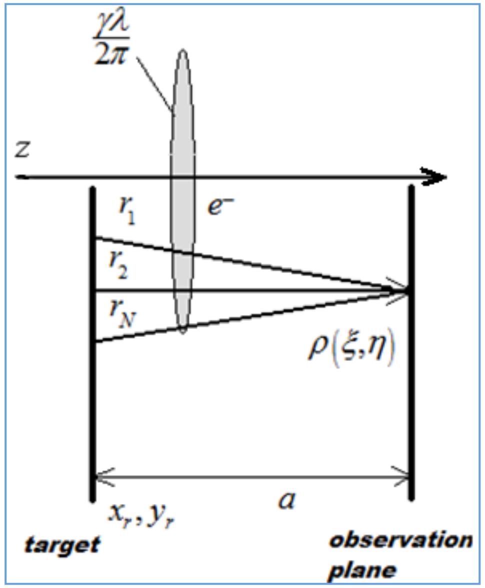


The normalized power spectrum from a 2mm Gaussian beam obtained with virtual photon model with the same parameters as for time-domain simulations (blue curve).
Time-domain simulations excluding any radiation more than 340 ps after the beam entry (green curve).
Modified time domain-simulations when surfaces of the model are transparent (red curve).

K.V.Lekomtsev@rhul.ac.uk

Two target configuration.





- Targets dimensions, distance between the targets and to the observation plane are fixed.
- Thin foil approximation is used.
- FDR and BDR are considered to be identical for given wavelength and a thin foil.
- The first stage of the process is electric field of FDR produced from the first target.
- The second stage of the process is reflection from the second target.
- Targets are assumed to be positioned in vacuum in infinite space.
- The destructive interference is observed.

K.V.Lekomtsev@rhul.ac.uk

Two target configuration.

$$E^{DR}_{x,y} = \frac{1}{4\pi^2}\int_{r1}\int E^1_{x,y}\left(x_{r1}, y_{r1}\right)\frac{e^{i\varphi}}{r}dy_{r1}dx_{r1} - \frac{1}{4\pi^2}\int_{r2}\int E^2_{x,y}\left(x_{r2}, y_{r2}\right)\frac{e^{i\left(\varphi-\frac{kd}{\beta}\right)}}{r}dy_{r2}\,dx_{r2}\ *$$

$x_{r1}, y_{r1}(x_{r2}, y_{r2})$ - the coordinates of an arbitrary elementary source on the first (second) target surface.

$E^{1(2)}_{x,y}$ - amplitude of an arbitrary elementary source positioned on the first (second) target surface.

r - distance from the elementary source on the target to the observation point.

φ - phase advance of the photons emitted by each elementary source to the observation point.

$\beta = v/c$ -the speed of an electric charge in terms of the speed of light.

K.V.Lekomtsev@rhul.ac.uk

*M.L. Ter-Mikaelyan, High Energy Electromagnetic Processes in Condensed Media, Wiley-Interscience, New York , 1972

Radiation spatial distribution.

$$\frac{d^2W^{DR}}{d\omega d\Omega} = 4\pi^2 k^2 a^2 \left[\left| E_x^{DR} \right|^2 + \left| E_y^{DR} \right|^2 \right]$$

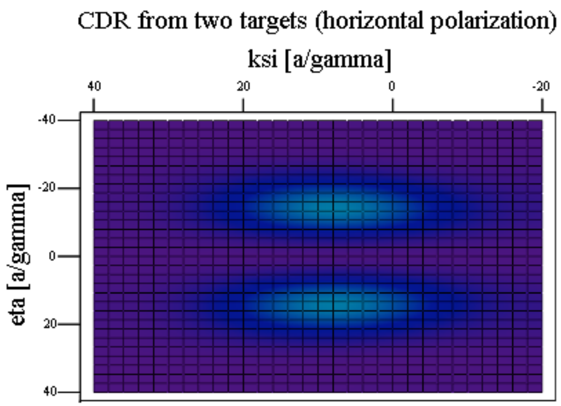
E_x^{DR} - vertical polarization component of the DR from the target/targets

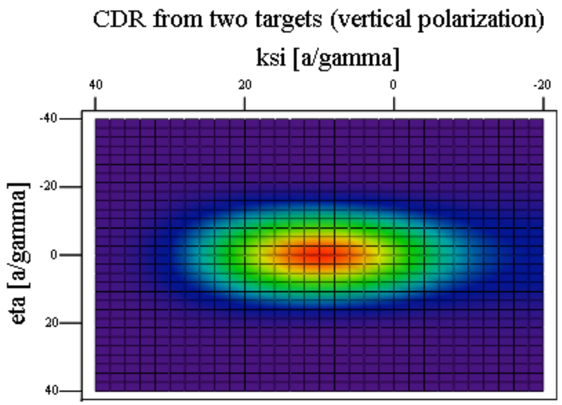
E_y^{DR} - horizontal polarization component of the DR

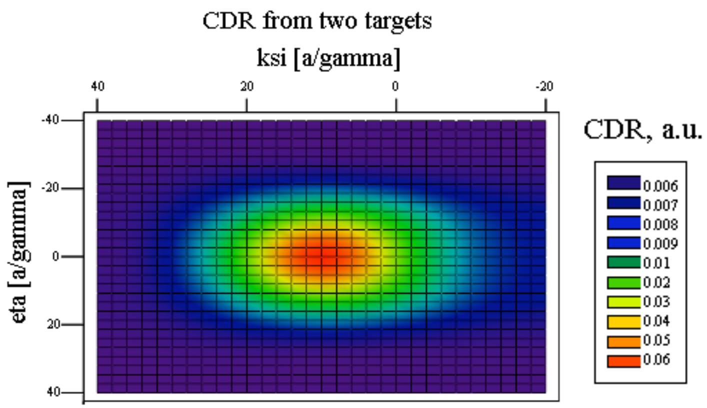
$k = \frac{2\pi}{\lambda}$ is the wave number where λ is the wavelength of DR

a - distance between the target and the observation point

CDR distribution from the two target configuration

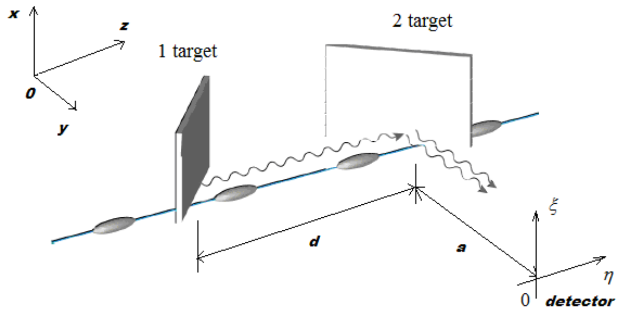






$impact_{1target} = 10\,mm;\ impact_{2target} = 10\,mm$

$impact_{1target} = 30\,mm;\ impact_{2target} = 10\,mm$

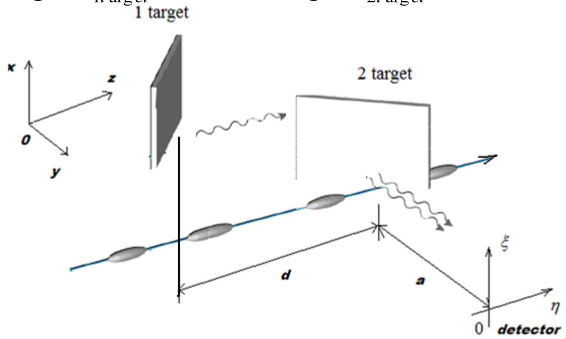


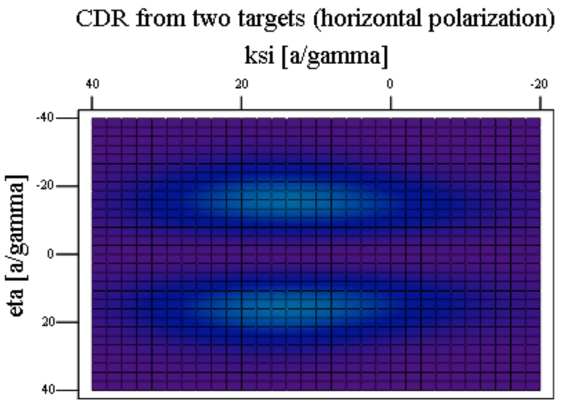
Targets dimensions:

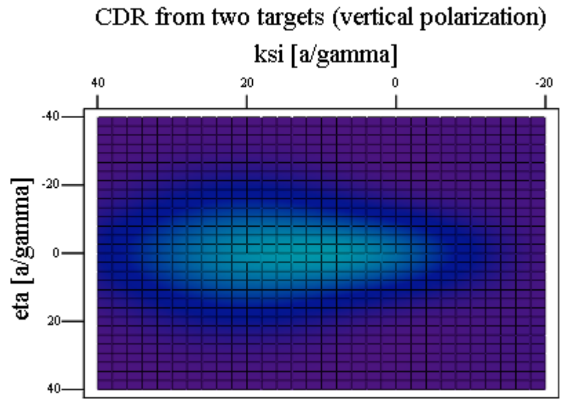
$$40mm \times 60mm$$

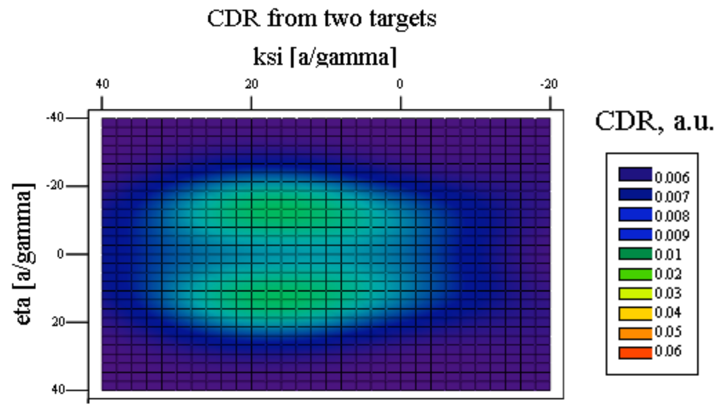
$$\gamma = 235$$

$$\lambda = 5mm$$



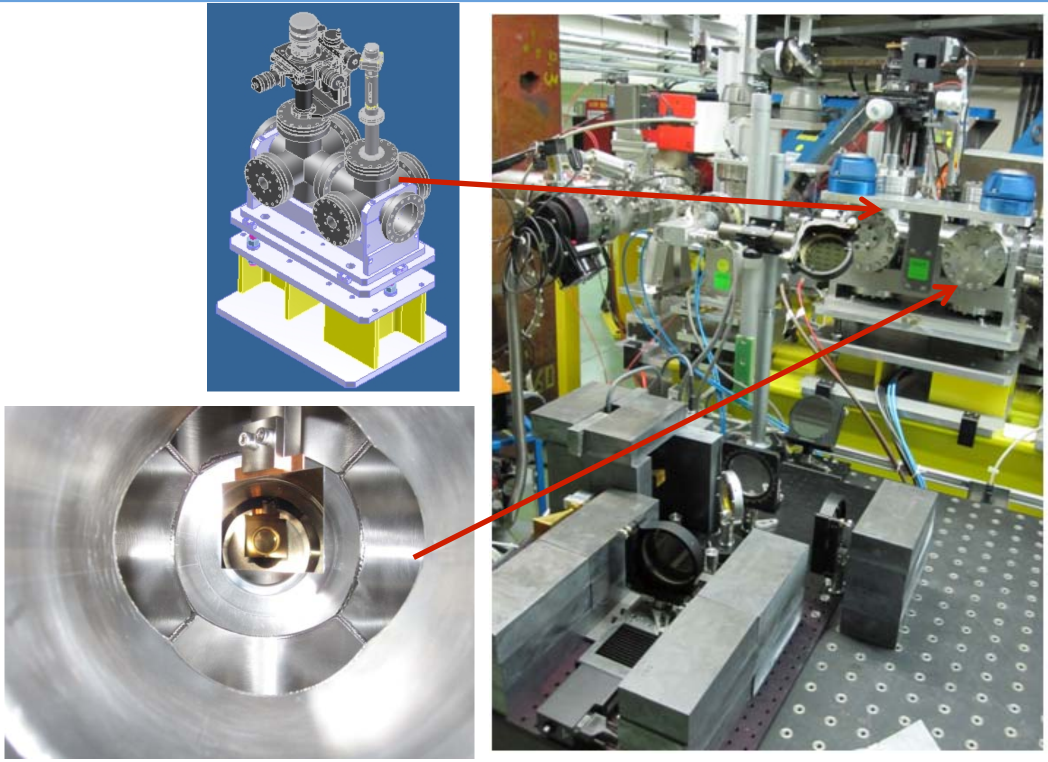


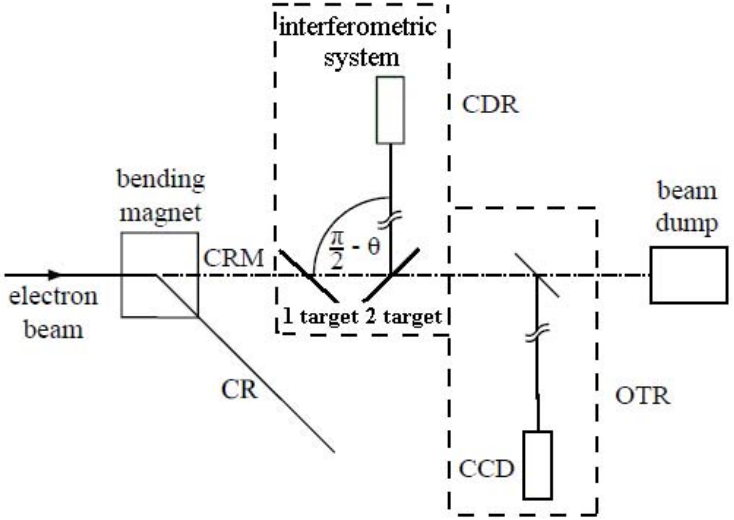




K.V.Lekomtsev@rhul.ac.uk

Experimental setup at CTF3





- Two UHV six-way crosses contain aluminium coated silicon targets (60mmx40mm) to one side of the beam.
- The targets are attached to the UHV manipulators, which provide precise control of rotational and vertical translation axes for the downstream target and vertical translation axis for the upstream target.
- The radiation originated from the targets is translated vertically by the periscope towards the interferometer.

K.V.Lekomtsev@rhul.ac.uk

Interferometric system

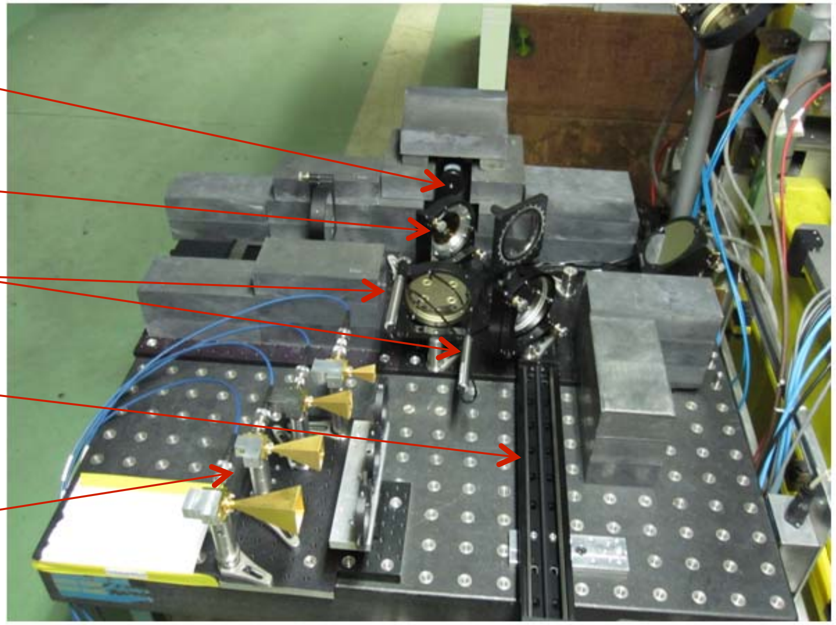
Pyroelectric detector.

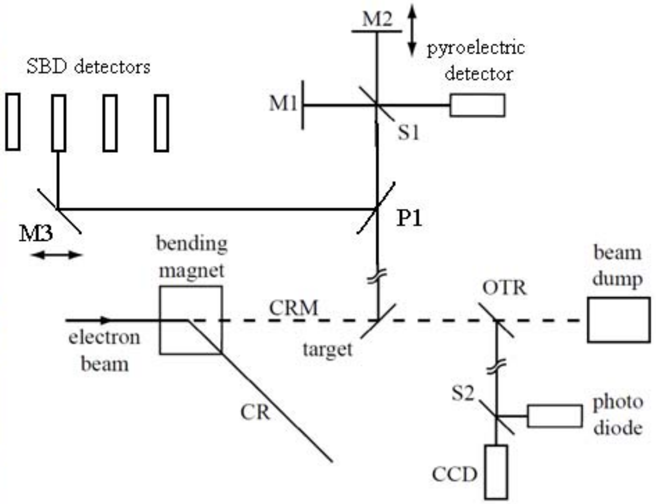
Silicon splitter.

Mirror actuators.

Additional linear stage.

Schottky barrier diode detectors.





$$S_{coh}(\omega) = N^2 S_e(\omega) F(\omega)$$

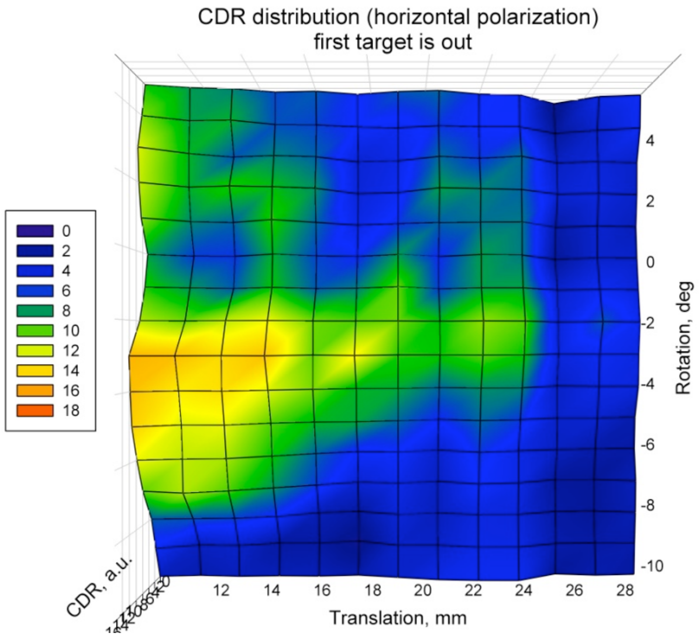
$S_{coh}(\omega)$ - coherent radiation spectrum. N - number of electrons in the bunch.

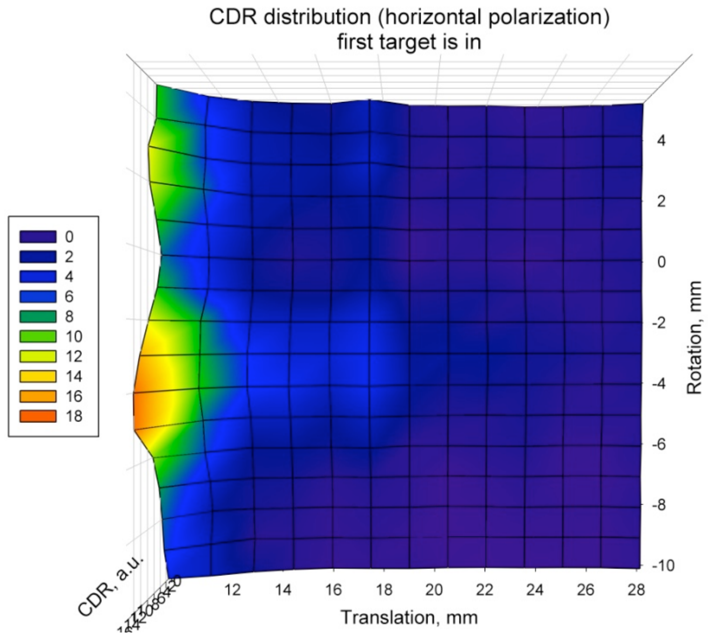
$S_e(\omega)$ - single electron spectrum. $F(\omega)$ - longitudinal bunch form factor.

K.V.Lekomtsev@rhul.ac.uk

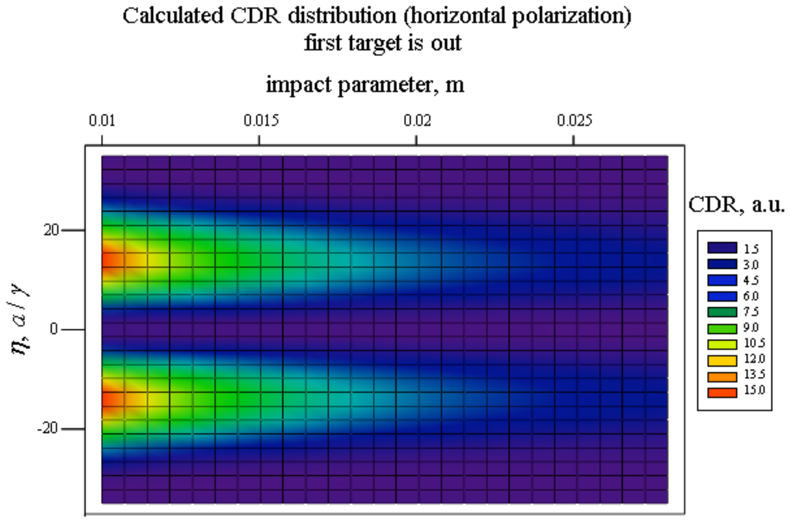
Experimental results & Simulations

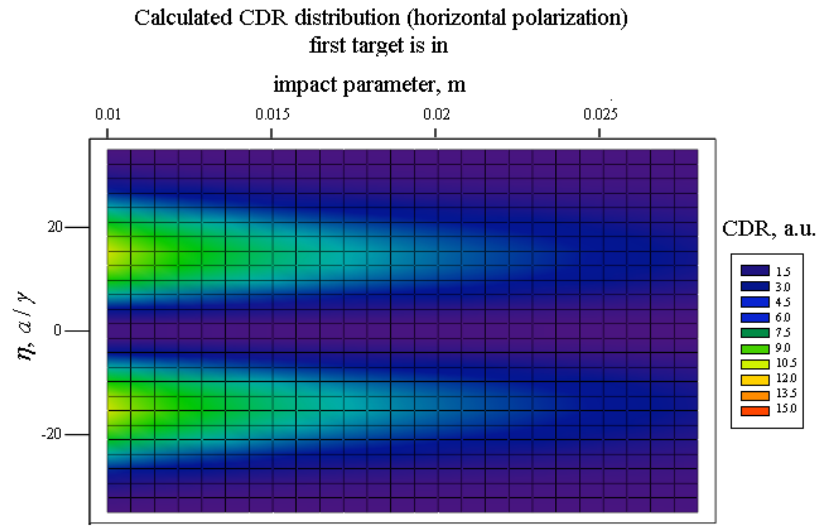
Experiment





Simulations





Conclusions & Outlook

- Recent upgrade has been performed which included: installation of the second target with UHV manipulator, new pyroelectric detector, set of Schottky Barrier Diode detectors, new silicon beam splitter, mirror actuators and automatization of the corresponding components.
- Background contribution studies have been performed.
- 2D scans of the CDR distribution have been done to prove that the second target effectively blocking the backgrounds originating from upstream the setup. Measurements have been performed for different targets position in order to find the optimal two target configuration.
- Good agreement was revealed between measured and simulated CDR distributions, apart from the inequality of peak intensities and distortions caused by the backgrounds.
- Interferometric measurements haven't been finalized due to insufficient sensitivity of the pyroelectric detector and tough background conditions.

- As a solution a new more sensitive pyroelectric detector will be installed in the near future.
- Shielding will also be improved in order to cut off beam-based backgrounds and also backgrounds originating from the CRM line of CTF3.
- Interferometric measurements will be resumed as soon as necessary improvements are done.