Coherent Diffraction Radiation Imaging Methods to Determine RMS Bunch Length*

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Abstract

The measurement of the bunch length with high resolution is very important for latest generation light sources and also a key parameter for the optimization of the final beam quality in high gradient plasma accelerators. In this contribution we present progress in the development of novel single shot, RMS bunch length diagnostic techniques based on imaging the near (source) and far fields of coherent THz diffraction radiation (CDR) that is produced as a beam interacts with a solid foil or an aperture. Recent simulation results show that the profile of a THz image of the point spread function (PSF) of a beam, whose radius is less than the image produced by a single electron, is sensitive to bunch length and can thus be used as a diagnostic. The advantages of source field over far field imaging are examined and the results of a recent high energy CTHzDR experiments at SLAC/FACET are presented. Plans for experiments to further validate and compare these imaging methods for both moderate and high energy charged particle beams are discussed.

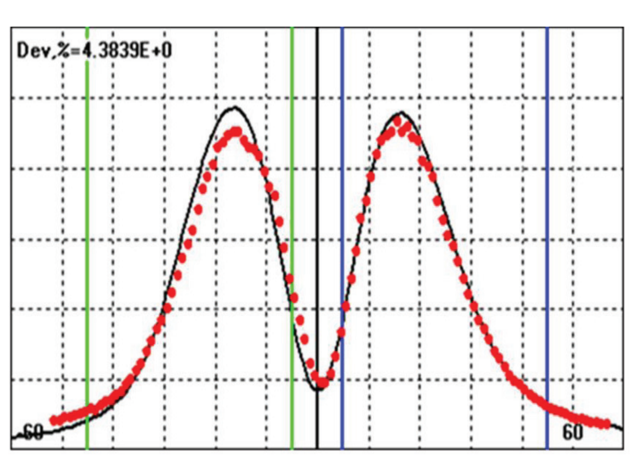
Angular Distribution Bunch Length Diagnostic

Angular Distribution (AD) of CDR from a slit or aperture can be calculated from the integrated spectral angular density of DR from single electron multiplied by the longitudinal form factor of the pulse and **is a function of the bunch length:**

$$\frac{dI^{CDR}_{bunch}}{d\Omega} \approx N_e^2 \int_{\Delta\omega} \frac{d^2 I_e^{DR}}{d\omega\, d\Omega} S_z(\sigma_z,\omega)\, d\omega$$

Proof of Principle AD bunch length experiment done at PSI (100 MeV) [2].

Fit of measured (red) to theoretical line scan of CDR AD (black)



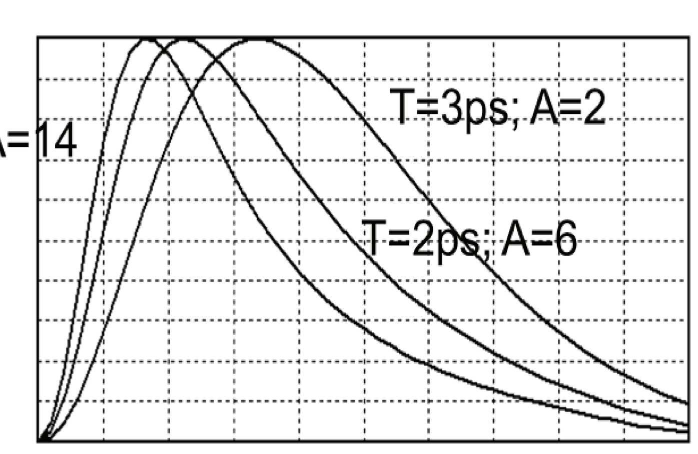
Comparison of CDR AD bunch length method with EO sampling technique

Method	Bunch Compressor Tune	T(ps) single Gaussian fit
AD CDR	PBU-0	0.8
E-O technique	PBU-0	0.75
AD CDR	PBU+3	1.0
E-O technique	PBU+3	1.0

Theoretical Dependence of PSF on Bunch Length

According to the theory of virtual photons, **the Spatial Distribution of CDR** from a transversely coherent source, e.g. the PSF of CDR, which is related to the AD by Fourier transformation over spatial frequency (as in normal optics) **should also be sensitive to the longitudinal beam size.**

Theoretical CDR PSF distributions from an annular radiator (R_{out}=25mm, Rin=5mm), E = 100MeV, for various bunch lengths



How to observe the CDR PSF? image a beam with transverse size much less than the width of the CDR image of a single electron.

Advantages of imaging PSF over imaging AD:

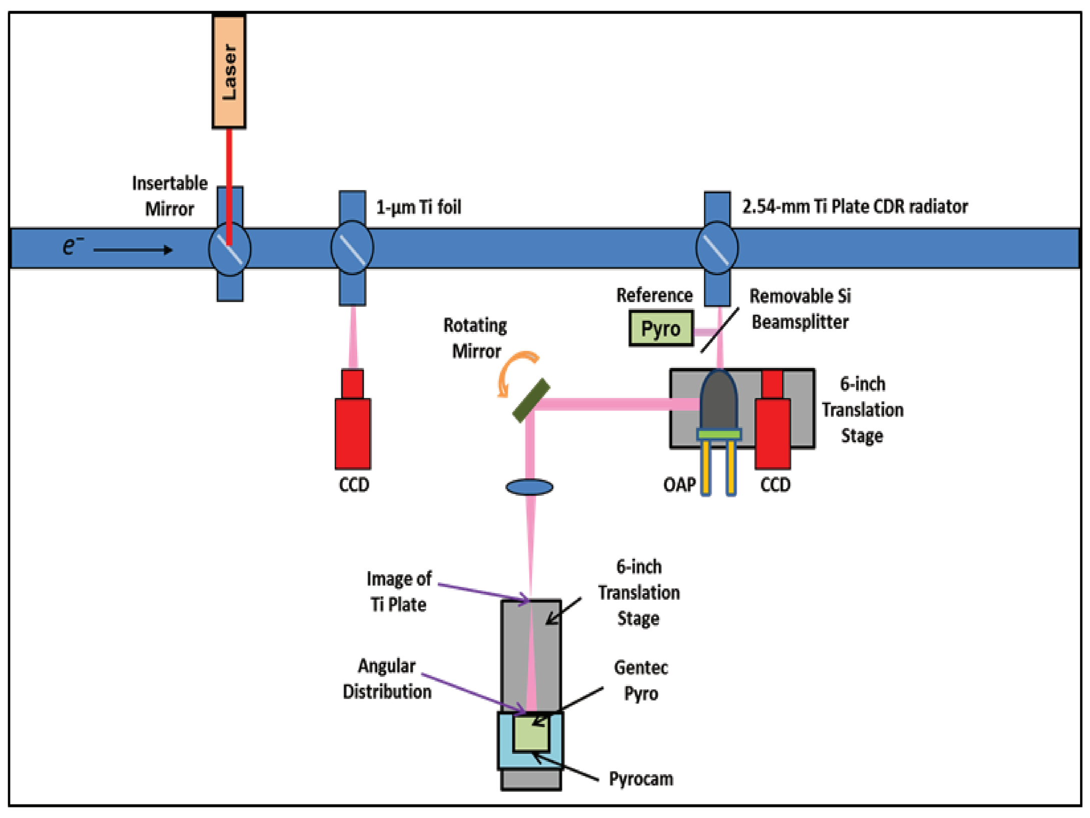
1. Less susceptible to upstream sources (problem for high energies, i.e. long coherence lengths, L ~$\gamma^2\lambda$
2. Easier to observe (more photons per detector pixel)

CDR AD and PSF Imaging Experiments at FACET

FACET parameters:

E = 20 GeV,
Q ~ 1.1 nC;
Single bunch;
rep rate: f = 10 Hz

Transverse beam size =250 μm
Bunch length = 60 - 80 μm FWHM
THz band: 18-200 μm (0.15-2 THz)



Angular Distribution Imaging Results:

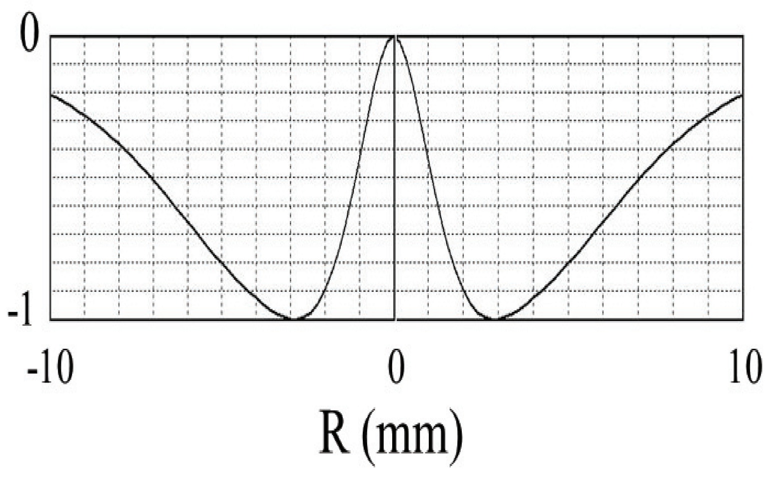
1. Observed characteristic two lobe AD pattern predicted by theory
2. AD much wider and much less intense than theoretically predicted; insensitive to pulse length.

Probable cause:

Destructive interference from upstream sources, within coherence length at 20GeV (km scale at THz wavelengths)
Two known close upstream sources: slit (CDR) relative bunch length monitor, OSR from dipole magnet.

CDR PSF Imaging Results:

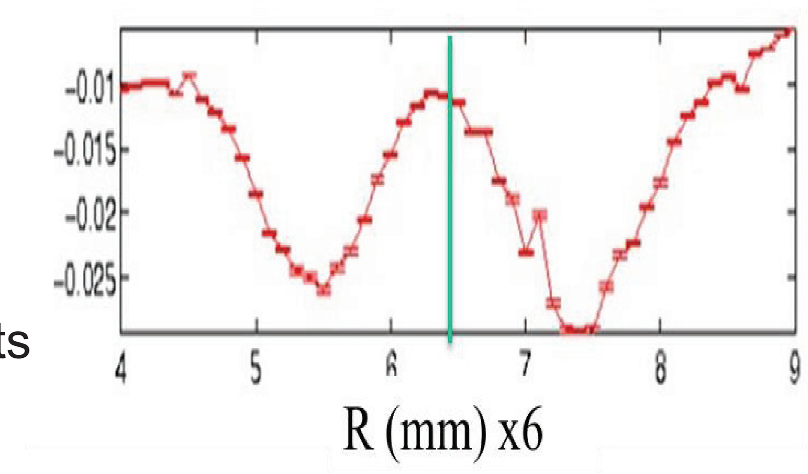
Theoretical horizontal scan of CDR on image plane (inverted)
Bunch length FWHM=60 μm.
Transverse Beam Size FWHM = 100 μm
<< FWHM of CDR PSF



Measured Spatial Distribution

1. qualitatively: follows theory
2. quantitatively: peak to peak ~ 2 x > theory

$\Rightarrow$ calibration error, focusing problem
$\Rightarrow$ additional simulations + experiments needed and are being planned.



References

[1] A. Shkvarunets, R. Fiorito, PRAB, 11, 012801 (2008).
[2] A. Shkvarunets, R. Fiorito, et. al. Proc. of DIPAC07, Venice IT (2007).

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