Experimental observation of submillimeter coherent Cherenkov radiation for a bunch length diagnostic at CLARA facility

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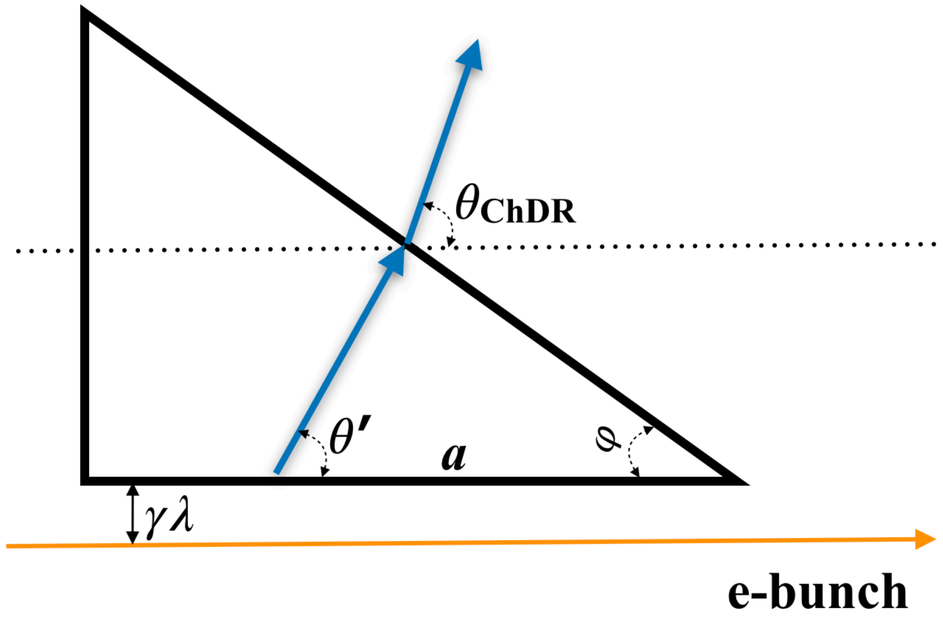
Coherent Cherenkov Diffraction radiation (CChDR):

- Allow noninvasive diagnostic
- Relatively high intensity
- Highly directional
- New technique

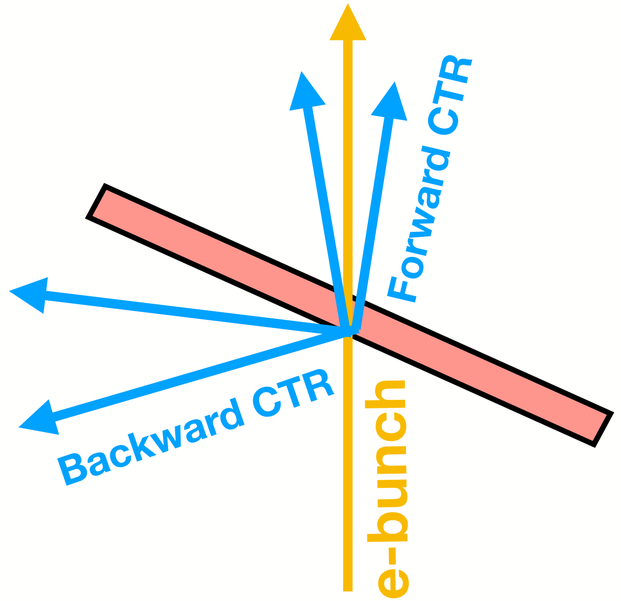


λ - wavelength

γ - Lorenz factor

Coherent Transition Radiation (CTR):

- Well studied and widely used



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Form factor F(w) - is a function describing coherent emission from an electron bunch and defined by a bunch length and shape

How does diagnostic works?

$$p(z) = \frac{1}{\pi c}\int_0^\infty \sqrt{F(W)}\cos(\psi(w) - z\frac{w}{c})dw$$

$$F(w) = \frac{S_{coh}(w)}{S_{single}(w)}$$

→ Kramers-Kronig analysis

$S_{coh}(w)$ Coherent spectrum radiated from the bunch of electrons, obtained via interferometry and Fourier transform

$S_{single}(w)$ Single electron spectrum, calculated through the theory of spectral-angular distribution

$F(w) = \frac{S_{coh}(w)}{S_{single}(w)}$ Bunch Form-factor

$\psi(w)$ Minimal phase. Interferometry procedure doesn't give us phase information, which is needed for profile reconstruction.

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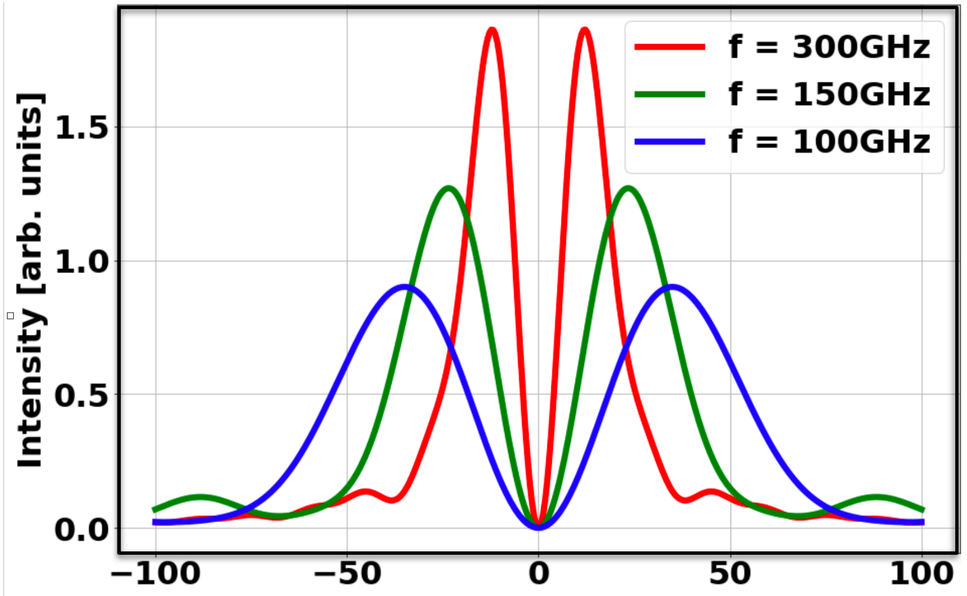
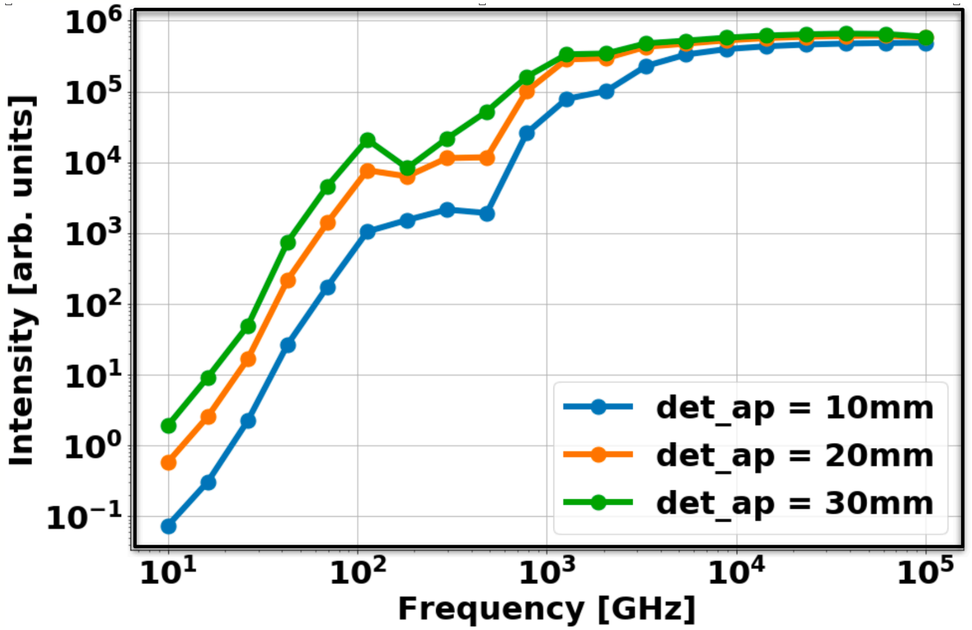
Model of Transition radiation spectrum from a single electron

Models takes into account the following parameters:

- Energy = 35MeV
- TR target size = 5 cm in diameter
- Distance between target and detector = 10 cm
- Detector aperture = 4 cm in diameter





TR single electron spectral-angular distribution (LEFT) single electron spectrum (RIGHT)

Karataev Physics Letters A, Volume 345, Issue 4-6, p. 428-438., Jul 2005

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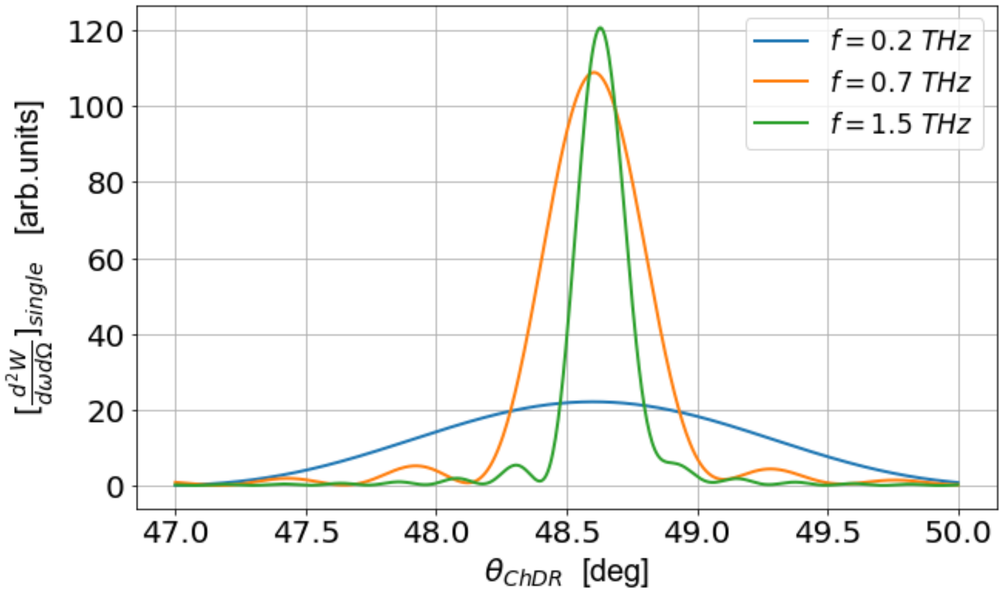
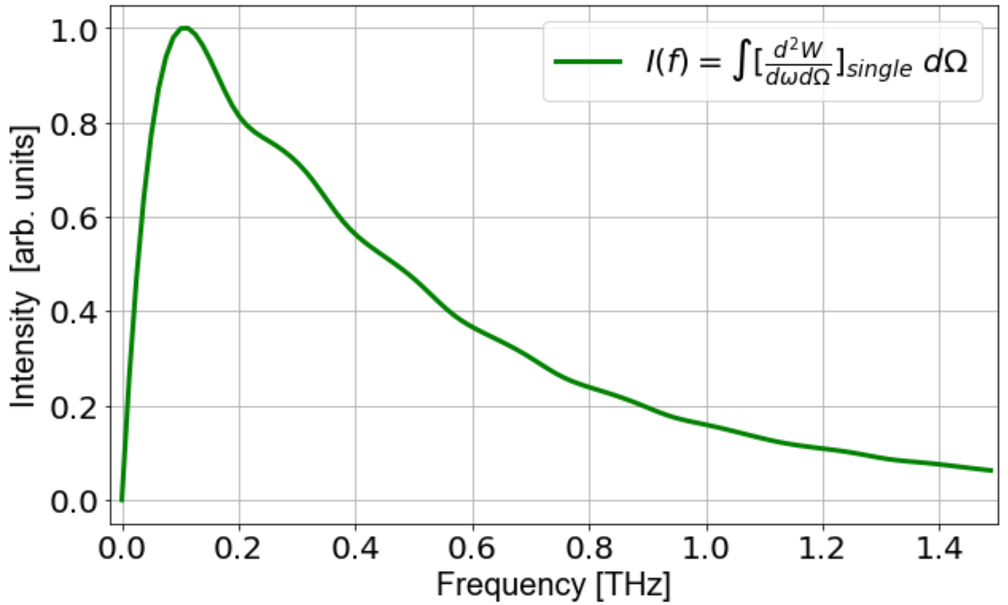
Model of Cherenkov diffraction radiation spectrum from a single electron

Models takes into account the following parameters:

- Energy = 35 MeV
- Cherenkov target dimensions (prismatic target) = 5 cm (base size).
- Cherenkov target refractive index = 1.4 (teflon)
- Distance between target and detector = 10 cm
- Detector aperture = 3.5 cm in diameter
- Impact parameter (distance between beam and target) = 2 mm
- Angle between target and particle direction = 0 deg





ChDR single electron spectral-angular distribution (LEFT) single electron spectrum (RIGHT)

M.V. Shevelev and A.S. Konkov, J. Exp. Theor. Phys. (2014) 118: 501.

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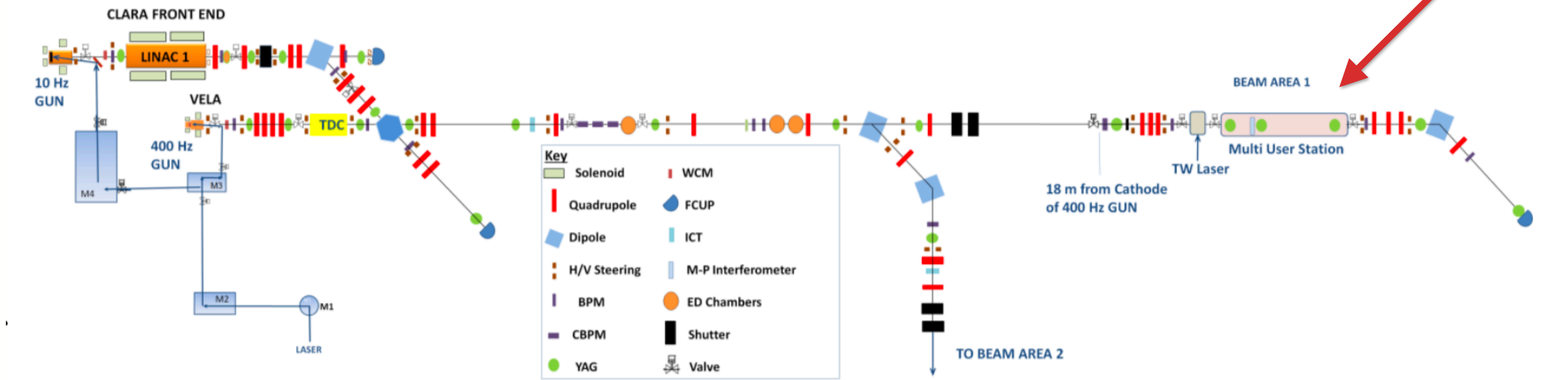
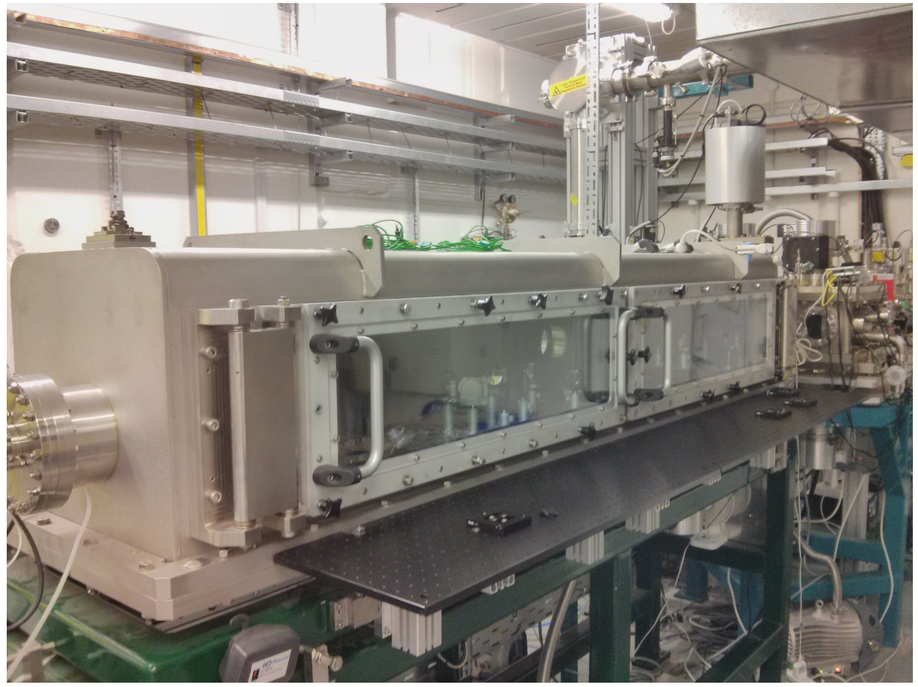
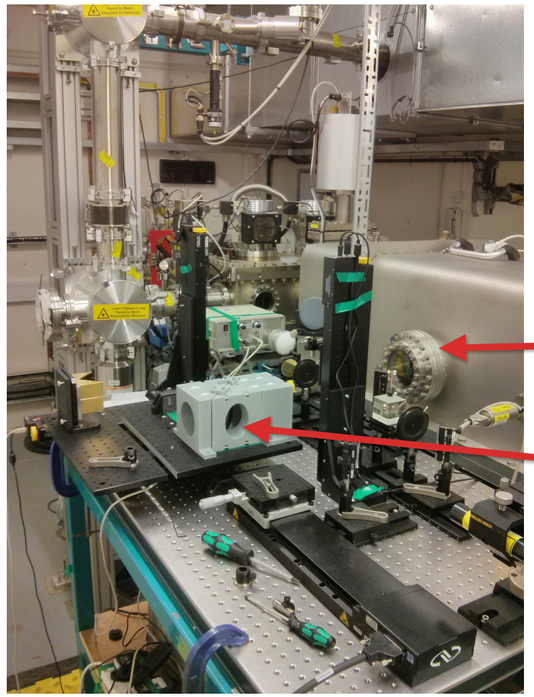
Experimental work at CLARA



BA1





- f = 10Hz
- E = 35 MeV
- Longitudinal beam size was about 0.2-0.3 ps with charge ranging within 70-100 pC
- 200 microns RMS transversal bunch size

Quartz output window

MPI

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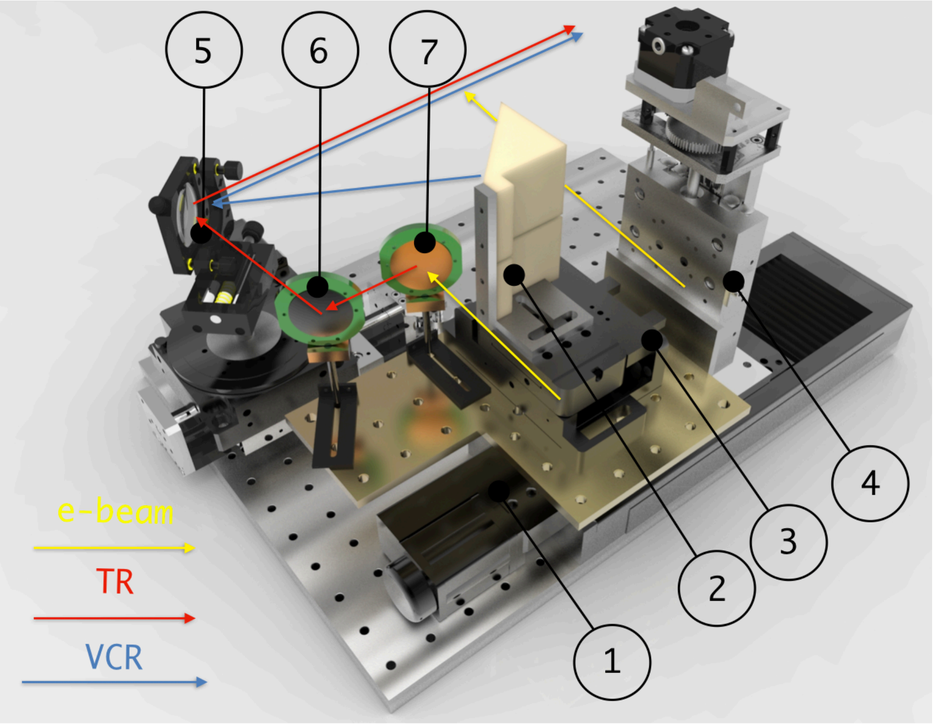
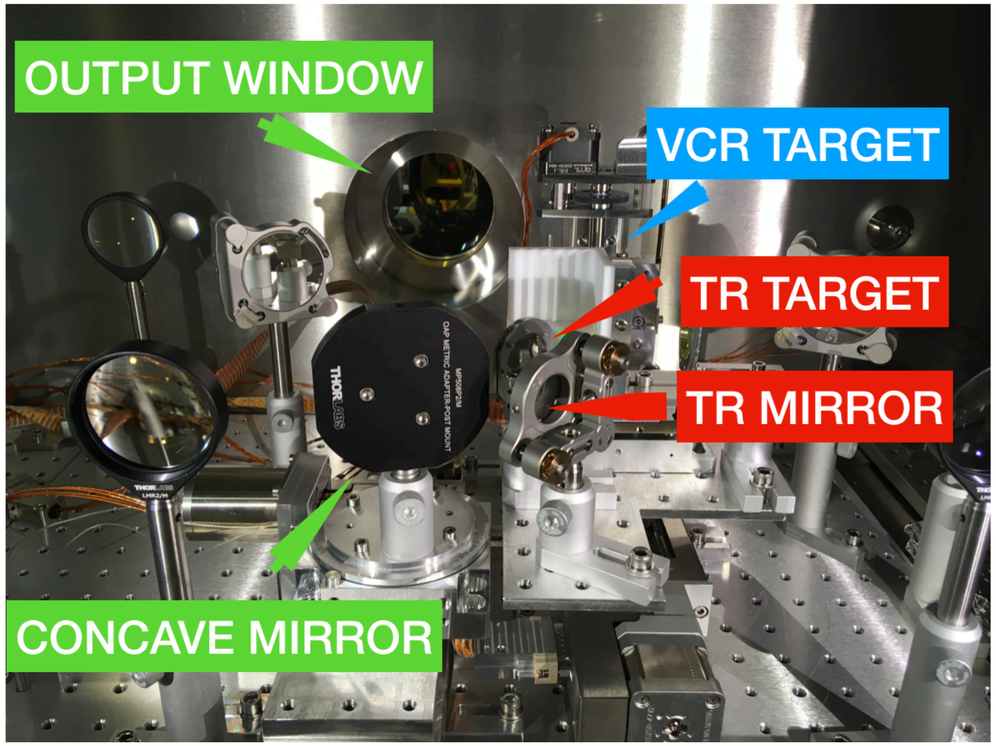
Setup inside chamber





1 — Horizontal positioning stage
2 — Teflon (VCR) target
3 — Tip-Tilt stage
4 — Vertical positioning stage
5 — Concave mirror
6 — Mirror for TR
7 — TR target

Both TR and ChDR scans were conducted during same accelerator run

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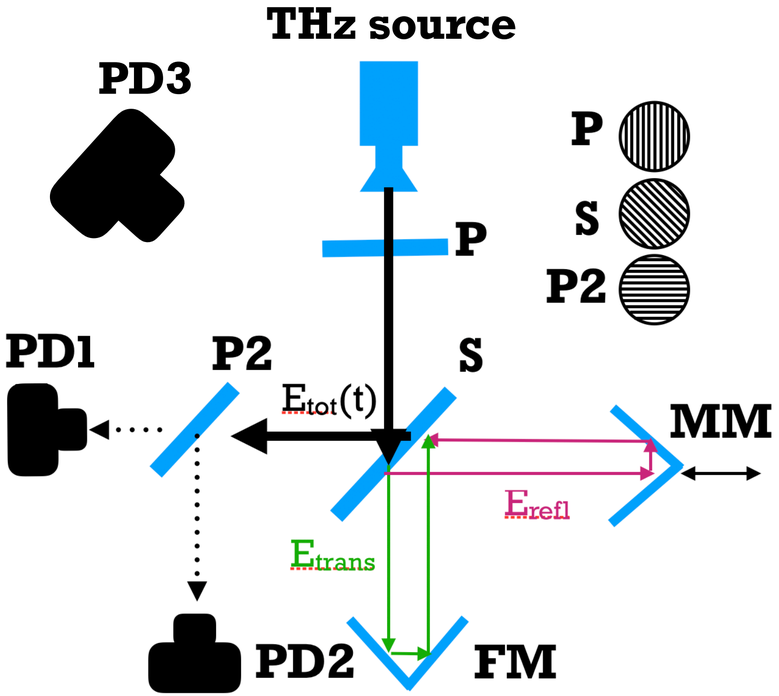
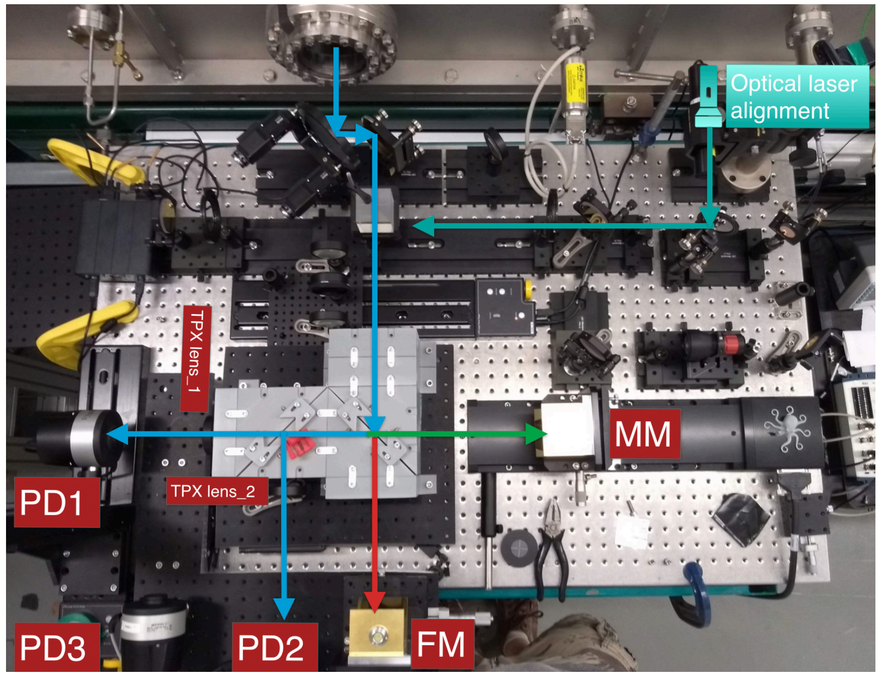
MPI Interferometer





Martin-Pupplet interferometer has a higher signal to noise ratio. Using of two anticorellated outputs allows us to provide intensity fluctuation normalisation.

$$I(x) = \frac{U_h(x) - U_v(x)}{U_h(x) + U_v(x)}$$

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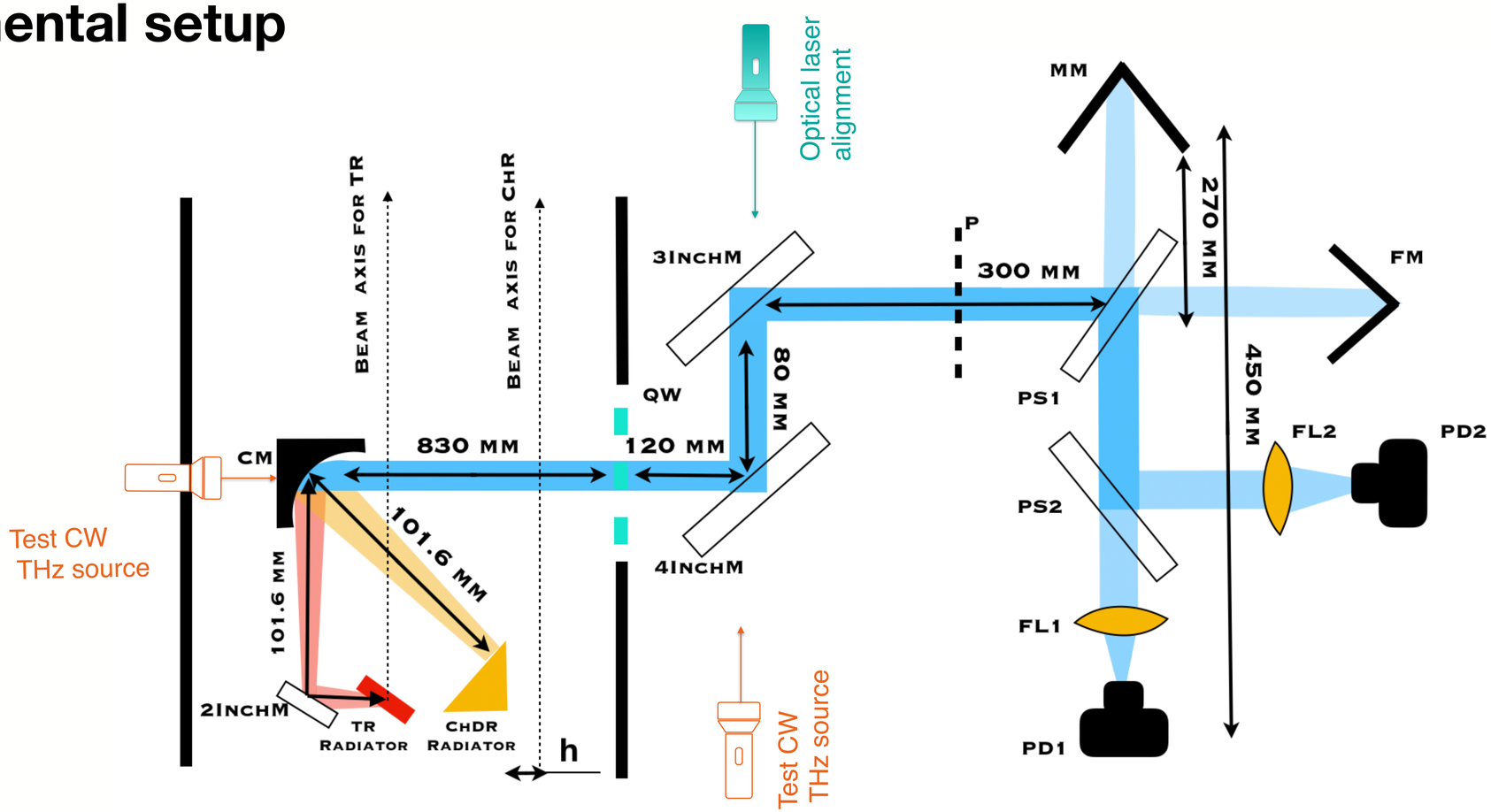
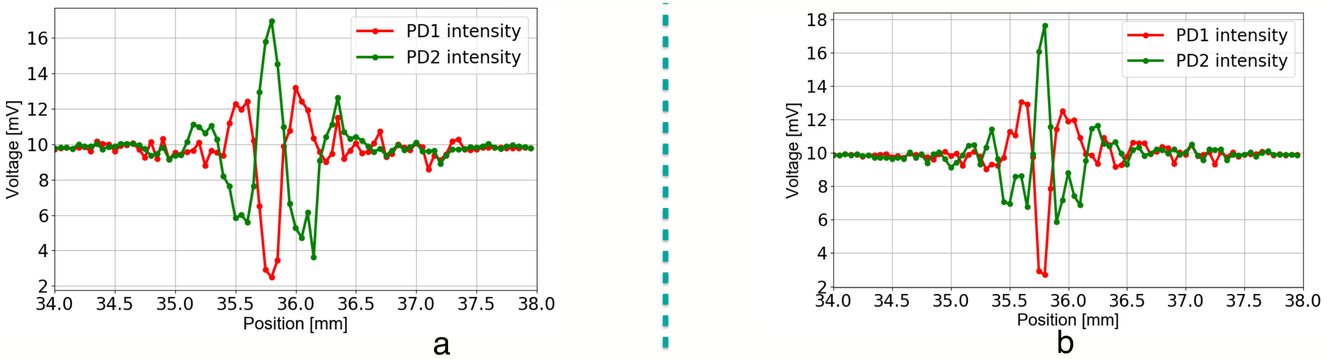
Full experimental setup



Experimental setup for ChDR and TR extraction and interferometry: CM - Concave Mirror; QW - Quartz Win- dow; 4inchM - 4 inches Mirror; 3inchM - 3 inches Mirror; P - Polarizer; PS1, PS2 - Polarizing beam Splitters; FM - Fixed Mirror, MM - Movable Mirror; PS2 - Polarizing beam Splitter; FL1, FL2 - Focusing Lenses with focal length 101.6 mm; PD1, PD2 - Pyroelectric Detectors (Gentec THz51).

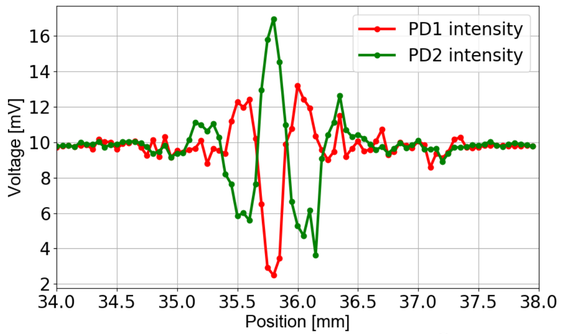
Results



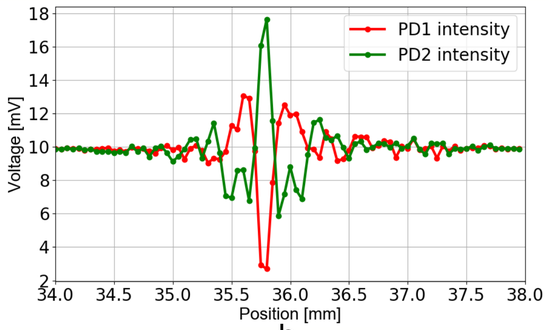
Interferograms of coherent ChDR diffraction radiation (LEFT) and coherent TR (RIGHT)

- f = 10Hz
- E = 35 MeV
- Distance between ChDR radiator and beam h = 2mm
- Charge ranging was about 100-70 pC
- 200 microns RMS transversal bunch size
- Distance between ChDR radiator and electron beam is 2mm
- 50 samples accumulation for 1 step of movable mirror.
- Triangular appodization window is the only post-processing technique used.
- PD1 and PD2 intensity were normalised on signal prom PD3, which collected all noise from the environment (vibrations, acoustic noise, light fluctuation, etc.)

Results

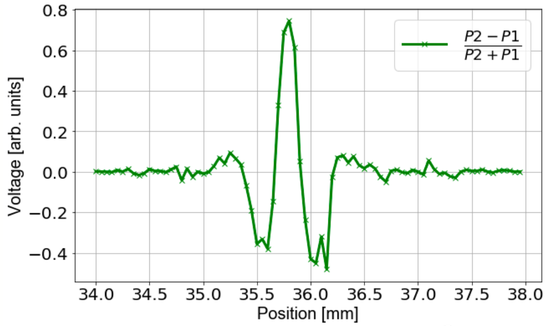


a

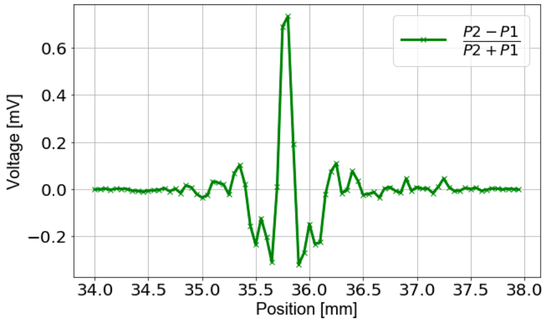


b

Interferograms of coherent ChDR diffraction radiation (LEFT) and coherent TR (RIGHT)



a



b

Normalised interferograms of coherent ChDR diffraction radiation (LEFT) and coherent TR (RIGHT)

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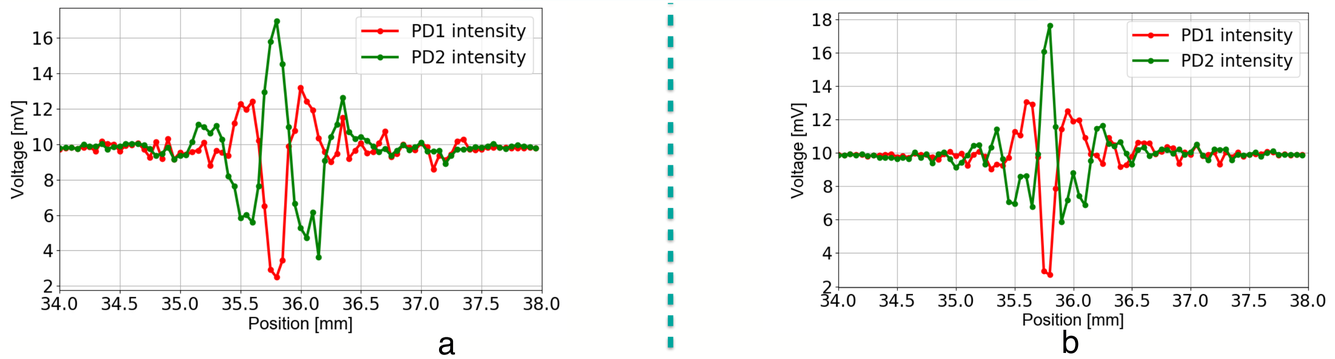
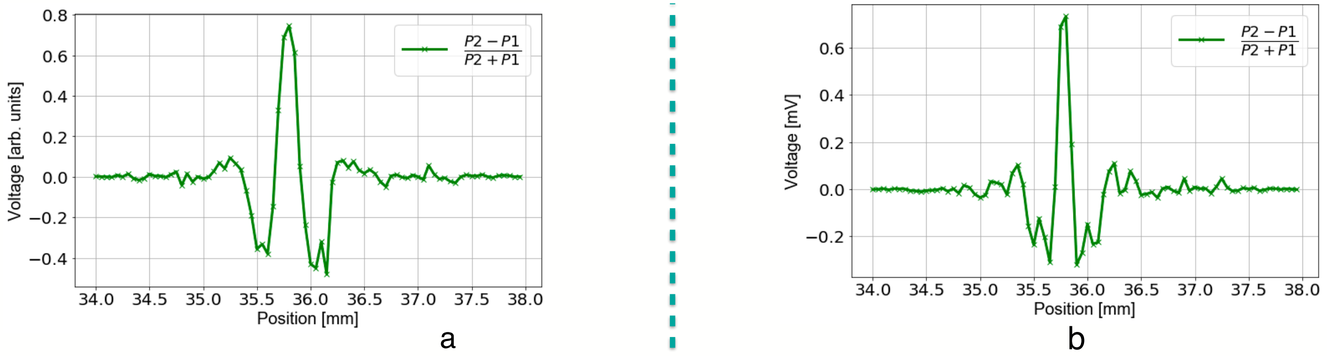
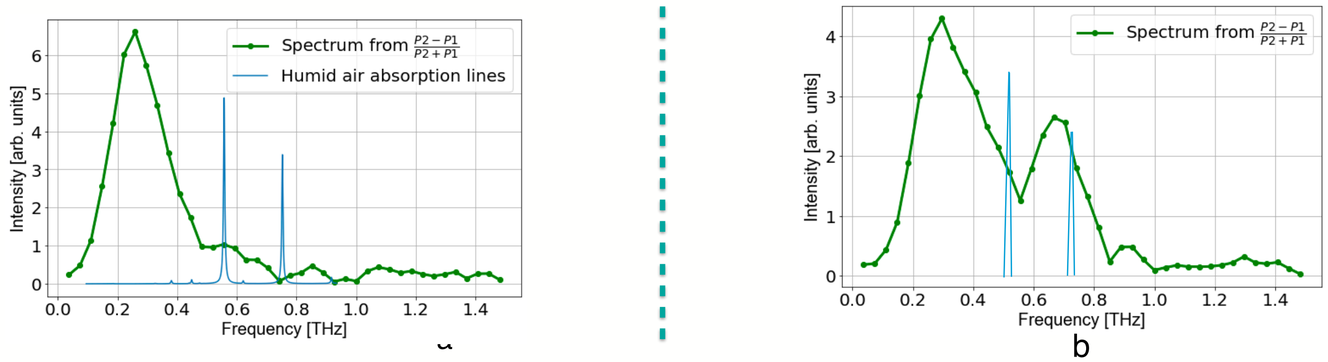


Interferograms of coherent ChDR diffraction radiation (LEFT) and coherent TR (RIGHT)



Normalised interferograms of coherent ChDR diffraction radiation (LEFT) and coherent TR (RIGHT)



Spectrum of coherent ChDR diffraction radiation (LEFT) and coherent TR (RIGHT)

- f = 10Hz
- E = 35 MeV
- Distance between ChDR radiator and beam h = 2mm
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- Distance between ChDR radiator and electron beam is 2mm
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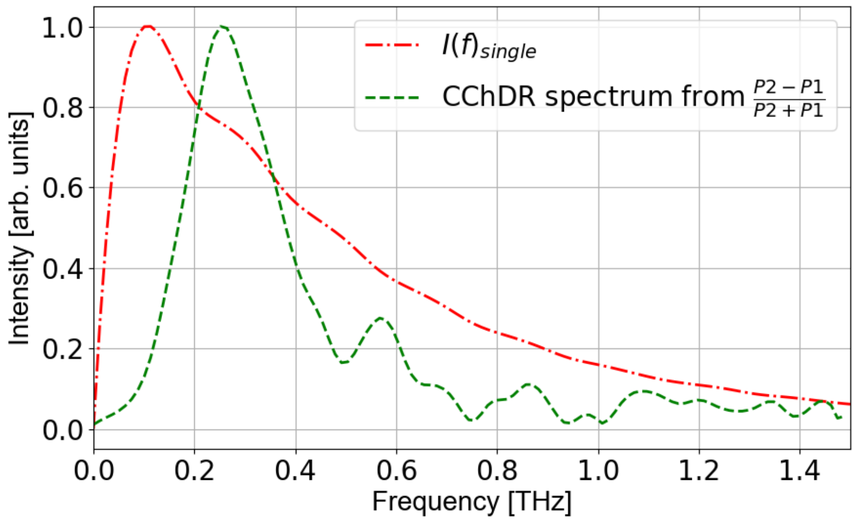

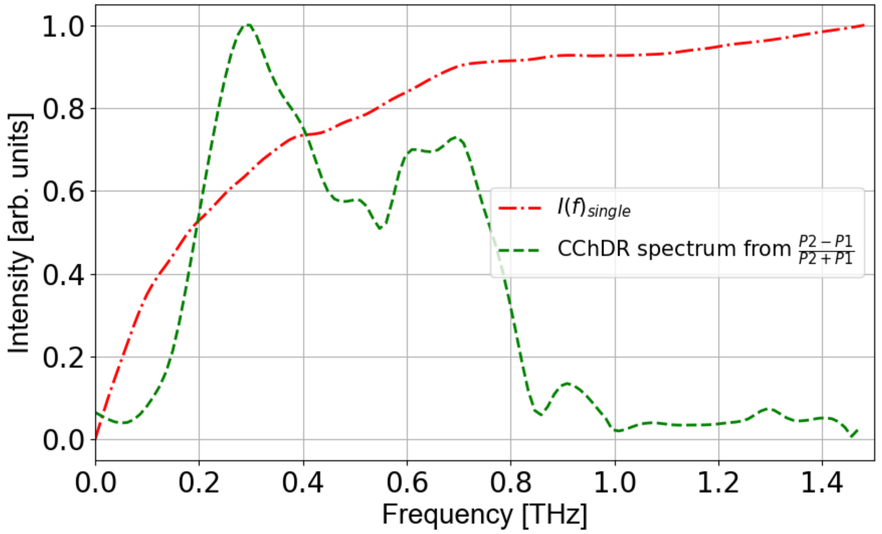

Single electron (red) spectrum and spectra of CChDR and TR (green)

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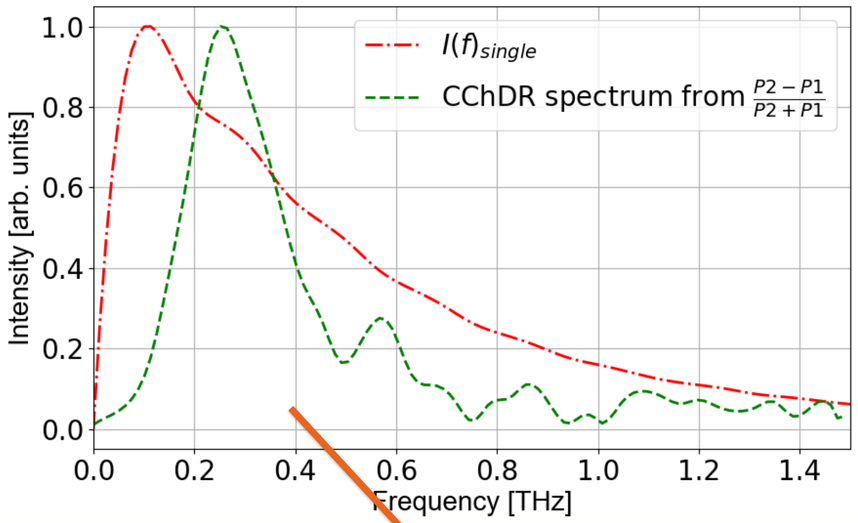

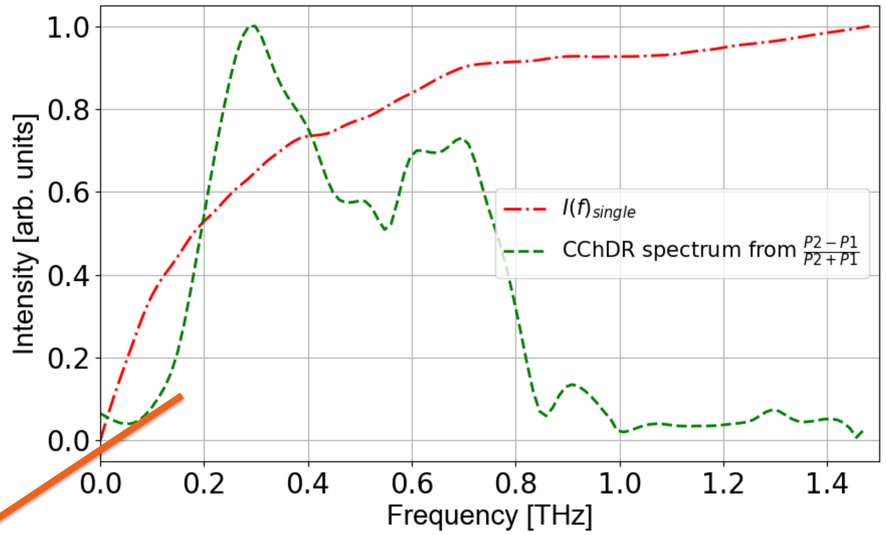

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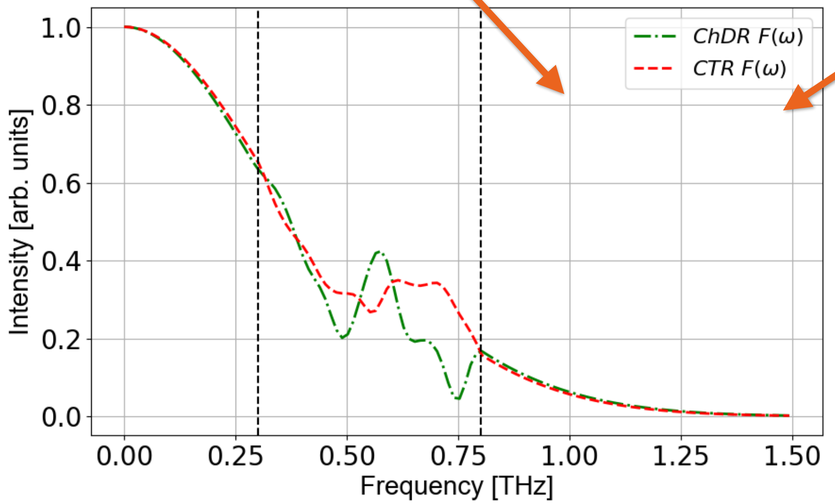

Extrapolated form-factor for both ChDR (green) and TR (red). Extrapolation according to:

M Micheler et al. "Longitudinal beam profile monitor at CTF3 based on Coherent Diffraction Radiation." In: *Journal of Physics: Conference Series* 236 (June 2010), p. 012021.

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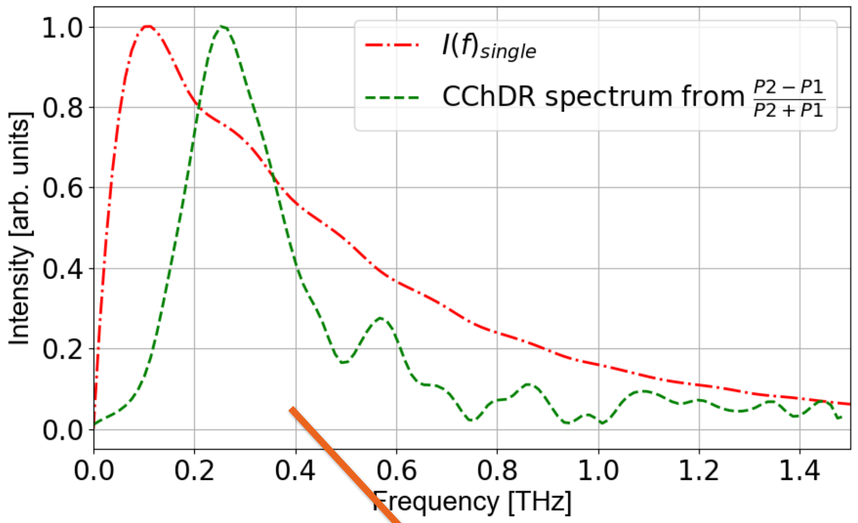
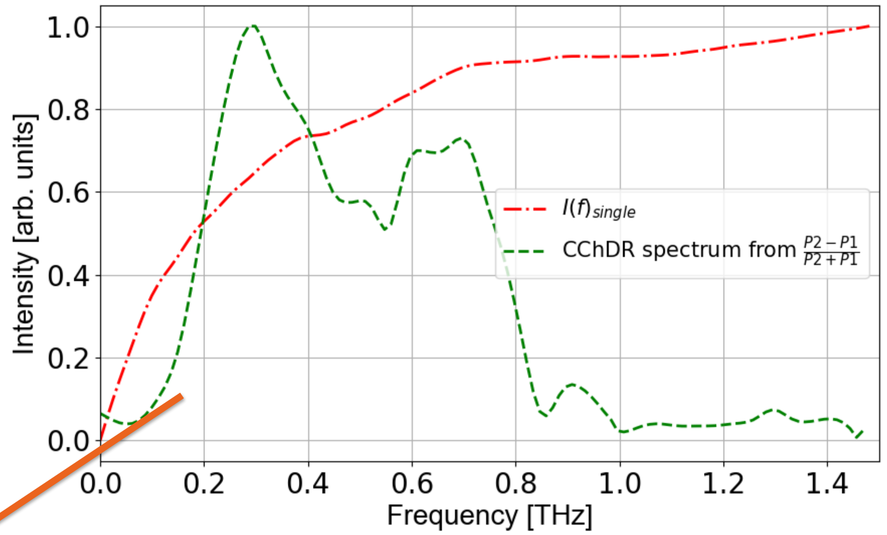
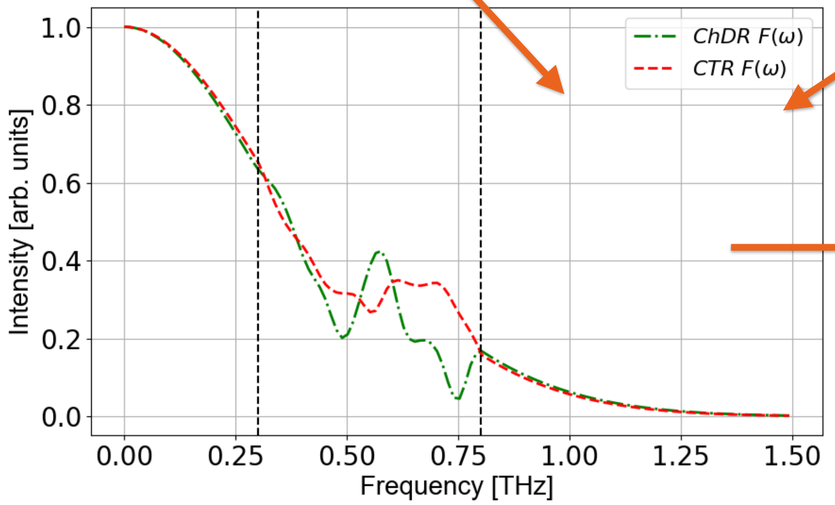




Single electron (red) spectrum and spectra of CChDR and TR (green)



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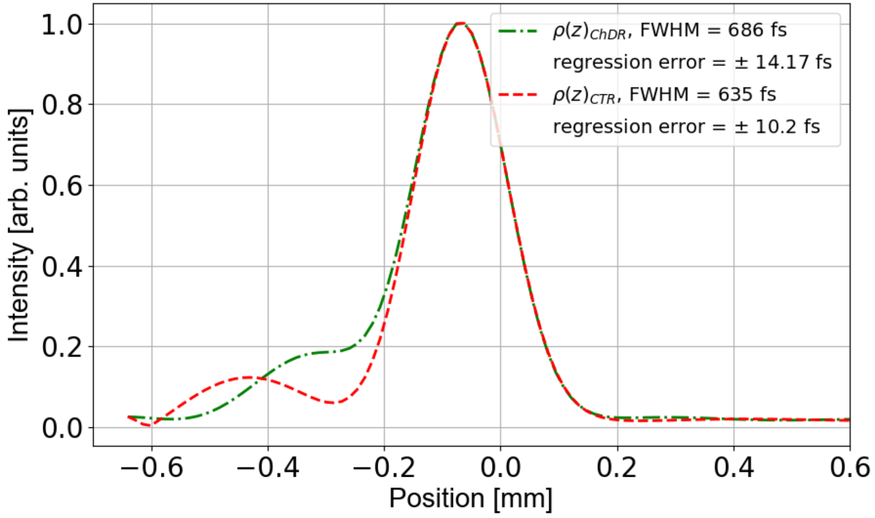

Bunch profile reconstruction via ChDR (green) and TR (red)

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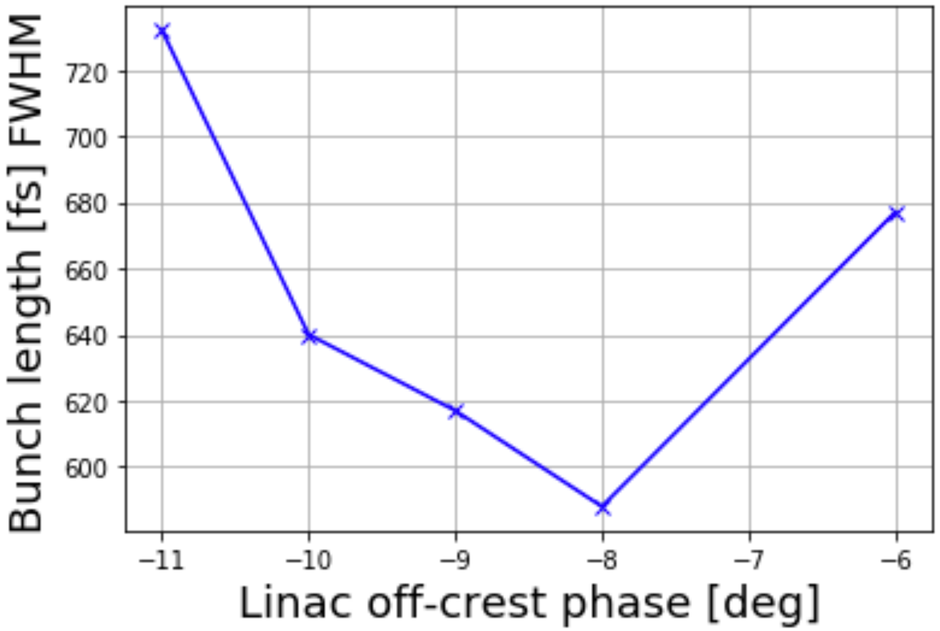
CChDR reconstruction for different bunch compression parameters:



CChDR for different bunch compression parameters (linac off-crest phase)

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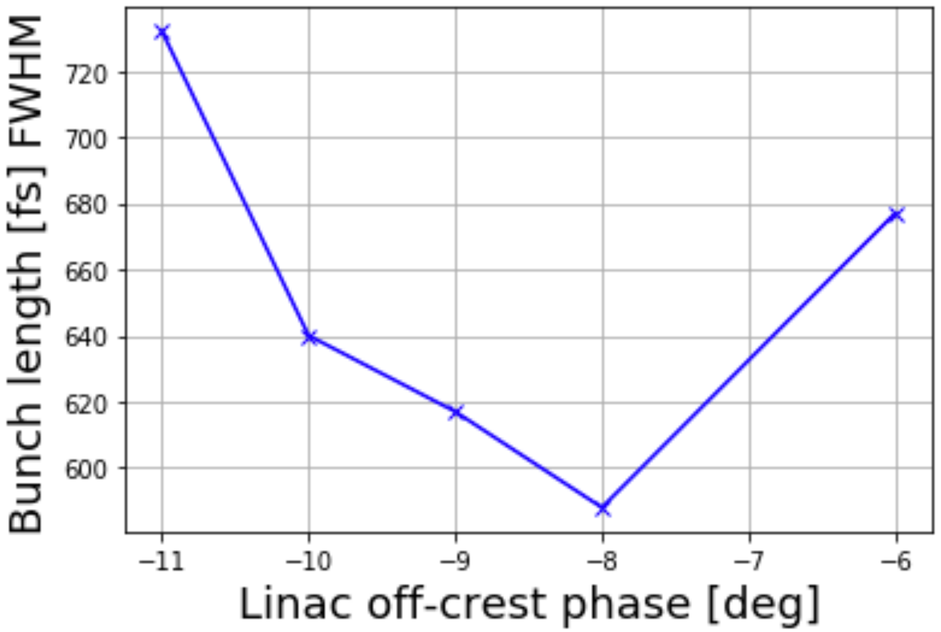
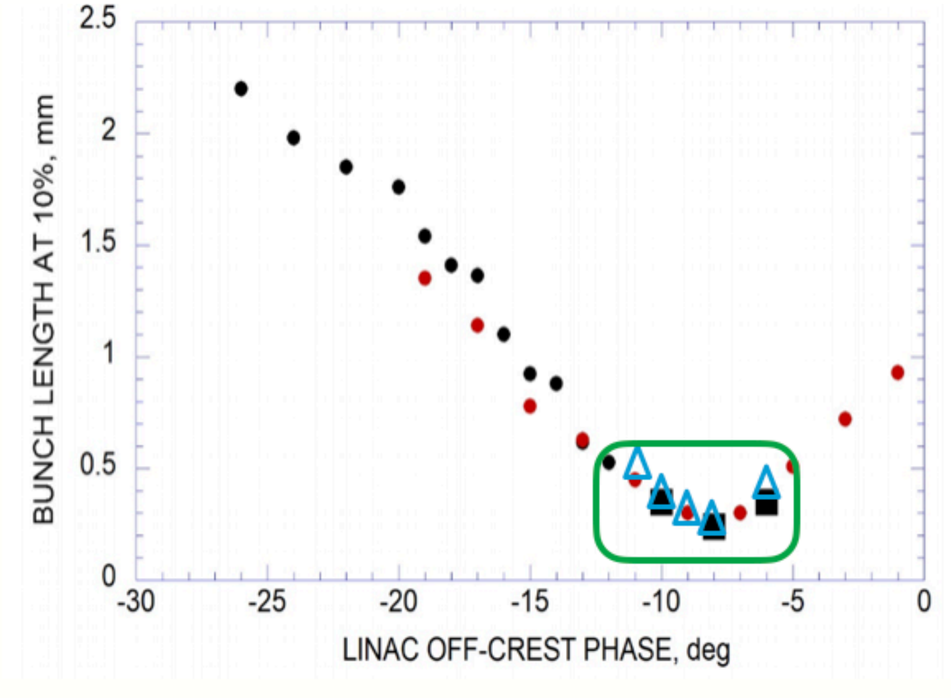
CChDR reconstruction for different bunch compression parameters:





CChDR for different bunch compression parameters (linac off-crest phase)

- CChDR scan
- CTR scan
- Dielectric Wakefield (DWA) Acceleration scan
- ELEGANT code beam simulation

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Summary:

- We have observed Cherenkov Diffraction radiation and Transition radiation at CLARA beam line.
- Coherent spectra for both ChDR and CTR have been measured.
  We need to investigate fundamental studies of Cherenkov radiation including angular distribution and dependance on distance between target and beam.
- We reconstructed the bunch profile and demonstrated some sensitivity to small bunch variations due to the linac off-crest change

Thank you for your attention!

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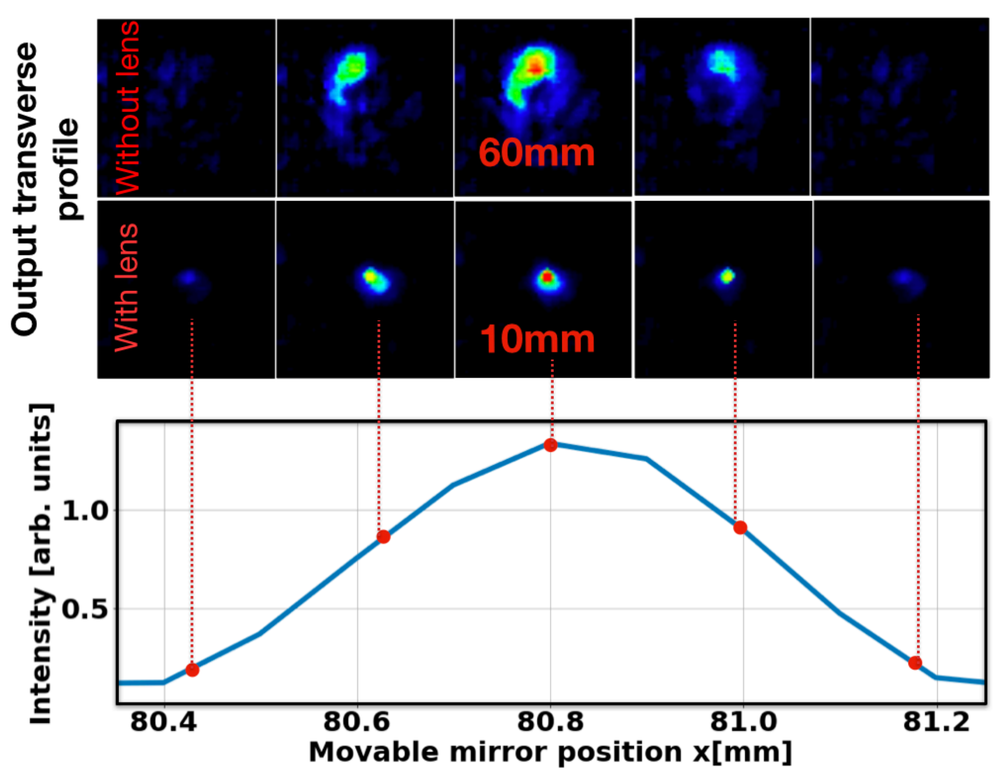
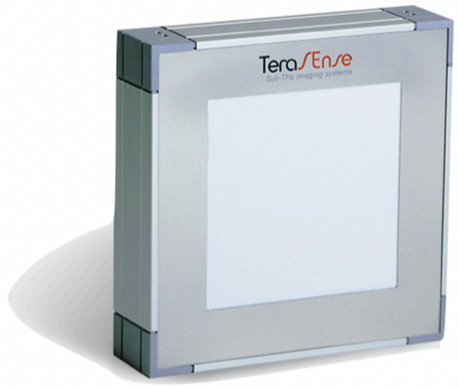
MPI alignment

By using THz camera and test CW THz source we were able to align interferometry system with good precision





- Frequency range: 10 GHz — 1THz;
- 4096 pixels (64 x 64 array)
- 1.5mm pixel pitch
- Framerate, exposure and accumulation control
- NEP=1nW/sqrt(Hz)

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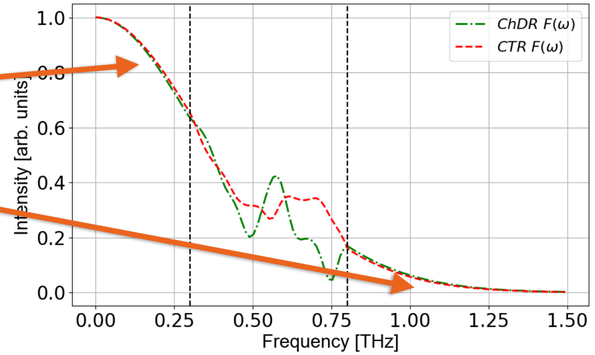
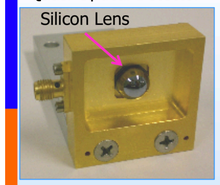
Reduce the influence of extrapolation procedure

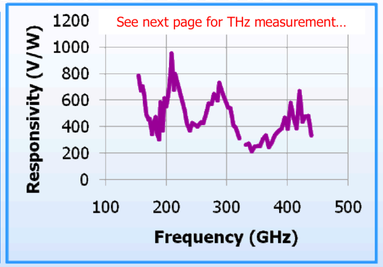


Quasi-Optical Broadband Detectors

Quasi-Optical Detector



- Frequency Range 100-1000 GHz
  - Performance expected to ~2 THz
- Responsivity 500 V/W typical
  - NEP ~ 10 pW/rtHz
- Antenna directivity 25-35 dB nom.
- Sub-ns response time



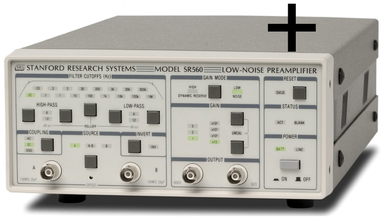
quazi-optical Schottky detectors

VS

MEASUREMENT CAPABILITY	
Spectral Range [a]	
Frequency	0.1 - 30 THz
Wavelength	3000 - 10 µm
Max Measurable Power	140 µW
Noise Equivalent Power [b]	1.0 nW [1.0 x 10^{-9} W/(Hz)^{½}]
Rise Time (0-100%)	< 0.2s
Sensitivity (Typical) [b]	70 kV/W
Chopping Frequency	5 Hz (Required)
Calibration Uncertainty	Contact Us

Low-Noise Voltage Preamplifier

SR560 — DC to 1 MHz voltage preamplifier



- *4 nV/√Hz input noise*
- *1 MHz bandwidth*
- *Variable gain from 1 to 50,000*
- *AC or DC coupled*
- *Two configurable signal filters*
- *Differential and single-ended inputs*
- *Line or battery operation*
- *RS-232 interface*

Experimental and simulation parameters

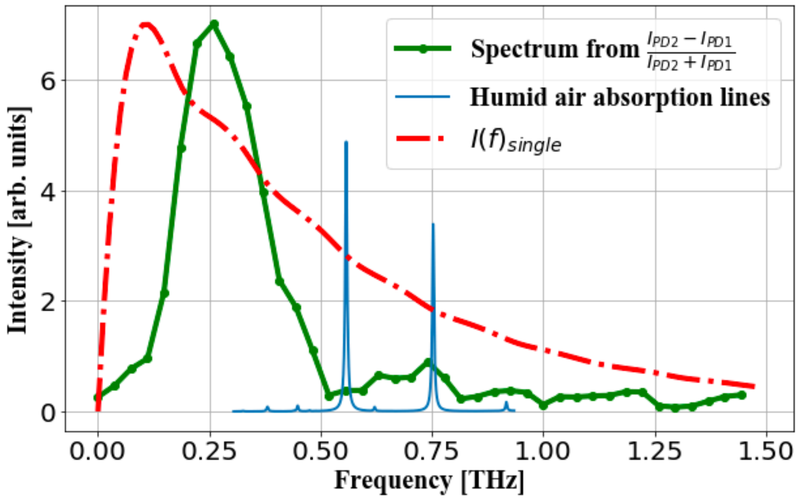
Table 1: Simulation and experimental parameters

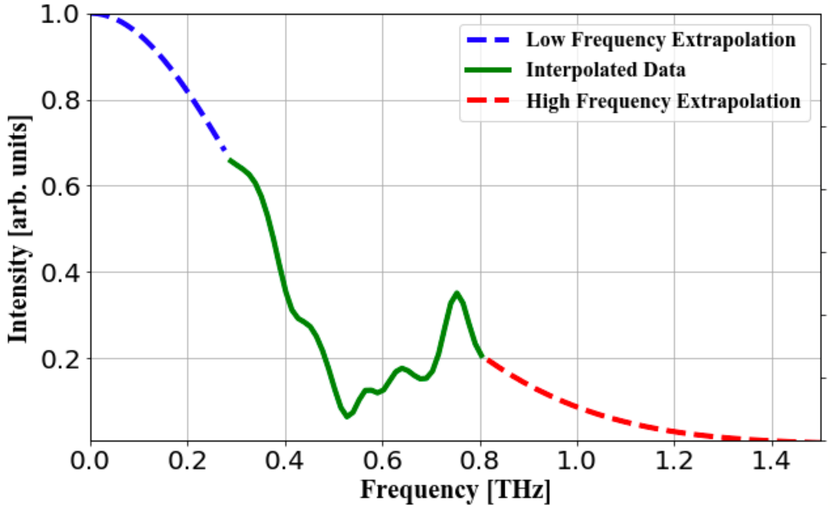
Parameters	**Value**
Lorentz - factor γ	70
Target length a	5 cm
Vertex angle of the prism φ	45°
Angle between radiator surface and beam direction α	0°
Radiation frequency f	[0-1.5] THz
Index of refraction $n(f)$	1.4 (Teflon)
Impact parameter h	[1.5-2.5] mm
Azimuthal angle ϕ	[10-30]°
Polar angle θ	[40-60]°

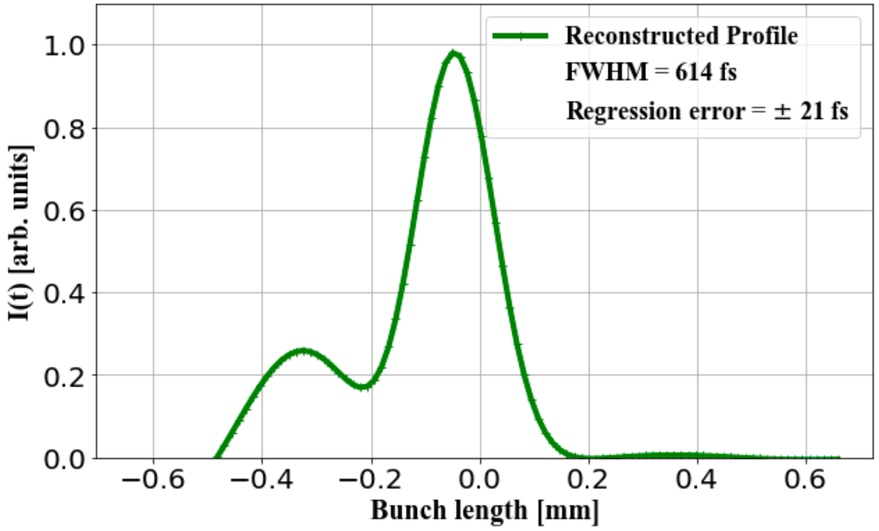
Table 2: CLARA machine parameters

Parameters	**Value**
Electron energy E	35 MeV
Longitudinal beam compression ρ	[2-0.3] ps
Bunch repetition rate	10 Hz
Charge C	[70-100] Pc
Transverse beam size σ	200 μm

More results for ChDR reconstruction (for a phase = -9deg):







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Experimental results: