THz@CLEAR: 2018 summary

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on behalf of and in collaboration with

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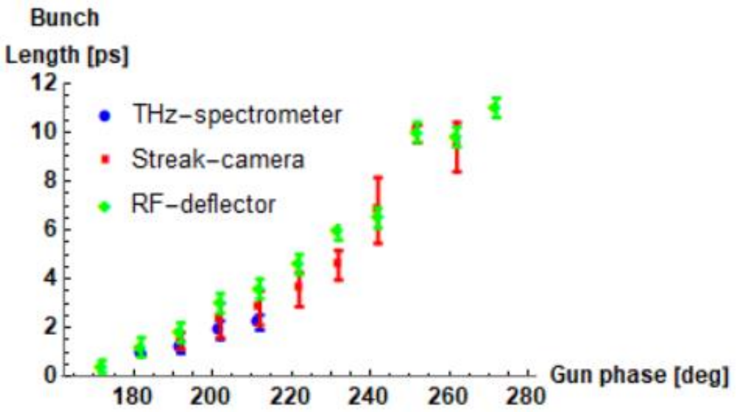
Outline

- The CLEAR THz source
- A Coherent Cherenkov-Diffraction-based Beam Position Monitor
- A Coherent Cherenkov-Diffraction-based Bunch Length Monitor
- Tests on High-Intensity THz field generation and Electromagnetic Shadowing
- Exotic applications of THz radiation
- Conclusions

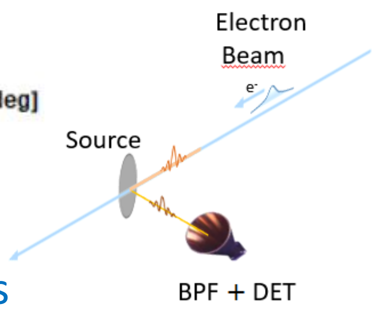
A THz source based on Coherent Transition Radiation (CTR)



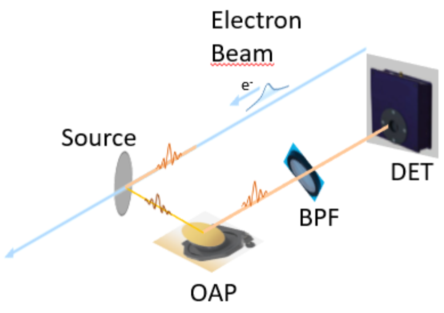
Spectrally and angularly characterized CTR source, by means of band-pass filtered Schottky diodes

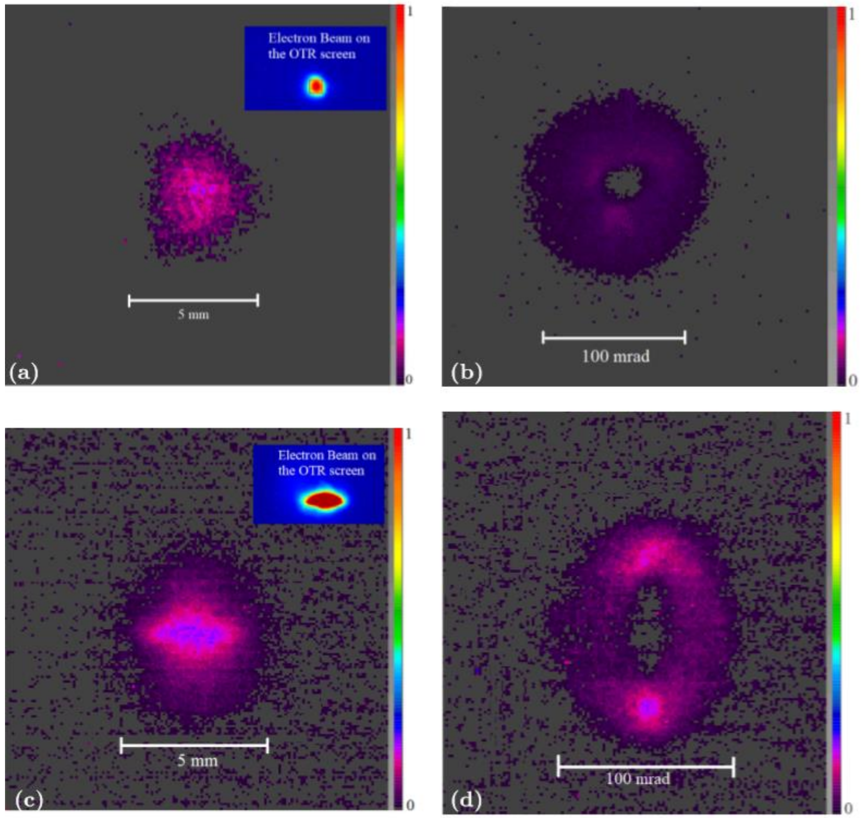
Application: bunch length diagnostics

SETUP 1



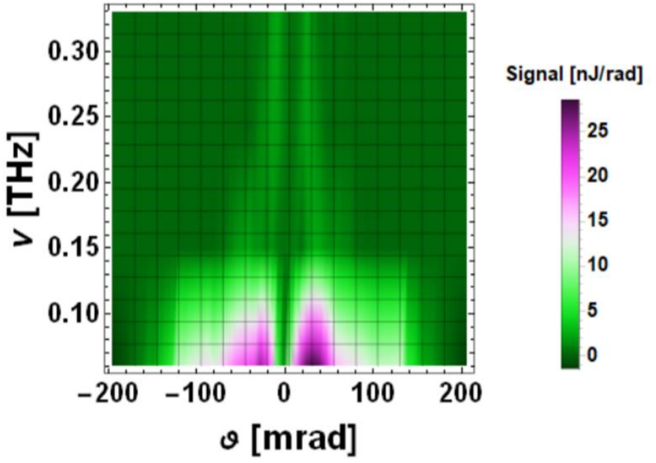
SETUP 2



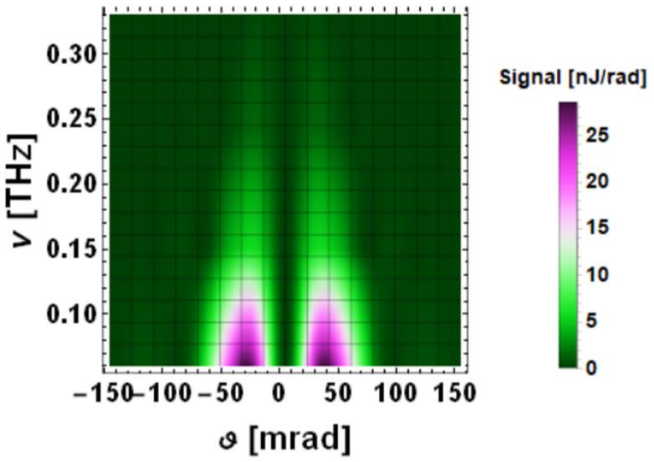


Source characterized both in near and far-field by means of a THz camera,
angular distribution/polarization shaping
by different beam focusing at the radiator plane

Experiment



Simulation



See Ref. Curcio, A., et al. "A beam-based (sub-)THz source at the CERN Linear Electron Accelerator for Research" *Physical Review Accelerators and Beams* (2019).

Comparison among different radiation mechanisms and source performances of the CLEAR THz source

Comparison among Coherent Transition Radiation (CTR),
Coherent Diffraction Radiation (CDR) and
Coherent Cherenkov-Diffraction Radiation (CChDR)

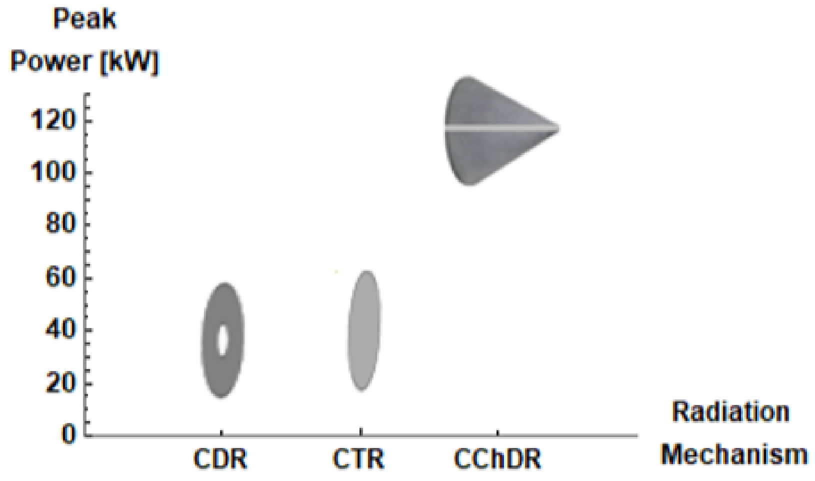


Figure . Peak power of the CLEAR (sub-)THz source for the following electron beam parameters (per single bunch): 215 MeV, 1.5 ps, 40 pC. The experimental points have been represented by the sketch of the radiators corresponding to the different radiation mechanisms explored.

More recent tests with novel designs of CChDR targets and higher charge/shorter compression have demonstrated >1 MW peak power

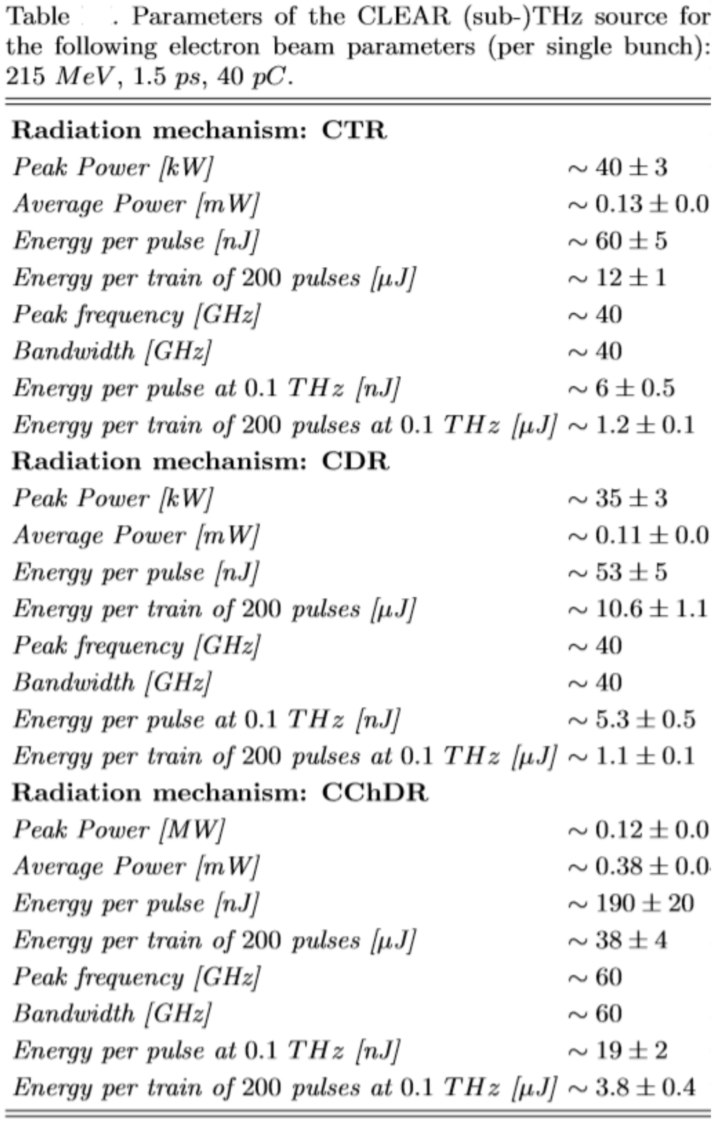


Table . Parameters of the CLEAR (sub-)THz source for the following electron beam parameters (per single bunch): 215 MeV, 1.5 ps, 40 pC.

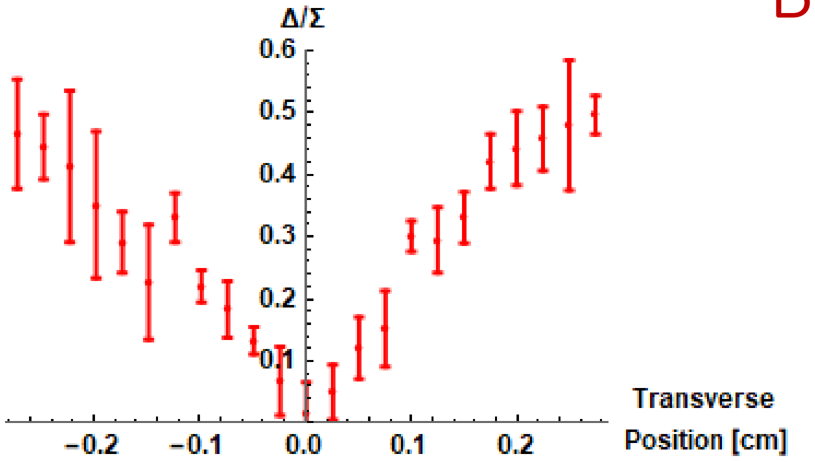
Radiation mechanism: CTR	
Peak Power [kW]	$\sim 40 \pm 3$
Average Power [mW]	$\sim 0.13 \pm 0.0$
Energy per pulse [nJ]	$\sim 60 \pm 5$
Energy per train of 200 pulses [μJ]	$\sim 12 \pm 1$
Peak frequency [GHz]	~ 40
Bandwidth [GHz]	~ 40
Energy per pulse at 0.1 THz [nJ]	$\sim 6 \pm 0.5$
Energy per train of 200 pulses at 0.1 THz [μJ]	$\sim 1.2 \pm 0.1$
Radiation mechanism: CDR	
Peak Power [kW]	$\sim 35 \pm 3$
Average Power [mW]	$\sim 0.11 \pm 0.0$
Energy per pulse [nJ]	$\sim 53 \pm 5$
Energy per train of 200 pulses [μJ]	$\sim 10.6 \pm 1.1$
Peak frequency [GHz]	~ 40
Bandwidth [GHz]	~ 40
Energy per pulse at 0.1 THz [nJ]	$\sim 5.3 \pm 0.5$
Energy per train of 200 pulses at 0.1 THz [μJ]	$\sim 1.1 \pm 0.1$
Radiation mechanism: CChDR	
Peak Power [MW]	$\sim 0.12 \pm 0.0$
Average Power [mW]	$\sim 0.38 \pm 0.0$
Energy per pulse [nJ]	$\sim 190 \pm 20$
Energy per train of 200 pulses [μJ]	$\sim 38 \pm 4$
Peak frequency [GHz]	~ 60
Bandwidth [GHz]	~ 60
Energy per pulse at 0.1 THz [nJ]	$\sim 19 \pm 2$
Energy per train of 200 pulses at 0.1 THz [μJ]	$\sim 3.8 \pm 0.4$

Longitudinal diagnostics, high-intensity field production and studies on electromagnetic shadowing

CChD-based BPM
And
Bunch Length Monitor

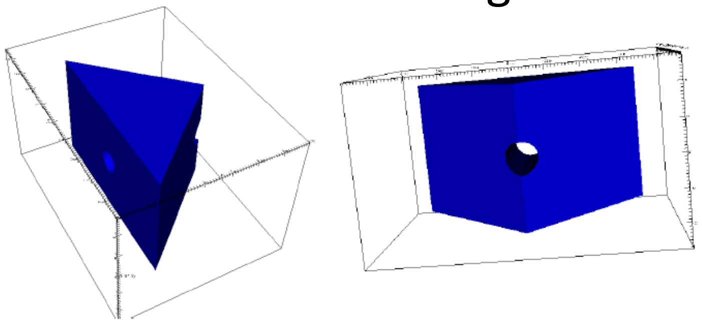
Experiments on high-intensity
THz generation and
Electromagnetic Shadowing

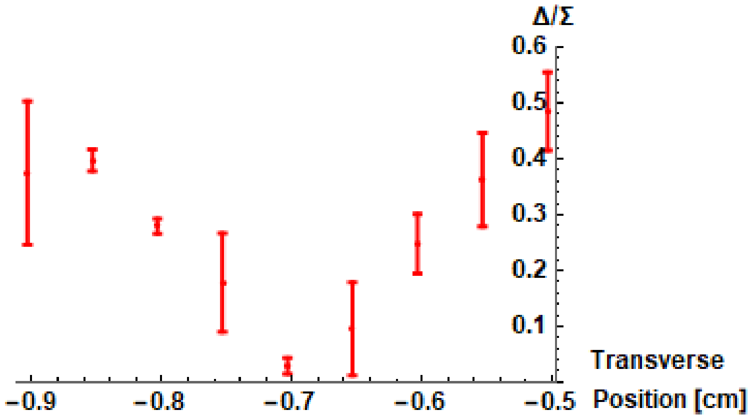
A Coherent Cherenkov-Diffraction-based Beam Position Monitor



Beam centered

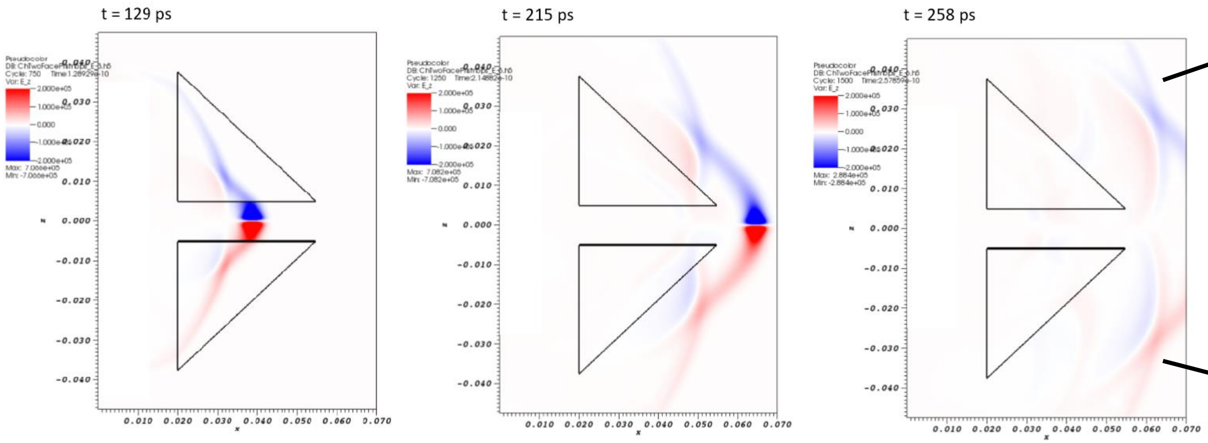
Radiator design





Beam not centered

Some simulations (courtesy of **K. Lekomtsev**)



Detector 1 with signal Sleft

Detector 2 with signal Sright

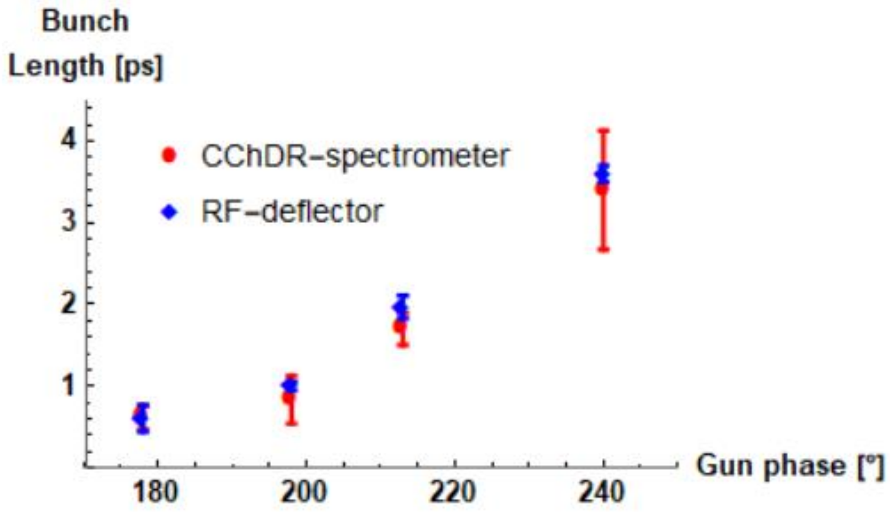
B.P.M. formula

$$\left|\frac{\Sigma}{\Delta}\right| = \left|\frac{S_{left} - S_{right}}{S_{left} + S_{right}}\right|$$

Important note: This B.P.M., based on coherent radiation, is sensitive only to bunches shorter than a certain threshold bunch length!

Longitudinal diagnostics with CChDR

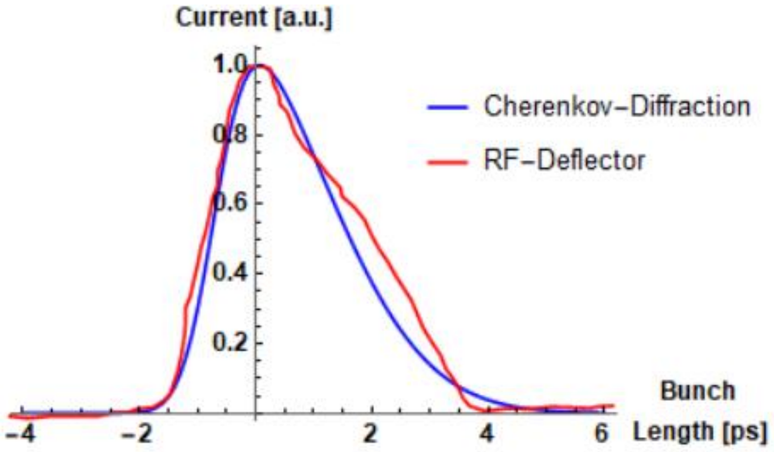
Using two diodes (84 GHz and 113.5 GHz)



Measurement made by exploiting a one-parameter formula for a gaussian bunch (far-field assumed).

$$\sigma_\tau = \sqrt{\left|\frac{1}{\omega_1^2-\omega_2^2}\left[\log\left(\frac{S_1\omega_2}{S_2\omega_1}\right)+\frac{(\omega_1-\omega_2)a}{\gamma c}\right]\right|}$$

Using three diodes (60 GHz, 84 GHz and 113.5 GHz)



$$\frac{S_1}{S_2} = \frac{|j(\omega_1,\sigma_\tau,\alpha)|^2}{|j(\omega_2,\sigma_\tau,\alpha)|^2}\frac{\omega_1}{\omega_2}e^{-\frac{(\omega_1-\omega_2)a}{\gamma c}}$$

$$\frac{S_1}{S_3} = \frac{|j(\omega_1,\sigma_\tau,\alpha)|^2}{|j(\omega_3,\sigma_\tau,\alpha)|^2}\frac{\omega_1}{\omega_3}e^{-\frac{(\omega_1-\omega_3)a}{\gamma c}}$$

Measurement made by exploiting a two-parameter system for a skew-gaussian bunch

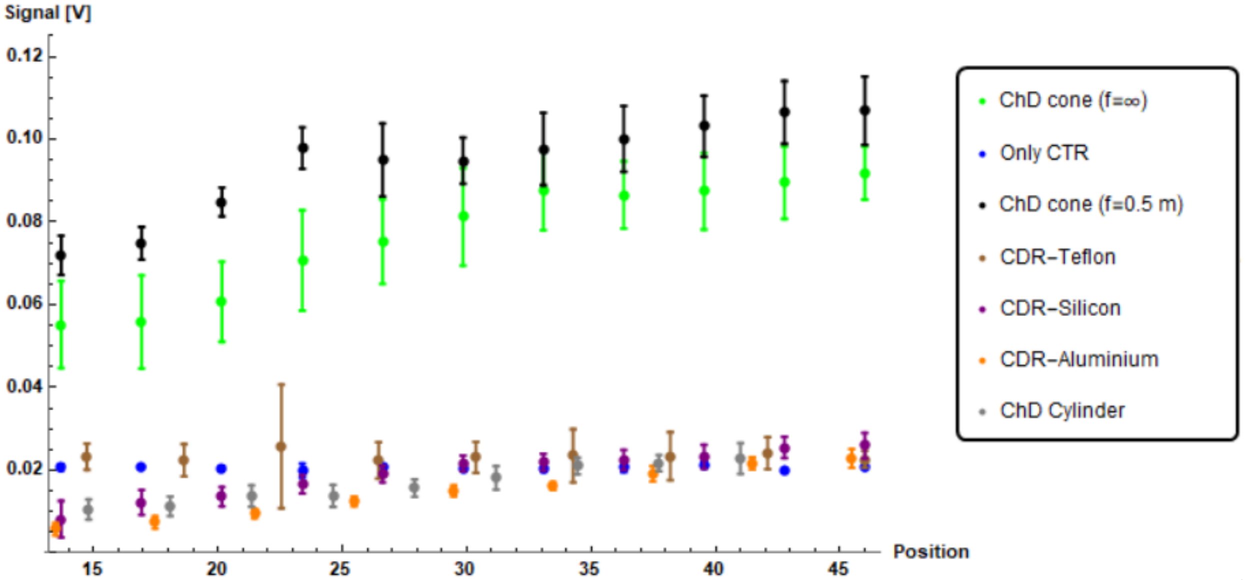
$$j(\omega,\sigma_\tau,\alpha) = Q_0 e^{-\frac{\sigma_\tau^2\omega^2}{2}}\left[1+erf\left(i\frac{\alpha\sigma_\tau^2\omega}{\sqrt{1+2\alpha^2\sigma_\tau^2}}\right)\right]$$

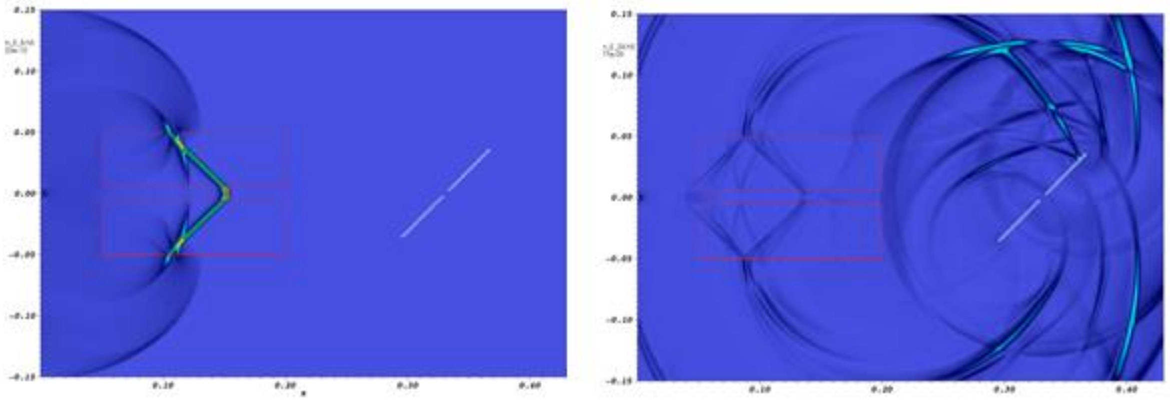
Important note: distance between the prism and the diodes around 10 cm

Electromagnetic Shadowing

Measurements performed at 0.17 THz with a band-pass-filtered Schottky diode
Studying the interaction between an arbitrary source of forward THz radiation with a CTR source

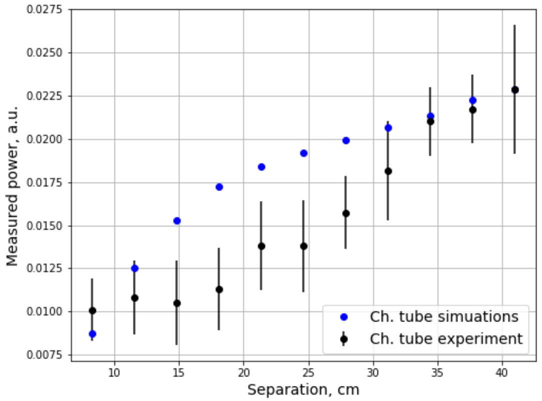
An overview of all radiators tested
Scanning the distance between the sources and the CTR mirror





The bunch propagates in this case through the hollow dielectric cylinder, then it generates transition radiation on the metallic mirror

(courtesy of **K. Lekomtsev**)

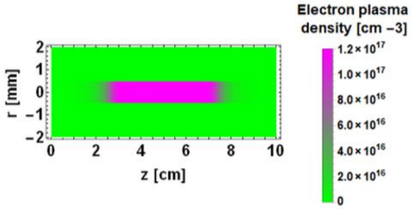


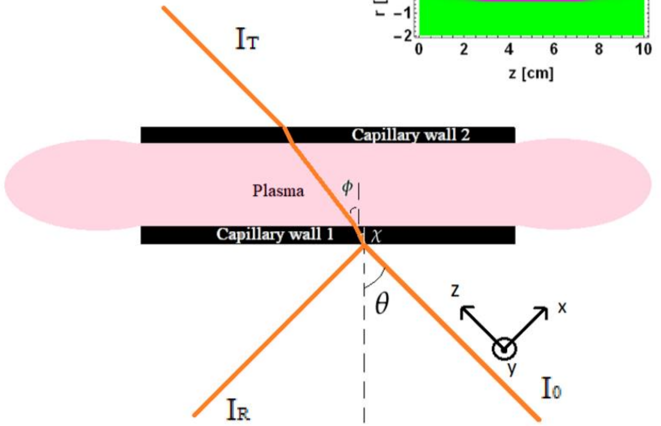
Important note: Shadowing observed also with the ChD cylinder (radiation output not expected)

A new interpretation of the shadowing: the bunch field is restricted by the boundary conditions and it needs time/space to recover and induce radiation at the plane of the second source?

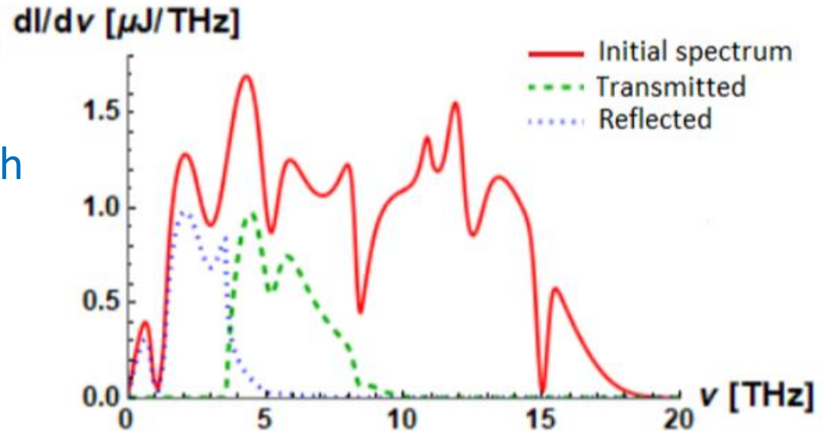
Exotic applications of THz radiation: diagnostics of plasma density and temperature

Measuring transmitted and reflected THz light





In this case laser-based THz source, for CLEAR 100-200 fs bunch length needed

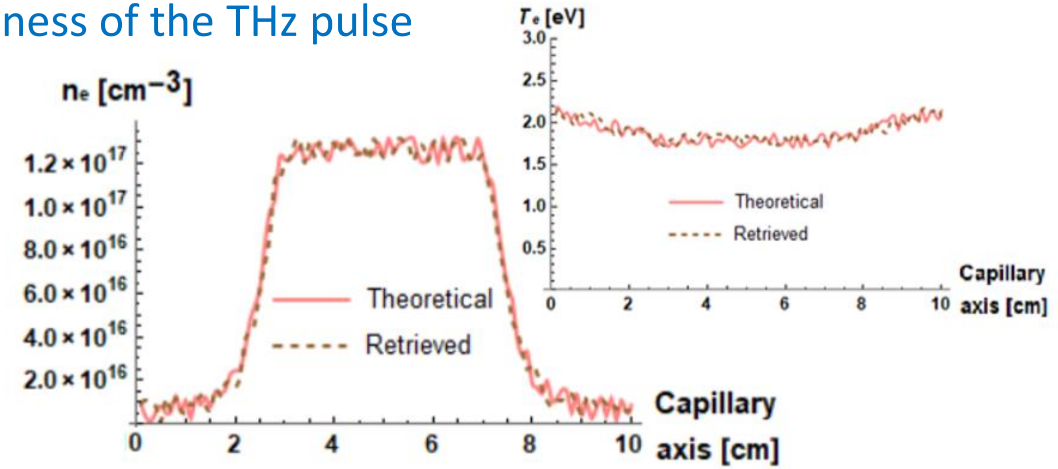


Method generalizable to a symmetry axis for spatial resolution; temporal resolution also ensured by the shortness of the THz pulse

Solving a system of two equations yielding both the electron plasma density and temperature as solutions

$$\frac{I_R}{I_0} = \int d\omega S(\omega) R(n_e, T_e, \omega)$$

$$\frac{I_T}{I_0} = \int d\omega S(\omega) T(n_e, T_e, \omega)$$



See Ref. Curcio, A. & Petrarca, M. “Diagnosing plasmas with wideband THz pulses" *Optics Letters* (2019).

Conclusions and perspectives

- We have set up and fully characterized a new THz source @CLEAR based on different mechanisms (CTR, CDR, CChDR)
- We have succesfully tested a Cherenkov-Diffraction teflon prism both for transverse and longitudinal diagnostics;
- We have explored different targets for high-intensity THz generation but also for Electromagnetic Shadowing experiments, finding a new interpretation of this phenomenon;
- We are going to possibly test new radiators and enhance the beam performances for high-intensity THz generation, in order to go towards the application of THz for acceleration at CLEAR;
- New applications other than beam diagnostics and acceleration like plasma diagnostics…