THz@CLEAR: 2018 summary

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on behalf of and in collaboration with

CLEAR team,
BI department (CERN),
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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

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

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)

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

Table 1. Parameters of the CLEAR (sub-)THz source for the following electron beam parameters (per single bunch): 215 MeV, 1.5 ps, 40 pC.

<table>
<thead>
<tr>
<th>Radiation mechanism: CTR</th>
<th>Peak Power [kW]</th>
<th>∼ 40 ± 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average Power [mW]</td>
<td>∼ 0.13 ± 0.0</td>
</tr>
<tr>
<td></td>
<td>Energy per pulse [nJ]</td>
<td>∼ 60 ± 5</td>
</tr>
<tr>
<td></td>
<td>Energy per train of 200 pulses [μJ]</td>
<td>∼ 12 ± 1</td>
</tr>
<tr>
<td></td>
<td>Peak frequency [GHz]</td>
<td>∼ 40</td>
</tr>
<tr>
<td></td>
<td>Bandwidth [GHz]</td>
<td>∼ 40</td>
</tr>
<tr>
<td></td>
<td>Energy per pulse at 0.1 THz [nJ]</td>
<td>∼ 6 ± 0.5</td>
</tr>
<tr>
<td></td>
<td>Energy per train of 200 pulses at 0.1 THz [μJ]</td>
<td>∼ 1.2 ± 0.1</td>
</tr>
</tbody>
</table>

Radiation mechanism: CDR

<table>
<thead>
<tr>
<th>Peak Power [kW]</th>
<th>∼ 35 ± 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Power [mW]</td>
<td>∼ 0.11 ± 0.0</td>
</tr>
<tr>
<td>Energy per pulse [nJ]</td>
<td>∼ 53 ± 5</td>
</tr>
<tr>
<td>Energy per train of 200 pulses [μJ]</td>
<td>∼ 10.6 ± 1.1</td>
</tr>
<tr>
<td>Peak frequency [GHz]</td>
<td>∼ 40</td>
</tr>
<tr>
<td>Bandwidth [GHz]</td>
<td>∼ 40</td>
</tr>
<tr>
<td>Energy per pulse at 0.1 THz [nJ]</td>
<td>∼ 5.3 ± 0.5</td>
</tr>
<tr>
<td>Energy per train of 200 pulses at 0.1 THz [μJ]</td>
<td>∼ 1.1 ± 0.1</td>
</tr>
</tbody>
</table>

Radiation mechanism: CChDR

<table>
<thead>
<tr>
<th>Peak Power [MW]</th>
<th>∼ 0.12 ± 0.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Power [mW]</td>
<td>∼ 0.38 ± 0.0</td>
</tr>
<tr>
<td>Energy per pulse [nJ]</td>
<td>∼ 190 ± 20</td>
</tr>
<tr>
<td>Energy per train of 200 pulses [μJ]</td>
<td>∼ 38 ± 4</td>
</tr>
<tr>
<td>Peak frequency [GHz]</td>
<td>∼ 60</td>
</tr>
<tr>
<td>Bandwidth [GHz]</td>
<td>∼ 60</td>
</tr>
<tr>
<td>Energy per pulse at 0.1 THz [nJ]</td>
<td>∼ 19 ± 2</td>
</tr>
<tr>
<td>Energy per train of 200 pulses at 0.1 THz [μJ]</td>
<td>∼ 3.8 ± 0.4</td>
</tr>
</tbody>
</table>
Longitudinal diagnostics, high-intensity field production and studies on electromagnetic shadowing.
A Coherent Cherenkov-Diffraction-based Beam Position Monitor

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).

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

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

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

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

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

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

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

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

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

Conclusions and perspectives

We have set up and fully characterized a new THz source @CLEAR based on different mechanisms (CTR, CDR, CChDR)

We have successfully 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...