THz@CLEAR:

Source and diagnostics for electron acceleration

Alessandro Curcio (Fellow) BE-ABP-LAT, supervisor: Roberto Corsini

CERN

In collaboration with:

Prof. Massimo Petrarca (Università La Sapienza)
Dr. Thibaut Lefebvre BE-BI-QP (CERN)
The CLEAR team

Outline

- First tests of (sub)THZ generation @ CLEAR with Coherent Transition Radiation (CTR)
- Preliminary results for longitudinal diagnostics and plans
- Possible longer-term applications of THz radiation
- Conclusions

First tests of (sub)THz generation @ CLEAR: CTR

Beam parameters (single bunch):

- Energy=170 MeV
- r.m.s. duration: 3-6 ps
- r.m.s. size: 100 micron
- Charge: 60 pC

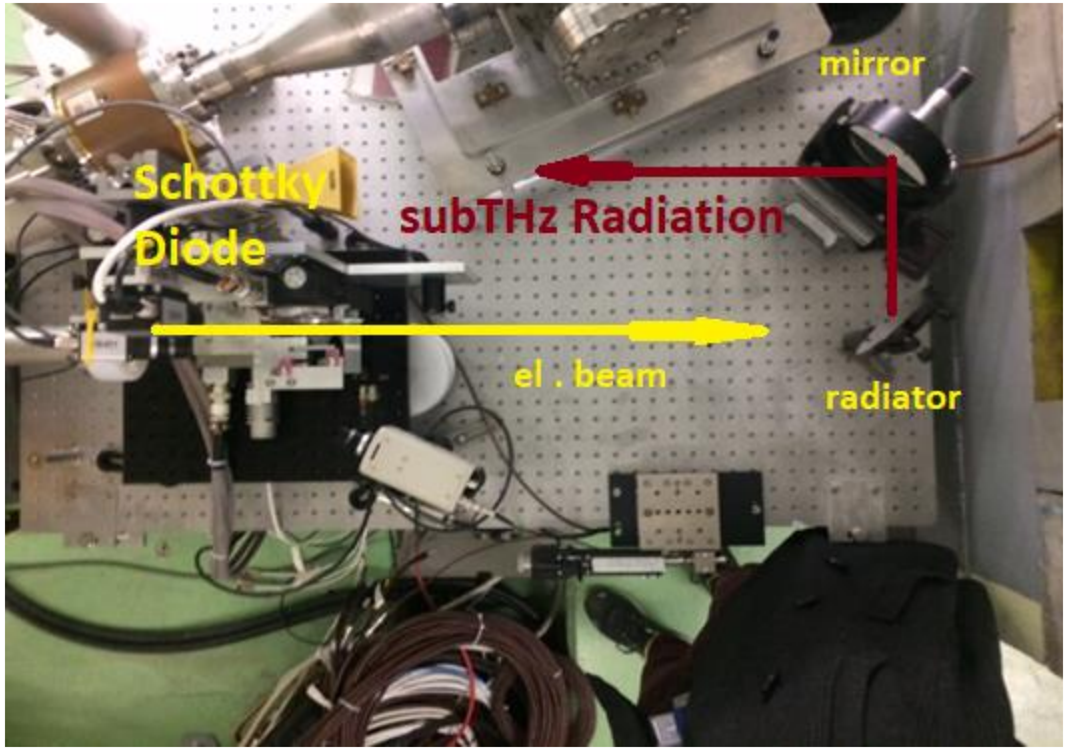
Radiator parameters:

- Al-coated wafer
- 10 cm diameter

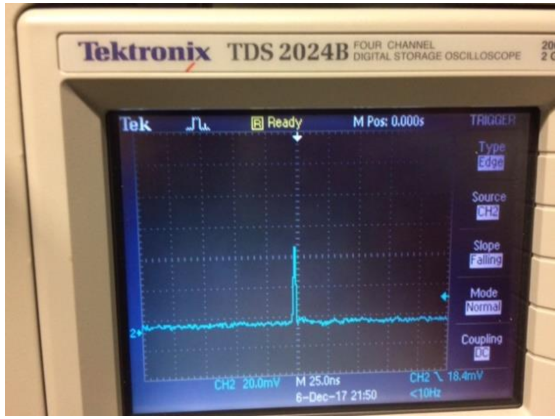
Detectors:

- Schottky diodes
- 26.5-40 GHz (first test)
- Covering bands up to 100 GHz (forthcoming tests)

Picture of the Setup



Raw signal on the oscilloscope



M Pos: 0.000s

Type Edge

Source CH2

Slope Falling

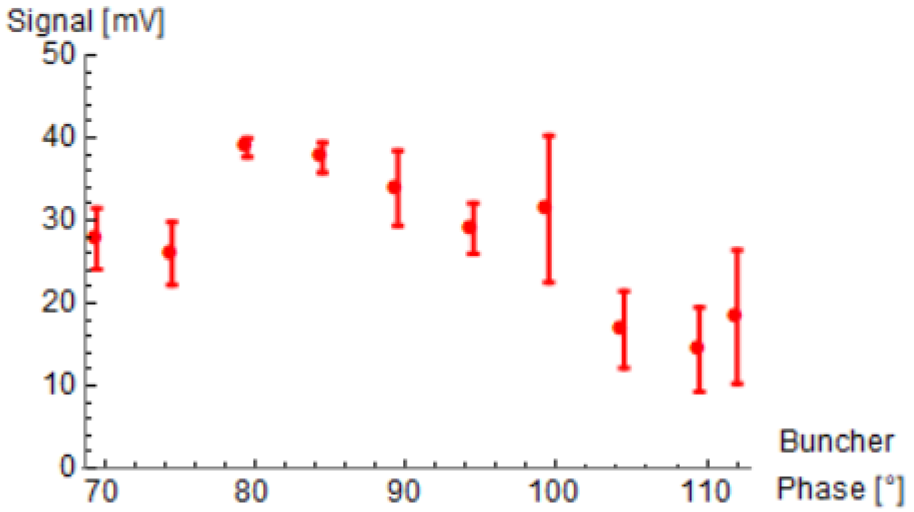
Mode Normal

Coupling DC

CH2 20.0mV M 25.0ns CH2 18.4mV

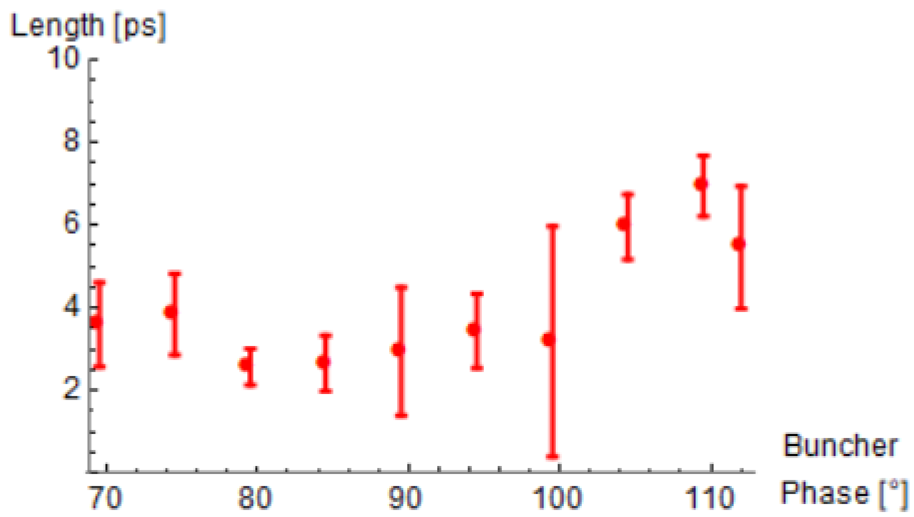
6-Dec-17 21:50 <10Hz

Preliminary results for longitudinal diagnostics



Peak signal versus buncher phase

95 degrees is the phase which maximize the bunch energy!



By assuming a gaussian bunch and rescaling according to simulations (''Validation of ASTRA for use on the CLEAR photo-injector'', Aime Rosse, October 2017), we scanned a length between 3 -5 ps !

Problem to solve: spurious signal of the same order of that coming from the radiator but still correlated to the bunch length !
Solution: Installation of parabolic mirrors for the radiation transport from the radiator to the detector.

Next plans for longitudinal diagnostics

One way is to completely characterize the CTR spectrum, retrieving then from there the bunch form factor and therefore the bunch length

(no single shot!)

A second way is to detect the CTR signal S at least with two detectors
(angle of collection and photon energy must be different for different detectors),
then taking the ratio between signals, comparing with the theory and
finding the bunch length which minimizes the difference between theory and experiment:

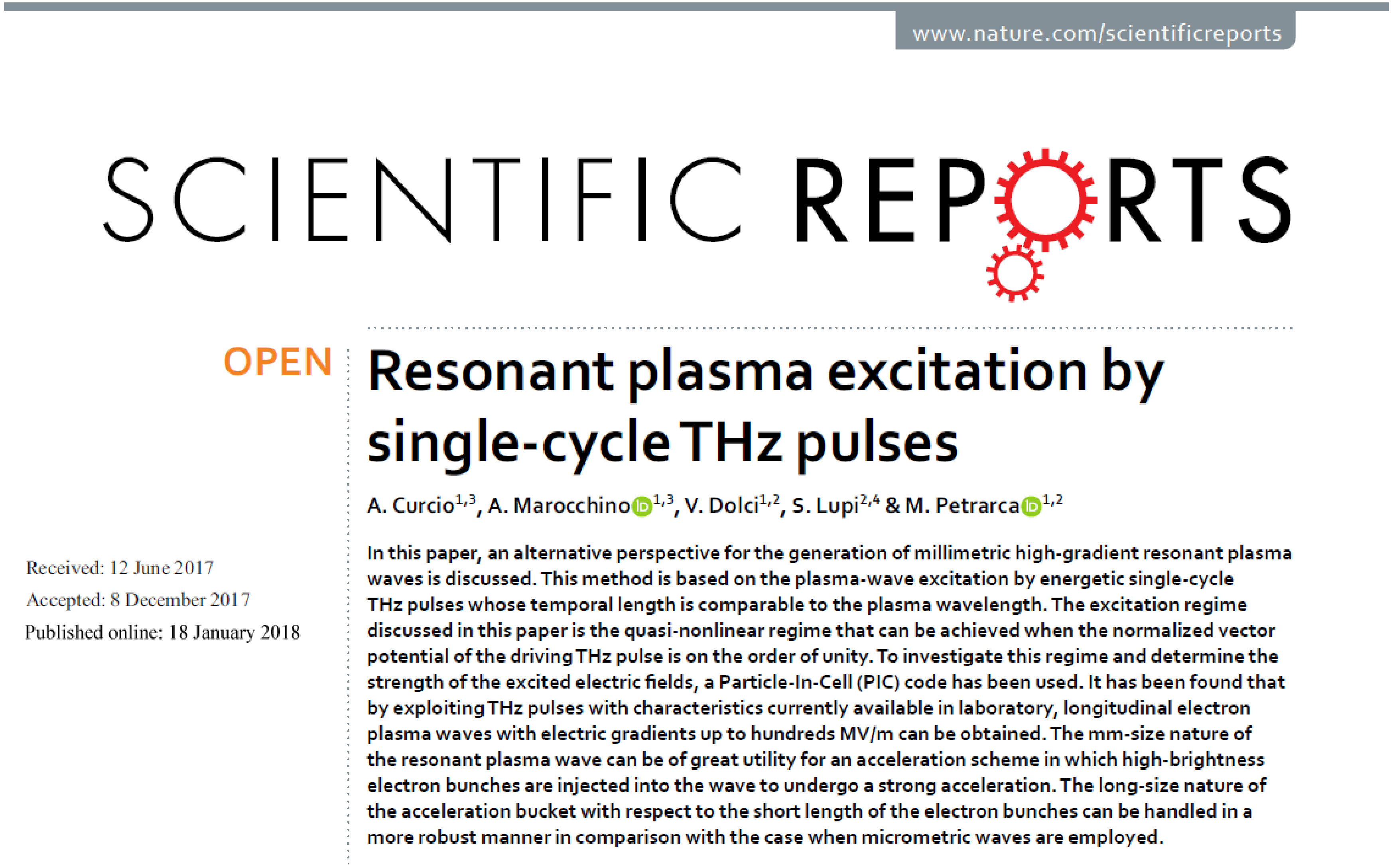
(single shot!)

$$F(\omega_1^2 - \omega_2^2, \sigma_\tau)\frac{\frac{dI_{sp}}{d\Omega d\omega}(\omega_1, \Omega_1)}{\frac{dI_{sp}}{d\Omega d\omega}(\omega_2, \Omega_2)} = \frac{S_1(\omega_1, \Omega_1)}{S_2(\omega_2, \Omega_2)}$$

Ratio between two signals

Theoretical expectation for the signal ratio due to a gaussian bunch

$$\sigma_\tau = \sqrt{\left|\frac{1}{\omega_1^2 - \omega_2^2} \log\left\{\frac{\frac{dI_{sp}}{d\Omega d\omega}(\omega_2, \Omega_2)}{\frac{dI_{sp}}{d\Omega d\omega}(\omega_1, \Omega_1)}\frac{S_1(\omega_1, \Omega_1)}{S_2(\omega_2, \Omega_2)}\right\}\right|}$$



www.nature.com/scientificreports

SCIENTIFIC REPORTS

OPEN

Resonant plasma excitation by single-cycle THz pulses

A. Curcio[1,3], A. Marocchino[1,3], V. Dolci[1,2], S. Lupi[2,4] & M. Petrarca[1,2]

Received: 12 June 2017
Accepted: 8 December 2017

In this paper, an alternative perspective for the generation of millimetric high-gradient resonant plasma waves is discussed. This method is based on the plasma-wave excitation by energetic single-cycle THz pulses whose temporal length is comparable to the plasma wavelength. The excitation regime discussed in this paper is the quasi-nonlinear regime that can be achieved when the normalized vector potential of the driving THz pulse is on the order of unity. To investigate this regime and determine the strength of the excited electric fields, a Particle-In-Cell (PIC) code has been used. It has been found that by exploiting THz pulses with characteristics currently available in laboratory, longitudinal electron plasma waves with electric gradients up to hundreds MV/m can be obtained. The mm-size nature of the resonant plasma wave can be of great utility for an acceleration scheme in which high-brightness electron bunches are injected into the wave to undergo a strong acceleration. The long-size nature of the acceleration bucket with respect to the short length of the electron bunches can be handled in a more robust manner in comparison with the case when micrometric waves are employed.

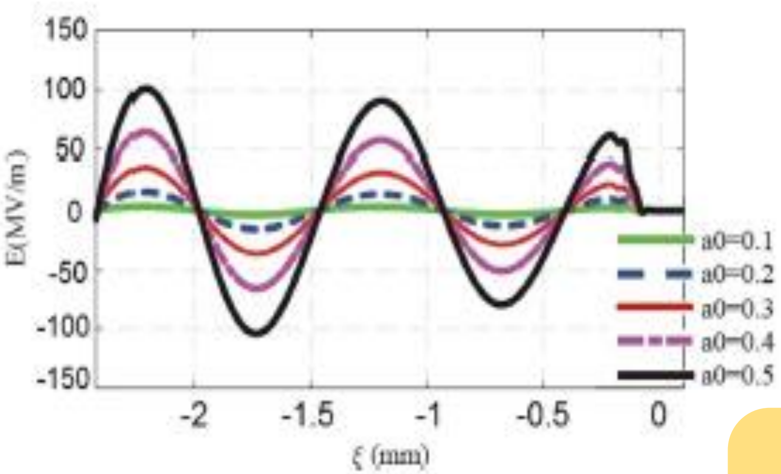
https://www.nature.com/articles/s41598-017-18312-y

High-intensity application:
THz-driven electron plasma waves

Background: Laser WakeField Acceleration (LWFA), compact accelerators, hundreds GV/m over several cm already demonstrated in non linear self-injection schemes…

Drawbacks: low efficiency, high-power (10-100 TW, at least!) InfraRed (IR) laser systems needed, serious issues with electron synchronization in external injection experiments…

Why THz? Higher efficiency for high-gradient generation of plasma waves with millimetric period!



$$a_0 \sim 8.5 \times 10^{-10} \sqrt{I_0[\mathrm{W/cm^2}]\lambda_0[\mu\mathrm{m}]^2}$$

State of the art: a0=0.2, produced by the optical rectification of IR light, using sub TW laser systems, corresponding to tens MV/m gradients.

There are already proposed solutions to overcome these values!

a0>>0.2 would be possible with 100 fs (or even less) nC-class bunches, exploiting CTR light, with current parameters @CLEAR 1-10 MV/m would be possible

$$R = 1 \simeq 156\frac{E_{THz}}{E_{IR}}$$

156 times less energy needed for producing the same gradients usually generated by IR lasers

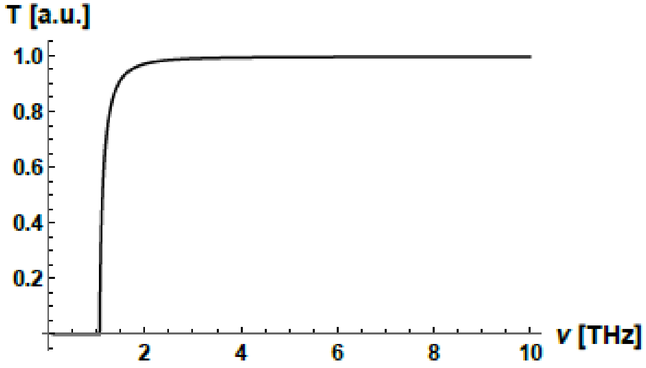
Low intensity application:
THz as plasma diagnostics?

Typical plasma densities and temperature for Particle WakeField Acceleration (PWFA) and guiding (plasma lens) experiments in discharge-capillaries are 10^15-10^17 cm^-3 and 1-10 eV.

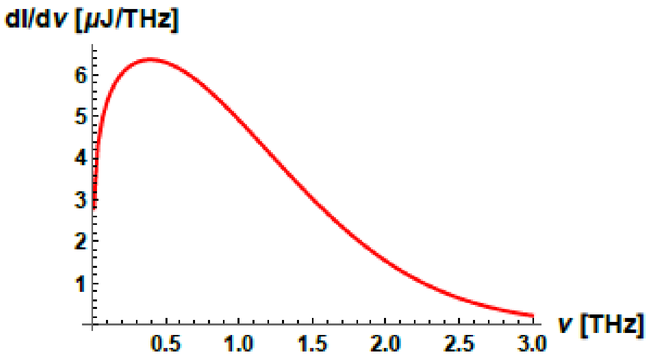
The corresponding plasma frequencies are in the range 1-10 THz!

This means that for a direct-probing of the these plasmas we can use the high refractivity of the THz radiation!

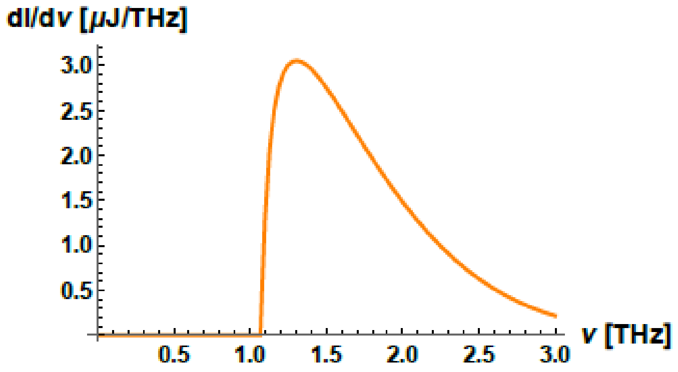
In some specific configurations (currently under study, not shown here) THz could serve as single shot diagnostics both for density and temperature…below the simplest example:



Transmission function for a plasma With density around 10^16 cm^-3, oblique THz incidence, considering electron-ion collisions at 4 eV



CTR spectrum emitted by a 200 MeV, 100 fs r.m.s., 100 pC electron bunch impinging on 3cm-radius metallic screen



Transmitted spectrum to be measured.
Also time domain measurements are allowed…

Conclusions and perspectives

- Preliminary tests have been already done of sub-THz generation by CTR.
- The possibility to use CTR for longitudinal diagnostics has been explored, but still further tests are needed with more complex setups to make it working with more reliability and control.
- Applications of THz radiation @ CLEAR for electron acceleration, electron-plasma acceleration and plasma diagnostics are currently under developement .
- Before starting any THz-based experiment @ CLEAR, a complete characterization of the CLEAR-based THz source is needed, which is the plan of next months.