Study and application of acceleration based on Laser Plasma and THz radiation

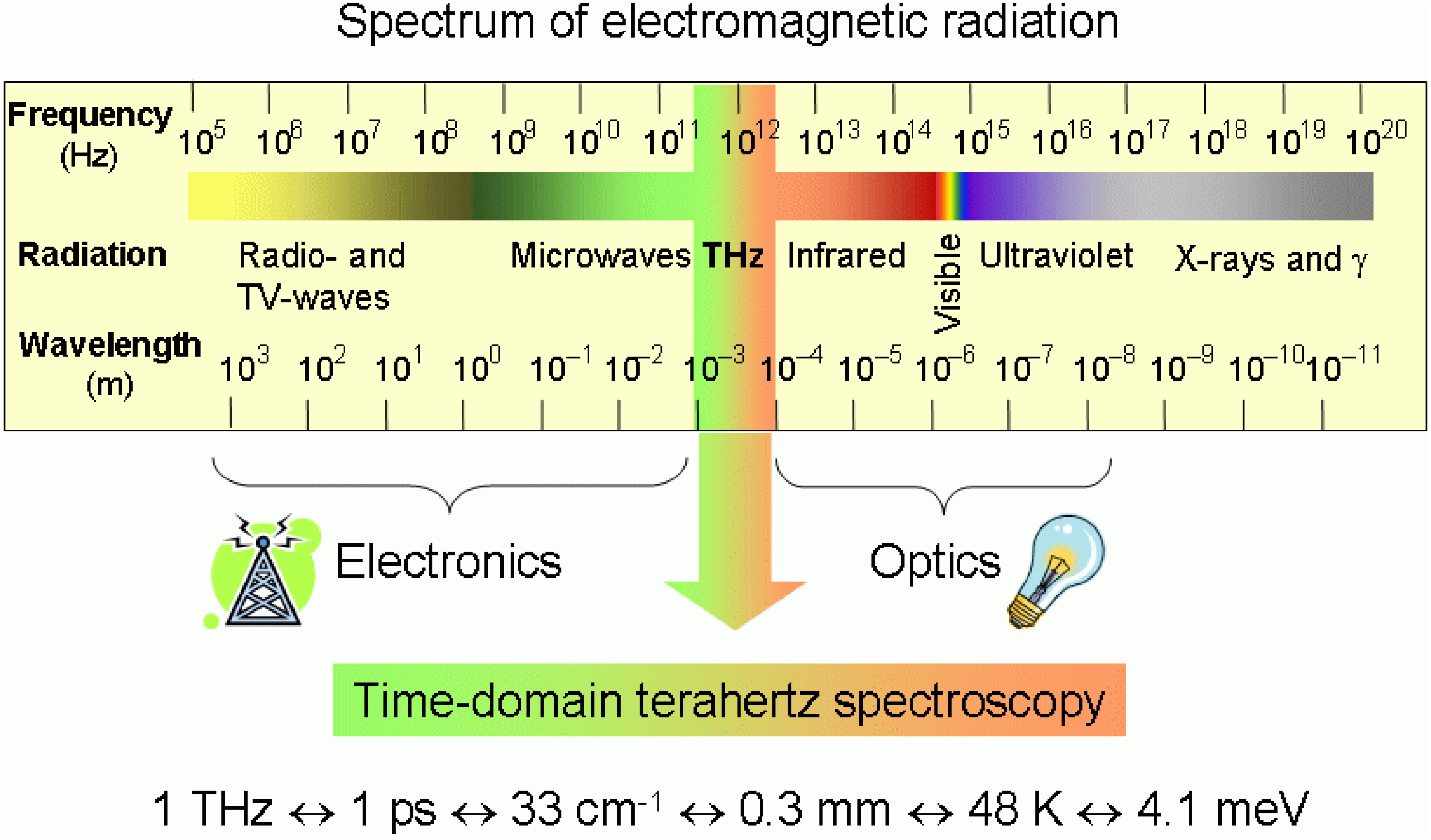
Valerio Dolci
Supervisor: Prof. Massimo Petrarca

Overview

- Introduction to THz radiation
- Direct acceleration schemes
- My work on direct THz acceleration
- Indirect acceleration schemes
- My work on indirect THz acceleration
- Study on THz generation
- Study on THz diagnostic
- Future work for the last year and beyond

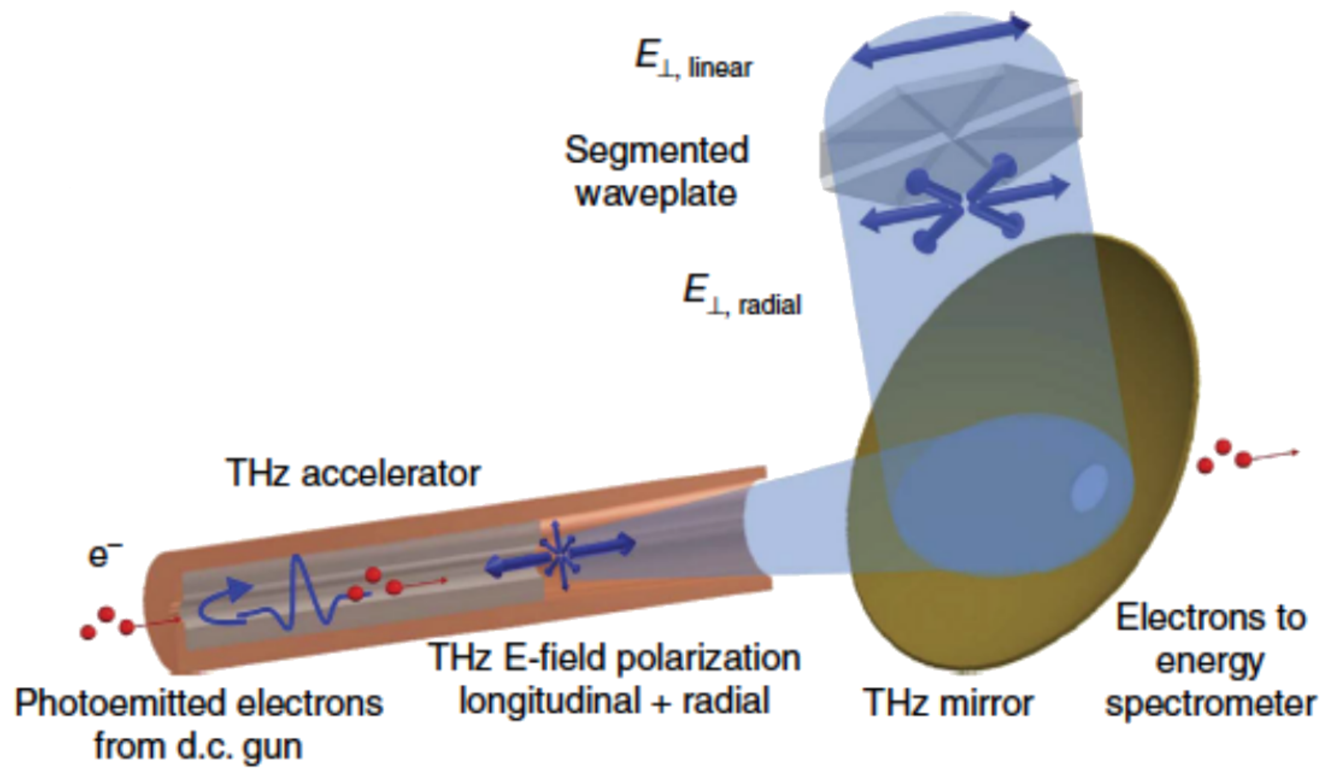
Introduction THz

Terahertz radiation (1 THz corresponds to ~ 4 meV photon energy, or ~ 300 μm radiation wavelength) has a strong impact in many areas of research. In literature, proof of principle electron acceleration experiments induced by THz pulses have been reported, therein showing that a strong THz field can be used to boost the electron energy in a short space interval.



Direct acceleration

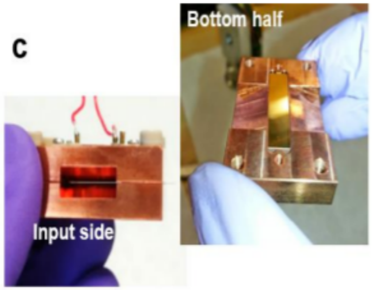
For "direct" schemes is intended the direct use of the THz electric field as source for the longitudinal field needed for the acceleration of charged particles. Terahertz-driven accelerating structures enable high-gradient electrons accelerators with simple accelerating structures, high repetition rates and significant charge per bunch.

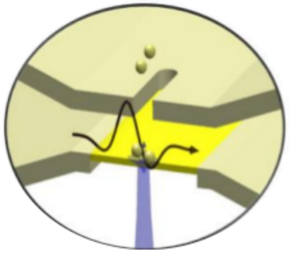


E. Nanni et al., Nature Comms. **6:8486** (2015)

Example of Thz acceleration

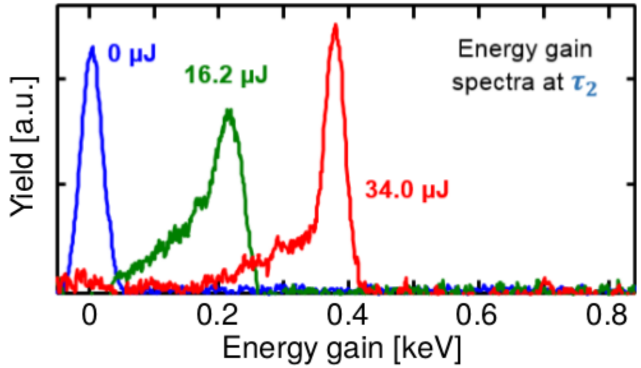
THz Gun: 0 → 0.8 keV acceleration





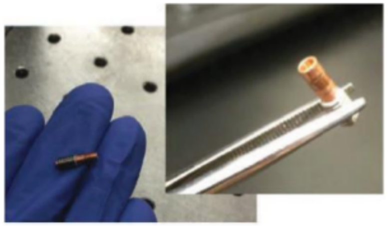
Parallel-Plate structure with 75 μm gap

$E_z \approx 0.3$ GV/m

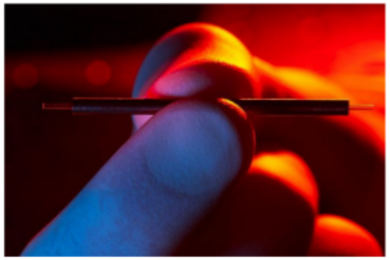


W. Huang, et al., Optica 3, 1209 (2016)
A. Fallahi, et al., PRSTAB 19, 081302 (2016)

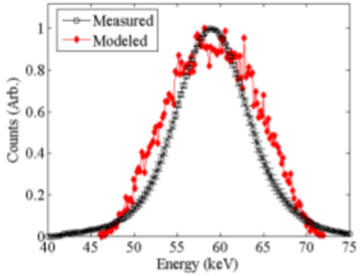
THz LINAC: ±7 keV energy modulation



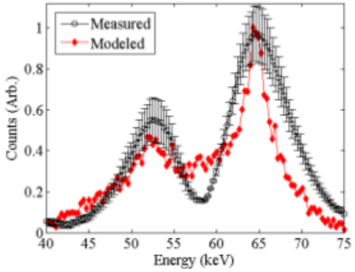
mm-scale THz waveguide



Charge injected from 60 keV DC-gun from Dwayne Miller group



THz Off



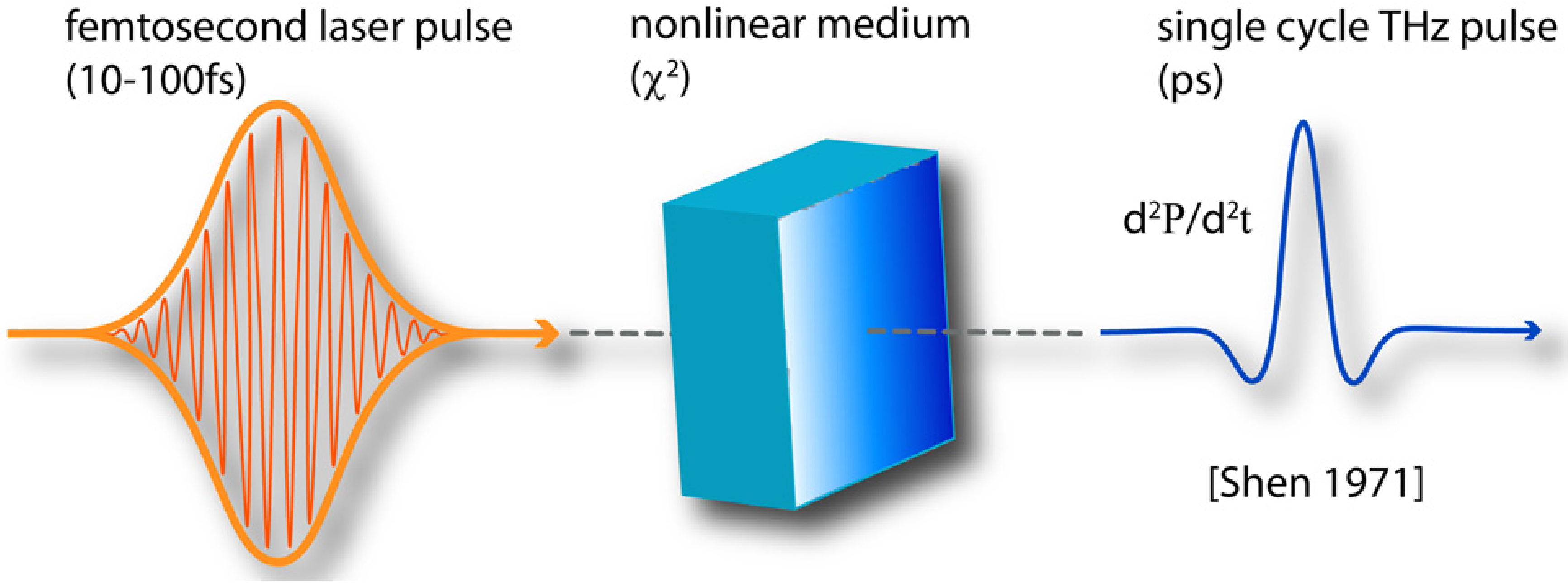
THz On

E. Nanni et al., Nature Comm. ***6****, 8486 (2015)*

My work in direct THz acceleration

The propagation of the THz pulse inside those structures changes the THz phase and shape resulting in a sub-optimal field in the accelerating region. Therefore, the possibility to change the shape and phase of the THz pulse before the structure can allow an enhancement in the acceleration process.
I have shown that in OR schemes it is possible to control the phase and shape of the emitted THz pulse "simply" changing the non-linear phase of the pump laser pulse.

OPTICAL RECTIFICATION SCHEME



THz shaping in OR process

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Optics Letters

Terahertz-based retrieval of the spectral phase and amplitude of ultrashort laser pulses

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

[1]*INFN National Laboratories of Frascati, Frascati, Italy*
[2]*S.B.A.I. Department of the Rome University "La Sapienza", Rome, Italy*
[3]*INFN Roma1, Rome, Italy*
[4]*Physics Department of the Rome University "La Sapienza", Rome, Italy*
**Corresponding author: massimo.petrarca@uniroma1.it*

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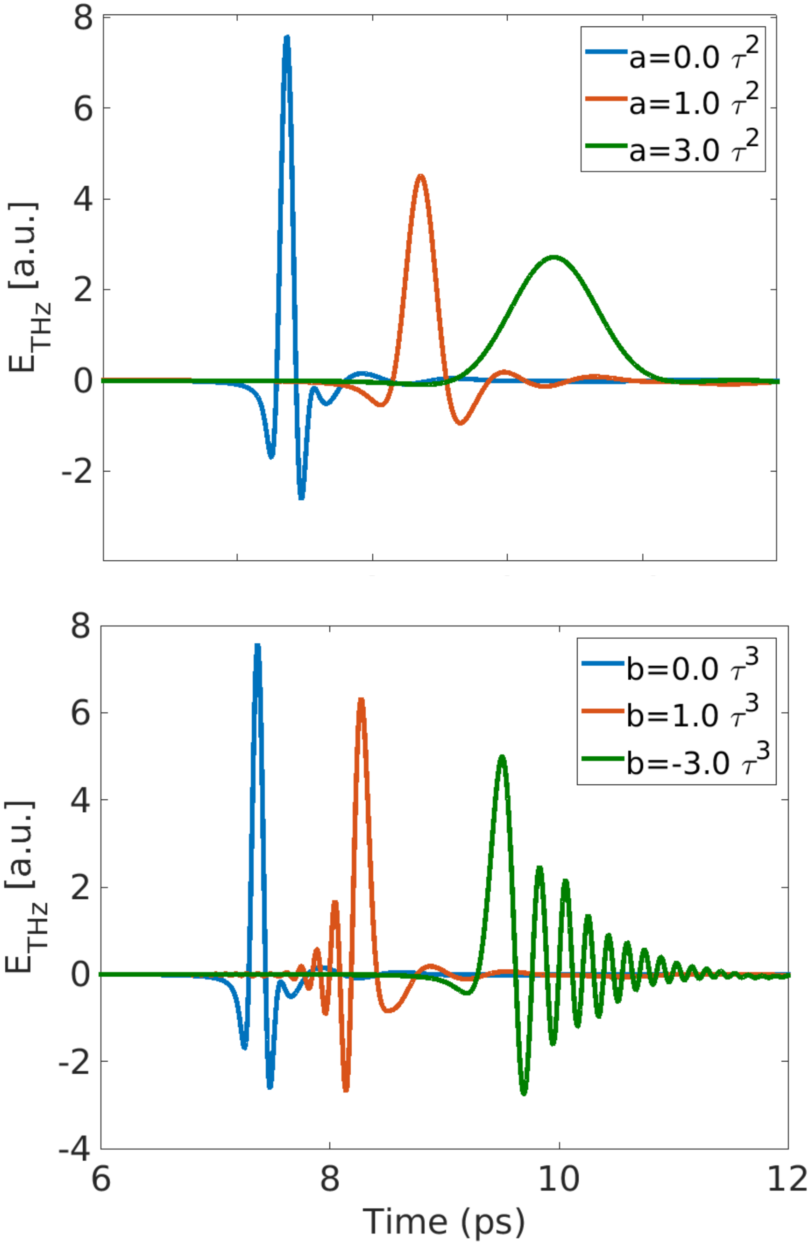
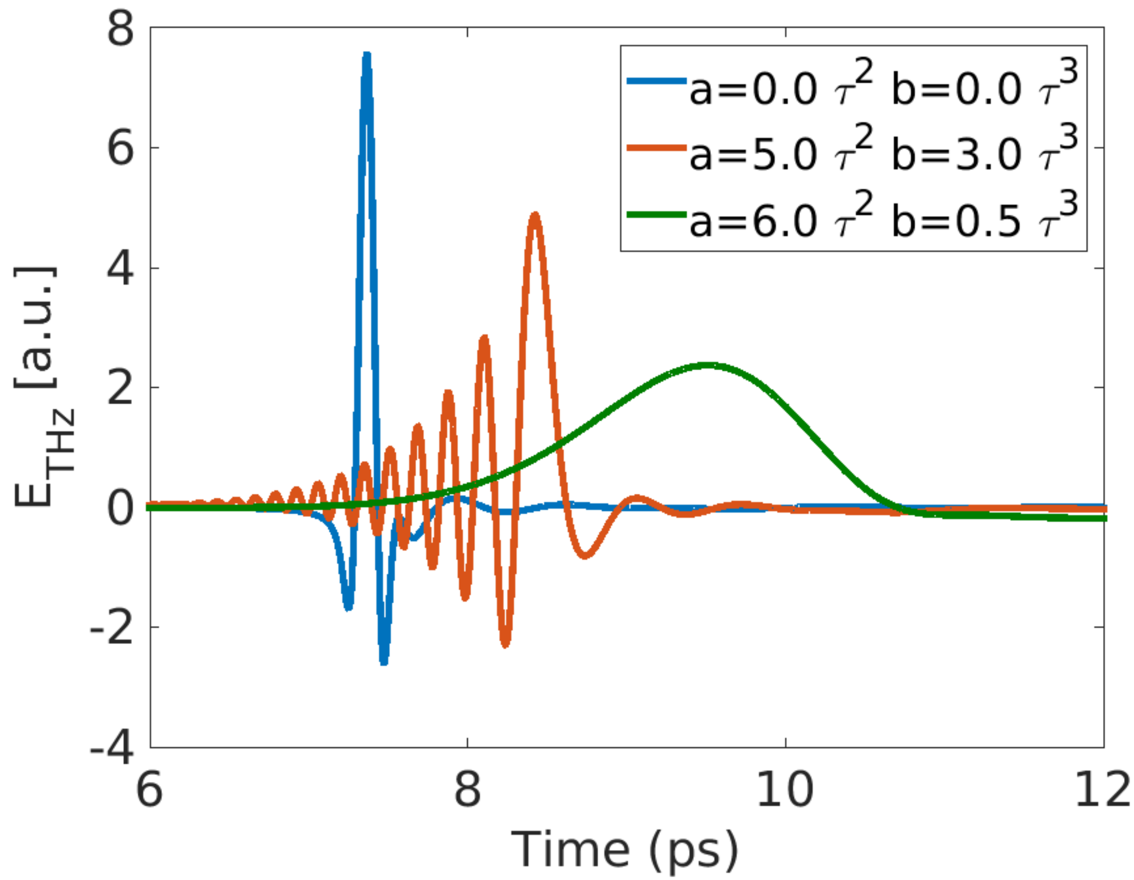
Intensity and phase retrieval of IR laser pulse by THz-based measurement and THz waveform modulation

Valerio Dolci[a,b,*], Valerio Cascioli[b,c], Alessandro Curcio[a,d], Luca Ficcadenti[a], Stefano Lupi[c,b], Massimo Petrarca[a,b]

[a] *S.B.A.I. department of the Roma University "La Sapienza", Rome, Italy*
[b] *INFN Roma1, Rome, Italy*
[c] *Physics Department of the Roma University "La Sapienza", Rome, Italy*
[d] *INFN National Laboratories of Frascati, Frascati, Italy*

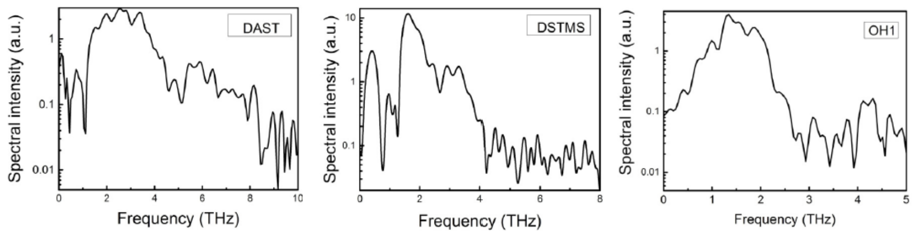
THz shaping results

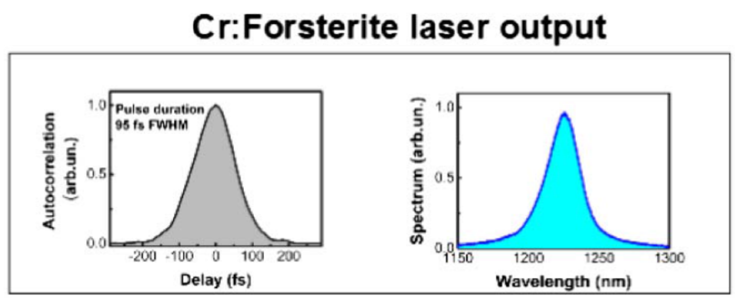


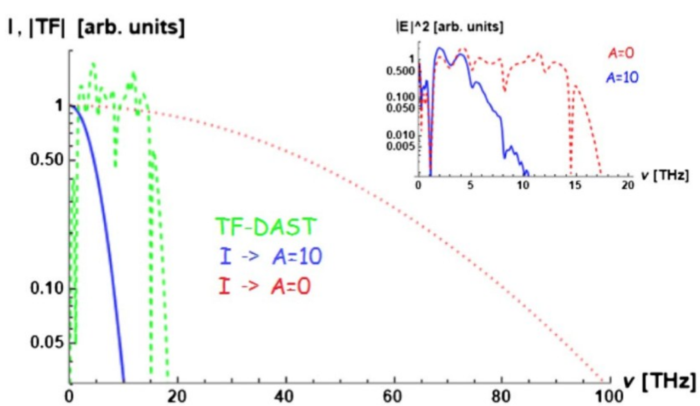


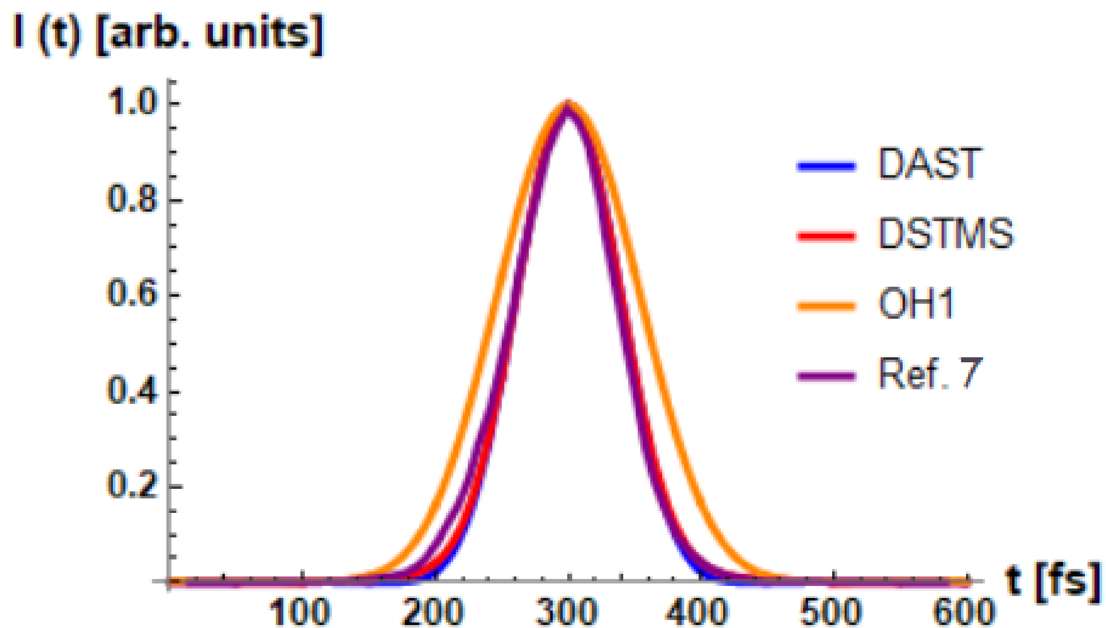
Laser diagnostic using OR

During this studies we also found that, by reversing the shaping technique, it is possible to use the emitted THz pulse from OR process as a diagnostic for the pumping laser. This technique can in principle be used for the complete retrieval of the pump laser characteristics. This technique can be applied to sub-fs laser pulse if pre-chirped before the OR crystal.



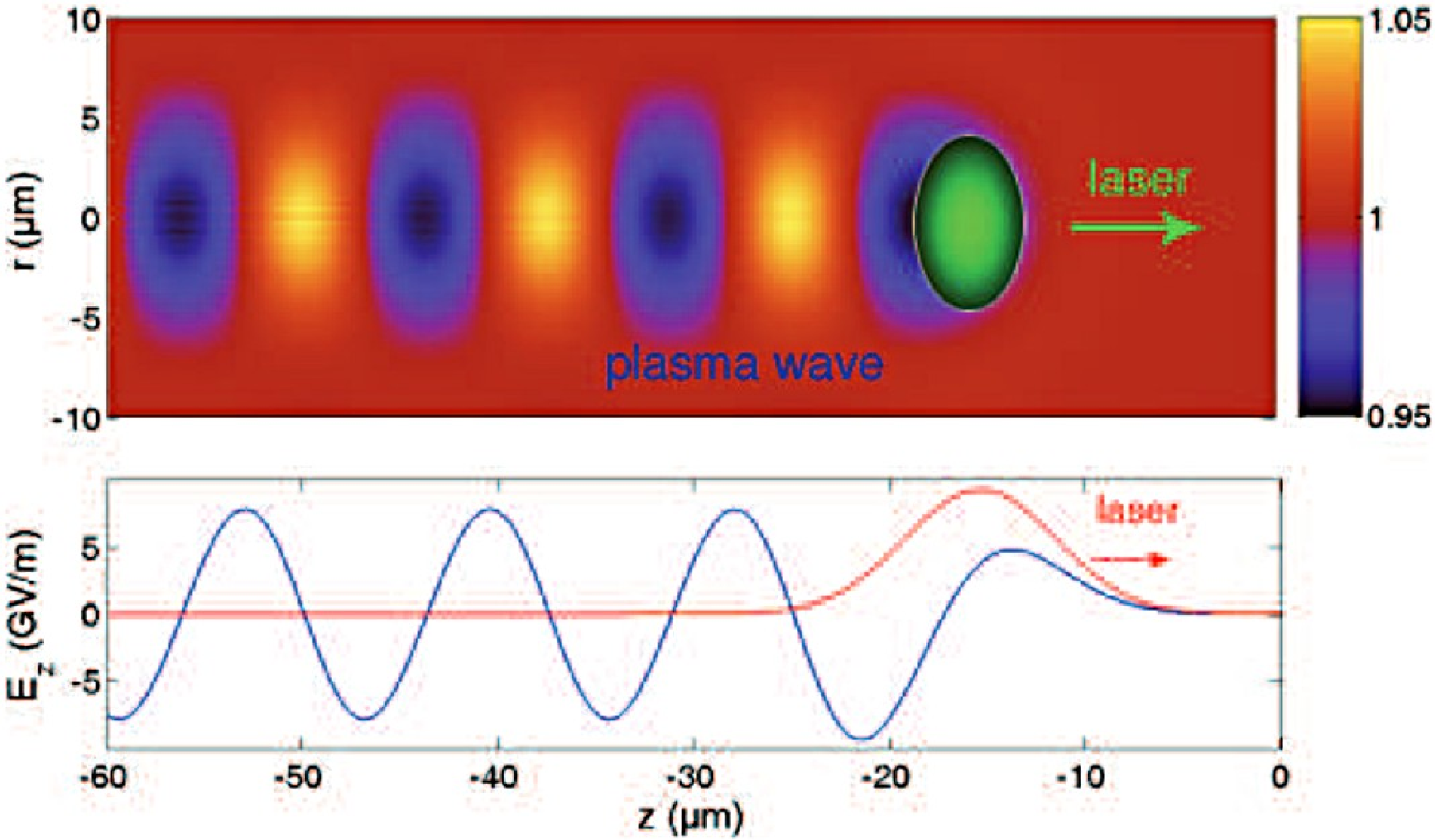






Indirect acceleration

In "indirect" schemes laser pulse are focused in a gas/plasma target generating a wakefield wave in the plasma, that can sustain longitudinal electric fields of the order of 100 GV/m, this electric field can be exploited for particles acceleration. This is known as Laser WakeField Acceleration (LWFA). In LWFA the laser pulse works as the driver for the formation of the plasma wave.



THz wakefield acceleration

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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]

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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

THz-WFA PIC simulatuons

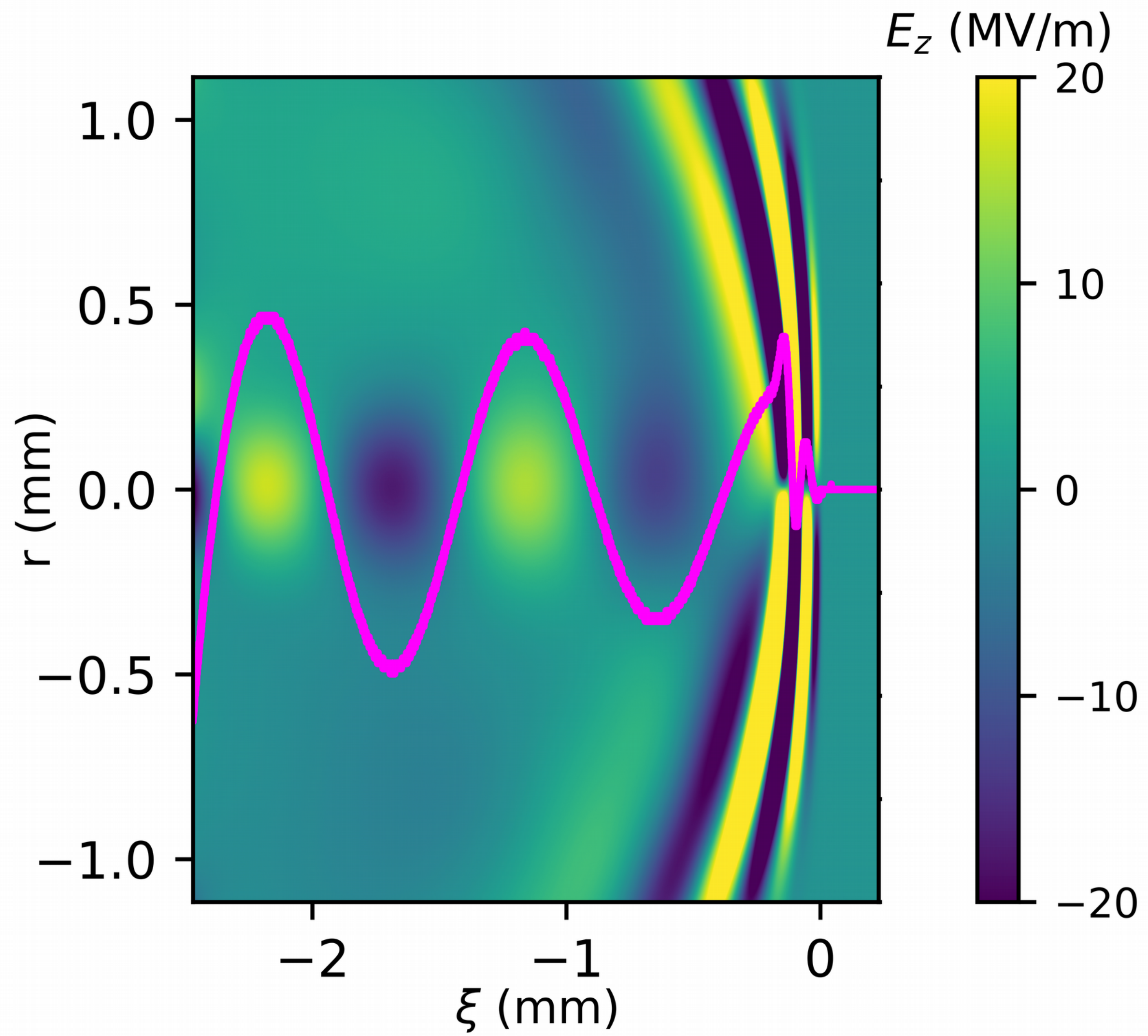
The work was done mainly using Particle In a Cell (PIC) simulations with already achieved parameters for the THz pulse and for the plasma. We did a complete scan over the THz and plasma parameters showing that the scaling law for the maximal longitudinal electric field generated in the wakefield is in good agreement with the well known scaling law for the laser-plasma interaction in the 1D linear case.

Background and mesh setup:

Longitudinal cell resolution:	0.2 µm
Transversal cell resolution:	1.6 µm
Longitudinal point:	51000
Transversal point:	1440
Particle per cell:	25

TeraHertz pulse working point:

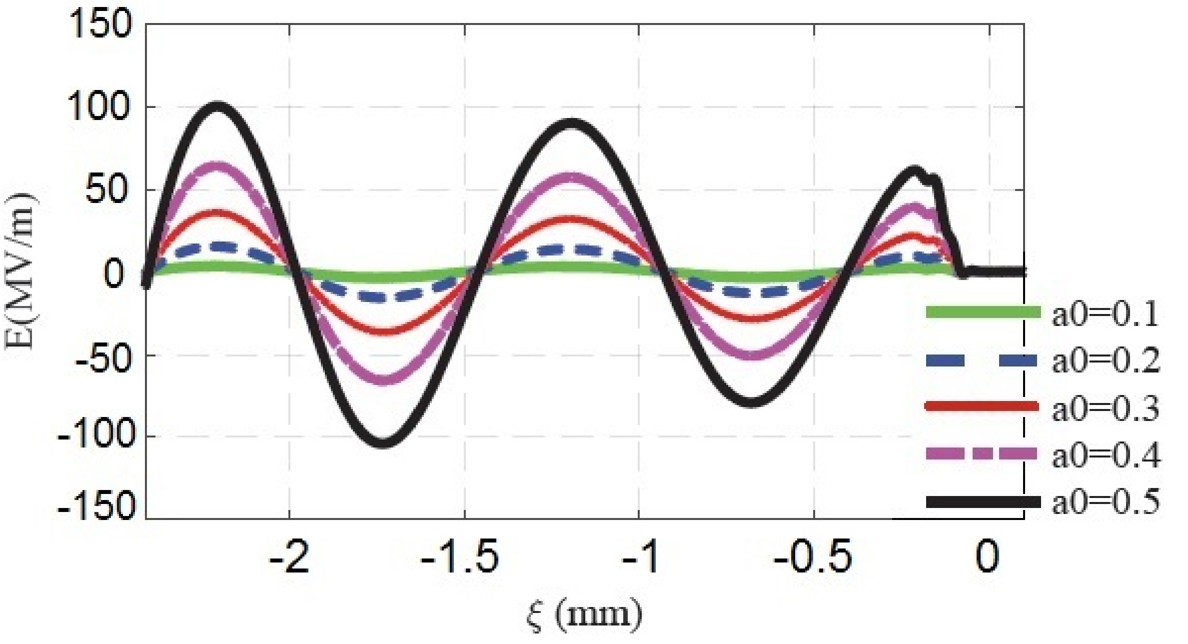
Pulse central frequency:	$\nu_0 \simeq 3\ \mathrm{THz}$
Pulse length:	$L \simeq 105\ \mu\mathrm{m} \simeq \lambda_p/10$
Plasma density:	$n_0 = 1 \times 10^{15} cm^{-3}$
Radial width:	$w_0 = 270\ \mu m$

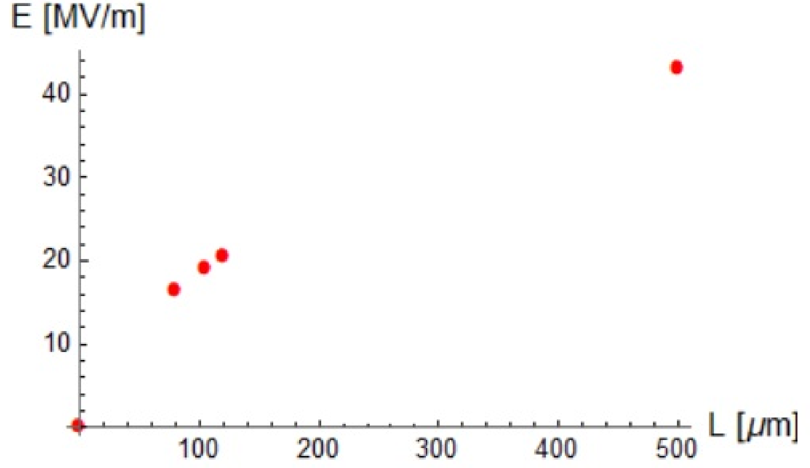


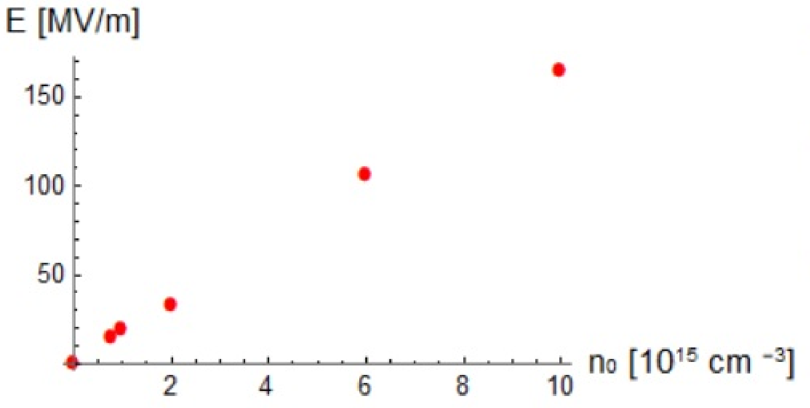
THz-WFA PIC results

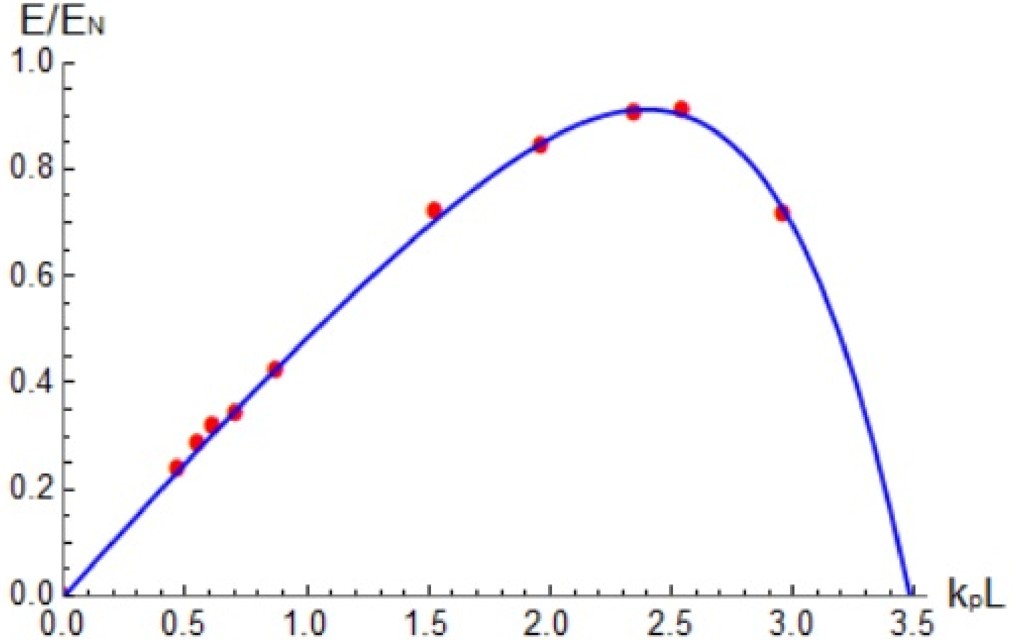
$$E_N(V/m) = E_{wb}\frac{a_0^2}{2\sqrt{1+\frac{a_0^2}{2}}}$$

$$E_{wb} = m_e\omega_p c/e \sim 96\sqrt{n_0(cm^{-3})}[V/m]$$









THz generation studies

One of the most important topic in THz applications is the control and optimization in the generation of the THz pulse, in order to achieve high energy conversion efficiency and to have the best matching conditions for different applications.

My studies on generation are focused on the OR process and in the research of suitable materials for a better energy conversion efficiency. In OR, the knowledge of the optical parameters of the non-linear crystal in use allows a better matching of the laser parameters and crystal dimensions. From those parameters one can so find the best combination of crystal length, laser wavelength and duration that will maximize the THz energy and spectrum.

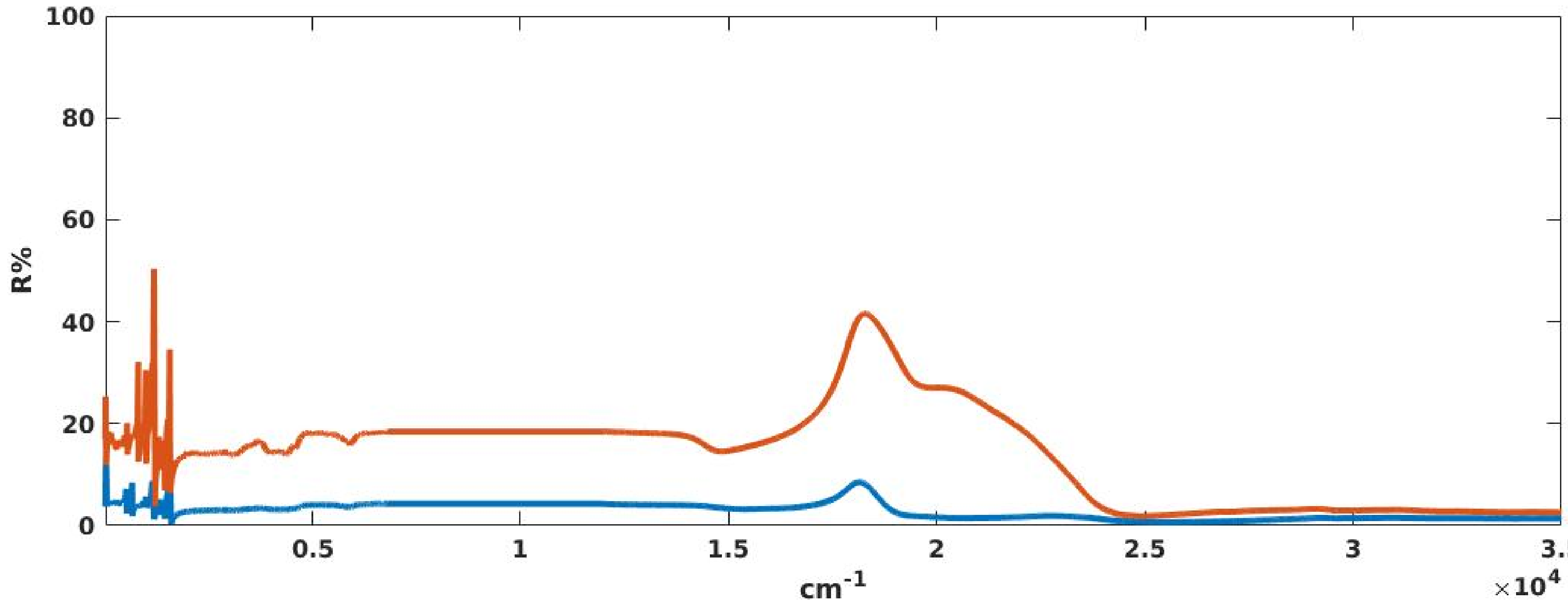
I have done measures on two different organic cristals used in Optical Rectificaton. In order to obtain new knowledge on the optical properties of those crystals, I have done transmission and reflection measures on 3 different machines:

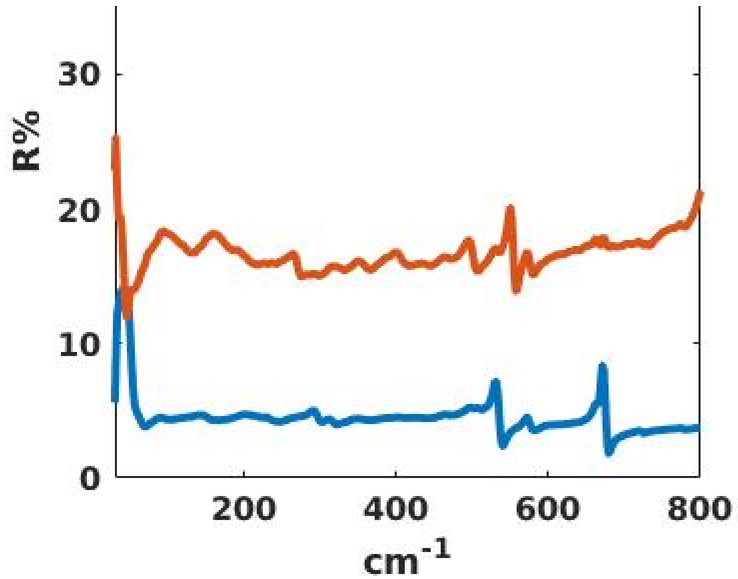
- ~30 cm^{-1} to ~ 700 cm^{-1}, at ELETTRA synchrotron at Trieste, Italy

- ~600 cm^{-1} to ~ 12000 cm^{-1}, at ELETTRA synchrotron at Trieste, Italy

- ~6000 cm^{-1} to ~ 35000 cm^{-1}, at TERALAB, “La Sapienza”

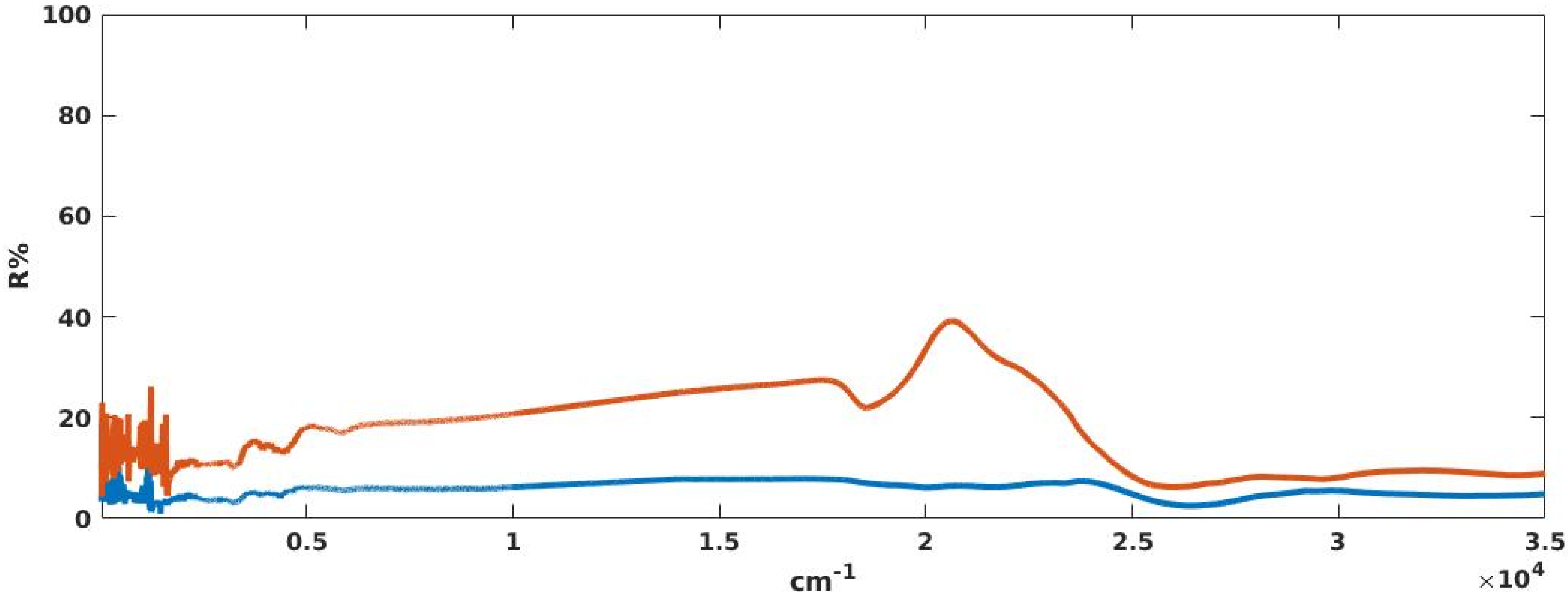
DSTMS data

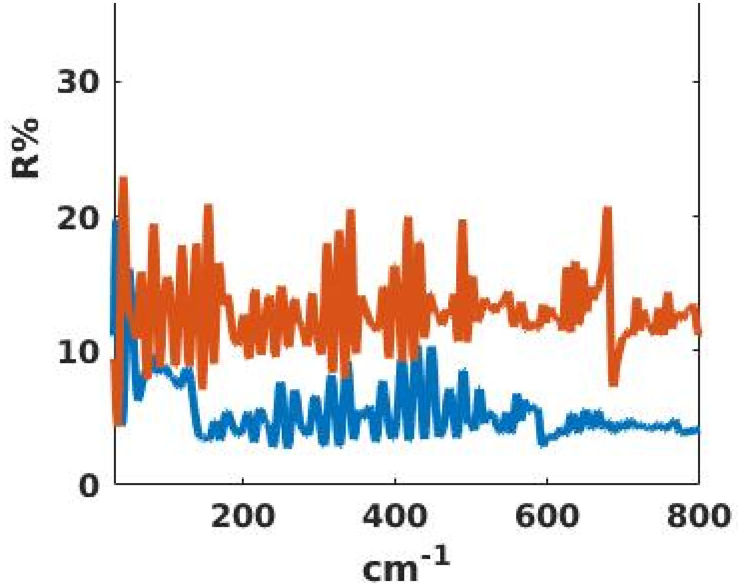




The data are now under work for publication.

HMQ_TMS data





The data are now under work for publication.

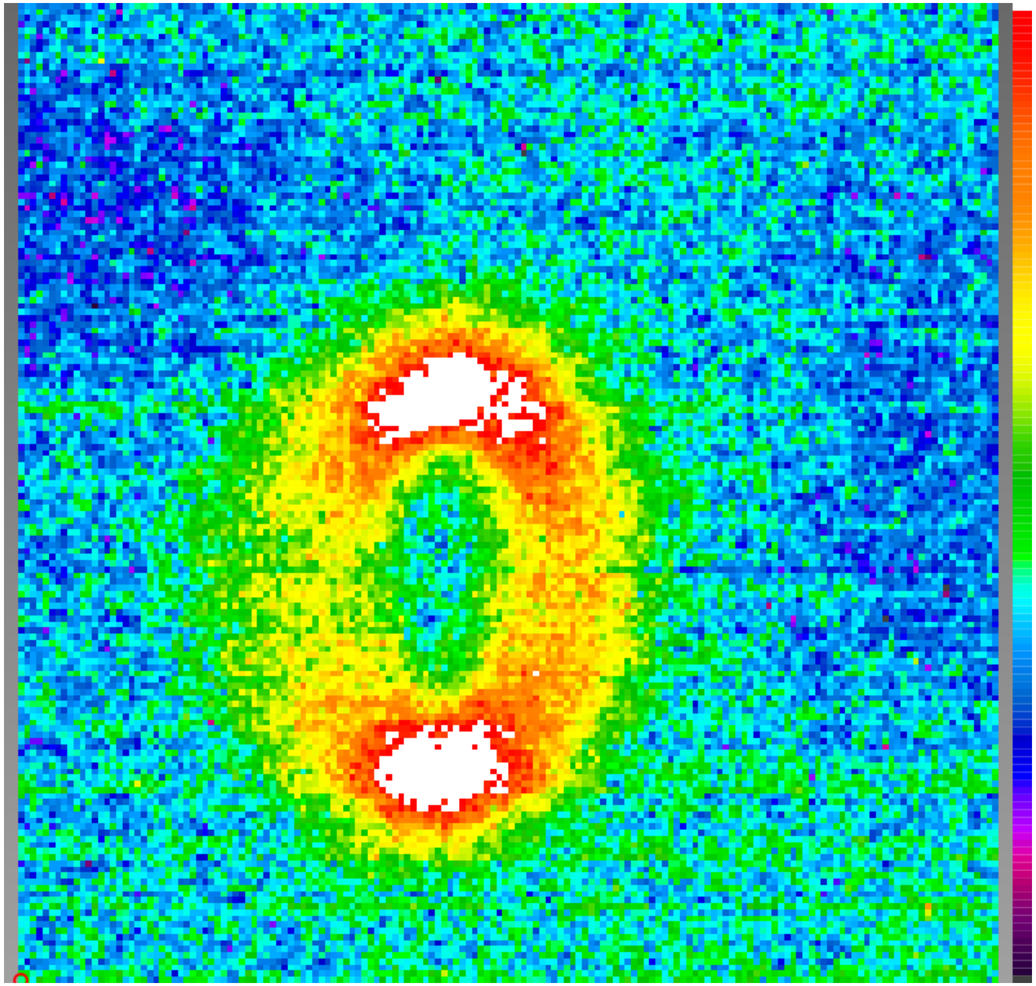
Study on THz diagnostic

The THz radiation can also be used as diagnostic for charged particles bunches. The radiation generated from the interaction of an electron bunch with solid target will generate radiations via Coherent Transition Radiation or Diffraction Radiation. The spectrum of this emitted radiation can span in the THz region and so can be used as measure for the charge, energy and length of the particle bunch.

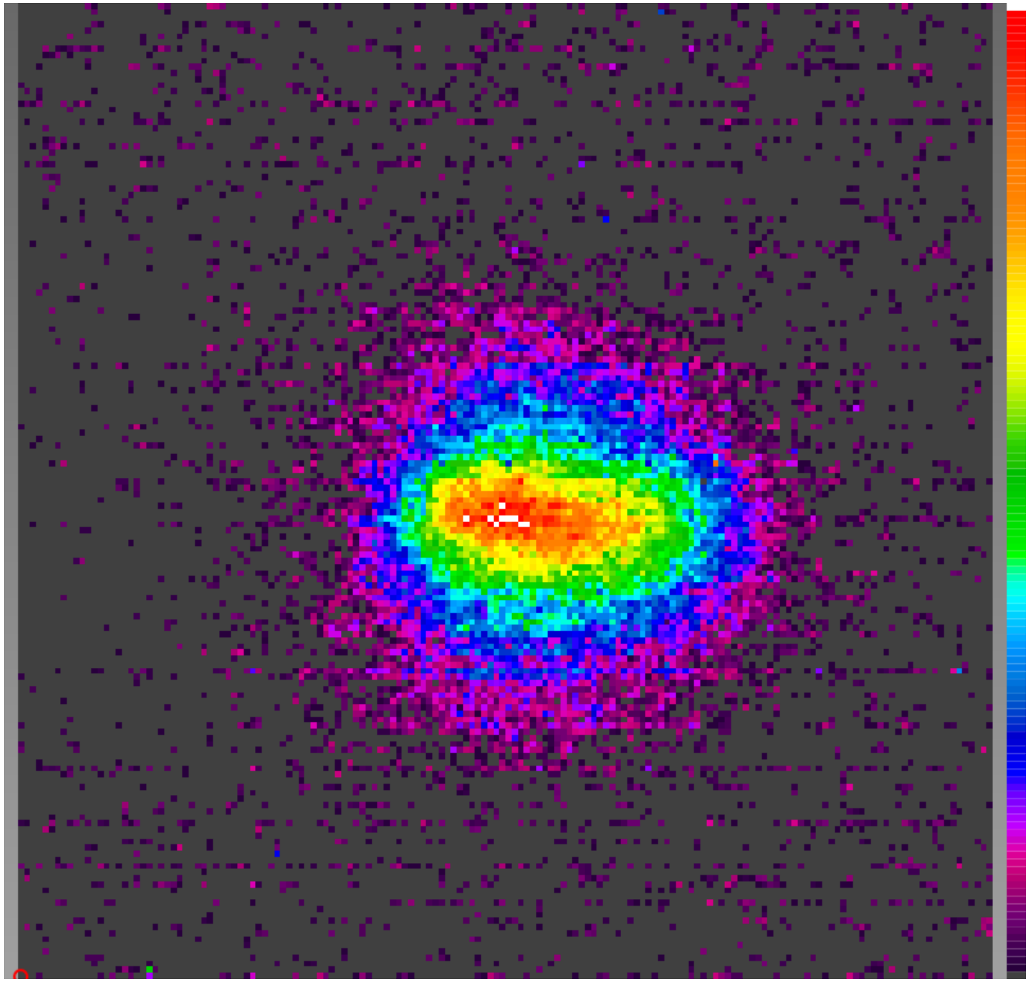
The work was done at the CLEAR collaboration at CERN, using different kinds of targets for the generation of CTR and CDR. The THz radiation was detected using a pyrocam near the focus of an off-axis parabolic mirror. The data were also taken using different band-filters allowing to get data at specific THz frequencies.

THz diagnostic results (1/2)

CTR Far-Field



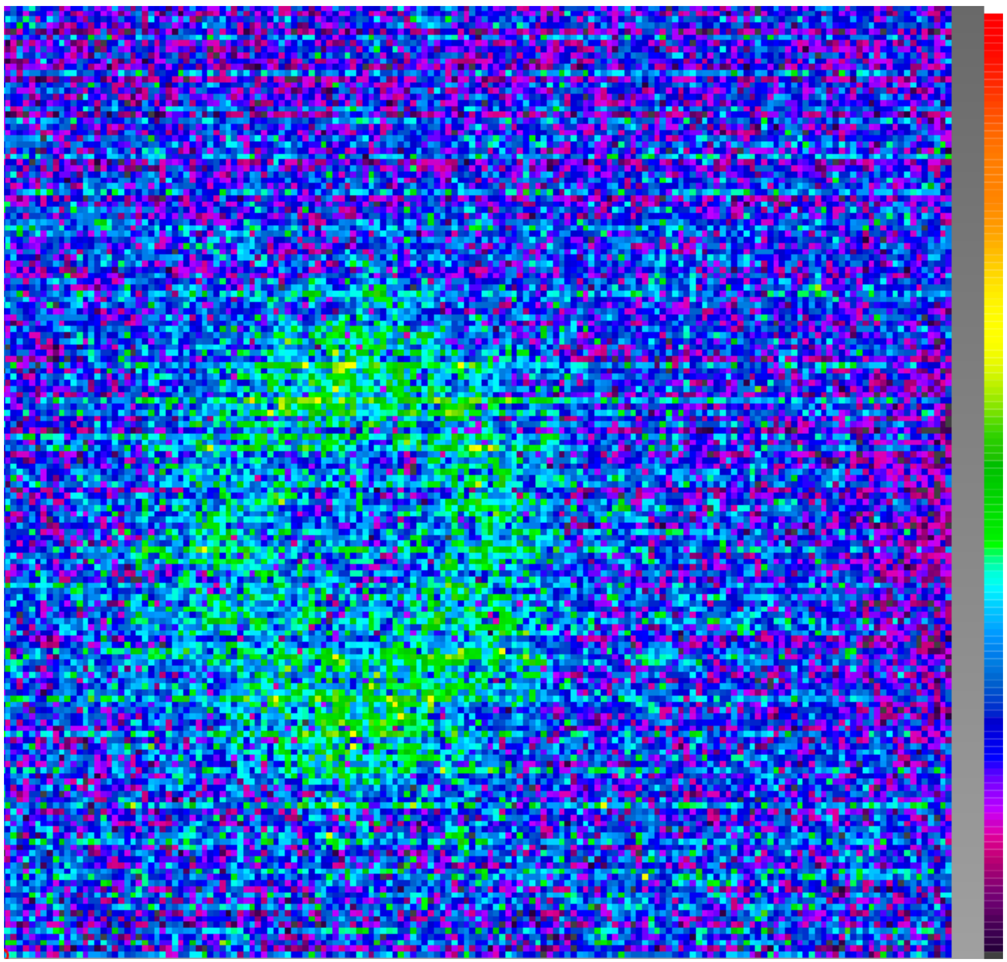
CTR Near-Field



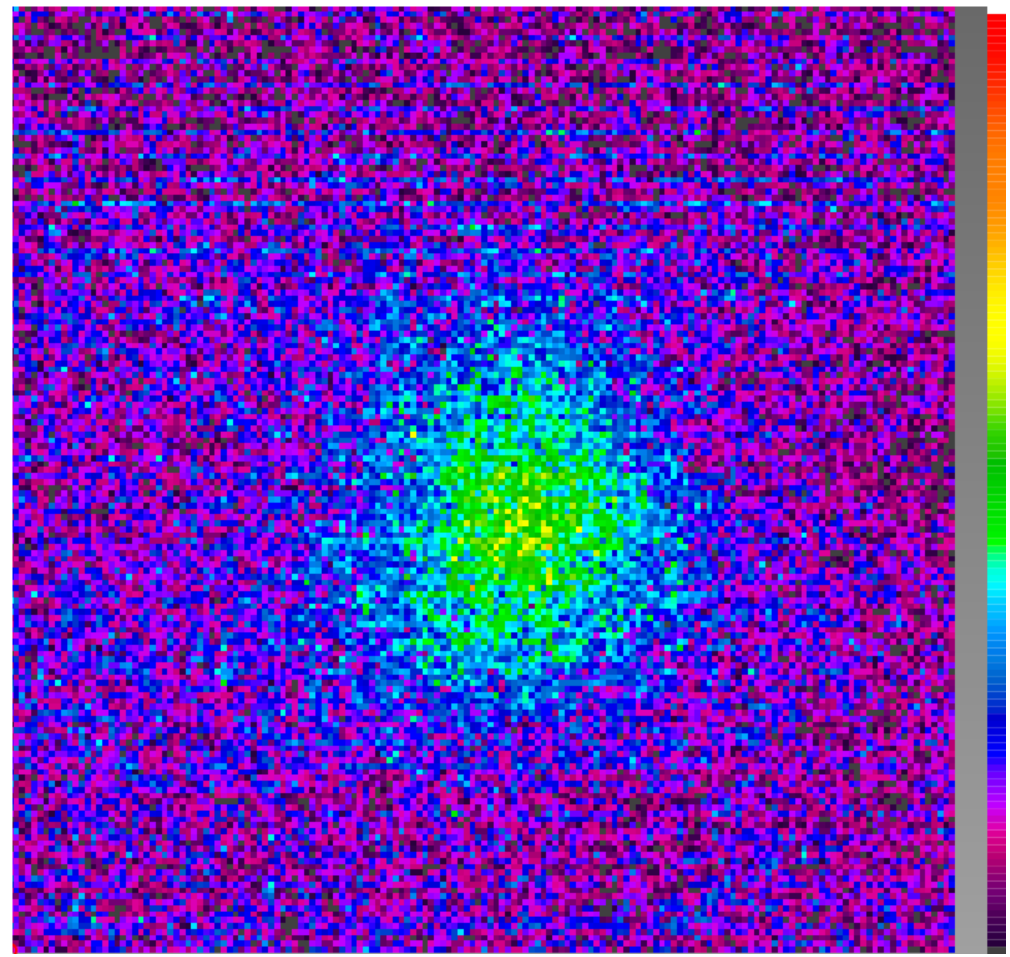
The data are now under work for publication.

THz diagnostic results (2/2)

CTR Far-Field using a THz filter



CTR Near-Field using a THz filter

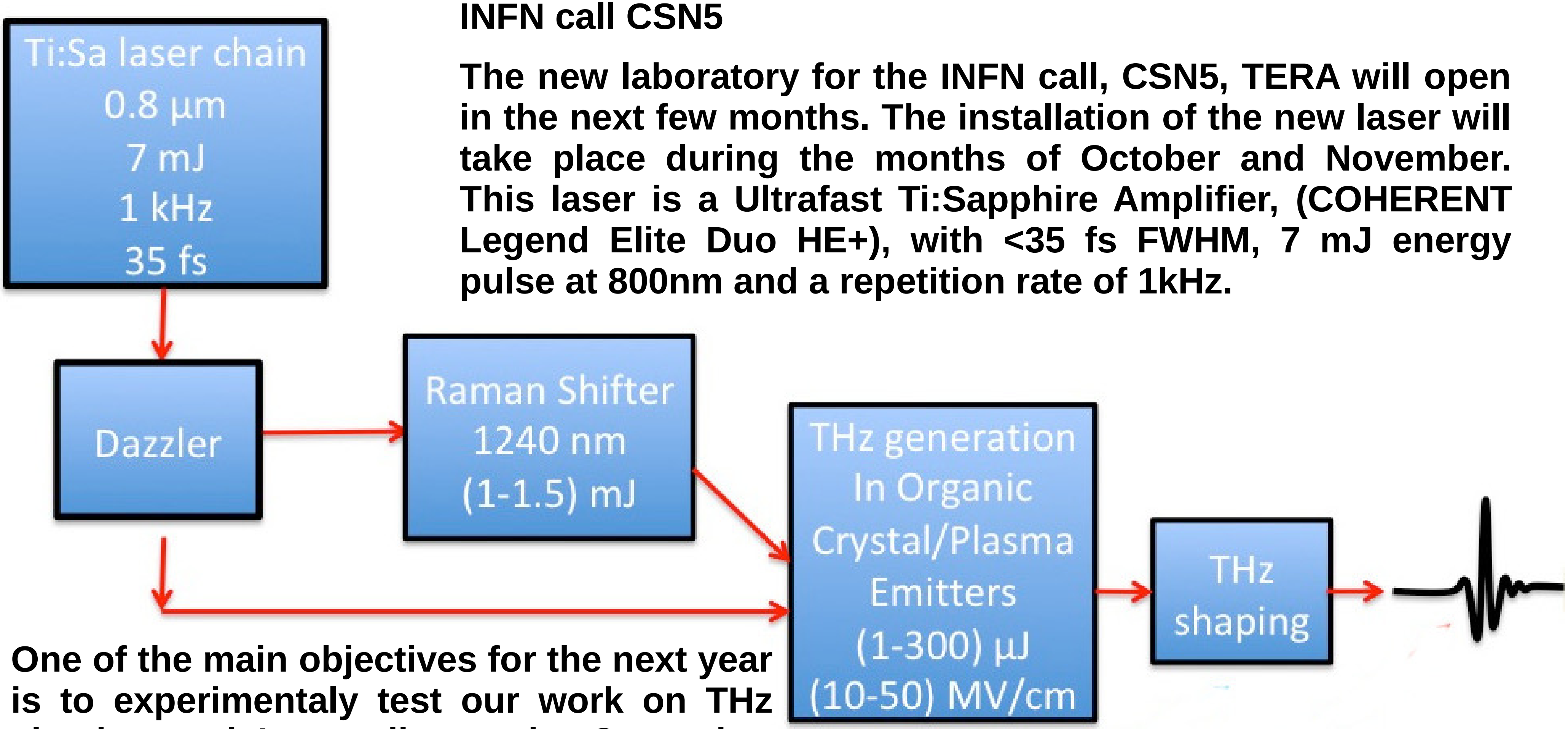


The data are now under work for publication.

Future work for the last year

TERA: Terahertz ERA
INFN call CSN5

The new laboratory for the INFN call, CSN5, TERA will open in the next few months. The installation of the new laser will take place during the months of October and November. This laser is a Ultrafast Ti:Sapphire Amplifier, (COHERENT Legend Elite Duo HE+), with <35 fs FWHM, 7 mJ energy pulse at 800nm and a repetition rate of 1kHz.



One of the main objectives for the next year is to experimentaly test our work on THz shaping and Laser diagnostic. One other objective will be to continue the experiments in bunch diagnostic using the THz radiation.

THz spectroscopy