Development of a fiber-optics polarization resolving THz spectrometer for harsh environment diagnostics application

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CONSORZIO RFX
Ricerca Formazione Innovazione

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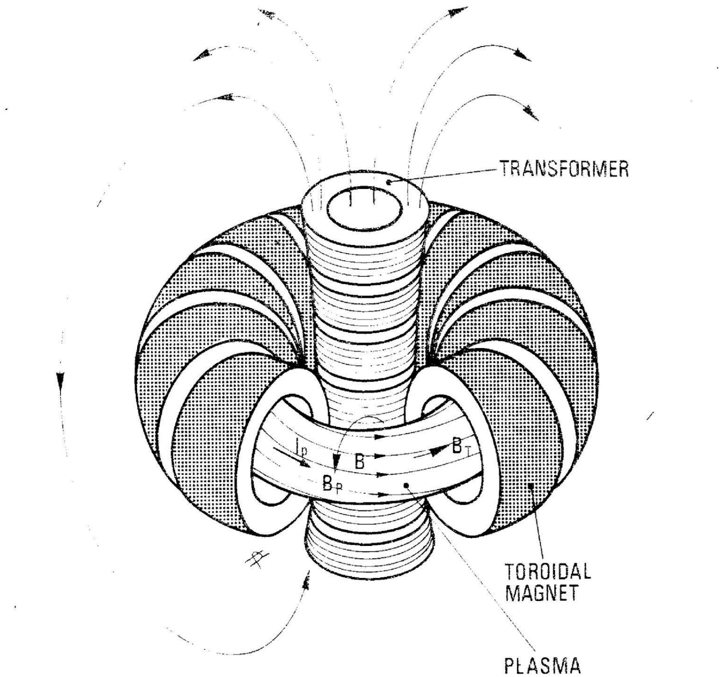
Introduction & Objective

- Scope of the thesis
- Experimental Technique
- Laboratory set-up
- Experimental Tests
- Conclusions

Tokamak and diagnostics



The Tokamak's plasma exhibits relevant optical properties in the region of the millimetre and sub-millimetre electromagnetic waves (emw) leading to the development of various diagnostics tools capable to extract physical parameters of the dynamics of operation of the Tokamak.

Plasma Index of refraction N

$$N^2 = 1 - \frac{X(1-X)}{1-X-\frac{1}{2}\pm[(\frac{1}{2}Y^2 sin^2\theta)^2+(1-X)^2Y^2cos^2\theta]^{\frac{1}{2}}}$$

$$X = \frac{\omega_p^2}{\omega^2} \text{ and } Y = \frac{\Omega}{\omega} \text{ and } \omega_p = \sqrt{\frac{n_e e^2}{\epsilon_0 m_e}} \text{ and } \Omega = \frac{eB}{m_e}$$

Interferometry, Polarimetry and Reflectometry

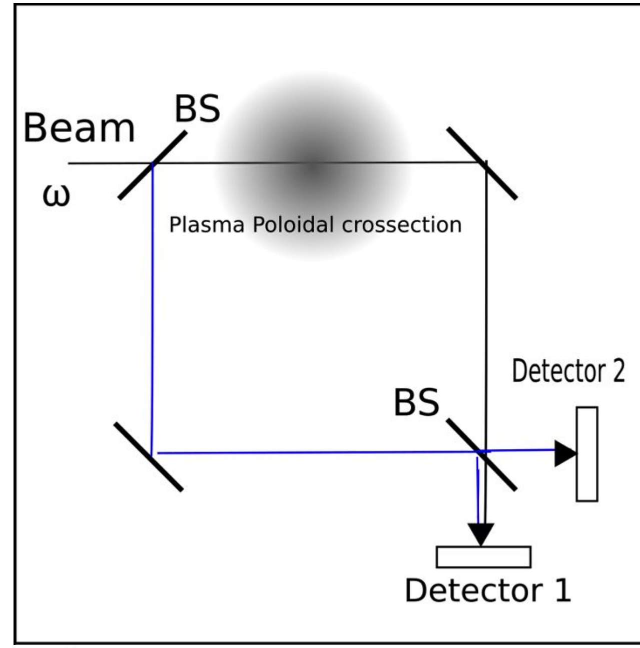
A emw propagating through the plasma will undergo a phase shift.

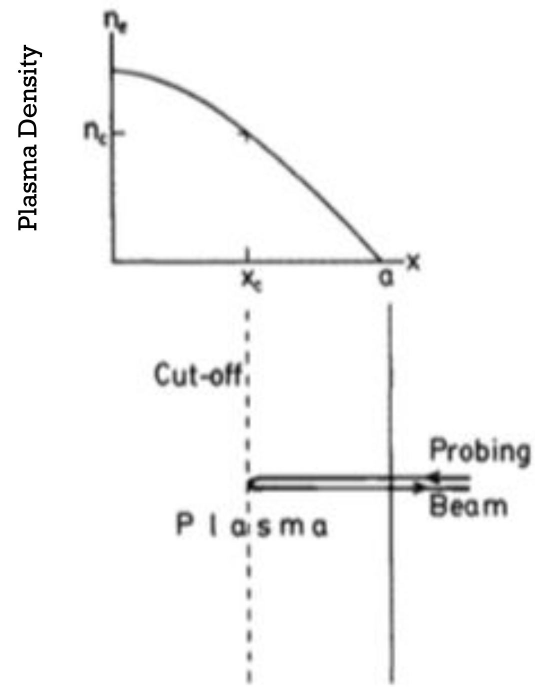
$$\Delta\phi = \frac{-\omega}{2cn_c}\int n_e dl$$

A plasma becomes slightly birefringent in presence of magnetic field.

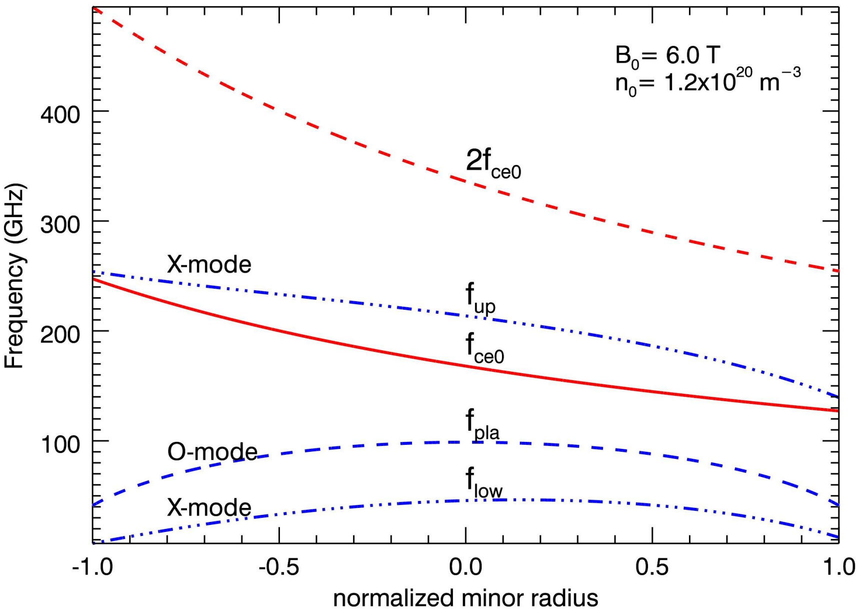
$$\alpha = \frac{1}{2}\frac{XY\cos\Theta}{(1-X)^{\frac{1}{2}}}\frac{\omega}{c}z$$

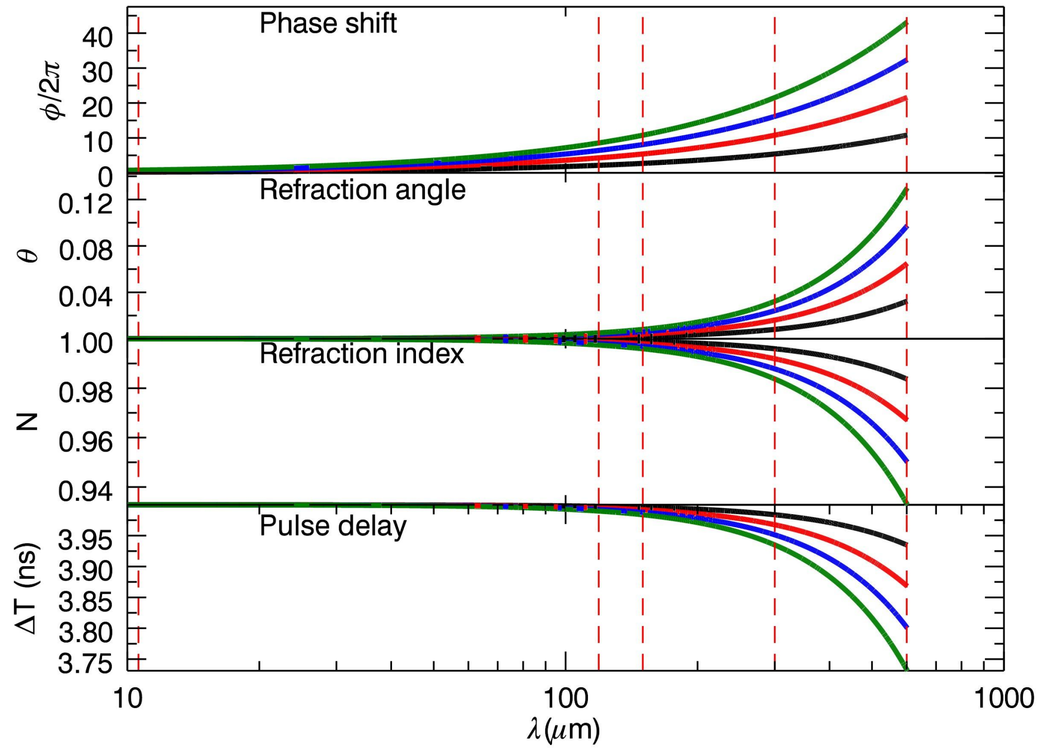
A wave with a fixed frequency propagates in the plasma until its density reaches the cut-off density value upon which the wave is reflected.





THz – Plasma Diagnostics





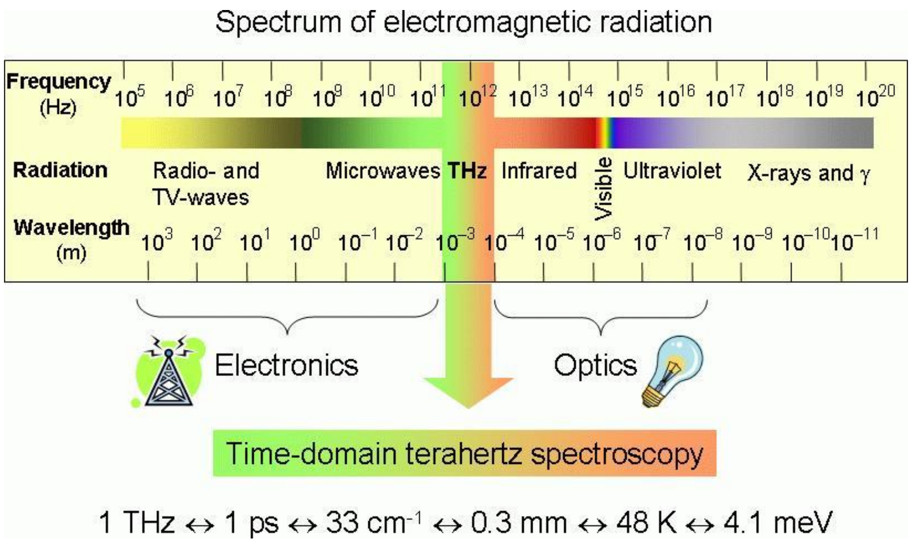
Accessibility of EM, Simulation of relevant properties of EMW propagating trough FTU plasma.

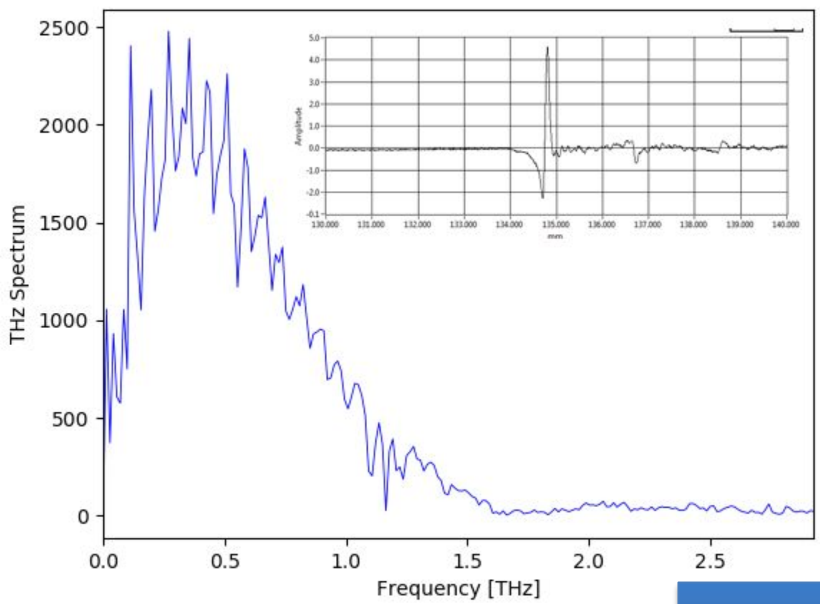
X-mode reflectometry: parametric curves of equal accessibility of FTU radius vs. peak density n_0 magnetic field B_0.

Bornatici, Bombarda

THz Radiation & TDS

THz – consists of electromagnetic waves within the band of frequencies from 0.3 to 3 Terahertz (THz).
It is also known as the submillimeter band, and its radiation as submillimeter waves, especially in astronomy. The technique utilized is the
Time Domain Spectroscopy (TDS).

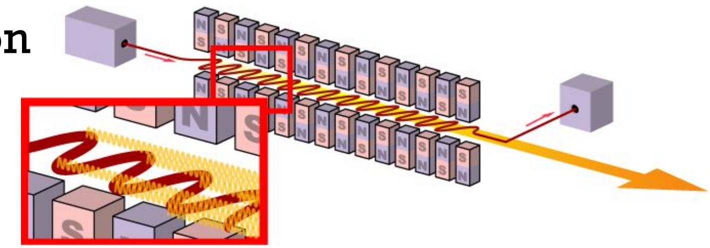




wikipedia

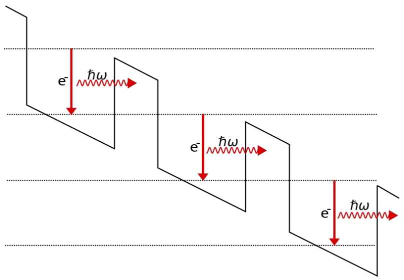
THz Sources and Detectors

Free Electron Laser



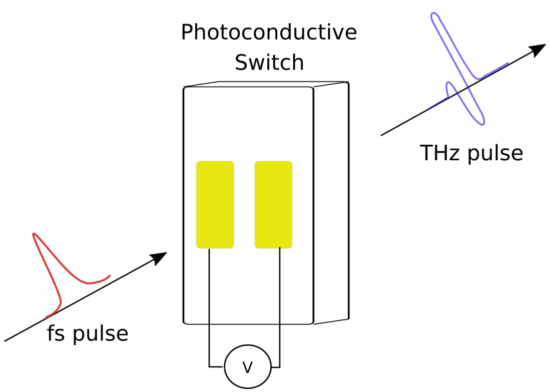
They use an electron beam accelerated at relativistic energy interacting with a magnetic field.
They have a broad tunability and high power levels with low temporal resolution and high cost.

Quantum Cascade Laser



High amplitude laser beam at fixed frequency in the order of the THz. Particular is the capacity of be a tunable laser with narrow bandwidth emission between 1.2 to 4.9 THz with lower bandwidth of 10 GHz and output of 140 mW.

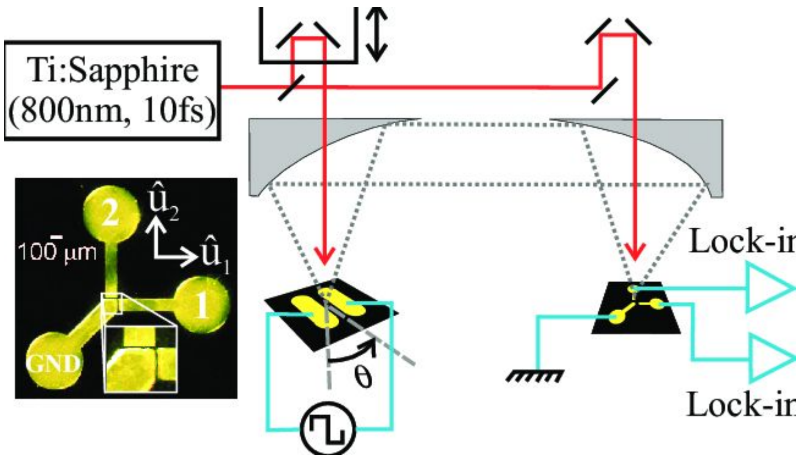
Photo Conductive Antenna



The typical bandwidth produced is 5 THz, the power is on the order of tens mW and DR is about 60 dB.

THz Sources and Detectors

Photo Conductive Antenna



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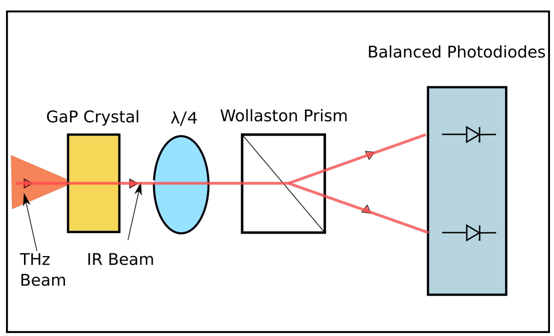
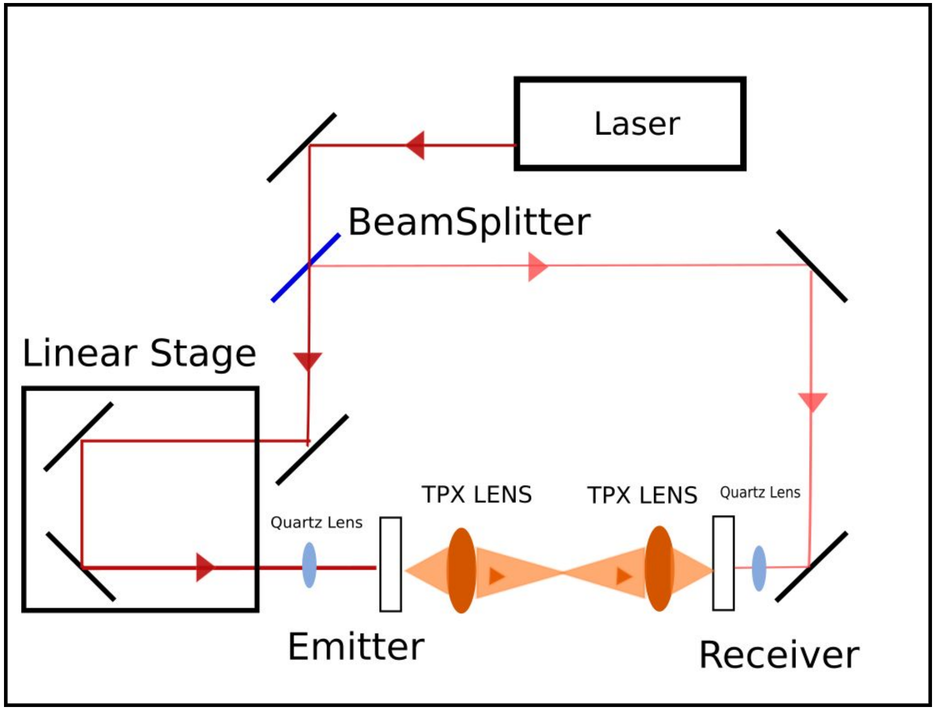
E.O. Sampling



Electro-optical sampling is a process that aims to detect incoming THz pulse by exploiting the frequency mixing property of a nonlinear medium, that presents a birefringent variation caused by an incoming electric field.

Castro camus

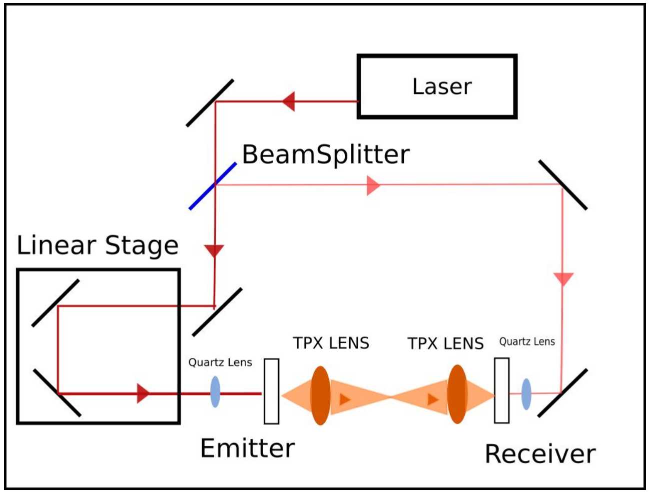
Instrumentation

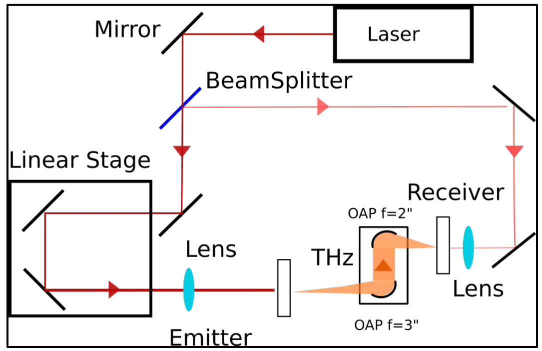


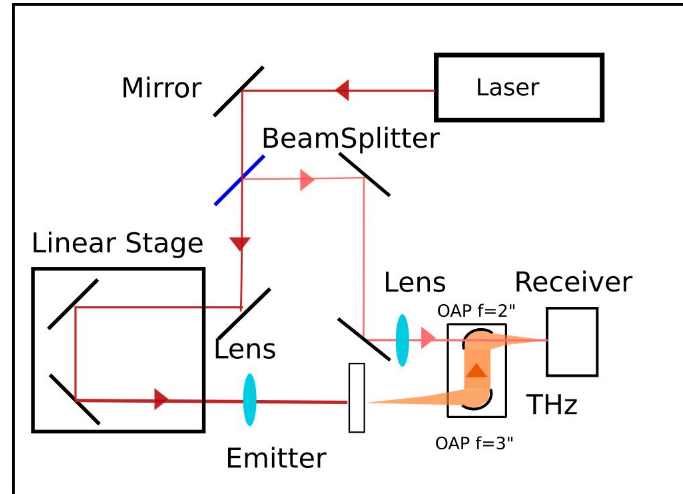
A Ti-Sapphire Mira 800 nm mode-locked laser. The device generates a 170 fs long pulse that is separated into two branches by a beamsplitter the pump branch where the THz pulse is generated and probe branch , where the THz pulse is detected.

The linear stage introduces an optical path difference between the source and the detector.

Experimental Set Ups I



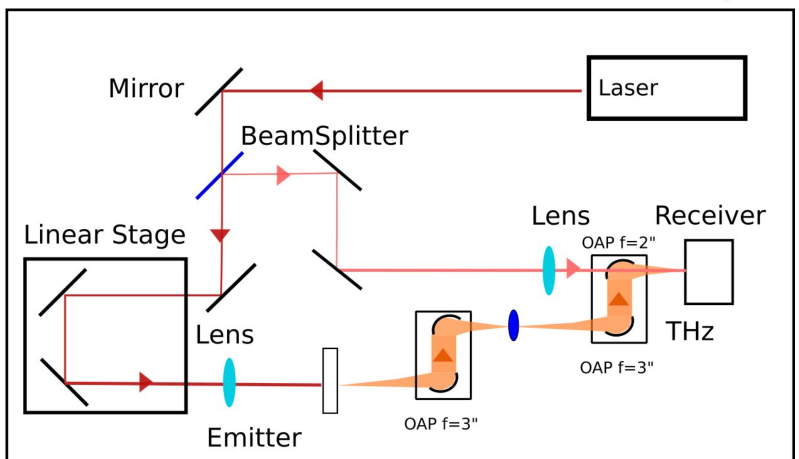




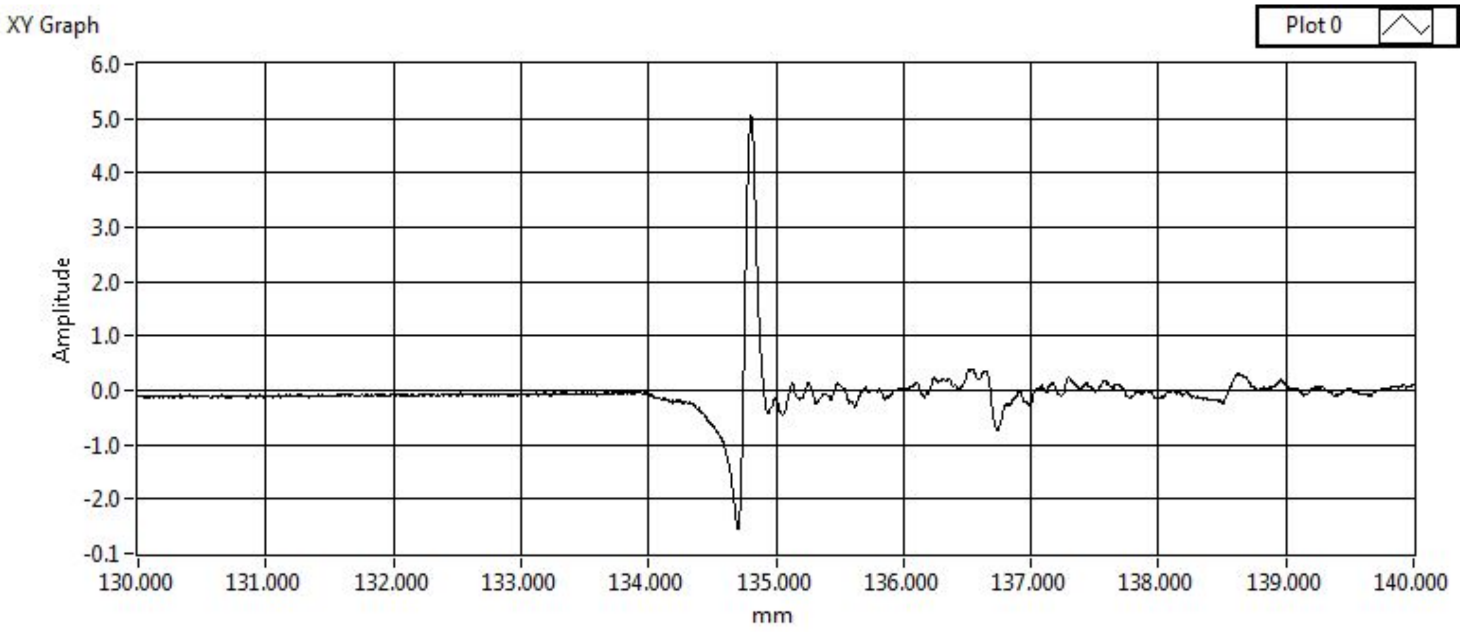
2015

2019

Evolution of the experimental set up in the Frascati Laboratory

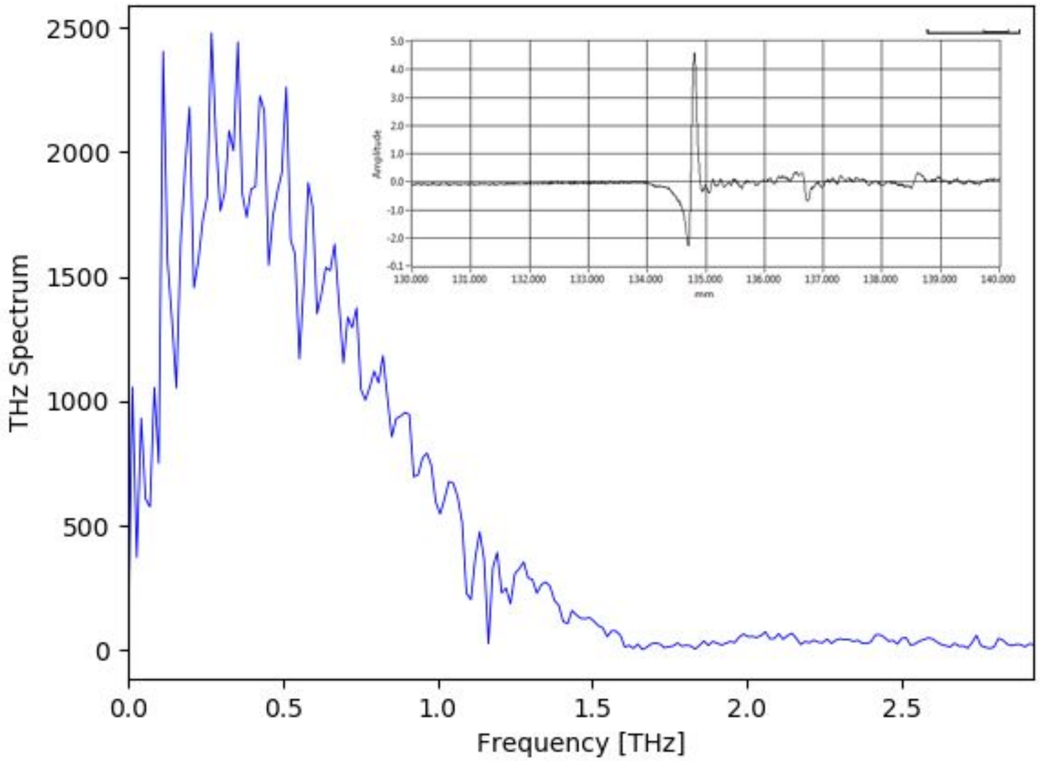


Frascati Measurements I



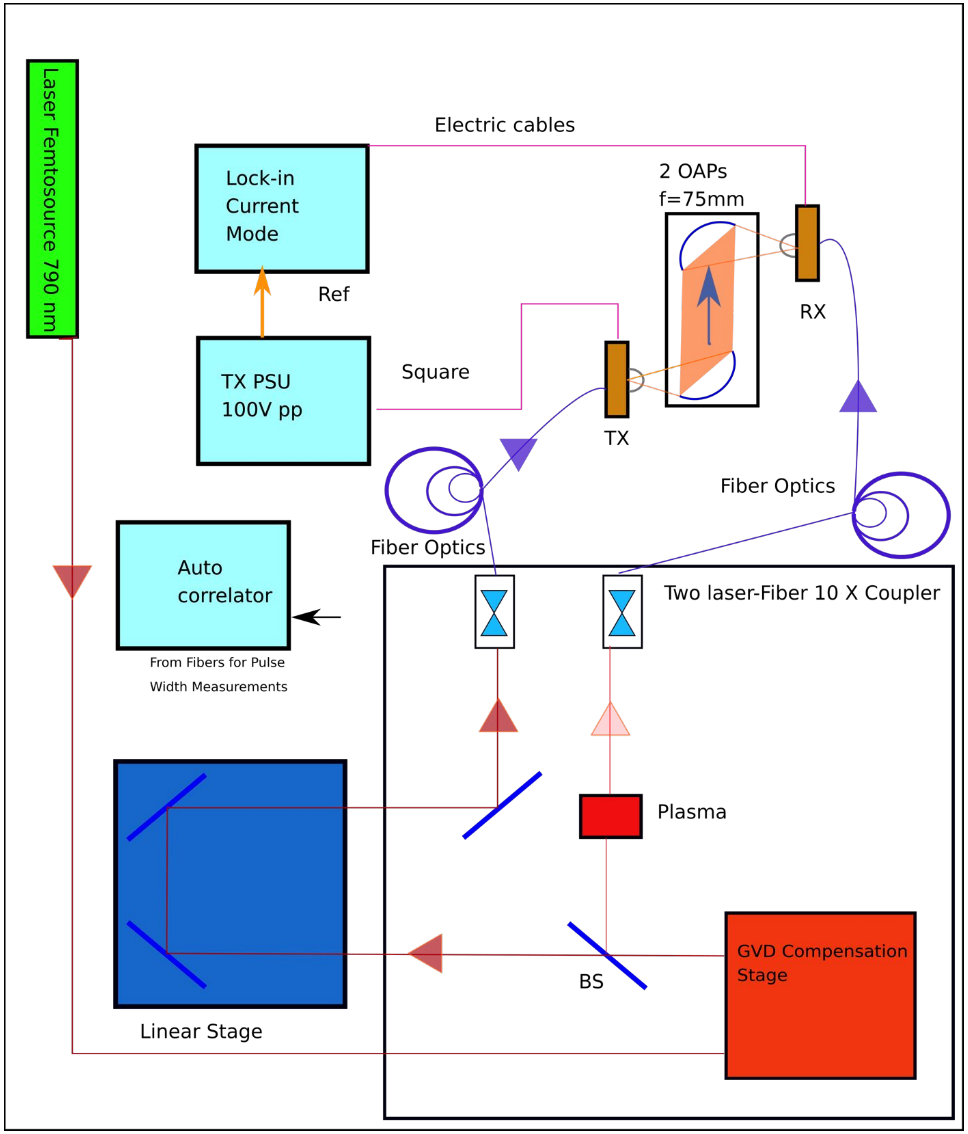
Example of measured pulse with electro optical sampling and relative Fourier Trasform.

Frascati Measurements II



Example of measured pulse with electro optical sampling and relative Fourier Trasform.

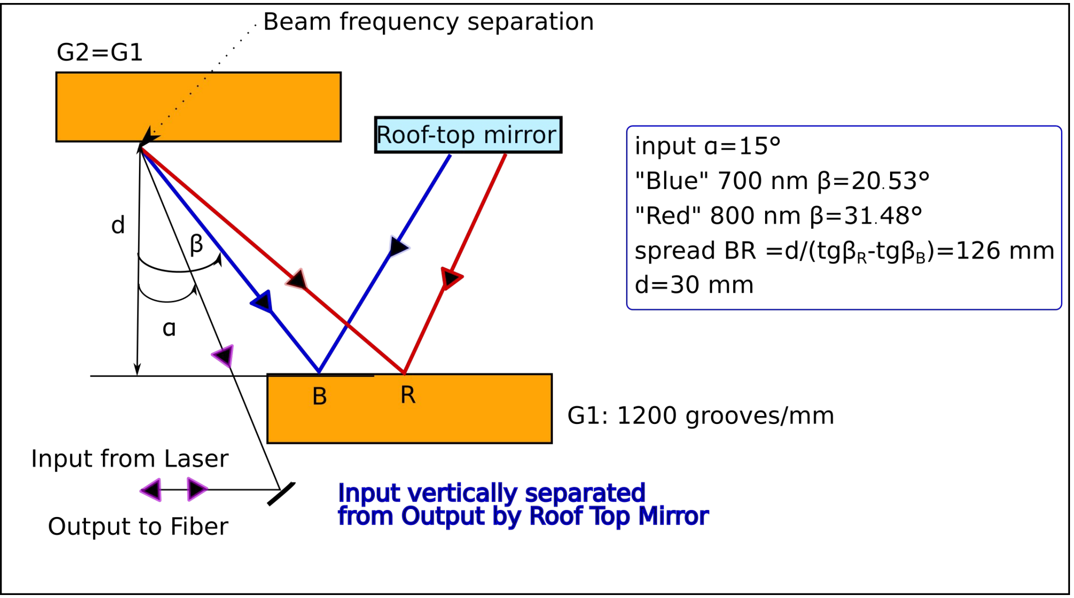
Optical Fibers

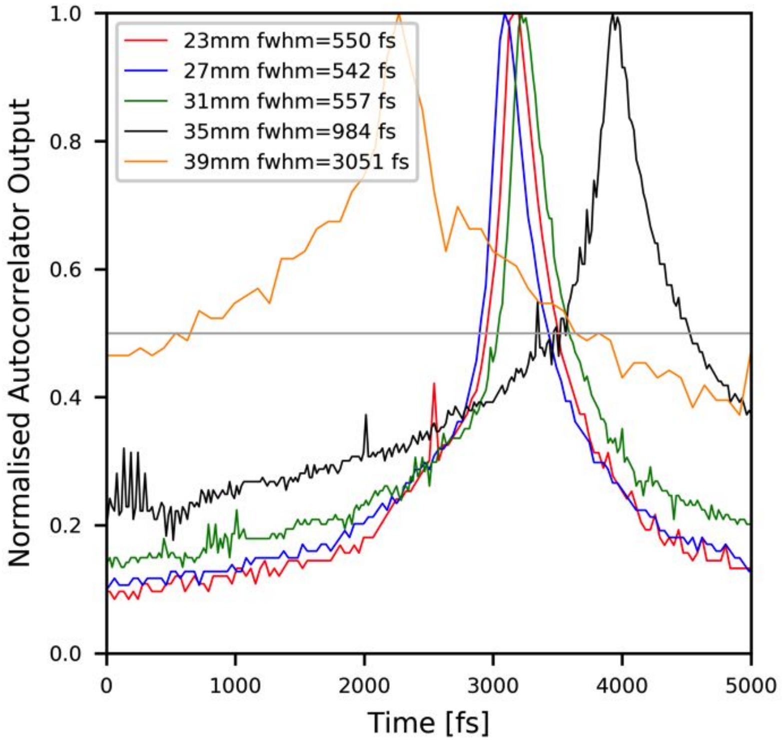


The IR laser radiation can be guided to the THz generation and detection devices by single mode optical fibers for considerable lengths (>10 m).

This will of course pose the issue of Group Velocity Delay (GVD) compensation, since the initially narrow THz pulse will be broadened by the dispersive properties of the fibers.

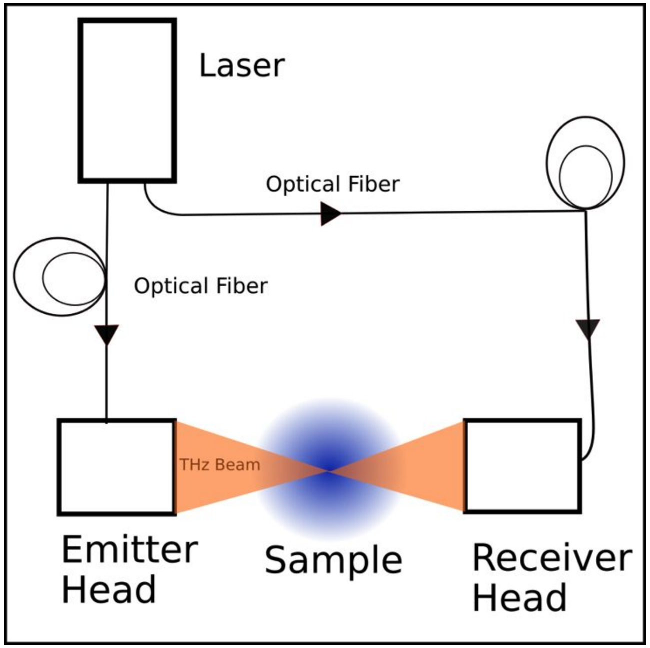
Fiber Optics Test

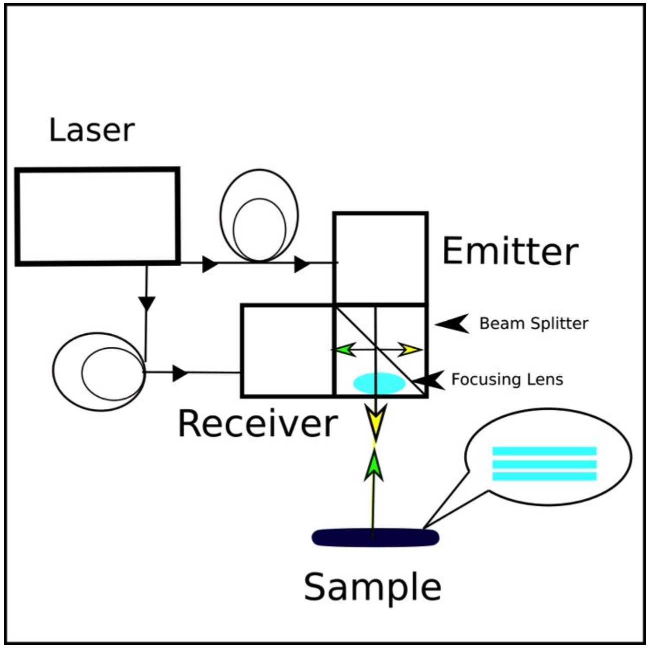




Two holographic gratings Spectrogon model 715.700.550 with 1200 grooves/mm and Littrow angle at 780 nm = 27.90 deg provide the required negative dispersion, which compensates for the fiber positive dispersion"Red" and "Blue" wavelengths are symbolic names to refer to the laser pulse spectral limits.

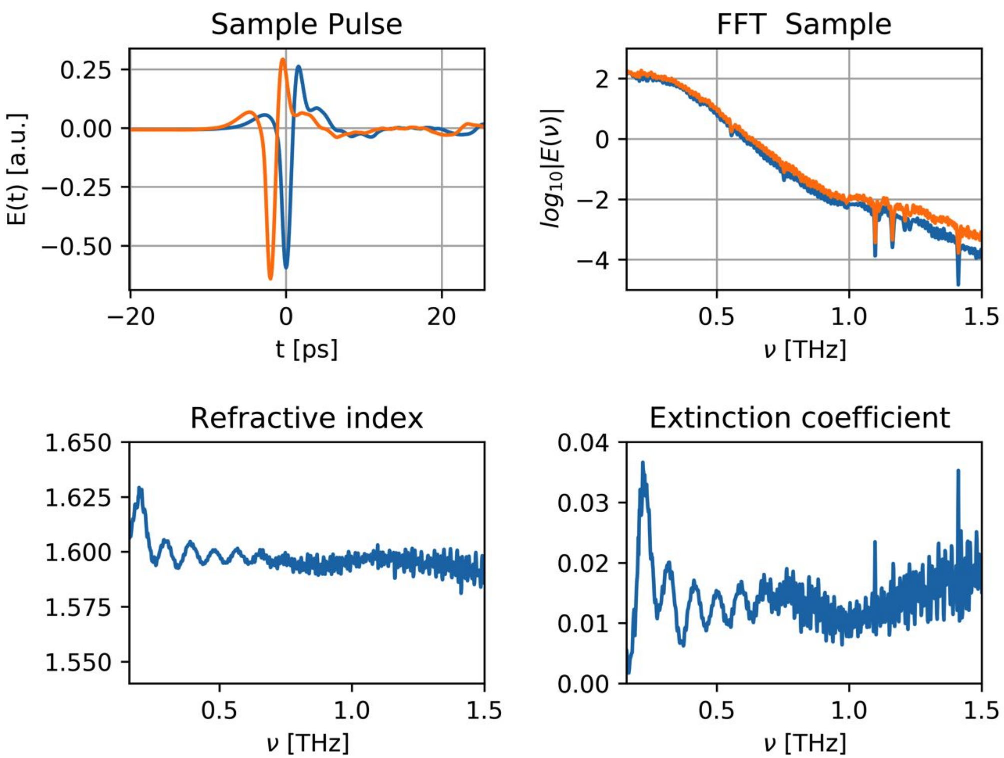
Experimental Set Up II





C.I.O. @ Leon (Mexico) experimental Set up Picometrix
Two heads, with system lens of focal length of 13.5 cm , one emitter the other receiver, linked to the main seed laser by two 5 meter optical fibers.

Trasmission measurements



The objective of the measurement is to estimate the index of refraction and the absorption index of a sample of known thickness using THz-TDS.

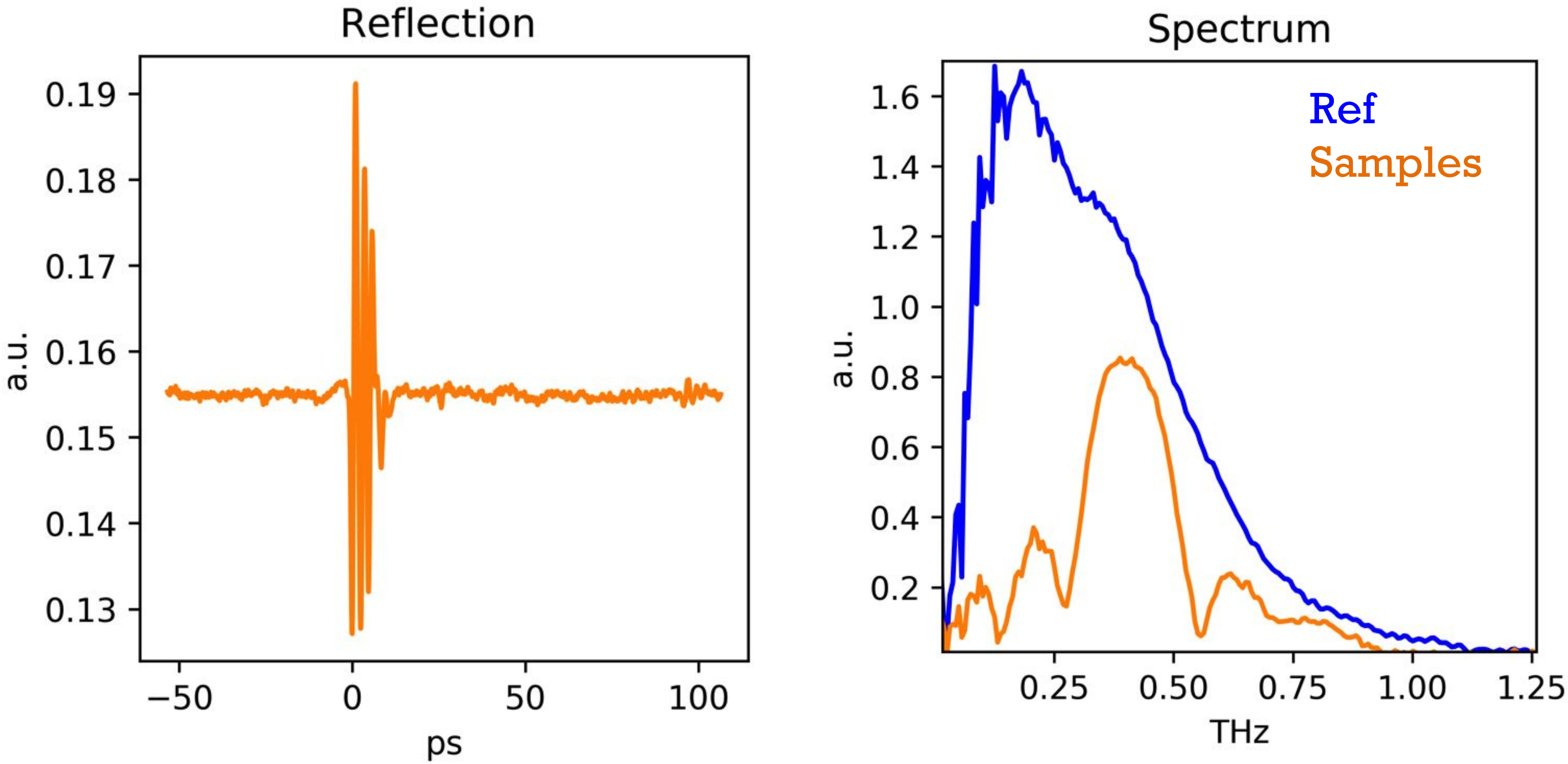
The sample was a disk 1 mm thick, 1 inch wide, 3D printed with Polylactic acid (PLA)

$$n(\omega) = 1 - \frac{c}{d\omega}\Delta\phi$$

$$k(\omega) = -\frac{c}{d\omega} ln(\frac{E(\omega)_{smp}}{E(\omega)_{ref}})$$

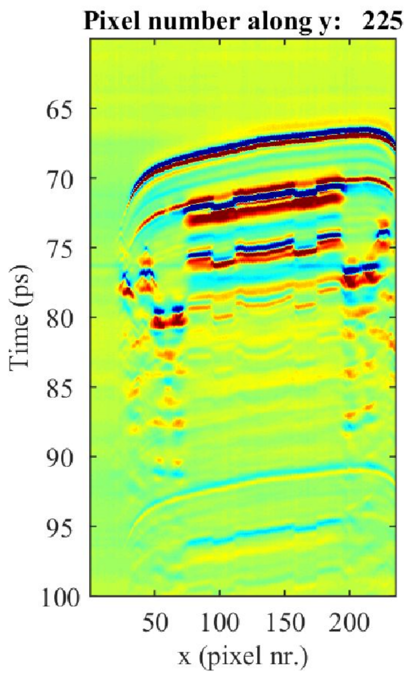
N(ω) =n(ω) +i k(ω)

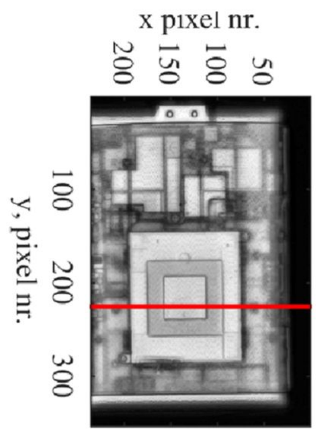
Reflection measurements I

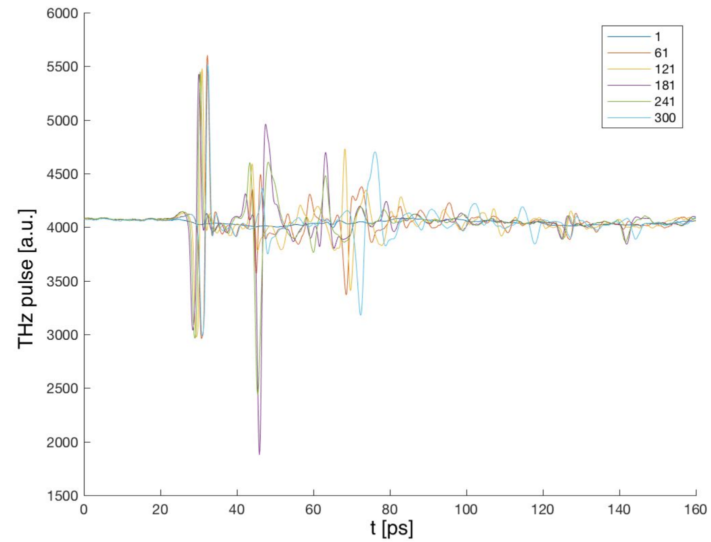


A less complex framework beneficial for studying the different propagation properties of the pulse. The number of planes corresponds to the number of the peaks in the reflected pulse. The travelling time of the pulse corresponds to the distance of each paper

Reflection measurement II

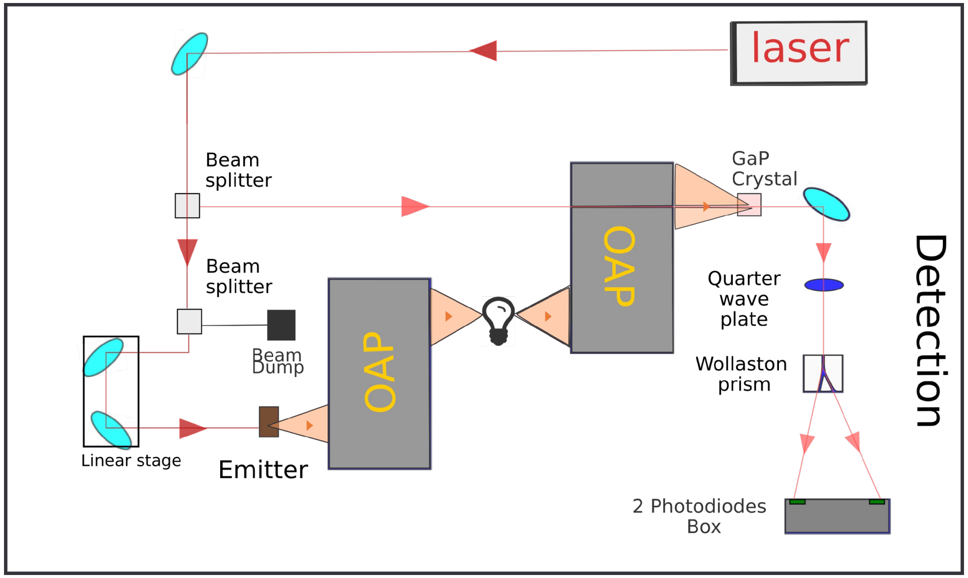






In the case of the X-Y scan output of the electronic device, reflected electric field peak is reconnected to its thickness and index of refraction of the device internal components.

Plasma Measurement I



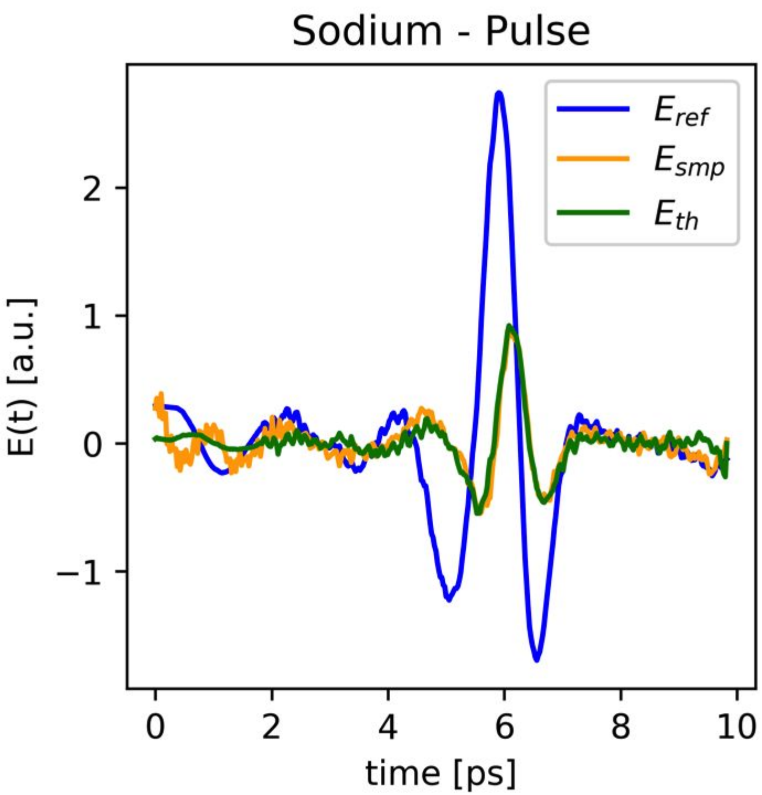
$$H(\omega, n_e, \nu_e) = \frac{S_{smp}(\omega)}{S_{ref}(\omega)} = exp(i\frac{\omega L}{c}(1 - n(\omega, n_e, v_e)))$$

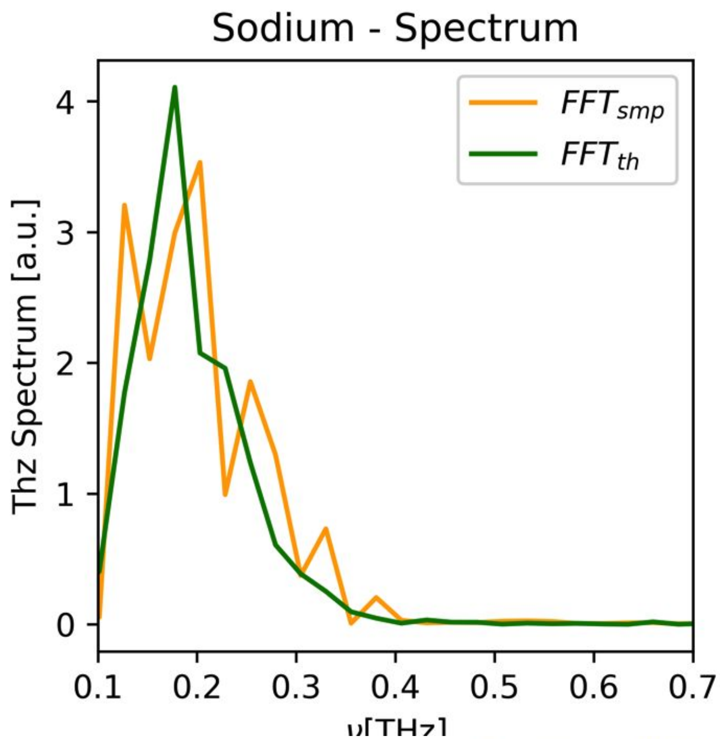
Using a simple model for a plasma slab of uniform density in the cold plasma approximation is possible to reproduce the Plasma Transmission Function.

Is then possible to deduce the electron density and

the electron collision rate.

Plasma Measurements II





Lamp Type	$n_e[10^{20}m^{-3}]$	$\nu_e[THz]$
Hg - HPK125	0.4	1.5
Na - 93122E	1.9	0.9
Cs - 93105E	4.9	1.3

Using the simple analysis method showed in the slide before, we estimated the parameters of Hg (HPK), Na and Cs plasmas in the spectroscopic lamps.

Conclusions

Developing a THZ laboratory set up in the field of Plasma Fusion Research.

Study of the challenges for its applications.

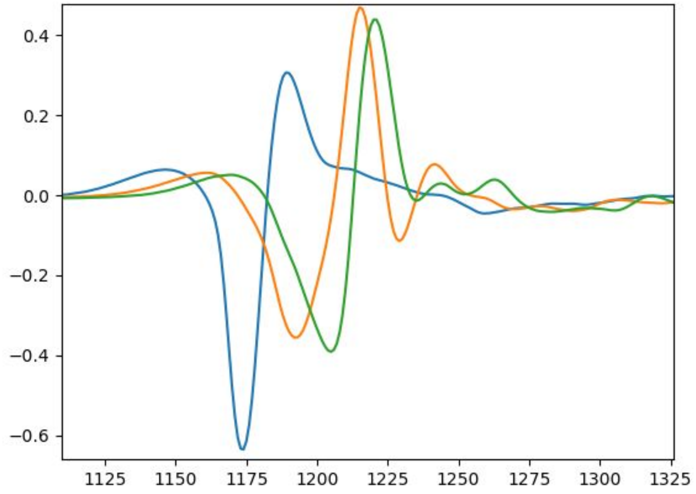
Framework of experiment to give proof of principles and sample constructions.

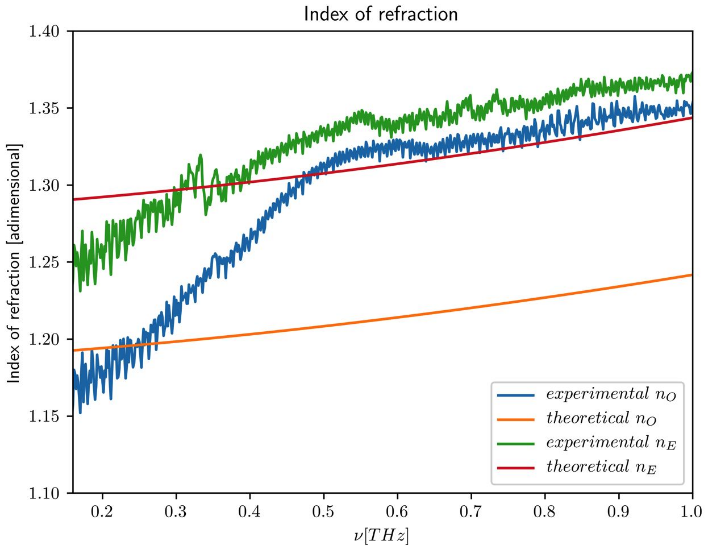
Future Work

- Study the Fiber Optics system
- Create a test Plasma Chamber
- Prototype

MAPS

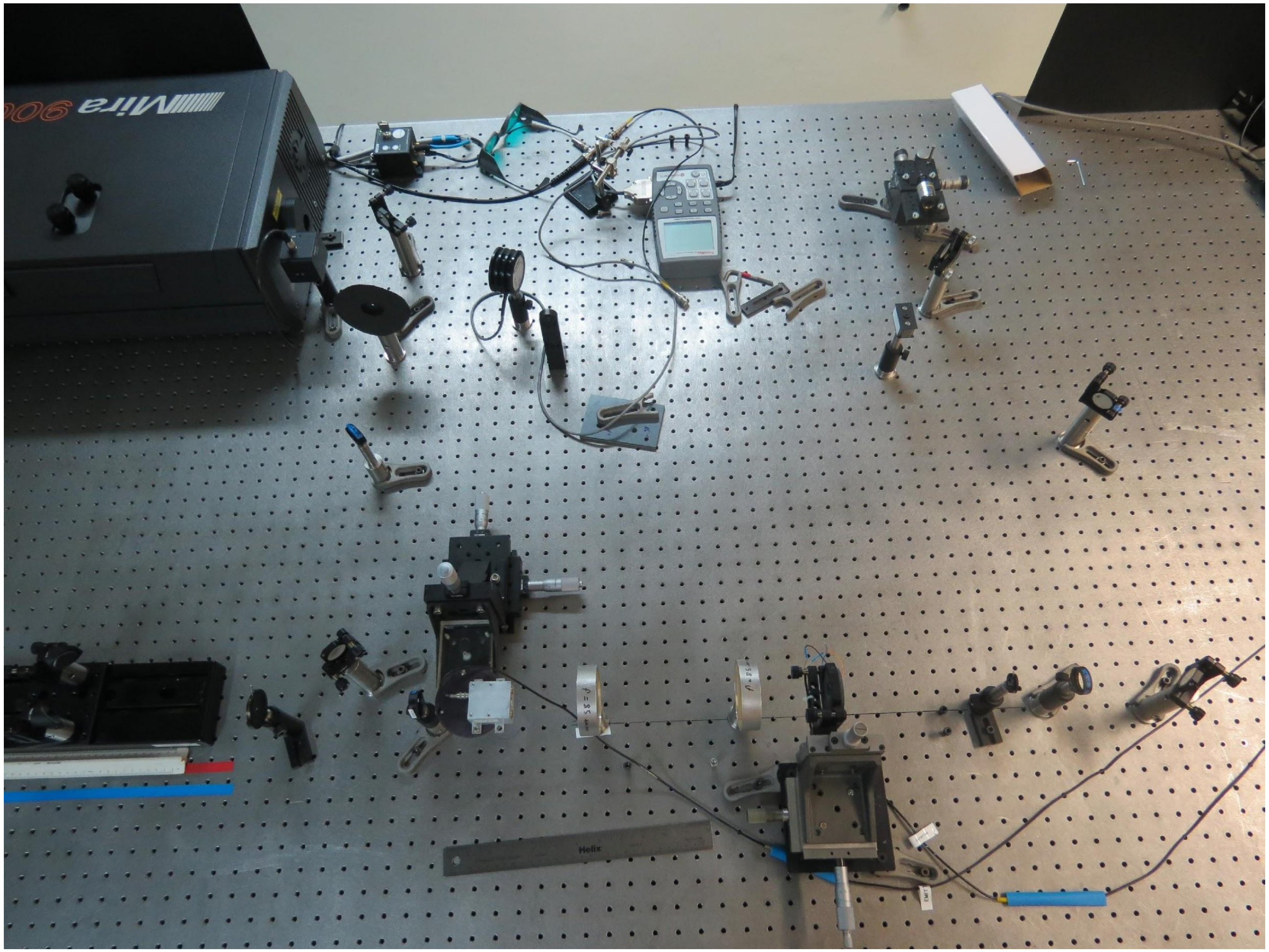
Polarimetry Measuremnts





Using the same optical set-up of the PLA index of refraction measurement, a 3D printed carved disk was positioned onto a rotating holder in the sample position, with the zero position indicated by the grooves of the disk placed parallel to horizontal polarisation of the THz wave.

Experimental Set Ups I



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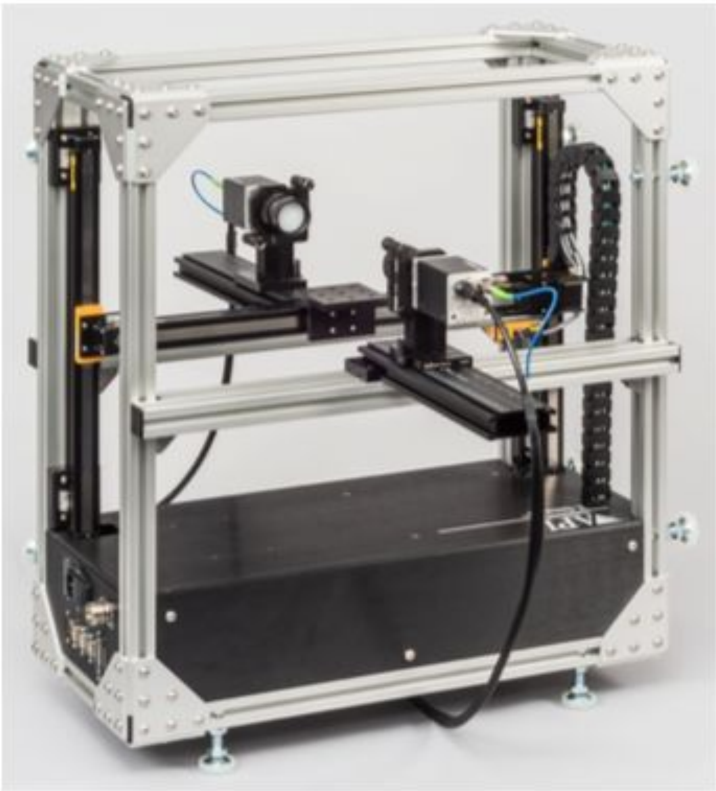

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