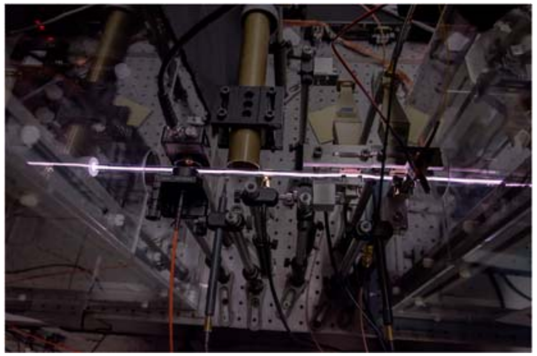
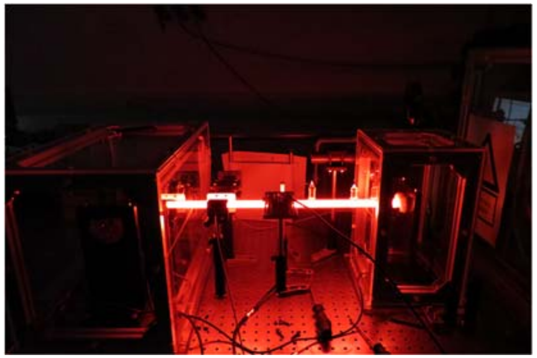


THz diagnostics for the plasma density and charged particle self-modulation measurement in AWAKE experiments

Roxana Tarkeshian, Olaf Reimann, Patric Muggli
Max –Planck Institüt für Physik

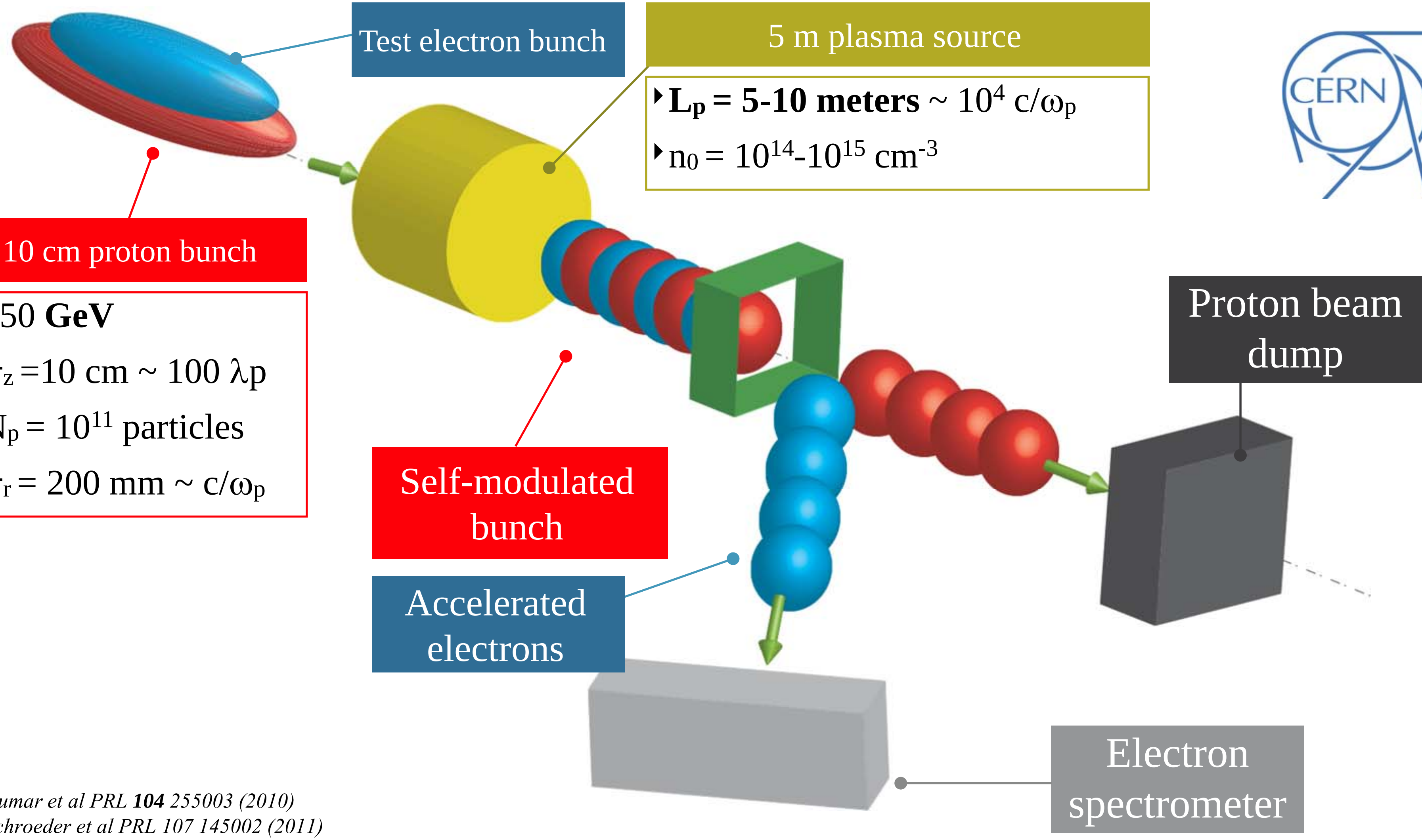


1st European Advanced Accelerator Concepts Workshop
June 2013

Overview

- Self-modulated proton driven wakefield acceleration
- p^+ - bunch modulation measurement
  - CTR and microwave measurement
  - TCTR and electro-optic measurement
    - Dispersive Fourier Transform method
    - * Time lensing/stretching
- Plasma density measurement
  - Cutoff frequency method
    - Chirped photo-mixing
    - THz-time domain spectroscopy
  - Optical emission spectroscopy (OES)

Self-modulated proton driven wakefield acceleration



- L_p **= 5-10 meters** ~ 10^4 c/ω_p
- $n_0 = 10^{14}$-10^{15} cm^{-3}

- 450 **GeV**
- σ_z =10 cm ~ 100 λp
- $N_p = 10^{11}$ particles
- σ_r = 200 mm ~ c/ω_p

*N. Kumar et al PRL **104** 255003 (2010)*
C. Schroeder et al PRL 107 145002 (2011)
A. Pukhov et al PRL 106 145003 (2011)

J. Vieira | 17th May 2013 | GoLP Global Seminar, Lisboa

CTR - microwave measurement

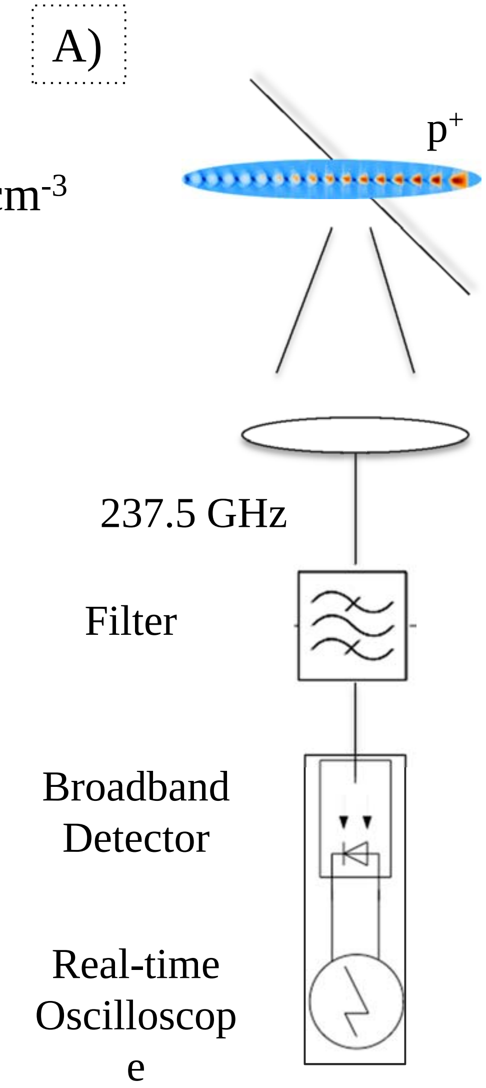
1st day measurement setup:

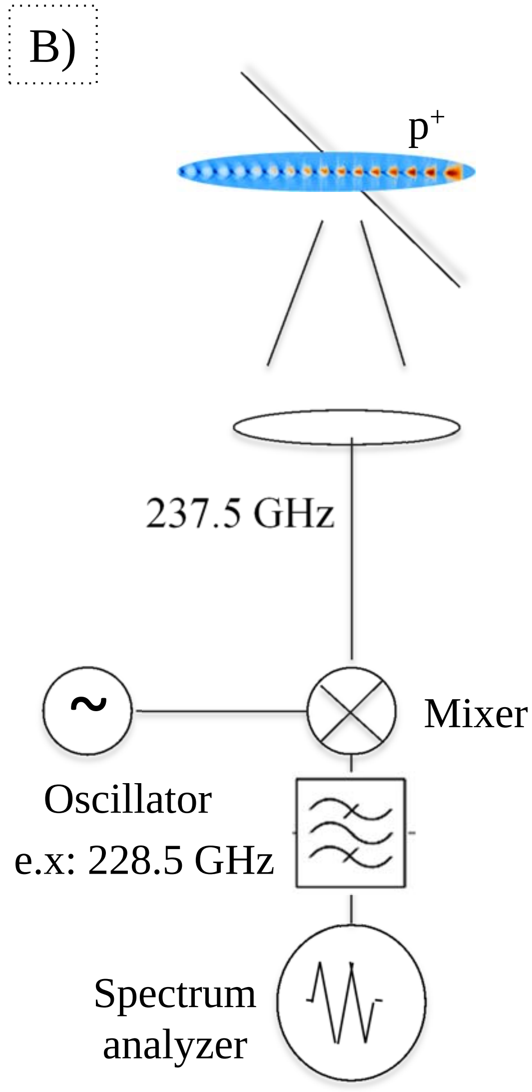
f_p = 237.5 GHz @ n_e= 7 *10 ^{14} cm^{-3}

Sensitivity is an issue..

Incoherent TR measurement

- Streak camera measurement
- Shot – noise measurement





Transverse coherent transition radiation (TCTR)

- The total current of bunch *($J = 2\pi\sigma_0^2 e n_0 v_0$)* remains unmodulated.

→ no signature of the p^+ bunch modulation in forward CTR.

- Bunch radius modulation

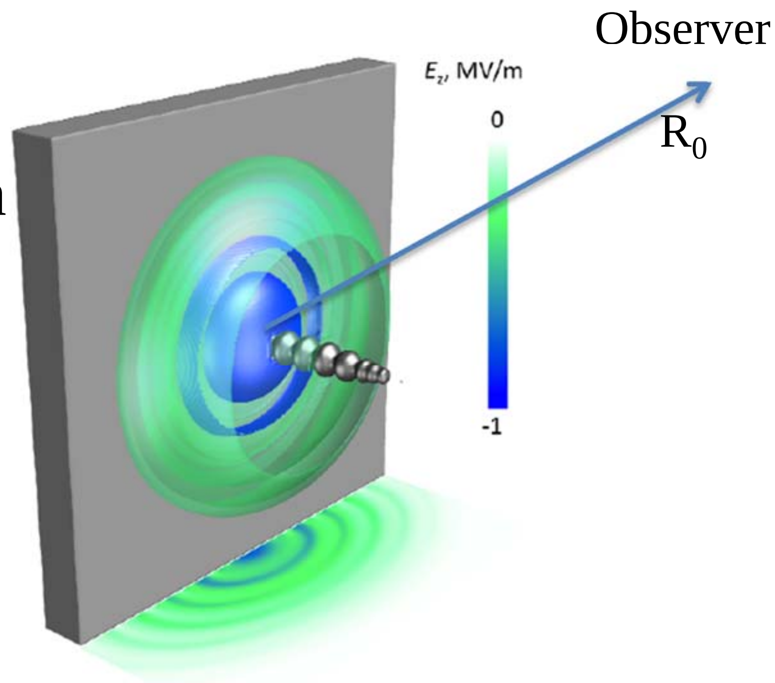
$$\sigma(t', z) = \sigma_0 \left[1 + \epsilon f\left(k(z - v_0 t')\right)\right]$$

ε : modulation depth
f : modulation function
t' : retarded time

- Radiation field at R_0

$$E(t, R_0) = -2\epsilon \frac{J}{cR_0} (k\sigma_0)^2 \beta_0^3 f''(-kv_0 t)$$

J : total bunh current $J = 2\pi\sigma_0^2 e n_0 v_0$
kv_0 : emitted radiation frequency



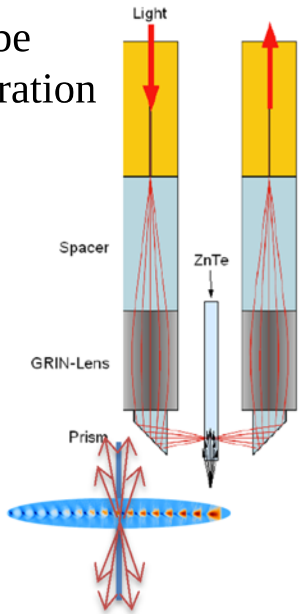
Pukhov, PR STAB, 2012

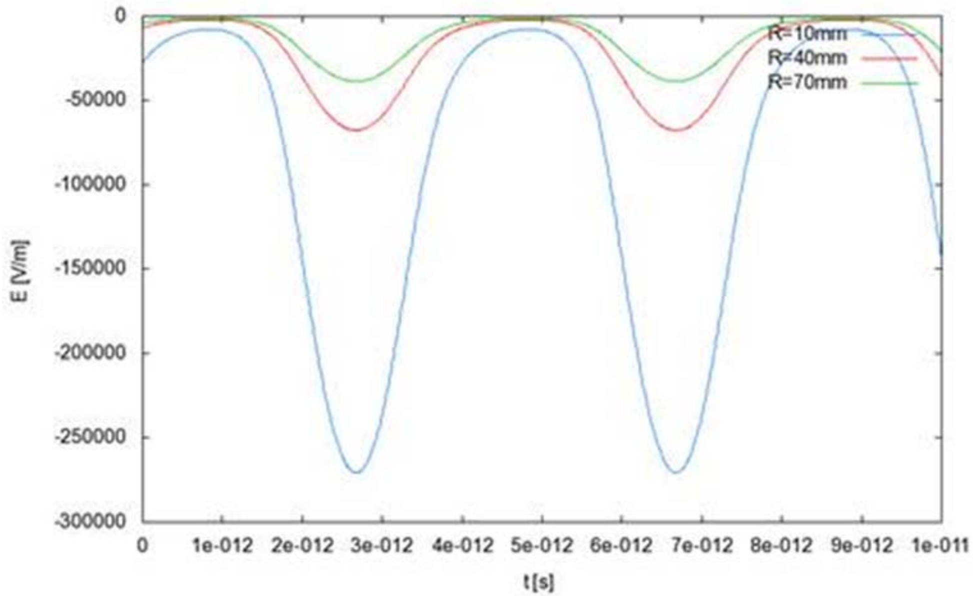
TCTR measurement using EO sampling

- Transverse CTR
  - Parallel E-field component to the screen
  - Signal is modulated by beam density to first order

    237.5 GHz @ $n_e \sim 7{*}10^{14}$ cm^{-3}
  - Field is proportional to the beam density
  - Hundredths of kV/m at about 10 mm distance
  - High frequency detection by EOS

Probe configuration





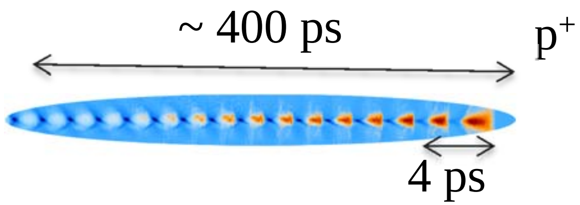
Typical E-field at different radial positions.

Dispersive Fourier Transformation (DFT)

Max-Planck-Institut für Physik (Werner-Heisenberg-Institut)

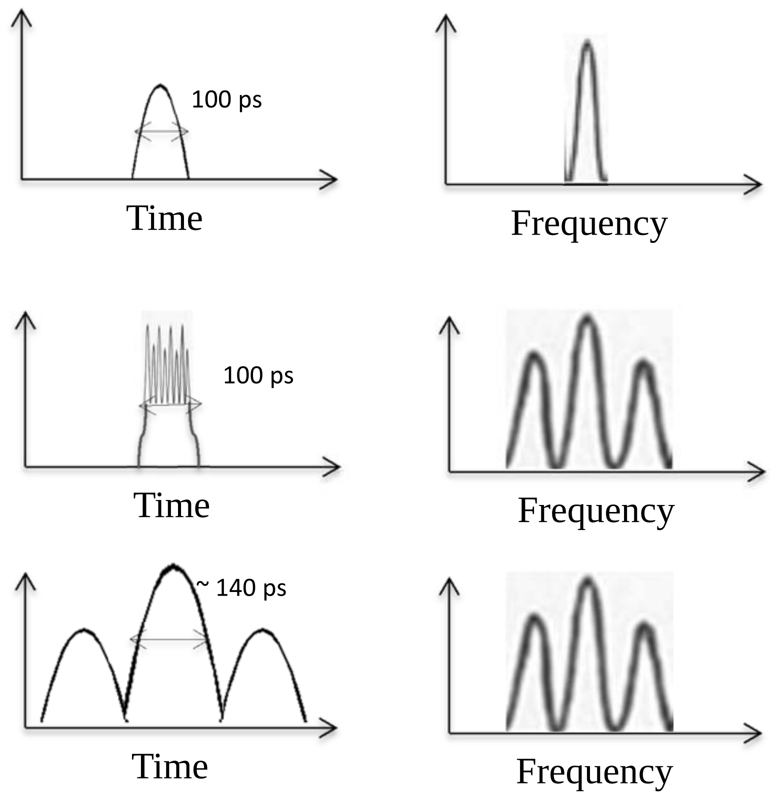
AWAKE

Principle Idea:



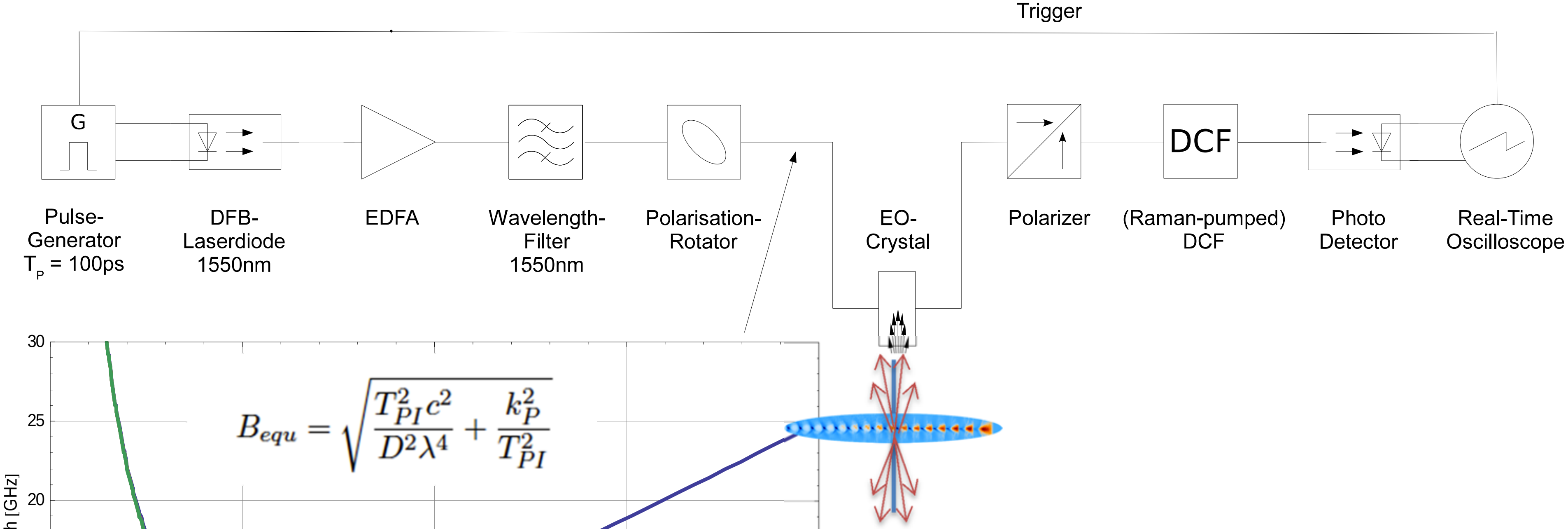
λp =1.3 mm ~ 4 ps @ n_e= 7 *10 ^{14} cm^{-3}

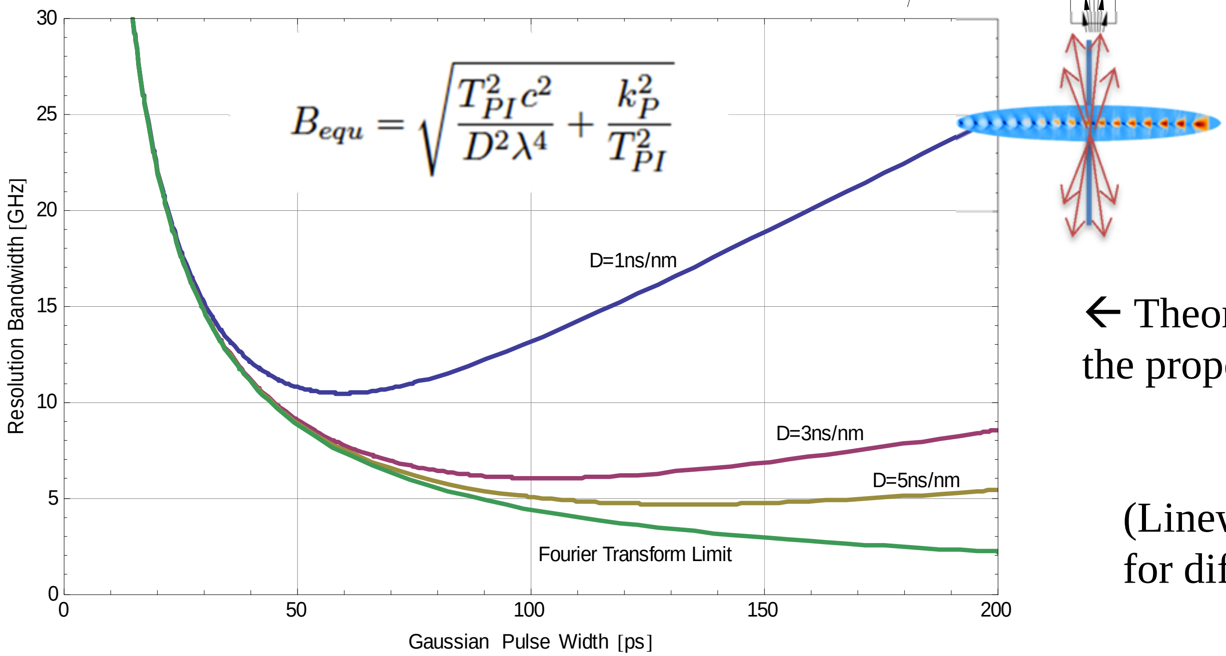
- Optical frequency for the measurement (@1550 nm)
  Short Optical pulse (~ 100 ps)
  (time slice from modulated p^+ bunch)
- Modulation by E-field of the plasma wake, via the EO effect
  (phase modulator)
- Frequency-time mapping
  (GVD in anomalous fiber)
- Real-time oscilloscope for detection of modulated optical signal



Principle setup for DFT method

* different time slices using many lasers.





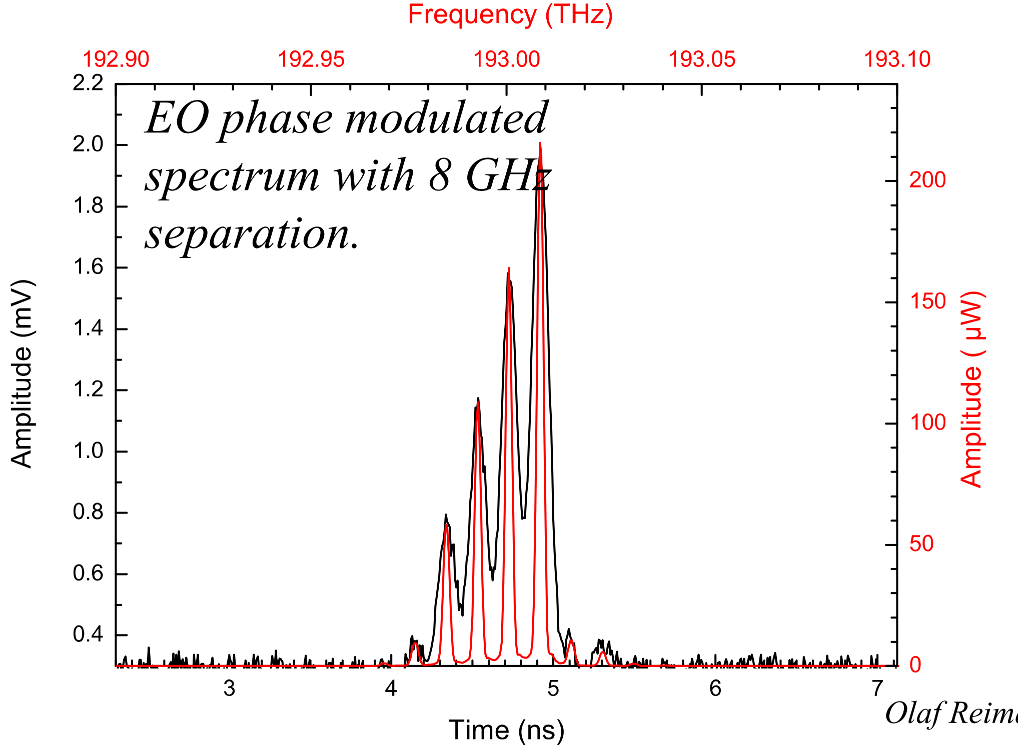
← Theoretical frequency resolution of the proposed setup

(Linewidth vs. input pulse width) for different fiber dispersions

Comparative measurement

- Black :Measurement using 8GHz BW real-time oscilloscope single shots by DFT method

- Red : averaged over 10^6 shots by optical spectrum analyzer



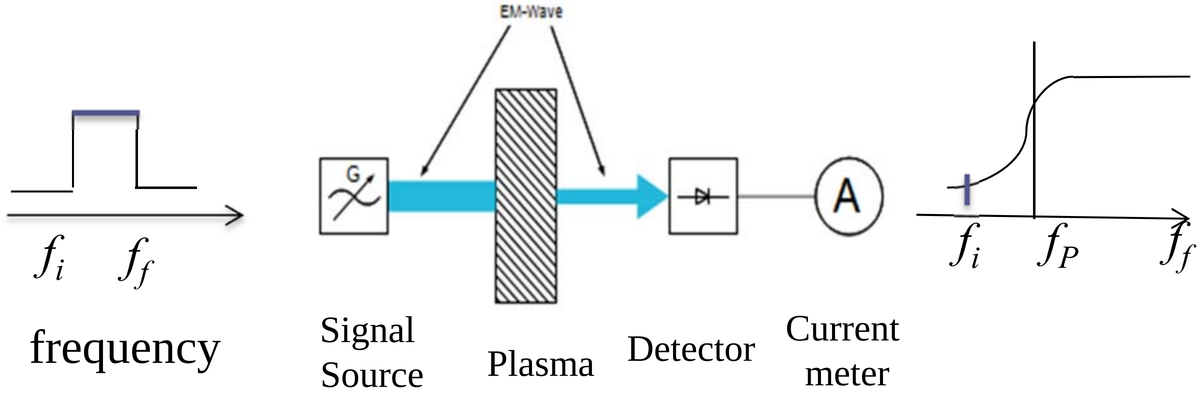
Olaf Reimann, CERN meeting, 2012

- Plasma Density measurements

Cutoff- frequency method

$\omega_p = (n_e e^2/\varepsilon_0 m_e)^{1/2}$

N_e (1/cm³)	f_p (GHz)
7e14	237.5
1e14	89.8
3e13	50
9e12	26
1e11	2.8



- Scanning over a frequency range (10 … 600 GHz)
- Measure the frequency dependent transmission (broadband detector)

Microwave/THz Generation & measurement

For $\delta n/n \sim 1\%$ → frequency resolution better than 500 MHz @ 10^{14} cm^{-3}

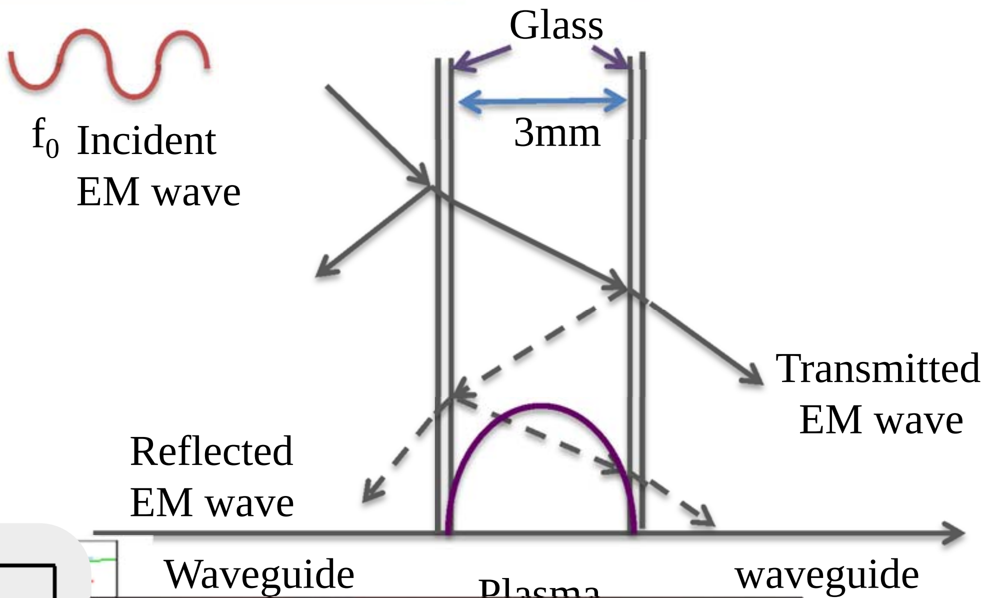
Analytical investigation

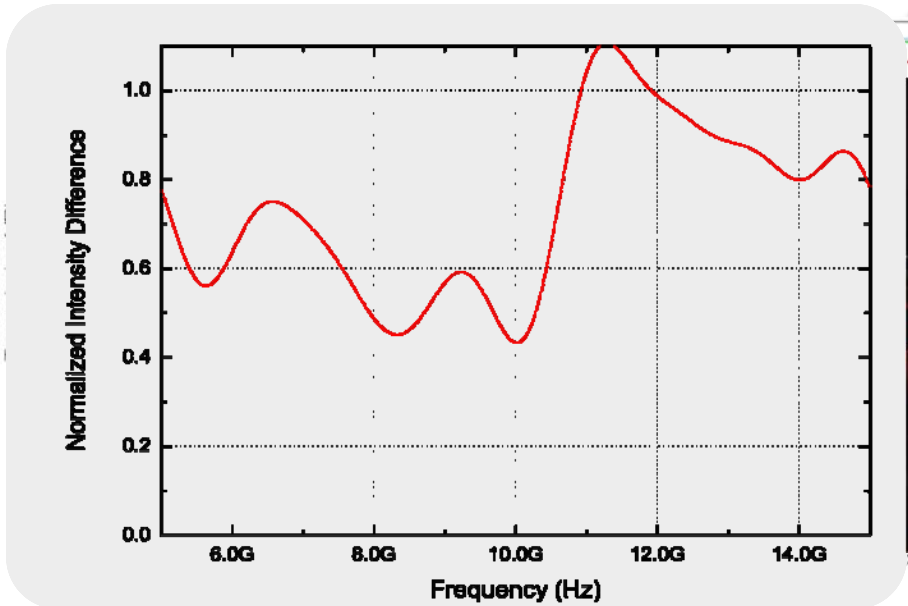
- Complex dielectric constant:

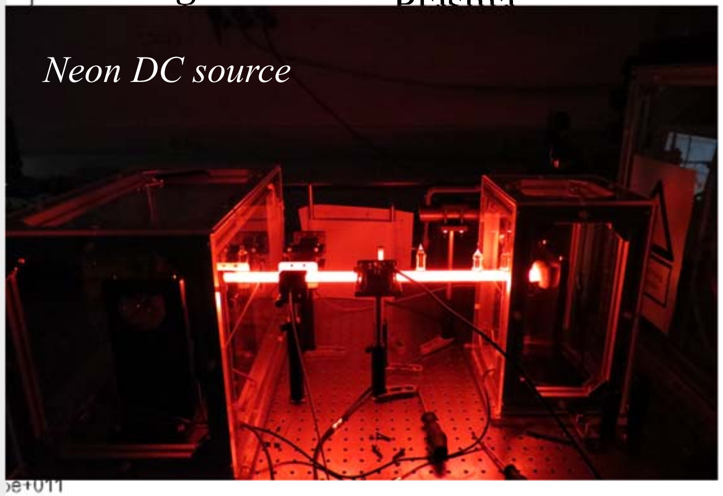
$$\varepsilon = 1 - \frac{\omega_P^2}{\omega^2 + \nu^2} + i\frac{\nu}{\omega}\frac{\omega_P^2}{\omega^2 + \nu^2}$$

- absorption coefficient

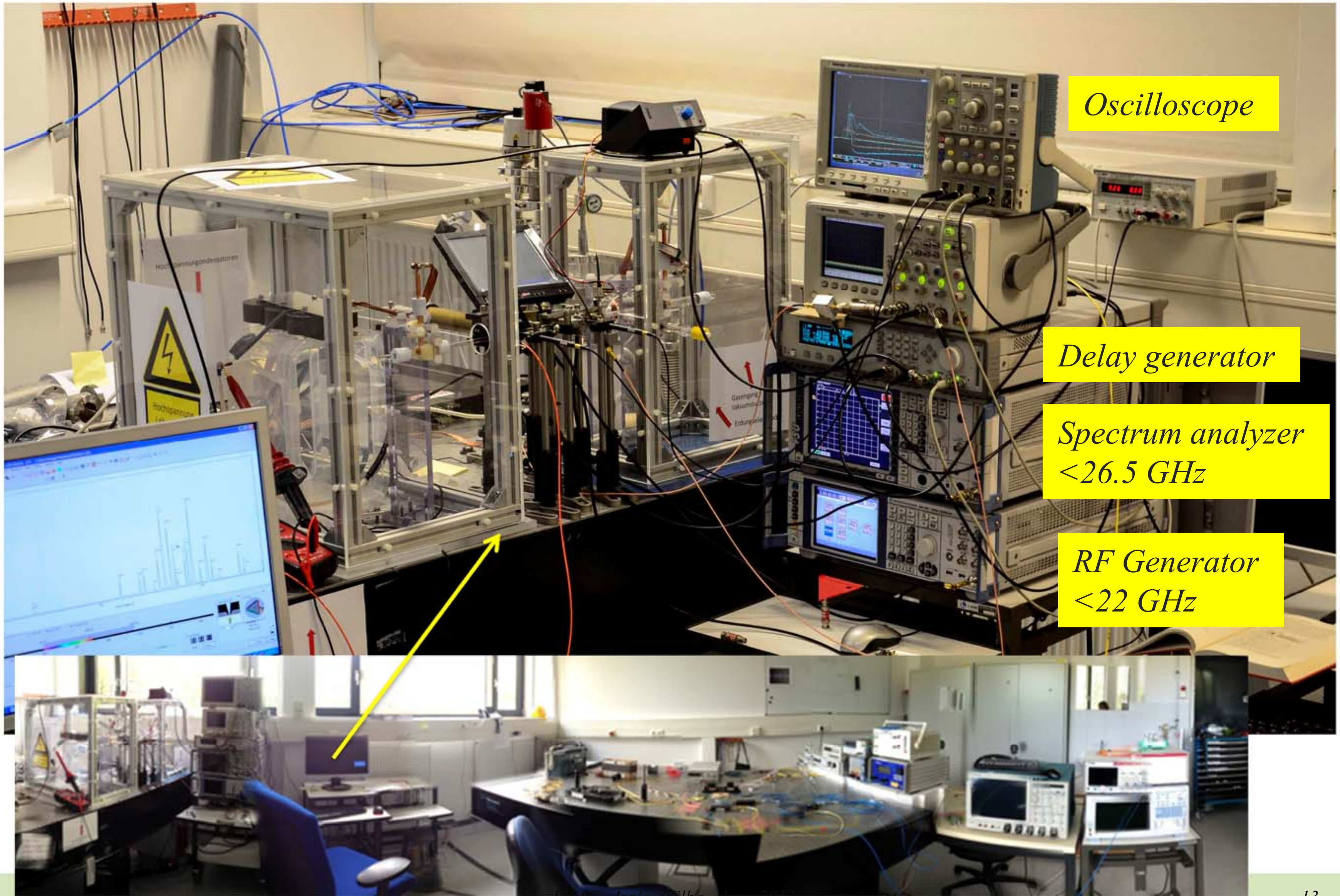
$$a = \frac{\omega}{c_0}\mathrm{Im}(\sqrt{\varepsilon})$$



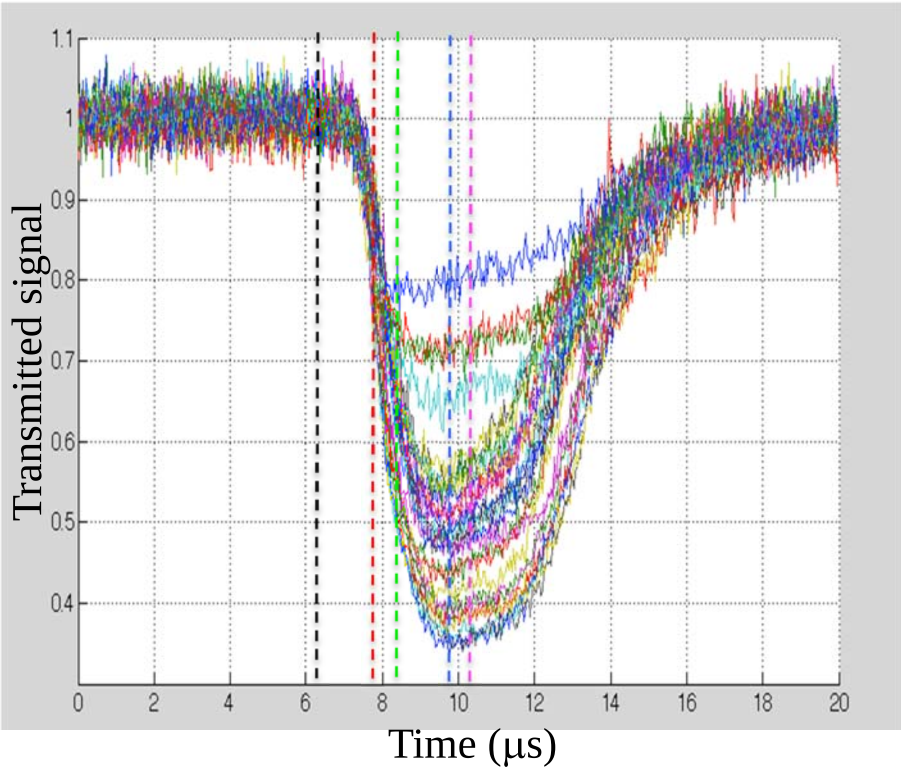


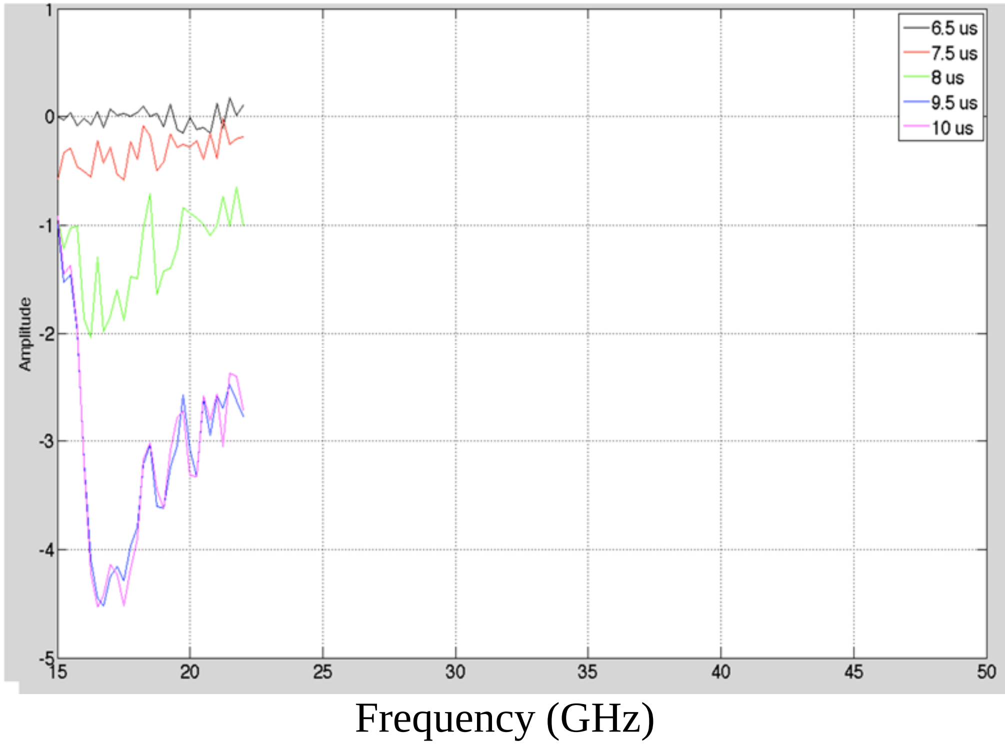


Experimental setup – Ar discharge source



Transmitted signal using Horn antenna & RF generator





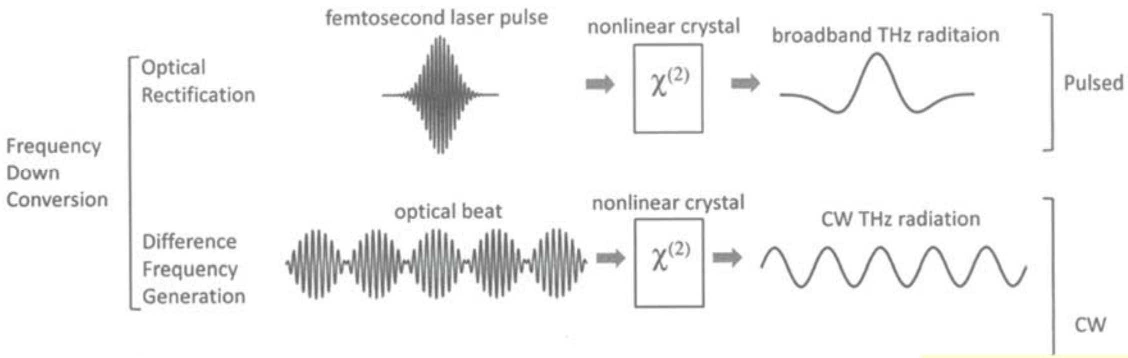
Parameter	Value
Frequency	15 -22 GHz
Sweep time	20 us
Pressure	0.531 mbar
Voltage	5.97kV

THz generation & detection

Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

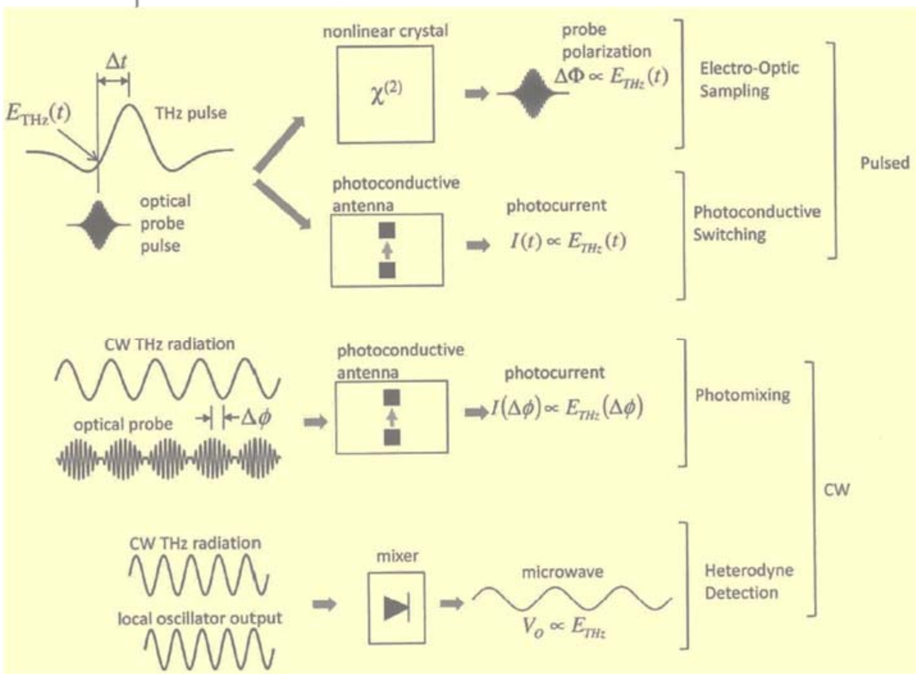
AWAKE

Non-linear optical techniques for the THz generation:



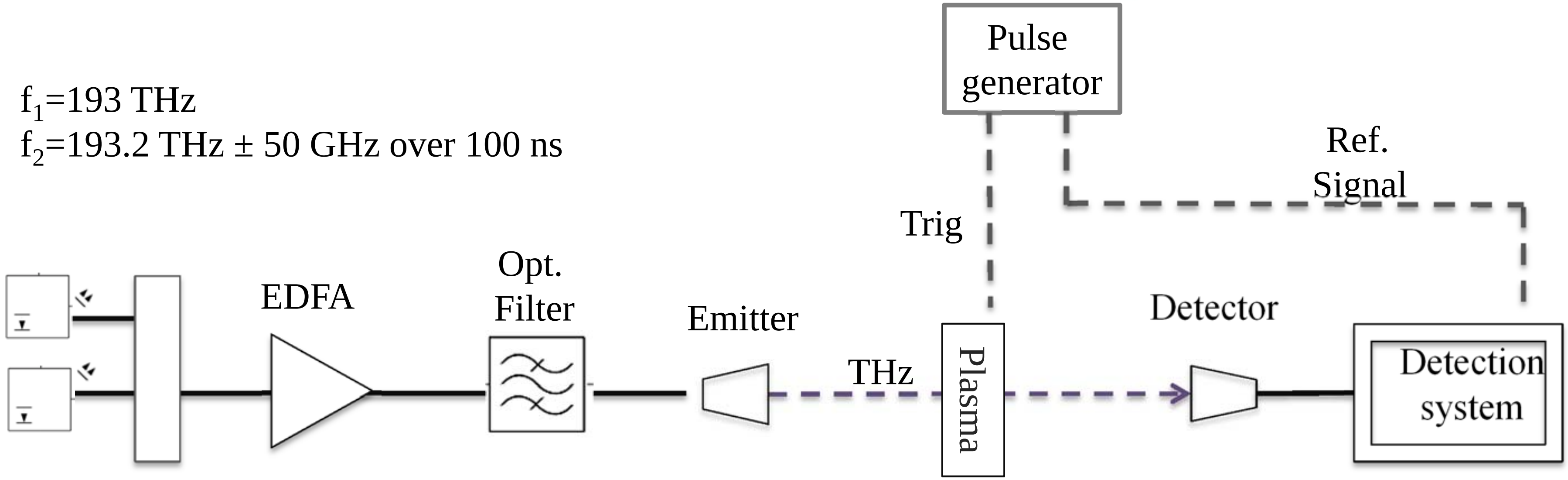
Y. Lee, THz science and technology, Springer, 2008

THz detection schemes →

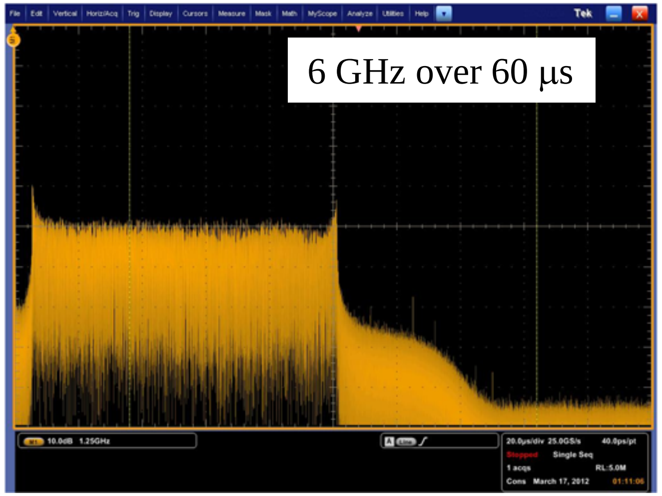


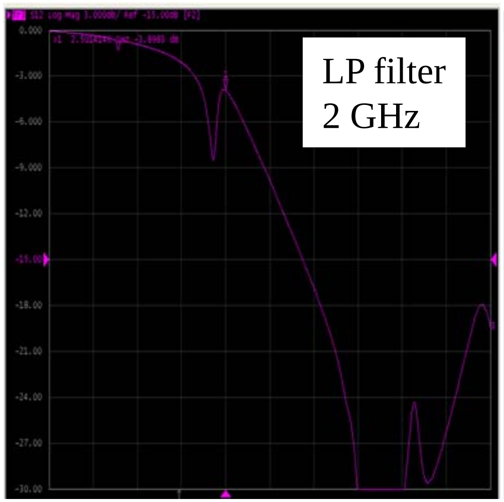
Chirp photo-mixing

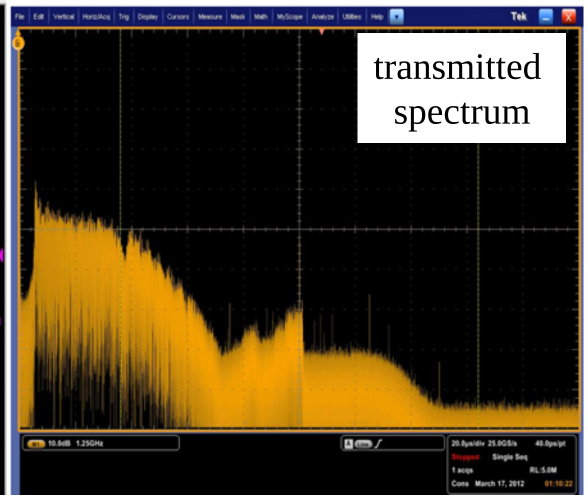
f_1=193 THz
f_2=193.2 THz ± 50 GHz over 100 ns



First test :



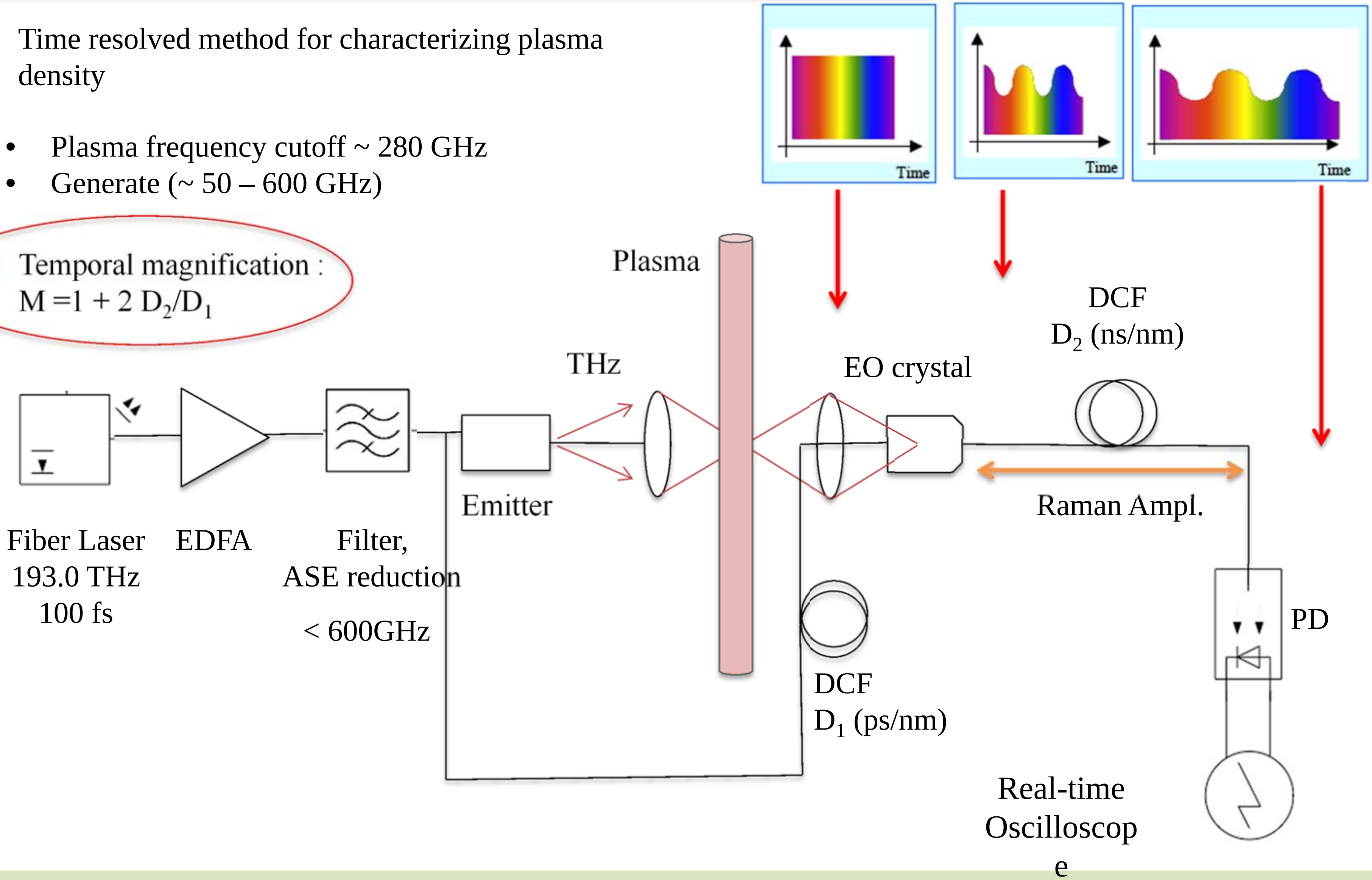




THz- time domain spectroscopy

- Time resolved method for characterizing plasma density
  - Plasma frequency cutoff ~ 280 GHz
  - Generate (~ 50 – 600 GHz)

- Temporal magnification : $M = 1 + 2\,D_2/D_1$



Optical emission spectroscopy (OES)

Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

AWAKE

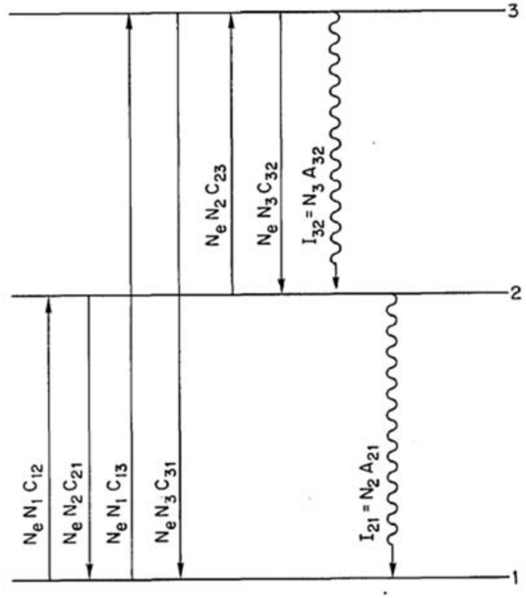
Density sensitive line-ratio measurement (LRM):

- building up a population model for a given pair of excited levels
- considering their dominant population and depopulation process
- density ratio of the two levels

$$\frac{I_{21}}{I_{31}} = \frac{n_2 A_{21}}{n_3 A_{31}}$$

- the ratio is a function of T_e, n_e ,…
  operating parameters (pressure, plasma dimension...)
- fitting the calculated ratio with the measured emission intensity ratio --> obtain plasma parameters

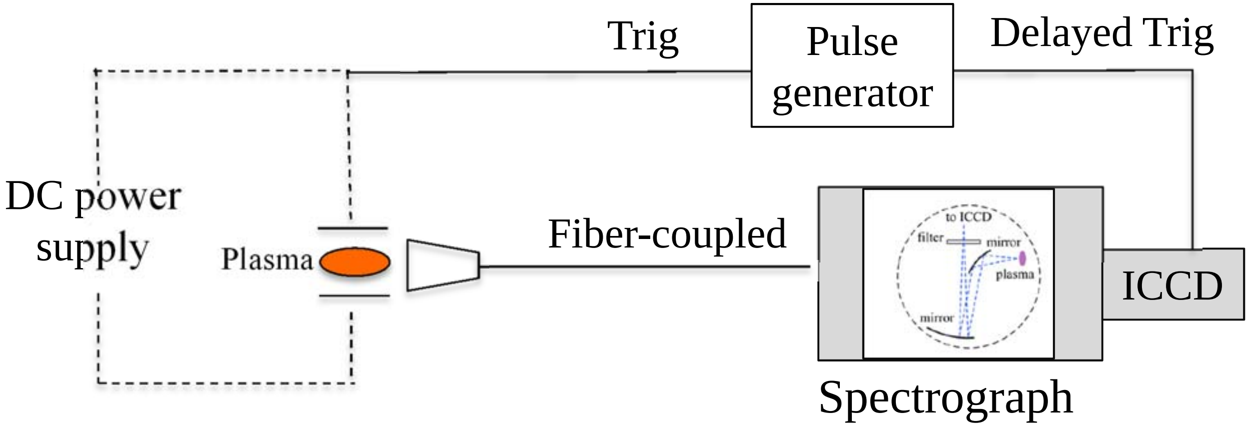
Finding sensitive lines …



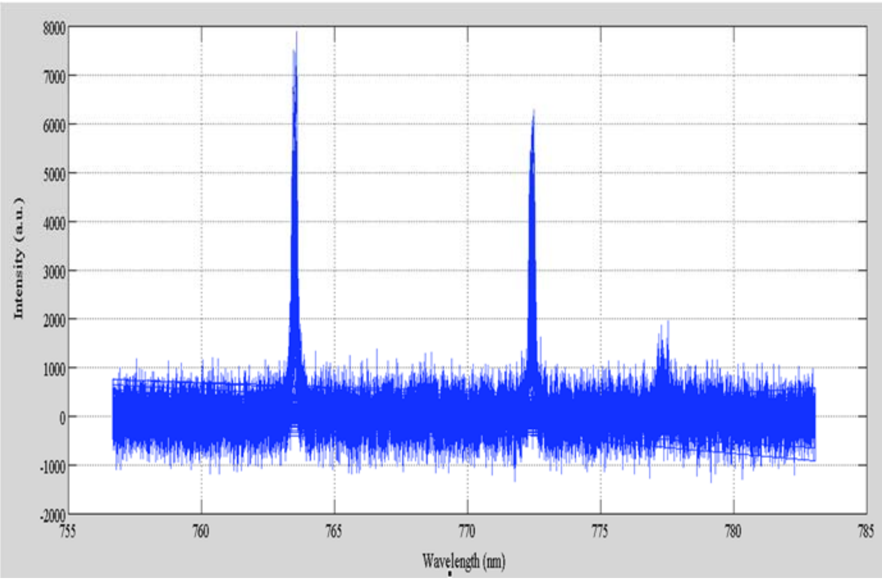
Feldmann, J.Opt. Soc. Am, 1977

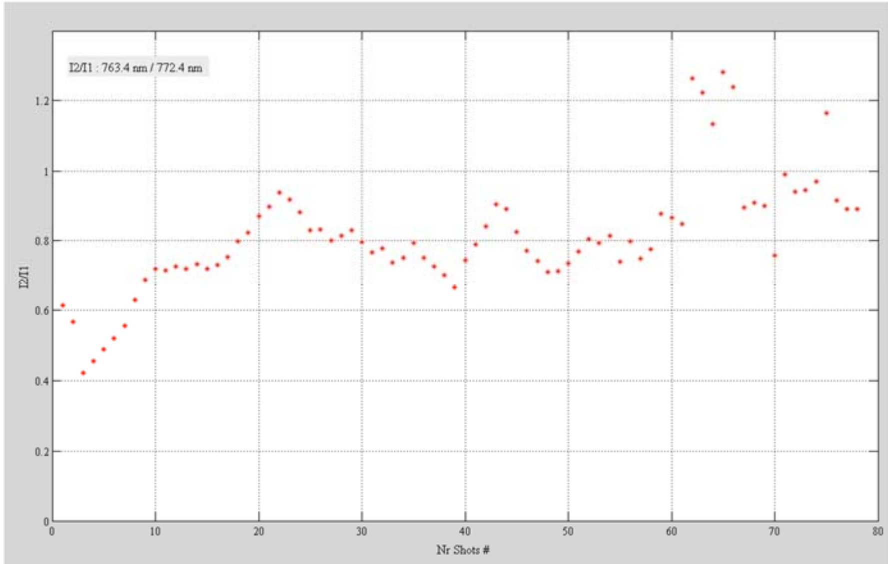
Hypothetical 3-level ion

Experimental setup for LRM

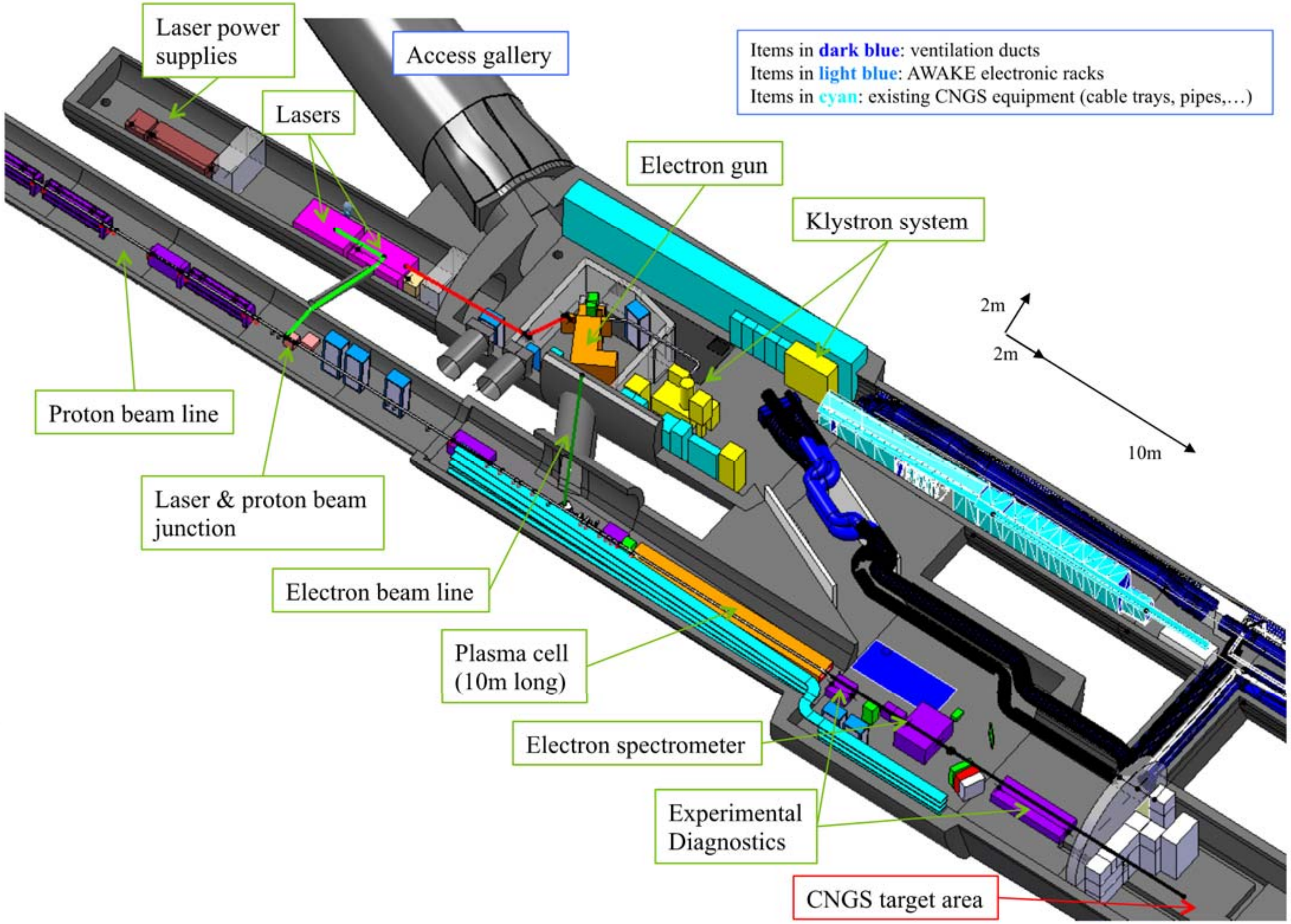


Measurement results oN argon DC source





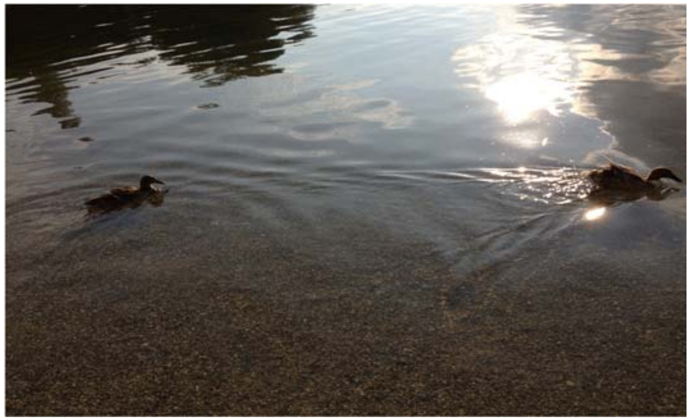
Integration at Cern



CERN group

Summary

- Test and improve the experimental setup (EO sampling, DFT, Time lensing)
  - laboratory scale
  - test of the setup at SLAC
  - test of the setup at Zeuthen
- Simulation for diagnostic purposes (by Scott Mandry)
- Improving the cutoff frequency measurement setup
- THz generation and detection scheme over 100 ns
- Line ratio measurement
  - Argon discharge source
  - Neon DC discharge source
  - Argon helicon discharge source in Greifswald



Thanks for your attention!