Characterization of single-cycle THz pulses at the CTR source at FLASH

Steffen Wunderlich[1]
Matthias C. Hoffmann[2], Sebastian Schulz[1],
Stephan Wesch[1], Laurens Wißmann[1], and Bernhard Schmidt[1]

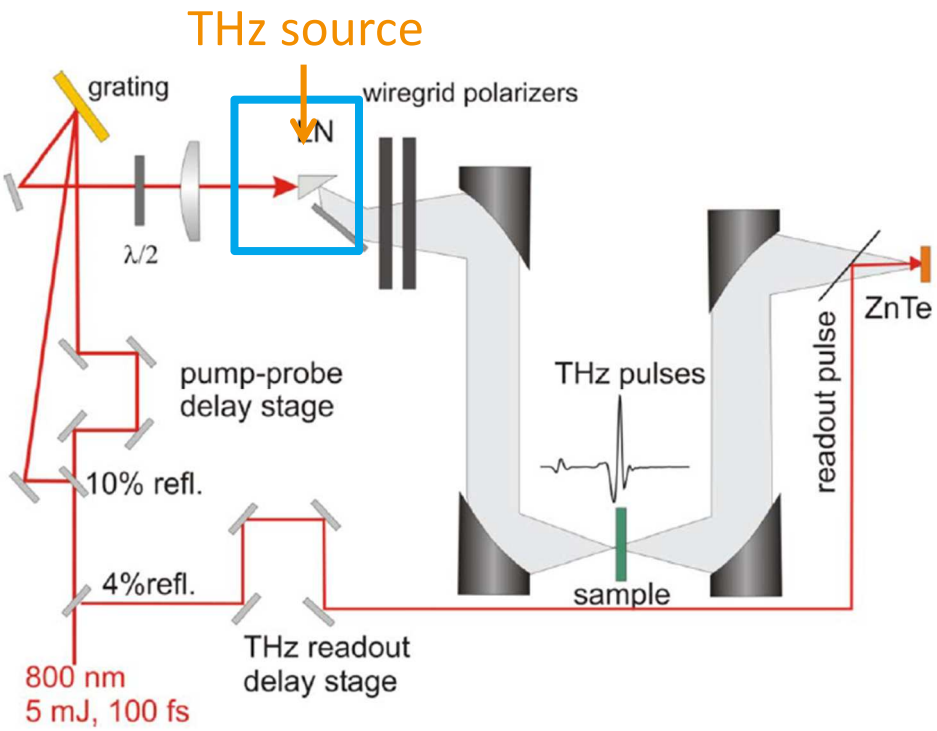
[1] Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany
[2]SLAC National Accelerator Laboratory, Menlo Park, CA, USA

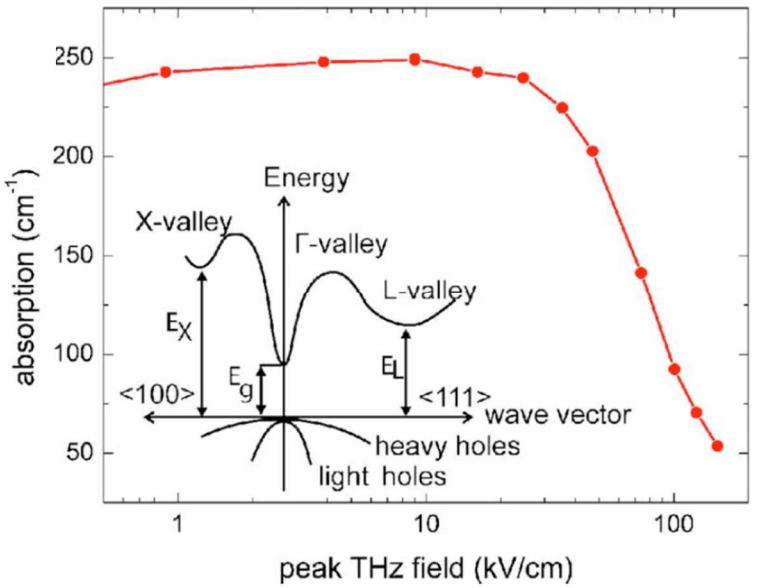
DPG Tagung Göttingen – 01.03.2012

Introduction

» THz pump / THz probe of semiconductors

$1\ \mathrm{THz} \mathrel{\widehat{=}} 300\ \mu\mathrm{m} \mathrel{\widehat{=}} 4.1\ \mathrm{meV} \Rightarrow$ mobility of free carriers in n-type GaAs





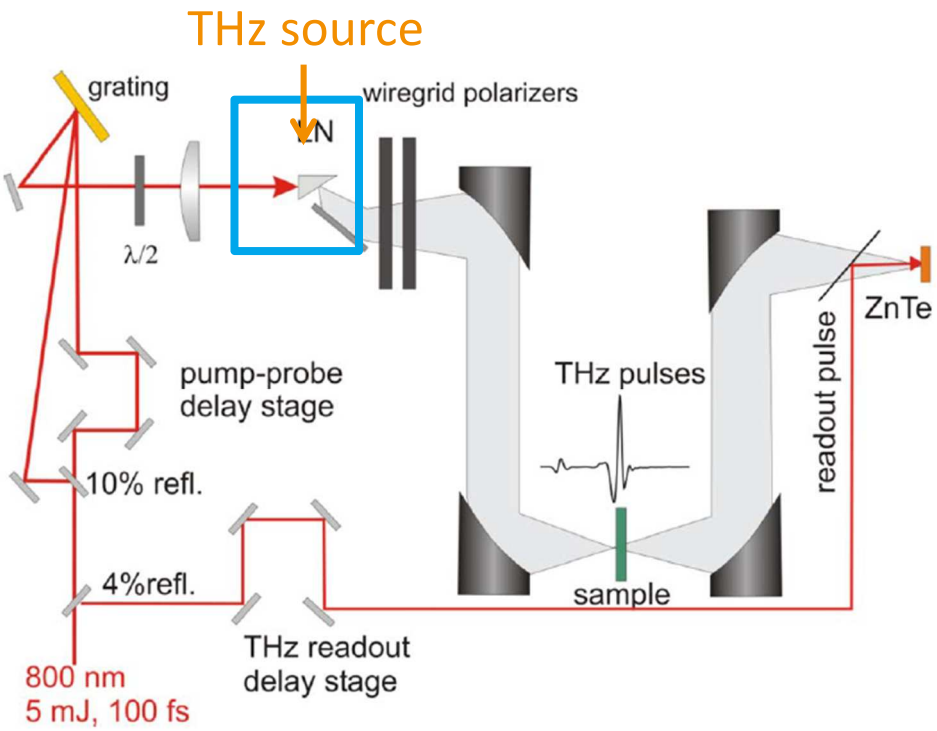
of the pump beam

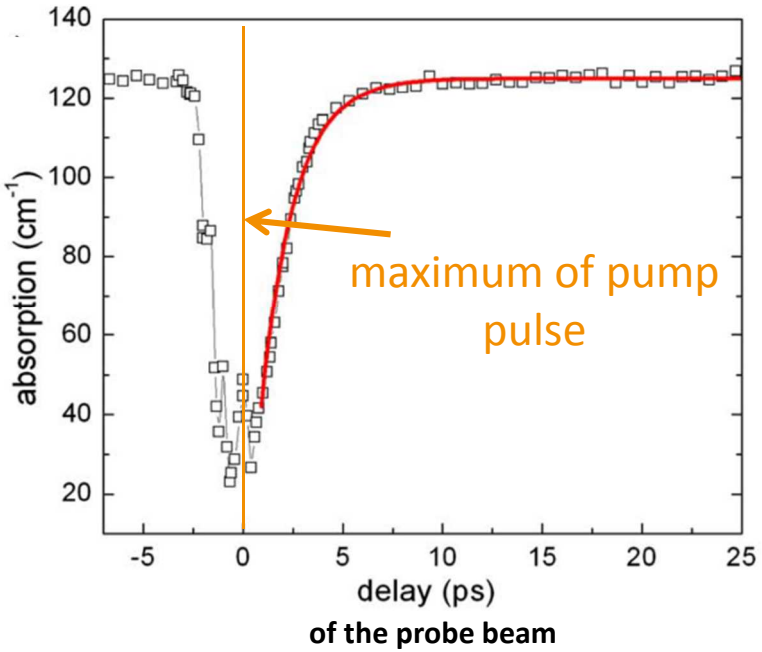
[1] (all)

Introduction

» THz pump / THz probe of semiconductors

$1\ \mathrm{THz} \mathrel{\widehat{=}} 300\ \mu\mathrm{m} \mathrel{\widehat{=}} 4.1\ \mathrm{meV}$ ⇒ mobility of free carriers in n-type GaAs





of the probe beam

[1] (all)

Introduction

- Pulsed THz sources
  - » photoconductive switches
  - » optical rectification

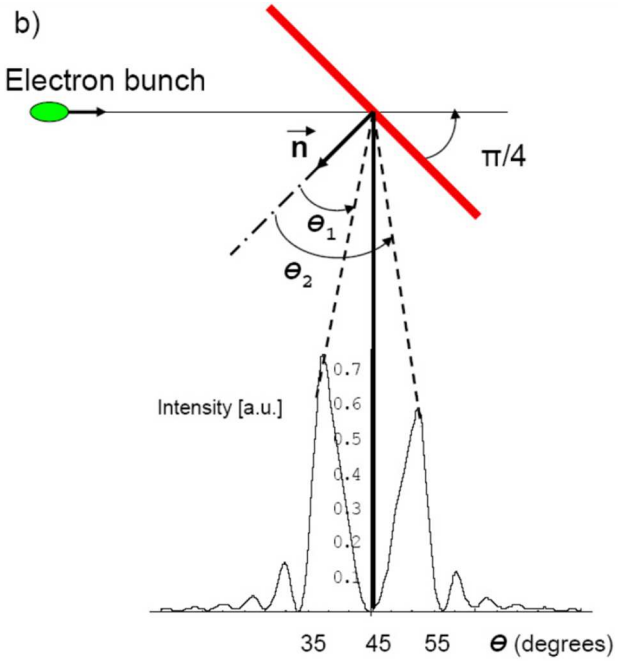
} laser-driven

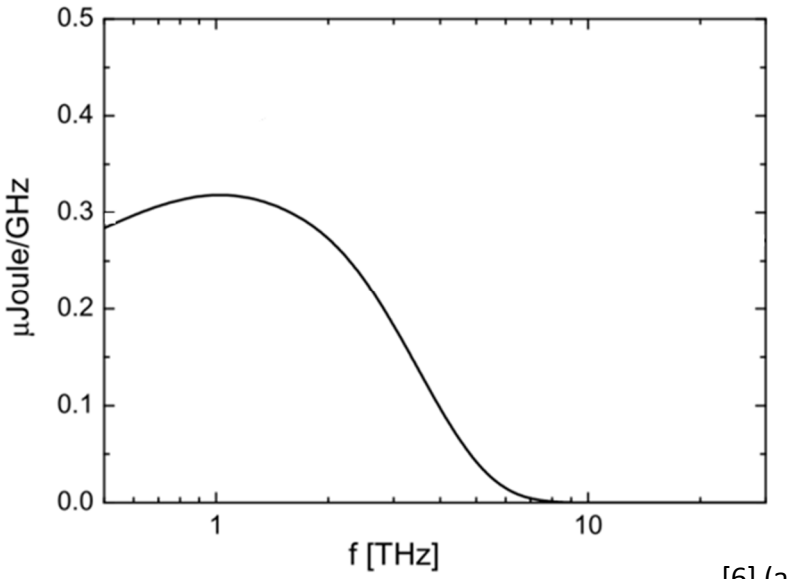
  - » free-electron laser
  - » undulator radiation
  - » coherent transition radiation

} accelerator-driven

Background

- Coherent transition radiation (CTR)
  - » angular distribution in the far field
    intensity maximum at $\theta = \gamma^{-1}$
  - » spectrum (Gaussian bunch):





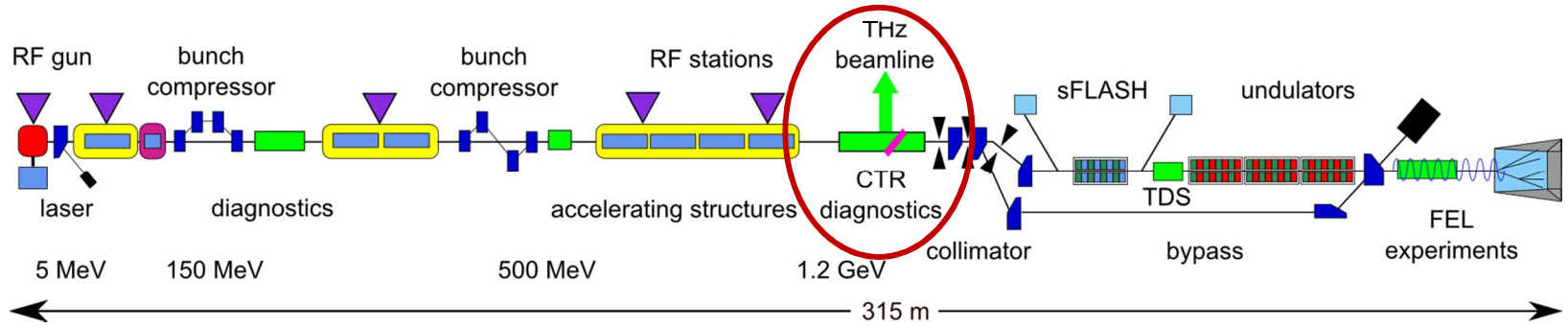
[6] (all)

far field $D > \gamma^2 \lambda$

$\gamma = 1000, \lambda = 0.3\ \text{mm} \rightarrow D = 300\ \text{m}$

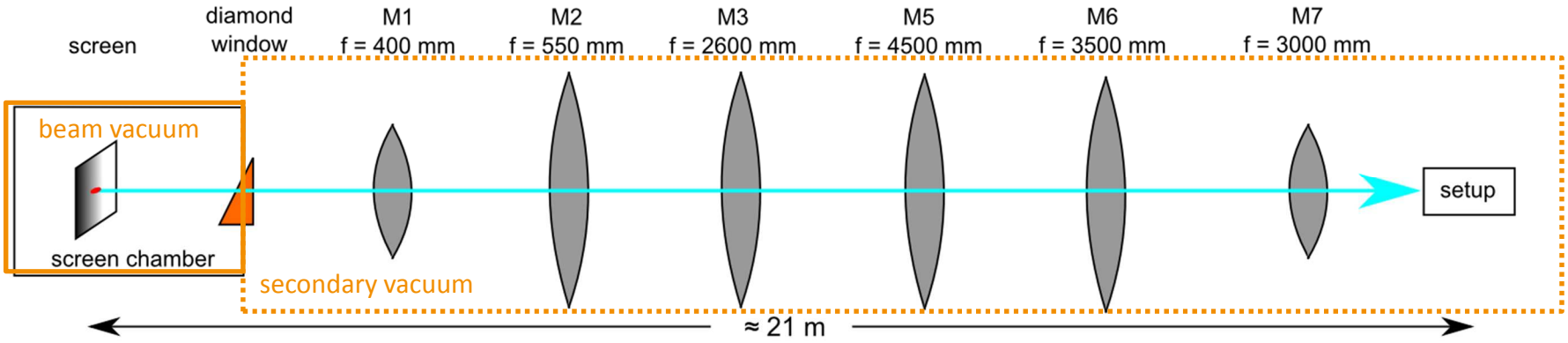
Background

- The THz-beamline at FLASH



[7]

screen material: 150 nm aluminum on 380 µm silicon



Background

- The electro-optic (EO) effect

  polarization induced by an electric field

in general: $\vec{P} = \epsilon_0 \chi \vec{E}$

$$= \epsilon_0 \left(\chi_e^{(1)} \vec{E} + \chi_e^{(2)} \vec{E}^2 + \chi_e^{(3)} \vec{E}^3 + \ldots \right)$$

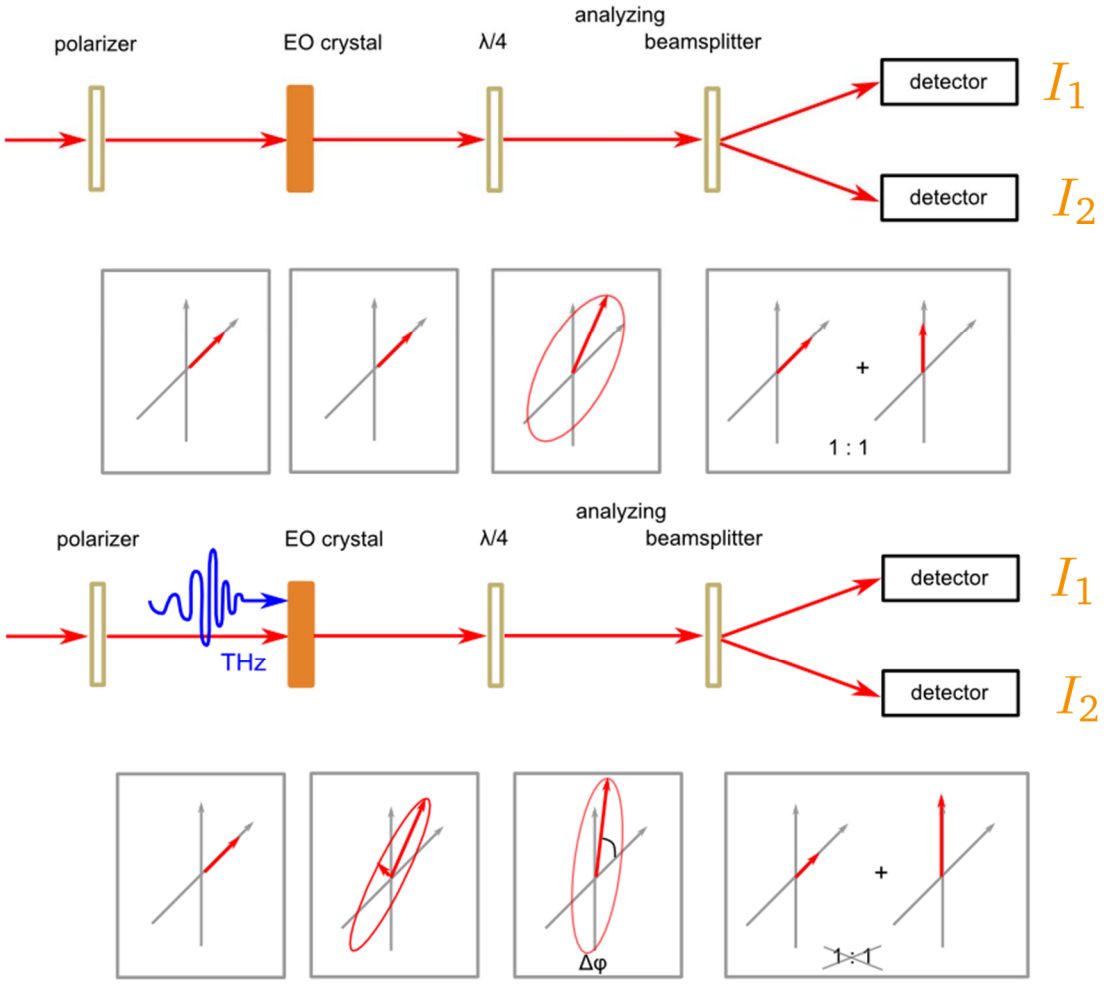
$\Delta n \propto E$ Pockels

$\Delta n \propto E^2$ Kerr

linear EO effect

[9]

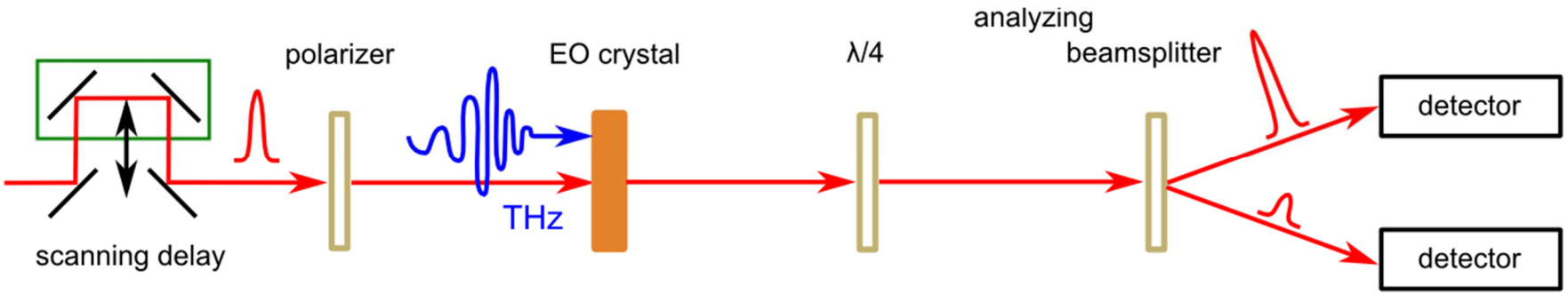
Background

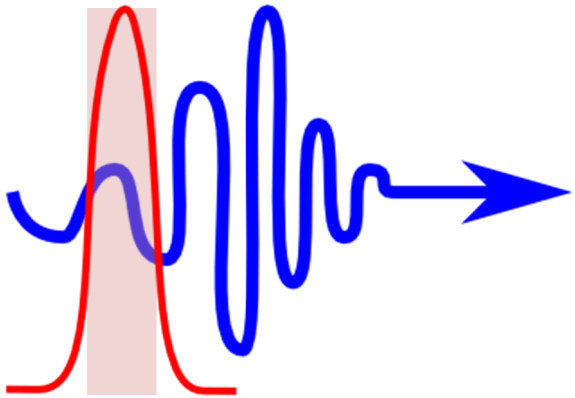


$$\Gamma(\alpha) = \frac{\pi\, d}{\lambda}\, n_0^3\, E_{\mathrm{THz}}\, r_{41} \sqrt{1 + 3\cos^2(\alpha)} = \sin^{-1}\left(\frac{I_1 - I_2}{I_1 + I_2}\right)$$

Background

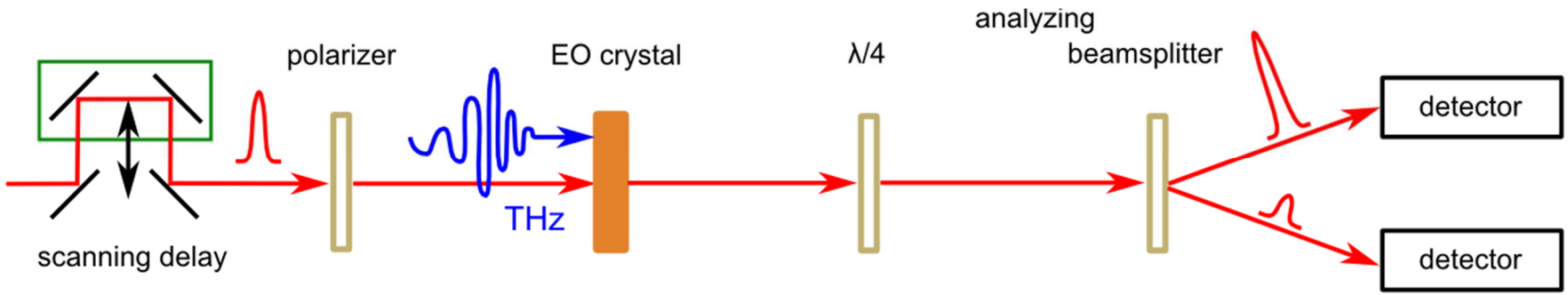
- Sampling

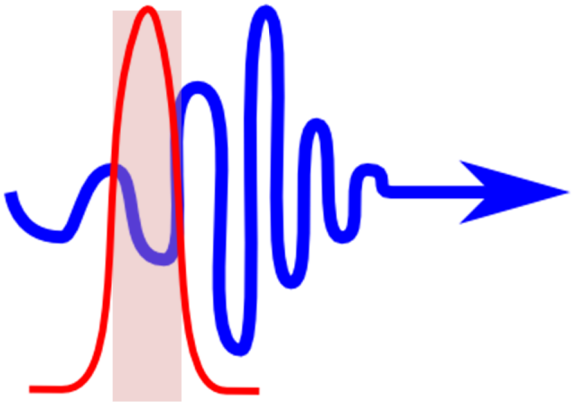




Background

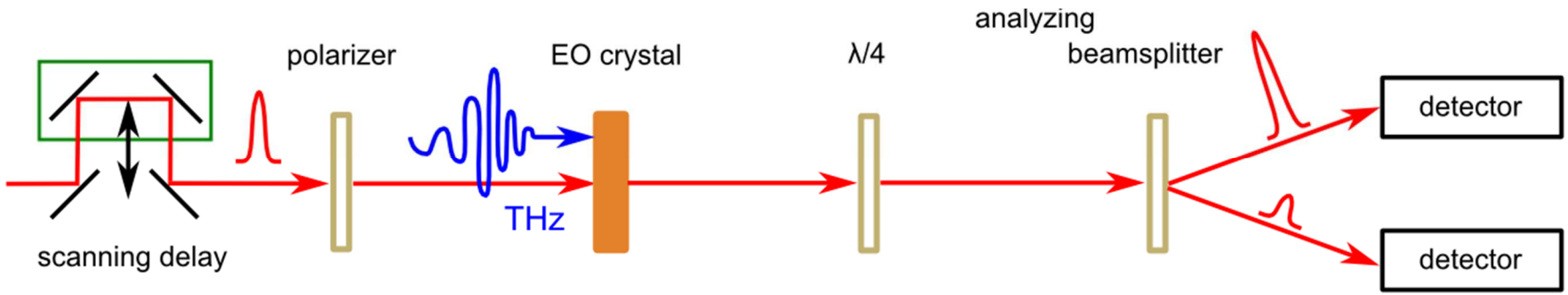
- Sampling

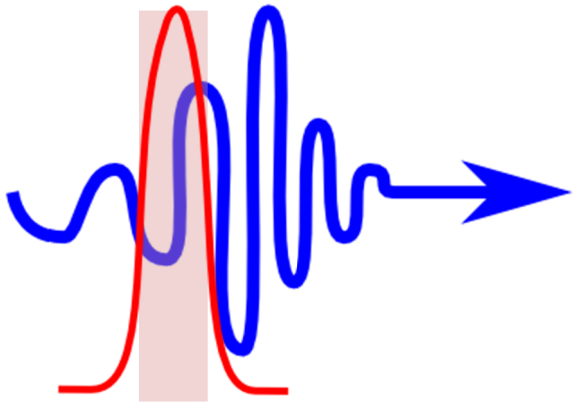




Background

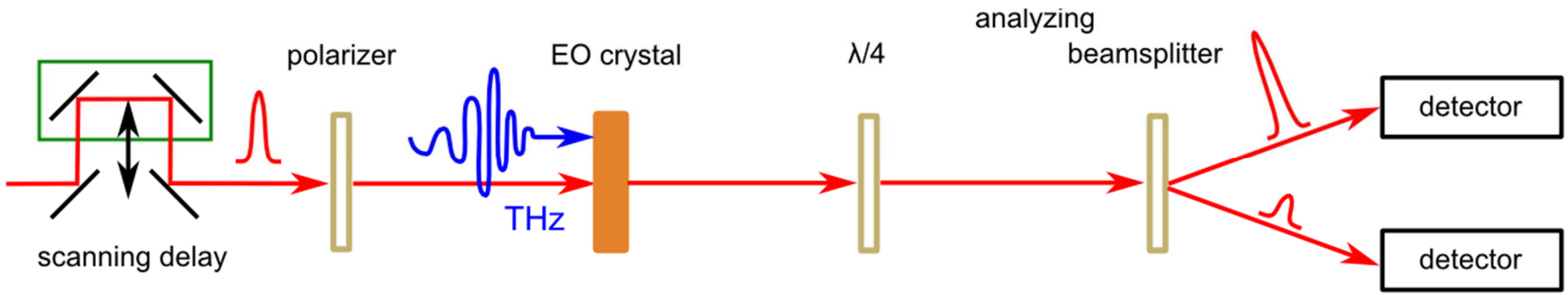
- Sampling

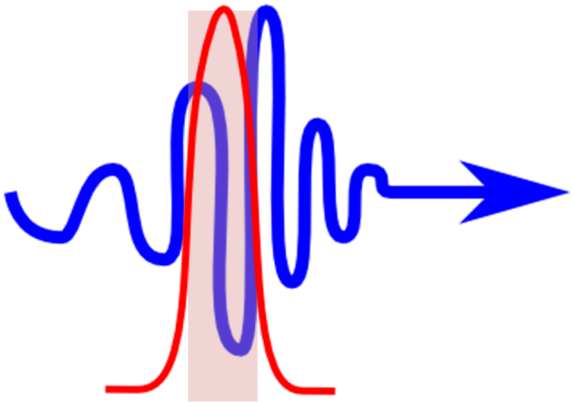




Background

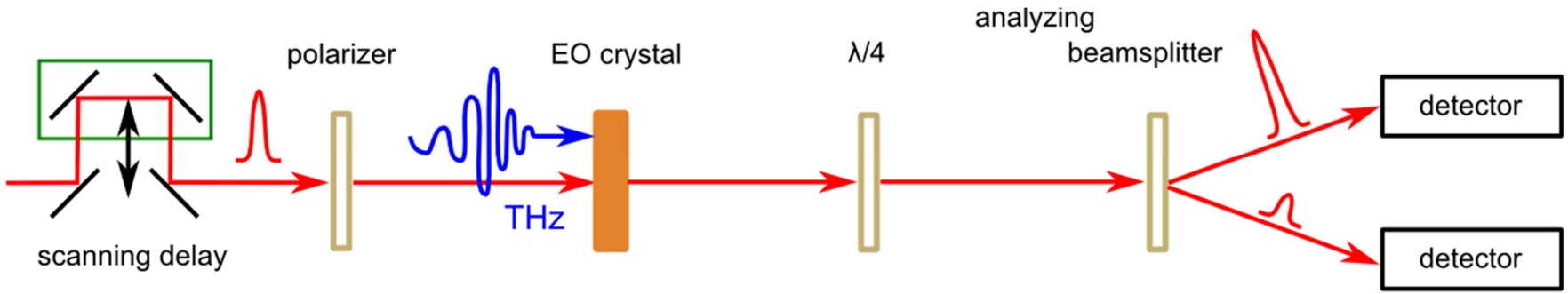
- Sampling

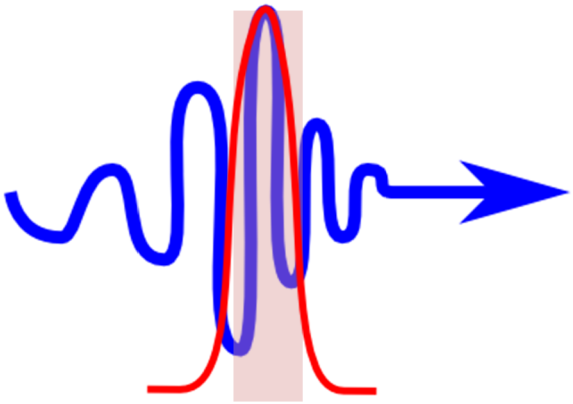




Background

- Sampling





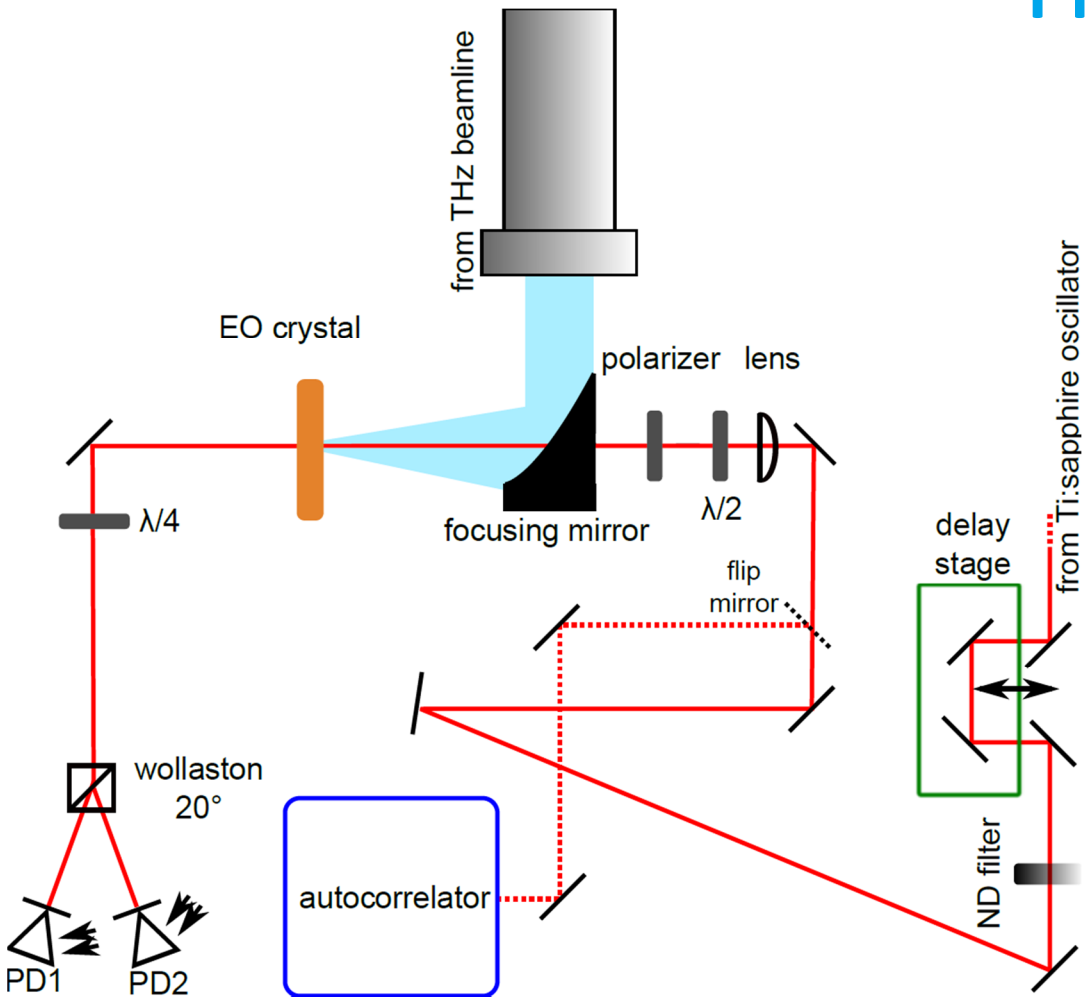
laser pulse width

$t_{\mathrm{FWHM}} \approx 30$ fs

synchronization
laser – electron bunch

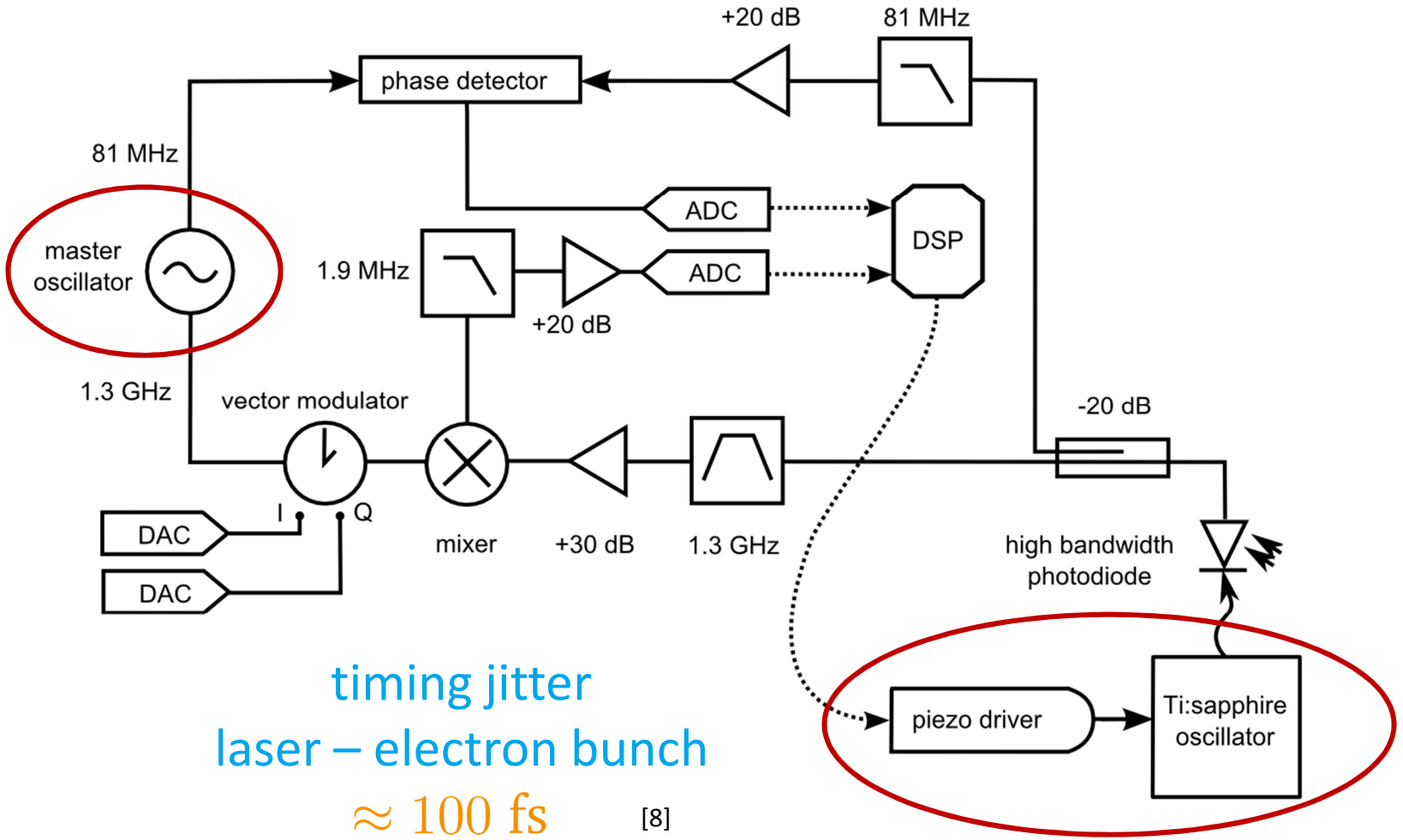
≈ 100 fs [8]

The Experiment



The Experiment

- Synchronization



timing jitter
laser – electron bunch
≈ 100 fs [8]

The Experiment

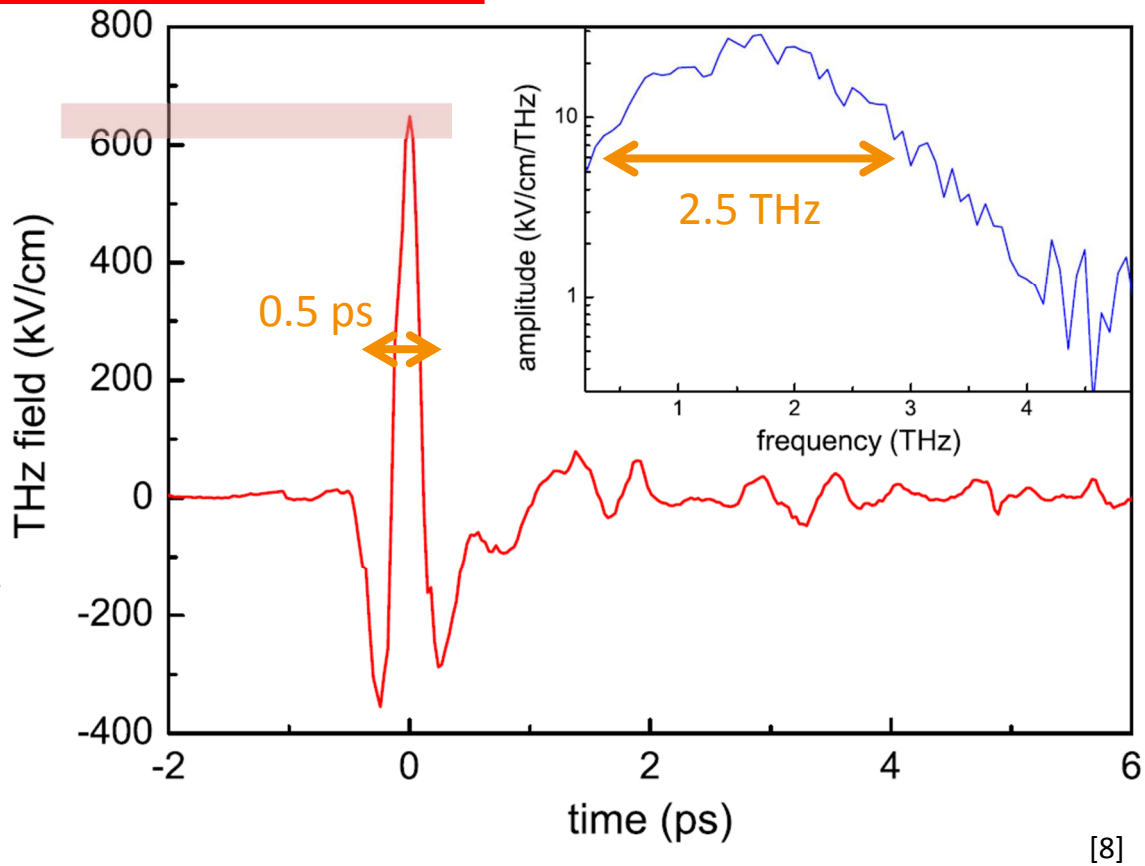
- Results

GaP 0.2 mm
vacuum

SASE parameters
700 MeV
0.6 nC

$> 1\ \mathrm{MV/cm}\ @\ 100\ \mu\mathrm{J}$

with attenuation of 2



[8]

Outlook

Use CTR source for experiments
for nonlinear optics, material science…

- Optimization of electron beam parameters for output power
- Benefit from the laser-based synchronization

Summary

CTR source of THz pulses with world-leading field strengths and bandwidth for various applications

$1\ \mathrm{MV/cm} @ 100\ \mu\mathrm{J}$

References and further reading

1 Hoffmann, M.C., Hebling, J., Hwang, H.Y., Yeh, K.-Lo & Nelson, K.A. THz-pump/THz-probe spectroscopy of semiconductors at high field strengths. *J. Opt. Soc. Am. B* 26, 29-34 (2009).

2 Hoffmann, M.C. & Fülöp, J.A. Intense ultrashort terahertz pulses: generation and applications. *Journal of Physics D: Applied Physics* 44, 083001 (2011).

3 Fruhling, U. et al. Single-shot terahertz-field-driven X-ray streak camera. *nature photonics* 3, 523-528 (2009).

4 Michel, P. et al. First lasing of the ELBE MID-IR FEL. Proceedings of the 2004 FEL Conference (2004)

5 Oepts, D., Van Der Meer, A.F.G. & Van Amersfoort, P.W. The Free-Electron-Laser user facility FELIX. Infrared Physics and Technology 36, 297-308 (1995).

6 Casalbuoni, S., Schmidt, B. & Schmüser, P. Far-Infrared Transition and Diffraction Radiation Basics Part 1: Elements of Diffraction Theory. *TESLA Report 2005-15* (2005).

7 Schreiber, S. et al. FLASH upgrade and first results. Proceedings of FEL2010 198-201 (2010).

8 Hoffmann, M.C. et al. Coherent single-cycle pulses with MV/cm field strengths from a relativistic transition radiation light source. *Optics letters* **36**, 4473-4475 (2011).

9 Griffiths, D.J. Introduction to Electrodynamics. Prentice Hall (1999).