A Double-Prism Spectrometer for the Longitudinal Diagnosis of fs-Electron Bunches with Mid-Infrared Transition Radiation.

Steffen Wunderlich[@], Eugen Hass, Minjie Yan and Bernhard Schmidt

Deutsches Elektronen-Synchrotron DESY, 22603 Hamburg, Germany

Motivation.

- The operation of free-electron lasers delivering x-ray pulses with femtosecond lengths requires electron bunch lengths in the same order of magnitude
- Electron bunch lengths on the sub-10 fs scale are a also direct consequence from the process of laser-driven plasma wake field acceleration
- Spectroscopy of characteristic radiation of these bunches is an attractive and cost-effective method to measure the bunch length
- The capability for single-shot operation and an increased sensitivity to handle decreasing bunch charges < 10 pC are key requirements for conventional and novel acceleration concepts

Coherent transition radiation (CTR) of femtosecond electron bunches.

- Coherent spectrum carries bunch length information [1]

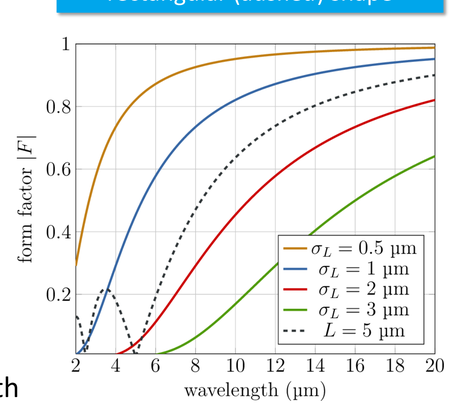
$$\frac{\mathrm{d}^2U}{\mathrm{d}\omega\,\mathrm{d}\Omega} \approx \frac{\mathrm{d}^2U_1}{\mathrm{d}\omega\,\mathrm{d}\Omega}\, N^2\, |F(\omega,\Omega)|^2$$

with the form factor

$$F(\omega,\Omega) = F(\vec{k}) = \int_{-\infty}^{\infty} \rho_{3\mathrm{D}}(\vec{r})\, \exp(-i\,\vec{k}\,\vec{r})\,\mathrm{d}\vec{r}$$

- Phase retrieval processes can access a possible time-domain profile, showing an impressive agreement with direct time-domain diagnostics [2]

Form factors for lengths < 10 fs for 3D Gaussian (*solid*) and rectangular (*dashed*) shape



Double-Prism Spectrometer.

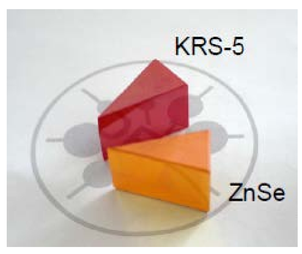
Dispersive stage – ZnSe prisms

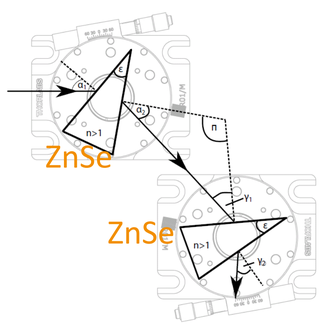
wavelength range (2 – 18) µm

- Continuous dispersion without higher orders
- Double-prism design to adapt the dispersion to the detector array

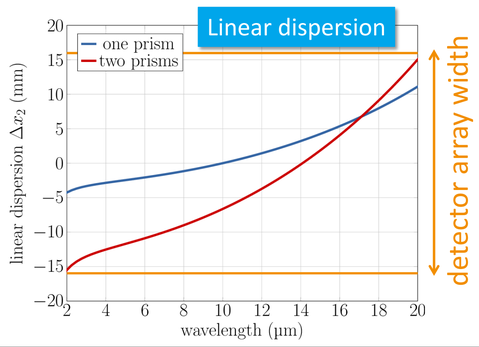
Detector System – Mercury Cadmium Telluride (HgCdTe, MCT)

- Sensitivity ≈ 100 times higher than for pyro-electric detectors
- Line-array of 128 elements (InfraRed Associates Inc.)
- Parallel read-out electronics for single-shot operation
- Cooled to 77 K for low-noise operation

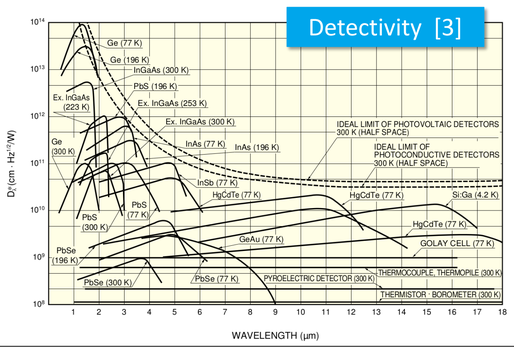




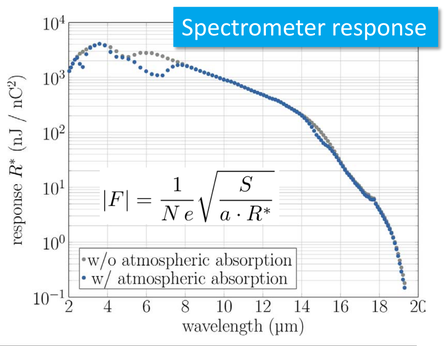
Linear dispersion



Detectivity [3]



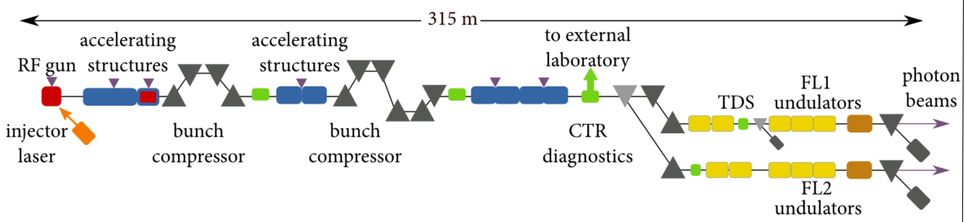
Spectrometer response



Measurements at FLASH.

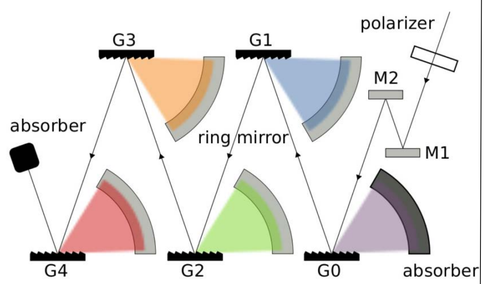
- Measurements taken at the CTR source at FLASH at DESY in Hamburg
- Spectrometer is set up and calibrated using band pass filters between (2 – 16) µm
- Cross-calibration with calibrated multi-stage grating spectrometer CRISP4 [1, 2]
- Comparative measurements conducted for two bunch compression settings
- Bunch lengths ~ 50 fs (rms) according to the transverse deflecting structure (TDS)
- Bunch charges of 232 pC (setting 1) and 146 pC (setting 2)
- Beam energy 970 MeV

Overview of the FLASH facility



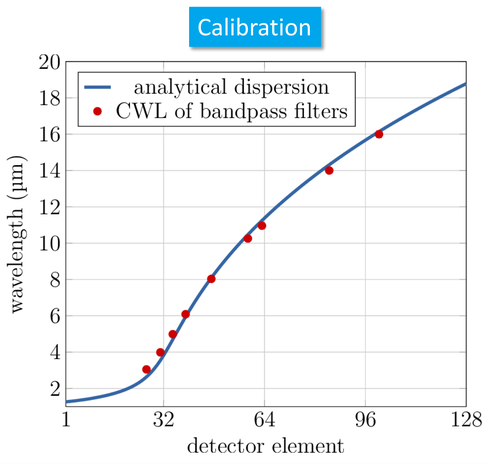
Multi-stage spectrometer CRISP4

- Two sets of four gratings covering (5 – 430) µm
- 120 calibrated pyro-electric detectors
- Retrieved time-domain profiles in striking accordance with the transverse deflecting structure (TDS)

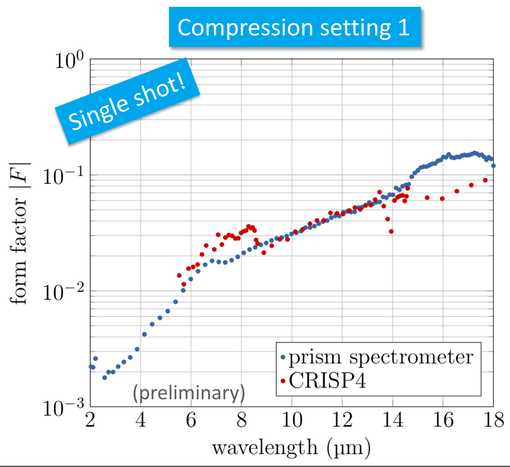


[2]

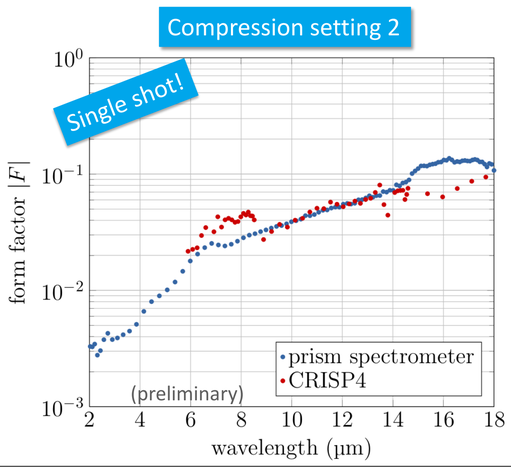
Calibration



Compression setting 1



Compression setting 2



Summary & Outlook.

- Double-prism spectrometer for sub-10 fs electron bunches yielding pC charges
- Single-stage measurements from (2 – 18) µm in a single-shot with a detector array providing a high signal-to-noise ratio
- Agreement with established diagnostics
- Absolute detector response under investigation: calibration at an intensity and wavelength standard in preparation

References.

other prism spectrometer setups e.g. at HZDR (multi-path, single-prism, MCT) [4] and LCLS (single-prism, pyros) [5]

[1] S. Wesch et al., NIM A, 665, 40 (2011).
[2] E. Hass et al., Proceedings of IBIC 2013, Oxford, UK, pp. 154-7, MOPC37
[3] Hamamatsu Solid State Division, Technical Information SD-12 (2011)
[4] O. Zarini, A. Debus et al., DPG-Frühjahrstagung Göttingen 2013 (Poster), T 129.17
[5] T. J. Maxwell et al., Phys. Rev. Lett. 111, 184801 (2013)

Further references can be found in the proceedings contribution.

3rd International Beam Instrumentation Conference
Monterey, CA, USA
September 14 – 18, 2014 – Contribution MOPD08

[@] **contact:**
steffen.wunderlich@desy.de

The project has been supported by the BMBF under contract 05K10GU2 & FS FLASH 301.

HELMHOLTZ ASSOCIATION