Electron bunch length characterization at the Metrology Light Source using THz radiation

A. Pohl [1, 2], N. Deßmann [1,2], A. Hoehl [3], R. Müller [3], G. Ulm [3], M. Ries [4], G. Wüstefeld [4], S. Pavlov [2], and H.-W. Hübers [1, 2]

[1] Department of Physics, Humboldt-University of Berlin, Newtonstr. 15, 12489 Berlin, Germany
[2] Institute of Optical Sensor Systems, DLR e.V., Rutherfordstrasse 2, 12489 Berlin, Germany
[3] Physikalisch-Technische Bundesanstalt (PTB), Abbestrasse 2-12, 10587 Berlin, Germany
[4] HZB für Materialien und Energie, Albert-Einstein-Str. 15, 12489 Berlin, Germany

Introduction

The development of electron storage rings emitting ultra-short and brilliant pulses in the THz range made significant progress over the last decade [1]. The Metrology Light Source (MLS) is the first electron storage ring with a dedicated electron optics for low-alpha operation and an optimized THz beamline [2]. Both are necessary for the generation of stable high power THz coherent synchrotron radiation (CSR) [3]. The emitted CSR power depends on the length and the shape of the electron bunch [4], [5]. For analysis of the picosecond THz pulses spectrally resolved autocorrelation (SRAC) and cross-correlation measurements are a promising tool [6].

Experimental Setup

In order to generate two collinear beams from the THz pulses we utilize a Martin-Puplett interferometer type approach. As shown in Fig. 1 the divergent THz beam is collimated from its intermediate focus by an off-axis parabolic mirror (f = 450 mm). A free standing wire grid divides the incoming horizontally polarized σ-mode of the THz beam in two beams. The maximum temporal shift of the delay line is 2.7 ns allows the correlation of two consecutive pulses at the MLS. The minimum step size corresponds to a delay well below 0.1 ps. After recombination the beam is spectrally analyzed with an evacuated Fourier transform spectrometer (FTS) by using a second grid as an analyzer. The measured intensity *I* depending on the rotation angle of the analyzer is given by a constant intensity superimposed by an interferometric intensity term. For $I_{1,2}$ representing the horizontal and the vertical polarization components, the auto-correlation function is obtained by :

$$a(\omega,\tau)=\frac{I_1(\omega,\tau)-I_2(\omega,\tau)}{I_1(\omega,\tau)+I_2(\omega,\tau)}$$

For comparison, direct pulse correlations with a zero-bias Schottky diode combined with band-pass filters were measured. Both measurements were obtained in low-alpha mode at a bunch current of approximately 1.5 mA.

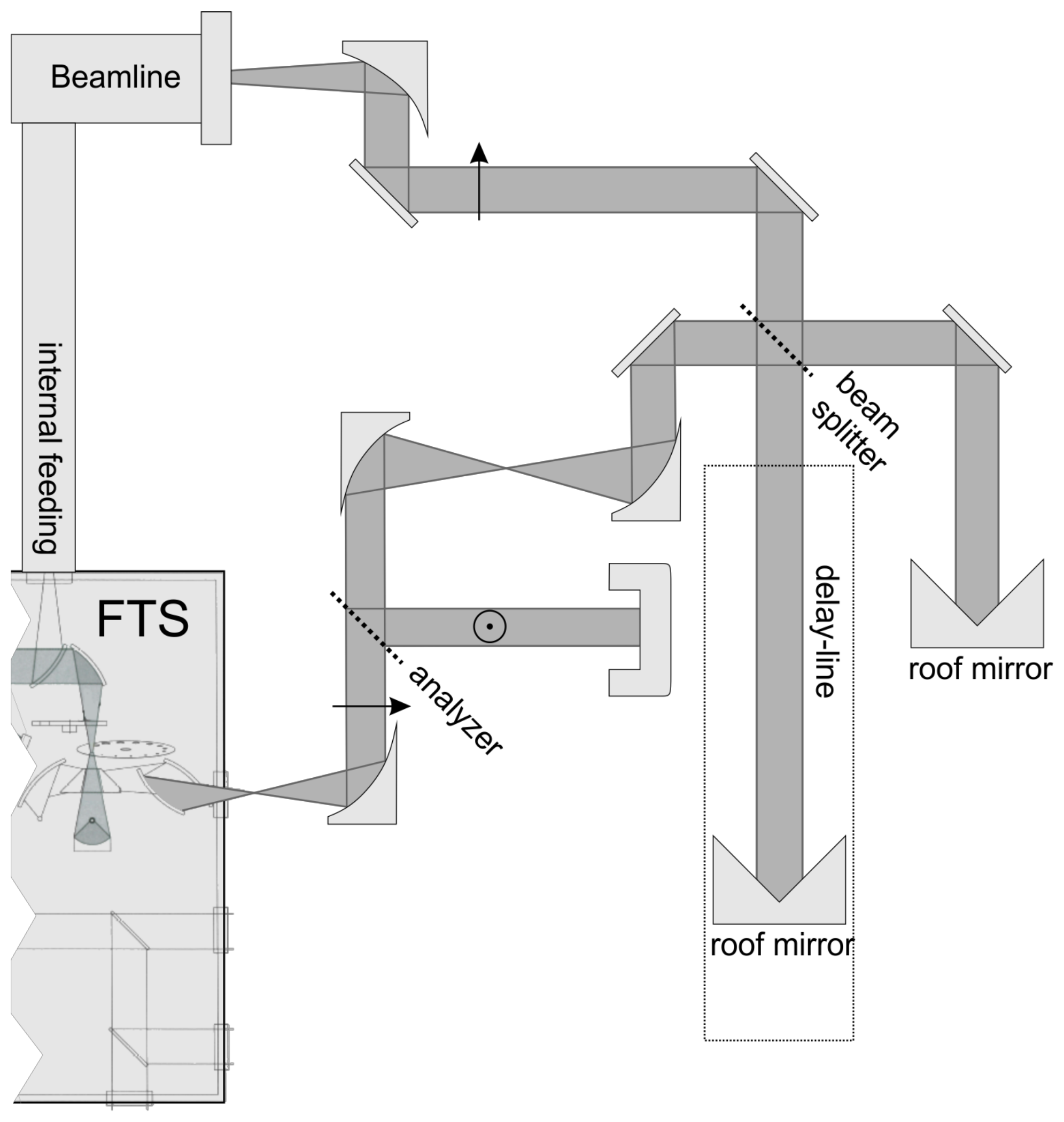

Fig. 1. Sketch of the setup at the MLS THz beamline.

Results

A SRAC function *a(ω,τ)* is shown in Fig. 2a. Due to the reconstruction the offset is corrected and the spectral amplitude is normalized to one. Any drift or signal loss due to the decreasing beam current is corrected. Low frequencies are supressed by the beamline chamber and the FTS beam splitter efficiency. Fig. 2b shows the cross-correlation between two consecutive CSR pulses. Due to the pulse to pulse jitter high frequency correlations fade out. The cut-off frequency is 275 GHz (3 dB signal loss) which corresponds to a single bunch jitter of 1.2 ps. Fig. 3 shows a cross-section of the SRAC with the corresponding autocorrelation fit model. By assuming a gaussian charge distribution a bunch width of 17.5 ± 1.3 ps is found, as given in Fig. 4. The low frequency behavior of the SRAC shows an increasing pulse duration with decreasing frequency due to diffraction in the beamline chamber. The frequency selective autocorrelation from the Schottky diode measurement shows the same behavior.

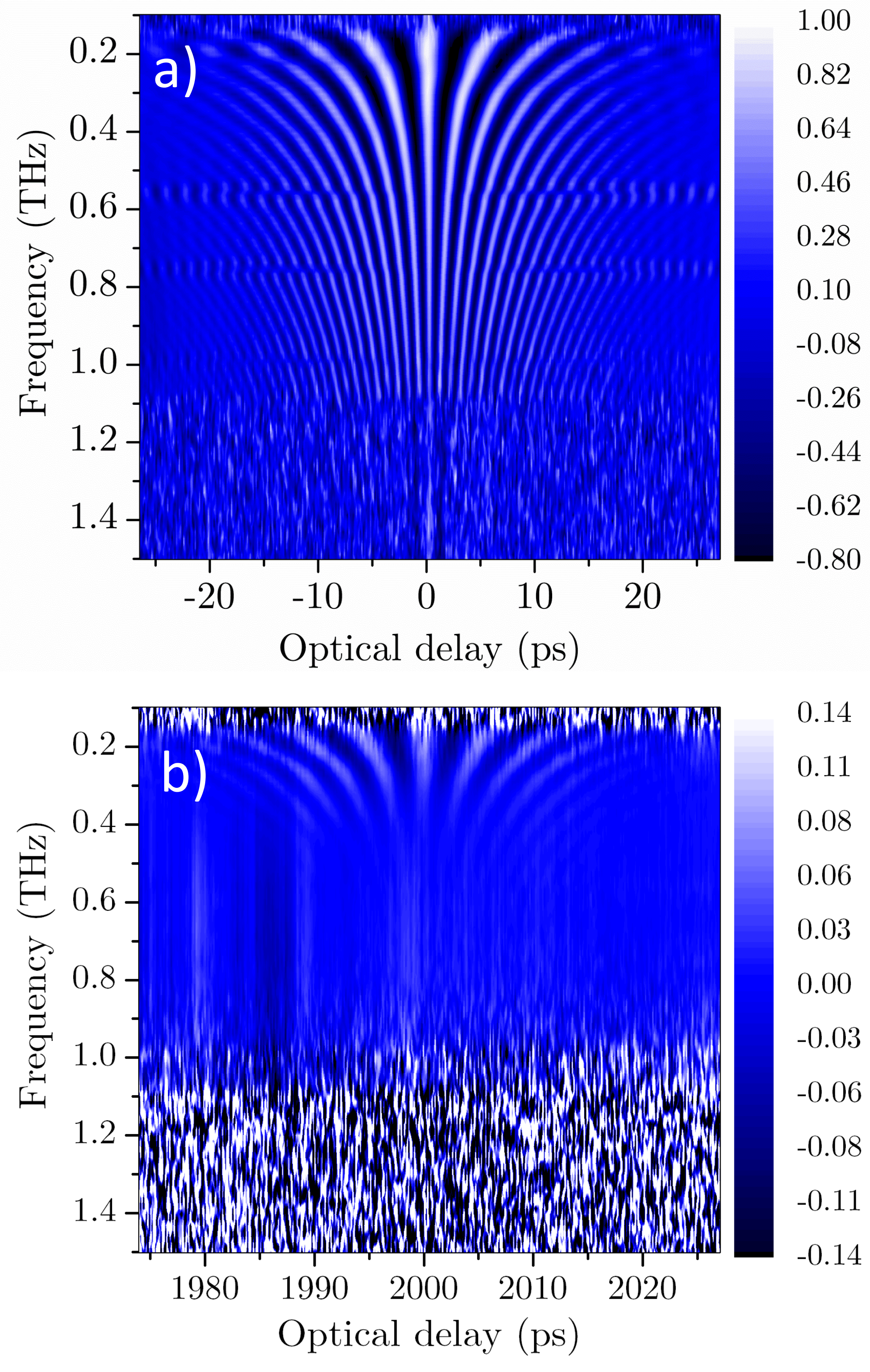

Fig. 2. Spectrally resolved autocorrelation pattern (a) and cross-correlation of consecutive pulses (b) of the coherent THz regime.

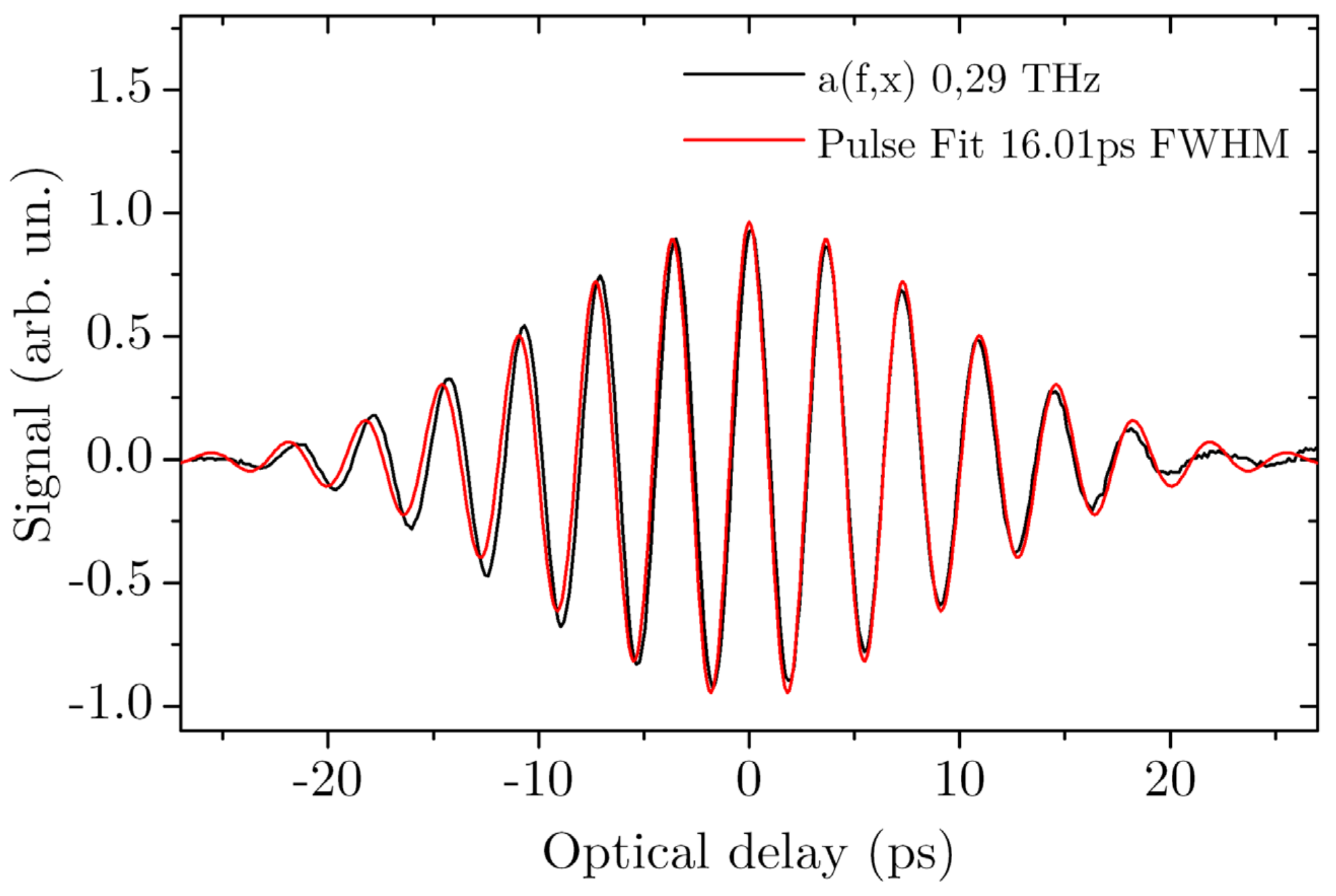

Fig. 3. Linear autocorrelation meassured with a zero-bias Schottky- diode (top). Coresponding gaussian pulse width (bottom).

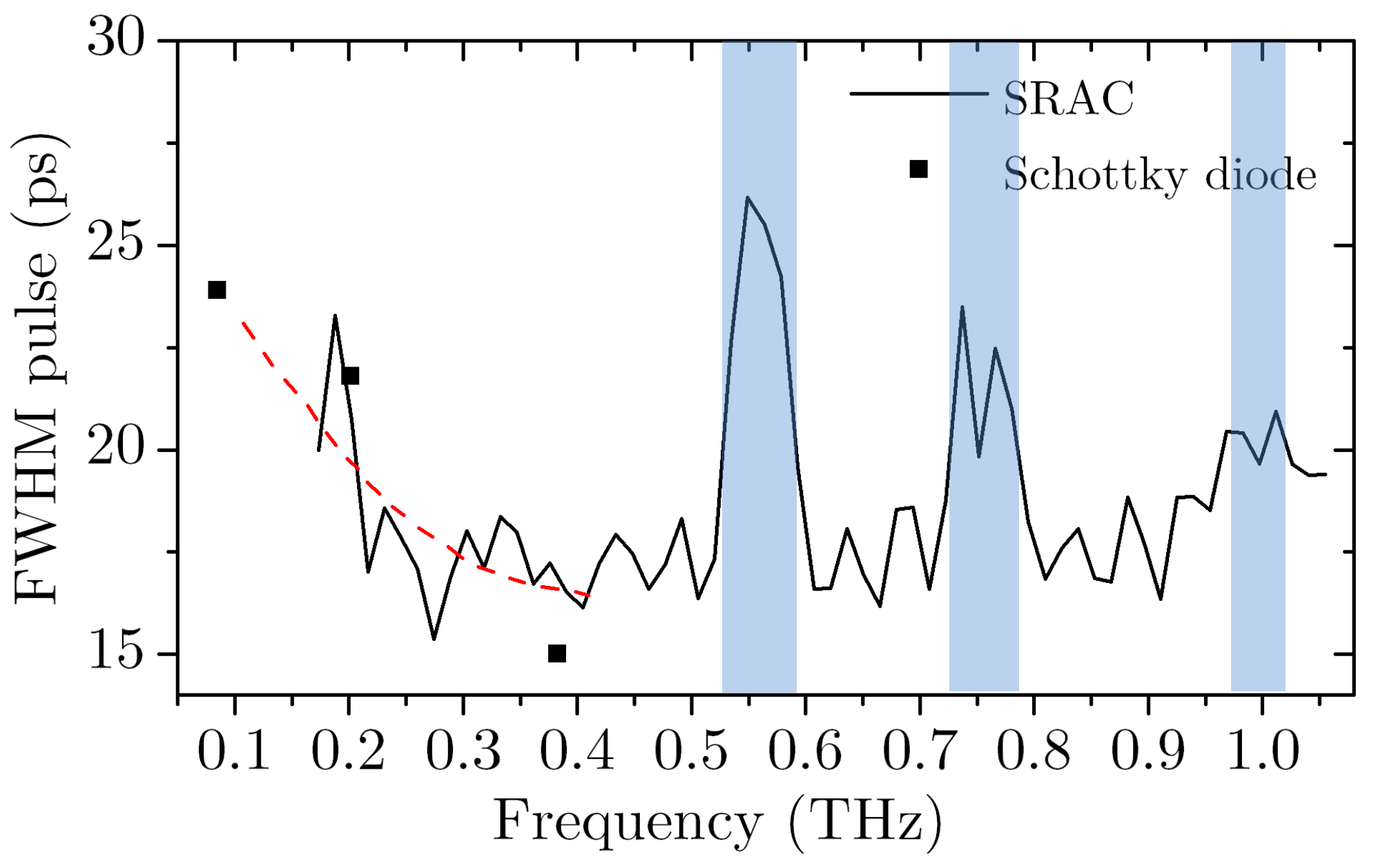

Fig. 4. Electron bunch width from SRAC. Water absorption blue.

Acknowledgement

This research has been funded by the German federal Ministry of Education and Research (Grant No. 05K10KTC). A. Pohl and N. Deßmann acknowledges support by the Helmholtz Research School on Security Technologies.

References

[1] Abo-Bakr et al. (2002). “Steady-state far-infrared coherent synchrotron radiation detected at BESSY II”, *Phys. Rev. Lett.*, *88*, 254801, 2002.
[2]J. Feikes et al., “Metrology Light Source: The first electron storage ring optimized for generating coherent THz radiation”, *Phys. Rev. ST Accel. Beams. 14*, 2011, 030705.
[3] R. Klein et al., “Operation of the Metrology Light Source as a primary radiation source standard”, *Phys. Rev. ST Accel. Beams 11*, 110701, 2008.
[4] H.-W. Hübers et al., “Time domain analysis of coherent terahertz syncrotron radiation”, *Appl. Phys. Lett.* 87, 184103, 2005.
[5] P. Probst et al., “YBa2Cu3O7-*δ* quasioptical detectors for fast time-domain analysis of terahertz synchrotron radiation”, *Appl. Phys. Lett.* 98, 2011.
[6] A. Pohl et al., “Field transients of coherent terahertz synchrotron radiation accessed via time-resolving and correlation techniques”, *J. Appl. Phys.*, *119*, 114903, 2016.