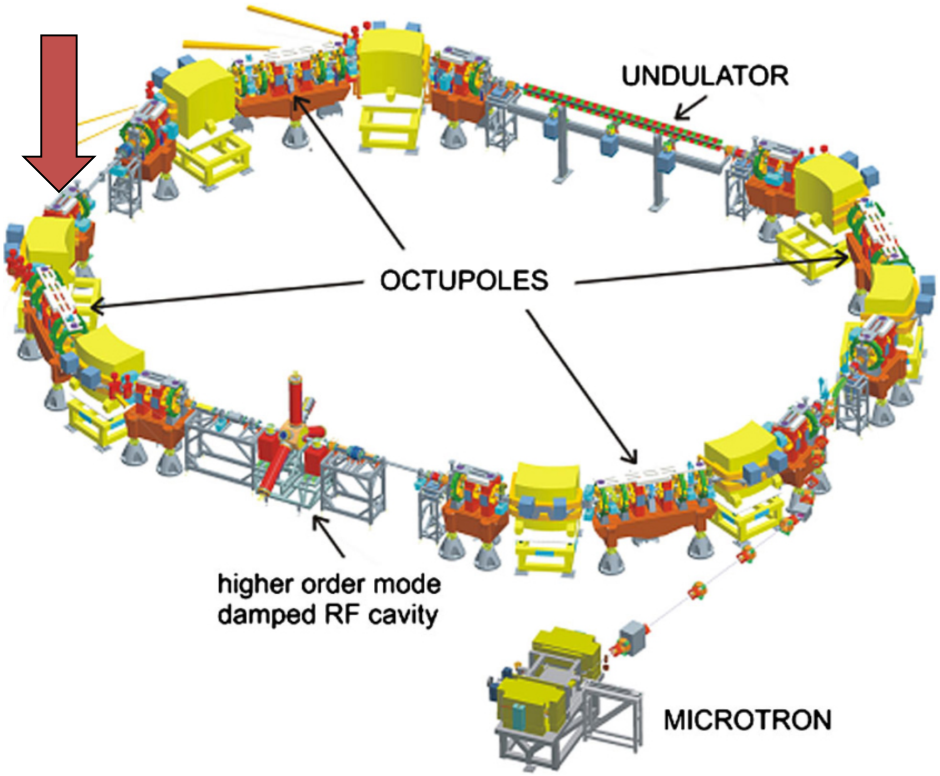
Duration of coherent synchrotron radiation pulses accessed via time-resolving and correlation techniques

A. Pohl,[1,2] A. Semenov,[2] H.-W. Hübers,[1,2] A. Hoehl,[3] M. Ries,[4] G. Wüstefeld,[4] G. Ulm,[3] K. Ilin,[5] P. Thoma,[5] and M. Siegel[5]

[1]Humboldt-Universität zu Berlin, Institute of Physics, Newtonstraße 15, 12489 Berlin, Germany
[2]Institute of Optical Sensor Systems, German Aerospace Center (DLR), Rutherfordstrasse 2, 12489 Berlin, Germany
[3]Physikalisch-Technische Bundesanstalt (PTB), Abbestraße 2-12, 10587 Berlin, Germany
[4]Helmholz-Zentrum Berlin, Albert-Einstein-Str. 15, 12489 Berlin, Germany
[5]Institute of Micro- and Nanoelectronic Systems, Karlsruhe Institute of Technology (KIT), Hertzstrasse 16, 76187 Karlsruhe, Germany

Metrology Light Source

- Electron current 1 pA – 200 mA (1 - $2 \cdot 10^{11}$ e^-)
- Max. energy E_0 630 MeV
- Circumference 48 m
- Fill pattern typ. 80 bunches
- Revolution freq. f_{rev} 6.25 MHz
- RF frequency f_{rf} 500 MHz
- THz Beamline 100 µm – 7 mm
  (100 cm^{-1} – 1.4 cm^{-1})



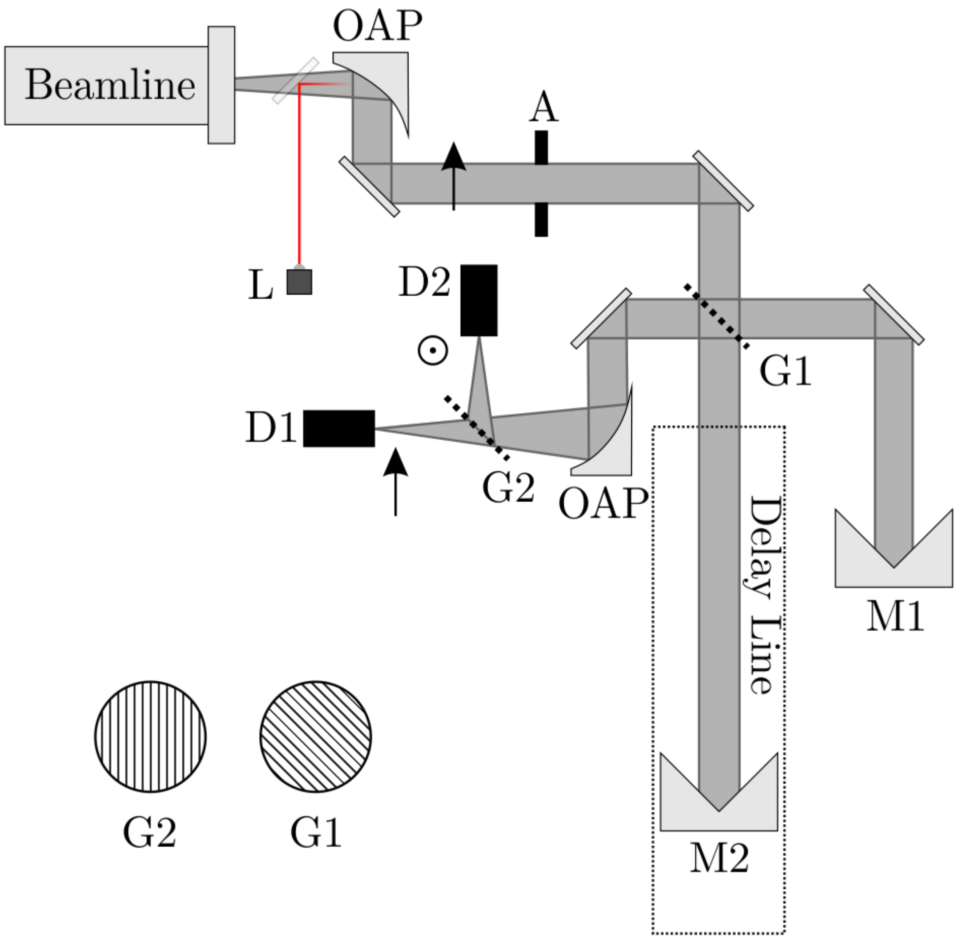
J. Feikes et al., *Phys. Rev. ST Accel. Beams. 14*, 2011, 030705

Setup

- Martin-Puplett Interferometer Setup
- Off-axis parabolic mirror OAP:

  (*f* = 450 mm, 167 mm)
- Wiregrid, G1 @ 54.7°, G2 @ 0°
- Roof mirror M1 / M2
- 400 mm delay line (max. 2.67 ns)
- D1 / D2 detectors
- Power: 1.0 mW @ G2

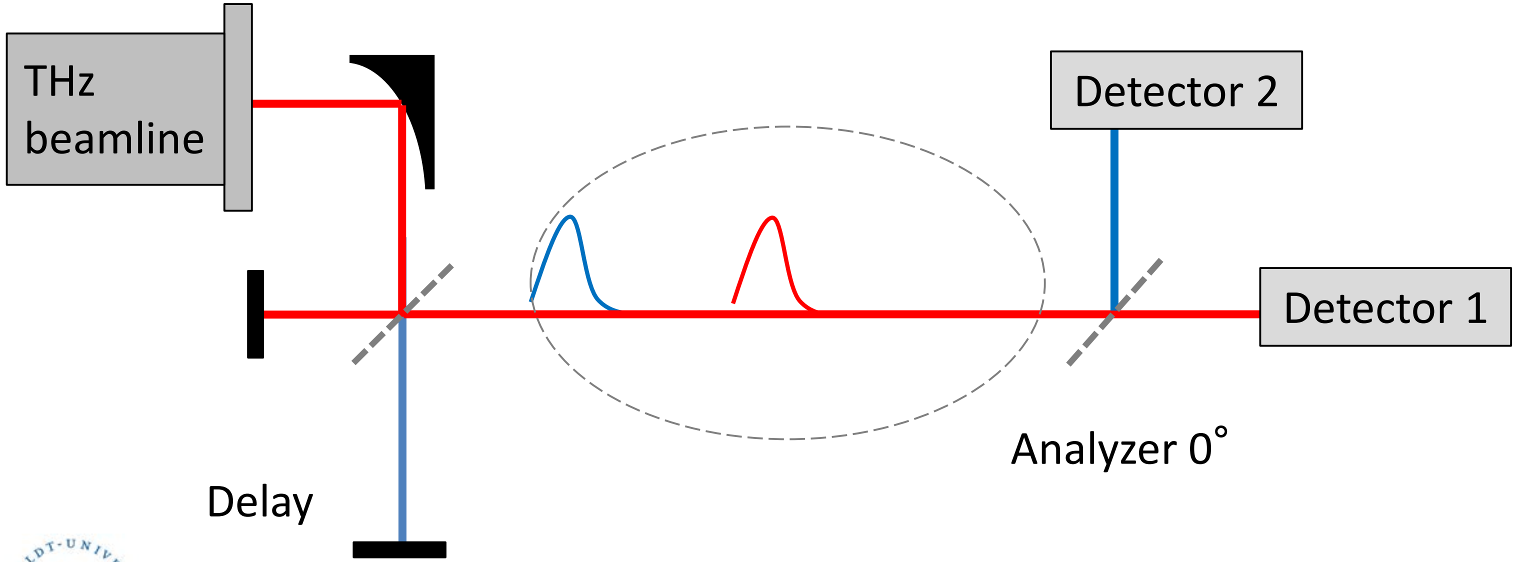
  6.4 mW total (150 mA, low-α)



Correlation meassurement

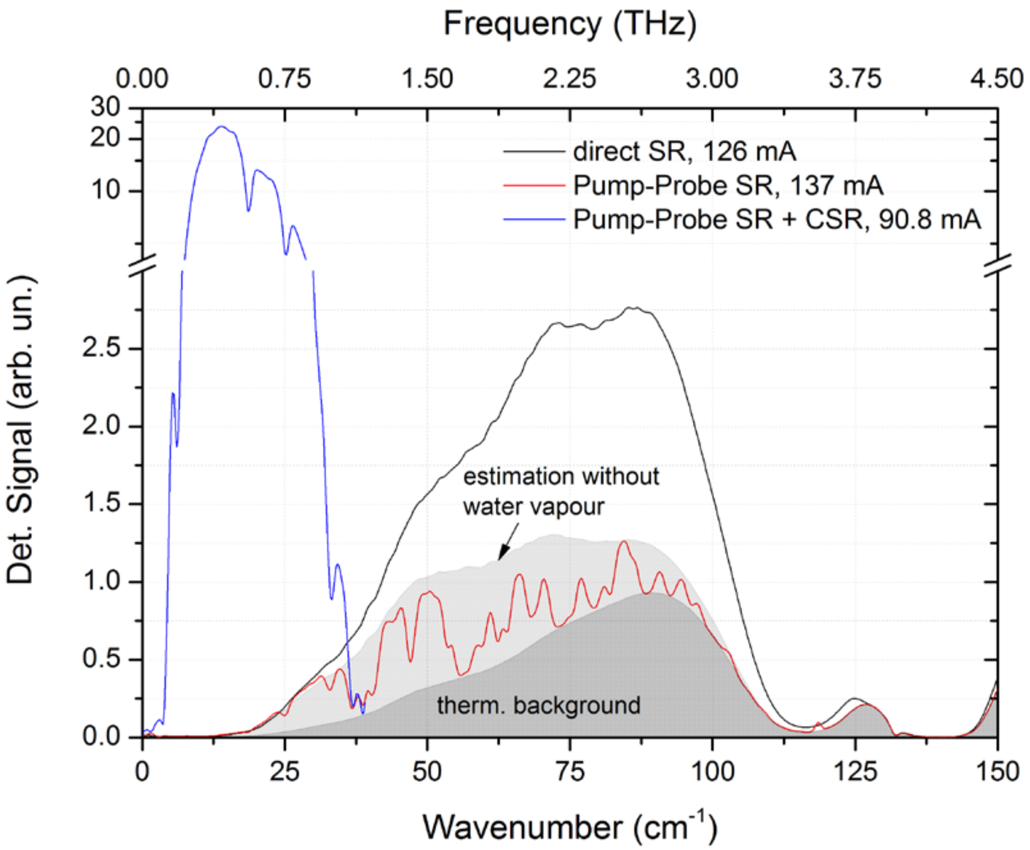
- Correlation of the THz pulse with itself
- 2 linear polarized pulses superimpose at the wiregrid
- Measured intensity : $I_{1,2}(\omega,t) = c\varepsilon_0 \overline{\left[E_1(\omega,t) + E_2(\omega,t+\delta t)\right]^2} = I_{in}(\omega)(1 \pm \cos(\omega\delta t))$

Difference Interferogram $a(\delta t)$ → intensity independent $a(\delta t) = \frac{I_1(\delta t) - I_2(\delta t)}{I_1(\delta t) + I_2(\delta t)}$

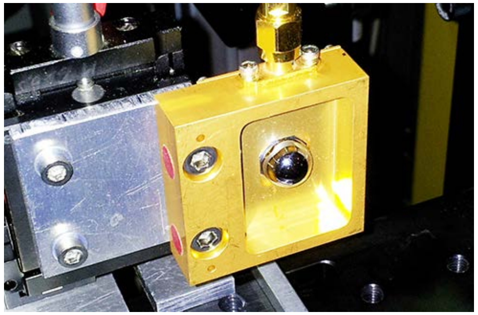


MLS Spectra

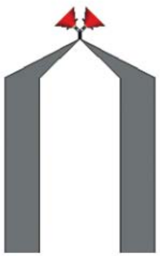
- Measured with FTS
- Coherent emission spectra (blue)
- Incoherent emission spectra (red)

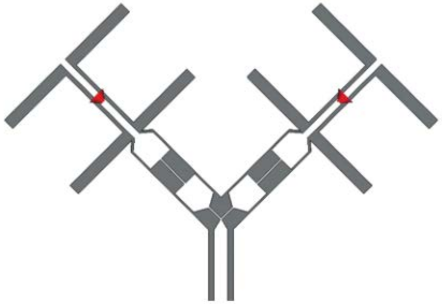


Three comparative measurements



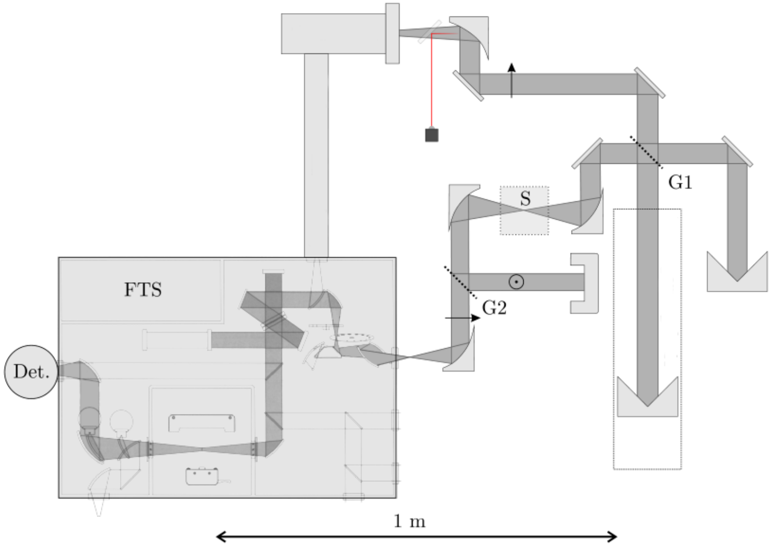
I. Direct detection - Zero bias Schottky diode
(with Log-spiral antenna glued to 12 mm silicon lense)





II. Field correlation - YBCO Detector
(high T superconductor, 2 microbridges,
polarization sensitive twin-slot antenna,
T_c= 82 K @ 1 K transition)

III. Frequency resolved autocorrelation via FTS



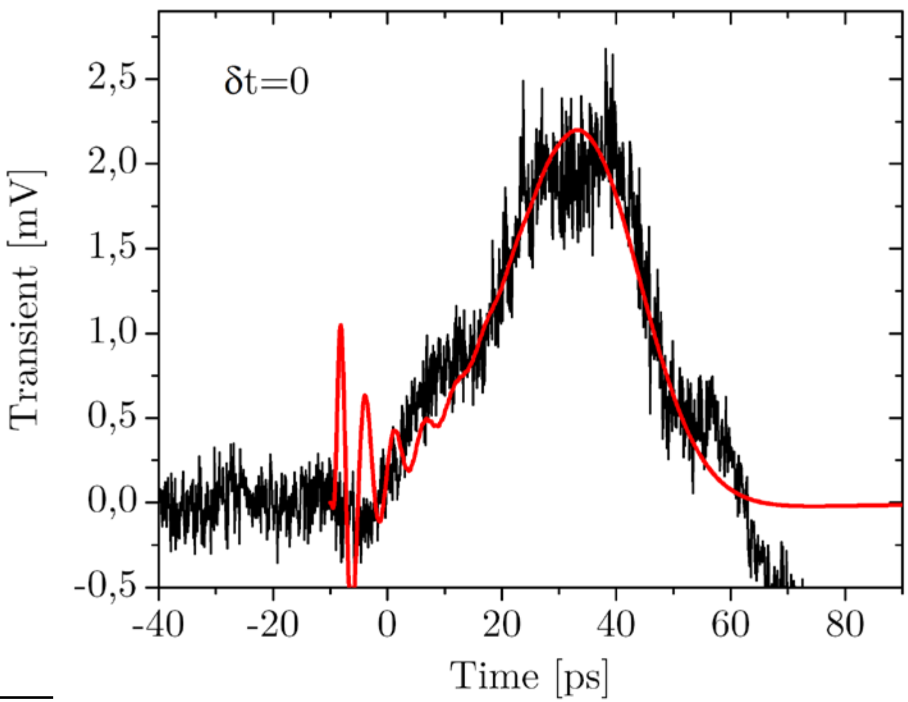
I. Direct pulse response

- Schottky diode detector
- Time resolved transients of THz pulses
- Fit via Duhamel integral

$$V(t) = \int \operatorname{sgn}[E(\xi)]\, \frac{dE(\xi)}{dt}\, h(t-\xi)\, d\zeta$$

- With $E(\xi) = \delta(\xi)$

→ gives system time response τ_R=26 ps

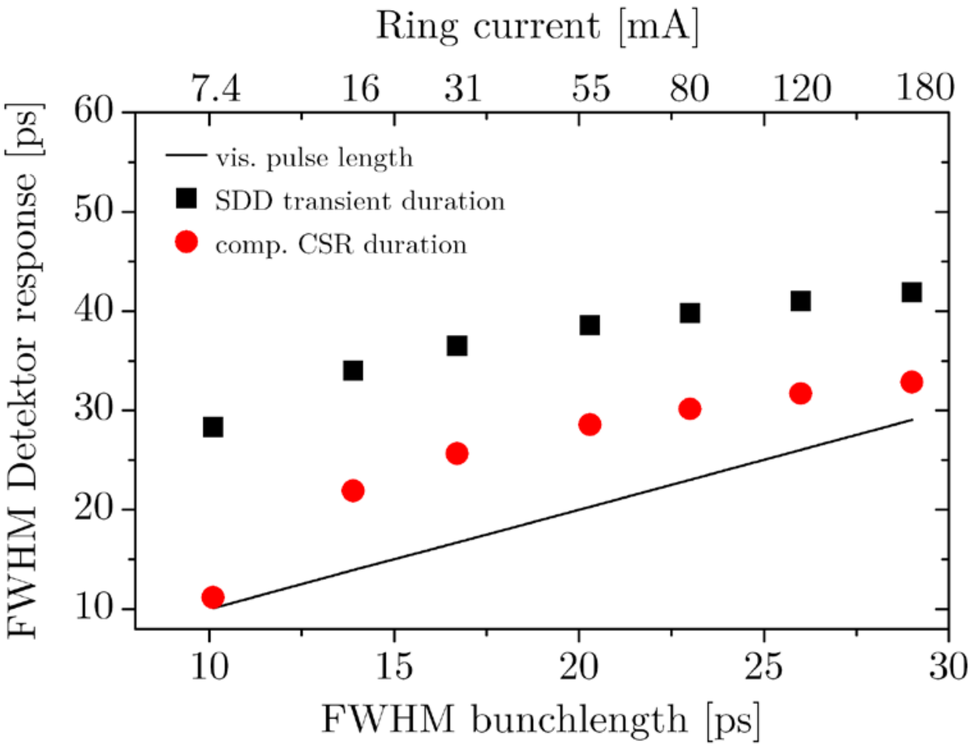


- CSR pulse duration: $\tau_{CSR} = \sqrt{\tau_{Diode}^2 - \tau_R^2}$

A. Pohl et al., J. Appl. Phys. **119**, 2016, 114903

FWHM duration of CSR pulses

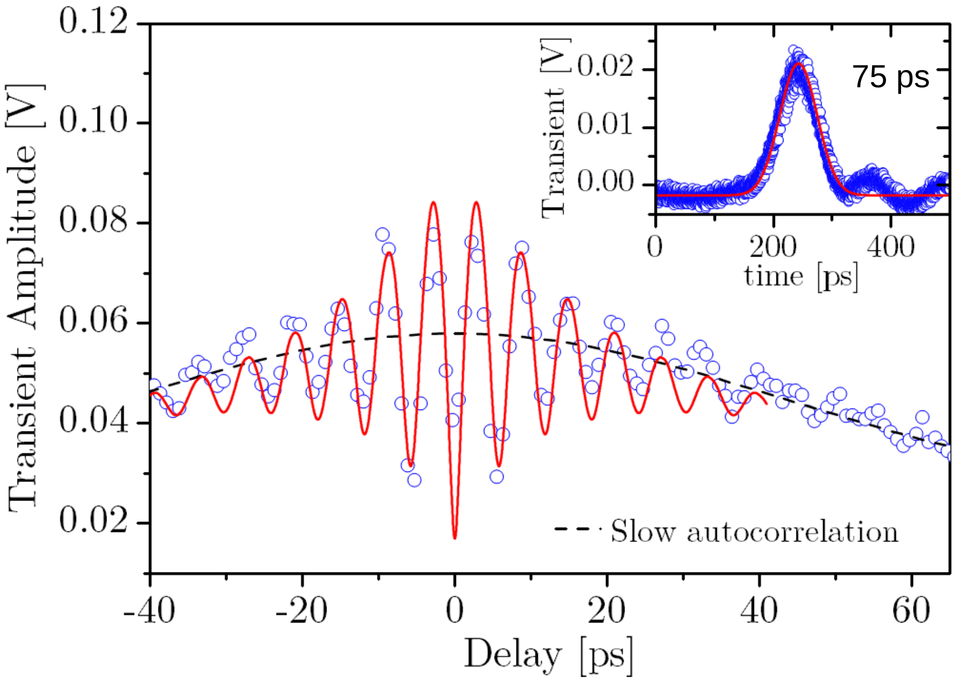
- Systematically larger pulse duration than VIS pulse length
- VIS pulse length: streak camera @ 470 nm



II. Field correlation

- YBCO detector
- Fit procedure to model CSR field

  → CSR duration



Fit experimental inteferogram *I* by *m*odelling field transient *E* with Envelope *B* and computed spectrum *S*

$$E(t, dt, \tau, \phi) = B(t, dt, \tau) \int \sqrt{S(f)} \cos\left(2\pi f (t + dt) + \phi\right) \mathrm{d}f$$

$$B(t, dt, \tau) = 2\left(n(t + dt)/\tau\right)^2 \exp\left(-n(t + dt)\tau^{-1}\right)$$

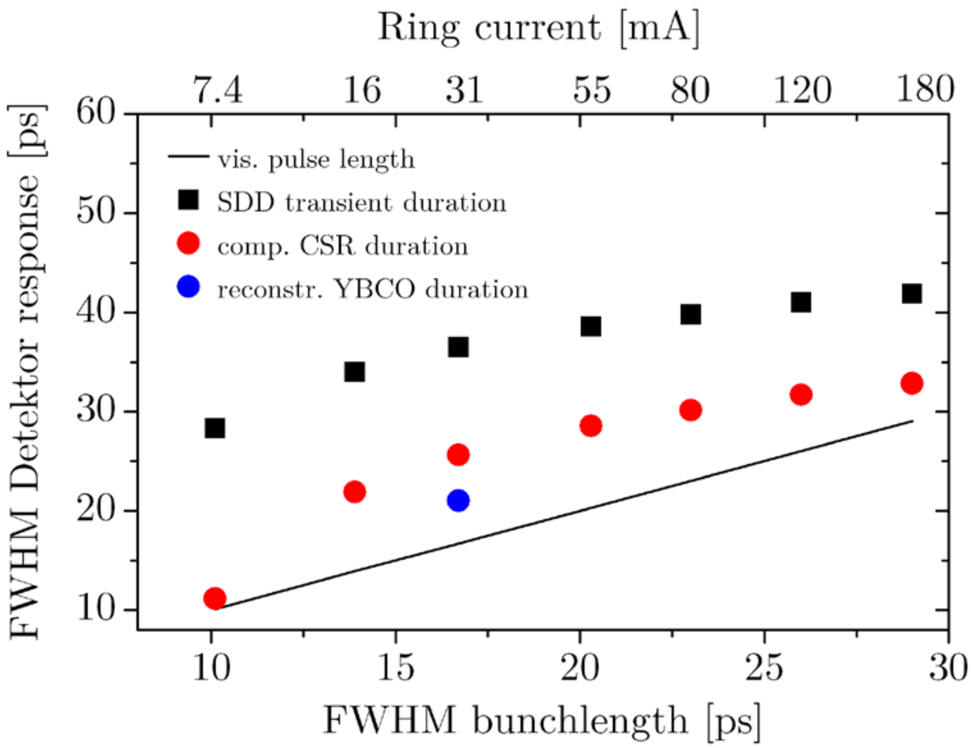
$$I(dt, \tau) = K \int \left| E(t, 0, \tau, 0) + E(t, dt, \tau, \frac{\pi}{2}) \right|^p \mathrm{d}t$$

- Baseline due to saturation of amplifier for intense CSR (bursting)

A. Pohl et al., J. Appl. Phys. **119**, 2016, 114903

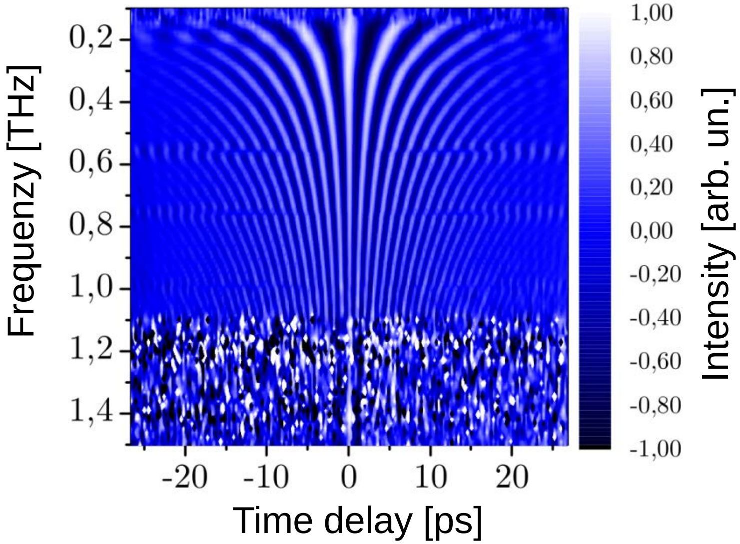
FWHM duration of CSR pulses

- 21 ps calculated @ 17 ps VIS bunch length



III. Spectrally resolved pulse duration

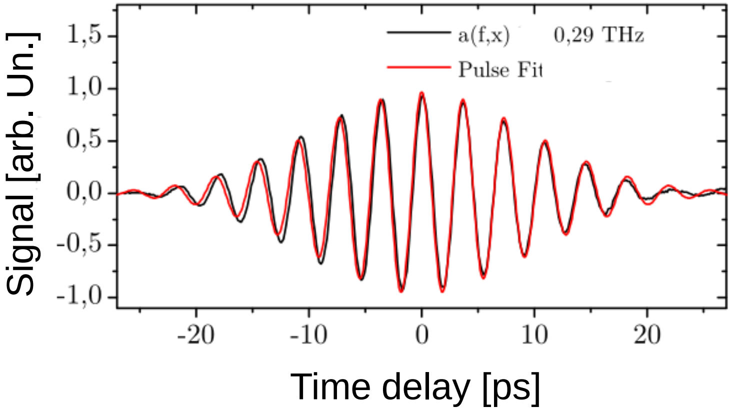
- Spectra in horizontal & vertical polarization @ different time delay
- Calculation of $a(f, \delta t)$



- Fit:

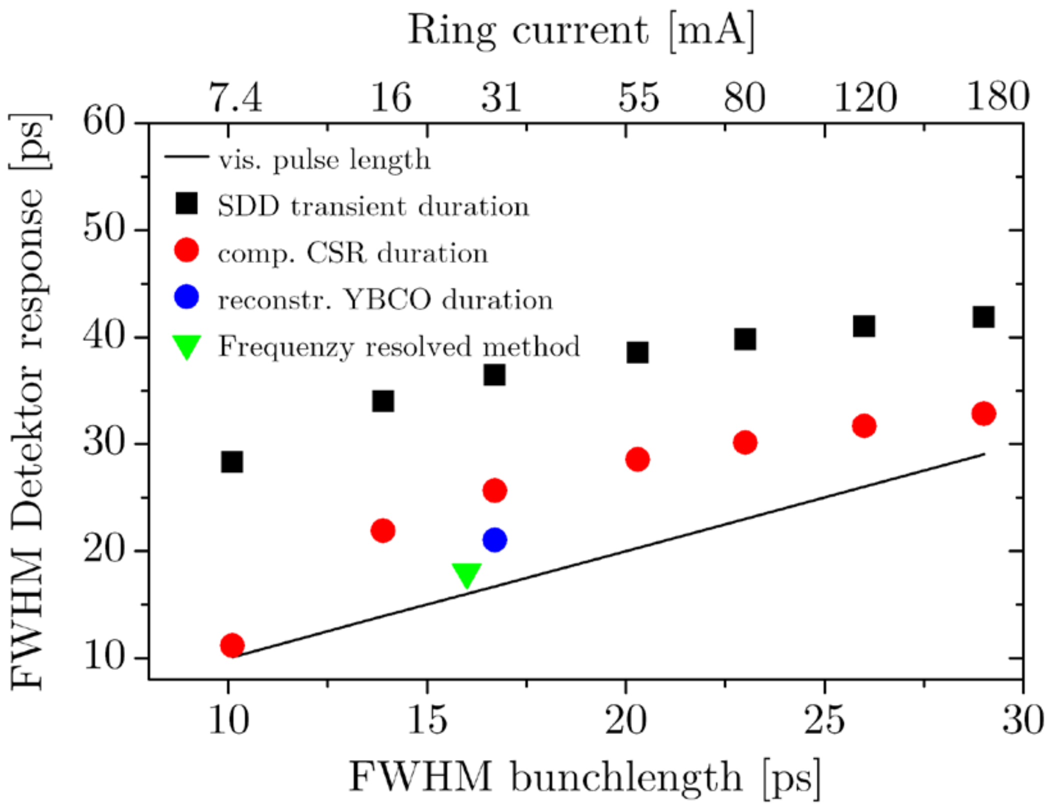
$$a(f,t)_{\mathrm{FIT}} = A \exp\left[-\frac{(t-s)^2}{2\sigma^2}\right] \sin\left[f(t-s)\right] + B$$

- Estimation of gaussian pulses
- Envelope → pulse duration

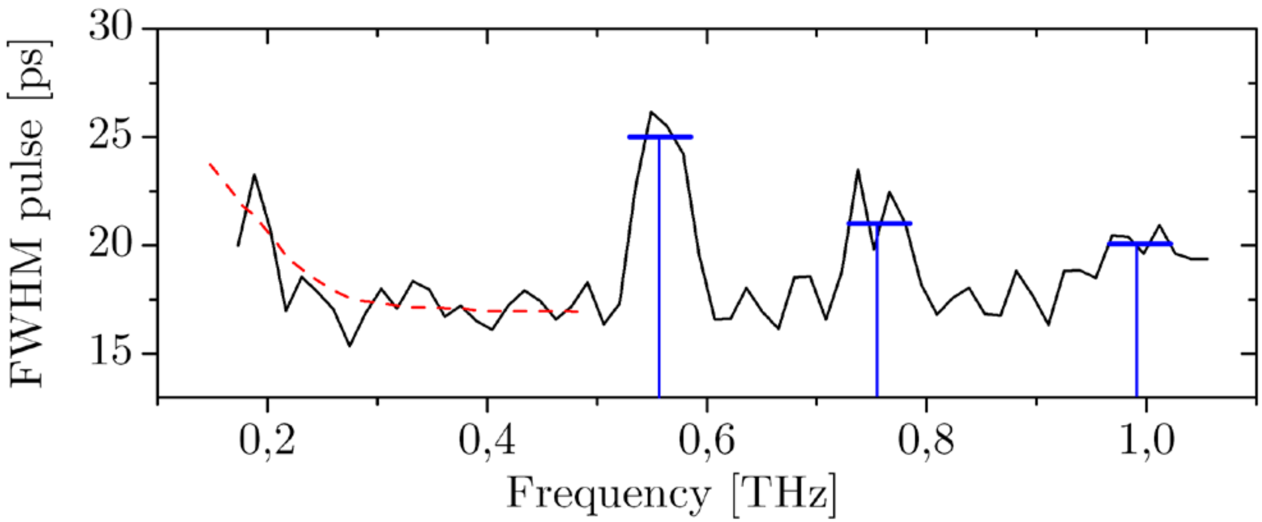


Spectrally resolved pulse duration

- Average 18 ps @ 16 ps VIS pulse duration



Spectrally resolved pulse duration



- Water absorption is visible → pulse lengthening due to dispersion
- Low frequencies show larger pulse durations → internal beamline reflections

H.-W. Hübers et al., *Appl. Phys. Lett. 87*, 2005, 184103

Conclusion

I. Schottky diodes → fast enough for direct THz pulse analysis and reconstruction of ps pulse durations

II. YBCO detectors → can provide pulse durations close to VIS - by field correlation and reconstruction of the CSR field

III. Frequency resolved method → gives information of frequency dependend pulse durations

Thanks for your attention

HELMHOLTZ
ZENTRUM BERLIN
für Materialien und Energie

PTB Physikalisch
Technische
Bundesanstalt
Braunschweig und Berlin

DLR

HUMBOLDT-UNIVERSITÄT
ZU BERLIN

Helmholtz
Research
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