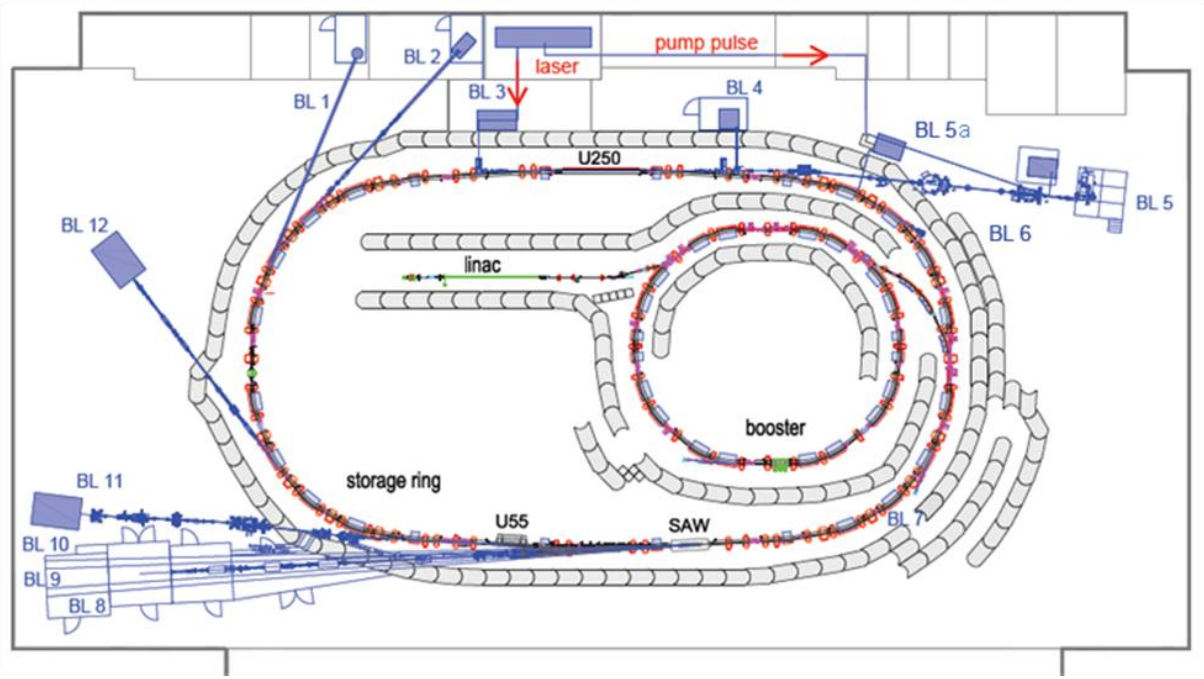
DELTA Status Report

Raffael Niemczyk, Center for Synchrotron Radiation

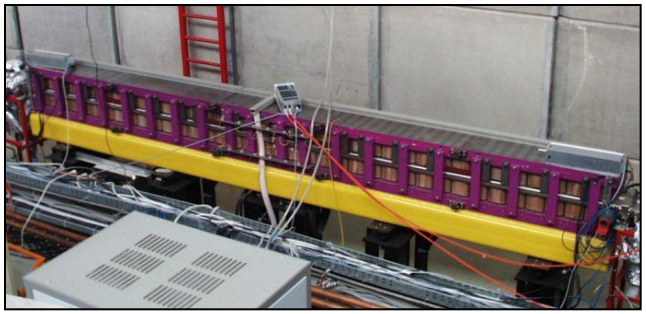
4th ARD ST3 Workshop, Berlin 2016

DELTA – a university-based synchrotron light source



Parameters

circumference	115.2 m
beam energy	1.5 GeV
hor. emittance	15 nm rad
beam current (mb)	130 mA
beam current (sb)	20 mA
rms energy spread	7e-4
rms bunch length	40 ps
user operation	2000 h/y
machine studies	1000 h/y



Accelerator research at DELTA

General accelerator physics and operation of DELTA

- DFG-Großgerät Art. 91b GG: "Supraleitender Multipolwiggler für die Synchrotronstrahlungsquelle DELTA" (M. Tolan)

Generation and control of laser-induced VUV and THz pulses

- BMBF-Verbundforschung: "Gezielte Formung und Diagnose von Elektronenpaketen und Strahlungspulsen" (S. K.)
- MERCUR: "Photoelektronenspektroskopie mit fs-Zeitauflösung..." (S. K., U. Bovenspiepen, C.M. Schneider)

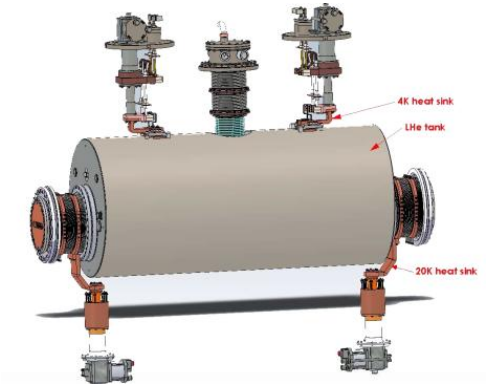
Laser-electron interaction for FEL seeding

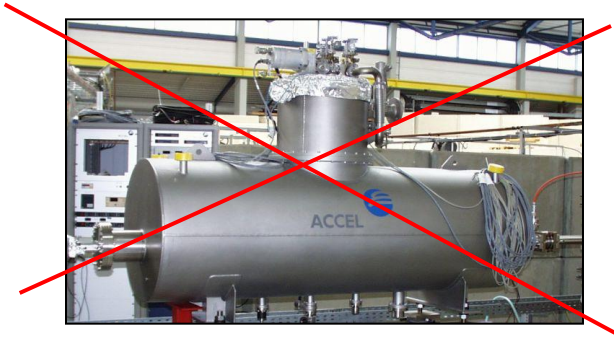
- BMBF-Verbundforschung: "Optimierung der Laser-Elektronen-Wechselwirkung für EEHG bei FLASH" (S. K.)

Beam dynamics, instabilities, diagnostics, etc.

- BMBF-Verbundforschung: "Untersuchung kollektiver Instabilitäten und ihrer Dämpfung für die Erweiterung des LHC" (S. K.)

New superconducting wiggler (7 T) and RF upgrade (second cavity, solid-state amp) within the next two years.





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Education

One-year master course on accelerator physics

- 2 h lecture
- 1 h exercises
- 1 h seminar
- field trips (e.g. to BESSY, MLS, DESY, PITZ)

Bachelor course on instrumentation

- 2 h lecture
- 1 h exercises

W1 professor position

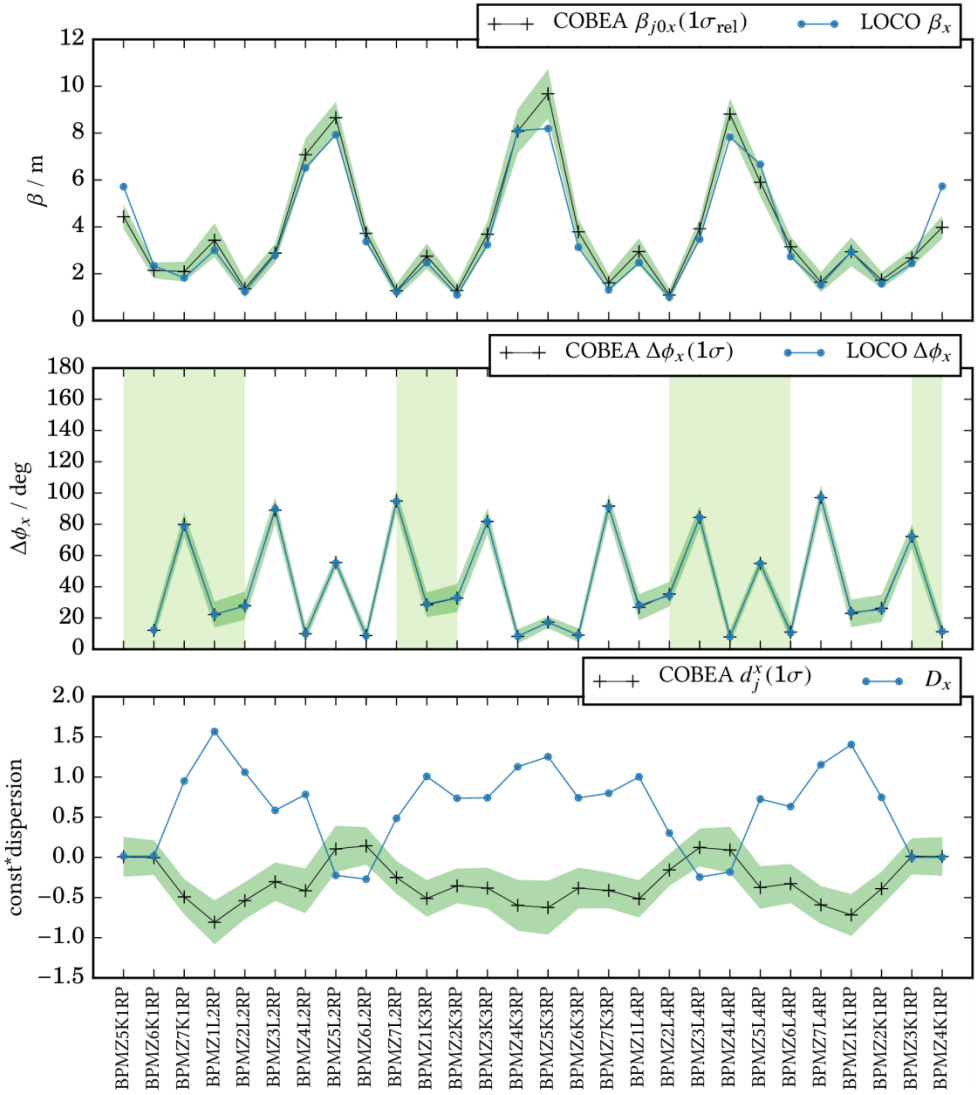
- to be advertised soon

Optics and Beam Diagnostics

(B. Riemann, P. Hartmann, T. Weis)

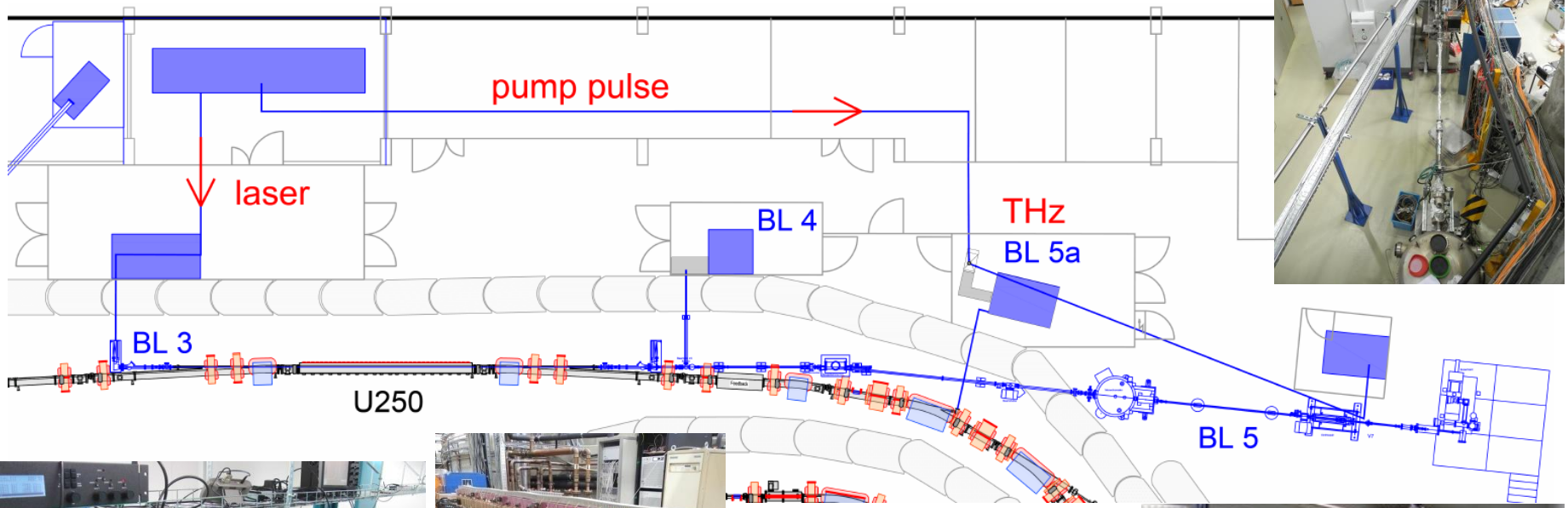
New method to determine optical functions

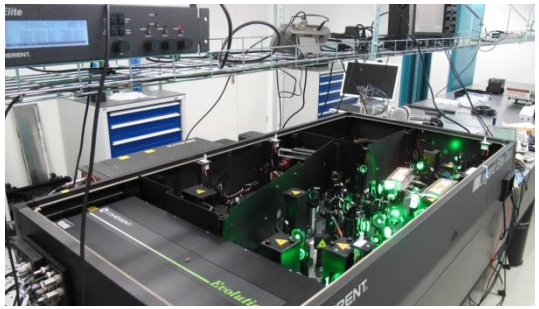
- very robust
- less input parameters needed
- blind cross-check successful

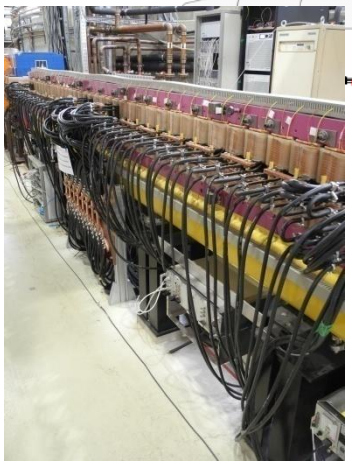


Source for ultrashort VUV and THz pulses

(F. Bahnsen, M. Bolsinger, F. Götz, M. Jebramcik, M. Höner, S. Hilbrich, H. Huck, M. Huck, S. Khan, N. Lockmann, C. Mai, A. Meyer auf der Heide, R. Molo, R. Niemczyk, H. Rast, G. Shayeganrad, M. Suski, P. Ungelenk, D. Zimmermann [TU Dortmund],
S. Cramm, S. Döring, L. Plucinski, C. Schneider [FZ Jülich and U Duisburg-Essen],
N. Hiller, V. Judin, J. Raasch, M. Siegel, P. Thoma [KIT Karlsruhe],
S. Bielawski, C. Evain, M. Le Parquier, E. Roussel, C. Szwaj [U Lille/France],
C. Gutt, M. Reiser, T. Sant, S. Warsow [U Siegen])



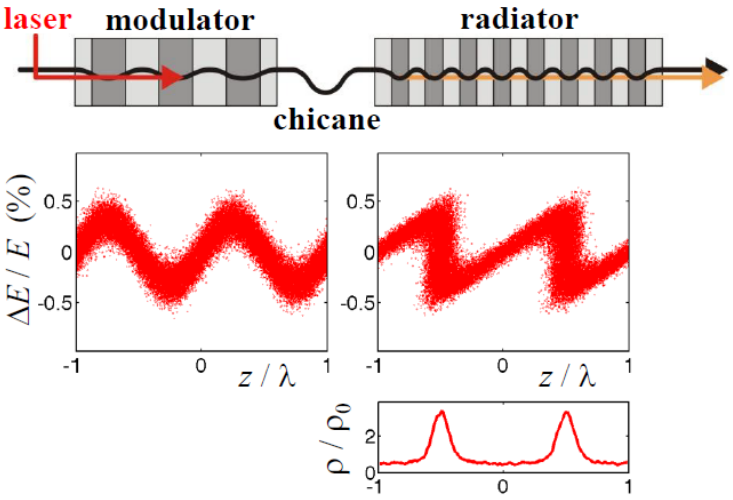




Source for ultrashort VUV and THz pulses

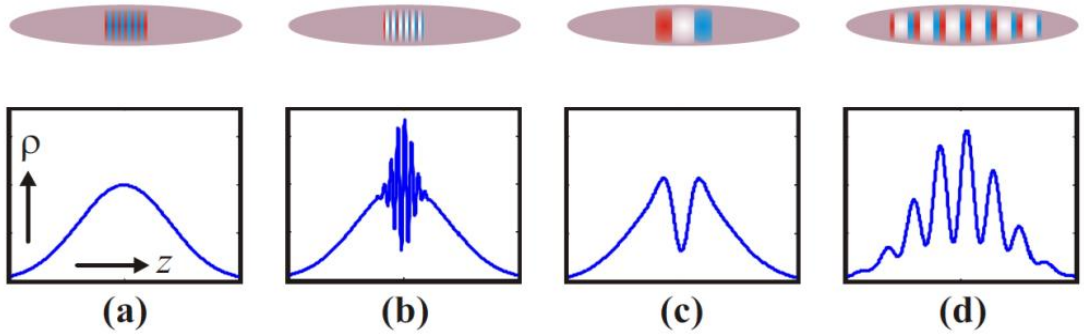
Coherent harmonic generation (CHG)

- laser-induced energy modulation of a small slice
- density modulation in a magnetic chicane
- coherent radiation at harmonics of the laser wavelength
  (80 nm realised, goal: 53 nm)



Coherent Terahertz (THz) radiation

- short dip due to energy dependent path lengths
- broadband radiation
- chirped pulse beating:
  multi-dip modulation → narrowband THz radiation

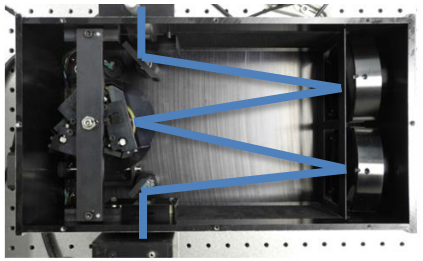


energy modulation | density modulation → VUV | single dip → broadband THz | multiple dips → narrowband THz

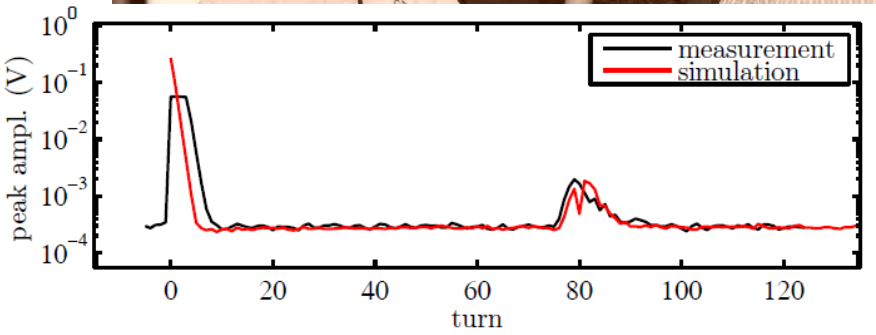
Source for ultrashort VUV and THz pulses

Recent activities

- **investigation of single-shot CHG spectra**
- **high-cost low-resolution autocorrelator: twofold energy modulation**
- **Schottky barrier detector: THz signal for 80 turns after laser interaction**
- **sub-THz spectrometer: multi-turn spectral observations**
- **ongoing: generation of narrowband radiation, electro-optical detection**
- **cooperation with KIT, Univ. Lille 1, Univ. Siegen etc.**



single-shot spectrometer

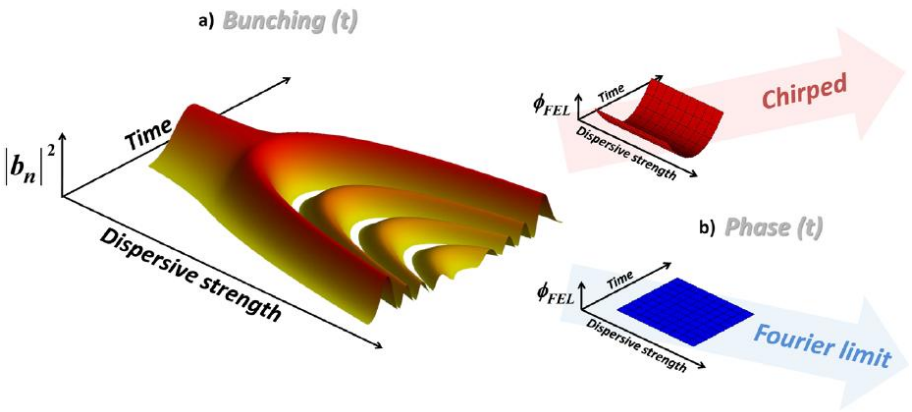


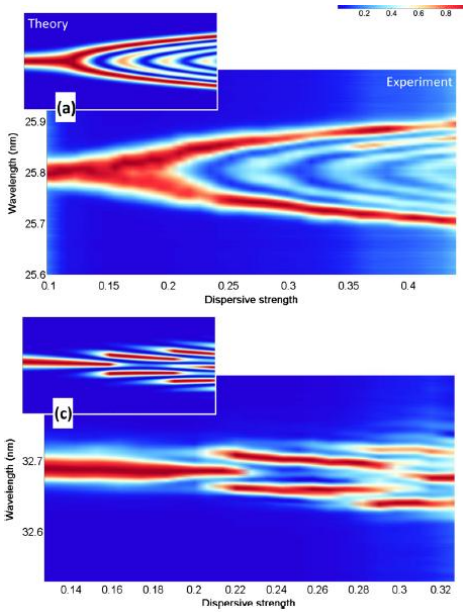
P. Ungelenk
PhD thesis
Dortmund 2015

first Schottky-detector measurements, March 2015

Source for ultrashort VUV and THz pulses

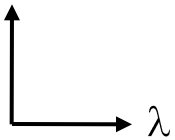
D. Gauthier et al., **Spectrotemporal Shaping of Seeded FEL Pulses**, PRL 115, 114801 (2015)

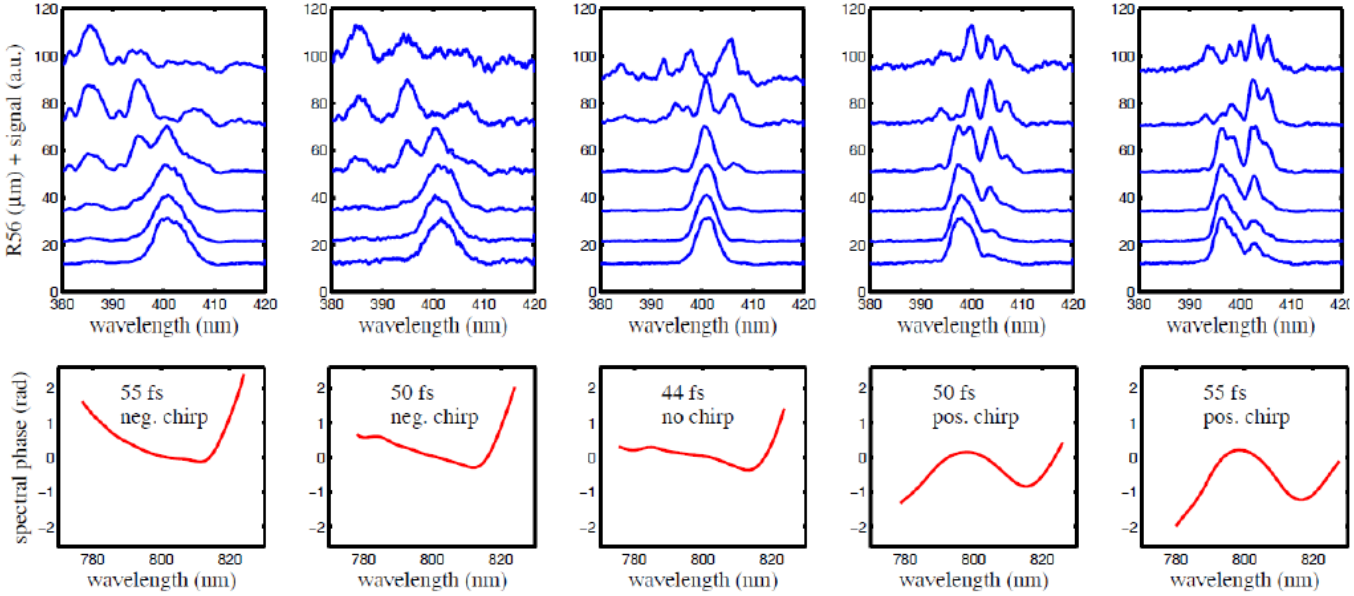




chicane strength

spectral phase





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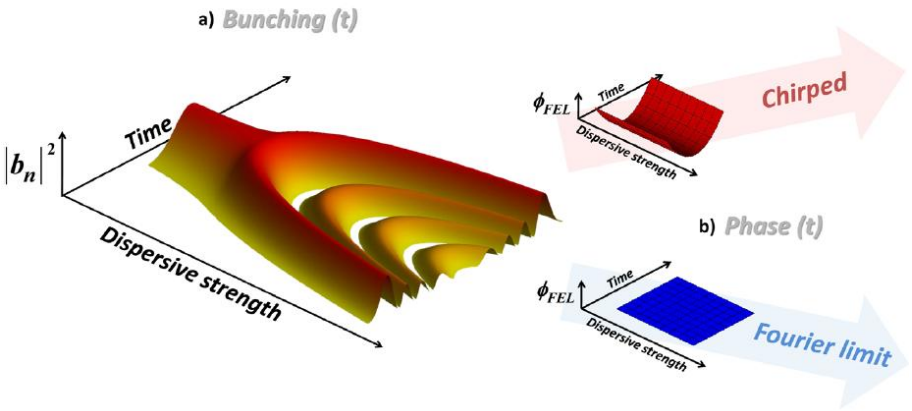
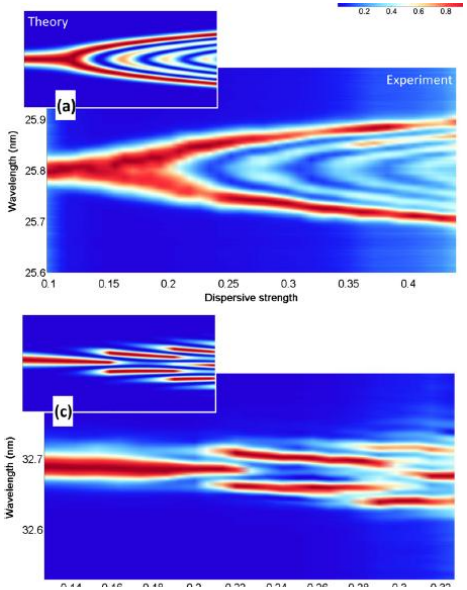
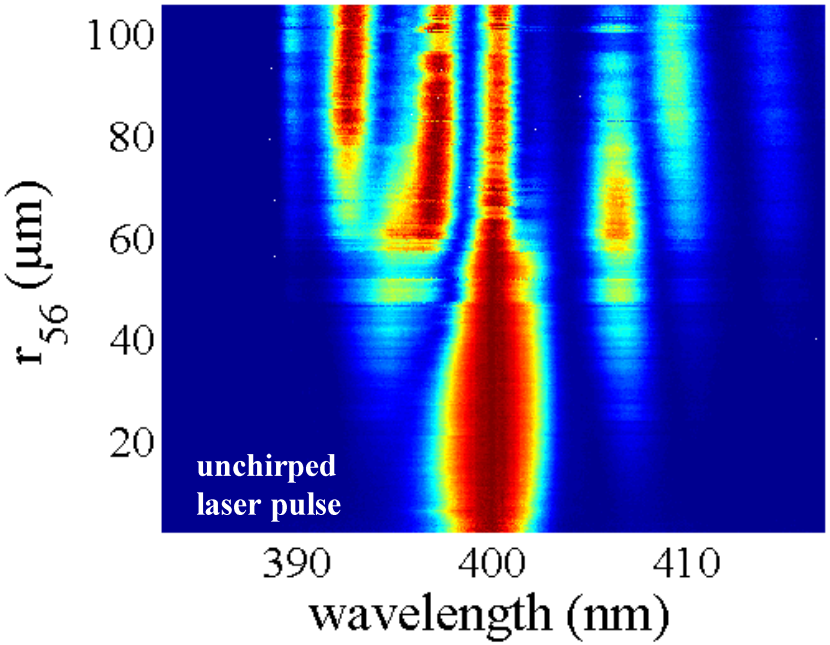
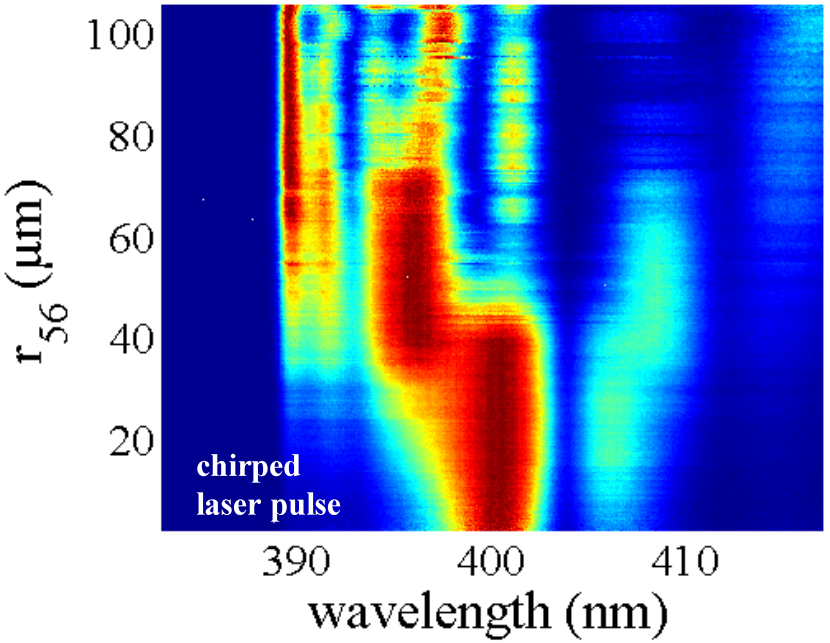




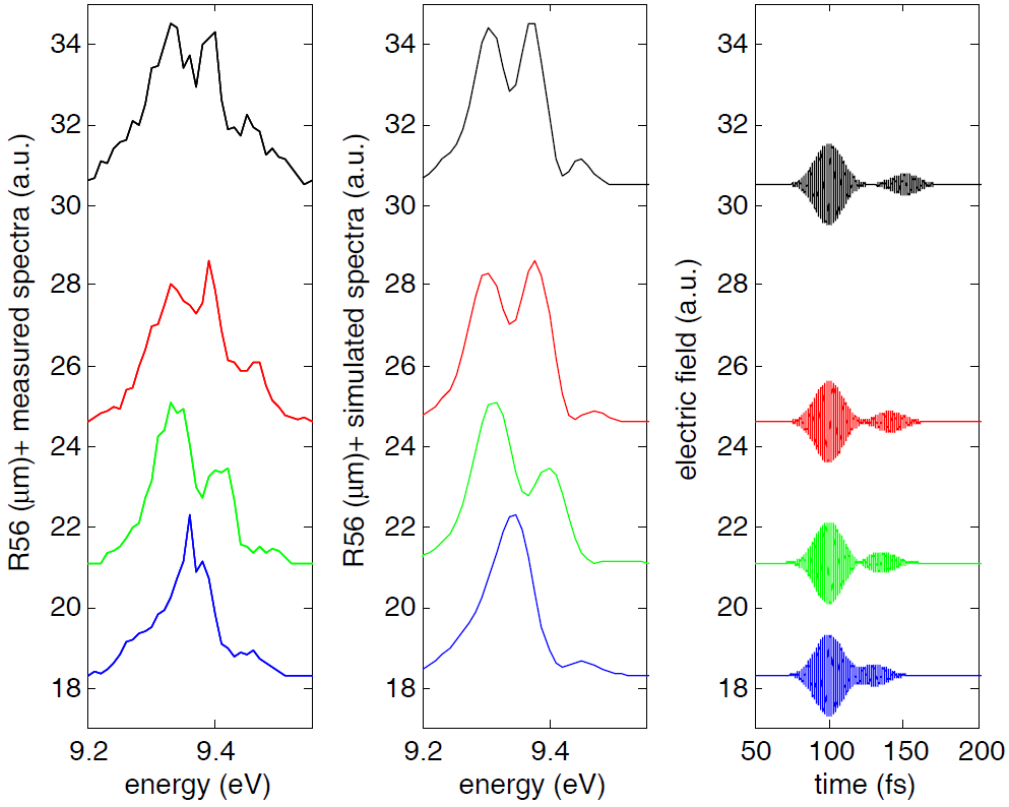


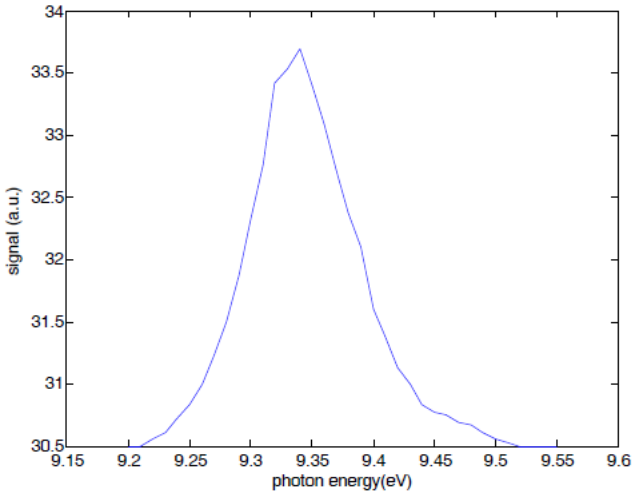


Source for ultrashort VUV and THz pulses

First CHG User experiment

- **in preparation (FZ Jülich, U Duisburg-Essen)**
- **photon energy: 9.35 eV (3rd harmonic of 400nm)**
- **astonishing CHG spectra**





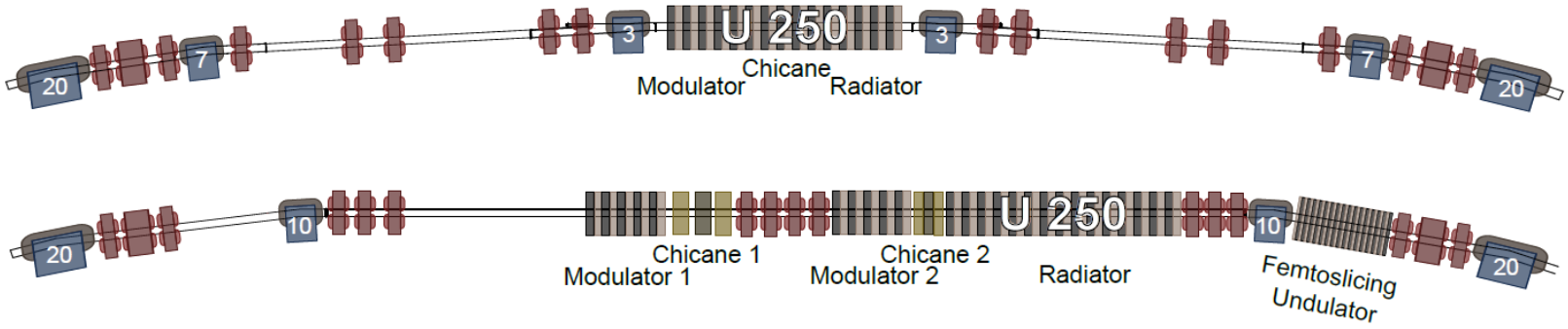
interference of CHG radiation and *ghost* radiation.

EEHG (*echo-enabled harmonic generation*) bei DELTA

Support by the Helmholtz-ARD-Initiative (FZ Jülich)

- Twofold laser-electron interaction, higher harmonics
- modulators: 2 short undulators (in house, currently tested)
- radiator: reuse undulator U250
- long straight section needed
- additional undulator needed for *femtoslicing*
- new optics defined
- design of the vacuum chambers to be defined within next weeks

Idee: G. Stupakov, PRL 102 (2009), 074801
SLAC: D. Xiang et al., PRL 105 (2010), 114801
SINAP: Z. Zhao et al, Nature Photonics 6 (2012), 360



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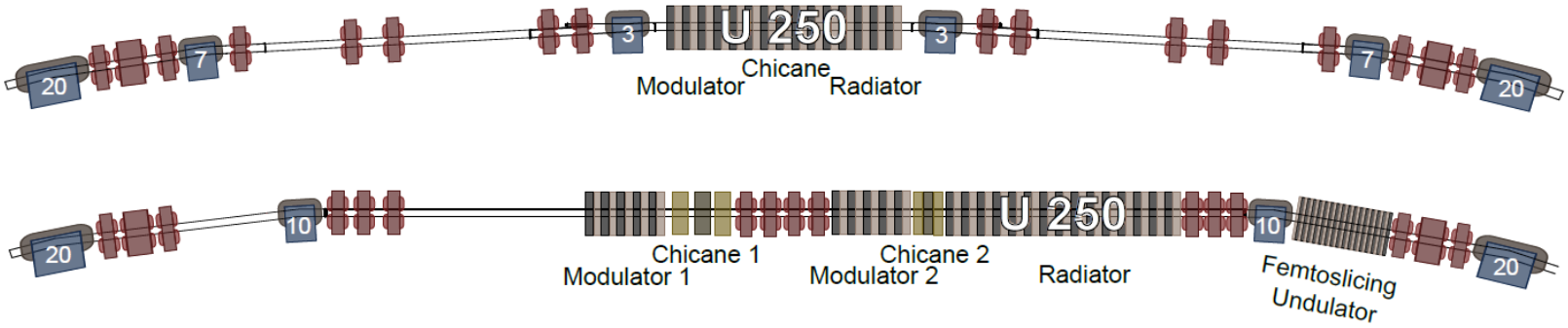

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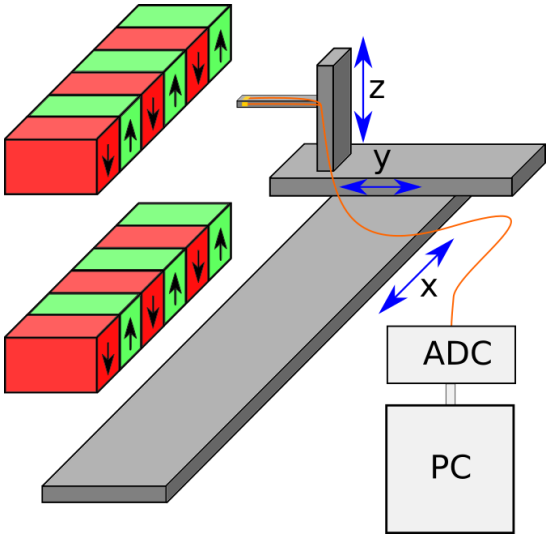
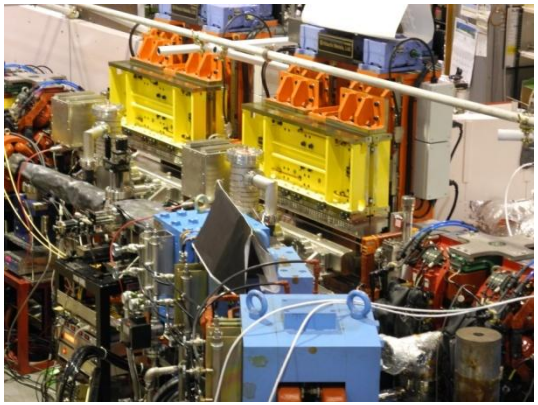


Goals

Pump-probe experiments with CHG in user operation
- address all practical issues

Characterization of CHG radiation
- beyond previous achievements (ACO, ELETTRA, UVSOR)

Echo-enabled harmonic generation at a storage ring
- significant alterations to the storage ring



B. Girard et al., PRL 53 (1984), 2405
M. Labat et al., PRL 101 (2008), 164803
E. Allaria et al., PRL 100 (2008), 174801

Practical seeding issues

Laser and electron beam stability
- issues: electron beam motion, instabilities, laser pointing stability

Laser beam transport and focus
- issues: narrow apertures, mirror degradation

Spectral overlap
- issues: hysteresis of electromagnetic undulator

Longitudinal overlap
- issues: synchronization, picosecond timing, jitter

Transverse overlap
- issues: limited diagnostics on position and laser waist

Laser pulse properties
- issues: variation of energy modulation, chirp

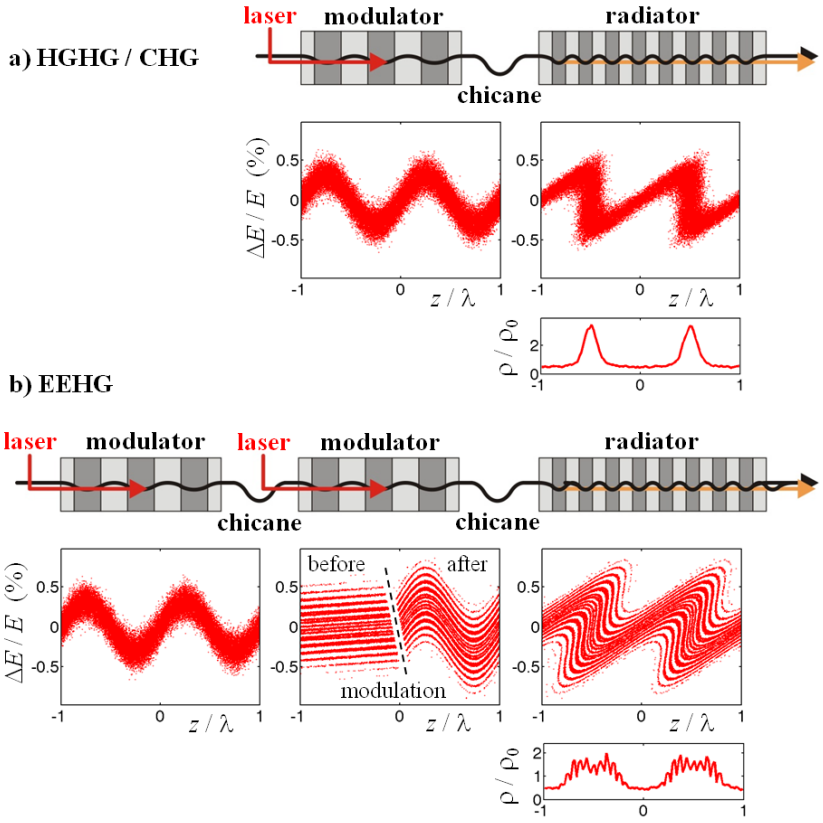
Thank You for your attention!

Acknowledgements

Thanks to

- CHG group, colleagues at DELTA, faculty of physics, FZ Jülich
- colleagues at other labs: HZB, KIT, DESY, SLS, ...
- funding: BMBF, DFG, NRW, Helmholtz (ARD)

Laser-induced ultrashort VUV- und THz pulses



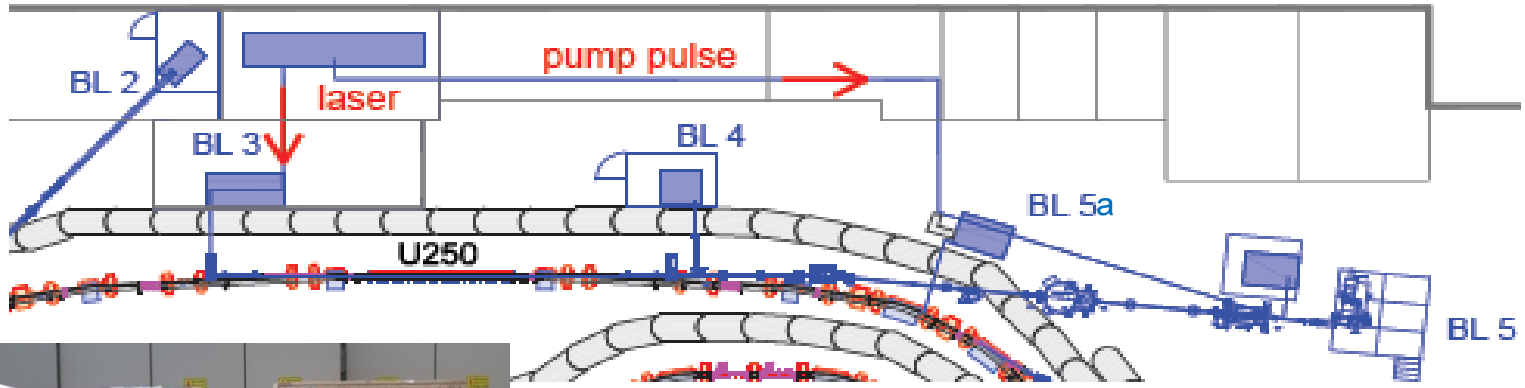
CHG (coherent harmonic generation)

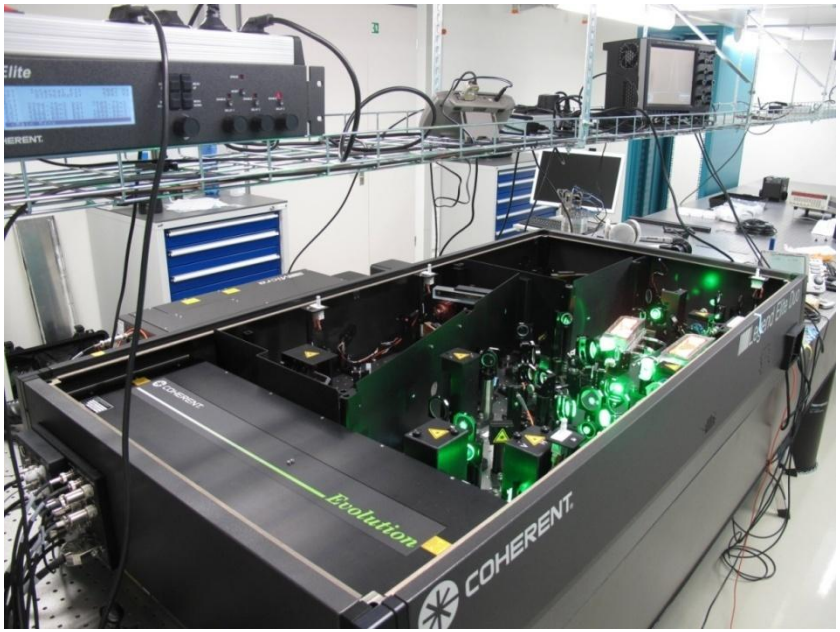
- laser-induced energy modulation in 1. undulator
- density modulation using a chicane
- coherent emission of harmonics in 2. undulator
- coherent THz radiation over several turns

EEHG (echo-enabled harmonic generation)

- using 3 undulators and 2 chicanes
- more complex density modulation
- higher harmonics, shorter wavelengths

Setup of the short-pulse facility





Laser lab with Ti:sapphire system

- 800 nm wavelength
- 8 mJ at 1 kHz repetition rate
- 40 fs pulse duration
- wavelengths: SHG, THG and OPA
- diagnostics: FROG and SPIDER

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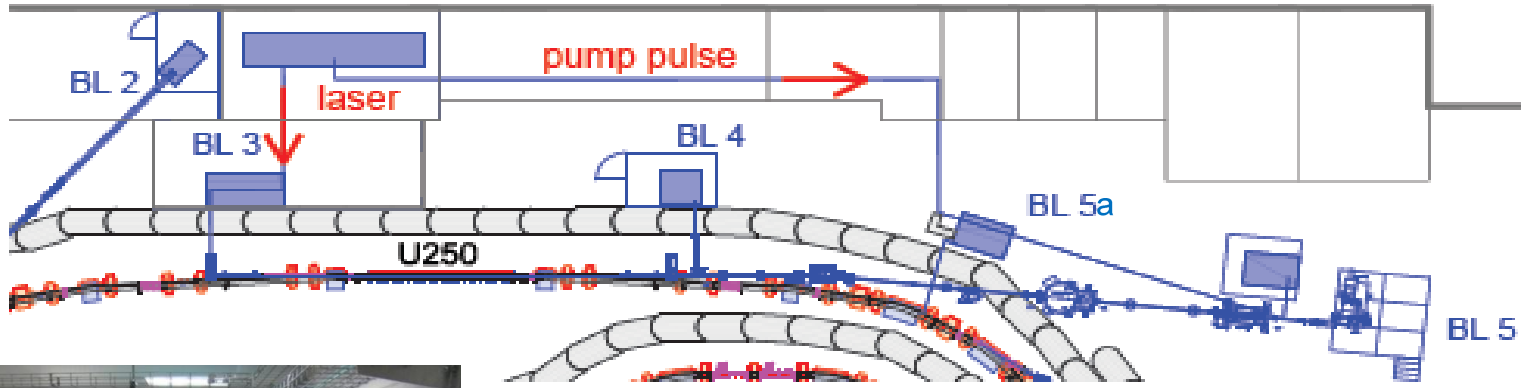
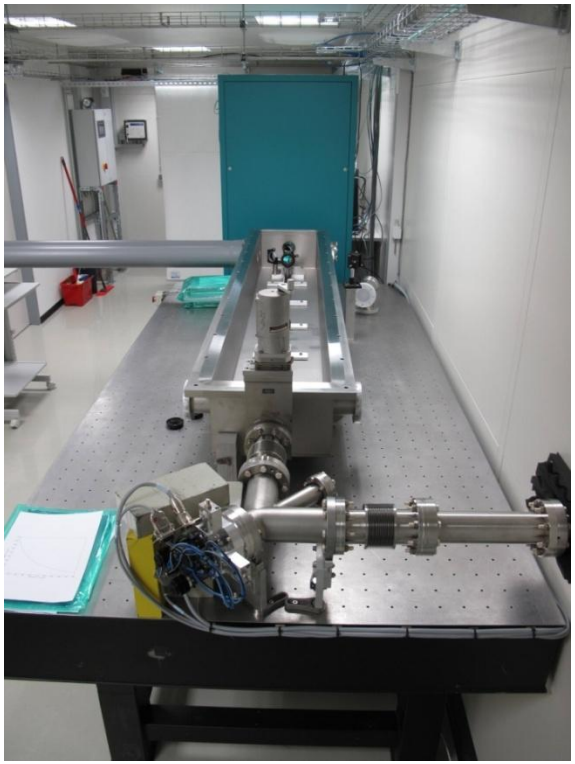
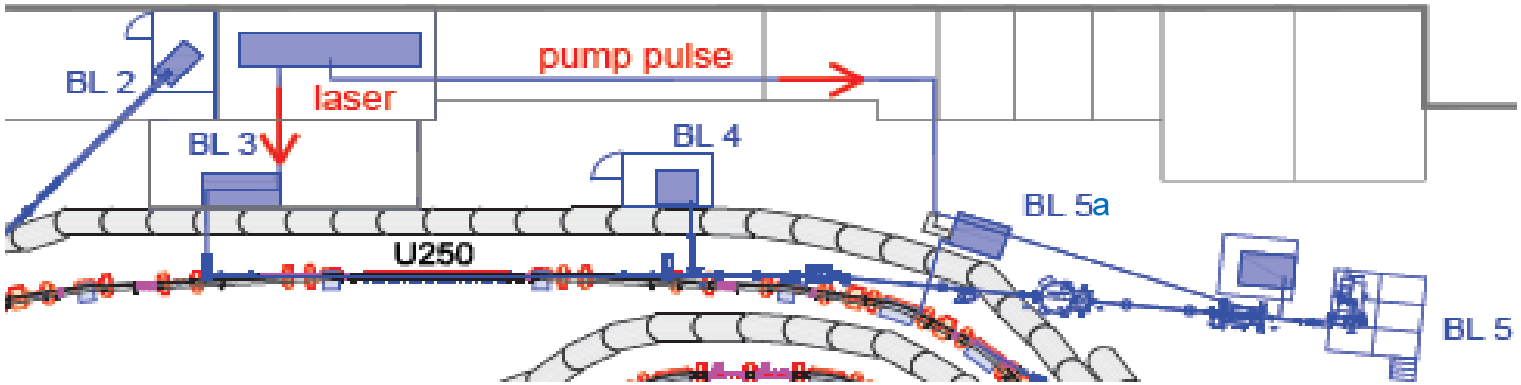




Telescope and BL 3

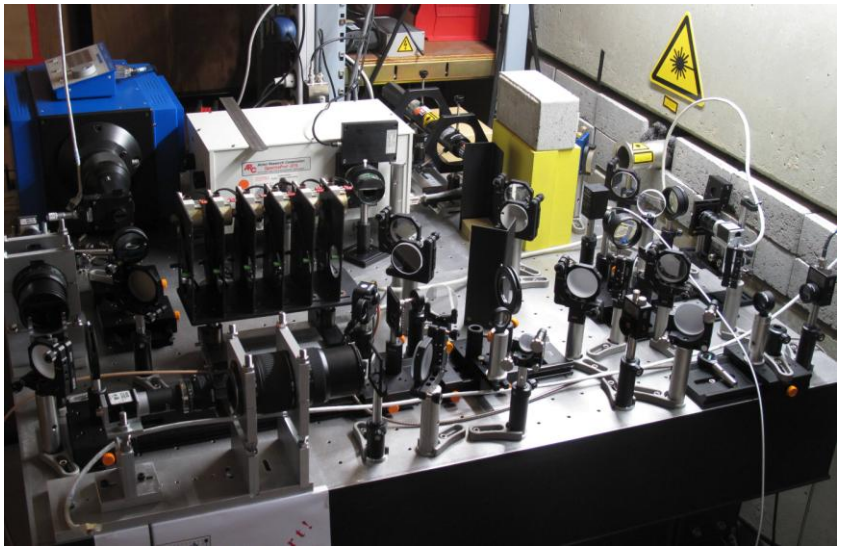
- lenses for 800 nm
- mirrors for 400 nm
- mirrors , timing etc. in DELTA control system

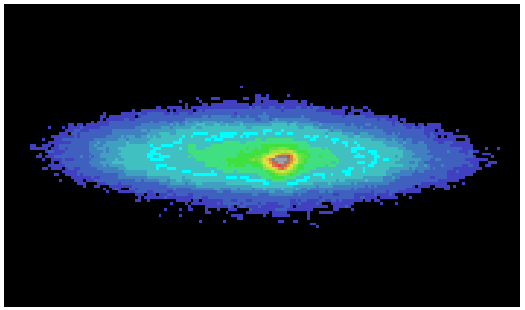
Setup of the short-pulse facility

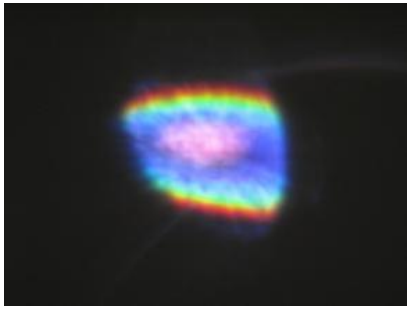


Diagnostics station BL 4

- water-cooled mirror
- longitudinal overlap: photodiodes, streak camera
- transverse overlap: cameras
- Czerny-Turner spectrometer with APD *)
- CCD spectrometers, powermeter etc.
- gated UV iCCD camera **)

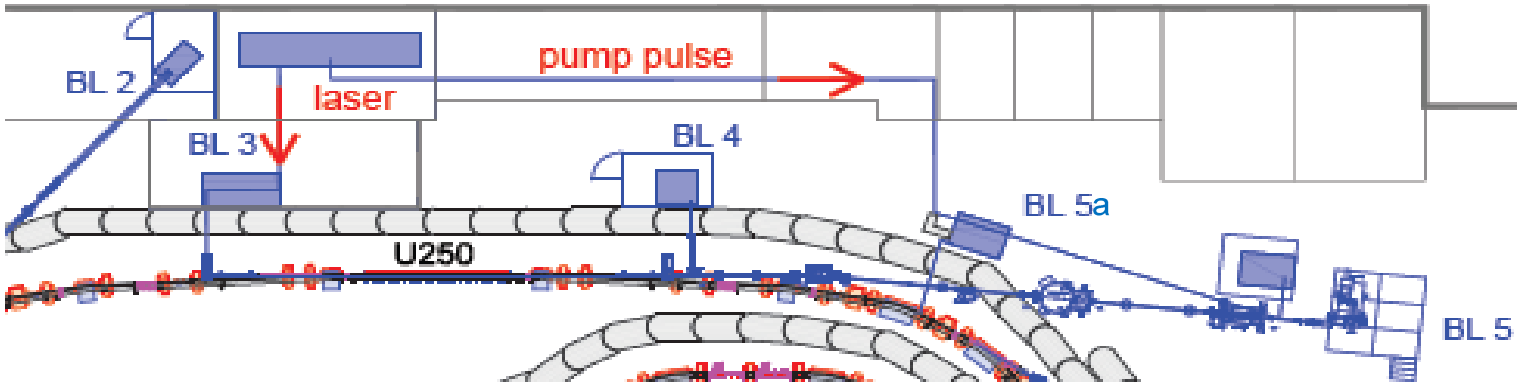






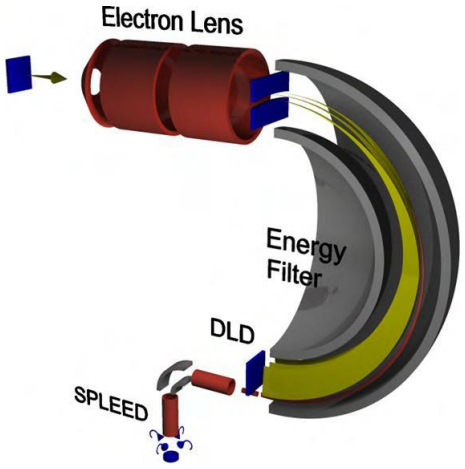
*) APD was prepared by K. Holldack (HZB)
**) courtesy B. Schmidt, S. Wunderlich (DESY)

Setup of the short-pulse facility



VUV beamline BL 5

- plane-grating monochromator
- photoelectron spectrometer with 2D detector
- beamline for pump pulse and laser hutch
- pump and probe pulses on sample within 1 ps



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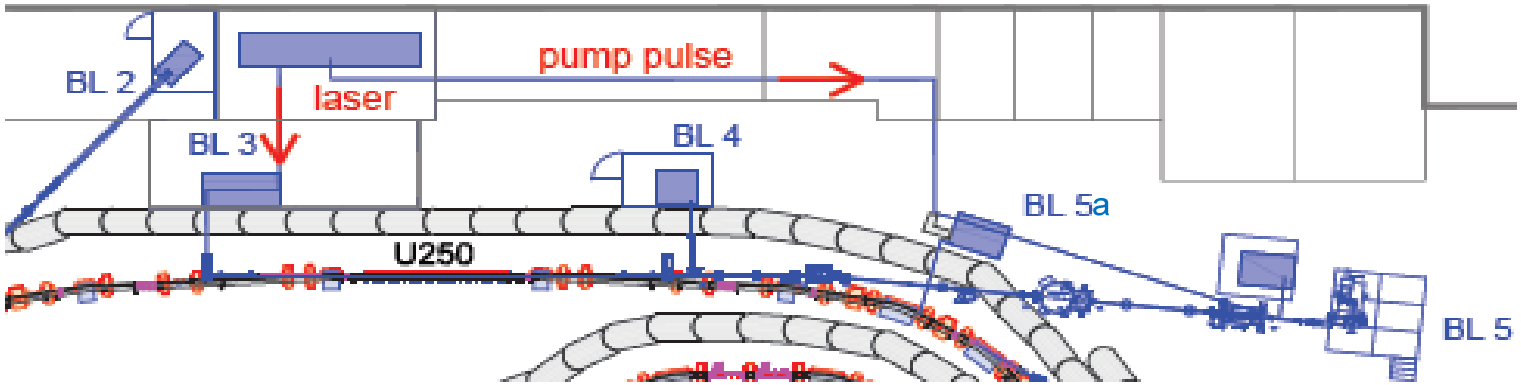
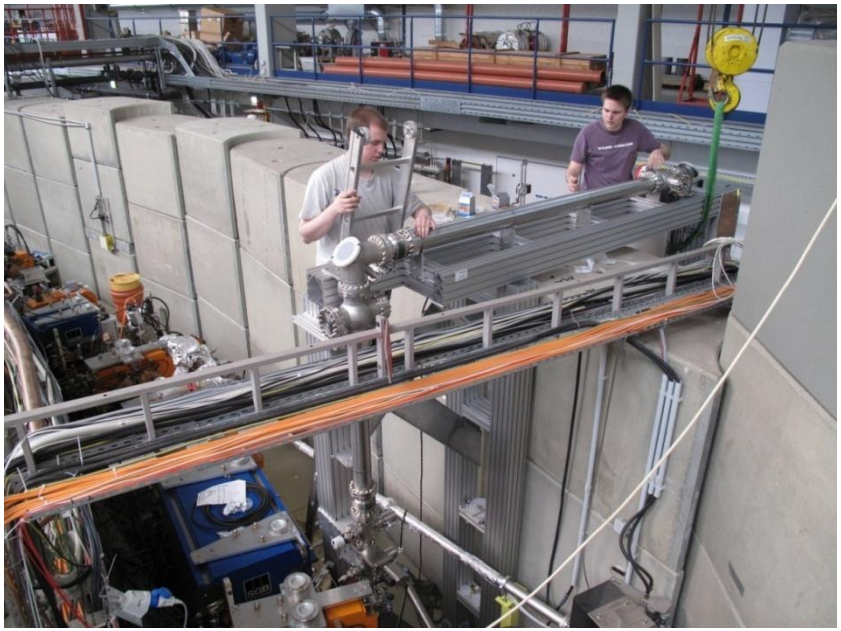


Terahertz beamline BL 5a

- 6 toriodal mirrors *)
- He-cooled InSb bolometer
- FT-IR spectrometer with He-cooled Si bolometer
- soon: ultrafast N_2-cooled YBCO bolometer **)

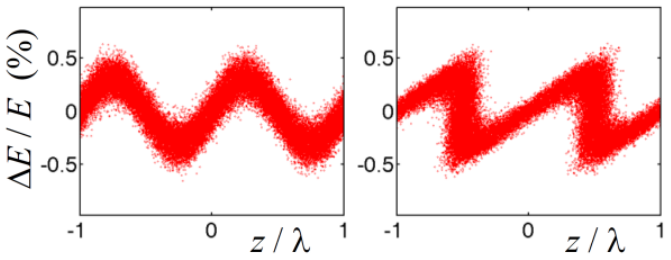


*) thanks to K. Holldack (HZB), V. Schlott (PSI) et al.
**) P. Thoma (KIT-IMS), N. Hiller, V. Judin (KIT-LAS)

Characterization of CHG radiation

CHG intensity versus chicane strength (R_{56})

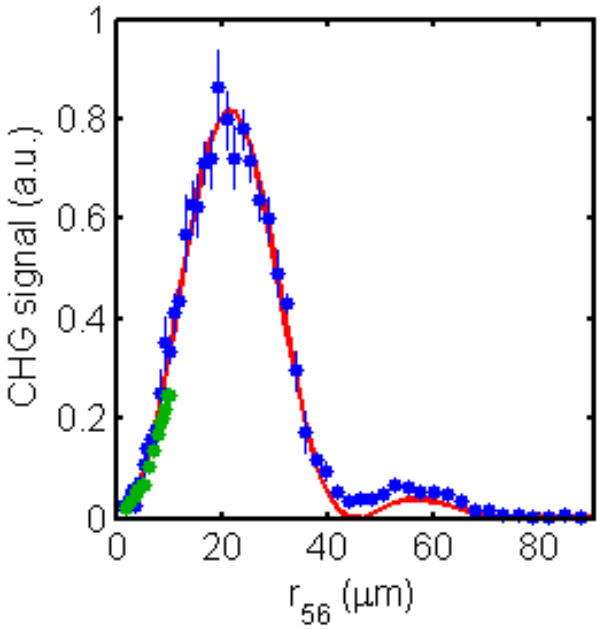
- first guess $\Delta z_{\mathrm{opt}} = R_{56} \cdot \left(\Delta E / E \right)_{\mathrm{max}} \approx \lambda_{\mathrm{seed}} / 4$

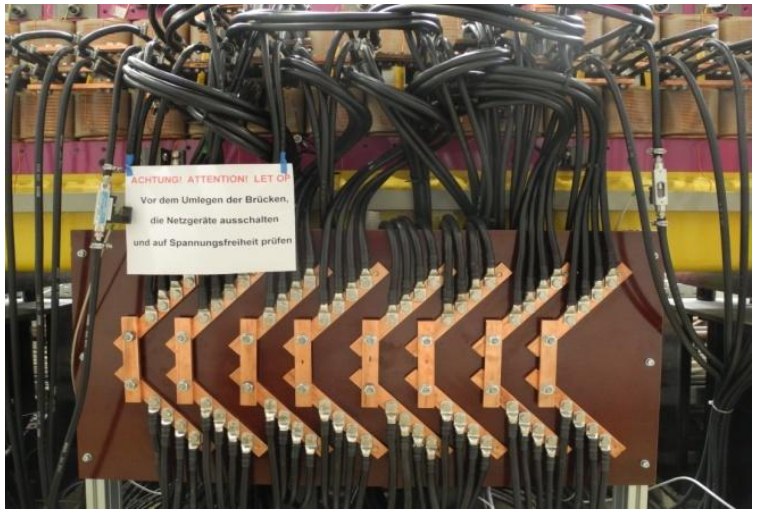


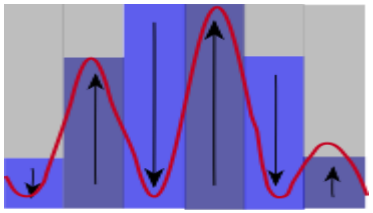
- theory $P_n = P_1 \cdot \left(n_b + n_{sl}^2 \cdot b_n^2 \right)$

bunching factor:

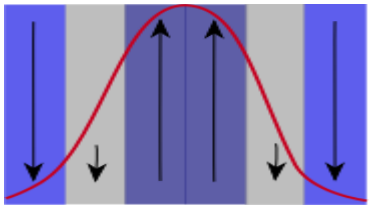
$$b_n = 2 \cdot \exp\left(n^2 B^2 / 2 \right) \cdot J_n\left(n \cdot A \cdot B \right) \quad \text{with} \quad A \equiv \Delta E / \sigma_E \qquad B \equiv R_{56} \frac{2\pi}{\lambda} \frac{\sigma_E}{E}$$







rewired chicane:

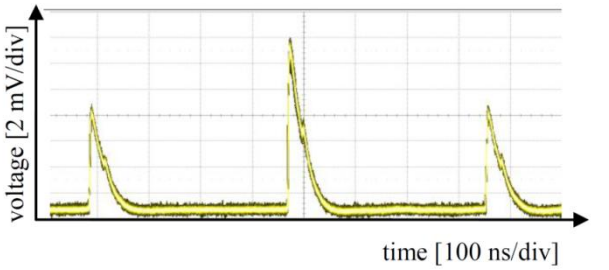


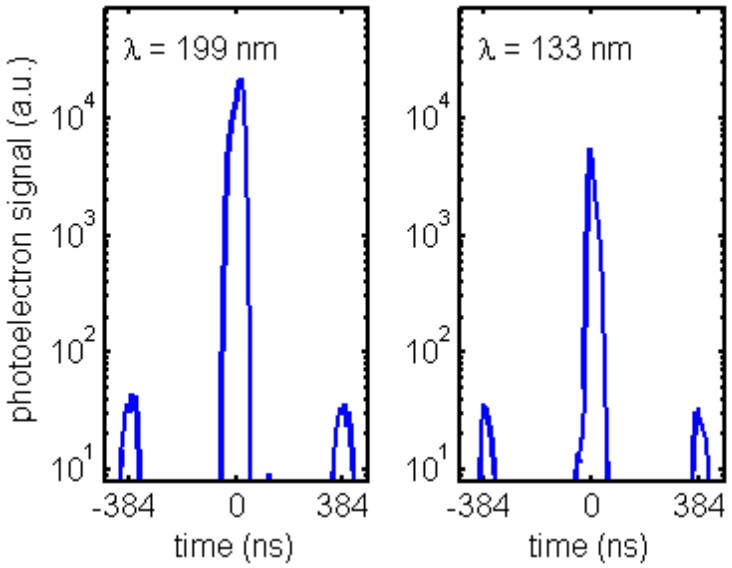
Characterization of CHG radiation

CHG intensity versus incoherent intensity

- theory $P_n = P_1 \cdot \left(n_b + n_{sl}^2 \cdot b_n^2 \right) \rightarrow P_{\mathrm{coh}} / P_{\mathrm{inc}} = \frac{n_{sl}^2}{n_b} b_n^2 = \frac{n_b}{10^6} b_n^2$ with $n_{sl}^2 \approx \frac{n_b}{10^3}$

$n_b (10\ \mathrm{mA}) \cong 2.4 \cdot 10^{10}$





First signal 2011

2. harmonic of 800 nm: factor 2

Now routinely:

2. harmonic of 400 nm: factor 600

4. harmonic of 800 nm: factor 100

3. harmonic of 400 nm: factor 150

Characterization of CHG radiation

CHG spectra

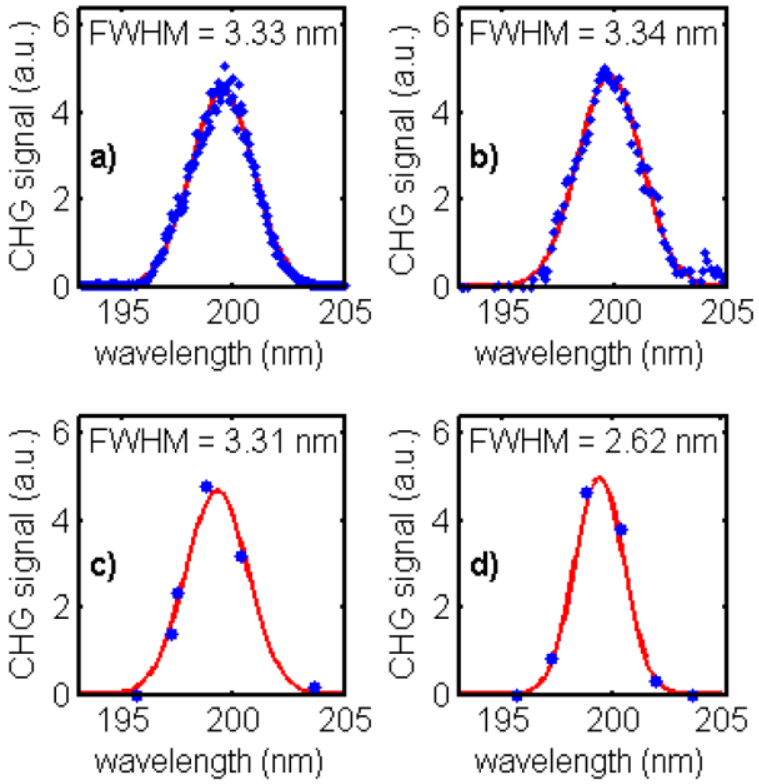
a) Czerny-Turner spectrometer with APD
(wavelength scan with grating)

b) CCD spectrometer
(background from 2600 turn subtracted)

c) Photoelectrons
(wavelength scan with monochromator)

d) Photoelectrons
(smaller exit slit)

Close to the Fourier limit



Characterization of CHG radiation

CHG spectra

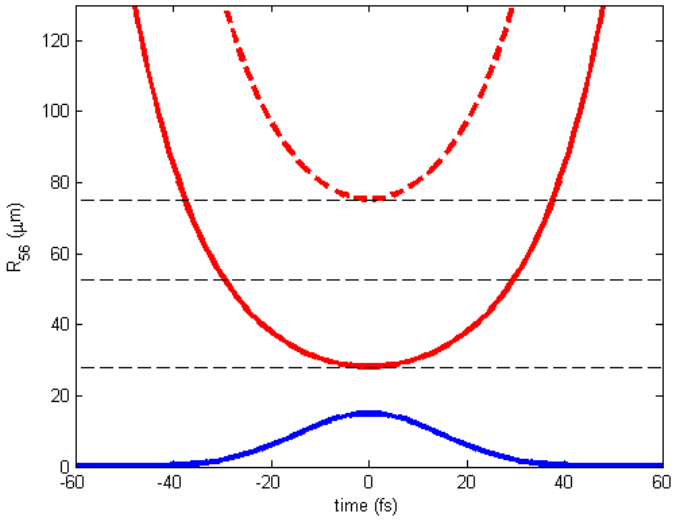
- theory $P_n = P_1 \cdot \left(n_b + n_{sl}^2 \cdot b_n^2 \right)$

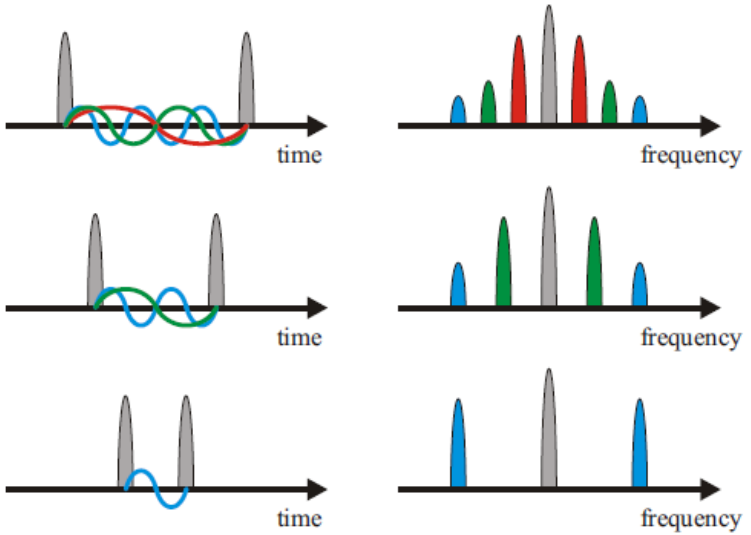
bunching factor:

$$b_n = 2 \cdot \exp\left(-n^2 B^2 / 2 \right) \cdot J_n\left(n \cdot A \cdot B \right) \quad \text{with} \quad A \equiv \Delta E / \sigma_E \qquad B \equiv R_{56} \frac{2\pi}{\lambda} \frac{\sigma_E}{E}$$

- Gaussian laser pulse: position-dependent energy modulation $A = A(x, y, z)$

- expect double pulse for large R_{56} → spectra with interference fringes



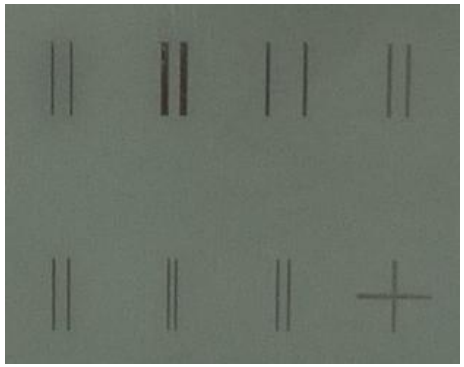


Characterization of CHG radiation

CHG coherence

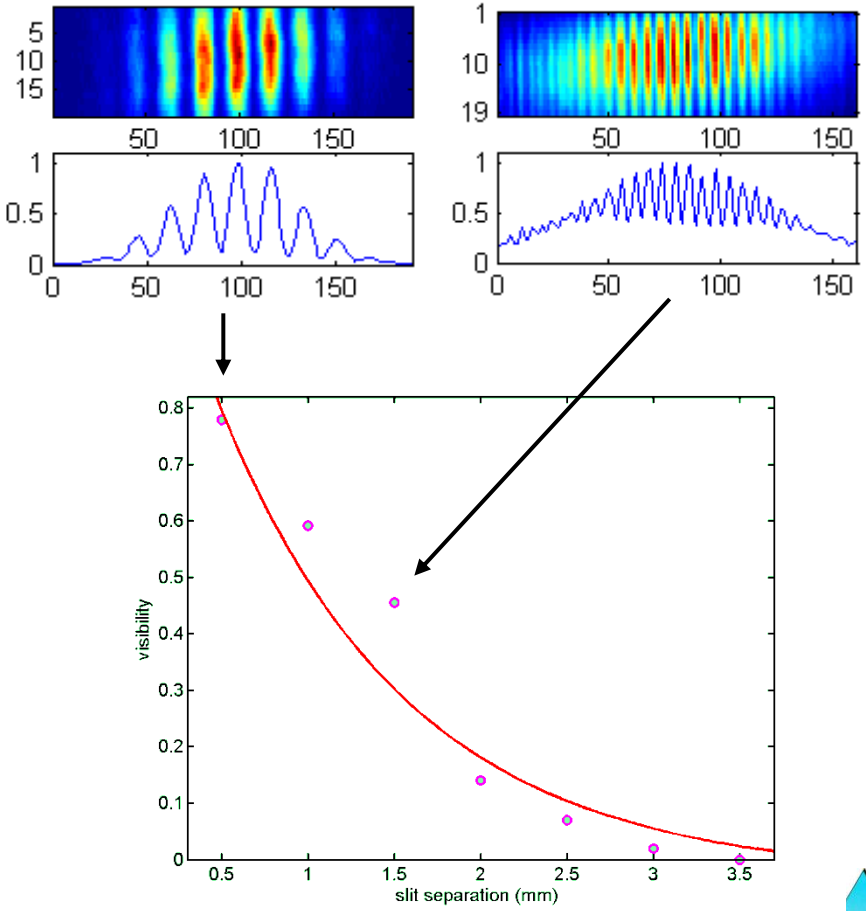
- transverse coherence:
  double-slit experiment
  speckle patterns

- longitudinal coherence:
  double-slit pattern with delay
  Michelson interferometer



Gated iCCD camera
courtesy B. Schmidt,
S. Wunderlich (DESY)

Example at 200 nm wavelength

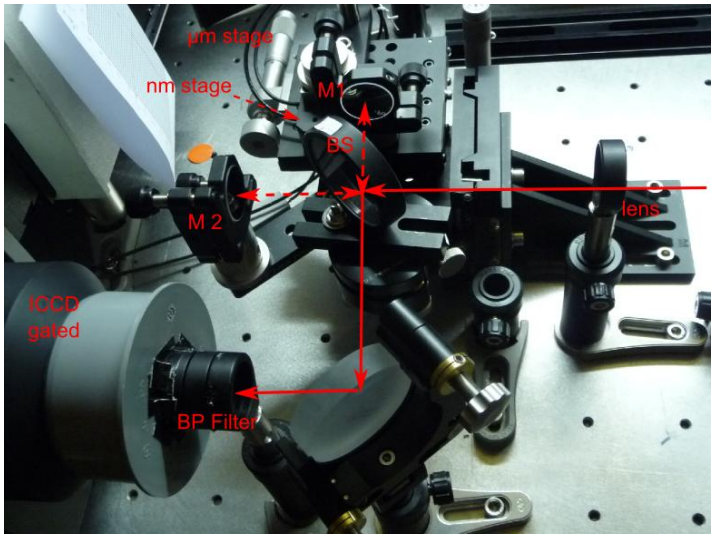


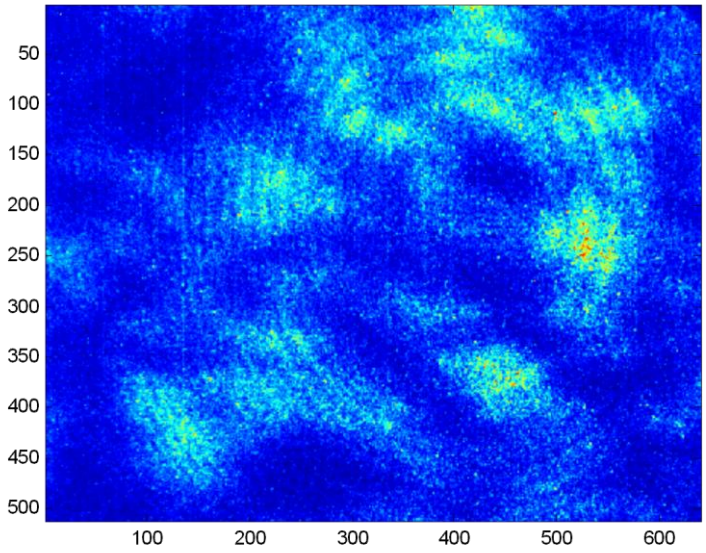
Characterization of CHG radiation

CHG coherence

- transverse coherence:
  double-slit pattern
  speckle patterns

- longitudinal coherence:
  Michelson interferometer
  double-slit pattern with delay



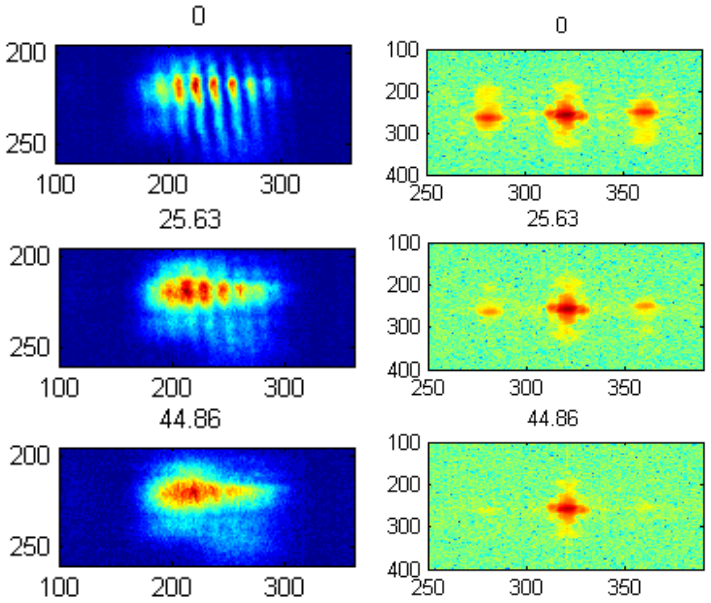


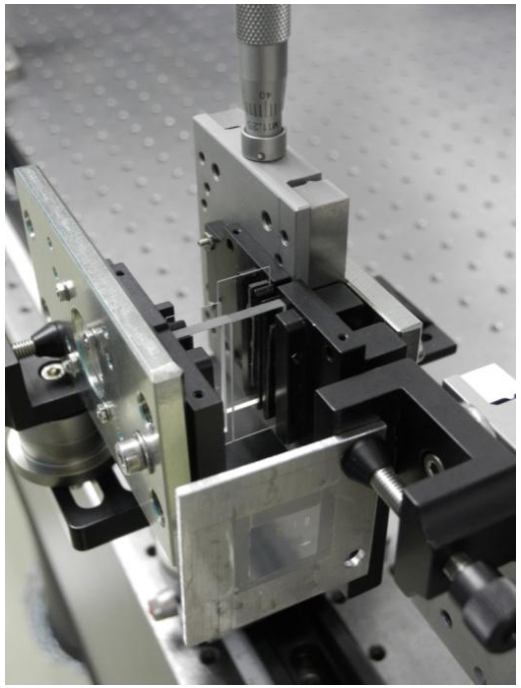
Characterization of CHG radiation

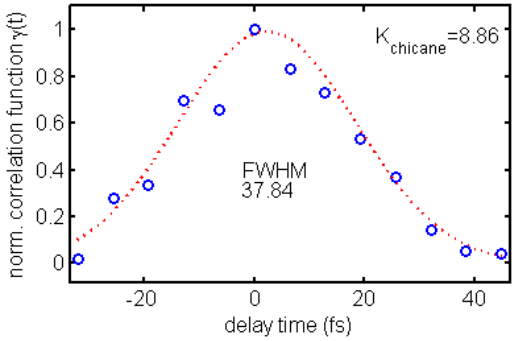
CHG coherence

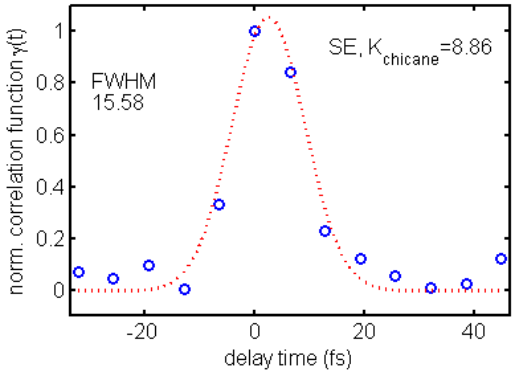
- transverse coherence:
  double-slit pattern
  speckle patterns

- longitudinal coherence:
  Michelson interferometer
  double-slit pattern with delay









Beam dynamics (tomorrow)

Bunch-by-bunch feedback

- wakefield studies
- injection studies
- beam loss monitor

Coherent Terahertz radiation

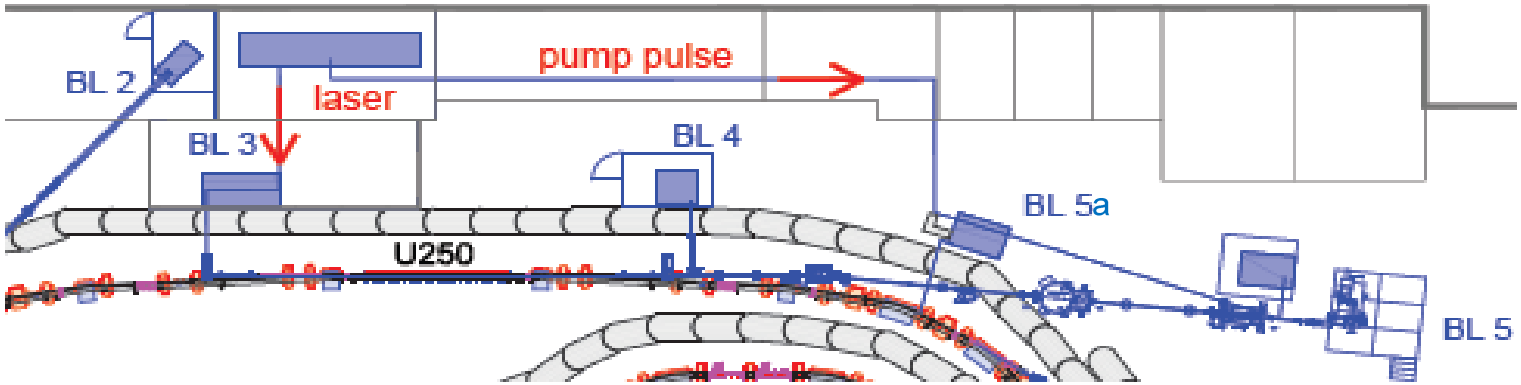
- THz spectra
- fast bolometers
- narrow-band THz radiation
- seeding and paramentric rf oscillation

Acknowledgements

Thanks to

- CHG group, colleagues at DELTA, faculty of physics, FZ Jülich
- colleagues at other labs: HZB, KIT, DESY, SLS, ...
- funding: BMBF, DFG, NRW, Helmholtz (ARD)

Setup of the short-pulse facility



Undulator U250

- soft-x-ray undulator for beamline BL 5 and storage-ring FEL
- 7 + 3 + 7 periods of 250 mm length
- new power supplies for K > 10 (800 nm at 1.5 GeV)
- chicane rewired for $R_{56} = 130\ \mu m$