

# DELTA: Status and New Developments

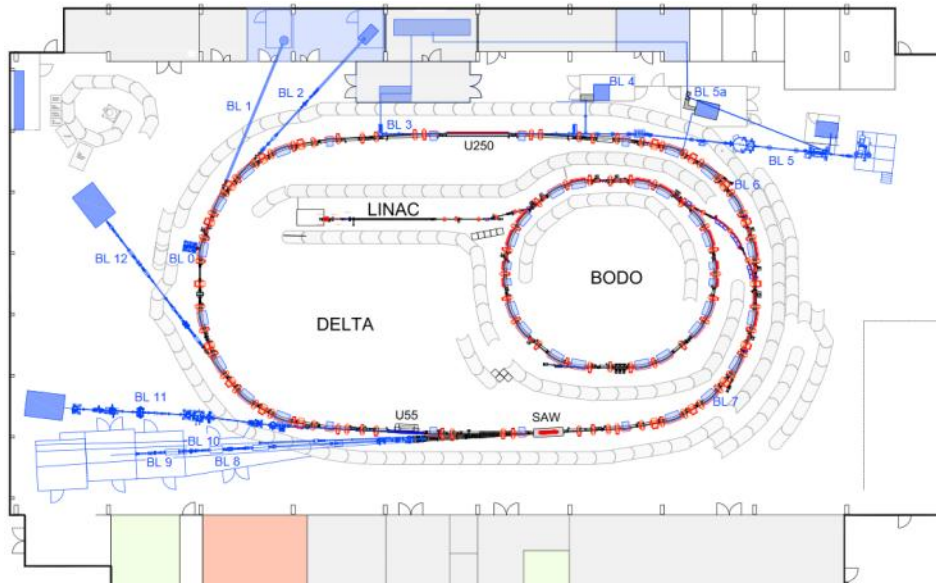
1

Shaukat Khan, Zentrum für Synchrotronstrahlung

Dortmund, Nov 21, 2017

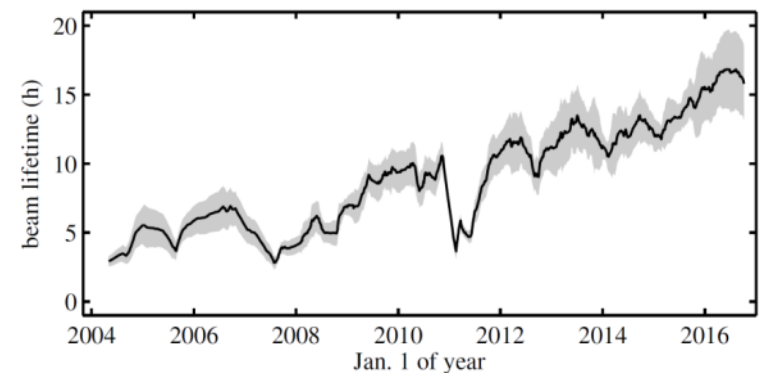
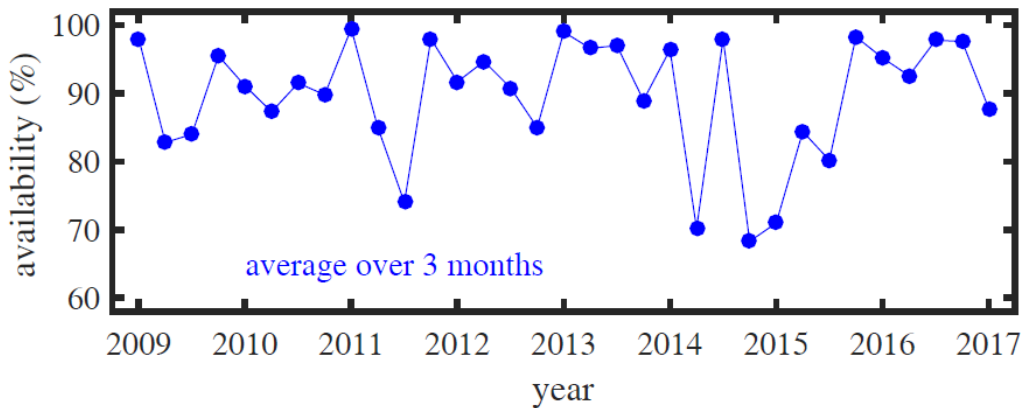


# Parameters and availability



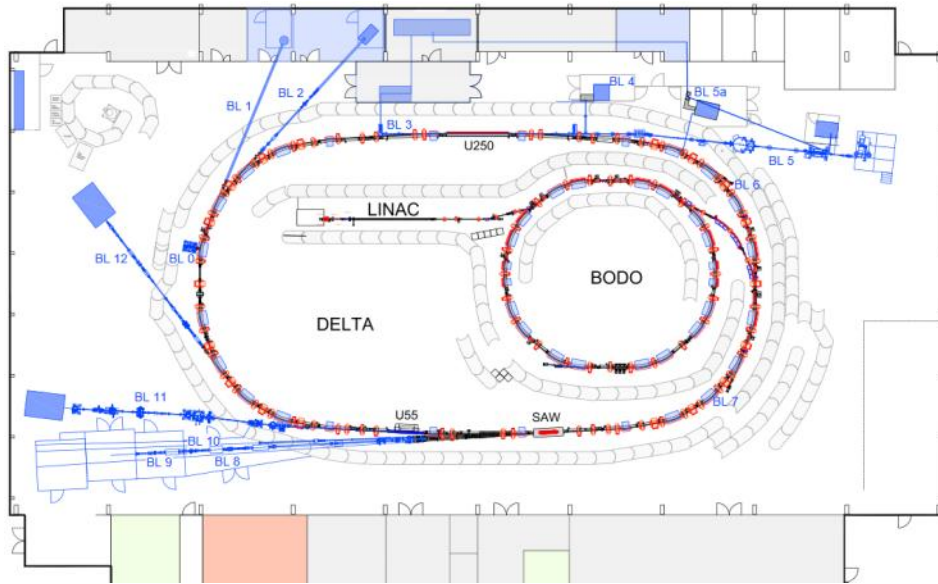
## Parameters

circumference	115.2 m
beam energy	1.5 GeV
beam current	130 mA multi-bunch
beam current	20 mA single bunch
beam lifetime	~14 h at 100 mA
hor. emittance	~16 nm rad
bunch length	40 ps rms
user operation	2000 h/y (20 weeks/y)
machine studies	1000 h/y (10 weeks/y)



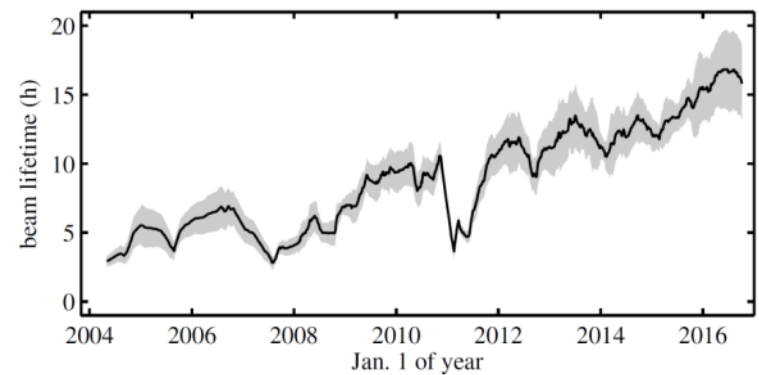
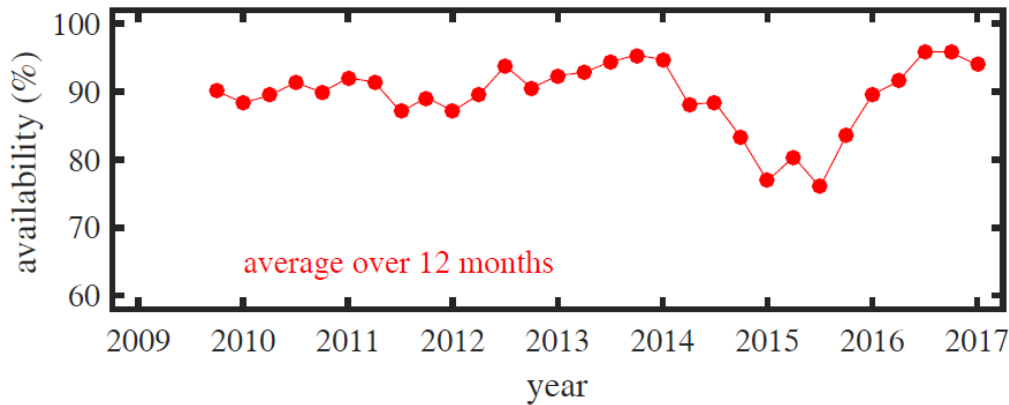
(J. Friedl, G. Schmidt, P. Ungelenk)

# Parameters and availability



## Parameters

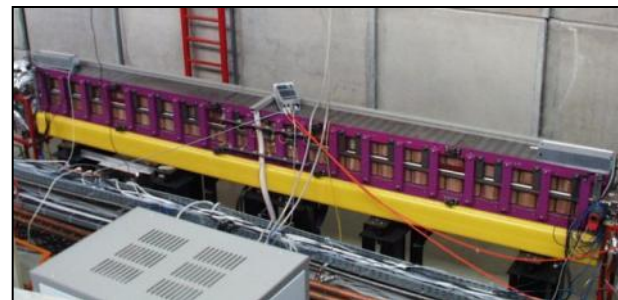
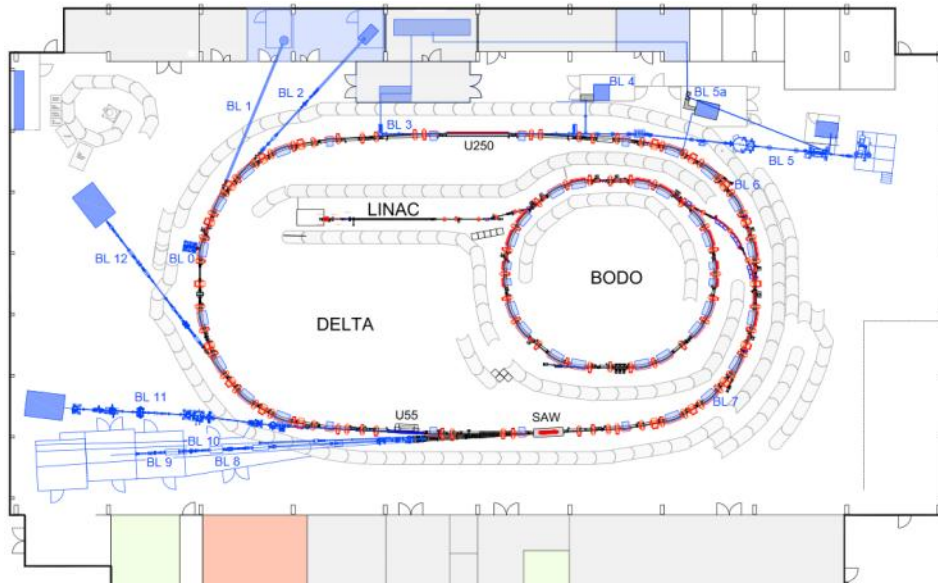
<b>circumference</b>	<b>115.2 m</b>
<b>beam energy</b>	<b>1.5 GeV</b>
<b>beam current</b>	<b>130 mA multi-bunch</b>
<b>beam current</b>	<b>20 mA single bunch</b>
<b>beam lifetime</b>	<b>~14 h at 100 mA</b>
<b>hor. emittance</b>	<b>~16 nm rad</b>
<b>bunch length</b>	<b>40 ps rms</b>
<b>user operation</b>	<b>2000 h/y (20 weeks/y)</b>
<b>machine studies</b>	<b>1000 h/y (10 weeks/y)</b>



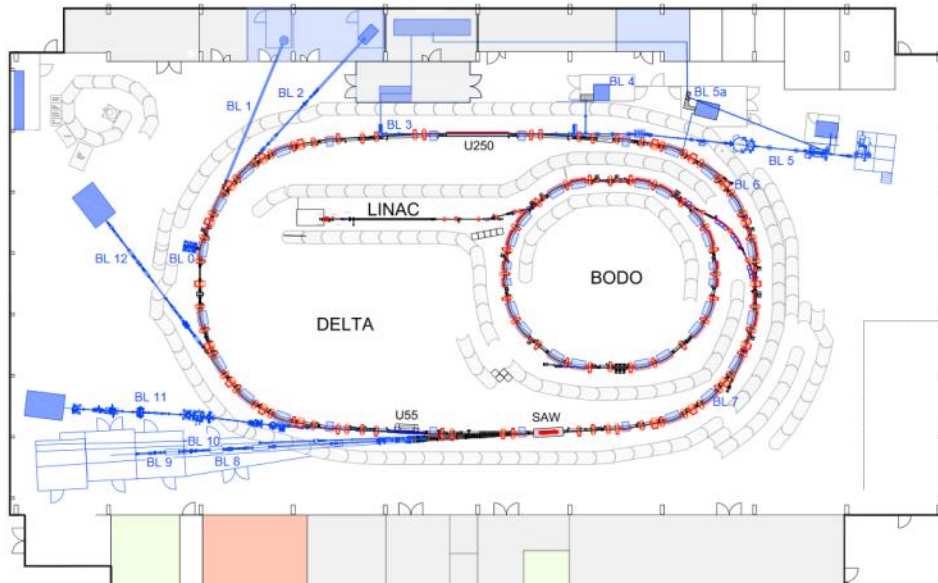
(J. Friedl, G. Schmidt, P. Ungelenk)



# Insertion devices



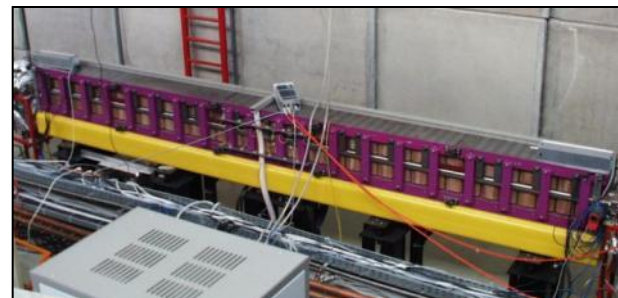
# Insertion devices



**U250 repaired summer 2017  
without venting the vacuum chamber**



(G. Dahlmann, T. Dybiona,  
B. Hippert, P. Kortmann,  
T. Schulte-Eickhoff)

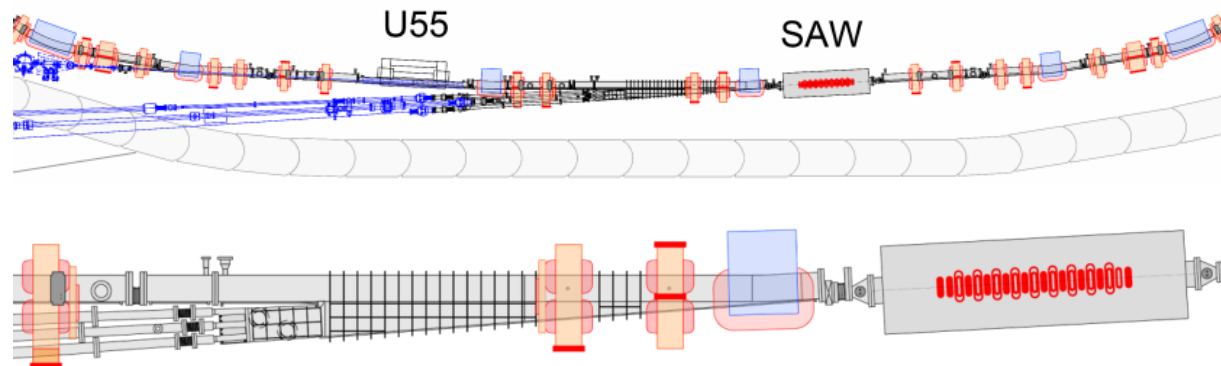
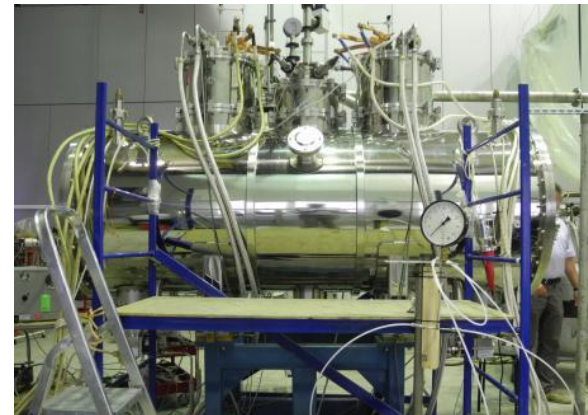


# Superconducting wiggler

(W. Brembt, P. Hartmann, B. Hippert, S. Khan, V. Kniss, P. Kortmann, M. Paulus, D. Schirmer, G. Schmidt, C. Sternemann, M. Tolan)

## Superconducting asymmetric wiggler

- is ageing, no support from manufacturer
- new device funded and ordered (arrival 2018)**
- no asymmetry option
- higher field (5.3 T  $\rightarrow$  7 T)
- more periods (5  $\rightarrow$  10)
- less He consumption (130 l/week  $\rightarrow$  none)



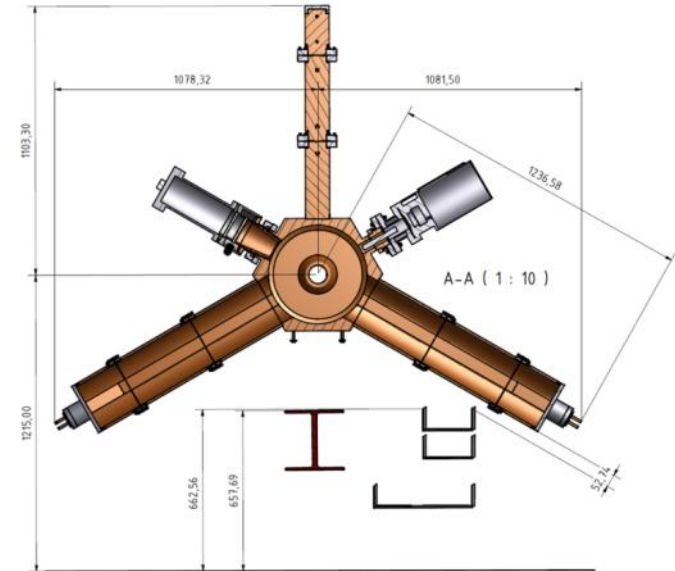
# RF upgrade

(W. Brembt, P. Hartmann, V. Kniss, T. Weis)

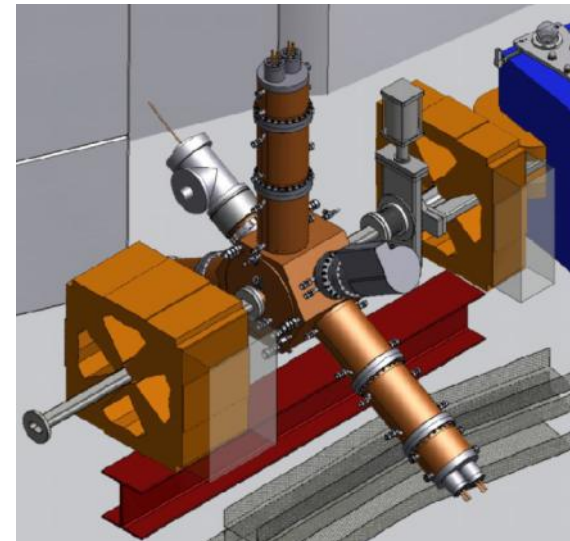
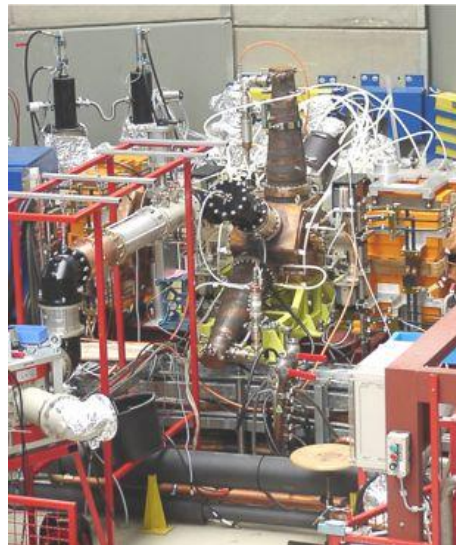
**500 MHz European HOM-damped cavity**  
funded and ordered (beginning of 2018)

**500 MHz solid-state amplifier**  
installed in 2017

- 75 kW for the storage ring
- 20 kW for the booster synchrotron



(Courtesy Research Instruments GmbH)







# Stability, lifetime and all that

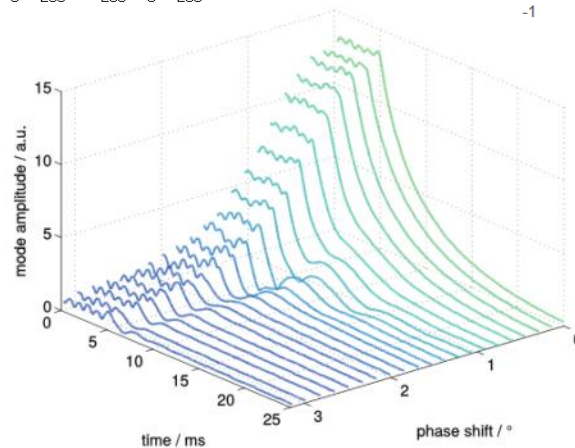
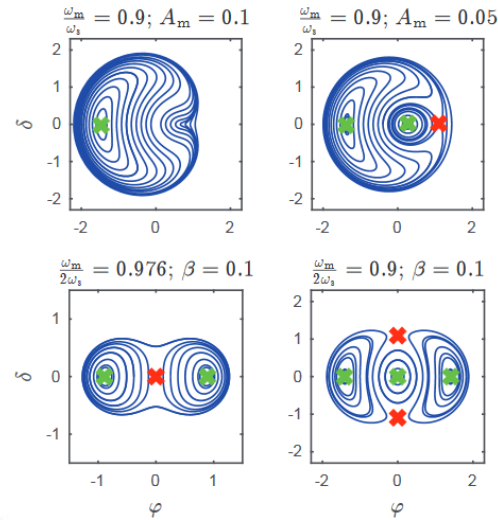
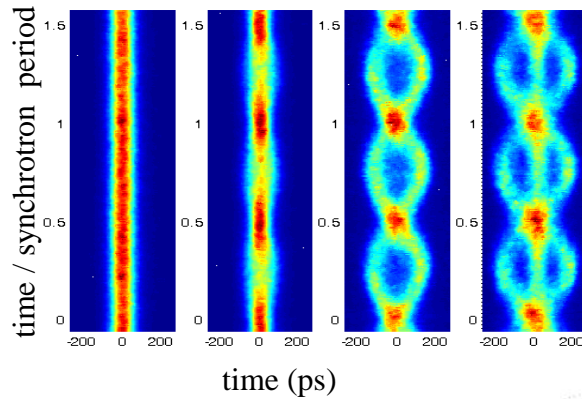
(M. Bursy, M. Höner, A. Jebramcik, S. Khan, M. Sommer)



## Bunch-by-bunch feedback systems (installed 2011)

- damp longitudinal and transverse oscillations, used for accelerator studies and diagnostics

### example: RF phase modulation



M. Jebramcik, master thesis, TU Dortmund (2016)  
 M. Jebramcik et al., IPAC 2016, Busan/Korea, p.2847.

M. Sommer, dissertation, TU Dortmund (in preparation)  
 M. Sommer et al., IPAC 2016, Busan/Korea, p. 1720.

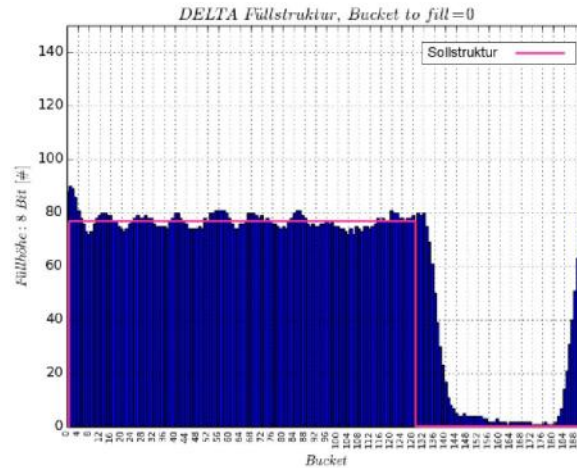
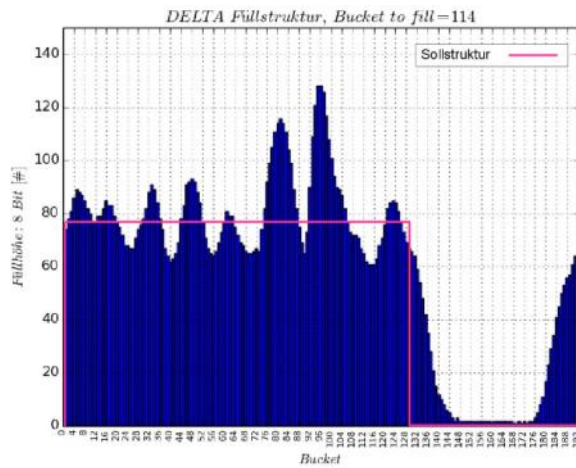


# Filling pattern

(Y. Bernau, P. Hartmann, T. Weis)

## Injection timing and filling pattern

- arbitrary shapes possible, improved quality

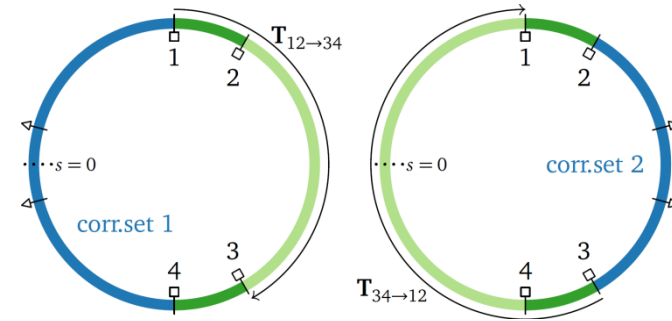


Y. Bernau, master thesis, TU Dortmund (2016)

# COBEA algorithm

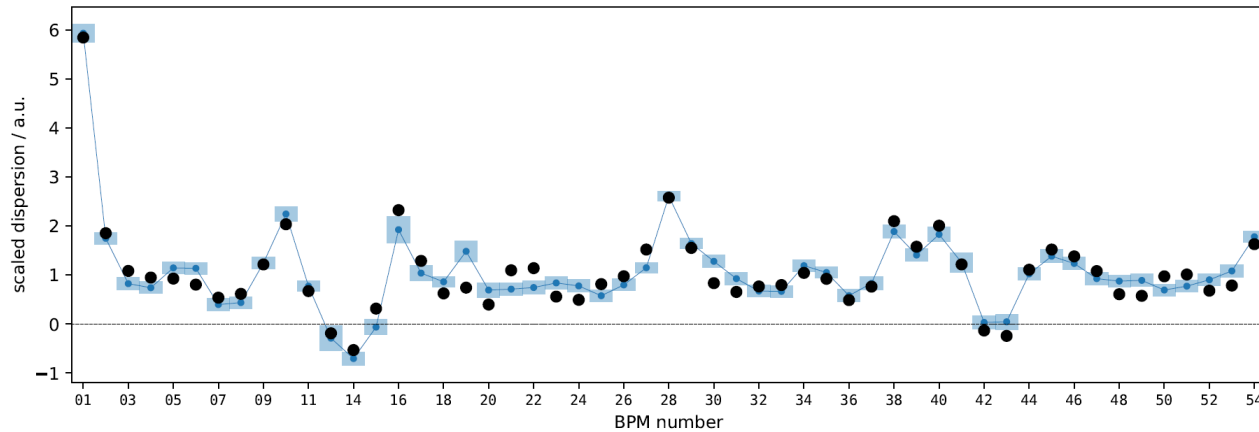
(B. Riemann, T. Weis)

**Optical functions from the resonance matrix**  
**- without the full lattice information**



B. Riemann, dissertation, TU Dortmund (2016).

B. Riemann et al., IPAC 2017, Copenhagen/Denmark, p. 676.

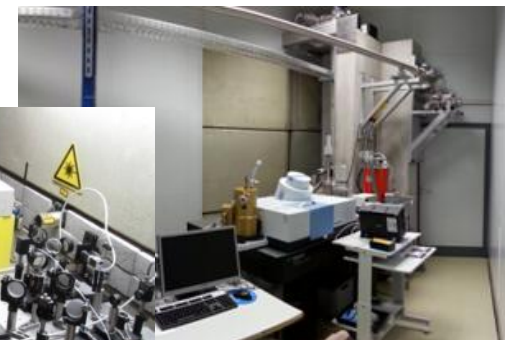
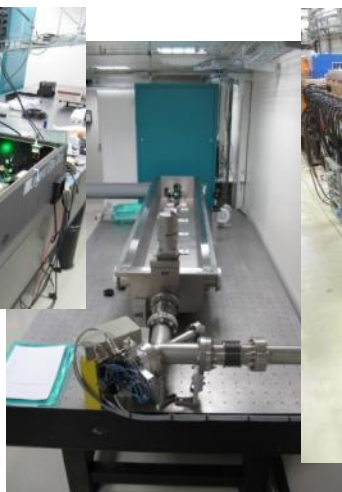
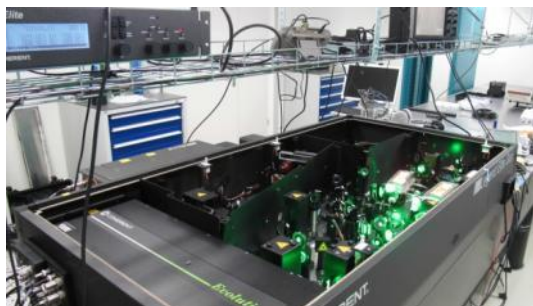
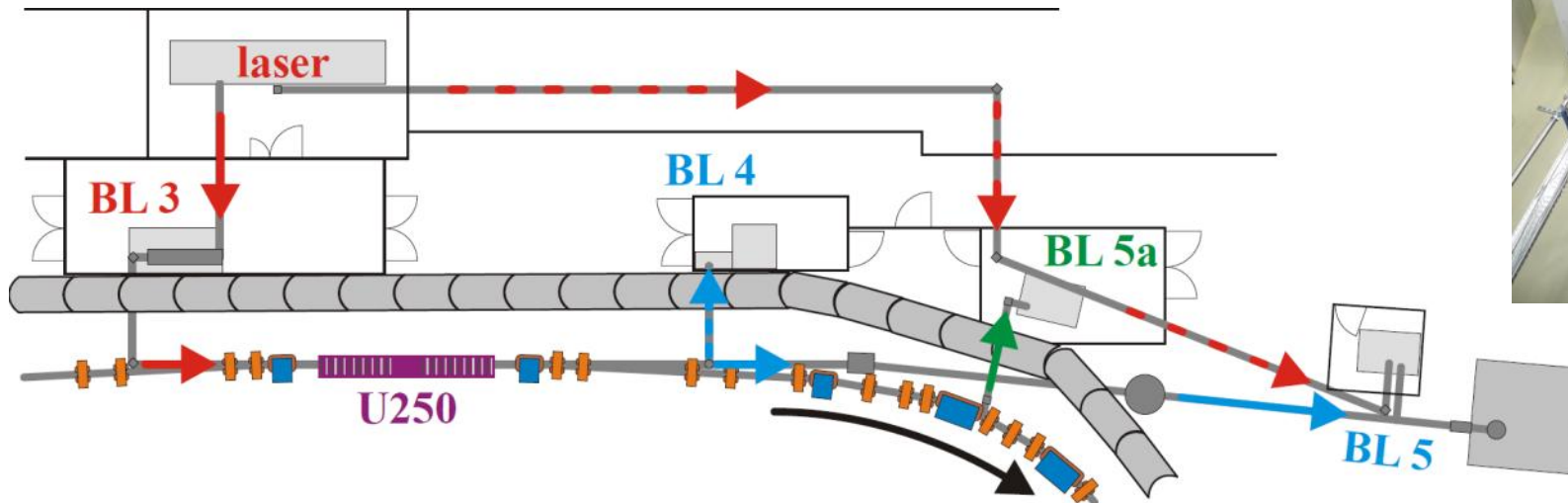


COBEA

RF detuning

# Facility for ultrashort VUV and THz pulses

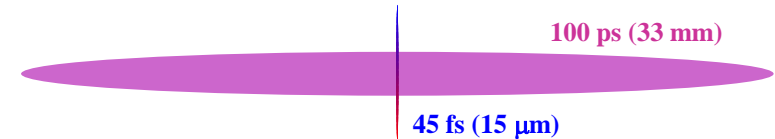
B. Büsing, N. Lockmann, S. Khan, D. Krieg, C. Mai, A. Meyer auf der Heide, B. Riemann, B. Sawadski, M. Schmutzler, F. Teutenberg [TU Dortmund]  
 S. Cramm, L. Plucinski, C. Schneider [FZ Jülich and U Duisburg-Essen]  
 M. Cinchetti, S. Ponzoni [TU Dortmund]



# Facility for ultrashort VUV and THz pulses

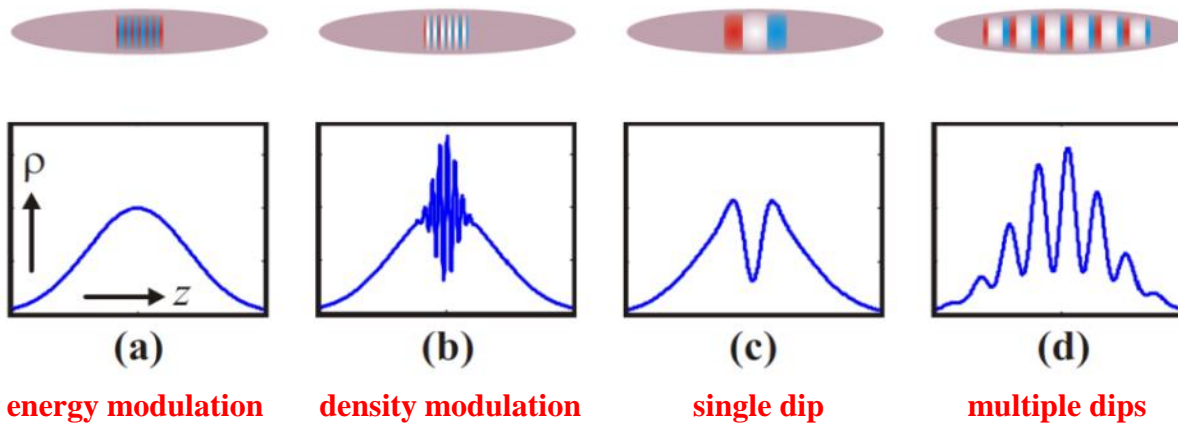
## Coherent harmonic generation (CHG)

- laser-induced energy modulation within a bunch "slice"
- density modulation in a magnetic chicane
- coherent radiation at harmonics of the laser wavelength (so far 80 nm, goal 53 nm)



## Coherent terahertz (THz) radiation

- short "dip" due to energy-dependent path length
- broadband coherent THz radiation
- narrowband coherent THz radiation from multiple dips



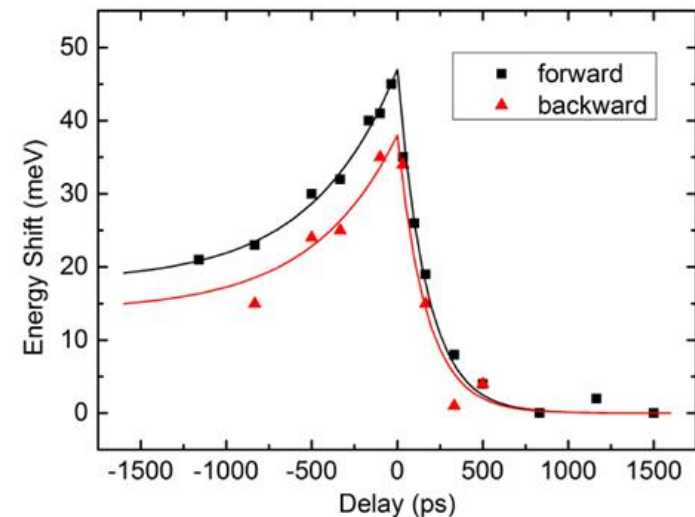
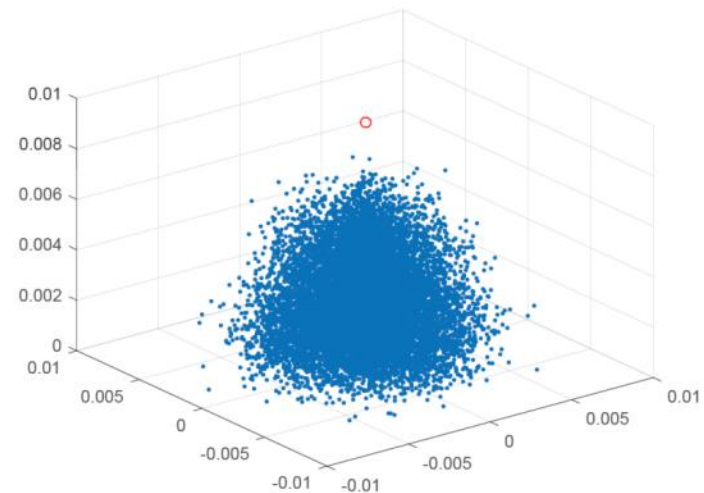
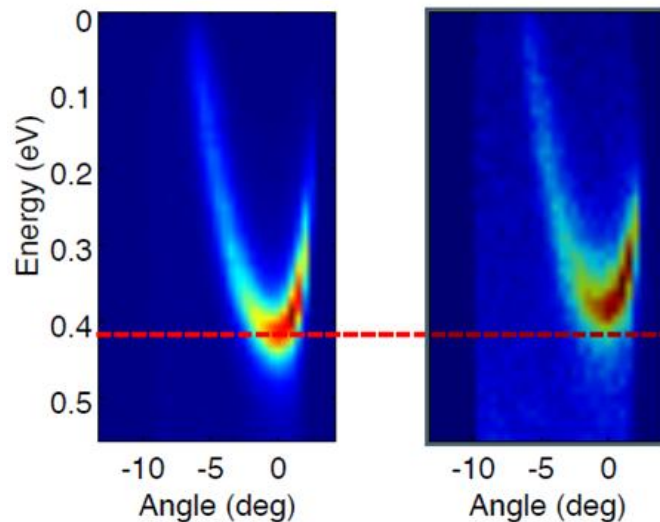
# Facility for ultrashort VUV and THz pulses

## Coherent harmonic generation (CHG)

- laser-induced energy modulation within a bunch "slice"
- density modulation in a magnetic chicane
- coherent radiation at harmonics of the laser wavelength (so far 80 nm, goal 53 nm)

2017: first pump-probe result, space charge effect

2018: not yet reproduced, beamline vacuum problems



S. Khan et al., IPAC 2017, Copenhagen/Denmark, p. 2578.

# Echo-enabled harmonic generation at DELTA

Supported by Helmholtz ARD initiative (FZ Jülich)

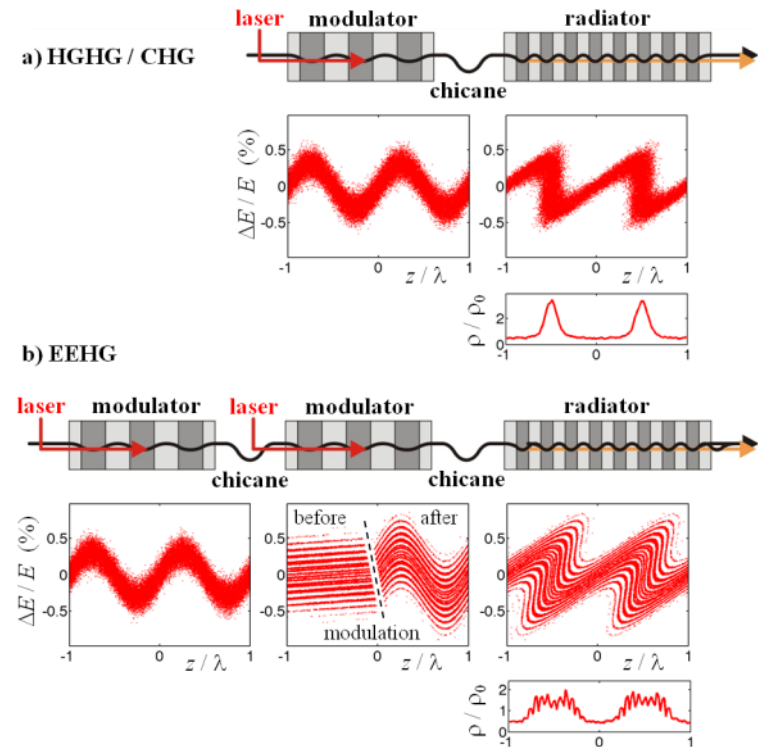
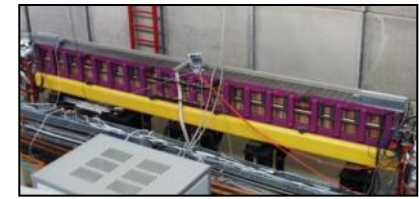
- modulators: 2 short undulators
- radiator: present U250 undulator
- requires longer straight section
- modified storage ring optics
- additional undulator for "slicing"

G. Stupakov, Phys. Rev. Lett. 102, 074801 (2009)

D. Xiang et al., Phys. Rev. Lett. 105, 114801 (2010)

Z.T. Zhao et al., Nature Photonics 6, 360 (2012)

E. Hemsing et al., Nature Photonics 10, 512 (2016)



# Echo-enabled harmonic generation at DELTA

Supported by Helmholtz ARD initiative (FZ Jülich)

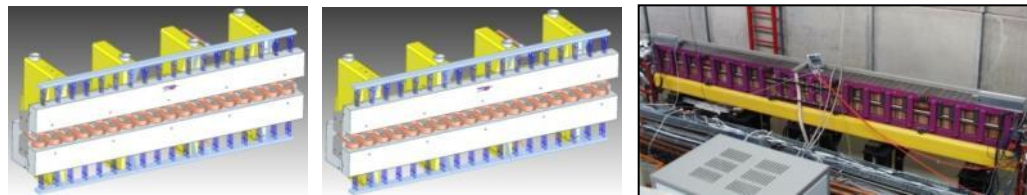
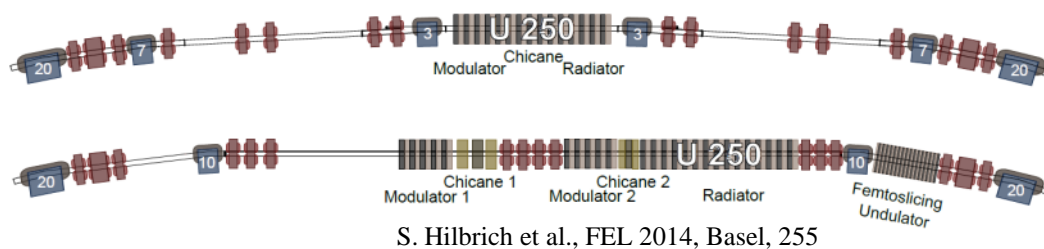
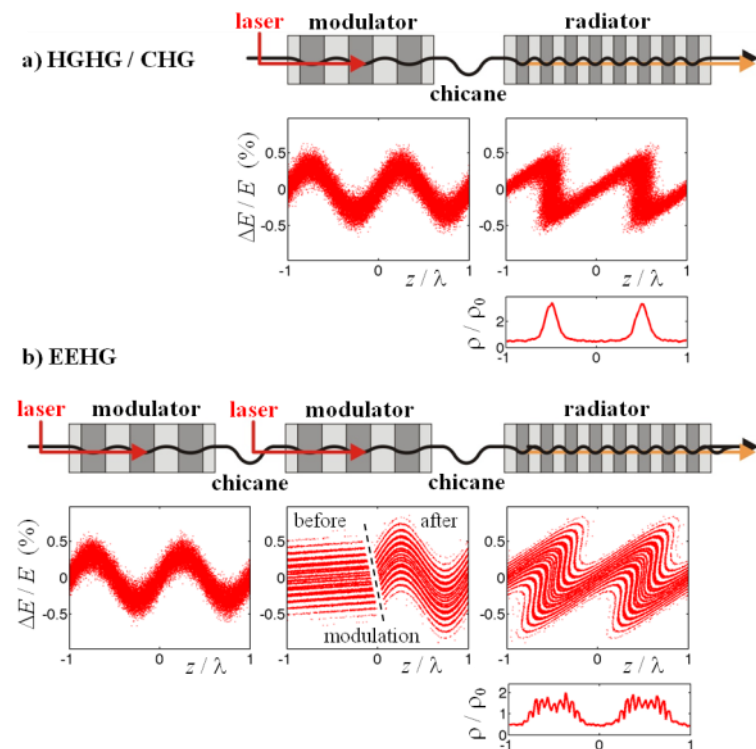
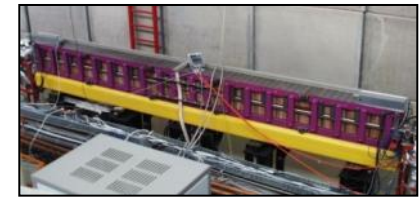
- modulators: 2 short undulators
- radiator: present U250 undulator
- requires longer straight section
- modified storage ring optics
- additional undulator for "slicing"

G. Stupakov, Phys. Rev. Lett. 102, 074801 (2009)

D. Xiang et al., Phys. Rev. Lett. 105, 114801 (2010)

Z.T. Zhao et al., Nature Photonics 6, 360 (2012)

E. Hemsing et al., Nature Photonics 10, 512 (2016)



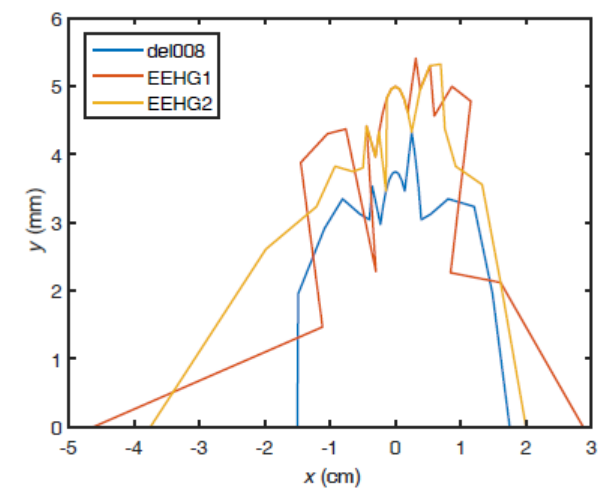
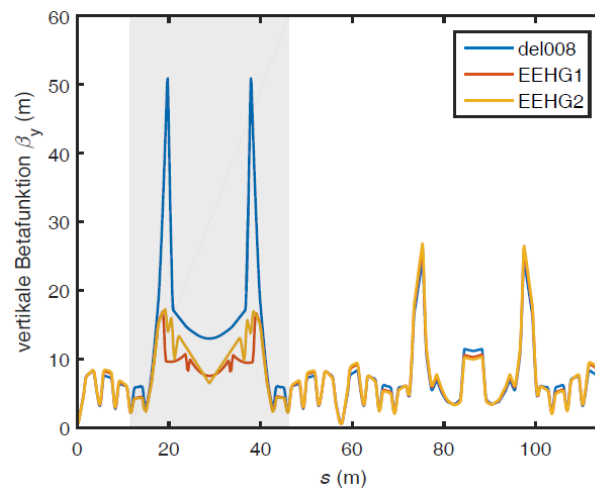
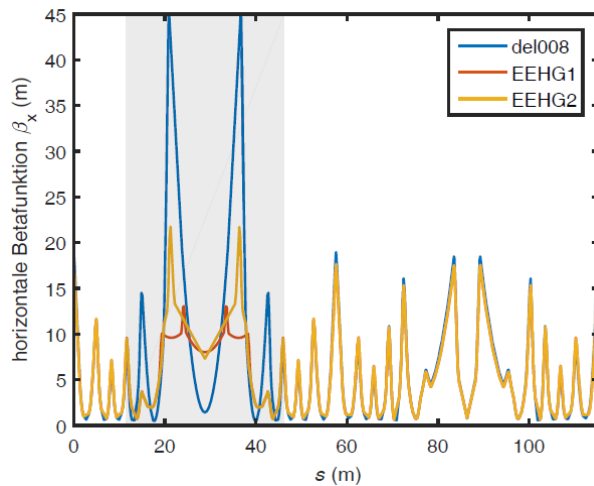
Courtesy Scanditronix AB



# Echo-enabled harmonic generation at DELTA

Supported by Helmholtz ARD initiative (FZ Jülich)

- modulators: 2 short undulators
- radiator: present U250 undulator
- requires longer straight section
- modified storage ring optics
- additional undulator for "slicing"

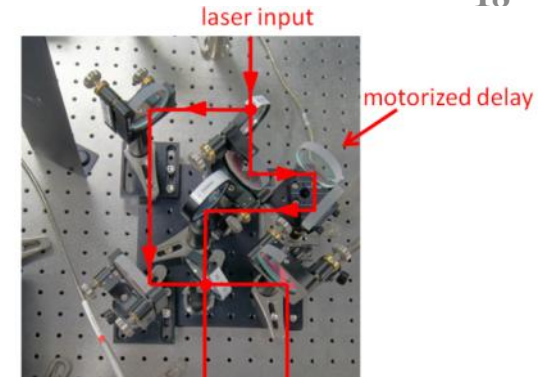
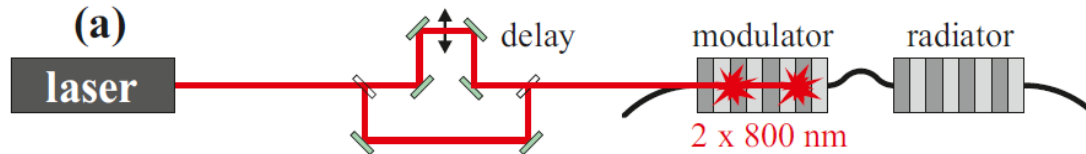


B. Büsing, master thesis, TU Dortmund 2017

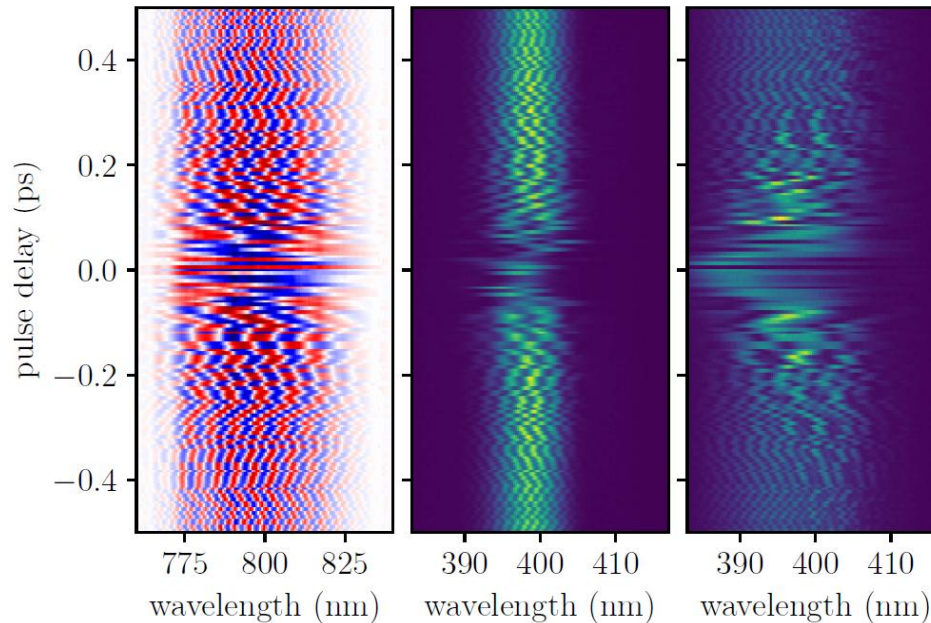
J. Bengtson, priv. comm.

# Echo-enabled harmonic generation at DELTA

Seeding with double pulses: towards EEHG-like energy modulation  
 Modulation with two 800-nm laser pulses in 1 modulator



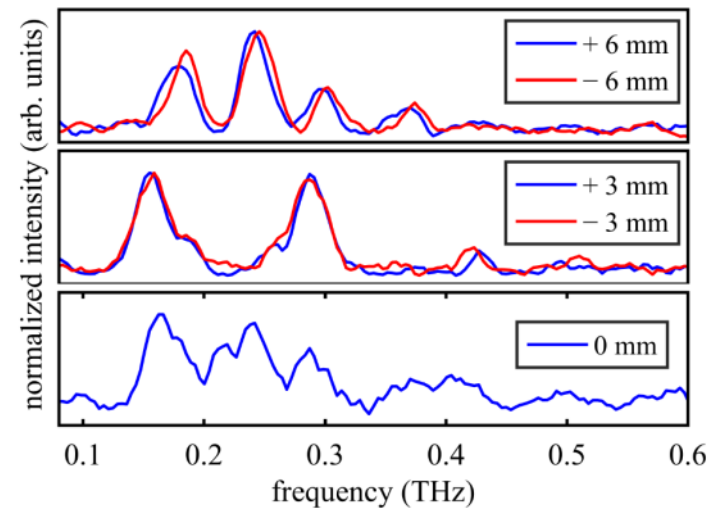
small (sub ps) delay:  
 interference pattern in laser and CHG spectra



unchirped

chirped laser

large (many ps) delay:  
 interference pattern in THz spectra

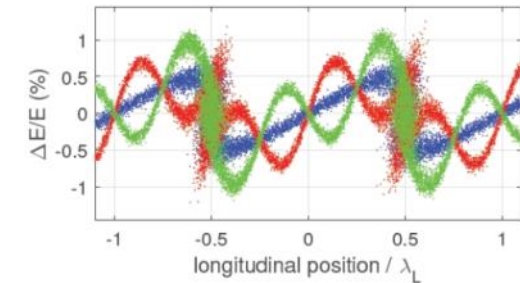
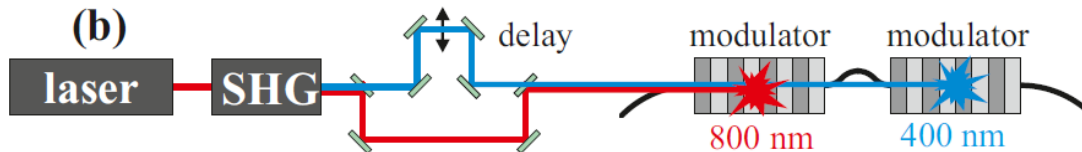


S. Khan et al., IPAC 2017, Copenhagen/Denmark, p. 2578.

# Echo-enabled harmonic generation at DELTA

## Seeding with double pulses: towards EEHG-like energy modulation

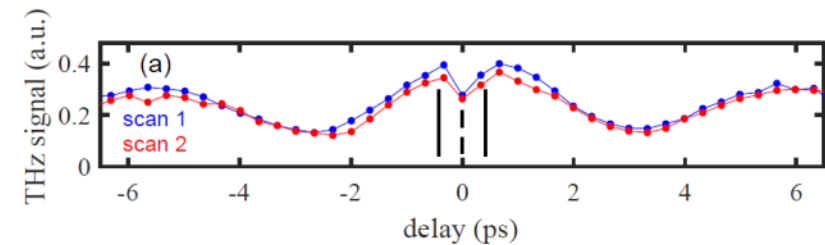
### Modulation with 800-nm and 400-nm laser pulses in 2 modulators



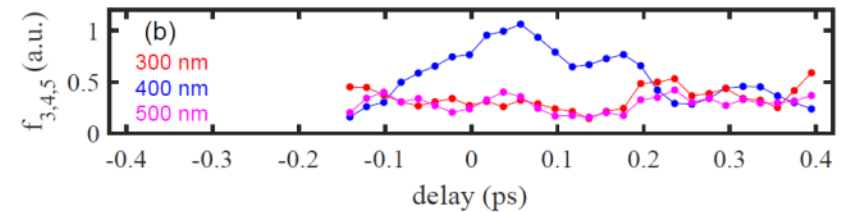
### Goal:

Twofold modulation of the same electrons using three different diagnostic techniques

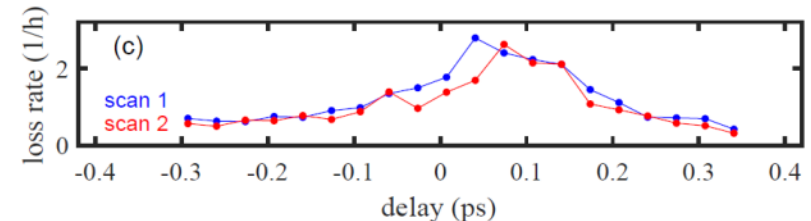
#### 1) Interference in THz signal



#### 2) 400-nm modulation of THz signal



#### 3) Increased loss rate at reduced RF power



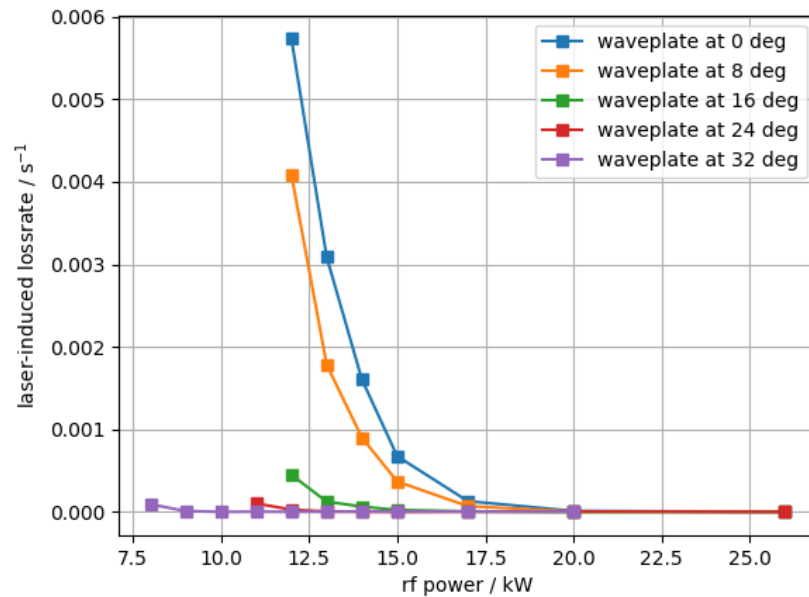
A. Meyer auf der Heide, IPAC 2017, Copenhagen/Denmark, p. 2582.  
S. Khan et al., FEL 2017, Santa Fe/NM/USA, MOP027.

# Facility for ultrashort VUV and THz pulses

## Laser-induced energy modulation

beam loss rate under variation of

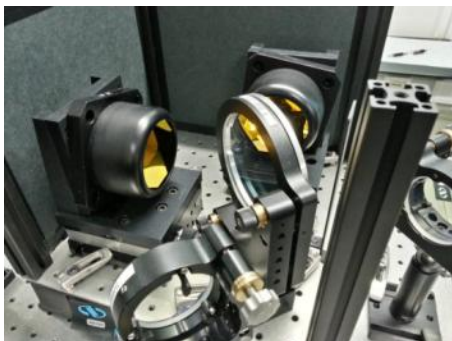
- modulation amplitude
- RF power



# Facility for ultrashort VUV and THz pulses

## Coherent emission of Terahertz radiation

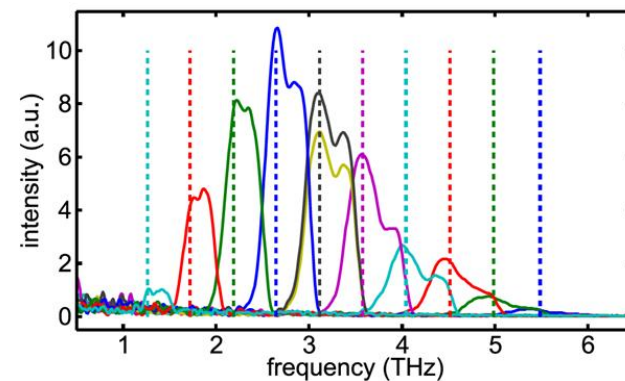
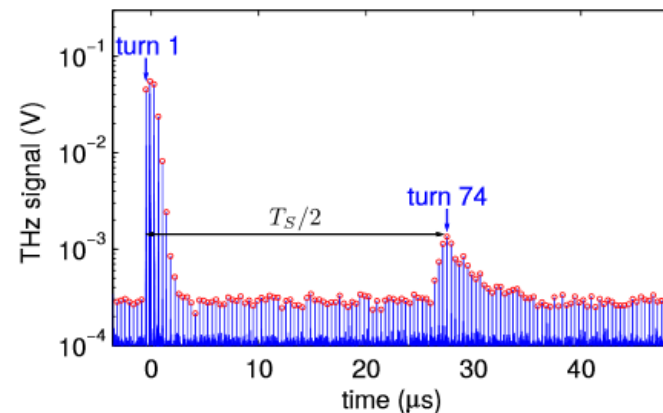
- diagnostics of laser-electron interaction
- short laser pulse: broadband THz radiation
- long modulated pulse: narrowband THz radiation
- sub-THz signal after 1/2 synchrotron period
- construction a sub-THz spectrometer
- electro-optical sampling



S. Bielawski et al., Nature Physics 4, 390 (2008)

C. Evain et al., PRST-AB 13, 090703 (2010)

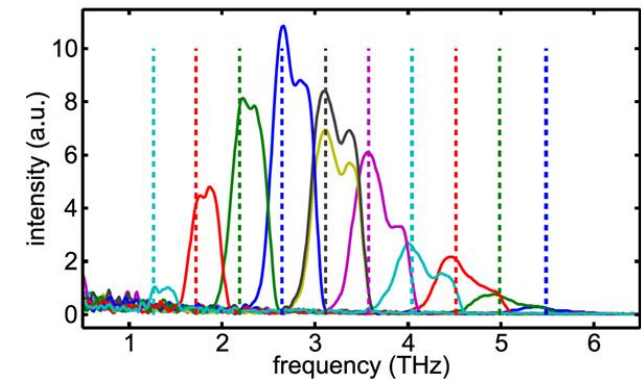
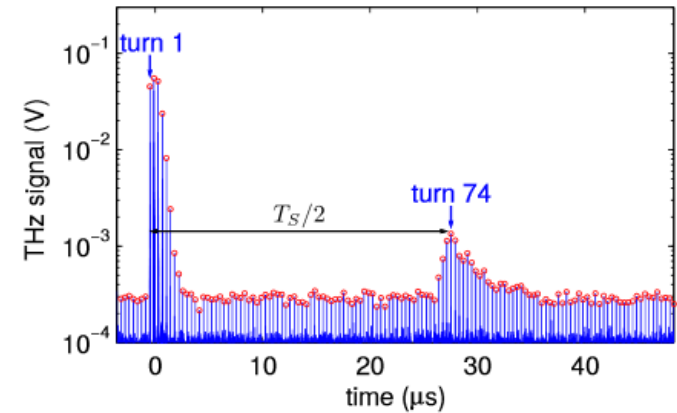
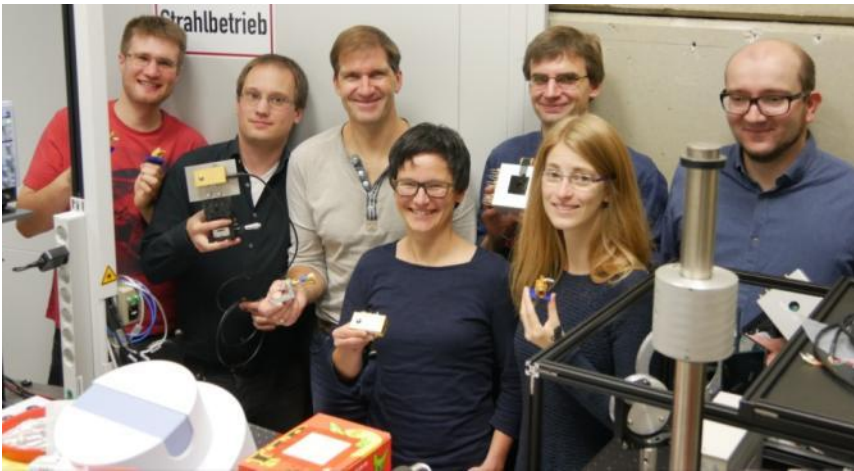
P. Ungelenk et al., PRAB 20, 020706 (2015)



# Facility for ultrashort VUV and THz pulses

## Coherent emission of Terahertz radiation

- diagnostics of laser-electron interaction
- short laser pulse: broadband THz radiation
- long modulated pulse: narrowband THz radiation
- sub-THz signal after 1/2 synchrotron period
- construction a sub-THz spectrometer
- electro-optical sampling

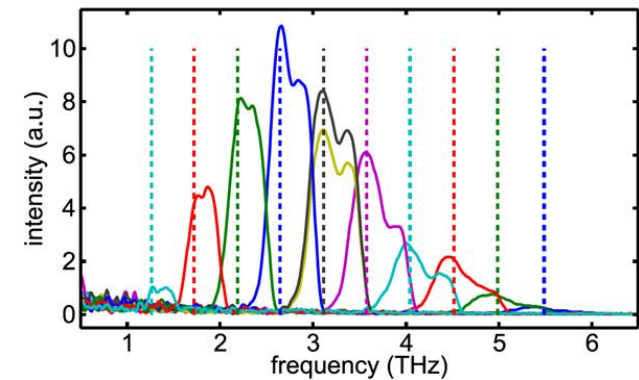
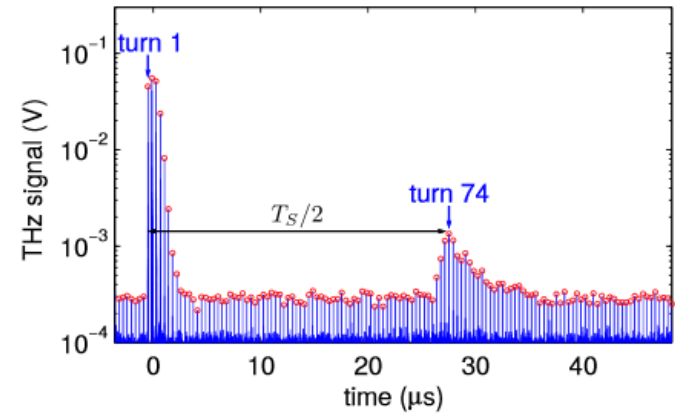
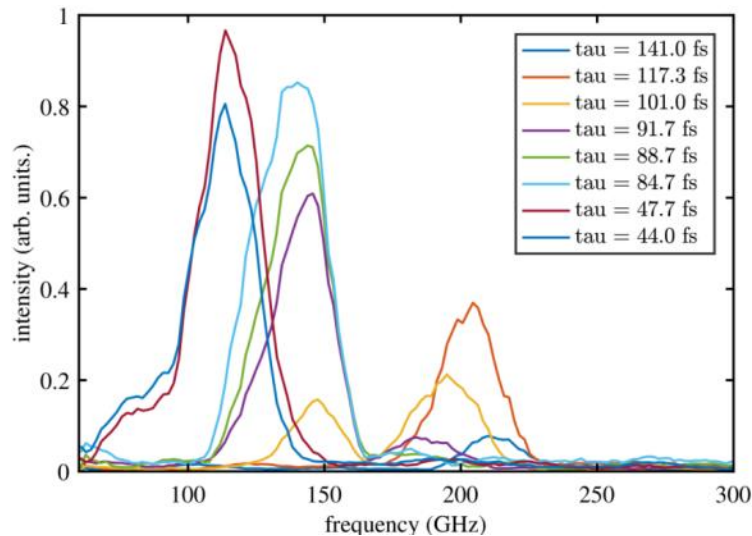


**Friday, Oct 13, 2017:** with colleagues and detectors from TU Dortmund, KIT Karlsruhe, DESY Hamburg, TU Dresden, PSI Villigen

# Facility for ultrashort VUV and THz pulses

## Coherent emission of Terahertz radiation

- diagnostics of laser-electron interaction
- short laser pulse: broadband THz radiation
- long modulated pulse: narrowband THz radiation
- sub-THz signal after 1/2 synchrotron period
- construction a sub-THz spectrometer
- electro-optical sampling



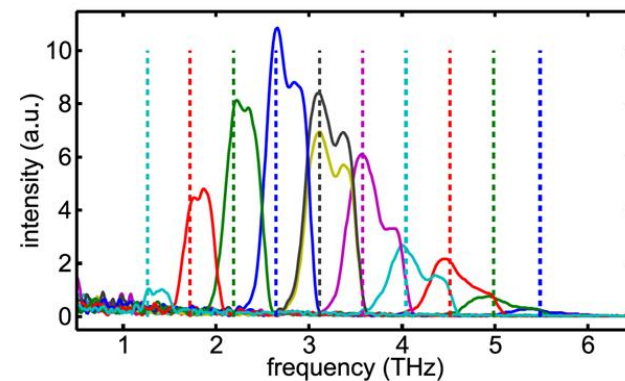
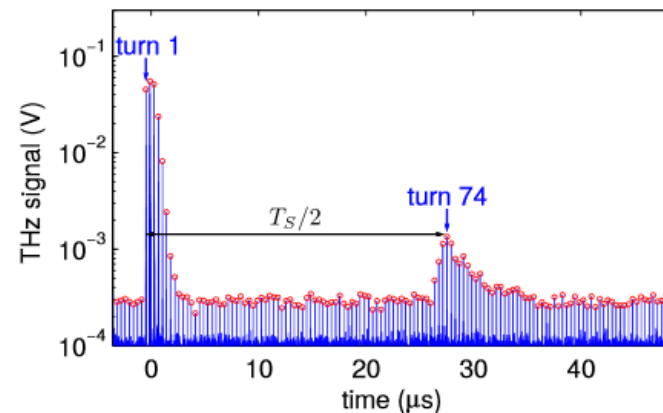
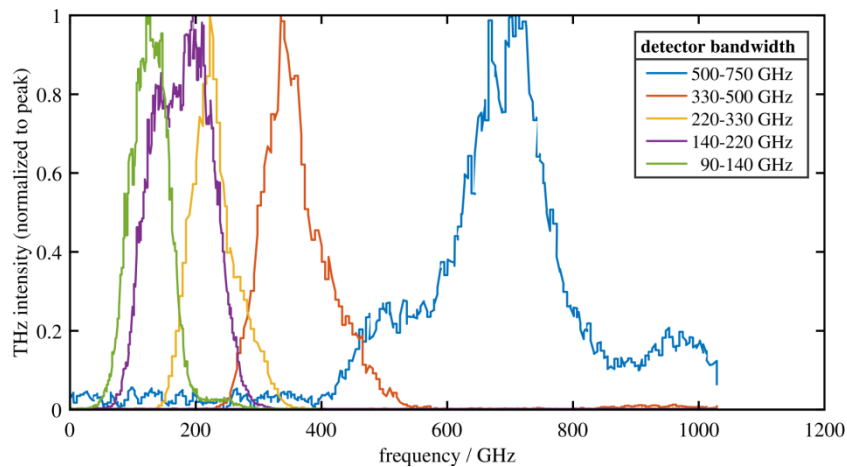
## narrowband sub-THz spectra

C. Mai, dissertation, TU Dortmund (in preparation)

# Facility for ultrashort VUV and THz pulses

## Coherent emission of Terahertz radiation

- diagnostics of laser-electron interaction
- short laser pulse: broadband THz radiation
- long modulated pulse: narrowband THz radiation
- sub-THz signal after 1/2 synchrotron period
- construction a sub-THz spectrometer
- electro-optical sampling



## response of narrowband detectors from KIT Karlsruhe

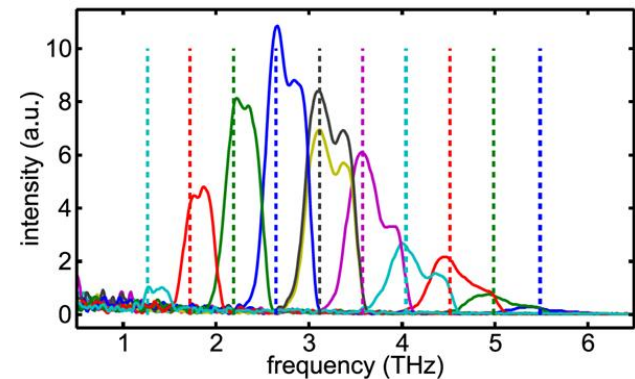
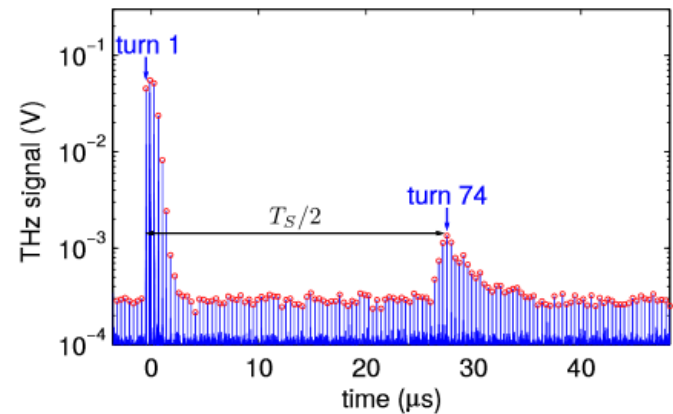
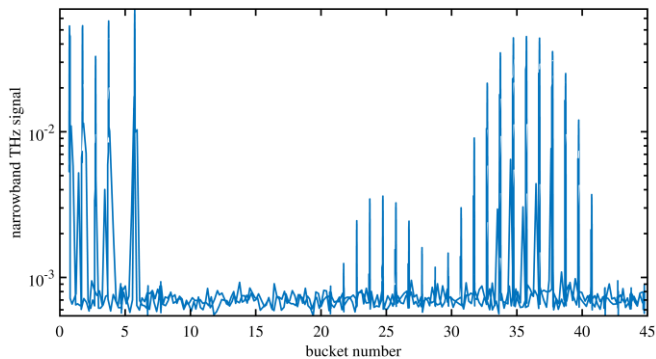
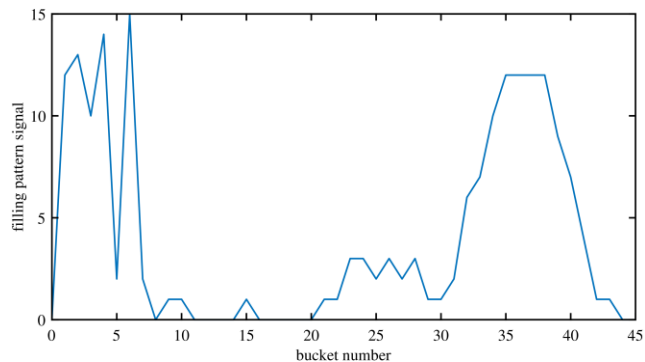
C. Mai, dissertation, TU Dortmund (in preparation)



# Facility for ultrashort VUV and THz pulses

## Coherent emission of Terahertz radiation

- diagnostics of laser-electron interaction
- short laser pulse: broadband THz radiation
- long modulated pulse: narrowband THz radiation
- sub-THz signal after 1/2 synchrotron period
- construction a sub-THz spectrometer
- electro-optical sampling



**filling pattern detected with (sub-)THz radiation while sweeping the laser timing**

C. Mai, dissertation, TU Dortmund (in preparation)

# Accelerator physics in the bachelor and master curriculum

## Bachelor, master, PhD theses

### One-semester course on instruments

- 2 hrs lecture
- 1 hr exercises

### Two-semester accelerator course

- 2 hrs lecture
- 1 hr exercises
- 1 hr seminar
- field trips  
(Berlin, Hamburg, Mainz...)



# The Future of DELTA

**Workshop on July 15, 2016**

**The next 10 years**

- **consolidation and improvement**
- **7-T wiggler and RF upgrade**
- **EEHG short-pulse source**

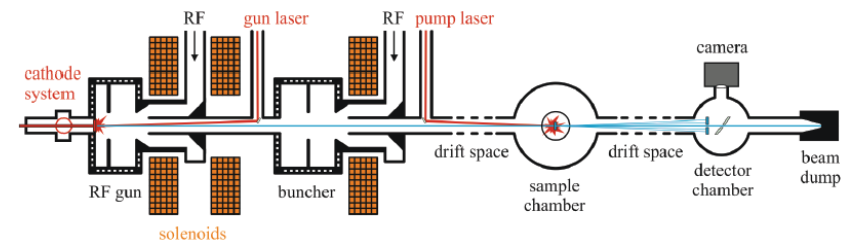


# The Future of DELTA

Next workshop on February 20, 2018

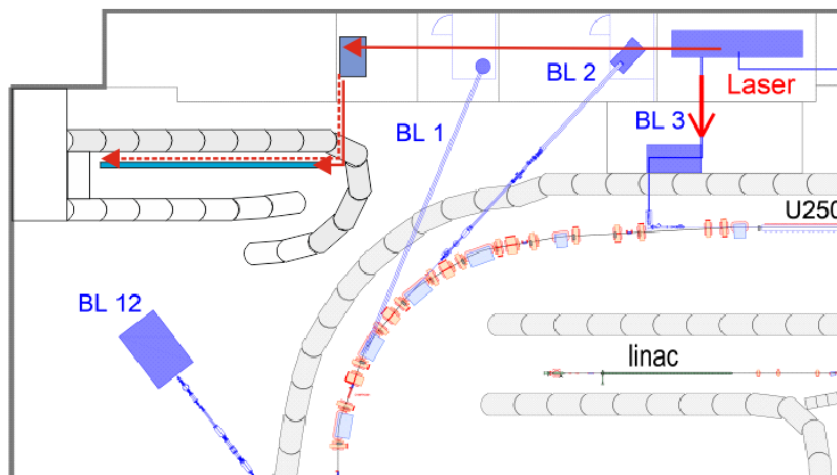
The next 10 years

- consolidation and improvement
- 7-T wiggler and RF upgrade
- EEHG short-pulse source



**MERCUR grant to develop an electron source for ultrafast electron diffraction (UED@DELTA)**

- 2 PhD positions (Dortmund and Duisburg-Essen)





Thank you

Ministerium für Innovation,  
Wissenschaft und Forschung  
des Landes Nordrhein-Westfalen



**DFG** Deutsche  
Forschungsgemeinschaft

 **Mercator Research Center Ruhr**  
Eine Initiative der Stiftung Mercator  
und der Universitätsallianz Ruhr

 **Bundesministerium  
für Bildung  
und Forschung**

