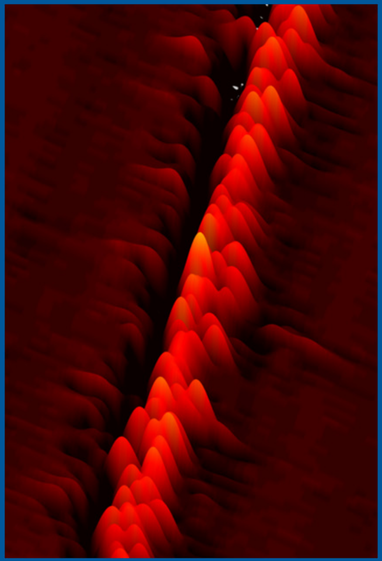
Photondiagnostics for X-ray FELs



M. Gensch

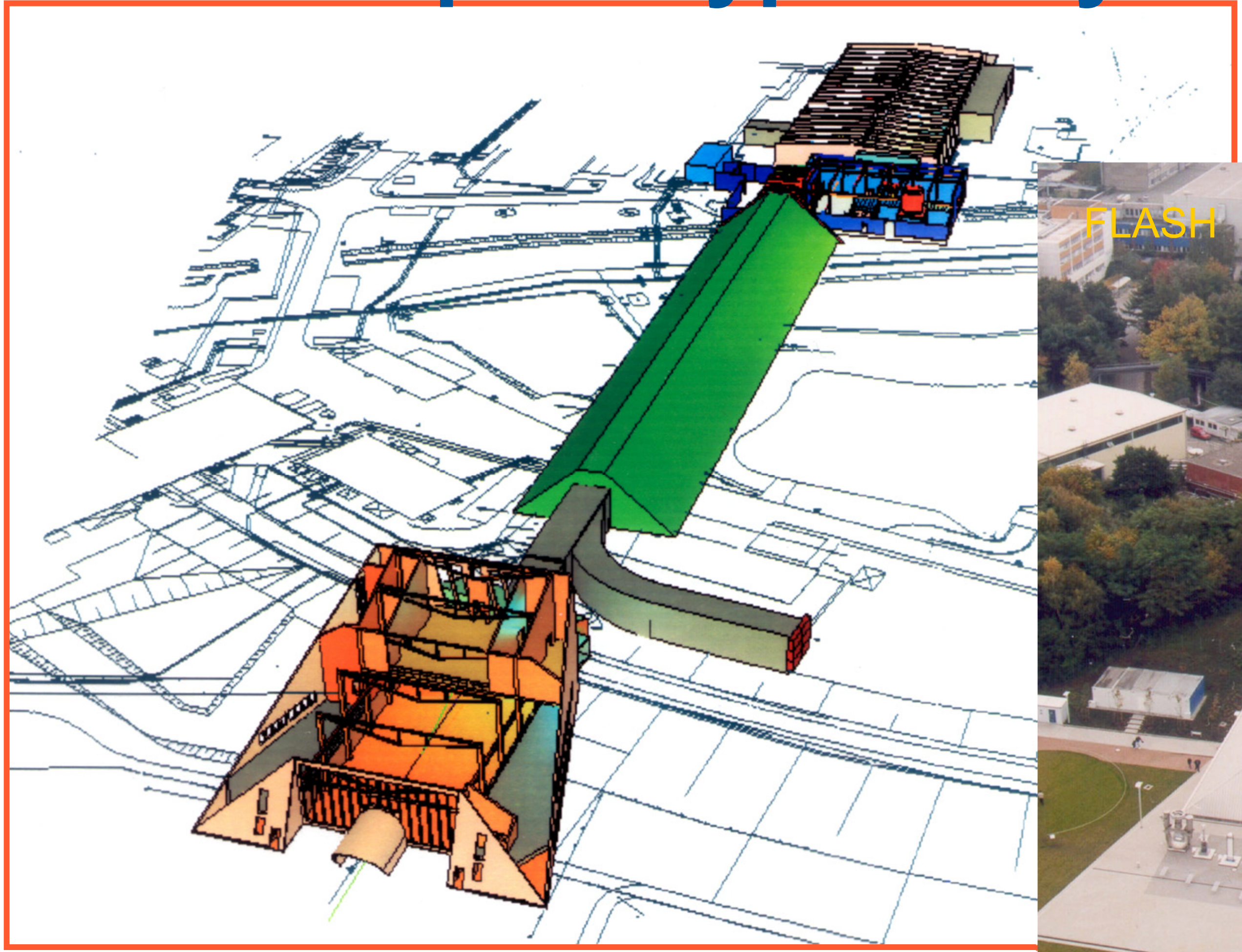
AG Coherent THz Radiation
Institute for Radiationphysics / Institute for Ion-Beam Physics and Materials Research
Helmholtz-Zentrum Dresden-Rossendorf

- „Routine“ diagnostic
- Diagnostic challenges

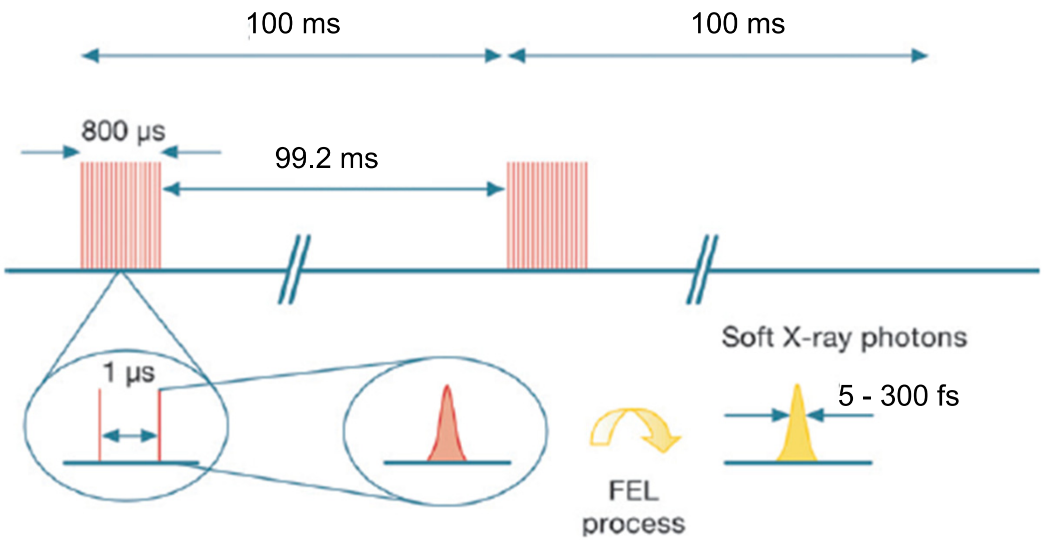
HZDR

HELMHOLTZ
ZENTRUM DRESDEN
ROSSENDORF

FLASH – prototype X-ray FEL user fac. (since 2005)



Pulse scheme @ FLASH



Tiedtke, K. et al.. New Journal of Physics 11 (2009) 023029

Parameters of FLASH

Wavelength range (fundamental):

4.3 - 48 nm

FEL harmonics (@4.3 nm):

3 rd : 1.4 nm

5 rd : 0.86 nm

Spectral width (FWHM):

0.5-1 %

Pulse energy:

up to 100 μJ (average),

200 μJ (peak)

Pulse duration (FWHM):

5? - 300 fs

Peak power (fundamental):

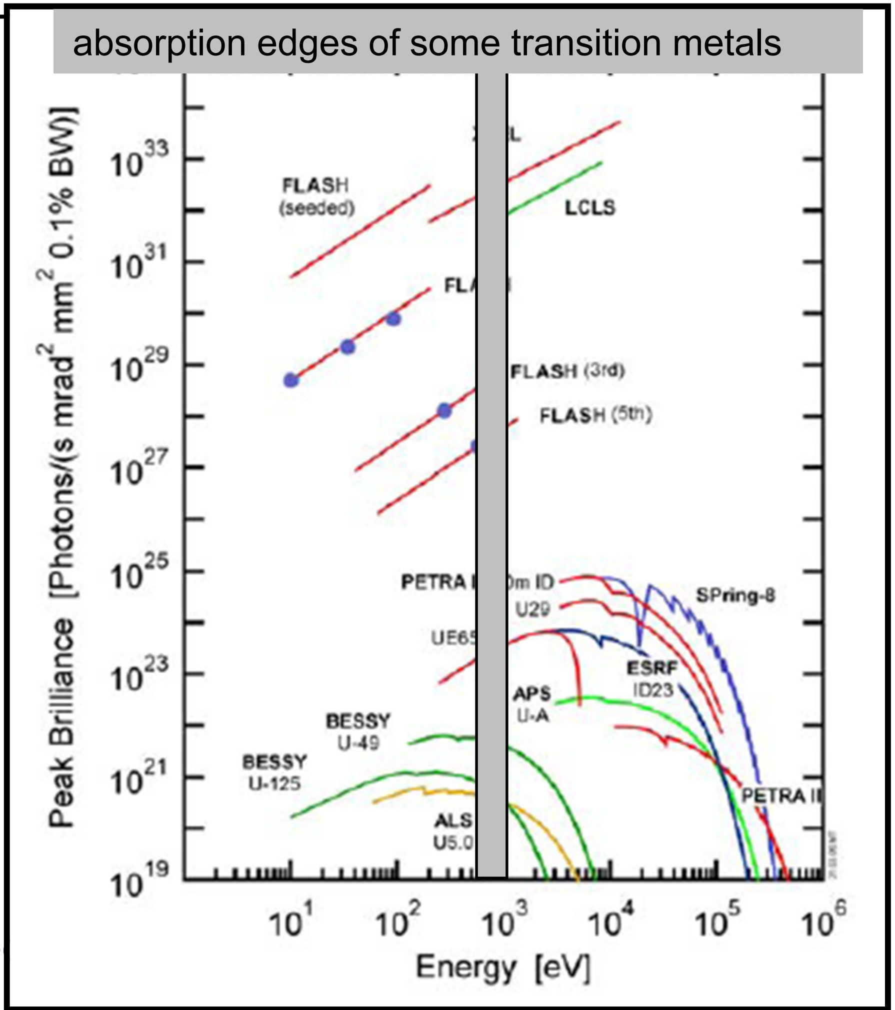
few GW

Average power (fundamental):

up to 0.1 W (up to 3000 pulses / se

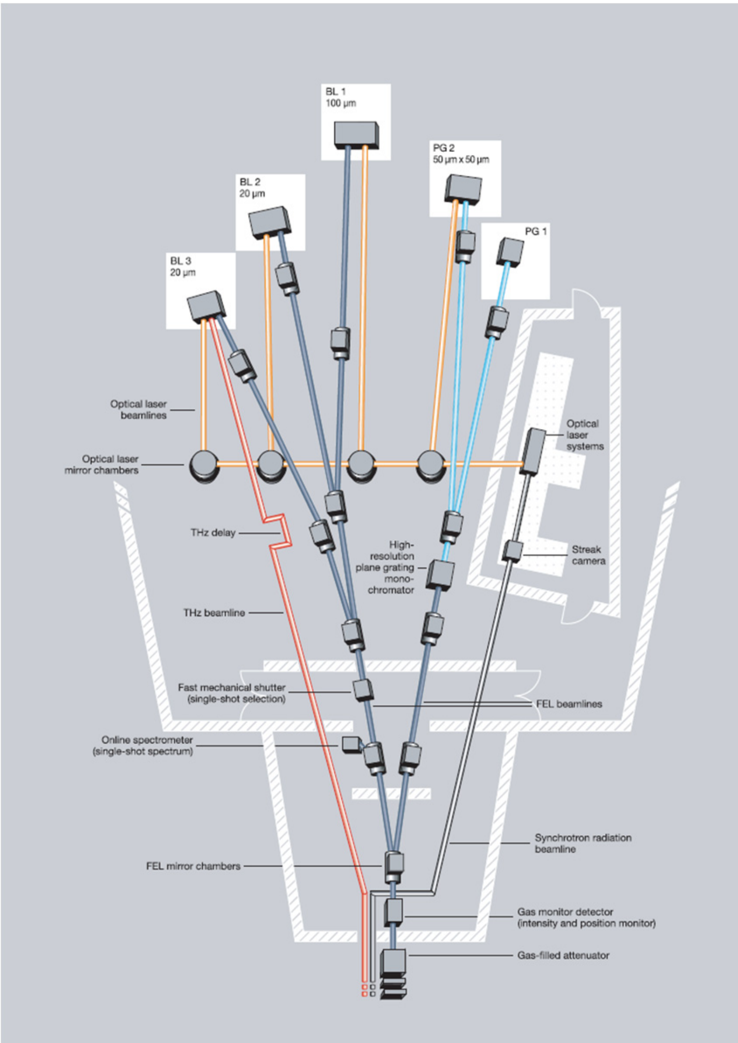
Peak brilliance:

up to 5×10^{29}



peak brilliance

Layout of X-ray beam distr. @ FLASH



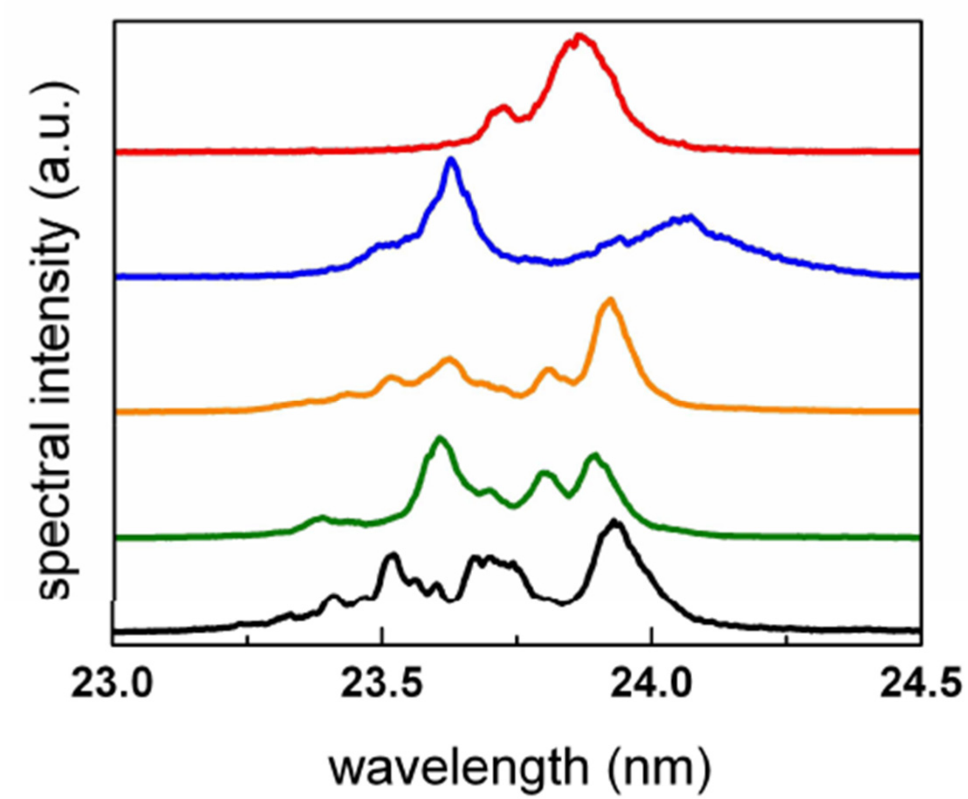
	BL1	BL2	BL3	PG1	PG2
Monochromatization	–	–	–	Yes	Yes
Optical elements	4	3	5 (4)	8	6
Focusing	Toroidal	Ellipsoidal	Ellipsoidal (none)	KB[a]	Toroidal
Focus size approx. (μm, FWHM)	100	20	20	5	50
Distance undulator end-focus (m)	76	73	72.2	75.2	72.5
Distance last flange-focus (m)	1.281	0.636	0.637	0.758	0.758
Transmission at 13.5 nm (%)	65[b]	64 ± 4	59 ± 6	–	64[c]

[a]Kirkpatrick–Baez.
[b]Calculated.
[c] ~64% for the zeroth-order diffration of the 200 lines mm^{-1}.

Tiedtke, K. et al.. New Journal of Physics 11 (2009) 023029

User requirements -> ONLINE monitoring

Single shot spectra

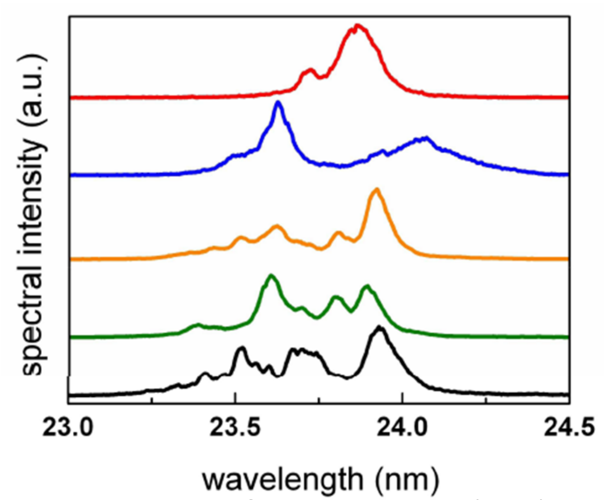


Mitzner, R et al.. Optics Express, 16 (2008) 19912

-> properties vary from pulse to pulse!

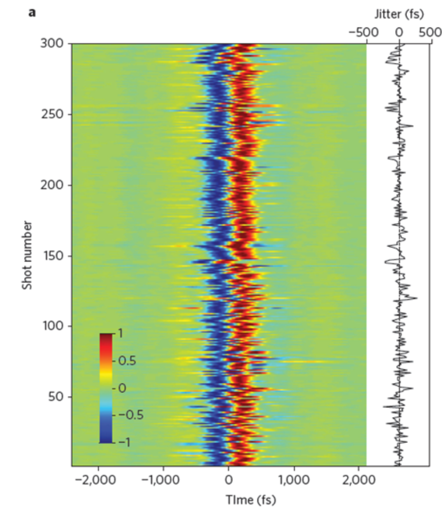
User requirements -> ONLINE monitoring

spectra



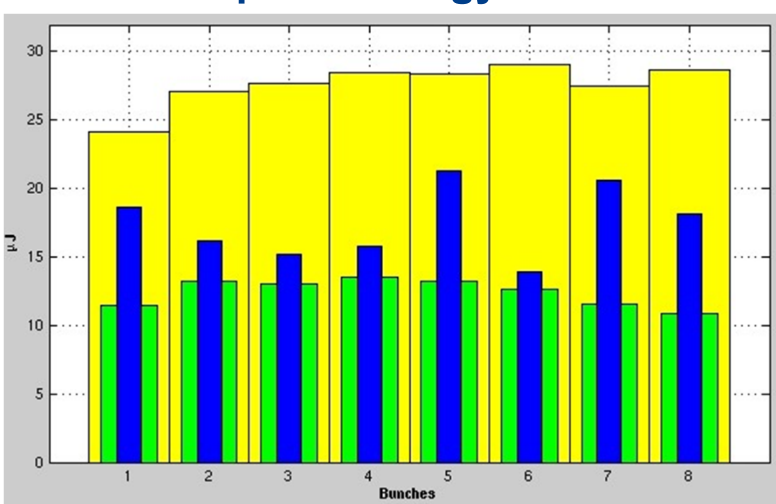
Mitzner, R et al., Optics Express, 16 (2008) 19912

Arrival time



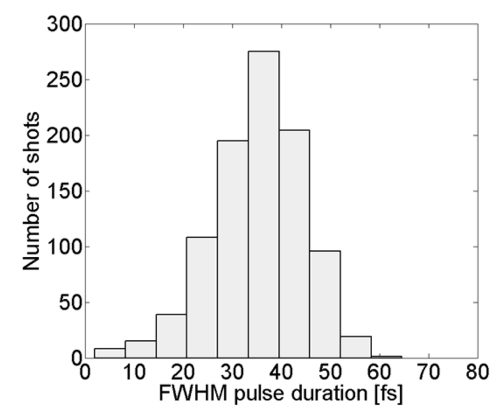
Tavella, F; Stojanovic, N.; Geloni, G; Gensch, M.; Nature Photon., 5 (2011), 162.

pulse energy



Tiedtke, K. et al.. New Journal of Physics 11 (2009) 023029

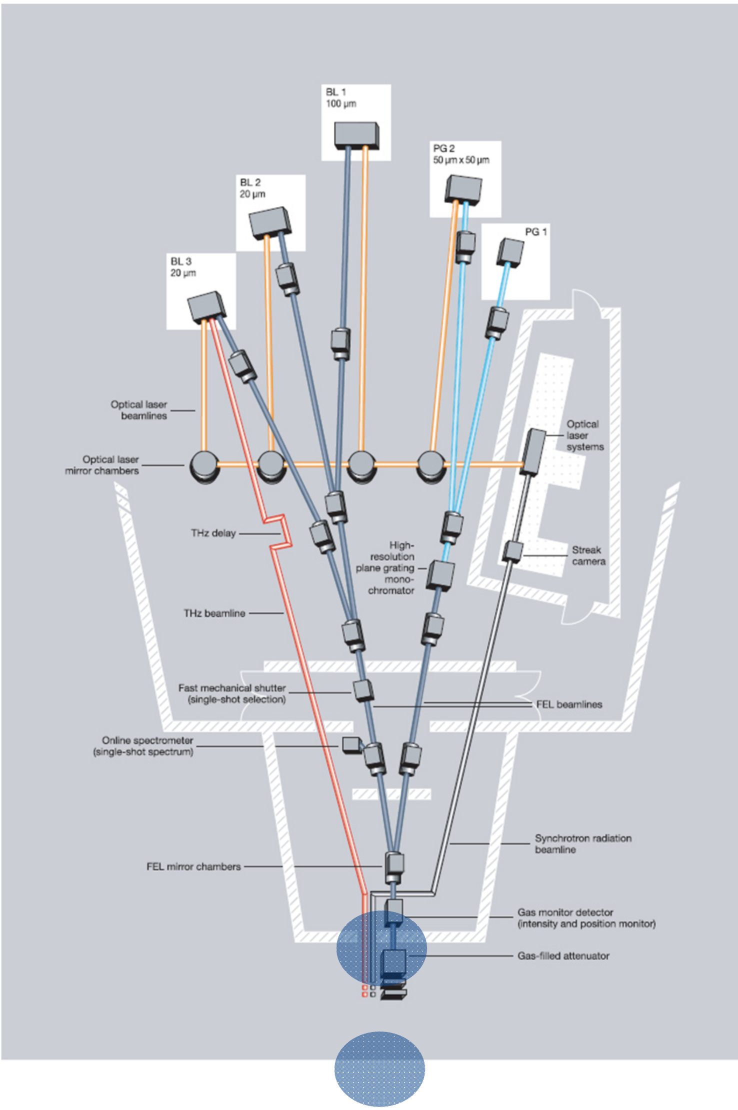
temporal structure / pulse duration)



Fruehling, U; Wieland, M.; Gensch M. et. al., Nature Photon., 3 (2009), 529.

- **„Routine“ diagnostic**
- Diagnostic challenges

Monitoring intensity and beam position



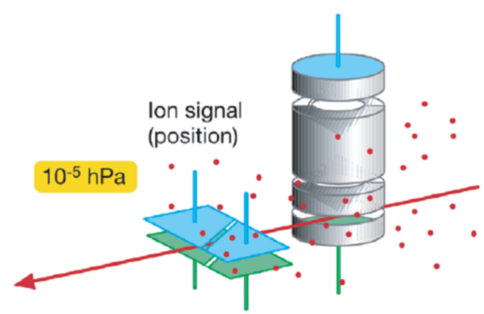
Working principle

Single photoionisation:

$$N = N_{ph} \times n \times \sigma \times l$$

N	Number of electrons or ions
N_{ph}	Number of photons
n	Target density
σ	Photoionisation cross section
l	Length of interaction volume

Experimental setup



Tiedtke, K. et al.. New Journal of Physics 11 (2009) 023029

Monitoring intensity and beam position

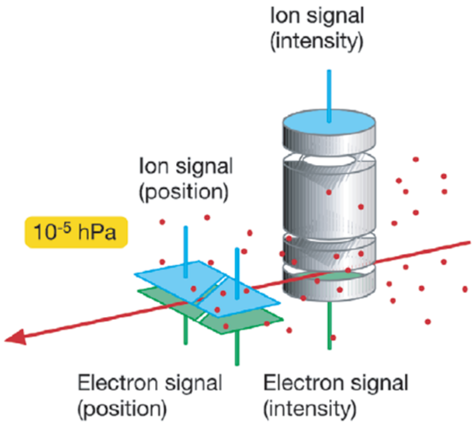
Working principle

Single photoionisation:

$$N = N_{ph} \times n \times \sigma \times l$$

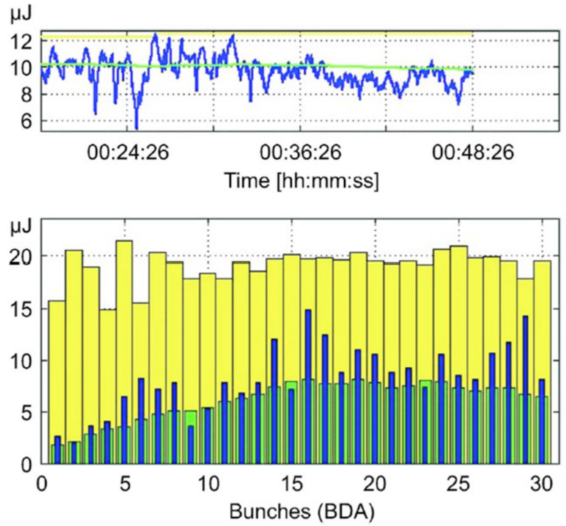
N	Number of electrons or ions
N_{ph}	Number of photons
n	Target density
σ	Photoionisation cross section
l	Length of interaction volume

Experimental setup



Tiedtke, K. et al.. New Journal of Physics 11 (2009) 023029

Results:



Tiedtke, K. et al.. Journal of Applied Physics, 103 (2008) 094511

Monitoring intensity and beam position

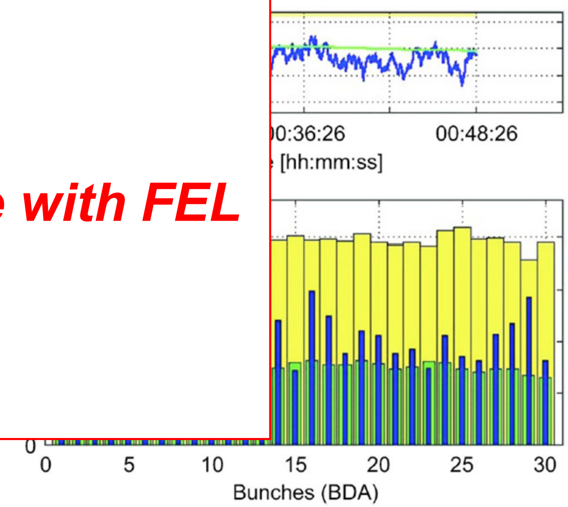
Working principle

Single photoionisation:

$N = N_{ph} \times n \times \sigma \times l$

- N Number of electro
- N_{ph} Number of photo
- n Target density
- σ Photoionisation c
- l Length of interact

Results:



Tiedtke, K. et al.. Journal of Applied Physics, 103 (2008) 094511

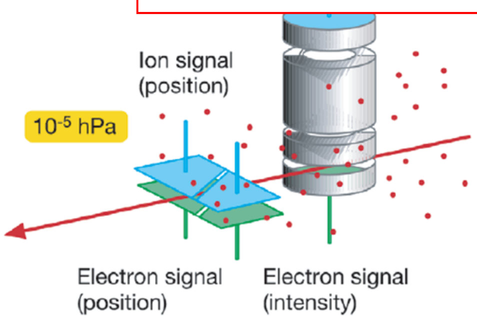
Merits:

- ***can operate ONLINE***
- ***calibrated***
- ***rep. rate commensurate with FEL***

Drawbacks:

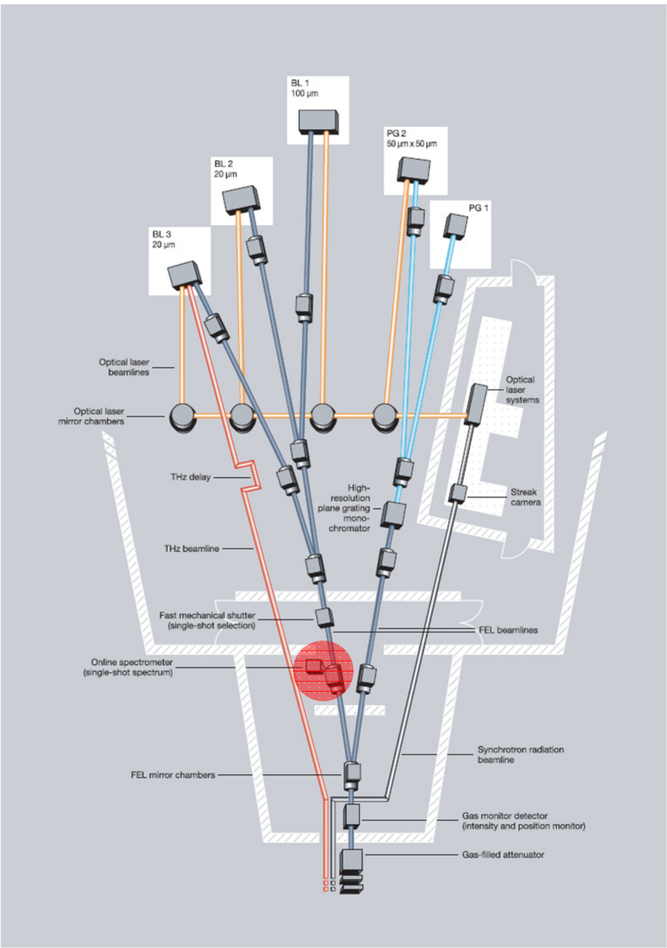
-

Experimental setup

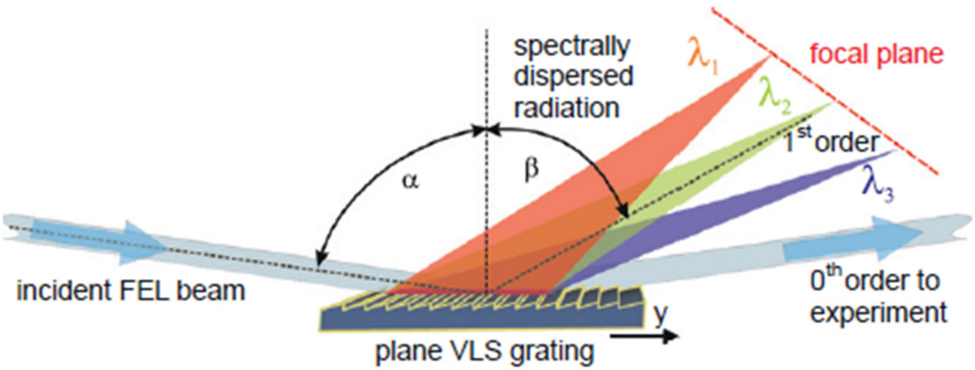


Tiedtke, K. et al.. New Journal of Physics 11 (2009) 023029

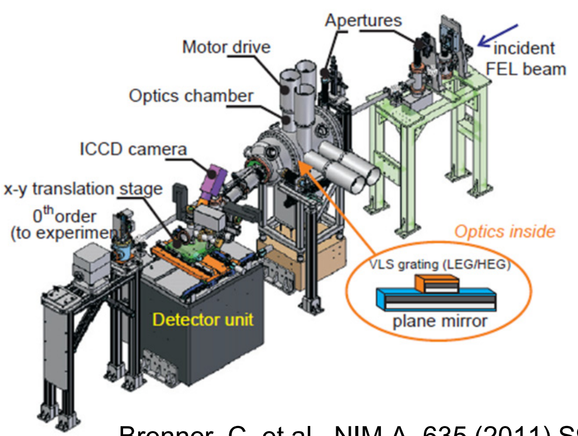
Monitoring of Wavelength



Working principle



Experimental setup

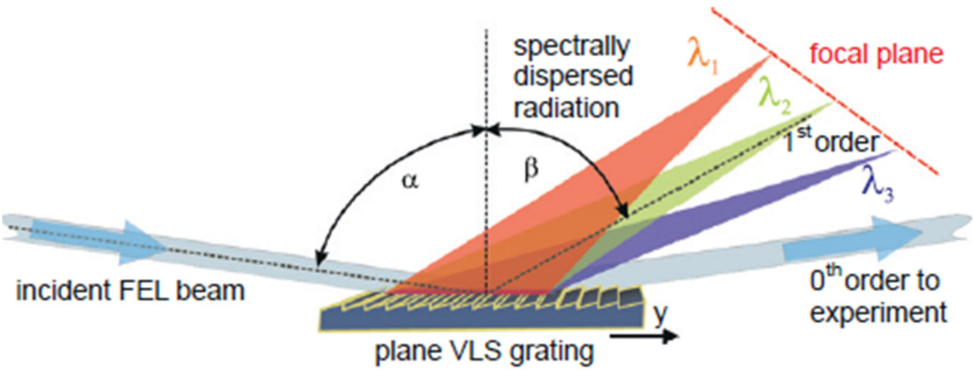


Brenner, C. et al.. NIM A, 635 (2011) S99-S103

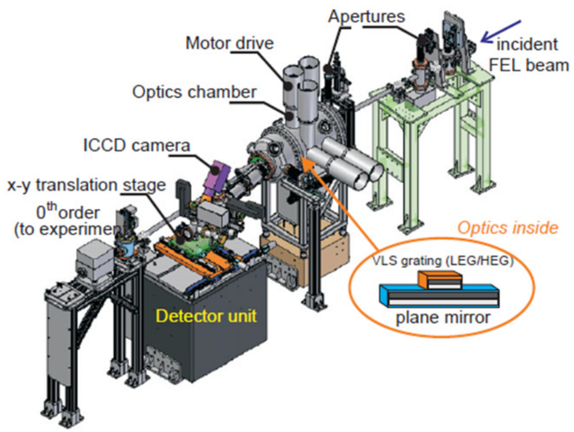
DRESDEN concept HZDR

Monitoring of Wavelength

Working principle

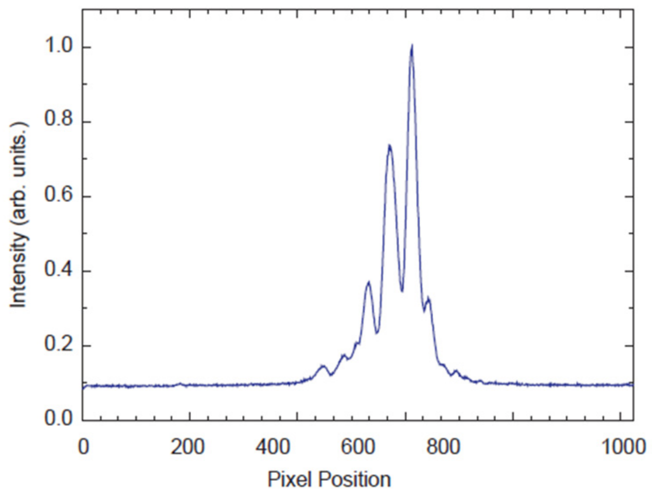


Experimental setup



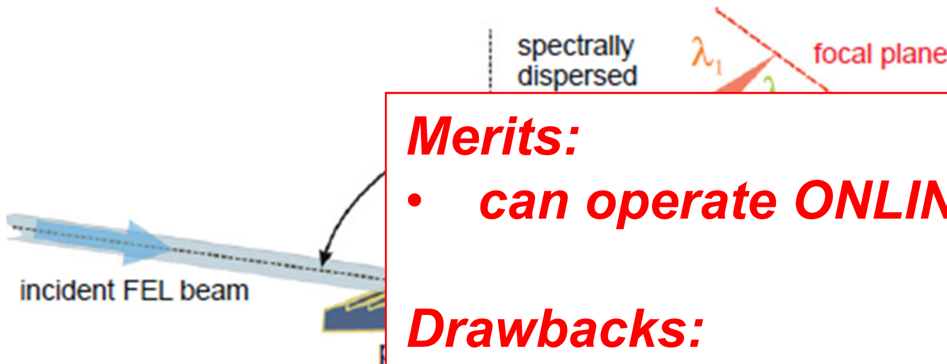
Brenner, C. et al.. NIM A, 635 (2011) S99-S103

Results:

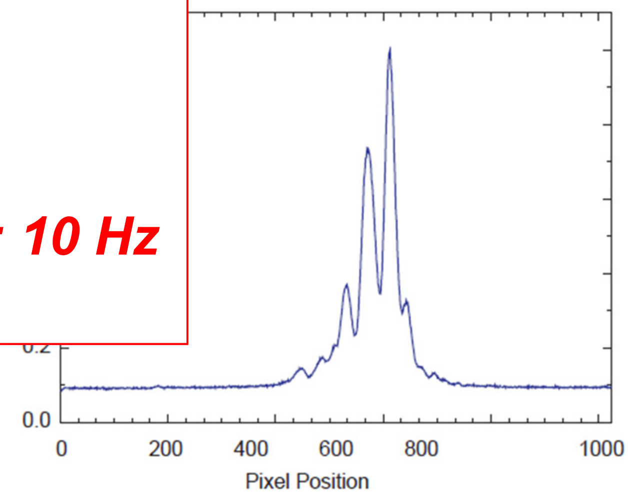


Monitoring of Wavelength

Working principle



Results:



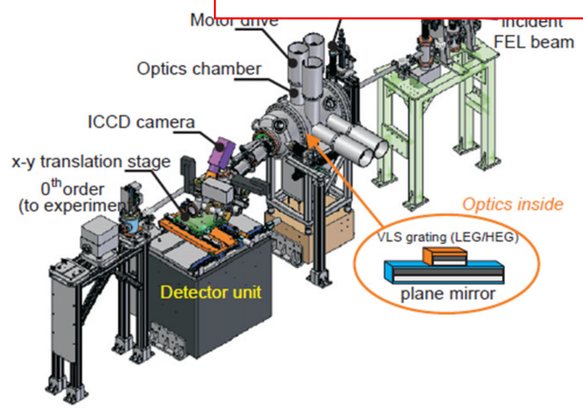
Merits:

- ***can operate ONLINE***

Drawbacks:

- ***rep. rate limited by CCD: 10 Hz***
- ***difficult calibration***

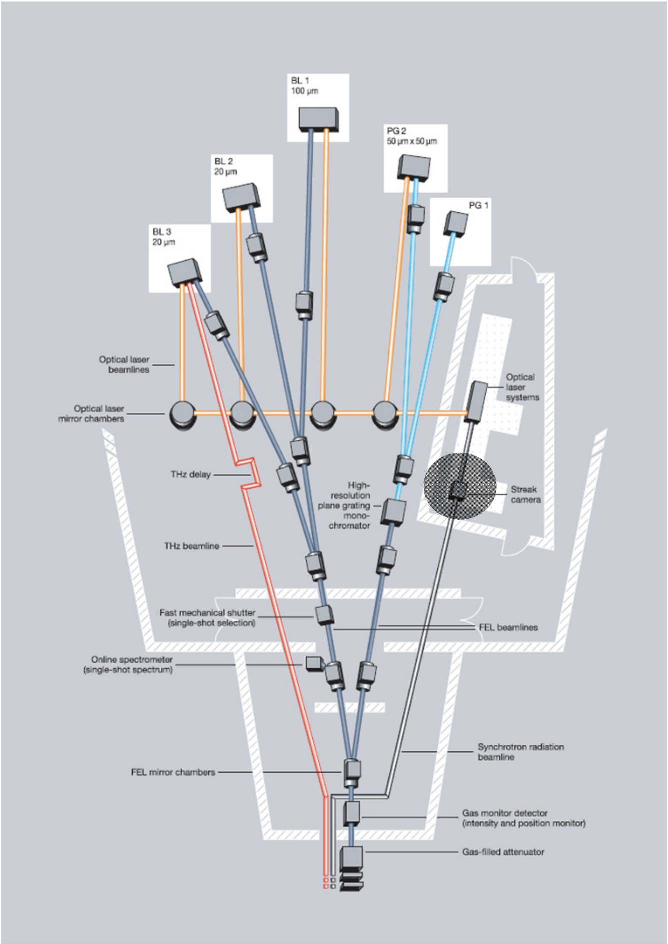
Experimental setup



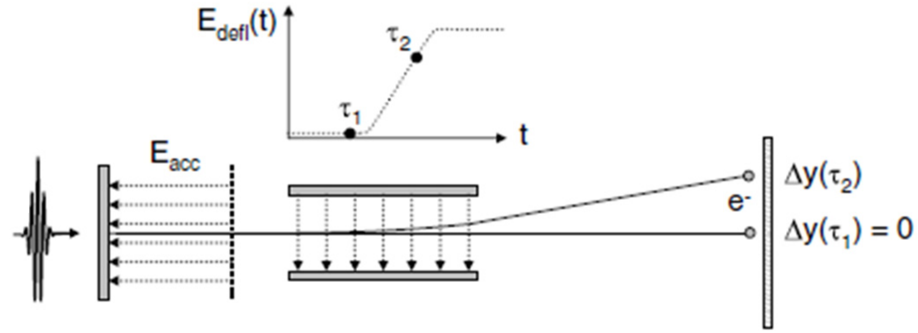
Brenner, C. et al.. NIM A, 635 (2011) S99-S103

„Routine“ Monitoring of Arrival time

1. Streak camera

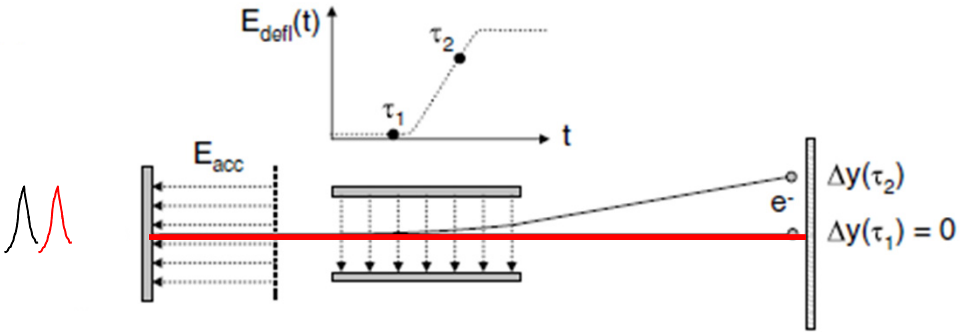


Working principle



e.g. Drescher, M et al.. J. Phys. B: At. Mol. Opt. Phys., 43 (2010) 194010

Experimental setup



Synch. rad.

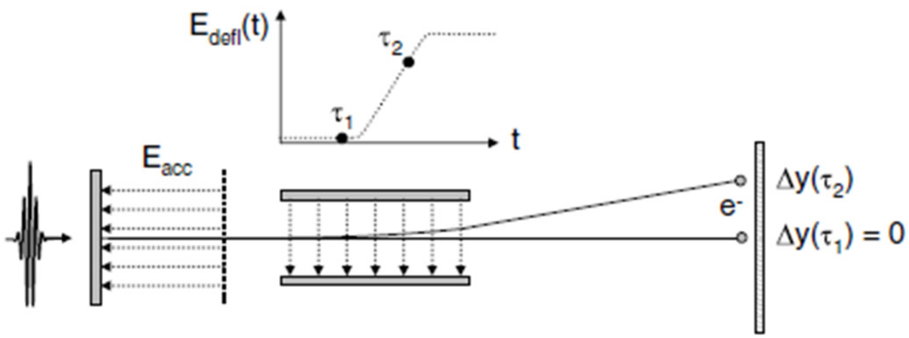
Laser

e.g. Drescher, M et al.. J. Phys. B: At. Mol. Opt. Phys., 43 (2010) 194010

„Routine“ Monitoring of Arrival time

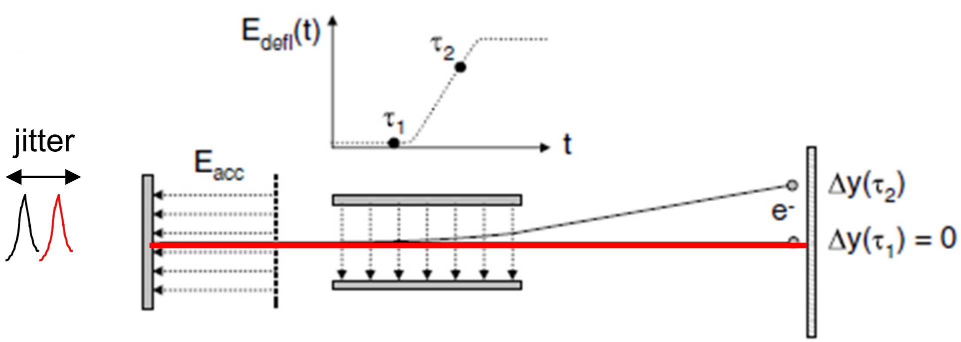
1. Streak camera

Working principle



e.g. Drescher, M et al.. J. Phys. B: At. Mol. Opt. Phys., 43 (2010) 194010

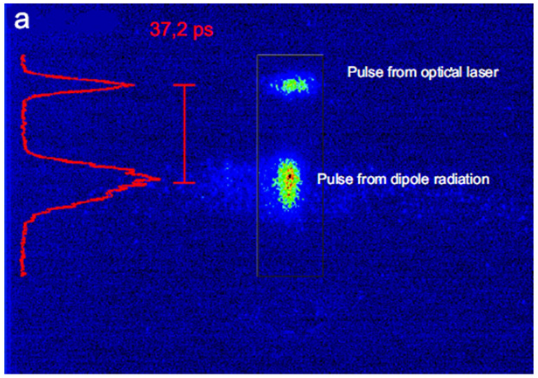
Experimental setup

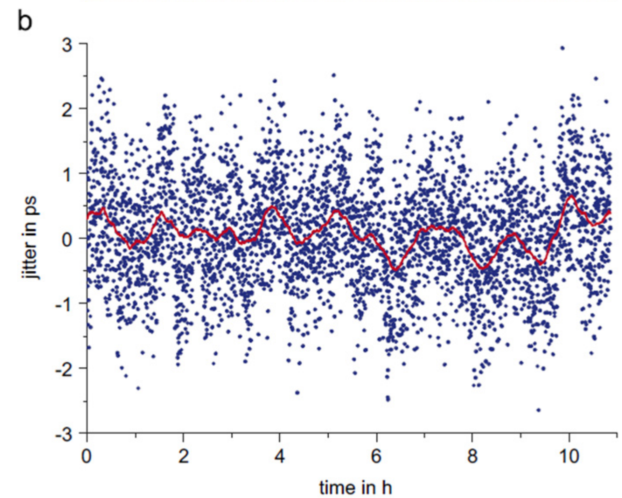


Synch. rad.
Laser

e.g. Drescher, M et al.. J. Phys. B: At. Mol. Opt. Phys., 43 (2010) 194010

Results:



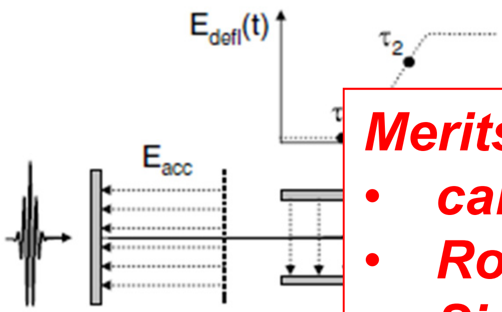


Radcliffe, P. et al.. NIM A, 583 (2007) 516-525

„Routine“ Monitoring of Arrival time

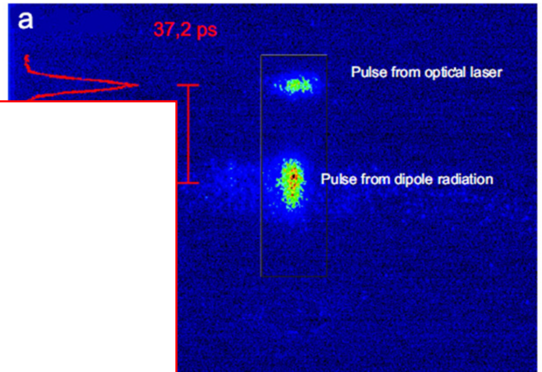
1. Streak camera

Working principle

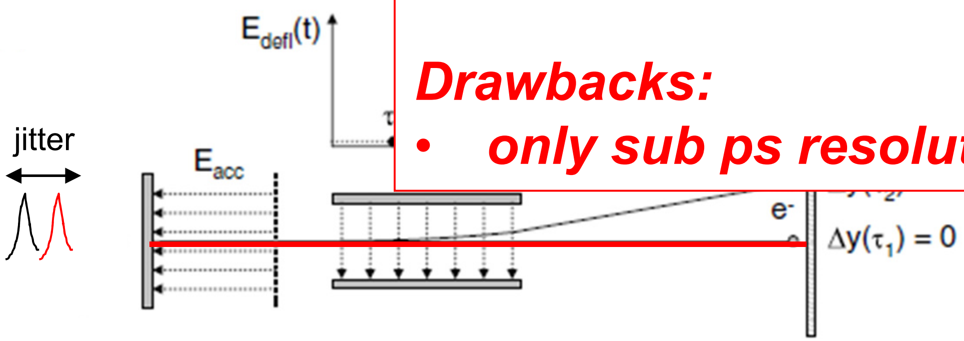


e.g. Drescher, M et al.. J. Phys. B: A

Results:



Experimental setup



Synch. rad.

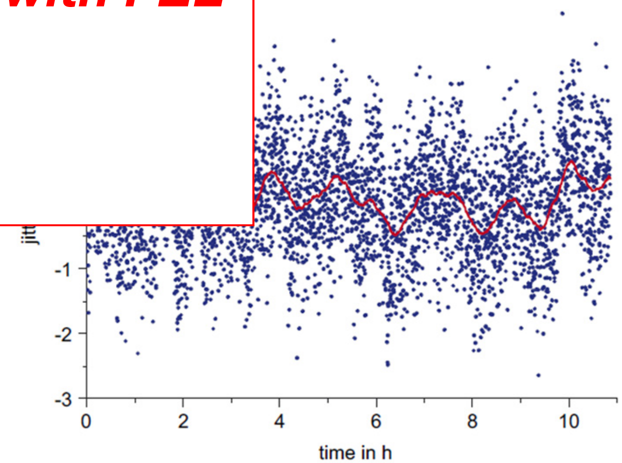
Laser

Merits:

- *can operate ONLINE*
- *Robust*
- *Single shot*
- *rep. rate commensurate with FEL*

Drawbacks:

- *only sub ps resolution*

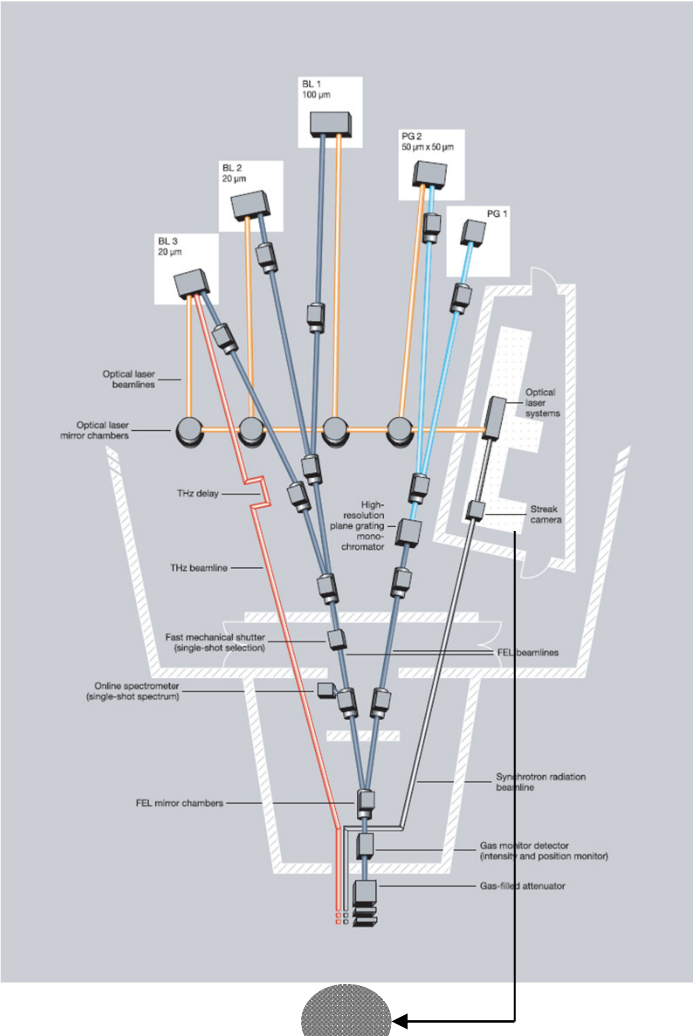


Radcliffe, P. et al.. NIM A, 583 (2007) 516-525

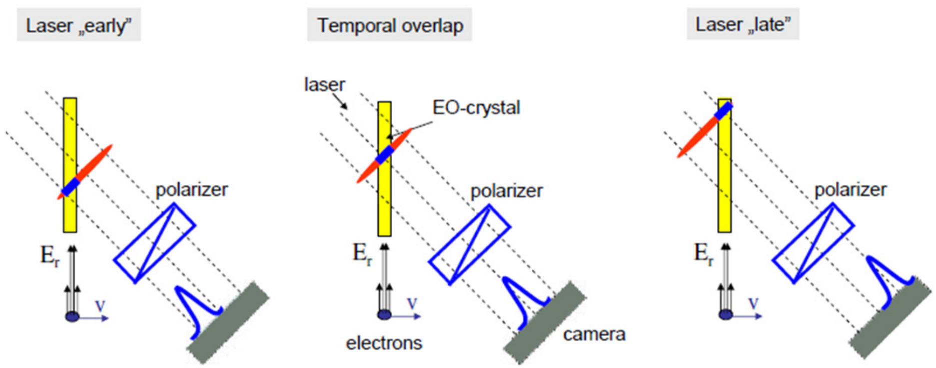
e.g. Drescher, M et al.. J. Phys. B: At. Mol. Opt. Phys., 43 (2010) 194010

„Routine“ Monitoring of Arrival time

2. Electro-optic arrival time derived from electron bunch arrival time

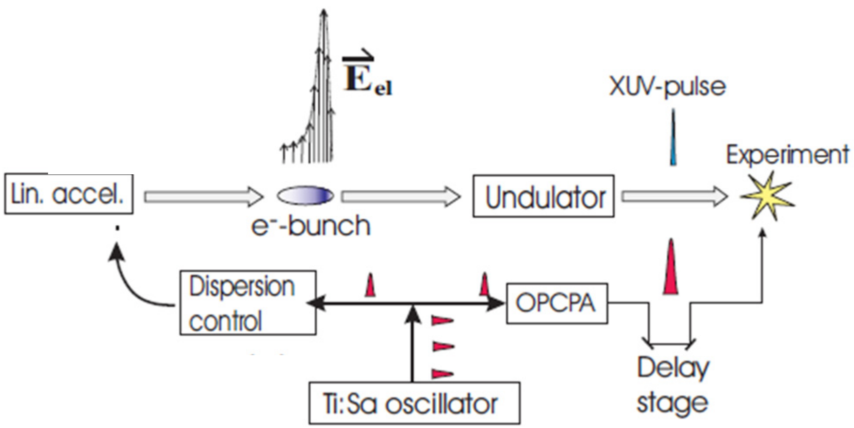


Working principle



Redlin, H. et al.. NIM A, 635 (2011) S88-S93

Experimental setup

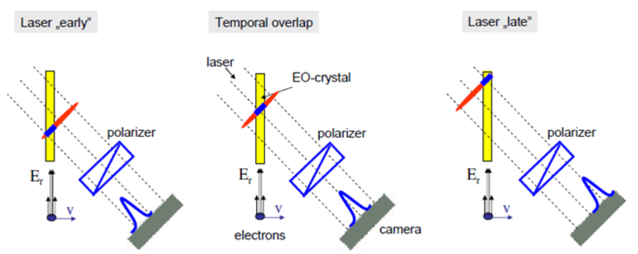


Azima, A et al.. Appl. Phys. Lett. (2009) 144102

„Routine“ Monitoring of Arrival time

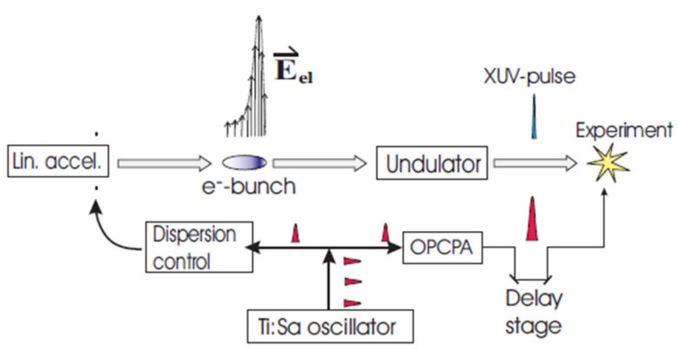
2. Electro-optic arrival time derived from electron bunch arrival time

Working principle



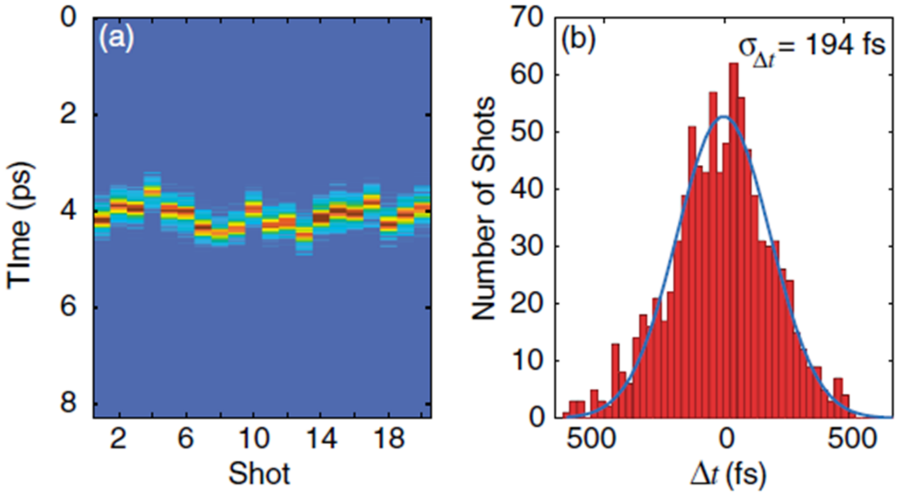
Redlin, H. et al.. NIM A, 635 (2011) S88-S93

Experimental setup



Azima, A et al.. Appl. Phys. Lett. (2009) 144102

Results:

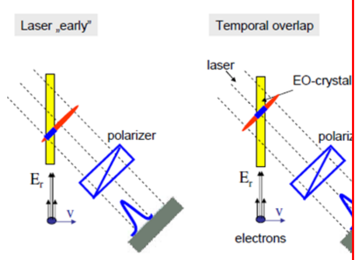


Cavalieri, AL. et al.. Phys. Rev. Lett. (2005) 114801

„Routine“ Monitoring of Arrival time

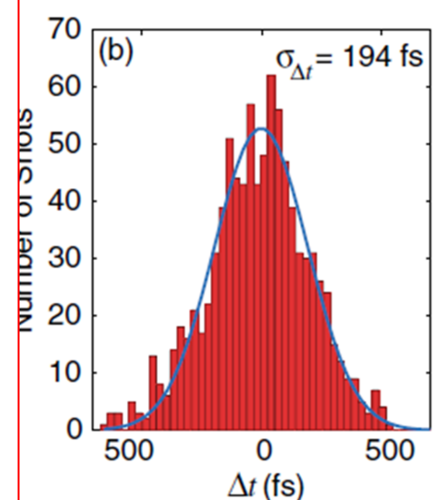
2. Electro-optic arrival time derived from electron bunch arrival time

Working principle



Redlin, H. et al.. NIM

Results:



ys. Rev. Lett. (2005) 114801

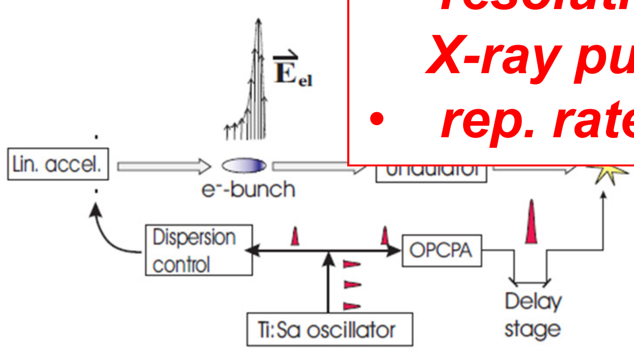
Merits:

- ***can operate ONLINE***
- ***Single shot***
- ***improved resolution:120 fs (FWHM)***

Drawbacks:

- ***indirect measurement***
- ***resolution not commensurate with X-ray pulse duration***
- ***rep. rate limited by laser***

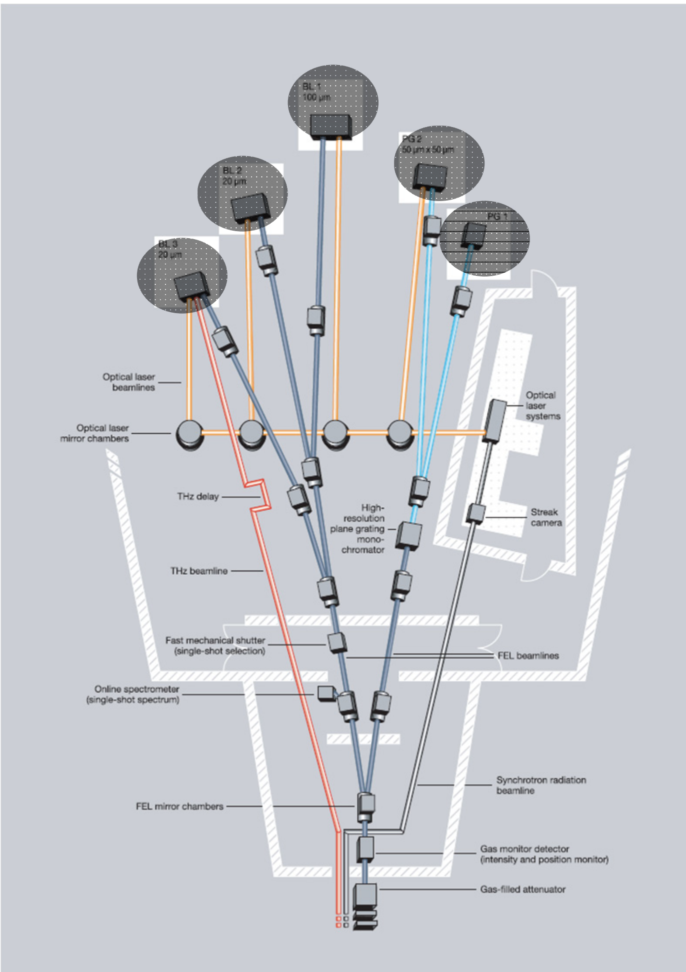
Experimental setup



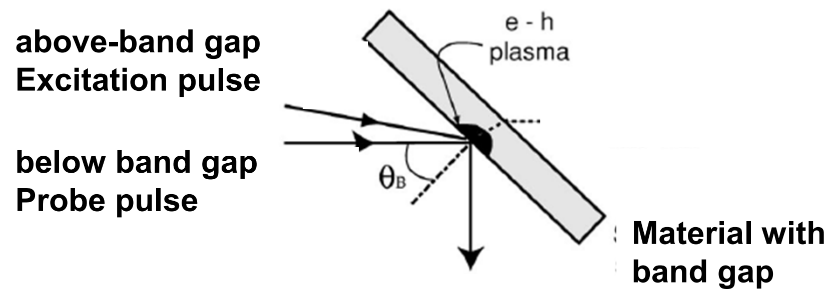
Azima, A et al.. Appl. Phys. Lett. (2009) 144102

„Routine“ Monitoring of Arrival time

3. X-ray/NIR cross correlator

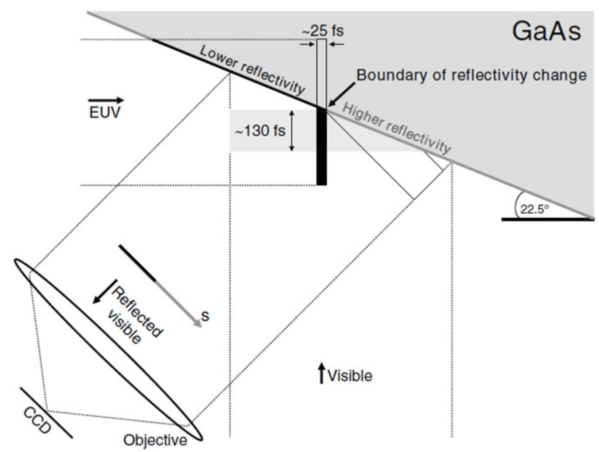


Working principle



e.g. Doty, MF et al.. Rev. Sci. Instr., 75 (2004) 2921

Experimental setup

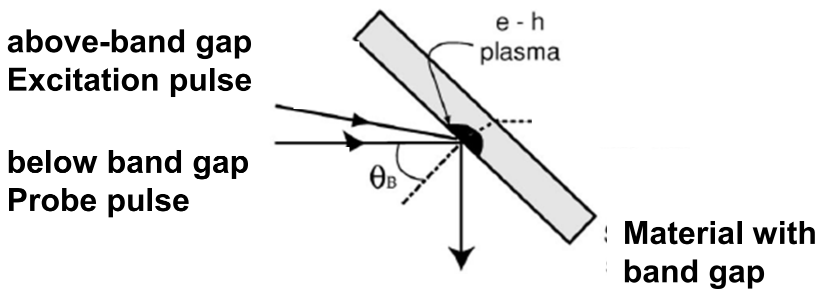


Maltezopoulus, T et al.. New Journal of Physics. (2008) 033026

„Routine“ Monitoring of Arrival time

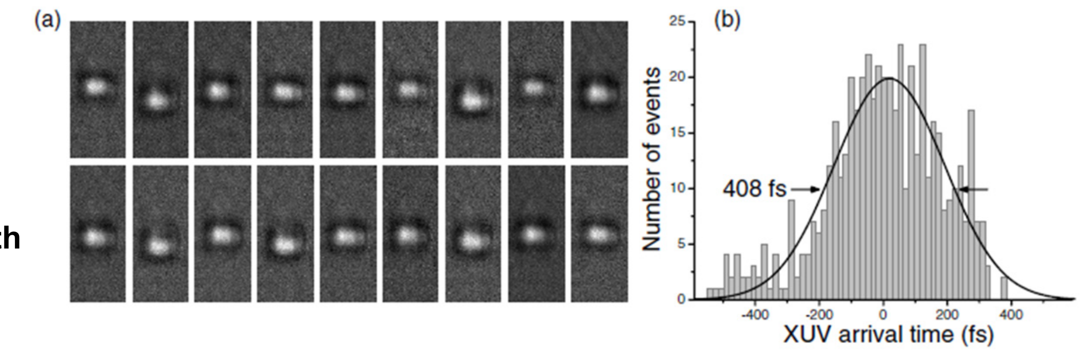
3. X-ray/NIR cross correlator

Working principle

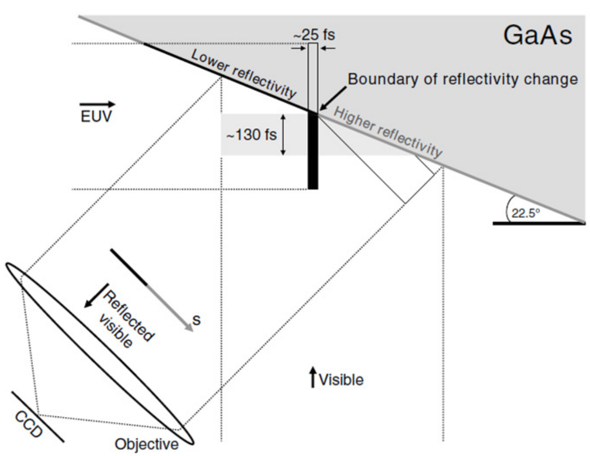


e.g. Doty, MF et al.. Rev. Sci. Instr., 75 (2004) 2921

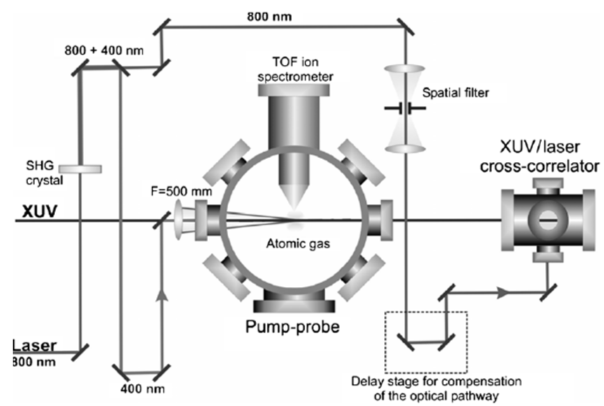
Results:

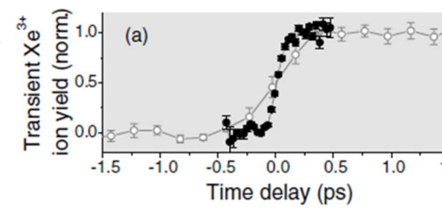


Experimental setup



Maltezopoulus, T et al.. New Journal of Physics. (2008) 033026





Drescher, M et al.. J. Phys. B: At. Mol. Opt. Phys., 43 (2010) 194010

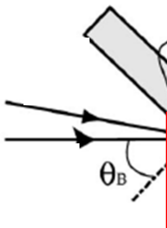
„Routine“ Monitoring of Arrival time

3. X-ray/NIR cross correlator

Working principle

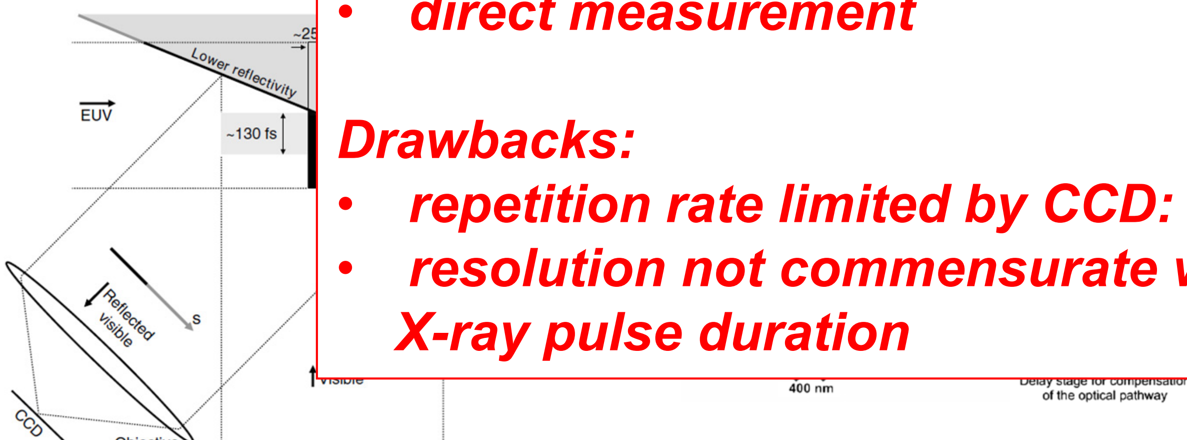
above-band gap Excitation pulse

below band gap Probe pulse



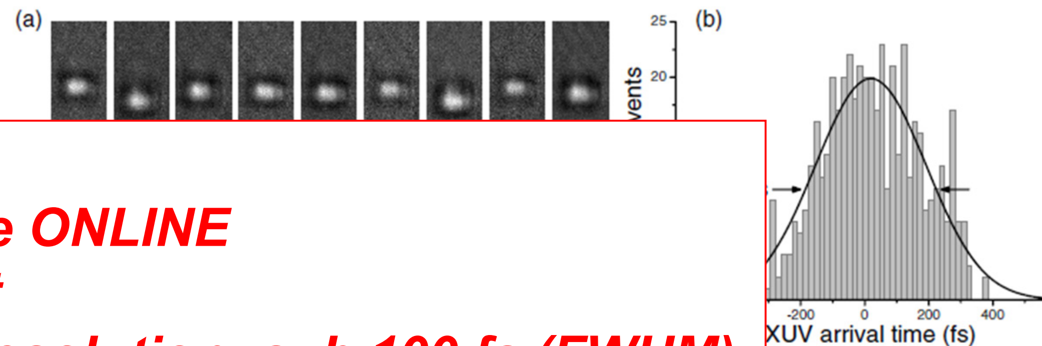
e.g. Doty, MF et al.. Rev. Sci. Instr.

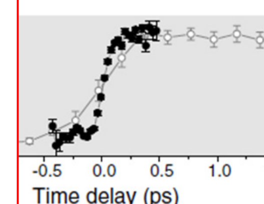
Experimental setup



Maltezopoulus, T et al.. New Journal of Physics. (2008) 033026

Results:





Merits:

- ***can operate ONLINE***
- ***Single shot***
- ***improved resolution: sub 100 fs (FWHM)***
- ***direct measurement***

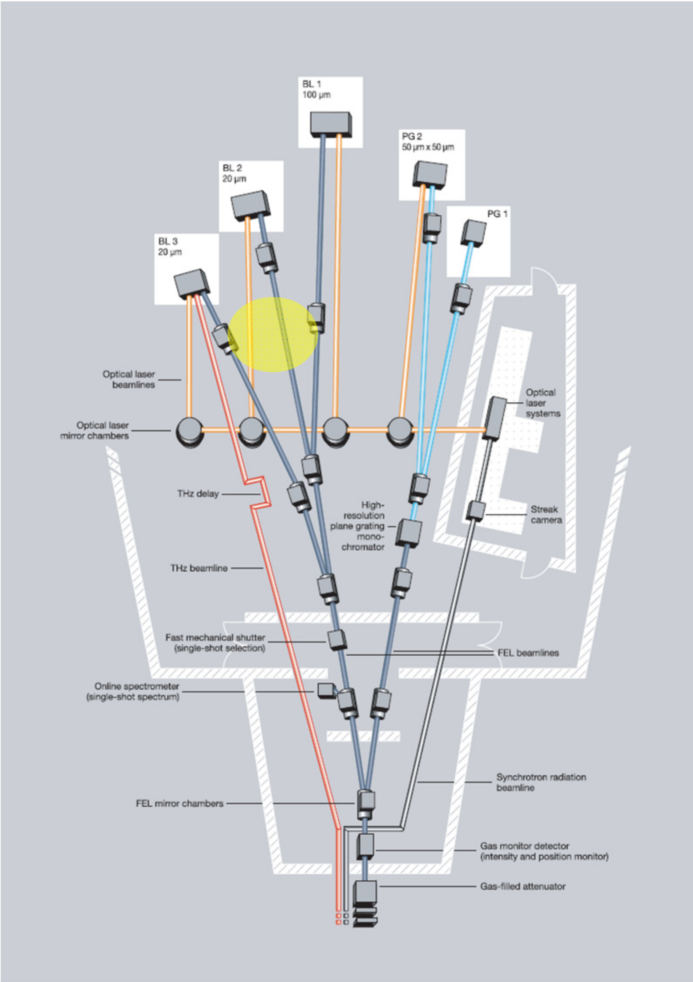
Drawbacks:

- ***repetition rate limited by CCD: 10Hz***
- ***resolution not commensurate with X-ray pulse duration***

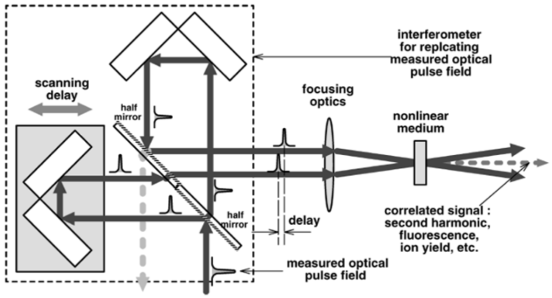
Drescher, M et al.. J. Phys. B: At. Mol. Opt. Phys., 43 (2010) 194010

„Routine“ Monitoring of Pulse duration??

Autocorrelation

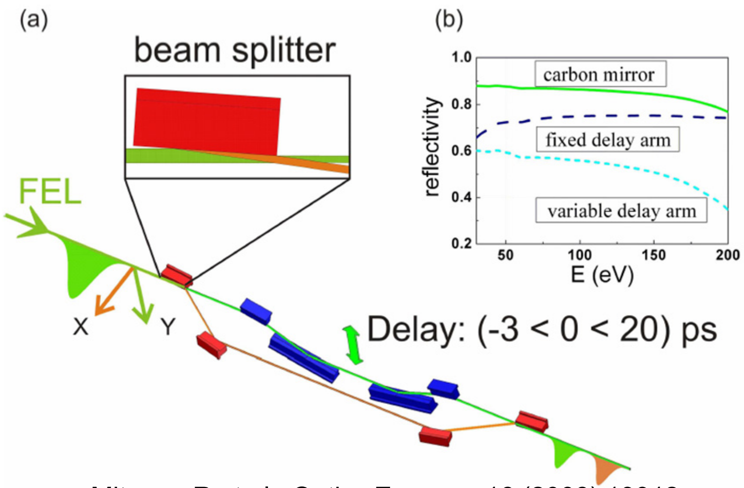


Working principle



e.g. Nabekawa, Y et al.. ADVANCES IN MULTI-PHOTON PROCESSES AD SPECTROSCOPY, Vol 18., cop. Worldscientific Publishing Co. Ptc. Ltd.

Experimental setup

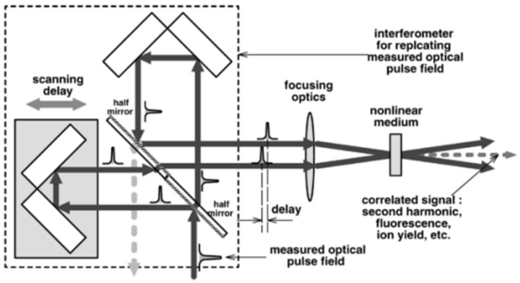


Mitzner, R et al.. Optics Express, 16 (2008) 19912

„Routine“ Monitoring of Pulse duration??

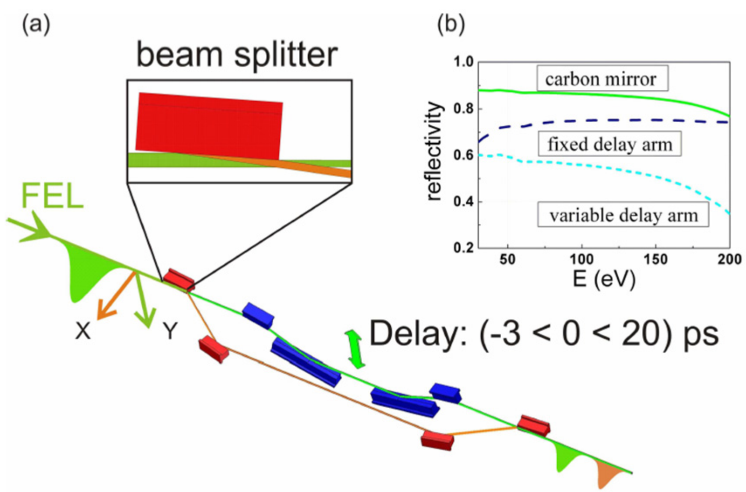
Autocorrelation

Working principle



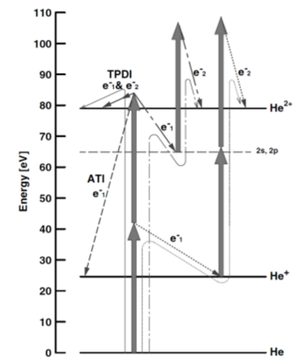
e.g. Nabekawa, Y et al.. ADVANCES IN MULTI-PHOTON PROCESSES AD SPECTROSCOPY, Vol 18., cop. Worldscientific Publishing Co. Ptc. Ltd.

Experimental setup

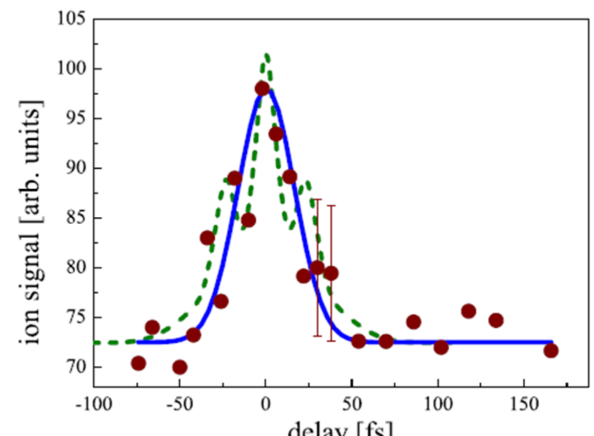


Mitzner, R et al.. Optics Express, 16 (2008) 19912

Results: two photon ionization of He @ 23.9 nm:



e.g. Nabekawa, Y et al.. ADVANCES IN MULTI-PHOTON PROCESSES AD SPECTROSCOPY, Vol 18., cop. Worldscientific Publishing Co. Ptc. Ltd.

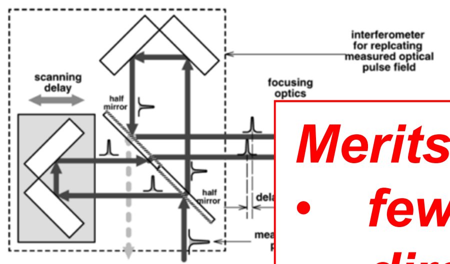


Mitzner, R et al.. Phys. Rev. B 80 (2009), 025402

„Routine“ Monitoring of Pulse duration??

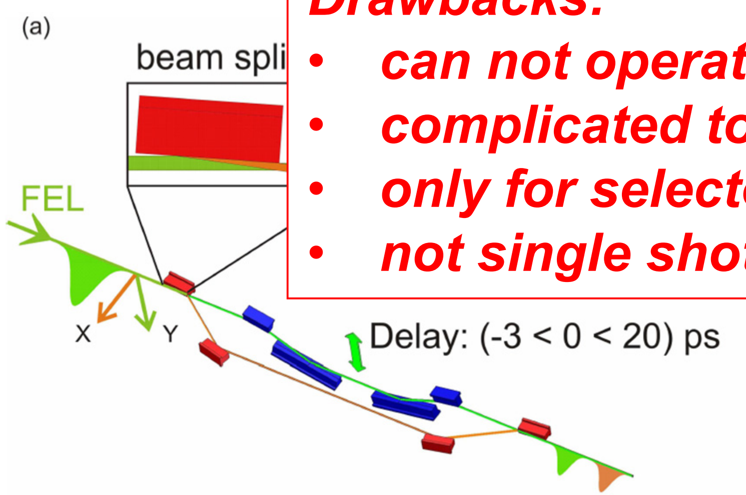
Autocorrelation

Working principle



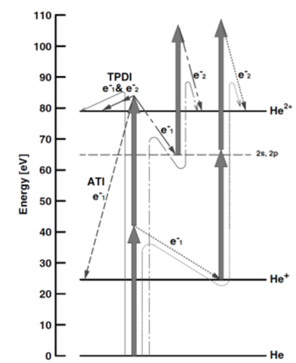
e.g. Nabekawa, Y et al.. ADVANCES IN M
Vol 18., cop. Worldscientific Publishing Co.

Experimental setup

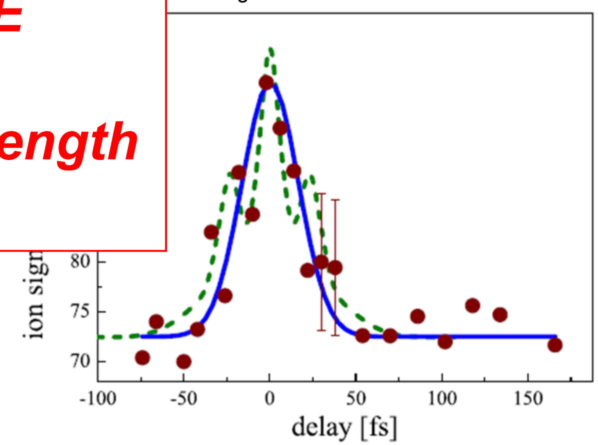


Mitzner, R et al.. Optics Express, 16 (2008) 19912

Results: two photon ionization of He @ 23.9 nm:



ANCES IN MULTI-PHOTON PROCESSES AD SPECTROSCOPY,
ublishing Co. Ptc. Ltd.



Mitzner, R et al.. Phys. Rev. B 80 (2009), 025402

Merits:

- ***few femtosecond resolution***
- ***direct measurement***

Drawbacks:

- ***can not operate ONLINE***
- ***complicated to handle***
- ***only for selected wavelength***
- ***not single shot***

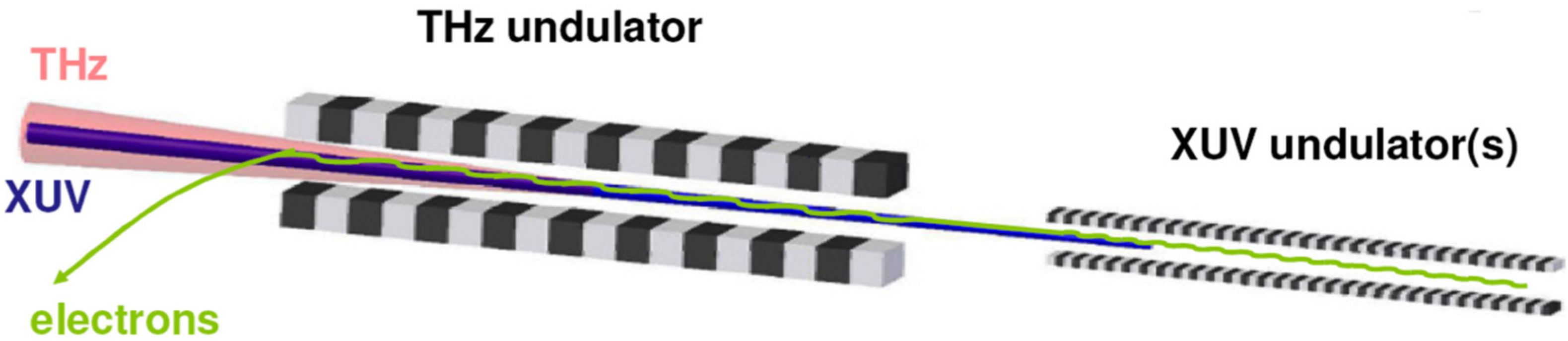
- „Routine“ diagnostic

- **Diagnostic challenges**

  1. Pulse duration

  2. Arrival time

Nice tool: THz undulator beamline



THz properties

Cascaded design:

• tunable, narrow bandwidth, fourierlimited pulse duration

• intrinsic Synchronization to X-ray pulse

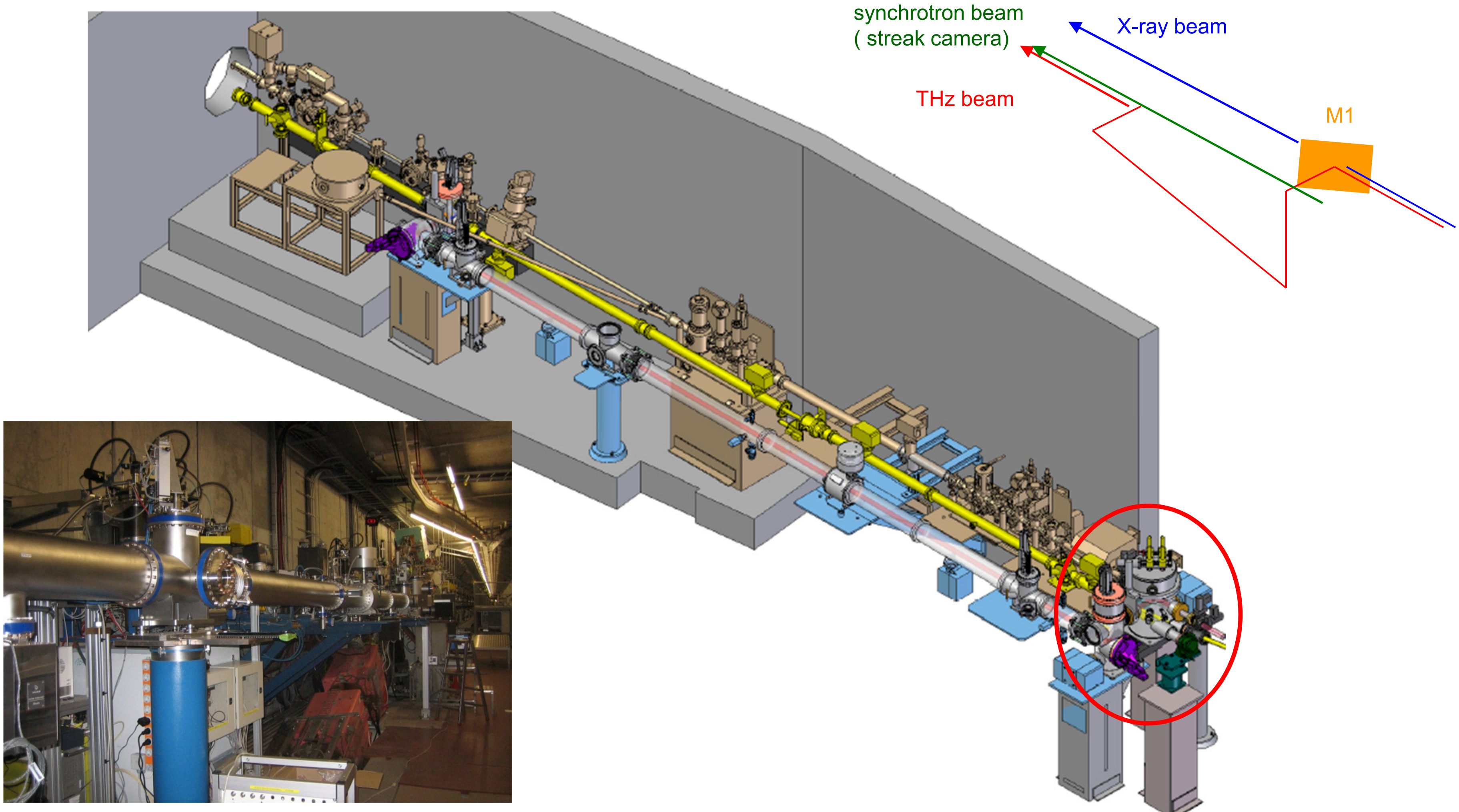
• Parasitic operation

• Intensity ~ **Ne**^{2}

• Coherent and CPE stable

Gensch, M. et al., Infrared Phys. Technol. 51, (2008) 423-425.

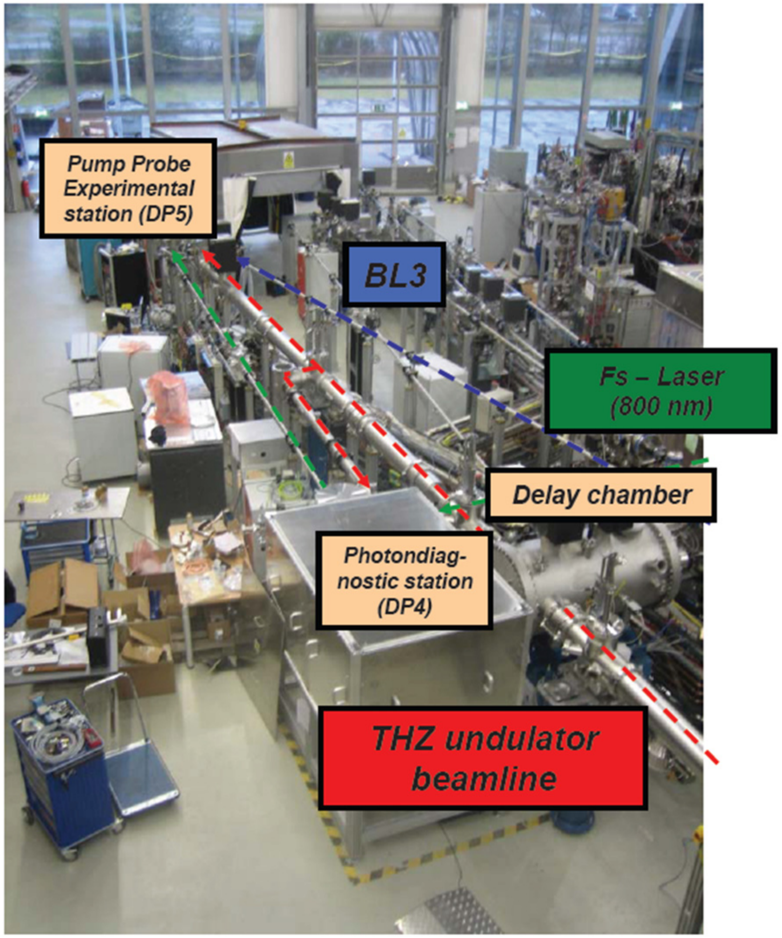
Nice tool: THz undulator beamline



view up - stream in the tunnel

Gensch, M. et al., Infrared Phys. Technol. 51, (2008) 423-425.

Nice tool: THz undulator beamline



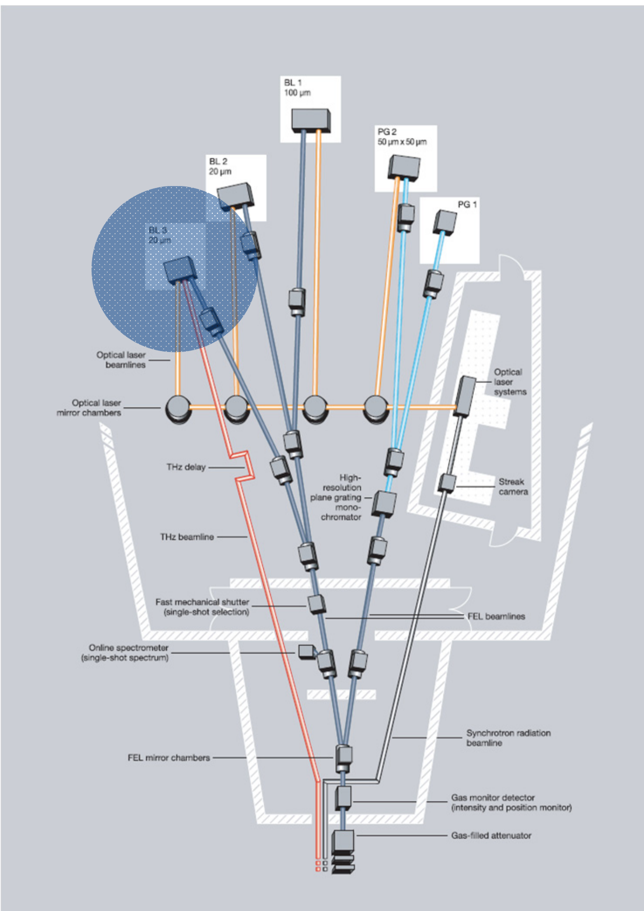
view down - stream in the experimental hall

Gensch, M. et al., Infrared Phys. Technol. 51, (2008) 423-425.

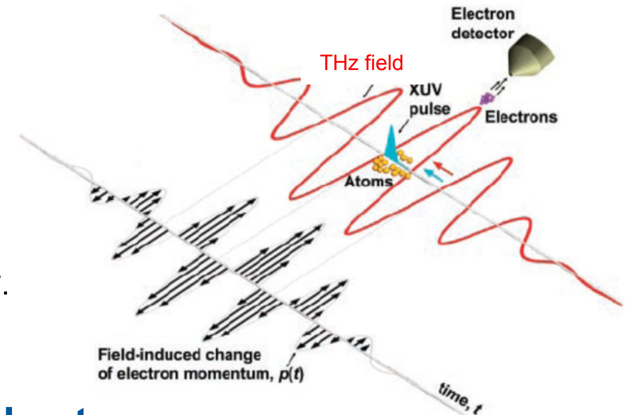
Diagnostic challenges: Pulse duration

Terahertz field-driven X-ray streakcamera

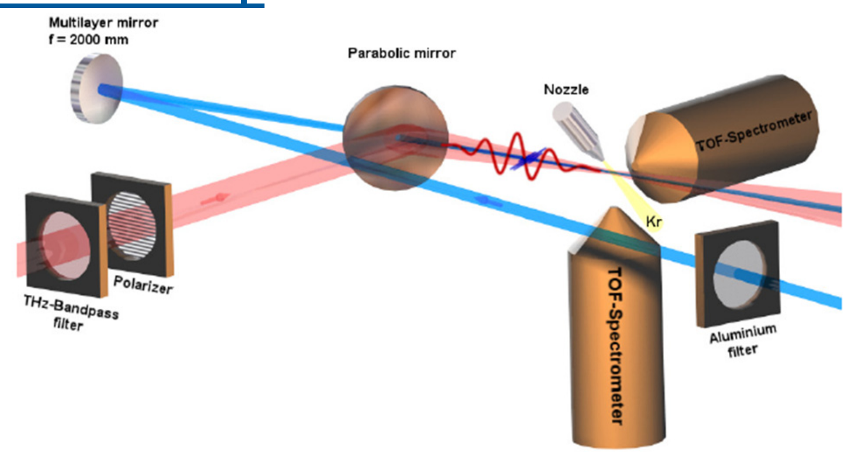
Working principle



Goulielmakis, E et. al., Science 305 (2004) 1267.



Experimental setup

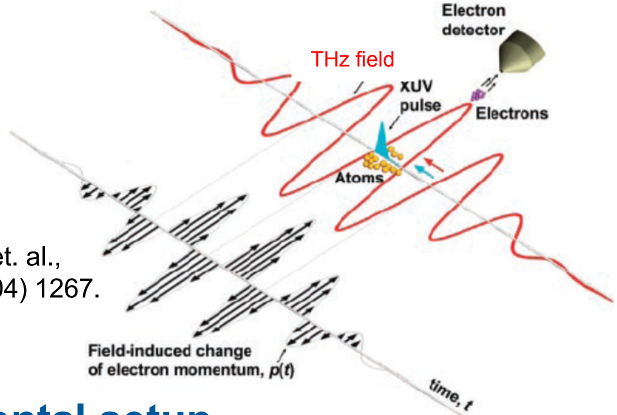


Fruehling, U; Wieland, M.; Gensch M. et. al., Nature Photon., 3 (2009), 529.

Diagnostic challenges: Pulse duration

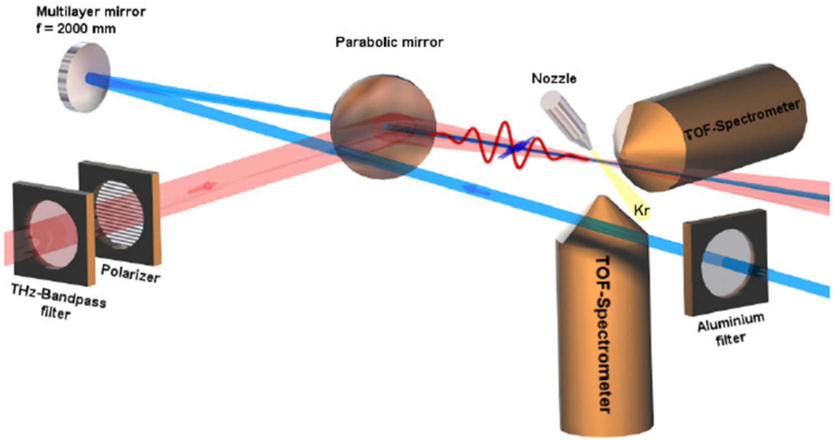
Terahertz field-driven X-ray streakcamera

Working principle



Goulielmakis, E et. al., Science 305 (2004) 1267.

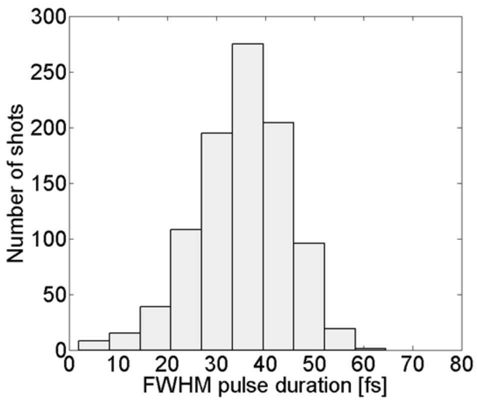
Experimental setup



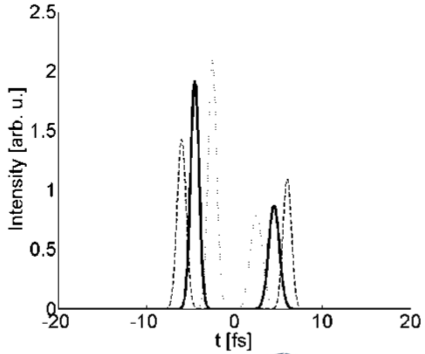
Fruehling, U; Wieland, M.; Gensch M. et. al., Nature Photon., 3 (2009), 529.

Results @ 13.5nm:

distribution of pulse durations



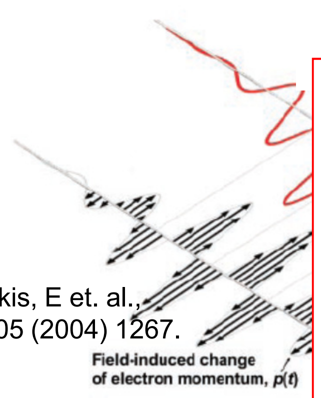
Single shot reconstruction of temporal structure



Diagnostic challenges: Pulse duration

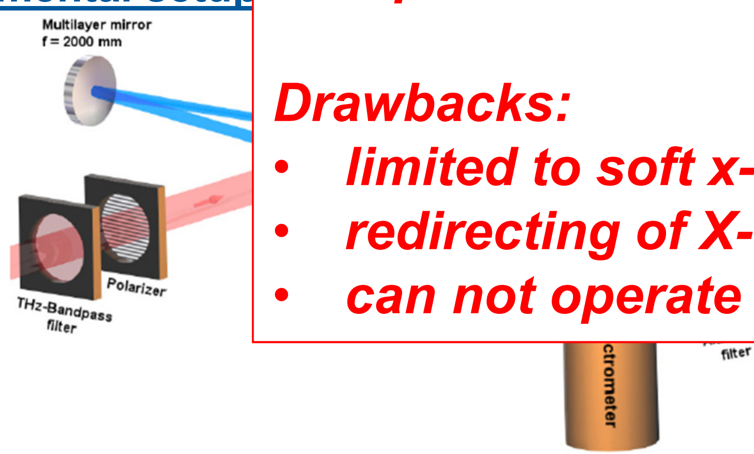
Terahertz field-driven X-ray streakcamera

Working principle



Goulielmakis, E et. al., Science 305 (2004) 1267.

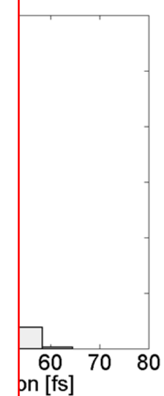
Experimental setup



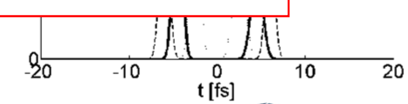
Fruehling, U; Wieland, M.; Gensch M. et. al., Nature Photon., 3 (2009), 529.

Results @ 13.5nm:

distribution of pulse durations



temporal structure



Merits:

- ***Sub 10 fs resolution***
- ***direct determination***
- ***Single-shot***
- ***robust***
- ***repetition rate commensurate with FEL***

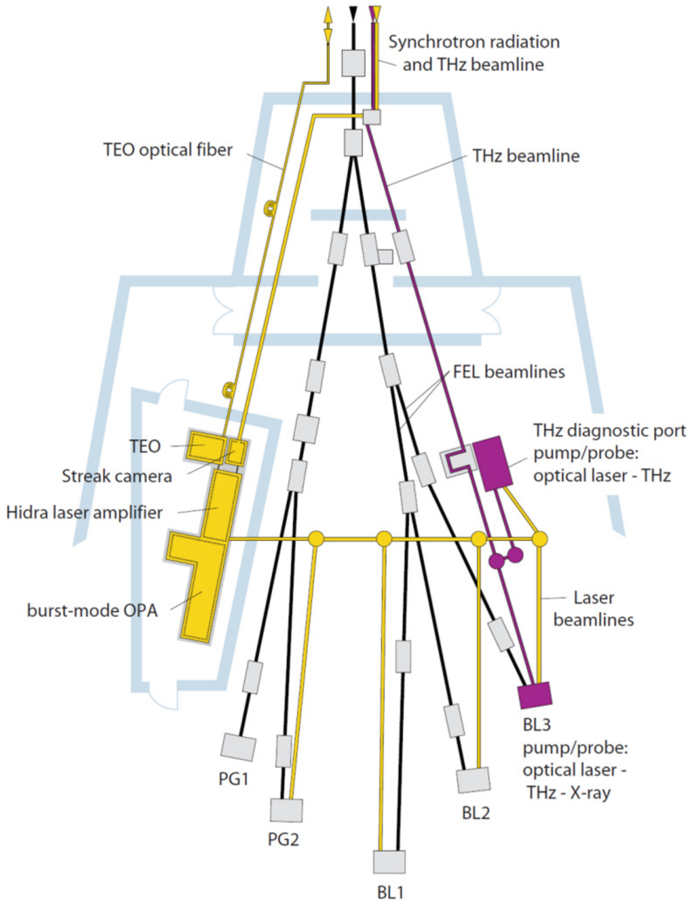
Drawbacks:

- ***limited to soft x-ray spectral range***
- ***redirecting of X-ray beam required***
- ***can not operate ONLINE***

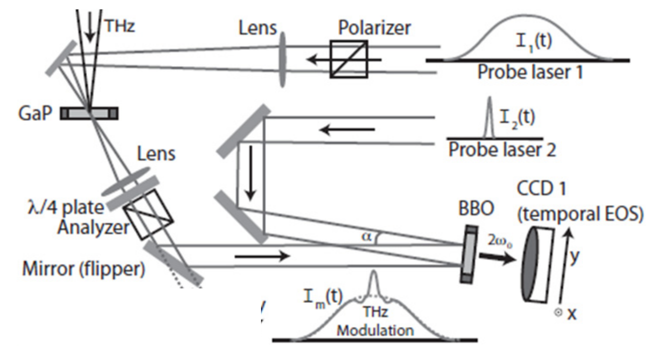
DRESDEN concept

Diagnostic challenges: Arrival time

THz – NIR crosscorrelation

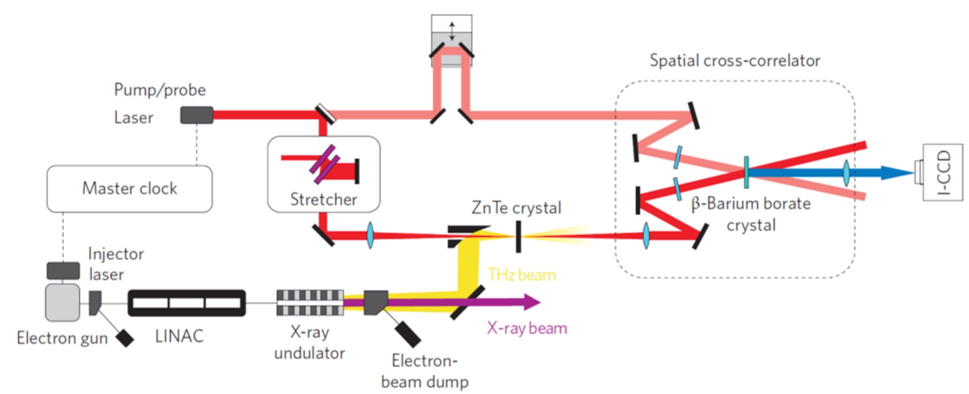


Working principle



van Tilborg, J. et. al.; Opt. Lett., 32 (2007), 313.

Experimental setup

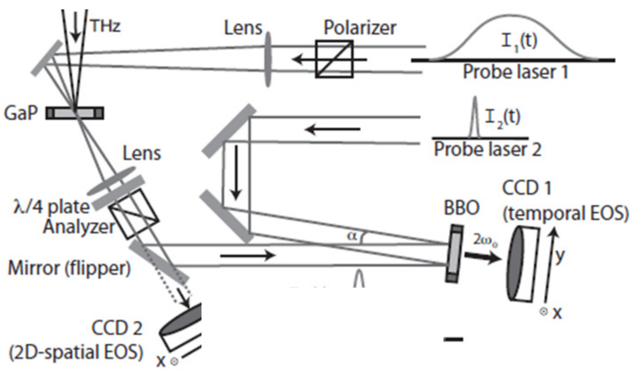


Tavella, F; Stojanovic, N.; Geloni, G; Gensch, M.; Nature Photon., 5 (2011), 162.

Diagnostic challenges: Arrival time

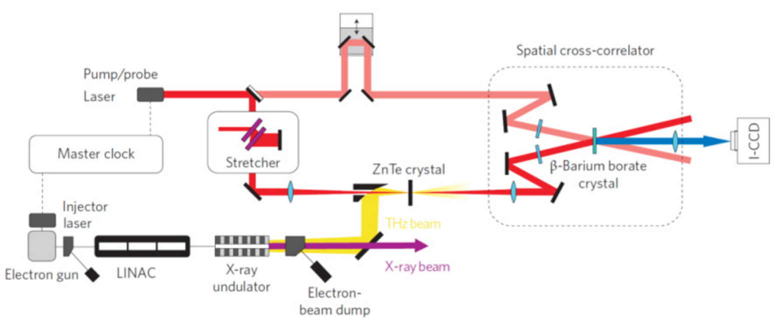
THz – NIR crosscorrelation

Working principle

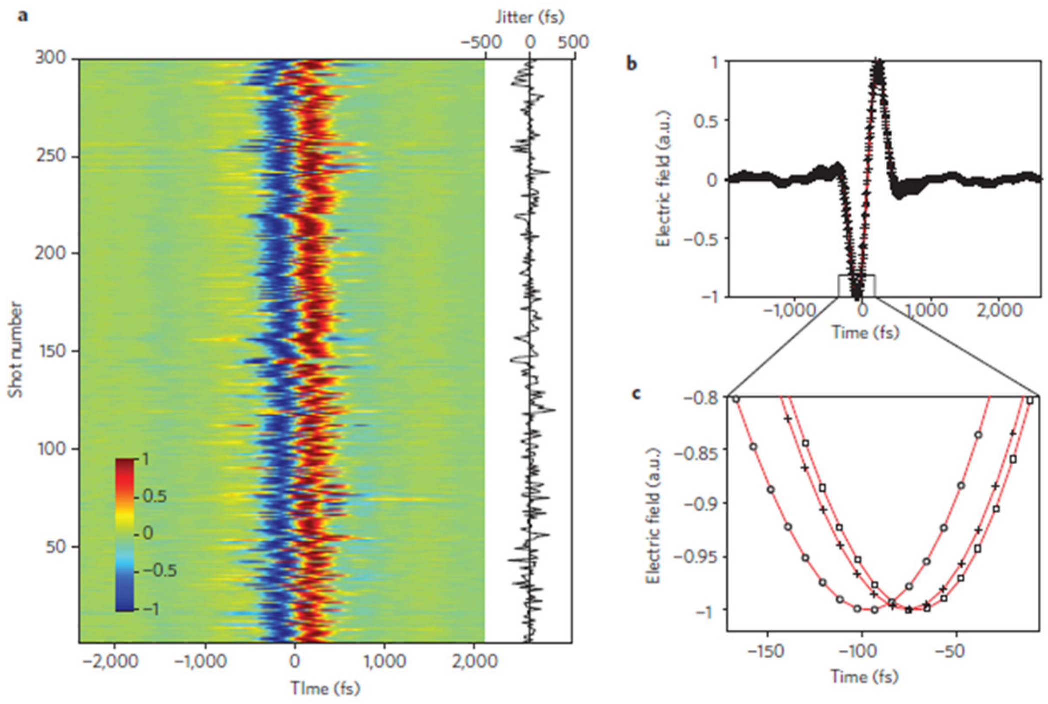


van Tilborg, J. et. al.; Opt. Lett., 32 (2007), 313.

Experimental setup



Results:



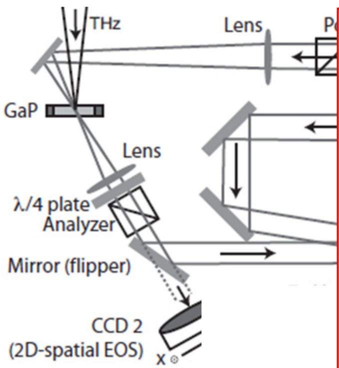
Tavella, F; Stojanovic, N.; Geloni, G; Gensch, M.; Nature Photon., 5 (2011), 162.

DRESDEN concept HZDR

Diagnostic challenges: Arrival time

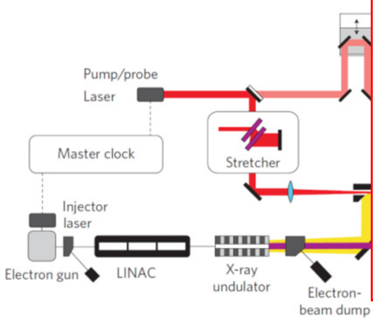
THz – NIR crosscorrelation

Working principle



van Tilborg, J. et. al.; Op

Experimental setu

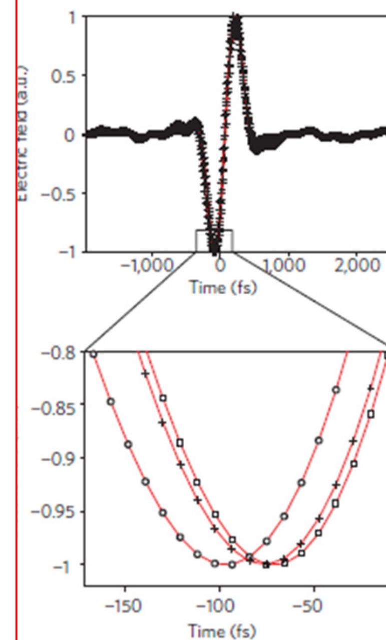


Merits:

- ***sub 10 fs resolution***
- ***single-shot***
- ***robust***
- ***can operate ONLINE***

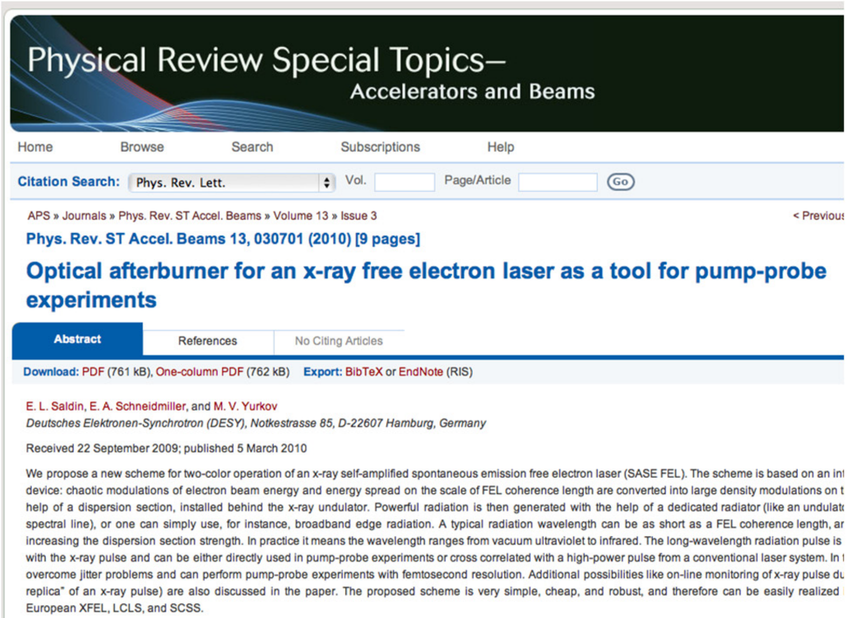
Drawbacks:

- ***Indirect determination***
- ***Repetition rate limited by CCD camera read out***
- ***<u>Precision determined by „coherent“ electron bunch duration</u>***



Tavella, F; Stojanovic, N.; Geloni, G; Gensch, M.; Nature Photon., 5 (2011), 162.

Diagnostic challenges: Arrival time + Pulse duration?


Physical Review Special Topics– Accelerators and Beams

Home | Browse | Search | Subscriptions | Help

Citation Search: Phys. Rev. Lett. Vol. Page/Article Go

APS » Journals » Phys. Rev. ST Accel. Beams » Volume 13 » Issue 3 < Previous

Phys. Rev. ST Accel. Beams 13, 030701 (2010) [9 pages]

Optical afterburner for an x-ray free electron laser as a tool for pump-probe experiments

Abstract | References | No Citing Articles

Download: PDF (761 kB), One-column PDF (762 kB) Export: BibTeX or EndNote (RIS)

E. L. Saldin, E. A. Schneidmiller, and M. V. Yurkov

Deutsches Elektronen-Synchrotron (DESY), Notkestrasse 85, D-22607 Hamburg, Germany

Received 22 September 2009; published 5 March 2010

We propose a new scheme for two-color operation of an x-ray self-amplified spontaneous emission free electron laser (SASE FEL). The scheme is based on an int device: chaotic modulations of electron beam energy and energy spread on the scale of FEL coherence length are converted into large density modulations on t help of a dispersion section, installed behind the x-ray undulator. Powerful radiation is then generated with the help of a dedicated radiator (like an undulato spectral line), or one can simply use, for instance, broadband edge radiation. A typical radiation wavelength can be as short as a FEL coherence length, ar increasing the dispersion section strength. In practice it means the wavelength ranges from vacuum ultraviolet to infrared. The long-wavelength radiation pulse is with the x-ray pulse and can be either directly used in pump-probe experiments or cross correlated with a high-power pulse from a conventional laser system. In t overcome jitter problems and can perform pump-probe experiments with femtosecond resolution. Additional possibilities like on-line monitoring of x-ray pulse du replica" of an x-ray pulse) are also discussed in the paper. The proposed scheme is very simple, cheap, and robust, and therefore can be easily realized European XFEL, LCLS, and SCSS.

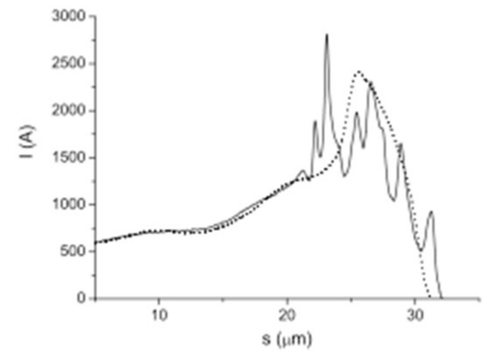


FIG. 8: Modulation of current in the head of electron bunch lasing at 7 nm in VUV undulator of FLASH and passing FIR undulator with R_{56} equal to 250 μm (solid), and with $R_{56} = 0$ (dots). Only small part of the bunch is shown, bunch head is on the right

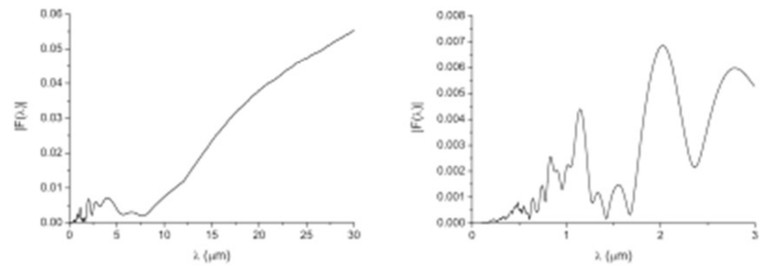


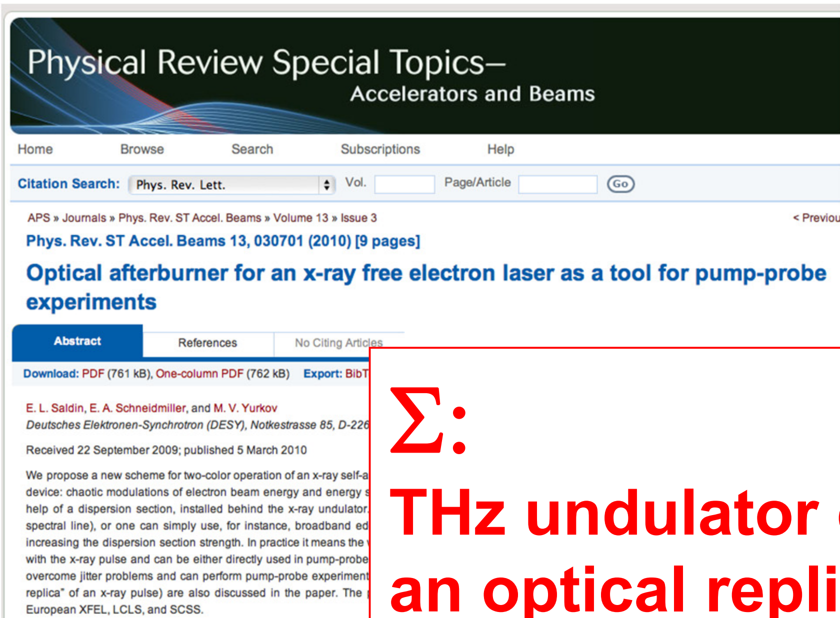
FIG. 9: Modulus of the bunch form factor (corresponding to realization in time domain shown in Fig. 8) versus wavelength, and an enlarged fraction of this plot.

Optical afterburner:

- Modulations of electron bunch energy on optical scale

E.L. Saldin, E.A. Schneidmiller and M.V. Yurkov, *Phys. Rev. ST Accel. Beams 13, 030701 (2010)*

Diagnostic challenges: Arrival time + Pulse duration?



Physical Review Special Topics–
Accelerators and Beams

Home Browse Search Subscriptions Help

Citation Search: Phys. Rev. Lett. Vol. Page/Article Go

APS » Journals » Phys. Rev. ST Accel. Beams » Volume 13 » Issue 3 < Previous

Phys. Rev. ST Accel. Beams 13, 030701 (2010) [9 pages]

Optical afterburner for an x-ray free electron laser as a tool for pump-probe experiments

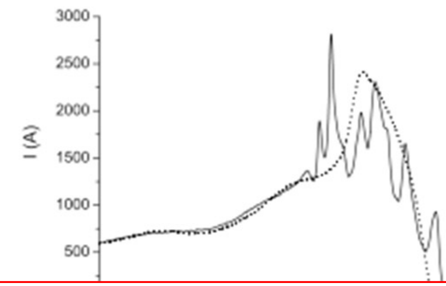
Abstract | References | No Citing Articles

Download: PDF (761 kB), One-column PDF (762 kB) Export: BibT

E. L. Saldin, E. A. Schneidmiller, and M. V. Yurkov
Deutsches Elektronen-Synchrotron (DESY), Notkestrasse 85, D-226

Received 22 September 2009; published 5 March 2010

We propose a new scheme for two-color operation of an x-ray self-a
device: chaotic modulations of electron beam energy and energy s
help of a dispersion section, installed behind the x-ray undulator.
spectral line), or one can simply use, for instance, broadband ed
increasing the dispersion section strength. In practice it means the
with the x-ray pulse and can be either directly used in pump-probe
overcome jitter problems and can perform pump-probe experiment
replica" of an x-ray pulse) are also discussed in the paper. The
European XFEL, LCLS, and SCSS.



Σ:

THz undulator can be used to generate an optical replica of the X-ray pulse!

undulator of FLASH

ts). Only small part of

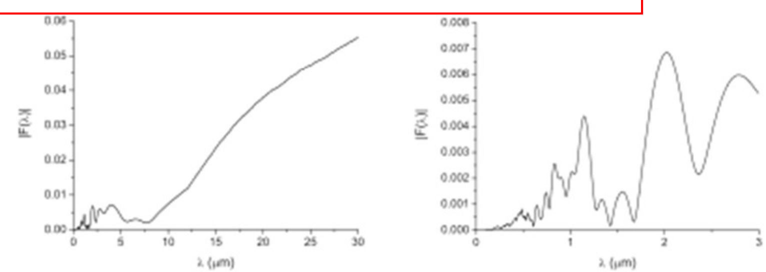
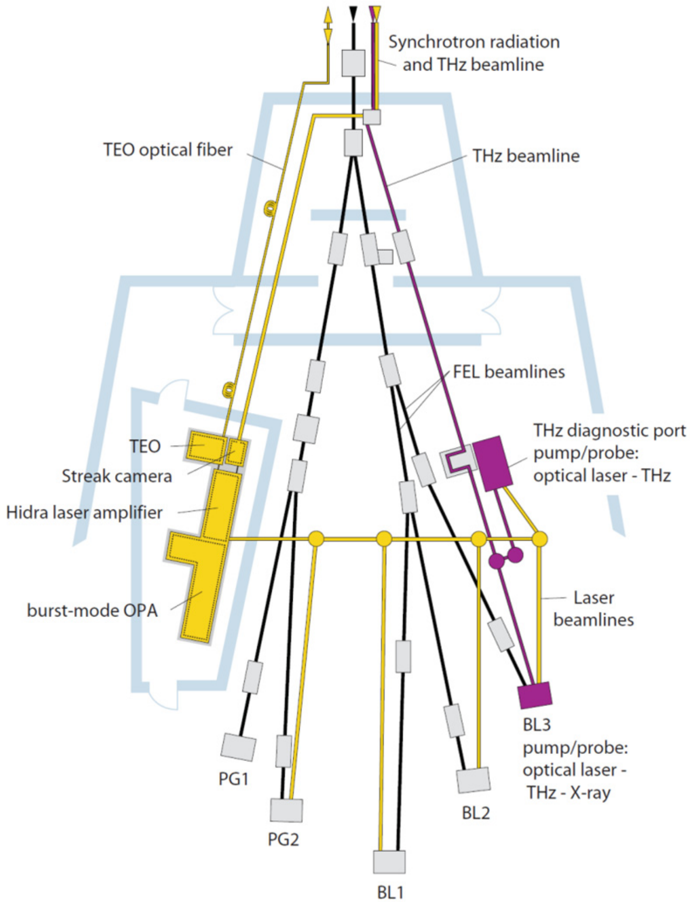


FIG. 9: Modulus of the bunch form factor (corresponding to realization in time domain shown in Fig. 8) versus wavelength, and an enlarged fraction of this plot.

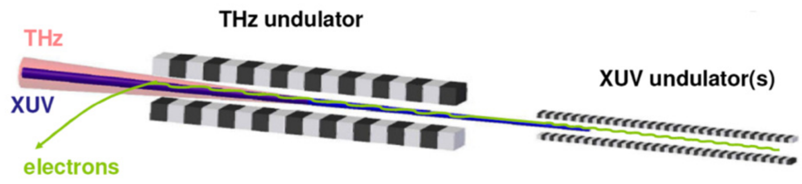
Optical afterburner:
- Modulations of electron bunch energy on optical scale

E.L. Saldin, E.A. Schneidmiller and M.V. Yurkov, *Phys. Rev. ST Accel. Beams 13, 030701 (2010)*

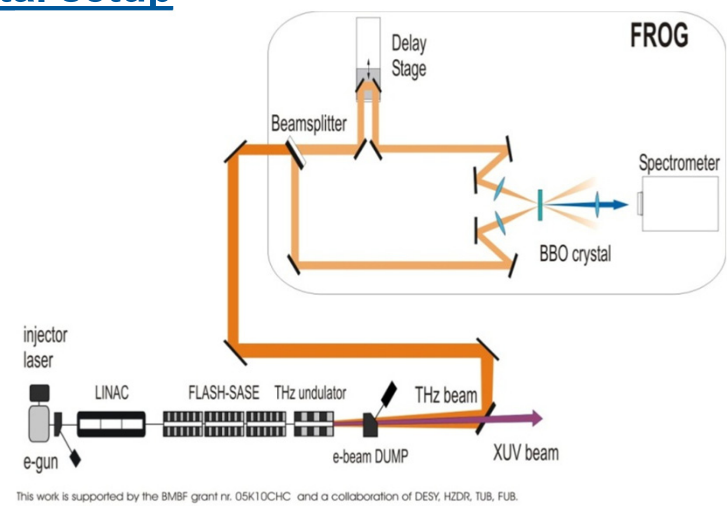
Diagnostic challenges: Arrival time + Pulse duration?



Working principle

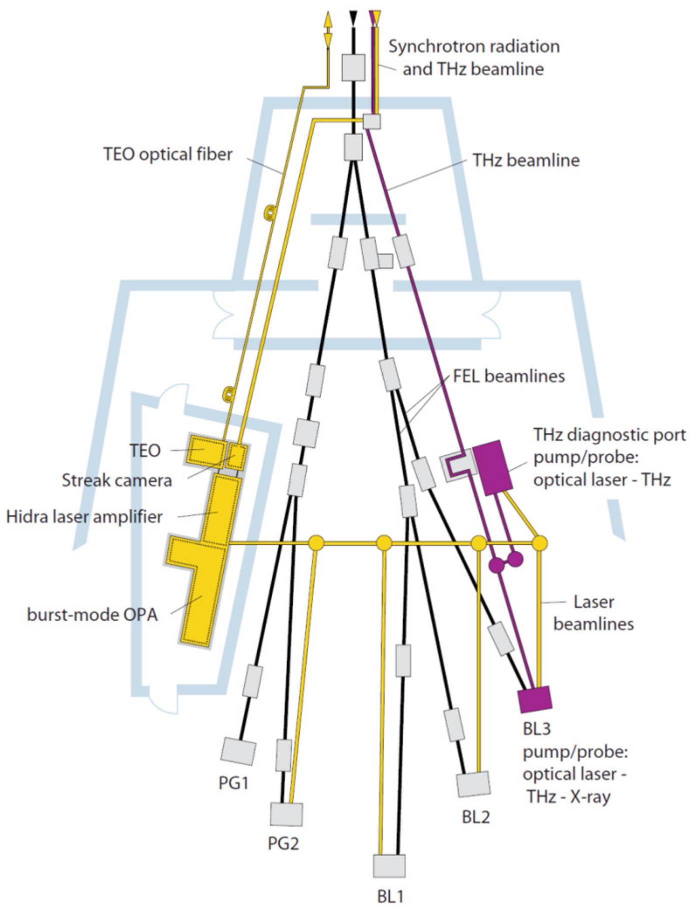


Experimental setup



work is supported by the BMBF grant nr. 05K10CHC and a collaboration of DESY, HZDR, TUB, FUB and MPSD-CFEL

Diagnostic challenges: Arrival time + Pulse duration?

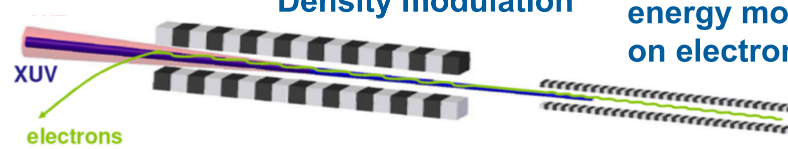


Working principle

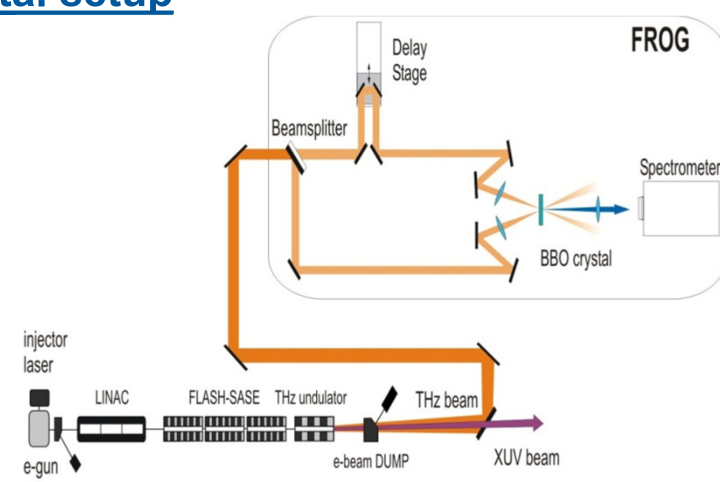
3. Optical replica of X-ray pulse emitted

2. R56 of THz undulator Converts energy into Density modulation

1. SASE generates energy modulation on electron bunch



Experimental setup



This work is supported by the BMBF grant nr. 05K10CHC and a collaboration of DESY, HZDR, TUB, FUB.

work is supported by the BMBF grant nr. 05K10CHC and a collaboration of DESY, HZDR, TUB, FUB and MPSD CFEL

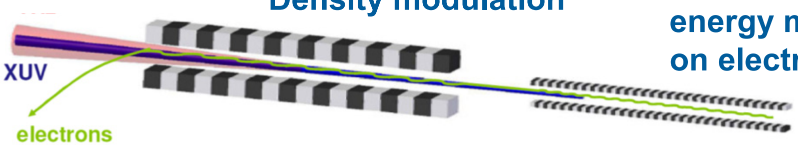
Diagnostic challenges: Arrival time + Pulse duration?

Working principle

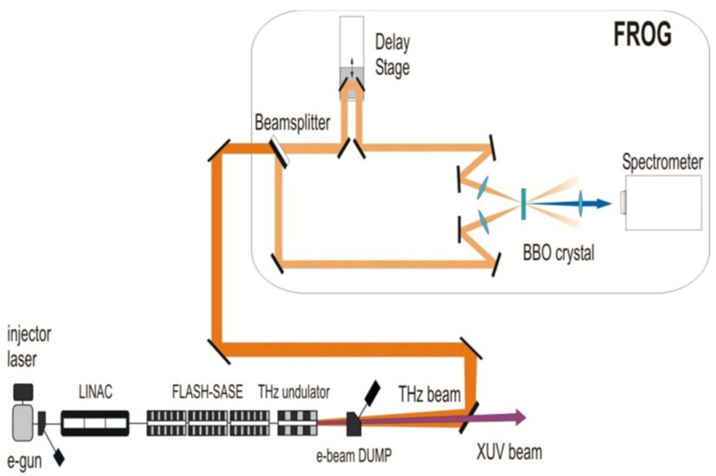
3. Optical replica of X-ray pulse emitted

2. R56 of THz undulator Converts energy into Density modulation

1. SASE generates energy modulation on electron bunch



Experimental setup



This work is supported by the BMBF grant nr. 05K10CHC and a collaboration of DESY, HZDR, TUB, FUB.

Results:

To be published

To be published

work is supported by the BMBF grant nr. 05K10CHC and a collaboration of DESY, HZDR, TUB, FUB, MPSD-CFEL

Diagnostic challenges: Arrival time + Pulse duration?

Potential merits:

Pulse duration:

- *presently 30 fs (thickness of BBO)*
- *robust*
- *convenient to handle*
- *no external laser system required*
- *Single shot (if pulses can be amplified)*

Arrival time:

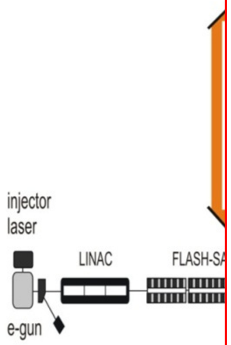
- *(crosscorrelation) feasible if pulses can be amplified*
- *few fs resolution possible*

Drawback:

Indirect determination

-> need to verify our results at different FEL tunes and by comparison to other methods

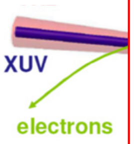
Experimen



This work is supported by the BMBF grant nr. 0

Working pr

3. Optical replic
X-ray pulse emi



work is supporte
collaboration of DESY, HZDR, TUB, FUB, MPSD-CFEL

Summary

Available routine diagnostic:

1. Pulse energy
2. Spectral content

Still work todo!:

3. (Arrival time) – **not commensurate with FEL!**
   potential solution:
   -> THz/NIR crosscorrelation*
   -> optical replica/optical afterburner*
4. (Pulse duration) – **not ready to use**
   potential solution:
   -> Streaking (possibly makeing use of table top THz)
   -> optical replica/optical afterburner*

**require merely high transmission optical beamline from enf of the accelerator*

THANK YOU !

Acknowledgement:

DESY FS-BT, HASYLAB vacuum group, DESY MVP, DESY FLA
A.L. Cavalieri, M. Foerst (MPSD-CFEL), W. Seidel (HZDR), K.Tiedtke, H. Wabnitz, J. Feldhaus,

B. Faatz, M. Yurkov, E. Schneidmiller, V. Kocharyan, E. Saldin (DESY) +

<u>Nikola Stojanovic</u>, Franz Tavella (DESY), Gianluca Geloni (X-FEL)

and through the PIDID Proposal, BMBF grant no 05K10CHC +BMBF grant no 05K10KEB