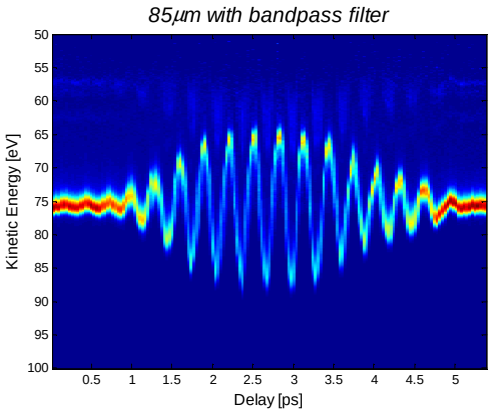
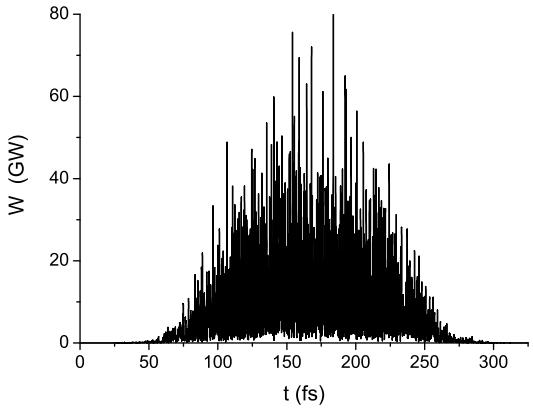
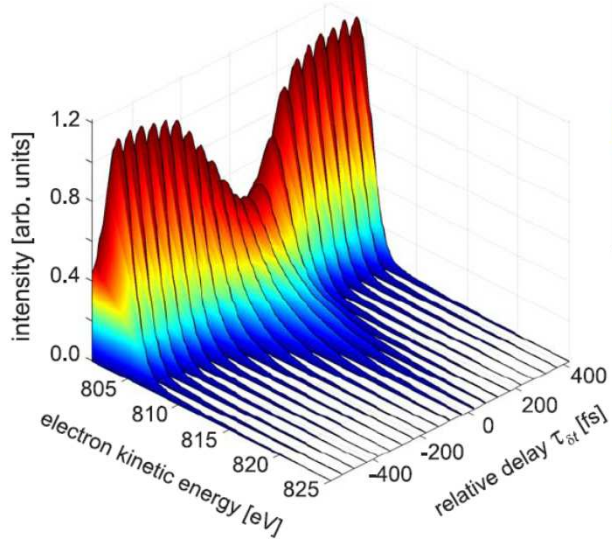
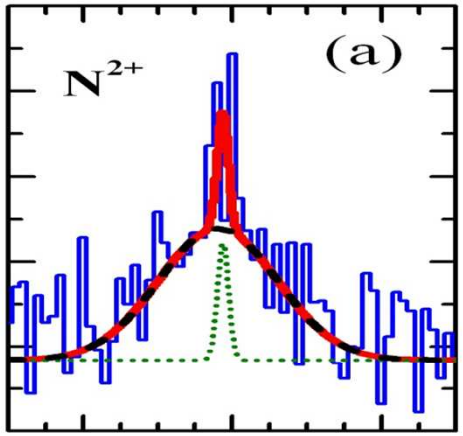
XUV pulse duration @ FLASH









Stefan Düsterer
for the "pulse duration team"

HELMHOLTZ ASSOCIATION

DESY

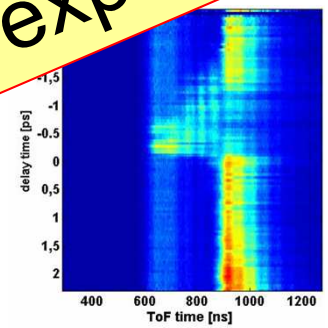
Importance of the pulse duration

> **FEL characterization**

> **non-linear physics**

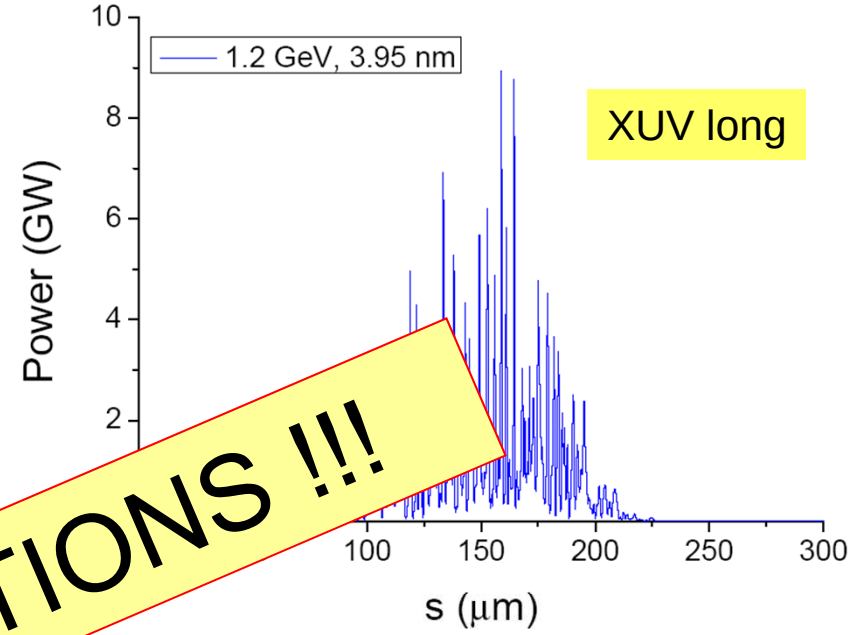
> **Ultra-fast**

- **Short** (< 50 fs) pulses
- **Monitor** the pulse duration
  (average for now – substructure for future)
- Constant pulse duration over **pulse train**
- Constant over **all shifts** of the experiment



SASE pulse – what we have to deal with?

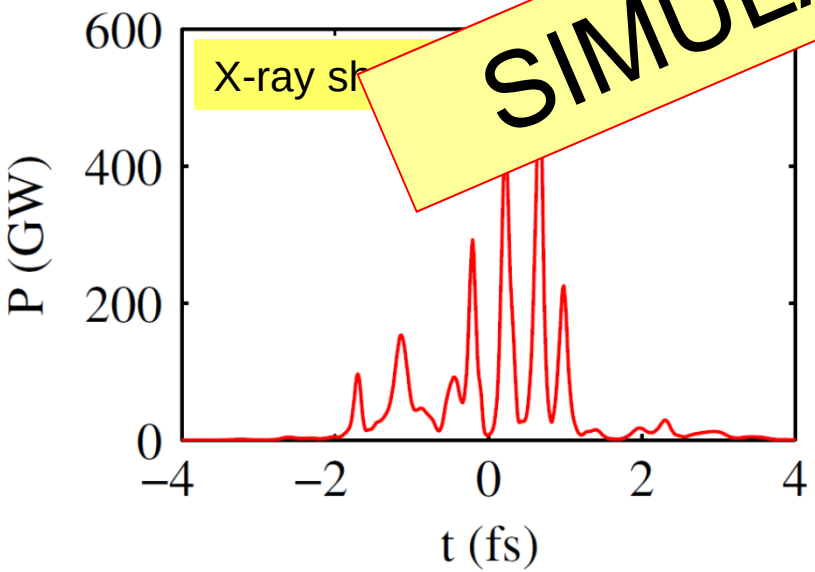
X-ray long

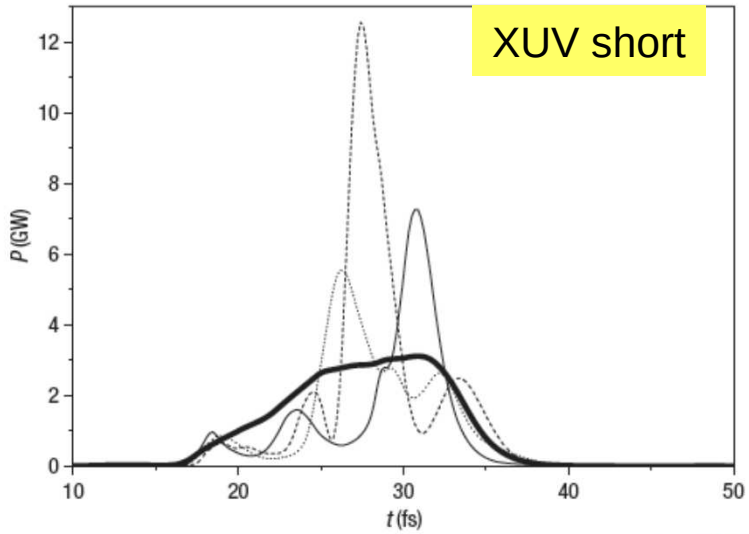


XUV long

SIMULATIONS !!!

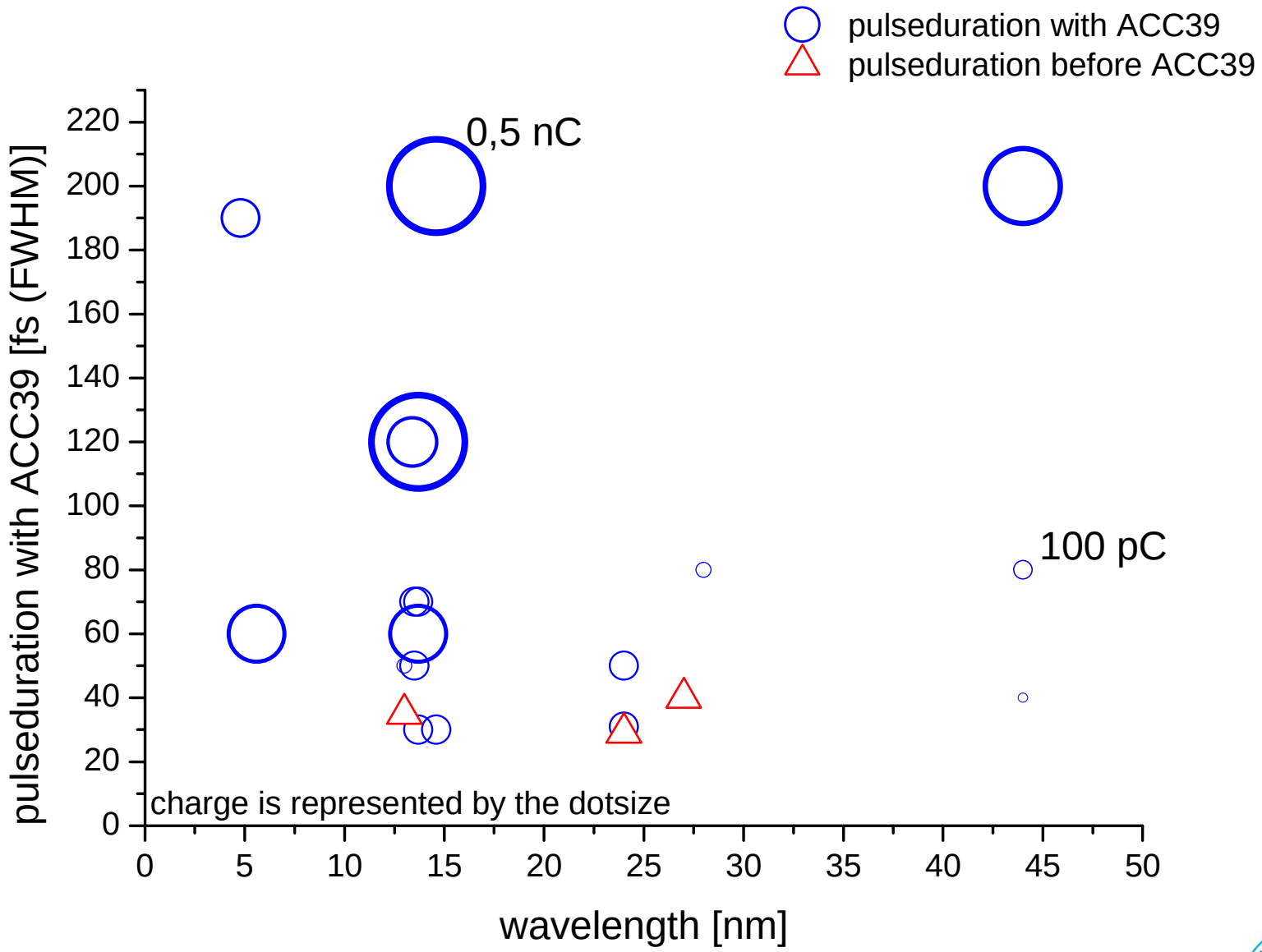
X-ray sh





XUV short

Overview: pulse durations 2007-2012



Schedule … what was done

Schedule for the short pulse studies Feb / Mar 2012

				last update: 15.12.2011	
		morning shift (7:00-15:00)		***afternoon shift (15:00 -23:00)***	***night shift (23:00 -7:00)***
27.2.12	Mo	**maintenance**	**shift exchange meeting**	**recover from 9mA startup**	**Startup 13.5 +- 0.1 nm,** 250 kHz, as many pulses as possible
28.2.12	Tu	**Startup 13.5 +- 0.1 nm,** 250 kHz, (BL2 AC. Parasitic) as many pulses as possible		PREP EXP *THz streak BL3 (13.5 nm)*	PREP EXP *Afterburner (13.5 nm)*
29.2.12	We	PREP EXP *AC BL2* (Afterb. Parasitic?) (13.5 nm)		PREP EXP *PG2 setup (13.5 nm)*	PREP EXP *PG2 AC (13.5 nm)*
1.3.12	Th	PREP EXP *Reserve*		**setup short pulse 13.5 +- 0.1nm** , 250 kHz, as many pulses as possible	**setup short pulse 13.5 nm** , 250 kHz, as many pulses as possible
2.3.12	Fr	Spectr PG2 / statistics **EXP** *PG2 AC (13.5 nm)*		Spectr PG2 / statistics **EXP** *THz streak BL3 (13.5 nm)*	**EXP** *Afterburner (13.5 nm)*
3.3.12	Sa	Spectr PG2 / statistics **EXP** *BL2 AC (13.5 nm)*		Spectr PG2 / statistics **EXP** *PG2 AC (13.5 nm)*	EXP Reserve
4.3.12	Su	**setup short pulse 24.0 +- 0.2 nm ,** 250 kHz, as many pulses as possible		**setup short pulse 24.0 +- 0.2 nm ,** 250 kHz, as many pulses as possible	**setup short pulse 24.0 +- 0.2 nm ,** 250 kHz, as many pulses as possible
5.3.12	Mo	Spectr PG2 / statistics **EXP** *PG2 AC (24.0 nm)*		Spectr PG2 / statistics **EXP** *THz streak BL3 (24.0 nm)*	**EXP** *Afterburner (24.0 nm)*
6.3.12	Tu	Spectr PG2 / statistics **EXP** *BL2 AC (24.0 nm)*		EXP Reserve	EXP Reserve
7.3.12	We	**Maintainance**			
8.3.12	Th				

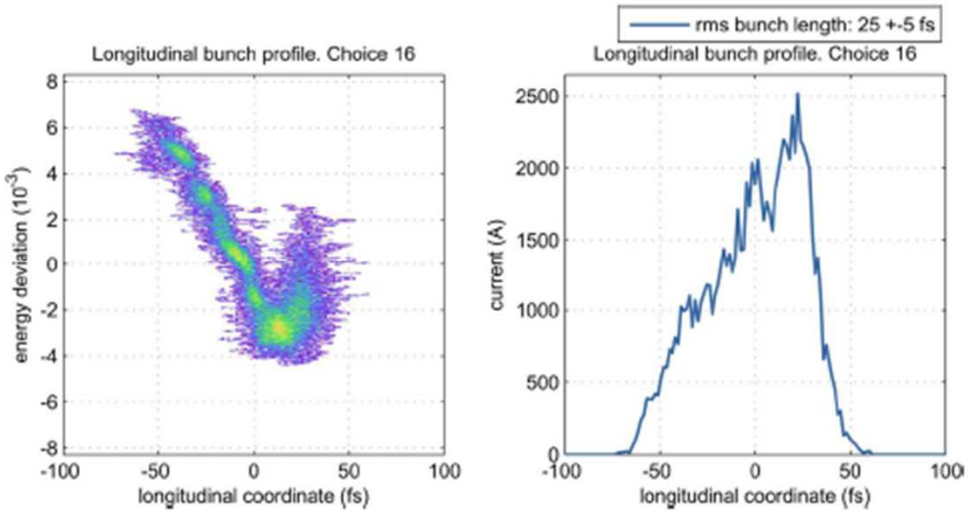
Goals for the short pulse studies

1. Calibrate **“indirect”** methods (fast) against **“direct”** ones (time consuming)
2. How good is the correlation between **electron** diagnostics/pulse length and **photon** diagnostic / pulse length
3. Find out **advantages / disadvantages** of different methods
4. Define recipe **how to tune** short pulses

The methods for photon pulse measurements

- Indirect methods / Electrons
  - Crisp – THz spectrometer
  - LOLA
  - Beam Compression Monitor (BCM)
- Indirect methods / Photons
  - Spectral characteristics
  - Pulse energy fluctuations
  - “afterburner”
- Direct methods / Photons
  - Autocorrelation
  - Reflectivity measurements
  - THz streaking

Electron Diagnostics: LOLA



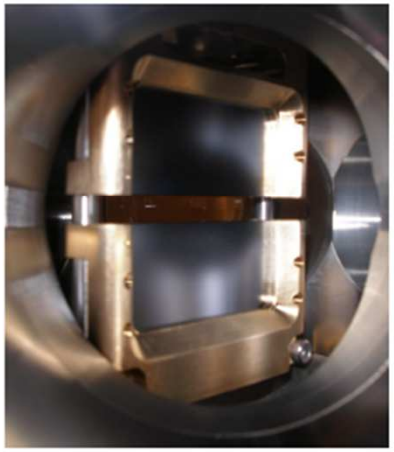
PRO:
- very good resolution
- pulse duration and energy spread

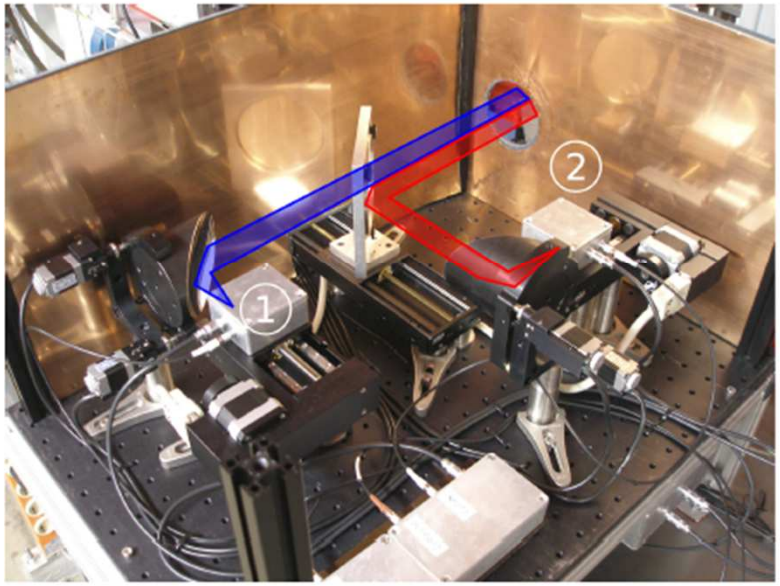
CON:
- only for single bunches so far (work in progress)
- Not parasitic

Electron Diagnostics: BCM

Setup

BCM (Beam Compression Monitor)





Courtesy of S.Wesch

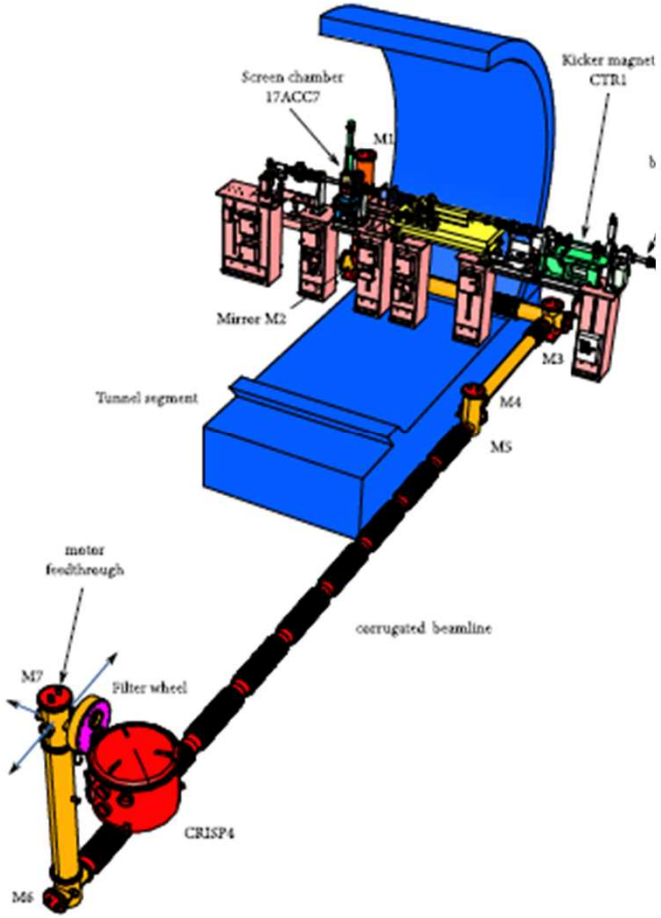
PRO:
- parasitic
- bunch resolving

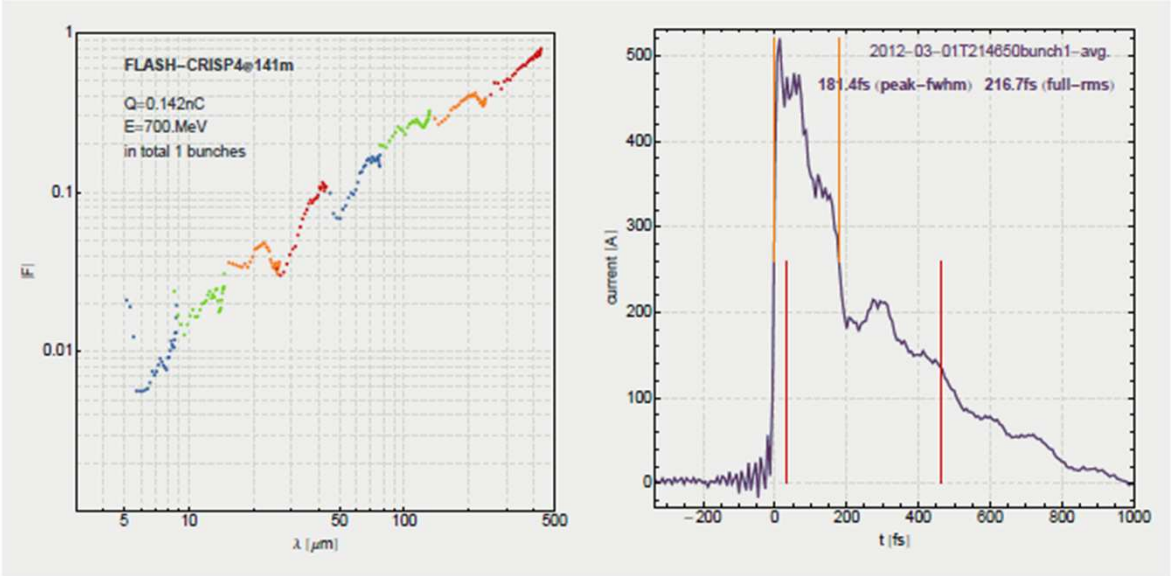
CON:
- no info about bunch shape / energy spread

Electron Diagnostics: CRISP

Beamline overview

Spectrometer





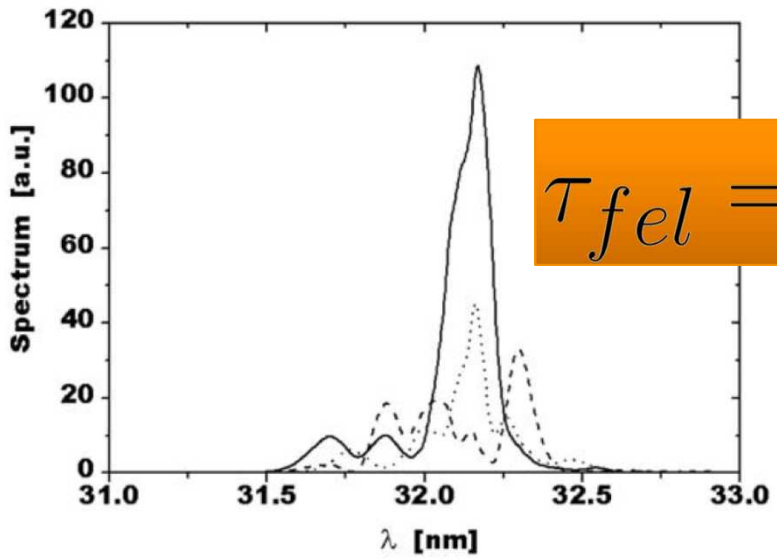
PRO:

- reconstructed bunch shape for single bunches
- Easy to use
- **works for bhunchtrain**

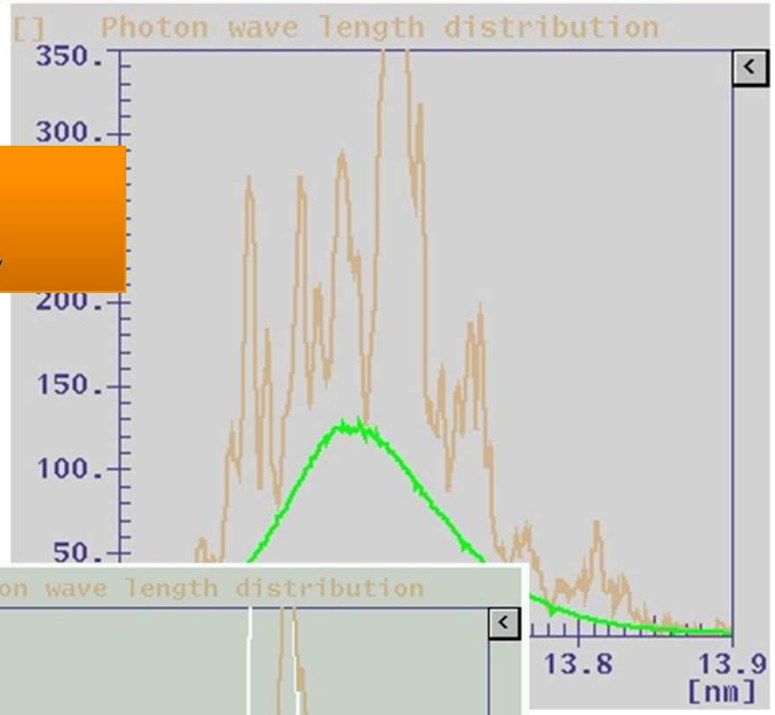
CON:

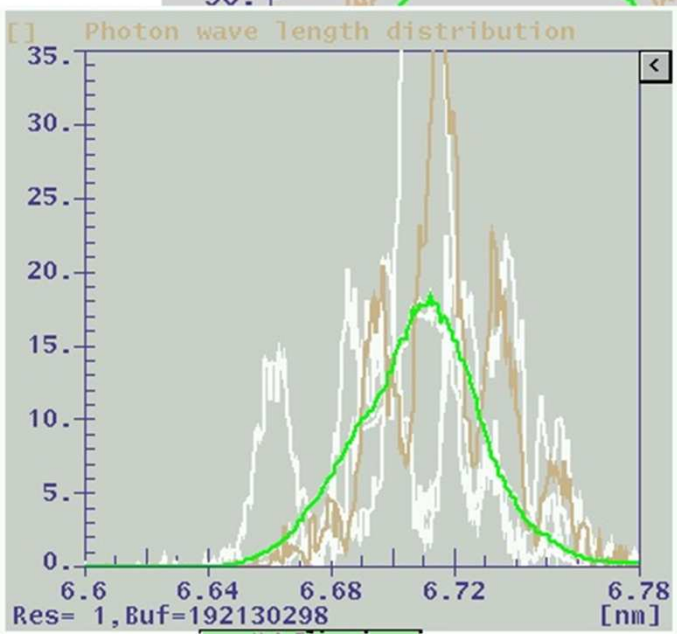
- Needs complicated math to get to bunch shape (no energy spread)
- Not parasitic

Indirect PHOTON methods: spectral spikes - correlations



$$\tau_{fel} = M\tau_{coh}$$



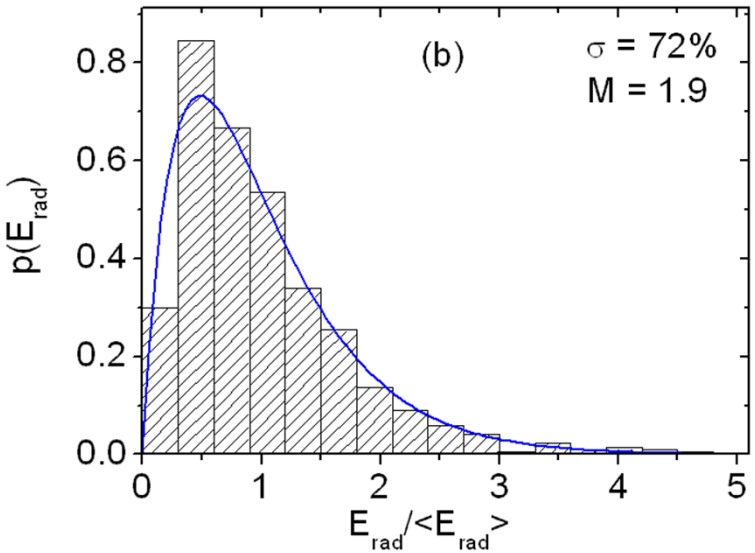


PRO:
- Rel. easy to use / analysis tools exist
- bunch resolved !

CON:
- not parasitic
- assumptions needed for reconstruction

Courtesy N. Gerasimova

Indirect PHOTON methods: Statistical fluctuations



PRO:
- rel. easy to use
- Relies on well tested theory

CON:
- (strictly)only valid for **linear regime**
- Only **lower limit for pulse dur.** in saturation
- remove machine-related fluctuations
- Spatial and temporal modes are mixed

$$\tau_{fel} = M\tau_{coh}$$

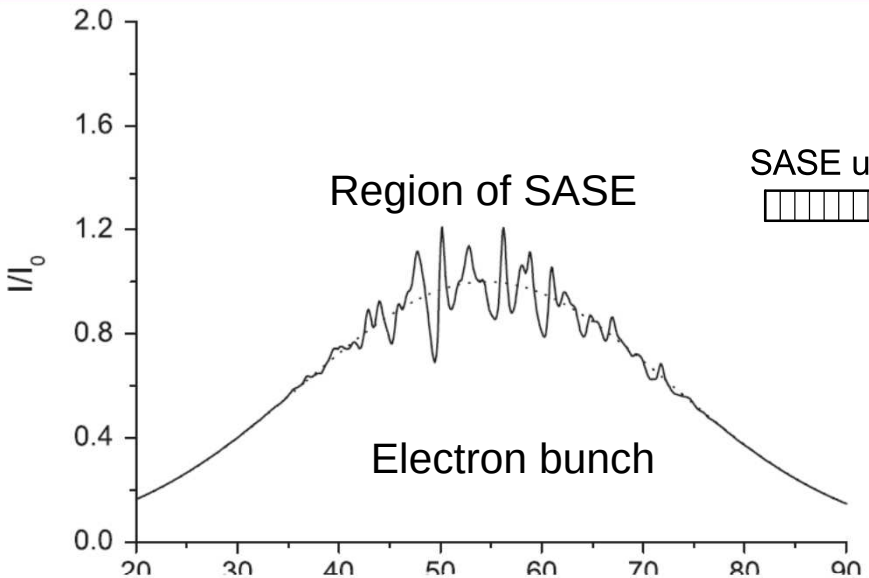
$$p(W) = \frac{M^M}{\Gamma(M)}\left(\frac{W}{<W>}\right)^{M-1}\frac{1}{<W>}\exp\left(-M\frac{W}{<W>}\right)$$

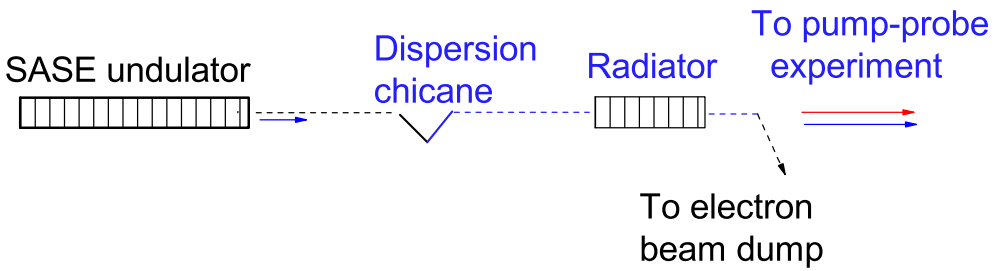
$$M^{-1} = \sigma_W^2 = <(W-<W>)^2> / <W>^2$$

Ackermann et al., Nature Photon.1(2007)336

Courtesy: E. Schneidmiller, M. Yurkov

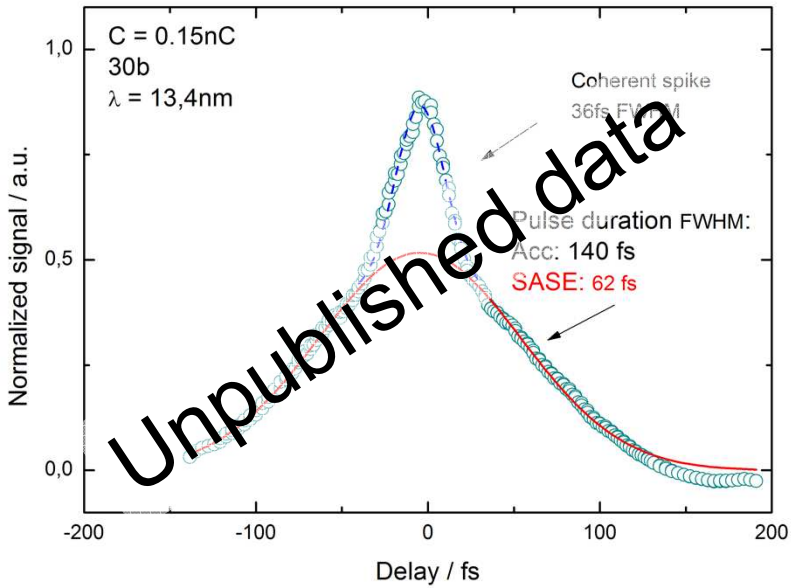
Indirect PHOTON methods: “afterburner”





- **Optical pulse has the same envelope as FEL pulse**

Saldin, Schneidmiller, Yurkov, Phys. Rev. ST-AB 13(2010)030701



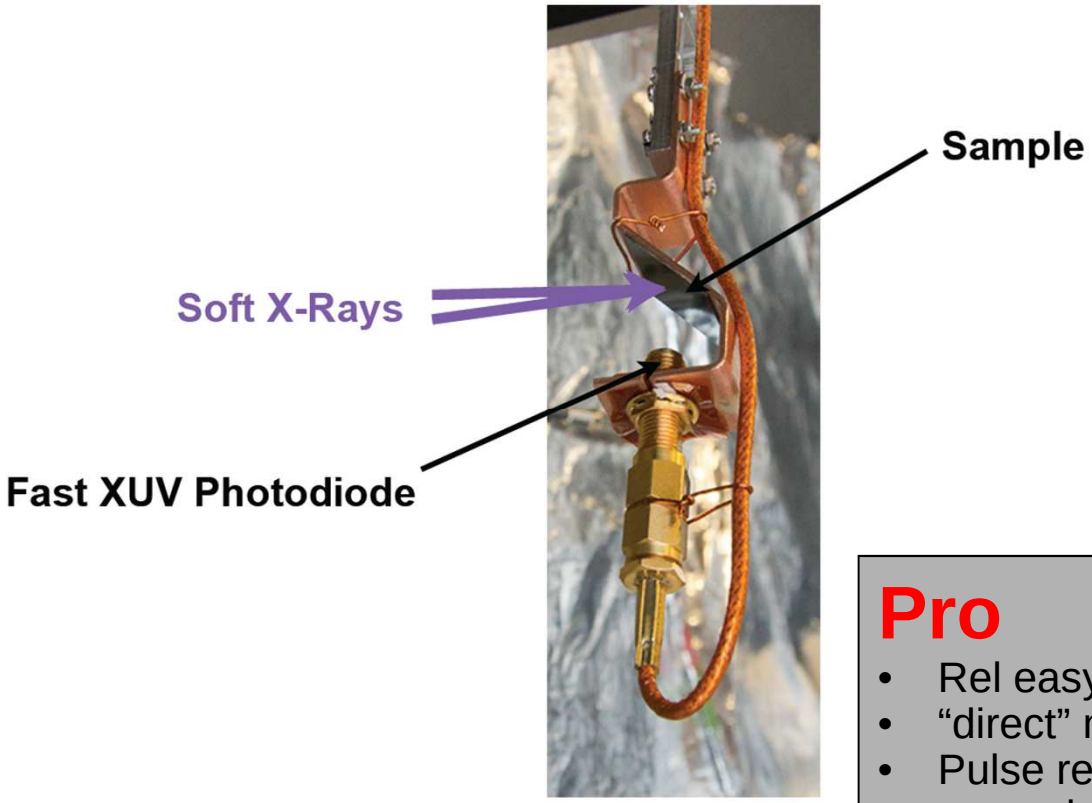
PRO:
- rel “simple to use”
- **in principle** single-shot pulse envelope
- **in principle** parasitic

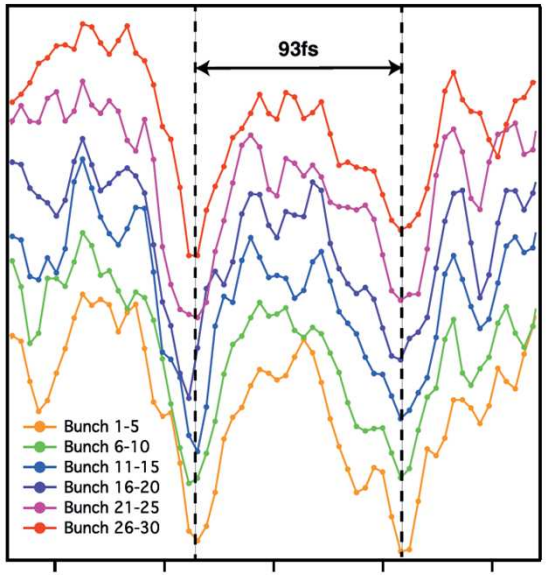
CON:
- not bunch resolved (so far)
- applicable parameter range to be determined

Direct methods

Direct PHOTON methods: XUV reflectivity

X-Ray Reflectivity of Si_3N_4





versität Hamburg

Hamburg, 03.04

Pro

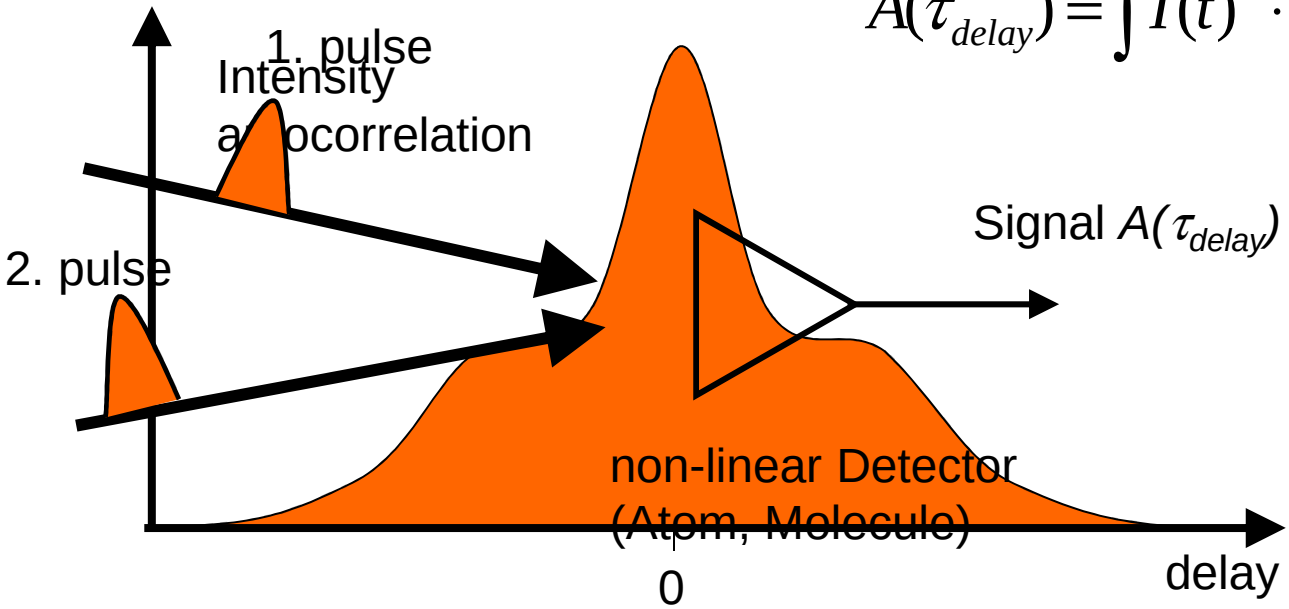
- Rel easy to implement
- “direct” measurement
- Pulse resolving – but needs averaging over several minutes.

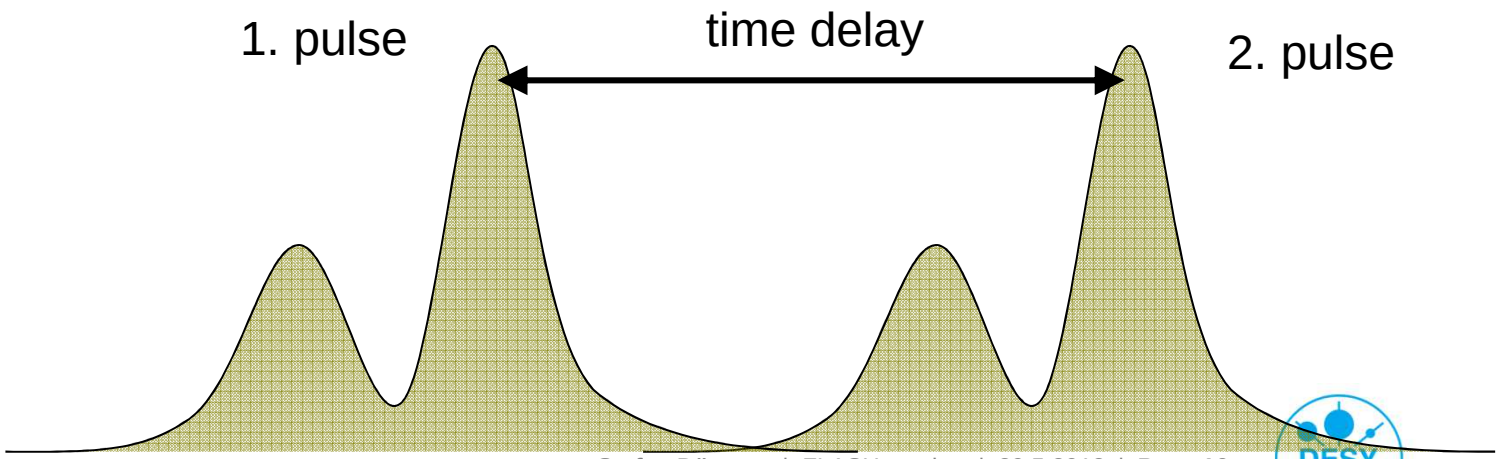
- **Con**

- Not parasitic (so far)
- Not really understood so far
- Applicable parameter range not known (so far)

Direct PHOTON methods: auto correlation

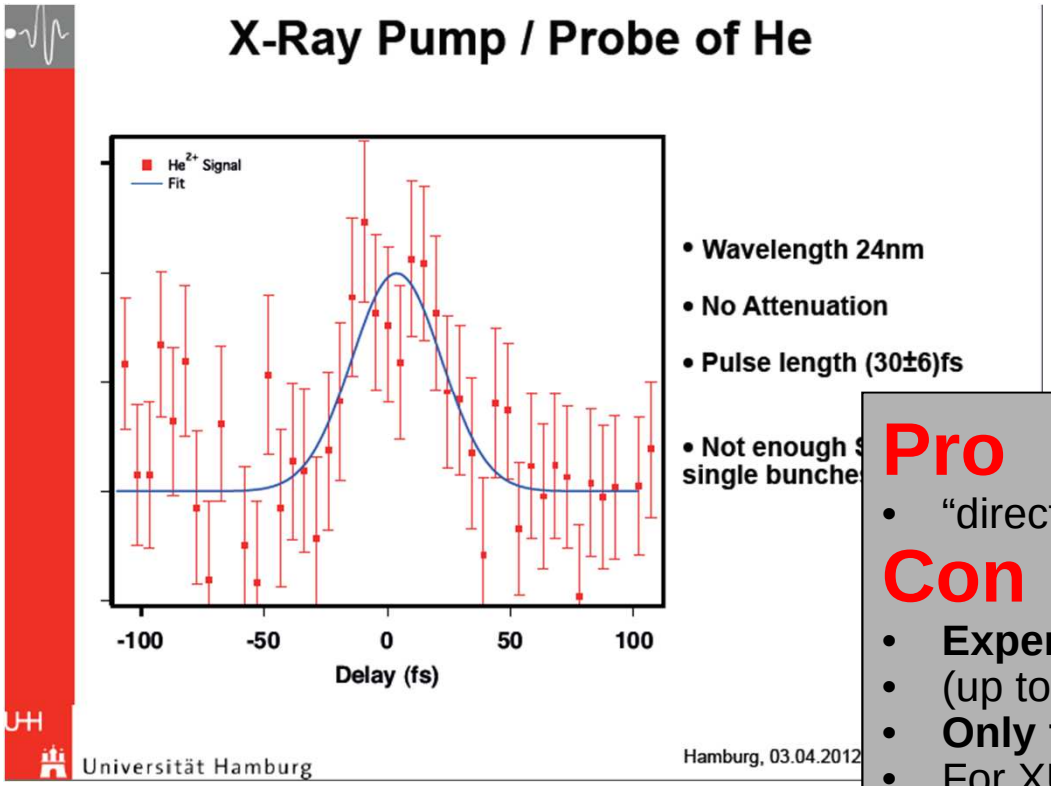
$$A(\tau_{delay}) = \int I(t)^n \cdot I^n(t - \tau_{delay})dt$$





Courtesy R. Moshammer

Direct PHOTON methods: auto correlation



Pro

- "direct" measurement (for known reactions)

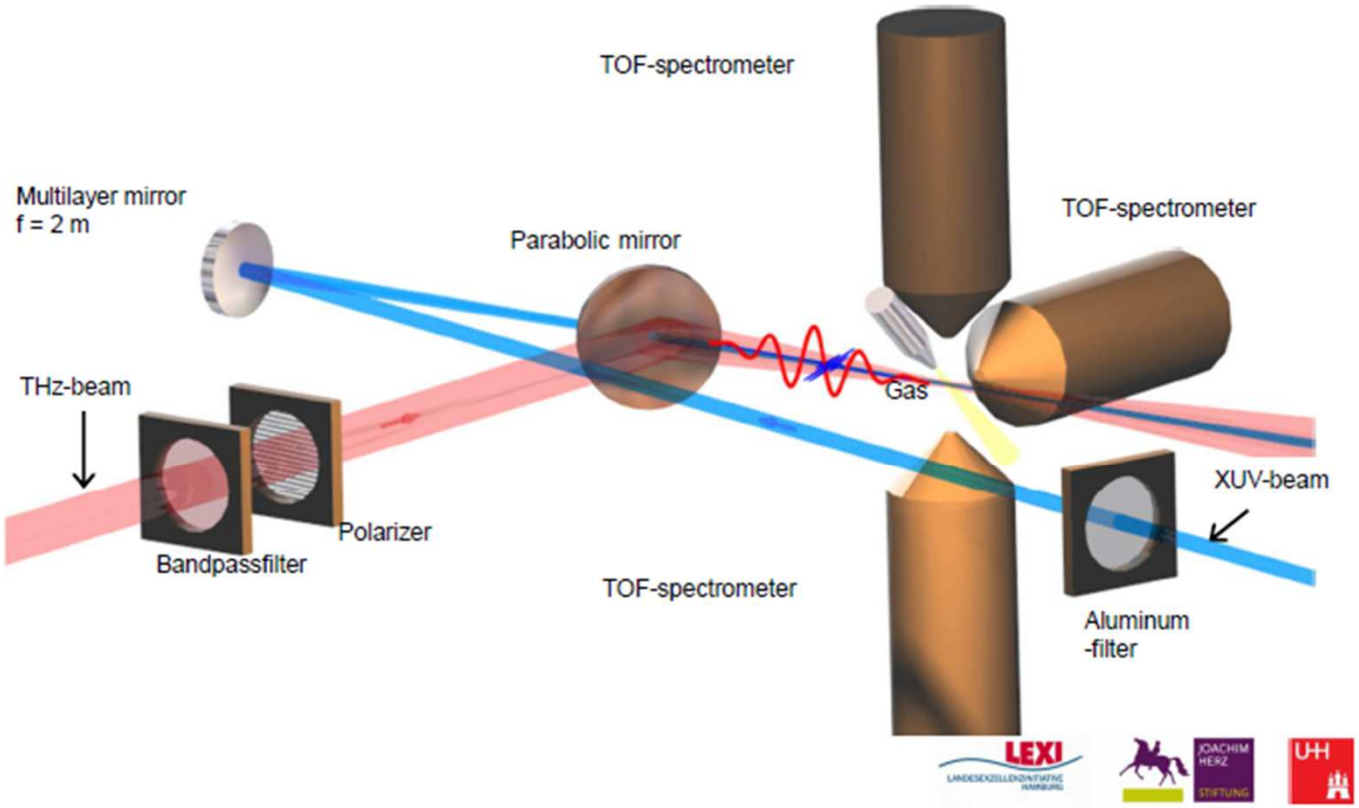
Con

- **Experimentally challenging** (takes long time)
- (up to now) averaging technique
- **Only for VUV well defined reactions. (< 25 nm)**
- For XUV several path lead to same ionization state
  - Simulations needed
  - "complete" diagnostics (e.g. reaction microscope)
- For XUV / x-ray: ionic targets ?

Direct PHOTON methods: THz streaking

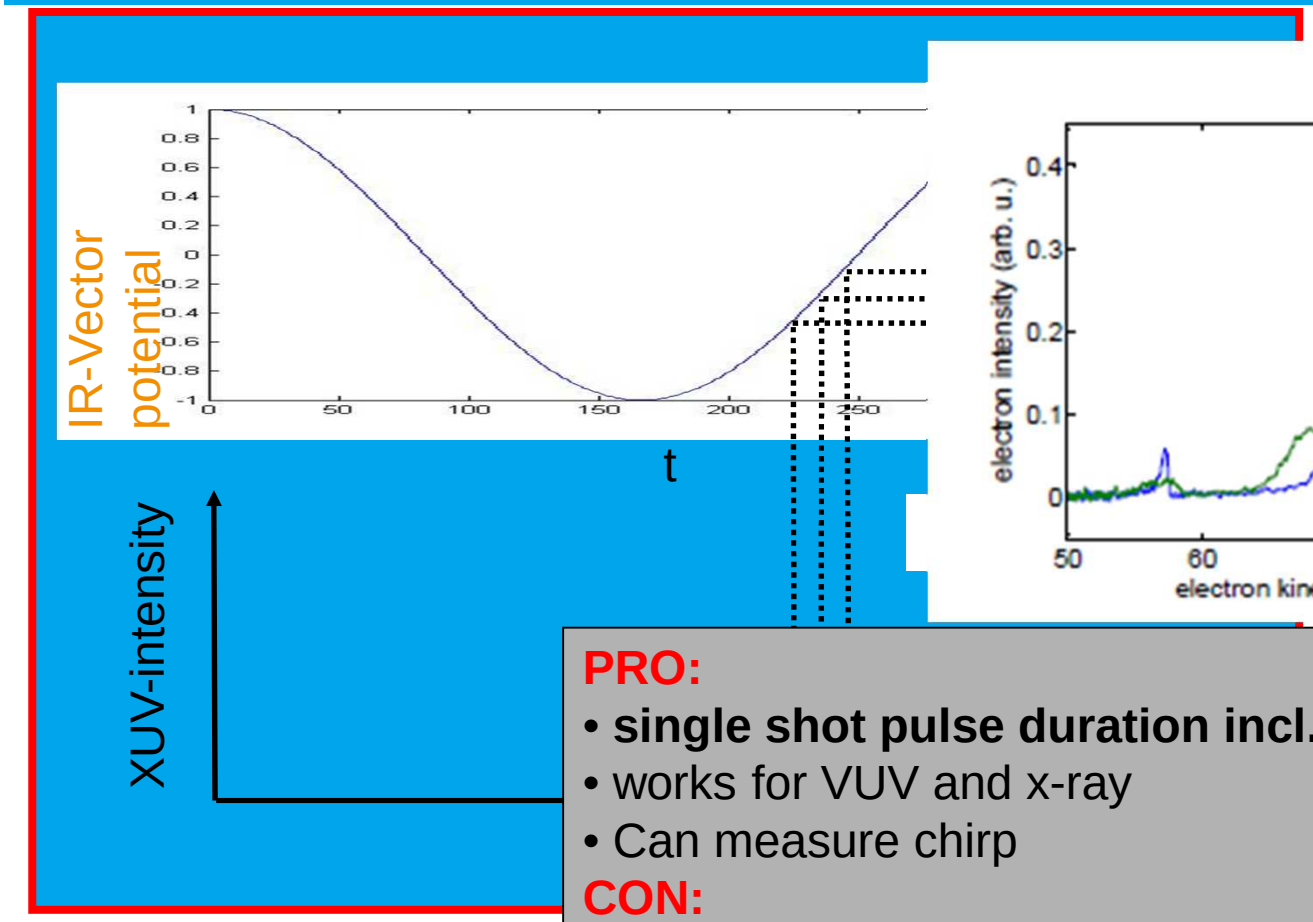
THz streak camera for femtosecond XUV pulse length measurement

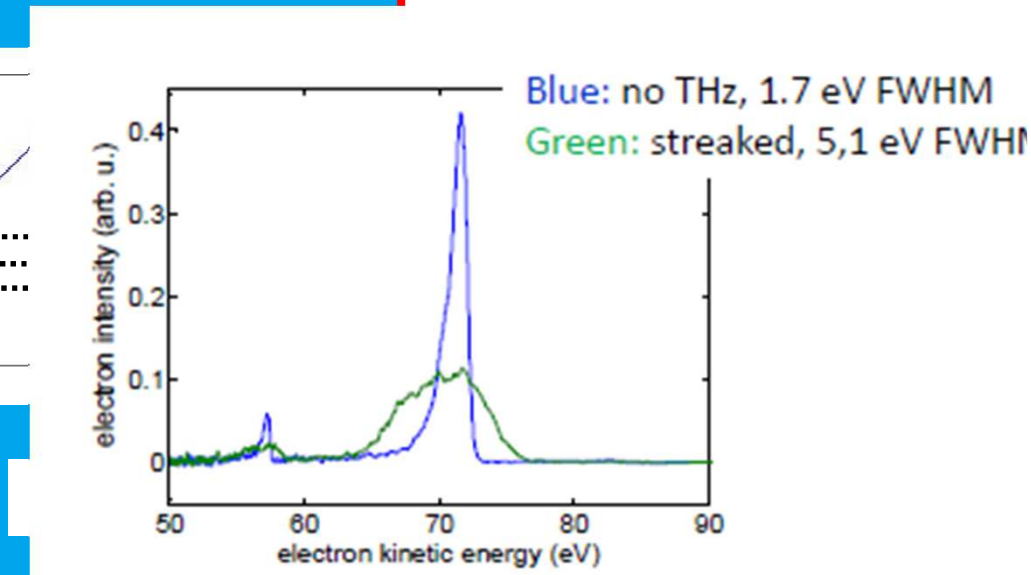
Experimental setup



Courtesy M. Drescher

Direct PHOTON methods: THz streaking





PRO:

- **single shot pulse duration incl. substructure !!**
- works for VUV and x-ray
- Can measure chirp

CON:

- experimentally demanding
- needs multilayer focusing - only for specific wavelength
- Problems with very low charge
- **for future: needs tailored diagnostic / sources**

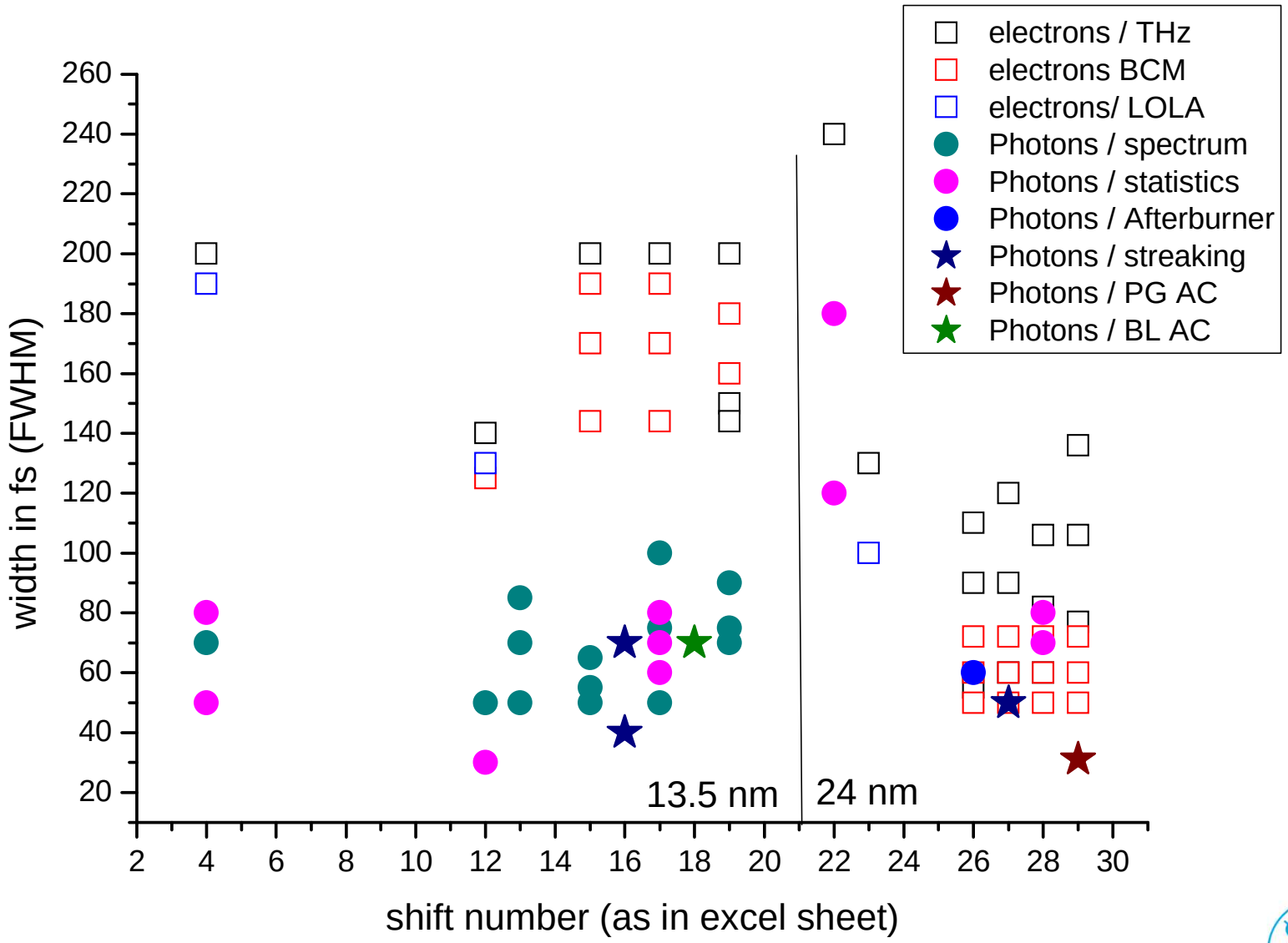
Courtesy M. Drescher

What was measured ???

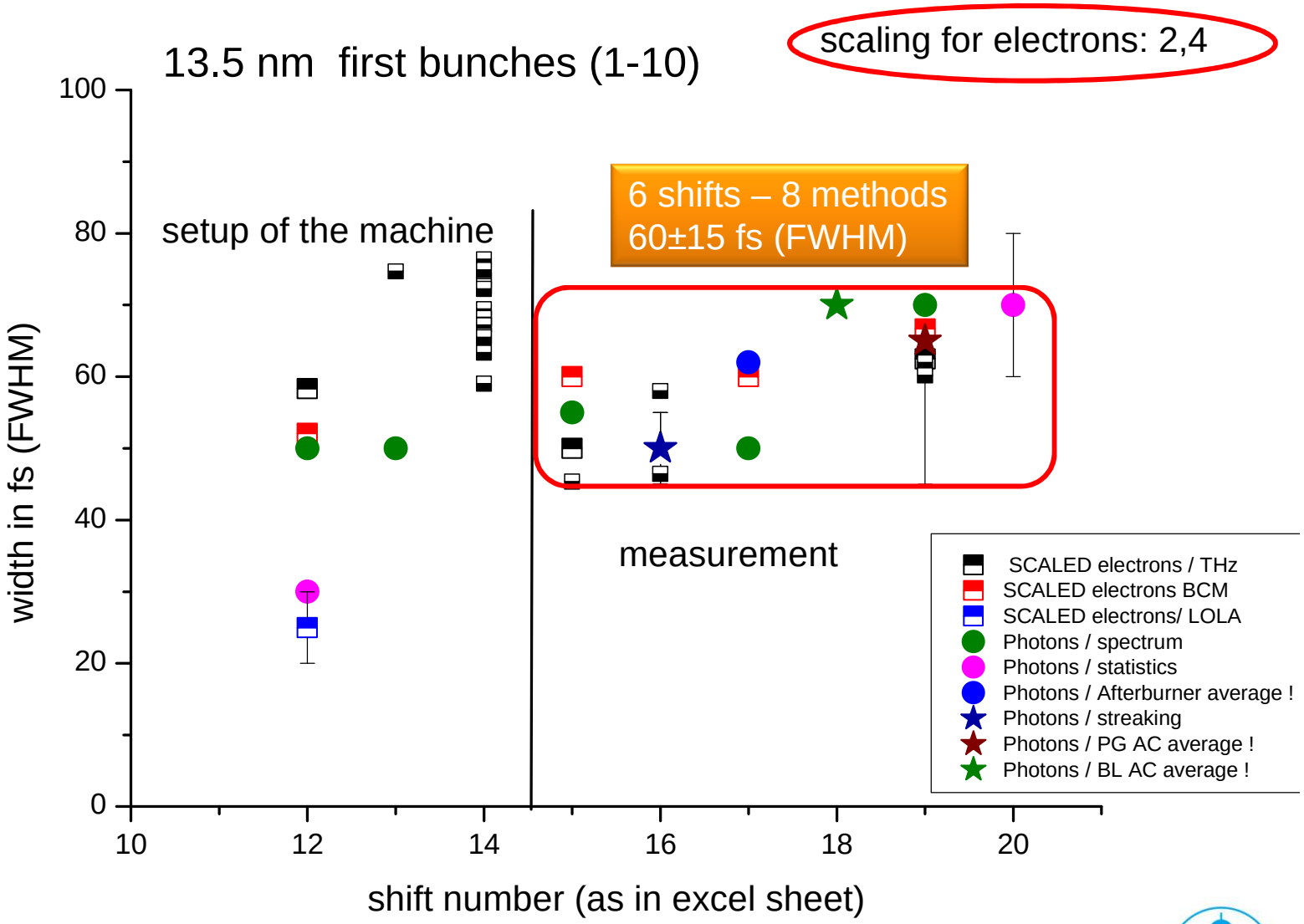
Machine parameters:

- **13.5 nm, 150 pC, ~ 50 µJ, 30 bunches, 250 kHz -> goal ~ 50 fs**
- **24.0 nm, 130 pC, ~ 50 µJ, 30 bunches, 250 kHz -> goal ~ 50 fs**

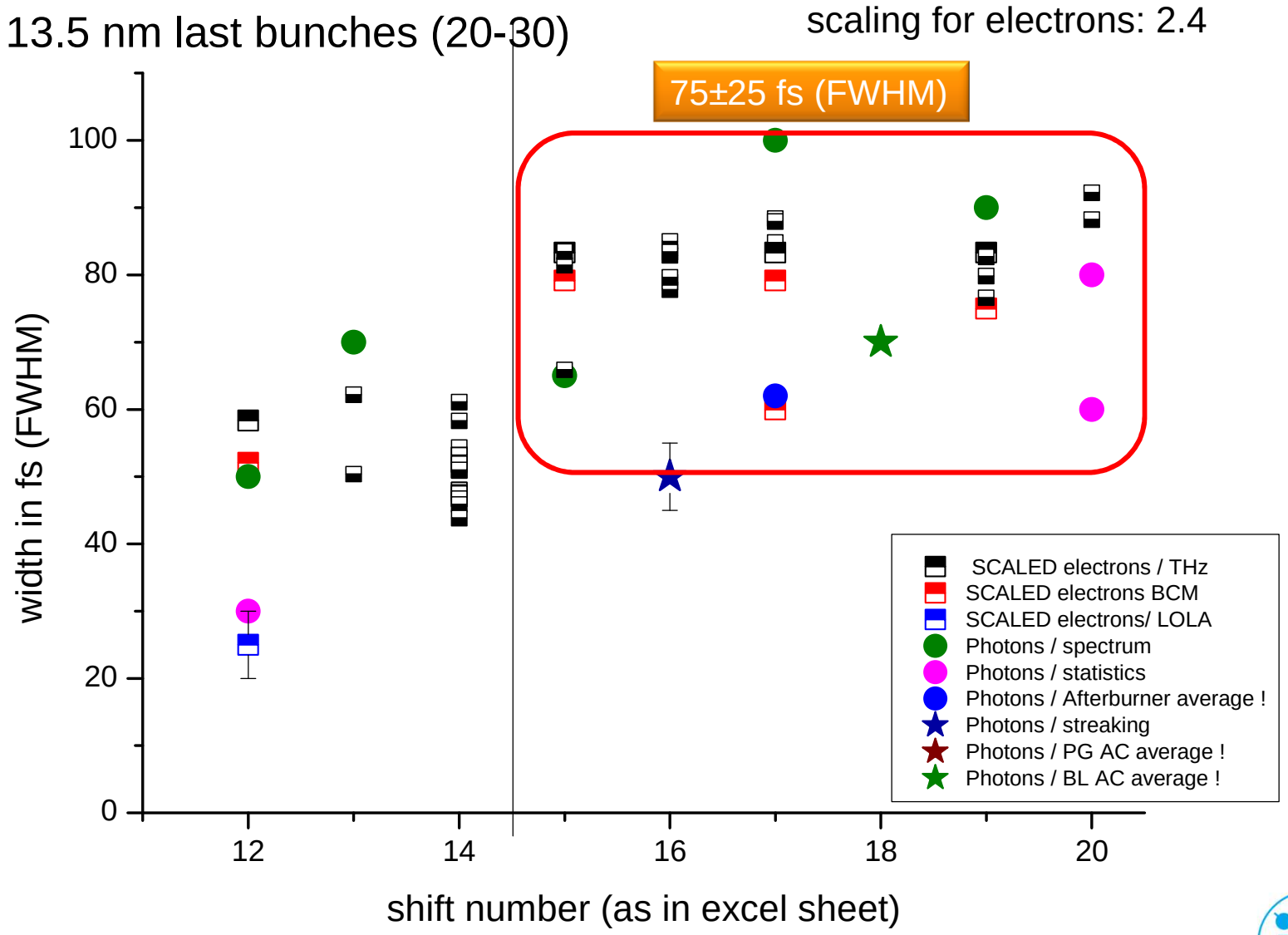
Collection of data – first look on the logbook data



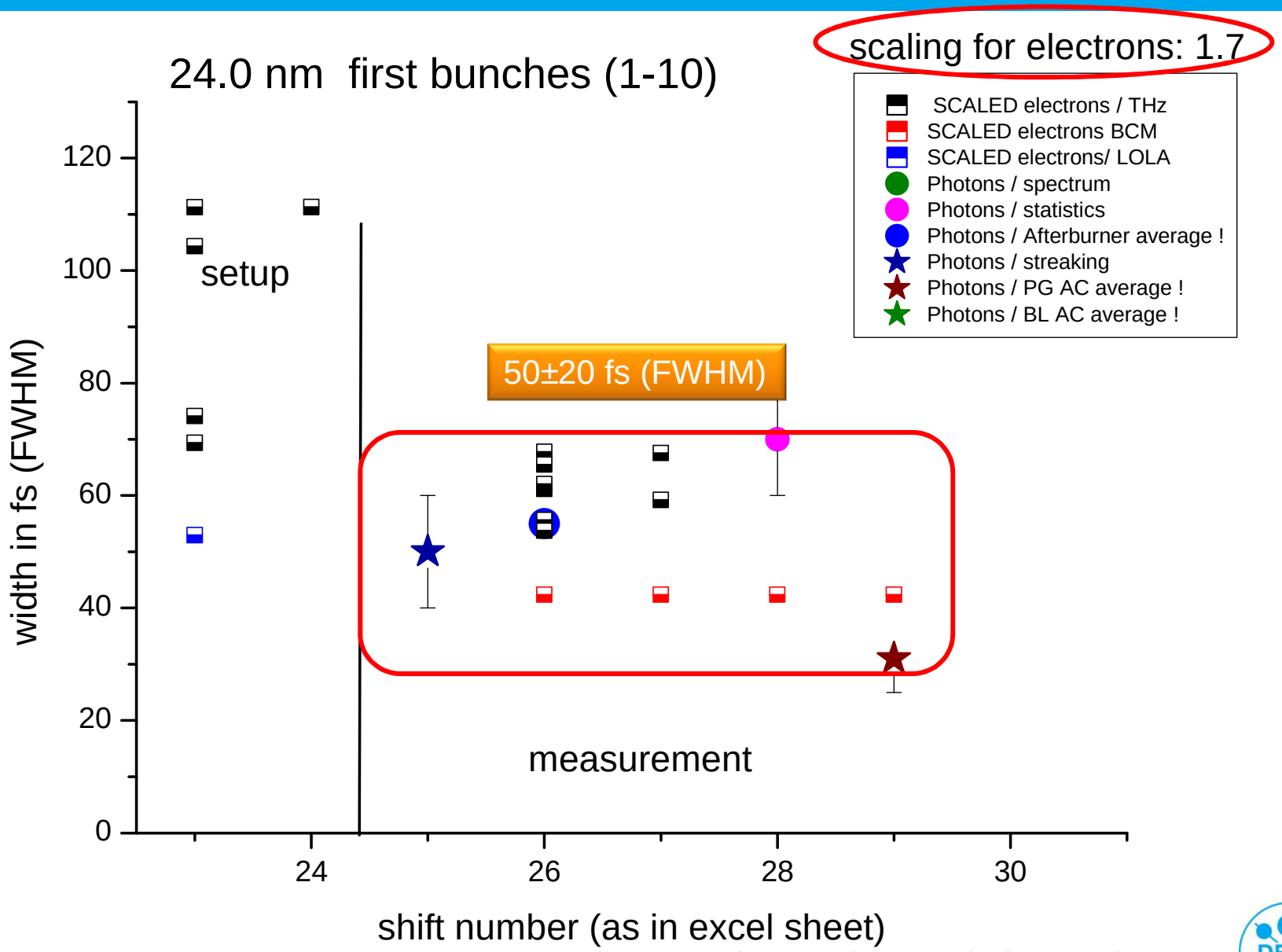
Results: 13.5 nm – first bunches



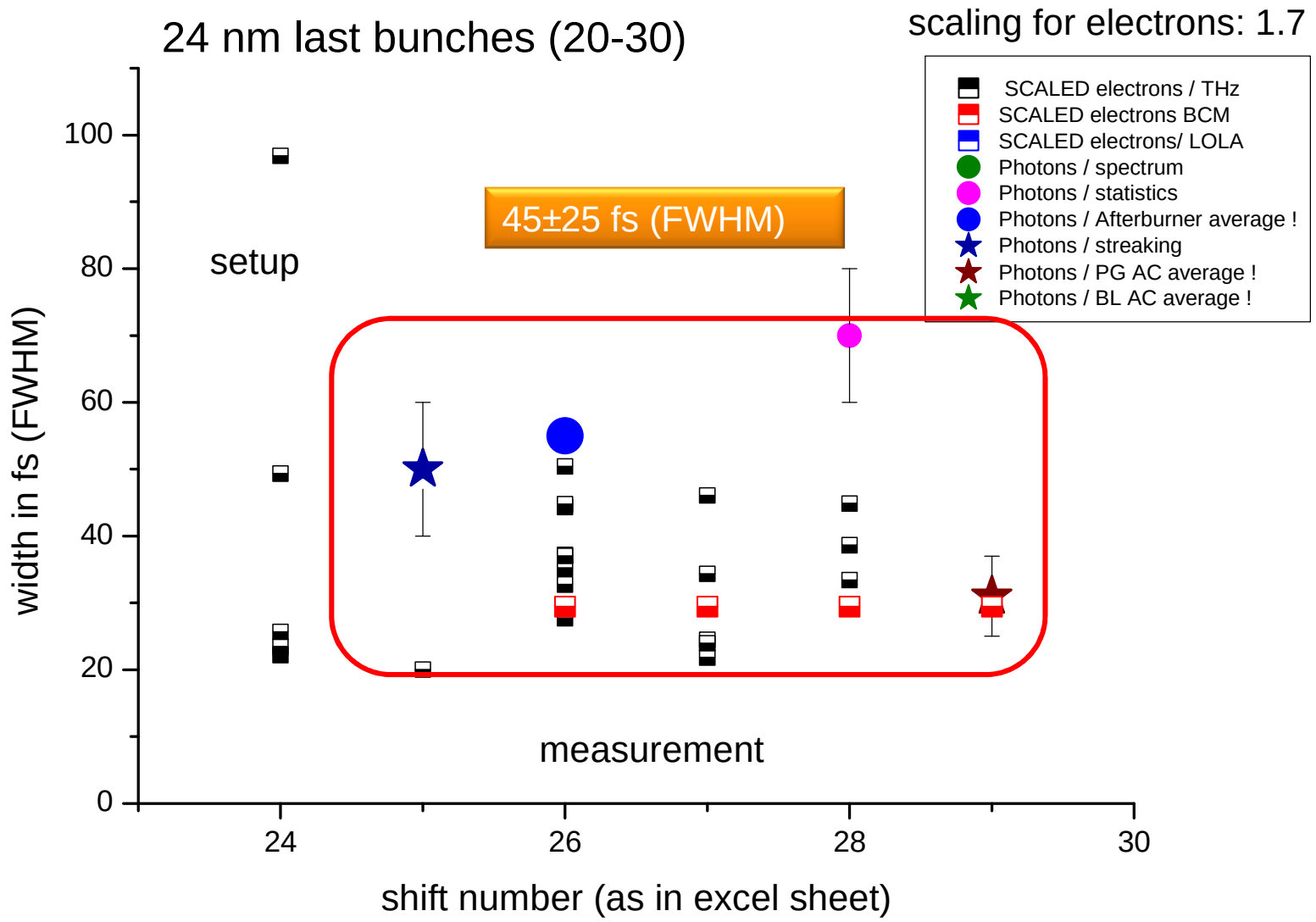
Results: 13.5 nm – last bunches



Results: 24.0 nm – first bunches



Results: 24.0 nm – last bunches



Things to consider - slippage

> "Ultra low" charge - but still "long" pulses (streaking) 28 nm

- 80pC BUT ~ 80 fs (~ 35µJ)

> Slippage @ long wavelength (28 nm)

- Saturation in middle of undulator (~ 500 periods – cycles in a
- 500 x 28 nm = 14 µm ~ **40 fs IN ADDITION to** electr se duration
- detectable in spectrum / statistics, afterburner ?

Reason for different scaling 13.5 nm and 24 nm ???

Goals … what do we have …

1. Calibrate “indirect” methods (filled circles) against “direct” ones (filled stars)

- Reasonable agreement …
- Max 25 fs error bars (over several shifts) **including machine changes !**

2. How good is the correlation between electron diagnostics (open squares) and indirect (direct) methods

- Overall good correlation
- Different (empirical) scaling for 13 nm and 24 nm (2.4 and 1.7)
- Slippage … ?
- **Need for more data to compare**

3. Find out advantages / disadvantages of different methods

- Direct methods are all complicated
- **Push indirect methods to become “online diagnostic tools”**

4. Define recipe how to tune short pulses

- … Siggi and the “machine” …

Outlook

- Push **indirect PHOTON methods** to be (more) “operator friendly” ***operating hopefully soon***
- Develop and test (cross-calibrate) electron bunch length diagnostics
- Continue with such campaigns – collect data / knowledge
- Develop direct methods – ***on a medium term scale***
  - Laser-based THz *streaking* as (future) pulse length monitor
  - Keep eyes open for novel techniques

Current user time again stresses the need for “online” pulse length diagnostics !!!

Thanks

to all participants