XUV pulse duration @ FLASH

85µm with bandpass filter

Stefan Düsterer for the “pulse duration team”
Importance of the pulse duration

- FEL characterization
- Non-linear physics
- Ultra-fast dynamics
  - 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?

SIMULATIONS !!!

X-ray long

X-ray short

XUV long

XUV short
Overview: pulse durations 2007-2012

- Charge is represented by the dot size.
- Charge: 0.5 nC and 100 pC.
- Pulseduration with ACC39 and before ACC39.

Graph showing wavelength [nm] vs. pulseduration with ACC39 [fs (FWHM)].
### Schedule for the short pulse studies Feb / Mar 2012

<table>
<thead>
<tr>
<th>Date</th>
<th>Day</th>
<th>Morning Shift</th>
<th>Afternoon Shift</th>
<th>Night Shift</th>
</tr>
</thead>
<tbody>
<tr>
<td>27.2.12</td>
<td>Mo</td>
<td>maintenance</td>
<td>recover from 9mA startup</td>
<td>Startup 13.5 ± 0.1 nm, 250 kHz, as many pulses as possible</td>
</tr>
<tr>
<td>28.2.12</td>
<td>Tu</td>
<td>Startup 13.5 ± 0.1 nm, 250 kHz, (BL2 AC, Parasitic)</td>
<td>PREP EXP THz streak BL3 (13.5 nm)</td>
<td>PREP EXP Afterburner (13.5 nm)</td>
</tr>
<tr>
<td>29.2.12</td>
<td>We</td>
<td>PREP EXP AC BL2 (Afterb, Parasitic?) (13.5 nm)</td>
<td>PREP EXP PG2 setup (13.5 nm)</td>
<td>PREP EXP PG2 AC (13.5 nm)</td>
</tr>
<tr>
<td>1.3.12</td>
<td>Th</td>
<td>PREP EXP Reserve</td>
<td>setup short pulse 13.5 ± 0.1 nm, 250 kHz, as many pulses as possible</td>
<td>setup short pulse 13.5 nm, 250 kHz, as many pulses as possible</td>
</tr>
<tr>
<td>2.3.12</td>
<td>Fr</td>
<td>Spectr PG2 / statistics</td>
<td>EXP PG2 AC (13.5 nm)</td>
<td>EXP Afterburner (13.5 nm)</td>
</tr>
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<td>3.3.12</td>
<td>Sa</td>
<td>Spectr PG2 / statistics</td>
<td>EXP BL2 AC (13.5 nm)</td>
<td>EXP Reserve</td>
</tr>
<tr>
<td>4.3.12</td>
<td>Su</td>
<td>setup short pulse 24.0 ± 0.2 nm, 250 kHz, as many pulses as possible</td>
<td>setup short pulse 24.0 ± 0.2 nm, 250 kHz, as many pulses as possible</td>
<td>setup short pulse 24.0 ± 0.2 nm, 250 kHz, as many pulses as possible</td>
</tr>
<tr>
<td>5.3.12</td>
<td>Mo</td>
<td>Spectr PG2 / statistics</td>
<td>EXP PG2 AC (24.0 nm)</td>
<td>EXP Afterburner (24.0 nm)</td>
</tr>
<tr>
<td>6.3.12</td>
<td>Tu</td>
<td>Spectr PG2 / statistics</td>
<td>EXP BL2 AC (24.0 nm)</td>
<td>EXP Reserve</td>
</tr>
<tr>
<td>7.3.12</td>
<td>We</td>
<td>Maintenance</td>
<td>EXP Reserve</td>
<td>EXP Reserve</td>
</tr>
<tr>
<td>8.3.12</td>
<td>Th</td>
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</tr>
</tbody>
</table>

**Schedule ... what was done**

Last update: 15.12.2011

- **morning shift** (7:00-15:00)
- **afternoon shift** (15:00-23:00)
- **night shift** (23:00-7:00)
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
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**

\[ \tau_{\text{rel}} = M \tau_{\text{coh}} \]

**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

\[
\tau_{f el} = M \tau_{coh}
\]

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

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


Courtesy: E. Schneidmiller, M. Yurkov
Indirect PHOTON methods: “afterburner”

- Optical pulse has the same envelope as FEL pulse

**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


Unpublished data
Direct methods
Direct PHOTON methods: XUV reflectivity

X-Ray Reflectivity of Si$_3$N$_4$

**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

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

1. pulse

Intensity autocorrelation

2. pulse

Delay

Signal \( A(\tau_{\text{delay}}) \)

non-linear Detector (Atom, Molecule)

1. pulse

Time delay

2. pulse

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

Experimental setup

THz streak camera for femtosecond XUV pulse length measurement

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

- electrons / THz
- electrons BCM
- electrons / LOLA
- Electrons / statistics
- Electrons / Afterburner
- Photons / spectrum
- Photons / Afterburner
- Photons / streaking
- Photons / PG AC
- Photons / BL AC

- Width in fs (FWHM)
- Shift number (as in excel sheet)

Values:
- 13.5 nm 24 nm
**Results: 13.5 nm – first bunches**

- **13.5 nm first bunches (1-10)**

- **scaling for electrons: 2.4**

- **setup of the machine**

- **6 shifts – 8 methods**
  - 60±15 fs (FWHM)

- **measurement**

- Graph showing width in fs (FWHM) vs. shift number (as in excel sheet)

- Data points categorized by:
  - SCALED electrons / THz
  - SCALED electrons BCM
  - SCALED electrons / LOLA
  - Photons / spectrum
  - Photons / statistics
  - Photons / Afterburner average!
  - Photons / streaking
  - Photons / PG AC average!
  - Photons / BL AC average!
Results: 13.5 nm – last bunches

13.5 nm last bunches (20-30)

scaling for electrons: 2.4

width in fs (FWHM)

shift number (as in excel sheet)

75±25 fs (FWHM)

scaling for electrons: 2.4

13.5 nm last bunches (20-30)
**Results: 24.0 nm – first bunches**

- Scaling for electrons: $1.7$

**Graph: 24.0 nm first bunches (1-10)**

- **Setup**
  - SCALED electrons / THz
  - SCALED electrons BCM
  - SCALED electrons / LOLA
  - Photons / spectrum
  - Photons / statistics
  - Photons / Afterburner average!
  - Photons / streaking
  - Photons / PG AC average!
  - Photons / BL AC average!

**Measurement**

- Width in fs (FWHM) 50±20 fs (FWHM)

**Shift number (as in excel sheet)**

- 24
- 26
- 28
- 30
Results: 24.0 nm – last bunches

24 nm last bunches (20-30)

setup

45±25 fs (FWHM)

measurement

width in fs (FWHM)

shift number (as in excel sheet)

scaling for electrons: 1.7

24 26 28 30

0 20 40 60 80 100

SACLED electrons / THz
SACLED electrons BCM
SACLED electrons/ LOLA
Photons / spectrum
Photons / statistics
Photons / Afterburner average
Photons / streaking
Photons / PG AC average
Photons / BL AC average

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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 period)
  - 500 x 28 nm = 14 µm ~ 40 fs IN ADDITION to electron pulse 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