Synchronization and pump-probe experiments

by
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Outline

- Pump-probe infrastructure
  - VUV + VUV
  - VUV + optical
- Temporal overlap and jitter
- As example: the “pump-probe chamber”
Time-resolved measurements at the FEL

fs-excitation AND fs-probe is needed

VUV-VUV experiments

VUV-optical experiments

- Many interesting processes are triggered by visible rather than by VUV light
- The visible laser is much more flexible
  - larger time-delay (ns ...)
  - variable pulse length / chirping
  - change color, polarization ...

Problem:
temporal overlap and jitter between the two independent sources
Synchronization and pump-probe experiments at the VUV-FEL User Facility

**Principal setup of the auto-correlator**

top view - fixed arm

![Diagram of principal setup of the auto-correlator](image)

- **Delay range:** -3...25 ps / 1 fs resolution
- **Translation stage:** <1 µm / 1 µrad angle deviation
- **Angle adjustment:** 1 µrad

**Side view - variable arm**

![Diagram of side view - variable arm](image)

beam splitter

detection
• Technical design completed
• Installed in beamline ~ end 2005
Layout of the experimental hall
Optical delay lines

Laser hutch

EOS

Streak camera

Beamline delays

Optical beamline
Optical delay lines

- Dielectric mirrors reflect
  - 760 - 850 nm TiSa (150 fs -> 10 ps)
  - AND 524 nm Nd:YLF (10 ps)
- 4 ns motorized delay with 20 fs resolution
- 7 ns manual delay (rough timing)
- 14 m Delay for streak camera measurements
- Delay for Nd:YLF
- Beam position / angle monitors
- Automatic correction for beam deflections
- Collinear alignment laser (HeNe)
- Variable polarization
- Variable laser pulse energy
(planned) Geometry of the optical beamline

- FEL and opt. laser are not collinearly delivered
- Evacuated beamline (10⁻⁶ mbar / independent of FEL vacuum)
  - Beam height 1.5 m (10 cm below FEL)
  - Beamline ends (window flange)
    - 0.5 m up-stream the FEL focal spot
    - 0.5 m offset sideways (beamline dependent)
  - Coupling the opt. laser into the FEL interaction chamber has to be taken care of by the experiment!
- Relay imaging of laser -> high stability
- ≈ 10 mm (FWHM) laser beam diameter
Temporal overlap

- The time difference between the optical laser pulse and the FEL at the **EXIT** of the laser beamline can be provided (and adjusted) with ~200 ps accuracy.

- The fine adjustment of the **temporal overlap (< 200 ps)** has to be performed **by the actual experiment** (using streak camera, using the actual experiment ...)

**The 4 ns optical delay line is available!**
Timing signals

- Trigger
  - for each pulse train (single shot, 1, 5 or 10 Hz)
  - trigger max. 20 ms before FEL pulse train
  - Accuracy ± 1 ns

- Time stamps for macro bunches (→ T. Nunez)

- Frequencies synchronized to the accelerator
  (for streak cameras, lasers ...)
  - 9. MHz
  - 81. MHz
  - 108. MHz
  - 1300. MHz
Jitter between optical laser and FEL

Systematic drifts within the macropulse:
~300 fs

Changes from macropulse to macropulse:
~600 fs

Longterm drifts:
> ps

The pulses are NOT drawn to scale!
Jitter ...

„ideal“ experiment

„Real“ FEL experiment
binning of the data

knowing the arrival time of each FEL pulse

one can correct the measured data
ways to measure the jitter ...

• use dipole radiation + streak camera (DESY)
  or optical correlation
  (J. Larsson / Lund)

• use Electro-Optical Sampling (EOS) (DESY/ SPPS-SLAC)

• use sidebands in photo-electron spectrum
  (M. Drescher / Bielefeld)
Synchronization and pump-probe experiments at the VUV-FEL User Facility

**Dipole radiation + laser**

- Injector laser
- Linac
- Clystron
- Main oscillator
- Dipole radiation + laser
- Bending magnet
- Visible synchrotron radiation
- Electrons
- Linac undulator
- Electron pulse compression
- Pump-probe laser
- Streak Camera
  - Slow feedback
  - Goal: drift < ps / h
- Optical correlation
  - Pulse to pulse diagnostic

**Graph:**
- Lund Laser center
- Time shift between independent light pulses, ps
- Delay stage displacement, mm
- Relative SFM intensity, arb. unit
- ~340 fsec
Electro Optical Sampling at the VUV-FEL

pump-probe fs-laser for FEL-experiments

Realized with < 50 fs precision At SPPS / SLAC
Superposition of visible and VUV pulse in a noble gas jet

Sidebands (intensity prop. to intensity of IR)

Electron spectrometer

Visible fs laser pulse

\( h\omega_{ir} = 1.55 \text{eV} \)

15.76 eV

Ar(IP)

M. Meyer, P.O’Keeffe
LURE
Single-shot FEL-IR cross correlator

visible strong fs- laser pulse

FEL SASE pulse

Gas jet

- resolution ~ 30 fs
- Parasitic – does not destroy the FEL pulse

(1D) imaging electron spectrometer
## Jitter diagnostics

<table>
<thead>
<tr>
<th>Method</th>
<th>Laser power</th>
<th>Rep. rate</th>
<th>Source</th>
<th>Planned resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dipole rad. + Streak camera</td>
<td>Parasitic</td>
<td>Bunch to bunch (10 Hz)</td>
<td>Electrons</td>
<td>&lt; 300 fs</td>
</tr>
<tr>
<td>Dipole rad. + Opt. correlation</td>
<td>&gt; 50 % of laser power</td>
<td>Pulse to pulse (1 MHz)</td>
<td>Electrons</td>
<td>&lt; 50 fs</td>
</tr>
<tr>
<td>EOS</td>
<td>Parasitic</td>
<td>Pulse to pulse (1 MHz)</td>
<td>Electrons</td>
<td>&lt; 50 fs</td>
</tr>
<tr>
<td>Photoelectrons</td>
<td>10 µJ / pulse</td>
<td>Pulse to pulse (1 MHz)</td>
<td>FEL Photons</td>
<td>&lt; 30 fs</td>
</tr>
</tbody>
</table>

All diagnostics are experiments themselves
Tests are promising - detailed operating schedule cannot (yet) be given
The pump-probe chamber

- Designed for collinear pump-probe experiments in gas phase - photoelectron TOF spectroscopy (M. Meyer, LURE)
- UHV compatible (1600 l/s turbo)
- Technical design completed
- Currently constructed in DESY machine shop
The pump-probe chamber

- Align chamber to FEL
  -> all degrees of freedom

- Various (redundant) diagnostics for FEL and optical laser for focal region (offline)

- Extension
  - Damage / stray electrons
    (FEL still focused at end of chamber)
  - **Online** diagnostic
    (4 quadrant thermopile)
  - Docking for streak camera
    (+ scatterer)

Available for user experiments (if announced in time)
Optical setup outside the chamber

- **telescope:**
  - adjust beam diameter
  - move focus (z)
  - correct for chromatic aberration of relay imaging
- **motorized mirrors** - move focus (x,y)
- **Generation of higher harmonics**
  (optical + VUV streak camera)
- **position/angle detection**
- **pulse duration monitor**
Focusing the laser beam

- **Focusing**: using off-axis parabola with hole
- Moving the focus in vacuum **from outside**
  - transverse direction: change angle
  - longitudinal: change divergence (delay is not altered)

Beam at parabola

Focused intensity: $> 10^{13}$ W/cm$^2$
Diagnostics
**Observation panel**

Mounted on motorized manipulator + encoder with 1 µm resolution

**Observed beams:**
- alignment laser for FEL
- FEL (attenuated)
- alignment laser for TiSa
- TiSa

scattering image of alignment lasers, TiSa and FEL

20x enlarged images of optical lasers

knife edge scan of FEL and TiSa
Conclusion

- VUV-VUV auto-correlator device will be build by BESSY (in beamline ~ end 2005)

- Optical beamlines will be installed together with the FEL beamlines
- light path from optical beamline to experiment has to be constructed by the experiment

- The temporal overlap (< 200 ps) has to be measured by each experiment itself
- Experiments for jitter diagnostic with sub 50 fs are on the way (hopefully available end of 2005)

- Pump-probe chamber (including diagnostics) tested and ready for photoelectron measurements (M. Meyer) April 2005
- Available for user pump-probe experiments
The end
Schematic EOS setup

- fs-laser oscillator (50 fs, 3 nJ, 800 nm)
- Optical diode
- Grating compressor: compensation for first order dispersion
- Pulse shaper: Higher order compensation
- 150 m long glass fiber to transport laser pulses into the accelerator tunnel
- Feedback signal for changes in fiber length
- Amplifier
- Amplified laser beam (150 fs, 100 µJ, 800 nm)
- 30 m to experiment
- FEL beam
- Undulator
- ZnTe crystal = actual EO-sampling
- 150 m to experiment

Compressor + pulse shaper + 150 m glass fiber together have no dispersion: laser pulses after the fiber are short again.

- CCD
- Pockels cell:
  - Pulses needed for EOS can pass
  - the others are reflected providing signal for the fiber length stabilization

FEL beam
Expanding Linac
Electrons

Deviations from the nominal time coincide with the presence of a feedback signal from the fiber length compensation system.