Jitter-free time resolved resonant CDI experiments using two-color FEL pulses generated by the same electron bunch

Marco Zangrando, Flavio Capotondi & FERMI team

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OUTLINE
of the talk

- FERMI@Elettra
- Photon Beam Transport System (PADReS)
- DiProI endstation
- Two-color experiment: source peculiarities
  PRESTO + KAOS contribution results
- Discussion and perspectives
- Acknowledgments
Parameters:

- FEL-1: 86-20 nm
- FEL-2: 20-4 nm
- Pulse length: <100 fs FWHM
- Bandwidth: 20-40 meV rms
- Polarization: LH-LV-RC-LC
- λ fluctuation: within BW

Beamlines:

- **DiProI**: Diffraction and Projection Imaging  
  (M. Kiskinova, F. Capotondi)
- **LDM**: Low Density Matter  
  (C. Callegari)
- **EIS-TIMEX**: Elastic and Inelastic Scattering  
  (C. Masciovecchio, E. Principi)

Open to external users since 12/2012
2nd external users Run: scheduled
3rd call for users: deadline in 10/2013
FEL-2 open to users in late 2014
Motivations

- Pump-probe techniques to study non-equilibrium transient states of matter → extended to HHG- and FEL-generated pulses (either X-ray or synchronized optical and X-ray pulses pairs)
- Advantage of XUV/X-ray photons: they can stimulate and probe electronic transitions from core levels, providing chemical selectivity as well
- Ultrabright FELs overcome the pulse intensity and wavelength tunability limitations of HHG sources

Requests

- Generate two FEL pulses with precisely controlled time delay, wavelength and intensity ratio
- Perform proof-of-principle XUV-pump / XUV-probe experiment that examines the dynamics of a thin-metal layer structure exposed to high intensity XUV excitation
Online (non invasive)  
Shot-to-Shot  
~97% of FEL \rightarrow beamlines  
1% of FEL \rightarrow YAG + triggered CCD  
Resolving Power \sim 15000 @32.5nm (2.5meV)  
Available information: wavelength, BW, spectral content  

FEL photon energy  
38.19eV \pm 1.1meV (rms)  
FEL bandwidth  
22.5meV  
Spectral purity  
5.9e-4
PHOTON TRANSPORT SYSTEM

KB focusing mirrors

KAOS (Kirpatrick-Baez Active Optics System)
Bendable plane mirrors in Kirkpatrick-Baez configuration

Focal length: 1.2-1.75 m
Incidence angle: 2°

Best spot 10 µm x 13.5 µm

Wave-front sensor
Loaned from DESY

WFS measurements in collaboration with:
L. Raimondi and PADReS
DESY + Laser-Lab. Gottingen
Image Optics + CEA and LOA
DiProI ENDSTATION
Core capabilities

**Forward scattering scheme**
- Single shot FEL pulse diffraction experiment and P&P experiment
- Magnetic Res-scattering
  - In collaboration with G. Grübel, C. Gutt (DESY)
  - J. Lüning (Univ. Paris)

**Installed on dedicated FERMI beamline:** June 2011
**Open to User Experiments:** December 2012

**Versatile modular construction allowing exchange and/or adding new components**

**Particle injector**
- Aerosol particle injector coupled to TOF.
- Developed by J. Hajdu et al.
- Un. Uppsala
- Commissioning in 2013

**Instrument design in collaboration with:**
- H.N. Chapman, S. Bajt, H. Fleckenstein, J. Schulz, J. Hajdu, M. Bogan

**Examples of experiments**

- M. Bogan et al. NanoLett. 2009, AST 2010

**Device configurations**
- Indirect
- Direct
- Off axis
- Magnetic Direct and Off axis
- Loan - CFEL

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**Source Coherence**

*Young’s Experiment*

- 2 mm

- 2 µm-1

Intensity [A.U.]

- 0.0
- 0.2
- 0.4
- 0.6
- 0.8
- 1.0

Exchange momentum [µm]⁻¹

- -3
- -2
- -1
- 0
- 1
- 2

**CDI from reciprocal to real space**

*Single FEL shot

~20 µJ at 32.5 nm*

**Gaussian-Schell model**

- Based on the decomposition of statistical radiated fields into a sum of independently propagating transverse modes.
- Gives information on the modal spatial distribution of emitted radiation.
- Analysis about:
  - 50% first mode
  - 25% second one
  - 15% third one
  - 6% fourth one

**Phase retrieval algorithm**

In collaboration with:

- H.N. Chapman, S. Bajt, M. Barthelmes

Further info on DiProI endstation:

**Two-color experiment**

**Scheme + Source features**

**Electron bunch**

Two seeding Laser Pulses

Δt  

**FEL amplifier**

Two FEL Pulses

Δt

**Achievable delay:** 300 – 700 fs (December 2012)

**Seed pulses:**
- independently tunable in 260-262 nm
- 180 fs-long (FWHM)
- variable time separation and intensity ratio
- splitting introduced in the seed fundamental

**e⁻ bunch:**
- mildly compressed 750 fs-long
- preserve the temporal uniformity of current and energy

**In collaboration with:**
- F. Bencivenca, D. Fausti, Fermi Commissioning Team (L. Giannessi, E. Allaria, et al.)
- Lasers Team (M. Danailov, et al.), PADReS Team (L. Raimondi, M. Zangrando, et al.)

**Jitter**

0.005 % Shot-to-Shot spectral

~15% Shot-to-Shot intensity
TWO-COLOR EXPERIMENT
PRESTO + KAOS

Pulse wavelengths

Pulse stabilities

Pulse intensities


Interpulse delay

Spatial overlapping

Two pulses tuned to wavelengths across the Ti-M edge

The two pulses have different wavelengths so to be diffracted at different angles → detected at different positions on the CCD
At high fluence → evidence for dramatic changes in the Ti electronic structure: high degree of ionization that shifts the Ti edge to shorter wavelengths making the grating ‘transparent’ for the second pulse [low-F → <1% of Ti atoms ionized – high-F → ~100% of Ti atoms ionized (in some tens of fs)]

The pulse length (~90 fs) and the delay (max 500 fs) are shorter than the time scales of hydrodynamic expansion 1 - 10 ps

The experimental results can be reproduced using a 2.3 nm-long edge shift \( i.e., \) when the probe \( \lambda \) is not anymore in the absorption edge window.
The present scheme (2 seeding pulses) can generate interpulse delays down to 150-200 fs. To decrease further the delay (to values comparable to the FEL pulse length) a different approach should be followed: seeding with a single, frequency-chirped pulse → spectro-temporal splitting in FEL deep saturation regime.
CONCLUSIONS and perspectives

- FERMI and DiProI: operative and versatile
- Successful generation of two FEL pulses with precisely controlled wavelengths, time delay and intensity ratio
- Test experiment on Ti-grating: successful

- Further investigations with different delays (50-300fs → 1ps)
- Investigation of magnetic phenomena varying the interpulse delay and intensity ratio
### DiProI
M. Kiskinova (coordinator), F. Capotondi (BL scientist), E. Pedersoli (post-doc)

### Lasers
M. Danailov, A. Demidovich, I. Nikolov (pump&probe laser)

### Others
R. Godnig (technician), R. Menk (consulting for detectors), R. Borges (software), C. Spezzani, F. Bencivenga, C. Masciovecchio, D. Fausti, and all the FERMI TEAM (collaboration for instrumentation and experiments)

### PADReS
M. Zangrando, N. Mahne, L. Raimondi, C. Svetina (beamlines, optics)

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### Collaborators

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<th>Collaborators</th>
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<tr>
<td>FEL Science</td>
<td>H. Chapman, S. Bajt, A. Barty et al.</td>
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<td>Lawrence Livermore National Laboratory</td>
<td>A. Nelson, M. Frank et al.</td>
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<td>DESY</td>
<td>B. Keitel, K. Tiedtke, E. Plönjes-Palm et al.</td>
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<td>PULSE STANFORD</td>
<td>M. Bogan et al.</td>
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<td>UPPSALA UNIVERSITET</td>
<td>J. Hajdu et al.</td>
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<td>Laser-Laboratorium Göttingen e.V.</td>
<td>K. Mann, T. Mey, B. Schäfer et al.</td>
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