Elettra
Sincrotrone
Trieste

FEL 2013 | Manhattan, USA
35th International Free-Electron Laser Conference
August 26-30, 2013

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

Marco Zangrando, Flavio Capotondi
& FERMI team

www.elettra.eu

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

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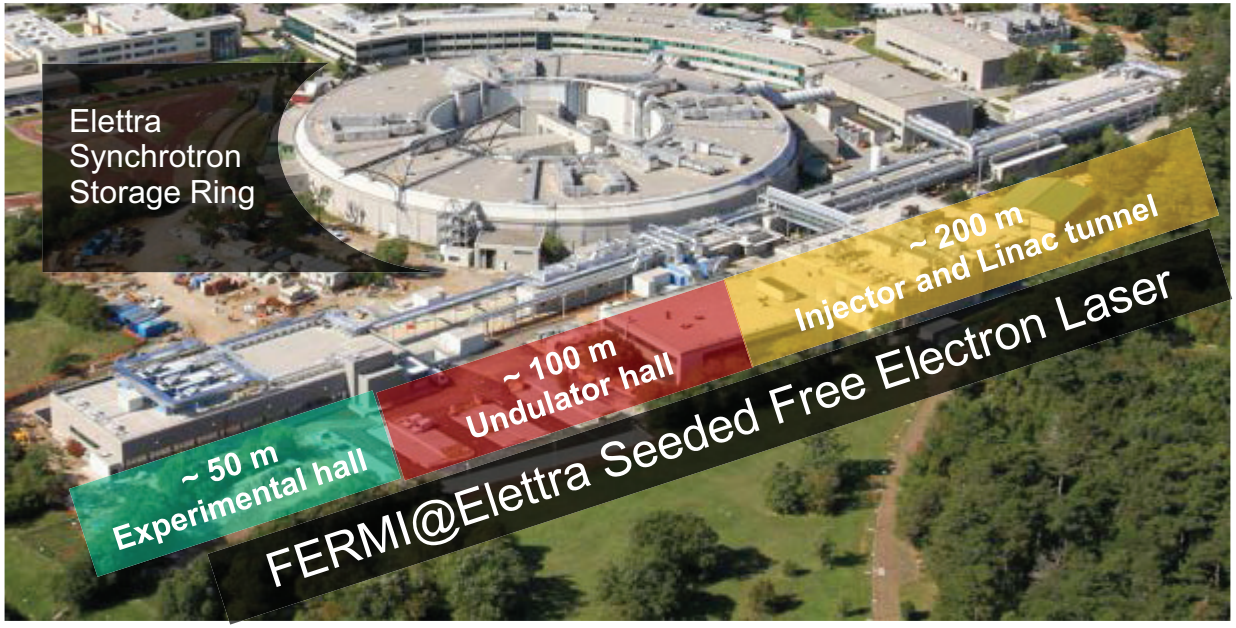
FERMI@Elettra
Layout + Parameters

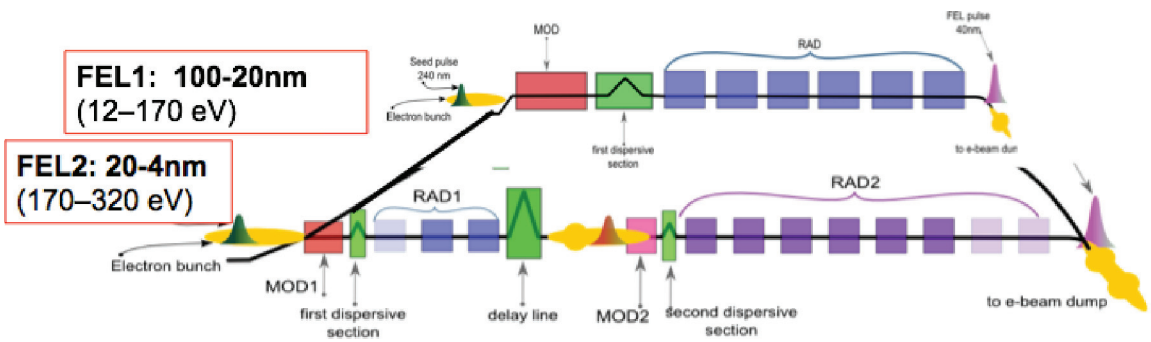


Parameters:

- 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

TWO COLOR PUMP-PROBE
Motivations and Requests

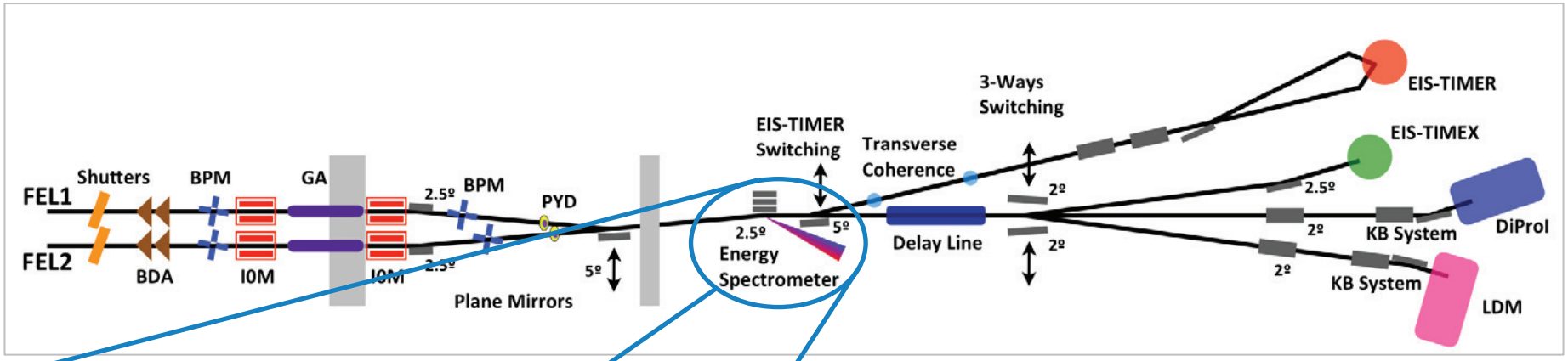
Motivations

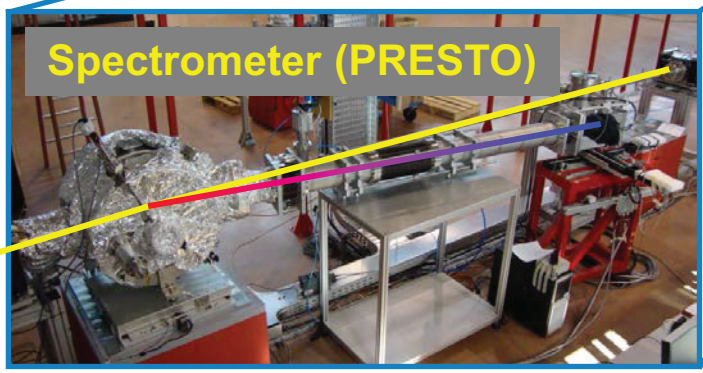
- Pump-probe techniques to study non-equilibrium transient states of matter
  → extended to HHG- and FEL-generated pulses (either X-ray or synchronized optical and X-ray pulses pairs)
- Advantage of XUV/X-ray photons:
  they can stimulate and probe electronic transitions from core levels, providing chemical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

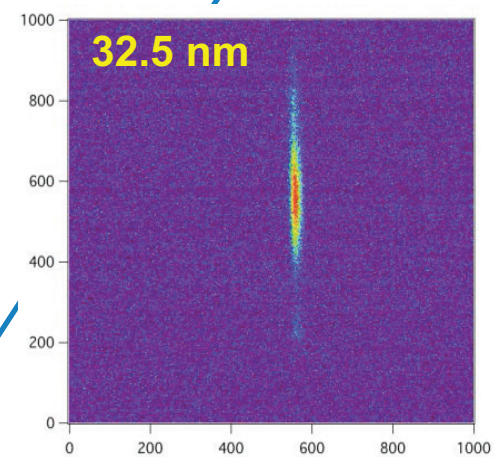
Requests

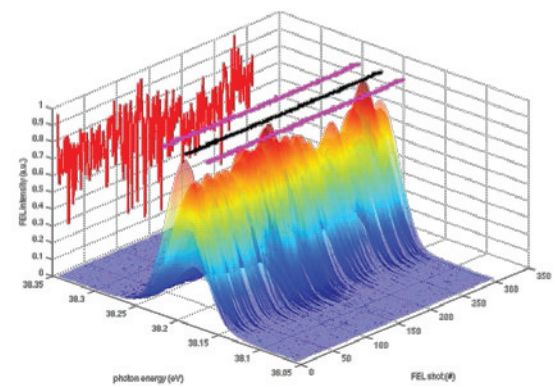
- Generate two FEL pulses with precisely controlled time delay, wavelength and intensity ratio
- Perform proof-of-principle XUV-pump / XUV-probe experiment that examines the dynamics of a thin-metal layer structure exposed to high intensity XUV excitation

PHOTON TRANSPORT SYSTEM
Energy Spectrometer





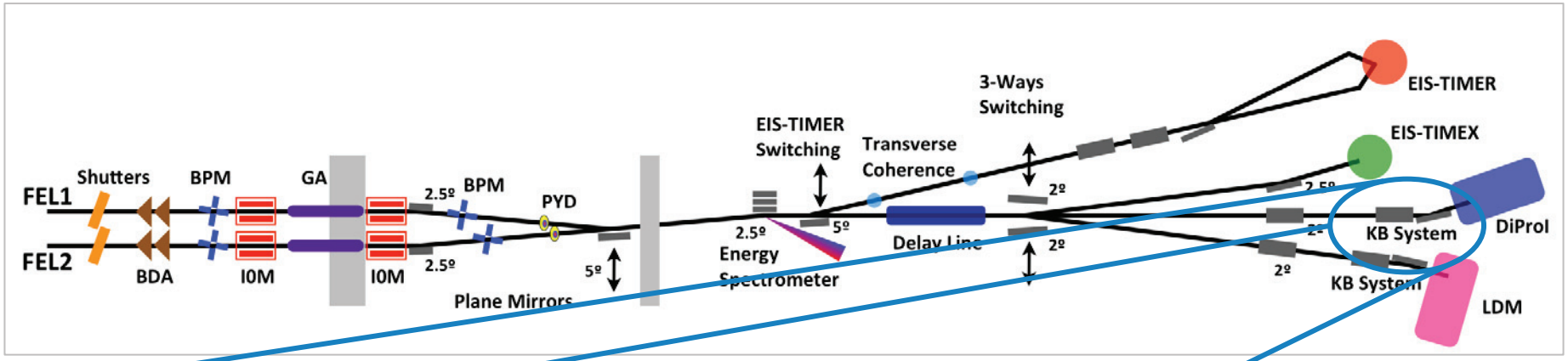


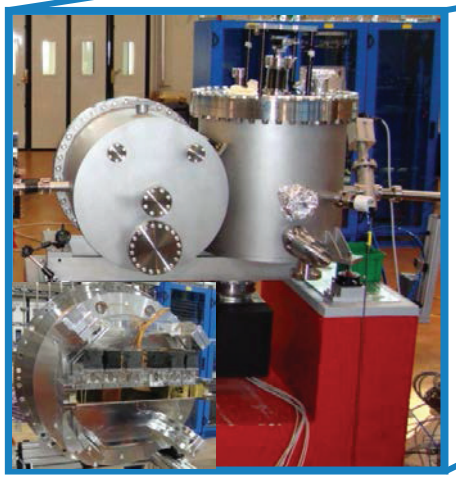


- **Online (non invasive)**
- **Shot-to-Shot**
- **~97% of FEL → beamlines**
- **1% of FEL → YAG + triggered CCD**
- **Resolving Power ~15000 @32.5nm (2.5meV)**
- **Available information: wavelength, BW, spectral content**

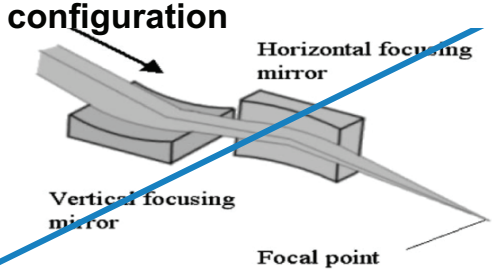
FEL photon energy
38.19eV±1.1meV (rms)
FEL bandwidth
22.5meV
Spectral purity
5.9e-4

PHOTON TRANSPORT SYSTEM
KB focusing mirrors

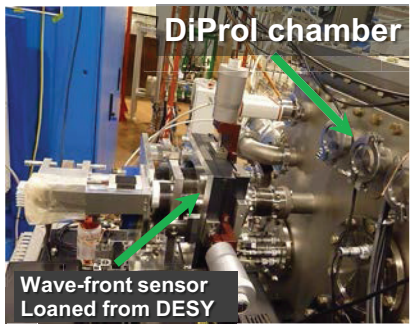




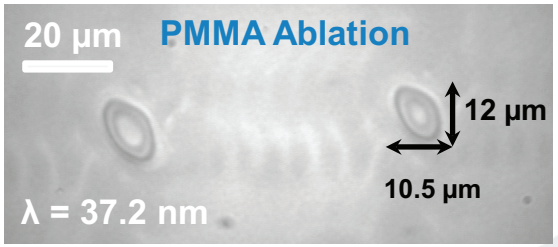
KAOS
(Kirpatrick-Baez Active Optics System)
Bendable plane mirrors in Kirkpatrick-Baez configuration

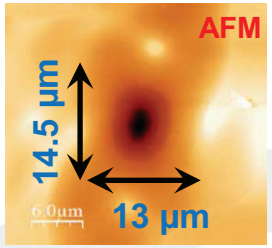


WFS measurements in collaboration with:
L. Raimondi and PADReS
DESY + Laser-Lab. Gottingen
Image Optics + CEA and LOA



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





Best spot 10 µm x 13.5 µm

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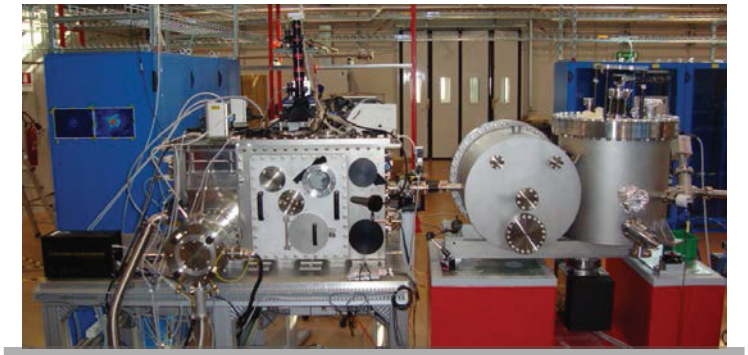
DiProI ENDSTATION
Core capabilities

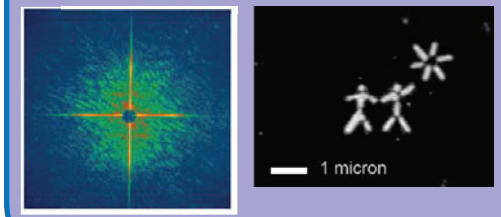


Installed on dedicated FERMI beamline: June 2011
Open to User Experiments: December 2012

Versatile modular construction allowing exchange and/or adding new components

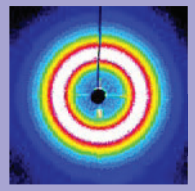
Forward scattering scheme

Single shot FEL pulse diffraction experiment and P&P experiment



H.N. Chapman et al. Nature Physic 2007

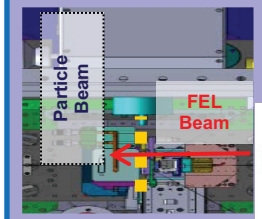
Magnetic Res-scattering

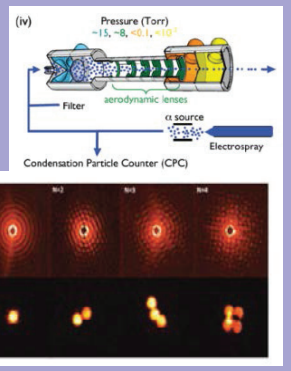


In collaboration with G.Grübel, C. Gutt (DESY)
J. Lüning (Univ.Paris)

B. Pfau et al Nature Com. (2012)

Particle injector

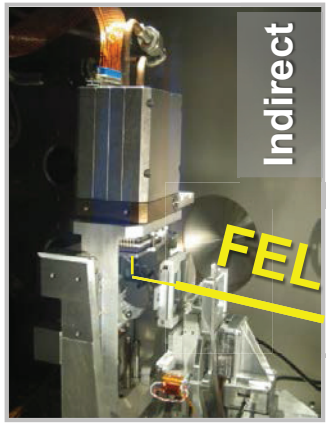


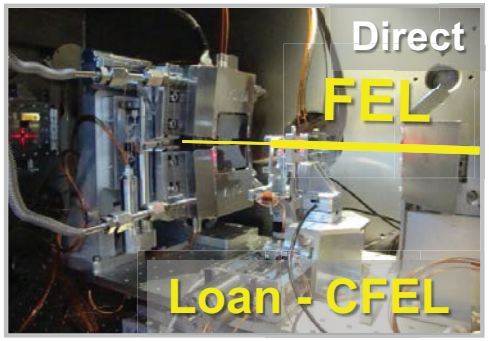


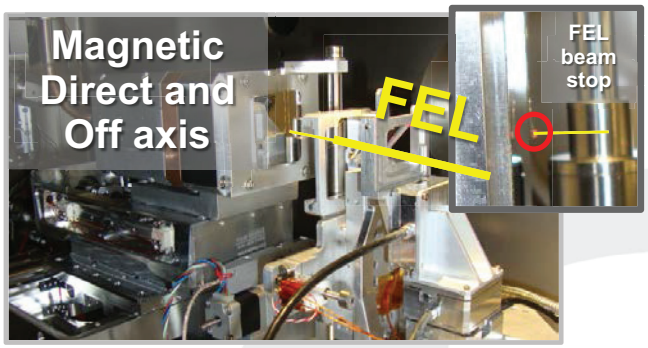
M, Bogan et al. NanoLett. 2009, AST 2010

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



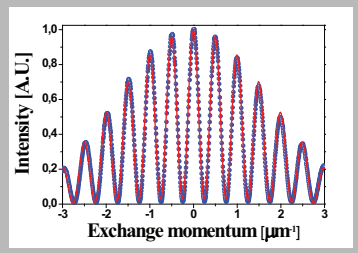


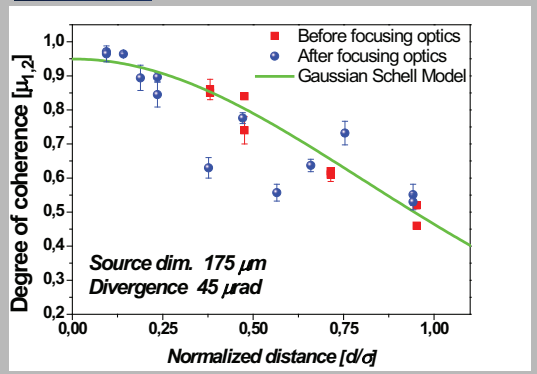


DiProI ENDSTATION
Commissioning results

Source Coherence

Young's Experiment





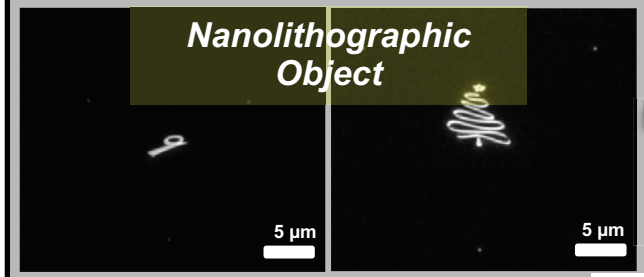
Gaussian-Schell model

Based on the decomposition of statistical radiated fields into a sum of independently propagating transverse modes.

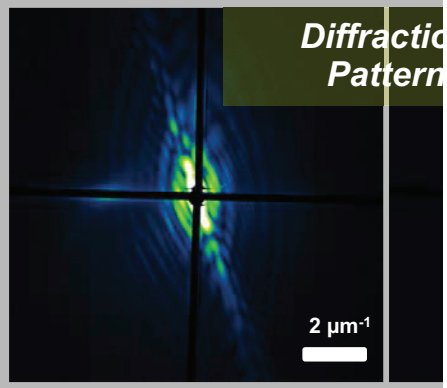
Gives information on the modal spatial distribution of emitted radiation.

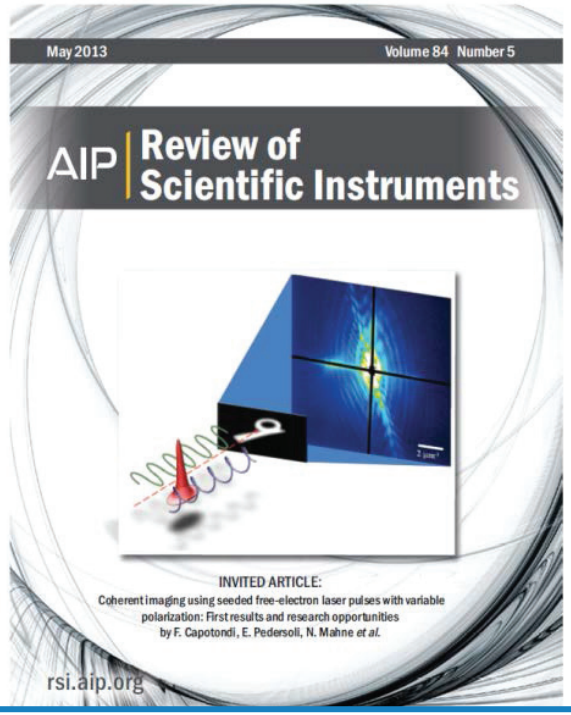
Analysis about
- **50% first mode**
- **25% second one**
- **15% third one**
- **6% fourth one**

CDI from reciprocal to real space



Single FEL shot ~20 μJ at 32.5 nm





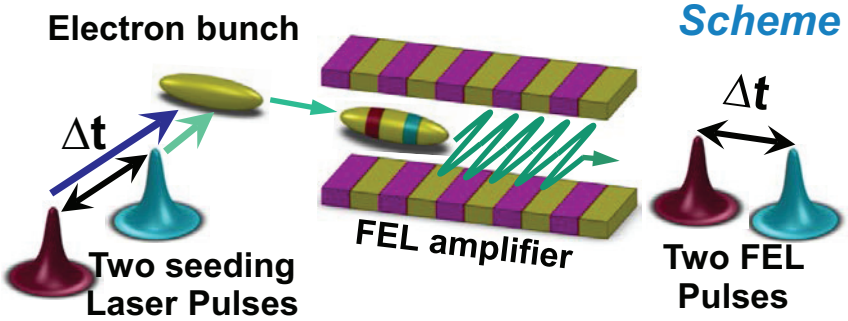
Phase retrieval algorithm

In collaboration with:
H.N. Chapman, S. Bajt, M. Barthelmess

Further info on DiProI endstation:
F. Capotondi, et al., Rev. Sci. Instrum. 84, 051301 (2013)

TWO-COLOR EXPERIMENT
Scheme + Source features

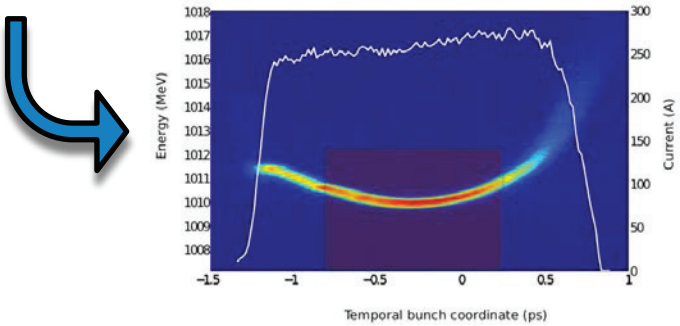
Pulses Generation Scheme

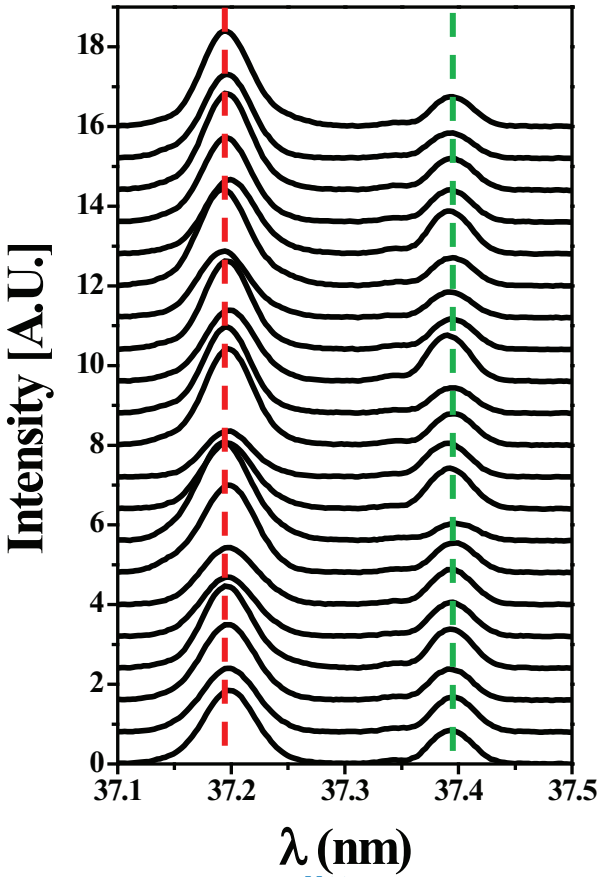


Achievable delay: 300 – 700 fs (December 2012)

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



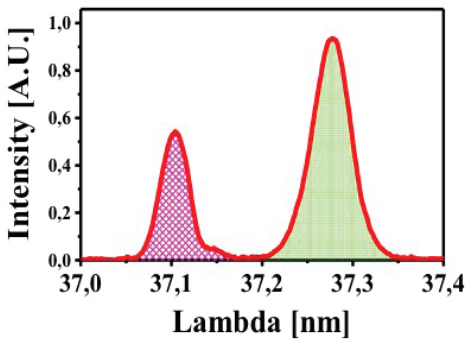


Jitter
0,005 % Shot-to-Shot spectral
~15% Shot-to-Shot intensity

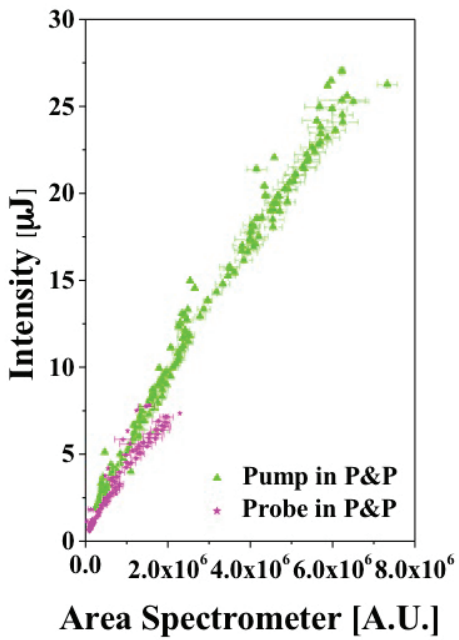
In collaboration with:
F. Bencivenca, D. Fausti, Fermi Commissioning Team (L. Giannessi, E. Allaria, et al.)
Lasers Team (M. Danailov, et al.), PADReS Team (L. Raimondi, M. Zangrando, et al.)

TWO-COLOR EXPERIMENT
PRESTO + KAOS

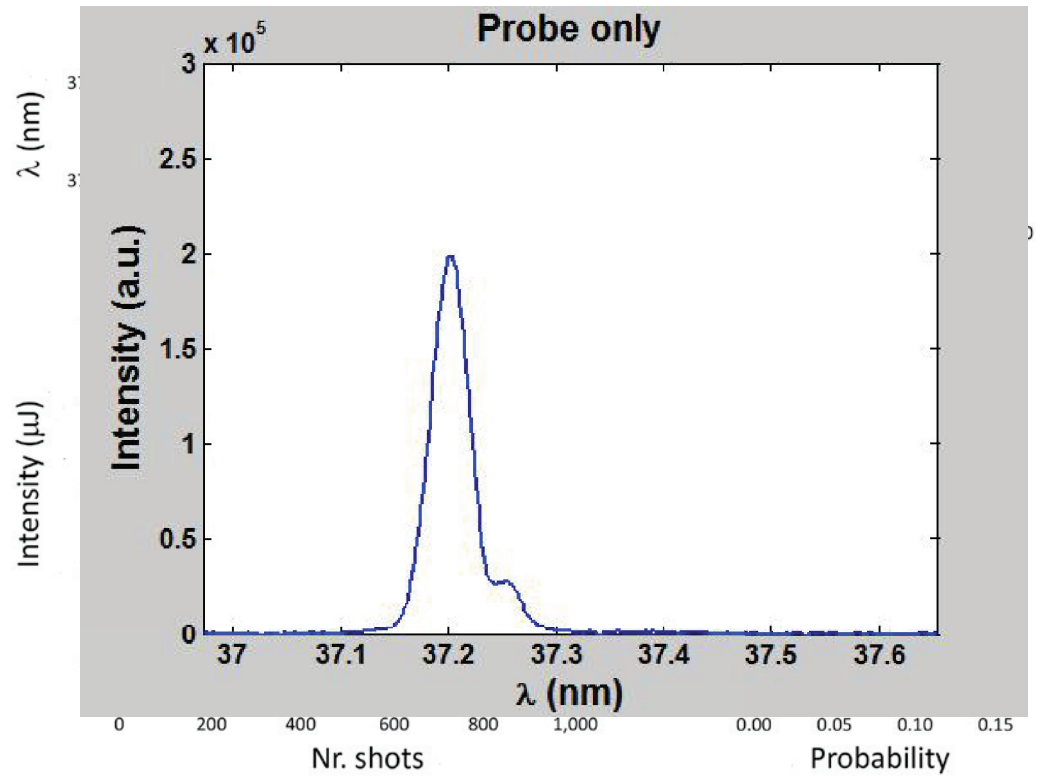
Pulse wavelengths



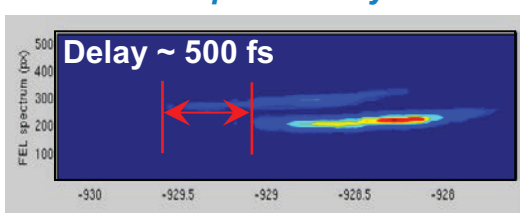
Pulse intensities



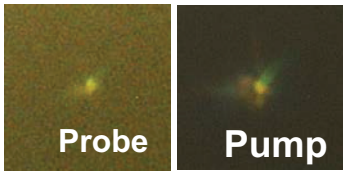
Pulse stabilities



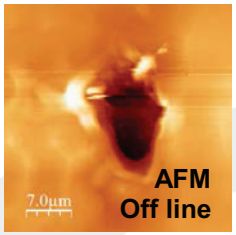
Interpulse delay



Spatial overlapping



On line PMMA Ablation

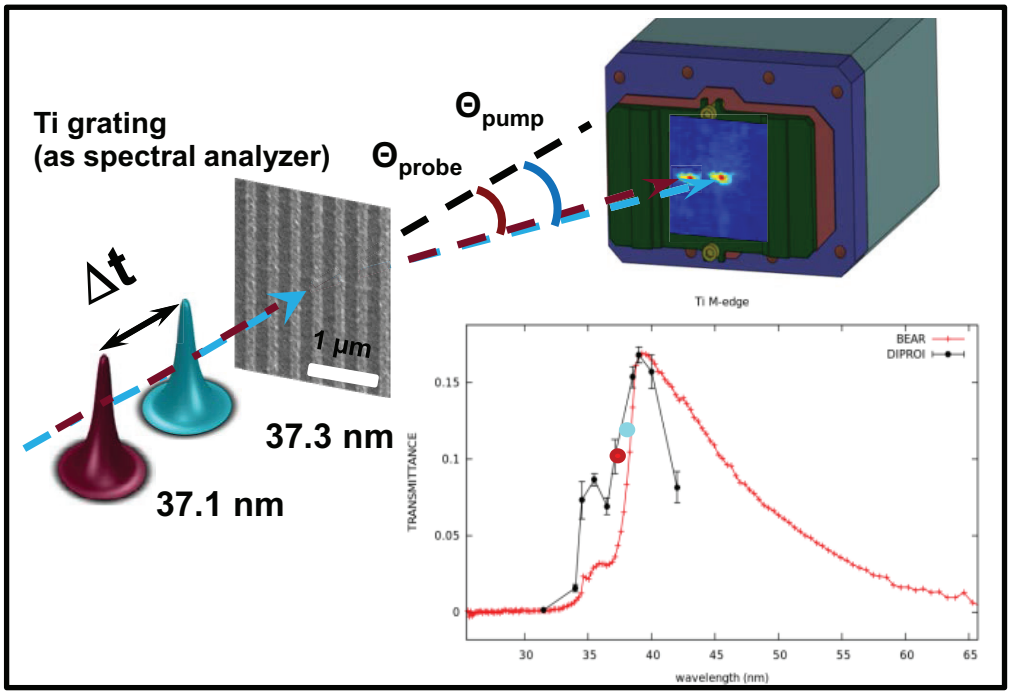


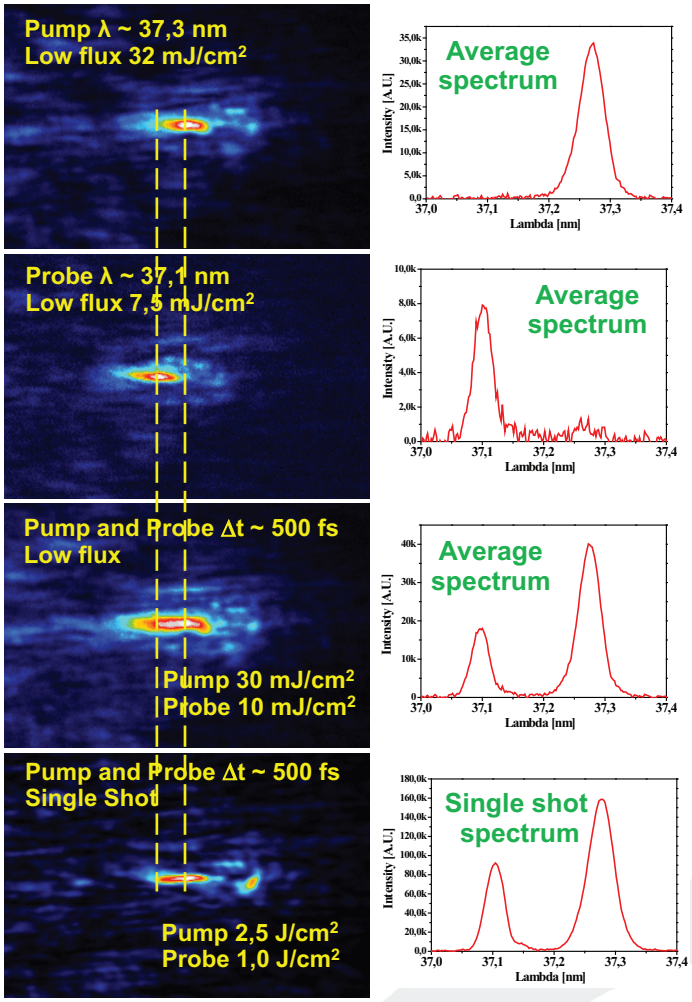
E. Allaria, et al., Nature Comm., to be published (2013)

Marco Zangrando– marco.zangrando@elettra.eu

TWO-COLOR EXPERIMENT
Experimental setup + Results

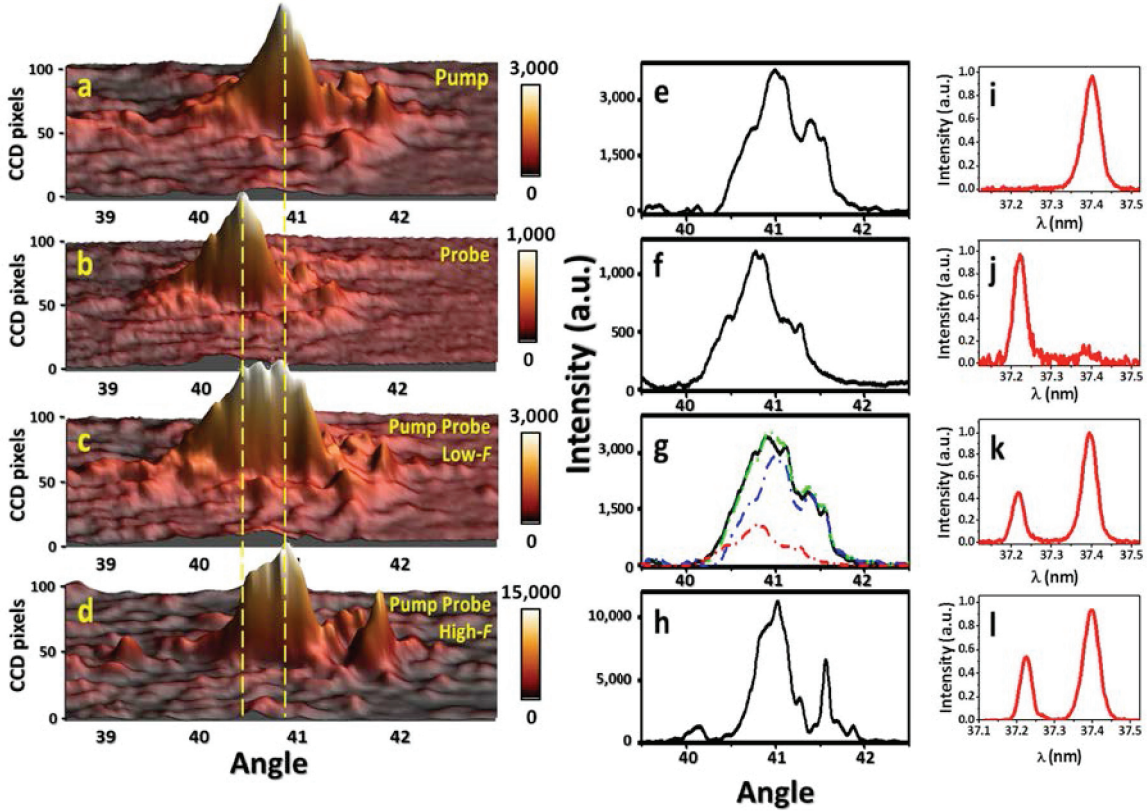
Two pulses tuned to wavelengths across the Ti- M edge





The two pulses have different wavelengths so to be diffracted at different angles → detected at different positions on the CCD

TWO-COLOR EXPERIMENT
Results (continued)

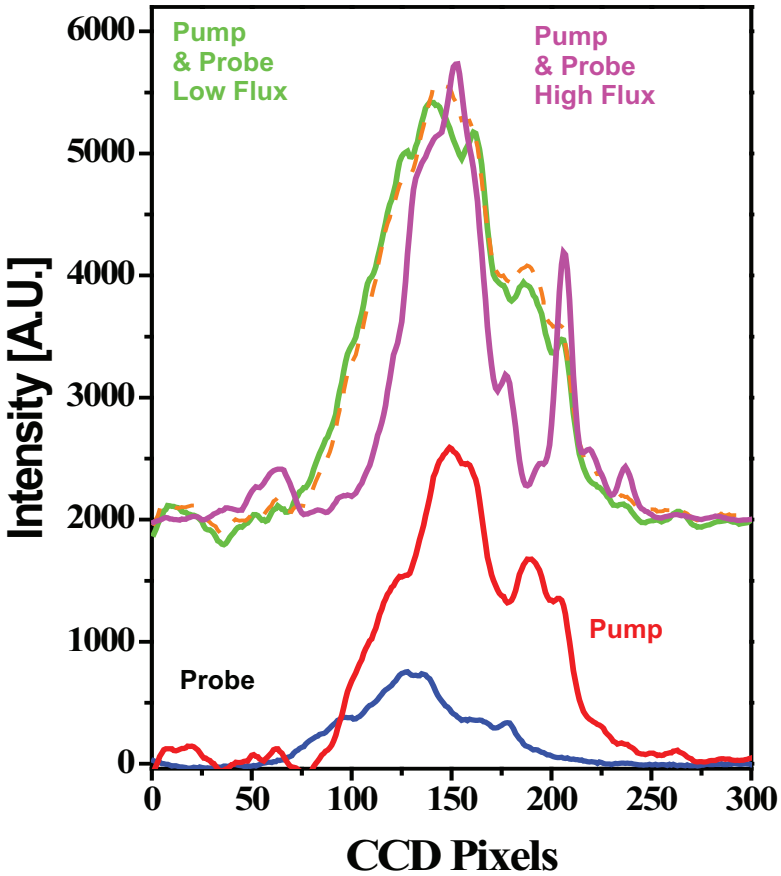


At high fluence → evidence for dramatic changes in the Ti electronic structure: high degree of ionization that shifts the Ti edge to shorter wavelengths making the grating 'transparent' for the second pulse [low-F → <1% of Ti atoms ionized – high-F → ~100% of Ti atoms ionized (in some tens of fs)]

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

E. Allaria, et al., Nature Comm., to be published (2013)

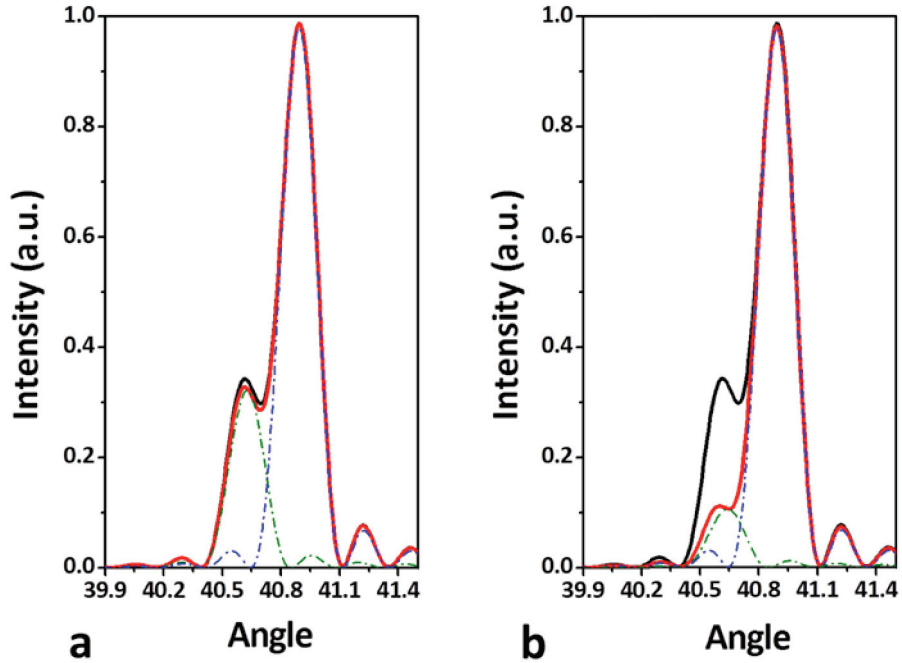
TWO-COLOR EXPERIMENT
Comparison with theory



PRL 107, 218102 (2011) PHYSICAL REVIEW LETTERS week ending 18 NOVEMBER 2011

Multiwavelength Anomalous Diffraction at High X-Ray Intensity

Sang-Kil Son (손상길),[1,*] Henry N. Chapman,[1,2,†] and Robin Santra[1,2,‡]
[1]*Center for Free-Electron Laser Science, DESY, Hamburg, Germany*
[2]*Department of Physics, University of Hamburg, Hamburg, Germany*
(Received 23 May 2011; published 14 November 2011)



0.5 nm-shift of the edge

2.3 nm-shift of the edge

The experimental results can be reproduced using a 2.3 nm-long edge shift *i.e.,* when the probe λ is not anymore in the absorption edge window

TWO-COLOR EXPERIMENT
Reducing the interpulse delay

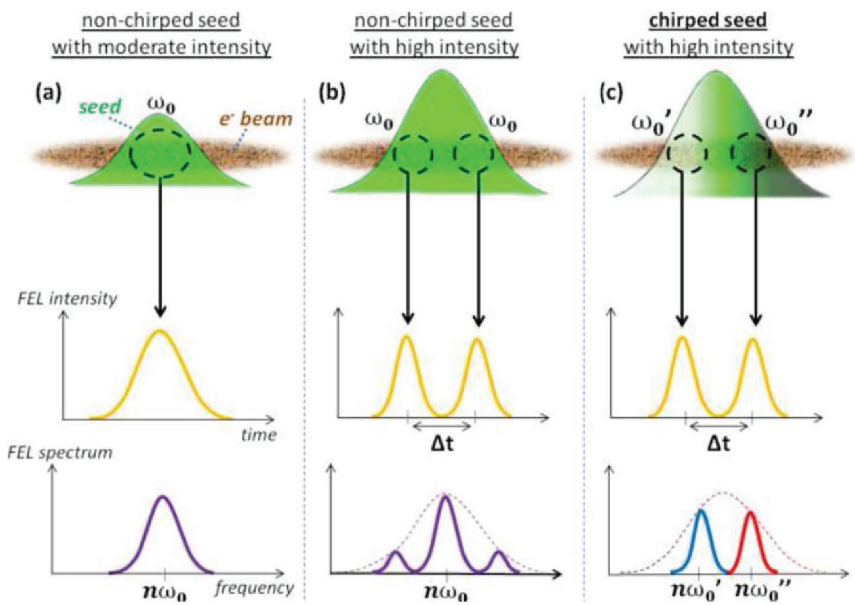
The present scheme (2 seeding pulses) can generate interpulse delays down to 150-200 fs. To decrease further the delay (to values comparable to the FEL pulse length) a different approach should be followed:

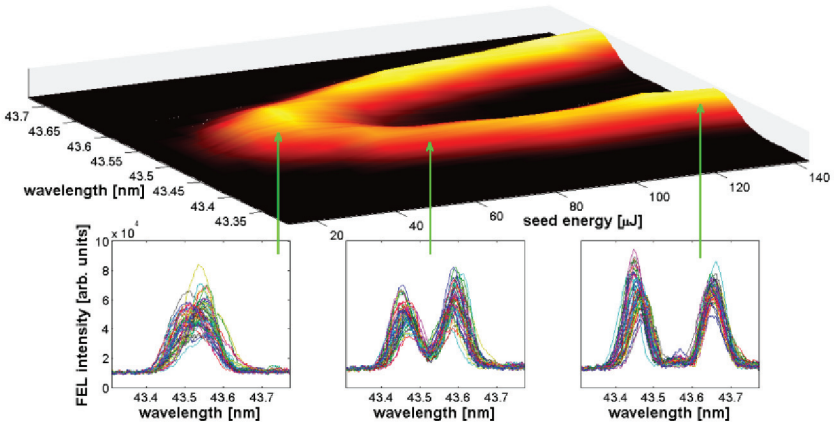
seeding with a single, frequency-chirped pulse → spectro-temporal splitting in FEL deep saturation regime

PRL **110,** 064801 (2013) PHYSICAL REVIEW LETTERS week ending 8 FEBRUARY 2013

Chirped Seeded Free-Electron Lasers: Self-Standing Light Sources for Two-Color Pump-Probe Experiments

Giovanni De Ninno,[1,2] Benoît Mahieu,[1,2,3] Enrico Allaria,[2] Luca Giannessi,[2,4] and Simone Spampinati[2]
[1]*Laboratory of Quantum Optics, University of Nova Gorica, Nova Gorica 5001, Slovenia*
[2]*Sincrotrone Trieste, Trieste 34149, Italy*
[3]*Service des Photons Atomes et Molécules, Commissariat à l'Energie Atomique, Centre d'Etudes de Saclay, Gif-sur-Yvette 91191, France*
[4]*ENEA C.R. Frascati, Frascati 00044, Italy*
(Received 9 August 2012; revised manuscript received 16 December 2012; published 4 February 2013)





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

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COLLABORATORS
Internal and external

Elettra Sincrotrone Trieste

DiProl: 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)

FEL SCIENCE

DESY UHH

H. Chapman
S. Bajt
A. Barty et al.

PULSE STANFORD

M. Bogan et al.

Lawrence Livermore National Laboratory

A. Nelson
M. Frank et al.

UPPSALA UNIVERSITET

J. Hajdu et al.

DESY

B. Keitel
K. Tiedtke
E. Plönjes-Palm et al.

Laser-Laboratorium Göttingen e.V.

K. Mann
T. Mey
B. Schäfer et al.

THANK YOU !