Resonant Coherent Diffraction Imaging: new opportunities for free electron laser science

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Elettra/FERMI Team

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PARTNERS:

Henry Chapman, Sasa Bajt, Anton Barty et al.

Janos Hajdu et al.

Mike Bogan et al.

Arthur Nelson, Mike Pivovaroff, Matthias Frank et al.

Contents

- *Status of FERMI@Elettra commissioning*
- *Core capabilities of DiProI end-station*
- *Present status and commissioning tests*
- *Outlook: Res-CDI science perspectives at FERMI*

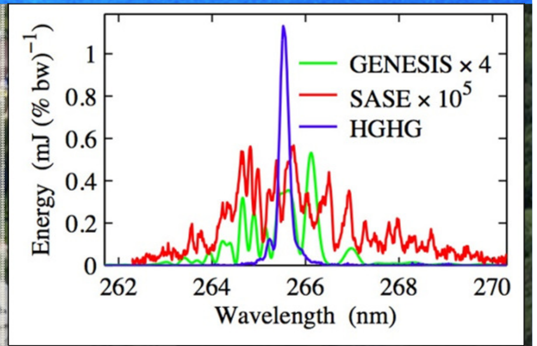
Topic 1

- <u>***Status of FERMI@Elettra commissioning***</u>
  - ***Core capabilities of DiProI end-station***
  - ***Present status and commissioning tests***
  - ***Outlook: Res-CDI science perspectives at FERMI***

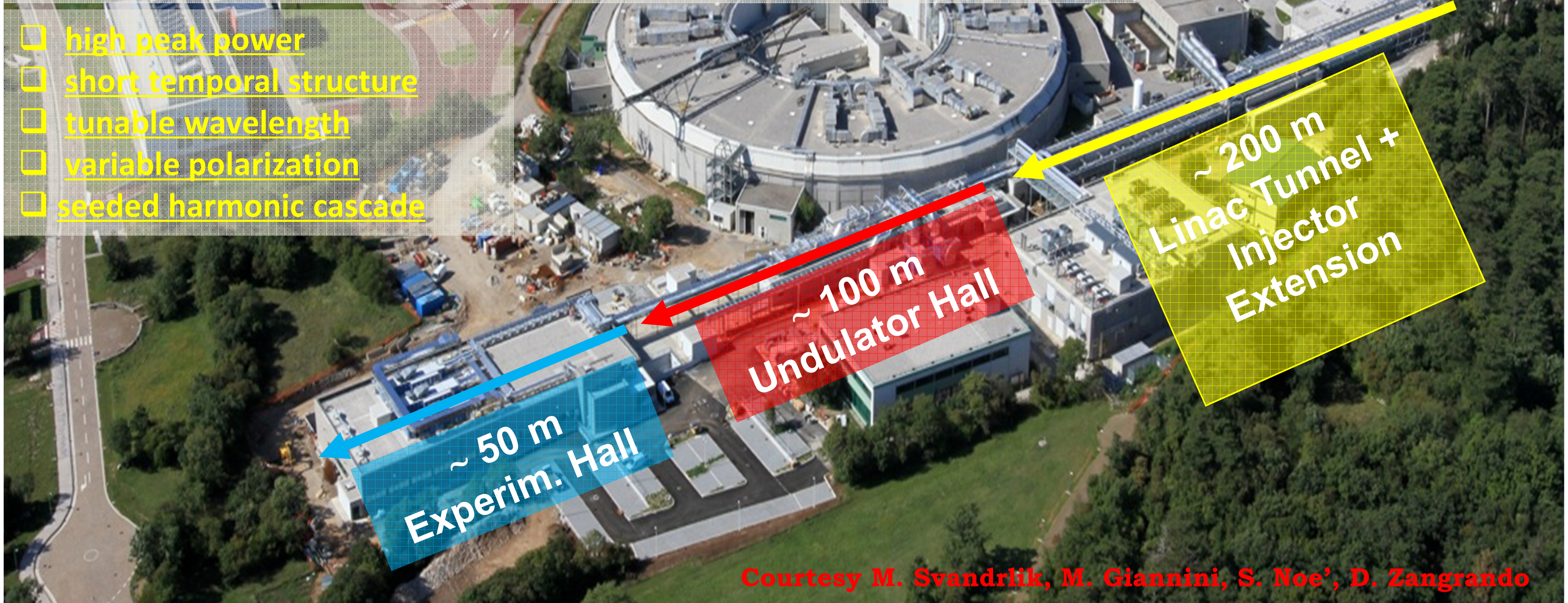
THE FERMI@ELETTRA PROJECT

FERMI@Elettra is a single-pass seeded FEL user-facility.

- Two separate FEL amplifier will cover the spectral range from 100 nm (12 eV) to 4 nm (320 eV).
- Based on the high gain harmonic generation scheme FERMI will provide users with photon pulses of 50-100 fs with unique characteristics:

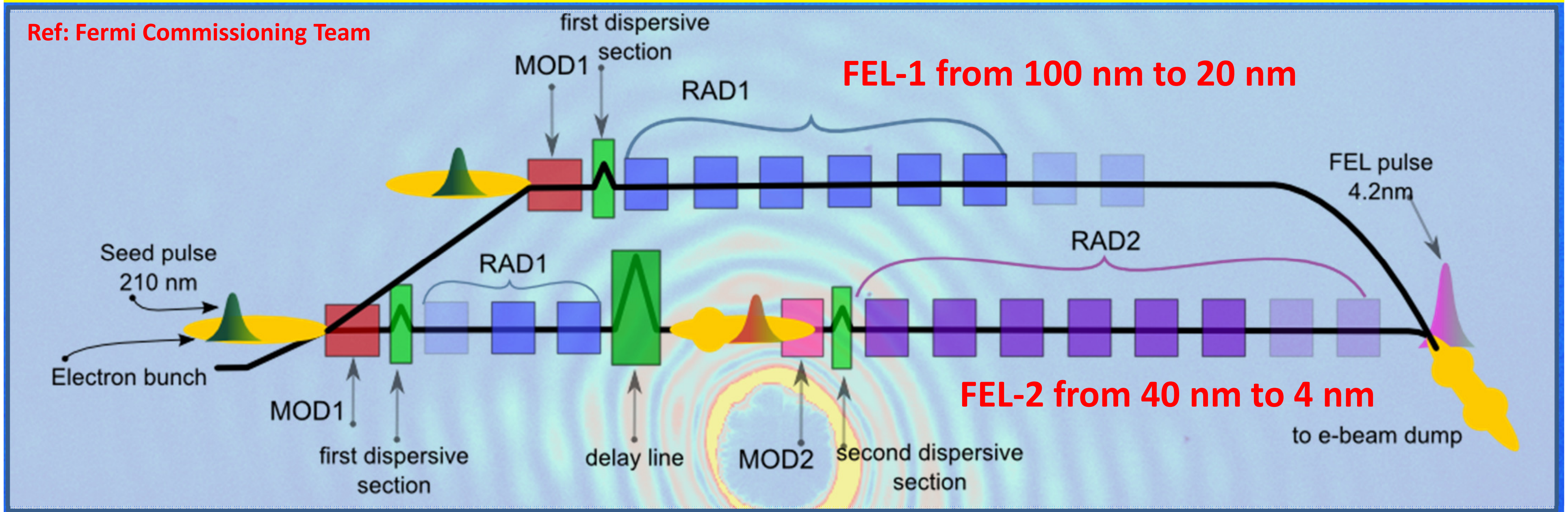


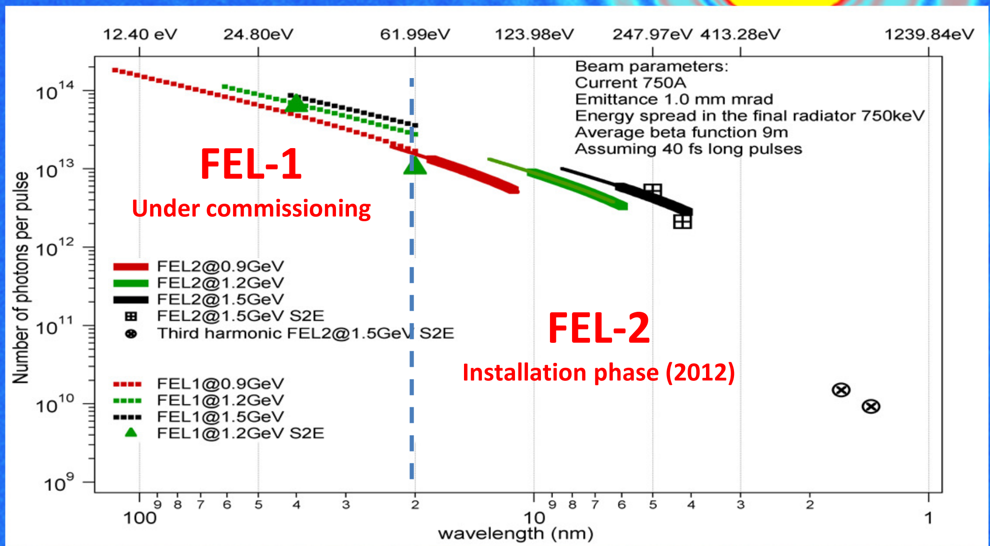
- high peak power
- short temporal structure
- tunable wavelength
- variable polarization
- seeded harmonic cascade



Courtesy M. Svandrlik, M. Giannini, S. Noe', D. Zangrando

FEL-1 and FEL-2 + Beamline

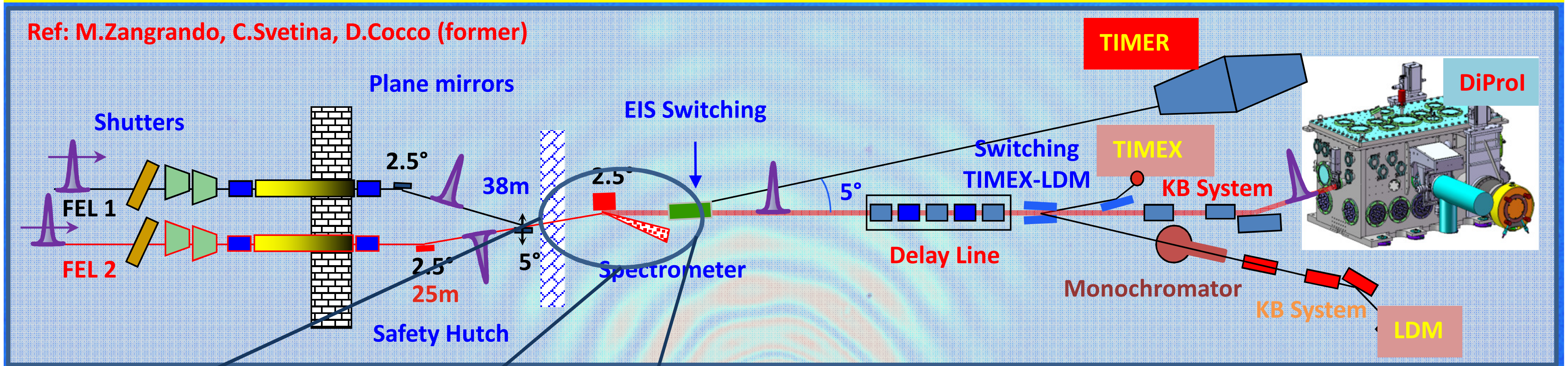


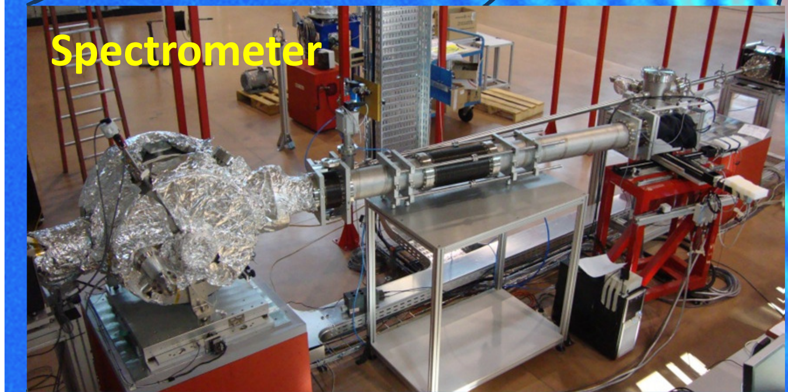


Fast Tunability,
Multiple polarization,
Spectral purity,
100-1000 fs pulse width.

FEL-1 and FEL-2 + Beamline

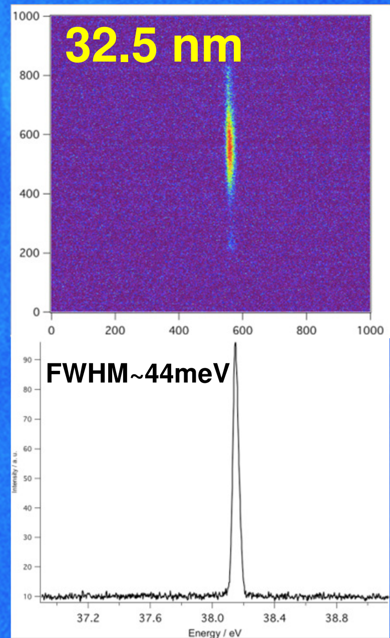
Ref: M.Zangrando, C.Svetina, D.Cocco (former)



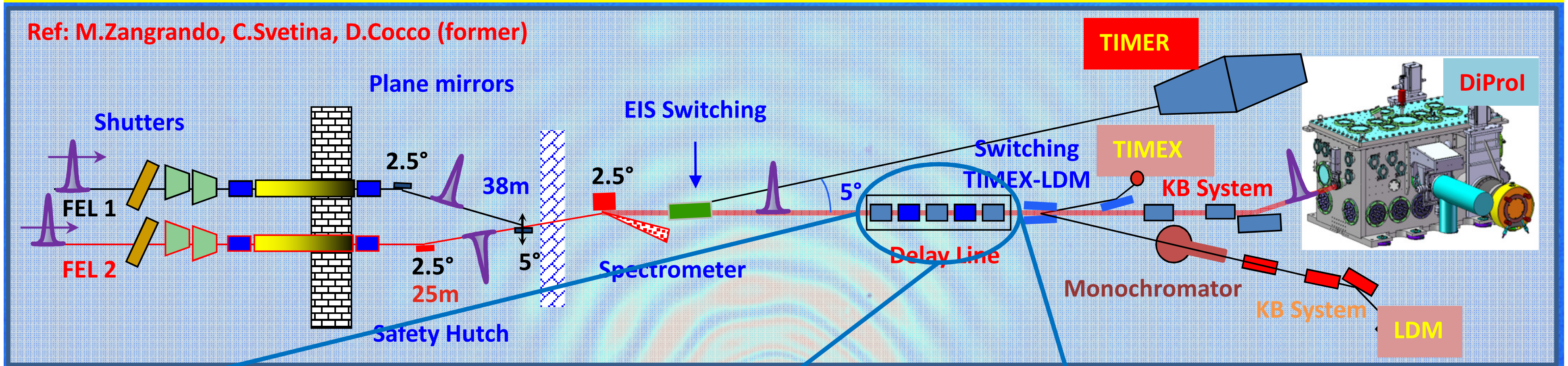


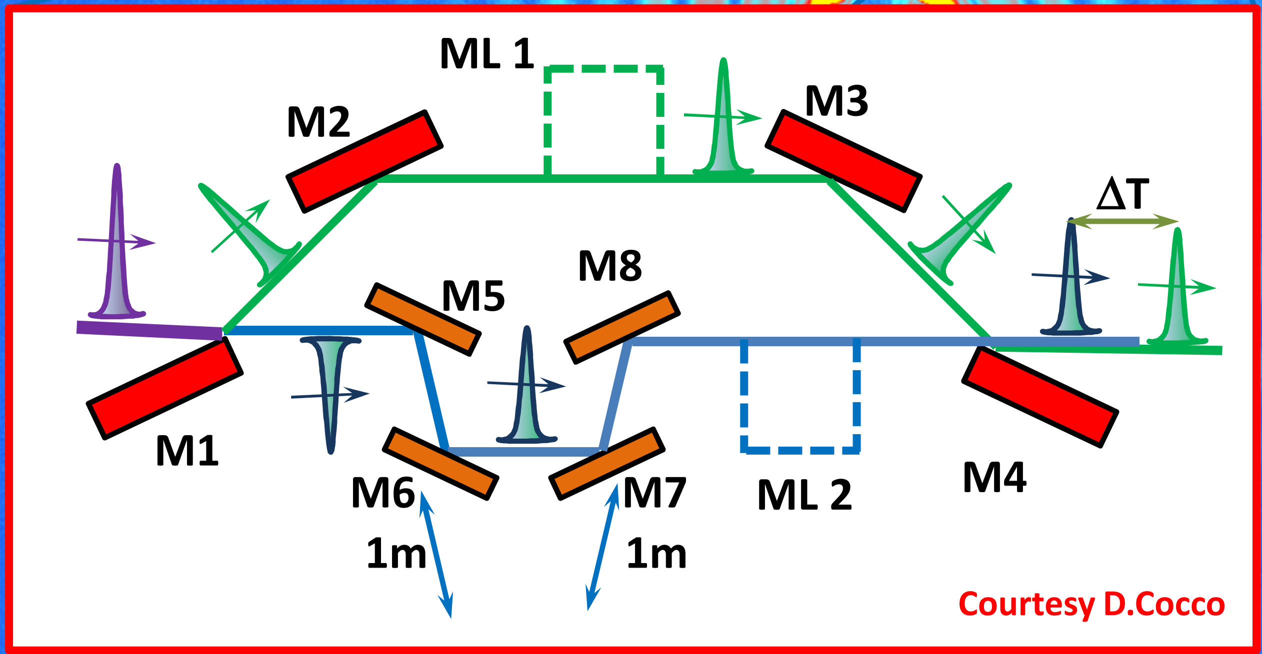
On-line
FEL single-shot spectral diagnostic tool
Special mirror (planar+greeting)
About 99 % of FEL radiation toward BLs 1 % of FEL radiation toward light converter fast CCD spectrometer branch

Ref. C.Svetina *et al. SPIE (2011)*



FEL-1 and FEL-2 + Beamline





Capability:

-2.5 ps < ΔT < 35 ps

without MLs

ΔT up to 1 ns with MLs

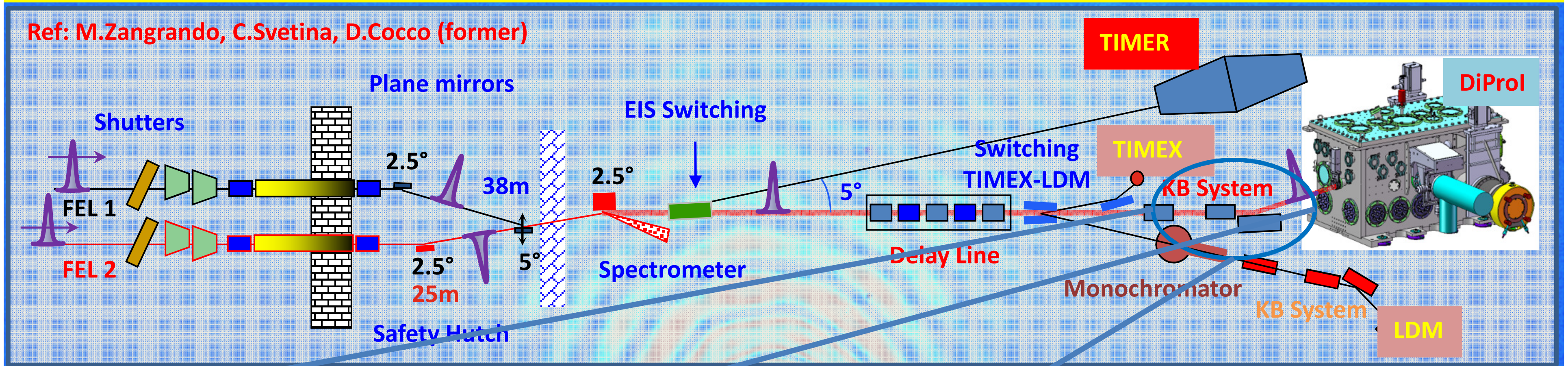
Two color Pump&Prob

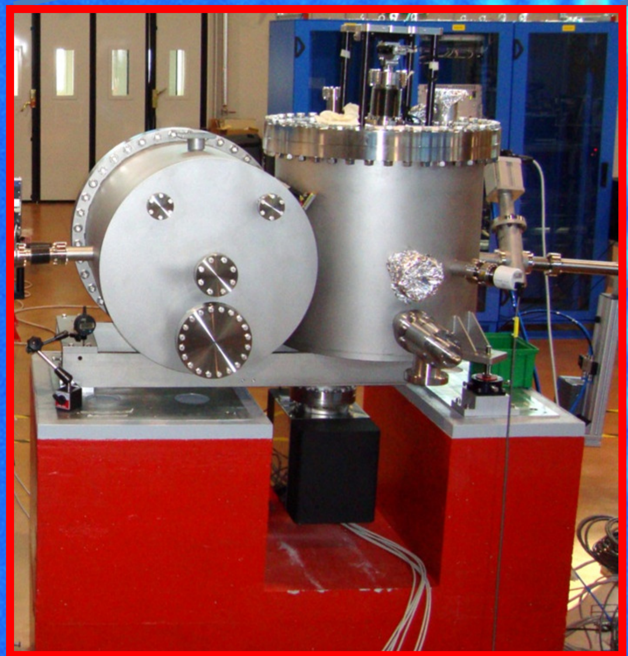
Pump: 1st

Probe: 1st or 3rd (at multilayer wavelength)

FEL-1 and FEL-2 + Beamline

Ref: M.Zangrando, C.Svetina, D.Cocco (former)



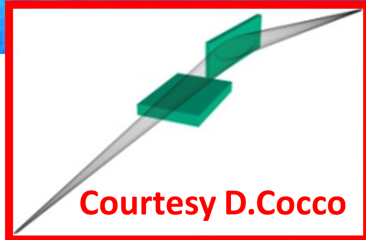


Bendable planar mirrors in Kirkpatrick-Baez configuration

Focal length : 1,2 m

Flux : 1×10^{12} ph/pulse (1×10^{16} W/cm^2) @ 5 nm

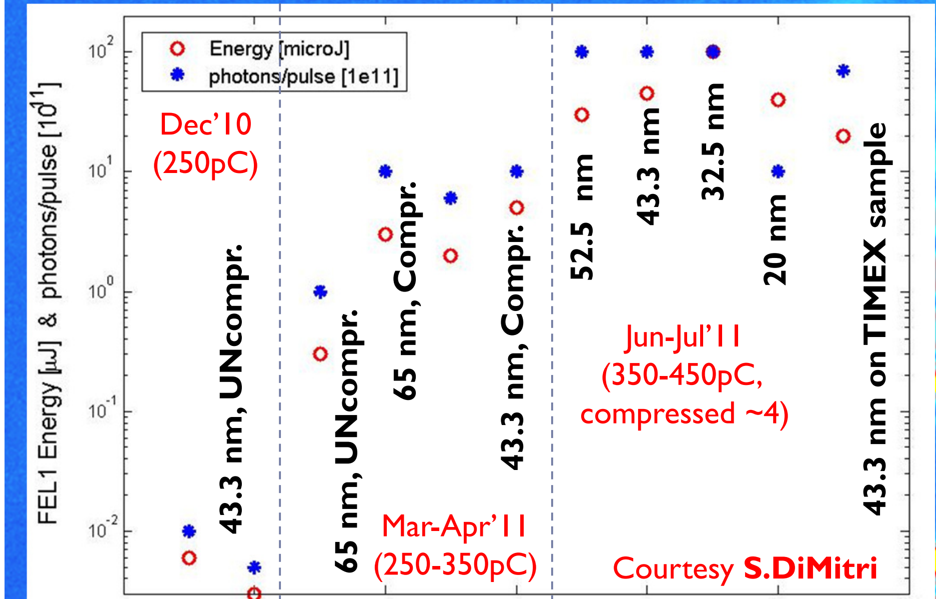
Min Spot (KB) : 3X5 µm^2 (*slope error 0.5 µrad*)
1.5x2.5 µm^2 *perfect*

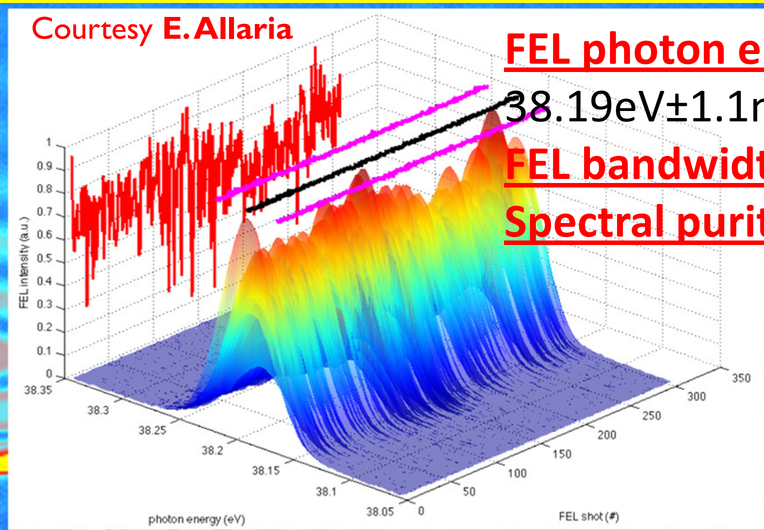


Courtesy D.Cocco

FEL-1 status (main goal achieved)

Improvement in peak power



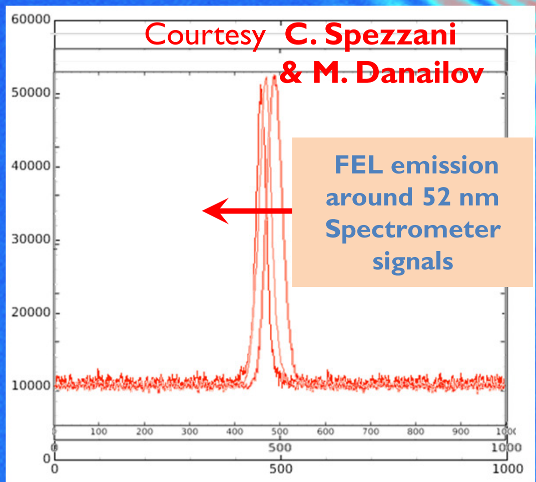


FEL photon energy 38.19eV±1.1meV (RMS)
FEL bandwidth 22.5meV
Spectral purity 5.9e-4

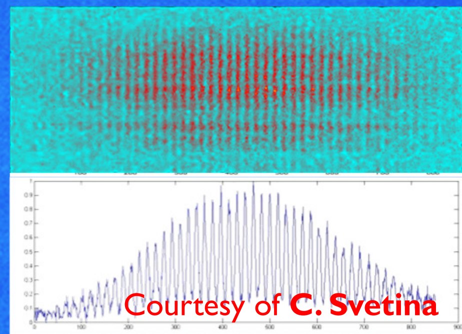
In addition to the very narrow spectrum FERMI is characterized by a very good spectral stability. Both short and long terms measurements show that the spectral peak move less than 10^{-4}(☺ *for CDI !!!*)

Fine FEL tuning around 52 nm has been achieved by changing the seed laser wavelength of 1 nm (0.4%).

(☺ *for r-CDI !!!*)



Transverse coherence
Young experiment
FEL at 32.5 nm
Slits separation=0.8 mm
slit width = 20 μm
(☺ *for CDI !!!*)

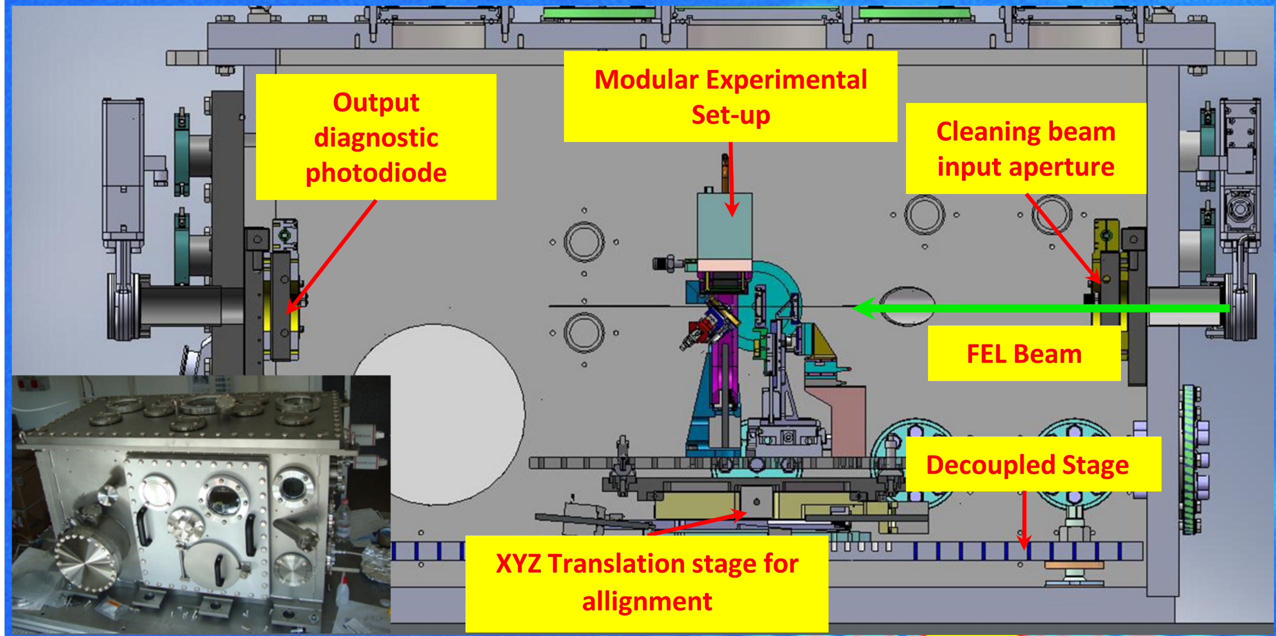


Topic 2

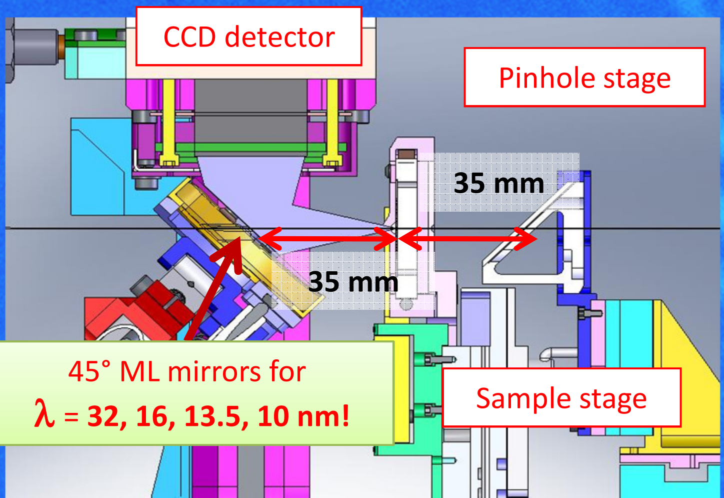
- *Status of FERMI@Elettra commissioning*
- ***Core capabilities of DiProI end-station***
- *Present status and commissioning tests*
- *Outlook: Res-CDI science perspectives at FERMI*

DiProl – Core capabilities

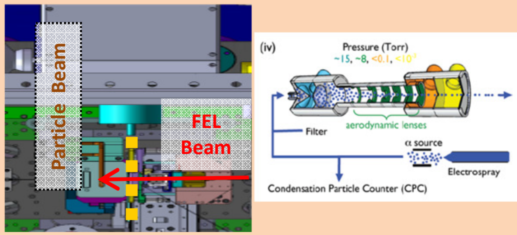
(FEL-1 phase detection system limited to few wavelengths)



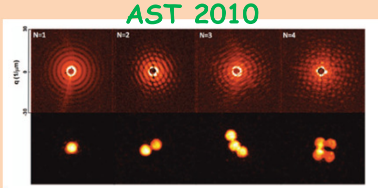
Versatile modular construction and many ports allowing exchange and /or adding new components.



Particle injector

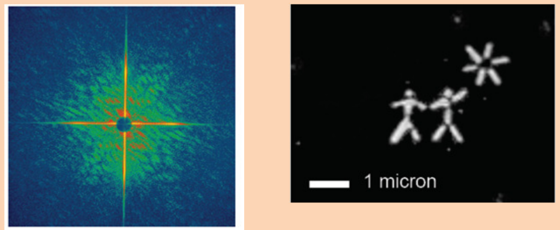


M,Bogan et al. NanoLett. 2009, AST 2010



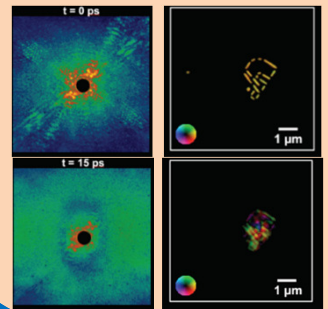
Forward scattering scheme

Single shot FEL pulse



H.N. Chapman et al. Nature Physic 2007

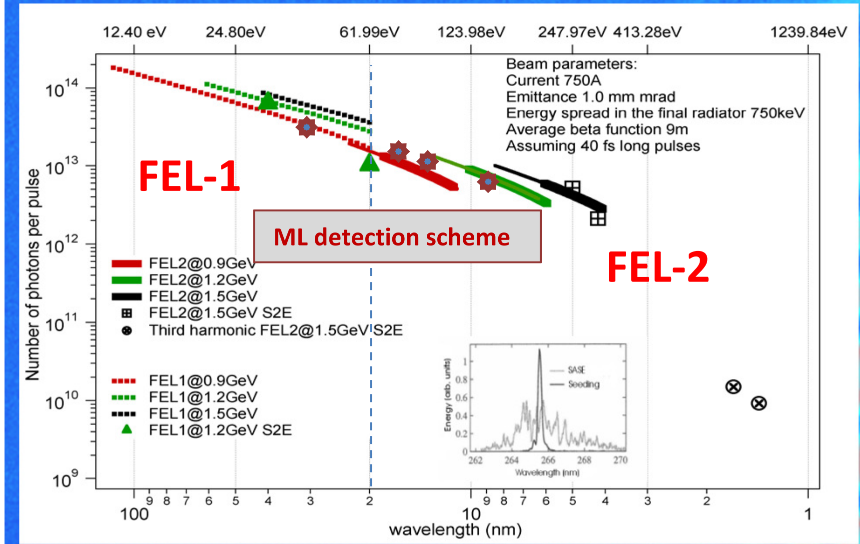
Pump external laser + single shot FEL pulse



A. Barty et al. Nature Phot. 2008

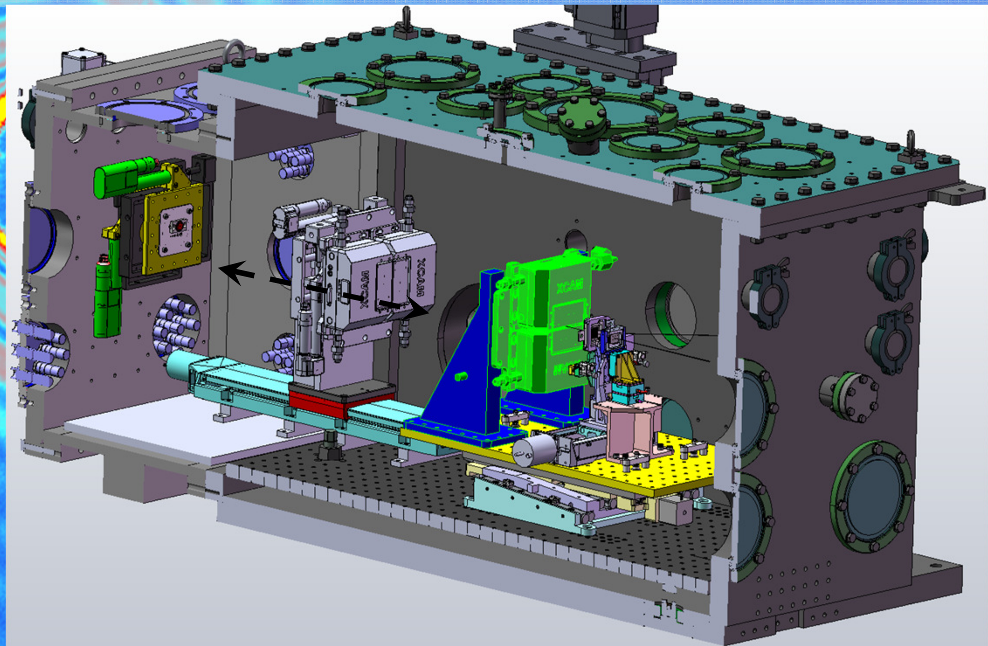
DiProI – Core capabilities

(FEL-2 phase - direct detection system)



DiProI – explores the FERMI full coherence and tunability required for resonant CDI

Direct Detection scheme necessary



GREAT ADVANTAGE

- No need for wavelenght dependent ML 45° mirror
- Gain ~ factor 3 collecting angle => better resolution

MORE CARE NEEDED:

- 45° MLM filters inelastic scattering from the sample
- Larger data storage (~5 Tbytes/week)

Topic 3

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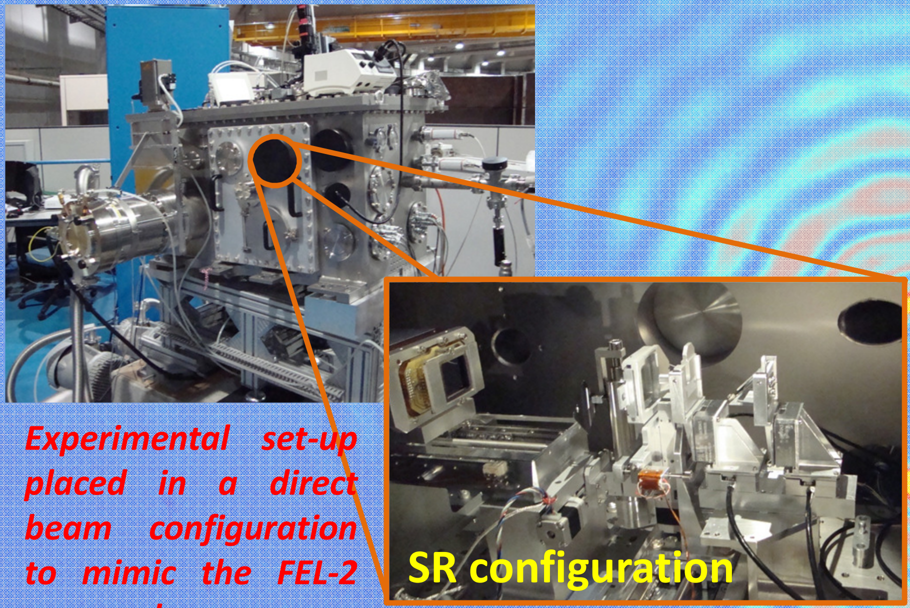
Status of DiProl Project

Pre-commissionig @ Elettra SR
(Nanospectroscopy BL)

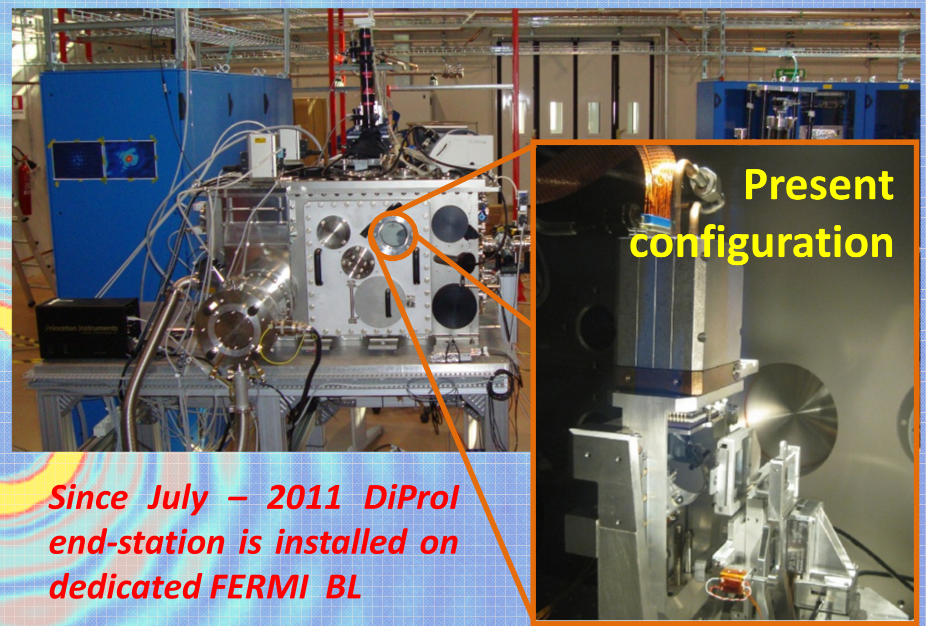


Experimental set-up placed in a direct beam configuration to mimic the FEL-2 approach.

- *Performed pilot Res-CDI tests at the Co and Fe L-absorption edge.*
- *Developed new approach for combining edge-holography & CDI.*

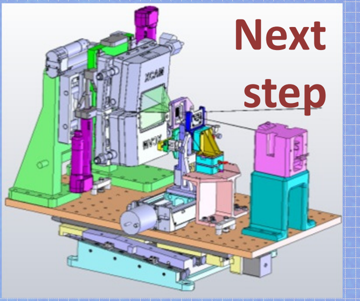
E. Pedersoli, *et al.*
RSI 82, 043711 (2011)

Commissionig @ FERMI FEL
(DiProl BL)



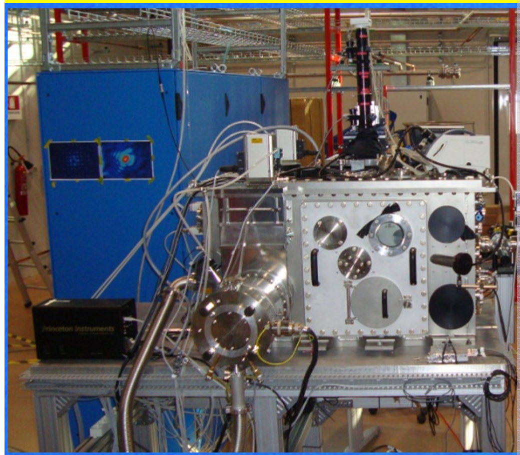
Since July – 2011 DiProl end-station is installed on dedicated FERMI BL

- ✓ *Aligned the optical axis of the instrument with respect to the FEL beam.*
- ✓ *Test measurements using pin-hole and regular arrays in integrative mode.*



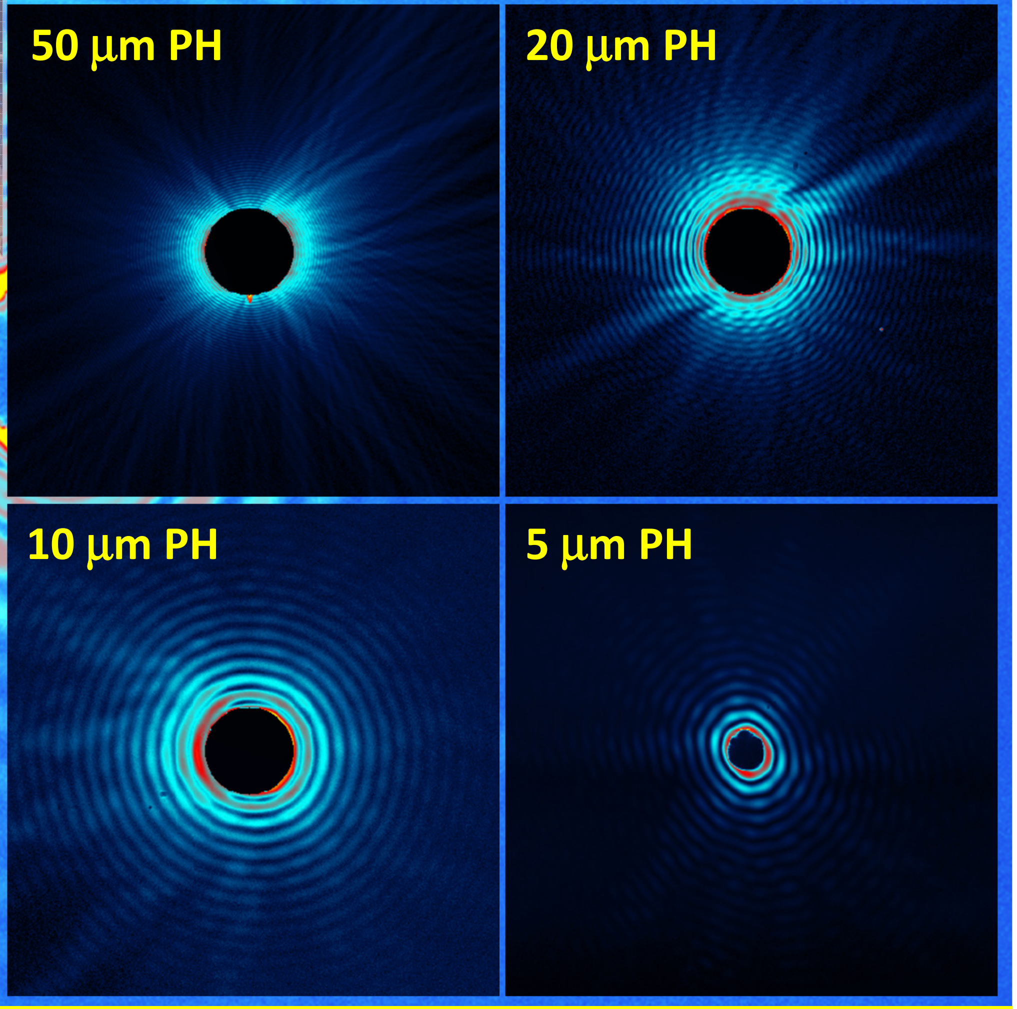
Install X-Cam CCD system shared with CFEL-DESY

First beam with FERMI-FEL

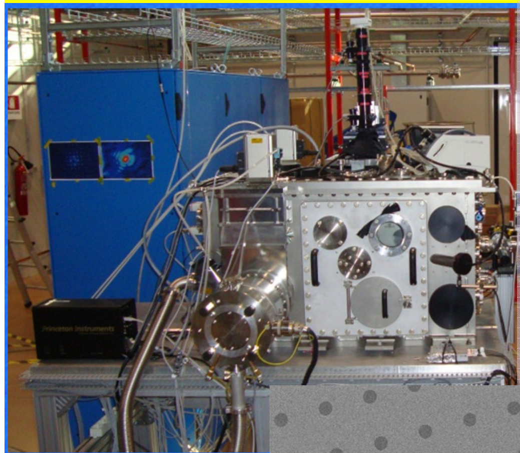


Since July – 2011 DiProI end-station is installed on dedicated FEL BL.
DiProI is the first end-station, of the FERMI@Elettra project, installed in its final position.

First test using FEL – radiation at 32.5 nm.
First images in integrative mode
(the focusing was not available).



First beam with FERMI-FEL



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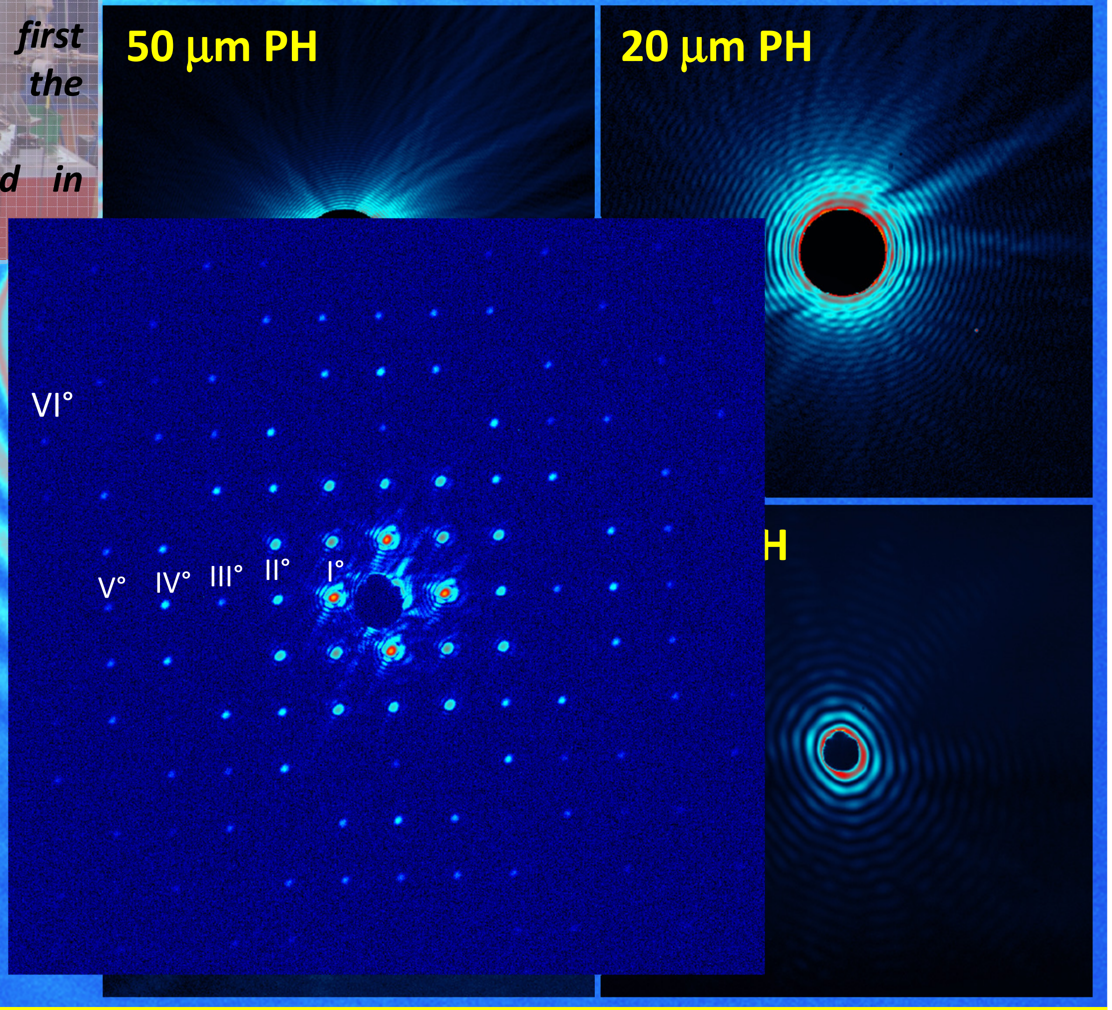
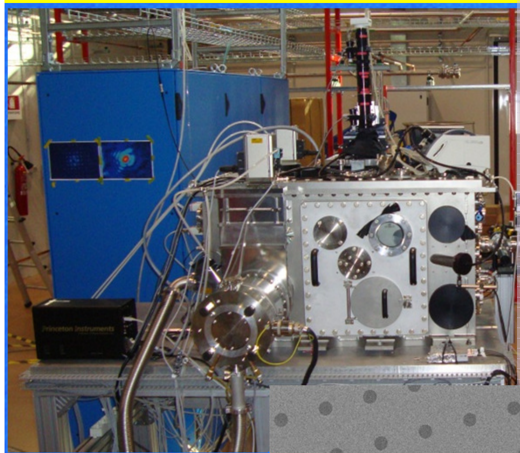


Coherence diffraction test with a periodic array. Beam passes through a 20 μm pin-hole, attenuated with Al filters. 6 diffraction orders demonstrate good FEL coherence. Interference fringes due to a finite dimension of the sample illuminated area are visible as well.

First beam with FERMI-FEL



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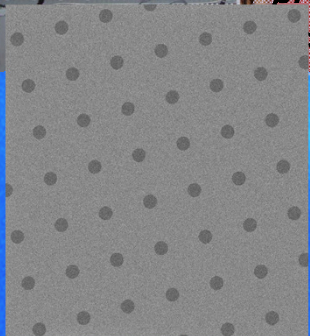

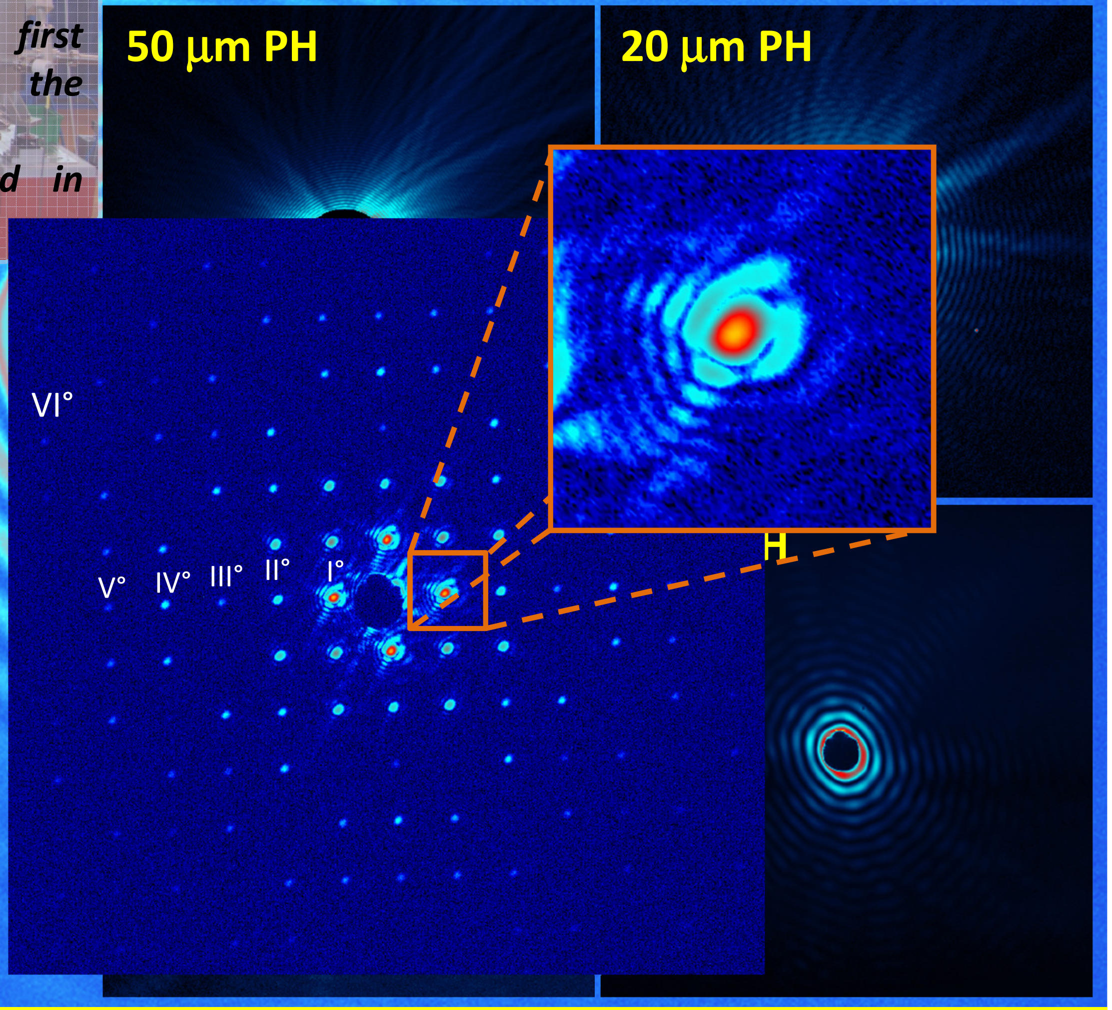

Coherence diffraction test with a periodic array. Beam passes through a 20 μm pin-hole, attenuated with Al filters. 6 diffraction orders demonstrate good FEL coherence. Interference fringes due to a finite dimension of the sample illuminated area are visible as well.

Topic 4

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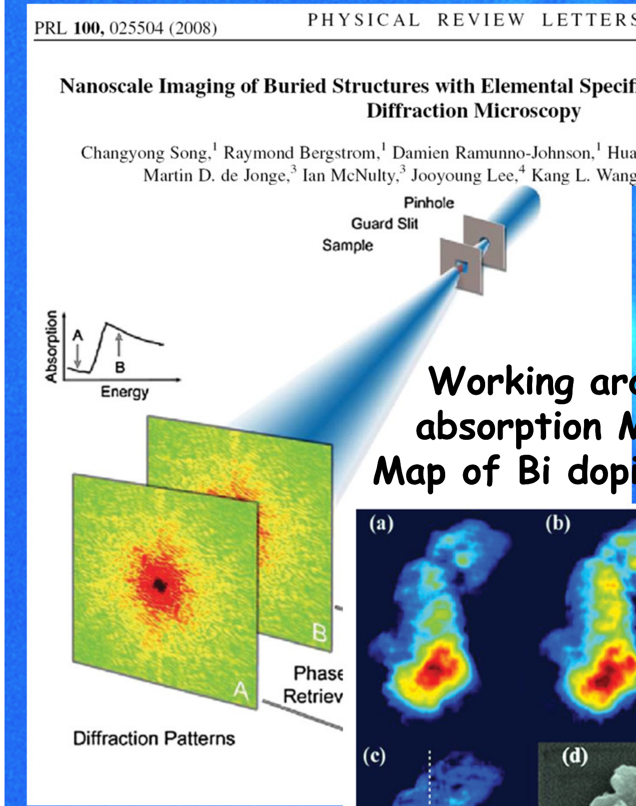
- ***Outlook: Res-CDI science perspectives at FERMI***

Why Res-CDI

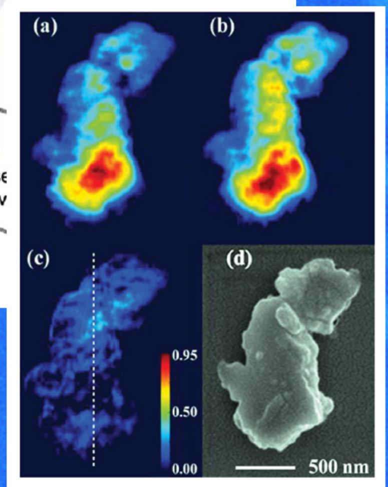
The speckle pattern: instantaneous capture of geometry and electron density. Res-CDI adds element and magnetic information.

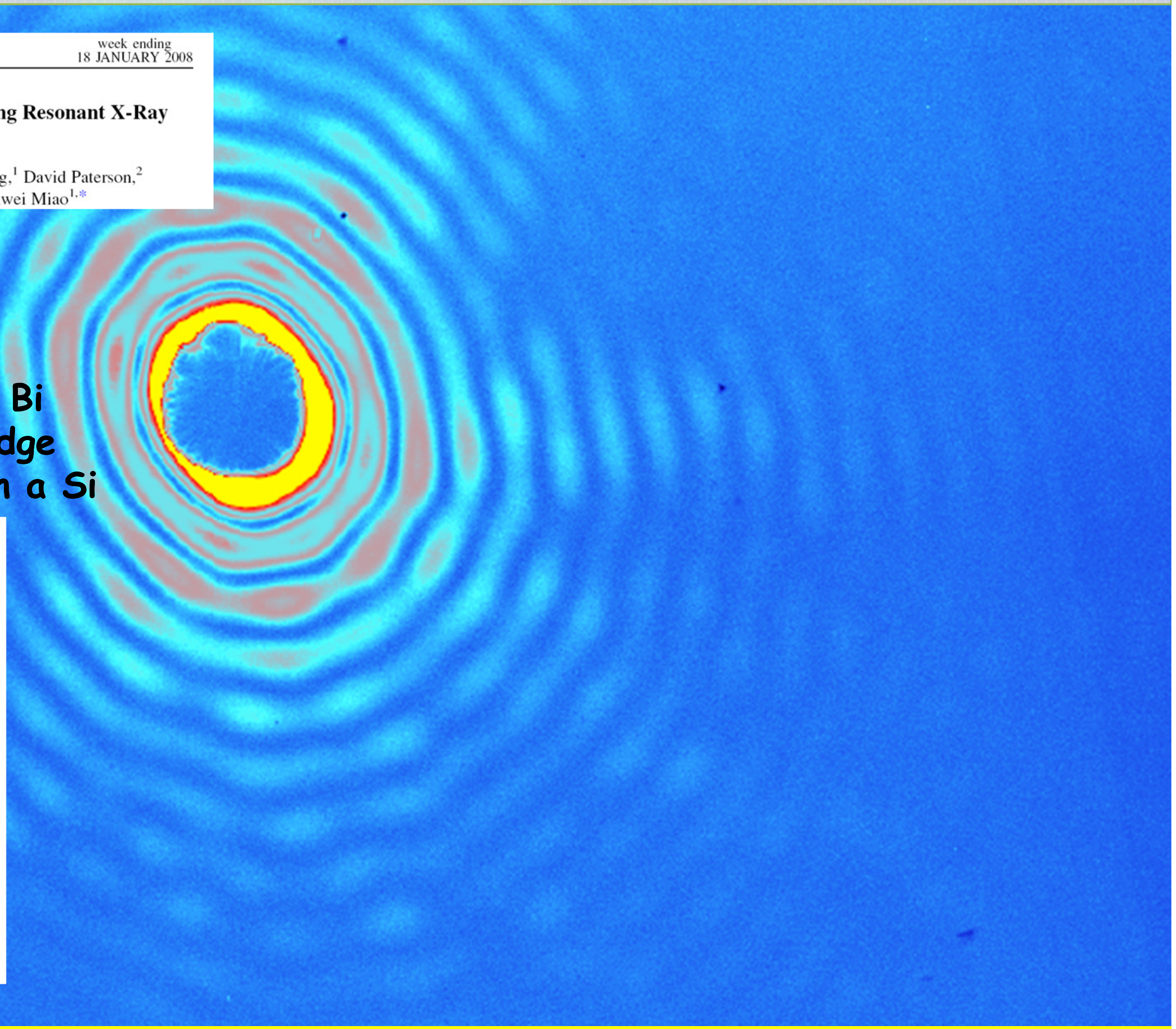

PRL 100, 025504 (2008) PHYSICAL REVIEW LETTERS week ending 18 JANUARY 2008

Nanoscale Imaging of Buried Structures with Elemental Specificity Using Resonant X-Ray Diffraction Microscopy

Changyong Song,[1] Raymond Bergstrom,[1] Damien Ramunno-Johnson,[1] Huaidong Jiang,[1] David Paterson,[2] Martin D. de Jonge,[3] Ian McNulty,[3] Jooyoung Lee,[4] Kang L. Wang,[4] and Jianwei Miao[1,*]

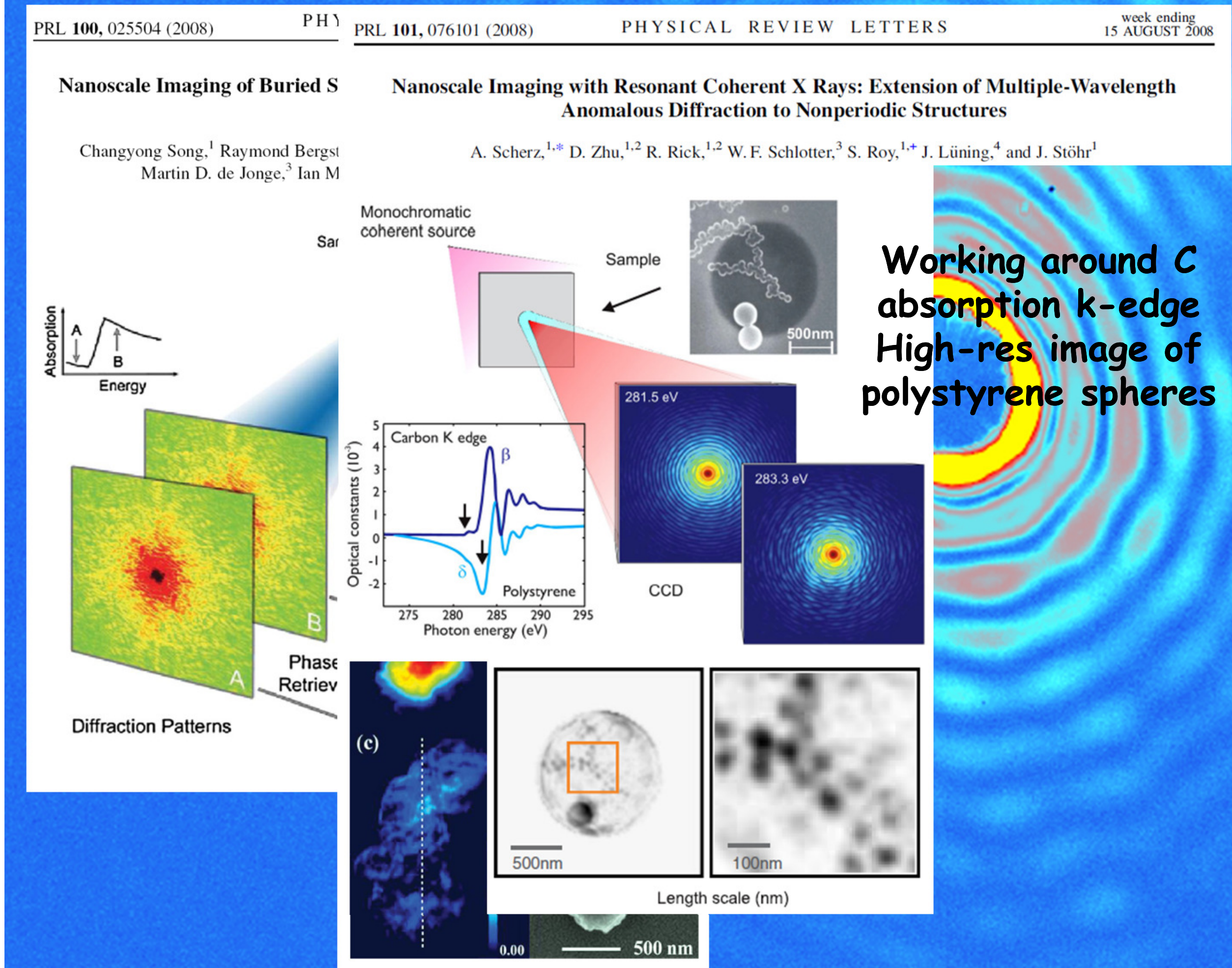
Working around Bi absorption M_5-edge
Map of Bi doping in a Si





Why Res-CDI

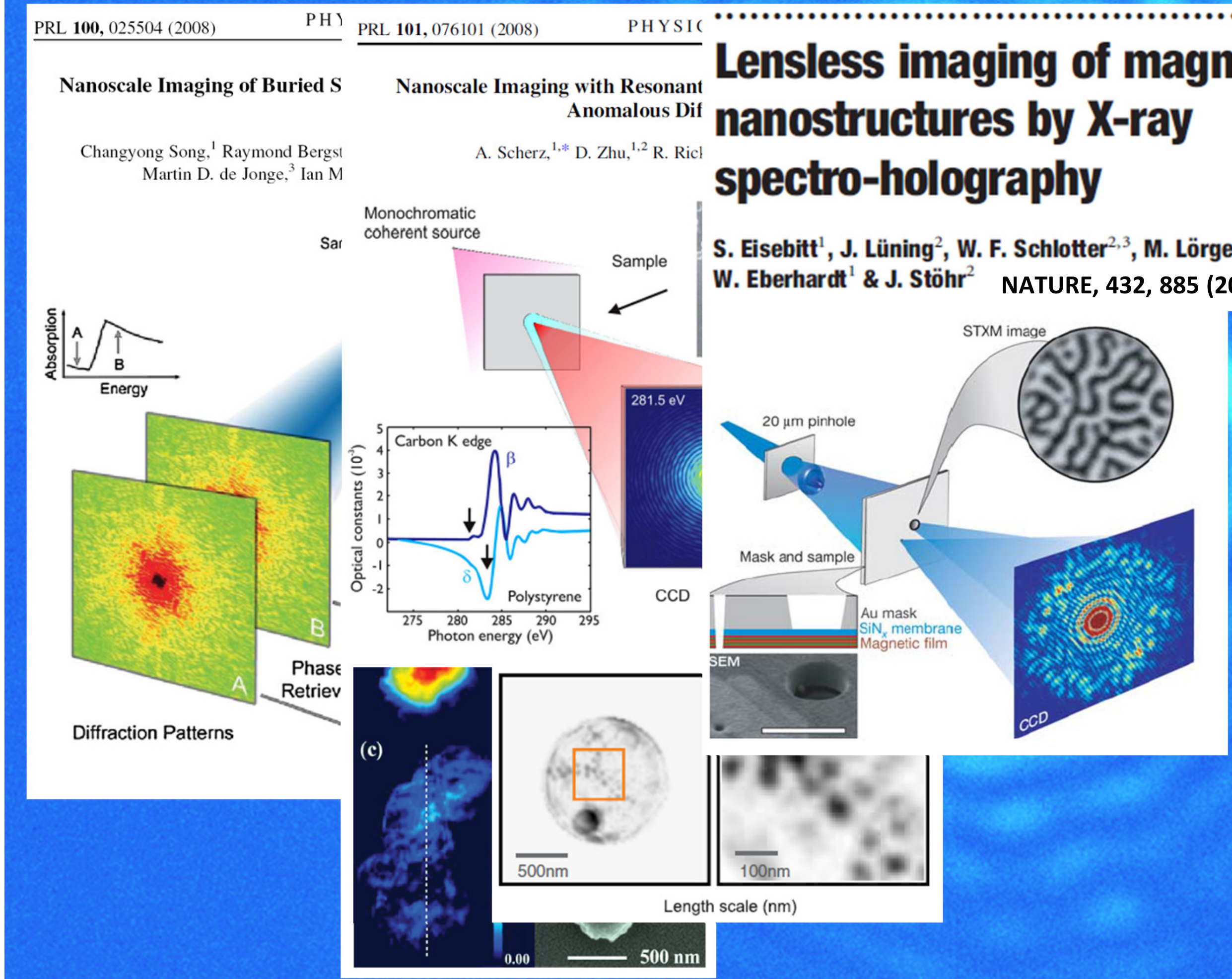
The speckle pattern: instantaneous capture of geometry and electron density. Res-CDI adds element and magnetic information.



Working around C absorption k-edge
High-res image of polystyrene spheres

Why Res-CDI

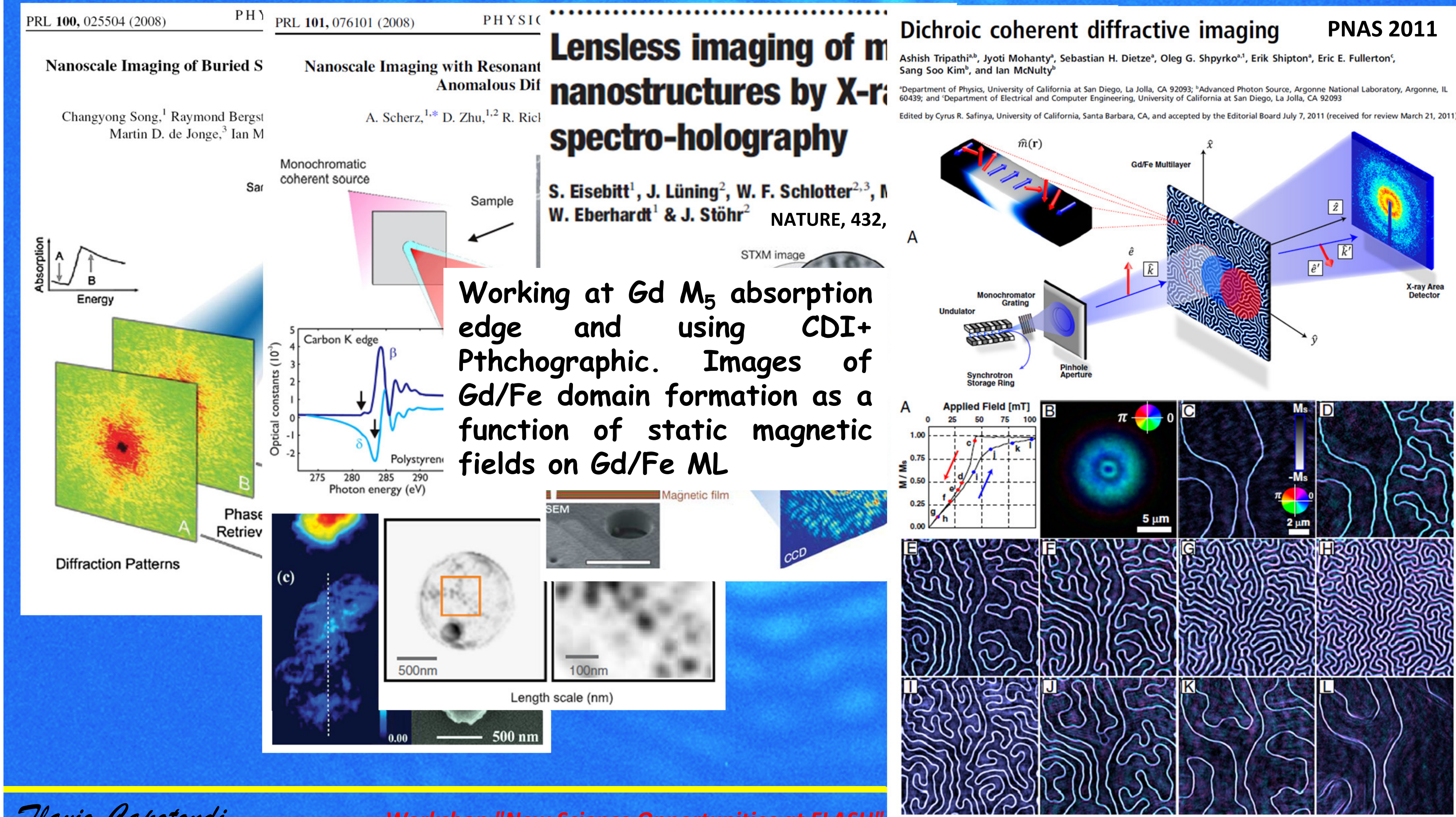
The speckle pattern: instantaneous capture of geometry and electron density. Res-CDI adds element and magnetic information.



Holographic image of random magnetic domains in a Co/Pt ML sample, Co L_3-edge absorption edge.

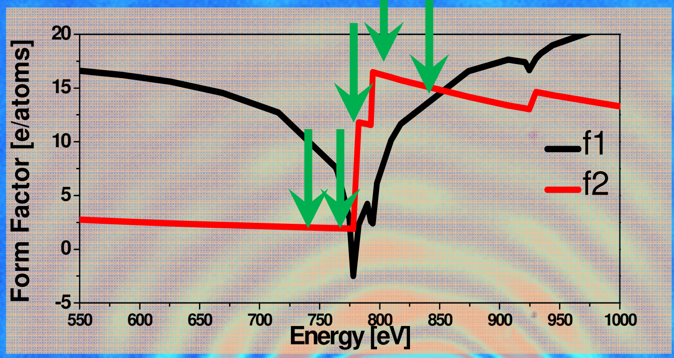
Why Res-CDI

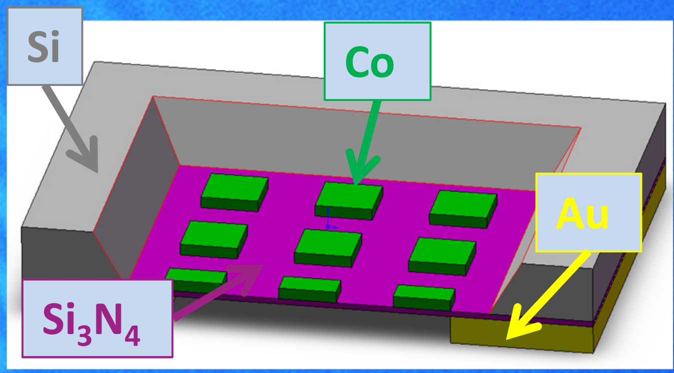
The speckle pattern: instantaneous capture of geometry and electron density. Res-CDI adds element and magnetic information.

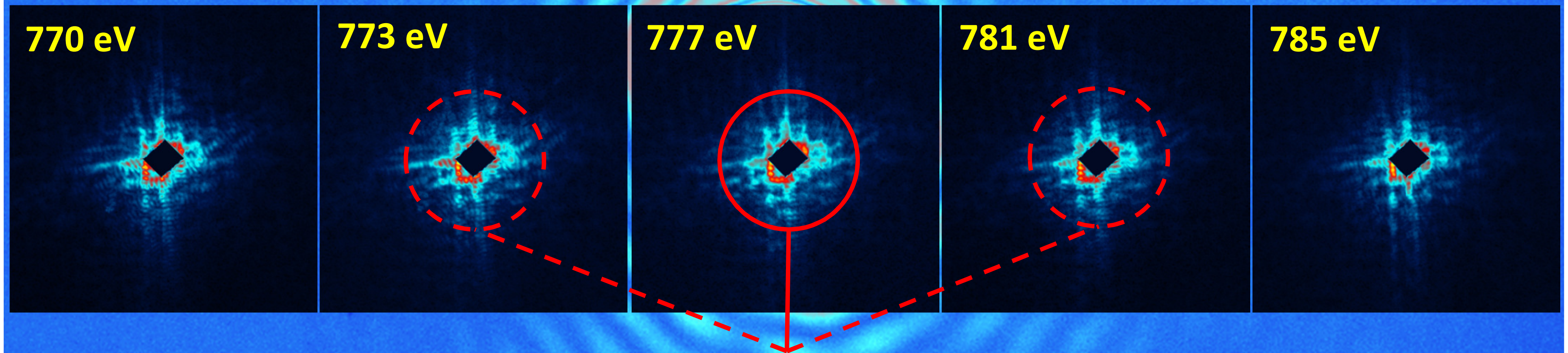


Working at Gd M_5 absorption edge and using CDI+ Pthchographic. Images of Gd/Fe domain formation as a function of static magnetic fields on Gd/Fe ML

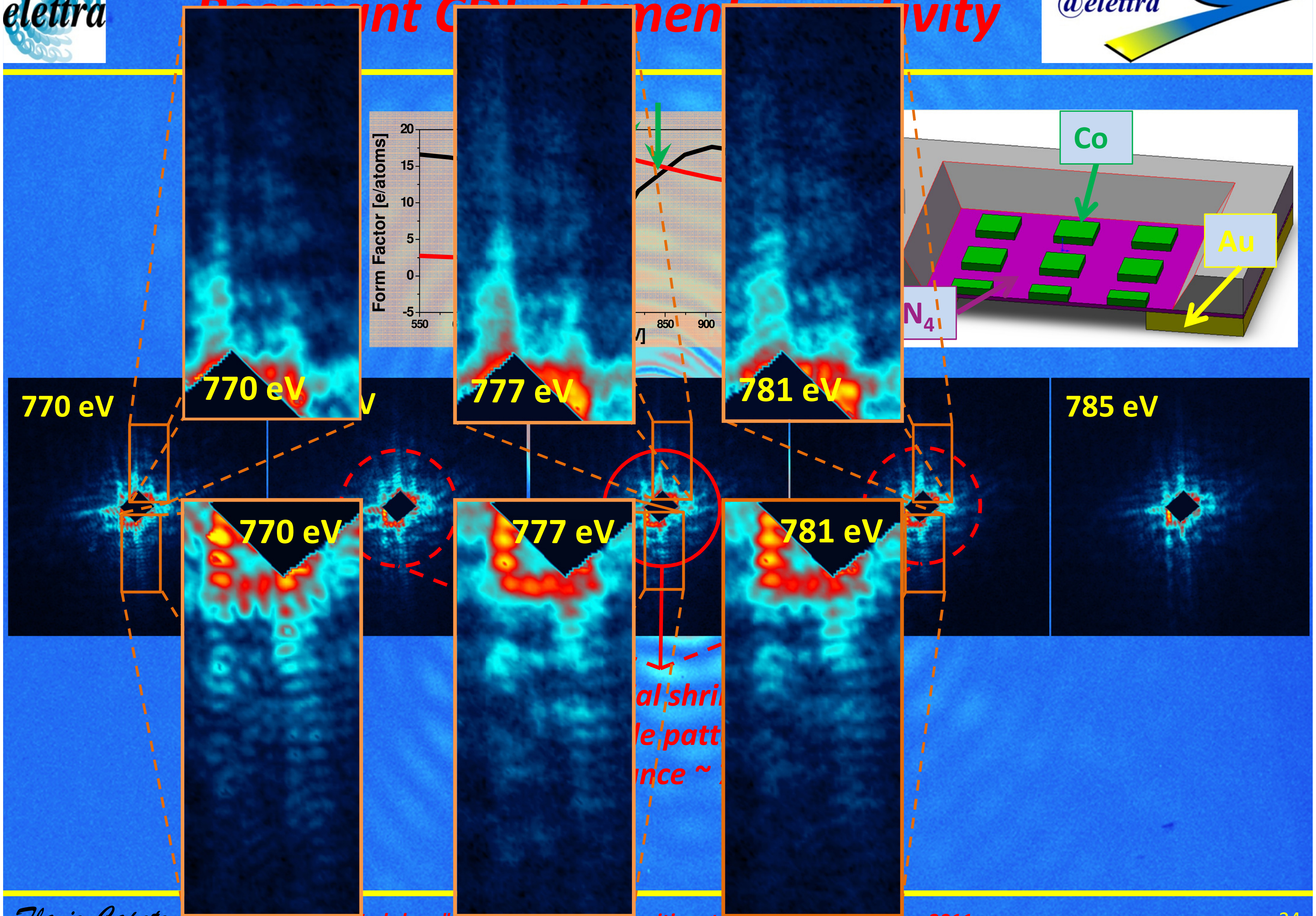
Resonant CDI: element sensitivity



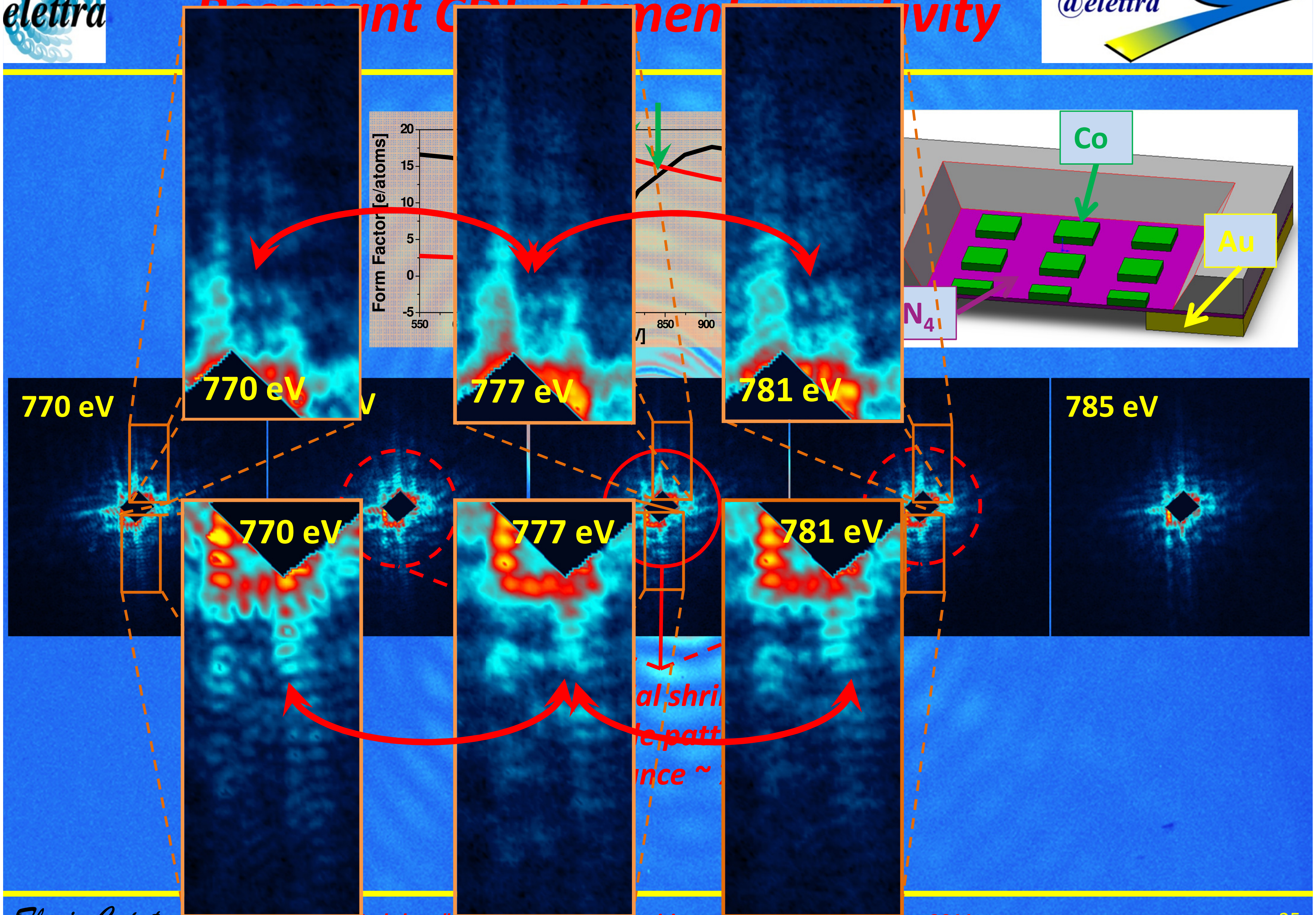




Partial shrink speckle pattern at resonance ~ 777 eV



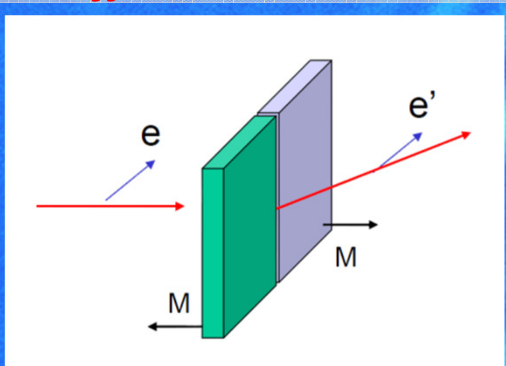
770 eV
777 eV
781 eV
785 eV
Form Factor [e/atoms]
Co
Au
N_4



770 eV
777 eV
781 eV
785 eV
Co
Au
N_4
Form Factor [e/atoms]
20
15
10
5
0
-5
550
850
900

Resonant CDI: magnetic sensitivity

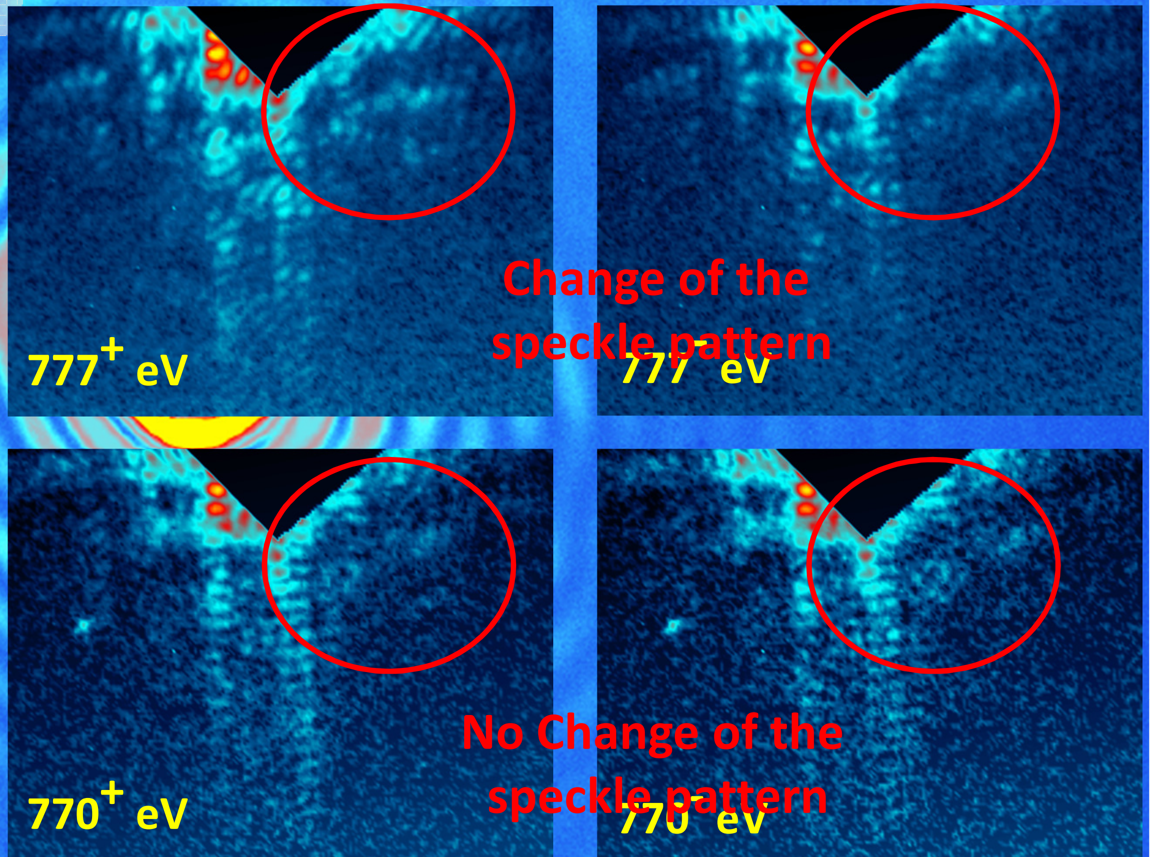
Left and right elliptically polarization of incomming beam enhance magnetic related component of sample's diffracted beam.



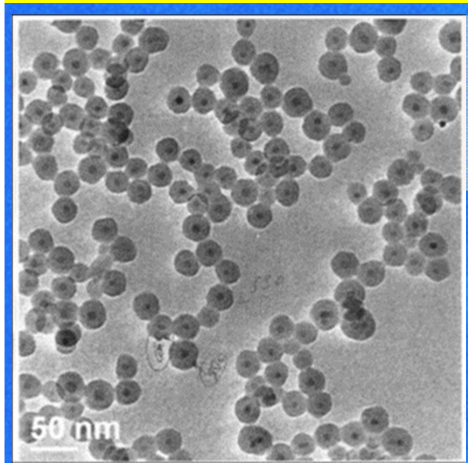
charge — magnetic — magnetic

$$f_n = \mathbf{e}'\cdot\mathbf{e}\,F_n^c - i(\mathbf{e}'\times\mathbf{e})\cdot\mathbf{M}_n F_n^{m1} + (\mathbf{e}'\cdot\mathbf{M}_n)(\mathbf{e}\cdot\mathbf{M}_n)F_n^{m2}$$

At resonance you
enhance this contribution
for out of plane magnetization
at normal incidence

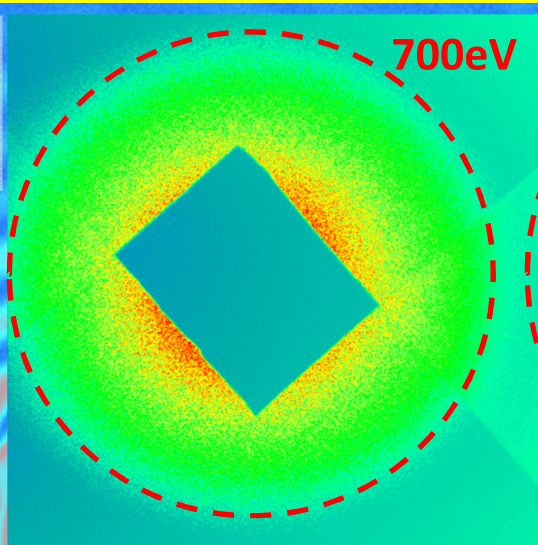


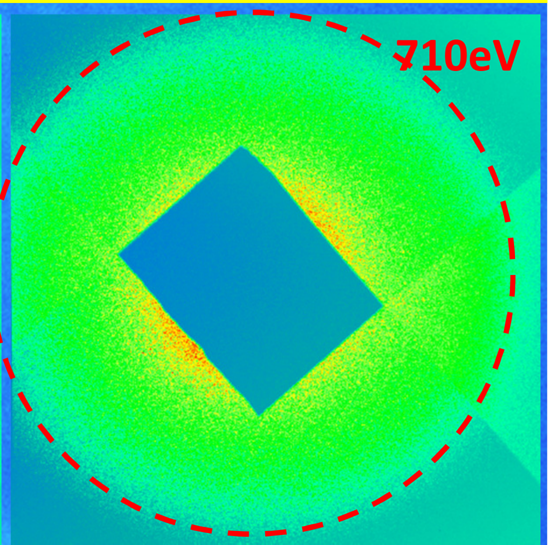
Resonant CDI core shell (... more)

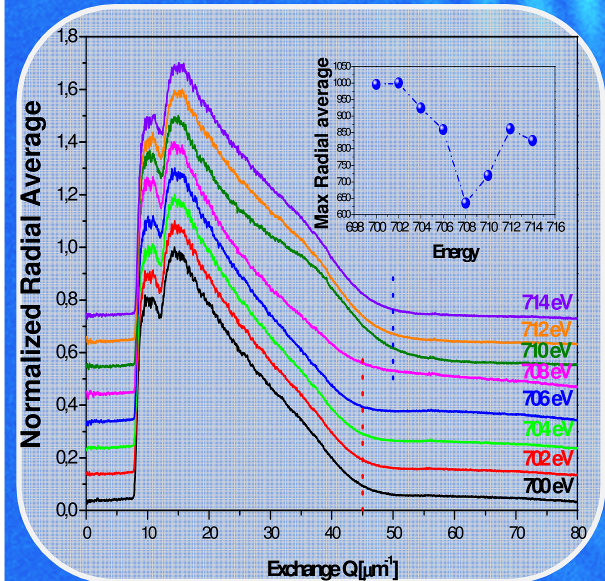


Sample cortesy A. Nelson

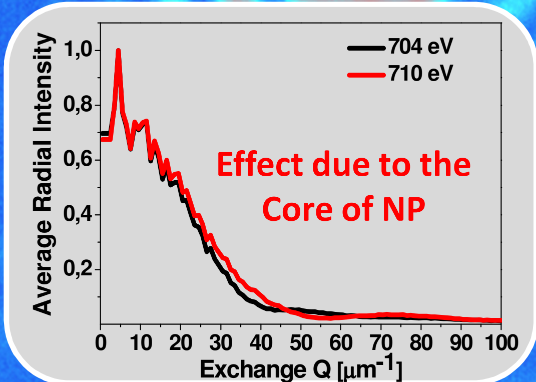
CS nanoparticle 35-40 nm
$CoFe_2O_4$ as core (~15 nm)
SiO_2 as shell (~15 nm).
About 100 particle/μm^2



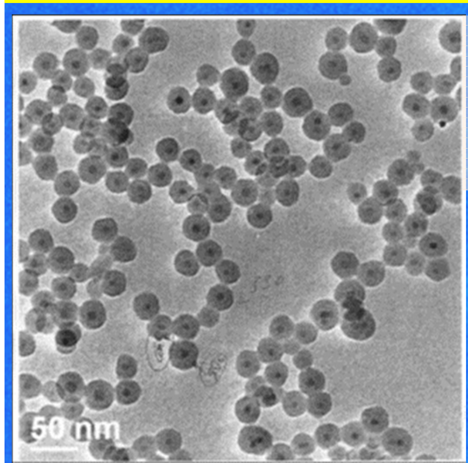




Considering the optical constant change at resonance a simple model reproduces the shift of minima.

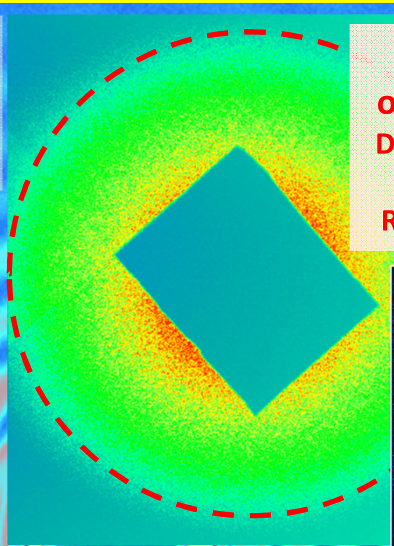


Resonant CDI core shell (... more)



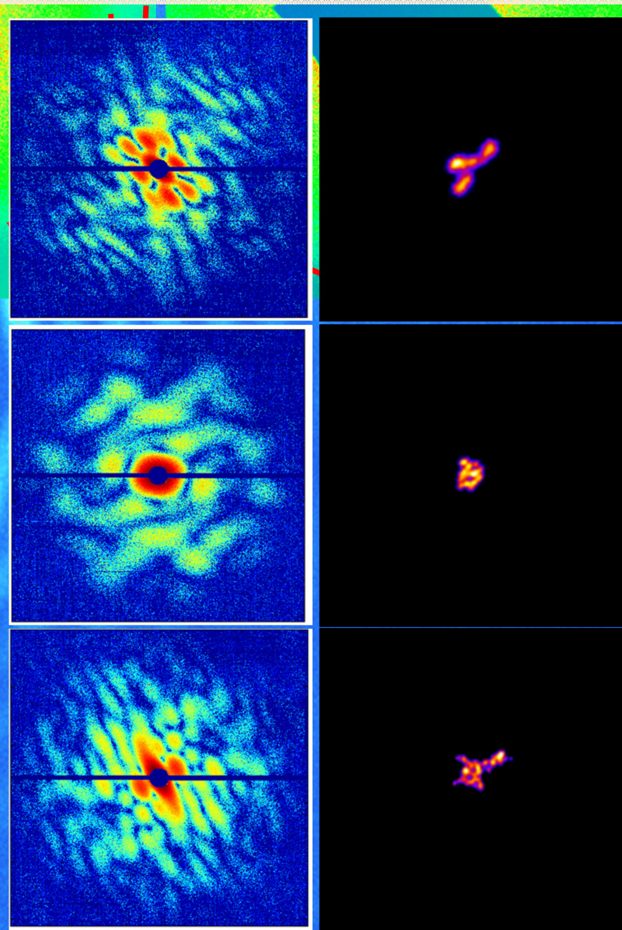
CS nanoparticle 35-40 nm
$CoFe_2O_4$ as core (~15 nm)
SiO_2 as shell (~15 nm).
About 100 particle/μm^2

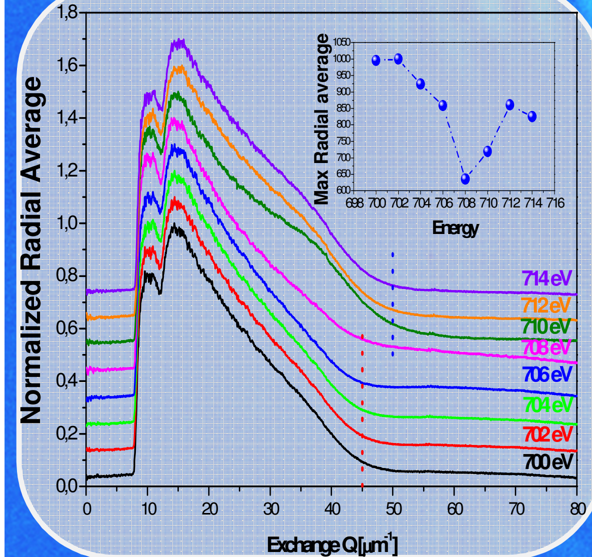
Sample cortesy A. Nelson



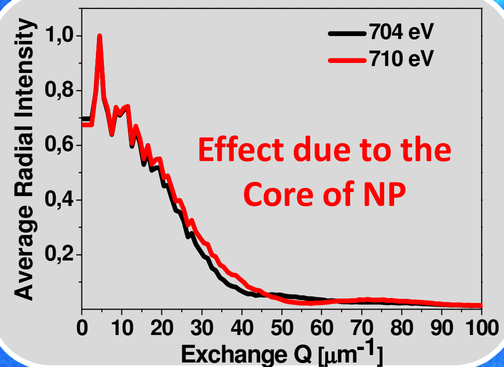
Injected CS nanoparticle on LCLS beam @ 1.2KeV (CAMP-Chamber)

Data collection in collaboration with H.Chapman, M.Bogan, A.J. Nelson, J.Hajdu, E.Pedersoli.
Reconstruction in collaboration with A.V. Martin

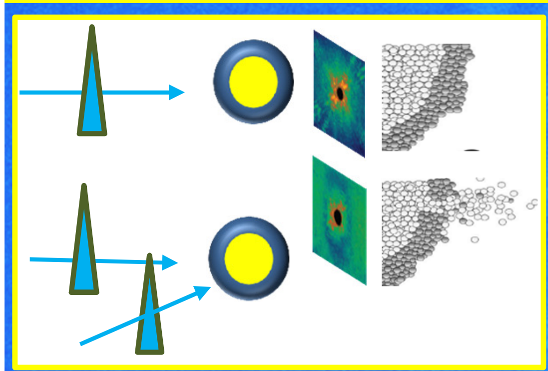




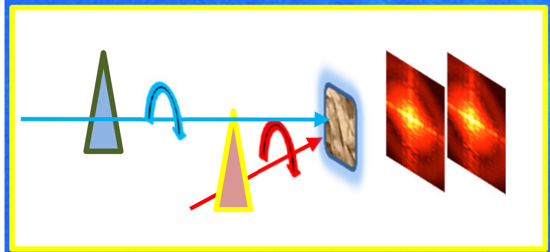
Considering the optical constant change at resonance a simple model reproduces the shift of minima.



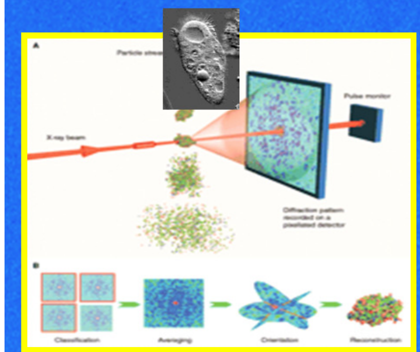
FERMI full longitudinal coherence is opening new opportunities for single shot Res-CDI: chemical and magnetic information



Exploring the behaviour of anisotropic nanostructures, fabricated by different elements, e.g. under "extreme conditions" or in variable chemical environment:
spatial evolution of the constituent elements at different time scales, using as a pump an optical laser or a split in time FEL pulse. (LLNL, SLAC, CFEL)



Exploring the multiple polarization of the Fermi pulses through resonant CDI, used to enhance the magnetization scattering contrast by tuning the pulse wavelengths to the *M* (1st harmonics) or *L* (higher harmonics) edges of the relevant elements. Time resolved experiments using autocorrelator or pump laser. (Partners & Spezzani, Mentes, Sacchi, Lüning…)



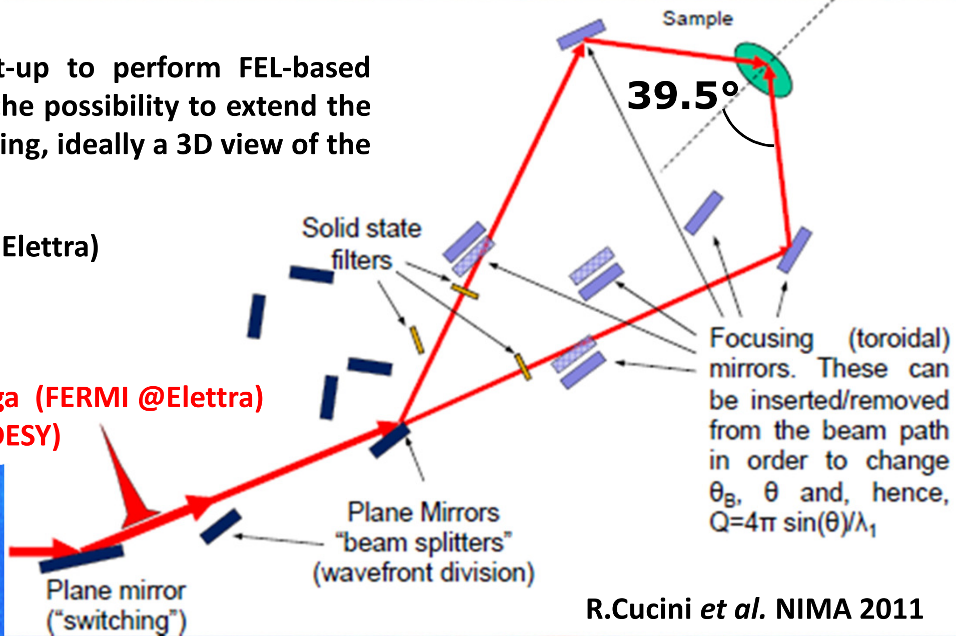
CDI of living cells: monitoring the conformation states of the constituents of these dynamic systems. Sufficient penetration depth between the C1*s* and O1*s* edge (FERMI-2) and the radiation damage is still negligible for pulse lengths up to 100 fs. <u>Important issue of nanotoxicology:</u> effect of different agents (e.g. NPs) on morphology modifications of single-cell organism and agent distribution.
(CFEL-Uppsala-FERMI) ***<u>TRIAL FOR SINGLE SHOT 3D IMAGING</u>***

Future Up-Grade (stero/strobo-CDI)

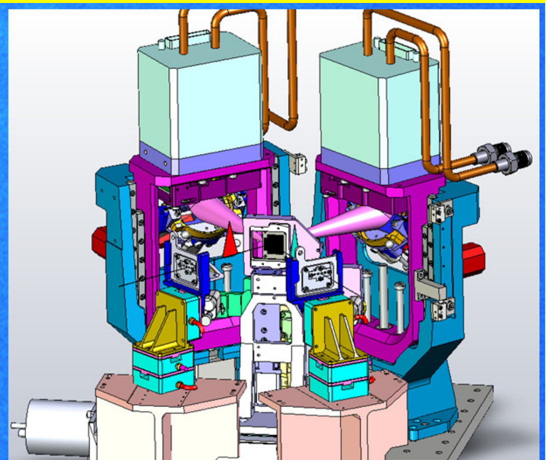
•**Aim of the project:**
Realize an experimental set-up to perform FEL-based experiments which exploits the possibility to extend the CDI technique to stereo-imaging, ideally a 3D view of the investigated object.

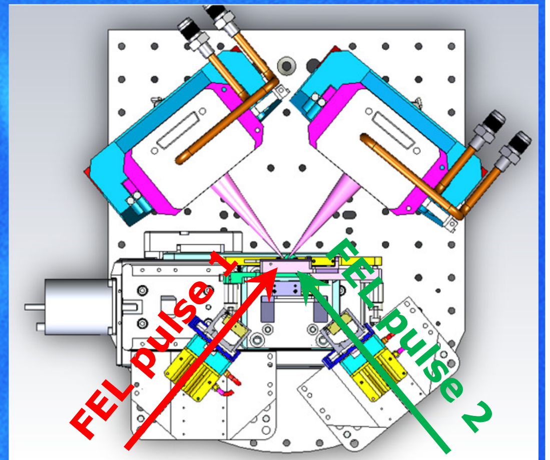
TIMER-EIS Beamline (Fermi@Elettra)
Optical design M.Zangrando

In collaboration with:
C.Masciovecchio, F.Bencivenga (FERMI @Elettra)
S.Bajt, H.N. Chapman (CFEL-DESY)

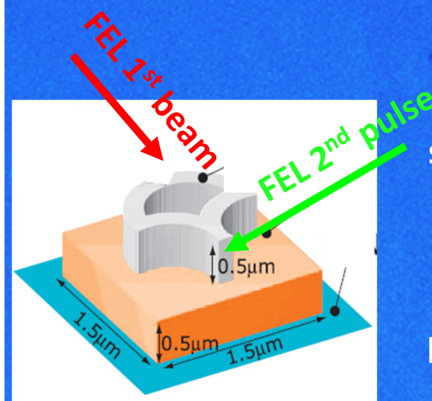


R.Cucini *et al.* NIMA 2011

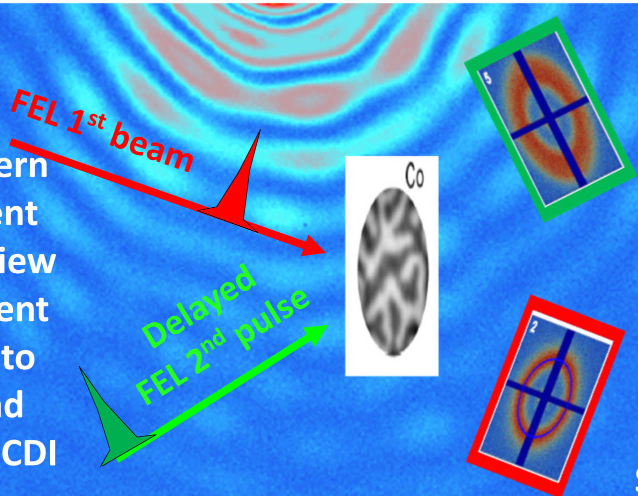




Possible experiments



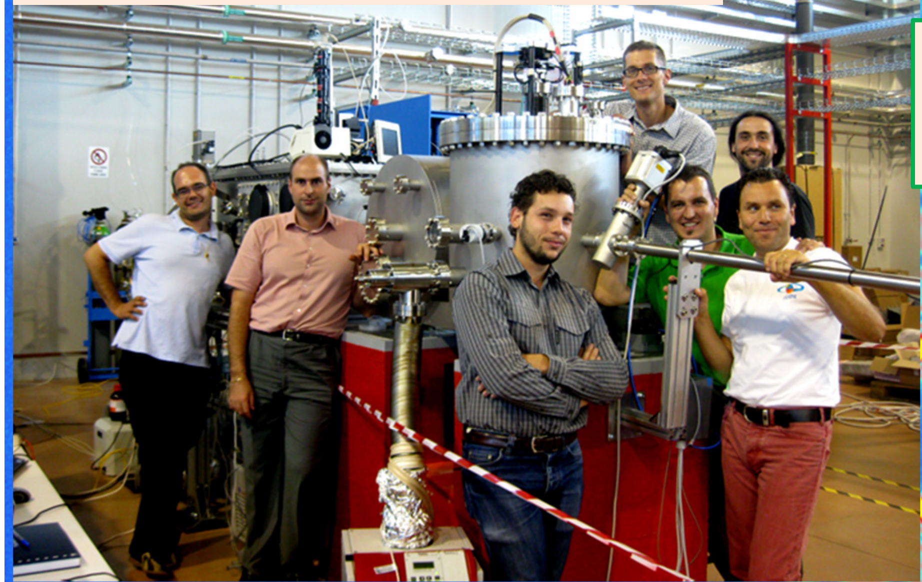
Diffraction pattern strongly different since different view angle has different feature, easier to reconstruct and perform a stero-CDI



Res-CDI,
Strobo FEL-FEL P&P experiment recorded on different CCD.
Strobo-CDI (ML-mirror λ=20 nm)

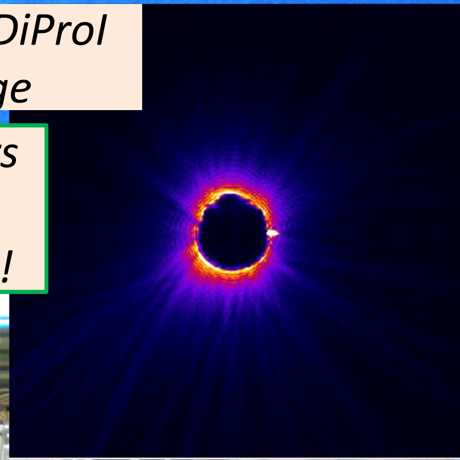
MOVING AHEAD

__22-07-11 5:00 p.m.__ DiProl
connected to FERMI beamline



Left to right: F.Capotondi,E.Pedersoli, C.Svetina,M.Zangrando,
R.Cucini, R.Gobessi, D.Cocco

__26-07-11 12:00 a.m.__ DiProl
First FEL-CDI image



Optical axis of 3 chambers
aligned in only 4 days
starting from a scratch !!!

DiProl Experimental Team

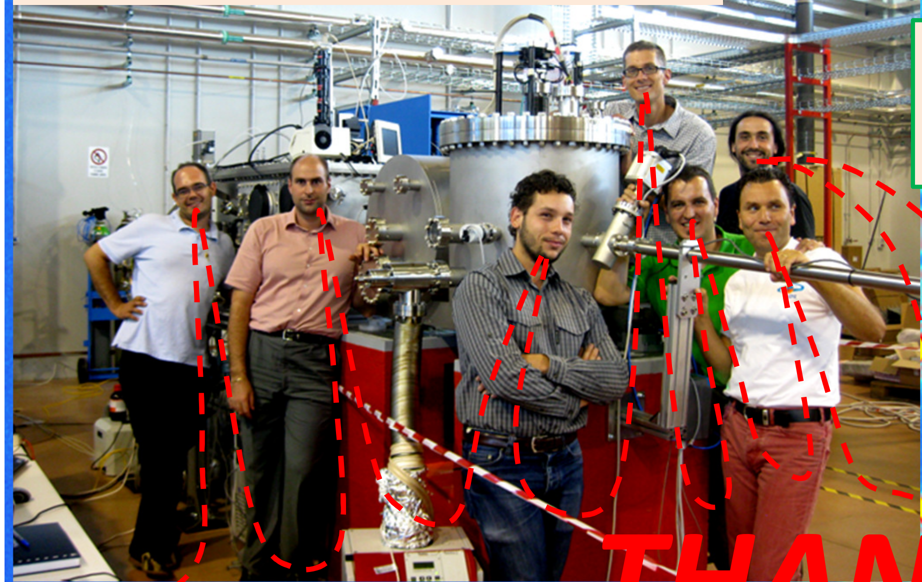
Left to right: R.H. Menk, F.Capotondi, E.Pedersoli, M.Kiskinova

Acknowledgements

G. Passos (Software develop), G.Sandrin (Technician)
and the over 50 members of Fermi TEAM

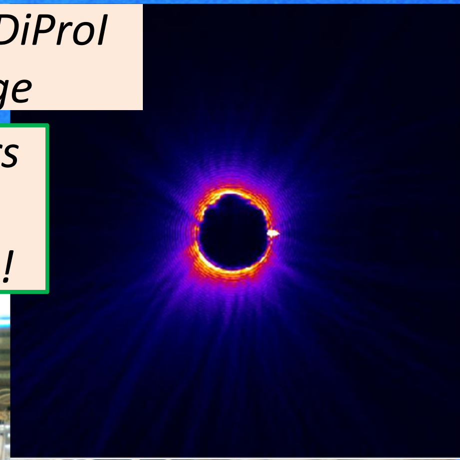
MOVING AHEAD

22-07-11 5:00 p.m. DiProI
connected to FERMI beamline



Left to right: F.Capotondi,E.Pedersoli, C.Svetina, M.Zangrando, R.Cucini, R.Gobessi, D.Cocco

26-07-11 12:00 a.m. DiProI
First FEL-CDI image



Optical axis of 3 chambers aligned in only 4 days starting from a scratch !!!

DiProI Experimental Team

Left to right: R.H. Menk, F.Capotondi, E.Pedersoli, M.Kiskinova

THANK YOU FOR YOUR ATTENTION !!!

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