Challenges and opportunities for pump-probe spectroscopy at synchrotron radiation sources

Fausto Sirotti (PMC, Polytechnique & SOLEIL- Synchrotron)

TREES, Trieste- December 3rd 2018

Summary

- Which pump which probe
- Examples
  - Magnetization dynamics
    - In real and reciprocal space
  - Electronic structure & phase transition
    - in FeRh and half metal manganite
- Discussion & Conclusion

Which Pump, which probe

Exciting Pump:

- Magnetic pulse
- **Electric/current pulse**
- **Laser pulse**

Measuring probe:

- **Synchrotron Pulse**
- Laser Pulse
- HHG
- FEL

Repetition rate
Energy/pulse

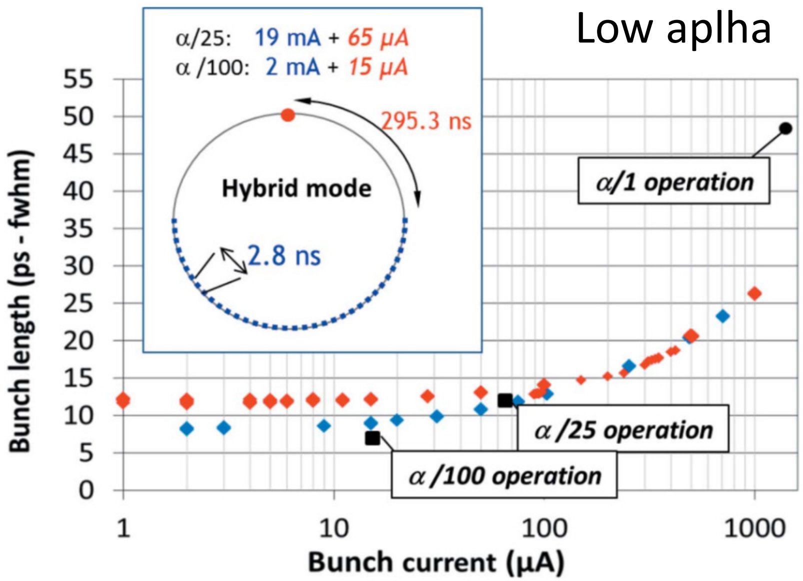
↔

Repetition rate
Photons/pulse

Excitation is essential to define the experiment
Changing excitation is like changing the sample

Short pulses: slicing <–> low alpha

Low aplha



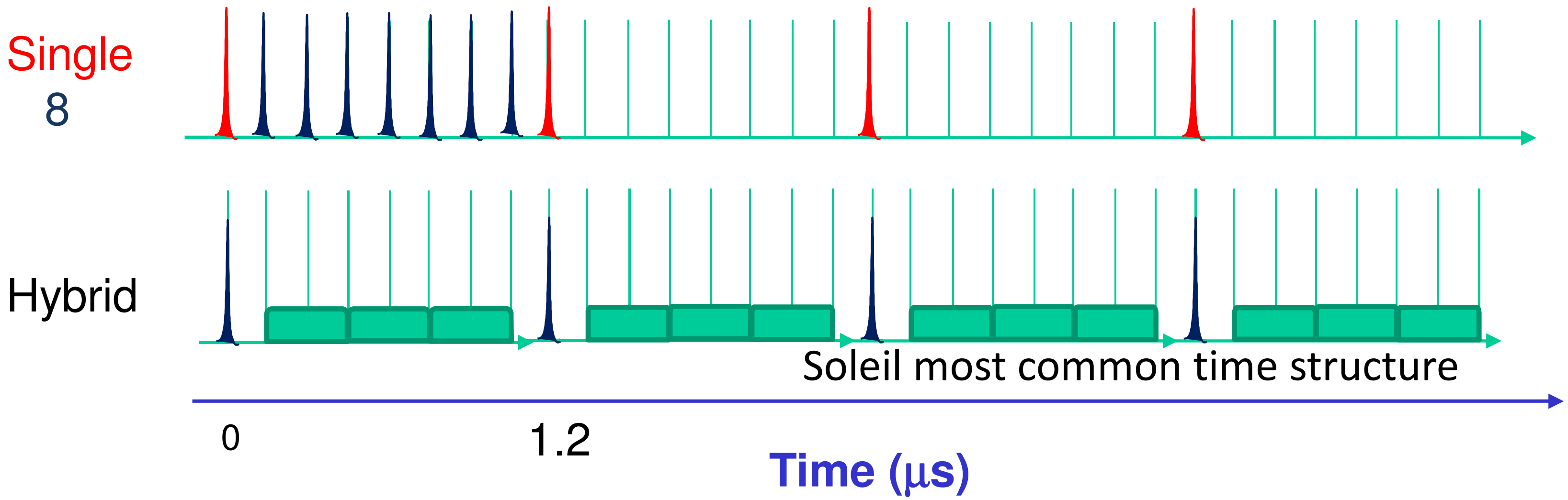
J. Synchrotron Rad. (2017). 24, 886–897

Slicing photon flux ?
$10^6 – 10^7$?

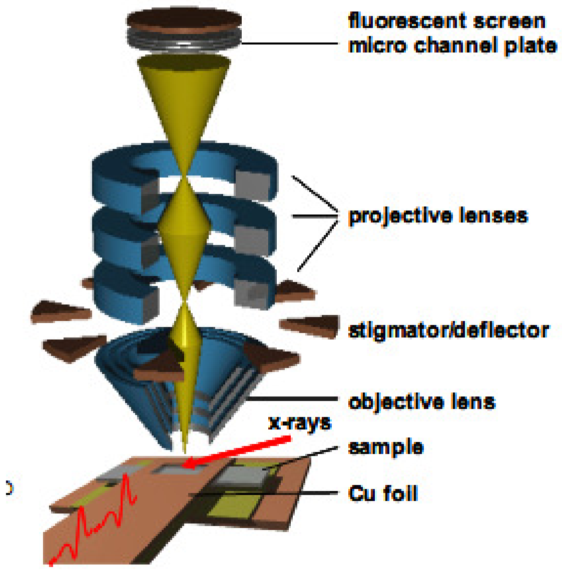
- Total flux
- Repetition rate

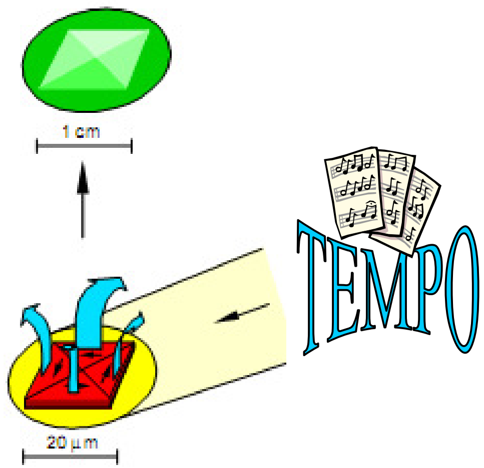
Synchrotron radiation
Time structure

Synchrotron pulse duration: 50 ps
High repetition rate.



Magnetization Dynamics



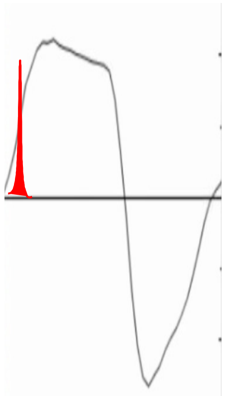


J. Vogel Institut Néel
V. Uhlir
S. Pizzini
N. Rougemaille
L. Ranno
O. Fruchart
V. Cros CNRS/Thales
E. Jimenez
J. Camarero Universidad Autonoma de Madrid,
C. Tieg ESRF

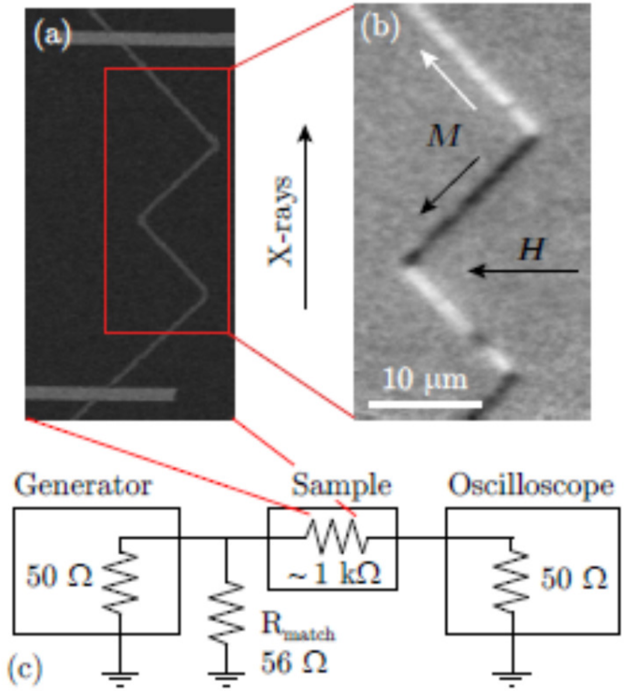
Phys. Rev. B, 2010, 81(22),224418
Phys. Rev. B, 2011, 83(2),020406
Phys. Rev. Lett., 2012, 108(24),247202

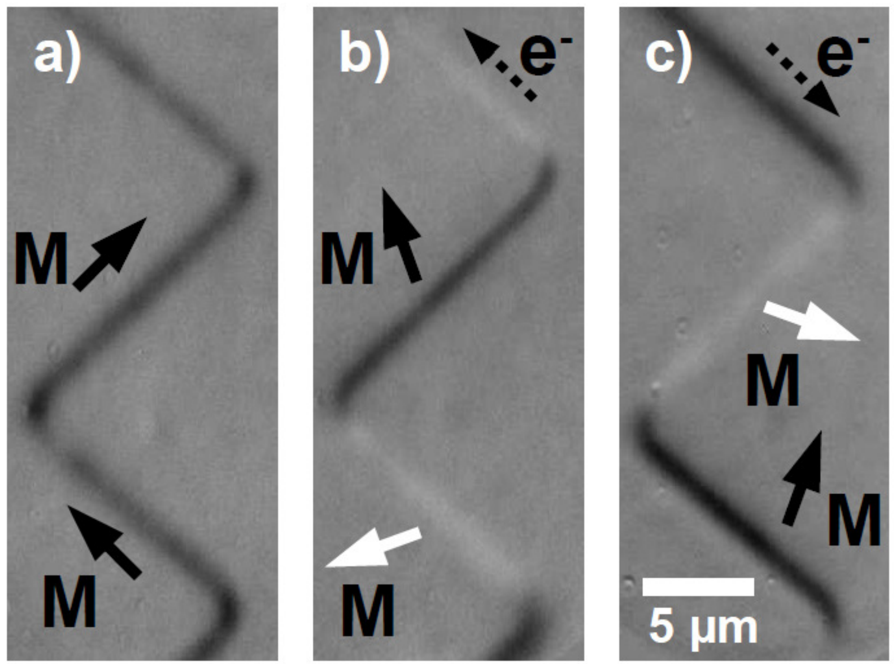
Synchrotron radiation
Time structure

Synchrotron pulse duration: 50 ps
High repetition rate: 6 MHz ,

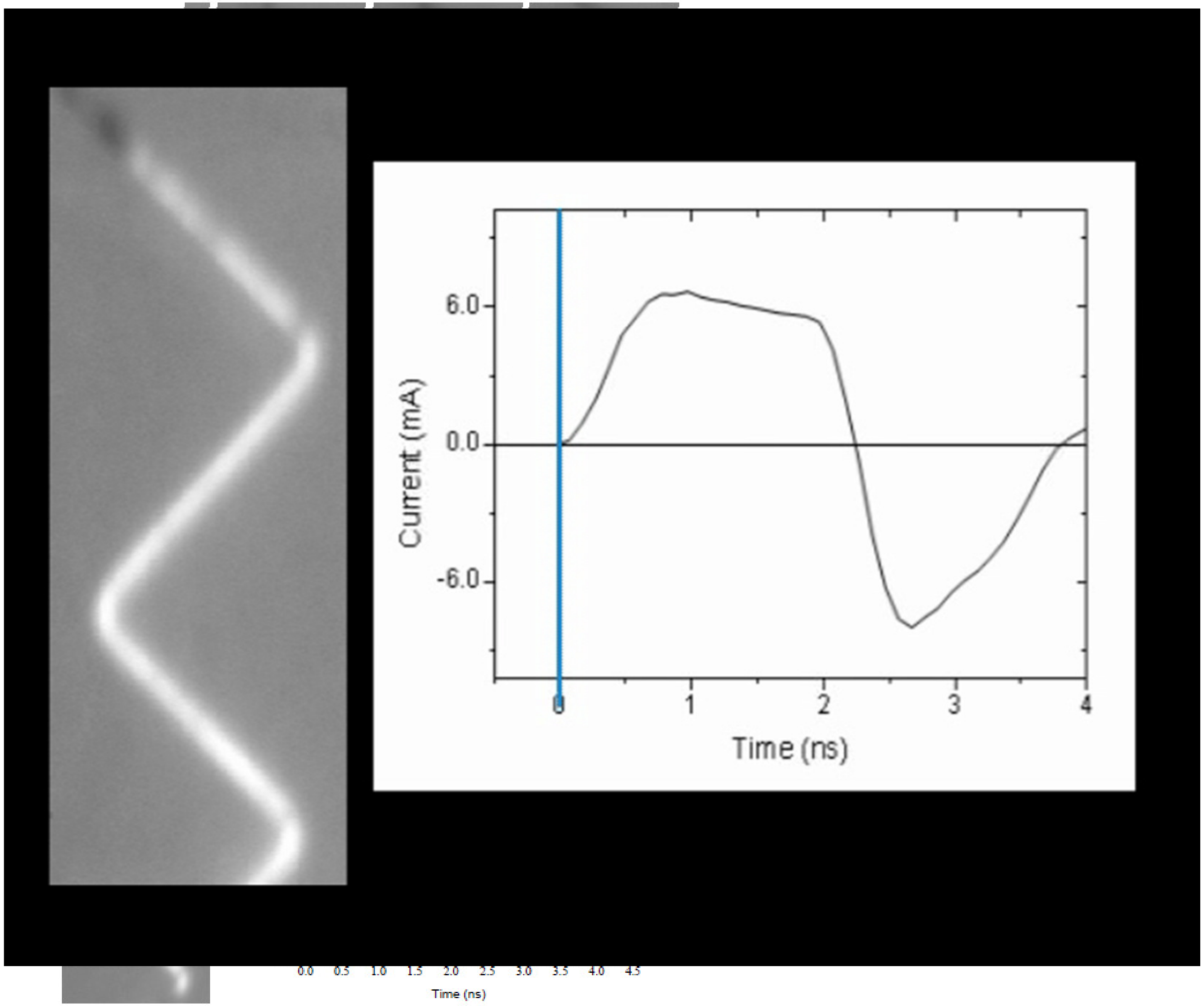


Magnetization Dynamics

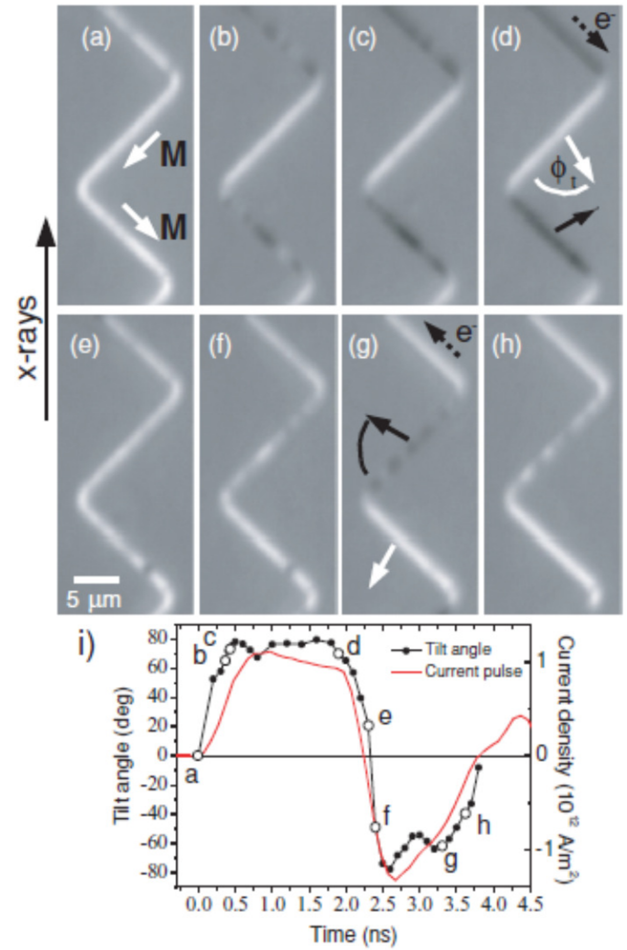




Magnetization Dynamics



Electron microscopy with polarized X-rays



Study of laser excitations in nanostructures:
Electron transport, heat transport

Imaging secondary electrons
XMCD contrast – element specific

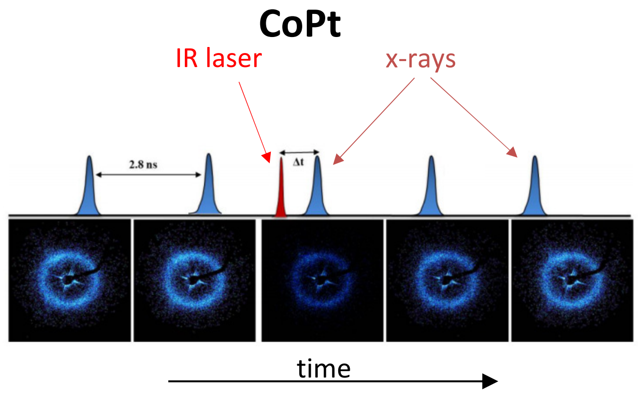
Could be done in low alpha mode,
Slicing only with high repetition rate

Samples are the challenge

Phys. Rev. B, 2011, 83(2),020406

Magnetization Dynamics

ps Time Resolved Resonant Magnetic Scattering Using SOLEIL's Low-Alpha Mode



Synchrotron SOLEIL (SEXTANTS)
Horia Popescu, Victor Lopez-Flores, Maurizio Sacchi, Nicolas Jaouen

Synchrotron SOLEIL (TEMPO)
Mathieu Silly, Christian Chauvet, Fausto Sirotti
Philippe Hollander

LCPMR, Paris VI
B. Tudu, R. Delaunay, J. Lüning

Synchrotron SOLEIL (Sources)
Marie-Agnès Tordeux , Amor Nadji

ELETTRA (Detectors and Instrumentation
Luigi Stebel, Rudi Sergo, Giuseppe Cautero

IPCMS, Strasbourg
Christine Boeglin

LPS, Orsay
Gregory Malinowski

SPINTEC, Grenoble
Marina Tortarolo

CSNSM, Orsay
Cédric Baumier, F. Fortuna

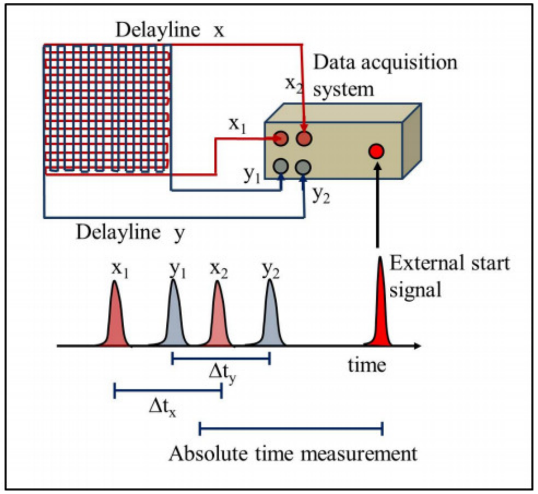
FemtoSlicing

Specificities TEMPO

2D time resolved detector (Elettra)

MCP

Single count detector :



4 Mcounts/s

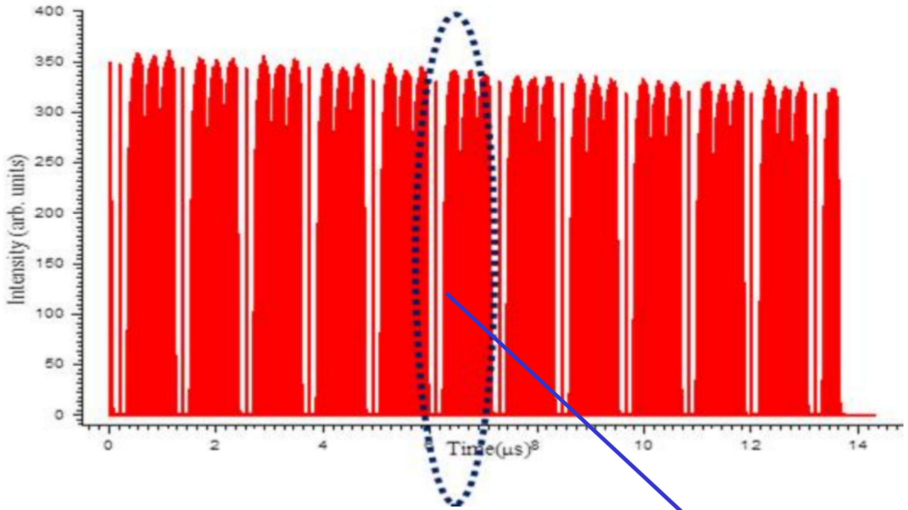
27 ps temporal resolution

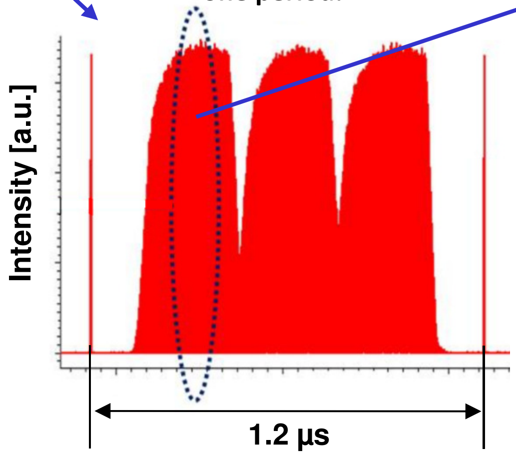
60 µm spatial resolution

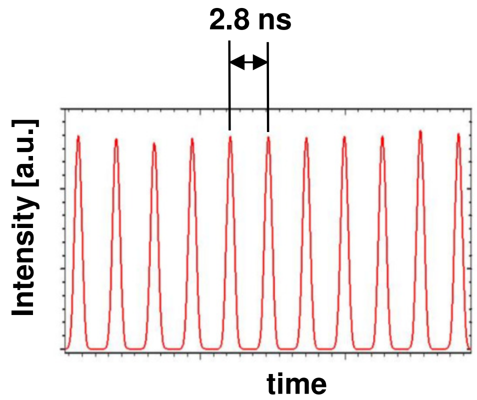
G. Cautero et al. / Nuclear Instruments and Methods in Physics Research A 595 (2008) 447–459 :

Low-Alpha time hystogram as seen by the detector

70 kHz: 12 synchrotron periodes





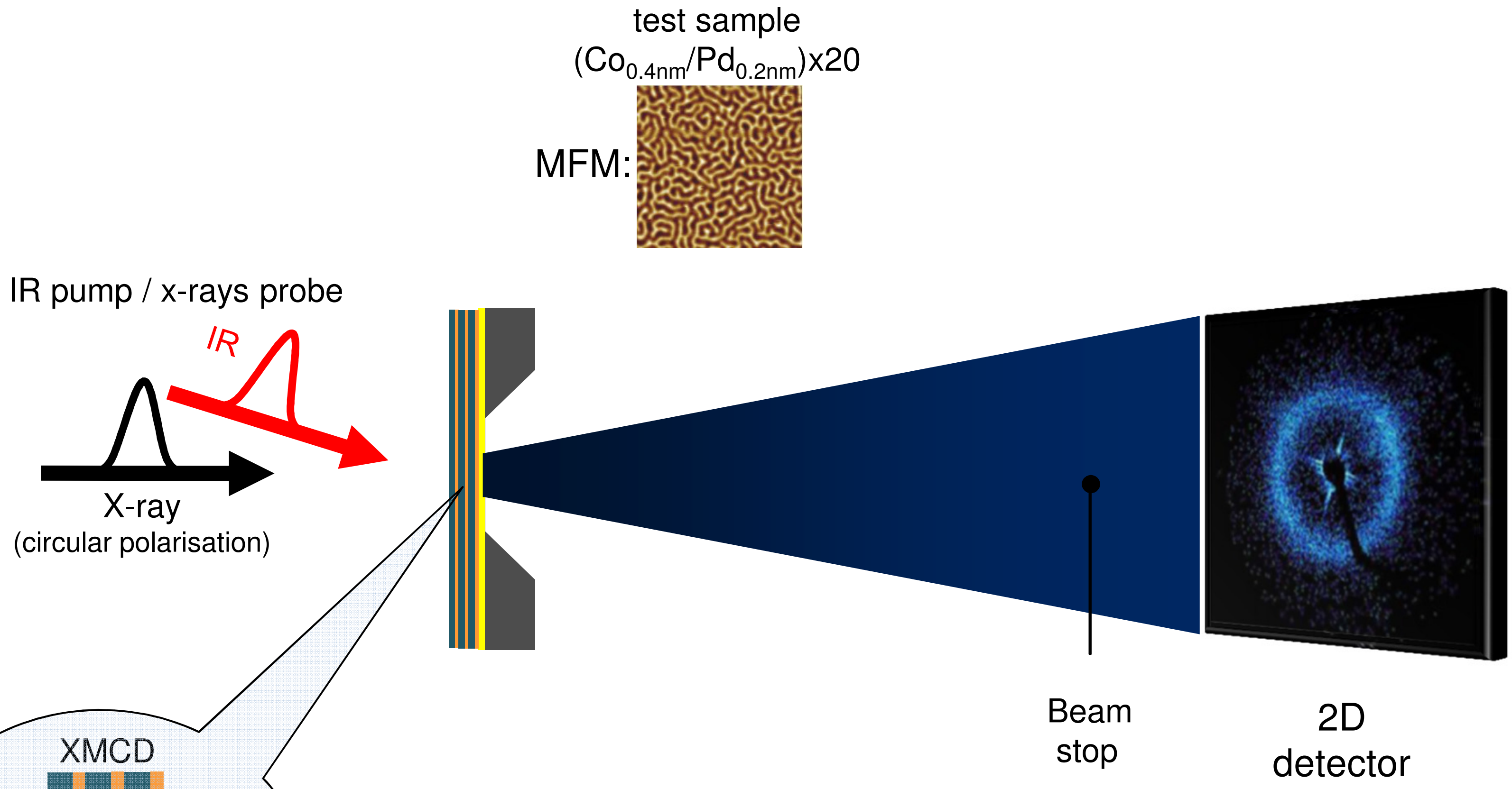


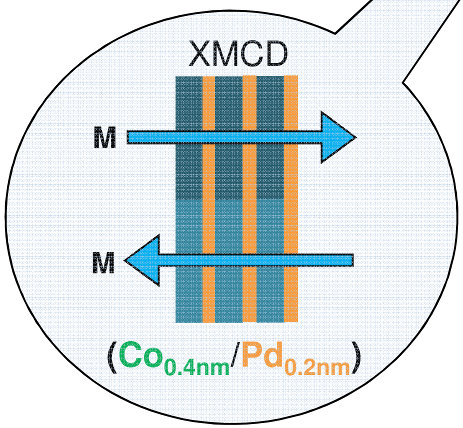
70 kHz : the laser frequency was decreased in order to avoid the sample overheating

312 bunches
65 µA / bunch

SOLEIL SYNCHROTRON

Magnetization dynamics using small angle x-rays scattering (SAXS)

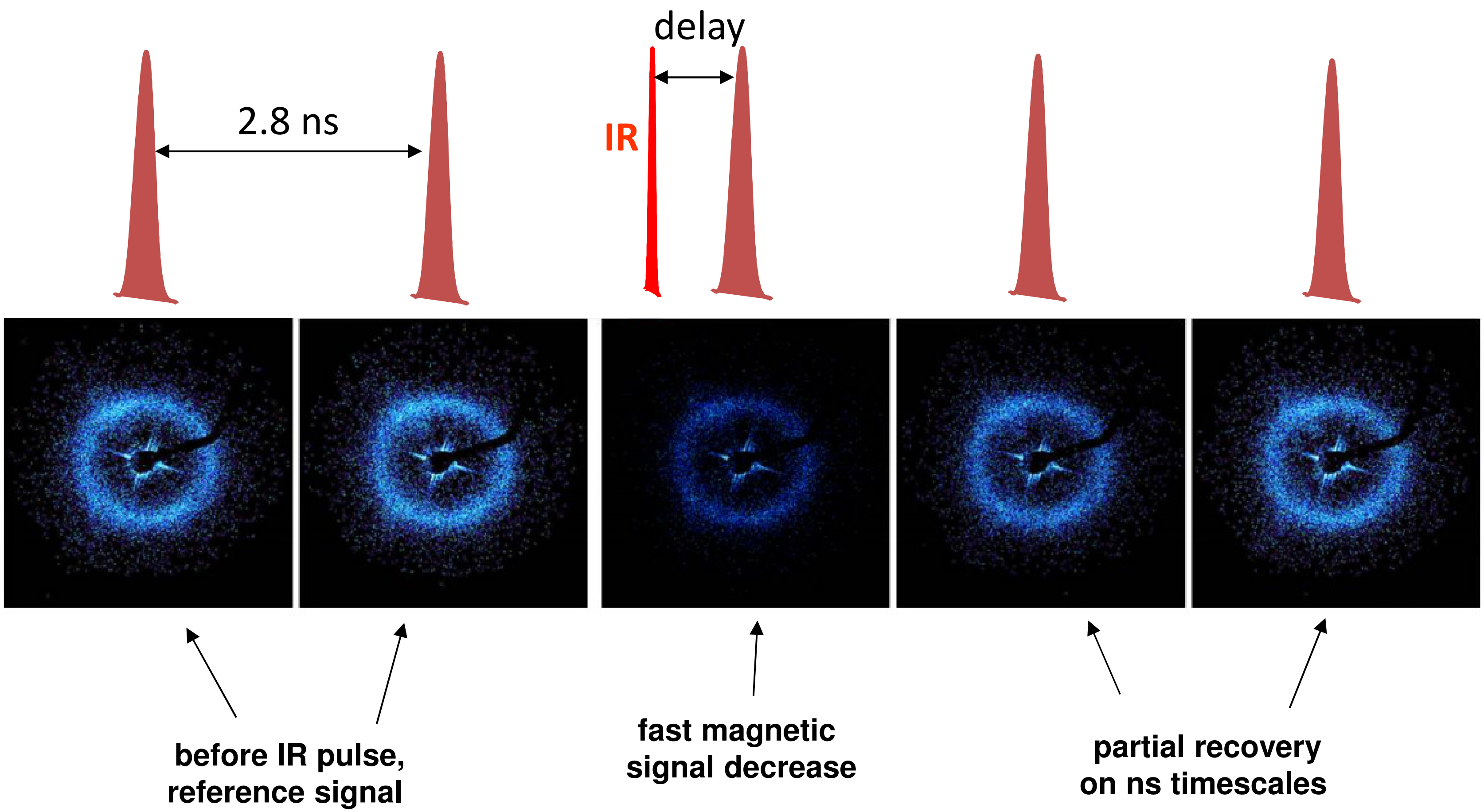




Integrated intensity → measure of the local magnetization

Form of scattering pattern → spatial information

Resonant (Co L_3) magnetic small angle scattering pattern

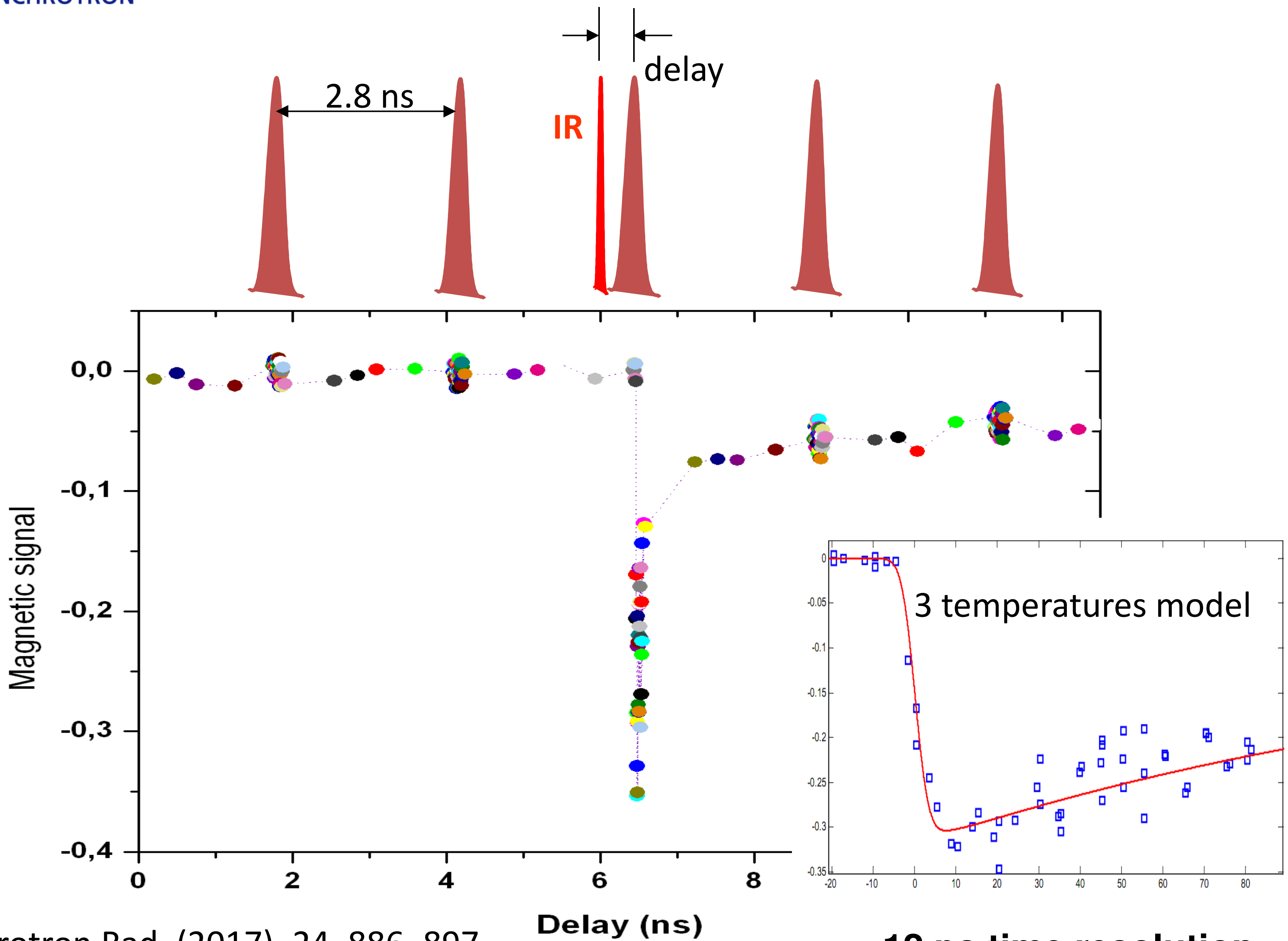


Laser fluence: 15 mJ/cm^2

Integration time: 3 min at 70 kHz

J. Synchrotron Rad. (2017). 24, 886–897

Low-Alpha multi-bunch: fast (ps) and slow (ns) dynamics



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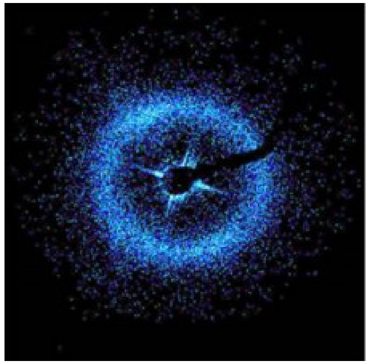
12 ps time resolution

Time resolved resonant magnetic scattering



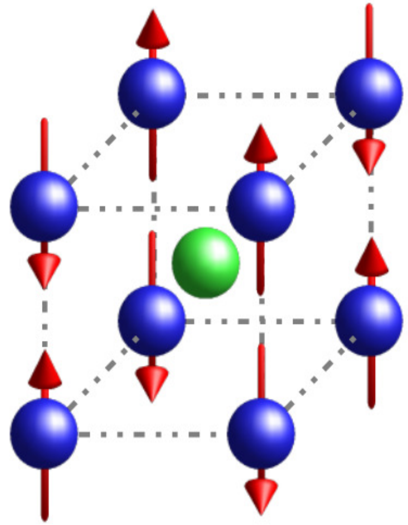
Study of magnetization dynamics in nanostructures:

Coherent imaging
XMCD contrast – element specific
Low alpha mode, Slicing
FEL - collaborations

Federico Pressacco, Vojtech Uhlır, Matteo Gatti, Alessandro Nicolaou, Azzedine Bendounan, Jon Ander Arregi, Sheena K. K. Patel, Eric E. Fullerton, Damjan Krizmancic, and Fausto Sirotti

The phase transition in FeRh

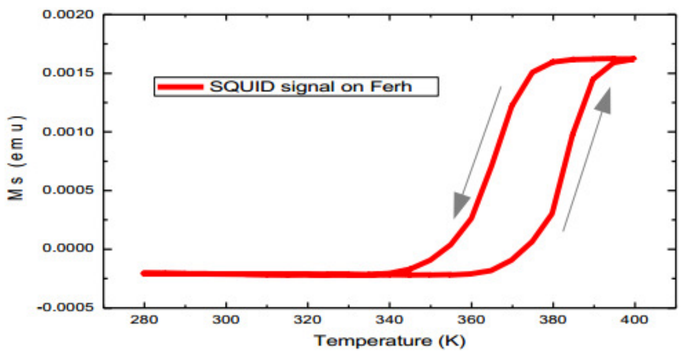
In FeRh the transition involves both the Magnetic Order and the Lattice Structure;



Below T_c	Above T_c
$Fe = \pm 3.3\,\mu_B$	$Fe = 3.1\,\mu_B$
$Rh = 0\,\mu_B$	$Rh = 0.9\,\mu_B$

The volume is expanded of about 1% bulk samples or in thick films;

- Isotropically in bulk or in thick films;
- Along the out of plane direction for thin films



$$T_{FM \rightarrow AFM} = 385\,K \quad T_{AFM \rightarrow FM} = 395\,K$$

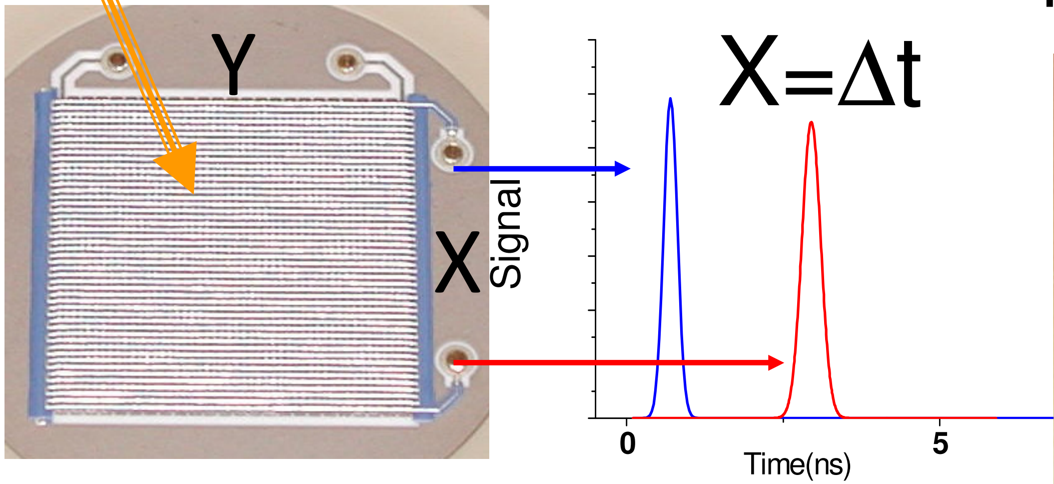
Special Time resolved detector

4 Mcounts/s
27 ps temporal resolution
60 µm spatial resolution

2D detector

Elettra
L. Stebel
R. Sergo
P. Pittana
G. Cautero

Electrons cascade from Micro channel plate



research papers

Journal of
Synchrotron
Radiation
ISSN 0909-0495

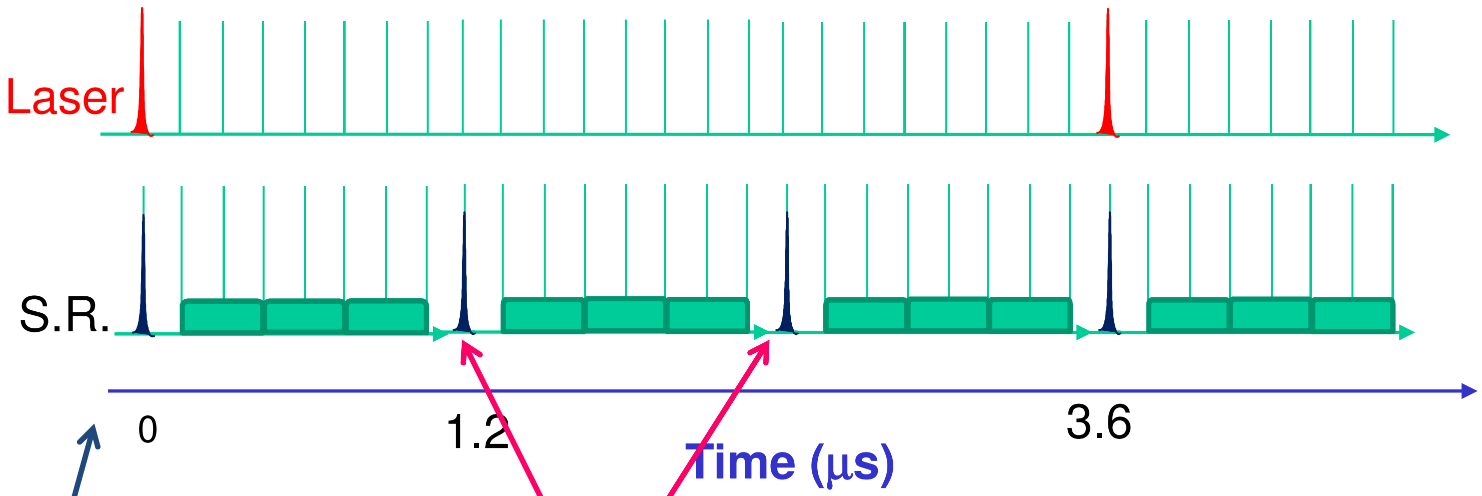
Time-resolved photoelectron spectroscopy using synchrotron radiation time structure

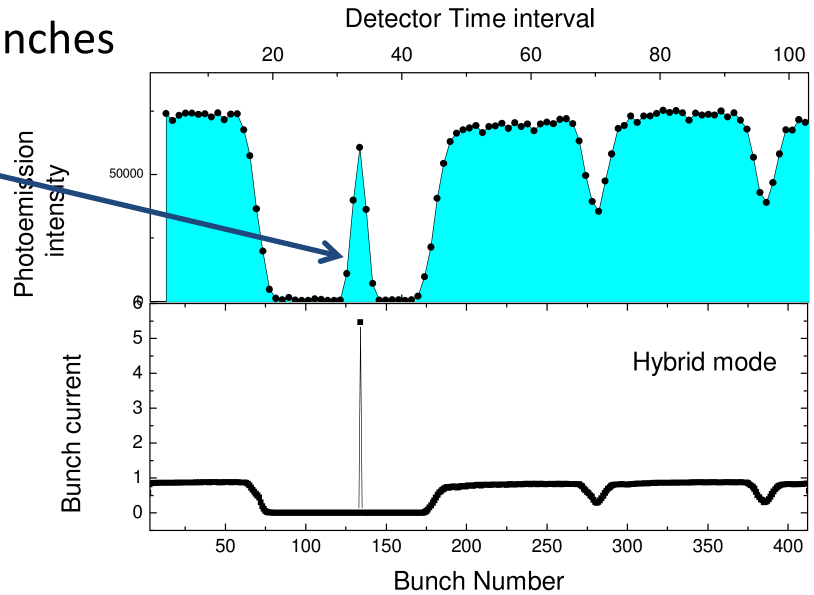
N. Bergeard,[a] M. G. Silly,[a] D. Krizmancic,[b] C. Chauvet,[a] M. Guzzo,[a,c] J. P. Ricaud,[a] M. Izquierdo,[a] L. Stebel,[d] P. Pittana,[d] R. Sergo,[d] G. Cautero,[d] G. Dufour,[e] F. Rochet[e] and F. Sirotti[a*]

Received 2 March 2010
Accepted 13 December 2010

Journal of Synchrotron Radiation, 2011, 18(2): 245-250

Photoemission experiments





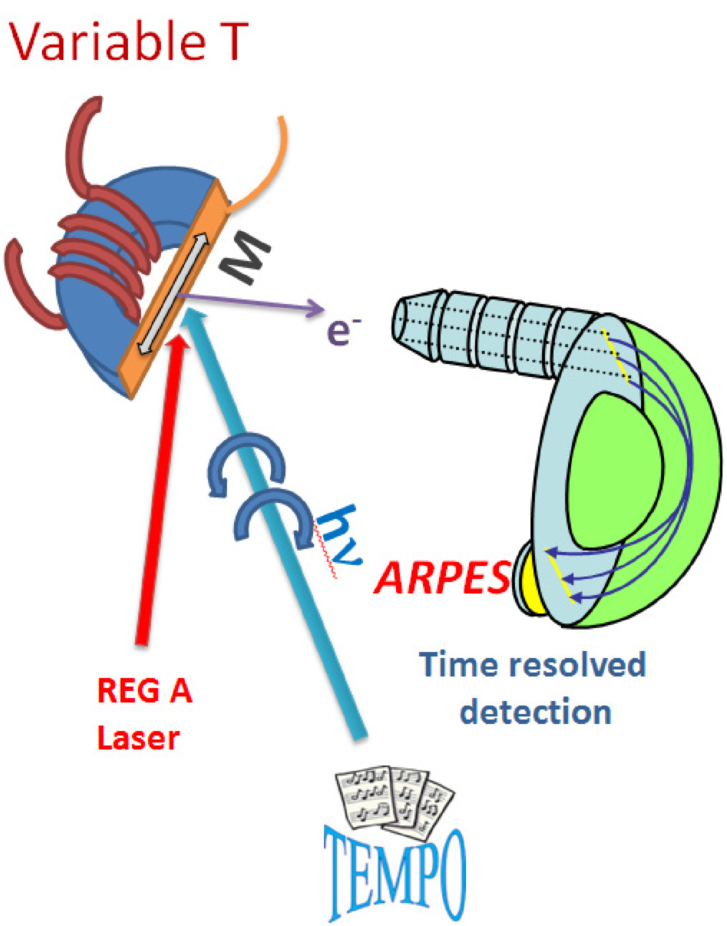
Time resolved detection

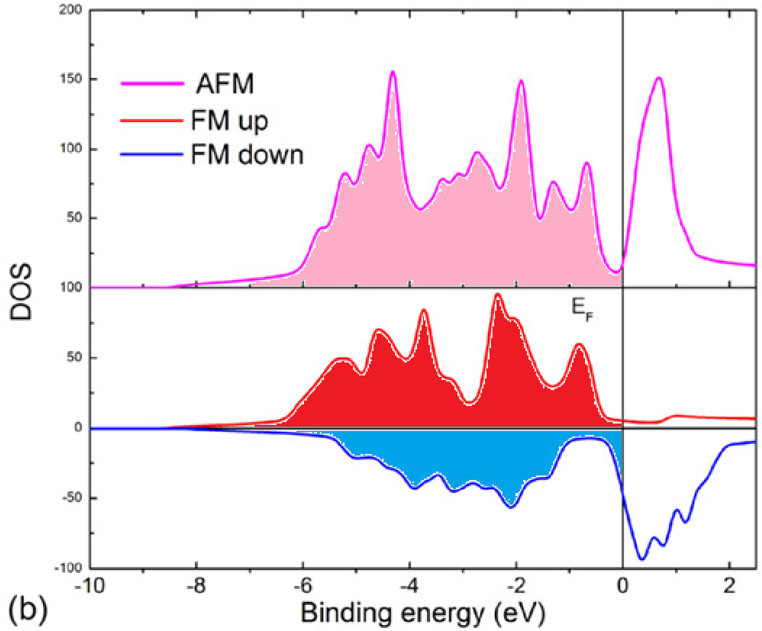
Synchrotron pulse duration: 50 ps

High repetition rate.

Journal of Synchrotron Radiation, 2011, 18(2): 245-250

FeRh: magnetism and electronic structure



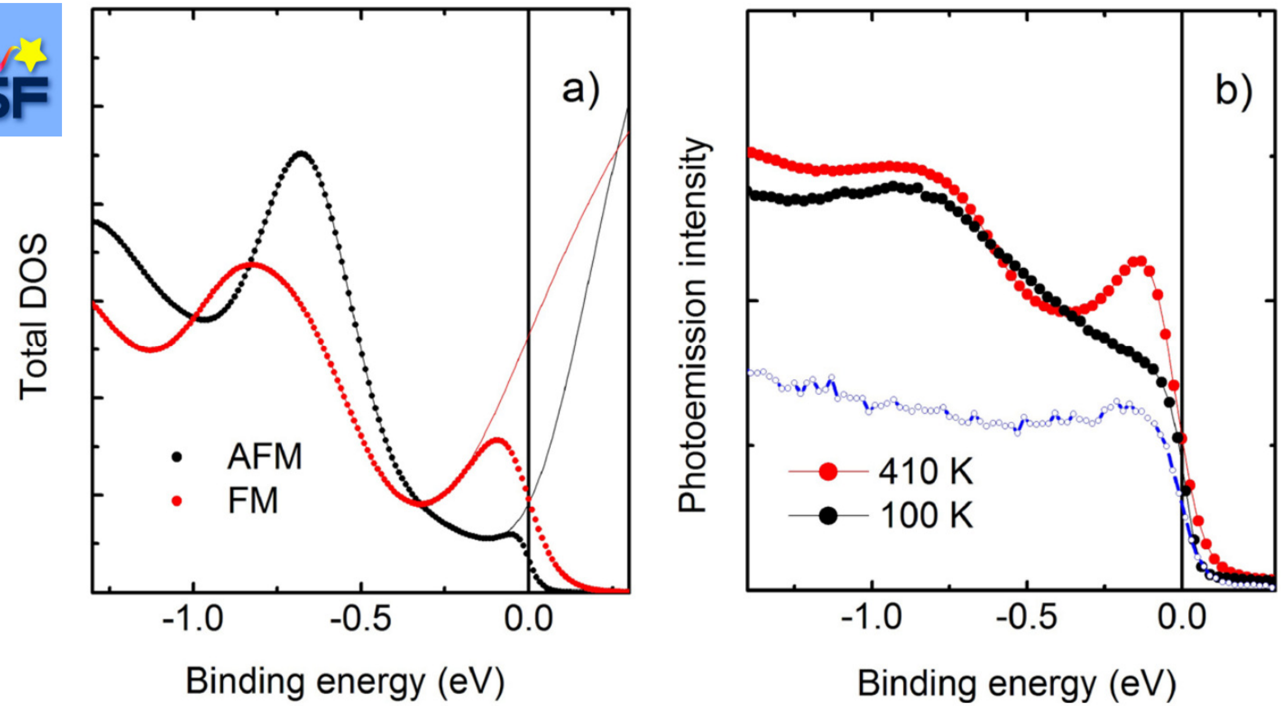


Theory:
M. Gatti, LSI & ETSF Palaiseau

Modification of the electronic structure

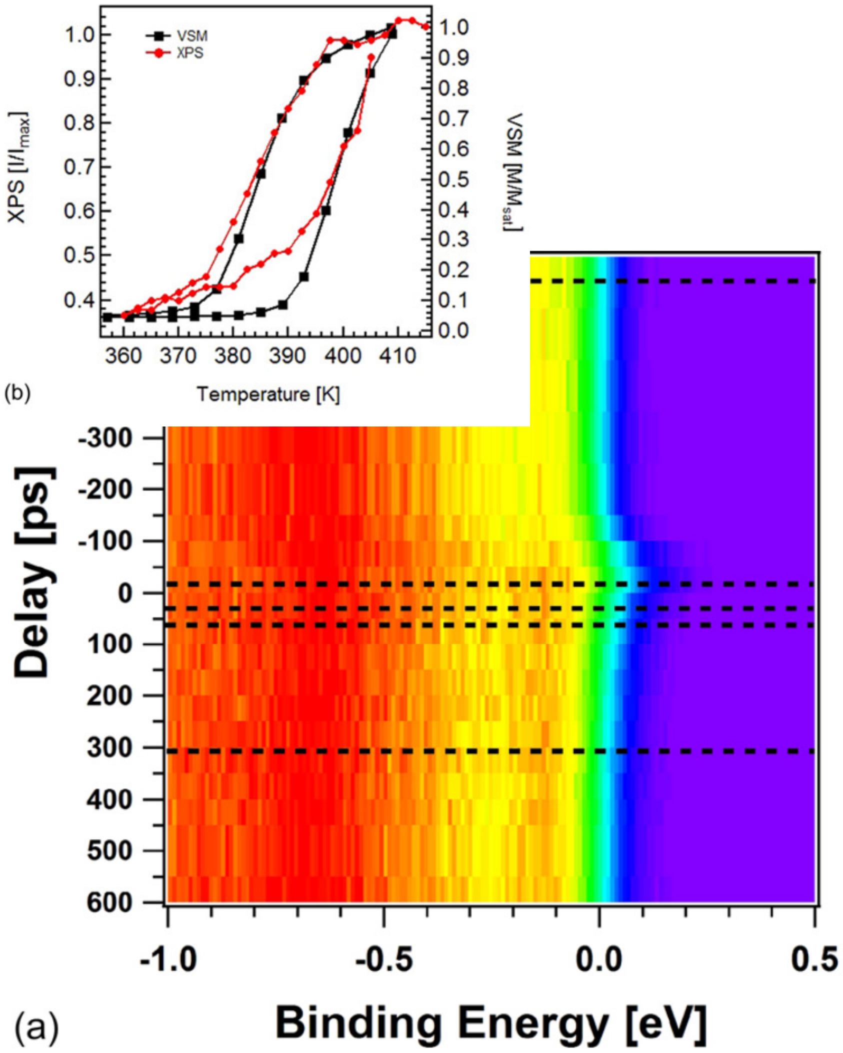
F. Pressacco, M. Gatti et al. *Scientific Reports, 2016, 6 : art.n° 22383*

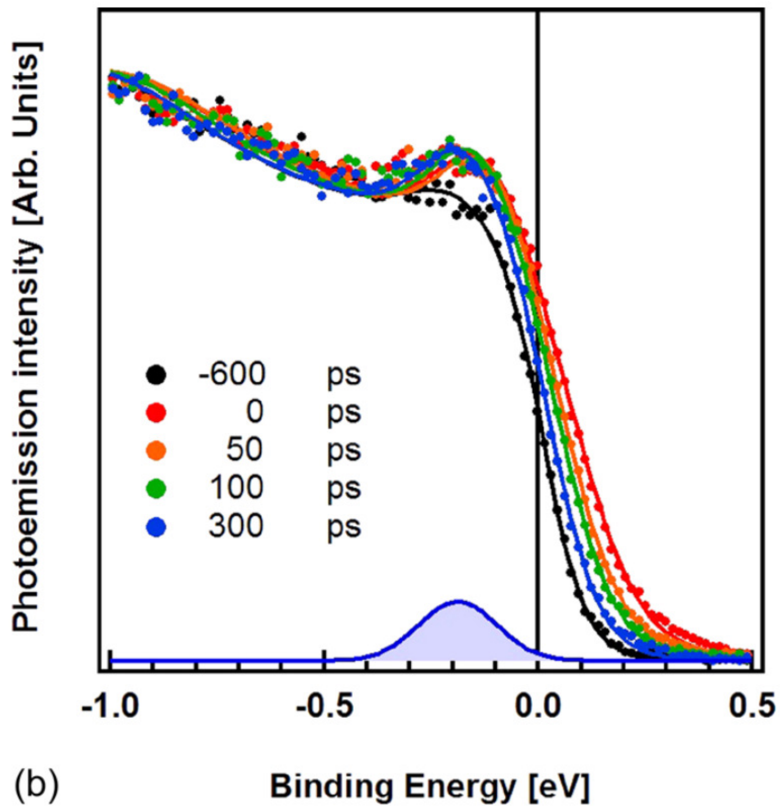
Modification of the electronic structure



Shape of band structure well characterize the magnetic phase

FeRh: magnetism and electronic structure

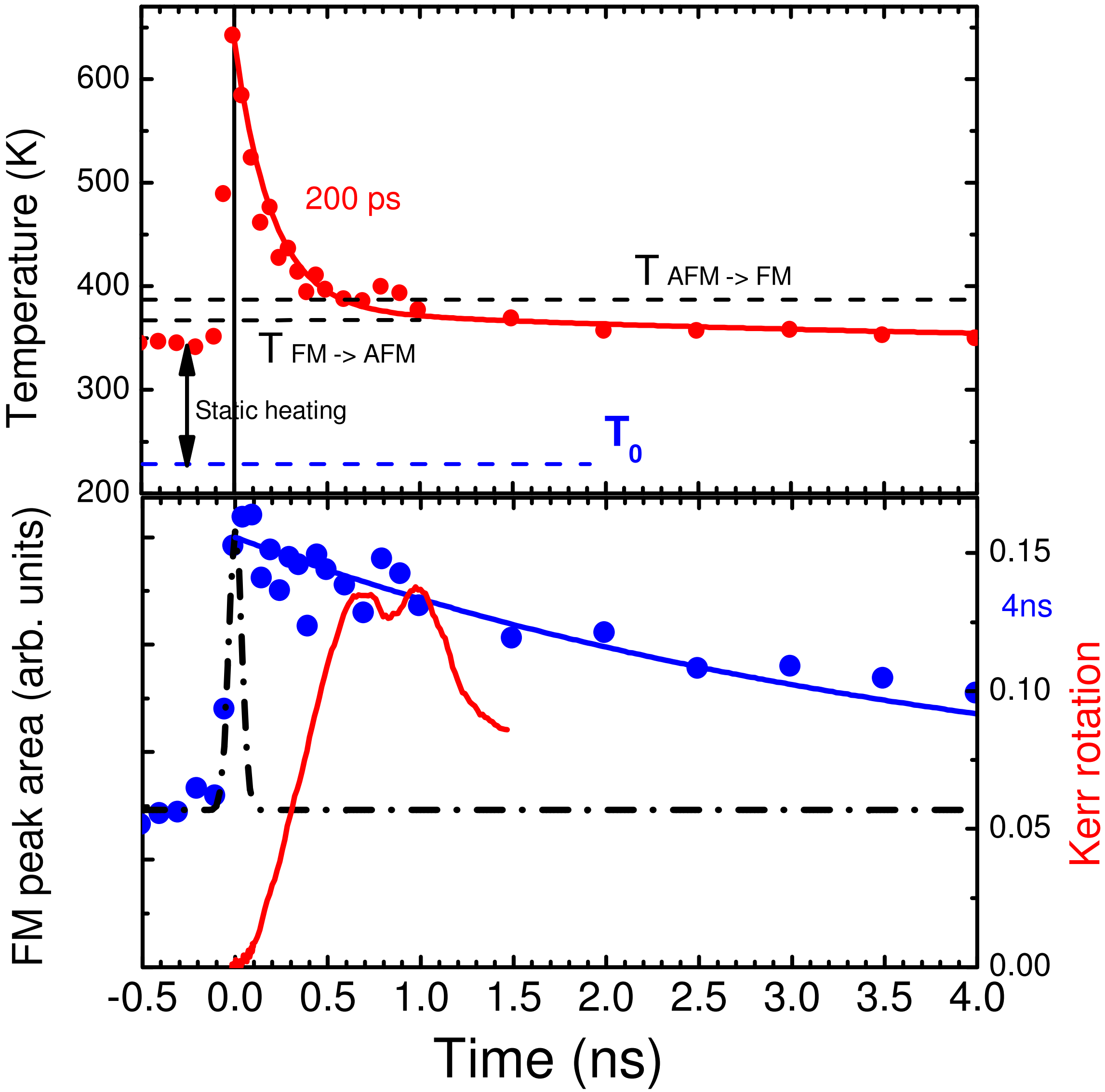




Laser excited
Phase transition

F. Pressacco et al. Struct. Dyn.5, 034501 (2018)

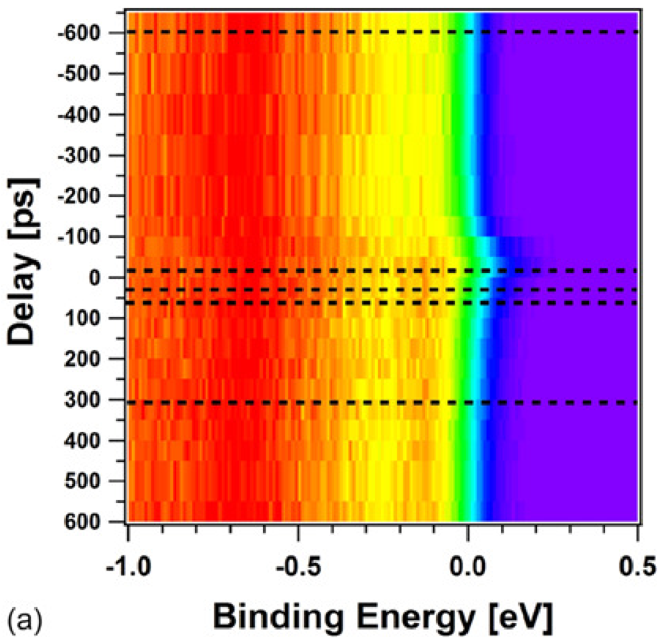
FeRh: magnetism and electronic structure



Temperature

Electronic structure

Valence Band photoemission



(a)

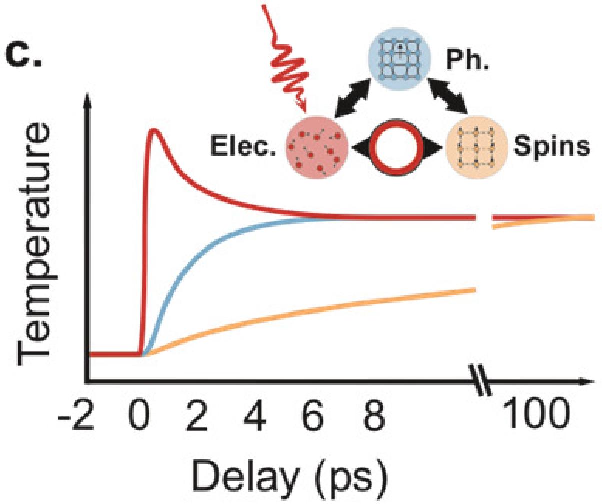
Electronic & magnetic properties

Study of recovery process.
Preparation of tools for FEL & HHG
Studies motivated by pump/probe
50 ps & Low alpha mode
Synchrotron operation needed

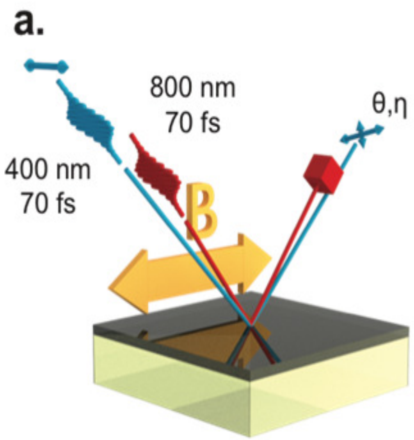
FEL & HHG

Magnetization dynamics of half-metallic manganite

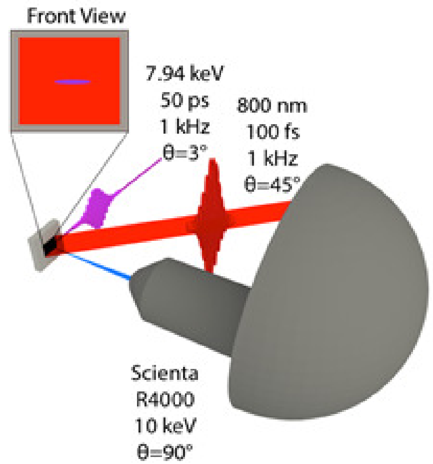
T. Pincelli, R. Cucini, A. Verna, F. Borgatti, M. Oura, K. Tamasaku, H. Osawa, T.L. Lee, C. Schlueter, S. Gunther, C.H. Back, M. Dell'Angela, P. Orgiani , A. Petrov, F. Sirotti, R. Ciprian, V. A. Dediu, I. Bergenti, P. Graziosi, F. Miletto Granozio, Y.Tanaka, M. Taguchi, H. Daimon, J. Fujii, G. Rossi, and G. Panaccione



In a half-metallic system, the direct spin-electron de-excitation channel is almost suppressed due to the absence of available spin-flip processes.



Pump-probe MOKE setup.

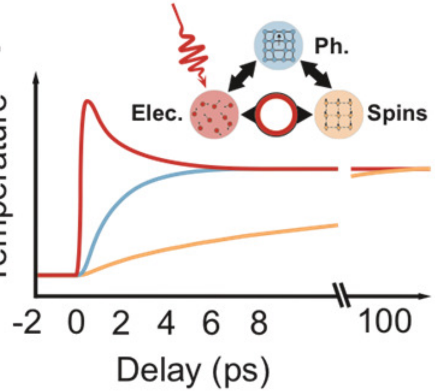


Pump-probe ***HAXPES*** *setup*

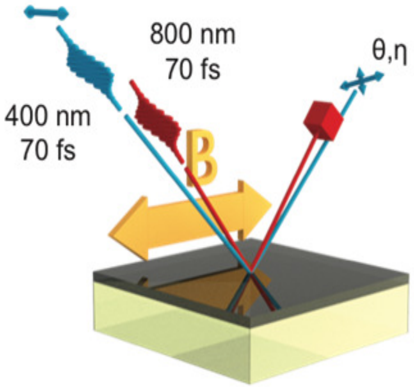
Magnetization dynamics of half-metallic manganite

In a half-metallic system, the direct spin-electron de-excitation channel is almost suppressed due to the absence of available spin-flip processes.

c.

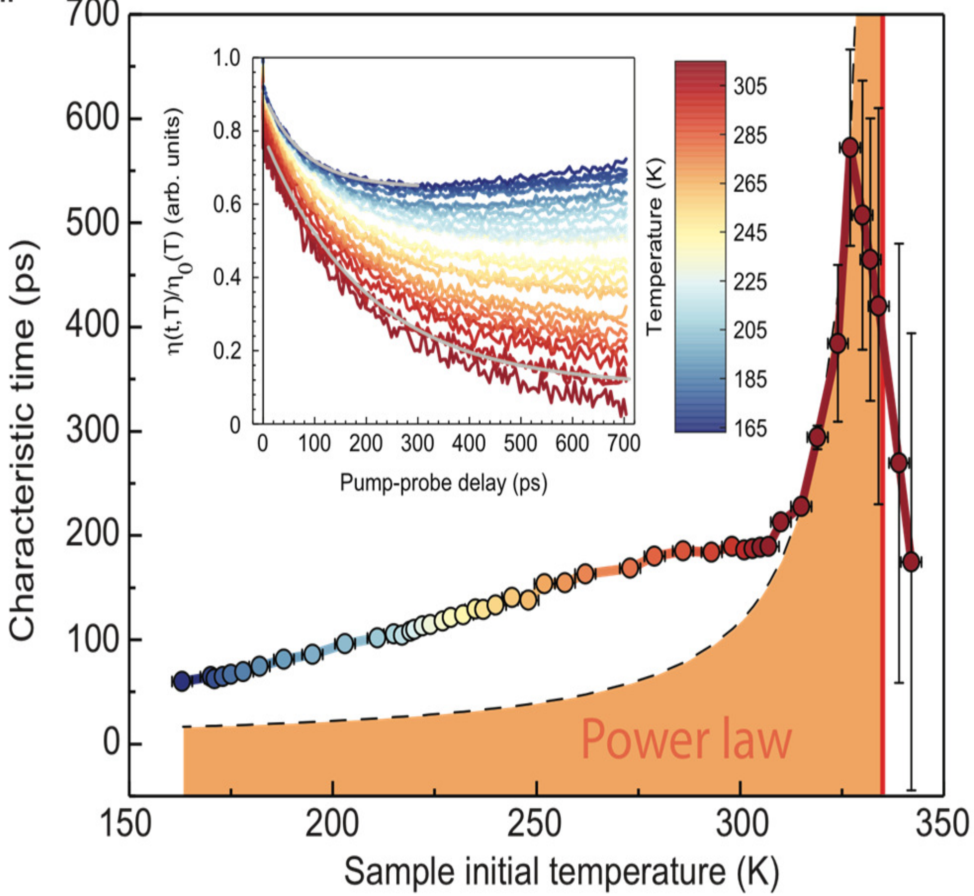


a.



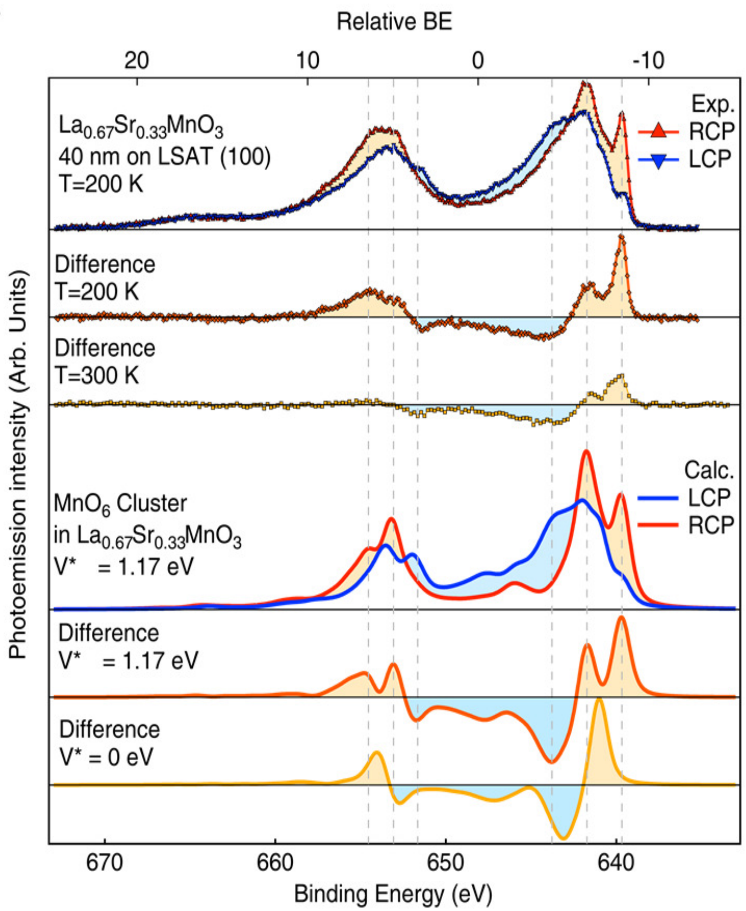
Pump-probe MOKE setup.

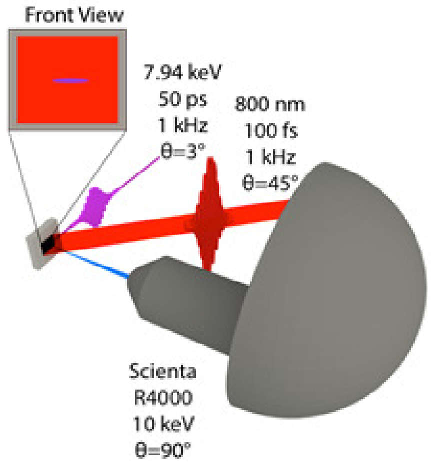
f.



iom Istituto Officina dei Materiali

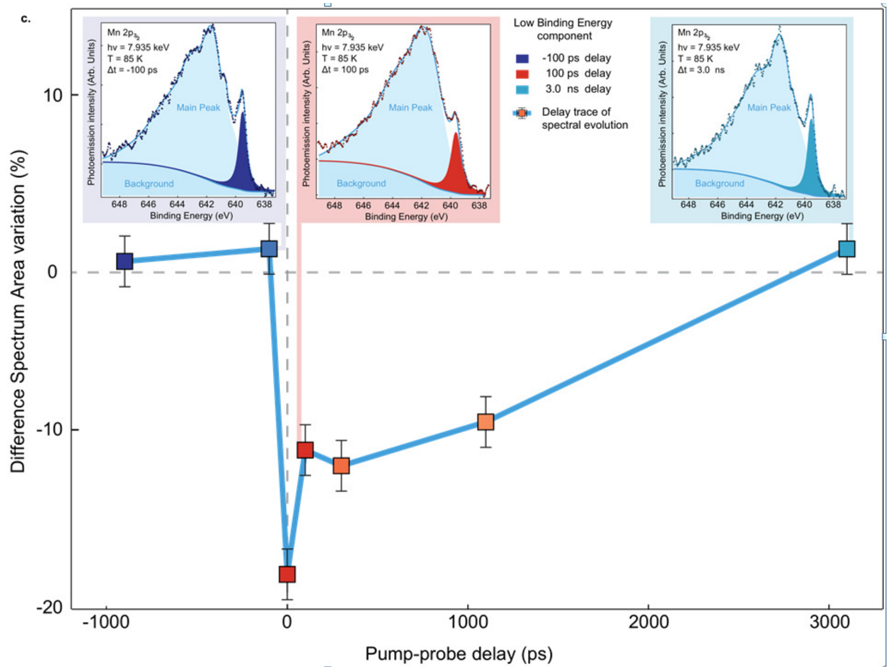
Magnetization dynamics of half-metallic manganite



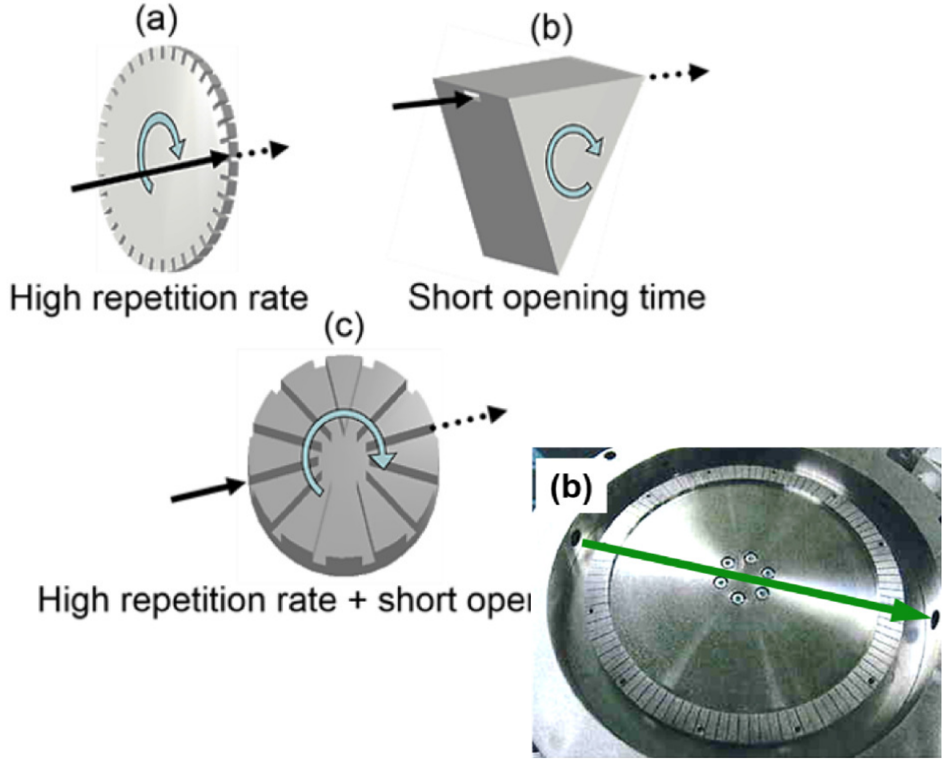


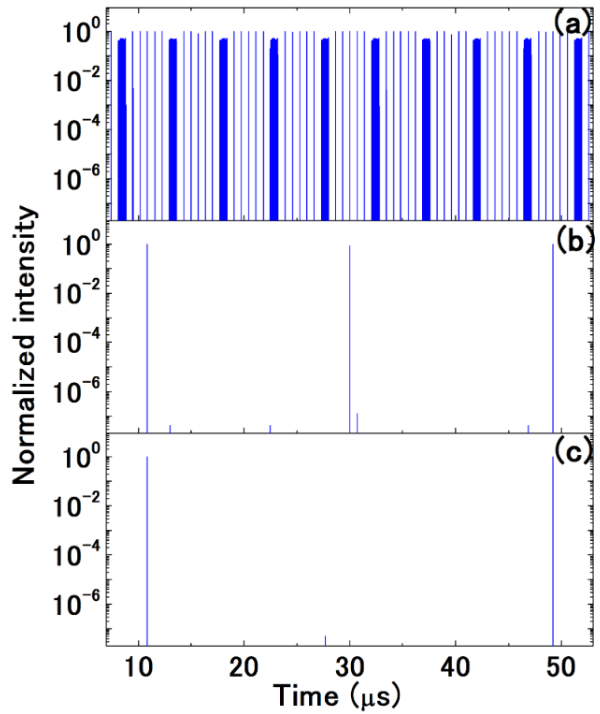
Pump-probe HAXPES setup

1 KHz – X-ray Chopper



Pump probe with hard X-rays





H. Osawa et al. Japanese Journal of Applied Physics **56**, 048001 (2017)

HAXPES Band photoemission

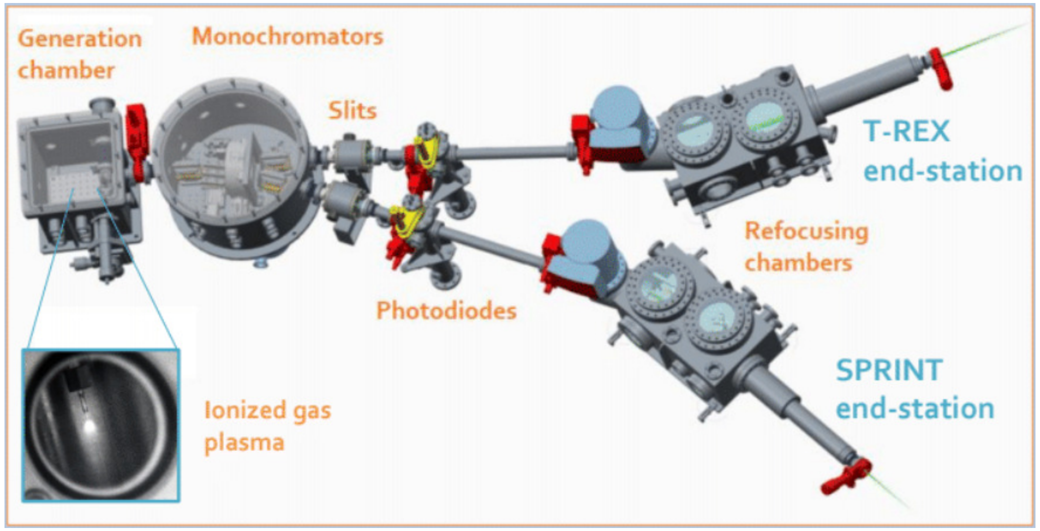
Electronic & magnetic properties

Studies motivated by pump/probe experiments

50 ps & Low alpha mode
Synchrotron operation

FEL & HHG

Sprint



Conclusions

Physical processes are characterized by **pump** characteristics (pulse duration, energy, polarization)
The pump laser is important in defining the initial state

- System dynamics can then be followed on different time scales

Synchrotron are complementary to FEL, HHG and laser

- Important to make the link between time scales and overlap time intervals of excitation and decay
- better sample characterization on synchrotrons

Strong and regular interaction with fs sources

Physics should drive collaborations to apply the most adapted source

Conclusions

Operation:

Ideally pump probe and normal synchrotron activity should be possible on demand -> Hybrid mode operation of storage rings.

Time resolved detection x-ray choppers
to switch between normal and time resolved mode

Short (few days) and rare (every six months) beamtime period allocated for special operating modes are not effective for scientific activity development

Conclusion

- *TR-X-PEEM - Electron microscopy with polarized X-rays*
- *Time resolved resonant magnetic scattering*

- *ARPES and HAXPES can be used to study laser excited phase transitions in pump/probe experiments*
- Electronic and magnetic properties measured at the same time
- Theoretical predictions are necessary to describe details of non equilibrium spectroscopy

Physics should drive collaborations to apply the most adapted source

Strong and regular interaction with fs sources


Thank you
for your attention