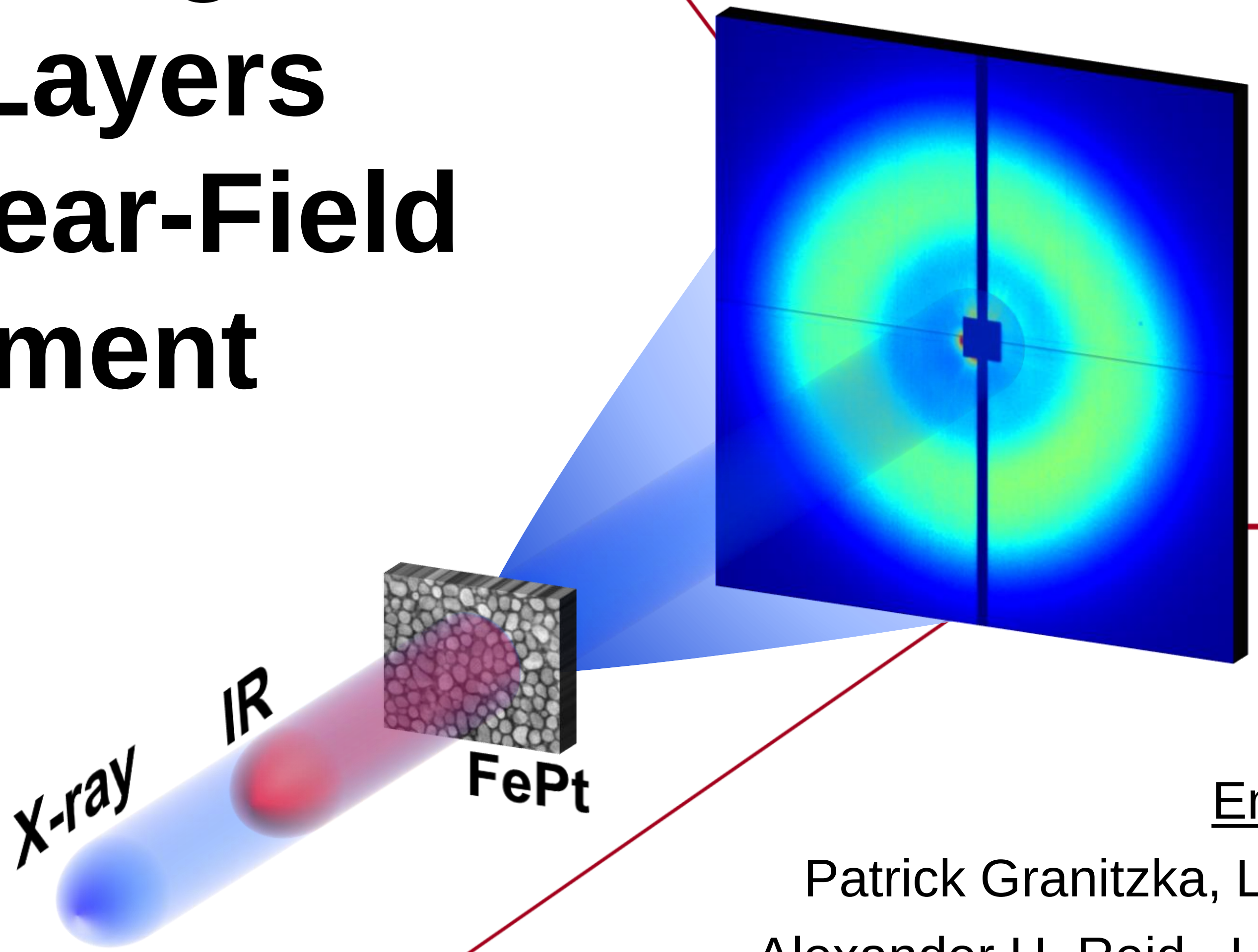
Magnetic Switching in Granular FePt Layers Promoted by Near-Field Laser Enhancement

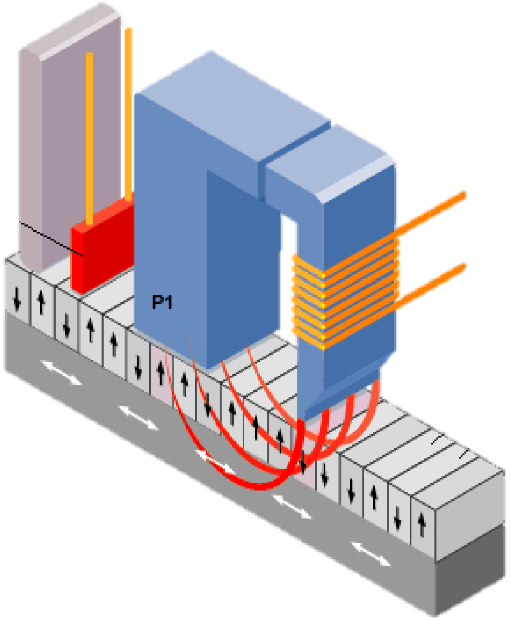


Emmanuelle JAL,
Patrick Granitzka, Loïc Le Guyader
Alexander H. Reid , Hermann A. Dürr
K. Hirsch,T. Liu, D. Higley, Z. Chen, T. Chase, H. Ohldag, W. F. Schlotter, G. Dakovski, M. Hoffmann, E. Arenholz, P. Shafer, V. Mehta, O. Mosendz, O. Hellwig, Y.K. Takahashi, E. Fullerton

European XFEL Users Meeting 2018

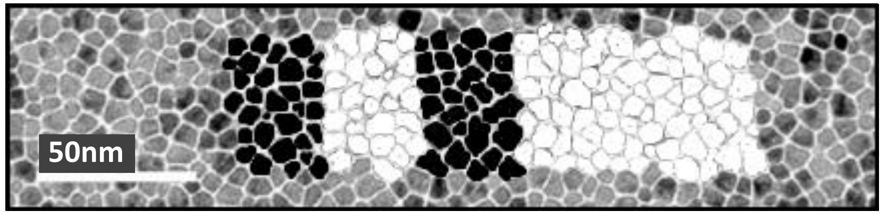
Introduction

- Magnetic storage
  - Manipulation of magnetization



  - Need to increase density
    => reduce magnetic cluster size
    - If reduce number of nanoparticles, S/N increase
    - Reduce nanoparticle sizes

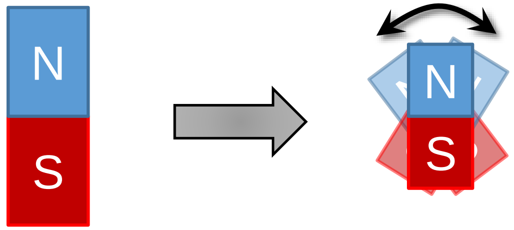
Perpendicular Magnetic recording media



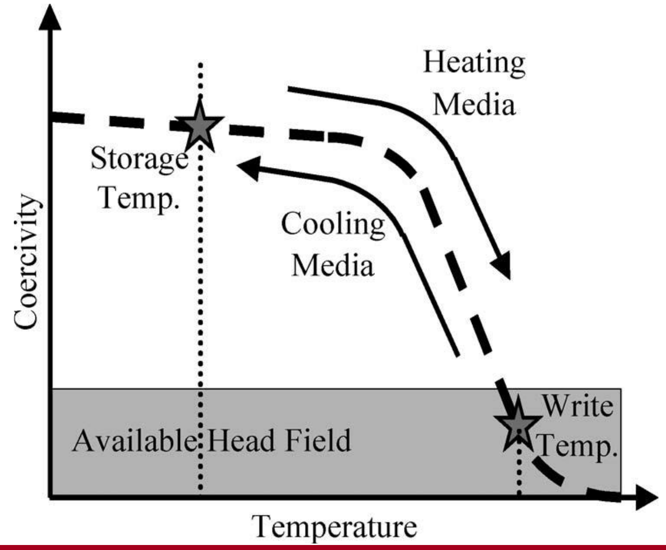
D. Weller, et al. Phys. Status Solidi A 210, 1245 (2013)

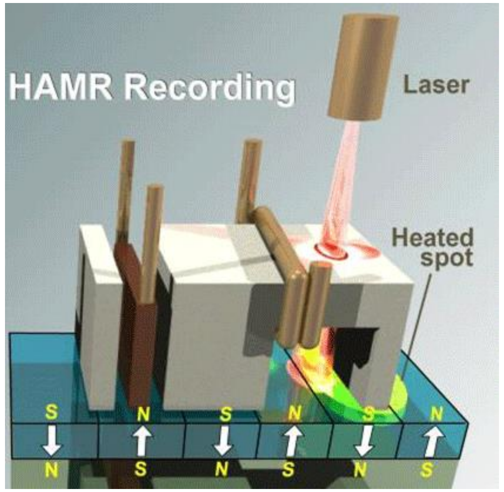
Introduction

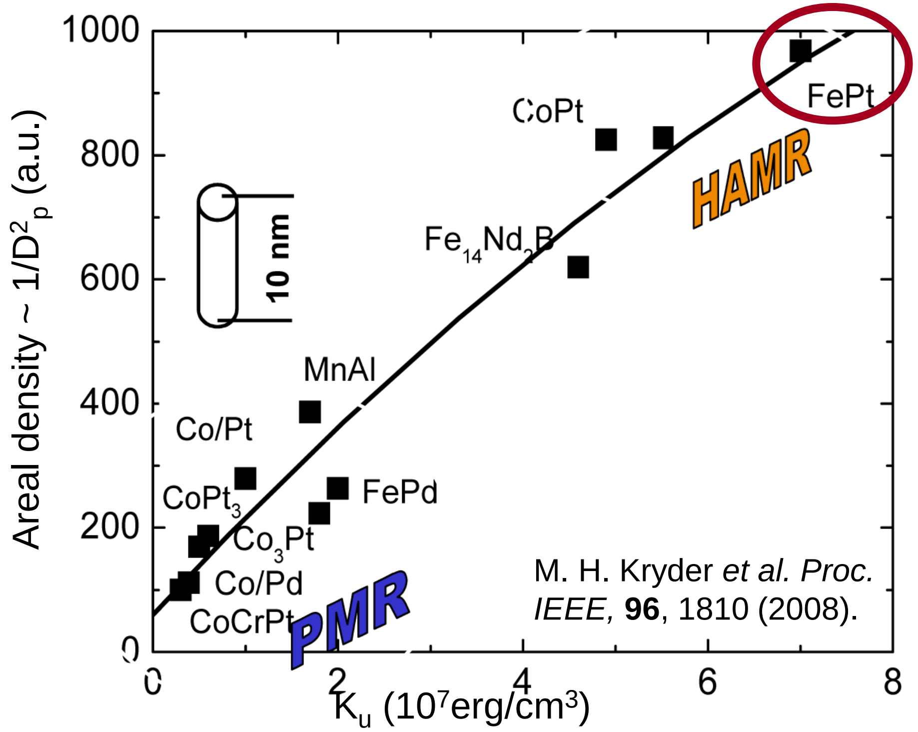
- Reduce nanoparticle sizes
  - Superparamagnetic limit
    - $K_u \cdot V = 60\ k_BT$



  - High perpendicular anisotropy
    - Strong field or High temperature
    - Heat Assisted Magnetic Recording



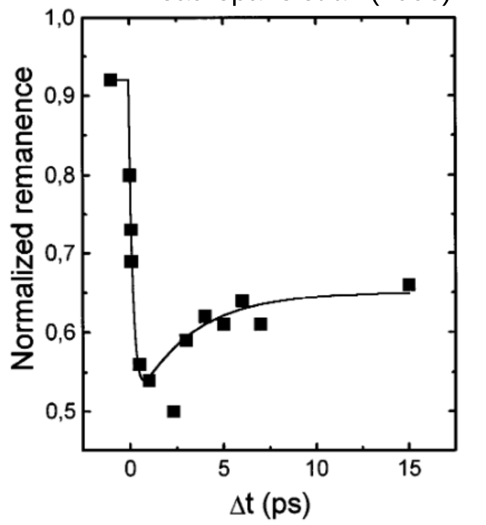




Introduction

- Femtomagnetism

E. Beaurepaire *et al.* (1996)

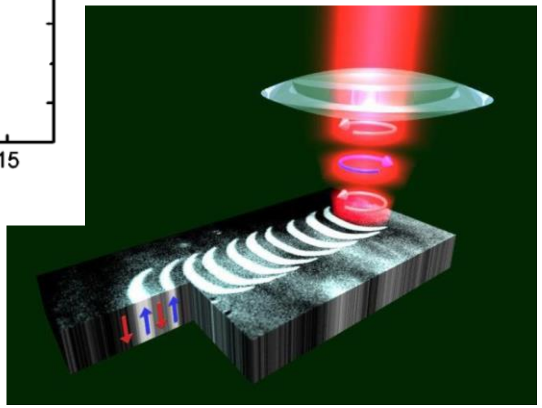


- All Optical Switching
  - Ferrimagnetic materials: Need of two sub-lattices.

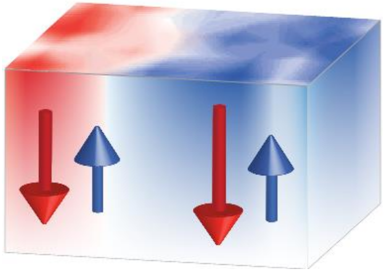
    I. Radu *et al*, Nature **472**, 205 (2011)

  - Ferromagnetic materials: FePt foreseen for next hard drive generation (HAMR)
    - How to optimize AOS ?
    - What is the mechanism driving the switching ?

C.D. Stanciu, 2007

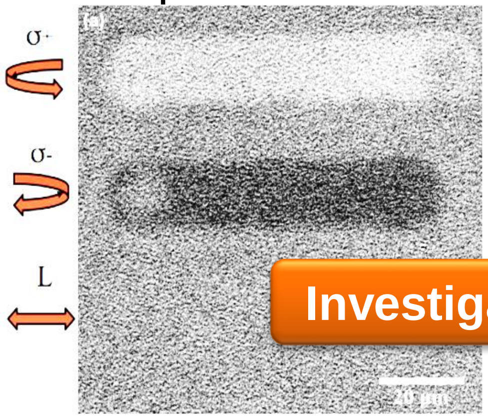


GdFeCo



C.E. Graves *et al*, Nat. Mat. **12,** 293 (2013).

Nanoparticles of FePt



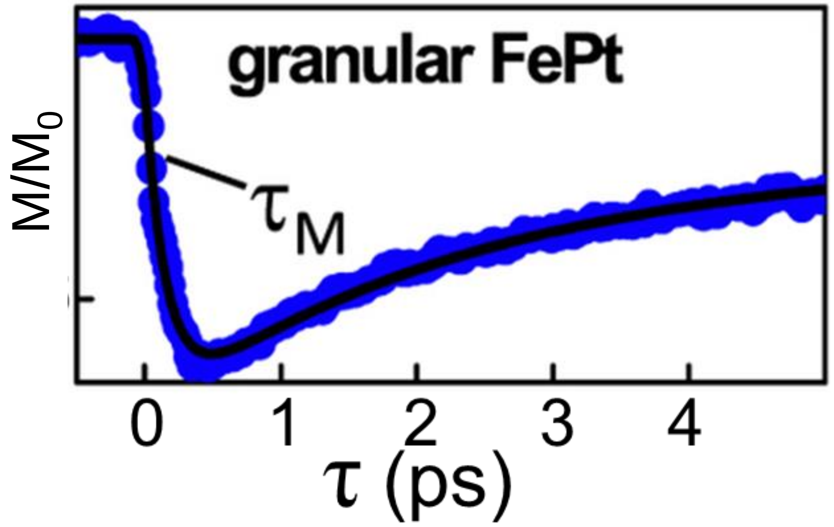
Investigation of magnetic switching in FePt

C-H. Lambert *et al, Science Express 10.1126/science.1253493*

Introduction

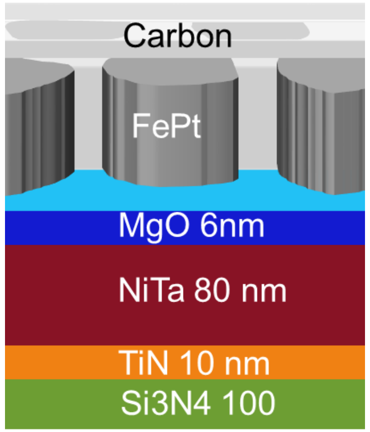
- Physics
  - HAMR
  - Ultrafast demagnetization

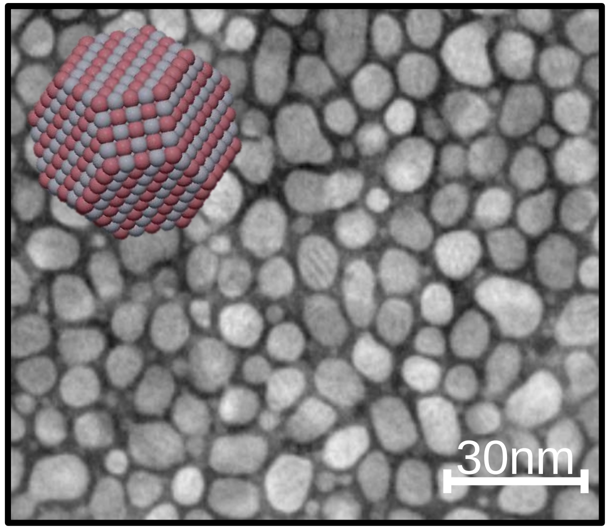
J. Mendil *et al*. Scientific Reports 4, 3980 (2014)

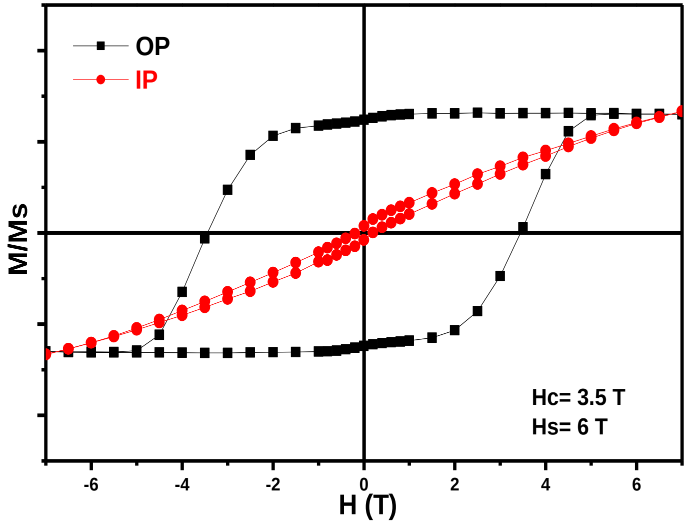


Do all the grains switch?
Is there some grains size dependence?

- Properties
  - Grain sizes around 10 nm
  - Phase L_{10}
  - PMA, Hc ~3.5 T and Hs ~ 6 T
  - On SiN membrane (HGST)



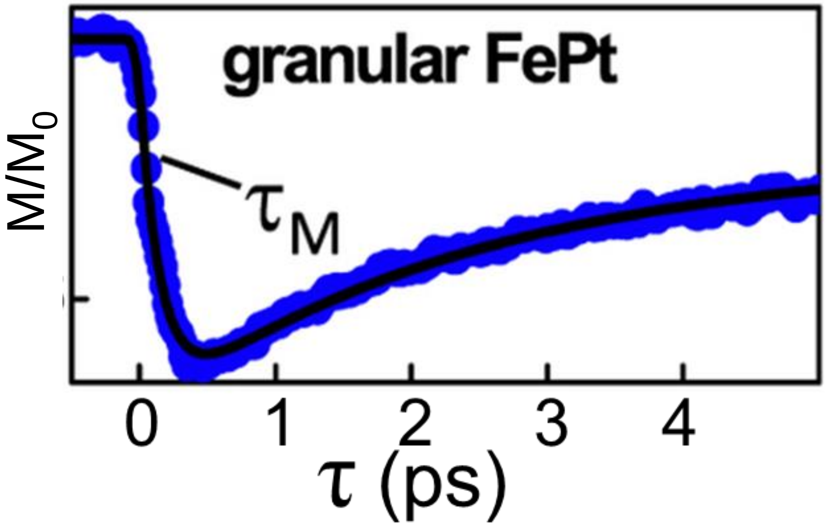




Introduction

➢ Physics
- HAMR
- Ultrafast demagnetization

J. Mendil *et al*. Scientific Reports 4, 3980 (2014)



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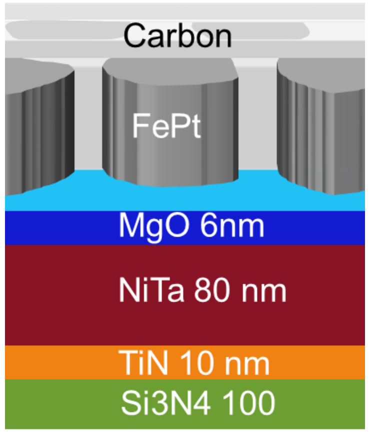
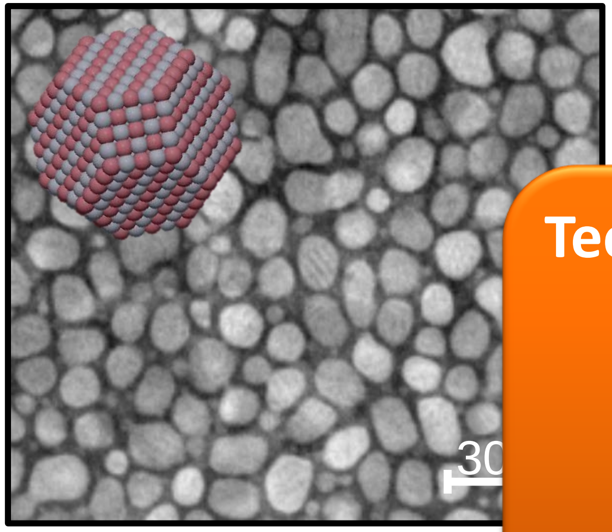
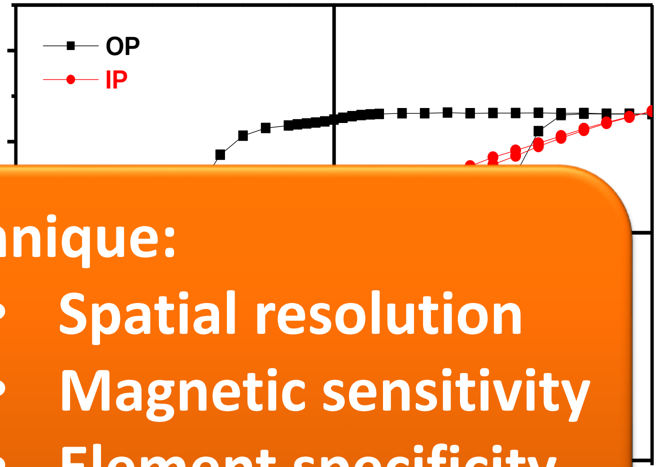


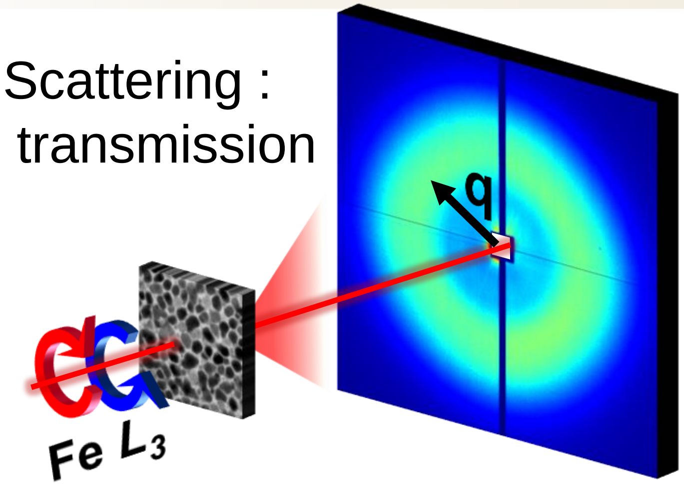


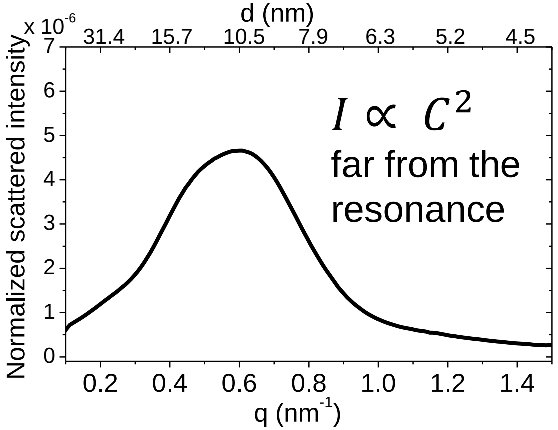


Technique:
- **Spatial resolution**
- **Magnetic sensitivity**
- **Element specificity**
- **Time resolved**

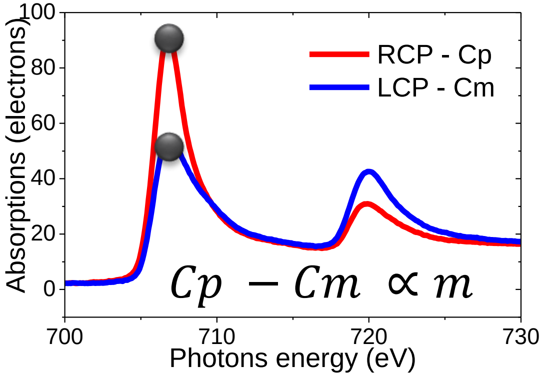
Principle of Resonant Magnetic Small Angle X-ray Scattering (SAXS)

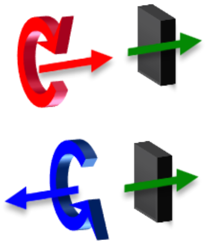
Scattering : In transmission





Spectroscopy : X ray Magnetic dichroïsm

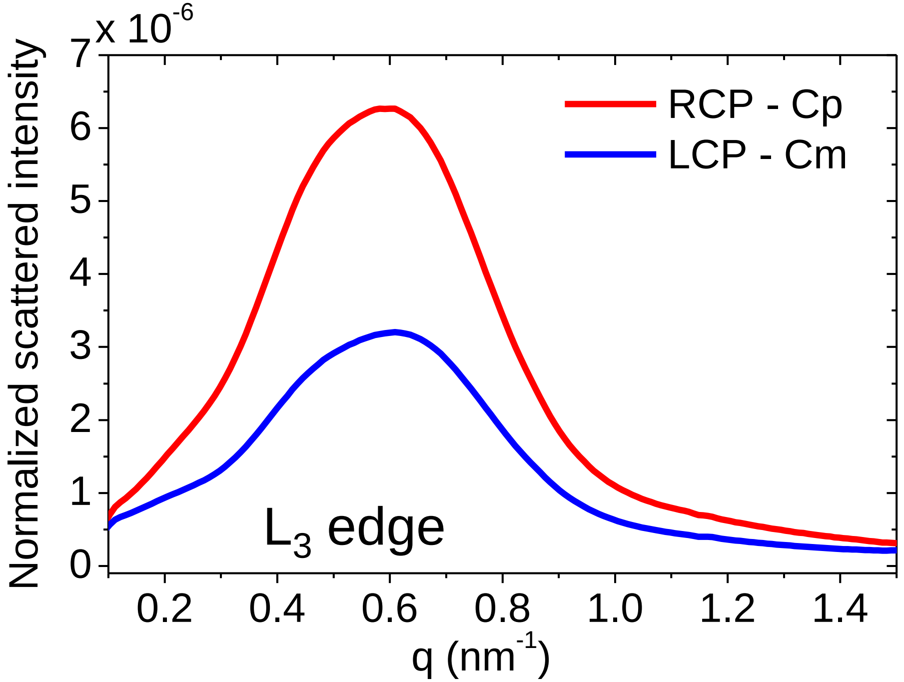




Resonant Magnetic Small Angle X-ray Scattering

$$I^{\pm} \propto C^2 + M^2 \pm 2MC$$

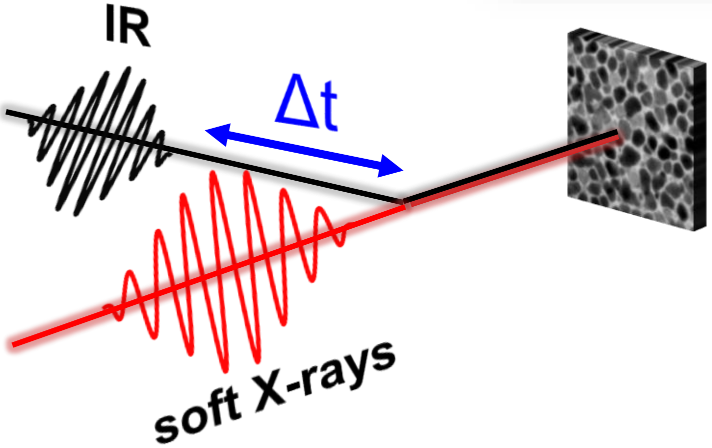
- $ave = \frac{Cp+Cm}{2} \propto C^2 + M^2$
- $diff = Cp - Cm \propto 4MC$



Time Resolved Resonant Magnetic SAXS experiment

SLAC

- Pump-Probe experiment
  - Pump = IR laser
    - λ = 800nm
    - Pulse of 60fs
    - Ø = 165µm^2
    - Circular polarization
  - Probe = soft X-ray
    - E = 708eV
    - Pulse of 50fs
    - Ø = 60µm^2
    - Circular polarization

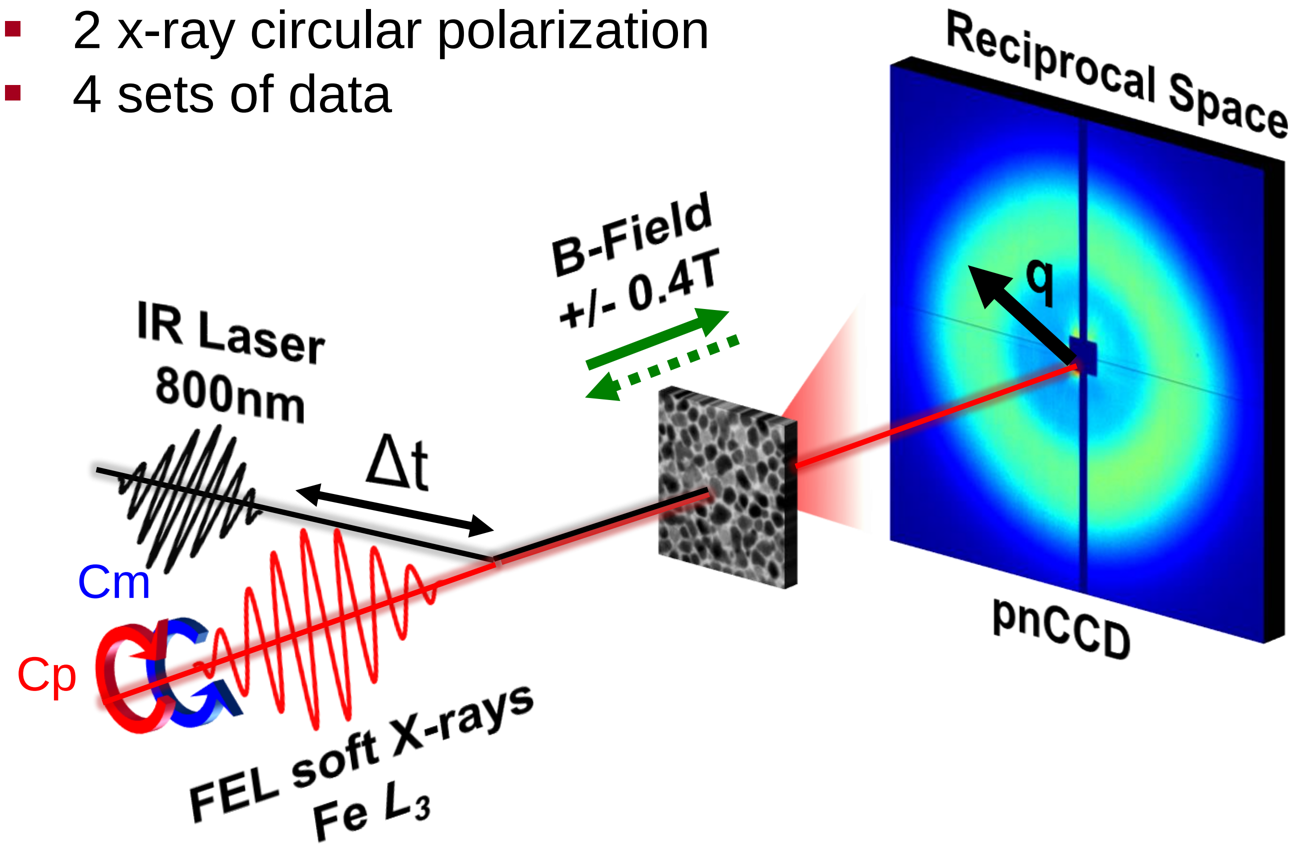


- X-FEL @ LCLS, SXR

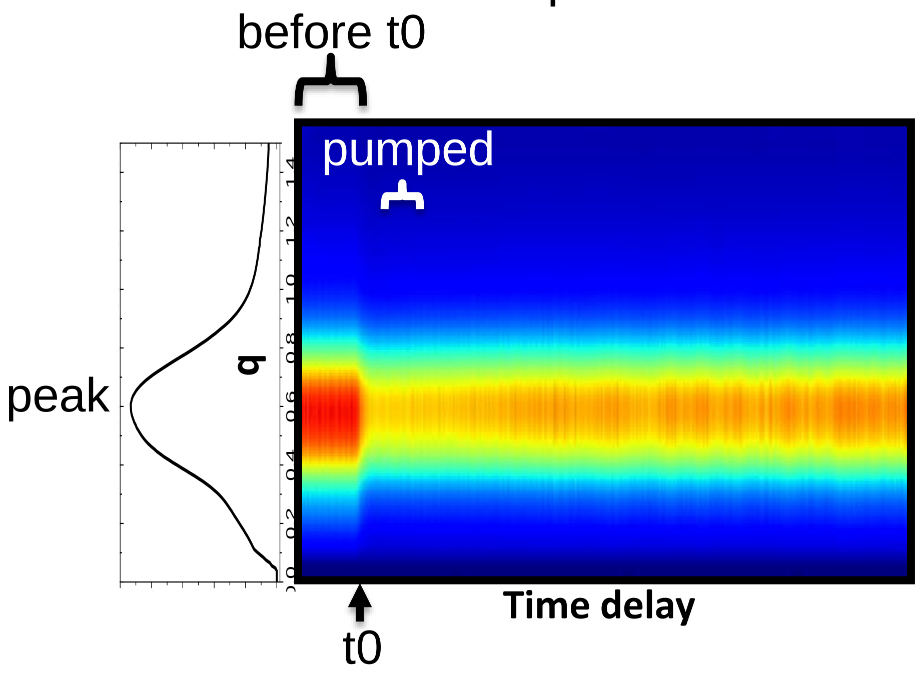
LCLS

Time Resolved Resonant Magnetic SAXS experiment

- Experimental condition
  - Applied field: +/- 0.4 T
  - 2 x-ray circular polarization
  - 4 sets of data



- Analysis
  - Q scans
    - Before t0 ~ static
    - Pumped
  - Time delay scans
    - At the peak

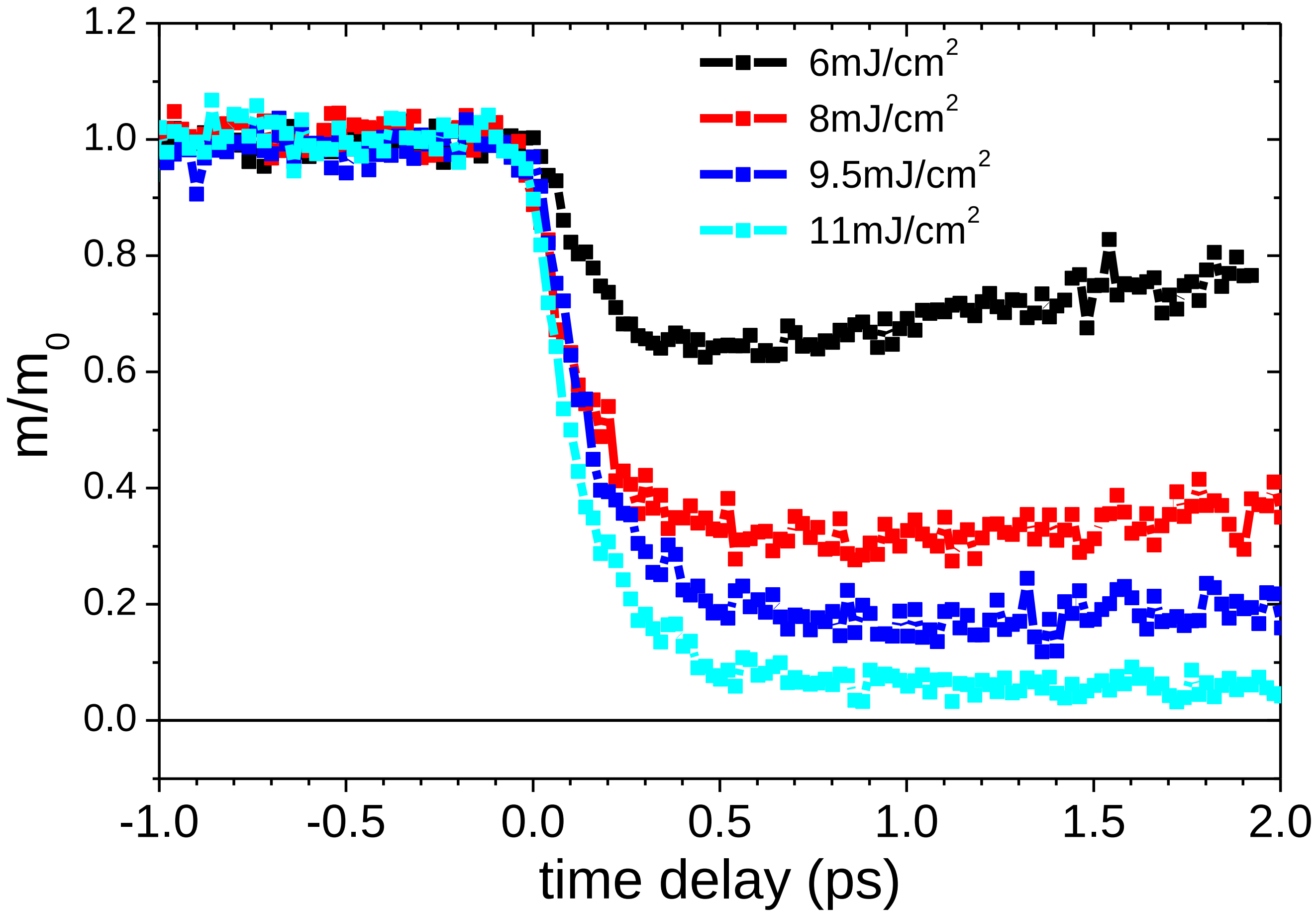


TR - SAXS on FePt:
Results, time delay scans

- Ultrafast demagnetization in FePt
  - Hp
  - $diff = Cp - Cm \propto 4MC$
  - C is constant over time delay

- Expected behavior
  - $\tau_{demag} = 146 \pm 15\ fs$
  - Demagnetization = f(IR fluence)

J. Mendil *et al*. Scientific Reports 4, 3980 (2014)



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Results, time delay scans

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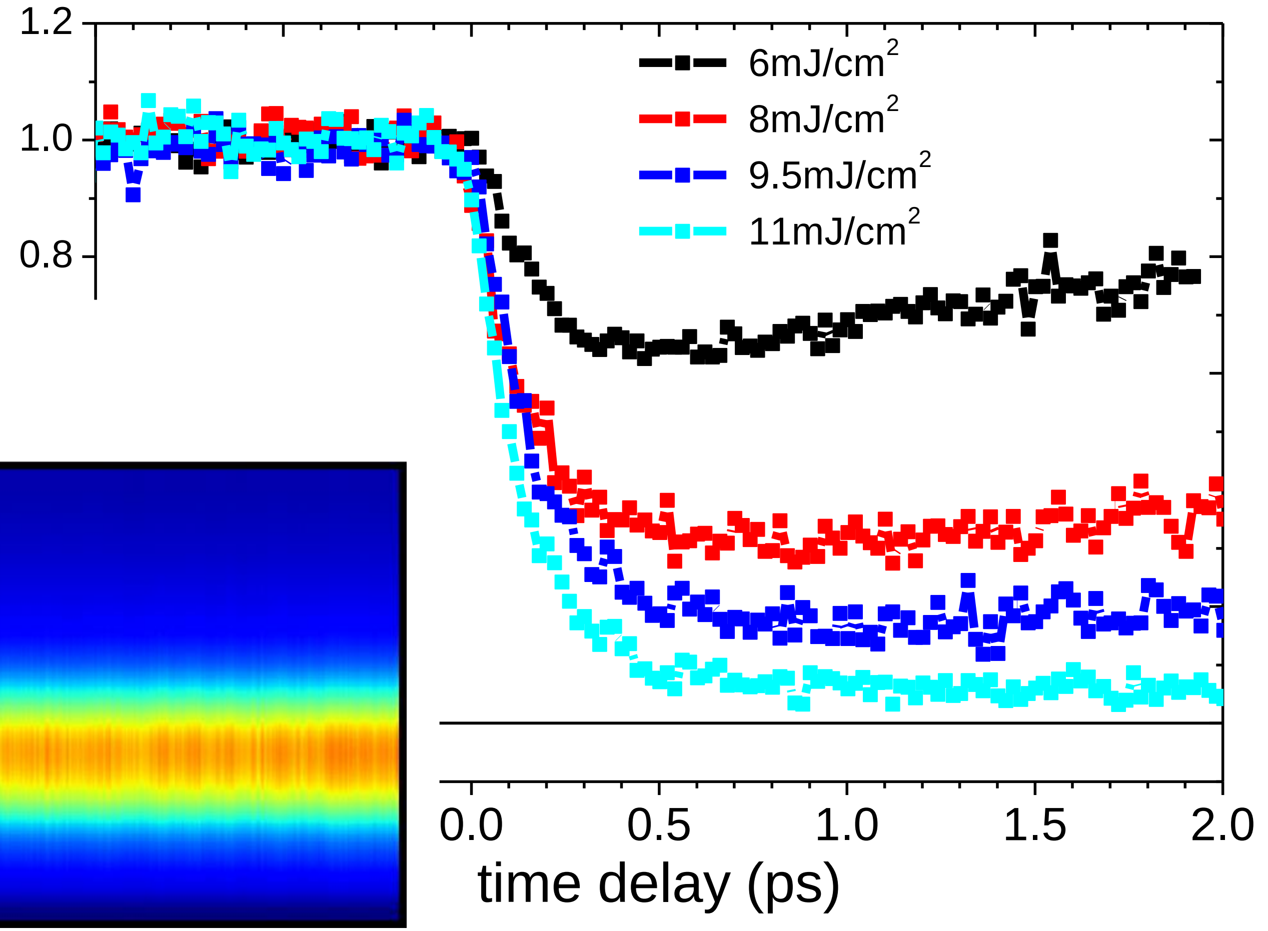

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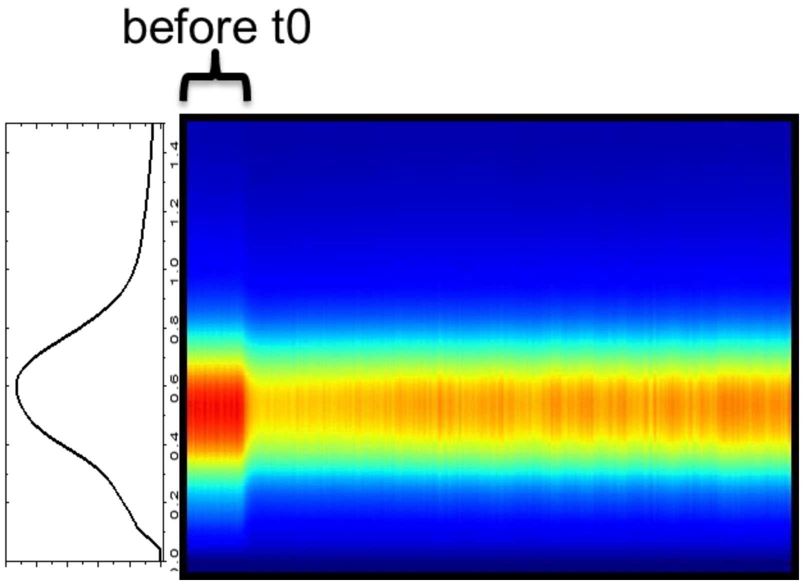
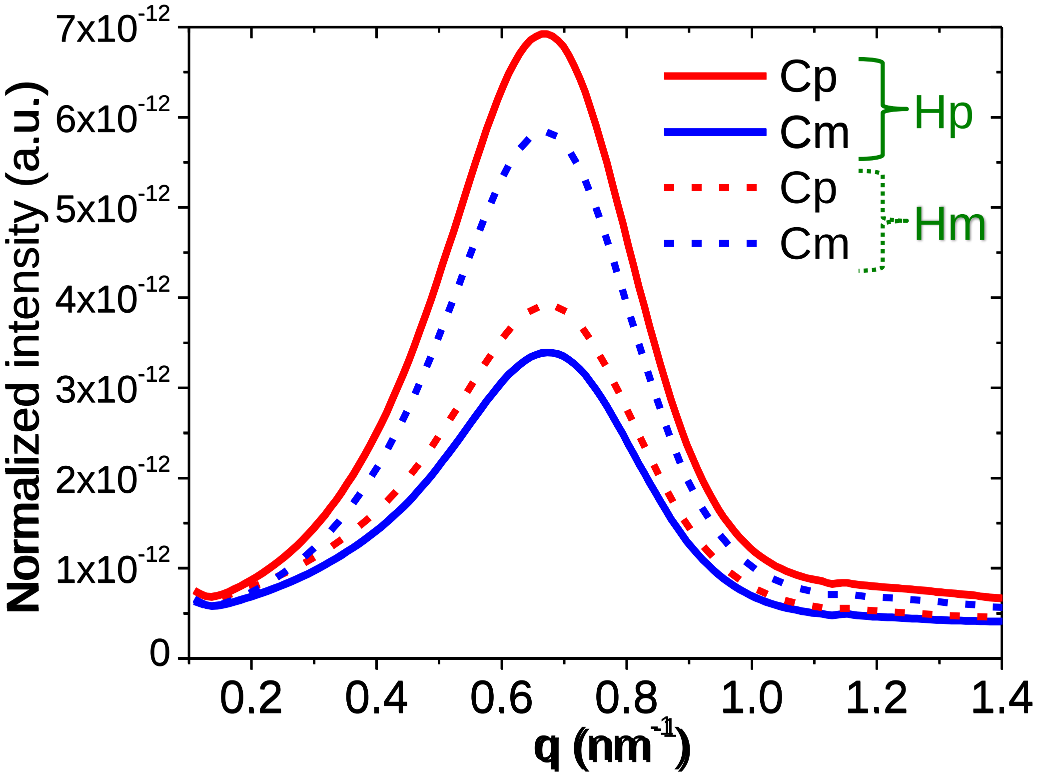
J. Mendil *et al*. Scientific Reports 4

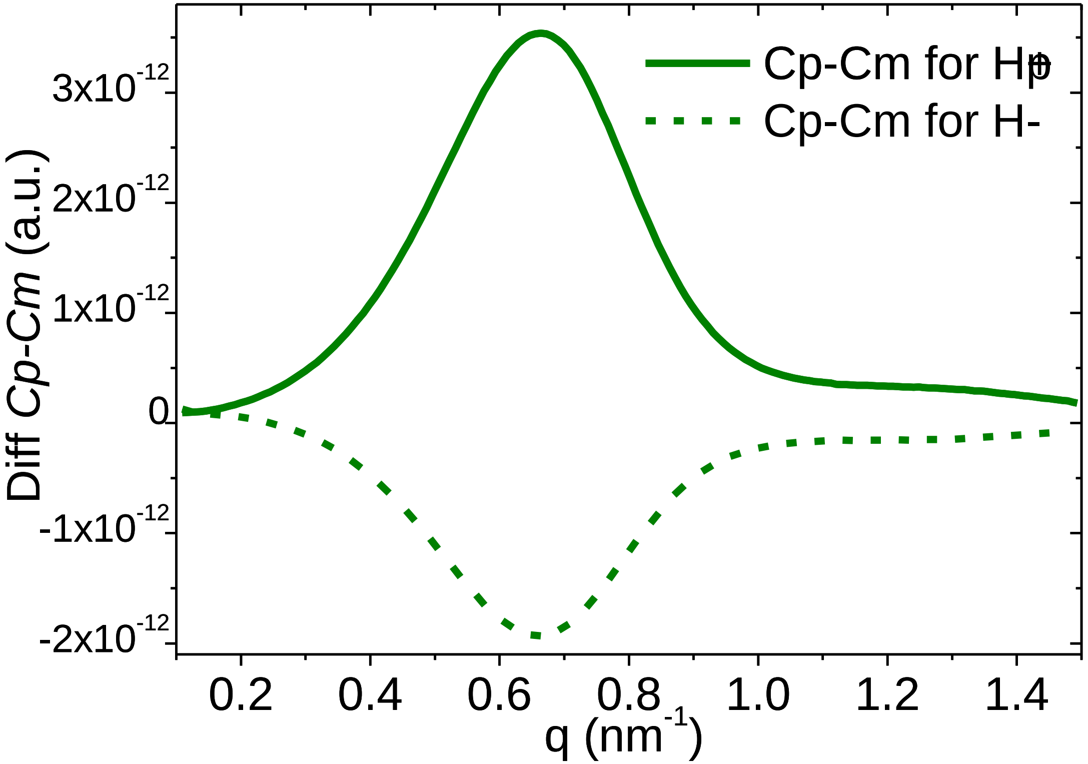


TR - SAXS on FePt:
Results, Q scans before t0, 11mJ/cm²

- scattered Intensity
  - Difference for H+ and H-



- $diff = Cp - Cm \propto 4MC$
  - Magnetization switching



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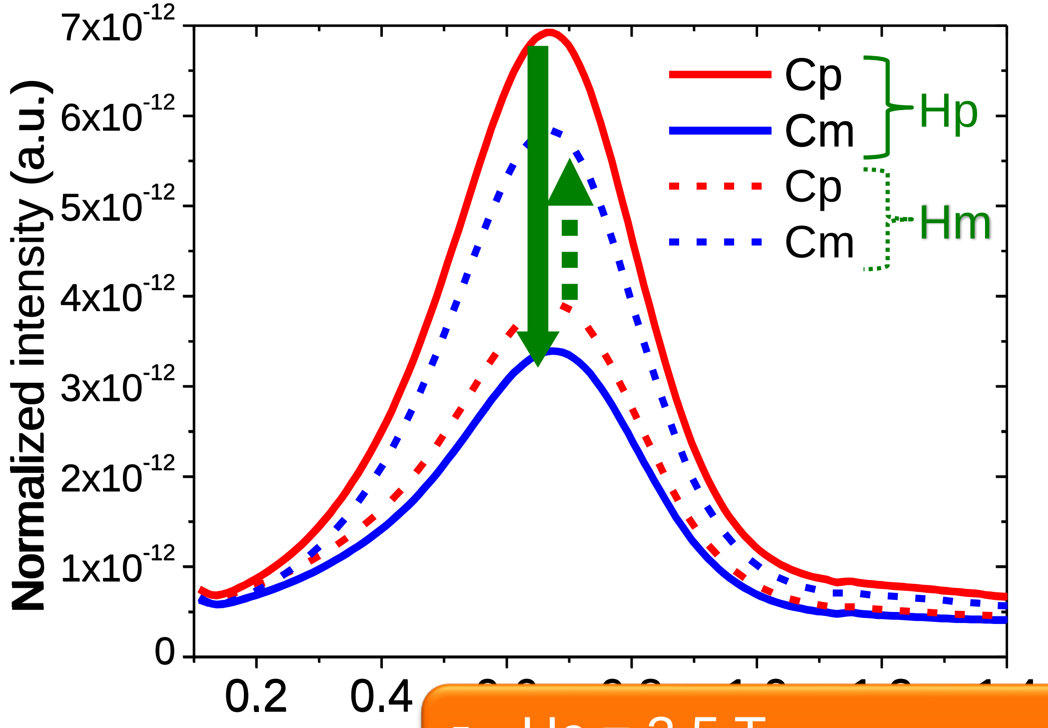

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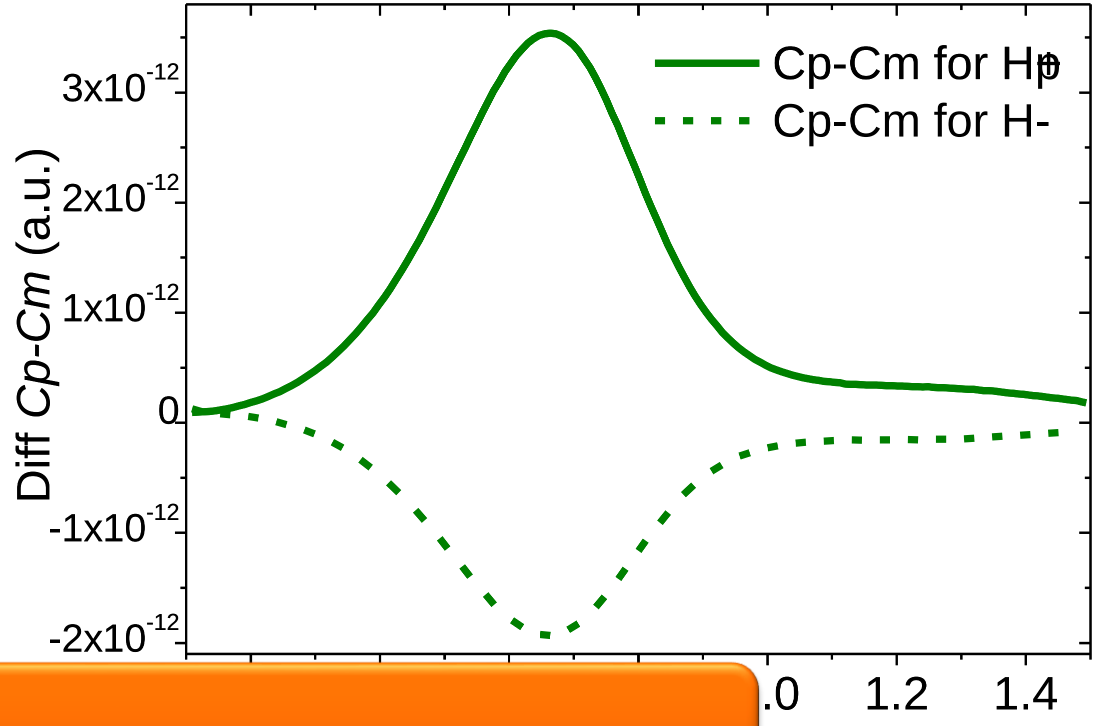
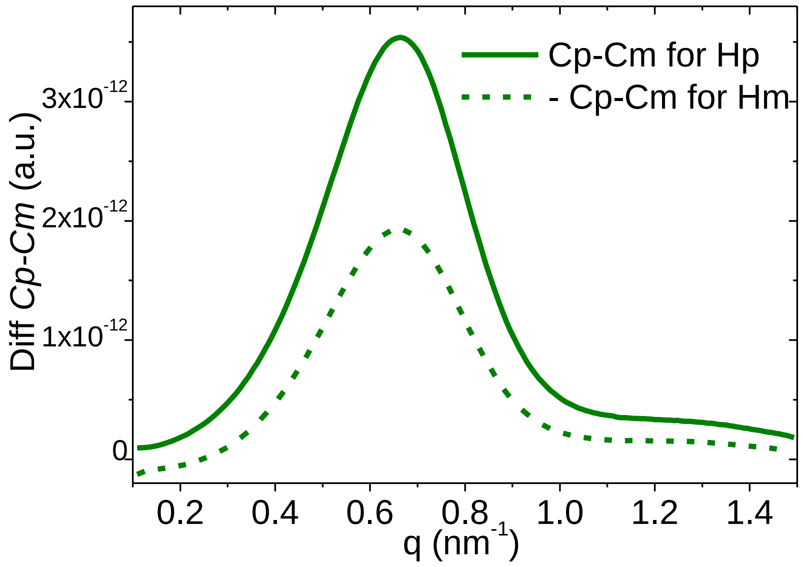
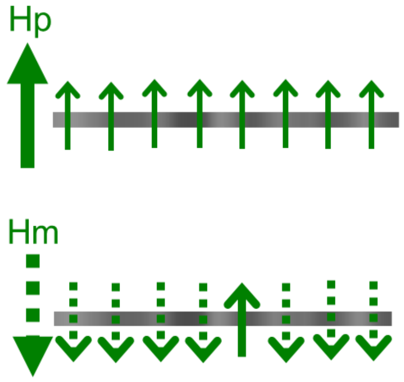


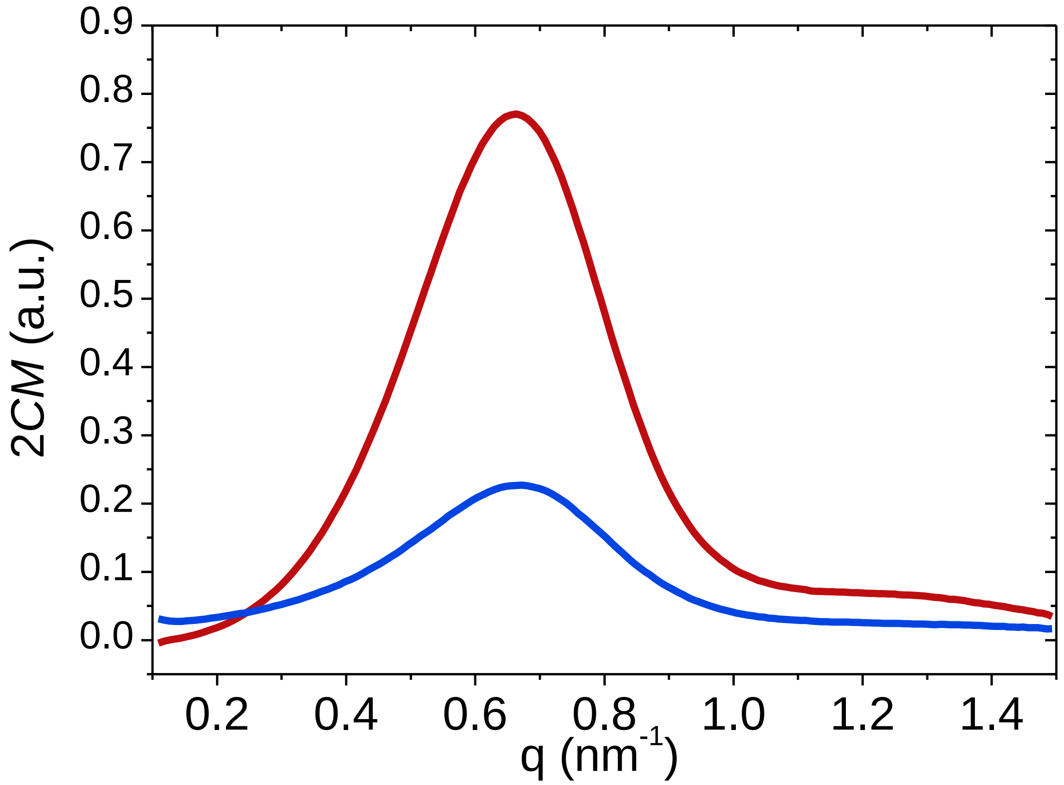
- Hc = 3.5 T
- Applied field of +/-0.4T ⇨ Magnetization switching due to laser

TR - SAXS on FePt:
Results, Q scans before t0, 11mJ/cm²

- Isolating not-switching nanoparticles from switching one





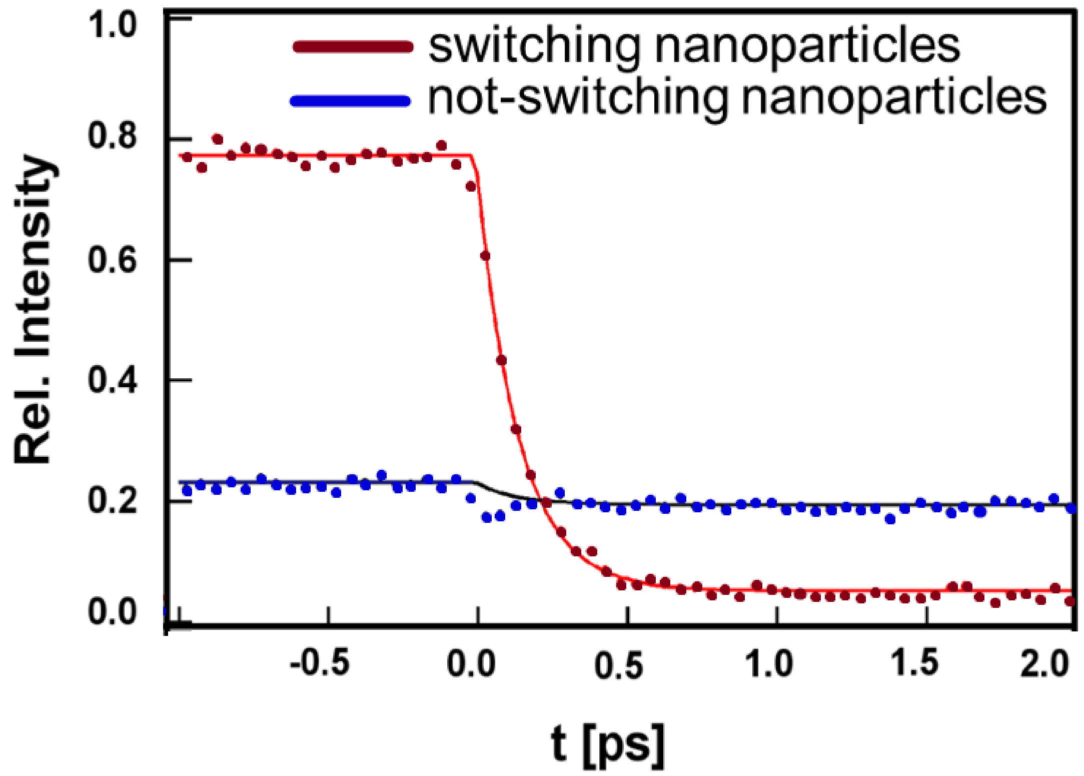


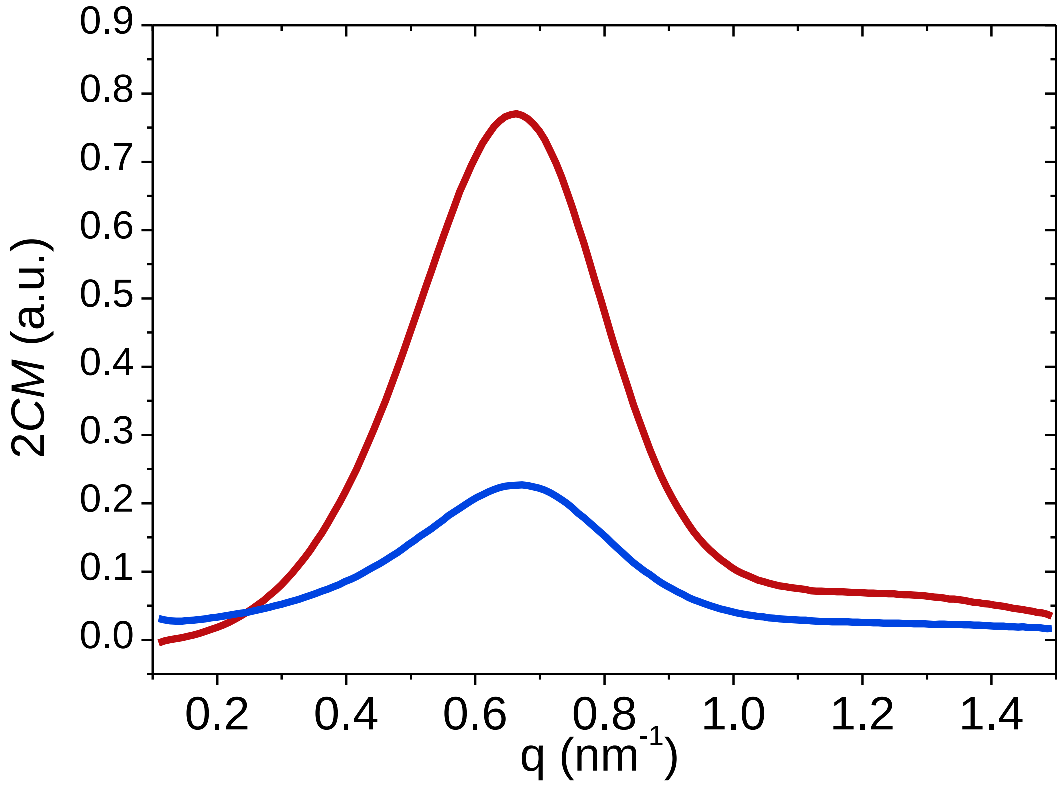
- switching nanoparticles $\propto \frac{\mathrm{Hp}-\mathrm{Hm}}{2} \propto 2M_sC$
- not-switching nanoparticles $\propto \frac{\mathrm{Hp}+\mathrm{Hm}}{2} \propto 2M_{ns}C$

Hypothesis: All nanoparticles are not switching

TR - SAXS on FePt: Results, time scans at the peak, 11mJ/cm²

- Isolating not-switching nanoparticles from switching one



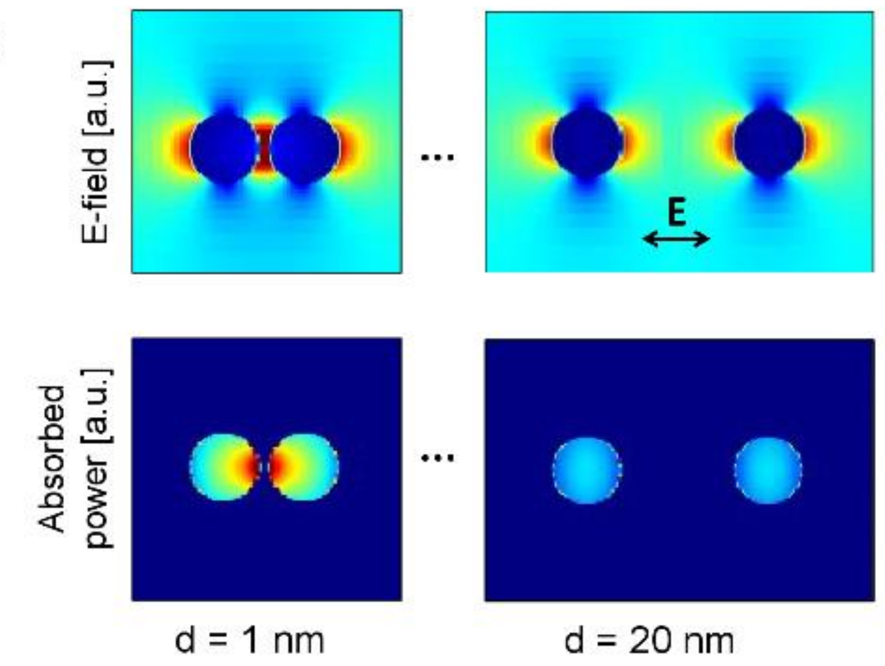


Hypothesis: Not-switching nanoparticles are not sensitive to the excitation laser

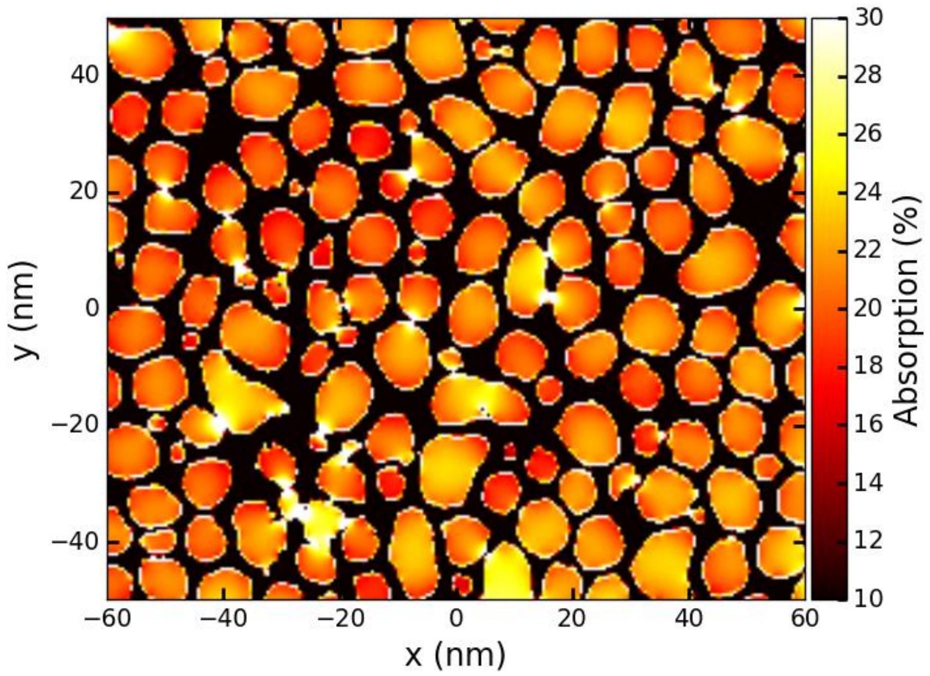
TR - SAXS on FePt:

Modeling the Near-Field Nanoparticle Response, 11mJ/cm^2

- Dielectric properties of individual nanoparticles
  L. Le Guyader *et al*. Nat Comm (2015), Lumerical software
  - Finite difference time domain (FDTD) simulations



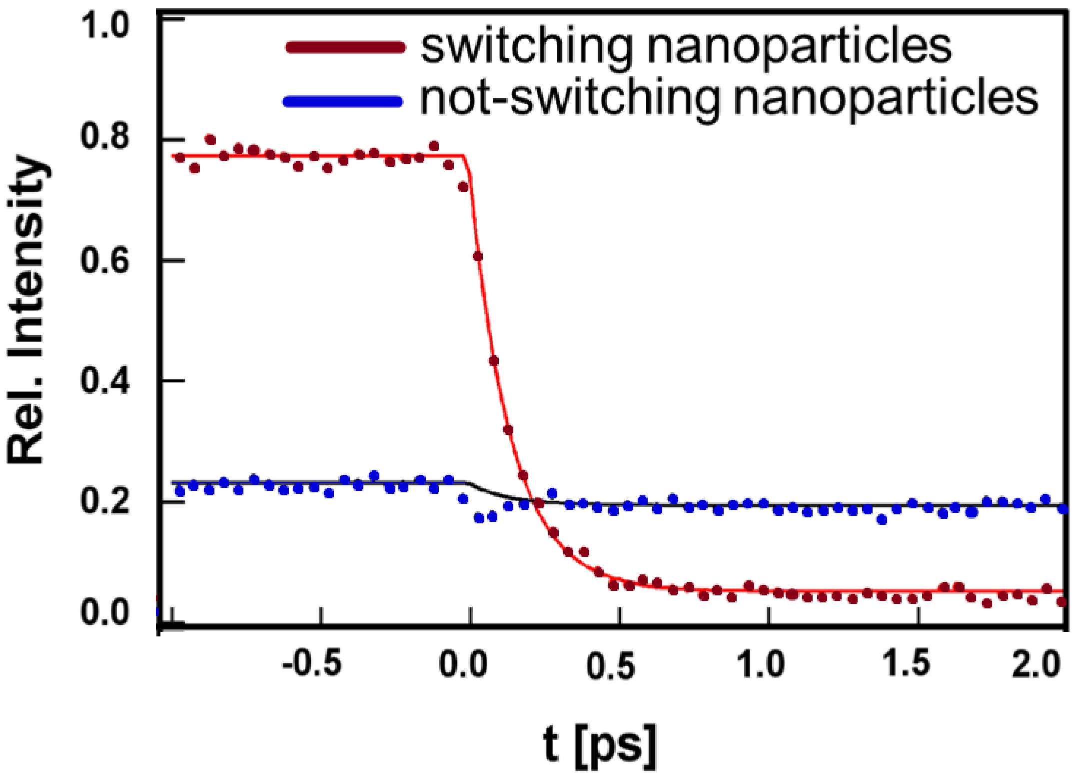
- IR Absorption profile
  - Inhomogeneous
  - Low absorption



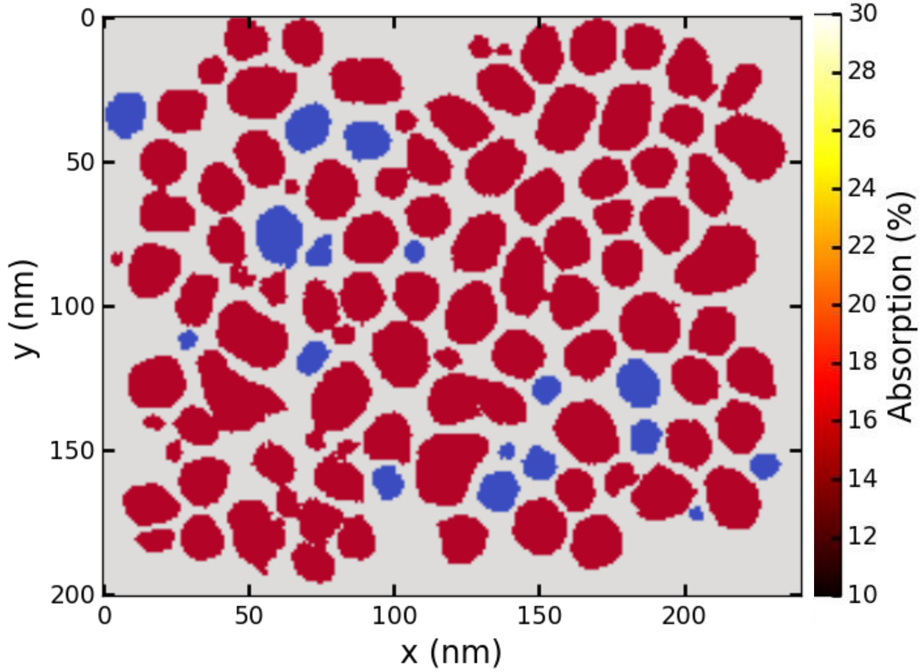
TR - SAXS on FePt:
Modeling the Near-Field Nanoparticle Response, 11mJ/cm^2

- Dielectric properties of individual nanoparticles

L. Le Guyader *et al*. Nat Comm (2015), Lumerical software

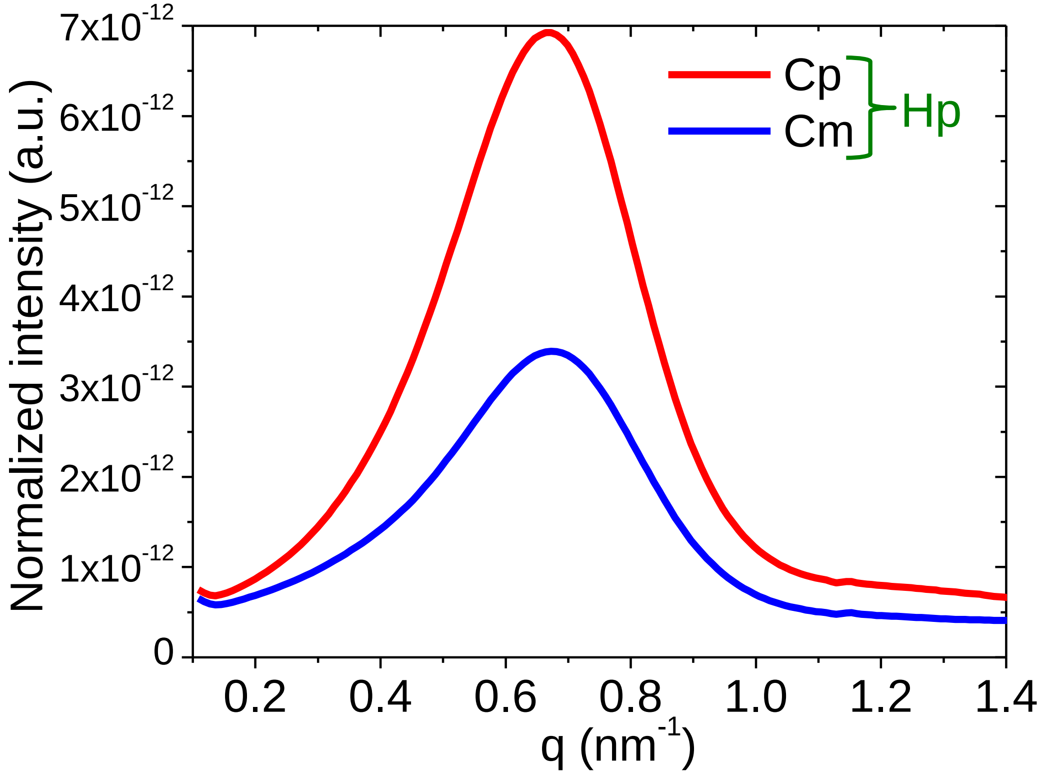


- IR Absorption profile
  - Inhomogeneous
  - Low absorption
  - No size dependence

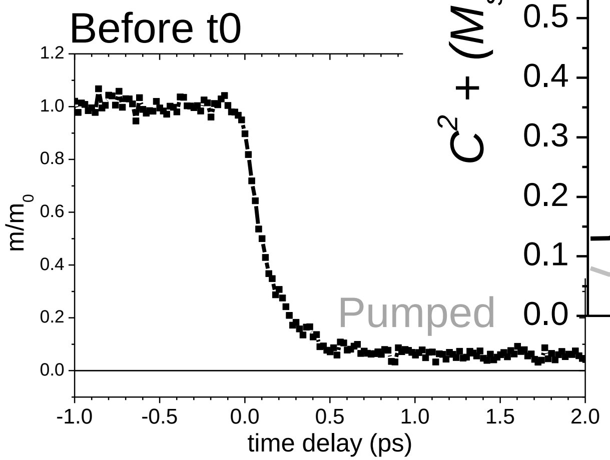


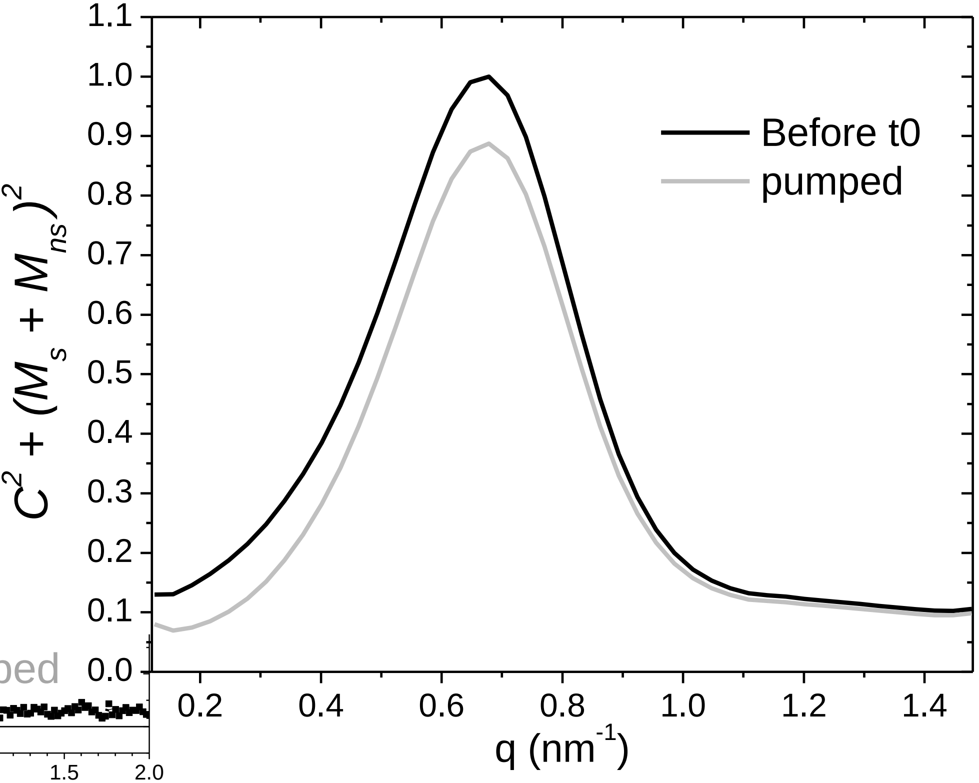
TR - SAXS on FePt:
Results, Q scans, 11mJ/cm²

- scattered Intensity Hp
  - $I \propto C^2 + (M_s + M_{ns})^2 \pm 2(M_s + M_{ns})C$



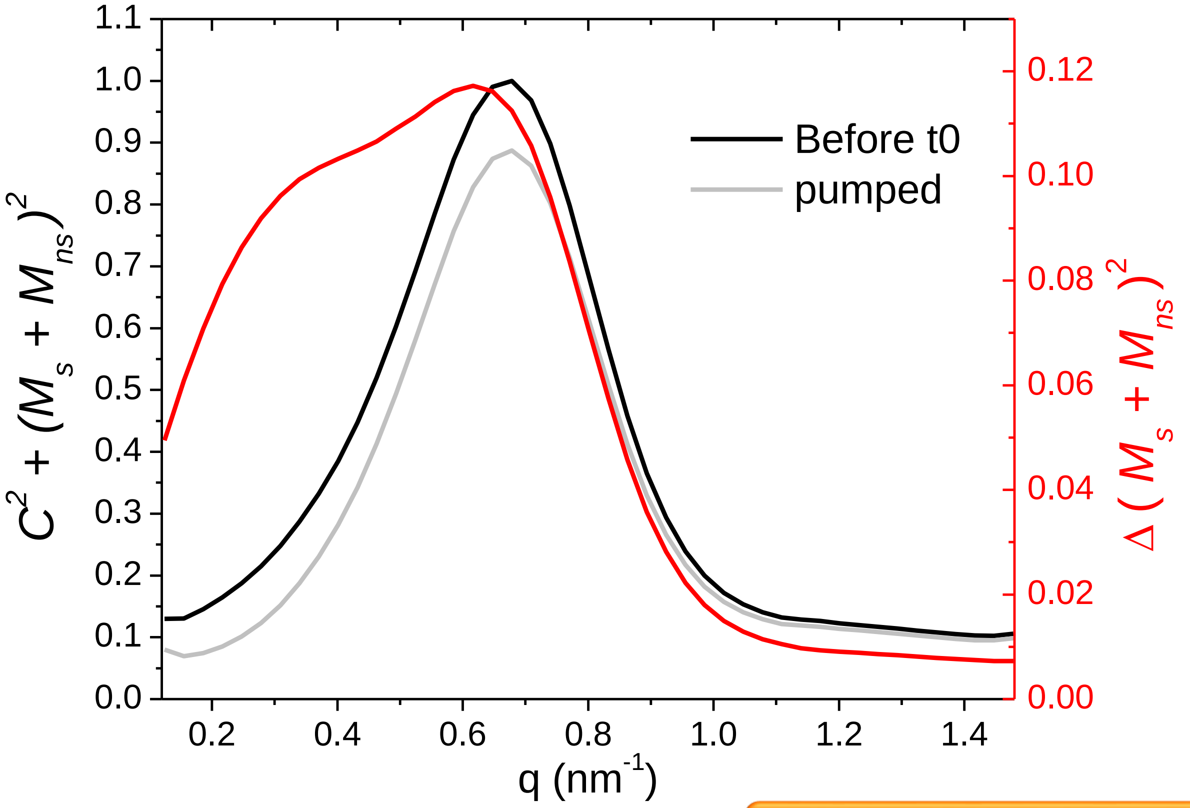
- $ave \propto C^2 + (M_s + M_{ns})^2$
  - $C^2 \gg M^2$
  - Shape = C^2





Q scans, 11mJ/cm^2

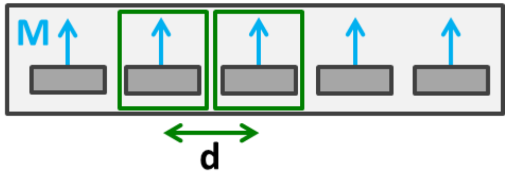
- $ave = C^2 + (M_s + M_{ns})^2$
  - $C^2 \gg M^2$
  - Shape = C^2



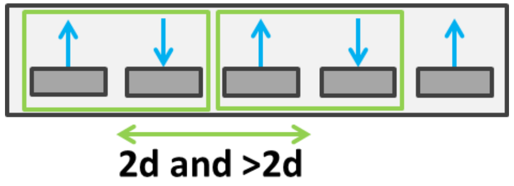
- $\Delta(M_s + M_{ns})^2$

Magnetic correlations

- FM



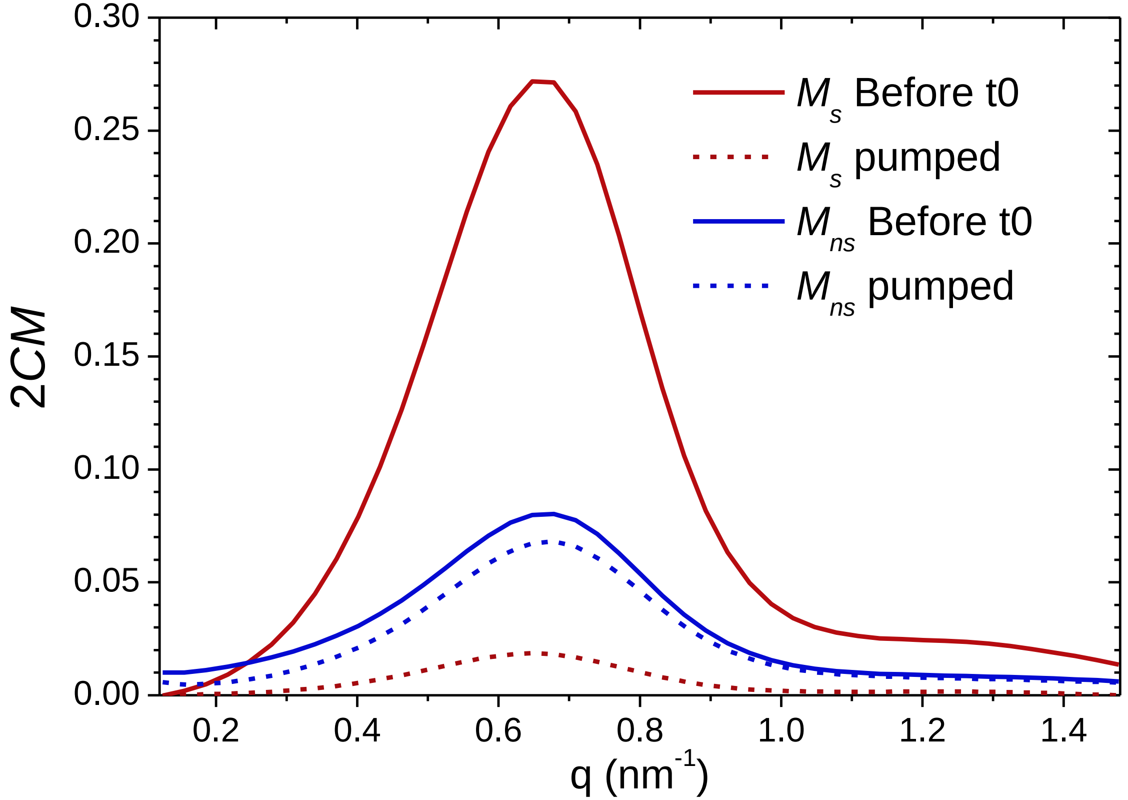
- AF and longer



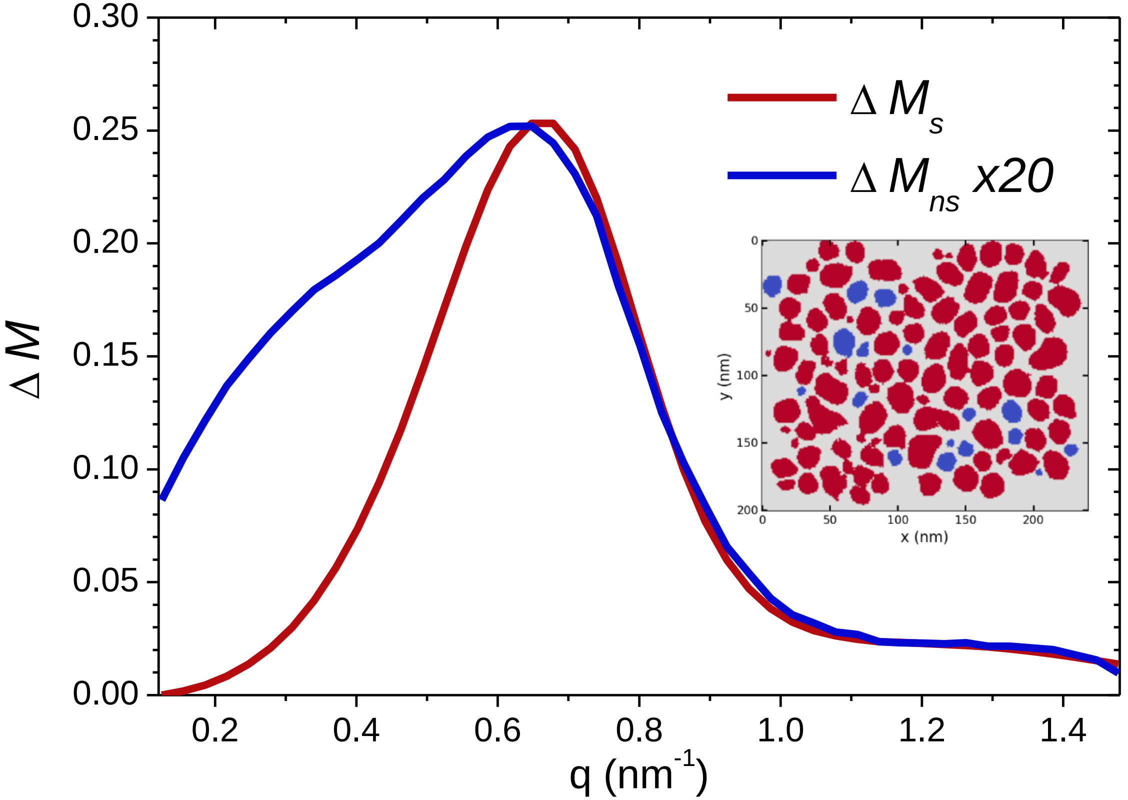
2 type of magnetic correlations

II. Magnetic switching in FePt after an ultrafast laser pulse
Q scans, 11mJ/cm²

- C, M_s, and M_{ns}
  - not-switching nanoparticles almost no demagnetization ⇨ confirm low IR absorption

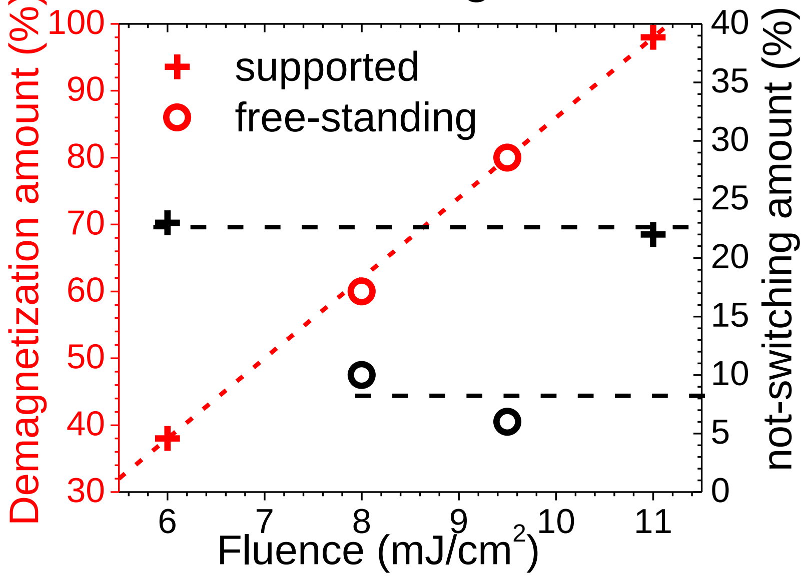


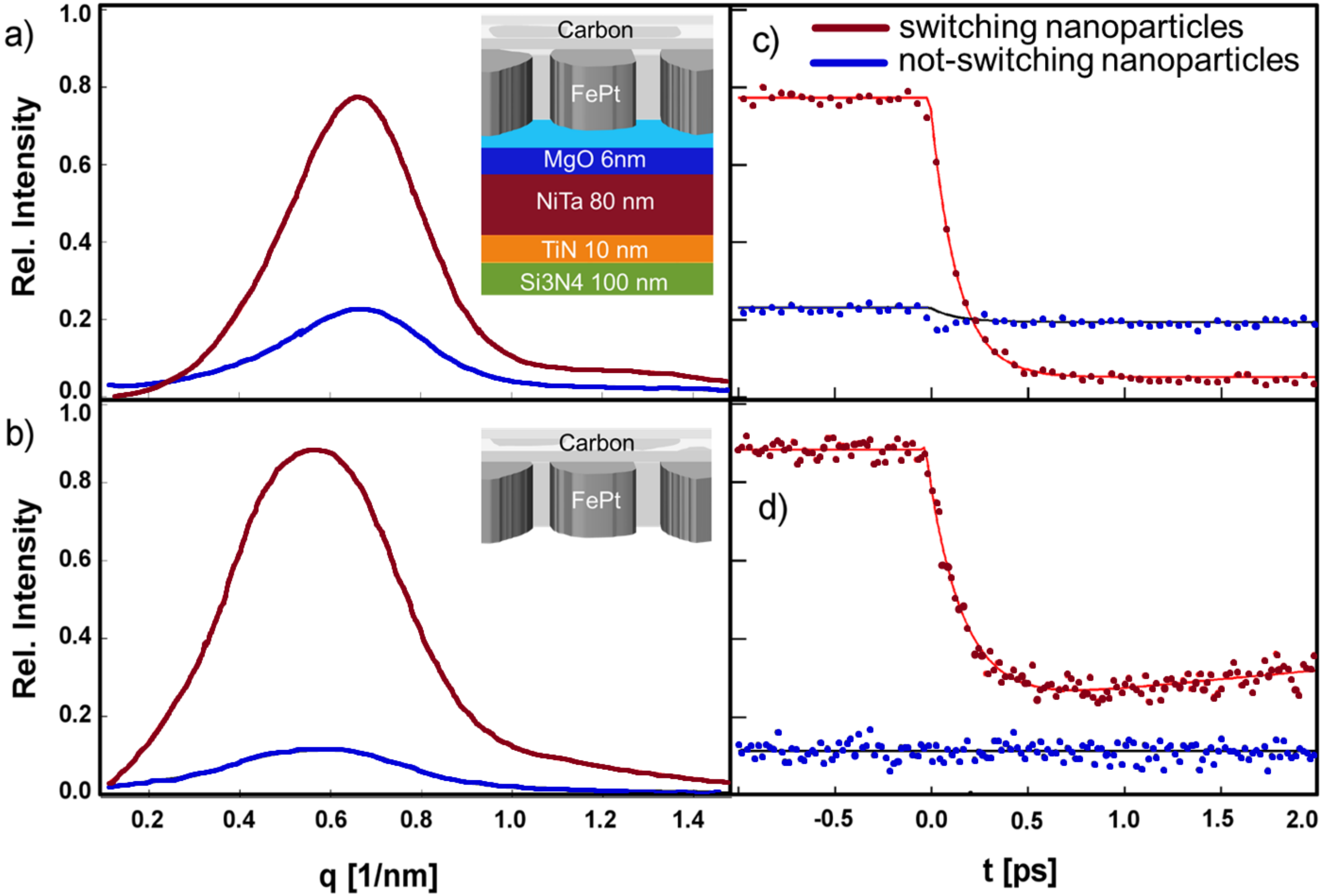
- ΔM_s, and ΔM_{ns}
  - switching= FM interaction
  - not-switching = FM + AF + longer interaction



TR - SAXS on FePt: Results, different samples

- Supported FePt nanoparticles
  - 11 mJ/cm^2
  - 20% of not-switching
- Freestanding FePt nanoparticles
  - 9.5 mJ/cm^2
  - 10% of not-switching





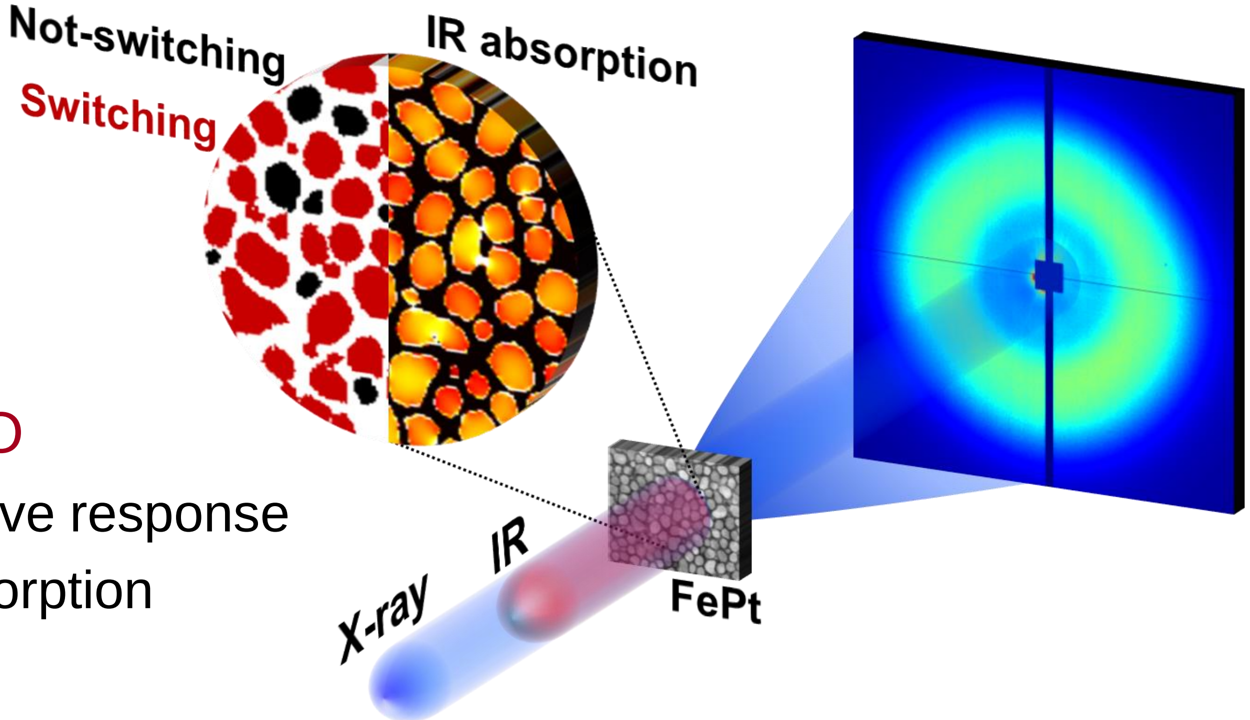
Heat sink plays a role in switching

Message to take home

➢ Magnetic switching in FePt induced by ultrafast laser pulse under a 0.4T applied field

➢ Do all the grains switch? NO
- IR absorption inhomogeneous
- Low absorption = not switching
- Heat sink decrease the switching amount

➢ Is there some grains size dependence? NO
- Inhomogeneity of IR absorption due to collective response
- No fluence dependence of number of low absorption grains

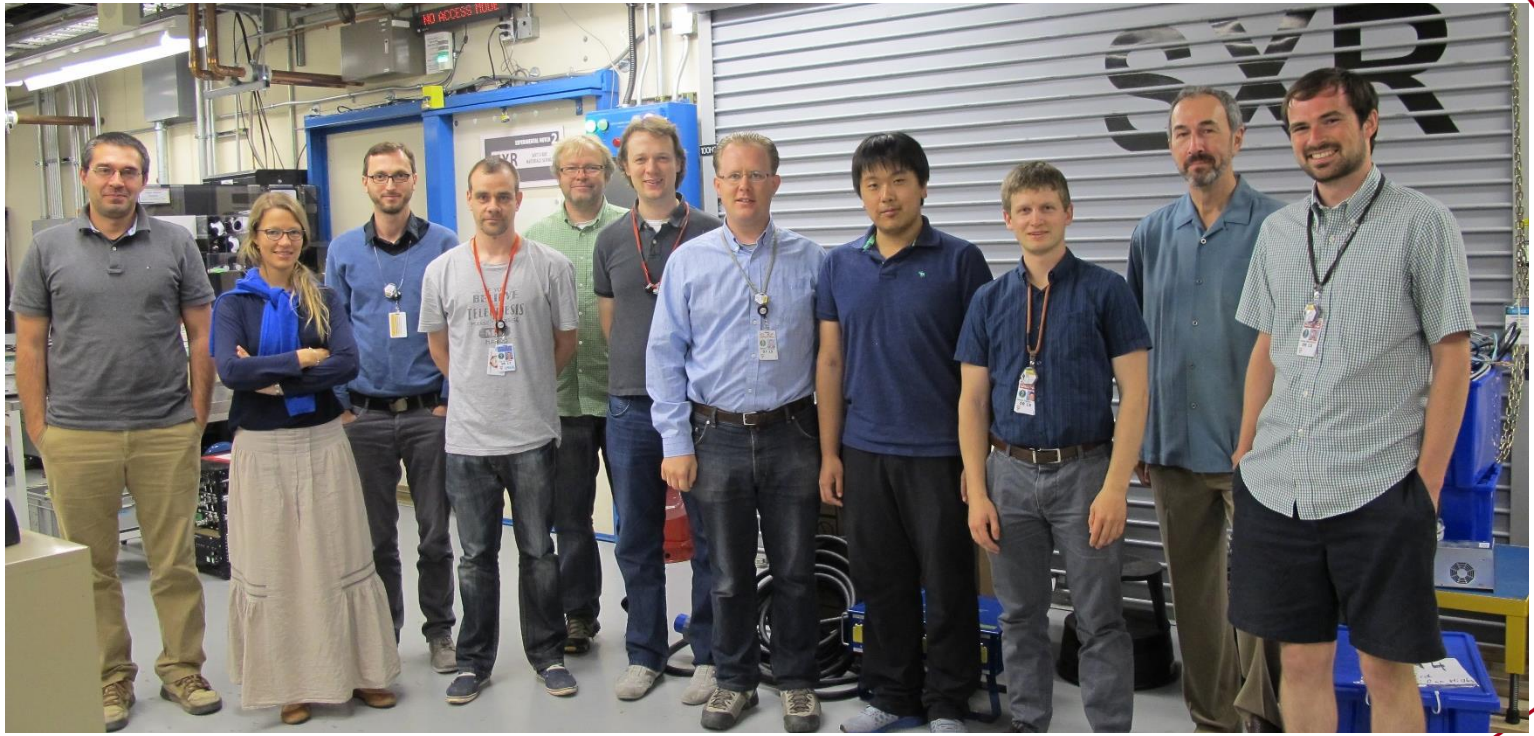


Does ultrast demagnetization process play a role?

P. W. Granitzka*, **E. Jal***, et al, NanoLetters, DOI: 10.1021/acs.nanolett.7b00052 (2017)

SLAC NATIONAL ACCELERATOR LABORATORY

Acknowledgments



Hermann Dürr

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Thank you for your attention