Ultrafast Magnetisation Dynamics at the Low-Fluence Limit Supported by External Magnetic Fields

39th International Free-Electron Laser Conference

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HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

DESY.

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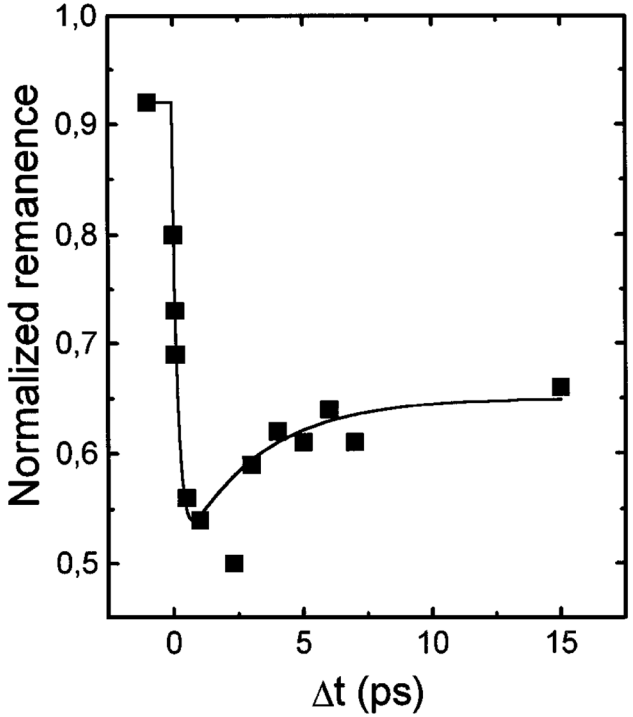
Motivation

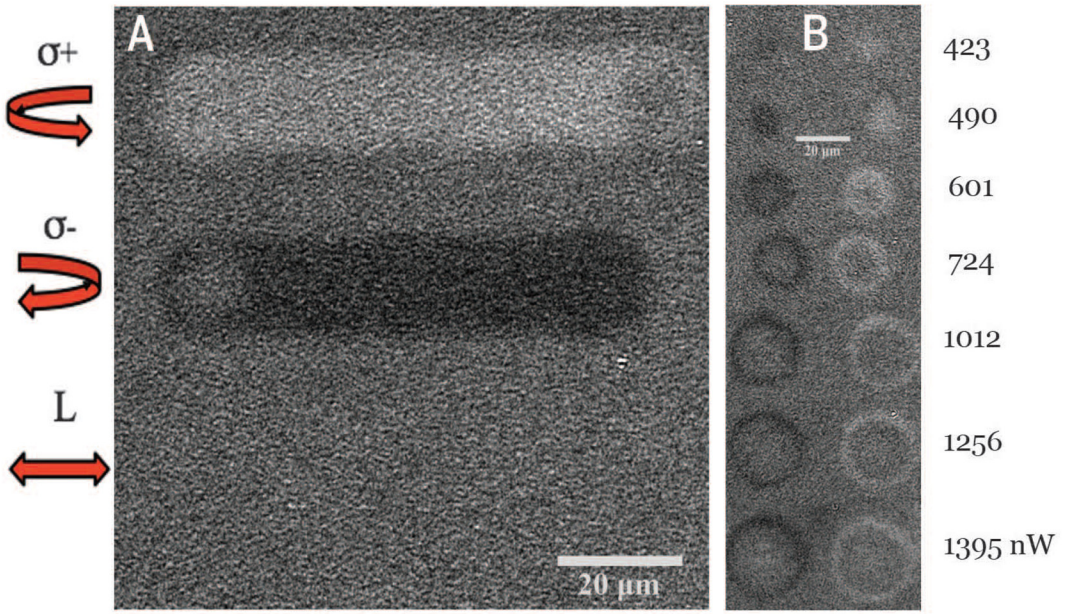
Manipulation of Magnetisation by Infrared (IR) Laser-Light

Ultrafast Demagnetization in Ni within ≅ **260 fs** upon pumping by 60 fs IR pulses



E. Beaurepaire *et al.*, Phys. Rev. Lett., **76**, 4250 (1996)

All-optical helicity dependent switching (AO-HDS) in ferromagnets like Co/Pt multilayers



C-H. Lambert *et al.*, Science, **345**, 1337 (2014)

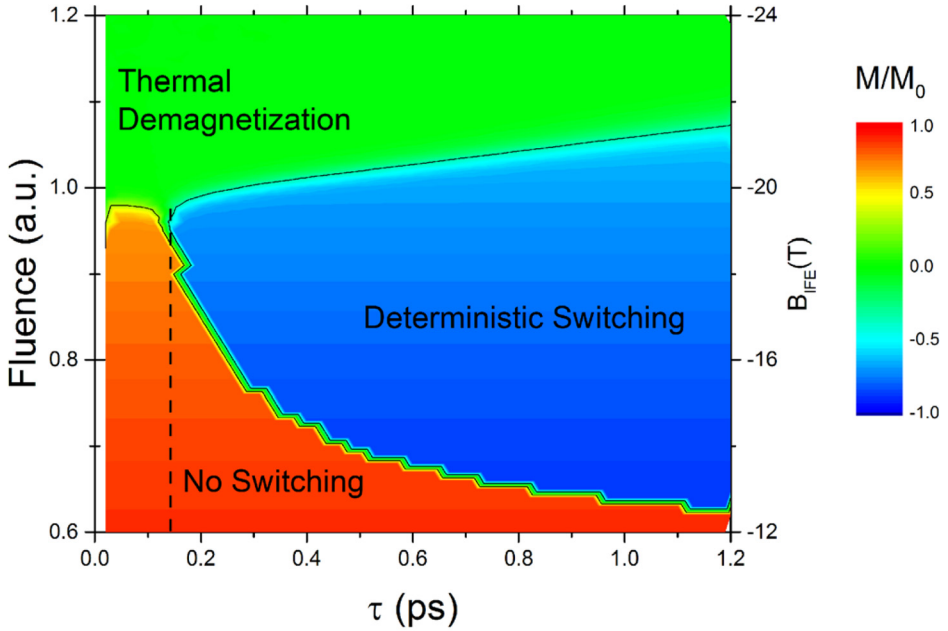
Role of IR-laser in AO-HDS?

Heat-Pulse? and/or **Field-Pulse?**

Single-pulse deterministic switching in ferromagnets possible?

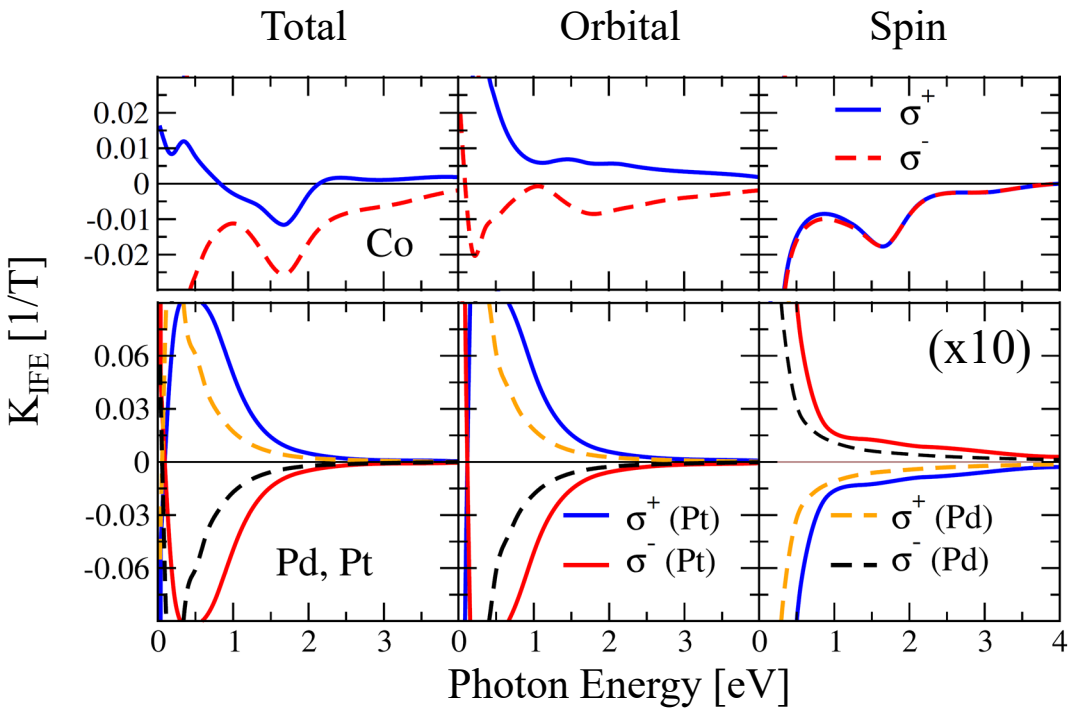
Motivation

Recent Findings in AO-HDS



T. D. Cornelissen *et al.*, Appl. Phys. Lett., **108**, 142405 (2016)

Prediction of **thresholds** for **laser fluence** and duration of inverse Faraday effect **(IFE)-induced magnetic field**

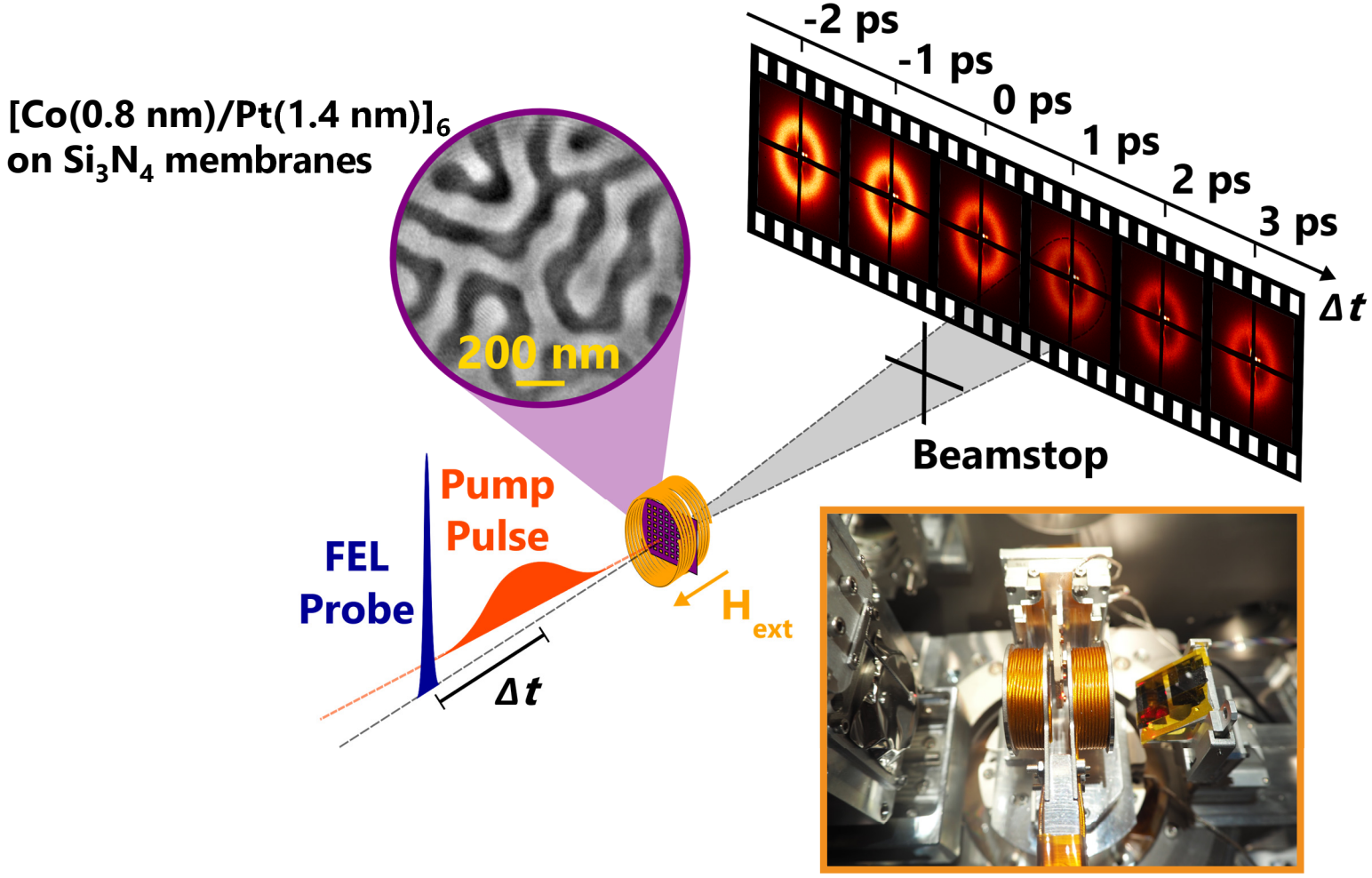


M. Berritta *et al.*, Phys. Rev. Lett., **117**, 13 (2016)

Co: total IFE vs. helicity is **asymmetric**
Pt: total IFE vs. helicity is **antisymmetric**

Experiment Setup

Time-Resolved Magnetic Small-Angle X-ray Scattering (tr-mSAXS)



Experimental Conditions at FERMI@Elettra - DiProI beamline

IR Pump

Wavelength: 800 nm
Spotsize: $(333 \times 560)\ \mu m^2$
Pulse Length: 3.5 ps
Fluence: $3.4\ mJ/cm^2$

FEL Probe

Wavelength: 20.8 nm
(resonant to Co $M_{2,3}$ - edge)
Spotsize: $(90 \times 100)\ \mu m^2$
Pulse Length: 70 fs
Fluence: $11\ mJ/cm^2$

Measurement Scheme

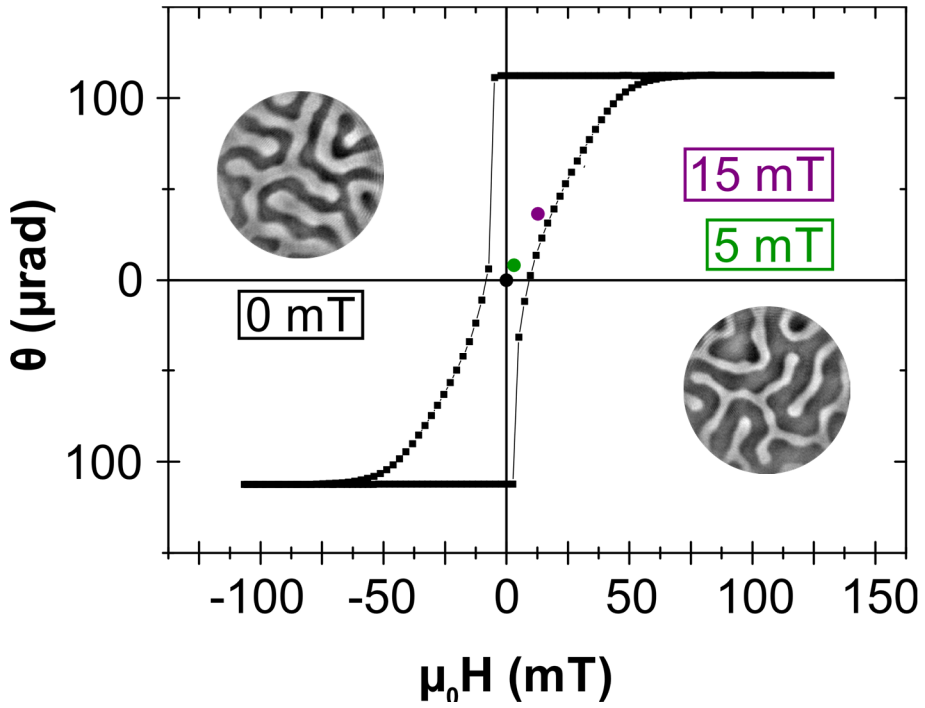
FEL-only / Pump-Probe / Dark at a repetition rate of 50 Hz

Experiment Setup

Time-Resolved Magnetic Small-Angle X-ray Scattering (tr-mSAXS)

$[Co(0.8\ nm)/Pt(1.4\ nm)]_6$ on Si_3N_4 membranes

Applying external magnetic fields
Lifting energetic degeneration of up- and down-magnetised domains



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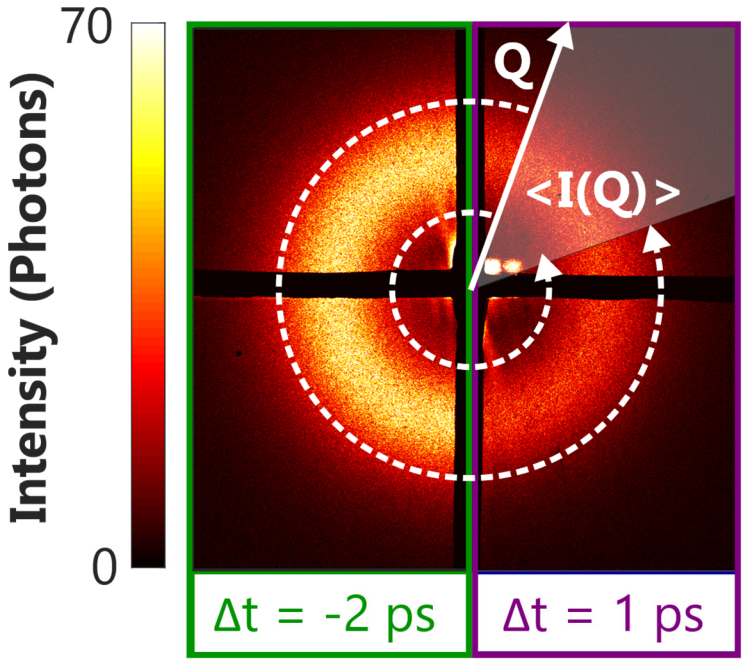
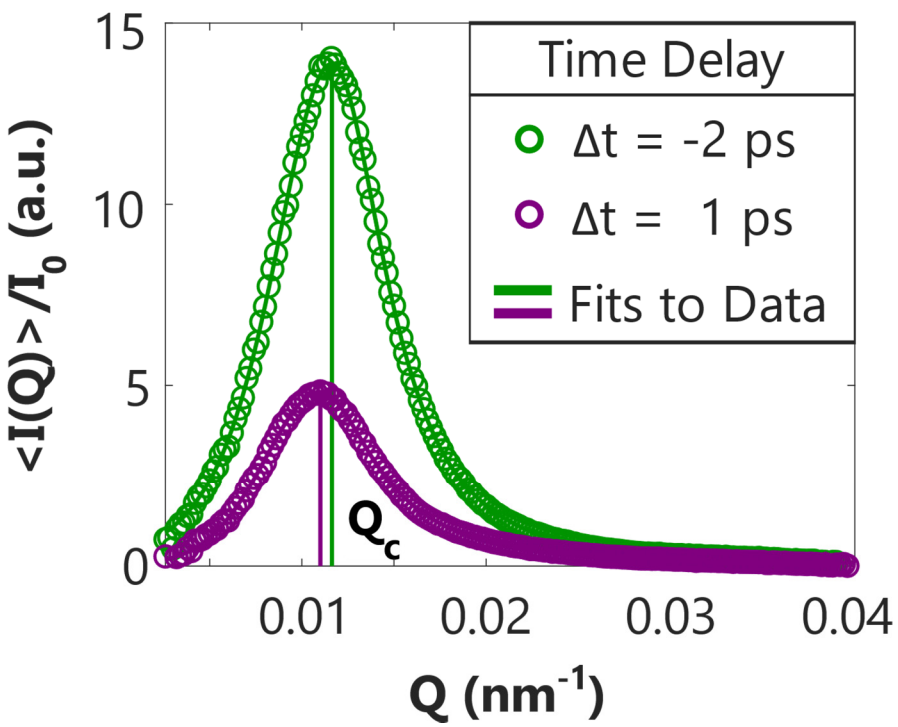
Data Analysis

Extracting Magnetisation Dynamics



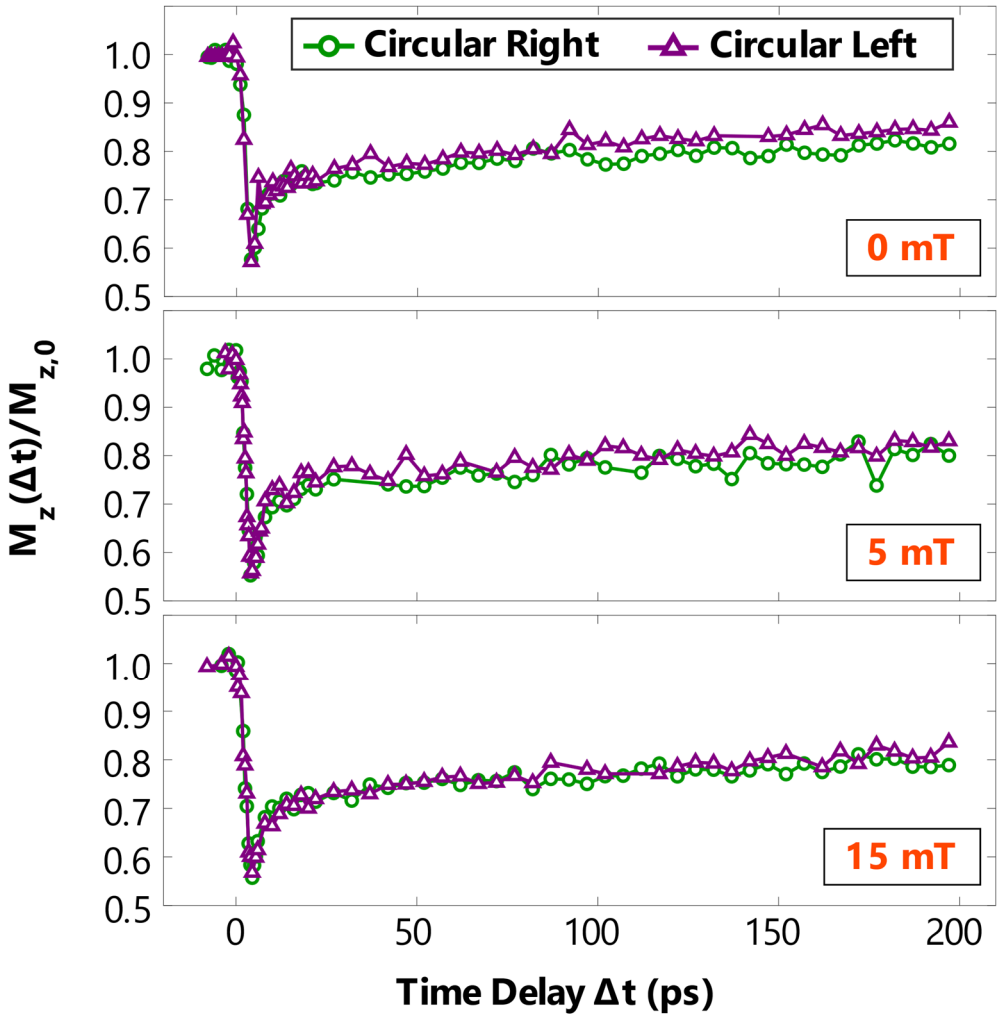


unpumped (Δt = -2 ps) and **pumped (Δt = 1 ps)** multi-domain state

Q_c: characteristic scattering length
$I(Q_c) \propto M_z^2$: z-component of magnetisation

Results

Ultrafast Demagnetisation



Ultrafast Demagnetization

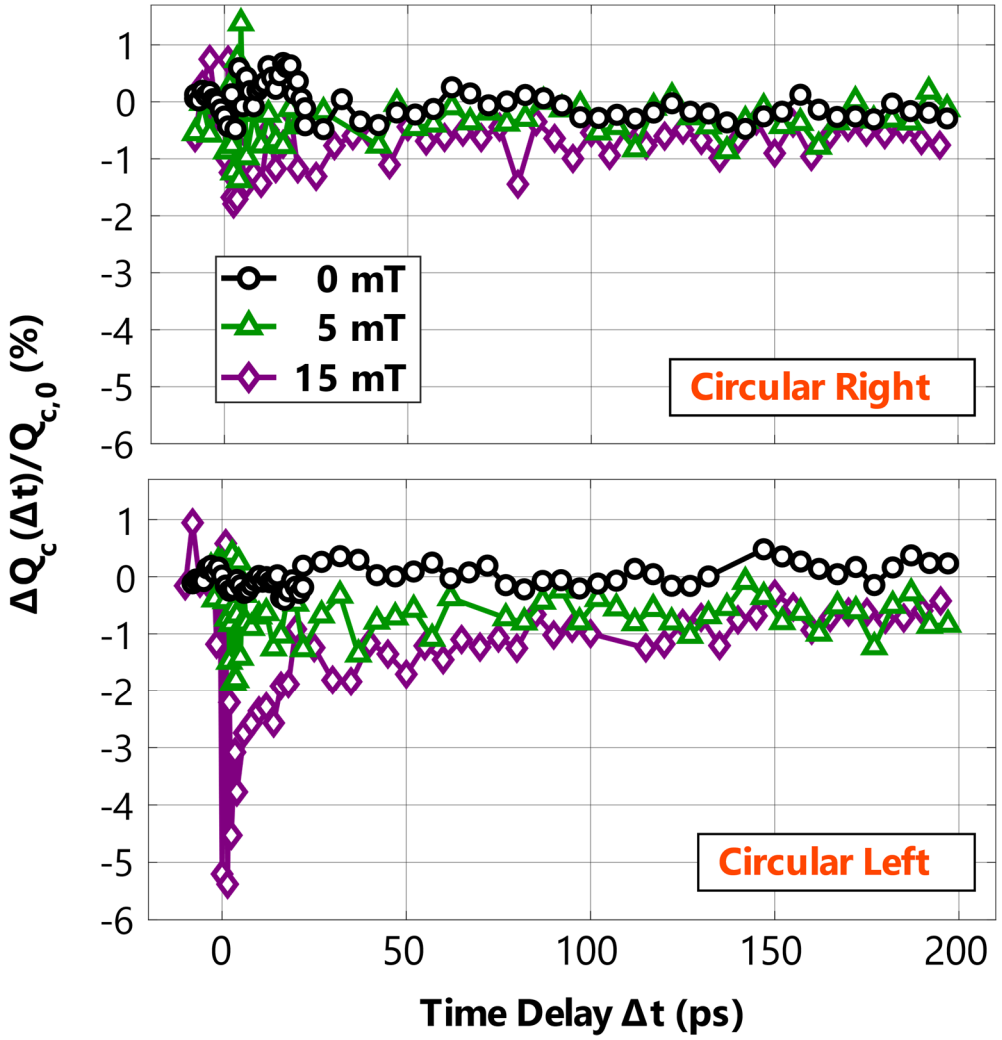
Strength: **55**% compared to the unpumped case

Timescale: within the pulse length of **3.5 ps**

→ **No helicity nor field dependence in demagnetisation**

Results

Transient Magneto-Structural Changes



Ultrafast Demagnetization

Strength: $\mathbf{55\%}$ compared to the unpumped case

Timescale: within the pulse length of $\mathbf{3.5\ ps}$

→ **No helicity nor field-dependence in demagnetisation**

Transient Magneto-Structural Changes

Strength: $\cong \mathbf{2\%}$ for circular right (**CR**) and $H_{\mathrm{ext}} = 15\ \mathrm{mT}$

$\cong \mathbf{5.5\%}$ for circular left (**CL**) and $H_{\mathrm{ext}} = 15\ \mathrm{mT}$

Timescale: within the pulse length of $\mathbf{3.5\ ps}$

→ **Helicity dependent transient magneto-structural changes**

→ **Shifting to lower threshold by out-of-plane magnetic fields**

Conclusion & Outlook

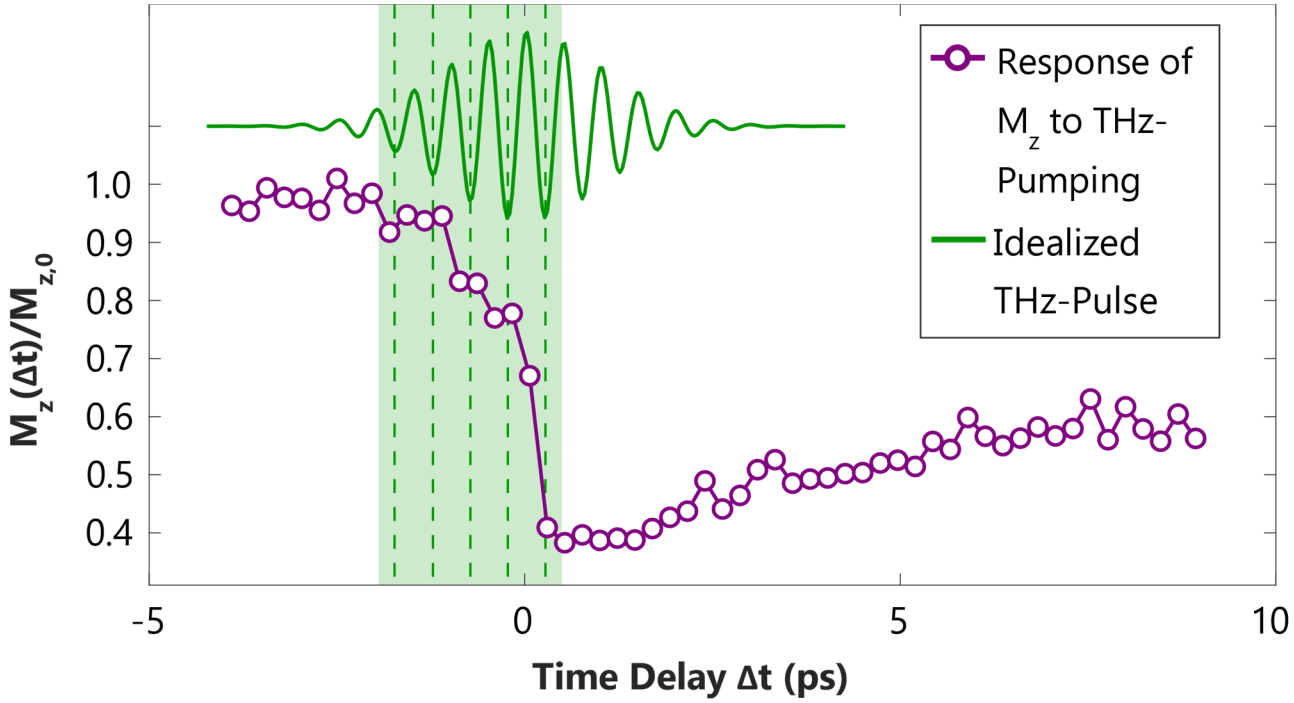
NIR-pump
Helicity dependent transient magneto-structural changes in nanometre-sized domains

Out-of-plane magnetic fields shift the threshold fluence to lower values

THz-pump
Polychromatic THz-radiation ($2 - 10$ THz)

Study coherent response of magnetisation to pump pulse's H-field

Upgrades of THz-beamline [1] and FLASH2020+ [2]
→ improved experimental control



[1] E. A. Schneidmiller *et al.*, Phys. Rev. Accel. Beams, **20**, 020705 (2017)
[2] R. Pan *et al.*, J. Synchrotron Rad., **26**, 700 (2019)