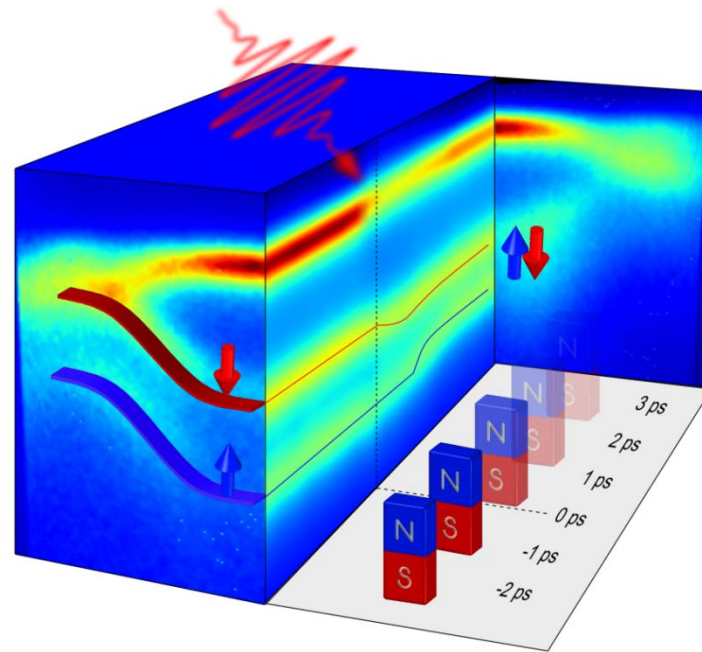


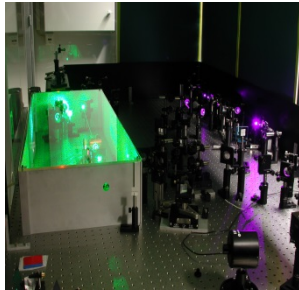
Magnetization dynamics in lanthanides

new frontiers in spin-dependent band mapping at BESSY^{VSR}

Martin Weinelt



Ti:Sa



UV 10 mW

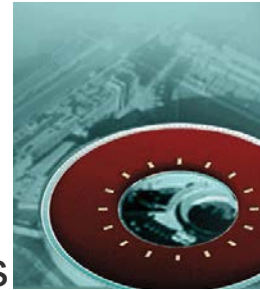
86 MHz, 0.1 nJ

10^9 photons / pulse

80 MHz pump, 1 nJ

10^{17} photons / s, 50 fs

BESSY



10^{13} photons / s
(@ 0.1A, 0.1% BW)

500 MHz

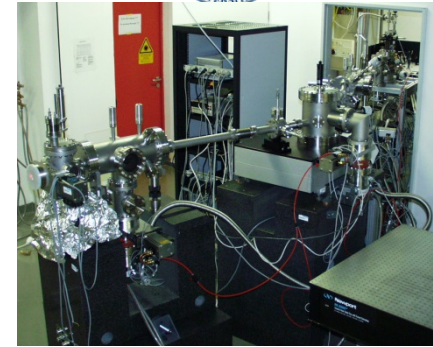
10^5 photons / pulse

1.25 MHz

10^{11} photons / s, 3 ps

10^9 photons / s, 700 fs

HHG



10 kHz

10^5 photons / pulse

pump, 500 μ J \sim J / cm²

10^9 photons / s, 100 fs

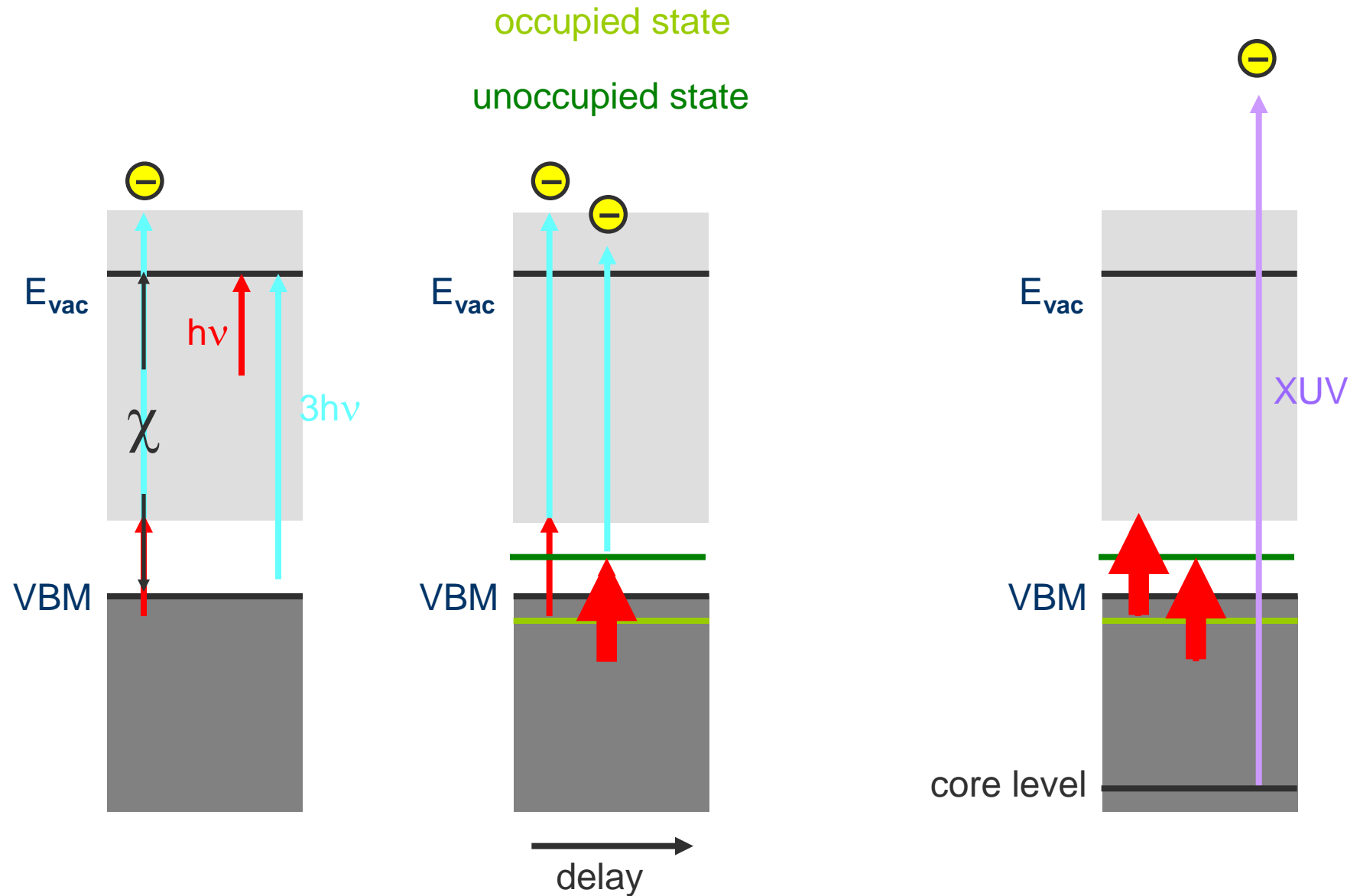
Space-charge problem:

S. Passlack et al., J. Appl. Phys. **100** (2006) 024912.

A. Pietzsch et al., New J. Phys. **10** (2008) 033004.

limit at $E_{\text{kin}} \sim 80$ eV: 10^7 photons / pulse

Two-photon photoemission

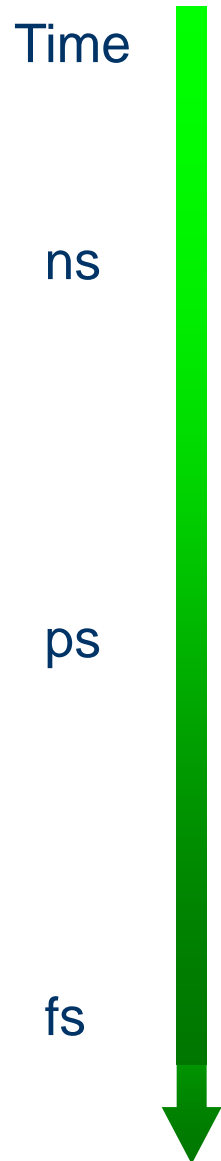


Our Goal:

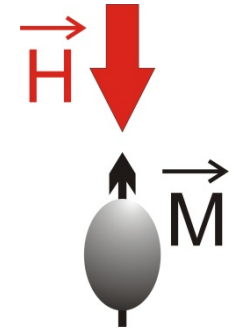
Follow the signatures of „phase transitions“
in the transient electronic band structure

Our BESSY^{VSR} Goal:

Spin- and time-resolved ARPES

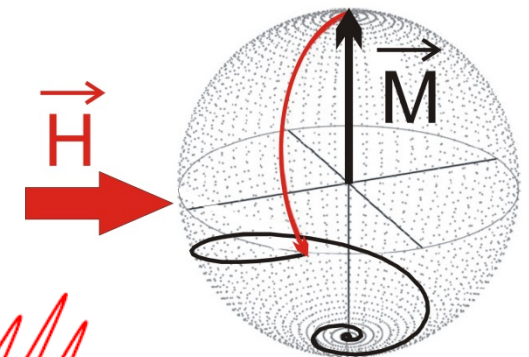


Conventional switching: Domain-wall nucleation and propagation > 1 ns



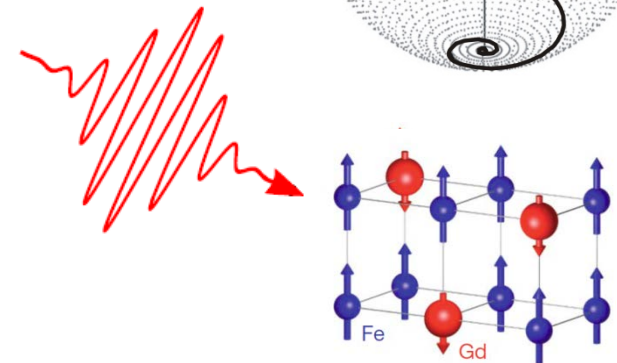
ns

Coherent rotation of magnetization: „precessional switching“ > 10 ps



ps

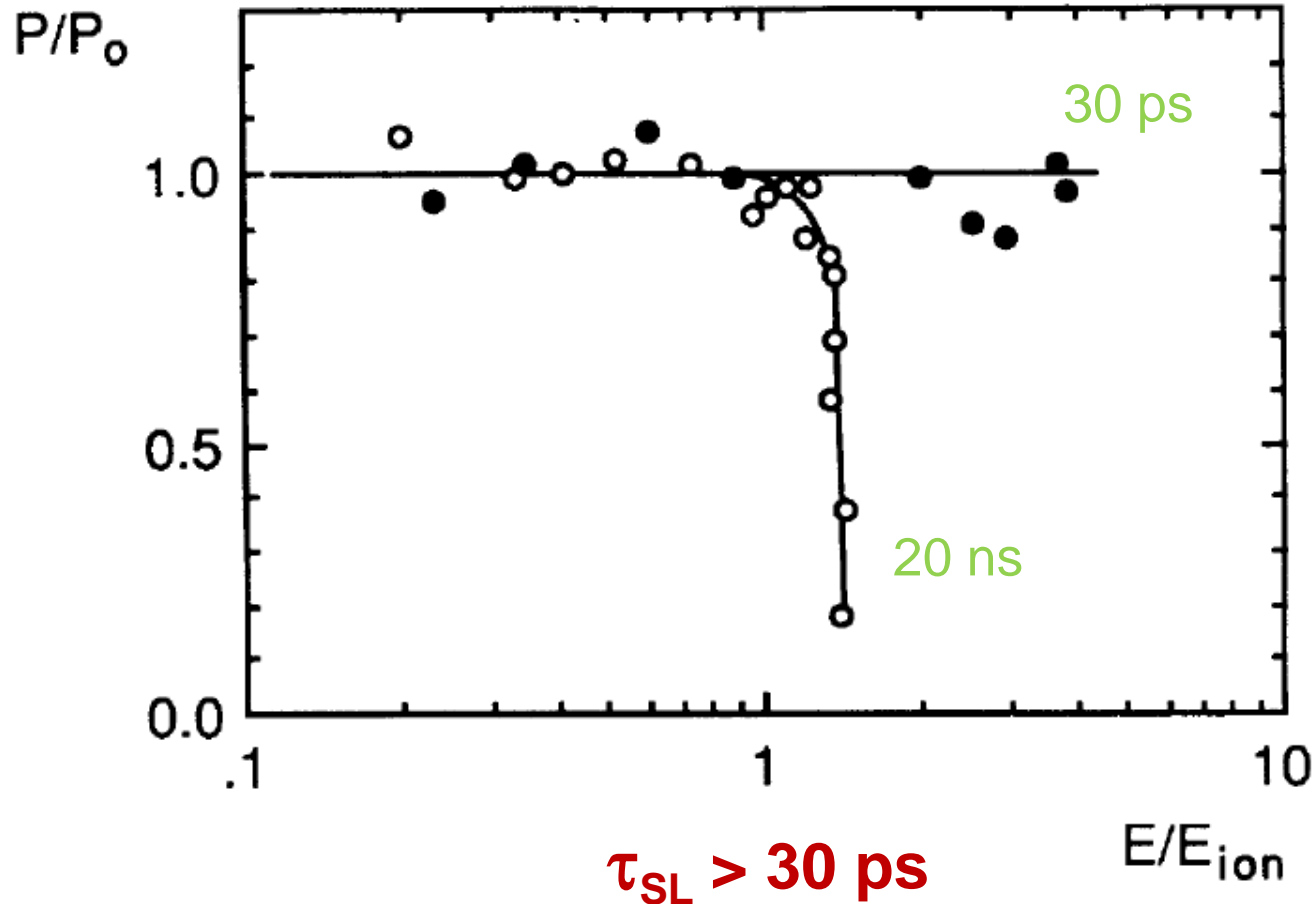
Laser-induced magnetic switching !



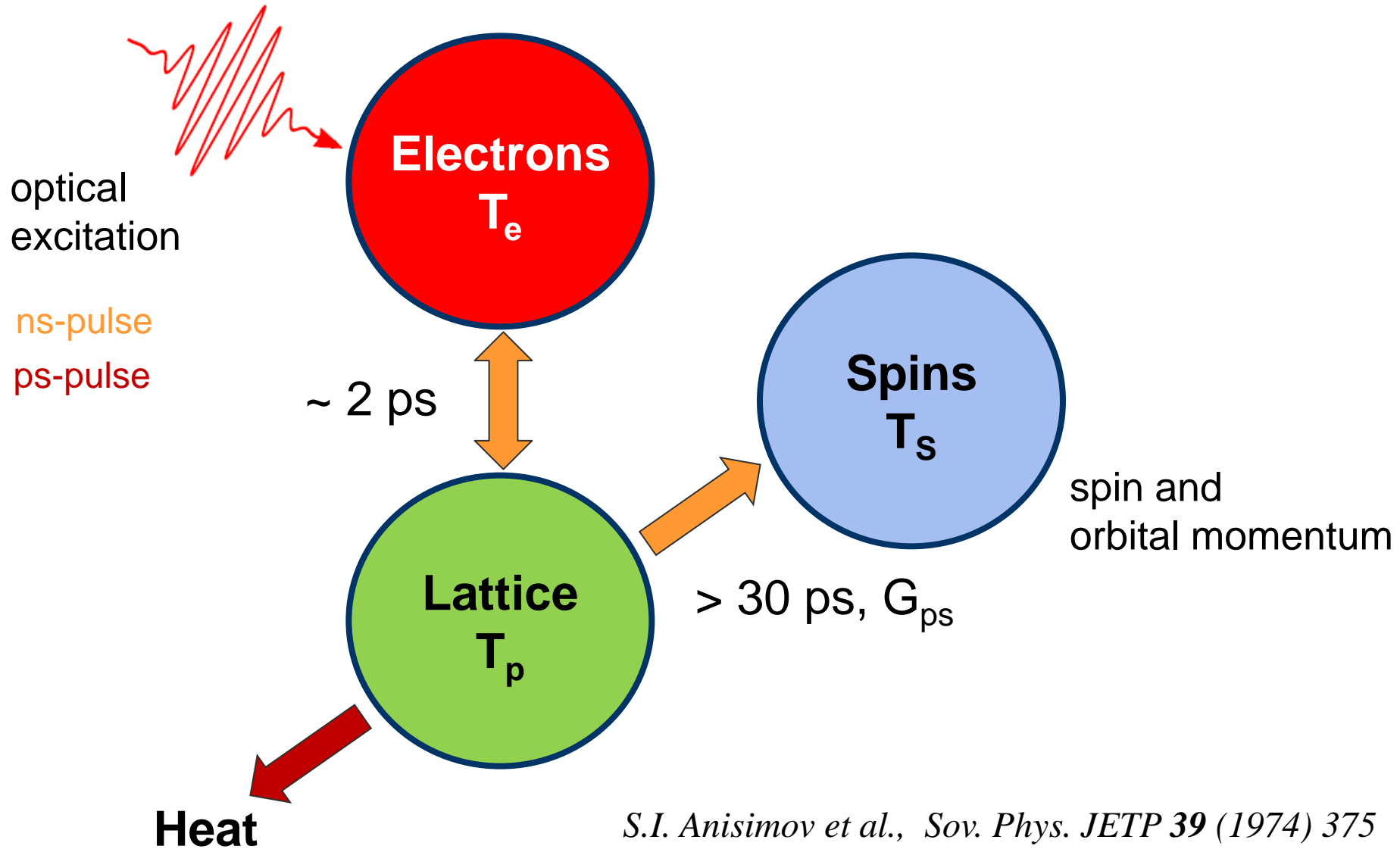
I. Radu et al., Nature 472 (2011) 205.

T.A. Ostler et al., Nature Communications 3 (2012) 666.

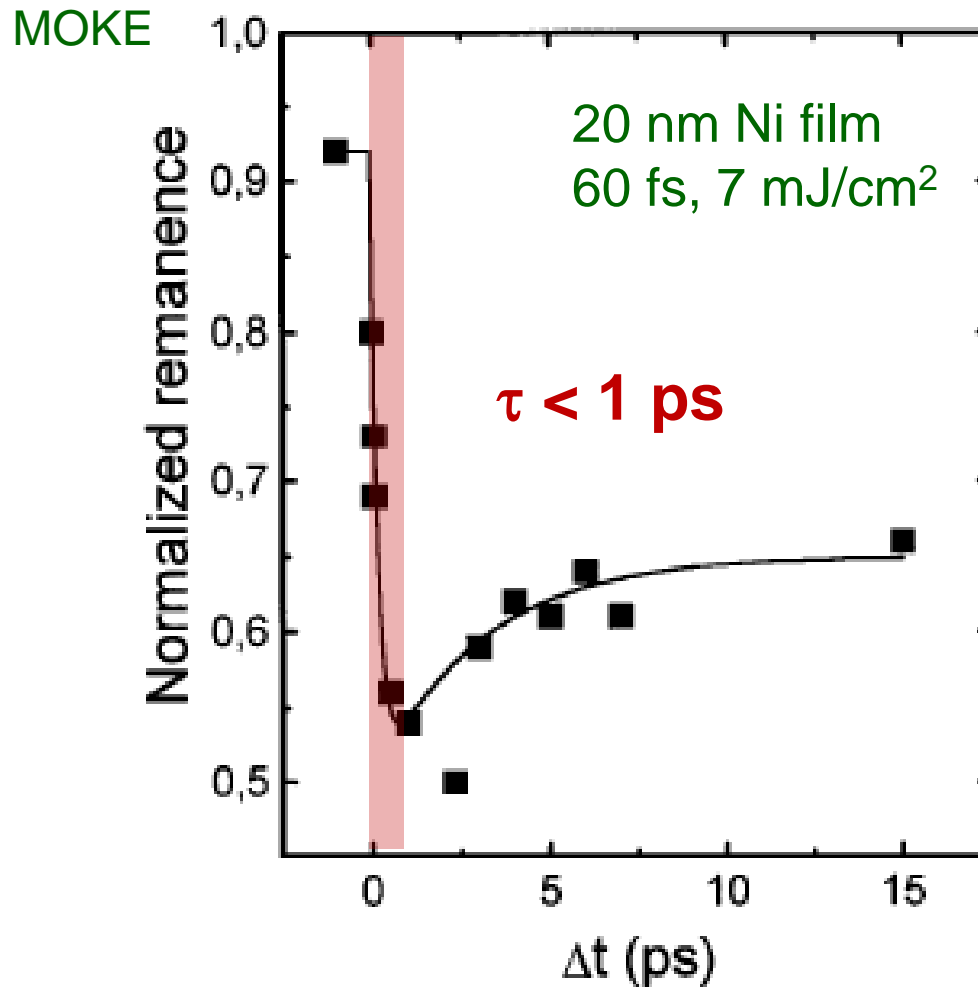
Spin polarization



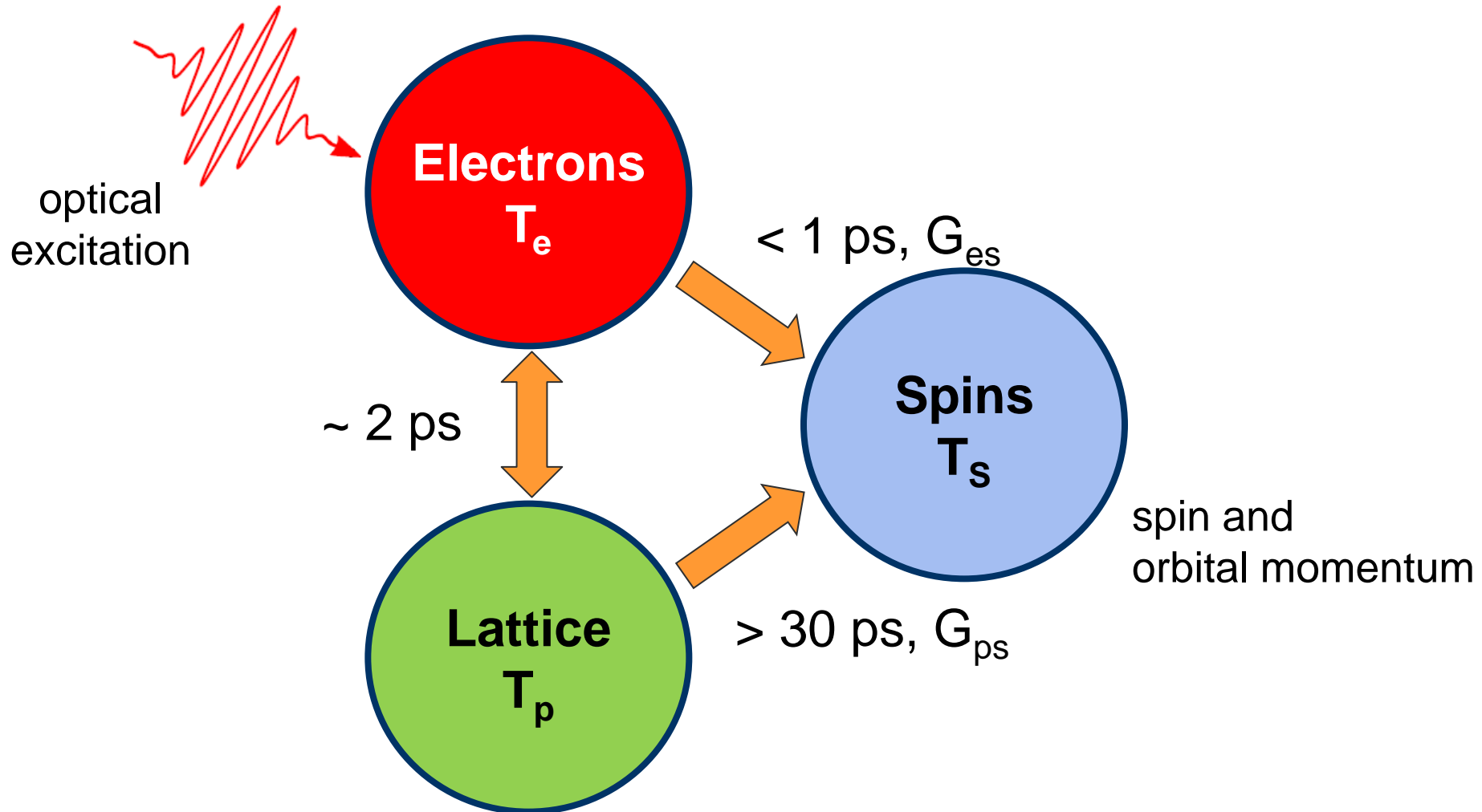
A. Vaterlaus et al., Phys. Rev. B **46** (1992) 5280



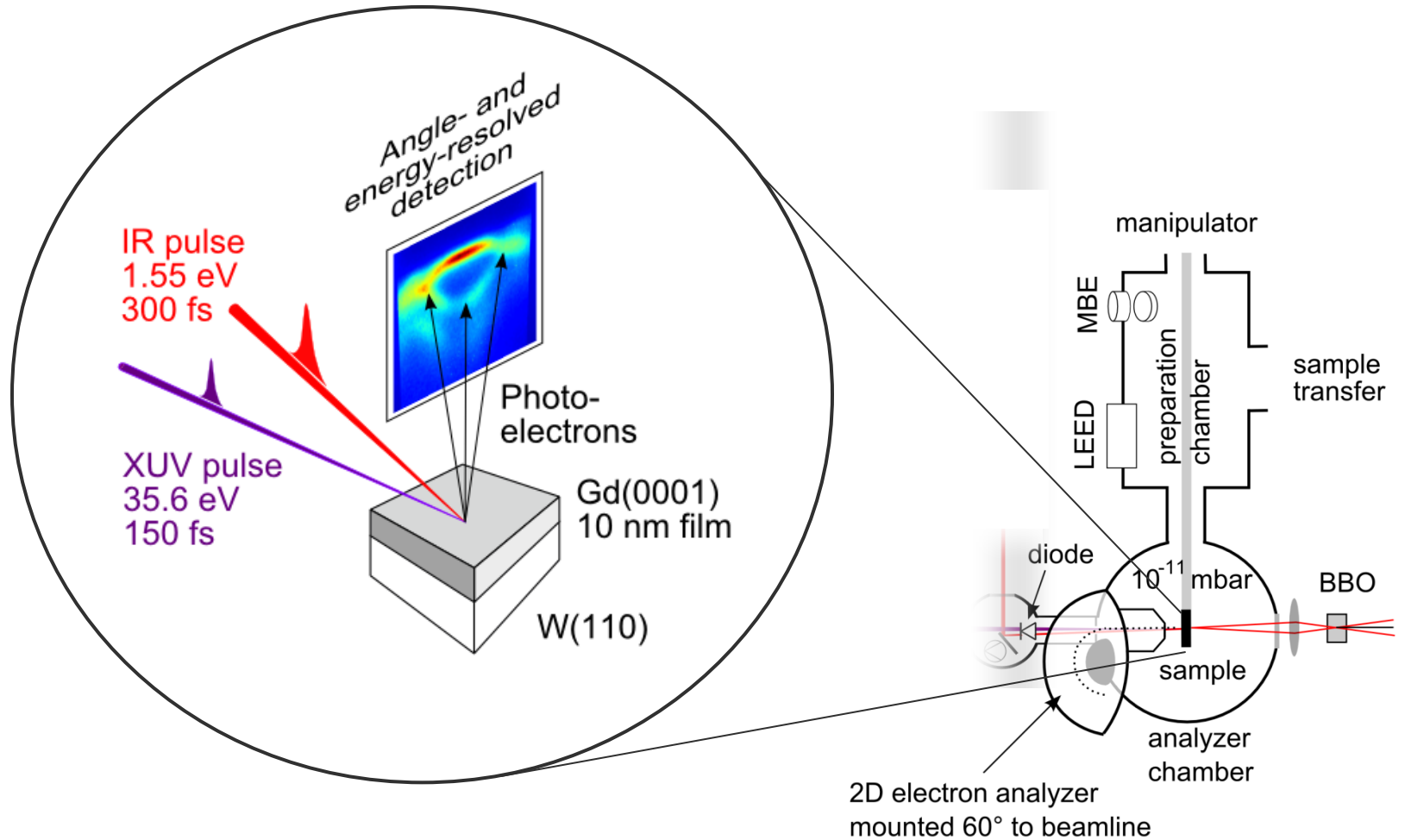
S.I. Anisimov et al., Sov. Phys. JETP 39 (1974) 375
A. Vaterlaus et al., Phys. Rev. Lett. 67 (1991) 3314



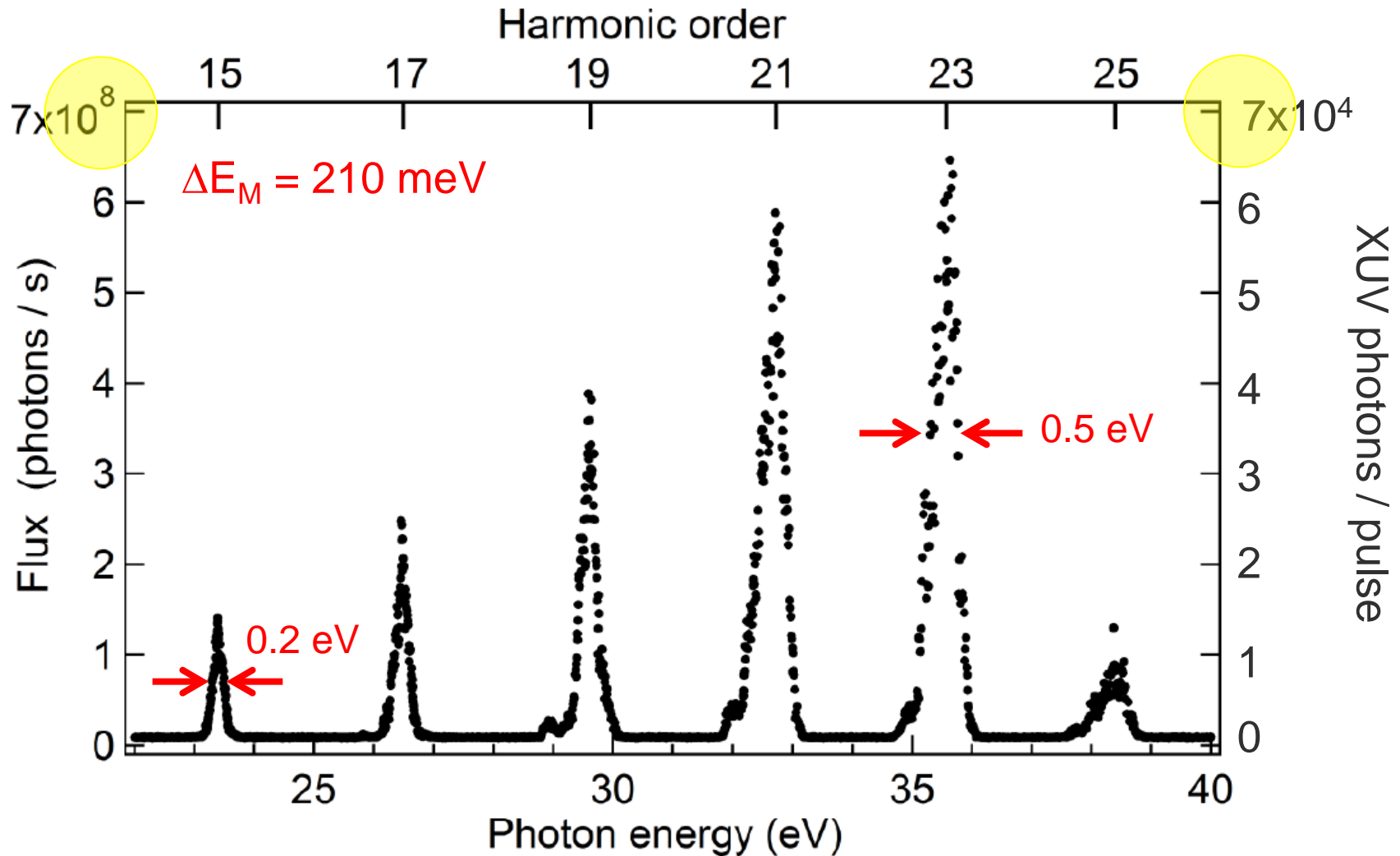
E. Beaurepaire, J.-C. Merle, A. Daunois, and J.-Y. Bigot., Phys. Rev. Lett. 76 (1996) 4250



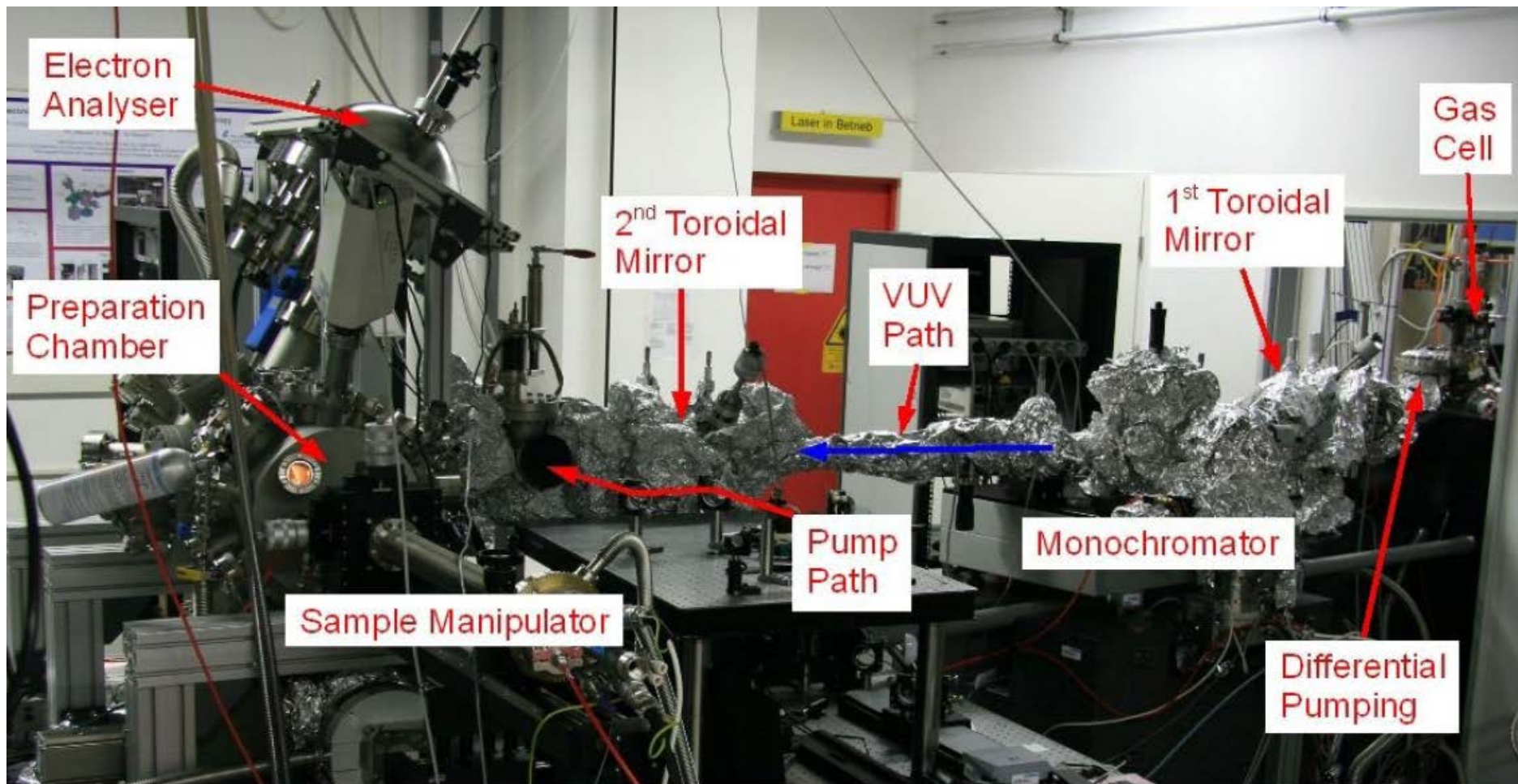
S.I. Anisimov et al., Sov. Phys. JETP 39, (1974) 375
A. Vaterlaus et al., Phys. Rev. Lett. 67 (1991) 3314
E. Beaurepaire et al.; Phys. Rev. Lett. 76 (1996) 4250



Higher harmonic spectrum of Argon

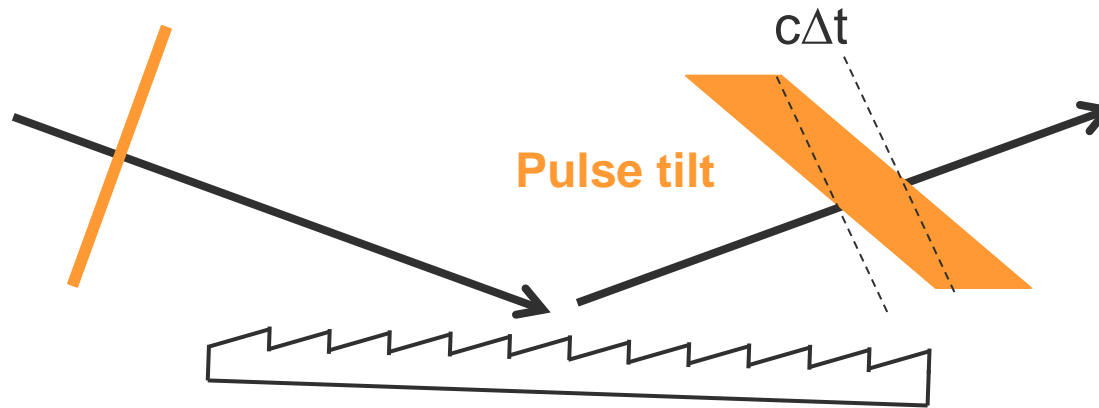


XUV sensitive silicon photodiode (AXUV100)



35 eV XUV-pulse, 100 fs pulse duration, 150 meV energy resolution, 10^8 photons/s

Rev. Sci. Instrum. **84** (2013) 075106



O.E. Martinez, Opt. Comm. **59** (1986) 229

large IR focal length: 600 mm
small divergence of VUV beam: 4 mrad
slit - grating distance: 330 mm
200 lines / mm

Pulse broadening (35 nm):

decrease in bandwidth: $\Delta t \simeq N \cdot \lambda / c$

~ 90 fs

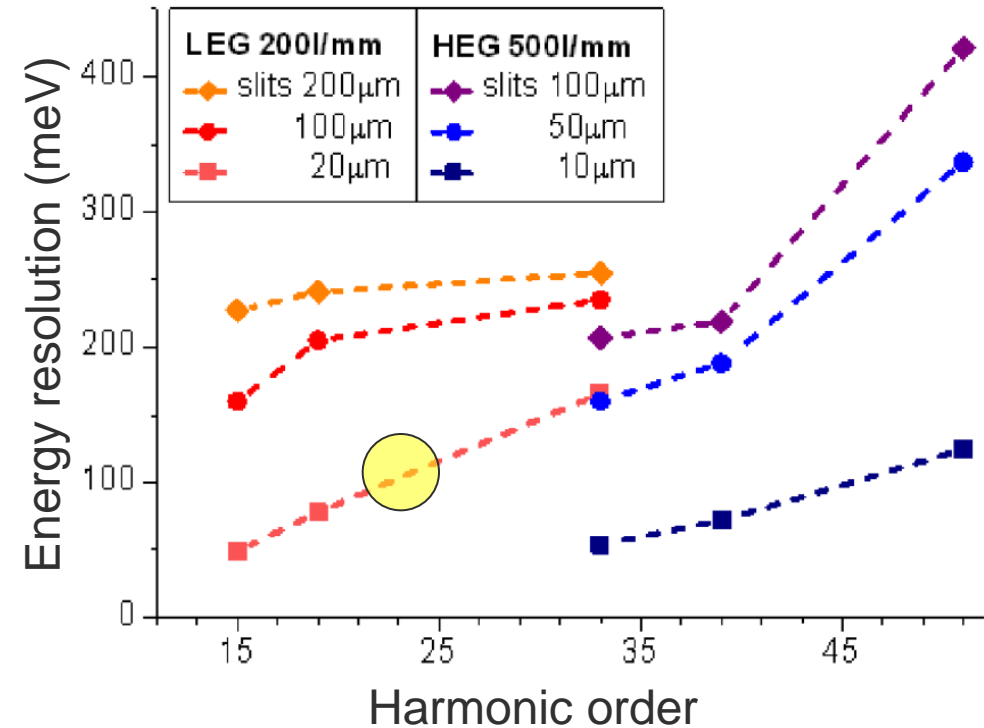
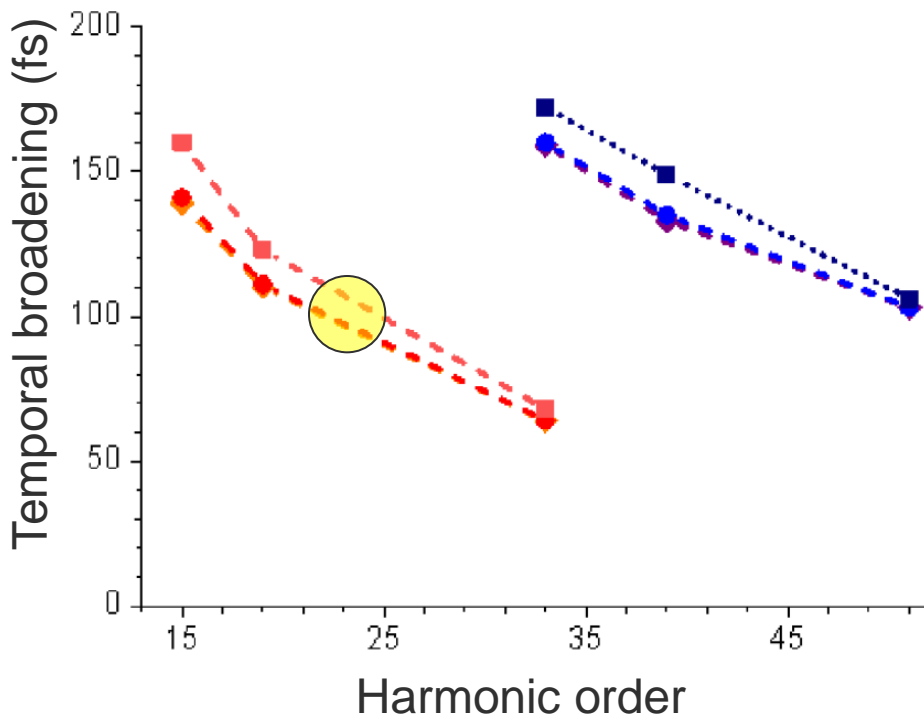
$N = \text{spot size} \cdot \text{lines/mm}$

Group-velocity dispersion: $\Delta t \propto \lambda^3 \cdot N^2$

~ 8 fs

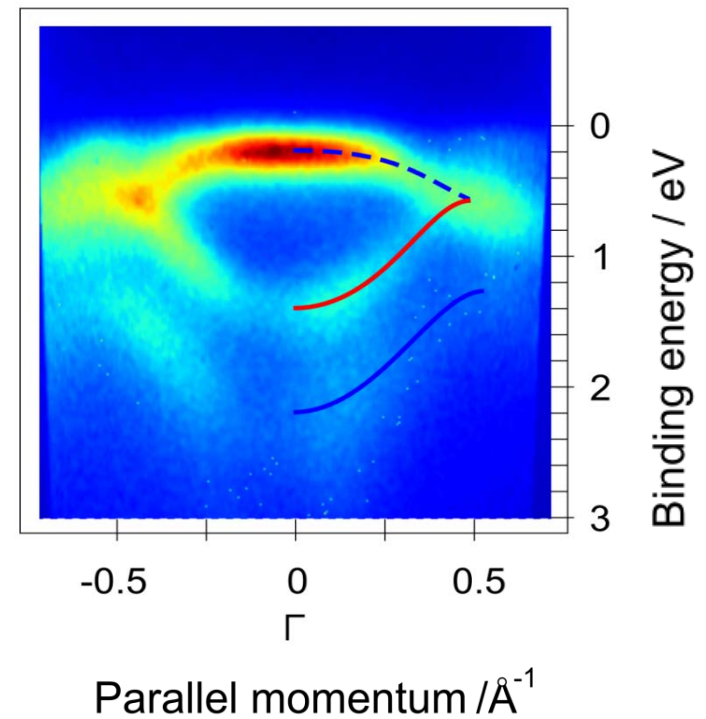
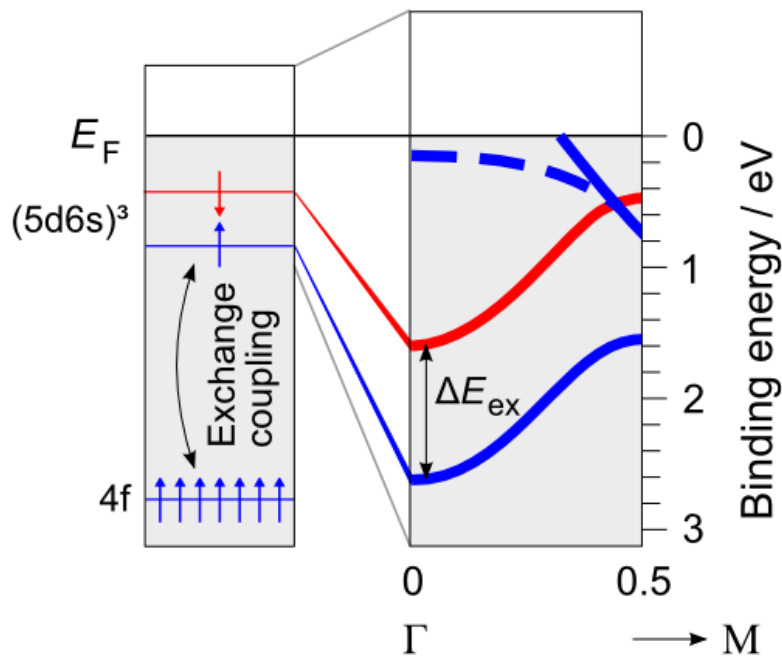
Energy - chirp:

~ 30 meV



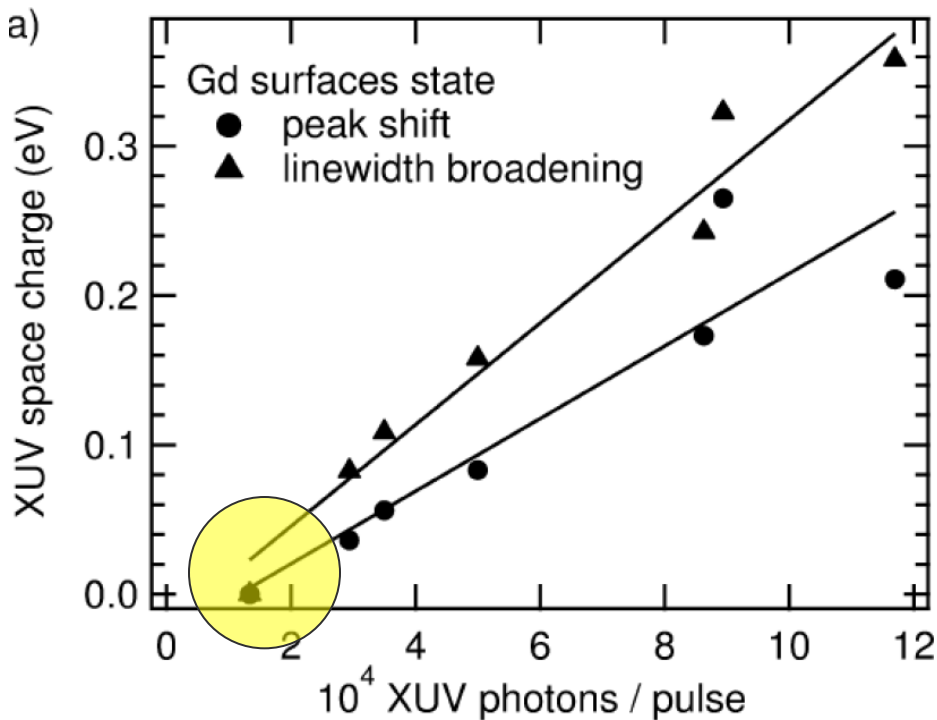
Olaf Schwarzkopf, Helmholtz Zentrum Berlin

REFLEC CODE, F. Schäfers, Technical Report 201, BESSY, (1996)

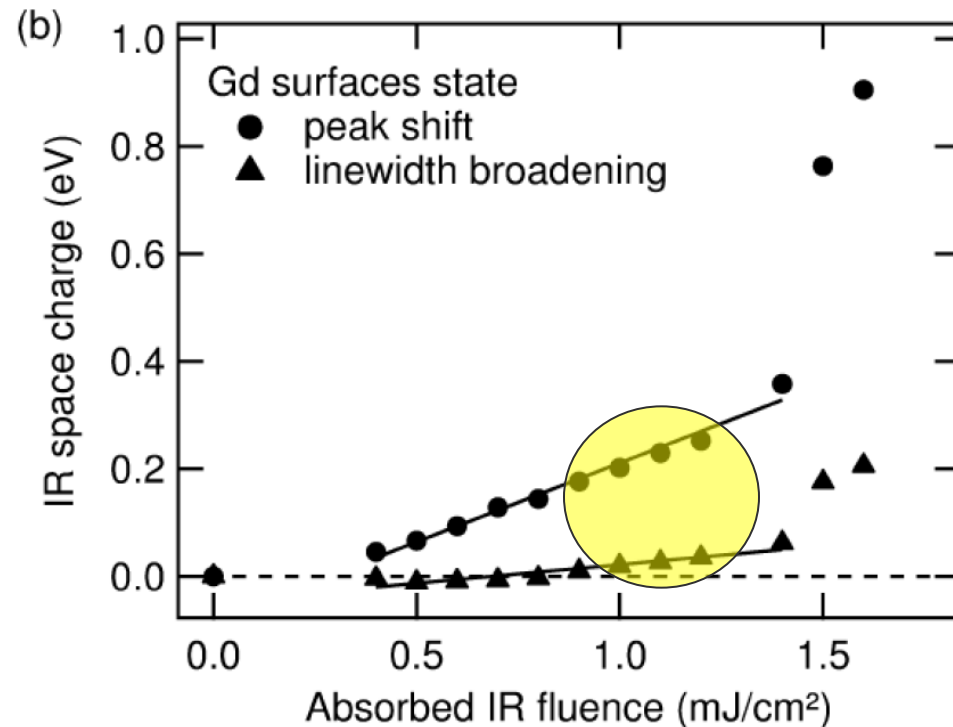


Gd: $(5d6s)^3$ exchange splitting

XUV probe-pulse



IR pump-pulse



35 eV XUV-pulse, 100 fs pulse duration, 150 meV energy resolution, 10^8 photons/s

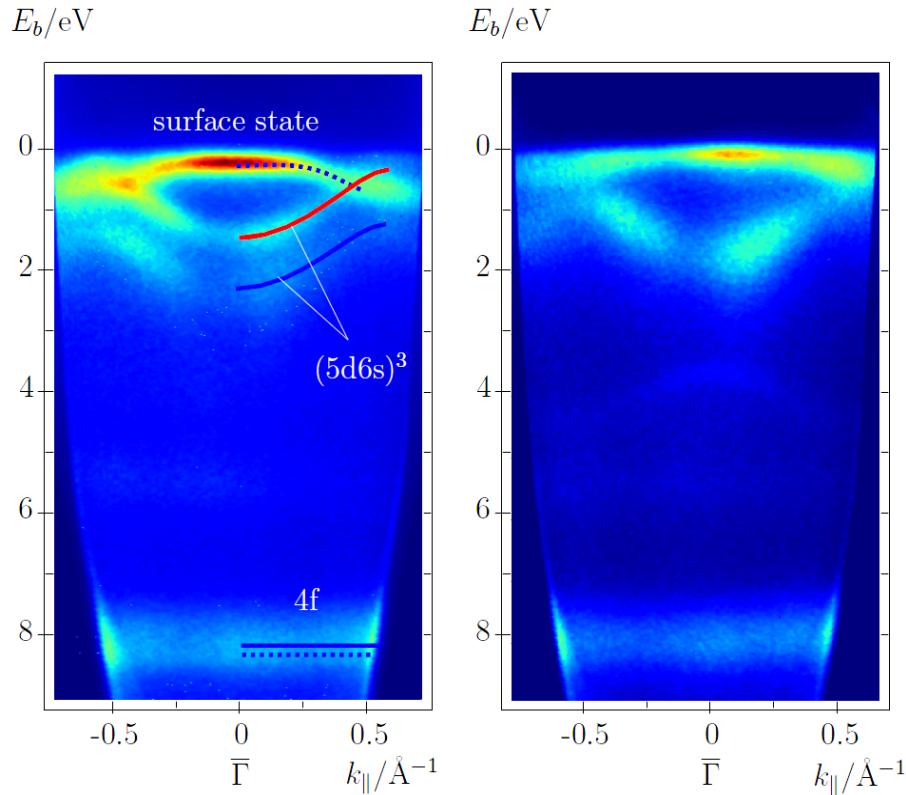
0.5 electrons/pulse @ 10 kHz repetition rate

(5d6s)³ Exchange Splitting

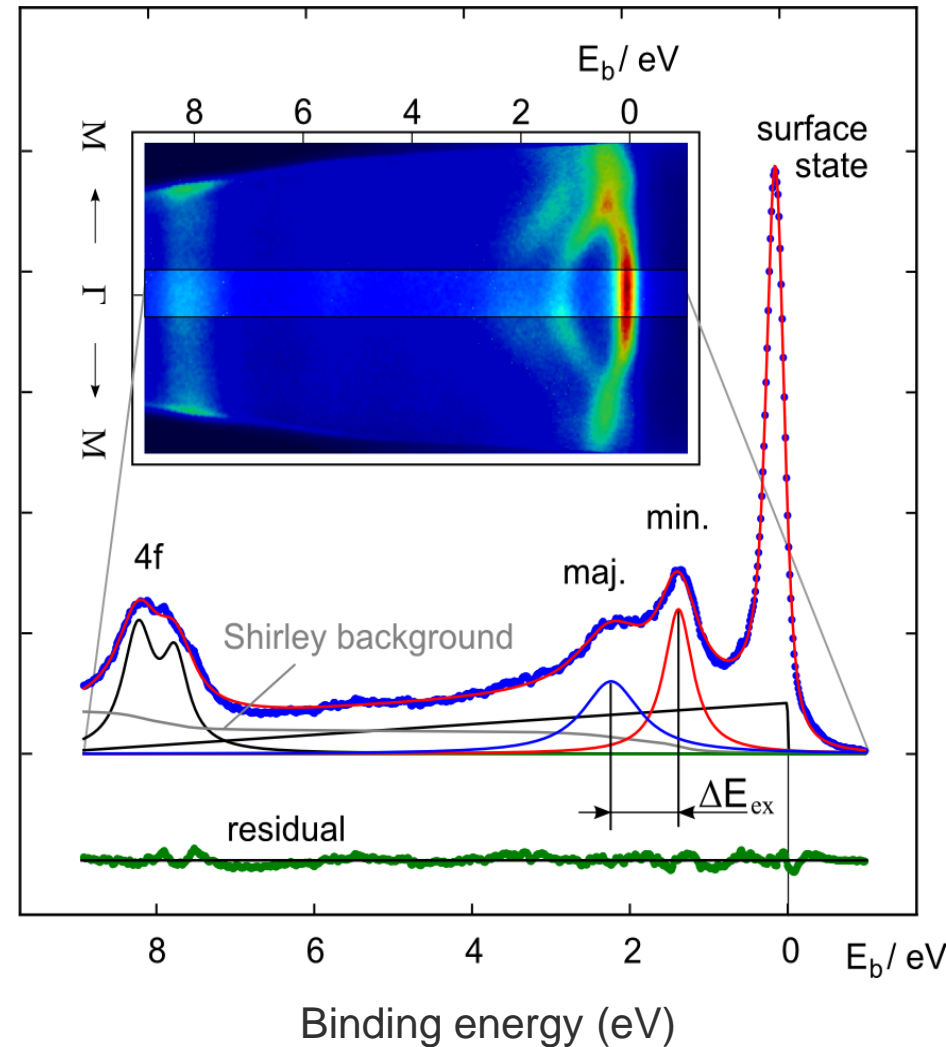
Gd (0001) on W(110) ($T_C=293\text{K}$)

ferromagnetic
T=100K

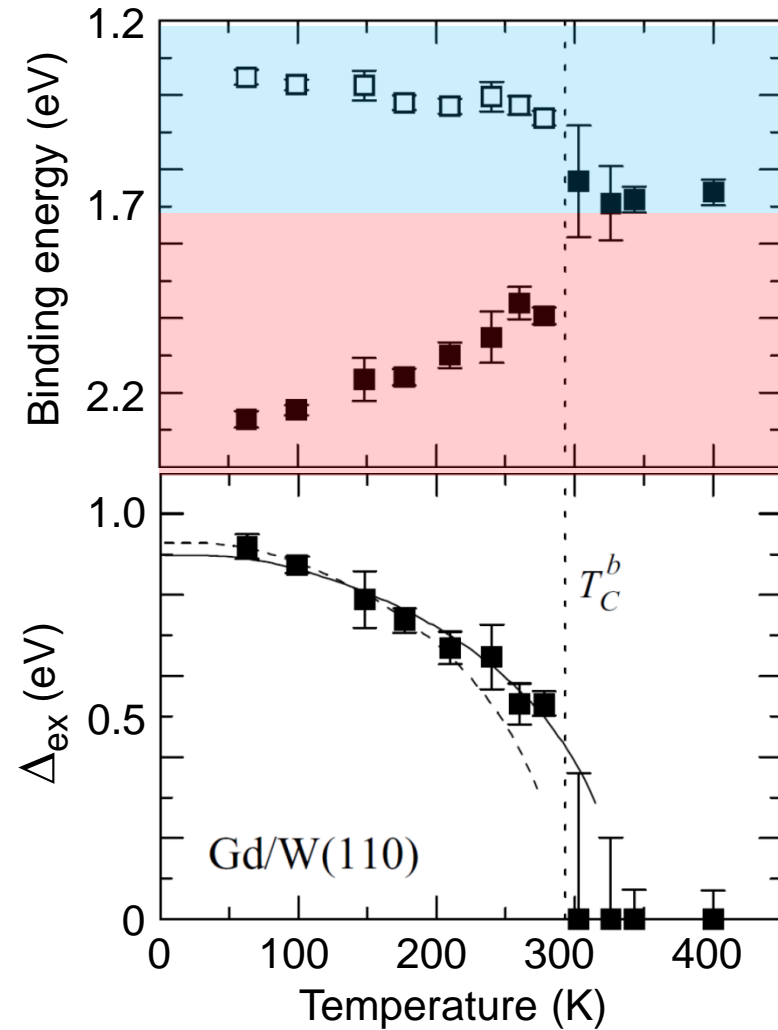
paramagnetic
T=300K



k_{\parallel} is measured in Γ -M direction



Gd / W(110)



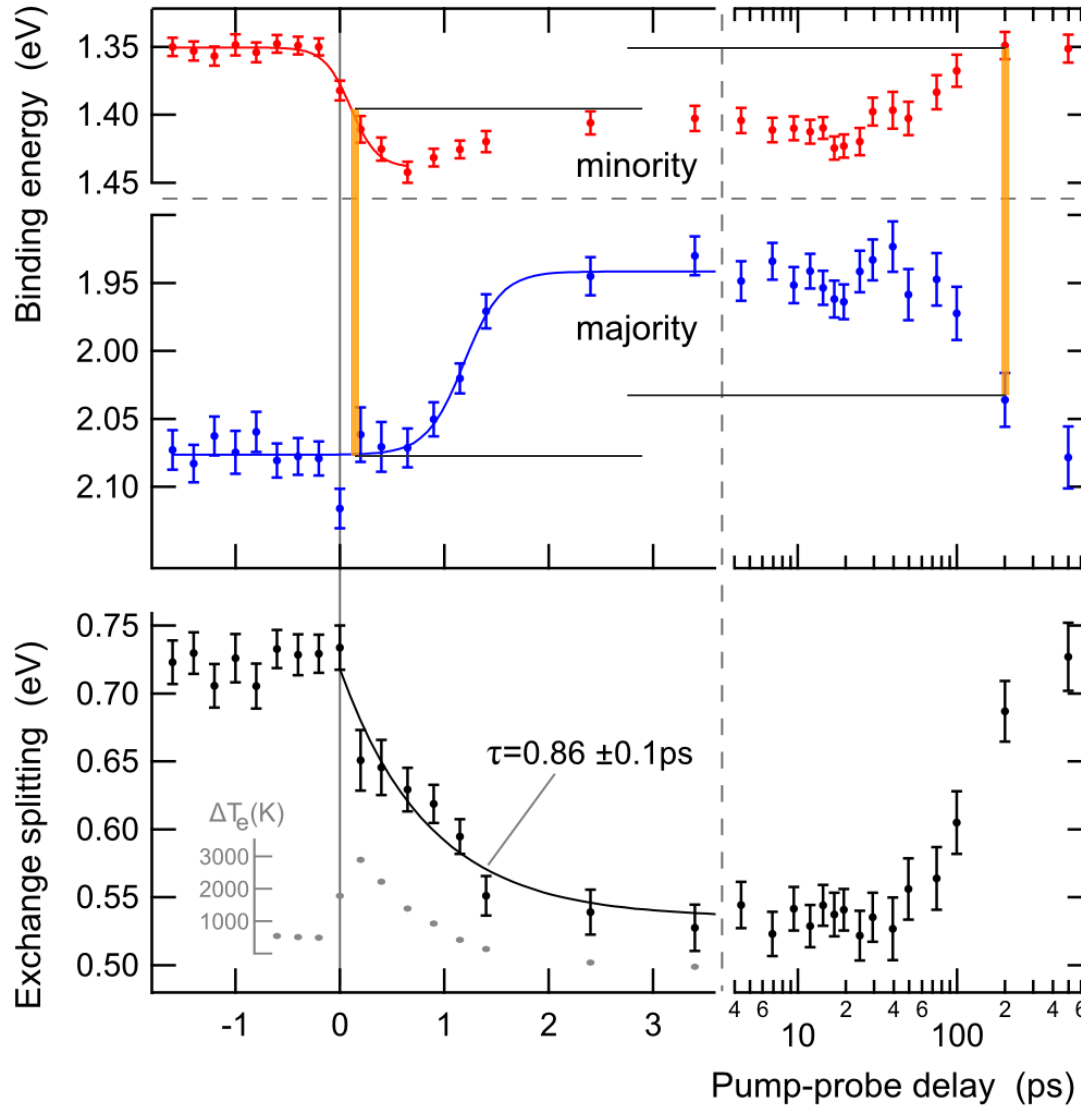
Δ_2 majority spin bulk-band

Δ_2 minority spin bulk-band

exchange splitting Δ_{ex}

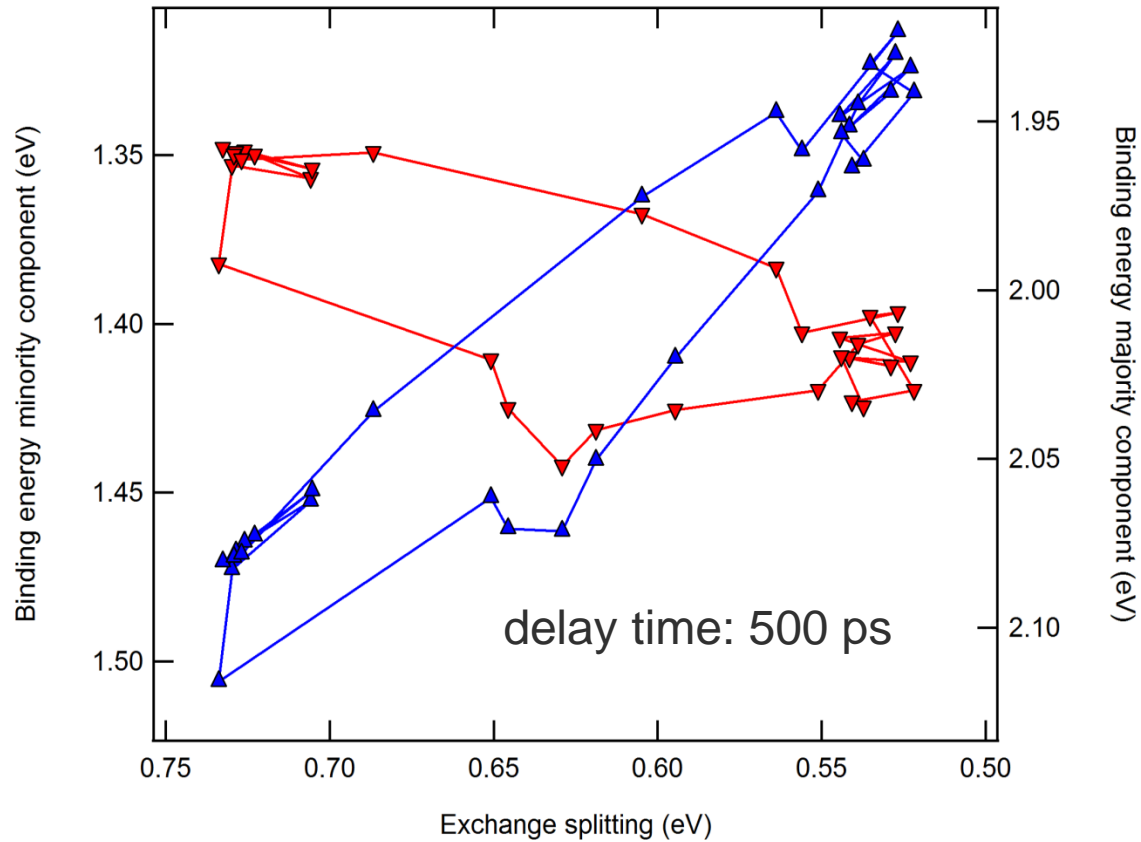
C. Schüßler-Langeheine, PhD thesis, FU Berlin, 1999

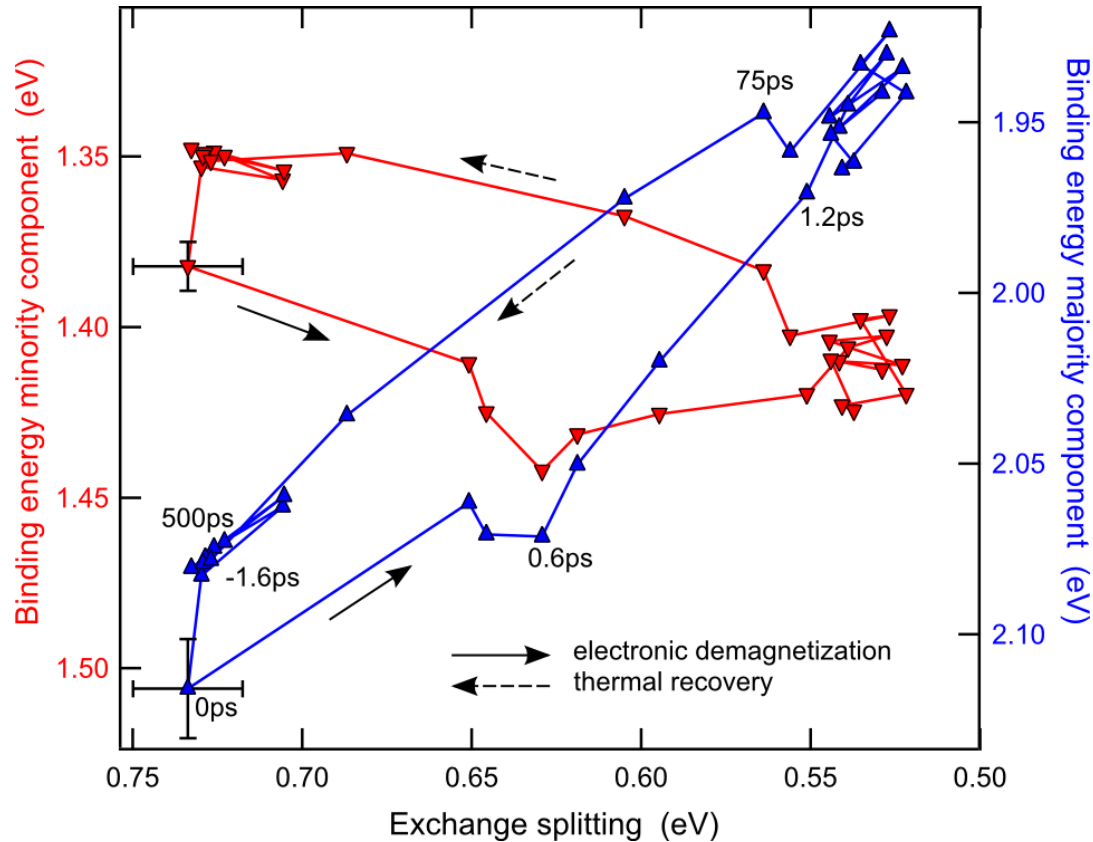
Ultrafast Demagnetization of Gd



PRL 109, 057401 (2012)

Gd: band position vs exchange splitting

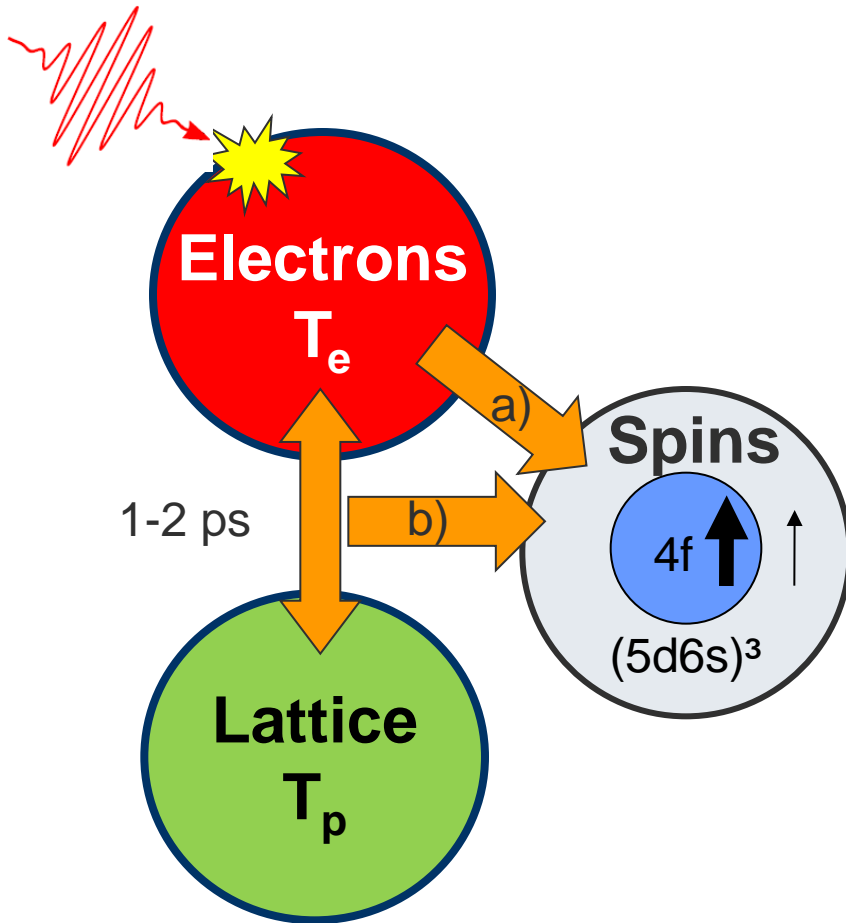




- Hysteresis: valence and 4f spins not in equilibrium during demagnetization
- Instantaneous response of minority spin band
- 1 ps delayed response of the majority spin band

PRL 109, 057401 (2012)

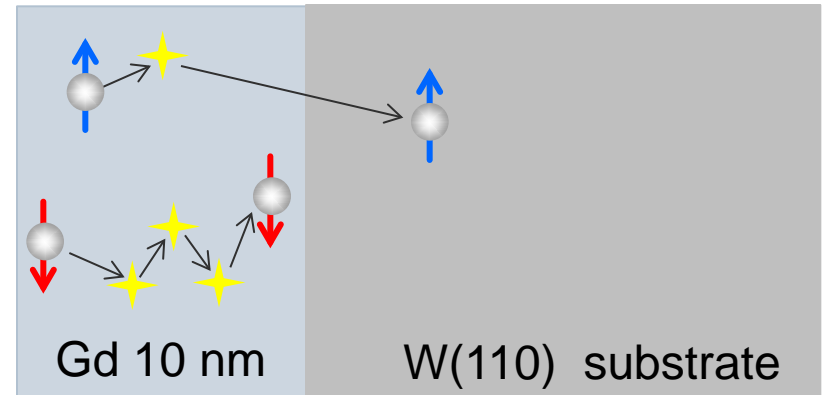
Three Temperature Model



Beaurepaire *et al.* PRL **76** (1996) 4250
 Hübner, Bennemann PRB **53** (1996) 3422

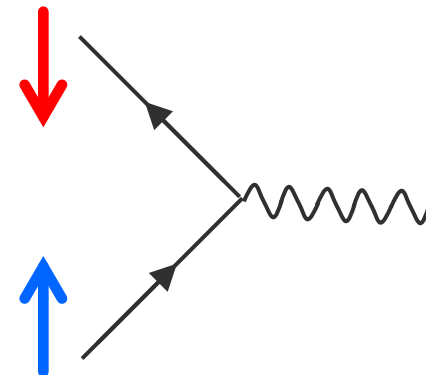
a) Superdiffusive spin transport

Battiato *et al.*, PRL **105** (2010) 027203
 Rudolf *et al.*, Nature Comm. **3** (2012) 1037

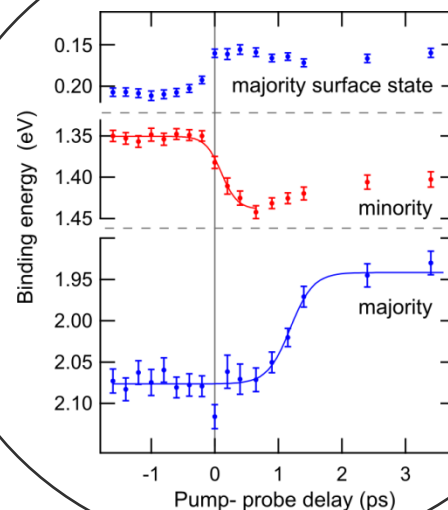
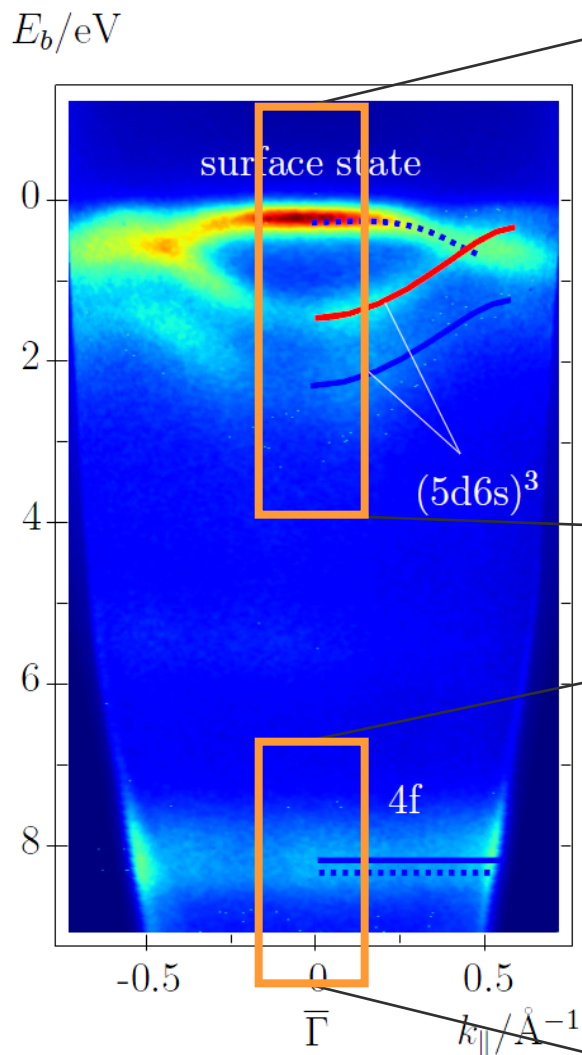


b) Electron-phonon spin-flip scattering

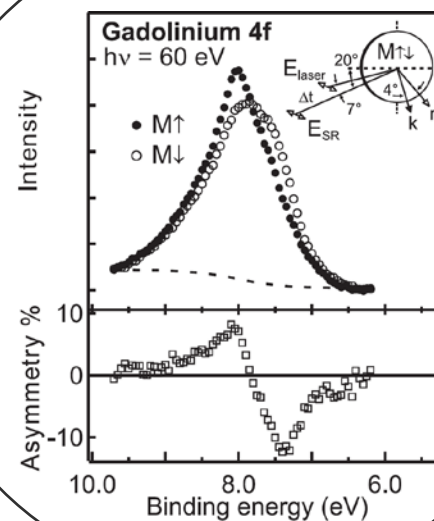
Koopmans *et al.*, Nature Mat. **9** (2010) 259



Magnetism in the 4f system

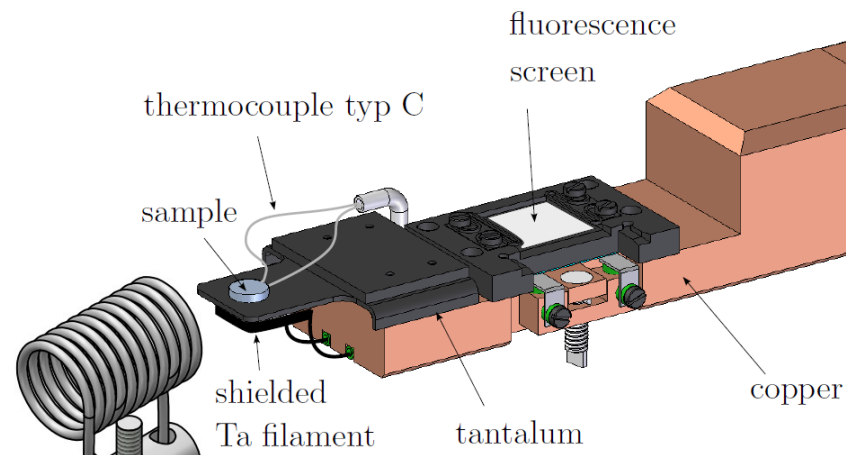
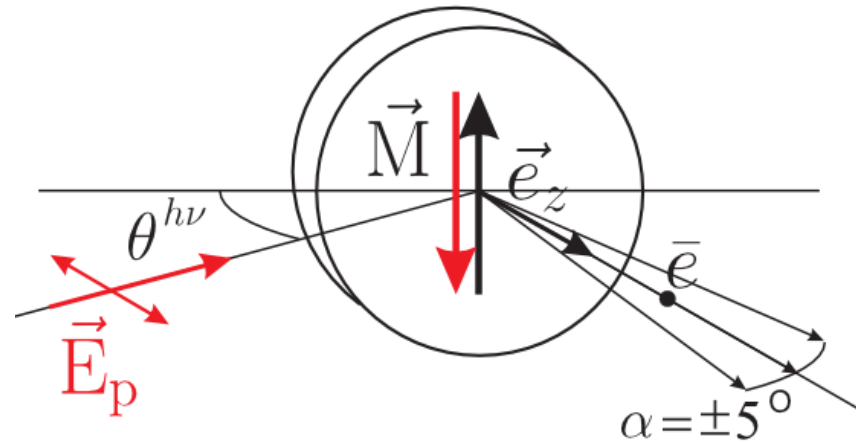


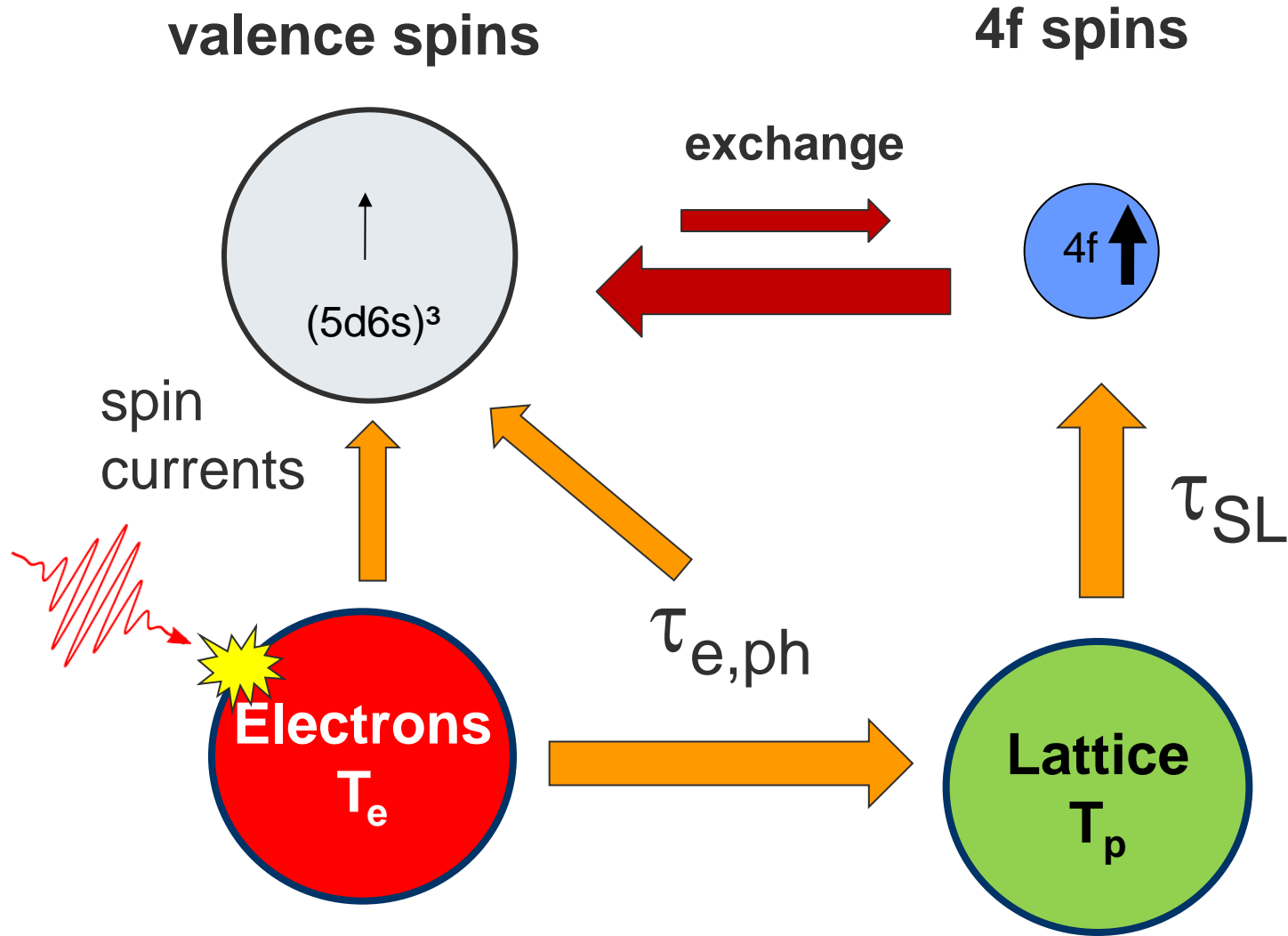
MLD



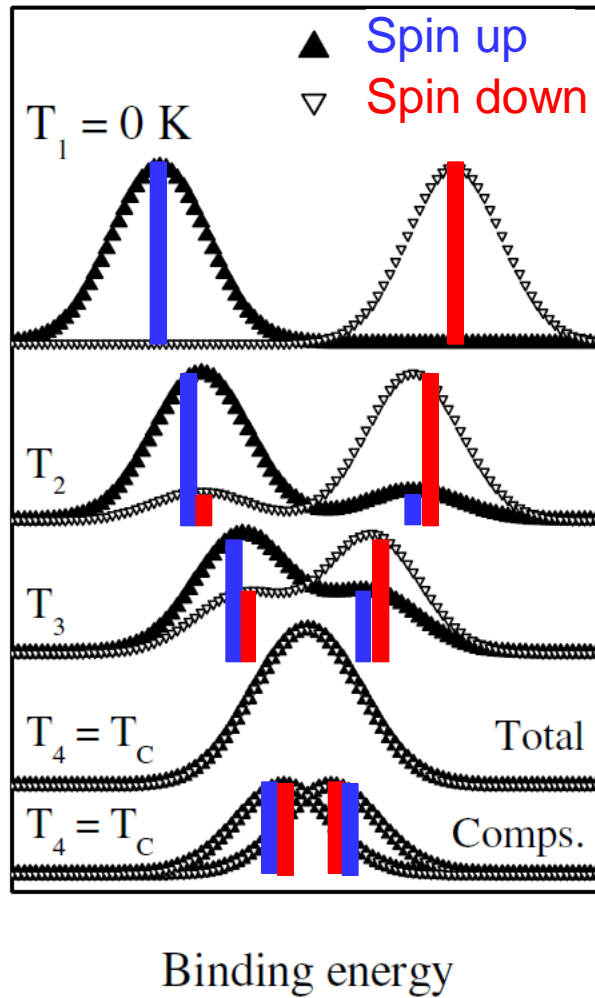
PRL 100, 107202 (2008)

O. Krupin, *PhD-Thesis* (2004) , FU-Berlin



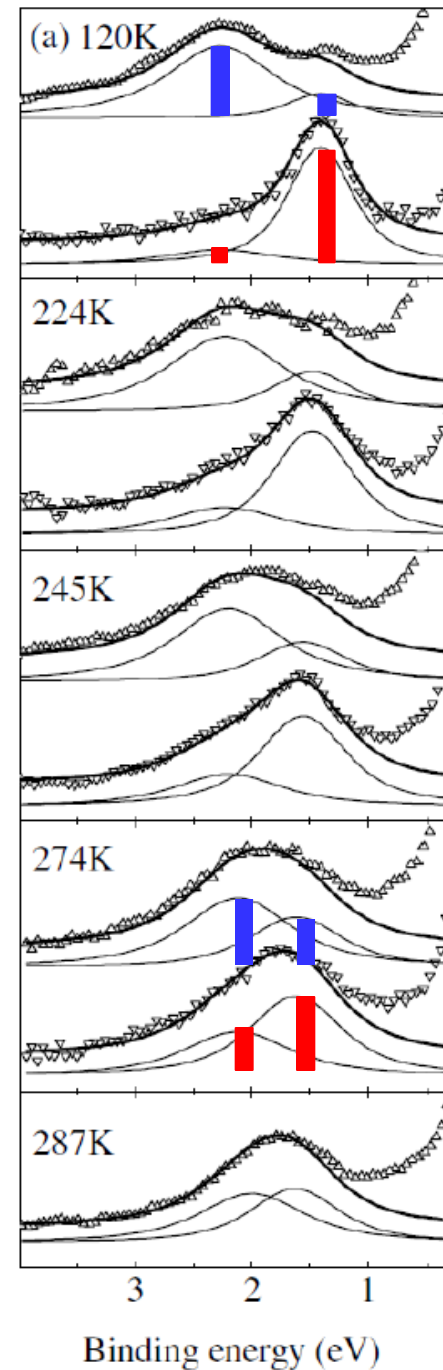


Spin mixing and ΔE_{ex} in Gd



$T = 120 \text{ K}$

$T = 280 \text{ K}$



K. Maiti et al., Phys. Rev. Lett. 88 (2002) 167205

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Johannes Gutenberg Universität Mainz



Max Born Institute



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