# Exploring Ultrafast Magnetic Switching
# Is there a speed limit?


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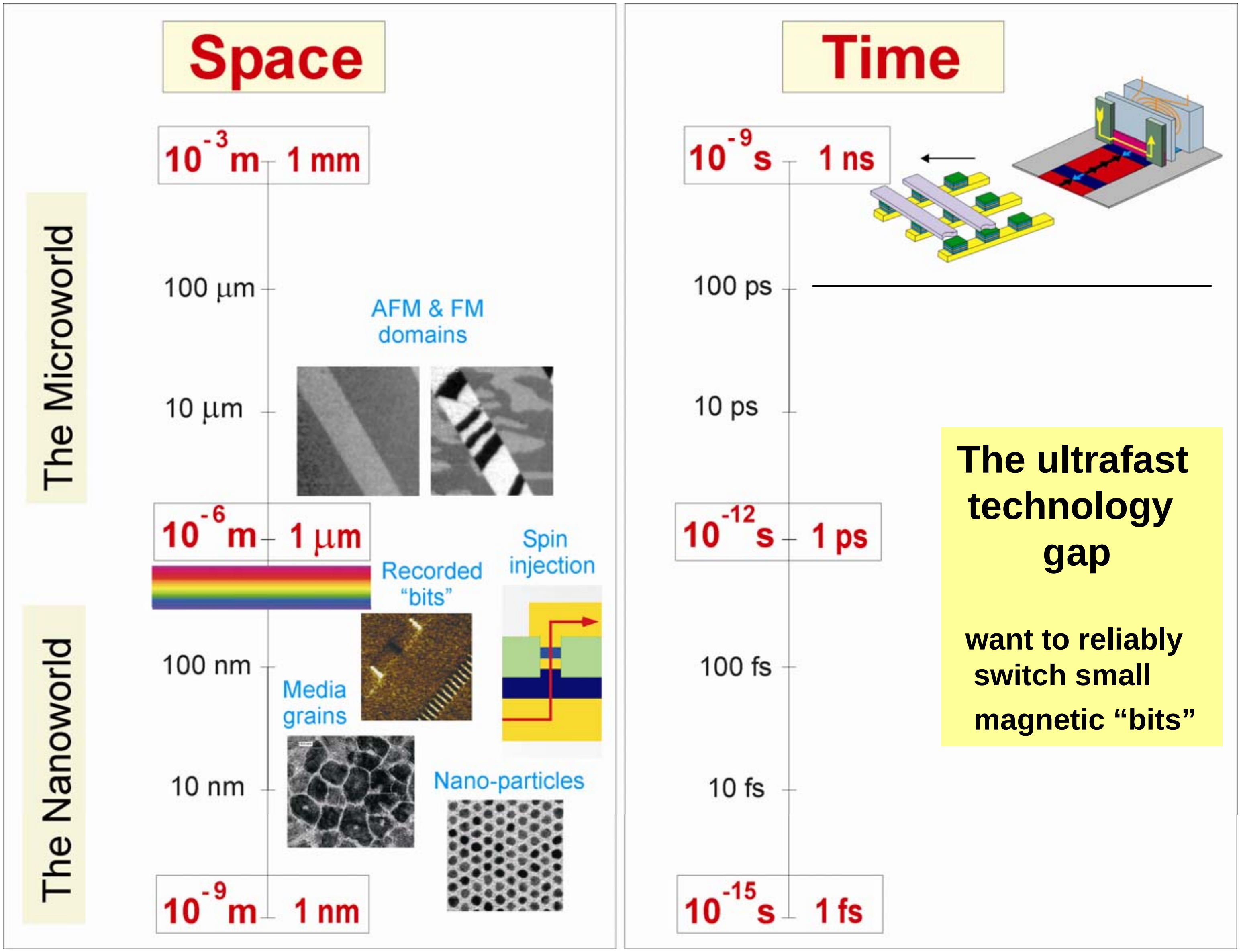
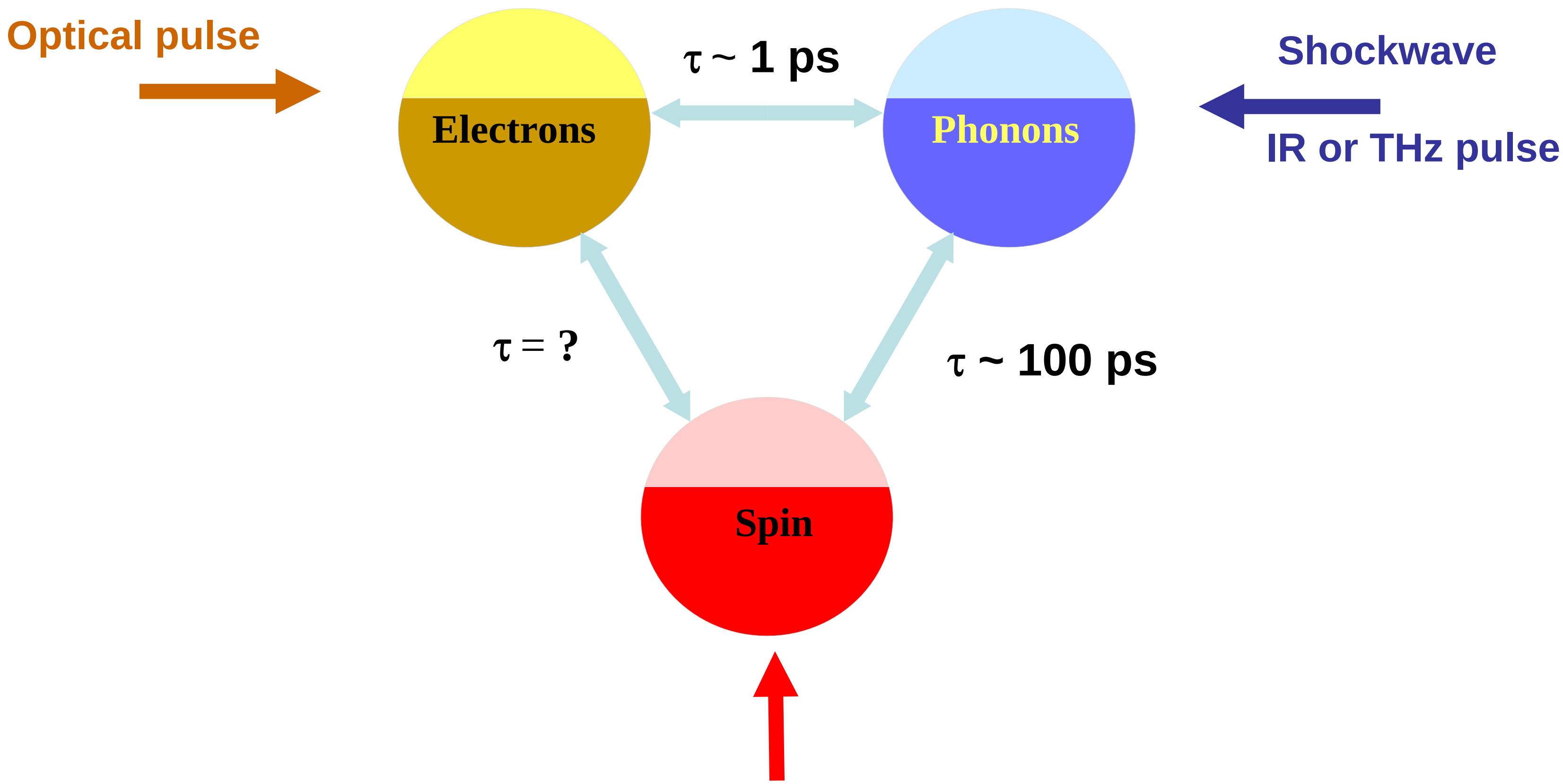
**samples**

# The Technology Problem: Smaller and Faster



**Faster than 100 ps….**

Mechanisms of ultrafast transfer of **energy** and **angular momentum**

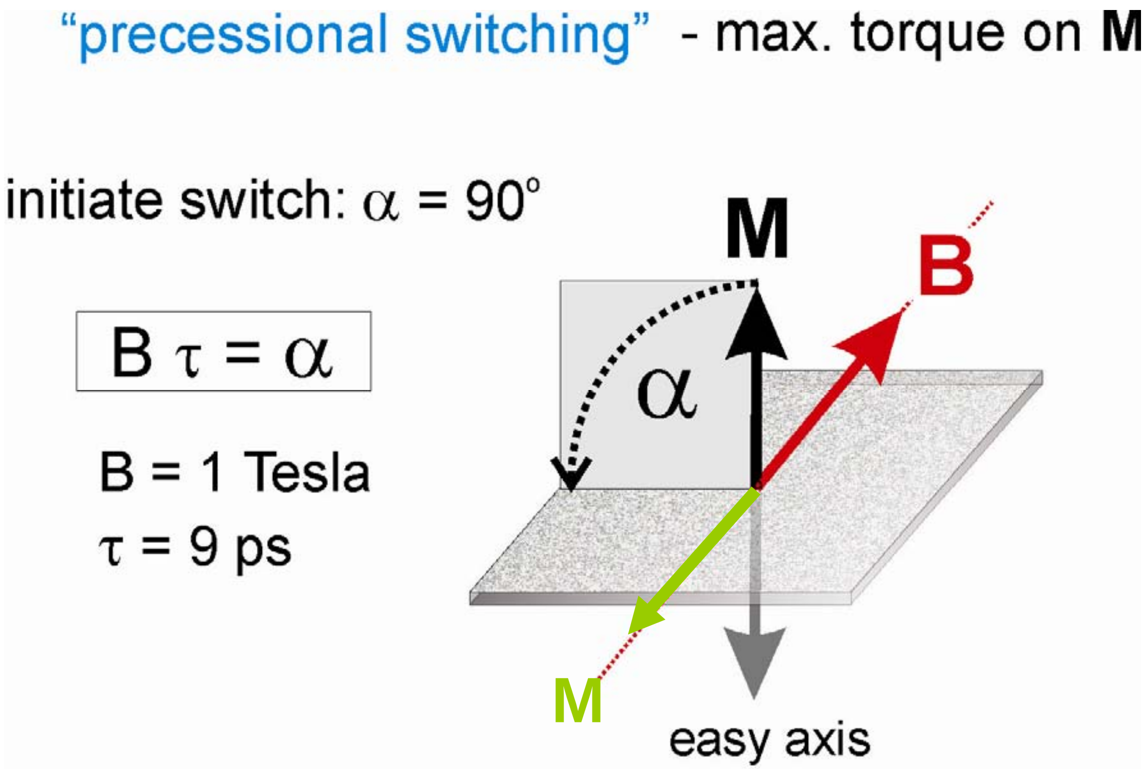



*Most direct way:*

**Conventional (Oersted) switching - limited by 100 ps**

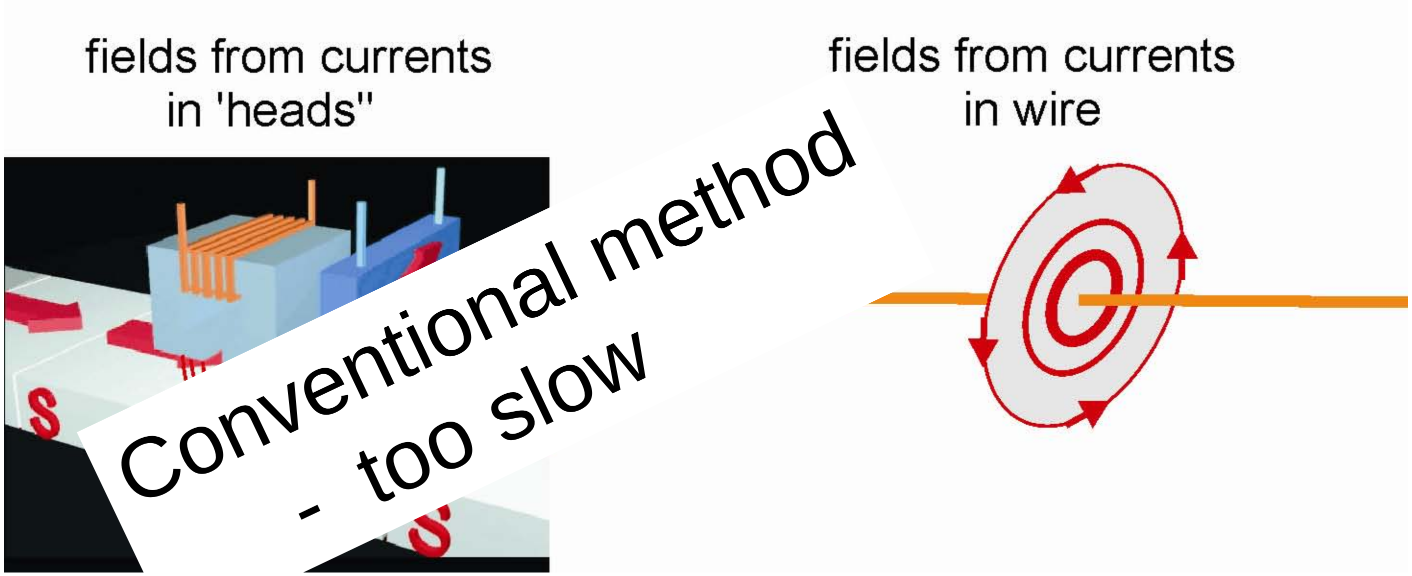
**Precessional switching**

# The simplest case: precessional switching

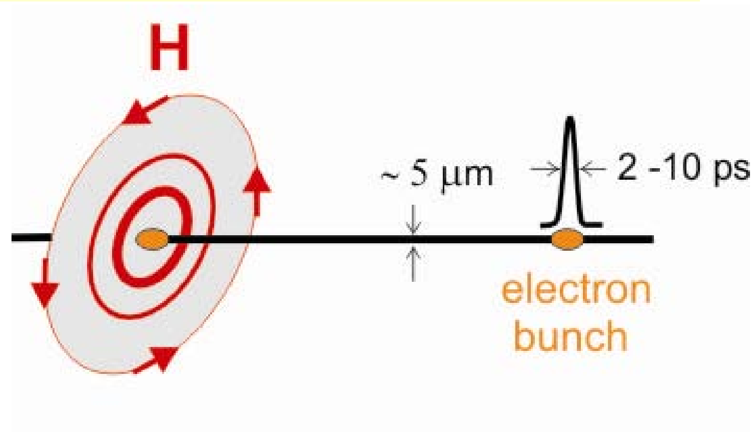



Conventional (Oersted) switching

# Creation of large, ultrafast magnetic fields



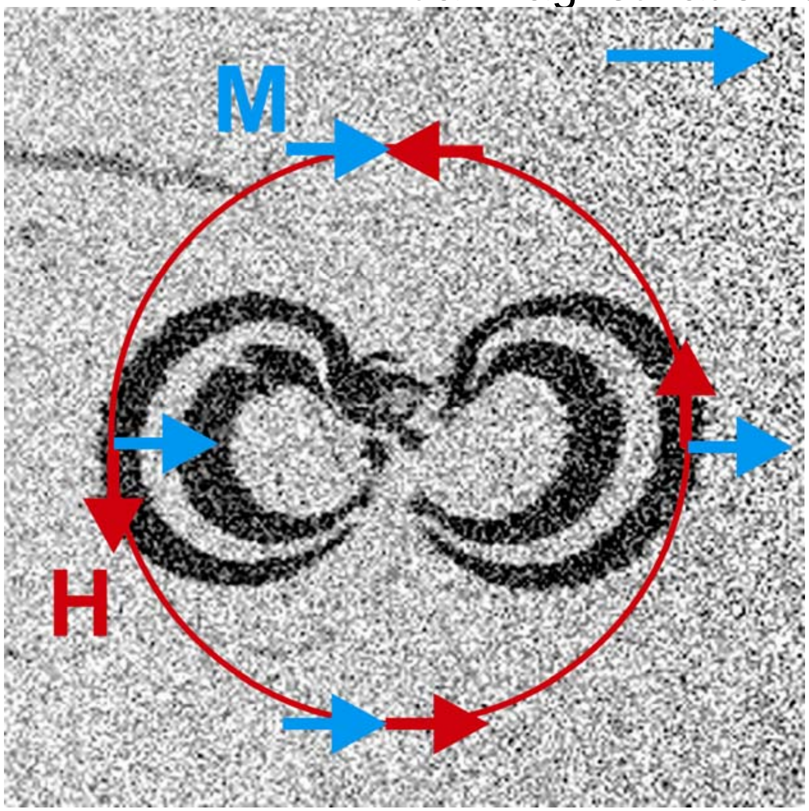

**Ultrafast pulse – use electron accelerator**




C. H. Back et al., *Science* **285**, 864 (1999)

# Torques on in-plane magnetization by beam field

Initial magnetization of sample

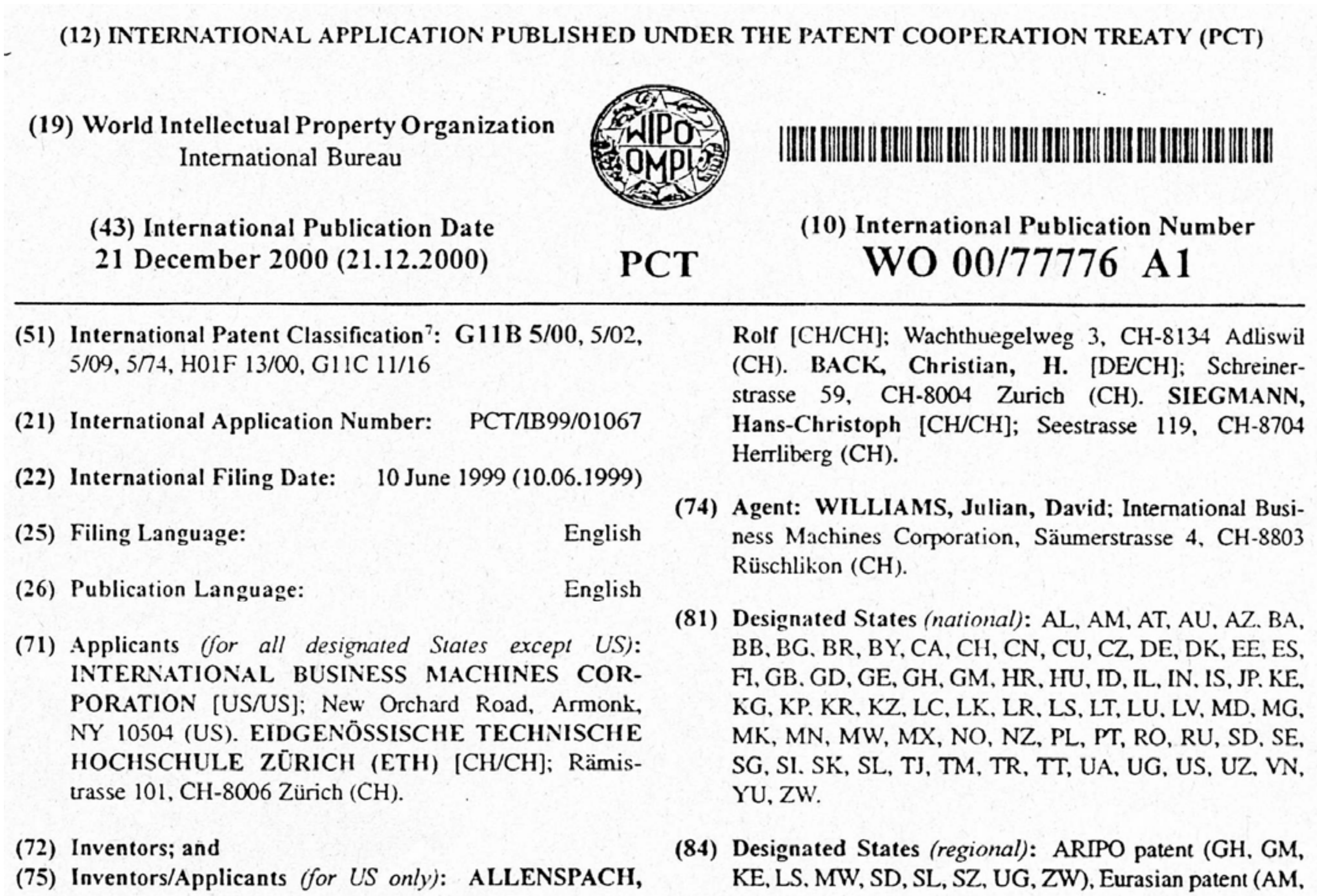



**Max. torque**

**Min. torque**

Fast switching occurs when **H** ⊥ **M**

# Precessional or ballistic switching: 1999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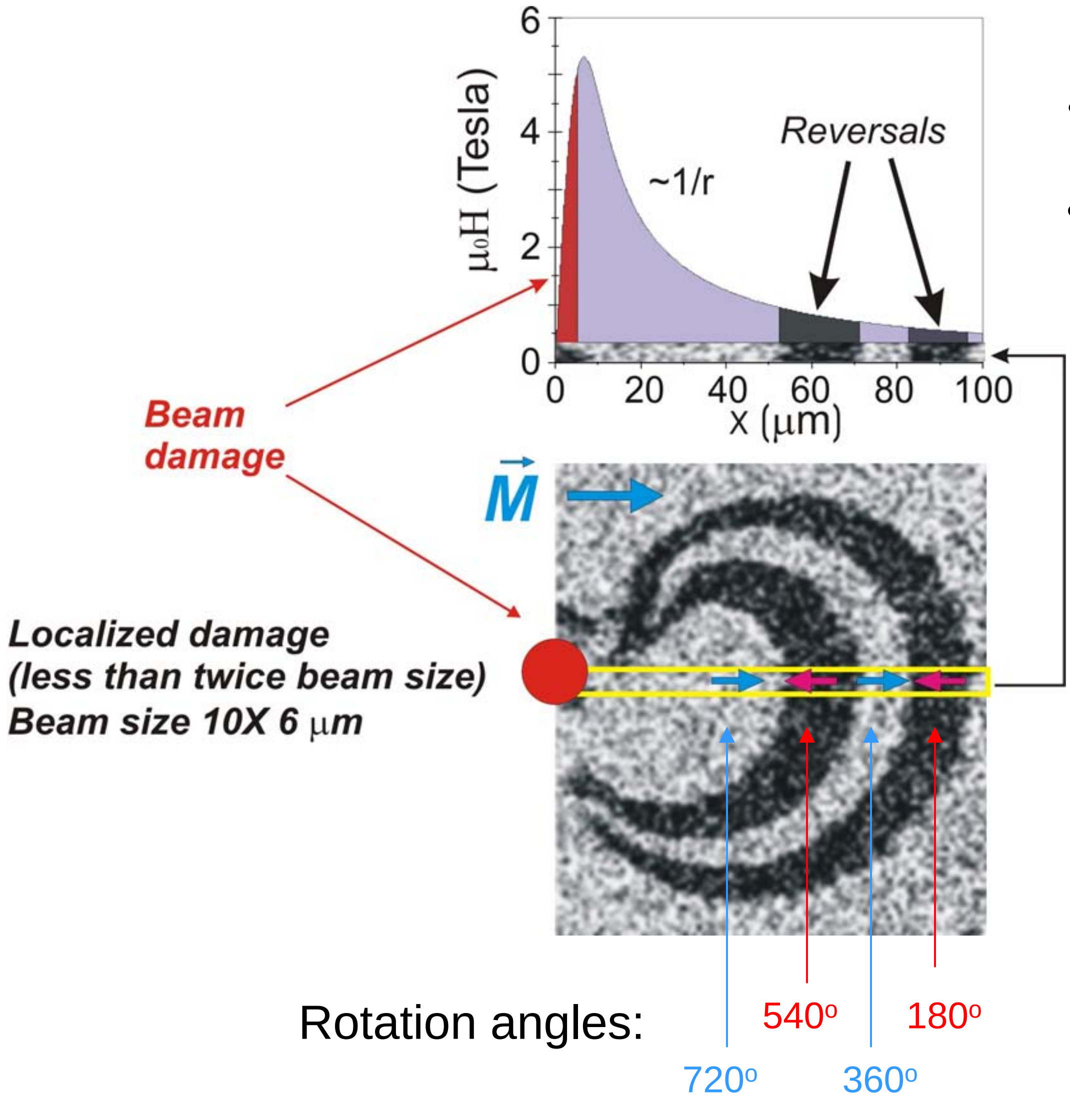
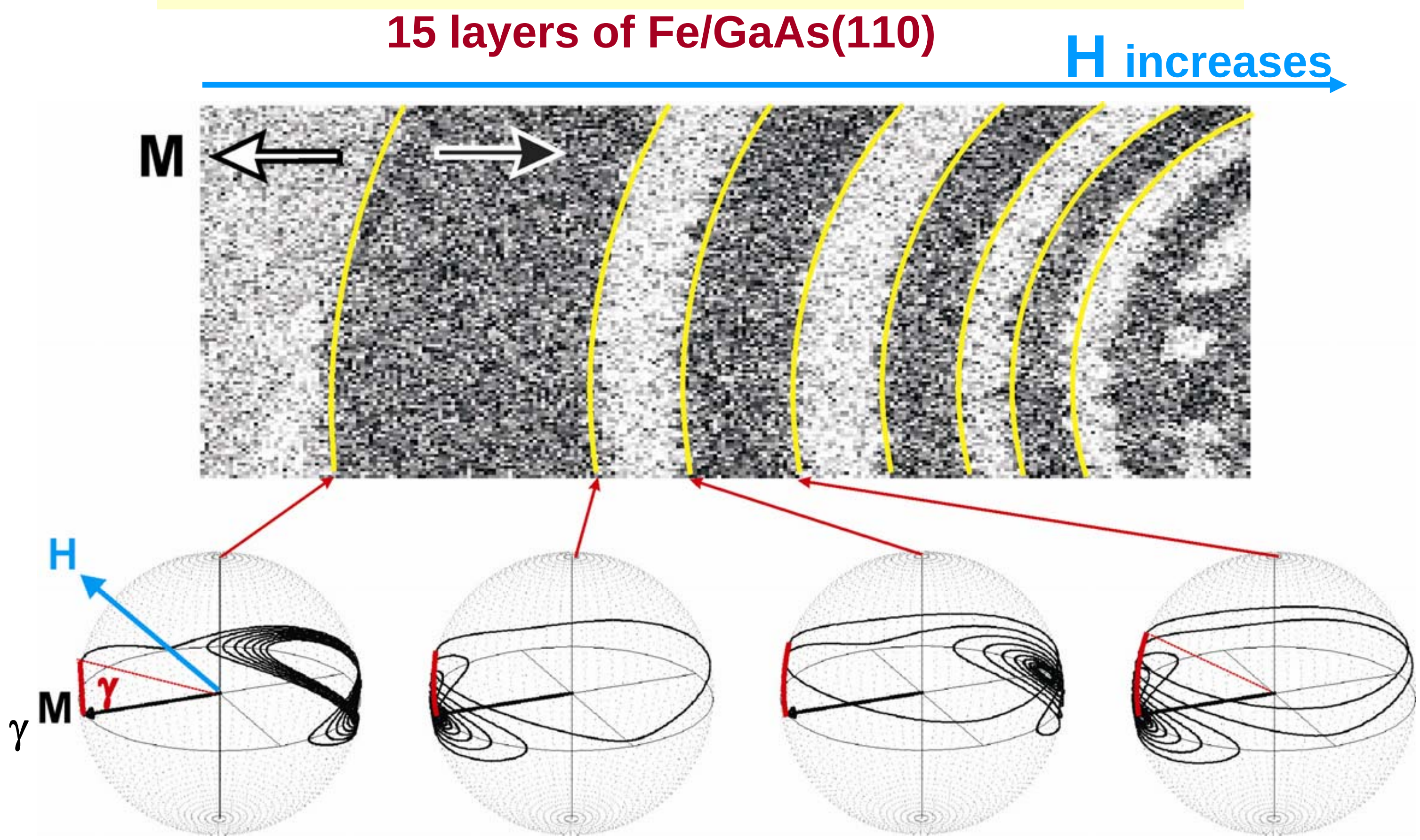
# In-Plane Magnetization: Pattern development




- Magnetic field intensity is large
- Precisely known field size

# Origin of observed switching pattern

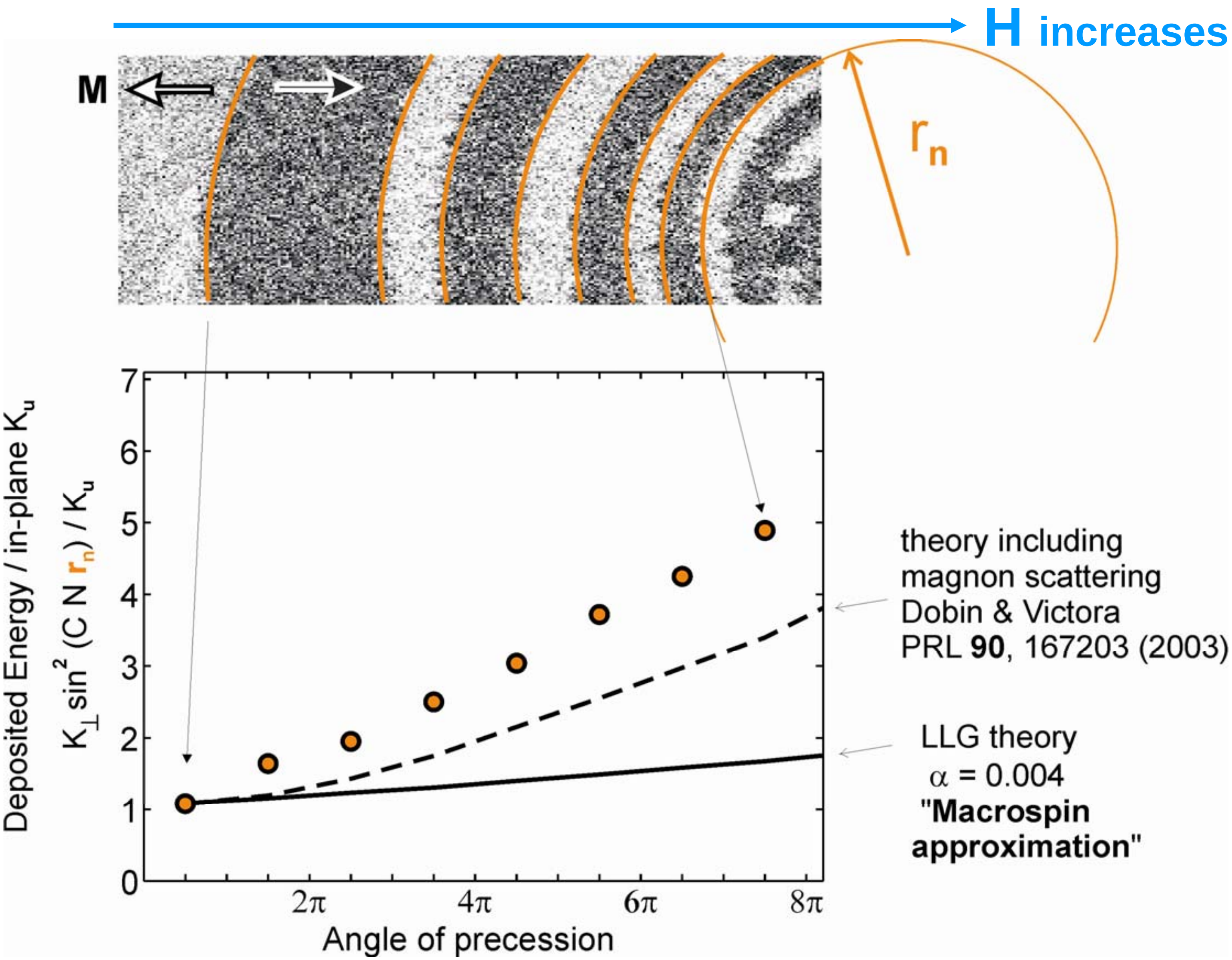



*In macrospin approximation, line positions depend on:*

- angle $\gamma = B\,\tau$
- in-plane anisotropy $K_u$
- out-of-plane anisotropy $K_\perp$
- LLG damping parameter $\alpha$

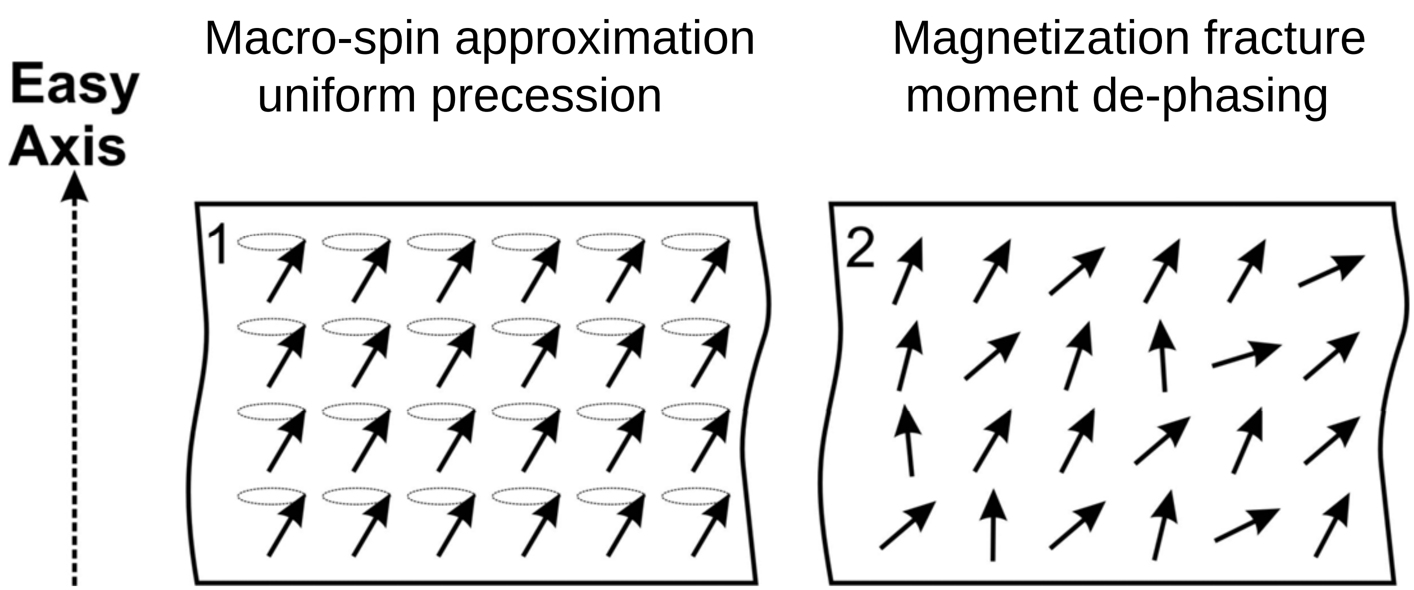
from FMR data

# Breakdown of the Macrospin Approximation




With increasing field, deposited energy far exceeds macrospin approximation
this energy is due to increased dissipation or spin wave excitation

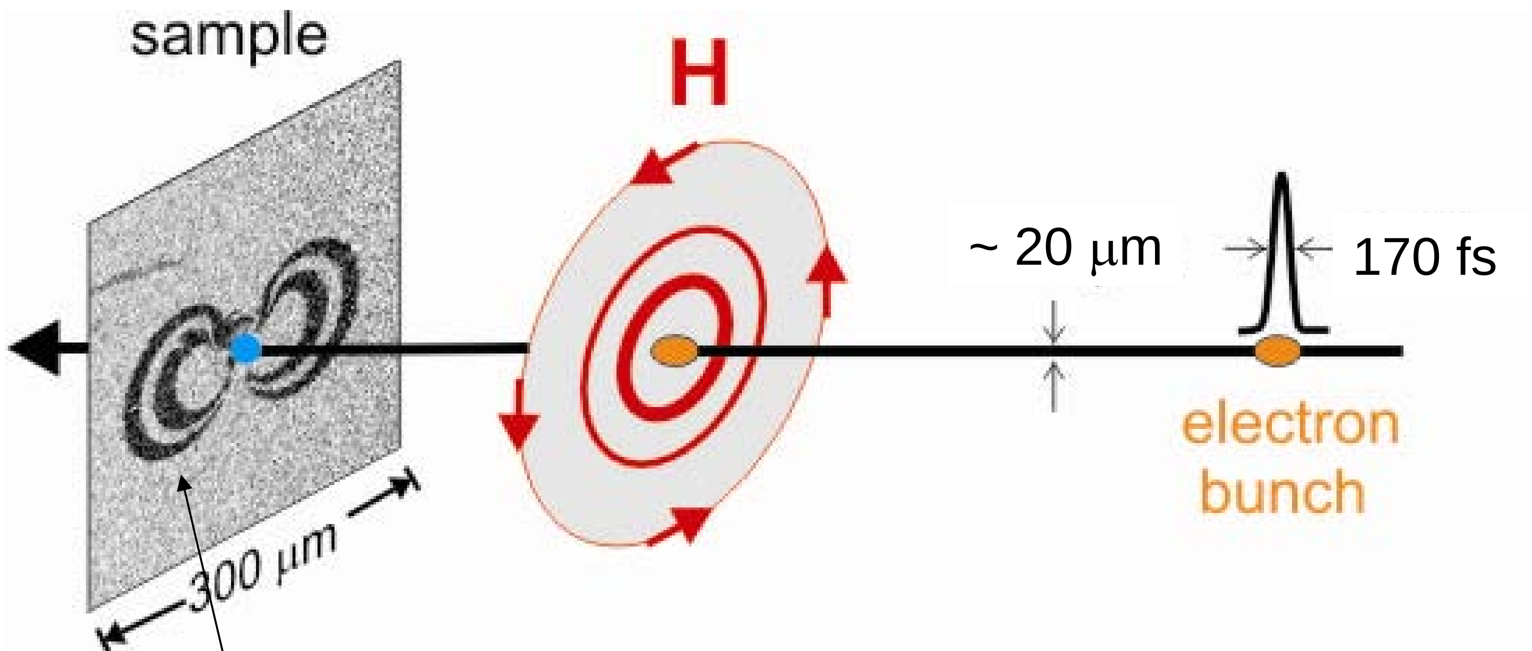
# Magnetization fracture under ultrafast field pulse excitation




**Breakdown of the macro-spin approximation**

Tudosa *et al.*, Nature **428**, 831 (2004)

# Results with ultrafast magnetic field pulses




Magnetic pattern
with **2 ps** electron bunch

Tudosa *et al.* Nature **428**, 831 (2004)

# New results with a 10 times shorter ( 167 fs ) pulse

Magnetic pattern of 10 nm Fe film with

**167 fs** bunch length

Pattern size 470 µm by 980 µm

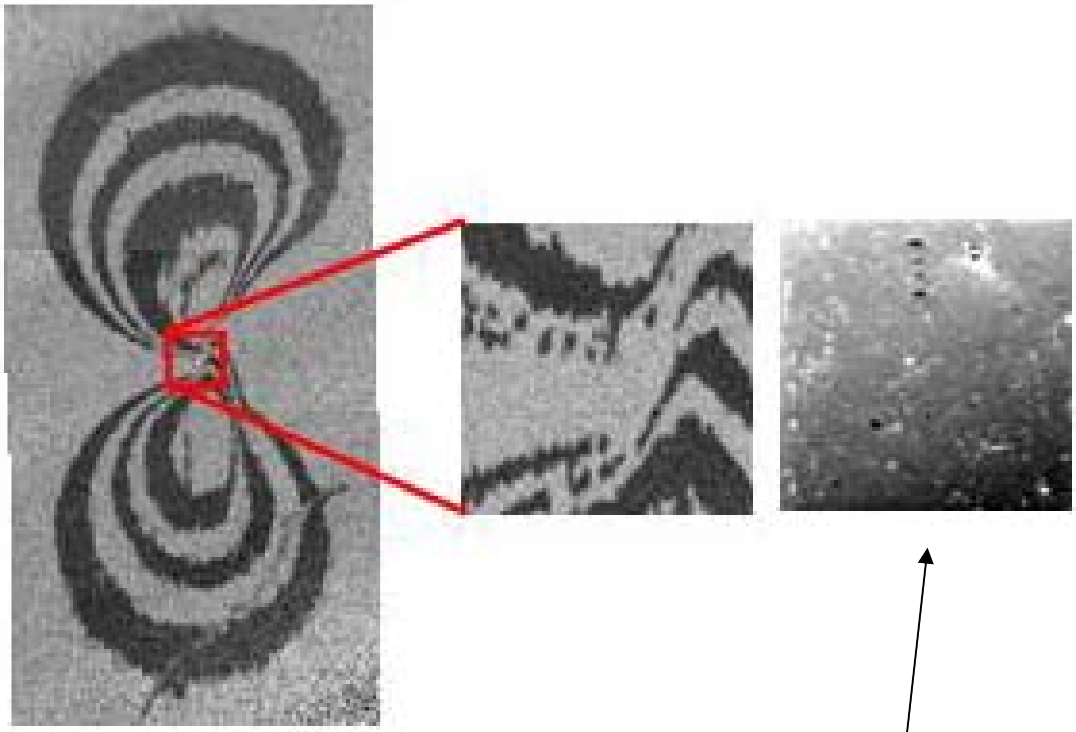
Pattern is severely asymmetric – should follow circles

No switching for certain magnetic field orientations !

Violates conventional laws of angle-dependence
of magnetic torque

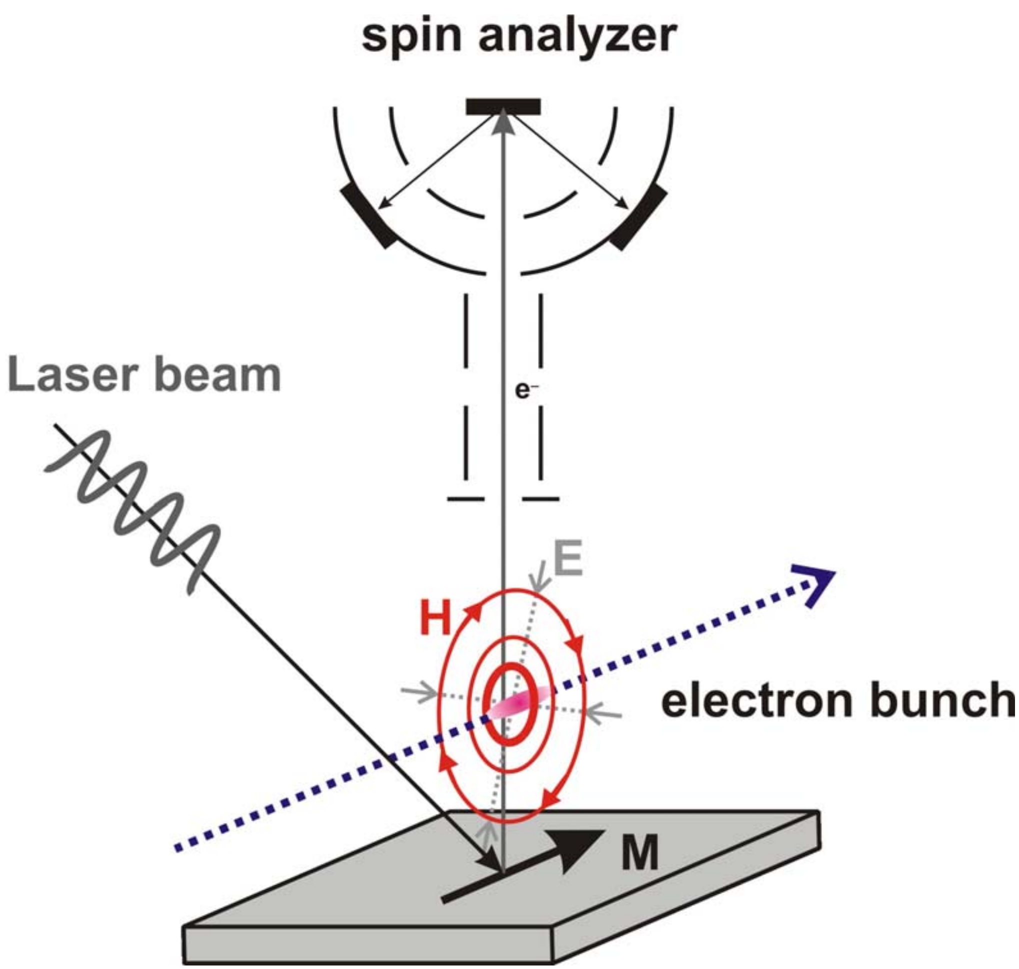
Puzzle is unresolved at present…..

## Surprising result: No beam damage at ultrafast time scales



- Inspection of beam impact area reveals no damage !
- Sample did not get hot !
- Sub-picosecond energy dissipation must exist (photons, electrons)
- Dissipation faster than electron-phonon relaxation time (ps)

# Pump-Probe Dynamics with SLAC-pulses



# Summary

- The breakdown of the macrospin approximation for fast field pulses limits the reliability of magnetic switching

- At ultrafast speeds (~ 1 ps) new phenomena exist
one approaches timescales of fundamental interactions between electrons, lattice and spin

- In the future, e-beam “pump”/ laser “probe” experiments are of interest as well

For more, see: http://www-ssrl.slac.stanford.edu/stohr

and

J. Stöhr and H. C. Siegmann
***Magnetism: From Fundamentals to Nanoscale Dynamics***
800+ page textbook ( Springer, May 2006 )