Picosecond Time Resolved Microscopy on Magnetic Structure Using X-PEEM

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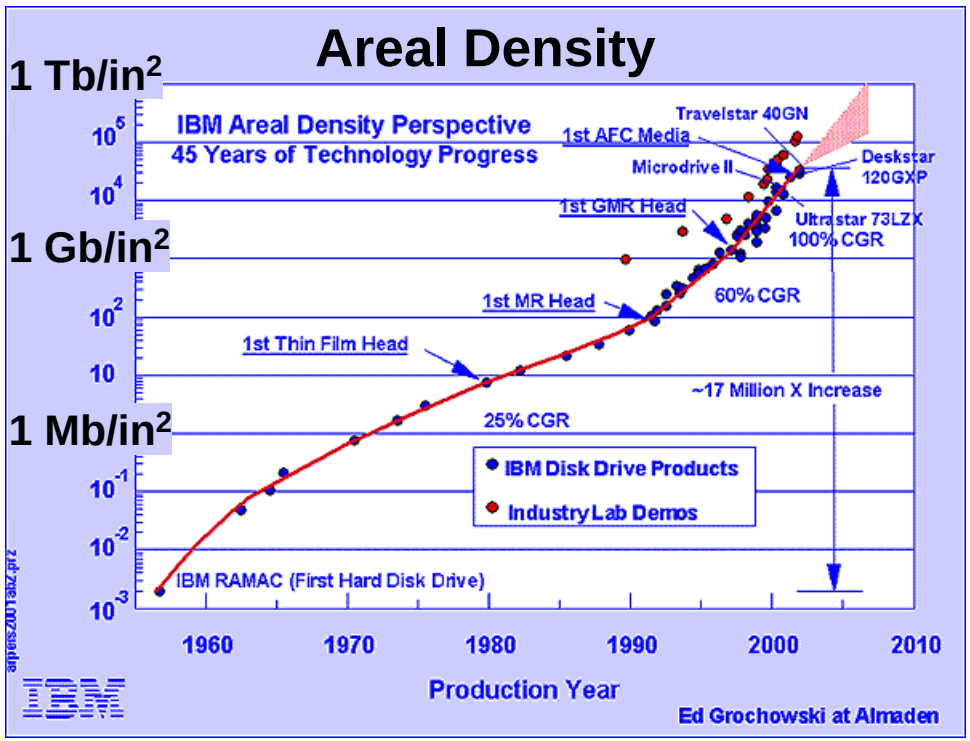
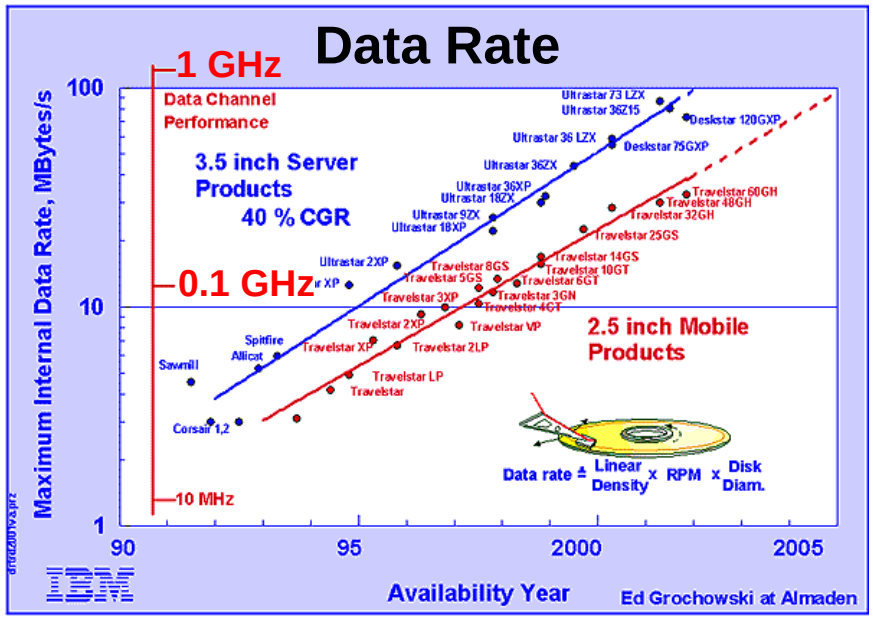
Introduction

State of the Art Technology:

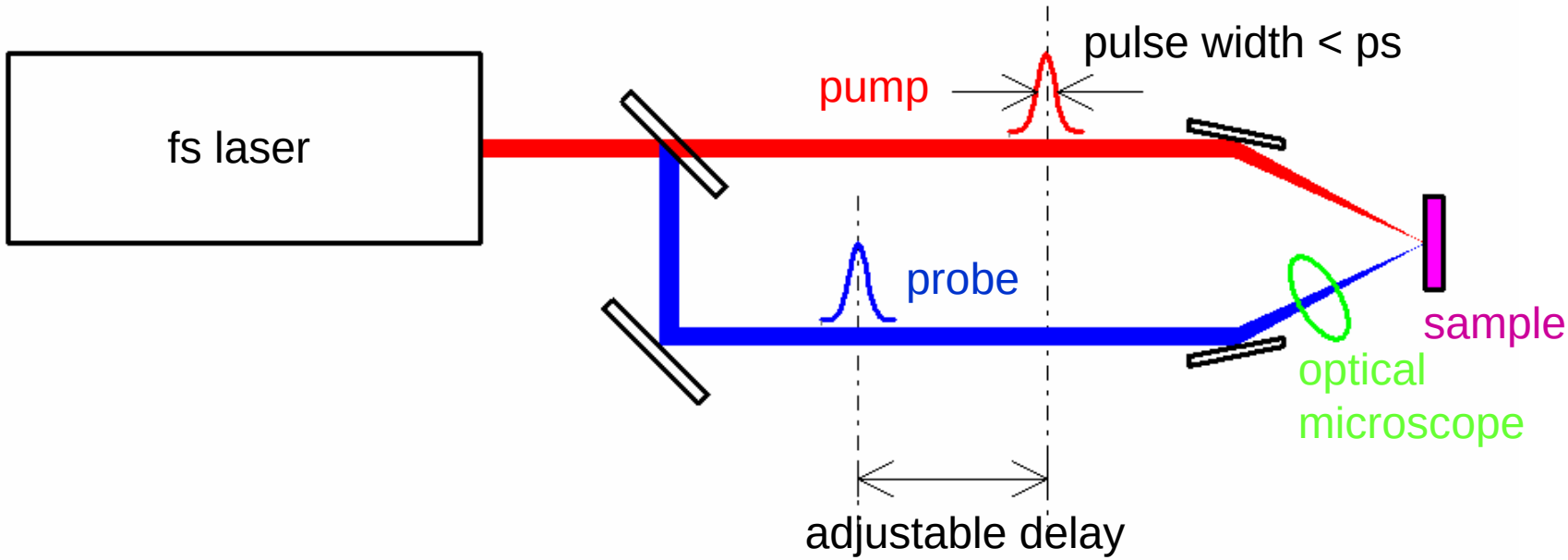
- **Switching time ~ 1 ns**
- **Magnetic element size ~ 300 nm**





Study on < 1 ns & < 100 nm scale is urgent

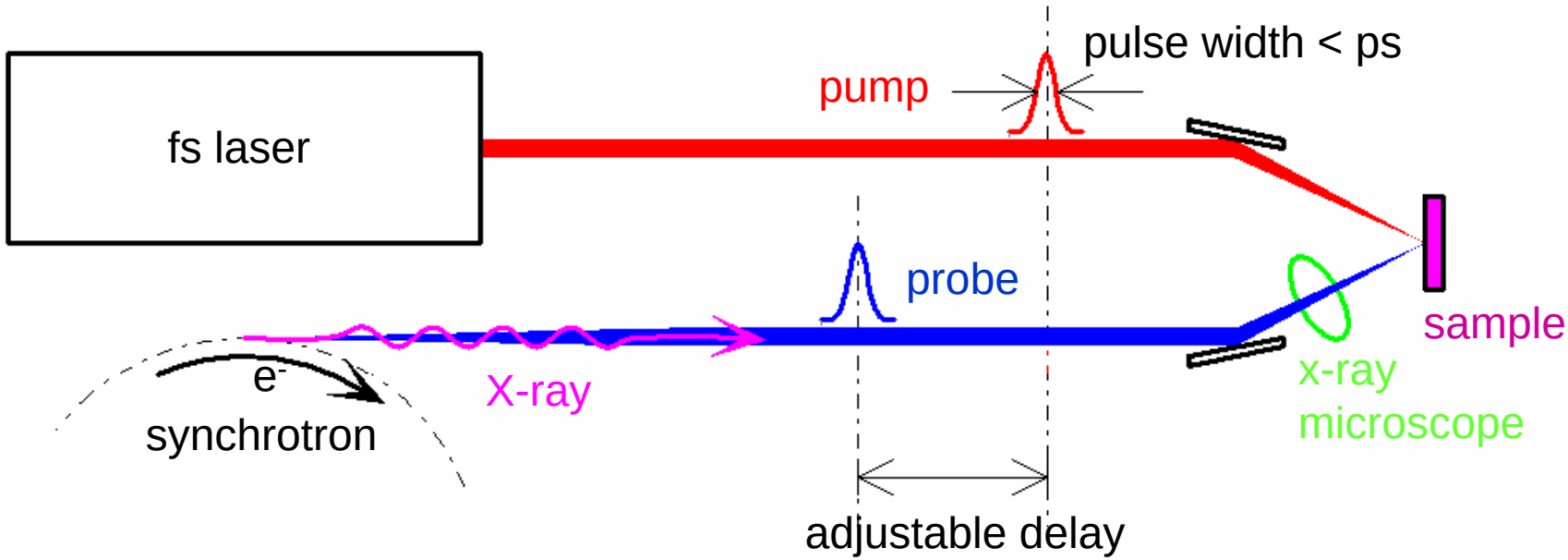
Optical Pump-Probe Technique



Very high time resolution (~ ps) can be achieved easily.

But, the spatial resolution is limited by diffraction (~ 400 nm).

Two-color Pump-Probe Technique



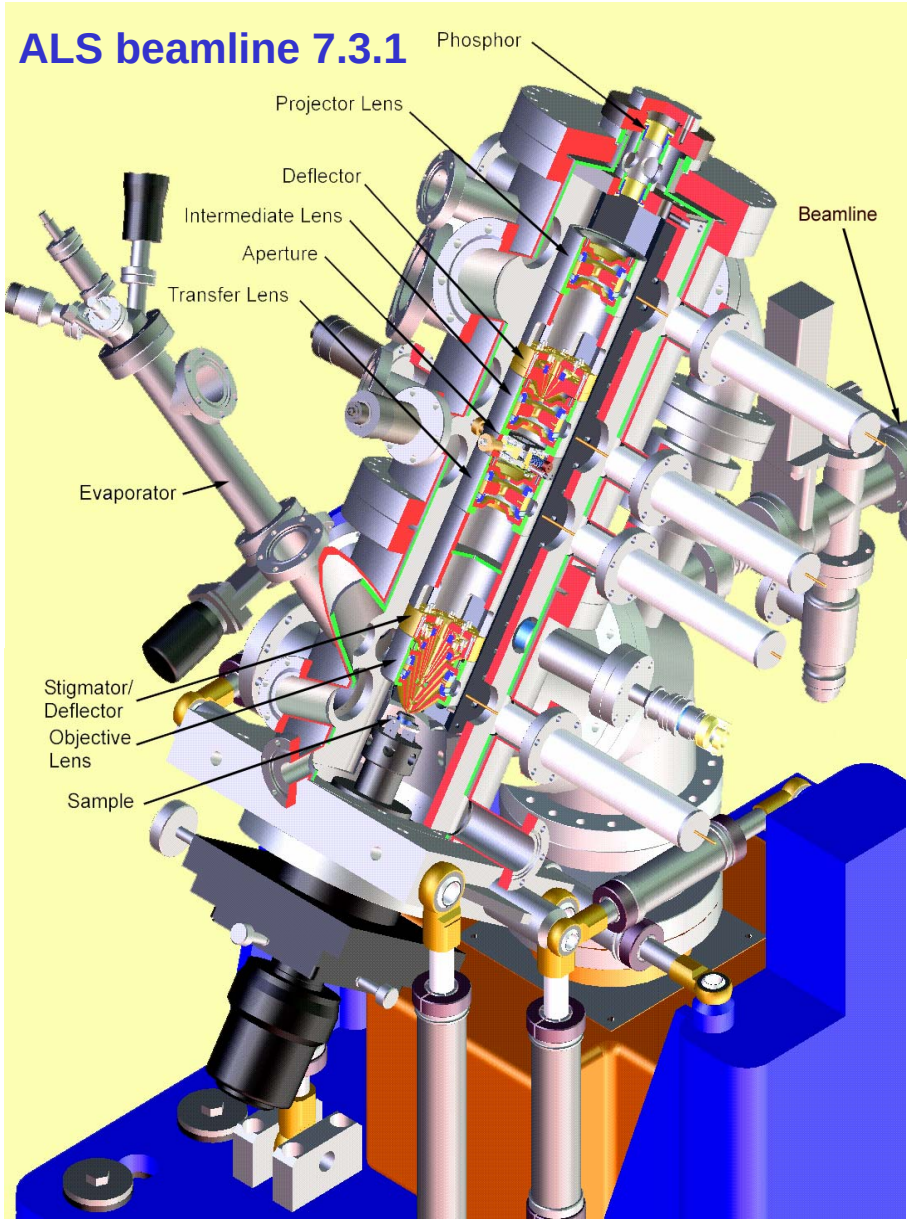
Very high time resolution (~ ps) can be achieved easily.

But, the spatial resolution is limited by diffraction (~ 400 nm).

Time resolution is given by synchrotron pulse (~ 50 ps).

The spatial resolution is given by X-ray microscope (~ 50 nm).

Photo-Emission Electron Microscope



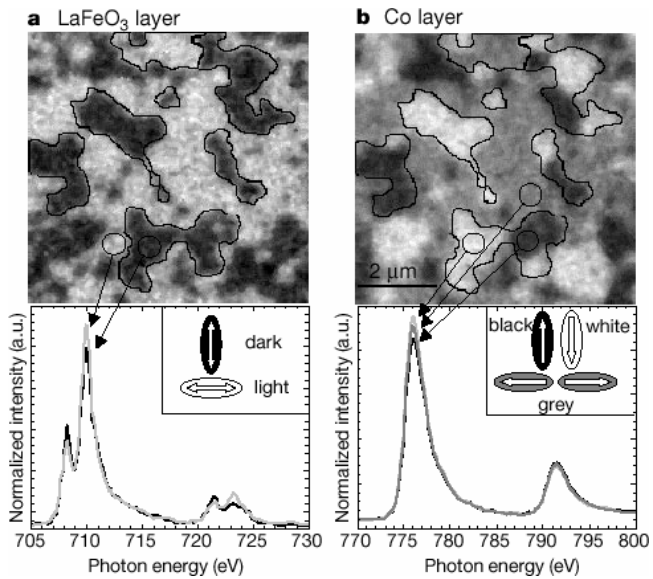
Strong Features

Resolution ~ 50 nm

Magnetic contrast

Element contrast

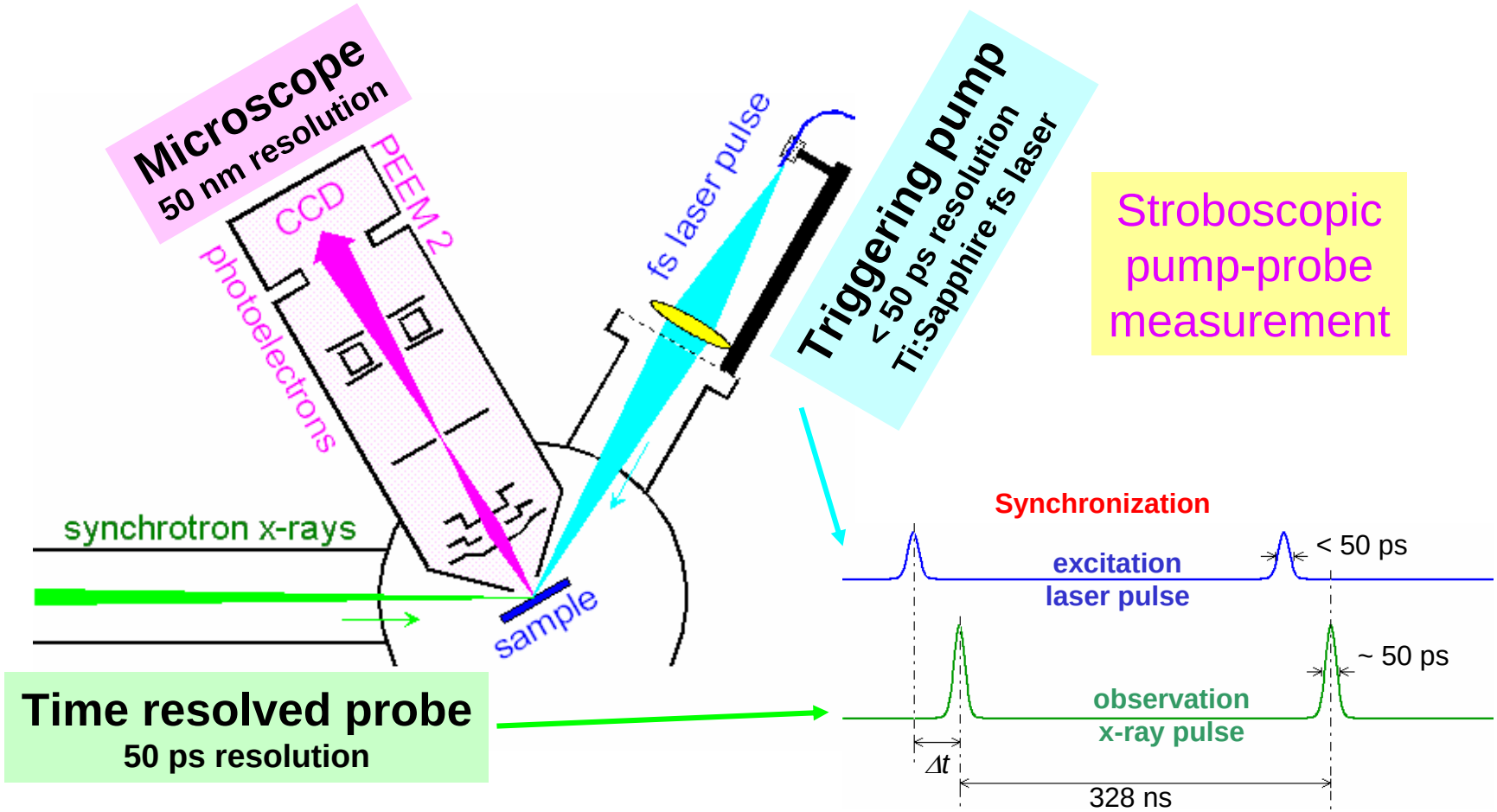
Surface sensitive



F. Nolting *et al*., Nature **405**, 769 (2000).

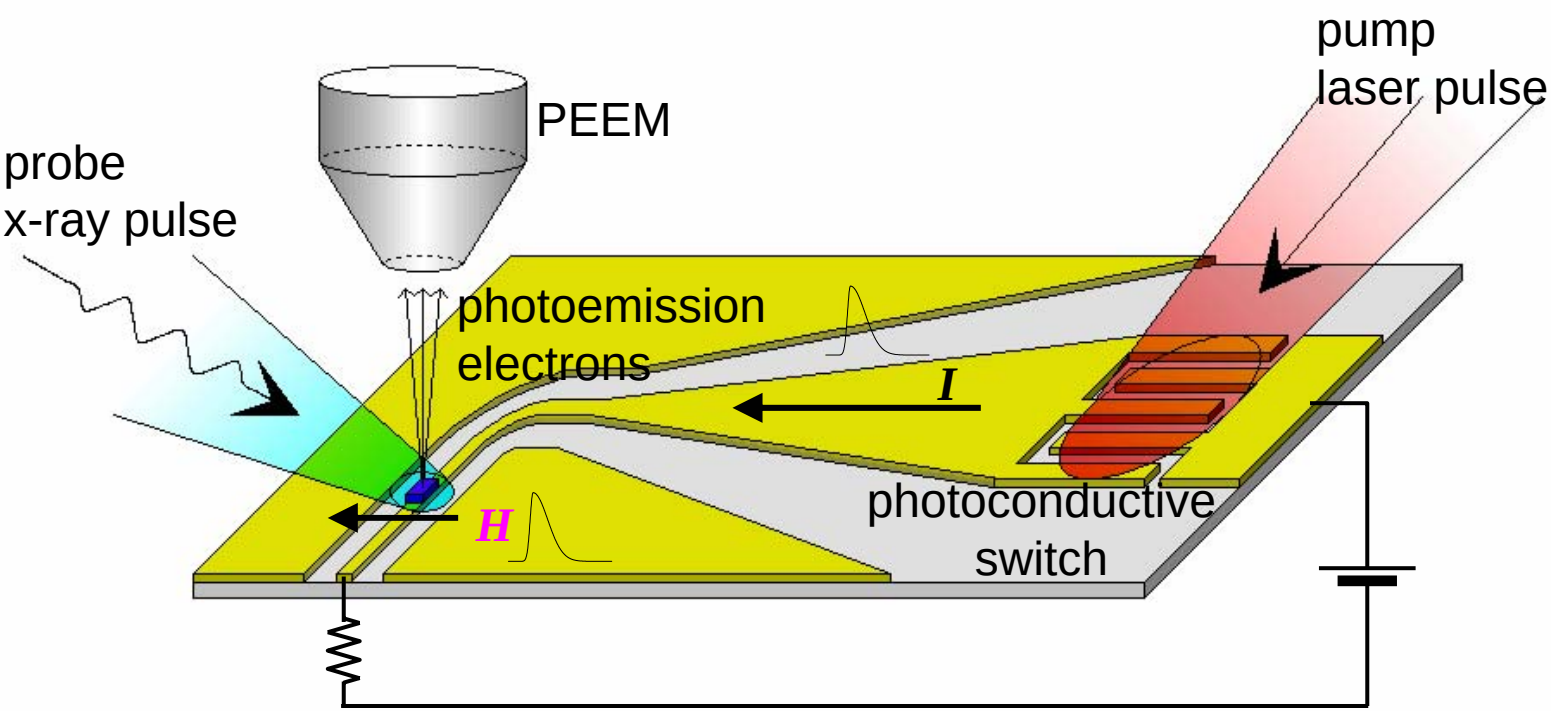
A Time Resolved PEEM Microscope

Exceptional spatial resolution of PEEM + intrinsic time resolution of ALS

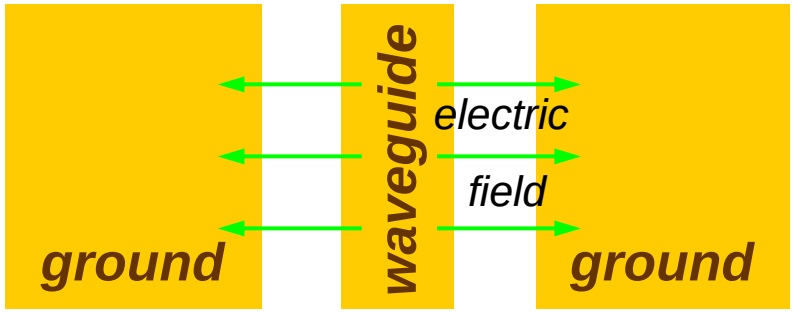


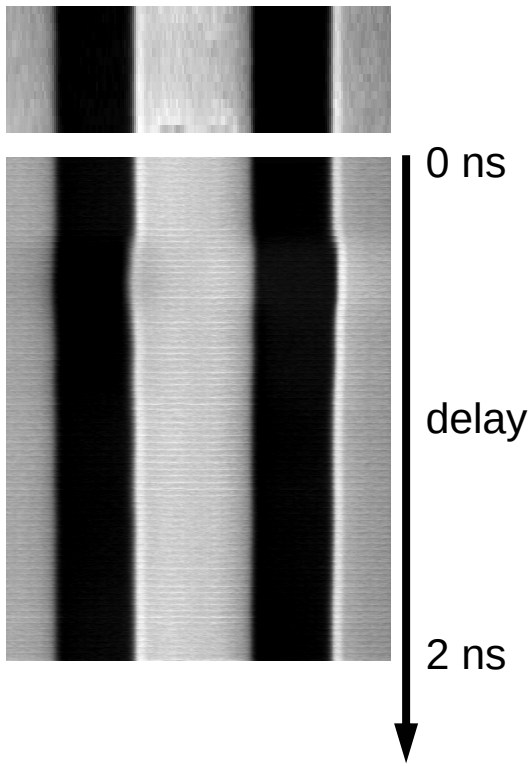
A New Time Resolved Microscope

Exceptional spatial resolution of PEEM + intrinsic time resolution of ALS

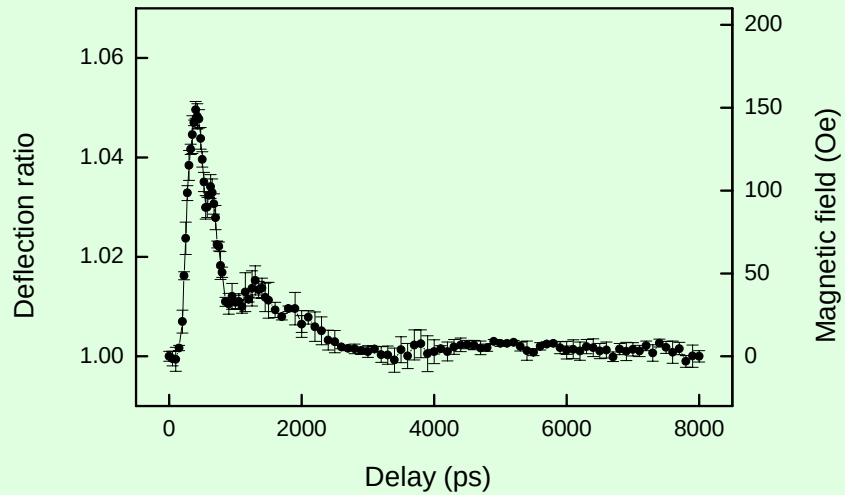


Pulse Measurement





PULSE PROFILE

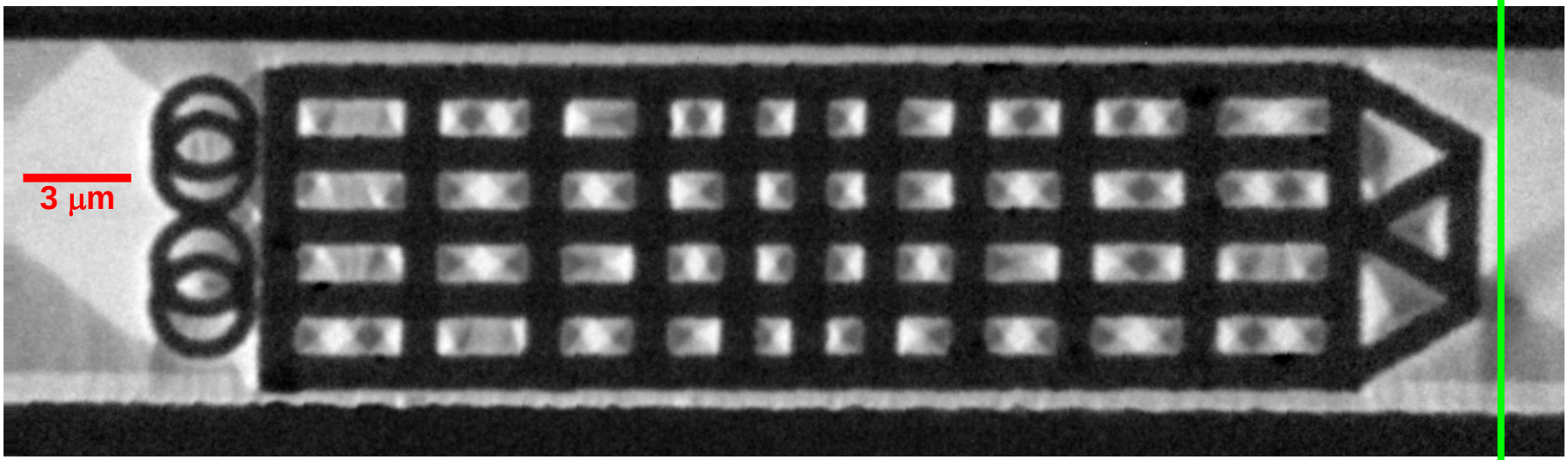


Magnetic Field Pulse

< 50 ps rising time
> 300 ps decaying time
with some reflection
~ 15 mT at Maximum

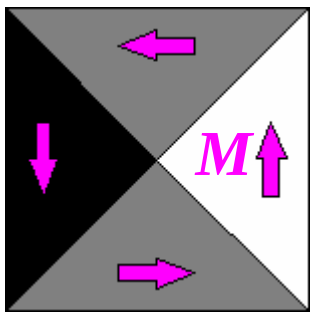
Typical Ground States of Magnetic Patterns

20 nm $Co_{90}Fe_{10}$ films with in-plane anisotropy (1 μm) x (1-3 μm) rectangles



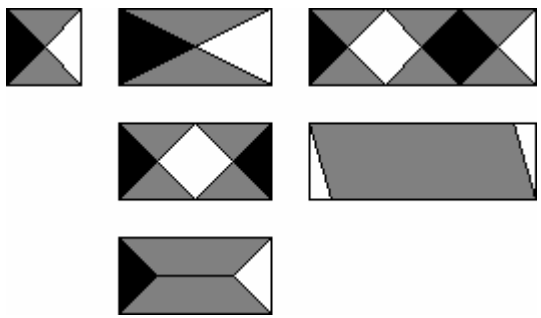
relevant size & shape for magnetic application

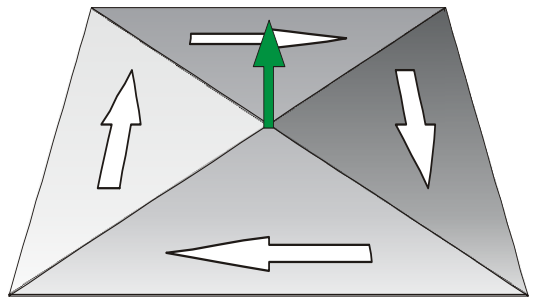
Observation x-rays



Contrast & Magnetization

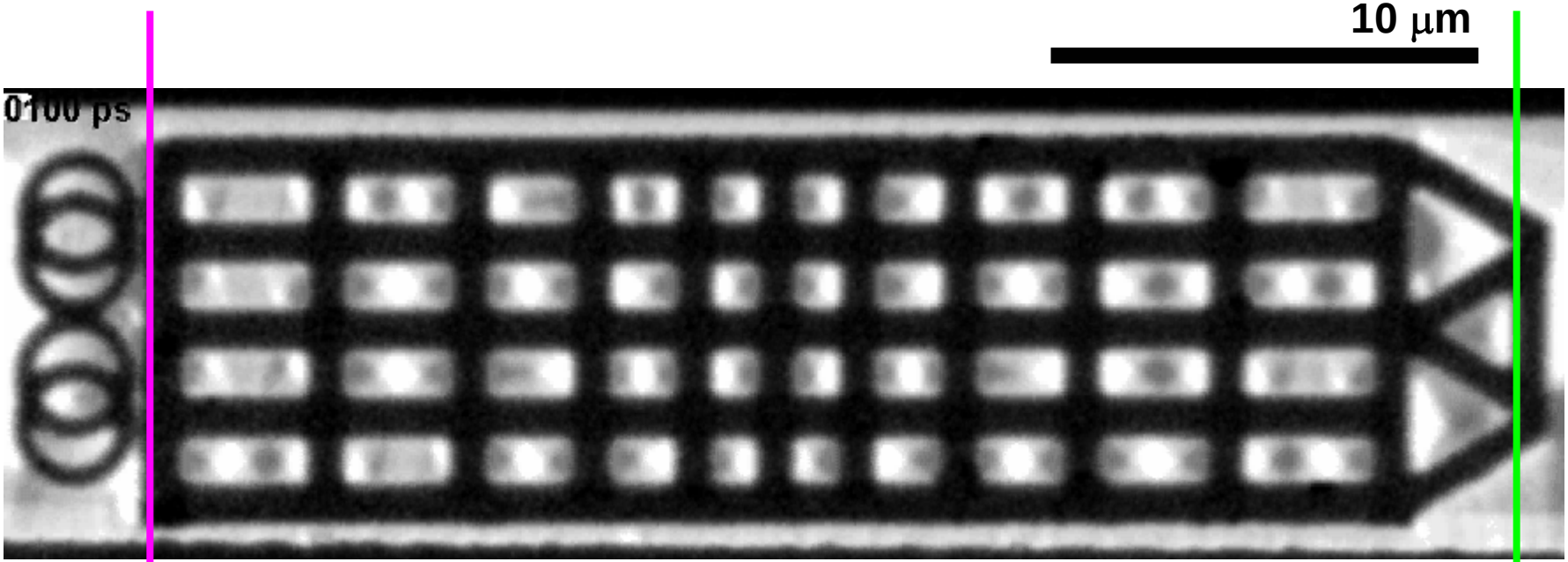
Ground energy states





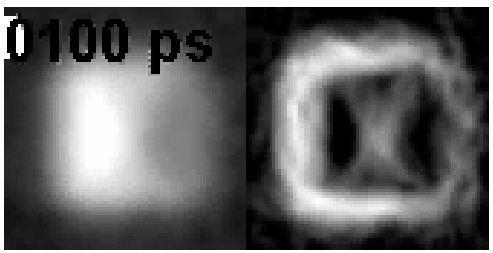
Magnetic vortex

Time Resolved Images

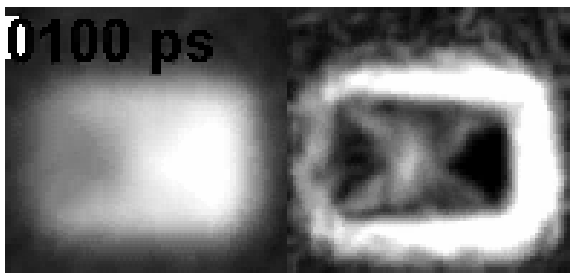


Magnetic field pulse
(~300 ps in the beginning)

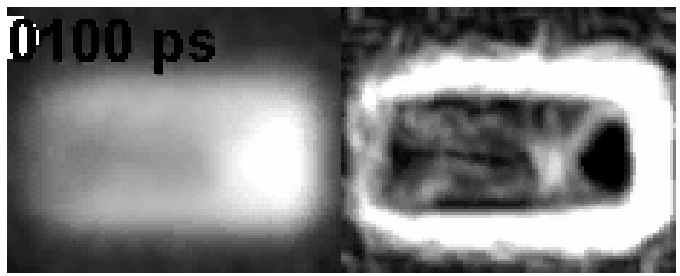
Observation x-rays



1 μm x 1 μm



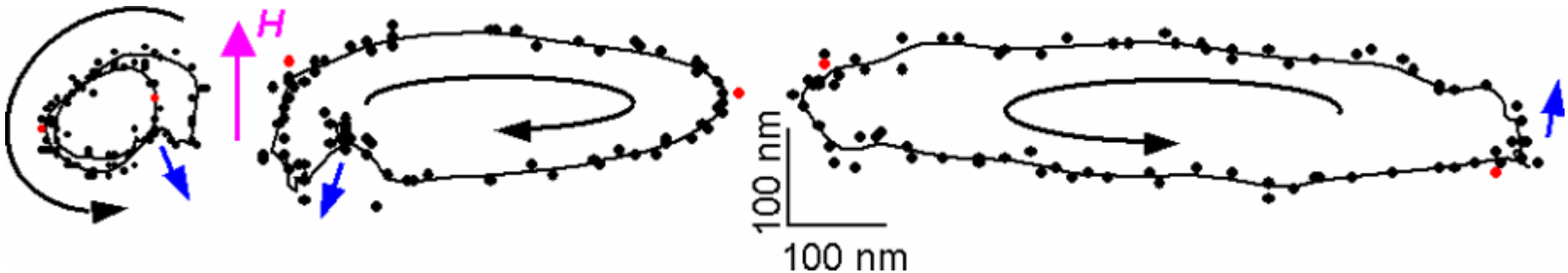
1.5 μm x 1 μm

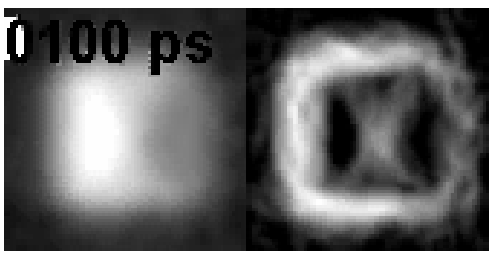


2 μm x 1 μm

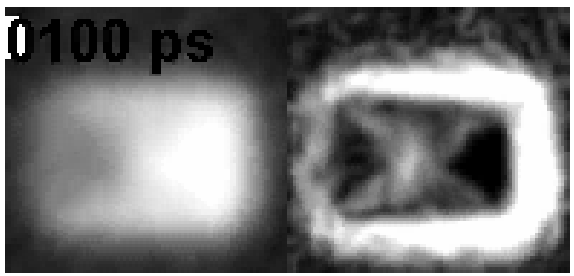
Vortex Trajectory

Parallel or Antiparallel acceleration under a field

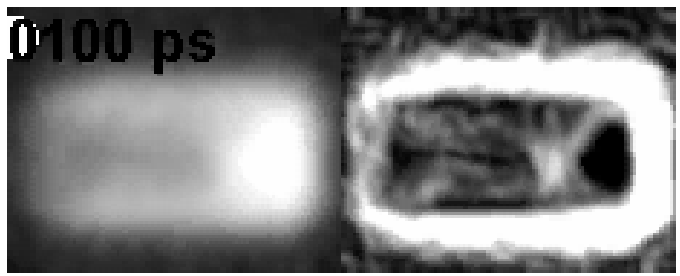




1 μm x 1 μm



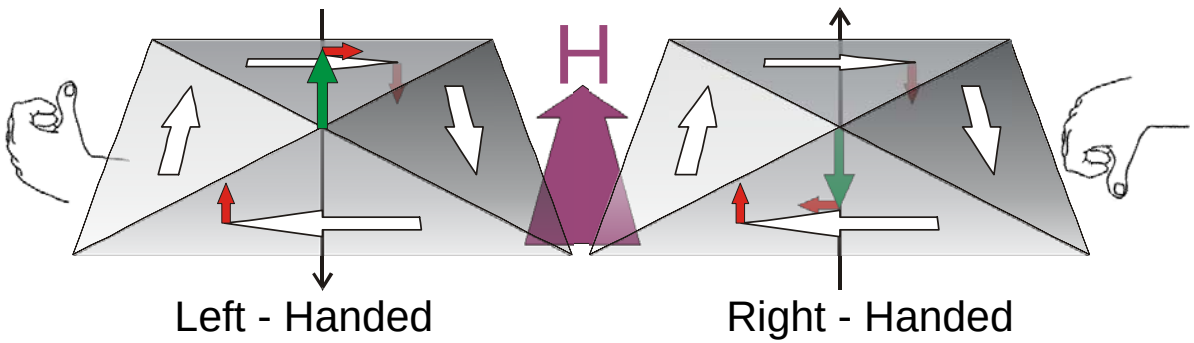
1.5 μm x 1 μm

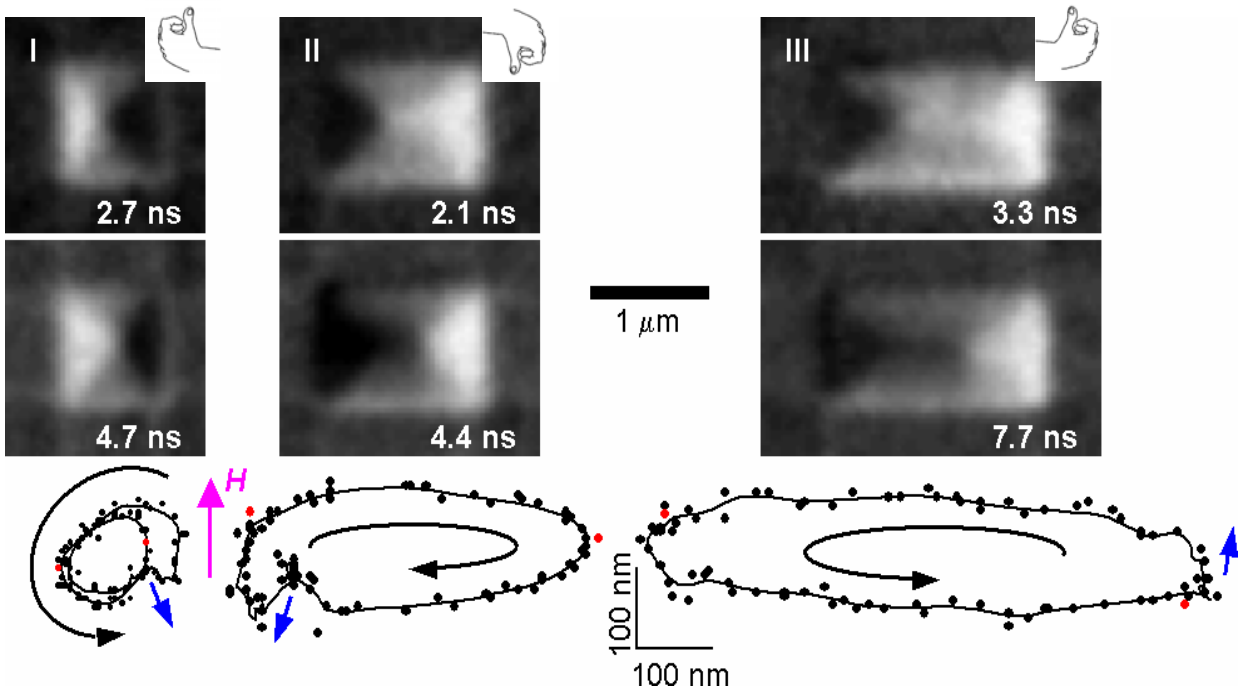


2 μm x 1 μm

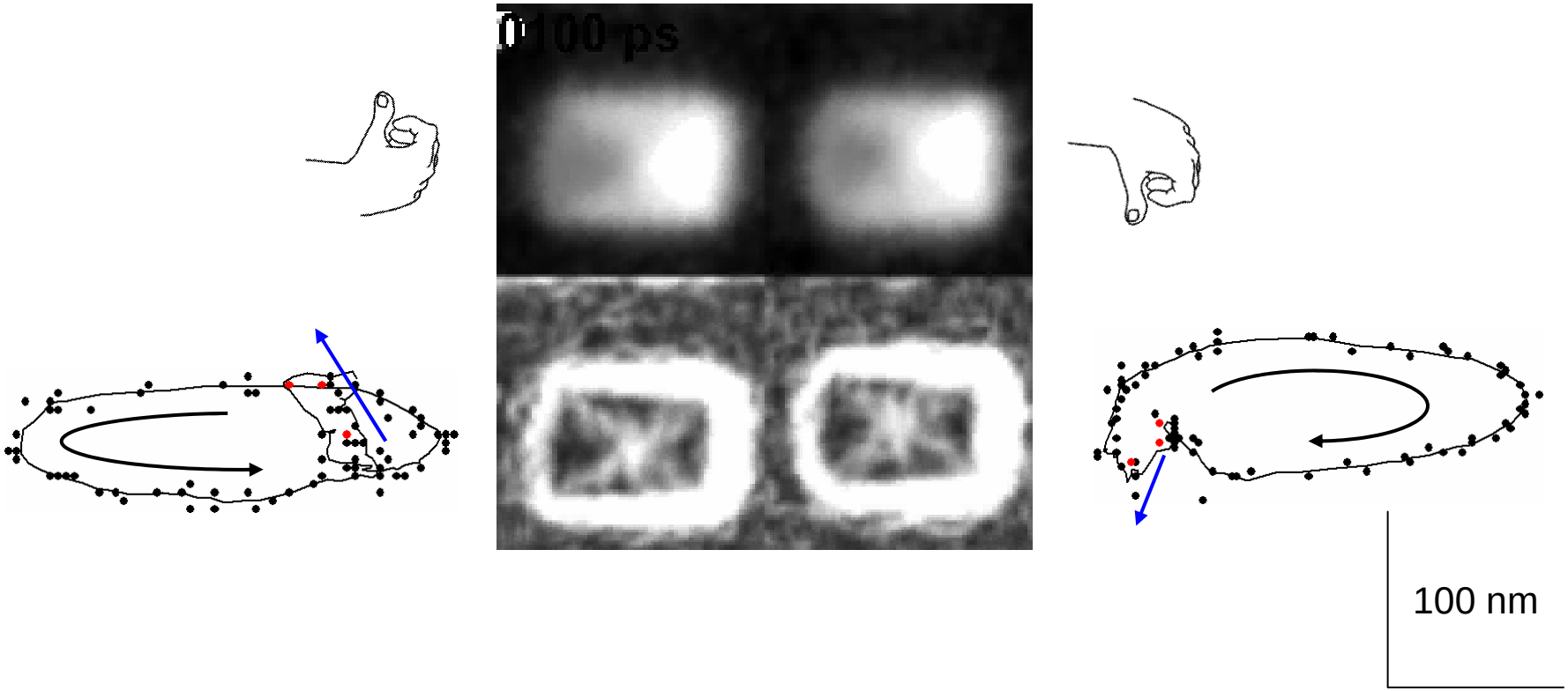
3D Consideration of Handedness

$$\frac{d}{dt}\mathbf{m} = -\gamma \mathbf{m} \times \mathbf{H}_{eff} \qquad \text{LLG}, \alpha = 0$$





Importance of Handedness



Small volume of perpendicular polarization determines vortex motion.

(~ 10^6 spins, 20 nm) **(> 10^{10} spins, 1 μm)**

Summary

- ***Development of time resolved x-ray microscopy***
  - We have developed techniques to study magnetization dynamics on relevant time and length scales (~100 ps, 100 nm)

  - essential for the understanding of fast magnetic phenomena

- ***Direct observation of magnetic vortex dynamics***
  - observation of Gyrotropic vortex rotation

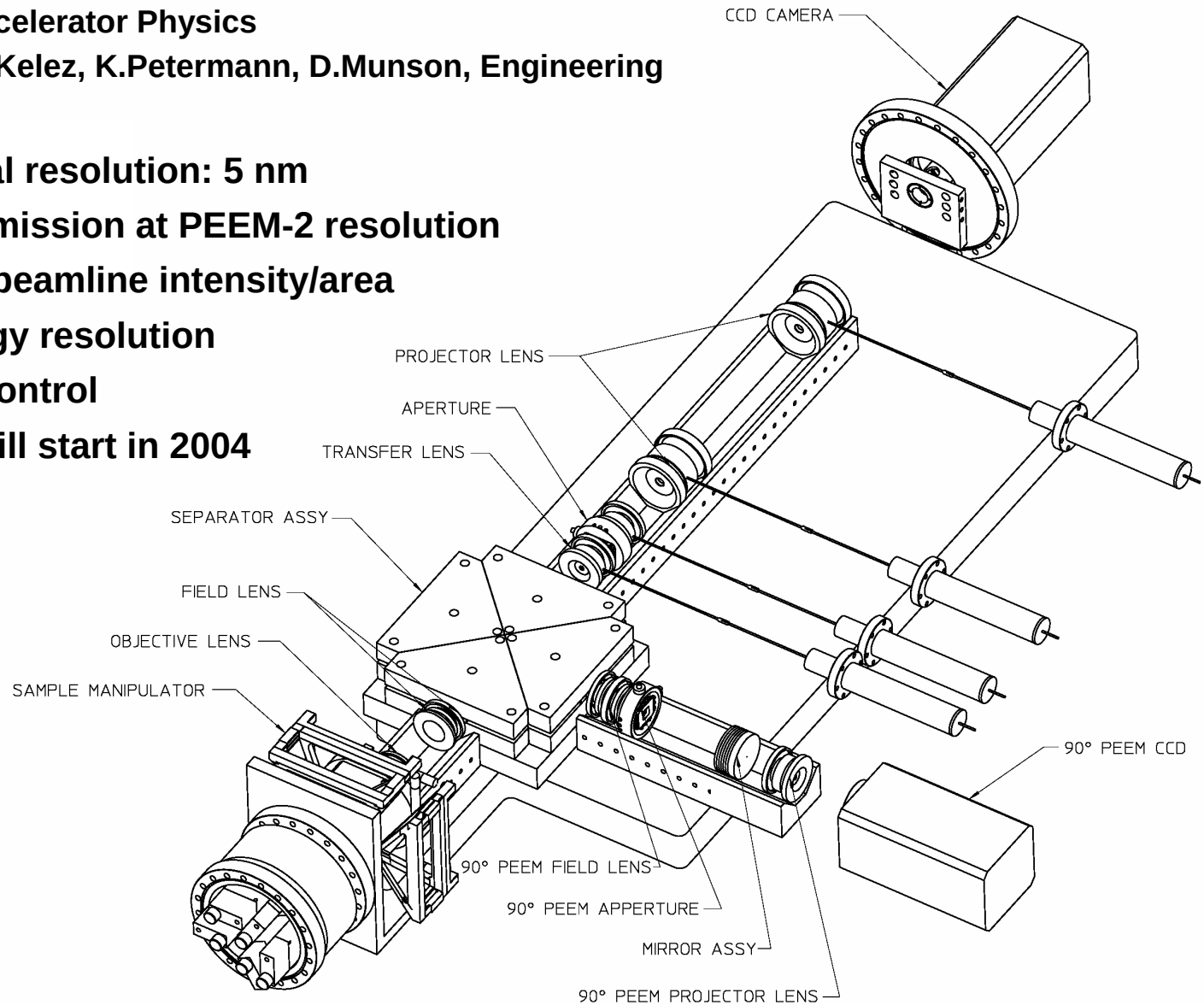
  - importance of 3D magnetic structure (handedness)

  - determination of strong internal magnetic field on vortex core

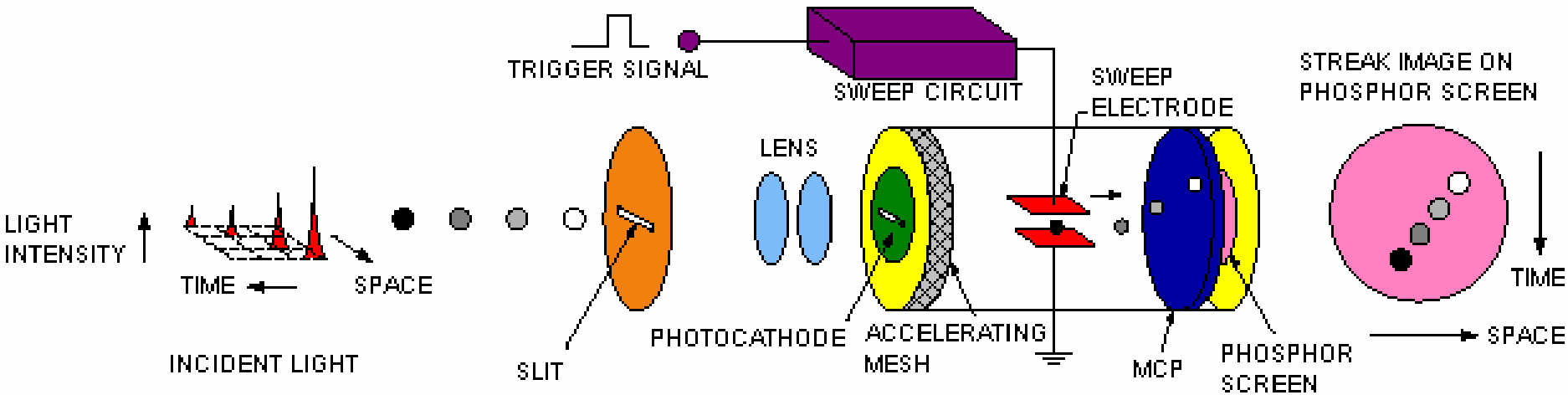
ALS PEEM3 (better spatial resolution)

F.Jun, A.MacDowell, H.Padmore, A.Scholl, M.Marcus, P.Schmid, A.Doran, T.Warwick, ESG
Weishi Wan, D.Robin, Accelerator Physics
R.Schlueter, R.Duarte, N.Kelez, K.Petermann, D.Munson, Engineering

- **~10x higher spatial resolution: 5 nm**
- **~10x higher transmission at PEEM-2 resolution**
- **100-1000x higher beamline intensity/area**
- **3-10x higher energy resolution**
- **Full polarization control**
- **Commissioning will start in 2004**



Streak Camera (better time resolution)



Modified from Hamamatsu Photonics Streak Camera Guide

- **Time resolution is limited by jittering, ~ a few ps**
- **1D spatial imaging (2D with time)**