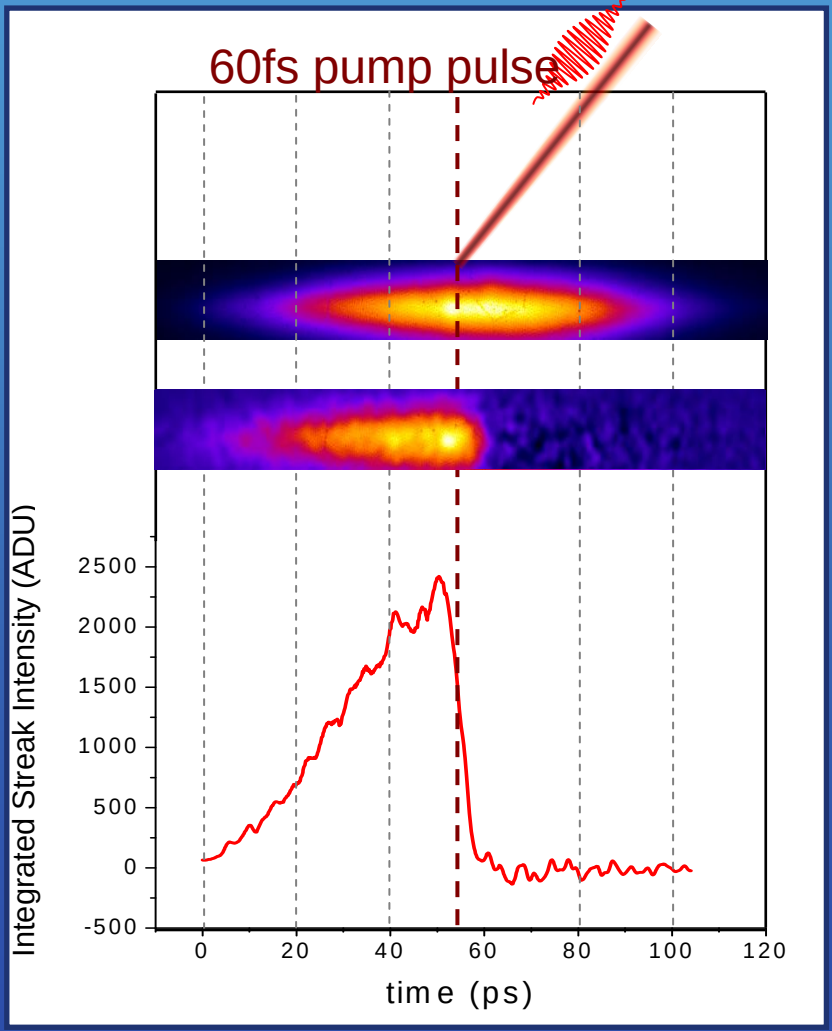
Ultrafast Streak Camera Development at the Advanced Light Source

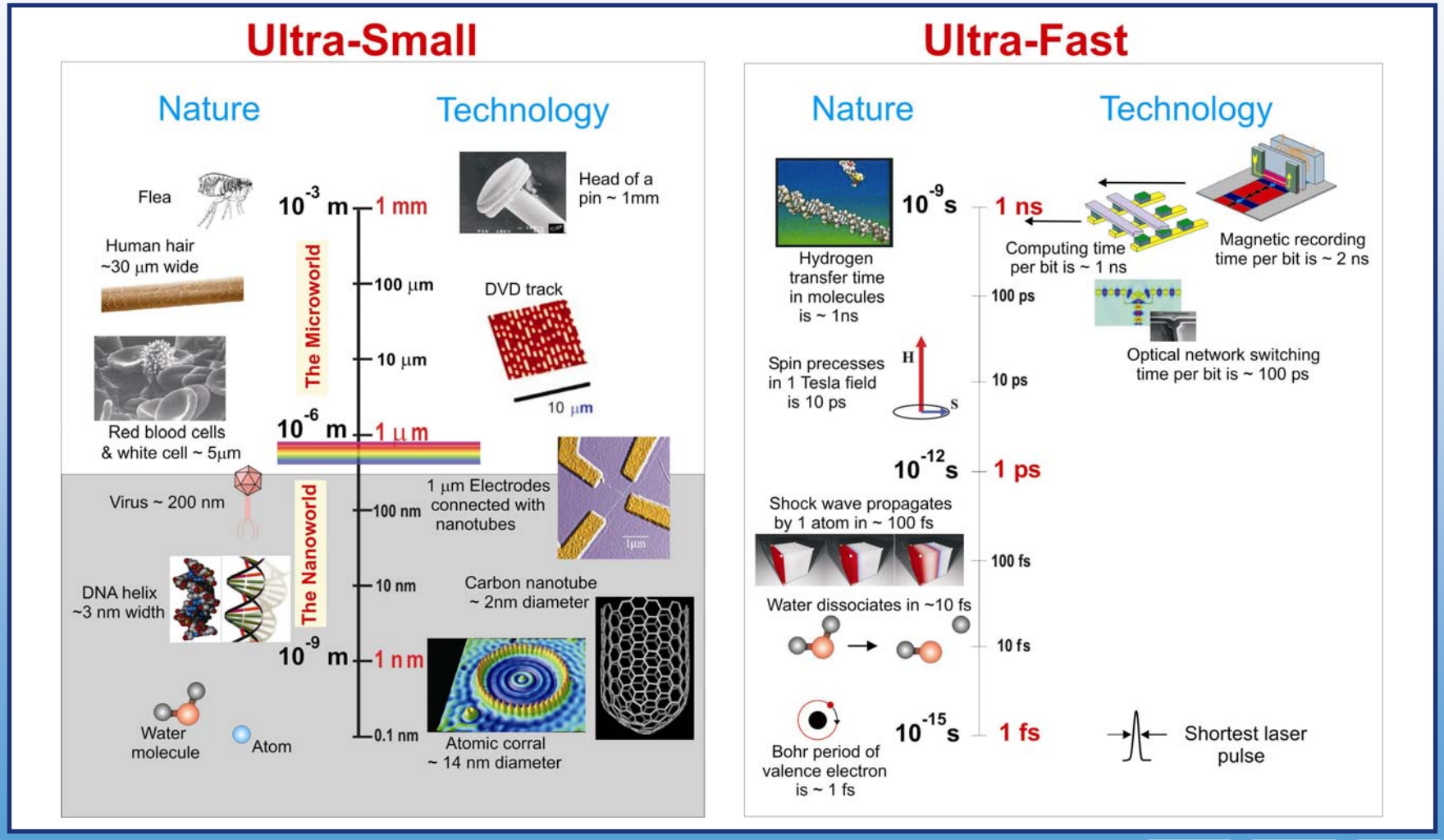
ESG
ADVANCED LIGHT SOURCE
EXPERIMENTAL SYSTEMS GROUP



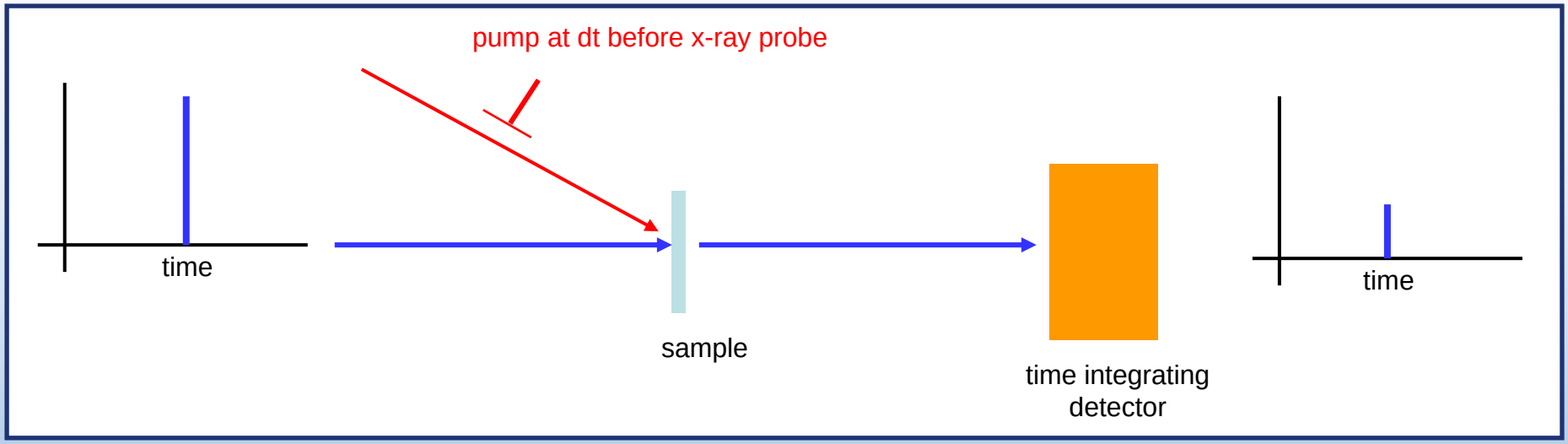
- Introduction and Motivation
- ALS Streak Camera Program
- Applications
- Future Plans
- Publications
- Acknowledgement
- Brief Overview

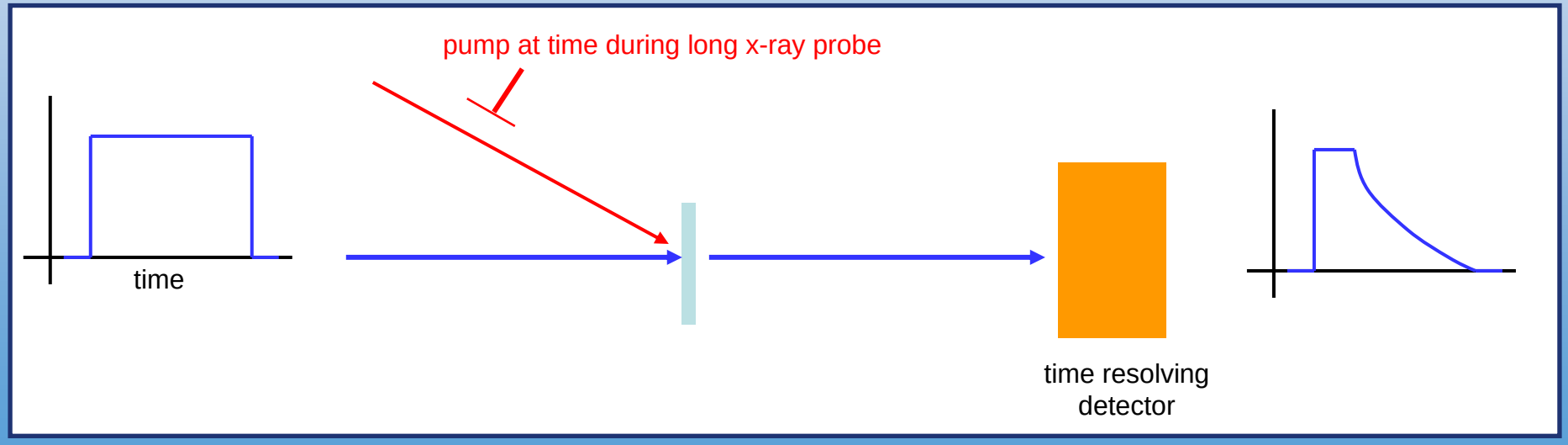
Introduction

Front field: study the ultra small and ultra fast worlds



Ultra-fast X-ray Measurements





ALS Streak Camera Program

Transmission streak camera:

- Providing ultrafast magnetic dynamics study
- improving temporal resolution

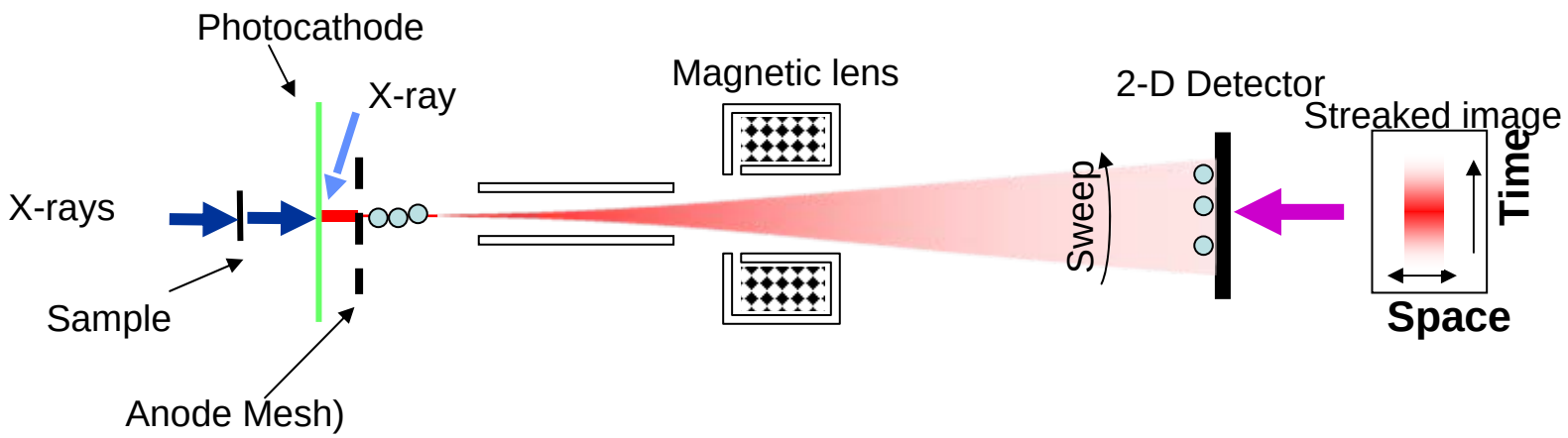
Reflection streak camera:

- Slicing diagnostic and related experiment

Dual-sweep streak camera

- Photocathode: Radiation-hard, alignment, high voltage, 25μm,10μm
- Photo-conductive switch: fabrication technique, mounting mechanism, fast rise-time,
- Electron optics: large FOV, reducing fringe field
- Meander-plate: increase sweep speed, dv/dt, deflection aberration
- Start-to-end modeling

Ultrafast Detector: Streak Camera Principle

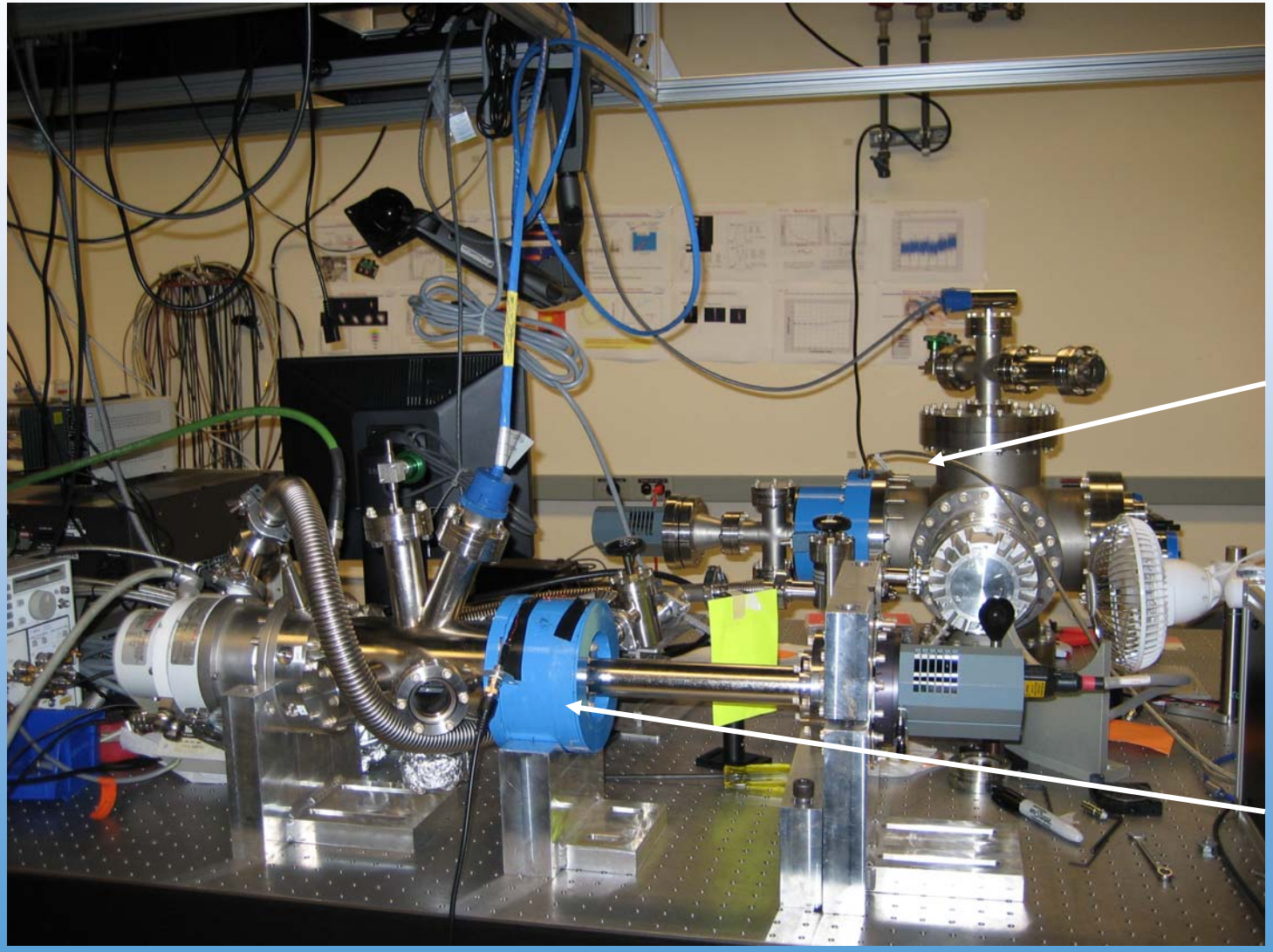


Convert fast time information into space information that can be recorded on an area detector

Features:

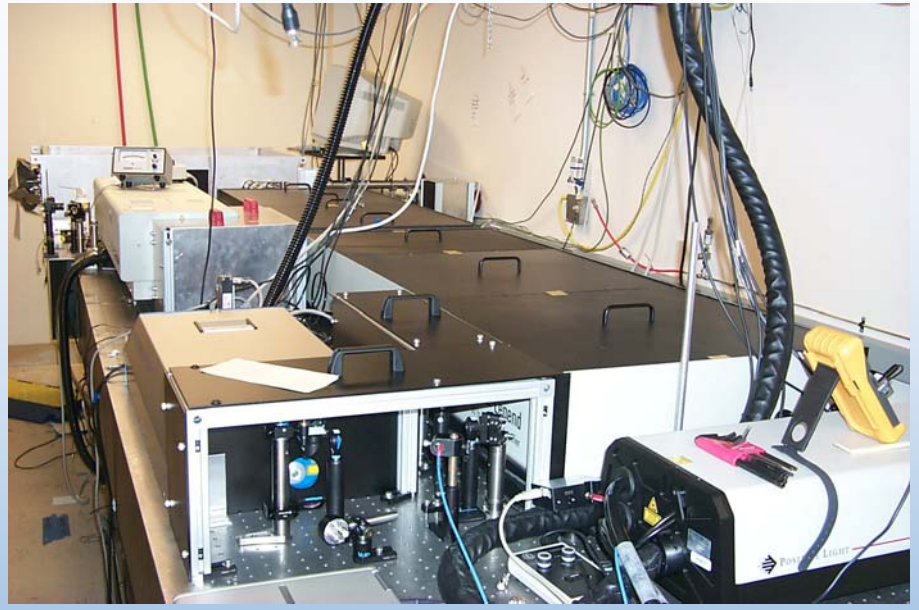
- good temporal resolution (at present psec, could be 100 fsec or better)
- records the whole temporal response (ps-ns)
- wide photon energy range 10ev to 10kev
- in principle could be used to record the temporal and spectrum simultaneously

ALS Ultrafast Streak Camera R&D Lab



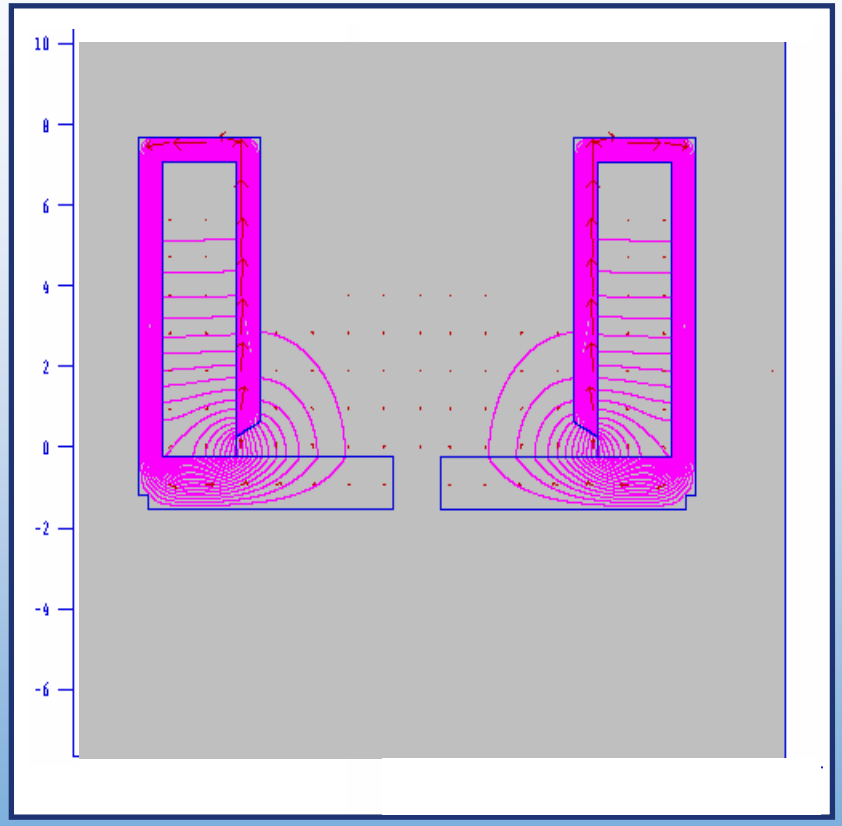
Ti:sapphire fs Laser Systems

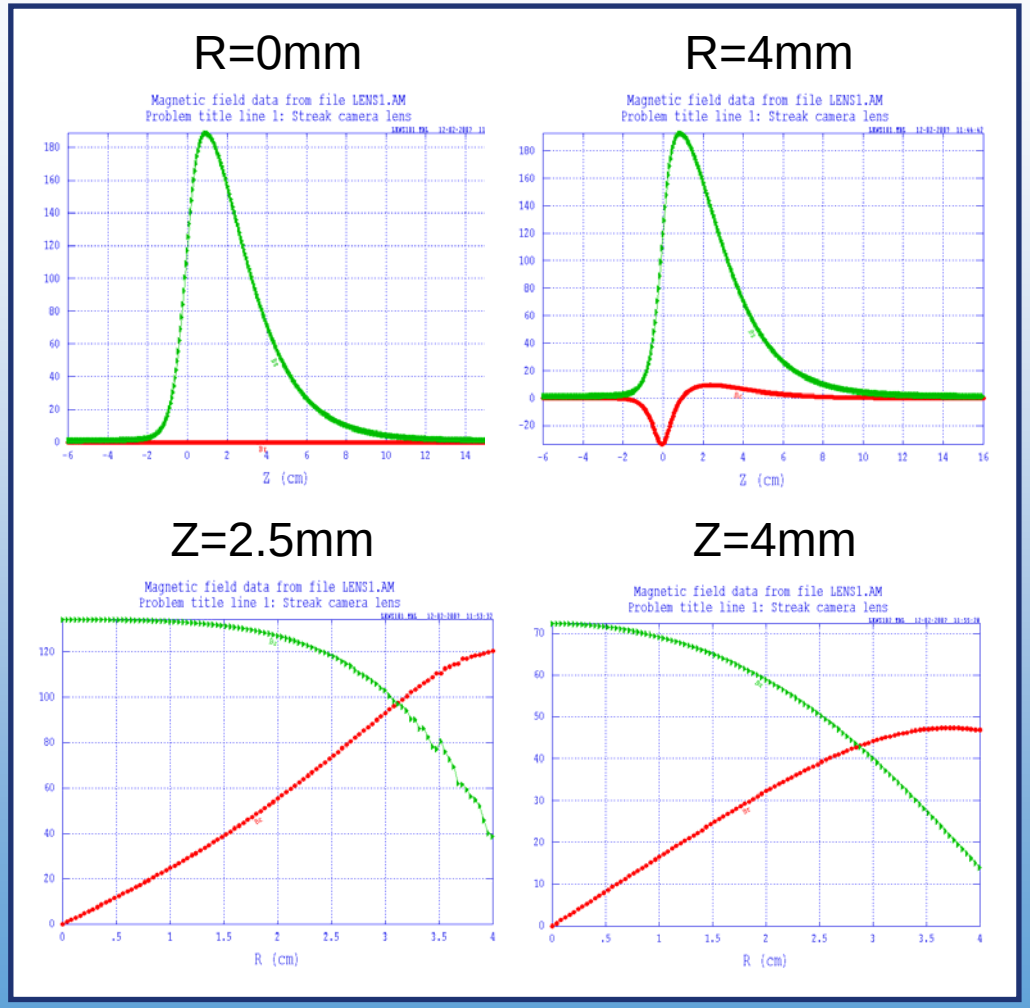
Femto-laser Oscillator
Positive Light Legend Laser:
30 fsec, 1 mJ / pulse, 1 KHz



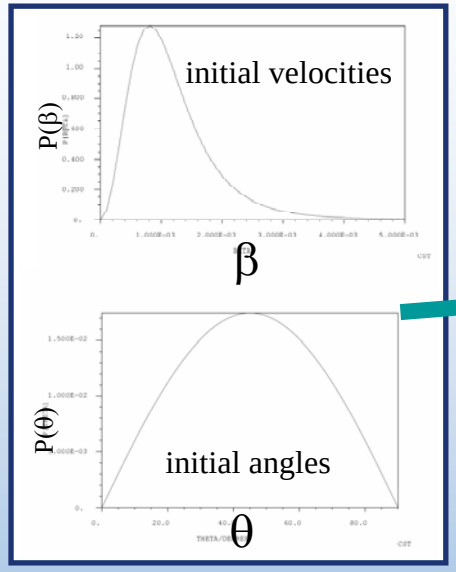
KMlab 62.5 MHz oscillator
Positive Light Legend Laser:
30 fsec, 0.6 mJ / pulse, 5 KHz

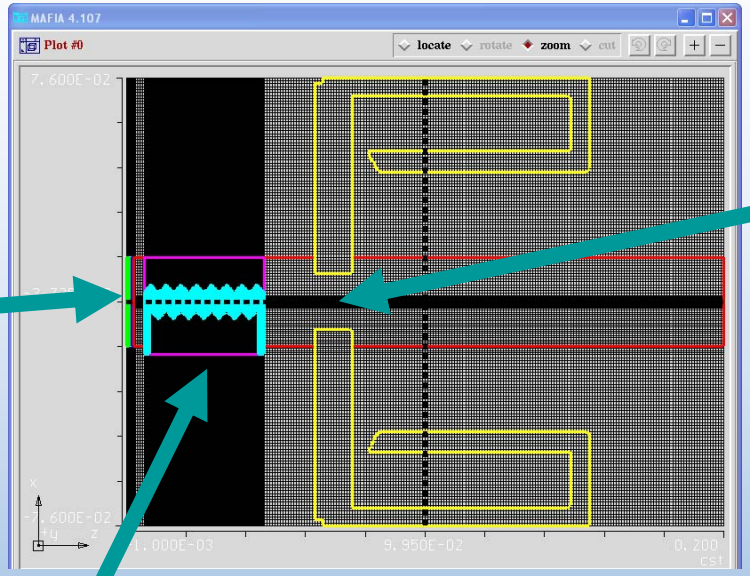
Solenoid Lens Field Distribution

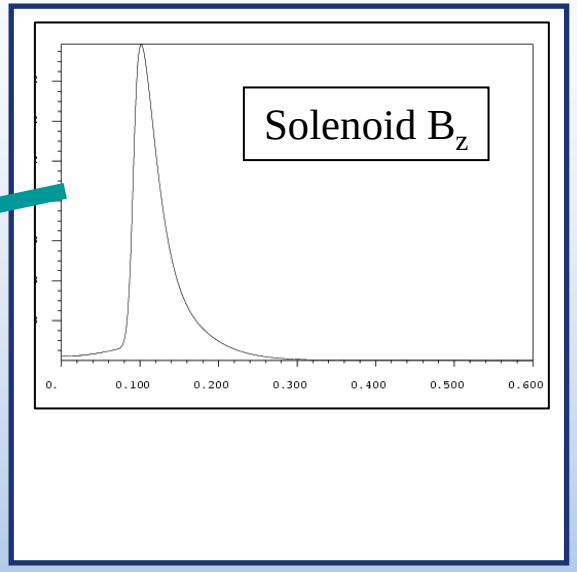


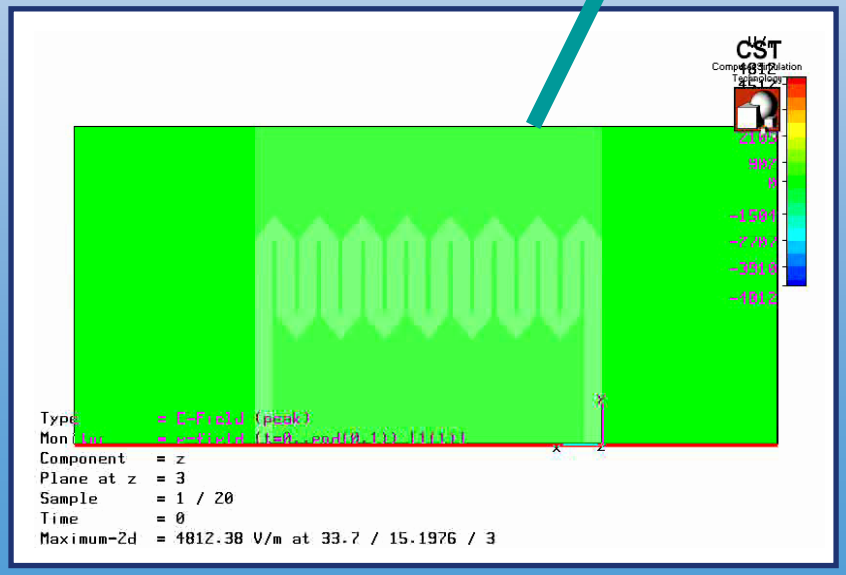


3D Field Modeling: Start-to-end





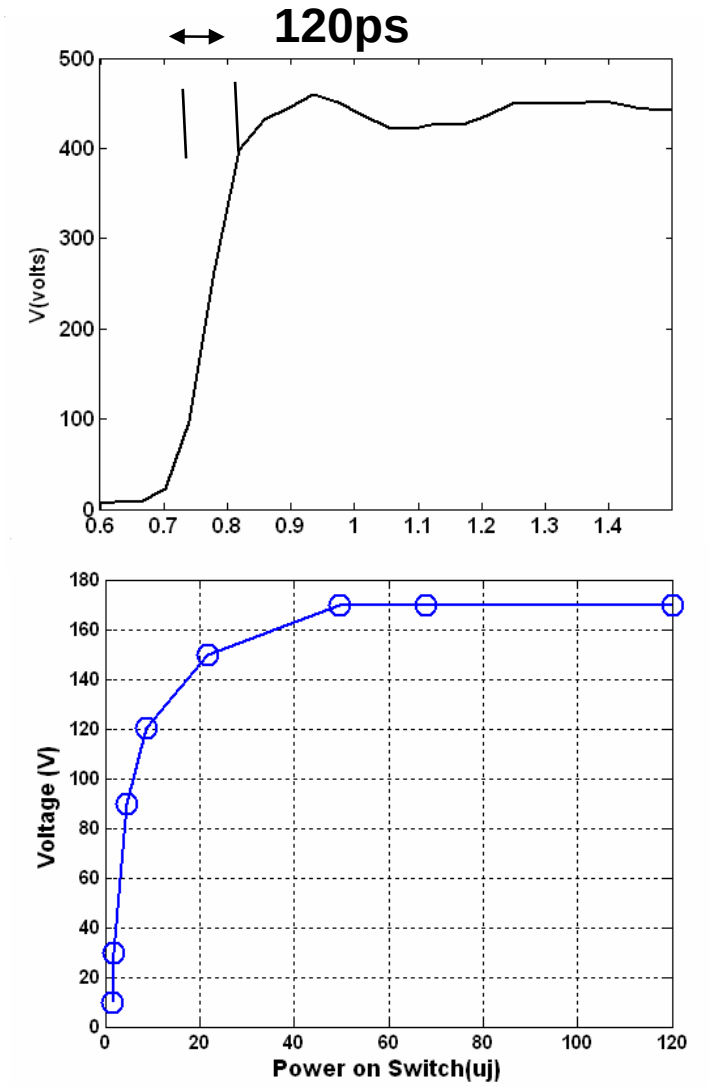




Developed in MAFIA environment

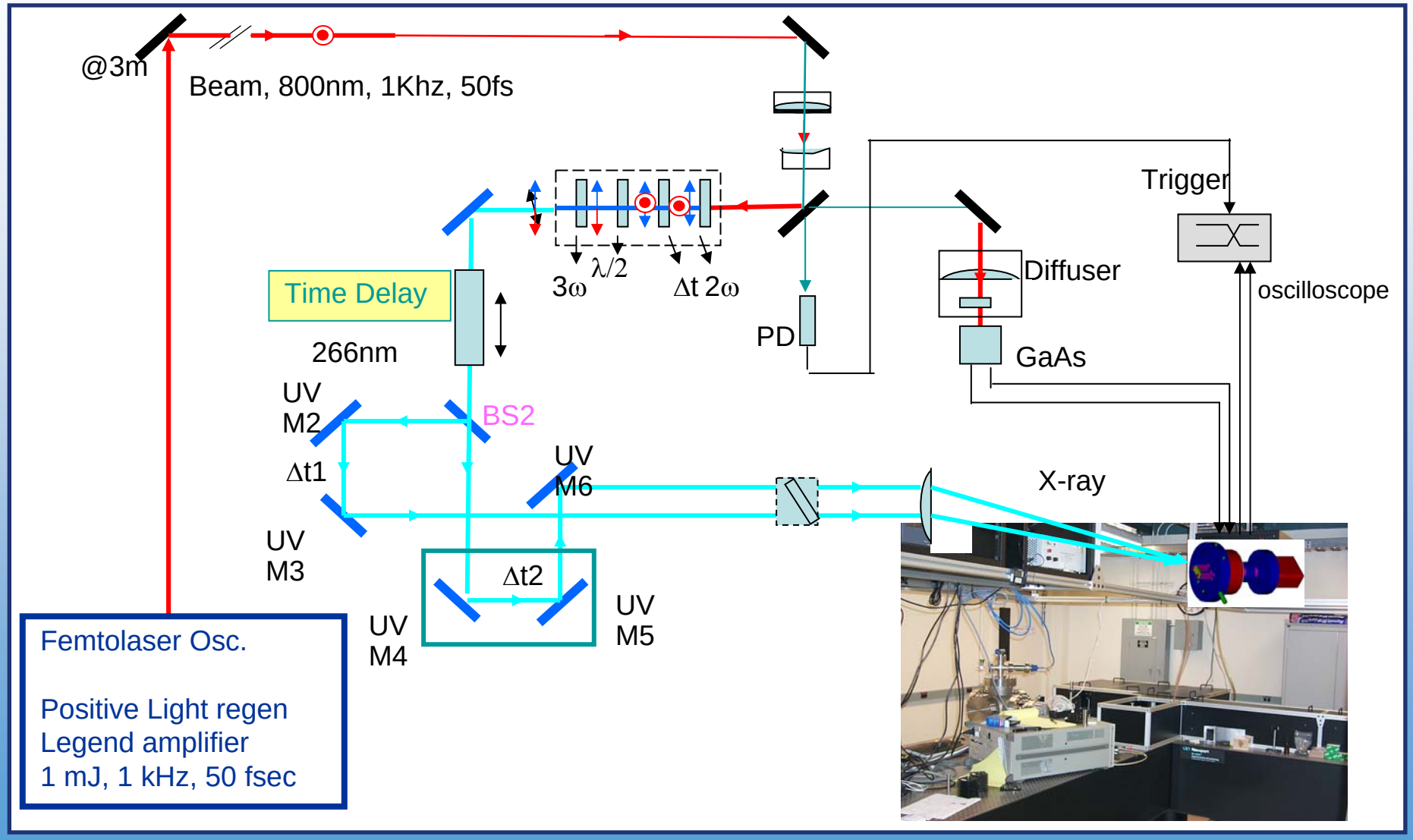
- Photocathode-anode
  - –User-defined initial SE distribution
  - –Velocity dispersion
  - –PIC space charge
- Deflector
  - –Full 3D time-dependent EM field representation
  - –User-defined input pulse
- Focussing system
  - –3D field map for magnetic or electric focussing
  - –Lens aberrations included

ALS-made PC Switch Performance

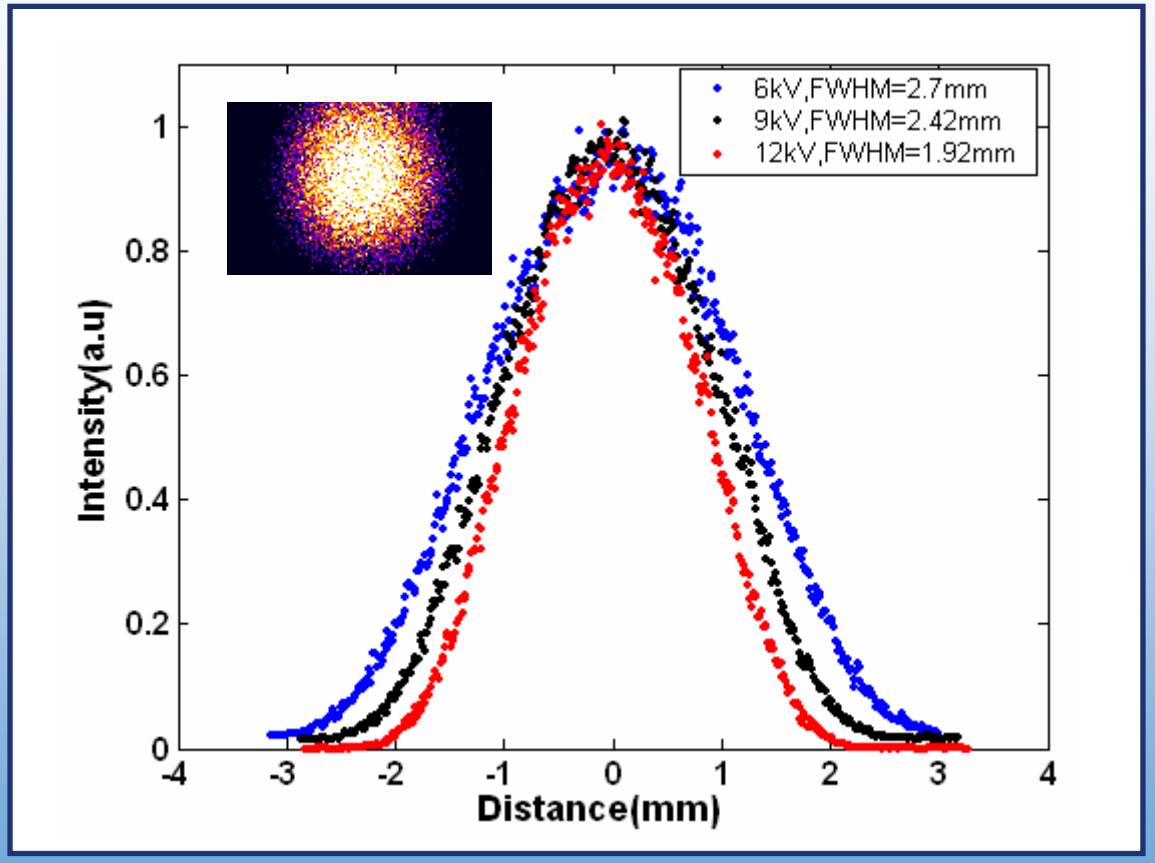


- Semi-insulating GaAs
  –fabricated in-house
- Reliable 1kHz, 5 KHz operation at 600V
- 10-90% ramp ~t-120-380 psec depending on cable length, switch mounting mechanism
- Switched efficiency ~75-90%
- Saturation regime laser power: 60uj

Optical Layout for Streak Camera Measurement



Unfocus Beam: Measuring Photoemission Electron Energy Width



Angle=sqrt(E/V)sin(pi/4)

Average: 0.54ev, Au Work function: 4.2ev, UV 4.7ev

Au surface quality

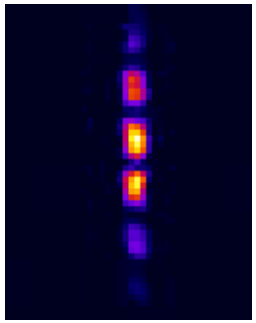
alignment

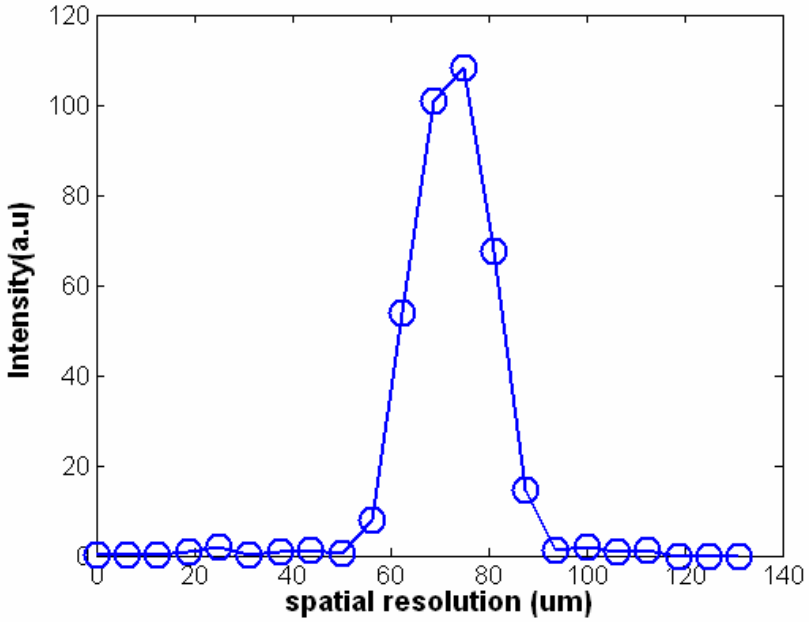
Static Mode: Basic Performance

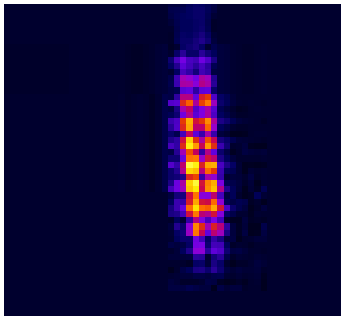
25um Au Cathode

12kev,mesh750lpl

Peroid:25um+8um

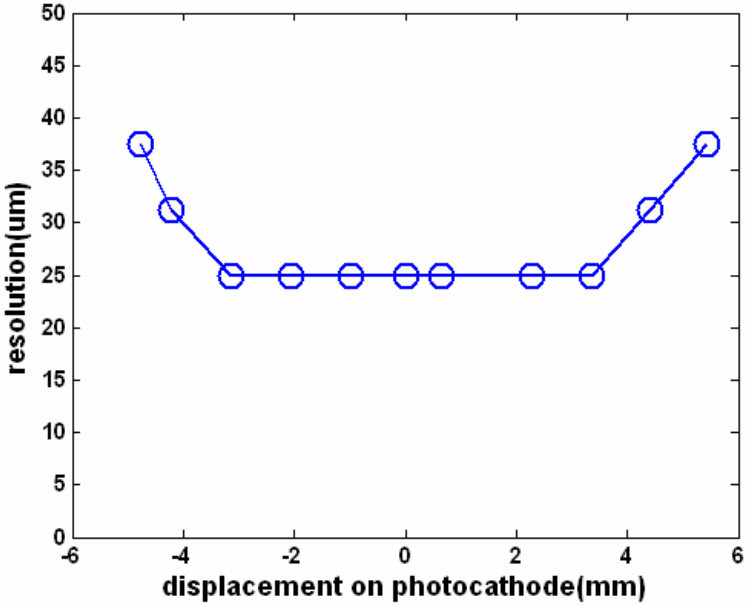






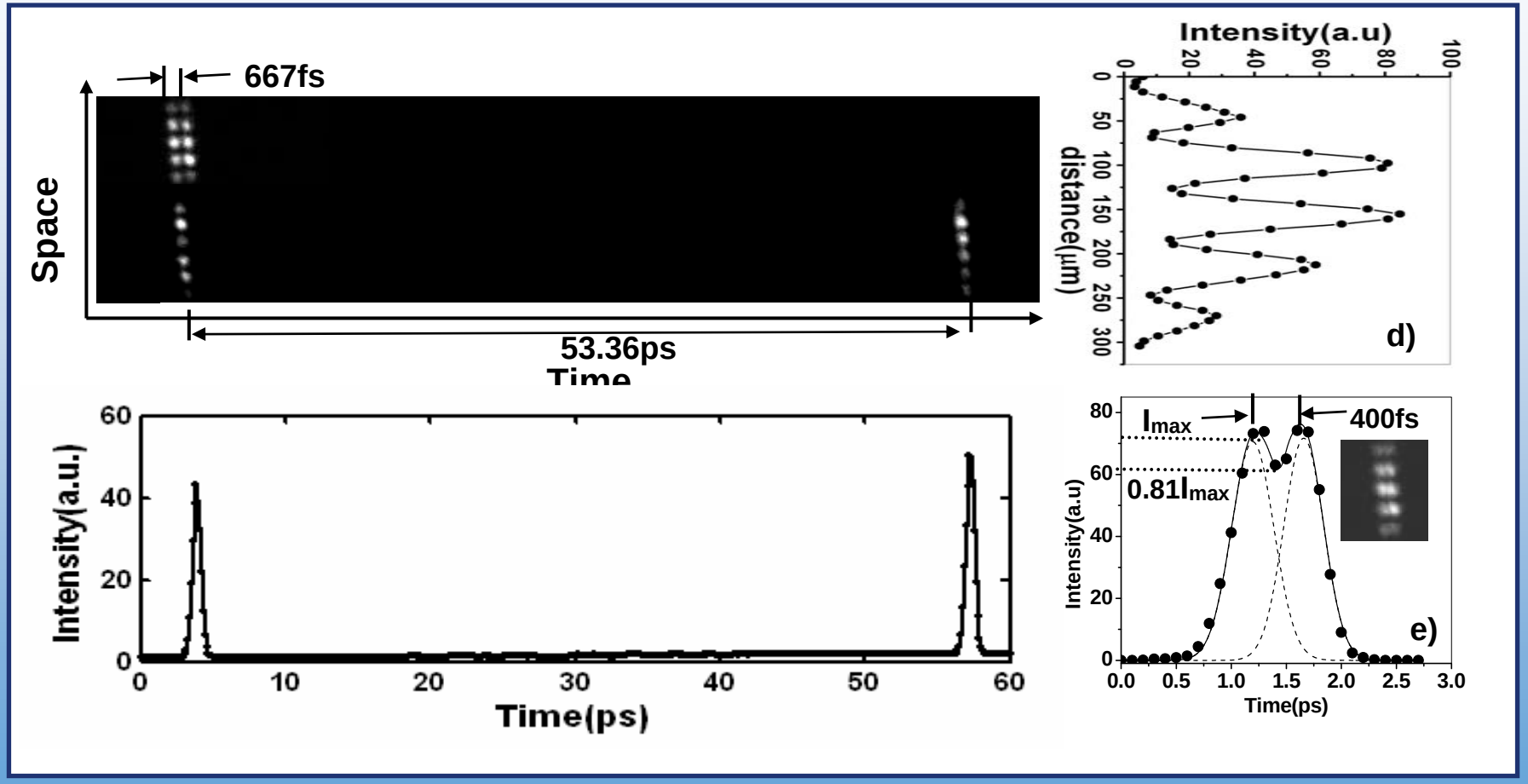
12kev,mesh1500lpl

11um+5.6um



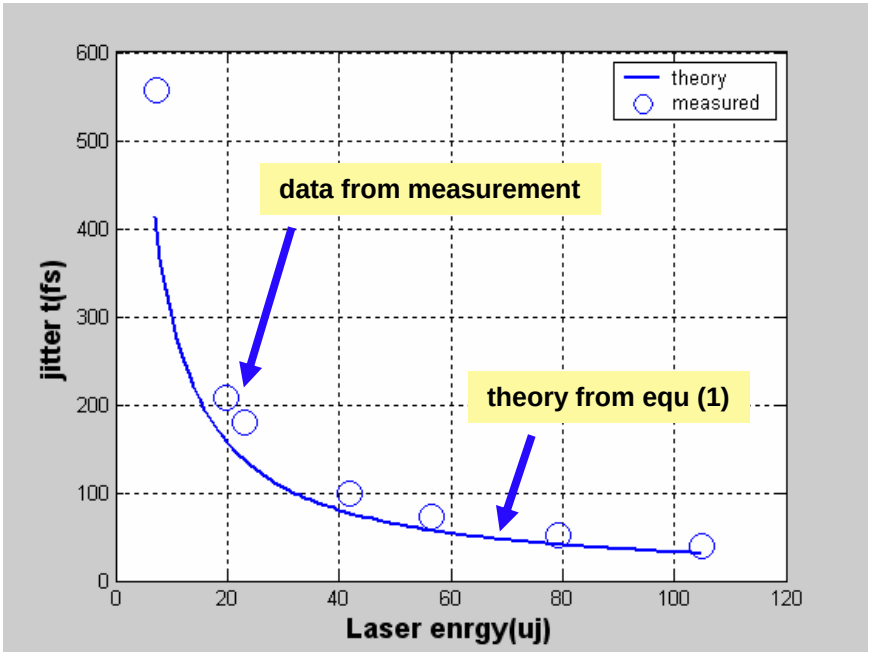
High Spatio-temporal Resolution in Accumulation Mode

25μm Au photocathde, 1000shots



1) Good resolution in both time and space
2) Lens using same current for static and dynamic mode
3) Maintain over 53ps range

Jitter Measurement

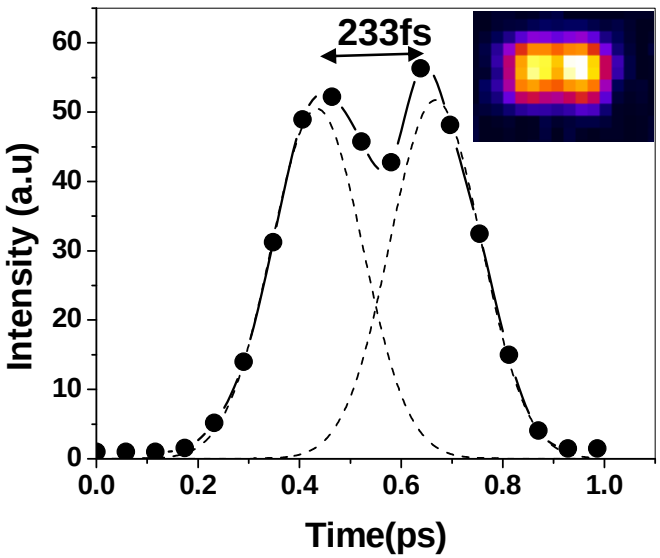


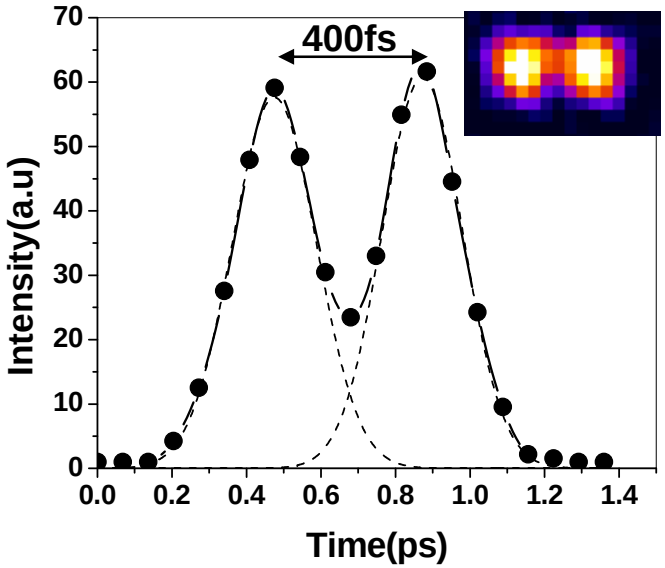
We have 60fs jitter

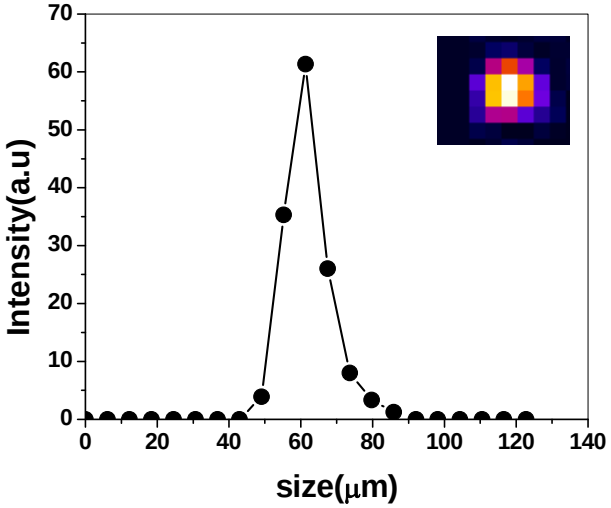
$$\tau_j = t_{ramp} \cdot \frac{\Delta E_L}{E_L} \cdot \frac{\alpha}{\alpha + 50\Omega \cdot E_L(\mu J)}, \quad (1)$$

where t_{ramp} is the combined rise time of the switch-generated ramping pulse and the deflection plates, $\Delta E_L/E_L$ is the shot-to-shot laser energy fluctuation, α is so called the sensitivity coefficient and E_L the incident laser energy.

World's Fastest Streak Camera







Time Domain Pulse Measurement: Michelson Interferometer

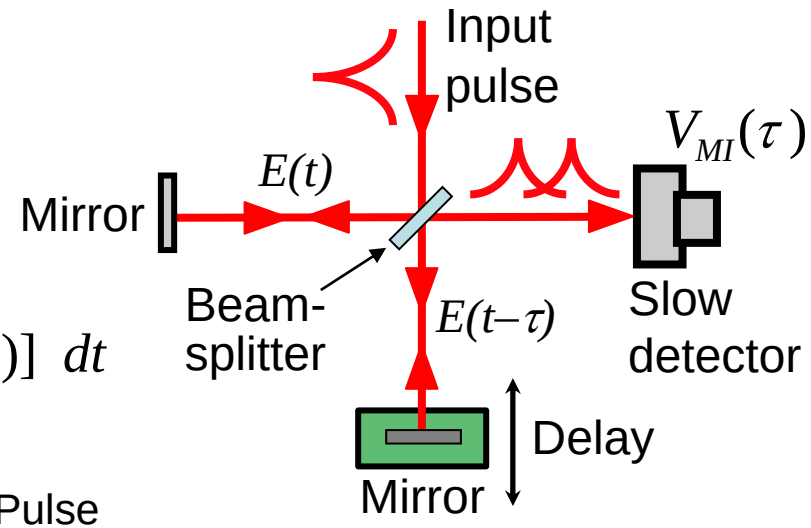
The detected voltage will be:

$$V_{MI}(\tau) \propto \int_{-\infty}^{\infty} \left|E(t) - E(t-\tau)\right|^2 dt$$

$$= \int_{-\infty}^{\infty} \left|E(t)\right|^2 + \left|E(t-\tau)\right|^2 - 2\,\mathrm{Re}[E(t)E^*(t-\tau)]\ dt$$

$$V_{MI}(\tau) \propto 2\int_{-\infty}^{\infty} \left|E(t)\right|^2 dt \longleftarrow \propto \text{Pulse energy}$$

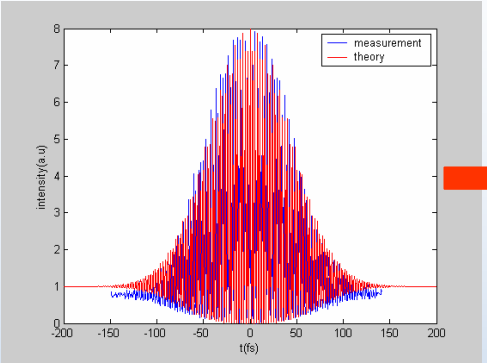
$$-\ 2\,\mathrm{Re}\int_{-\infty}^{\infty} E(t)E^*(t-\tau)\ dt \longleftarrow \text{“Interfer-ogram”}$$

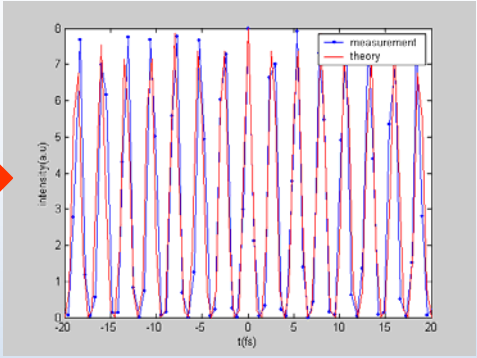


Two photons process:

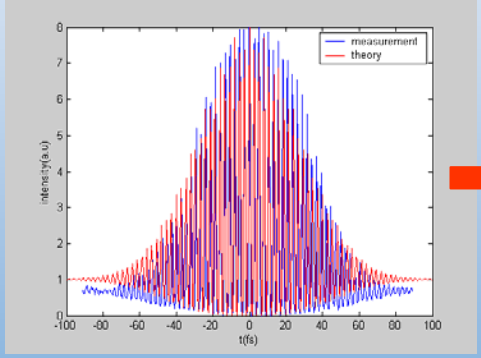
$$V^{2P}(\tau) = \int_{-\infty}^{\infty} \left|[E(t) - E(t-\tau)]^2\right|^2 dt$$

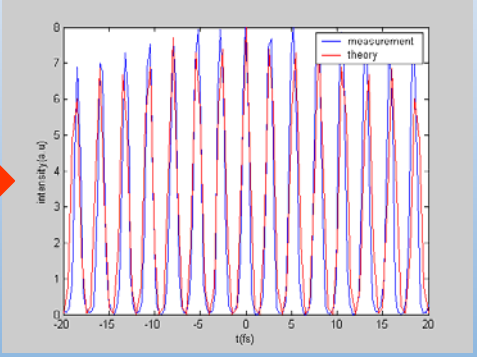
Pulse Measurement



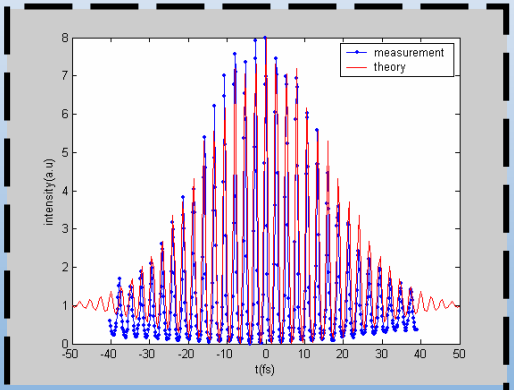


Gaussian: **94fs** in FWHM

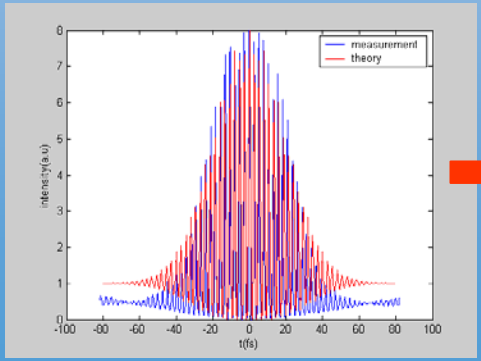


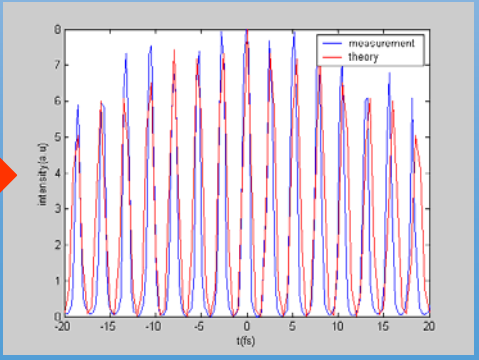


Gaussian: **60fs** in FWHM



Gaussian: **35fs** in FWHM





Gaussian: **42.3fs** in FWHM

Application: Ultrafast Magnetism Dynamics

What mechanisms and timescales are involved in ultrafast magnetization?

- using a laser field, using external magnetic field, using spin injection

Can we engineer new materials for ultrafast control of magnetization

- control by electric fields – eg. multiferroic materials

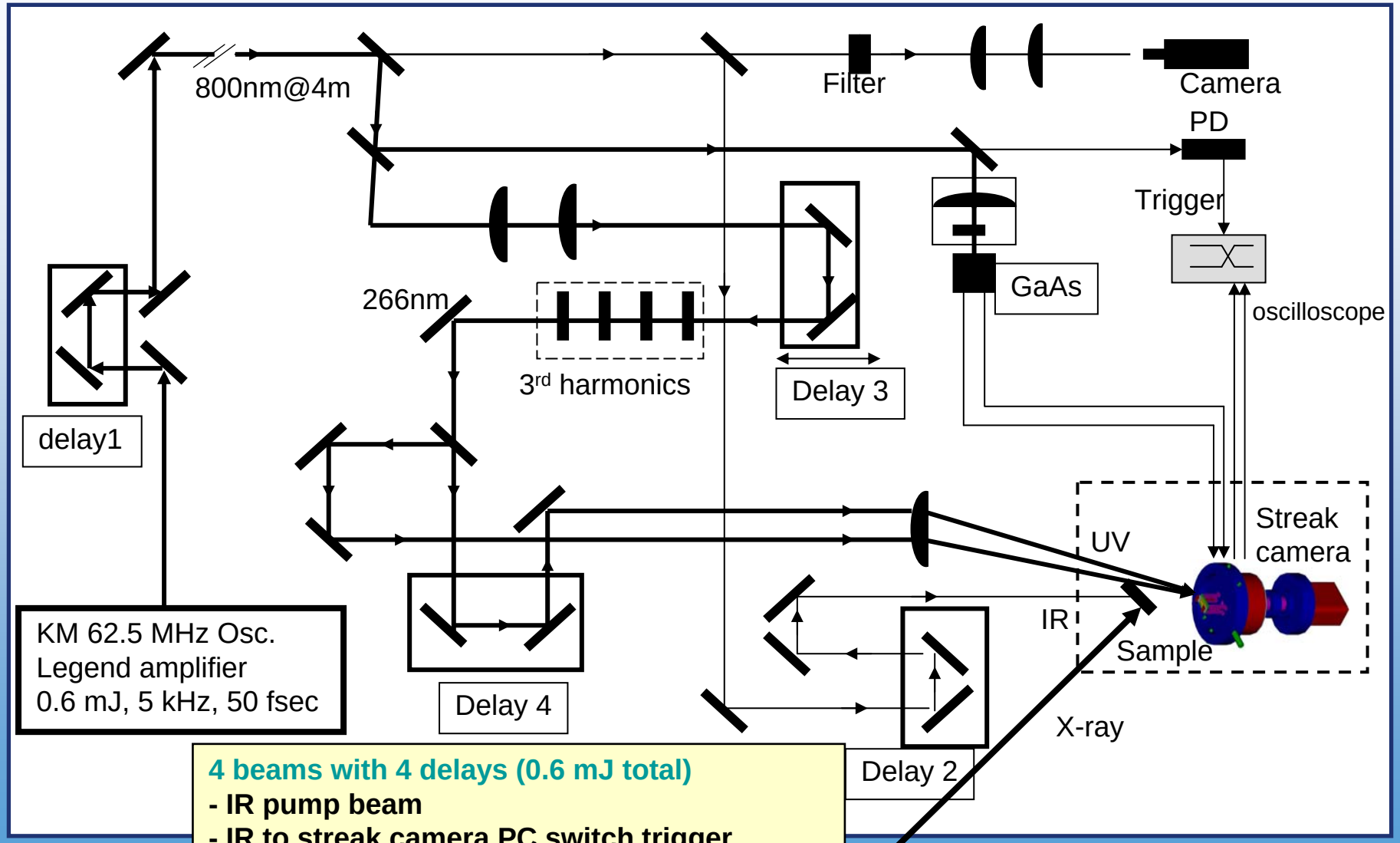
How does energy flow in a magnetic system when changing the magnetization?

- how is energy coupled from the field to the spin system to the lattice

The Key Tool: Time Resolved X-ray Magnetic Circular Dichroism (XMCD)

- psec temporal resolution
- can be allied with x-ray microscopy
- gives us information per element in a multi-element system
- gives us spin and orbital magnetic moments

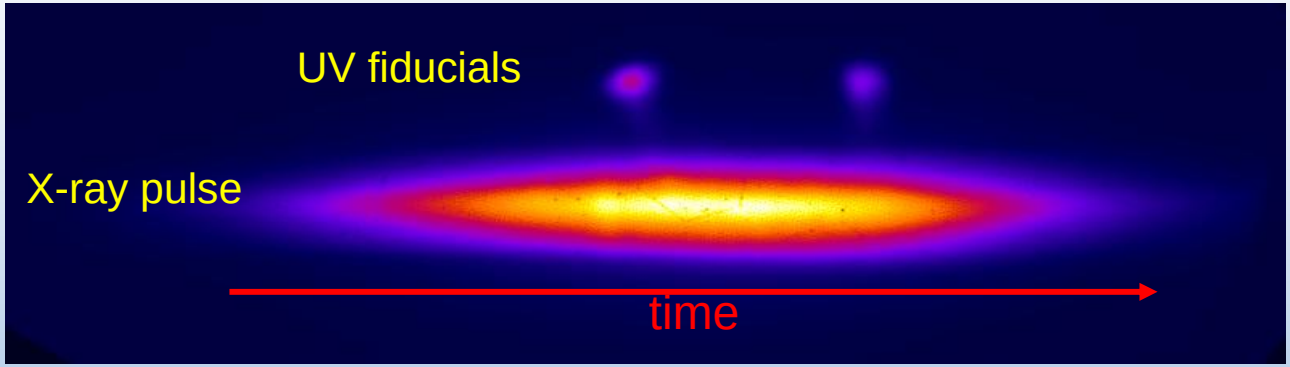
Optical Layout for Magnetism Dynamics Experiment



4 beams with 4 delays (0.6 mJ total)

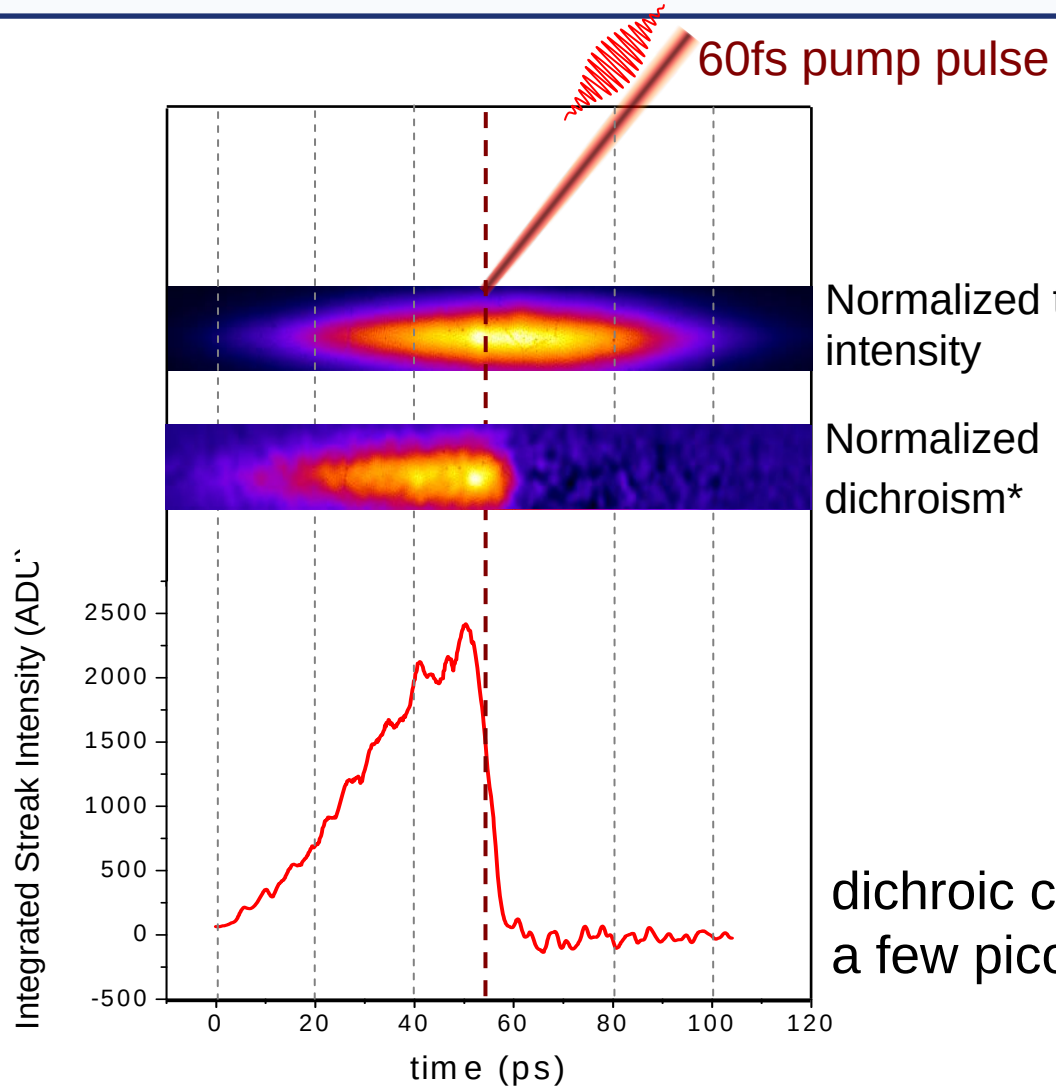
- **IR pump beam**
- **IR to streak camera PC switch trigger**
- **uv for temporal fiducial to photocathode**
- **uv for timescale calibration to photocathode**

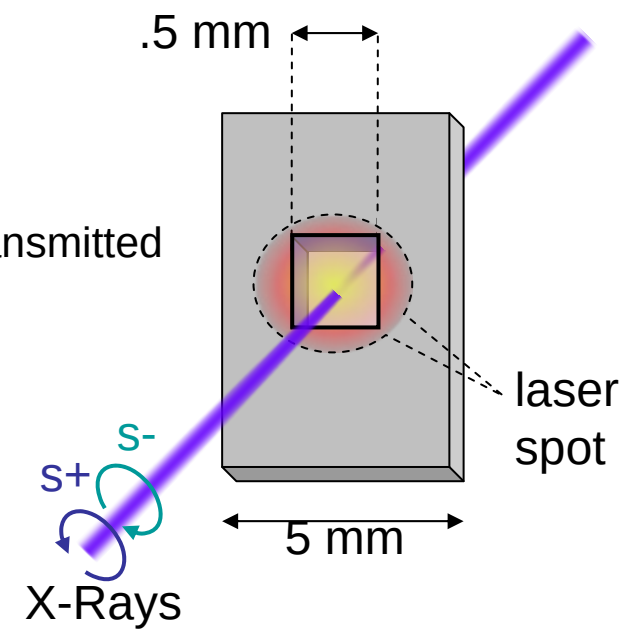
Streaked X-ray Pulse



- Entire 50 ps fwhm captured with every laser shot
- 5 kHz laser repetition rate
- 500 MHz x-ray pulse repetition rate

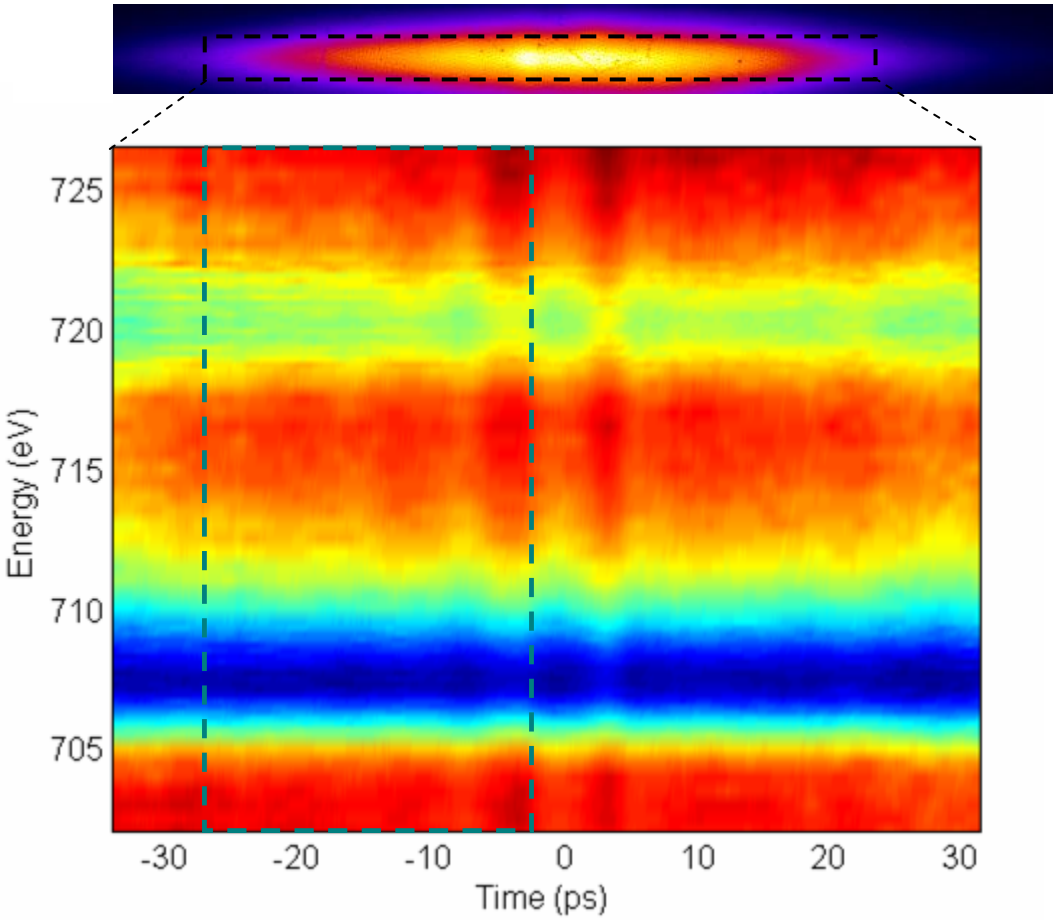
TR-XMCD: Fe L3 Edge



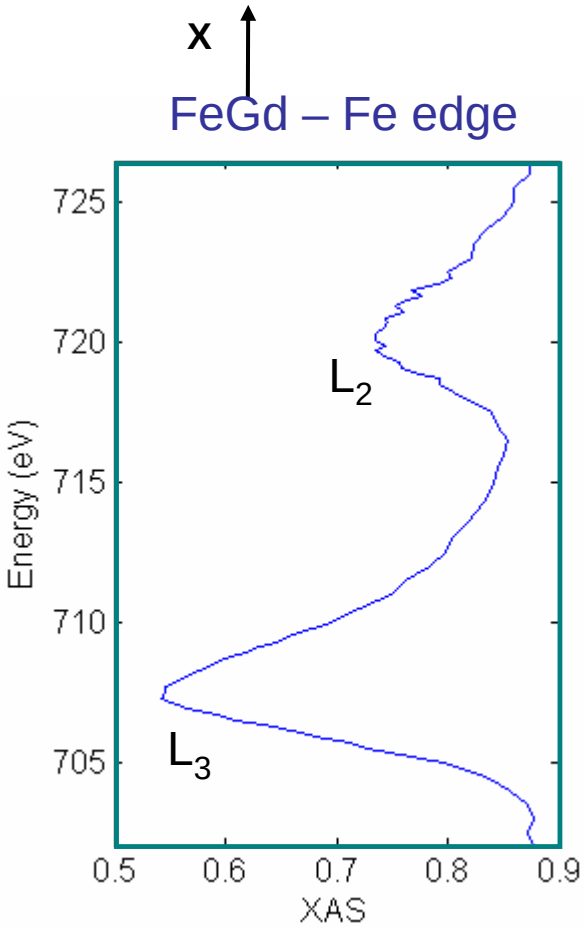


dichroic contrast is lost in a few pico-seconds

TR-XMCD Spectra Map

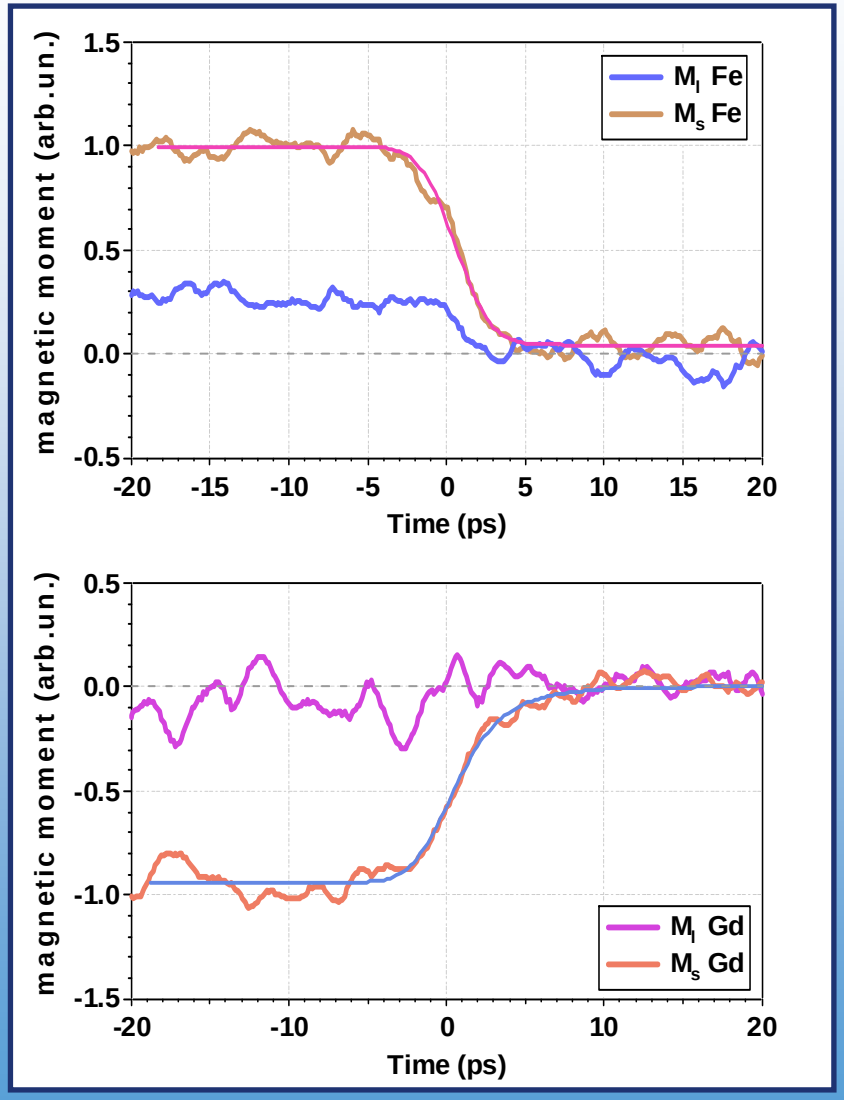


H = +20 mT, right photon polarization



Time-resolved absorption spectra obtained by combining streaks at different photon energy

Ultra-fast Magnetism Dynamics: FeGd



Simplified Sum Rules:

$m_s(Fe) \sim 3/2\ (L_3 - 2L_2)$

$m_l(Fe) \sim 2\ (L_3 + L_2)$

$m_s(Gd) \sim 3/2\ (M_5 - 3/2\ M_4)$

$m_l(Gd) \sim 3\ (M_5 + M_4)$

Gd orbital moment vanishes for all delay

no transient increase of orbital momentum

After Deconvolution:

Fe: $\tau = 1.1 \pm 0.7$ **ps**

Gd: $\tau = 2.4 \pm 0.3$ **ps**

Future Plan

- Short term
  - Pulsed high accelerating voltage
  - Robust photocathode
  - Faster switch and circuit
  - Slow sweep
  - Laboratory 6-9ev source
  - RSC optimization
- Long term

  New generation of ultrafast x-ray streak camera

  -correction of time chirp in accelerating area
  - Ultimate temporal resolution in the X-ray range

XFEL Application: Plasma Physics

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Heating of Thin Foils with a Relativistic-Intensity Short-Pulse Laser

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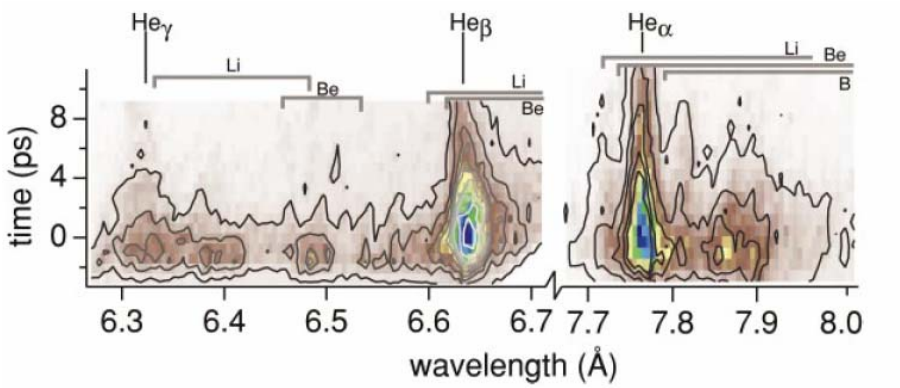
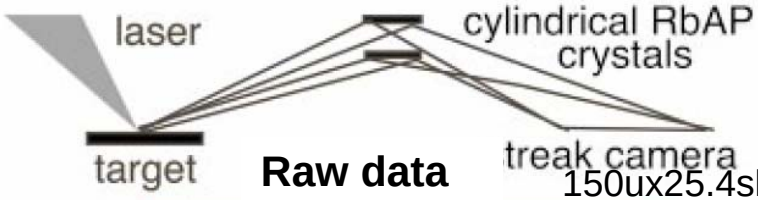
(Received 5 October 2001; published 11 December 2002)

processed data

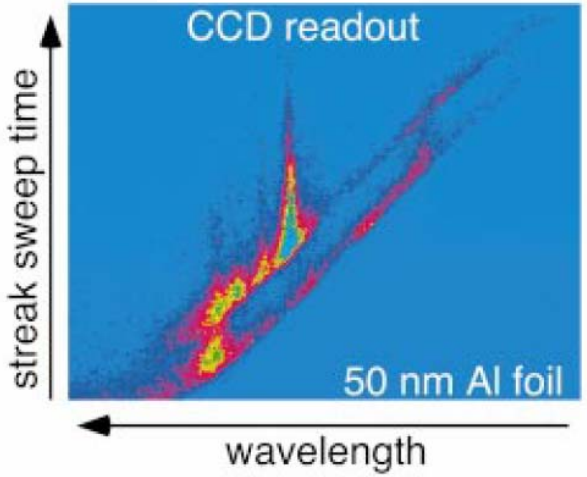


400nm, 150fs, 10^{19}w/cm^2, S-pol



Raw data

150ux25.4slit CsI



$1s^2$-$1s2p$

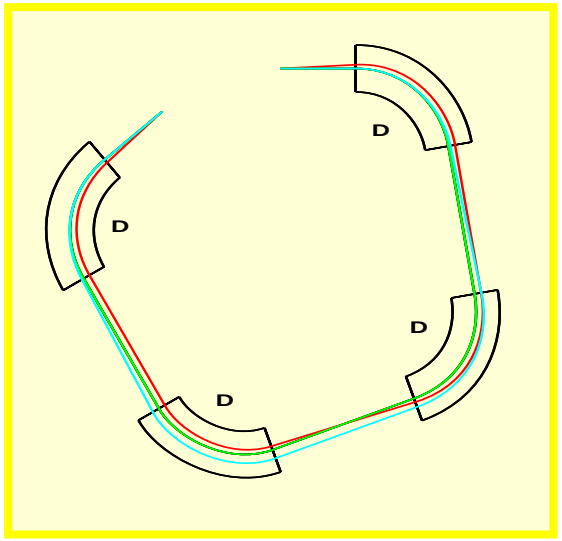
$1s^2$-$1s3p$

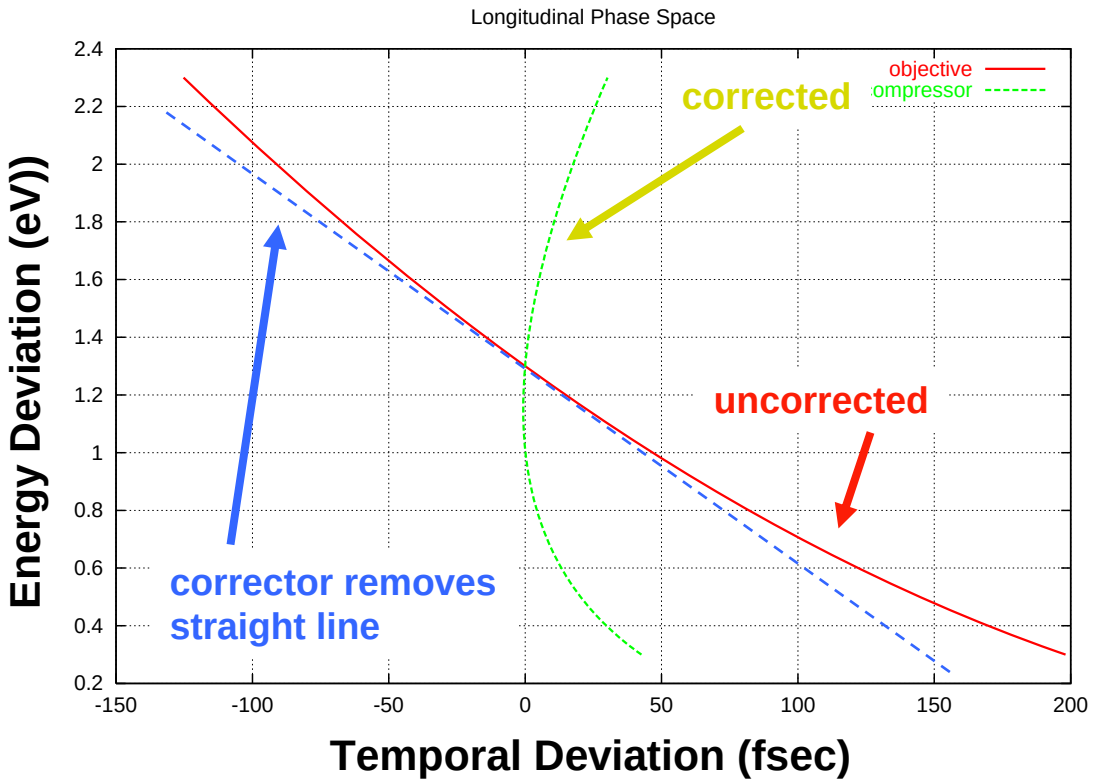
$1s^2$-$1s4p$

Two distinct phases: 500fs, No uniform, hot dense plasma observed, need XFEL

- Single shot ?
  - space charge limits # of electrons for a certain temporal resolution and accuracy
- Simultaneous spectroscopy
  - good imaging along slit needed; 2d high quality imaging

Dispersion Corrected Streak Camera

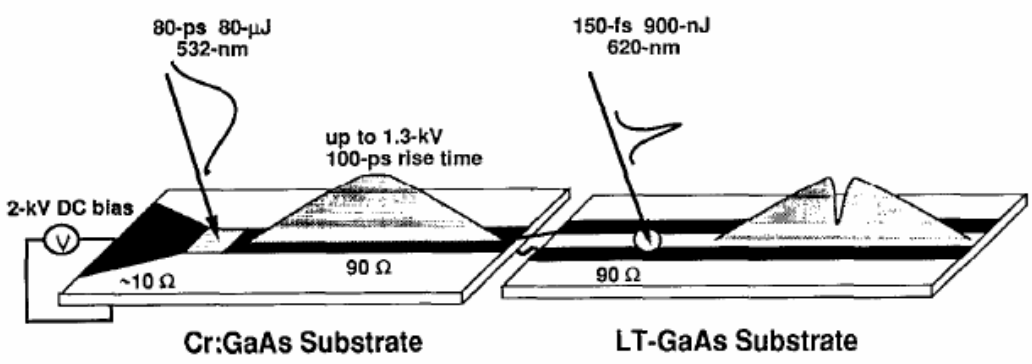


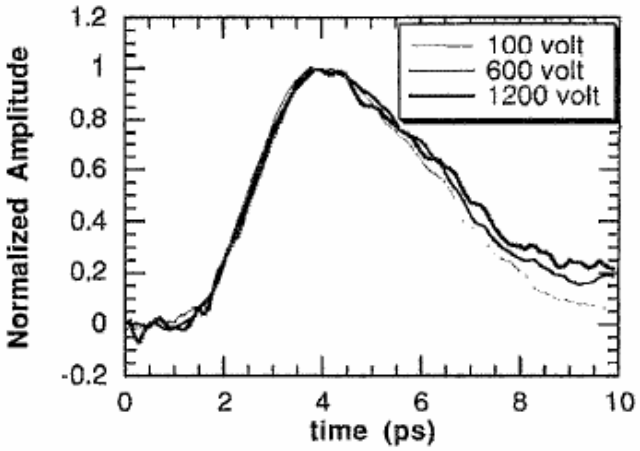


- 4 dipoles can be arranged to be double focusing, achromatic, zero angular time of flight dispersion and with defined dT/dE for correction
- < 50 fsec resolution from initial simulation!

Ultra-fast PC-switch

- Combine the high switching voltage of the larger chip with high switching speed of smaller chip
- 1.5mm switch operates in linear regime to bias 100u strip line
- Works by pulse biasing the smaller chip for shorter times than required for breakdown
- 1.4 ps rise times
- Switching of up to 1.3kV
- Efficiencies of 60-70%
- Rise time independent of electric field





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K.Opachich, G.Huang, M.Greaves
A.Comin, A.Bartelt, Christopher, W.Wan

Not in Picture:
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C.Weber, K. Engelhorn

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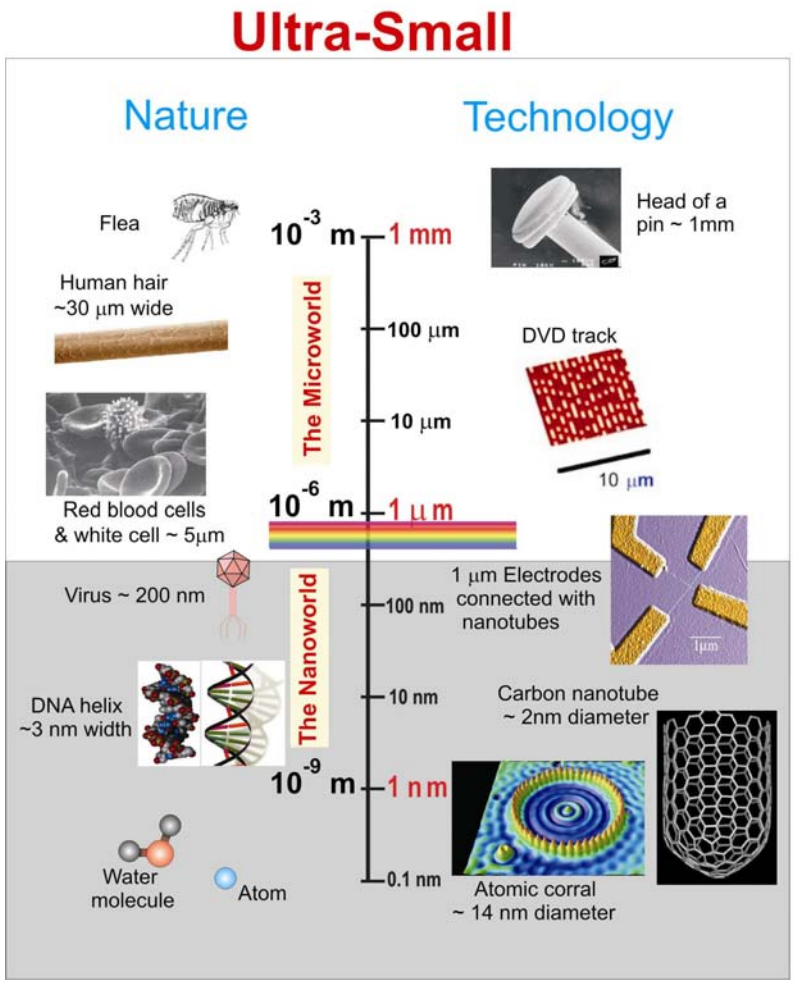
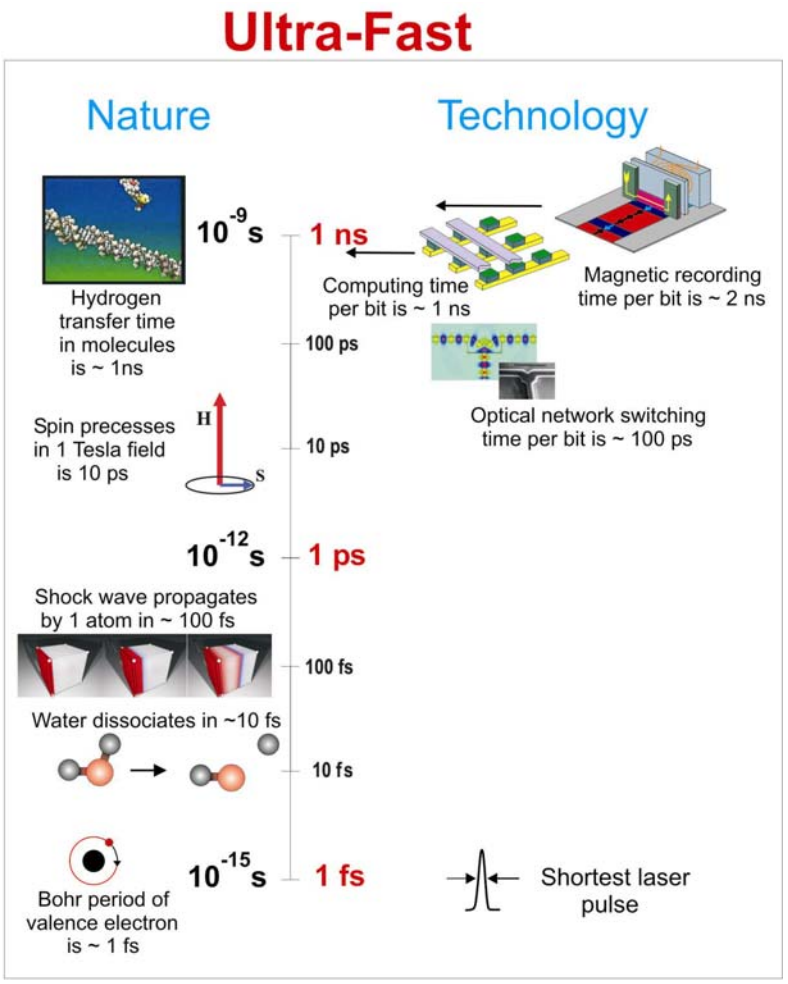
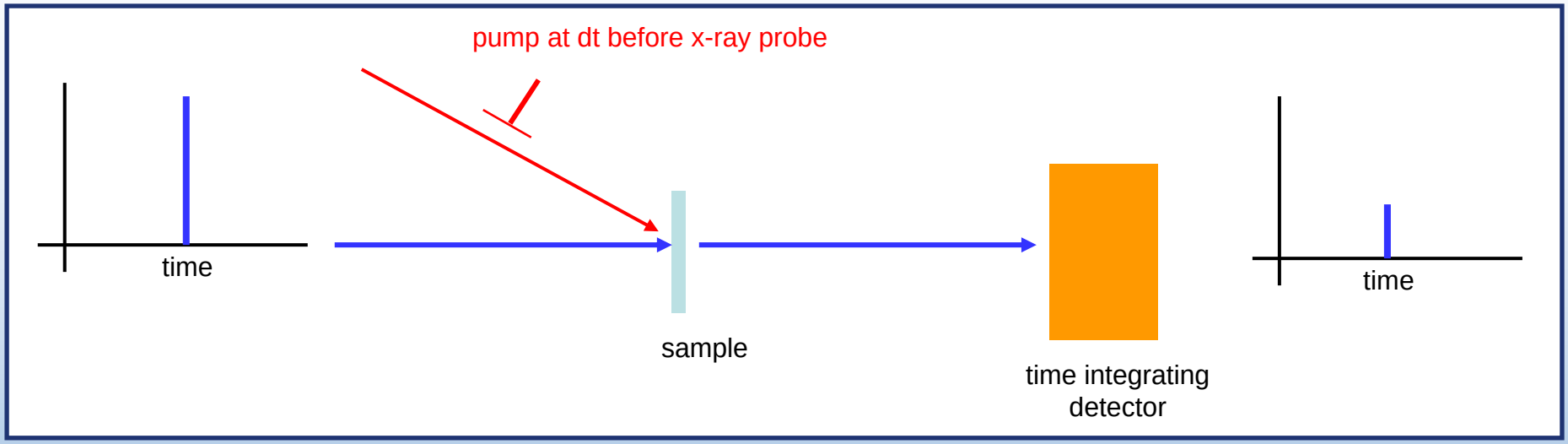
Introduction

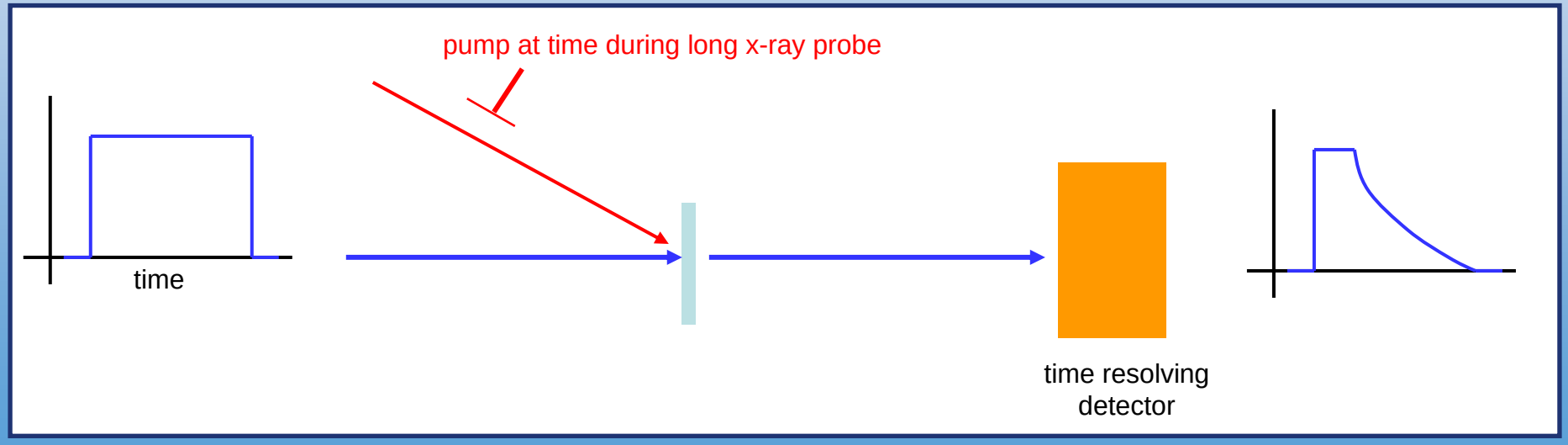
Front field: study the ultra small and ultra fast worlds





Ultra-fast X-ray Measurements





ALS Streak Camera Program

Transmission streak camera:

- Providing ultrafast magnetic dynamics study
- improving temporal resolution

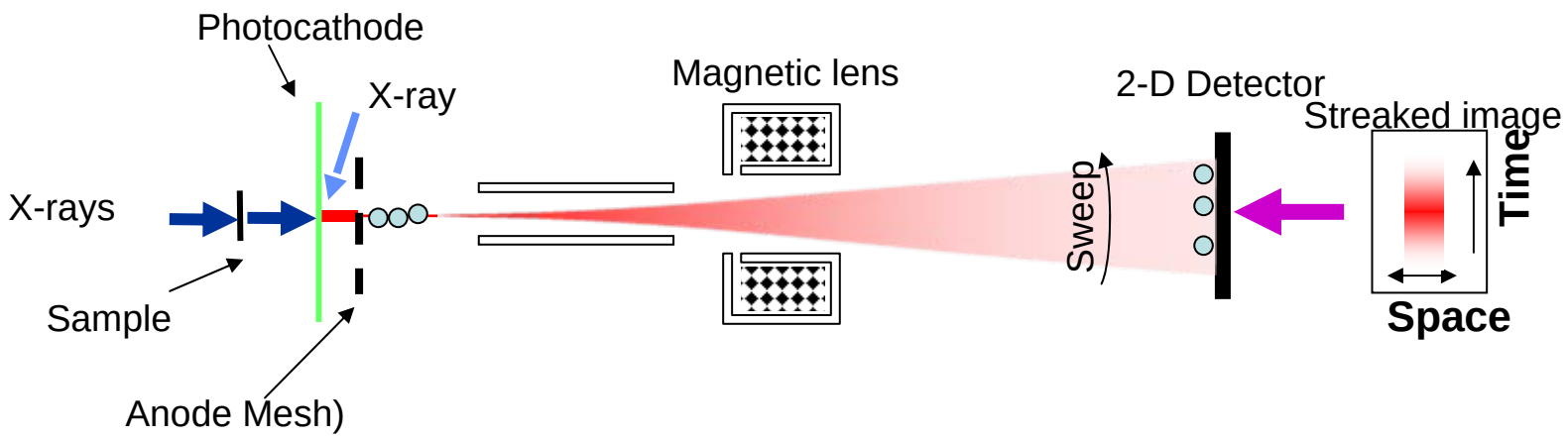
Reflection streak camera:

- Slicing diagnostic and related experiment

Dual-sweep streak camera

- Photocathode: Radiation-hard, alignment, high voltage, 25μm,10μm
- Photo-conductive switch: fabrication technique, mounting mechanism, fast rise-time,
- Electron optics: large FOV, reducing fringe field
- Meander-plate: increase sweep speed, dv/dt, deflection aberration
- Start-to-end modeling

Ultrafast Detector: Streak Camera Principle

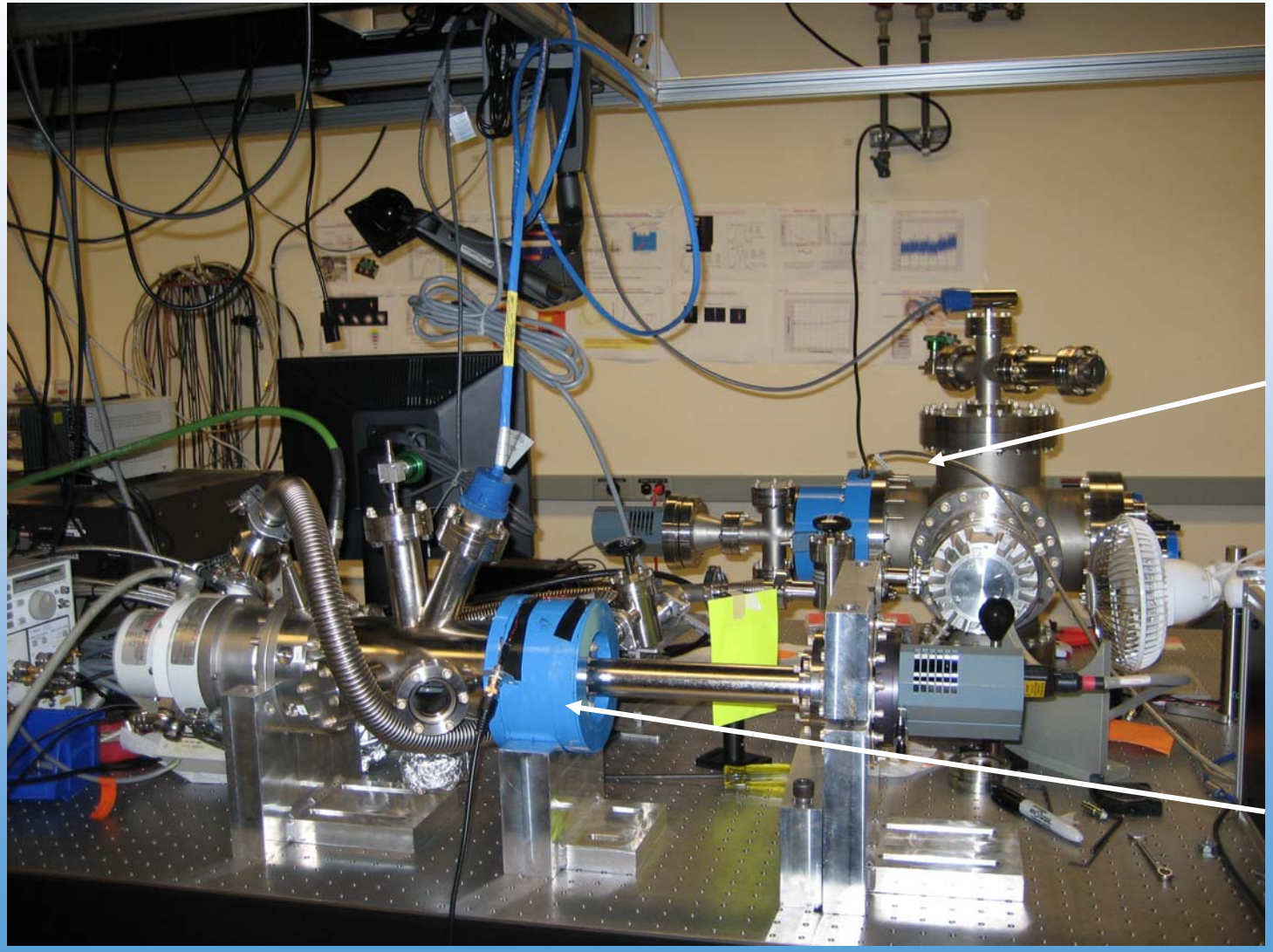


Convert fast time information into space information that can be recorded on an area detector

Features:

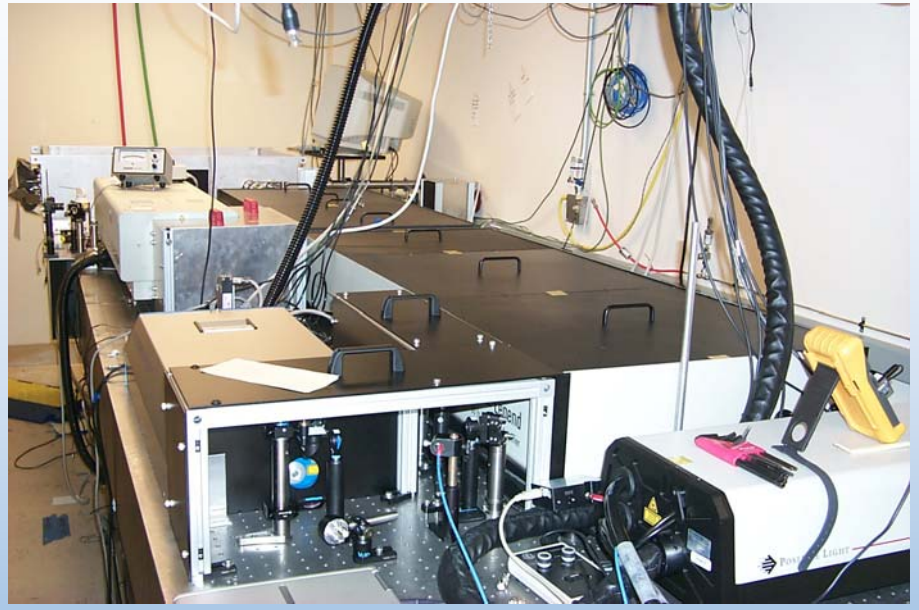
- good temporal resolution (at present psec, could be 100 fsec or better)
- records the whole temporal response (ps-ns)
- wide photon energy range 10ev to 10kev
- in principle could be used to record the temporal and spectrum simultaneously

ALS Ultrafast Streak Camera R&D Lab



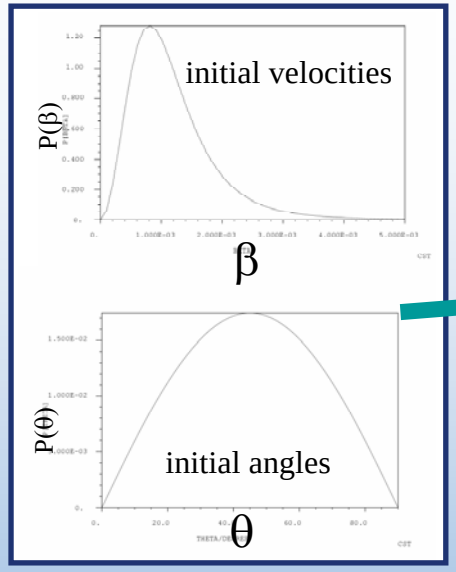
Ti:sapphire fs Laser Systems

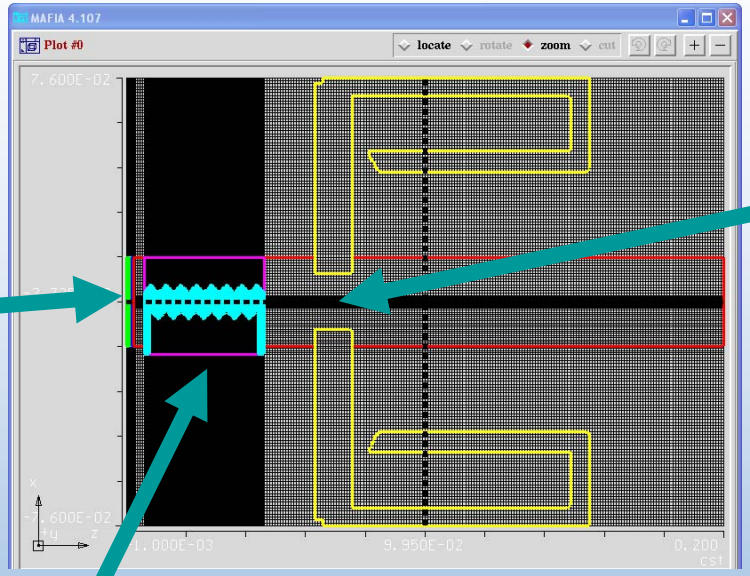
Femto-laser Oscillator
Positive Light Legend Laser:
30 fsec, 1 mJ / pulse, 1 KHz

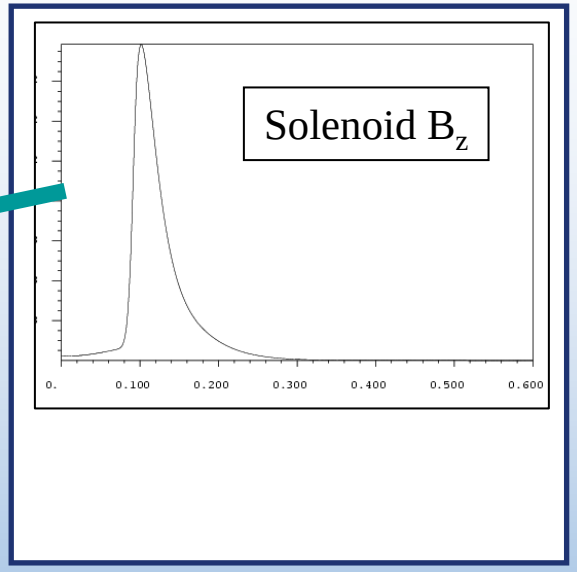


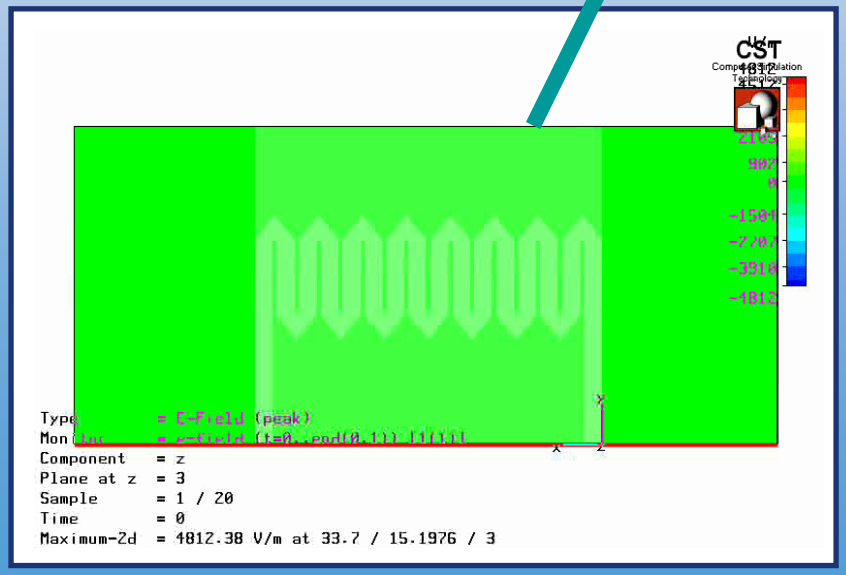
KMlab 62.5 MHz oscillator
Positive Light Legend Laser:
30 fsec, 0.6 mJ / pulse, 5 KHz

3D Field Modeling: Start-to-end







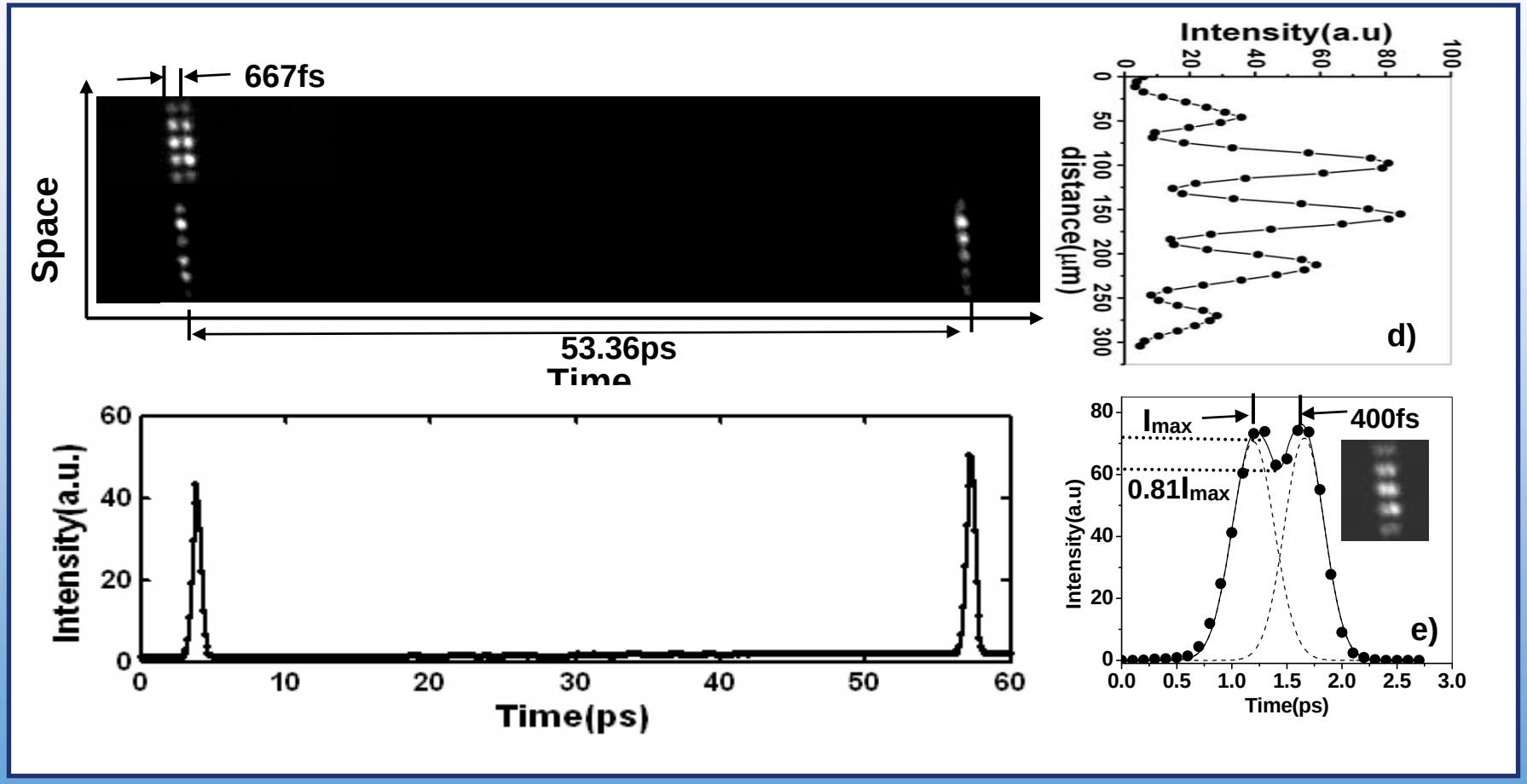


Developed in MAFIA environment

- Photocathode-anode
  - –User-defined initial SE distribution
  - –Velocity dispersion
  - –PIC space charge
- Deflector
  - –Full 3D time-dependent EM field representation
  - –User-defined input pulse
- Focussing system
  - –3D field map for magnetic or electric focussing
  - –Lens aberrations included

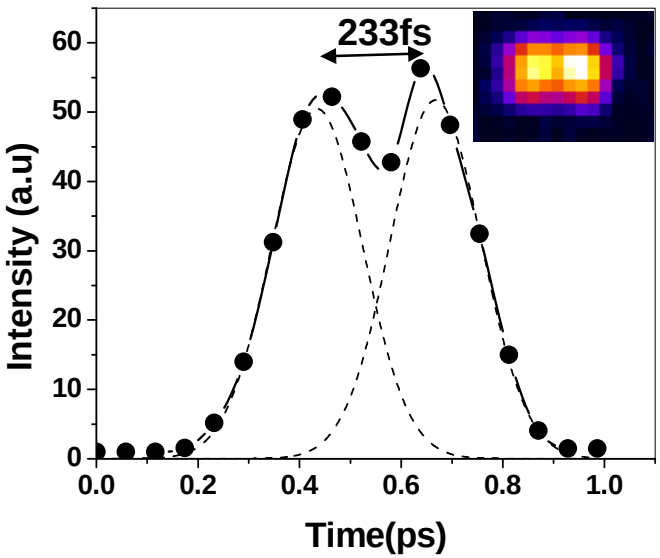
High Spatio-Temporal Resolution in Accumulation Mode

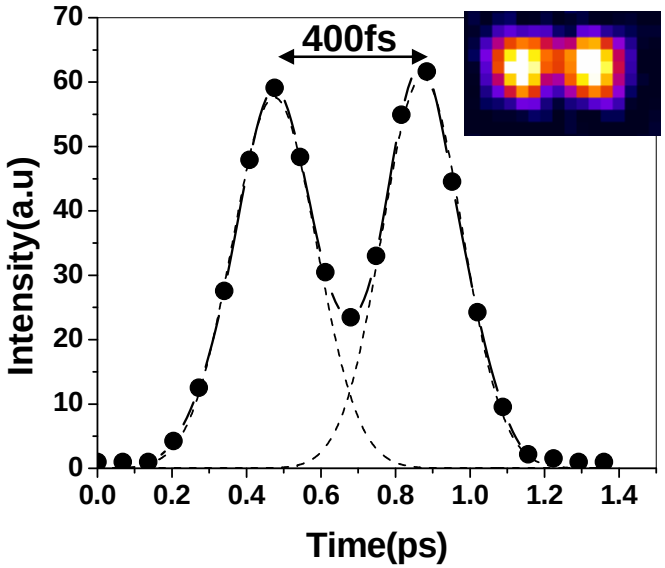
25μm Au photocathde, 1000shots

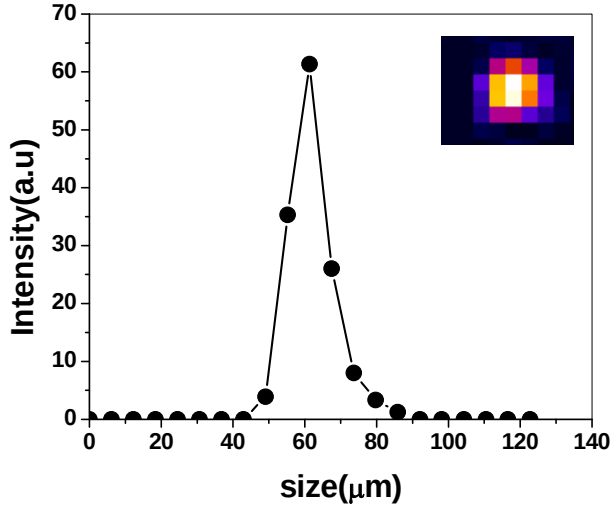


1) Good resolution in both time and space
2) Lens using same current for static and dynamic mode
3) Maintain over 53ps range

World's Fastest Streak Camera







Application: Ultrafast Magnetism Dynamics

What mechanisms and timescales are involved in ultrafast magnetization?

- using a laser field, using external magnetic field, using spin injection

Can we engineer new materials for ultrafast control of magnetization

- control by electric fields – eg. multiferroic materials

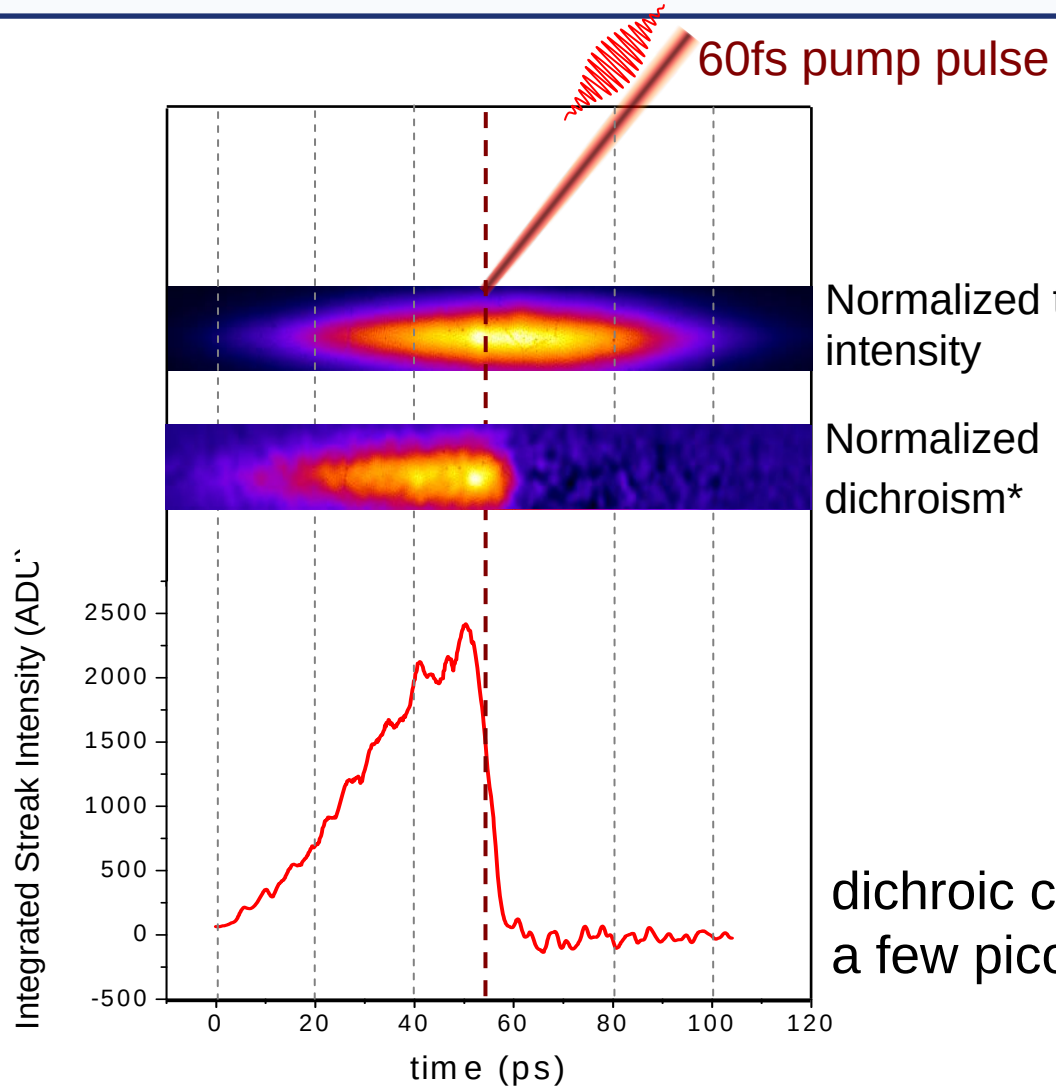
How does energy flow in a magnetic system when changing the magnetization?

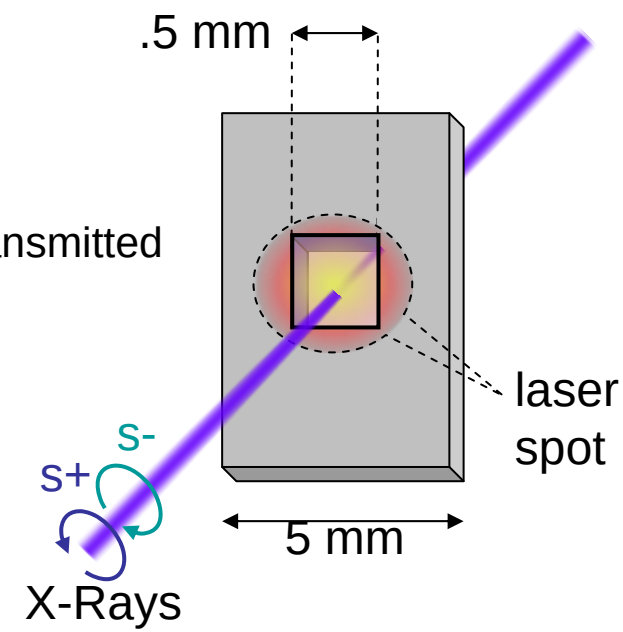
- how is energy coupled from the field to the spin system to the lattice

The Key Tool: Time Resolved X-ray Magnetic Circular Dichroism (XMCD)

- psec temporal resolution
- can be allied with x-ray microscopy
- gives us information per element in a multi-element system
- gives us spin and orbital magnetic moments

TR-XMCD: Fe L3 Edge

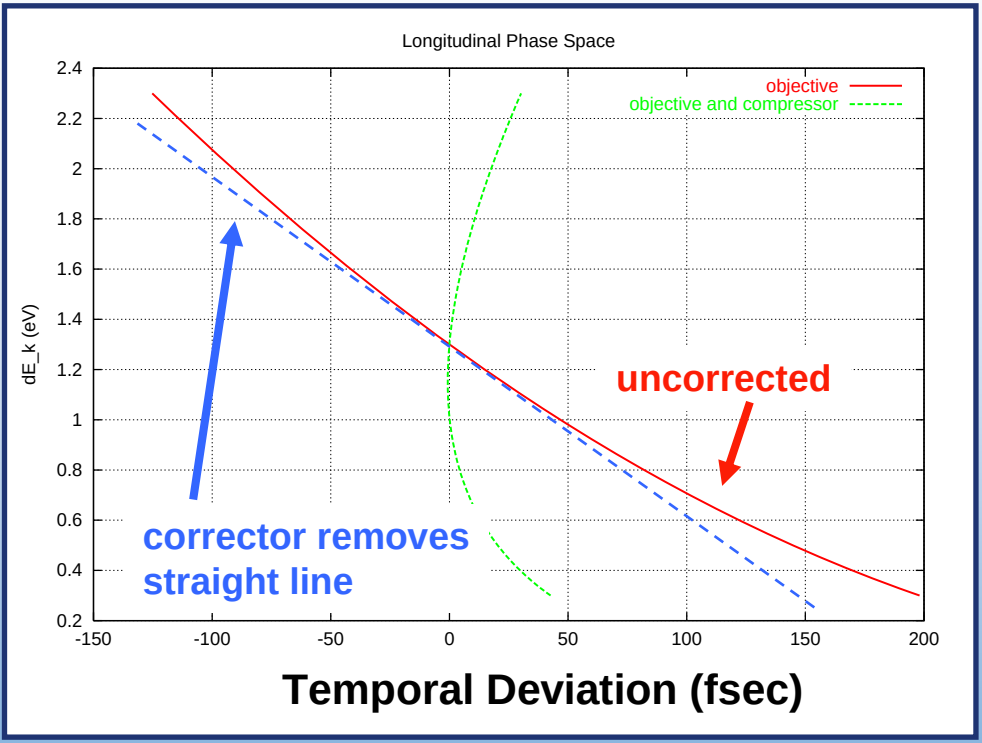




dichroic contrast is lost in a few pico-seconds

Future Plan

- Short term
  - Pulsed high accelerating voltage
  - Robust photocathode
  - Faster switch and circuit
  - Slow sweep
  - Laboratory 6-9ev source
  - RSC optimization
- Long term

  New generation of ultrafast x-ray streak camera

  -correction of time chirp in accelerating area
  - Ultimate temporal resolution in the X-ray range