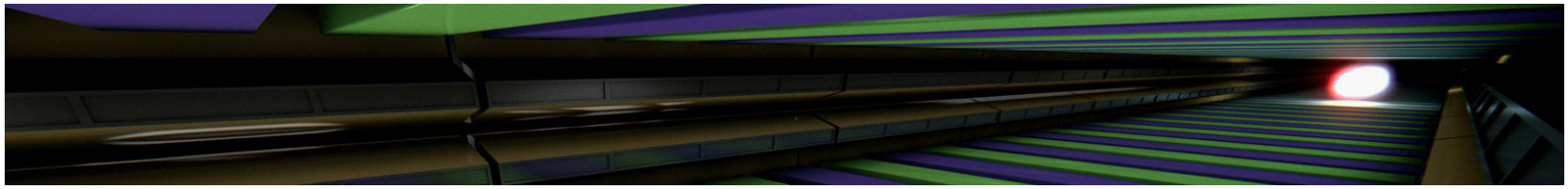
European XFEL



Dichroism in the two-color multi-photon ionization of helium

Michael Meyer

SQS Scientific Instrument

European XFEL, Hamburg, Germany

Science@FEL_2014

PSI, Villingen, September 15-17, 2014

Outline

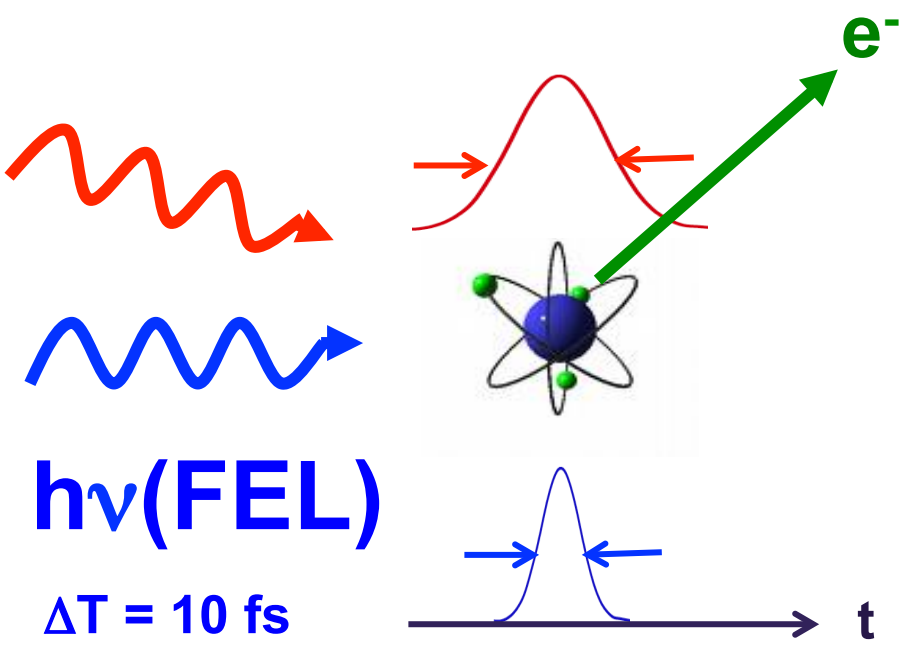
- **Introduction**
  - Two-color (XUV-FEL + Optical Laser) photoionization
  - Circular Dichroism (CD) in the photoionization
- **Two-color two-photon Photoionization**
  - CD for FEL beam diagnostics
- **Two-color multi-photon Photoionization**
  - CD for studying photoionization dynamics
- **Two-color resonant multi-photon Photoionization**
  - CD for characterizing intermediate states
- **Summary**

Atomic Photoionization dynamics

Optical laser (800 nm)

100 fs, 1 mJ, 100 μm
> 10^{12} W/cm^2

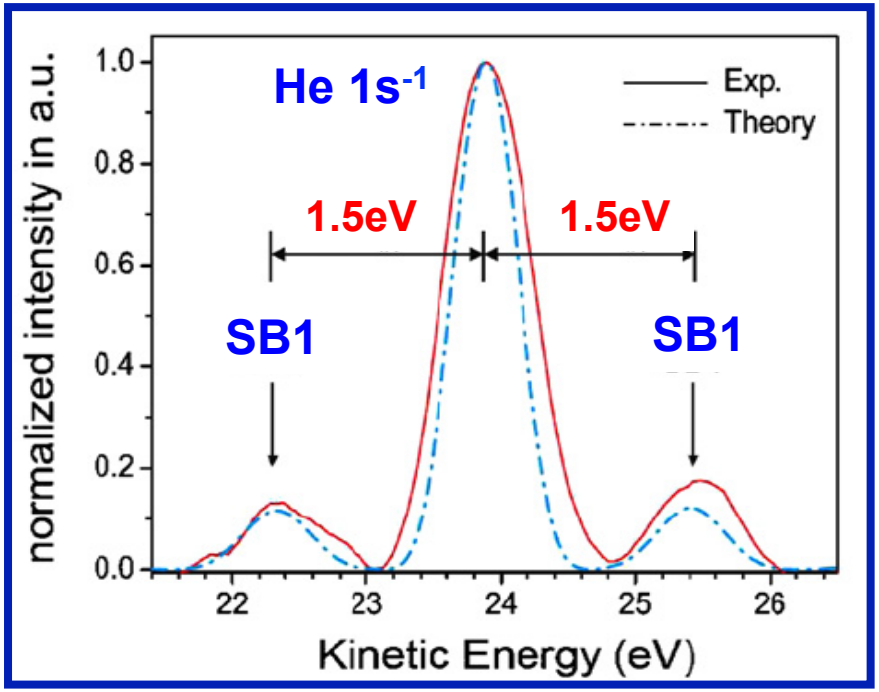
ΔT = 10 fs



Atom = Multi-Electron System

Electron interactions

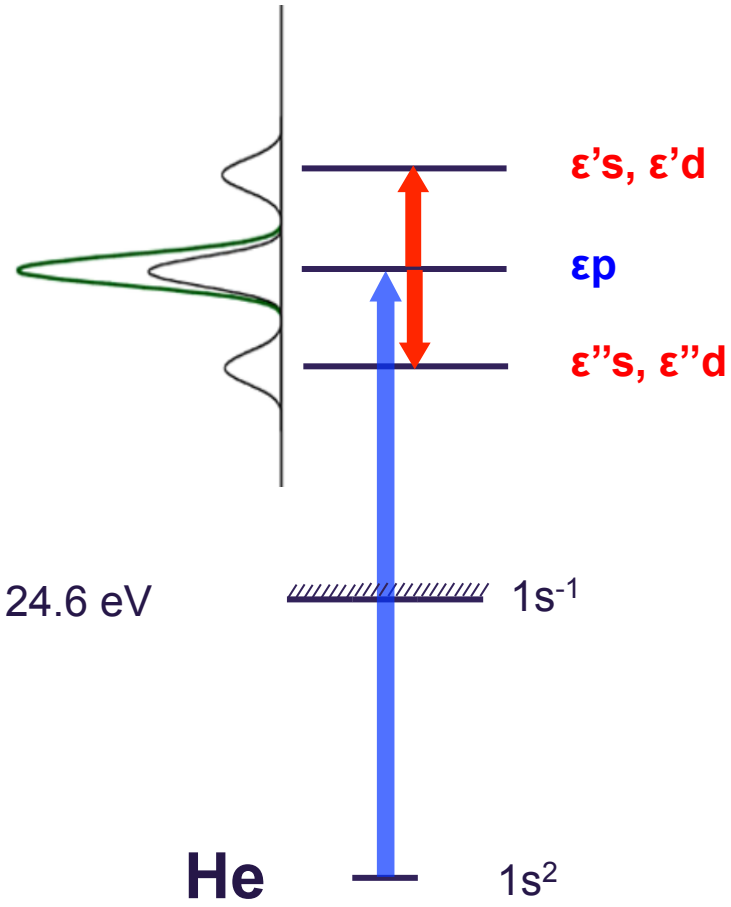
Relaxation processes

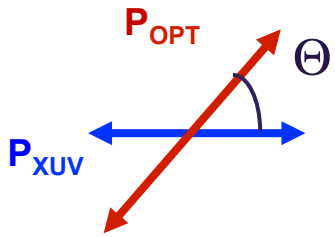


Theory: Maquet, Taieb, J. Mod. Opt. 54, 1847 (2007)

Dichroism in the photoionization

2-color Above Threshold Ionization

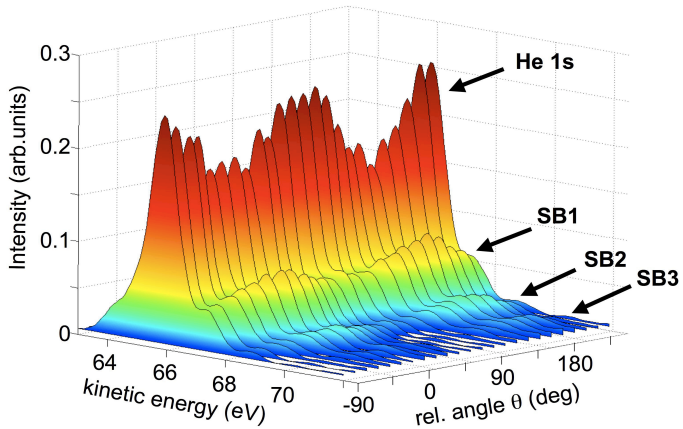




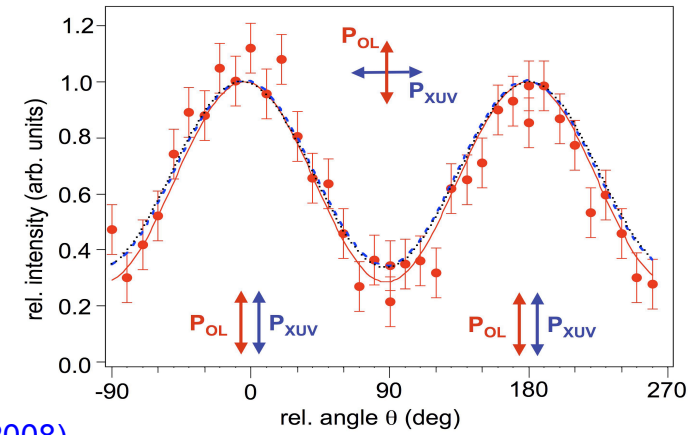
Determination of Partial waves

Linear Dichroism

FLASH



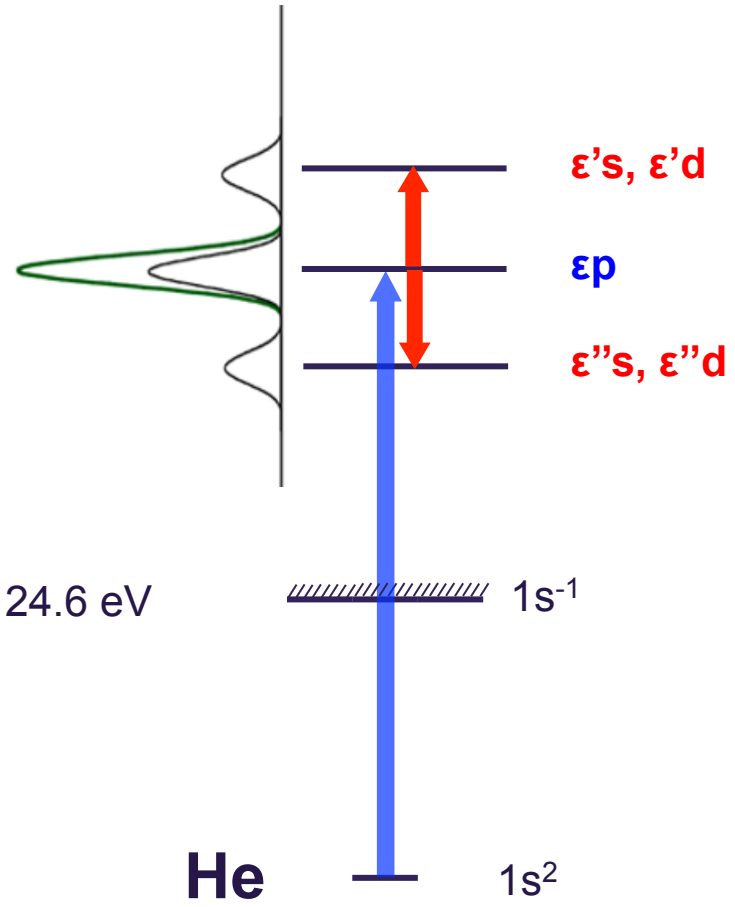
$$\sigma(\theta) = 3S_d + (5S_s + S_d)\cos^2\theta$$

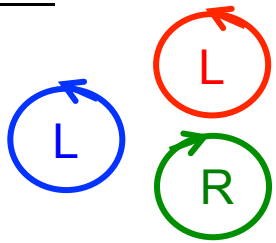


Meyer et al., PRL 101, 193002 (2008)

Dichroism in the photoionization

2-color Above Threshold Ionization





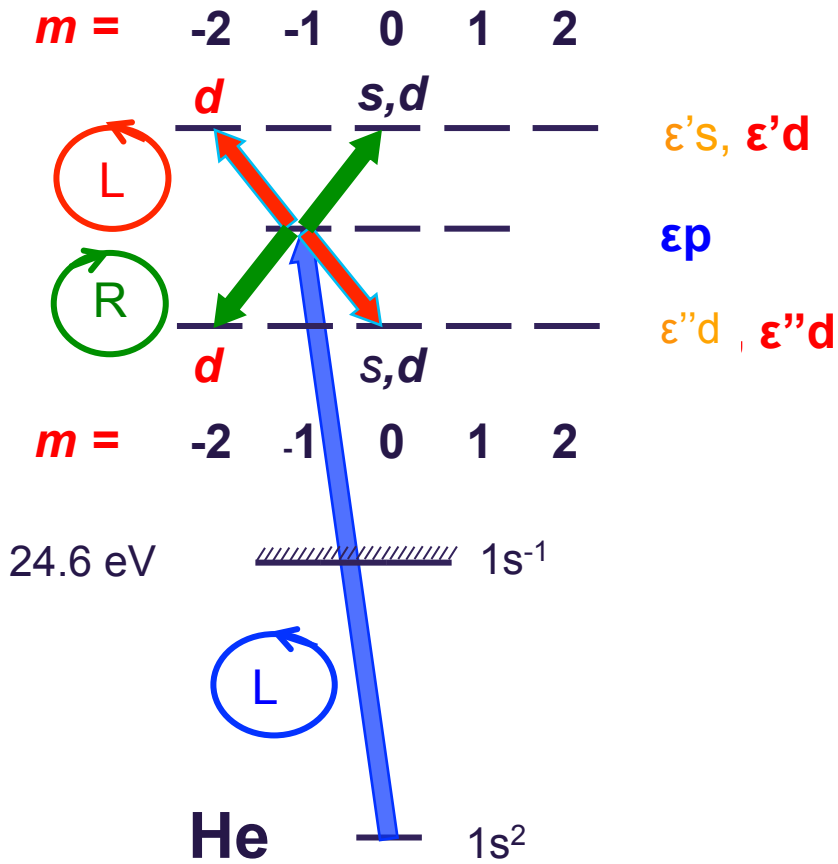
Δm=±1

Critical test of theory

&

Diagnostic for radiation

Circular Dichroism



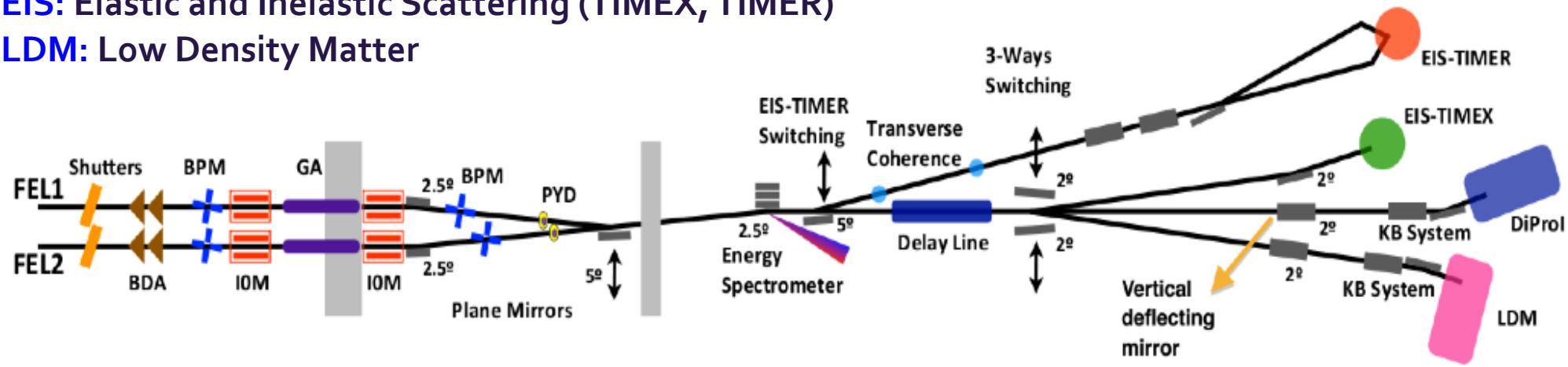
European XFEL

FERMI@Elettra

FEL1 parameters:

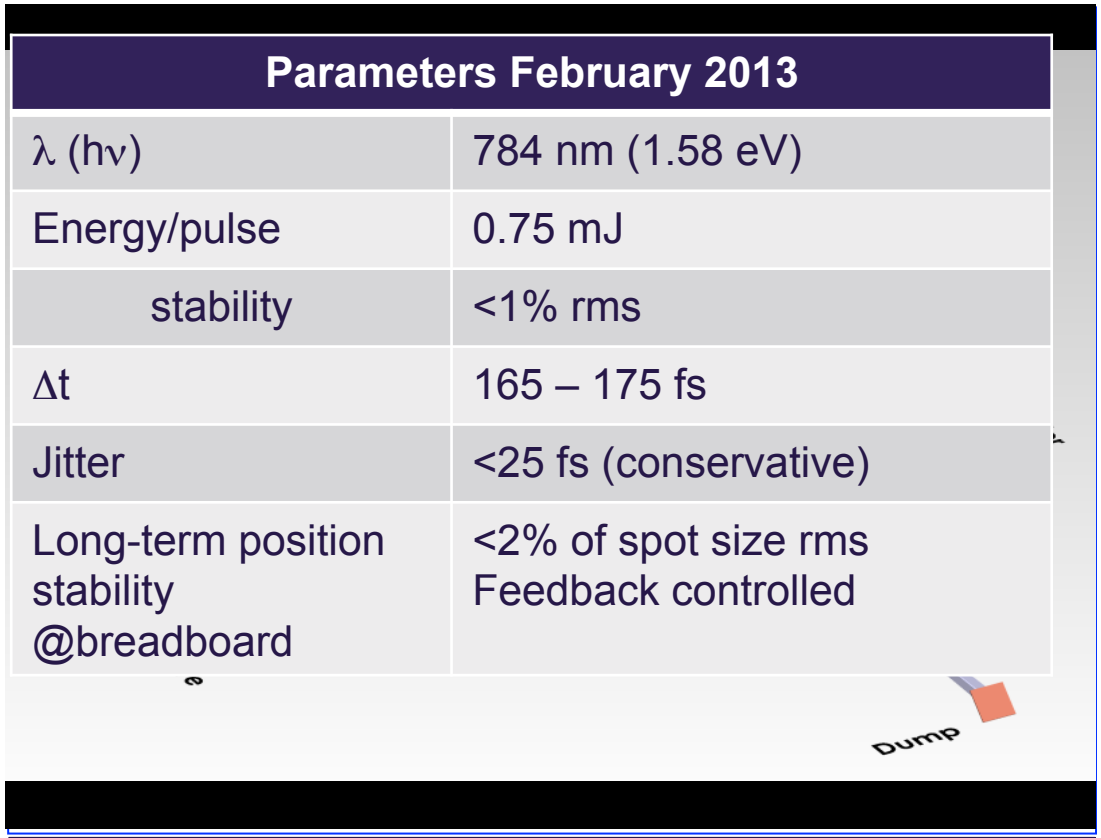
Photon energy	19 - 62 eV
Tunability	continuous
Pulse length (FWHM)	30 - 100 fs
Bandwidths (rms)	5×10^{-4}
Polarization	linear, **circular**
Repetition rate	10 Hz
Pulse energy	30 – 100 μJ

DiProl: Diffraction and Projection Imaging
EIS: Elastic and Inelastic Scattering (TIMEX, TIMER)
LDM: Low Density Matter



The LDM endstation

Parameters February 2013	
λ ($h\nu$)	784 nm (1.58 eV)
Energy/pulse	0.75 mJ
stability	<1% rms
Δt	165 – 175 fs
Jitter	<25 fs (conservative)
Long-term position stability @breadboard	<2% of spot size rms Feedback controlled



V. Lyamayev *et al*. **A modular end-station for atomic, molecular, and cluster science at the Low Density Matter beamline of FERMI@Elettra**
J. Phys. B (Special issue Aug 2013)

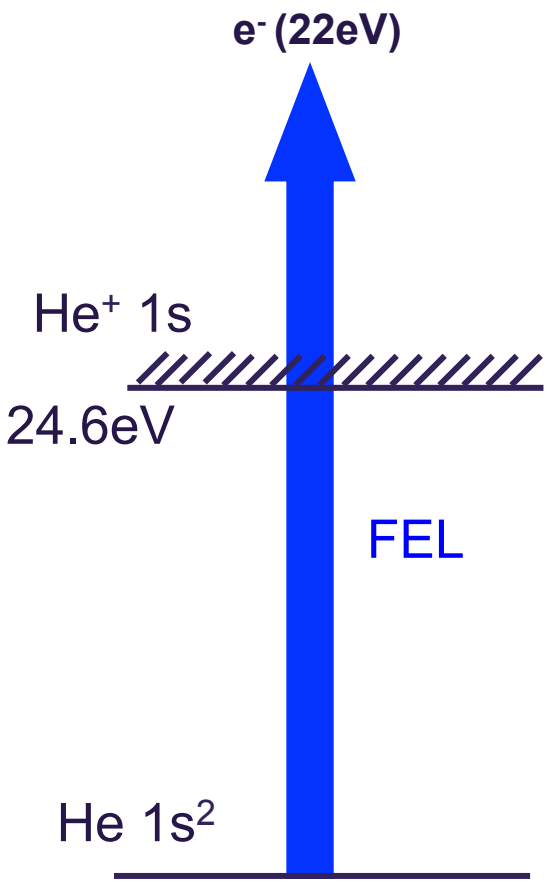
VMI: e^-,ions
E:1-100 eV
ΔE: 4%

TOF: ions
$\Delta m/m$=350 (w/ VMI)
$\Delta m/m$=14000 (alone)

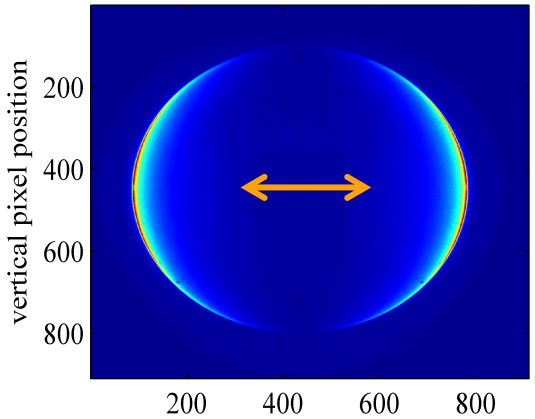
To be installed:
B-TOF
Scattering detector

FERMI@Elettra

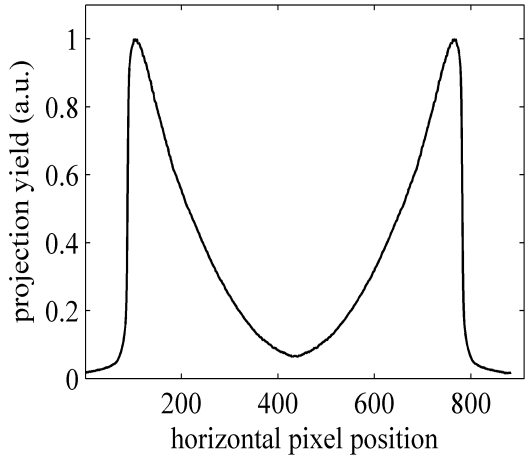
Single photon ionizati



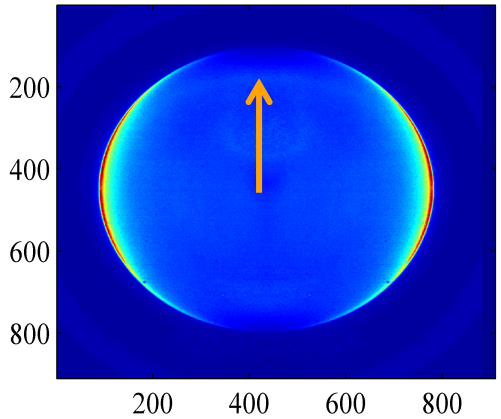
Linear Polarization



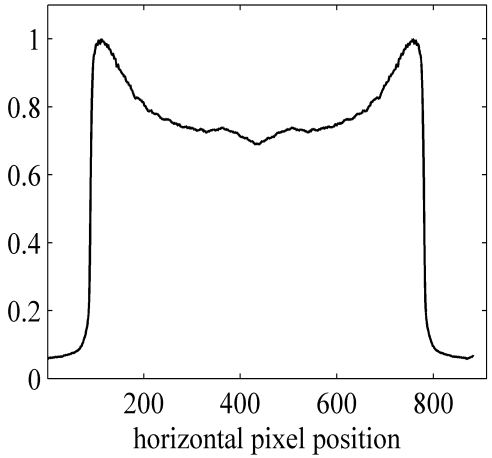
$I(\theta) = 1 + \beta P_2(\cos\theta)$



Circular Polarization

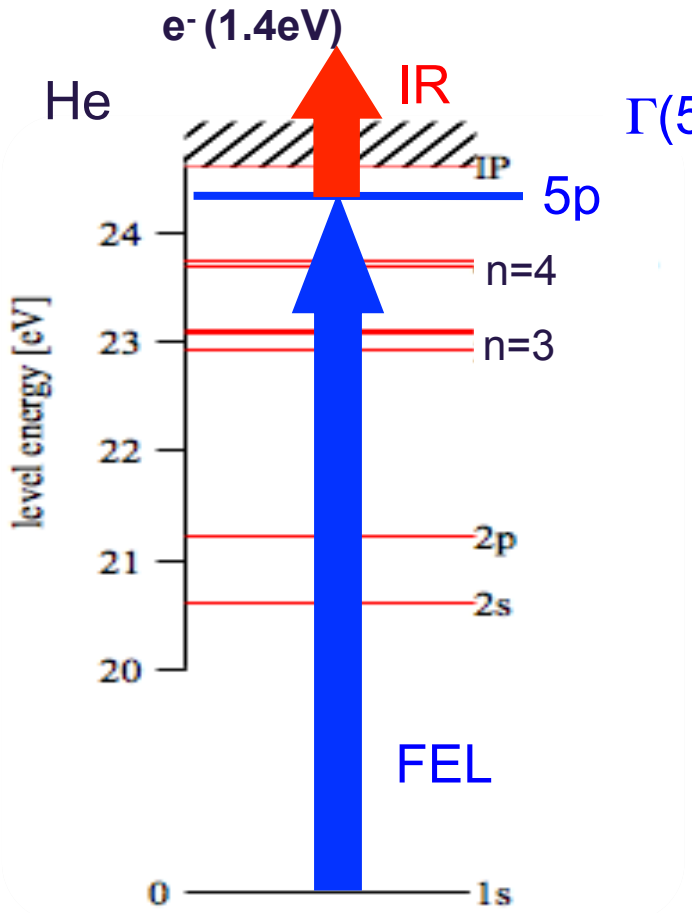


$I(\theta) = 1 - \beta/2\, P_2(\cos\theta)$

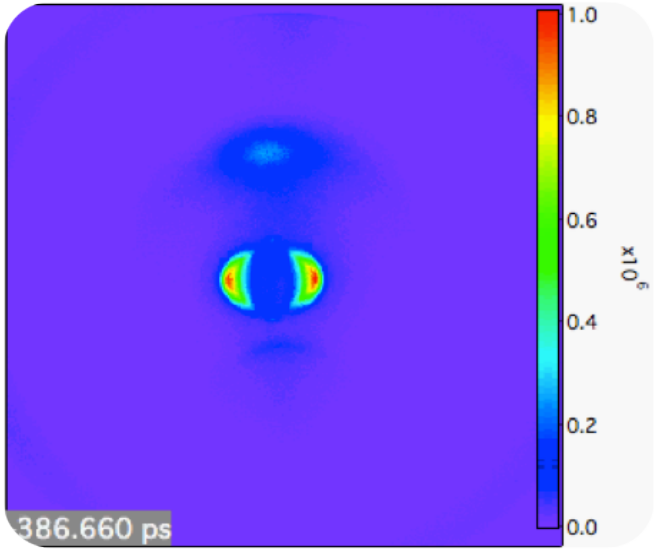


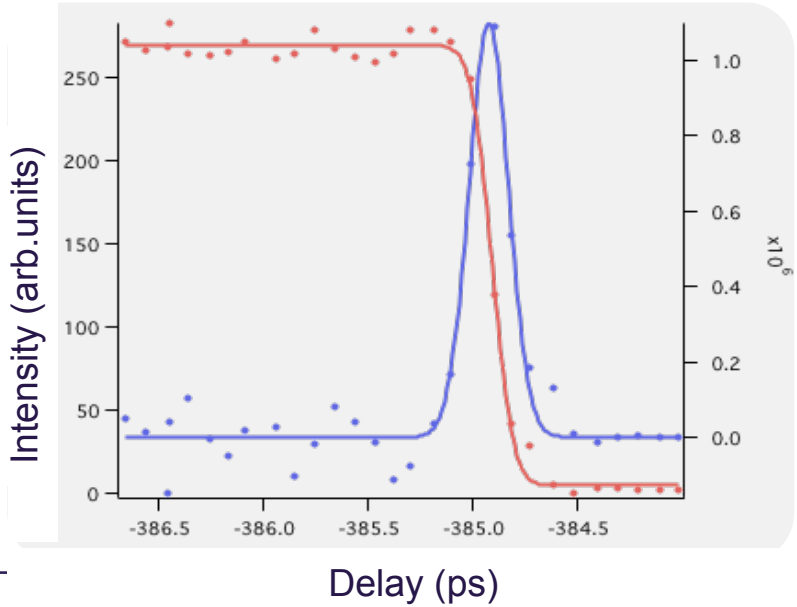
Pump-probe

Two-color resonant two-photon ionization



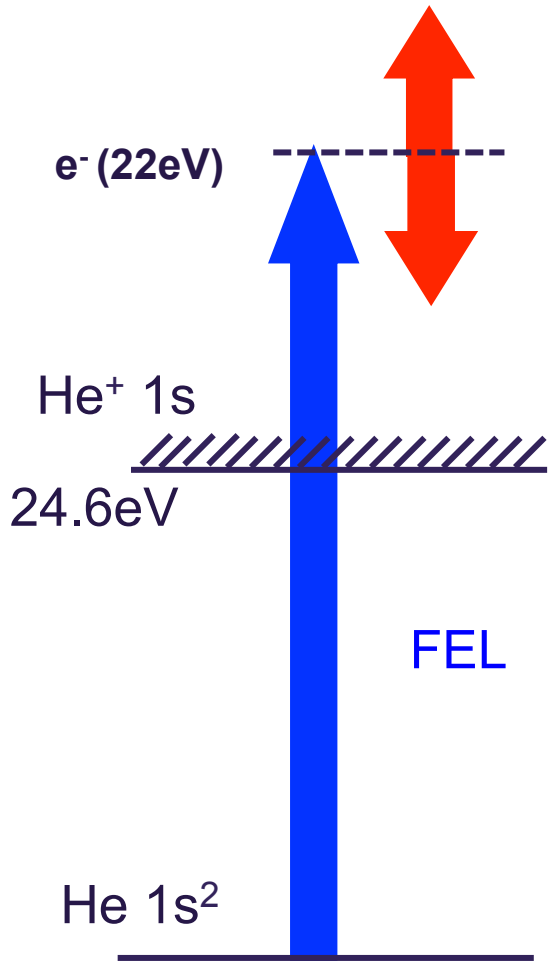
Lifetime
$\Gamma(5p) = 7.7$ ns



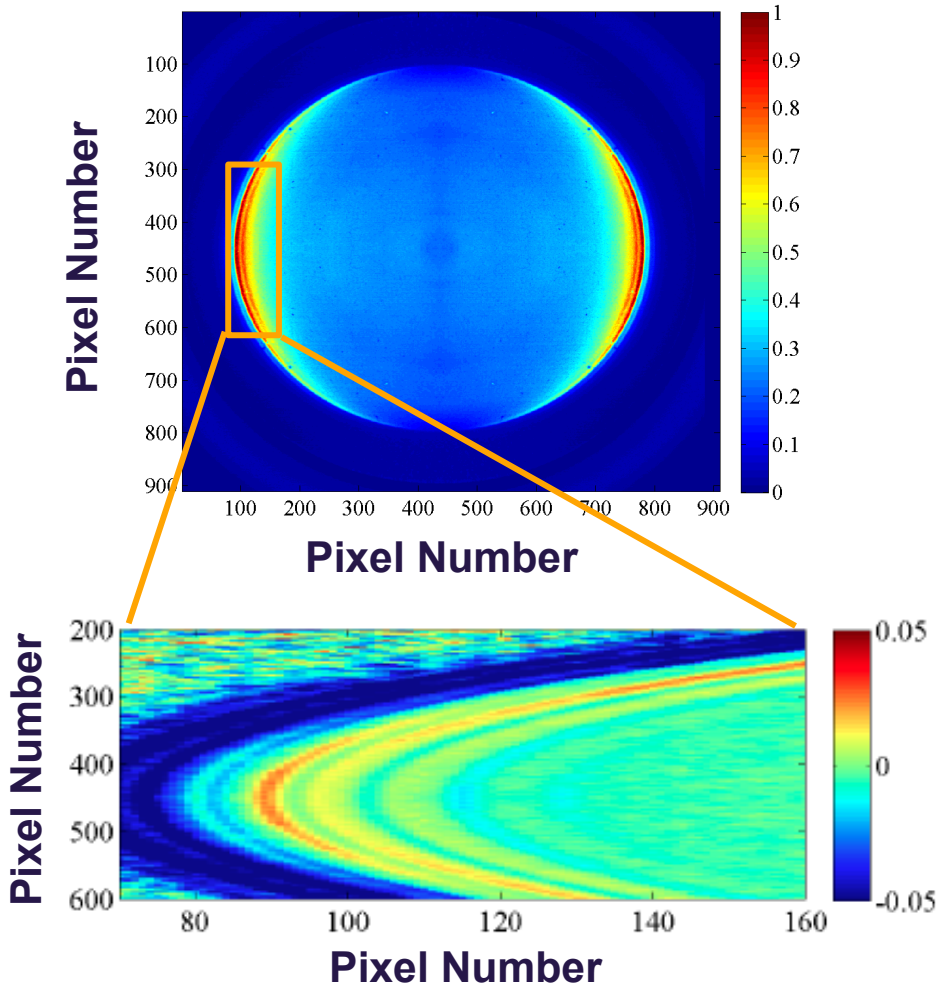


Two-color Above Threshold Ionization (ATI)

Two-color photoionization



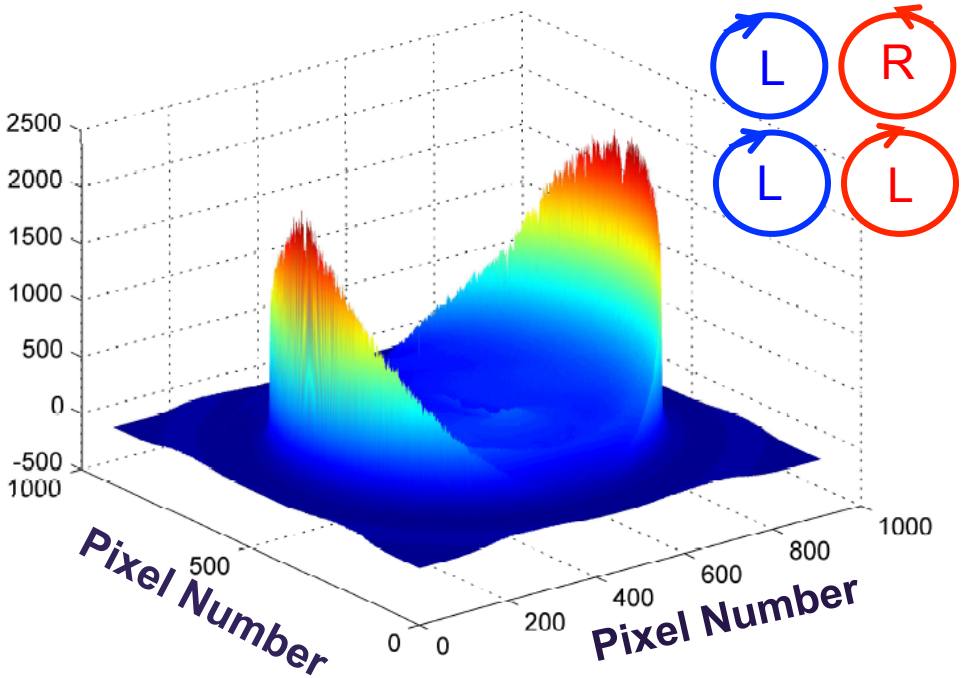
Angular Distribution



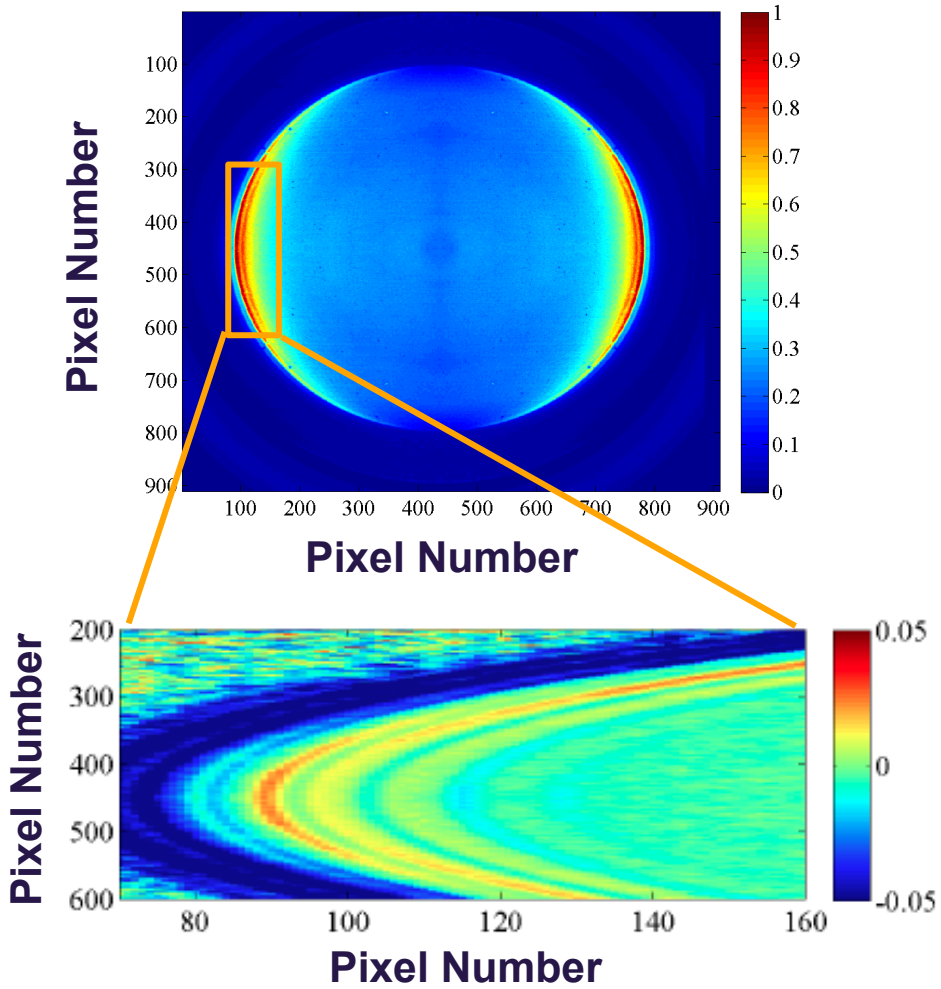
CD in two-color ATI

L Right-handed Left-handed R

Polarization



Angular Distribution



Circular dichroism

CD = R – L / (R+ L)

Circular dichroism in two-color photoionization

Low intensity

7×10^{10} W/cm^2

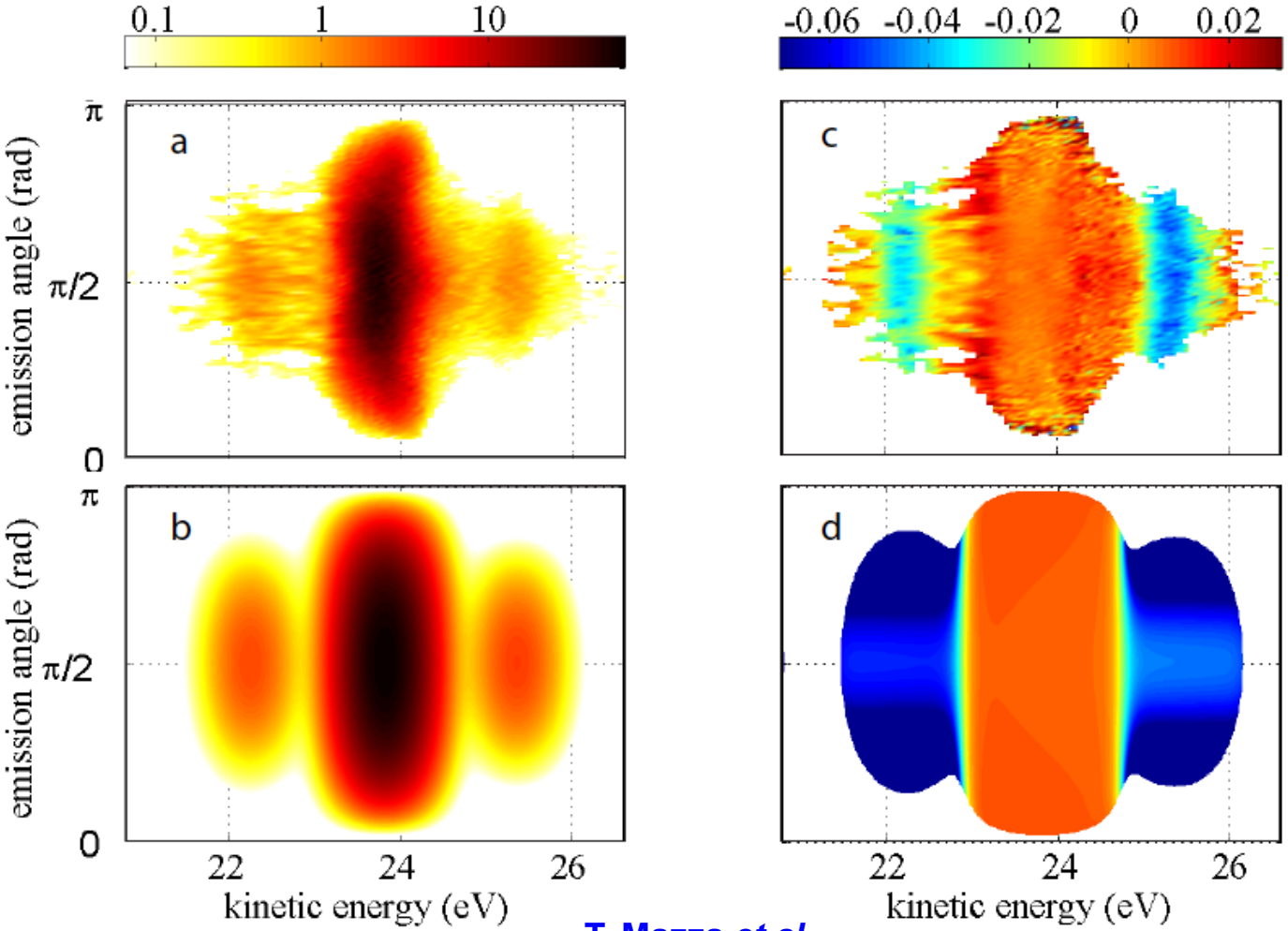
Single sideband

Two-photon process

Theory: SFA

Strong Field Approximation

$10^{10} - 10^{13}$ W/cm^2



A. Kazansky, N. Kabachnik et al.
PRL107, 253002 (2011)
PRA 85, 053409 (2012)

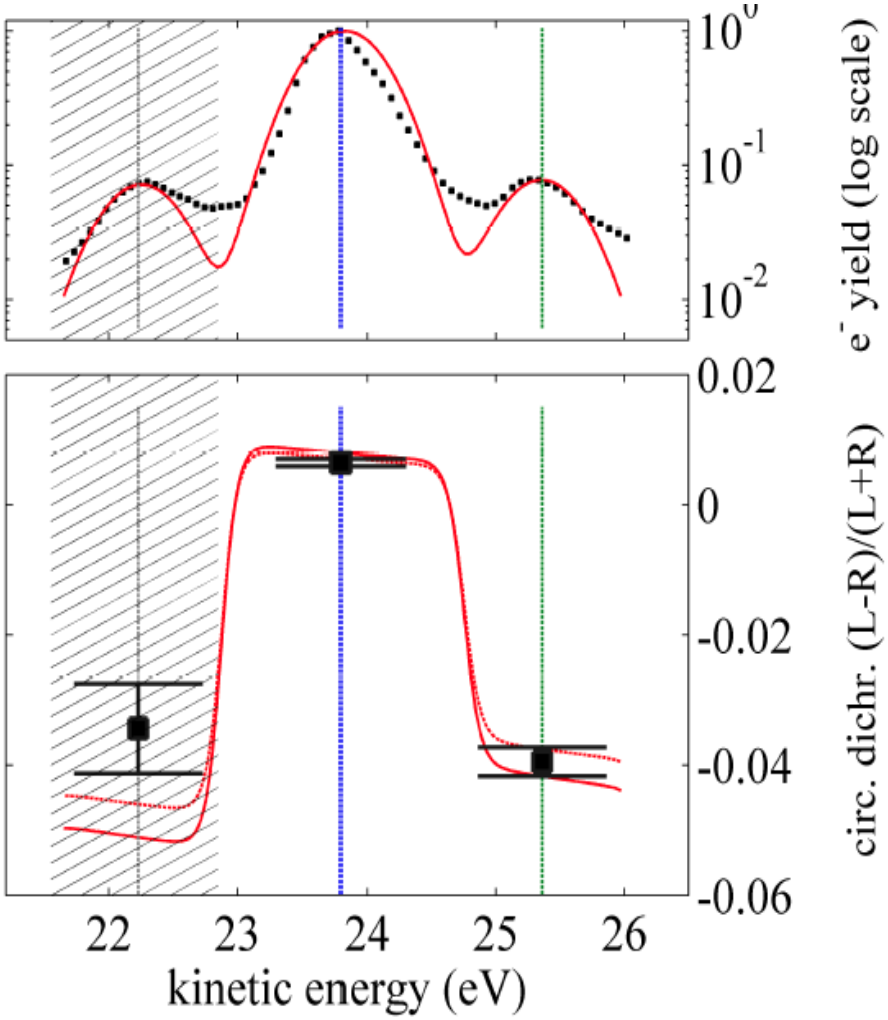
PES

T. Mazza *et al.*
Nat. Commun.
5:3648 (2014)

CD

European XFEL

Circular dichroism in two-color photoionization



Experimental Circular Dichroism

⇩

Circular polarized FEL beam !!

Excellent agreement with theory

CD (SB) = - 0.04

⇩

1) Degree of circular polarization

P = 0.95 +0.05/-0.08

2) Sign of CD → Sign of helicity

Left-handed circular polarization

Circular dichroism in multi-color photoionization

High intensity

2×10^{12} W/cm^2

Multiple sidebands

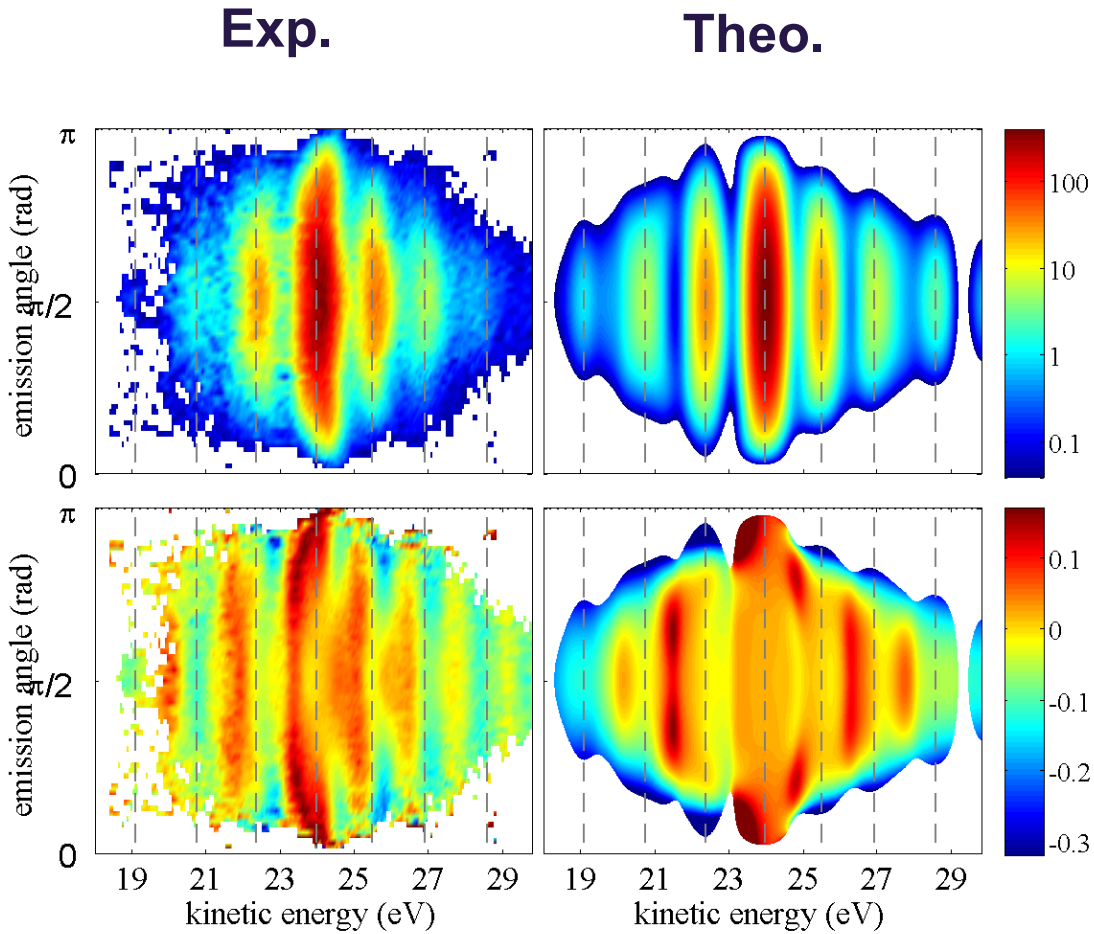
Multi-photon process

Theory: SFA

Strong Field Approximation

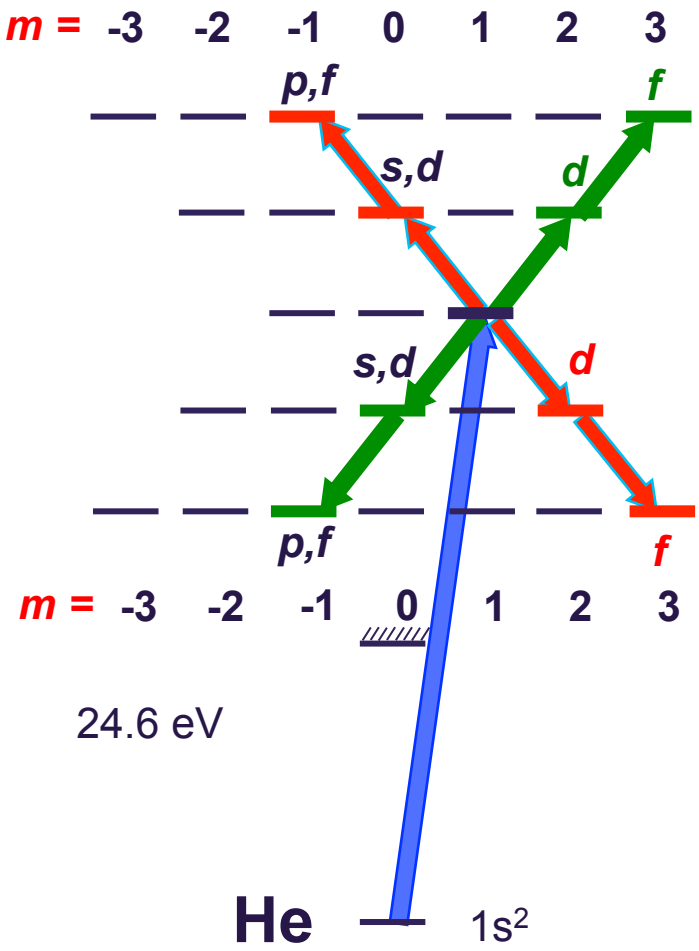
$10^{10} - 10^{13}$ W/cm^2

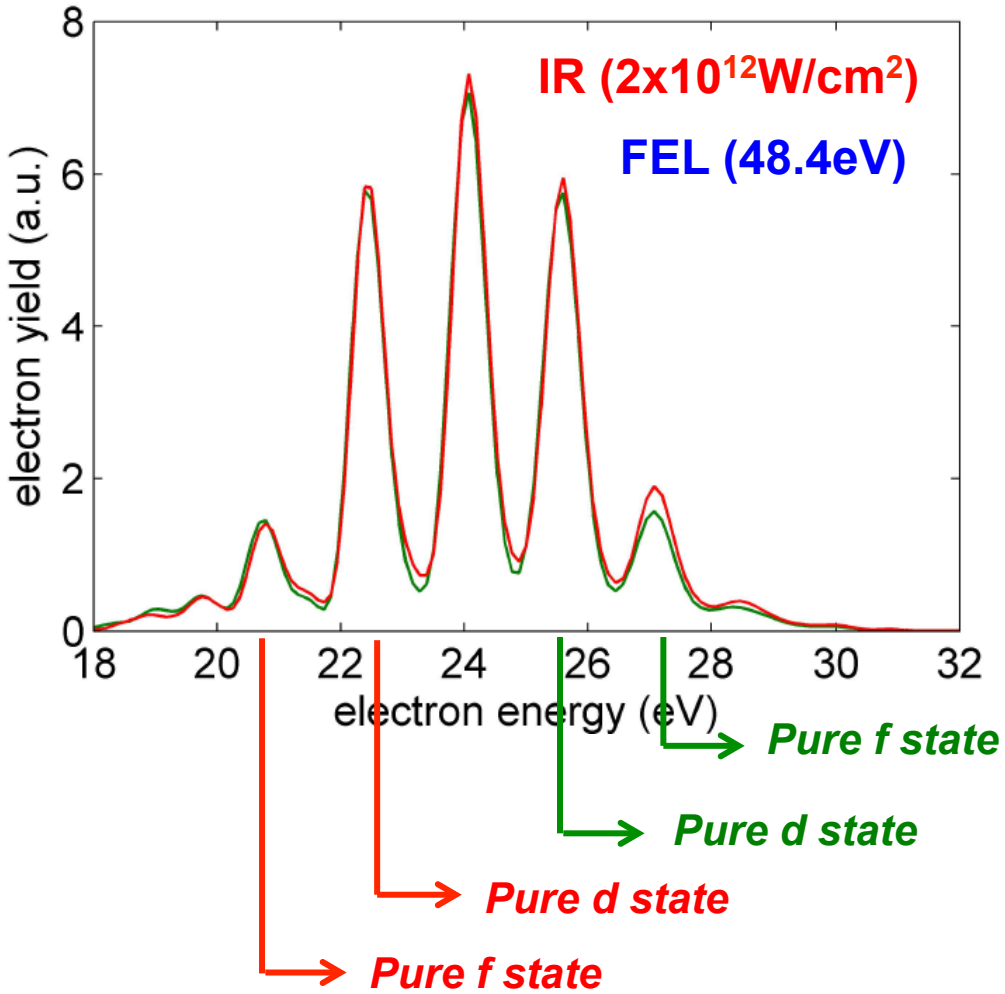
$$CDAD = \frac{|\mathcal{A}_{\vec{k}}^{RR}|^2 - |\mathcal{A}_{\vec{k}}^{RL}|^2}{|\mathcal{A}_{\vec{k}}^{RR}|^2 + |\mathcal{A}_{\vec{k}}^{RL}|^2}$$



A. Kazansky, N. Kabachnik et al.
PRL107, 253002 (2011)
PRA 85, 053409 (2012)

Circular dichroism in two-color ionization of Helium





European XFEL

Angular distribution in two-color ionization of Helium

$$W_n(\Theta) = W_{n,0}\, \beta_n\, P_n(\cos\Theta)$$

A. Grum-Grzhimailo,
E. Gryzlova

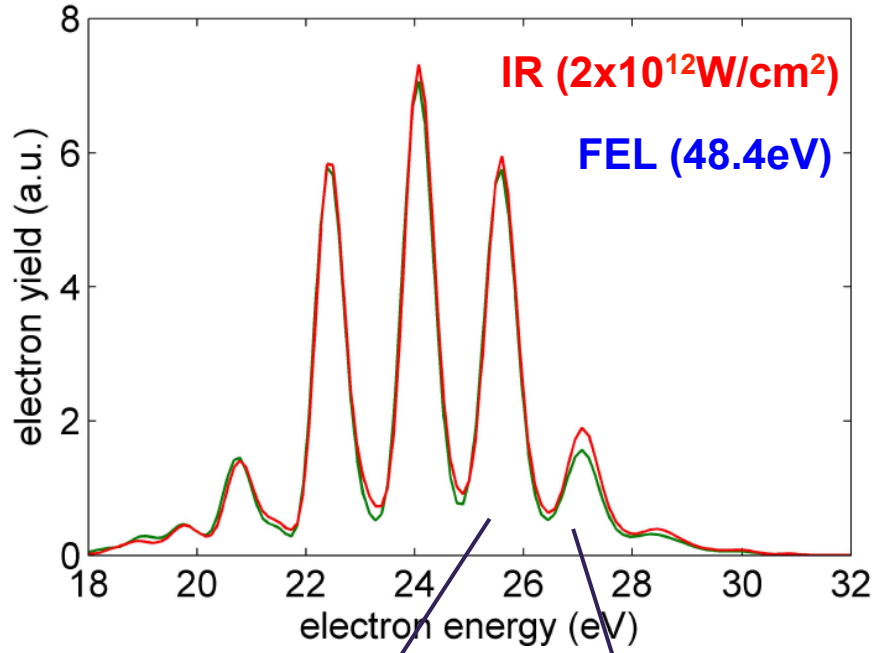
Theory

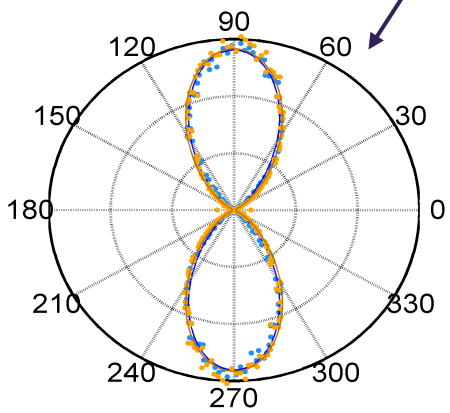
	$n_y = 2$	$n_y = 3$	$n_y = 4$
β_2	-1.43	-1.67	- 1.82
β_4	0.43	0.82	1.13
β_6	0	-0.15	0.36
β_8	0	0	-0.05

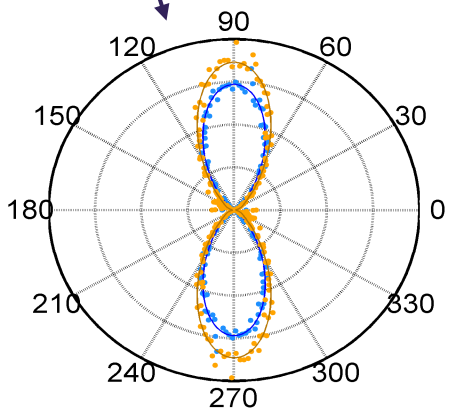
Experiment

N=2: $\beta_2 = -1.44$, $\beta_4 = 0.45$

N=3: $\beta_2 = -1.55$, $\beta_4 = 0.76$, $\beta_6 = -0.18$

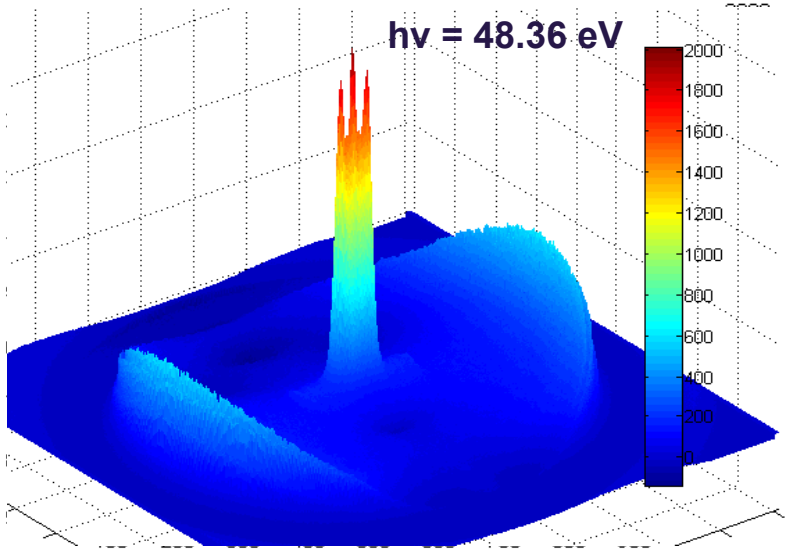


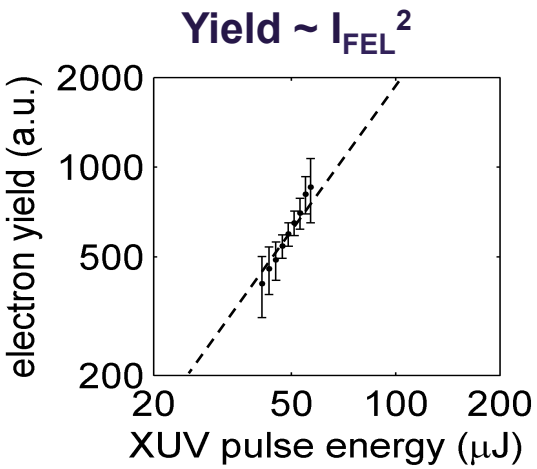




European XFEL

CD in the ionization of resonantly excited states





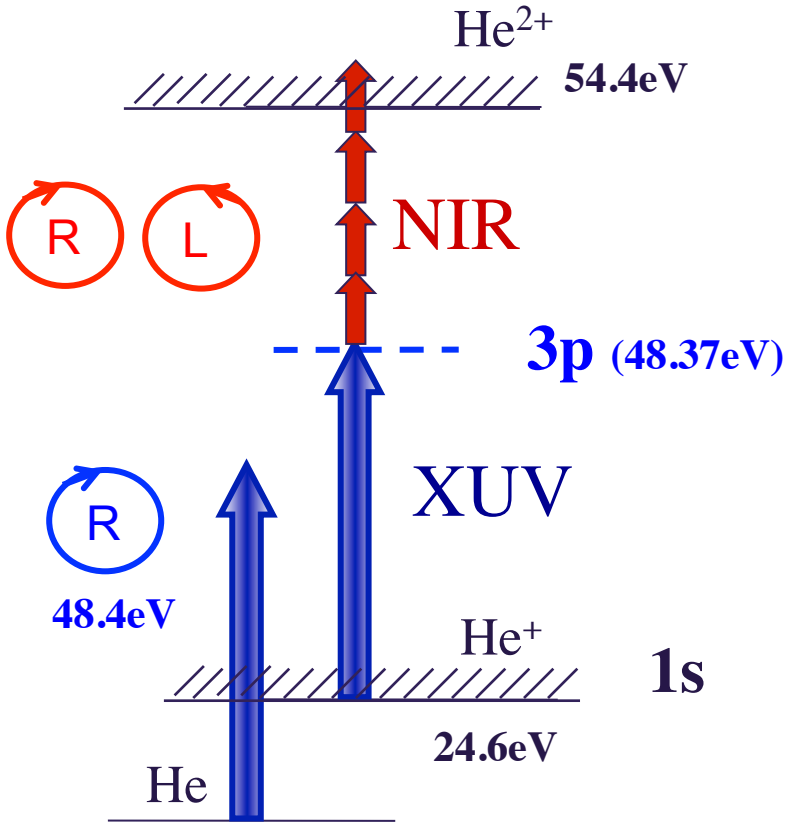
Two-body system

Ideal test ground for theory

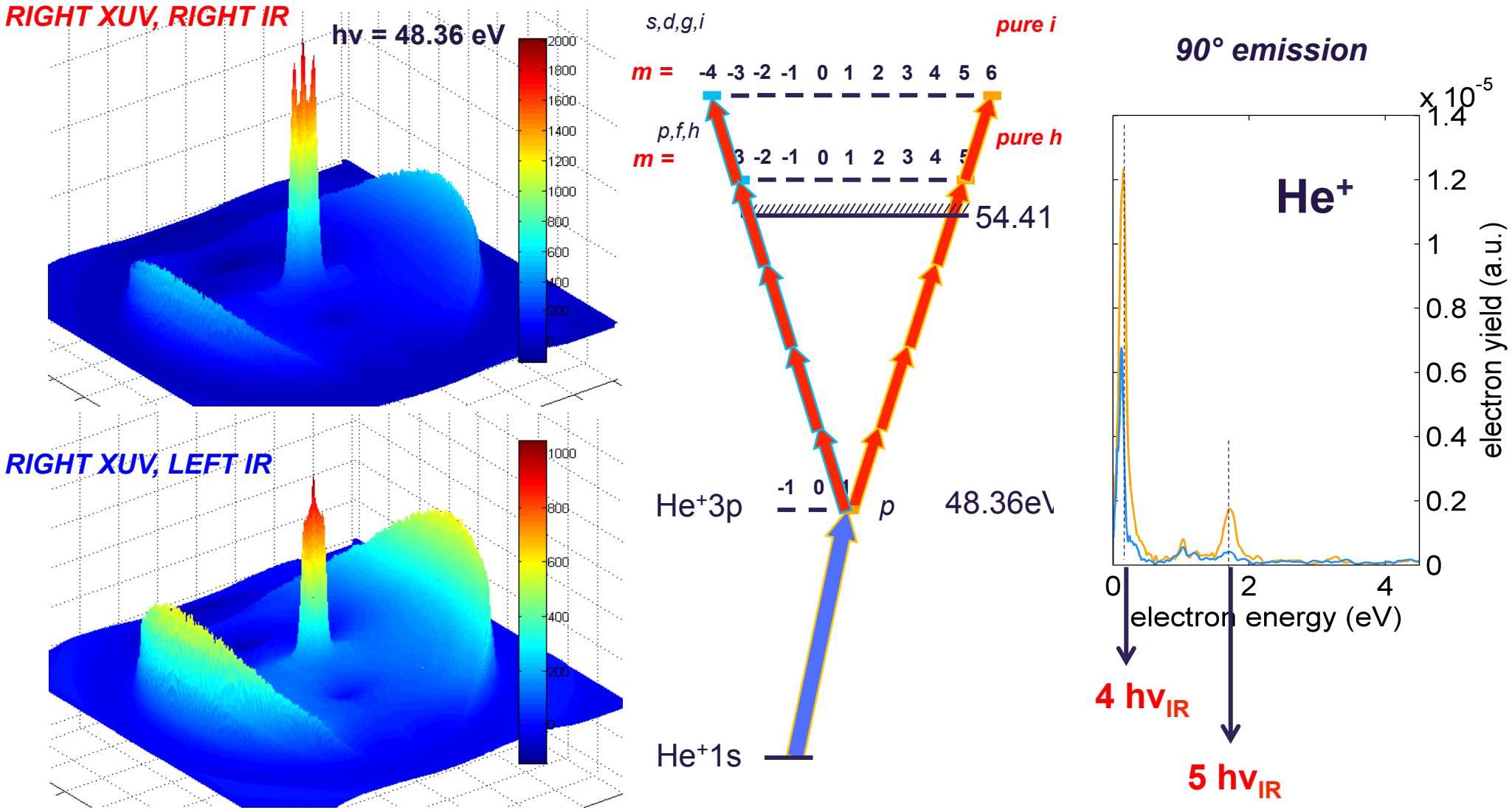
Spectroscopy on ions

Photoionization dynamics

He $1s^2$ + $h\nu_{XUV}$ + N x $h\nu_{OL}$



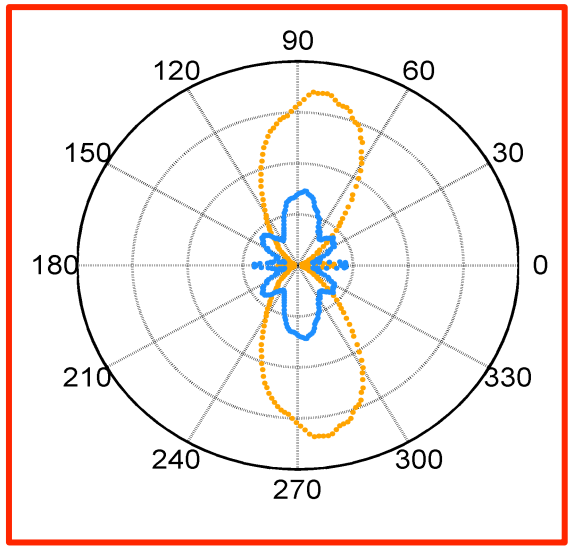
CD in the ionization of resonantly excited states

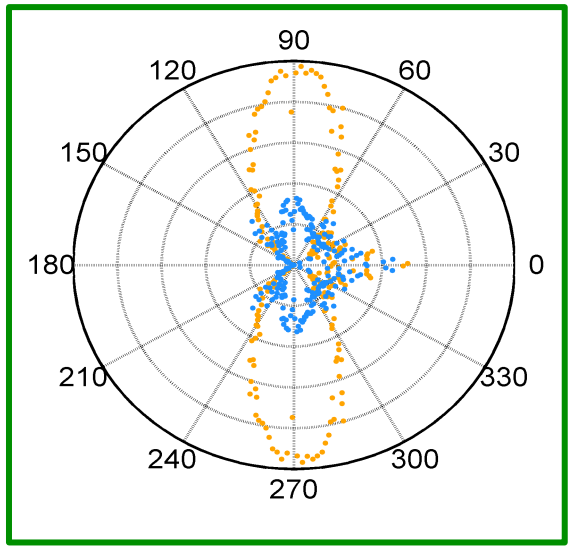


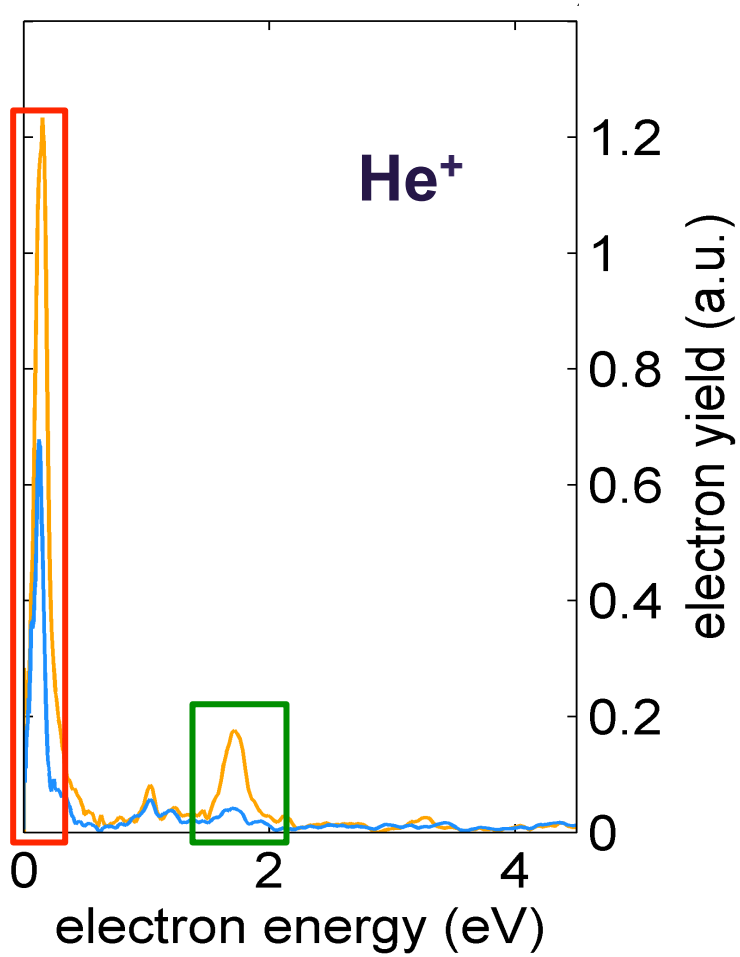
European XFEL

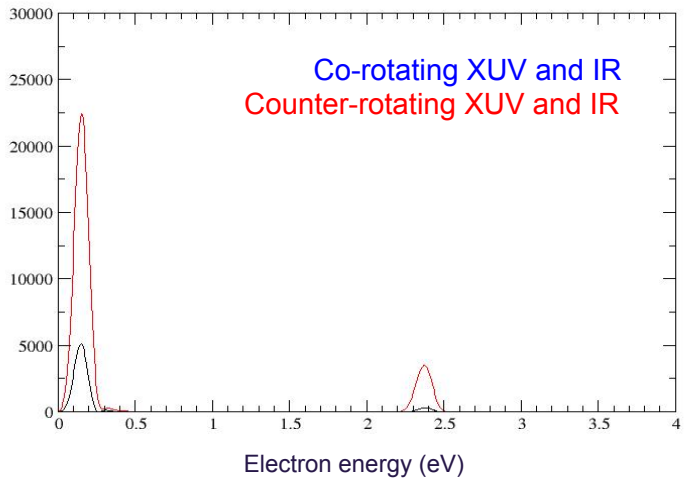
CD in the ionization of resonantly excited states

RIGHT XUV, RIGHT IR ***RIGHT XUV, LEFT IR***









Theory:
A. Kazansky, N. Kabachnik)

TDSE solution in SAE approximation accounting for
- CIPO EM field
- Ionic field

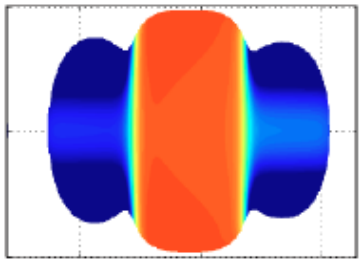
Present state:
- 2D model
- No PAD yet

Summary

FERMI

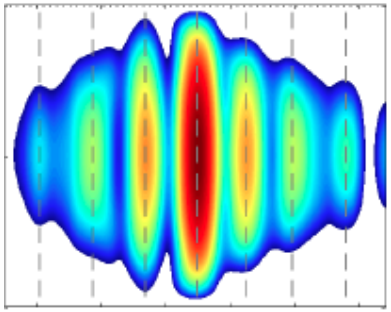
Circular dichroism in two-color two-photon Ionization

- Characterization of FEL pulses



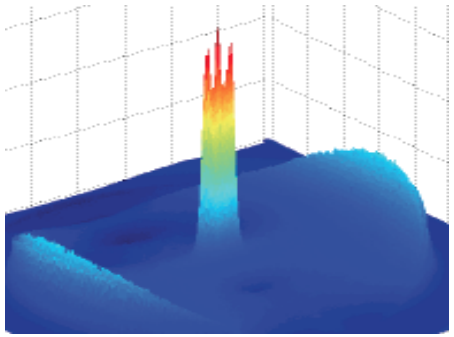
CD in two-color multi-photon ATI

- Characterization of multi-photon processes
- Partial electron waves



CD in two-color resonant multi-photon Ionization

- Resonant multi-photon processes
- Spectroscopy of ionic species



Collaborations

Experiment

European XFEL
T. Mazza, M. Ilchen, , A. De Fanis,
J. Rafipoor, S. Bakhtiarzadeh, M. Meyer

Dublin City University
M. Kelly, N. Walsh, J. Costello

Tohuku University
K. Ueda

Theory

European XFEL / Moscow State University
N.M. Kabachnik

Moscow State University
A. G. Grum-Grzhimailo, E. Gryzlova

State University St. Petersburg
A. N. Kazansky

FERMI (LDM)

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M. Di Fraia

University of Milano
M. Devetta

TU Berlin
Y. Ovcharenko, Th. Möller

University Freiburg
V. Lyamayev, F. Stienkemeier


Thank you for your attention !!!
European XFEL