Imaging and Controlling Electron Rescattering Dynamics in Bicircular Femtosecond Laser Fields

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Abstract

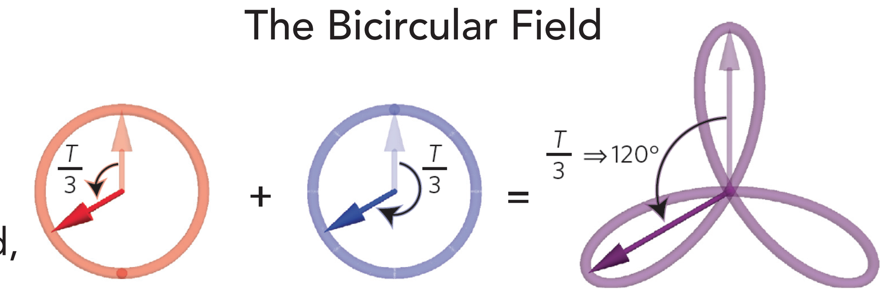
- **Motivation** - Laser-driven electron-ion rescattering has recently been demonstrated as a powerful tool for the self-interrogation of molecular structure on ultrafast time scales. When driven by a circularly polarized two-color field, (e.g., the bicircular field) the ionized electrons are driven in 2D trajectories, which can further extend the "toolkit" of rescattering-based imaging techniques.

- Experiment - We investigate electron-ion rescattering in two-color circularly polarized laser fields, in which the electrons are steered in two-dimensions before rescattering off of the parent ion.

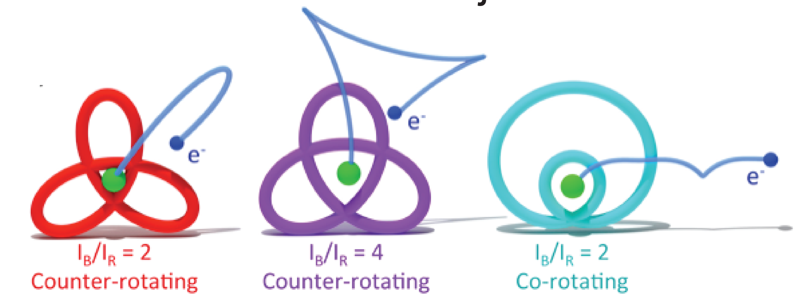
- Results -

1. Electron-ion rescattering depends sensitively on the intensity ratio of the two-color field.
2. Optimal high-energy electron-ion rescattering is achieved when the ponderomotive energy of the two fields are approximately equal.
3. The kinetic energy spectrum of returning electrons exhibit a narrow energy bandwidth for a wide range of intensity ratios.

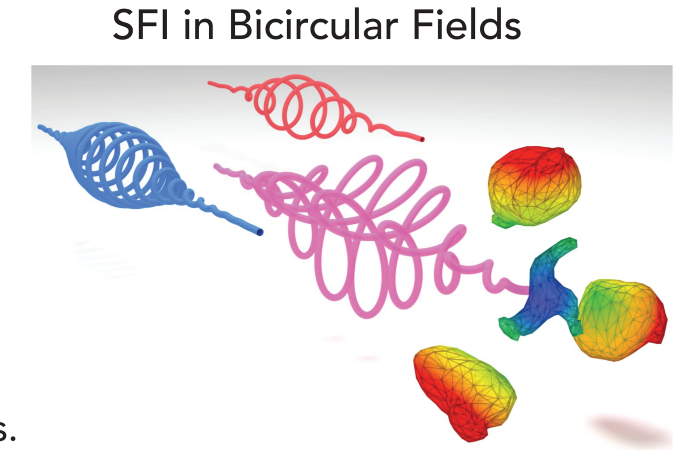
The Bicircular Field



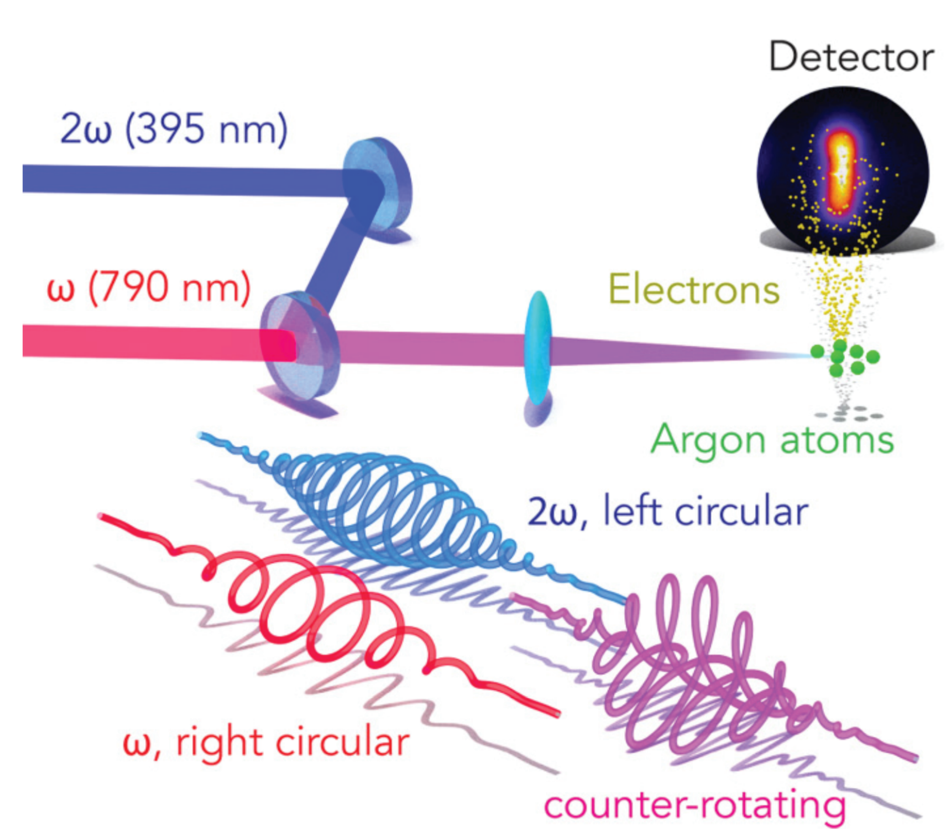
2D Electron Tracjectories



SFI in Bicircular Fields



Bicircular Electron Rescattering Experiment



- Fundamental pulses derived from KM Labs Wyvern HP (45 fs, 790 nm, 3 mJ, 4 kHz).
- Second harmonic (395 nm) generated in a 200-μm-thick beta barium borate (BBO) crystal.
- Driving laser polarizations were controlled via half and quarter waveplates in each arm.
- The fundamental and second-harmonic beams were spatially and temporally overlapped via a Mach-Zender inteferometer.
- Full photoelectron momentum distributions were recorded using a high-energy velocity map imaging (VMI) spectrometer.
- Photoion yields were also recorded by operating the VMI in time-of-flight (TOF) mode.

References

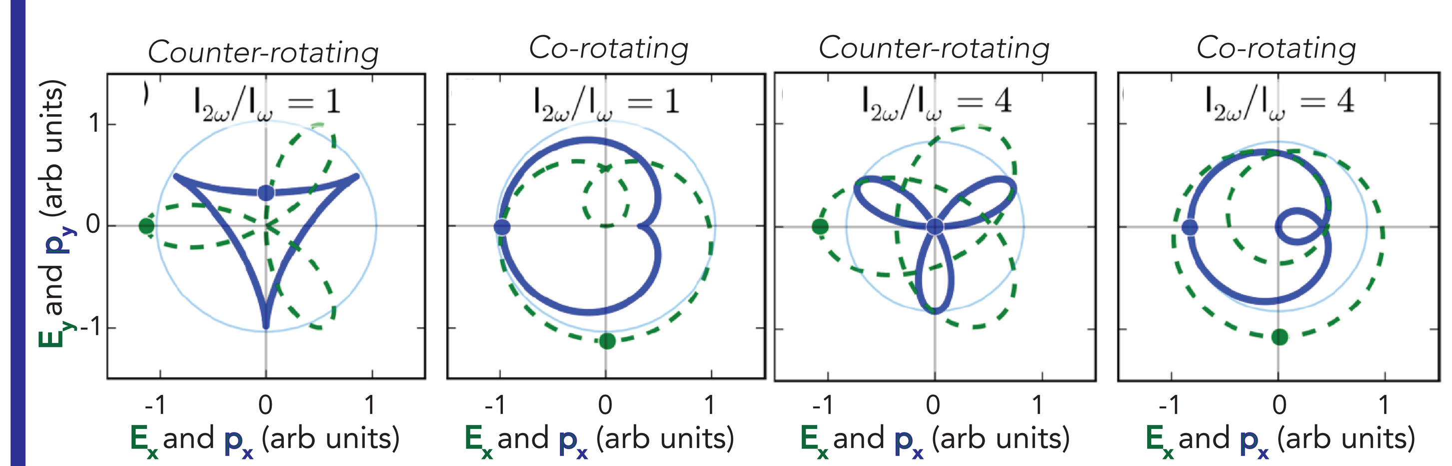
[1]Mancuso, C. A. et al. Strong-field ionization with two-color circularly polarized laser fields. *Phys. Rev. A.* 91, 031402(R) (2015).
[2]Mancuso, C. A. et al. Controlling electron-ion rescattering in two-color circularly polarized femtosecond laser fields. *Phys. Rev. A* **93**, 053406 (2016).
[3]Mancuso, C. A. et al. Controlling nonsequential double ionization in two-color circularly polarized femtosecond laser fields. *Phys. Rev. Lett.* **In Press**.
[4]Miloŝević, D. B. Possibility of introducing spin into attoscience with spin-polarized electrons produced by a bichromatic circularly polarized laser field. *Phys. Rev. A.* 93, 051402(R) (2016).

Electron Rescattering in Bicircular Femtosecond Laser Fields

Electron Kinematics in A Bicircular Field

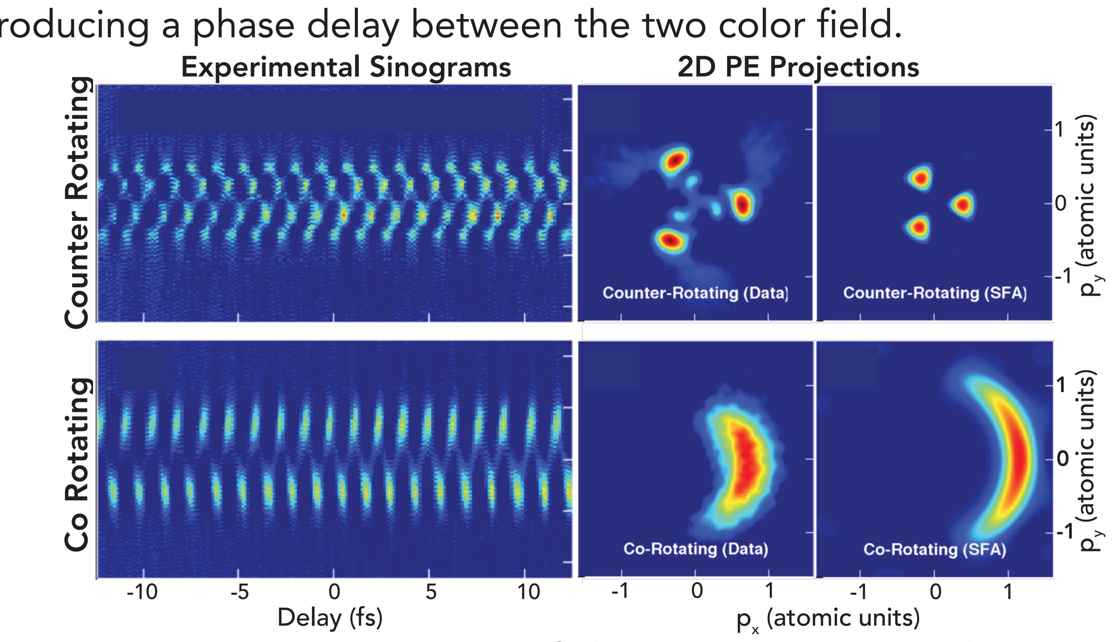
- The kinematics of liberated electrons is largely governed by the vector potential, *A(t)*, of the bicircular field.

$$A_x(t) = \frac{1}{\sqrt{2}}\left[\frac{E_1}{\omega_1}cos(\omega_1) + \frac{E_2}{\omega_2}cos(\omega_2)\right], \quad A_y(t) = \frac{1}{\sqrt{2}}\left[-\frac{E_1}{\omega_1}sin(\omega_1) + \frac{E_2}{\omega_2}sin(\omega_2)\right]$$

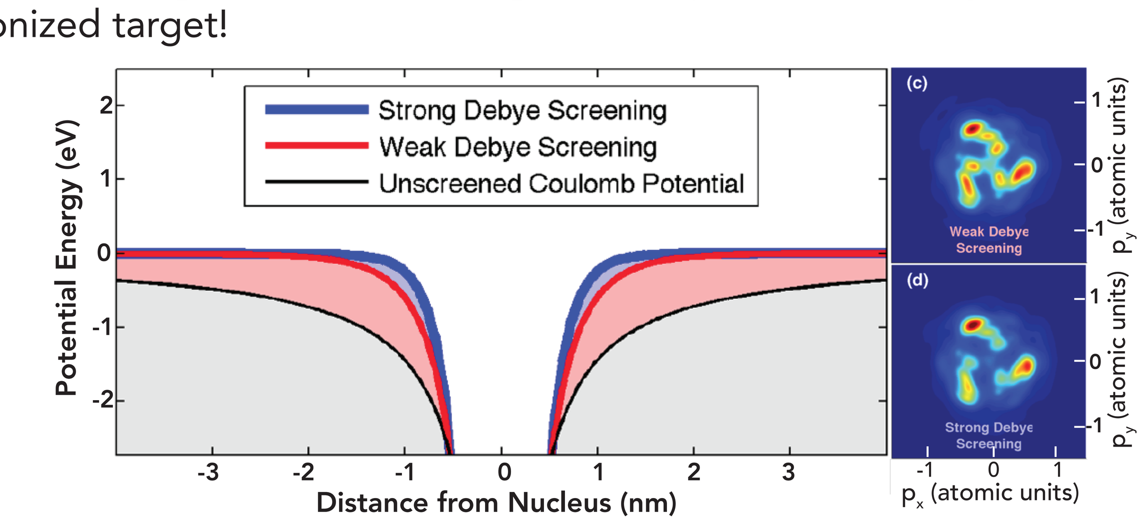


Reconstructed Photoelectron (PE) Distributions

- The bicircular electric field (hence, PE distribution) can be rotated by introducing a phase delay between the two color field.

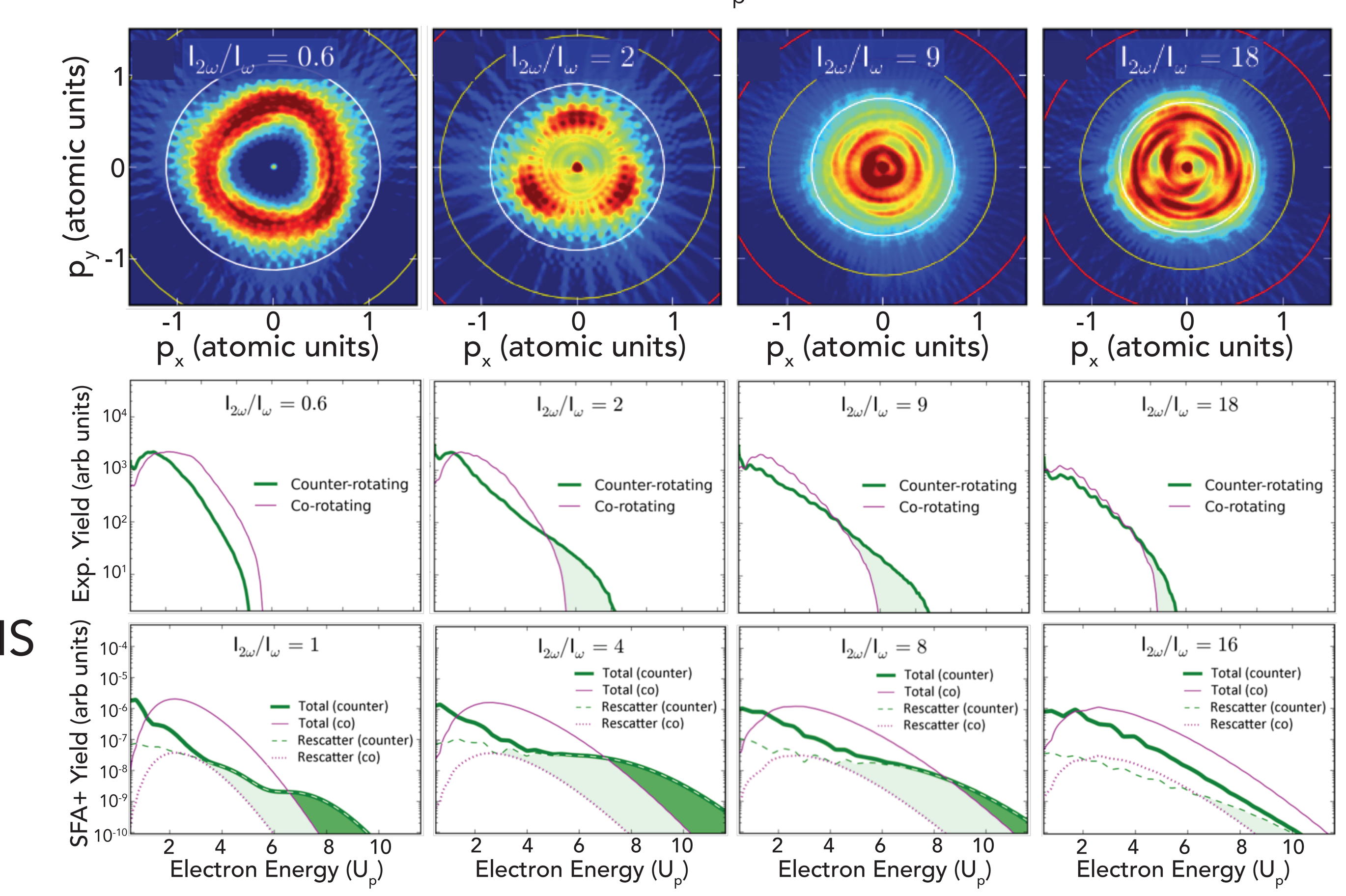


- Rescattering in counter-rotating fields depends sensitively on structure of ionized target!



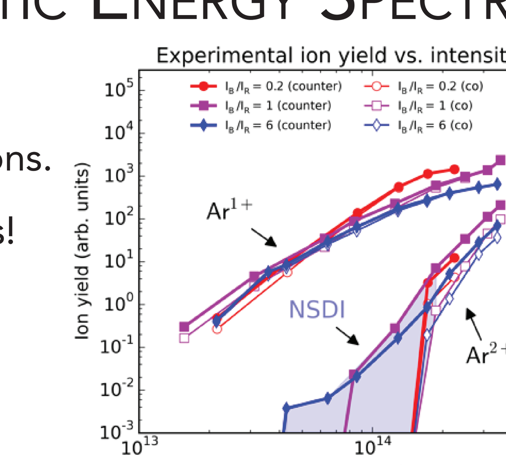
Optimization of Electron-Ion Rescattering

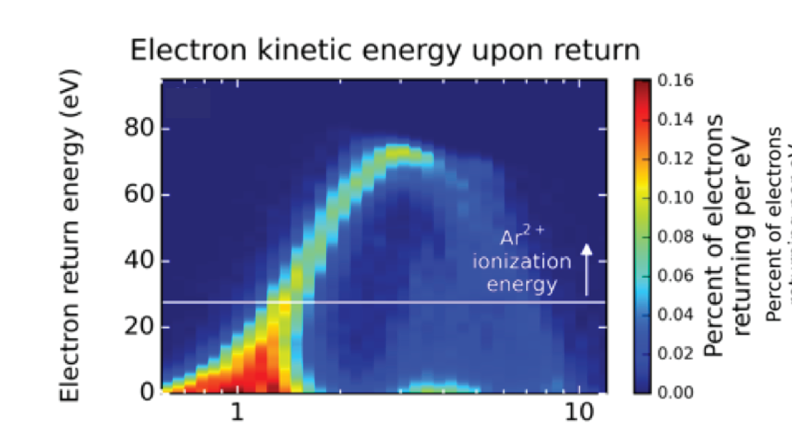
- In the bicircular field, electron rescattering dynamics are governed by the ponderomotive potentials ($U_p \propto I\lambda^2$) of the two fields.

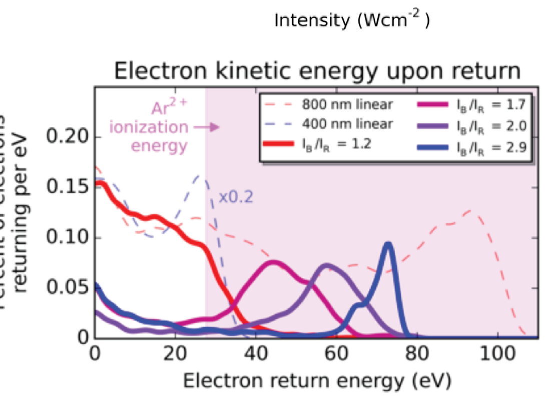


Returning Electron Kinetic Energy Spectra

- The presence of nonsequential double ionization (NSDI) can help to inform on the kinetic energies of returning electrons.
- First observation of NSDI in these fields!
- Classical trajectory Monte Carlo simulations provide insight into the kinematics of returning electrons.







Conclusions and Outlook

- We find that counter-rotating circularly polarized laser fields can efficiently return electrons to their parent ion.
- The electron dynamics in these structred fields can be controlled via field parameters accessible in the lab.
- **The bicircular field also allows for the introduction of spin-polarization effects into attoscience!**
- **The control over the electron kinematics can be utilized to control the polarization properties of circularly polarized high harmonic generation (HHG).**