Strong-Field Ionization in Bicircular Laser Fields

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Ionization with intense bicircular laser pulses is studied using a classical ensemble method utilizing a high-performance computing cluster. Electron momenta, energy, timing, and rescattering trajectories are explored as a function of laser field parameters.

J. L. Chaloupka, "Single and Double Ionization of Helium in Intense Bicircular Laser Fields," **Journal of Physics B: Atomic, Molecular and Optical Physics** 53 (18), 185601 (2020).

J. L. Chaloupka and D. D. Hickstein, "Dynamics of Strong-Field Double Ionization in Two-Color Counterrotating Fields," **Physical Review Letters 116**, 143005 (2016).
C. A. Mancuso, *et al.*, "Controlling Nonsequential Double Ionization in Two-Color Circularly Polarized Femtosecond Laser Fields," **Physics Review Letters 117**, 133201 (2016).
C. A. Mancuso, *et al.*, "Observation of ionization enhancement in two-color circularly polarized laser fields," **Physical Review A 96**, 023402 (2017).
J. P. Paquette and J. L. Chaloupka, "Effect of realistic focal conditions on the strong-field ionization of helium," **Physical Review A 79**, 043410 (2009).

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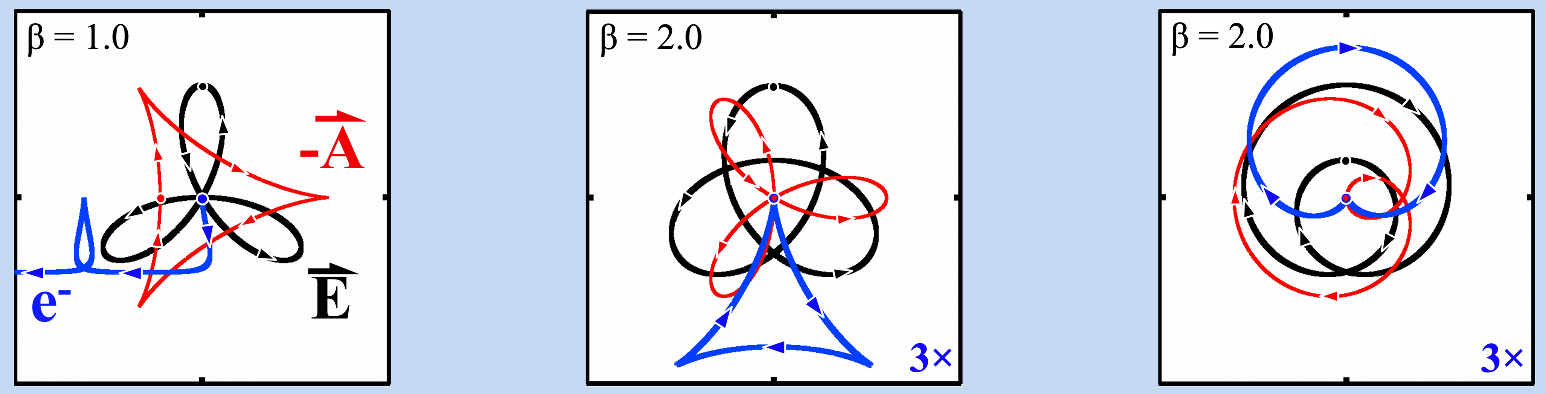
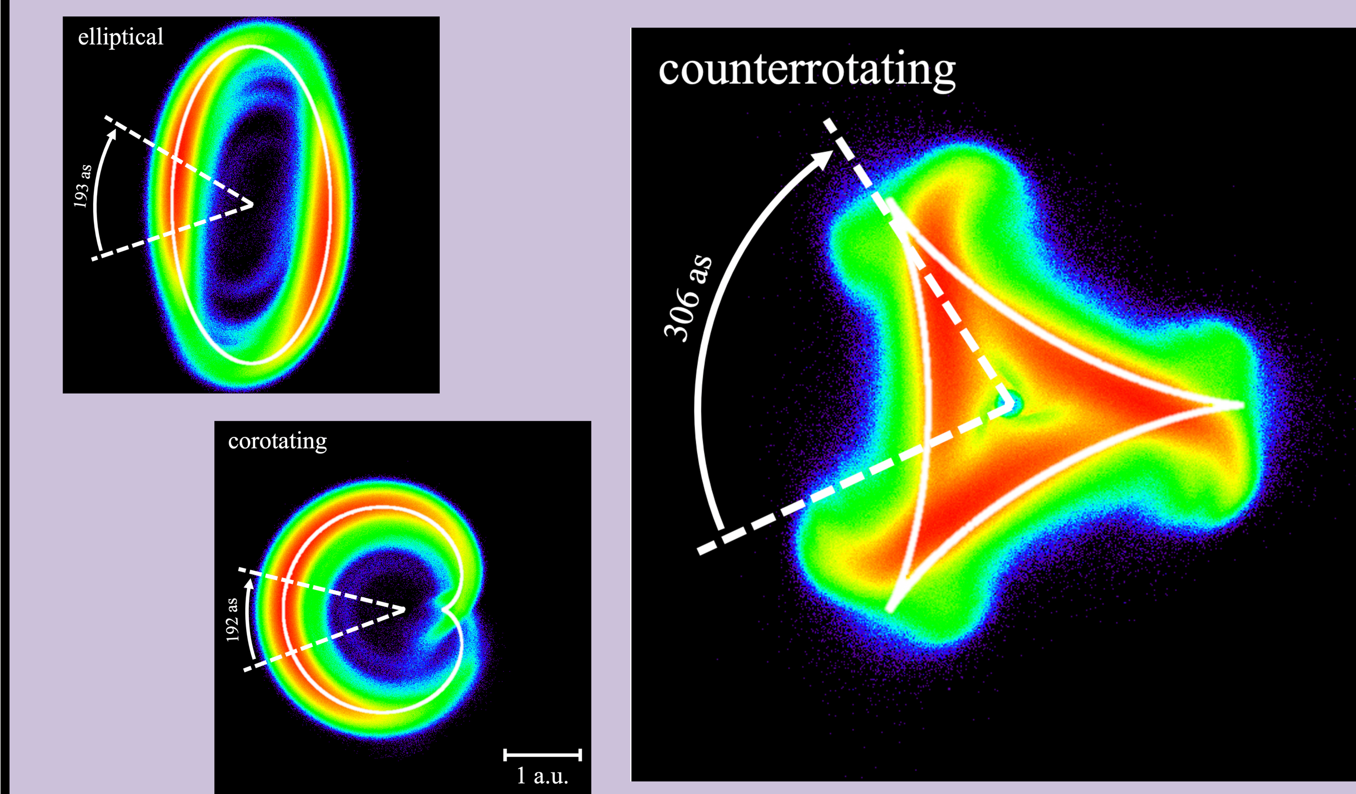
Simple Trajectories



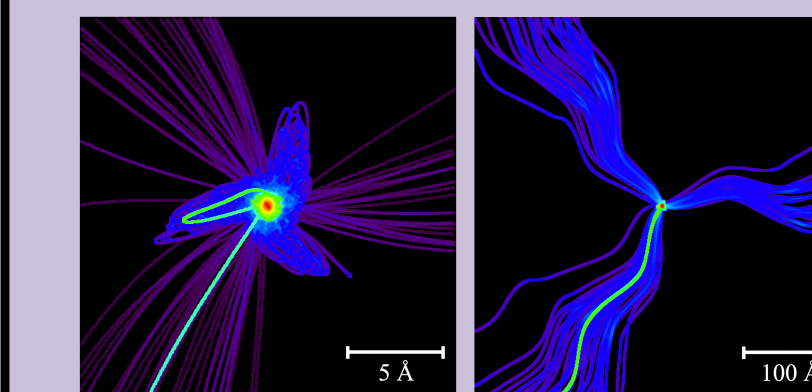
Bicircular laser fields are generated by combining two pulses of circularly polarized light of different colors, rotating in the same (corotating) or opposite (counterrotating) directions. In this work we study the effect of intense 2ω:ω pulses (400nm : 800nm) interacting with a model helium atom using the classical ensemble computational method. In order to set the stage for the results from the full simulation, the "simpleman model" is first used, where the effects of the Coulomb potential are ignored and the electron is released into the field with zero kinetic energy. An electron released at the peak of a β=1.0 counterrotating pulse (above left, where β equals the amplitude ratio of the two frequencies) is driven primarily away from the parent ion by the looping electric field, while release across all phases of the field results in a triangular electron momentum distribution, as shown by the negative vector potential. A β=2.0 counterrotating pulse (middle) supports returning electron trajectories for release at the peak of the field, while a β=2.0 corotating pulse (right) leads to returning trajectories for release at a field *minimum*. So while it is possible to drive rescattering with both counterrotating and corotating pulses, it is expected to occur at a much lower rate for corotating pulses.

Single Ionization Electron Momenta

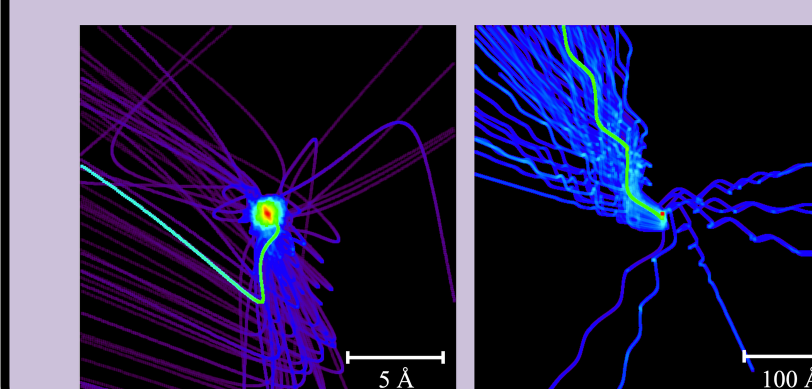


The electron momentum distributions in the transverse plane for elliptical (ε=0.5), counterrotating (β=1.0), and corotating (β=1.0) pulses show the clear effect of the ionic potential on electron trajectories and the resulting final momenta. The lower dashed lines indicate where the distributions should peak if the ionic potential is ignored, and the upper dashed lines indicate where the distributions actually peak. This shift to later times is most pronounced for counterrotating fields, where the electron trajectories are in general closer to the ion.

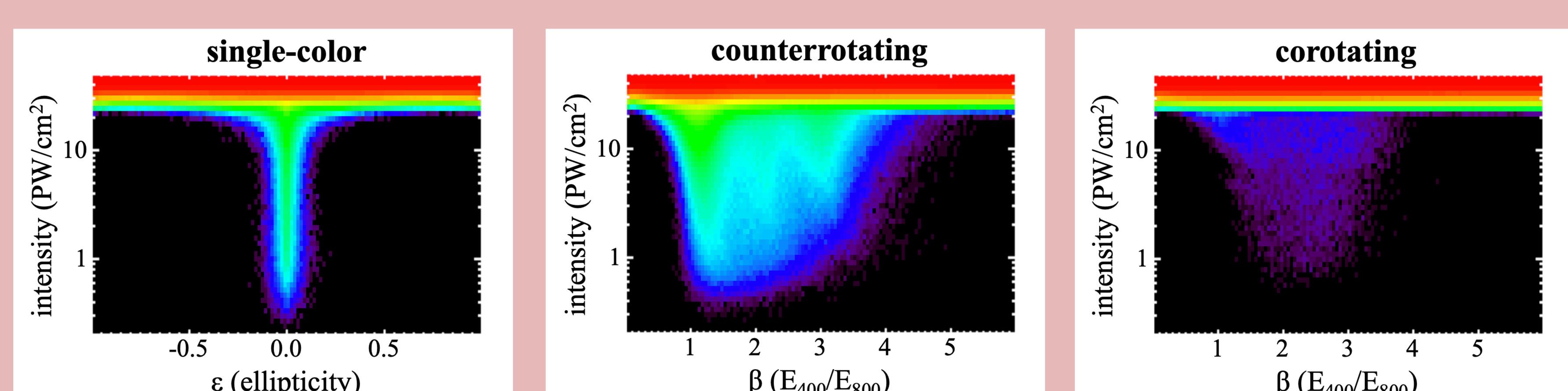
Electron Trajectories



Electron trajectories from small ensembles of 100 simulation runs show how interaction with the ionic potential results in high energy electrons (>75 eV, above) as well as how the electrons released near the peak of the field (±1 as, below) do not drift directly to the left as predicted by the simpleman model, but have their trajectories significantly distorted.

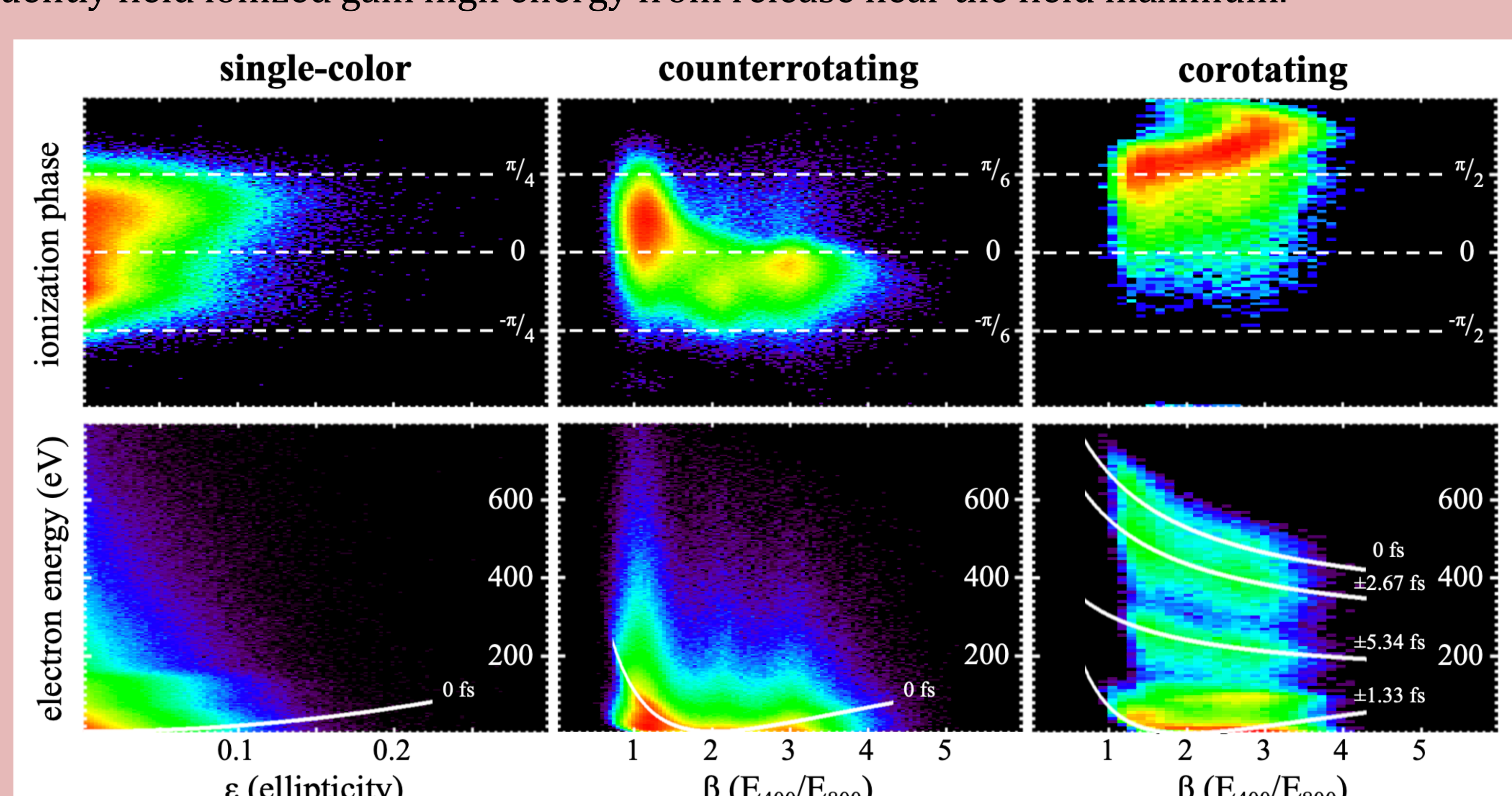


Double Ionization Yield, Phase, and Energy

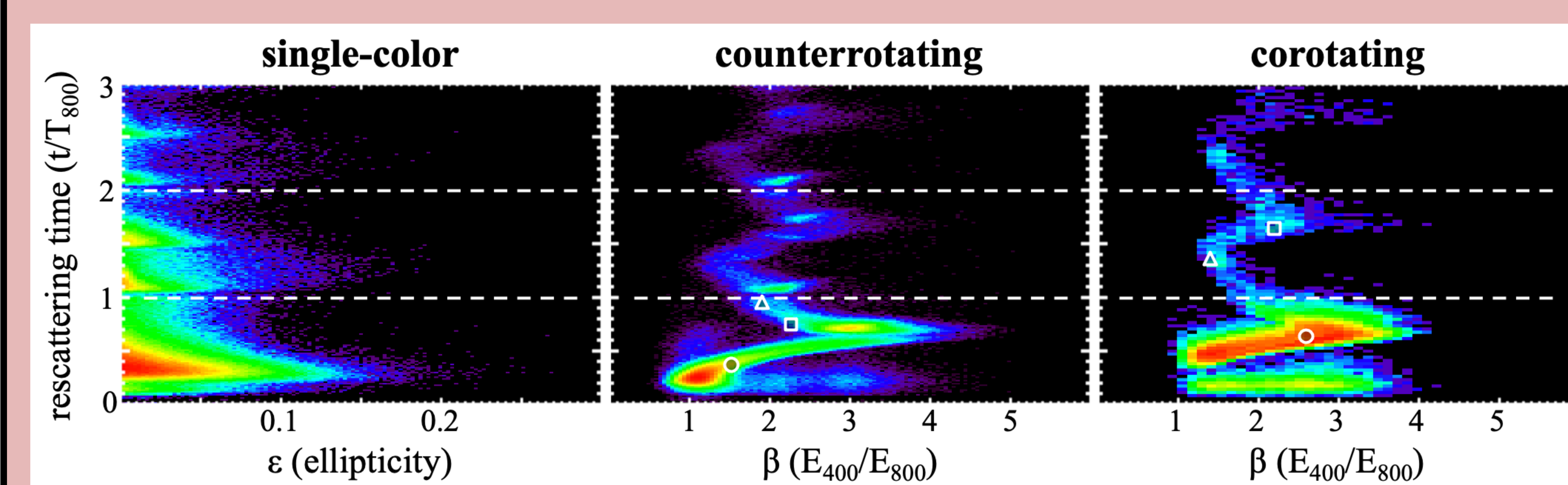


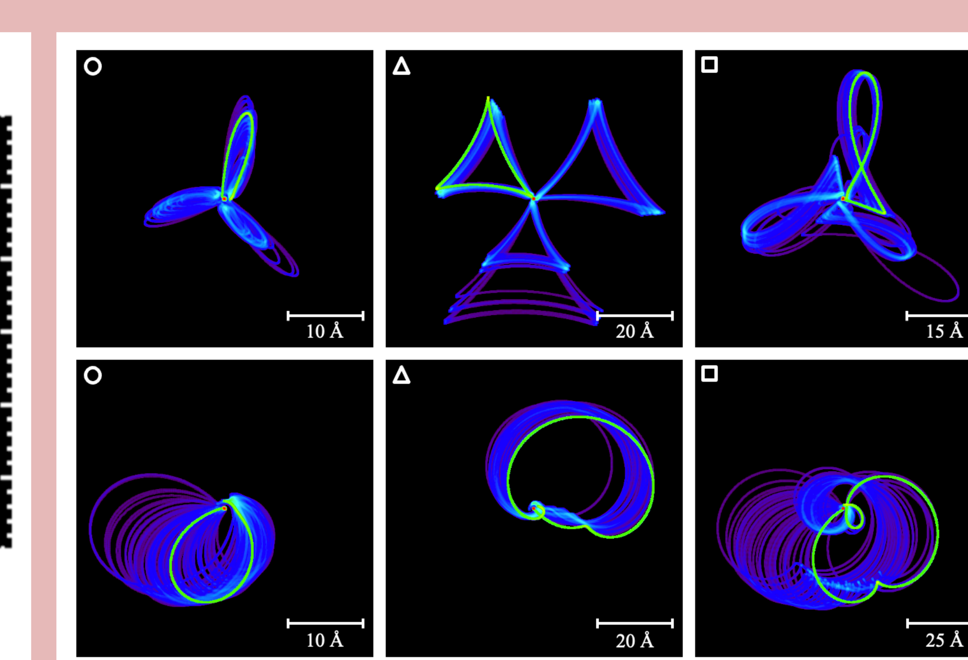
Double ionization yields as a function of intensity and ellipticity show non-sequential double ionization (NSDI) only for linear or mildly elliptical single-color pulses (above left). But counterrotating bicircular pulses generate significant NSDI across a broad range of amplitude ratios (middle). Corotating fields also generate a broad region of NSDI, albeit at a much lower rate (right).

The ionization phase for bicircular pulses varies as a function of amplitude ratio (below), indicating sensitivity to the rescattering trajectories that contribute to NSDI. For corotating fields, ionization occurs near the field minimum, resulting in low electron energies, while electrons that are excited and subsequently field ionized gain high energy from release near the field maximum.



Double Ionization Timing, Electron Momenta, and Trajectories





Rescattering timing, defined as the time from the release of the first electron to its time of nearest return, shows fascinating structure for bicircular pulses (above left), corresponding to specific electron trajectories (above right). For counterrotating fields, the trajectories that contribute to rescattering are either looping, triangular, or a combination of the two. For the case of the "fish-shaped" trajectory, the electron returns to the ion along a very different path than its original release trajectory.

Different ionization pathways can be distinguished in the resulting electron momentum distributions. For example, the patterns generated with a β=2.0 counterrotating pulse (below left) by the first and second electron released through impact ionization are significantly different than those generated through excitation ionization. The composite image shows which mechanism is most likely throughout the total electron momentum distribution in the transverse plane. For a β=3.0 corotating pulse (middle), the differentiation is much more dramatic, since returning trajectories occur for release near the field minimum, while field ionization occurs near the field maximum. Finally, the contribution to double ionization from looping or triangular trajectories with a β=2.0 counterrotating pulse is shown (right).