# Strong field double ionization of Helium with ultra-short phase stabilized circularly polarized laser pulses

**M. S. Schöffler*†[1], X. Xie†, S. Roither†, D. Kartashov†, A. Baltuska†, M. Kitzler†**

* Institut für Kernphysik, Goethe University Frankfurt, Frankfurt, Germany
† Photonics Institute, Vienna University of Technology, Vienna, Austria

**Synopsis:** We have studied the double ionization of Helium induced by intense (up to $1\times10^{16}$ W/cm$^2$) ultra-short (4-4.5 fs) circularly polarized laser pulses with a stabilized CEO phase.

In the past 20 years numerous experiments have studied double ionization of atoms in strong laser fields. While the first electron is released via tunnel-ionization, the remaining second electron is released either due to another tunnel ionization (sequential), or due to a recollision-process, with the first electron (non-sequential). The sequential process becomes dominant at high intensities. For circular polarization only sequential ionization is possible.

Pioneering experiments by Maharjan and coworkers have shown that [1] the momentum distribution of $Ne^{2+}$ when ionized by circularly polarized light shows two distinct peaks. This was explained by the sum and difference momenta of the two sequentially emitted electrons. In the relative angle between the two electrons the time between the two emissions is encoded on an attosecond scale (see angular streaking by Eckle et al. [2]).

For our studies we used a COLTRIMS reaction microscope (Cold Target Recoil Ion Momentum Spectroscopy) [3]. The target was provided by a supersonic gas jet of pre cooled Helium atoms. Two sharp moveable knife edges sliced the gas jet to a size of ≈20 µm, much shorter than the Rayleigh length. This reduced the diminishing influence of intensity averaging within the focal volume. With a spherical mirror of 60 mm focal length we achieved intensities up to $1\times10^{16}$ W/cm$^2$, pulse durations as short as 4-4.5 fs (FWHM) and a circularity of 85 %. Additionally we measured the carrier envelope offset (CEO) phase [4] for every single laser shot in coincidence with the ion's momentum. The created ions were projected with a weak homogenous electric field onto a position and time sensitive detector with delay line anode for position read out.

Fig. 1 shows the $He^{2+}$ momentum distribution in the polarization plane integrated over all CEO phases (left) and for certain phase (right). In contrast to all previous experiments this shows not only two, but rather three rings!

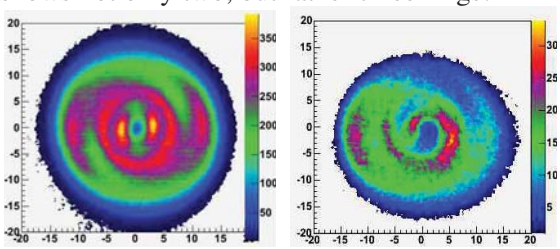

**Figure 1.** $He^{2+}$ momentum distribution in the polarization plane. (Left) integrated over all CEO phases, (Right) for a certain CEO phase.

This very surprising and exciting result cannot be understood in the simple picture of sum and difference momentum of the electrons. Even in such a short laser pulse the electrons can be released at different laser (half-)cycles, leading to different momenta for the first and second released electrons. Various combinations finally lead to more than the well-known double ring structure. A snap shot of the ionization process is shown in fig. 1 (right), where the CEO phase was fixed. Here even 4 peaks/rings, can be observed, corresponding to two different ionization times for the 1st and 2nd released electron.

Simulations using the strong field approximation show qualitative agreement, but similarly to the experiment both are extremely sensitive to all optical parameters of the pulse as intensity and pulse duration.

## References

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†[1] E-mail: schoeffler@atom.uni-frankfurt.de