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Divergence control of High-Harmonic Generation

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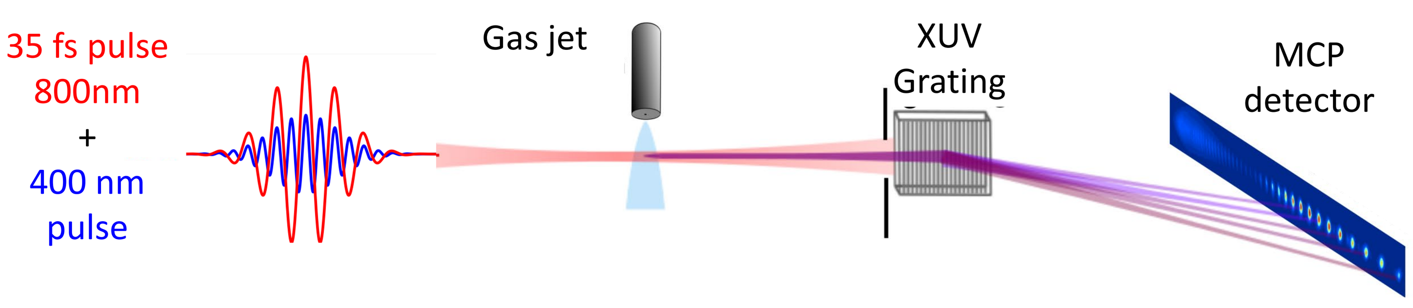
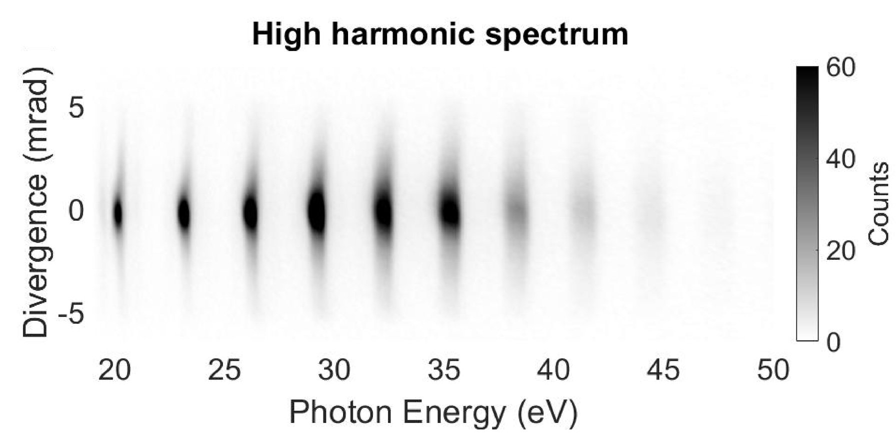
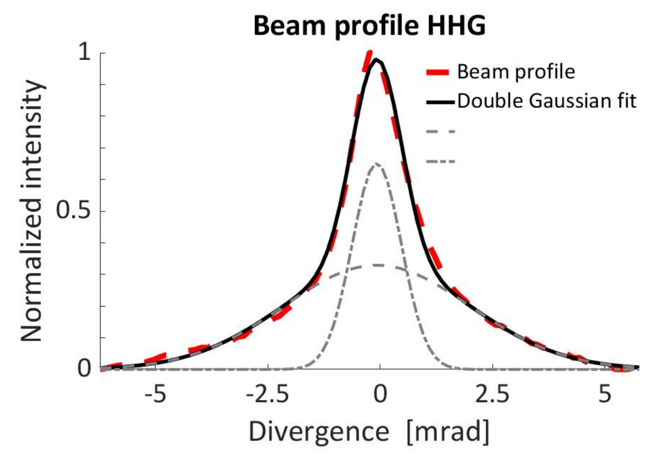
Introduction

High-harmonic generation (HHG) is a technique that enables broadband, ultrafast, and highly coherent extreme ultraviolet sources. However, the conversion efficiency of the process is low, but most applications of HHG require high-brightness sources. In addition, the HHG pulses have a double-Gaussian beam profile that gives rise to chromatic aberrations, which are rooted in the quantum-mechanical nature of the generation mechanism. By using both 800 nm and 400 nm femtosecond pulses for the generation process, we can manipulate the attosecond electron dynamics of the HHG process, which impacts the phase front of the generated pulses. We have shown by an extensive parameter study that the relative polarization, the ratio between and the phase of the two fields can be used to improve the beam profile by suppressing the tails of the spatial profile, while increasing the yield. Our result pave the way towards high-brightness HHG sources with improved beam profiles.







Origin of divergence in HHG

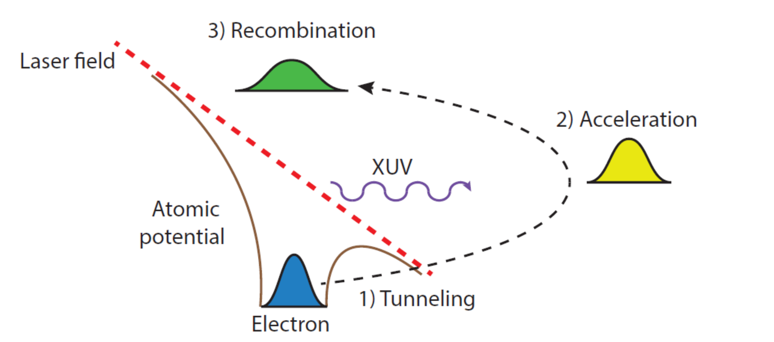


Fig. 1 – Three step model of HHG. 1) Tunneling of the electron out of the atomic potential. 2) Acceleration of the electron in the electric field of the laser, therefore gaining kinetic energy. 3) Recombination of the electron with the parent ion.

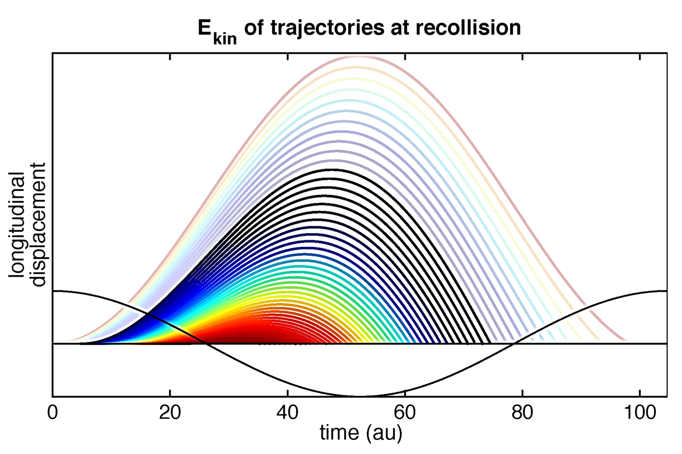


Fig. 2 – The ionization time determines the trajectory of the electron and the energy of the emitted photon (different colors). There are two trajectories that contribute to each energy: Long and short.

$$\phi_{i,q}^{total} = q\psi_f + \varphi_{i,q}^{dipole}$$

q = harmonic order

$i = s, l;$

$$\varphi_{i,q}^{dipole} = \alpha_i I(r)$$

$\alpha_s \ll \alpha_l$

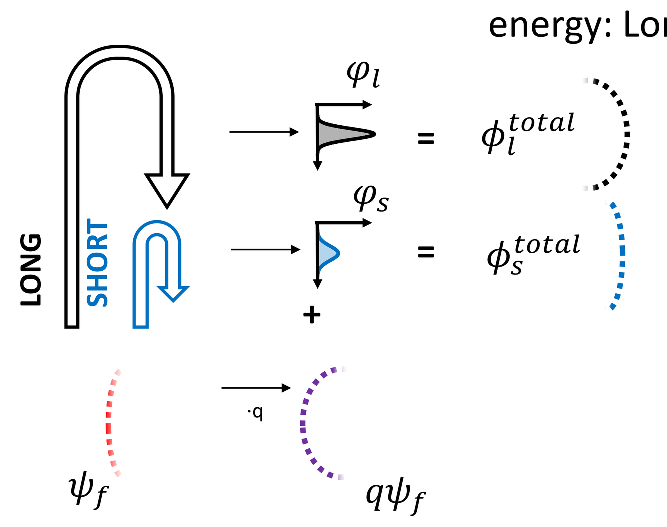
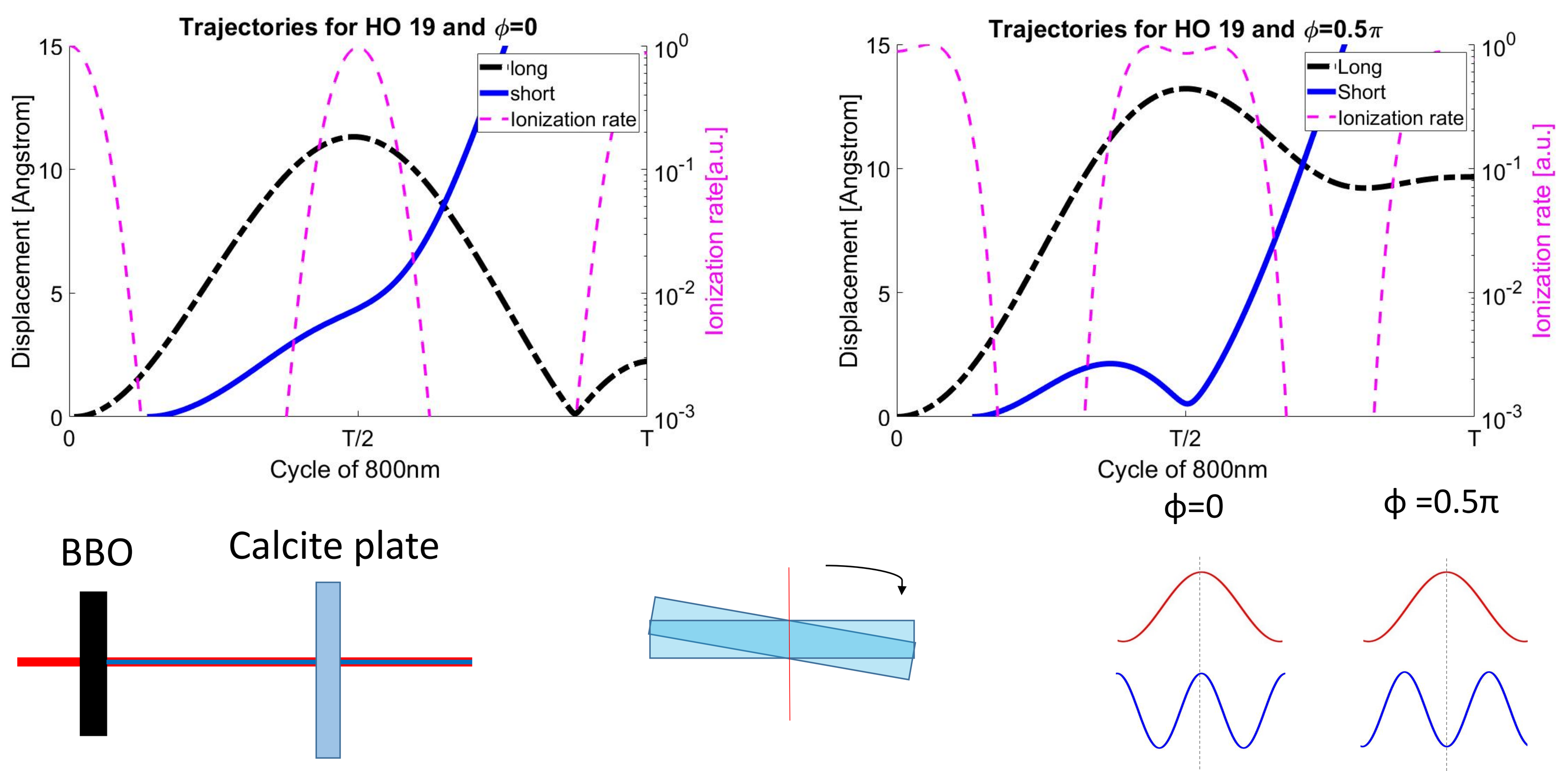


Fig. 3 – The divergence of the HHG is directly related to the phase front curvature of the beam, which is related to the excursion of the electron

Trajectory Selection



Results

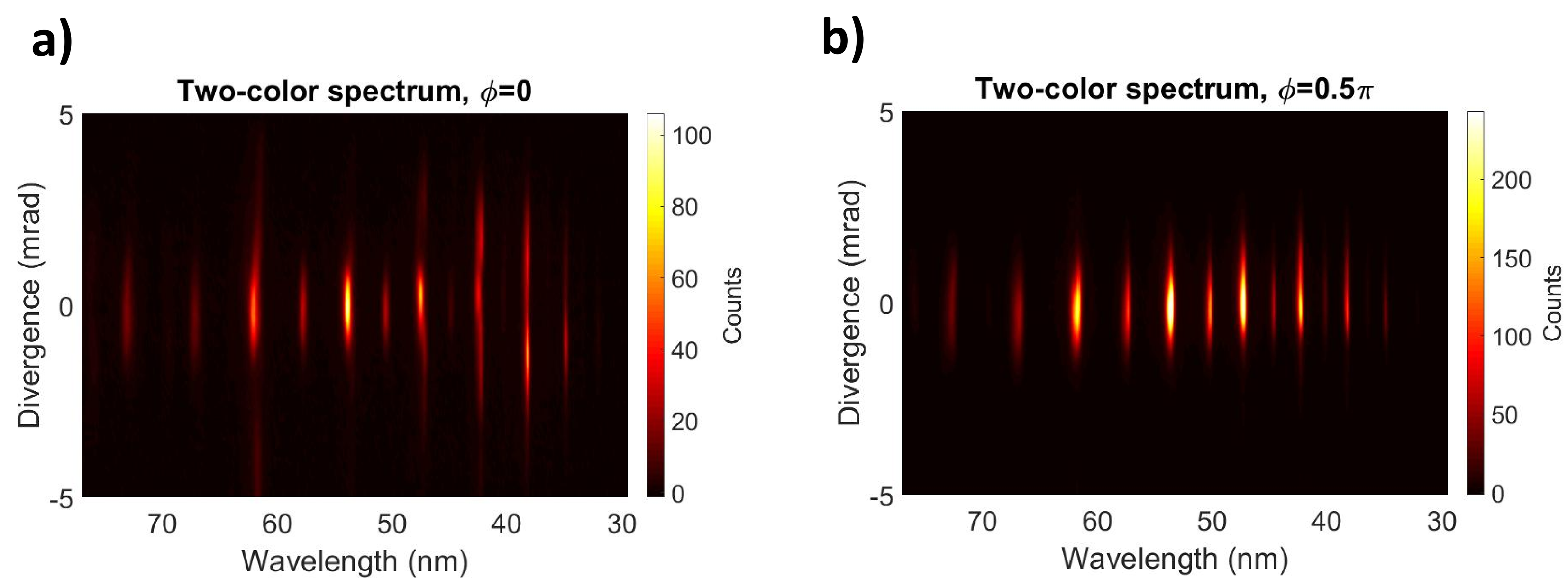


Fig. 4 – a) The harmonic spectrum for a relative phase delay of 0 rad. b) The harmonic spectrum for a relative phase of 0.5 π rad.

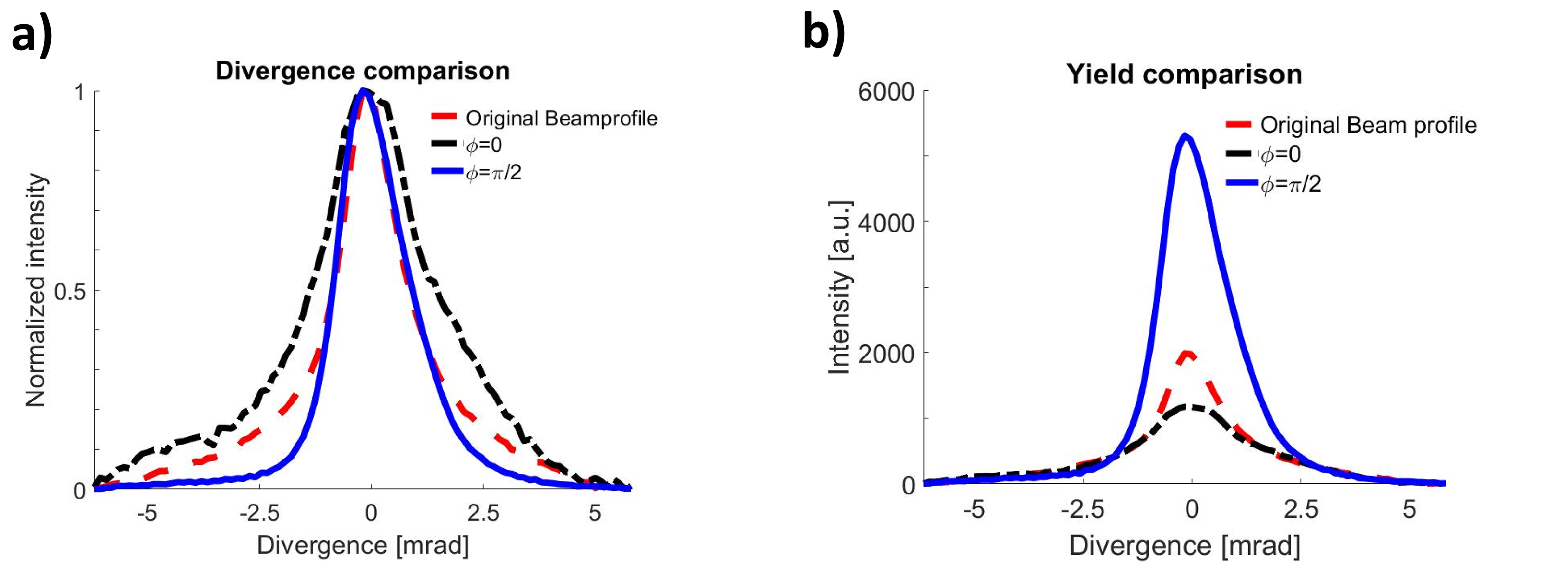


Fig. 5 – a) The normalized beam profile of the harmonic spectrum, showing suppression of signal in the wings for a relative phase of 0.5 π. b) The beam profile of the harmonic spectrum, showing an increased yield for a relative phase of 0.5 π. For both profiles the gas jet was positioned before the focus and the relative intensity of the 400 nm was 25%.

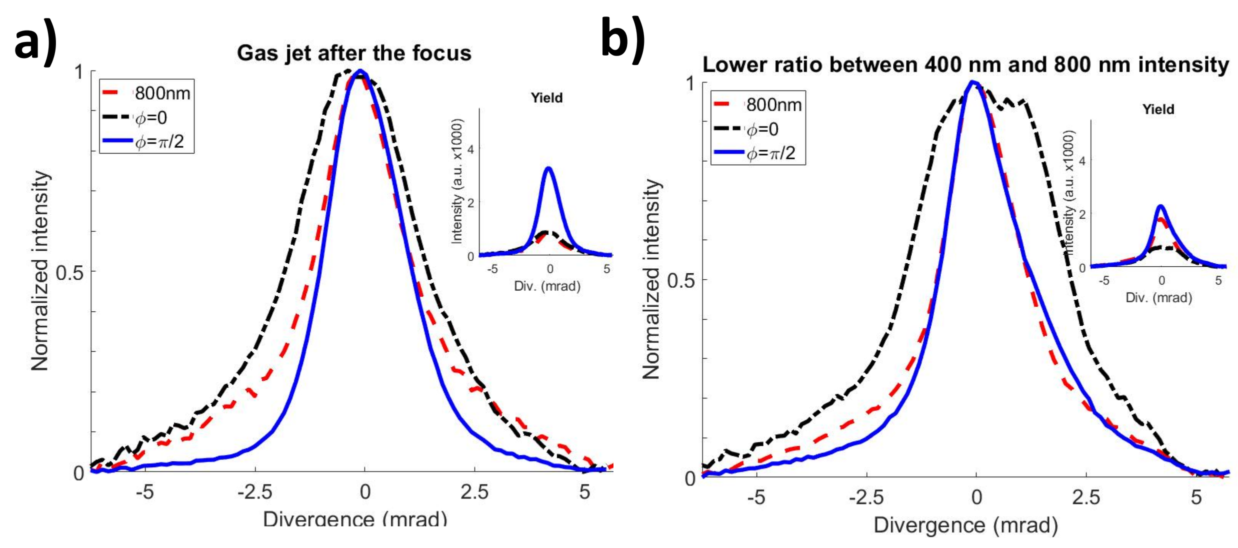


Fig. 6 – Divergence and yield comparison for **a)** gas jet after the focus and **b)** 11% relative intensity of 400 nm compared to 800 nm.

Conclusion

- Adding a perpendicular 400nm pulse to the generation process enables divergence control, while at the same time increasing the photon yield.
- Trajectory selection enables divergence control, while manipulation of the instantaneous ionization rate influences the yield.
- Easy to implement optics.
- Enables micro-focussing of HHG: interesting for nonlinear XUV spectroscopy, imaging and diffraction metrology applications.

References

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