High Harmonic Generation with Two Non-Collinear Drivers: A Unique Gateway to Extreme Nonlinear Phenomena

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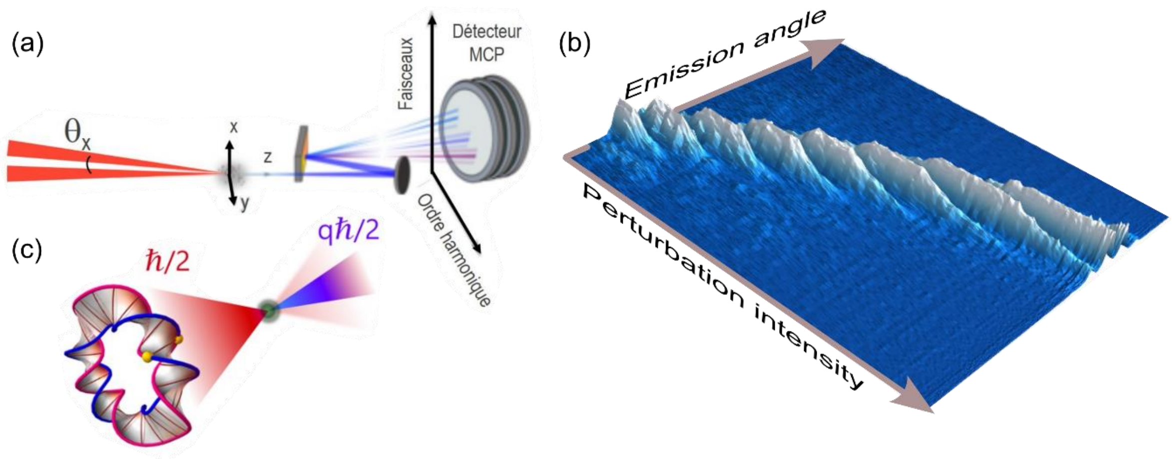
The ability to generate attosecond-duration light pulses provides powerful tools to probe and track the ultrafast dynamics of electrons in atoms, molecules, and condensed matter. At the heart of these new light sources lies high-order harmonic generation (HHG), a process traditionally understood as the interaction between matter and an intense laser field. Recently, however, HHG has been revisited as a versatile platform for extreme quantum optics. When driven by two laser beams, multiple harmonic beamlets are emitted for each order, naturally leading to an interpretation in terms of photon interactions. This framework allows for a retrieval of fundamental conservation laws, including those governing energy, spin, and orbital angular momenta, as established over the past decade. However, a fully photon-based interpretation for the yield of the harmonic beamlets has remained elusive.

We will present experimental evidence showing that HHG can indeed be described as a superposition of simultaneous photonic processes. Specifically, the harmonic generation results from the coherent addition of multiple interfering processes. Beyond the minimum number of photons required to produce a given harmonic, each harmonic channel involves one or more additional photon pairs, associated with the combination of stimulated absorption and emission events. A simple theoretical model enumerating the different contributing pathways has been proposed and is in agreement with experimental data.

In the second part of this seminar, we will show how HHG serves as an ideal testbed for advanced nonlinear optics. Notably, when HHG is driven by structured beams—beams that are neither eigenstates of spin nor orbital angular momentum, but rather a hybrid of both—the generalized angular momentum is transferred to the harmonics. This discovery establishes deeper connections between quantum optics and extreme nonlinear optics, while opening new avenues for angular momentum engineering. These results promise novel spectroscopic techniques, enabling access to specific quantum states through new selection rules and facilitating the study of asymmetric structures.



(a) Experimental sketch of HHG with two non collinear drivers. The angle between the two drivers is along x, while the grating disperses along y. (b) Yields of harmonic beamlets emitted at different emission angle along x, as a function of the intensity of the perturbing beam. (c) Sketch of HHG driven by two beams forming a polarization Möbius strip.

References

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