# Study of High Harmonic Generation in high repetition rate systems

A.Pelissier, Arthur K.Mills, David Jones - *July 2017*

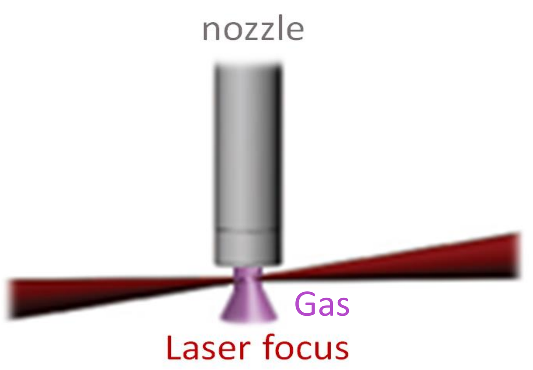
Ultrafast Spectroscopy laboratory, Dept. of Physics & Astronomy, University of British Columbia, Vancouver, Canada

ULTRAFAST SPECTROSCOPY LABORATORY

## Abstract

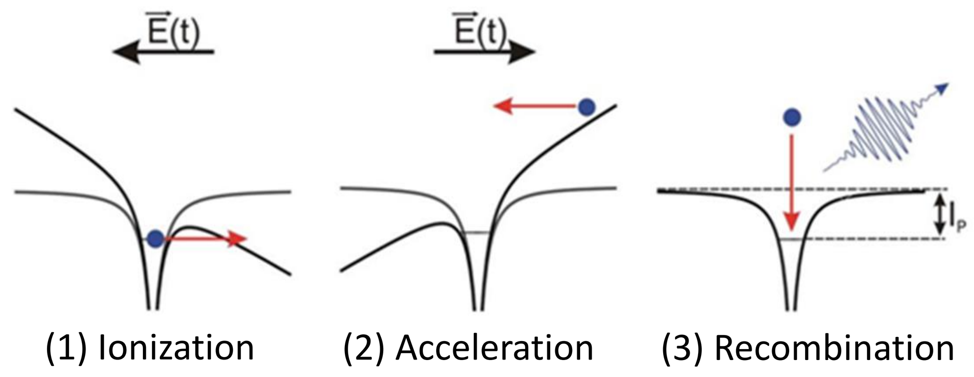
High Harmonic Generation (HHG) is a highly nonlinear process and adjusting the parameters such as driving field intensity, gas pressure or nozzle diameter to optimize the power output is not obvious. We calculate the high harmonics amplitude considering supersonic gas flow at the nozzle outlet, ions dynamic in the plasma, quantum atomic response, phase matching and absorption. Measurements conducted with a femtosecond enhancement cavity (fsEC) and numerical simulations performed with *MATLAB* and *COMSOL* are presented.

## I. High Harmonic Generation (HHG)




- ✓ Create coherent XUV light
- ✓ Use a noble gas target
- × Intense laser field required
- × Highly nonlinear process

### *The semi-classical three steps model*

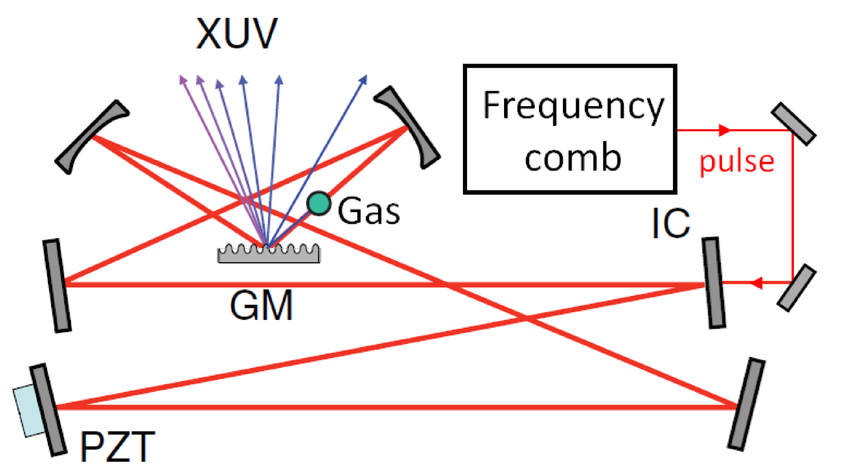



*XUV generation due to the recombination of electron steered by an intense laser field*

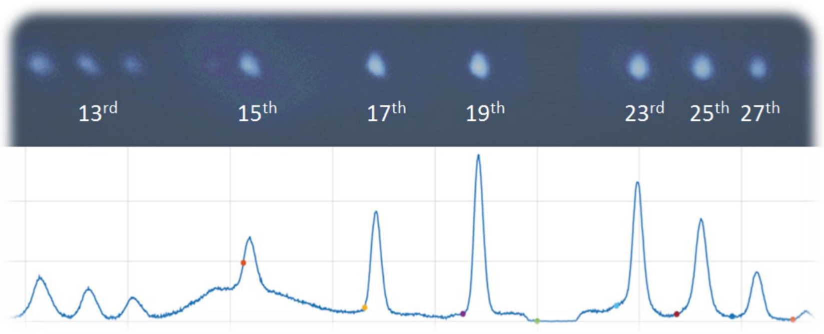
### *Harmonic order*

- = Ratio between the fundamental and the harmonic wavelength
- It is an odd number
- Limited by the ionization potential and the laser field intensity.

## II. Femtosecond Enhancement Cavity (fsEC)




*Experimental setup*




*Measured harmonic spectra*

### *High repetition rate*

- The laser frequency is 60 MHz (17 ns between each pulse).
- The light has to do a complete cavity round between each pulse.
- Extreme precision of the cavity length is required.

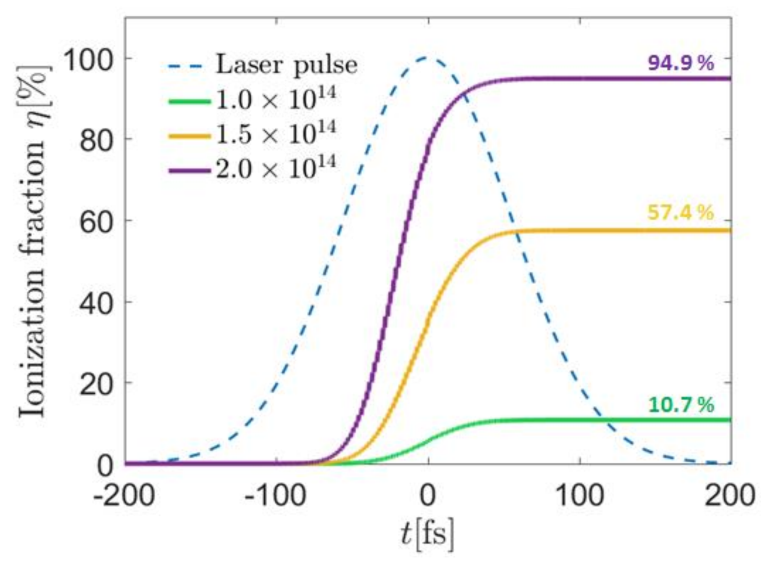
### *Tight focus*

- The high power involved in the HHG process require a tight focus (beam radius of 20 um).

## III. Ions and atom dynamic

### *Laser Ionization*

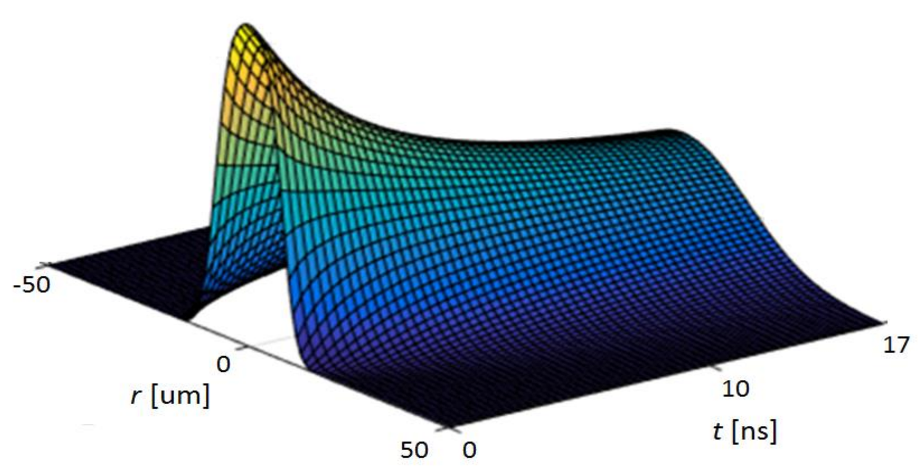
- The intense laser electric field ionize the gas target, it is highly nonlinear with intensity.




*Ionization by the laser pulse for different peak intensities (W/cm²)*

### *Decay between pulses*

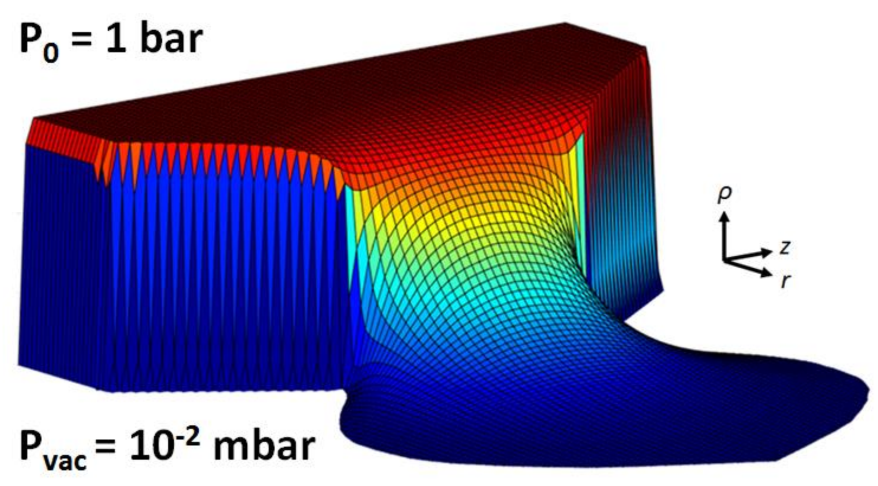
- **Recombination:** The population of ionized atoms may recombine to an excited neutral state.
- **Ambipolar diffusion:** Freed electron leave behind a positive charge density of ions which will then be drawn away by the resulting electric field.




*Ions decay with ambipolar diffusion and recombination between each pulse*

### *Gas expansion at the nozzle outlet*

- High pressure gradient between the nozzle ($P_0$) and the vacuum chamber ($P_{vac}$).
- The gas expand at the nozzle outlet at supersonic speed ($V$ = 300 m/s).

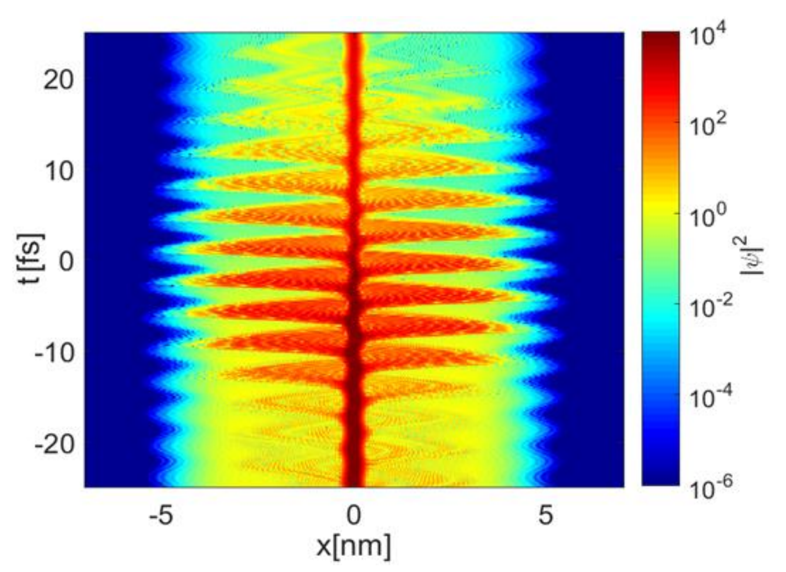



*Gas density distribution at the nozzle outlet*

## IV. Harmonics amplitude calculation

### *Dipole response*

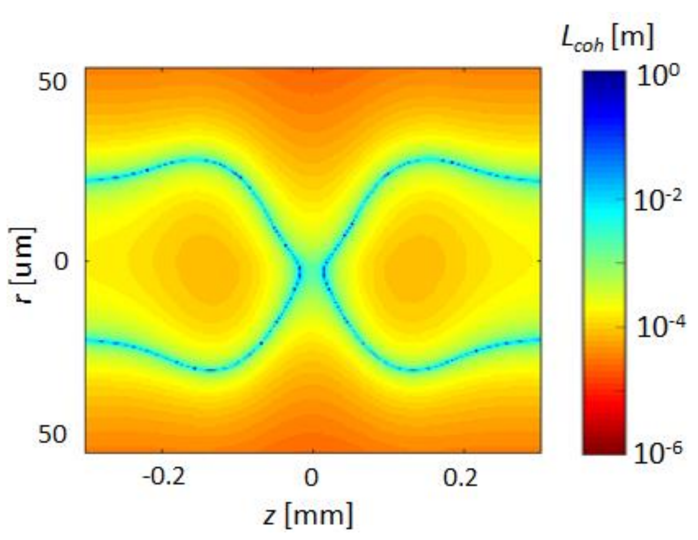
- The atomic response is calculated with the Schrödinger equation.




*Time evolution of the electron wave-function in the space domain*

### *Phase matching*

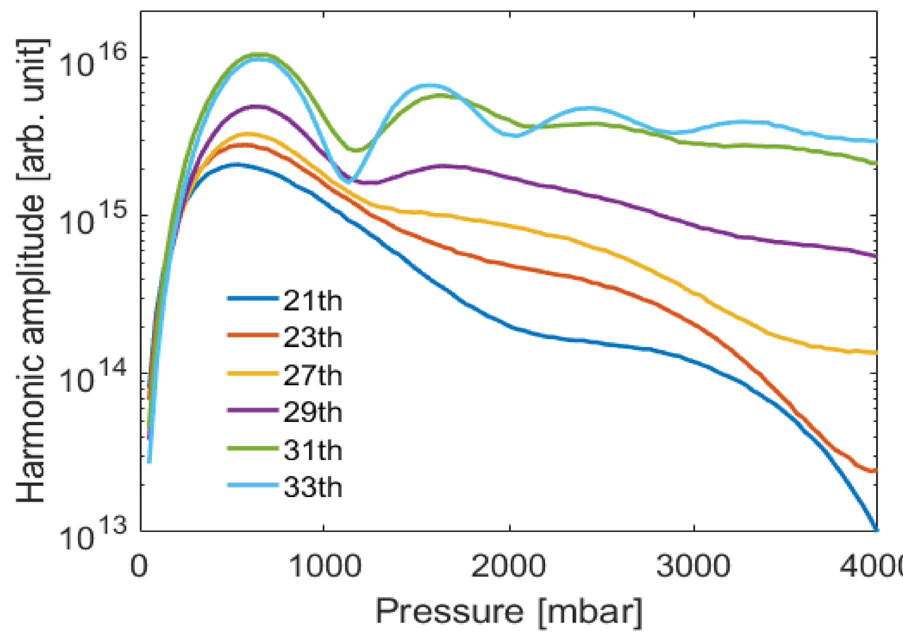
- The amplitude of the generated field is maximized when the phase mismatch between the fundamental and harmonics is zero.
- The phase matching is strongly affected by ions.




*Surface plot of the coherence length near the focus*

### *Harmonic power output*

- The harmonic amplitude can now be calculated.




*Calculated Harmonic amplitude as a function of pressure for harmonics 21rd to 33th*