High Harmonic Generation in Laser Plasma Interaction

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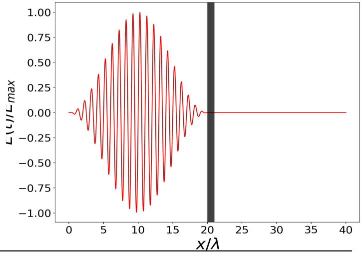
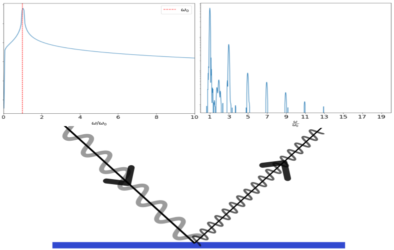
Introduction

Ultra high light intensity interactions with matter provide an opportunity to investigate new physical phenomena that have yet to be explored or have been only minimally explored in laboratory settings.

- Intensity of $10^{23}\ W/cm^2$ has been reached experimentally.[1]
- QED at $I = 10^{25} W/cm^2$. Schwinger field at $I = 10^{29} W/cm^2$.[2]
- Plasma is overdense if $\omega < \omega_p$.
- Harmonics are generated by interaction of laser with overdense plasma.





[1] *Henri Vincenti* 10.1103/physrevlett.123.105001

[2] *Jin Woo Yoon et al* 10.1364/OPTICA.420520

Summary of Work Done in the Previous Semester

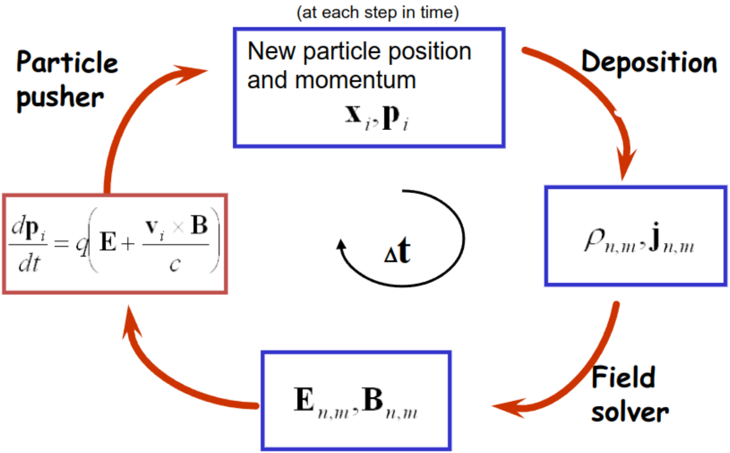
- Interaction of intense laser pulse with overdense and underdense plasma
- Change in effective critical density of plasma for relativistic laser pulse
- The oscillations of plasma surface increases with increase in intensity and surface oscillations have even harmonics.
- Study of high harmonics generation in normal incidence
  - Only odd harmonics are generated
  - Increasing intensity and pulse duration increases number of harmonics
  - No effect due to envelopes
- Study of high harmonics generation in oblique incidence
  - For p-polarization E_x gives even harmonics and E_y gives odd harmonics
  - For s-polarization E_z gives odd harmonics and E_x gives even harmonics

What Now?

- Effect of pre-plasma
- Effect of Super Gaussian (SG) envelope
- 2D simulation for oblique incidence and different polarization

PIC Algorithm

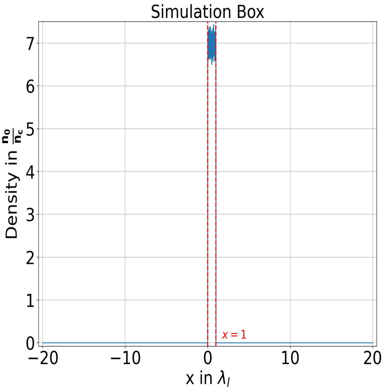
PIC is a numerical approach that simulates a collection of particles that interact via external and self-induced electromagnetic fields.



Simulation Details: 1D

We want to study the effect of super Gaussian envelope on the generated high harmonics. We performed some simulations in 1D3V. Here are some parameters:

- Particles per cell: 100
- Number of cells: 16000
- Wavelength $\lambda_l = 1\mu m$
- Pulse duration $= 20\tau$ ($\tau \approx 3.3fs$)
- Simulation time $= 40\tau$
- Intensity of laser for $a_0 = 0.5$ is $I = 3.425 \times 10^{17} W/cm^2$
- The density to critical density ratio is $n_0/n_c = 4$



Previously, we performed simulations with p- and s-polarized laser incidence at oblique angle in 1D.

Oblique Incidence: Transformations

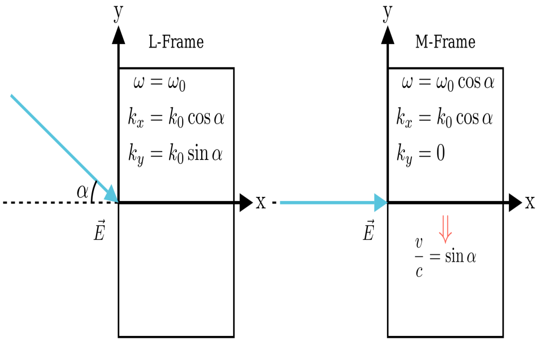
- We follow Bourdier[3] to make a transformation which lets us simulate oblique incidence in 1D.

For p-polarization

$$\mathbf{E}_L = E_0(-\sin\alpha\hat{x} + \cos\alpha\hat{y})$$
$$\mathbf{E}_M = E_0\cos\alpha\hat{y}$$
$$c\mathbf{B}_L = E_0\hat{z}$$
$$c\mathbf{B}_M = E_0\cos\alpha\hat{z}$$

For s-polarization

$$\mathbf{E}_L = E_0\hat{z}$$
$$\mathbf{E}_M = E_0\cos\alpha\hat{z}$$
$$c\mathbf{B}_L = E_0(\sin\alpha\hat{x} - \cos\alpha\hat{y})$$
$$c\mathbf{B}_M = -E_0\cos\alpha\hat{y}$$

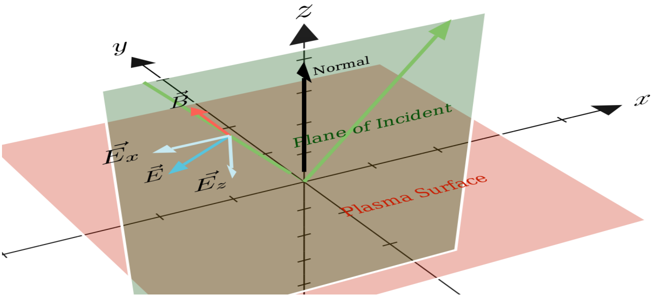


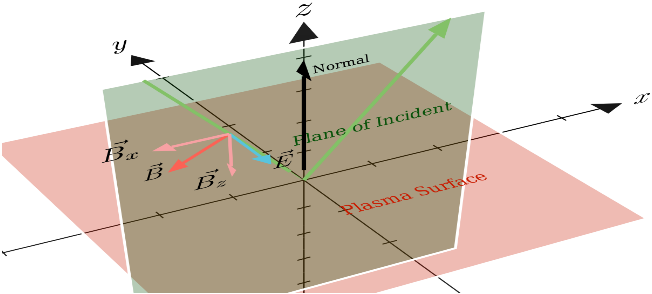
[3] *Bourdier,A.* 10 . 1063 / 1.864355

p- and s- Polarized Laser: Selection Rule

p-Polarization

p-Polarized: Even, Odd
s-Polarized: None

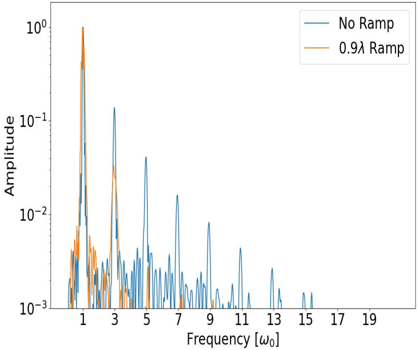




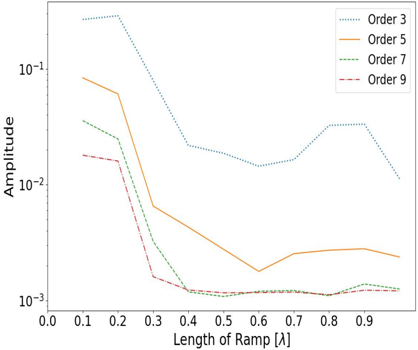
s-Polarization

p-Polarized: Even
s-Polarized: Odd

Results: Effect of Pre-Plasma

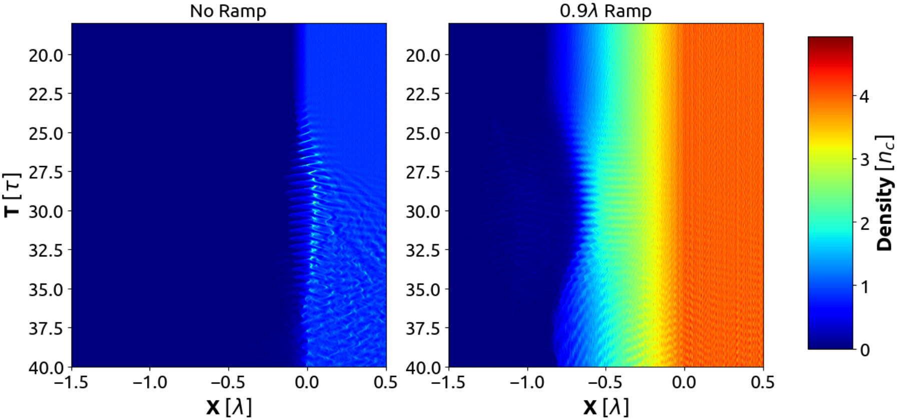


The spectrum of the reflected field with and without a pre-plasma. A suppression in the HHG amplitude is observed for case with pre-plasma.



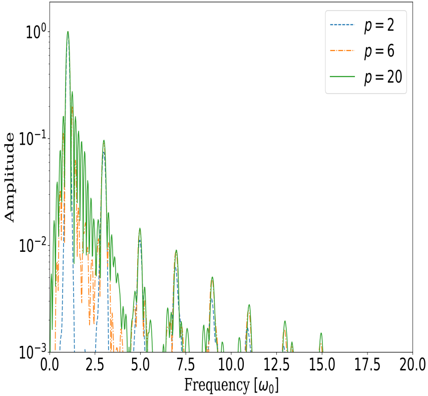
The peak of different harmonics for different ramp. The figure shows that as the ramp length increases, the amplitudes of the harmonics decreases.

Results: Effect of Pre-Plasma

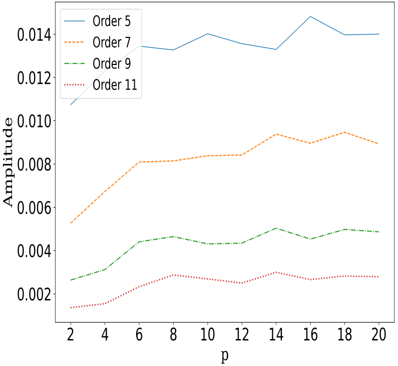


The laser is not able to interact with the main plasma and hence the efficiency of HHG is reduced.

Results: SG Envelope



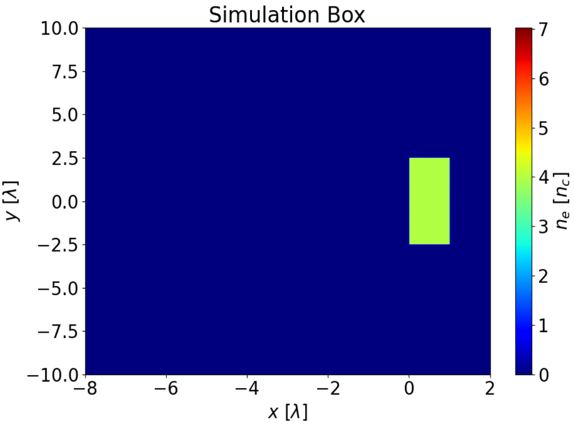
The spectrum of SG envelopes with power 2,6, and 20 is shown in a single plot. A small increase in the peak amplitude is observed with increasing power.



This figure shows the peak amplitude of the HHG as a function of the power of the SG envelope. The peak amplitude increases with increasing power.

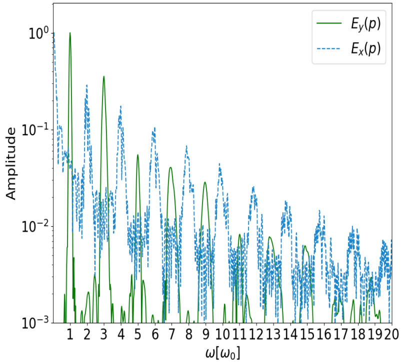
Simulation Details: 2D

To compare the results of the 1D oblique incidence using Bourdier transformation, we did some 2D simulations using EPOCH. Most of the simulation parameters are the same.

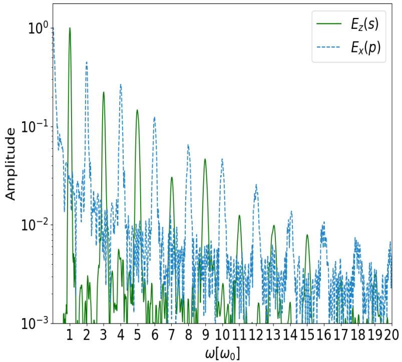


- Box size has been changed
- $N_x = 2000$ and $N_y = 4000$
- The pulse width is now 8τ
- Simulation is run for 30τ

Results: p- and s-Polarized Laser Using 1D Simulations

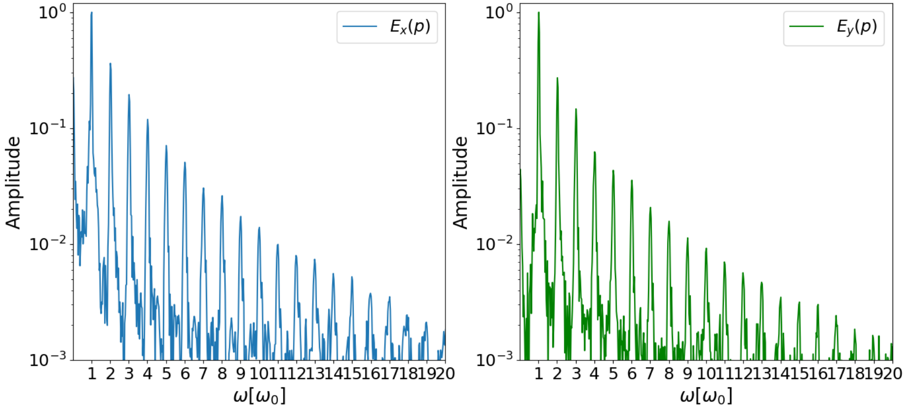


The spectrum of HHG for p-polarized light. Simulation parameters are $\alpha = \pi/4$, the density is $n_0 = 7n_c$ and $a_0 = 4$. We see that E_x gives rise to even harmonics and E_y gives rise to odd harmonics.



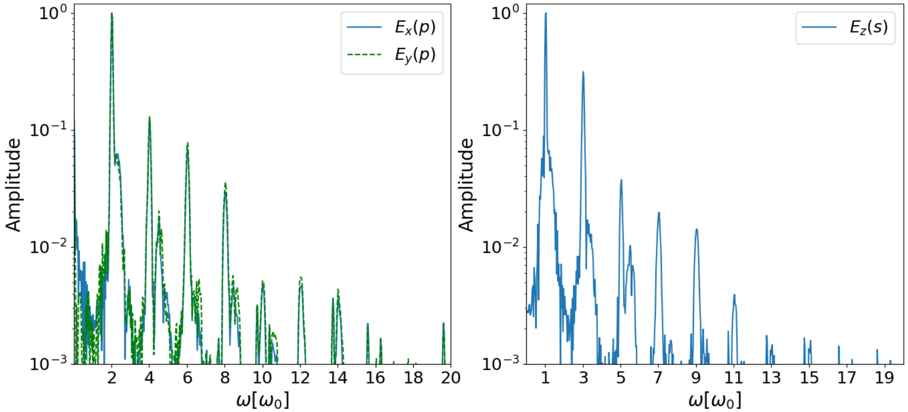
The spectrum of HHG for s-polarized light. Simulation parameters are $\alpha = \pi/4$, the density is $n_0 = 7n_c$ and $a_0 = 4$. Here s-polarized odd and p-polarized even harmonics are generated.

Results: p-Polarized Laser Using 2D Simulations



The spectrum shows that both E_x and E_y has odd as well as even harmonics, in contrast with the 1D case. E_z is zero. Simulation parameters are $\alpha = \pi/4$, the density is $n_0 = 7n_c$ and $a_0 = 4$.

Results: s-Polarized Laser Using 2D Simulations



Fields E_x and E_y has even harmonics, as expected by the selection rule. E_z has odd harmonics. This time, results are similar to the 1D case. Simulation parameters are $\alpha = \pi/4$, the density is $n_0 = 7n_c$ and $a_0 = 4$.

Current Status and Future Scope

Current Status

- Presence of pre-plasma reduces the quality of HHG generated.
- SG envelopes results in a small shift in peak amplitudes.
- For p-polarized laser, even and odd p-polarized harmonics.
- For s-polarized laser, odd s-polarized harmonics and even p-polarized harmonics.

Future Scope

- Study oblique incidence and polarization more rigorously.
- Do 2D simulations.
- Compare it with the 1D results.

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