Particle-in-cell simulation of a Laser-Wakefield based High gradient accelerator

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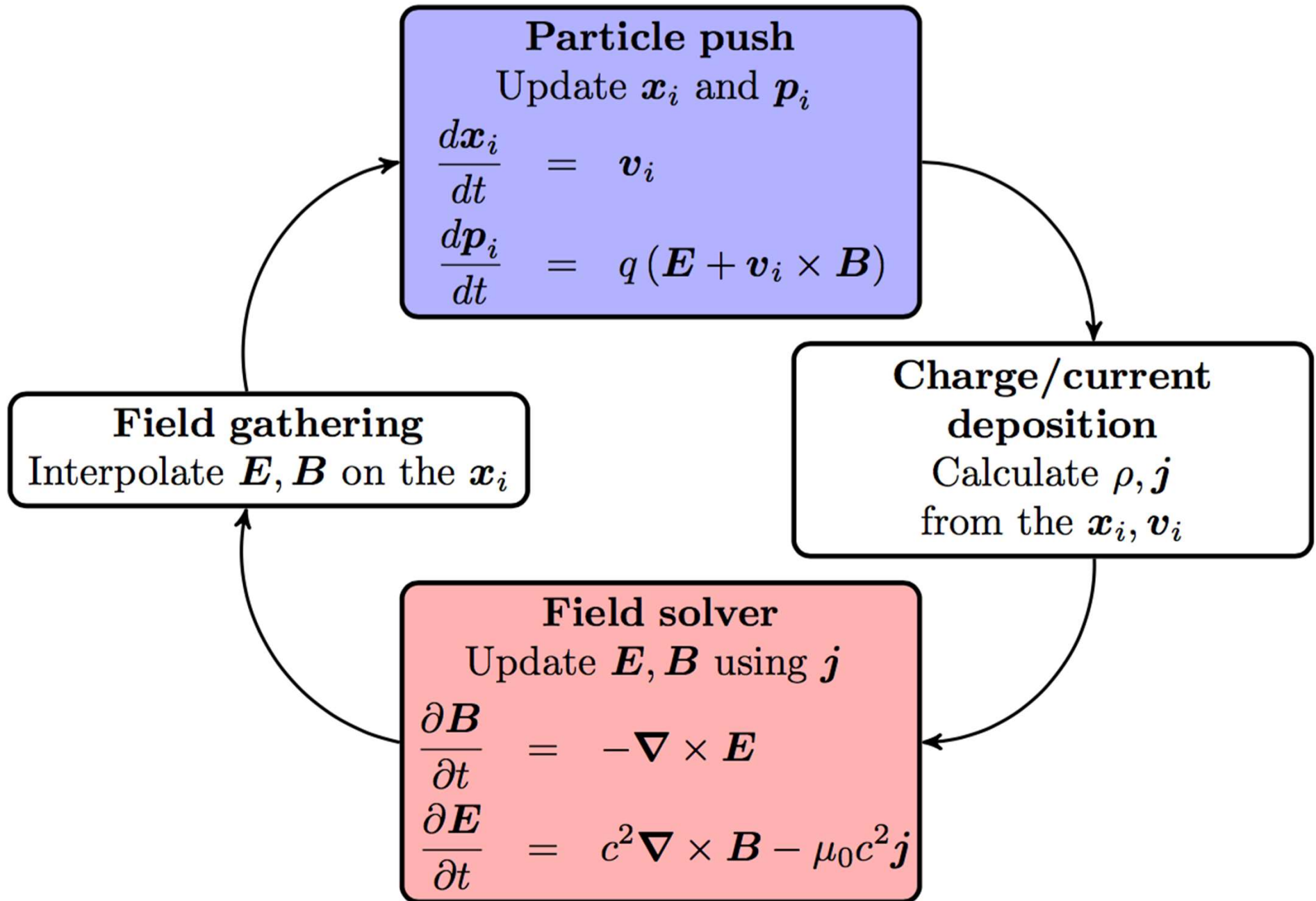M.P.C. Autonomous College Baripada, Odisha, India

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Introduction

›   We present Particle-in-cell simulation of a Laser-Wakefield based High gradient accelerator

›   This study is carried out using FBPIC particle in cell code.

›   FBPIC is a Specialized code, for plasma-based acceleration in nearly-cylindrical geometry

The Particle In Cell cycle

‣ The charged particles are represented by macroparticles (which lump together several physical particles), while the fields are represented on a grid.

‣ The time evolution of the system is simulated by taking discrete time steps.

‣ At each timestep:

– The values of E and B are gathered from the grid onto the macroparticles.

– The particles are pushed in time.

– The charge and current of the macroparticles are deposited onto the grid.

– The fields E and B are pushed in time.

Particle push
Update $\boldsymbol{x}_i$ and $\boldsymbol{p}_i$

$$\frac{d\boldsymbol{x}_i}{dt} = \boldsymbol{v}_i$$

$$\frac{d\boldsymbol{p}_i}{dt} = q\left(\boldsymbol{E} + \boldsymbol{v}_i \times \boldsymbol{B}\right)$$

Field gathering
Interpolate $\boldsymbol{E}, \boldsymbol{B}$ on the $\boldsymbol{x}_i$

Charge/current deposition
Calculate $\rho, \boldsymbol{j}$
from the $\boldsymbol{x}_i, \boldsymbol{v}_i$

Field solver
Update $\boldsymbol{E}, \boldsymbol{B}$ using $\boldsymbol{j}$

$$\frac{\partial \boldsymbol{B}}{\partial t} = -\boldsymbol{\nabla} \times \boldsymbol{E}$$

$$\frac{\partial \boldsymbol{E}}{\partial t} = c^2 \boldsymbol{\nabla} \times \boldsymbol{B} - \mu_0 c^2 \boldsymbol{j}$$

Cylindrical grid with azimuthal decomposition
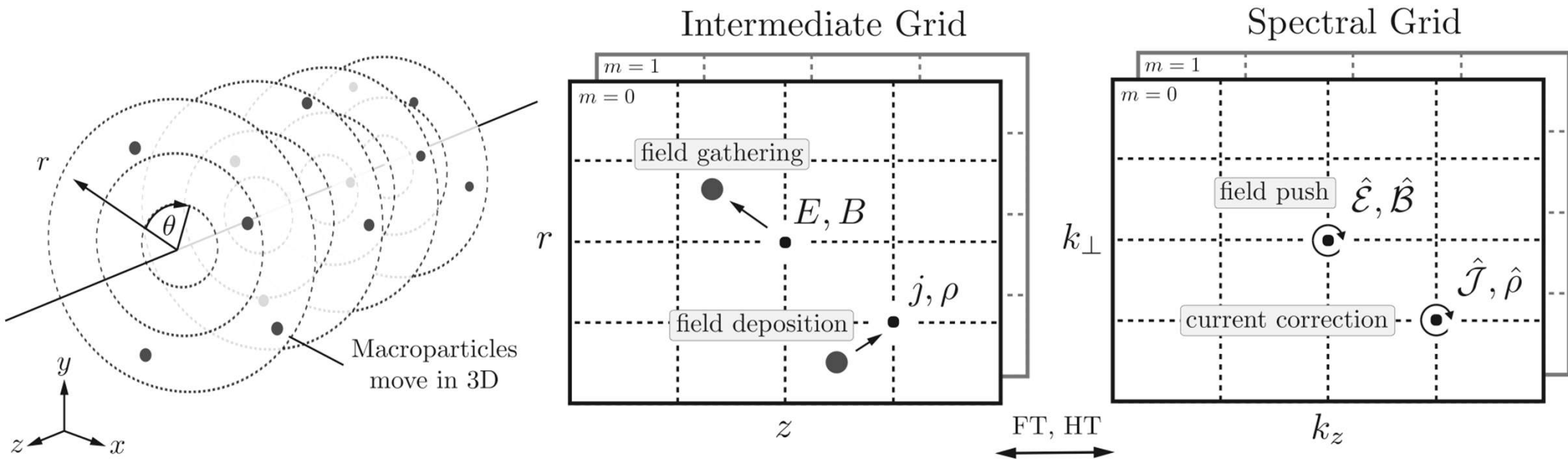
▶ The fields are decomposed into azimuthal modes

$$F(r, z, \theta) = Re \left[\sum_{m=0}^{N_m - 1} \hat{F}_m(r, z) e^{im\theta} \right]$$

▶ m=0: purely cylindrical mode

▶ m=1: dipole mode

▶ m=2: quadrupole mode

▶ Each azimuthal mode is represented by a 2D r-z grid

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Input Parameters for FBPIC simulation

Electron density	10^{19} cm^{-3}
Laser amplitude	2.0
Laser beam waist	6.2 μm
Laser duration	7 fs

(i) Ez in the mode all at 3.25e-13 s (iteration 2600)

(ii) rho in the mode all at 3.25e-13 s (iteration 2600)

(iii) electrons: t = 3.25e-13 s (iteration 2600)
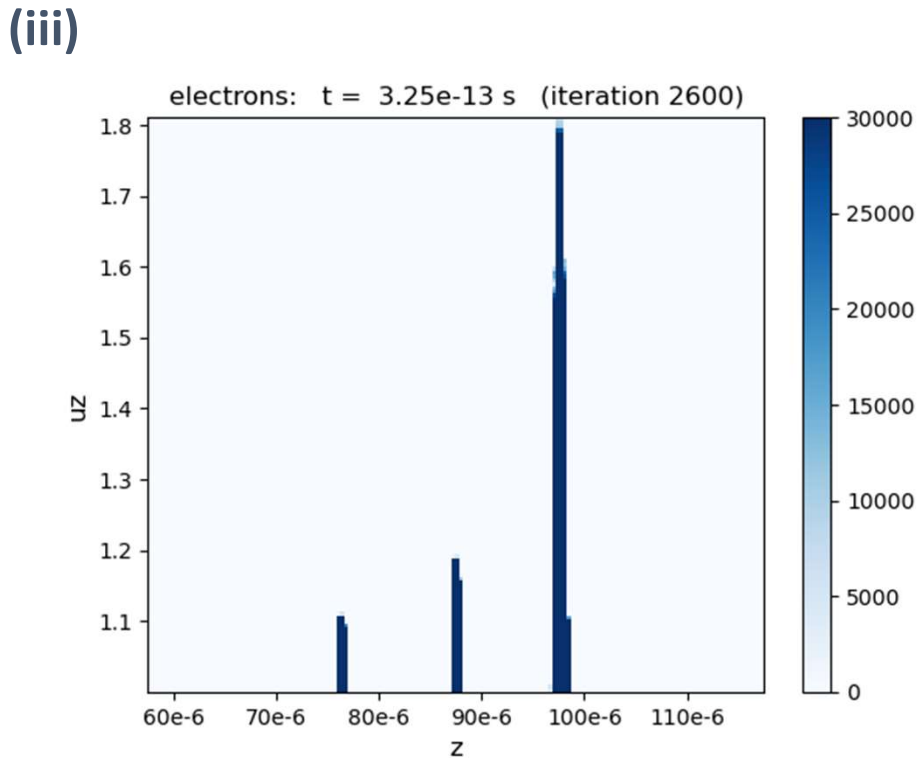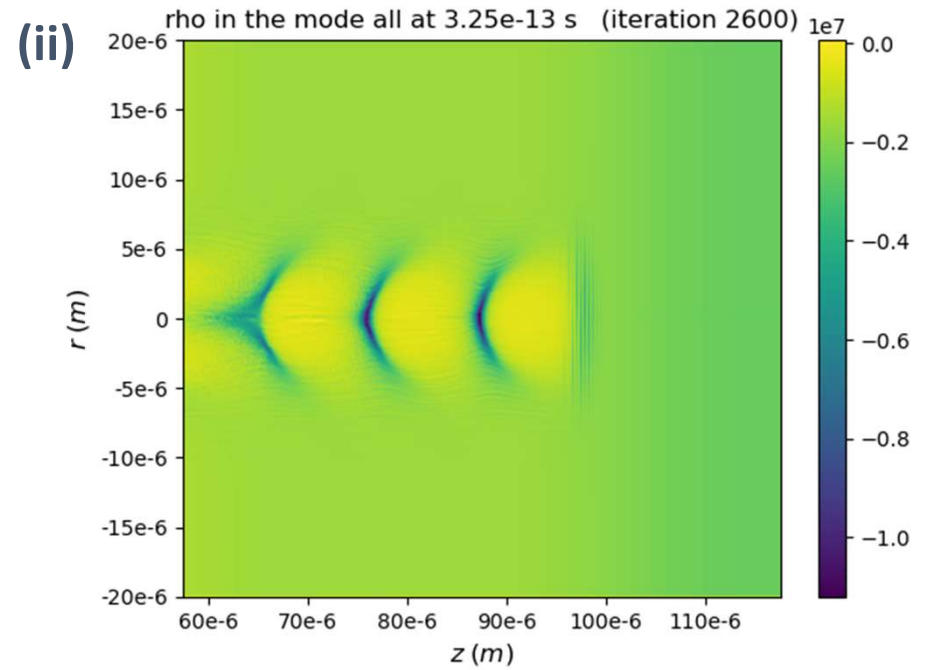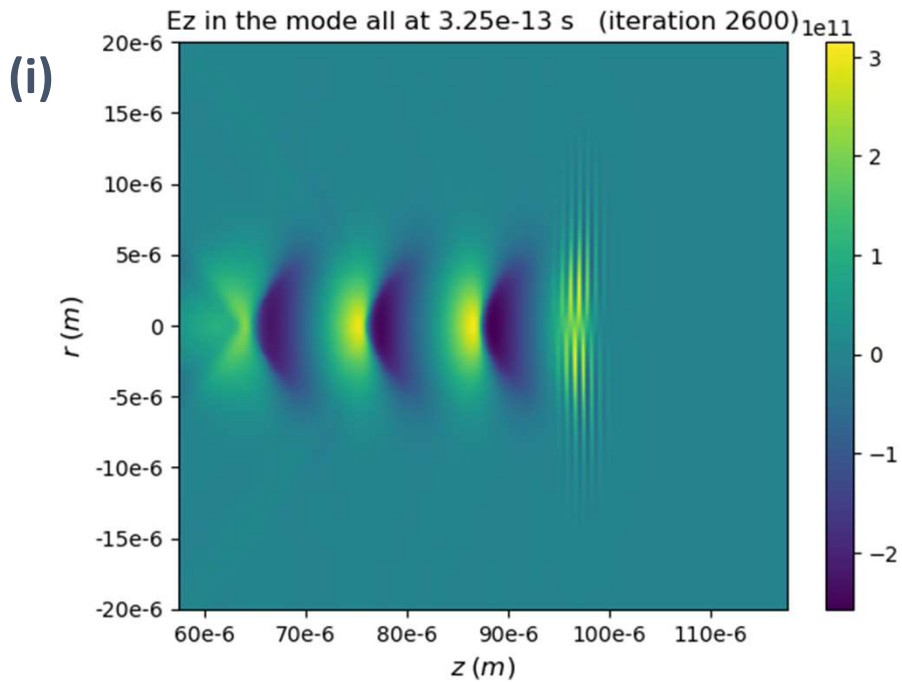
Figure : Before Density Modulation Wakefield of Laser Pulse and the accelerated electron bunch behind it (i) Electric field (ii) charge density (iii) phase space plot of electron bunch
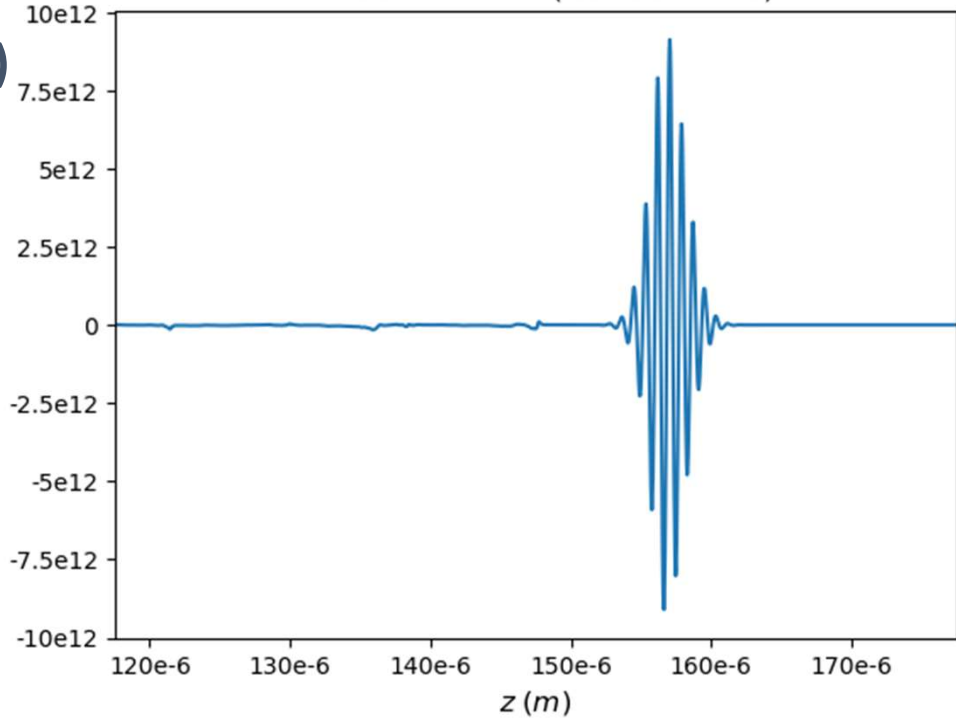
(i) Ez in the mode all at 5.25e-13 s (iteration 4200)

(ii) rho in the mode all at 5.25e-13 s (iteration 4200)

(iii) electrons: t = 5.25e-13 s (iteration 4200)
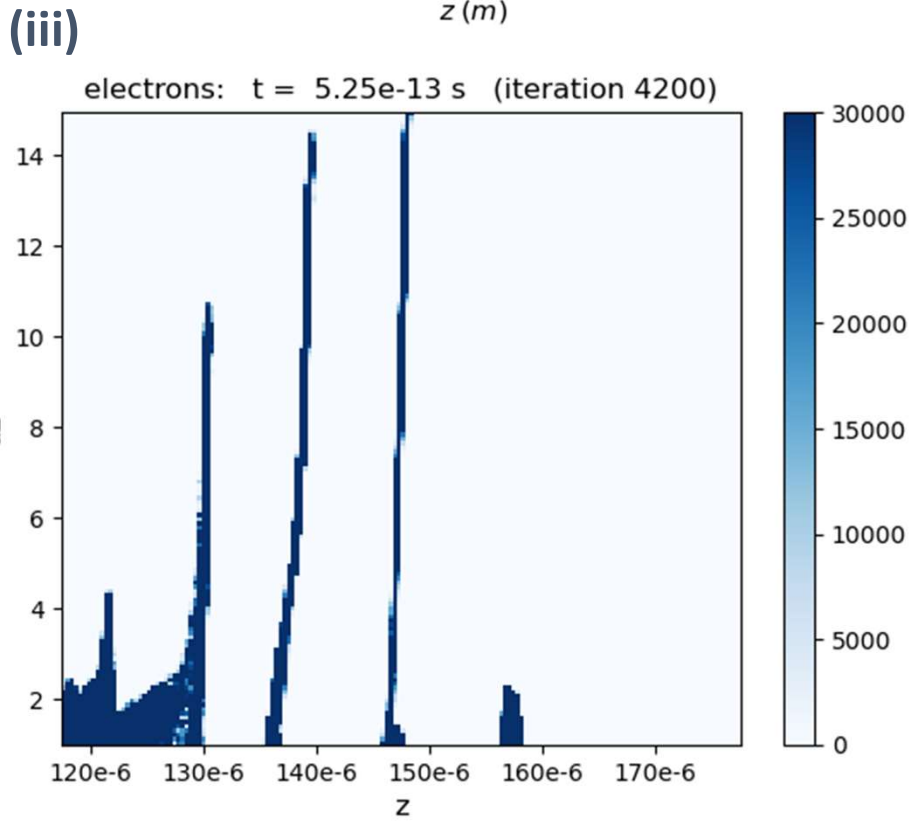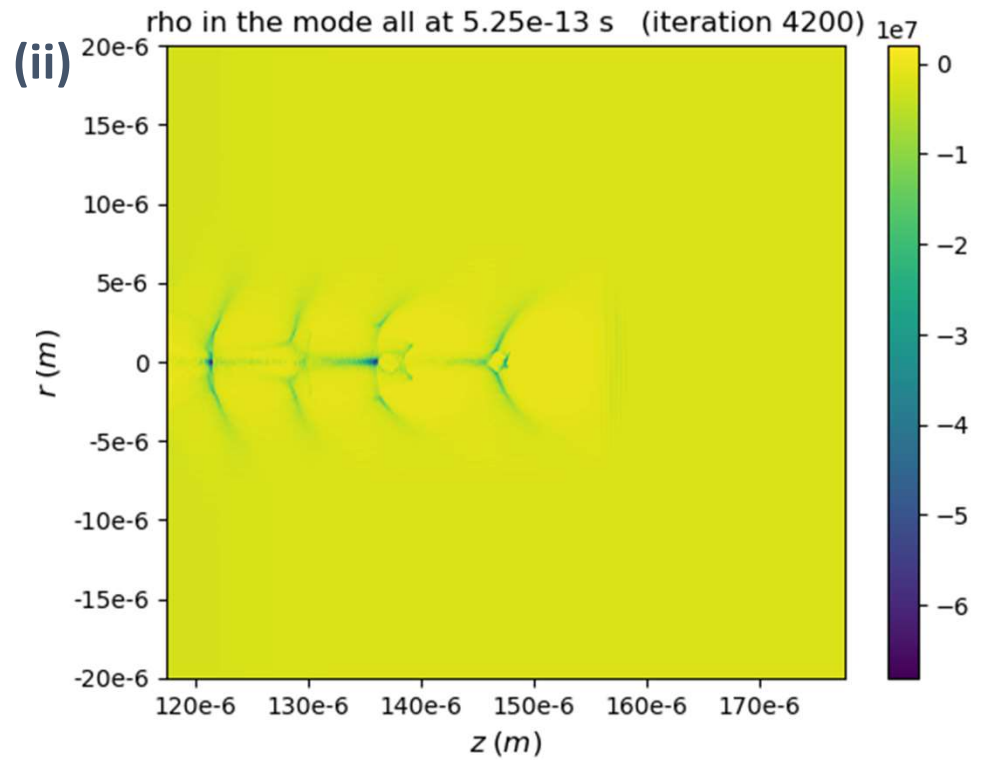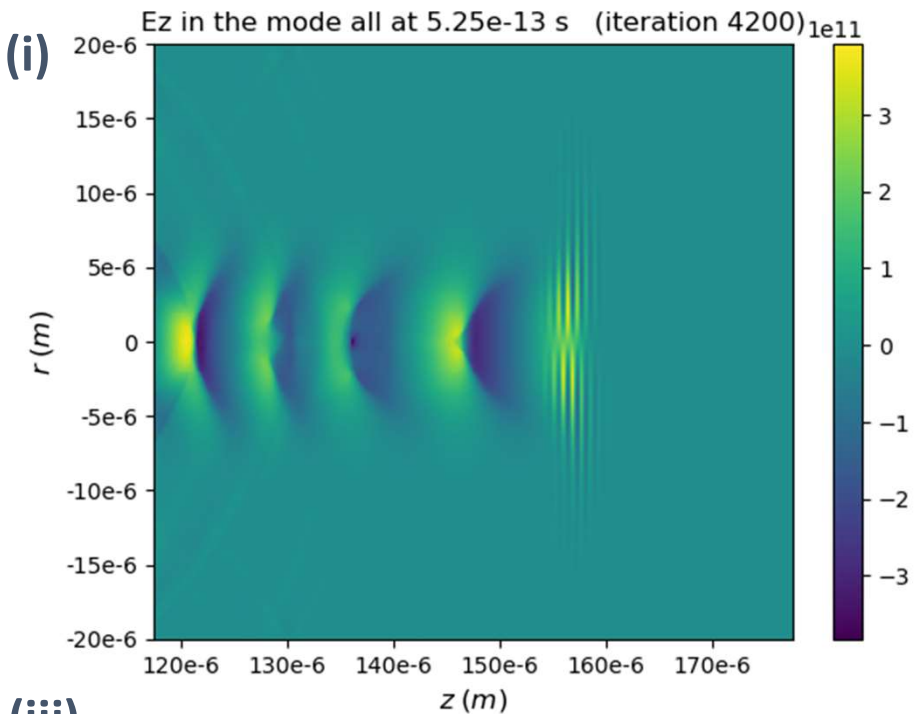
Figure : After Density Modulation Wakefield of Laser Pulse and the accelerated electron bunch behind it (i) Electric field (ii) charge density (iii) phase space plot of electron bunch

(iv)
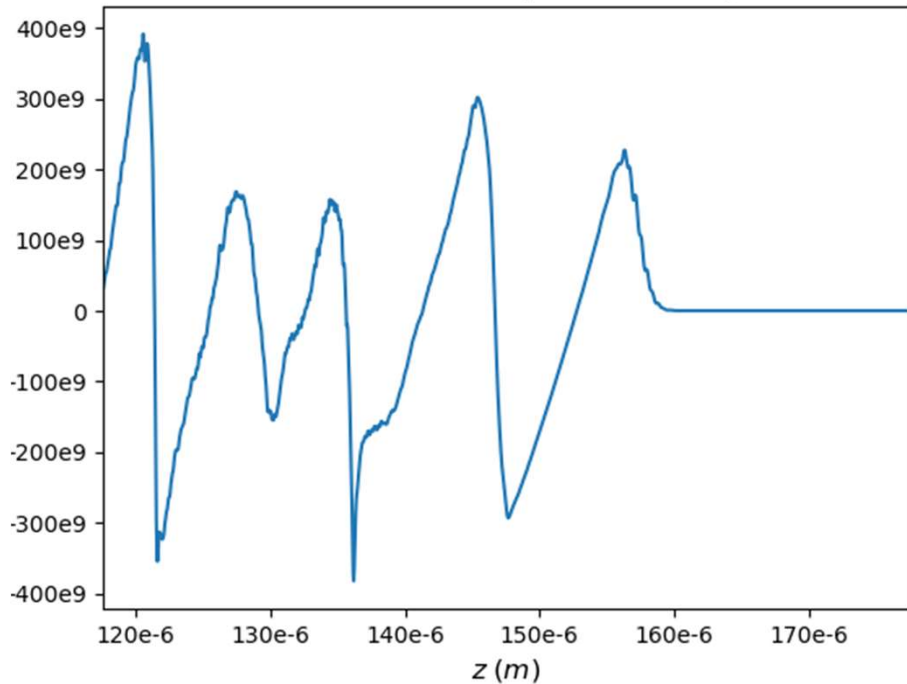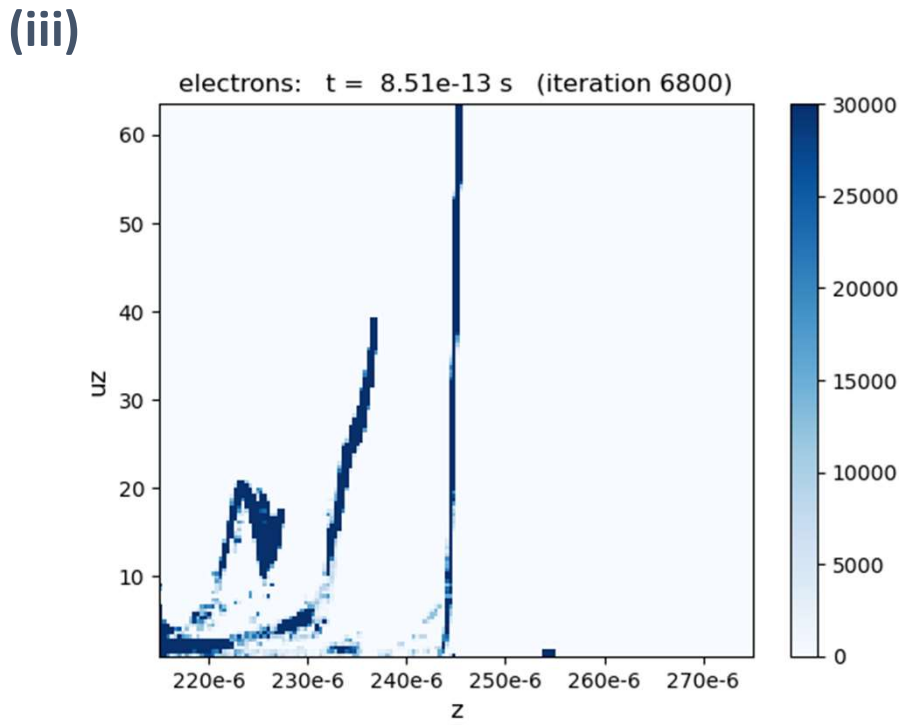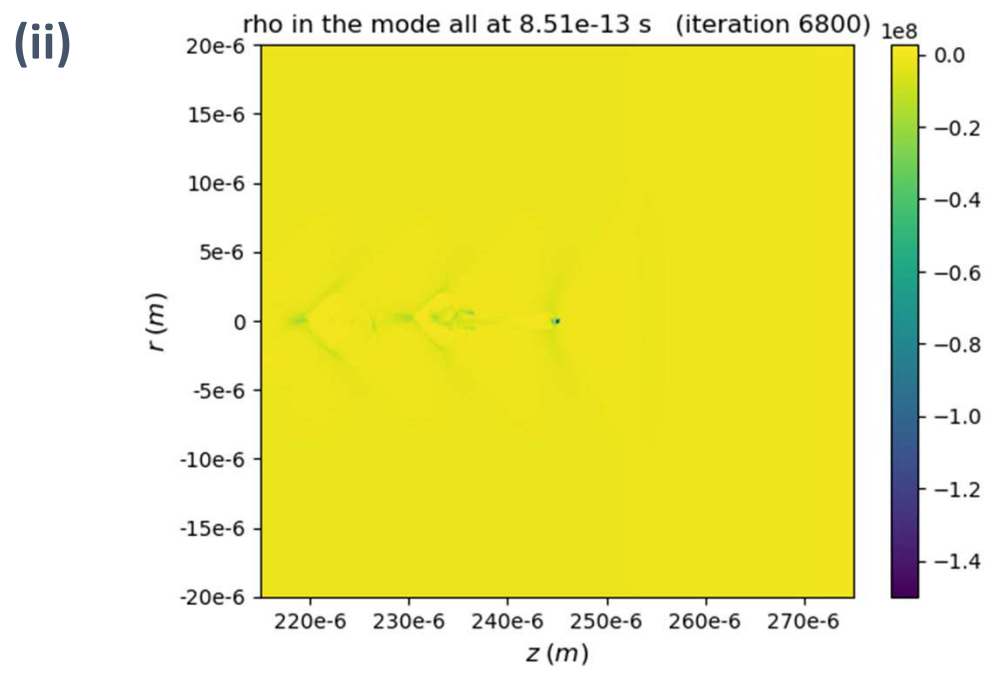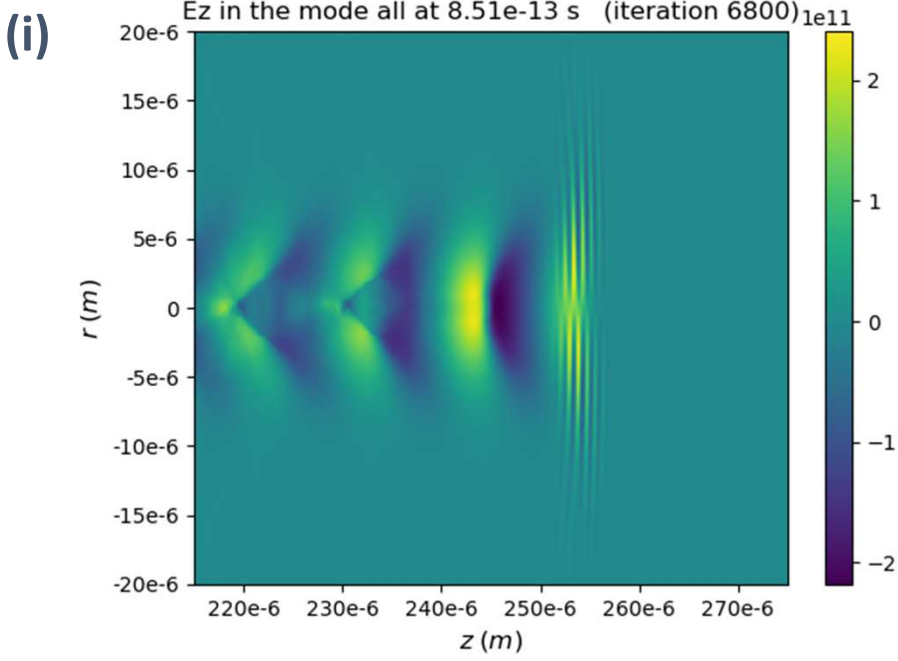
Er at 5.25e-13 s   (iteration 4200)

(v)

Ez at 5.25e-13 s   (iteration 4200)

After Density Modulation Wakefield of Laser Pulse and the accelerated electron bunch behind it (iv) Laser's Electric field along z (v) Electric field along the bubble

(i)

Ez in the mode all at 8.51e-13 s   (iteration 6800)

(ii)

rho in the mode all at 8.51e-13 s   (iteration 6800)

(iii)

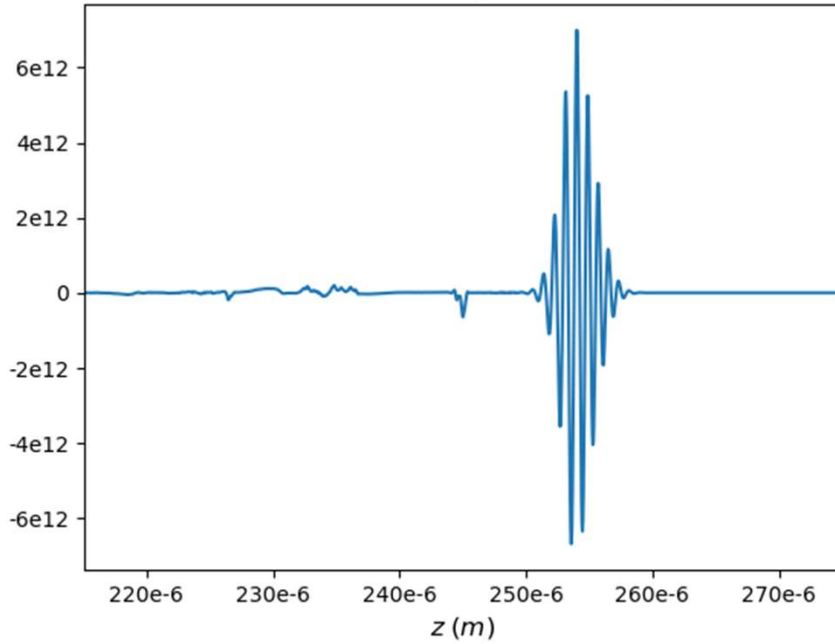electrons: t = 8.51e-13 s   (iteration 6800)

Figure : Before end of plateau Wakefield of Laser Pulse and the accelerated electron bunch behind it (i) Electric field (ii) charge density (iii) phase space plot of electron bunch

(iv)

Er at 8.51e-13 s   (iteration 6800)
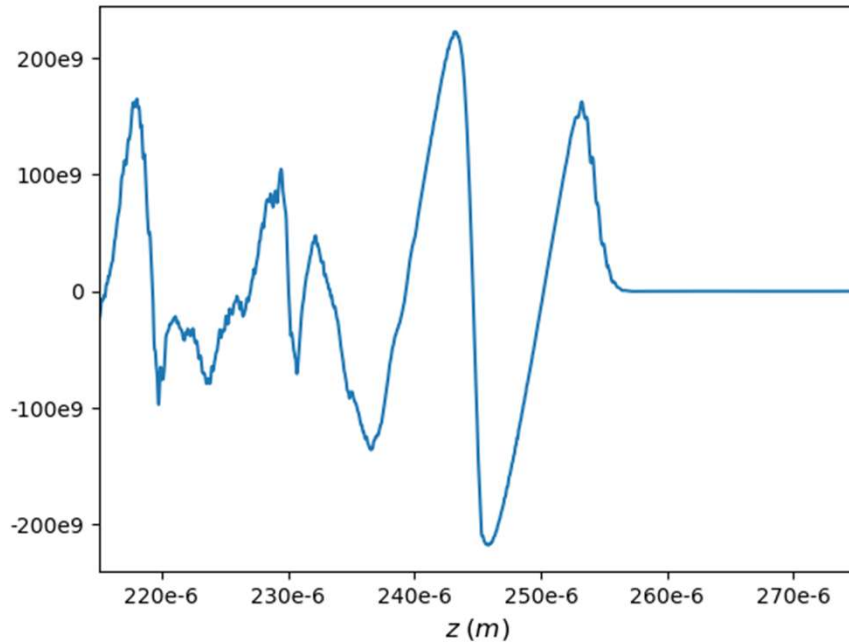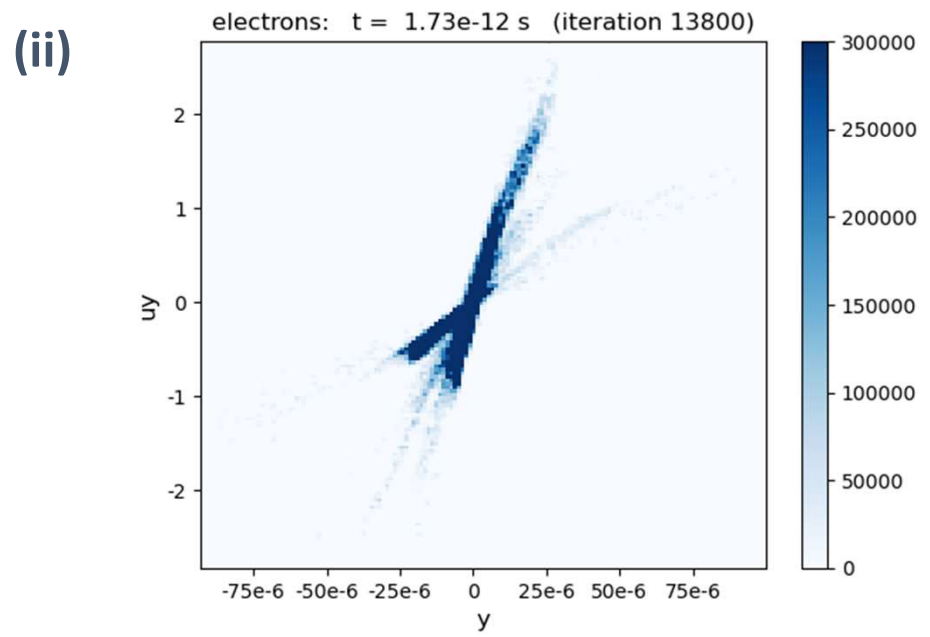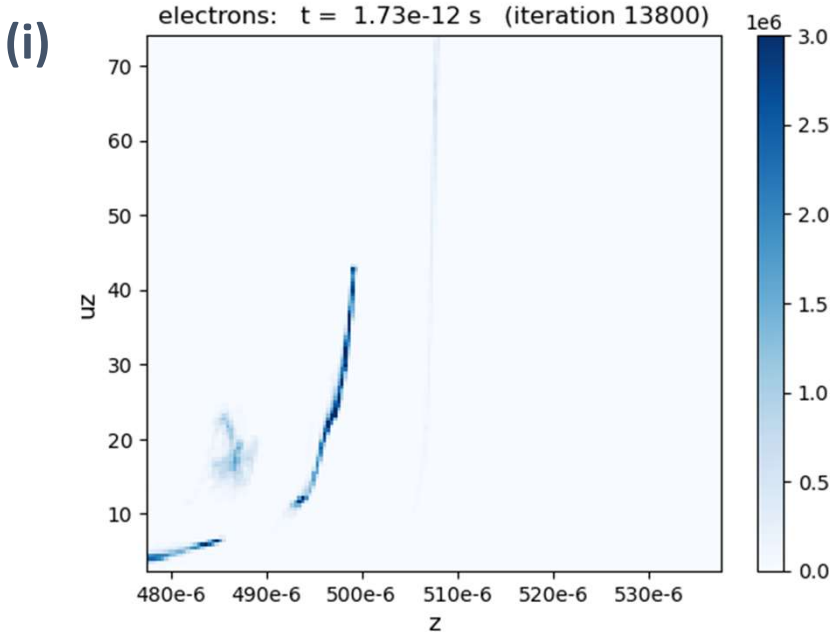
(v)

Ez at 8.51e-13 s   (iteration 6800)

Figure : Before End of Plateau Wakefield of Laser Pulse and the accelerated electron bunch behind it (iv) Laser's Electric field along z (v) Electric field along the bubble
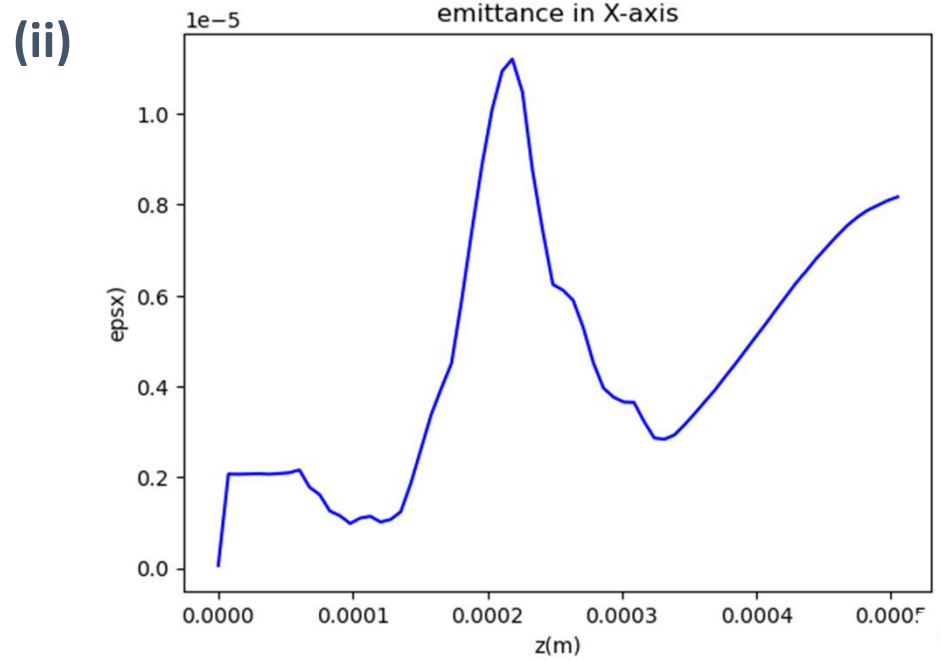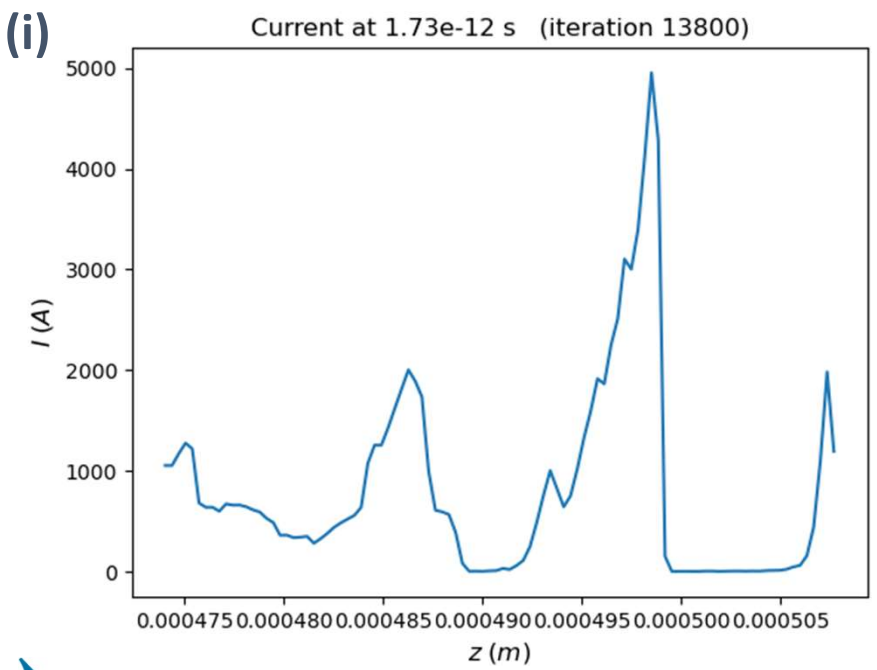
Figure : Phase space of the electron bunch (i) Longitudinal (ii) Transverse

Figure : (i) output current   **(ii) emittance**

Typical Output parameters

Peak particle Energy	About 20 MeV
Divergence	0.092 mrad
Current	5 kA
Emittance	8.17 mm-mrad

THANK YOU