**A tutorial on Particle in Cell simulation**

**of Laser Wakefield Acceleration**

**Checklist:**

* Check that you have included the correct units in your answers and in your plot.
* Check that you have included the correct labels (with relevant units) in your plot.
* If more than one plot is asked, check that all plots are included.
* If a script is asked for an exercise, send it to the instructor.

**Exploring the Input Namelist:**

* **Exercise 1 :**
* nc (cm-3) =
* E0 (TV/m) =
* **Exercise 2 :**
* Lx (μm) =
* Lr (μm) =
* nx =
* nr =
* dx (μm) =
* dr (μm) =

**Laser pulse in vacuum**

* **Exercise 3 :**
* waist (μm) =
* LFWHM (field, fs) =
* LFWHM (intensity, fs) =
* xcenter,laser (μm) =
* xfocus,laser (μm) =
* **Exercise 4 :**
* a0 =
* I (W/cm2) =
* **Exercise 5 :**
* xR (μm) =
* Include a plot of the comparison
* **Exercise 6 :**
* Lr (μm) =
* Qualitative explanation of the results (you may include also an image)

**Laser wakefield excitation**

* **Exercise 7 :**
* n0 / nc =
* underdense plasma or overdense plasma?
* Number of macro-particles =
* Number of macro-particles in a 3D window =
* **Exercise 8 :**
* λp (theoretical, μm) =
* λp (estimate from the plot , μm) =

* **Exercise 9 :**
* Include a plot of the comparison
* **Exercise 10 :**
* Include the requested plot
* **Exercise 11 :**
* Include a plot of the comparison for Ex and a plot for the comparison of -Rho/e.
* Include a plot of the plasma wave period (in μm) as function of the a0 of the laser.

**Laser wakefield acceleration of an electron bunch**

* **Exercise 12 :**
* Q (pC)=
* Rms size along x = σx (μm) =
* Rms size along y = σy (μm) =
* Rms size along z = σz (μm) =
* Energy E (mec2) =
* Energy E (MeV) =
* Relative energy spread δE/E (%) =
* Normalised emittance along y = εny  (mm-mrad) =
* Normalised emittance along z = εnz  (mm-mrad) =
* Number of bunch macro-particles =
* Center bunch (μm) =
* **Exercise 13 :**
* Include the plots showing the plasma wave and the electron bunch
* **Exercise 14 :**
* Include the plots with the number density and the longitudinal electric field Ex on the propagation axis
* **Exercise 15 :**
* ΔE (mec2)=
* ΔE (MeV) =
* L (μm) =
* Eacc (GV/m) =
* Report here all the bunch parameters at the start (timestep = 0) and at the end of the simulation (timestep = 10000). You can copy and paste the output of the script Compute\_bunch\_parameters.py.
* **Exercise 16 :**
* Include a plot of the bunch parameters evolution
* Estimate of the accelerating gradient in GV/m (with calculation) =
* Estimate of the accelerating gradient in GV/m (from the plot of Exercise 14) =
* **Exercise 17 :**
* Include a plot with the results of the four simulations (Ex of the simulations in the same window) with a qualitative comment
* Include a plot with the results of the four simulations (charge in pC vs energy gain in MeV)
* Can you explain why the bunch gains more (or less) energy varying the charge?

(You may refer to the first image to explain)

* **Exercise 18 :**
* Include the plots with the comparison of the Rho/e and Ex of the four simulations.
* Include a plot with the results (delay\_behind\_laser in μm vs energy gain in MeV).
* What do you observe and how do you explain it?
* **Exercise 19 :**
* Include the plots and send the script to the instructor.
* **Exercise 20 :**
* Include a plot of the bunch energy spectrum at the start and at the end of the simulation, with a brief comment on the changes you see.
* Send the script to the instructor.