Modelling & Simulation

Hands on II/II

R. A. Fonseca[1,2], Jorge Vieira[1]

[1] GoLP/IPFN, Instituto Superior Técnico, Lisboa, Portugal

[2] DCTI, ISCTE-Instituto Universitário de Lisboa, Portugal

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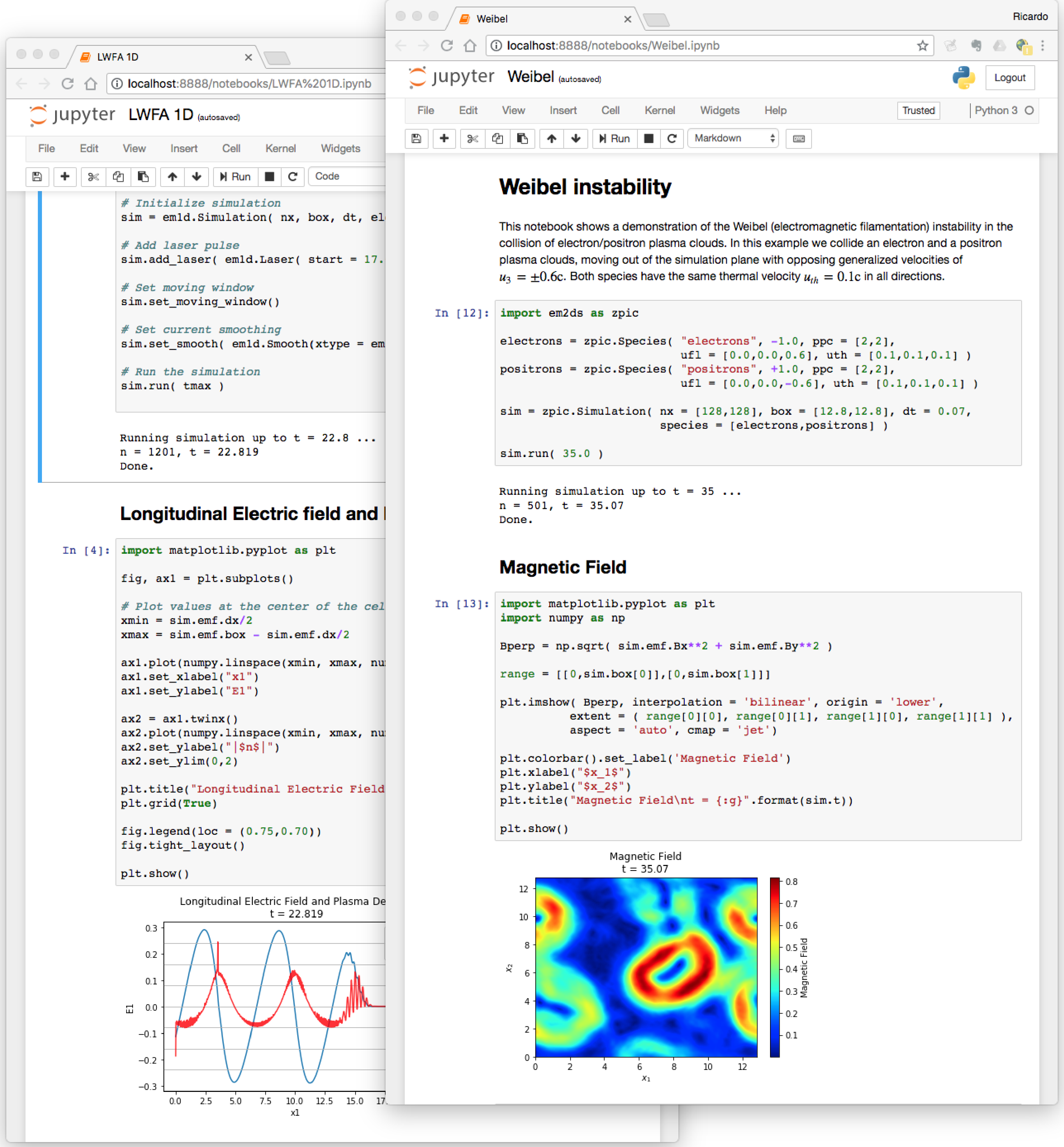
The ZPIC educational code suite

- **ZPIC code suite**
  - Open-source PIC code suit for plasma physics education
  - Fully relativistic 1D and 2D EM-PIC algorithm
  - Eletrostatic 1D/2D PIC algorithm
- **Requirements**
  - No external dependencies, requires only C99 compiler
  - Optional Python interface
- **Jupiter Notebooks**
  - Includes set of Python notebooks with example problems
  - Detailed explanations of code use and physics
- **Also available through Docker**
  - If you just want to run the notebooks you can use a Docker image available on DockerHub: **zamb/zpic**



zpic@edu

Come find us on GitHub
github.com/zambzamb/zpic

Launch a ZPIC notebook

- **Option 1 - Compile from source** **https://github.com/zambzamb/zpic**

  i. Compile the code in the python subfolder using the Makefile:

  ```
  $ make
  ```

  ii. Launch the Jupyter notebook from the source folder:

  ```
  $ jupyter notebook LWFA1D.ipynb
  ```

- **Option 2 - Use a Docker Container** **https://www.docker.com/products/docker-desktop** **https://docs.docker.com/install/linux/docker-ce/centos/**

  i. Install Docker

  ii. Launch the zpic container

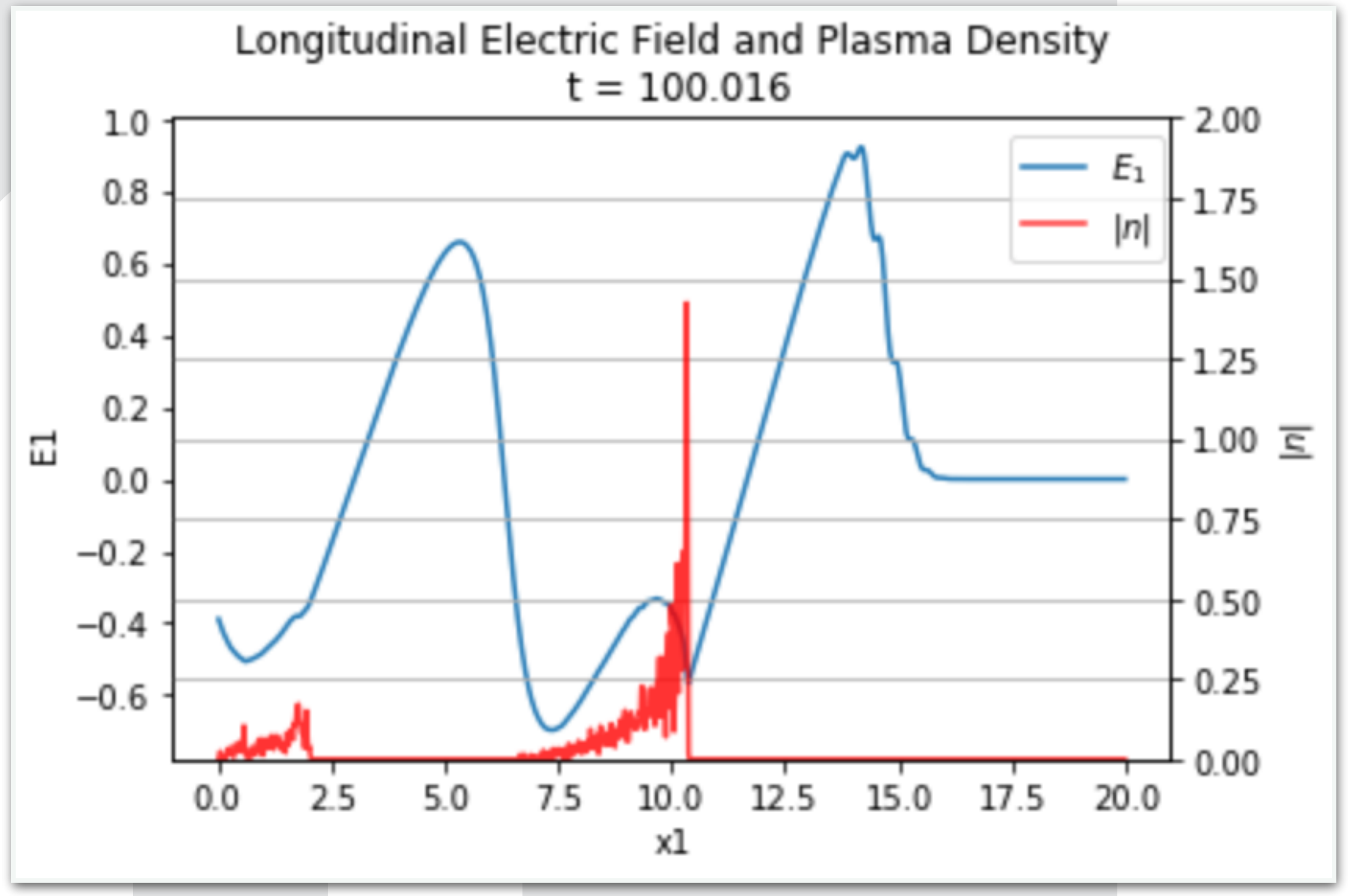
  ```
  $ docker run -p 8888:8888 -t -v $PWD:/home/jovyan/work zamb/zpic
  ```

  – This mounts the directory **$PWD** on the directory **work** on your container so you can save changes to the existing notebooks or create new ones

Example: Laser Wakefield Accelerator

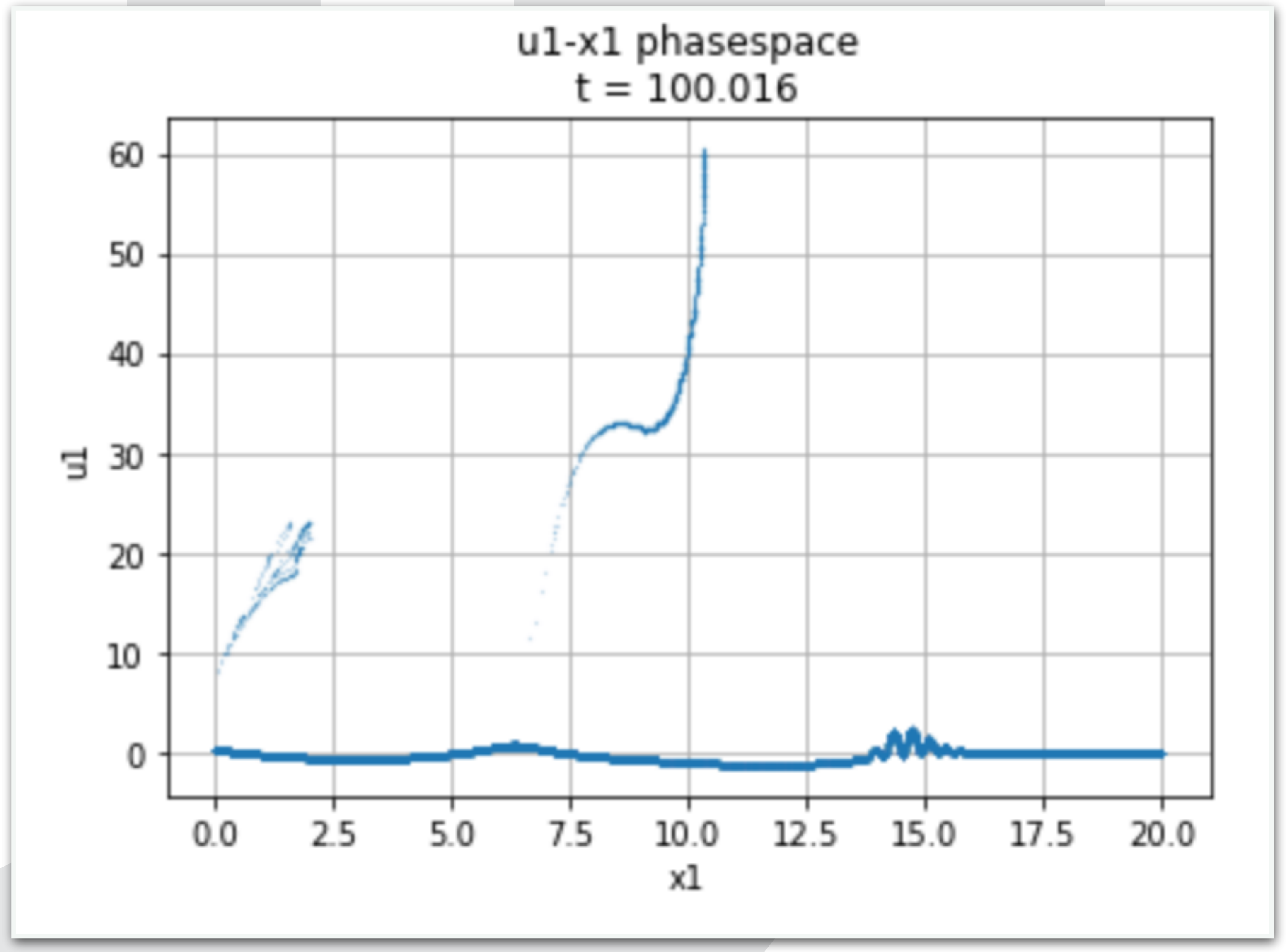
Simulate a laser wakefield accelerator:

- Add an ultra-intense laser beam as a driver (a_0~2)
- Choose laser length smaller than λ_p



Questions:

1. can you observe particle injection and trapping?
2. is the energy gain consistent with the longitudinal electric field values?
3. describe and justify the shape for the plasma electric field in the region where particles accelerate
4. could you accelerate positrons in this plasma wave? where would you place them and with what initial velocity/energy? try to simulate!



LWFA

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LWFA 1D | PWFA 1D | LBWFA 1D

localhost:8889/notebooks/LWFA%201D.ipynb#

jupyter LWFA 1D Last Checkpoint: 11/26/2018 (autosaved)

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Run Markdown

Laser Wakefield Accelerator

1D simulation of a laser wakefield accelerator.

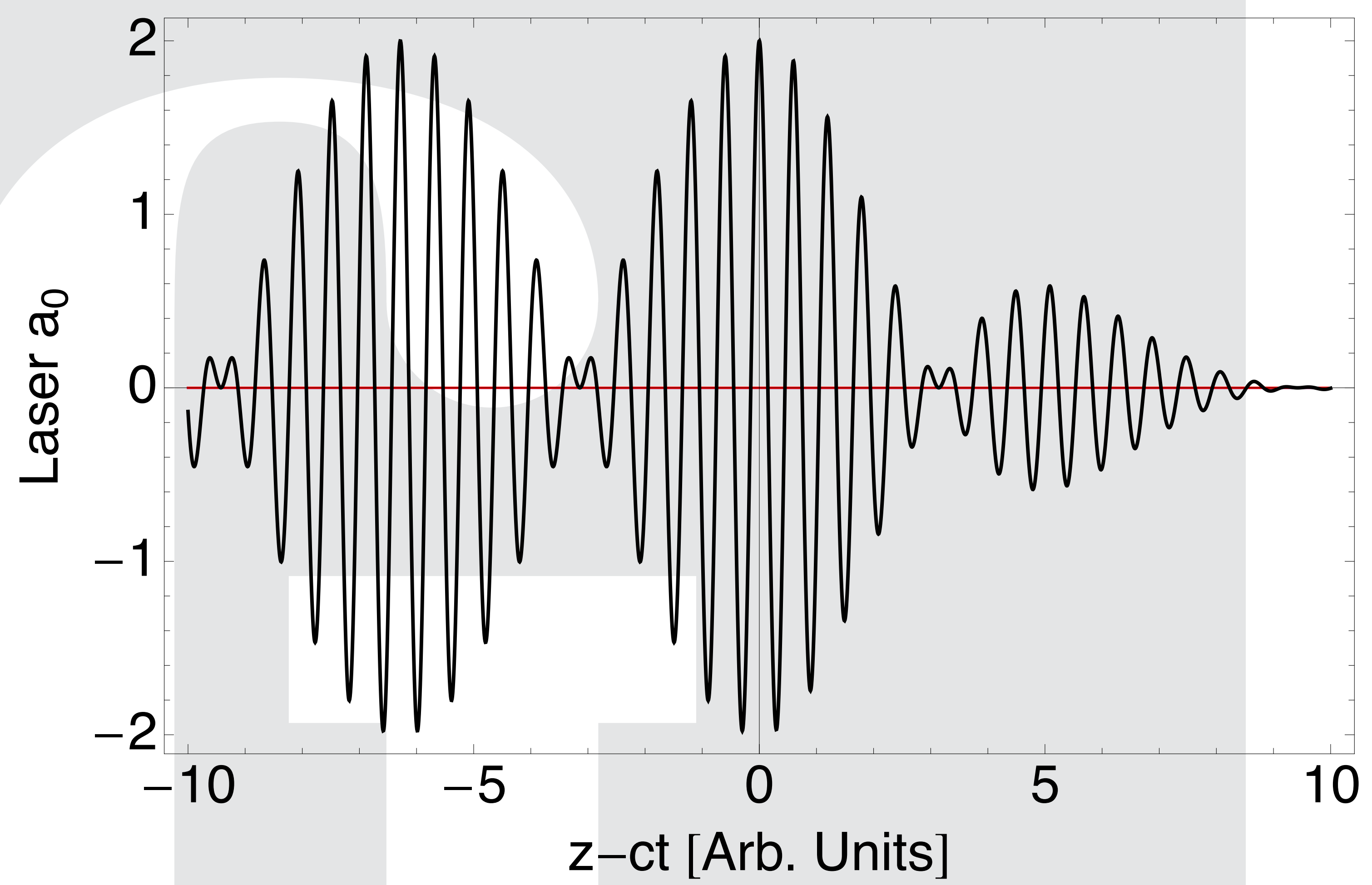
In [1]:

```python
import em1d
import numpy

# Time step
dt = 0.019

# Simulation time
tmax = 22.8

# Number of cells
nx  = 1000

# Simulation box size
box = 20.0


## Background plasma

# Particles per cell
ppc = 128

# Use a step density profile
electrons = em1d.Species( "electrons", -1.0, ppc,
                          density = em1d.Density( type = "step", start = 20.0))

# Initialize simulation
sim = em1d.Simulation( nx, box, dt, species = electrons )

# Add laser pulse
sim.add_laser( em1d.Laser( start = 17.0, fwhm = 2.0, a0 = 1.0, omega0 = 10.0, polarization = numpy.pi/2 ))

# Set moving window
sim.set_moving_window()

# Set current smoothing
sim.set_smooth( em1d.Smooth(xtype = "compensated", xlevel = 4) )

# Run the simulation
sim.run( tmax )
```

Example: plasma beat wave accelerator

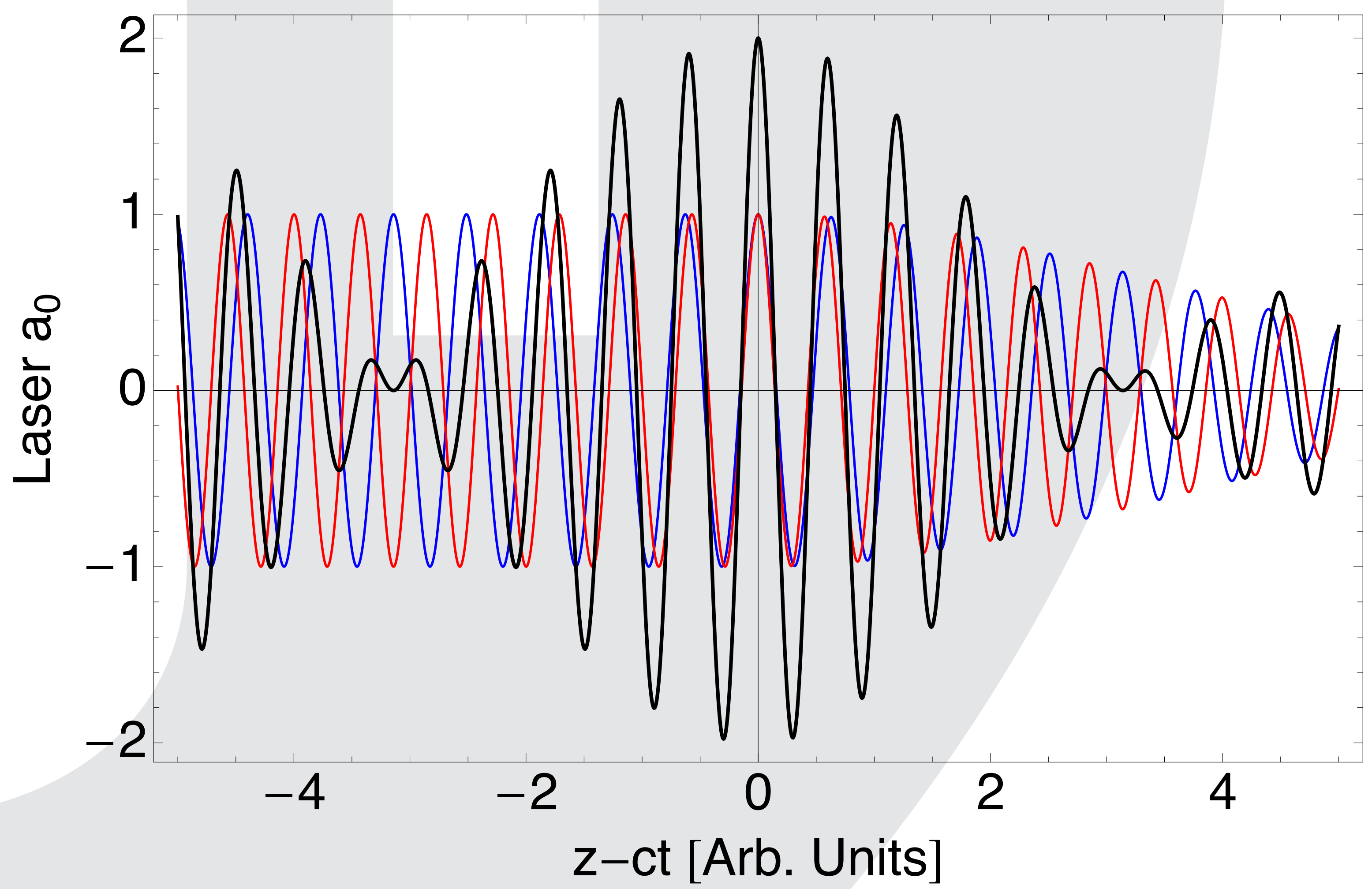
Simulate a plasma beat-wave accelerator:

- Super-impose three laser modes with frequencies differing by ω_p (e.g. $\omega_0 = 10, 11\ \omega_p$)
- Choose Laser length $\gg \lambda_p$



Questions:

1. why does the plasma wave amplitude increase along the pulse?
2. what happens if the the initial frequencies of the lasers are not separated by the plasma frequency? Why?
3. compare the trapping threshold, as a function of the peak laser a_0, for a standard LWFA (with pulse length smaller than λ_p) with the beat-wave accelerator. Which one is the lowest?
4. Decrease the amplitude of the laser side bands and run the simulation for longer times. What happens to the laser?



LWFA 1D | PWFA 1D | LBWFA 1D

localhost:8889/notebooks/cas/LBWFA%201D.ipynb

jupyter LBWFA 1D Last Checkpoint: a minute ago (autosaved)

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Run | Code

Laser Plasma Beatwave Accelerator

1D simulation of a laser plasma beatwave accelerator.

In [1]:

```python
import em1d
import numpy

# Time step
dt = 0.019
# Simulation time
tmax = 100.
# Number of cells
nx   = 1250
# Simulation box size
box = 50.0
# Particles per cell
ppc = 128

# Use a step density profile
electrons = em1d.Species( "electrons", -1.0, ppc,
                          density = em1d.Density( type = "step", start = 50.0))

# Initialize simulation
sim = em1d.Simulation( nx, box, dt, species = electrons )

# Add laser pulses
sim.add_laser( em1d.Laser( start = 50.0, rise = 20.0 , flat = 40.0 ,  fall = 1.0 , a0 = 0.5, omega0 = 10.0, polarizatio
sim.add_laser( em1d.Laser( start = 50.0, rise = 20.0 , flat = 40.0 , fall = 1.0, a0 = 0.5, omega0 = 11.0, polarization =

# Set moving window
sim.set_moving_window()
# Set current smoothing
sim.set_smooth( em1d.Smooth(xtype = "compensated", xlevel = 4) )

# Run the simulation
sim.run( tmax )
```

```
Running simulation up to t = 100 ...
n = 5264, t = 100.016
Done.
```

Longitudinal Electric field and Plasma Density

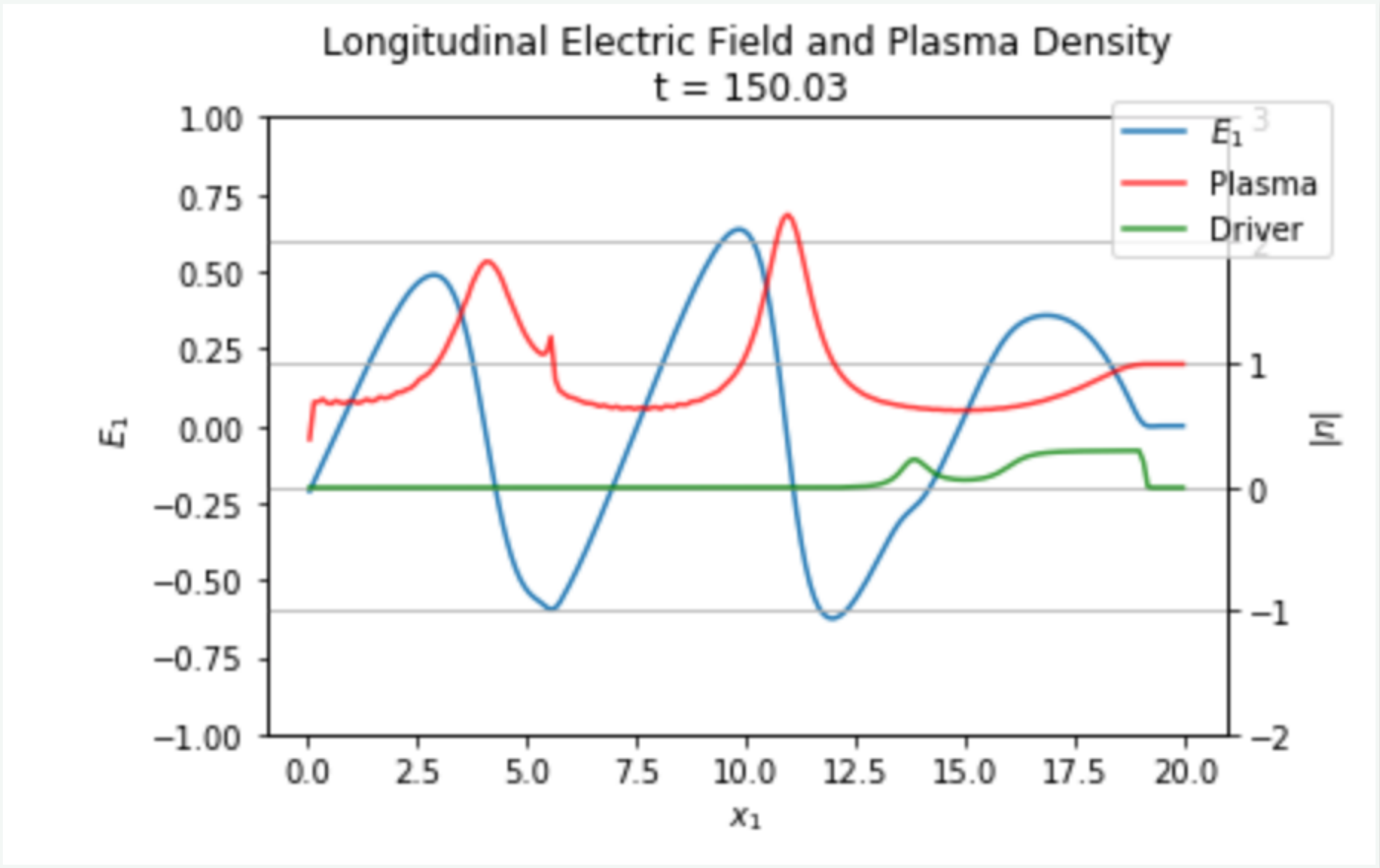
In [11]:

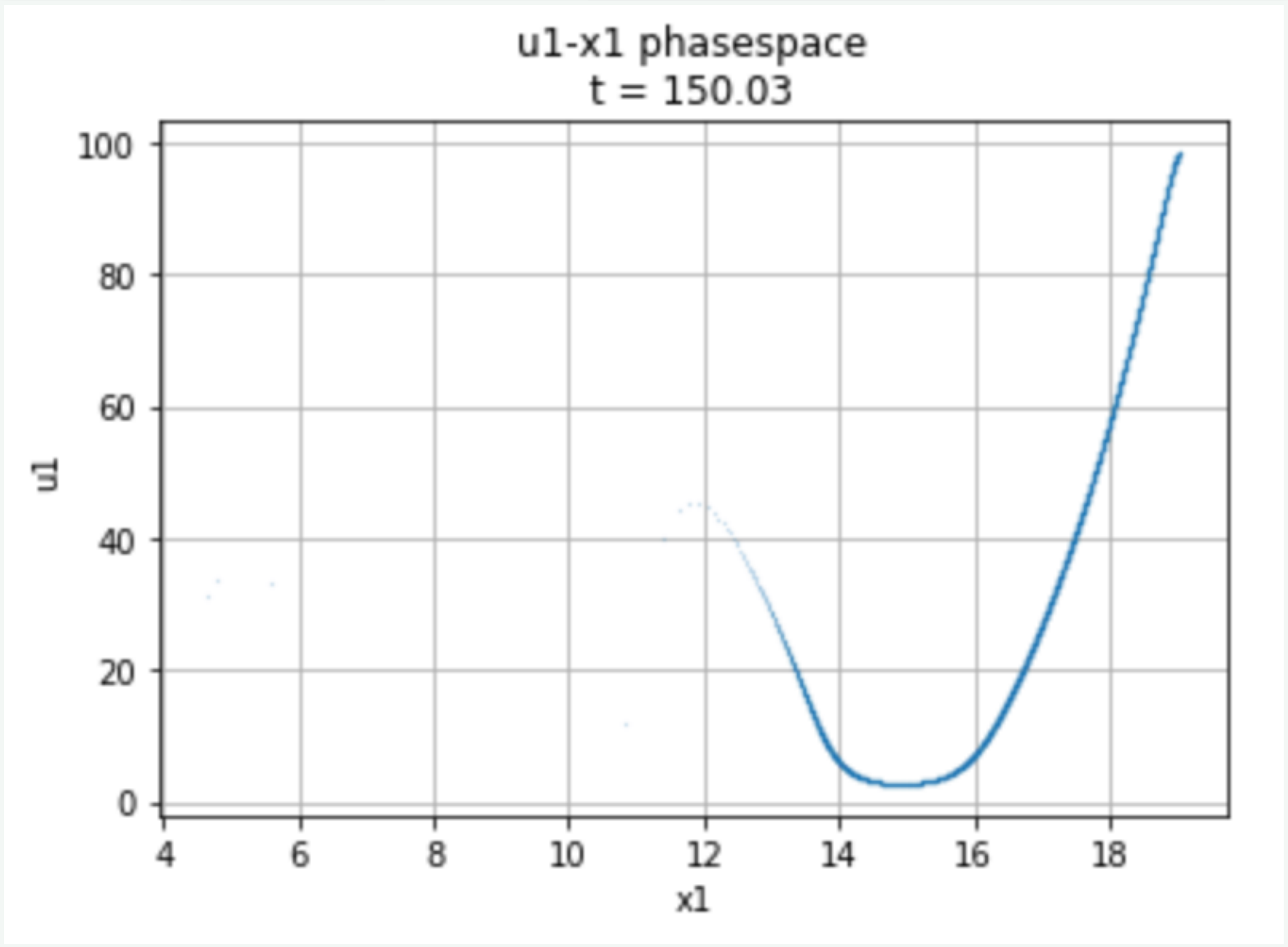
```python
import matplotlib.pyplot as plt
```

Example: plasma wakefield accelerator

Simulate a plasma wakefield accelerator:

- Use an ultra-relativistic particle beam as a driver
  - e.g. u_{fl} = 100, length ~ 10 c/ω_p, density ~ 0.3
- Choose plasma length $\gg \lambda_p$





Questions:

1. Why does the head of the driver loose energy?
2. What happens to the energy of the driver if it has a length comparable to λ_p?
3. What is the phase velocity of the plasma wave?
4. Can you observe plasma electron trapping and acceleration?

PWFA

LWFA 1D | PWFA 1D | LBWFA 1D

localhost:8889/notebooks/cas/PWFA%201D.ipynb

jupyter PWFA 1D Last Checkpoint: a few seconds ago (autosaved)

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Plasma Wakefield Accelerator

1D simulation of a plasma wakefield accelerator.

In [63]:

```python
import em1d
import numpy

# Time step
dt = 0.09
# Simulation time
tmax = 150.
# Number of cells
nx   = 200
# Simulation box size
box = 20.0

# Particles per cell
ppc = 128

# Use a step density profile
electrons = em1d.Species( "electrons", -1.0, ppc,
                          density = em1d.Density( type = "step", start = 100.0))

driver = em1d.Species( "driver", -1.0, ppc,
                          density = em1d.Density( n = 0.3 , type = "slab", start = 8.0 , end = 19.0 ),
                          ufl=[100.0,0.0,0.0])

# Initialize simulation
sim = em1d.Simulation( nx, box, dt, species = [electrons,driver] )

# Set moving window
sim.set_moving_window()

# Set current smoothing
sim.set_smooth( em1d.Smooth(xtype = "compensated", xlevel = 4) )

# Run the simulation
sim.run( tmax )
```

```
Running simulation up to t = 150 ...
n = 1667, t = 150.03
Done.
```

Longitudinal Electric field and Plasma Density