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HPC User Meeting

Using HPC Cluster for AWAKE Simulation Studies

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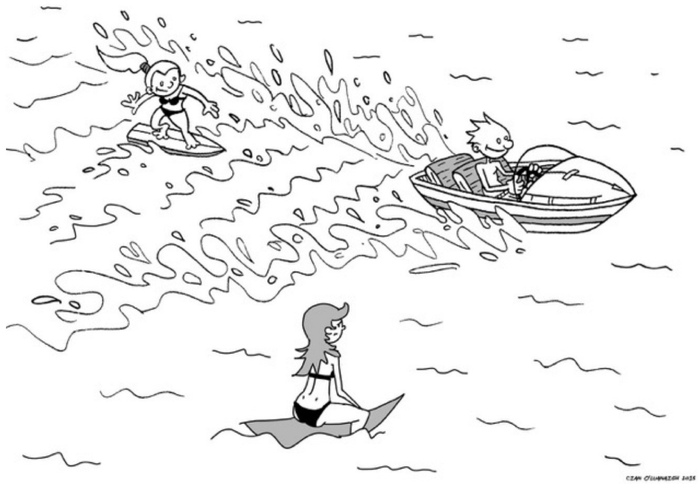
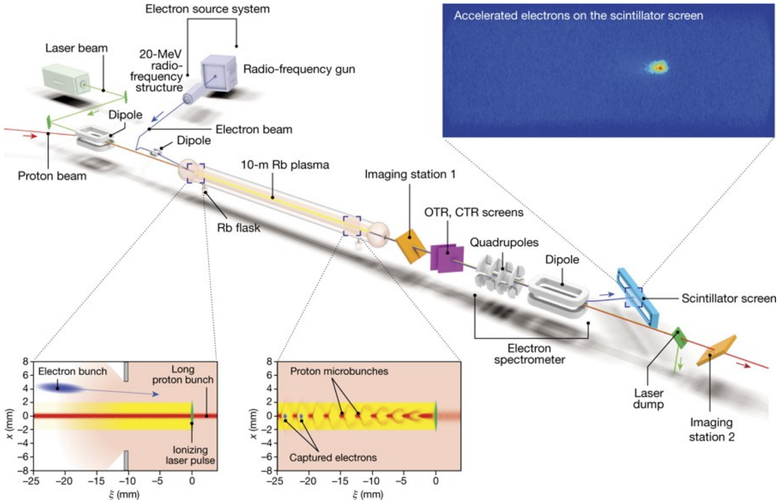
Overview of AWAKE Project





E. Adli et. al., Nature **561**, 363–367 (2018)

AWAKE Run 1 (2013-2018)

➔ Advanced Proton Driven Plasma Wakefield Acceleration Experiment (AWAKE) is a proof-of-principle experiment.

➔ Experimentally demonstrated (for the 1st time worldwide) the electron acceleration by the plasma wakefield driven by proton bunch:

- ✔ Long CERN SPS proton beam modulates into short microbunches,
- ✔ Short microbunches create resonant plasma wakefield,
- ✔ The Injected low energy electron beam behind the proton beam is captured by the wakefield and accelerates to higher energies.

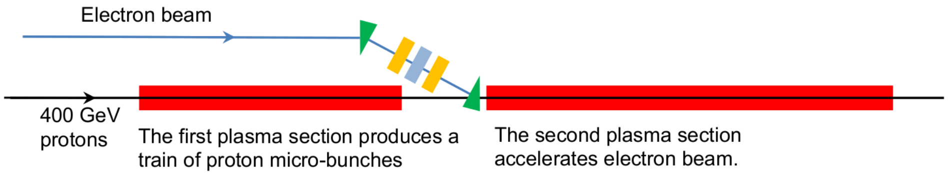
➔ There are plans in AWAKE Run 2 to improve the quality of the accelerated electron beam.

AWAKE Run 2 (2021-2024)

Goal of Run 2

➔ Aims to demonstrate the scalability and the acceleration of electrons to high energies while maintaining the beam quality.

➔ A different layout than run 1 with two plasma cells



Why simulation needed?

➔ How to inject electron beam?

➔ What are the optimum parameters for the initial electron beam?

➔ Control of (self-modulated) proton driver?

➔ How should be the gap between plasma cells?

➔ Interaction of electron/proton beams with plasma density gradients.

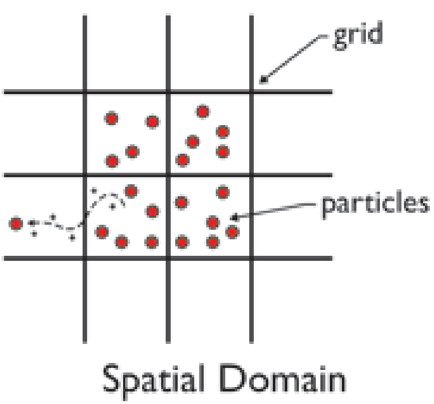
➔ …

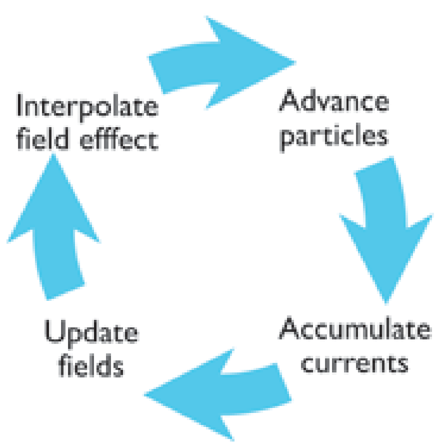
So, we start using WARP code for AWAKE simulation.

WARP Code on HPC

About WARP

- Particle-in-Cell (PIC) code,
- 3D/2D/Cylindrical coordinates,
- Fully electromagnetic,
- MPI parallel,
- Developed at Berkeley (Open source),
- WARP is usually a computationally heavy code.





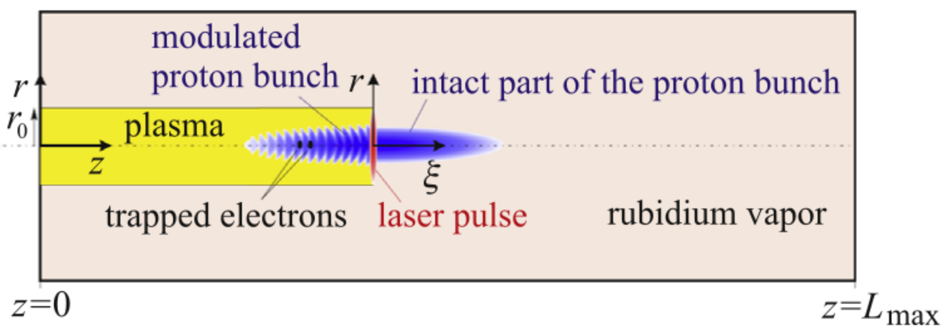
WARP on HPC

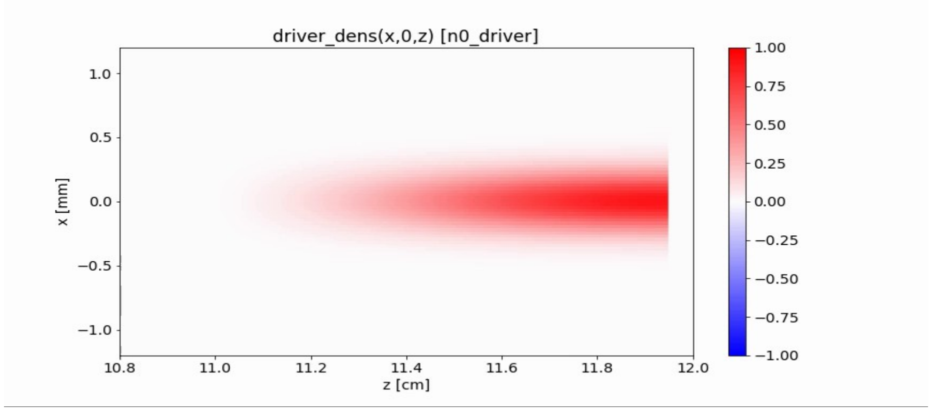
- WARP was new for AWAKE, so we start working to it from scratch
- HTCondor was not good for MPI parallel code, then started using HPC cluster.
- Installed on HPC with OpenMPI
- Uses partition batch-long and batch-short

WARP CPU Usage

- Usually use 10-40 nodes to run jobs
- 2D cylindrical jobs with moderate simulation window and resolution
- 3D jobs with small window and reasonable resolution

WARP Results 1: Proton Beam Self-modulation





AWAKE Parameters

- Proton beam length 12 cm!
- Simulation window close to the AWAKE parameters:

  3.2mm * 3.2mm * 8cm

- Simulation window moves ~8m (Hundred thousands of time steps)
- Resolution also matters!

3D WARP Simulation on HPC

- 2 cm proton beam cut in half
- Smaller simulation window

  Dimension : 2.4mm * 2.4mm * 1.2cm

  Num. Grids: 96 * 96 * 400

- Simulation window moves over 6m (500000 time steps)
- Moderate resolution

  With 320 CPUs run during ~2d:5h ~ 17000 CPU hour

Computer Needs for a Larger Window

A rough estimate

- Simulation window dimension

  2.4mm * 2.4mm * 1.2cm ~ times 7 =======> 2.4mm * 2.4mm * 8.4cm

- CPU needs

  320 CPU (10 Nodes) ~ times 7 =======> 2240 CPU (70 Nodes)

- Run time

  ~ 2days:5hours

- Run time in CPU hour

  ~ 1.7e4 CPU hour ~ times 7 =======> 1.19e5 CPU hour

- Diagnostics, resolution and the number of macro-particles can increase the CPU needs and run time.

WARP Results 2: Proton Microbunches, Resonant Wakefield and Electron Injection

Electron Injection and Acceleration

➔ Different schemes for electron injection are proposed and should be explored by simulation.

➔ With electron beam in simulation, the resolution (grid size) should be higher (lower).

➔ Here, we assume a train of proton microbunches interacting with plasma to create a resonant wakefield.

➔ The electron beam behind the proton driver will be captured and accelerated by the wakefield.

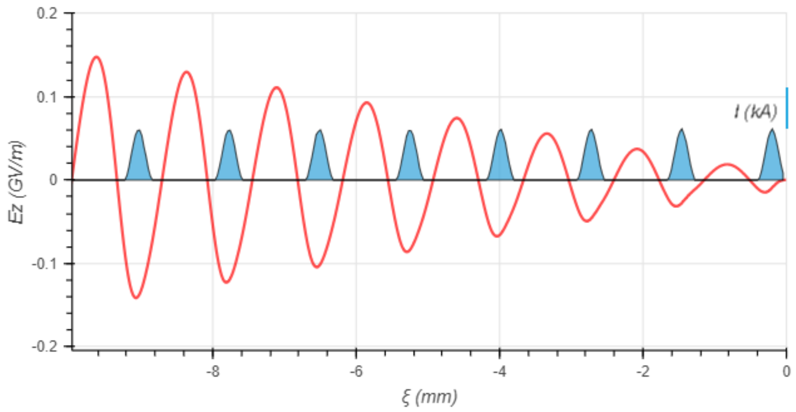
➔ Simulation window moves ~8.5cm into palsma.

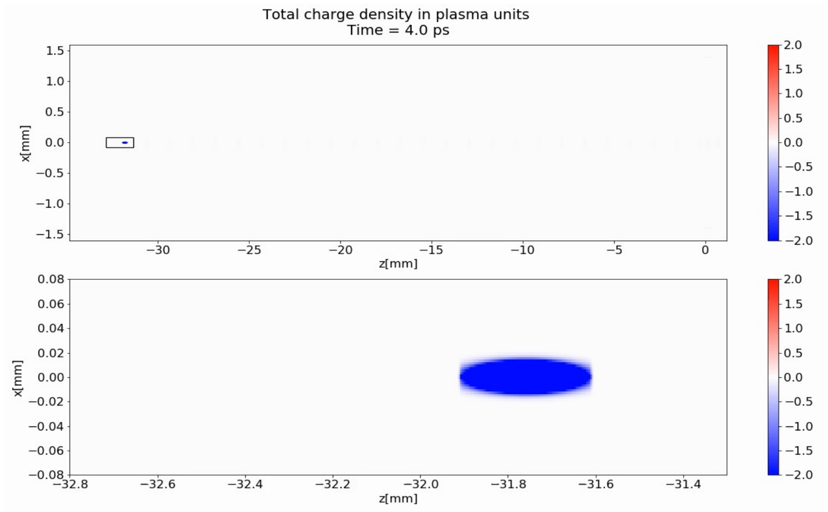
➔ Simulation is in 2D cylindrical coordinates (1.6mm * 3.6cm).

➔ Number of Grids 800 * 12000

With 1024 CPUs run during ~1h:44min

~ 1775 CPU hour





WARP Issues on HPC

- ➔ Sometimes, lack of sufficient resources for jobs (cluster is too busy!).
- ➔ Heavier jobs need more CPUs than those available at HPC!
- ➔ WARP outputs can be very large data files, so moving them to the eos/swan for further analysis will be very time consuming.
- ➔ For installation, I encountered some issues regarding OpenMPI/MVAPICH2 and mpi4py package (but now is installed by OpenMPI and works well).
- ➔ Sometime similar jobs run with very different times?
- ➔ Jobs that run on more nodes usually take longer time to start iteration of the code?
- ➔ Finding the optimum CPUs to run WARP.

AWAKE Plans and Summary

→ **AWAKE has for the first time demonstrated proton driven plasma wakefield acceleration of externally injected electrons to 2 GeV in 10 m.**

→ AWAKE Run 1 was a proof-of-concept experiment. DONE!

→ Aim of **AWAKE Run 2** starting 2021 after CERN's Long Shutdown 2 is to achieve high-charge bunches of electrons accelerated to **high energy, about 10 GeV,** while maintaining **beam quality** through the plasma and showing that the process is **scalable**.

- We need to perform detailed plasma simulations now in order to inform the beam line and plasma design as well as to define specifications for beam parameters, diagnostics and layout designs.

→ Use the AWAKE scheme for **particle physics applications** such as fixed target experiments for dark photon searches and also for future electron-proton or electron-ion colliders.