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Electron acceleration using high power lasers

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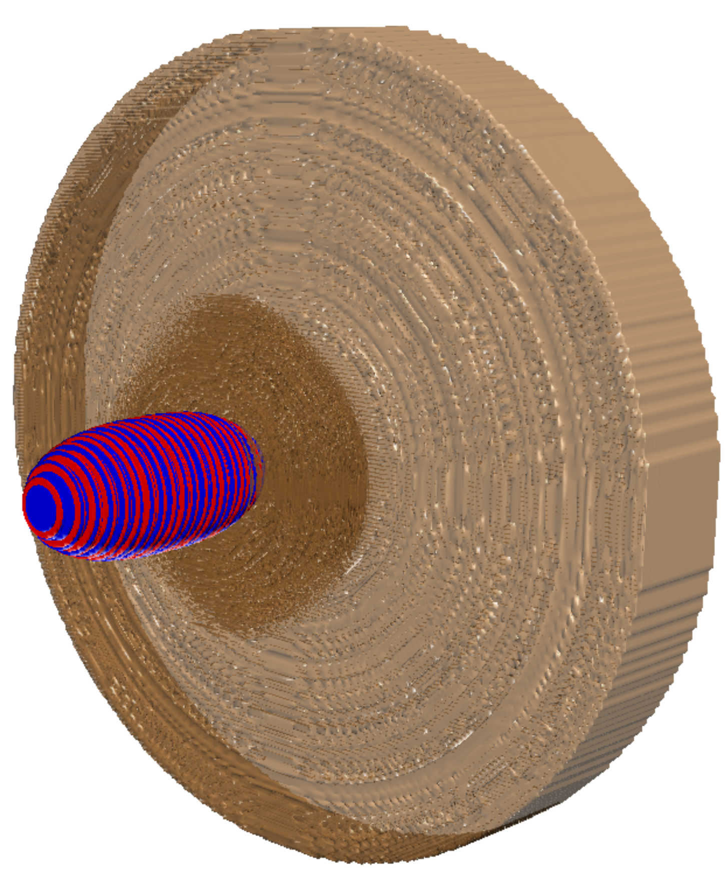
Particle acceleration by the laser pulses

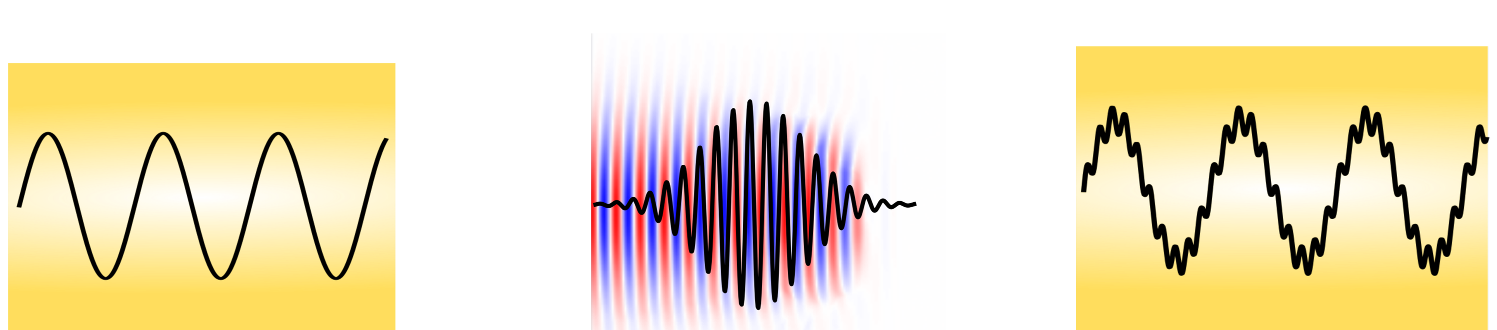
The acceleration of particles has been an important part of physics for decades. Conventional accelerators need very **long distances** to accelerate particles to the required energies. Using laser pulses instead would lead to a significant **reduction of the length** needed. This would result in better accessibility of accelerators for research, industry, or healthcare facilities. Laser pulses can accelerate particles to strongly relativistic energies because of their high power delivered at **femtosecond timescales**. Nowadays, laser intensities available are of order 10^{22} W/cm^2, and even higher are expected in near future.



Laser pulse entering the plasma target

Direct laser acceleration

Many mechanisms and setups were proposed to accelerate electrons or ions over the years. One of them is called **direct laser acceleration** which can provide electron beams with energies up to hundreds of MeV and charge in order of hundreds of nC at a distance of a few millimeters. It occurs in systems, where **relativistic laser pulse** propagates through transparent gaseous plasma.



$$\omega_\beta = \frac{\omega_p}{\sqrt{2\gamma}} \qquad \omega_L = \omega_0\left(1-\frac{v_{||}}{c}\right) \qquad \omega_\beta \simeq \omega_L$$

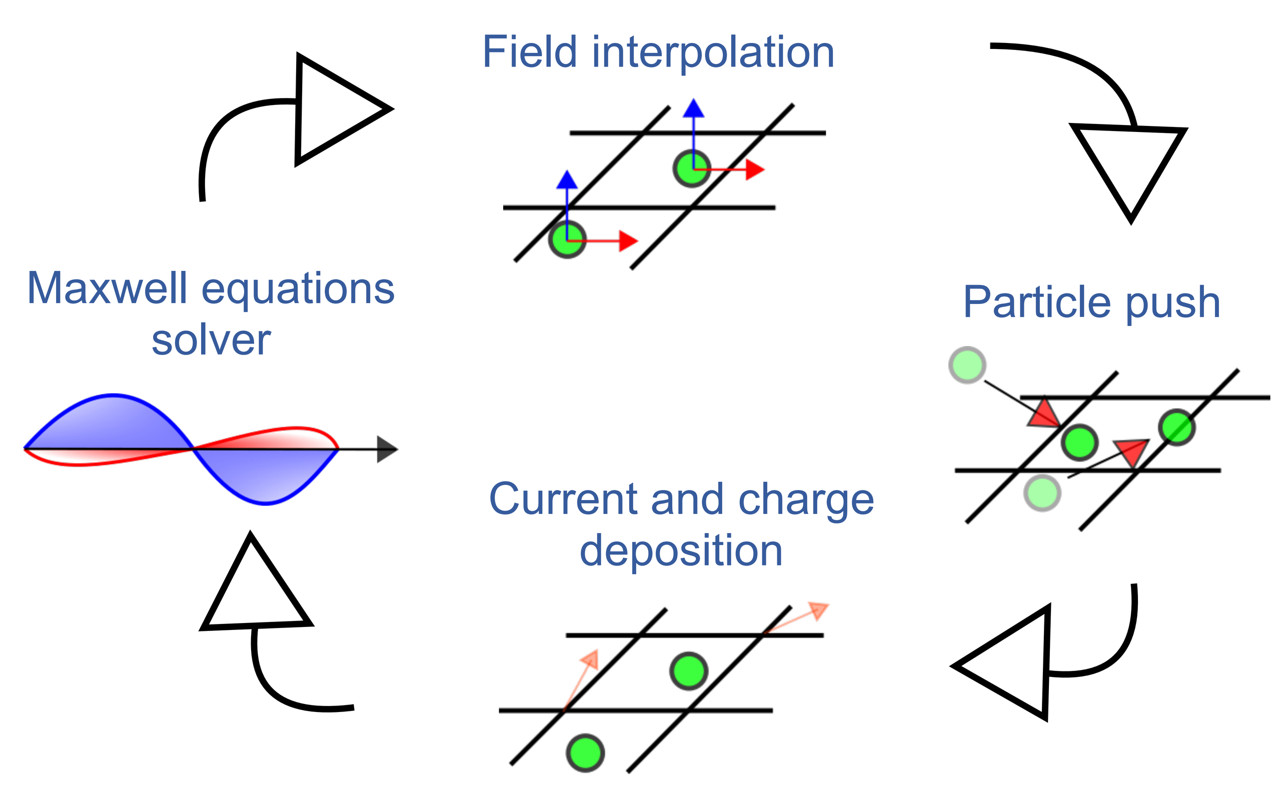
Acceleration is possible because of the resonance between oscillations in the field of the laser ω_L and plasma channel ω_β.

Optimization of the acceleration process

- The **energy** and **quality** of the accelerated electron beam depend nonlinearly on many parameters such as pulse profile and intensity, plasma density, interaction length, or material of the target
- The **optimal** acceleration can be achieved by properly shaping the density of the plasma
- How does the **varying density profile** influences acceleration?
- How it can be used to maximize the energy and charge of the electron beam?

Particle-in-cell simulations

The Particle-in-cell method is used for **numerical modeling** of plasmas which includes the description of the motion of particles and **electromagnetic fields** present in the system. The number of particles in such systems is too big to be modeled even at HPC facilities. To overcome this, macroparticles are present in the simulations instead to reduce their number and decrease the computational time.

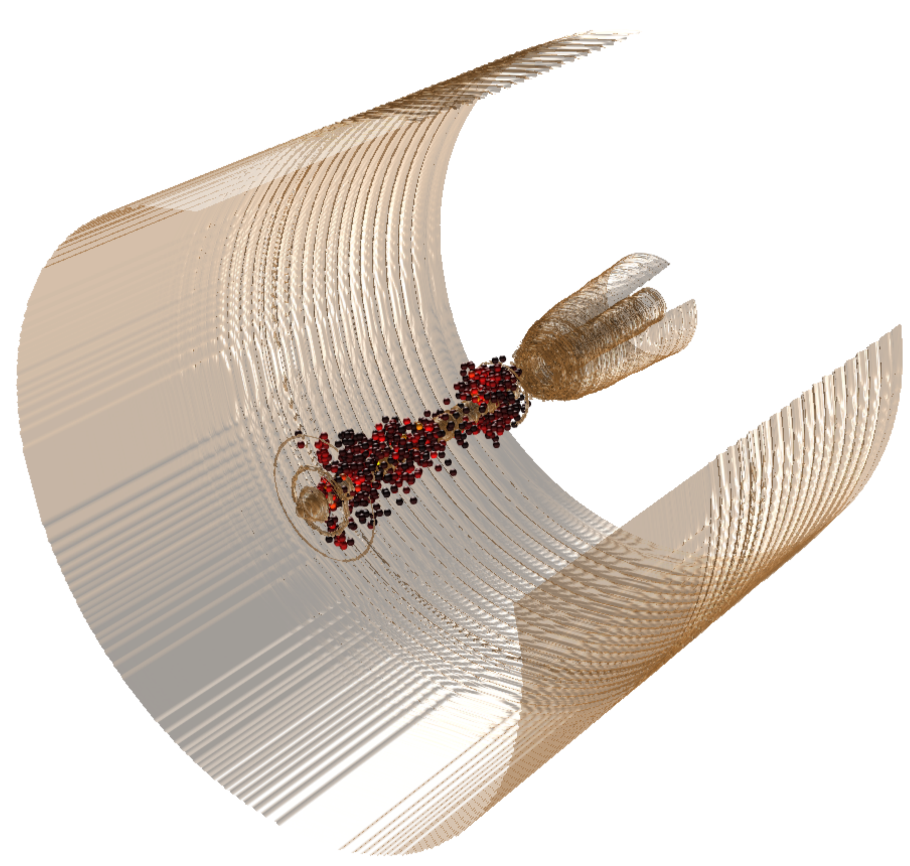


The scheme of particle-in-cell algorithm

In particle-in-cell code, particles can move **freely in space**, whereas electromagnetic fields are stored on the simulation **grid**. Formally, the algorithm solves the kinetic Vlasov equation along with Maxwell equations for the electromagnetic field. Additionally, collisions or various quantum electrodynamics effects can be included.

Quasi 3D algorithm

- 3D simulations need to be used for the **correct quantitative description**, but they are too demanding
- Up to 10^{11} macroparticles might be needed to resolve the physics correctly
- Instead, quasi 3D geometry can be used taking advantage of the **symmetries** of the problem
- It dramatically reduces the number of macroparticles and simulation time



Electrons propagating through the plasma channel

Acknowledgements

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