Modeling of QED Pair Production with a Particle-in-cell Merging Algorithm

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Plasma physics in extreme fields requires taking into account Quantum Electrodynamics (QED) effects such as non-linear Compton scattering (emission of hard photons) and Breit-Wheeler pair production. Such effects intervene typically in astrophysical scenarios (neutrons stars) or in laser-plasma interactions at ultra high intensities ($I > 10^{23}$ W/cm^2). The self-consistent modeling of these scenarios is very challenging: if one attempts to carry out QED-PIC simulations, it is very likely that some localized regions of extremely strong field will produce a vast number of electron-positron pairs. In some cases, the number of pairs and photons that grow exponentially in the simulation may be beyond the maximum number of particles that each processor can handle. This typically causes a memory overflow and the simulation comes to a halt.

This difficulty can be overcome using the concept of macro particles to resample the 6D phase space. When a large number of particles is created, they can be merged into fewer particles with higher particle weights. Ref. [1] presents a simple scheme where excess particles are deleted and their statistical weight is redistributed evenly among the rest of the particles. This conserves the total charge, but neither the total energy nor the total momentum, thus introducing differences in the particle distribution. Here we present a novel particle-merging [2] scheme that preserves the energy, momentum and charge locally and thereby minimizes the potential influence to the relevant physics. This new algorithm has been tested in various scenarios, from classical plasma physics problems to more extreme scenarios, showing that the physics is not altered when particles are merged during the simulation. Finally we show multidimensional fully self-consistent QED-PIC simulation results that could not have been obtained without the particle merging.

[1] A. N. Timokhin, *Mon. Not. R. Astron. Soc*. **408** (2010)

[2] M. Vranic, T. Grismayer, et. al., *to be submitted* (2014)