PICSAR-QED: a Monte Carlo module to simulate strong-field quantum electrodynamics in particle-in-cell codes for exascale architectures

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Physical scenarios where the electromagnetic fields are so strong that quantum electrodynamics (QED) plays a substantial role are one of the frontiers of contemporary plasma physics research. Investigating those scenarios requires state-of-the-art particle-in-cell (PIC) codes able to run on top high-performance computing (HPC) machines and, at the same time, able to simulate strong-field QED processes. This contribution presents the PICSAR-QED library[1], an open-source, portable implementation of a Monte Carlo module designed to provide modern PIC codes with the capability to simulate such processes, and optimized for HPC. We present detailed tests and benchmarks that we carried out to validate the physical models in PICSAR-QED, to study how numerical parameters affect such models, and to demonstrate its capability to run on different architectures (CPUs and GPUs). We also discuss its integration with WarpX[2, 3], a state-of-the-art PIC code designed to deliver scalable performance on upcoming exascale supercomputers. Finally, we present the results of some production simulations carried out with WarpX and PICSAR-QED to investigate strong-field QED effects in ultra-intense laser-solid interaction[4] (see Fig. 1).

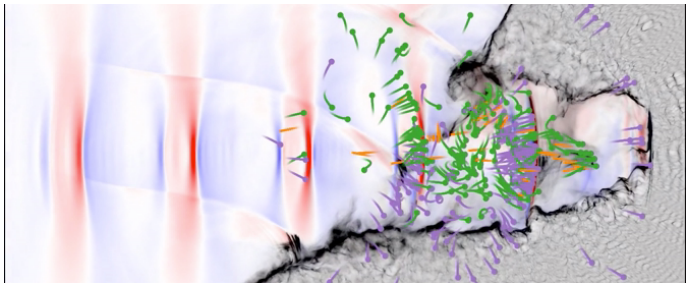

Figure 1: *Snapshot of a 2D Particle-In-Cell simulation performed with WarpX+PICSAR-QED. The interaction of an ultra-intense beam (blue-red scale) between a solid target (grayscale) results into the emission of high-energy photons (orange rays) and the generation of electron/positron pairs (green and purple particles), two processes simulated with PICSAR-QED.*

References

[1] L.Fedeli et al. New Journal of Physics, in press, DOI: https://doi.org/10.1088/1367-2630/ac4ef1 (2022)

[2] A.Myers et al., Parallel Computing **108**, 102833 (2021)

[3] WarpX github repository: https://ecp-warpx.github.io/

[4] L.Fedeli et al., Physical Review Letters **127**, 114801 (2021)