# Simulation of self-field effects in intense em-fields

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## INTRODUCTION

The focus of research of the Computational and Plasma Physics group is the interaction of strong electromagnetic fields with the quantum vacuum and with matter. We make use of large scale numerical computation to solve a set of transport equations. The group collaborates with laser teams at the Max-Planck-Insitute of Quantum Optics. There are a number of topics that have been addressed in recent years.

We have derived a set of mean field transport equations that describe the self-field effects of radiation and electron-positron pair production from seed photons, seed electrons and positrons in strong em-fields. Self-radiation and electron-positron pair production rely on the elementary processes of radiation and pair production in constant crossed field approximation. Radiation and pair production are controlled by their corresponding quantum efficiencies and characteristic formation lengths. With the help the seed particles and appropriate external field configurations both the formation lengths and quantum efficiencies for radiation and pair production can become large enough to trigger cascading. Cascading leads to an exponentil growth of radiation and electron - positron pairs.

Our framework of transport equations consists of extended Vlasov equations for incoherent hard photons, electrons, positrons, and Maxwell's equations for low frequency conherent radiation. The extended Vlasov equations are solved with the help of quasi-element approximations for the one-particle correlation functions of photons, electrons, and positrons. Maxwell equations are solved with the help of FDTD discretization. With the help of the transport equations ordinary equations of motion for quasi-elements are derived. From mass balance event generators for pair production and self-radiation are obtained. From momentum balance the equations of motion of quasi-elements in the mean field with radiation reaction and pair creation are obtained. Pair creation implies that pair production diminishes the one-particle photon correlation function. In the course of a typical simulation the number of quasi-elements can rapidly change. As a consequence the computational load per thread can change. Since our simulations are distributed the need for balancing the computational load arises. This is achieved with the help of many independent simulation patches per computational thread so that patches can be shifted to threads with less computational load at any time. Since the simulation framework utilizes a grid and quasi-elements multiple numerical physics models can be implemented.

Coherent Trident pair production in constant crossed fields is a second order process unlike incoherent Trident pair production from real photons emitted from real pairs and consecutive real pair production obtained from real photons. The calculation of the coherent Trident cross section in constant crossed fields requires extensive computation. The latter might dominate pair production if the spatial extent of the constant crossed field is smaller than the formation length of a typical hard photon emitted in the same field. Under those conditions it is not possible to generate enough intermediate real photons that could drive pair production.

Adaptive Particle Refinement (APR) is a technique that is capable of re-sampling the one-particle correlation functions required in our transport equation framework. APR is designed in a way that mass, momentum and variance of the correlation functions is conserved locally for each point in phase space during the process. In addition, the re-sampling is free of divergence. This implies that no additional charges and currents are introduced during resampling. With the help of APR local fluctuations of the correlation functions can be limited to pre-defined levels while the computational load remains manageable at the same time.

Adaptive Mesh Refinement (AMR) is a technique that is capable of refining the discretization. With the help of AMR it is possible to improve the accuracy of em-field solvers locally while controlling the overall computational load. The problem with non-constant discretizations is that there is a change of refractive index on the numerical grid at resolution boundaries. This leads to em-wave reflection at resolution boundaries. We have been able to design a solver that does not have this problem.

For a number of applications the coherent radiative interaction of multiple charges is required. Such a need exists for electrons trapped in the acceleration bucket of a linear, particle driven wakefield. In order to understand the feasibility of wakefield acceleration of electrons the upper limit of the beam load is a key issue since wake field accelerators tend to be low luminosity devices. We have created a Molecular Dynamics (MD) code that can simulate the direct radiative particle-particle interaction. We use the MD code to improve predictions of electron trapping in wake fields and to address the problem of dynamic beam loading during wake field acceleration.

## RECENT WORK

A first achievement in 2013 has been the completion of the Plasma Simulation Code (PSC) with load balancing and GPU support. The PSC is one of first and one of the few codes that feature load balancing and GPU support. In addition, the code scales on most modern distributed accelerated compute platforms and is further developed to incorporate Adaptive Particle Refinement in the future [1].

Another achievement has been the derivation of analytical expressions for the Trident process. The latter is a second order process and descibes direct electron - positron pair production in strong em-fields in constant crossed field approximation. Direct pair production without real intermediate photons can dominate pair production for specific field conditions [2].

A third achievement is a preliminary formulation of polarized photon production in seeded electron - positron cascades. Presently, most transport equation frameworks for strong em-fields neglect polarization effects of radiation. Under specific field conditions polarization effects of radiation can enhance pair production [3].

A fourth achievement comprises the accurate numerical integration of the Landau - Lifshitz equation. As an example the scattering of electrons in a strong em-pulse has been investigated. It has been shown that electron trajectories in the em-field are highly nonlinear. Some of the electrons have been trapped in the em-field of the light pulse [4].

The PSC is presently developed further to improve the accuracy of radiation and electron - positron pair reaction effects. An accurate accounting of reaction is needed to predict cascading, wakefield acceleration and electron scattering from strong em-fields accurately. It is also planned to improve the versatility of the PSC for laser - plasma simulations in classical mean field approximation without reaction effects.

## REFERENCES

[1] K. Germaschewski, W. Fox, N. Ahmadi, L. Wang, S. Abbott, H. Ruhl, and A. Bhattacharjee, arXiv:1310.7866 [physics.plasm-ph].

[2] B. King and H. Ruhl, Phys. Rev. D88, (2013), 013005, arXiv:1303.1356 [hep-ph].

[3] B. King, N. Elkina, and H. Ruhl, Phys. Rev. A87, (2013), 042117, arXiv:1301.7001 [hep-ph].

[4] N. Elkina, A. Fedotov, C. Herzing, and H. Ruhl, arXiv:1401.7881 [physics.plasm-ph].

### Publications

1. K. Germaschewski, W. Fox, N. Ahmadi, L. Wang, S. Abbott, H. Ruhl, and A. Bhattacharjee, arXiv:1310.7866 [physics.plasm-ph].
2. B. King and H. Ruhl, Phys. Rev. D88, (2013), 013005, arXiv:1303.1356 [hep-ph].
3. B. King, N. Elkina, and H. Ruhl, Phys. Rev. A87, (2013), 042117, arXiv:1301.7001 [hep-ph].
4. N. Elkina, A. Fedotov, C. Herzing, and H. Ruhl, arXiv:1401.7881 [physics.plasm-ph].

### Theses

1. C. Winnerlein, *Event generators for electron - positron pair production*, Master thesis, LMU 2013.
2. M. Imgrund, *On the two-stream instability in pulsar magnetospheres*, Master thesis, LMU 2013.
3. K. Iqbal, *Radiation effects on relativistic electrons in strong external fields*, PhD thesis, LMU 2013.