Modeling of Nonlinear Compton Scattering and Radiation Reaction Experiments

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Based on the work: *Amaro and Vranic PPCF 66 045006 (2024)*

PhD in Physics

Motivation

Near future laser facilities will reach peak intensities capable of probing SFQED processes:

- **Radiation Reaction** (visible effects on the final electron spectrum)
- **Nonlinear Compton Scattering** (γ-ray emission)
- **Nonlinear Breit-Wheeler** e^+e^- pair production

Accurate predictions of particle spectra in laser-electron / laser-photon scattering usually accomplished using **expensive 3D PIC-QED simulations.**

We developed a **fast semi-analytical model** for the final photon and electron energy and angular distributions.

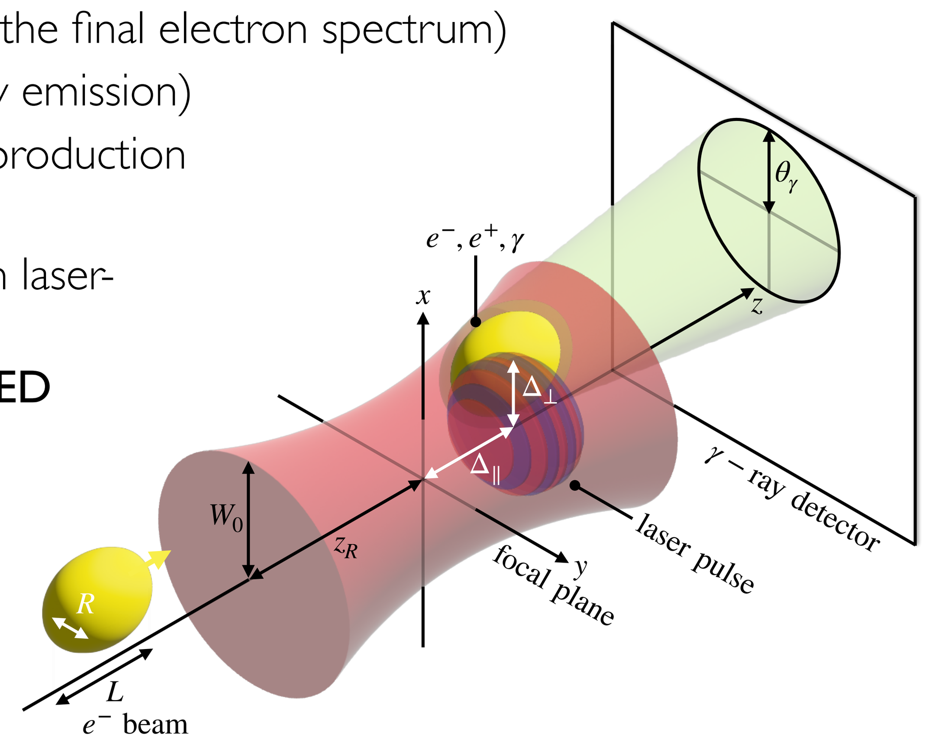

Figure 1: Scattering of a relativistic electron beam (yellow) and an intense, focused laser (red).

Particle tracks diagnostics

In particle-laser scattering it's important to track the maximum field a_0, the quantum parameter χ of the interaction and the laser fluence Φ.

We develop a simple post-processing tool to track these metrics from OSIRIS simulations to support analysis of experiments. Here we showcase results for a CP Plane-Wave.

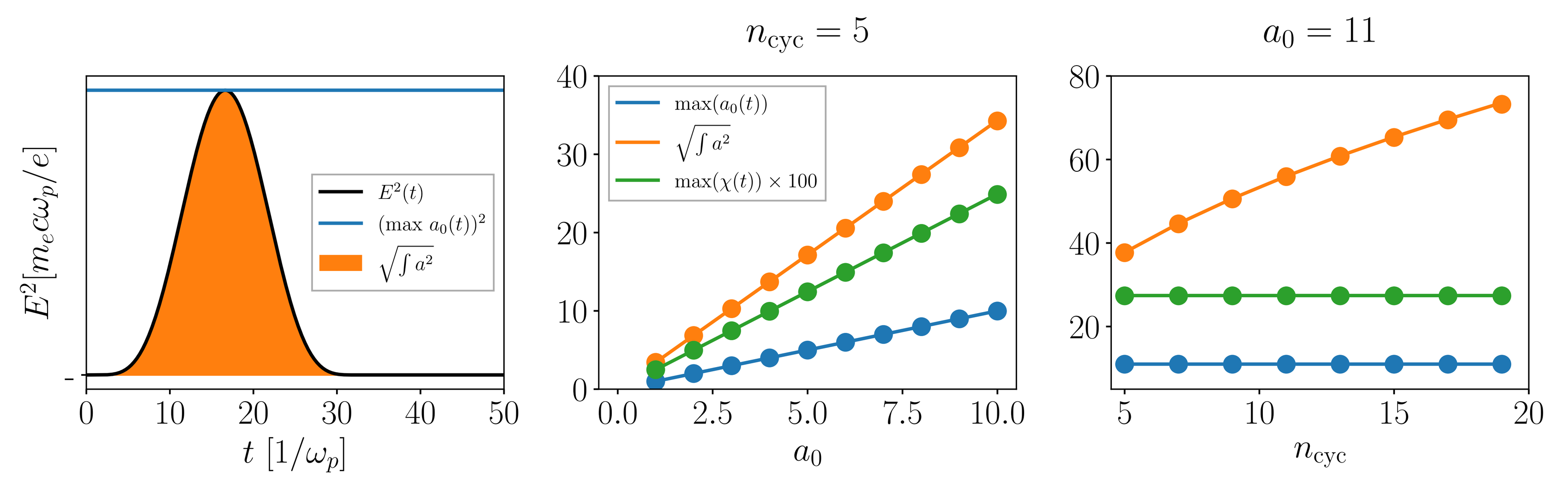

Figure 2: (left) definition of the 3 observables, (middle+right) parameter scan benchmarks

Tracks in focused laser collision

In a focused laser collisions, different particles will interact with the laser at different local maximum intensities. We can directly extract from the ballistic trajectories in quasi-3D simulations the $a_{0,\rm eff}$-distributions.

In this case we turn off Radiation Reaction. Its presence deforms the distribution in maximum χ depending on the model chosen: Classical, Semiclassical, Quantum.

In 0° collisions, there is a 1:1 correlation between $\max\, a_0$ and Φ, which is no longer the case for interactions at an angle.

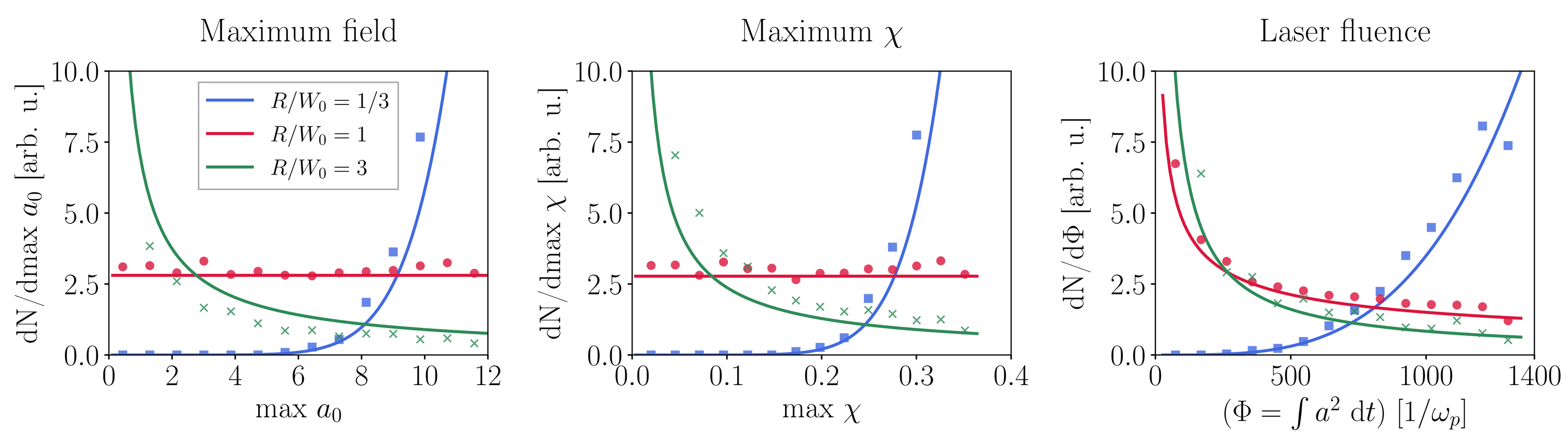

Figure 3: Particle track distributions for Short Beam geometries: lines-theory, markers-OSIRIS

Tight-Focusing regime

In the original formulation, the paraxial form of a focused Gaussian laser was assumed.

However, here we show that the predictions are robust even in the Tight-Focusing regime.

We fix the ratio R/W_0 (which should lead to a shape-invariant spectrum) and decrease the laser spotsize.

The electron energy distribution after Classical Radiation Reaction changes when $W_0 \leq \lambda$.

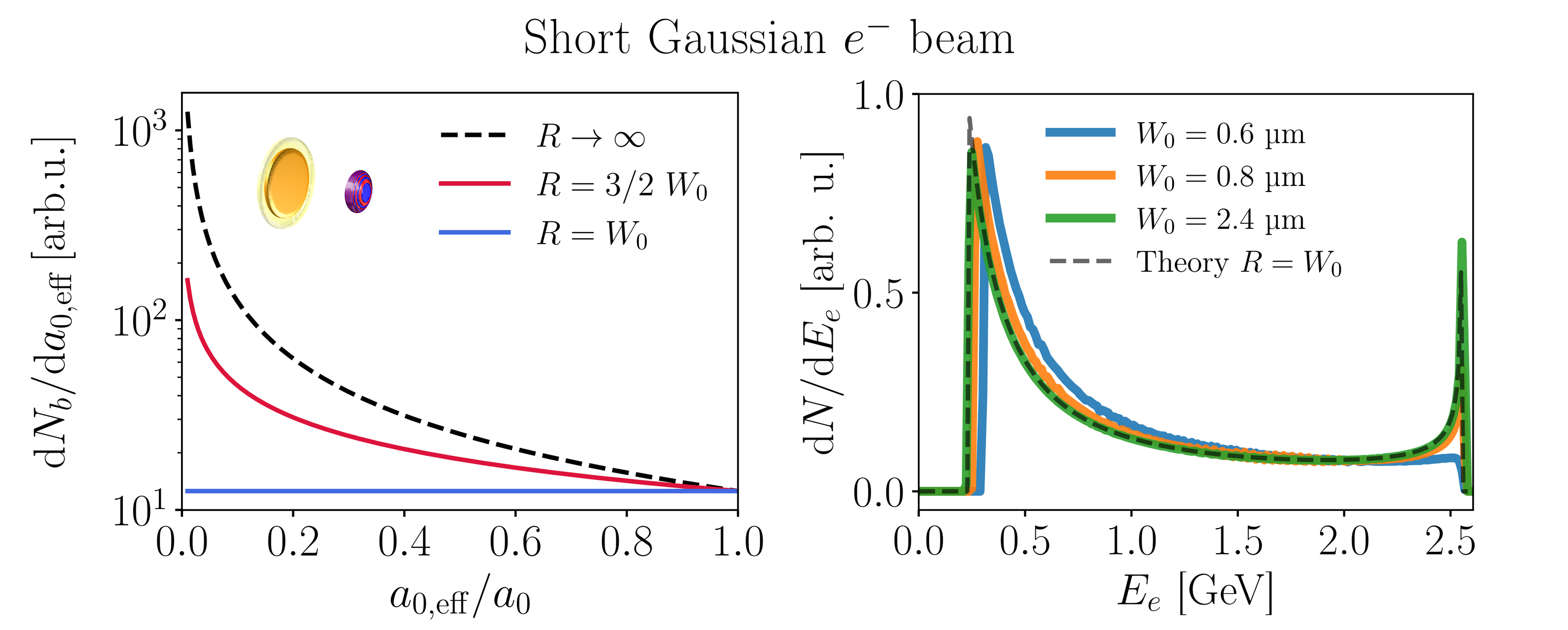

Figure 4: (left) Short beam geometry, (right) final electron spectrum after CRR.

Locally Monochromatic Approximation (LMA)

The $a_{0,\rm eff}$ approach can also directly be applied to the LMA model of photon emission.

Here we collect several photon spectra from PW simulations and varying $a_{0,\rm eff} \leq a_0$.

We combine these datasets weighted by the $dN_b/da_{0,\rm eff}$ distribution.

Same setup as in *New J. Phys. 23 085008 (2021)*

$$\eta=0.1, \theta_{\rm col}=0°, n_{\rm cyc}=15, \lambda=0.8\ \mu{\rm m}, W_0=5\lambda$$

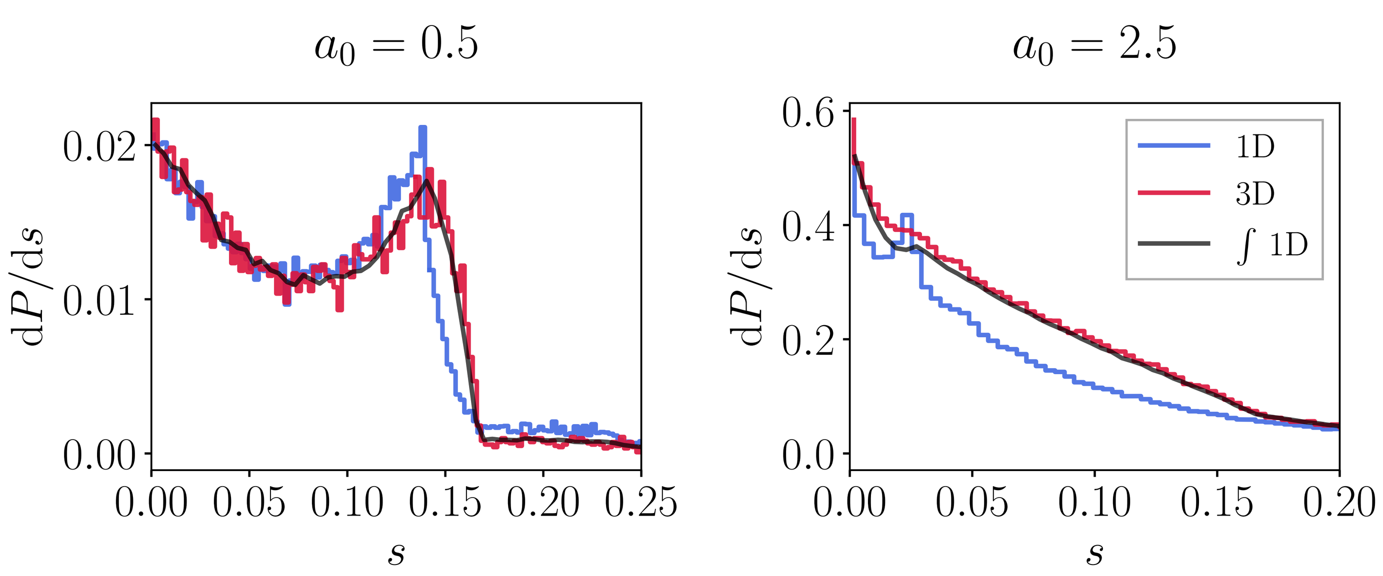

Figure 5: Final photon spectra from LMA emission in a Gaussian laser and disk of electrons.

Chirped electron beams

LWFA-produced electron beams are often chirped: there is some degree of correlation between the inter-beam coordinate and the energy of each electron.

Analytical spectra can still be derived for electrons undergoing Classical Radiation Reaction with a higher-dimensional mapping than for $a_{0,\rm eff}$, now including energy γ_0.

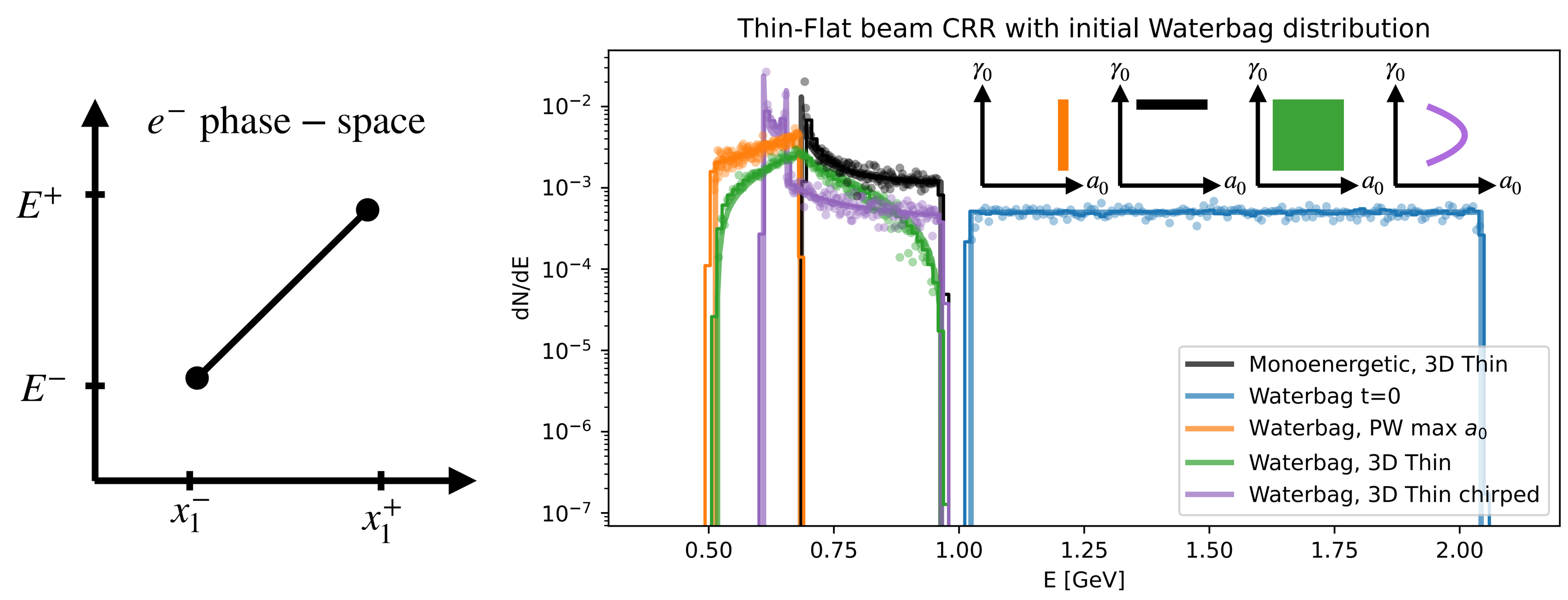

Figure 6: (left) chirp as correlation, (right) electron spectra for various configurations.

Conclusions

We have extended the previous framework of effective laser intensity distributions to other setups of physical relevance for future beam-laser scattering experiments in SFQED. In many cases, analytical results can be derived.

Our main goal is to quickly predict the observables of a given theoretical physics model within SFQED or experimental setup, circumventing costly 3D simulations.

Code: **https://github.com/OsAmaro/QScatter**

QScatter

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Some simulations were run on MN5 Barcelona Supercomputing Center.