Growth rate and distribution function of a QED cascade

T. Grismayer, M. Vranic, L.O. Silva

GoLP/Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Universidade de Lisboa, Lisbon, Portugal

Quantum electrodynamics (QED) cascades describe the exponential growth of an electron-positron-photon plasma in an intense electromagnetic (EM) field. Exponential growth is only possible if both an electric field and a magnetic field are present. In a nutshell, the electric field allows for every new generation of leptons to be re-accelerated after their creation whereas the magnetic field plays a key role for the emitted radiation as well as for the decay of the photons. In the laboratory, QED cascades can be triggered in a standing EM wave which results from the overlap of two lasers [1]. In Astrophysics, the magnetospheres of rotating astrophysical compact objects such as neutron stars can become charge starved, giving rise to the formation of vacuum gaps in which pair plasma is produced [2].

There has been a great endeavor in the past decade to study these cascades (i) analytically with semi-phenomenological models or (ii) numerically from first principles with PIC codes. The main conclusions of these numerical works indicate that a sort of universal behavior is reached during in the exponential phase (before screening) characterized by a quasi-steady state distribution function.

However, a rigorous kinetic model is still lacking. We will show here that it is possible in some special cases (purely rotating field for the laboratory and static E field-curved magnetic field for Astrophysics) to integrate the Boltzmann equation and extract perturbatively exact solutions for the growth rate and the distribution function. Beyond the academical technicity of the problem, this result is important to better understand the development of the cascade, to provide analytical results for codes benchmark, and finally allows for finding heuristic rates for pair creation in given EM fields which can be further used in plasma code (thus alleviating the complexity of full QED implementation).

[1] A. R. Bell & J. G. Kirk, PRL 101, 200403 (2008), A. M. Fedotov et al., PRL 105, 080402 (2010), V. F. Bashmakov et al., Phys. Plasmas 21, 013105 (2014), T. Grismayer et al., Phys. Rev. E 95, 023210 (2017).

[2] A.N. Timokhin, MNRAS. 408, 2092 (2010), F. Cruz et al., ApJ, 908, 149 (2021), A. Philippov et al., PRL 124, 245101 (2020), F. Cruz et al., ApJ Lett. 124, 245101 (2021)