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Field Theoretic Description for Laser Plasma Acceleration: A Proposal

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Study of interaction of radiation with plasmas admits two distinct but equivalent treatments. The conventional plasma approach treats the plasmon simply as a property of the plasma while Compton scattering, involving the transverse polarization of radiation is modified by the fact that radiation propagates in a medium. On the other hand, a field theoretic approach treats them on par. Plasmon is but the longitudinal mode of the photon which, by virtue of its interaction with the plasma, acquires an effective mass [1].

This duality is of relevance to Laser plasma accelerators (LPA) [2]. The remarkably large acceleration over very short distances when an intense laser beam interacts with a plasma holds many parallels with strong field effects which are studied in quantum electrodynamics (QED) [3]. In QED, the vacuum itself dons the role of a medium – with its properties getting modified by strong external fields. In contrast, in LPA, we start with a matter medium which is subjected to an intense radiation field. It is, therefore, pertinent to explore if a field theoretic approach would shed light on the dynamics of plasma interaction.

Indeed, laser plasma interaction studies have been studied in involving PIC simulations. The success has been spectacular, but the beautiful physics underlying the acceleration process is not that vivid, hidden as it would be by the details of highly complicated numerical simulations. This gives yet another motivation to investigate a parallel approach which, at present, may not be numerically accurate but conceptually more transparent.

Yet another set of phenomena involves pair creation and annihilation in LPA which have been observed. These quintessential quantum phenomena requiring a field theoretic description. It would be ideal if there is one such which works both with and without a medium.

In this talk, I present an outline of the program to study LPA in an effective field theoretic approach [4, 5] . First, I present the formalism which involves setting up of quantization rules for the Maxwell field (Radiation) in a medium and the corresponding rules for evaluating various amplitudes for both radiation- charge interaction and electron-electron interactions. I show that a unified description of Compton scattering and plasmon interaction emerges. These two processes essentially drive the acceleration of electrons.

As a preliminary illustration, we show that even within a simplistic approach, where even the nonlinear effects – so crucial to the acceleration phenomenon are neglected, one can develop an intuitive appreciation of the mechanism behind the acceleration process, as being driven by the rich dielectric properties of the medium. This is depicted in Fig 1 which shall be discussed at length in the talk.   In fact, an extrapolation which is rather gross but not entirely unjustified suggests that multi scattering effects could lead to a very good agreement with the experiments.

In short, the field theoretic approach holds promise for giving an alternative description of acceleration and QED processes in a plasma. It would be further enriched if higher order effects are to be computed.

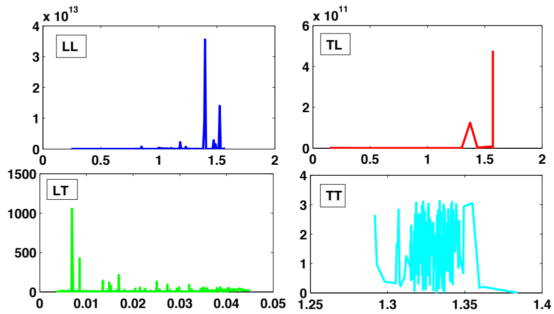

Fig 1: Contributions from various radiation modes to the differential cross section as a function of scattering angle of the electron.

References
[1] P W Anderson, Phys Rev, 130, 439 (1963)
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[3] M Altarelli et. Al., Arxiv: 1905.0059
[4] R Kumar, V Ravishankar and V Krishan, Physics of Plasmas, 19, 093115 (2012); Phys. Lett A, 376, 2053 (2012)