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Numerical modeling of GeV positron generation in relativistic laser-plasma interaction

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With the advent of ultra-intense laser system, such as ELI-NP and LMJ facilities, one can access relativistic laser plasma interaction in a laboratory. The strong electromagnetic field and a resultant plasma's collective effect accelerate charged particles to relativistic regime. Such energetic particles have been attractive due to the motivations in fundamental research and applications: detection of QED phenomena, laboratory astrophysics, and bright γ-ray sources for radiation therapy and photo-nuclear spectroscopy. In recent years, a lot efforts have been devoted for detection of linear Breit-Wheeler (LBW) process using bright γ-ray sources driven by the intense laser light. The LBW process is one of QED phenomena, where one electron-positron pair is generated via collision between two high-energy photons, such as X-ray and γ-ray. LBW process supposedly converts photons to pair-plasmas, so that it determines opacities for energetic photons in the universe. However, nobody has verified LBW process of real photons in experiments due to its small cross section(~10^{-25}cm^2). In order to realize LBW process, one needs collisions between high-energy photons with high-directivity and high-density, and signals of generated positrons is crucially important. Although several verification schemes of LBW using intense laser light have been proposed with a help of a particle-in-cell (PIC) simulations [1,2], the details of positrons' dynamics in the laser-plasma interaction has been unknown.

In this work [3], we have found that a simple regime where a near-critical density plasma irradiated by the intense laser light induces positrons, and they form collimated positron beam with relativistic energies.

We developed a numerical model of LBW process in a PIC code, PICLS, which can compute the radiation transport self-consistently within PIC calculation [4]. It has been demonstrated that an ultra-short petawatt laser light self-organizes a photon collider in a near critical over-dense plasma and produces positrons via the LBW process. We have performed 2D-PIC simulation using the PICLS code. In the simulations, an ultra-short petawatt laser light is focused on a carbon target consisting of carbons. The laser peak intensity, pulse duration, and wavelength are 3×10^{22} W/cm^2, 30fs, and 0.8μm respectively. The initial electron density of the target is set to be $2.8n_c$, where n_c is the non-relativistic critical density of laser light. As radiation processes of electrons, we consider synchrotron radiation and Bremsstrahlung. Such an ultra-intense laser pulse propagates in the over critical plasma by its relativistic transparency with inducing a self-generated magnetic channel structure inside the pulse. A positive electrostatic field appears at the pulse front as the result of electron accumulation due to the laser photon pressure. Due to the self-generated magnetic field, the laser light can drive relativistic electrons, which emit collimated gamma-ray photons via synchrotron radiation, via direct laser acceleration. At the pulse front, on the other hand, plasma electrons are accelerated backward with relativistic energies by the strong positive electrostatic field. The relativistic backward electrons emit photons backward via radiative decay when they collide with the laser pulse. The forward and backward photons then decay and induce electron-positron pairs via LBW process. The generated positrons are accelerated by the same positive electrostatic field to GeV energies with a small divergence of ±10 degrees.

We also investigated the effects of target density configuration on the positron generation and acceleration processes. It was found that positrons are produced and accelerated in the almost same way in the initial electron density range of $0.5\text{-}5.6n_c$. We also observed that pair-creation is triggered effectively when the laser pulse reaches the near critical density region.

In the talk, we'll introduce the simulation models in PICLS code including radiation transport and LBW process, and show details of the simulation results.

References

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