§13. Simulation Study on Pair Production in Laser-produced Plasmas

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Recent high-intensity laser technology provides a new experimental approach to high-energy plasma dynamics strongly coupled with gamma-ray emission and pair production. Such dynamics play an important role in plasma phenomena around active astronomical objects such as neutron star magnetospheres and accretion discs around black holes.

Previously, pair production experiments have been carried out using gold target[1,2]. Basic process leading to the pair production would be Bethe-Heitler process in nuclear field: gamma ray emission from high-energy electron via Bremsstrahlung and pair production from the emitted gamma ray[3]. This process is enhanced in strong nuclear field of high-Z material, such as gold. Systematic experimental data have been obtained about positron energy spectrum and their dependency on experimental conditions such as laser pulse duration and target thickness. These results are, however, not fully described by current numerical simulations. This is because traditional simulation schemes cannot address full picture of positron generation mechanism, which could be a combined process of collective plasma dynamics and quantum stochastic reactions.

A new simulation scheme has been developed to demonstrate the laser-plasma interaction and resulting pair production process in solid target[4]. The simulation scheme is based on relativistic particle-in-cell method[5]. In addition, following two calculation processes are integrated: (1) a conservative semi-Lagrangian scheme (CIP method[6]) for gamma ray transport and (2) a Monte-Carlo scheme for Bremsstrahlung and pair production. The gamma ray transport is described by a fluid description in 5-dimensional real + momentum space. Figure 1 gives schematic diagram of calculation cycle.

The developed scheme is applied to a test simulation relevant to the positron production experiment. The simulation results show a basic process leading to the positron ejection from the target: (1) Electron acceleration due to laser-plasma interaction in the under-dense region at the target surface (2) Bremsstrahlung from the accelerated electrons and pair production from gamma ray inside the solid target (3) Positron acceleration toward the laser propagation direction due to sheath electric field at the target rear side. Figure 2 shows electron density profile at ct = 42[μm], where c denotes light speed. Pulse laser penetrates under-dense region at the target surface and electrons are accelerated in this region. Figure 3 shows positron density profile at ct = 82[μm]. Density is normalized to critical density N_{cr} for the incident pulse laser. Positrons mainly locate inside the high-density target region. Some positrons are ejected from the center of target rear side where sheath electric field is dominant.

1) T. Cowan *et al*, Laser and Particle Beams **17** 773 (1999)
2) H. Chen *et al*, High Energy Density Physics **7** 225 (2011)
3) W. Heitler "The Quantum Theory of Radiation" (The Oxfort University Press) 1954
4) T. Moritaka *et al*, Journal of Physics: Conference Series **454**, 012016 (2013)
5) C. K. Birdsall and A. Langdon "Plasma Physics via Computer Simulation" (Adam Hilger) 1991
6) T. Yabe *et al*, Mon. Wea. Rev. **129** 332 (2001)

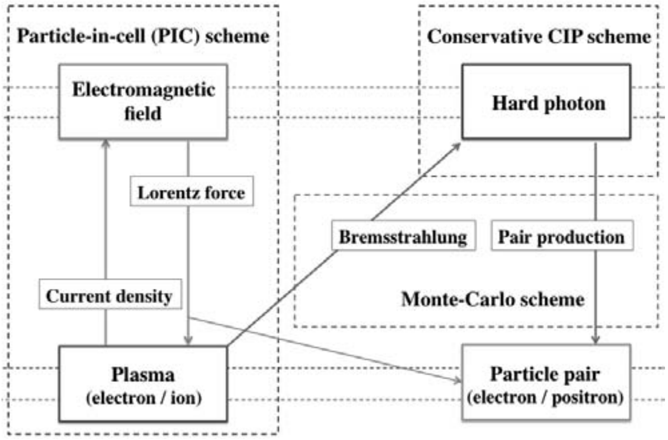

Fig. 1 : Schematic diagram of the simulation scheme

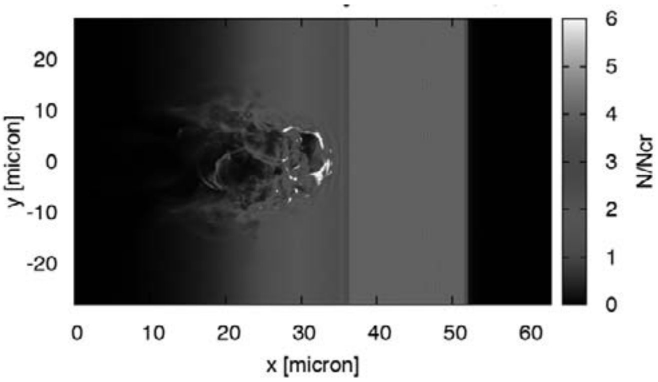

Fig. 2 : Spatial profile of electron density (ct = 42[μm])

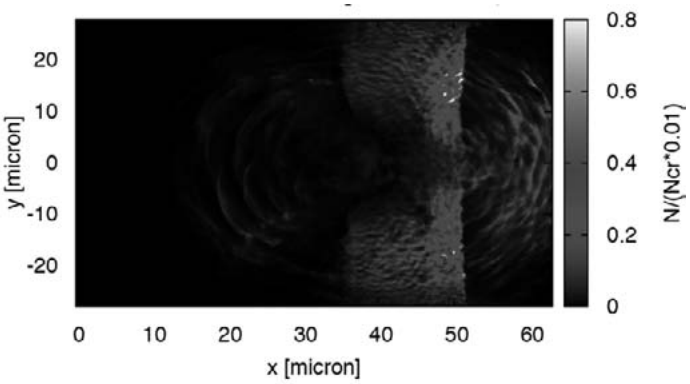

Fig. 3: Spatial profile of positron density (ct = 82[μm])