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

Moritaka, T., Ong, J.F., Wadagaki, T., Teo, W.R., Takabe, H. (ILE. Osaka Univ.), Horiuchi, R.

We have developed a new framework of particle-in-cell(PIC) scheme to investigate intense laser - material interaction[1)]. PIC scheme is a standard simulation method to examine kinetic plasma dynamics. Additional microscopic reactions such as Bremsstrahlung and pair production should be taken into account for plasma dynamics interacting with relativistic electrons and gamma photons. These processes are incorporated by using Monte-Carlo approach. Radiation transport mediating photon reactions is given by a multi-dimensional fluid description. The developed scheme was applied to the pair production experiments using intense laser and thin gold target[2)], and successfully demonstrated the basic properties of observed positron energy spectrum.

The simulation scheme is now being improved to include physics of quantum electrodynamics(QED) in extremely intense electromagnetic (EM) fields, i.e., strong-field QED. Typical reactions are non-linear Compton scattering and multi-photon Breit-Wheerer process[3)]. Unlike the interactions among gamma photon, relativistic electron and high-Z nucleus, strong-field QED is not fully understood by accelerator experiments since the interaction thresholds are determined by background field strength. Cutting-edge intense laser facilities are expected to prove some of the strong-field QED physics[4)]. Using a part of the developed simulation scheme, experiments on quantum correction of photon emission and pair production in intense laser field are proposed to Extreme Light Infrastructure (ELI-NP)[5)].

As the first step, we consider the interaction between electron beam and pulse laser. Two numerical schemes are combined for electron dynamics and photon emission. Equations of motion with radiation reaction terms[6)] are employed for continuous low energy photon emission. Stochastic high energy photon emission is evaluated by Monte-Carlo approach. We have confirmed that expected value of total electron energy loss is consistent with the total cross section of quantum photon emission in intense EM field[7)], $e^{\pm} + n\gamma_L \rightarrow e^{\pm} + \gamma_h$, where $e^{\pm}$, γ_L, γ_h and n stand for electron(positron), low energy photon of background EM field, emitted gamma photon and absorbed photon number. Emitted gamma photon moves in a straight line with pair production in intense EM field[7)], $\gamma_h + n\gamma_L \rightarrow e^- + e^+$.

Figure 1 shows extracted orbits of electron and positron in the 3rd generation (indicated by the arrows). Here "generation" indicates the number of (photon emission + pair production) cycle until the particles are generated. Other gray lines give particle orbits for other generations (0th, 1st and 2nd generations). Peak intensity of pulse laser and electron beam energy are 10^{23} [W/cm^2] and 4 [GeV], respectively. The simulation results indicate that large number of electron-positron pairs are spontaneously generated from one electron via chain reactions of photon emission and pair production.

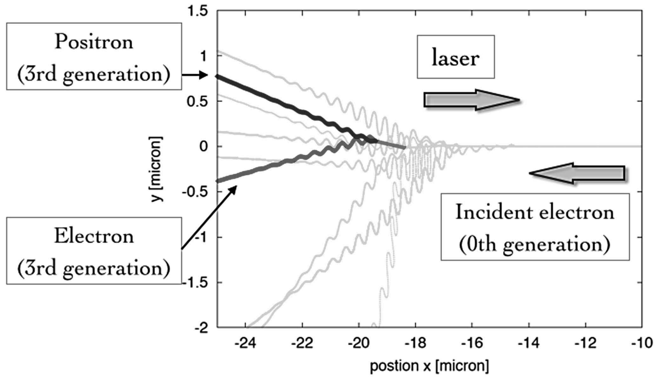

Fig. 1: Extracted orbits of electron and positron.

We have examined roles of laser pulse structure on the chain reaction[8)]. Incident electron loses its energy by radiation reaction dramatically at the edge of pulse laser. This process limits gamma photon emission and resulting pair production in intense EM field at the pulse center. Once the chain reaction is achieved, the pair production rate increases as laser intensity becomes large. This is because gamma photon can penetrate into the pulse center without contenuous energy loss and secondary electron-positron pair emits gamma photons in intense electromagnetic field. Roughly laser intensity $\sim 10^{23}$ [W/cm^2] and electron beam energy $\sim O(1)$[GeV] are required for the chain reaction and effective increase of positron number.

1) T. Moritaka *et al*, J. Phys.: Conf. Ser. **454** 012016 (2013)

2) T. E. Cowan *et al*, Laser and Particle Beams **17** 773 (1999), H. Chen *et al*, High Energy Density Physics **7** 225 (2011)

3) A. Nikishov and V. Ritus, Sov. Phys. JETP **19**, 529 (1964), G. Breit and J. A. Wheeler, Phys. Rev. **46**, 1087 (1934)

4) S. V. Bulanov *et al*, Nuclear Instruments and Methods in Physics Research A **660** 31 (2011)

5) Technical Design Report "*Combined Laser Gamma Experiments at ELI-NP*"

6) I. V. Sokolov *et al*, Phys. Rev. E **81** 036412 (2010)

7) A. A. Sokolov and I. M. Ternov "*Radiation from Relativistic Electrons*" (1986)

8) T. Moritaka and H. Takabe, 23rd LPHYS (Sofia, July 14-18, 2014)