Muon Production and Acceleration with Ultrashort High Intensity laser

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Muons, which play a crucial role in both fundamental and applied physics, have traditionally been generated through proton accelerators or from cosmic rays. With the advent of ultra-short high-intensity lasers capable of accelerating electrons to GeV levels, it has become possible to generate muons in laser laboratories. In this work[1], we show the proof of principle experiment for muon production with an ultra-short, high-intensity laser device through GeV electron beam bombardment on a lead converter target. The muon physical signal is confirmed by measuring its lifetime[2] which is the clear demonstration of laser-produced muons. Geant4 simulations were employed to investigate the photo-production, electro-production, and Bethe-Heitler processes response for muon generation and their subsequent detection. The results show that the dominant contributions of muons are attributed to the photo-production/electro-production and a significant yield of muons up to 0.01 μ/e- out of the converter target could be achieved. This laser muon source features compact, ultra-short pulse and high flux. Therefore, its implementation in a small laser laboratory is relatively straightforward, significantly reducing the barriers to entry for research in areas such as muonic X-ray elemental analysis, muon spin spectroscopy and so on. Moreover, laser produced muons by the Bethe–Heitler process have velocities close to the laser wakefield. It is possible to accelerate those muons with laser wakefield directly. Therefore we propose an all-optical ‘Generator and Booster’ scheme to accelerate the produced muons by another laser wakefield[3]. The trapping and acceleration of muons are analyzed by one-dimensional analytic model and verified by two-dimensional particle-in-cell (PIC) simulation. It is shown that muons can be trapped in a broad energy range and accelerated to higher energy than that of electrons for longer dephasing length. We further extrapolate the dependence of the maximum acceleration energy of muons with the laser wakefield relativistic factor γ and the relevant initial energy E_0. It is shown that a maximum energy up to 15.2 GeV is promising with $\gamma = 46$ and $E_0 = 1.45$ GeV on the existing short pulse laser facilities.

References

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