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Laser-Driven Compact Muon Source: Production and Optimization for Versatile Applications

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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. In this work, we show the first proof of principle experiment for novel muon production with an ultra-short, high-intensity laser device through GeV electron beam bombardment on a lead converter target. 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 $0.01 \mu/e^-$ out of the converter target could be achieved. This laser-driven compact muon source from GeV-level electrons presents an alternative to cosmic-ray and large-scale proton-accelerator-based muon sources thus significantly lowering technical barriers for muon-based research. We further systematically investigate muon production mechanisms. Our analysis addresses critical requirements for both high-energy collimated muon beams and specialized applications such as muon spin rotation/resonance/relaxation research utilizing surface/decay muons. Our simulations derive optimized target configurations to specific application demands and characterize key performance parameters of the generated muon sources. These findings provide foundational guidance for establishing practical muon research capabilities within compact laser laboratories.

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