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Generation of 10 kT axial magnetic fields using multiple conventional laser beams: A sensitivity study for kJ PW-class laser facilities

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Strong magnetic fields are essential for research in high-energy density (HED) science, astrophysics, and controllable nuclear fusion. Plasma properties can be influenced by the presence of magnetic fields of different scales. Multi-kilotesla magnetic fields have various applications in HED science and laboratory astrophysics, but they are not readily available. In our previous work [1], we developed a novel approach for generating such fields using multiple conventional laser beams with a twist in the pointing direction. This method is particularly well-suited for multi-kilojoule petawatt-class laser systems, which are designed with multiple linearly polarized beamlets. Such multi-kJ PW-class laser systems as LFEX, NIF ARC, Petal, and the upcoming SG-II UP, composed of multiple linearly polarized (LP) beamlets, allow experimental investigation of magnetic field generation in bulk plasmas within the relativistic regime by delivering the highest energy within picoseconds.

Utilizing three-dimensional kinetic particle-in-cell (PIC) simulations, we examine critical factors for a proof-of-principle experiment, such as laser polarization, relative pulse delay, phase offset, pointing stability, and target configuration, and their impact on magnetic field generation[2]. Our general conclusion is that the approach is very robust and can be realized under a wide range of laser parameters and plasma conditions. We also provide an in-depth analysis of the axial magnetic field configuration, azimuthal electron current, and electron and ion orbital angular momentum densities. Supported by a simple model, our analysis shows that the axial magnetic field decays owing to the expansion of hot electrons. When compared with other schemes using circularly polarized (CP) or Laguerre–Gaussian beams, the multibeam configuration has several advantages. In particular, our approach requires only an LP Gaussian beam configuration, making it suitable for advanced high-power, high-intensity multibeam laser systems. Despite the challenges associated with pointing directions, the results underscore the feasibility of achieving a strong and sustained axial magnetic field using thoughtfully designed multibeam setups. The results may provide new opportunities to study kT-scale magnetic fields where the magnetic field energy density is greater than 10^{11} J m^{−3}, which is usually the baseline in HED science.

References

[1] Phys. Rev. Lett. **130**, 155101 (2023)
[2] Matter Radiat. Extremes 10, 017201 (2025)

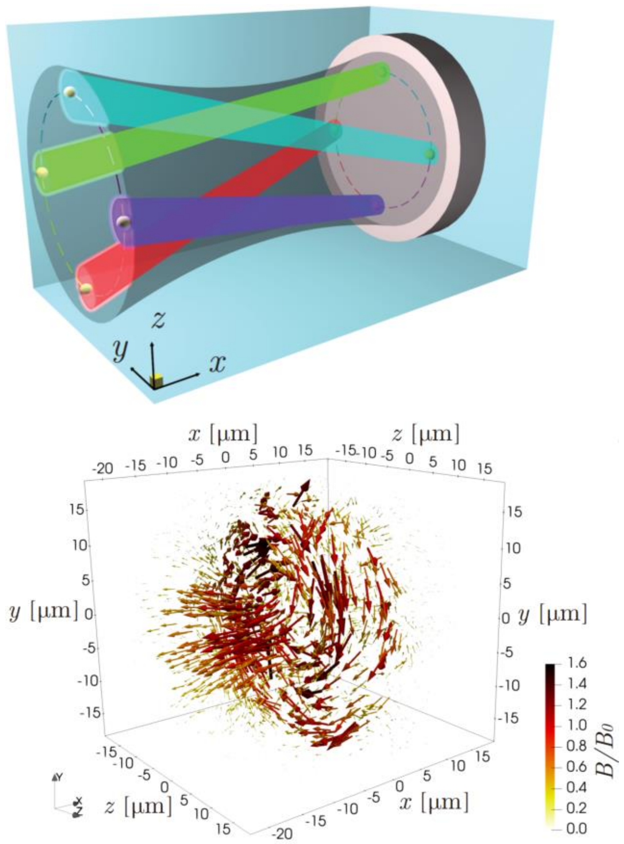

Figure 1. (Top)3D schematic of the target and four regular laser beams with twisted pointing directions carrying AM collectively. The colored cylinders indicate the beams. (Bottom) 3D magnetic vector field and magnetic field line structure when laser beams are reflected away.