

Generation of ultra-relativistic monoenergetic electron bunches via a synergistic interaction of longitudinal electric and magnetic fields of a twisted laser

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A wave-front twist that can be achieved via reflection off a fan-like structure for a high-intensity laser pulse^[1] alters the topology of the laser fields. The circular polarized ($\sigma = \pm 1$ correspond to the right and the left circularly polarized) helical (Laguerre-Gaussian) beam with a twist index $l = -\sigma$ has a unique field structure where the transverse fields have helix-like wave-fronts which tend to zero on-axis where, at focus, there are large on-axis longitudinal magnetic and electric fields.

We use 3D simulations to demonstrate that high-quality ultra-relativistic electron bunches can be generated upon reflection of a twisted laser beam off a plasma mirror^[2]. The unique topology of the beam creates an accelerating structure dominated by longitudinal laser electric and magnetic fields in the near-axis region. We show that the magnetic field is essential for creating a train of dense mono-energetic bunches. For a 6.8 PW laser, the energy reaches 1.6 GeV with a spread of 5.5%. The bunch duration is 320 as, its charge is 60 pC and density is $\sim 10^{27}/\text{m}^3$. The results are confirmed by an analytical model for the electron energy gain. In Figure 1(a)&(b), the electrons injections are shown with or without the effects of longitudinal magnetic fields. The longitudinal field profiles along the axis are shown in Figure 1(c).

We also prove that such an electron acceleration scheme can be successfully applied using significantly lower laser power and using oblique incidence^[3]. Specifically, we show that results of a 600 TW laser beam. In addition to this, the scheme is demonstrated to be tenable with an angle of incidence as high as 25. Our results show that the electron acceleration by helical beams is not limited to high-power high-intensity lasers and can be successfully explored at a wide range of laser facilities. This opens up new paths towards attosecond electron beams, or attosecond radiation, at many laser facilities around the world.

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References

- [1] Y. Shi *et al*, Phys. Rev. Lett. 112, 235001 (2014)
- [2] Y. Shi *et al*, Phys. Rev. Lett. 126, 234801 (2021)
- [3] Y. Shi *et al*, Plasma Phys. Control. Fusion (in review, 2021)

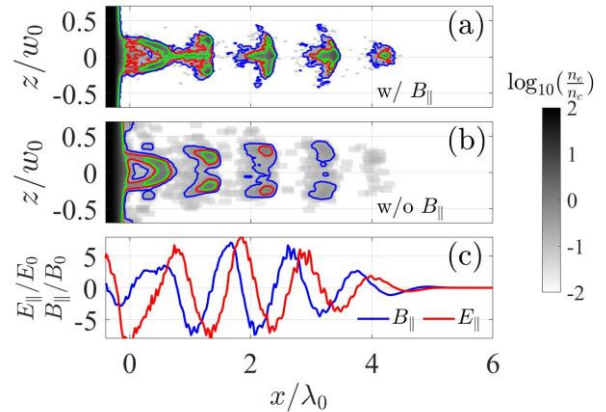


Figure 1. Electron injection into a reflected laser beam with twisted wave-fronts in 3D PIC simulations with (a) and without (b) B_x in the electron equations of motion. The density is shown on a log scale at $t = 9$ fs. The blue, red, and green contours denote $n_e = 0.1n_c$, $0.5n_c$, and n_c , where n_c is the critical density. The profiles of longitudinal electric, E_{\parallel}/E_0 , and magnetic, B_{\parallel}/B_0 , fields on axis are shown in (c), where $E_0 = B_0 = m_e c \omega / |e|$.