Extreme field generation and high-quality proton acceleration driven by Bessel-Gaussian lasers

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Novel light fields beyond conventional Gaussian pulses offer compelling opportunities in the field of relativistic laser-plasma interactions. Notably, Bessel-Gaussian lasers are attracting considerable attentions. Bessel beam is a propagation invariant type of solutions to the Helmholtz equation, exhibiting intriguing properties such as high resistance to diffraction and the ability to self-heal after encountering obstacles. These characteristics have led to diverse applications, including extended depth-of-focus imaging, long-distance underwater optical transmission, material processing, and high harmonic generation in both gas targets and relativistic plasmas.

Here we explore extreme field generation and high-quality proton acceleration with Bessel-Gaussian lasers. Through 3D particle-in-cell simulations, we show that high harmonic generation from Bessel-Gaussian laser-driven curved relativistic plasma mirrors exhibits self-healing properties up to the relativistic and extreme nonlinear regime. This self-recovery process allows a secondary intensification of reflected harmonics beyond the focal region of the curved plasma mirrors, and thus extends the extreme field region in both space and time, beneficial for extreme field applications such as probing strong-field quantum electrodynamics phenomena.

To address the challenges of simultaneously increasing cut-off energy, reducing beam divergence, and achieving high repetition rates in laser proton acceleration, we propose magnetic vortex acceleration in near-critical-density plasmas driven by Bessel-Gaussian pulses. Compared to traditional Gaussian or Laguerre-Gaussian lasers, first-order Bessel-Gaussian driving pulses enables a substantial enhancement in both proton cutoff energy and beam collimation. Highly-collimated proton beams reaching 280 MeV can be obtained at a realistic laser intensity of 5×10^{21} W/cm². We identify that the improvement stems from the unique multi-ring intensity profile, which generates uniform plasma channels and sustains intense, long-lived accelerating fields.

These results demonstrate the great potential of Bessel-Gausian lasers for advancing relativistic laser-plasmas studies.

References
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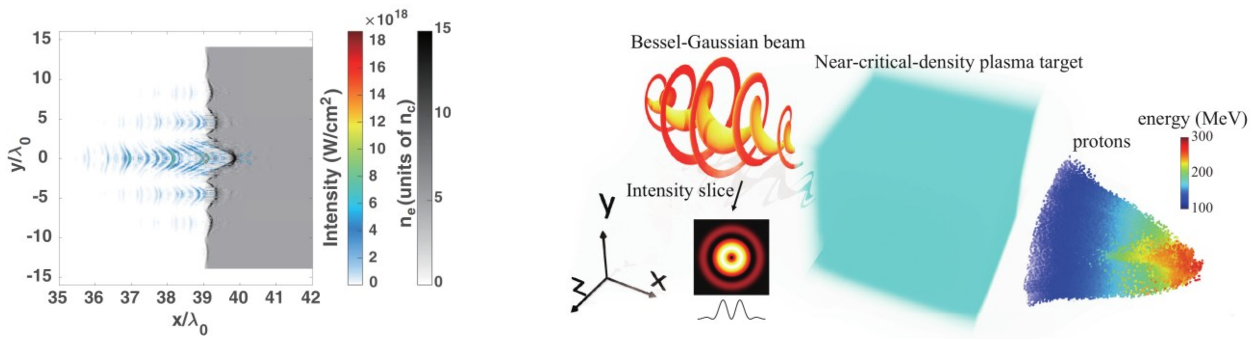

Figure1. (Left) Focusing of high-order harmonics by curved plasma mirrors generated by zeroth-order Bessel-Gaussian laser radiation pressure-induced plasma surface denting. (Right) Magnetic vortex proton acceleration in near-critical-density plasmas driven by first-order Bessel-Gaussian lasers. Spatial energy distribution of the accelerated proton beams from 3D PIC simulations are shown.