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Collider-quality electron bunches from an all-optical plasma photoinjector

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In recent years, plasma accelerators have advanced significantly toward producing beams suitable for colliders, aiming to replace conventional MV/m RF fields with GV/m fields of nonlinear plasma waves. Realizing a plasma-based collider requires electron bunches with high charge (hundreds of pC), low normalized emittance (~100 nm), and energy spread below 1%. Minimizing energy spread during acceleration involves flattening the accelerating field, which is achievable with a trapezoidal charge distribution.

We present a plasma photoinjector concept that enables collider-quality electron bunch generation using two-color ionization injection. The spatiotemporal control over the ionizing laser creates a moving ionization front inside a nonlinear plasma wave, generating an electron bunch with a current profile that flattens the accelerating field. Particle-in-cell (PIC) simulations of the ionization stage show the formation of an electron bunch with 220 pC charge and low emittance (ϵ_x = 171 nm-rad, ϵ_y = 76 nm-rad). Quasistatic PIC simulations of the acceleration stage show that this bunch is efficiently accelerated to 20 GeV over 2-meters with an energy spread below 1% and emittances of ϵ_x = 177 nm-rad and ϵ_y = 82 nm-rad. This high-quality electron bunch meets Snowmass collider requirements and establishes the feasibility of plasma photoinjectors for future collider applications.

Authors: JAIN, Arohi (Stony Brook University); JOSHI, Chandrashekhar (UCLA); PIERCE, Jacob (UCLA); YAN, Jiayang (Stony Brook University); PALASTRO, John (University of Rochester, Laboratory for Laser Energetics); BABZIEN, Marcus (Brookhaven National Laboratory); Dr PALMER, Mark (Brookhaven National Laboratory); DOWNER, Michael (University of Texas at Austin); POLYANSKIY, Mikhail (Brookhaven National Laboratory); VAFAEI-NAJAFABADI, Navid (Stony Brook University); SAMULYAK, Roman (University of Texas at Austin); SIMPSON, Tanner (University of Rochester, Laboratory for Laser Energetics); MORI, Warren (UCLA); LI, William (Brookhaven National Laboratory)

Presenter: LI, William (Brookhaven National Laboratory)

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