From Sub-keV to Multi-GeV: Progress and the State-of-the-Art of Laser Plasma Electron Acceleration Research

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The acceleration of particles to multi-GeV energies in short distances by the extremely strong local gradients achievable in plasmas *via* laser excitation became the topic of intensive experimental and theoretical research worldwide in the last four decades. After several laser installations and upgrades from the TW to multi-hundred TW level in LBNL, the BELLA (Berkeley Lab Laser Accelerator) system with its PW peak-power, 1 Hz repetition rate, and $\sim$35 fs pulses was designed and developed into a uniquely dedicated laser plasma acceleration (LPA) research tool. The 'BELLA-PW' is a Chirped Pulse Amplification laser system (a.k.a. CPA, – see Nobel Prize in Physics – 2018), and it is used for studying laser-plasma interactions occurring at extreme high laser intensities. The peak intensity of the focused femtosecond laser beam reaches the relativistic photon-electron interaction regime, allowing electron acceleration experiments involving gas jets, gas cells, and capillary discharges as primary plasma sources.

The latest two upgrades of the BELLA laser were recently completed and are now producing new experimental results. The first upgrade is the so-called "Second Beamline" (PW-2BL), where the fully amplified, still stretched pulses of the laser are split before compression, allowing two independently adjustable high intensity pulses to interact with a variety of target arrangements with up to $\sim$40 J total energy. The new BELLA PW 2BL allows to conduct the next generation of LPA experiments, such as staging, laser-driven waveguides for increased electron energy, and positron acceleration. The other upgrade is labeled as "Interaction Point #2" (PW-iP2), in which setup the already compressed PW laser pulses of the original beamline are transported to a new target chamber equipped with a short focal length (0.5 m) optic, resulting in a small focal spot in the order of $\sim$3 μm and very high laser intensity of $>5\times10^{21}$ W/cm^2. An overview of the special considerations, planning, and implementation processes related to radiation shielding, laser and radiation interlock systems required for the safe and efficient operation of the new BELLA PW beamlines and the conduction of the ongoing experiments will also be presented. In addition to the latest results, emerging applications of laser-based particle acceleration will also be discussed.