Electron acceleration and generation of high-brilliance x-ray radiation with the kilojoule and subpicosecond PETAL laser

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Recent progress in high-power laser technology has spurred development of petawatt and picosecond laser facilities, which raises the question of the extension of some applications developed for high intensity and short pulse laser (< 100 fs) to new regimes. This paper concentrates on the possibility to generate an electron wakefield accelerator and an associated betatron X-ray source on the kilojoule and subpicosecond PETAL laser, which is implemented on the Laser Megajoule (LMJ) facility in France. We explore two physically distinct scenarios through Particle-in-Cell simulations. A denser plasma (~10\textsuperscript{18} cm\textsuperscript{-3}) is first used, such that the period of electron Langmuir oscillations is much shorter than the pulse duration, leading to longitudinal breakup (“self-modulation”) of the picosecond-scale laser pulse and excitation of a rapidly evolving broken plasma wake. It is found that electron beams with a charge of several tens of nC can be obtained, with a quasi-Maxwellian energy distribution including a tail extending to a few-GeV level. In the second scenario, at lower plasma densities (~ 2.8 \times 10\textsuperscript{16} cm\textsuperscript{-3}), the pulse blows out plasma electrons, creating a single accelerating cavity, while the use of a density downramp helps to inject a nC quasi-monoenergetic electron bunch, which is then accelerated beyond 1 GeV. In both case the X-ray sources offer broad-band spectra with a slowly decaying amplitude extending on 10’s of keV. A high number of photons (~10\textsuperscript{12}) is calculated in the self-modulated regime. The lower value obtained in the blowout regime (> 10\textsuperscript{9} photons) is compensated by a smaller source duration and transverse size, which increase the x-ray brilliance by more than an order of magnitude against the self-modulated case, also favouring high spatial and temporal resolution in x-ray imaging. In all explored cases, accelerated electrons emit synchrotron x-rays of high brilliance, B > 10\textsuperscript{20} photons/s/mm\textsuperscript{2}/mrad\textsuperscript{2}/0.1%BW. Synchrotron sources driven by picosecond kilojoule lasers may thus find an application in x-ray diagnostics on facilities such as the LMJ or National Ignition Facility (NIF).