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Half-wavelength velocity bunching: non-adiabatic temporal focusing of charged particle beams

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X-ray Free-Electron Lasers (XFELs) and MegaElectronVolt Ultrafast Electron Diffractometers (MeV UEDs) are revolutionary scientific instruments that allow visualising the dynamics in a wide range of systems from atoms and molecules to phonons, magnons and plasmons. Femtosecond (fs) electron beams are at the heart of XFELs and MeV UEDs, and the formation of fs electron beams with ultrahigh densities in the phase space is the subject of active research. We report an interesting regime of non-adiabatic compression of electron beams by two orders of magnitude. Via analytical calculations and numerical simulations, we show that few MeV electron beams (an isolate ensemble of electrons in a beam) can be trapped and compressed by a strong electromagnetic field within a half of the wavelength. Furthermore, in a multi-cell accelerating cavity, the bunch is first compressed and then accelerated, thus allowing one to preserve very short bunch duration. For example, a 3 ps 16-pC 1-MeV electron bunch is compressed to 30 fs rms and accelerated to 12 MeV in a TESLA uperconducting cavity. This proposed mechanism of compression, which is another mode of velocity bunching, It opens the door for obtaining very high electron densities in the phase space.

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