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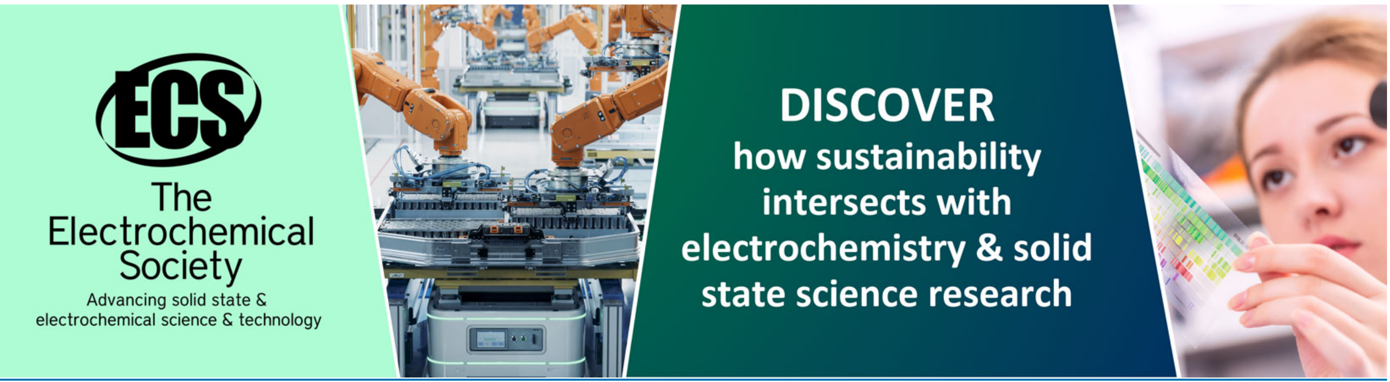

Coherent effect in ionization loss of relativistic electron ensembles in ultrathin targets

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Synopsis Ionization loss of relativistic electron bunches in ultrathin targets is considered. It is shown that the effect of coherent amplification of ionization loss comparing to Bethe-Bloch result, analogous to such effect in radiation, can take place for sufficiently small bunches with high particle densities. It is demonstrated that such effect can manifest itself for bunch parameters achievable on modern accelerator facilities.

Ionization loss of a particle ensemble, moving in substance, is usually just a sum of independent losses of separate particles of the ensemble. In the present work it is shown that the value of a particle ensemble (bunch) ionization loss can exceed the mentioned sum by several orders of magnitude for ensembles of sufficiently high density and small spatial size. Such effect is analogous to the effect of coherent amplification of radiation intensity by electron bunches. The point is that the process of ionization loss, like radiation, is characterized by its typical frequencies ω_{0i} (the characteristic atomic frequencies of the substance) and corresponding wavelengths $\lambda_{0i} \sim 1/\omega_{0i}$ Therefore, in the case when the longitudinal size (along the direction of particles motion) of a particle ensemble is confined within a wavelength λ_{0i}, it is natural to expect strong interference effects in ionization loss originating from the interference of the proper fields of the particles. For this also the transversal size of the ensemble should not exceed the characteristic transversal size ρ_0 of a particle's proper field in substance. Due to polarization of the substance (causing the so-called density effect in ionization loss) this size is estimated as $\rho_0 \sim 1/\omega_p$, where ω_p – is the plasma frequency. This value is rather small and extremely high particle densities of the ensembles are needed for manifestation of the interference effects in ionization loss. Due to this fact fact that up to now the discussed effects we considered just for the simplest cases of naturally created ensembles of several particles situated very close to each other. This, particularly, includes Cudakov effect [1] of a high-energy electron-positron pair ionization loss suppression in the vicinity of its creation point and a related effect in ionization loss of charged particles created in the result of a low-energy molecule splitting in substance [2, 3].

We show that the condition on the particle density in the bunch is significantly weakened if consider ionization loss in sufficiently thin targets, where the density effect is absent. The same holds for thin boundary layers of thick targets, where the discussed effects can lead to a considerable amplification of a bunch energy deposition in the vicinity of the target surface. In such layers the value of ρ_0 is defined by the typical size of the Coulomb field in vacuum and reads $\rho_0 \sim \gamma/\omega_{0i}$, where γ is the particle Lorenz-factor. For ultrarelativistic particles this value significantly exceeds $1/\omega_p$. In this case the discussed effects can be manifested at bunch parameters achievable on modern free-electron lasers (e. g., European XFEL), as well as on a series of accelerators presently under construction (e. g., SINBAD). In the present work we estimate the value of ionization loss for the bunch parameters typical for the mentioned facilities and investigate its dependence on the bunch size and shape.

References

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