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Quantum to Classical Transition of Free Electron Interaction with Light

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We present a theory for free electrons interaction with radiation in both classical and quantum regimes and delineate their transition, based on a model of quantum electron wavepacket (QEW). The theory has general validity for a wide range of free electron interaction and radiation sources, including Free Electron Lasers, Cerenkov radiation, and transition radiation. We exemplify our analysis with the schemes of Smith-Purcell radiation and dielectric laser acceleration (DLA). These interactions, which were studied in terms of point particle physics, have a quantum nature in a phenomenon known as "photon-induced near-field electron microscopy"(PINEM).
Our QEW model identifies three universal distinct interaction regimes: (i) near-point-particle acceleration/deceleration DLA regime, (ii) PINEM regime of multiphoton induced electron energy sidebands, and (iii) anomalous PINEM regime (APINEM) of a newly reported periodic spectral bunching. See the three regimes in Fig.2.
The formulation displays the transition of the FEL stimulated gain expression from the quantum to classical limit. Elsewhere we provided extension of the semiclassical model to quantum electrodynamics to include spontaneous emission and spontaneous superradiance by modulated QEW similar to the classical prebunched-beam superradiant FEL in the classical point-particle picture。

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