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Energy-conserving theory of plasma wakefield in the bubble regime

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We present a new energy-conserving theory of plasma wakefield in the strongly nonlinear ("bubble" or "blowout") regime in which a driver (a short high-power laser pulse or a high-density electron bunch) propagating in underdense plasma excites a spherical cavity called a "bubble". This regime is widely used in modern wakefield acceleration experiments. However, due to the highly nonlinear nature of the interaction, the theoretical description of it remains challenging. Existing phenomenological models [1] can describe the structure of the bubble and the longitudinal electric field in it, but usually rely on fitting parameters and still provide an unsatisfactory fit to results of particle-in-cell (PIC) simulations in the case of smaller size bubbles.

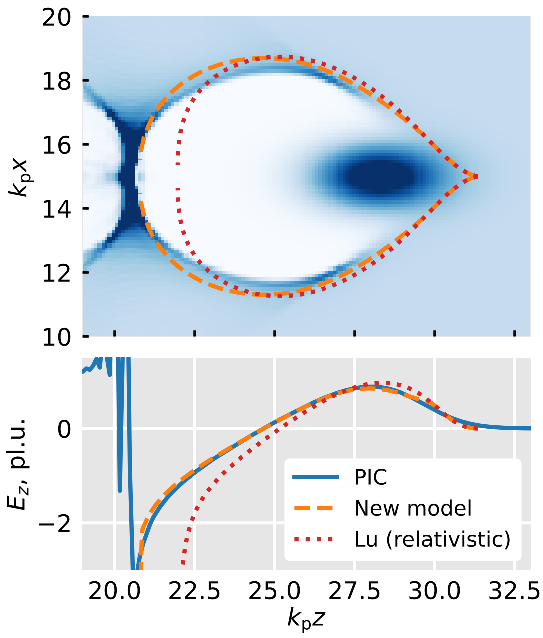

Figure 1: Comparison between PIC simulations of an electron-driven bubble and the predictions of the new model as well as the Lu's model [1] in the relativistic limit.

In the new theory, we derive an equation for the boundary of the bubble starting from the energy conservation law. This equation does not contain additional fitting parameters and accurately describes the boundary of the bubble and the accelerating field in it in a wide range of driver parameters, including the case of small transverse sizes of the bubble. We develop a way to self-consistently describe the excitation of the bubble by an electron driver based on the new theory. We also show that the new model becomes identical to the previous models in the limit when the size of the bubble is large enough. The predictions of the new model are verified by 3D PIC simulations and demonstrate very good correspondence (see Fig. 1).

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References

[1] W. Lu et al. Phys. Rev. Lett. **96**, 165002 (2006)