Finite-Temperature Effects and Warm-Fluid Modeling in Plasma Wakefield Acceleration

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Plasma wakefield acceleration (PWFA) represents one of the most promising routes toward compact high-gradient accelerators. While its modeling has long relied on the cold-plasma approximation, several physical and technological developments now call for the inclusion of finite-temperature effects. Thermal pressure becomes relevant near the wave-breaking threshold, where it regularizes singular cold-fluid solutions, moreover, in high-repetition-rate facilities, cumulative energy deposition and beam-induced heating can modify the nonlinear wake dynamics and the structure of the accelerating cavity.

In this talk, we investigate the physics of relativistic warm plasmas by deriving and comparing different warm fluid models obtained from the Vlasov–Maxwell system through distinct closure assumptions. These warm-fluid descriptions retain the essential kinetic information of finite-temperature plasmas while remaining free from statistical noise. By means of fully nonlinear simulations, benchmarked against particle-in-cell (PIC) results, we analyze how fluid closures affect the description of thermal pressures and pressure anisotropies in the PWFA regimes, and analyze the effect of temperature on the blowout cavity, altering both its longitudinal and transverse dimensions as well as the associated electromagnetic fields. Moreover, we present an extension of the cold-fluid Lu model [1] for the geometric description of the blowout cavity that takes into account thermal effects.

This systematic study delineates the domain of validity of warm-fluid approaches and clarifies when kinetic effects must be explicitly resolved—offering a pathway toward large-scale, noise-free modeling of next-generation plasma-based accelerators.

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[1] W. Lu, C. Huang, M. Zhou, W. B. Mori, and T. Katsouleas, Phys. Rev. Lett. **96**, 165002 (2006).