Exploring astrophysical condition with *ab initio* kinetic PIC simulation

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The fireball model allows for explaining the origin and amplification of magnetic fields in astrophysical settings [1]. A relativistic fireball consists of a flow of electrons and positrons in an electronically quasi-neutral state. Interactions of these beams with the background plasma are believed to trigger microinstabilities responsible for the field growth. Very recently, fireball beams have been experimentally generated [2], thus providing a platform to explore such processes in the laboratory.

In this work, we carried out a detailed numerical and theoretical study with multidimensional particle-in-cell (PIC) simulations performed with the PIC code Osiris [3]. The aim of our work is to determine the required laboratory conditions under which the fireball beam becomes unstable. In this work, we show that the ratio between the density of the fireball and background plasma controls a transition between the current filamentation instability (CFI) and the competing transverse two-stream instability. When the density ratio is higher than unity the CFI can grow as long as the beam expansion rate, caused by a finite emittance, is larger than the CFI growth rate. We find that the longitudinal energy spread, typical of plasma-based accelerated electron-positron fireball beams, plays a minor role in the growth of CFI. Finally, we investigate the role of the transverse offsets between the centroids of the electron and positron beam spatial distribution. We find that the CFI can also grow as long as the transverse offsets between the beam centroids are smaller than a fraction of the beam transverse dimensions.

References

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