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Optimizing High-Energy Photon Generation via Nonlinear Inverse Compton Scattering in Structured Targets Using 3D PIC Simulations

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The generation of high-energy synchrotron-like radiation through Nonlinear Inverse Compton Scattering (NICS) and bremsstrahlung radiation during the interaction of ultra-intense laser pulses with structured targets is a critical area of research. This study, conducted using 3D particle-in-cell simulations with the fully relativistic simulation code Smilei, investigates the parameters that influence radiation yield, focusing on photon density, energy, and angular distribution.

We demonstrate the benefits of using high-intensity pulses ($a_0 > 150$) with laser parameters from previous experimental campaigns at ELI-NP. The target configuration consists of a dual-layered assembly: a fully ionized, low-density carbon plasma layer, followed by a high-density plasma acting as a plasma mirror. The low-density plasma focuses the laser pulse, enhancing compression and serving as a source of high charge and energy. The high-density layer reflects the laser pulse toward the high-energy electrons generated in the first phase.

Using 3D simulations with the Smilei code, we studied the behavior of the laser pulse inside the low-density layer, highlighting the self-focusing effect and the enhancement of pulse intensity. We comprehensively evaluate the impact of target configuration and geometry, as well as laser characteristics, on the production efficiency of NICS photons. By analyzing the complex dynamics of laser-target interactions, we identify optimal target parameters for NICS production, improving our understanding of the resultant radiation characteristics.

The insights gained from this study are pivotal for guiding experimental setups and interpreting experimental results, particularly in discerning the contributions of various mechanisms involved. Our findings have significant implications for developing next-generation photon sources and advancing fundamental research in high-energy-density physics using multi-petawatt laser systems, such as the 10 PW laser infrastructure of ELI-NP.

To save computational resources, we propose a novel scheme for simulating the reflective solid layer by replacing it with a reflecting boundary on one side of the simulation box. This allows for more resources to be utilized for more realistic modeling of the target and the physical processes involved in photon generation while reducing the overall cost of the simulation by up to a factor of 8 (for 2D geometries). This work not only advances theoretical knowledge but also lays the groundwork for practical applications in high-energy laser-plasma interactions, aiming to optimize radiation sources for various scientific and technological applications.

References:
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