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First ML-Based Start-to-End Simulation of a Plasma Acceleration Facility integrated into Geant4: PALLAS - laser-plasma accelerator test facility

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Plasma acceleration is a groundbreaking technology with applications in accelerator and light source facilities, medical and nuclear physics, and beyond. However, their development and optimization rely on computationally intensive Particle-in-Cell (PIC) simulations, requiring specialized expertise and multiple simulation tools, significantly limiting broader adoption.

Geant4 [1] is a widely used Monte Carlo (MC) simulation toolkit for modeling particle interactions with matter in high-energy, nuclear, accelerator, medical physics and space science. Many **Geant4** applications are adaptable for **plasma acceleration, which is currently missing in this toolkit**.

We present the first integration of a Machine Learning (ML)-based surrogate model [2-3], trained on PIC simulations, into Geant4 as a particle source. This enables the generation and tracking of plasma-accelerated beams within complete experimental setups, unifying plasma acceleration and MC-based simulations. Our implementation focuses on the PALLAS laser-plasma accelerator test facility [4], integrating its full experimental setup into Geant4. We describe the ML model, its integration into Geant4, and key simulation results, demonstrating the feasibility of start-to-end simulations of plasma acceleration applications within a unified framework.

[1] S. Agostinelli et al., NIMA 506, 250-303 (2003).
[2] G. Kane et al. arXiv2408.15845 (2024).
[3] P. Drobniak et al., PRAB 26, 091302 (2023)
[4] https://pallas.ijclab.in2p3.fr/

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