Contribution ID: **64**   Type: **Poster**

Developing neural network based surrogate models for predicting laser accelerated proton energy spectra

Tuesday, 31 March 2026 12:00 (2 hours)

Reliable and well-characterised laser-driven proton beams are essential for advancing laser-ion acceleration from fundamental research to practical applications such as medical physics [1]. However, shot-to-shot variability and the lack of robust, non-invasive diagnostics continue to limit progress. Recent advances in machine learning [2] offer a promising route to overcoming these challenges by enabling data-driven prediction of beam properties directly from experimental inputs.

Building on our group's previous work, reported in McQueen et al. [3], which demonstrated a neural-network synthetic diagnostic capable of predicting proton energy spectra from laser input parameters and back-reflected light, we now investigate the development of a more flexible surrogate model that removes the requirement for secondary reflected-light diagnostics. Using the same experimental dataset, we train a neural-network surrogate [4] that takes only laser and target parameters as inputs, learns underlying laser–plasma interaction dynamics, and predicts proton energy spectra with associated uncertainty quantification. This approach aims to increase model portability across different laser facilities, including those where reflected-light diagnostics are unavailable or impractical.

Further work will incorporate data from a dedicated experiment at the ELI-Beamlines facility, enabling systematic studies of parameter-space diversity and controlled scans. These investigations will assess how experimental variability and structured data collection impact the accuracy and generalisability of the surrogate model, contributing toward the long-term goal of autonomous, machine-learning-assisted accelerator operation.

[1] Kroll, F. et al. Tumour irradiation in mice with a laser-accelerated proton beam. Nat. Phys. 18, 316–322 (2022)

[2] Döpp, A. et al. Data-driven science and machine learning methods in laser–plasma physics. High Power Laser Science and Engineering, 11, e55. (2023)

[3] C. J. McQueen. et al. A neural network-based synthetic diagnostic of laser-accelerated proton energy spectra. Comm. Phys, 8, 66 (2025)

[4] B. Z. Djordjević. et al. Modeling laser-driven ion acceleration with deep learning. Phys. Plasmas 28, 4 (2021)

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Session Classification: Poster session