Contribution ID: **184** Type: **Oral Presentation**

Deep Learning–Driven Differentiable Autoplanning for Proton Therapy: A Proof-of-Concept

Proton therapy is widely recognized for its superior dose conformity and enhanced protection of healthy tissues compared to conventional photon-based radiotherapy, making it an increasingly valuable modality for treating complex cancers. However, fully realizing its potential is constrained by the computational demands of high-fidelity dose calculation and plan optimization. Although Monte Carlo (MC) simulations are the gold standard for dose estimation, their computational expense renders them impractical for iterative treatment plan optimization.

In this work, we introduce a deep-learning (DL)–based dose engine that achieves MC-level accuracy in a few milliseconds. Our approach employs a Graph Neural Network (GNN) architecture trained on MC-generated proton pencil beam dose distributions. This design features a cylindrical geometry—chosen for its alignment with rotational delivery systems—and optimizes computational efficiency. Moreover, the architecture affords fine control of spatial resolution near the Bragg peak, balancing precision with memory requirements.

Crucially, this solution is intended for treatment plan optimization. The network is trained over a broad range of beam parameters—energy, lateral position, and incidence angle—enabling continuous, fully differentiable dose prediction in real time. This capability allows direct gradient computation, making it straightforward to embed the dose engine into gradient-based optimization workflows. Consequently, plan optimization becomes a unified, differentiable process, where beam orientations, energies, and fluences can be jointly optimized via efficient gradient-based methods.

We will present validation results confirming the dose engine's accuracy against MC benchmarks, along with proof-of-concept single-field and multi-field proton therapy treatment plan outcomes. The ability to compute dose and its gradients in milliseconds opens the door to real-time, fully automated plan optimization, in which intricate physical and biological constraints can be directly incorporated into the objective function. Furthermore, by managing continuous degrees of freedom effectively, this framework shows substantial potential for advanced delivery strategies such as proton arc therapy, where dynamic modulation of beam parameters is paramount.

Authors: ARSINI, Lorenzo (Sapienza University of Rome); CACCIA, Barbara (Istituto Superiore di Sanità, Rome, Italy); CIARDIELLO, Andrea (Istituto Superiore di Sanità, Rome, Italy); GIAGU, Stefano (Sapienza Università di Roma, INFN Roma, Roma Italy); SARTI, Alessio (Universita' di Roma "La Sapienza"); MANCINI TERRACCIANO, Carlo (Sapienza and INFN)

Presenter: ARSINI, Lorenzo (Sapienza University of Rome)

Session Classification: Parallel session

Track Classification: Nuclear Physics Applications