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Spectral Reconstruction of High-Energy Photon Beams from Depth Dose Curves Using Neural Networks for Beam Characterisation In Radiotherapy

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ABSTRACT

Precise knowledge of high-energy photon spectra from clinical linear accelerators (linacs) is important for dosimetry in radiotherapy. High-energy photon spectra cannot be measured directly, so alternative methods are required for their determination. In this work, the spectral fluence of high-energy photon beams was reconstructed from depth dose curves using neural networks.

The model developed to reconstruct spectral photon fluence from depth dose curves is a recurrent neural network based on a gated recurrent unit incorporating physical laws, implemented as a physics-informed neural network. The uncertainties during training and reconstruction of the spectrum were investigated regarding the accuracy of the neural network. Due to the limited availability of high-energy photon spectra and corresponding depth dose curves, the training data for the neural network were generated using a combination of Monte-Carlo simulations and analytical models. A depth dose curve corresponding to a high-energy photon spectrum from a clinical linac can be considered as a linear combination of monoenergetic depth dose curves, that are weighted by the spectral photon fluence emitted by the linac. A large training dataset was therefore created by summing monoenergetic depth dose curves weighted with analytically calculated spectra.

The trained neural network was validated using measured depth dose curves. The spectra reconstructed from the depth dose curves were compared with Monte-Carlo simulated spectra from detailed accelerator head models. In general, the reconstructed spectra could reproduce all the essential features of realistic spectra and showed good agreement with them. The smallest spectral difference of 1.6 % was obtained for 6 MV beams, while it increased for beams with higher energies (21.5 % at 15 MV), the reason for which is still under investigation.

The neural network enables photon spectra to be quickly determined from simple measurements and will be used in the future to develop a method for unambiguous beam characterization of linacs.

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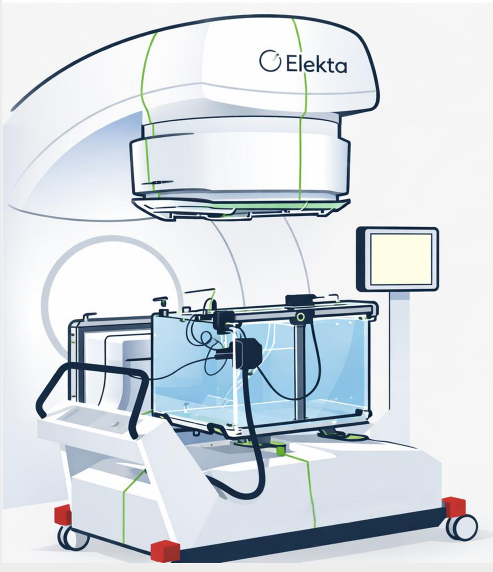
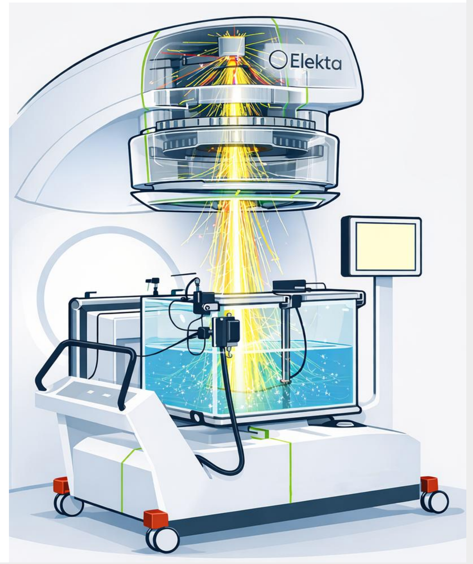
INTRODUCTION

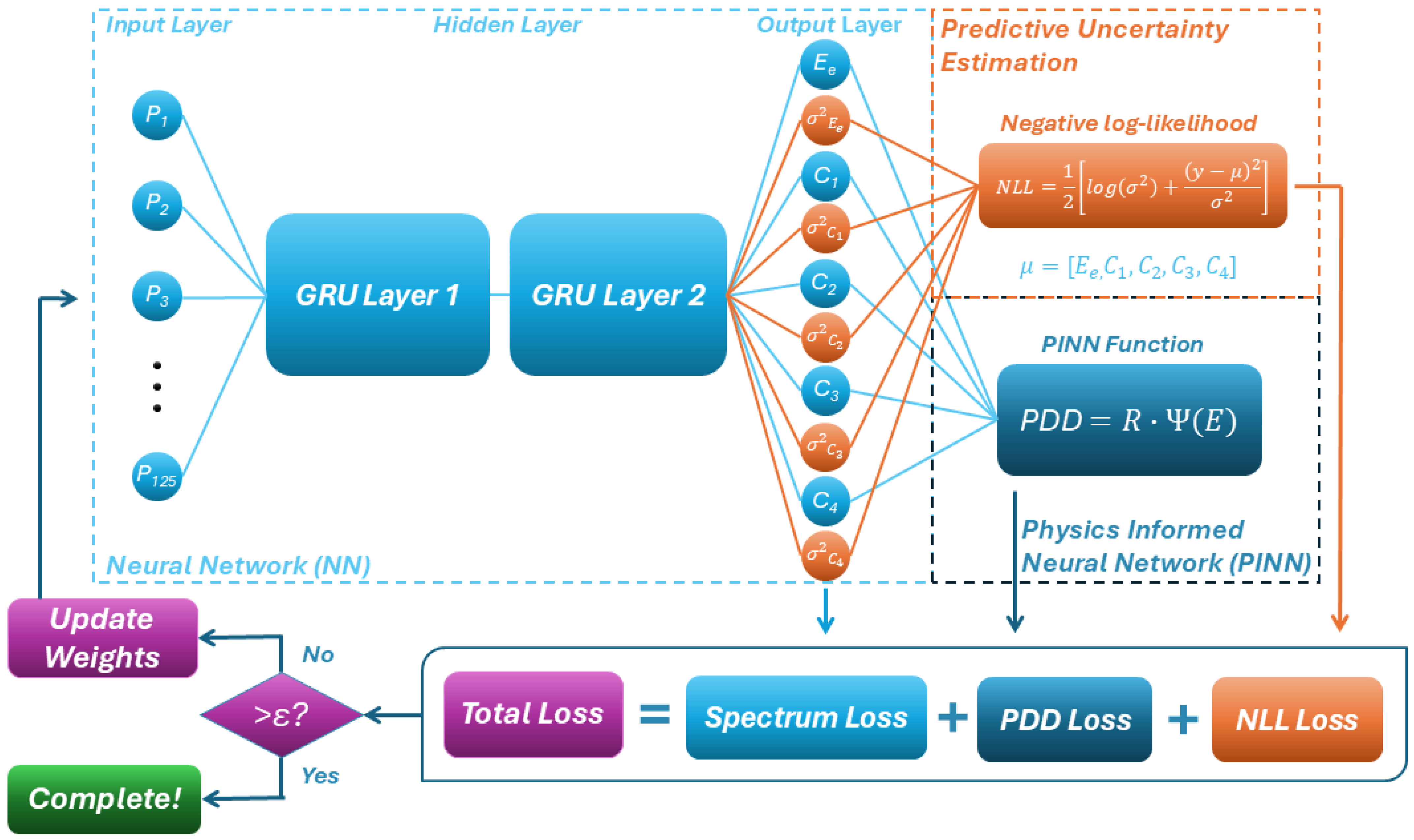
- Reduce uncertainties in dose measurements and calibration of detectors in high-energy photon beams from linear accelerators
- Spectral differences between linacs even of the same type and manufacturer
- Aim: Unambiguous characterization of the spectral photon fluence

$$D_{w,Q} = N_{D,w,Q_0} \cdot M_Q \cdot k_p \cdot k_S \cdot k_P \cdot k_{Q,Q_0}$$





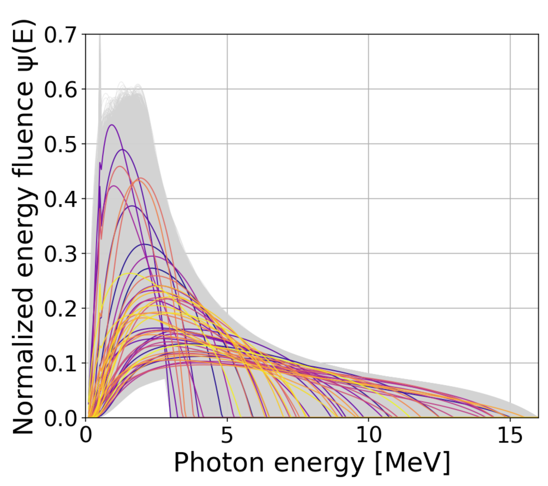
METHODS AND MATERIALS



- Analytical model for generation of high-energy photon spectra(1)

$$\Psi(E) = \left[\overbrace{\underbrace{\left(1 + C_3\frac{E}{E_e} + \left(\frac{E}{E_e}\right)^2\right)}_{\text{Energy dependance}}\underbrace{\left(ln\left(\frac{E_e(E_e-E)}{E} + 1.65\right) - 0.5\right)}_{\text{Shape approximation}}}^{\text{Represents bremsstrahlung spectrum}} + \underbrace{C_4\frac{\delta(E-E_{511})}{dE_{511}}}_{\text{Annihilation peak}}\right]\overbrace{e^{-\mu_W(E){C_1}^2-\mu_{Al}(E){C_2}^2}}^{\text{Photon attenuation by target and flattening filter}}$$

- Calculation of training data: linear combination of Monte-Carlo simulated monoenergetic depth dose curves in water weighted with analytically modelled spectra result in depth dose curves data



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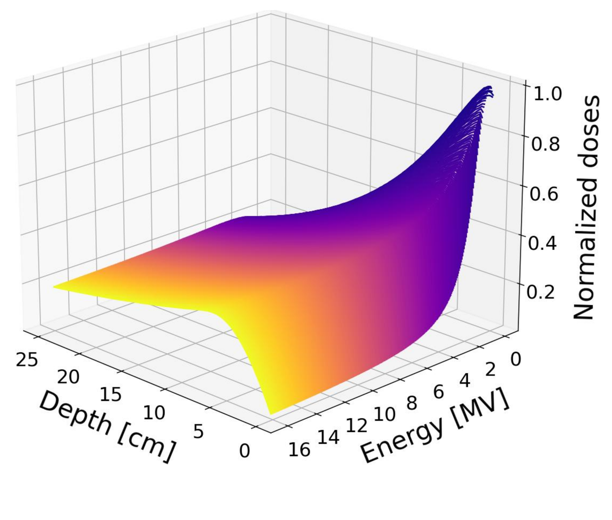

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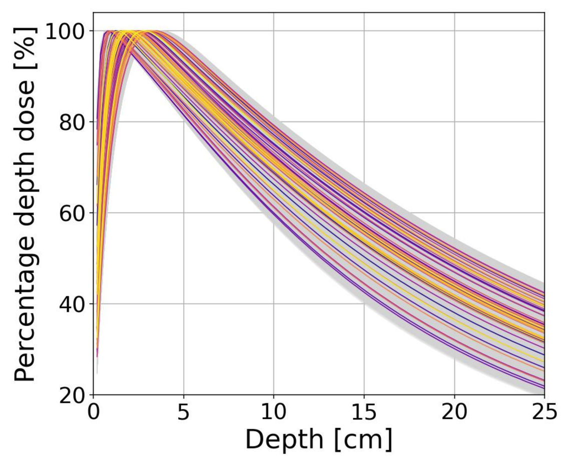
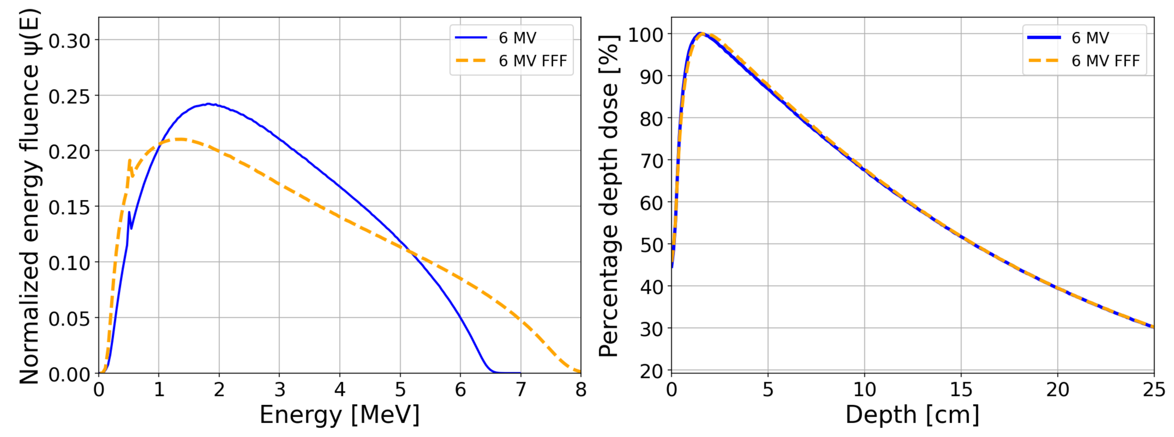
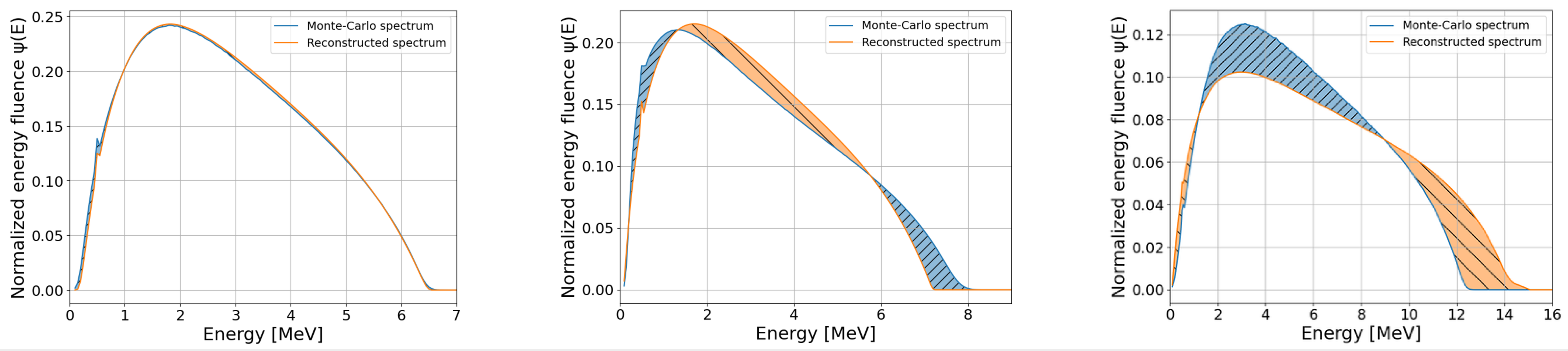


RESULTS

- Elekta 6 MV vs 6 MV FFF 10 x 10 cm², Monte-Carlo simulated spectra and measured depth dose curves



- Spectral differences between Monte-Carlo simulated Spectra and reconstructed Spectra for 6 MV (1.6 %), 6 MV FFF (11.5 %) and 15 MV (21.5 %)

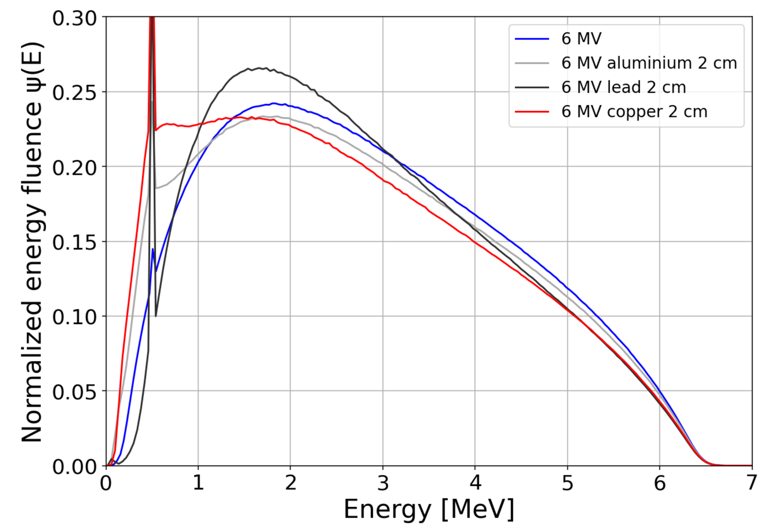


DISCUSSION

- Trained neural network provides physically meaningful fluence spectra from depth dose curves

<u>But:</u>

- *Inverse Problem:* identical depth dose curves can be caused by different spectra
- Without additional input data, the neural network is not able to distinguish between different spectra (beam qualities) that provide the same depth dose curve
- Additional potential input parameters are currently being investigated, including depth dose curves measured with additional filtrations or at off-axis positions



CONCLUSIONS

- The neural network developed in this work is useful for the reconstruction of high-energy photon spectra from measured depth dose curves to use it as a tool to find improved beam quality specifiers
- Future work will explore additional input parameters to unambiguously determine photon fluences from linear accelerators

REFERENCES

(1) Ali, E. S., & Rogers, D. W. (2012). Functional forms for photon spectra of clinical linacs. Physics in medicine and biology, 57(1), 31–50. https://doi.org/10.1088/0031-9155/57/1/31