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Development of Physics Informed Neural Networks (PINNs) for Modelling and Prediction of Data in the Form of Time Series

M.Gelfusa, T.Craciunescu, A.Murari, R.Rossi, J.Vega

TOR VERGATA UNIVERSITY OF ROME

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Background and motivation

Traditionally, in thermonuclear fusion the techniques utilised to analyse the data, to formulate hypotheses, or to develop models suffer from a fundamental dichotomy: they are based either on numerical simulations or on purely data-driven methodologies.

Physics-informed neural networks (**PINNs**) give the opportunity to combine both previous knowledge in mathematical form (for example established theories or conservation laws) and experimental data in the same model building process. Powerful form of data assimilation.

The prior knowledge of any physical model is utilised in the training as a regularization agent that reduces the space of candidate solutions, increasing the correctness of the final output.

Embedding this prior information into a neural network results in various potential advantages: enhancement of the information content of the available data, facilitation of the learning algorithm to identify the right solution, better generalization capability (including transfer from one experimental setting to another) and better capability to handle data sparsity (low amount of training examples).

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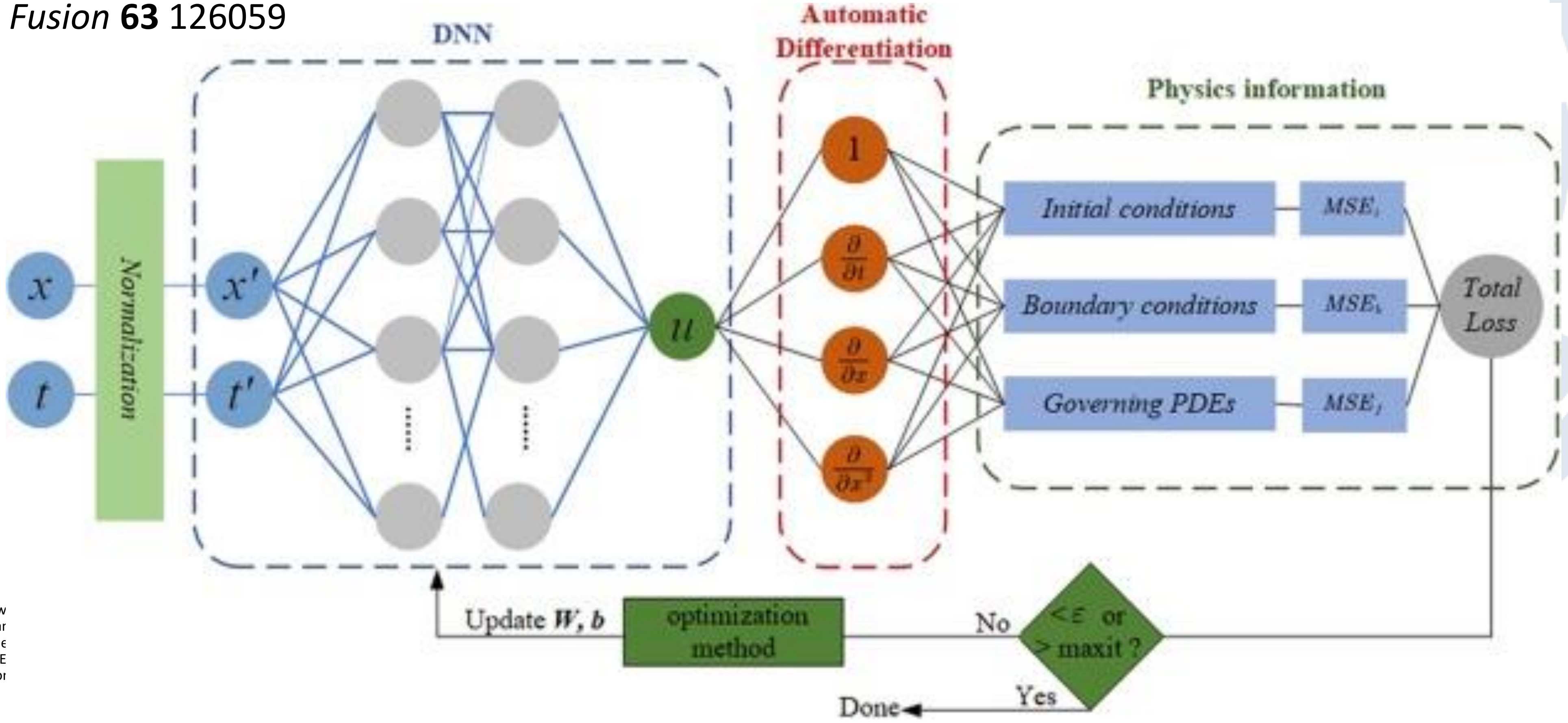
Scope

The main objective of this line of research is to build a first framework for the development of Plasma Physics-Informed Neural Networks, since this new methodology can lead to huge advancements in many fields of nuclear fusion, such as numerical simulations, modelling, physics understanding, and plasma control. Specific aim: take advantage of time indexing

Riccardo Rossi *et al* 2023 *Nucl. Fusion* **63** 126059

The basic architecture of a PINN for the solution of PDEs via deep learning



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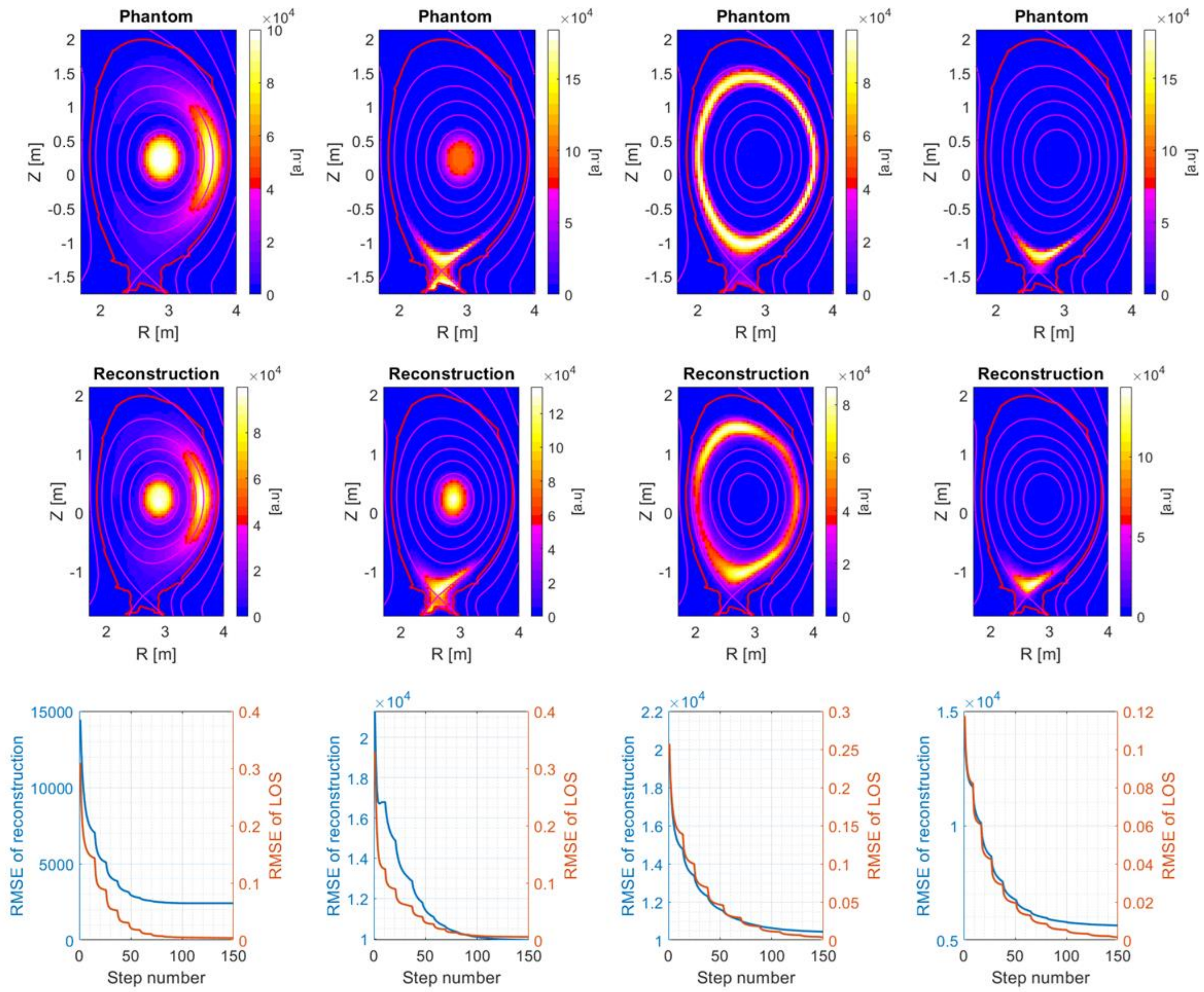
Project structure (1)

Step 1: Development of a time-resolved PINN-based tomography for both plasma diagnostic improvements and radiation transport studies and modelling.

- Work already started with the development of an updated tomographic method based on the Maximum Likelihood approach to provide also confidence intervals in the results.
- The new algorithm is self tuning and therefore does not require any manual intervention.



Ivan Wyss Pin board entry 145

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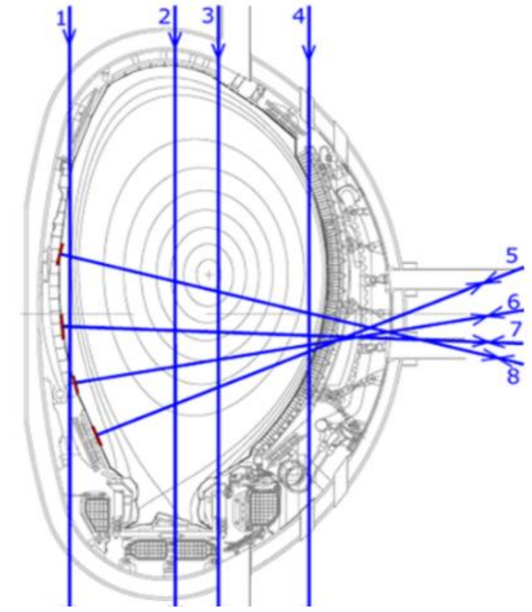
Project structure (2)

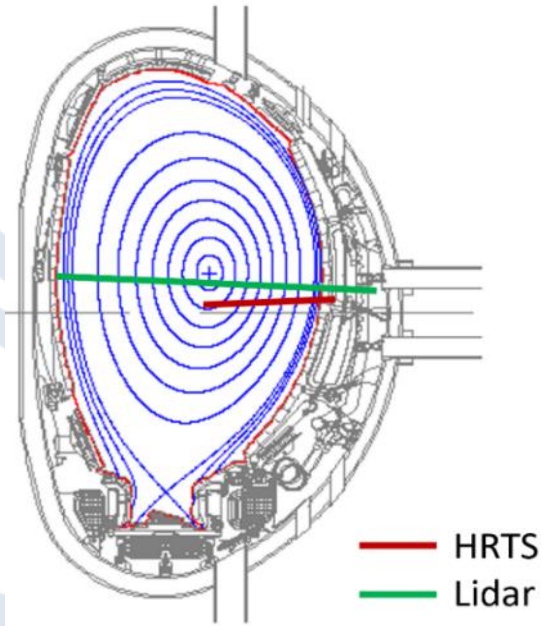
Step 2: Data fusion: development of a time-resolved multi-diagnostics profile reconstructions (electron/ion density and temperature). This method will ensure a better reconstruction of the various profiles combining different diagnostics, allowing the estimate of both the expected values and their uncertainties. Moreover, exploiting physics laws, it may be possible to reach conclusions that simple data-driven methodologies do not allow (super-resolution).

- Work started but various diagnostics still to be included (Riccardo Rossi *et al* 2022 *Plasma Phys. Control. Fusion* **64** 045002)



Step 3: Development of a PINN methodology for time-series modelling aimed at plasma control. Such an approach should allow for the development of simple, performing, and explainable models that may be implemented for both physics understanding and plasma control. The most likely killer application will be the control of the radiation fraction.

- Part of the project to be addressed next year



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Many thanks for Your Attention!

PLEASE WISH US GOOD LUCK.

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