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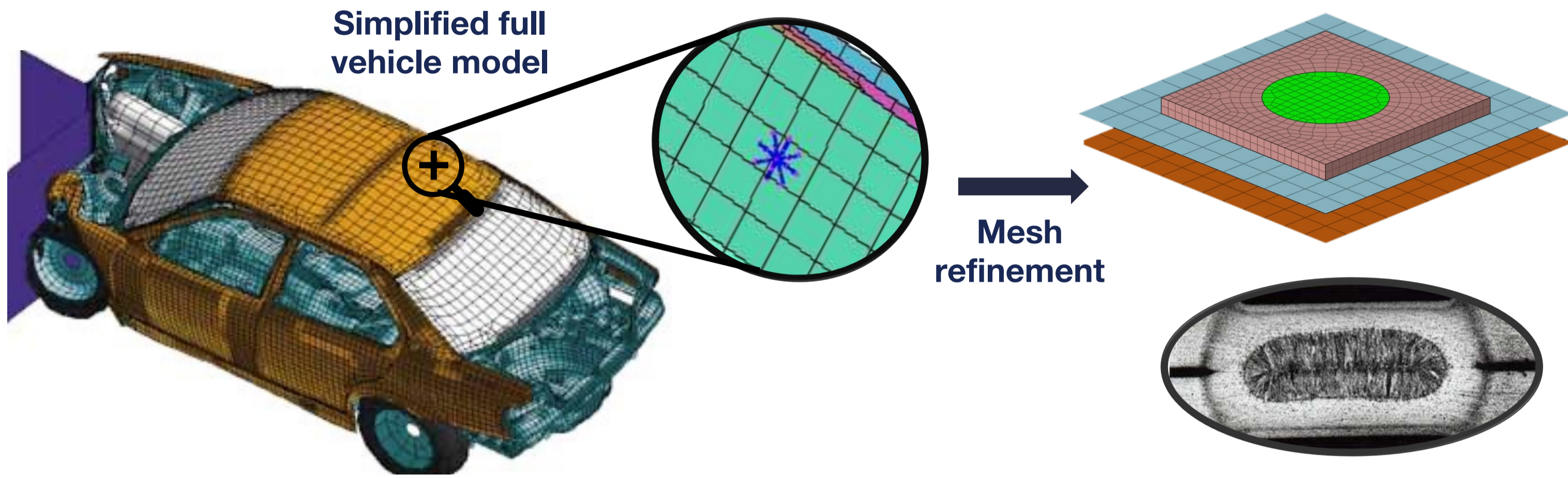
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# SCIENTIFIC MACHINE LEARNING AND PHYSICS-AUGMENTED NEURAL NETWORKS FOR HYBRID DIGITAL TWINS

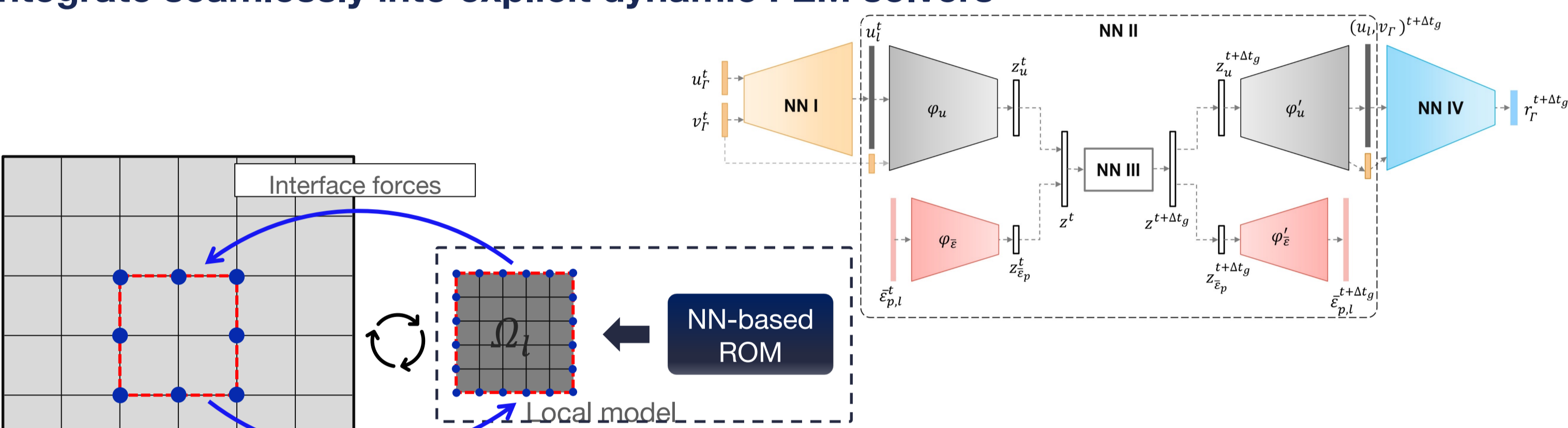
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Keywords: Artificial Neural Networks, Data-driven mechanics, Global-local coupling, Constitutive laws, Neural operators

## Spotwelds modelling with local/global coupling



Objective : develop a quick and accurate meta-model of spot-welded patches and integrate seamlessly into explicit dynamic FEM solvers



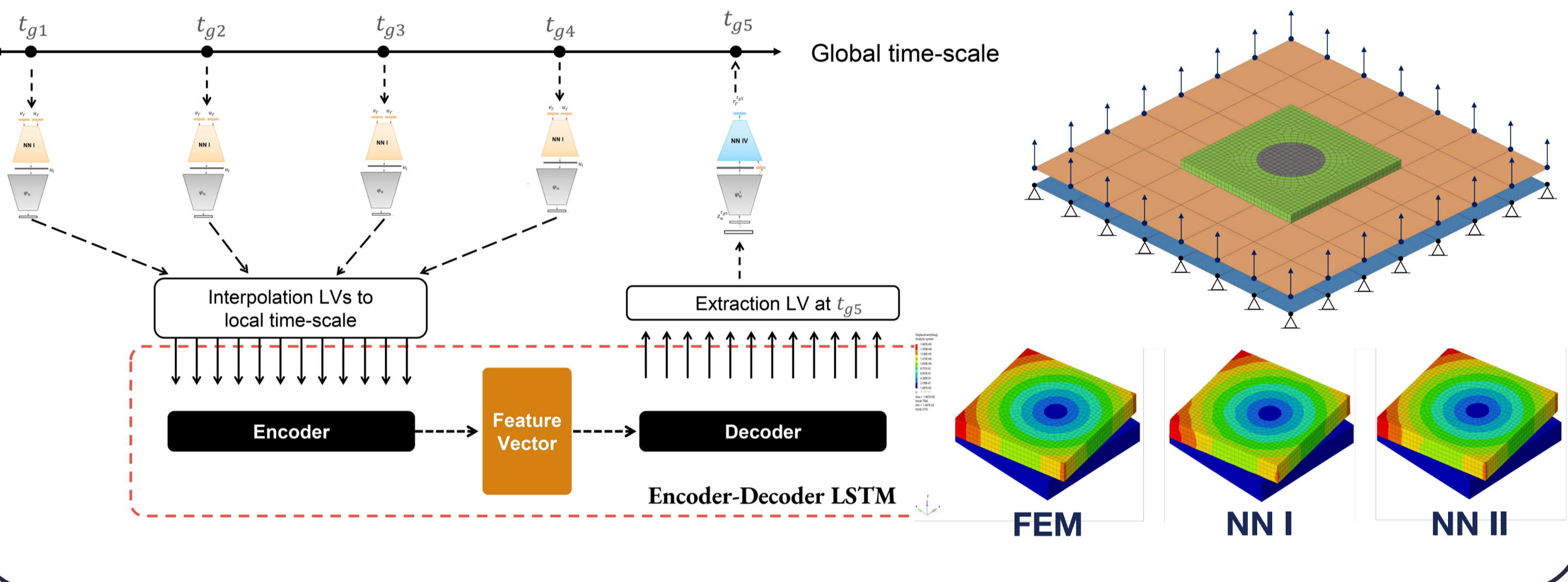
mapping from interface velocities to reaction forces

NN I maps interface quantities to local displacements

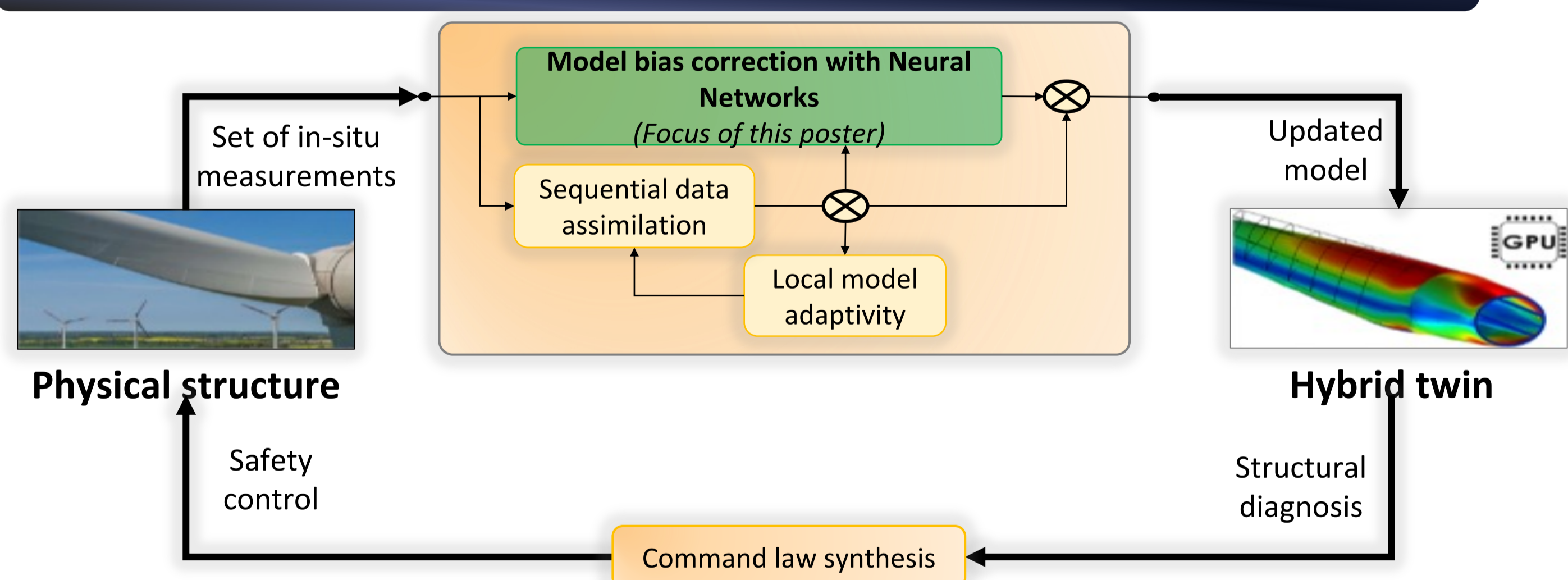
NN II extracts a reduced manifold from the local state

NN III predicts the time evolution of the latent vector

NN IV maps local displacements to interface forces



## Learning of complex constitutive models



$$\mathbf{p}_{opt} = \underset{\mathbf{p} \in \mathcal{P}}{\operatorname{argmin}} \left[ \min_{\hat{s} \in \mathcal{A}_d} \left[ \mathcal{E}_{CRE}^2(\hat{s}) + \frac{\alpha}{2} \int_0^T \|\Pi \mathbf{u} - \mathbf{u}_{obs}\|^2 \right] \right]$$

Weights and biases of the neural network

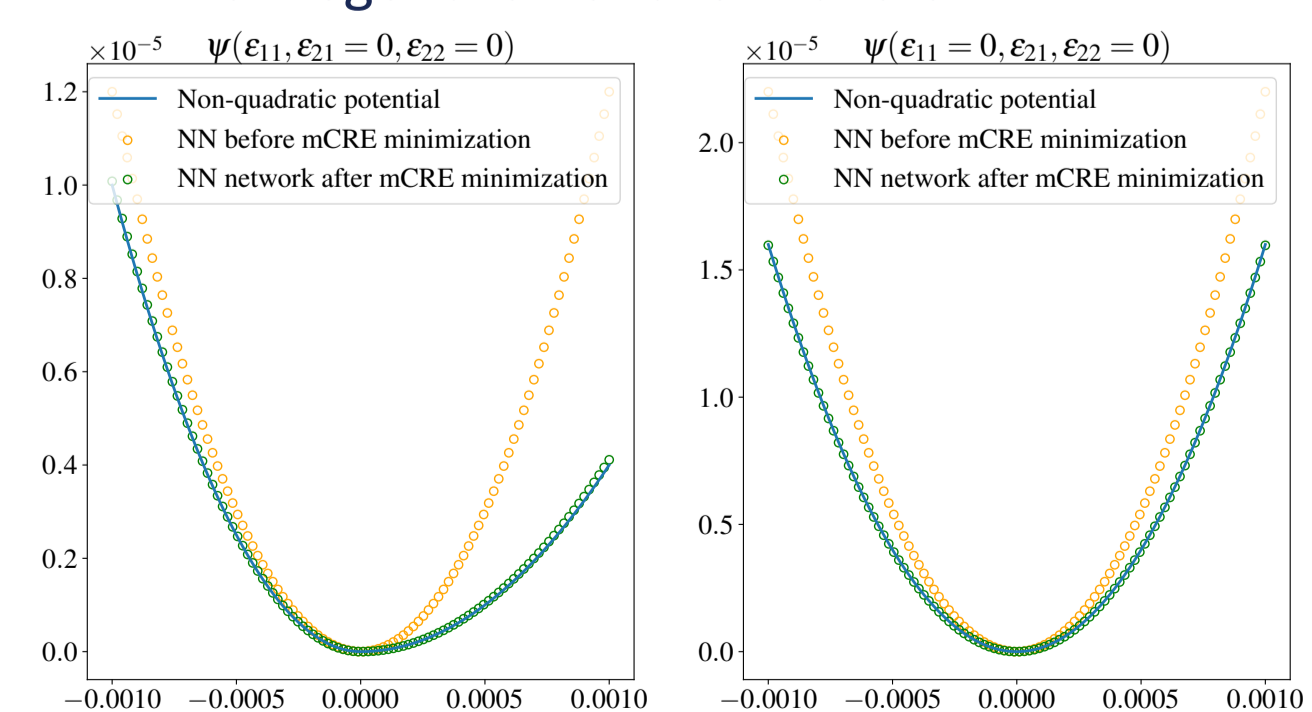
Distance to observations

Space of parameters defined such that physical requirements are satisfied

Static and kinematic admissibility guaranteed

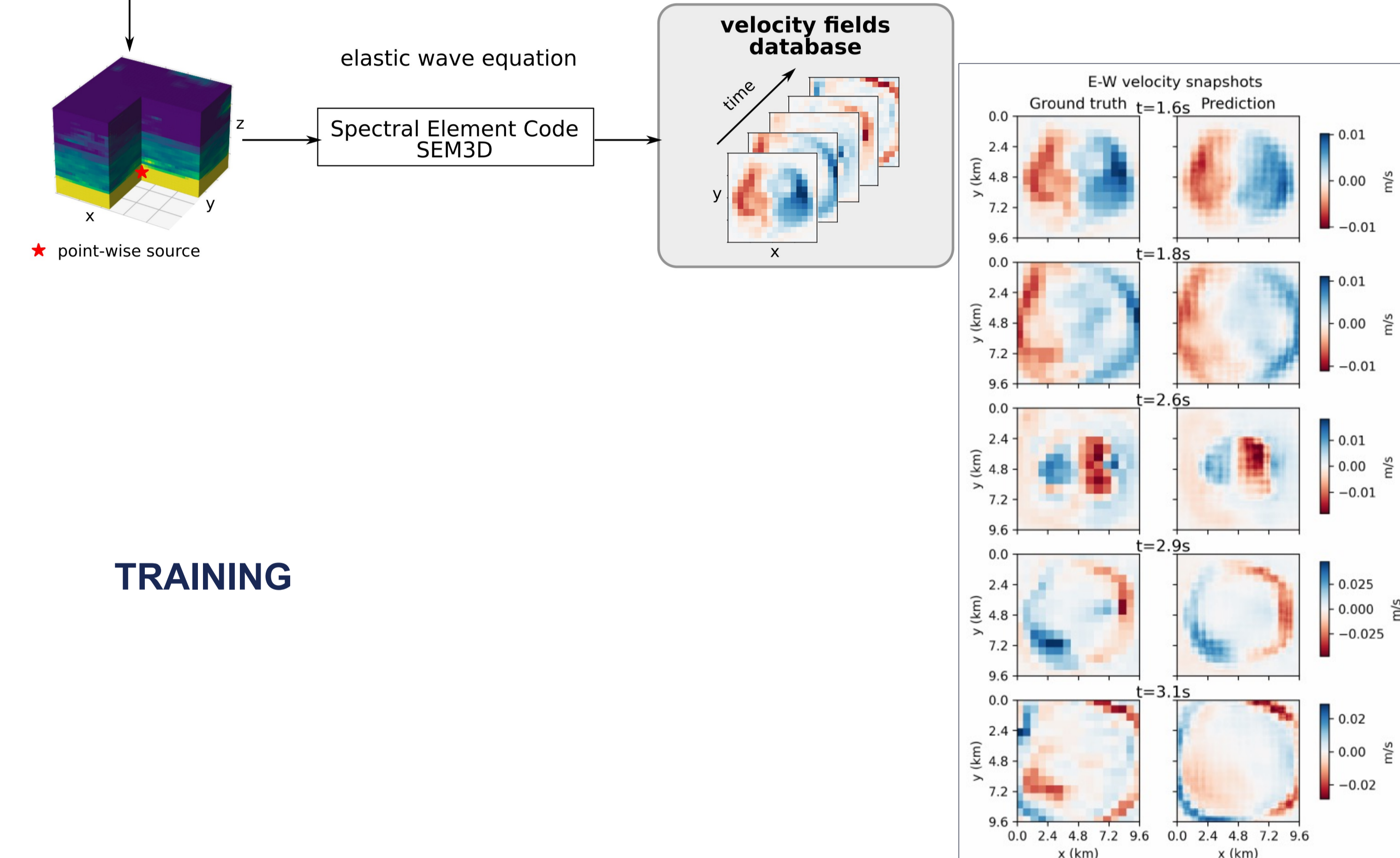
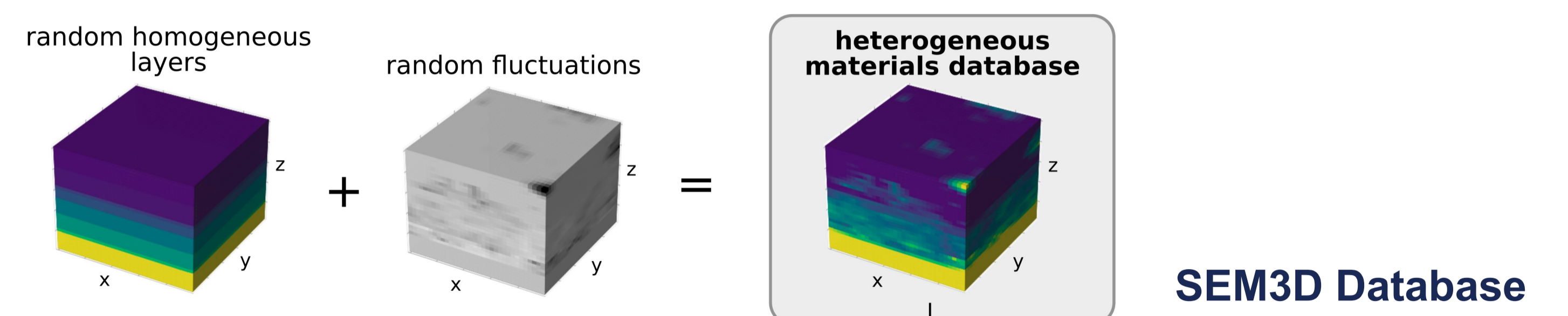
ALL RELIABLE INFORMATION GUARANTEED BY CONSTRUCTION

Model bias indicator based on the residual of Legendre-Fenchel transform

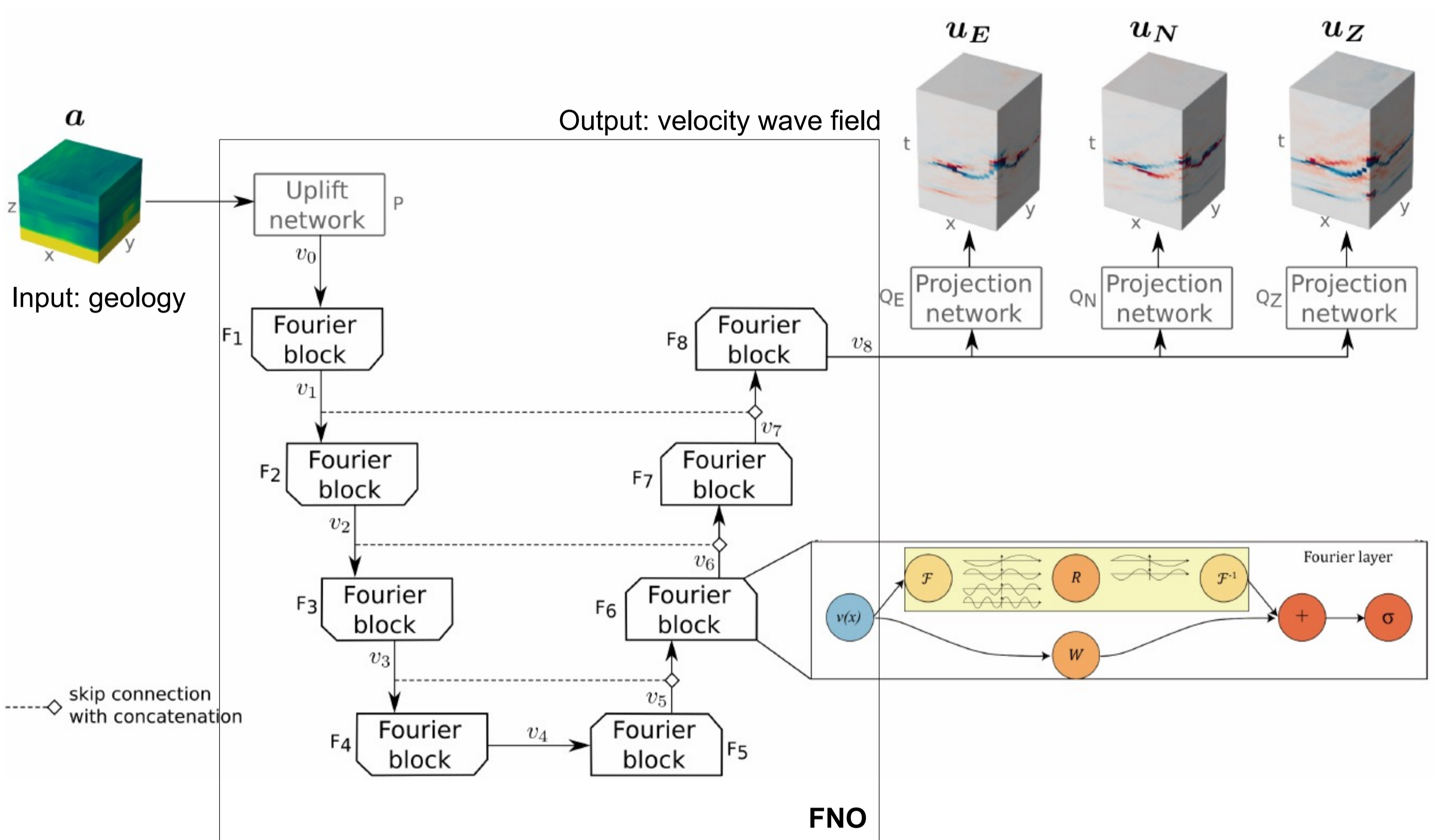


- Learning state equations & evolution laws
- Thermodynamically consistent strategy
- Convexity of potentials enforced with ICNNs
- Approach very robust to noisy data
- Automatic tuning of hyper-parameters

## Fourier neural operator for 3D wave propagation



TRAINING



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