ML-based acceleration of CAKE for real-time kinetic equilibrium reconstruction

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Outline

- Introduction
- NN training
- Training results
- Summary & Future works

Introduction

[1] Z Xing et al, Fus. Eng. Des. 163 (2021) 112163

- **CAKE (Consistent Automatic Kinetic Equilibrium reconstruction) [1]**

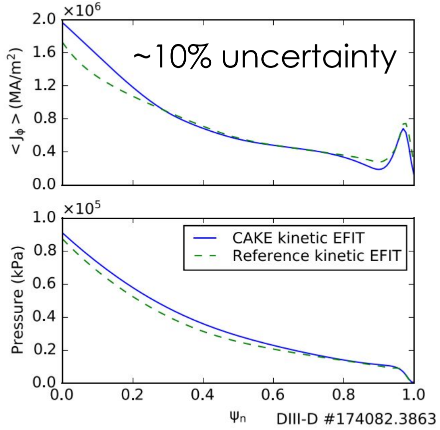
Magnetics
MSE
Thomson
CER
…

➡

Automated kinetic EFIT (CAKE)

Filtering channels
Constraints
NUBEAM/ONETWO
EFIT iteration

➡



(CAKE02)

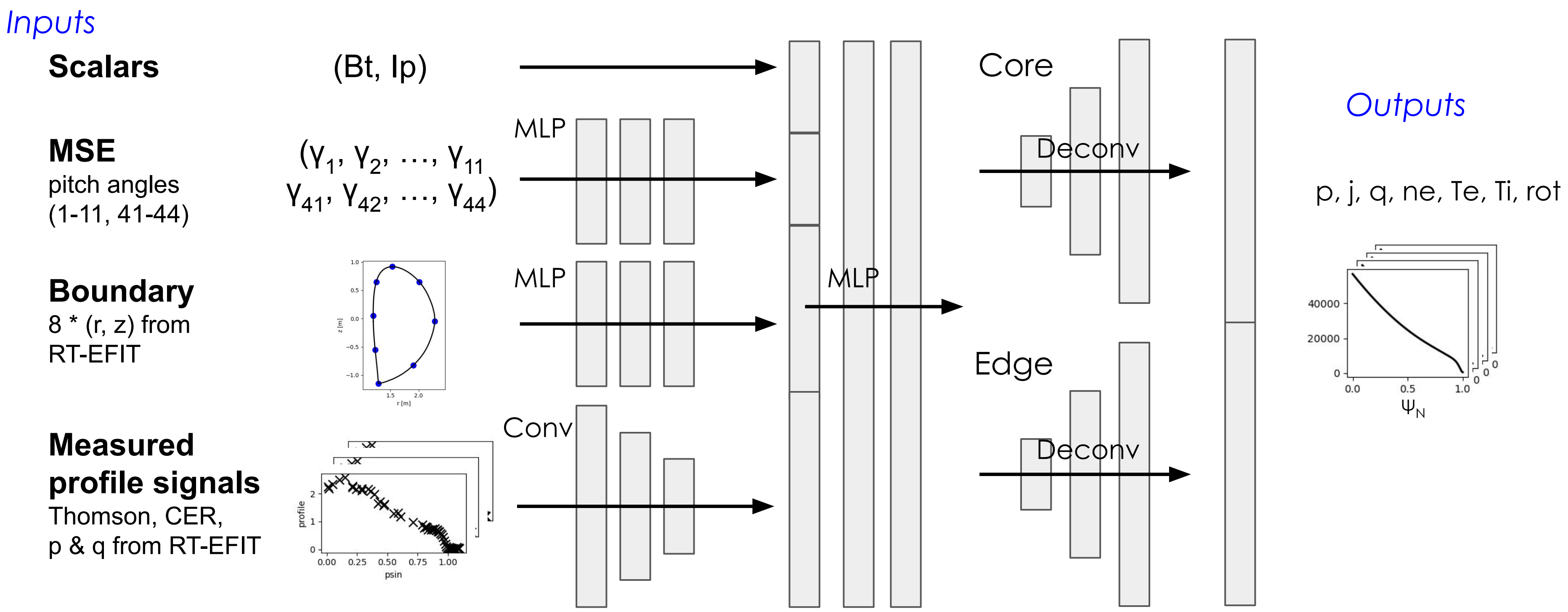
☺ Automated
Consistent
Robust

☹ Many iteration
Costly computation

(Not RT feasible)

➡ **Real-time kinetic EFIT is now ready by using neural net acceleration (CAKE-NN)**

Neural network architecture for CAKE-NN



“Multimodal neural network”

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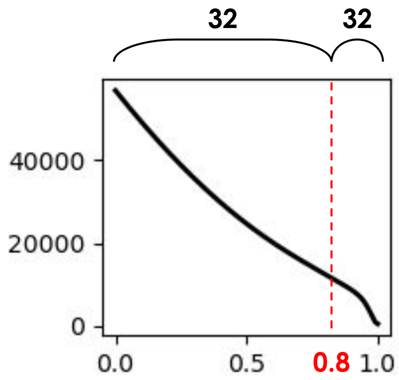
Training data collection

- Shots: 178000 - 192000 in DIII-D (MSE, Thomson, CER available)
- Interval: 100 ms averaged
- Prediction outputs: $p(\psi_N)$, $1/q(\psi_N)$, $j(\psi_N)$, $ne(\psi_N)$, $Te(\psi_N)$, $Ti(\psi_N)$, $V_{tor}(\psi_N)$
- Spatial resolution: 32 for core & 32 for edge

To avoid diverging at the boundary



- ~10000 samples after filtering outliers
- Train:Validation:Test = 7:2:1

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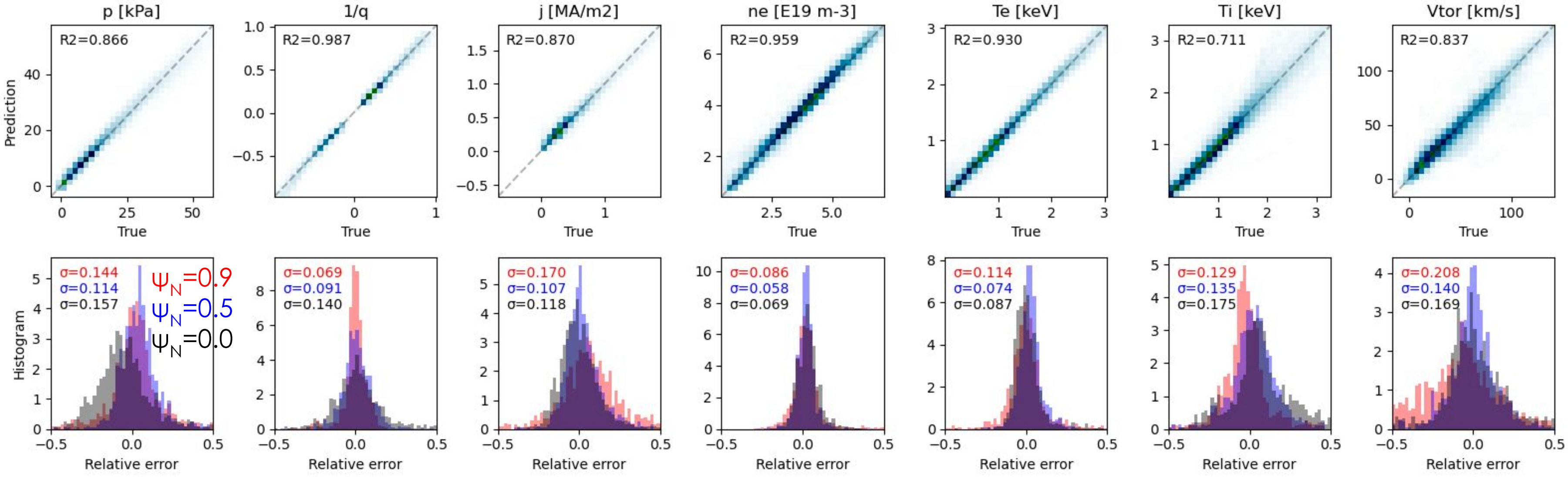
Training results of CAKE-NN

- **Regression for test dataset: Good!**



- The error of CAKE-NN is ~10%, which is the same level as the uncertainty of CAKE.
- CAKE-NN has similar reliability to CAKE, but much faster than that (**real-time feasible!**).

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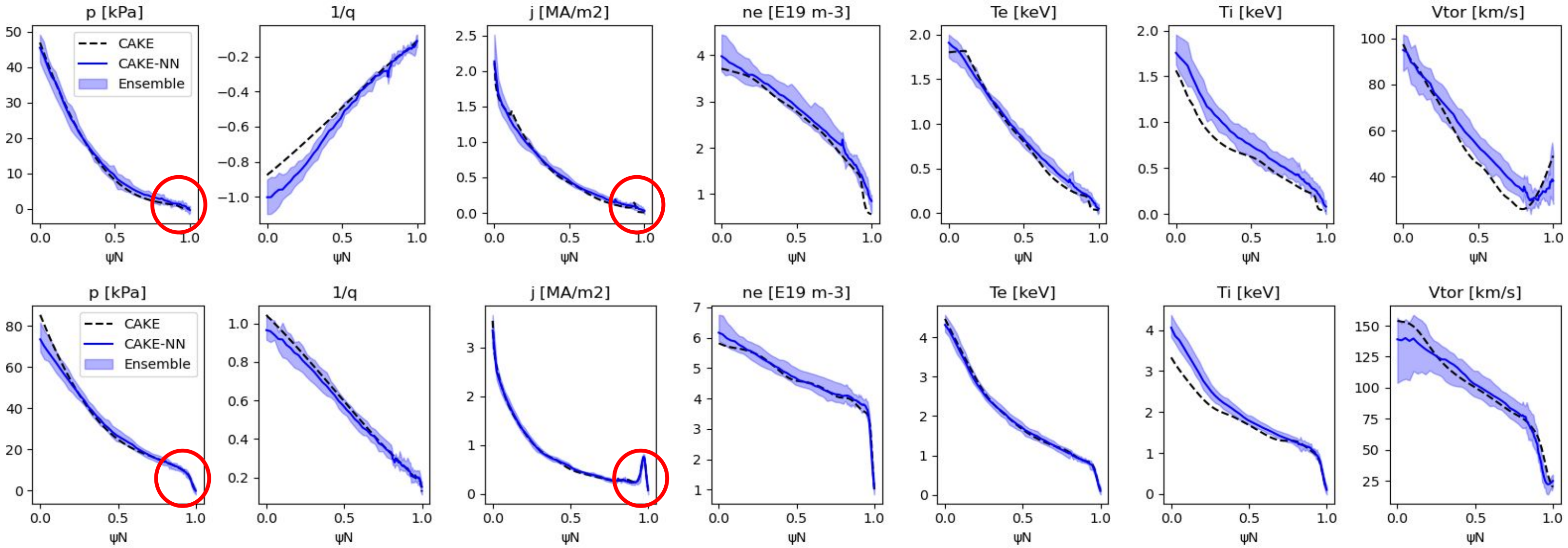
Training results of CAKE-NN

- **Prediction examples: Capturing physics patterns**

L-mode
190919_4800

H-mode
191005_5000



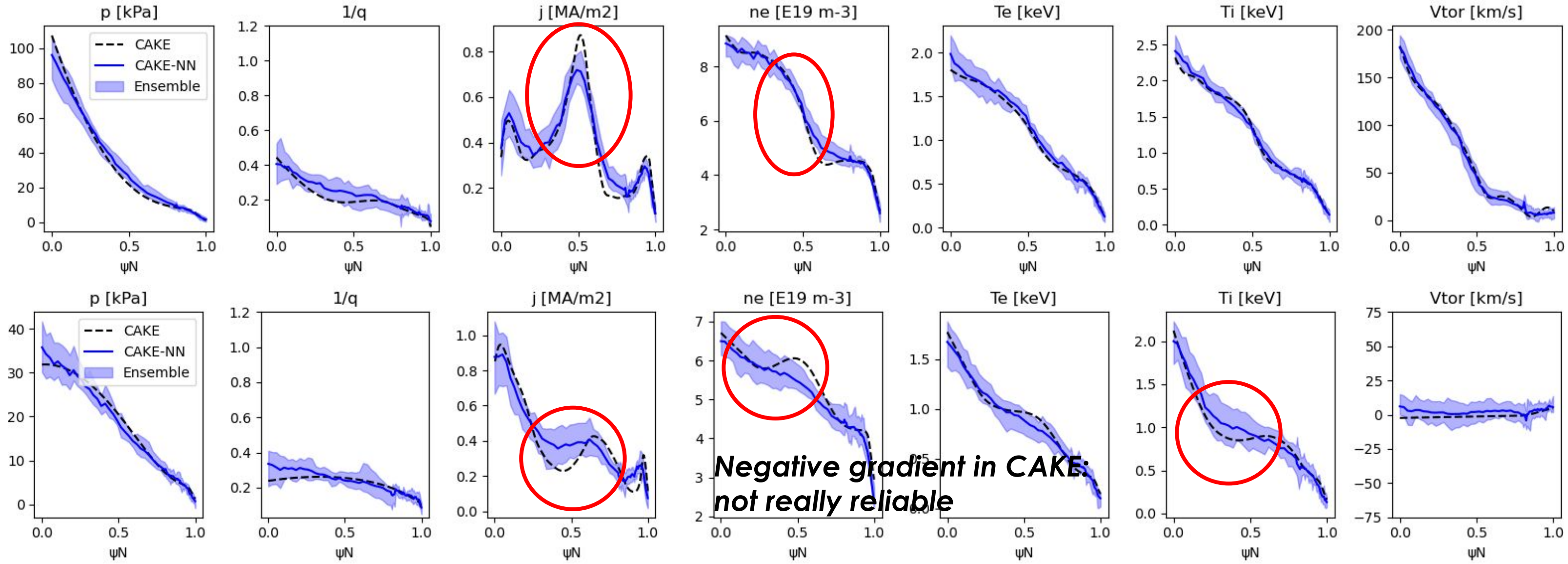
- CAKE-NN successfully captures different physics patterns such as the pedestal structure and bootstrap current in L- and H-mode plasmas.

Training results of CAKE-NN

- **Prediction examples: Robustness in <u>extreme cases</u>**

Strong ITB
190895_3600

Better than
CAKE
190899_4900



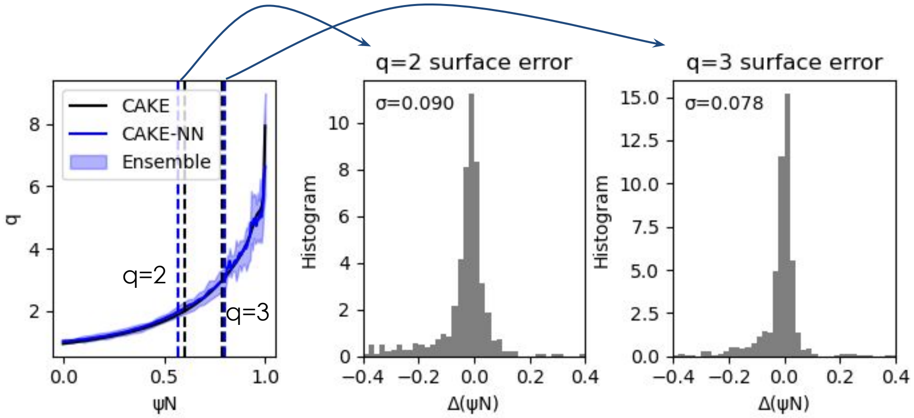
- CAKE is an automated system, so there can be unreliable results when measurements are noisy or missing.
- CAKE-NN shows more reasonable predictions for noisy inputs -> **More robust for real-time implementation**.
- But CAKE-NN shows quite jagged profiles for extreme cases: post-processing needed.

Training results of CAKE-NN

- **Physical reliability**

- Real-time prediction and control using CAKE-NN requires enough reliability to estimate physical information (ex. q=2 surface, pedestal height).

1. Estimation of (q = 2 and 3) surface



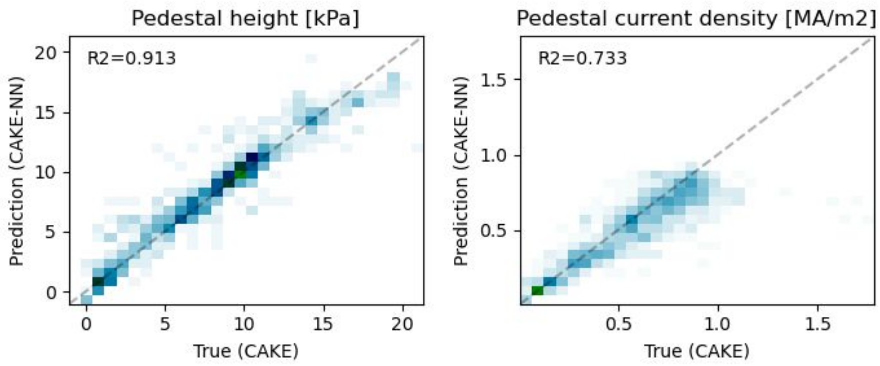
- Good ($\Delta(\psi_N) < 0.1$).

Training results of CAKE-NN

- **Physical reliability**

- Real-time prediction and control using CAKE-NN requires enough reliability to estimate physical information (ex. q=2 surface, pedestal height).

2. Estimation of pedestal information



- Pedestal height prediction is good.

- Pedestal current density prediction needs further improvement.

Summary & Future works

- **Summary**

- The NN acceleration of CAKE has been done for real-time implementation.
- CAKE-NN showed reasonable prediction accuracy for various cases.

- **Future works**

- Further optimization will be done (NN architecture, spatial resolution, …) to improve the accuracy.
- Post-processing should be considered for the output profiles.
- PCS implementation on DIII-D will be done **(~ 1 month)**.

- Possible applications: q=2 surface control, profile control, RT pedestal estimation, RT stability analysis

Thank you!

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