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Improving the time resolution of Thomson scattering via machine learning on reflectometry data

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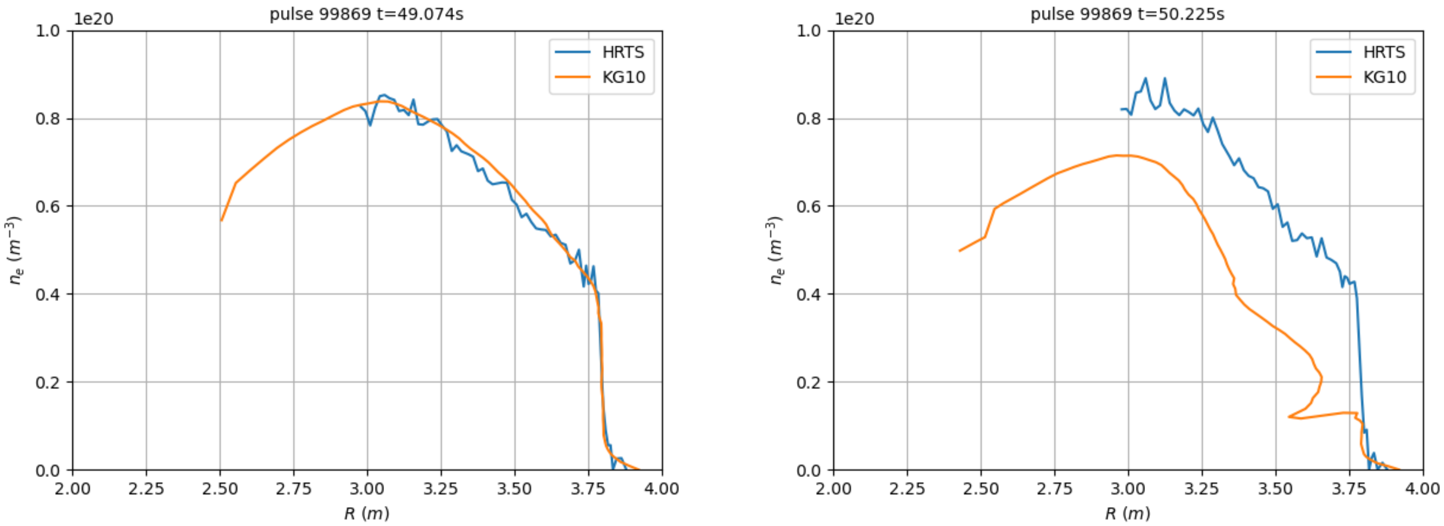
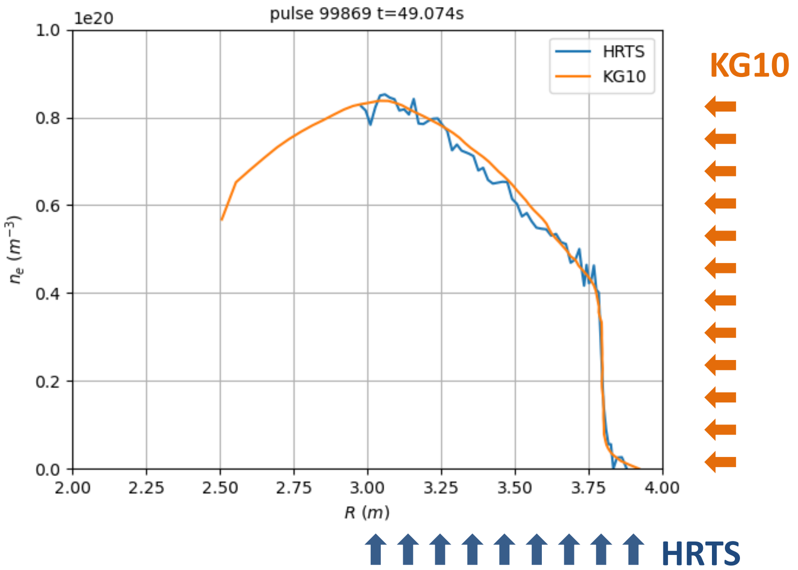
Motivation

- Measuring the density profile at JET
    - Thomson scattering (HRTS)
        - good spatial accuracy (~1cm) but low sampling rate (20 Hz)
    - Reflectometry (KG10)
        - high temporal resolution (1-10 kHz) but uncertainty in radial positions



Main goal

- Increase the time resolution of HRTS to study pedestal dynamics
  - e.g. ELMs on a time scale of 1-10 ms
- Combine the spatial accuracy of HRTS with the time resolution of KG10
  - for HRTS: positions are fixed, density values are measured (*laser scattering*)
  - for KG10: density values are fixed, positions are calculated (*frequency sweeping*)



Approach

- Predict HRTS-like profiles from KG10 data via machine learning

input KG10 → machine learning → output HRTS

- Training
  - the model is trained on examples where both HRTS and KG10 profiles are known
  - based on time-sync between HRTS and KG10
    - for each HRTS time t there is a KG10 time t' that is very near (timewise)

- Prediction
  - the model is used to predict the HRTS profile when the KG10 profile is known
  - yields a “virtual HRTS diagnostic” with the sampling rate of KG10

Training data

- Pulses from recent campaigns
  - KG10 was fully operational from end-2020
  - HRTS had some issues, fully operational from mid-2020

- C40 campaign (Mar-Jul 2021)
  - M18-01: Baseline scenario development for DT
  - M18-02: Hybrid scenario development for DT

- C41 (DTE2) campaign (Aug-Dec 2021)
  - M21-01: Hybrid scenario for high fusion performance in DT
  - M21-03: Baseline scenario for high fusion performance in DT

Training data

Campaign	Task/Experiment	Sessions	Pulses
C40	M18-01	8	31
C40	M18-02	7	40
C41	M21-01	13	75
C41	M21-03	13	74

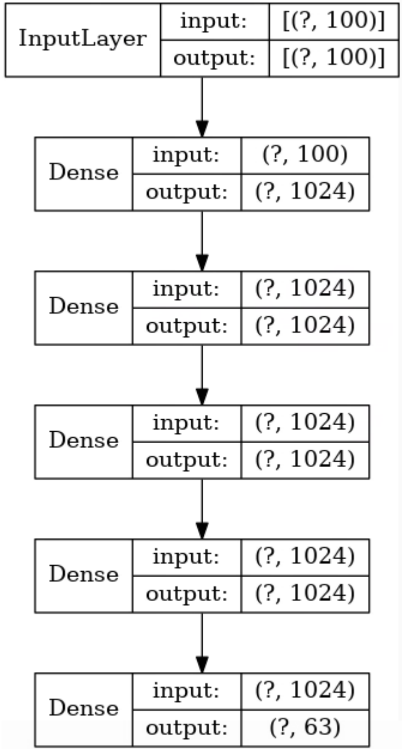
- Training data
  - 170 pulses in the range 98794-99953
    - sharing of experimental sessions, some pulses are counted twice in the table above
  - HRTS sampling rate is 20 Hz; assuming 30-second pulses, we should have:
    - (170 pulses) x (30 seconds) x (20 Hz) ≈ 10^5 training examples
  - In practice, we have 43 531 training examples of KG10-HRTS profile pairs
    - because the time frame of KG10 is shorter than HRTS

Model

- 4-layer dense neural net with input dim 100 (KG10) and output dim 63 (HRTS)

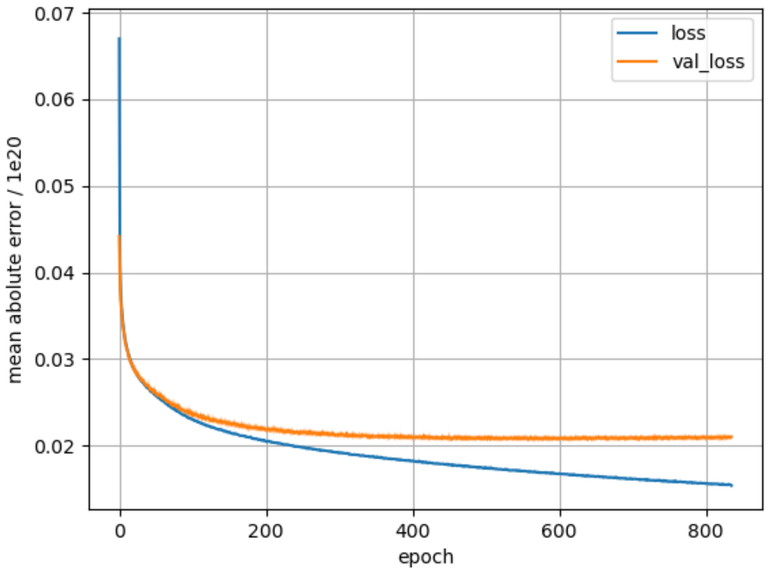
Layer (type)	Output Shape	Param #
dense (Dense)	(None, 1024)	103424
dense_1 (Dense)	(None, 1024)	1049600
dense_2 (Dense)	(None, 1024)	1049600
dense_3 (Dense)	(None, 1024)	1049600
dense_4 (Dense)	(None, 63)	64575

Total params: 3,316,799
Trainable params: 3,316,799
Non-trainable params: 0



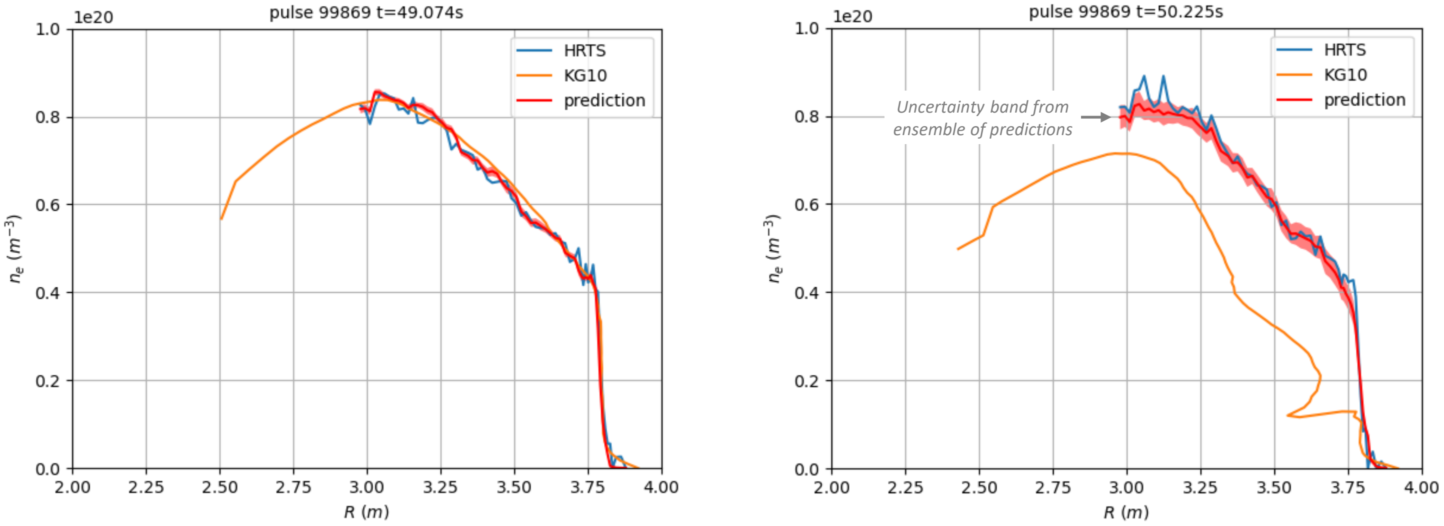
Model

- Training
  - 43 531 training examples of KG10-HRTS profile pairs
  - 90% for training, 10% for validation
  - trained in 5min on single GPU



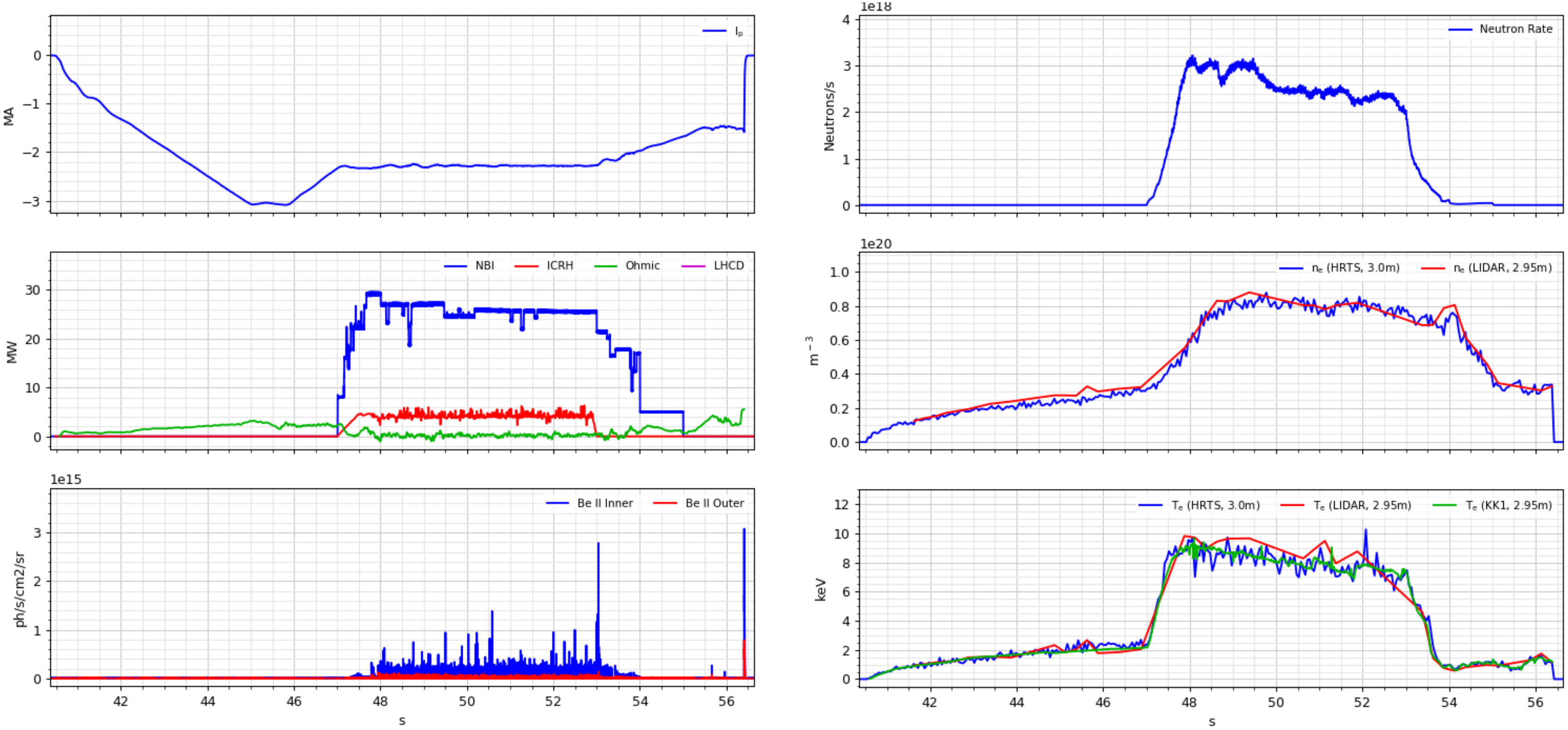
Results

- The model provides an accurate prediction of HRTS
- Overcomes some of the problems with KG10
- In general, the pedestal coincides with HRTS



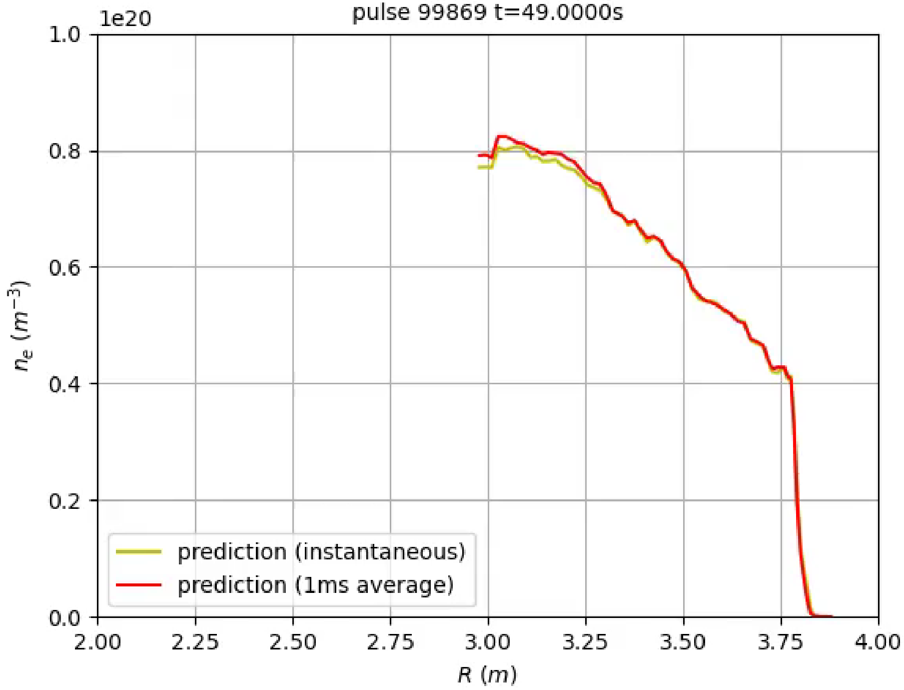
Results

- Analysis of DTE2 record pulse no. 99869



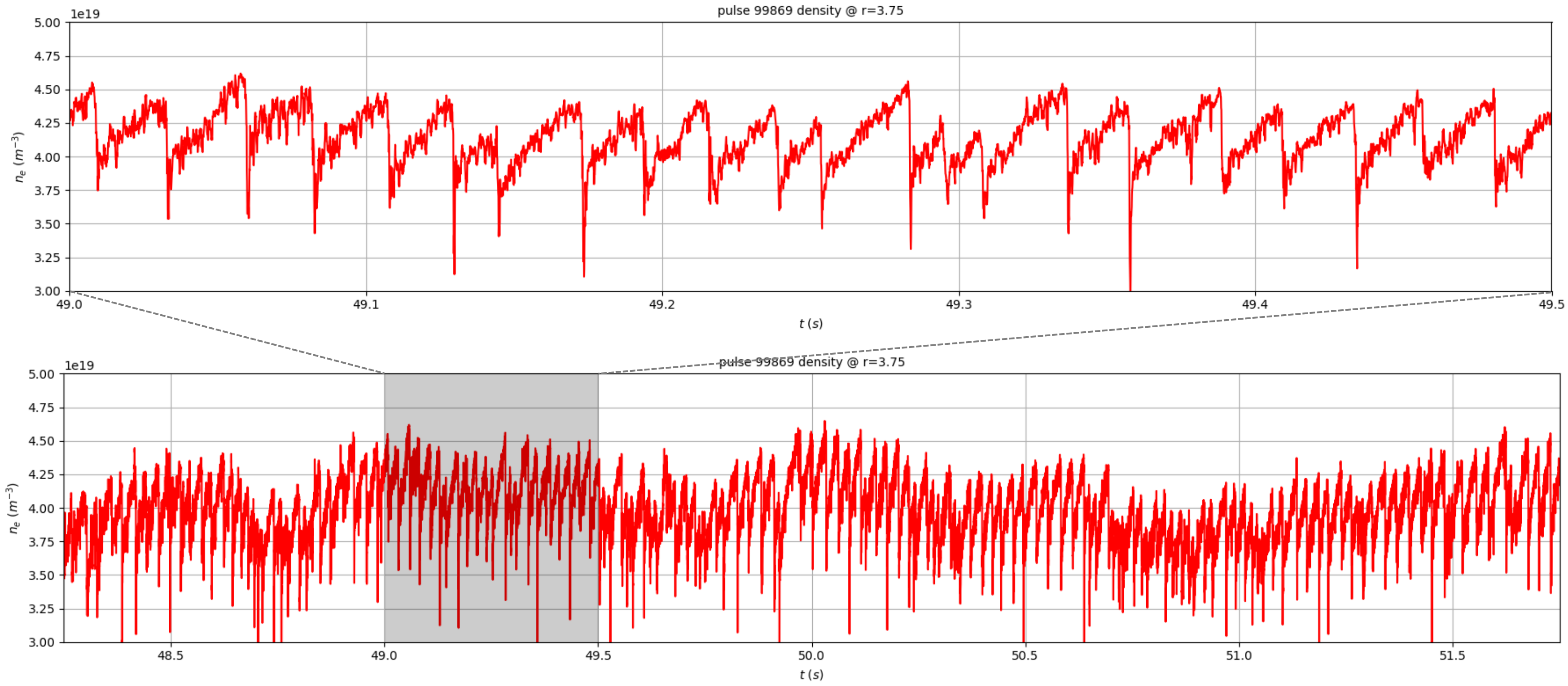
Results

- Analysis of DTE2 record pulse no. 99869



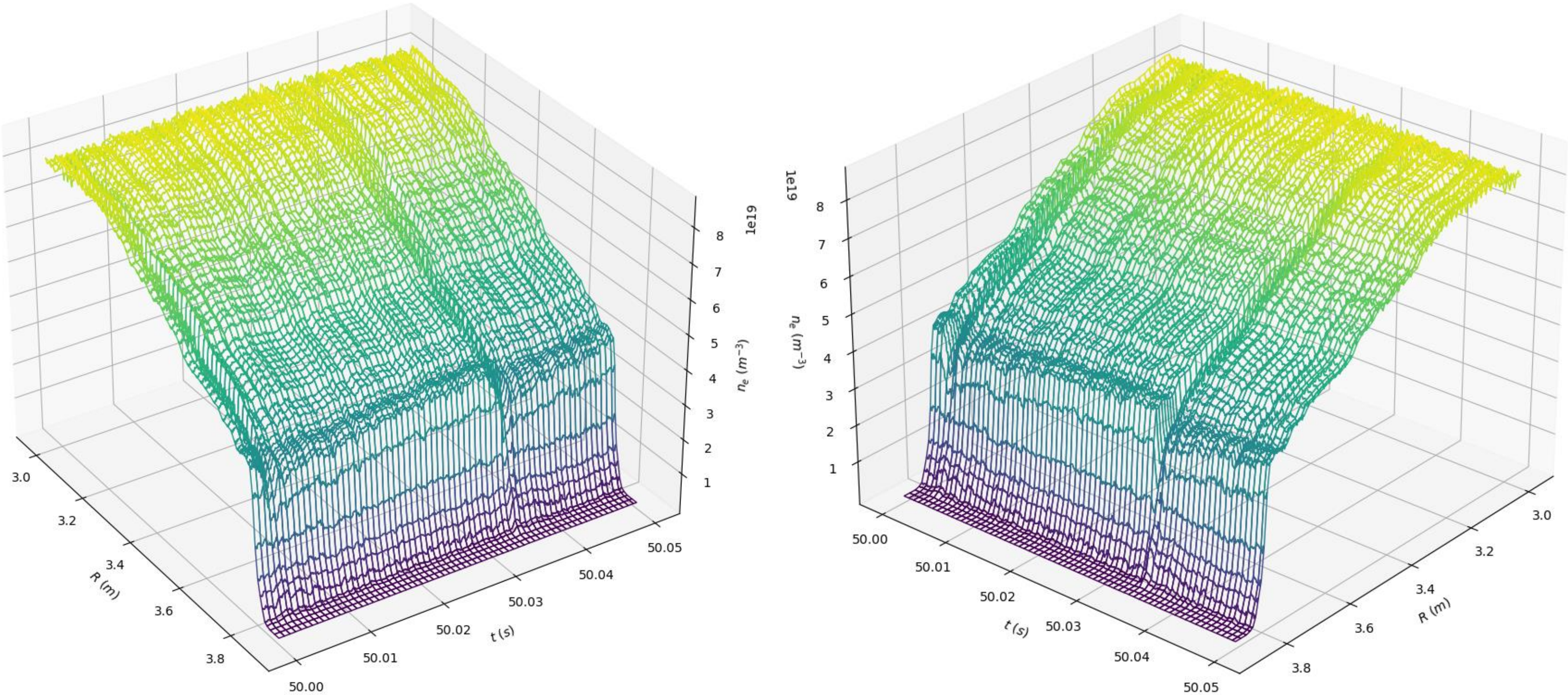
Results

- Analysis of DTE2 record pulse no. 99869 at $r = 3.75\ \mathrm{m}$



Results

- Analysis of DTE2 record pulse no. 99869 at around $t = 50.0\ s$



Conclusion

- Predicted HRTS with the time resolution of KG10
- Assuming HRTS provides the correct profile
    - but sometimes HRTS is calibrated on KG10
    - we call it “predicted HRTS” but it is a transformation of reflectometry data
    - a neural network (non-linear model) performs better than a linear model
    - most, but not all, deviations in the KG10 profile can be overcome
- The model is fast and can be applied on any pulse with KG10 data
    - ELMs and pedestal dynamics can be observed and analyzed in detail
    - pedestal height/width can be tracked at fixed position/density value
    - the lower frequency evolution of the density profile can also be analyzed

Thank you