IAEA 14th Technical Meeting on Control Systems, Data Acquisition, Data Management and Remote Participation
15-18 July 2024, Sao Paulo, Brazil

Real-time estimation of line-averaged plasma density on EAST using LightGBM

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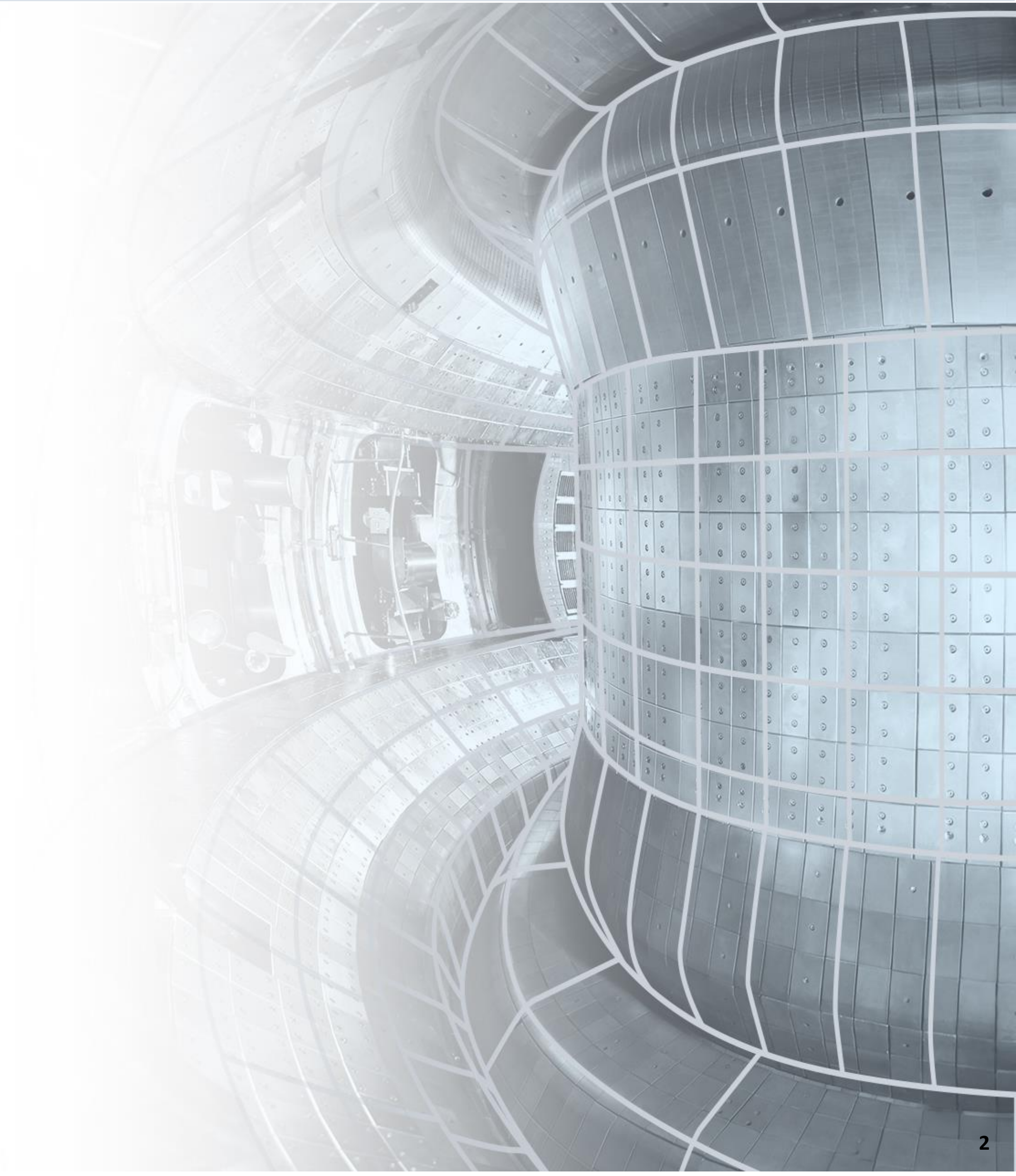
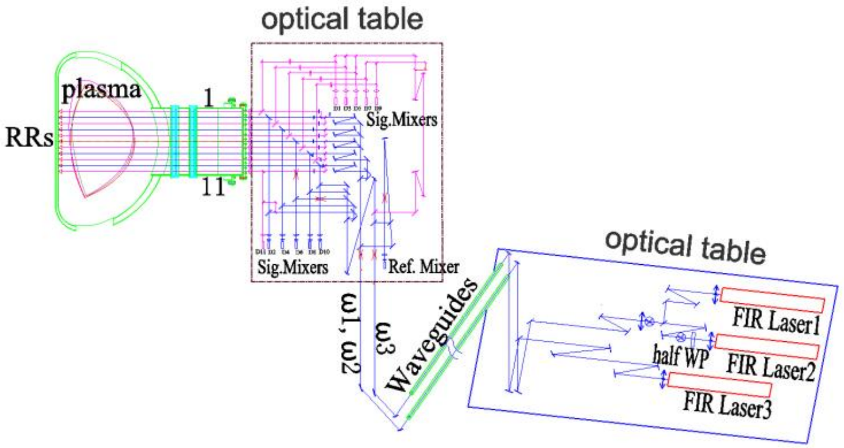


Plasma Density Measurement Methods on EAST Tokamak

In the EAST Tokamak, plasma density is a critical parameter, and its accurate measurement is essential for the success of experiments. Currently, EAST primarily uses two methods to measure plasma density: POINT measurement and HCN (Hydrogen Cyanide) measurement.

Point Measurement Method

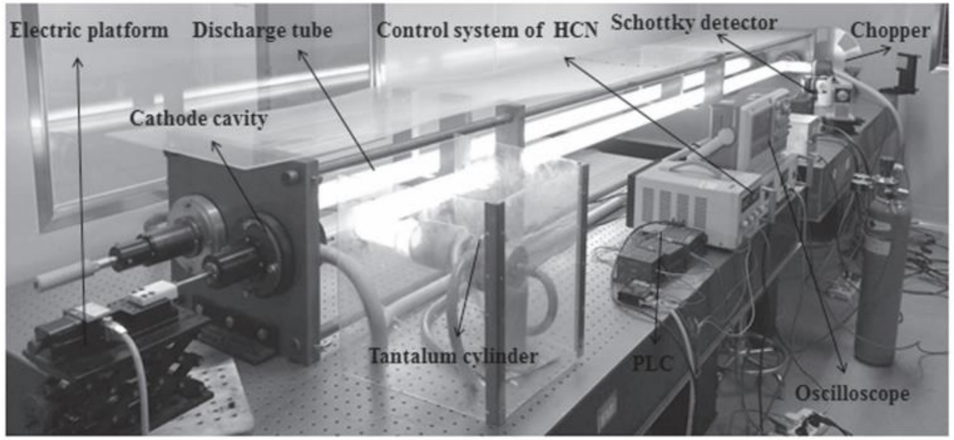
- The point measurement method typically uses microwave reflectometry or laser interferometry to obtain plasma density information.



11 channels optical layout of the EAST POINT system

HCN Measurement Method

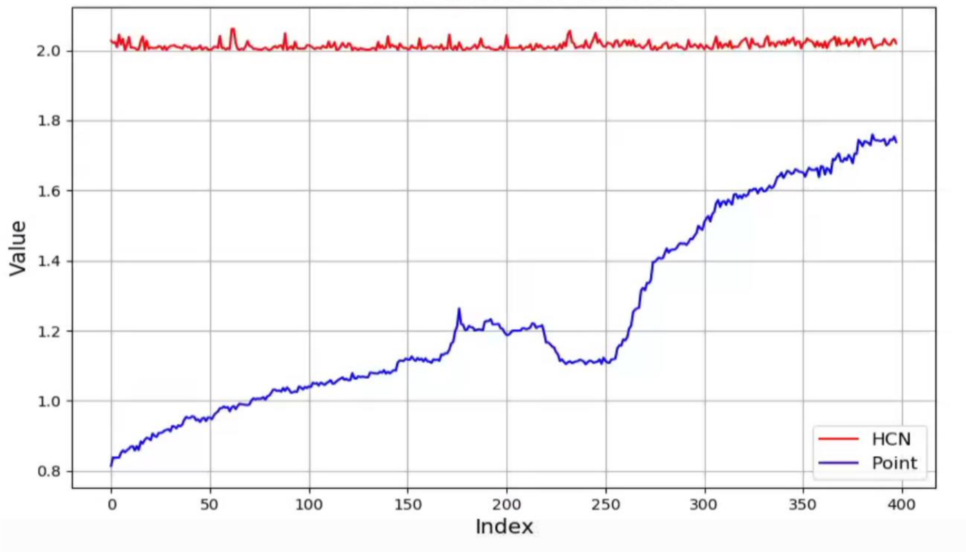
- The HCN measurement method employs an HCN laser interferometer, which infers plasma density by measuring the phase change of the laser as it propagates through the plasma.



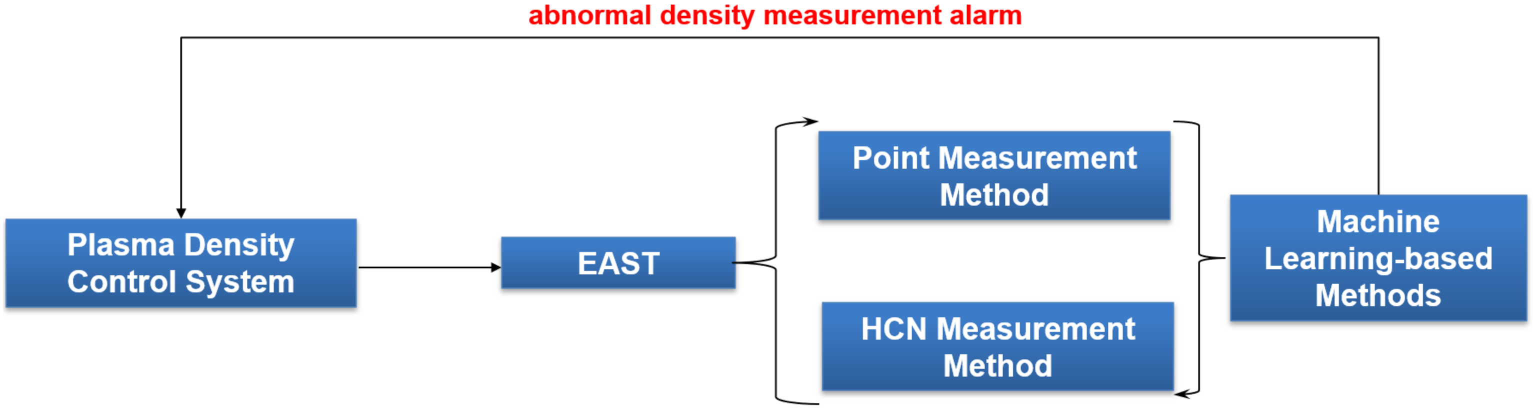
Experimental setup for the bench test of the HCN dual laser interferometer

Measurement Errors and the Need for Re-estimation

Measurement errors can significantly impact the accurate assessment of plasma density, leading to density control errors and potential plasma disruptions.

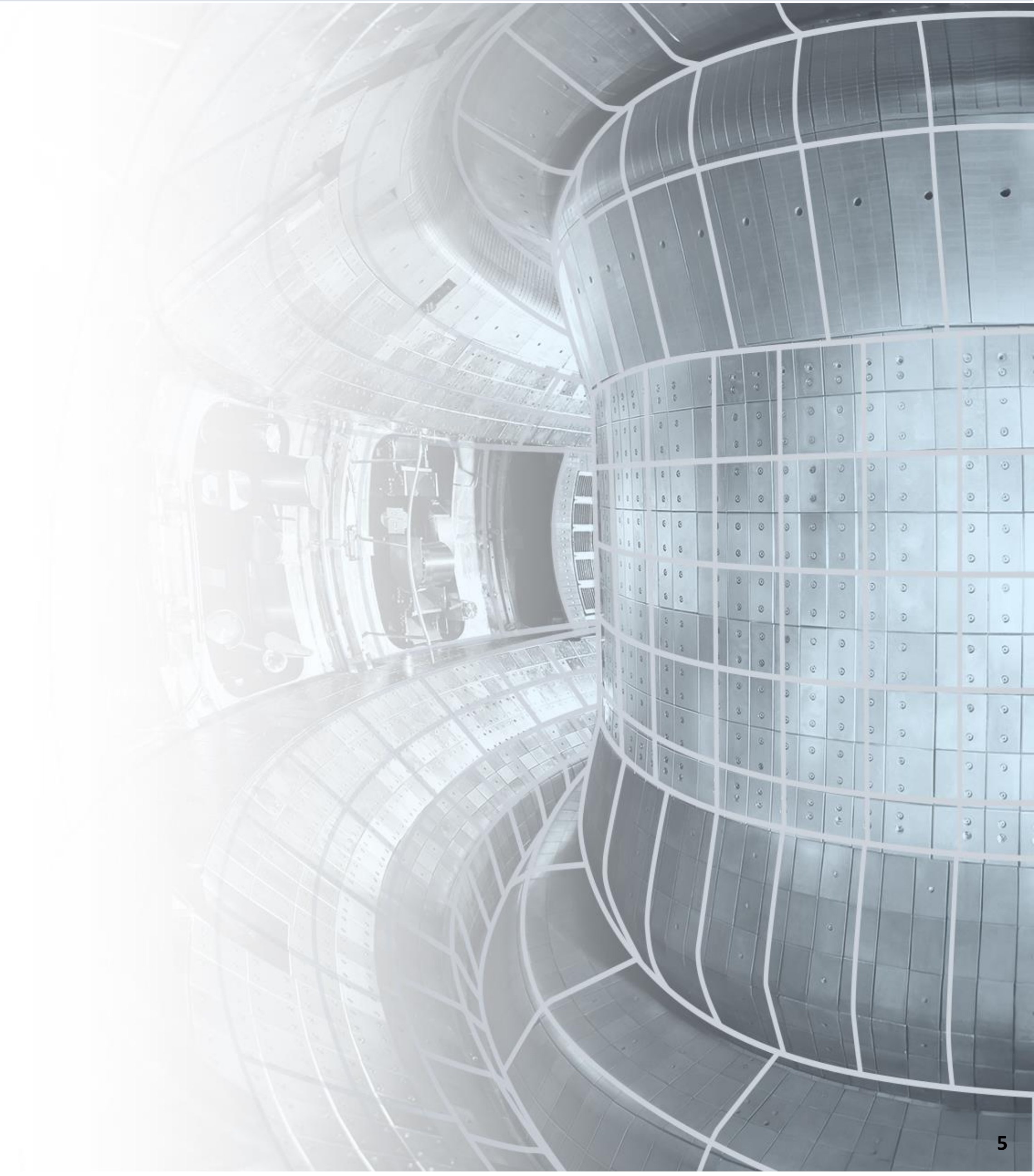


HCN and Point Measurement for Shot 134605



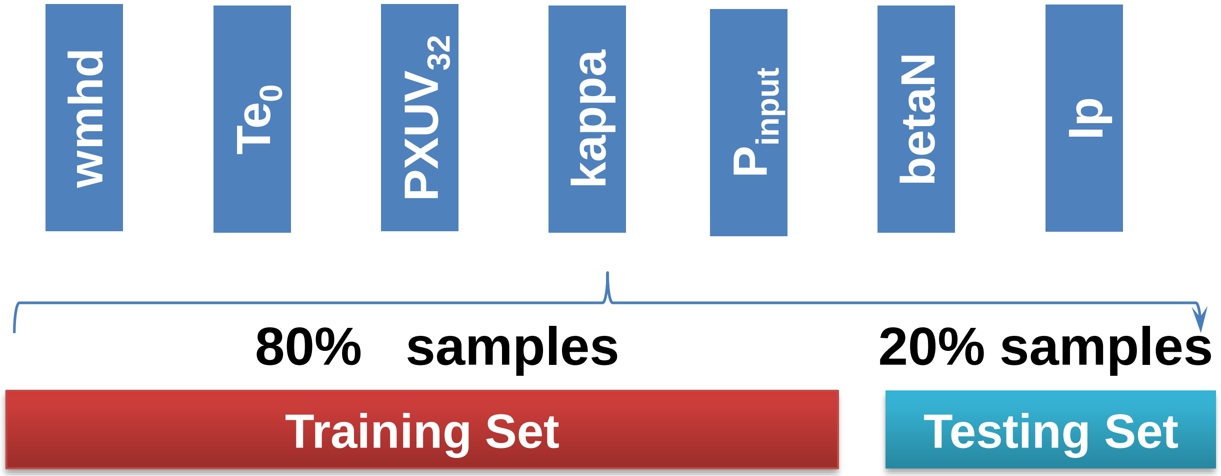
Structure of the Density Estimation System

Outline



Data Collection

To determine the reliability of the density signal used for density feedback control and still obtain relatively reliable density information to meet control requirements, this study applied the ensemble learning algorithm LightGBM to estimate plasma density information.

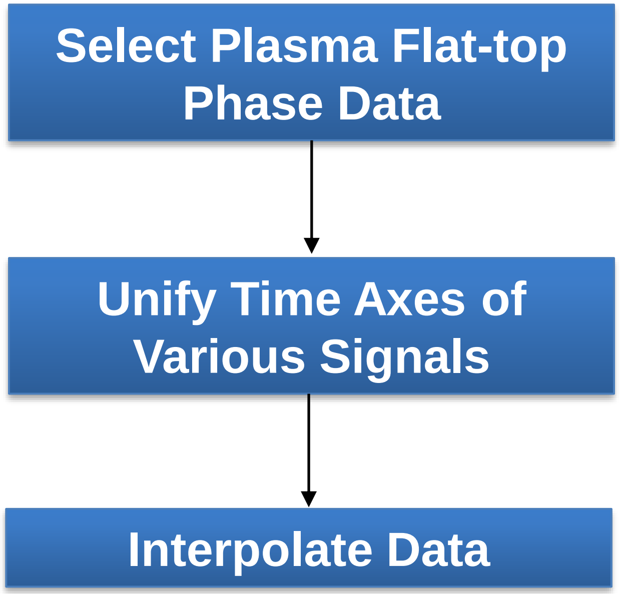


Model Input Features and Physical Descriptions

Features	Physical Descriptions	Units
BetaN	beta ratio	None
li	plasma internal inductance	None
wmhd	plasma stored energy	MJ
TE_0	Te at plasma center	eV
$PXUV_{32}$	radiation power of horizontal central channel of fast bolometer system	KW
Ip	plasma current	MA
P_{input}	total power	KW

Data Preprocess

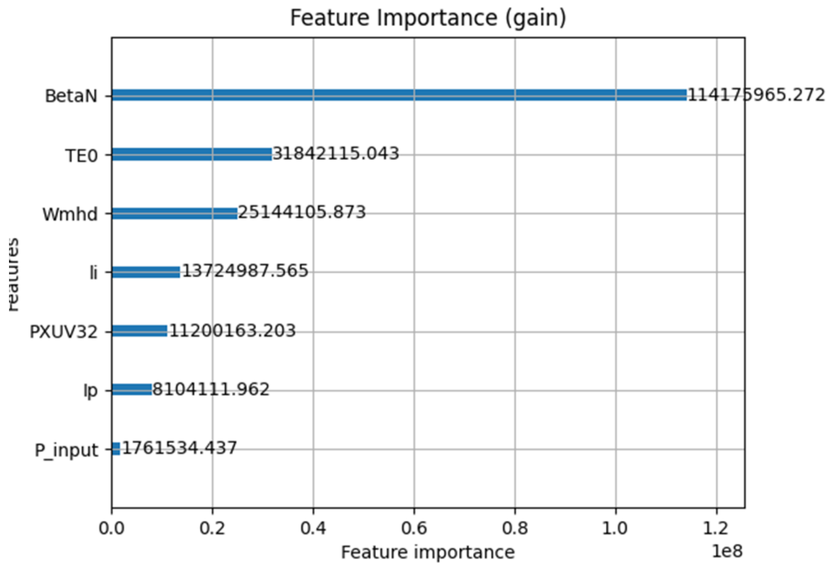
- First, data from the plasma flat-top phase are selected for regression.
- Next, the time axes of various signals are unified.
- After unifying the time axes, the data undergo interpolation.



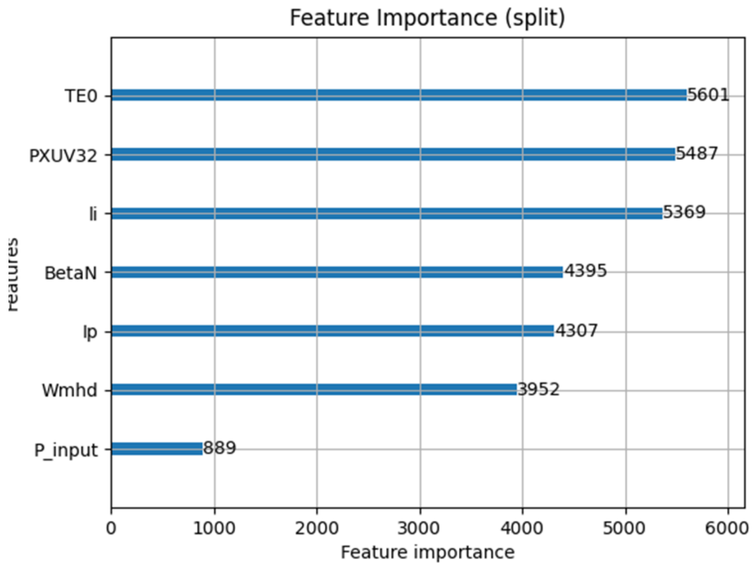
Data Preprocessing Workflow

Model Training and Evaluation

- The model chosen for this study is the LightGBM model. LightGBM is an efficient gradient boosting framework that uses tree-based learning algorithms. It is particularly well-suited for tasks that involve large datasets and require high accuracy.
- The Left Figure shows the feature importance (gain) in a LightGBM model. The horizontal bar chart indicates the relative importance of various features in terms of gain, which measures the contribution of each feature to reducing the loss function. The Right Figure shows the feature importance (split) in a LightGBM model. This horizontal bar chart reflects the frequency with which each feature is used to split the data across all trees in the model.



Feature Importance by Gain



Feature Importance by Split

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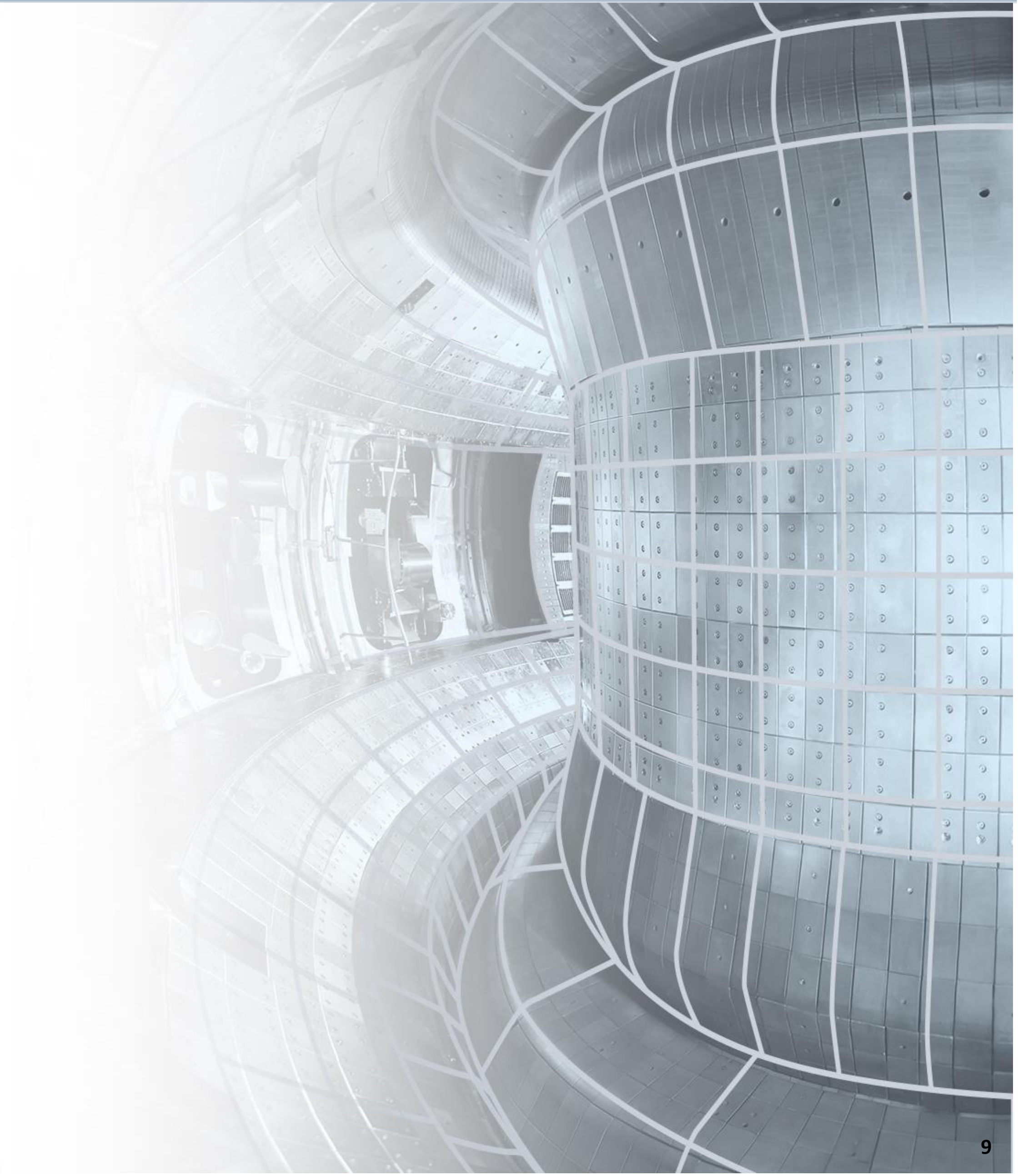


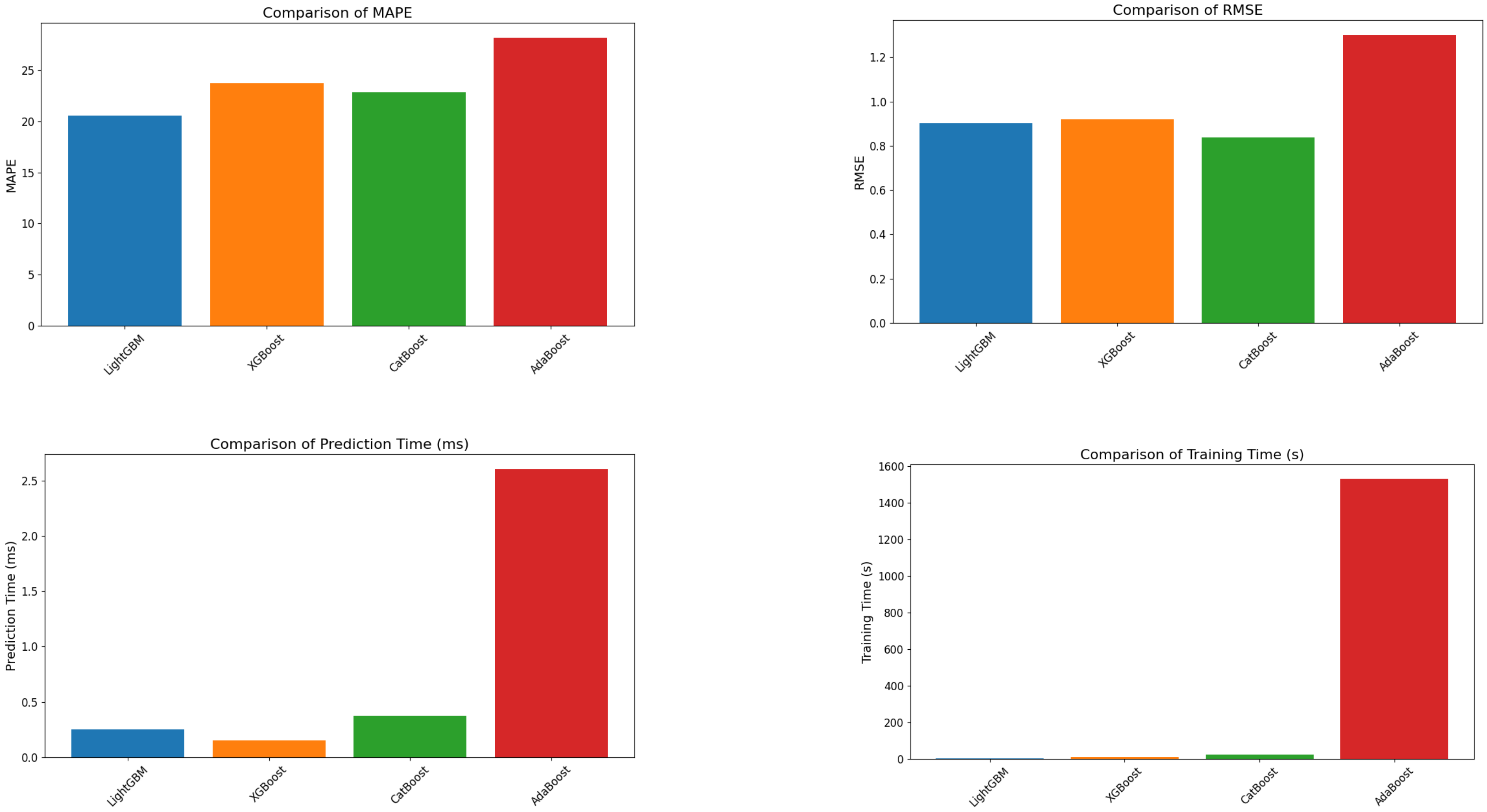
Model Performance Metrics

- These results highlight the effectiveness of the LightGBM model in providing accurate and fast plasma density estimations, which are essential for the successful operation and control of the EAST tokamak. The low error rates and high explanatory power of the model, combined with its rapid prediction capability, make it a valuable tool for real-time plasma density feedback control.

Table 2. Performance Metrics of the LightGBM Model

Metric	Result
MAPE	20.5%
RMSE	0.9
Training Time (s)	4.77
Prediction Time (ms)	0.260

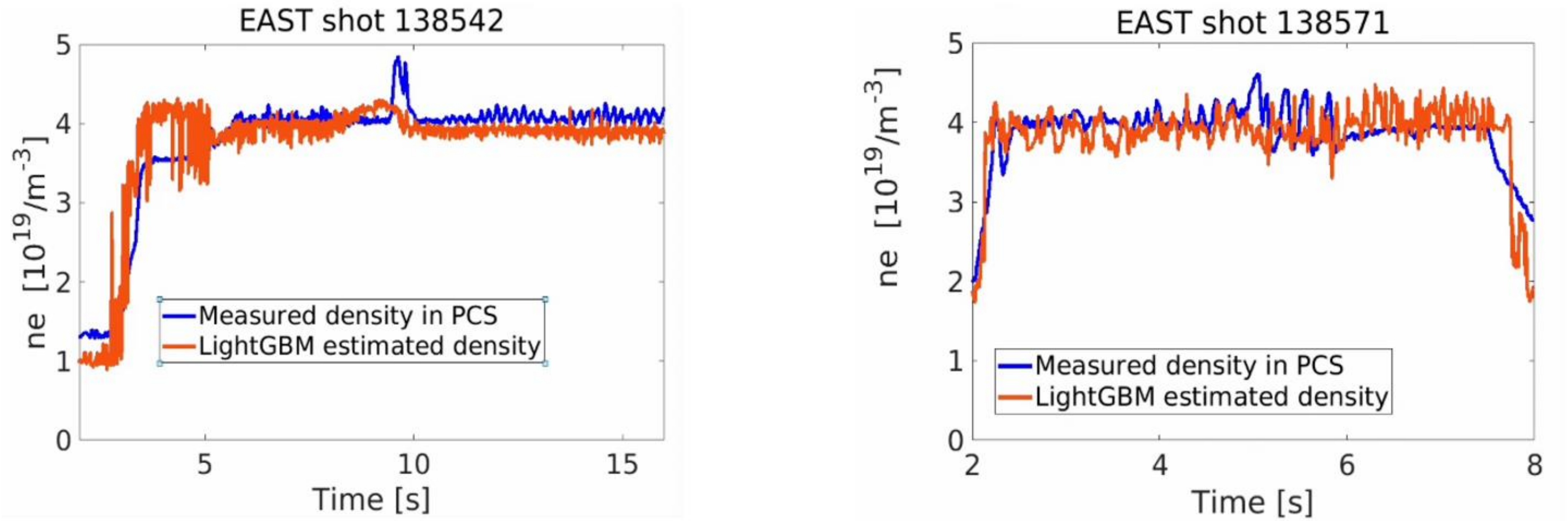
Comparison with Other Methods



Performance Comparison of Machine Learning Models

Test Results

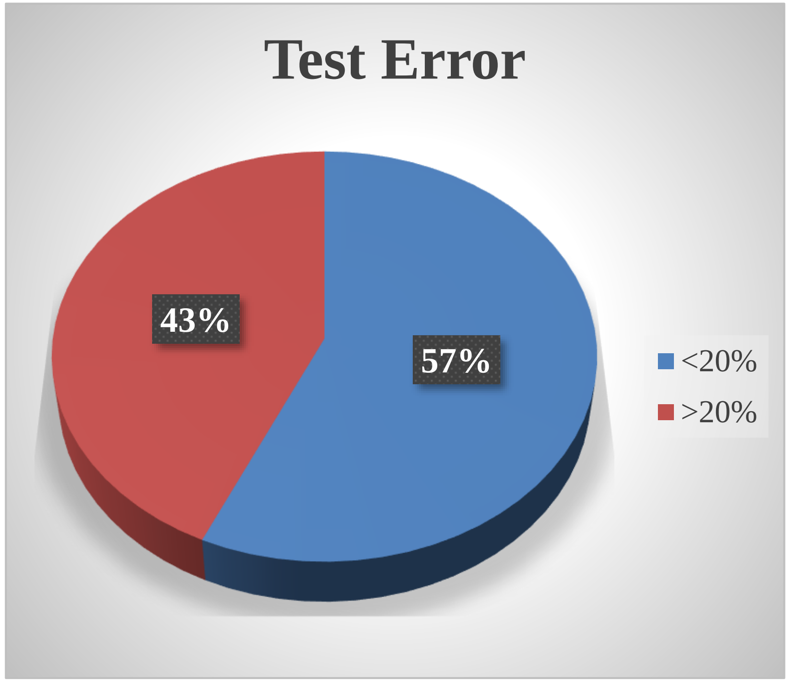
- The comparison results for two specific shots, EAST shot 138542 and EAST shot 138571, are illustrated in the figures below.

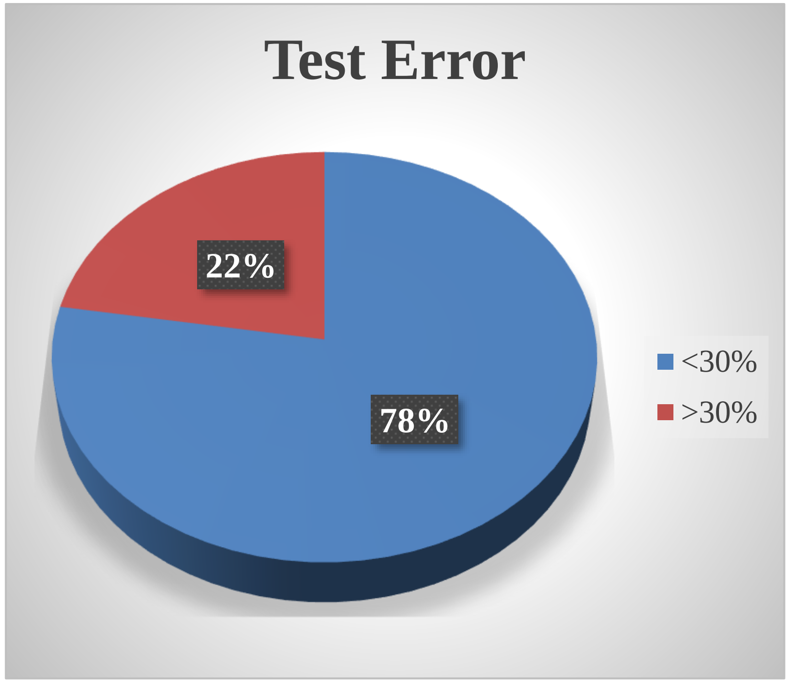


The comparison results for two specific shots, EAST shot 138542 and EAST shot 138571

Test Results

- **Error Analysis**
- 56.8% of the new samples have a test error less than 20%.
- 77.6% of the new samples have a test error less than 30%.





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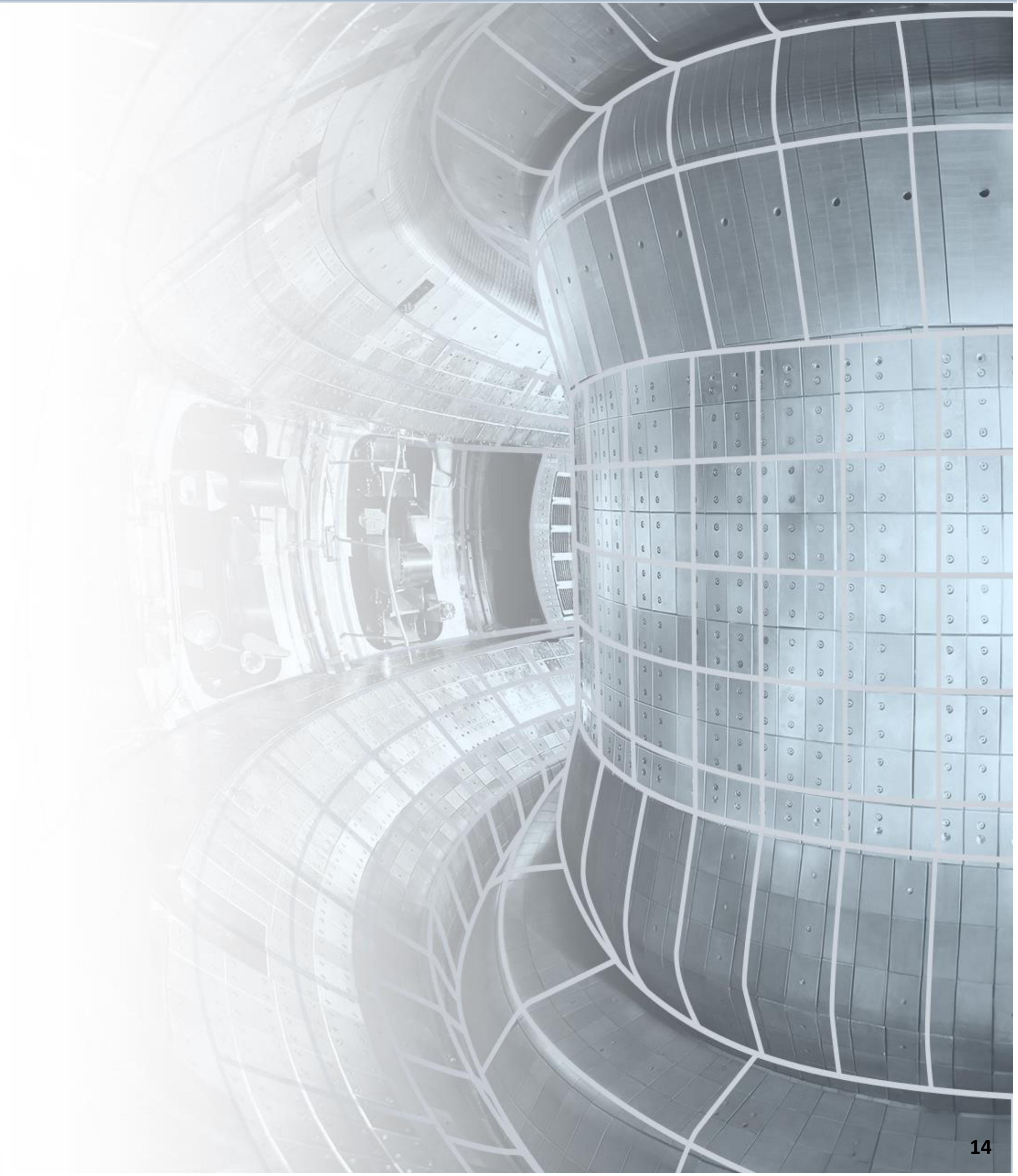

Discussion

- **Limitations of LightGBM for Plasma Density Prediction**:
  - High Error in Real-Time Computation
  - Insufficient Training Data
  - Inherent Limitations of LightGBM

- **Future Work**:
  - Expand the Training Dataset
  - Enhance Model Accuracy
  - Implement Robust Validation Techniques

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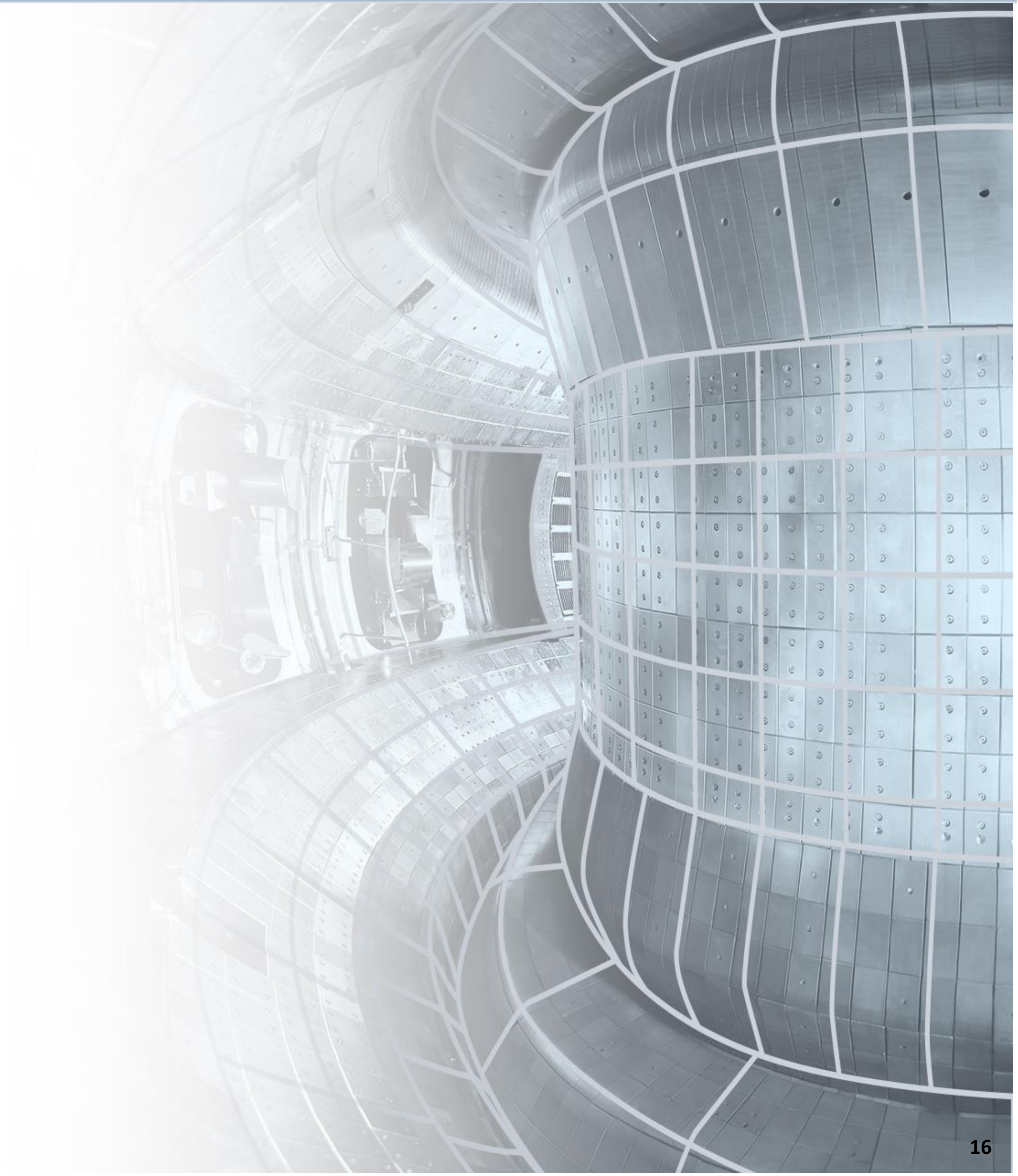
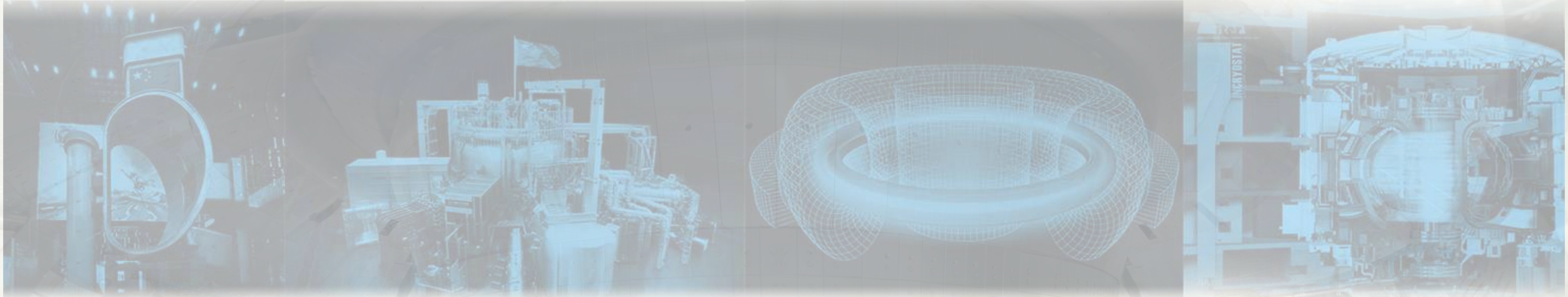


Summary

We applied the LightGBM model for real-time plasma density estimation on the EAST tokamak, addressing limitations of current methods with its efficiency and accuracy.

Our methodology involved collecting data from EAST experiments, preprocessing it, and achieving strong performance metrics with LightGBM, including a MAPE of 20.5% and a rapid prediction time of 0.260 milliseconds.

Despite these successes, we identified limitations such as higher errors during rapid plasma changes. Future work will focus on expanding the dataset and exploring other models to further improve accuracy and robustness.



Thank you !