A Preliminary Study on Experimental Data Analysis System and Breakdown Prediction Based on Neural Networks for EAST-NBI

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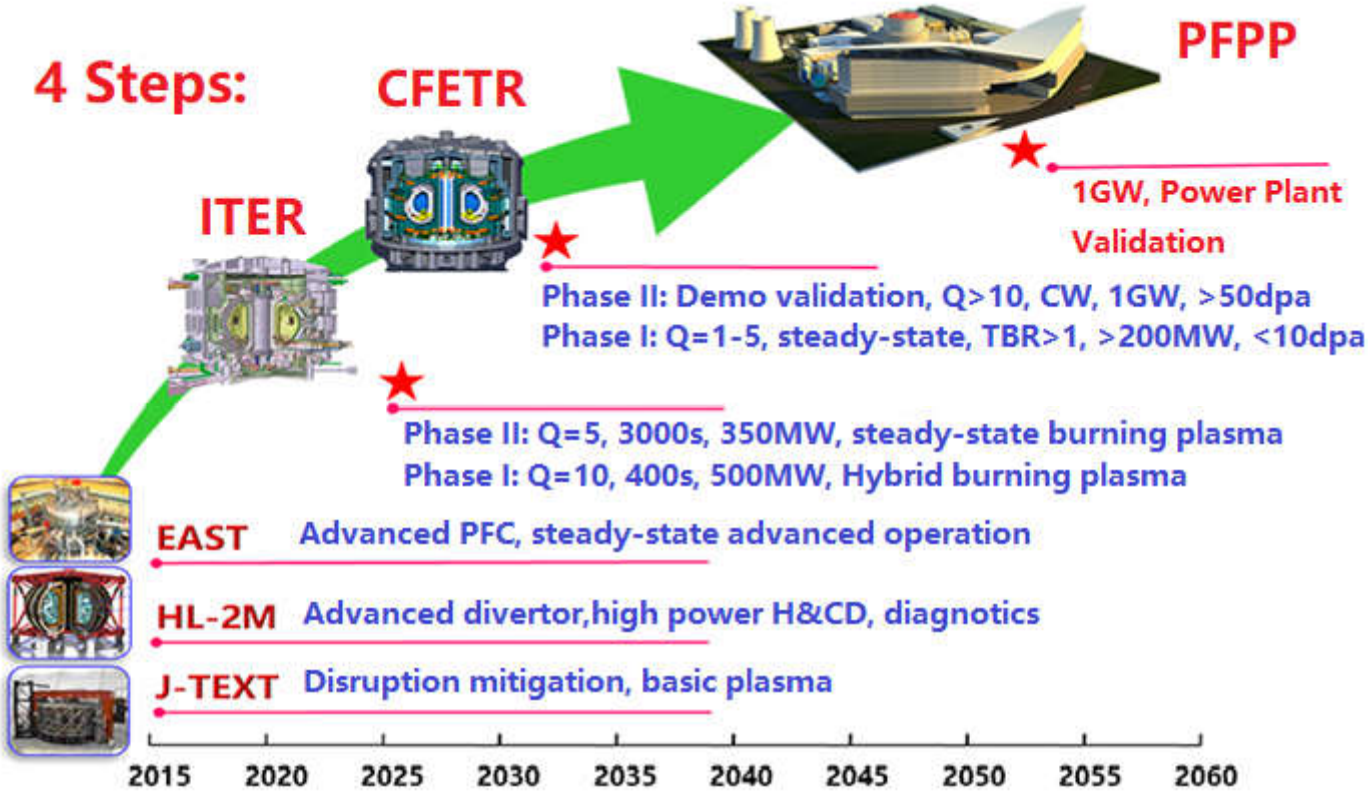
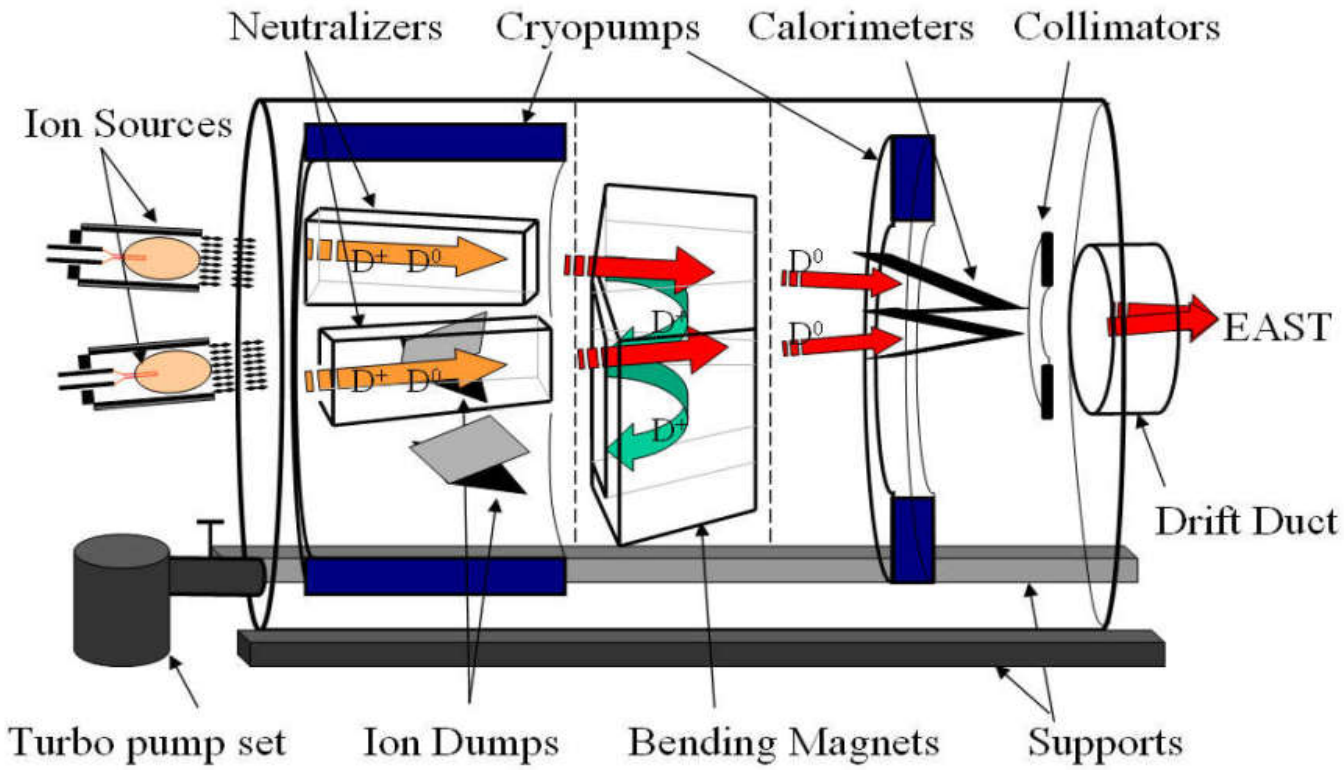
- Introduction to Neutral Beam Injector
- Introduction to the experiment of EAST-NBI
- Research Progress of Experimental Data Analysis
- Research on Breakdown Prediction Model of Ion Source
- Summary

Roadmap of Tokamak



Roadmap for the development of Tokamak

Neutral Beam Injector

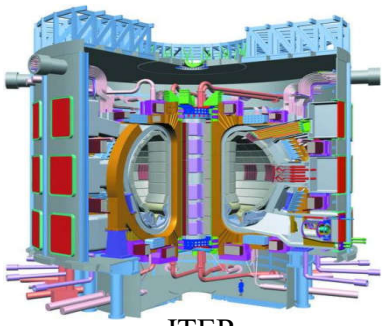


Schematic diagram of EAST-NBI composition structure

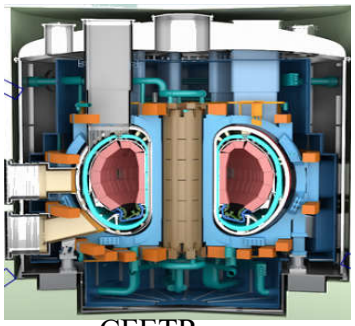
Neutral Beam Injector

Design parameters and operating status of some NBI devices at home and abroad:

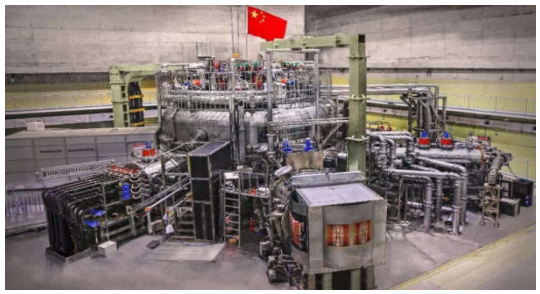
- ITER NBI： 1MV@**3600s** (In design)
- CFETR NNBI： 400kV@**3600s** (In design)
- KSTAR NBI： 120kV@300s（In operation ）
- EAST NBI： 80kV@100s（In operation ）
- HL-2M NBI： 80kV@100s（In operation ）
- JET NBI： 125kV@20s (In operation)
- JT-60U NBI： 500kV@30s（In operation ）
- DIII-D NBI： 75kV@5s（In operation ）



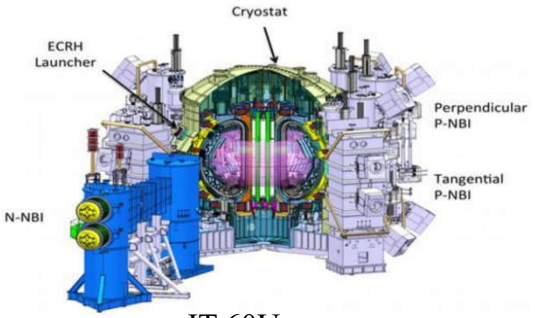
ITER



CFETR



EAST



JT-60U

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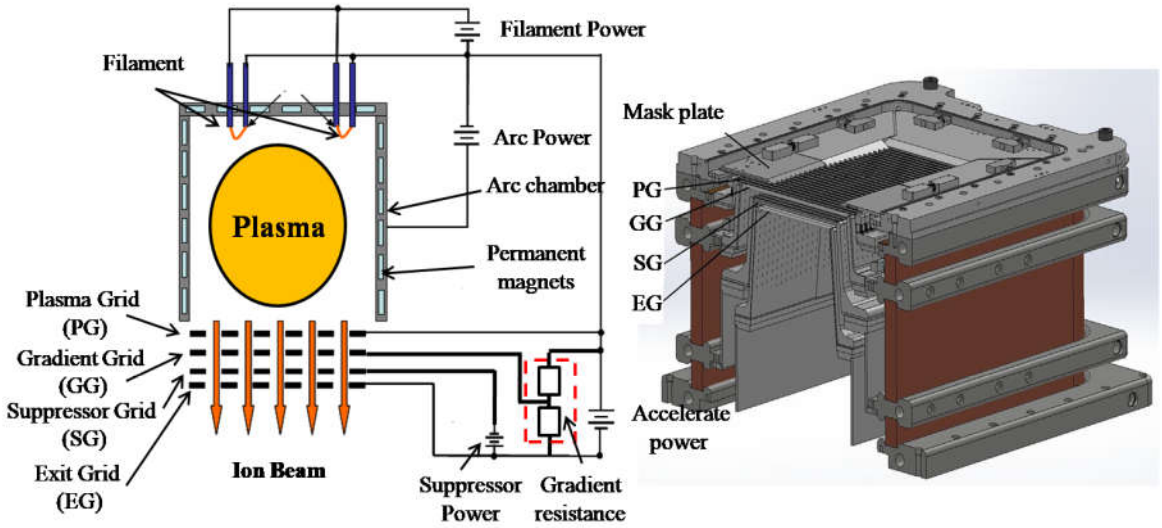
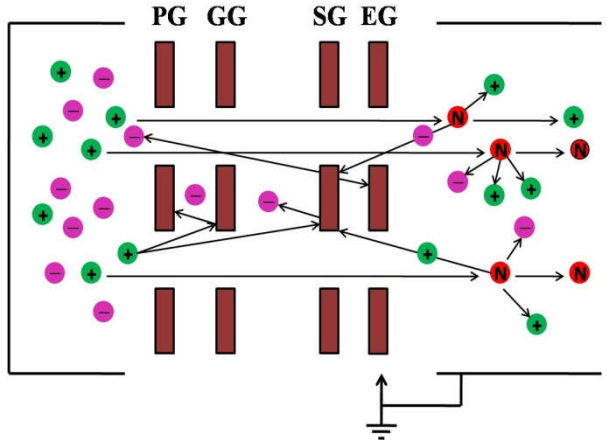
Basic principle of ion source breakdown



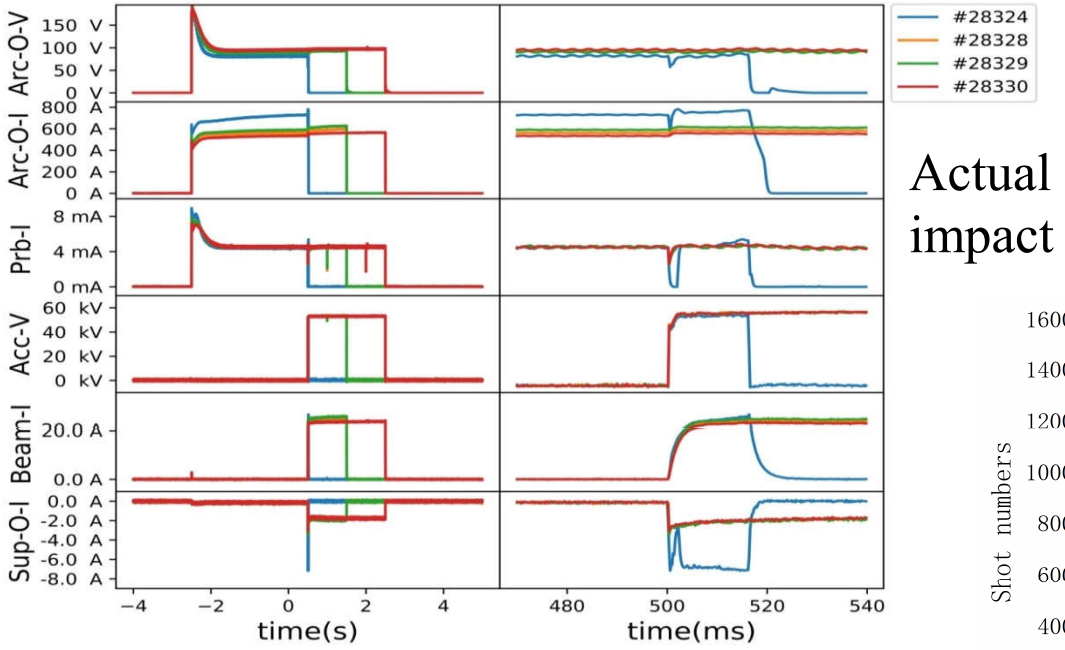
Structure diagram of EAST-NBI ion source



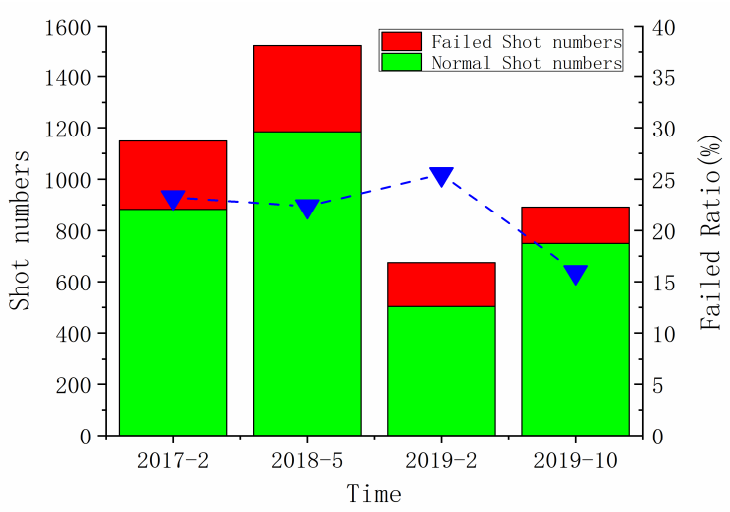
Schematic diagram of particle collision

Mismatched operating parameters lead to frequent collisions of ions between electrodes, which is the main cause of breakdown events!

Experiment summary of EAST-NBI



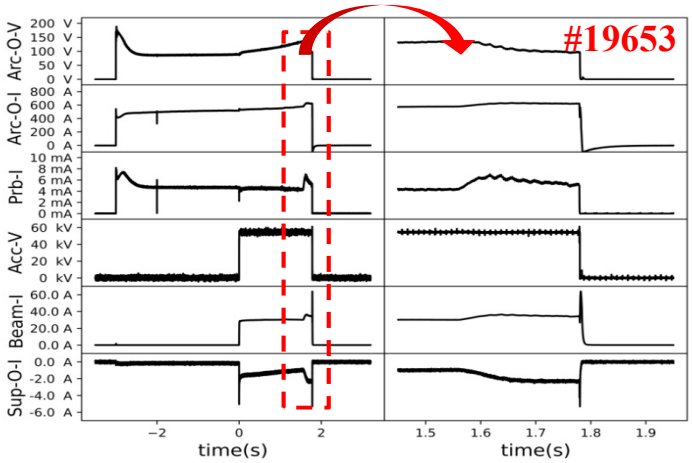
Actual operating parameters have a greater impact on the experiment, see left



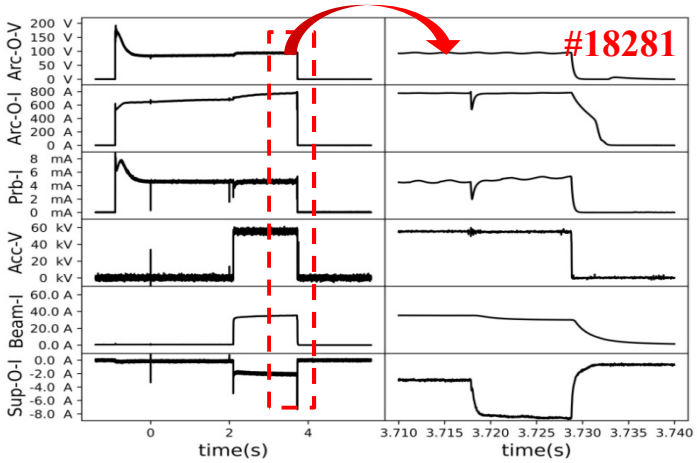
The total failure rate of NBI-2R exceeded more than **15%**, see right

Note: The shorter the set pulse, the lower the probability of a breakdown event, because the mismatch of parameters has not led to a breakdown event, and the discharge has ended, and a long pulse is more prone to a breakdown event.

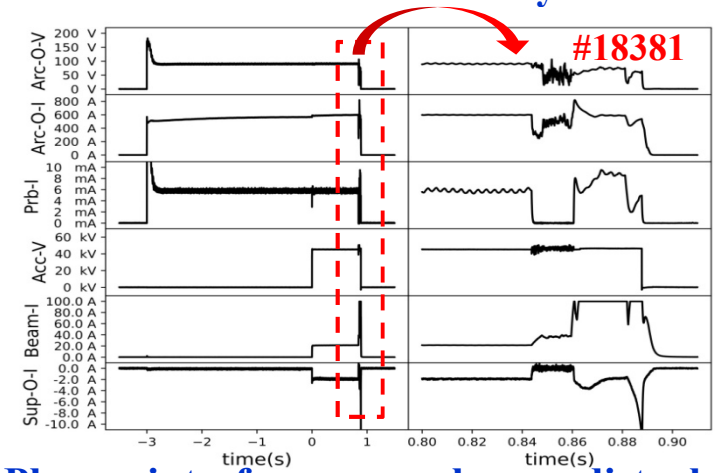
Summary of abnormal operation



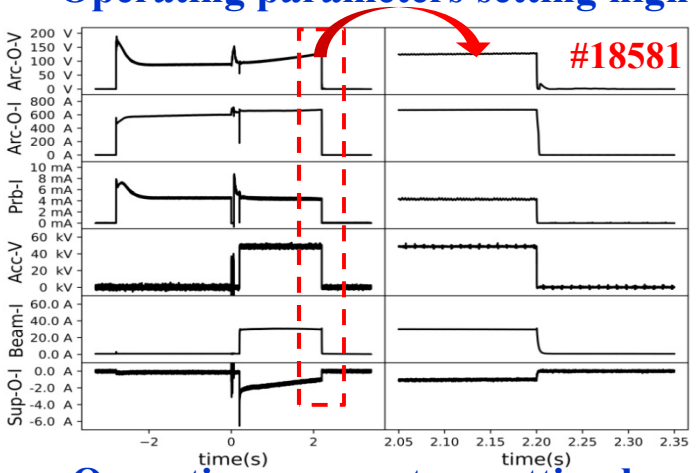
Plasma instability



Operating parameters setting high



Plasma interference or plasma disturbed



Operating parameters setting low

Changes of several common signals before the EAST-NBI breakdown event

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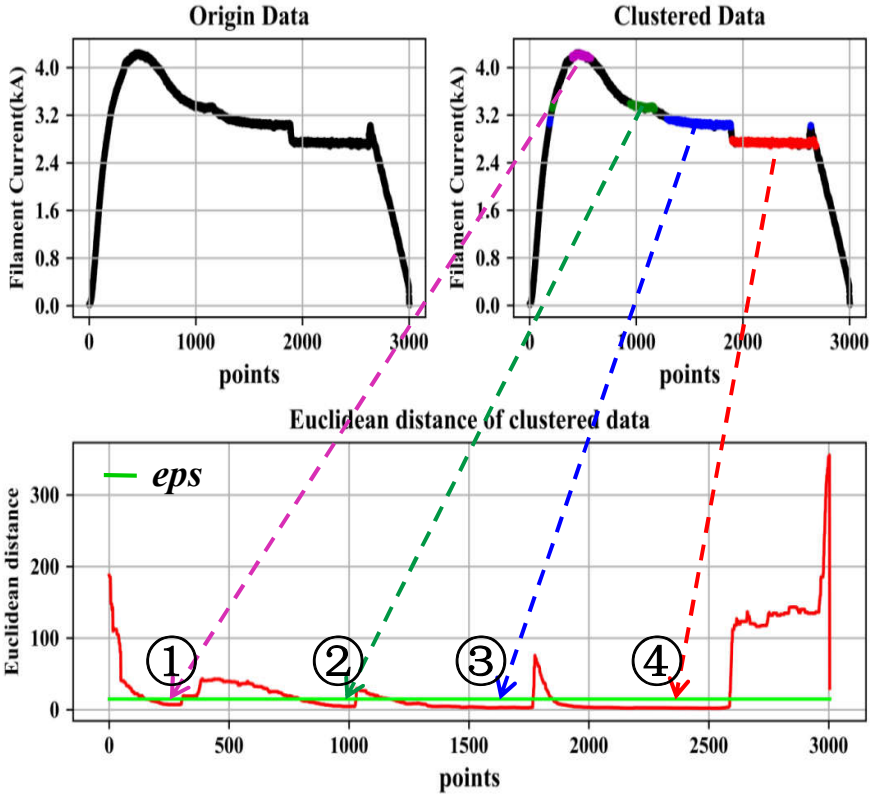
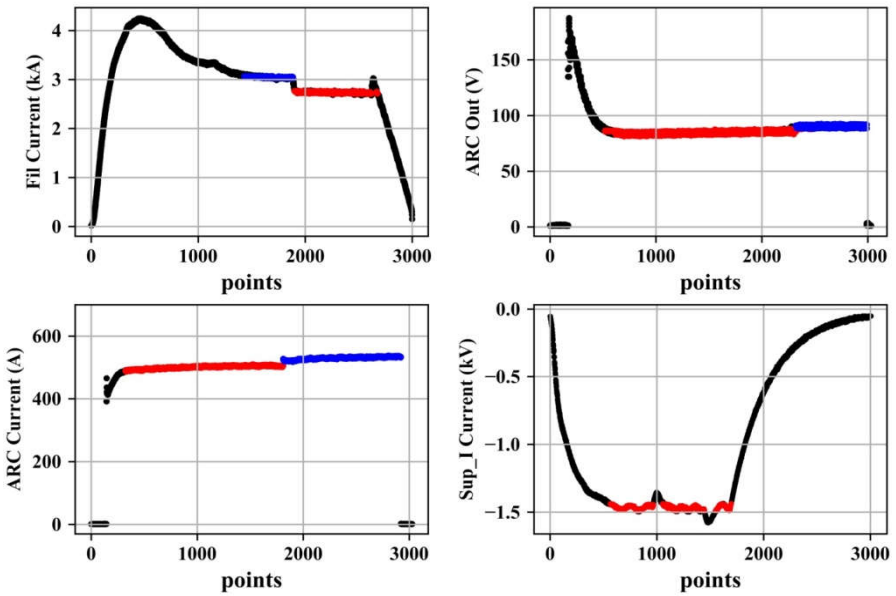
Calculate key-values by OPTICS algorithm



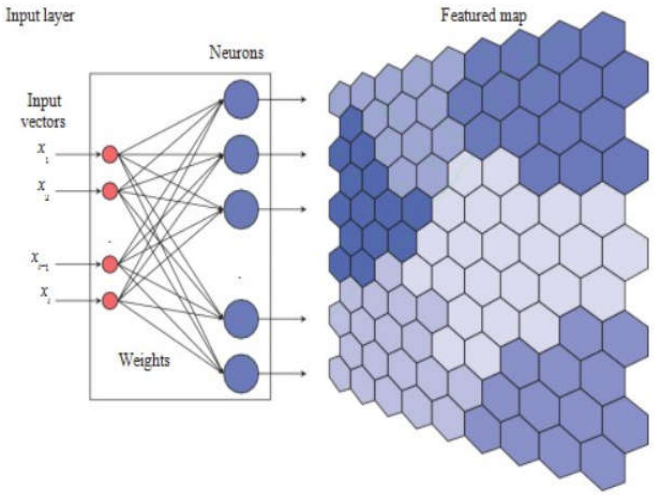
Calculate the key-value of filament current by OPTICS algorithm



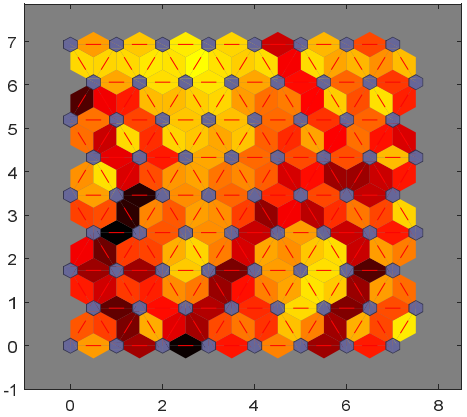
Calculate the key-values of different signals based on the OPTICS algorithm

Q: What kind of operating parameters are matched?

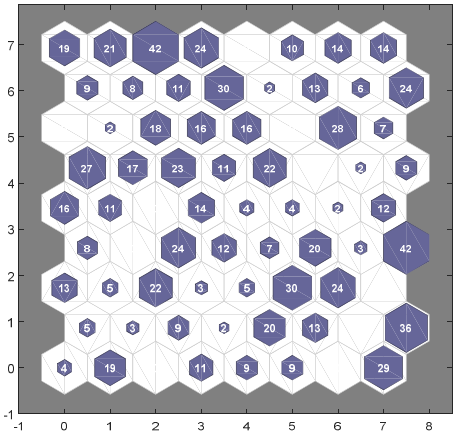
Pre-classification of data based on SOM



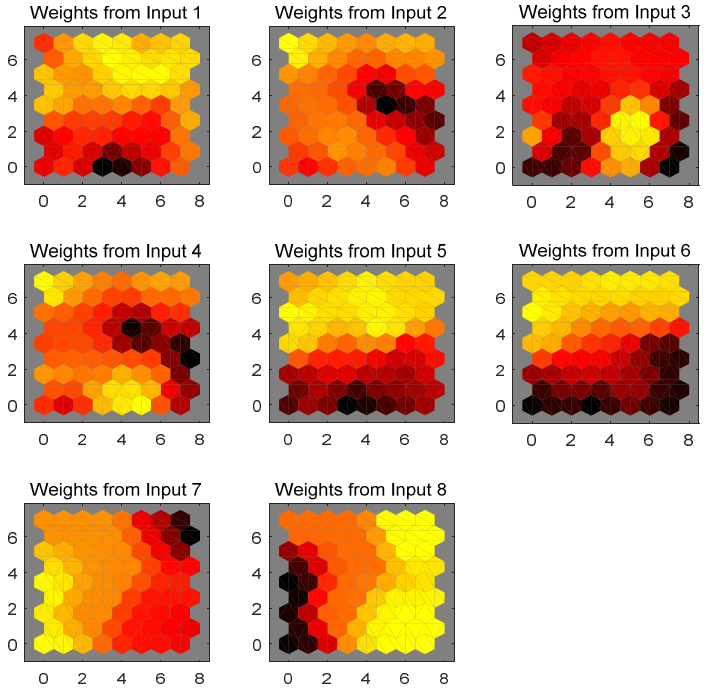
The basic principle of SOM
(**S**elf-**O**rganizing feature **M**ap)



Indicate the distance between neurons by colors

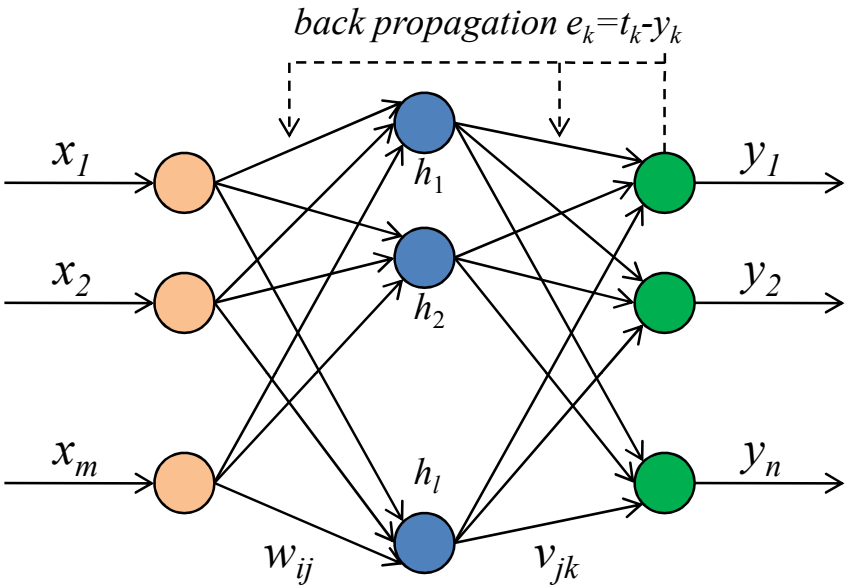


Hex-top topology

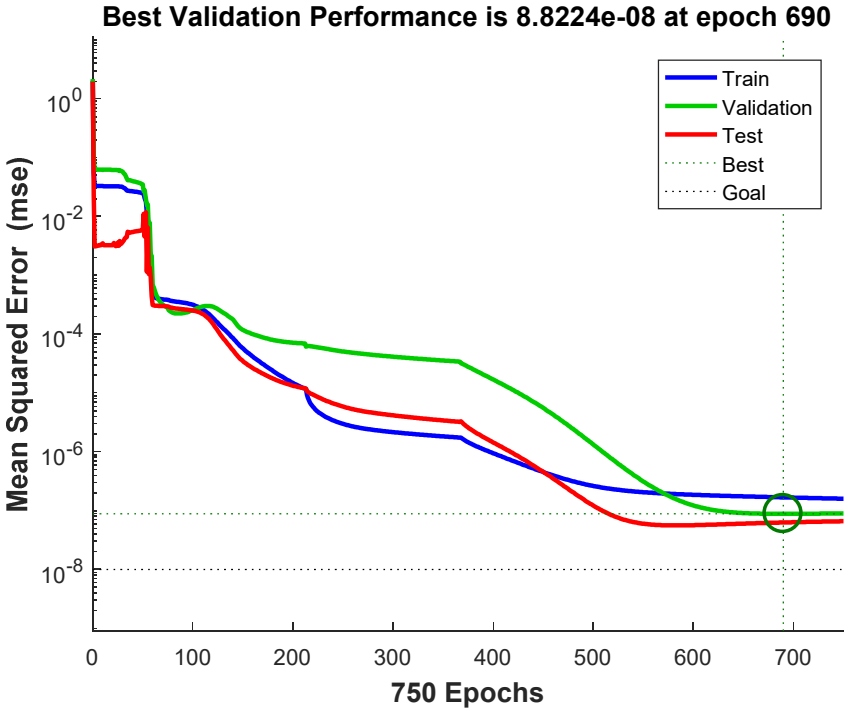


Demonstration of input weight in SOM in EAST-NBI data

Model and performance of BPNN

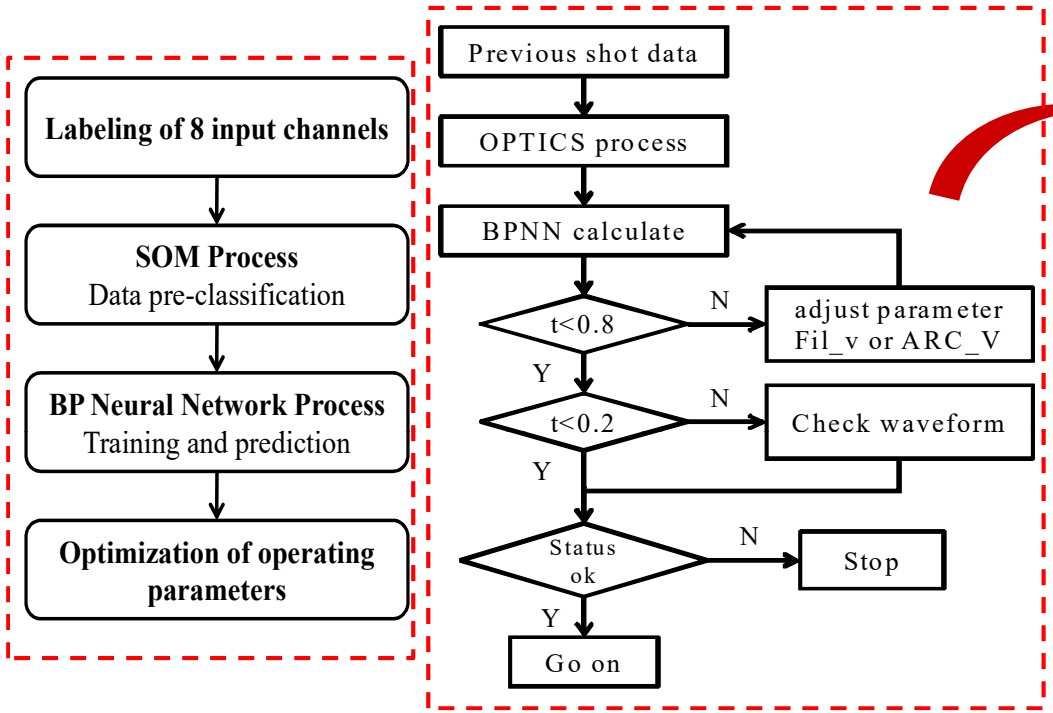


Structure diagram of BPNN

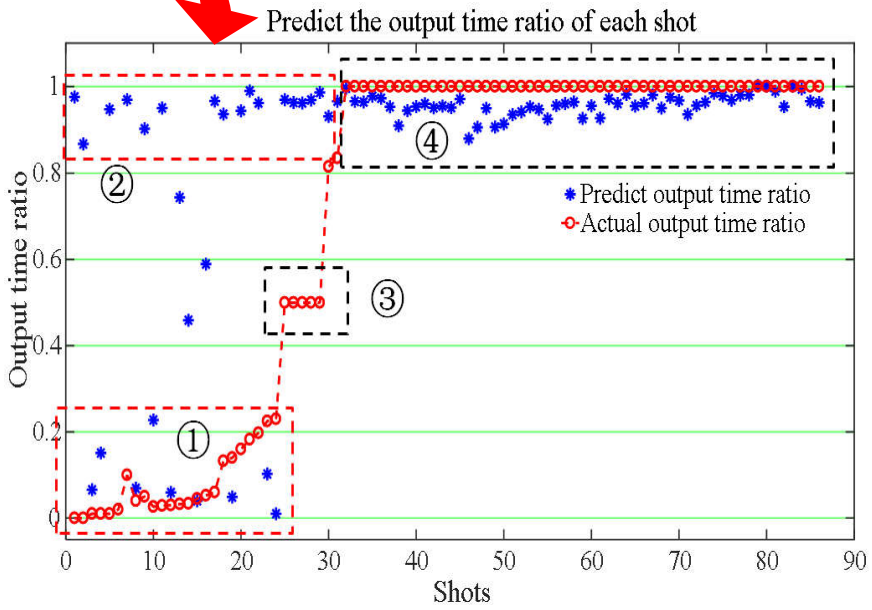


Performance of BPNN

Fault ratio prediction by Neural networks



Prediction of experimental parameters based on **SOM+BP**



The prediction accuracy rate is **86.2%** based on dataset of 2016-2019

Q: Why are the parameters of many shots matched, but the breakdown event still occurs?

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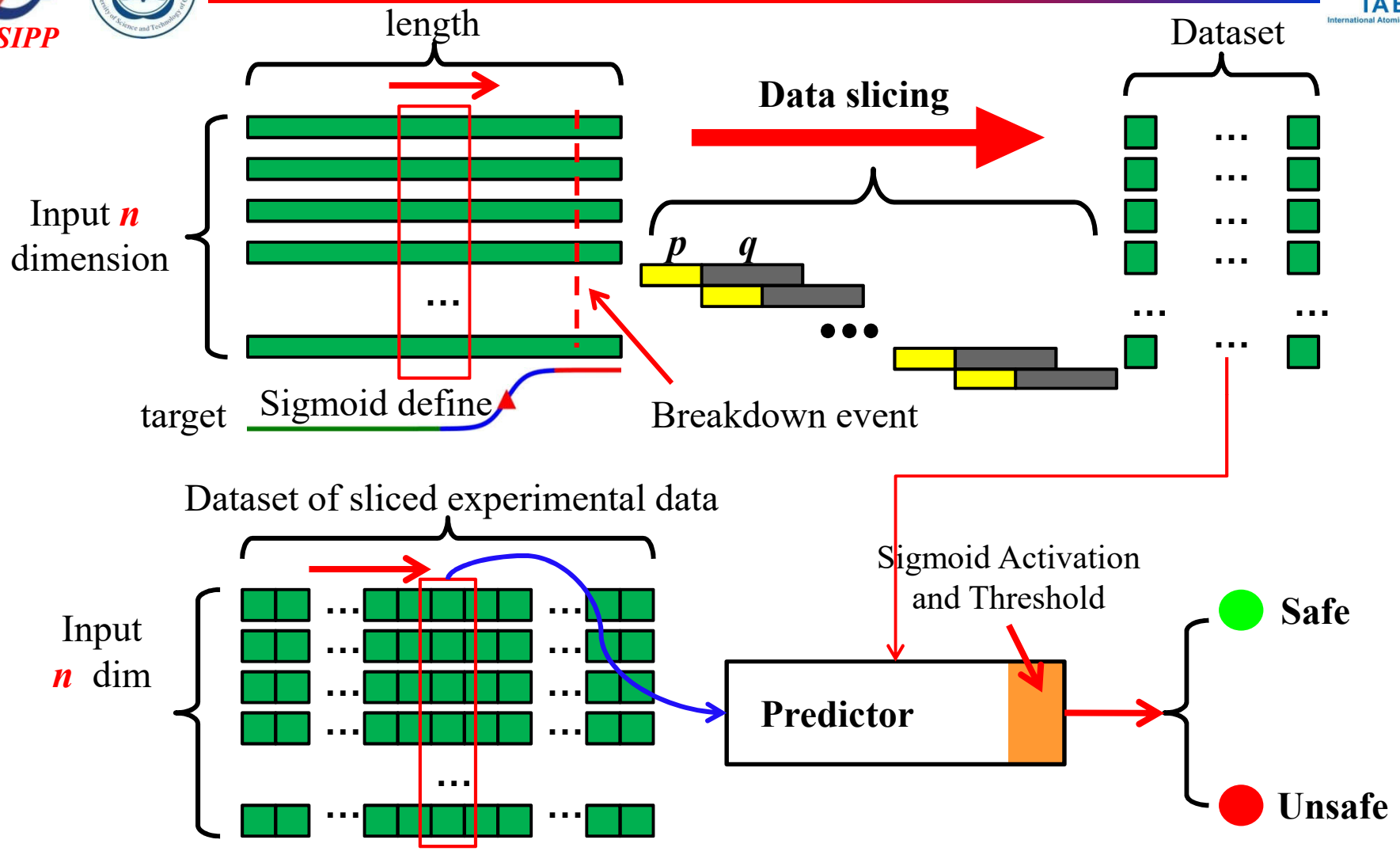
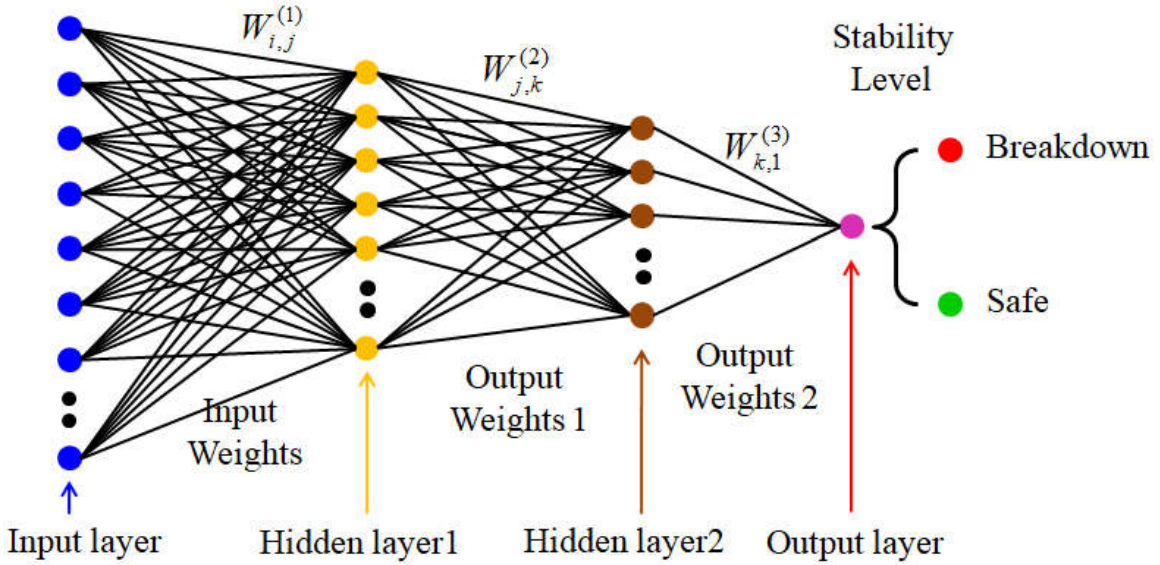
Data slicing method, Prediction model & method



Breakdown Prediction Model for Ion Source

Step.1 Use MLP-based models (Multi-Layer Perceptron)



$$y = f_3\left(\sum_{q=1}^{k} W_{q,1}^{(3)} \times f_2\left(\sum_{n=1}^{j} W_{n,q}^{(2)} \times f_1\left(\sum_{m=1}^{i} W_{m,n}^{(1)} \times x_m + b_m\right) + b_n\right) + b_q\right)$$

Breakdown prediction model of ion source based on MLP

Successful prediction

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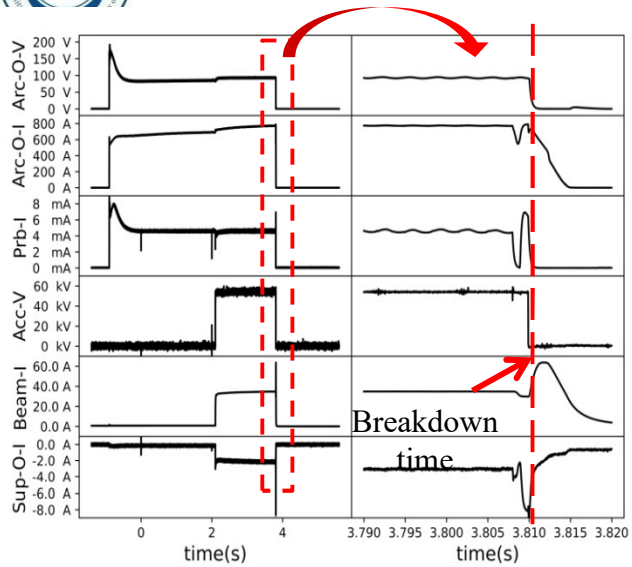
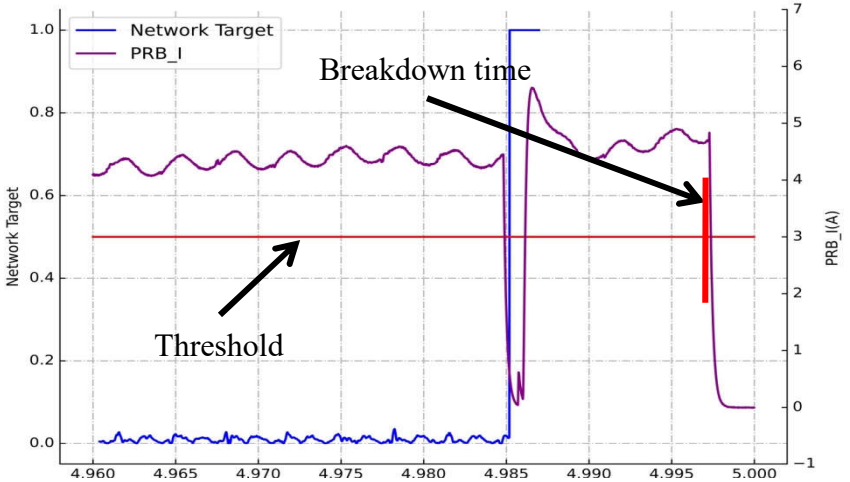
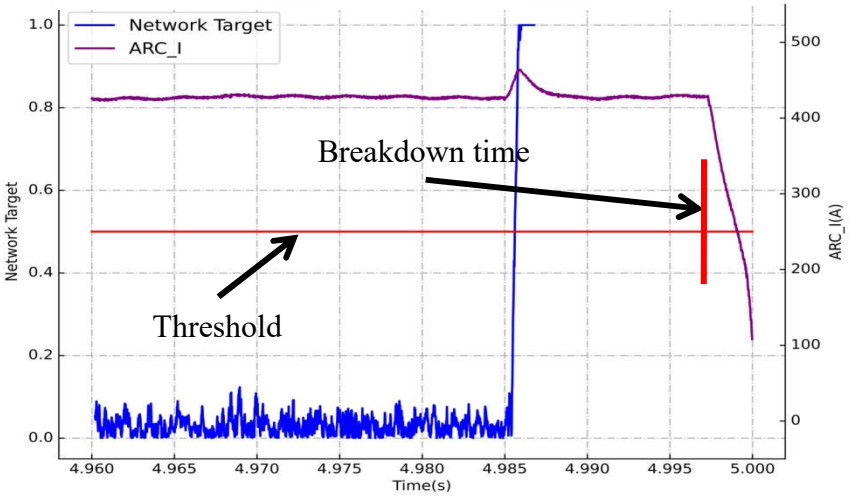
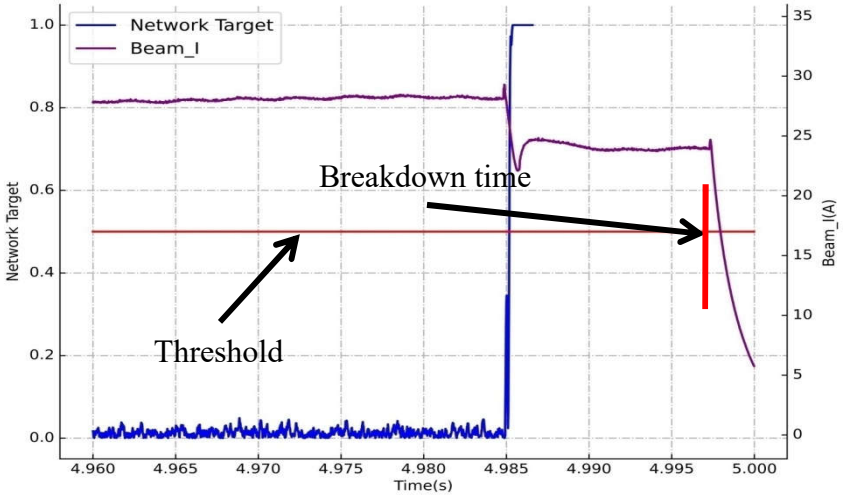


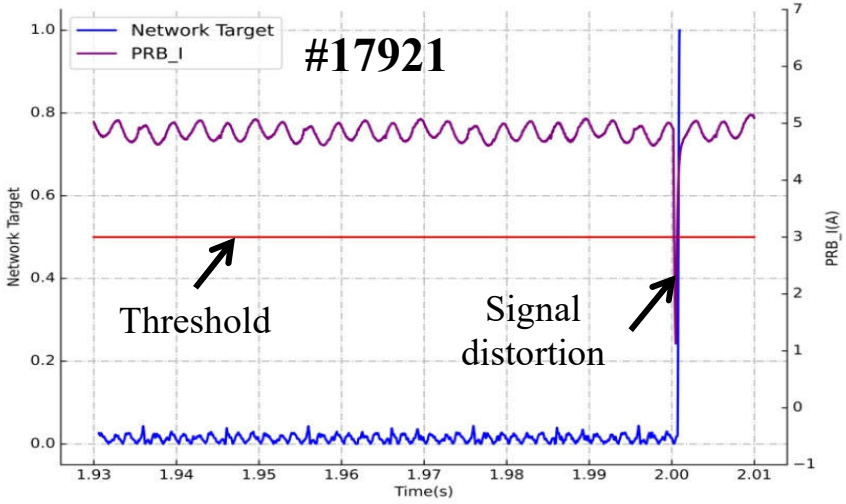
#18661

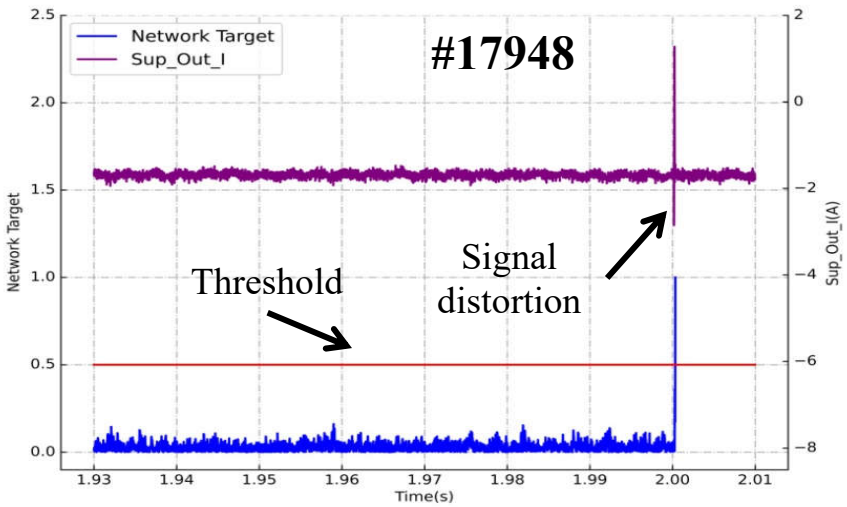






Fault prediction

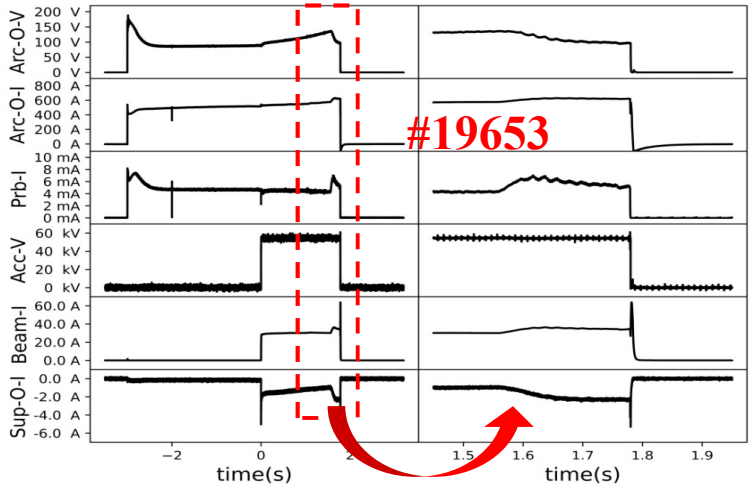


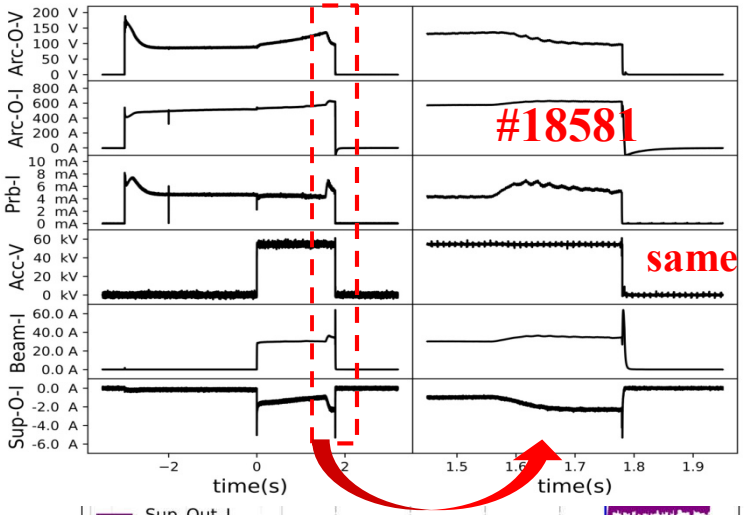


Misjudge the interference as the feature signal of breakdown

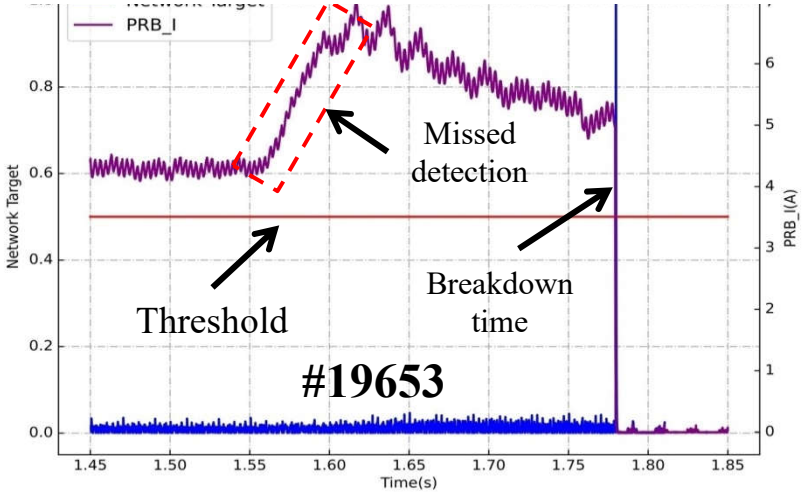
Try to use the **CNN** to solve the problem next step

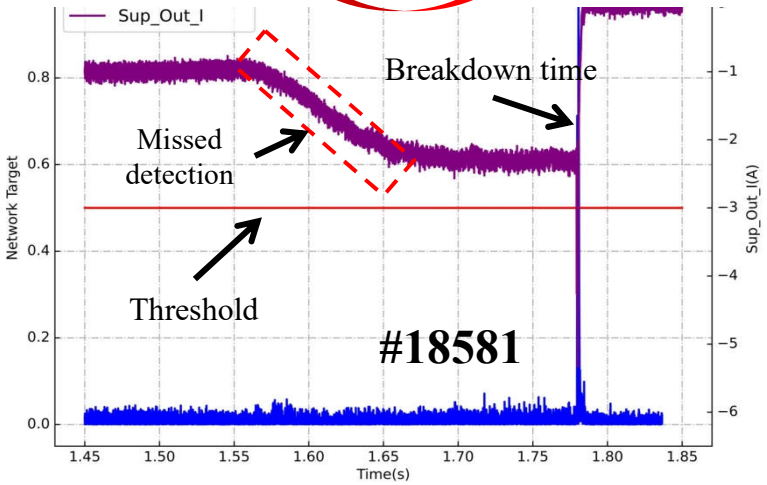
Fault prediction





same as #19653

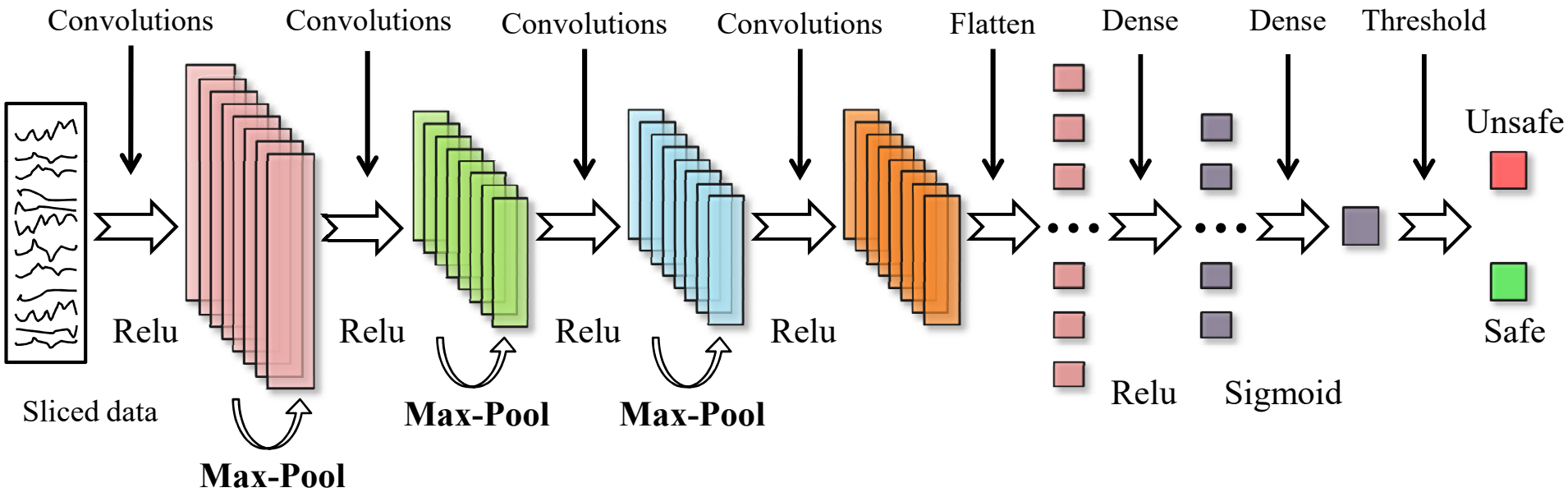




Try to use the **LSTM** to solve the problem next step

Breakdown Prediction Model for Ion Source

Step.2 Use CNN-based models (Convolutional Neural Network)



Training result of sliced data segment

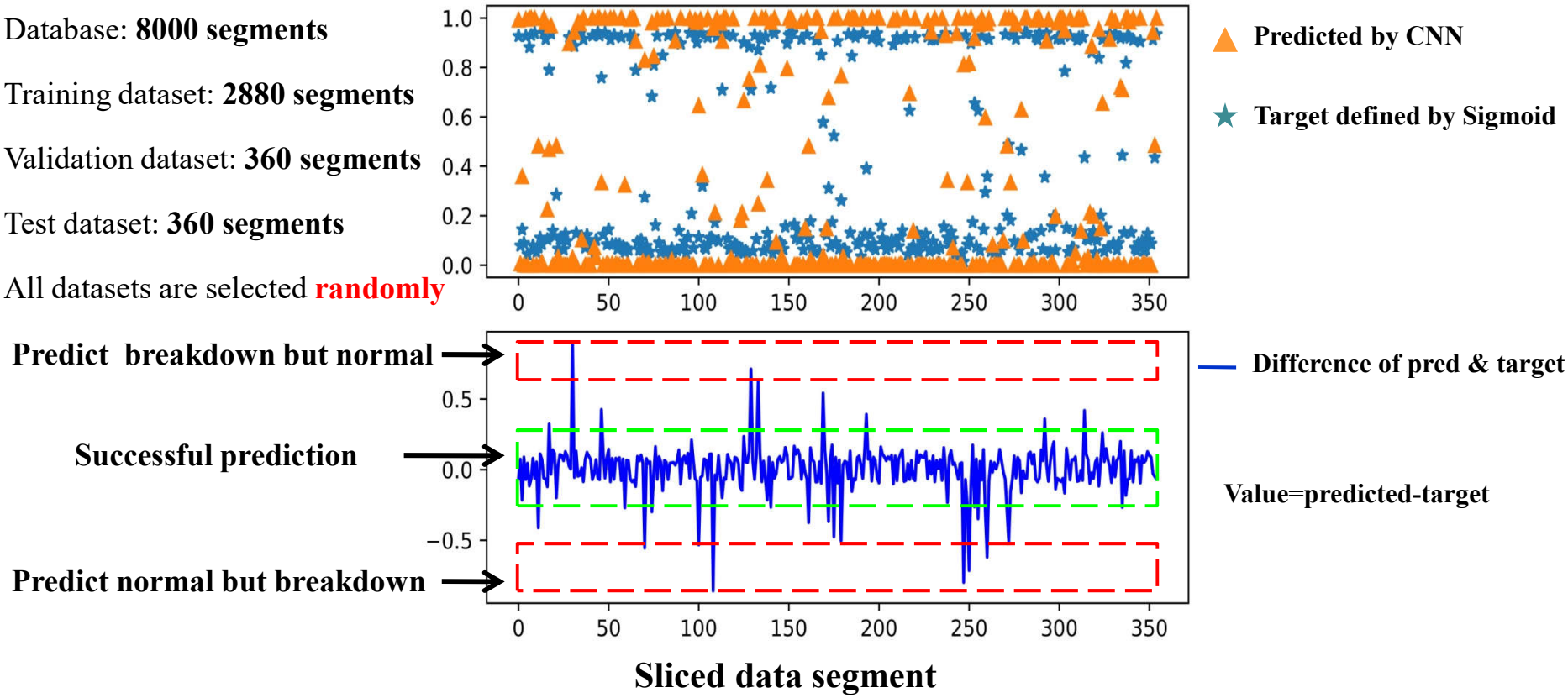
Database: **8000 segments**

Training dataset: **2880 segments**

Validation dataset: **360 segments**

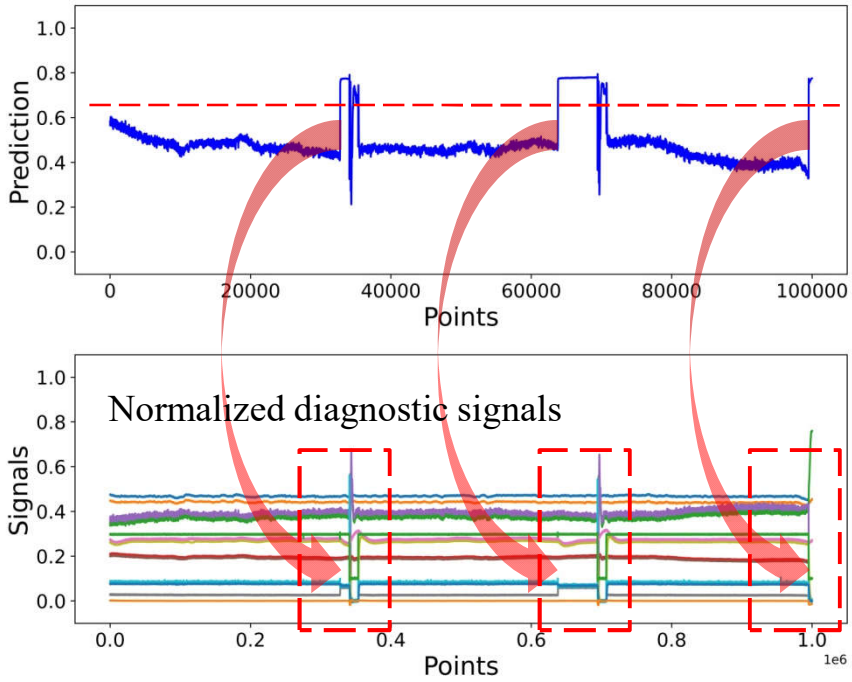
Test dataset: **360 segments**

All datasets are selected **randomly**

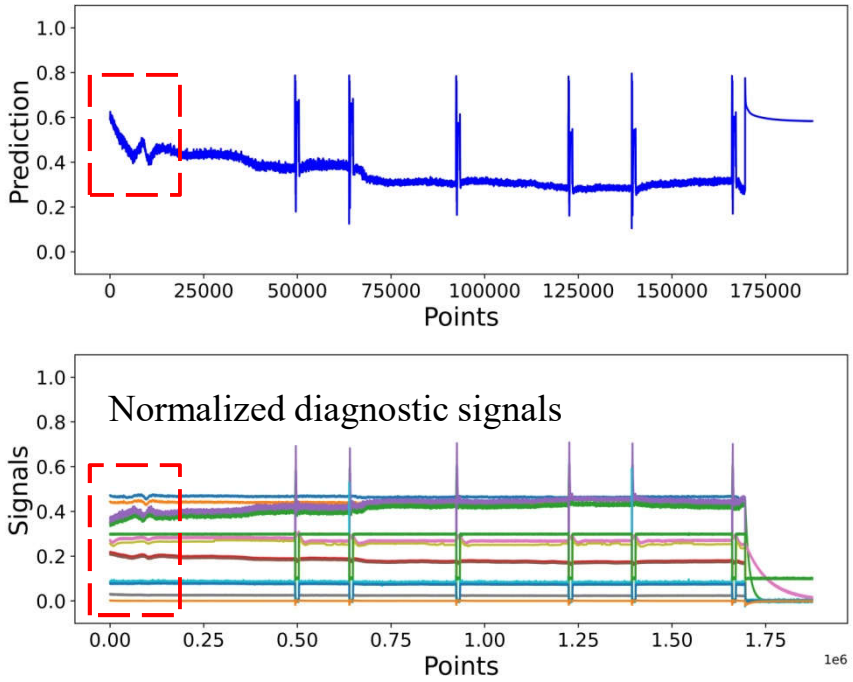


Q: Accurate prediction of slice data segment does not mean accurate prediction of a long segment data!

Successful prediction

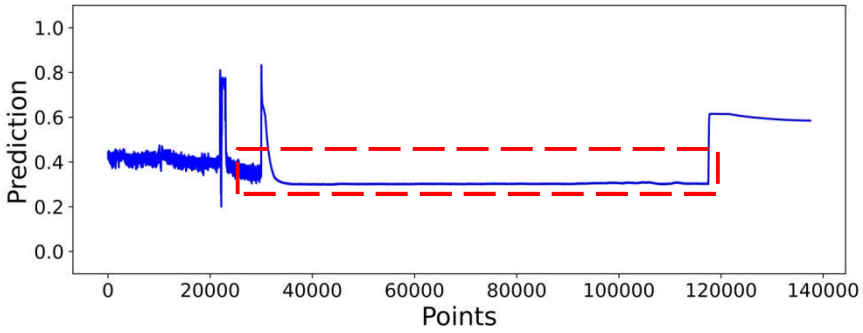


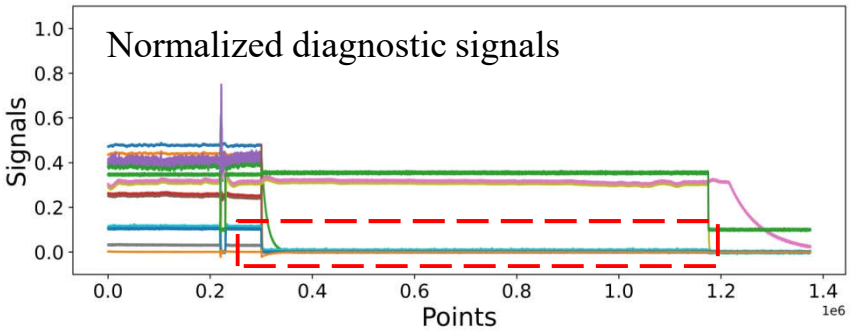
Accurately predict the characteristic waveform



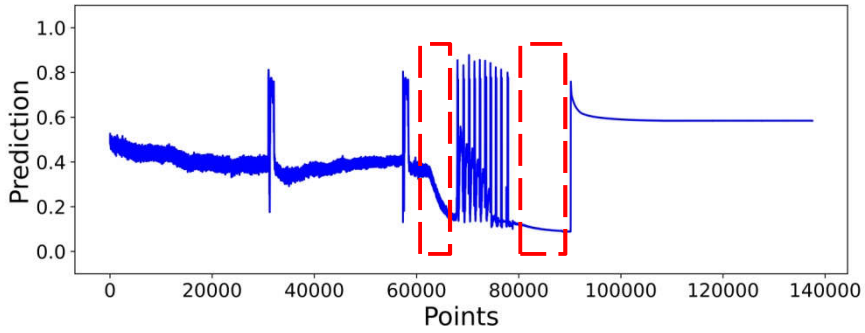
During the parameter adjustment process, the predicted probability of breakdown is reduced

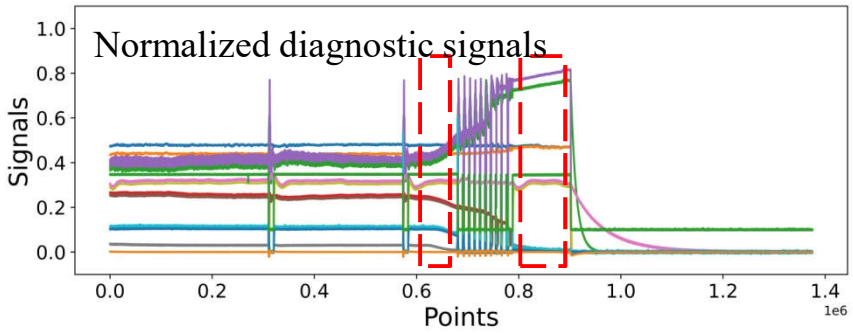
Fault prediction





Some operating parameters are faulty, such as plasma extinguishing, although no breakdown occurs at this time, it should still be restarted

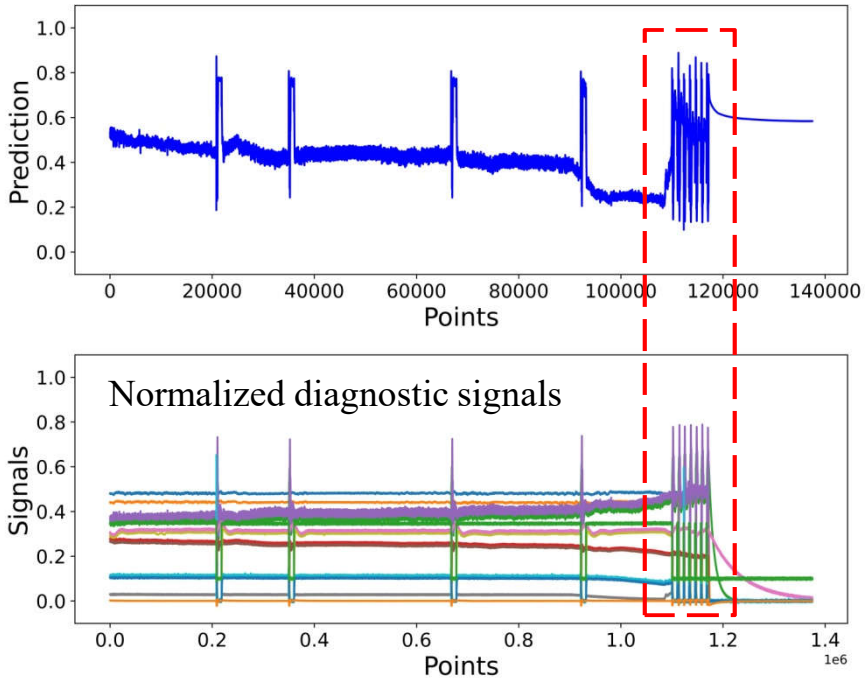


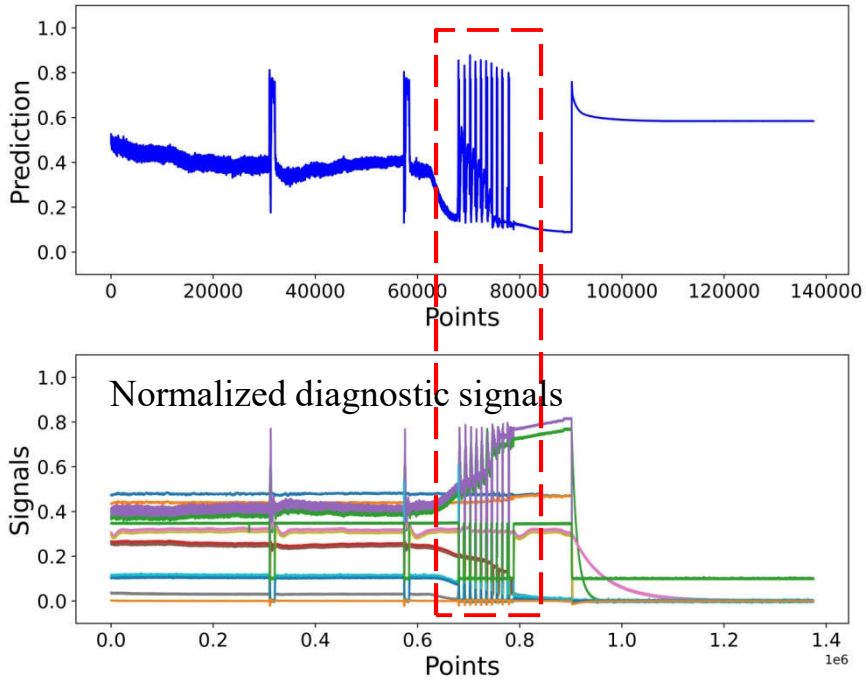


Although the parameters are no longer matched, the probability of a breakdown is predicted to be lower

Lagging predictions

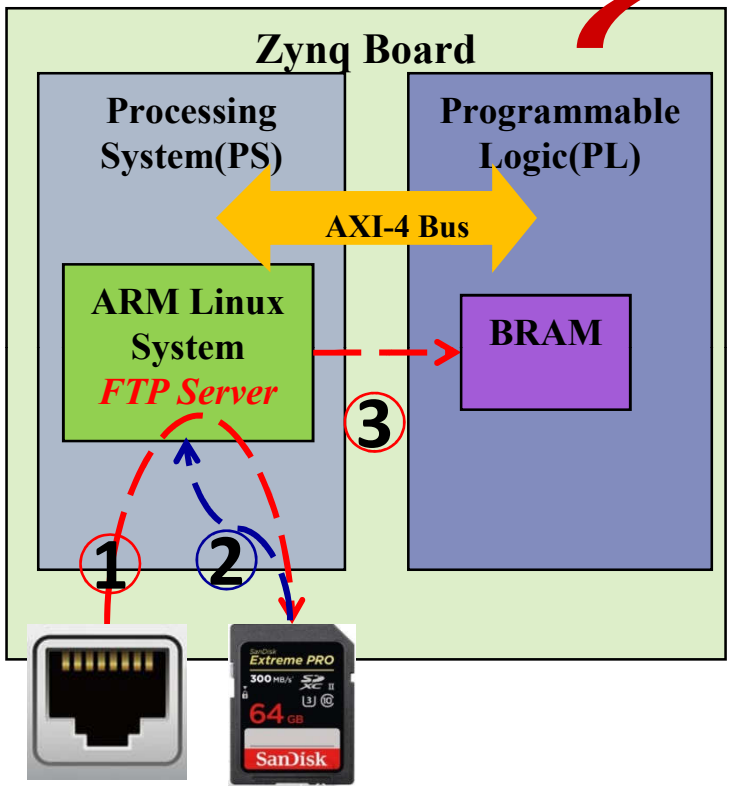
Frequent breakdown events caused by unadjustable operating parameters make predictions lagging



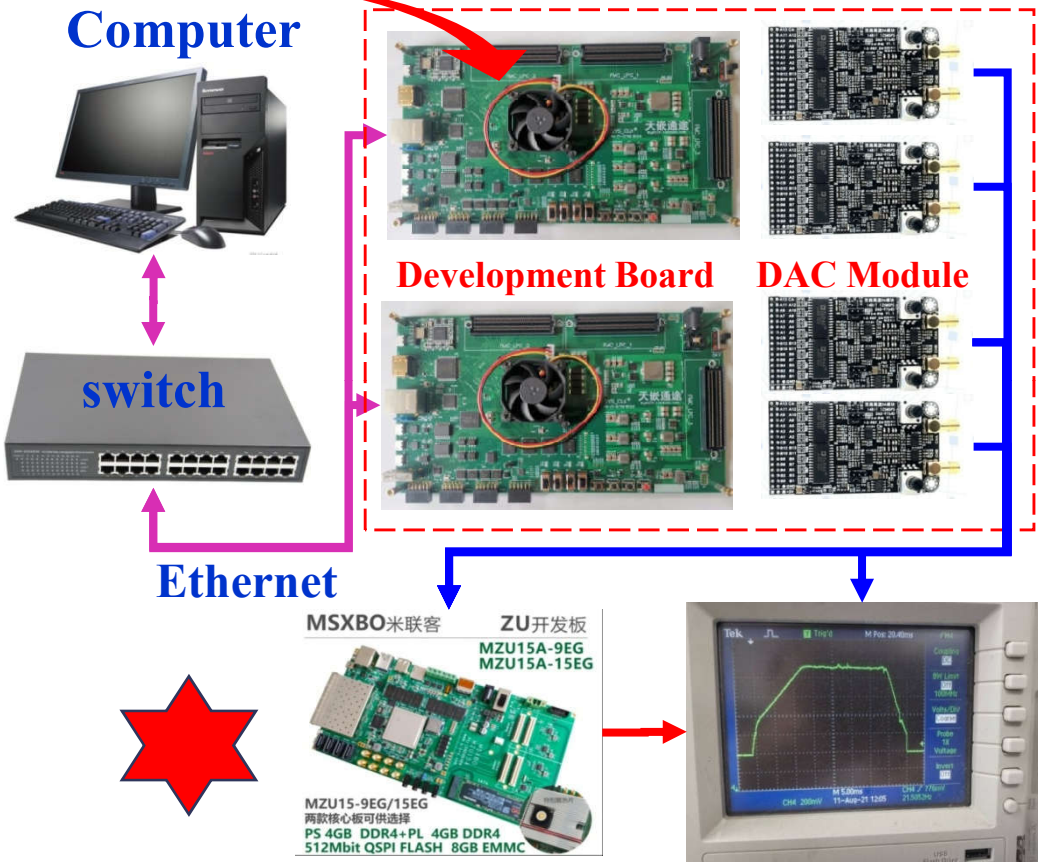


Realize prediction model and verification by FPGA

Step.3 Use FPGA



Schematic diagram of the inversion system structure (completed)



Neural network prediction FPGA board (under study)

Oscilloscope

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Summary

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- Compared with the disruption prediction of the tokamak, the prediction of the breakdown events for the NBI ion source is relatively simple, and it's easier to establish the model. Tokamak use PCS

- The breakdown time of the NBI ion source is very short, and the change of the diagnostic signal to breakdown event is only **a few ms**, and the processing time required is much less than the time required for the tokamak to disrupt, and the **FPGA** is the only way to implement this model.

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Thanks for your attention