Plasma Monitoring and Control with Real-Time Tomography at JET

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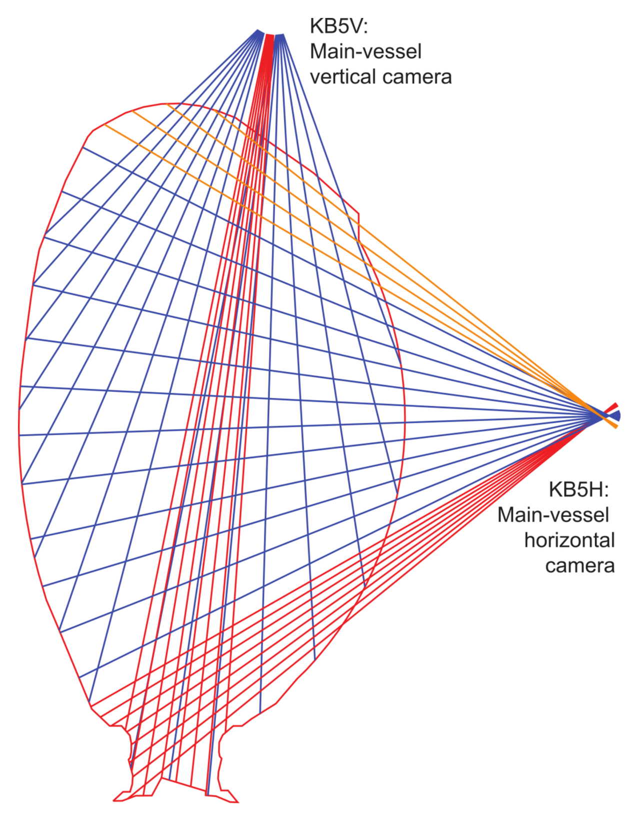
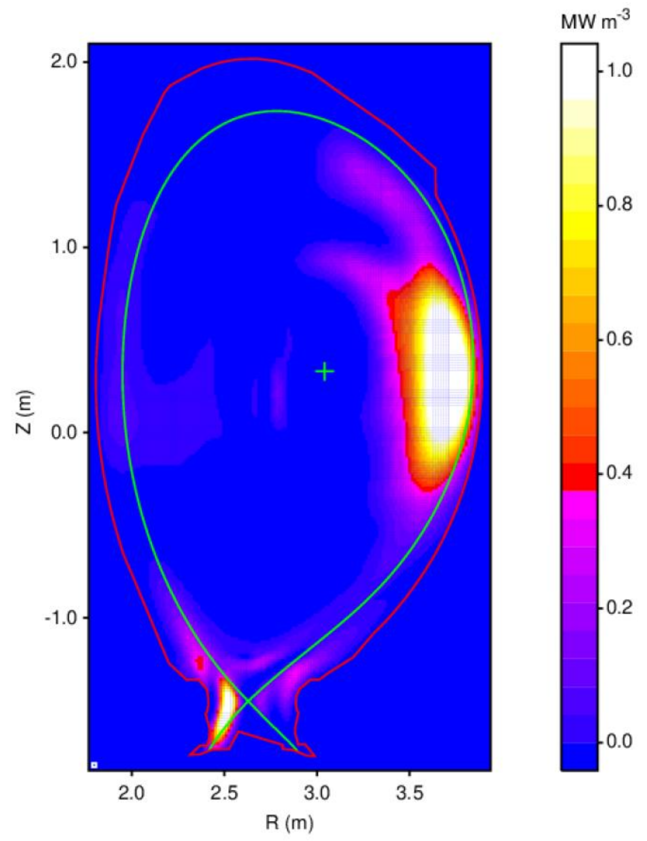
1. Bolometer tomography at JET



Bolometer data



Plasma profile

The JET bolometer system has two cameras (a horizontal and a vertical one) with 24 lines of sight each.

From the measurements of these cameras, it is possible to reconstruct the plasma radiation profile using tomography techniques.

The reconstruction process is computationally intensive and is typically done offline, after the pulse.

However, in this work we use a simpler model to perform the computation much faster, to the point that it can be used in real-time.

2. Tomographic reconstruction by matrix multiplication

Test:

Matrix (48×196×115) → Matrix multiplication

Bolometer data (n×48) → Matrix multiplication → Plasma profiles (n×196×115)

Training:

Plasma profiles (n×196×115) → Machine learning

Bolometer data (n×48) → Machine learning → Matrix (48×196×115)

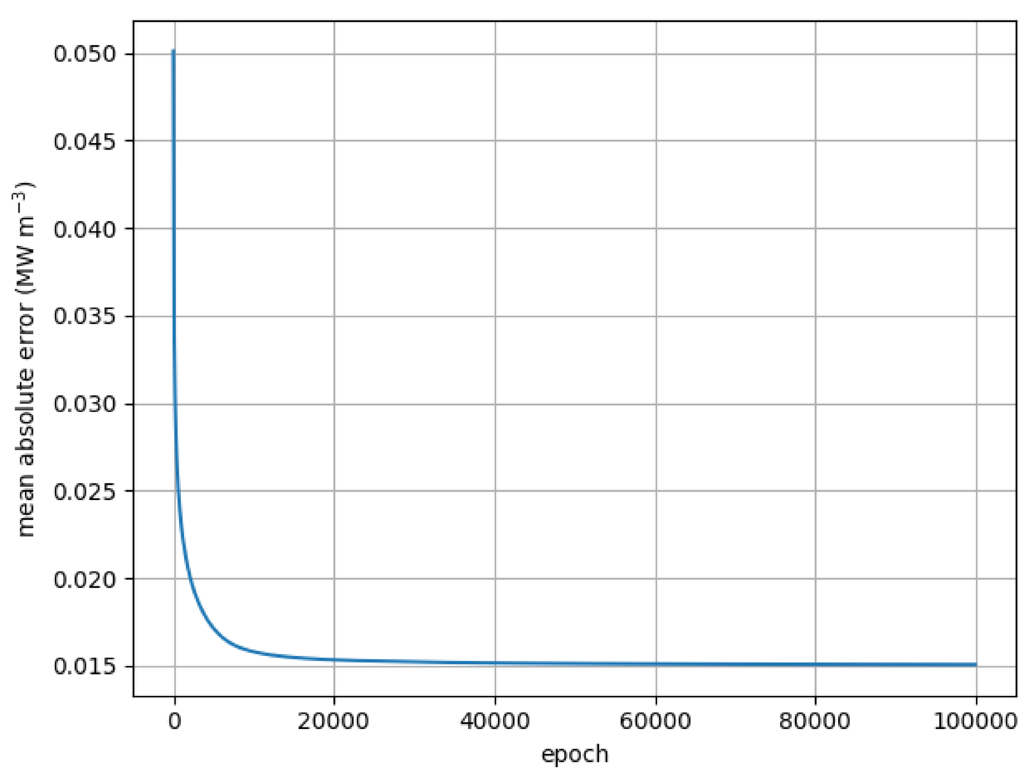
The model is based on matrix multiplication over the bolometer signals.

Given a batch of bolometer data (either a single sample or a batch of n samples) the plasma radiation profile is obtained by a single matrix multiplication step.

The matrix itself is obtained by training on a large number (~10,000) of existing reconstructions at JET.

Specifically, the matrix is found by using gradient descent to minimize the error between the training profiles and the result of matrix multiplication.

3. Training of the tomographic reconstruction matrix

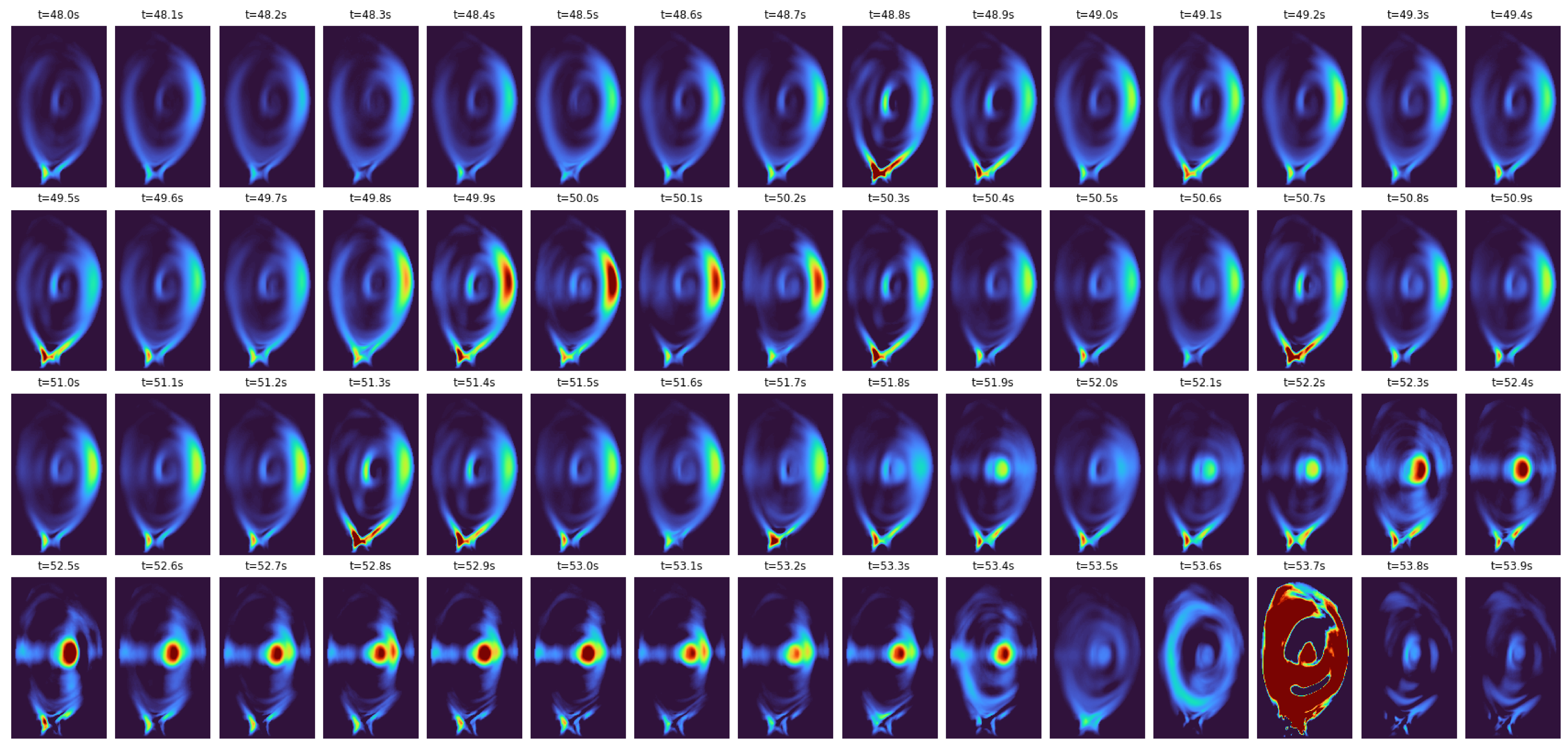


The figure on the left shows how the error decreases during the training process.

All training data was loaded onto a single GPU and the model was trained for many epochs.

The model converges to a minimum error of about 0.015 MW/m3, which is quite low (more sophisticated models, such as a neural network, have an error of around 0.010).

4. Real-time tomography

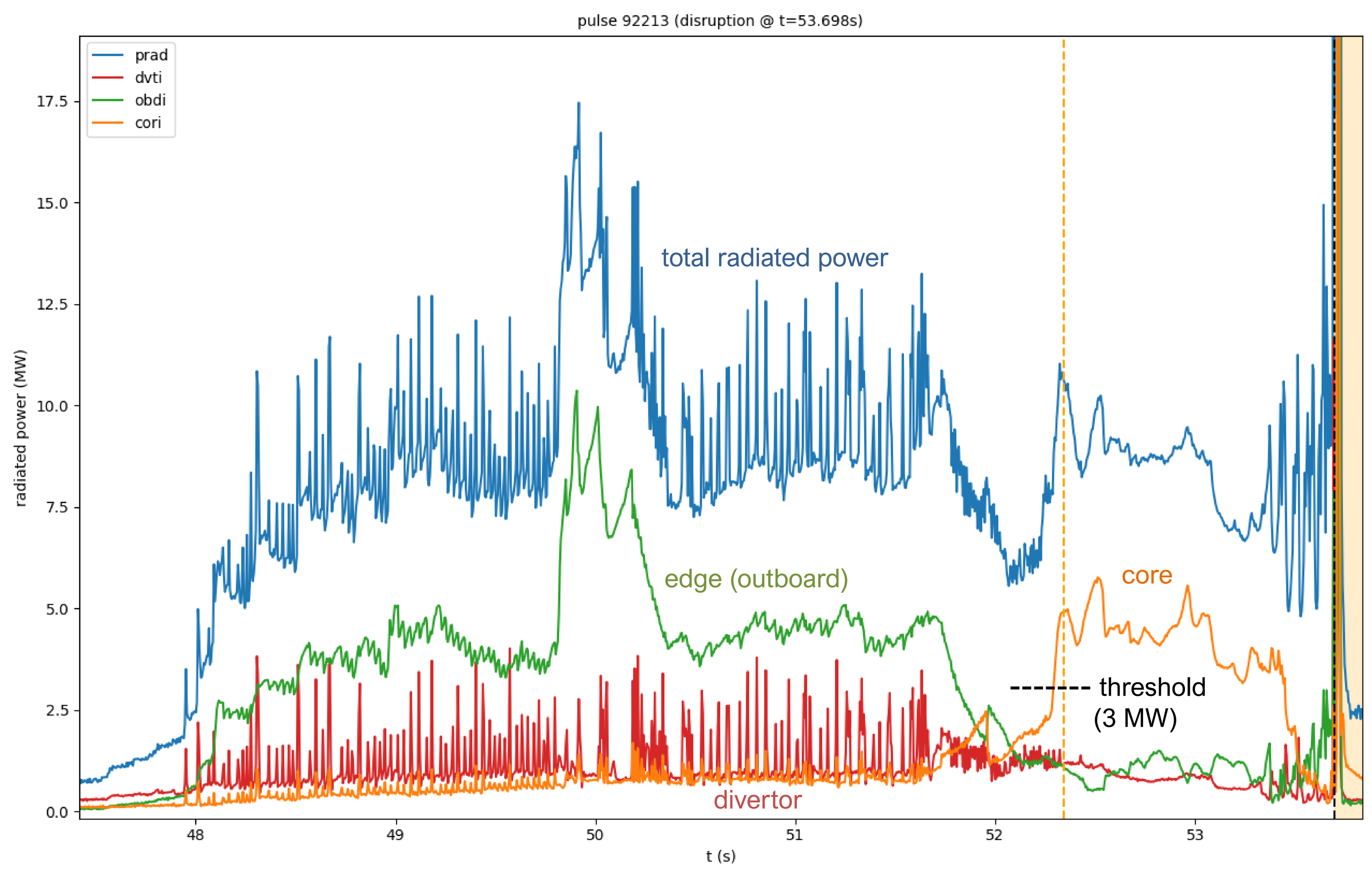


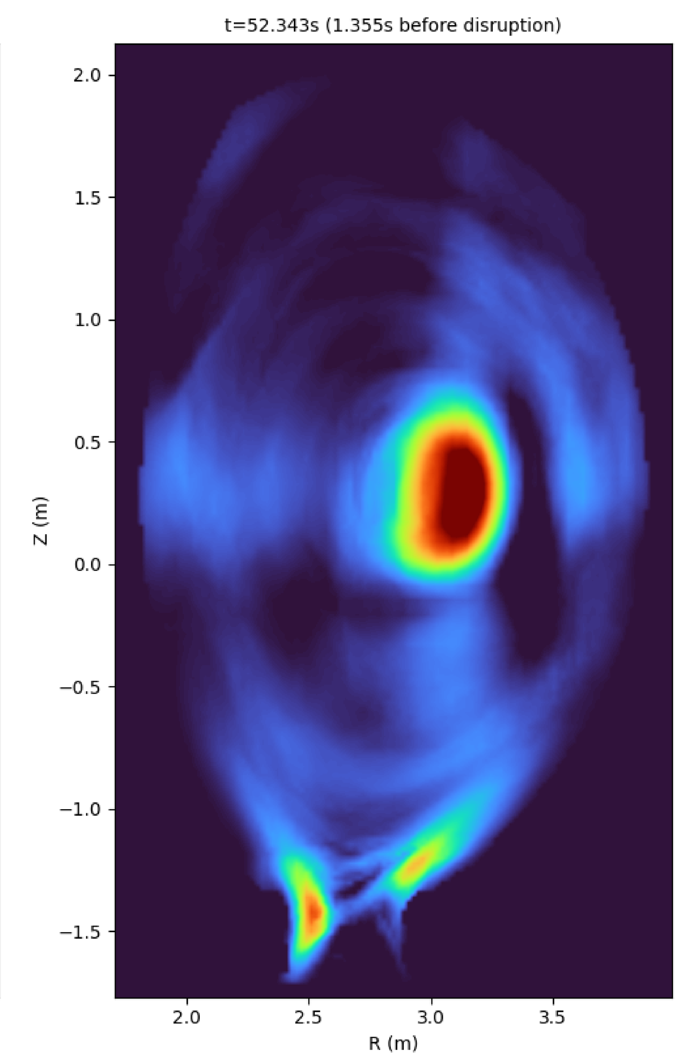
The sequence of frames on the left shows the real-time reconstructions produced by the model for an example pulse (92213).

Here it is possible to observe the development of a radiation blob at the outboard edge, followed by the development of a radiation blob at the plasma core, which eventually leads to a disruption.

One of the main advantages of real-time tomography is that it allows monitoring the radiated power in different regions of interest, namely at the edge, at the core, and at the divertor.

5. Radiated power in regions of interest



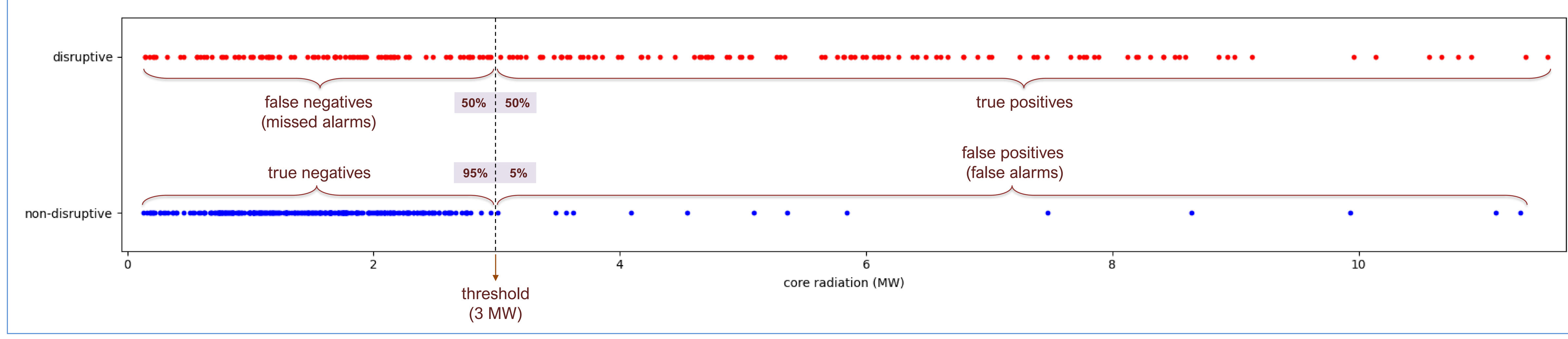


By integrating the plasma radiation profile in certain regions, it is possible to monitor the radiated power in those regions and keep track of signals such as those displayed on the left.

In this example pulse, it is apparent that edge radiation dominates up to a certain point, and then core radiation takes over.

In particular, when core radiation becomes too high, the plasma may develop a hollow temperature profile that eventually leads to a disruption by core collapse.

6. Alarm on core radiation



Using real-time tomography, it is possible to throw an alarm when core radiation exceeds a certain threshold.

This plot shows that by imposing a threshold of 3MW on core radiation it is possible to catch 50% of disruptive pulses with only a 5% false alarm rate.