A Human-in-the-Loop Active Learning Tool for Event Detection in Tokamak Discharges

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The identification and understanding of critical events in tokamak discharges, such as disruptions, edge-localized modes (ELMs), and confinement modes, is a cornerstone for enhancing operational stability and advancing fusion energy research [1, 2]. Traditional approaches for event detection rely heavily on pre-defined algorithms and offline analysis, which can be time intensive for domain scientists and limited by their inability to adapt to new scenarios, such as calibration shifts or new diagnostics. Existing databases of event data have been curated by hand [5, 6, 7] or used semi-supervised methods [8, 9]. Machine learning (ML) offers a powerful tool to capture and generalise from domain expertise but requires abundant labelled data which is costly to obtain [3, 4]. To address these challenges, we present an open-source human-in-the-loop active learning tool designed to iteratively refine machine learning models for event detection in tokamak discharge data.

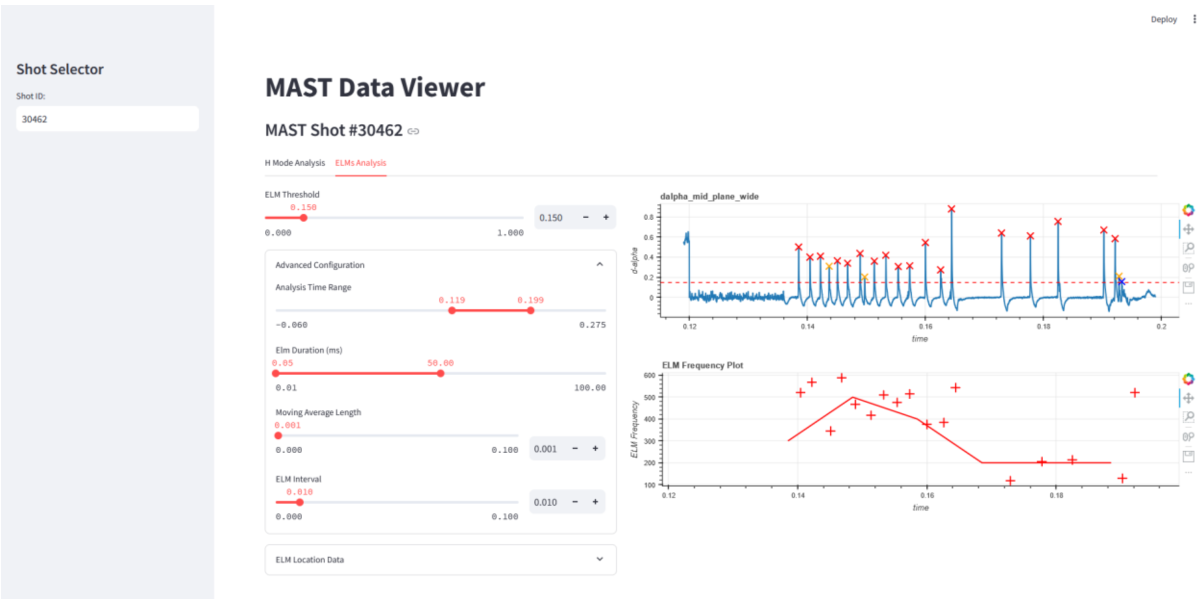

Figure 1 Prototype interface for Human-in-the-loop active learning for event tagging in tokamak discharges

Our approach integrates domain expertise with an active learning workflow, enabling researchers to guide the model through strategic data labelling and interactive feedback. Key features of the tool include:

- A user-centric interface for labelling event data, which improves model performance with minimal labelling effort.

- Active learning strategies to prioritize labelling discharges, focusing on the most uncertain or impactful samples.
- An open-source and extendable code base which can be easily extended to data from other tokamaks.

We demonstrate the tool's efficacy using experimental data from the historical record from the MAST tokamak. Results show that we can perform accurate, generalised event detection across a range of phenomena. Moreover, the iterative framework enables an adaptive system that evolves with experimental campaigns and new diagnostic modalities.

This work brings the power of machine learning directly to the control room to accelerate and enhance MAST-U researcher's analysis workflow. This work highlights the potential of combining expert knowledge and machine learning to address challenges in event detection and collect rich metadata on critical events, offering a pathway toward the necessary data for smarter tokamak operation and robust disruption mitigation strategies.

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