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# L-CAPE: Linac Condition Anomaly Prediction of Emergence

November 2021

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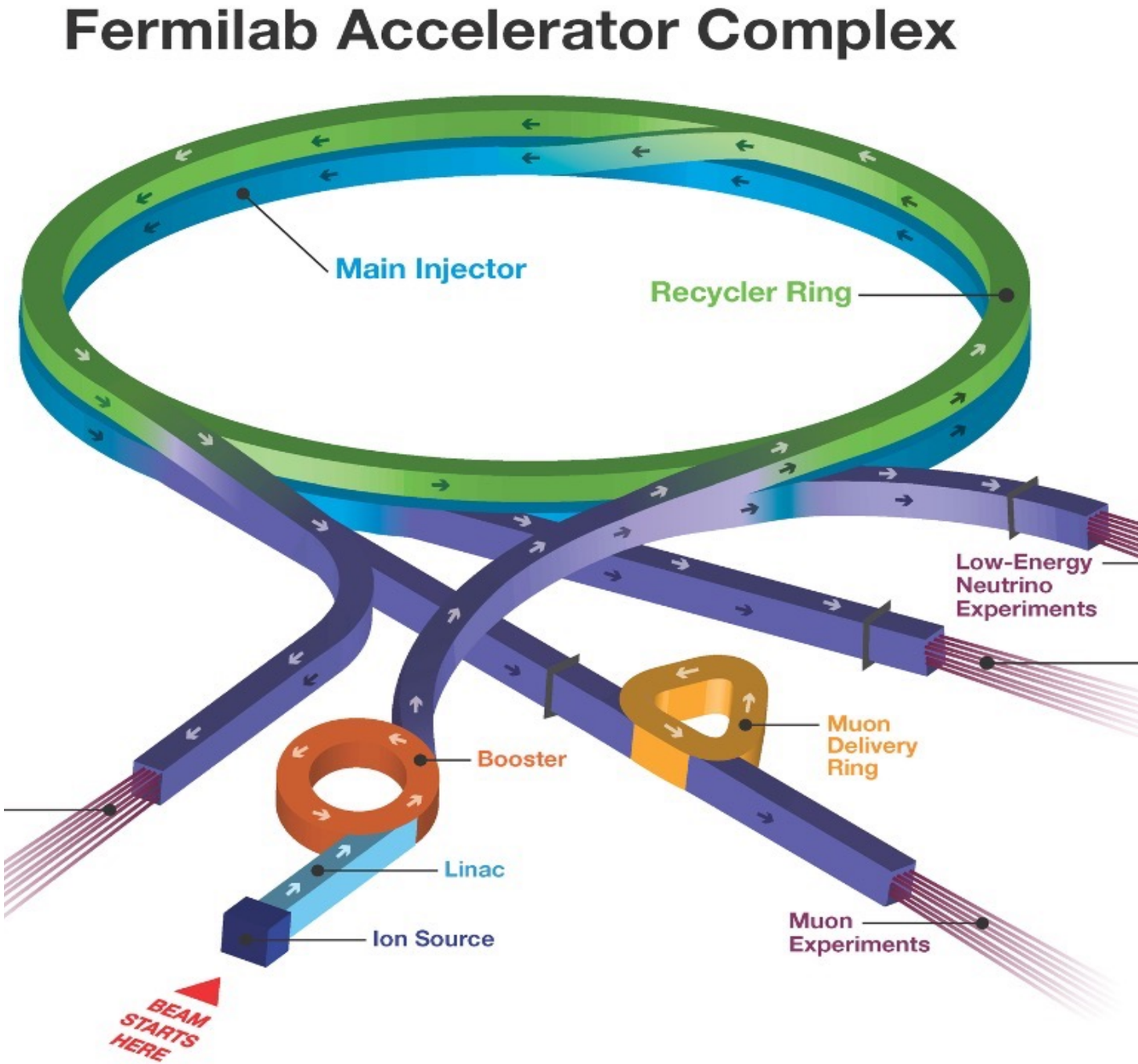
Gihan Panapitiya, **Jan Strube**

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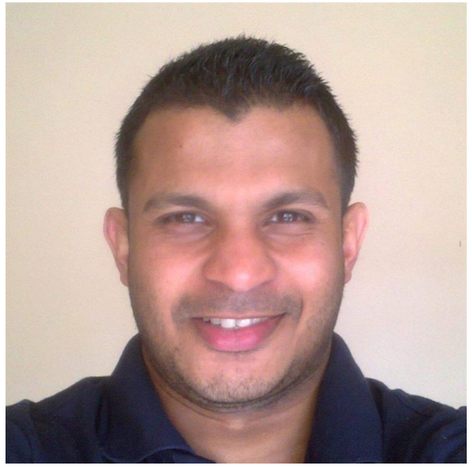

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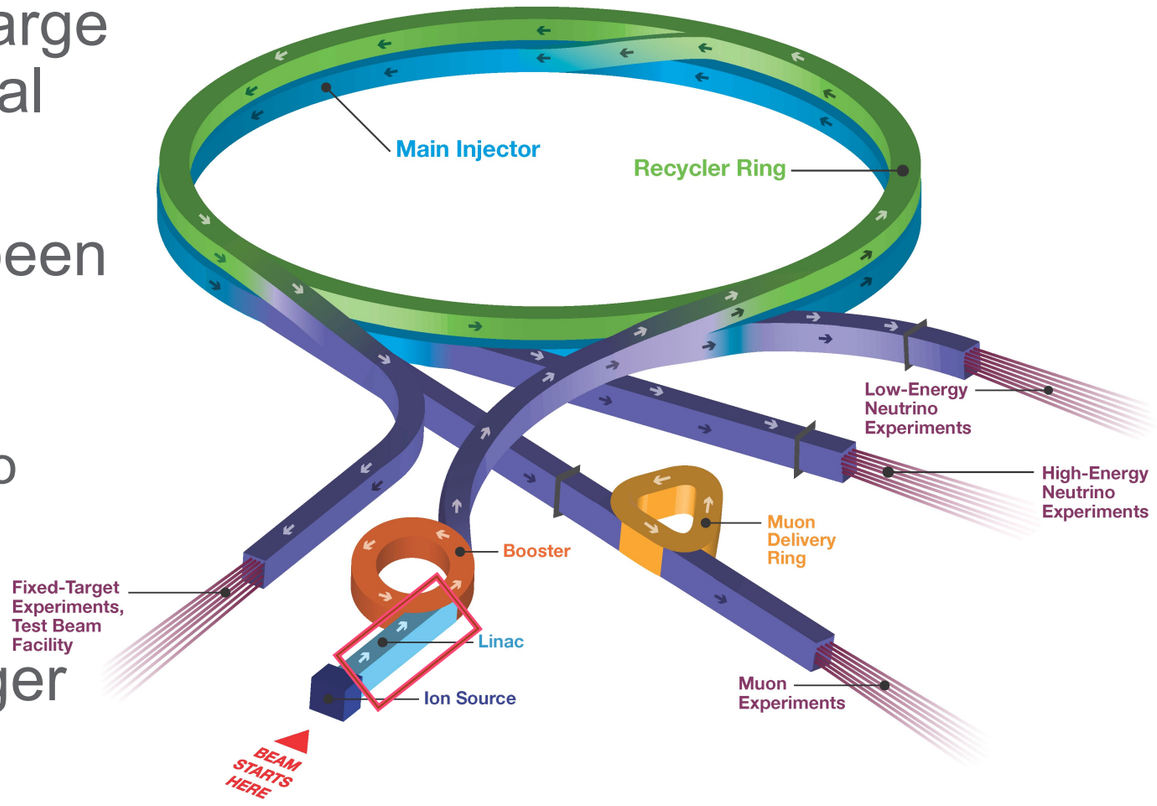
Data Scientist

# Project objective

- The FNAL accelerator complex is a large scientific user facility with a substantial energy footprint
- Instrumentation of the complex has been incremental, and the controls system does not have a global view
  - Downstream systems do not respond to outages upstream
- The energy savings of downstream systems going to standby during longer outages could be quite significant

**Fermilab Accelerator Complex**



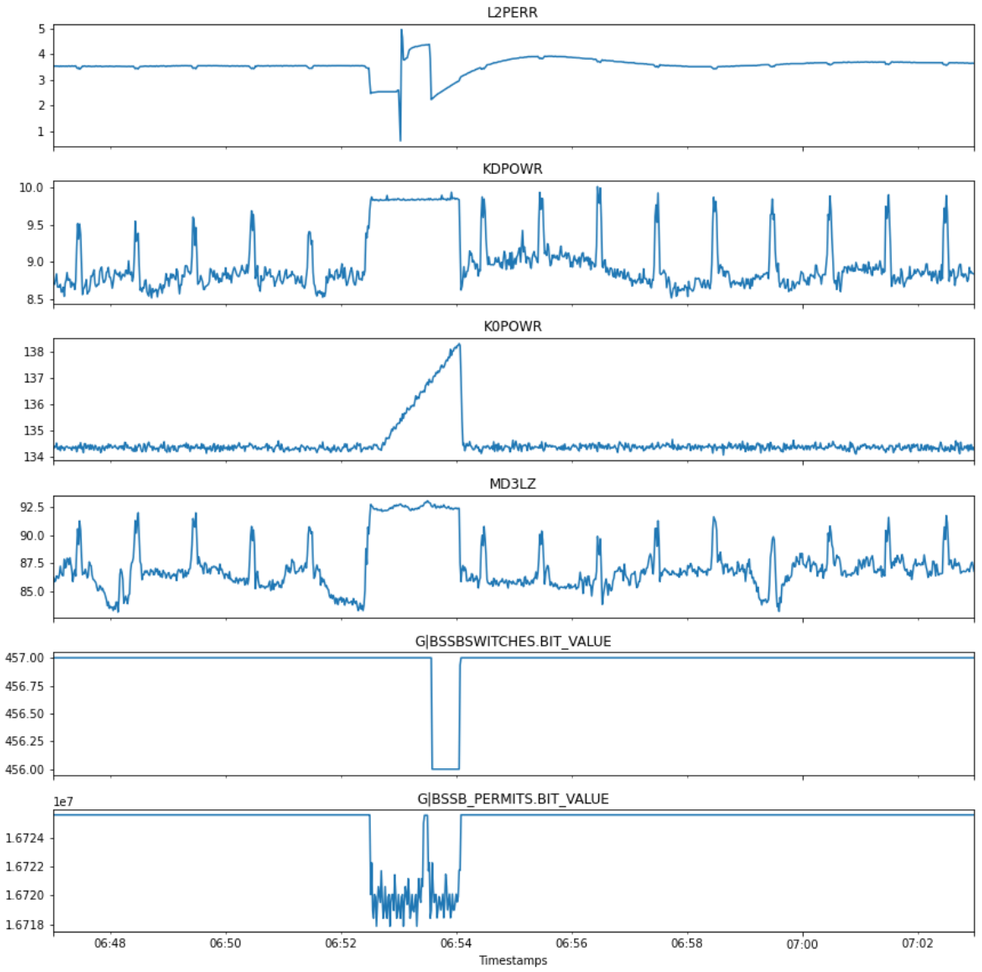
# Research Questions

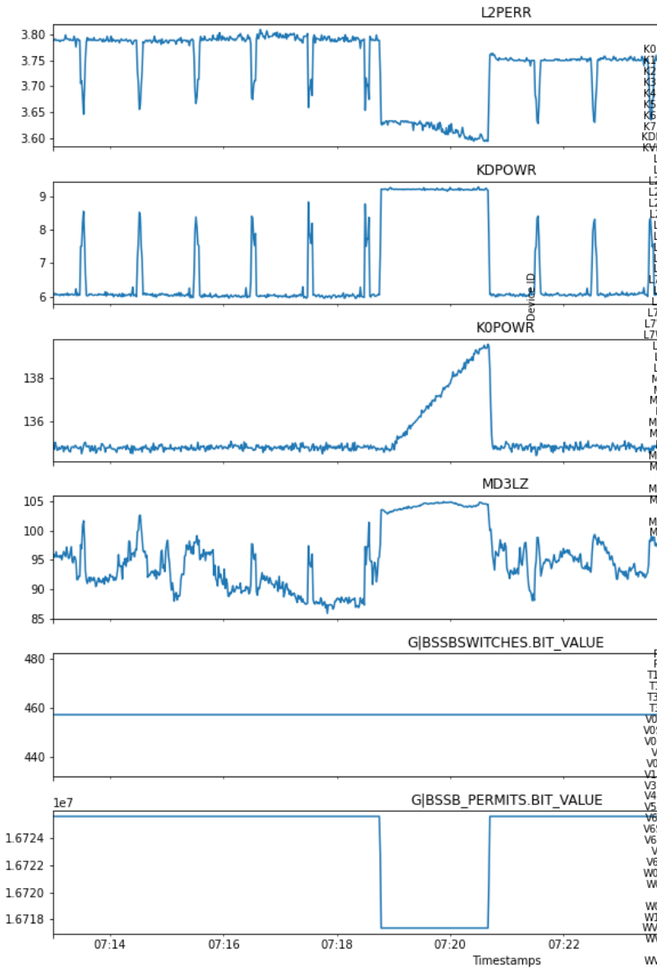
- **Can we reliably label different types of beam outages automatically?**
  - **With what accuracy?**
- **Can we reliably predict the occurrence and duration of beam outages?**
  - **How much in advance? With what accuracy?**

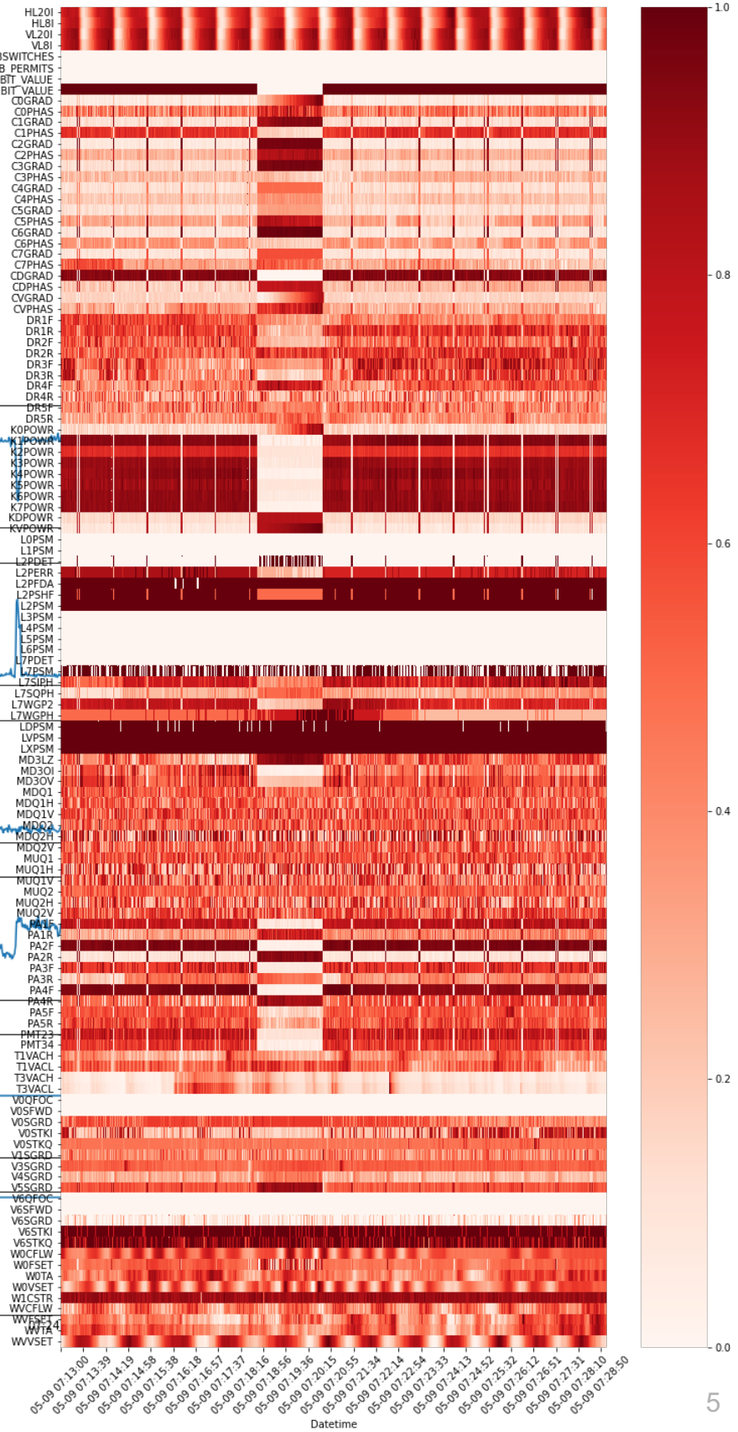
To answer these main questions, we are looking at related issues:

- How much of the data that is being stored is useful?
  - How many of the devices add no information?
  - How frequently do the devices need to be sampled?
- What kind of machine learning technique do we need to contend with short-term predictors of faults and long-term changes due to temperature/humidity ?
- How self-similar are the different systems? Can we re-use the same ML system and just feed it the same data from a different system?
  - Temperatures, voltages, currents, power, phase, …
- Are there trends / correlations between / within systems that we can exploit?

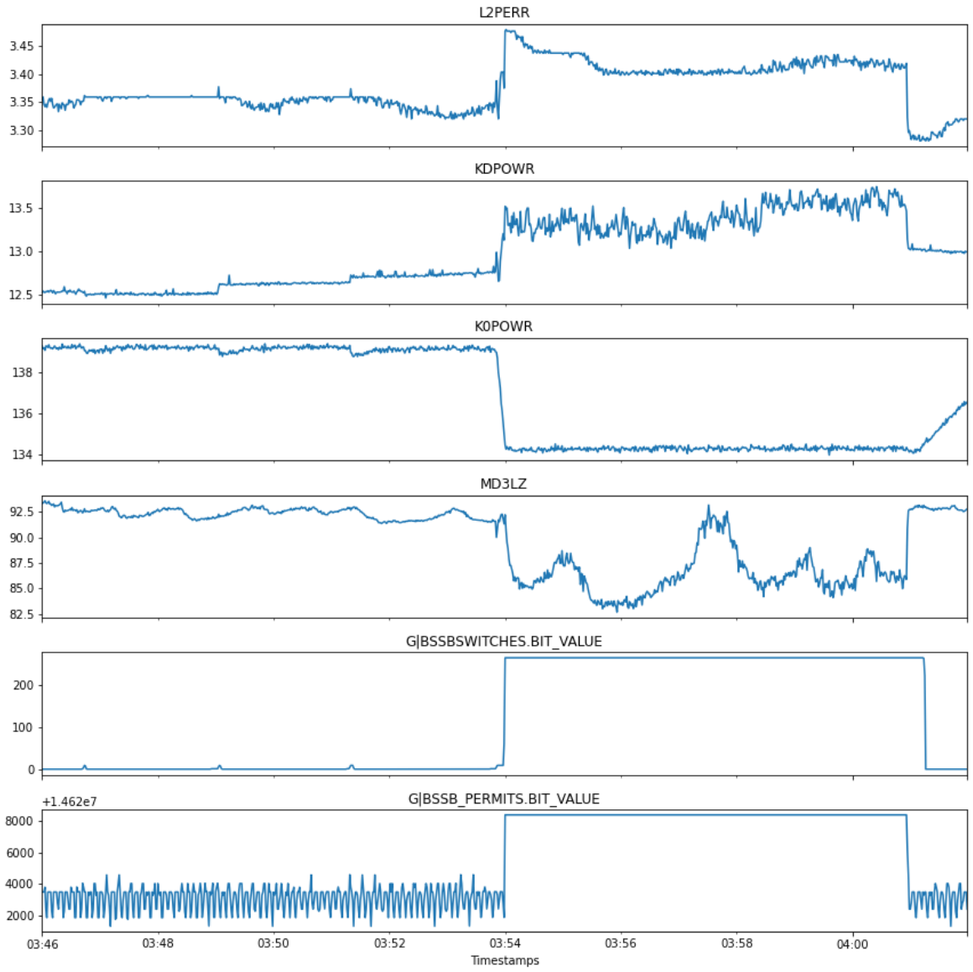
# Anomalous Patterns – KRF2 CS

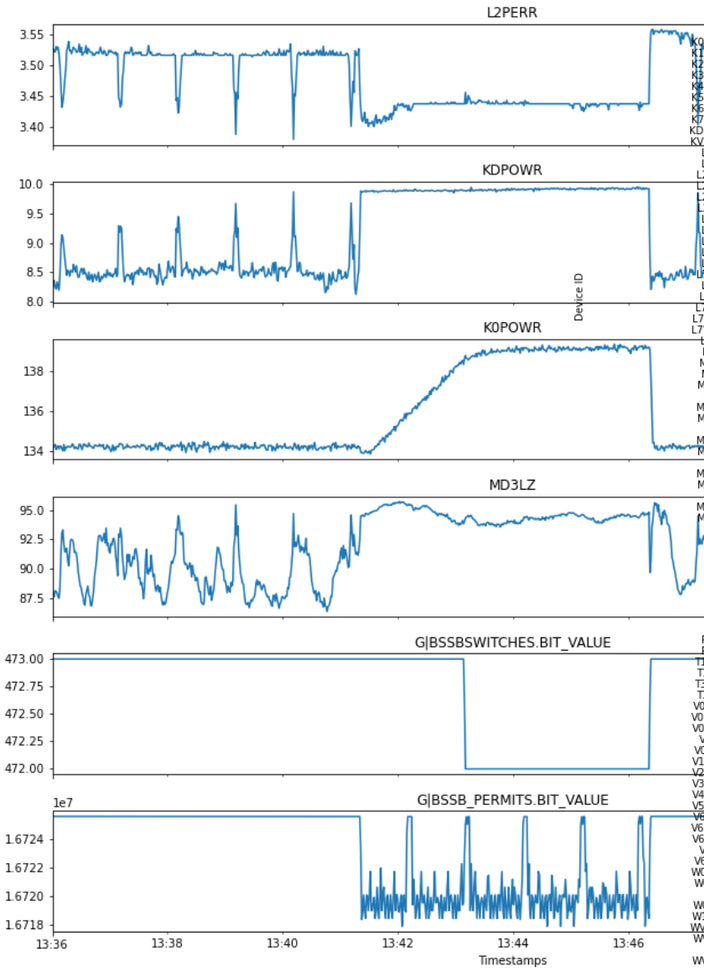


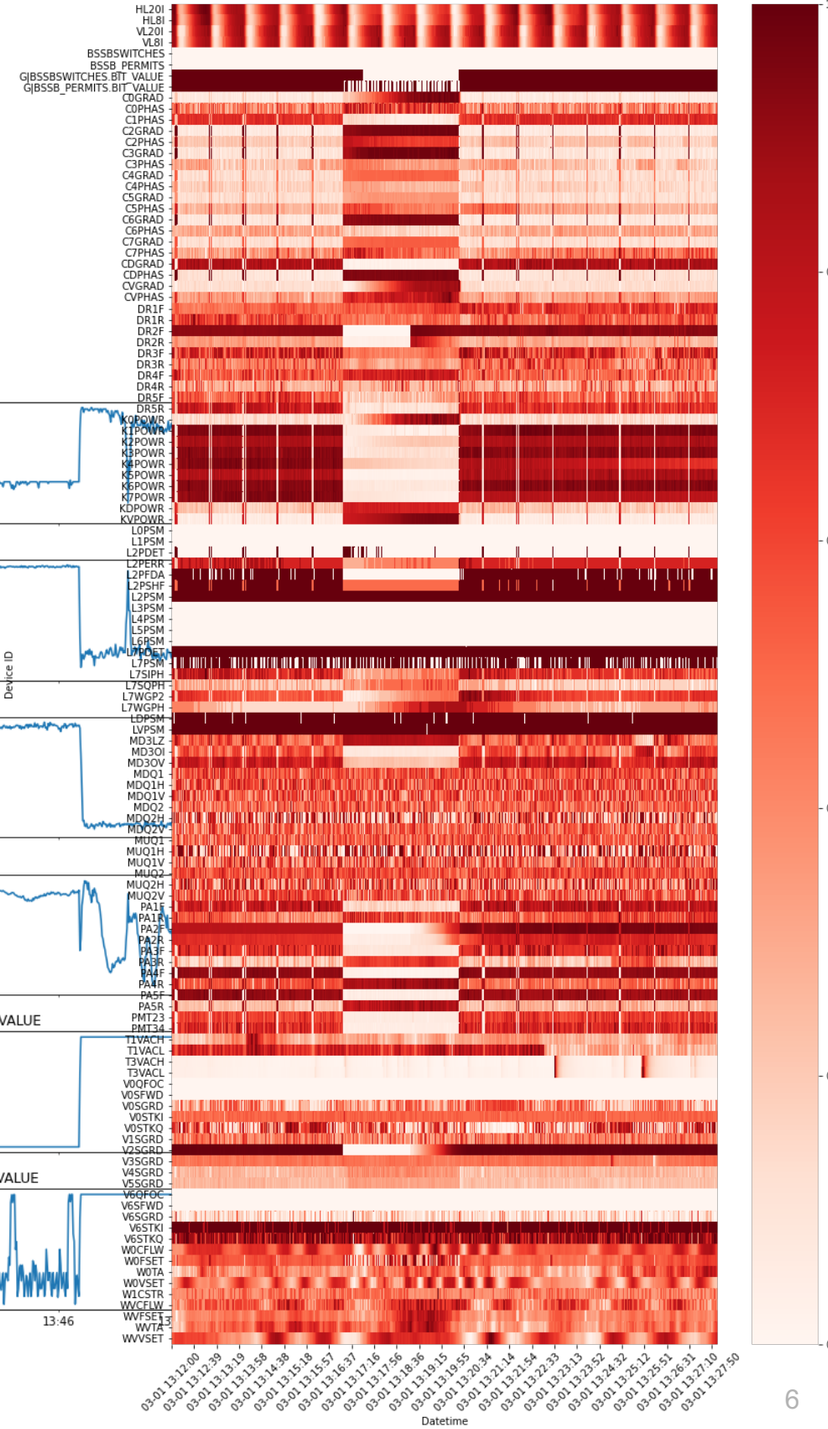



# Anomalous Patterns – LRF2 Overvoltage



# Real world data sets are messy

- 2945 different columns (devices), 2208 unique
  - Some devices are sampled at different frequencies
- Devices are sampled at different frequencies:
  - 98 devices sampled at 66 ms
  - 567 devices sampled at 1 s
  - 118 devices sampled at 10 s
  - 763 devices sampled at 15 s
  - 316 devices sampled at 30 s
  - 746 devices sampled at 120 s
- Time steps are not aligned
- There are gaps in the data (sometimes big gaps, > 10k time steps)
- Labels are subject to human error (typos, omissions, …)
- ~600 MB / h x 7600 h; 3.6 TB total

# Data analytics for the FNAL complex – overview

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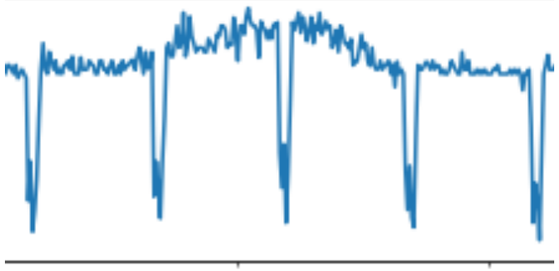
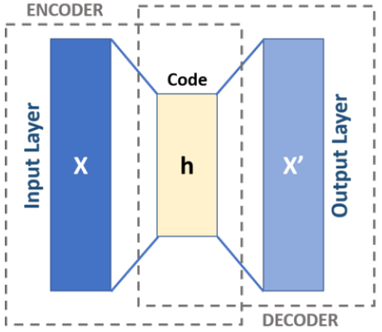
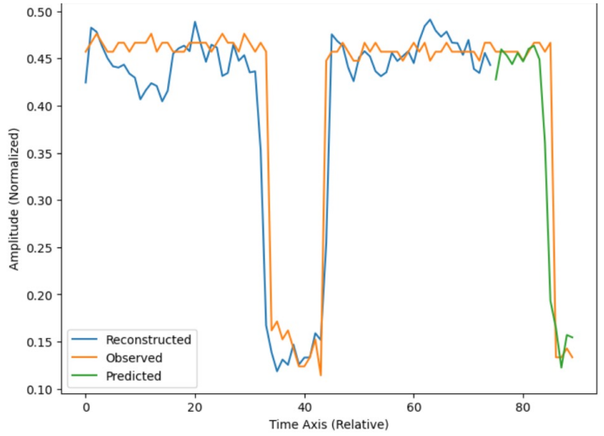
## Time-series data from devices

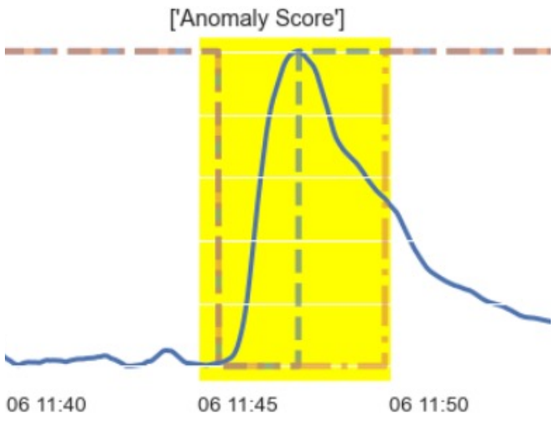


## LSTM autoencoder

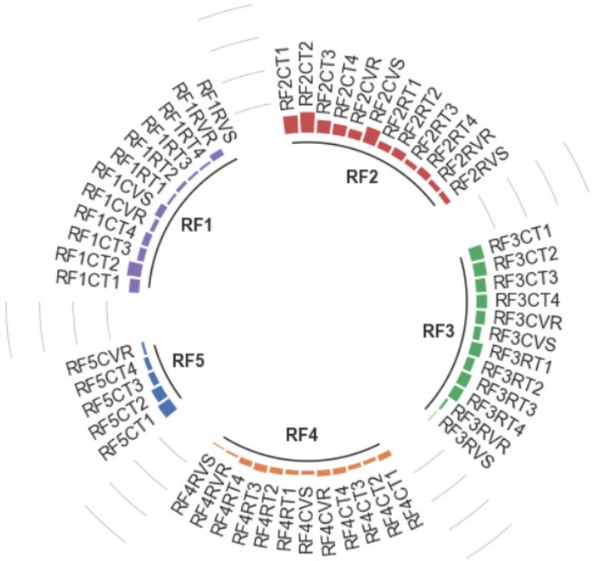



## Reconstruction error

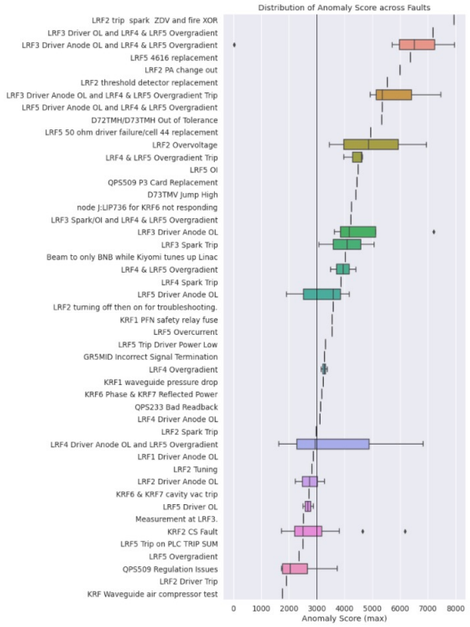



Combined anomaly score from all devices

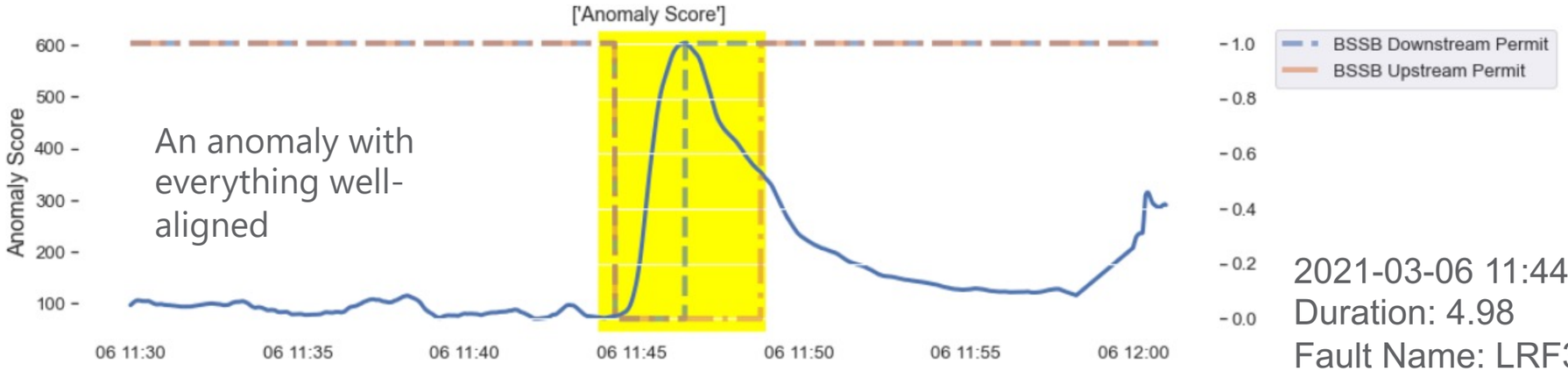



Breakdown of devices contributing to a given anomaly



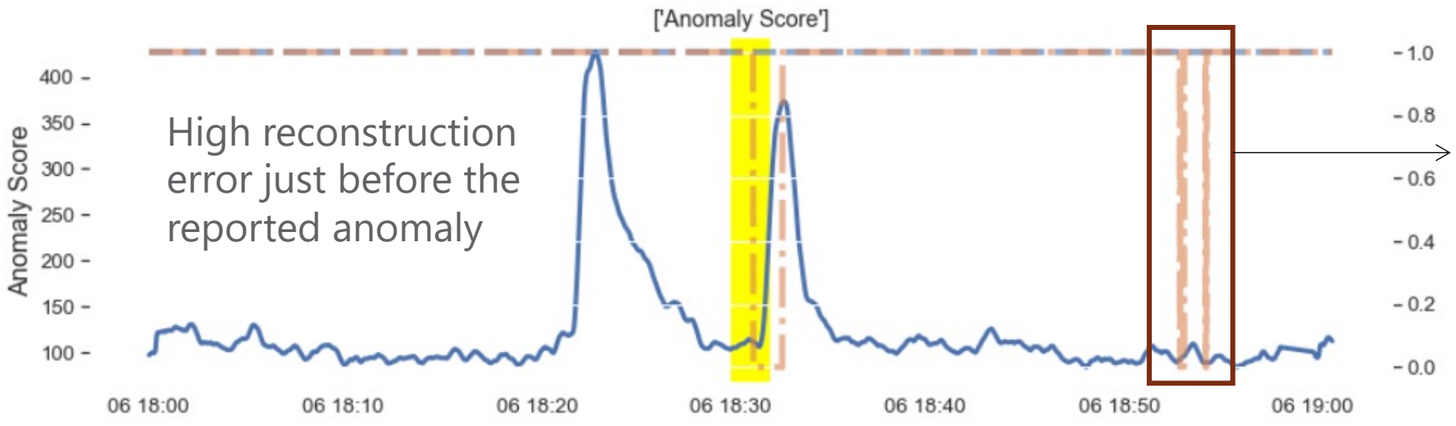

Thresholding to catch anomalies

# Detection using Anomaly Score




An anomaly with everything well-aligned

2021-03-06 11:44:00
Duration: 4.98
Fault Name: LRF3 spark trip



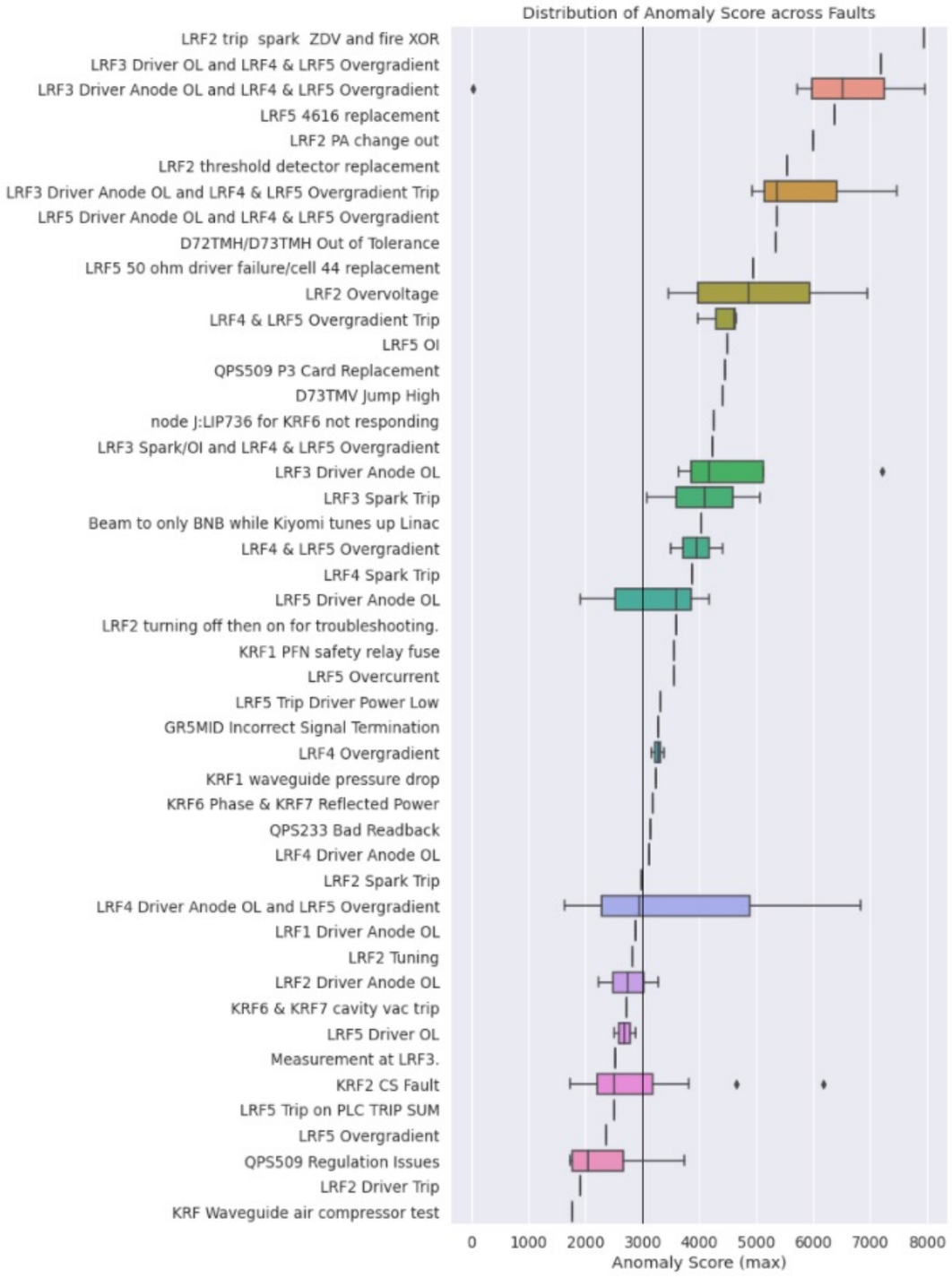

High reconstruction error just before the reported anomaly

Bits went down but reconstruction error was fine, and no fault was reported

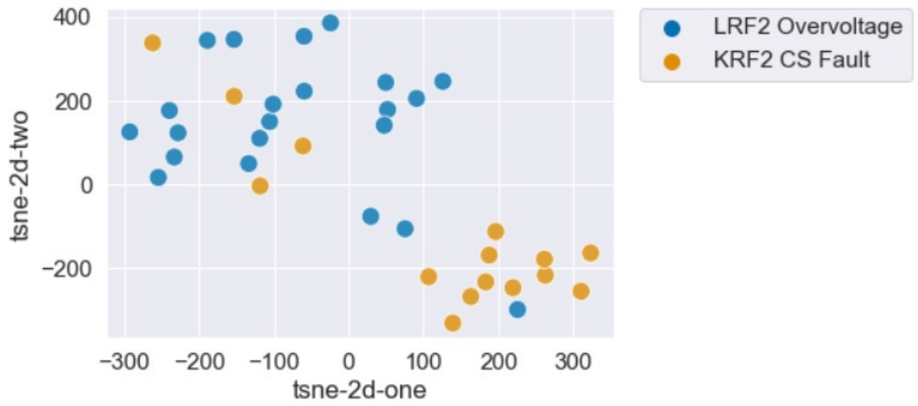
2021-03-06 18:30:00
Duration: 1.98
Fault Name: LRF3 spark trip

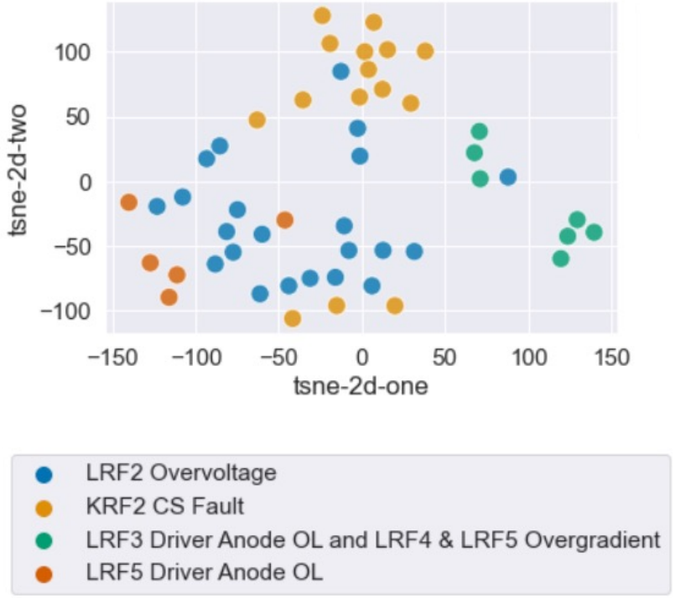
# Identification of Faults

- The plot shows the different labels that operators have assigned the outages
- The x-axis is the anomaly score that we attribute to each fault
  - Not all faults occur with the same frequency – we show the distribution of anomaly scores for each type of outage
- To identify faults automatically, we apply a threshold



# Unsupervised Fault Labeling

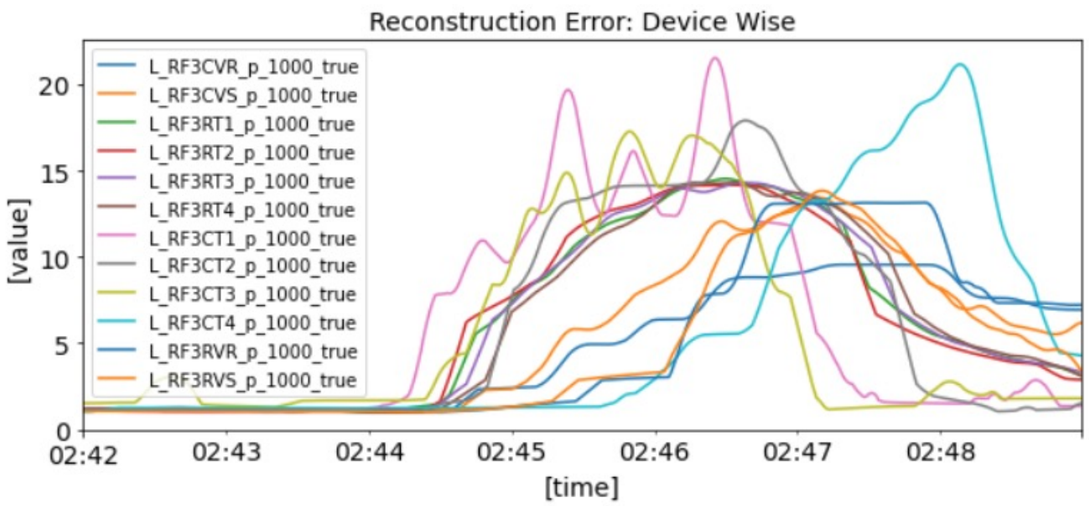




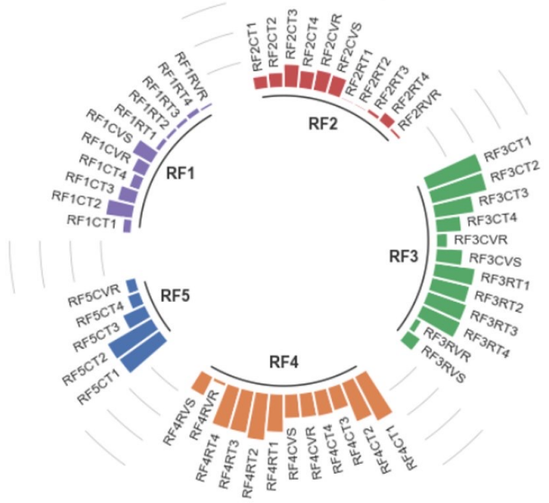

First look at our ability to distinguish between faults, using t-SNE

- Few, frequently occurring outages can be clustered by eye
- Adding more classes of outages with fewer occurrences complicates things
- Improvements will come from
  - Better clustering: Self-Organizing Maps; UMAP Clustering
  - Adding the time component of the outages

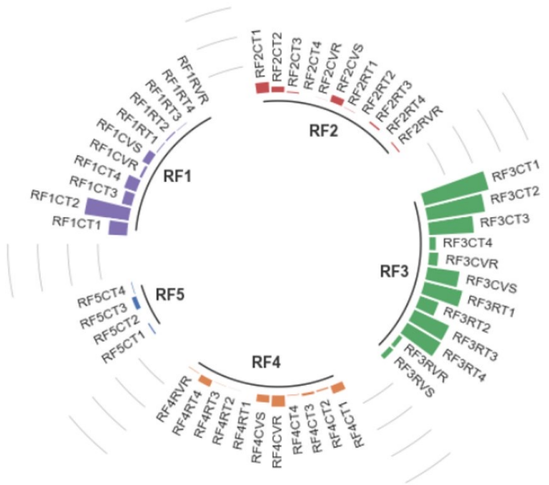
# Avenues for further classification improvement: Time dependence and fingerprinting




LRF3 Driver Anode OL and LRF4/5 Overgradient




LRF3 Driver Anode OL




Outages have a time component, where different devices respond with a different time constant

Different types of outages have different responses in different subsystems. We are working on exploiting this physical structure to improve labeling.

# Status and Next Steps

- Data cleaning and preparation routines are defined.
- The whole analysis chain prep → model → outage identification exists.
- We see some examples of the clustering working.
- There are still too many false positives. Improvements under study include
  - Better de-noising / modeling of devices
  - Pruning of devices in the anomaly score
  - Exploiting the time structure of outages.

- We will start to look at the forecasting. The current anomaly score is not powerful enough to predict outages and only starts deviating significantly after the start of the outage.

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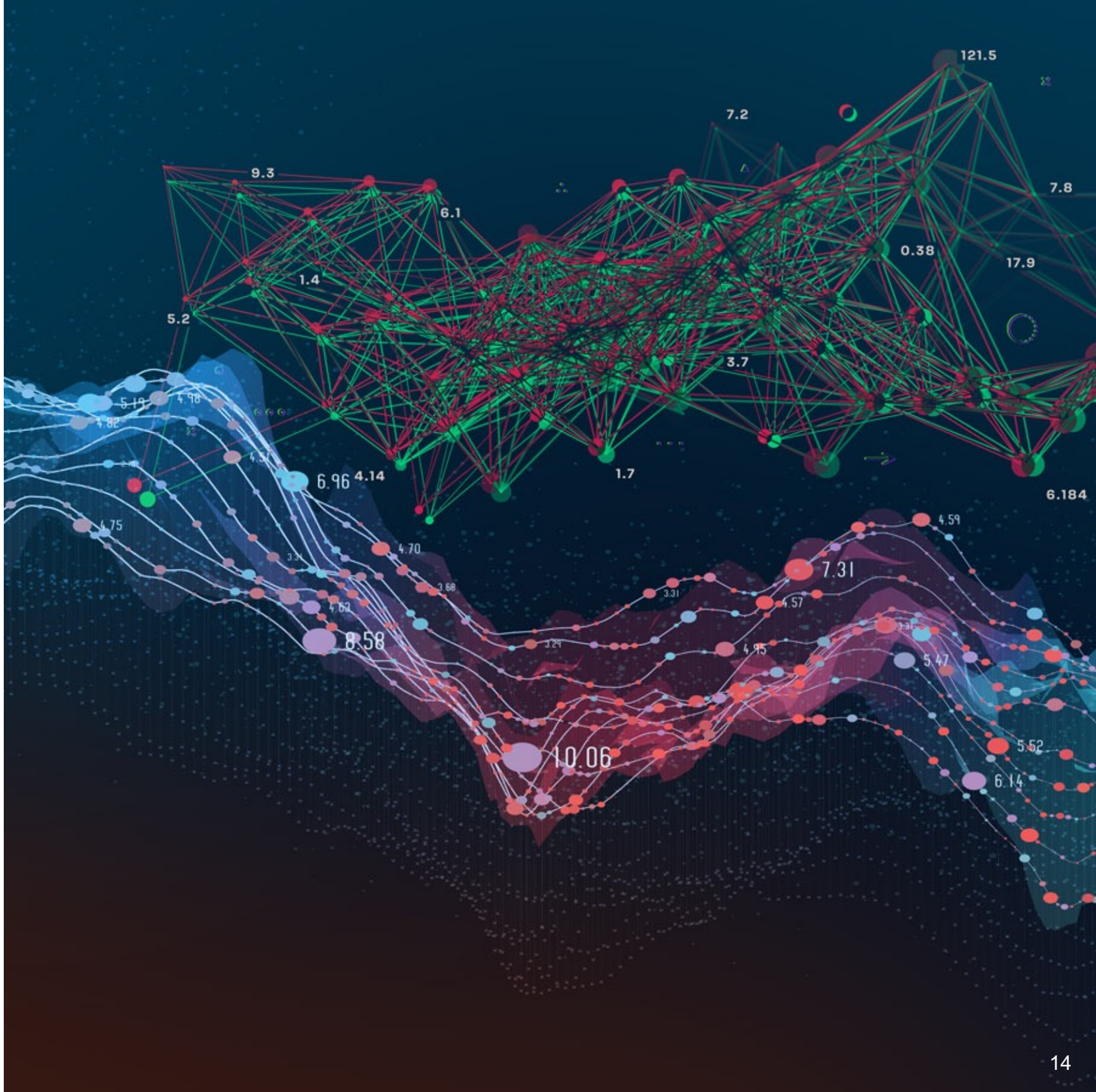
# Thank you