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Data analysis for the accelerator domain

I.FAST Task 10.6

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iFAST

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10.6 Task Summary

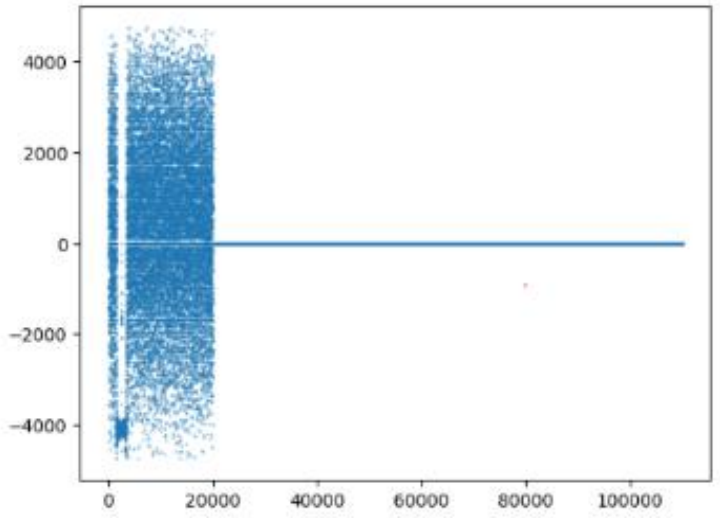
- Long term mission:
  - Develop low-latency Machine Learning (ML) techniques to improve performance and availability of high-power facilities at the intensity frontier
- Goal:
  - Identify signatures of potential errant beam conditions
- Scope:
  - Identify relevant data
  - Assess the predictive capabilities of selected ML models
  - Prototype: proof of principle demonstration
    - The most promising ML model to be implemented on a low-latency network of FPGAs processing signals from an array of detector channels

Data and prototyping setup

- Data acquired during commissioning of the ESS normal-conducting linac:
  - ESS Beam commissioning through DTL 4 (74 MeV)
  - Scalar data and waveform data from:
    - Beam Current Monitor (BCM)
    - Beam Position Monitor (BPM)
- Software: Python, Jupyter Notebooks, VS code
- Hardware: Local machine
- Challenges:
  - Limited Archiver capabilities
  - Data downloading speed
  - Data downloading format
  - Data query size
  - Local storage and retrieval

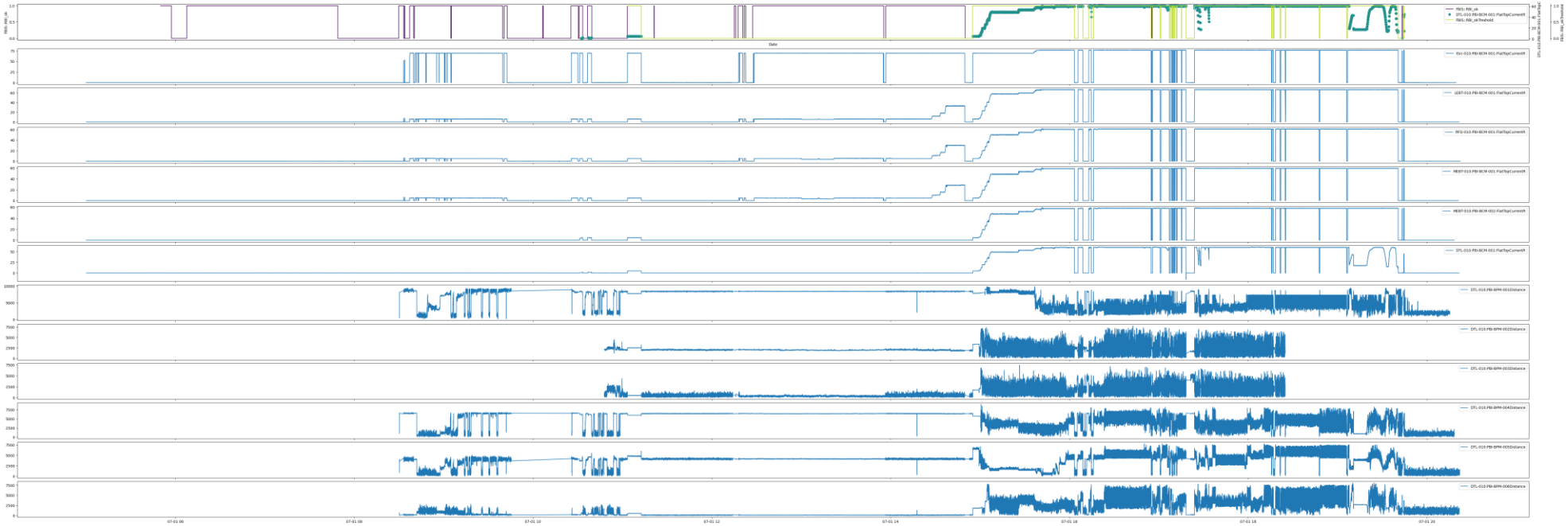
Processing Waveforms

- Usable count: ~12 000 machine cycles with beam pulse present
- Full Waveform size: 110 000 points
- Cut to leave only the representative part
  - ~3000 points



Filtering cycles with beam present

- Before the interlock
- Representative beam current
- Beam current value threshold

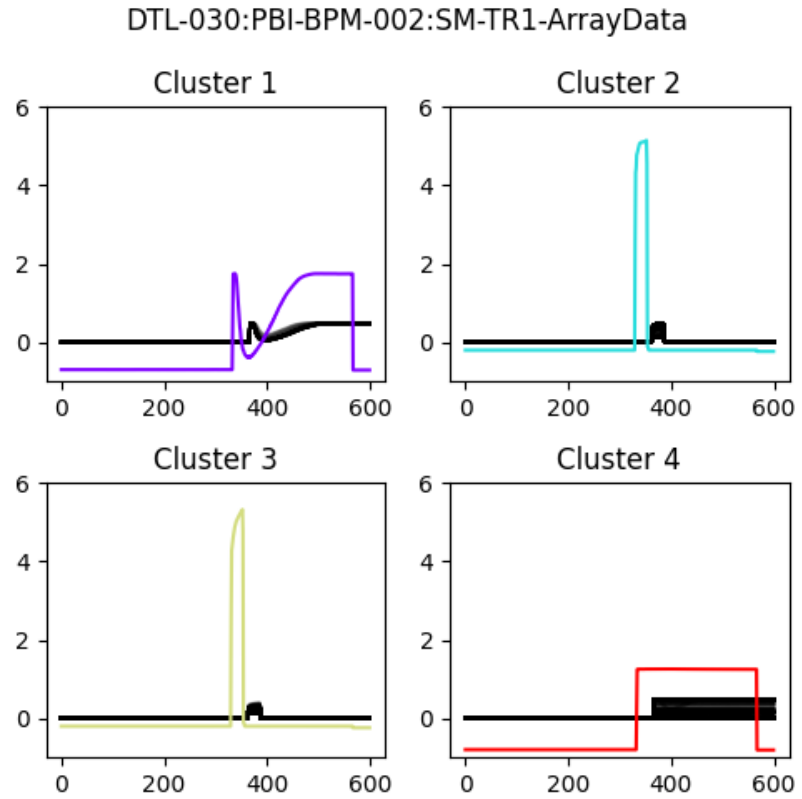


Clustering

- Grouping unlabeled examples
  - Relies on unsupervised machine learning
- Example feature data combined into similarity measure.
  - Similar examples grouped
- Approaches
  - Centroid-based clustering
  - Density-based clustering
  - Distribution-based Clustering
  - Hierarchical Clustering
  - Others…

Kshape Clustering

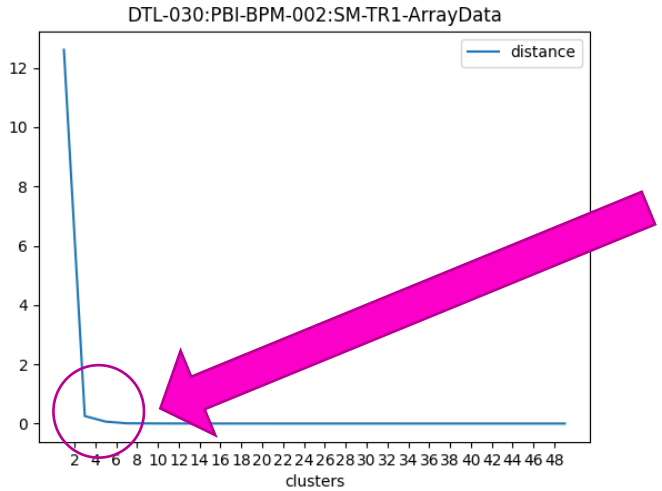
- Selection:
  - Waveforms are time series
  - Waveforms can be shifted in time
- K-Shape clustering
  - Clusters Waveforms according to shape
  - Using Dynamic Time Warping
    - Similarity measure includes time shift
  - Requires: cluster count
  - Outputs:
    - Cluster index for each example
    - Cluster center shape



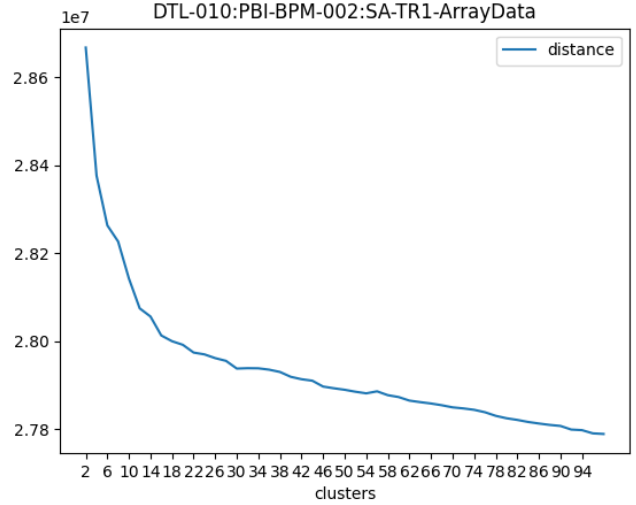
Estimating cluster count -Elbow method

- Graphically find the optimal cluster count- k value.
- Each cluster count calculates the Sum of the square distance between points in a cluster and the cluster centroid.
- Pick the value from the “Elbow point.”

BPM Phase data:
There is no clear Elbow point

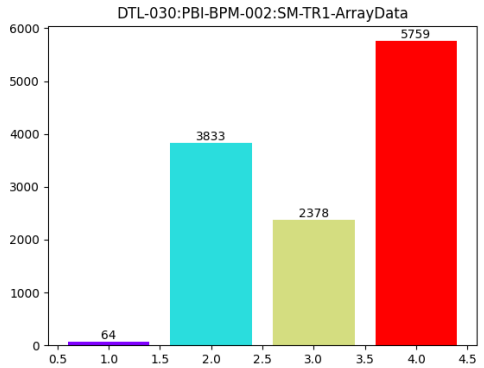


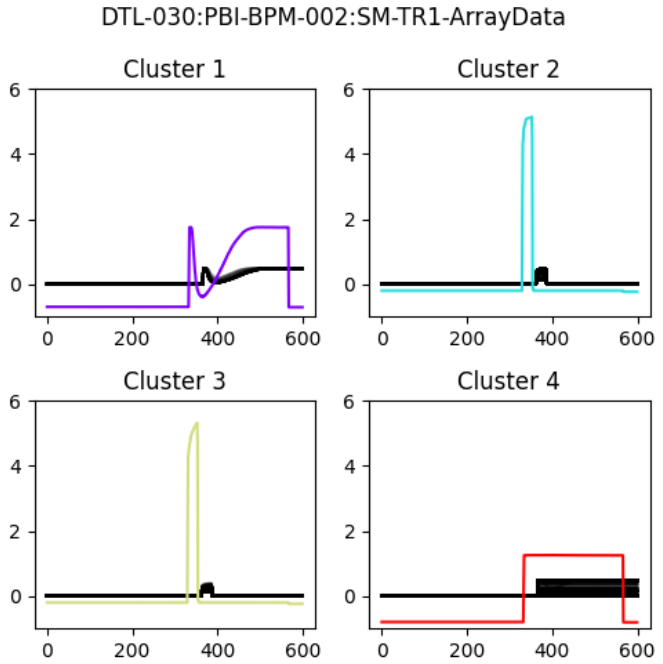
BPM Magnitude data;
Clear Elbow point

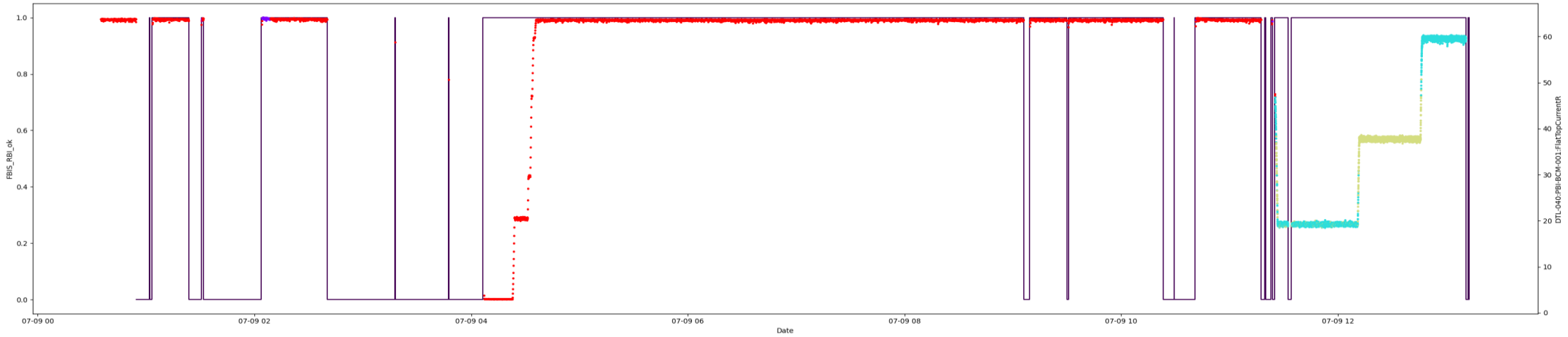


Searching for events before interlocks

- Clustering each individual waveform
- Determine cluster centre waveform
- Combine:
  - Clustering result
  - Current value
  - Interlocks

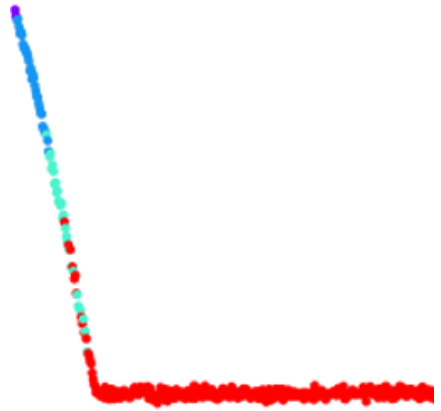




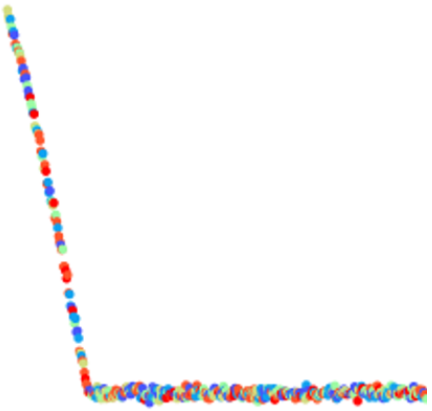


Initial results

- BPM Magnitude data sets:
  - Clusters waveforms
  - Some correlations with the current value
  - No apparent waveform change before the interlock



- BPM Phase data sets
  - No distinct waveforms with the k-shape method



Correlations between systems and/or data variables

Current work – Random forest method

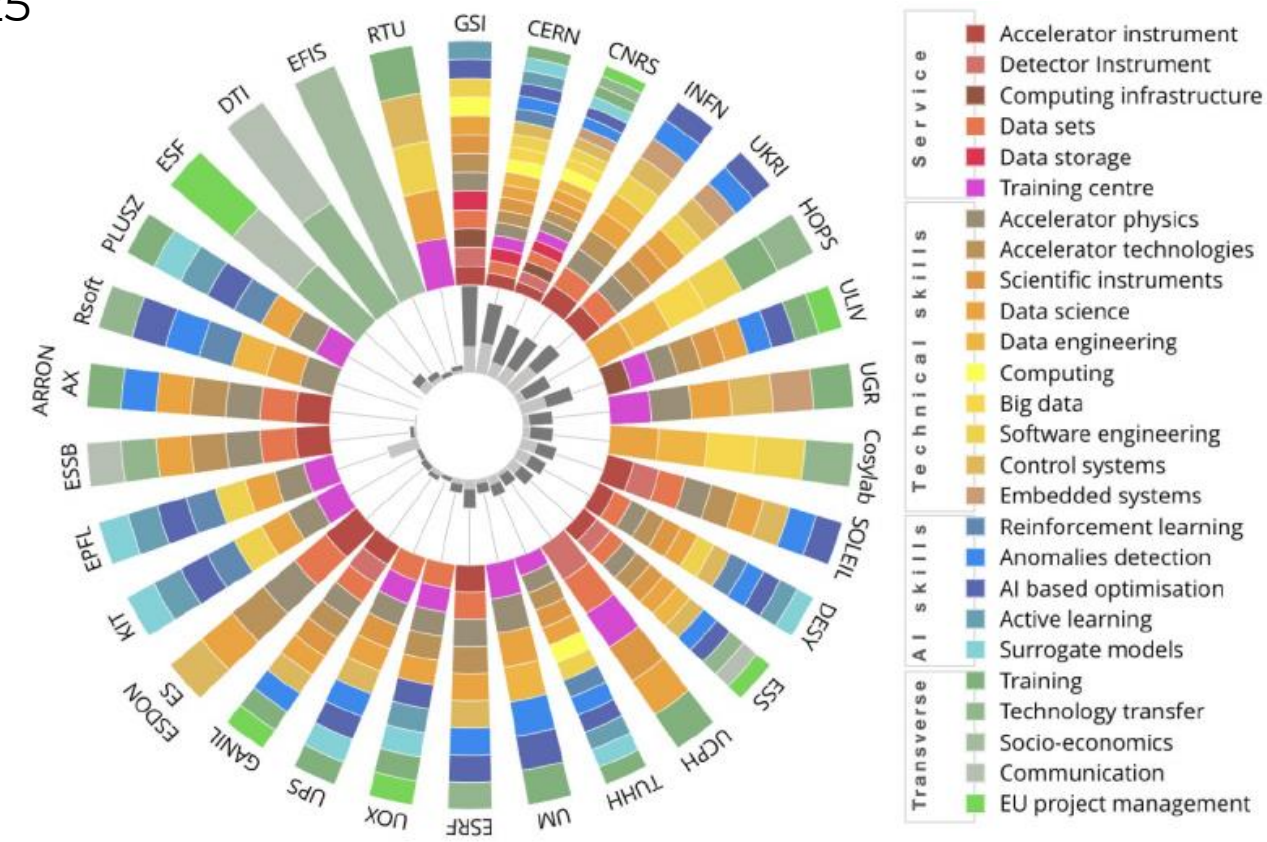
- Select a random machine cycle set with waveforms from different systems
- Use a random subset of waveforms to build decision trees

- Random Forest is created
  - Pass the data through the random forest to get predictions on the next waveform value.
  - Aggregate individual predictions to get the new value
- If there is a difference between prediction and actual value, there might be an **Event**

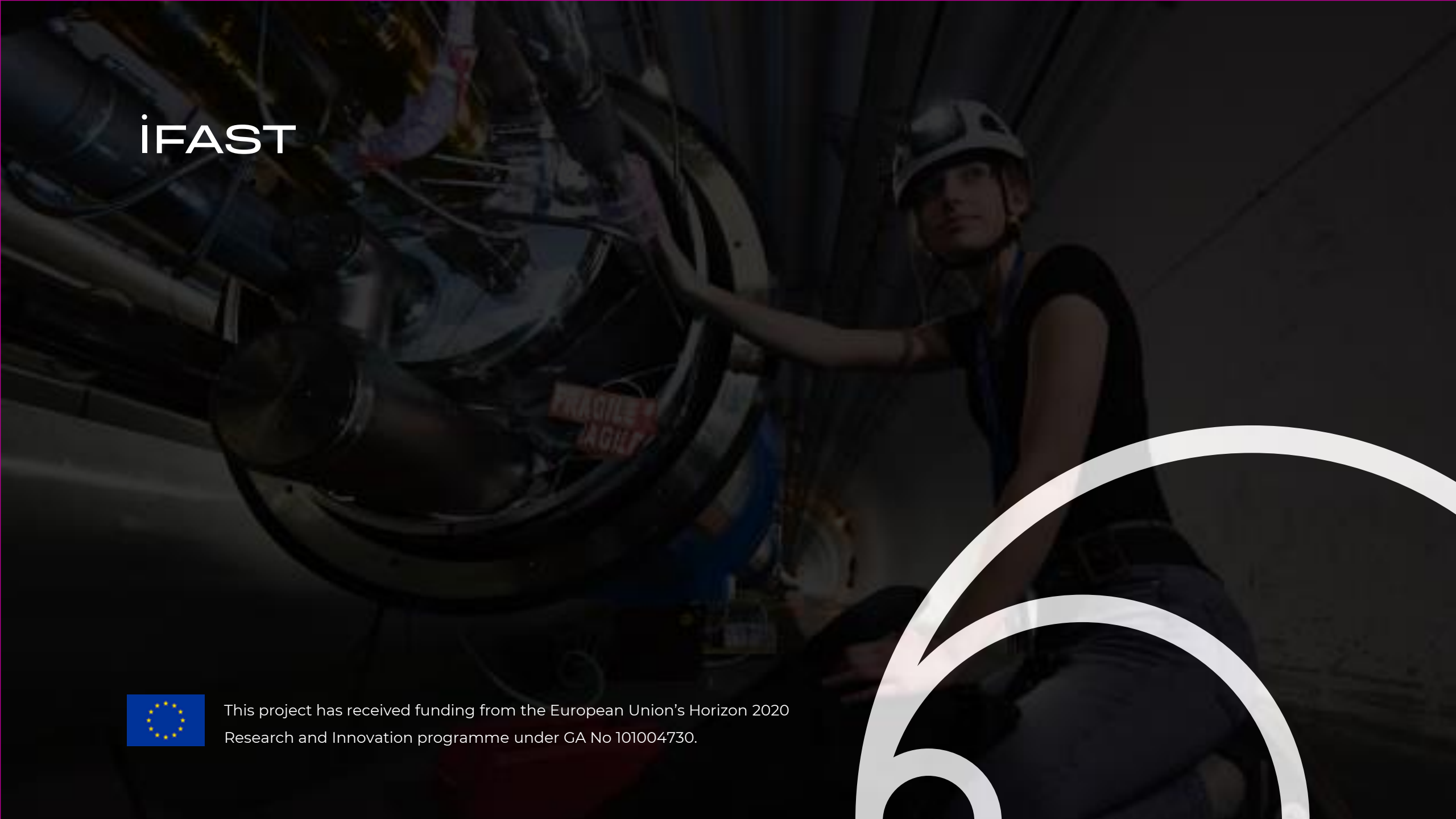
ARTIFACT

ARTificial Intelligence For Accelerators, user Communities and associated Technologies

- Horizon Europe proposal submitted in March
  - 4 year program startup planned 2025
  - 10MEUR
- Over 30 EU labs and organisations, GANIL, CERN, ESS, DESY, RTU, …
- 7 work packages
  - WP6: AI Algorithms and Methods
  - Task on anomalies detection identified (Task 6.3)
  - Significant experience in data formatting, handling & standardization
- Independent of funding success, a consortium in being established and collaboration is commencing



Yngve Levinsen



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