SOLARIS CENTRE

Beam qualification using Machine Learning Techniques applied to Libera Brilliance+

Libera Workshop 2025

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SOLARIS National Synchrotron Radiation Centre

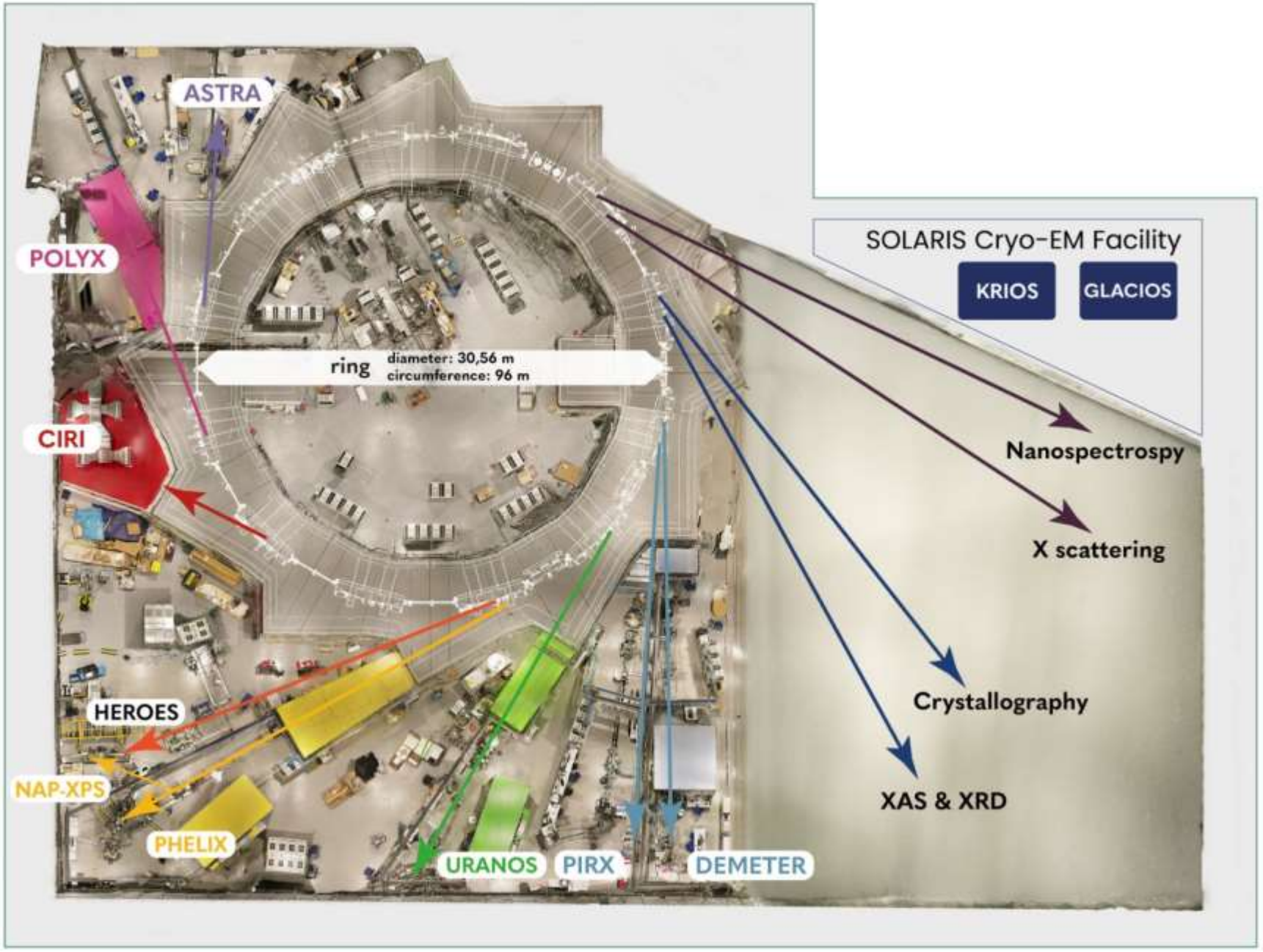
Agenda

- Introduction - SOLARIS facility
- Data streaming system
- Basic beam diagnostics using ML
- Plans for the future, sector wise diagnostic

SOLARIS facility

Synchrotron SOLARIS

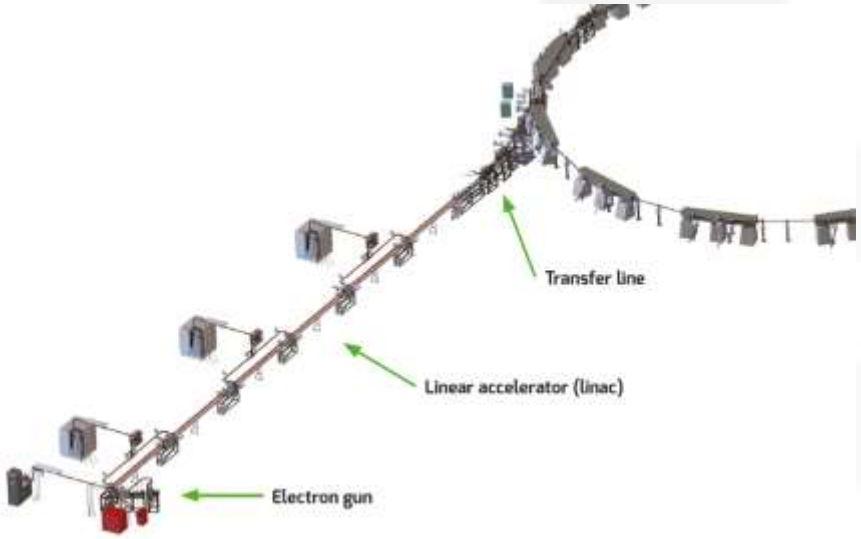
- 3rd generation light source
- 7 fully operational beamlines
- Two more beamlines are under construction
- The only synchrotron in Central Eastern Europe located in Poland



SOLARIS facility

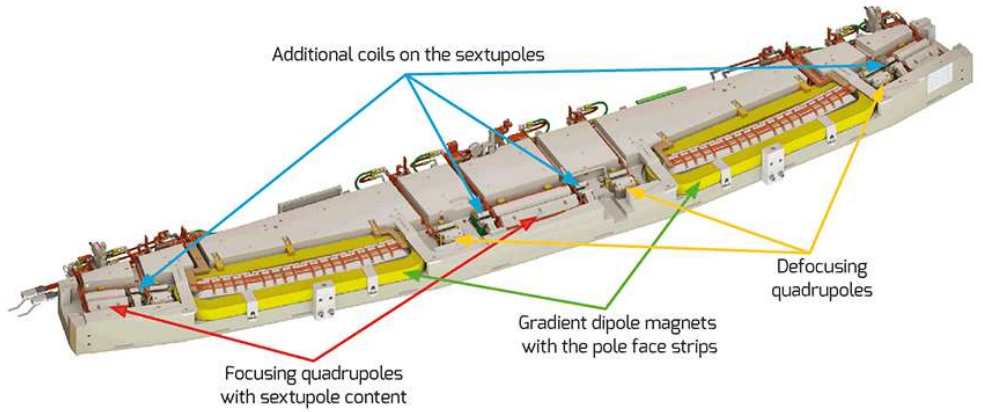
Linear accelerator

- 3 modulators,
- 6 accelerating structures,
- Delivered injection Energy - **536MeV**,
- Max beam current on output – **26 mA.**



Storage ring

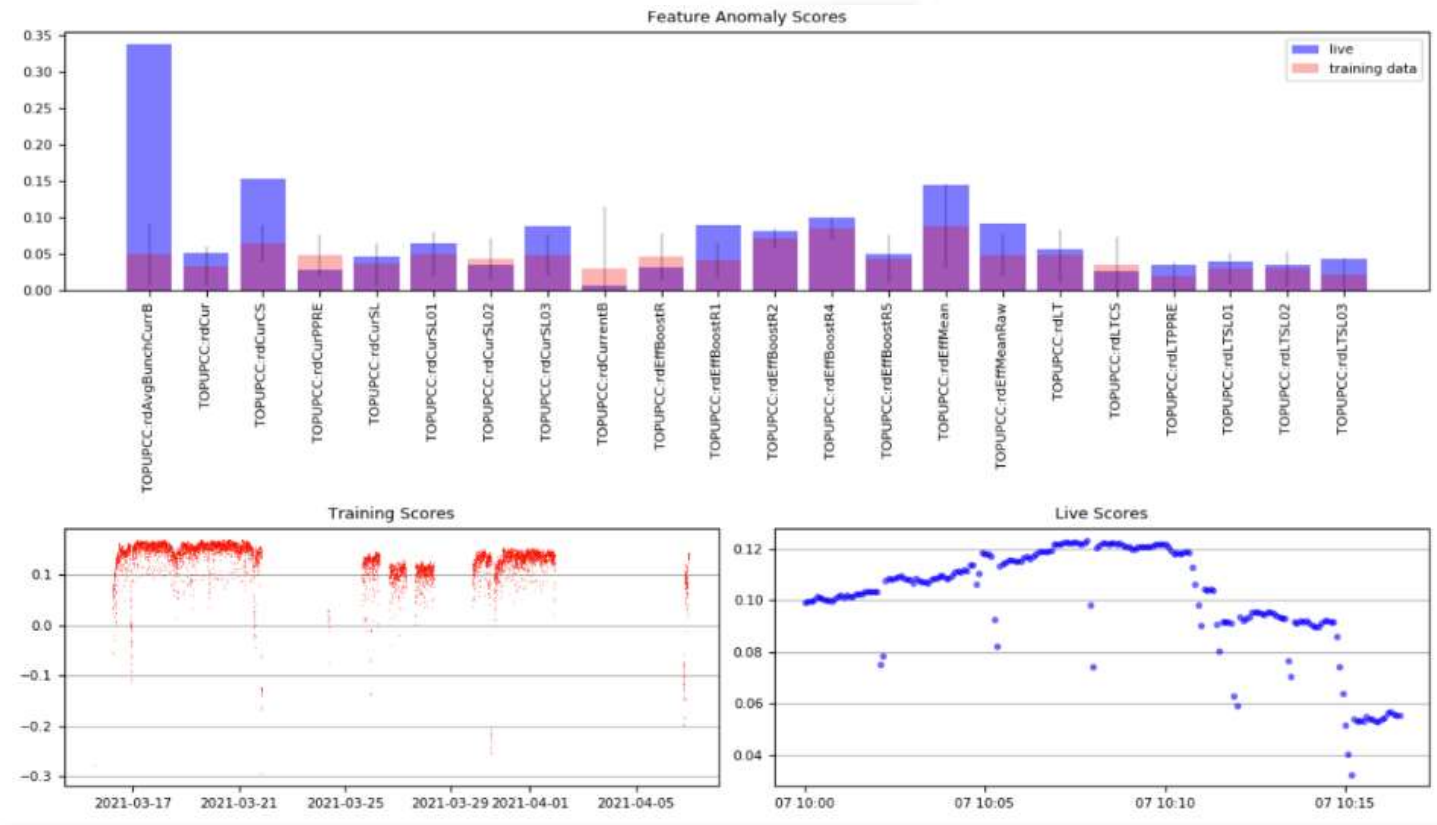
- Consists of **12 DBA cells**,
- Main RF frequency – **99,937 MHz**,
- Energy - **1,5 GeV**,
- Max beam current – **500 mA**,
- Circumference – **96 m.**

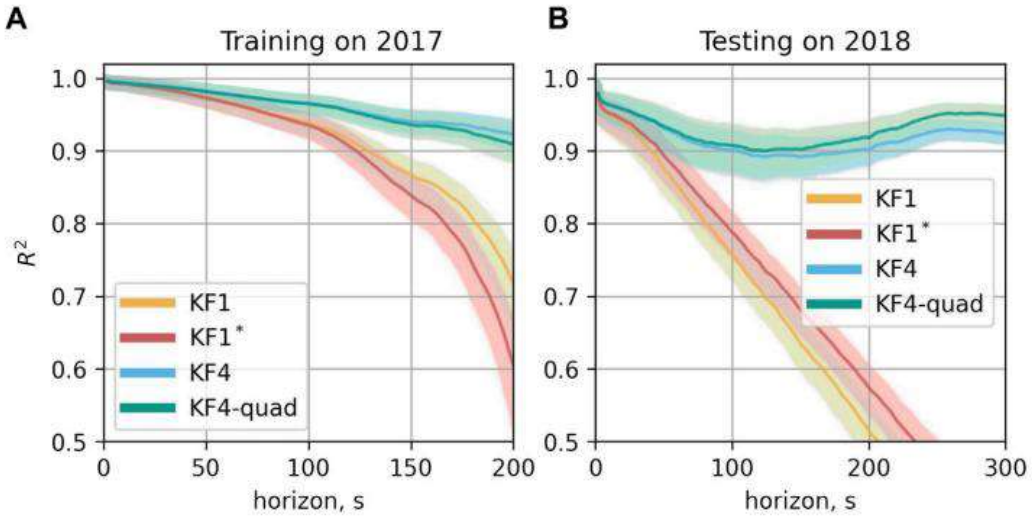


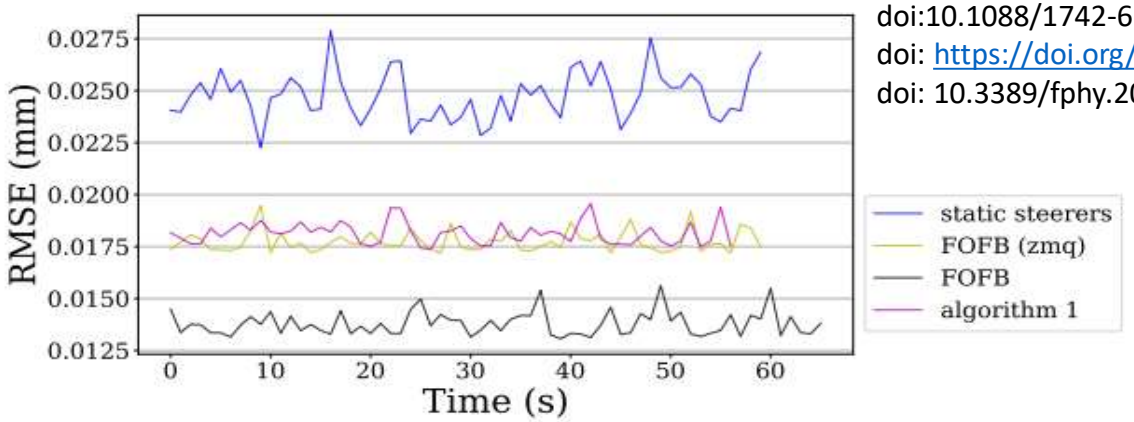
Machine learning in Synchrotron

What is done today

1. Optimization of injection efficiency
2. Beam loss forecasting and prevention
3. Beam stability enchantment
4. Anomaly detection
5. Accelerator lattice optimization







doi:10.1088/1742-6596/2687/6/062033
doi: https://doi.org/10.32479/ijeep.7605
doi: 10.3389/fphy.2022.960963

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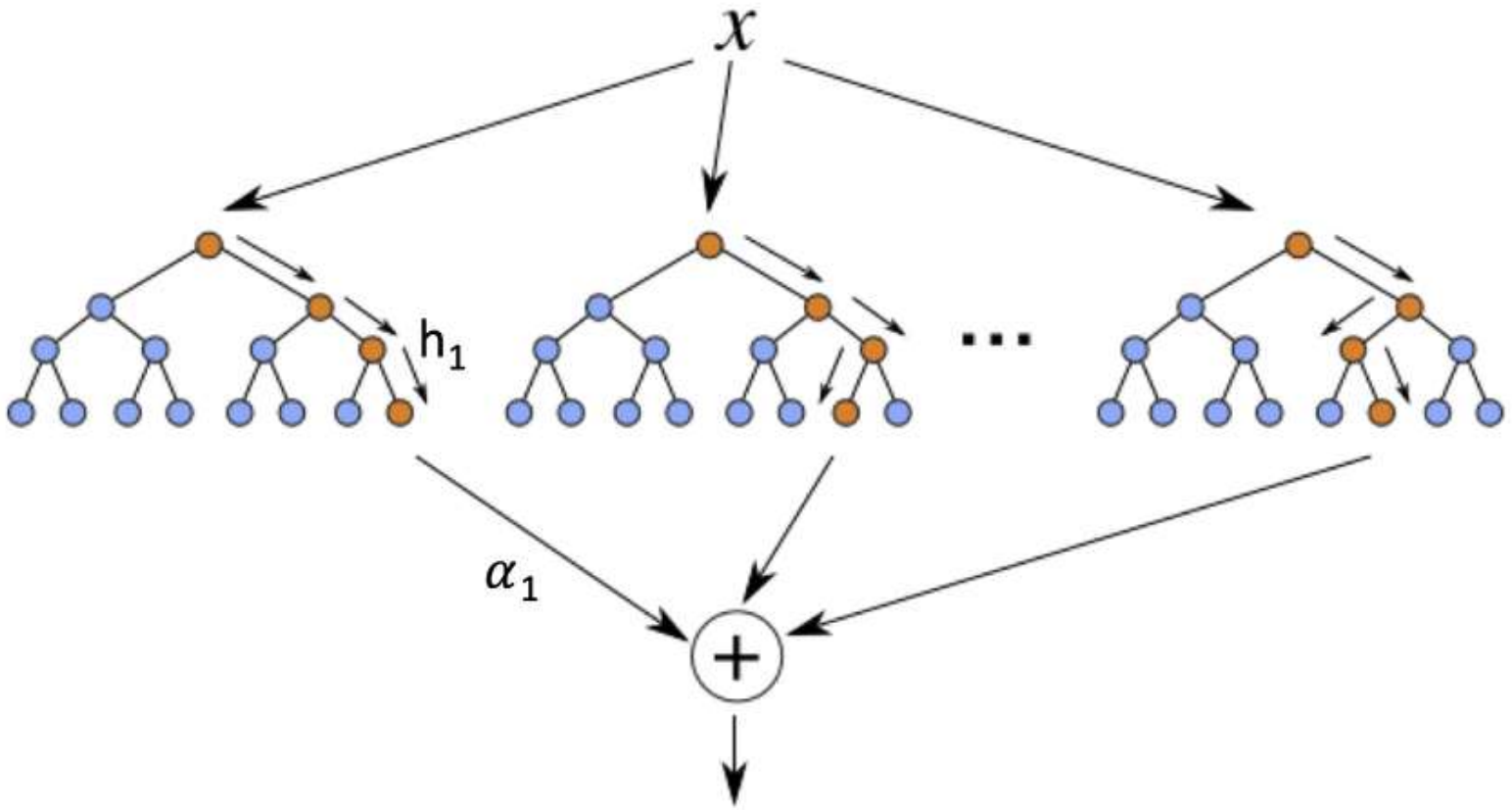
Beam anomaly detection – **Boosted Decision Tree**

XGBoost tree configuration

- Estimators numer: **600**
- Learning rate: **0.01**
- Max depth: **10**
- Objective: **binary:logistic**

Scenarios data collection

- RF active cavity power drop
- Magnet current fluctuation



Machine learning in Synchrotron

We currently operate:

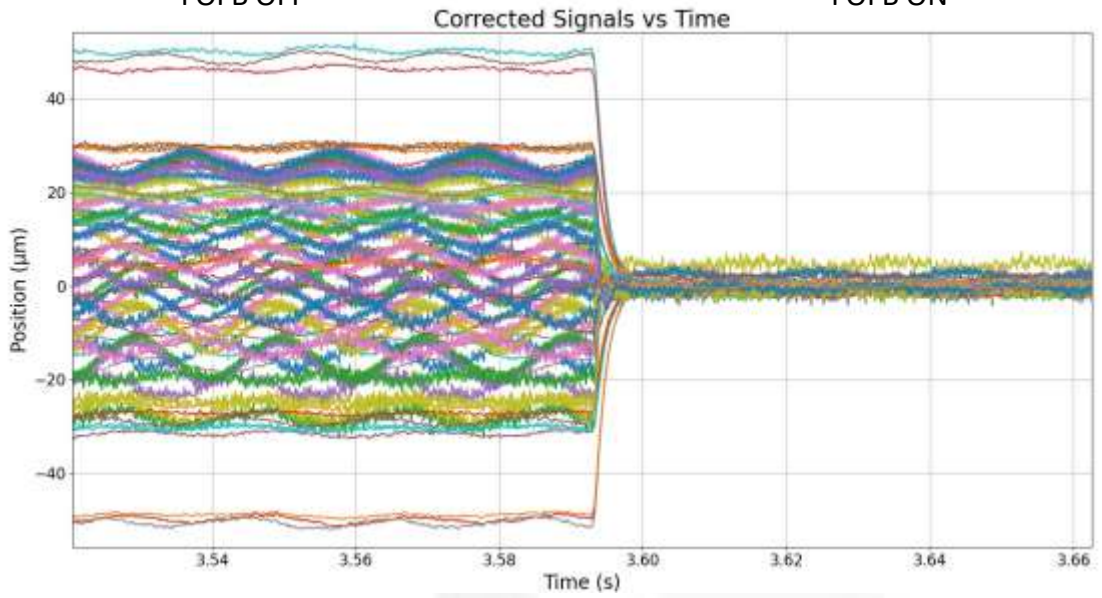
- 36 Libera Brilliance + (connected in 12 chassis) connected to 36 BPMs (one BPM in X,Y plane)
- We use GDX module for fast orbit feedback

- 4 Libera Photon for beam light measurement

We classify data coming form all 36 BPMs, collected at 10 kHz, and converted to FTT spectrum

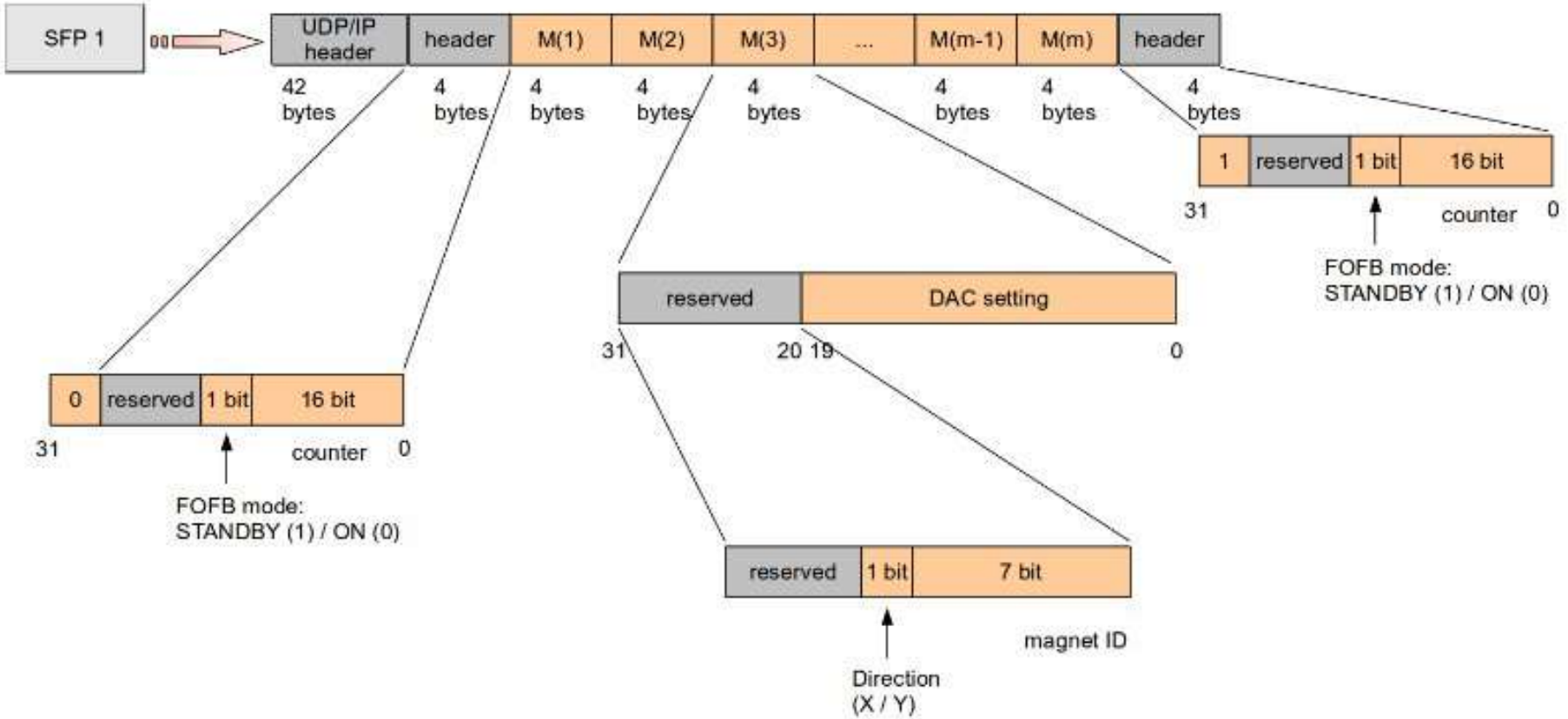
FOFB OFF

FOFB ON



Streaming System

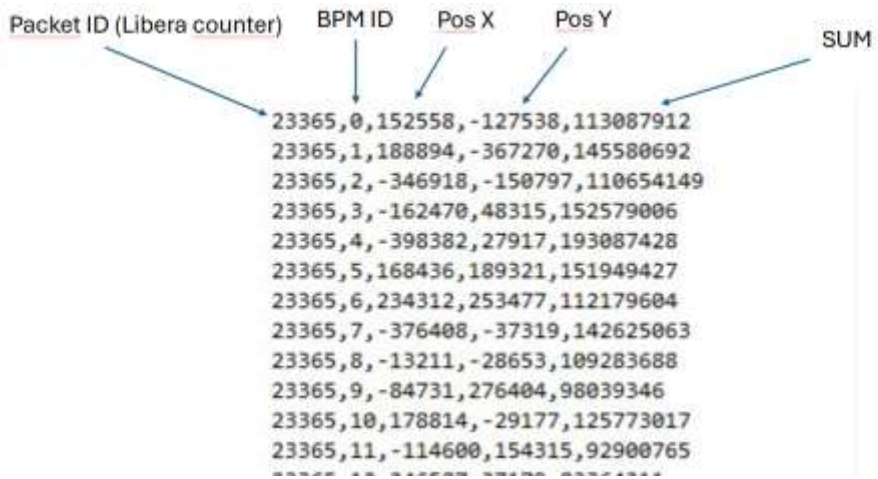
```
/* Magnet mode header */
struct libera_magnet_header_s {
    unsigned int counter : 16;
    unsigned int fofb_mode : 1;
    unsigned int reserved : 14;
    unsigned int end_of_packet : 1;
};

/* Magnet mode payload structure */
struct libera_magnet_s {
    unsigned int dac_setting : 20;
    unsigned int magnet_id : 7;
    unsigned int dir_x_y : 1;
    unsigned int reserved : 4;
};
```



*dac_setting is casted and sign extended to signed int 32-bit

First header, the payload structures with magnet position

Streaming System

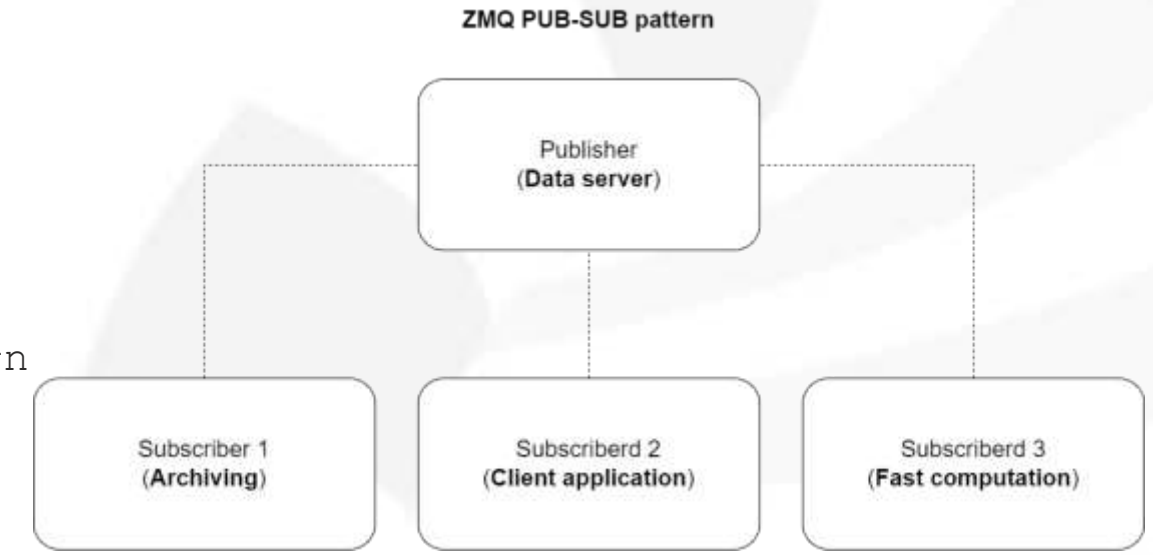


- This program opens UDP socket on the working machine then captures all the data sent by Libera and stores in e.g. CSV format
- Parse bitfields, format the data to nice, ASCII form
- Store received data in CSV file
- Possibility to capture the BPM & magnets setpoints data

Streaming System

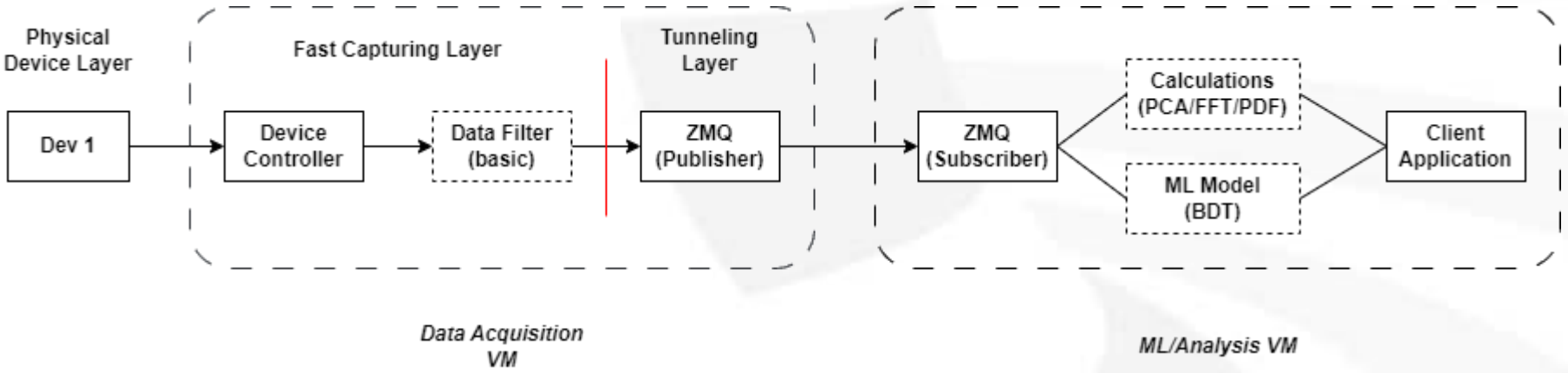
Technology:

- Written in Python 3.9
- ZMQ framework
- Build based on **Publisher-Subscriber** pattern



Abilieties:

- Operating on 10 kHz signal
- 3 MB/s online transmission
- Scallable



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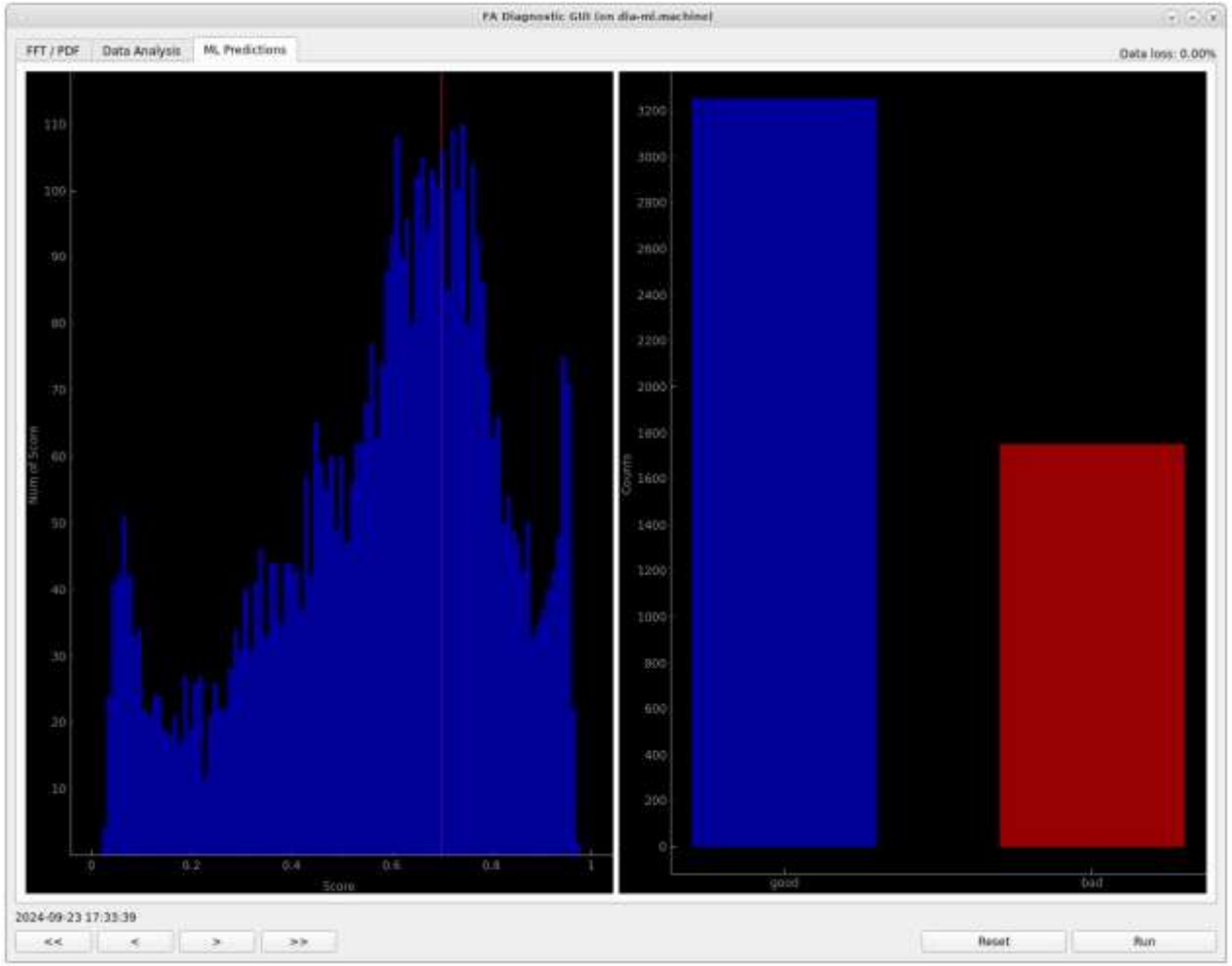
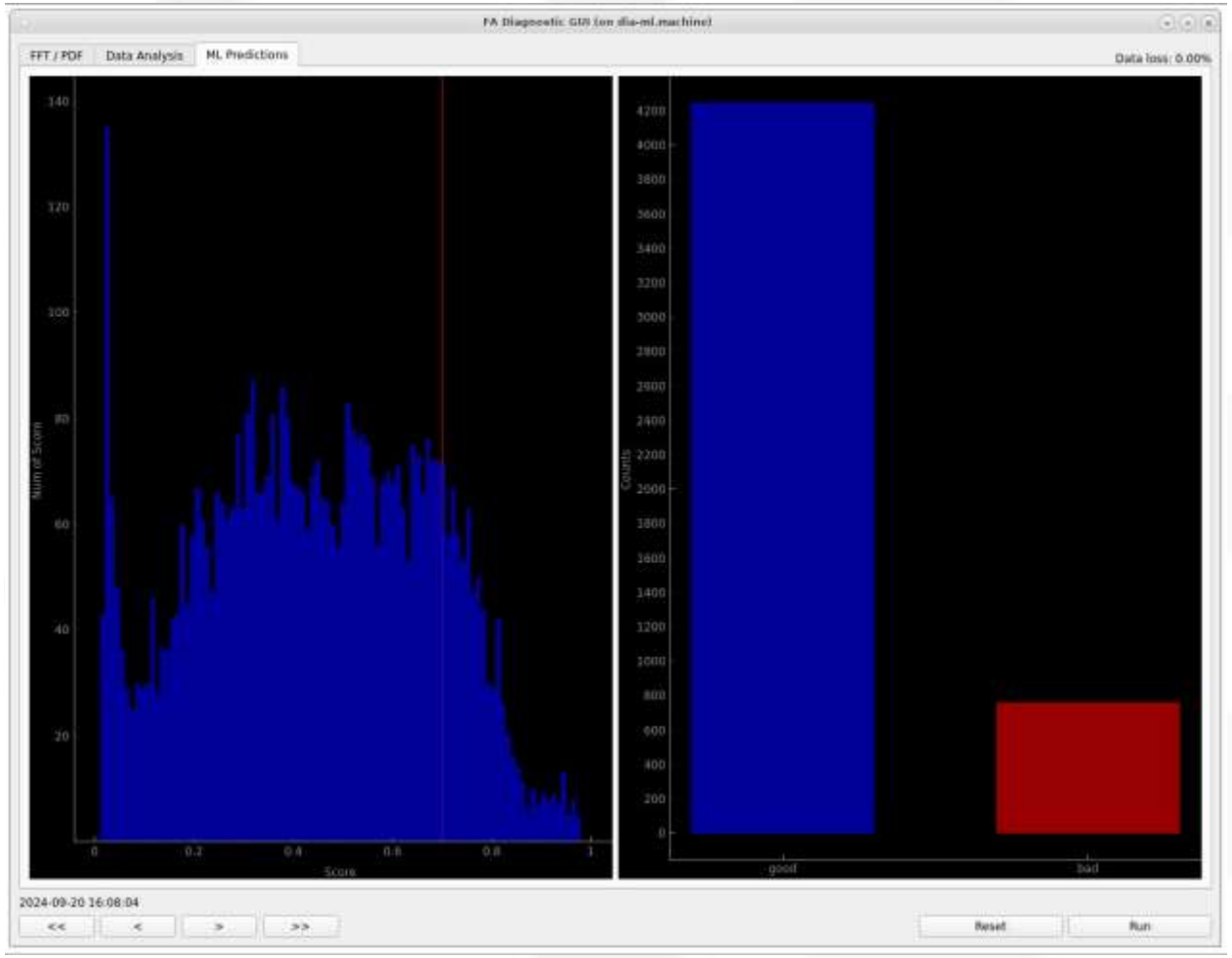
Beam anomaly detection – **Online application**

Kicker, 3000 V, 120 mA



Typical opperation



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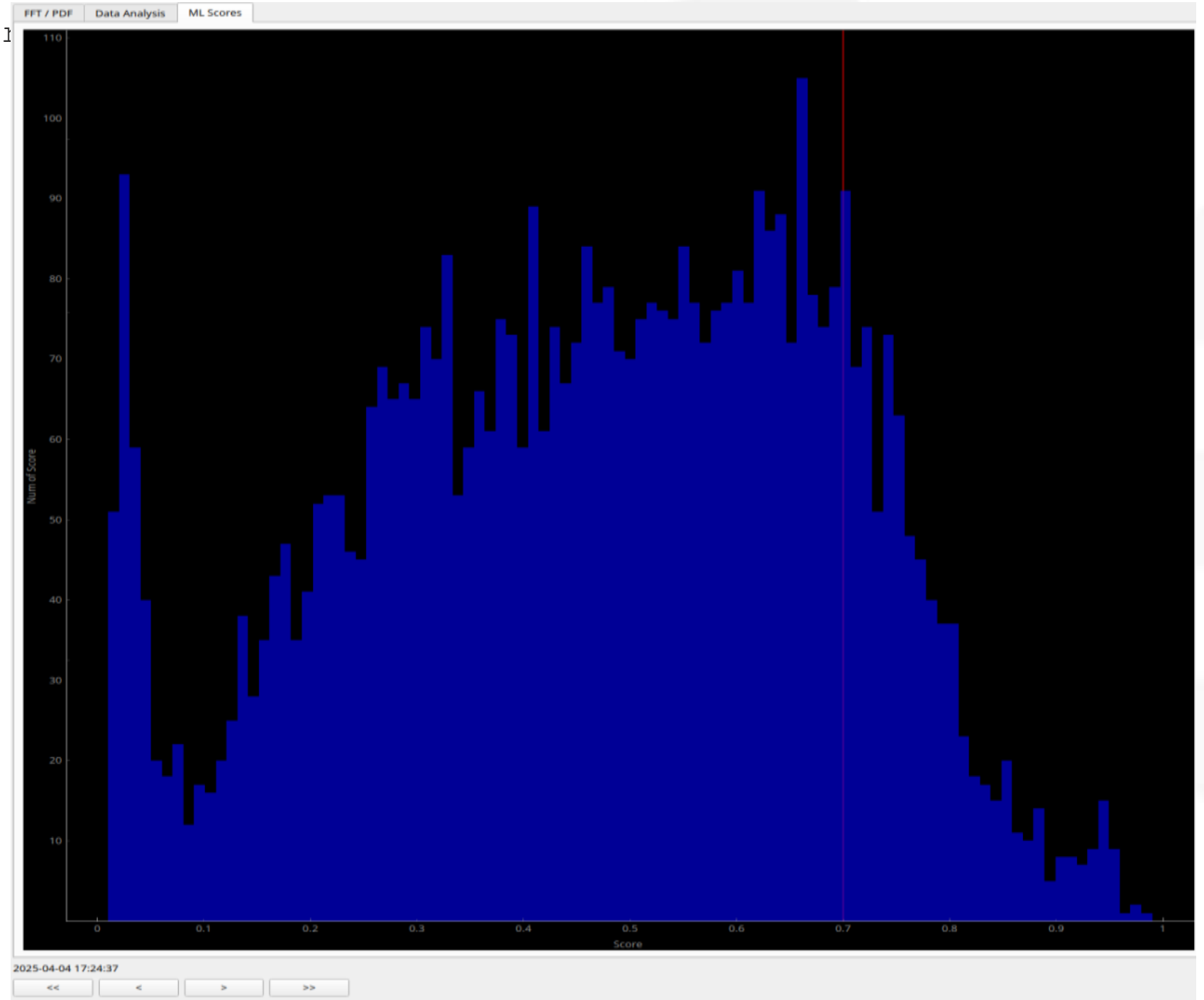
Beam anomaly detection –
Online application

Unfortunately, some sensitivity to intensity of stored beam, seen below 250 mA



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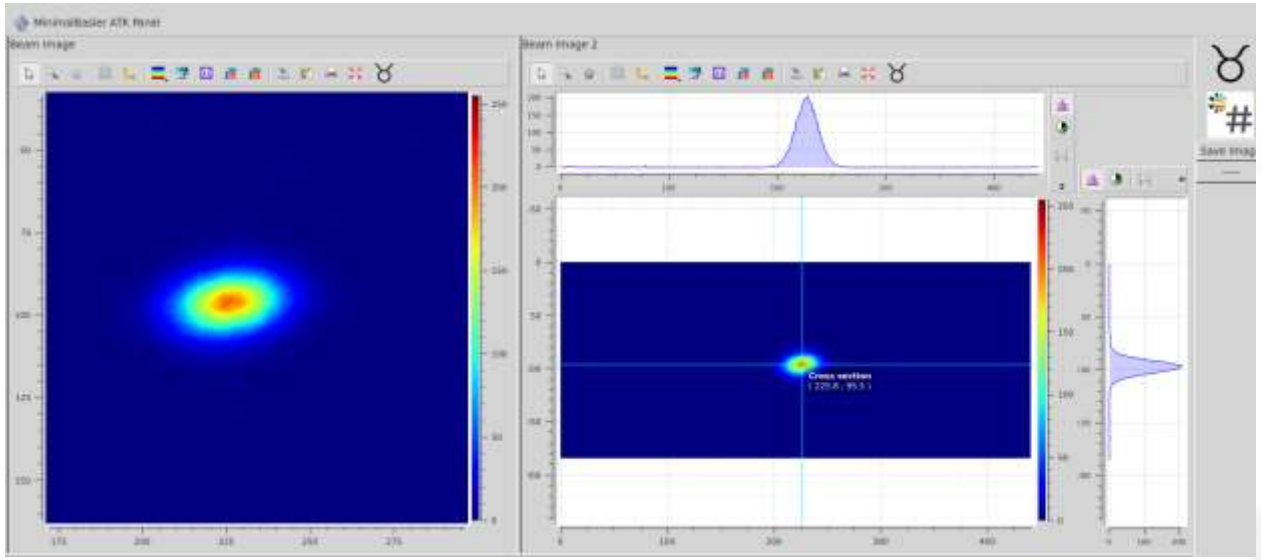
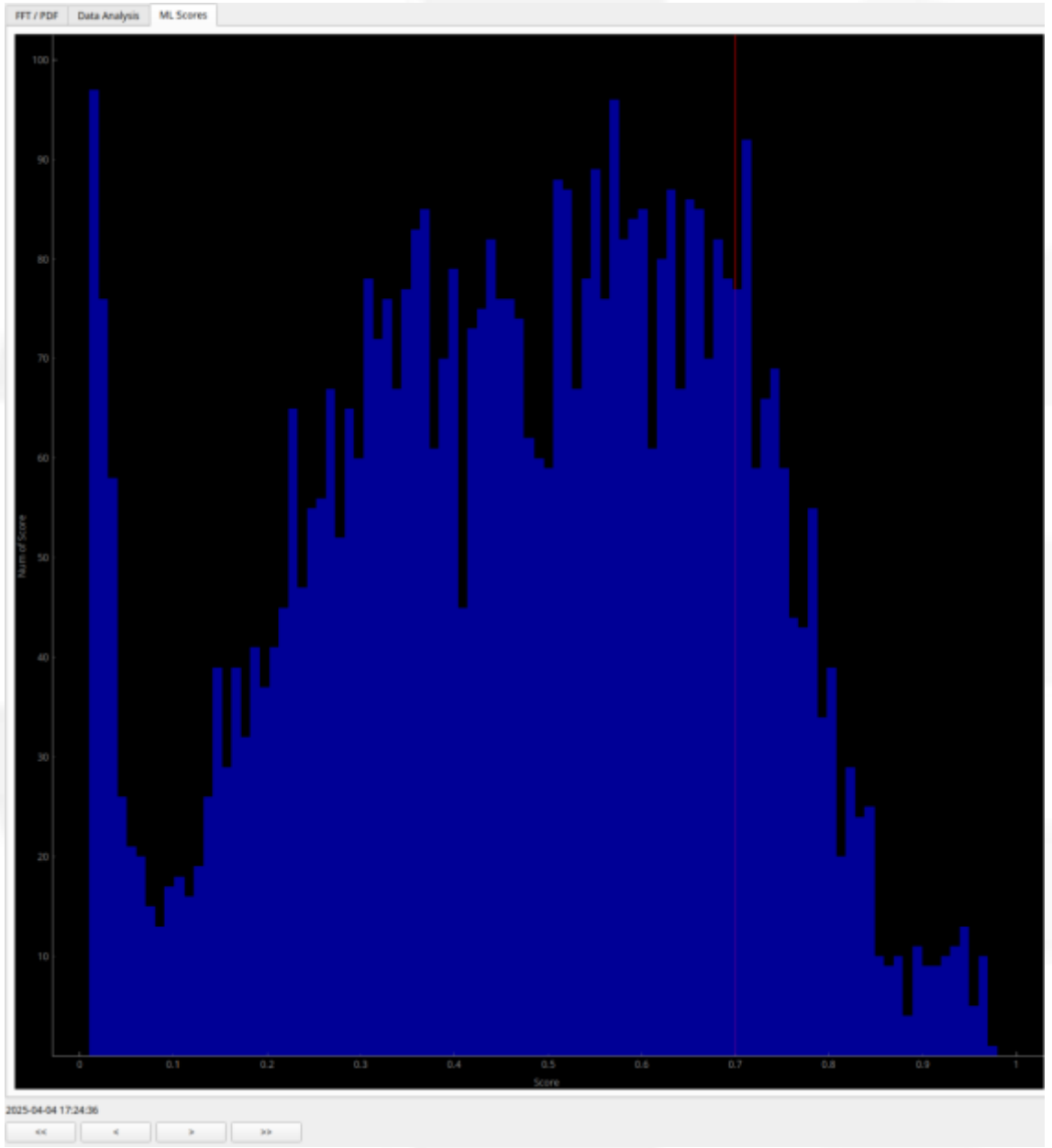
Beam anomaly detection – **Online application**





The ML score distribution follows the beam profile with a clear spike around 0, representing the electrons traveling at nominal momentum. The rest corresponds to beam spread (3.4 % RF momentum acceptance, halo etc..)

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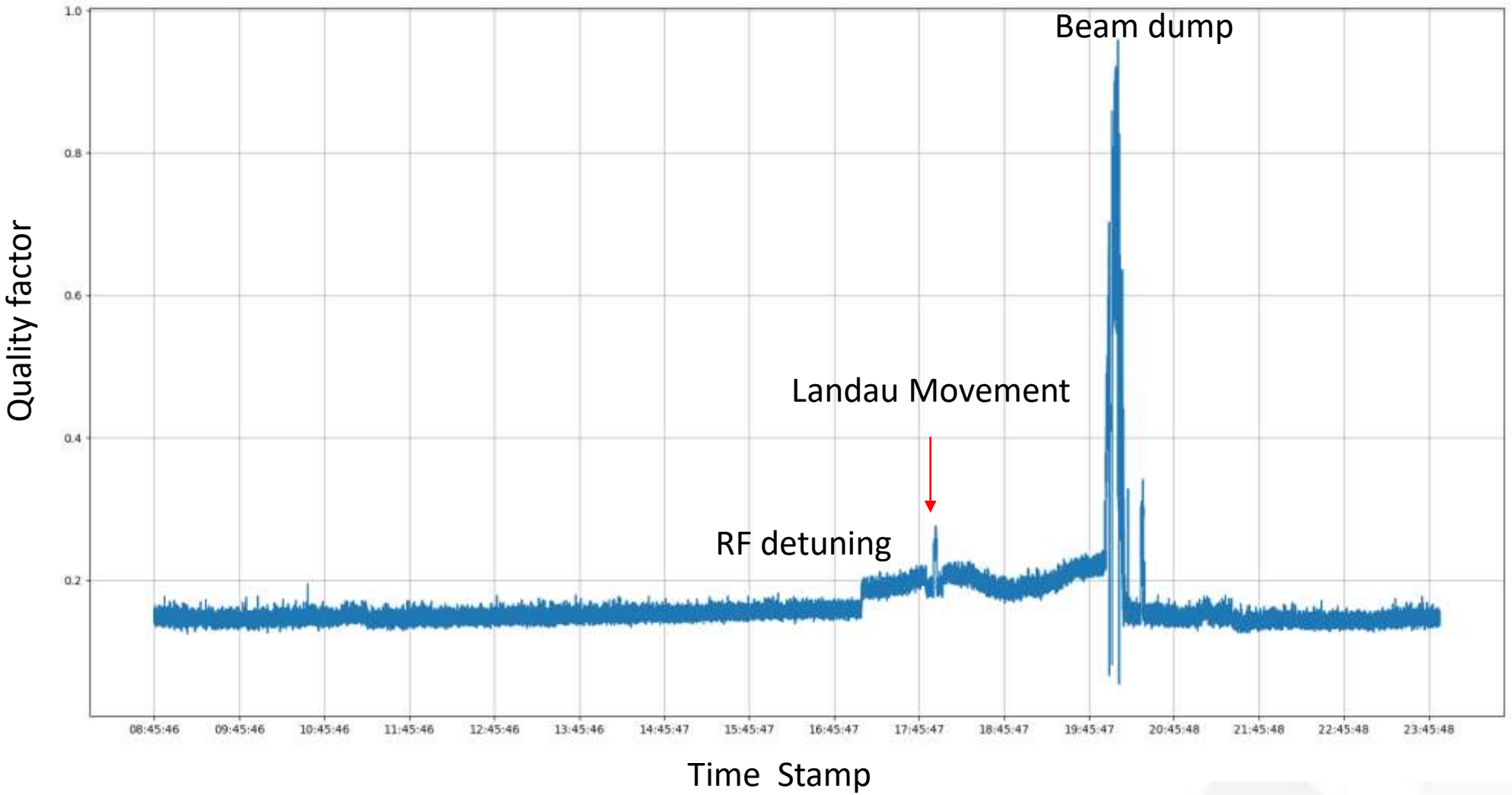
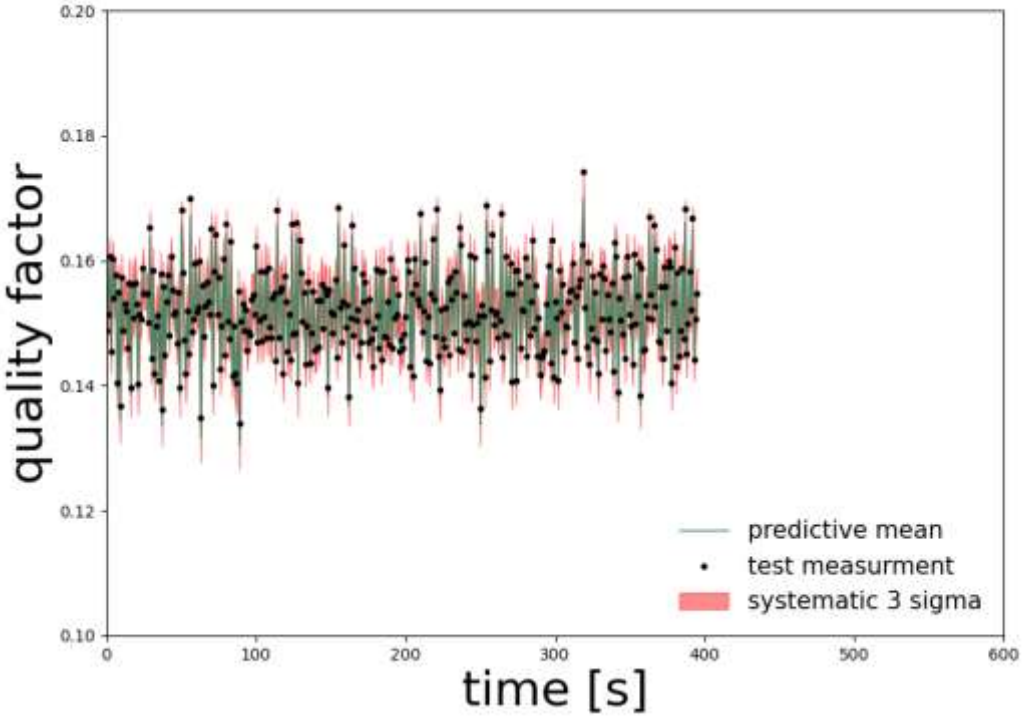
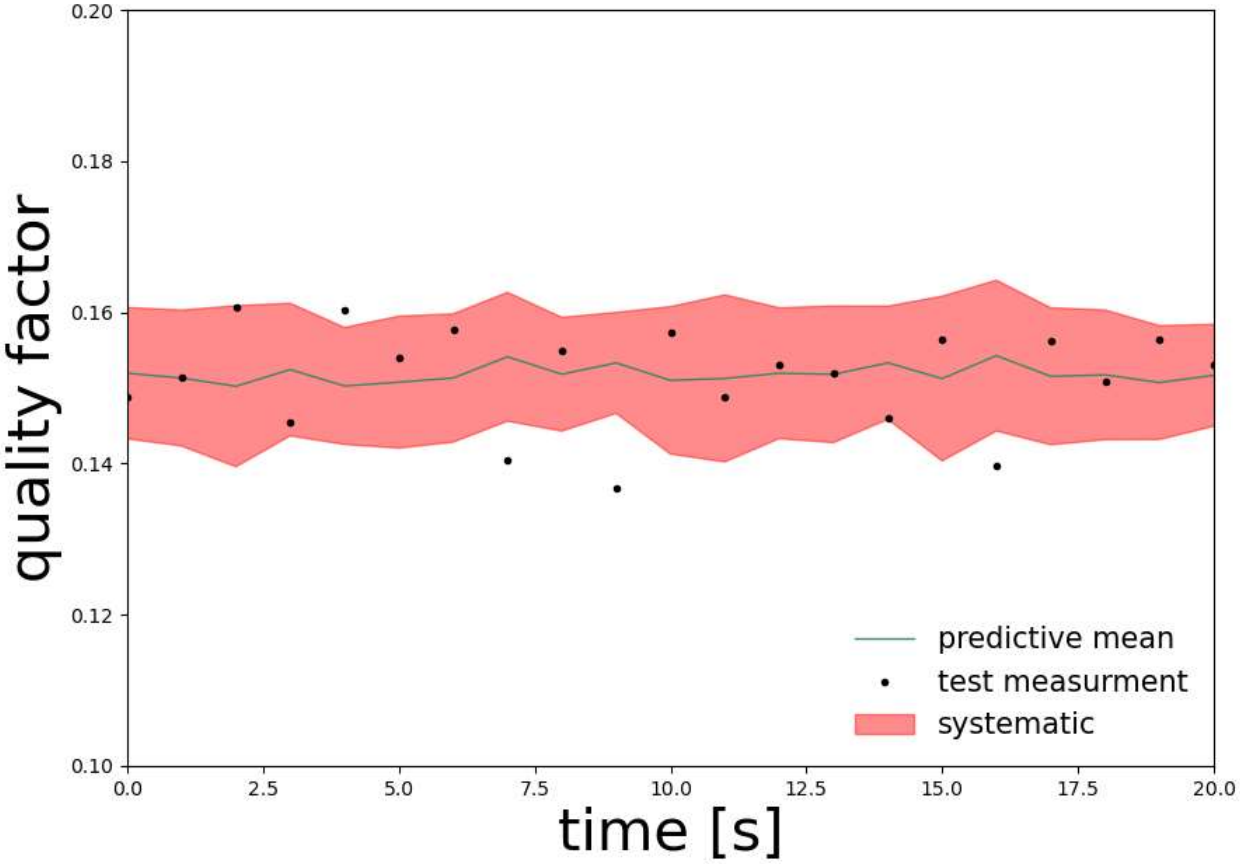
Beam anomaly detection – **Online application**



- Online beam qualty prediction 400 seconds ahead
- Prediction done by a single layer fed forward net designed in pyTorch (based on Macarov chain Montecarlo)





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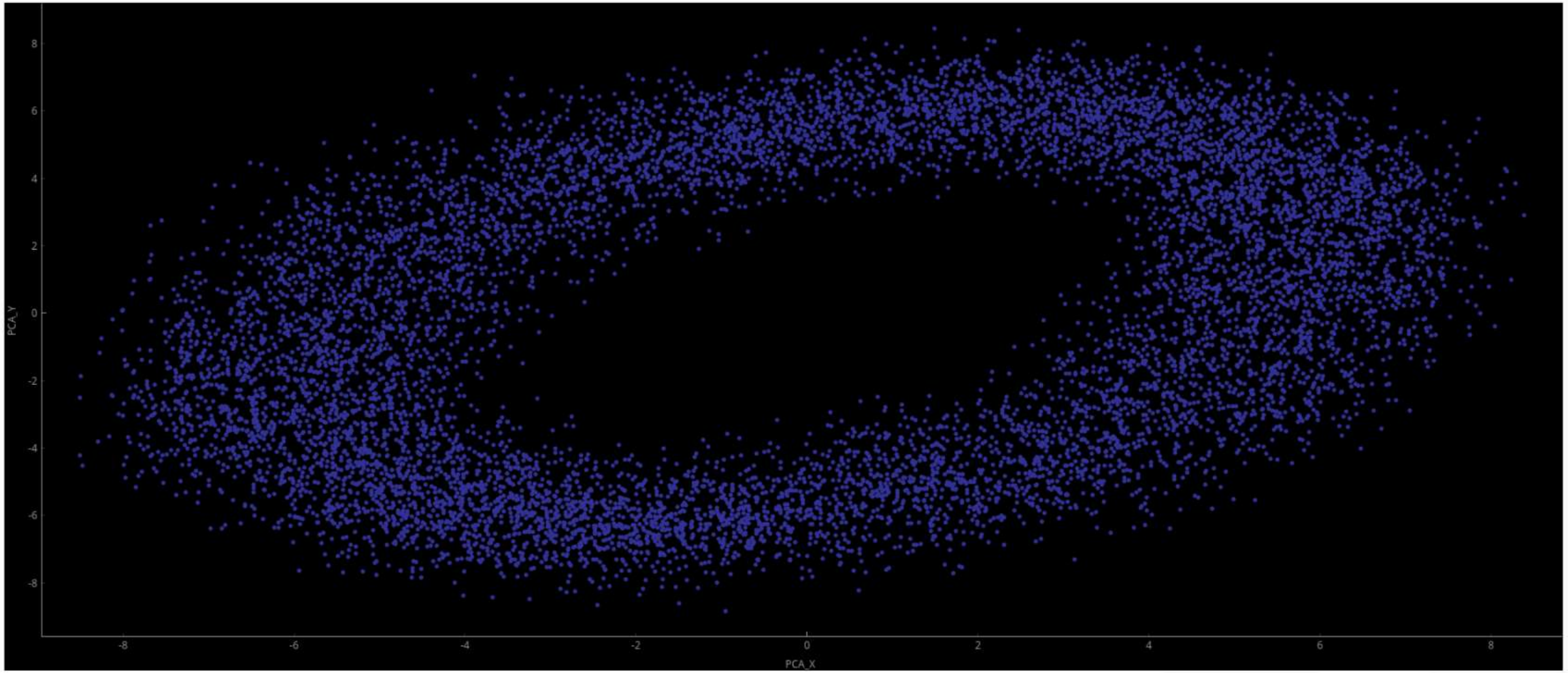
Beam anomaly detection – **Principal Component Analysis** **(good case)**

Tuned RF field, analysis done on first BPM after RF cavities



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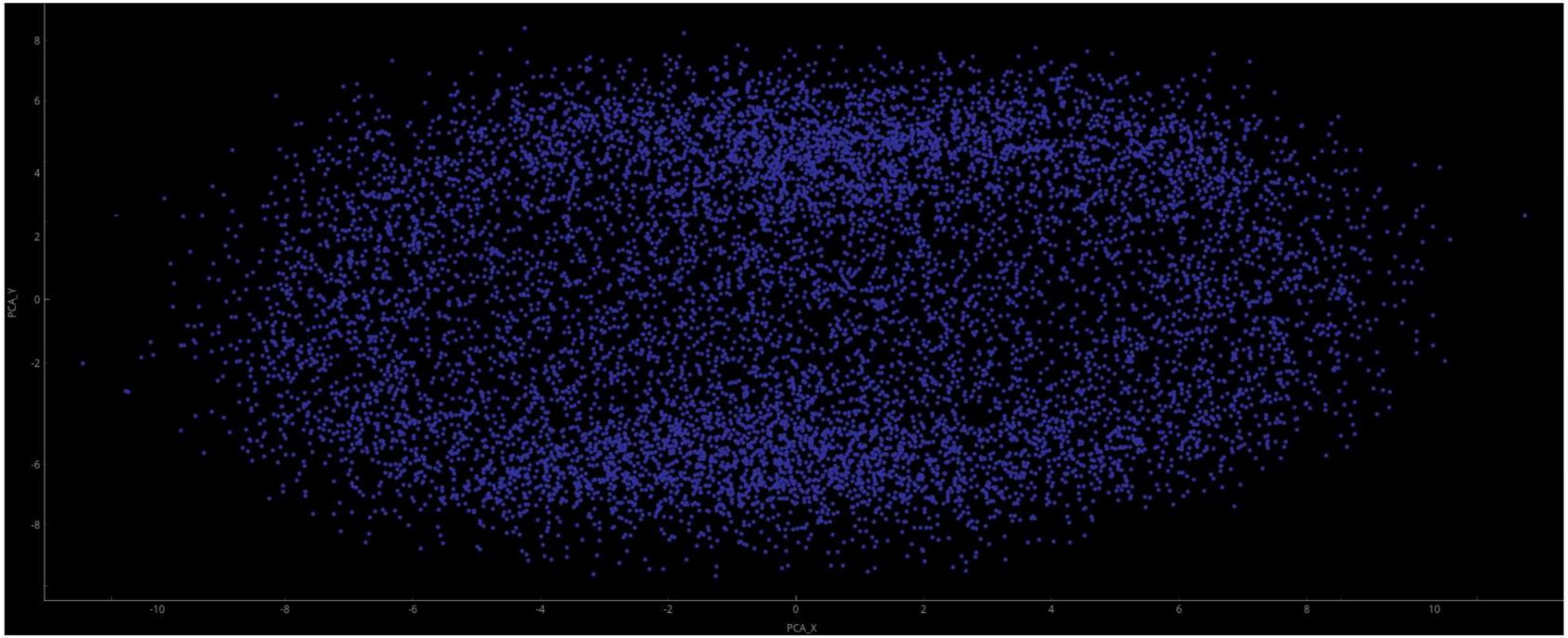
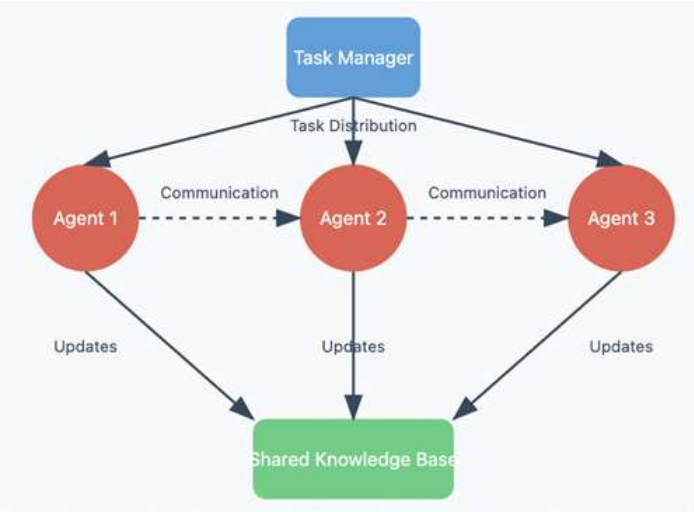
Beam anomaly detection – **Principal Component Analysis (bad case)**

Detuning of RF filed in CAV 1 and CAV 2 (handeld by nutaq)



Machine learning in Synchrotron- plans for the future

- Sector by sector diagnostic
- Fast data aquation for nutaq (RF tuning and general diagnostic)
- Fast images acquisition for two parasitic optical diagnostic beamlines (PINHOLE, LUMOS)
- Combining all ML output providing a multi agent system



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Thank you