SOLARIS CENTRE

Real time diagnostics and operation of SOLARIS

DEELS2025

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SOLARIS National Synchrotron Radiation Centre

Agenda

- Introduction - SOLARIS facility
- Data streaming system
- Basic beam diagnostics using ML, operation, RF tuning failures, plunger movement distortion
- Implementation of bunch-by-bunch feedback, first measurements, different operation modes, beam dynamics
- Plans for the future, sector wise diagnostic

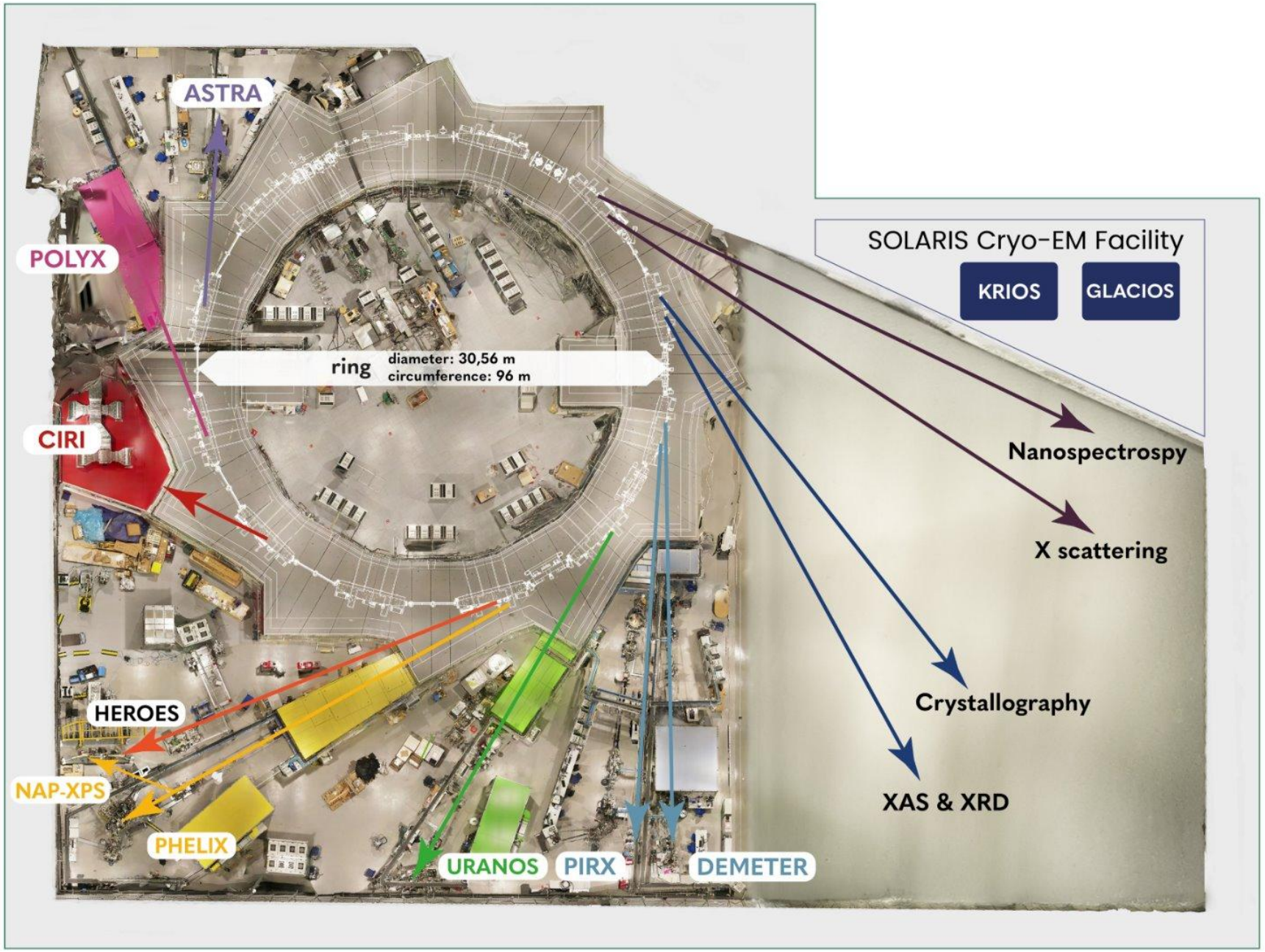
SOLARIS facility

Linear accelerator

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

Storage ring

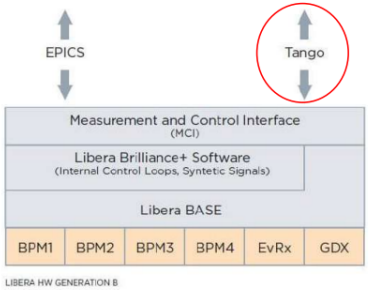
- Consists of **12 DBA cells**,
- Main RF frequency – **99,937 MHz,**
- Energy - **1,5 GeV,**
- Max beam current – **500 mA,**
- Circumference – **96 m.**
- 7 experimental beam lines in operation



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

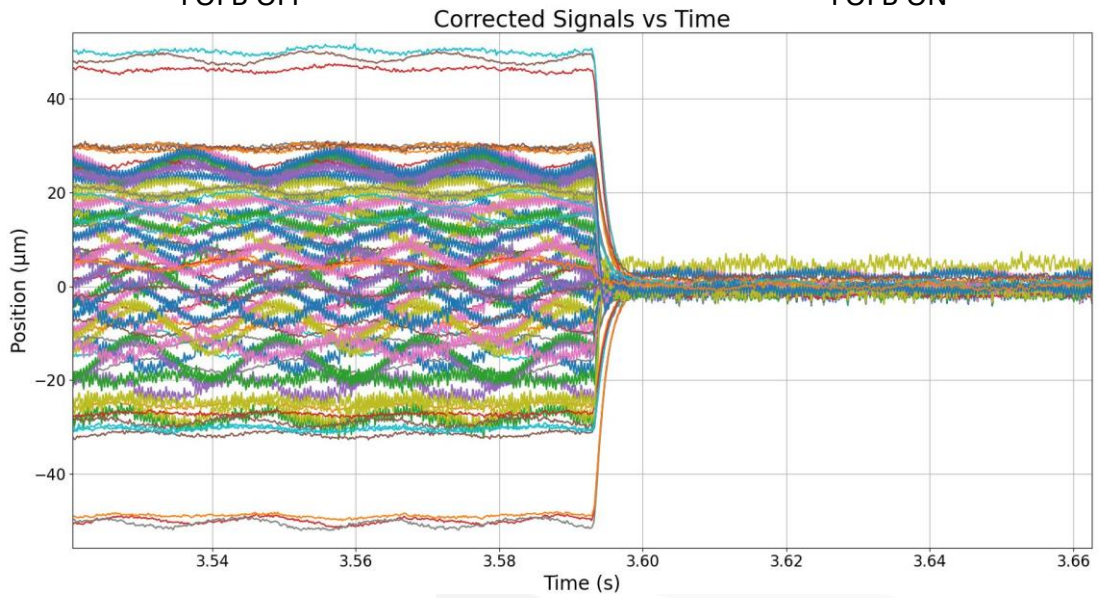


- 4 Libera Photon for beam light measurement

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

FOFB OFF

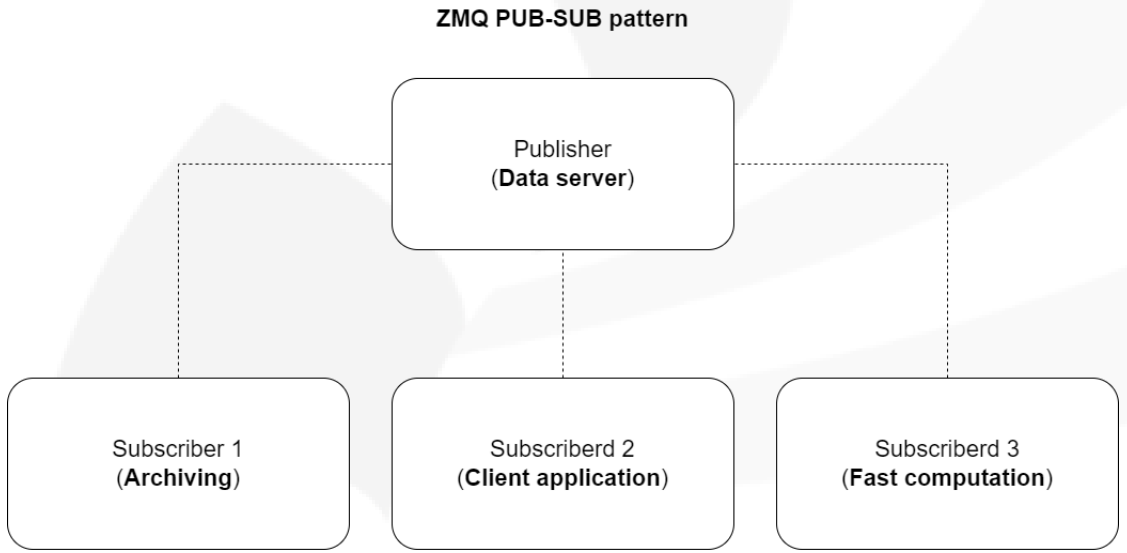
FOFB ON



Streaming System

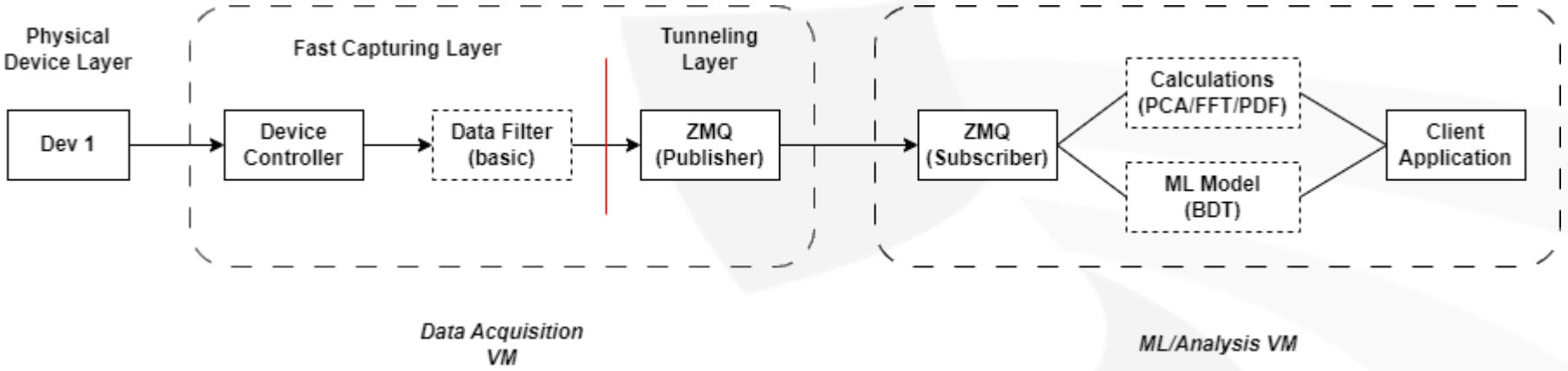
Technology:

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



Abilieties:

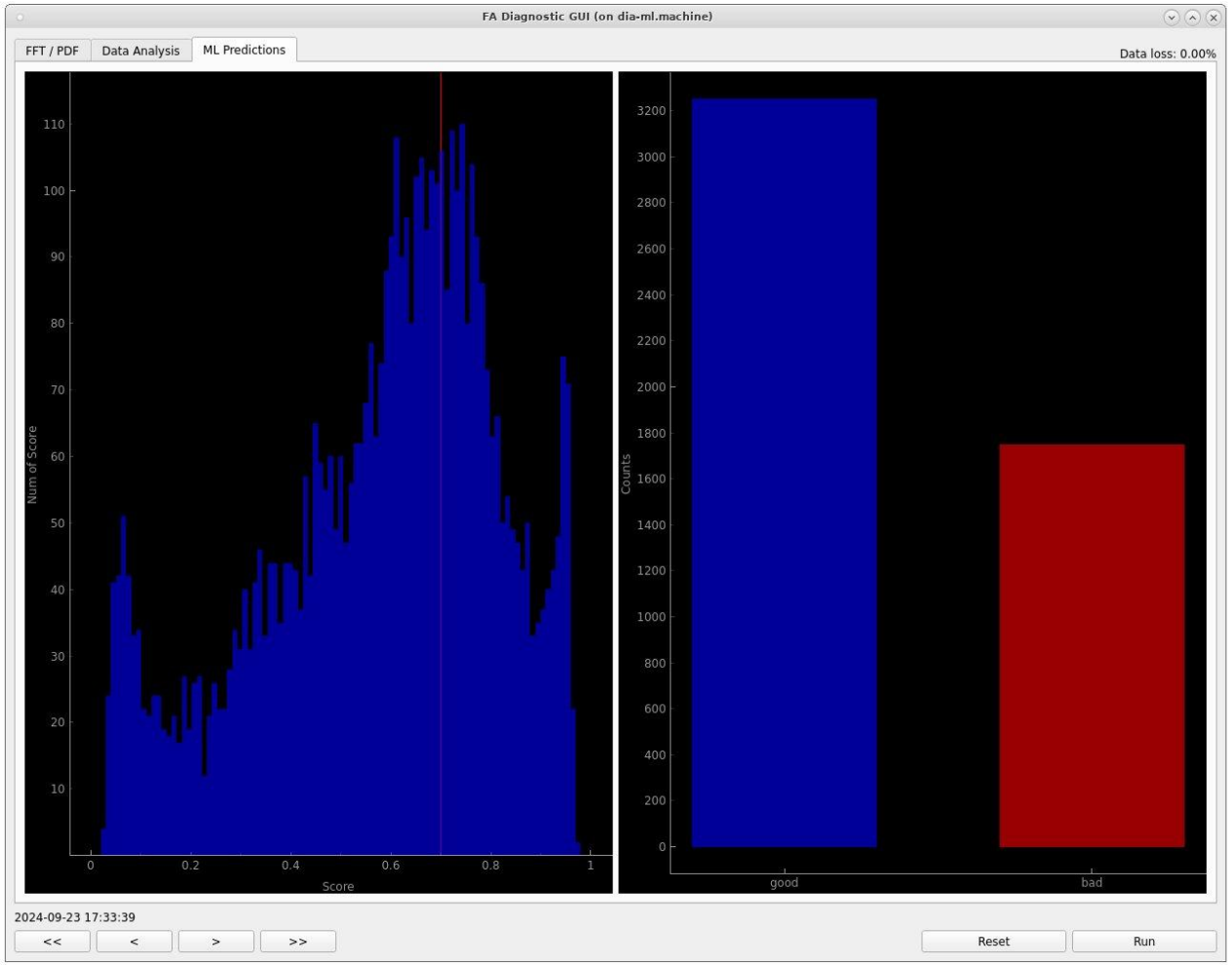
- Operating on 10 kHz signal
- 3 MB/s online transmission
- Scallable



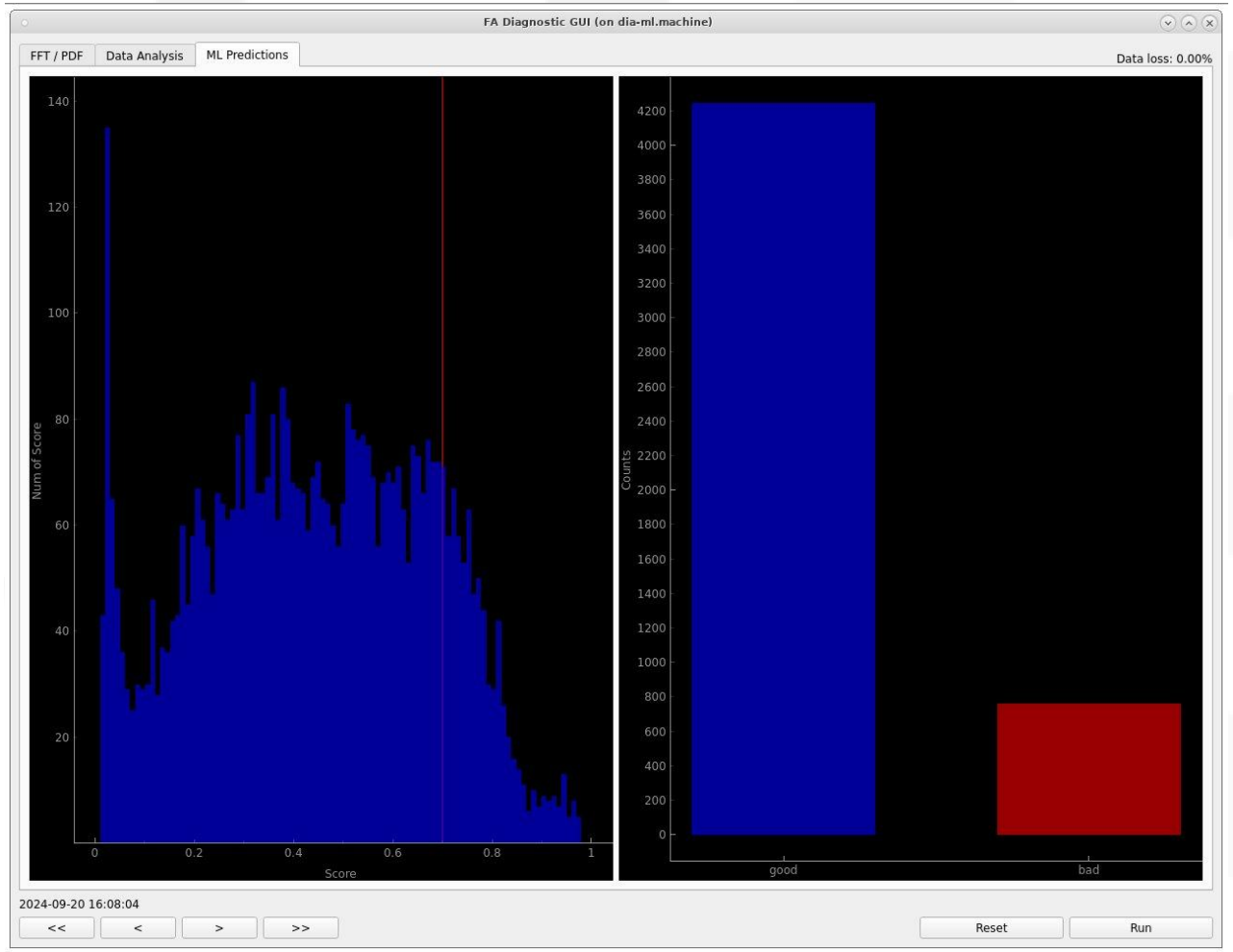
Machine learning in Synchrotron

Beam anomaly detection – **Online application**

Kicker, 3000 V, 120 mA

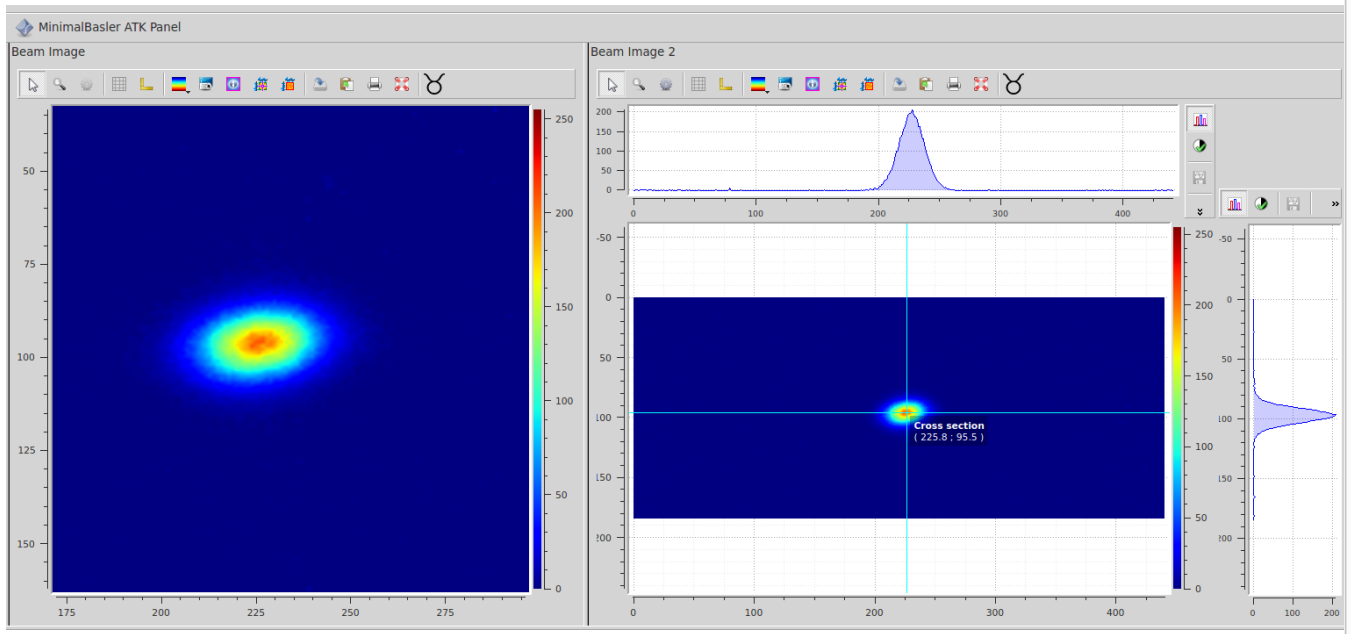


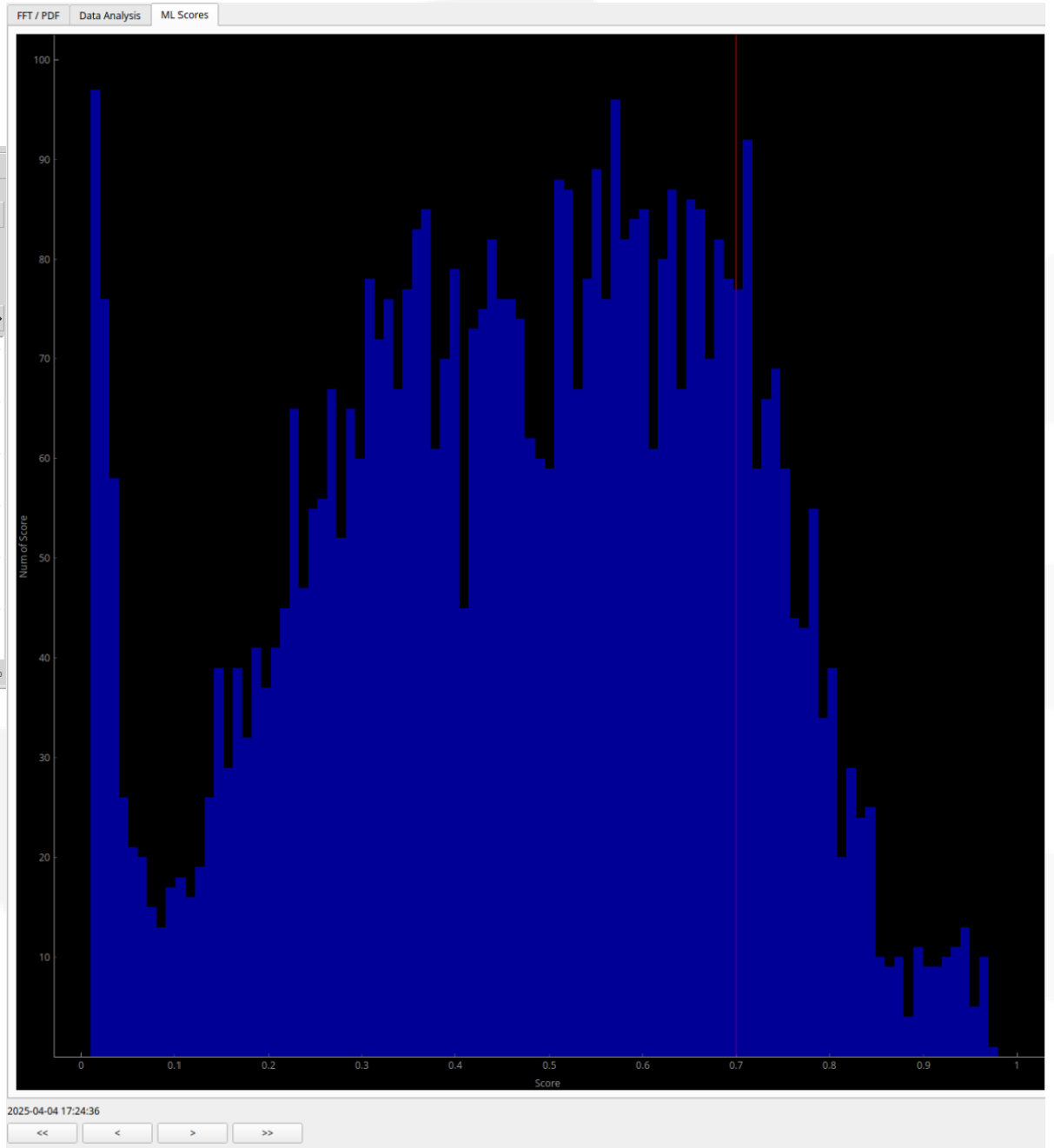
Typical opperation



Machine learning in Synchrotron

Beam anomaly detection – **Online application**

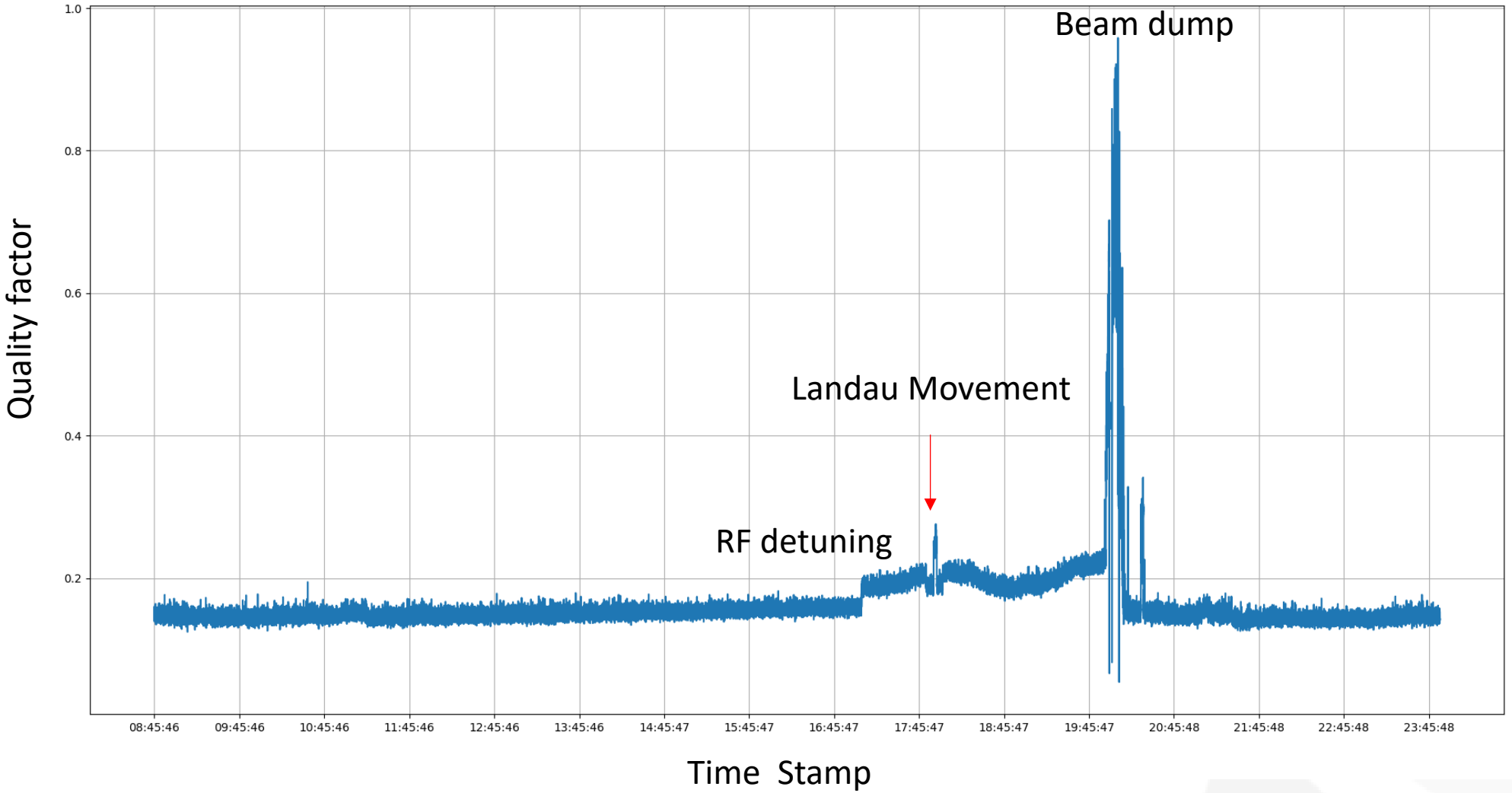




The ML score distribution follows the beam profile with a clear spike around 0, representing the electrons traveling at nominal momentum. The rest corresponds to beam spread (3.4 % RF momentum acceptance, halo etc..)

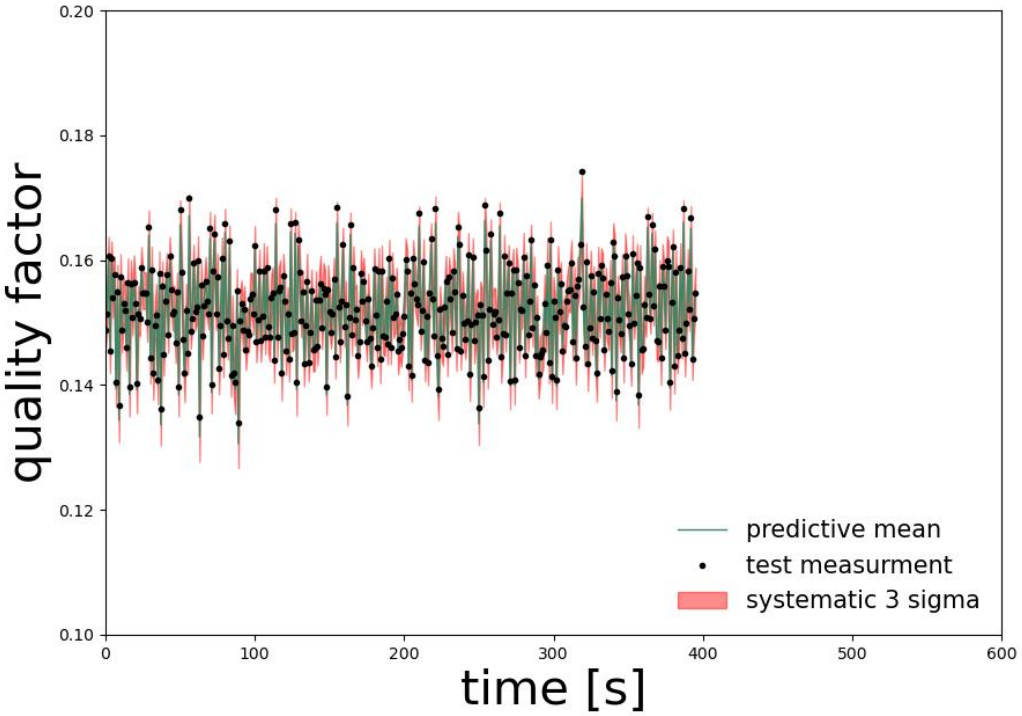
Machine learning in Synchrotron

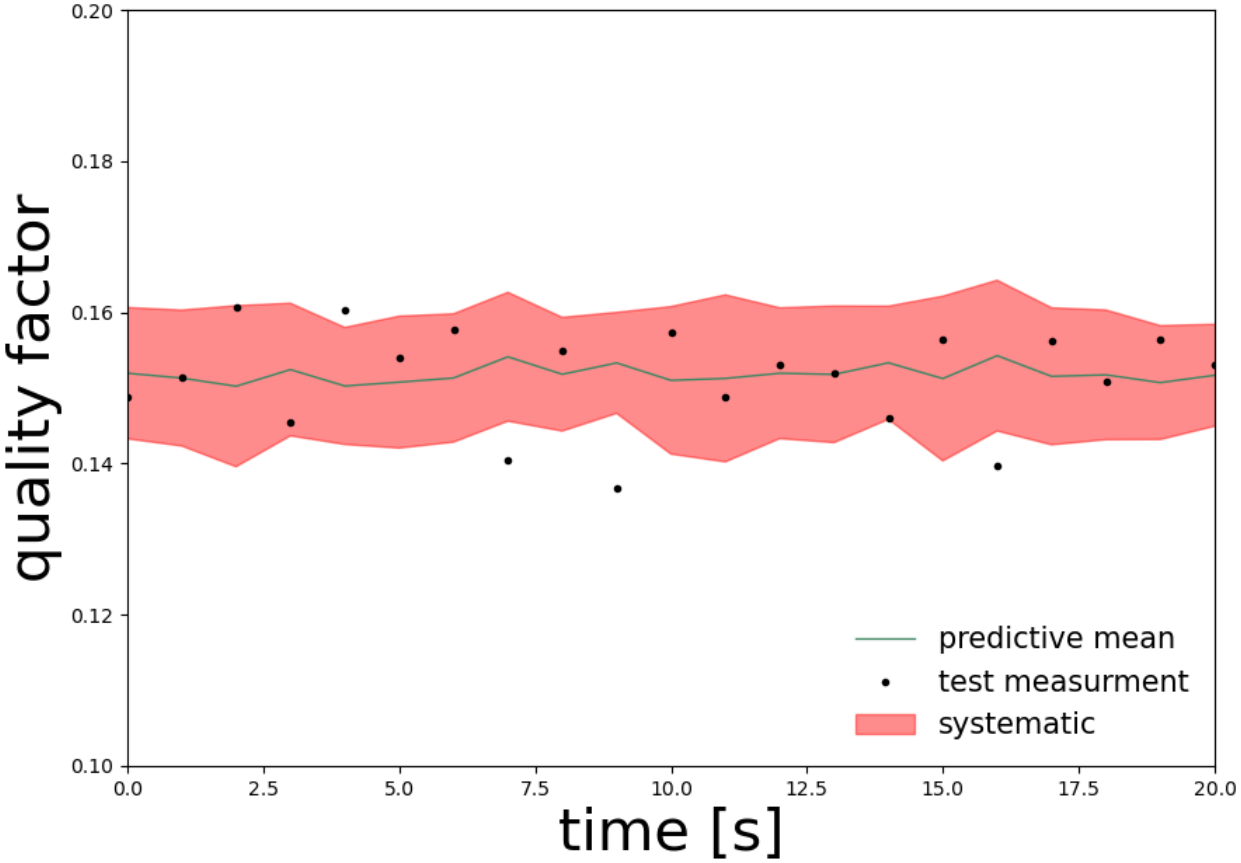
Beam anomaly detection – **Online application**



Machine learning in Synchrotron

- 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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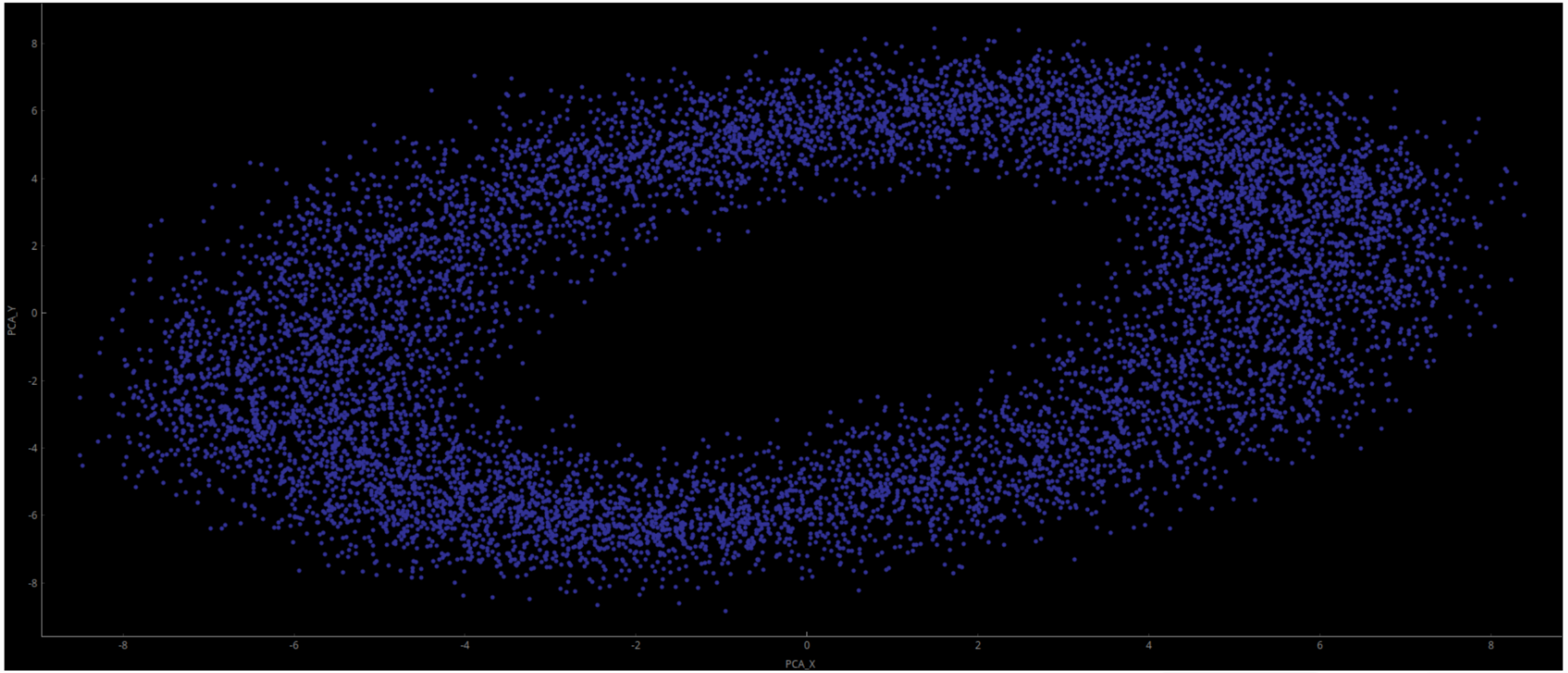
Machine learning in Synchrotron

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

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

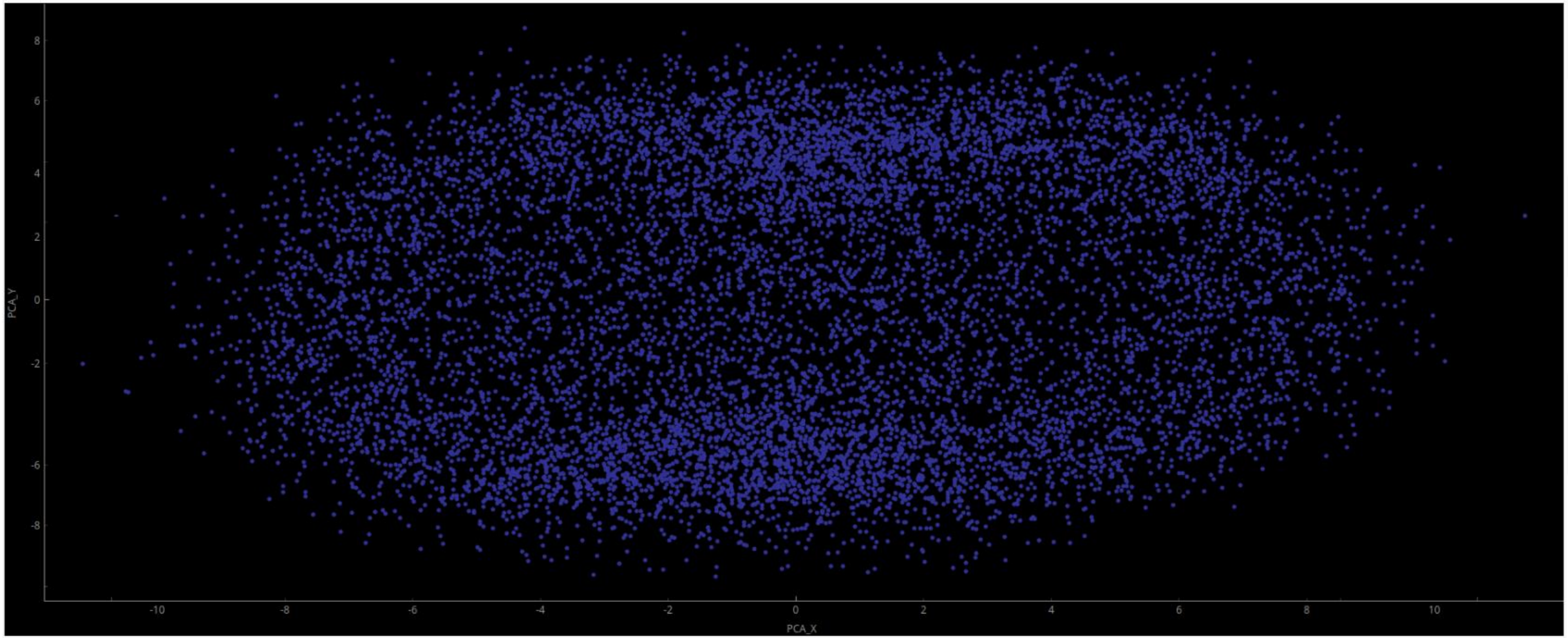


Machine learning in Synchrotron

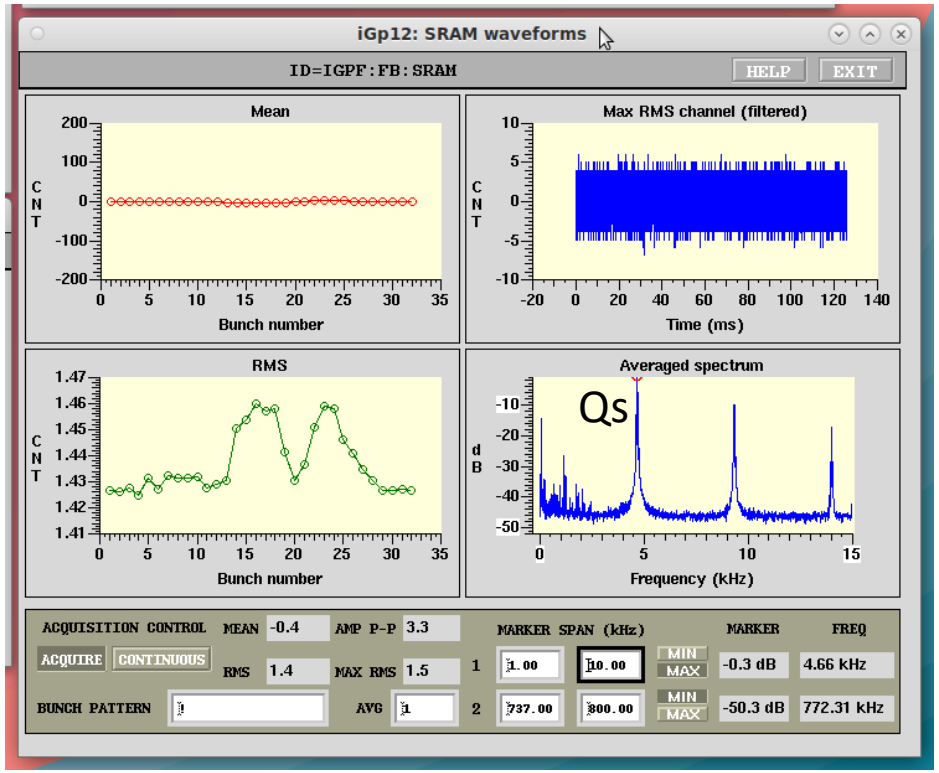
Beam anomaly detection – **Principal Component Analysis (bad case)**

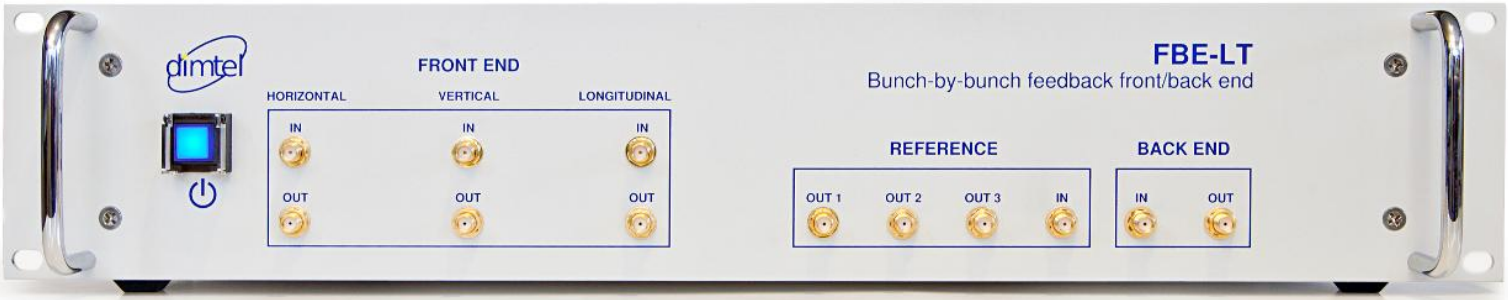
Detuning of RF filed in CAV 1 and CAV 2 (handeld by nutaq), usually, apers at lower currents

Stuck endplate on CAV1

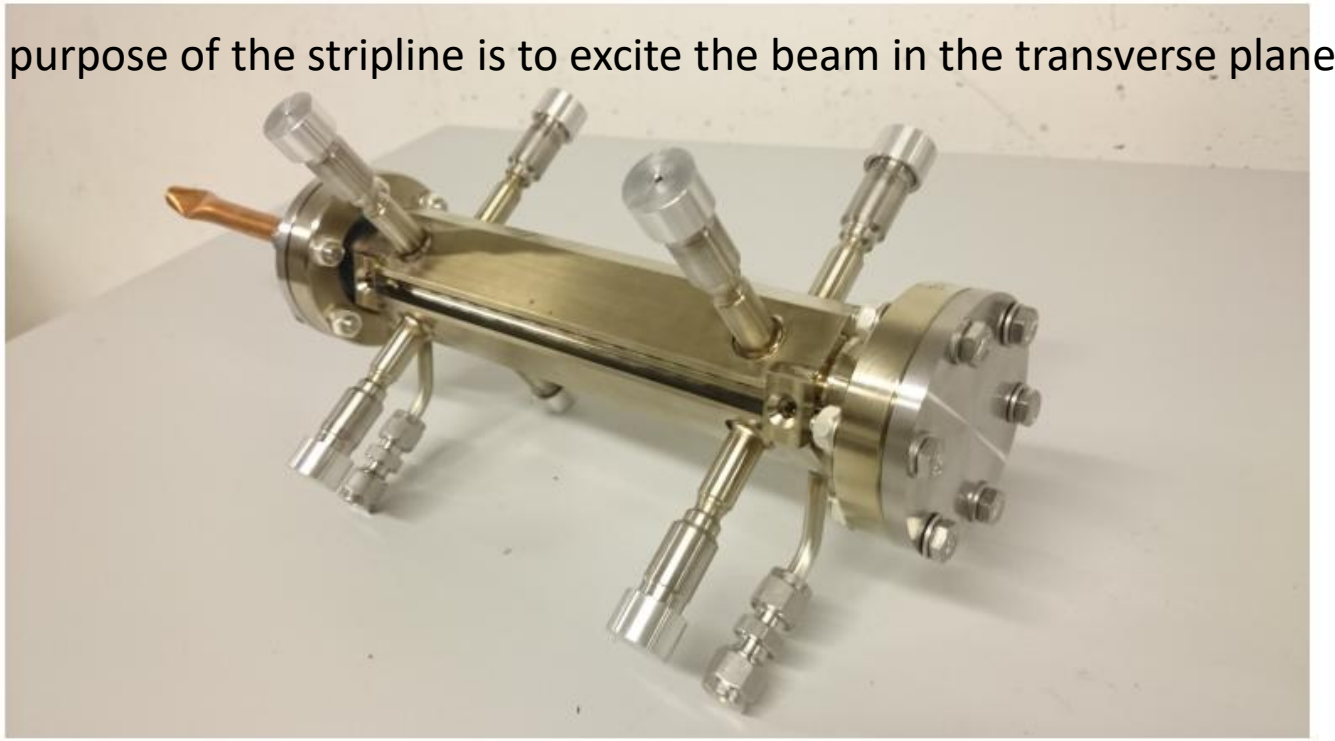


Bunch by Bunch feedback





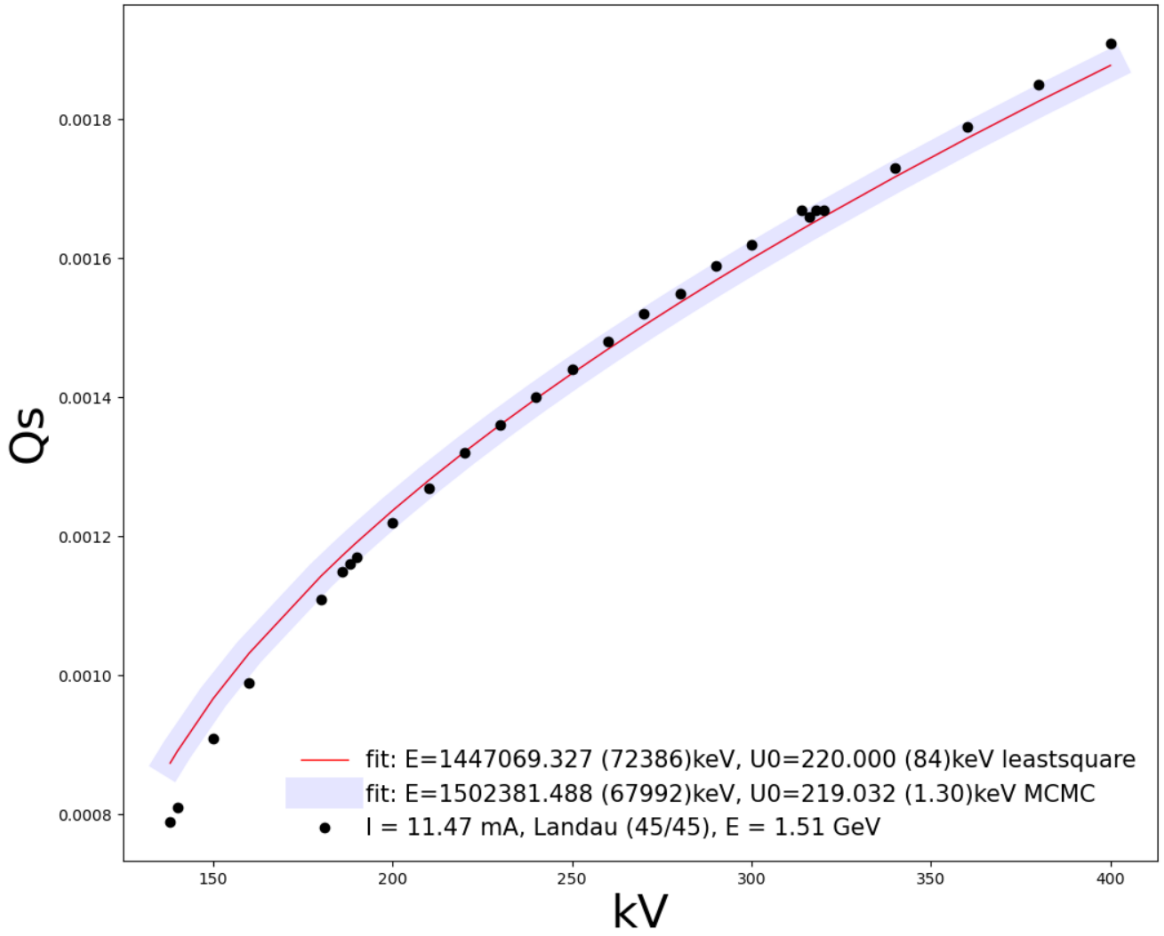
purpose of the stripline is to excite the beam in the transverse plane

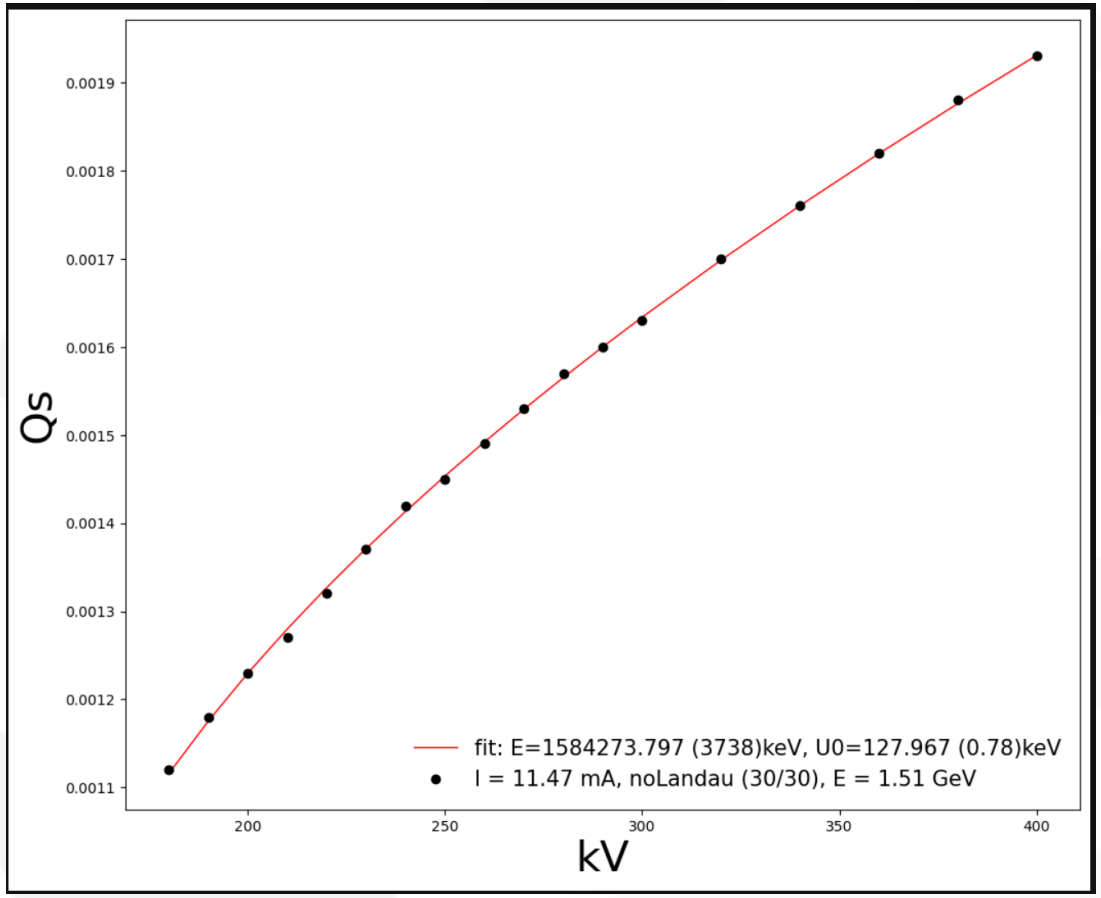


Mode of operation	U_1	U_2	U_3	U_4	$Z_s[\Omega]$
Diagonal (d)	V_0	0	$-V_0$	0	50.0
Horizontal (h)	V_0	$-V_0$	$-V_0$	V_0	50.0
Vertical (v)	V_0	V_0	$-V_0$	$-V_0$	50.0
Sum (Σ)	V_0	V_0	V_0	V_0	53.4

https://lucris.lub.lu.se/ws/portalfiles/portal/33463993/TEAT_7254.pdf

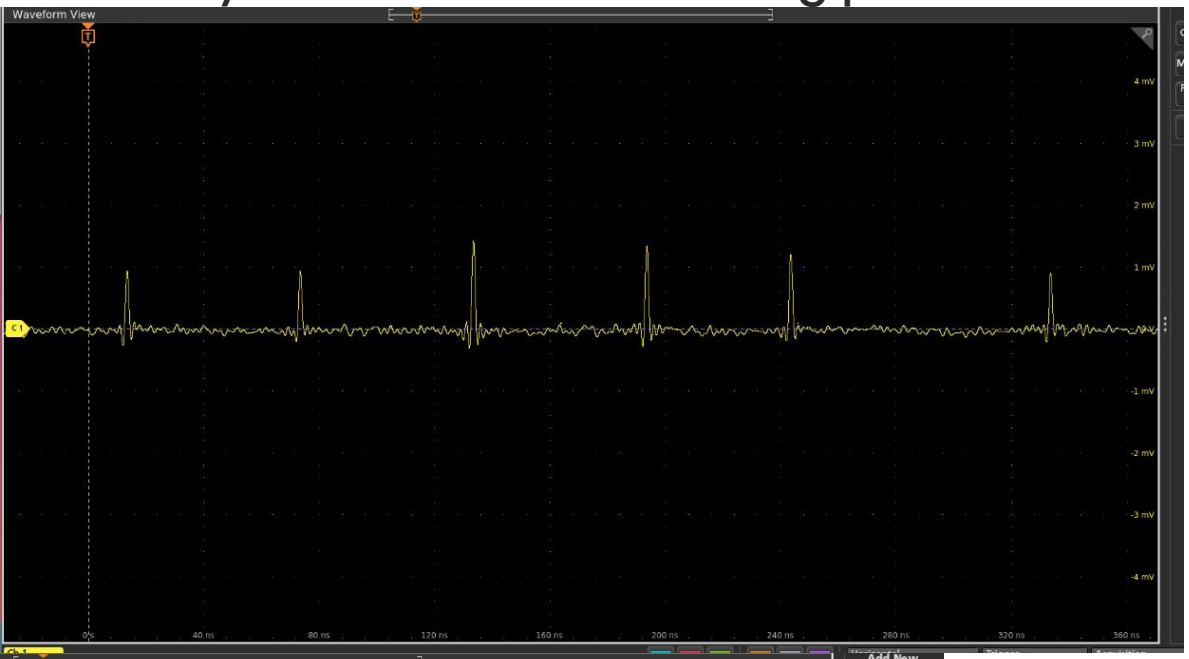
Bunch by Bunch feedback- Energy loss measurements

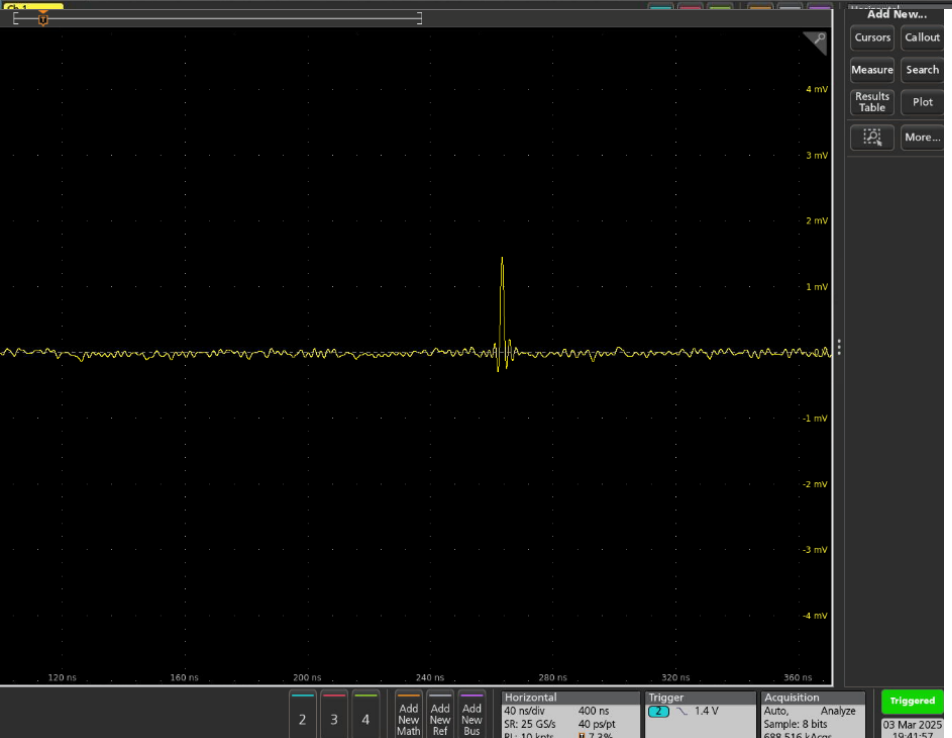




https://lucris.lub.lu.se/ws/portalfiles/portal/33463993/TEAT_7254.pdf

Bunch by Bunch feedback- Filling pattern





Sparse filling pattern, 2, 9, 15, 21, 27 form original 32

Single bunch, 12 mA

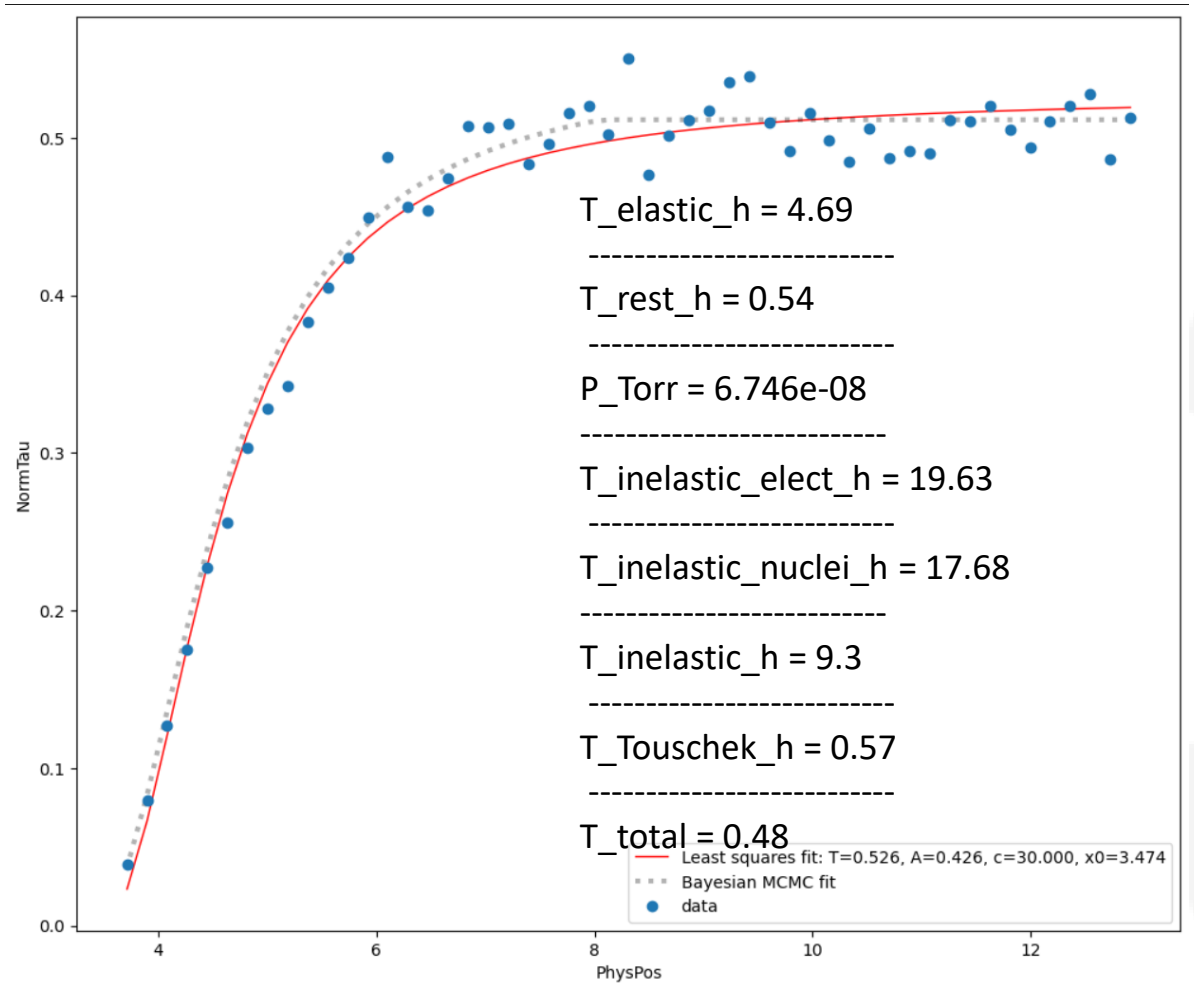
Bunch by Bunch feedback- Filling pattern, life time measurments

	25 mA 24.05.2024	**10 mA 21.11.2024 (Single Bunch)**	**20 mA 20.03.2024**	**300 mA 05.03.2024 Landau 47**	**300 mA 05.03.2024 Landau 30**	**300 mA 07.11.2023 0.5 GeV**	**300 mA 07.11.2023**	**290 mA 26.10.2023 0.5 GeV**
T_elastic [h]	35.06	52.8	12.0	98.3	92.07	28.9	76.73	30.27
T_rest [h]	2.19	0.37	2.06	14.2	39.5	39.9	20.09	27.03
P_Torr	**9.03e-09**	**6.00e-09**	**2.61e-08**	**3.2e-09**	**3.4e-09**	**1.09e-08**	**4.12e-09**	**1.04e-08**
T_inelastic_elect [h]	146.45	220.45	50	410.7	384.6	121.04	320.58	126.47
T_inelastic_nuclei [h]	131.60	198.60	45	370	346.5	109.04	288.81	113.93
T_inelastic [h]	69.48	104.48	24	194.6	182.3	57.36	151.93	59.93
T_Touschek [h]	**2.26**	**0.37**	**2.25**	**15.3**	**50.5**	**132.13**	**23.15**	**49.23**
T_total [h]	2.06	0.37	1.76	12.4	27.6	16.8	15.92	14.28

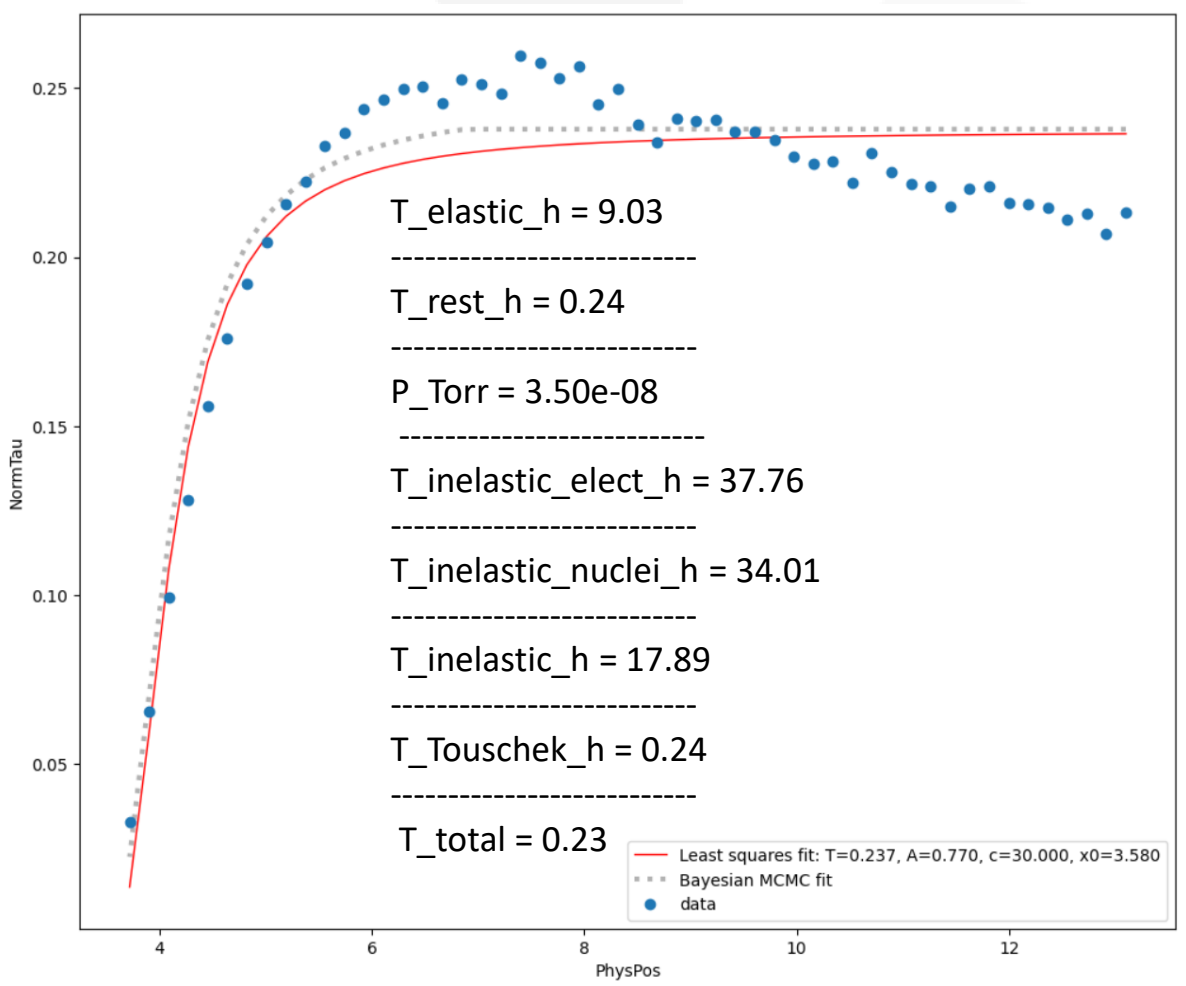
Bunch by Bunch feedback- Filling pattern, life time measurments

	100 mA 17.02.2025 (Kicker 100 V)	**50 mA 17.02.2025 (Kicker 100 V)**	**50 mA 17.02.2025 (Pinger 100V)**	**50 mA 17.02.2025 (Pinger +Kicker 100V)**	**100 mA 03.02.2025**	**50 mA 03.02.2025**	**10 mA 21.11.2024 (Single Bunch)**
T_elastic [h]	4.08	7.17	7.42	6.25	4.7	8.8	52.8
T_rest [h]	0.38	0.47	0.51	0.6	0.15	0.52	0.37
P_Torr	**7.75e-8**	**4.4e-8**	**4.26e-8**	**5e-8**	**6.73e-8**	**3.6e-8**	**6.00e-09**
T_inelastic_elect [h]	17	29.98	31	26	19.6	36.76	220.45
T_inelastic_nuclei [h]	15.36	27	28	23.5	17.7	33.12	198.60
T_inelastic [h]	8.08	14.21	14.7	12.4	9.31	17.42	104.48
T_Touschek [h]	**0.4**	**0.48**	**0.53**	**0.6**	**0.16**	**0.53**	**0.37**
T_total [h]	0.34	0.44	0.48	0.54	0.15	0.49	0.37

Bunch by Bunch feedback- Filling pattern, life time measurments

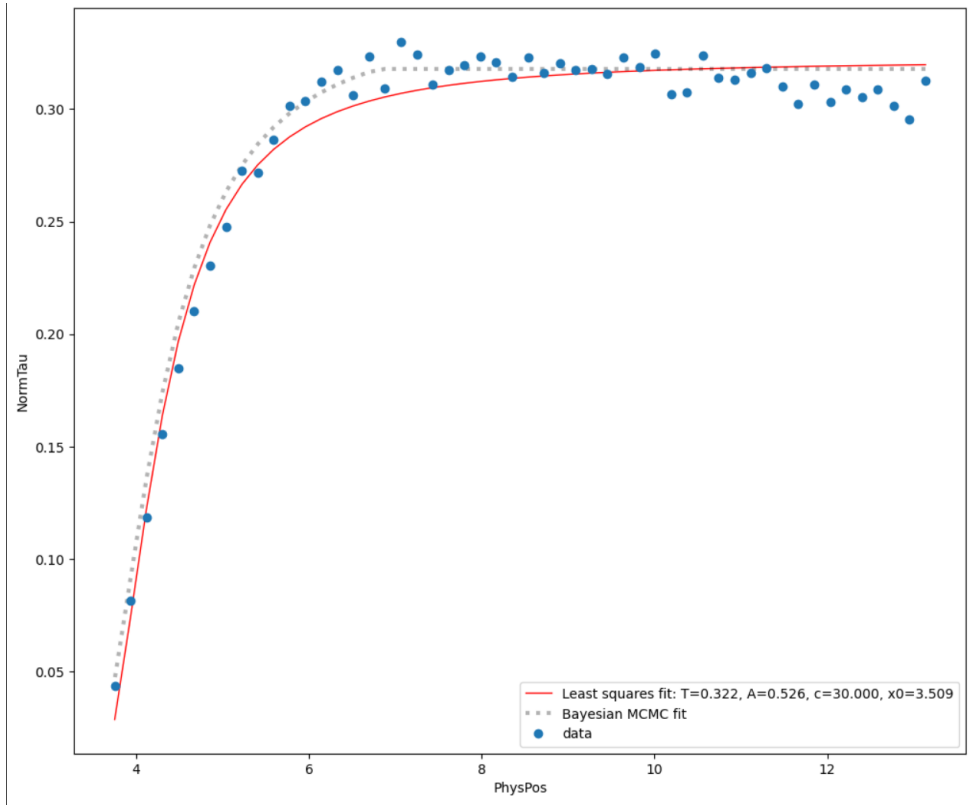


Normal stable

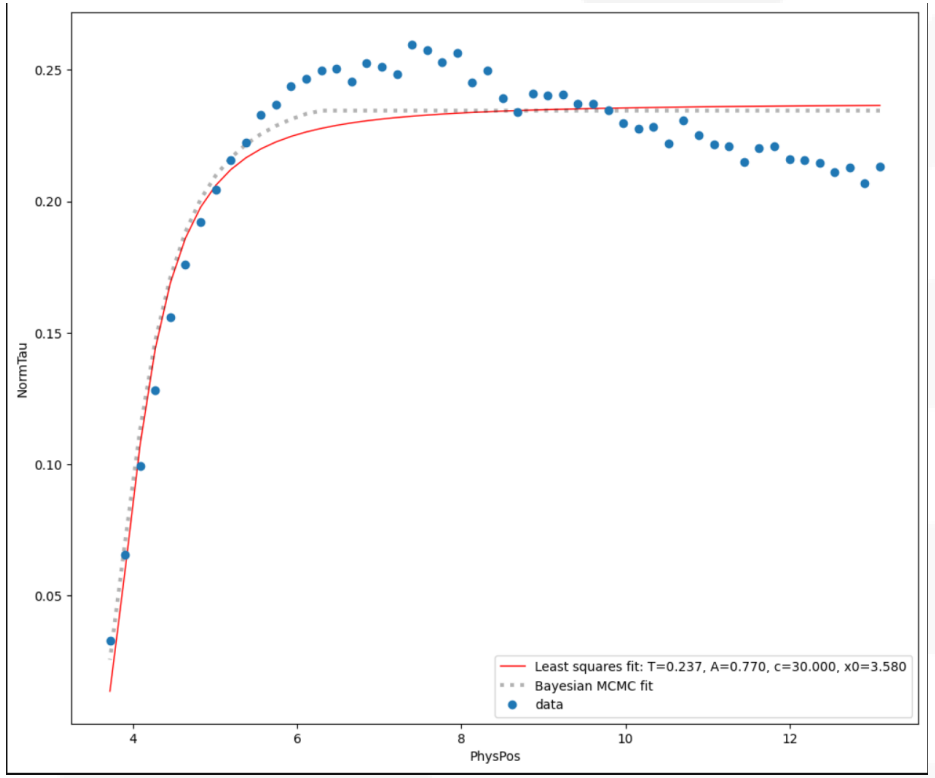


Normal excited

Bunch by Bunch feedback- Filling pattern, life time measurements



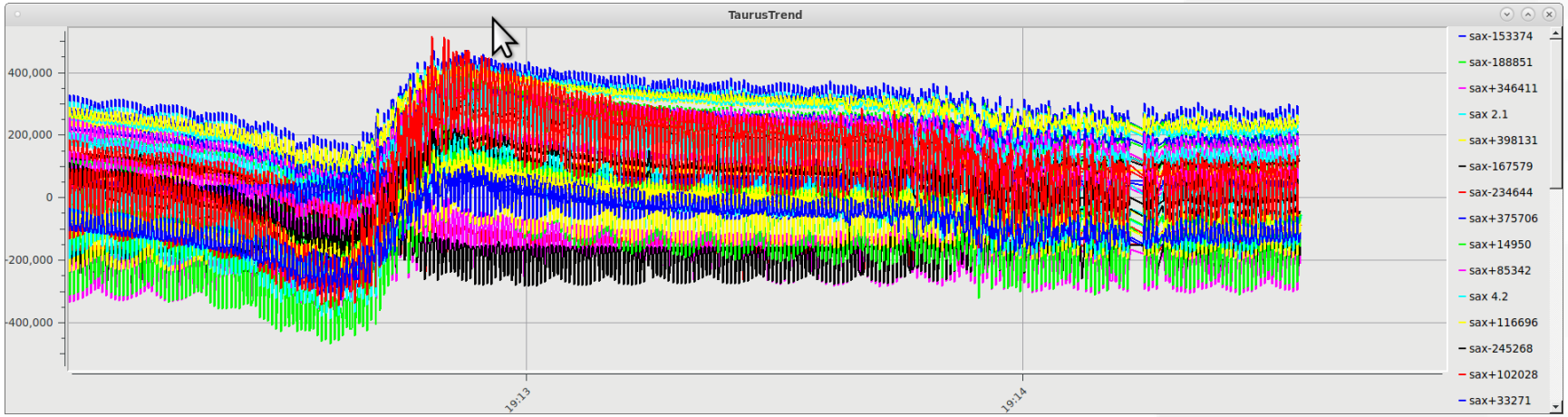
Sparse filling pattern with excitation



Sparse normal

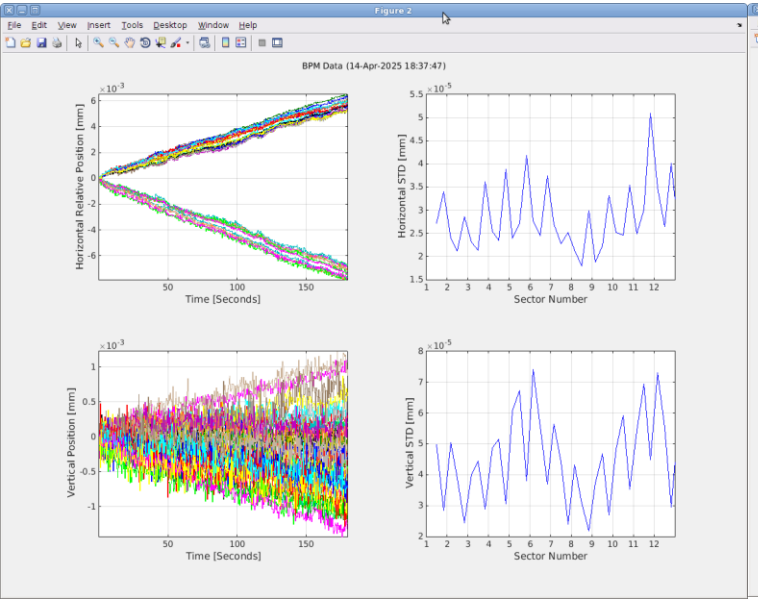
Solaris storage ring operation- Problems

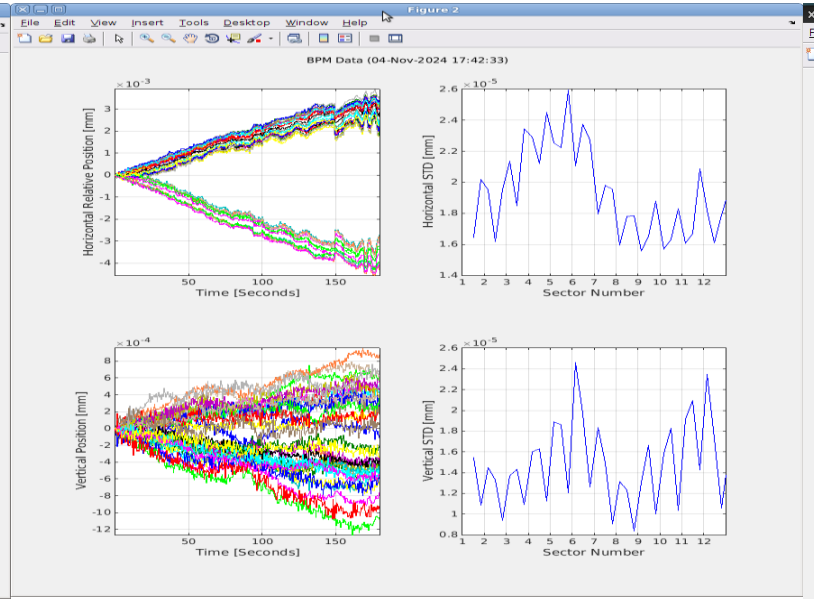
- End plate stuck in first active cavity, visible also on ML diagnostic
- Plunger distorted movement while tuning passive Landa cavity

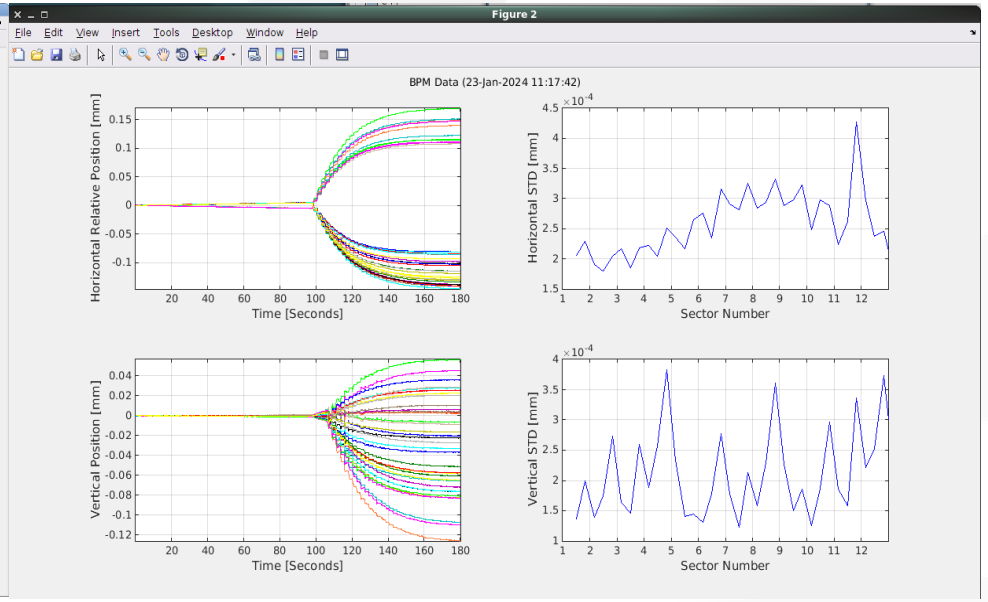


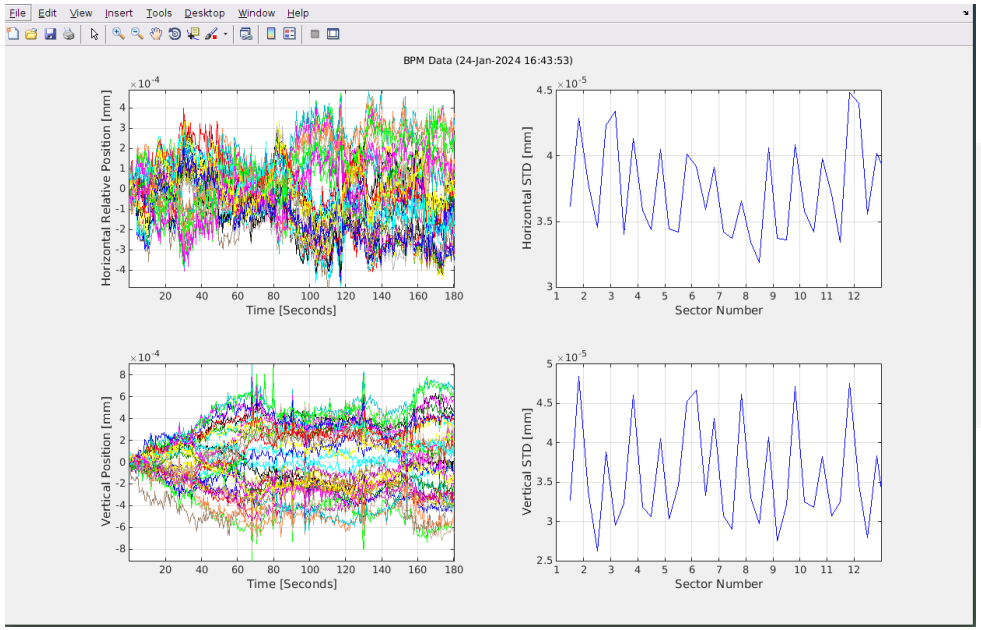
Strong drift on X-Axsis while injected beam in the ring

Solaris storage ring operation- Problems





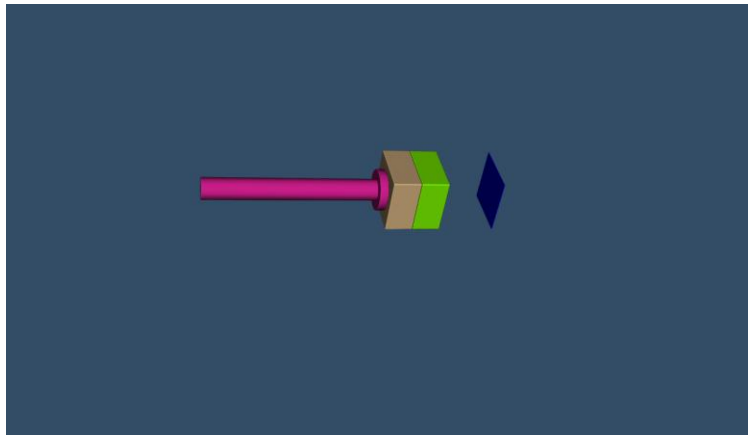


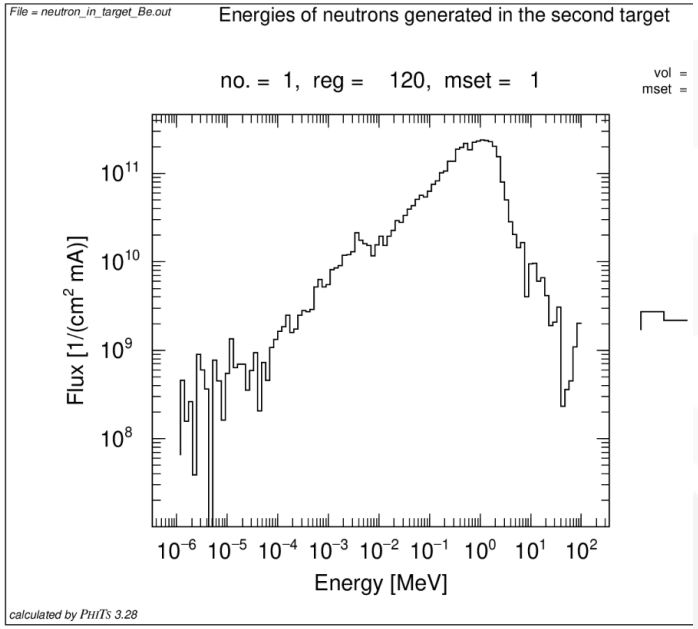


Stability after LOCO measurement

Summary

- SOLARIS has online ML based diagnostics and forecasting of beam quality
- We have installed and successfully commissioned bunch by bunch feedback
- There were some problems regarding stable operation, but the source of the problem was successfully found
- We plan to test a neutron converter target on SOLARIS injector liniac





Thank you

Linear accelerator

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- Delivered injection Energy - **536MeV,**
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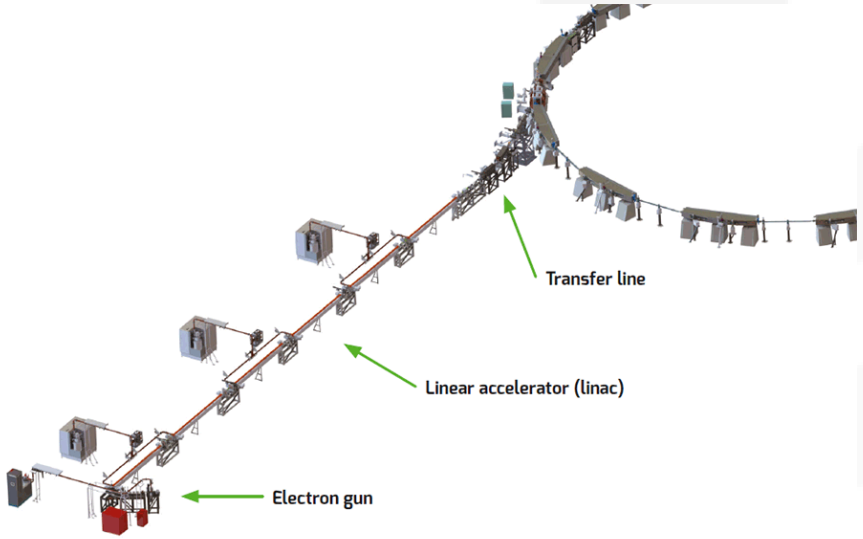

Storage ring

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- Main RF frequency – **99,937 MHz,**
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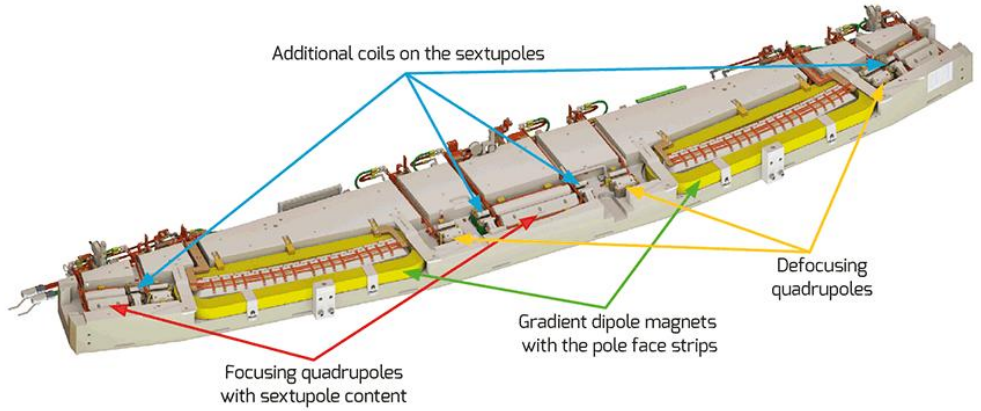
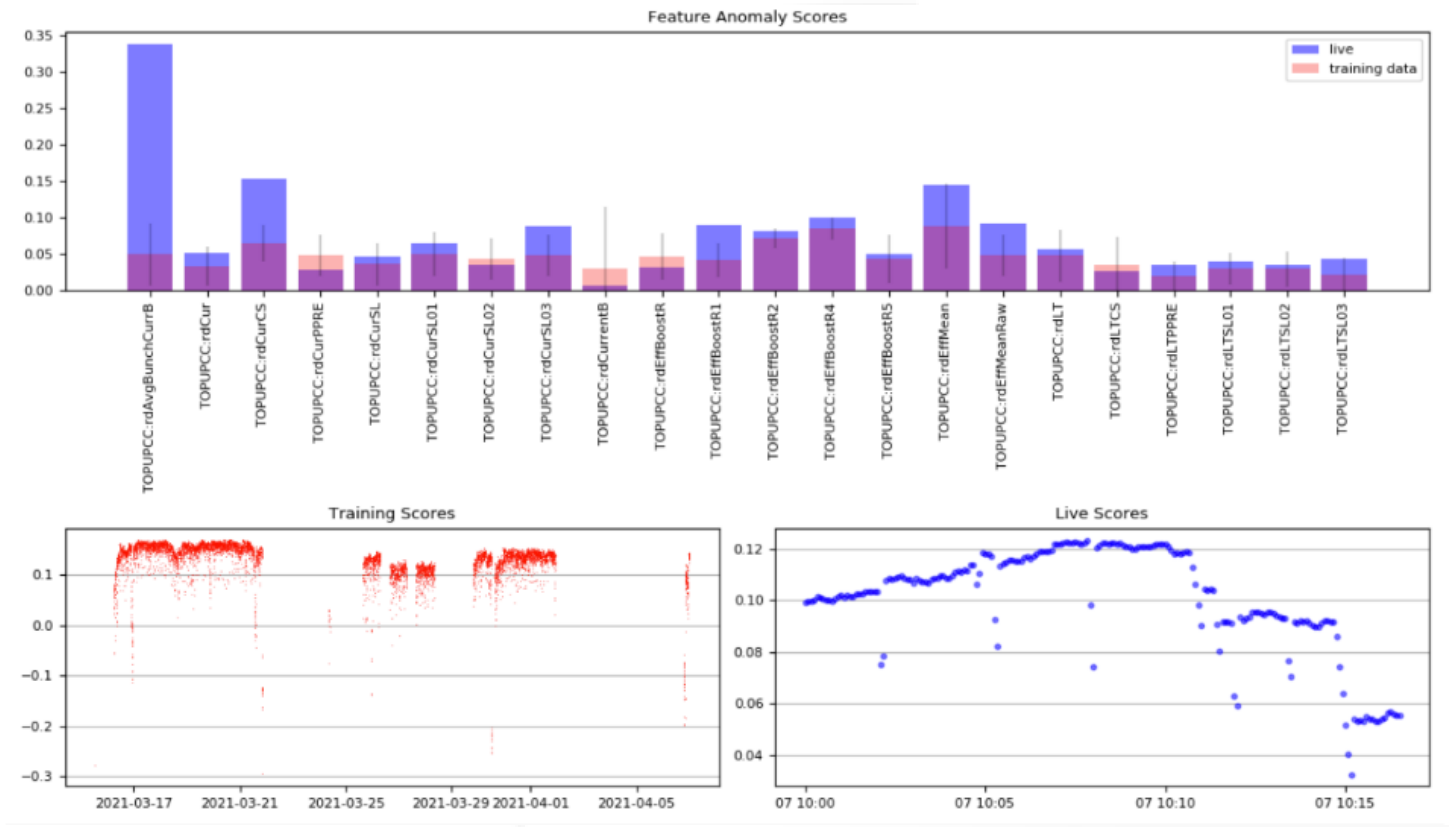
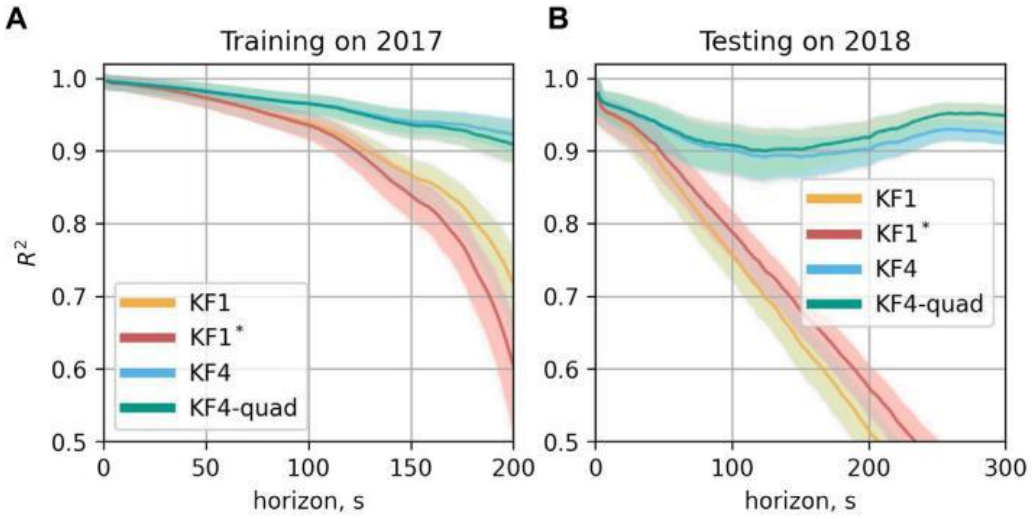


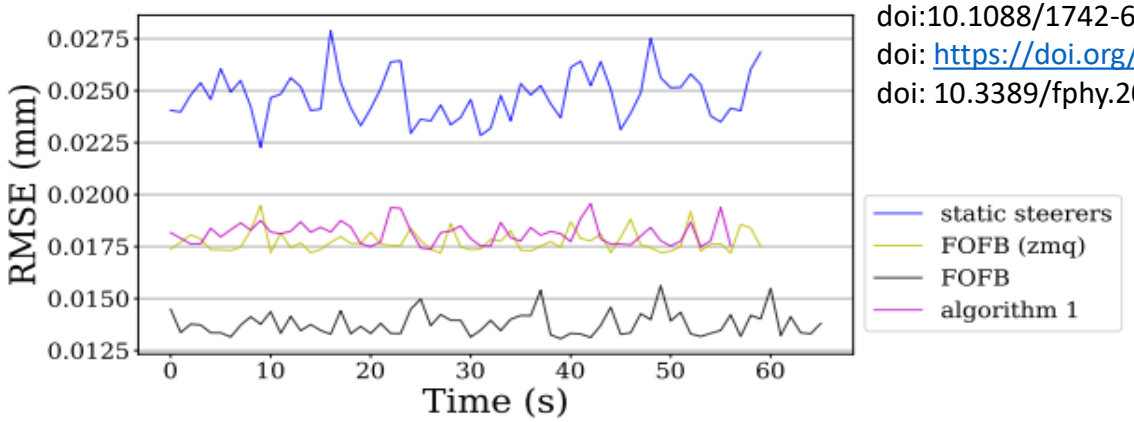
Machine learning in Synchrotron

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



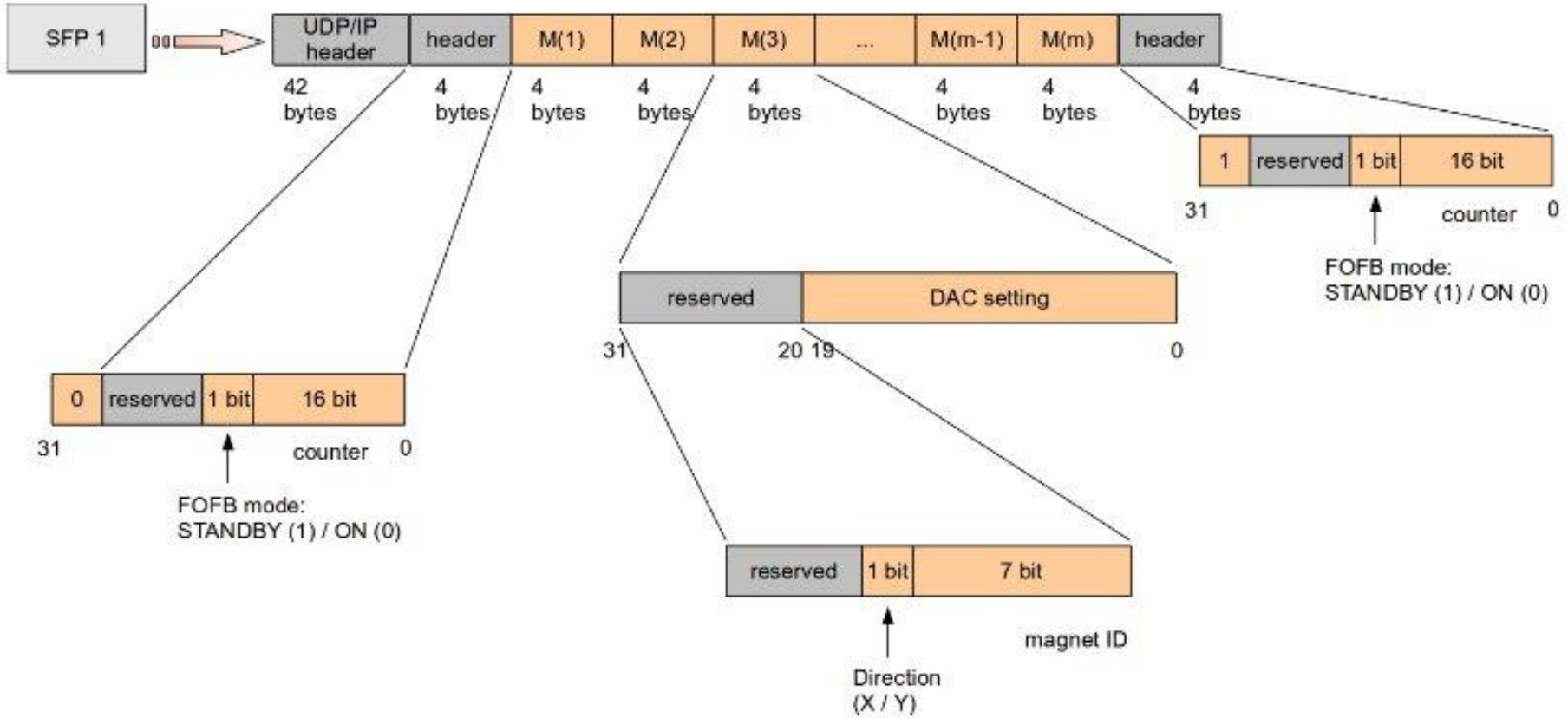




doi:10.1088/1742-6596/2687/6/062033
doi: https://doi.org/10.32479/ijeep.7605
doi: 10.3389/fphy.2022.960963

Streaming System

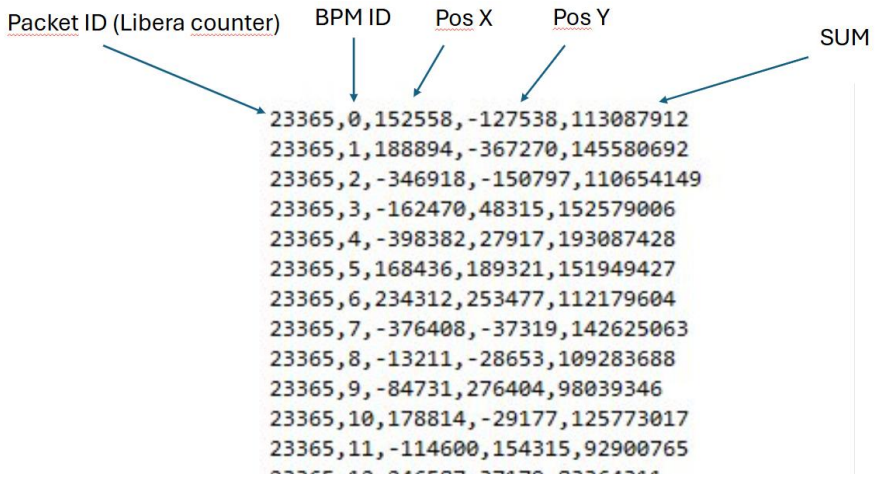
```
/* Magnet mode header */
struct libera_magnet_header_s {
    unsigned int counter : 16;
    unsigned int fofb_mode : 1;
    unsigned int reserved : 14;
    unsigned int end_of_packet : 1;
};

/* 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

Machine learning in Synchrotron

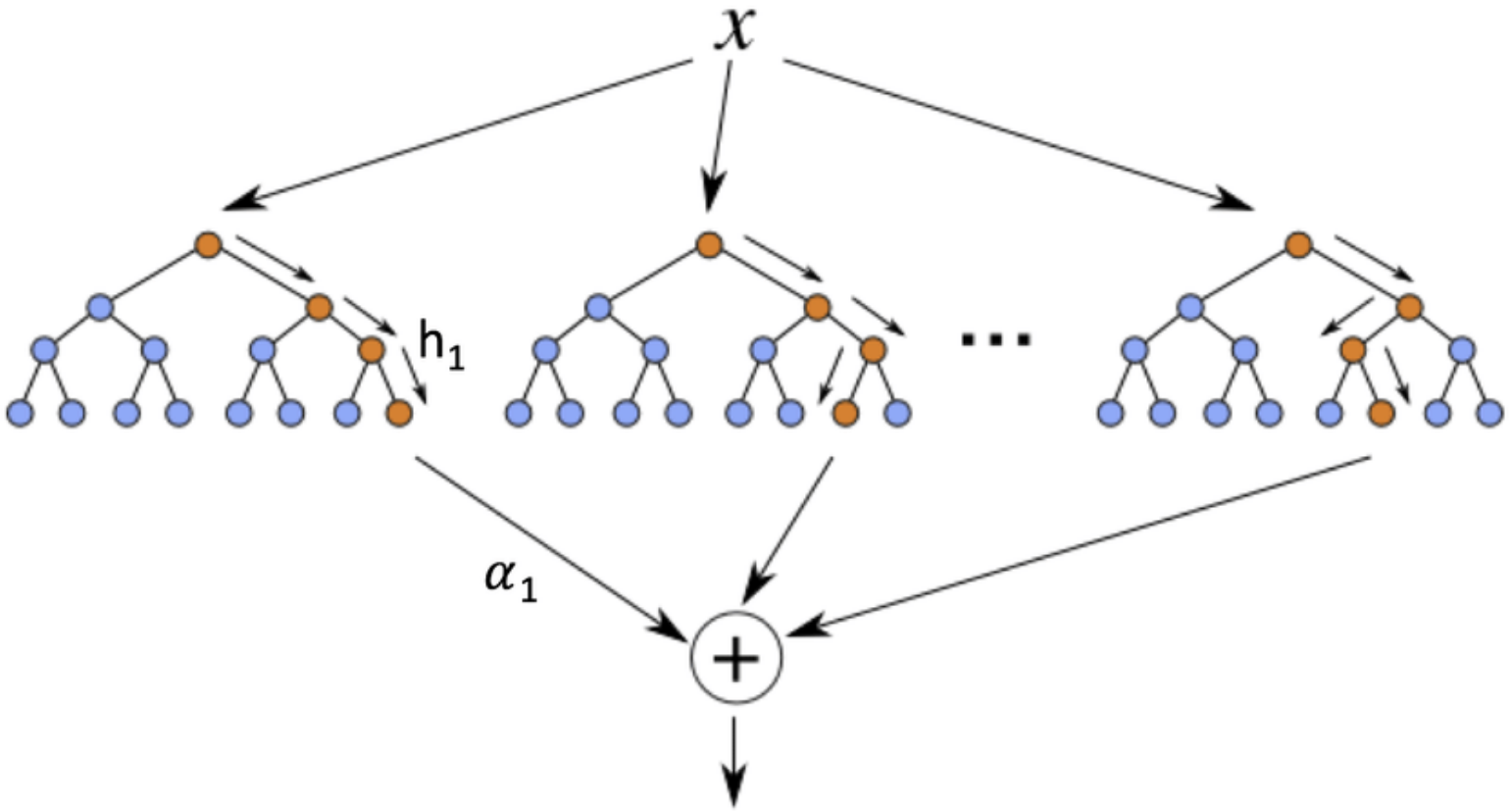
Beam anomaly detection - **Boosted Decision Tree**

XGBoost tree configuration

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

Scenarios data collection

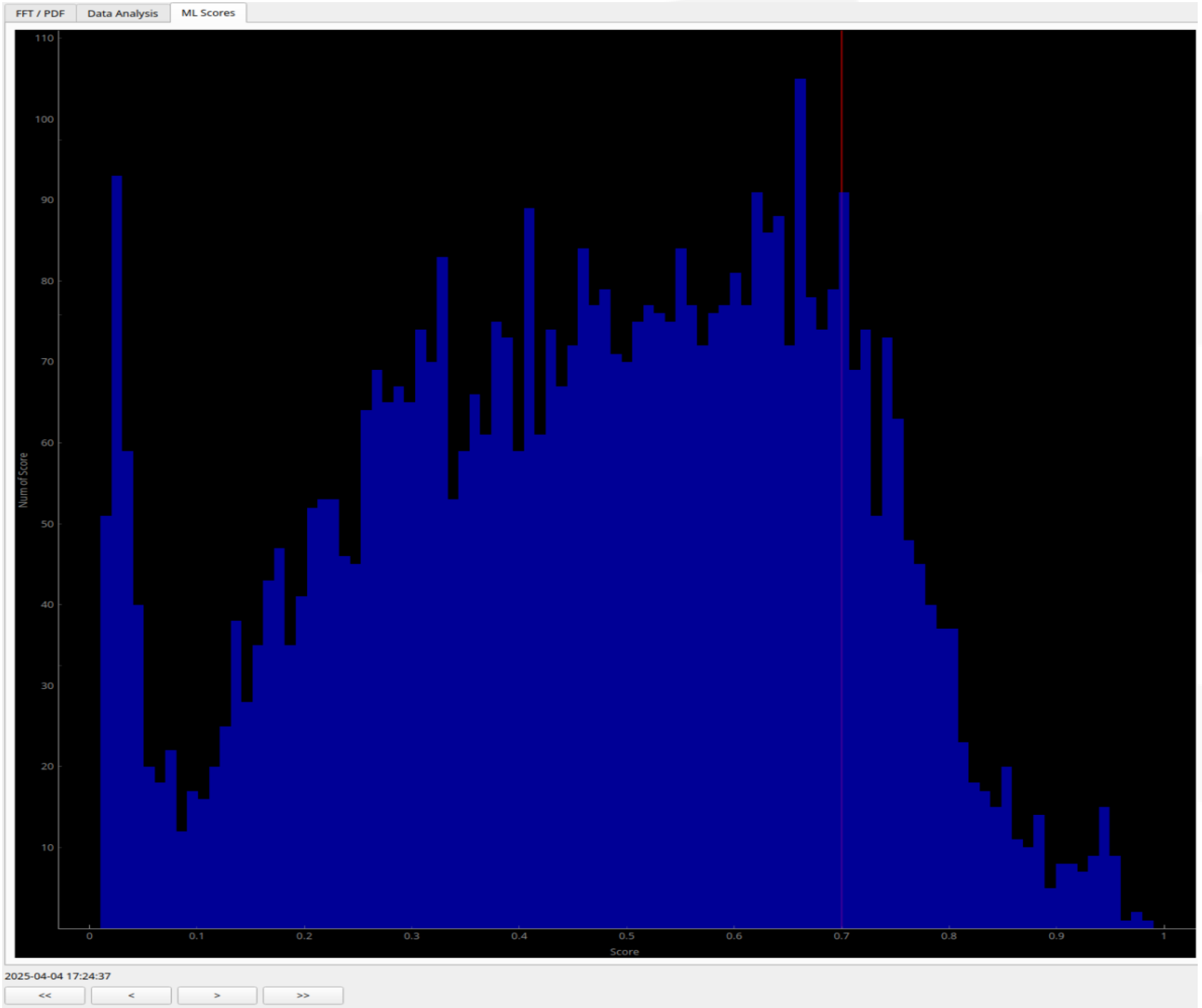
- RF active cavity power drop
- Magnet current fluctuation



Machine learning in Synchrotron

Beam anomaly detection – **Online application**

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

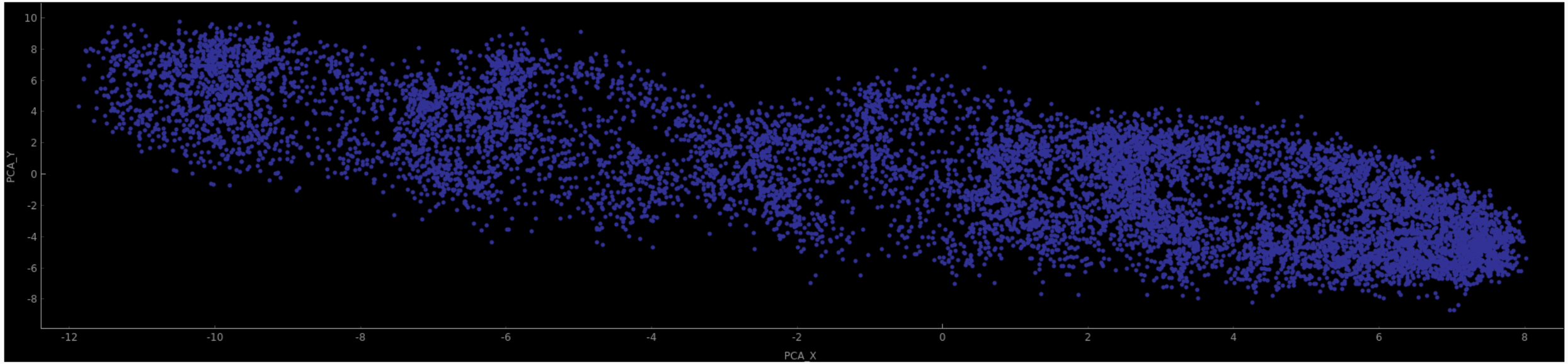


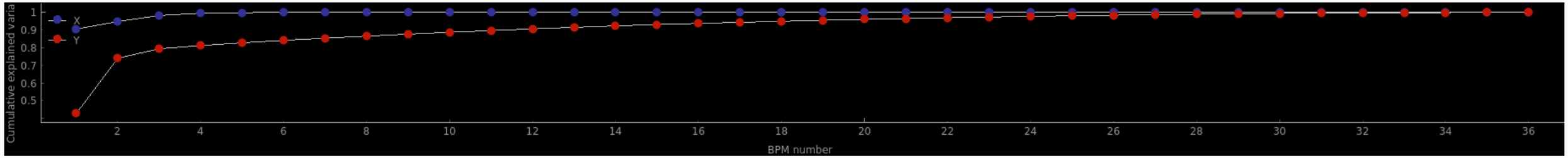
SOLARIS CENTRE

FA Diagnostic GUI (on dia-ml.machine)

FFT / PDF | Data Analysis | ML Scores

Data loss: 0.00%





PCA | Section 1 | BPM0X | BPM0Y

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