pyAT developments at Solaris, ML anomaly detection and measurement scripts porting

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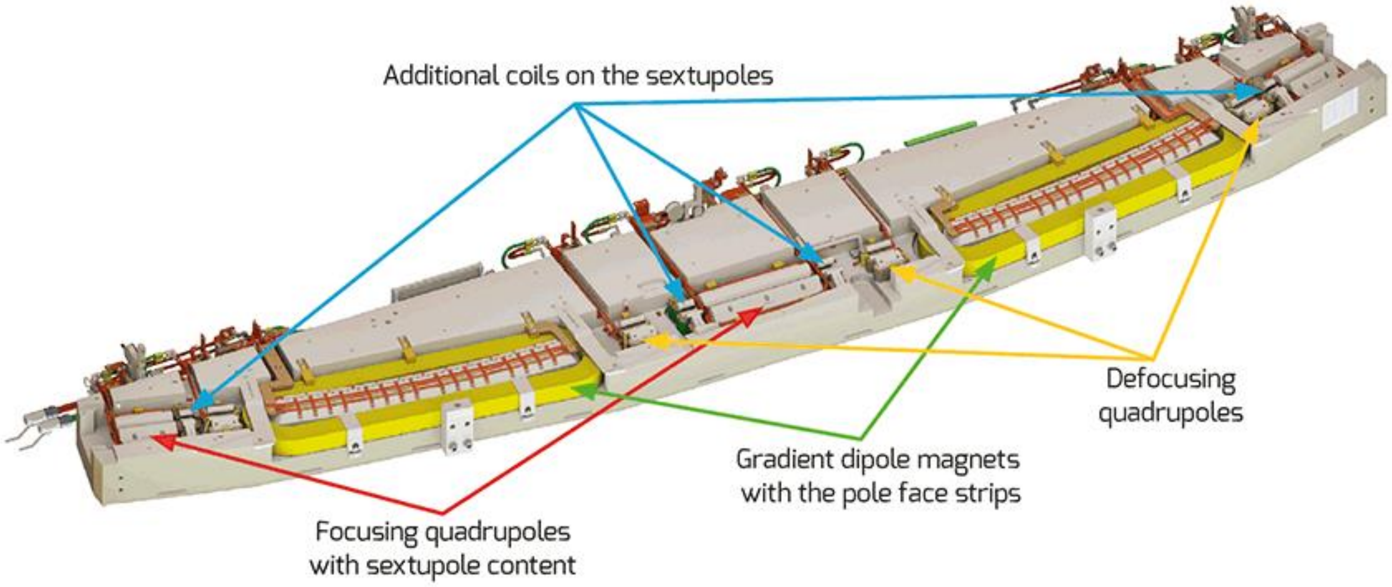
Agenda

- Introduction of the SOLARIS light source
- pyAT implementation at SOLARIS, lifetime simulation, realistic k-factors from LOCO fits
- Anomaly detection with ML, forecasting, detecting beam distortion, ground disturbance and BPM maintenance
- Measurement scripts porting to python
- Conclusions

The Solaris accelerator facility – electron storage ring

Energy	1.5 GeV
Max. current	500 mA
Circumference	96 m
Main RF frequency	99,93 MHz
Max. number of circulating bunches	32
Horizontal emittance (without insertion devices)	6 nm rad
Electron beam size (straight section center) σ_x, σ_y	184 μm, 13 μm
Electron beam size (dipole center) σ_x, σ_y	44 μm, 30 μm
Max. number of insertion devices	10
Momentum compaction	3.055×10^{-3}
Total lifetime of electrons	13 h

One DBA cell – 12 in the entire ring



Beam correction and diagnostic:

-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

pyAT implementation at SOLARIS

- Simulations of the storage ring
- Active cavities included
- Realistic k factors for dipoles and SQF-in/out included
- Tauchek time simulation vs measurement

```
Simulation of SOLARIS storage ring, no IDs, no Landau cavity.

Setup as follows:
Frac. tunes (6D motion): [0.24074793 0.17832712 0.0019657 ]
Energy: 1.500000e+09 eV
Energy loss / turn: 1.172449e+05 eV
Mode emittances: [6.12394576e-09 6.80792546e-36 1.33319094e-05]
Damping partition numbers: [1.46656042 0.99999951 1.53344006]
Damping times: [0.00566874 0.00831356 0.00542151] s
Energy spread: 0.000750828
Bunch length: 0.0177564 m
Cavities voltage: 397200.0 V
Synchrotron phase: 2.84195 rd
Synchrotron frequency: 6050.16 Hz

Tauschek 32 bunches sim: 26.4 (300mA), 1000 turns
Tauschek 32 bunches meas: 23.1 (300mA)
Tauschek 29 bunches meas: 26.6 (300mA)

RF setup.
99.92809621818222 MHz Radiation off
98.4918938031579 MHz Radiation on
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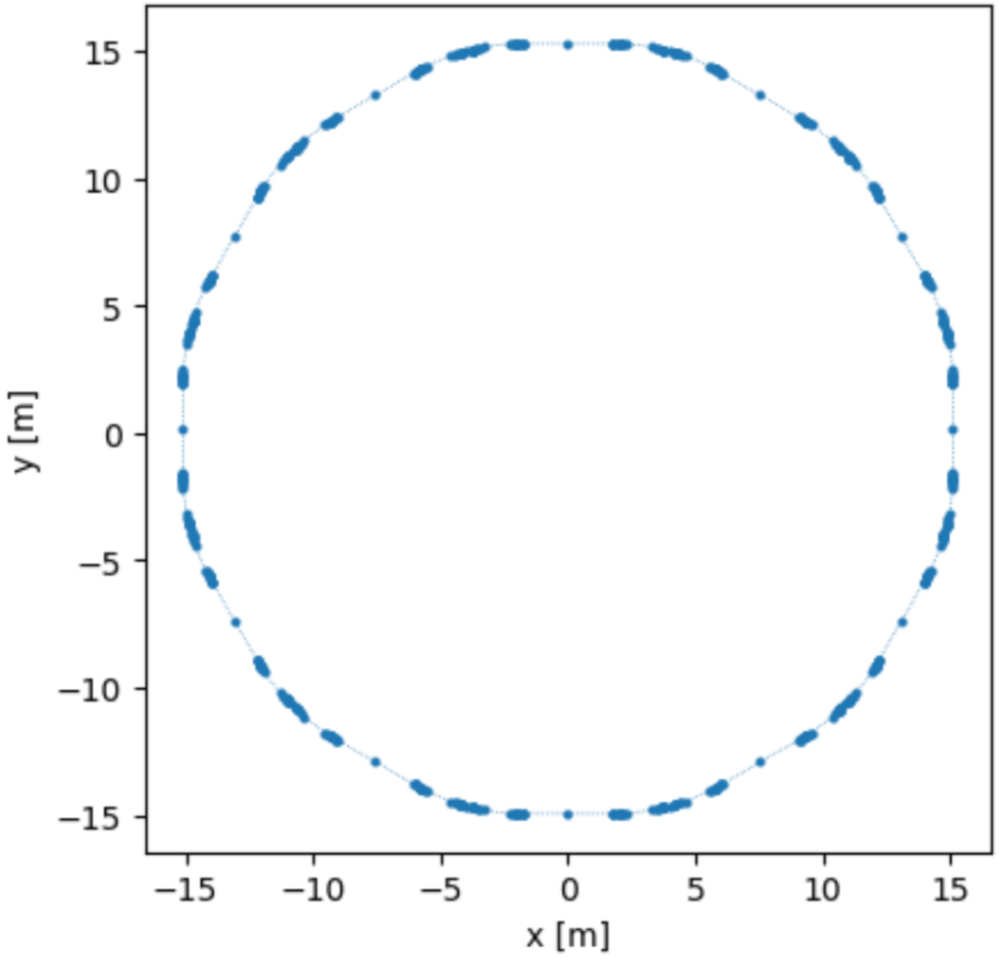
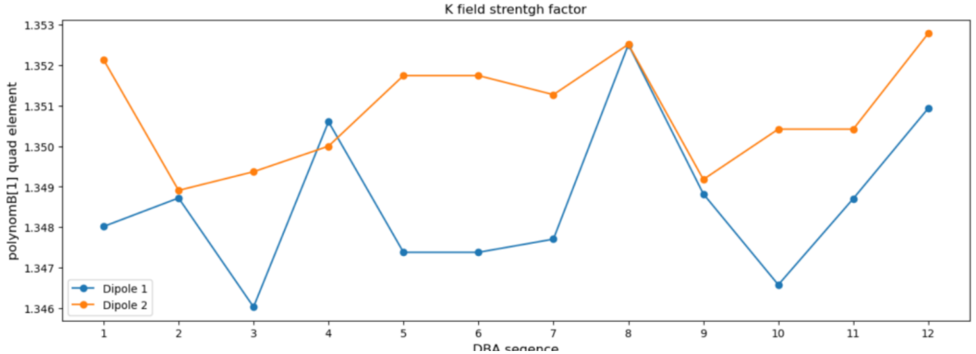
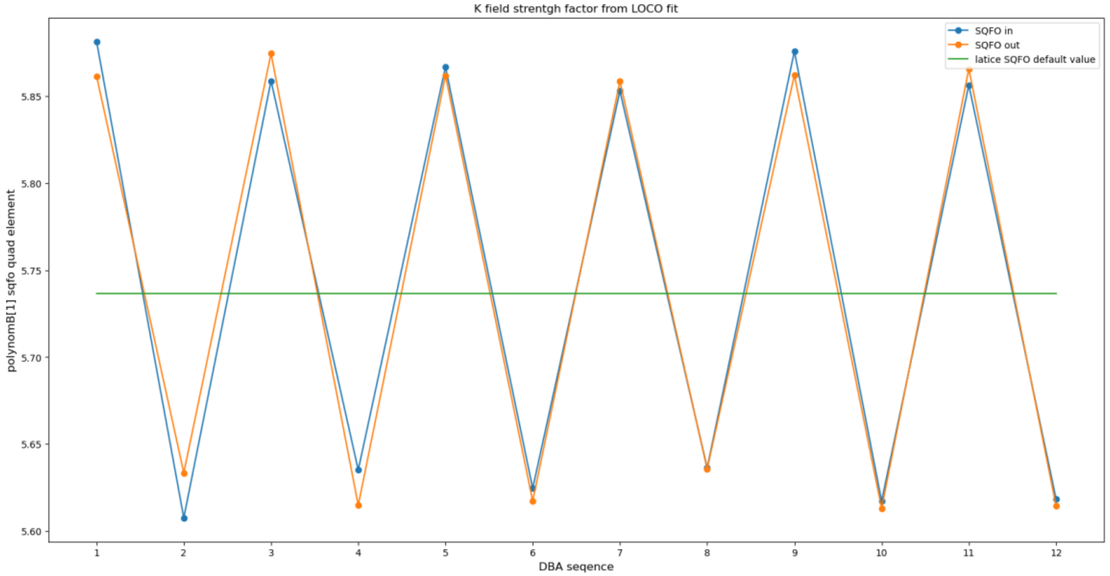
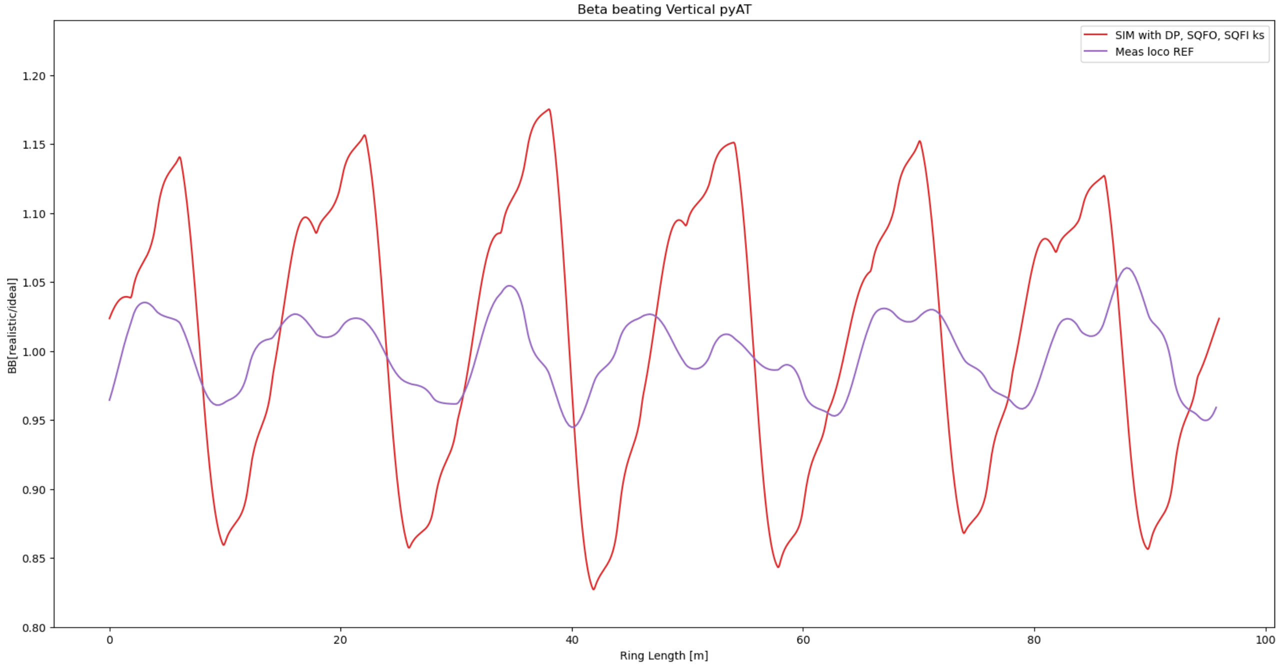


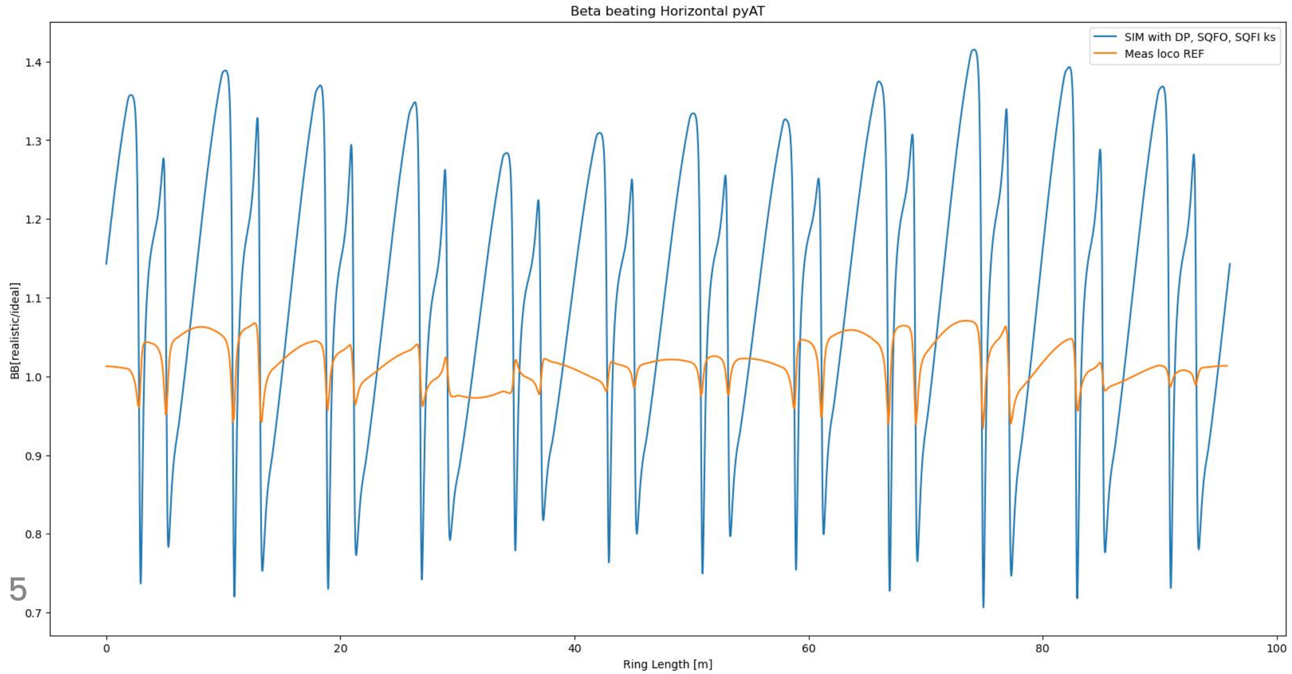
pyAT implementation at SOLARIS

- LOCO fits were used to estimate the SQFi/o horizontal focusing field strength (k)
- The quad element for the dipoles (vertical focusing) was also included in the simulation
- Beta beat calculations are overlapped with the ones coming from LOCO measurements









The problems

- Anomaly detection package for „on the fly” diagnostics (RF Cavity problem, mechanical movement)
- Undulator correction table generation
- Response matrix forecasting

The possible „<u>solution</u>”

- <u>**Fast deployment**</u>
- <u>**Engineering**</u> non-scientific approach (plug & play)
- Lots of ready to use easy packages
- In the future one can switch to <u>**Theano**</u> for custom neuron design, <u>**possible publication**</u>

Solutions for anomaly detection

Key features:

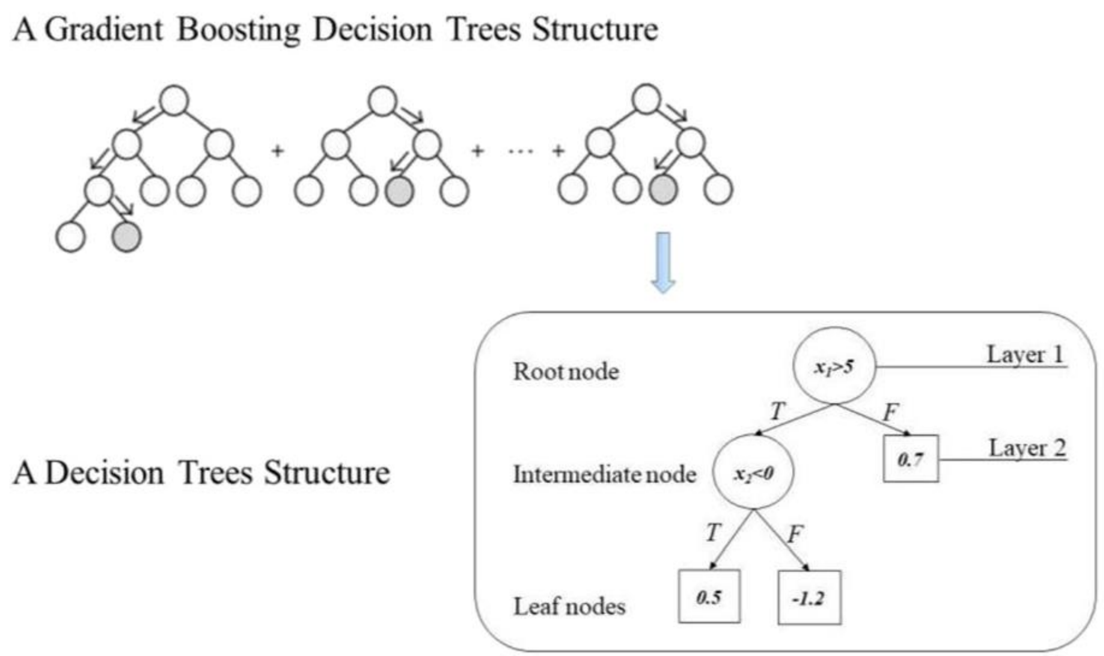
✓Multi class

✓Simple architecture – easy tune

✓Fast, utilize many cores on CPU

✓Low memory consumption

✓n- dimensional input/output



Collaborative effort between:
A. Wawrzyniak, M. Mleczko, M. Żurek, J. Wiechecki, M. Piszak, J. Biernat

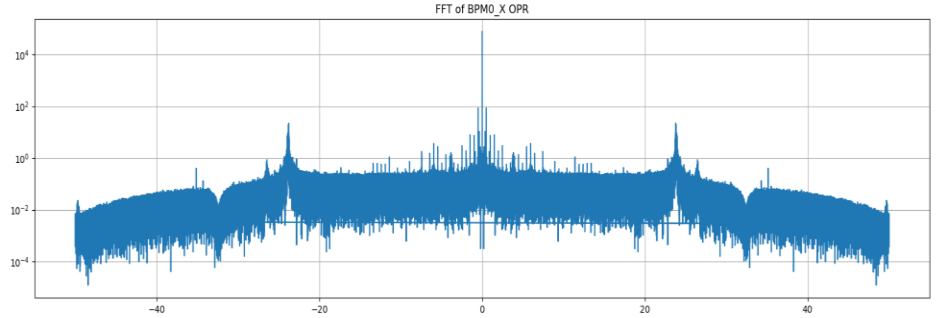
https://doi.org/10.1007/s00170-020-06078-z

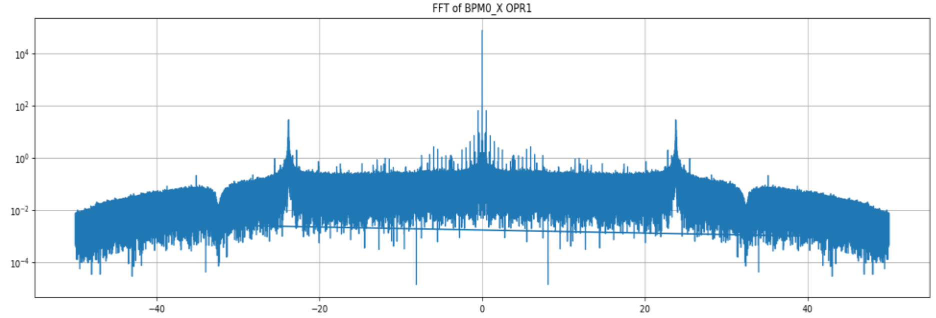
Solutions ready for deployment

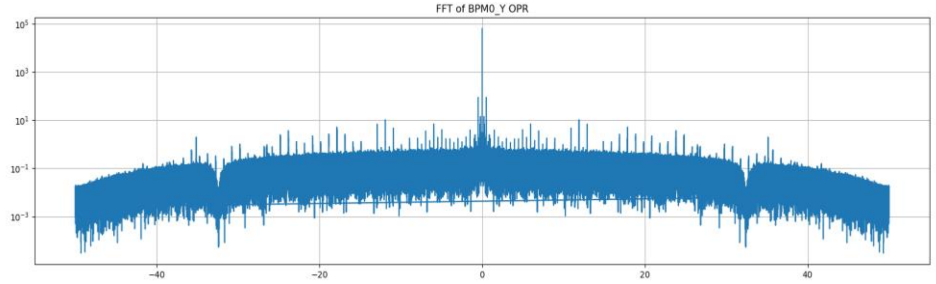
Acquisition system:

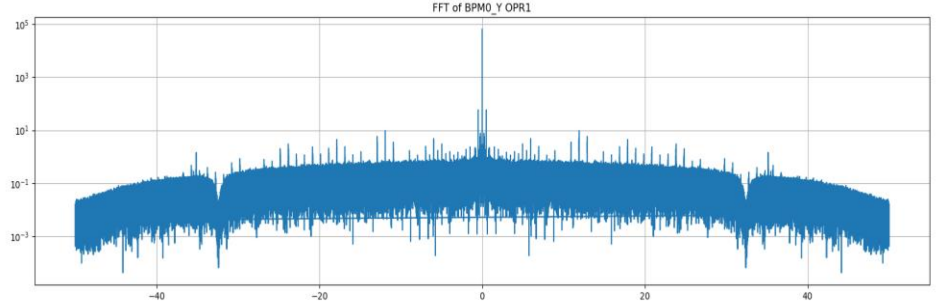
- Direct signal acquisition system from the BPMs
- 10 kHz data collection rate (one sample is 0.1 ms) for each BPM (72 observables)
- FFT and PDF calculation for a fixed window of time for each monitor
- Two scenarios considered: RF cavity 1 and cavity 2 power drop and ground disturbance

X,Y position readout FFT distribution for different operation days, time window is 1 minute- OPR acts as a **TRAINING** set and OPR 1 acts as **TESTING**



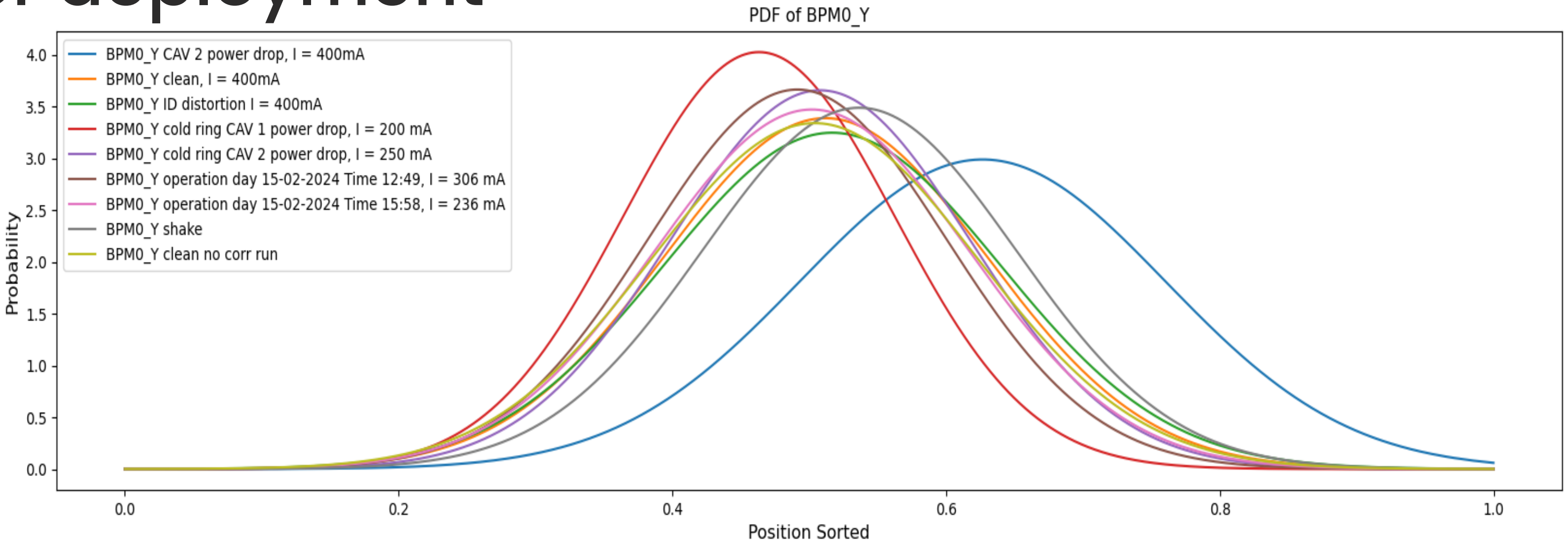


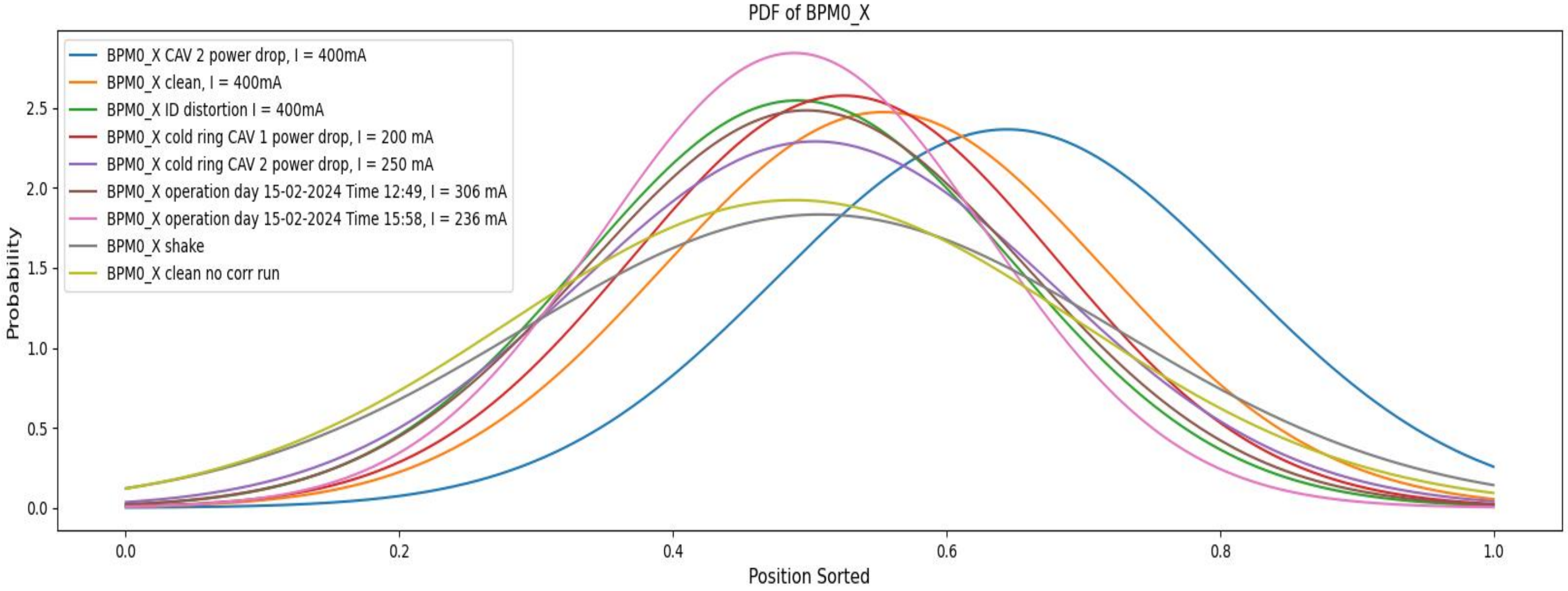




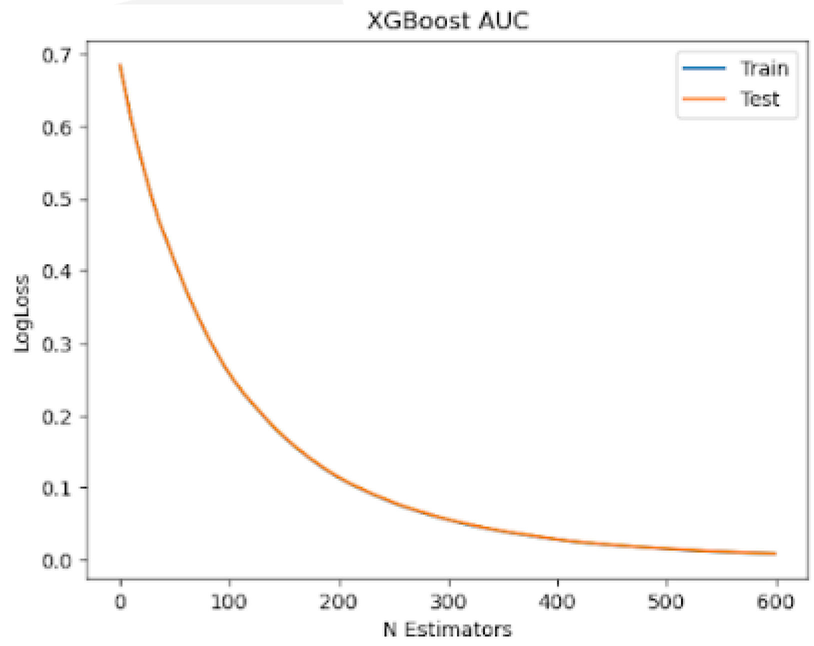
Solutions ready for deployment

Probability densities function for X and Y position normalized to 1. Different scenario included, 1 minute time window.



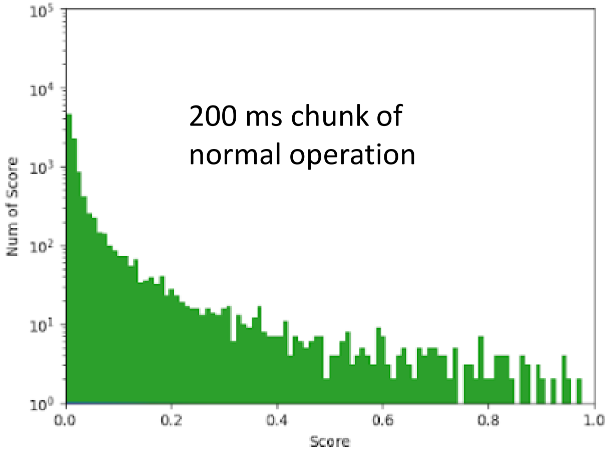


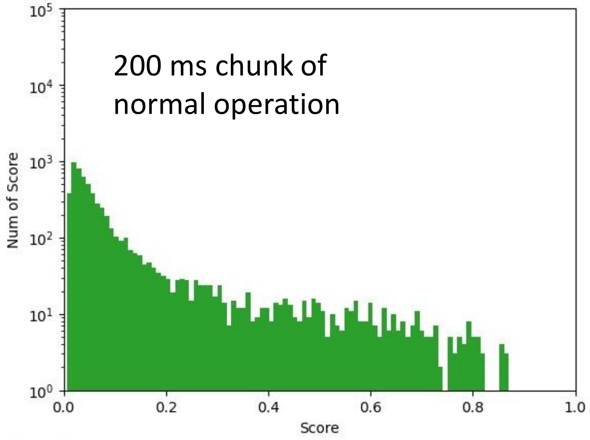
Solutions ready for deployment

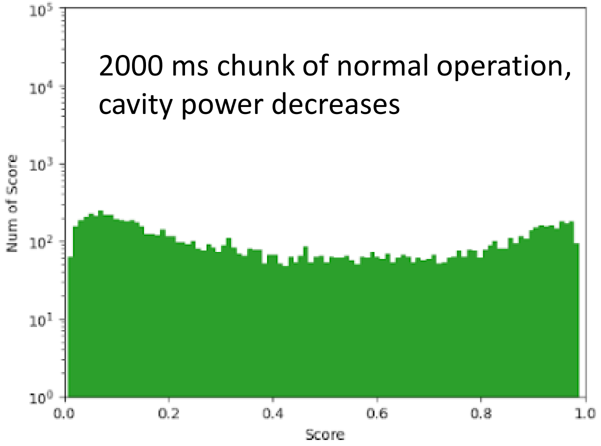


XGBoost tree configuration:

- Number estimators = 600
- Learning rate = 0.01
- Max depth = 10
- Objective = binary:logistic
- Verification based on standard **ROC** curve

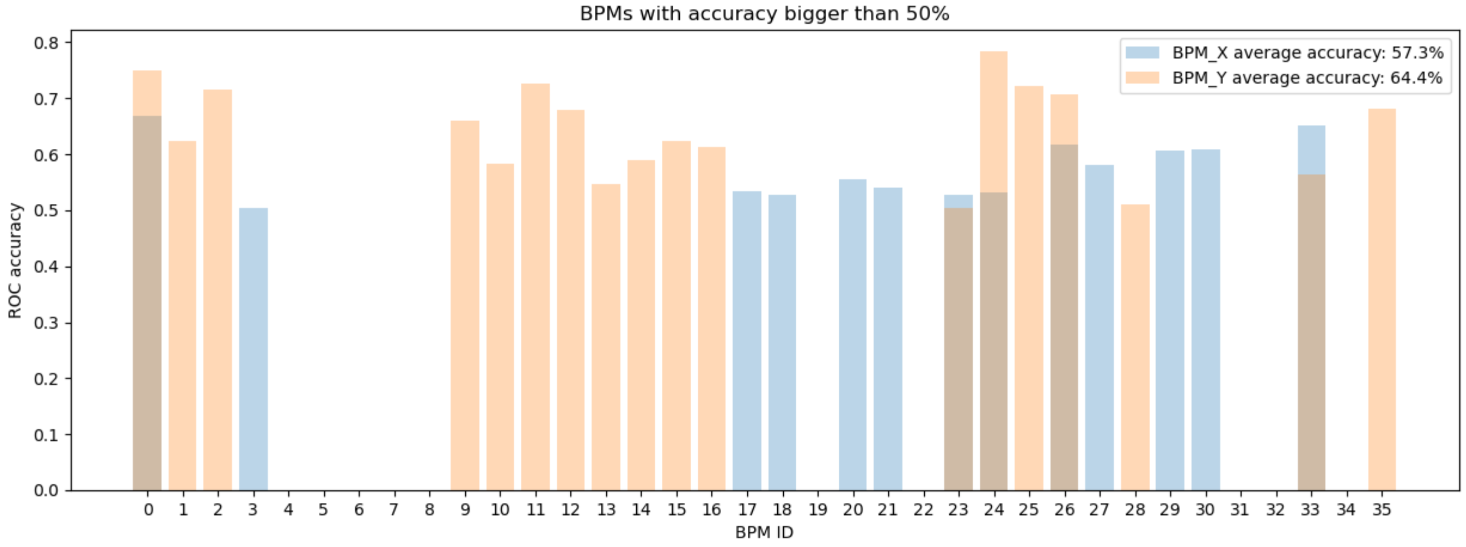




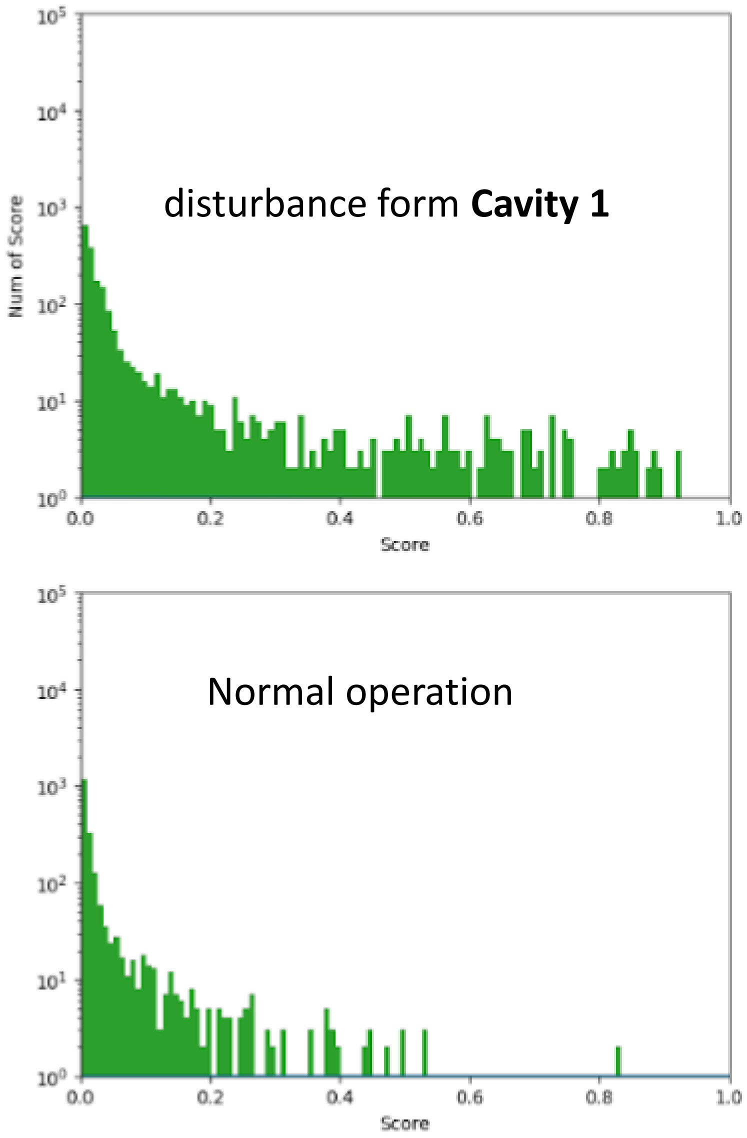


Solutions ready for deployment

- Similar test but the data for prediction comes from a **disturbance** from **Cavity 1**
- The beam current is reduced to **200 mA**
- Tests of BPM wise accuracy



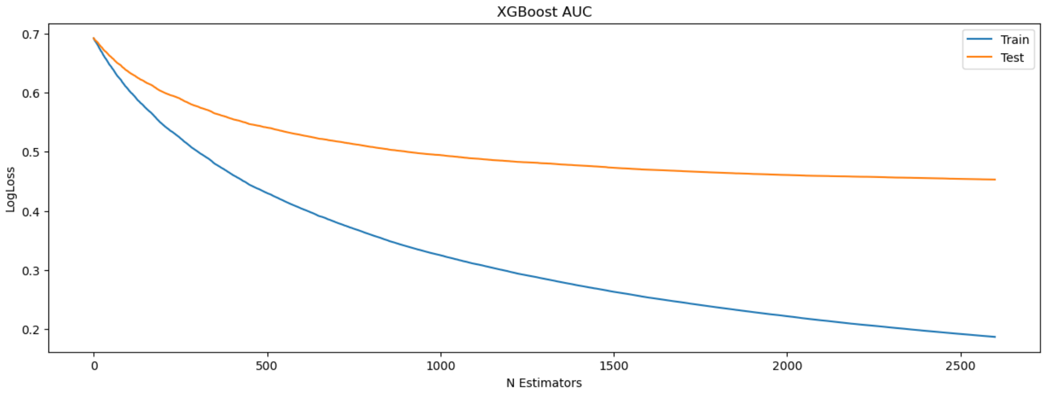
200 ms chunk

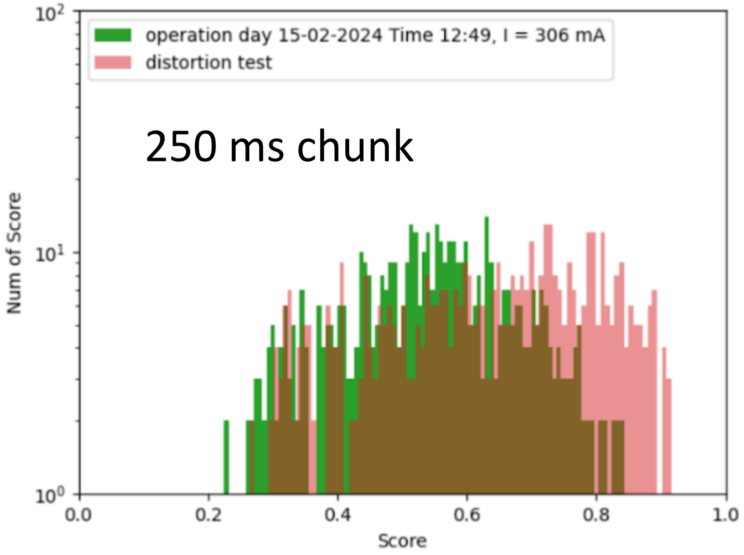


Solutions ready for deployment

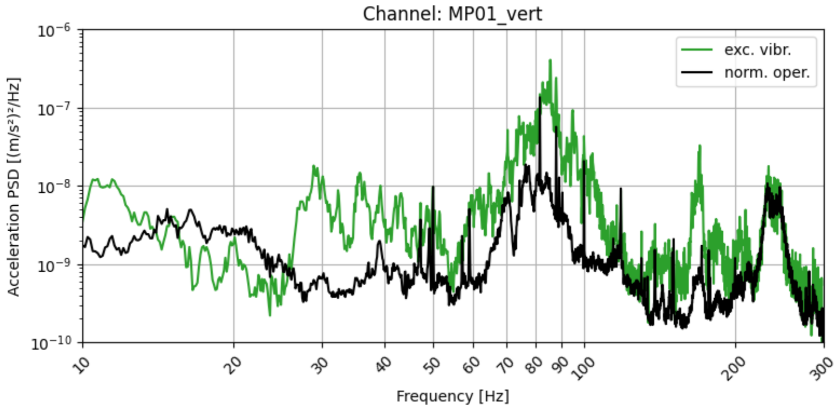
A glimpse into the test of ground disturbance detection and the influence of it on the beam position. Prediction done on a normal operation day with measurements and work on beam lines

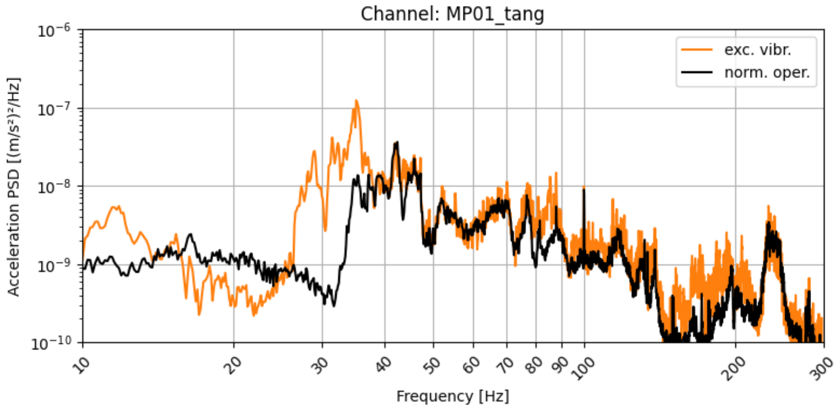
Source of vibration





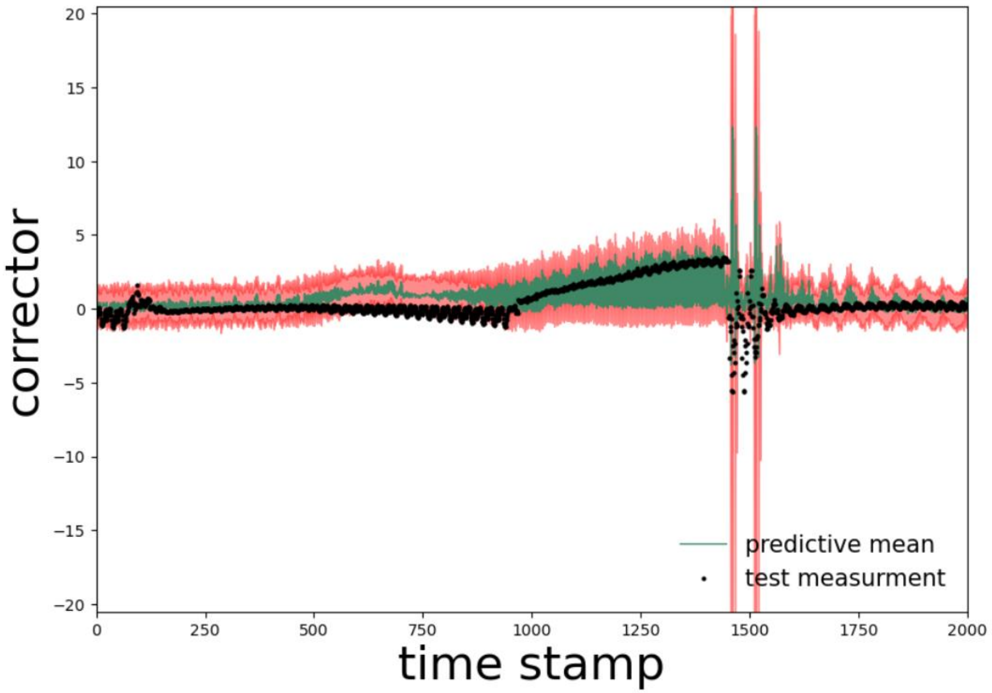
VMS ground disturbance detection





Solutions ready for deployment

- Bayesian neural network used for forecasting Undulator corrector current using Markov chain Monte Carlo for prior weight generation (100 bin – low precision due to PC computing power constrains)
- 2 years of previous operation used for training

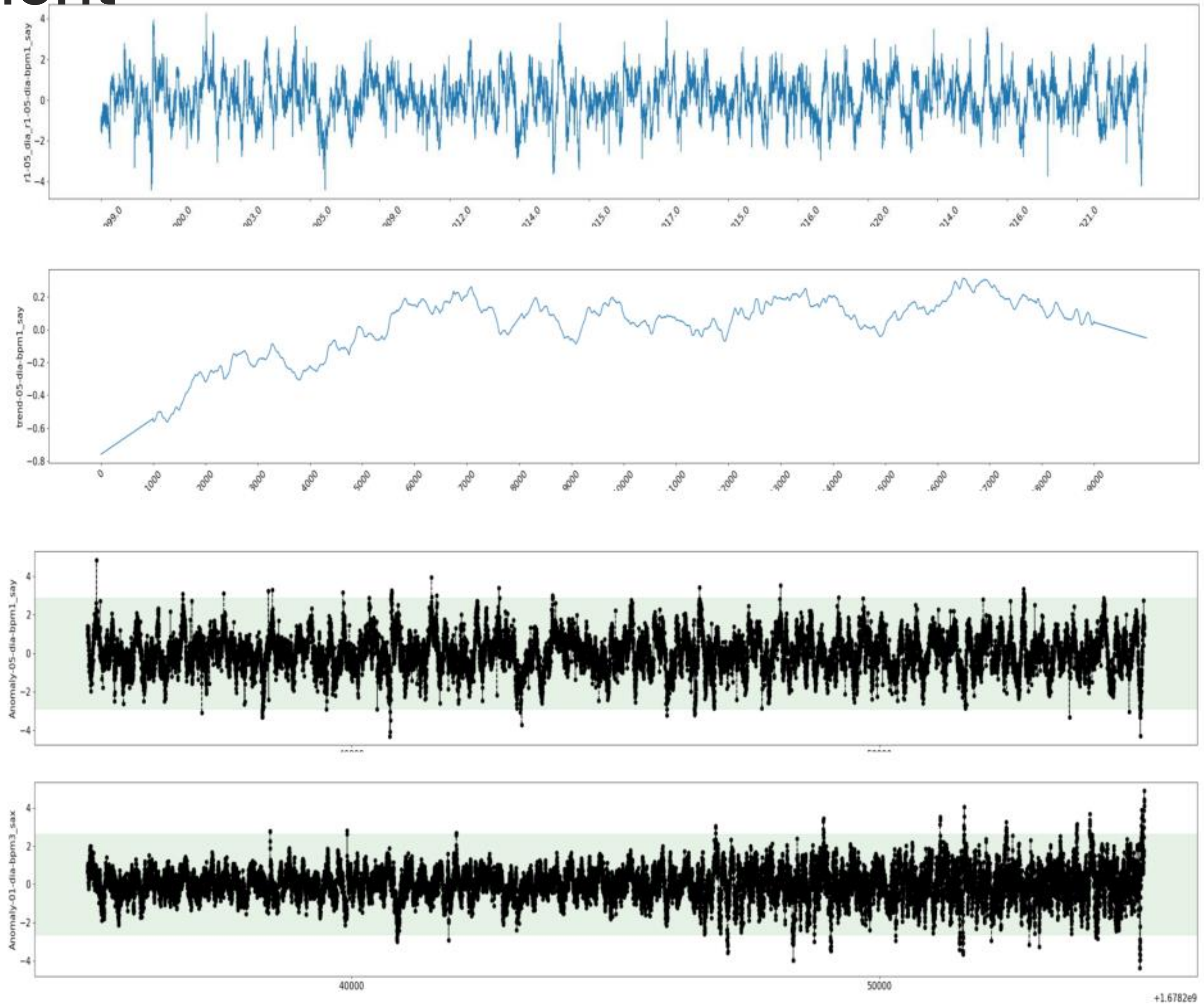


$$P(A|B) = \frac{P(B|A)P(A)}{P(B)}$$

$$V = \{v = (v_1, \ldots v_d) \in \{0,1\}^d : \sum_{i=1}^{d} v_i w_i \leqslant B\}$$

Bayes, T. 1764. "An Essay Toward Solving a Problem in the Doctrine of Chances", *Philosophical Transactions of the Royal Society of London* **53**, 370-418.

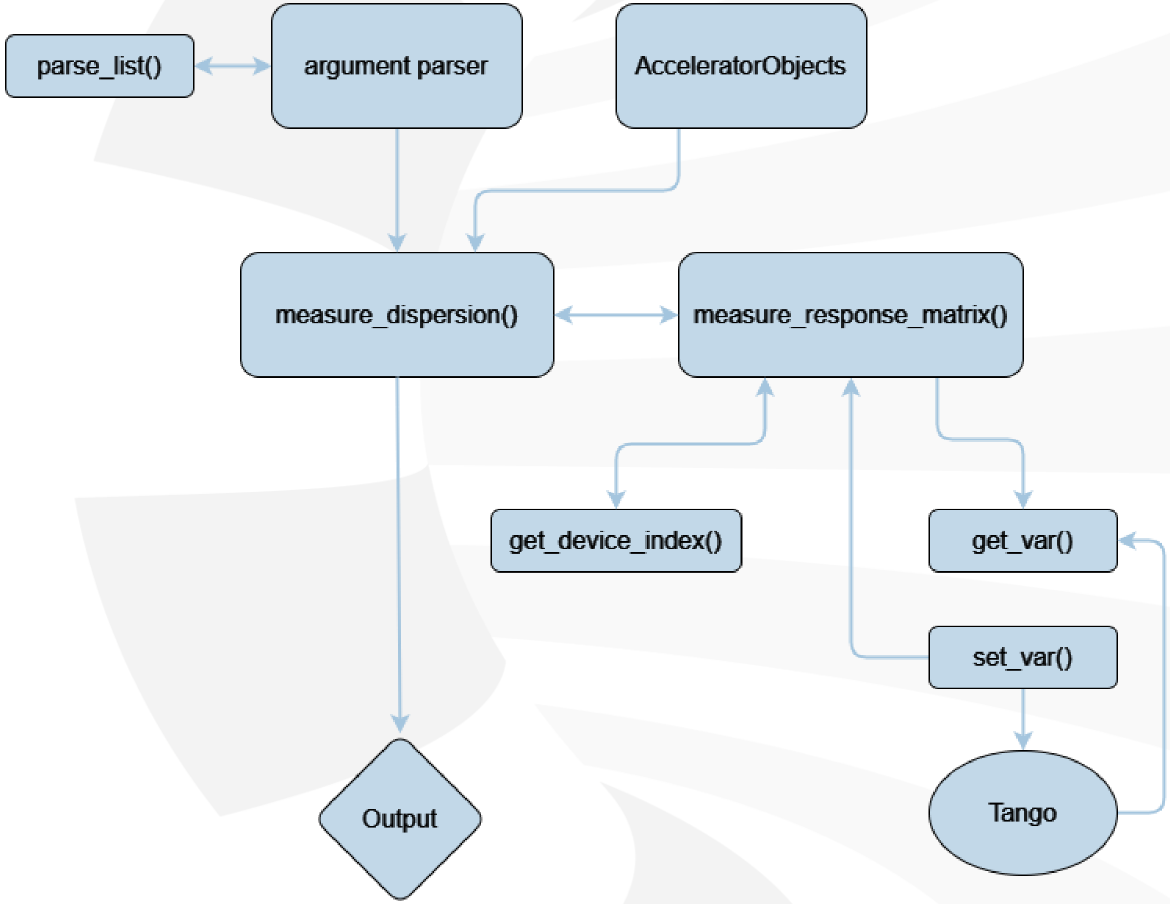
Solutions ready for deployment



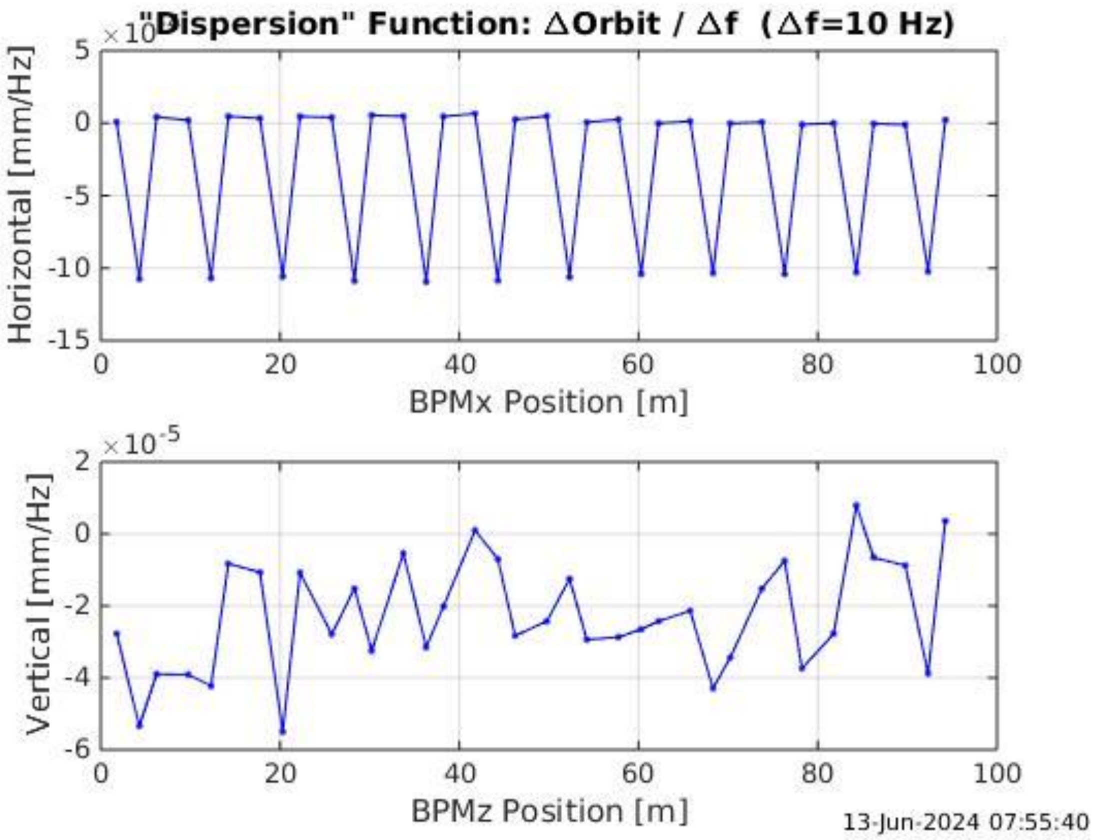
- Anomaly detection based on the trend estimation
- 5 sigma detection threshold (Green band)
- Useful for on-line BPM diagnostic, removing malfunctioning units on the fly
- Similar can be done with PCA

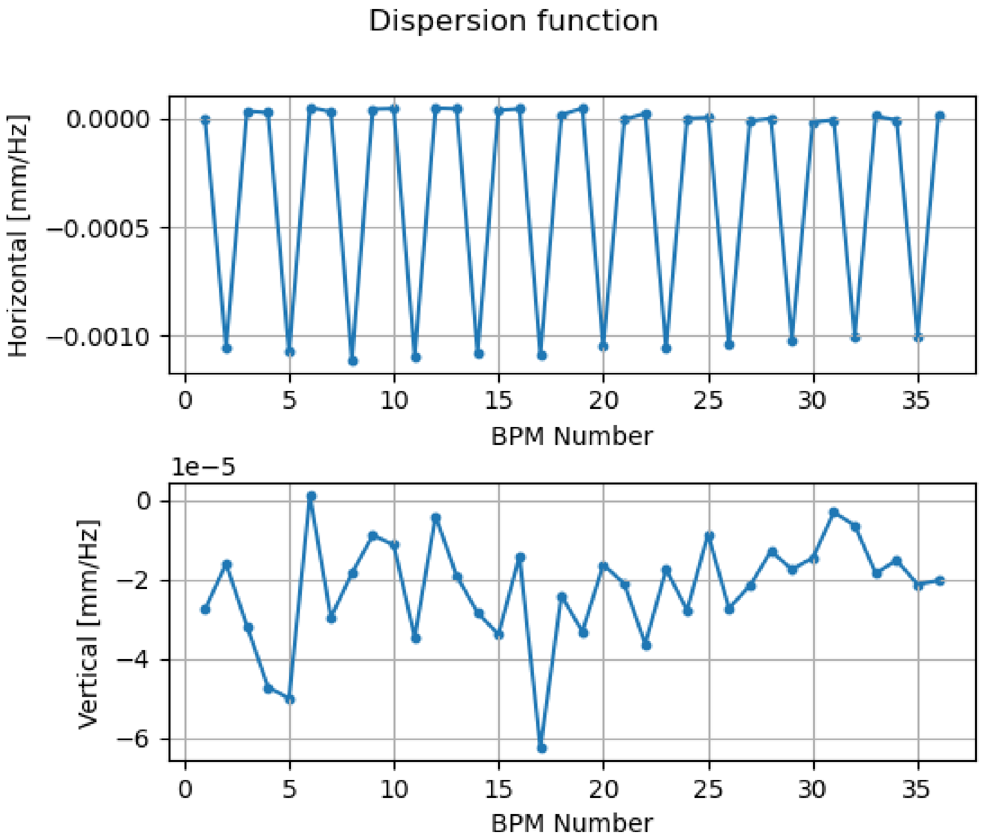
Measurement Scripts Porting

- Development of pyML, based on available MML scripts
- Simplified code structure and function dependencies
- Focus on preserving the original functionality, while improving accessibility and performance



Measurement Scripts Porting





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Conclusions

- We are moving towards fast solutions based on ML for beam diagnostics, corrections including effects coming from insertion devices
- At first, we will deploy algorithms based on TF and Keras to move to testing online as soon as possible
- In the future we plan to make a custom network design based on Theano
- Developments of pyML will continue

Thank you!

backup

https://arxiv.org/ftp/arxiv/papers/2005/2005.05744.pdf

Functional code form Solaris and past experiments

Long Short-Term Memory networks – usually just called "LSTMs" – are a special kind of RNN, capable of learning long-term dependencies. KI

Key features:

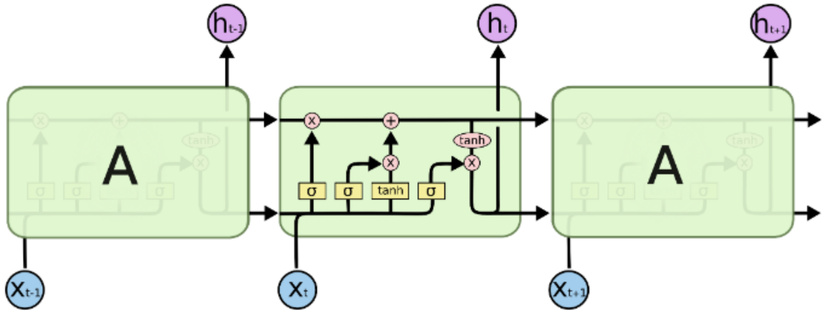
✓learning memory

✓Non- sequential

✓Fast, utilize many cores on a GPU

✓Low memory consumption compared to BSTS

✓n- dimensional input/output



The repeating module in an LSTM contains four interacting layers.

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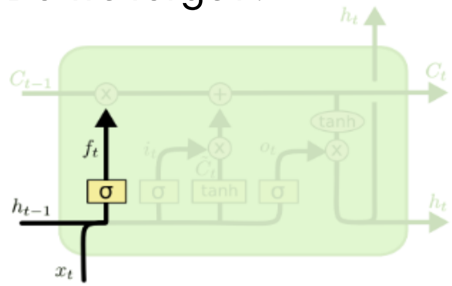
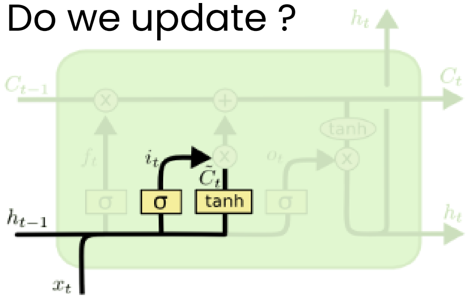
Do we forget ?



$$f_t = \sigma\left(W_f \cdot [h_{t-1}, x_t] \ + \ b_f\right)$$

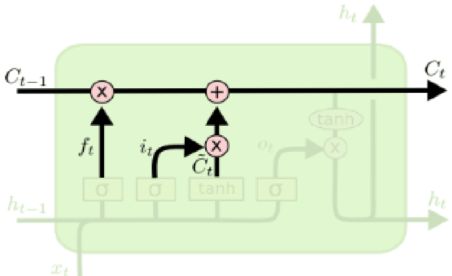
Do we update ?



$$i_t = \sigma\left(W_i \cdot [h_{t-1}, x_t] \ + \ b_i\right)$$

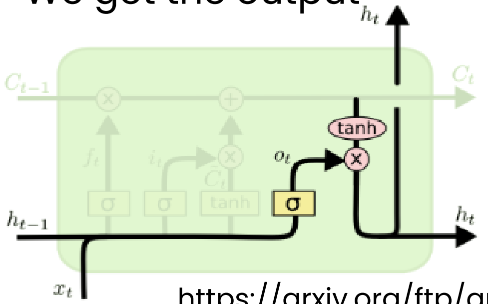
$$\tilde{C}_t = \tanh(W_C \cdot [h_{t-1}, x_t] \ + \ b_C)$$

We shift the cell to a new state



$$C_t = f_t * C_{t-1} + i_t * \tilde{C}_t$$

We get the output



$$o_t = \sigma\left(W_o \ [h_{t-1}, x_t] \ + \ b_o\right)$$

$$h_t = o_t * \tanh\left(C_t\right)$$

https://arxiv.org/ftp/arxiv/papers/2005/2005.05744.pdf

ALS-U

Constraints for ALS-U lattice optimization.

Natural emittance	$\epsilon_0 < 155\,\mathrm{pm\,rad}$
Maximum beta	$\beta_{x,y} < 30\,\mathrm{m}$
Maximum dispersion	$\eta_x < 15\,\mathrm{cm}$
Fractional tunes	$0.1 < \nu_{x,y} < 0.4$
Dispersion at center of straight	$\lvert\eta_x^*\rvert < 1\,\mathrm{mm}$
Beta at center of straight	$1\,\mathrm{m} < \beta_{x,y}^* < 5\,\mathrm{m}$
Beta in central arc bends (B3)	$\beta_{x,y}^{\mathrm{B3}} < 4\,\mathrm{m}$
Fractional tune difference	$\left\lvert \nu_x - \nu_y \right\rvert < 0.01$
Chromatic sextupole strength (SF, SD)	$b_2 < 900\,\mathrm{m}^{-3}$