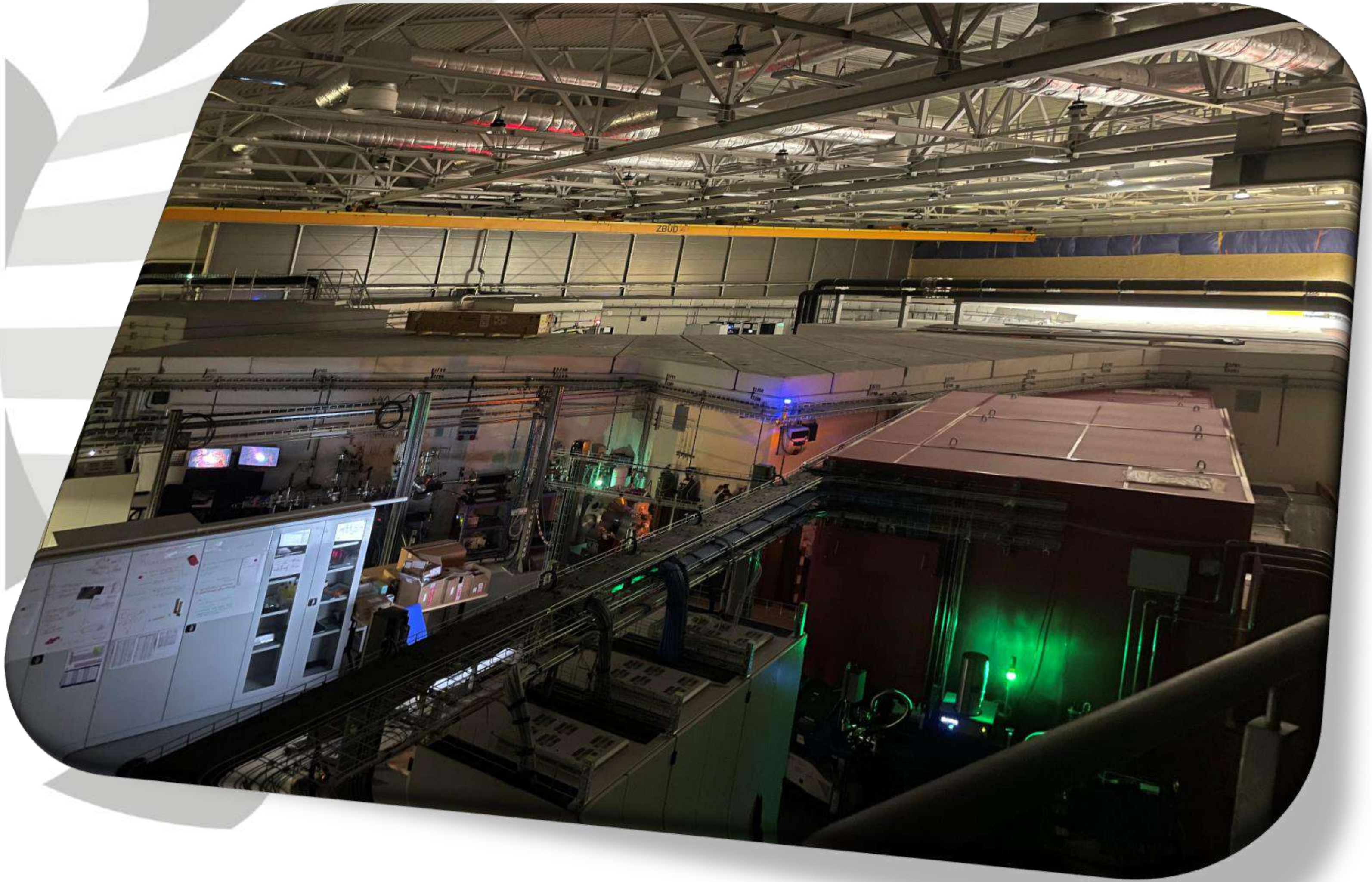
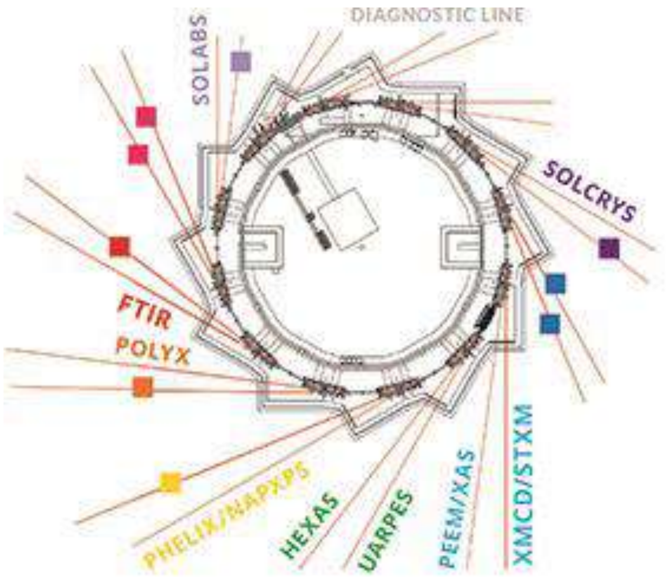




SOLARIS
CENTRE

Introduction of the Solaris facility and the status of operation of the Libera Brilliance+ BPM system

Jacek Biernat

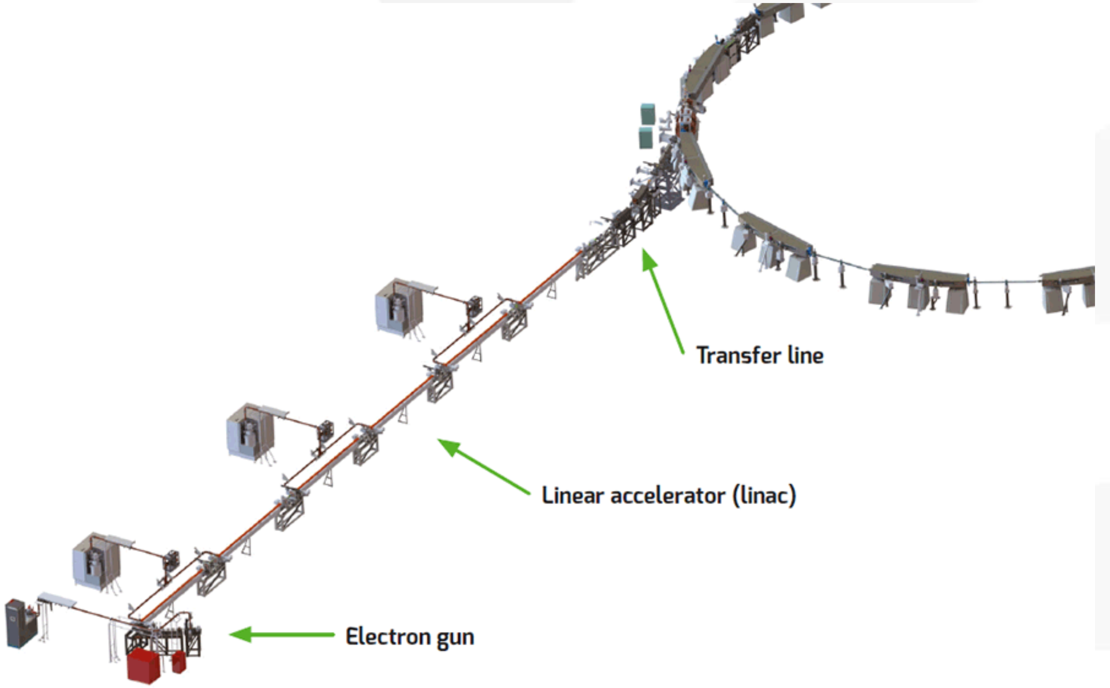
SOLARIS National Synchrotron Radiation Centre

Contents

- Introduction of the SOLARIS
- Present and the future of SOLARIS
- Machine Learning, Time Series analysis, Forecasting/ (possibly anomalous behavior detection) with neural networks
- Conclusions

The Solaris accelerator facility – linear booster accelerator

Delivered injection energy [MeV]	550
Single bunch charge [nC]	0,2
Beam current [mA]	600
Normalized emittance (rms) horizontal /vertical [mm mRad]	3,111/2,175
Energy spread at the injector exit [keV]	400
Length of a single electron bunch [ps]	14



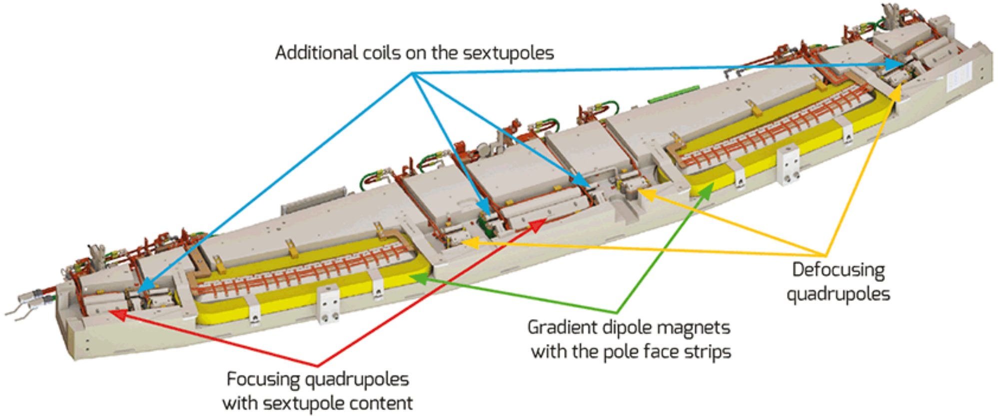
The thermionic electron radio frequency (RF) gun is a 3 GHz RF cavity. The source of the electrons is BaO. The pulsed electric field bunches an electron beam and accelerates it up to 2.8 MeV.

The linear accelerator (linac) consists of six 5 m long S-band travelling wave accelerating structures combined in three accelerating units. Each accelerating unit contains one SLED (SLAC Energy Double`r) cavity and **two linac** structures and is powered by an RF amplifier. Linac is 40 m long and delivers maximum beam energy of 600 MeV.

The transfer line composed of dipoles with a total bend angle of 27 degrees, which bend the beam in the vertical plane, as well as six focusing quadrupoles. The last element is a septum magnet, which connects the injector with the storage ring.

The Solaris accelerator facility – electron storage ring

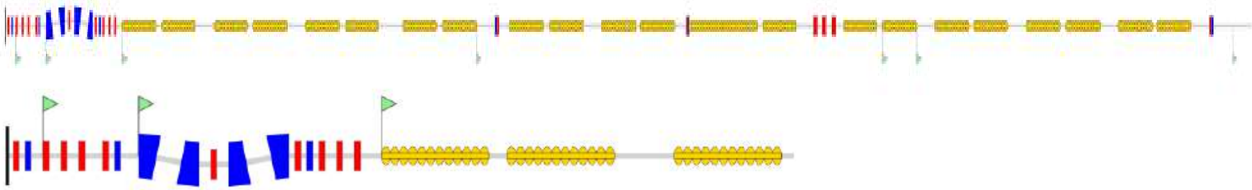
Energy	1.5 GeV
Max. current	500 mA
Circumference	96 m
Main RF frequency	99,93 MHz
Max. number of circulating bunches	32
Horizontal emittance (without insertion devices)	6 nm rad
Electron beam size (straight section centre) σ_x, σ_y	184 µm, 13 µm
Electron beam size (dipole centre) σ_x, σ_y	44 µm, 30 µm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



Current Status and what will be… in the near future

- **<u>Decay mode of operation</u>**
- Max energy of 1.5 GeV
- Slow orbit correction
- 6 experimental beam lines in operation
- 3 undulators in operation
- A set of diagnostic tools based on python
- Maximum of 32 bunches, single bunch mode possible

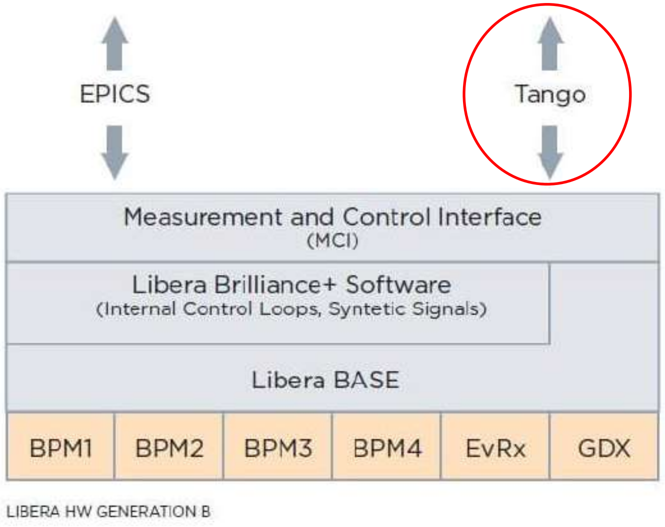
- Orbit tuning and response matrix calculation based on **real time ML**
- Accelerator subsystem diagnostic tools based on **time series** analysis/ **anomaly detection,** possible forecasting
- Real time diagnostic tool connected with **tango** and **mySQL hdb++** database
- GPU utilization for calculation speed up
- Small GPU cluster, possibly 3-4 NVIDIA based GPU (QUADRO ~ 32 GB ram per unit)
- **Top-up mode** (constant filling) and liniac upgrade up to 1.5 GeV



Libera at SOLARIS

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

- Mostly stable operation, some freezing on libera Brilliance+ nr 6
- **Mediocre state** of the documentation when it comes to the config files within the Libera operating system (Ubuntu), big learning threshold especially for **newcomers**

Long Short-Term Memory networks

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

Key features:

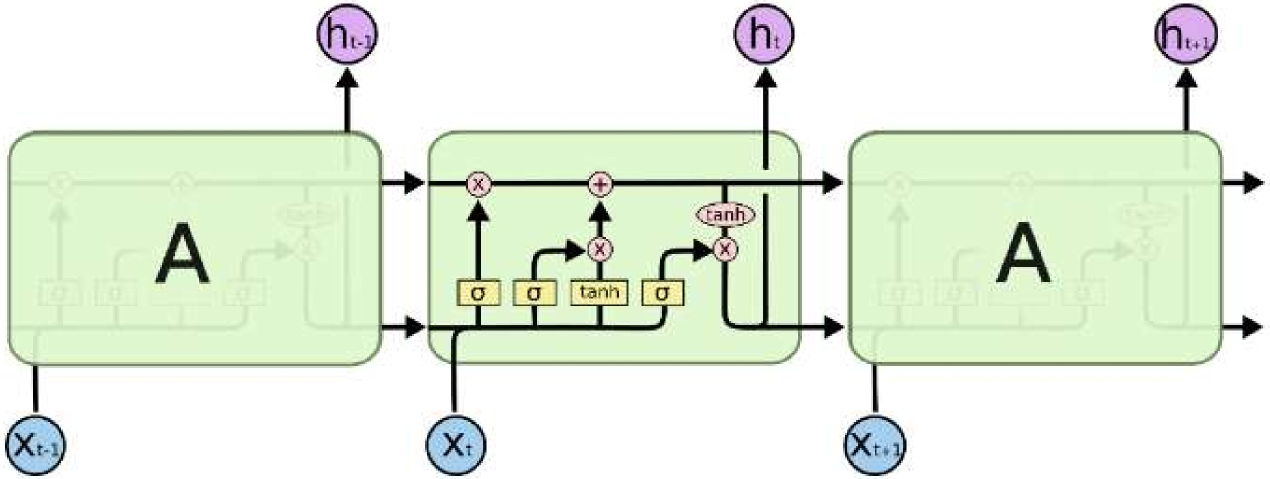
✓learning memory

✓Non- sequential

✓Fast, utilize many cores on a GPU

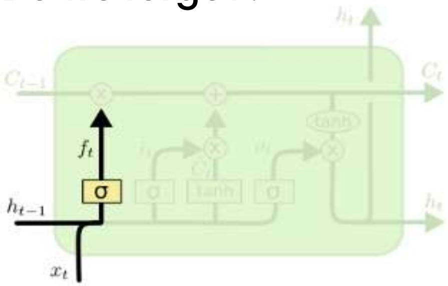
✓Low memory consumption compared to BSTS

✓n- dimensional input



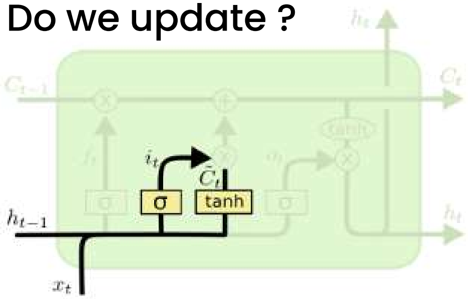
The repeating module in an LSTM contains four interacting layers.

Do we forget ?



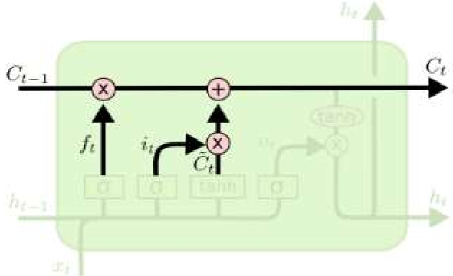
$$f_t = \sigma\left(W_f \cdot [h_{t-1}, x_t] \ + \ b_f\right)$$

Do we update ?



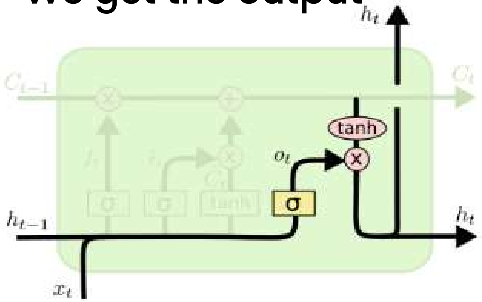
$$i_t = \sigma\left(W_i \cdot [h_{t-1}, x_t] \ + \ b_i\right)$$
$$\tilde{C}_t = \tanh(W_C \cdot [h_{t-1}, x_t] \ + \ b_C)$$

We shift the cell to a new state



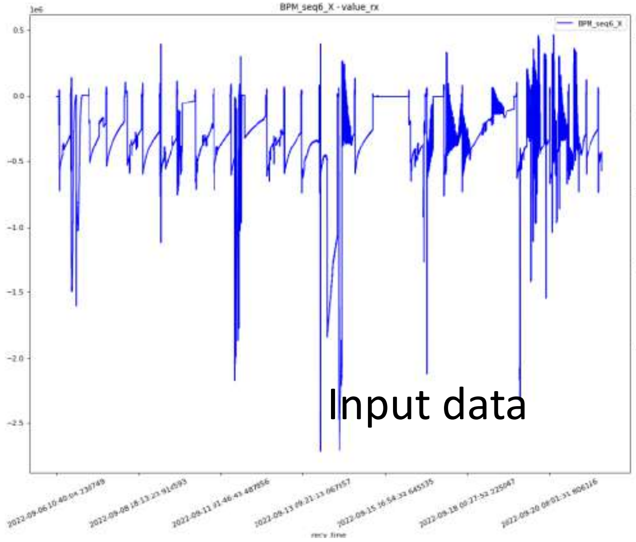
$$C_t = f_t * C_{t-1} + i_t * \tilde{C}_t$$

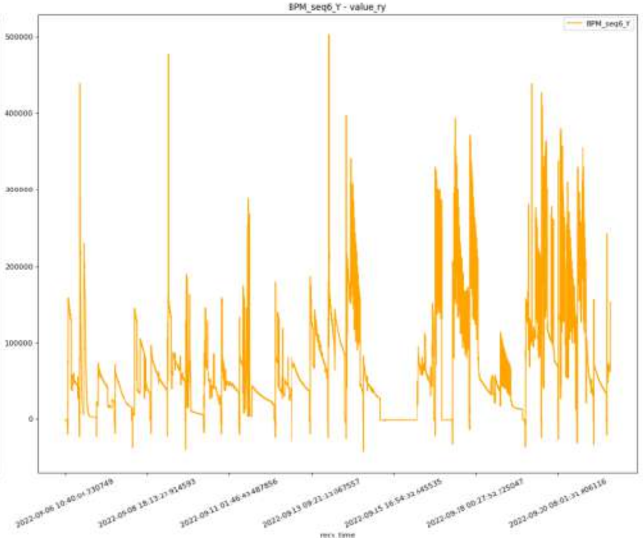
We get the output



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

Long Short-Term Memory networks



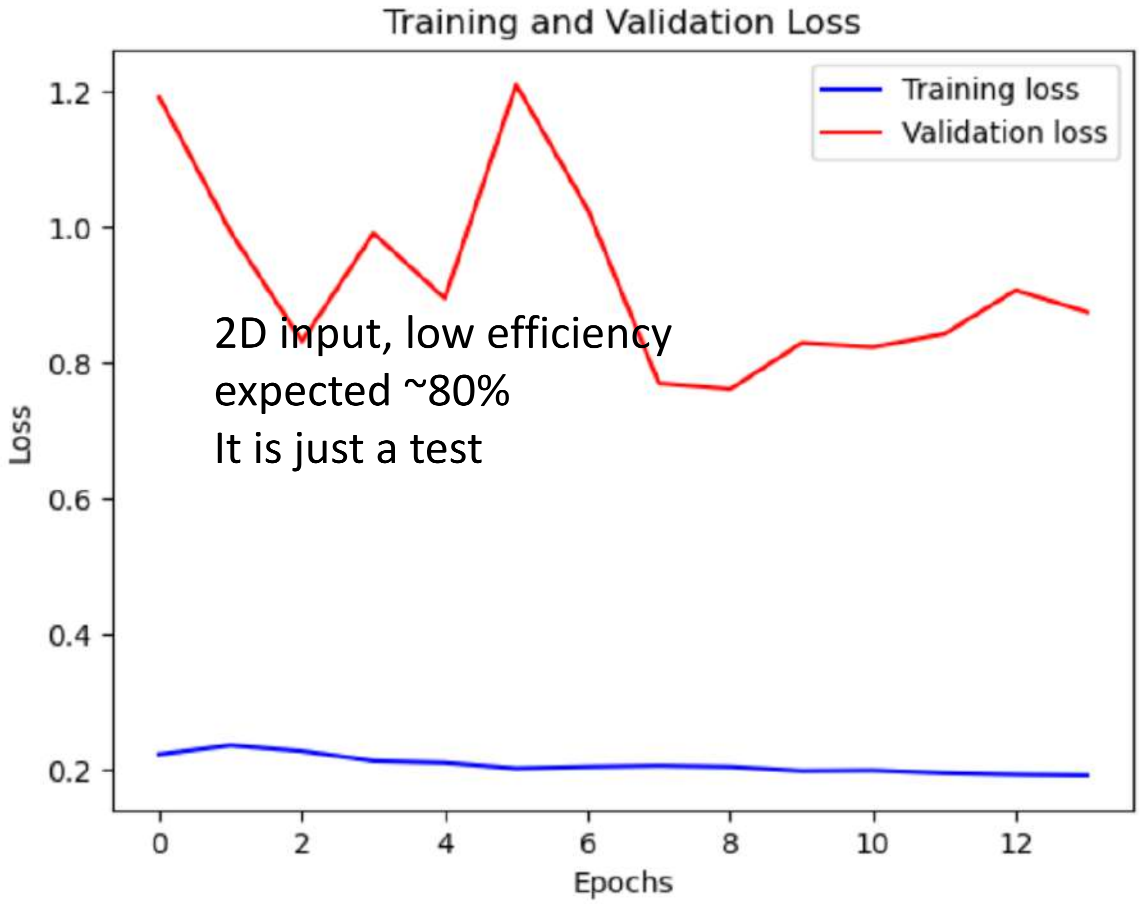



```
Model: "model"
_________________________________________________________________
 Layer (type)                Output Shape              Param #
=================================================================
 input_1 (InputLayer)        [(None, 1500, 2)]         0

 lstm (LSTM)                 (None, 32)                4480

 dense (Dense)               (None, 1)                 33

=================================================================
Total params: 4,513
Trainable params: 4,513
Non-trainable params: 0
_________________________________________________________________
```

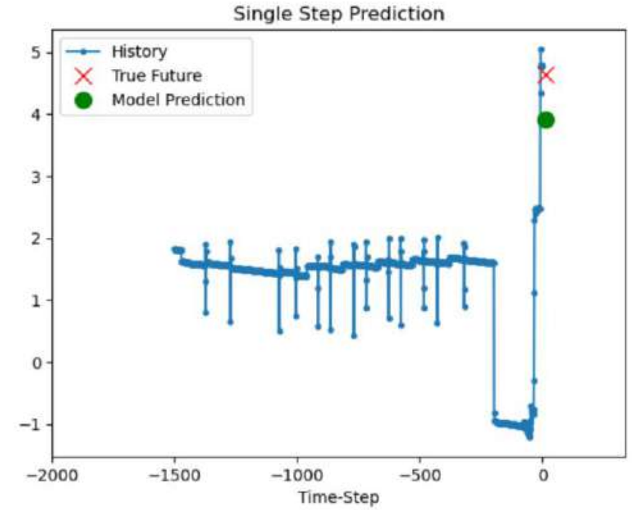
```
Epoch 1/20
3733/3734 [============================>.] - ETA: 0s - loss: 0.2220
Epoch 1: val_loss improved from inf to 1.19001, saving model to
model_checkpoint.h5
3734/3734 [==============================] - 143s 38ms/step - loss: 0.2231 -
val_loss: 1.1900
Epoch 2/20
3733/3734 [============================>.] - ETA: 0s - loss: 0.2358
Epoch 2: val_loss improved from 1.19001 to 0.99194, saving model to
model_checkpoint.h5
3734/3734 [==============================] - 141s 38ms/step - loss: 0.2364 -
val_loss: 0.9919
Epoch 3/20
3733/3734 [============================>.] - ETA: 0s - loss: 0.2270
Epoch 3: val_loss improved from 0.99194 to 0.83112, saving model to
model_checkpoint.h5
3734/3734 [==============================] - 143s 38ms/step - loss: 0.2278 -
val_loss: 0.8311
Epoch 4/20
3733/3734 [============================>.] - ETA: 0s - loss: 0.2118
Epoch 4: val_loss did not improve from 0.83112
3734/3734 [==============================] - 143s 38ms/step - loss: 0.2134 -
val_loss: 0.9903
Epoch 5/20
```

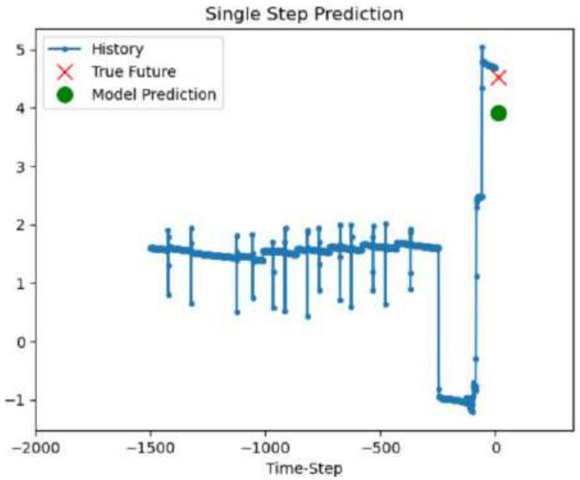
Checkpoint training method, kills training when the loss does not improve over time

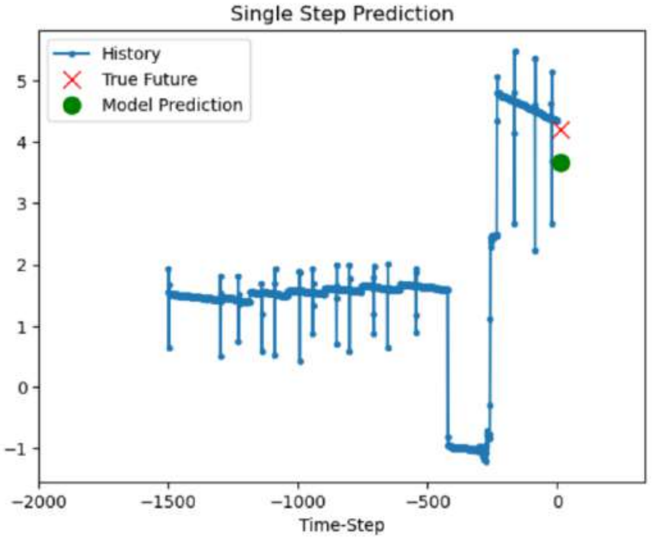
Long Short-Term Memory networks

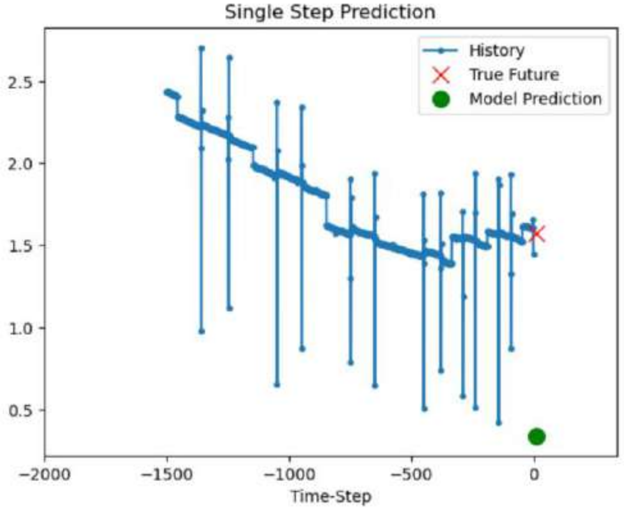


2D input, low efficiency
expected ~80%
It is just a test





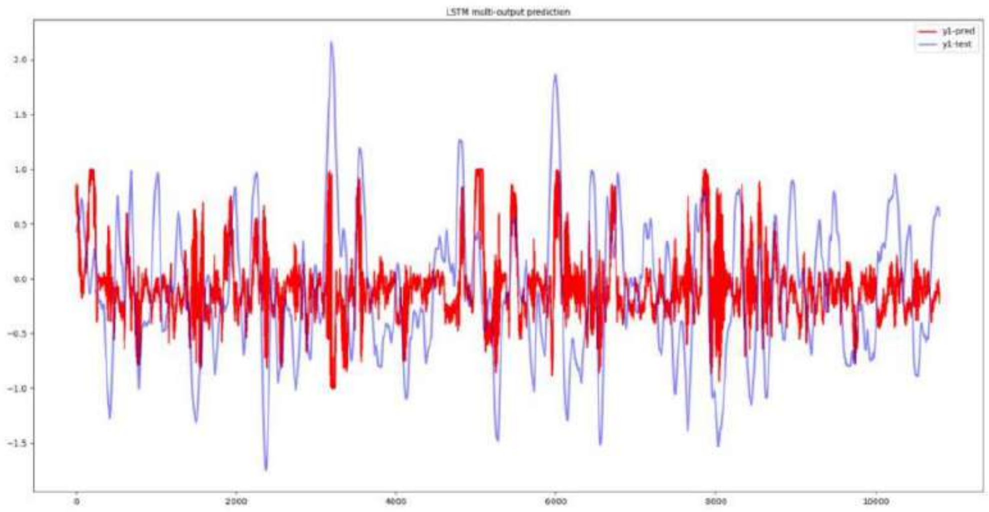


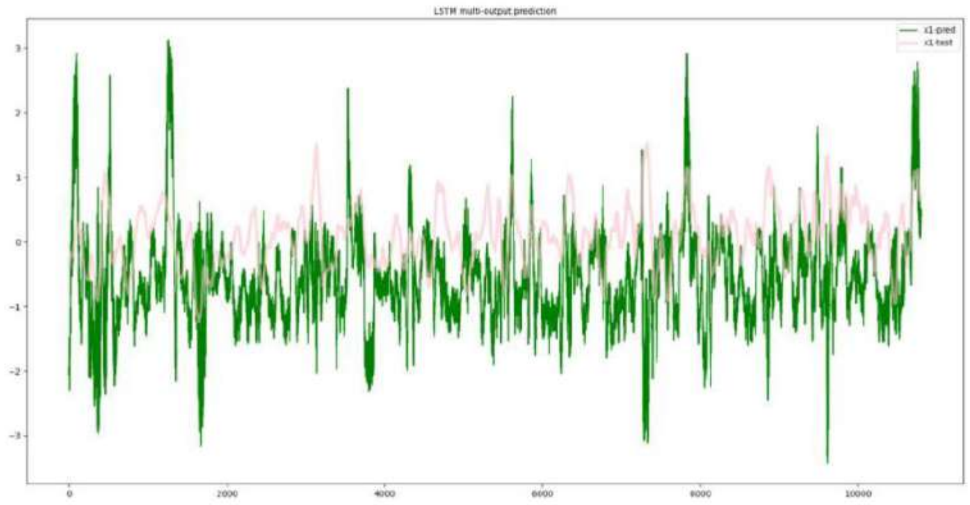


Long Short-Term Memory networks

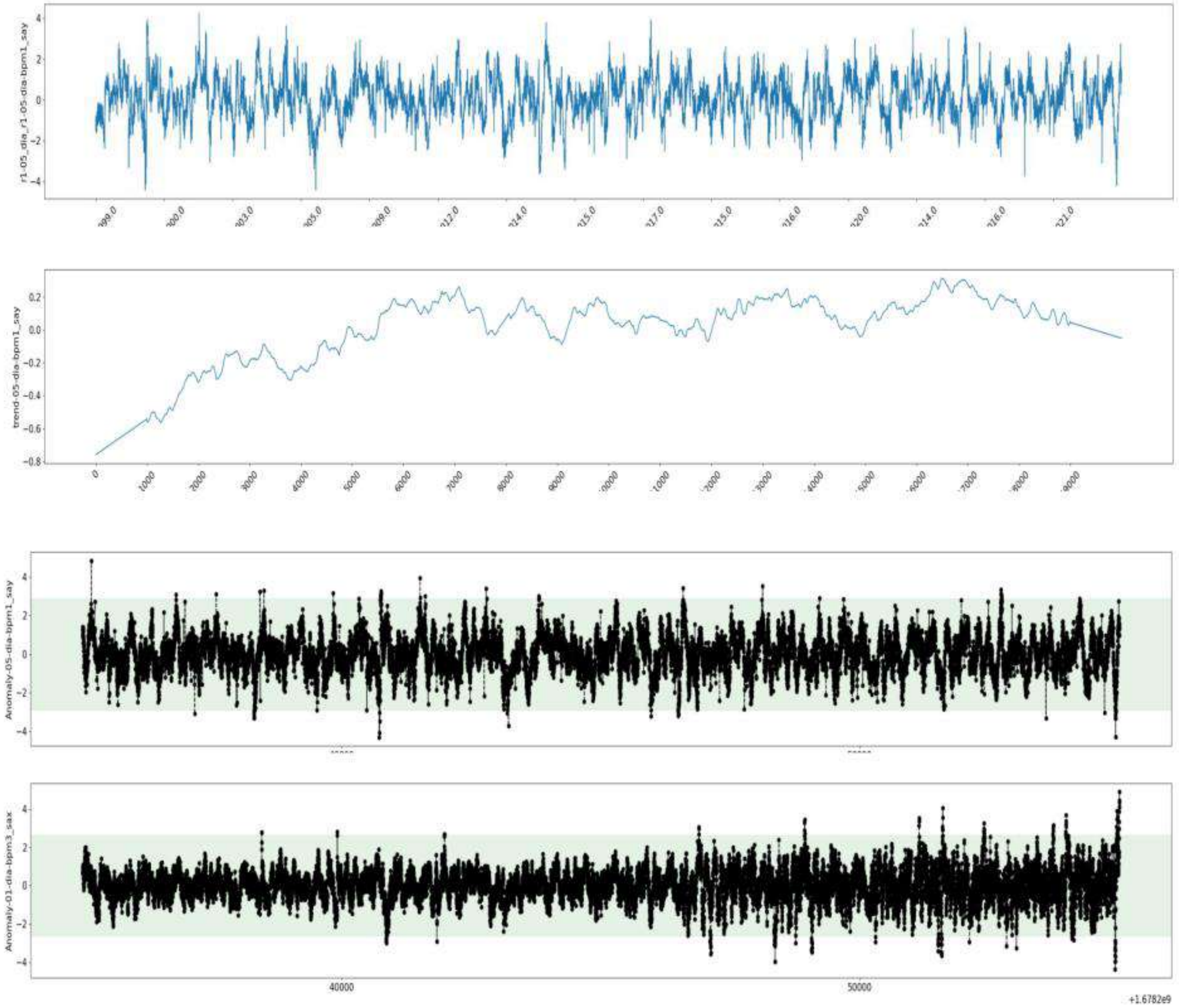
LSTM based forecast on a clean signal of the BPMY and PMX signal coming form Libera Brilliance+

- 1000 s forecast
- 20 runs used for training form injection to beam dump





Anomaly detection

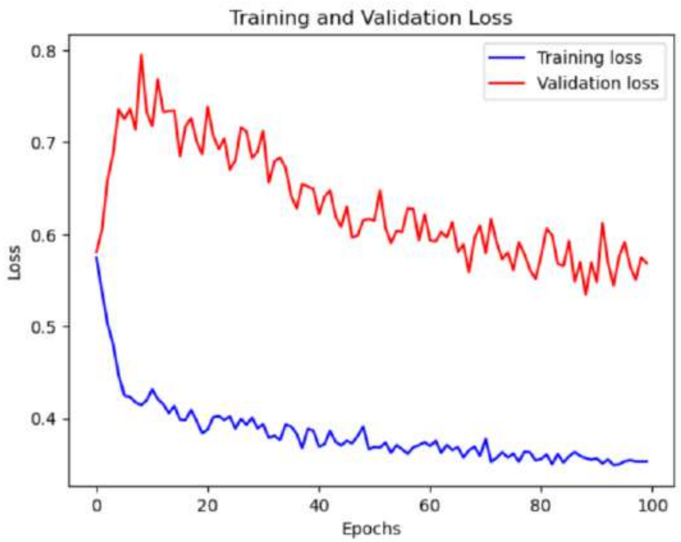


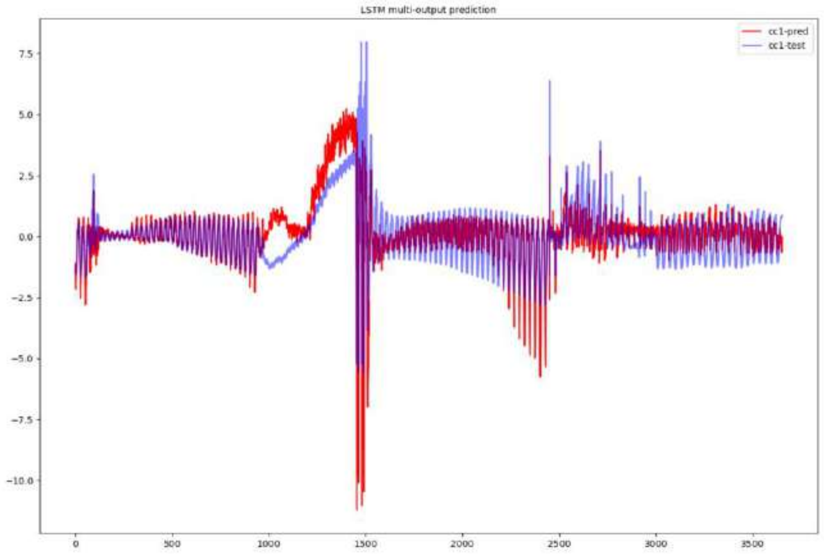
- Anomaly detection based on the trend estimation
- 5 sigma detection threshold (Green band)

Undulator table generation

- n input output forecasting LSTM based ANN
- Single LSTM layer
- Soft sign activation, tanh for recurrent activation
- Linear activation on output
- Single layer (feed forward for stability)
- 10% drop out for future Bayesian systematic studies
- Fast, 1 min trening validation and application on a RTX 5000 quadro

```
Model: "model"
_________________________________________________________________
 Layer (type)                Output Shape              Param #
=================================================================
 input_1 (InputLayer)        [(None, 2, 1)]            0

 lstm (LSTM)                 (None, 1280)              6563840

 dropout (Dropout)           (None, 1280)              0

 dense (Dense)               (None, 2)                 2562

=================================================================
Total params: 6,566,402
Trainable params: 6,566,402
Non-trainable params: 0
_________________________________________________________________
```



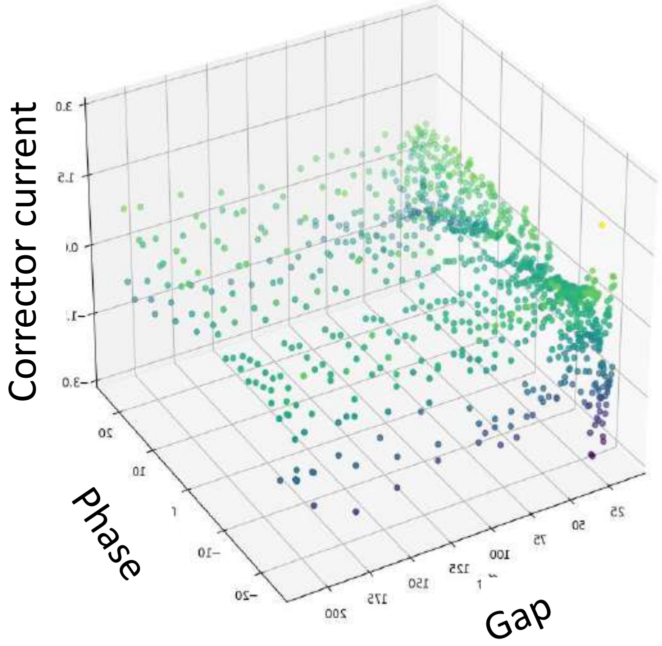


Expected, the training achieves a minimum, the validation and prediction should differ, the taring is done on 10 previous measurements

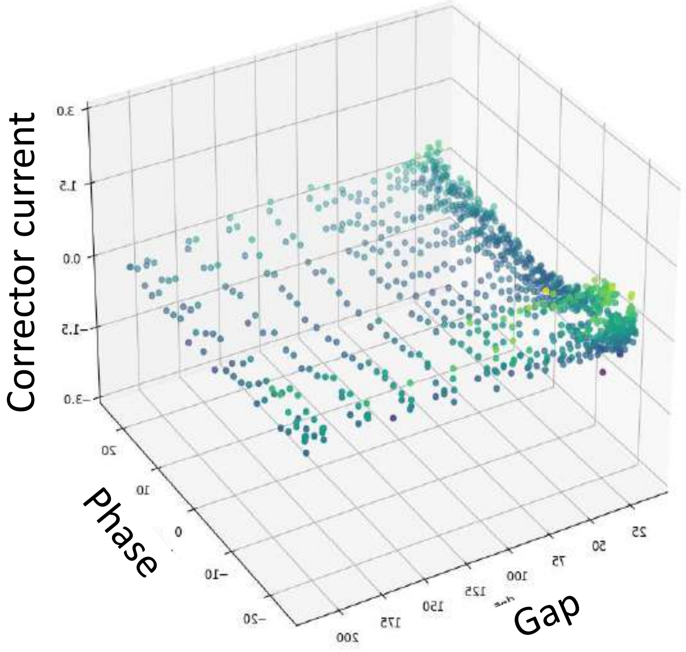
Undulator table generation

- Forecast of 4 corrector electrical currents
- This algorithm will be implemented to work online as a device server
- This will enhance the generation method of the tables (previous 15h of scan)

Corrector 1

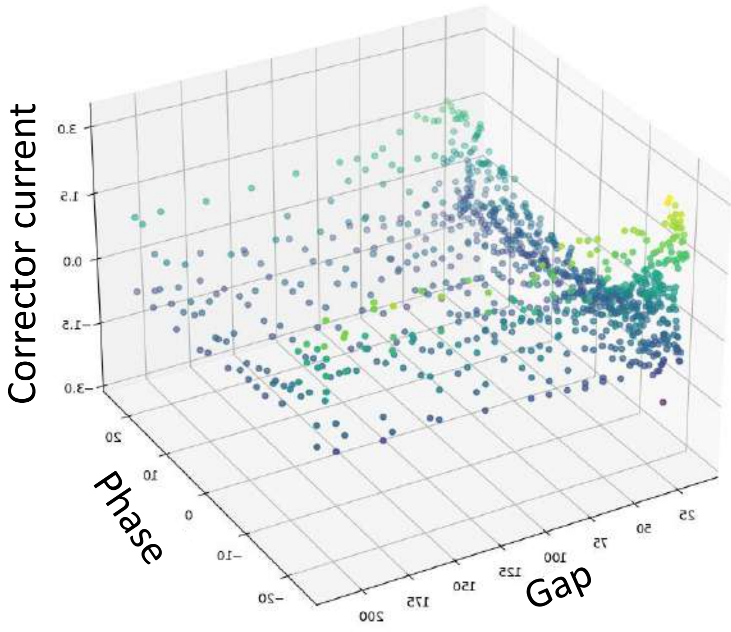


Corrector 4

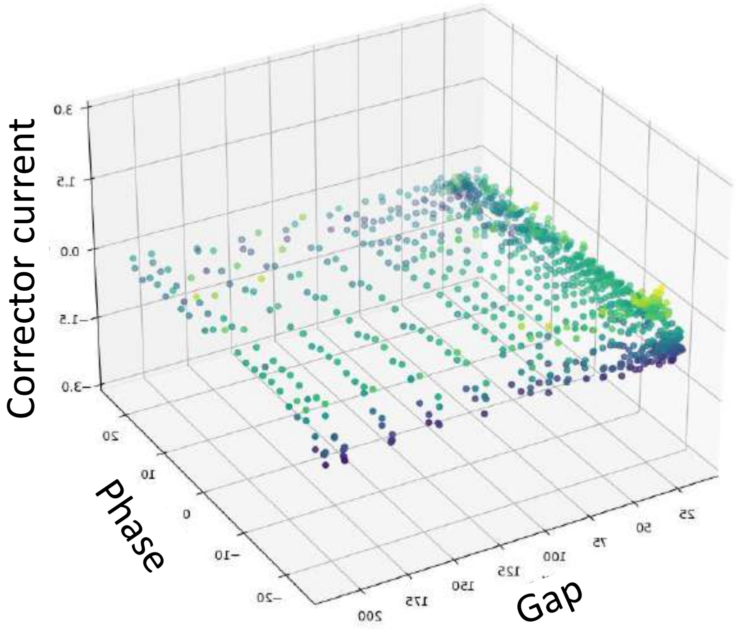


Undulator table generation

Corrector 2



Corrector 3



Conclusions

- A lot has been done in the sense of militance and operation, the ring runs at the desired beam intensity
- We are moving into modern python **diagnostics tools**
- Libera solutions operate mostly stable with some hiccups on machine nr 6
- We can provide a valuable contribution into the synchrotron radiation society (~50+ operating facilities in the world) with the planed ML forecasting algorithms