Denoising of optics measurements using Autoencoder Neural Networks

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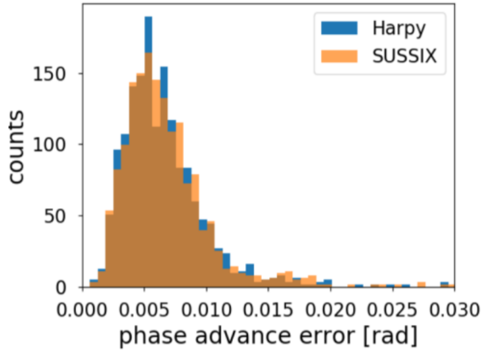
Optics measurements and noise

- **Noise artifacts** appear due to instrumentation imperfections
- **Uncertainties** in the calculation using current optics analysis methods

→ Less accurate estimation of optics functions
→ Missing data points due to faulty Beam Position Monitors
→ Less effective optics corrections computed based on measured deviations of optics function from design

Courtesy of L. Malina



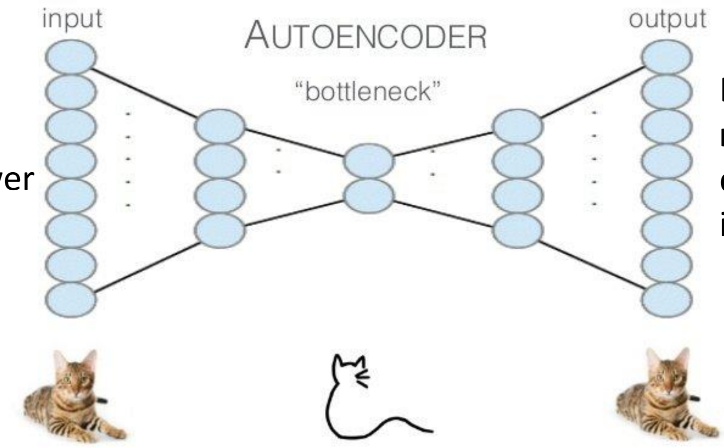
Measurement errors of phase advances in LHC:
comparison between currently used methods for turn-by-turn data analysis

How can we benefit from Autoencoders?

- A special **neural network** designed to reproduce given input as output of the network.

Applications:
- Image processing, sensor signal processing, dimensionality reduction

Encoder: **compressing** the input data to lower dimensions



Decoder: **reconstructing** the data into original input.

Applying Autoencoder to phase advance measurements obtained from harmonic analysis of turn-by-turn data

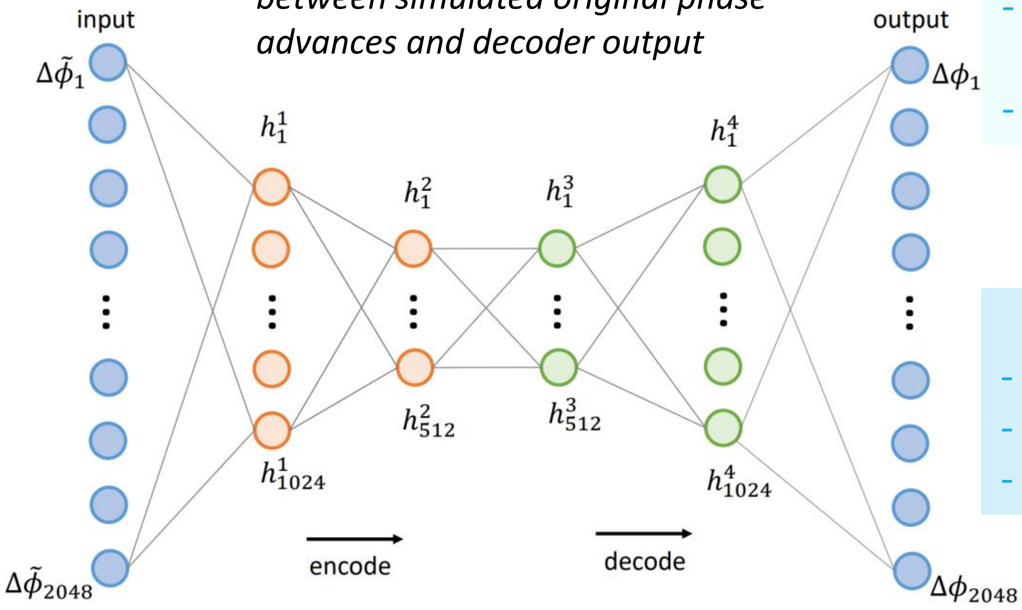
How does it work?

Training and Test on simulations:

Input:

- Simulated phase advance deviations **including noise**
- - replacing **10% of input values = 0** (faulty BPMs)

*Minimizing a **loss function** = difference between simulated original phase advances and decoder output*



Output:

- **original** simulated phase advance deviations
- **Full** set of phase advance values

Application to LHC measurements:

Input:

Measured phase advance deviations:

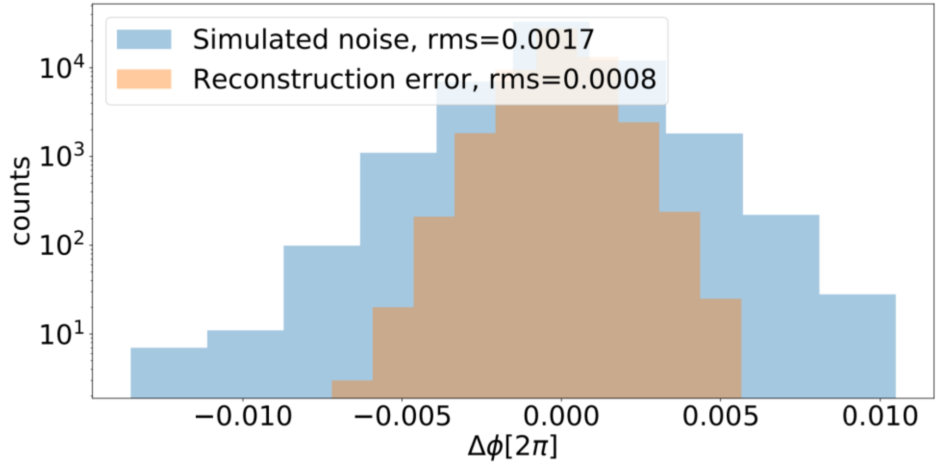
- include errors
- no information at the location of cleaned faulty BPMs

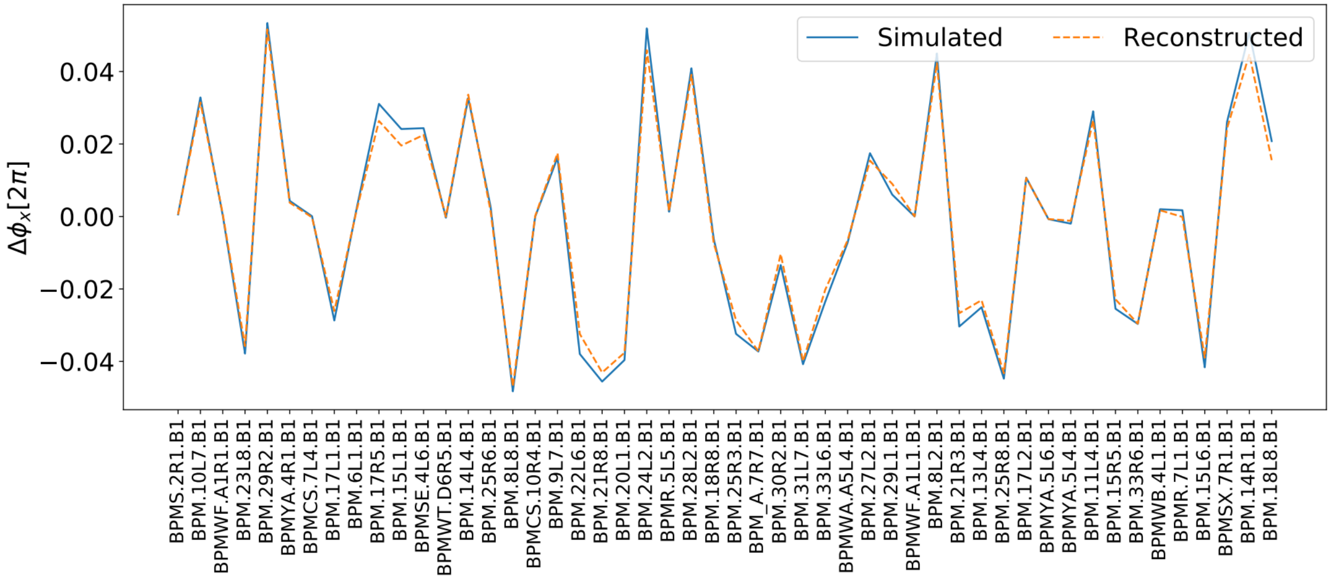
Output:

- Full set of phase advances
- **Reconstruction** of missing data
- Phase advances with **reduced noise**

Results on simulations

Reconstruction of missing values in a validation sample, Beam 1





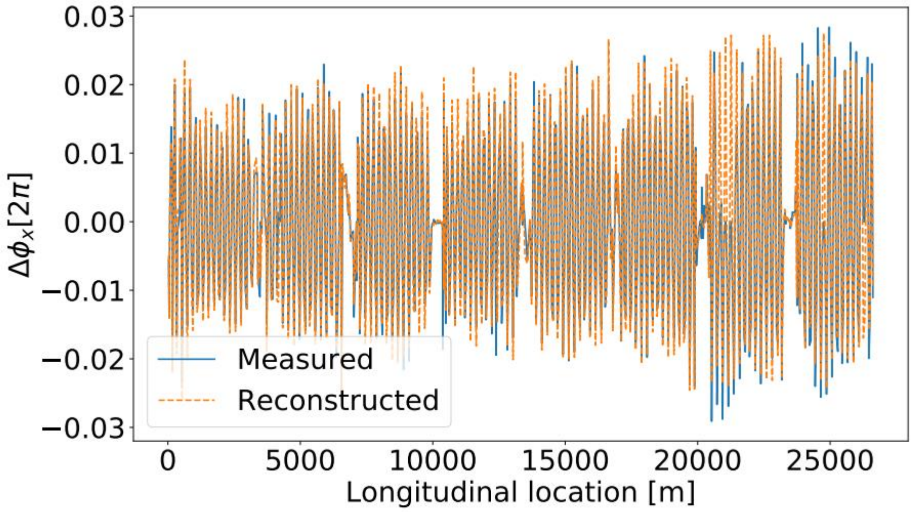
- ✓ **Denoising full set of phase advance deviations**: reconstruction error is by factor 2 smaller than simulated realistic noise, estimated from previous measurements data.
- ✓ **RMS error of prediction = 5%**

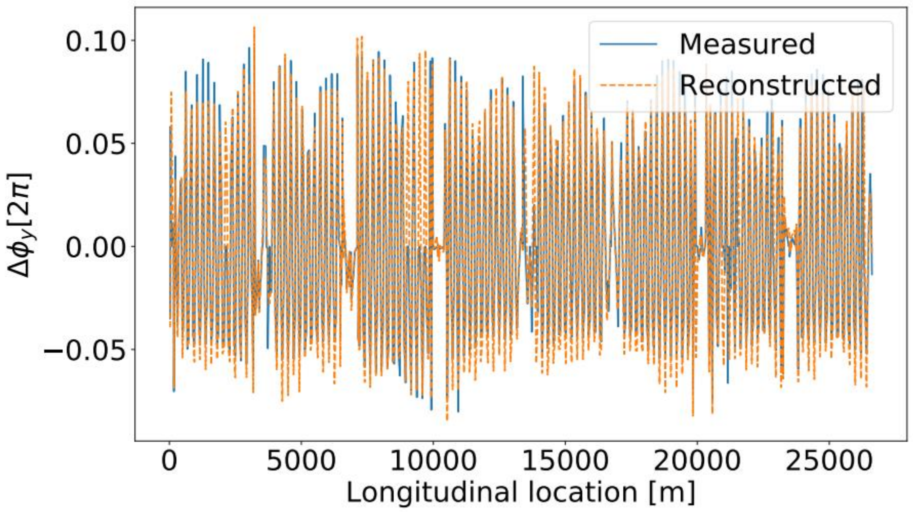
- ✓ **Missing BPMs**: possibility to obtain reliable estimation of the phase advance deviations at the location of faulty BPMs

Results on LHC measurements data

** Unlike in simulations, here the "true values" are not known, measurement contains noise and unknown information at the location of faulty BPMs*

LHC commissioning in 2016, β^*=40 cm, Beam 1





Agreement between the measurement and autoencoder reconstruction: 88%

Conclusions

- Main advantage of autoencoder: possibility to combine two objectives using one ML-technique:
  - Reconstruction of missing data
  - Noise reduction
- ✓ Demonstrated on both, simulations and measurements data
- Next step: Application in LHC commissioning 2021