GitLab

The Application of Machine Learning in Schottky Spectra Analysis

Manuel Bradicic, Kacper Lasocha, CERN, Geneva, Switzerland

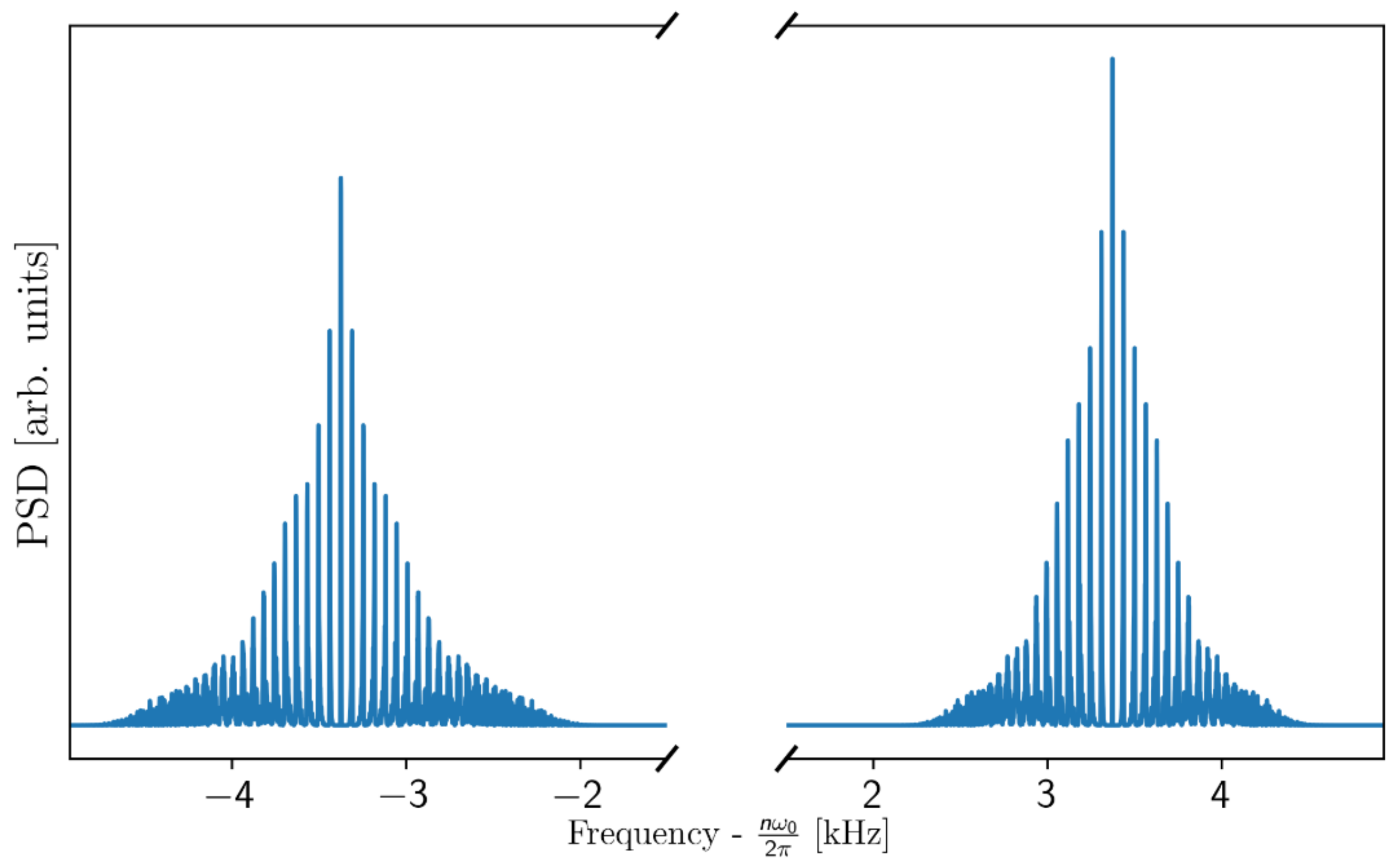
Motivation

- Schottky Spectra, that is random fluctuations of the macroscopic beam properties, such as position or intensity, contain rich information on beam and machine parameters crucial for preserving the beam stability.
- The Schottky noise signals have been a powerful diagnostics tool in many storage rings and synchrotrons (ISR, SPS, Tevatron, RHIC). In the LHC the Schottky-based diagnostic is problematic due to the presence of strong coherent components in the measured spectra
- The goal of this project is to analyze LHC Schottky spectra using Machine-Learning (ML) techniques, such as denoising autoencoders and variational autoencoders with adjusted loss function.

Schottky Spectra

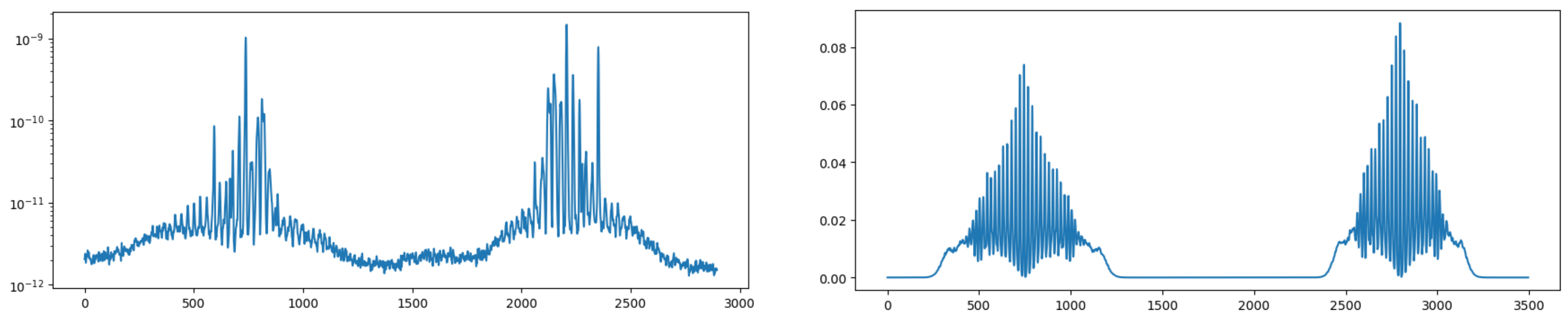
Schottky spectra encode the beam and machine parameters in the following manner:

1. **Betatron tune** (Q), given by the central frequencies of the sidebands
2. **Bunch length** $(4\,\sigma_{bl})$, given by the average of sidebands' widths
3. **Chromaticity** (Q'), given by the difference in sidebands' widths
4. **Synchrotron frequency** (f_s), given by the spacing of sidebands' sub-peaks
5. **Transverse emittance** $(\varepsilon_x,\ \varepsilon_y)$, given by the sidebands' cumulative power and shape of the sub-peaks



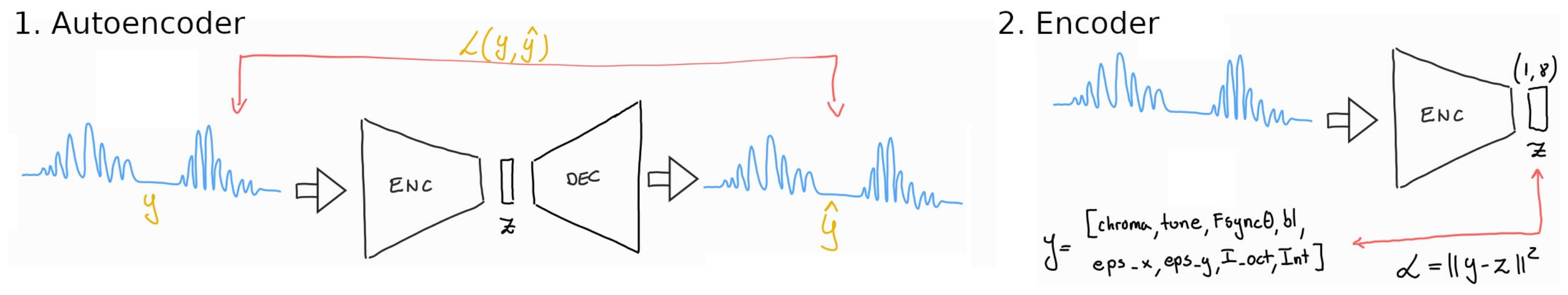
Dataset

- The real dataset consists of 211 hours of acquired data, taken in May 2024 during the STABLE phases of LHC fills. This corresponds to 3 million instantaneous spectra, which after the required averaging reduces to 30,000 independent samples. However, the presence of noise in the spectra (left figure) makes it more challenging to extract the desired parameters.
- To determine whether autoencoders can effectively extract parameters from the Schottky spectra, we generated a synthetic dataset consisting of 5,000,000 samples (right figure). Moreover, it allows us to crosscheck the parameters describing a spectrum, which is impossible with the data collected at the LHC, as the data requires unsupervised learning.

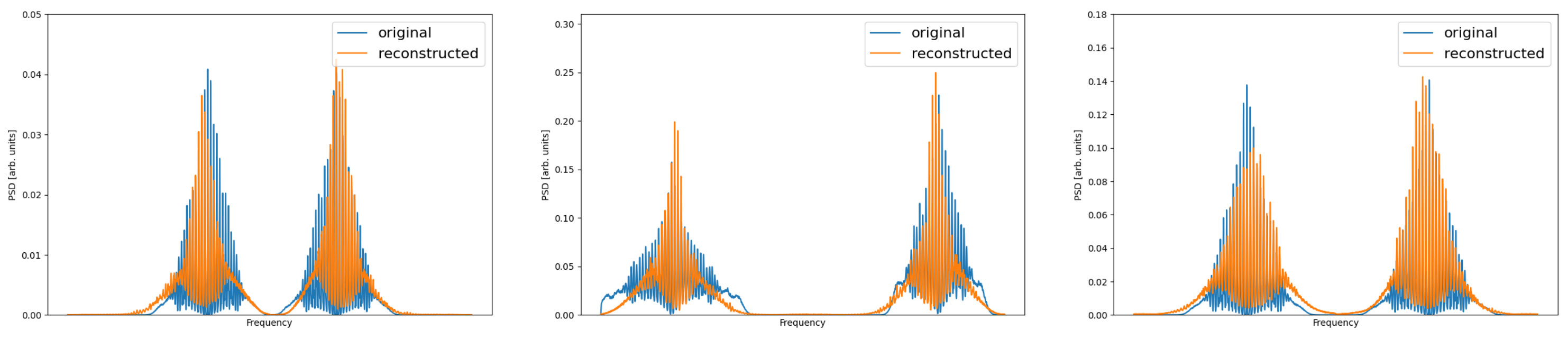


Autoencoders

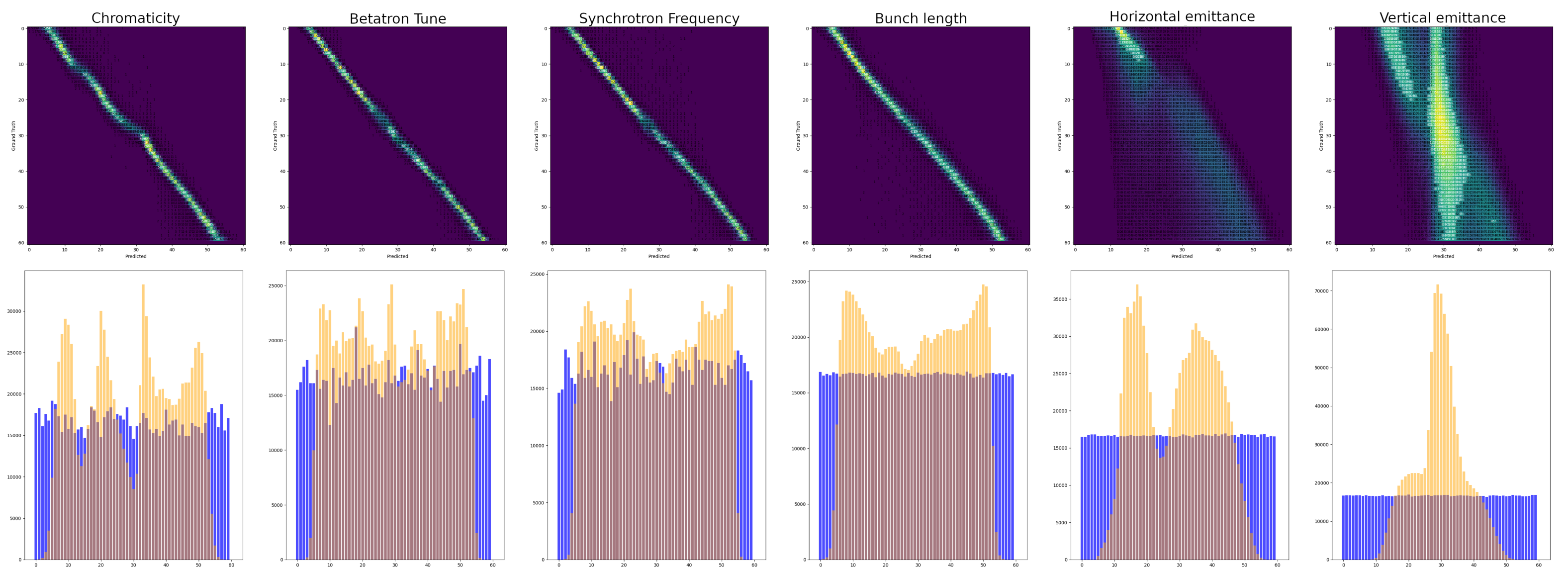
- An autoencoder is a type of neural network architecture designed to compress (encode) efficiently input data to its essential features, then reconstruct (decode) the original input from this compressed representation.



- By employing a 12-layer Autoencoder with layers structured in sizes that are powers of two and trained on synthetic data, we can reconstruct the signals as follows:



- Focusing only on the encoding, we can force the latent space to correspond to the true spectrum parameters. The confusion matrix, comparing the latent space of the encoder with the true data, reveals higher accuracy for certain parameters (such as chromaticity or tune), while exhibiting lower performance for horizontal and vertical emittance.

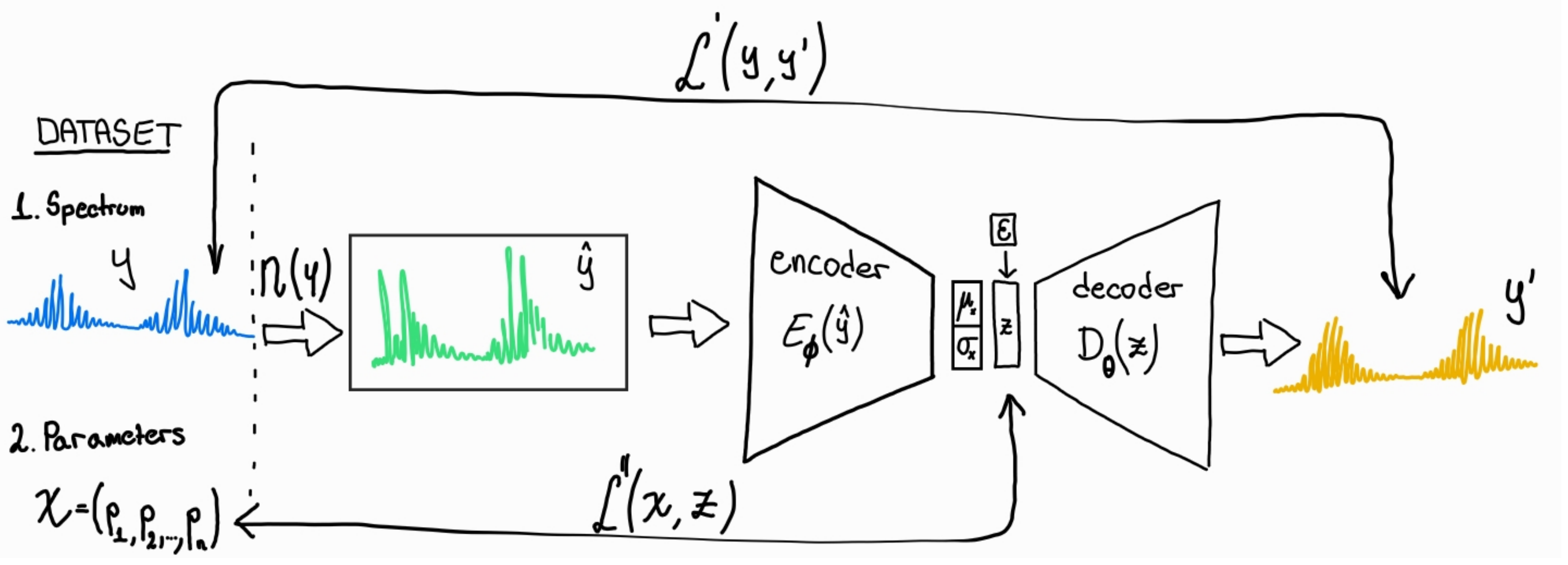


- For the so-far trained models, the optimal RMSE of the parameters reconstructed from synthetic data without the noise is given in the following table:

	Q	$4\,\sigma_{bl}$	Q'	f_s	ε_x	ε_y
RMSE	$2.1 \cdot 10^{-4}$	7.34 ps	0.279	0.046 Hz	0.443 µm	0.530 µm

Next Steps

- Fine-tune the existing models and explore various types of architectures which could be applied to our problem.
- Utilise a regular autoencoder, as well as a modified variational autoencoder to denoise the signal, as an intermediate step towards transforming the spectra into latent space of parameters described in the Schottky theory.
- Examine the performance of models trained on synthetic data when applied to real data from the LHC, and investigate with what precision the parameters can be derived.



KEY REFERENCES

[1] D. Boussard, "Schottky noise and beam transfer function diagnostics". *Proc. of 5th CERN Accelerator School*. (1995)

[2] S. Chattopadhyay, "Some fundamental aspects of fluctuations and coherence in charged-particle beams in storage rings". (1984)

[3] K. Lasocha et al., "Extraction of LHC Beam Parameters from Schottky Signals". *Proc. of 68th Adv. Beam Dyn. Workshop HB'23*. (2024)

KTH VETENSKAP OCH KONST

MORE INFORMATION

Manuel Bradicic
Accelerator Systems (SY) Department
Beam Instrumentation (BI) Group
Intensity and Tune (IQ) Section

manuel.bradicic@cern.ch