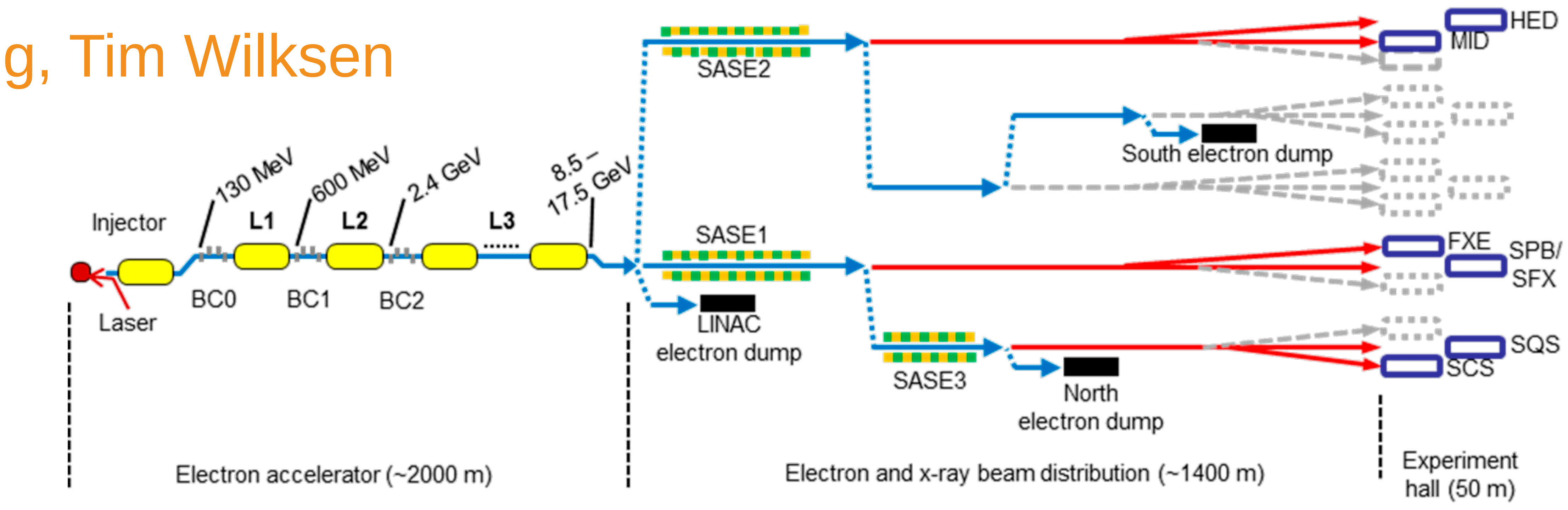
A Data-Driven Beam Trajectory Monitoring at the European XFEL

Antonin Sulc, Raimund Kammering, Tim Wilksen
DESY, Hamburg

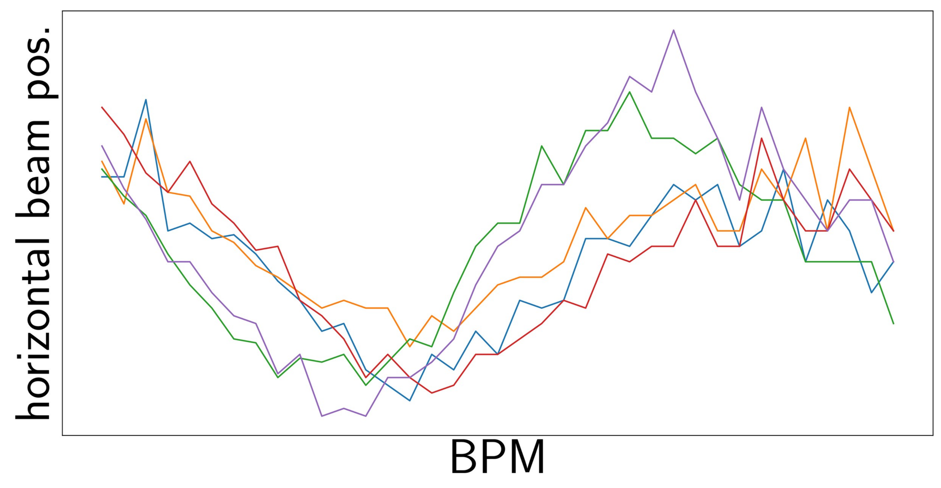
Abstract

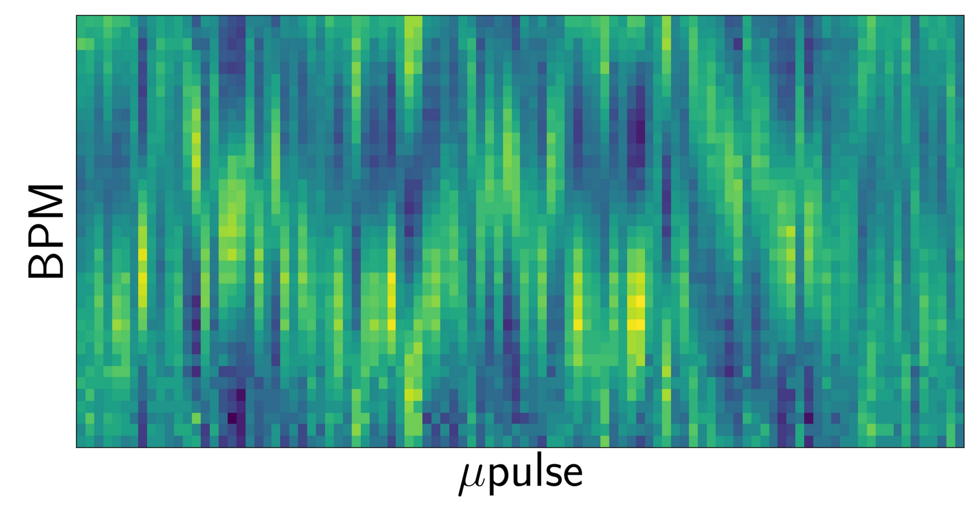
Interpretation of data from beam position monitors is a crucial part of the reliable operation of European XFEL. The interpretation of beam positions is often handled by a physical model, which can be prone to modeling errors or can lead to the high complexity of the computational model.

We show two data-driven approaches that provide insights into the operation of the SASE beamlines at European XFEL. We handle the analysis as a data-driven problem, separate it from physical peculiarities and experiment with available data based only on our empirical evidence and the data.



Inputs





Method

$\hat{\mathbf{D}} \rightarrow \mathbf{h}_1 = \mathrm{Transformer}_1(\hat{\mathbf{D}})$ (input=dim, output=dim) $\rightarrow \mathbf{h}_2 = \mathrm{Transformer}_2(\mathbf{h}_1)$ (input=dim, output=dim) $\rightarrow \phi = \mathrm{Linear}(\mathbf{h}_2)$ (input=dim, output=16) $\rightarrow s = \|\phi - \mathbf{c}\|_2$ (input=16, output=1)

features $f_\theta(\hat{\mathbf{D}})$

- The beam optics in the undulator lines are controlled by the use of a so-called FODO lattice.
- These alternating magnetic fields can introduce a periodic variation of the trajectory named betatron oscillation [1].
- We can observe a specific periodic pattern of the electron bunches passing through the FODO lattice.

Empirical Method

- *Assumption*: Beta-function must follow a period that reminds a period **pattern which reminds sine** function.
- We define g as a sine function parameterized with **amplitude, period, phase shift and frequency.**
- Individual beam pos. should mirror their fitted functions g.

$$r_x = \|g_{\phi_x}(n, \mu) - \hat{x}^\mu_n\|_2 \quad \text{and } r_y = \|g_{\phi_y}(n, \mu) - \hat{y}^\mu_n\|_2$$

Data-Driven Method

- *Assumption*: The anomalies are spread over multiple bunch trains.
- Working with sequences is particularly important in taking into consideration **anomalies that are spread over multiple bunch trains**.
- An attention layer [2] can **access all previous states** in sequences and weight them according to the learned relevance.
- The network architecture consists of a **two-layer transformer with a linear layer** in the output.
- Since we **do not have explicit labels** we adopted the One-Class-Loss [3] to train the model

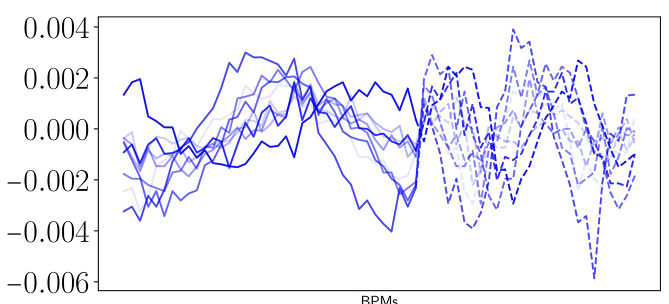
$$L(\theta) = \|f_\theta(\hat{\mathbf{D}}) - \mathbf{c}\|_2$$

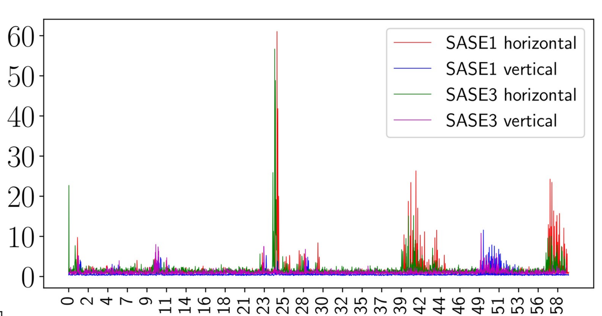
- The model f and hypersphere center c are gradually trained to transform inputs $\hat{D}$ to a lower-dimensional feature space where the common inputs are transformed to be close to c.

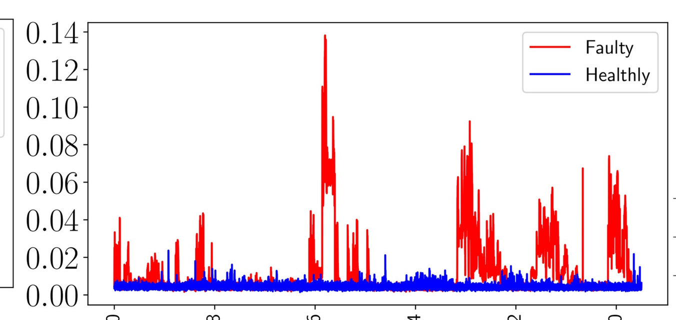
Results

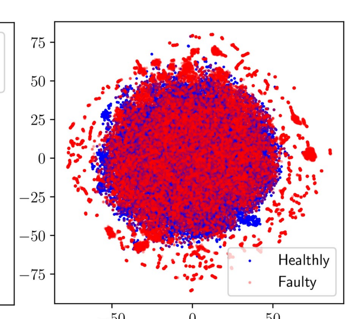
Crash of the undulator server after an unusual selection of colors for individual cells.

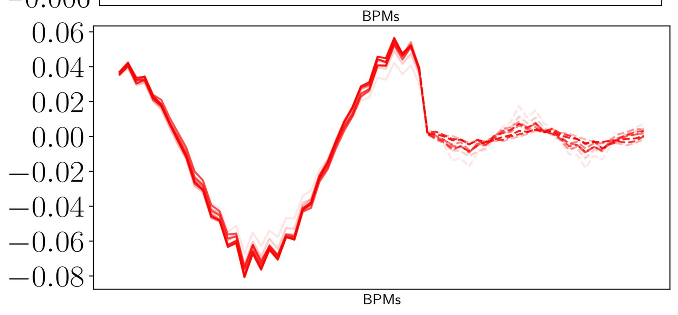
- Healthy / Faulty SASE1 and SASE3 Trajectories
- Horiz. and vert. r of the **empirical method**
- Anomaly scores s of **data-driven model**
- TSNE Embedding of f



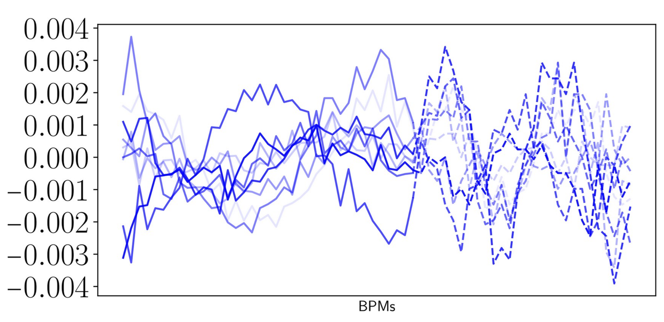


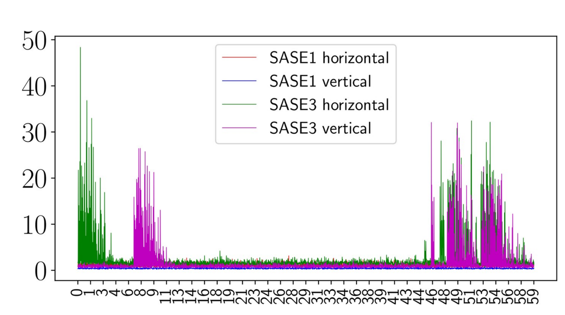


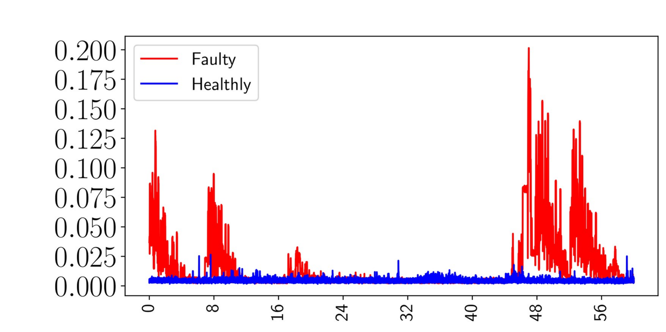


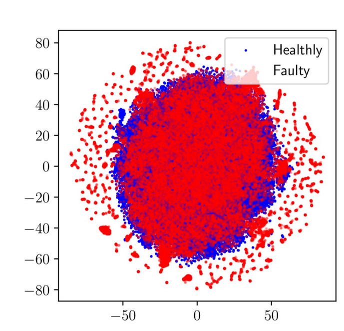


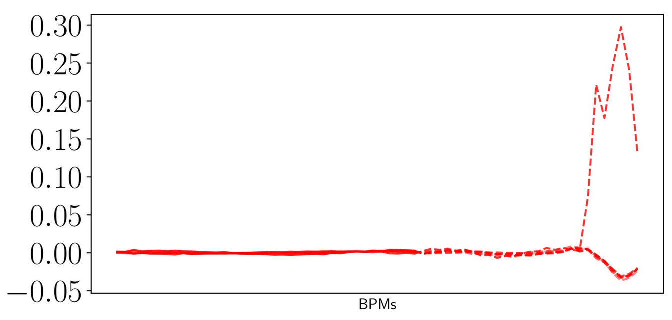
Phase shifter at SASE3 which does not move.











References

[1] B. Holzer, "Beam dynamics in synchrotrons," *arXiv preprint arXiv:1804.08873*, 2018
[2] A. Vaswani et al., "Attention is all you need," *Advances in neural information processing systems, vol. 30*, 2017
[3] L. Ruff et al., "Deep one-class classification," in *International conference on machine learning*, PMLR, 2018, pp. 4393–4402.

Conclusion

Two approaches for the analysis of beam dynamics at EuXFEL:

- **Empirical approach** based on our evidence about the beta-function which provides a direct interpretable indication of the beam position data by fitting a sine function.
- A **purely data-driven approach** that allows more complex inputs of the **inter-bunching** relations.
- The presented approach reveals that we **are already able to identify some issues taking place where beam trajectories.**
- Experiments show that **both approaches are similarly efficient** with revealing problems on beam trajectory.
- There is a **limited ability to correlate an issue with its effects on the position of the beam**.

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