Reconstruction of linear optics observables using Supervised Learning

Elena Fol

H. Garcia Morales, R. Tomás

CERN

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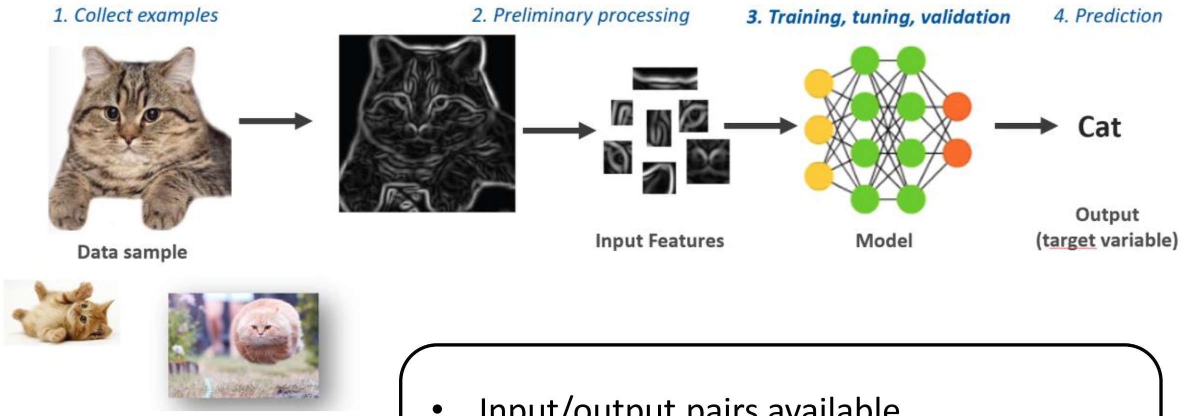
Motivation

- ***β*-function** at IPs is computed by performing k-modulation technique
- β-function around IPs provides important for optics corrections
- **Normalized dispersion** : important observable, independent of Beam Position Monitors calibration: several beam excitations with momentum shifts are required

→ **Time costly measurements procedure**
→ **Measurements are not always possible**
→ **Missing information in correction computation and historical data analysis**

Supervised Learning

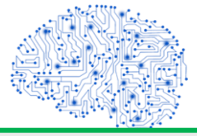


- Input/output pairs available
- Make prediction for **unknown input** based on **experience from given examples**

SL-based approach to reconstruct optics observables

Phase advance measurements*

Input



Output

Regression Model, Supervised Learning

***β*-function** at IPs

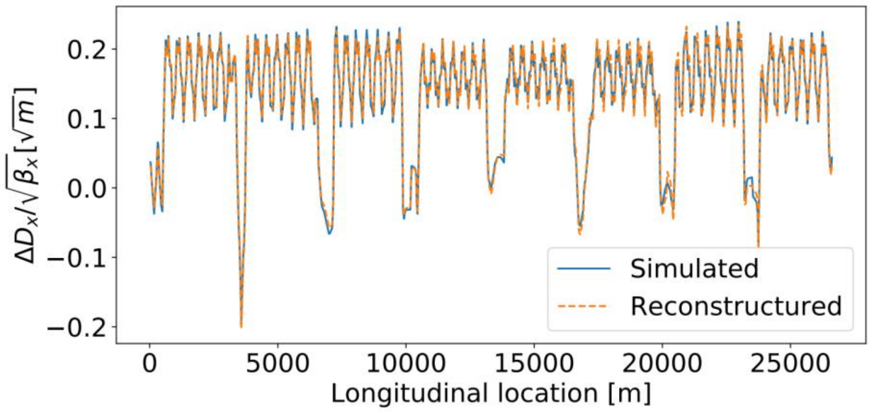
D_x/β_x at every BPM location

Simultaneously for beam 1 and 2

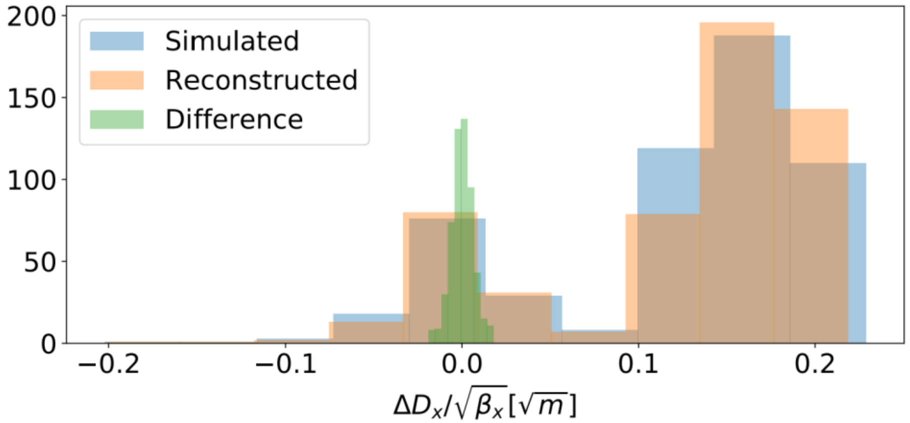
** Always available from turn-by-turn data at one beam excitation*

Reconstruction of normalized dispersion

- **Input**: simulated phase advance deviations, including noise, 1024 input variables
- **Output**: normalized dispersion $\Delta D_x/\sqrt{\beta_x}$ **,** 1024 output targets
- **Model**: Ridge Linear Regression
- 80 000 samples (80% training, 20% test)



Agreement between simulated and reconstructed values in one exemplary simulation

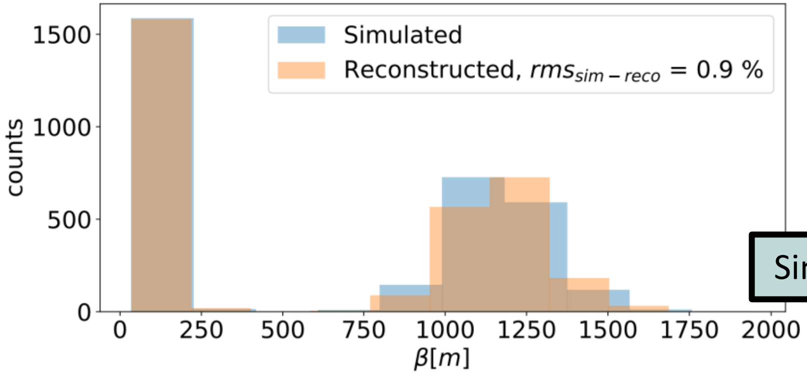


Statistics obtained from 1000 simulations

Simulated rms $\Delta D_x/\sqrt{\beta_x}$: 0.0802 $\sqrt{m}$
Relative RMS error of prediction: 7%

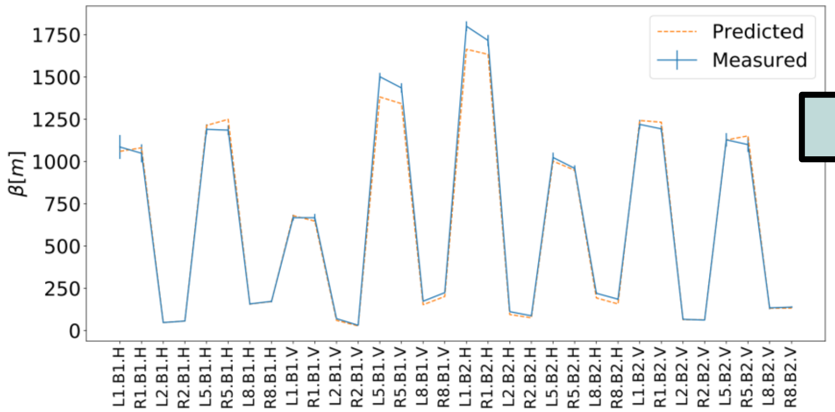
Reconstruction of β-function around Interaction Points

- **Input**: simulated phase advance deviations given noise (beam 1 and 2, horizontal and vertical planes), 2048 input variables
- **Output**: $\Delta\beta$ errors at 2 BPMs left and right from IPs 1, 2, 5 and 8 (32 targets in total)
- Ridge Regression, 80 000 training samples, (80% training, 20% test)



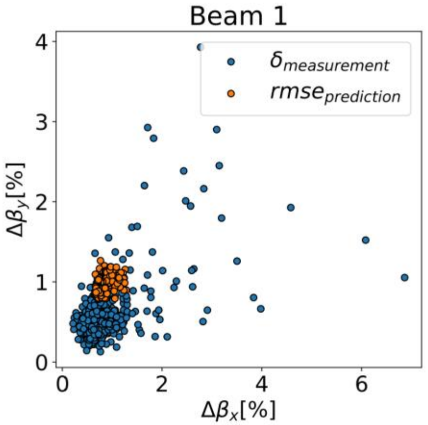
Simulations

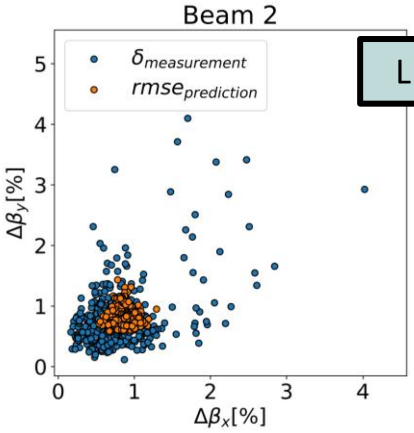
Reconstruction error: $\frac{\beta_{simulated} - \beta_{reconstructed}}{\beta\_simulated}$ **= 0.9%**



LHC Measurement

Agreement between measurement and prediction at BPMs around IPs





LHC Measurement

Uncertainties in the computation of β-function using traditional analysis and RMS error of ML-based β reconstruction.

ML-reconstruction:
- Is less affected by faulty BPMs
- Does not dependent on the β value
- Very good agreement between measurement and prediction

Conclusions & future work

	$\beta_{x,y}$	$D_x/\sqrt{\beta_x}$
$R^2_{train/test}$	0.995/0.996	0.81/0.8
$MAE_{train/test}$	4.49 / 4.61 [m]	0.0058 / 0.006 [$\sqrt{m}$]
$\frac{rms_{residual}}{rms_{true}}$	0.9%	7%

** Better performance of regression model for the reconstruction of β-function due to significant smaller amount of output targets*

→ Improvements are still possible

→ Further steps: boosting the prediction accuracy: more sophisticated regression models?

Achieved results:

- ✓ Providing **estimates of optics functions**, when time costly measurements techniques cannot be performed.
- ✓ Reconstruction of relevant observables, **without performing dedicated measurements** of these observables.
- ✓ Providing missing data
- ✓ Potential to **speed up** optics measurements and corrections.