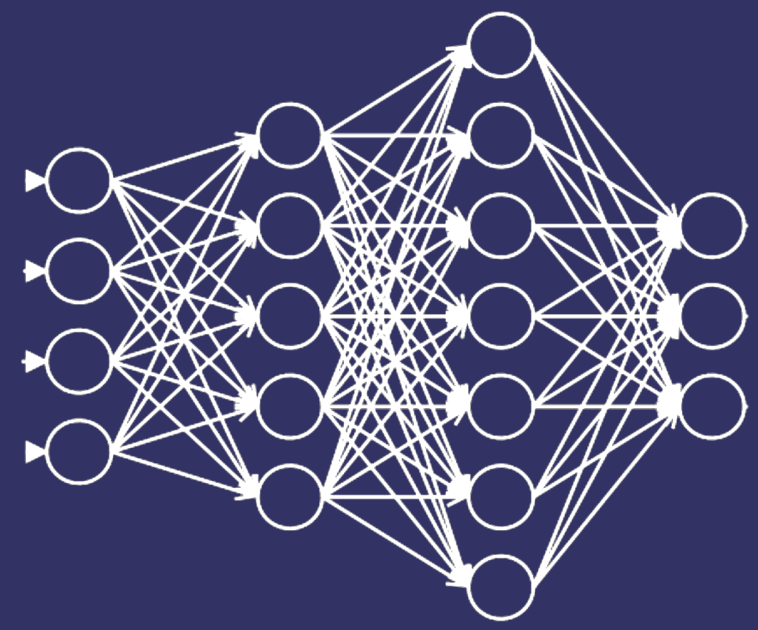# X-ray lens aberrations retrieved by deep learning from several beam intensity images

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In this study, we explore the capability of a Convolutional Neural Network (CNN) trained on synthetic data to accurately estimate the profile error in an x-ray lens. The CNN is able to retrieve the profile expressed as a list of Zernike coefficients from a series of intensity distributions simulated (or measured) at several positions. This approach offers a promising method for profile error assessment in x-ray lenses without wave-front sensor measurements, potentially reducing the need for time-consuming and costly characterization techniques. The results highlight the potential of using machine learning algorithms trained on synthetic data as a valuable tool in the field of x-ray optics for efficient and accurate error analysis.
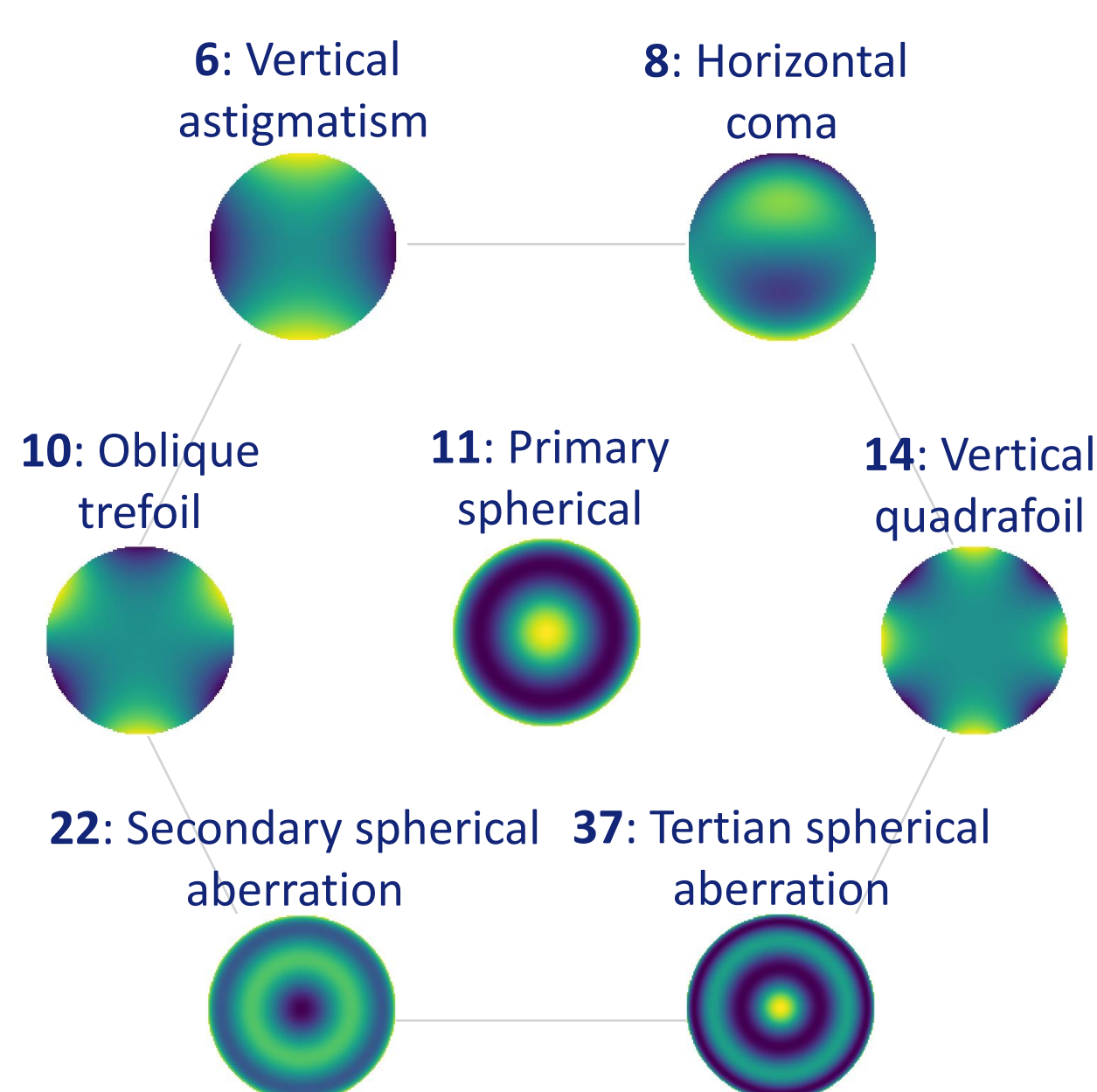
## Objective

By measuring several intensity beam profiles, retrieve a lens error profile using a CNN model.
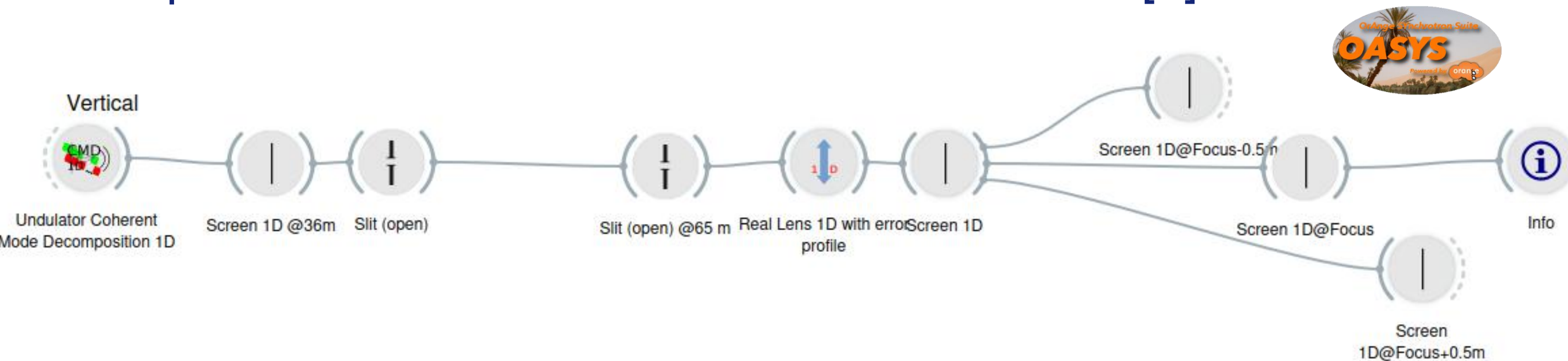
Synthetic data → CNN model → Lens error profile

Beamline → Measured beam profiles → CNN model
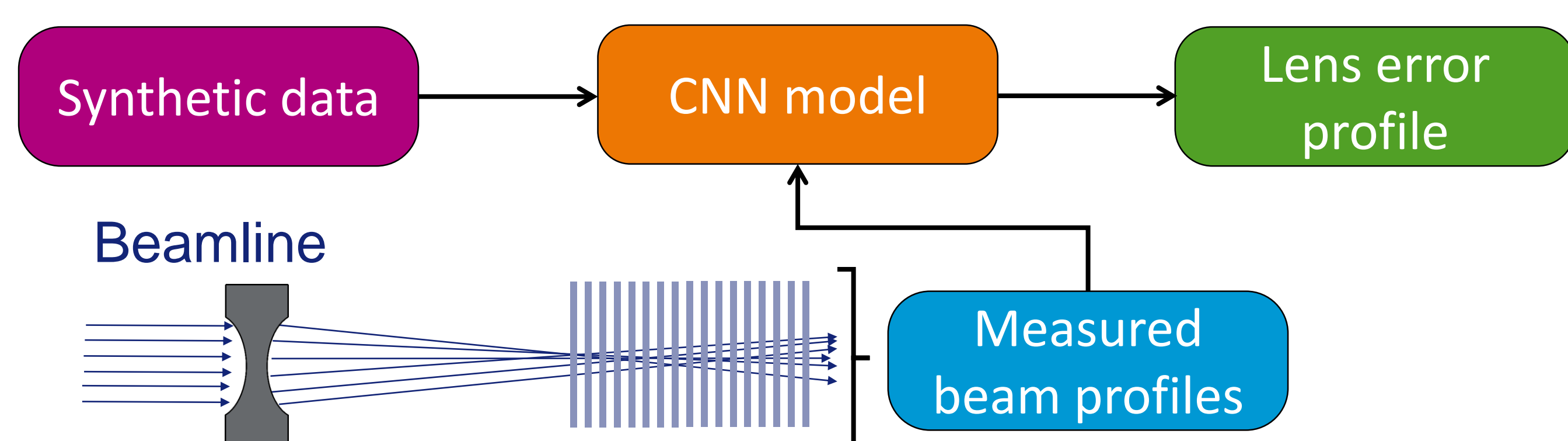
## Synthetic data

We started by creating a set of lens error profiles using random coefficients from seven picked Zernike polynomials.

6: Vertical astigmatism
8: Horizontal coma
10: Oblique trefoil
11: Primary spherical
14: Vertical quadrafoil
22: Secondary spherical aberration
37: Tertian spherical aberration

| Zernike Number | Sampling distribution | Interval |
|---|---|---|
| 6 | Normal | $\sigma=0.5$ |
| 8 | Normal | $\sigma=0.5$ |
| 10 | Normal | $\sigma=0.5$ |
| 11 | Uniform | $\pm0.5$ |
| 14 | Normal | $\sigma=0.5$ |
| 22 | Uniform | $\pm0.5$ |
| 37 | Uniform | $\pm0.5$ |

*All coefficients were multiply by a factor of 5 μm

Vertical axis sections of the error profiles were used in 1D full and partial coherence simulations with WOFRY [1].

Undulator Coherent Mode Decomposition 1D — Screen 1D @36m — Slit (open) — Slit (open) @65 m — Real Lens 1D with error profile — Screen 1D — Screen 1D@Focus-0.5m — Screen 1D@Focus — Info — Screen 1D@Focus+0.5m

For each error profile, we obtained intensity profiles for 64 propagation planes around the focusing plane, with a total of 5000 error profiles.
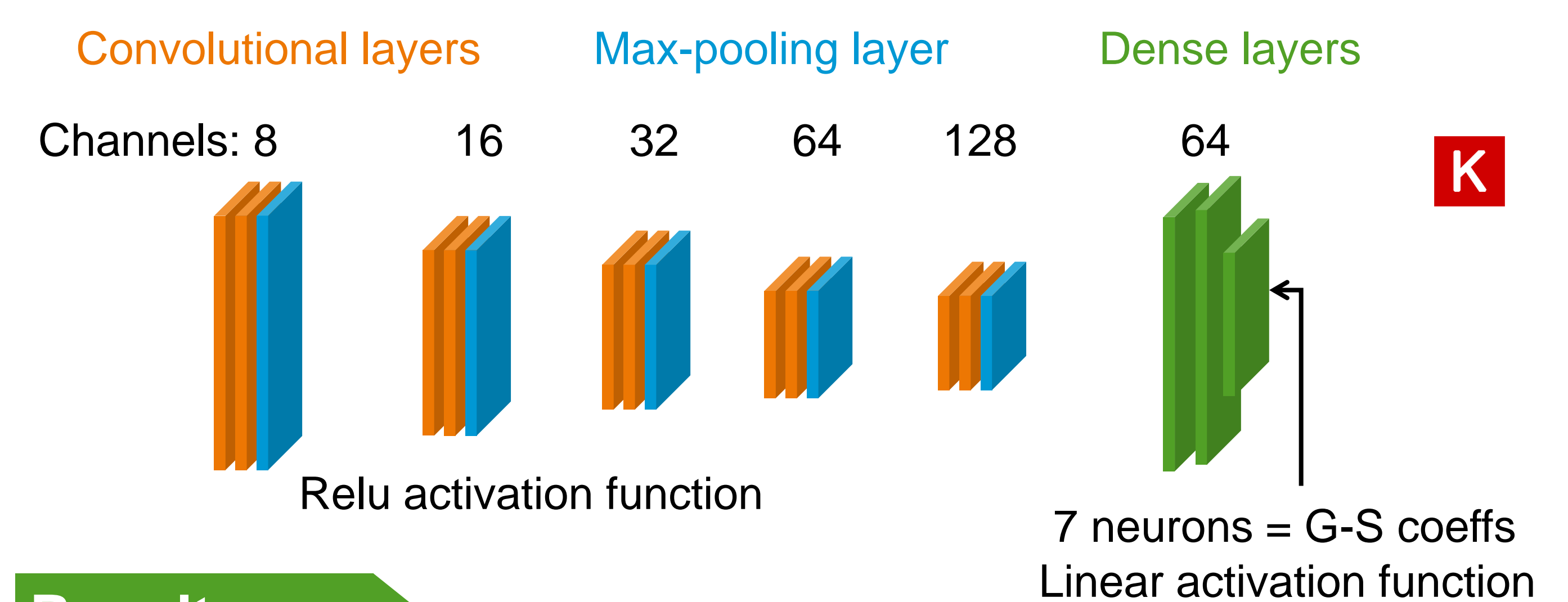
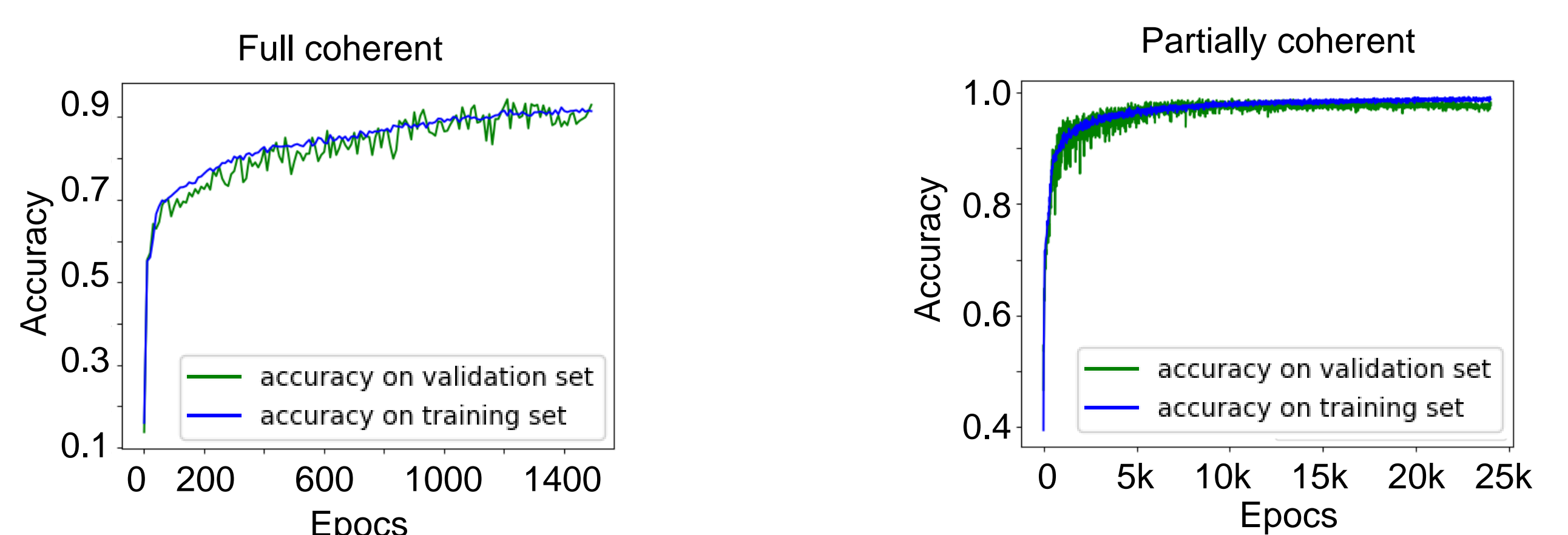Coeffs were transformed to an orthonormal base by the Gram-Schmidt (G-S) method
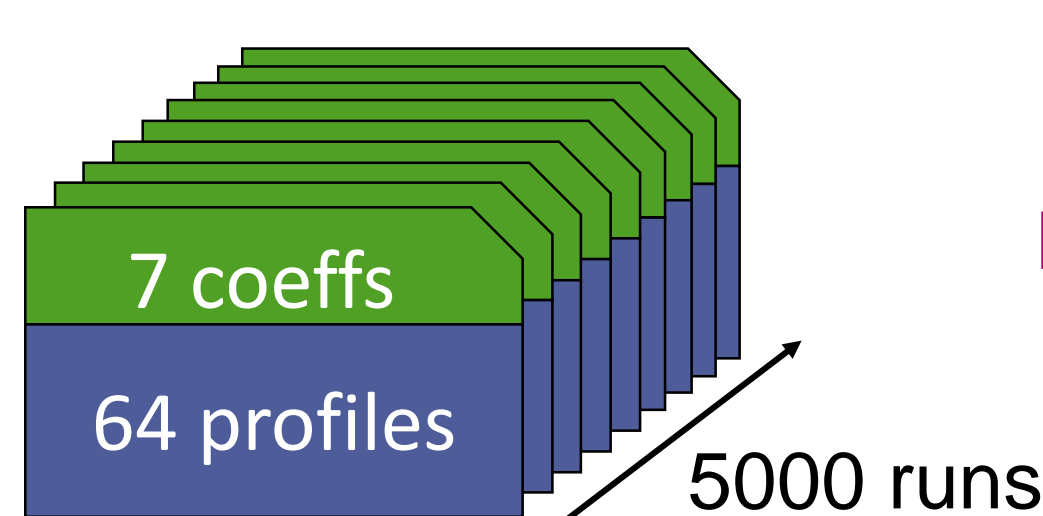
7 coeffs
64 profiles
5000 runs
Profiles with 256 points

## CNN model

Our approach is strongly inspired by Saha et al. in the visual microscopy field [2], we used Keras to build a CNN
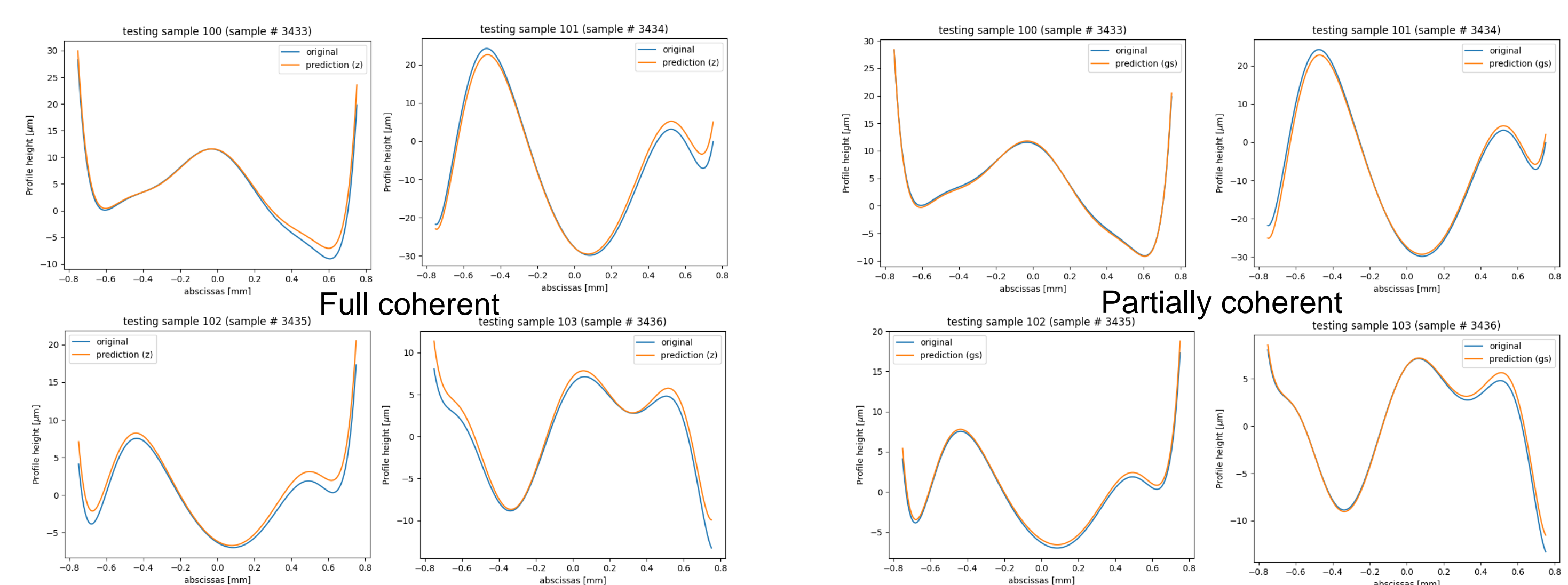
Convolutional layers — Max-pooling layer — Dense layers
Channels: 8   16   32   64   128   64

Relu activation function

7 neurons = G-S coeffs
Linear activation function

## Results

CNN accuracies:

Full coherent

accuracy on validation set
accuracy on training set

Partially coherent

accuracy on validation set
accuracy on training set

Retrieved error profiles vs originals:

testing sample 100 (sample # 3433)
testing sample 101 (sample # 3434)
testing sample 102 (sample # 3435)
testing sample 103 (sample # 3436)

Full coherent

testing sample 100 (sample # 3433)
testing sample 101 (sample # 3434)
testing sample 102 (sample # 3435)
testing sample 103 (sample # 3436)

Partially coherent

## Final Remarks

- A CNN trained with synthetic data is able to retrieve the profile error in an x-ray lens giving as input a set of intensity distributions measured or calculated at different positions. This study is published in [3].

TODO:

- Try fine tuning to reduce number of images planes.

- Test with experimental data.

- Implement procedure to 2D simulations.

[1] M. Sanchez del Rio et al. Journal of Synchrotron Radiation 29 (2022). https://doi.org/10.1107/S1600577522008736
[2] Saha et al. Optics Express 28 (2020). https://doi.org/10.1364/OE.401933
[3] M. Sanchez del Rio, R. Celestre and J. Reyes-Herrera Journal of Synchrotron Radiation 31 (2024). https://doi.org/10.1107/S1600577524004958

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