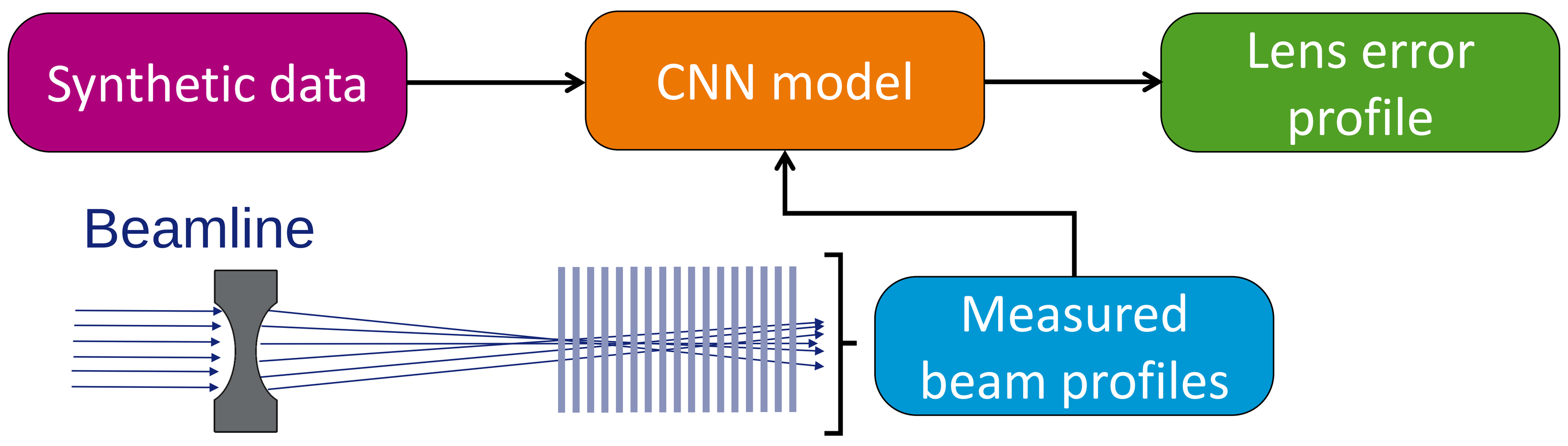
# X-ray lens aberrations retrieved by deep learning from several beam intensity images

Manuel Sanchez del Rio*, Rafael Celestre and Juan Reyes Herrera
*srio@esrf.eu

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.

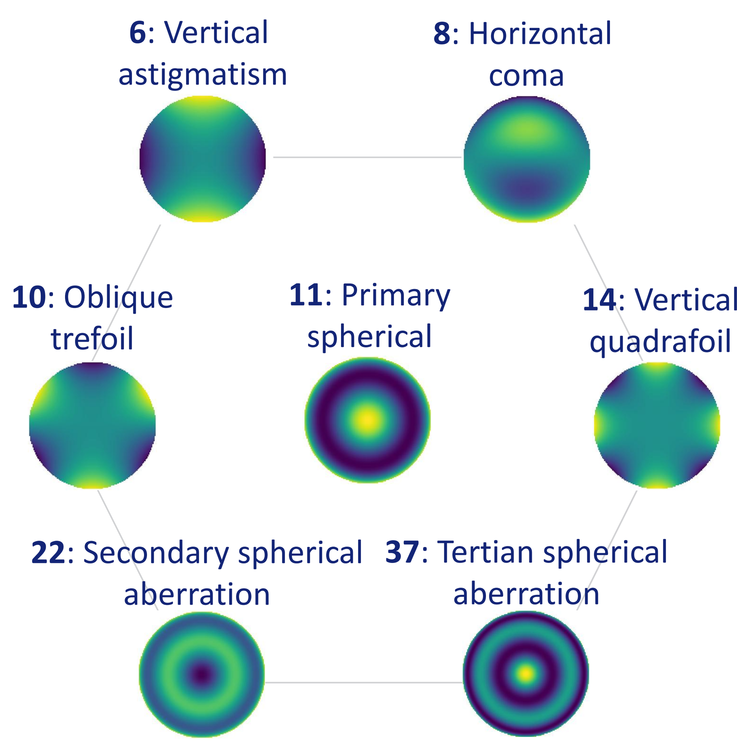
## Objective

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




## Synthetic data

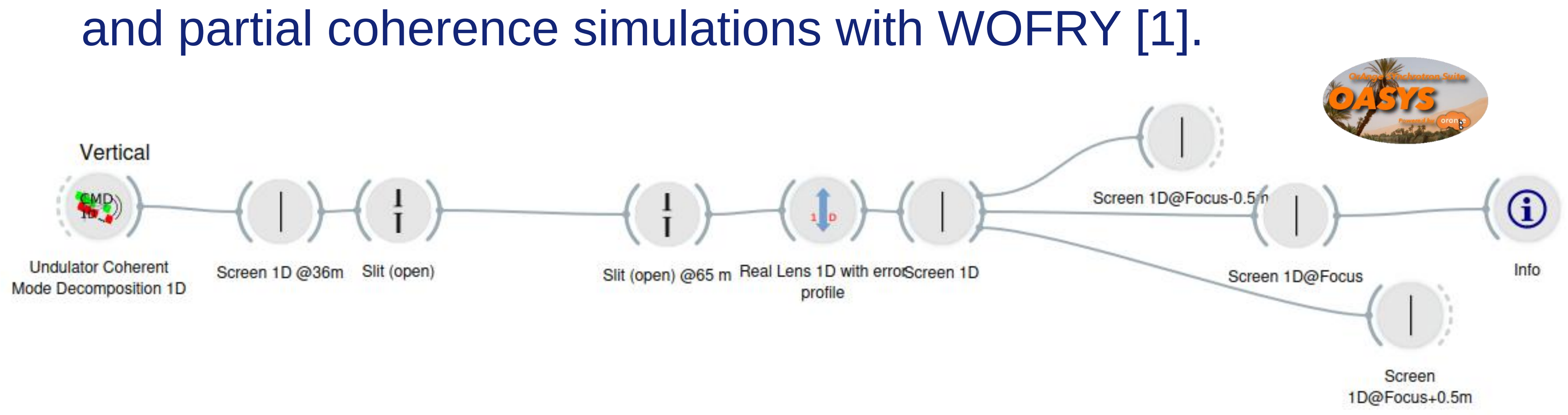
We started by creating a set of lens error profiles using random coefficients from seven picked Zernike polynomials.



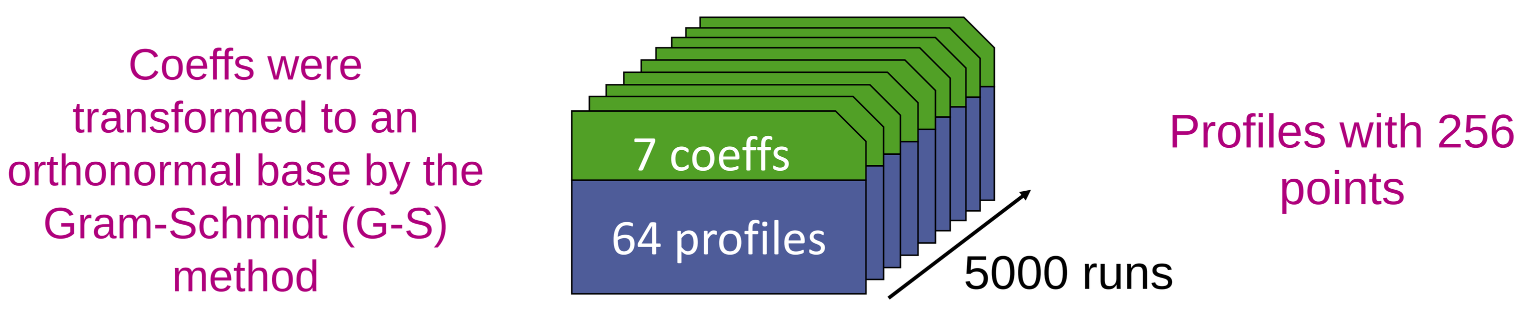

| Zernike Number | Sampling distribution | Interval |
|---|---|---|
| 6 | Normal | σ=0.5 |
| 8 | Normal | σ=0.5 |
| 10 | Normal | σ=0.5 |
| 11 | Uniform | ±0.5 |
| 14 | Normal | σ=0.5 |
| 22 | Uniform | ±0.5 |
| 37 | Uniform | ±0.5 |

*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].

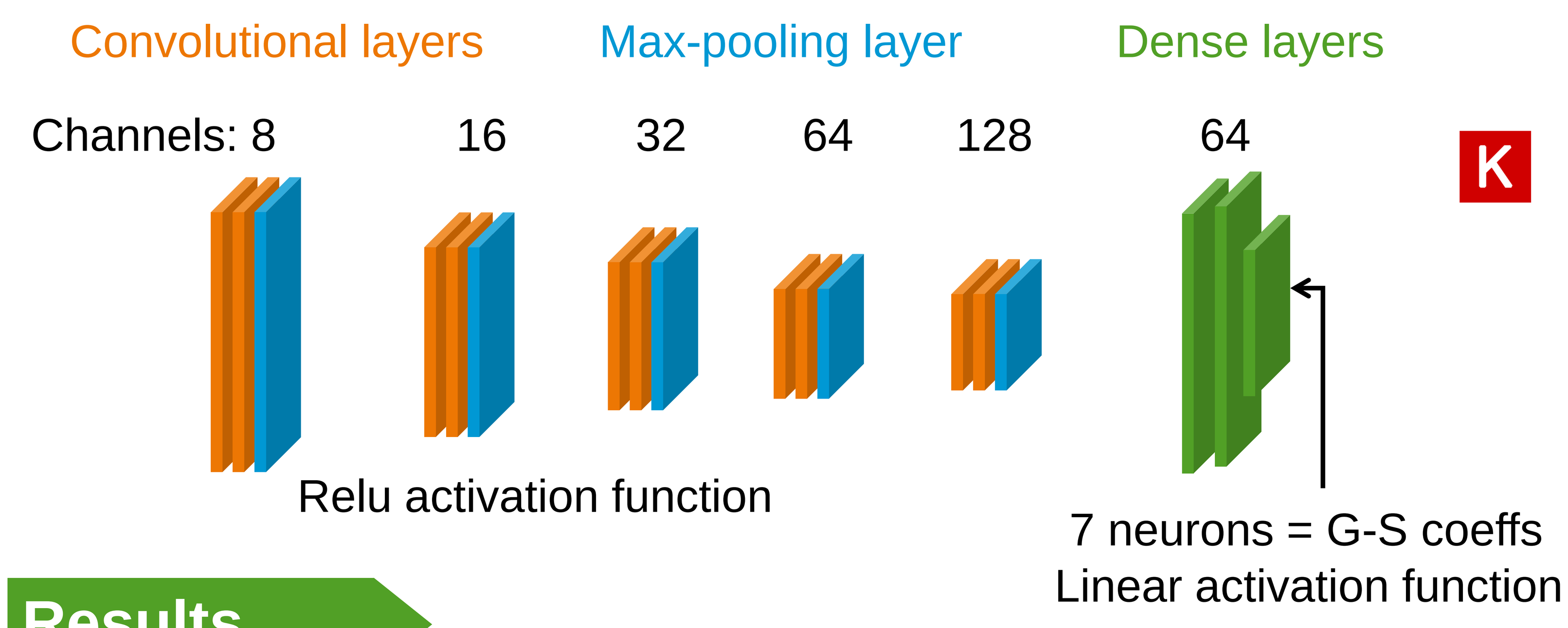



For each error profile, we obtained intensity profiles for 64 propagation planes around the focusing plane, with a total of 5000 error profiles.



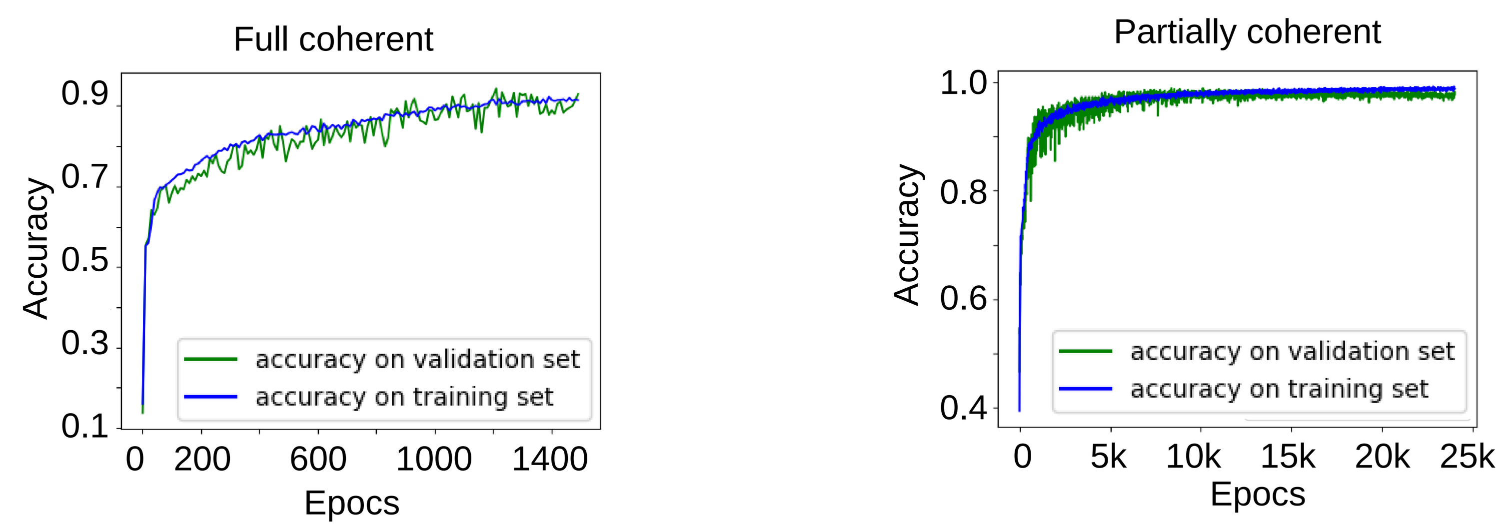

## CNN model

Our approach is strongly inspired by Saha et al. in the visual microscopy field [2], we used Keras to build a CNN

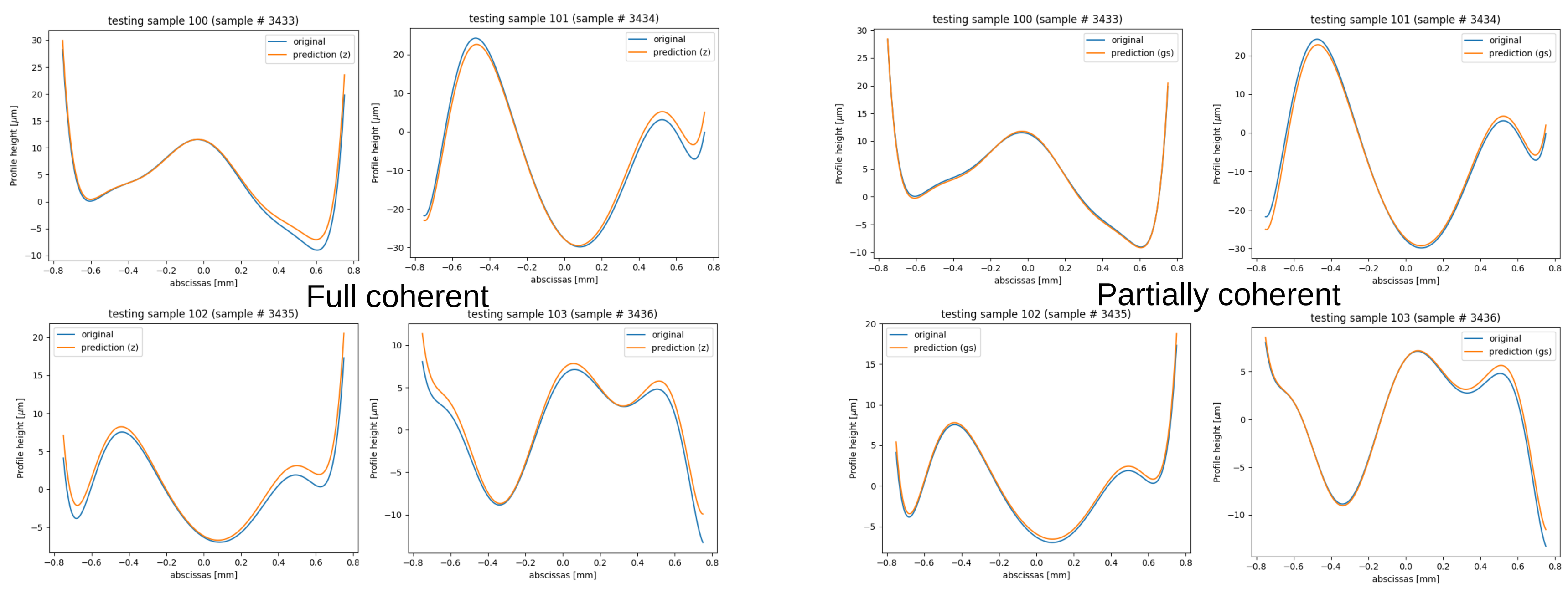



## Results

CNN accuracies:




Retrieved error profiles vs originals:




## 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

ESRF – The European Synchrotron – 71 Avenue des Martyrs, Grenoble, FRANCE - Tel +33 (0)4 76 88 20 00