# Aberration Measurements in Scanning Transmission Electron Microscopy using Deep Learning

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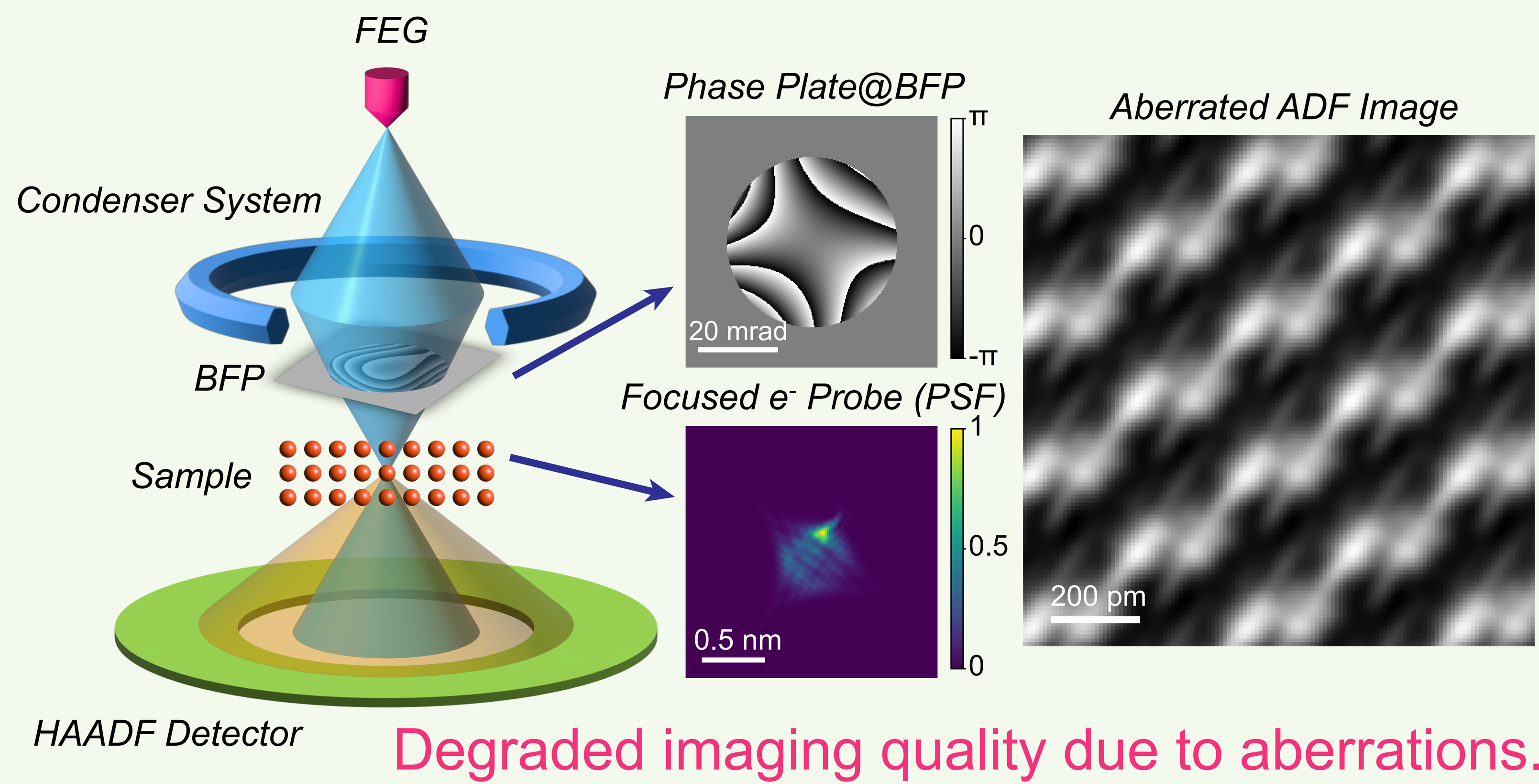
## Motivations

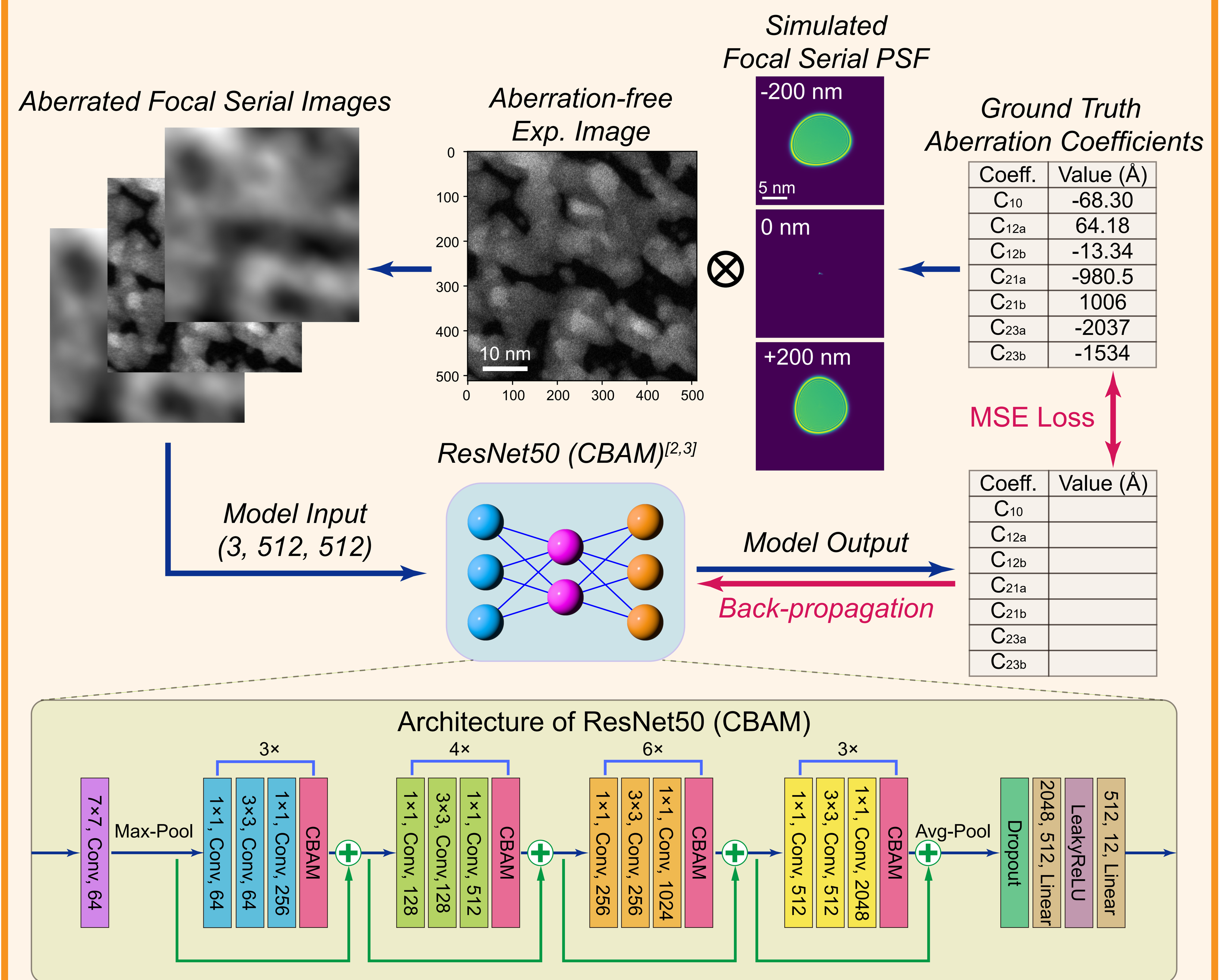



- Geometrical aberrations in electron microscopes hinder precise imaging & detection of samples under studies, making the quantitative interpretations upon experimental results intractable;
- The measurement of aberrations involve retrieving the phase distributions at the back focal plane lost during the detections;
- To effectively solve such an inverse problem, we developed a novel method by exploiting the advantages of deep learning;

Aberration phase factor@BFP[1]:

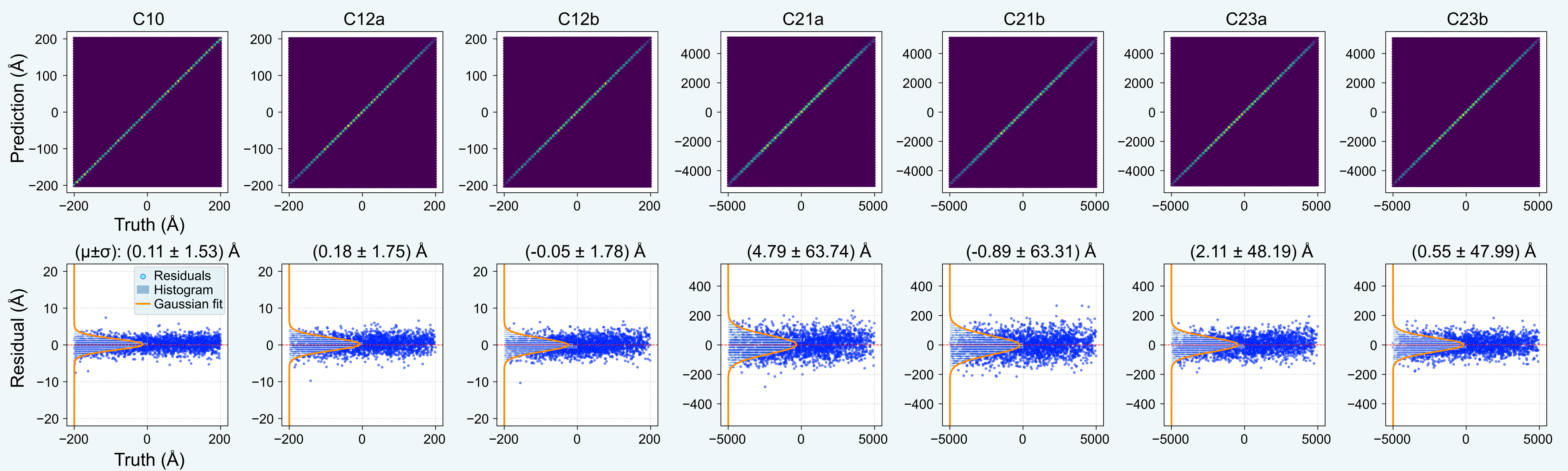
$$\chi(\alpha, \phi) = \frac{2\pi}{\lambda} \sum_{mn} \frac{1}{n+1} C_{nm} \alpha^{n+1} \cos[m(\phi - \phi_{nm})]$$

## Methods




- Starting from randomized aberration coefficients as the ground truth, training images were generated with the convolution between aberration-free experimental images and simulated focal serial PSFs. The model was trained such that precise end-to-end predictions of aberration coefficients would be accomplished.

## Results




- The 2D histograms (upper row) showed strong correlations between the ground truth aberration coefficients and the model predicted values;
- The residual scatter plots (lower row, cyan dots) together with the corresponding Gaussian fitted marginal distributions (orange line) showed symmetric distributions of prediction errors centered around zero, with the deviations lower than conventional measurement methods;

## Conclusions

- A customized CNN model dedicated to end-to-end aberration measurements in electron imaging was trained on focal serial STEM images generated with numerical simulation.
- The results showed outstanding precision of aberration measurements exceeding existing methods, highlighting the unique advantages of deep learning in solving inverse problems.

***Abbreviations:***

- FEG: Field Emission Gun;
- BFP: Back Focal Plane;
- ADF: Angular Dark Field;
- PSF: Point Spread Function;
- MSE: Mean Square Error;

## Acknowledgements & References

- The computations in this research were performed using the CFFF platform of Fudan University.

References:

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[2] He, K., et al. Deep residual learning for image recognition. in Proceedings of the IEEE conference on computer vision and pattern recognition. 2016.
[3] Sanghyun Woo , J.P., Joon-Young Lee, In So Kweon. CBAM: Convolutional Block Attention Module. in Proceedings of the European Conference on Computer Vision. 2018.