

X10 - Electron Ptychography: Experimental Considerations and Data Analysis

M&M 2026

Instructors

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Schedule

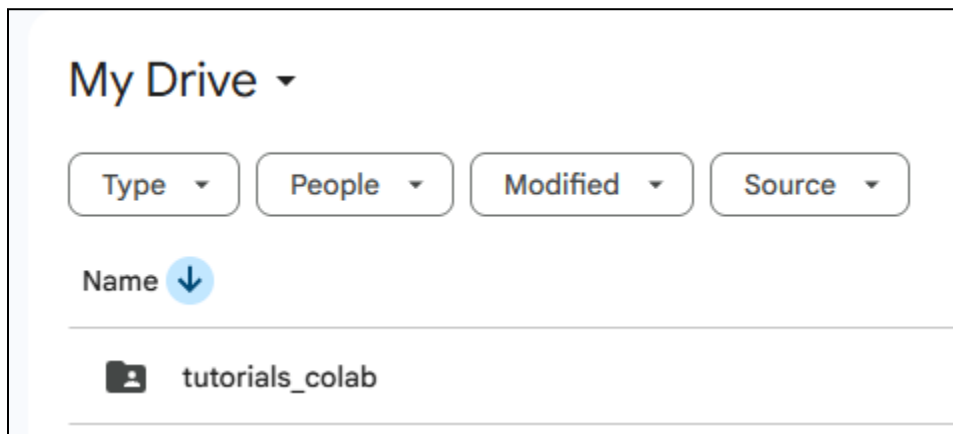
Time	Topic	Instructor
8:30–9:15	Welcome to the Wonderful World of Ptychography	David Muller
9:15–10:00	Phase Contrast in 4D-STEM & Exploring Raw Data	Steve Zeltmann
10:00–10:30	Coffee Break	
10:30–11:00	Scattering, Multislice, and Depth Resolution	David Muller
11:00–11:30	Tutorial: MEP reconstruction of thin samples	Chia-Hao Lee
12:00–13:00	Lunch Break	
13:00–13:30	Reading Ronchigrams & Experimental Parameters	Jim LeBeau
13:30–14:00	Tutorial: MEP reconstructions of thick samples	Chia-Hao Lee
14:00–14:30	Coffee Break	
14:30–15:00	Tutorial: MEP reconstructions of thick samples	Chia-Hao Lee
15:00–15:30	Optimization, Regularization, Noise, and Convergence	David Muller
15:30–16:00	Tutorial: MEP Visualization and Diagnosing Artifacts	Steve Zeltmann
16:00–16:30	Tutorial: Quantitative Analysis of MEP Reconstructions	Colin Gilgenbach
16:30–17:00	Electron Detectors	David Muller
17:00–17:15	Wrap-up	

Before the start of the course, please (1) download the course materials and (2) install the software that we will be using during the day. Conference center Wi-Fi can be very sluggish when all of us are trying to download these files.

(Step 1) Download Course Materials

Before the course starts, please download the necessary data:

- 1) **Download a copy of the “tutorials_local” folder to your laptop.** (There’s also a pre-zipped copy named **DOWNLOAD_ME.zip**, which has everything you need a local copy of).
- 2) **Make a copy of “tutorials_colab” in your own Google Drive.**



You may need to use your personal Google account for this, as many institutions disable Colab on their subscriptions. Check that you can reach colab.research.google.com on your account. Making a copy in your own Google drive means you will be able to save results and keep them for later exploration

All of the data for the course will be available from the M&M official Google Drive folder (the conference should share a link with you shortly, and we’ll update it here as well...)

A mirror of this data will also be available here in case of issues (but will NOT be archived after the course):

 **MM2026 – X10 – Course Materials**

(Step 2) Install Instructions

The course will use a mix of web-based resources and locally installed packages. The local packages require downloading some relatively large files, so please get these before coming to the course. The Wi-Fi in the conference center cannot be counted on to handle everyone in the course downloading large files at the same time!

- **py4DGUI** is used in the morning block for exploring 4D-STEM data. You can install it using conda (if you have it already, make sure you get the latest version!) following the instructions here: <https://github.com/py4dstem/py4D-browser>.

To install py4DGUI:

1) Install `conda`, if you don't have it. We recommend the miniforge installer if you are installing it fresh: <https://conda-forge.org/download/>

2) Create an environment to install packages into, and activate it:

```
conda create -n MM-X10 py4d-browser
```

```
conda activate MM-X10
```

```
pip install fast-acbf py4d-browser-fast-acbf
```

3) To run the browser: `conda run -n MM-X10 py4DGUI`

- **PtyRAD** is used for all MEP reconstructions. *Since we will run these in Google Colab, you simply need to run the notebooks we've provided to perform the installation.* However, it is a good idea to **make a copy of the tutorials_colab folder in your own Google Drive** so that you can access the results later. To install PtyRAD on your own computer after the course, follow the instructions here: <https://github.com/chiahao3/ptyrad>
- **Fiji** is used for visualizing MEP reconstructions, and we will use it in the afternoon. Download it here: <https://imagej.net/software/fiji/downloads>
- **Binder** is used to run the quantification notebooks. To access the pre-configured environment, just use this link:

<https://mybinder.org/v2/gh/hexane360/ptycho-quant-analysis/main?urlpath=%2Fdoc%2Ftree%2F01+ZnMgSe+-+peak+analysis.ipynb>

To run these notebooks on your own, after the course, instructions for locally installing the necessary packages are in the INSTALL.txt file.

Additional Resources

This course is based on the week-long Ptychography Workshop held at Cornell University in Summer 2025. The materials from that course are available online, including several hours of lectures, slides, and further tutorial notebooks:

- https://vod.video.cornell.edu/playlist/dedicated/1_zk2jdzmK/
- <https://cornell.box.com/s/b90mbcqwz211fwbbzee38uhv518jxu6>

Selected MEP papers with publicly-available datasets (either raw or reconstructed):

- Karapetyan et al. 3D atomic-scale metrology of strain relaxation and roughness in Gate-All-Around transistors via electron ptychography. Nat Commun 17, 3561 (2026). <https://doi.org/10.1038/s41467-026-69733-1>
- Chen et al. Electron ptychography achieves atomic-resolution limits set by lattice vibrations. Science 372, 6544 (2021). <https://doi.org/10.1126/science.abg2533>
- Nguyen et al. Achieving sub-0.5-angstrom-resolution ptychography in an uncorrected electron microscope. Science 383, 6685 (2024). <https://doi.org/10.1126/science.adl2029>
- Zhang et al. Atom-by-atom imaging of moiré phasons with electron ptychography. Science 389, 6758 (2025). <https://doi.org/10.1126/science.adw7751>

- Zhu et al. Insights into Chemical and Structural Order at Planar Defects in Pb₂MgWO₆ Using Multislice Electron Ptychography. ACS Nano (2025) 19 (5): 5568–5576.
<https://doi.org/10.1021/acsnano.4c14833>
- Zhu et al. Bridging experiment and theory of relaxor ferroelectrics with multislice electron ptychography. Science 392, 6797 (2026). DOI: [10.1126/science.ads6023](https://doi.org/10.1126/science.ads6023)
- Li et al. Atomically resolved imaging of radiation-sensitive metal-organic frameworks via electron ptychography. Nature Communications 16:914 (2025).
<https://doi.org/10.1038/s41467-025-56215-z>
- Gilgenbach et al. phaser: a unified and extensible framework for fast electron ptychography. Npj Computational Materials 12:89 (2026).
<https://doi.org/10.1038/s41524-026-01956-8>
- Kim et al. Quantifying Implantation-Induced Damage and Point Defects with Multislice Electron Ptychography. Nano Letters 25(17):6927–6934 (2025).
<https://doi.org/10.1021/acs.nanolett.5c00170>
- Küçükoğlu et al. Low-dose cryo-electron ptychography of proteins at sub-nanometer resolution. Nature Communications 15:8062 (2024).
<https://doi.org/10.1038/s41467-024-52403-5>. *Note: we have found that the Phi92 data uploaded to EMPIAR-12233 has alternate scan rows reversed. The dataset we uploaded to the course folder has been corrected for this (and binned by 4 to reduce file size). The apoferritin and TMV datasets do not have this problem.*
- Chen et al. Mixed-state electron ptychography enables sub-angstrom resolution imaging with picometer precision at low dose. Nature Communications 11:2994 (2020).
<https://doi.org/10.1038/s41467-020-16688-6>

Further reading:

- Ma et al. Information in 4D-STEM: Where it is, and How to Use it. Ultramicroscopy 283:114351 (2026). <https://doi.org/10.1016/j.ultramic.2026.114351>
- Chen et al. Mixed-state electron ptychography enables sub-angstrom resolution imaging with picometer precision at low dose. Nature Communications 11:2994 (2020).
<https://doi.org/10.1038/s41467-020-16688-6>
- Ma et al. Using Aberrations to Improve Dose-Efficient Tilt-corrected 4D-STEM Imaging. Microscopy and Microanalysis 32:2 (2026). <https://doi.org/10.1093/mam/ozag008>
- Denzer et al. Optimizing Atomic Number Contrast in Multislice Electron Ptychography. Microscopy and Microanalysis 31:5 (2025).