Free-Electron-Based Interferometry for Enhanced Phase-Resolved Near-Field Imaging

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Motivation

Deep Learning (DL) in microscopy:

- Outperforms conventional image processing algorithms [1].

Vision: DL to achieve **atomic scale** and **ultrafast time** resolution in electron microscopes while observing **previously inaccessible phenomena**.

In our work:

- Ultrafast transmission electron microscopy (UTEM), combines high spatial and temporal resolution.
- Pioneering UTEM application: photon-induced near-field electron microscopy (**PINEM**) [2], whereby electrons can image electromagnetic near-fields.

The underlying mechanism relies on quantum electron-photon interaction:

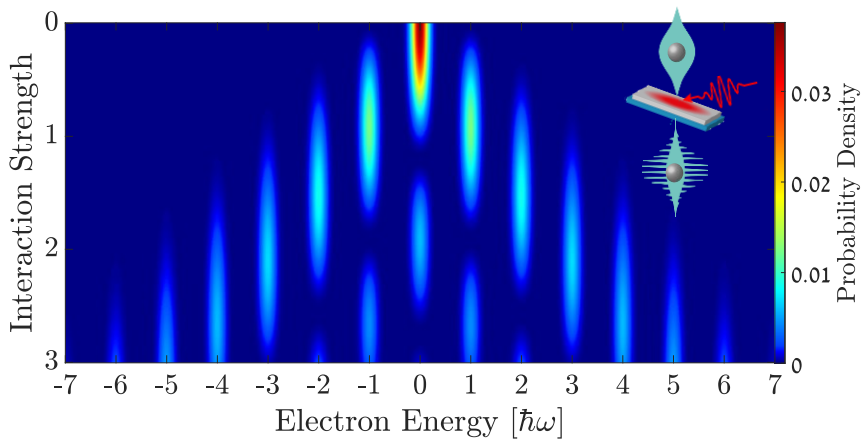

Fig. 1. PINEM interaction.

Methodology

Interferometric PINEM (iPINEM)

- **Novel electron interferometer scheme, bypassing the current limits of near-field microscopy**, by pre-shaping the electron wavefunction.
- **Over-constraint** scheme that enables **phase-resolved and enhanced amplitude imaging** with **better SNR** for **weaker fields**.

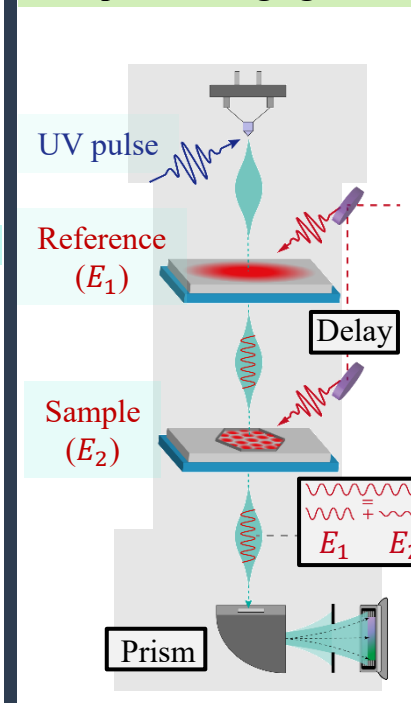

Fig. 2. Interferometric PINEM.

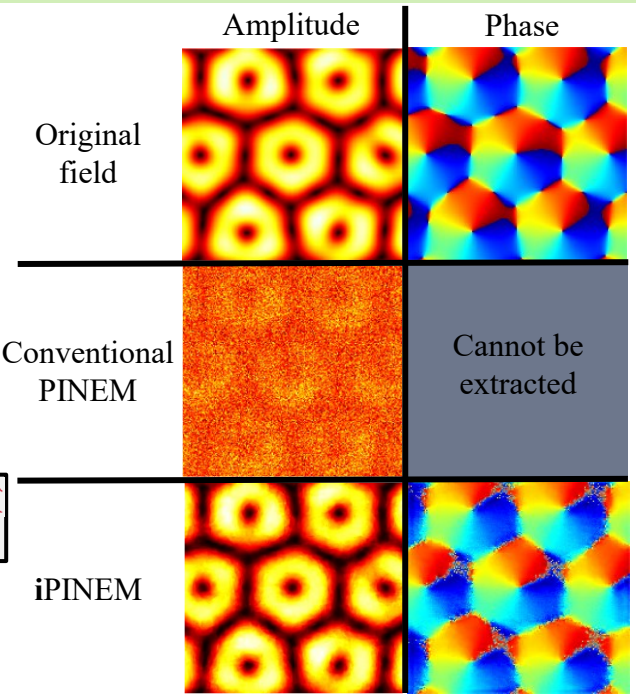

Fig. 3. Comparison of conventional PINEM to our interferometric PINEM.

PINEM Enhancement

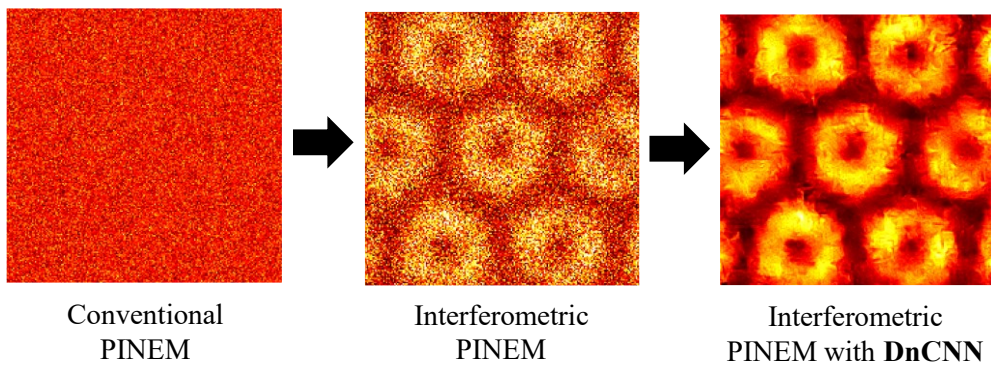

Fig. 4. Amplitude reconstruction enhancement **evolution** for very noisy measaments (SNR $\cong -20$dB) and weak interaction strength ($|g_{plasmon}| \cong 5 \cdot 10^{-2}$).

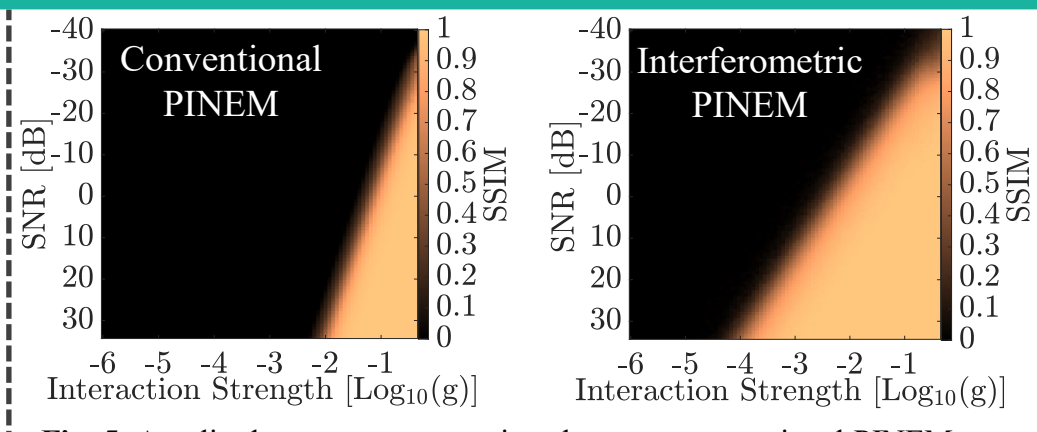

Fig. 5. Amplitude recovery comparison between conventional PINEM and interferometric PINEM.

Optimization Procedure

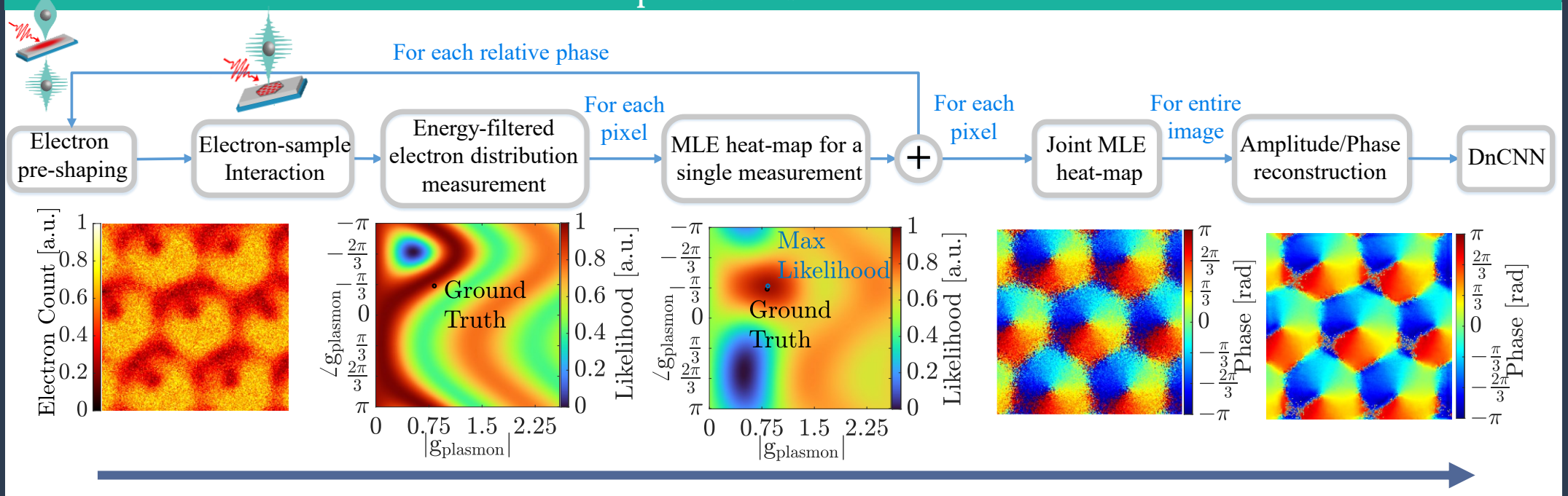

Fig. 6. Optimization procedure: block scheme (top) and visualization (bottom)

Conclusions

- **Interferometric-PINEM** gives **enhanced imaging signal** for **amplitude** and **phase**, therefore, enables to **image electron and light beam sensitive materials and cold excitonic physics**.
- **Our vision** is achieved via the **over-constraint nature** of the scheme.
- Inspired by **free-electron pre-shaping** [3-5,8] and **pseudo-heterodyne detection** in near-field scanning optical microscopy (NSOM) [9, 10].
- DL methods will utilize more degrees of freedom from the scheme and enable microscopy of previously inaccessible phenomena.

References

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