

Detecting Spin System Dynamics with Free Electrons

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In recent work [1,2], we developed SPINEM (Spin Electron Microscopy), which synergistically combines microwave (MW) spectroscopy with transmission electron microscopy (TEM) to leverage its high spatial resolution [3], enabling localized *in situ* detection of MW-driven spin transitions via a free-space electron probe.

Spin state polarization is achieved via the \mathbf{B}_0 magnetic field (170 mT) of the TEM's polepiece, while a custom-designed microresonator integrated into a TEM sample holder drives spin transitions and modulates the electron beam at a frequency of 5 GHz (see Fig. 1). This modulation enables phase-locked detection, allowing the isolation of spin precession contributions to the electron beam deflection with a sensitivity down to the picoradian scale. By sweeping the polarizing \mathbf{B}_0 field across the specimen's resonance, SPINEM spectra can be acquired with a spatial resolution of 30 μm .

These results advance quantum electron microscopy by uniting spin physics with high-resolution electron optics. SPINEM enables sensitive and precise detection of spin excitations and, with future improvements, such as the incorporation of advanced STEM techniques, promises high-resolution mapping of spin excitations through time-resolved 5D STEM measurements.

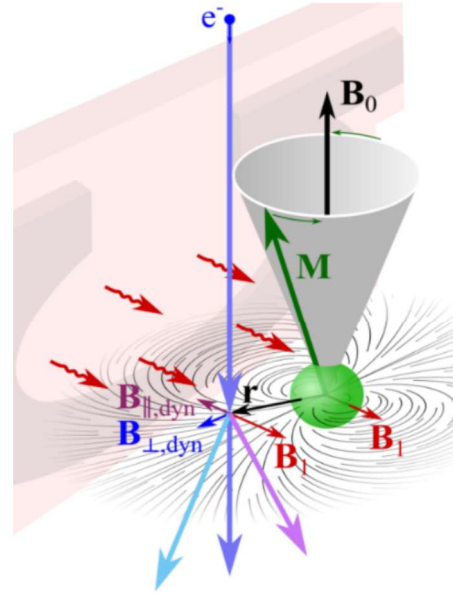


Figure 1: SPINEM spectra are acquired by sweeping the polarizing \mathbf{B}_0 field across the resonance, while keeping the driving \mathbf{B}_1 magnetic field constant to maintain a stable phase reference. At resonance, the specimen's magnetization \mathbf{M} begins to precess, inducing dynamic magnetic fields \mathbf{B}_{dyn} that deflect the electron beam.

References

- [1] A. Jaroš, et al., arXiv:2408.16492 (2024).
- [2] A. Jaroš, et al., arXiv:2503.06761 (2025).
- [3] Y. Kohno, et al., Nature 602, 234-239 (2022).

Acknowledgments

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