

Free-Electron – Bound-Electron Resonant Interaction with a Modulated Electron Beam

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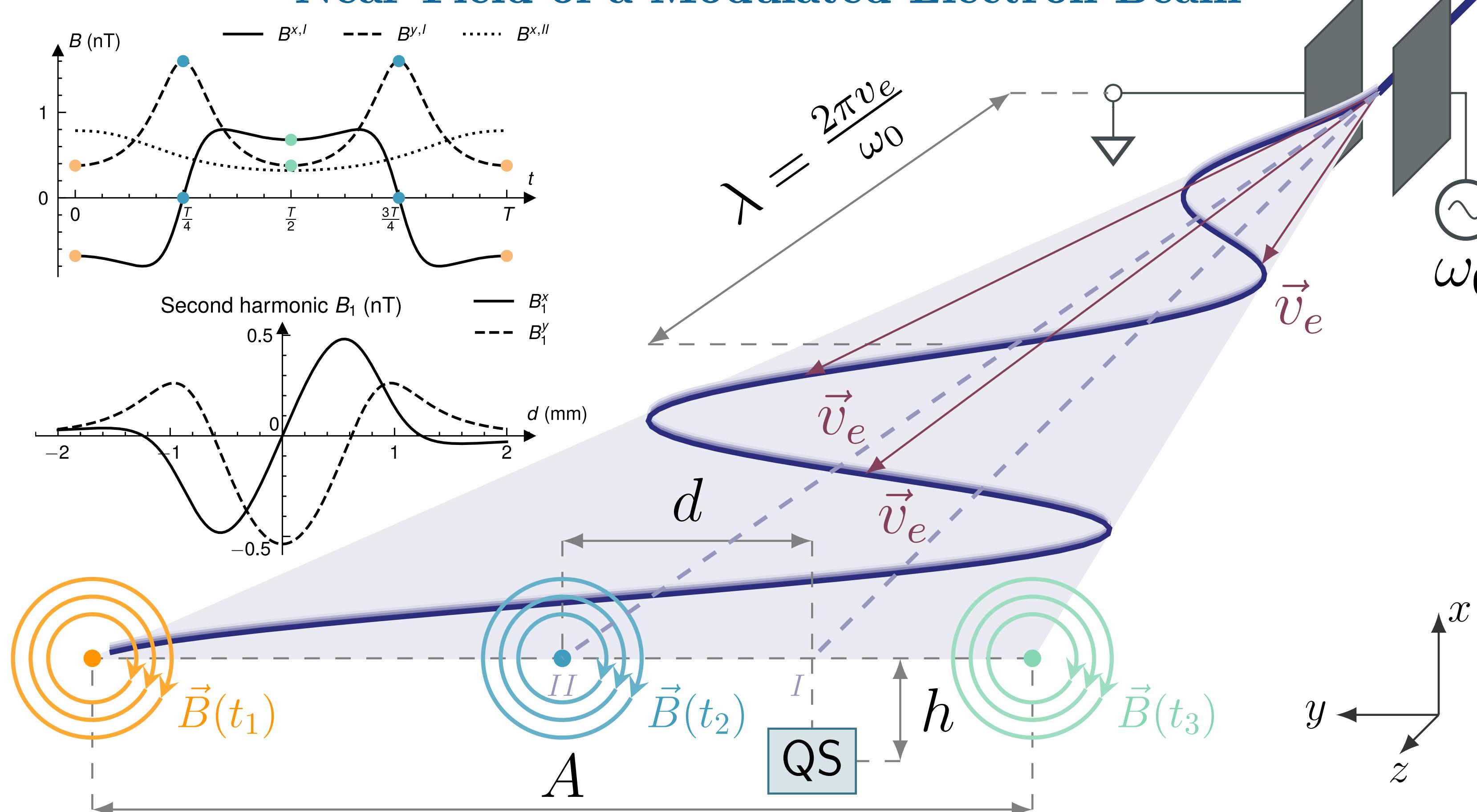
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Abstract

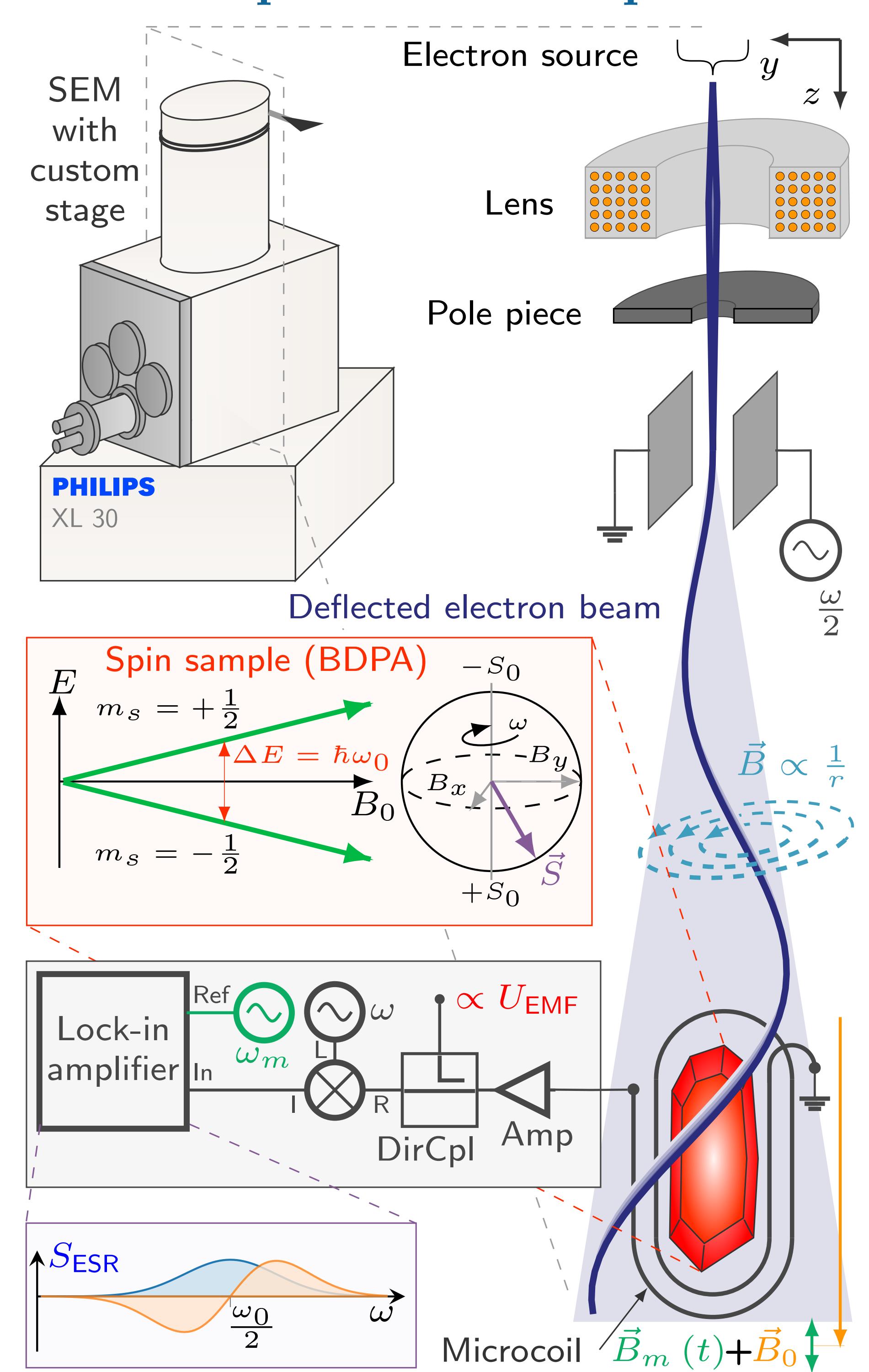
We present the first experimental realization of a novel approach to drive quantum systems (QS) [1], as it was recently proposed [2, 3]. This method utilizes the non-radiating near-field of a spatially modulated electron beam. This way, instead of single electron interaction, many electrons coherently drive the quantum

system, leading to new possibilities for controlling quantum states. For instance, control far below the diffraction limit of electro-magnetic radiation or painted potentials at atomic scales. For this experiment we customized a scanning electron microscope (SEM) to drive Zeeman-levels of an electron spin active sample.

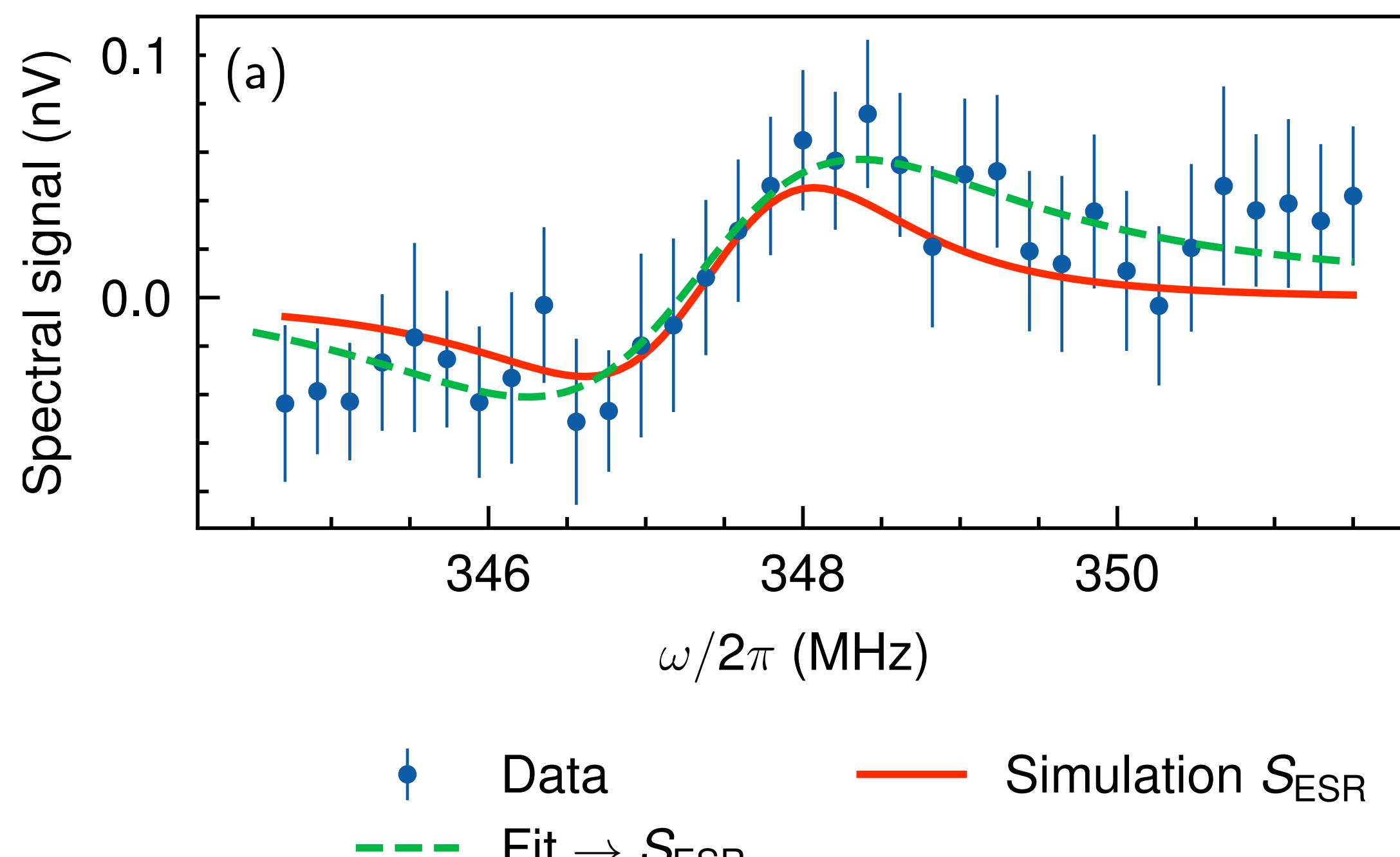
Near Field of a Modulated Electron Beam



Experimental Setup

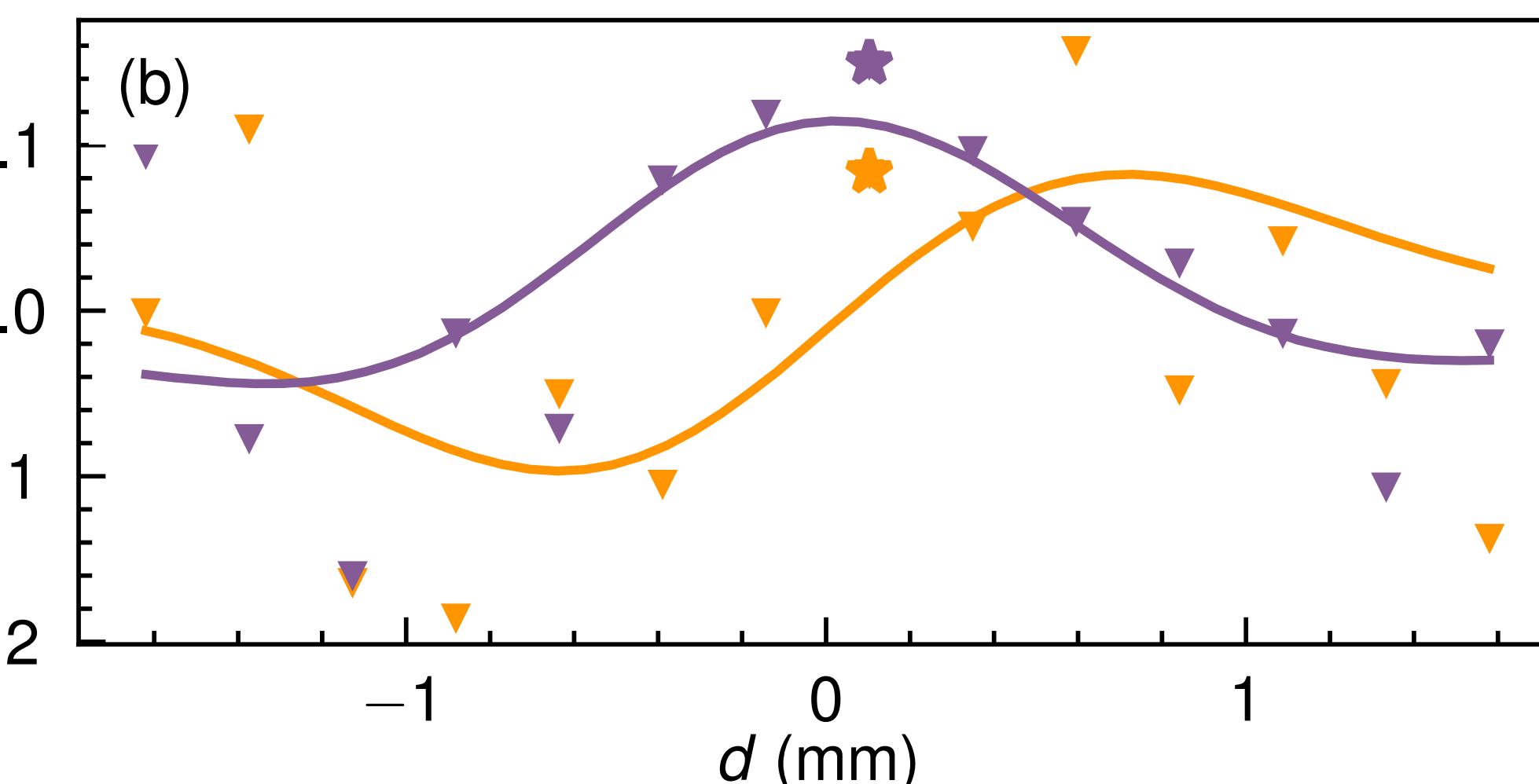


Results



ESR signal (nV)

(a) ESR spectrum induced by a modulated electron beam ($h \approx 0.6$ mm, $d \approx 0.1$ mm, $A \approx 0.9$ mm) differentially measured with electron beam: on/off. The signal includes both direct (S_{beam}) and indirect (U_{EMF}) driving of the spins.



I quadrature $\propto B_1^x$

\blacktriangledown $S_{\text{beam}} = S_{\text{ESR}} - \alpha U_{\text{EMF}}$

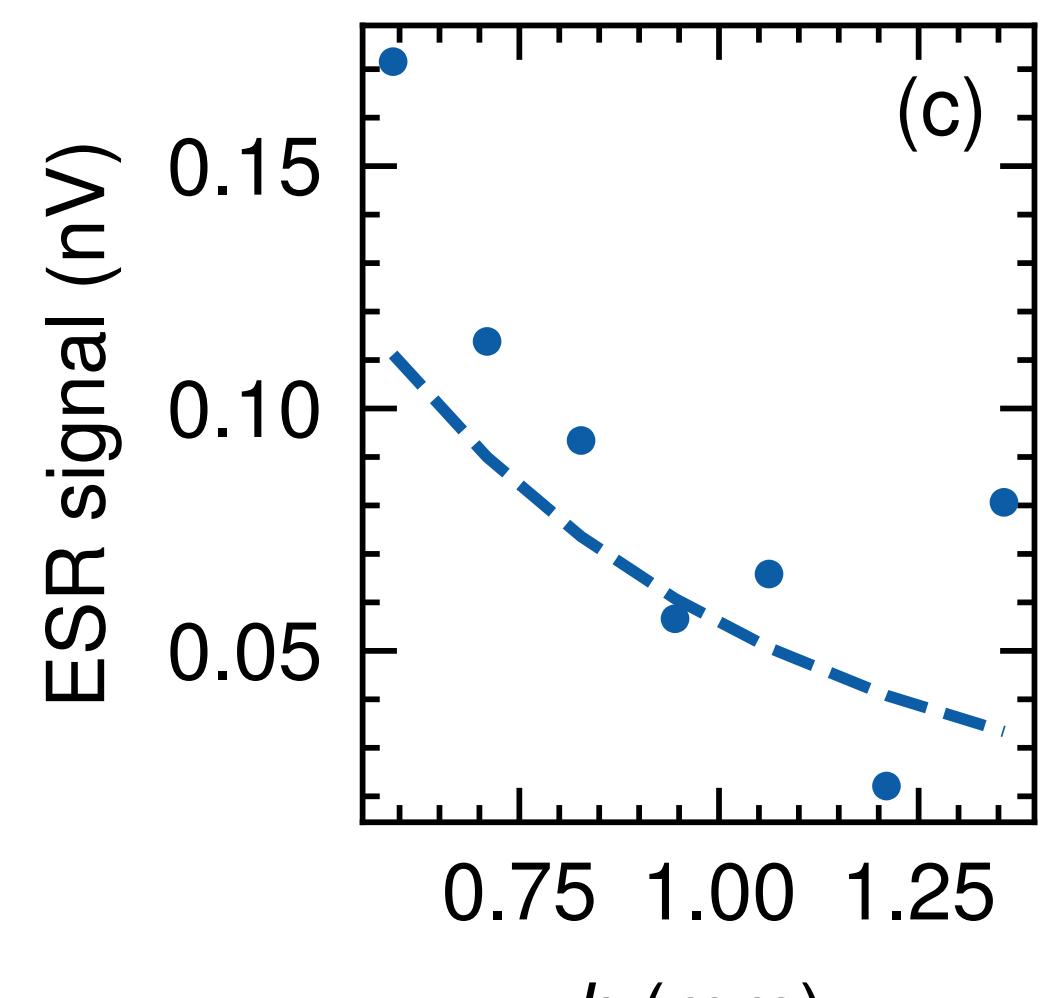
Simulation S_{beam}

Q quadrature $\propto -B_1^y$

\blacktriangledown $S_{\text{beam}} = S_{\text{ESR}} - \alpha U_{\text{EMF}}$

Simulation S_{beam}

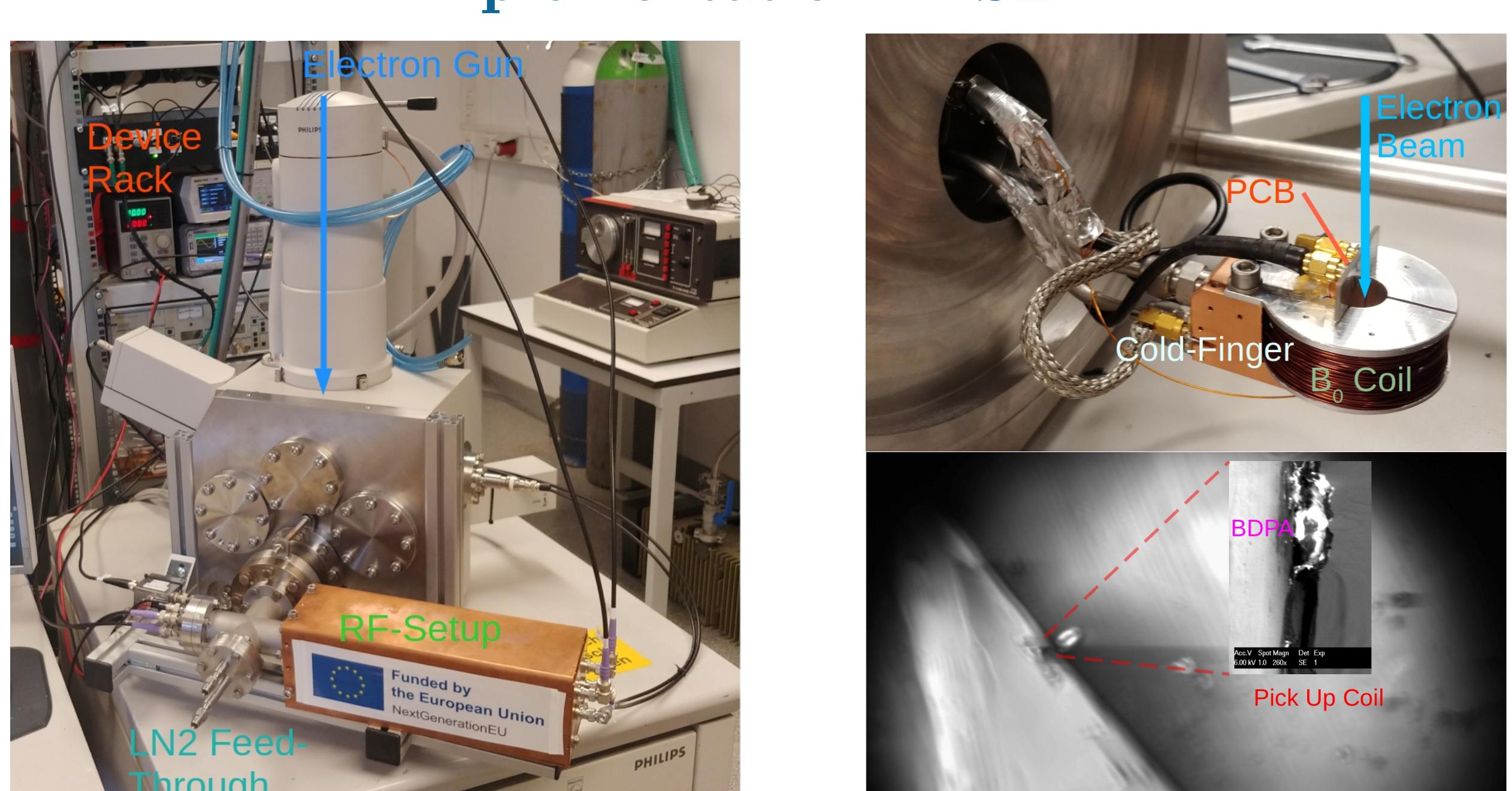
(b) Spatial dependence of the direct driving signal (S_{beam}) quadratures I and Q determined from the extracted magnitudes and phases from the fits of individual ESR spectra.



• Data
- - - Sim

(c) Vertical dependence of the beam driven ESR signal magnitude.

Implementation in SEM



FWF
ESQ
Discovery
Programme
Start Prize

ÖAW
ÖSTERREICHISCHE
AKADEMIE DER
WISSENSCHAFTEN

FFG
Promoting Innovation.

References

- M. Kolb, T. Spielauer, T. Weigner, et al., "Coherent Driving of a Quantum System with Modulated Free-Space Electrons," [10.48550/arXiv.2509.13904](https://arxiv.org/abs/2509.13904).
- D. Rätzel, D. Hartley, O. Schwartz, and P. Haslinger, "Controlling quantum systems with modulated electron beams," *Phys. rev. res.* **3**, 023247 (2021).
- A. Gover and A. Yariv, "Free-Electron-Bound-Electron Resonant Interaction," *Phys. rev. lett.* **124**, 064801 (2020).

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