Fano interference of the Higgs mode in cuprate high-T_c superconductors

Hao Chu*[1,2]* , Sergey Kovalev[3], Zi Xiao Wang[4], Lukas Schwarz[1], Tao Dong[4], Liwen Feng[1,5], Rafael Haenel[1,2], Min-Jae Kim[1,5], Matteo Puviani[1], Martin Bluschke[1,2], Gennady Logvenov[1], David J. Jones[2], Andrea Damascelli[2], Matteo Minola[1], Bernhard Keimer[1], Dirk Manske[1], Nanlin Wang[4], Jan-Christoph Deniert[3], Stefan Kaiser[1,5]

[1] *Max Planck Institute for Solid State Research, Heisenbergstr. 1, 70569 Stuttgart, Germany*
[2] *Quantum Matter Institute, University of British Columbia, Vancouver, BC V6T 1Z4, Canada*
[3] *Helmholtz-Zentrum Dresden-Rossendorf, Bautzner Landstr. 400, 01328 Dresden, Germany*
[4] *International Center for Quantum Materials, School of Physics, Peking University, Beijing 100871, China*
[5] *Institute of Solid State and Materials Physics, Technical University Dresden, 01062, Dresden, Germany*
*E-mail: haochu@mail.ubc.ca, s.kaiser@fkf.mpg.de

Despite decades of search for the pairing boson in cuprate high-T_c superconductors, its identity still remains debated to date. For this reason, spectroscopic signatures of electron-boson interactions in cuprates have always attracted significant attention. For example, the kinks in the quasiparticle dispersion observed by angle-resolved photoemission spectroscopy (ARPES) studies have motivated a decade-long investigation of electron-phonon as well as electron-paramagnon interactions in cuprates. On the other hand, the overlap between the charge-order correlations and the pseudogap in the cuprate phase diagram has also generated discussions about the potential link between them. In the present study, we provide a fresh perspective on these intertwined interactions using the novel approach of Higgs spectroscopy (Fig. 1(a)), i.e. an investigation of the amplitude oscillations of the superconducting order parameter driven by a terahertz radiation. Uniquely for cuprates, we observe a Fano interference of its dynamically driven Higgs mode with another collective mode (Fig. 1(b)), which we reveal to be charge density wave fluctuations based on an extensive doping- and magnetic field-dependent study. This finding is further corroborated by a mean field model in which we describe the microscopic mechanism underlying the interaction between the two orders. Our work demonstrates Higgs spectroscopy as a novel and powerful technique for investigating intertwined orders and microscopic processes in unconventional superconductors.

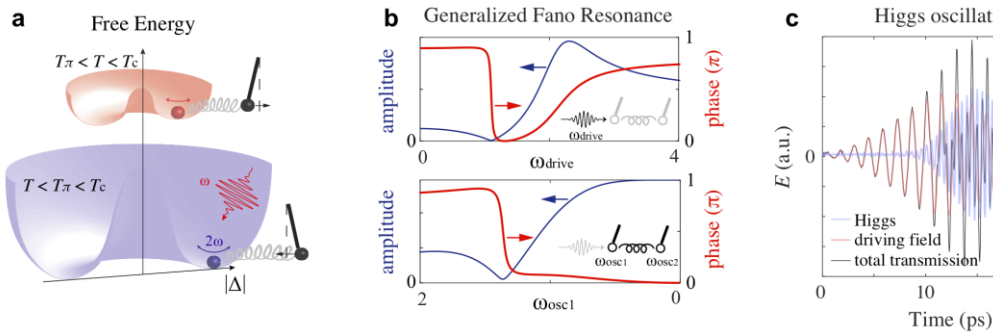

Figure 1. **a,** Amplitude oscillations of the superconducting order parameter (2ω), i.e. Higgs m by terahertz radiation (ω) and its coupling to an additional collective mode (black pendulu generalized Fano resonance describes the interference of a heavily damped (continuum) mo underdamped (discrete) mode, here represented as oscillator 1 and 2 respectively. As we sweep frequency (upper) or the resonance frequency of oscillator 1 while keeping driving frequ (lower), the Fano resonance/interference manifests as an asymmetrical lineshape in the amplitu (blue), and also the negative phase jump in phase response (red). **c,** Teraherz-driven Higgs (2ω) undergo sum frequency generation with driving pulse (ω) and lead to third harmonic (3ω) in transmission. Here shown is experimental data from a superconducting $La_{2-x}Sr_xCuO_4$ fi