Quantum Oscillations in the High-T_c Superconductor $YBa_2Cu_3O_{6+x}$ Near Optimal Doping

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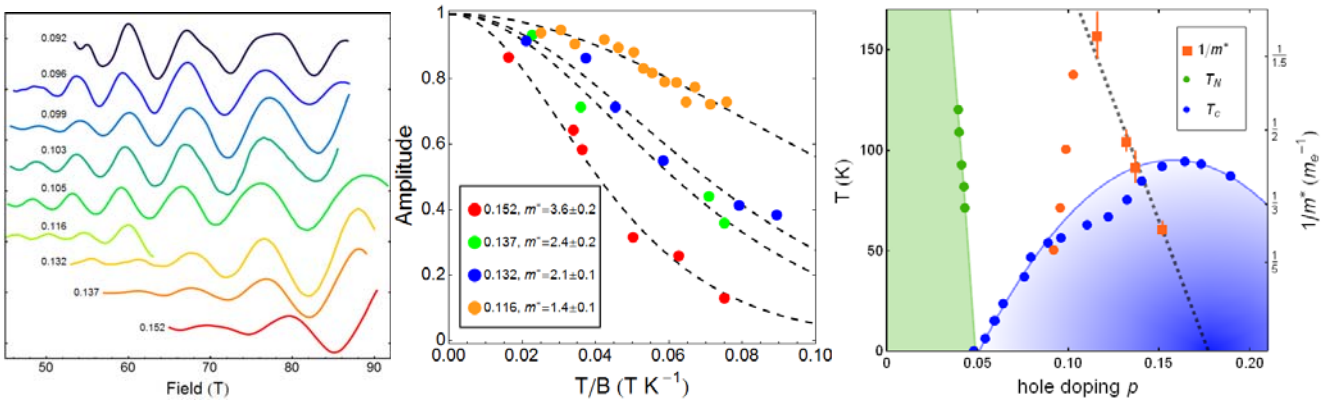
Introduction

High temperature superconductivity in the cuprates is maximum at an optimal doping of p=0.16, and it has been suggested that the dome-like phase diagram originates from an underlying quantum critical point (QCP). The cyclotron effective mass, as measured in quantum oscillation experiments, is a probe of the singular nature of electronic interactions at the QCP (i.e. the breakdown of Fermi liquid theory) [1]. However, to date the doping range over which quantum oscillations have been seen in $YBa_2Cu_3O_{6+x}$ (YBCO) has been too limited to address whether or not there is a signature of the QCP in the effective mass [2]. Here we report Shubnikov-de Haas oscillation measurements on YBCO at p=0.116, 0.132, 0.137, and 0.152, doubling the range over which oscillations have been seen in YBCO. The temperature dependence of the oscillations reveals an enhancement of the effective mass by almost a factor of 3 across this range, pointing to a QCP at p=0.18.

Experimental

Single-crystal $YBa_2Cu_3O_{6+x}$ samples were prepared at the University of British Columbia with evaporated gold-contacts in a geometry for c-axis transport. These samples were screened for sharp irreversibility-field transitions at the NHMFL-PFF in a 65 T short pulse magnet. C-axis resistivity and contactless in-plane transport (PDO) in fields up to 92 T were carried out on the screened samples at the PFF.

Results and Discussion



The left panel shows Shubnikov-de Haas oscillations from p=0.092 to 0.152. The small shift in the phase of the oscillations indicates that the oscillation frequency, and thus the Fermi surface area, changes by less than 10% while the doping changes by 50%. In contrast, the middle panel shows the evolution of the effective mass which increases by a factor of 2.5. The third panel shows the inverse effective mass increasing linearly toward p=0.18 (orange squares), implying the existence of a QCP at this doping. The orange circles are previously reported massess.

Conclusions

Using the ultra-high fields available at the PFF we have expanded Fermi surface measurements in YBCO to near-optimal doping. Given that the Fermi surface area remains relatively unchanged across this range, it is unlikely that the accompanying increase in effective mass is a band-structure effect. Instead, it likely originates from the divergent electronic correlations driven by quantum fluctuations at the QCP.

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References

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