# Spin susceptibility of charge ordered $YBa_2Cu_3O_y$ across the upper critical field

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## Introduction

The upper critical field $H_{c2}$ is a fundamental, and technologically important, property that measures the ability of a superconductor to withstand magnetic fields. Recently, there has been a controversy regarding $H_{c2}$ values in high-$T_c$ copper-oxides. The dispute has become particularly acute in the context of the competition between superconductivity and charge density wave (CDW) order in underdoped $YBa_2Cu_3O_y$. Since the issue has been tackled almost exclusively by macroscopic techniques so far, there is a clear need for local-probe measurements.

## Experimental

We have used NMR to measure the field dependence (up to 45 T on the NHMFL hybrid magnet) of the spin susceptibility $\chi_{spin}$ at low temperature ($T$) in charge ordered $YBa_2Cu_3O_y$. More specifically, we have measured the total $^{17}O$ Knight shift in four different crystals and have determined its spin part $K_{spin}$, proportional to $\chi_{spin}$ of the $CuO_2$ planes, by subtracting the orbital contribution, while the contribution from diamagnetic shielding was found to be negligible at the fields used. Even though in the cuprates, $\chi_{spin}$ is in general not related to $N(E_F)$ in a simple way, we expect the field dependence of $\chi_{spin}$ at low $T$ to reflect the field-dependence of $N(E_F)$.

## Results and Discussion

The central result of this study is the observation of an essentially linear increase in $\chi_{spin}$ up to a point in the range of 20 to 40 T, followed by a constant value. This saturation point agrees quantitatively with $H_{c2}$ values claimed in [G. Grissonnanche *et al*., Nat. Commun. 5, 3280 (2014)], showing a very large depression around $p$ = 0.12 doping (**Fig.1**). Our data further show that a large pseudogap persist above $H_{c2}$ in the zero-temperature limit and that $\chi_{spin}$ is insensitive to the onset of three-dimensional long-range charge-density-wave (CDW) order.

## Conclusions

Our results [1] show that short-range CDW order (already present in zero field) reconstructs the Fermi surface and reduces $H_{c2}$ in underdoped $YBa_2Cu_3O_y$. They also show that the pseudogap is a ground-state property, independent of the superconducting gap.

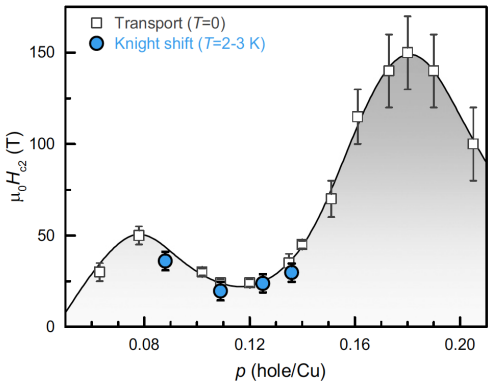


**Fig.1** Saturation field in Knight shift measurements (blue dots, this work) at T ~ 2 K, compared to $H_{c2}$ values extrapolated to $T$ = 0 from resistivity data [B. Ramshaw *et al*., Phys. Rev. B 86, 174501 (2012)].

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## References

[1] Zhou, R., *et al*., PNAS, **114**, 13148–13153 (2017).