Experimental report

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Title: Shortening of the correlation lengths and critical scattering in high-Tc cuprates

Research area: Physics

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Samples: $YBa_2Cu_3O_7$
$YBa_2Cu_3O_{6.6}$

Instrument	Requested days	Allocated days	From	To
D7	15	13	17/04/2015	30/04/2015

Abstract:

The phase diagram of high-Tc superconductors is dominated by the mysterious pseudo-gap (PG) phase out of which the superconducting state emerges. Recent ultrasound measurements have shown that the PG phase is a broken-symmetry state, whose order parameter remains to be unambiguously determined. Polarized neutron measurements in four different cuprate families, including $YBa_2Cu_3O_{6+d}$, have revealed the existence of an intra-unit-cell magnetic order, associated with the PG state. Our recent experiment on D7 allowed us to get a deeper insight on the intrinsic nature of this magnetic phase, through a better characterization of correlation lengths and critical scattering. This study was carried out on a nearly optimally doped $YBa_2Cu_3O_{6.85}$ sample. We would like now to follow the evolution of our observations for various hole doping levels using the underdoped $YBa_2Cu_3O_{6.6}$ and the weakly overdoped $YBa_2Cu_3O_7$.

Experimental report - D7 - April 2015
Intra-unit-cell magnetic correlations in $YBa_2Cu_3O_{6+x}$

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The phase diagram of cuprate high temperature superconductors is dominated by the pseudo-gap (PG) phase which presents highly unusual physical properties. Many theories attribute its origin to the proximity of a competing state, but there is a wide disagreement about the nature of this state. It has been proposed that the PG phase involves loop currents (LC) flowing within the CuO_2 square lattice [1]. Two loops per CuO_2 plaquette generate staggered orbital magnetic moments and break time-reversal symmetry but preserve lattice translation invariance, corresponding to an intra-unit-cell (IUC) magnetic order.

Using polarized neutron scattering in four cuprates families [2-5], including $YBa_2Cu_3O_{6+x}$, the existence of an IUC magnetic order was reported. This order develops below a temperature T_{mag} that matches the PG temperature T* as defined by the resistivity measurements. The observed symmetry is consistent with the LC phase [1]. Around optimal doping (p=0.16), where the superconducting transition is maximum, the magnetic critical temperature as well the magnetic intensity are reduced as one approaches the quantum critical doping [1,6] (p_c~0.2), where the PG state vanishes according to thermodynamic measurements. Even using polarized neutron diffraction, the observation of the static magnetic signal is difficult.

In $YBa_2Cu_3O_{6.85}$ (T_c=89K, p=0.15), we have been able to observe the IUC magnetic order that settles in below T~200K>T_c, proving the persistence of the IUC magnetic order near optimal doping [7]. However, the magnetic intensity is strongly reduced. Combining polarized neutron measurements on 4F1 (LLB) and D7 (ILL), the 3D magnetic correlations appears to develop at short range only (ξ_{ab}~20a) [7]. Using polarization analysis, we were able in addition to extract the components of the magnetic moment which display different temperature dependences. At low temperature, both in-plane and out-of-plane components are present, in agreement with the observation of a tilt of the magnetic moment [6]. Above T_{mag}, the in-plane component vanishes. At high temperature the magnetic moment is thus perpendicular to the CuO_2 plaquette, originally predicted in the loop current model [1]. Further, we observed a diffuse magnetic scattering away from the Bragg position. Applying the D7 polarization analysis relation for paramagnetic systems, typically valid for disordered magnetism, we demonstrated that the magnetic intensity exhibits a net maximum as a function of temperature at T_{mag}.

To go further, we performed an experiment on D7 by studying 2 samples: $YBa_2Cu_3O_{6.97}$ (T_c=92K, p=0.17) and $YBa_2Cu_3O_{6.75}$ (T_c=78K, p=0.135, T_{mag}=200K). The samples were aligned in a way to access wave vectors Q=(H,0,L). The measurements were carried out at k_i=1.3Å^{-1}. We performed similar measurements as done for the $YBa_2Cu_3O_{6.85}$ sample, in the SF and NSF channels for the X, Y and Z polarisations.

On the one hand, from preliminary measurements performed on 4F1 (LLB) on $YBa_2Cu_3O_{6.97}$, we know that there is no magnetic intensity appearing in the normal state, suggesting a deeper study in the superconducting state. On D7, we studied the trajectory going through Q=(1,0,-0.25) (Fig. a). We nevertheless observed a slightly depolarisation of the neutron beam below T_c. The flipping ratio decreases at low temperature. Because of this polarisation leakage, the study around the Bragg position (H=1) is difficult, however we are able more easily to study the diffuse scattering, and we especially focused on H=0.9. The Fig. b shows the magnetic intensity at H=0.9, after polarisation analysis $2I_X^{SF}+2I_Y^{SF}-4I_Z^{SF}$ typically used on D7 to extract the magnetic diffuse scattering. In addition, we summed over 10 detectors around H=0.9 to get better statistics. We notably observe a maximum of intensity around 70K (below T_c). Let note that we did not observe any particular effect as a function of temperature above T_c at H=0.9 and even at H=1. In this particular case, it seems that the intra-unit-cell magnetic correlations survive in the superconducting state. This study shows that T_{mag}~70K for $YBa_2Cu_3O_{6.97}$ (which is considerably lower than T_{mag}~200K for $YBa_2Cu_3O_{6.85}$). The doping dependence of the transition temperature is steep for the $YBa_2Cu_3O_{6+x}$ family.

On the other hand, for $YBa_2Cu_3O_{6.75}$, we report the temperature dependences of the magnetic moment components extracted around the Bragg position at Q=(1,0,1/8) (Fig. c) from polarisation analysis. Assuming that the background is decreasing as shown by the dotted line, the in-plane component would appear at low temperature (below T_{mag}) whereas the out-of-plane would be already present at high temperature (similarly to what we observed in $YBa_2Cu_3O_{6.85}$ [7]). The negative level is due to the fact that we observed higher intensities for the polarisation Z. The Fig. d corresponds to the temperature dependence of the magnetic intensity around H=0.9, it shows a maximum around 170K (~T_{mag}=200K). The peak occurs around T_{mag} similarly to what we observed previously but the intensity is smaller compared to the one at higher doping ($YBa_2Cu_3O_{6.97}$, Fig. c). The behaviour as a function of doping of this magnetic signal around H=0.9 is in agreement with the loss of magnetic correlations upon increasing the hole doping.

As a conclusion, in all studied samples we observe a peak of magnetic intensity (increasing with doping) around T_{mag} away from the Bragg position. Moreover, we confirm with a new sample that at the same temperature T_{mag}, the in-plane component appears whereas the out-of-plane component is present well above T_{mag}. The beam depolarisation and the poor statistics however appeals for more work in order to better estimate the different temperature dependences.

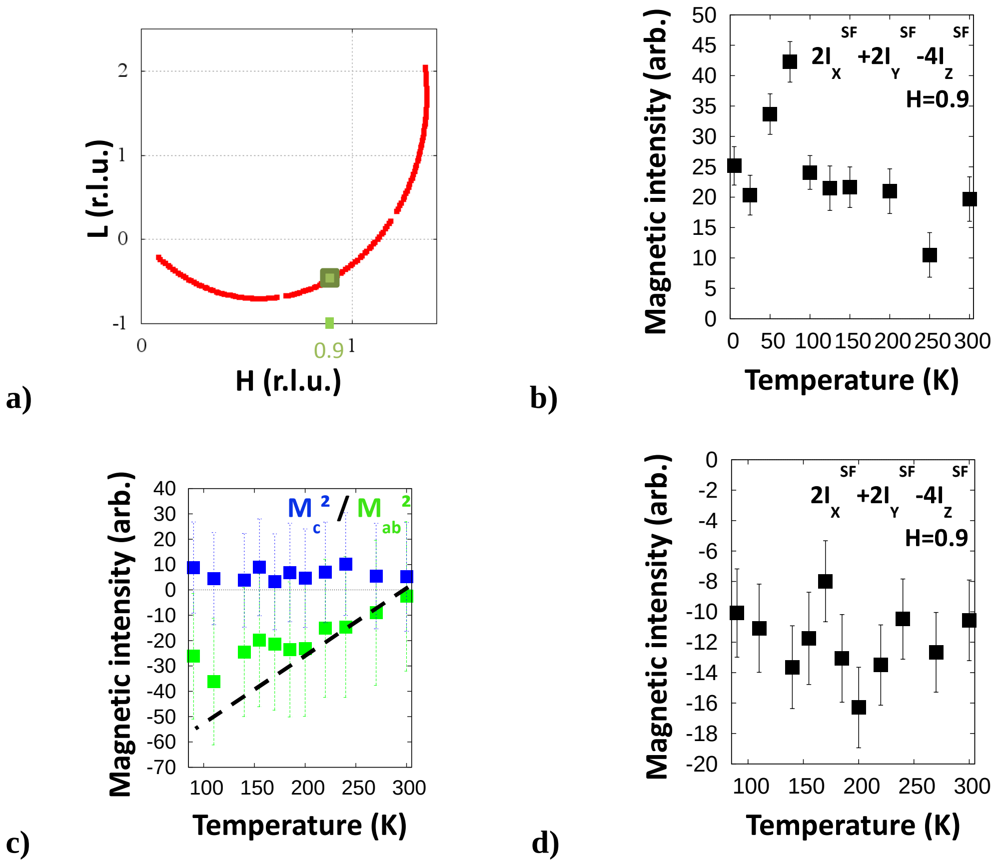

Figure. **a)** Reciprocal space studied on D7 with the $YBa_2Cu_3O_{6.97}$ sample. **b)** T-dependence of the magnetic signal measured around H=0.9 for $YBa_2Cu_3O_{6.97}$. **c)** T-dependence of the magnetic signal measured around H=1 for $YBa_2Cu_3O_{6.75}$. **d)** T-dependence of the magnetic signal measured around H=0.9 for $YBa_2Cu_3O_{6.75}$. In all panels, the magnetic signal is extracted from polarization analysis.

References:

[1] C.M. Varma, PRB 73 155113 (2006) ; [2] B. Fauqué et al, PRL 96 197001 (2006) ; [3] Y. Li et al, Nature 455 372 (2008) ; [4] V. Balédent et al, PRL 105 027004 (2010) ; [5] S. De Almeida-Didry et al, PRB 86 020504 (2012) ; [6] P. Bourges and Y. Sidis, CR Physique 12 461 (2011) ; [7] L. Mangin-Thro et al, Nature Communications 6 7705 (2015)