Experimental report

15/09/2016

Proposal: **4-02-474**

Council: 4/2016

Title: Search for orbital magnetic fluctuations in $YBa_2Cu_3O_7$

Research area: Physics

This proposal is a new proposal

Main proposer: **Jaehong JEONG**

Experimental team: Lucile MANGIN THRO
Jaehong JEONG
Philippe BOURGES
Yvan SIDIS

Local contacts: Mechthild ENDERLE

Samples: $YBa_2Cu_3O_{6.95}$

Instrument	Requested days	Allocated days	From	To
IN20 CPA	10	10	02/09/2016	12/09/2016

Abstract:

The mechanism leading high-temperature superconductivity (HTS) is challenging to explain. Although the quantum criticality of some magnetic orders is thought to play a role in cuprates, there is a longstanding debate about the origin of the ordered phase competing with superconductivity. Using polarized neutron diffraction, we have established an intra-unit-cell magnetic order in cuprate families, which can be described by a loop-current order proposed by C. M. Varma. The theory provides a novel mechanism for HTS related to the fluctuation of the observed order parameter. Therefore, we here propose to search for the orbital magnetic excitations in optimally doped $YBa_2Cu_3O_{6.95}$ in the normal state above Tc. We consider that thermal neutron triple-axis IN20 with CryoPAD polarization analysis is the most relevant to achieve our goal and request 10 days of beam time.

Experimental report - # 4-02-474 // IN20

Jaehong Jeong, Lucile Mangin-Thro , Philippe Bourges, Yvan Sidis, Mechthild Enderle

Scientific case

In many unconventional superconductors, the phase diagram as a function of a control parameter (pressure, magnetic field, doping) shows that superconductivity develops around the quantum critical point associated with another ordered state. Strong fluctuations, associated with the broken symmetry of such a state, are likely to couple with quasiparticles and may yield an attractive pairing, giving rise to superconductivity.

In high temperature superconducting cuprates, d-wave superconductivity develops as a function charge doping around the end point of the mysterious pseudo-gap phase. There are now growing evidence that such a phase is a true symmetry broken state. In particular, polarized elastic neutron scattering measurements has reported the pseudo-gap was accompanied by an intra-unit-cell (IUC) magnetic order. Such a state may correspond to staggered orbital magnetic moments produced by loop currents within the unit cell.

Search for the related magnetic fluctuations has motivated exp. #4-02-474. The detection of such fluctuations could open new routes to understand superconductivity, beyond conventional electron-phonon or spin-fermion theories. However, such an experiment is very challenging since these fluctuations are likely to be rather weak and widely spread in phase space.

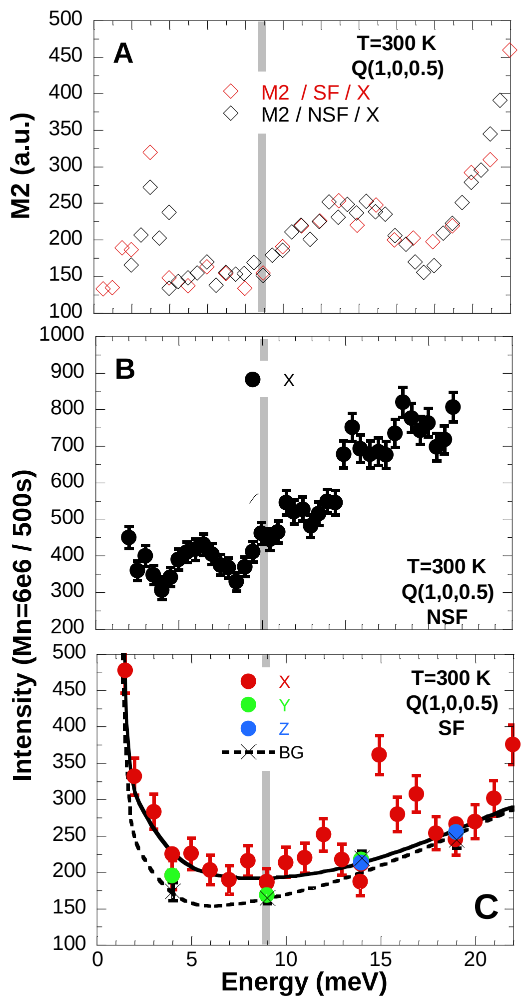


FIG.1: Energy scans at 300 K and **Q**=(1,0,0.5) : A) second monitor , which does depend neither on the polarization nor on the spin channel. B) Intenisty in the NSF channel. C) Intensity in the SF channel for polarisation **X**, **Y** and **Z**. The background (BG), from polarisation analysis is also shown.

Experimental results

Using a $YBa_2Cu_3O_{6.75}$ sample (T_c=78 K, T*~200 K, hole doping p=0.14), we have carried out a survey of magnetic properties at finite energy around the momentum **Q**=(1,0,L), associated with the observed IUC magnetic order. Measurements were performed on IN20 (E_f=14.7meV) with CRYOPAD.

Figure 1 the signals measured at room temperature and **Q**=(1,0,0.5) in: A- the second monitor , B-the non-spin flip channel (NSF) and C- the spin flip channel. Performing a constant energy scan at 9 meV seems by one of the best choices to minimize the risk of spurious scattering (second monitor) and the magnitude of the NSF leakage within the SF channel. This second effect is already limited by a pretty good flipping ration.

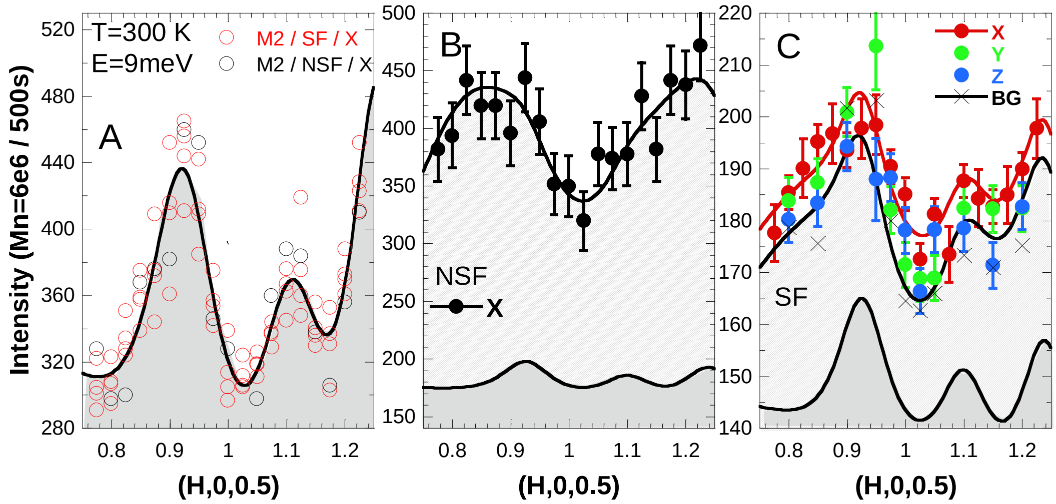
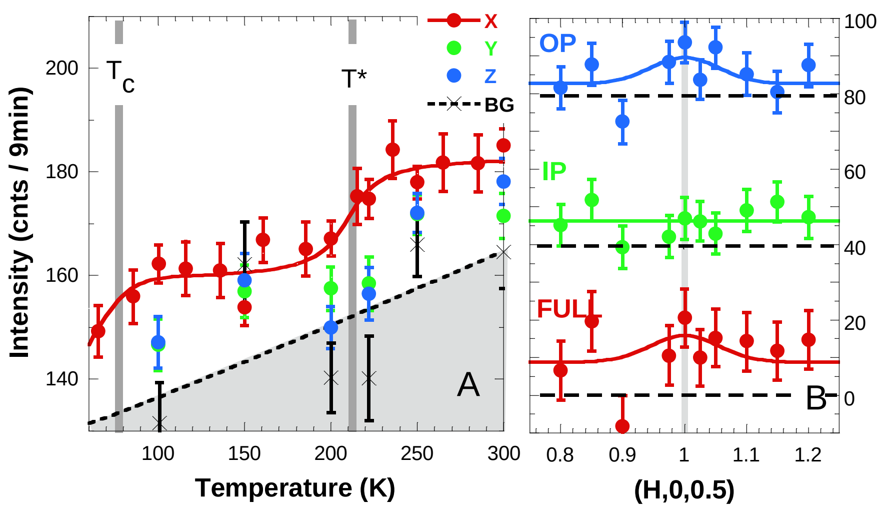


Fig.2: constant E-scan : A/ second monito M2,. B) NSF intensity with polarization X. C) SF intensity for **X**, **Y**, **Z** polarizations and background, **BG,** from polarization analysis

Figure 2 show a constant energy scan at T=300 K and E=9meV around **Q**=(1,0,0.5). In order to analyze the magnetic scattering in the SF channel, we performed a longitudinal polarization analysis on selected points of the scan. The SF background determined from polarization analysis is modulated. This background is made of a fraction of the intensity measured by the second monitor (M2, Fig.2-A). This spurious scattering has to be found in both SF and NSF measurements (grey area in Fig.2-B,C). Furthermore, the SF background incorporates the leakage of the NSF channel into the SF channel, given by the flipping ratio. In the NSF channel, one can clearly identify the phonon contribution on top of the NSF background. The magnitude of this phonon is determined by repeating the same scan at least at two distinct temperatures, where the phonon intensity is weighted by the detailed balance factor. Finally, on top of such a SF background, with a complex line shape, one see a rather weak magnetic intensity, whose magnitude does not exceed 2 to 3 counts /min.



Q=(1,0,0.5)
E=9meV,
T=300 K

Fig. 3-A : T-dependence of the intensity in the spin flip channel : **X**, **Y**, **Z** polarizations and background, **BG**

Fig.3- B : polarization analysis: full magnetic signal (**FULL**), in-plan (**IP**) and out-of-plane (**OP**) fluctuations

Fig. 3-A shows the T-dependence of the scattering intensity in the SF channel at 9 meV and **Q**=(1,0,0.5). Upon cooling down, the scattering intensity exhibits a step-like drop close to T*, pseudo-gap temperature, and even a much weaker one close to T_c. Fig. 3-B shows the results of a polarization analysis on the constant energy scan at 9meV and at room temperature (Fig. 2-C). A weak correlated signal is found around **Q**=(1,0,0.5). Interestingly, out-plane magnetic fluctuations seem more correlated that in-plane fluctuations. This would be consistent with orbital magnetic moments produced but loop currents confined within CuO_2 planes. These results are quite promising, but deserve complementary measurements.

Remarks

During the 10 days of the experiments, we spent 5 days to select the best place in phase space where to carry out the study. Since the magnitude of the signal we are looking for is about 1/10 of the scattered intensity in the SF channel, a typical counting time of 4h/point is required at minimum for a polarization analysis. As a result, each T-scan or a H-scan requires ~2 days to get a decent statistics. Additional measurements were performed at several temperatures and energies but their statistics remains too low to draw any definitive conclusions.

Comparison with unpolarized measurements

Before our polarized neutron measurement on thermal TAS IN20 at ILL, a pilot measurement was performed on the cold TAS 4F2 at LLB with an unpolarized neutron set-up (Fig. 4). The measurements carried at 3meV around **Q**=(1,0,0.5) show results which are consistent with that found on IN20. The temperature dependence shows a change around T* which may be ascribe to the disappearance of the signal located at **Q**=(1,0,0.5). This signal exhibits a Gaussian line shape with a q-width of ~0.13 r.l.u. Its magnitude is ~1 count/min. Moving from 4F2-LLB at E_f=5 meV to IN20-ILL at E_f=14.7 meV, one can crudely estimate a gain of a factor 40. The polarization of the neutron beam using Heusler monochromator and analyzer lowers the flux by a factor ~1/20. Thus, the orders of magnitude of signals found on 4F2 at 3meV and IN20 at 9 meV are consistent.

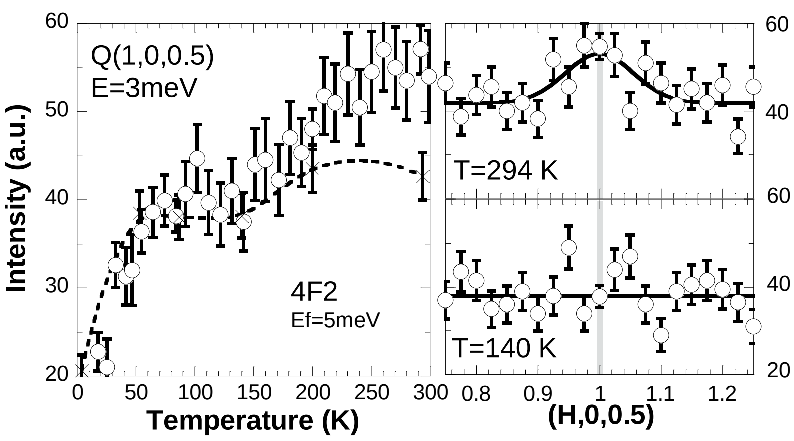


Fig. 4
Unpolarized neutron data from cold TAS 4F2 at ILL on the same sample. Temperature dependence at Q=(1,0,0.5) and 3meV and constant E-scan at 294 K and 140 K. The dashed line indicates the position of a q-independent background.