Experimental Report

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Title: Momentum dependence of the lower energy novel pseudogap excitation inHgBa2CuO4+d

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Researh Area: Physics

Main proposer: **GREVEN Martin**

Experimental Team: CHAN Mun
TANG Yang
GREVEN Martin
MANGIN-THRO Lucile

Local Contact: STEFFENS Paul

Samples: HgBa2CuO4

Instrument	Req. Days	All. Days	From	To
IN20 CPA	14	14	04/07/2013	18/07/2013

Abstract:

Our inelastic neutron scattering studies of the high-Tc superconductor Hg1201 led to the observation of two novel magnetic excitation branches associated with previously observed q=0 pseudogap magnetic order. The momentum dependence of the higher-energy mode is inconsistent with traditional magnetic form factors. This, in combination with preliminary polarized inelastic neutron scattering results, indicates possible dual magnetic and structural characteristics of the novel excitations. In an upcoming experiment on IN20, we will utilize polarized neutrons to disentangle magnetic and non-magnetic contributions to the high-energy mode. The low-energy mode does not obey traditional form factors either. Additionally, we observe an almost opposite momentum transfer dependence of the two modes: whereas the high-energy mode is weakest for momentum transfer in the ab plane, the opposite is true for the low-energy mode. This points toward a deep relationship between the two modes. In order to obtain a complete picture of the novel pseudogap excitations, we propose to extend our study of the form factor of the low-energy mode in Hg1201 with polarized neutrons on IN20.

Momentum dependence of the lower energy novel pseudogap excitation in $HgBa_2CuO_{4+d}$

Our previous inelastic neutron scattering results demonstrate the existence of novel magnetic excitations [1] that are likely related to the $\boldsymbol{q}=0$ pseudogap magnetic order [2-3]. Measurements of both under-doped ($Tc \approx 65\ K$; UD65) and nearly-optimally-doped ($Tc \approx 95\ K$; OP95) HgBa2CuO4+δ (Hg1201) reveal two weakly dispersive magnetic excitation branches throughout the entire Brillouin zone below the pseudogap temperature T^* [4] (#4-01-887). Curiously, our early results showed that the high-energy excitation is stronger when $\boldsymbol{Q}$//c-axis, while the low-energy mode is strongest when $\boldsymbol{Q}$//CuO_2 plane, this peculiar, opposite dependence of the momentum transfer suggests that the properties of both excitations are connected. Polarized neutron scattering measurements on IN20 proved the magnetic nature of both branches [1] (#4-01-888, and #4-01-1005). However, our recent work performed on IN1 (#4-01-1217) showed that the dependence of the high-energy mode on *c*-axis momentum transfer is highly non-monotonic and hence cannot be explained by a conventional magnetic form factor, suggesting magneto-structural coupling. Therefore we did not only focused on the primarily proposed goal to utilize the high polarized neutron flux at IN20 to study the momentum dependence low-energy excitation, but also devoted our time to measure the high-energy excitation, expecting to clarify the magnetic and structural properties of both modes.

Measurements were performed on our nearly-optimal-doped Hg1201 sample (OP95C) with doubled sample mass (previously 1.8g). Figure 1 shows both the spin-flip (SF) and non-spin-flip (NSF) full energy range scan of both excitation modes with the spin polarized along the momentum transfer direction (SFxx/NSFxx). It's difficult to observe clear peak with the large error-bars, but small bumps are discernable at ~55meV for the high-energy-mode and ~30meV for the low energy mode, as indicated by the arrows in the figure.

Three-points scans are made to determine the intensity of modes: one point at the peak center is measured as the peak intensity and two points on both sides of the peak shoulder serve as the background, and the intensity of modes are calculated by subtracting the average background from the peak center intensity. For high-energy-mode, the scans are centered at the 'peak' energies 54, 55 meV and the 'background' energies 46 and 62 meV, as shown in Fig. 2a and 2b; for the low-energy-mode, the scans are at 32 meV as peak and 1 point at 24 meV as background to save time, as shown in Fig.2d and Fig. 2e. The measurements are done with spin polarized parallel and perpendicular to the momentum transfer direction, in order to perform a longitudinal polarization analysis (LPA) on the data to determine if it's magnetic. Fig. 2c and Fig. 2f demonstrate the energy dependence of magnetic signals calculated by LPA, no apparent magnetic peak for both modes is observed considering the error-bars.

Surprisingly, when we plot the raw data change with time which is not shown here, we found that the counts are continuously dropping, which indicates a background drifting caused by the instrument. Furthermore, the flipping ratios are also changing for different energy transfers. Therefore we decided to spend the rest of beamtime to switch our measurement to the resonance excitation at lower energy range (~51 meV) in a Tc = 71K (UD71) sample. Fig. 3a illustrates the magnetic signal obtained from LPA of rocking scan data at 48 meV near the resonance energy. The magnetic signal peaks at the anti-ferromagnetic wave vector $\boldsymbol{q}_{AF}$ = (0.5,0.5) with an intensity of ~1 counts per minute. Following the same logic as what we did for OP95, we did the three-points scans at various energies around the resonance energy to determine the signal intensity at $\boldsymbol{q}_{AF}$. One point at (0.5,0.5) is measured as the peak, and two points at (0.3,0.3) and (0.7,0.7) serve as background. Fig. 3b shows the plot of the energy dependence of the magnetic signal intensity after LPA calculation at low temperature T = 2K (<< Tc). A magnetic signal with ~ 2 counts per minute is present at q_{AF} for lower energies near resonance energy, and disappears at high energy, which is expected.

There are several possible explanations why we were not able to identify the magnetic nature of the two pseudogap excitations. First, we know from previous results that the excitations are weaker than the resonance, hence the magnetic signal should have ~0.5 counts per minute considering the 1-2 counts per minute resonance intensity, which makes it difficult to be observed with ~0.5 counts per minute errorbars. Second, the background and flipping ratio drift may add more weight to the background intensity in our three-points scans. Therefore further studies with more counting time and better instrument configuration are required to confirm our result. We used part of the beamtime to confirm the magnetism of the excitations at q_{AF} in UD71, which gives insights to the understanding of the resonance and related hour-glass dispersion modes in combination with our other results [5].

References:

[1] Y. Li *et al.*, Nature **468** 283 (2010); Y. Li *et al.*, Nature Phys. **8**, 404 (2012).

[2] B. Fauqué *et al.*, Phys. Rev. Lett. **96**, 197001 (2006).

[3] Y. Li *et al.*, Nature **455**, 372 (2008); Y. Li *et al.*, Phys. Rev. B **84**, 224508 (2011).

[4] Y. Li et al., Nat. Phys. **8**, 404 (2012).

[5] M.K. Chan *et al.*, 'Antiferromagnetic fluctuations and pseudogap formation in underdoped cuprate high-temperature superconductors', *preprint submitted to Nature*.

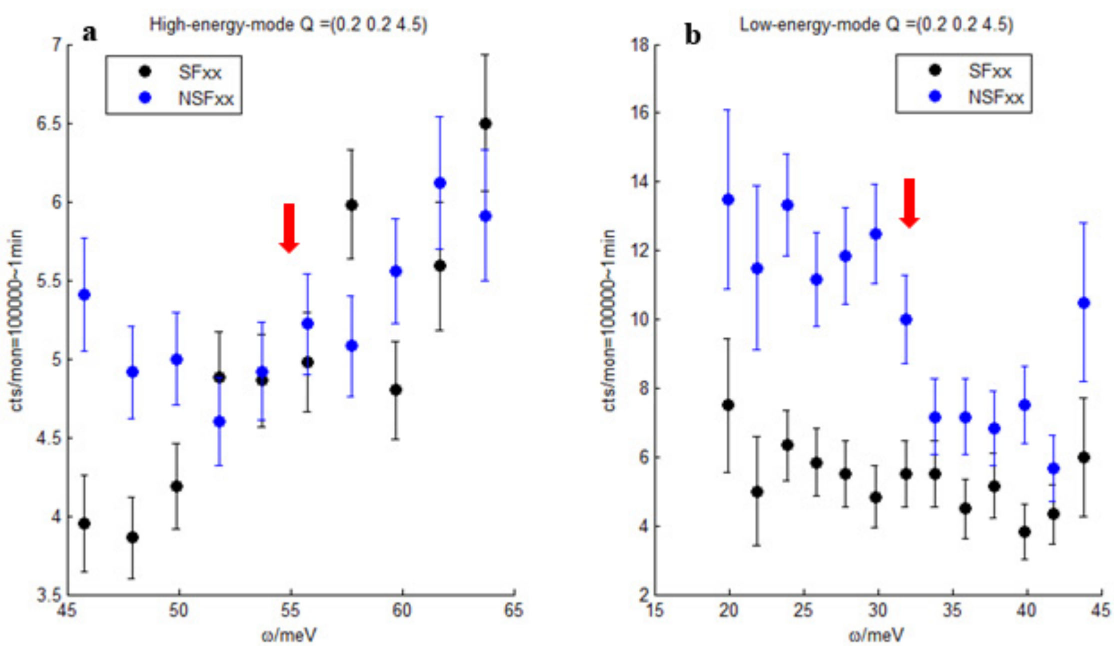

Figure 1: Full energy scan for the peudogap excitations. (a) The high-energy-mode (b) The low-energy mode. Black plots are the spin-flip channel data, blue plots are the non-spin-flip channel data. Small humps are indicated as the arrows, which are supposed to be the excitations.

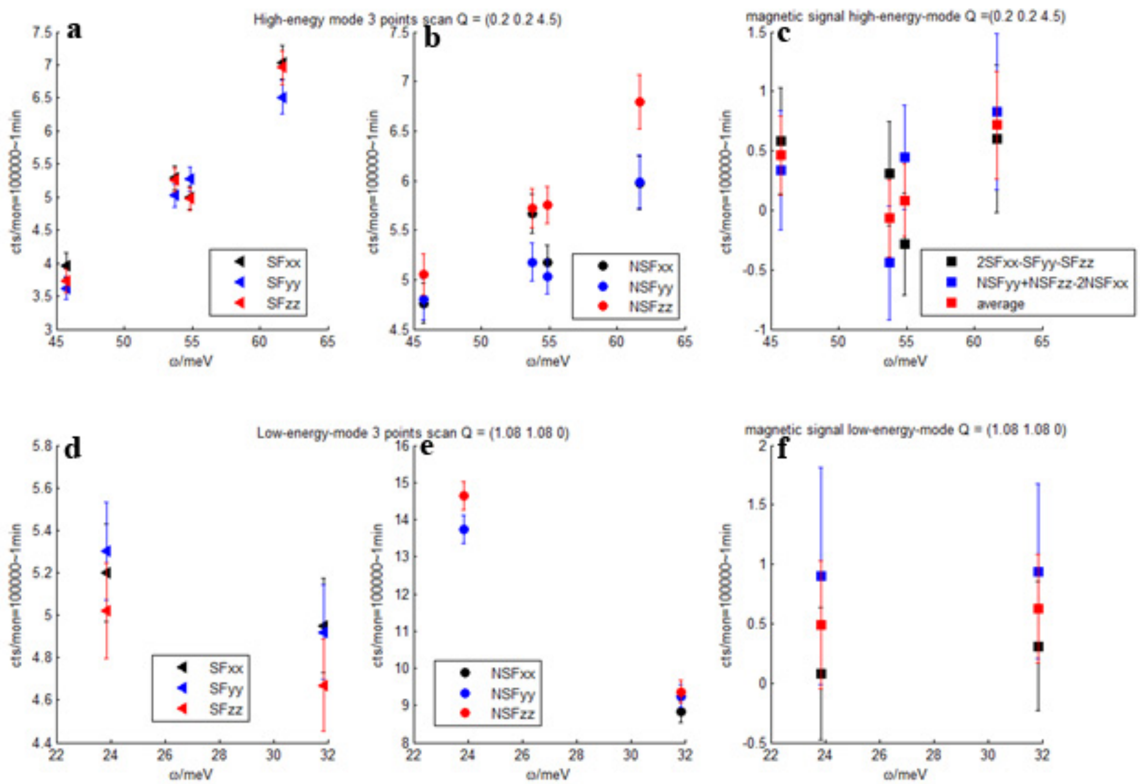

Figure 2: 3 points scan at all polarization channels. (a) and (b) The spin-flip and non-spin-flip data for all three polarizations of high-energy-mode. (d) and (e) Low-energy mode. Polarization directions are shown by different colors as indicated in the legends. (c) and (f) The magnetic signals are extracted by subtracting the background intensity from peak intensity, then LPA is applied. Black: spin-flip channel; Blue: non-spin-flip channel; Red: average of black and blue.

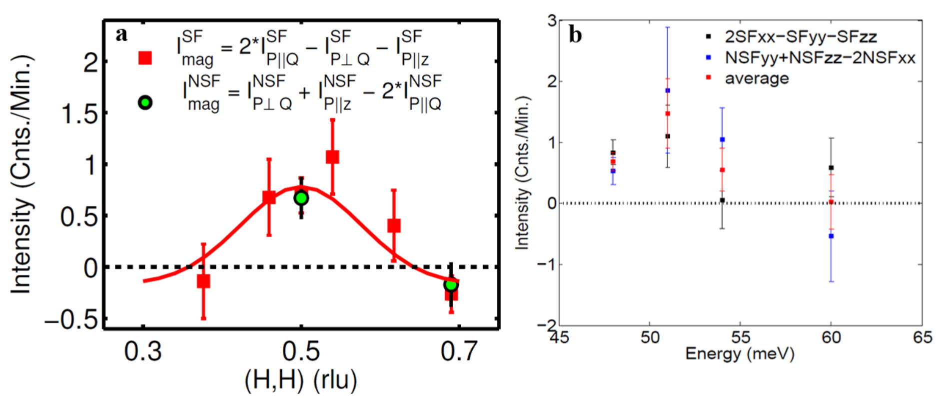

Figure 3: Energy dependence of the magnetic signal intensity. (a) The magnetic signal intensity extracted by LPA calculation of the NSF scattering (green circles) and SF scattering (red squares) at energy transfer 48meV. (b) The magnetic signals extracted by first subtracting the intensity at (0.7,0.7) from that at (0.5,0.5) to remove background effect, then do the LPA calculation of NSF channel (blue) and SF channel (black), the red plots are average of them.