Experimental Report

16/07/2015

Proposal: **4-01-1288** **Council:** 10/2012

Title: A magnetic analog of the isotope effect in cuprates

This proposal is a new proposal

Researh Area: Physics

Main proposer: **KEREN Amit**

Experimental Team: DRACHUCK Gil
KEREN Amit
KAPON Itzik

Local Contact: WILDES Andrew

Samples: (Ca_xLa_{1-x})(Ba_{1.75-x}La_{0.25+x})Cu_3O_y with x=0.4 and y=6.4

Instrument	Req. Days	All. Days	From	To
IN8	7	7	01/09/2014	08/09/2014

Abstract:

Since the discovery of high temperature superconductivity in the cuprates, it has been speculated that their pairing mechanism is due to magnetic interactions. However, this was never demonstrated in the laboratory. Such a demonstration would require an experiment similar to the isotope effect in metallic superconductors, namely, a measurement of Tc versus the strength of the magnetic coupling J, with no other structural changes. We are proposing to do this experiment using the (Ca_xLa_{1-x})(Ba_{1.75-x}La_{0.25+x})Cu_3O_y system with its 4 different families having different T_c^max, but identical structures. J should be measured with inelastic neutron scattering on IN8 and compared with Tc^max. Preliminary results show that the experiment is doable. However, the proposal is submitted as a new one due to scheduling problems.

Nodal gap versus incommensurate spin fluctuations in the cuprates

Amit Keren, Gil Drachuck, Itzik Kapon, Andrew Wildes

In this examine we tried to examine how the newly discovered nodal gap in underdoped LSCO is related to incommensurate spin fluctuations (ISF). For this purpose we used a LSCO crystal with doping x=1.92% which is on the boundary between the antiferromagnetic and spin glass phases. This sample has a diagonal gap in the charge sector which opens few degrees above the temperature at which incommensurate spin order stabilize in the magnetic sector. The results were published in Nature communications. On IN8 we checked if this temperature mismatch is a dynamical effect, and if it will decrease when performing inelastic neutron scattering measurements. Unfortunately the measurements failed due to insufficient *q* resolution which did not allow resolving the ISF component of the spin fluctuations.

In a recent set of ARPES experiments on few different underdoped cuprates superconductors a nodal gap was discovered both above and below T_c [1]. The nodal gap survives to the spin-glass phase, suggesting a magnetic origin of the gap. To investigate this possibility we examined a $La_{2-x}Sr_xCuO_4$ sample with x=1.92%, which is in the AFM phase. Raw muon data in this phase is depicted in the inset of Fig. 1(a). The muon rotation frequency ω and volume fraction are presented in Fig. 1(a). Although the magnetic phase transition is not well-defined, no muon rotation is found above $T_N=140$ K. As temperature is lowered, both ω and the volume fraction increase, and between 50 K and 25 K both quantities are constant. They start to increase again at $T < 25$ K. Similar results were obtained before [3] indicating that our sample is similar to others.

Raw neutron diffraction data on the x=1.92% sample are depicted in the inset of Fig. 1(b). We used a $(0,\ 1+\delta k,\ 0)$ scans in the orthorhombic notation, in which only the incommensurate part of the magnetic scattering is observed. We also measured the commensurate part using (1+δh, δh, 0) scan. In Fig. 1(b) we depict the integrated intensity of the commensurate and incommensurate peaks. The intensities grow as the temperature is lowered. The commensurate scattering starts at $T=130$ K, and the incommensurate contribution begins around $T=30$ K. Similar results were obtained before [4].

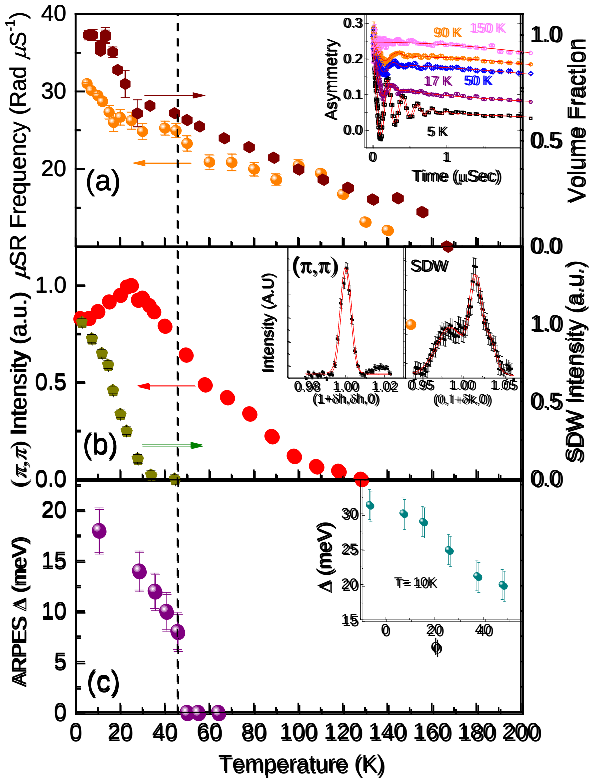

Figure 1 (a) Muon frequency and volume fraction. Inset: muon asymmetry and fit. (b) Neutrons commensurate and incommensurate peak intensity. Inset is raw commensurate (π,π) and incommensurate (SDW) peaks. (c) ARPES gap versus temperature. Inset is ARPES gap versus angle around the Fermi surface.

The ARPES raw data is depicted in Fig. 2(a-h). In the AF phase, the Fermi Surface (FS) is composed of four hole-pockets around M=(±π,±π), with an area proportional to *x* [2]. The figure presents raw ARPES data along a diagonal cut connecting the Γ and M points at various temperatures. At $T=63$ K the spectrum clearly crosses the Fermi energy, while at *10* K it clearly does not. This is even clearer when looking at the energy distribution curves (EDC) at the Fermi momentum k_f, which are depicted in Fig. 2(i), at different temperatures. These EDCs show quasi-particle peaks. At low *T* the peaks are at negative energy, but at high *T* they cross the Fermi energy. The gap is defined as the energy difference between the peak position and zero. At low temperatures, this gap opens everywhere on the FS, including on the diagonal (Γ-M line). In Fig. 2(j) we show the momentum distribution curve at E_f. We did not observe a change in k_f as the temperature is lowered.

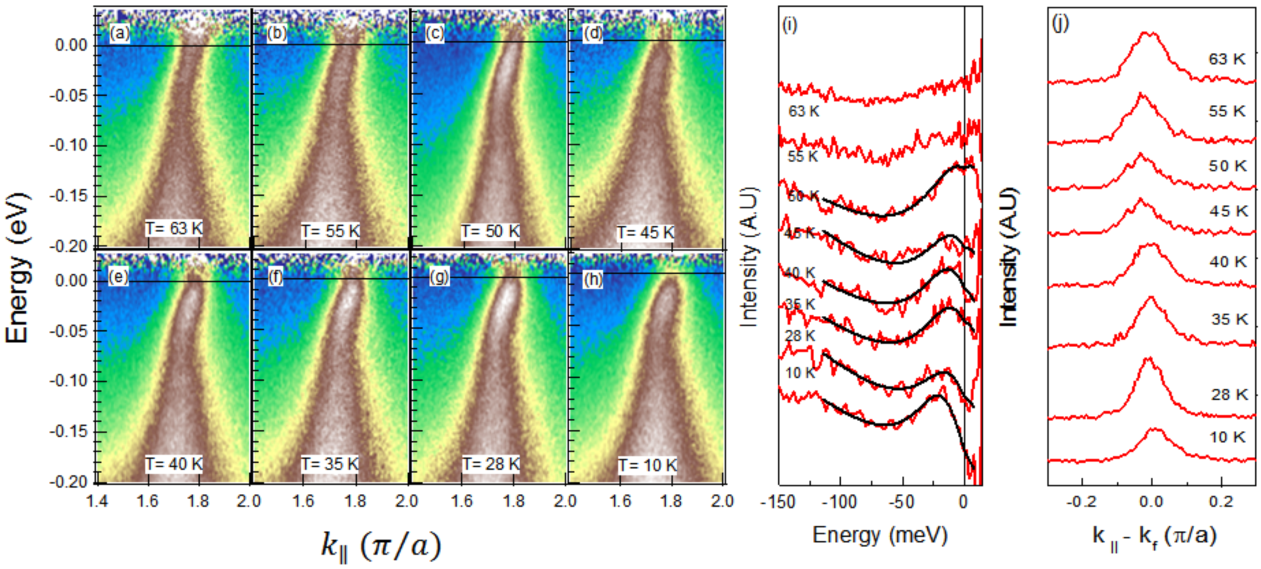

Figure 2 (a-h) Raw ARPES data along a diagonal cut. (i) EDC curves at the Fermi momentum showing quasi-particle peak. At low T the peaks are at negative energy. At high T they cross the Fermi energy. (j) MDC at different temperatures showing that k_f is T-independent.

Our gap data, summarized in Fig. 1(c), indicates that a charge gap (ARPES) and incommensurate order (Neutron and muon) appear in the system at nearly the same temperature, and probably due to coupling between the two degrees of freedom. However, there is ~*15* K difference between the temperatures in which the two phenomena occur. The question we wanted to address at IN8 is what happens to the incommensurate peaks at finite energy transfers. In this type of experiments we could pick up scattering from dynamic incommensurate spin fluctuations before they freeze out. Such fluctuations should start at $T > 30$ K. If indeed, at finite energy transfer, the incommensurate peaks start at higher temperature it means that incommensurate spin correlations and the gap are linked, but in a dynamic way.

We made an attempt to perform these measurements at the IN8 spectrometer in ILL even though the Cu monochromator was not completely refurbished. Consequently, we failed due to poor q resolution. This is demonstrated in Fig. 3 where broadening of the $(3, \delta k, 0)$ scan with increasing transfer energy is observed. But, it was impossible to separate the incommensurate and commensurate contributions even at zero energy transfer. We could not achieve higher energy transfers.

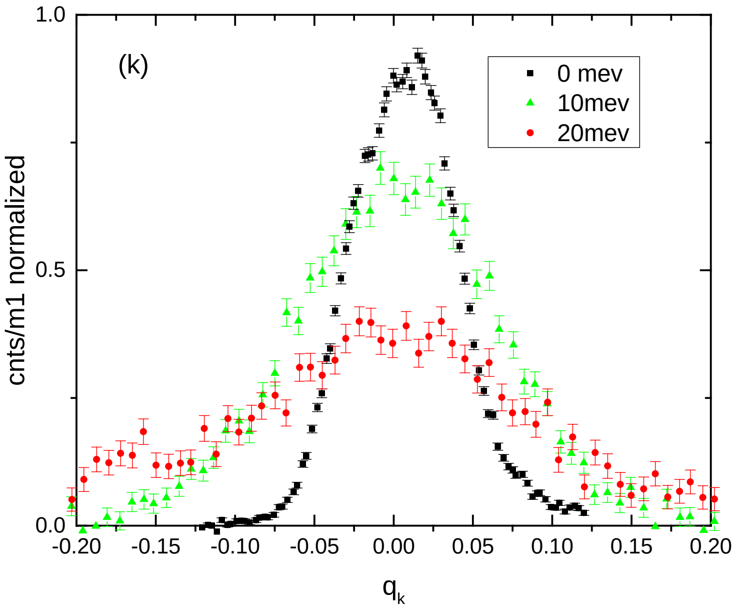

Figure 3 The best INS measurement of the same sample used with Rita-II but on the IN8 spectrometer at the ILL. The data was accumulated for 6 hours for each run. The scan is along the k direction around (300) at three different energies. A broadening is seen with increasing energy but, the different magnetic contributions cannot be resolved even at zero energy transfer.

[1] E. Razzoli et al., PRL **110**, 047004 (2013); I. M. Vishik et al., PNAS **109**,18 332 (2012); Yingying Peng et al., Nature Comm. **4**, 2459 (2013).

[2] K. M. Shen et al. PRB **69**, 054503 (2004).

[3] Ch. Niedermayer et al. PRL **80**, 3843 (1998).

[4] M. Matsuda et al. PRB **65**, 134515 (2002).