Experimental report

15/01/2024

Proposal: 4-02-614 **Council:** 10/2022

Title: Temperature evolution of quasi-elastic magnetic fluctuations in LSCO

Research area: Physics

This proposal is a new proposal

Main proposer: Kristine KRIGHAAR

Experimental team: Kristine KRIGHAAR
Kim LEFMANN

Local contacts: Markus APPEL
Jacques OLLIVIER

Samples: La_(2-x) Sr_x Cu O_4: x=0.07

Instrument	Requested days	Allocated days	From	To
IN5	2	0		
IN16B	5	4	03/11/2023	07/11/2023
ORIENTEXPRESS	1	1	03/11/2023	04/11/2023

Abstract:

One of the greatest unsolved problems in physics is the origin of high-Tc superconductivity (SC). The magnetism in La¬2-xSrxCuO4 (LSCO), and similar cuprate SC, is often found as static or dynamic stripes. However, it remains important to clarify the details of these stripes to pinpoint their relation to SC.

Recently, at the backscattering instruments IN16b (ILL) and DNA (JPARC), we were able to measure the development of the magnetic stripes in the quasielastic regime. This unprecedented energy resolution for stripe investigation led to the discovery of two new types of quasielastic stripe dynamics in a non-SC cuprate LSCO (x=0.05); at sub ¿eV and approx. 100 ¿eV.

We will follow up on our discovery by measuring the same temperature evolution of the quasielastic stripe signal, using both IN16b and IN5, on the SC cuprate LSCO (x = 0.07).

With this, we will for the first time be able to observe how static stripes convert over elastic and quasielastic to dynamic stripes in a cuprate, and to see in which way this unpinning of stripes correlates with the onset of SC. This will address one of the large open questions on stripes in SC cuprates.

Experiment report: Temperature evolution of quasi-elastic magnetic fluctuations in LSCO

Kristine M. L. Krighaar[1], Emma Y. Lenander[1, 2], Ana-Elena Tutueanu[1, 3], Markus Appel[3], Gedeminas Simutis[4], Chennan N. Wang[4], Masato Matsuura[5], Hiromu Tamatsukuri[5], Igor Zaliznyak[6], Genda Gu[6], John Tranquada[6], Machteld E. Kamminga[7, 1], and Kim Lefmann[1]

[1]Niels Bohr Institute, University of Copenhagen, Denmark - [2]Institute of Physics, Ecole Polytechnique Fédérale de Lausanne, Switzerland - [3]Institut Laue-Langevin, France - [4]Paul Scherrer Institute, Switzerland - [5]Materials and Life Science Division, J-PARC Center, Japan - [6] Condensed Matter Physics and Materials Science Division, Brookhaven National Laboratory, USA - [7]Debye Institute for Nanomaterials Science, Utrecht University, The Netherlands

1. Background

One of the greatest unsolved problems in physics is the origin of high-Tc superconductivity (SC). There is ample evidence that microscopic magnetic dynamics and correlations are coupled to SC. In La-based cuprates it is now known, by use of, *e.g.*, neutron scattering, that there is a subtle connection between SC and antiferromagnetism in these materials [1,2]. However, a full understanding is still lacking.

The magnetism in $La_{2-x}Sr_xCuO_4$ (LSCO), and similar cuprate SC, is found as static or dynamic stripes, *i.e.,* small patches of anti-ferromagnetism, separated by 'rivers' of charge, giving rise to magnetic signals at in-commensurate positions in Q [3]. However, it remains important to clarify the details of these stripes to pinpoint their relation to SC. Dynamic stripes are present at all temperatures, while static stripes appear only below the SC critical temperature, $T_N = T_c$, and only for low-doped samples $0.05 < x < 0.13$.

However, μSR measurements curiously find a much lower ordering temperature, $T_N < T_c$. This discrepancy [4] has been attributed to the different timescale between the methods. However, this was never observed directly, nor has any explanation been given for the strong correlation between SC and magnetic order when measured on the neutron timescale and not when measured on the μSR timescale.

Recently, at the backscattering instruments IN16b (ILL) and DNA (JPARC) [5], we were able to measure the development of the magnetic stripes in the quasielastic regime with unprecedented energy resolution. This both allowed us to observe the effects of measuring the signals at different time scales, addressing the discrepancy in ordering temperature between muons and neutrons, and led to the discovery of two new types of quasielastic stripe dynamics in non-SC cuprate LSCO (x=0.05): One sub μeV signal and one at approx. 100 μeV. These findings prompted us to further investigate the sub μeV signal for the x=0.05 as well as for the superconducting x=0.07 sample on IN16b.

1. Experiment

For our sample, we measured at the magnetic Q-vector [1 0 0] by integrating all signal of the 3 central detector tubes covering the q-position.

Making use of the fixed window (FW) scan to measure 0 μeV (30 min pr. point) and 3 μeV (40 min pr. point) energy transfers in the range 1.5 to 20 K to map the shift of the magnetic signal from elastic to quasi-elastic. This was done both for the x=0.05 and x=0.07 sample, as shown in figure 1 and 2. We find excellent agreement between the disappearance of the elastic magnetic signal from IN16b and the disappearance of the magnetic volume fraction in muSR. In addition, we see that the inelastic signal intensity at 3 mueV peaks around the temperature where the elastic magnetism disappears.

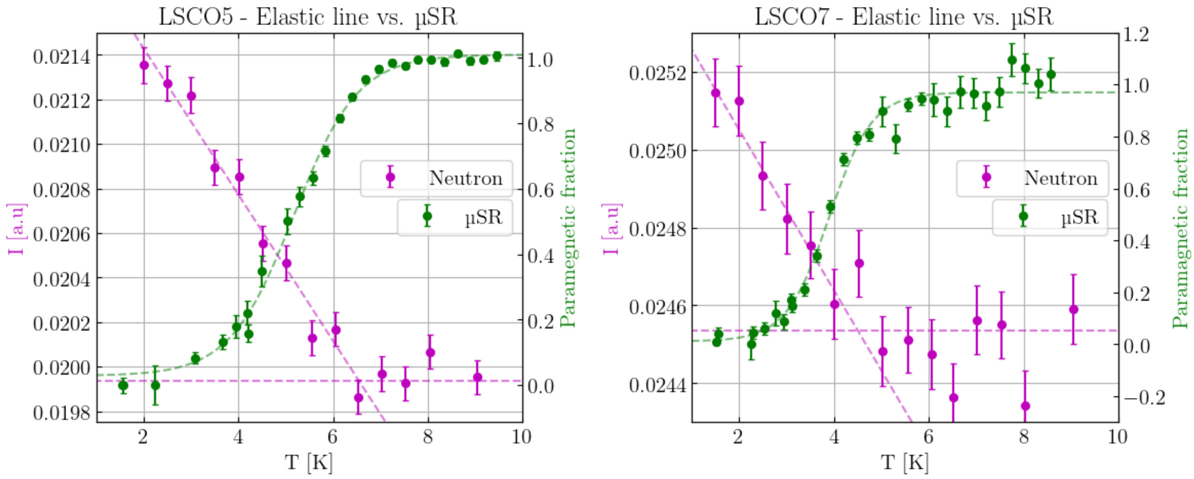

Figure 1: FW scan from IN16b of the elastic intensity magnetic peak compared to µSR data acquired from GPS at PSI. Shows agreement in the ordering temperature.

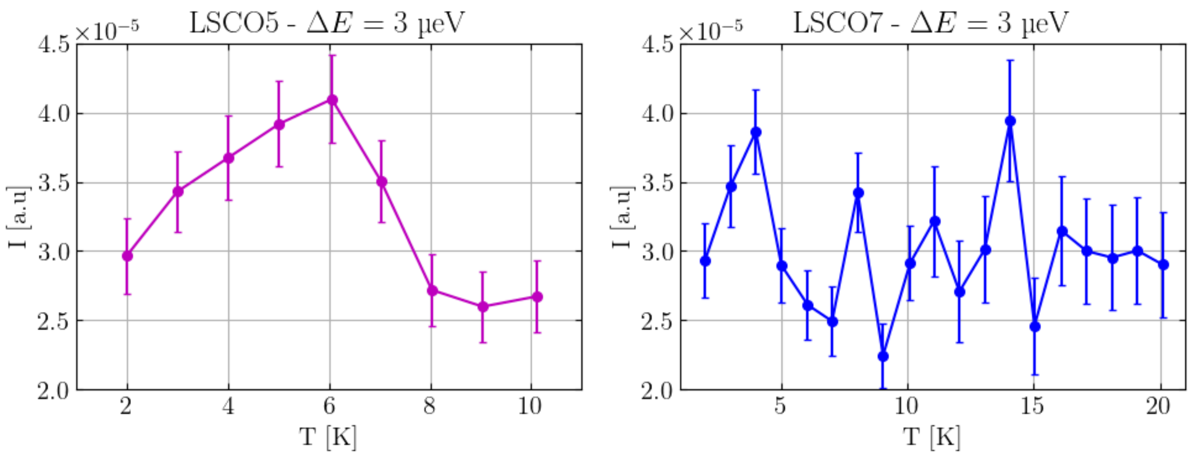

Figure 2: FW scan from IN16b at 3 µeV energy transfer. Clear difference between two, where the non-SC sample has a clear quasi-elastic component that tops out at 6 K. On the other hand, the SC does not have any resolvable signal at this energy transfer.

From the FW scans, we were able to determine the interesting temperatures to measure the full spectra using , at 2, 6 and 10 K for x=0.05 and 2, 3.5 and 5 K for the x=0.07 sample. Peaks were fitted and the Lorentzian broadening of both samples are compared, see figure 3. For the x=0.05 sample we see a clearly broader QENS signal at 6K = T_N, while we hardly see any difference in the signal from the x=0.07 sample.

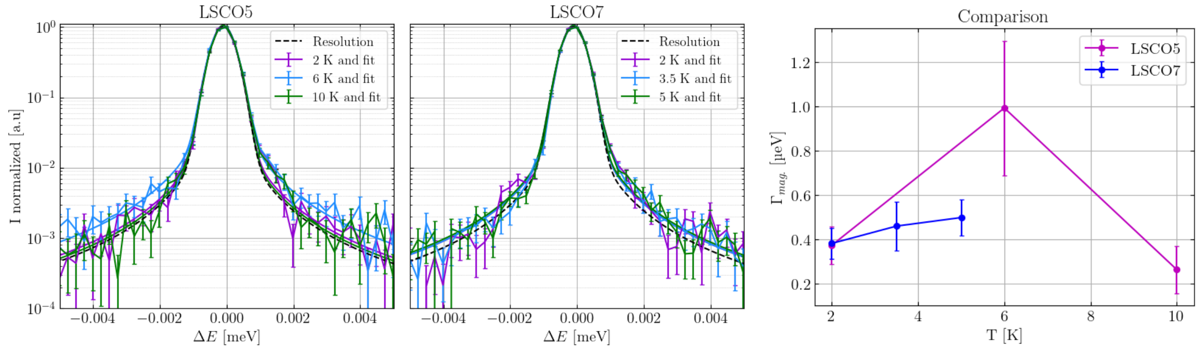

Figure 3: Overview of the QENS spectra for both x=0.05 and x=0.07 with the fitted curves. The left plots show the fitted widths of the Lorentz broadening.

In conclusion, we were able to acquire sufficient data of sufficient quality for publication, when combined with the earlier DNA data.

References

[1] B. Lake *et al.*, Nature **400** 43 (1999).
[2] B. Keimer *et al.*, Nature **518** 179 (2015).
[3] D. J. Scalapino, Rev. Mod. Phys., **84** 1383 (2012).
[4] B. Keimer *et al.*, PRB **45** 7430 (1992), T. P. Croft *et al.*, PRB **89** 224513 (2014), N. E. Hussey *et al.*, Philos. Trans. A **369** 1626 (2011), M. Kofu *et al.*, PRL **102** 047001 (2009).
[5] JPARC data set DNA, from proposal 2022A0332