EUROPEAN SYNCHROTRON RADIATION FACILITY

INSTALLATION EUROPEENNE DE RAYONNEMENT SYNCHROTRON

Experiment Report Form

The double page inside this form is to be filled in by all users or groups of users who have had access to beam time for measurements at the ESRF.

Once completed, the report should be submitted electronically to the User Office via the User Portal:

https://wwws.esrf.fr/misapps/SMISWebClient/protected/welcome.do

Reports supporting requests for additional beam time

Reports can be submitted independently of new proposals – it is necessary simply to indicate the number of the report(s) supporting a new proposal on the proposal form.

The Review Committees reserve the right to reject new proposals from groups who have not reported on the use of beam time allocated previously.

Reports on experiments relating to long term projects

Proposers awarded beam time for a long term project are required to submit an interim report at the end of each year, irrespective of the number of shifts of beam time they have used.

Published papers

All users must give proper credit to ESRF staff members and proper mention to ESRF facilities which were essential for the results described in any ensuing publication. Further, they are obliged to send to the Joint ESRF/ ILL library the complete reference and the abstract of all papers appearing in print, and resulting from the use of the ESRF.

Should you wish to make more general comments on the experiment, please note them on the User Evaluation Form, and send both the Report and the Evaluation Form to the User Office.

Deadlines for submission of Experimental Reports

- 1st March for experiments carried out up until June of the previous year;
- 1st September for experiments carried out up until January of the same year.

Instructions for preparing your Report

- fill in a separate form for each project or series of measurements.
- type your report, in English.
- include the reference number of the proposal to which the report refers.
- make sure that the text, tables and figures fit into the space available.
- if your work is published or is in press, you may prefer to paste in the abstract, and add full reference details. If the abstract is in a language other than English, please include an English translation.

	Experiment title: Resonant inelastic x-ray scattering as a probe of the superconducting gap in the high-Tc superconductors Bi2Sr2CaCu2O8+x and Bi2Sr2Ca2Cu3O10+x	**Experiment number**: HC 3324
Beamline: ID32	**Date of experiment**: from: 1 November 2017 to: 7 November 2017	**Date of report**: 10 Jul 2018
Shifts: 18	**Local contact(s)**: Davide Betto	*Received at ESRF:*

Names and affiliations of applicants (* indicates experimentalists):

Hakuto Suzuki*, Matteo Minola*, Emilie Lefrancois*, Bernhard Keimer – Max Planck Institute for Solid State Research

Matthieu Le Tacon – Karlsruhe Institute of Technology

Yingying Peng*, Roberto Fumagalli*, Lucio Braicovich, Giacomo Ghiringhelli – Politechnico di Milano

Report:

The goal of the proposal was to investigate the the modification of the Cu-L_3 Resonant Inelastic X-ray Scattering (RIXS) spectra across the superconducting (SC) transition temperature (T_c) in the Bi-based cuprates $Bi_2Sr_2CaCu_2O_{8+x}$ (Bi2212) and $Bi_2Sr_2Ca_2Cu_3O_{10+x}$ (Bi2223). In superconductors, the Cooper pair formation opens an energy gap in the the single-particle spectrum on the Fermi Surface (FS), which serves as the order parameter of the SC state. In the cuprate superconductors, it is established that the order parameter has a d_{x2-y2}-wave symmetry, where the sign changes along the x- and y-directions and the nodes are formed along the Brillouin zone diagonal. As a result, the charge and spin correlation functions are also renormalized upon entering the SC state, which we intended to observe in the present experiment. The measurement is made possible by the high resolving power of the ERIXS spectrometer at the beamline ID32 and the high T_c's of the optimally-doped Bi2212 and Bi2223 (90 and 110 K, respectively). In the previous experiments [1,2], we have investigated the modifications of the RIXS spectra at $\boldsymbol{q}_{//}$ = (0.15, 0) r.l.u., a momentum transfer where the calculated charge susceptibility suggests the most salient modifications across T_c (Fig. 1). The measurement was carried out

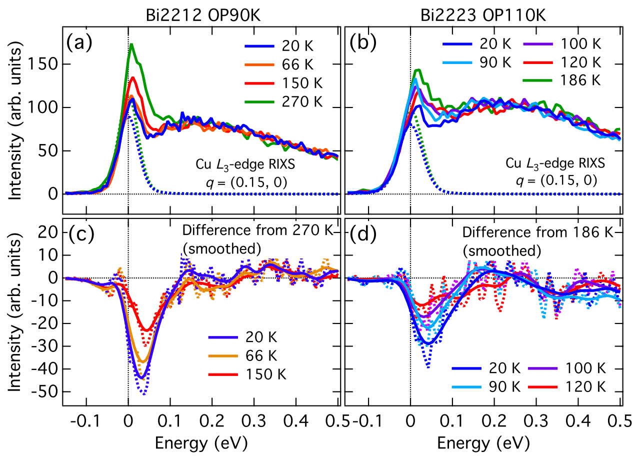

Fig. 1 Modifications of the Cu L_3-edge RIXS spectra across the SC transition in the optimally-doped Bi2212 and Bi2223 at $\boldsymbol{q}_{//}$ = (0.15, 0).

with σ-polarized incident light at the peak of the Cu L_3 absorption. A reduction of the RIXS spectral weight between the elastic line and the magnetic peak is clearly visible across the SC transition, whereas the paramagnon excitations remains substantially unchanged. This observation indicates that the changes are related to the opening of the SC gap. In this experiment HC3324 we performed further measurements in optimally-doped Bi2212 to pin down the origin of this modification. In particular, we investigated the $\boldsymbol{q}$ dependence of the modification, in order to judge whether the behaviour agrees with expectations from the $\boldsymbol{q}$ dependence of the particle-hole excitations across the d-wave SC gap. Furthermore, we also investigated an underdoped Bi2212 sample with T_c = 60 K (UD60K), aiming at elucidating how the pseudogap opening in the antinodal region of the Fermi surface affects the low-energy RIXS response, and whether the modification is analogous to that primarily caused by the SC gap and shown in Fig. 1.

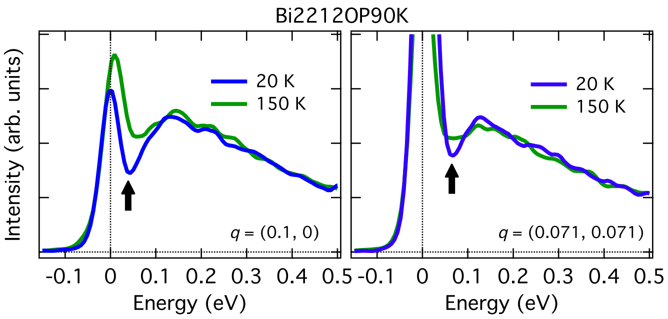

Fig. 2 Modifications of the Cu L_3-edge RIXS spectra of optimally-doped Bi2212 at $\boldsymbol{q}_{//}$ = (0.1, 0) and (0.071,0.071).

Figure 2 shows Cu L_3 RIXS spectra for Bi2212 OP90K above (150 K) and below T_c (20 K), measured at small momenta $\boldsymbol{q}_{//}$ = (0.1,0) and (0.071,0.071). The measurements were performed using the high-resolution setup (ΔE = 35 meV) with the σ-polarized x-ray photons. We have chosen these specific $\boldsymbol{q}_{//}$ values because the charge SC coherence factor becomes large at low momentum transfers, which may well cause a strong modification of the spectra upon entering the SC state. As expected from this theoretical consideration, we clearly observe a spectral weight depletion between the elastic line and the paramagnon peak, both at $\boldsymbol{q}_{//}$ = (0.1,0) and (0.071,0.071) (as indicated by the black arrows in Fig.2). We can thus confirm the reproducibility of the spectral depletion in the SC state. Furthermore, toghether with the previous data at $\boldsymbol{q}_{//}$ = (0.15,0) and (0.1,0.1), we can conclude that the rearrangement of the spectral weight is observed in $|\boldsymbol{q}_{//}|$<0.15 r.l.u.. This is exactly what is expected from the $\boldsymbol{q}$ dependence of charge susceptibility due to the particle-hole excitations. On the other hand, the expected concomitant pileup of the spectral weight ("2Δ" coherence peak in the terminology of Raman scattering) is not clearly observed within the energy window investigated, consistently with previous data. The theoretical interpretation on this issue is detailed in Ref. [2]. Finally, we show in Fig. 3 the RIXS spectra for the UD60K. As in optimally-doped Bi2212 and Bi2223, we clearly observe a spectral weight depletion both at $\boldsymbol{q}_{//}$ = (0.15,0) and (0.071,0.071) (black arrows). However, the spectra at 20 and 70 K almost overlap, showing little modification below T_c=60K. This indicates that the spectral modification here is mainly attributed to the pseudogap opening. These measurements thus provide a way to quantify the unoccupied side of the pseudogap via charge response with arbitrary $\boldsymbol{q}$. Data analysis is under way and possibly will lead to a new draft for a future publication.

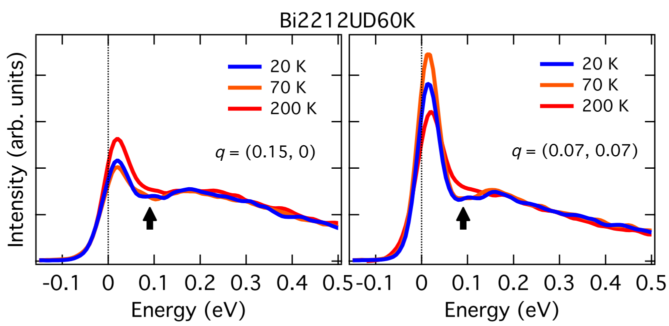

Fig. 3 Modifications of the Cu L_3-edge RIXS spectra of an underdoped Bi2212 (T_c=60 K) at $\boldsymbol{q}_{//}$ = (0.15, 0) and (0.071,0.071).

[1] Long Term Project Report for Long Term Proposal HC886
[2] H. Suzuki *et al.*, submitted.