| | Experiment title: Unveiling the energy scale of the charge density wave fluctuations in high temperature superconductor YBa2Cu3O6+x | Experiment number: HC861 |
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## Report:

We have recently discovered a fluctuating incommensurate charge-density-wave (ICDW) in underdoped superconducting cuprates using resonant inelastic x-ray scattering at the Cu-L3 edge, an approach which however cannot establish the low energy scale typical of these fluctuations. The main purpose of the present experiment was to determine this energy scale using high resolution hard x-ray scattering in order to unveil the origin of this new phenomenon.

In the original proposal, we planned to study at least 2 samples as function of temperature: $YBa_2Cu_3O_{6.6}$ (p = 0.12, $T_c$ = 61 K) in which we observed the ICDW and $YBa_2Cu_3O_{6.5}$ in which it disappeared.

For reasons that will appear clearer in the following, we could only measure the former during this experiment.

As stated in the proposal, the ICDW superstructure peak intensities are maximized at wave vectors (0.31 0 0.5) and (0 0.31 0.5), but along the 100 direction, one has also the contributions from the CuO chains superstructure (at h=0.4 in $YBCO_{6.6}$). Diffuse scattering screening of the sample prior to the beamtime revealed that more than a “background”, the signal arising from the chains in the 100 direction is so strong that it would prevent any exploitable measurement in this direction. For this reason, we focused only on the 010 direction.

For most of the temperatures at which the measurements were carried out, we have performed energy scans from -5 to 20 meV in longitudinal and transverse geometries in relevant region of the reciprocal space identified beforehand using diffuse scattering. Several measurements from -20 to 20 meV where however carried out to get the anti-Stokes part of the spectra and allow a precise determination of the quasi-elastic line

position. This point is crucial in the ICDW phase, to quantify "how elastic" ICDW superstructure peak actually is.
As the experiment has been carried out very recently, a lot of data remain to be analyzed and only preliminary conclusions will be given here.

1) We have unambiguously observed the signature of the ICDW in the IXS data. This consists in a substantial enhancement of the quasi-elastic intensity upon cooling. Following our previous finding using RIXS, we observed that the maximal intensity of the elastic peak occurred at T=Tc. The region of the reciprocal space in which the enhancement was observed is very narrow, almost limited by the extremely good momentum resolution of the instrument (0.015 r.l.u.), which forces us to use a very fine k-space grid for our study: up to 15 points in the dispersion. This is a factor of 2 larger than anticipated. For this reason we could not investigate a second sample during this beamtime.

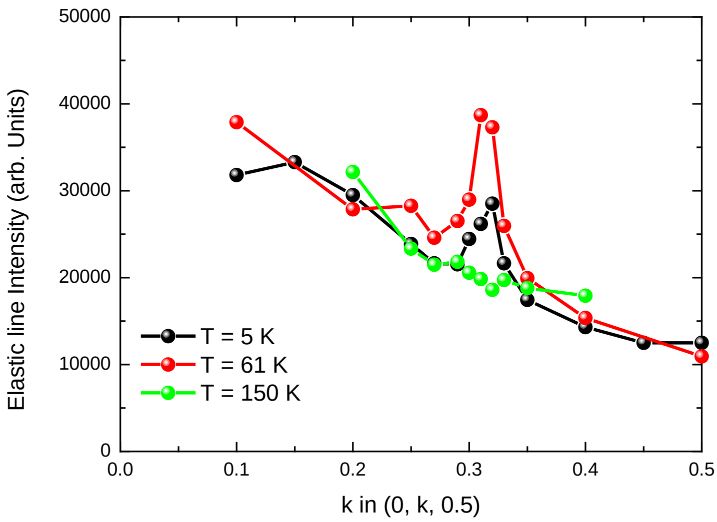


Fig. 1: Momentum dependence of the intensity of the quasi-elastic peak at various temperatures

2) We have performed measurements with two energy resolutions: 1.4 and 2.7 meV. The former is more time consuming due to the lower statistic (~9 lower than at 2.7) and the greater number of points required in a given energy interval. These measurements did not allow us to identify the energy scale of the CDW fluctuations, but only to assess an upper-limit of 100 μeV to this quantity.

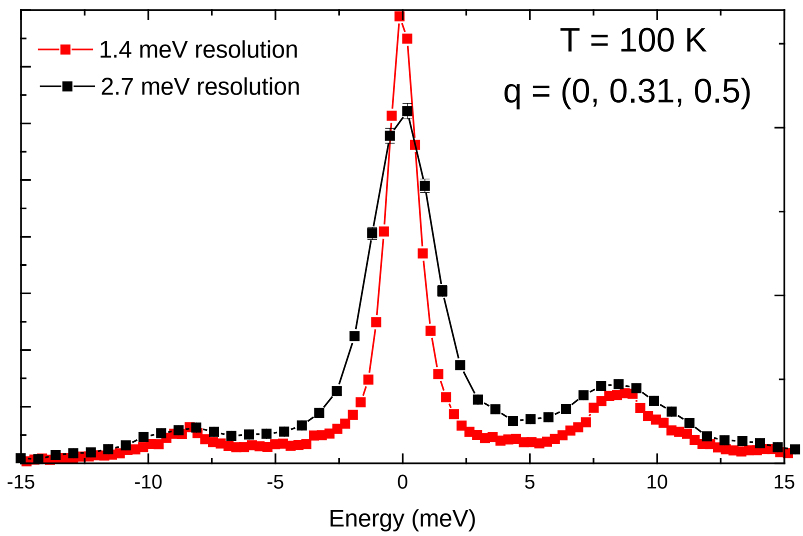

Fig. 2: IXS spectra at $q_{CDW}$ at T = 100 K taken with two energy resolutions (the 1.4 meV resolution has been rescaled by a factor ~10)

3) In “conventional” CDW systems, electron-phonon interaction plays a central role in the instability. It leads to the softening of a phonon mode, which energy vanishes at the phase transition, inducing a static distortion of the lattice. We have tried to determine whether such mechanism was at play in the present case. For this, we have measured the dispersion of the low energy phonons in longitudinal and transverse geometries, at various relevant temperatures. The analysis of these data is not advanced enough to give definitive conclusions at the present stage. We can however affirm that there is a clear (spectacular) signature of the CDW in the phonon spectrum, which is very different from the conventional “à la Peierls” one and indicates a very peculiar, unanticipated, manifestation of electron-phonon coupling in these compounds. To evaluate the impact of these effects on the physics of cuprates and their eventual role (friend or foe) in high temperature superconductivity, a systematic investigation of their doping dependence is required.