Report of experiment HC-4414 - Nematic response to uniaxial pressure of 2D charge density waves in $YBa_2Cu_3O_{6.67}$ investigated by Cu-L_3 RIXS

In this experiment, we aimed at the investigation of the two-dimensional charge density waves (CDW) in the superconducting cuprate $YBa_2Cu_3O_{6.67}$ ($YBCO_{6.67}$) when uniaxial stress along the *a* or *b* axis is applied. We previously found that the compression along one axis (for example the *a* axis) results in the enhancement of the CDW along the direction perpendicular to the stress (in reciprocal space, the [0K] direction), while the CDW in the parallel direction ([H0]) is barely affected [1]. In our previous work the strain was applied after the needle-shaped samples were already cooled down to base temperature (20 K), below the transition temperature involving the formation of the CDW domains. The enhancement of the "opposite" CDW could be due to the enlargement of previously existing domains or, in case these were pinned by structural defects, to the nucleation of new domains. With this latest beamtime we tried to address this question by putting the sample under uniaxial stress before the transition temperature was crossed, *i.e.* before the CDW phase started to condensate. This type of experiment is extremely difficult from a technical point of view, requiring a complex setup, a strain cell and, most importantly, needle-shaped crystals with dimensions 1mm x 200 µm x 75 µm which are easily broken. Given all of the above, we only managed to characterize an unstrained needle, the same needle after the application of strain along the *a* axis before cooldown and another needle in the same conditions as the latter but with the strain applied along the *b* direction. They are labeled "60K unstrained", "60K Strained A needle" and "60K Strained B needle", respectively, in Fig. 1-2. The applied stress is nominally -1% but there are

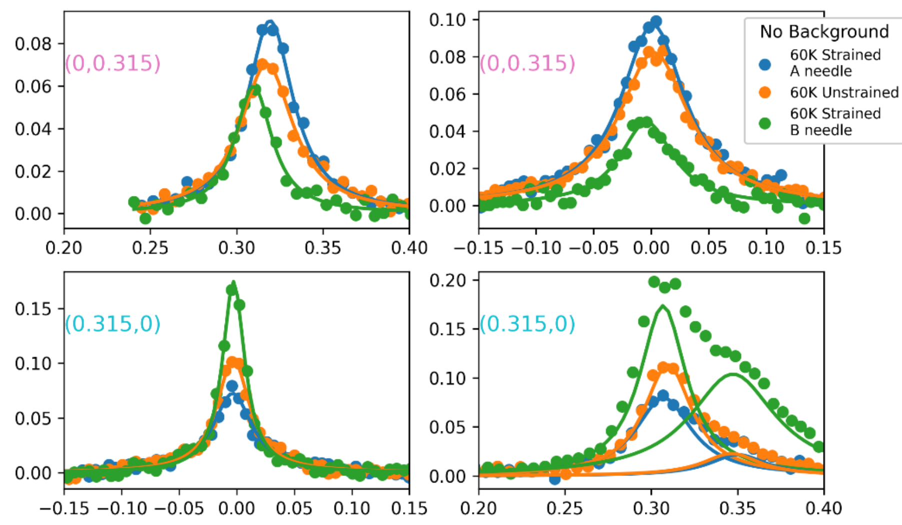

Figure 2: integrated intensity of the quasi-elastic peak of the RIXS spectra as a function of H or K close to the CDW peaks.

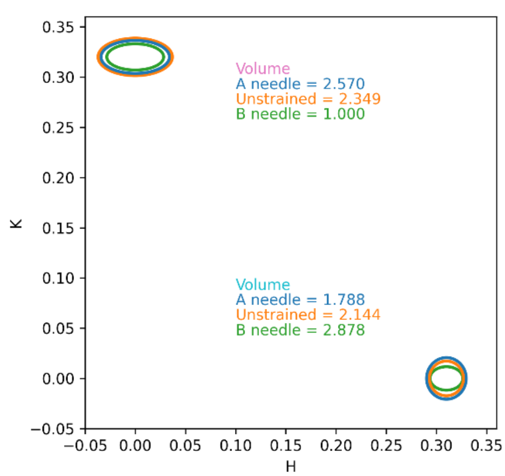

Figure 1: schematic view of the CDW peaks and their "scattering volume" for the three situations of Fig. 1

uncertainties in this respect, as discussed later. We acquired RIXS spectra varying H and K at the CDW wavevectors (0.315, 0) and (0, 0.315) using the ERIXS spectrometer at ID32 and integrated the quasi-elastic intensity, thereby obtaining the CDW intensity in the reciprocal space. In Fig. 1 we show the results of this procedure, together with Lorentzian fits, for the three samples. We point out that there is an addition peak at ~ (0.35, 0) due to the ortho-VII order of the CuO chains in $YBCO_{6.67.}$ A polynomial background was already subtracted from the raw data. From the curves, it can be clearly seen that we were able to reproduce our findings: the CDW perpendicular to the stress direction is enhanced. However, we found a marked reduction of the total intensity of the "parallel" CDW, which was not previously observed. In Fig. 2 we show a pictorial representation of the two CDWs for the three cases, together with the total "volume" of the scattering peaks. If one limits the examination to the data from the same needle, i.e. the "60K Strained A needle" and "60K Unstrained" cases, we find a very consistent picture: the total volume of the "perpendicular" CDW is increased in the strained case, while the FWHM in both directions is reduced, indicating a longer coherence length. The same cannot be said is one considers also the "B needle": the total volume of the scattering peak follows the same trend nicely but the FWHM is always lower than the other two cases, which is a puzzling behavior. Looking at the data in Fig. 1, it can be seen that the enhancement effect is much more pronounced than with the first needle, pointing to a higher degree of applied stress, even if it was nominally the same. In addition, we do not have a comparison with the unstrained situation on the very same "B needle", which does not allow us to evaluate the relative changes. We are going to apply for additional beamtime in order to address these issues and get more statistically relevant data. However, we can see that the application of uniaxial stress already at high temperature results in the reduction of the intensity of the "parallel" CDW, which is not seen when the stress is applied only later at low temperature. This implies that the domains are likely pinned by defects in the latter situation and thus unable to shrink in a significant way.

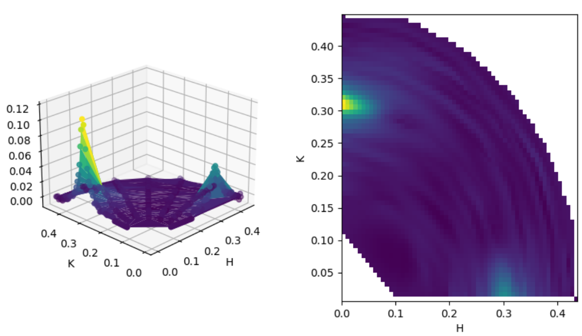

Figure 3: reciprocal space map showing the integrated quasi-elastic intensity in a quarter of the Brillouin Zone. No isotropic charge density fluctuation peak is visible.

In addition, recently there have been various reports of isotropic charge density fluctuations (CDF) at high temperature in both electron doped and hole doped cuprates [2-3]. These fluctuations are thought to be precursor of the static CDW, implying their partial condensation at low temperatures into the localized peaks in reciprocal space that are normally observed. We used part of the beamtime to investigate the presence of these isotropic CDF in our needle-shaped crystals but we were not able to find any clear evidence both at zero and finite energies. The results of the reciprocal space mapping for integration over the quasi-elastic signal are shown in Fig. 3.

[1] H.-H. Kim *et al.,* Phys. Rev. Letters **126**, 037002 (2021)

[2] M. Kang *et al.*, Nature Physics 15:335–340 (2019)

[3] F. Boschini *et al.*, Nature Communications volume 12: 597 (2021)