Supplementary information for

Vanishing nematic order beyond the pseudogap phase in overdoped cuprate superconductors

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SI References

Measurement and Temperature dependence of the (001) Bragg peaks

Here we present representative measurements of the (001) peak and its temperature dependence in Nd-LSCO at doping level $x = 0.17$. Raw data, as shown in Fig. S1, in this sample is collected by a photodiode (PD) detector. This detector integrates over the incident photon energies, which includes both 1st order and a subdominant 2nd order (at twice the desired photon energy) contribution from the beamline monochromator. This 2nd order light contribution enables the measurement of the strong (002) structural Bragg peak of Nd-LSCO at angles that coincide with the detection of the (001) peak with 1st order light. Note, in Fig. S1, the *L* value in reciprocal lattice vectors from Bragg's law is shown. However, due to refraction, the detected peak angles are different from the expected peak[28] at (001). Moreover, due to refraction, the (001) and (002) peaks are peaked at different angles or *L* values.

Upon heating from the LTT to LTO phase, the (001) Bragg peak vanishes – which is around 81 K for the $x = 0.17$ sample – and only the *T*-independent structural (002) Bragg peak remains. Contributions from the (002) structural Bragg peak, can be subtracted from the total intensity (001) to yield the (001) peak intensities. This is achieved by subtracting the high temperature scans (in the LTO phase) from the total intensity.

The resulting (001) peaks at selected temperatures for both the apical O-*K* edge (~533 eV) and Cu-*L* edge (~931.5 eV) is shown in Fig. S2, along with Lorentzian fits.

Lorentzian lineshape profile fit the data well and exhibit a full width at half maximum (FWHM) that is temperature independent, as shown in Fig. S2(c). This is consistent with the (001) peak width analysis in Supplementary Information of Ref. (28) for Nd-LSCO at $x = 0.125$, which discusses that the FWHM is determined by x-ray absorption length and not the correlation length of electronic nematicity. Similar temperature independent peak widths are seen at other absorption edges and doping levels.

The T-independent FWHM implies that the T dependence of the peak intensity and the integrated intensity is equivalent for the (001) peak. Scattering intensity plotted in Fig. S2(d) is obtained by the fitted-peak intensity (amplitude of the Lorentzian line shape) for the apical O-*K* (blue curve) and Cu-*L* (red curve) edge. Note that the data at the Cu-*L* and apical O-*K* edges in Fig. S2(d) is arbitrarily scaled to match in intensity below the LTO $\rightarrow$ LTT phase transition to highlight the difference in temperature dependence at the two transition edges.

For $x = 0.24$, we use an energy resolved Silicon Drift Detector (SDD) which can differentiate between the (001) and (002) peak contributions unlike the PD. Dataset and Lorentzian fits for this sample are shown in Fig. S3. Note that due to saturation of the energy resolved detector by the 2^{nd} order light ($E_i \sim 1066$ eV) at apical O-*K*, contribution from associated *L*-values have been clipped out in determining the fitting parameters as shown in Fig. S3(b).

Temperature dependence of the CDW peaks in Nd-LSCO

The CDW order is evidenced by a broad and weak peak above the fluorescent background signal in resonant scattering around the (CDW) peak maximum[1,28] ~ (δ 0 1.5). The temperature dependence of the CDW peaks at the Cu-*L* edge were measured by performing scans of the sample angle, at a fixed value of the detector angle for samples at Sr doping level of x = 0.17, 0.18, 0.19 and 0.24. These scans vary both *H* and *L*. However, since the CDW peaks are broad in *L* these scans primarily identify the peak and its width in *H*. We detect CDW order for x = 0.17 as shown in Fig. S4(a). A cubic background is subtracted from the data, and the resulting CDW peak are fit to Lorentzian line shapes, as shown in Fig. S4(b). Scattering intensity was obtained by measuring the fitted-peak amplitude at the Cu-*L* edge (shown in Fig. 3 of the main text). However, we did not observe signatures of CDW order at x = 0.18, 0.19 and 0.24 above our base temperature as shown in Fig. S4(c) and 4(d).

X-ray absorption (XAS) for Nd-LSCO at O-*K* and Cu-*L* edge

X-ray absorption (XAS) is measured as a function of photon energies – at the Cu-*L* and O-*K* edges – in Nd-LSCO at x = 0.17 using total fluorescence yield (TFY), as shown in Fig. S5. At ~931.5 eV, where Cu-*L* RSXS measurements in this study are performed, the XAS signal is dominated by the in-plane Cu 3*d* states[44]. Moreover, at ~528.5 eV, the XAS signal is sensitive to the O 2*p* states of the in-plane, O(1), states[45]. However, at

~532.3 eV, where O-*K* edge RSXS measurements in this study are performed, the XAS signal shows sensitivity to the apical oxygen, O(2), the states in the spacer layer which are hybridized with (La, M) states[34,46]. The XAS measurements are qualitatively consistent between all the measured samples from $x = 0.125$ to 0.24.

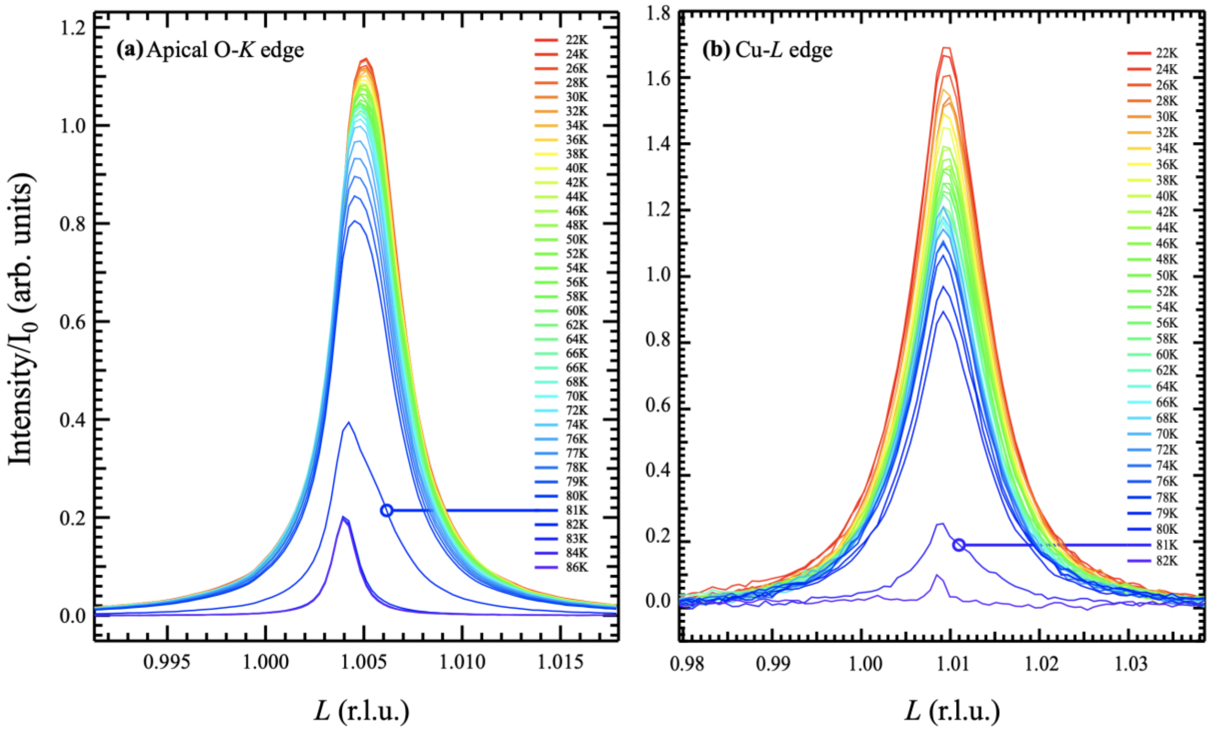

Figure S1. Raw dataset for (001) Bragg peaks as a function of temperature for Nd-LSCO at *x* = 0.17 using a photodiode detector. Recorded (001) peak intensity and shape as function of *L* at various temperatures at (a) apical O-*K* edge (~ 532 eV) and (b) in-plane Cu-*L* edge (~931.5 eV). The sharp (001) signal-intensity drop at ~81 K marks the LTT → LTO phase transition, above which the (001) peak vanishes and the photodiode only detects a weak, *T*-independent (002) structural Bragg peak coming from 2nd order light.

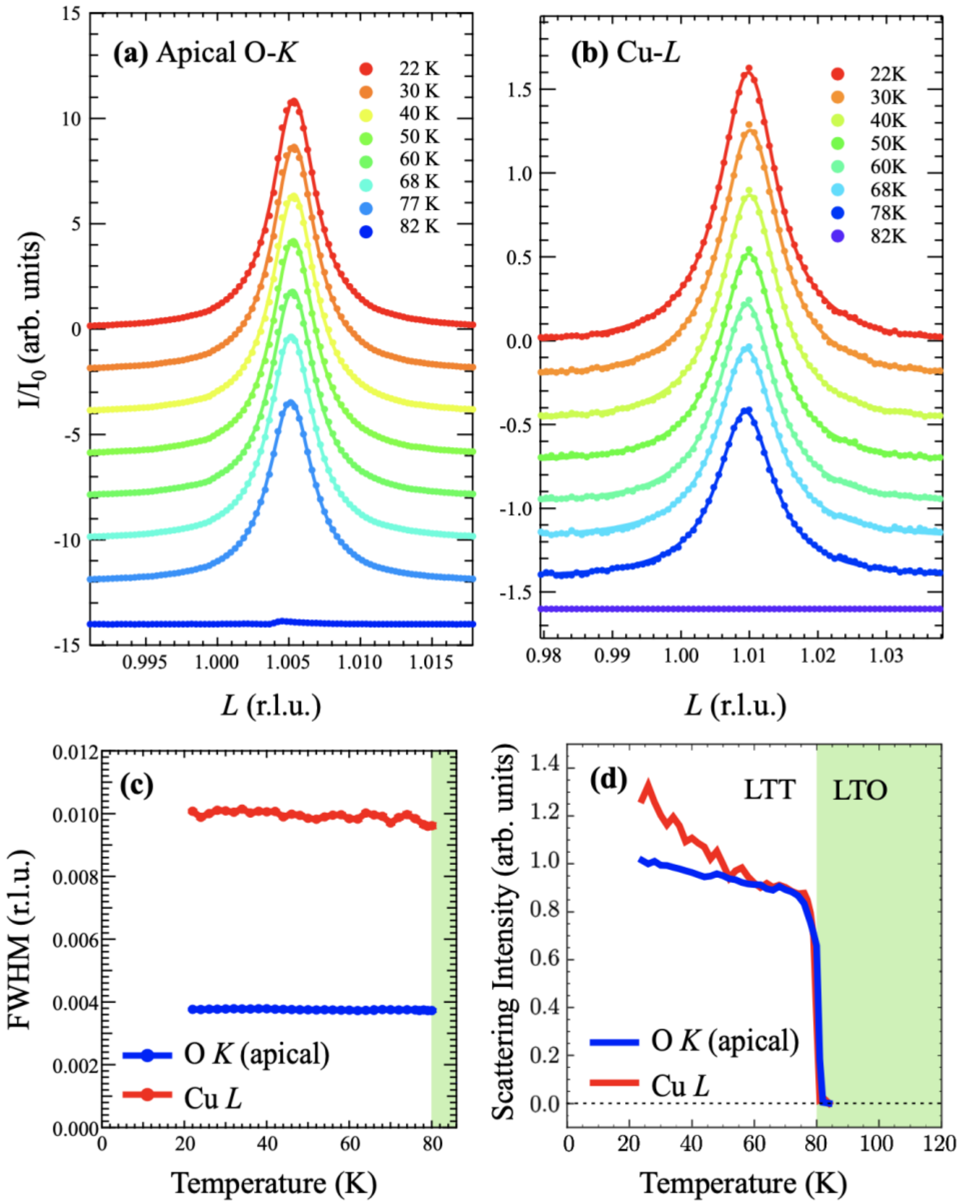

Figure S2. Temperature dependence of (001) Bragg peaks in Nd-LSCO at *x* = 0.17. Temperature dependence of the (001) Bragg peaks at **(a)** apical O-*K* edge (~532 eV) and **(b)** in-plane Cu-*L* edge (~931.5 eV). Solid lines are Lorentzian fits to the data (filled circles) at different temperatures. The peak intensity decreases with increasing temperature, but the width remains constant. **(c)** The *T* dependence of the FWHM of the Lorentzian fits for the (001) peak at the apical O-*K* and Cu-*L* edges. **(d)** The scattering intensity (peak amplitude of the Lorentzian fits) for both the edges. The intensities for apical O-*K* signal are normalized by the corresponding low-temperature values, $\boldsymbol{I_{\mathrm{O(001)}}} \sim \mathbf{24\ K}$, with the intensity for Cu-*L* edge scaled to match the O-*K* intensity at a temperature below the LTO $\rightarrow$ LTT transition. The white and green region indicate the LTT phase and the LTO phase respectively in (c) and (d).

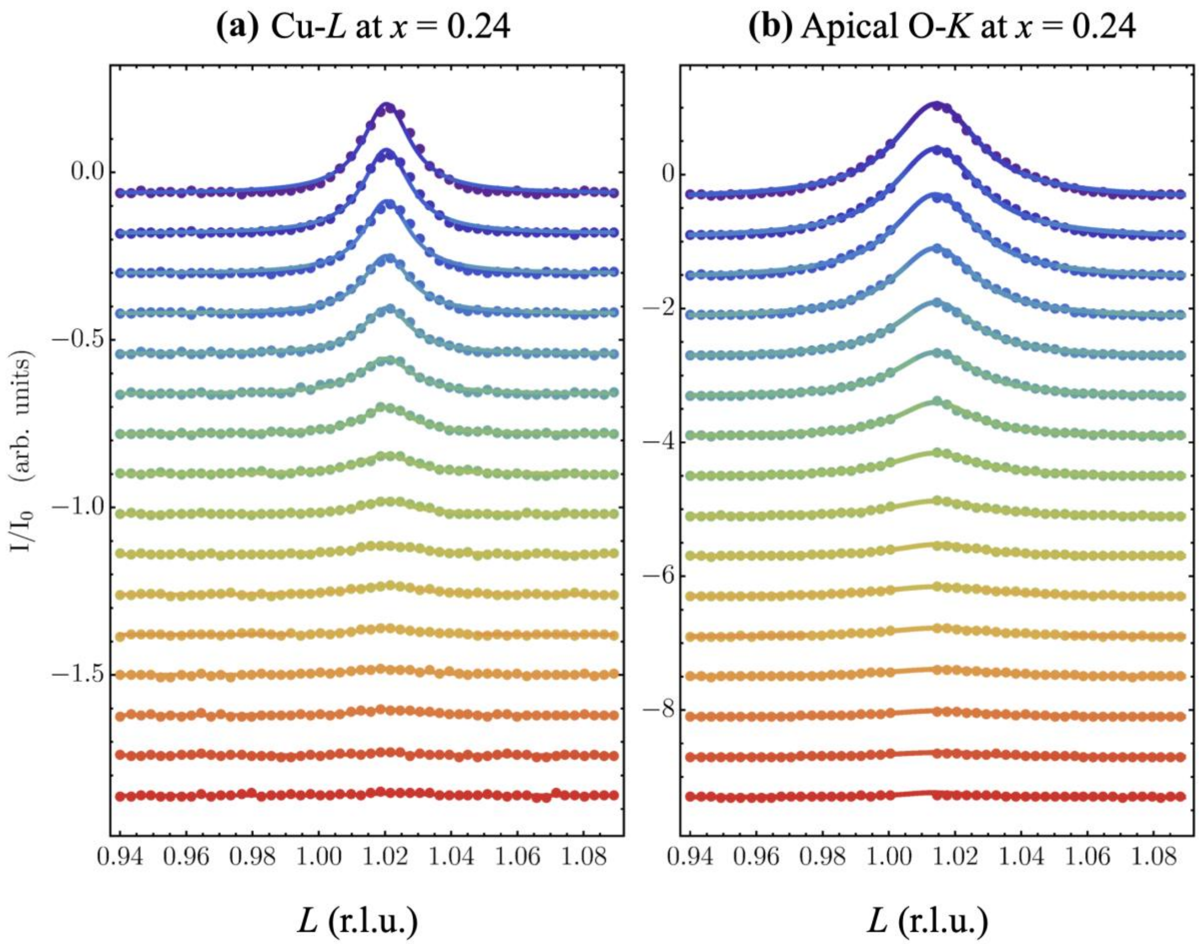

Figure S3. Temperature dependence of (001) Bragg peaks in Nd-LSCO at *x* = 0.24. Temperature dependence of the (001) Bragg peaks for *x* = 0.24 sample at **(a)** apical O-*K* edge (~532 eV) and **(b)** in-plane Cu-*L* edge (~931.5 eV). The peak intensity decreases with increasing temperature, but the width remains constant. Solid lines are Lorentzian fits to the data (filled circles) at different temperatures. The (001) peak intensity is recorded by tracking the amplitude of the Lorentzian fits, see Fig. 2F in the main text.

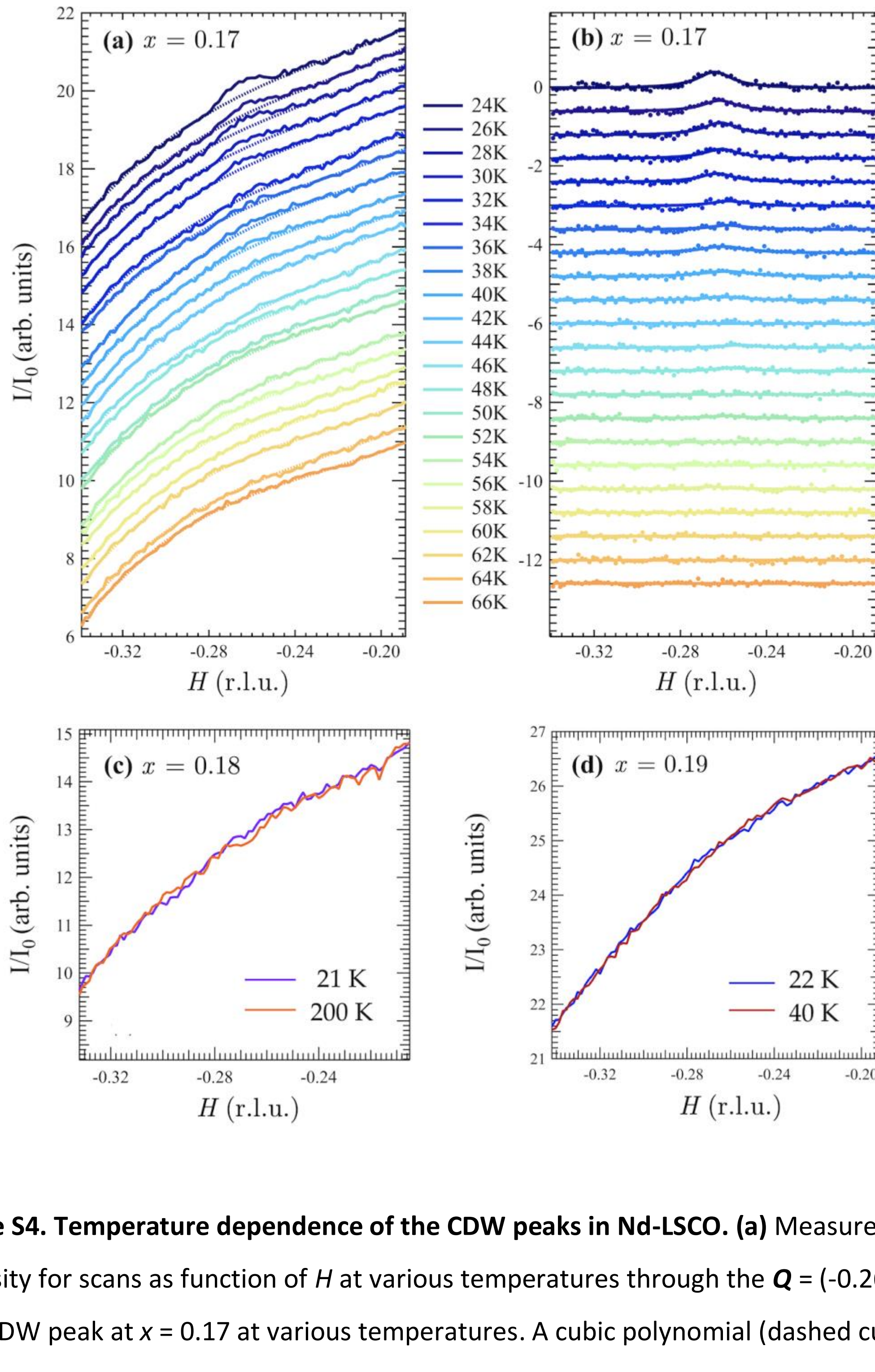

Figure S4. Temperature dependence of the CDW peaks in Nd-LSCO. (a) Measured intensity for scans as function of H at various temperatures through the $\boldsymbol{Q}$ = (-0.26, 0, 1.5) CDW peak at x = 0.17 at various temperatures. A cubic polynomial (dashed curve) is fit to the fluorescent background and subsequently subtracted from the data. **(b)** The polynomial background-subtracted data for x = 0.17. Solid lines are Lorentzian fits to the background-subtracted data (filled circles). In both (a) and (b) the data at different temperatures are offset for clarity. **(c)** and **(d**) Measured intensity through ***Q*** = (-0.26, 0, 1.5) for (c) x = 0.18 and (d) x = 0.19 at high temperature and at our base temperature (~22K) showing the absence of measurable CDW order in these samples.

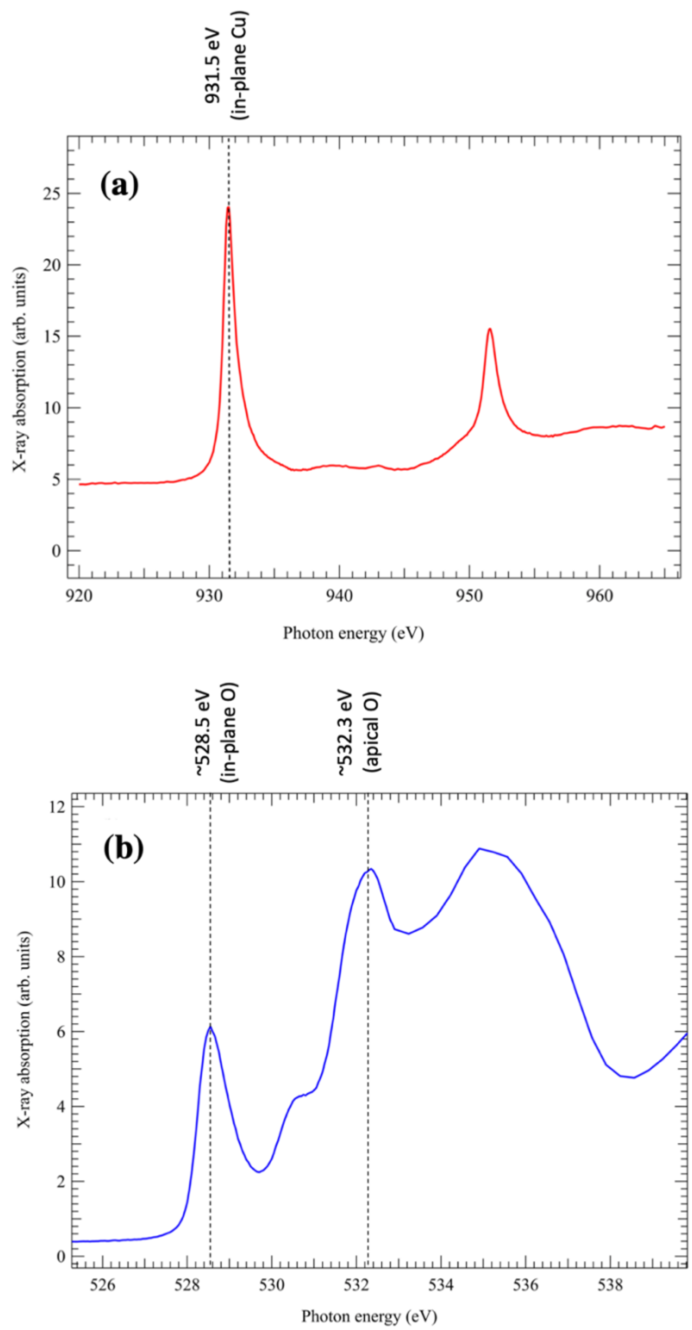

Figure S5. X-ray absorption (XAS) at the Cu-*L* and O-*K* edges in Nd-LSCO. The x-ray absorption (XAS) as a function of photon energy at the **(a)** Cu-*L* and **(b)** O-*K* edges in Nd-LSCO at x = 0.17 measured using total fluorescence yield (TFY).