Charge ordering in $YBa_2Cu_3O_y$ observed by hard x-ray diffraction

Paris– 26th of March - 2015

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Zürich University

Förderungsprofessuren Grant
"ERC" Starter Grant
MPBH Sinergia Network

MaNEP SWITZERLAND

Acknowledgements

H. M. Ronnow+team
M. Grioni+team
C. Fatuzzo

C. Matt
Y. Sassa
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Ch. Niedermayer
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J. B. Goodenough

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O. Gutowski, U. Rütt
A. Watenphul
M. von Zimmermann

M. Maansson
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O. Tjernberg

Ruixing Liang
Walter Hardy
Doug Bonn

T. Kurosawa
N. Momono
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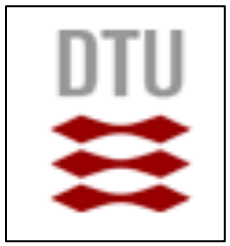

J. Larsen
N. B. Christensen

Outline

Charge-density-wave order in YBCO:

Hard x-ray diffraction

(1) Discussion of CDW anisotropy.
(2) Comparison of CDW in YBCO and stripes in LBCO

Questions

Why is the CDW peaked at 12% doping?
What is the relationship between CDW in YBCO and stripes in LSCO ?
Interplay and relationship between the AF and CDW orders (LSCO vs. YBCO)?
CDW and SC in other materials (dichalcogenides, K-doped BaBiO3, etc.)?

CDW

Is the pseudogap (PG) a crossover or a phase transition?
What is the relation between CDW and the PG?
Why and where does the pseudogap collapse?
Can we detect remnants of topological order in the pseudogap metal?
What is the origin of nematicity?
Is there a specific correlation between the PG and nematicity?
Is time-reversal symmetry broken in the PG phase?
Can we detect remnants of topological order in the pseudogap metal?

PG

Is there more than one QCP in the cuprate phase diagram and where are they?
Is an AFM QCP necessary for high-T_c superconductivity?
Linear resitivity in the nomal phase: still a mystery?

QCP

Why are these materials superconductors?
Why a dome of superconductivity?
What can we learn from other superconducting doped Mott insulators?

SC

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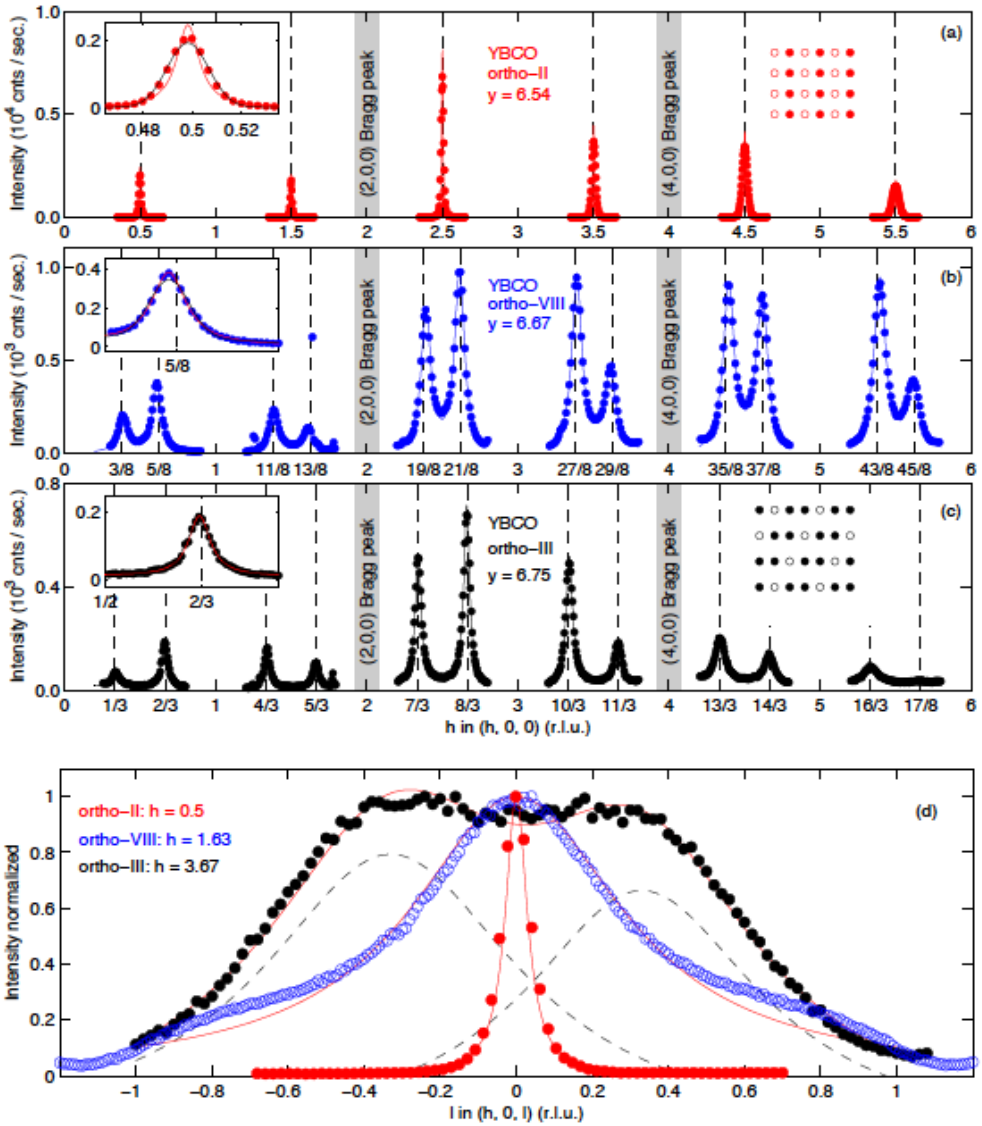
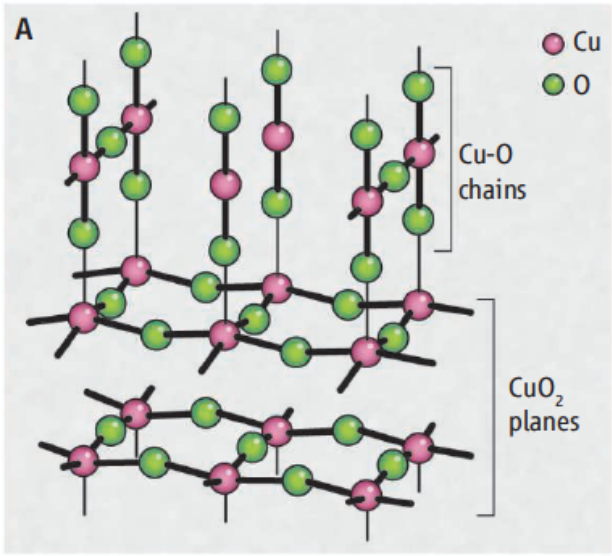
ARPES

(1) Probing pseudogaps
(2) Do stripe order have any influence of the antinodal lineshape?

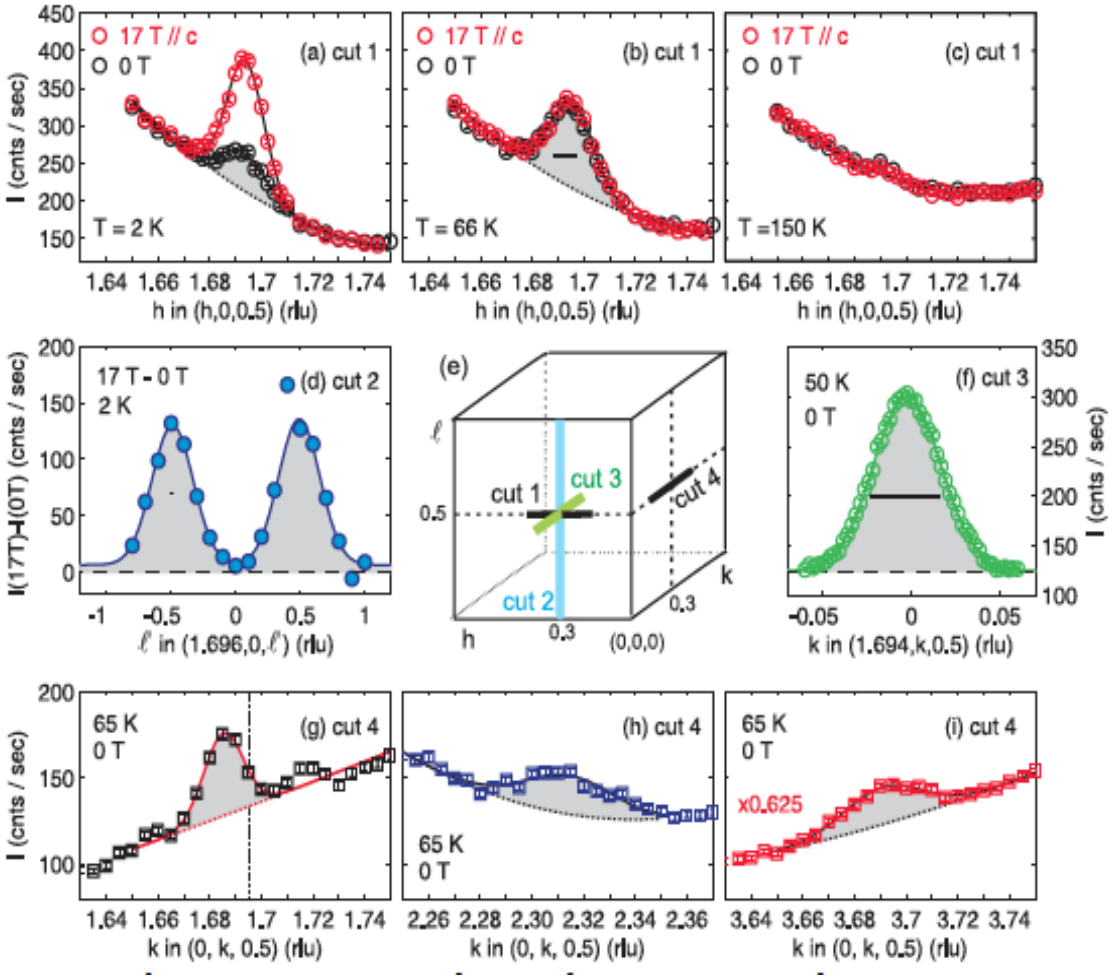
YBCO - Oxygen chain order





Tranquada,
Science **337**, 881 (2012)

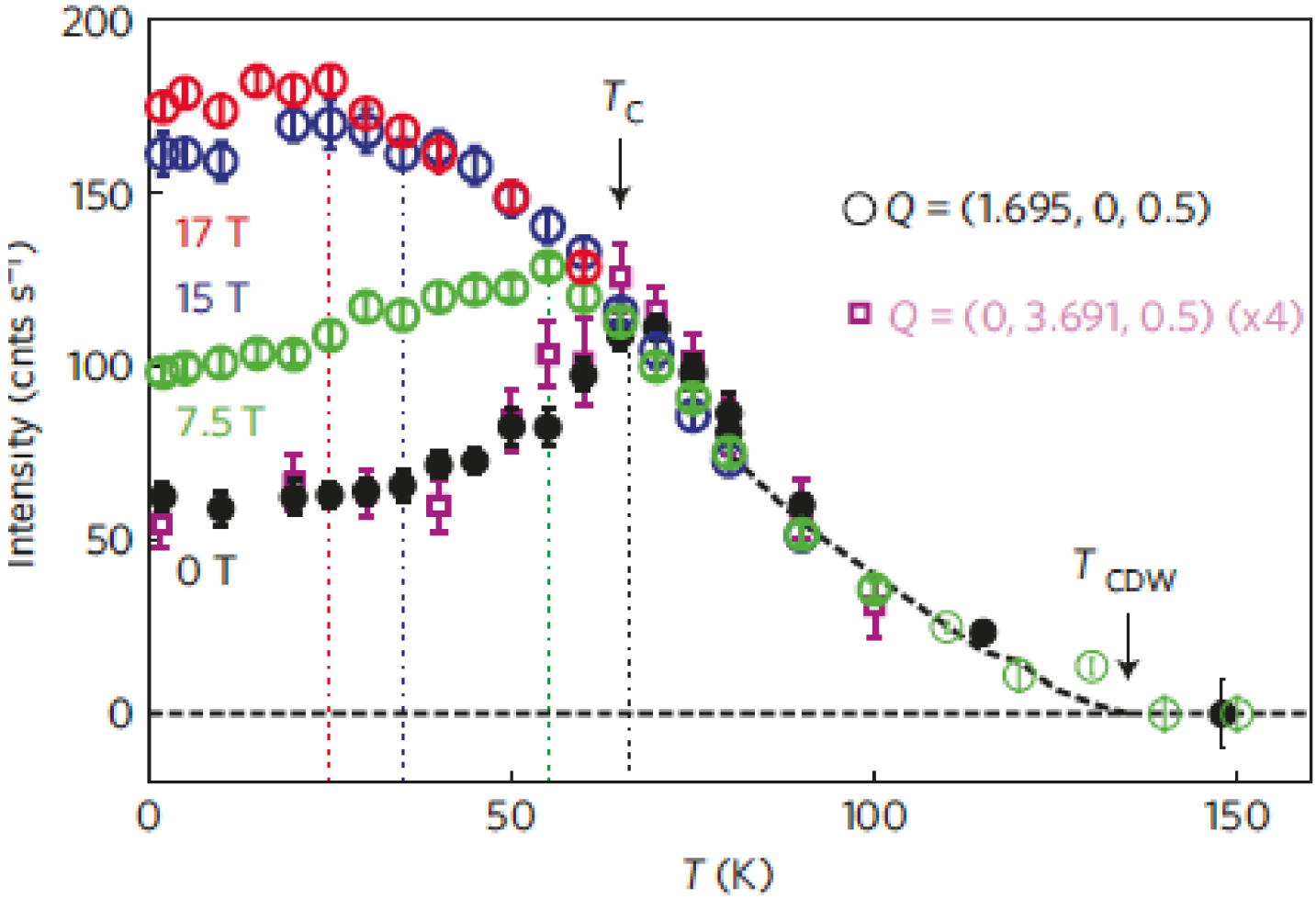
Charge order in YBCO probed by hard XRD



YBCO
ortho-VIII

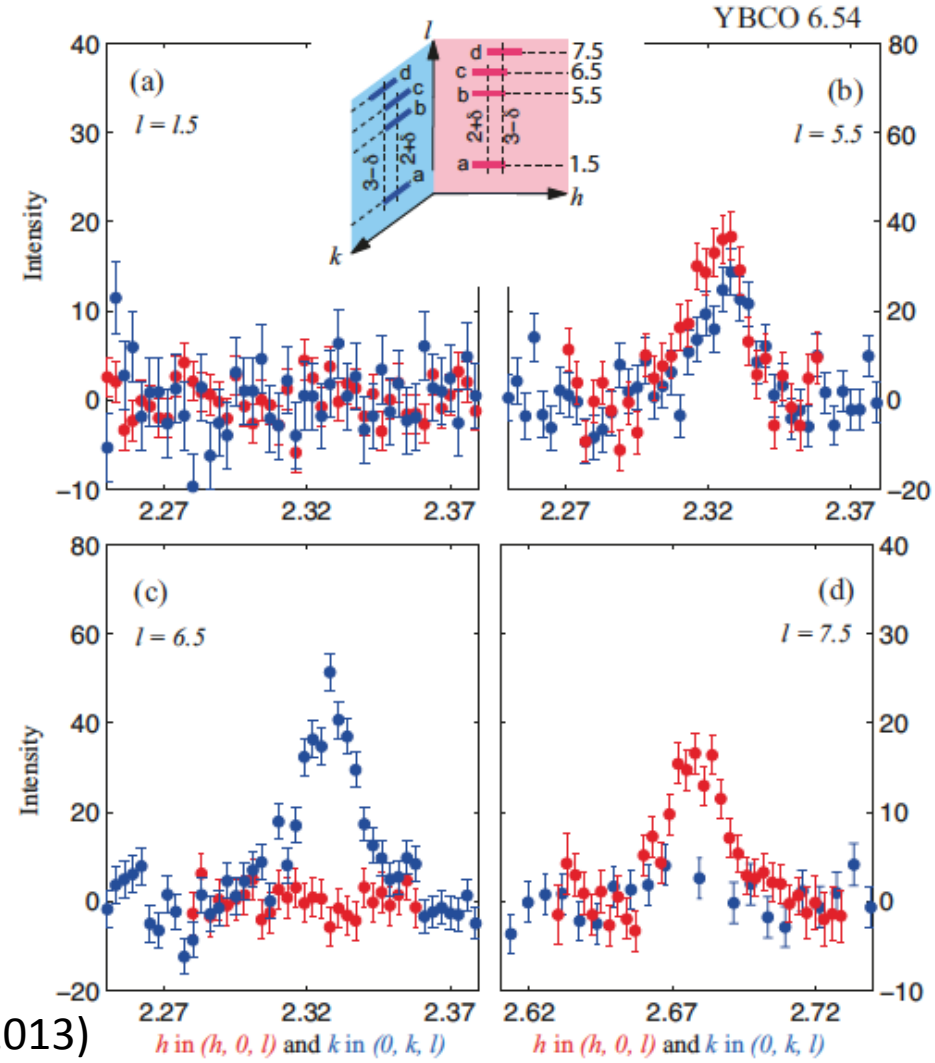
J. Chang *et al.*, *Nature Physics* **8**, 871–876 (2012)

Superconductivity and charge density wave order competing



J. Chang *et al.*, *Nature Physics* **8**, 871–876 (2012)

In-plane anisotropy in YBCO ortho-II:



E. Blackburn
PRL **110**, 137004 (2013)

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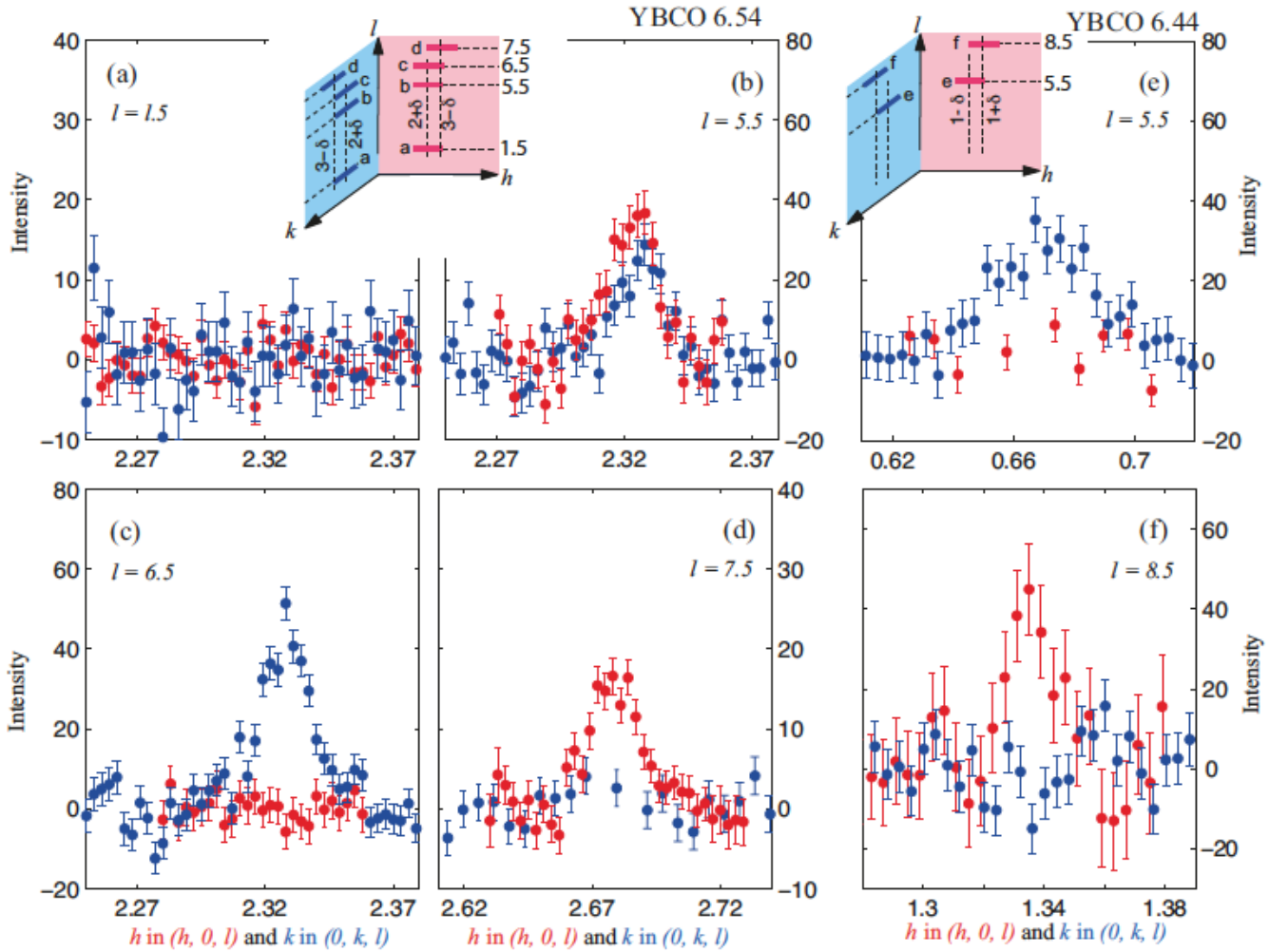

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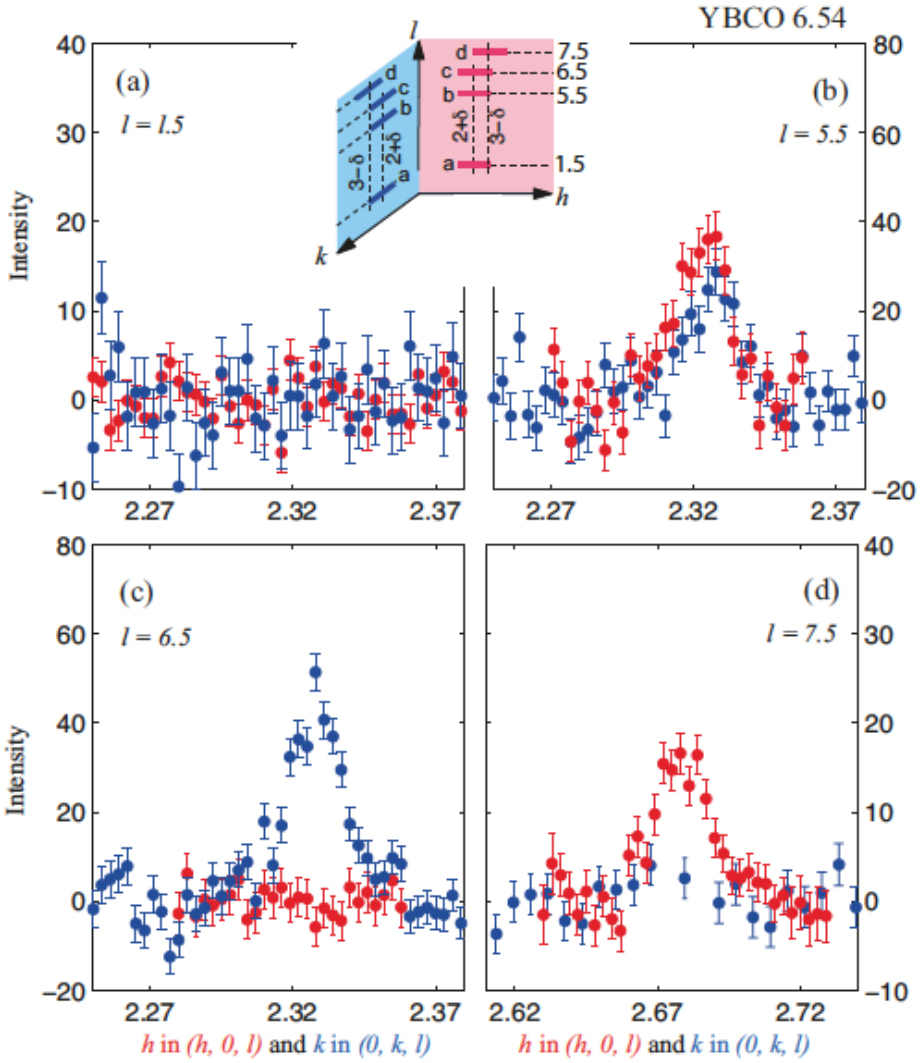

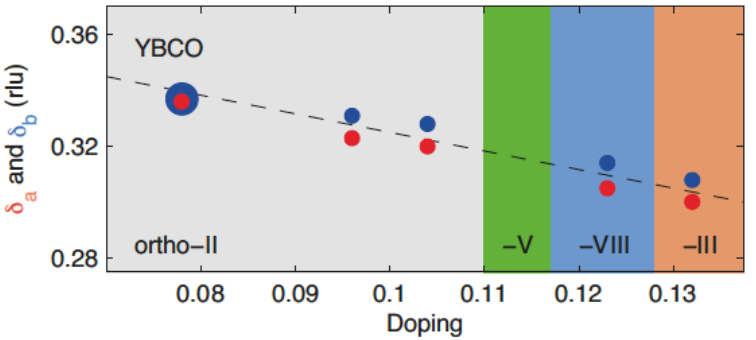

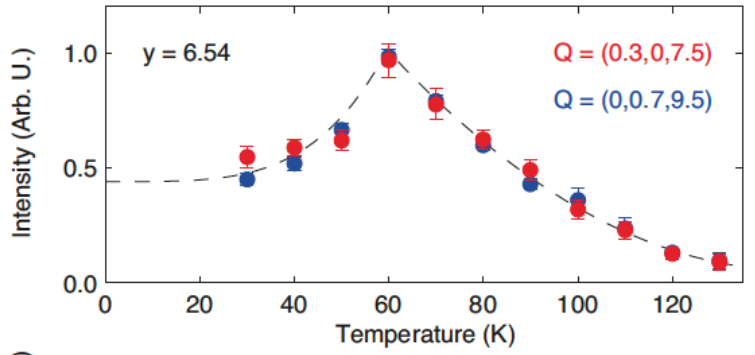

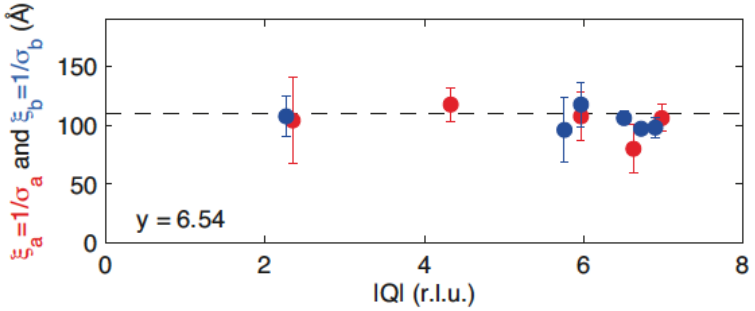

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Hard x-ray diffraction

(1) Discussion of CDW anisotropy.
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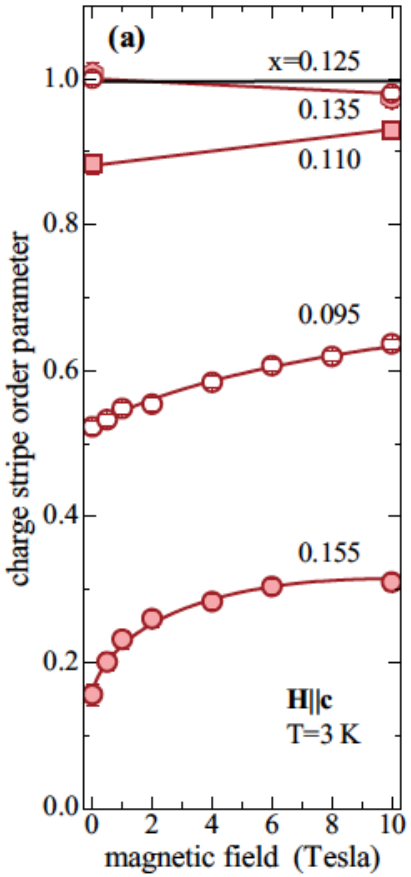
Pseudogap physics and charge order:

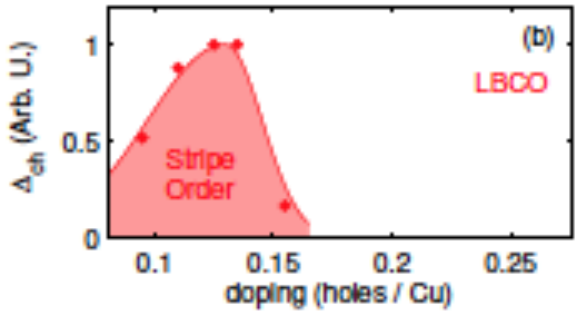
ARPES

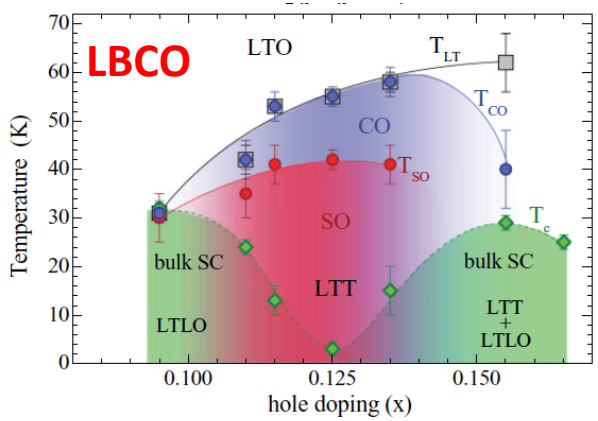
(1) Pseudogaps.
(2) Stripe order having impact on the antinodal lineshape?

Spin and charge order in La-based cuprates

$\Delta \sim I^{0.5}$ (x-ray diffraction)







M. Hücker et al.,
PRB 87, 014501 (2013)

M. Hücker et al.,
PRB 83, 104506 (2011)

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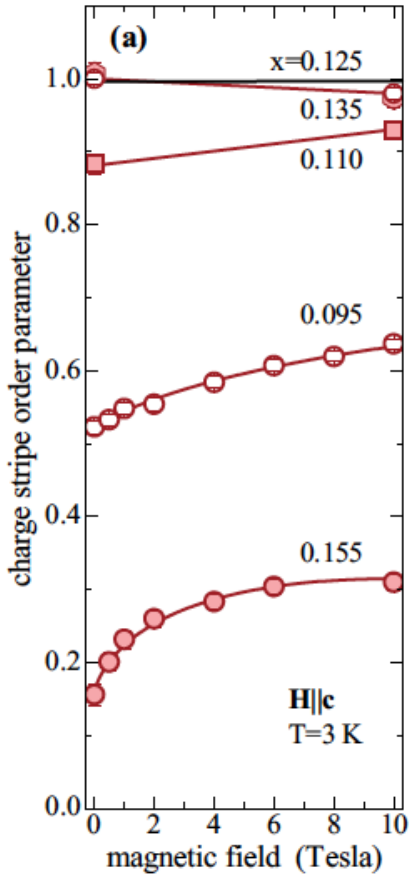
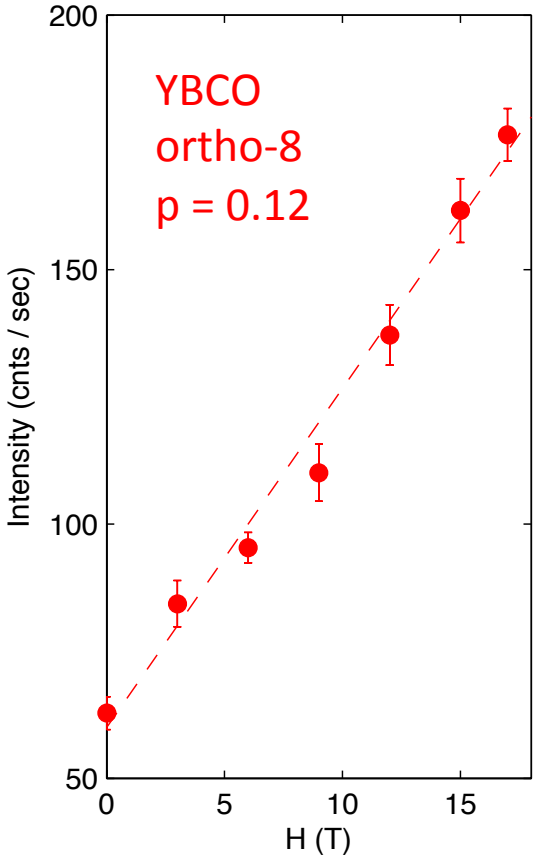
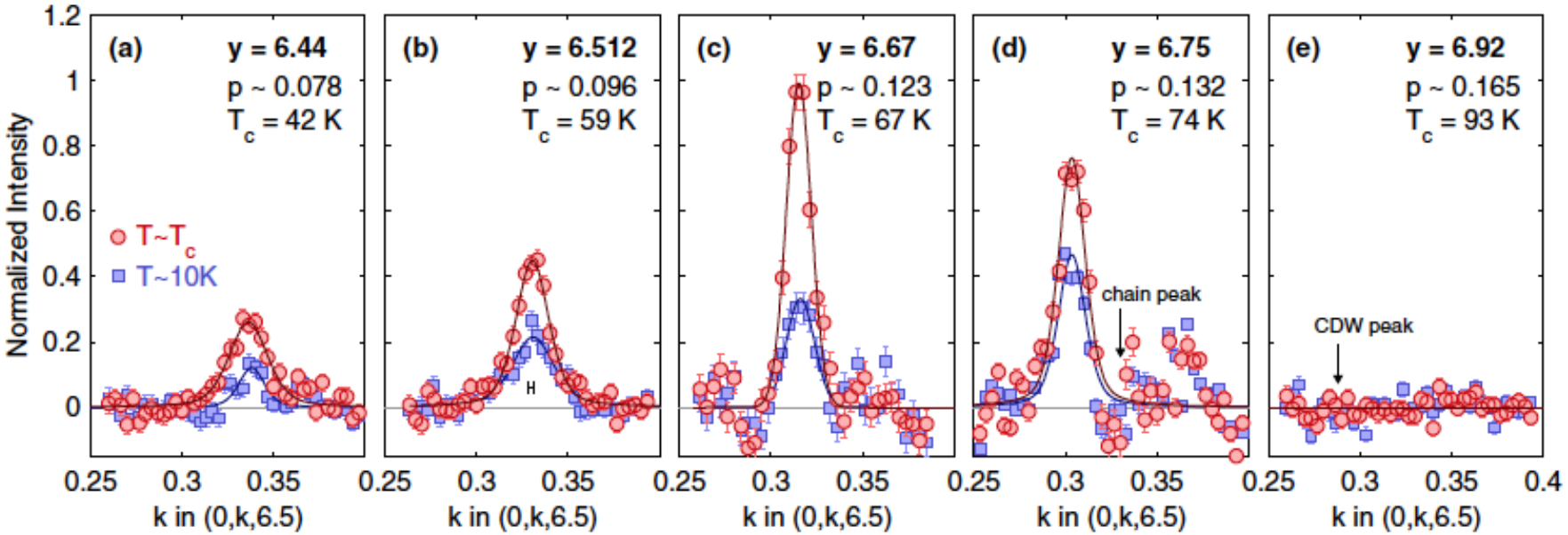




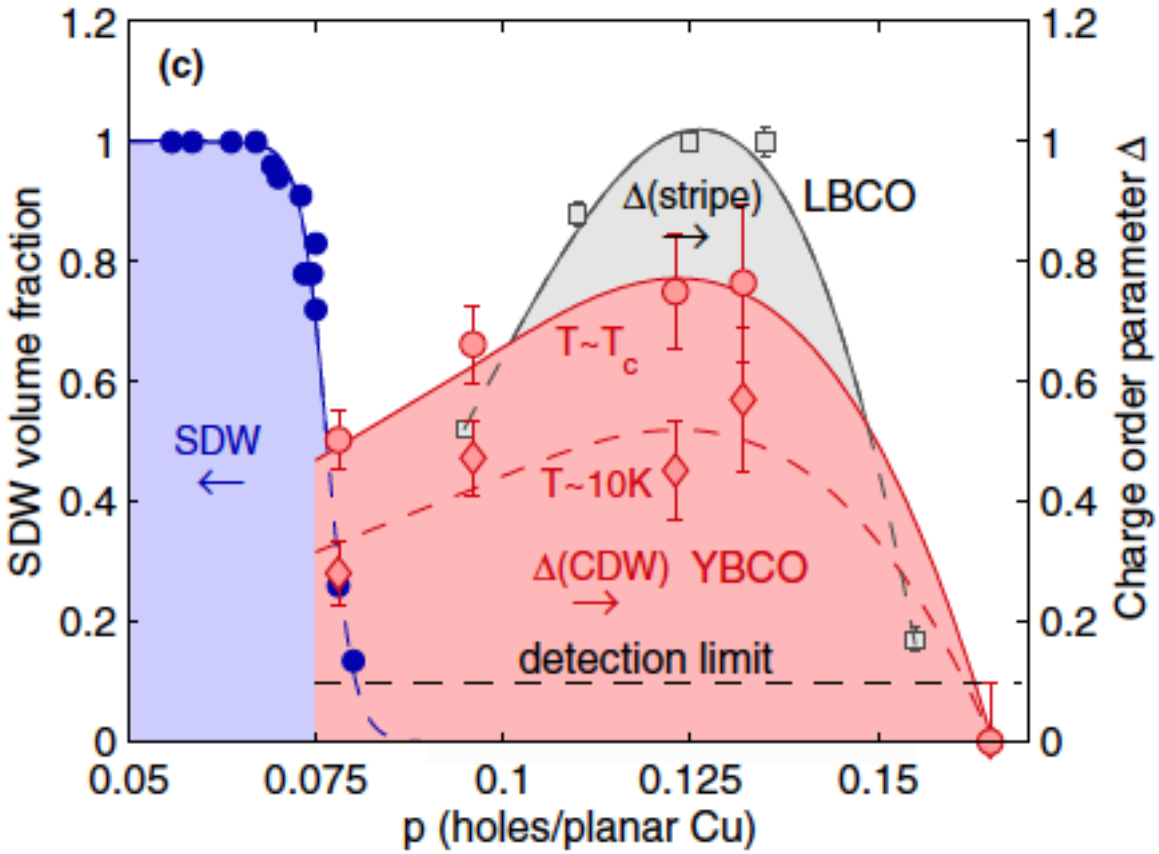
M. Hücker et al.,
PRB 87, 014501 (2013)

CDW along the reciprocal b-axis



Soft x-ray: Phys. Rev. B **90**, 054513 (2014)
Hard x-ray: Phys. Rev. B **90**, 054514 (2014)

Why is the CDW peaked at 12% doping?



S. Sanna *et al.*,
PRL **93**, 207001 (2004)

Phys. Rev. B **90**, 054514 (2014)

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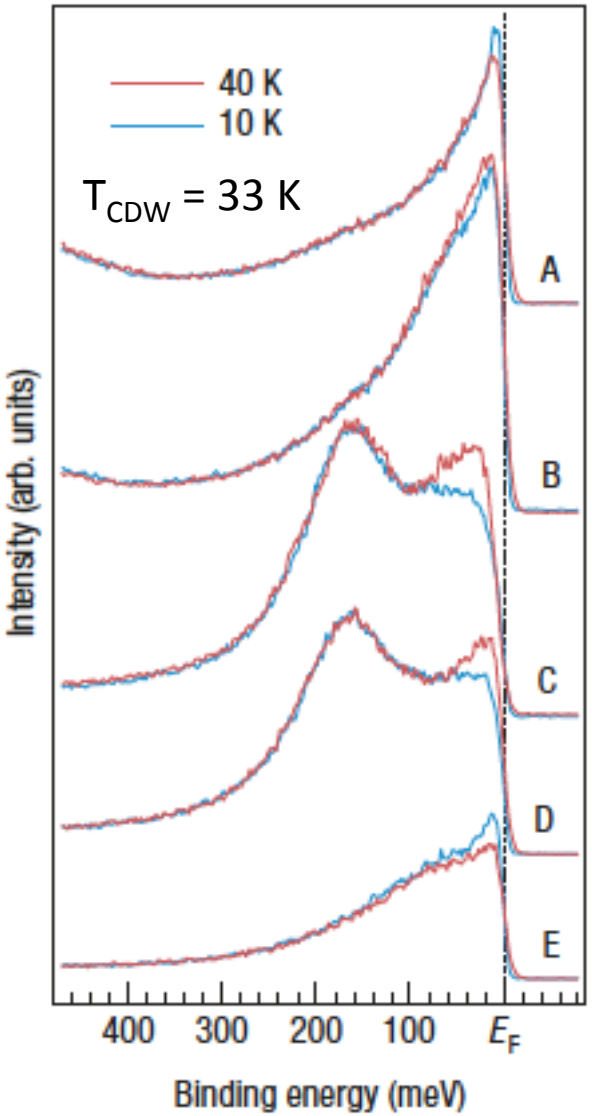
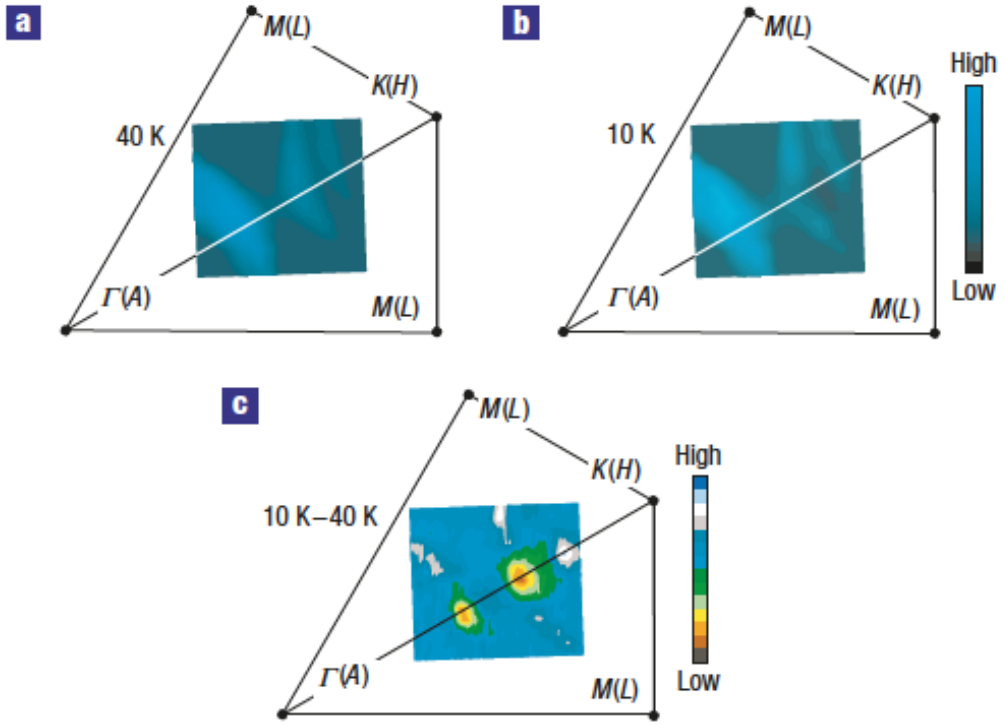
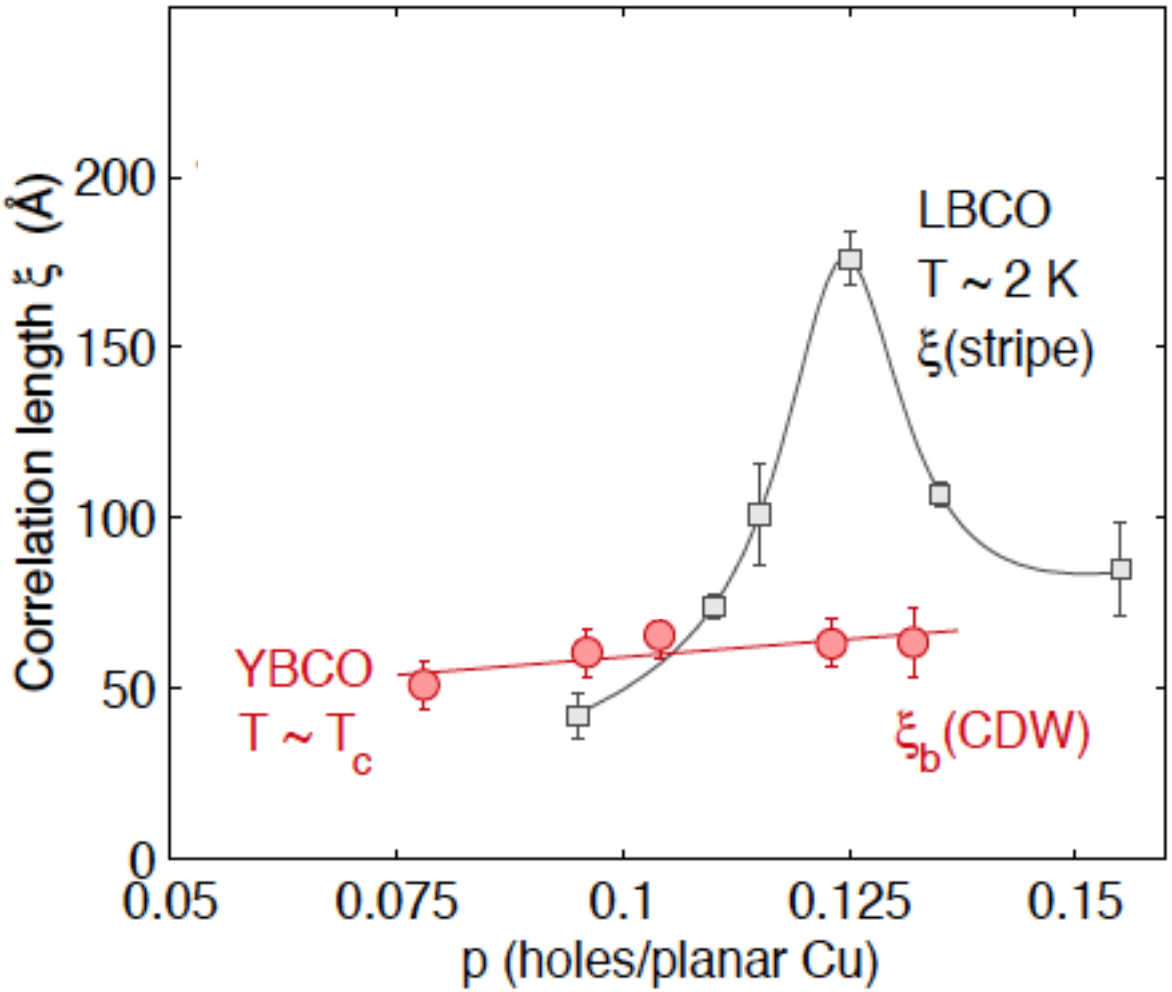
$NbSe_2$ - ARPES





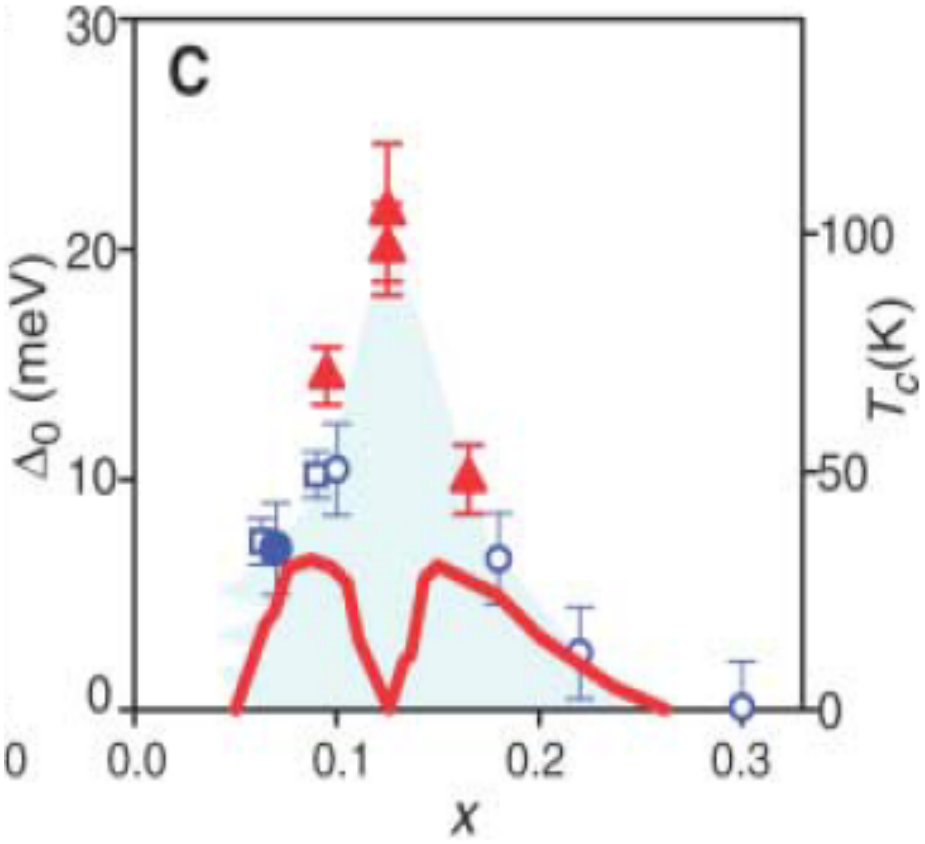
Kiss *et al.*, Nature Physics **3**, 720 (2007)

Long – range stripe order

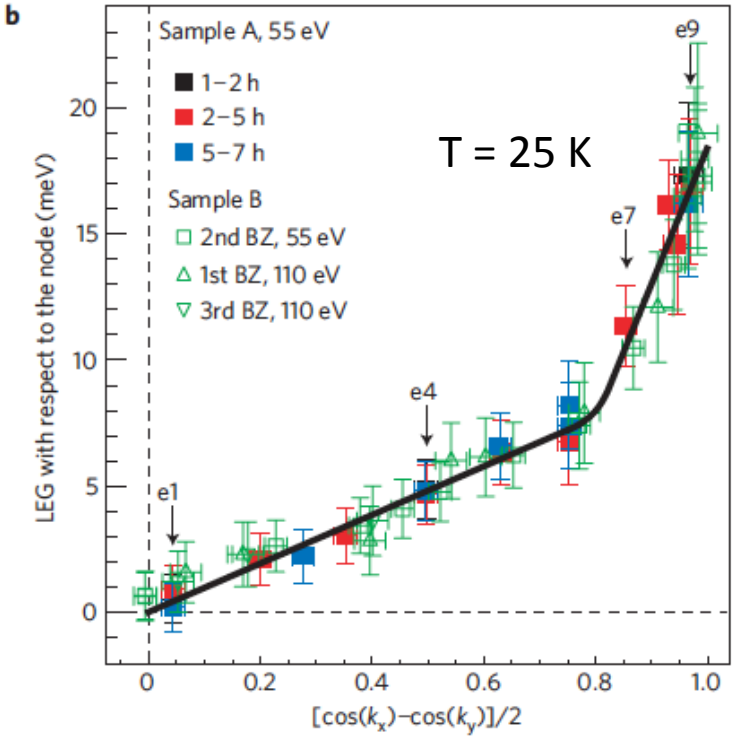


Pseudogap and charge order

LBCO

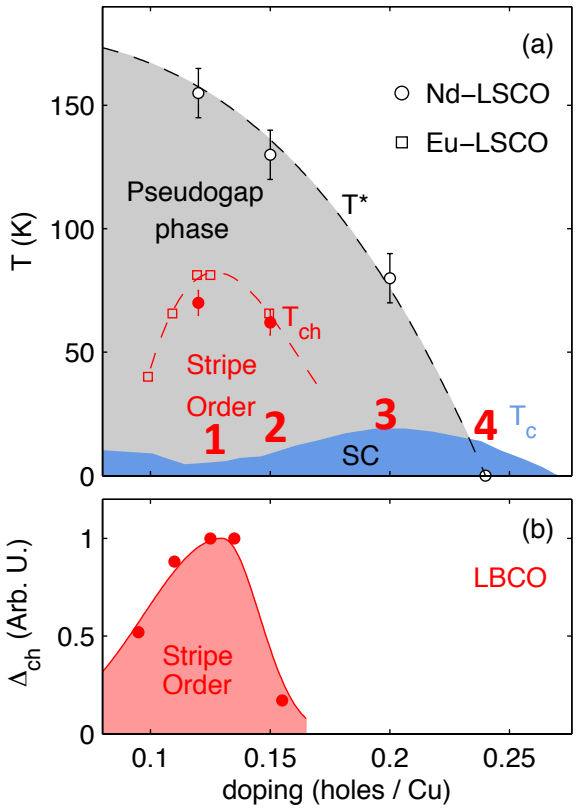


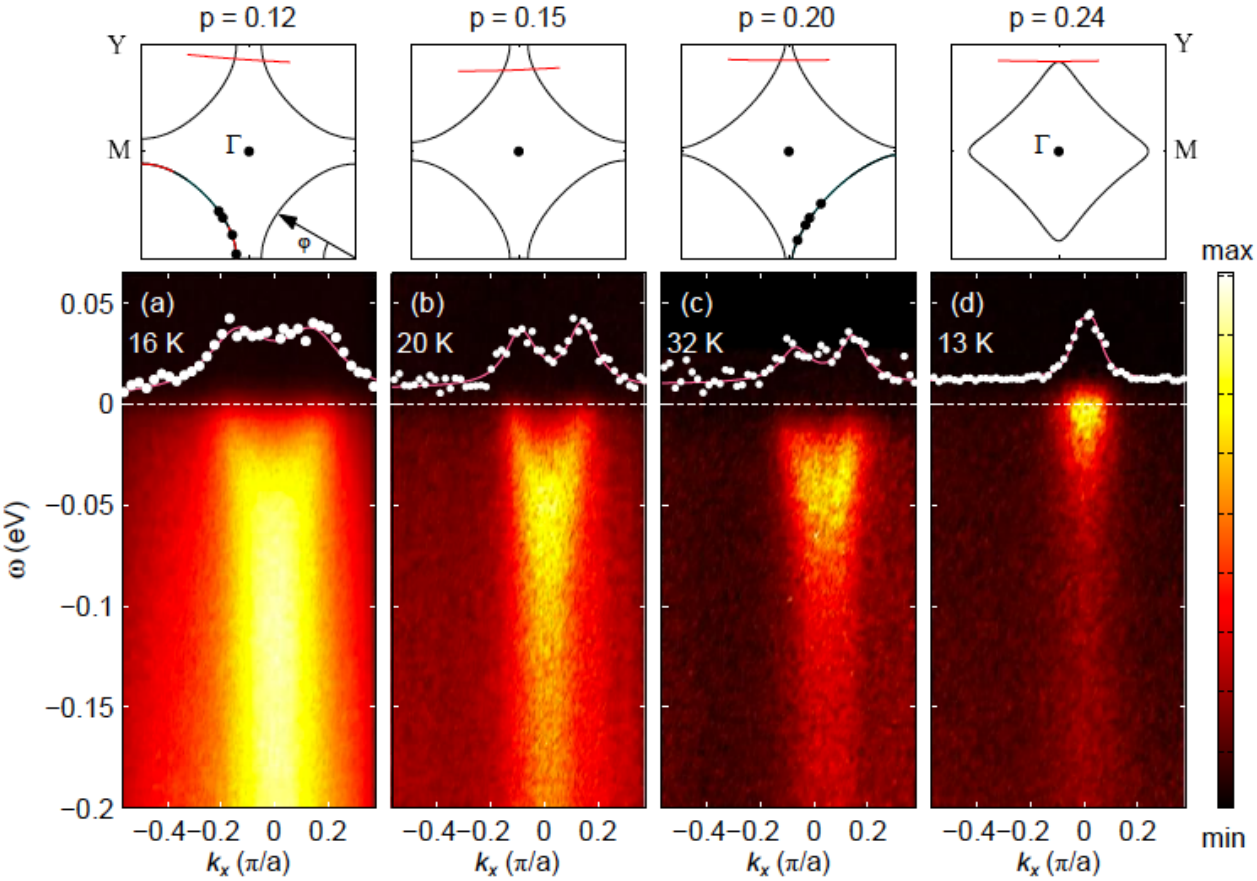
T. Valla *et al.*,
Science **314**, 1914 (2007)



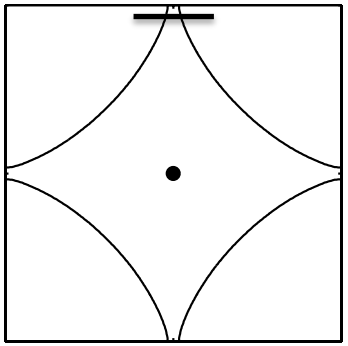
R. –H. He *et al.*,
Nature Physics **5**, 119-123 (2009)

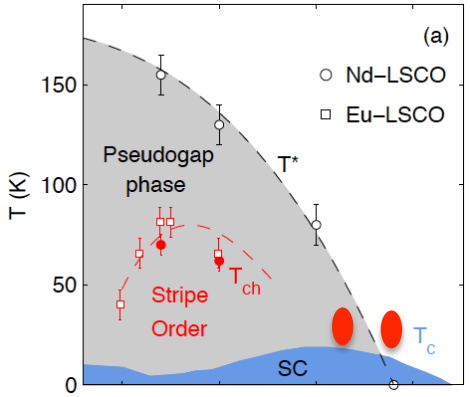
Anti-Nodal Spectra: Nd-LSCO

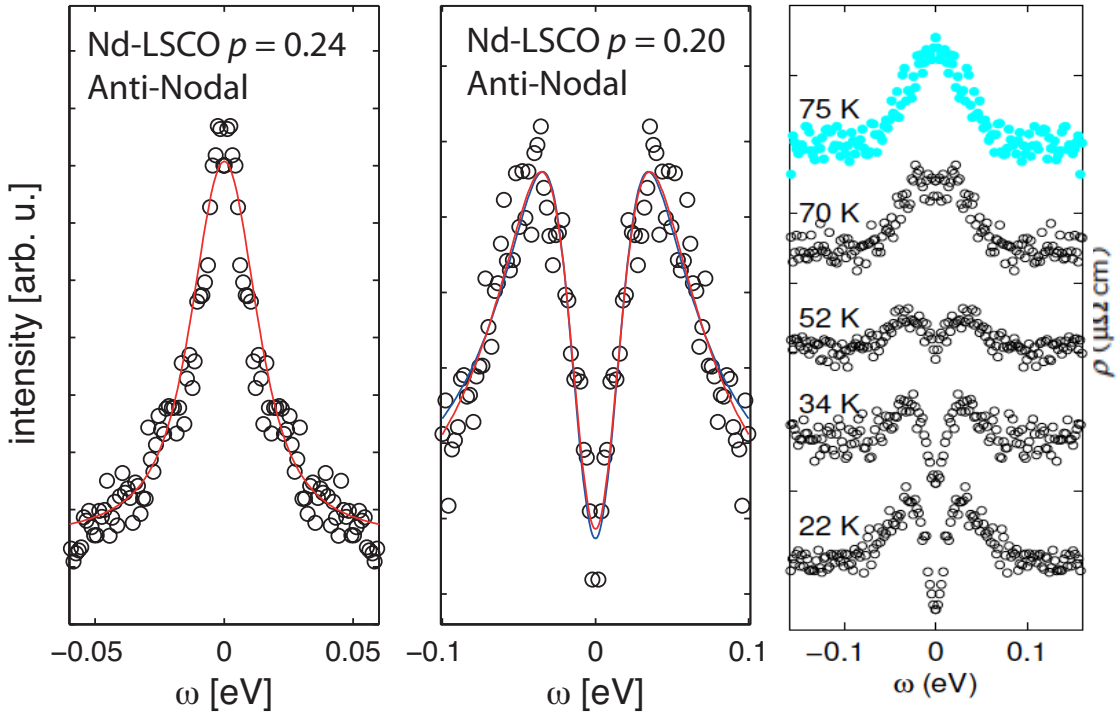


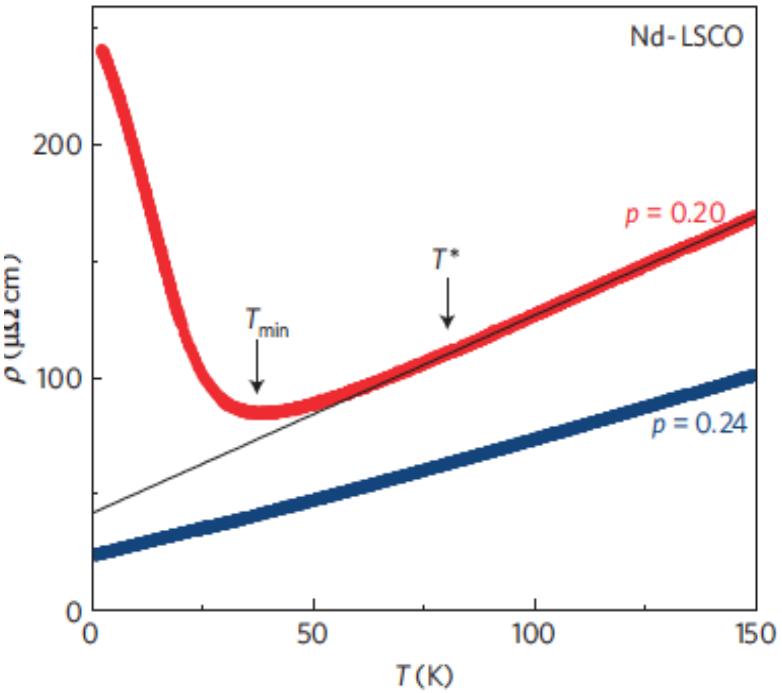


Anti-nodal spectra:







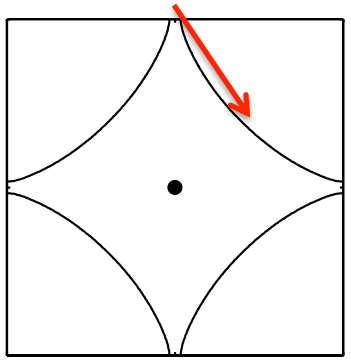


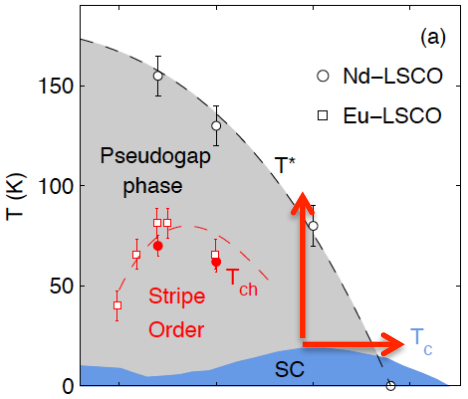
R. Daou et al.,
Nat. Phys. **5**, 31 (2009)

Parametrization:

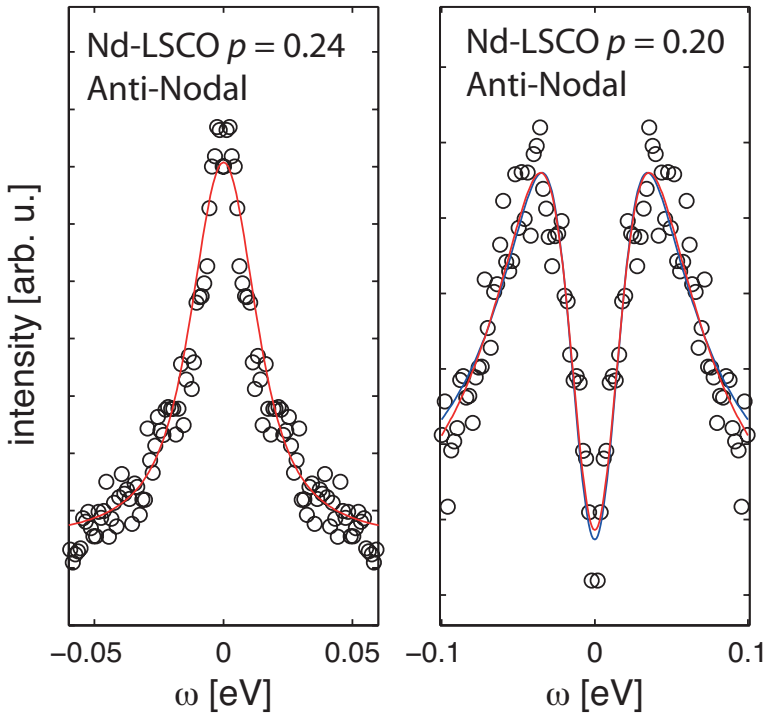
$$A(k_F,\omega) \sim -\mathrm{Im}\Sigma/[(\omega - \mathrm{Re}\Sigma)^2 + \mathrm{Im}\Sigma^2]$$

$$\mathrm{Re}\Sigma = \tilde{\Delta}^2/\omega \qquad \mathrm{Im}\Sigma = \Gamma$$

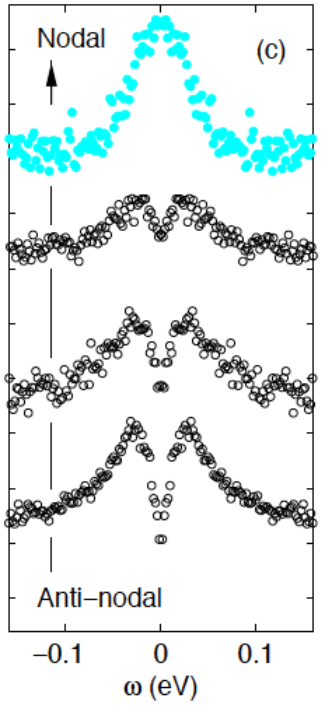




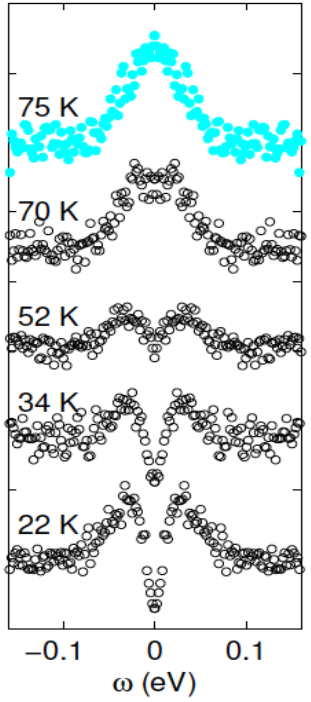
Doping dependence



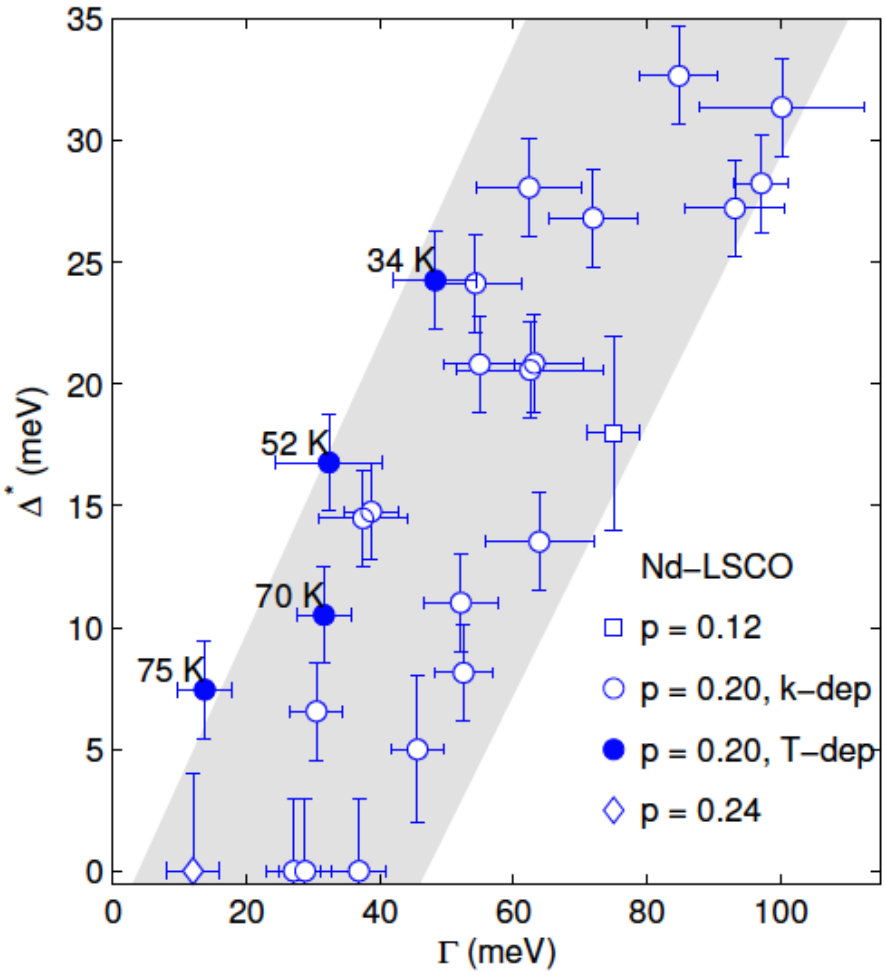
k-dependence



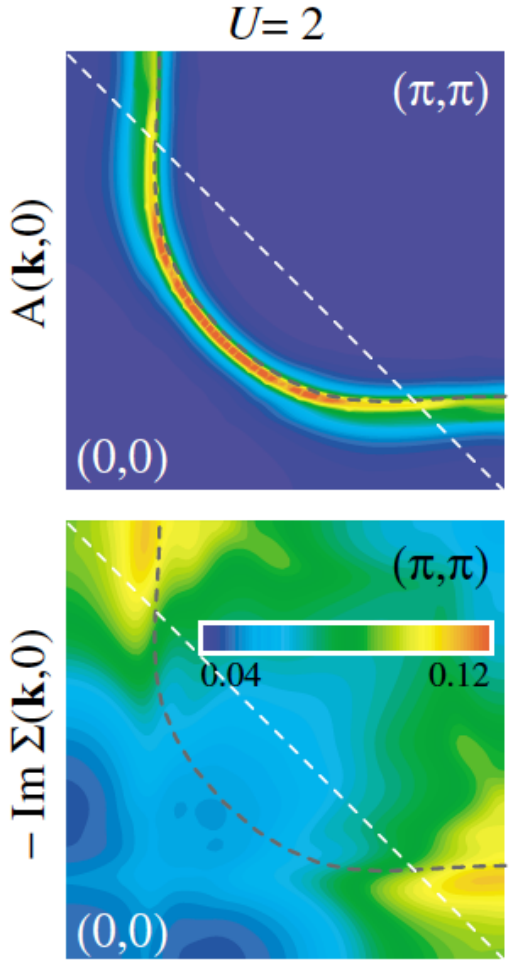
T-dependence



Pseudogap vs electron scattering



C. Matt et al.,
In preparation



D. Sénéchal & A.-M.S. Tremblay
PRL **92**, 126401 (2004)

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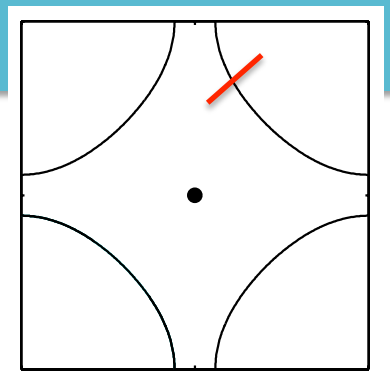
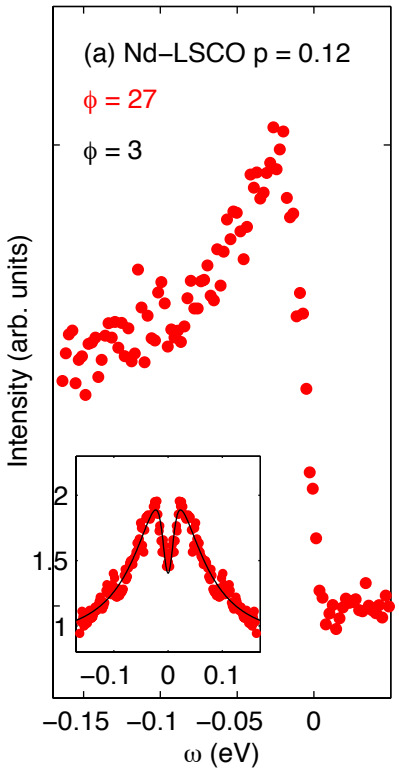
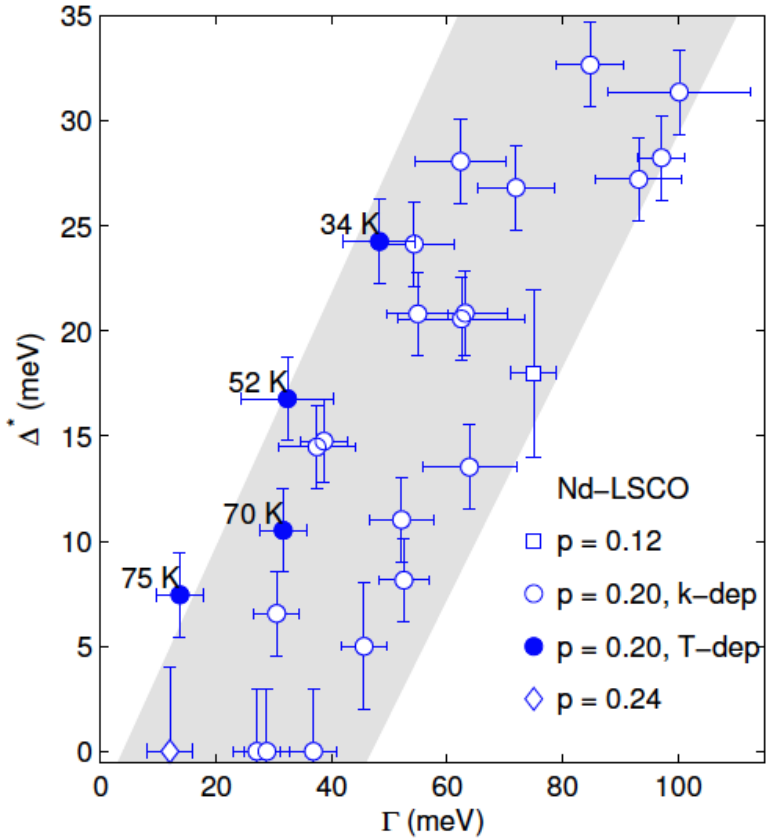
Stripe ordered Compound







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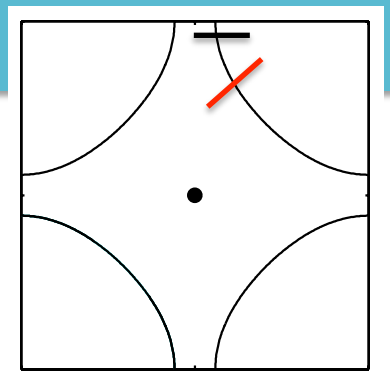
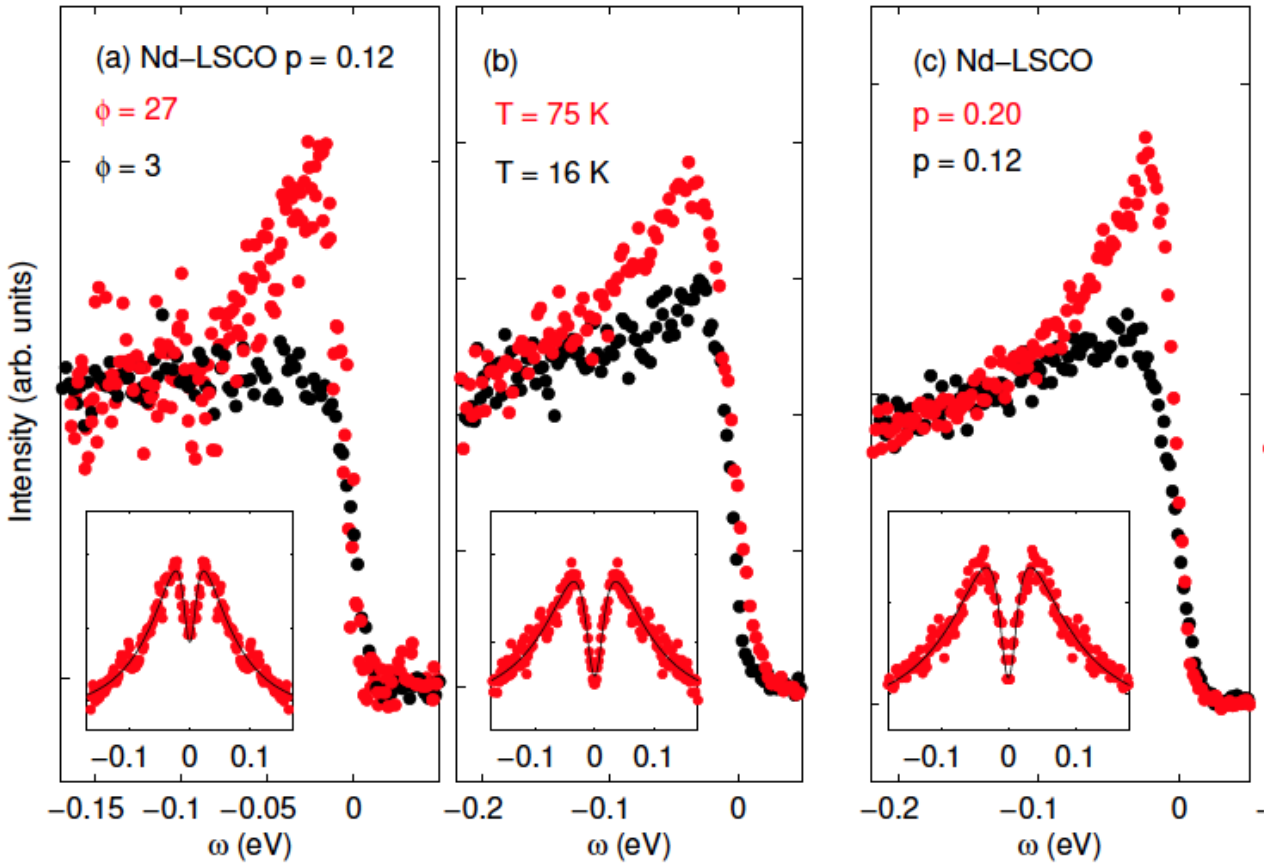
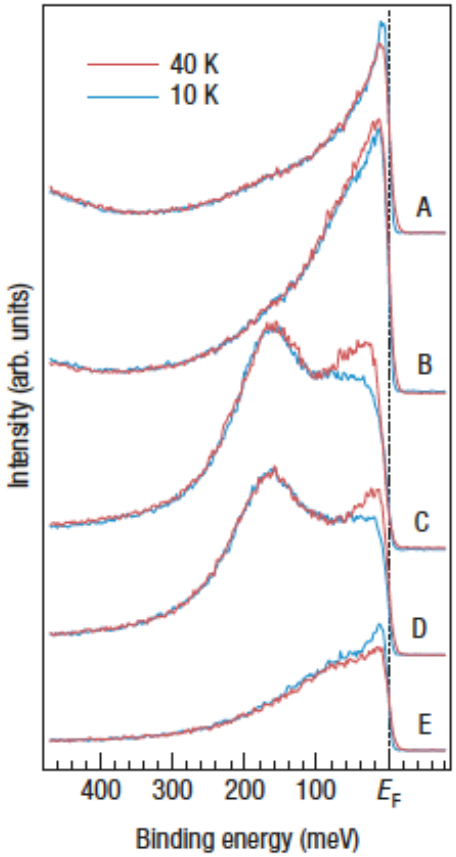


Nd-LSCO



$NbSe_2$



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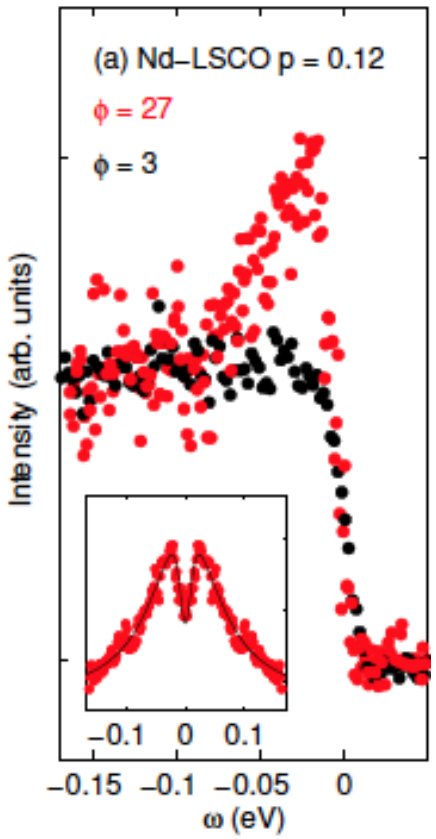

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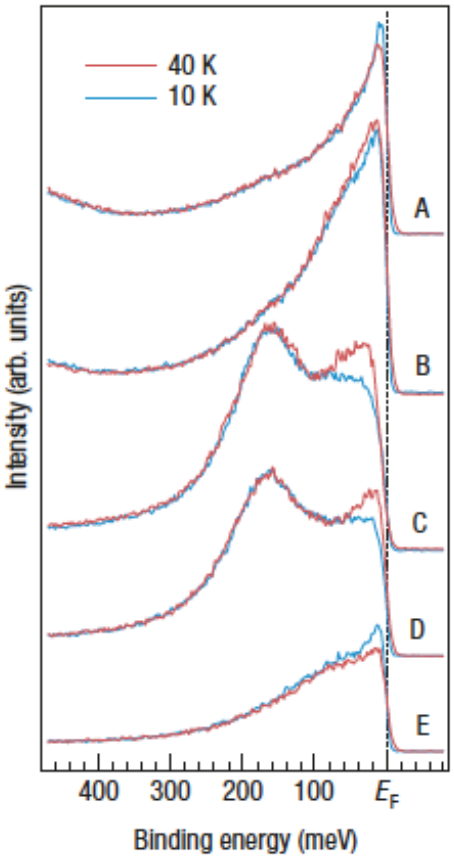
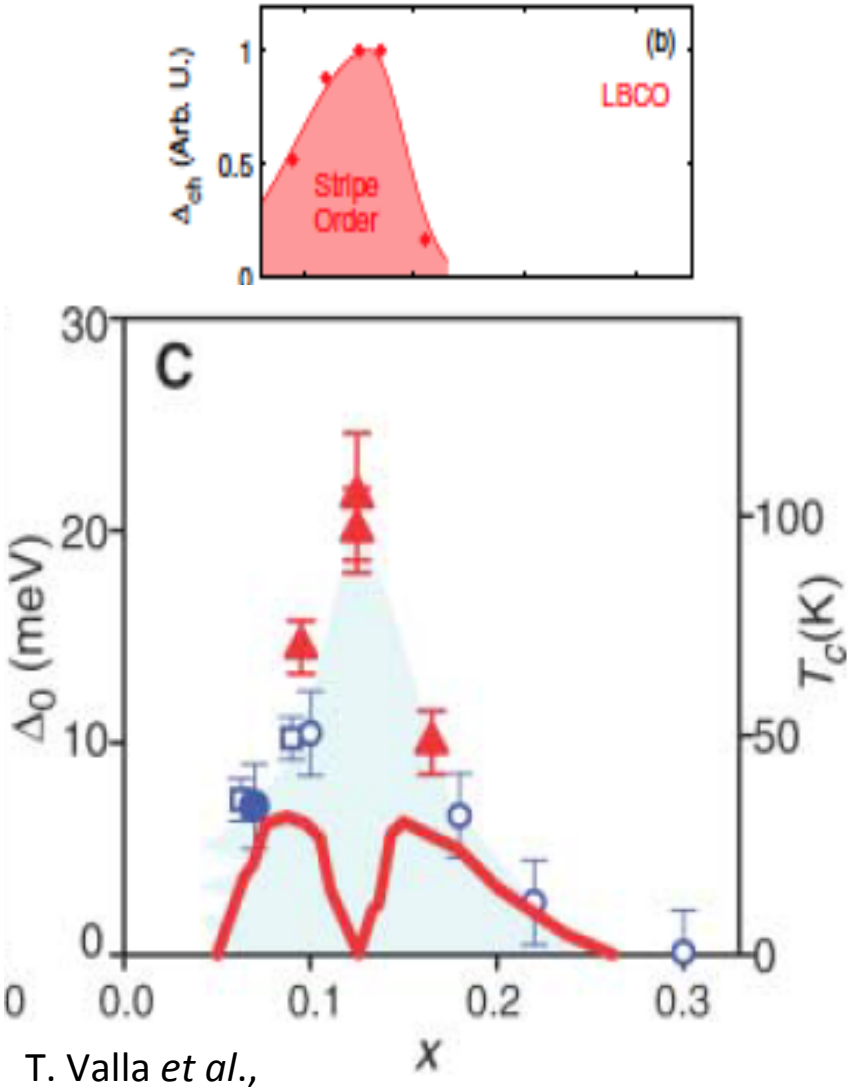
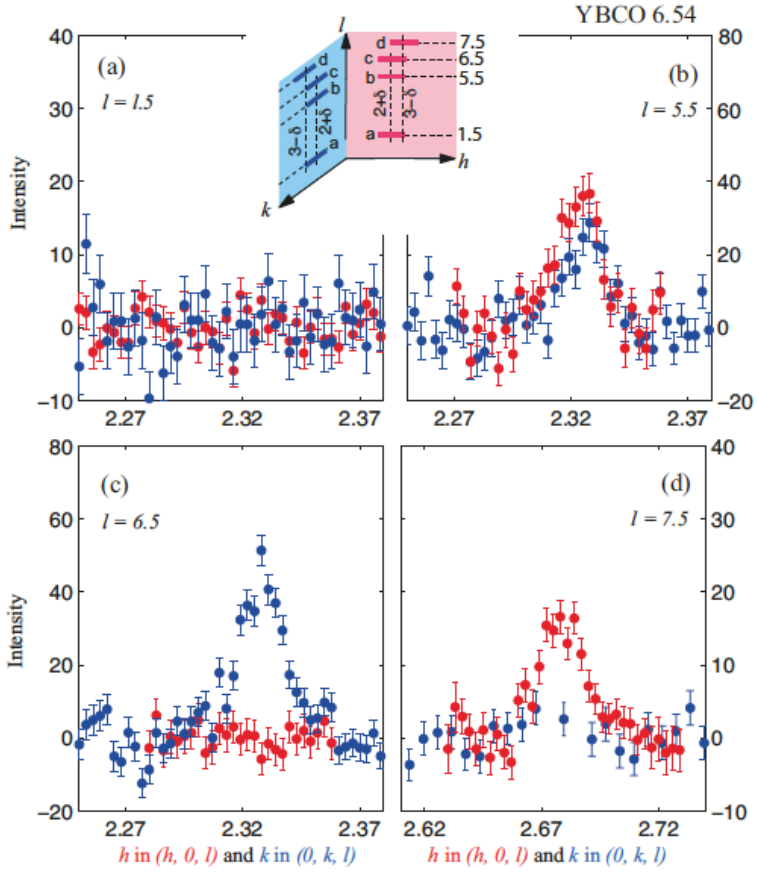


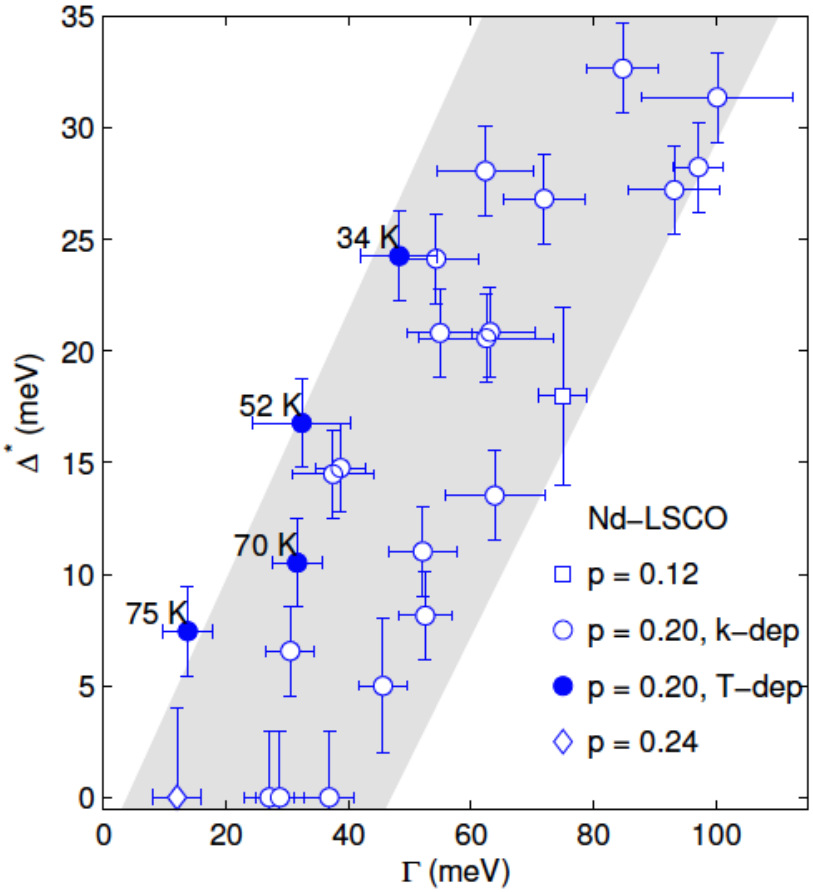
Kiss *et al.*,
Nature Physics **3**, 720 (2007)



T. Valla *et al.*,
Science **314**, 1914 (2007)

THANKS


YBCO 6.54
(a)
l = 1.5
(b)
l = 5.5
(c)
l = 6.5
(d)
l = 7.5
Intensity
h in (h, 0, l) and k in (0, k, l)


Δ* (meV)
Γ (meV)
34 K
52 K
70 K
75 K
Nd–LSCO
p = 0.12
p = 0.20, k–dep
p = 0.20, T–dep
p = 0.24