Study of the planar anisotropy of spin excitations In superconducting $YBa_2Cu_3O_{6+x}$

Y. Sidis

GDR-MICO *Autrans 2008*

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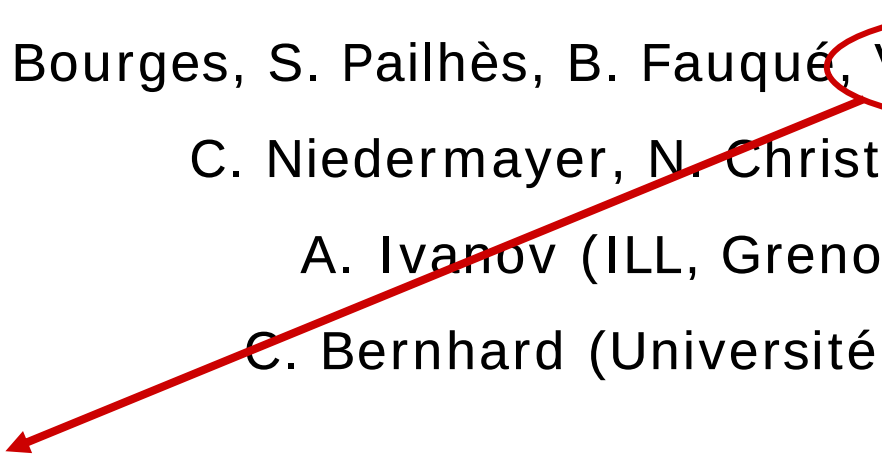
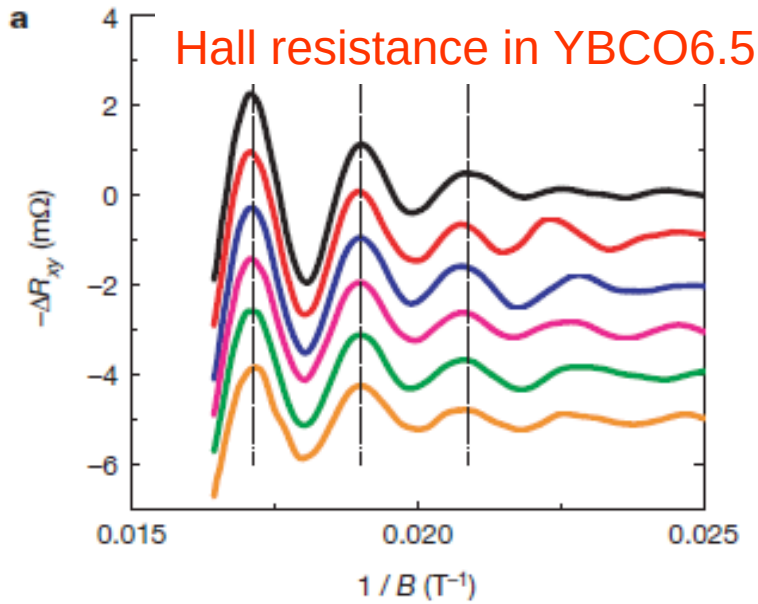


Poster P22

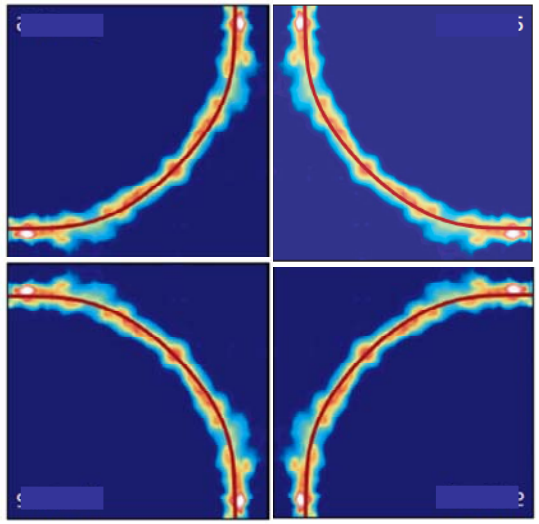
Outline

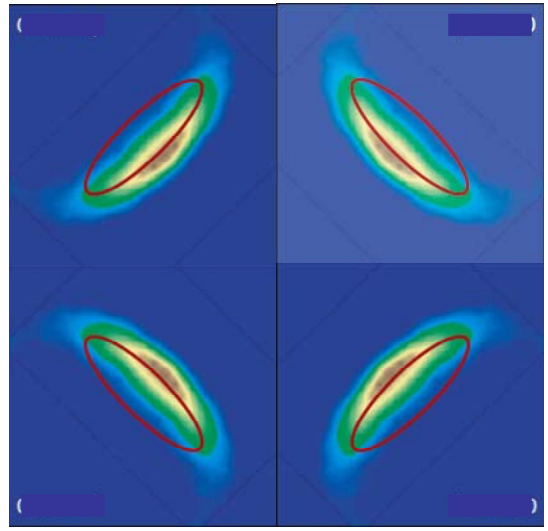
- Motivation: Quantum oscillations and FS reconstruction
- Low-energy excitations and the spontaneous onset of incommensurability
- Incommensurate, quasi-elastic spin correlations
- Effects of the application of a magnetic field
- Effects of non magnetic impurities
- Conclusions

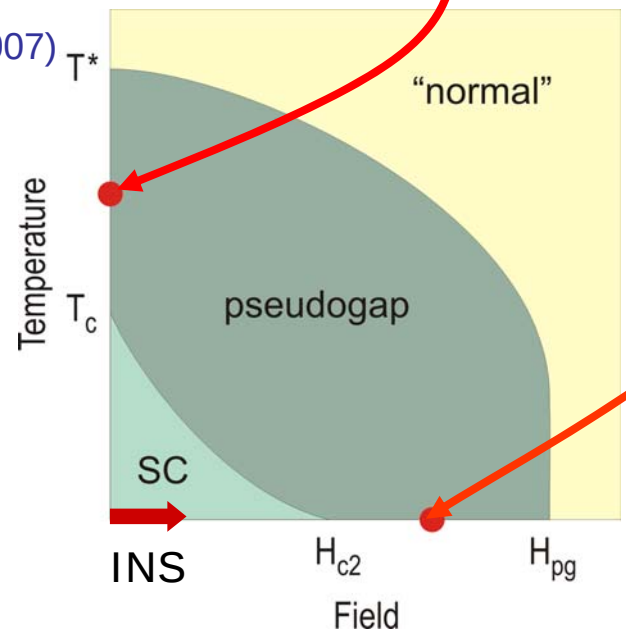
Motivation: Quantum oscillations



Doiron-Leyraud *et al.*, *Nature* 447, 565 (2007)

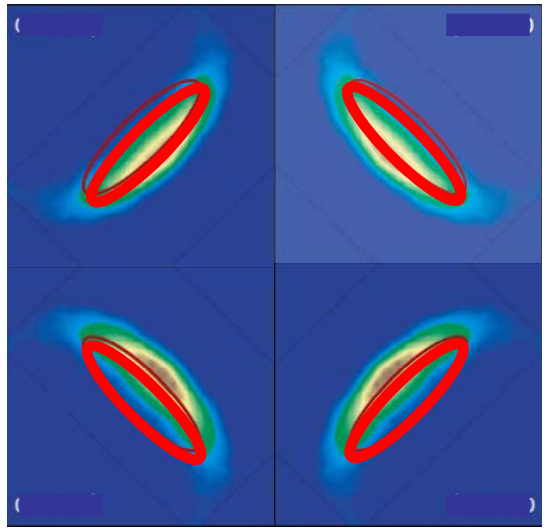






Motivation: Fermi-surface reconstruction

Fermi pockets?

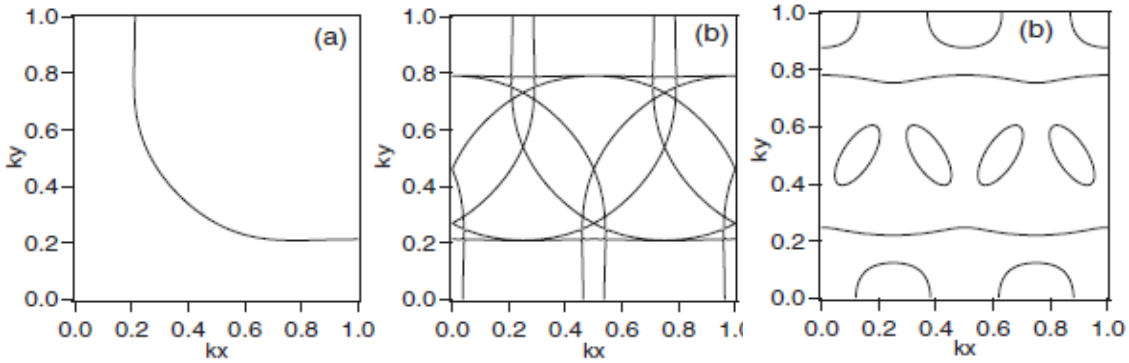


BUT: from the Hall resistivity the pockets should contain electrons, not holes!

IDEA: Fermi surface reconstruction

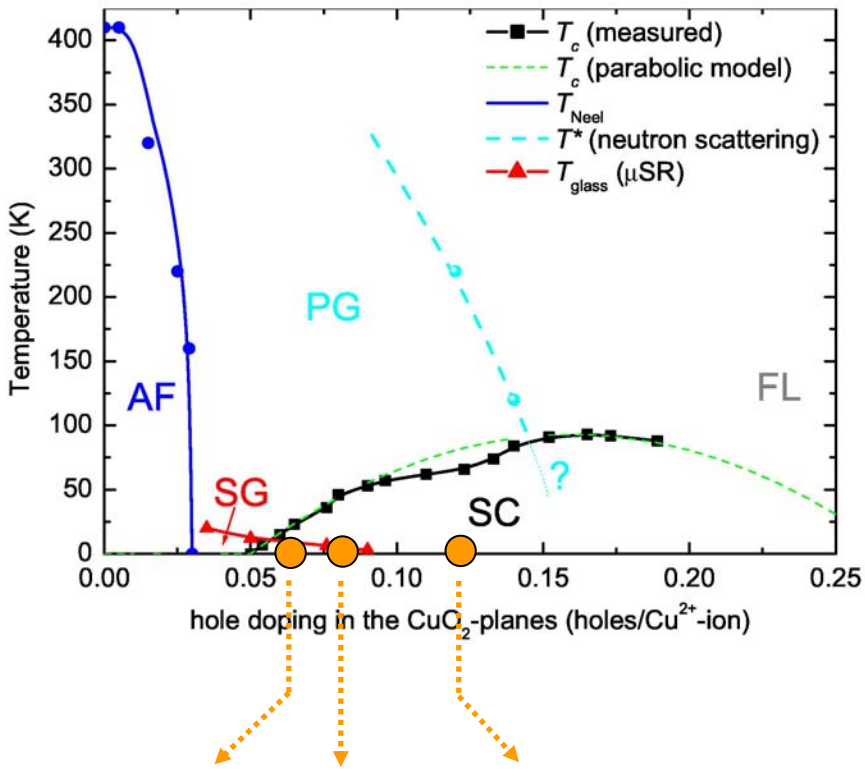
E.G.: due to commensurate antiferromagnetic order, d-density waves, commensurate or incommensurate spin modulations

Commensurate
1/8 stripe order



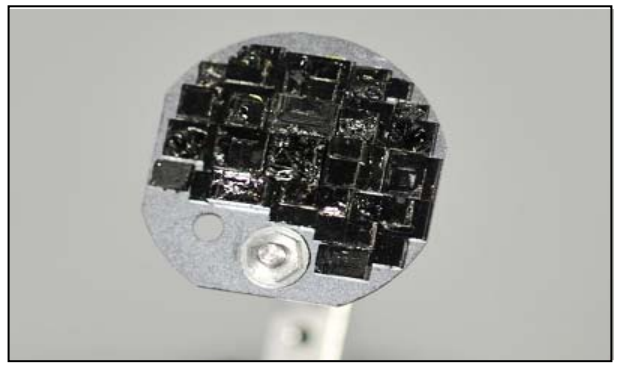
Millis and Norman, PRB 76, 220503(R), 2007.

Samples and phase diagram



p_h

Doping of the investigated $YBa_2Cu_3O_{6+x}$ samples

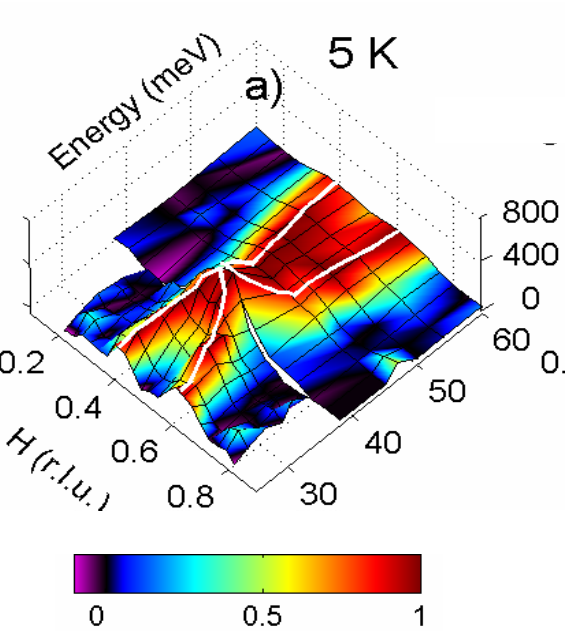


T_c = 10 K
p_h = 0.07?

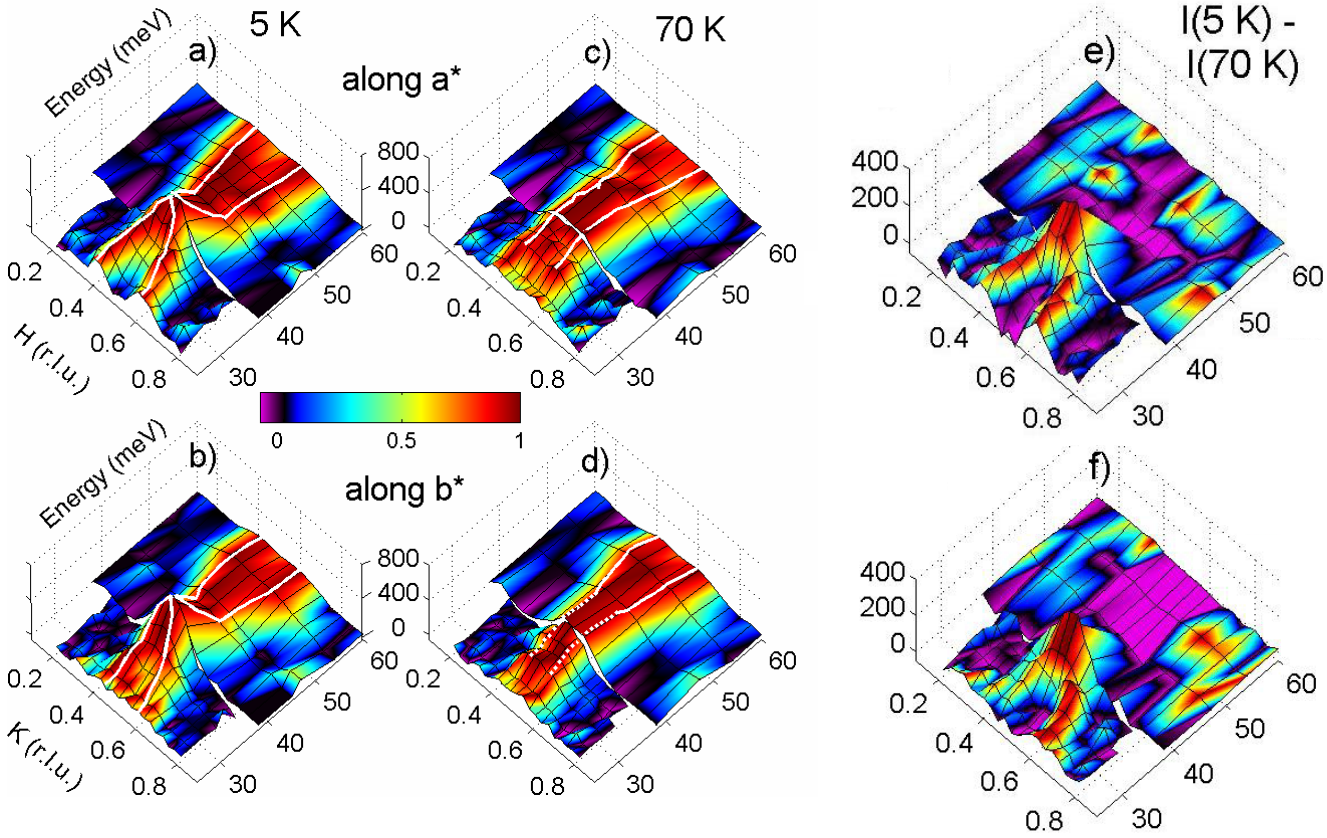
T_c = 35 K
p_h = 0.085

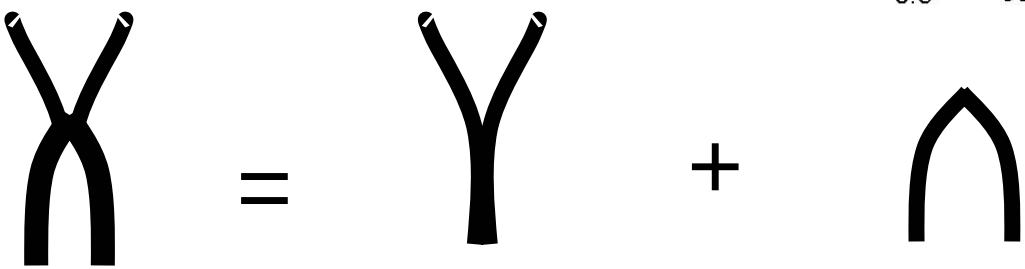
T_c = 61 K
p_h = 0.12

$YBa_2Cu_3O_{6.6}$ – T_c = 61 K



$YBa_2Cu_3O_{6.6}$ – T_c = 61 K





Competing state?

Resonance mode develops below T_c?

Hinkov et al.,

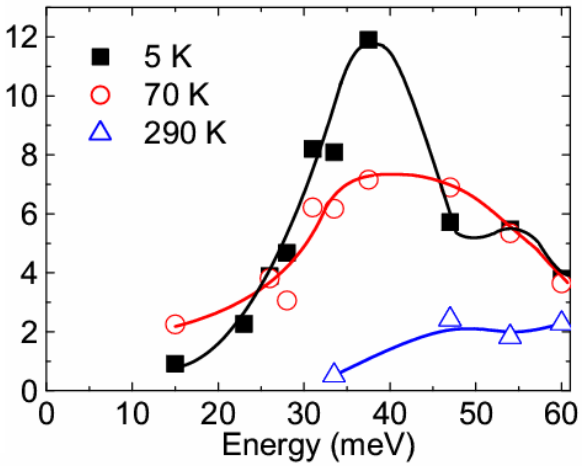
Nature Physics **3**, 780

Spectrum above T_c qualitatively different:

- No hour-glass dispersion
- No resonance anomaly
- „Y“-shaped dispersion

$YBa_2Cu_3O_{6.45}$ – T_c = 35 K

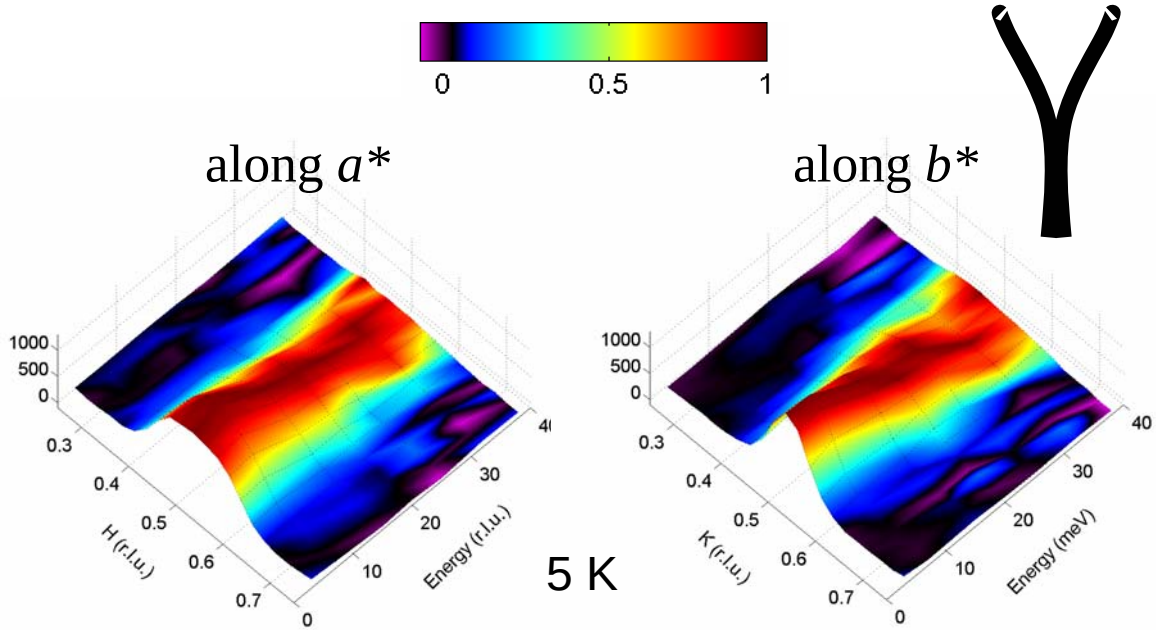
$YBa_2Cu_3O_{6.6}$



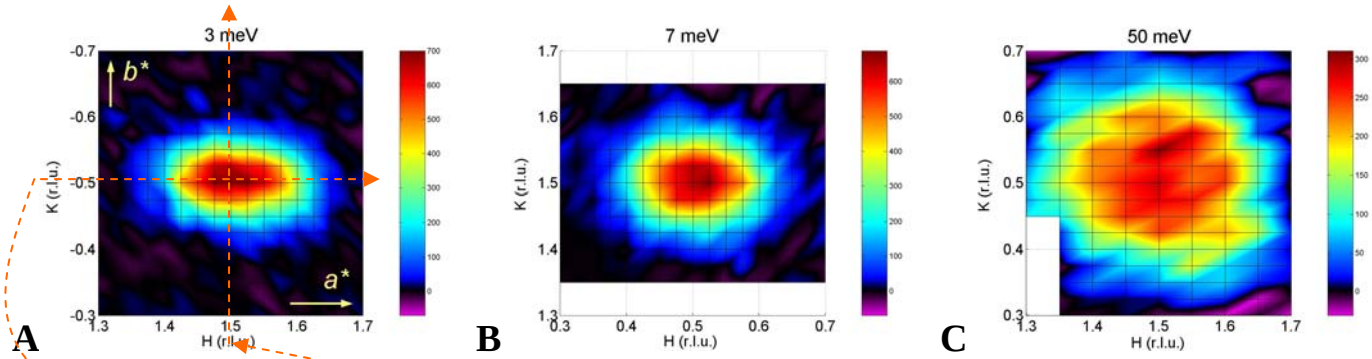
$YBa_2Cu_3O_{6.45}$

$YBa_2Cu_3O_{6.45}$

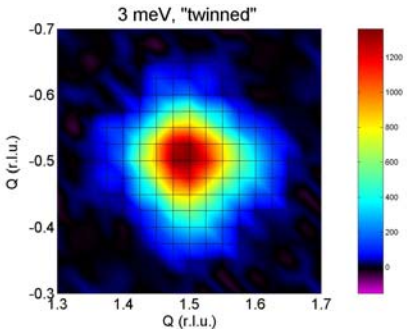
- Hardly any hour-glass dispersion
- Very weak resonance anomaly at best
- „Y“-shaped dispersion even below T_c – pure symmetry-broken phase showing up when superconductivity is weakened?

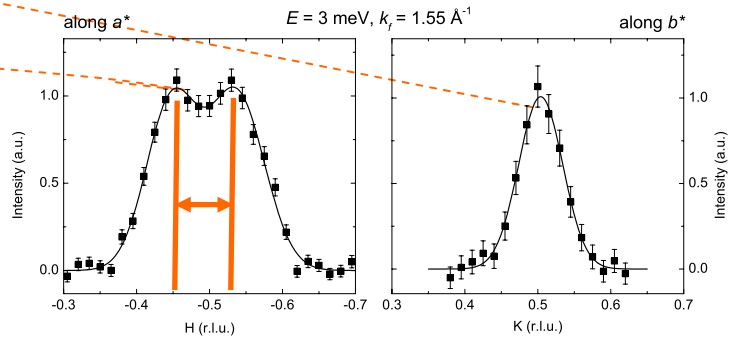


Spontaneous onset of incommensurability

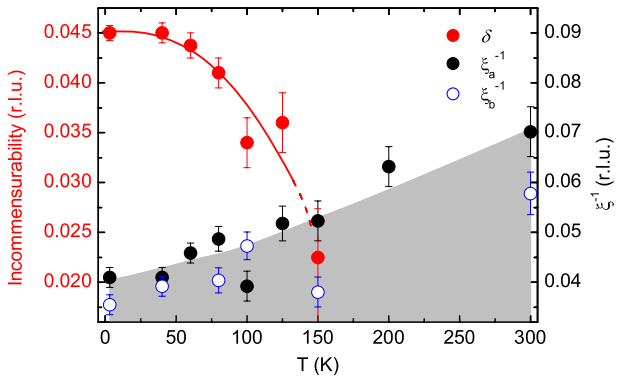


Hinkov et al., *Science* **319**, 597 (2008).





Incommensurability



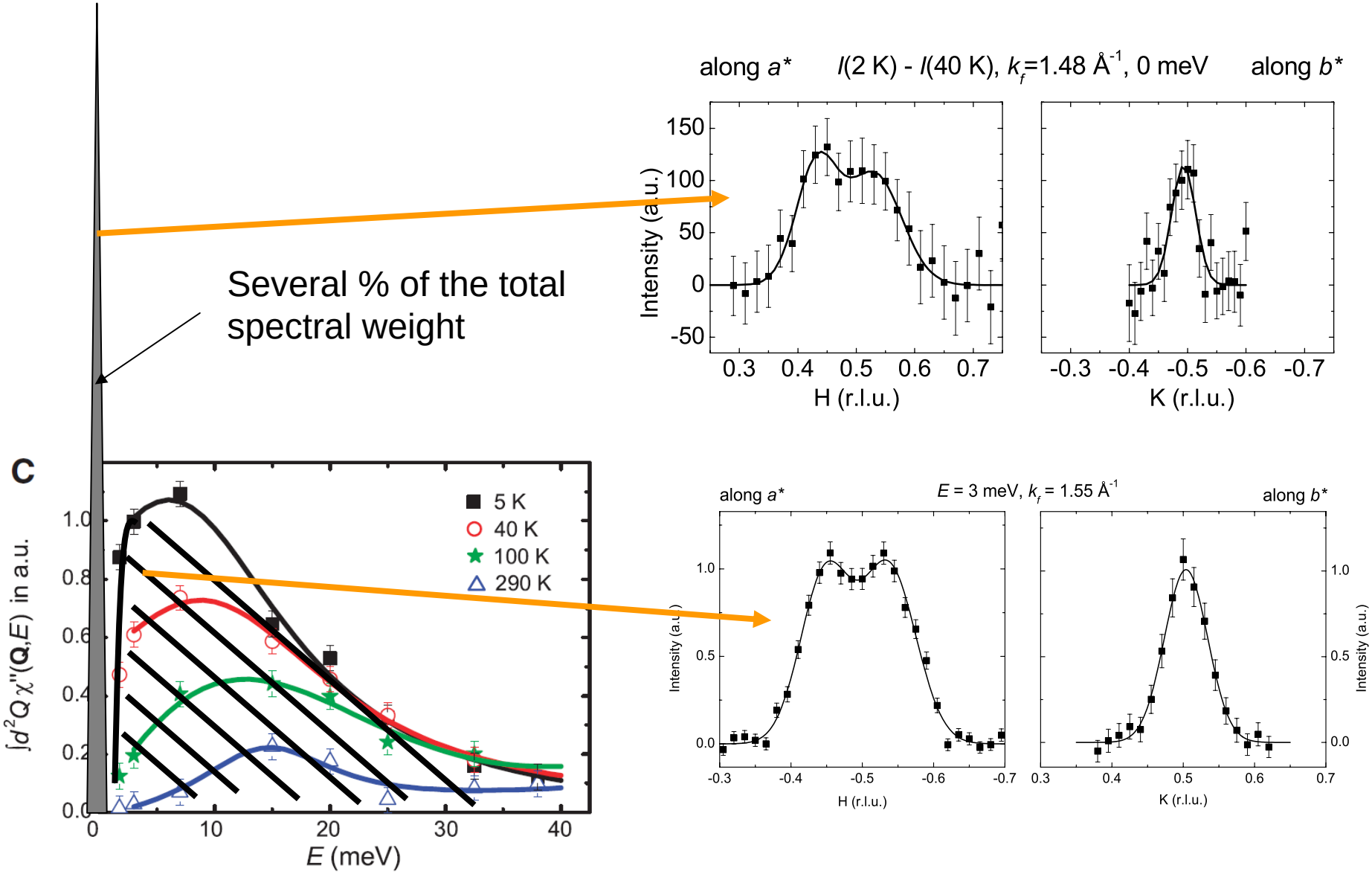
- Spontaneous onset of incommensurability at ~150 K

⇒Suggests underlying nematic phase transition, orthorhombic lattice distortion serves as weak orientational field

cf. Kivelson et al., *Nature* 393, 550 (1998)

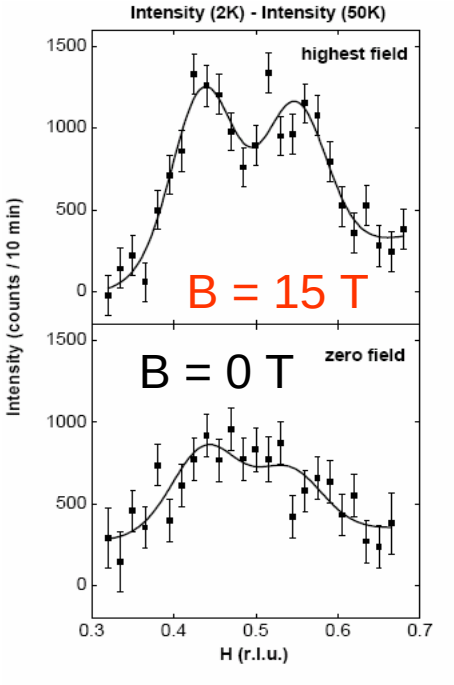
Spirals? (Sushkov et al.), FS deformation? (Yamase et al.), Stripes? (Tranquada and several others)

Quasi-elastic intensity

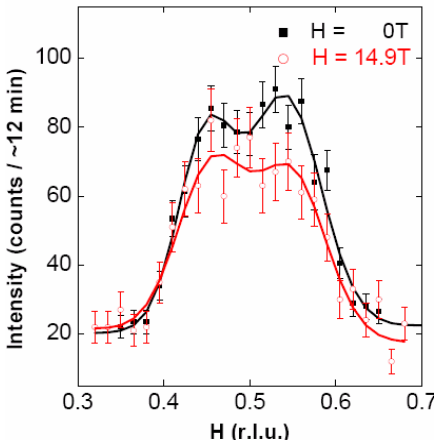


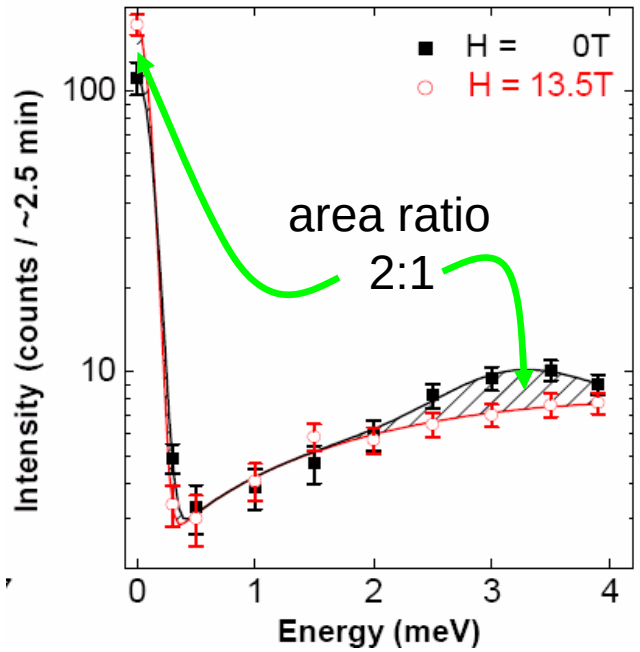
Effect of an external magnetic field

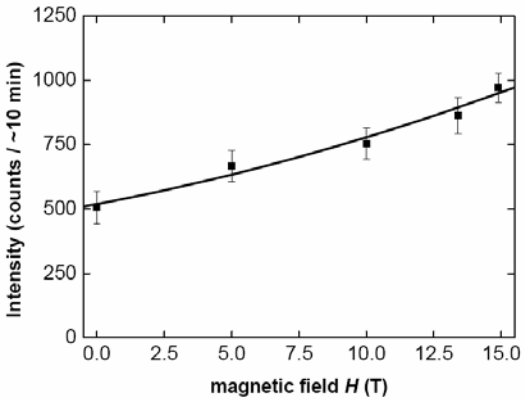
E = 0 meV

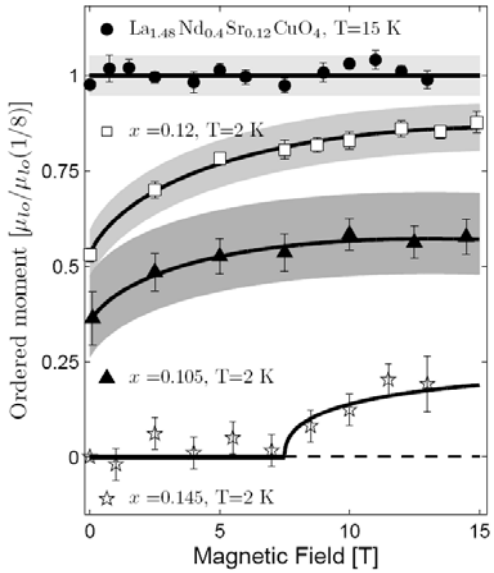


E = 3 meV



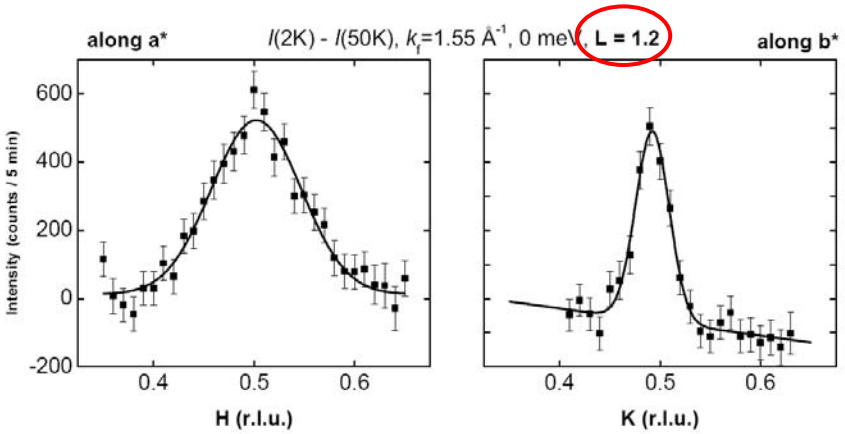


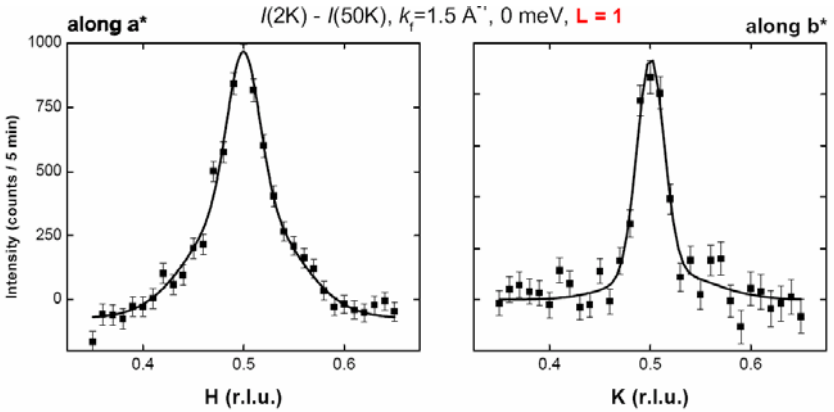


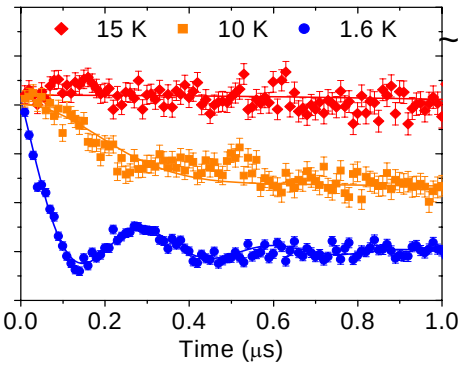


J. Chang *et al.*, arXiv:0712.2181, cf. also B. Lake et al., Nature

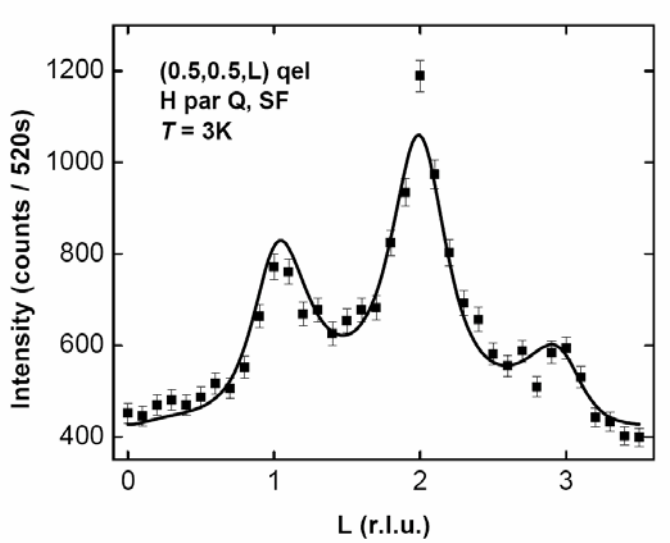
Severely underdoped YBCO, T_c = 10 K

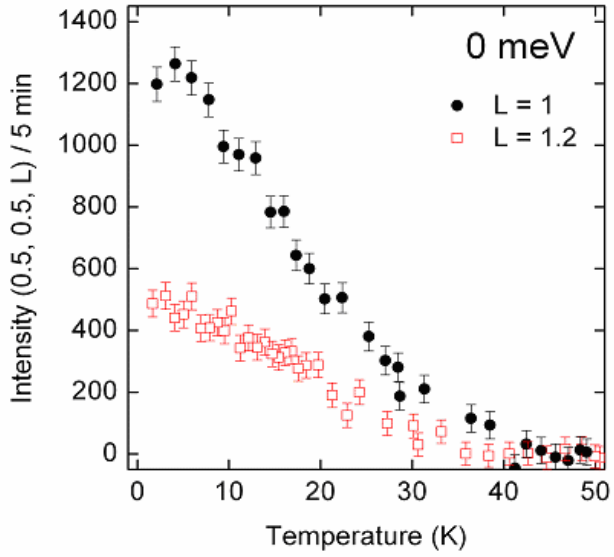




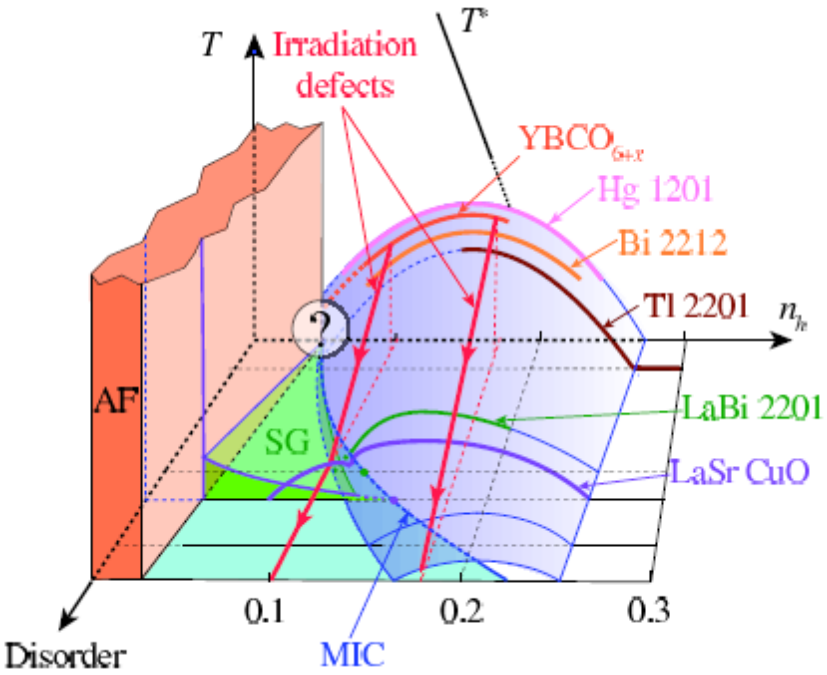


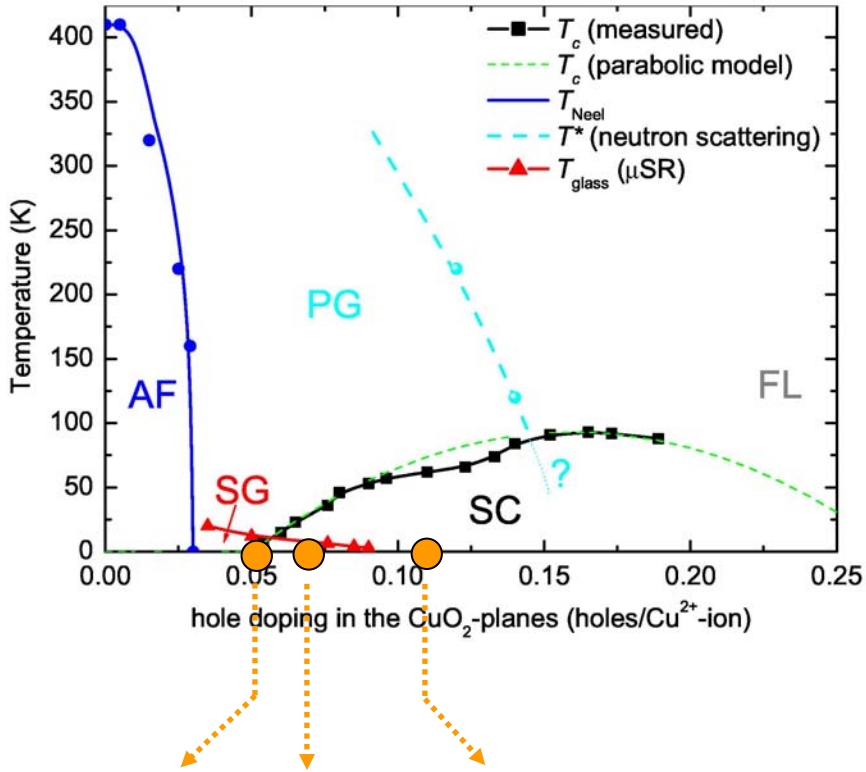
~ 0.5 μ_B





Zn substitution effect





Rullier-Albenque et al., *EPL* **81**, 37008 (2008).

T_c = 10 K
p_h = 0.07?

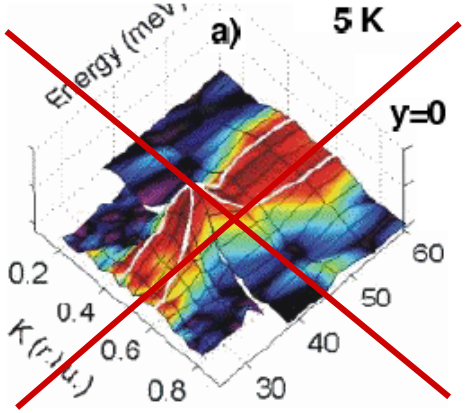
T_c = 35 K
p_h = 0.085

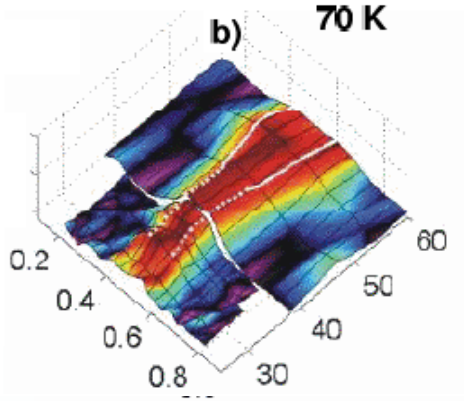
T_c = 61 K
p_h = 0.12

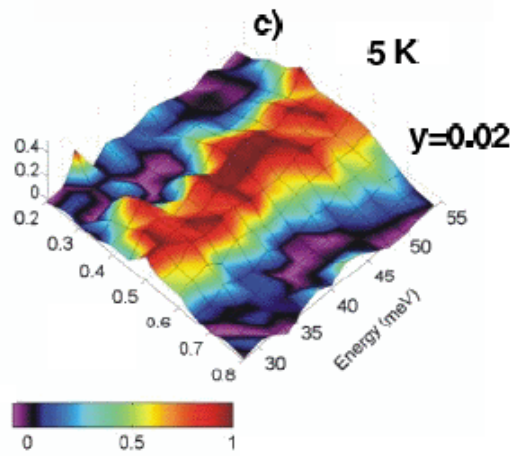
NO T_c
p_h = 0.085

T_c = 30 K
p_h = 0.12

Zn substitution effect



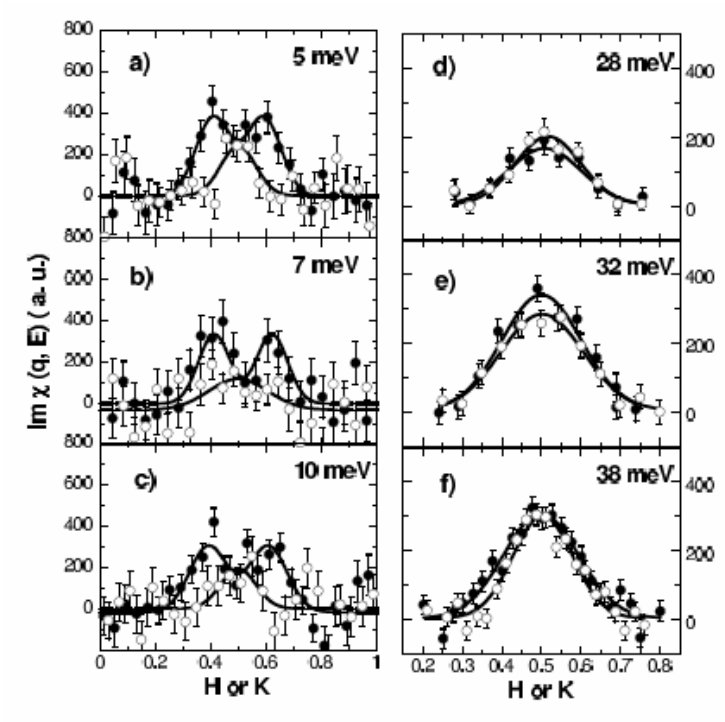




$YBa_2(Cu_{1-y}Zn_y)_3O_{6.6}$

* High energy: Y-shaped dispersion as in the normal state of the Zn free compound YBCO6.6

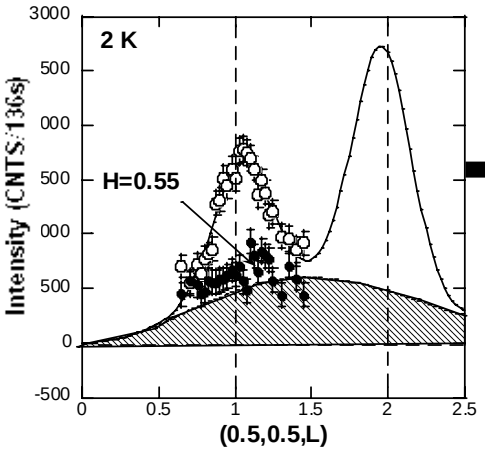
*Low E : quasi-1D incommensurate spin fluctuations as in YBCO6.45

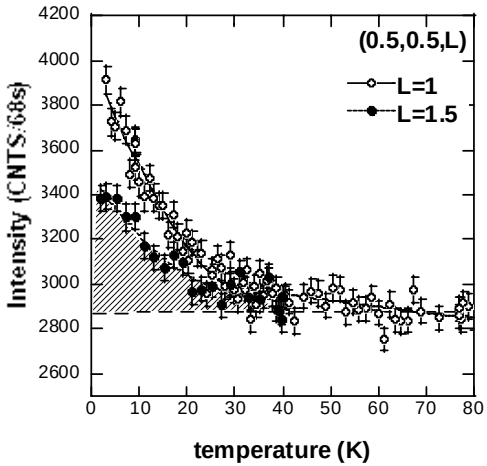


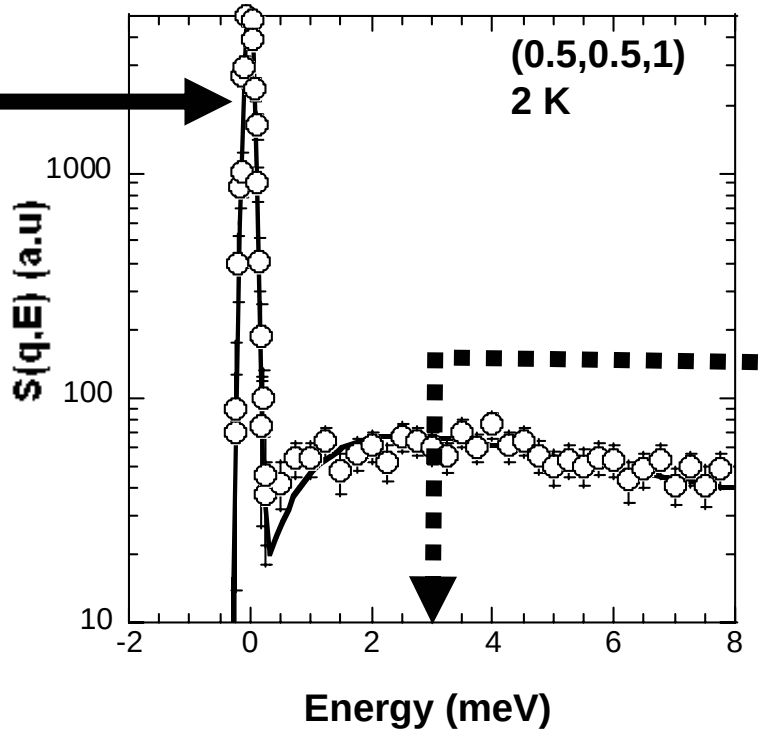
Zn substitution effect

$YBa_2(Cu_{1-y}Zn_y)_3O_{6.45}$

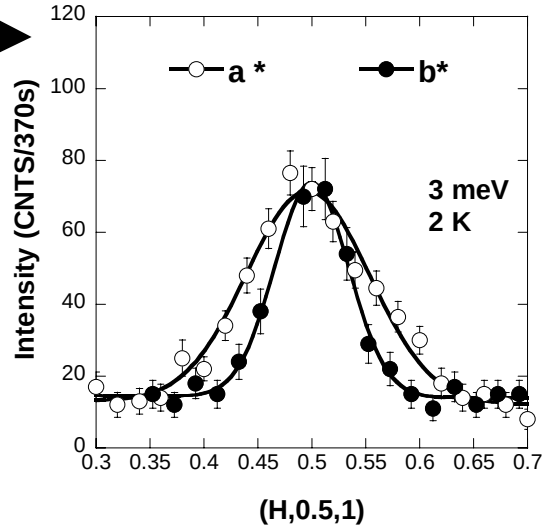
No superconducting sample !







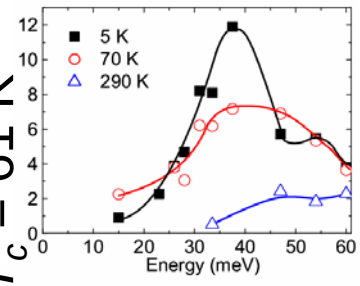
*same physics as in YBCO6.35 (Tc=10 K)

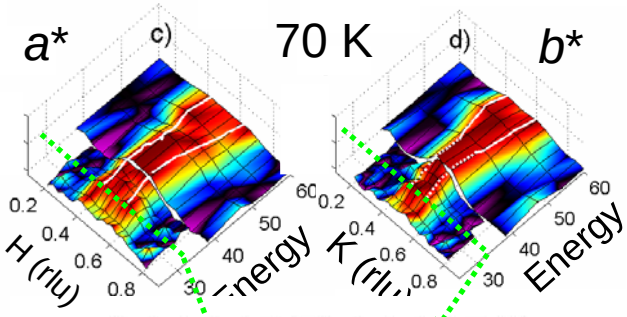


THE GREAT TABLE

Q-integrated χ | In-plane geometry, E>0 | Quasi-elastic int. | B-field effect

T_c = 61 K

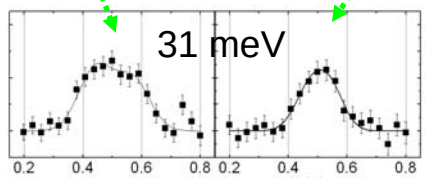




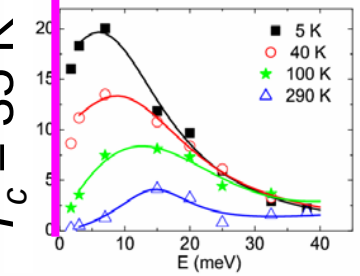
X

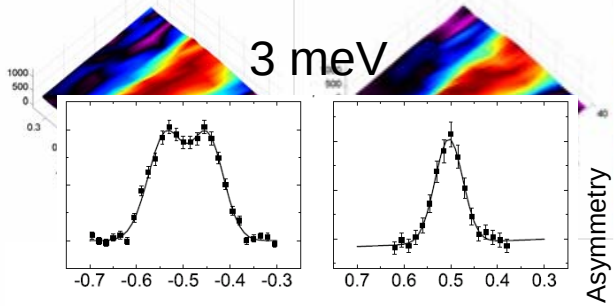
X

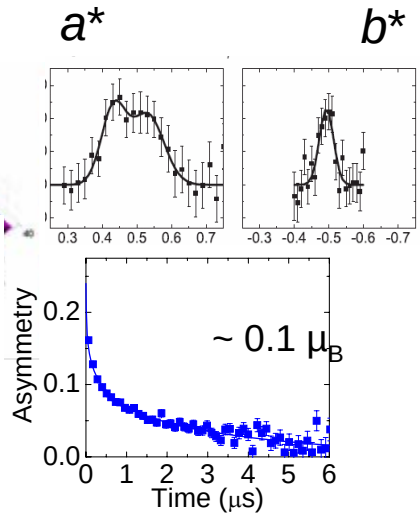
(at low E)

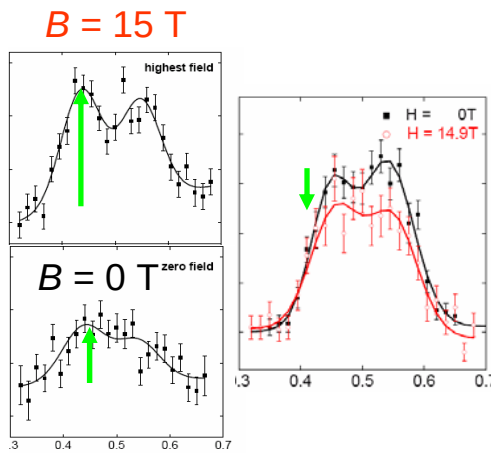


T_c = 35 K





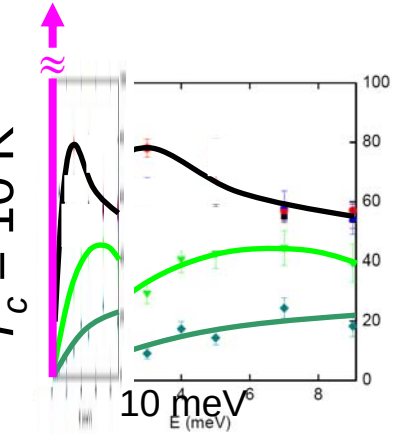


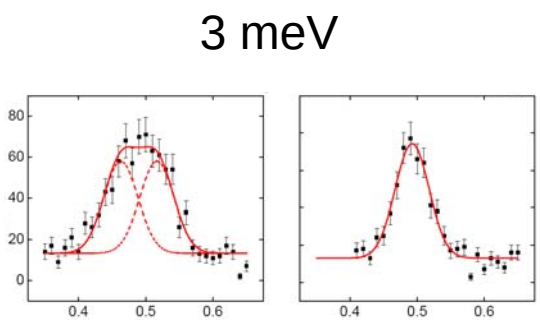


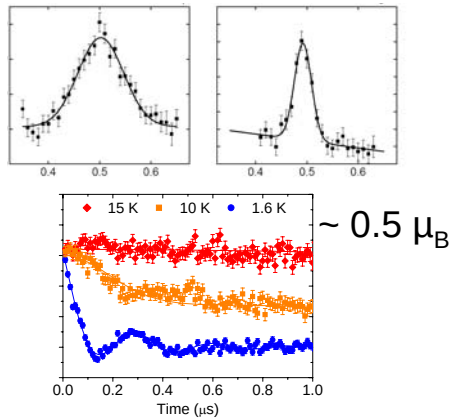
0 meV

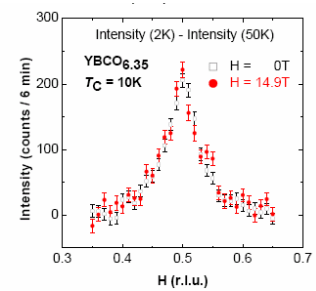
3 meV

T_c = 10 K









0 meV

Summary

- With underdoping, a state with strong in-plane anisotropy emerges, which appears to compete with superconductivity.
- Anisotropy of the excitation spectrum sets in spontaneously at 150K
- Quasielastic signal with the same in-plane anisotropy, which sets in at lower temperature, is enhanced by magnetic field
- The inelastic signal is suppressed by magnetic field around 2.5-4.0 meV
- Enhancement of the magnetic order at high fields might lead to stronger Fermi surface reconstruction, thereby explaining the seeming contradiction between ARPES and dHvA measurements.
- The underlying instability carrying the in-plane anisotropy is likely to be stabilized by disorder

Thank you for your attention and patience!