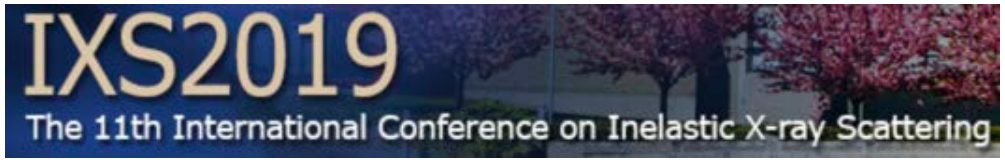

Evolution of the spin and charge excitations in high T_c cuprates

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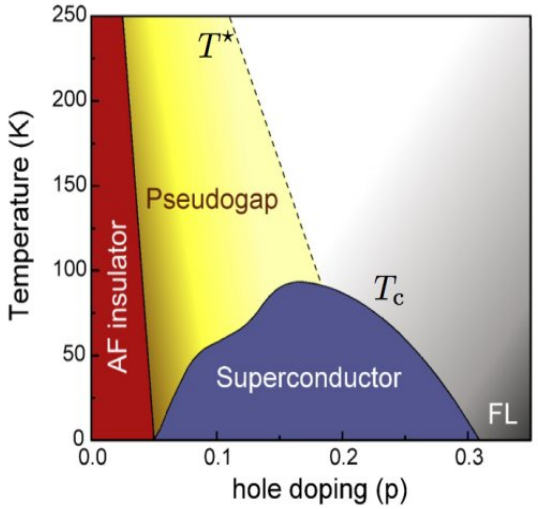
Outline

- Evolution of the spin excitation in the high T_c cuprate $(Bi,Pb)_2(Sr,La)_2CuO_{6+\delta}$ (Bi2201)

- Interplay of charge order and phonon in stripe-order cuprate $La_{1.8-x}Eu_{0.2}Sr_xCuO_4$ (LESCO)

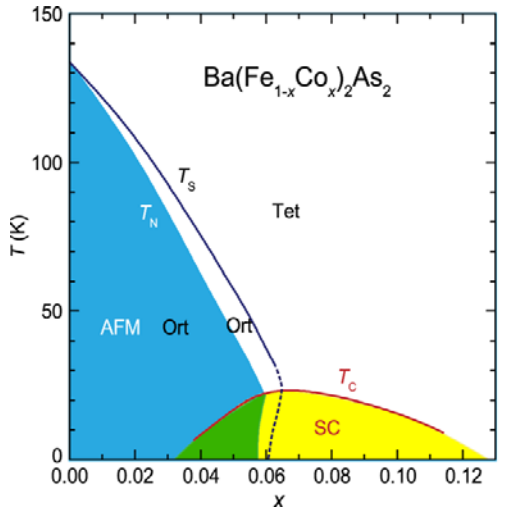
Origin of unconventional superconductor?

Cuprate superconductors



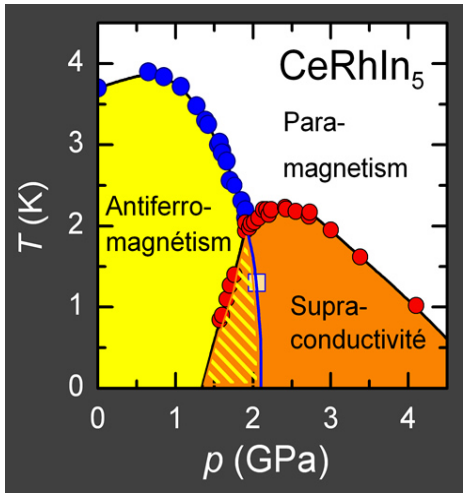
Courtesy LNCMI-Toulouse

Fe-based superconductors



J. Tranquada, Physics **3**, 41 (2010)

Heavy Fermion superconductors

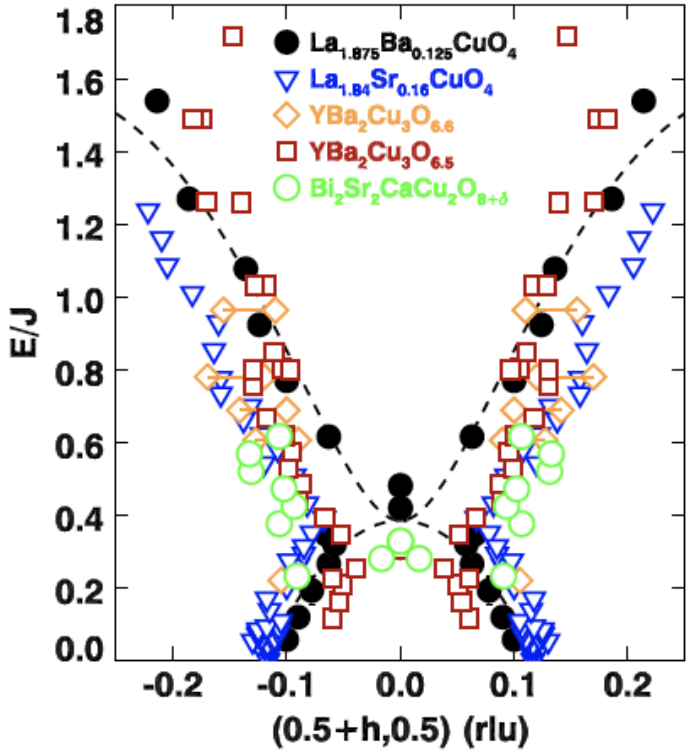


H. Hegger, et al., PRL **84**, 4986 (2000)

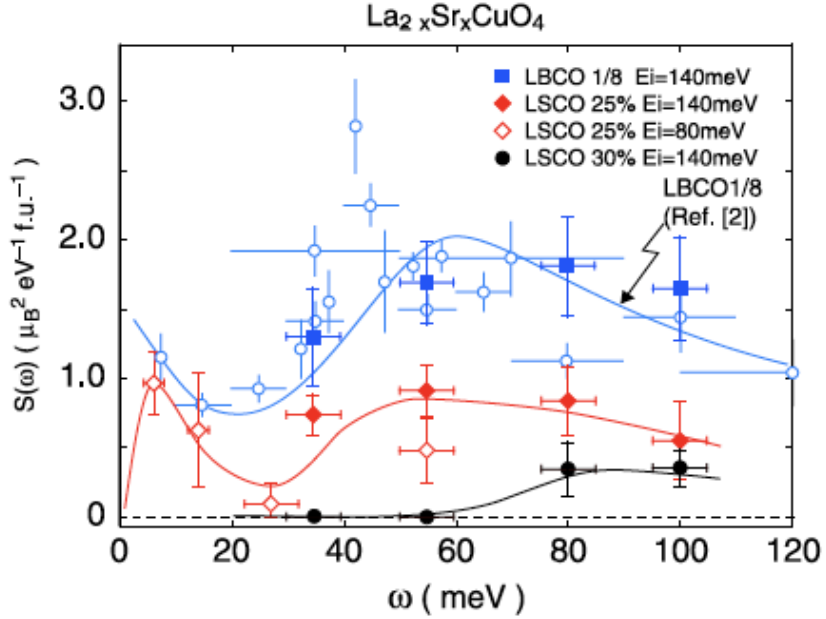
- Superconductivity emerges in proximity to antiferromagnetism.
- What is the role of spin excitation to SC?

How does spin excitation change with doping?

"Hour-glass" dispersion



M.Fujita et al., J. Phys. Soc. Jpn. 81 (2012) 011007.



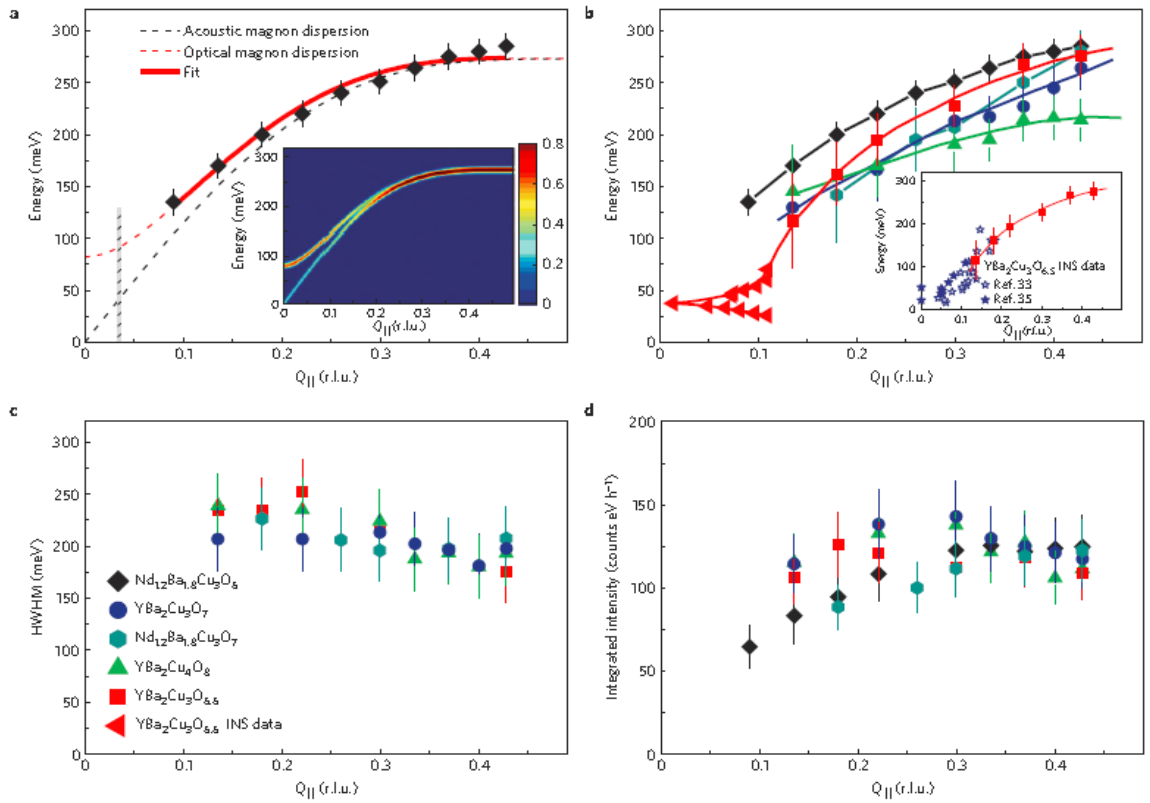
S.Wakimoto et al., Phy. Rev. Lett. 98 (2007) 247003.

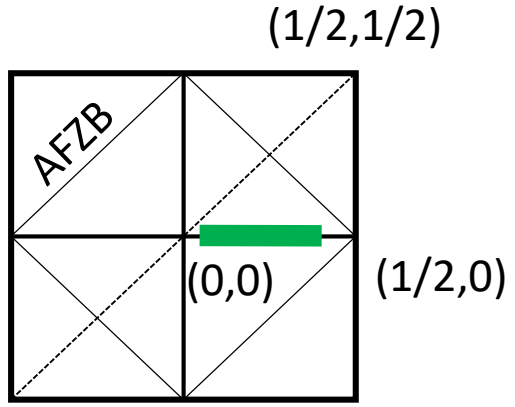
- Low-energy spin fluctuations disappeared in the heavily overdoped regime.

------Supporting spin fluctuations mediate the electron pairing in high-Tc superconductors.

Magnetic excitations persists across the whole phase diagram

Dispersion, linewidth and intensity of the magnetic excitations.



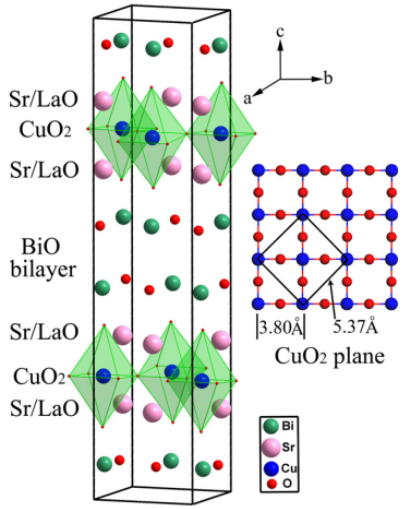


- This challenges high-energy magnetic fluctuation as a vital role in pairing mechanism.

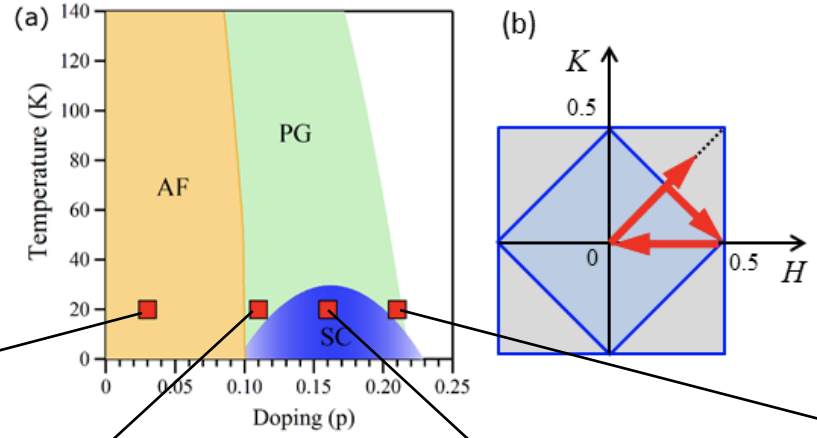
Dispersions and spectral weights of paramagnon (damped spin excitations) closely similar to those of magnons in undoped cuprates.

M. Le Tacon et al., Nat. Phys. 7, 725 (2011). M. P. M. Dean et al., Nat. Mater. 12, 1019 (2013). M. Le Tacon et al., Phys. Rev. B 88, 020501 (2013).

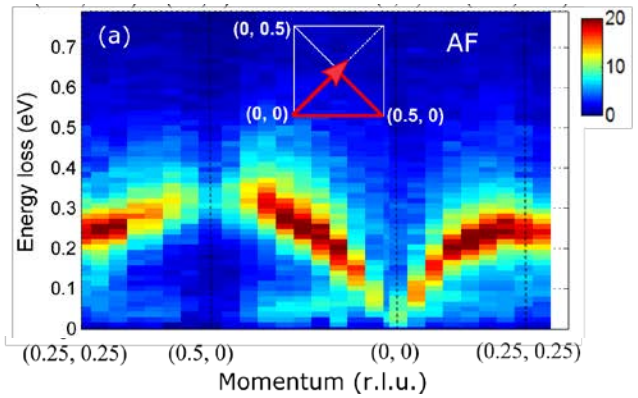
Doping/Momentum evolution of magnetic excitations

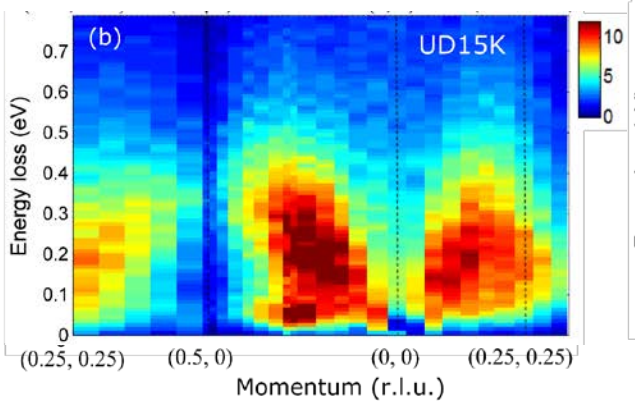


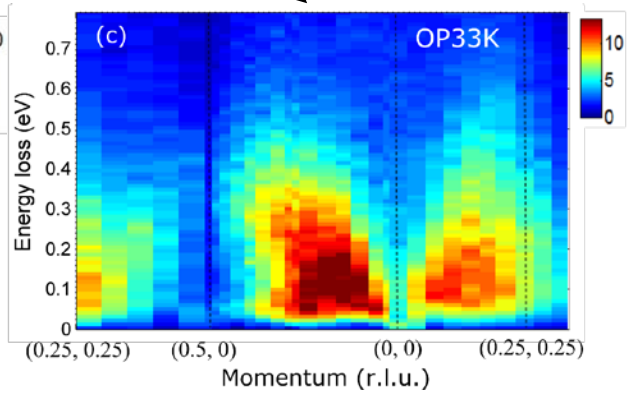
$(Bi,Pb)_2(Sr,La)_2CuO_{6+\delta}$

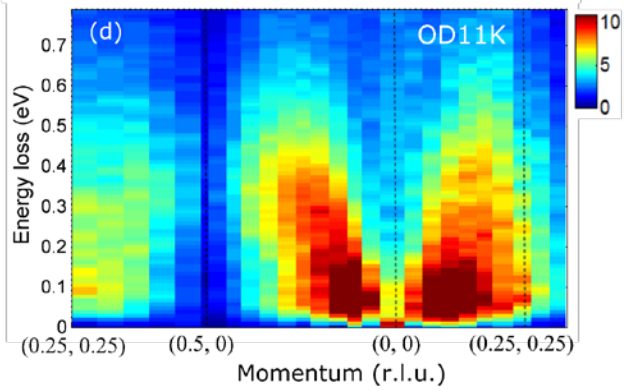


Cu L_3 RIXS @ID32, ESRF
ΔE=55 meV

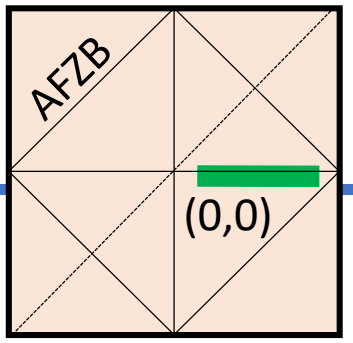






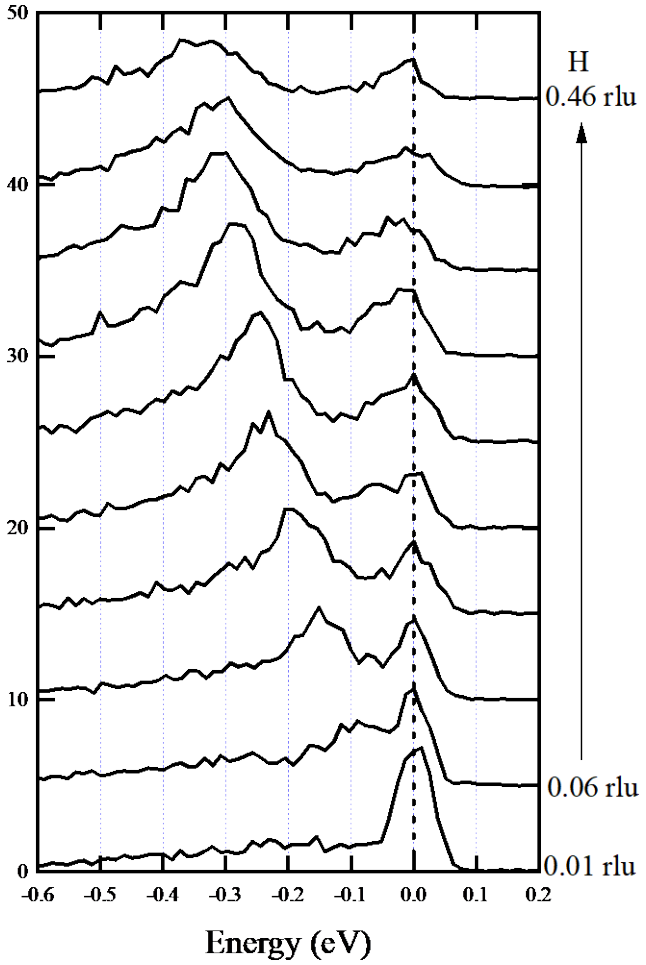


Y. Y. Peng et al, Phys. Rev. B 98, 144507 (2018).

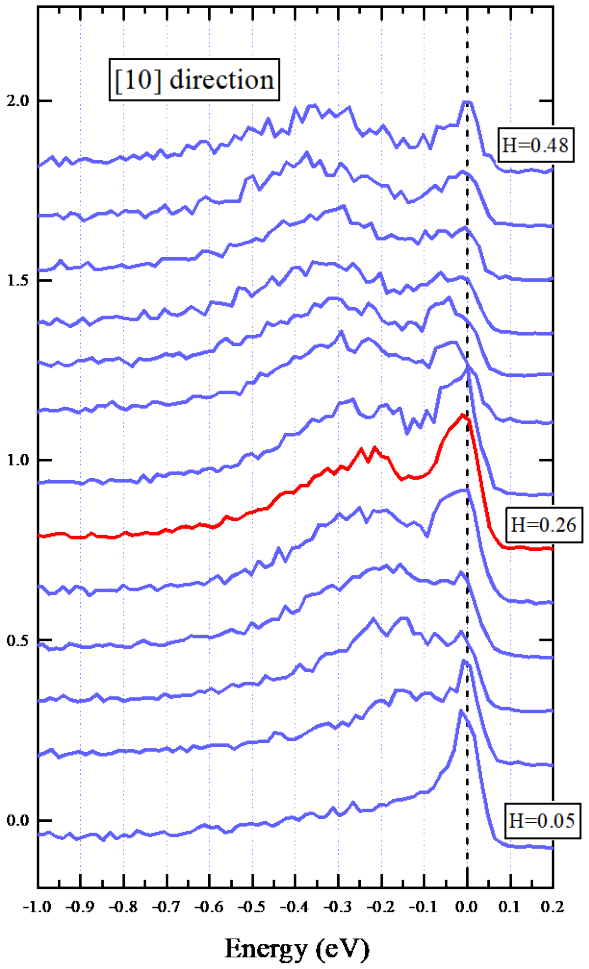


Magnetic excitation along [1,0] direction

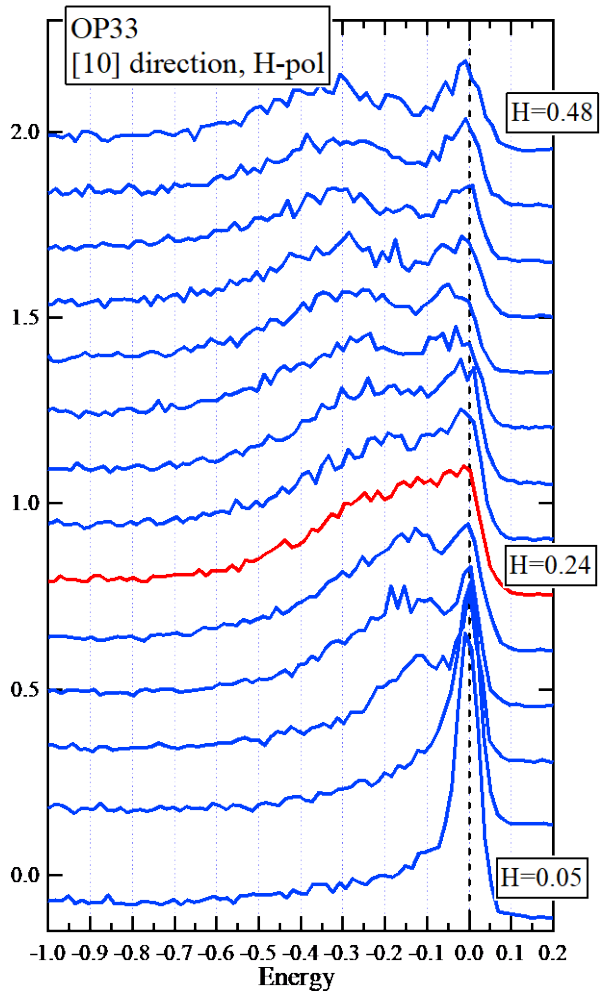
AF (p=0.03)



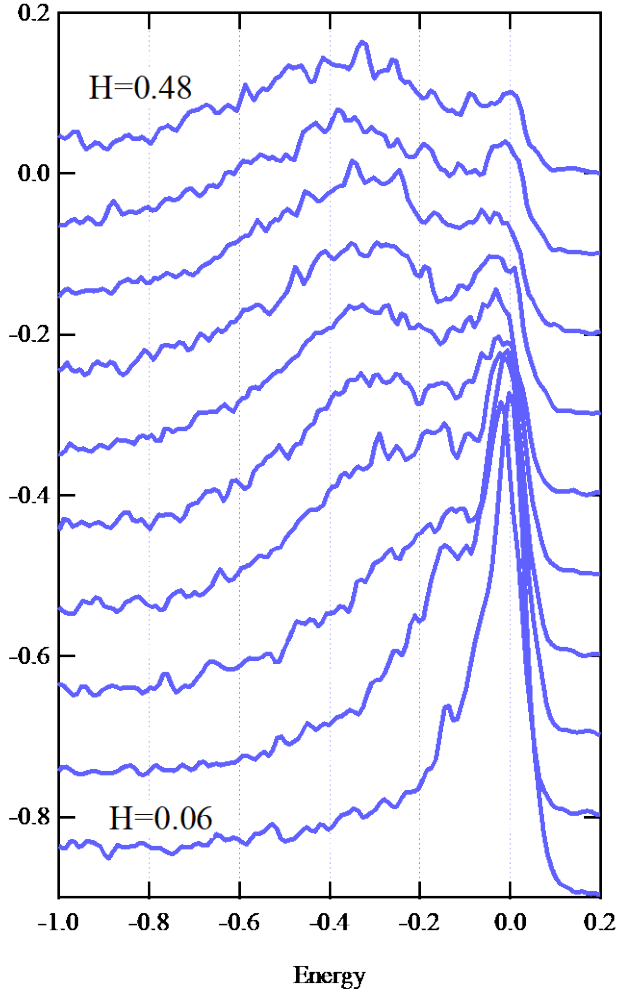
UD15K (p=0.11)

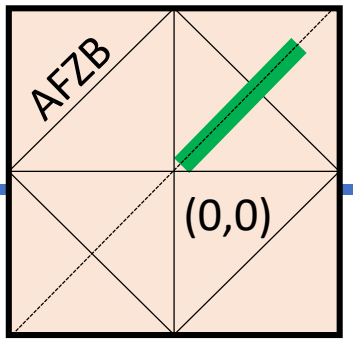


OP33K (p=0.16)



OD11K (p=0.21)





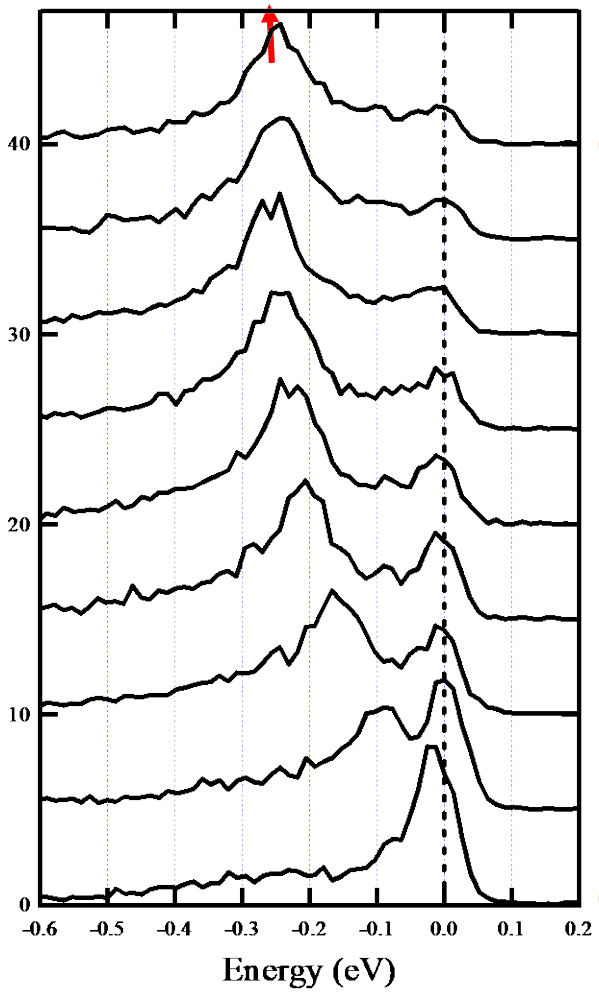
Magnetic excitation along [1,1] direction

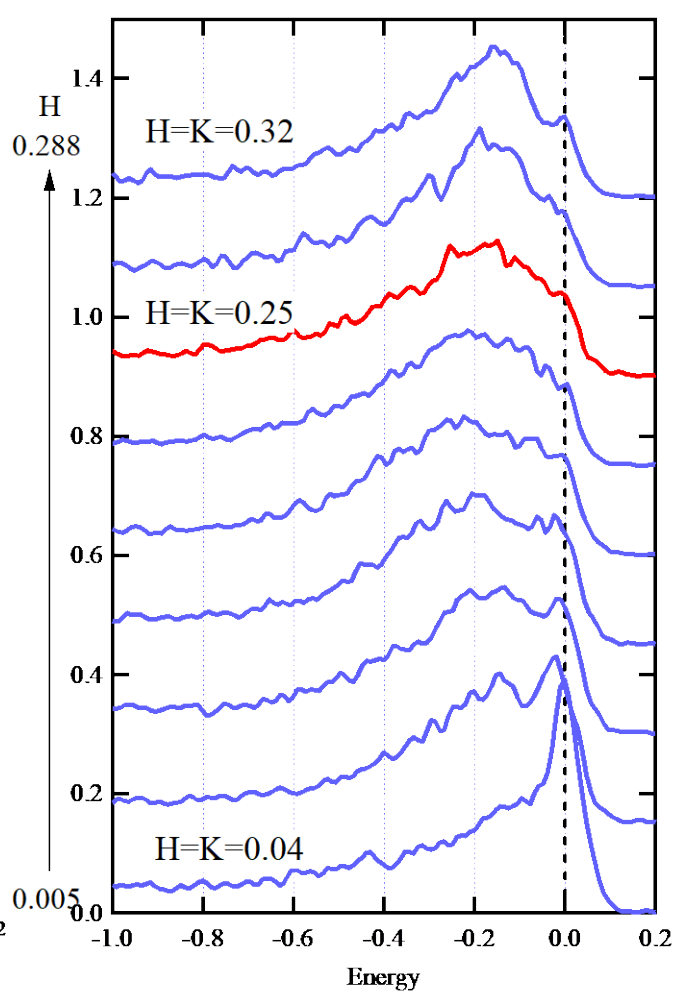
AF (p=0.03)

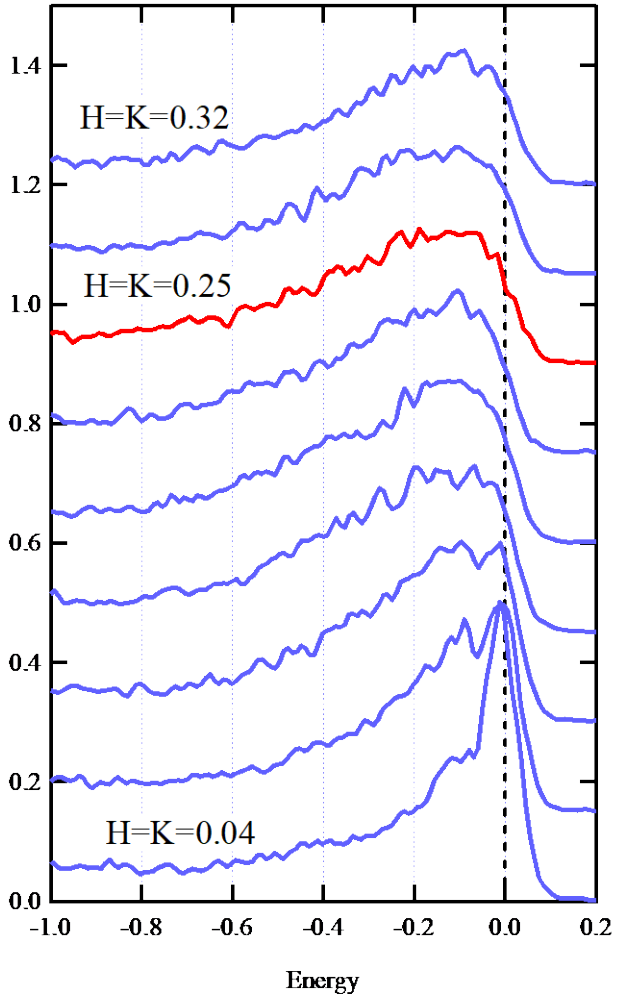
UD15K (p=0.11)

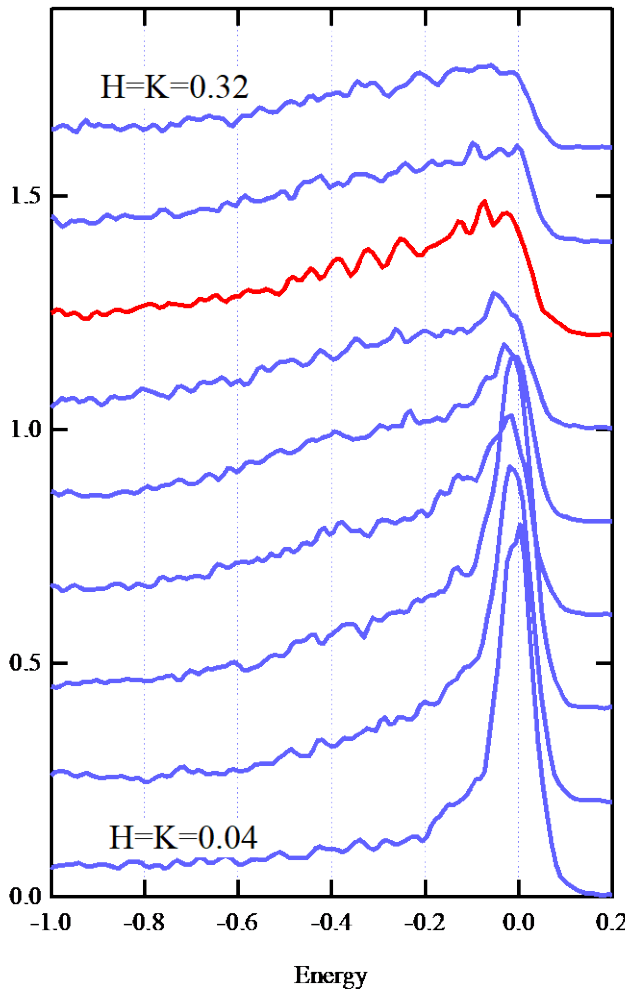
OP33K (p=0.16)

OD11K (p=0.21)

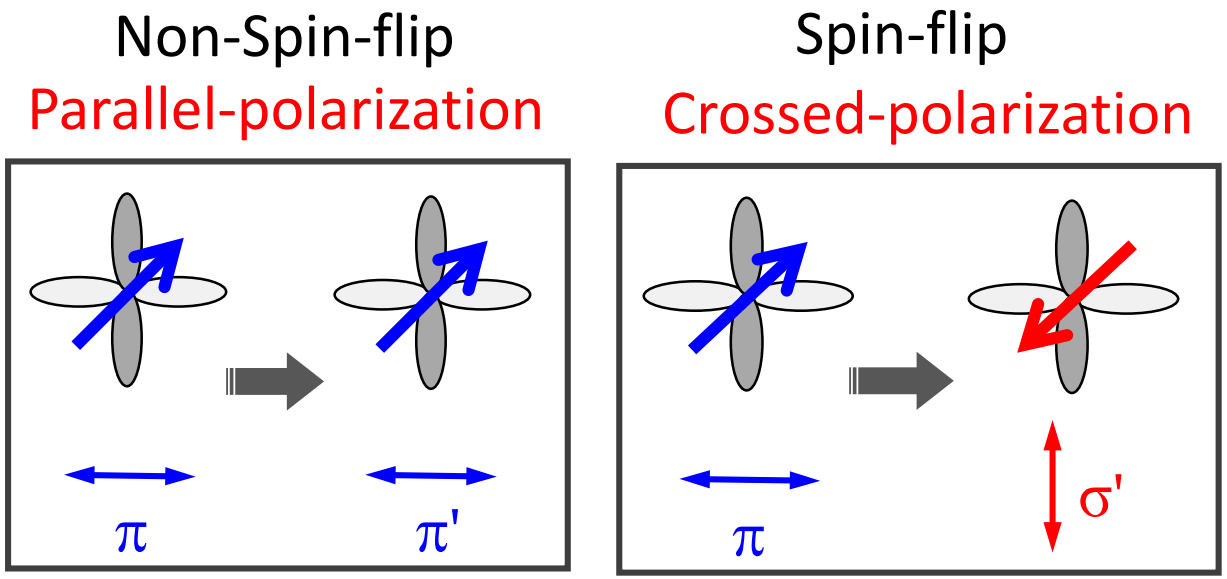


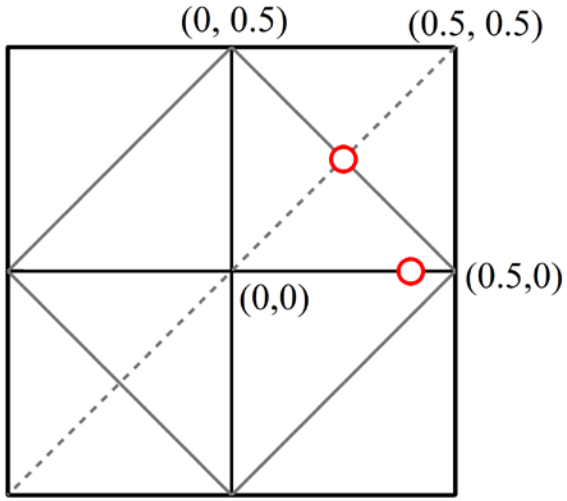


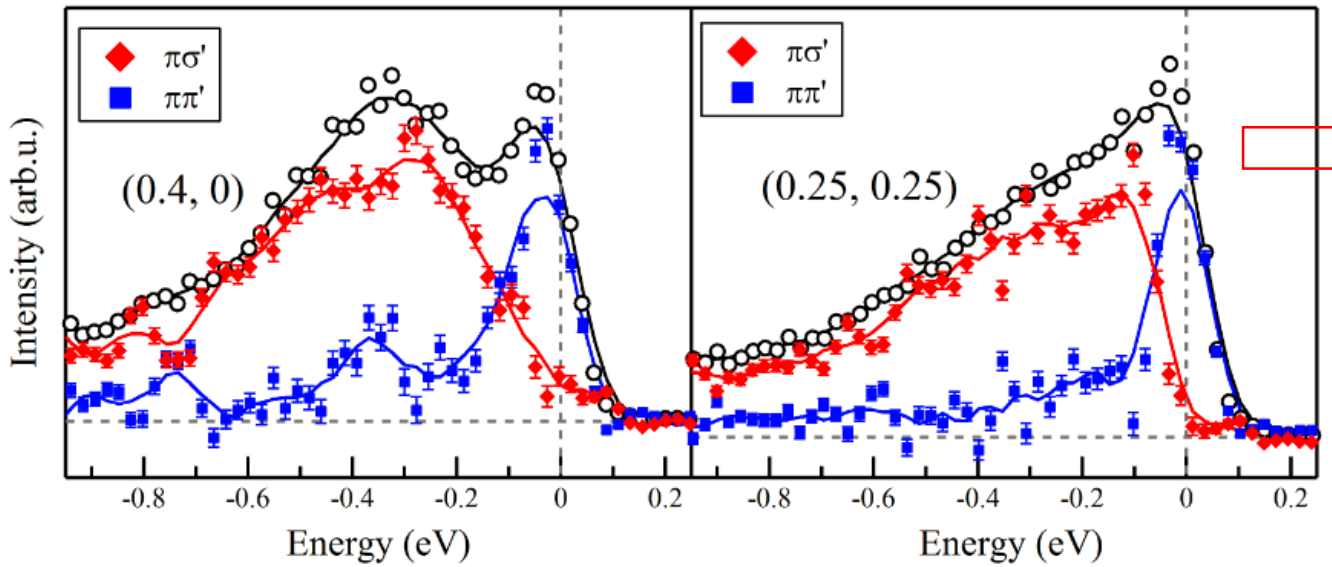




Fully polarized RIXS measurement of OD11K (*p*=0.21)







Paramagnon:
All spin-flip!

Doping dependence of undamped frequency and damping

Generic damped harmonic oscillator

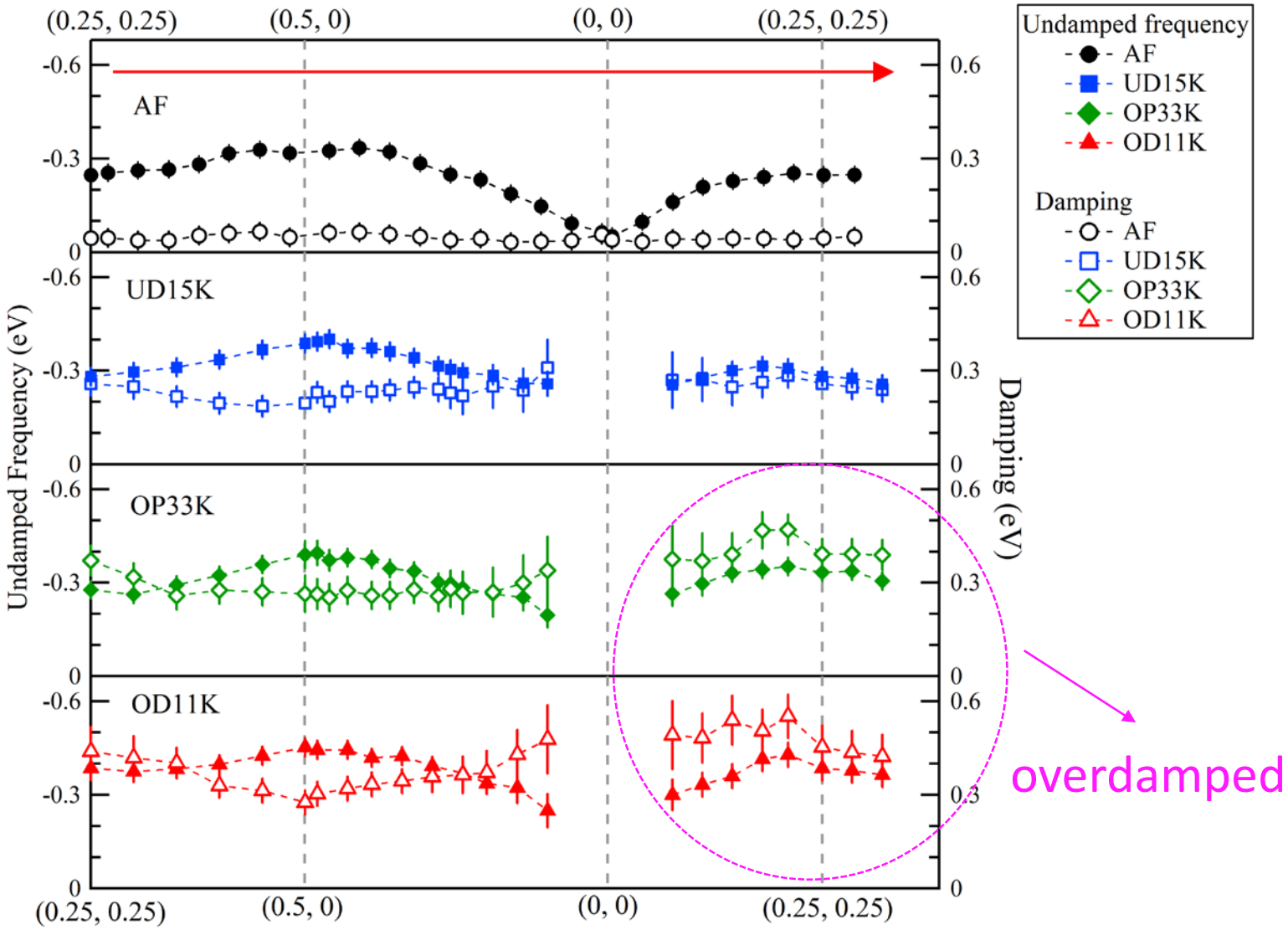
$$\chi''(\mathbf{Q},\omega) \propto \frac{\gamma\omega}{(\omega^2-\omega_0^2)^2+4\gamma^2\omega^2}$$

Undamped frequency ----- ω_0

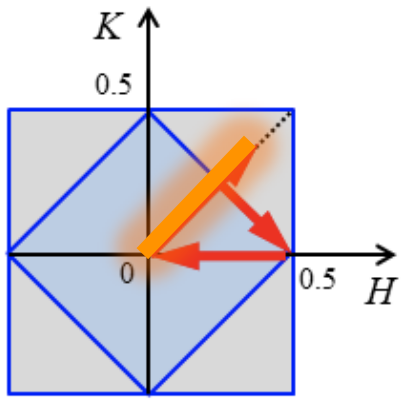
Damping (FWHM)----- γ

Valid for

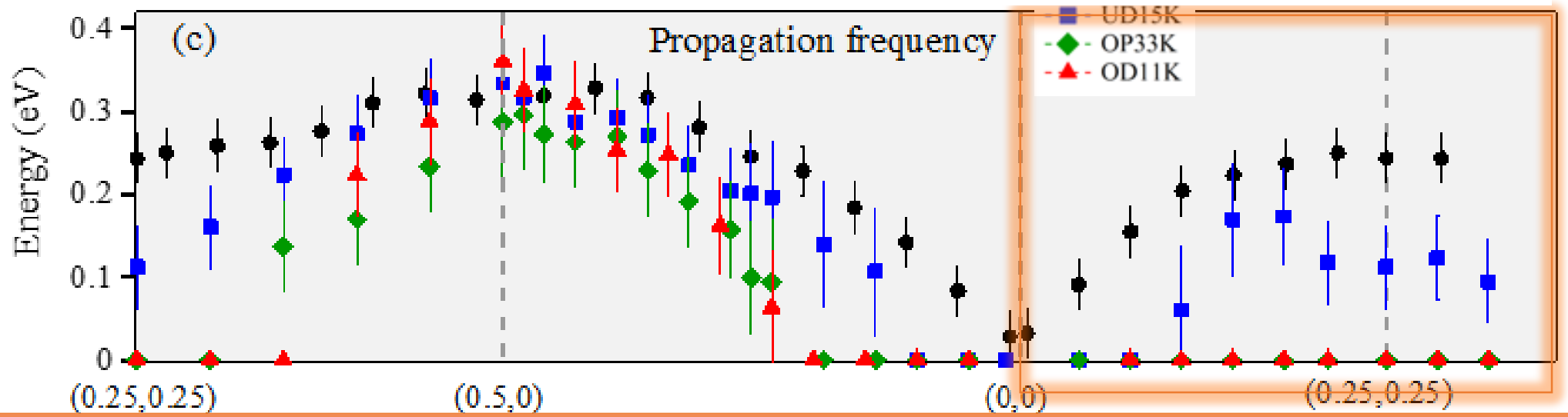
1. Underdamped ($\gamma<\omega_0$)
2. Critical damped ($\gamma=\omega_0$)
3. Overdamped ($\gamma>\omega_0$)



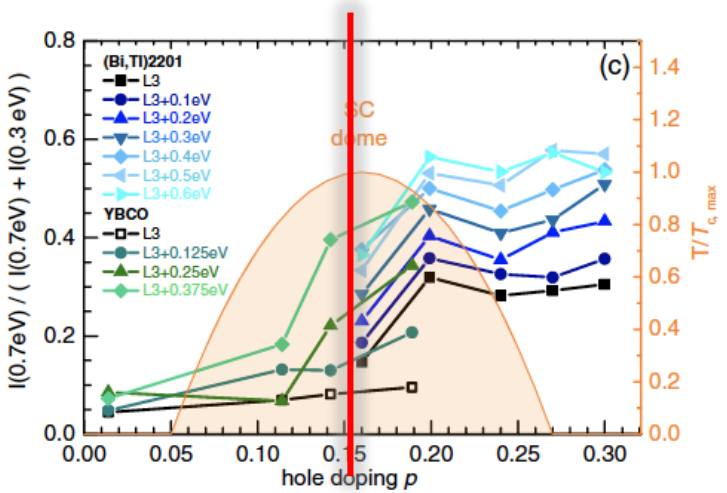
Doping/momentum dependence of paramagnon propagation



$$Propagation\ frequency = \sqrt{undamped\ frequency^2 - damping^2}$$



Along nodal direction, magnetic excitations stop propagating from optimal doping.



M.Minola et al., PRL 119, 097001 (2017)

Collective Spin Excitation

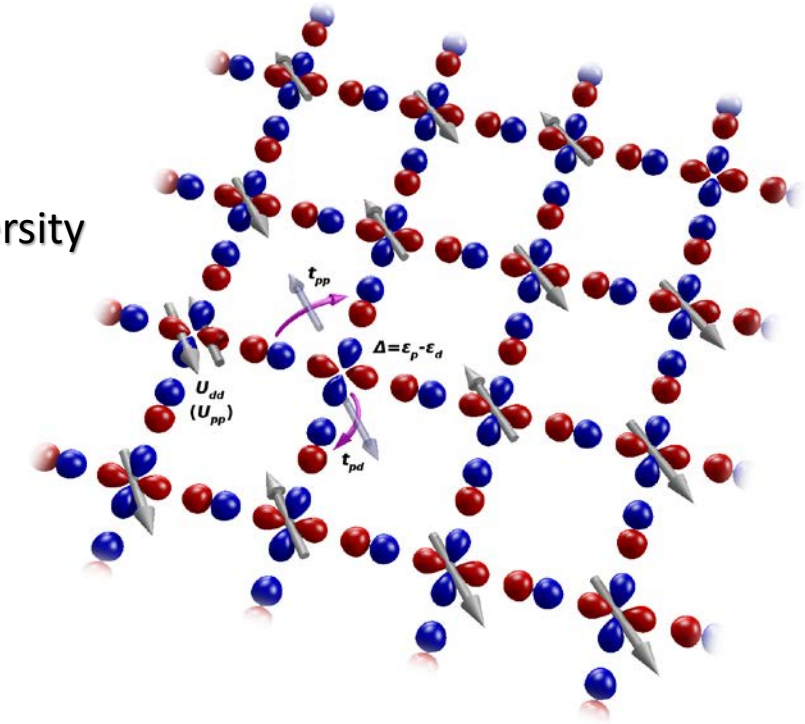
↓

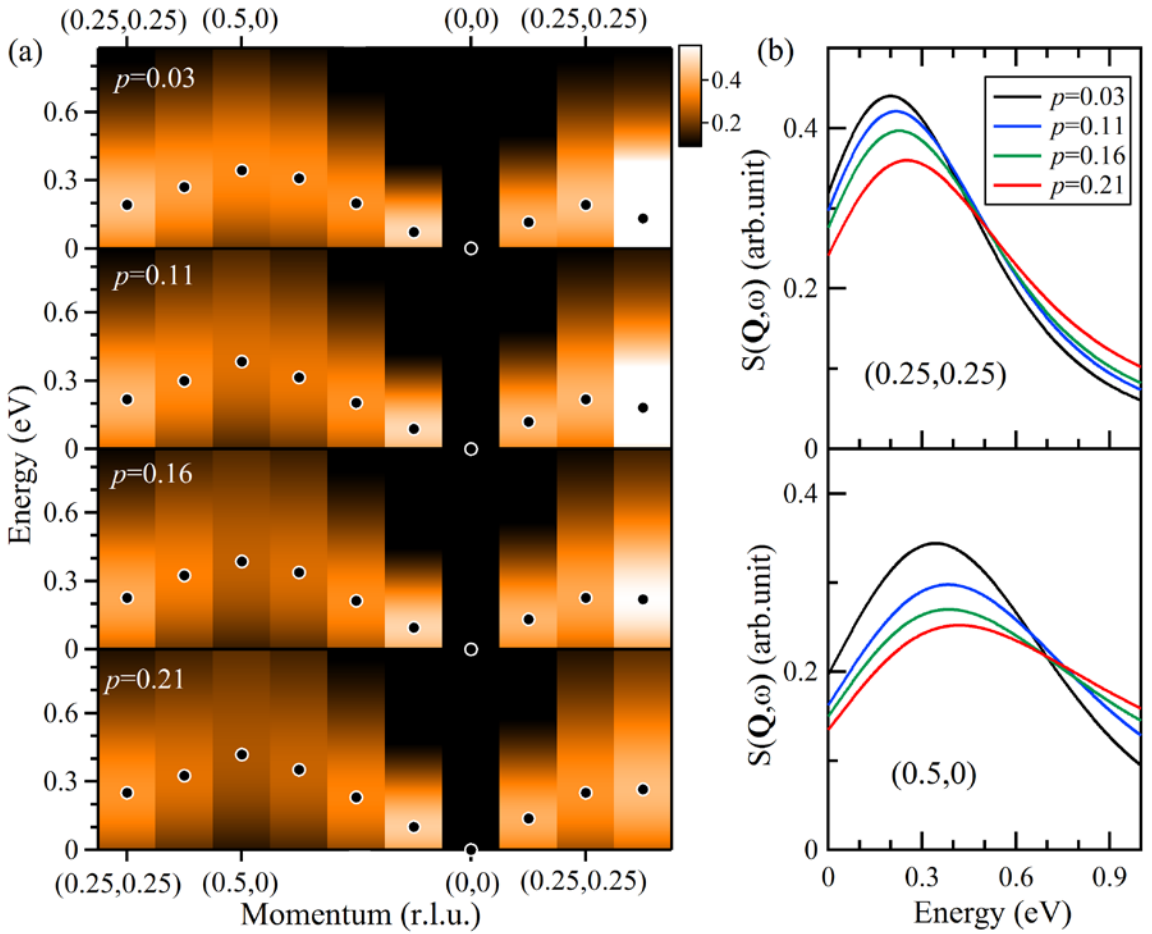
Incoherent Spin Excitations

Numeric: 3-band Hubbard model

E. Huang,
Stanford University

Determinant quantum Monte Carlo (DQMC)

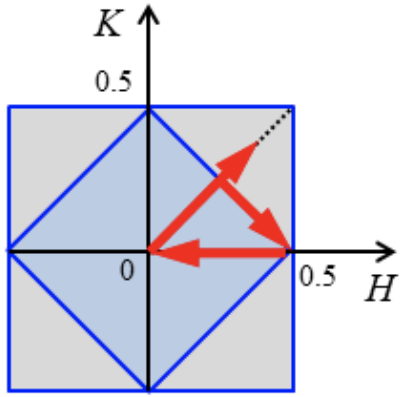




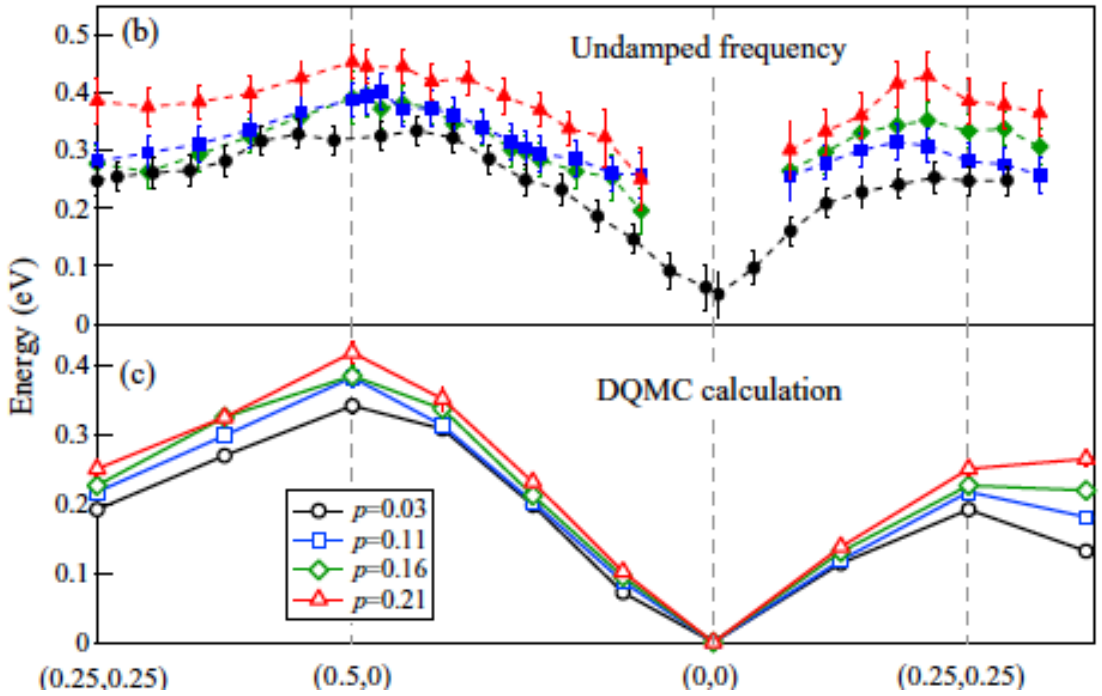
Y. Y. Peng et al, Phys. Rev. B 98, 144507 (2018).

With doping, the intensity of S(q, ω) decreases, and peak position increases.

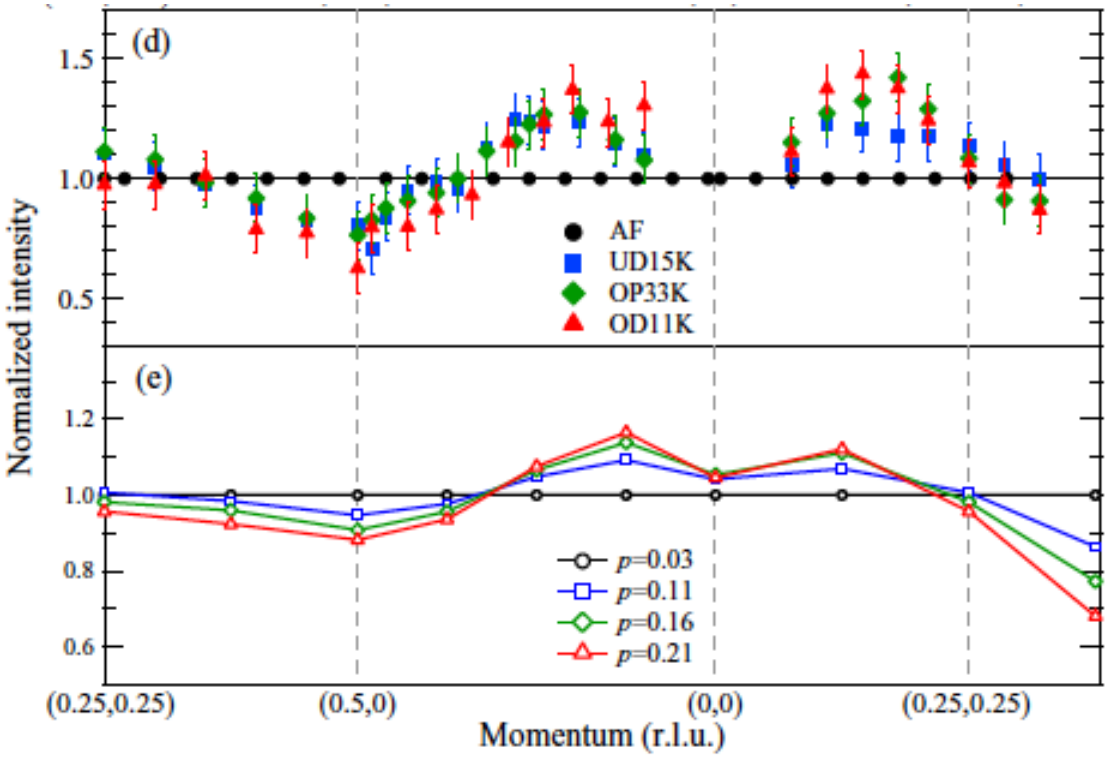
Doping/momentum evolution of paramagnon dispersions



Paramagnon dispersions

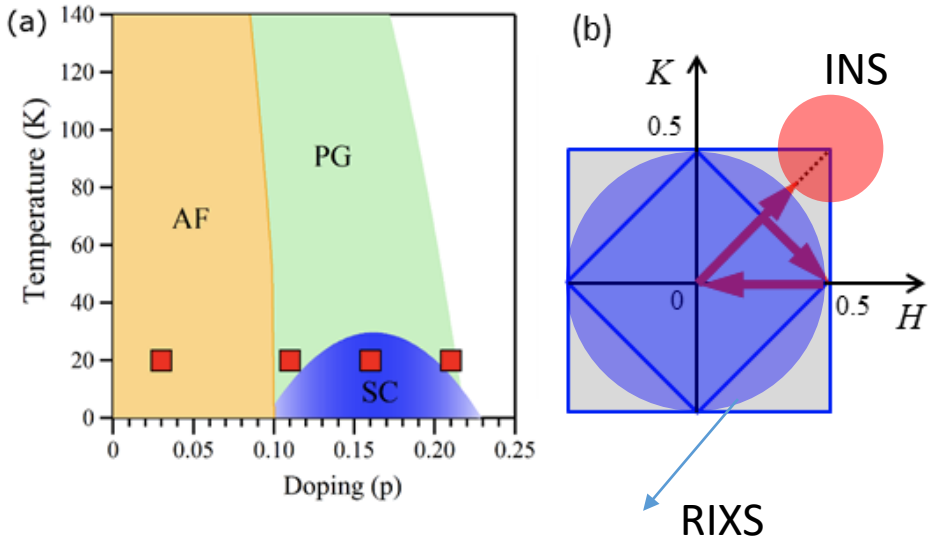


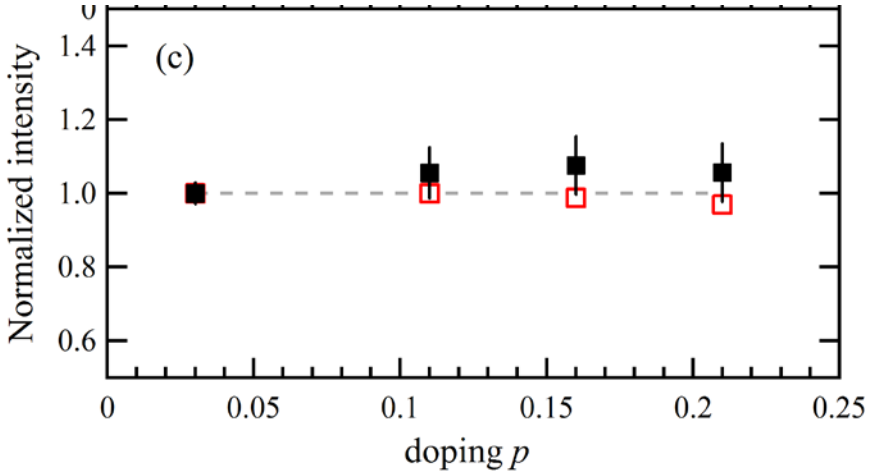
Paramagnon intensity evolution



- The doping dependence of the dispersion and intensity of paramagnon are consistent with DQMC calculation.

Doping/momentum evolution of intensity

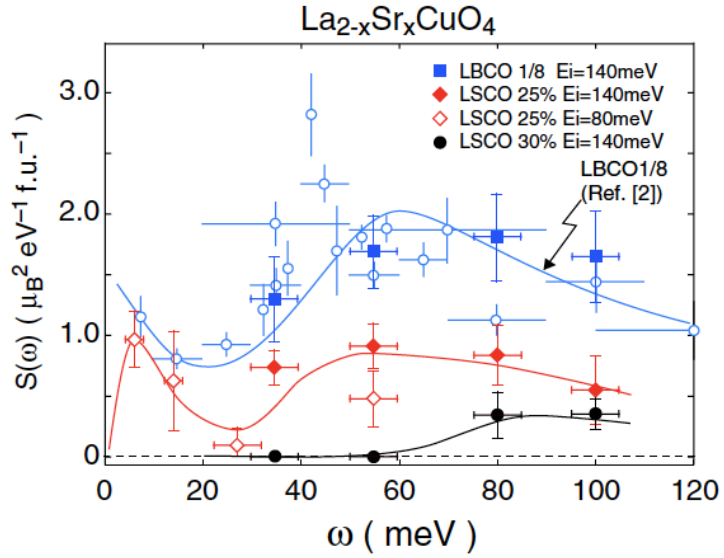




Y. Y. Peng et al, Phys. Rev. B 98, 144507 (2018).

- ❑ RIXS: spin intensity is constant with doping.
- ❑ INS: spin intensity decreases with doping

Upon doping the spin fluctuation related to SC is concentrated around $\mathbf{Q}_{AF}$=(0.5, 0.5).



S. Wakimoto et al., Phys. Rev. Lett. 98, 247003 (2007)

Summary

- Spin-flip nature of paramagnon persists up to heavily overdoped region.
- Upon doping the spin fluctuation related to SC is concentrated around $\mathbf{Q}_{AF}$=(0.5, 0.5).
- Electron-phonon coupling strength is enhanced near CO regime.

Thanks for your attention!