Neutron Scattering Studies of electron-hole symmetry in FeAs-based superconductors

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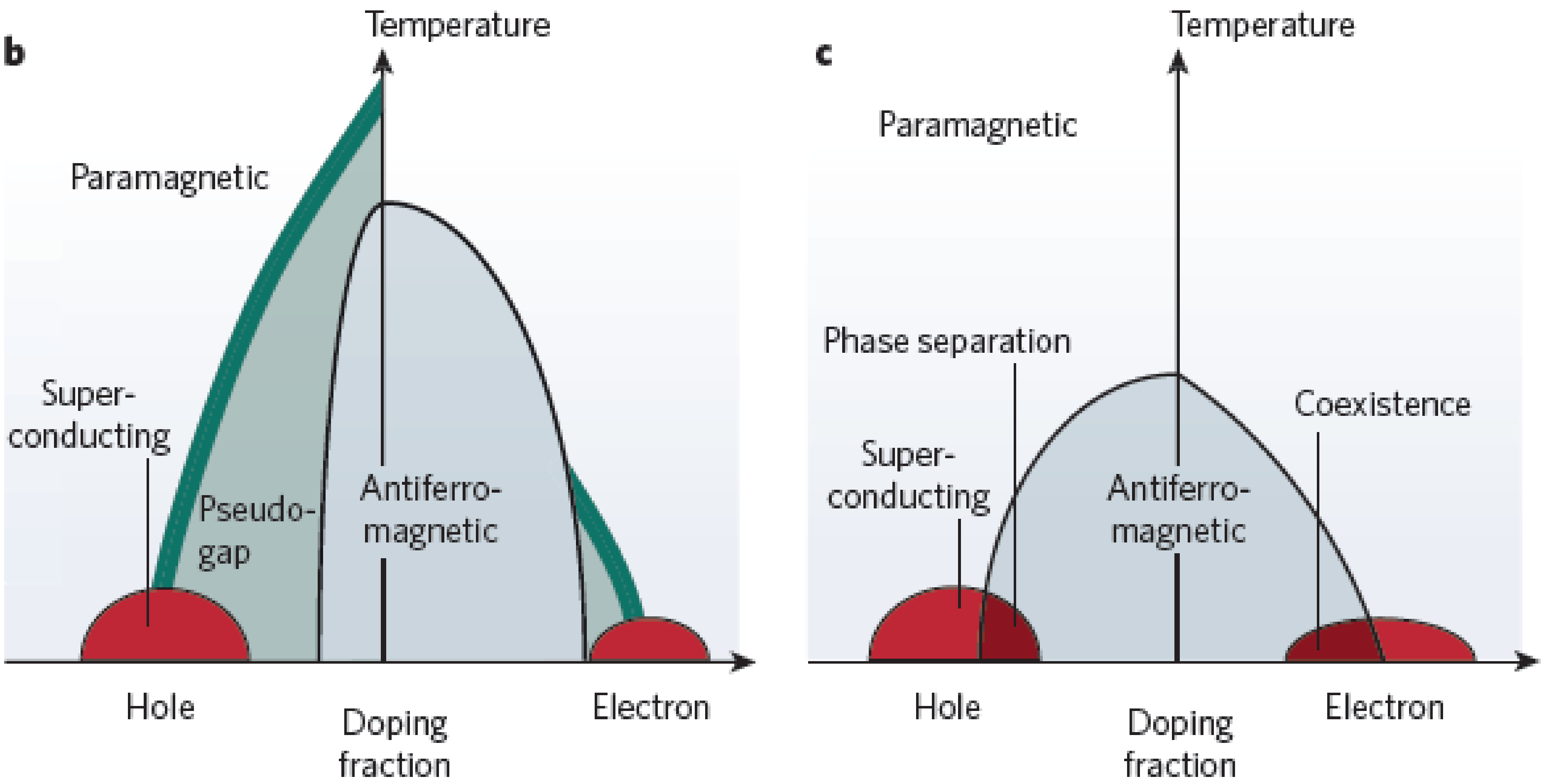
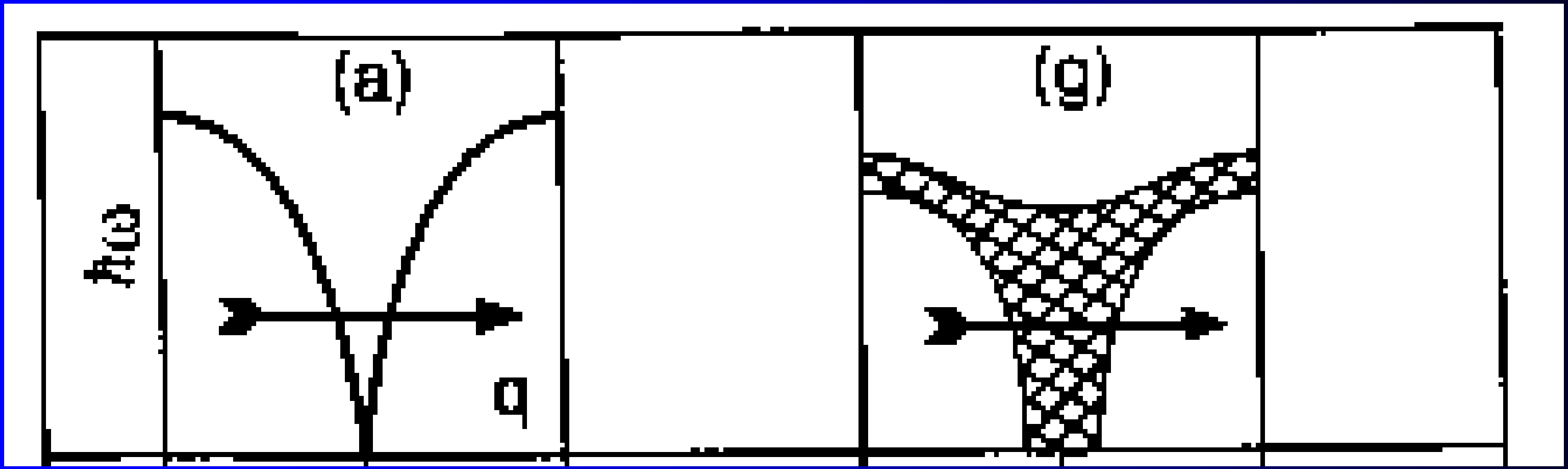
Phase diagrams of copper oxide and iron arsenide superconductors.



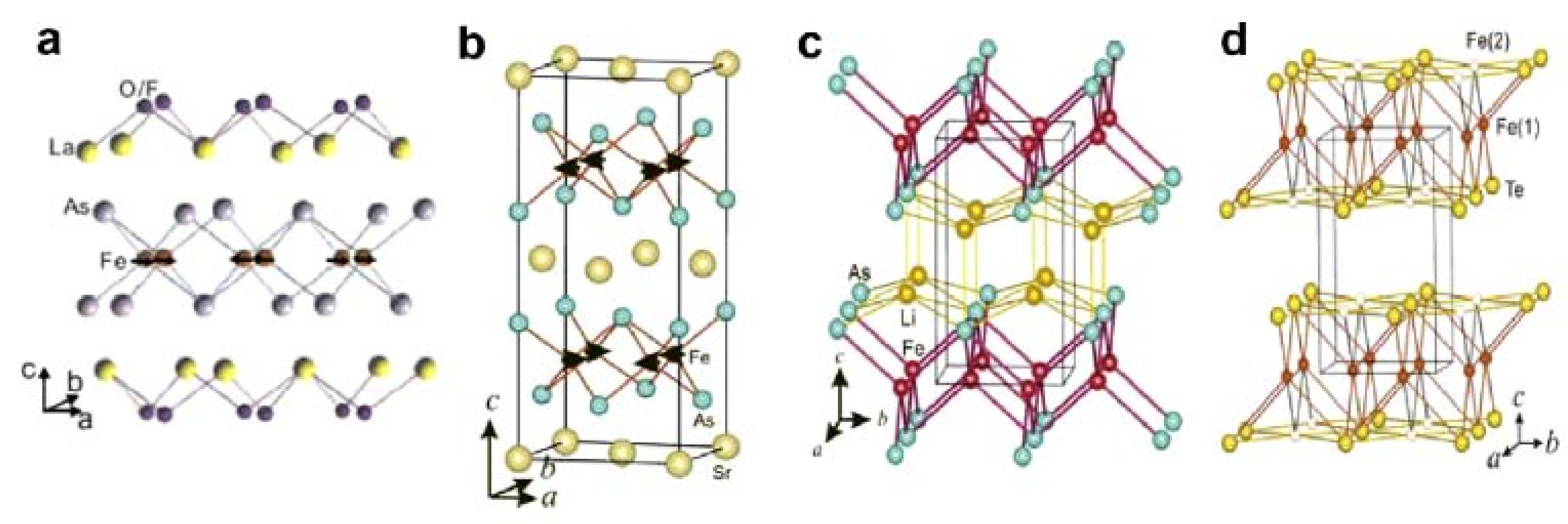
Mazin, Nature 464, 183 (2010).

Statement of the problem



- **How spin-waves in the parent compounds are modified as holes and electrons are doped into the parent compounds of high-T_c superconductors?**
- **How superconductivity interacts with spin excitations?**
- **What spin excitations can tell us about gap symmetry?**

Lattice structures of iron-based superconductors



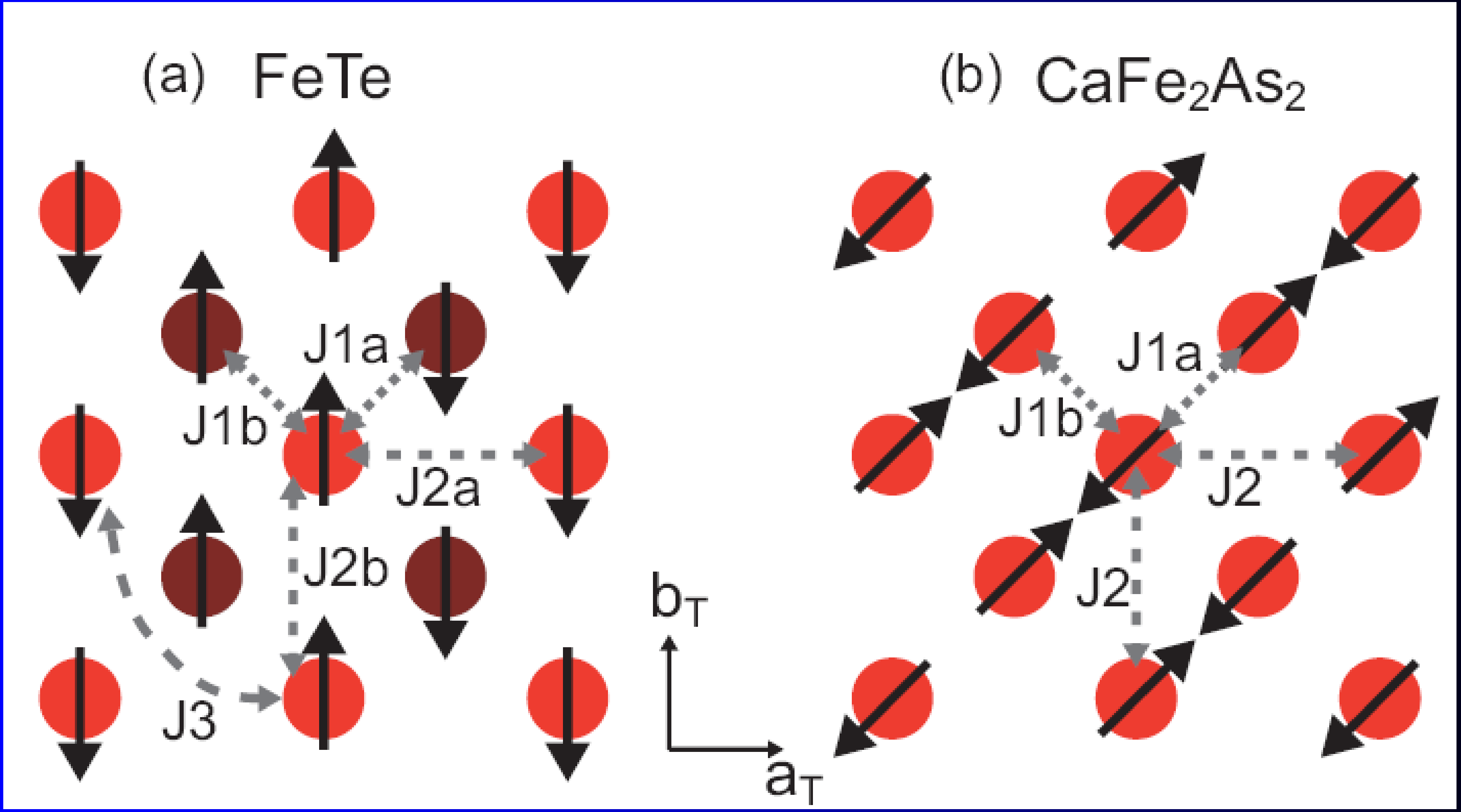
LaFeAsO
1111

BaFe2As2
122

LiFeAs
111

FeTe
11

Spin structures of Fe-based parent compounds

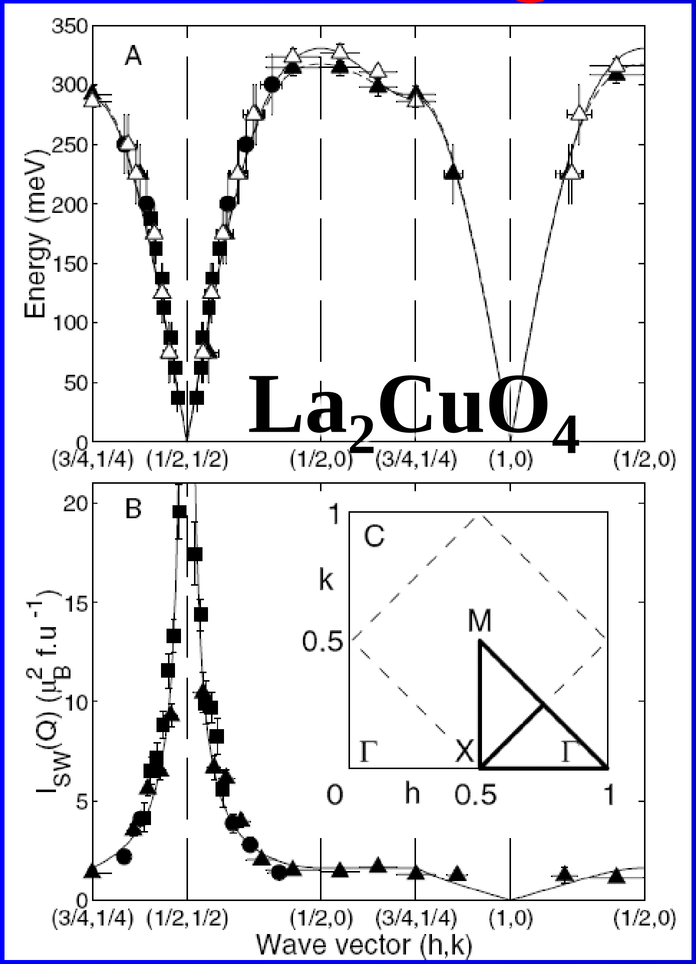


FeTe
11

CaFe2As2
122

What are the effective exchange couplings in FeAs?

Localized magnets

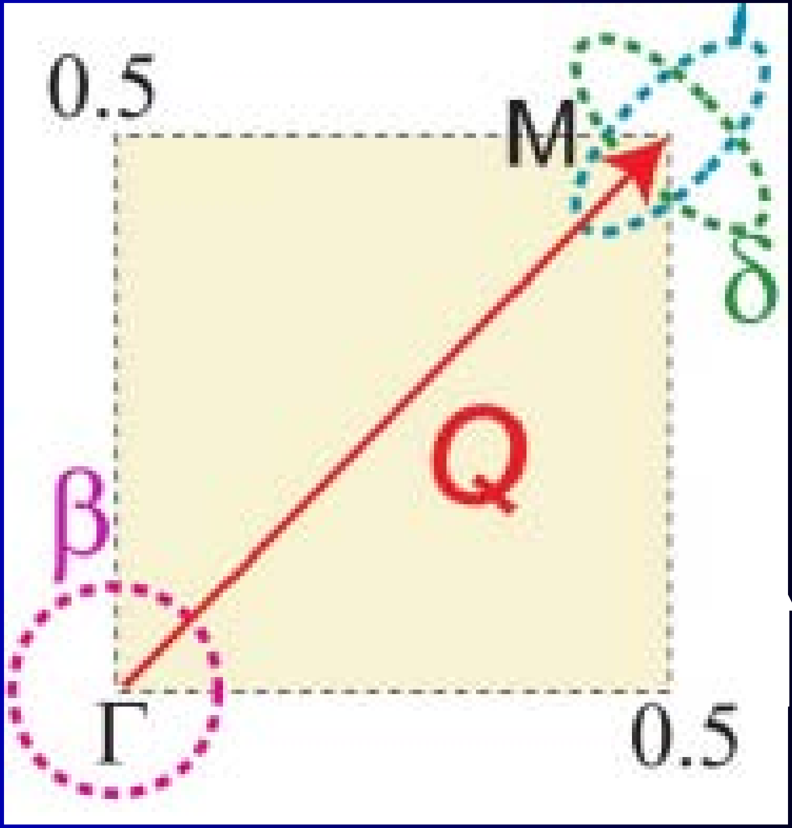


J = 112 meV

Coldea et al. PRL 86 5377 (2001)

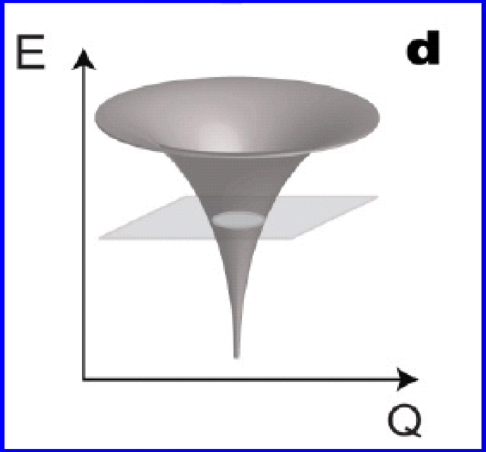
Exchange couplings between local moments

What about FeAs?



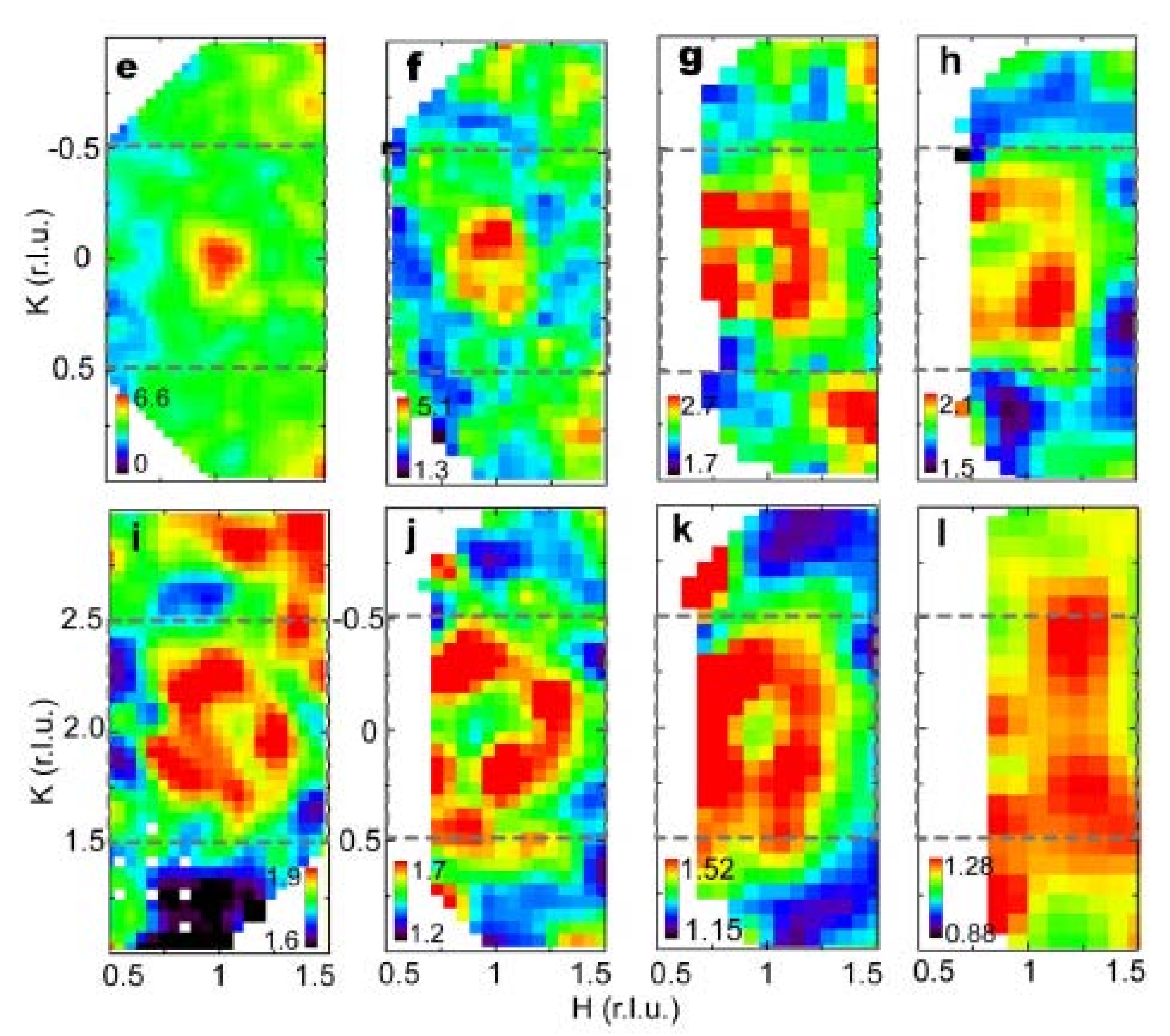
Fermi surface nesting in metals

Wave vector dependence of spin-waves in $CaFe_2As_2$



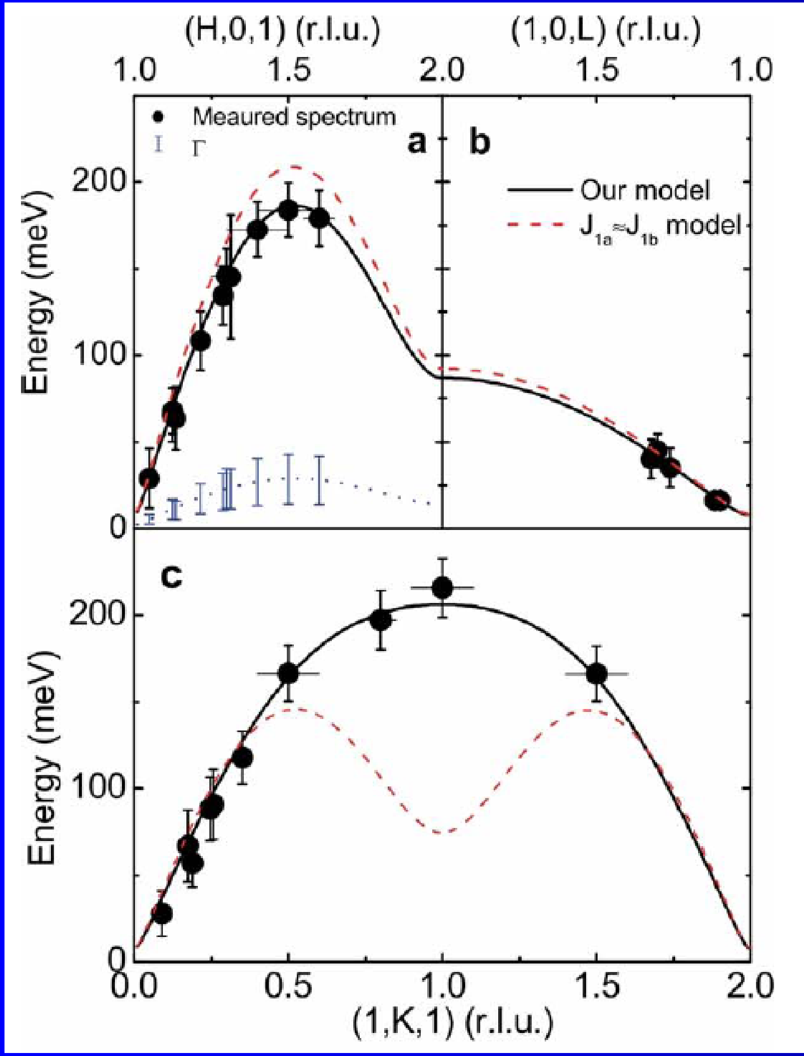
J. Zhao *et al.*, Nature Physics (2009)

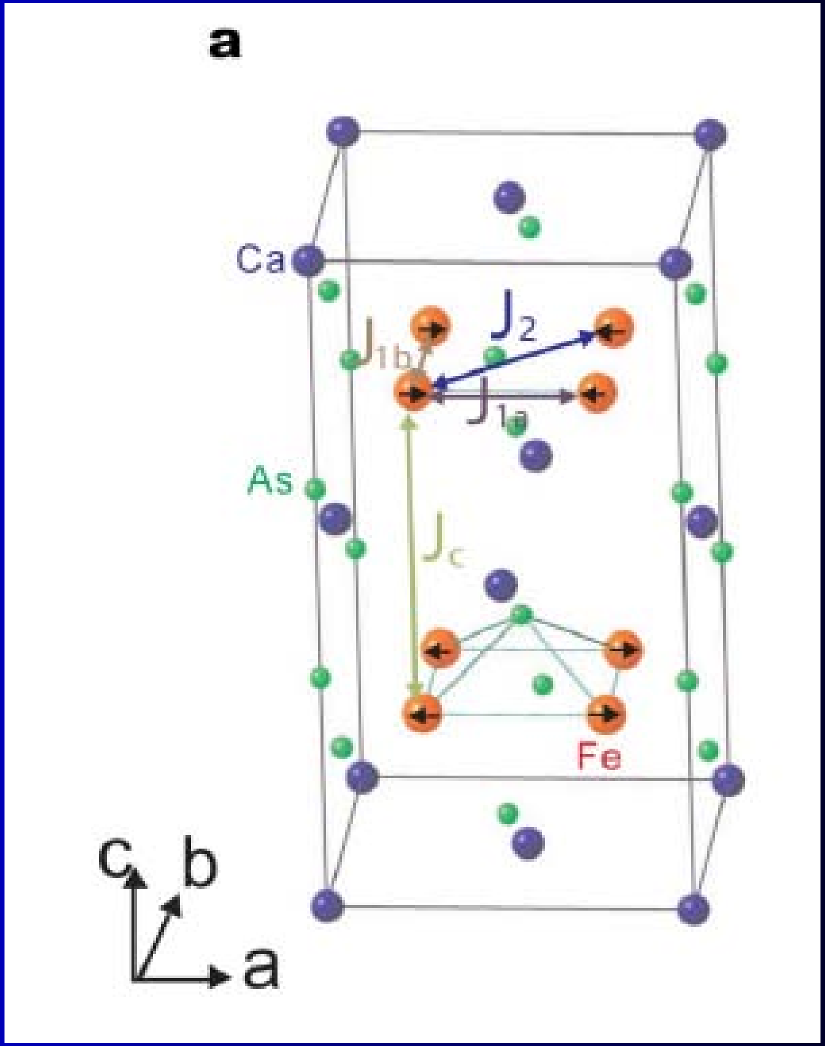
48 meV → 115meV



135meV → 175meV

Magnetic exchange couplings in $CaFe_2As_2$





SJ1a **= 49** ***SJ1b*** **= -5.7** ***SJ2*** **= 19** ***SJc*** **= 5.3 meV**

Jun Zhao *et al.*, Nature Physics 5, 555 (2009).

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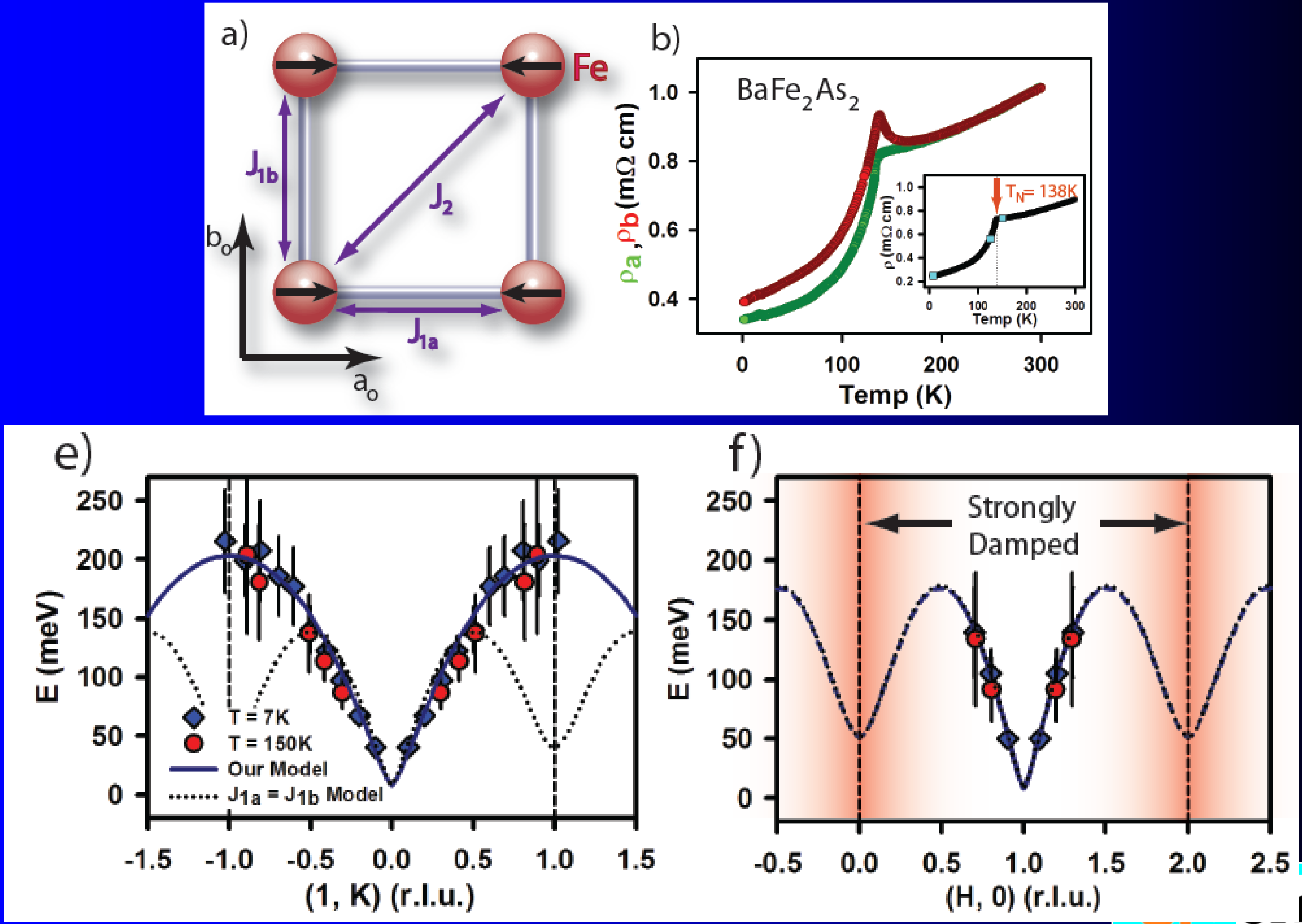
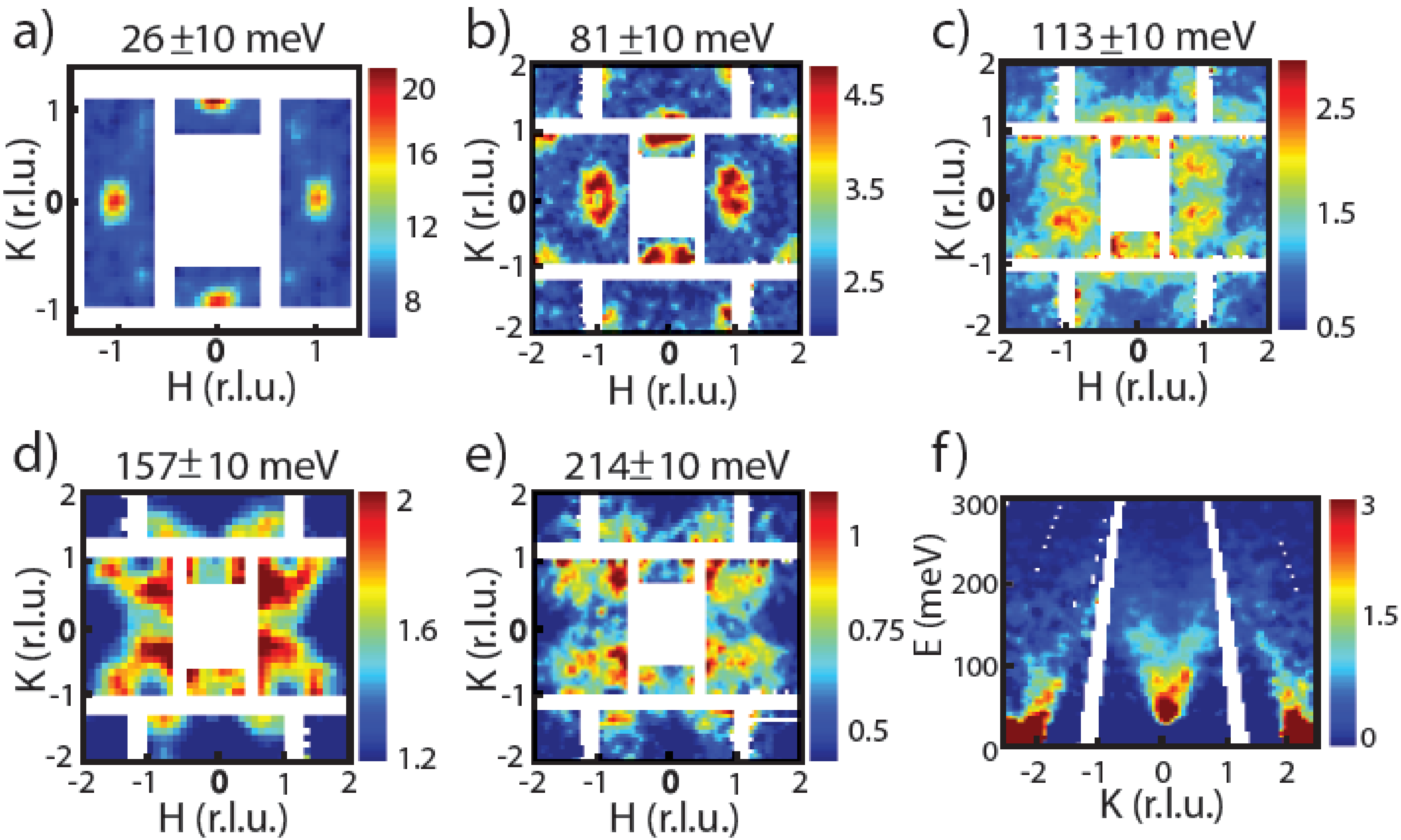
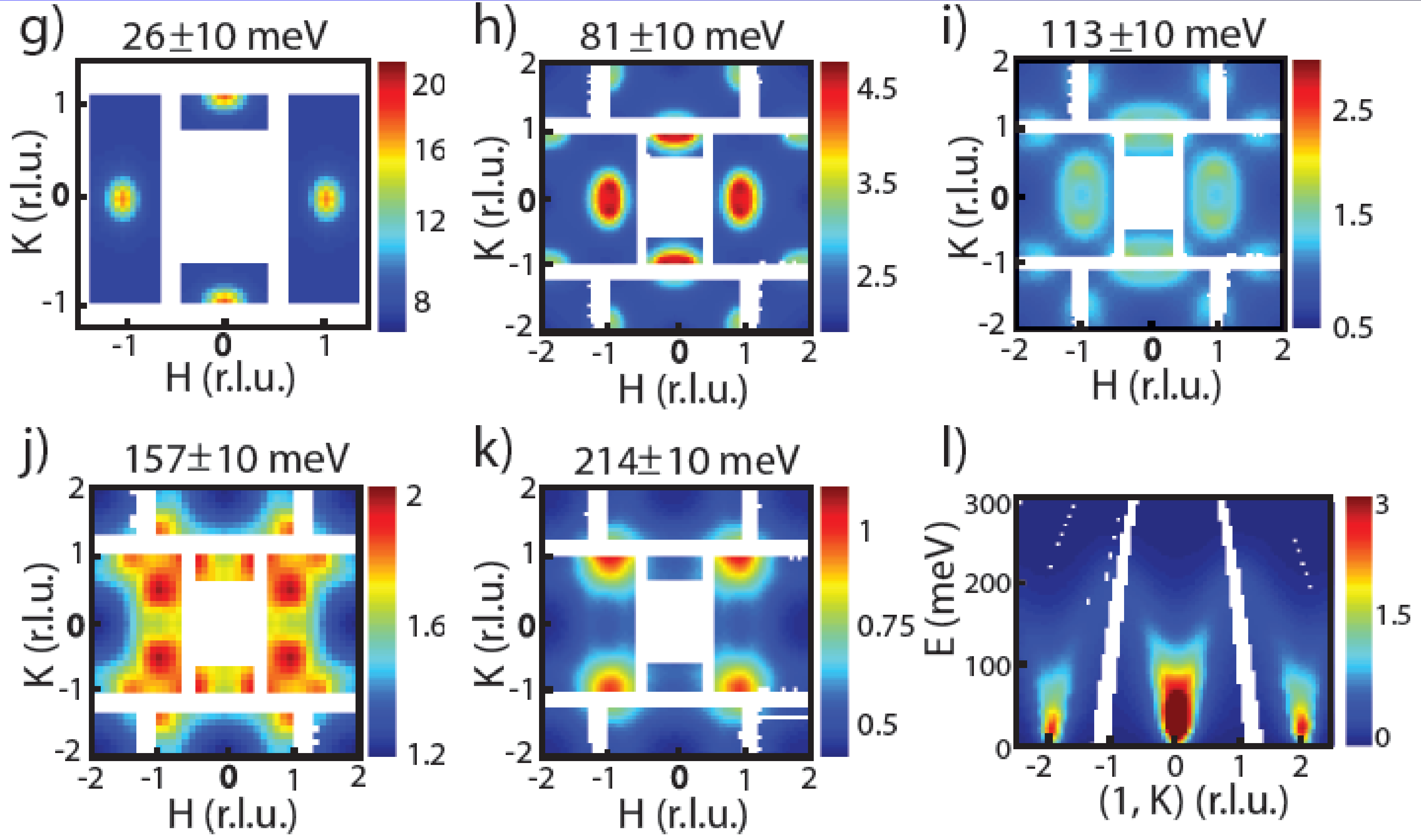
Wave vector dependence of spin-waves in $BaFe_2As_2$



Wave vector dependence of spin-waves in $BaFe_2As_2$

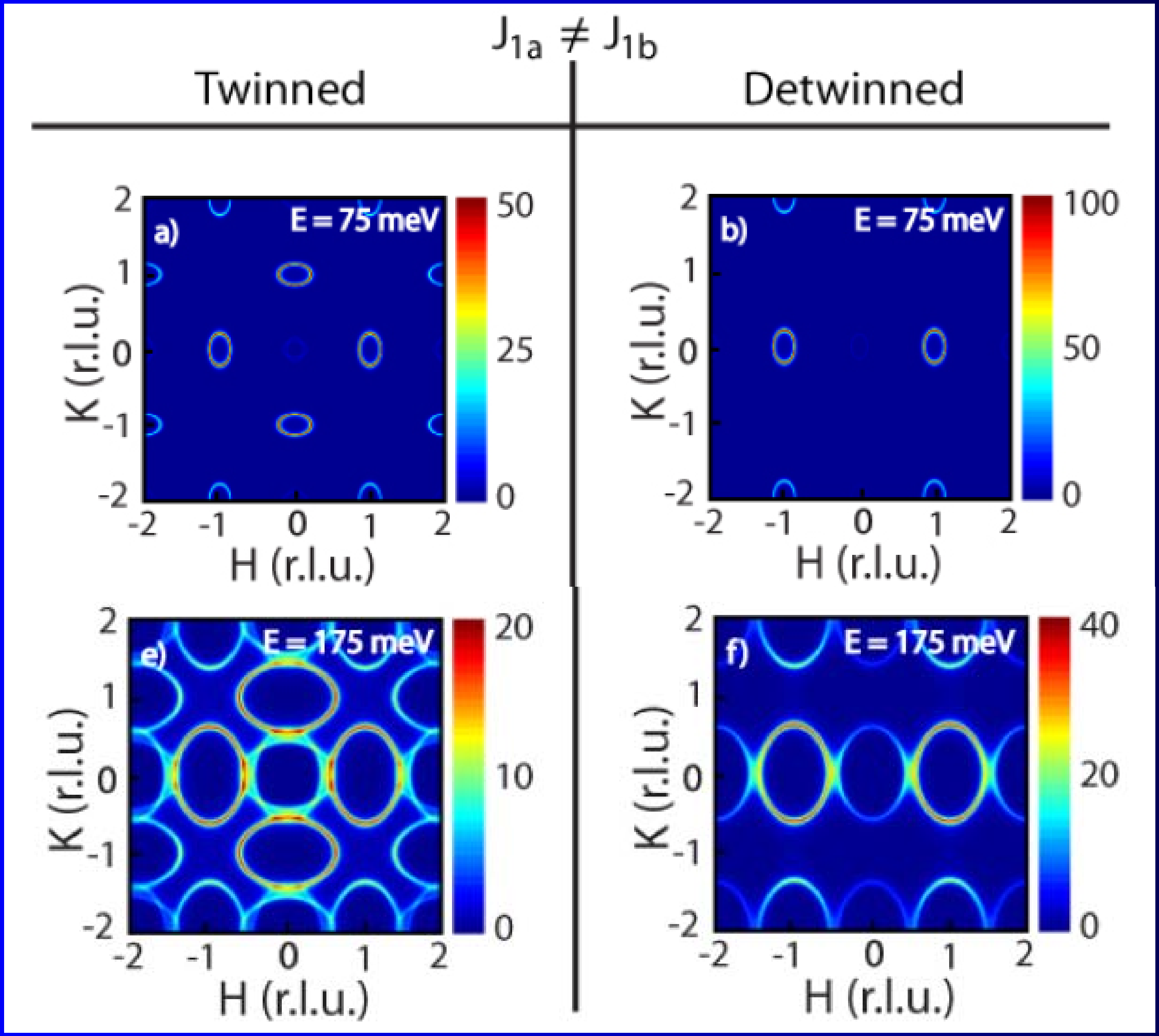


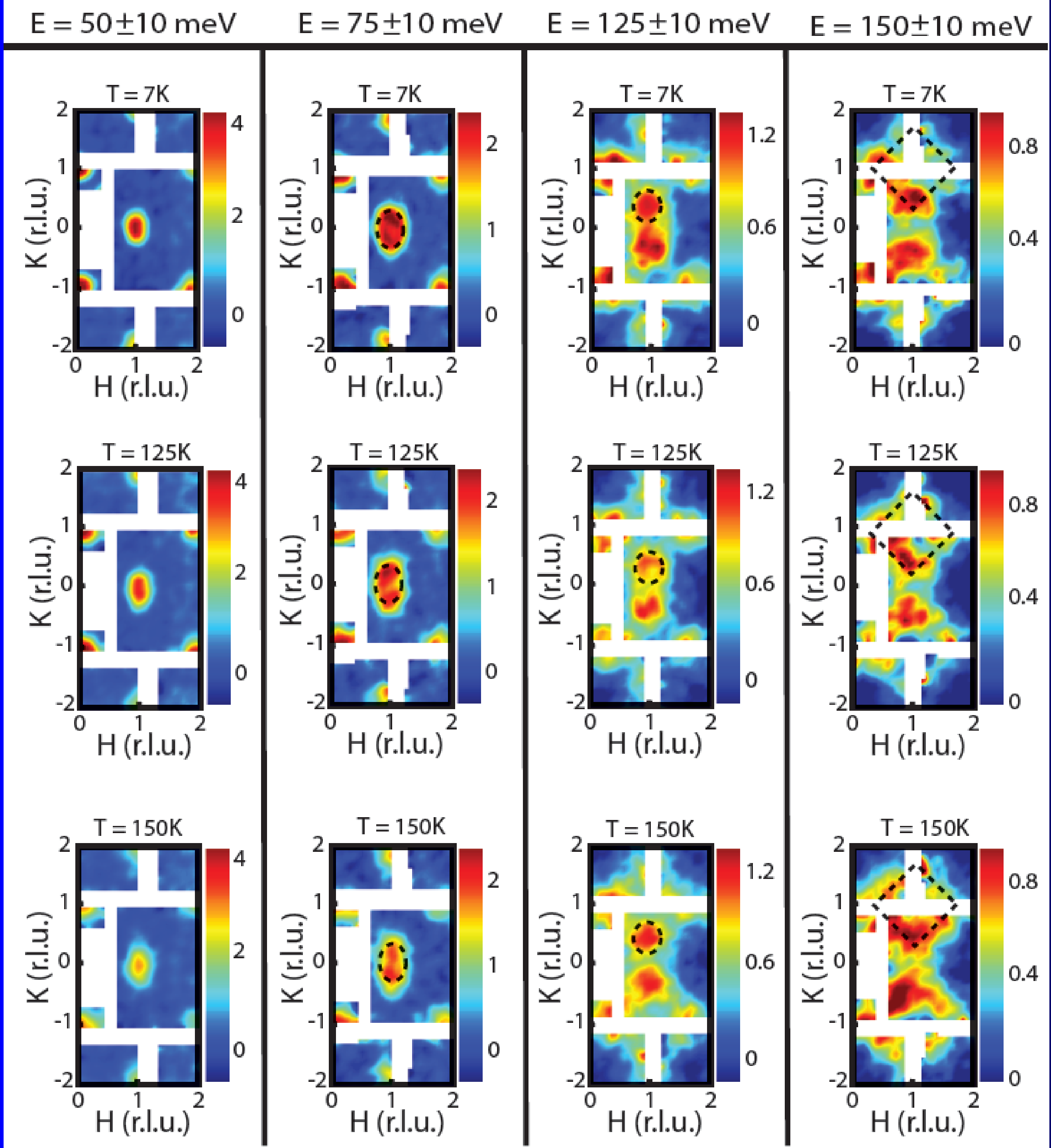
Model calculation of spin-waves in $BaFe_2As_2$



***SJ1a* = 59 meV *SJ1b* = -9 meV *SJ2*= 13 meV *SJ3* = 2 meV**

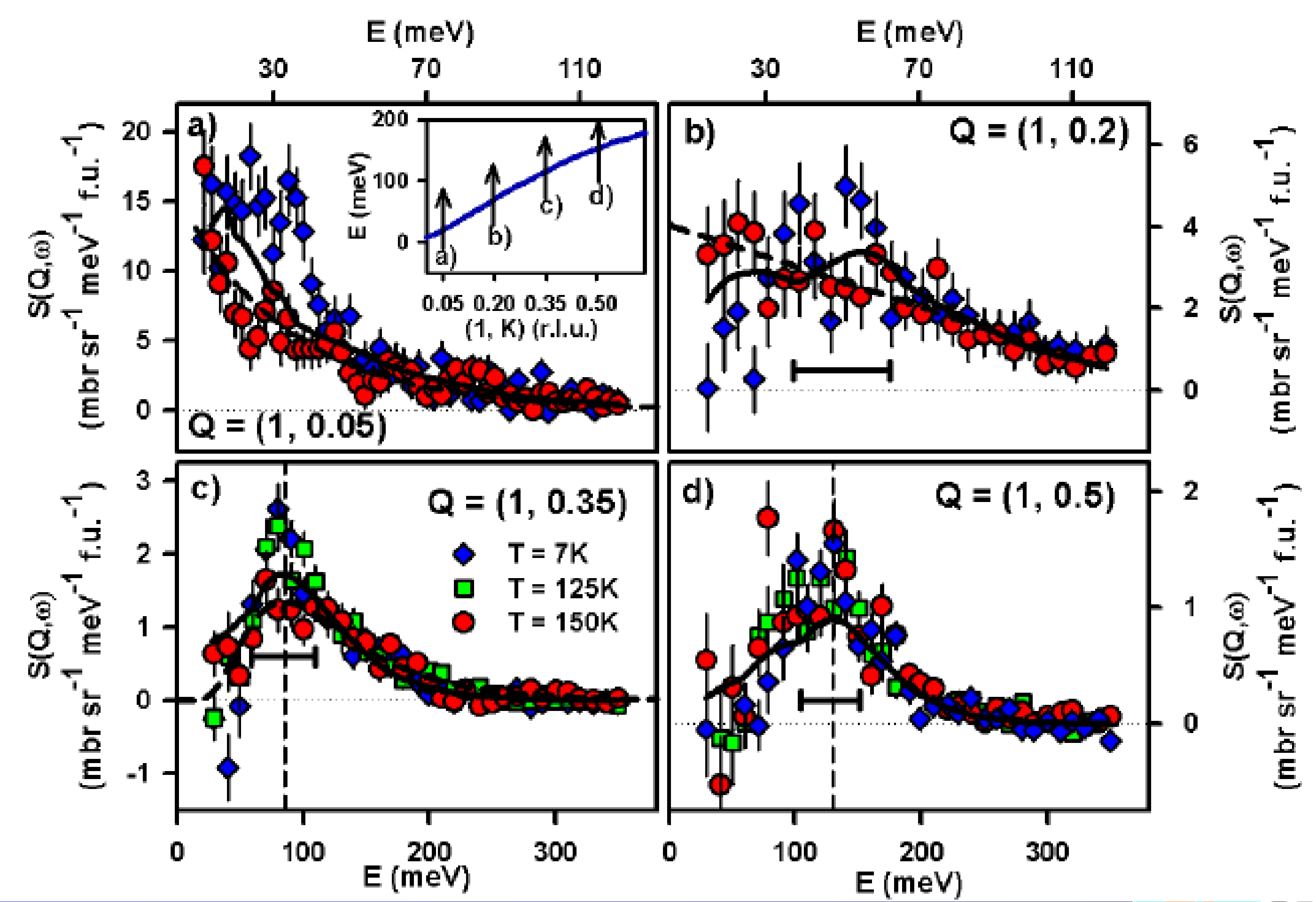
Model calculation on the effect of twinning to the spin-waves in $BaFe_2As_2$



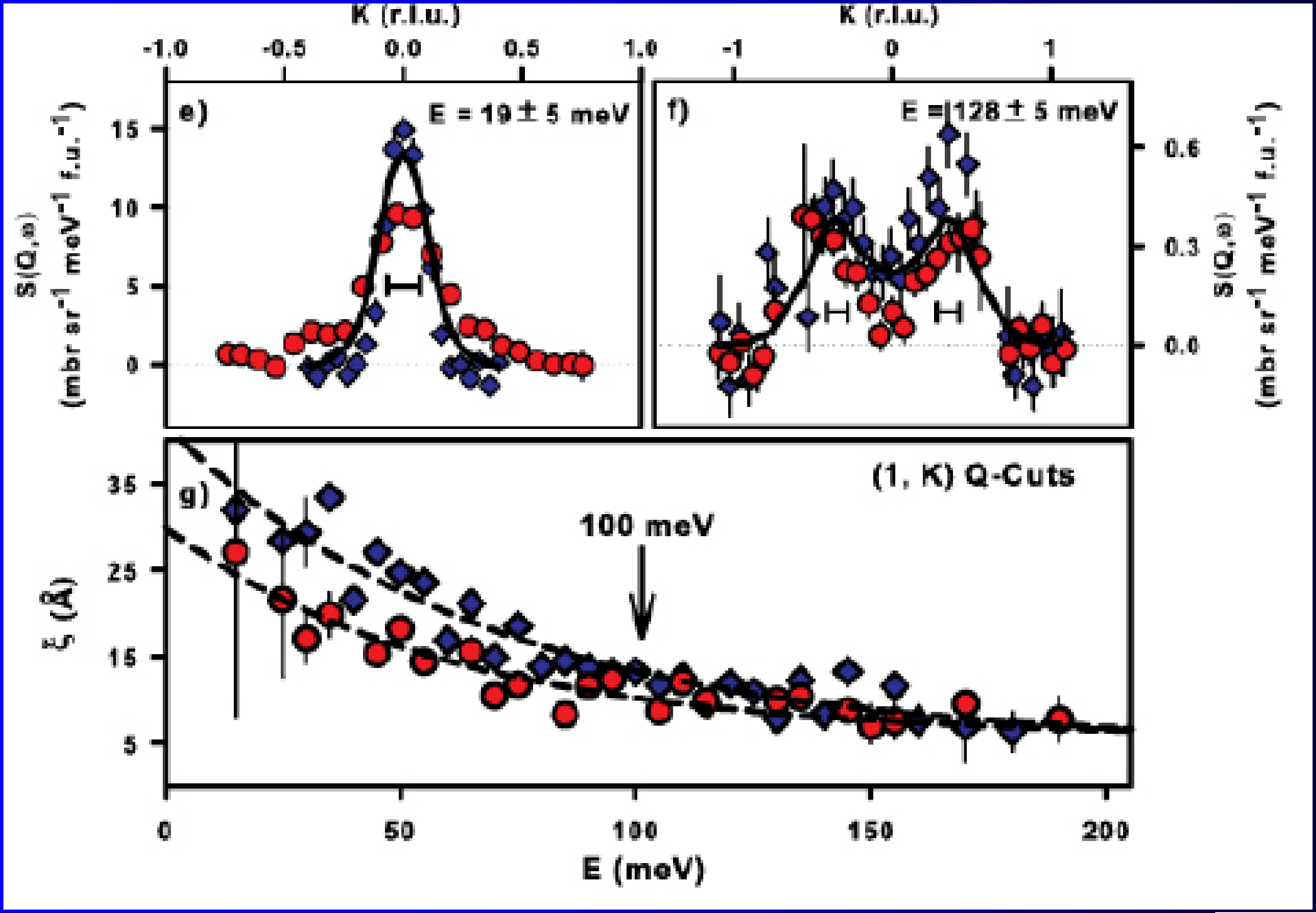


Temperature dependence of spin-waves in $BaFe_2As_2$

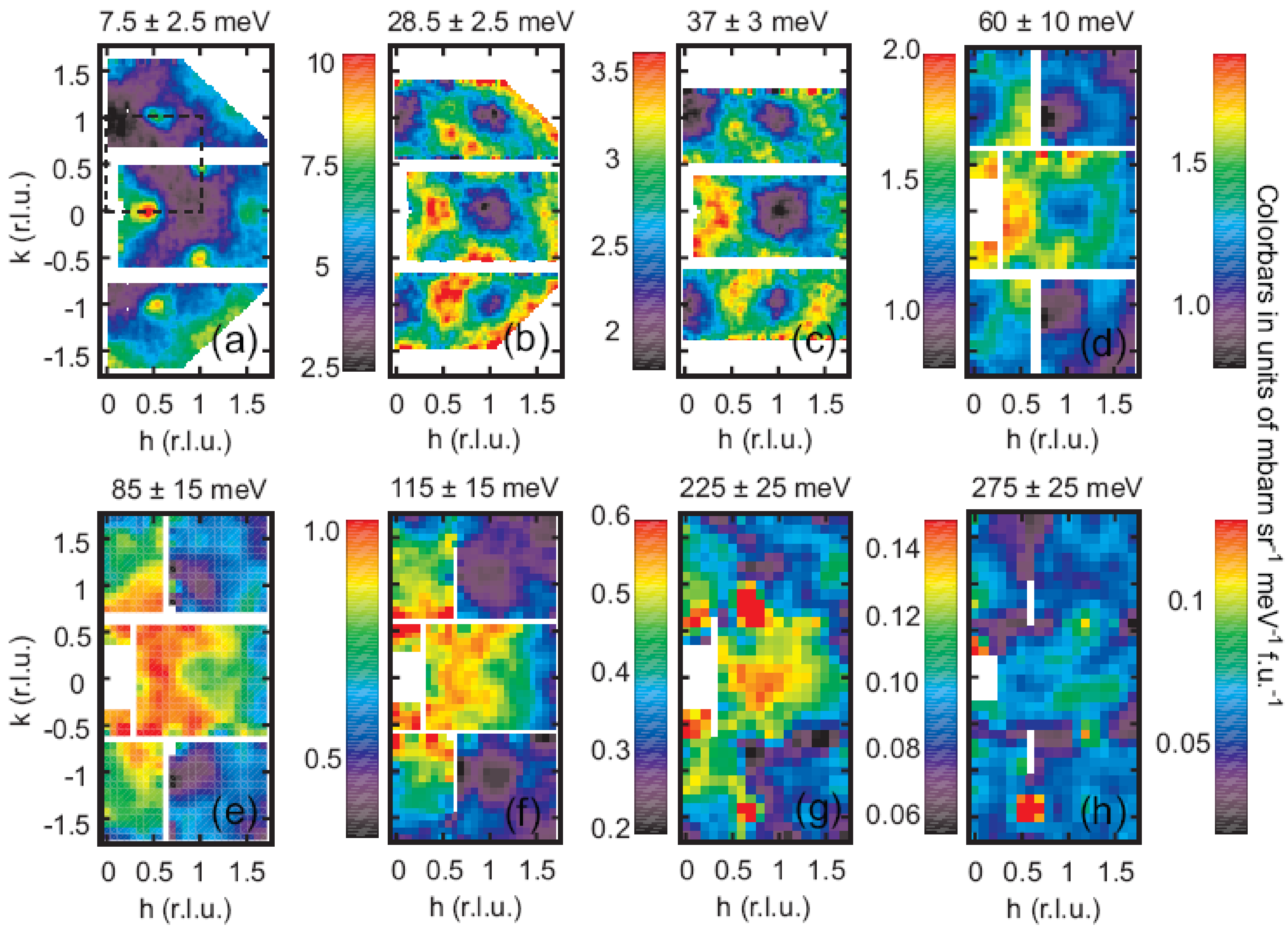
Temperature dependence of spin-waves in $BaFe_2As_2$



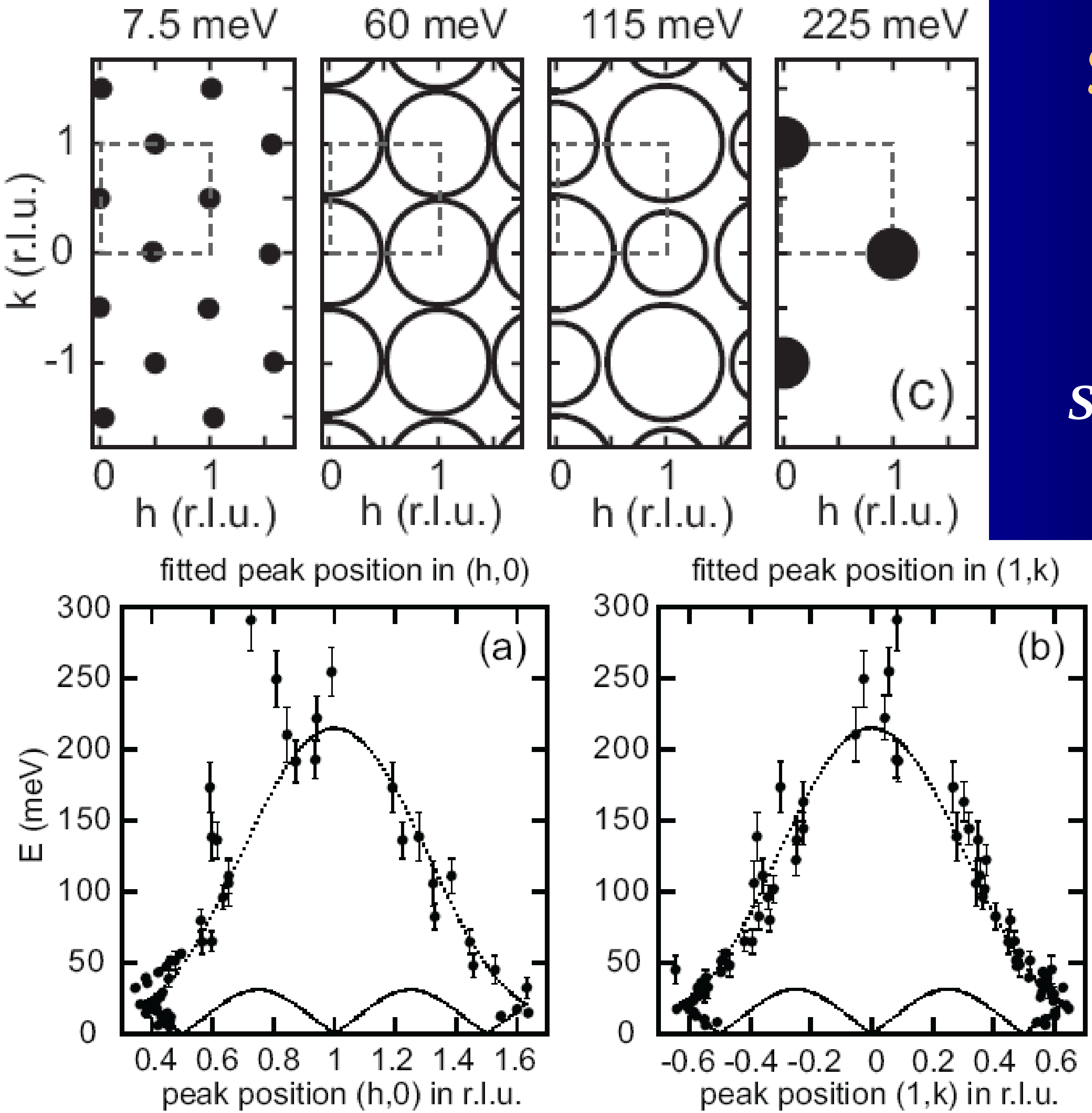
Energy dependence of spin-spin correlations above and below T_N in $BaFe_2As_2$



Spin waves in FeTe



Spin waves in FeTe



***SJ1a* = -17 meV**

***SJ1b* = -51 meV**

***SJ2a*=*SJ2b* = 22 meV**

***SJ3* = 6.8 meV**

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What have we learned about the spin waves in in FeAs and FeTe parent compounds?

Nearest neighbor exchange couplings are strong anisotropic for FeAs-based materials, and the exchange anisotropy persists to the paramagnetic state when the system becomes tetragonal. Having features for both local moment and itinerant electrons.

The nearest neighbor exchange couplings in FeAs and FeTe are quite different, but the next nearest neighbor exchange couplings are antiferromagnetic and directional independent for both FeAs and FeTe. Since the neutron spin resonance in FeAs and FeTe occurs in the same wavevector, this suggests that it is the next neighbor coupling that controls the resonance.

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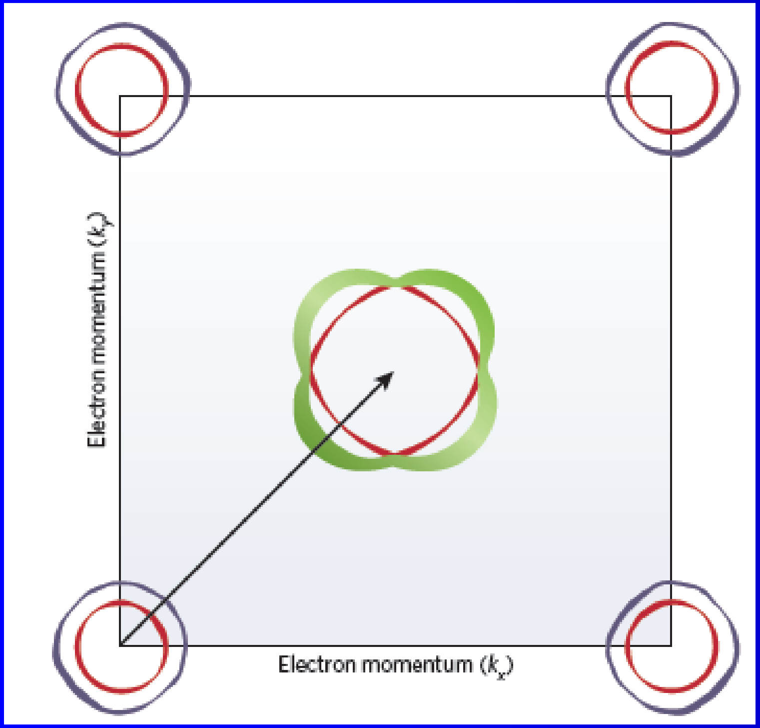
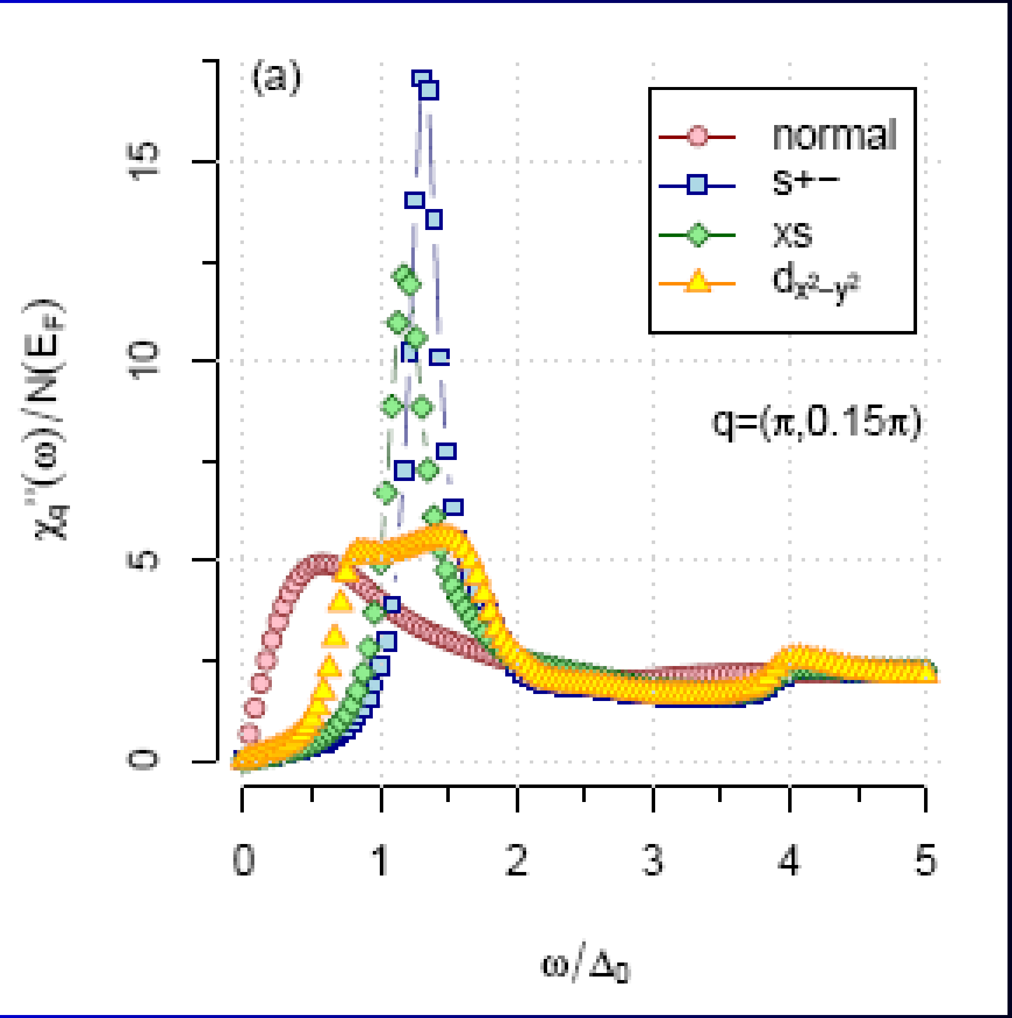
Resonance a spin exciton from s+- wave pairing.

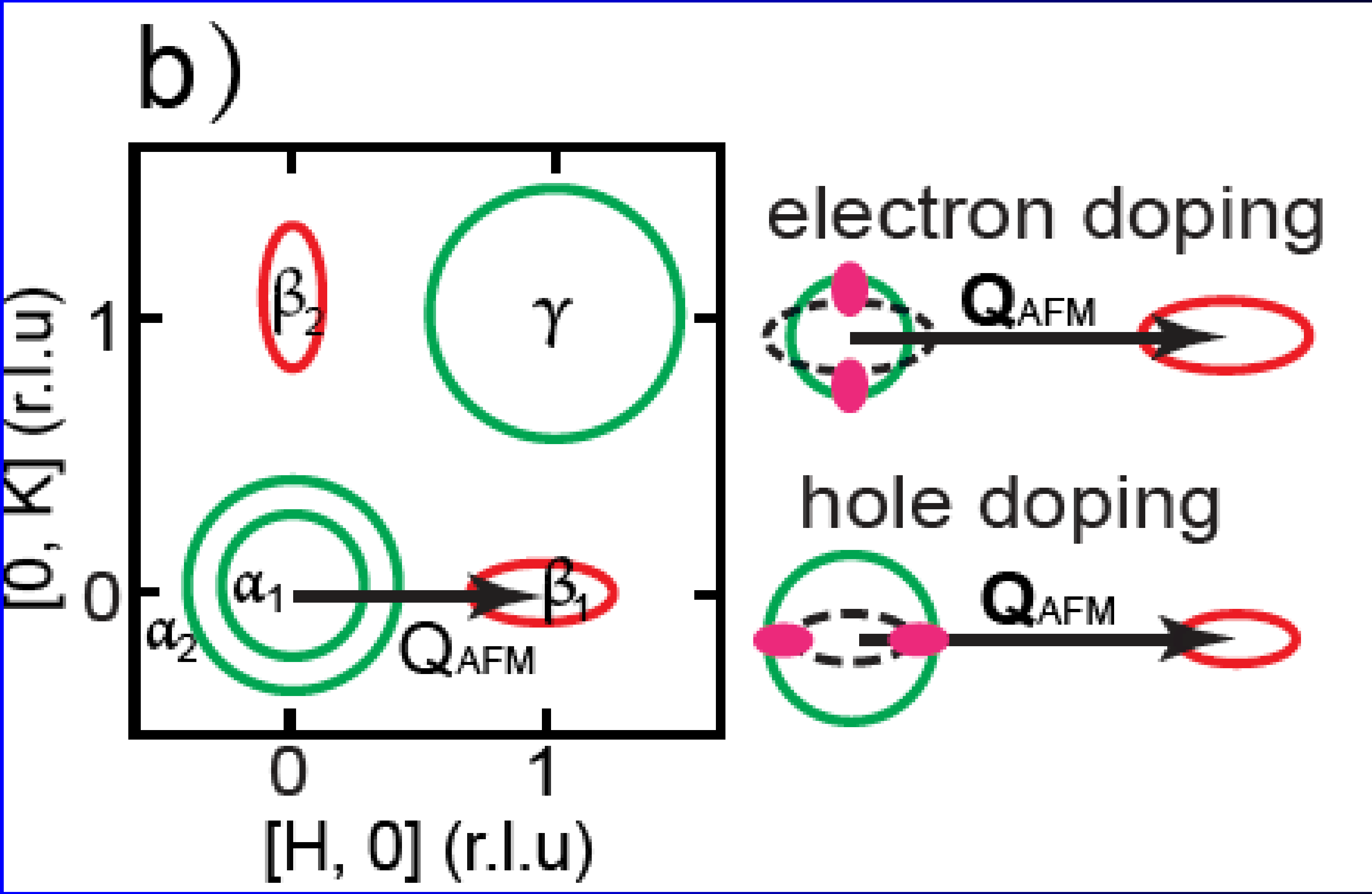




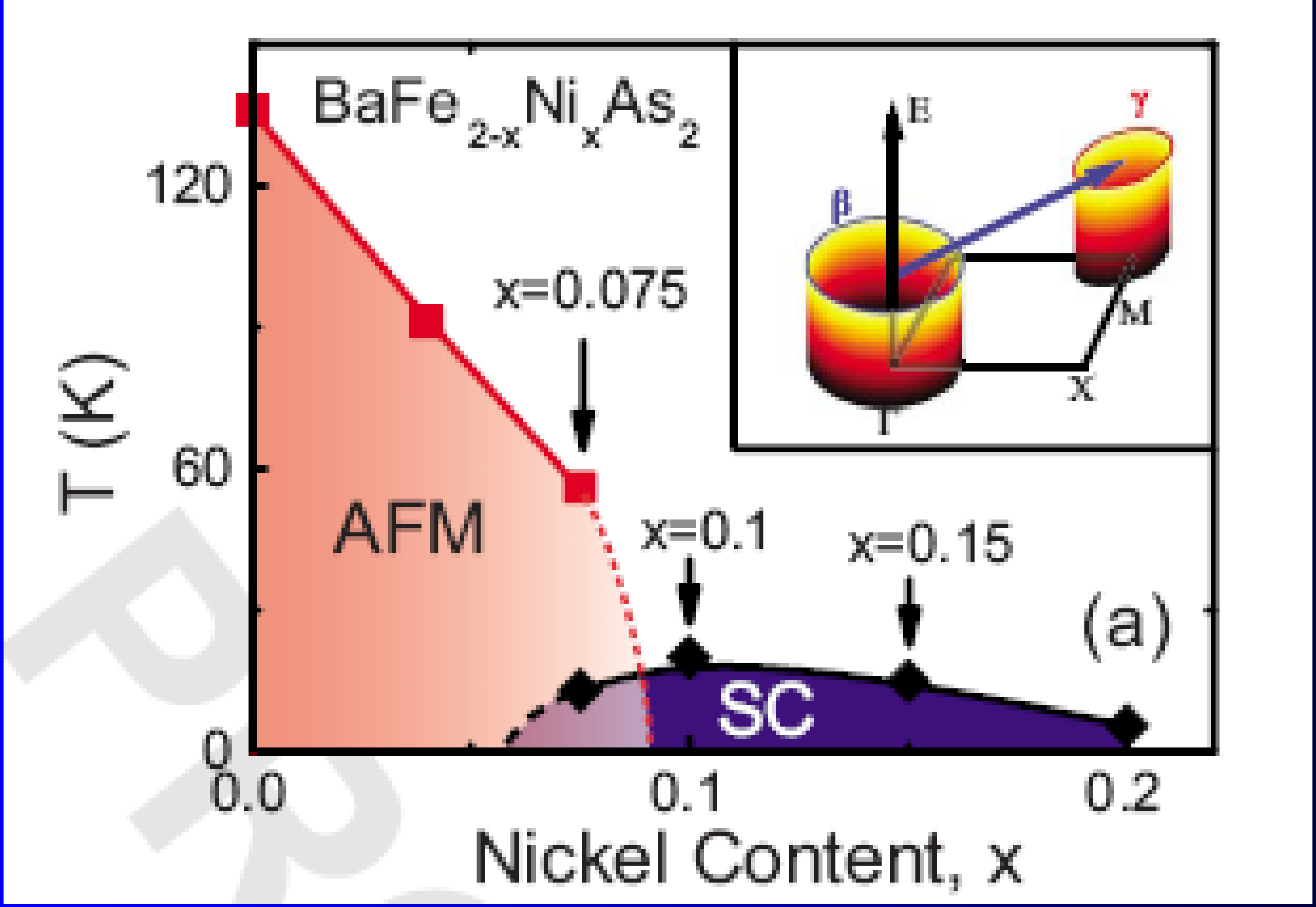
Mazin *et al.*,
PRL 101, 057003 (2008).
T. A. Maier *et al.*,
PRB 79, 134520 (2009).

$$\hbar\omega = |\Delta(k+Q)| + |\Delta(k)|$$

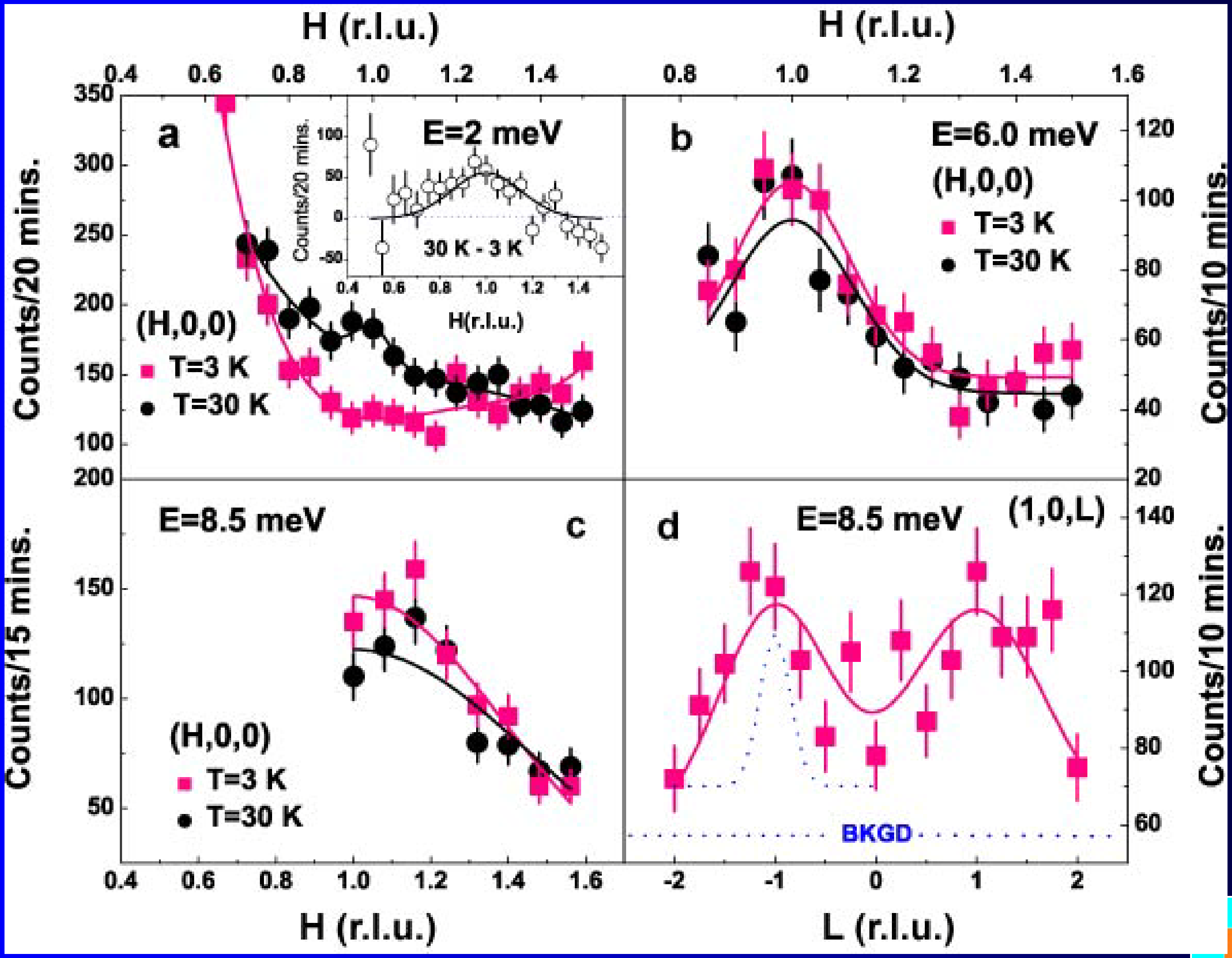
The effective of electron and hole doping?



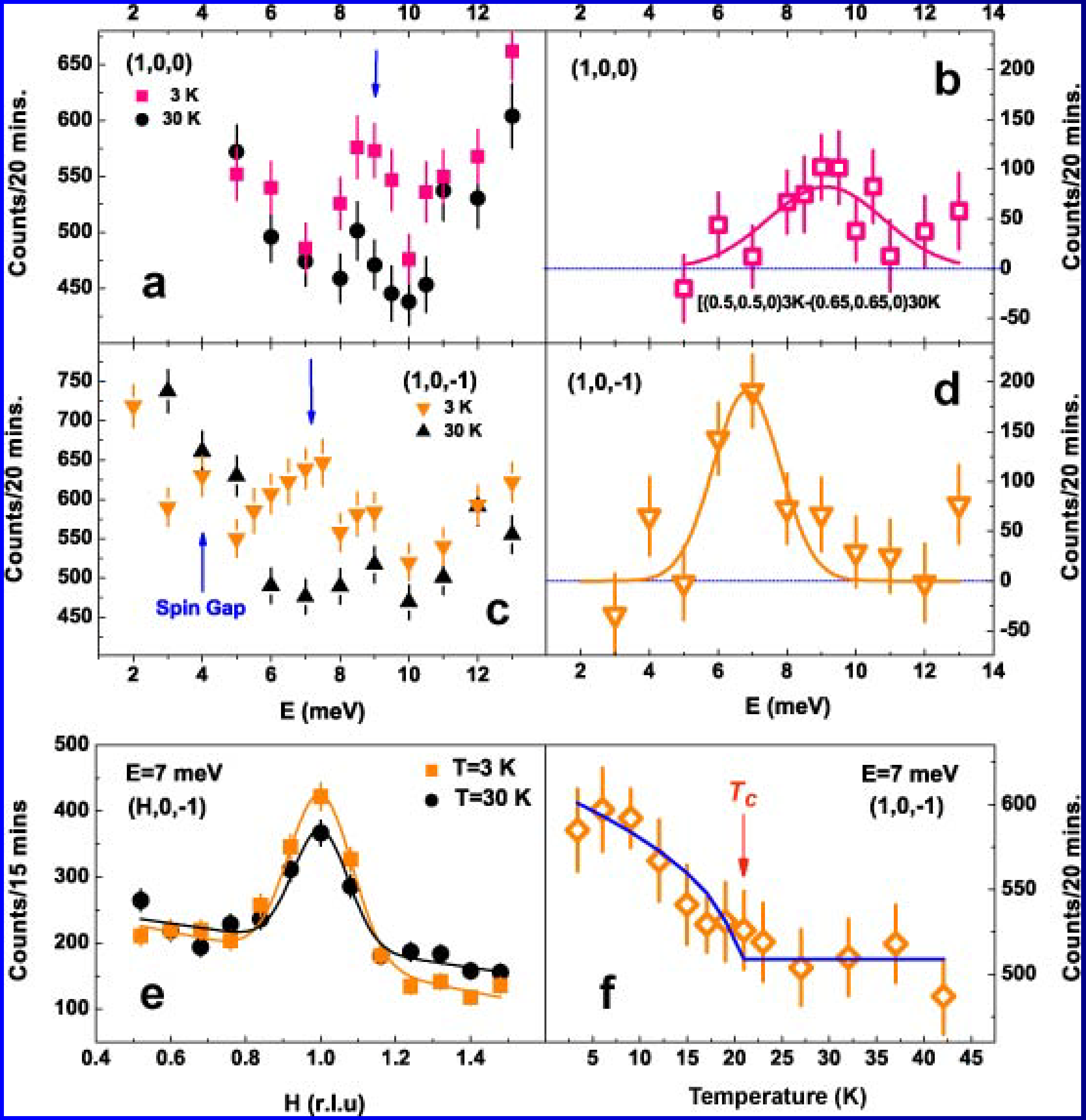
How do one use the resonance to probe superconducting gap nature of $BaFe_{2-x}Ni_xAs_2$?



Low-energy spin fluctuations in superconducting $BaFe_{1.9}Ni_{0.1}As_2$



Dispersion of the neutron spin resonance at Q=(1,0,0) and Q=(1,0,1) in $BaFe_{1.9}Ni_{0.1}As_2$



S. Chi *et al.*,
PRL 102, 107006 (2009).
S. Li *et al.*, PRB (2009).

Dispersion of the mode
Clean spin gap below the resonance.

Agree with thermo-conductivity data.

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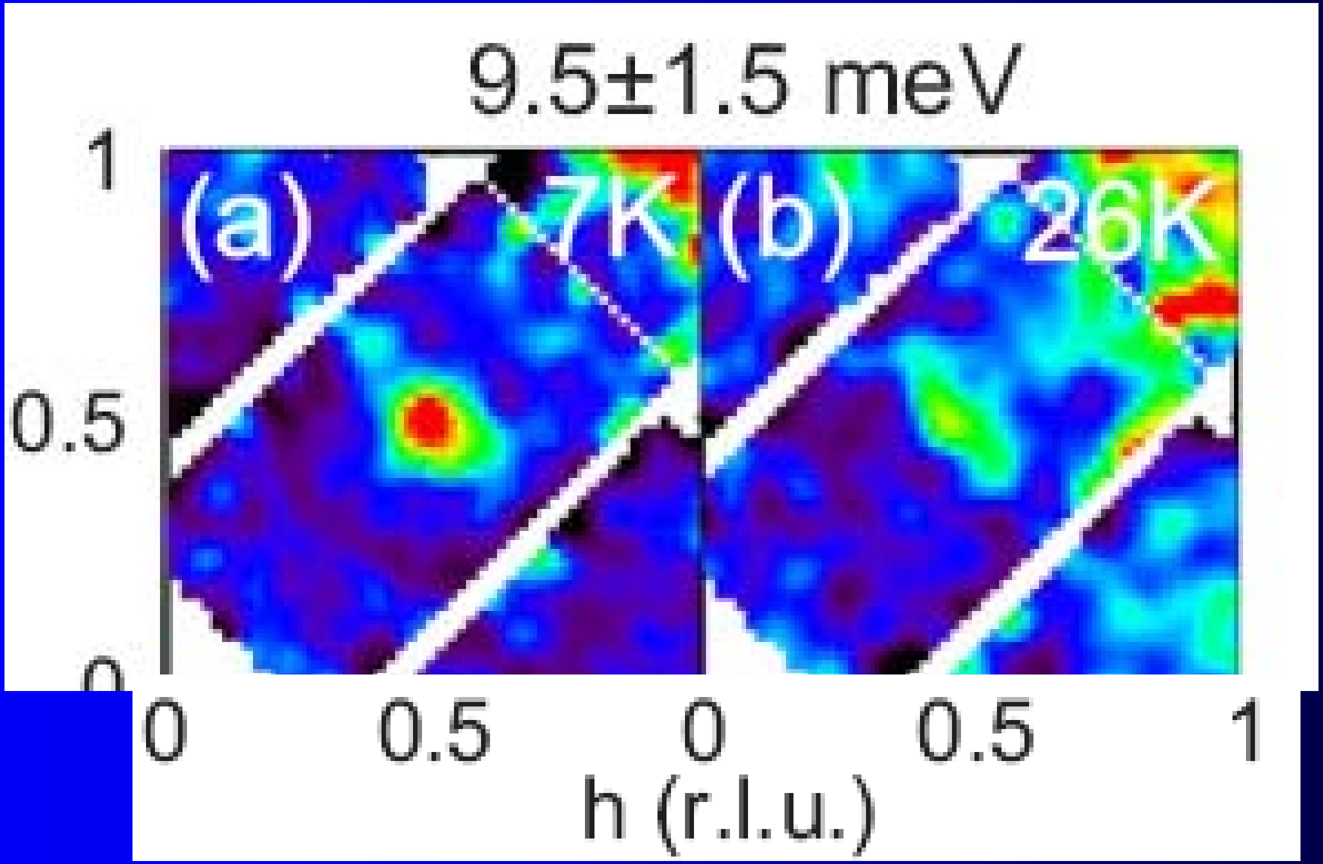
Momentum anisotropy of spin resonance at Q=(1,0,1) in $BaFe_{1.9}(Co,Ni)_{0.1}As_2$



PHYSICAL REVIEW B **81**, 064505 (2010)

Dispersive spin fluctuations in the nearly optimally doped superconductor $Ba(Fe_{1-x}Co_x)_2As_2$ ($x=0.065$)

C. Lester,[1] Jiun-Haw Chu,[2,3] J. G. Analytis,[2,3] T. G. Perring,[4] I. R. Fisher,[2,3] and S. M. Hayden[1]

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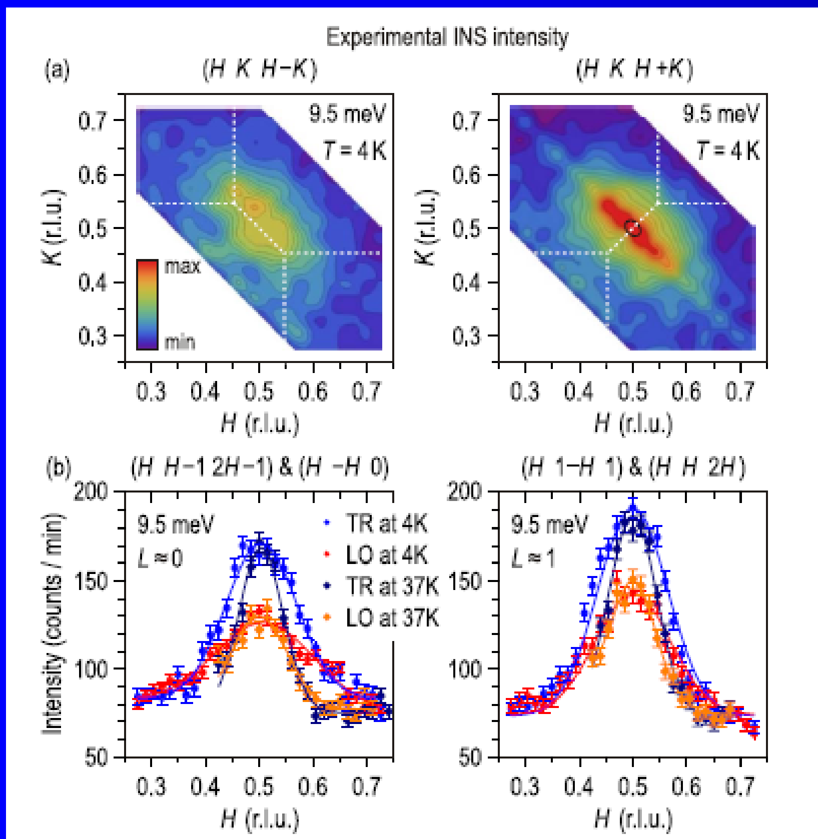
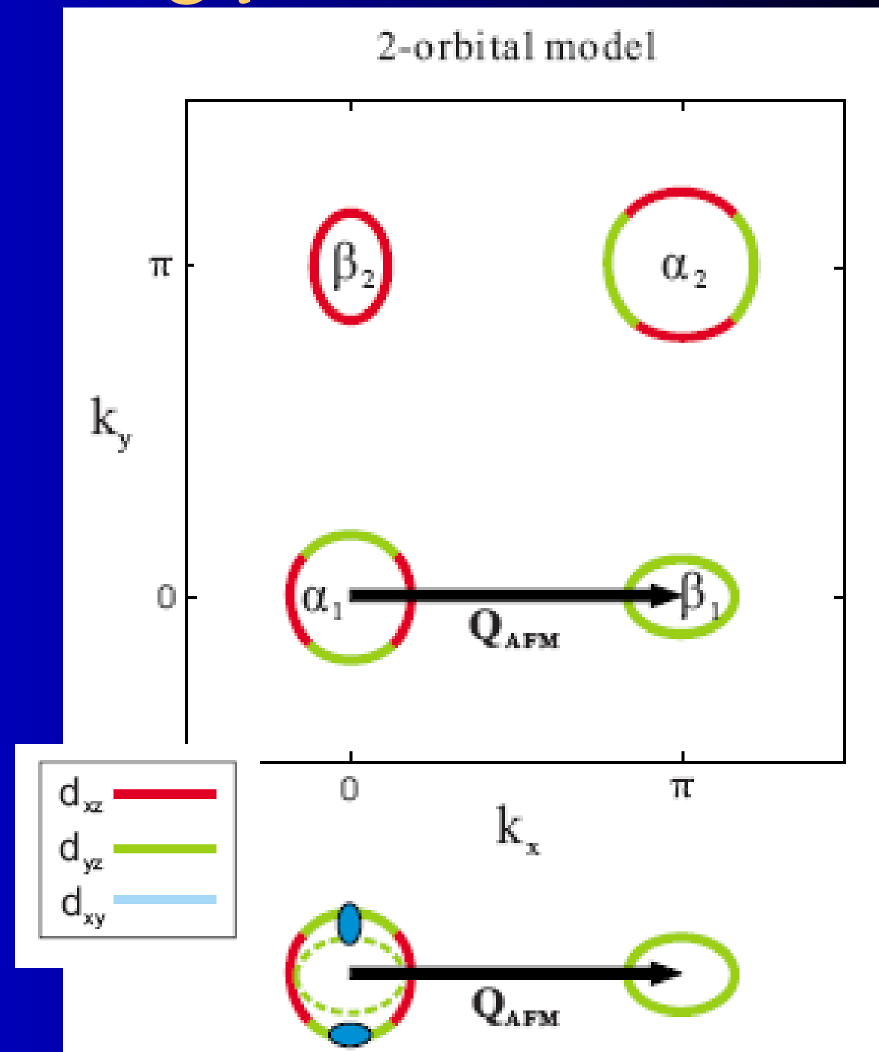
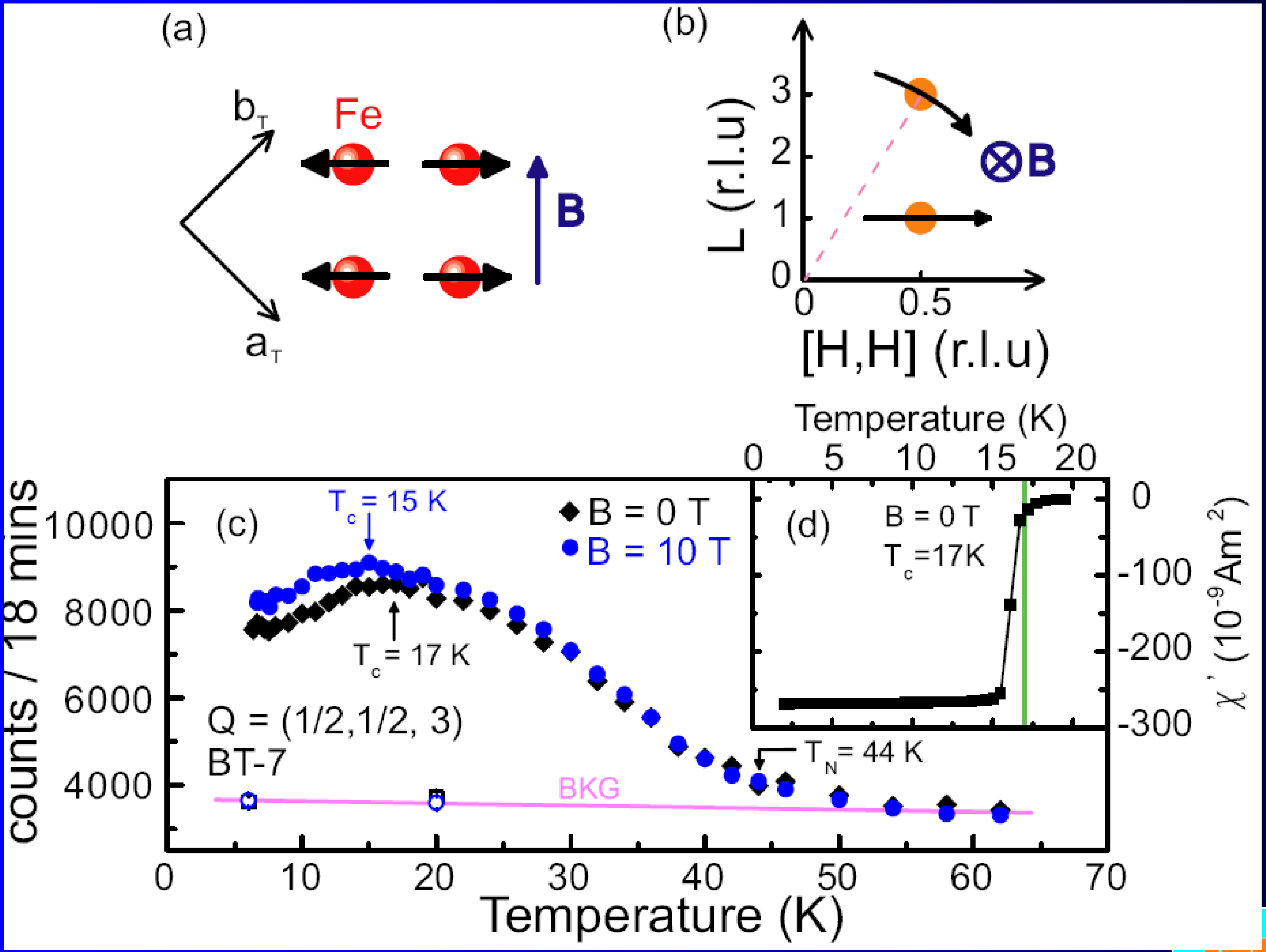
Momentum anisotropy of spin resonance in electron-doped case is due to intra-orbital, but interband pairing process!





Park *et al.*, PRB 82, 134503 (2010).
Zhang *et al.*, PRB 82, 134527 (2010).

Do we have microscopic or mesoscopic co-existing AF and superconducting phases?



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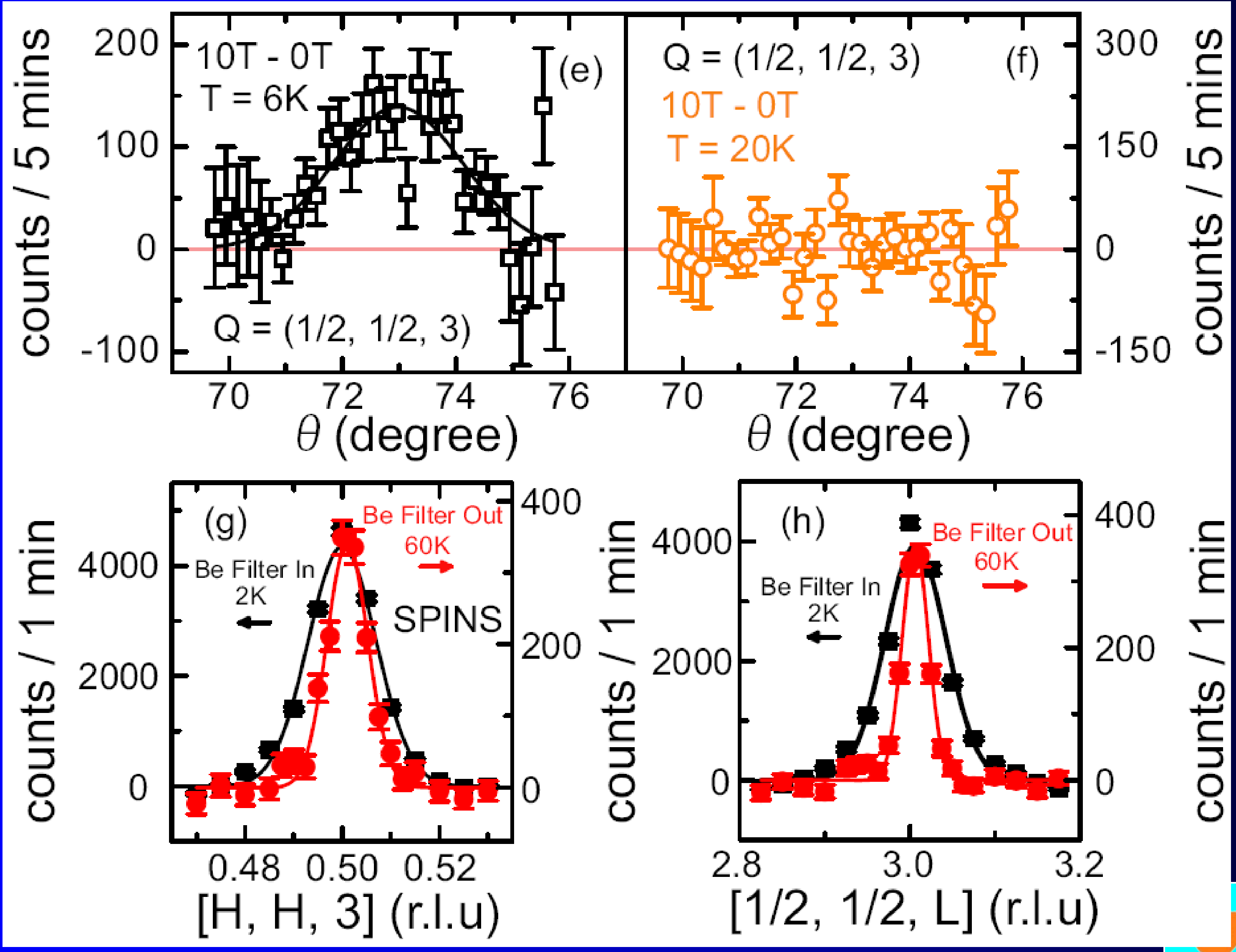
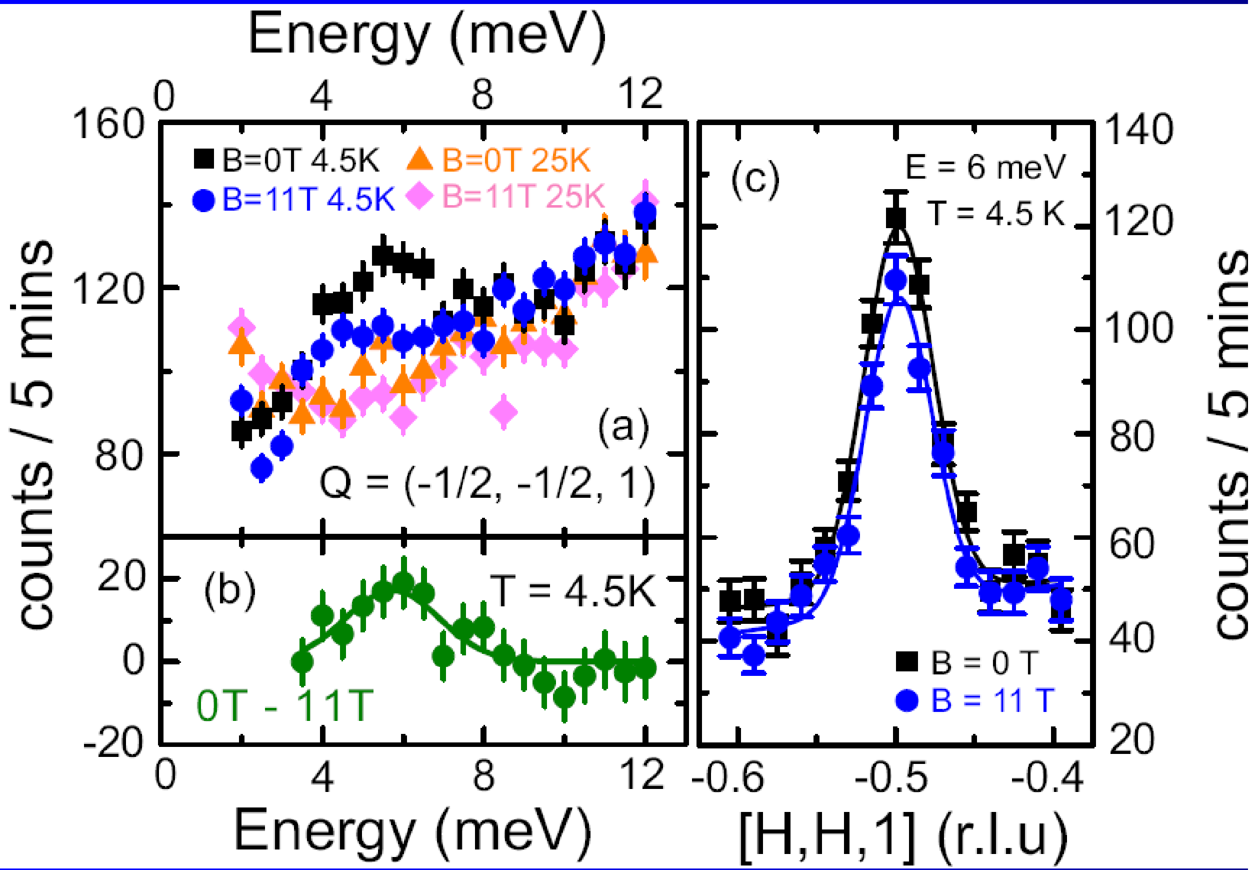
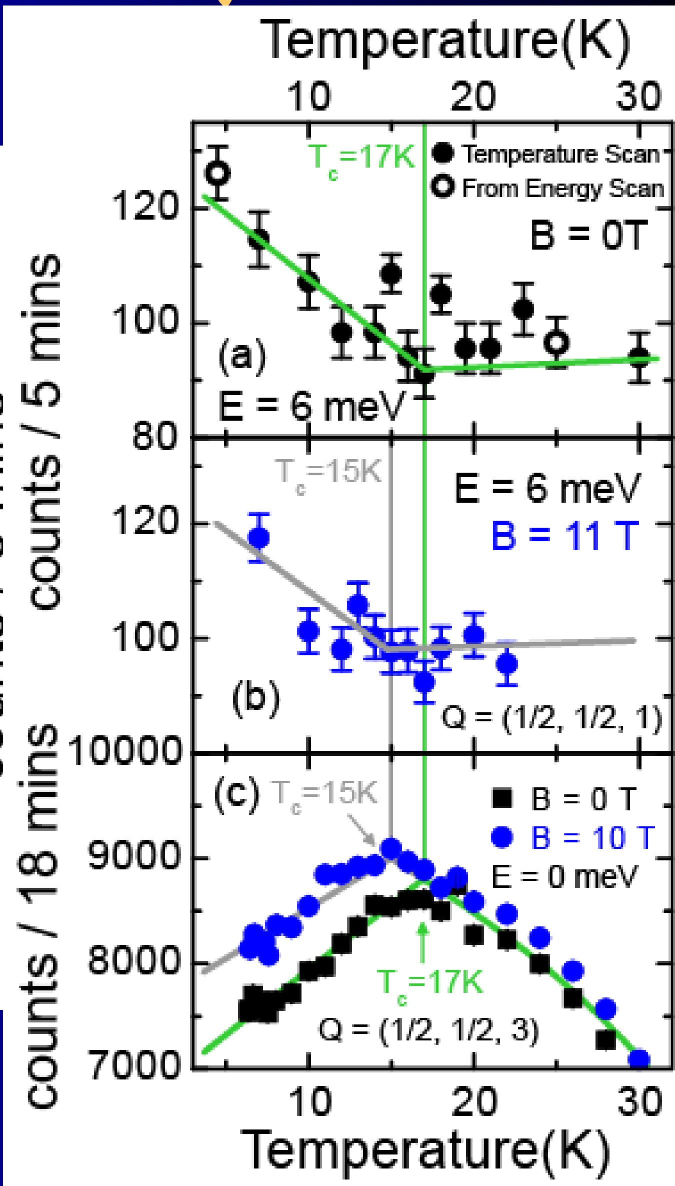
Do we have long range AF order co-existing with superconductivity?

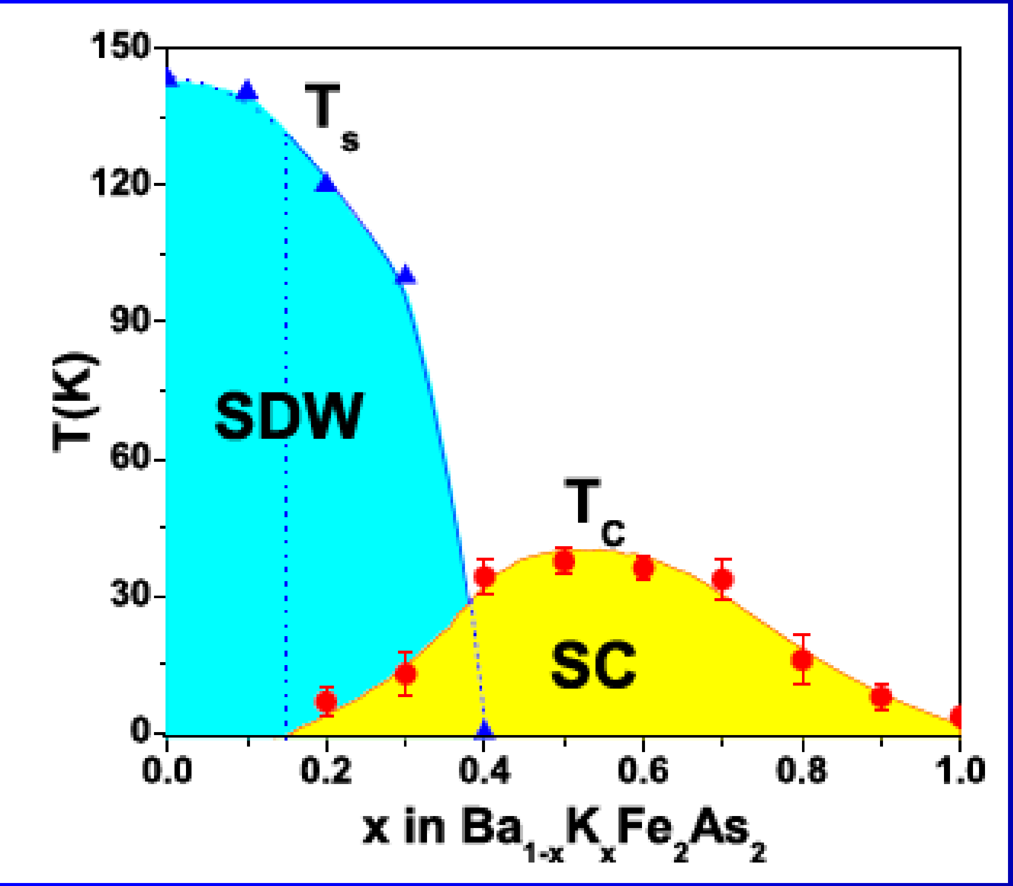


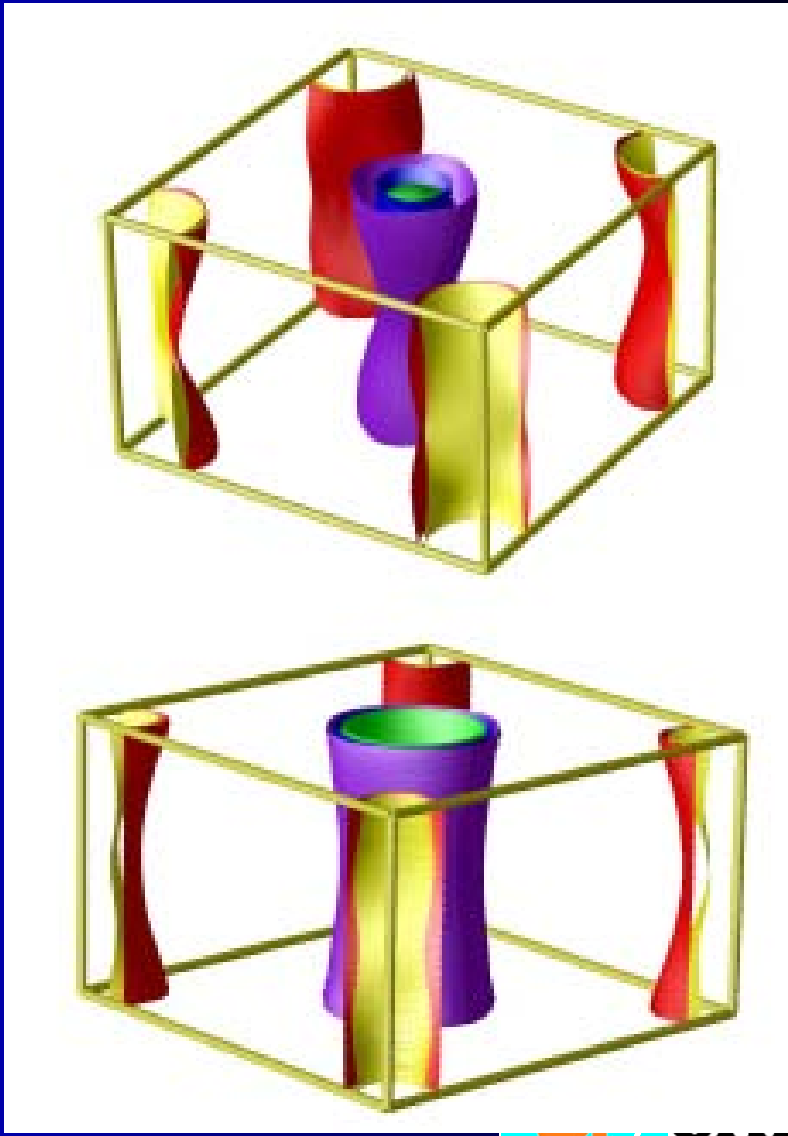
Do the field-induce AF order come from suppression of superconductivity? YES!





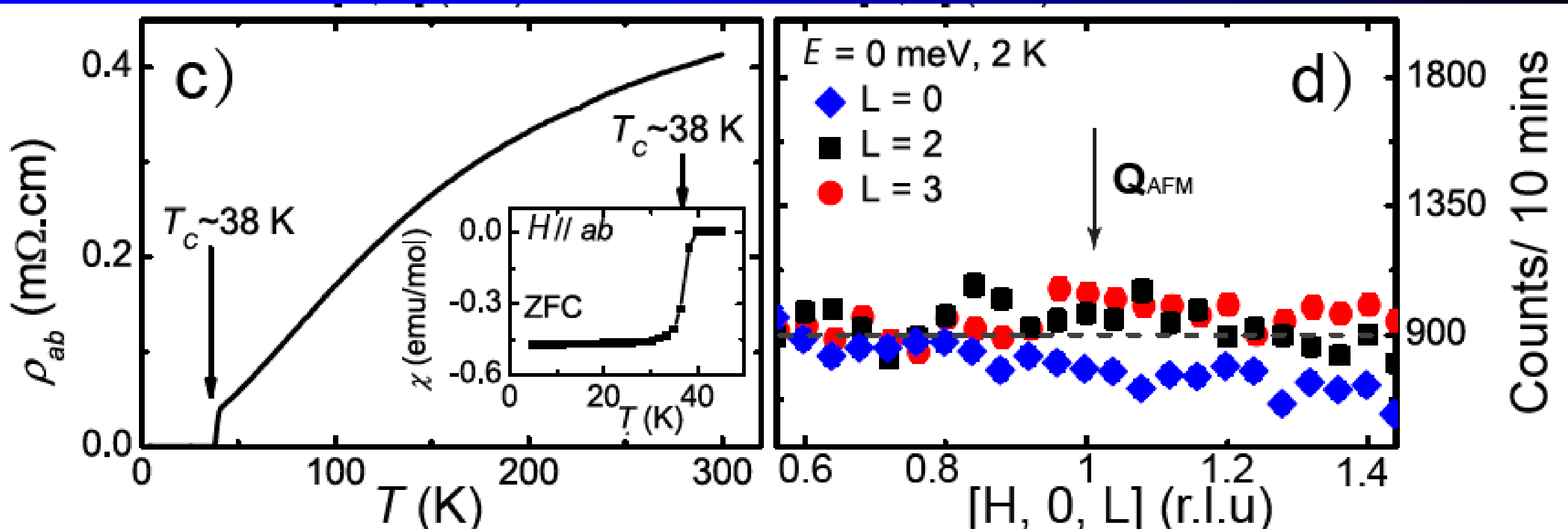
Is there electron-hole symmetry in spin excitations of 122 superconductors?



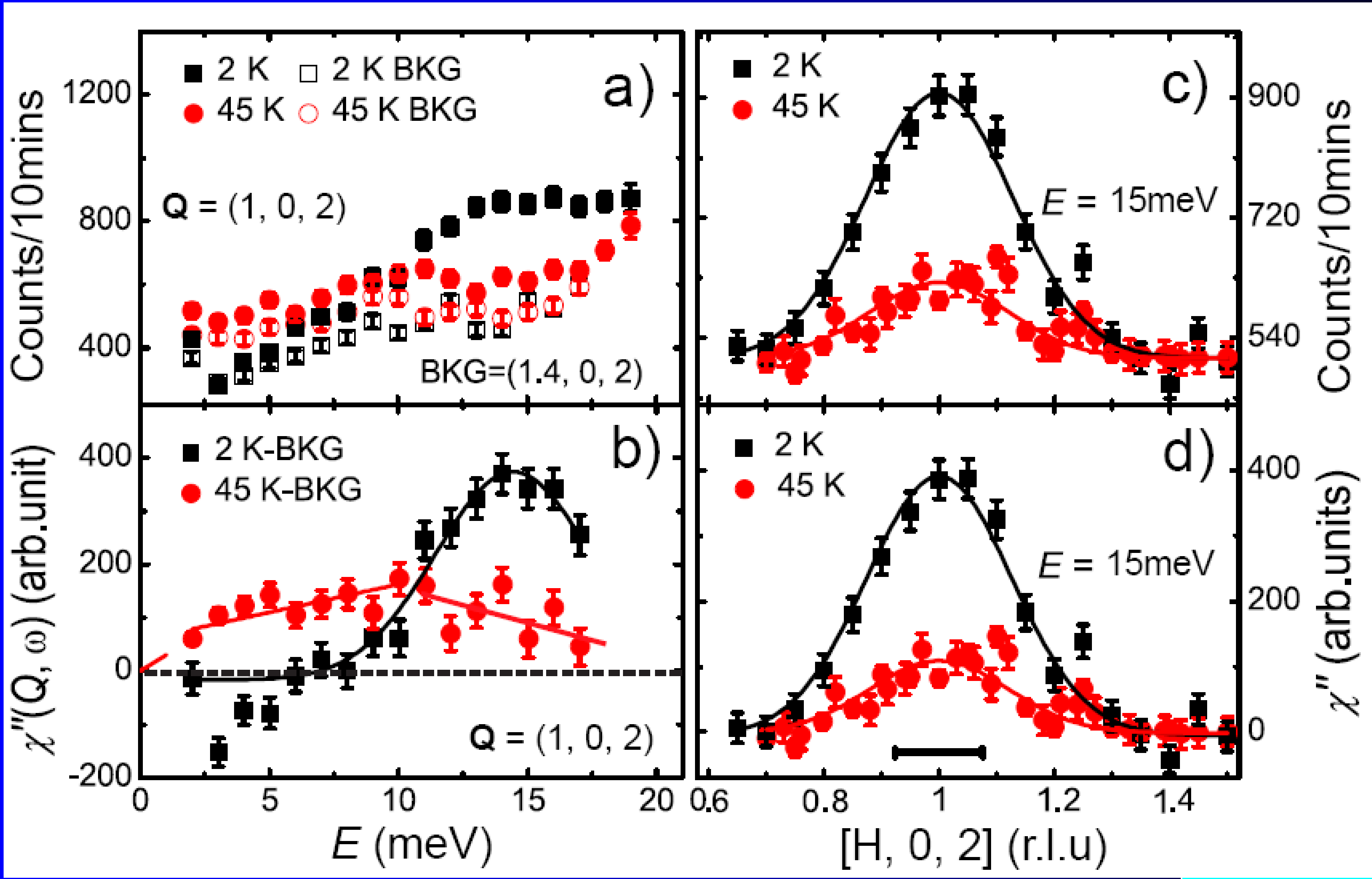


H. Chen *et al.*, EPL (2008).
Mazin & Schmalian, Physica C (2009).

$Ba_{0.6}K_{0.4}Fe_2As_2$ superconductor has no static antiferromagnetic order and sharp Tc.



Confirm neutron spin resonance in $Ba_{0.6}K_{0.4}Fe_2As_2$ superconductor



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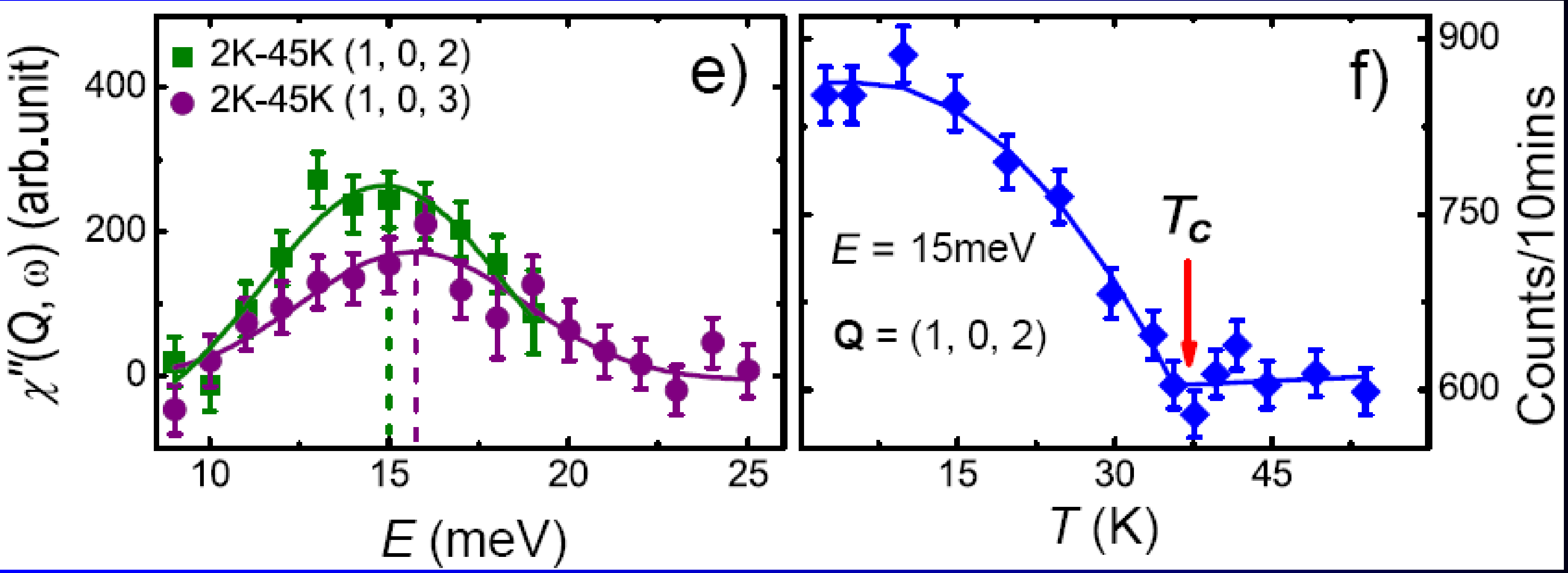
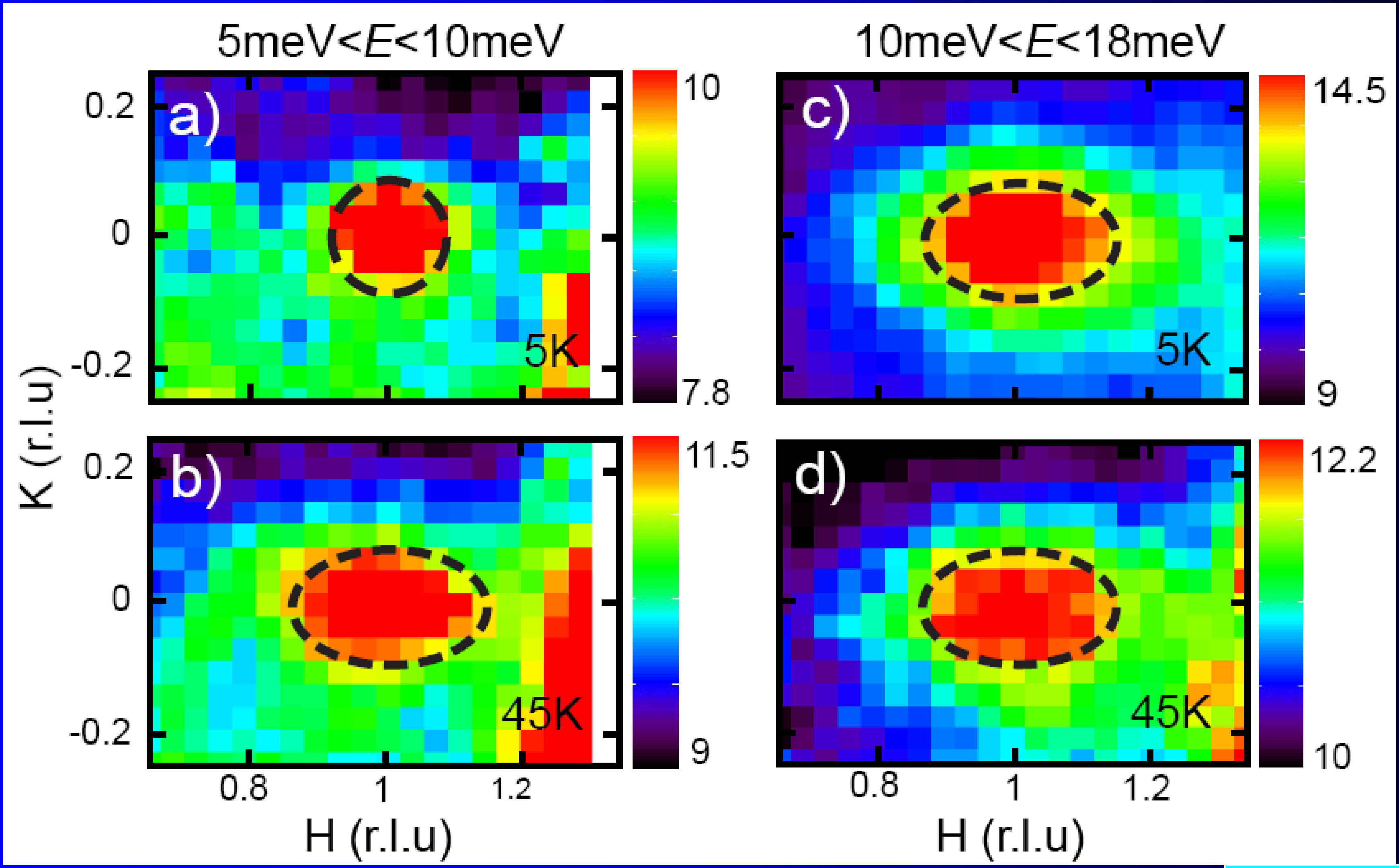
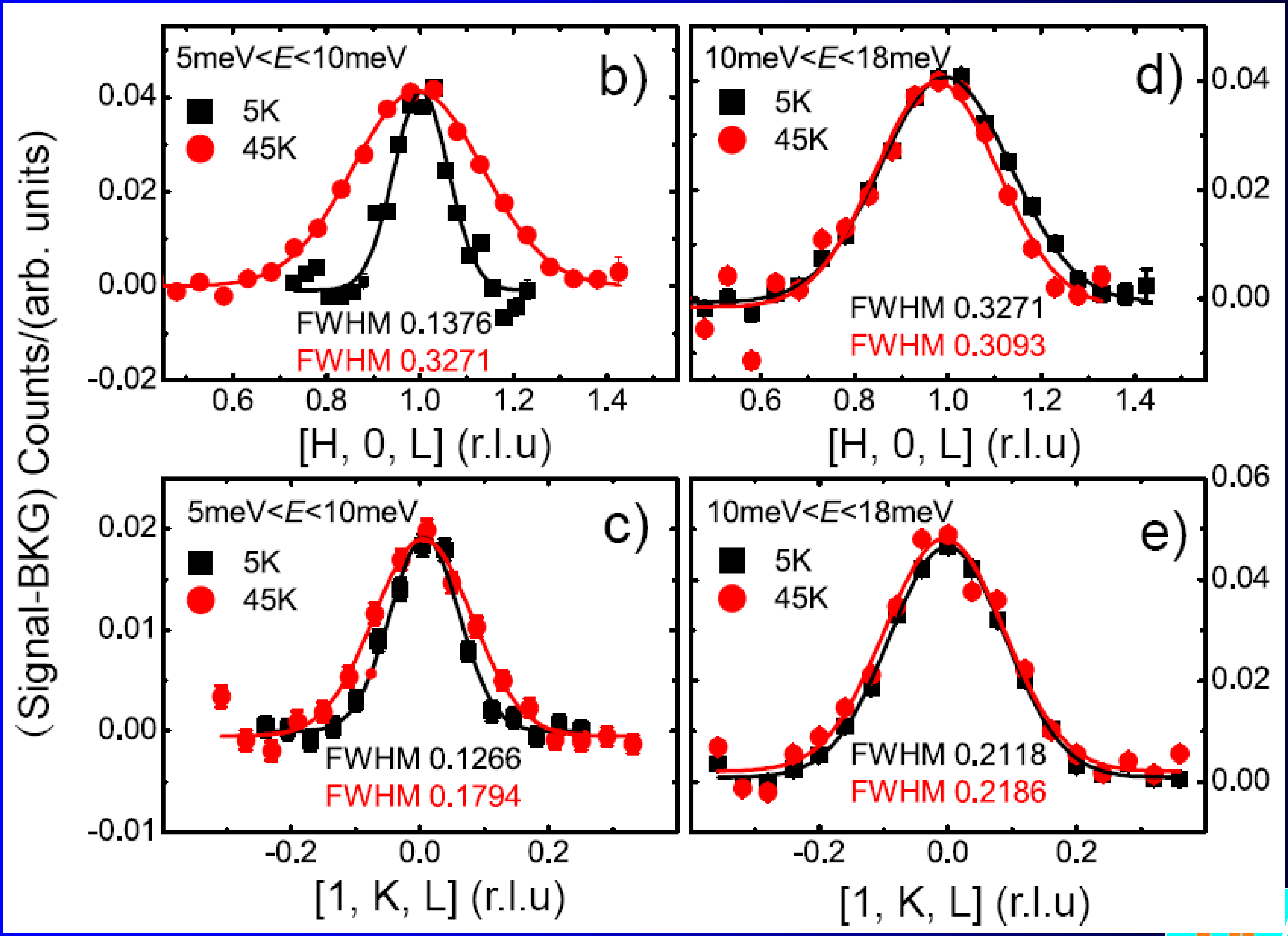
Neutron spin resonance in $Ba_{0.6}K_{0.4}Fe_2As_2$ superconductor has weak dispersion! Unlike that of the electron-doped materials!



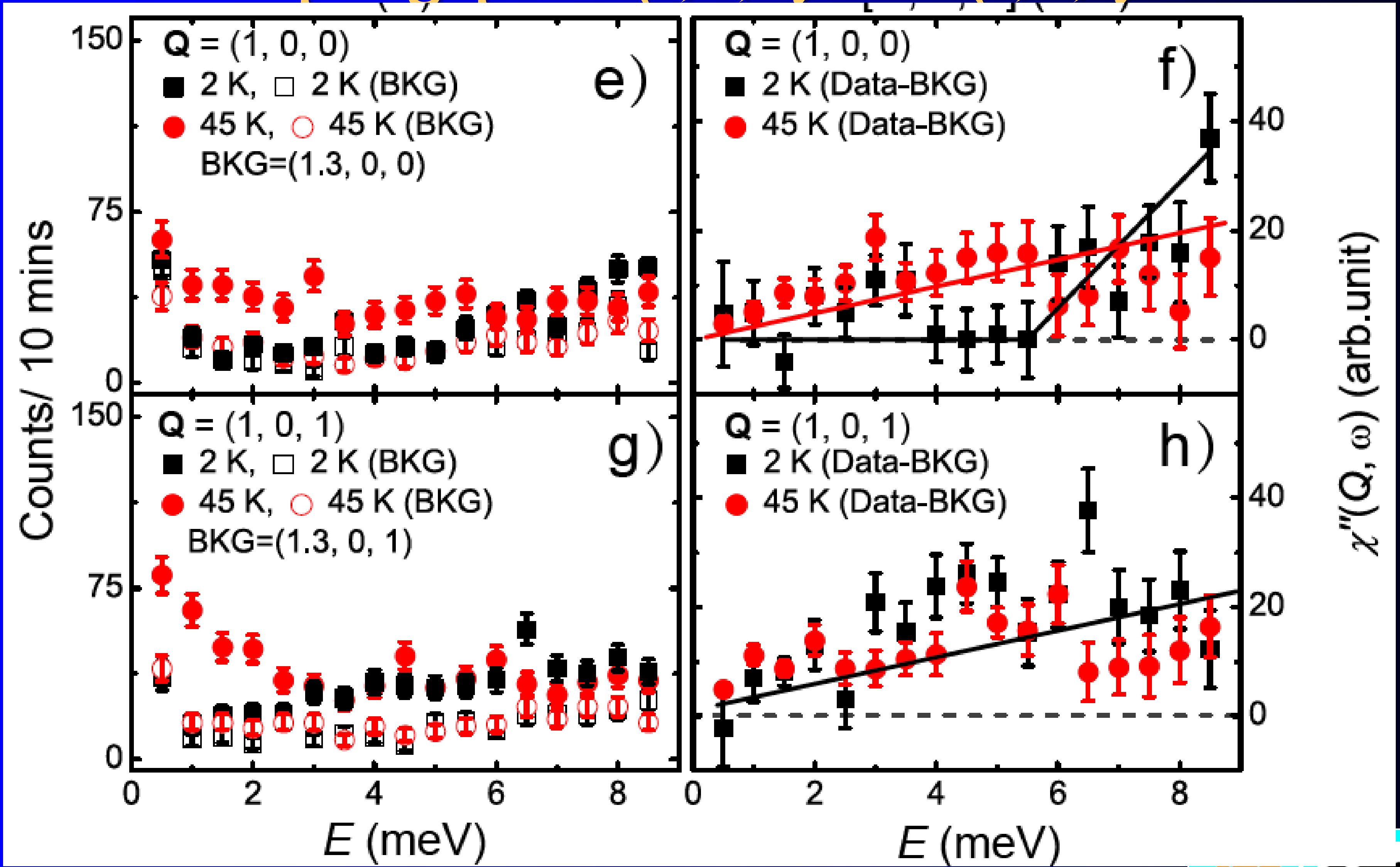
Temperature dependence of the neutron spin resonance and low-energy excitations



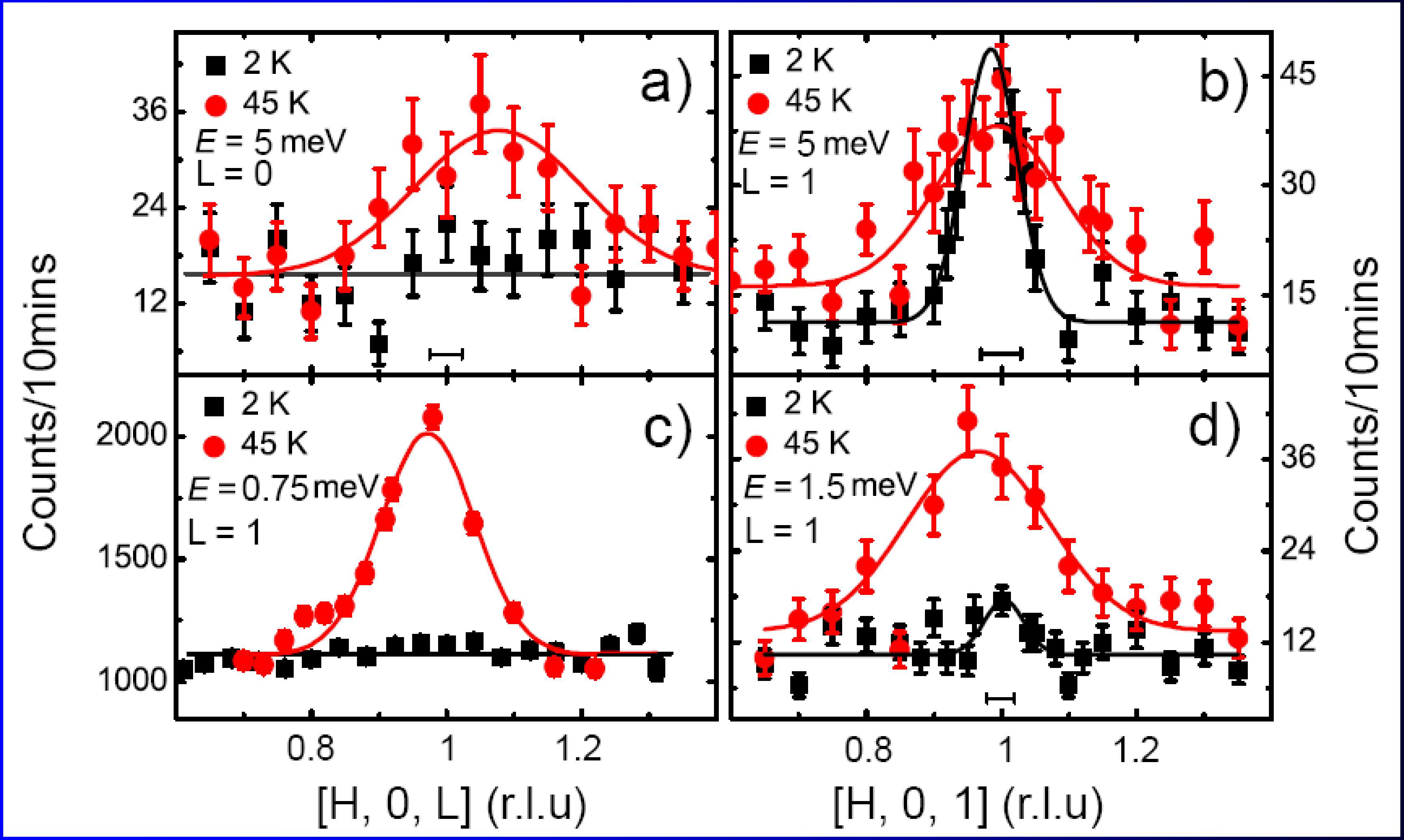
Temperature dependence of the resonance and low-energy excitations in H and K directions



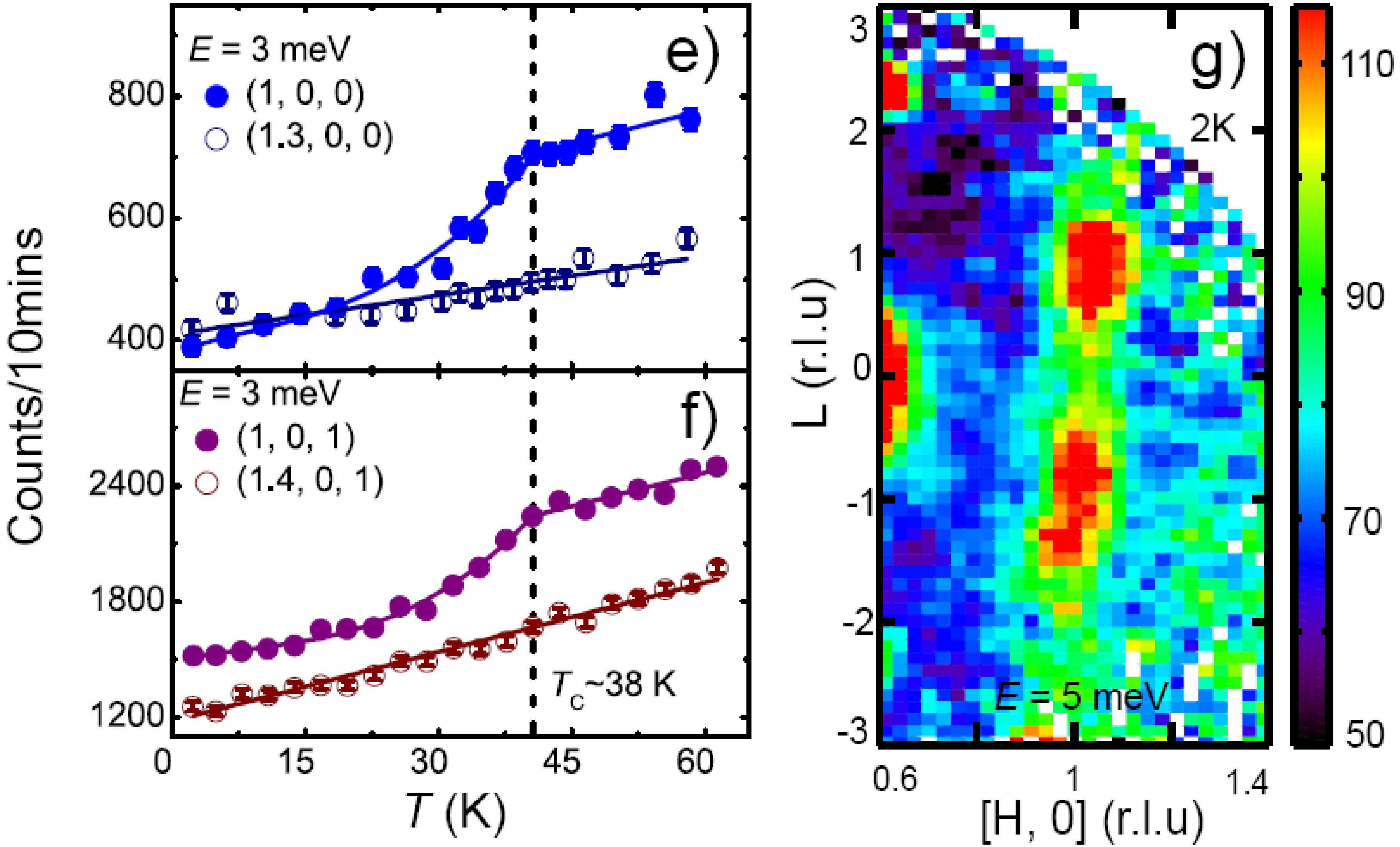
Wavevector dependence of the superconducting spin gaps at (1,0,0) and (1,0,1)



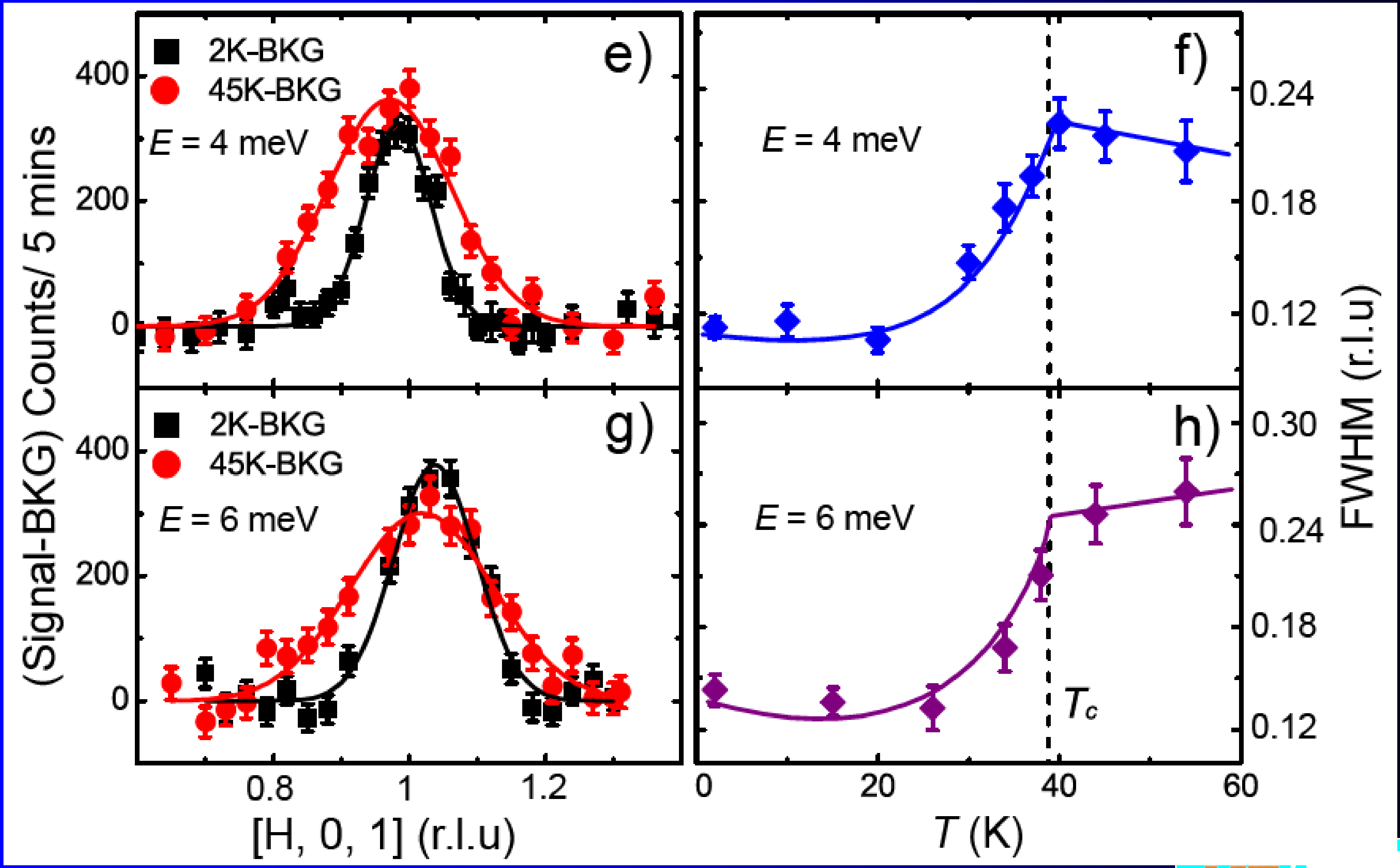
Wavevector dependence of the superconducting spin gaps at (1,0,0) and (1,0,1)



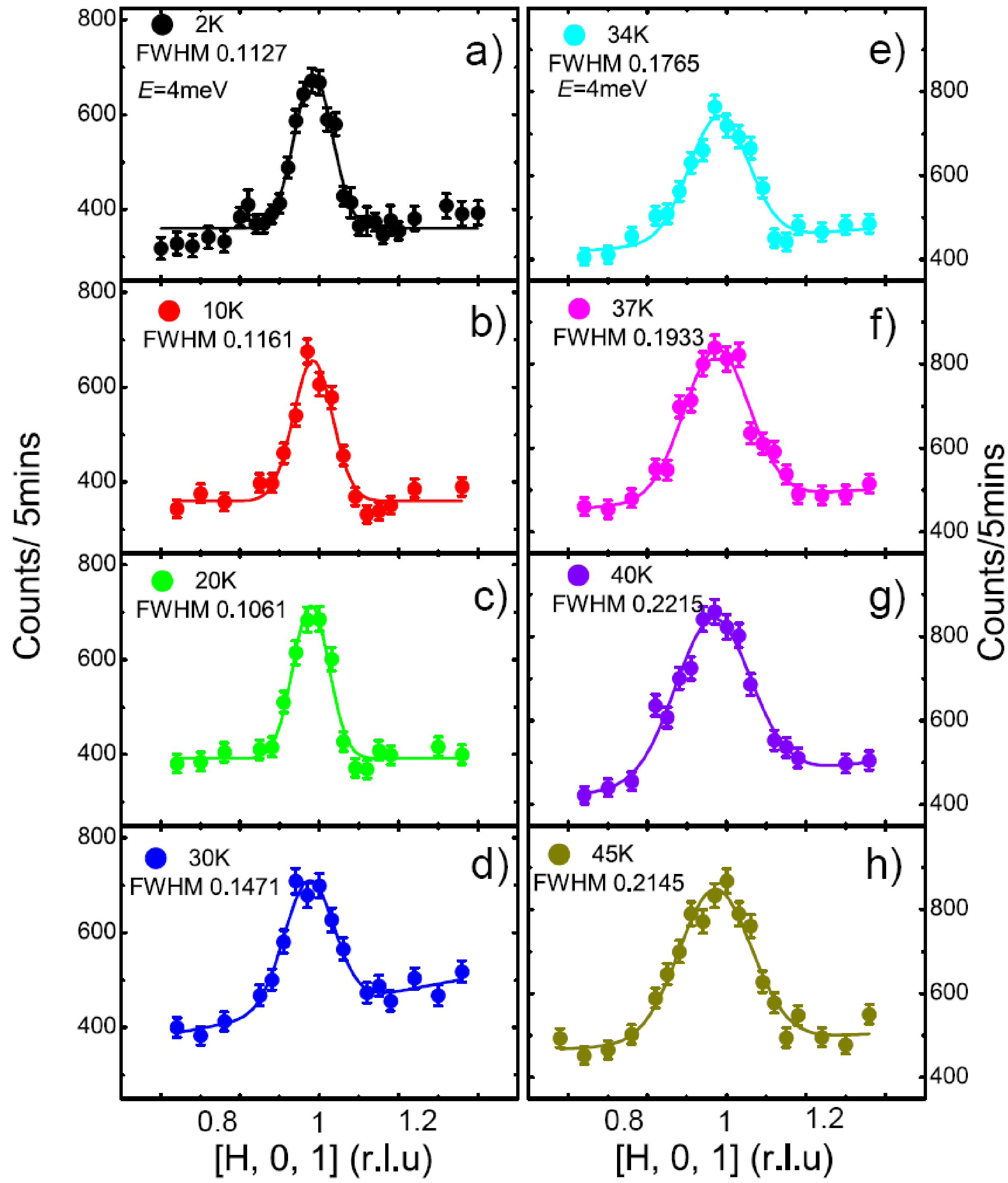
T-dependence of the low-energy spin excitations



Width of low-energy spin excitations



Temperature dependent width of low-energy spin excitations



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Summary

Spin excitations in superconductors have a resonance that is directly connected with superconducting gaps.

AF order is directly competing with superconductivity.

The resonance in FeAs is three-dimensional, much different from the copper oxides.

Spin excitations in hole and electron doped materials have some similarity and also differences. Local moments in hole-doped materials.