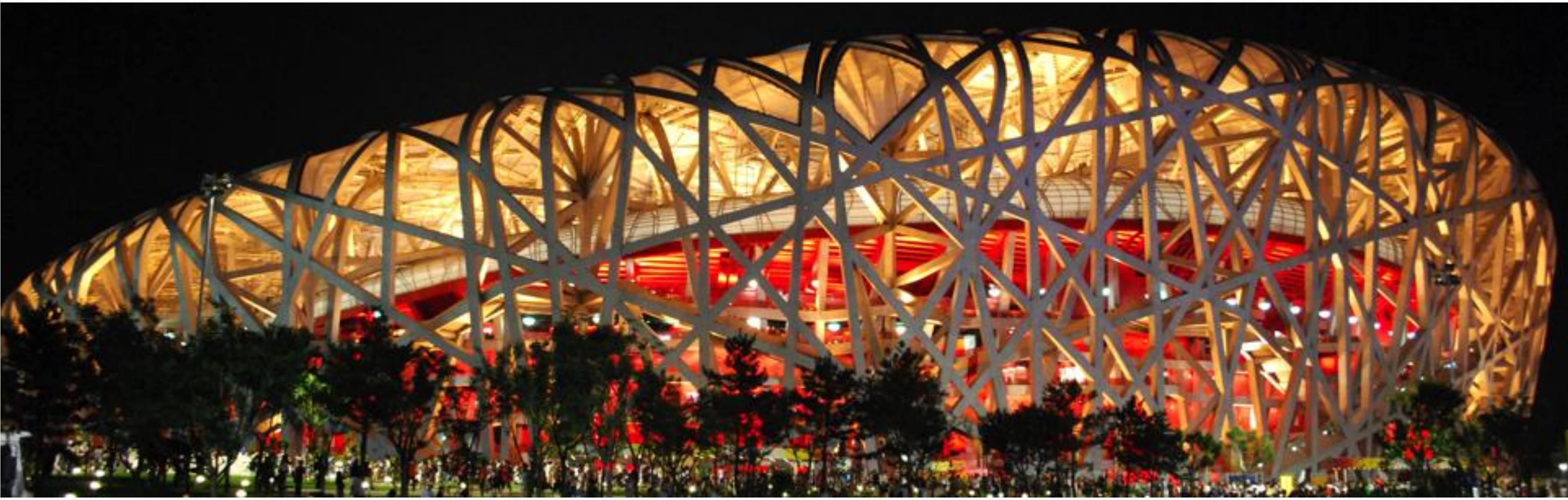
Strong and local pairing in iron-based superconductors as seen by photoelectrons



Hong Ding

Institute of Physics, Chinese Academy of Sciences

KITP Workshop on Strong Correlations and Unconventional Superconductivity, September 22, 2014

Outline

1. Review of our ARPES measurements of SC gap in many Fe-SCs

2. Observation of strong pairing on bands without Fermi surfaces in $LiFe_{1-x}Co_xAs$

3. Observation of a FL-NFL crossover in $LiFe_{1-x}Co_xAs$ due to spin-fluctuations @ FS nesting

4. A phenomenological understanding of Fe-SCs, and implications to Cu-SCs

Collaborators

ARPES:

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Renmin Univ.: Z.-H. Liu, S.-C. Wang

PSI: M. Shi, X.-Y. Cui, E. Razzoli, M. Radovic

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NMR: *Renmin Univ*: P.S. Wang, W.Q. Yu

Theory:

IOP/Purdue: J.-P. Hu   *IOP*: X. Dai, Z. Fang   *BC*: Z. Wang

Samples:

IOP: G.-F. Chen , N.-L. Wang, X.-L. Chen, C.-Q. Jin

Nanjing Univ.: H.-H. Wen   *Zhejiang Univ*.: G.-H. Cao, Z.-A. Xu, M.-H. Fang

UT: C.-L. Zhang, P.-C. Dai   *BNL*: G.-D. Gu

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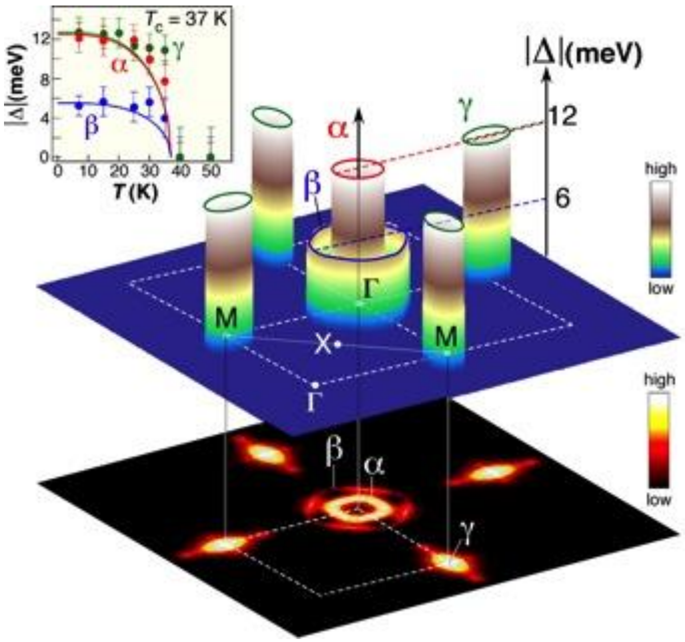
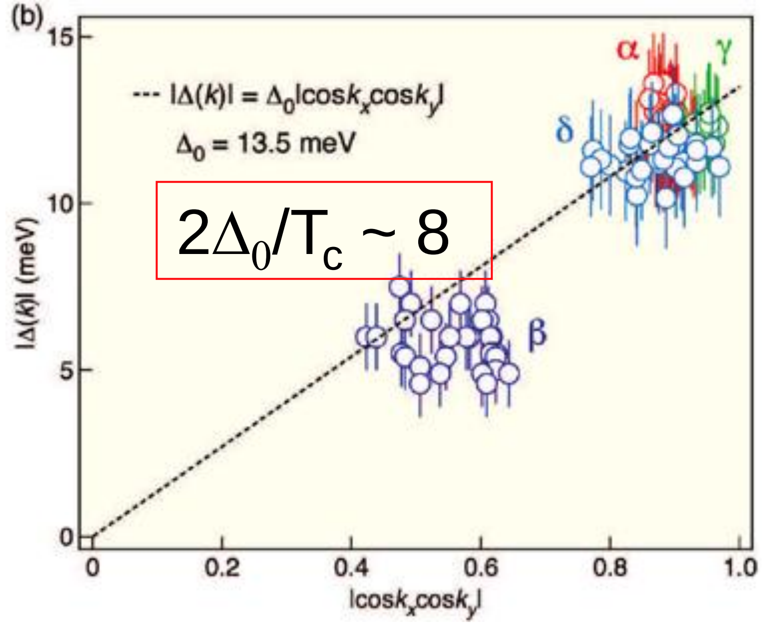
Nodeless FS-dependent SC gap in $Ba_{0.6}K_{0.4}Fe_2As_2$ (T_c = 37K)

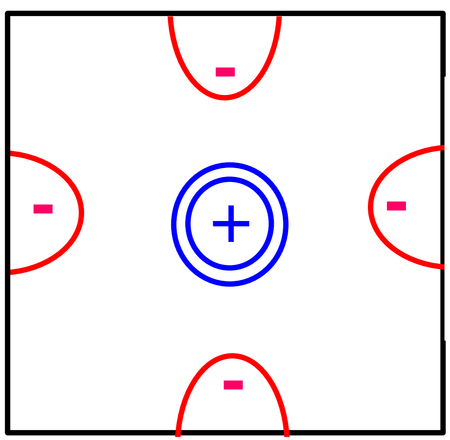




H. Ding *et al.*, EPL 83, 47001 (2008)

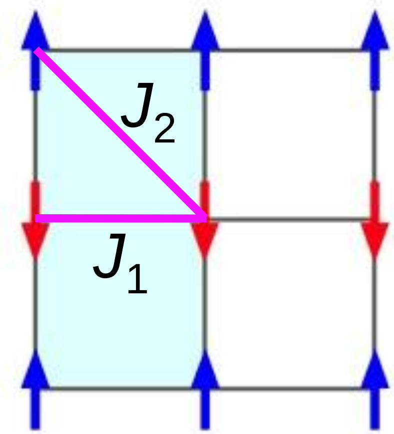
K. Nakayama *et al.*, EPL 85, 67002 (2009)

FS nesting



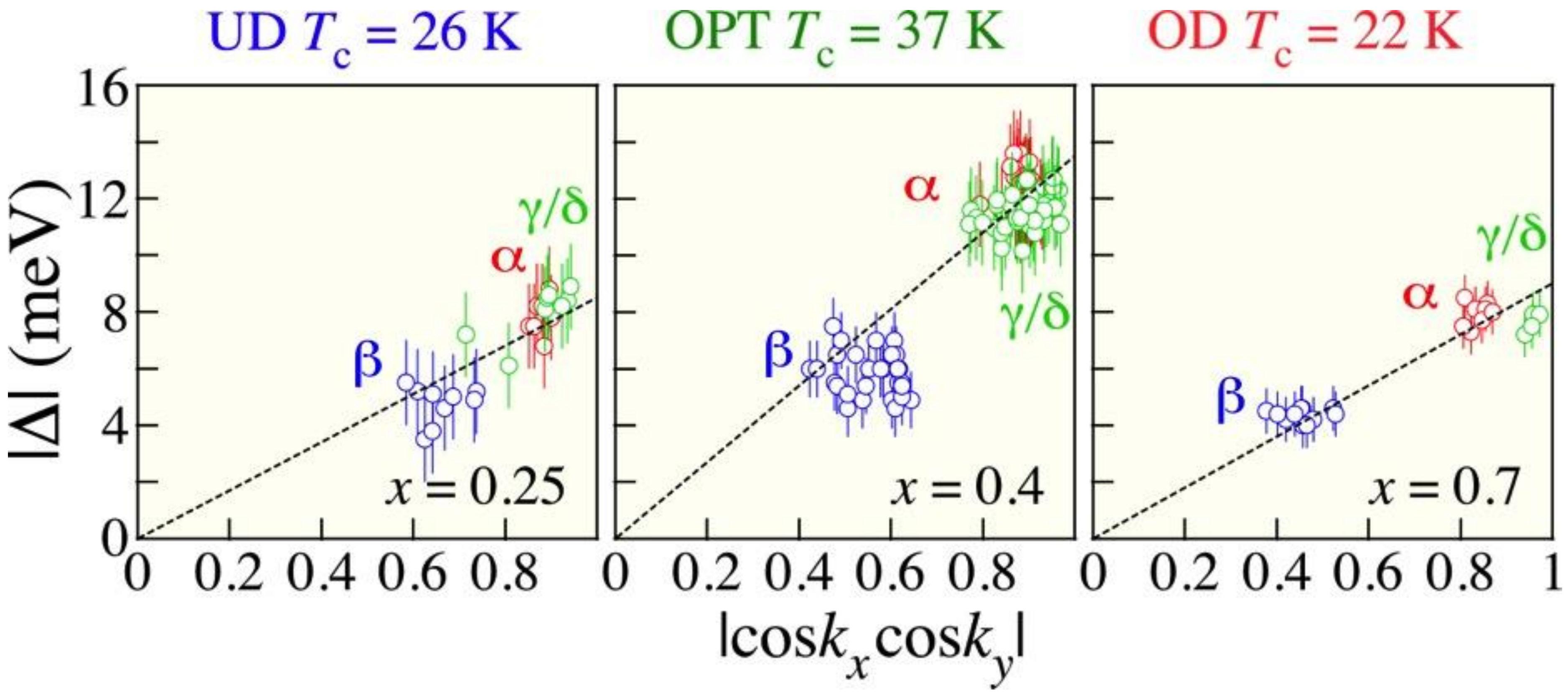
weak-coupling

local moment J_1-J_2



strong-coupling

$\cos k_x \cos k_y$ plot of SC gap

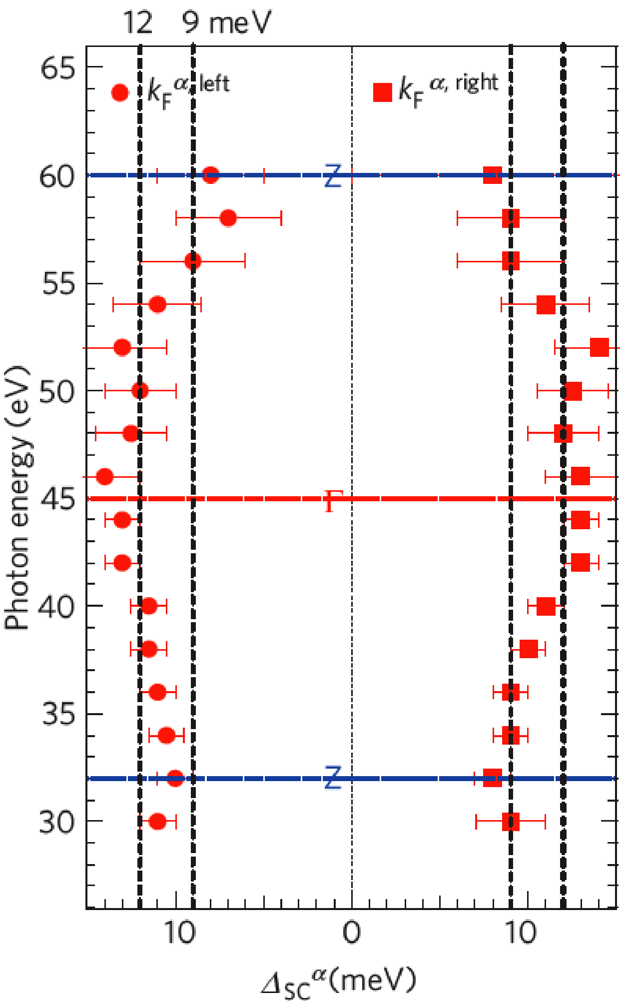


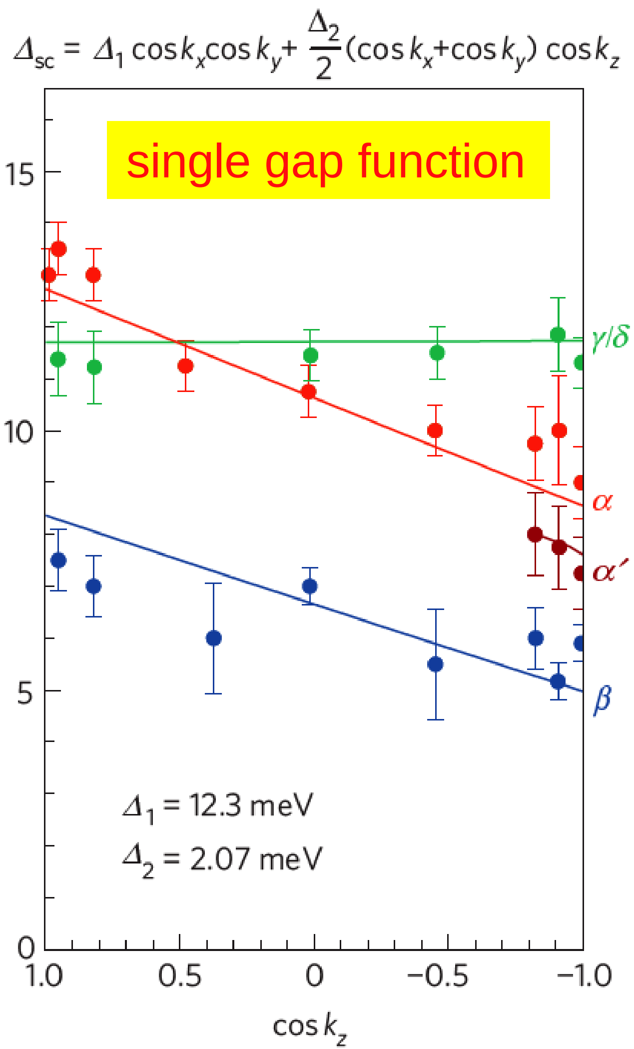
SC gap roughly follows $\Delta_0 \cos k_x \cos k_y$ irrespective of doping level

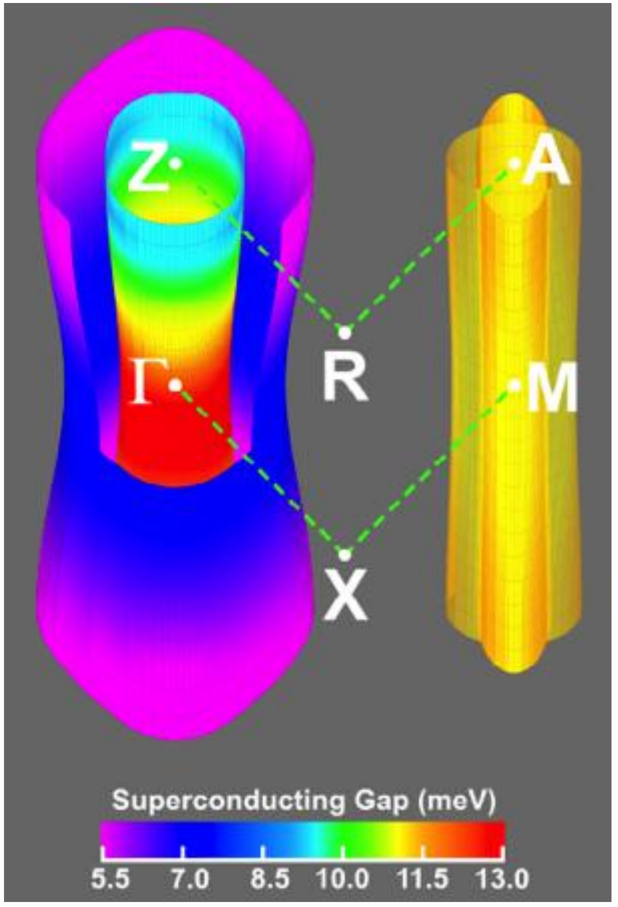
Y.-M. Xu *et al.*, Nature Comm. 2, 392 (2011)

K. Nakayama *et al.*, PRB 83, 020501(R) (2011)

kz dependence of SC gaps







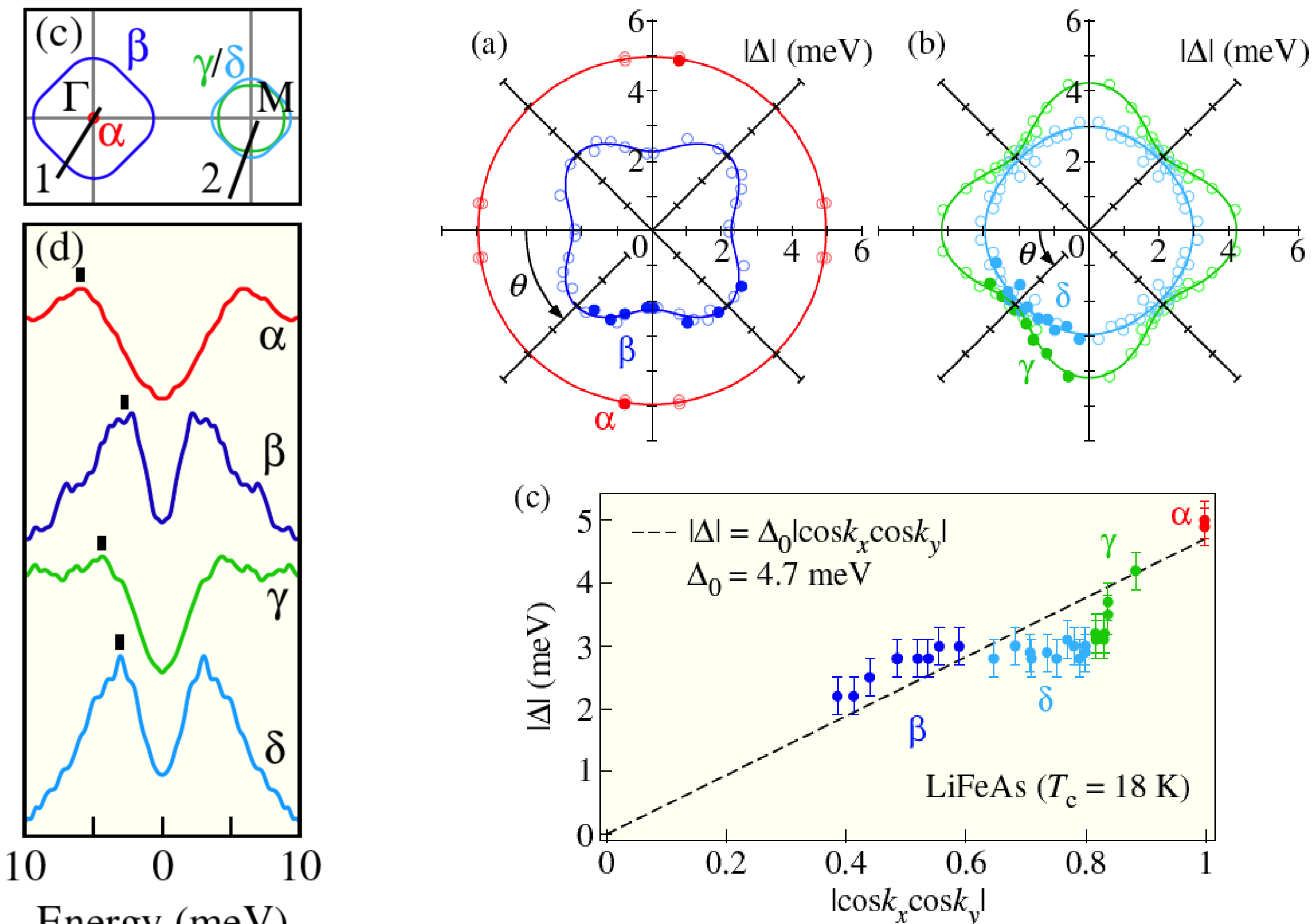
J_{ab} = 30

J_c = 5

$\Delta_2/\Delta_1 \approx J_c/J_{ab} \approx 0.17$

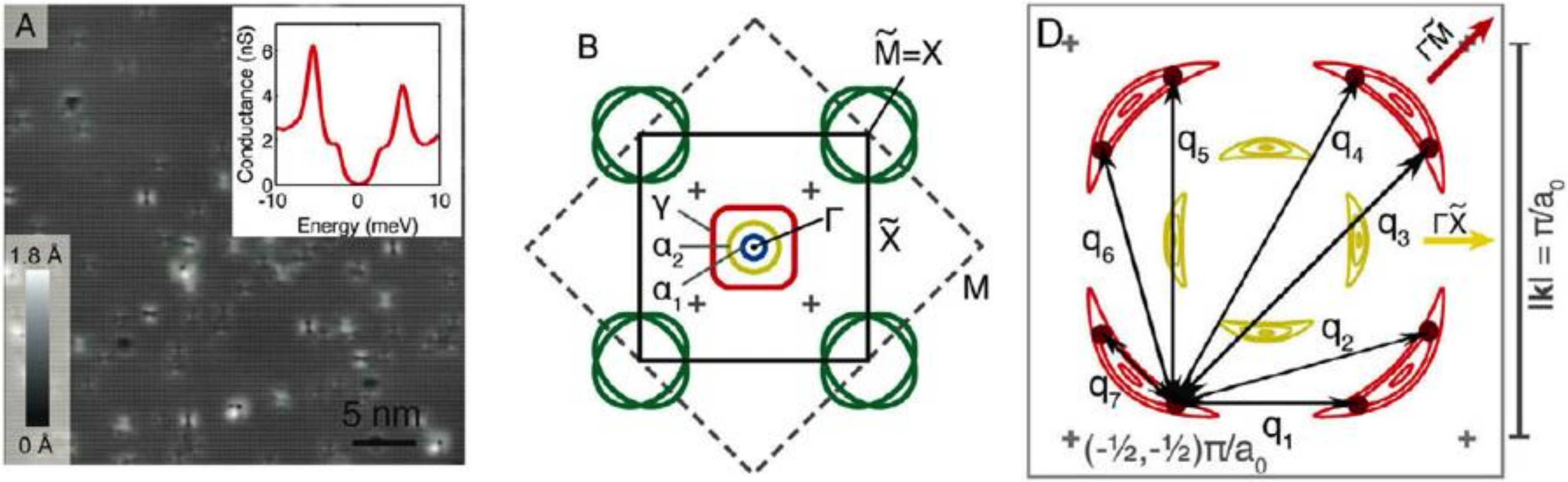
Y.-M. Xu *et al.*, Nature Physics 7, 198 (2011)

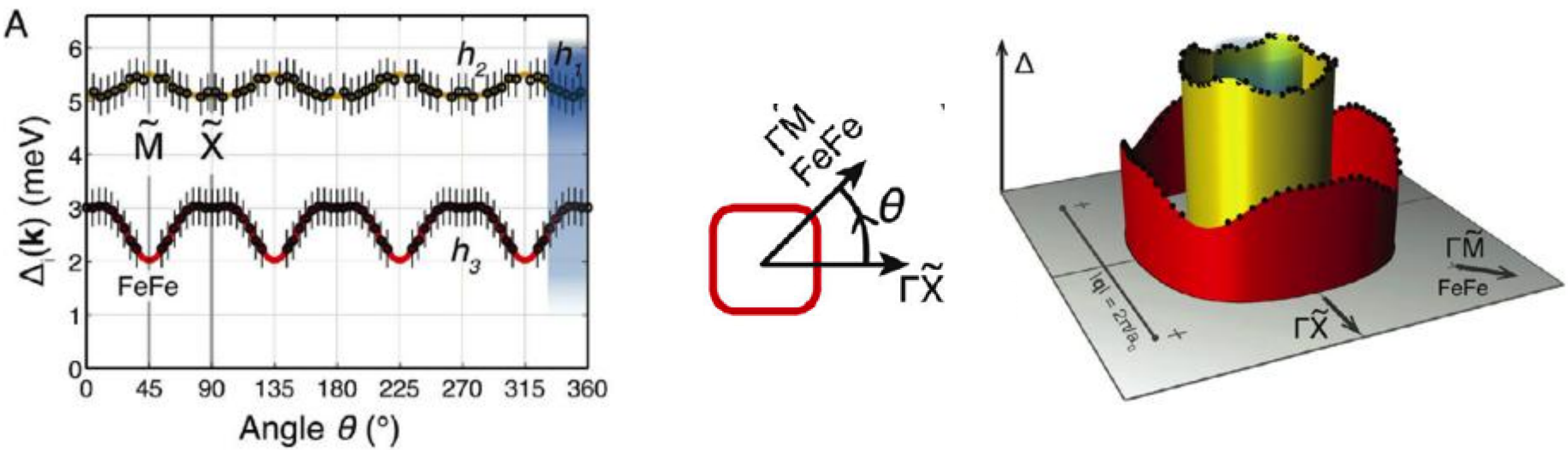
K-dependence of SC gap in LiFeAs



K. Umezawa et al, PRL 108, 037002 (2012)

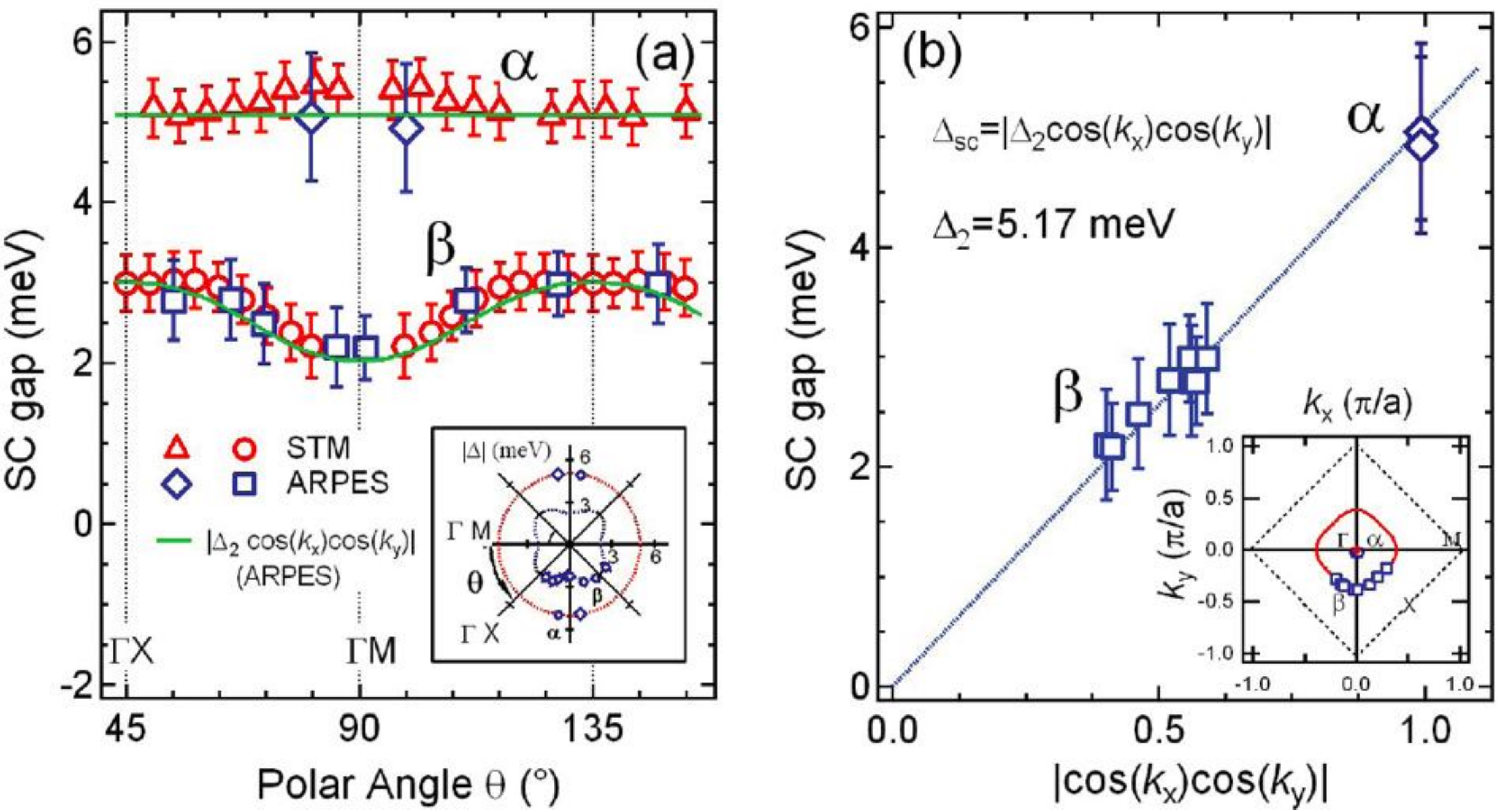
K-dependence of SC gap in LiFeAs: STM results





M. P. Allan et al., Science 336 563 (2012)

Comparison between ARPES and STM in LiFeAs consistent with $\cos k_x \cos k_y$

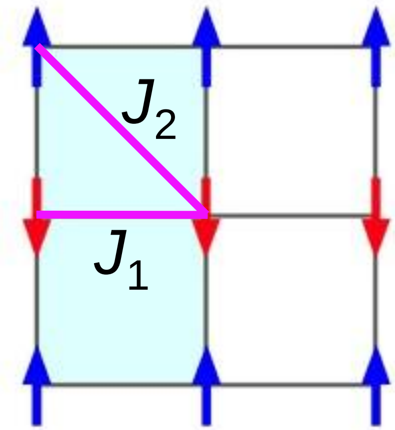


Y.-B. Huang *et al*., AIP Advances 2, 041409 (2012)

Modification of SC gap function in $FeTe_{0.55}Se_{0.45}$

FeAs

J_2 is large

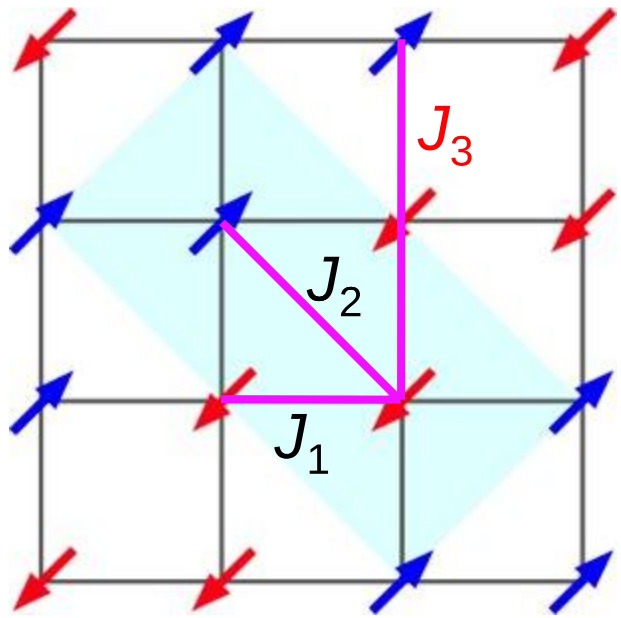


$s_{\pm}$-wave pairing

($\Delta_0 \cos k_x \cos k_y$)

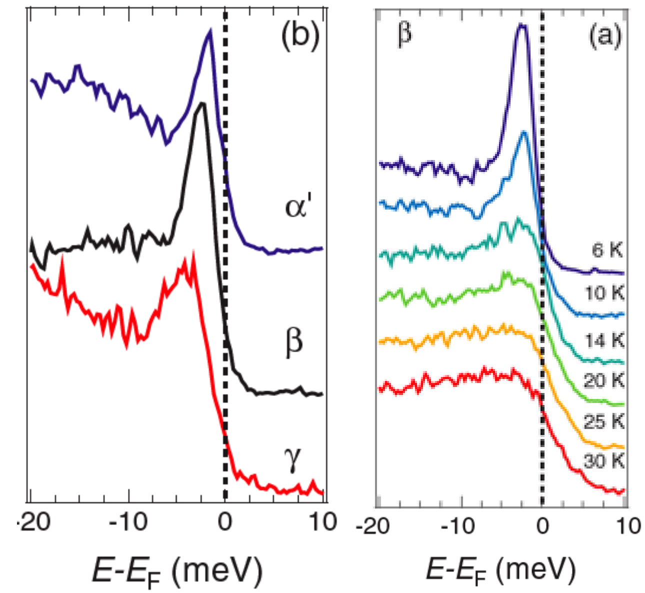
FeTe

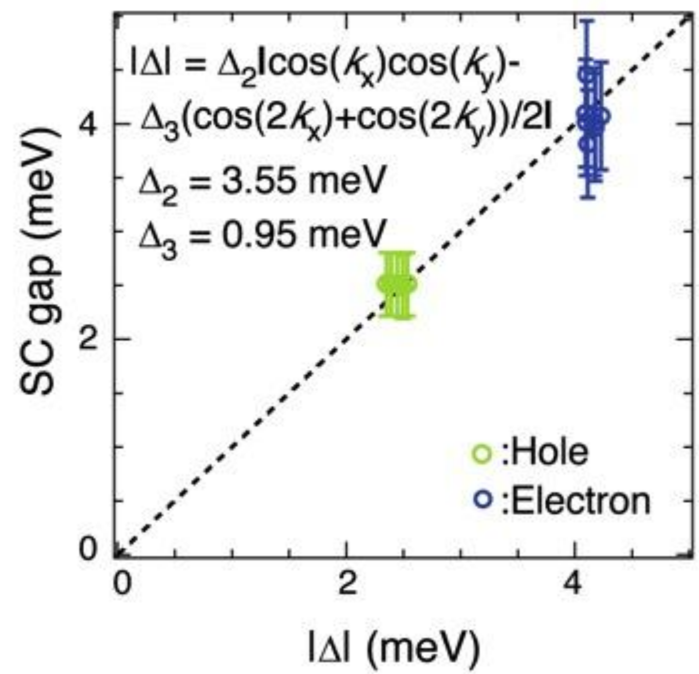
J_3 is no longer negligible



$s_{\pm}$-wave pairing

($\Delta_2 \cos k_x \cos k_y$
$- \Delta_3(\cos 2k_x + \cos 2k_y)/2$)

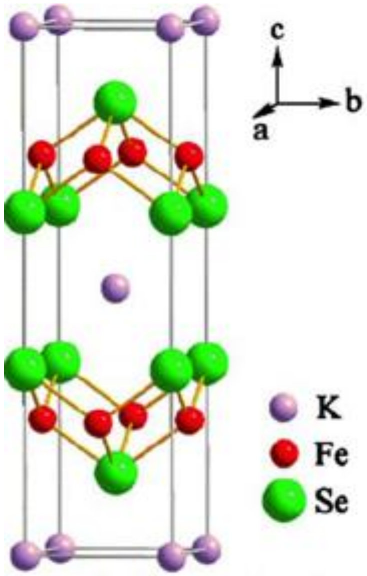


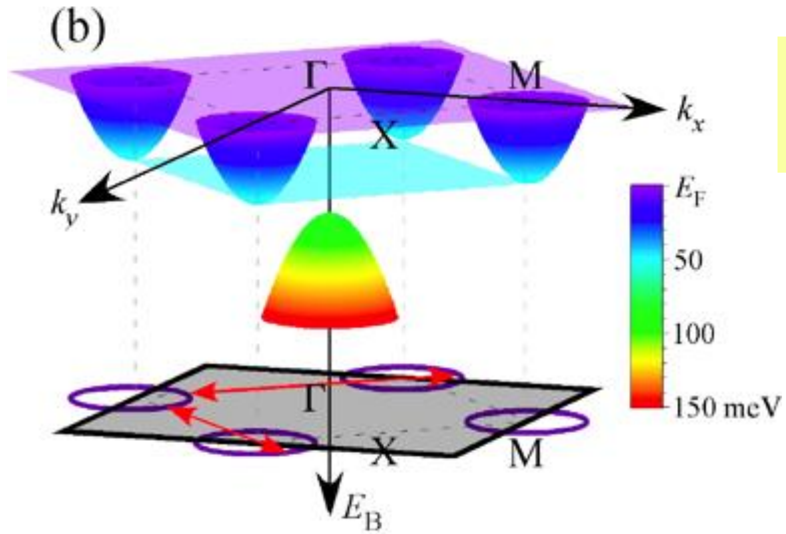


H. Miao *et al.*, PRB 85, 094506 (2012)

Isotropic SC gap in $(Tl,K)_xFe_{2-y}Se_2$

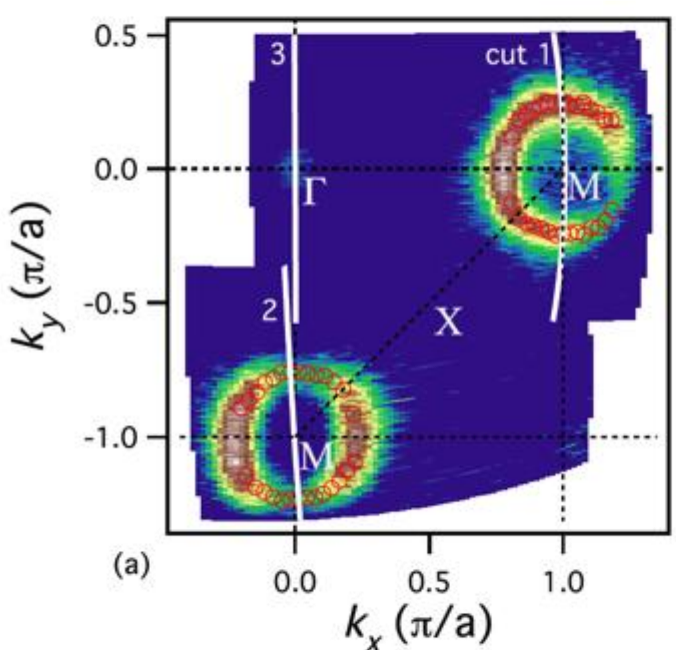
No FS nesting, no problem!

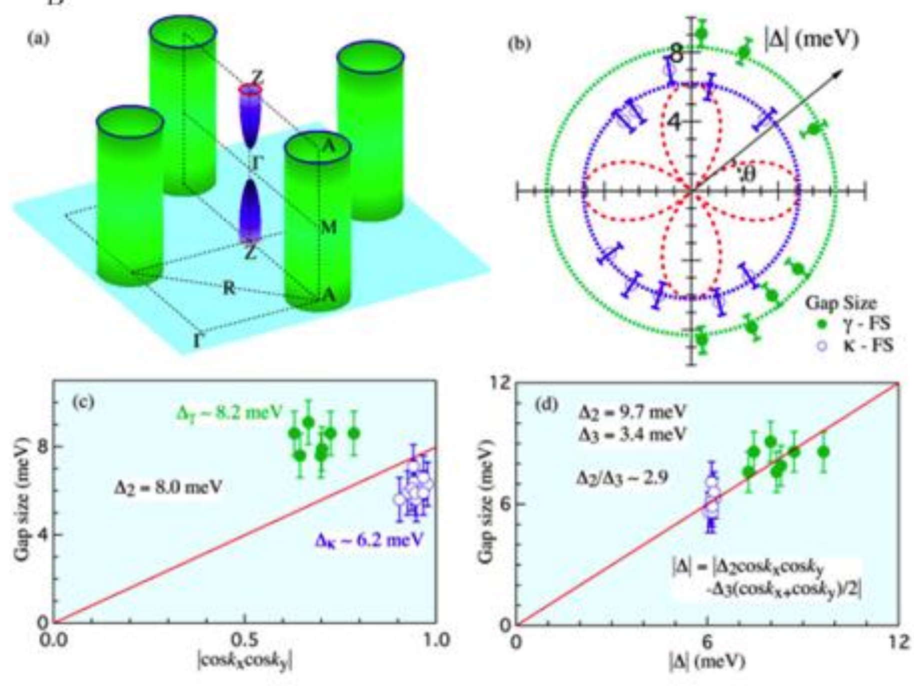




T. Qian *et al.*, PRL 106, 187001 (2011)

X.-P. Wang *et al.*, EPL 93, 57001 (2011)





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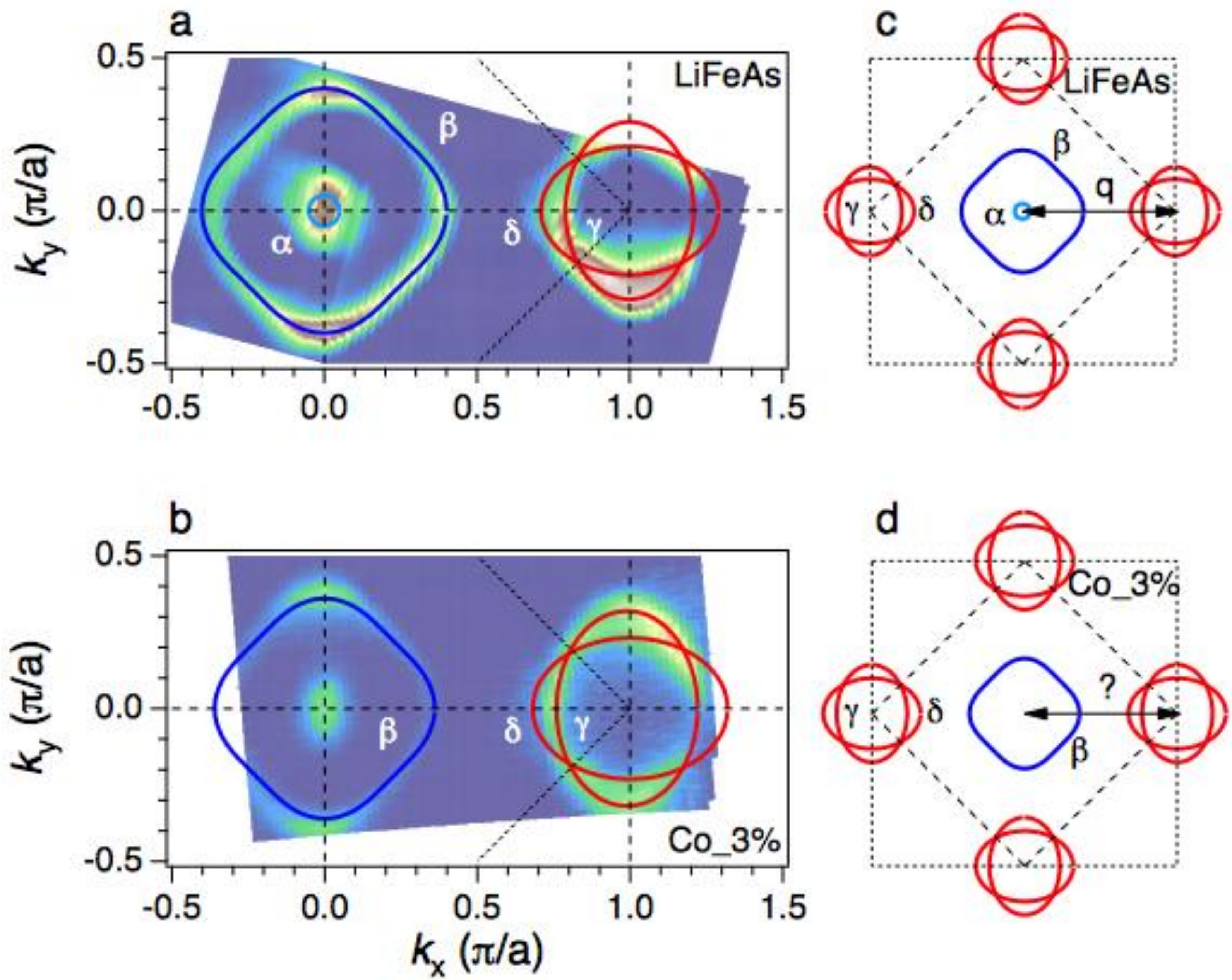
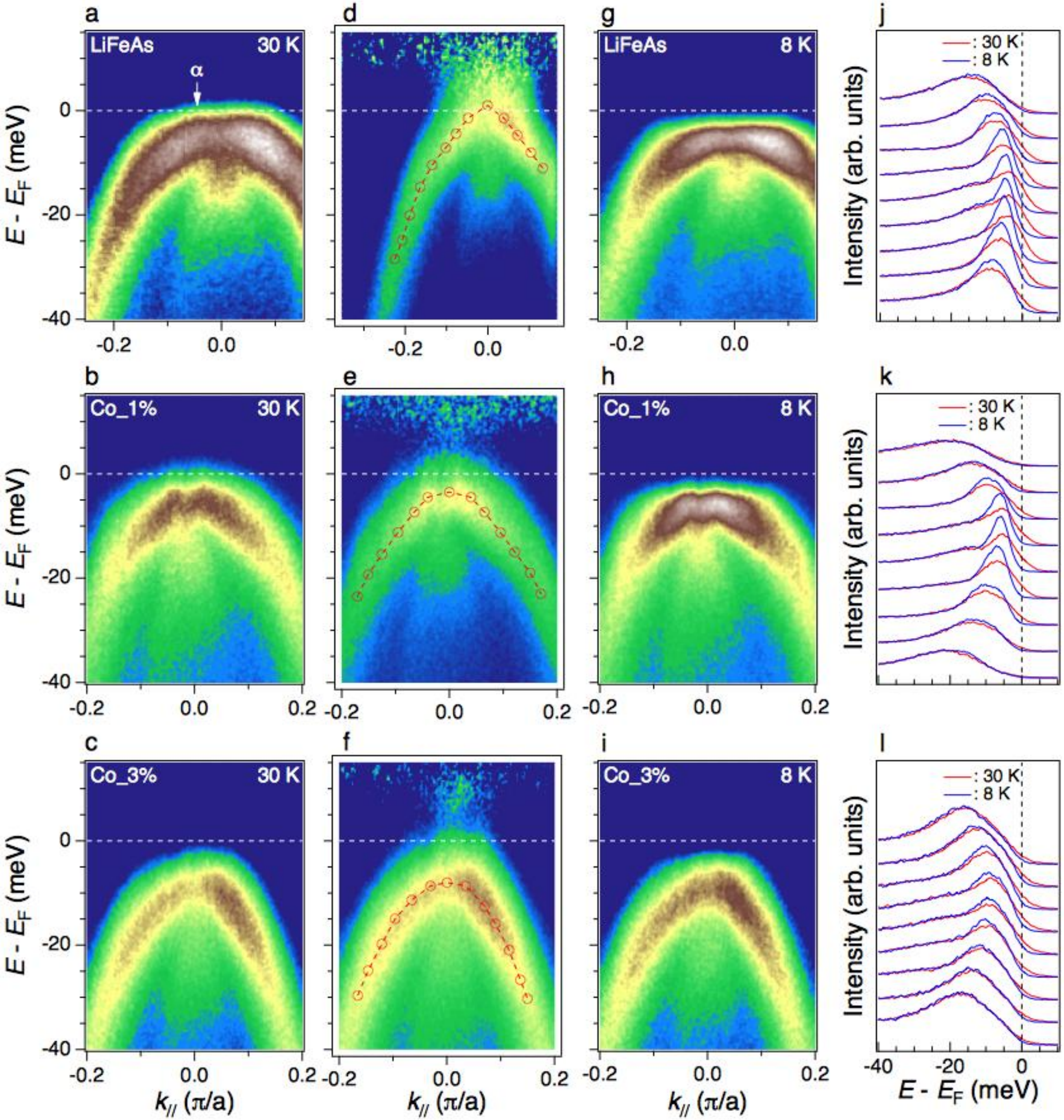
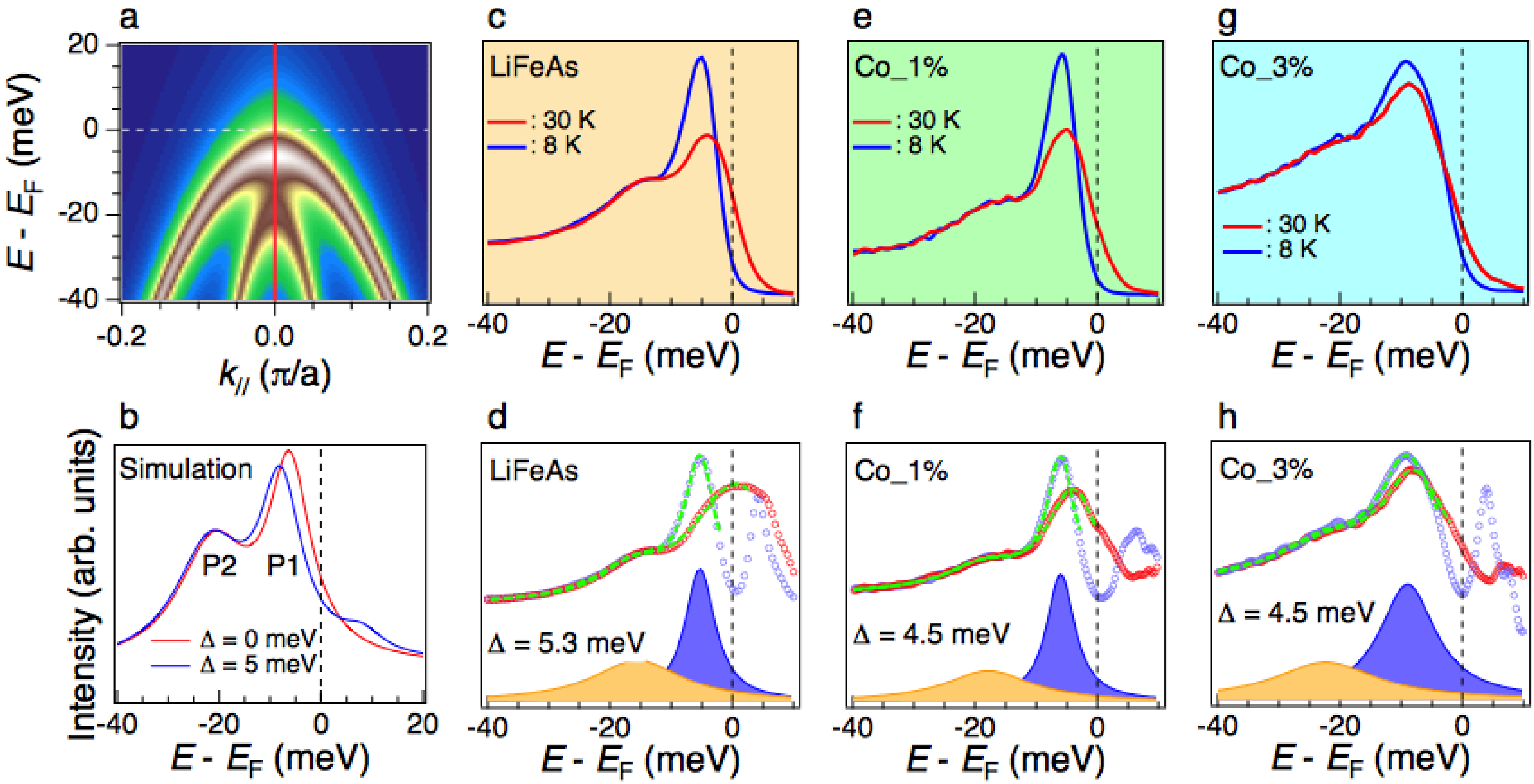
FS topology of pristine LiFeAs and $LiFe_{0.97}Co_{0.03}As$





a
LiFeAs
30 K
α
b
Co_1%
30 K
c
Co_3%
30 K
d
e
f
g
LiFeAs
8 K
h
Co_1%
8 K
i
Co_3%
8 K
j
: 30 K
: 8 K
k
: 30 K
: 8 K
l
: 30 K
: 8 K
E - E_F (meV)
k_// (π/a)
Intensity (arb. units)

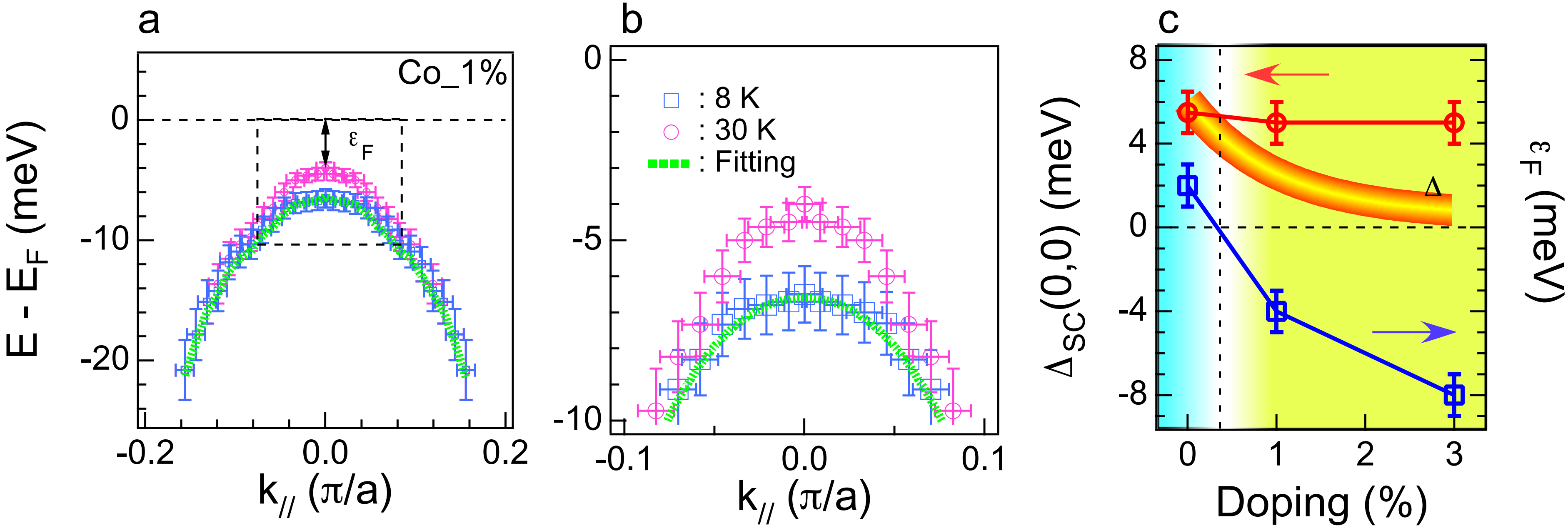
Extracting SC gap from EDCs



$$E_k = \sqrt{\varepsilon_k^2 + \Delta_k^2}$$

Extracting SC gap from dispersions

Failure of weak-coupling theories



$$E_k = \sqrt{\varepsilon_k^2 + \Delta_k^2}$$

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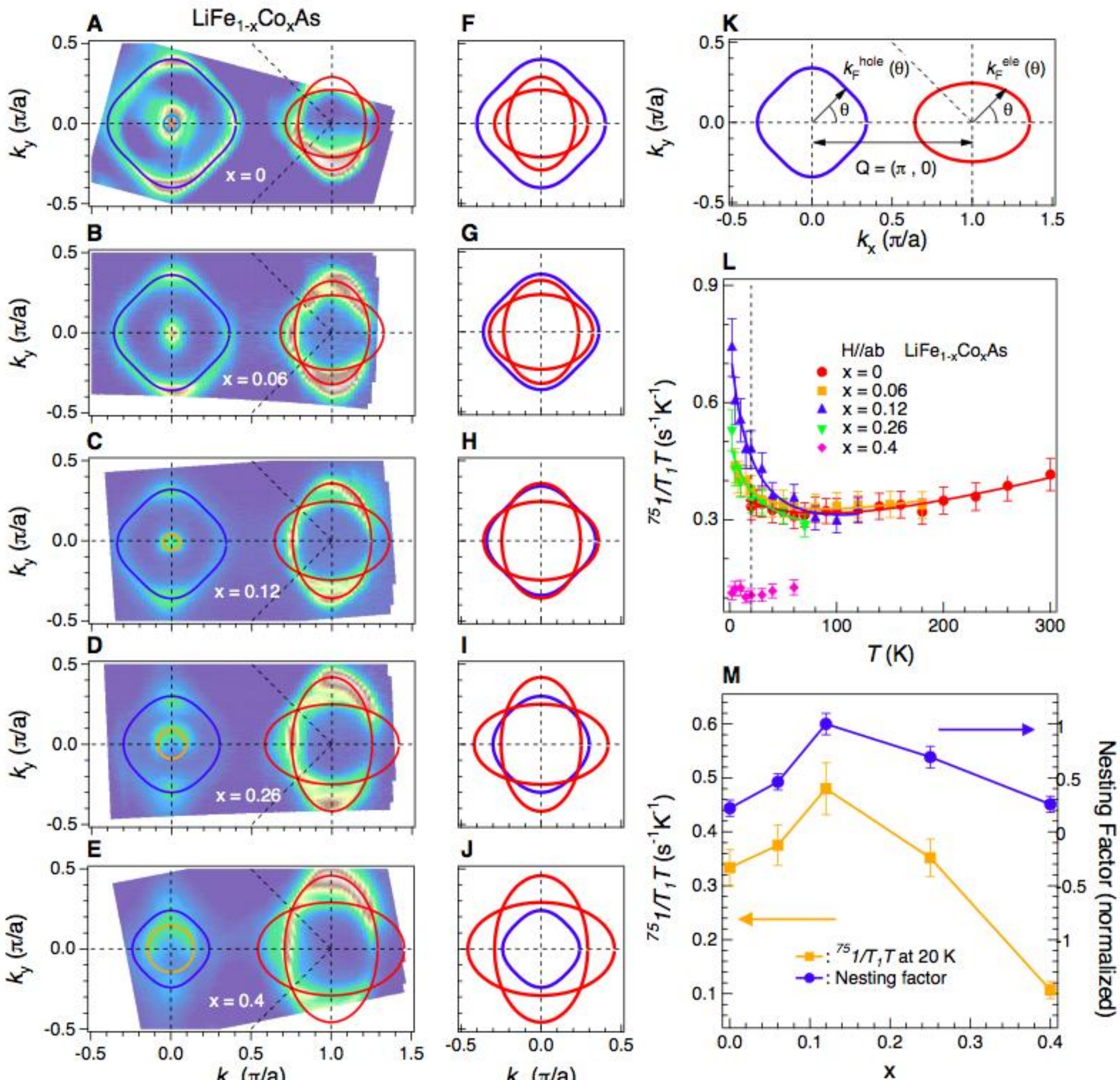
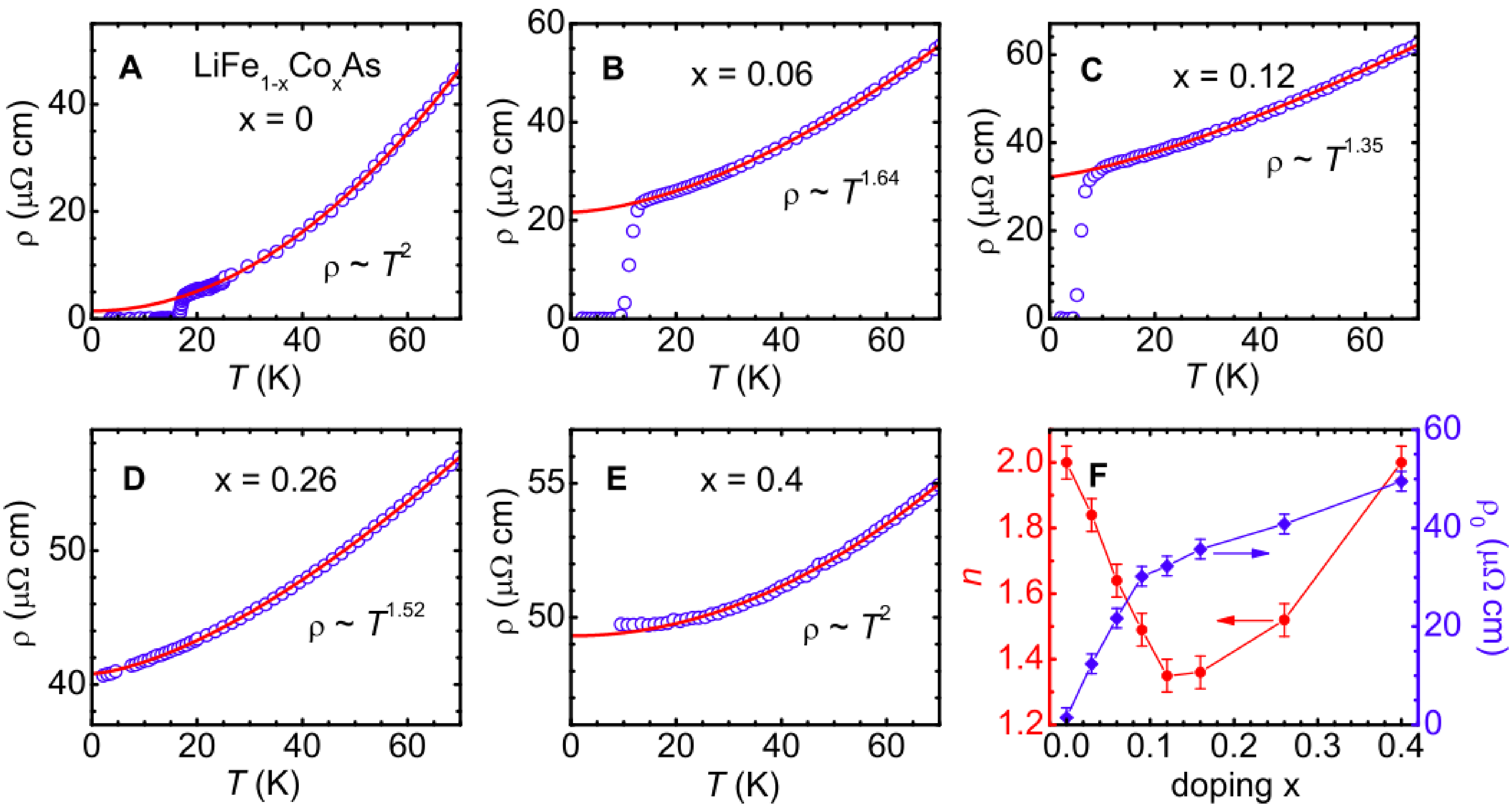
FS evolution and low-E spin fluctuations of $LiFe_{1-x}Co_xAs$



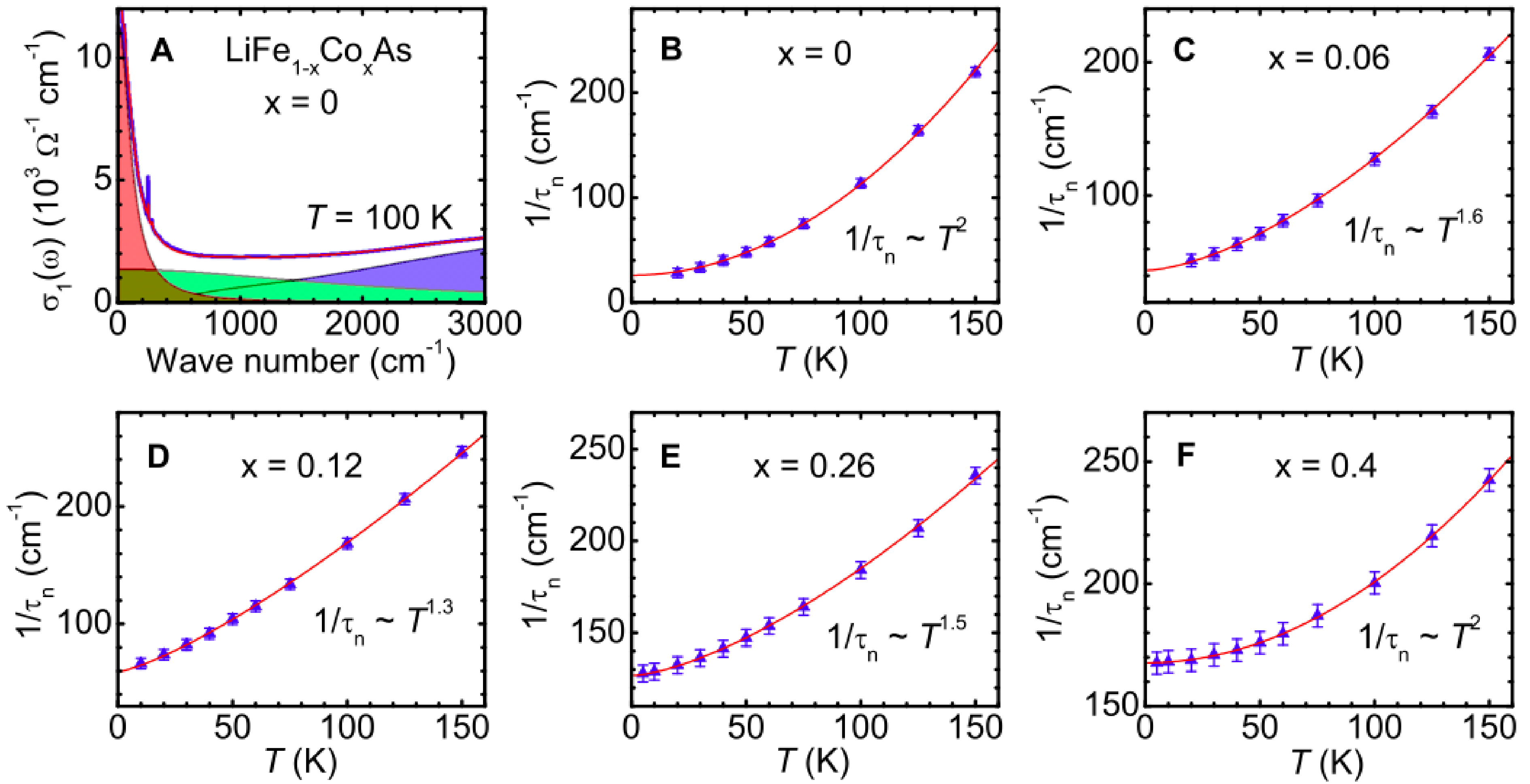
SC does not need FS nesting or low-E spin fluctuations!

FS nesting may stabilize AF ordering.

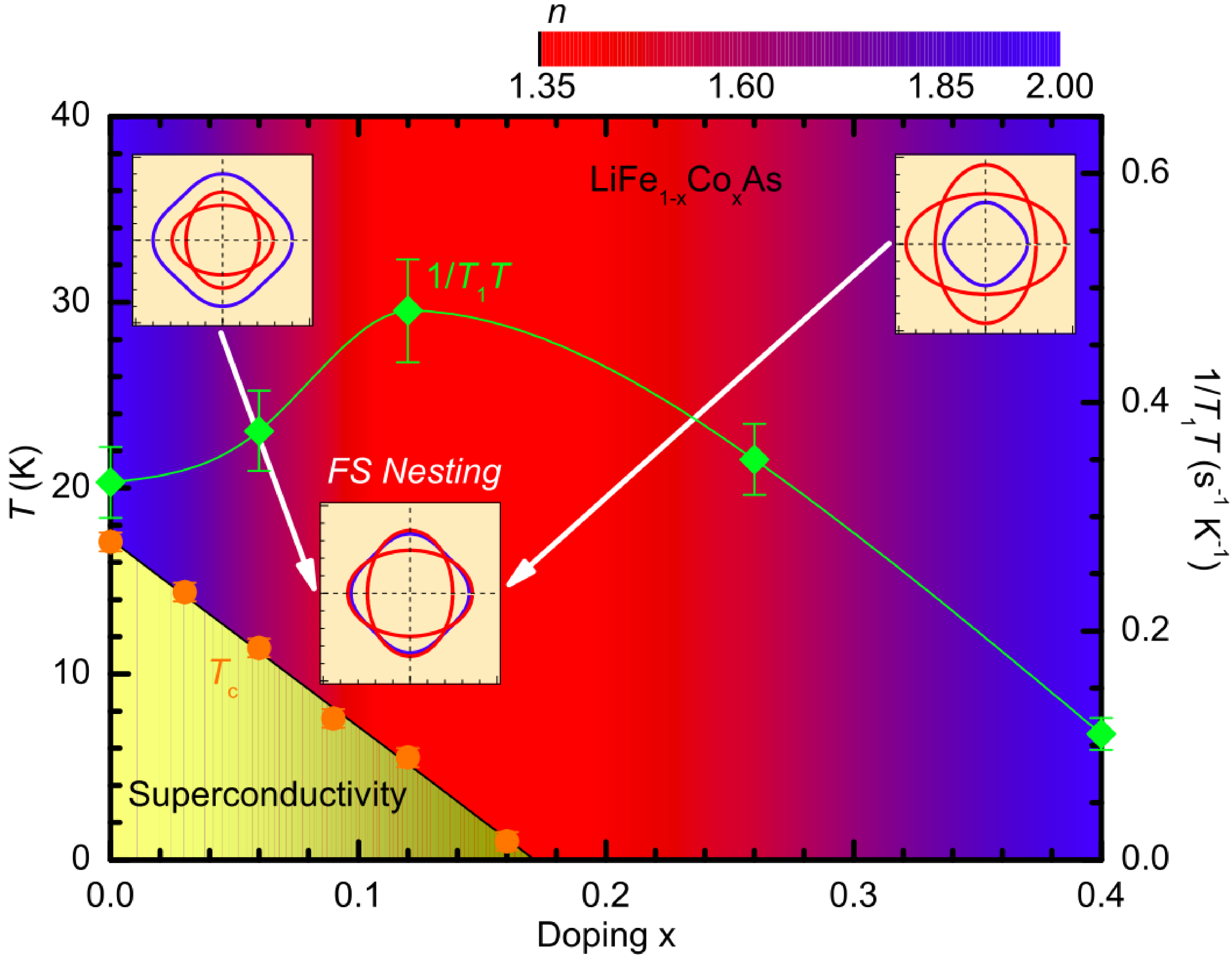
DC resistivity of $LiFe_{1-x}Co_xAs$



Optical conductivity and scattering rate of $LiFe_{1-x}Co_xAs$



FL-NFL crossover, spin fluctuations, and FS nesting



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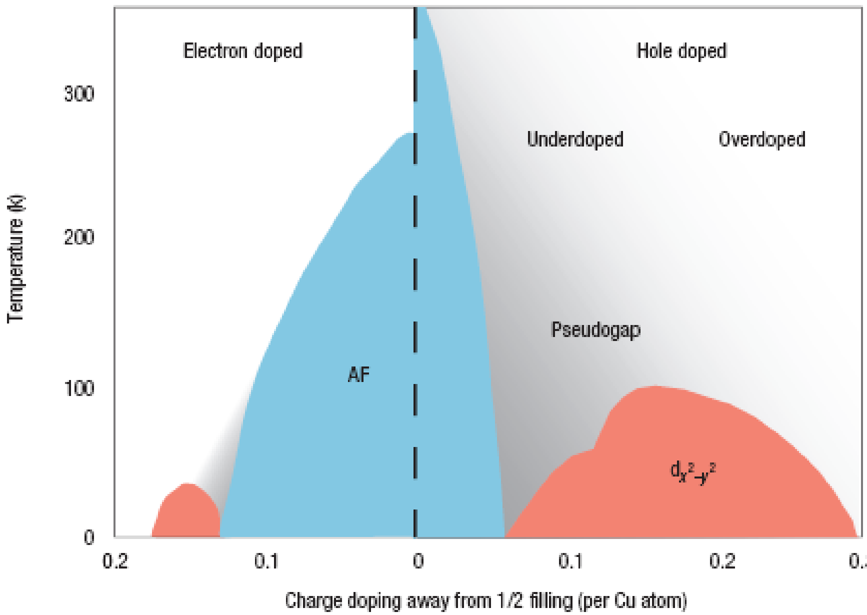
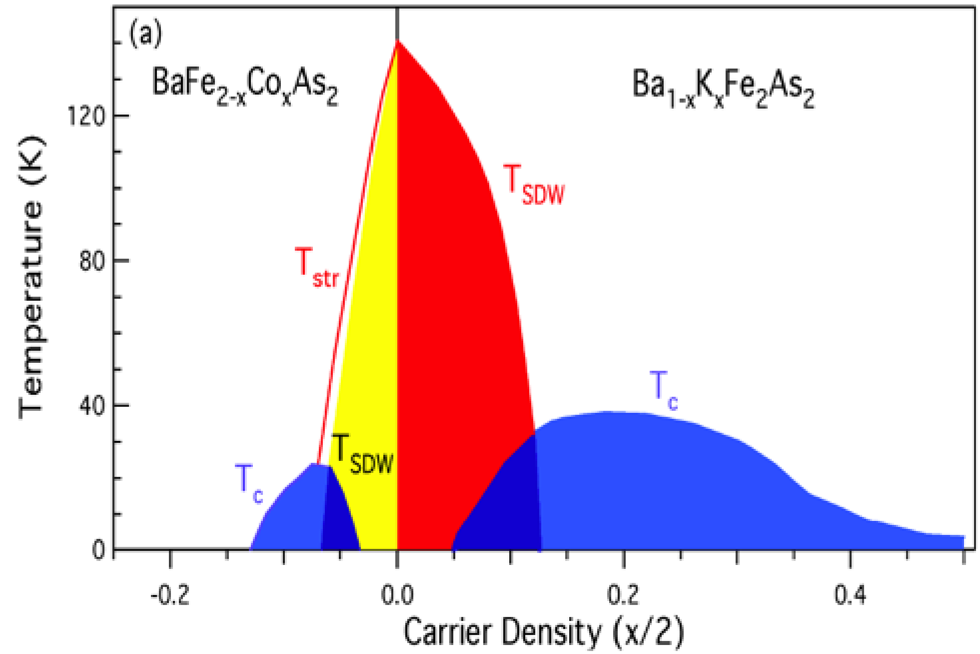
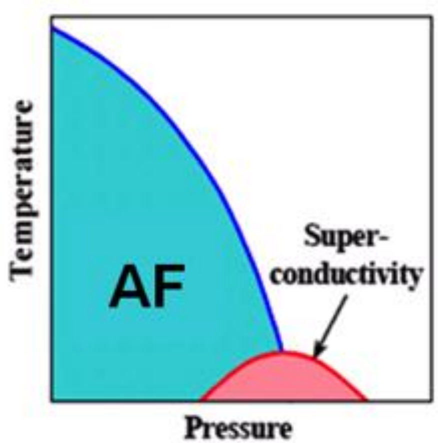
Phase diagrams of unconventional SCs

cuprate SC

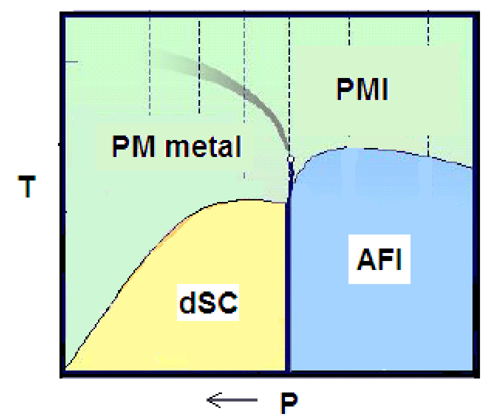


pnictide SC



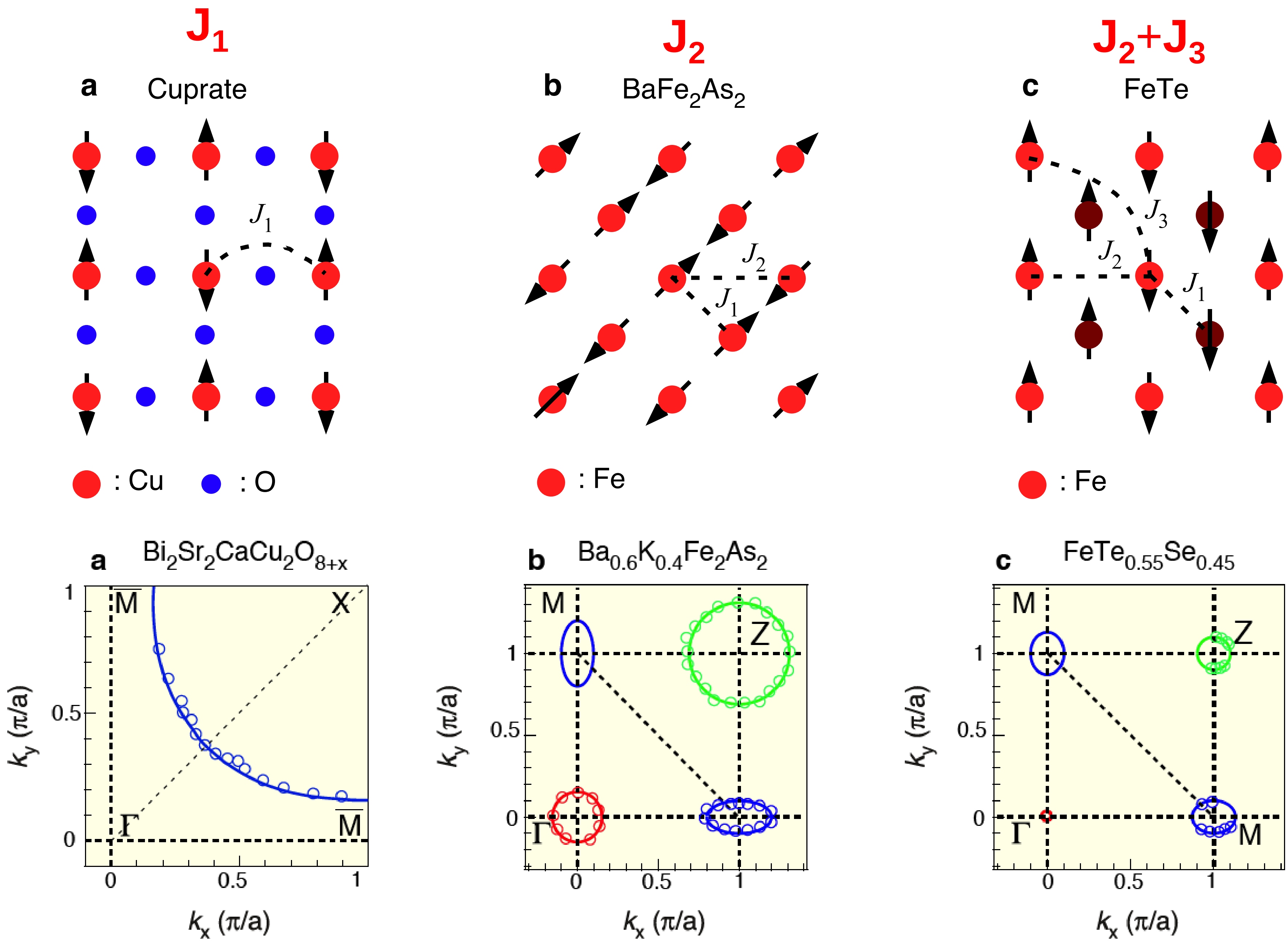


heavy fermion SC



organic SC

Three classes of high-T_c superconductors



Selection Rules of Pairing Symmetry

Self-consistent mean field equation for t-J model

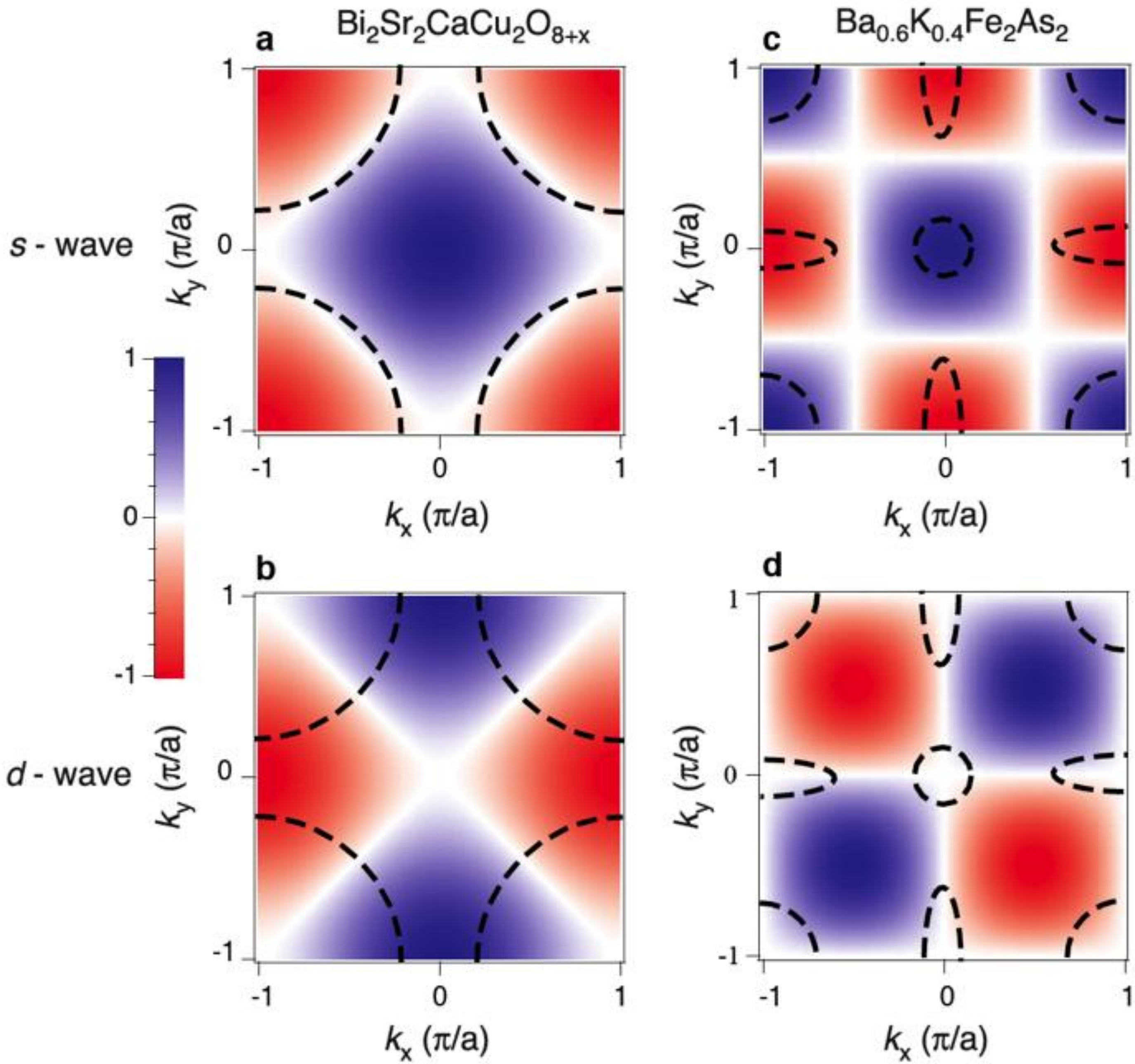
$$2T_c = J_\alpha \sum_k |f_\alpha(k)|^2 g(x(k, T_c)) \qquad g(x) = \frac{\tanh(x)}{x},\ x(k, T_c) = \frac{(\varepsilon(k) - \mu)}{2T_c}$$

Overlap strength between pairing form factor and Fermi surface

$$\mathrm{OS} = \sum_k |f(k)|^2 \delta(\epsilon(k) - \mu)$$

AF couplings & gap form	$Bi_2Sr_2CaCu_2O_{8+x}$	$Pr_{1-x}Ce_xCuO_4$	$Ba_{0.6}K_{0.4}Fe_2As_2$	$FeTe_{0.55}Se_{0.45}$	$KFe_{1.7}Se_2$
J_1: s-wave $(cosk_x + cosk_y)/2$	0.03	0.01	0.43	(0.29)	(0.01)
J_1: d-wave $(cosk_x - cosk_y)/2$	0.61	0.40	0.36	(0.55)	(0.74)
J_2: s-wave $cosk_x cosk_y$	–	–	0.62	0.71	0.55
J_2: d-wave $sink_x sink_y$	–	–	0.03	0.01	0.05
J_3: s-wave $(cos2k_x + cos2k_y)/2$	–	–	–	0.52	0.31
J_3: d-wave $(cos2k_x - cos2k_y)/2$	–	–	–	0.07	0.11

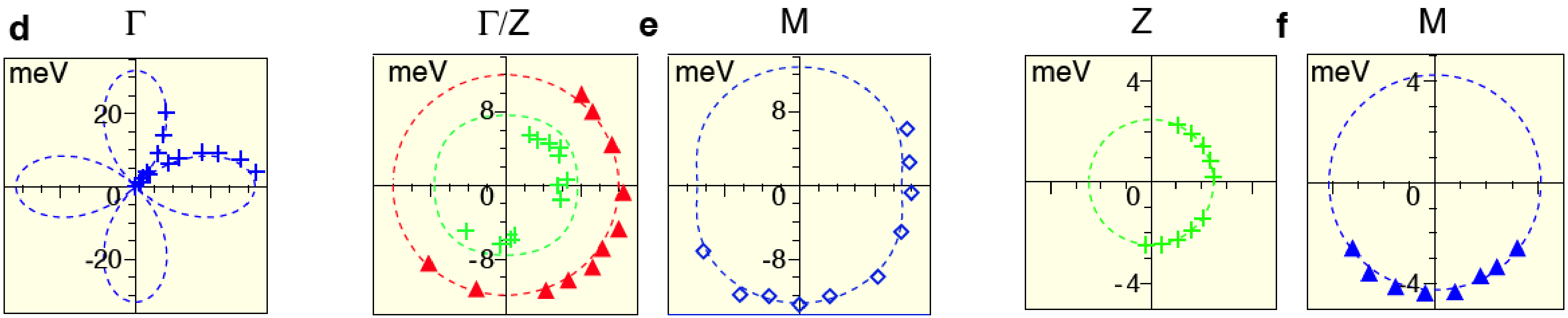
Overlap strength between pairing form factor and Fermi surface



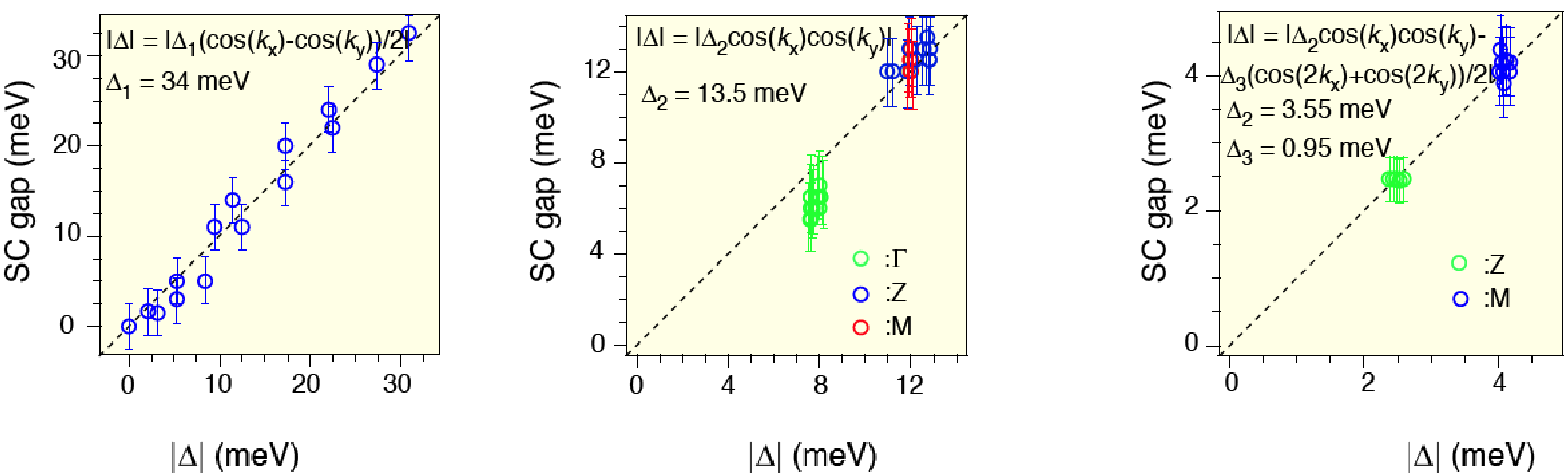
Three classes of high-T_c superconductors

J_1 **J_2** **J_2+J_3**

$Bi_2Sr_2CaCu_2O_{8+x}$ $Ba_{0.6}K_{0.4}Fe_2As_2$ $FeTe_{0.55}Se_{0.45}$

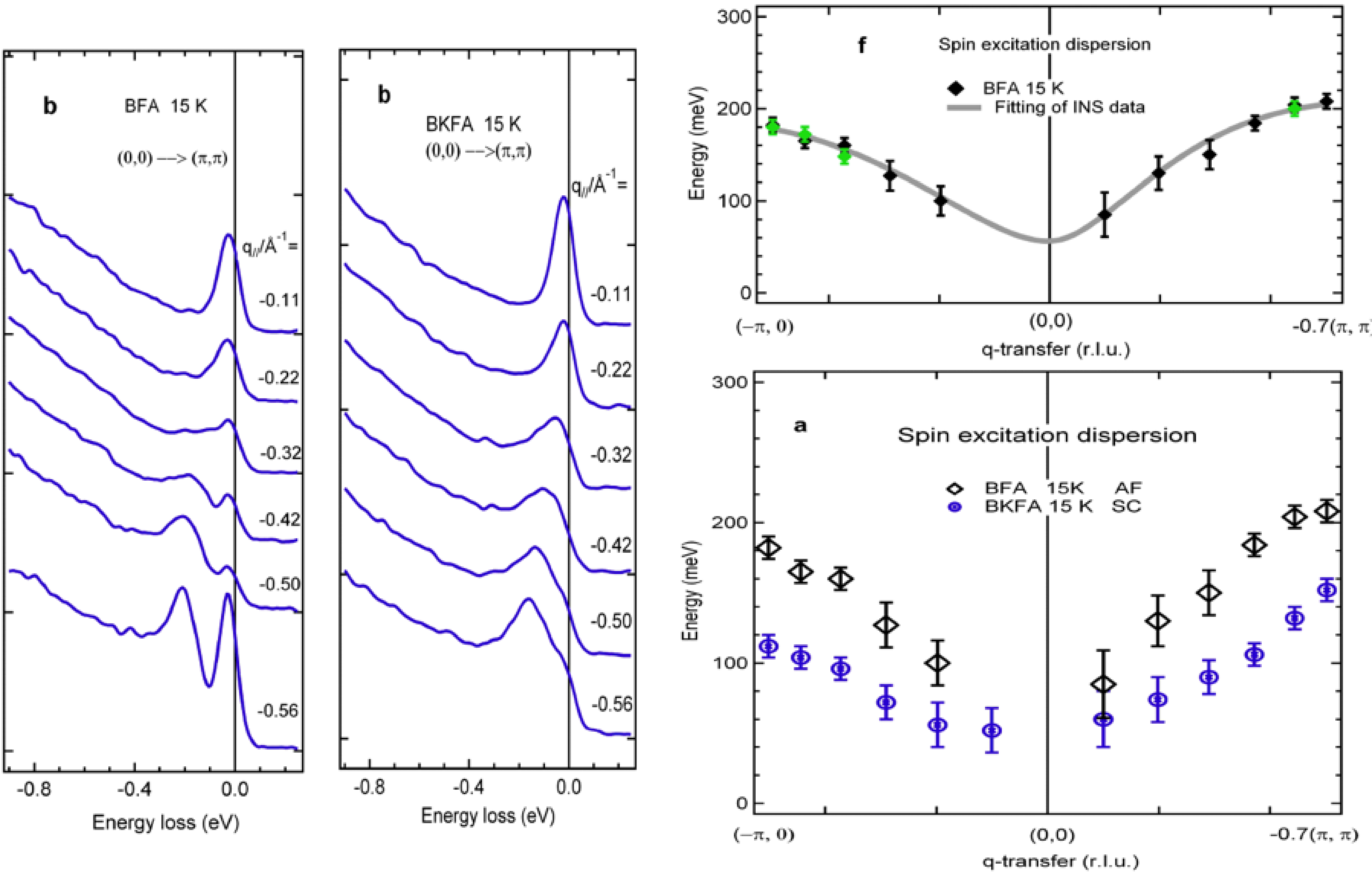


$|\Delta| = |\Delta_1(\cos(k_x)-\cos(k_y))/2|$ $|\Delta| = |\Delta_2\cos(k_x)\cos(k_y)|$ $|\Delta| = |\Delta_2\cos(k_x)\cos(k_y)-\Delta_3(\cos(2k_x)+\cos(2k_y))/2|$



J.-P. Hu and H. Ding, Scientific Reports 2, 381 (2012)

Persistent spin excitations in Fe-SCs



K. J. Zhou *et al.*, Nature Communications 4, 1470 (2013)

Summary

1. The SC gap of most Fe-SCs measured by ARPES is a simple sine/cosine function of (kx, ky, kz), strongly suggesting local pairing and strong coupling

2. Strong pairing can happen to bands without FS: smoking evidence for local-exchange (strong-coupling) approach

3. Low-energy spin-fluctuations, which can be enhanced by FS nesting, may not be essential to superconductivity

4. The magnetic exchange model (J_1-J_2-J_3) can describe magnetic order patterns and SC gap functions in Fe-SCs and Cu-SCs, suggesting an unified paradigm of high-T_c superconductivity

Thank you!