Кристаллическая структура, фазовый состав и сверхпроводимость новых соединений на основе FeSe

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Max Planck Institute for Solid State Research

Зеленогорск, 2013

MAX-PLANCK-GESELLSCHAFT

MPI-FKF Stuttgart

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Neutron scattering: J. T. Park, G. Friemel, J.-H. Kim, Yuan Li, V. Hinkov, B. Keimer;

LDA calculations: A. Yaresko;

Single crystals: C. T. Lin *et al.*

Augsburg University, Germany

Single crystals: V. Tsurkan, J. Deisenhofer, H.-A. Krug von Nidda, A. Loidl.

Université Paris-Sud

NMR measurements: J. Bobroff, Y. Texier, Y. Laplace.

Institut Laue-Langevin, Grenoble, France

Instrument support: A. Ivanov

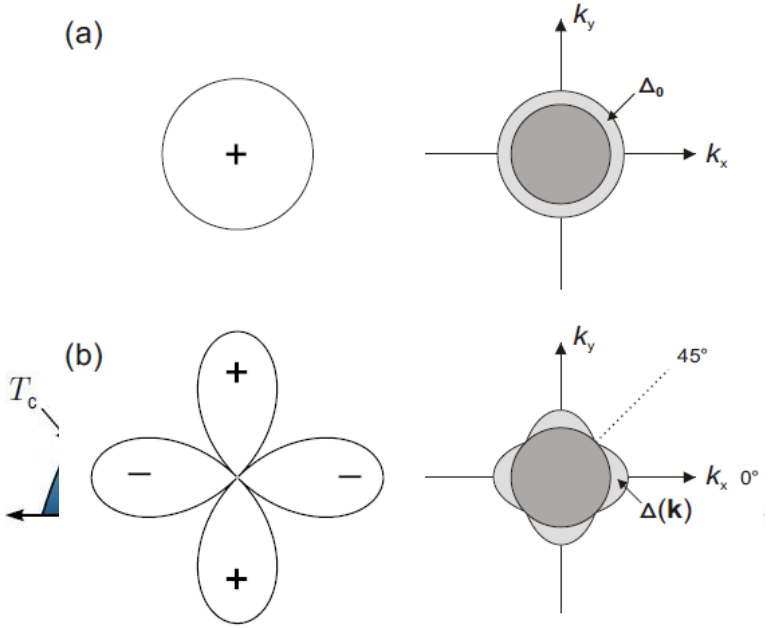
ISIS, Rutherford Appleton Laboratory

Instrument support: E. A. Goremychkin

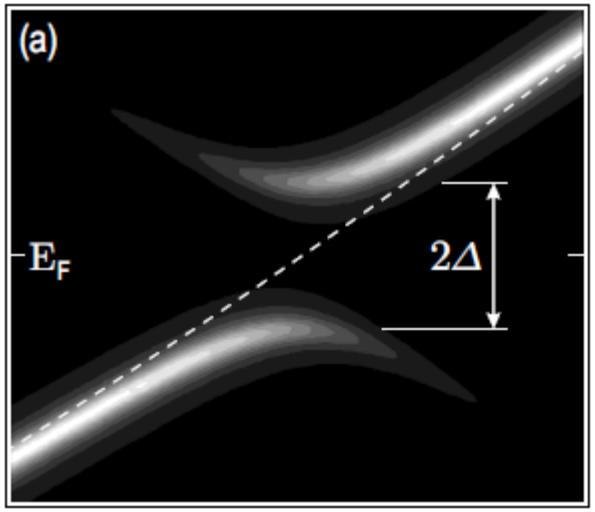
Oak Ridge National Lab

Band structure calculations: T. A. Maier

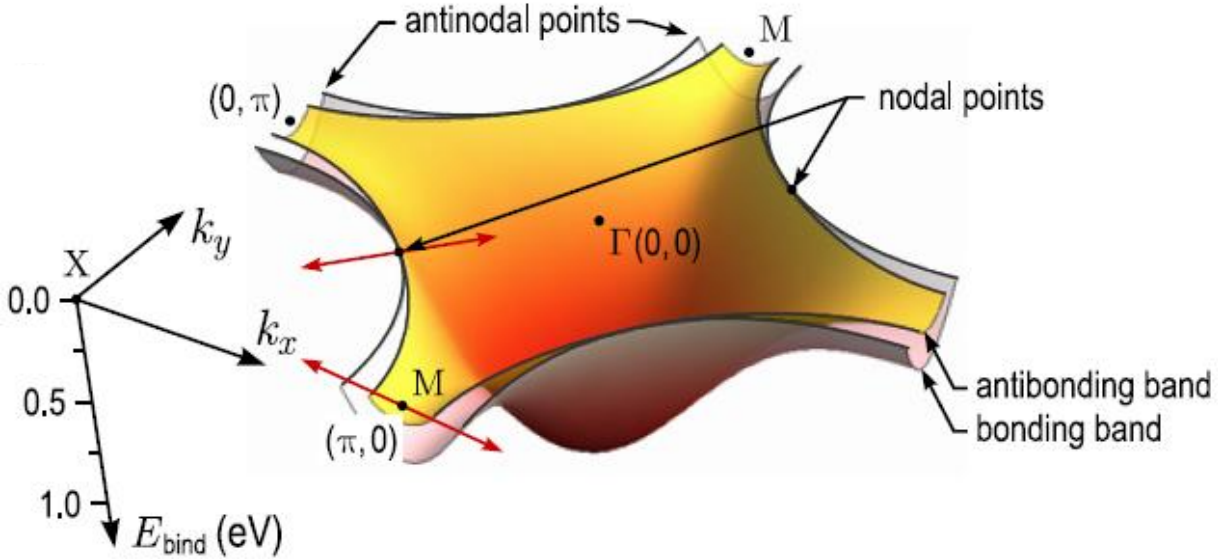
Unconventional superconductors

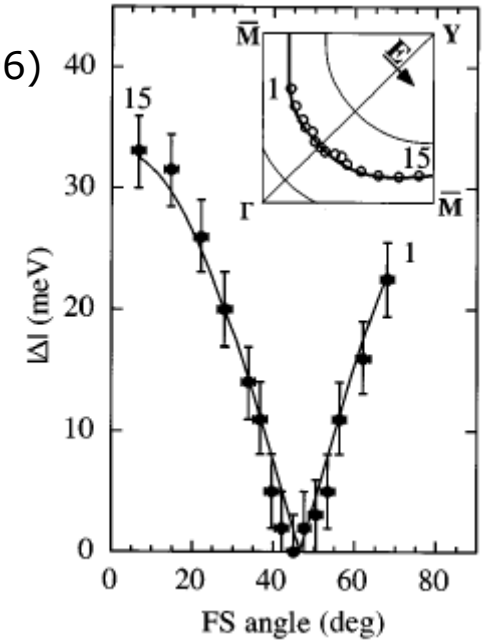


superconducting energy gap

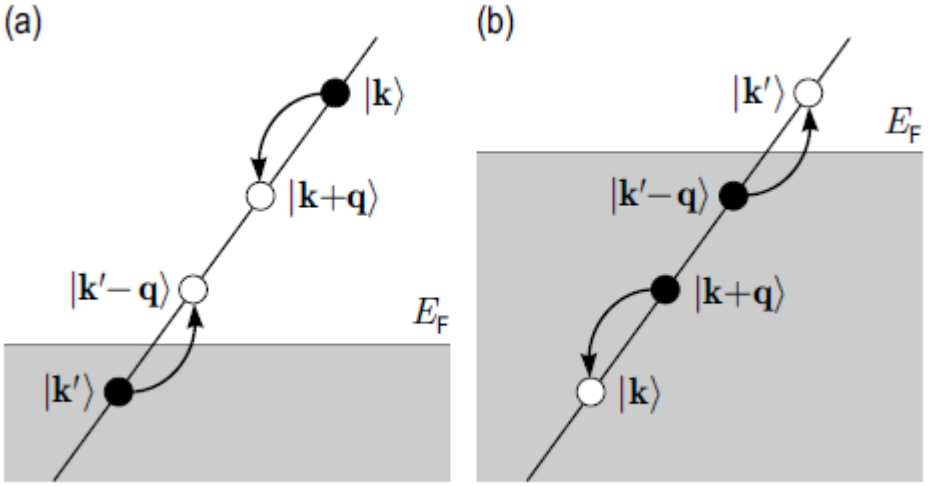


H. Ding *et al.*,
PRB **54**, R9678 (1996)





Particle-hole scattering

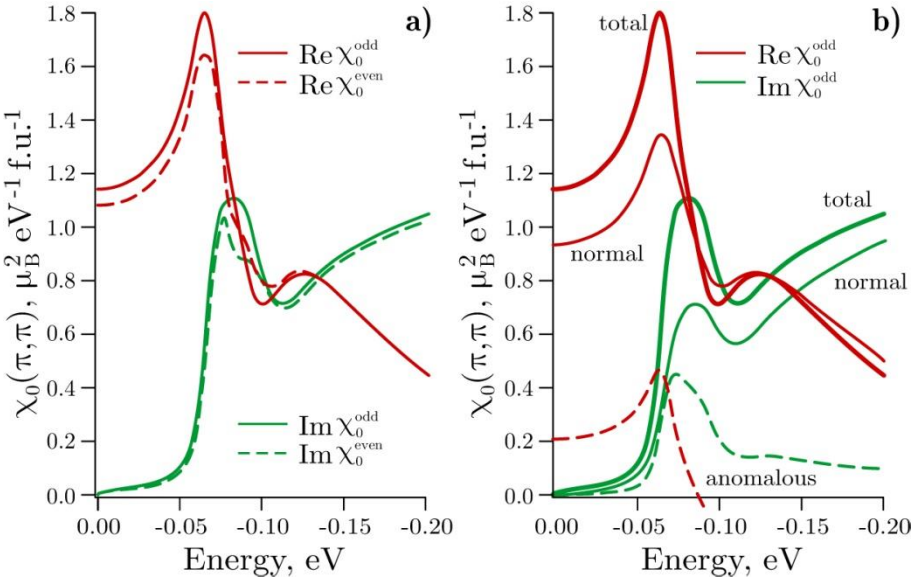


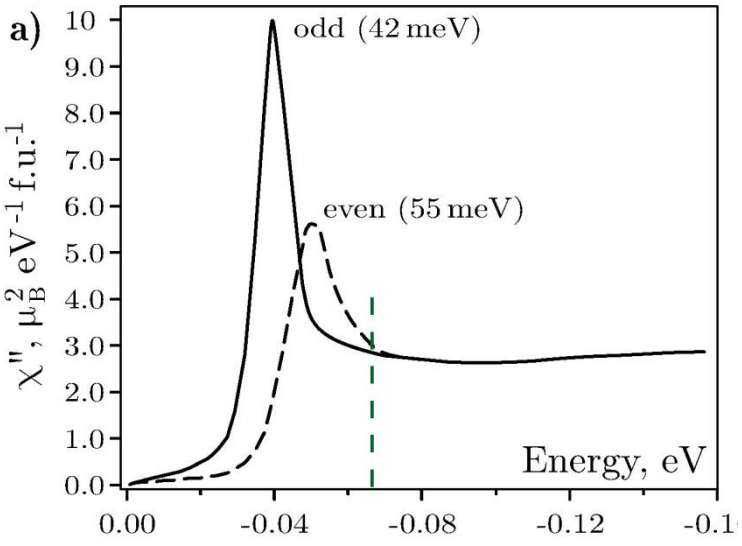
Lindhard susceptibility:

$$\chi_0(\mathbf{q},\omega) = 2\int \frac{\mathrm{d}\mathbf{k}}{(2\pi)^d} \frac{n_\mathrm{F}(\epsilon_\mathbf{k}) - n_\mathrm{F}(\epsilon_{\mathbf{k}+\mathbf{q}})}{\epsilon_\mathbf{k} - \epsilon_{\mathbf{k}+\mathbf{q}} + \omega + \mathrm{i}0^+}$$

Spin exciton below the particle-hole continuum:

$$\chi(\mathbf{q},\omega) = \frac{\chi_0(\mathbf{q},\omega)}{1 - g(\mathbf{q})\chi_0(\mathbf{q},\omega)}$$

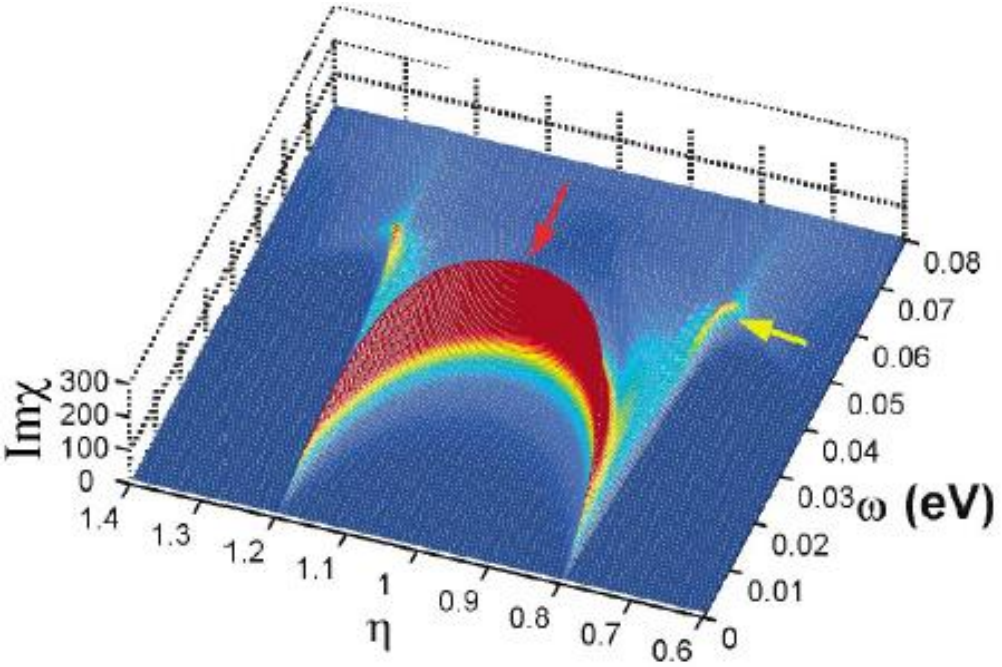




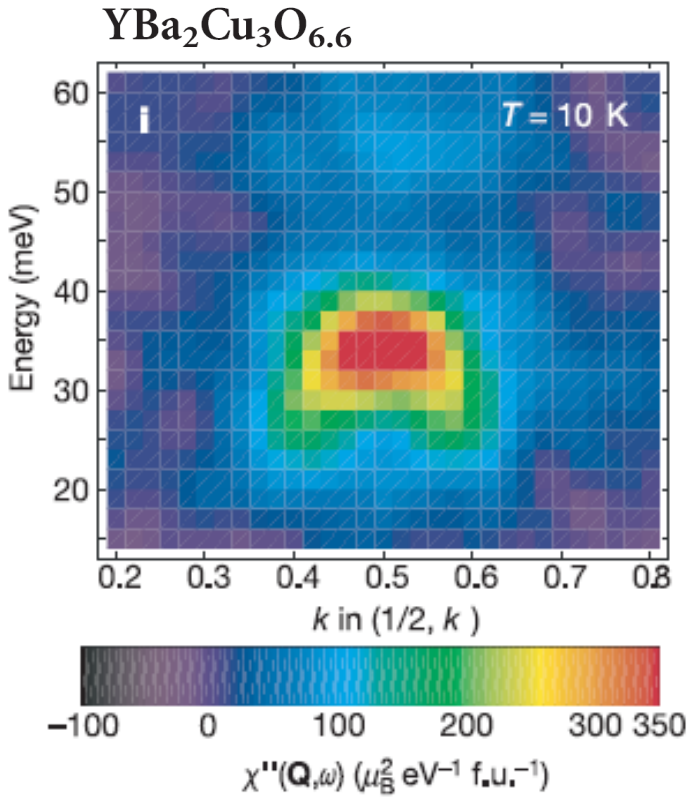
Resonant mode in copper oxides

"Hourglass" dispersion in cuprates:
Fermi-surface + *d*-wave gap

$$\chi(\mathbf{q}, \omega) = \frac{\chi_0(\mathbf{q}, \omega)}{1 - g(\mathbf{q})\chi_0(\mathbf{q}, \omega)}$$



I. Eremin *et al.*, Phys. Rev. Lett. **94**, 147001 (2005)

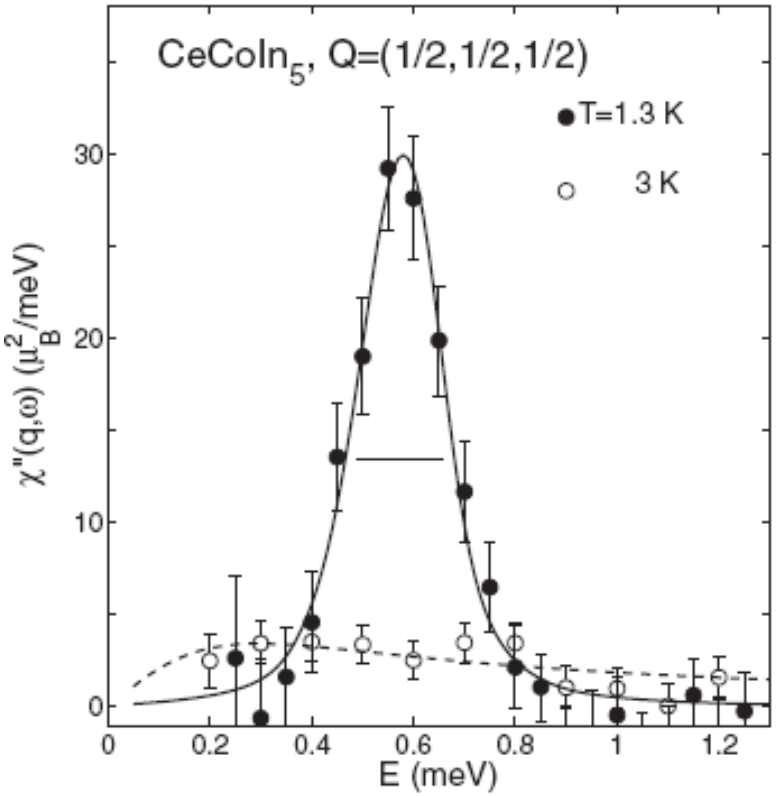


S. M. Hayden *et al.*,
Nature **429**, 531 (2004)

Original discovery:
J. Rossat-Mignod *et al.*,
Physica C **185**, 86 (1991)

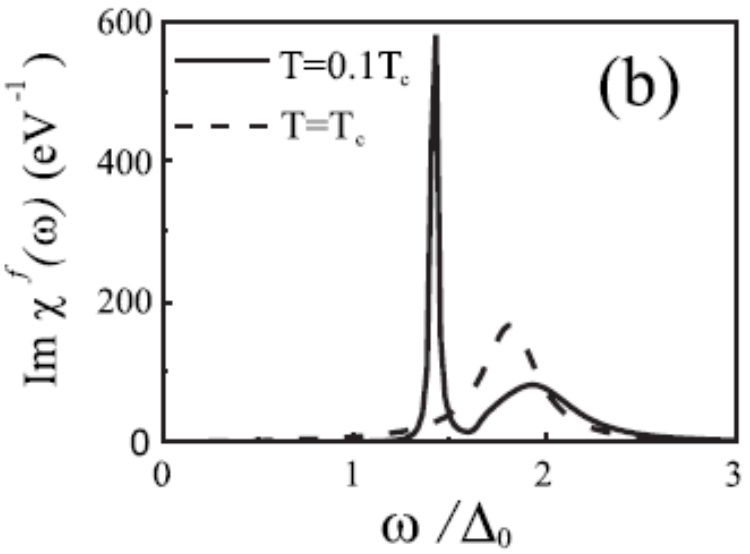
Magnetic resonant mode in $CeCoIn_5$

Heavy-fermion superconductor



C. Stock *et al.*,
Phys. Rev. Lett. **100,** 087001 (2008)

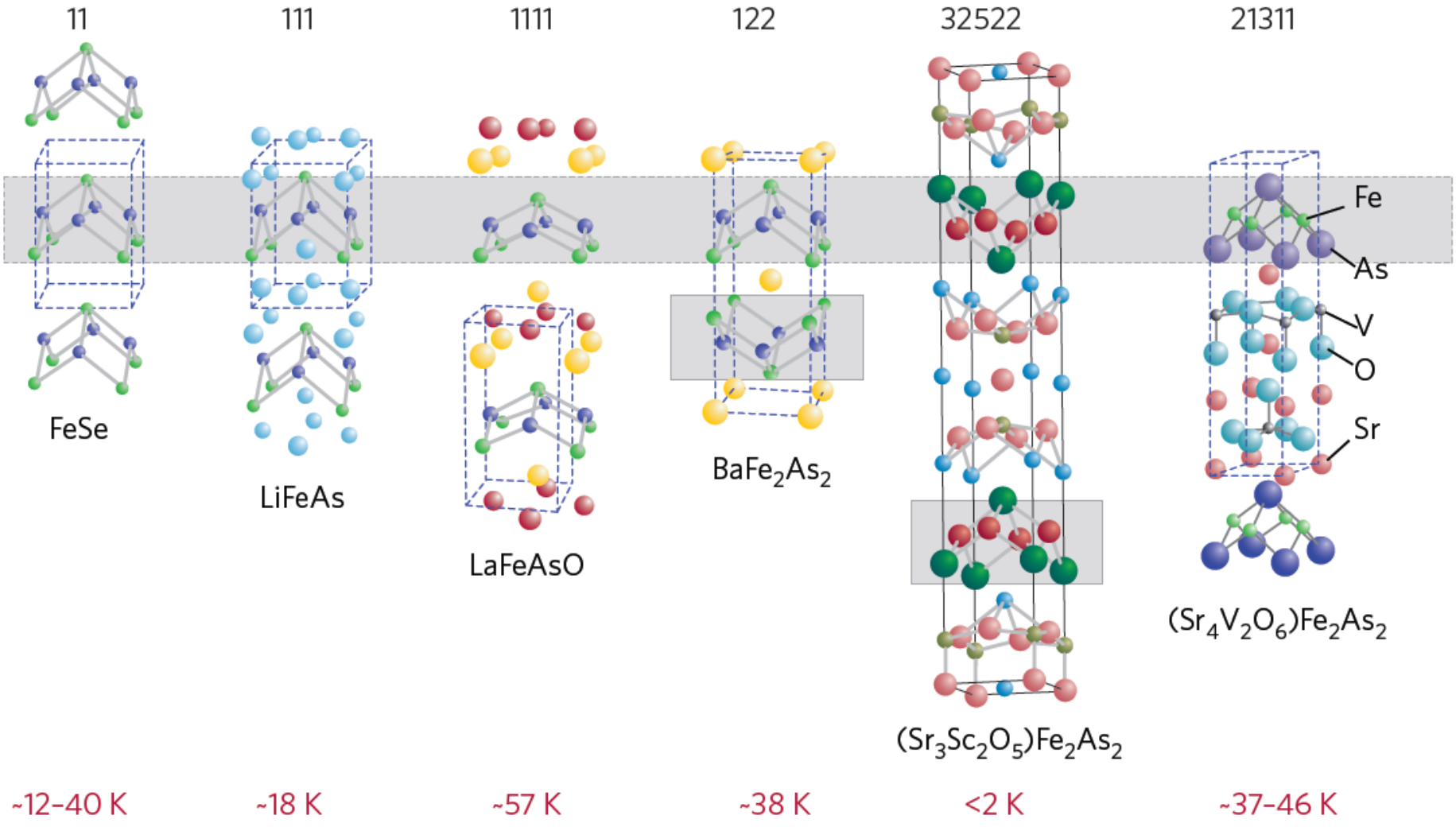
Theory:



A. Akbari *et al.*,
Phys. Rev. B **80**, 100504R (2009)

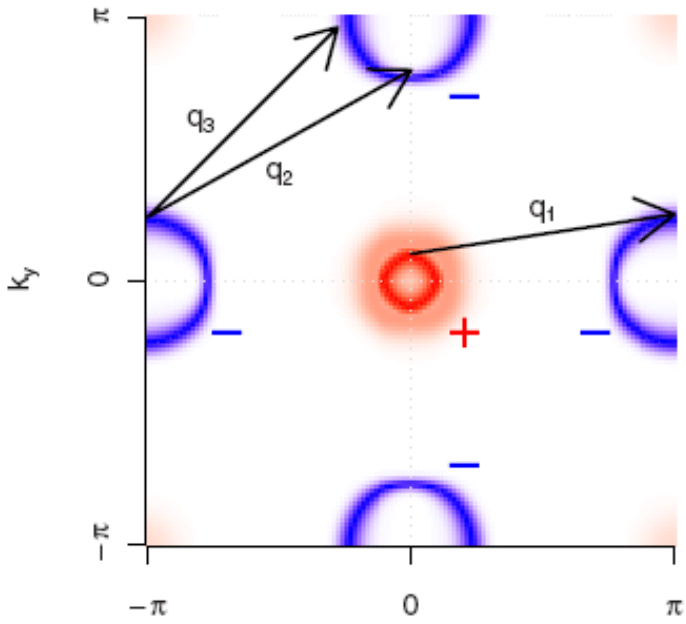
Iron-arsenide superconductors

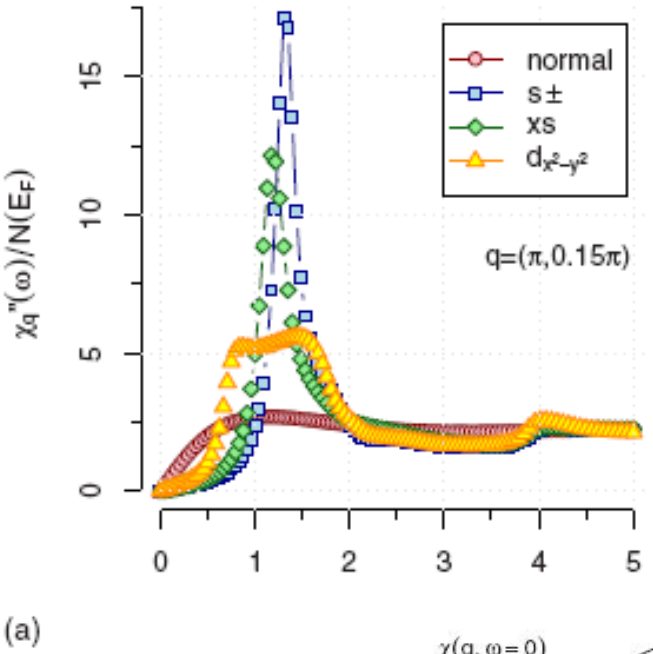
Fe-based superconductors



C. W. Chu, Nat. Phys. **5**, 787 (2009)

Resonant mode in Fe-based superconductors

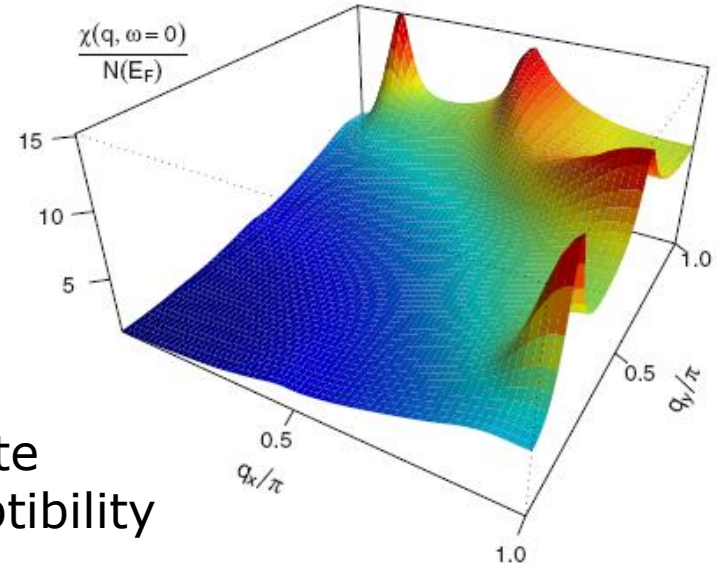




Isotropic, sign reversed s-wave

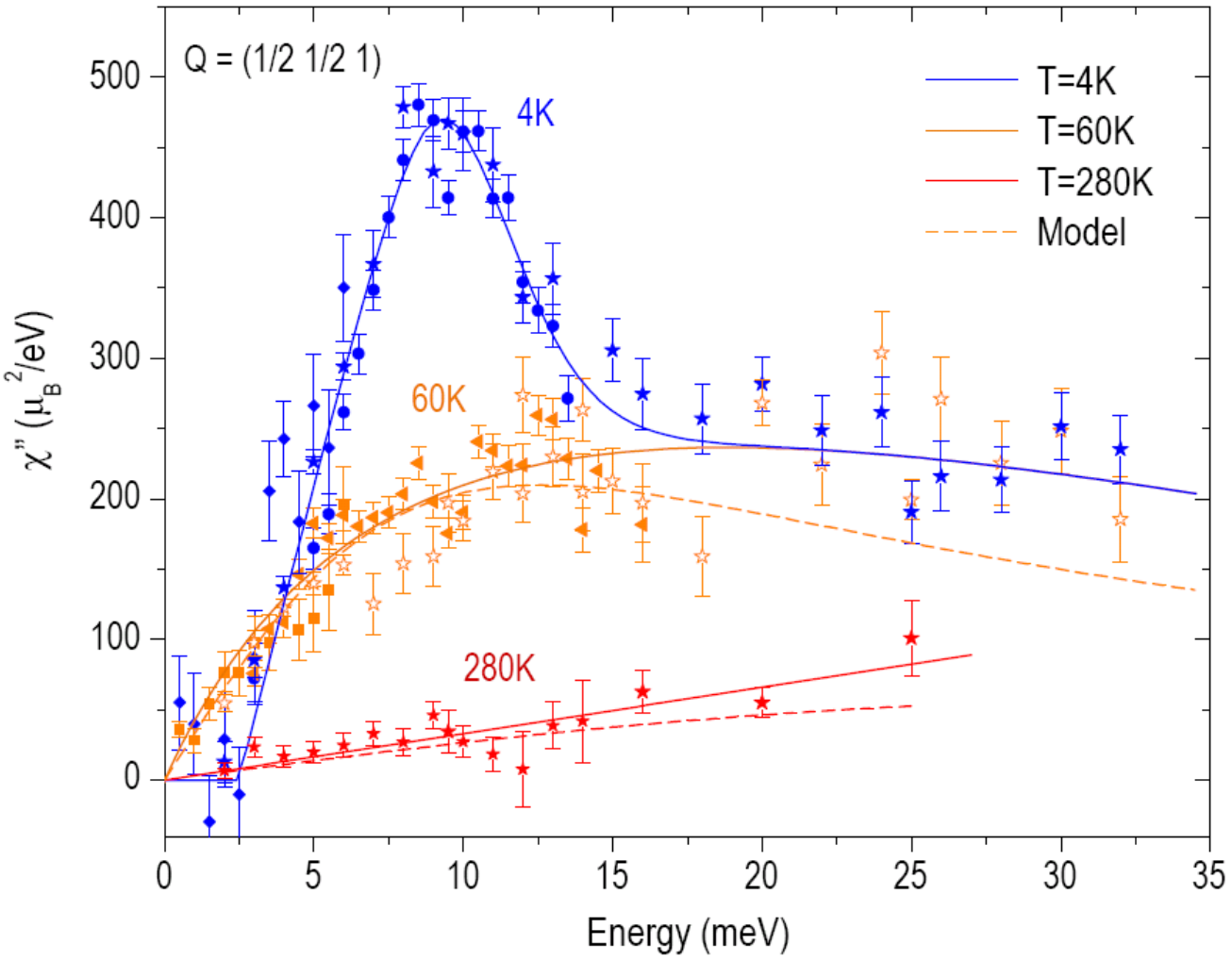
T. A. Maier et al.,
PRB **79**, 134520 (2009);

see also Eremin et al.,
PRB **78** 140509 (2008).



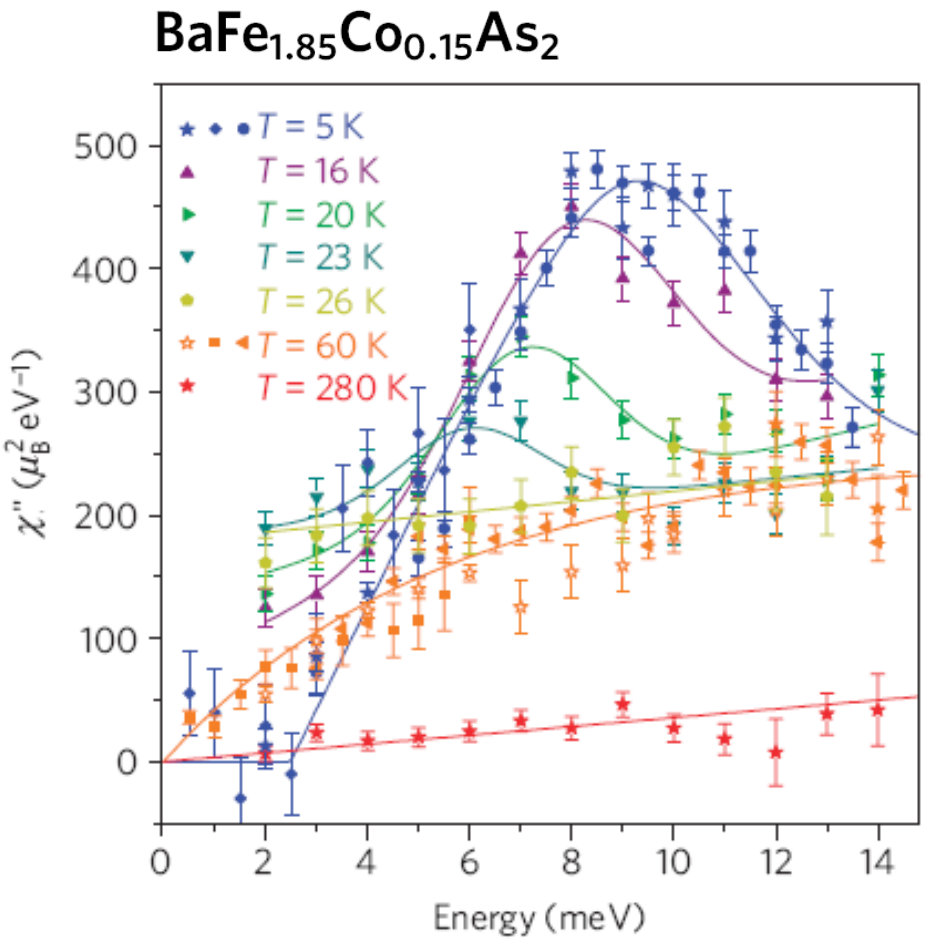
Normal state
spin susceptibility

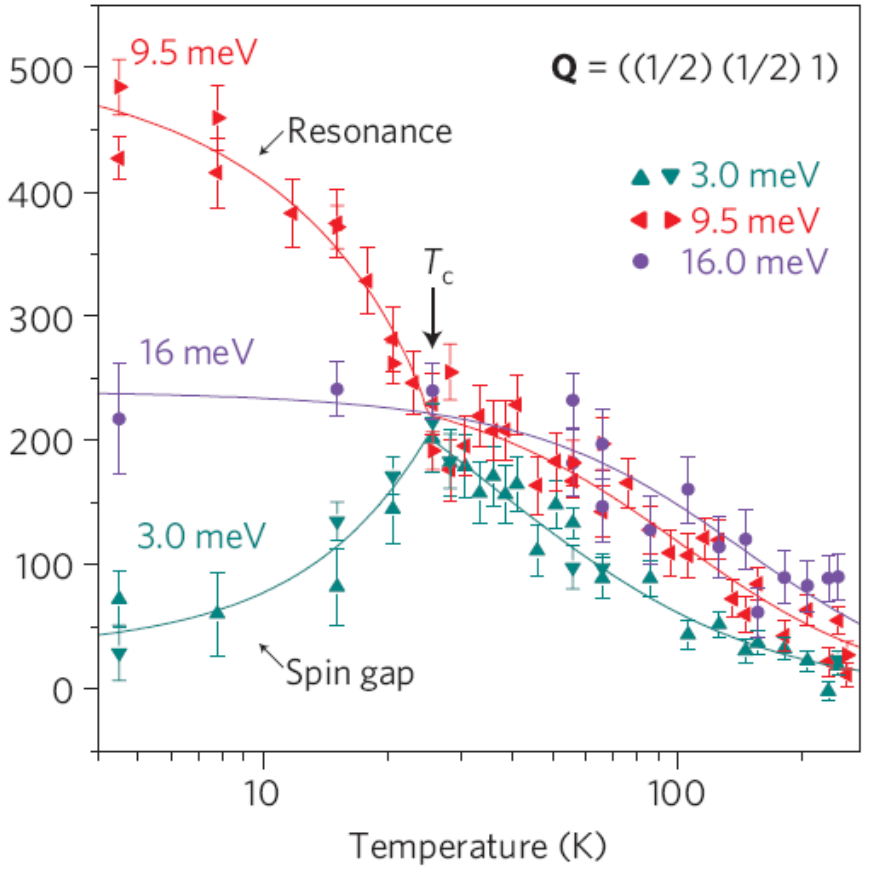
Magnetic resonant mode in $BaFe_{2-x}Co_xAs_2$



D. S. Inosov *et al.*, Nature Phys. **6**, 178 (2010)

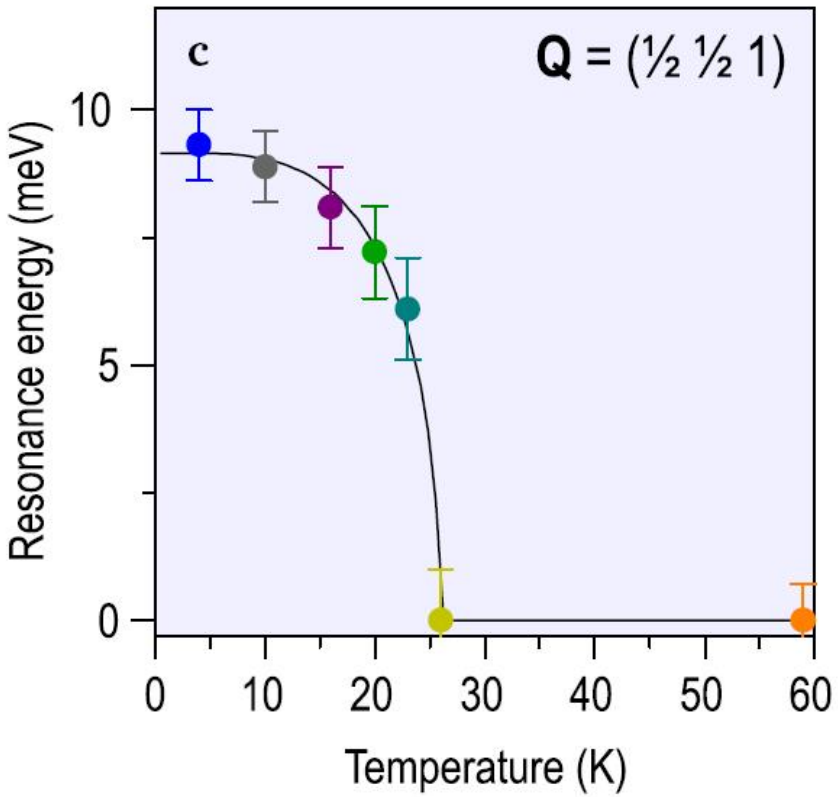
Magnetic resonant mode in $BaFe_{2-x}Co_xAs_2$

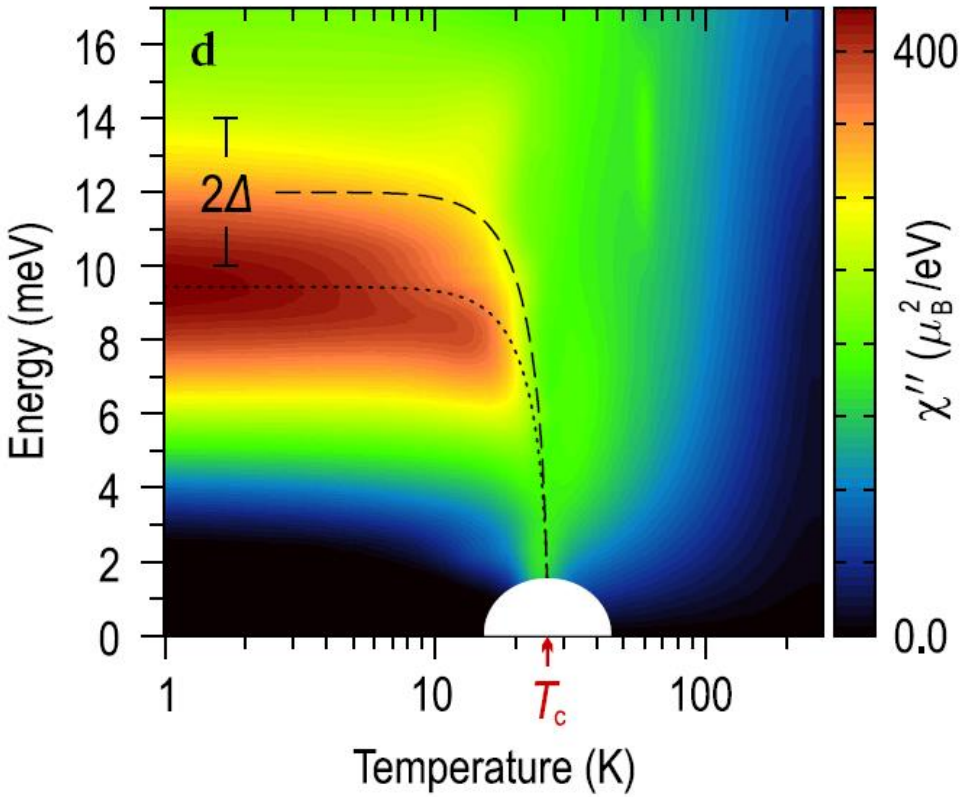




D. Inosov *et al.*, Nature Phys. **6**, 178 (2010)

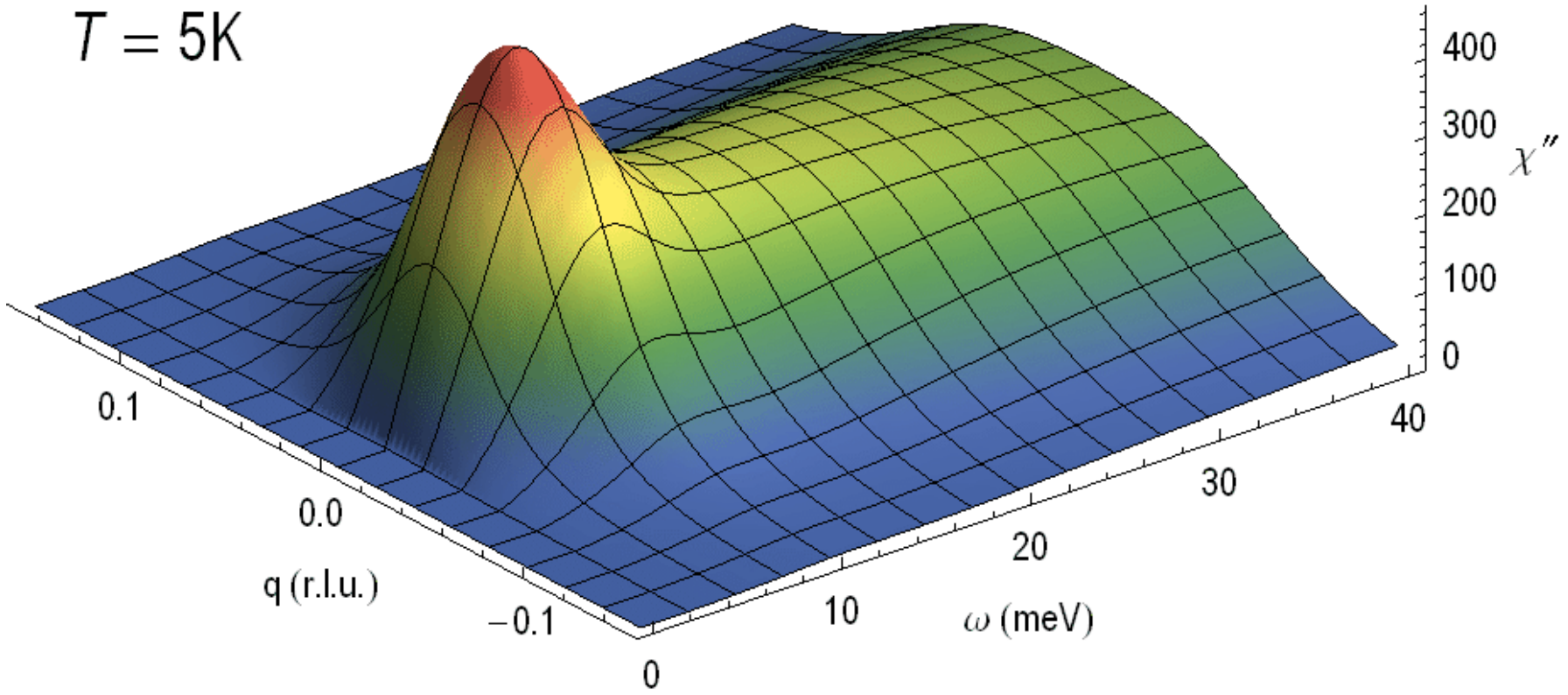
Temperature dependence of the resonance





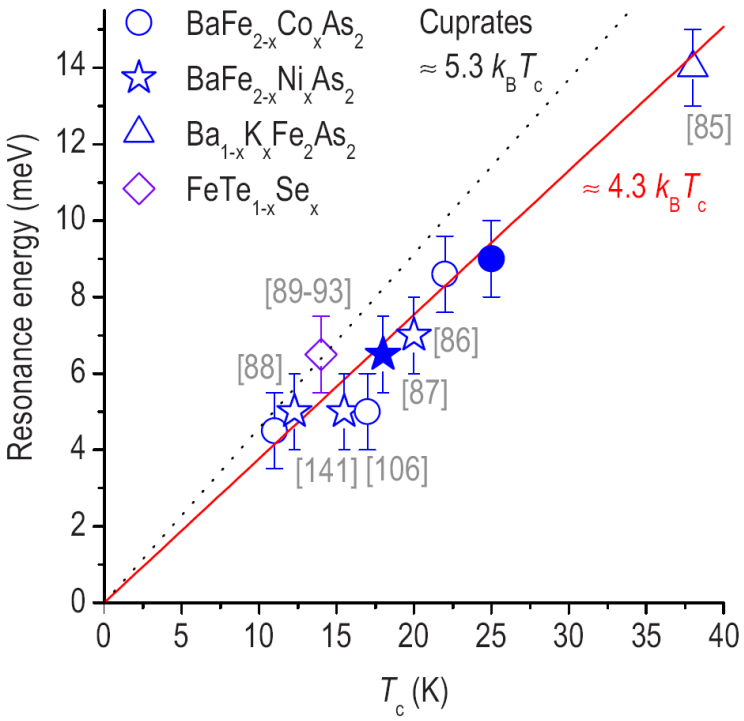
D. S. Inosov *et al.*, Nature Phys. **6**, 178 (2010)

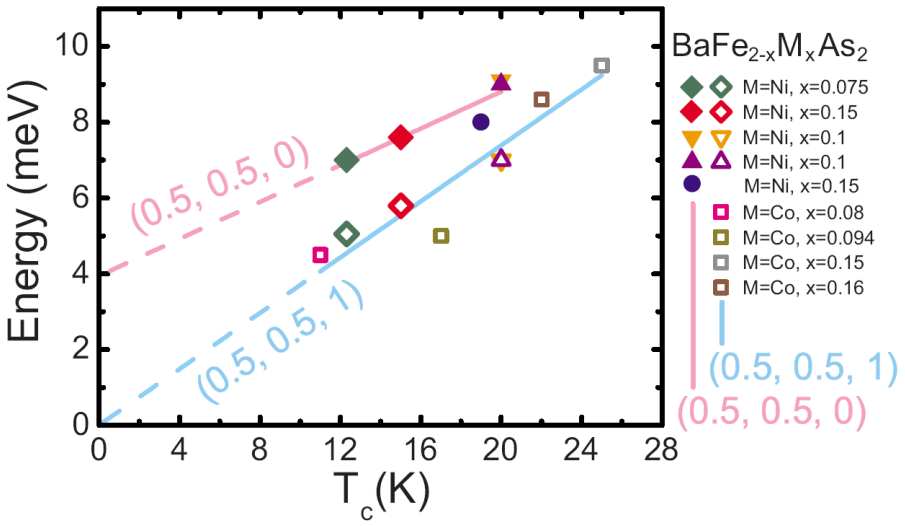
Q-, ω-, and *T*-dependence of the spin excitations

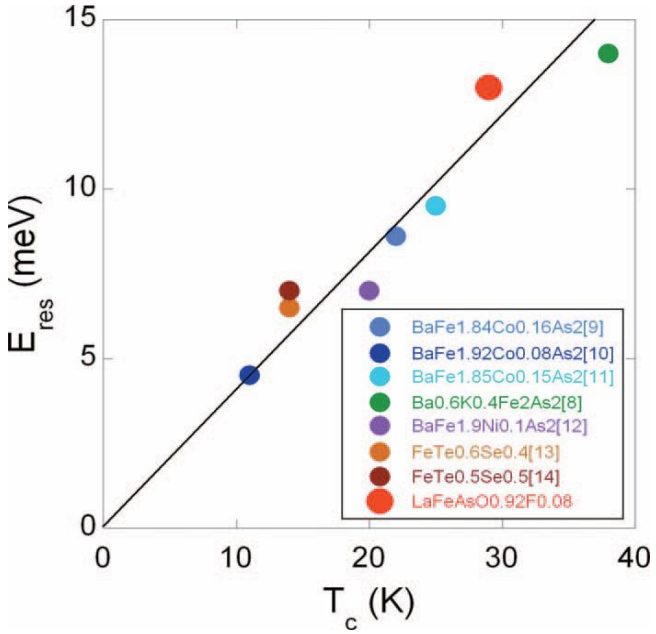


D. S. Inosov *et al.*, Nature Phys. **6**, 178 (2010)

Linear relationship between E_{res} and T_c



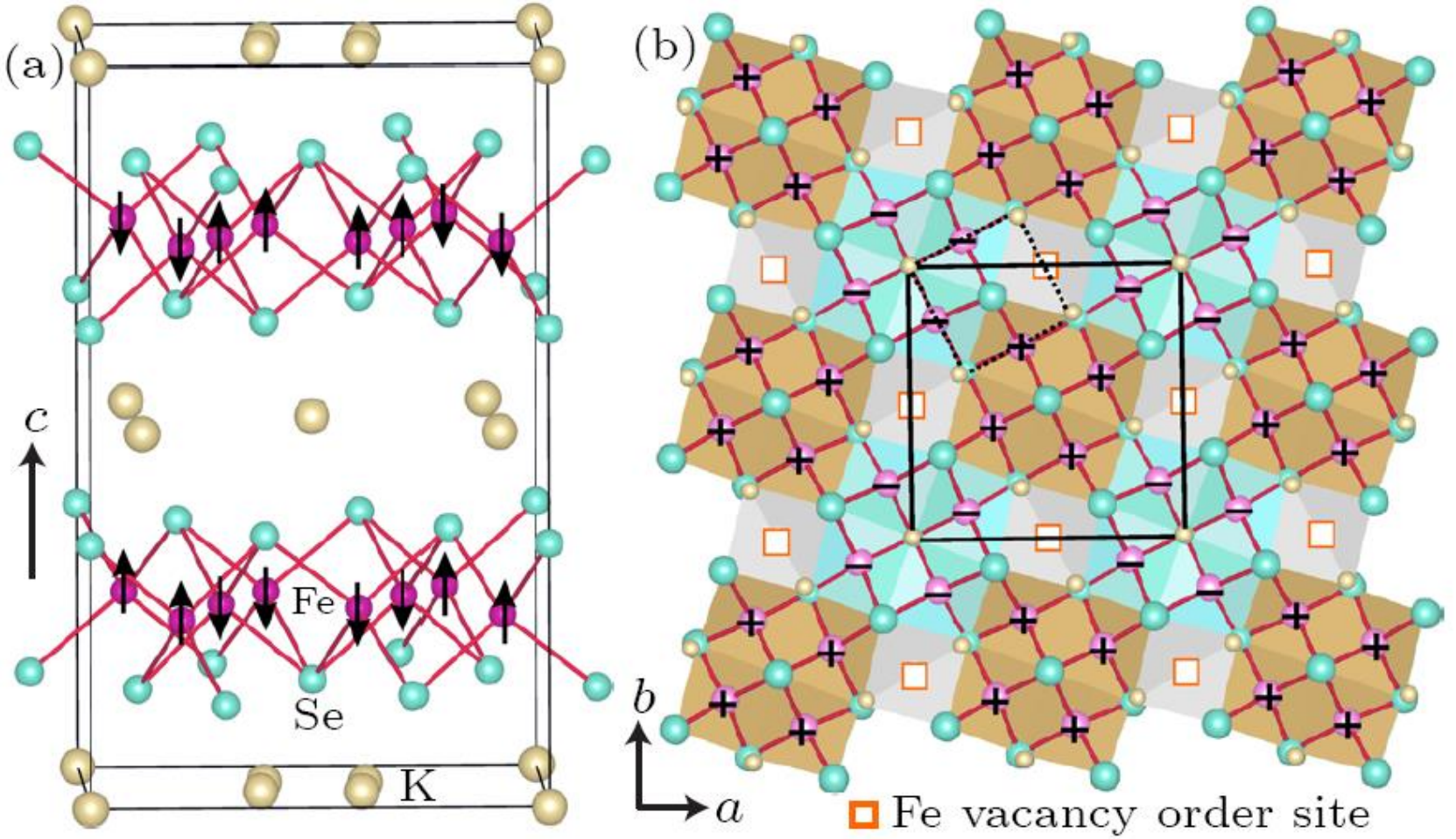




J. T. Park, D. S. Inosov *et al.*, PRB (2010);
M. Wang *et al.*, PRB **81**, 174524 (2010);
S. Shamoto *et al.*, PRB 82, 172508 (2010).

Magnetic resonant mode in $A_{1-x}Fe_{2-y}Se_2$

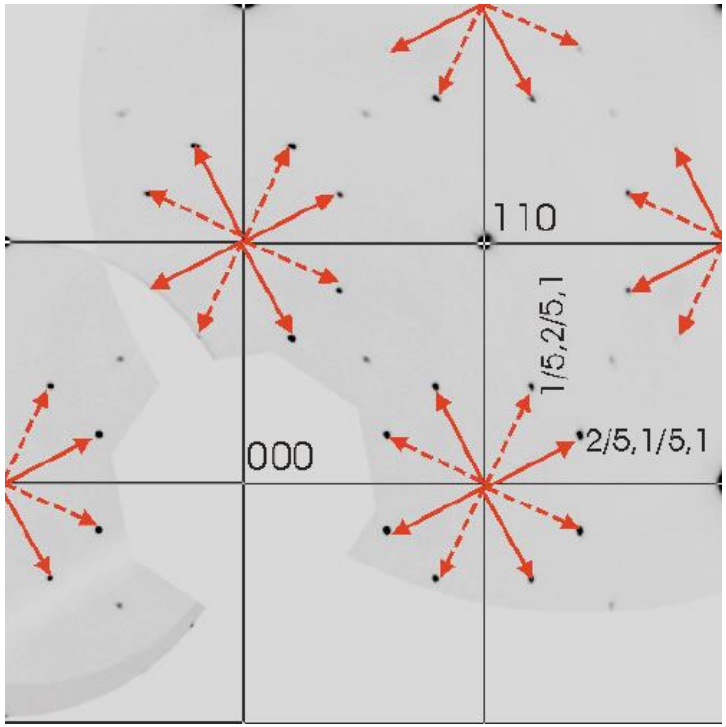
Iron selenides of the “245” family



F. Ye *et al.*, PRL **107**, 137003 (2011),
see also V. Yu. Pomjakushin *et al.,* PRB (2011).

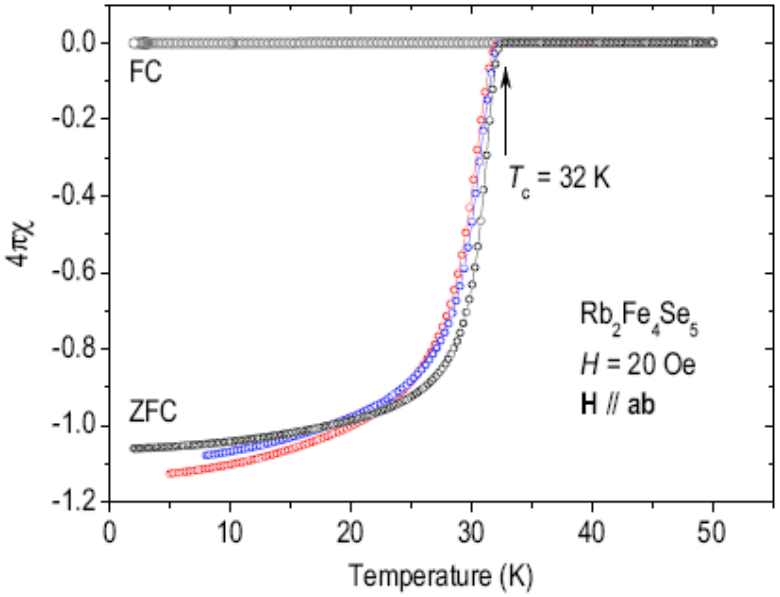
Magnetic order and iron-vacancy superstructure

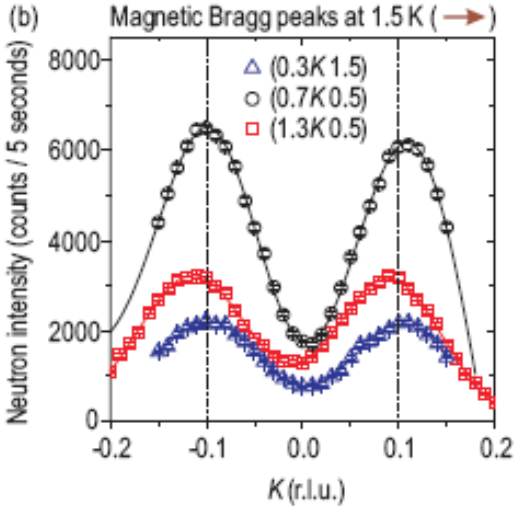
Fe-vacancy ordering

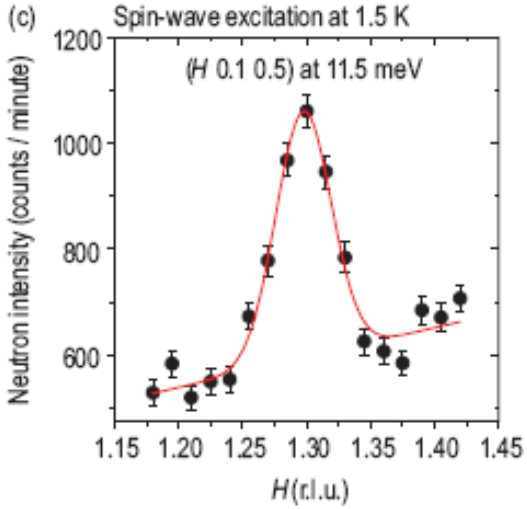


from V. Yu. Pomjakushin *et al.*,
Phys. Rev. B **83**, 144410 (2011);
JPCM **23**, 156003 (2011).

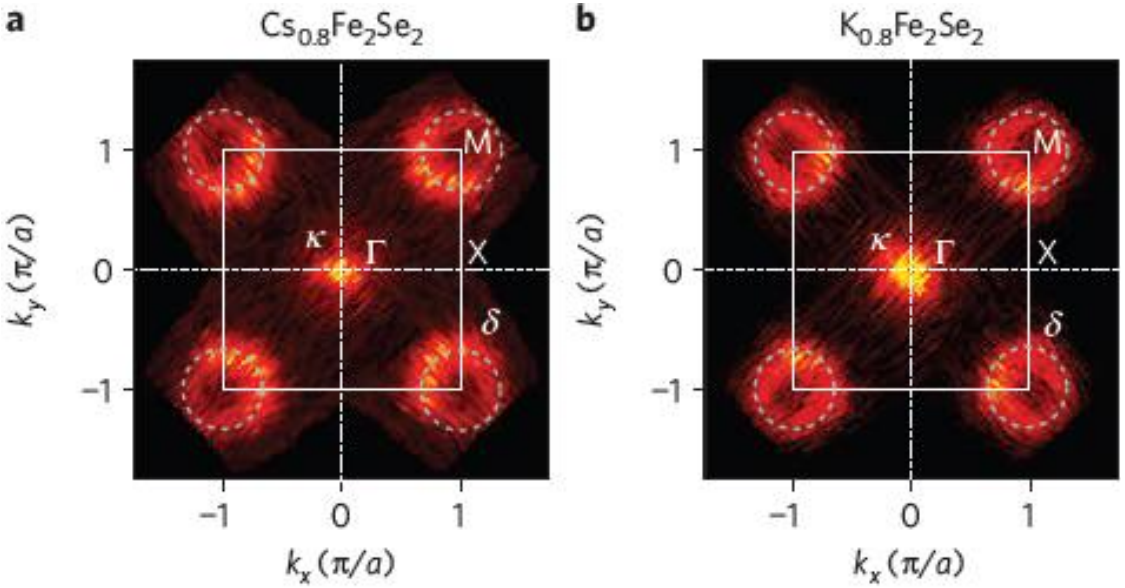
J. T. Park *et al.*,
PRL **107**, 177005 (2011)



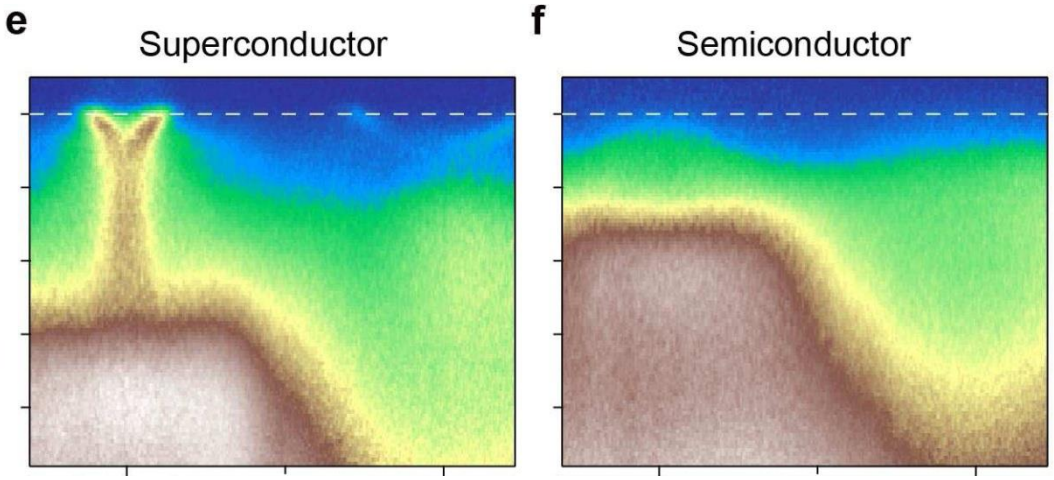




Metal or insulator?

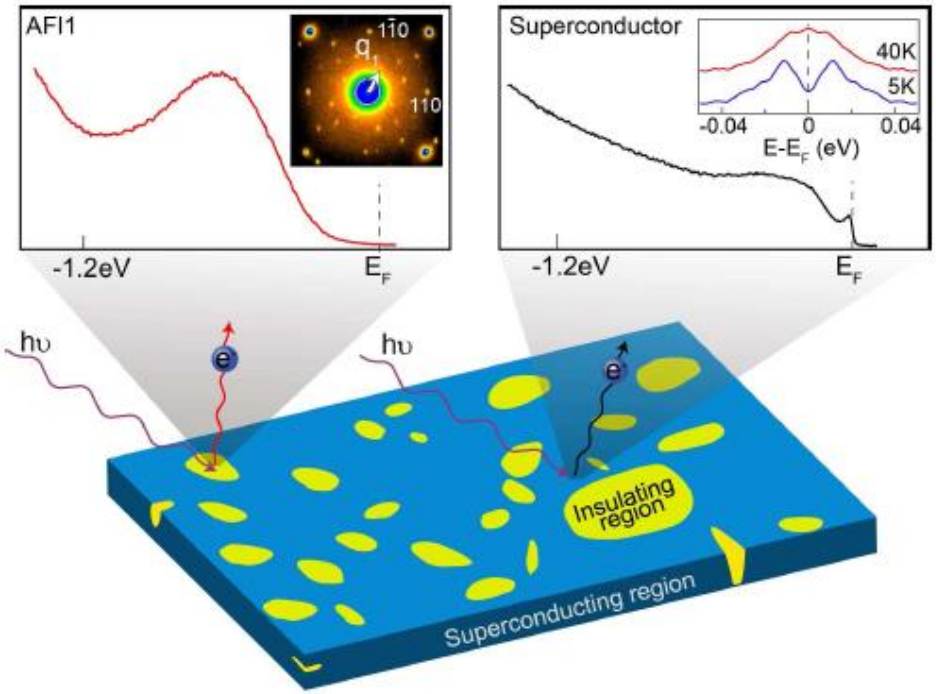


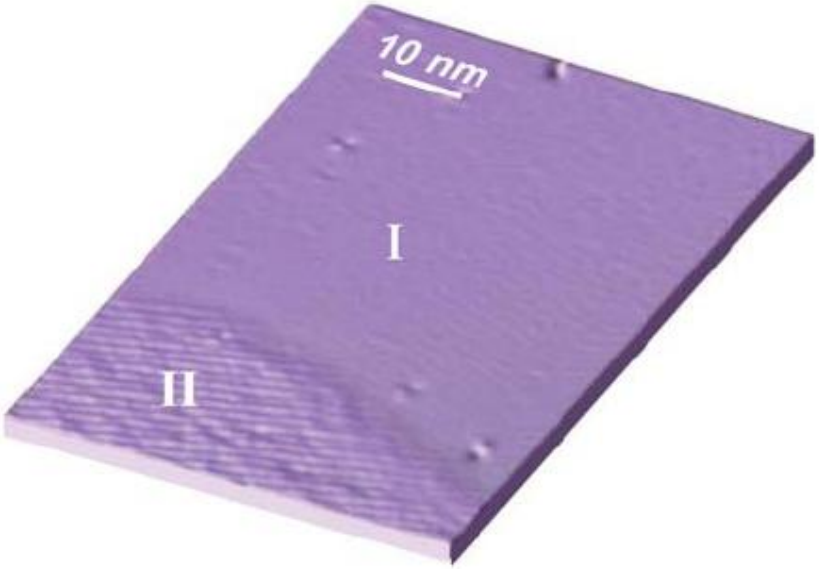
Y. Zhang et al., Nature Mater. (2011), see also T. Qian *et al.*, PRL (2011), D. Mou *et al.*, PRL (2011), X.-P. Wang *et al.*, EPL (2011), etc.

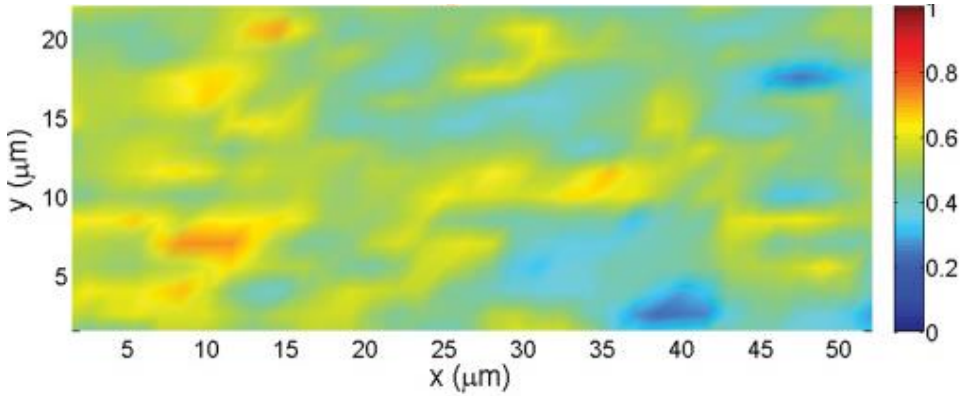


F. Chen *et al.*, PRX **1**, 021020 (2011)

Nanoscale phase separation

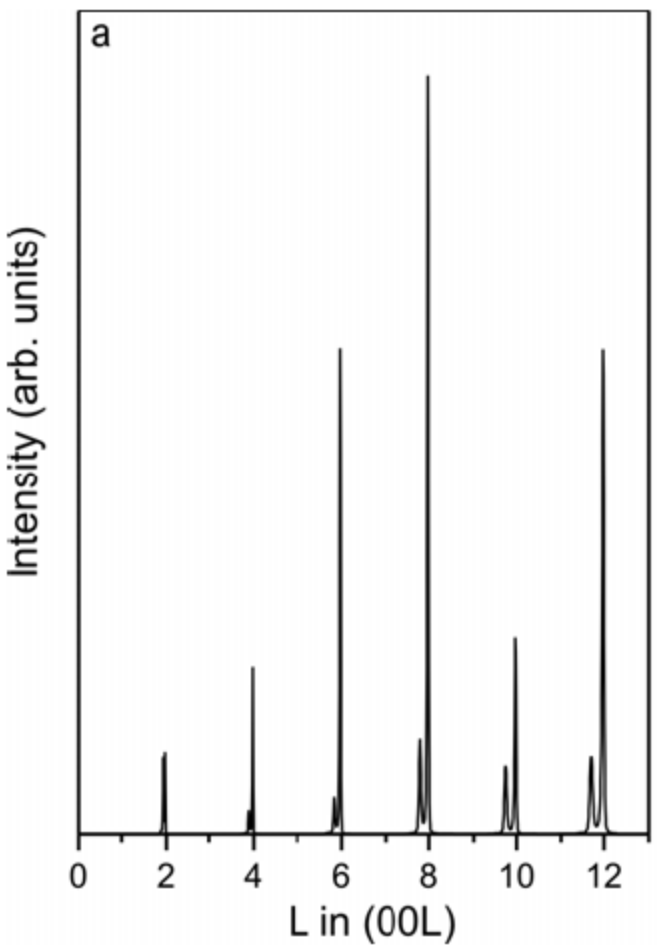


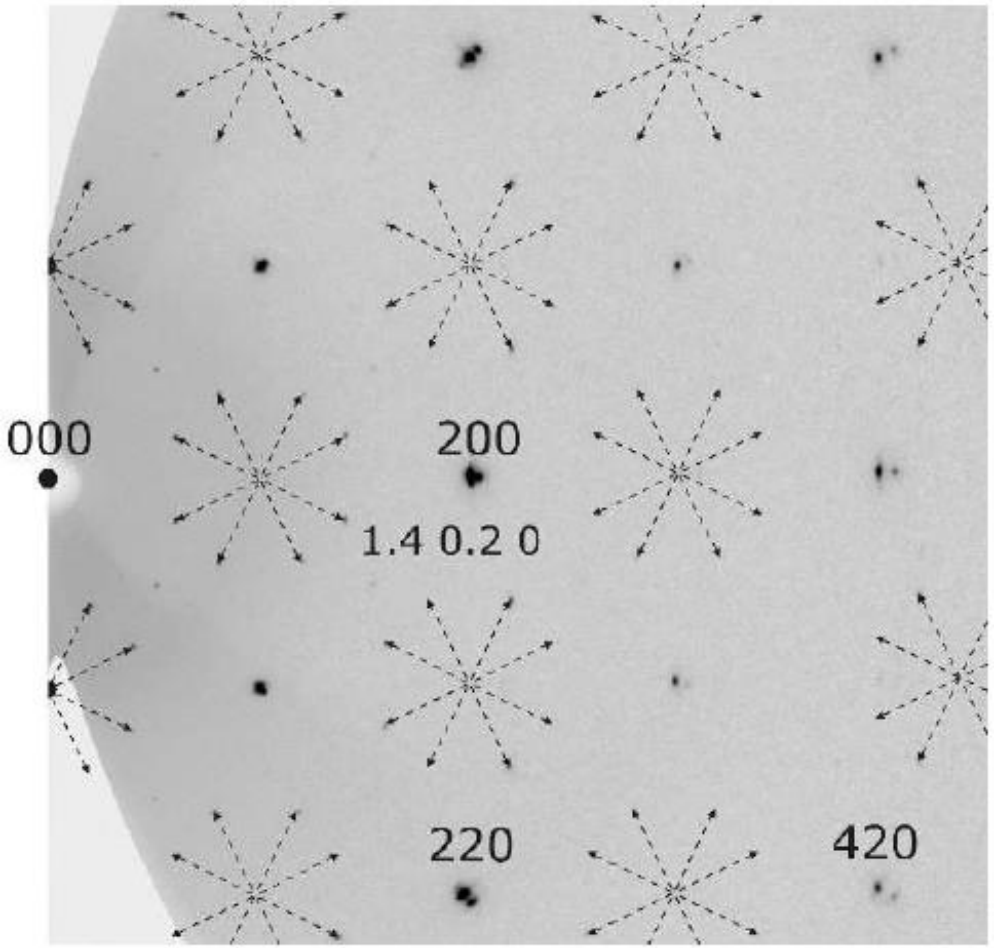




W. Li *et al.*, Nat. Phys. **8**, 126 (2012)
A. Ricci *et al.*, PRB **84**, 060511(R)
F. Chen *et al.*, PRX **1**, 021020 (2011)

Nanoscale phase separation



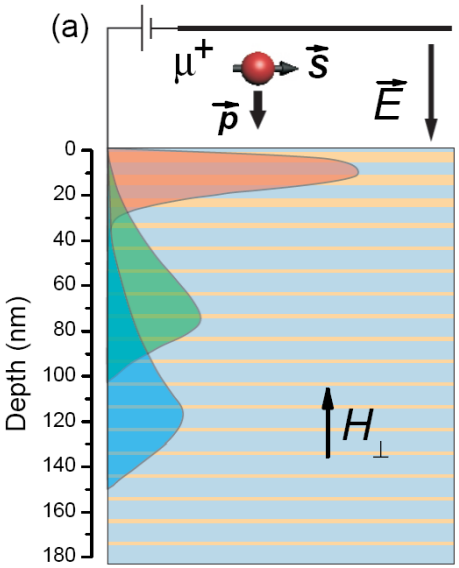


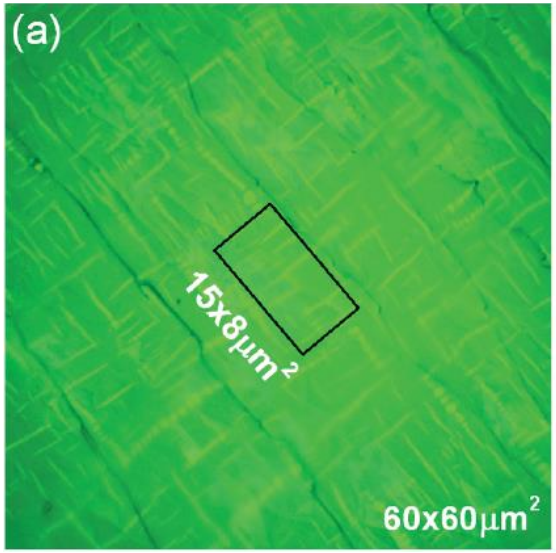
A. Bosak *et al.*, arXiv:1112.2569; V. Yu. Pomjakushin et al., arXiv:1204.5449

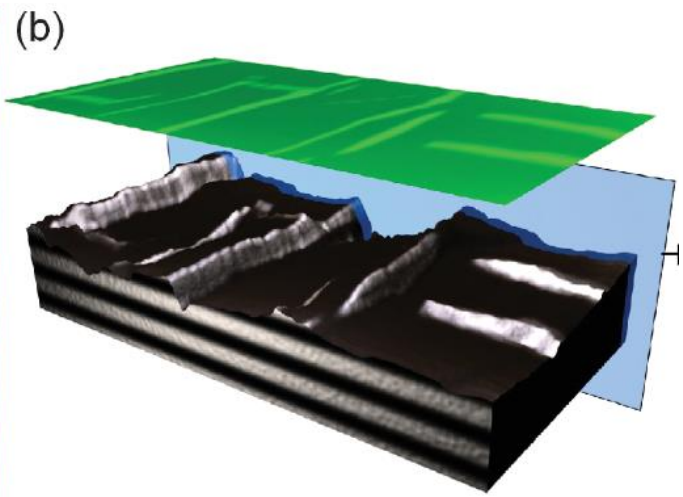
See also:

X. G. Luo *et al.,* NJP **13**, 053011 (2011); Y. Liu *et al.*, SUST **25**, 075001 (2012); etc.

Nanoscale layering of the two phases







near-field microscopy

A. Charnukha *et al.*, PRL **109**, 017003 (2012)

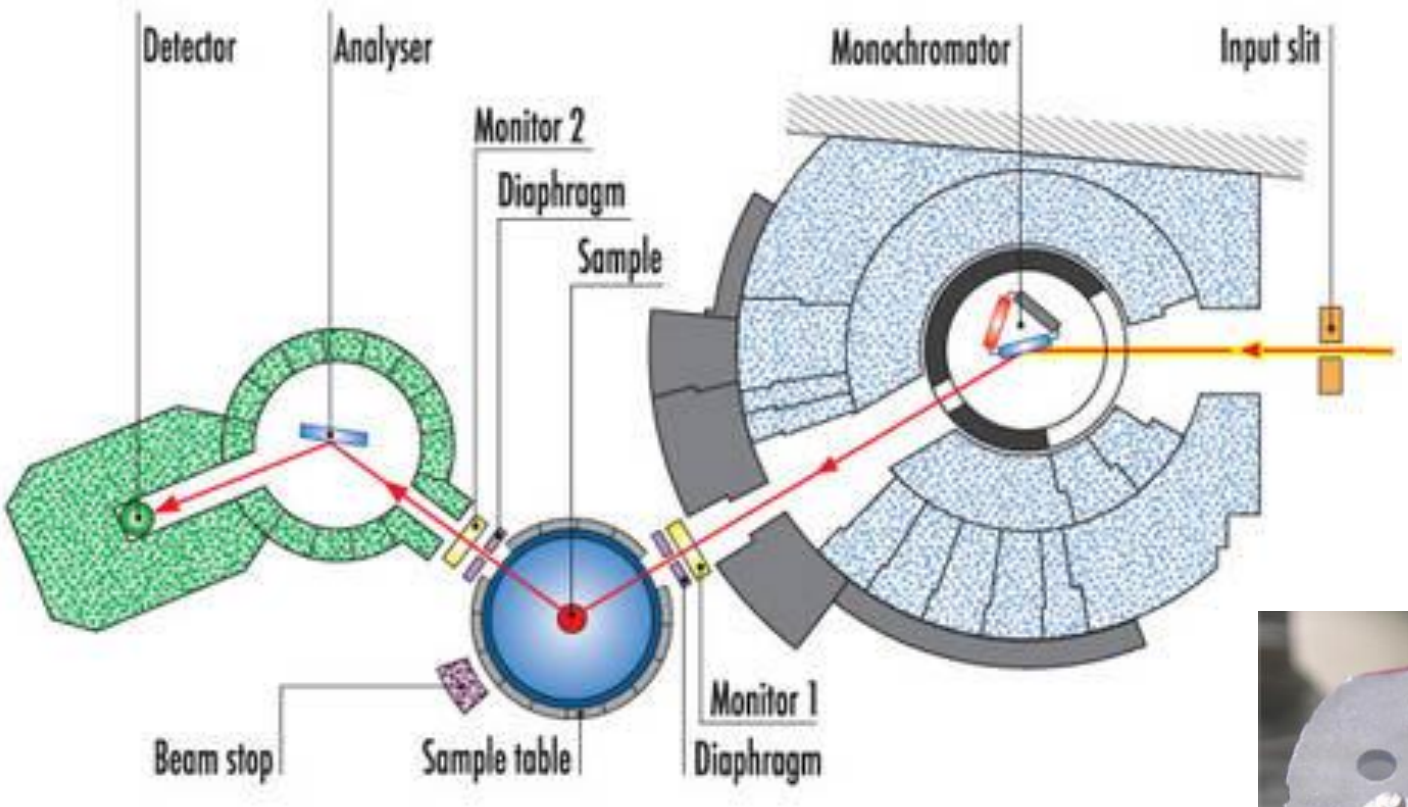
See also:
S. C. Speller *et al.*, arXiv:1204.5472
R. H. Yuan *et al.*, Sci. Rep. **2**, 221 (2012)

What is the composition and structure of the superconducting phase?

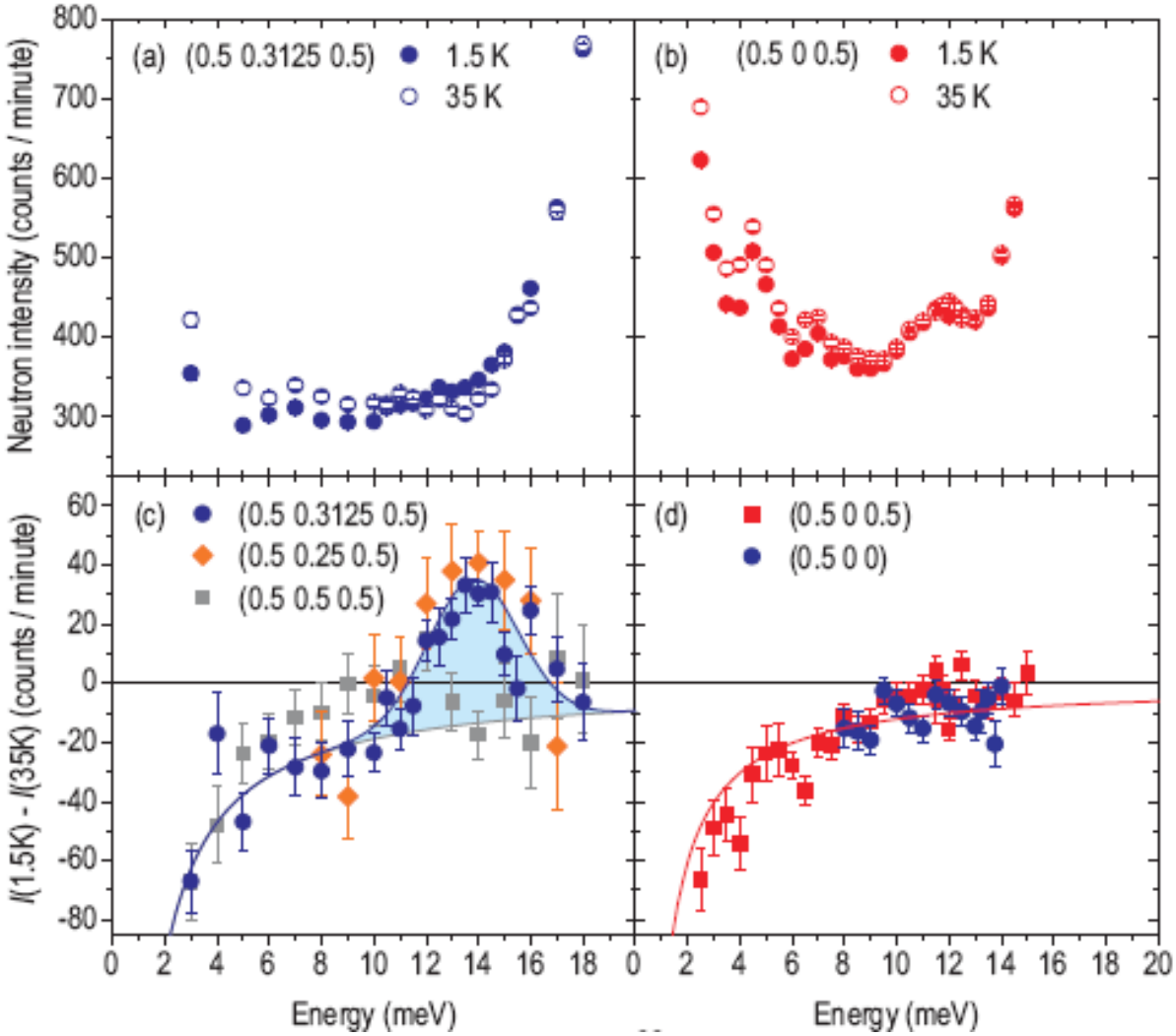
- **doping level/concentration of the alkali metal (K, Rb, or Cs)**
- **presence of vacancies**
- **vacancy order or disorder**

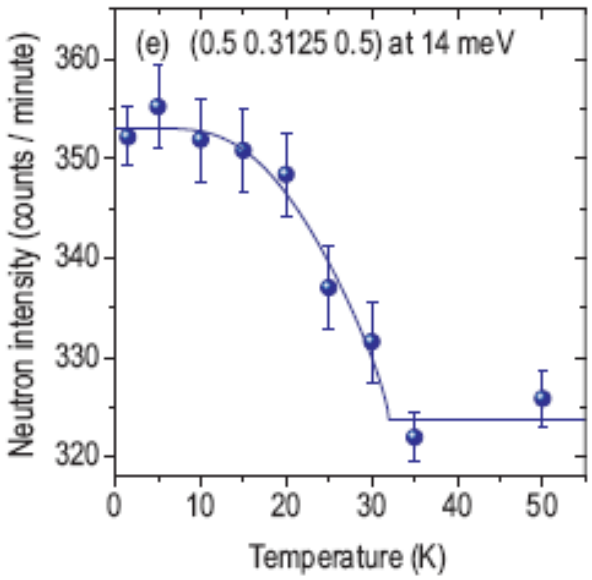
Inelastic neutron scattering on $A_{1-x}Fe_{2-y}Se_2$

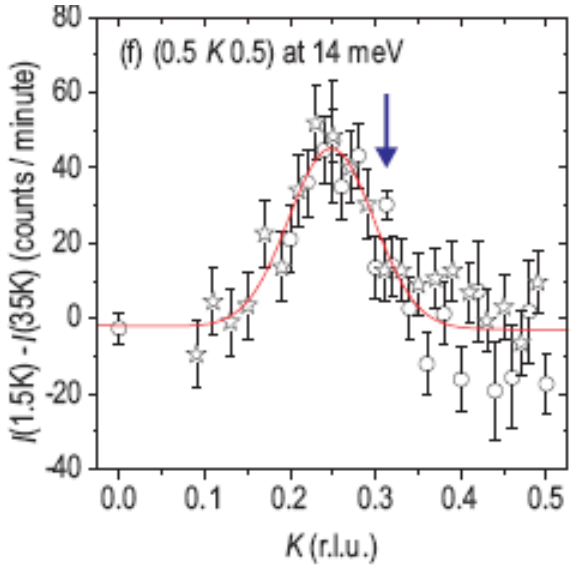
IN8 triple-axis spectrometer (ILL)



Resonant mode in $Rb_{1-x}Fe_{2-y}Se_2$

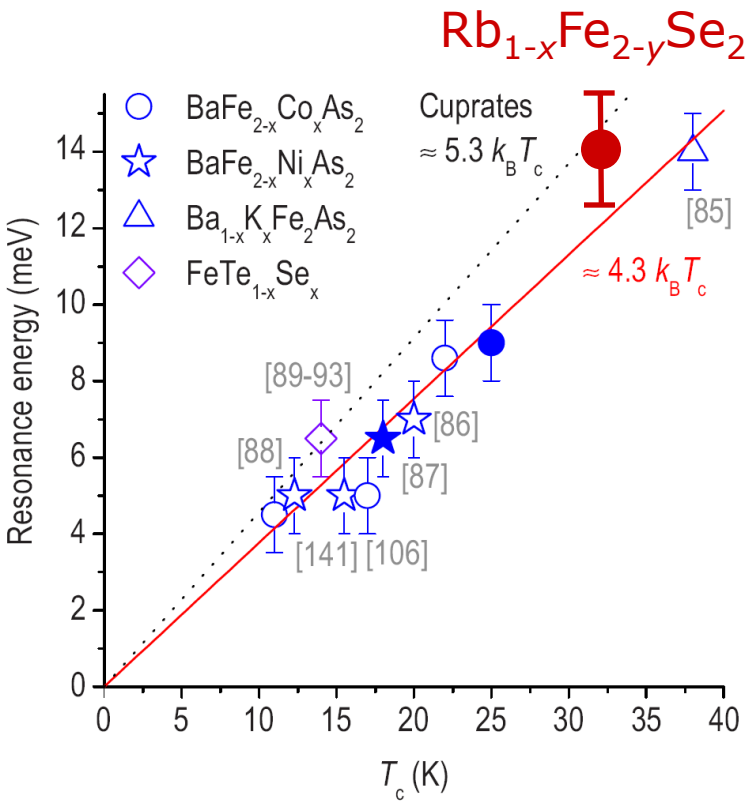


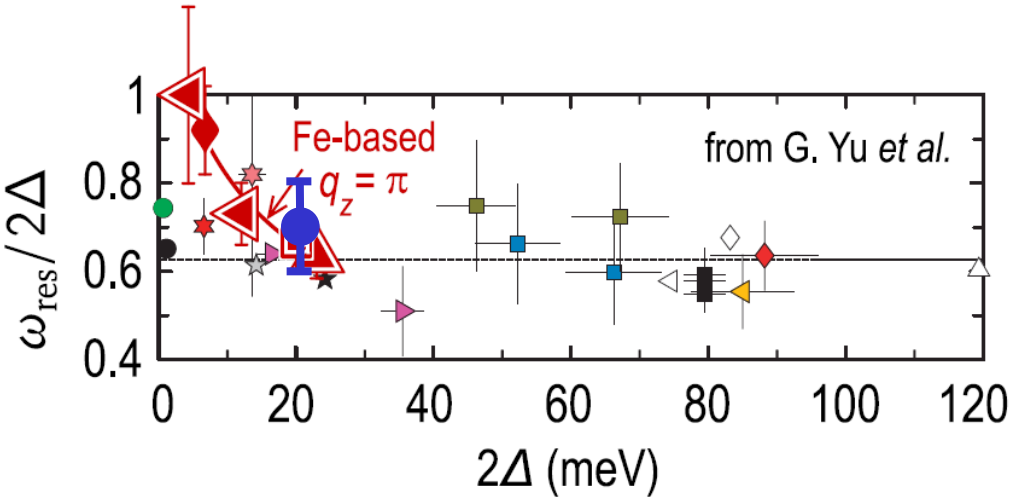




J. T. Park *et al.*, Phys. Rev. Lett. **107**, 177005 (2011)

Linear relationship between E_{res} and T_c

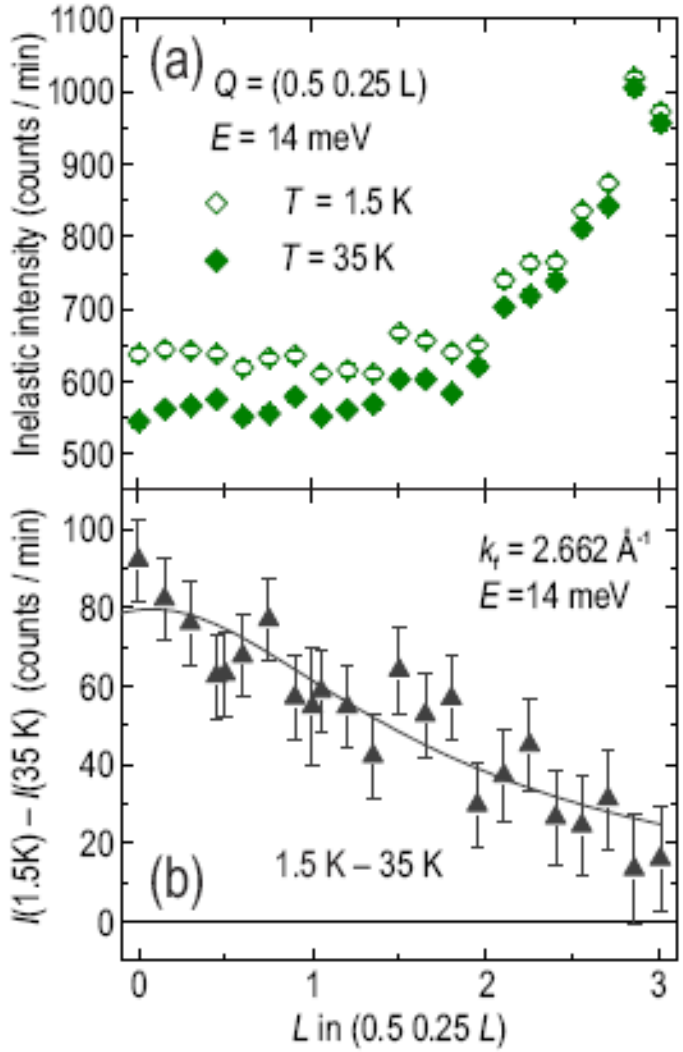


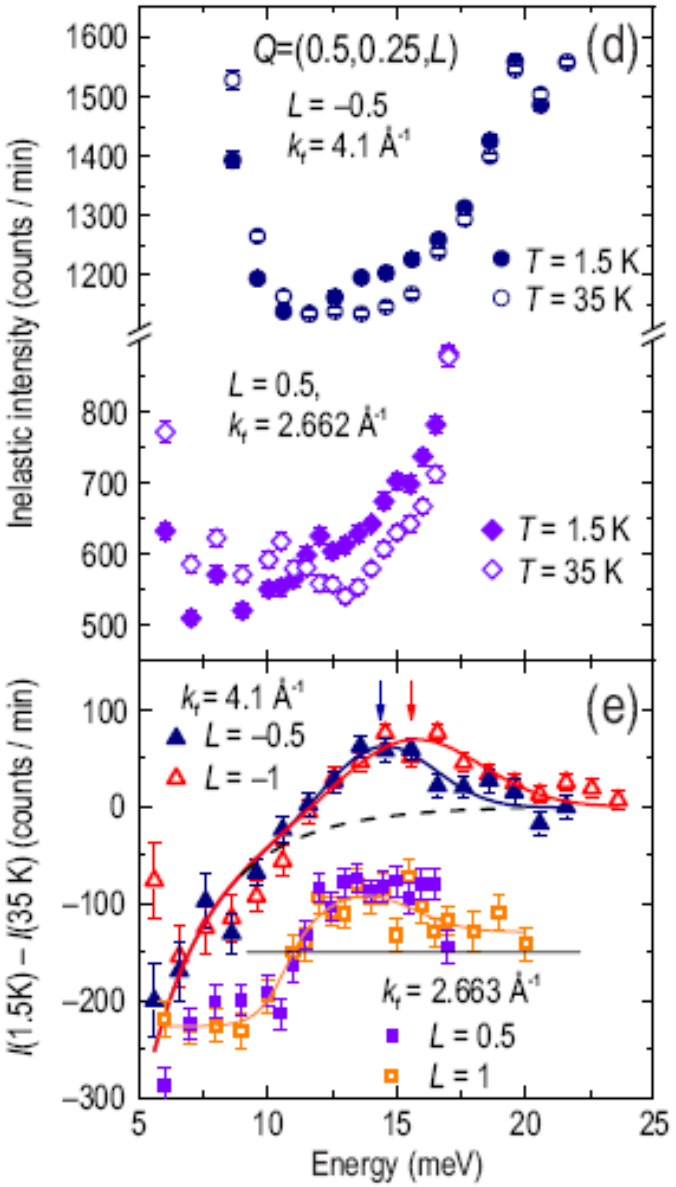


D. Inosov *et al.*, PRB **83**, 214520 (2011)

J. T. Park, D. S. Inosov *et al.*, PRB (2010);
M. Wang *et al.*, PRB **81**, 174524 (2010);
S. Shamoto *et al.*, PRB **82**, 172508 (2010).

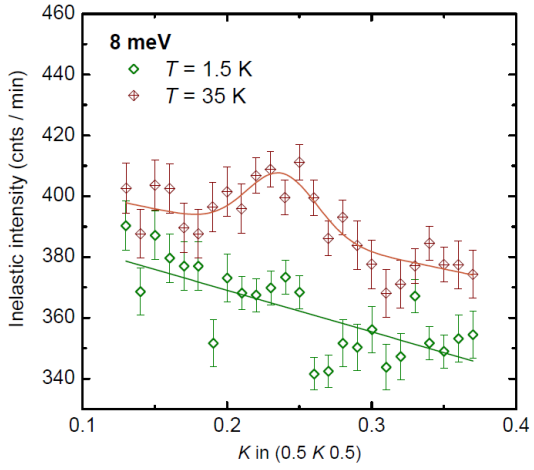
Quasi-two-dimensionality of the resonant mode

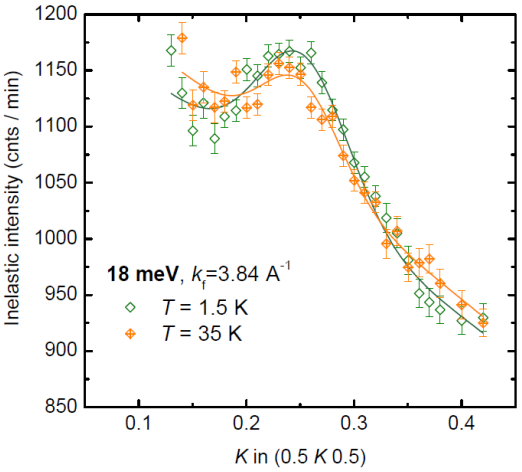


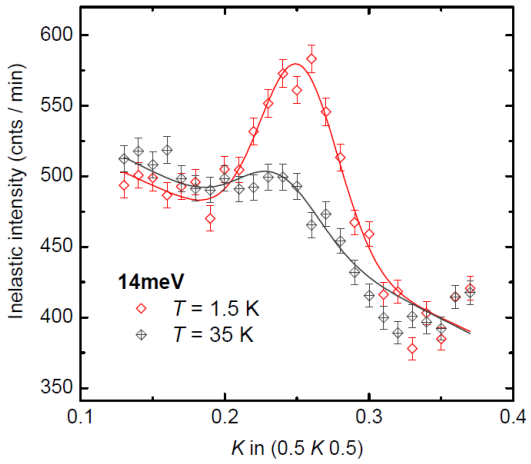


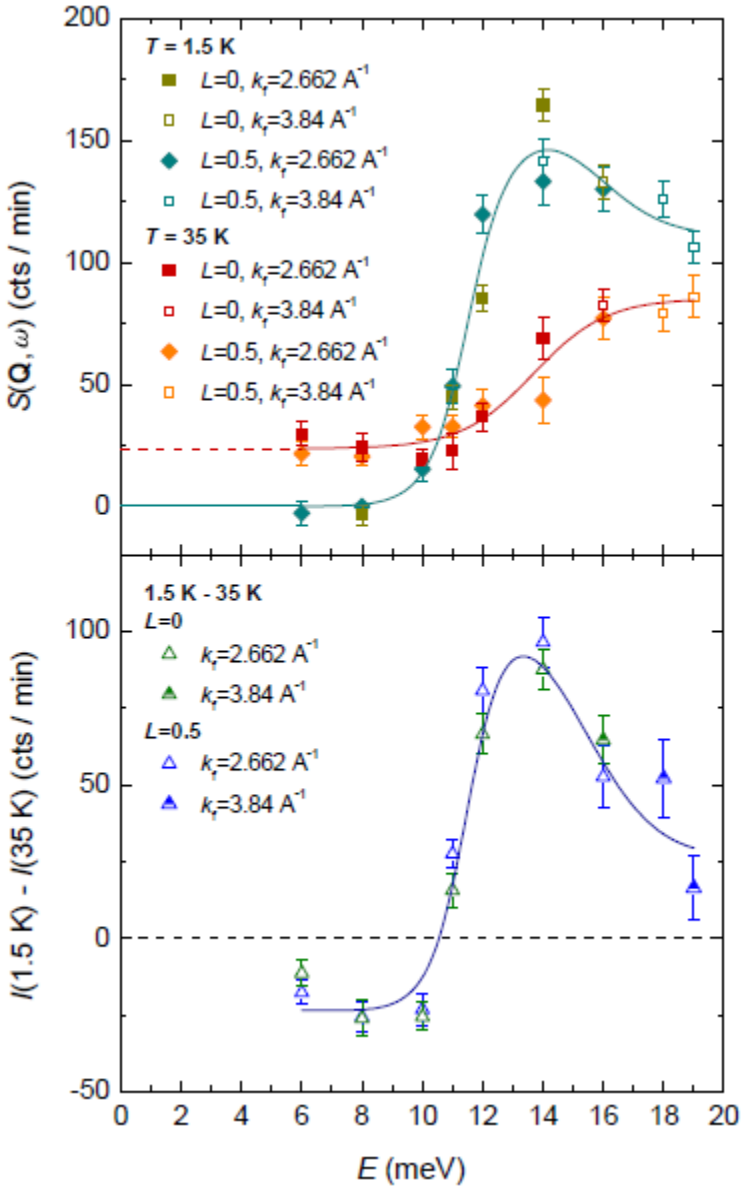
G. Friemel *et al.,* Phys. Rev. B 85 (2012), 140511(R)

Normal-state response



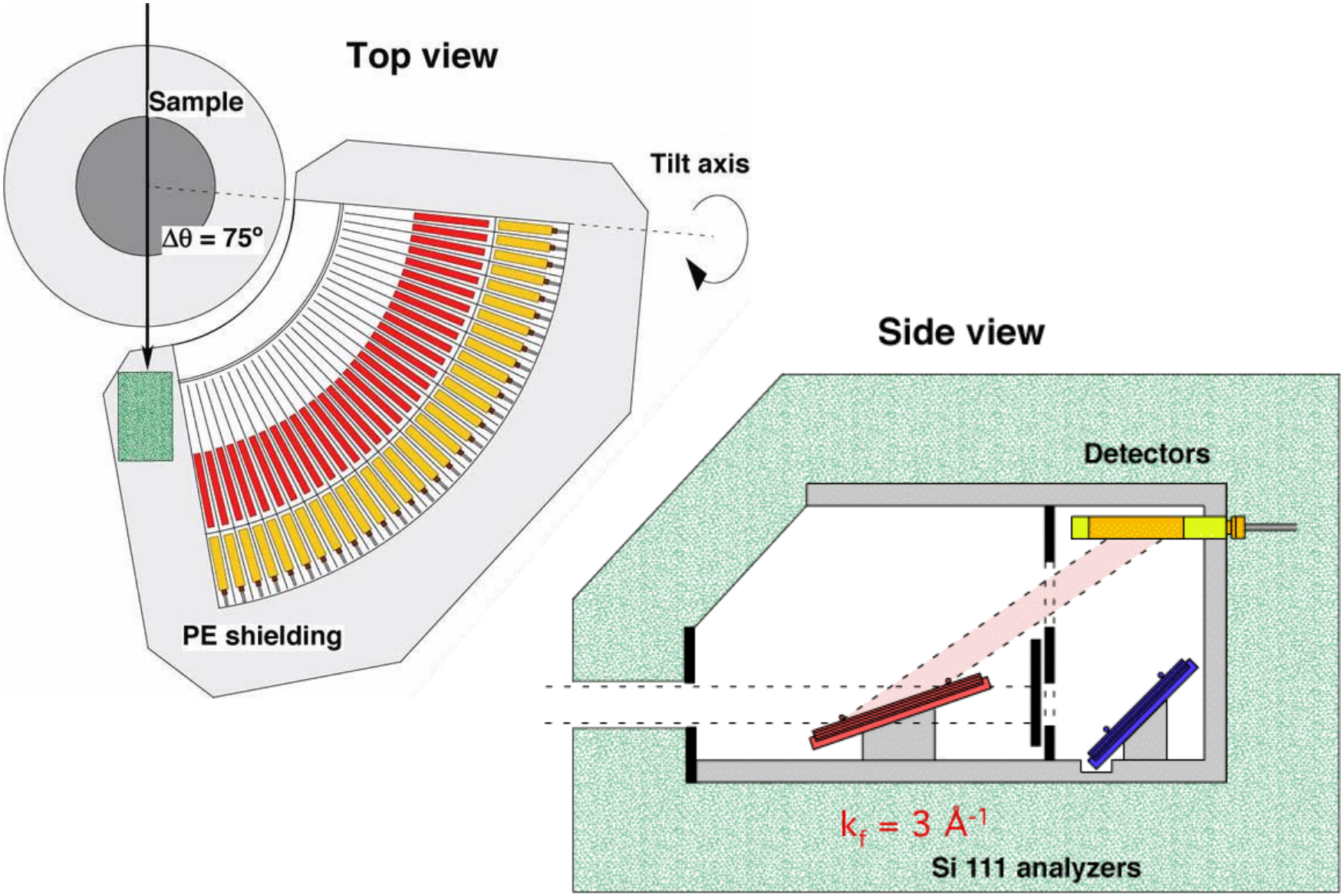




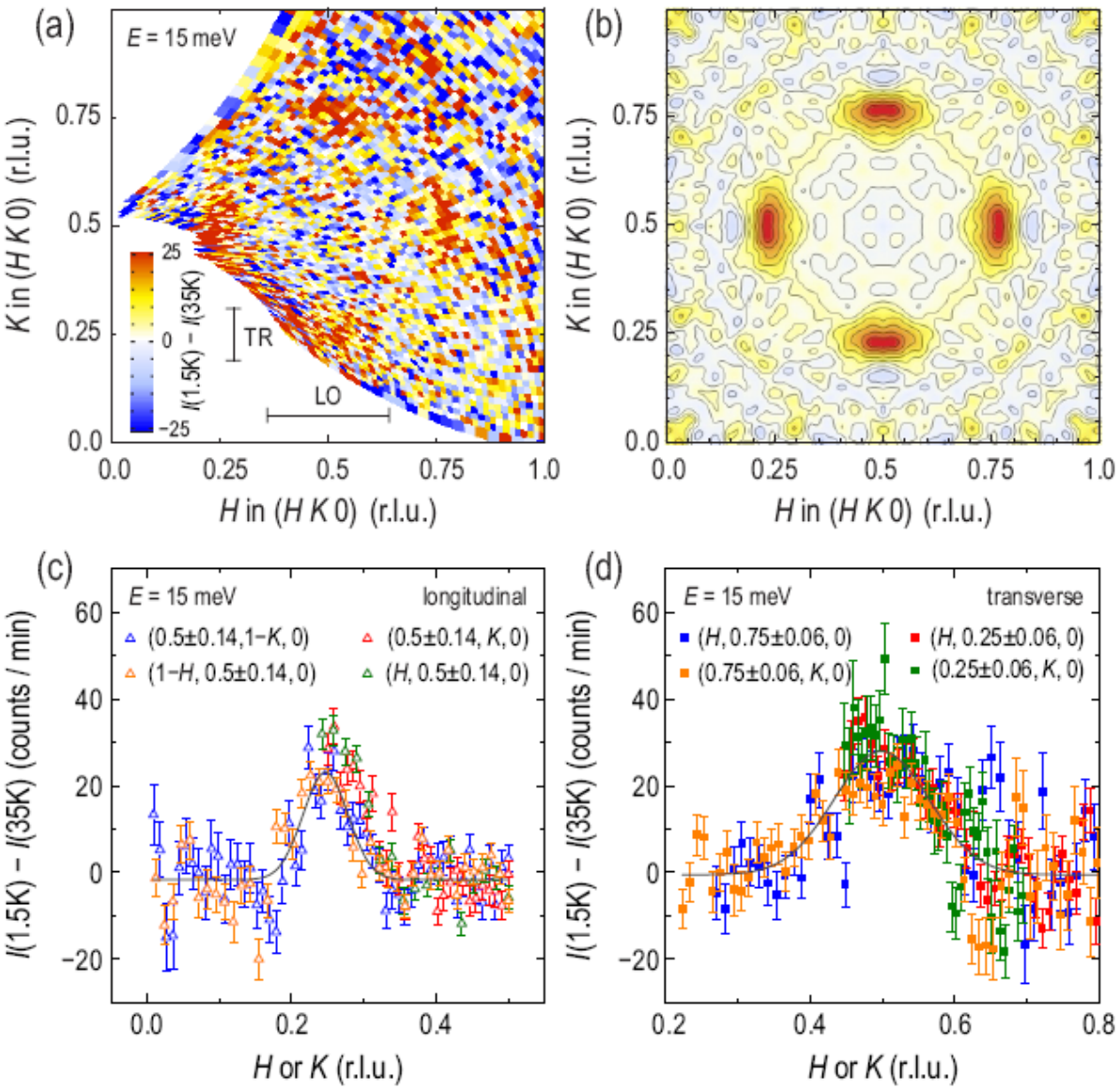


G. Friemel, D. Inosov *et al.* (unpublished data)

FlatCone multi-analyzer at IN8



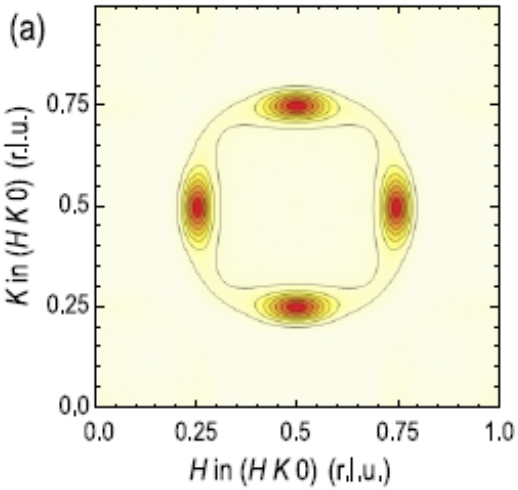
Reciprocal-space structure of the resonance

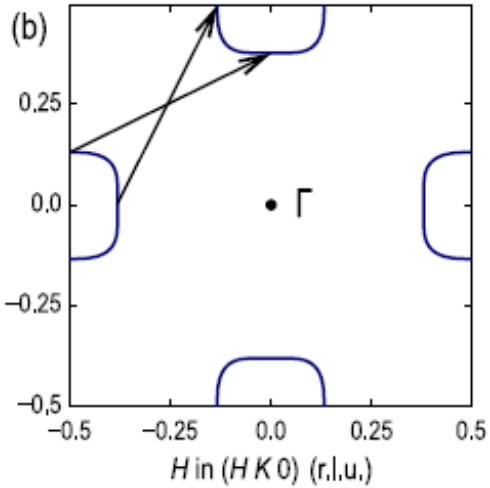


(*HK*0) scattering plane

G. Friemel, J. T. Park,
D. S. Inosov *et al.*
Phys. Rev. B **85**, 140511(R)

Bulk-sensitive estimates of the electron count





calculations by T. A. Maier
Phys. Rev. B **85** (2012), 140511(R)

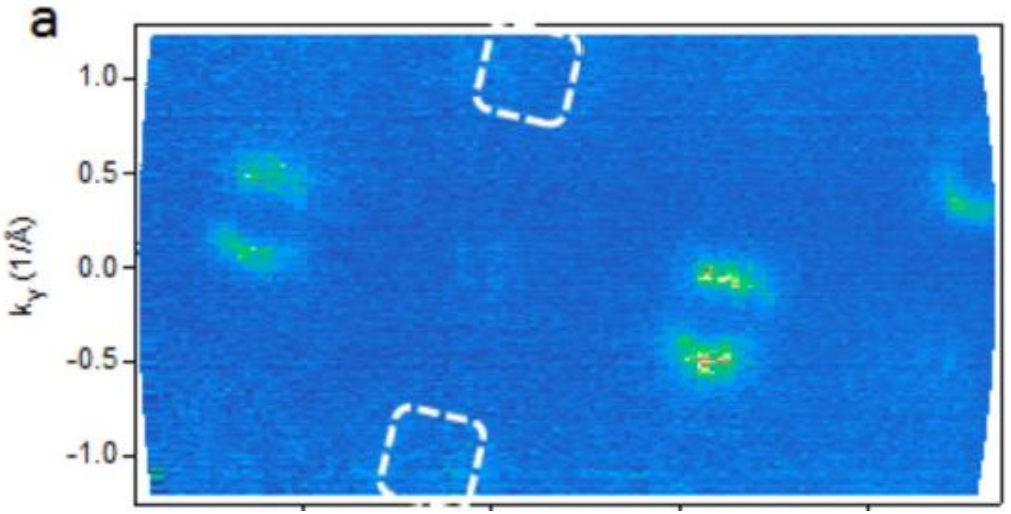
⇒ 0.18 electrons/Fe (INS + theory)

NMR: 0.15 electrons/Fe

Y. Texier *et al.*, PRL **108**, 237002 (2012)

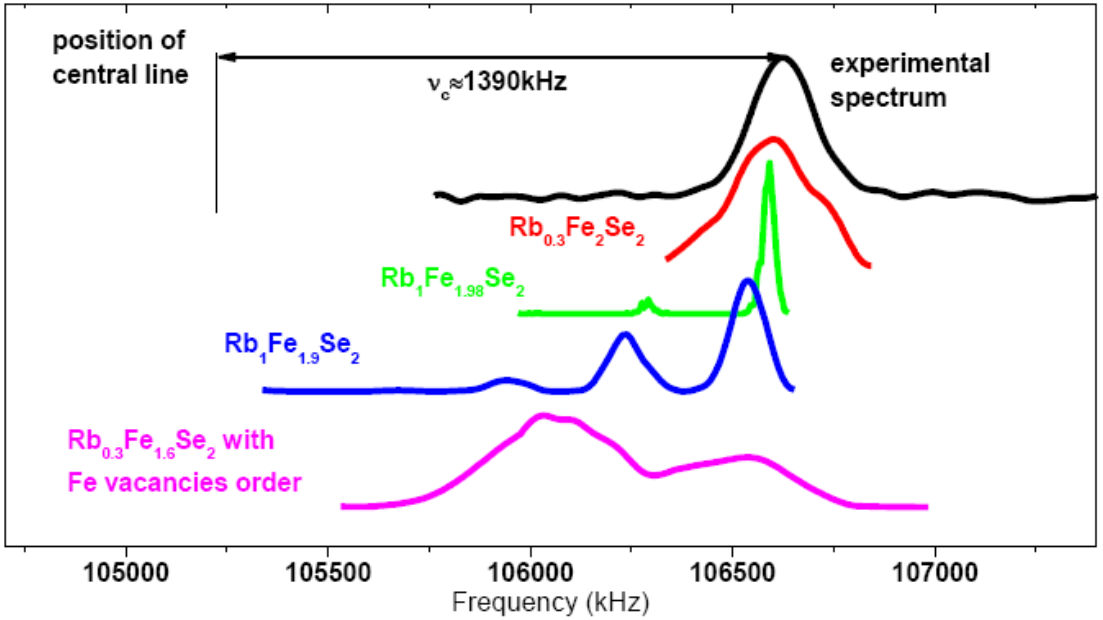
ARPES: 0.15 electrons/Fe

S. V. Borisenko *et al.*, arXiv:1204.1316



No superstructure in the Fe layer!

NMR evidence for a vacancy-free SC phase

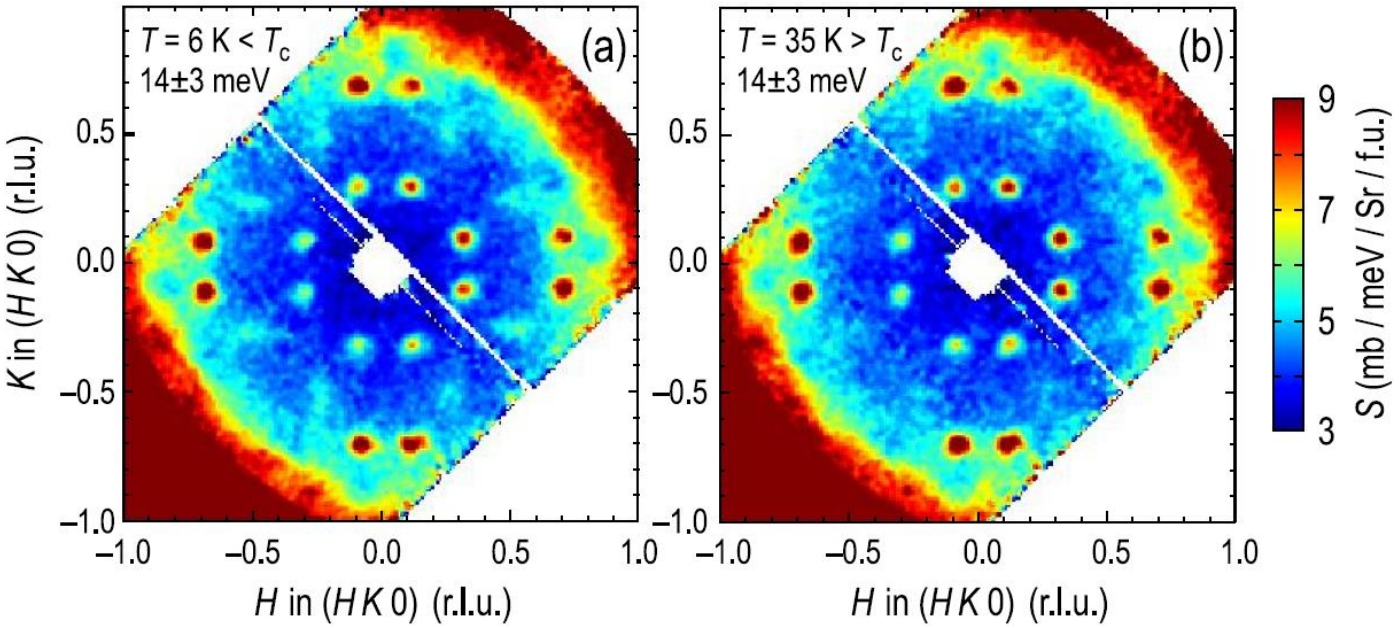


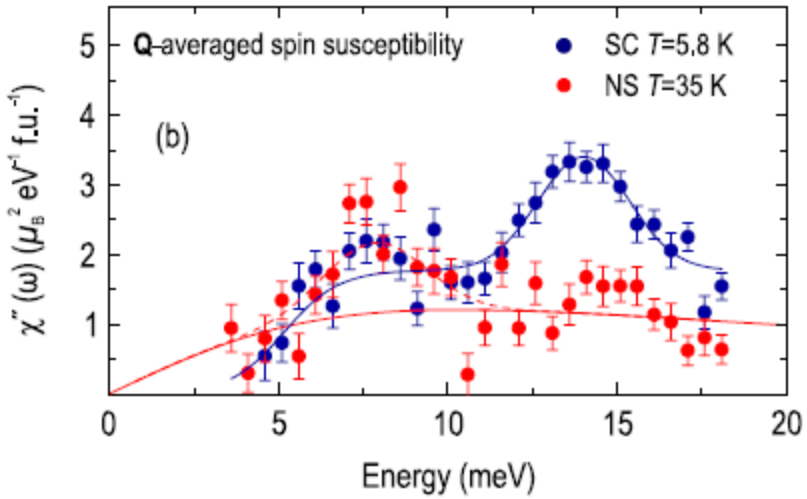
Y. Texier, J. Bobroff *et al.*, Phys. Rev. Lett. **108**, 237002 (2012)

Superconducting phase has no Fe vacancies!

It must be associated with the "compressed" minority phase with the $A_{0.3}Fe_2Se_2$ composition.

Spin excitations and resonant mode in $K_{1-x}Fe_{2-y}Se_2$





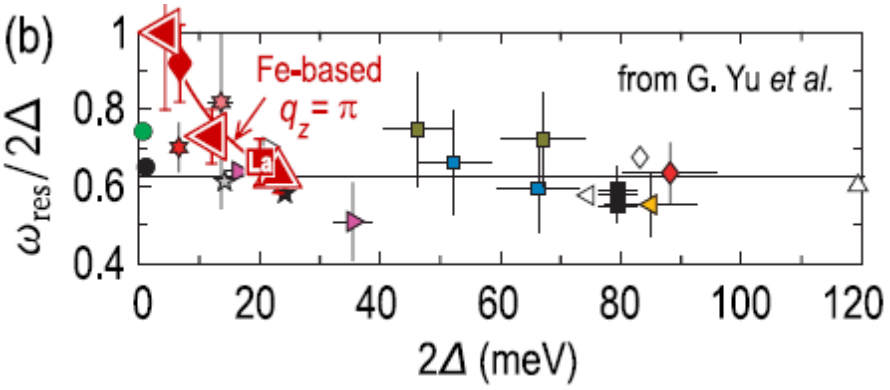
Total resonant spectral weight: 0.011±0.003 μ_B^2/f.u.

G. Friemel *et al.*, EPL **99**, 67004 (2012)

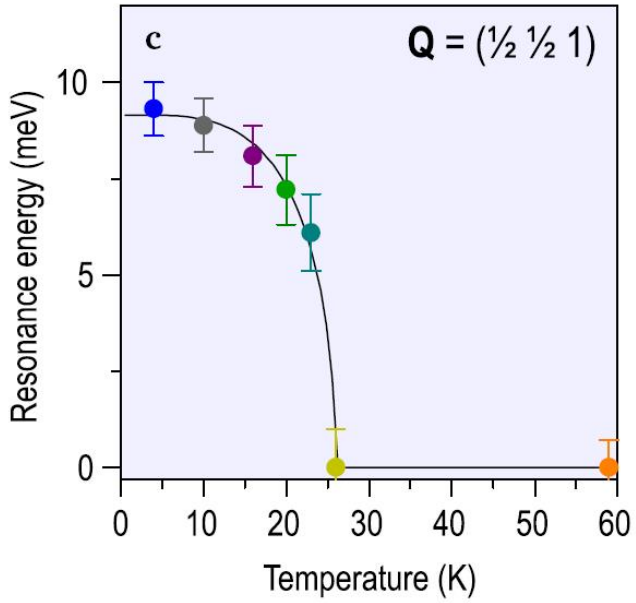
See also: A. Taylor *et al.*, PRB **86**, 094528

Summary, or what do we call a resonant mode?

1. Magnetic spectral weight.
2. Exciton of an "itinerant" character below the particle-hole continuum.
3. Temperature dependence, with an onset at T_c.



D. Inosov *et al.*, PRB **83**, 214520 (2011)



Thank you for your attention

PhD positions available in the neutron scattering group
at the Technical University of Dresden