Surfing q-space of a high temperature superconductor

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Ames Laboratory and Iowa State University

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US Department of Energy

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Outline:

- introduction

- origin of the collective mode

- topology of the Fermi surface

- AutoCorrelated (AC) ARPES

Joong-Mok Park — Ames Laboratory Spectroscopy Group
James Koll

J. C. Campuzano — University of Illinois at Chicago, Argonne Nat. Lab.
Utpal Chatterjee

M. R. Norman — Material Science Division, Argonne National Lab.
S. Rosenkranz

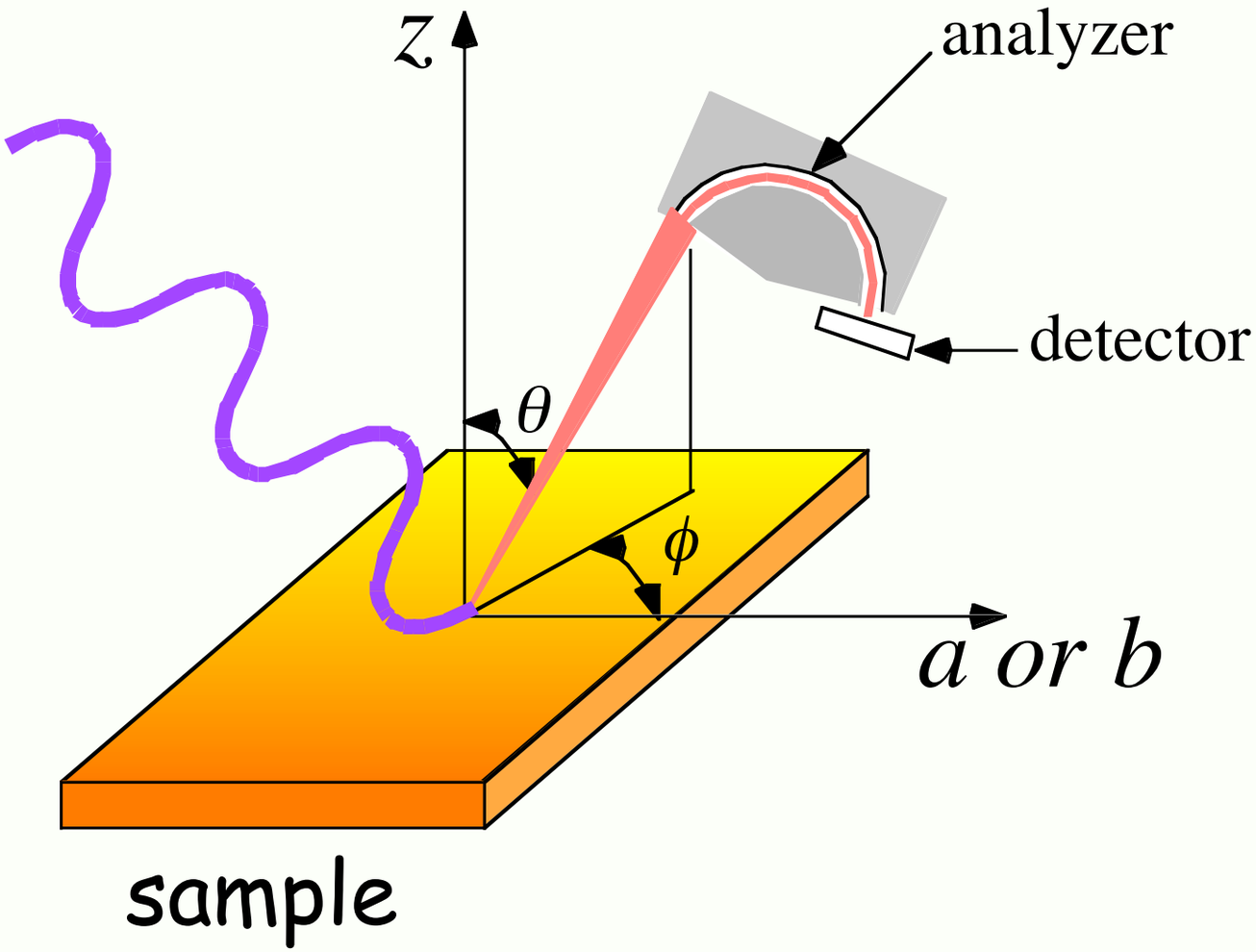
M. Randeria — Ohio State University

T. Takeuchi — Nagoya University, Japan

Z. Z. Li — Universite de Paris-Sud, Orsay, France
H. Raffy

K. Kadowaki — University of Tsukuba, Tsukuba, Japan

ARPES experiment



We need:

binding energy - E_b

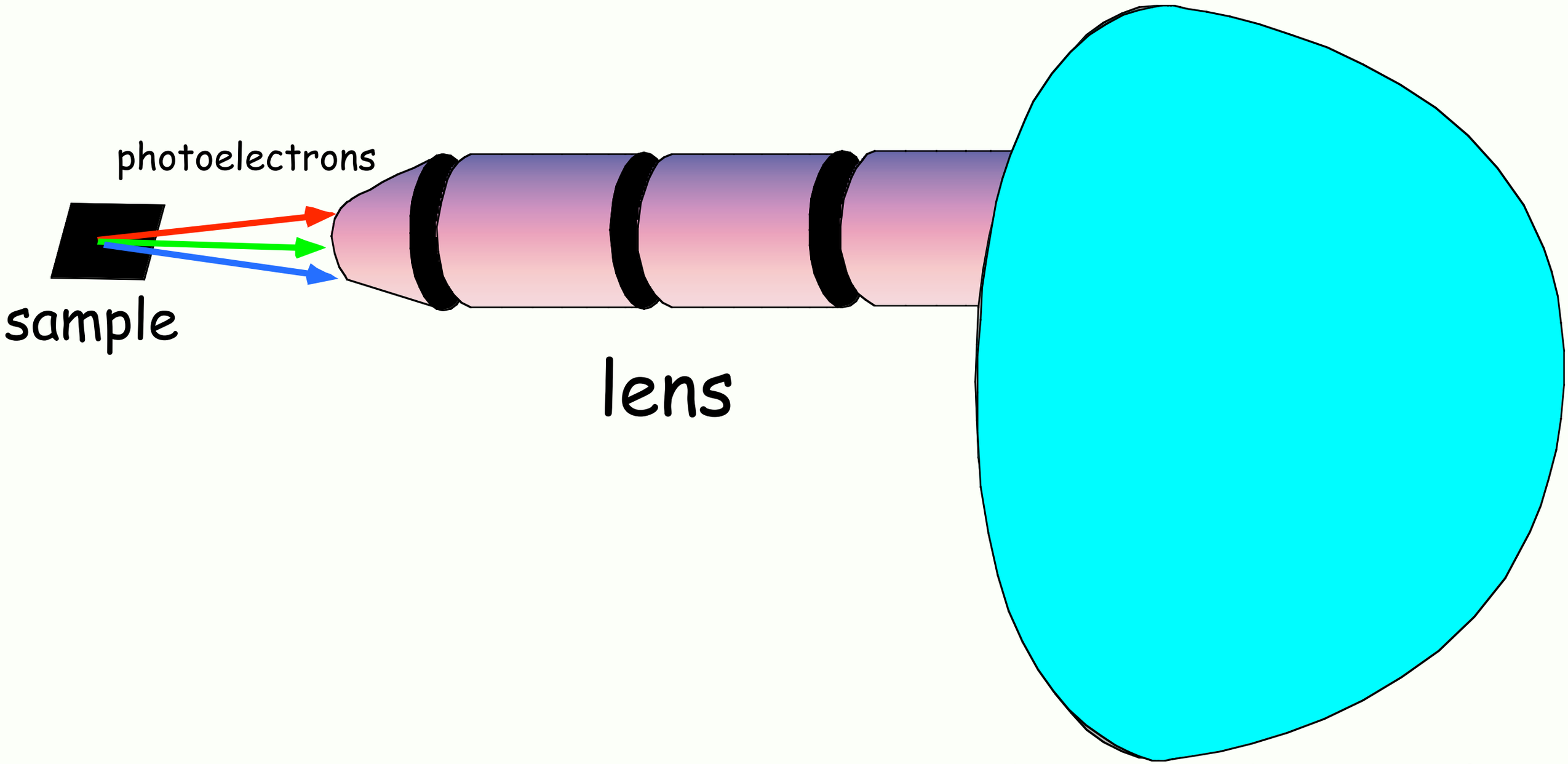
initial momentum - k^i

$E_b = E - h\nu + W$

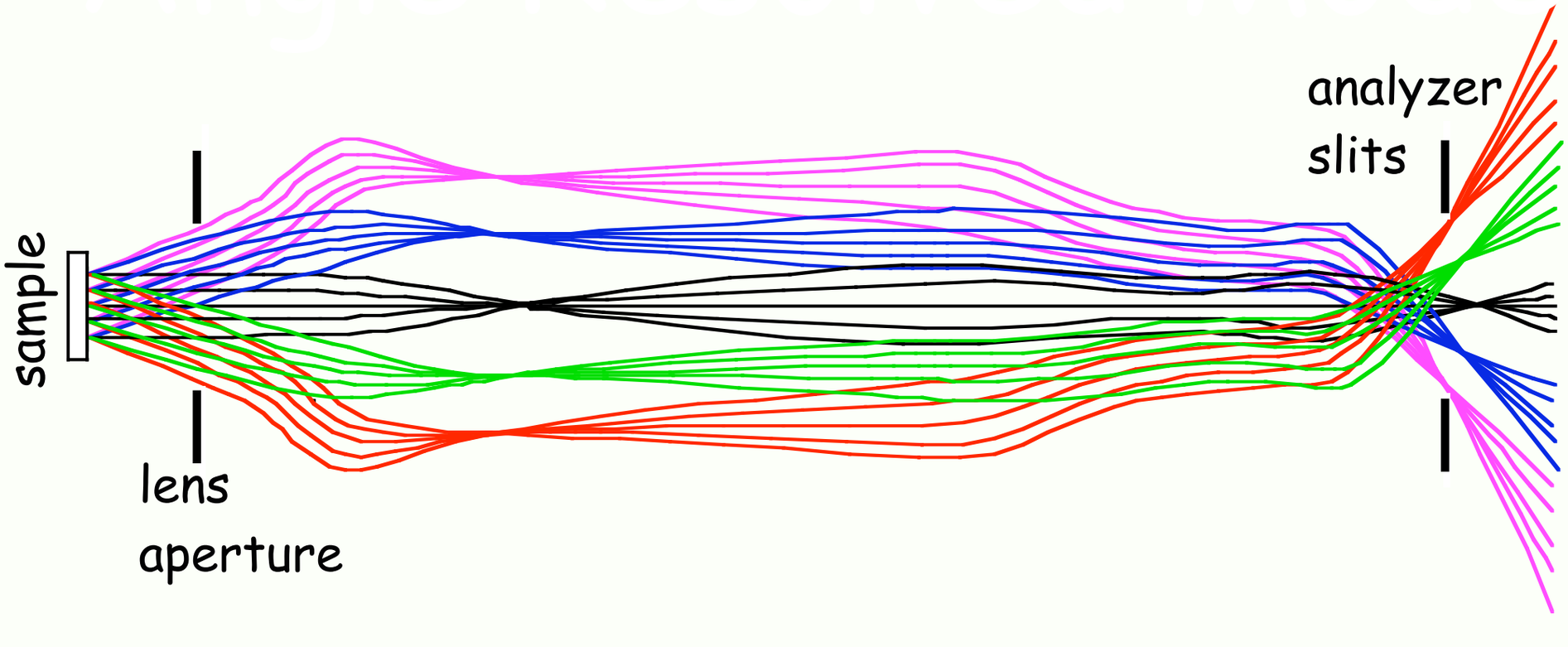
$k^i_{||} = k^f_{||} = \sqrt{2mE/\hbar^2}\ \sin\theta$

$k^i_{\perp} = 0$ for quasi 2D samples

Instrumentation:



angle resolved mode of the lens:

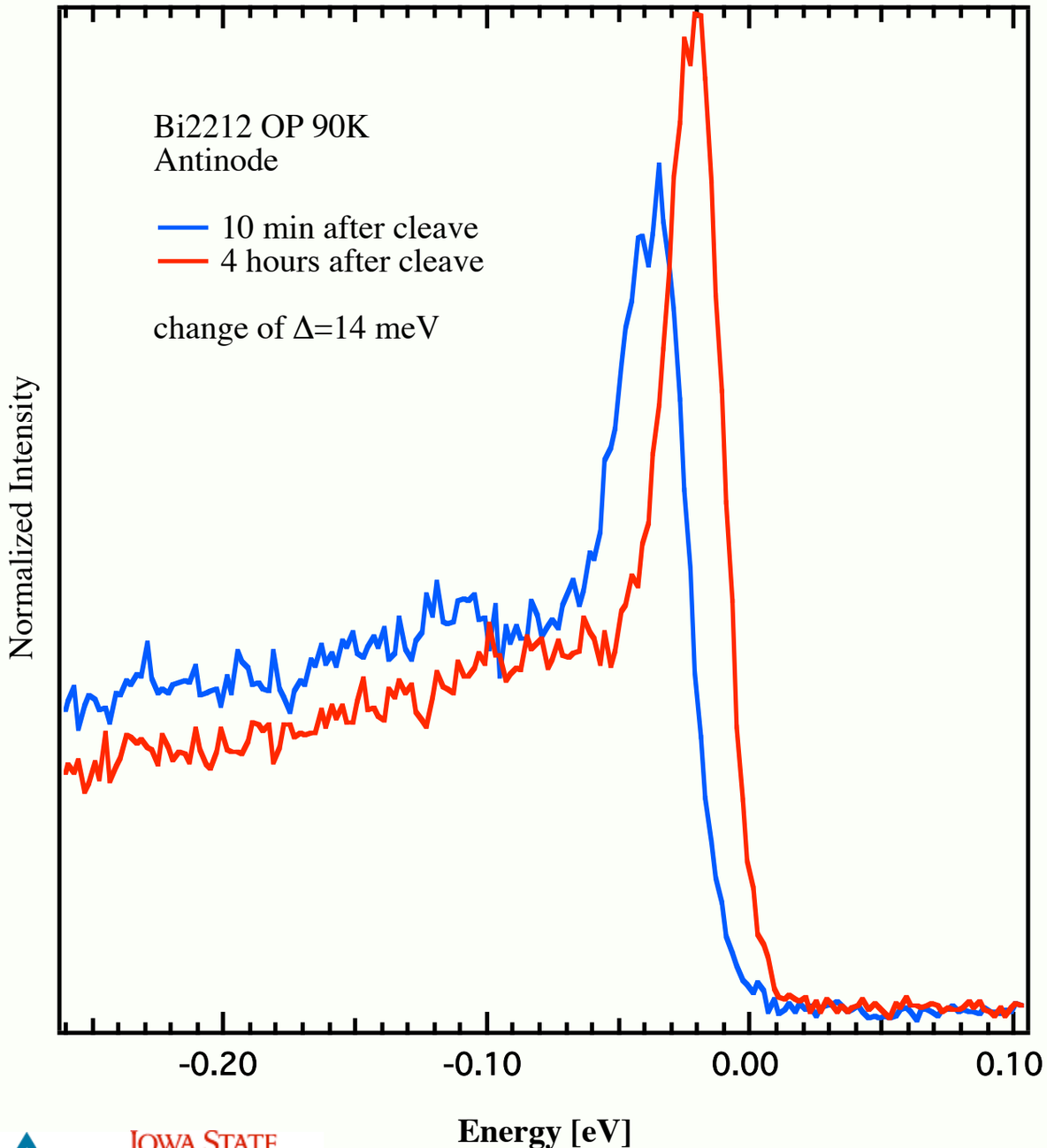


- 32x improvement of angular resolution
- 2D data acquisition: intensity vs kinetic energy & momentum

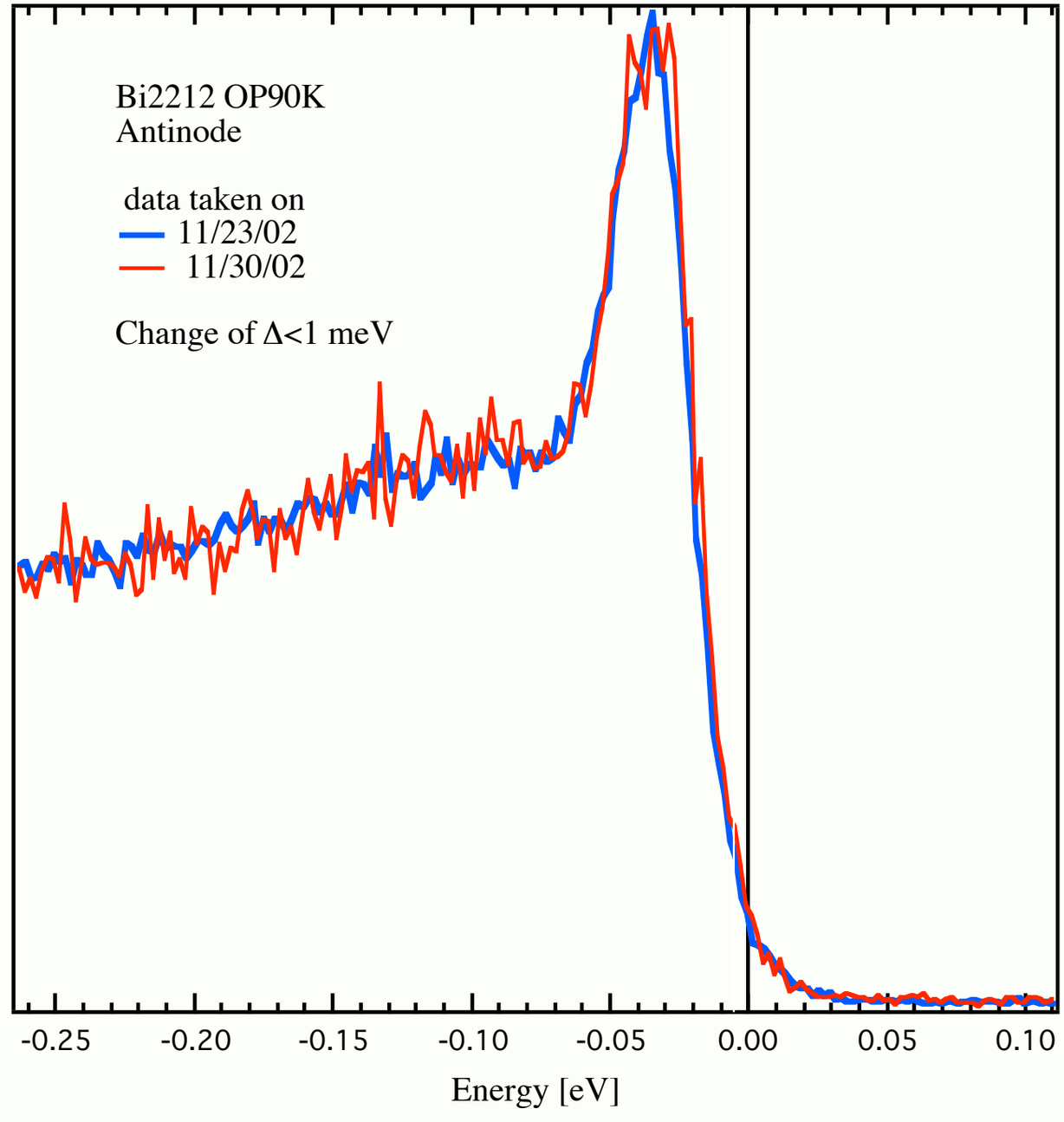
developed and perfected by
Bjørn Wannberg
Uppsala University/Gammadata-Scienta

Quality of the vacuum

March 1998



November 2002



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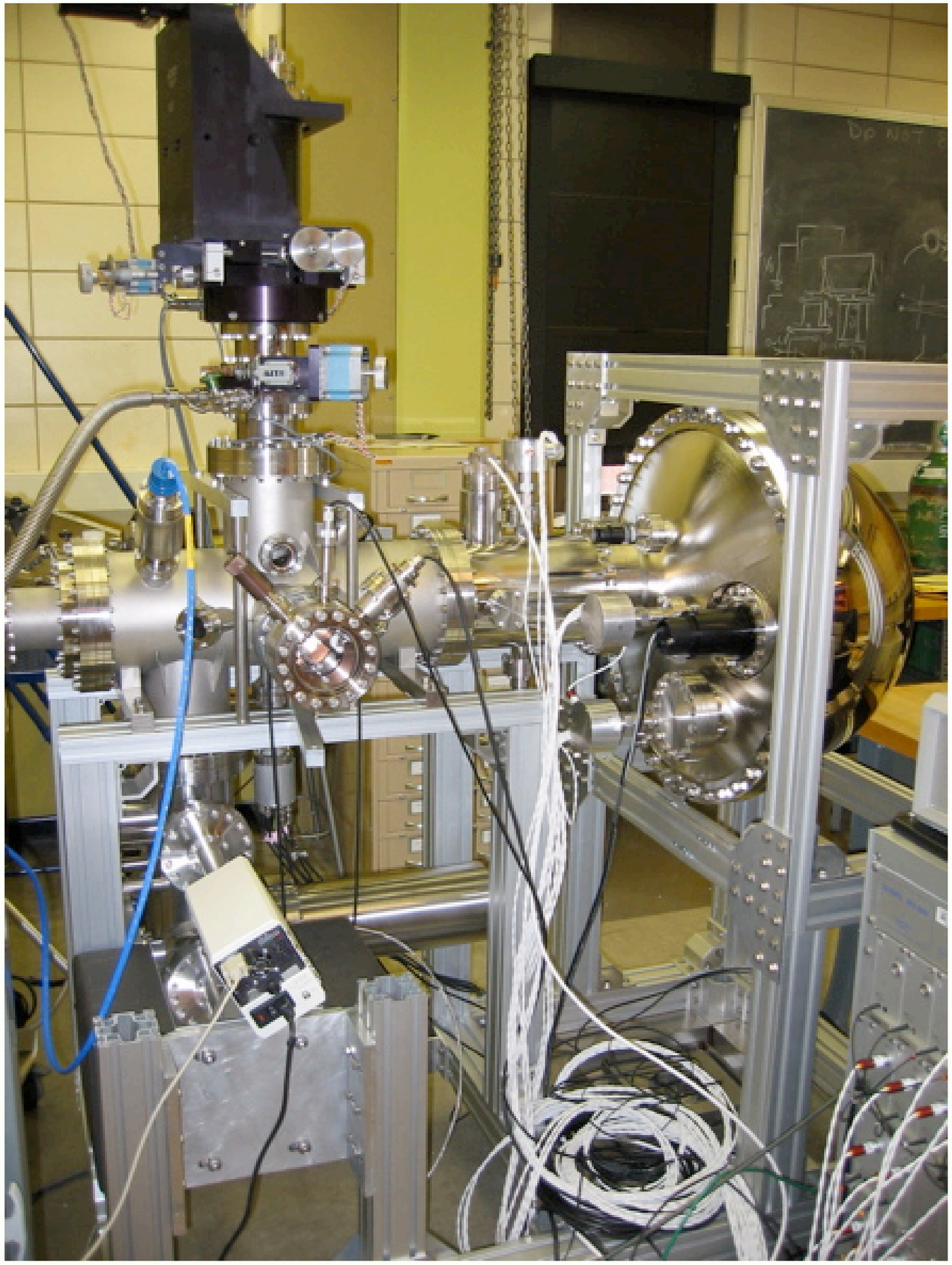
High precision lab-based ARPES spectrometer

Energy resolution:
~1.3 meV

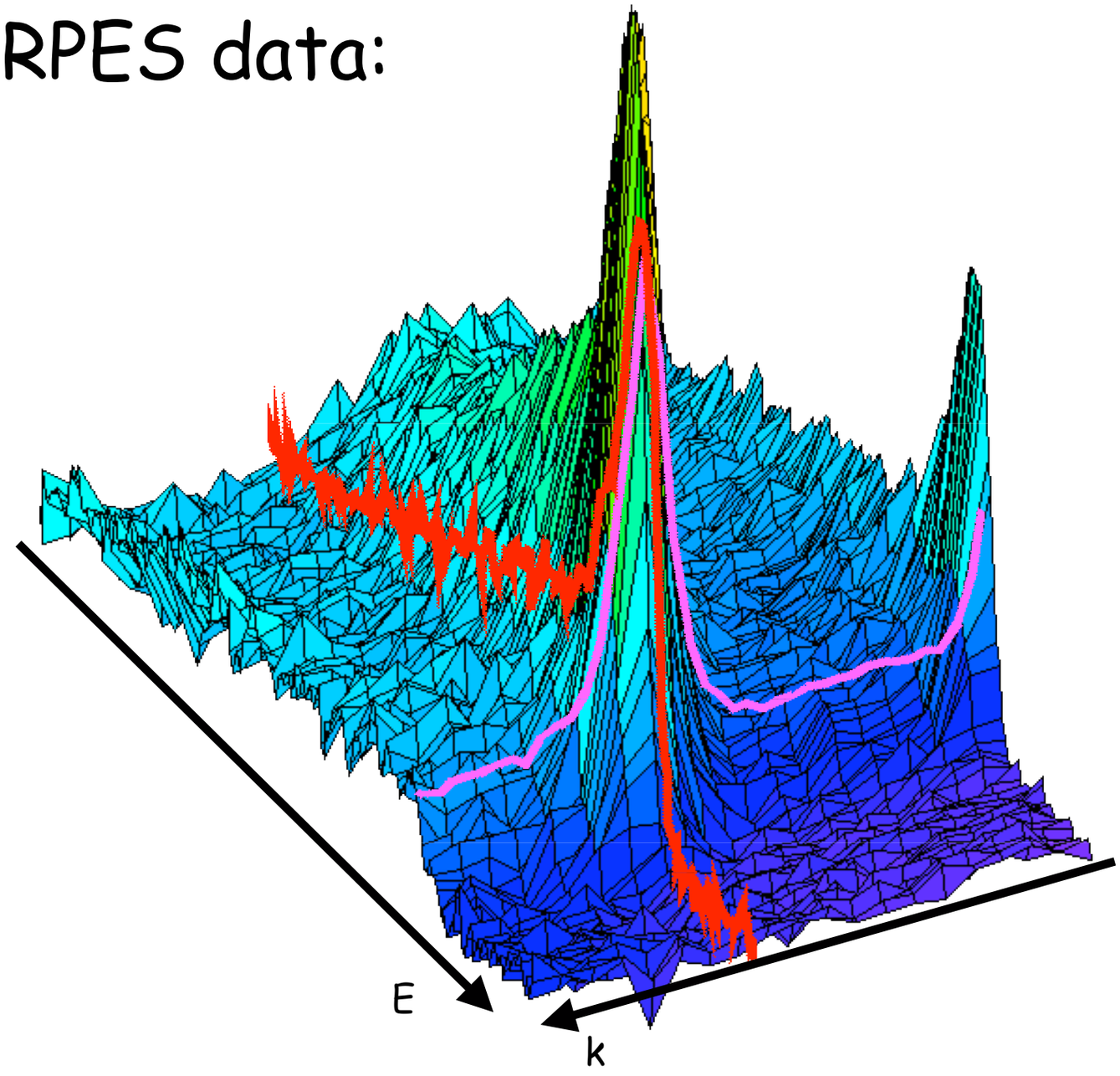
Angular resolution:
0.1 deg.

UV source:
10^{13} photons/sec.
soon: μm size beam

Sample positioning:
~1μm



Typical ARPES data:



ARPES intensity $I = \langle \Psi_i | \mathbf{A}\cdot\mathbf{p} | \Psi_f \rangle^2 A(\mathbf{k}, \omega) f(\omega)$

symmetry of Ψ

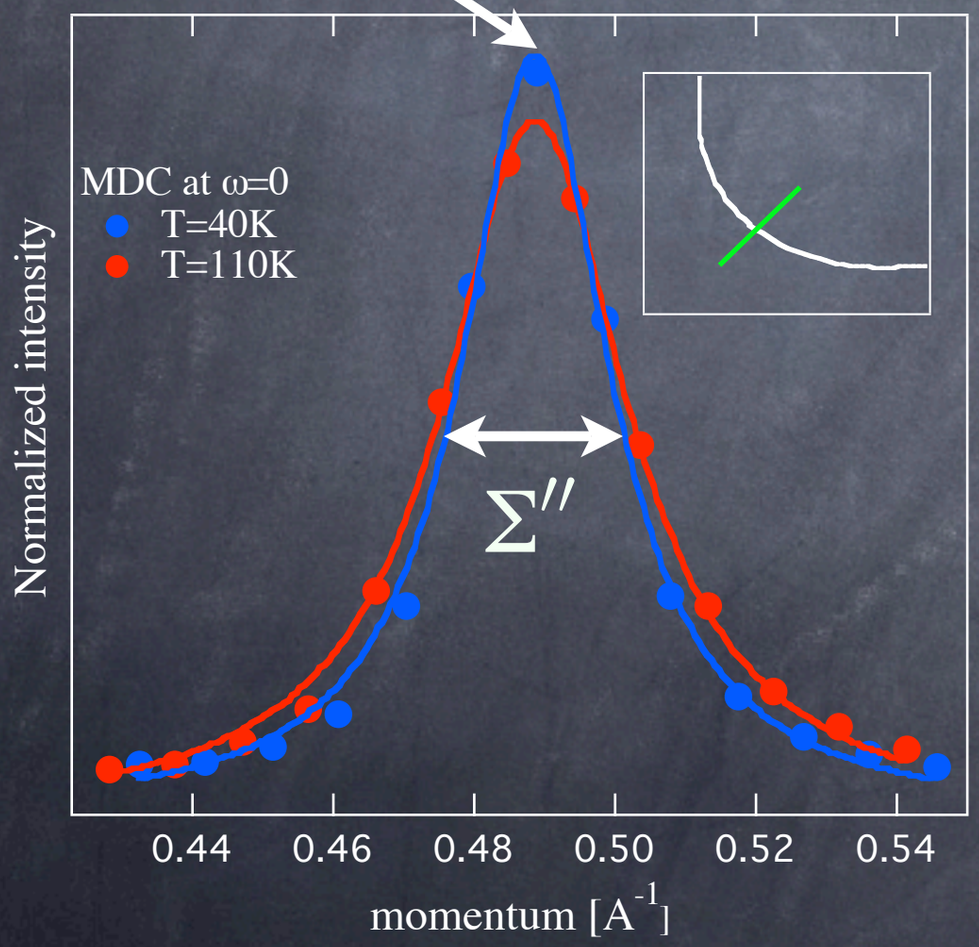
electronic structure + interactions

Spectral function and self energy

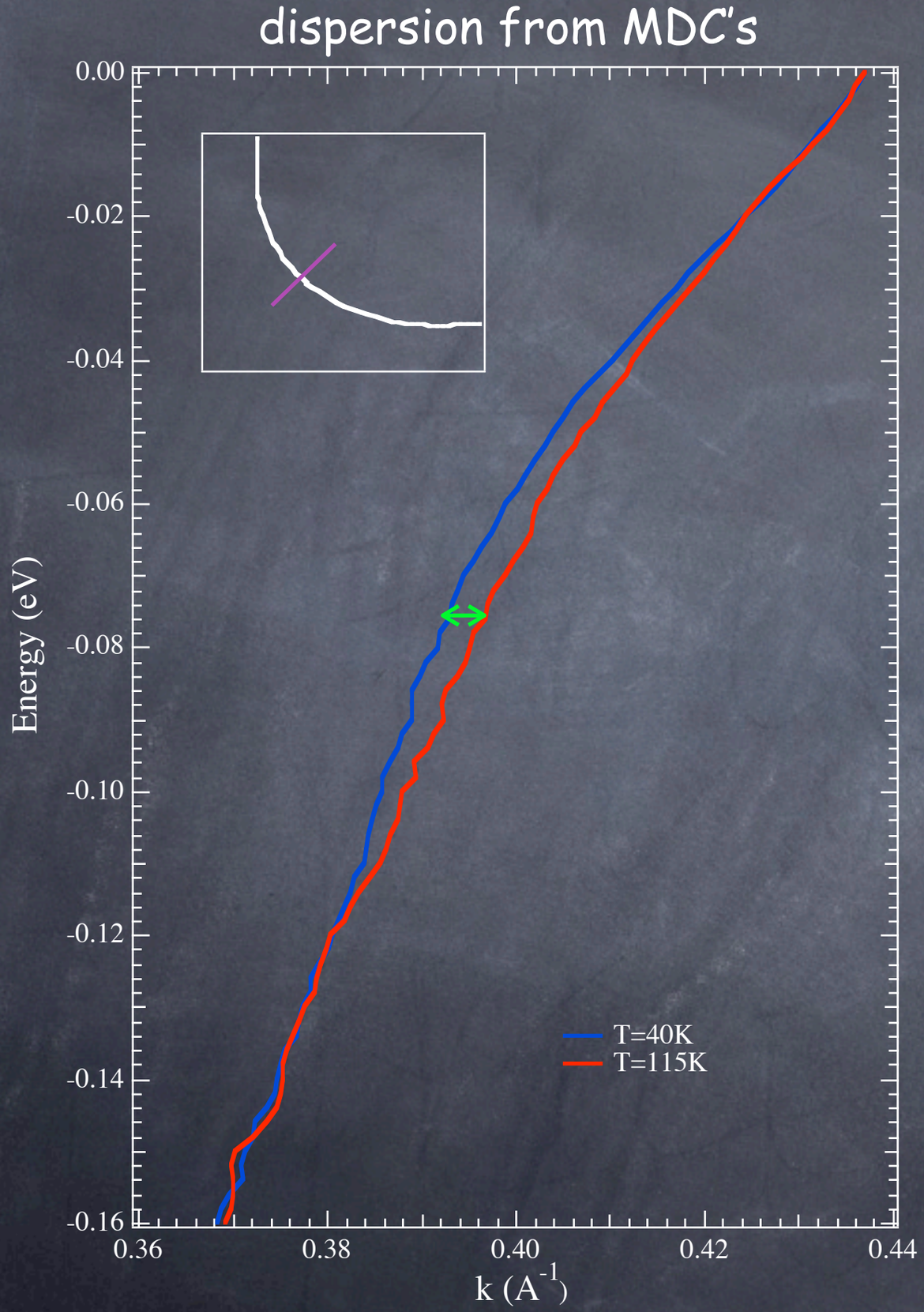
spectral function:

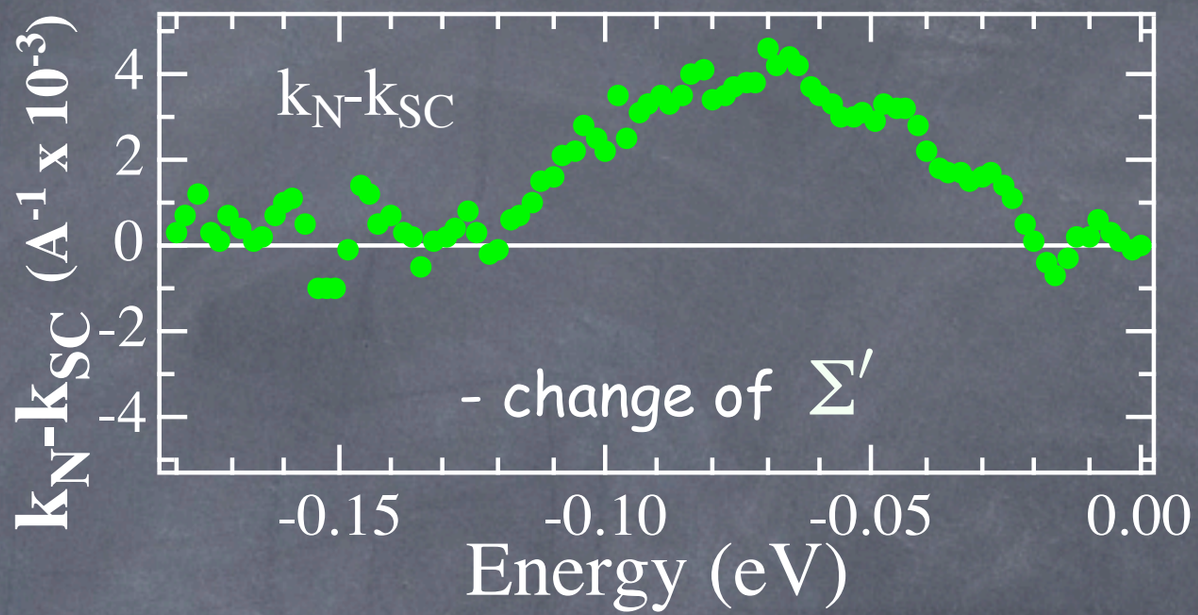
$$A(k,\omega) = \frac{1}{\pi}\frac{|\Sigma''(k,\omega)|}{[\omega - v_f^0(k-k_0) - \Sigma'(k,\omega)]^2 + [\Sigma''(k,\omega)]^2}$$

Σ' - real part of self energy, Σ'' - imaginary part of self energy

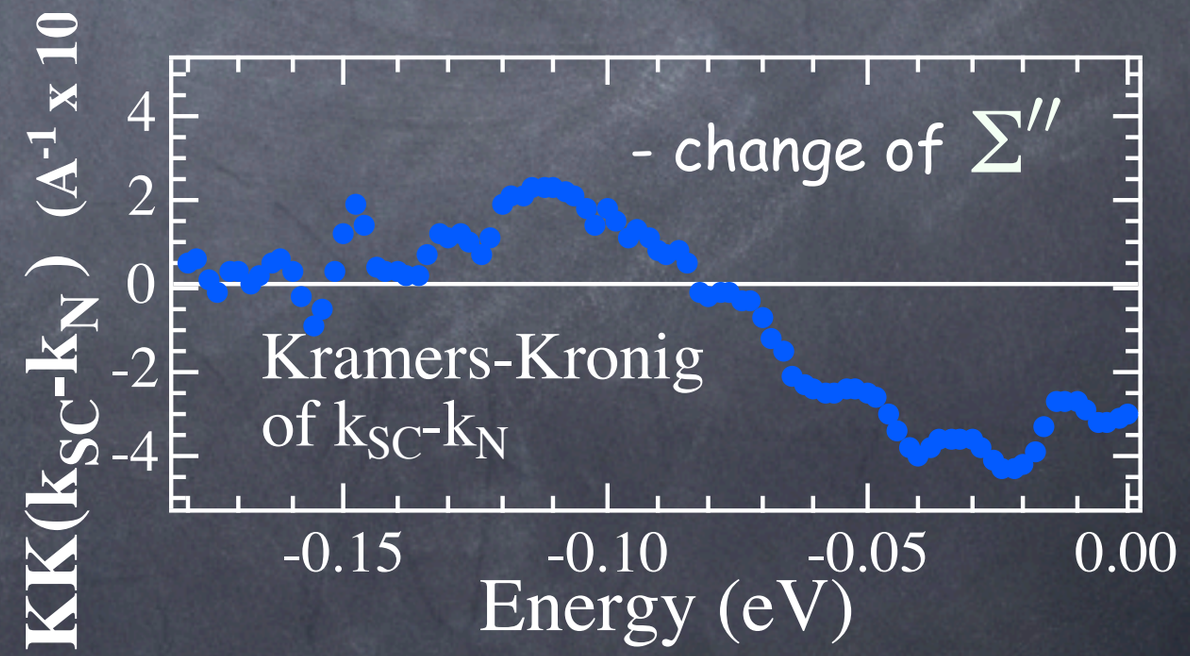


$$\Delta k = \frac{\Sigma''(k,\omega)}{v_f^0}$$



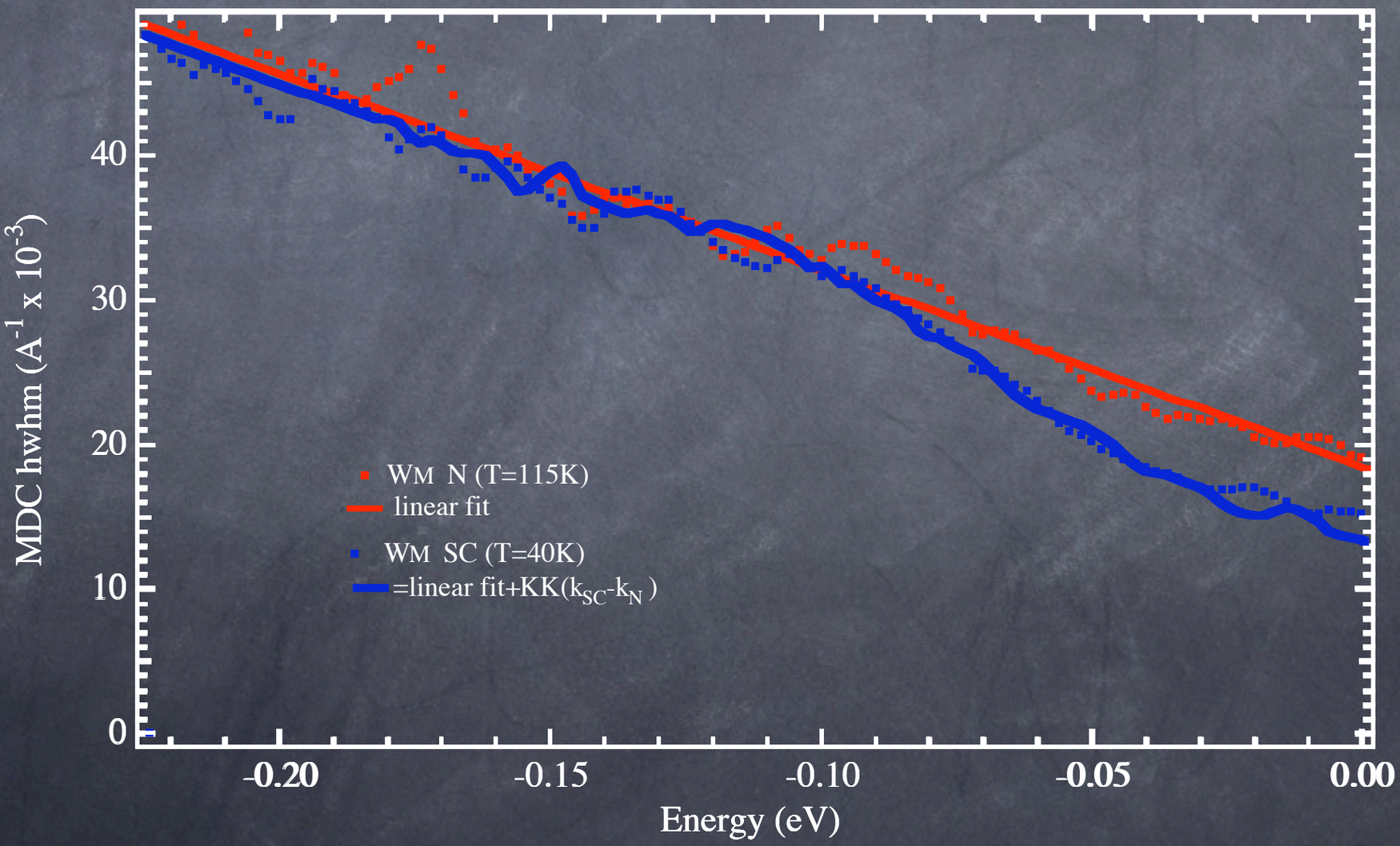


Kramers-Kronig transformation



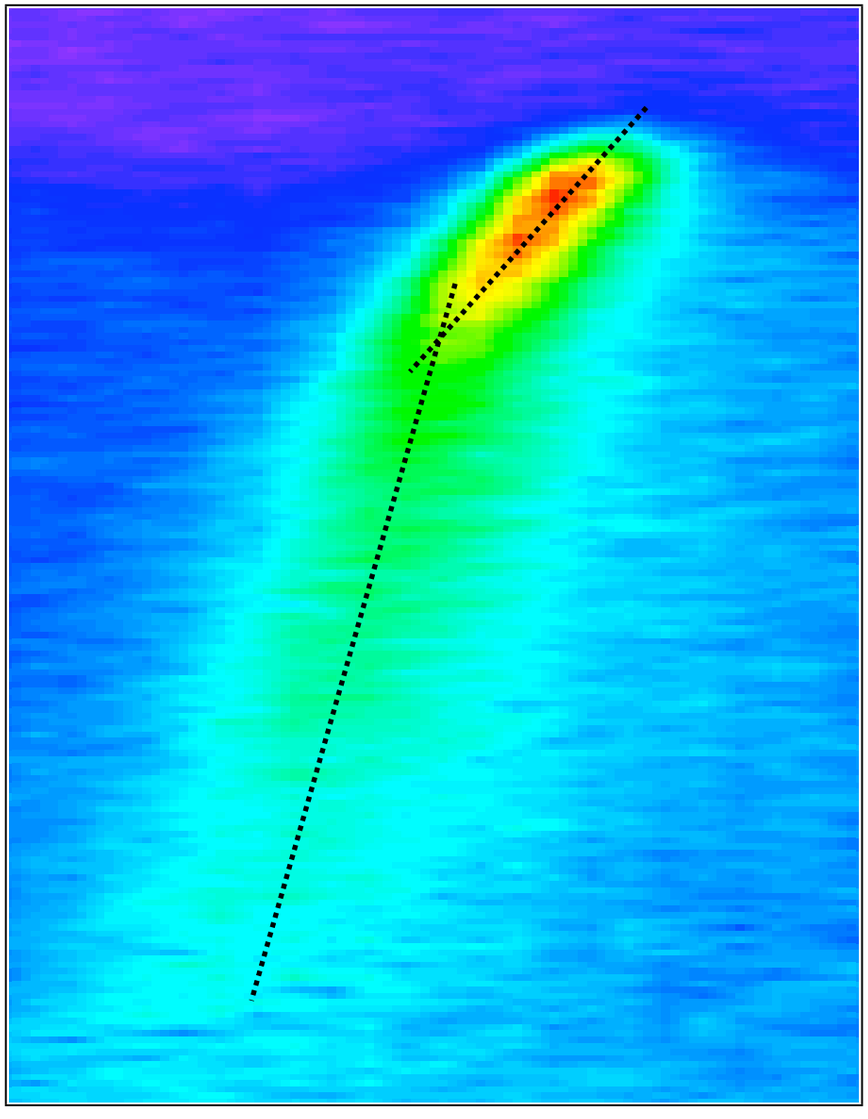
A. Kaminski et al., *Phys. Rev. Lett.* **86**, 1070 (2001)

The change of scattering rates obtained from MDC peak dispersion and MDC peak widths are the same



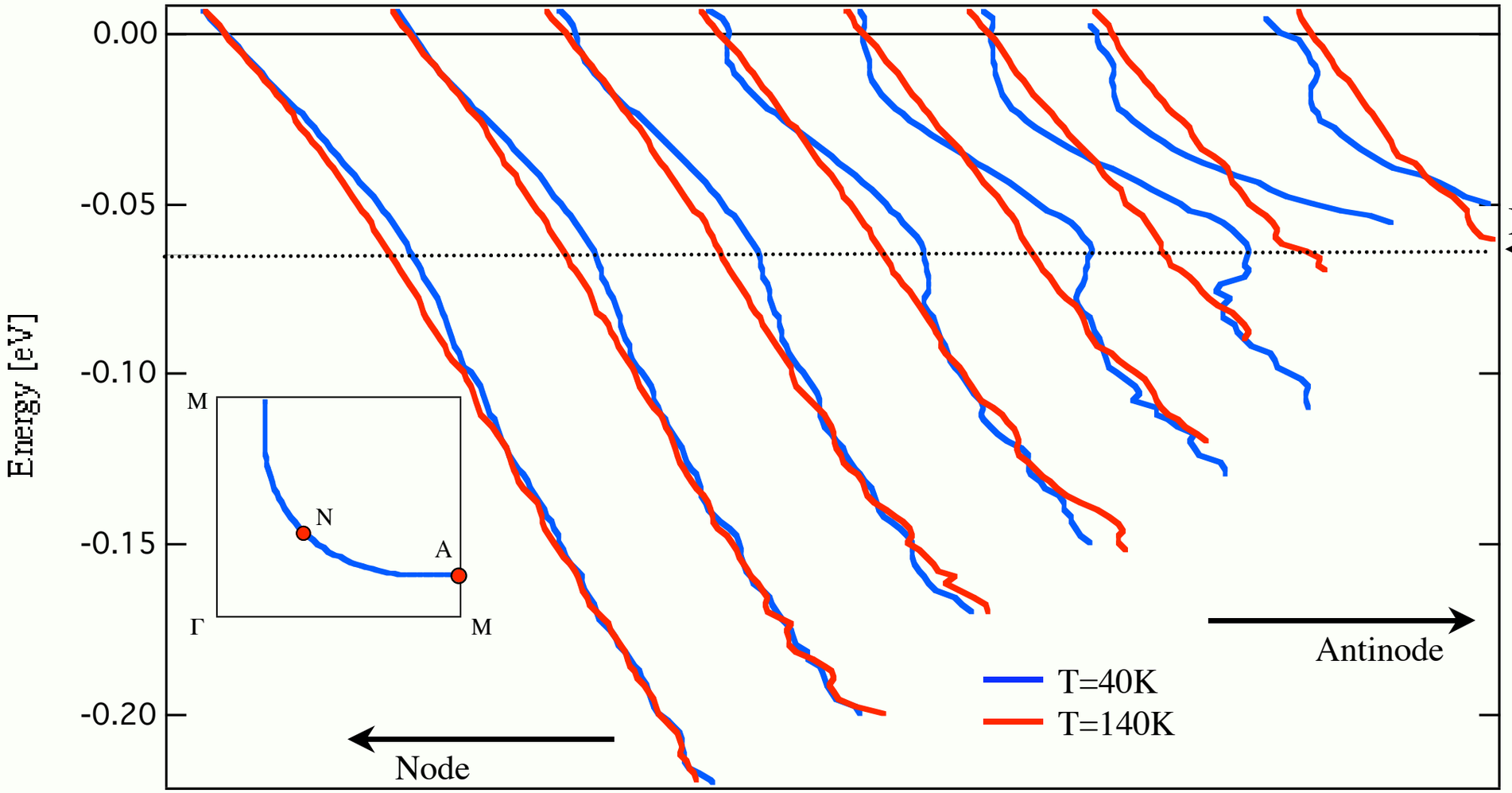
A. Kaminski et al., *Phys. Rev. Lett.* **86**, 1070 (2001)

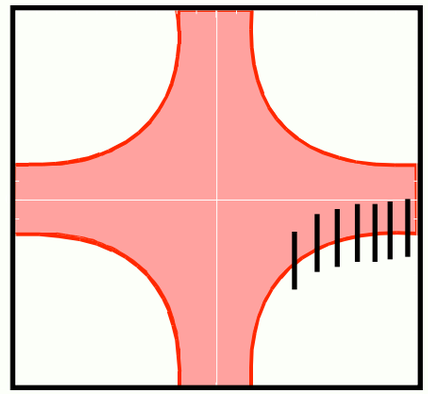
Renormalization effects in the superconducting state - magnetic of phonon origin?

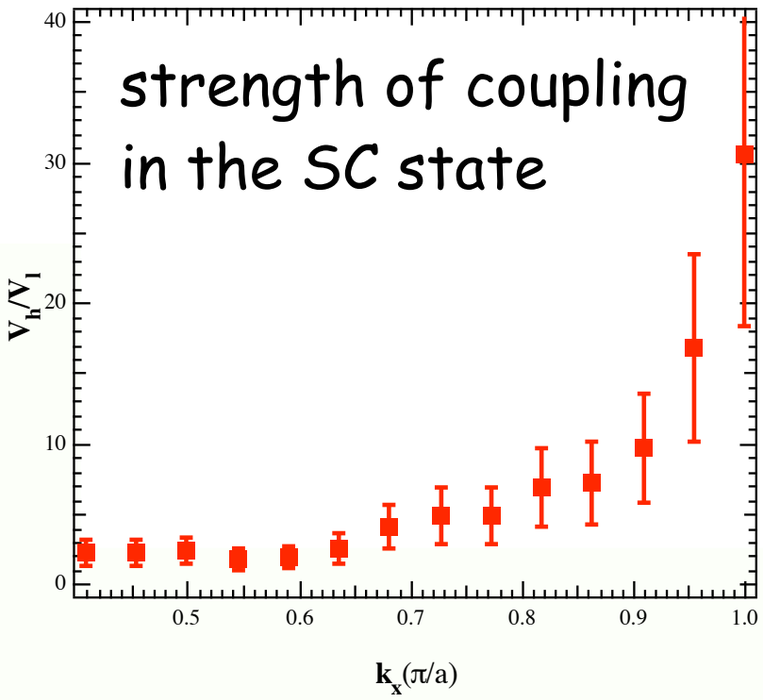


T. Valla et al., *Science* **24**, 2110 (1999)
P.V. Bogdanov et al., *Phys. Rev. Lett.* **85**, 2581 (2001)
A. Kaminski et al., *Phys. Rev. Lett.* **86**, 1070 (2001)

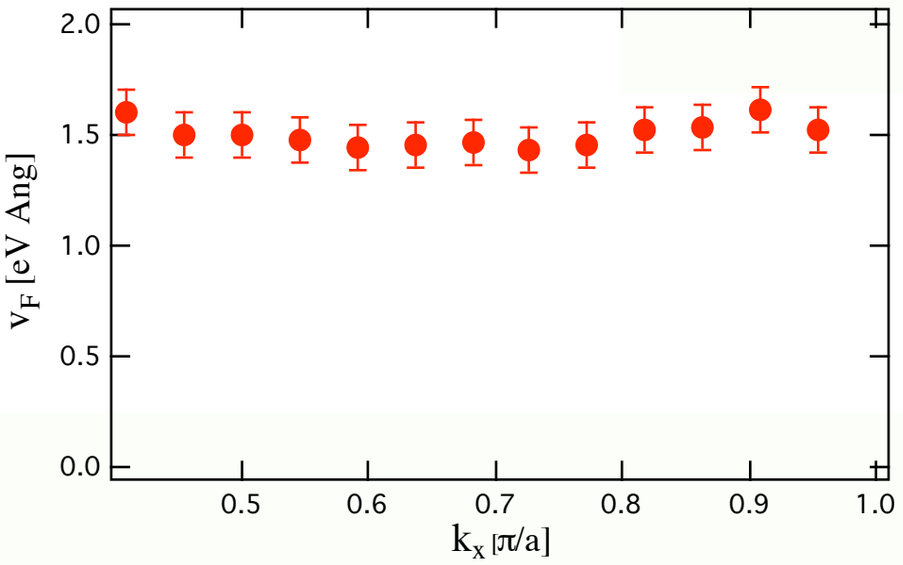
dispersion in normal and superconducting state







Fermi velocity in the normal state



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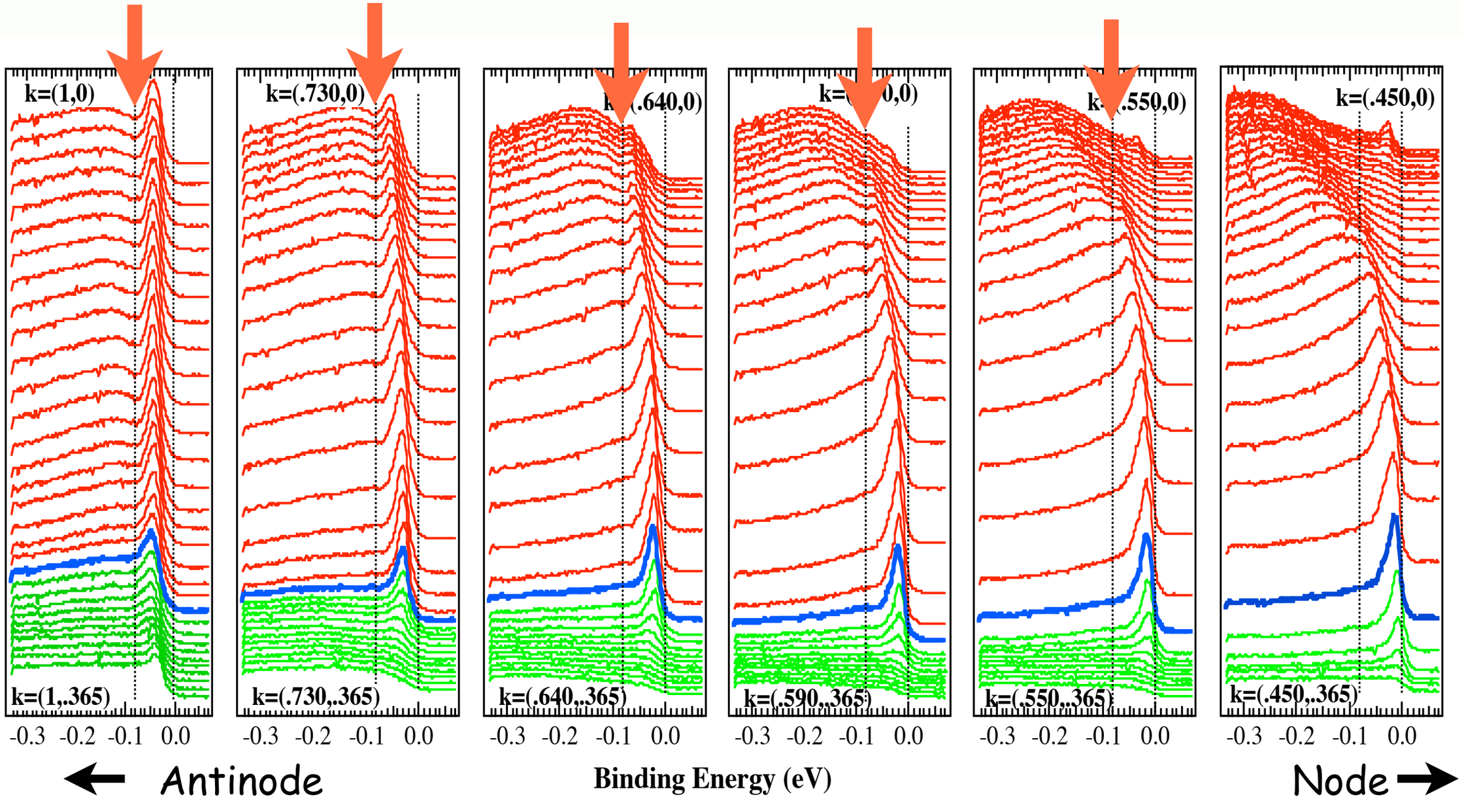
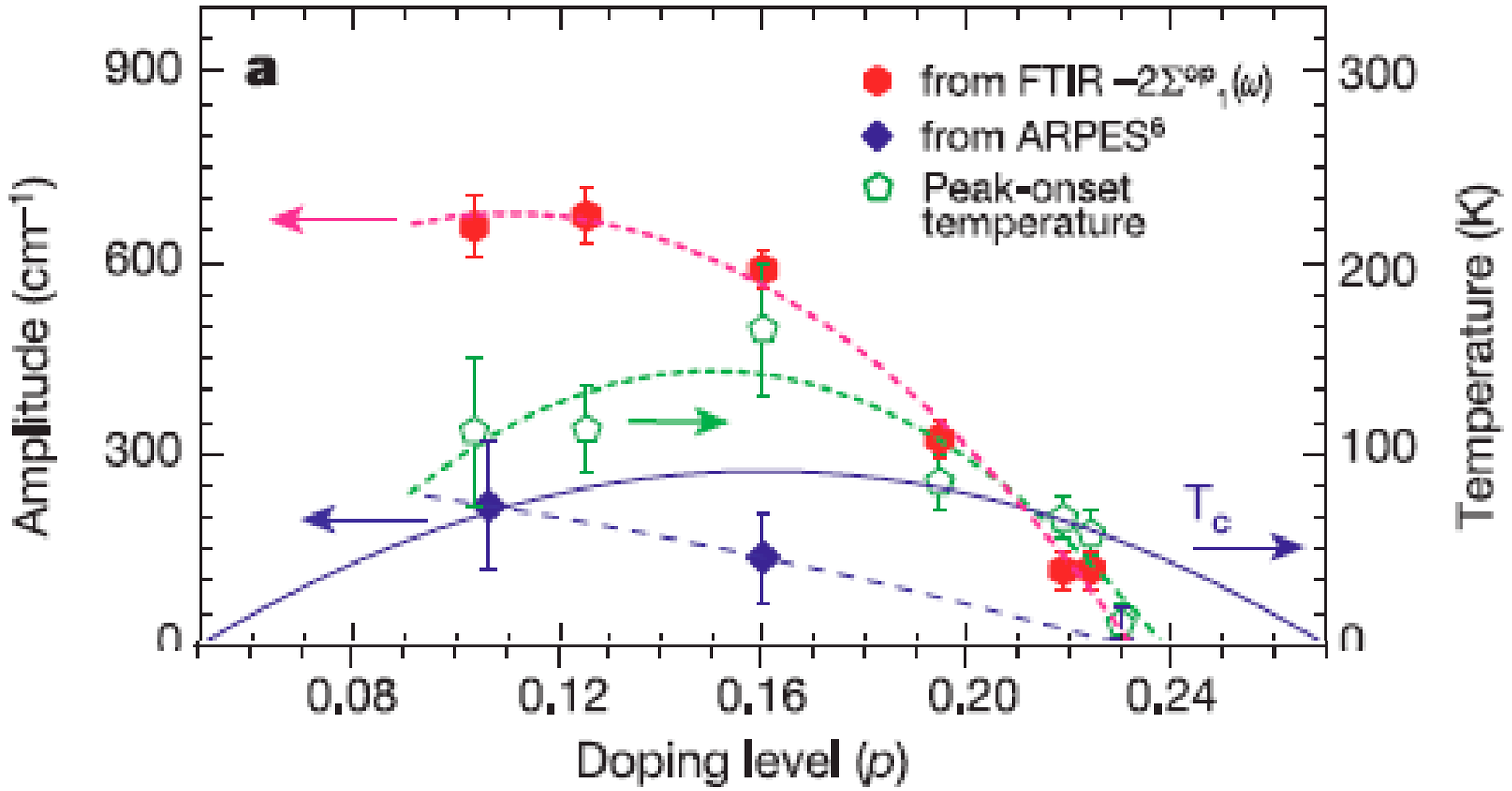
EDC's in the superconducting state



A. Kaminski et al., *Phys. Rev. Lett.* **86**, 1070 (2001)

Strength of coupling from optics and ARPES

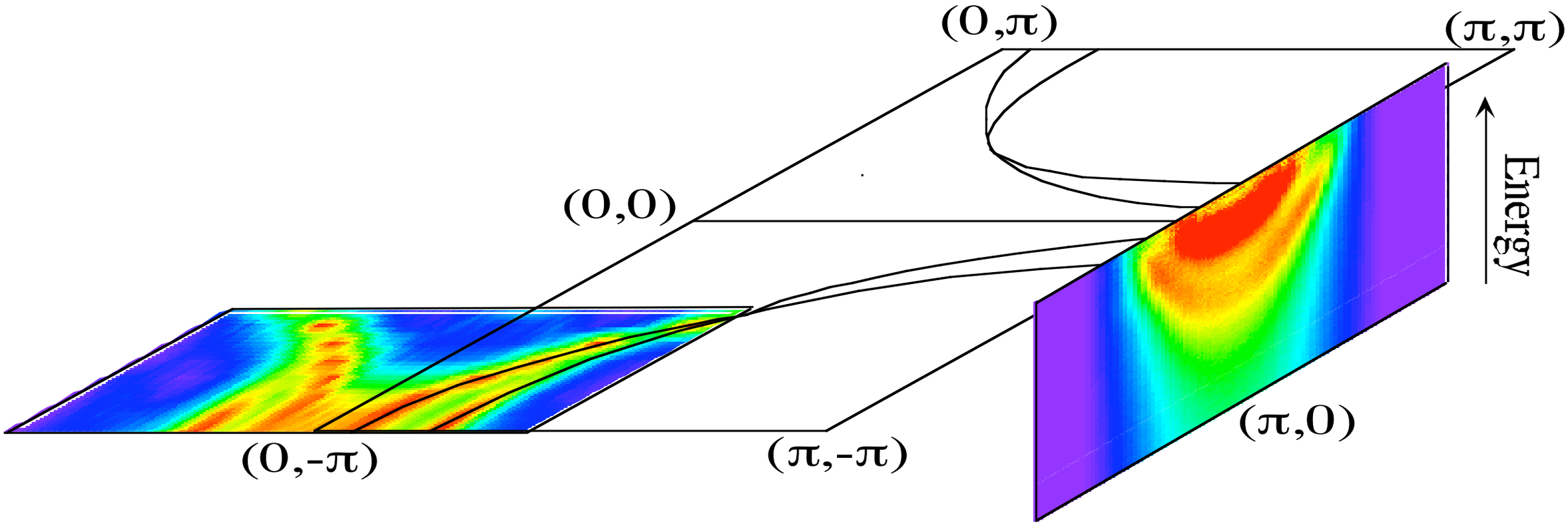


Hwang et al. *Nature* **427**, 714 (2004)

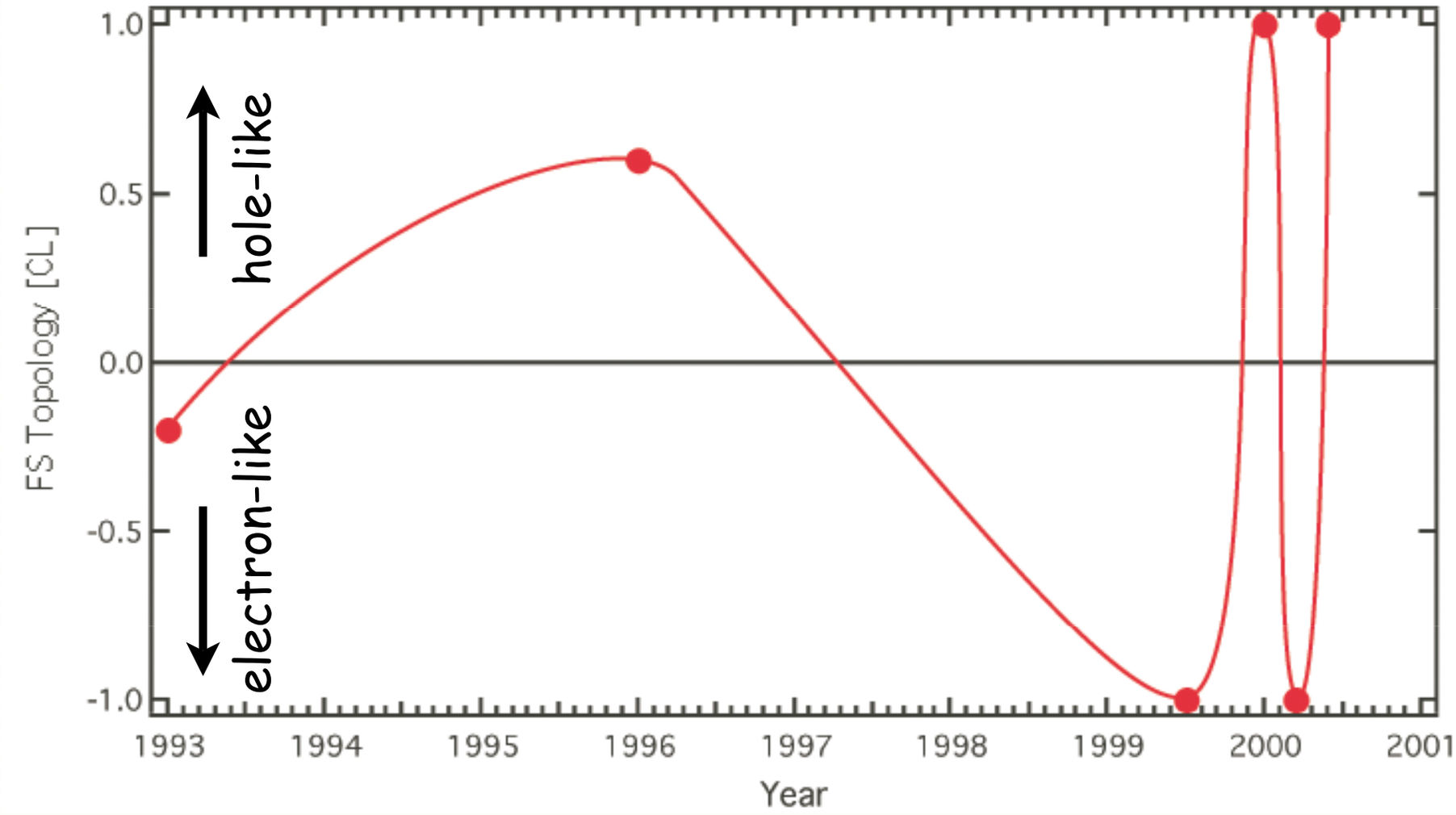
Score card

Properties of the bosonic mode	compatibility magnetic	phonons
1) isotropic energy $\Delta+\Omega$	yes	yes
2) momentum anisotropy	yes	yes, recently
3) temperature dependence	yes	not obvious
4) doping dependence	yes	not obvious

Topology of the Fermi surface



Time evolution of the Fermi surface of $Bi_2Sr_2CaCu_2O_{8+\delta}$

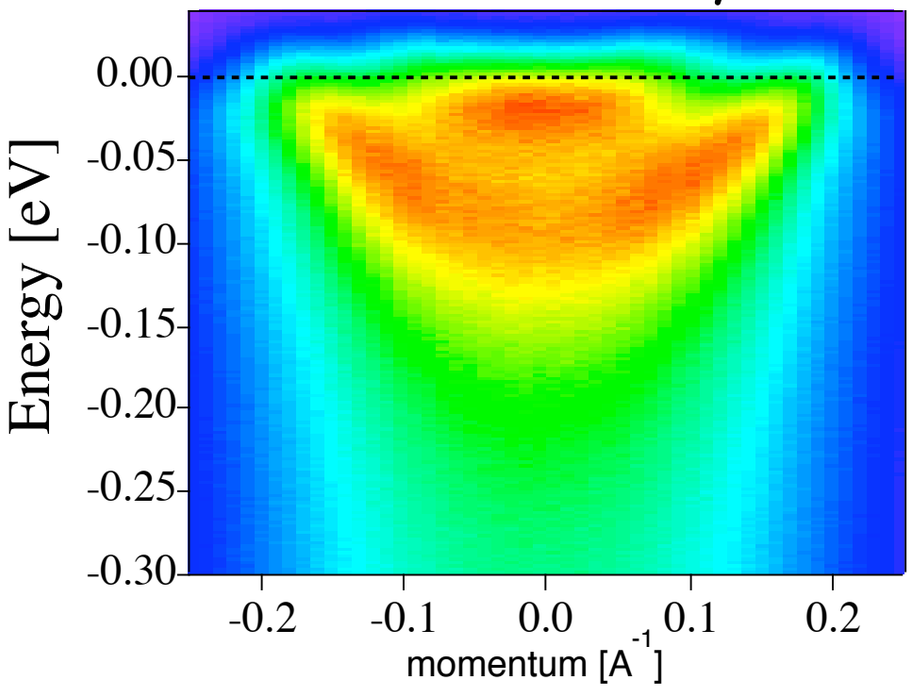


bilayer splitting
Feng et al.
(2001)

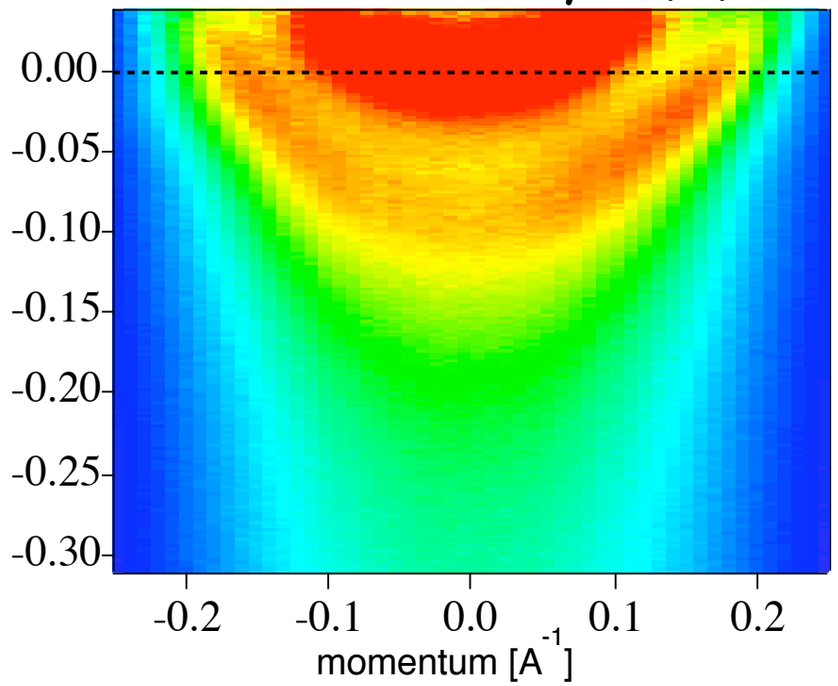
bonding sheet is hole-like

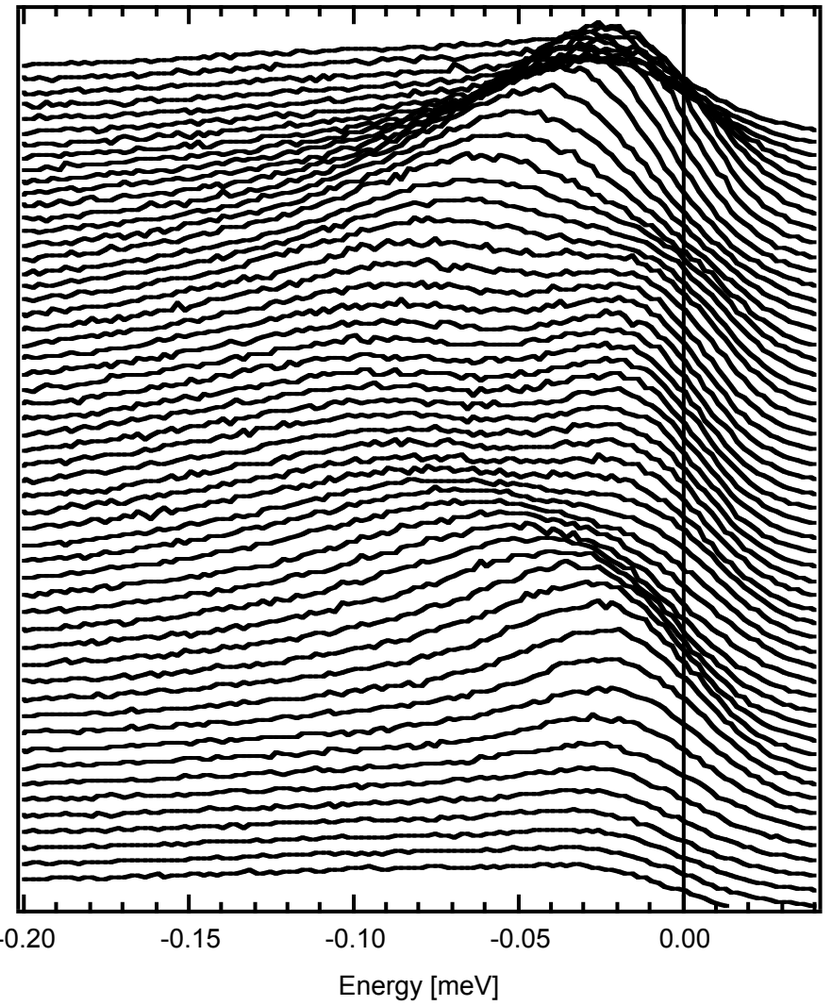
antibonding ???

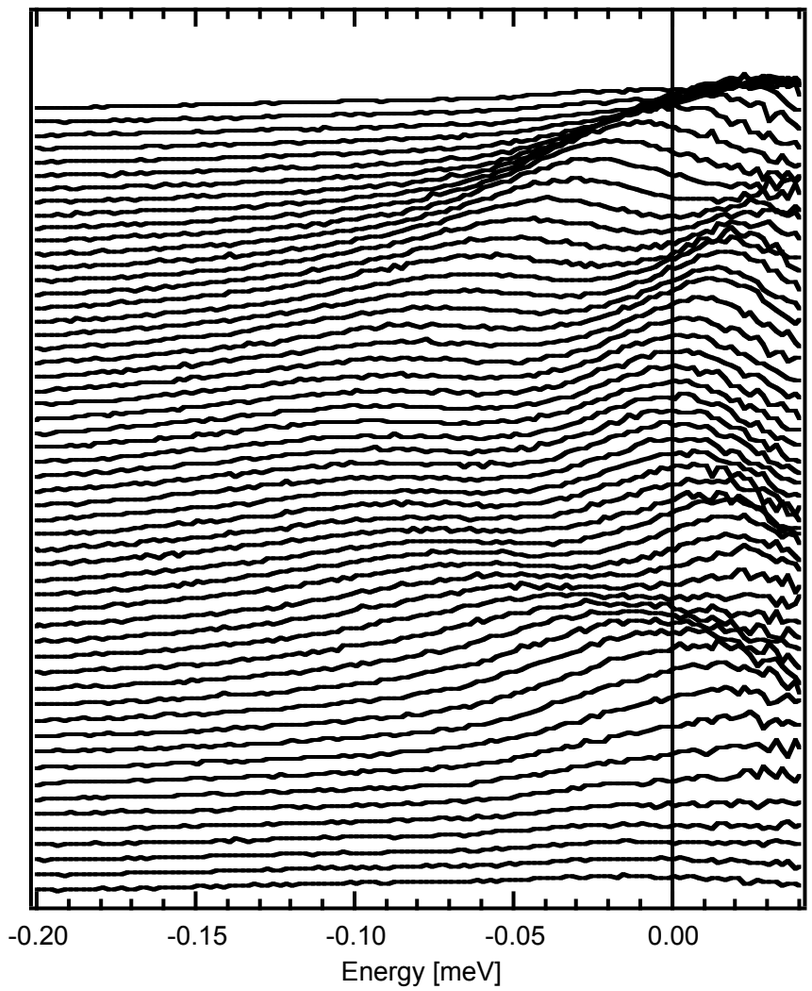
ARPES intensity



ARPES intensity/f(w)

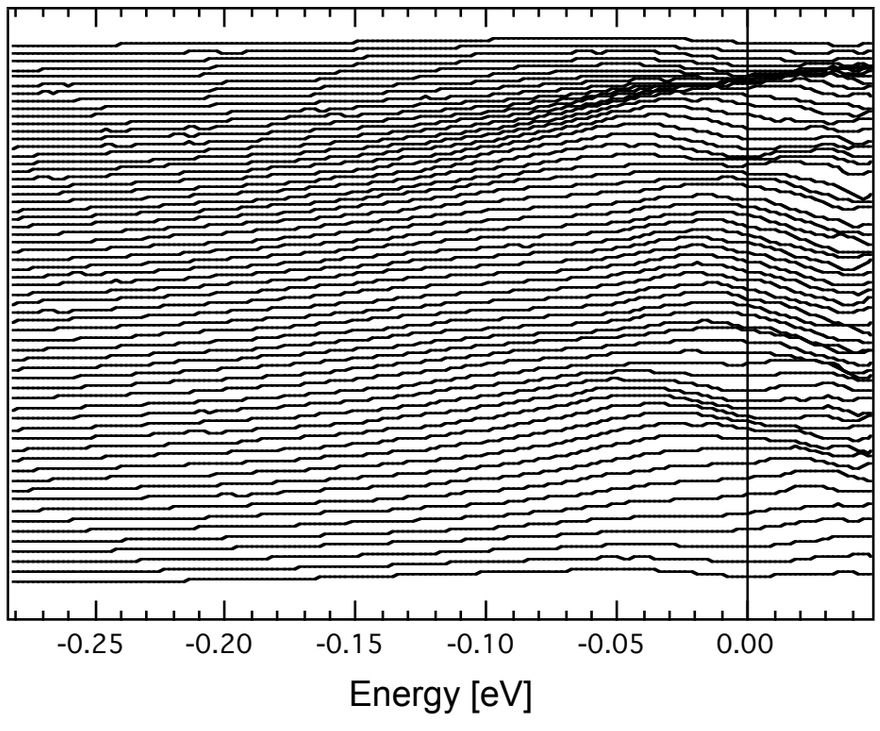


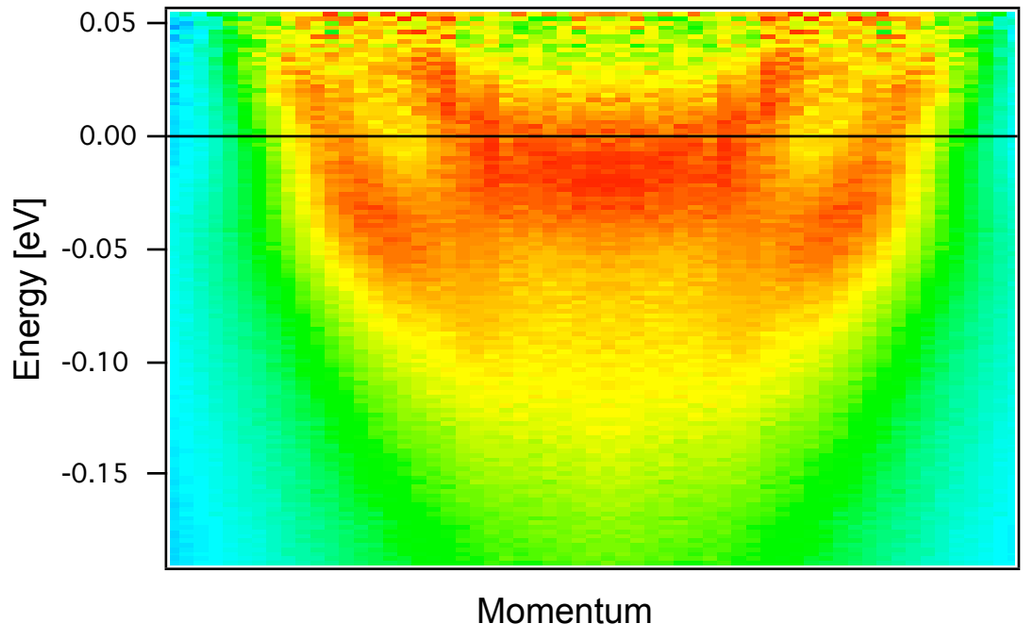


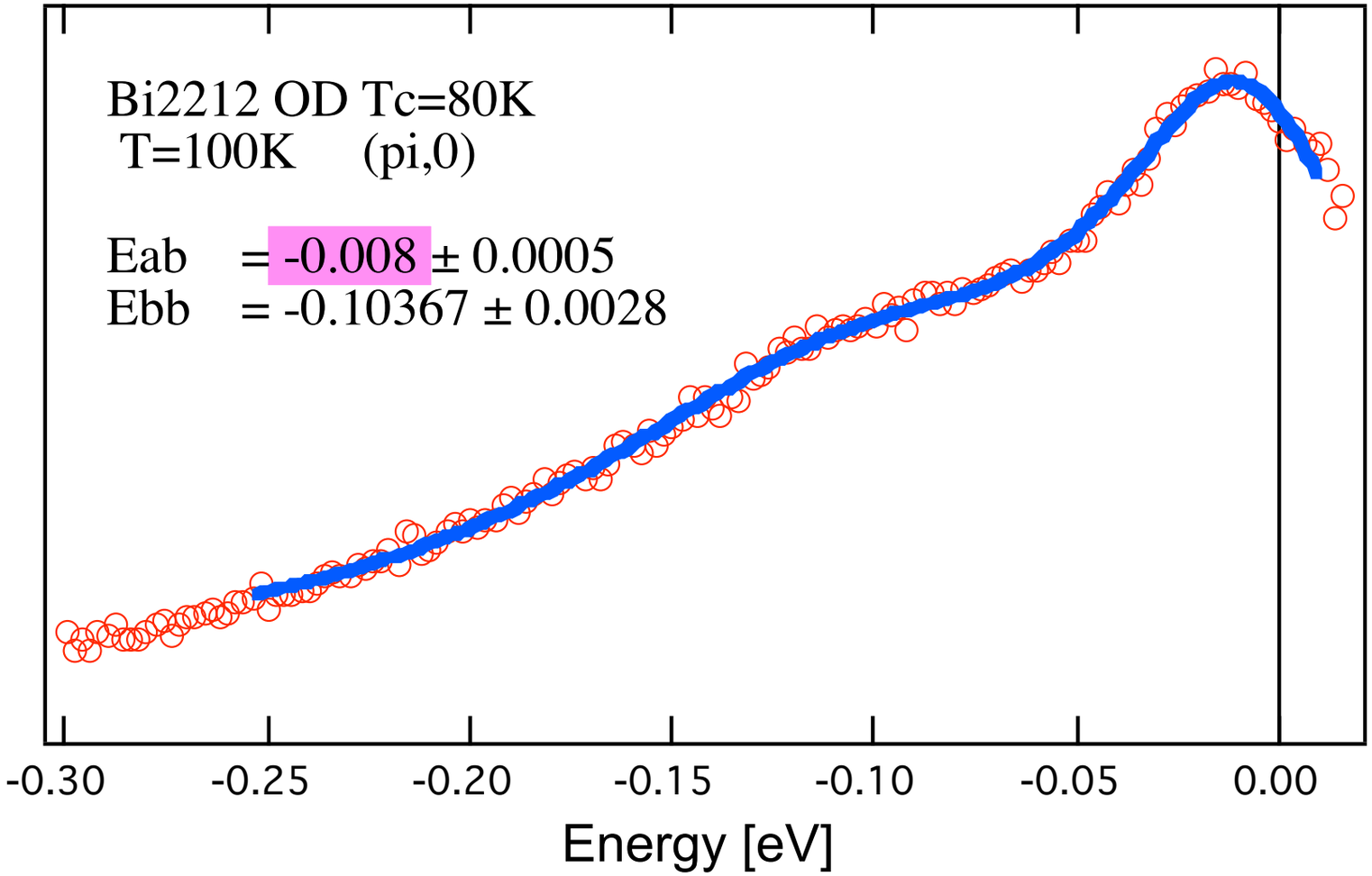


T=100K

Overdoped sample Tc=80K







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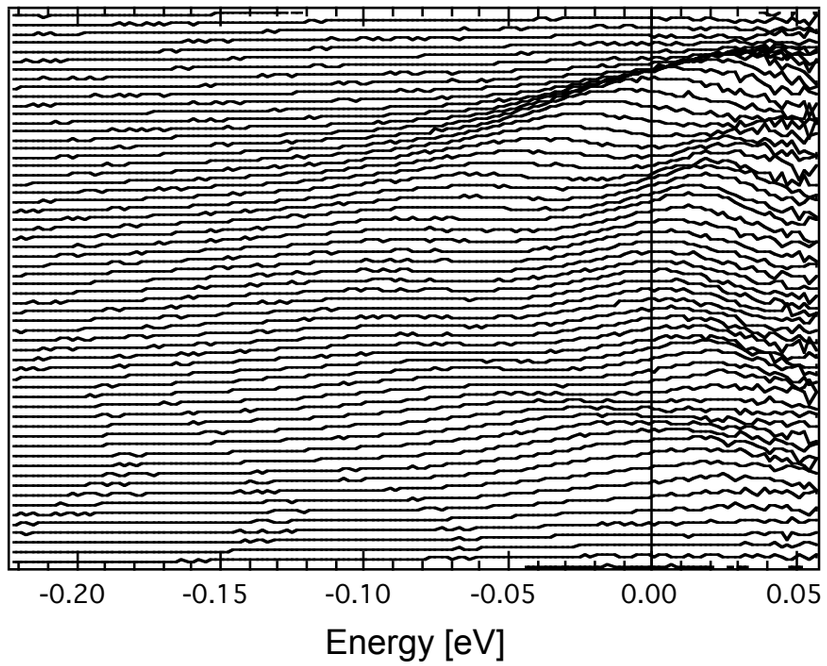
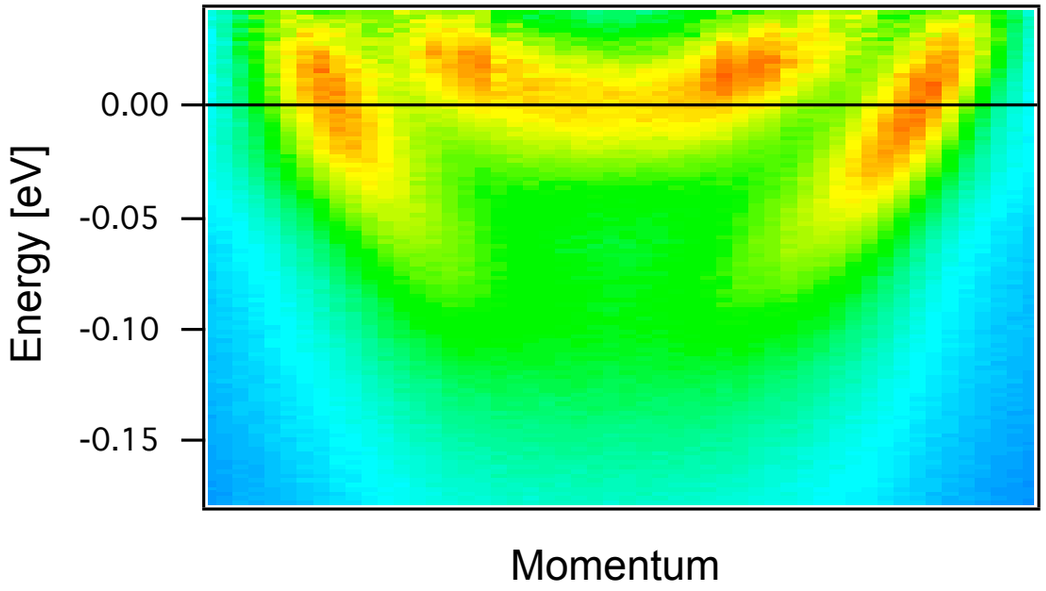
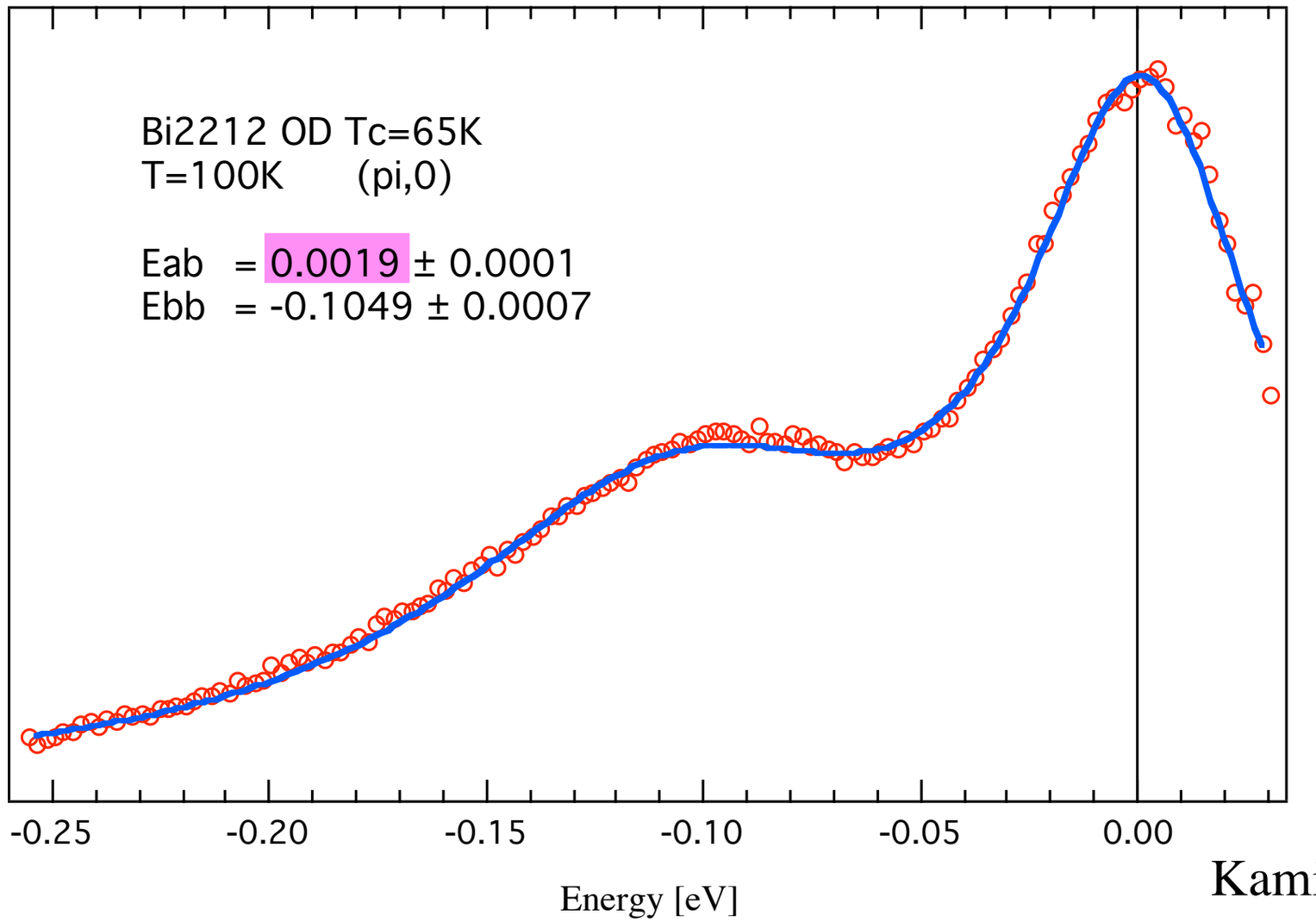
Overdoped sample Tc=65K







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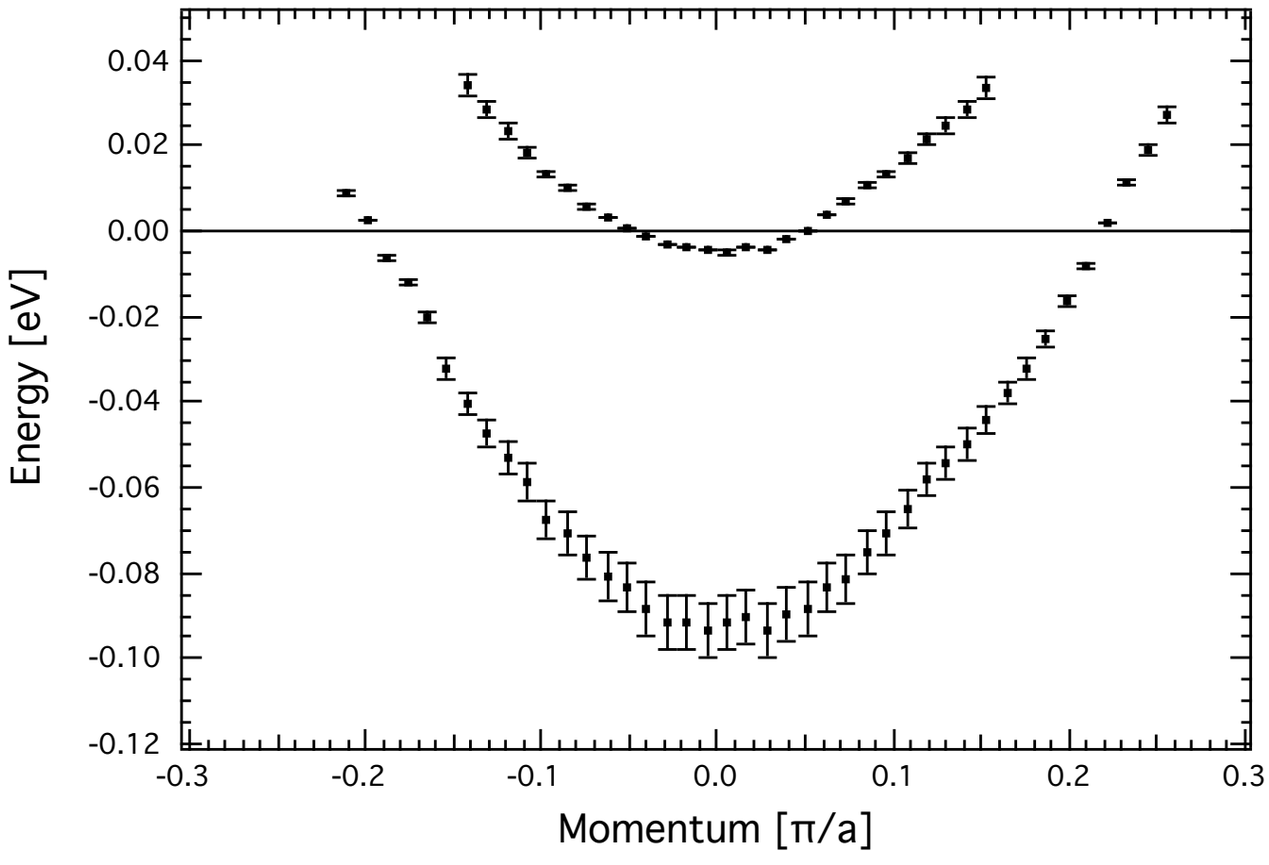
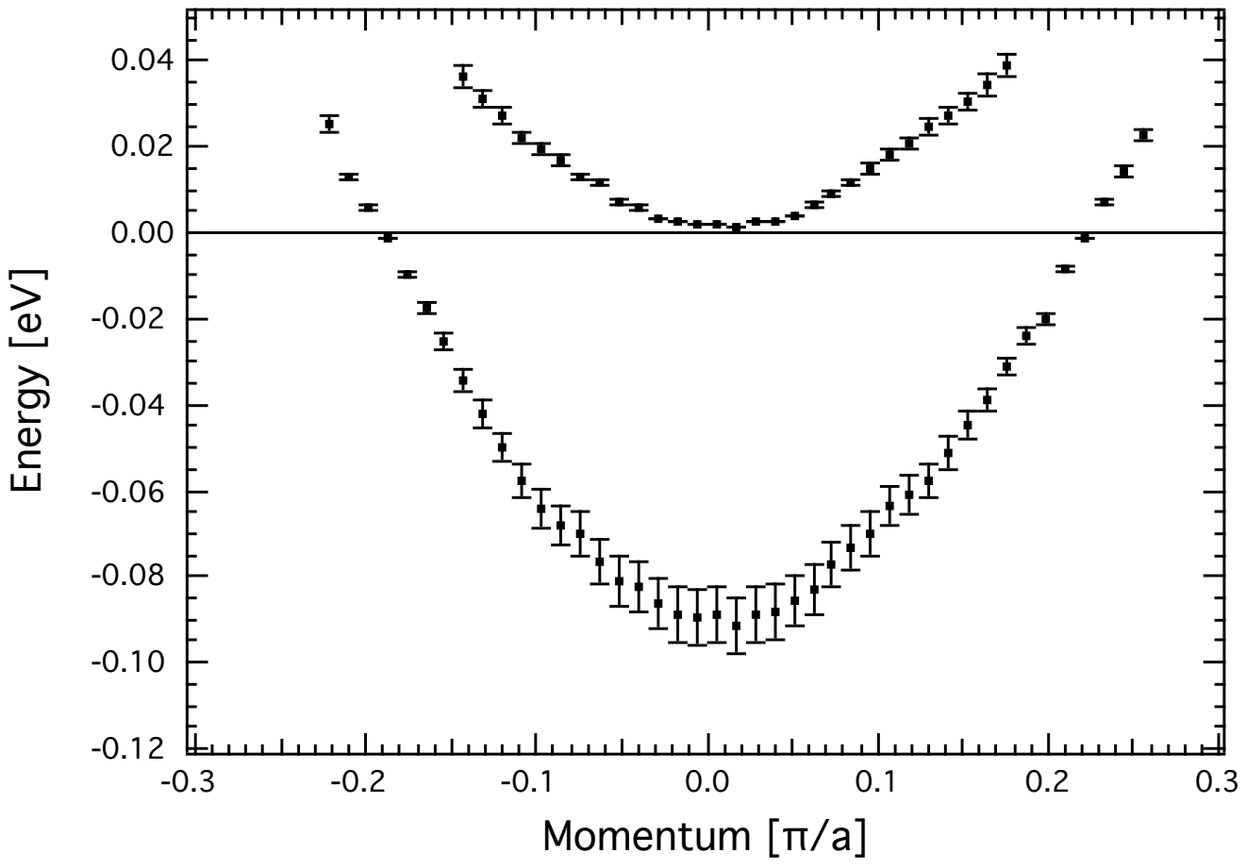
Kaminski et al. *Submitted*

Overdoped sample Tc=65K

k_x=0.9 π/a



k_x=π/a

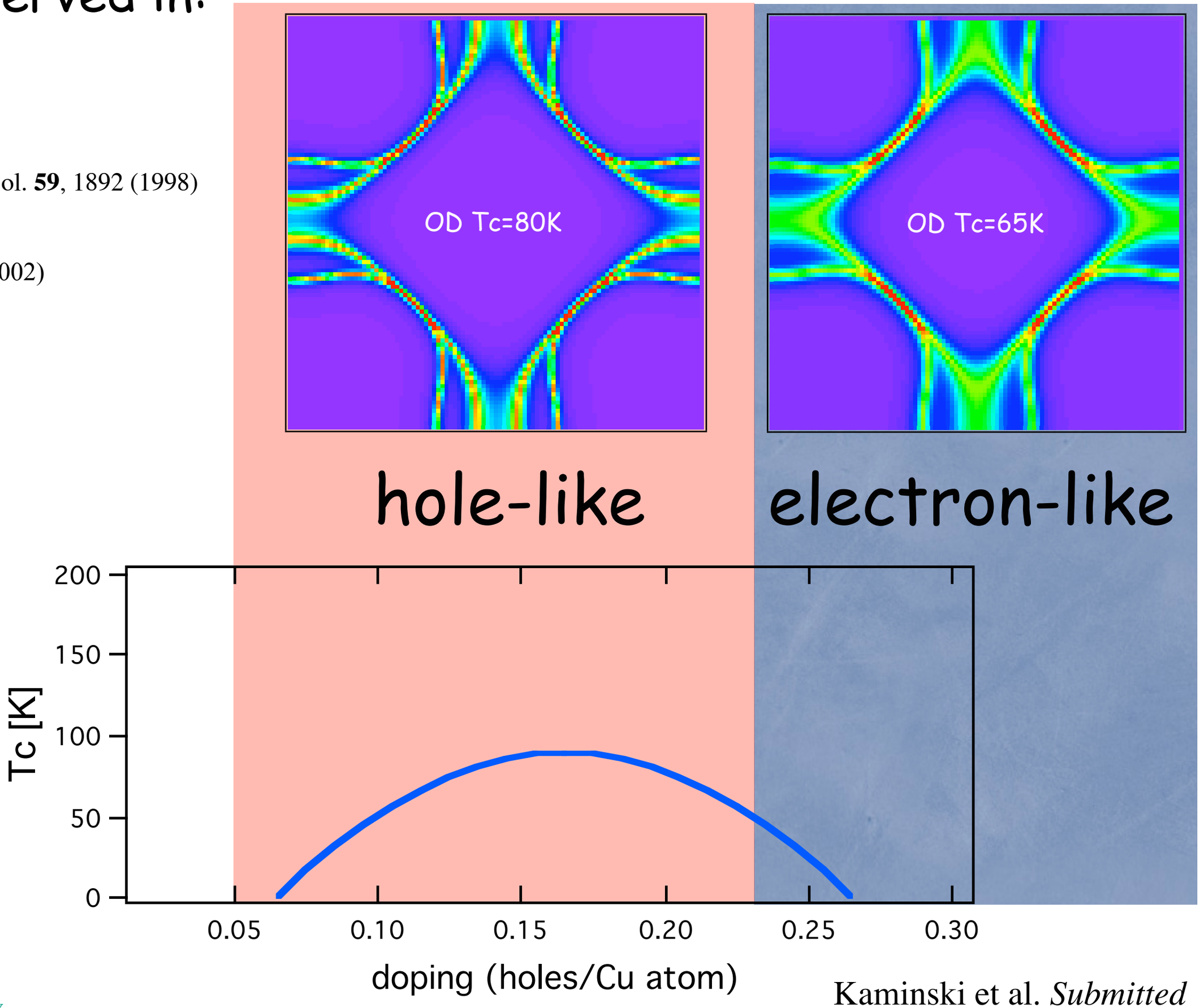


Also observed in:

LSCO

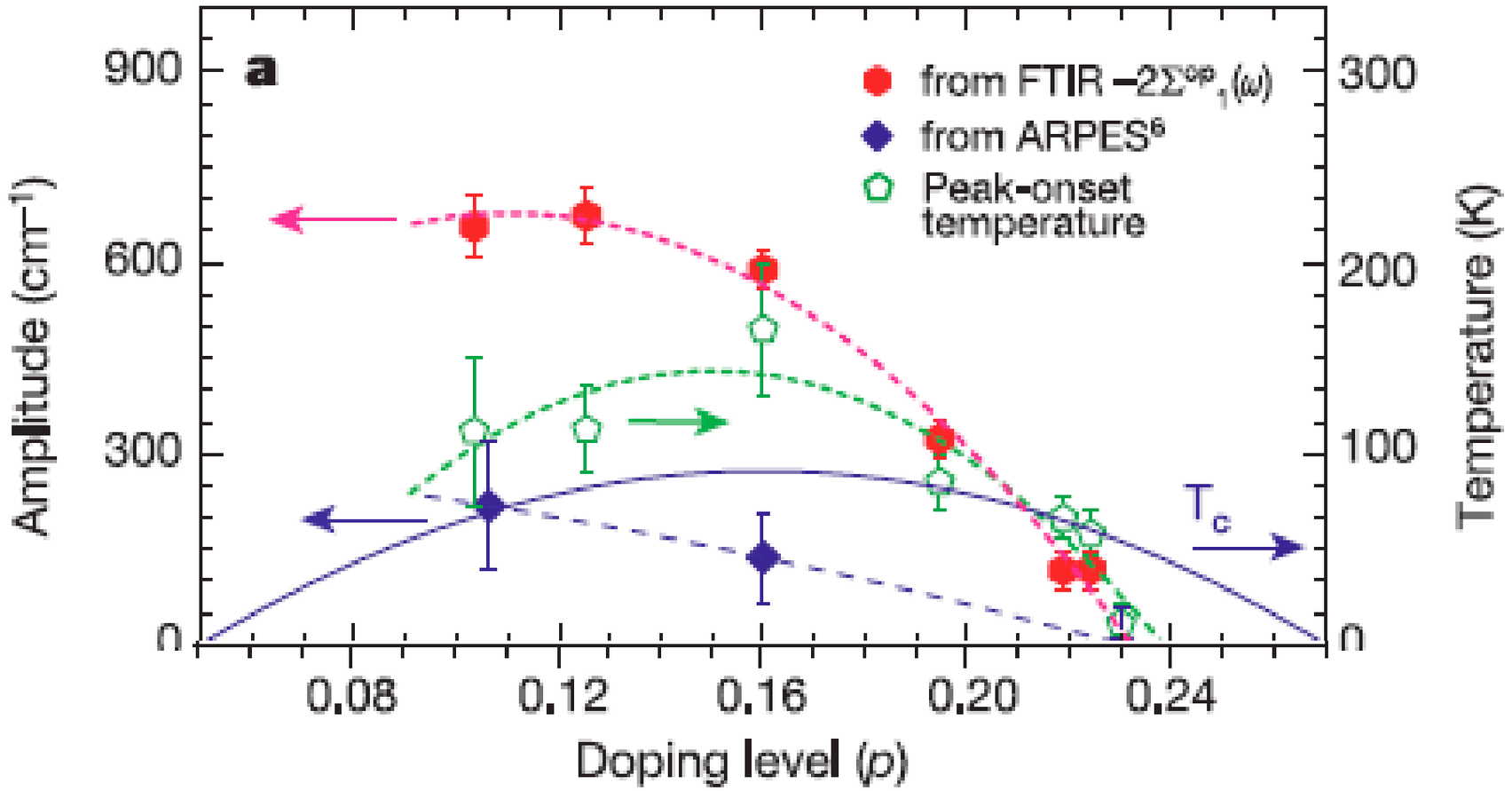
A. Fujimori et al.,
J. Phys. Chem. of Sol. **59**, 1892 (1998)

A. Ino et al.,
PRB **65**, 094504 (2002)



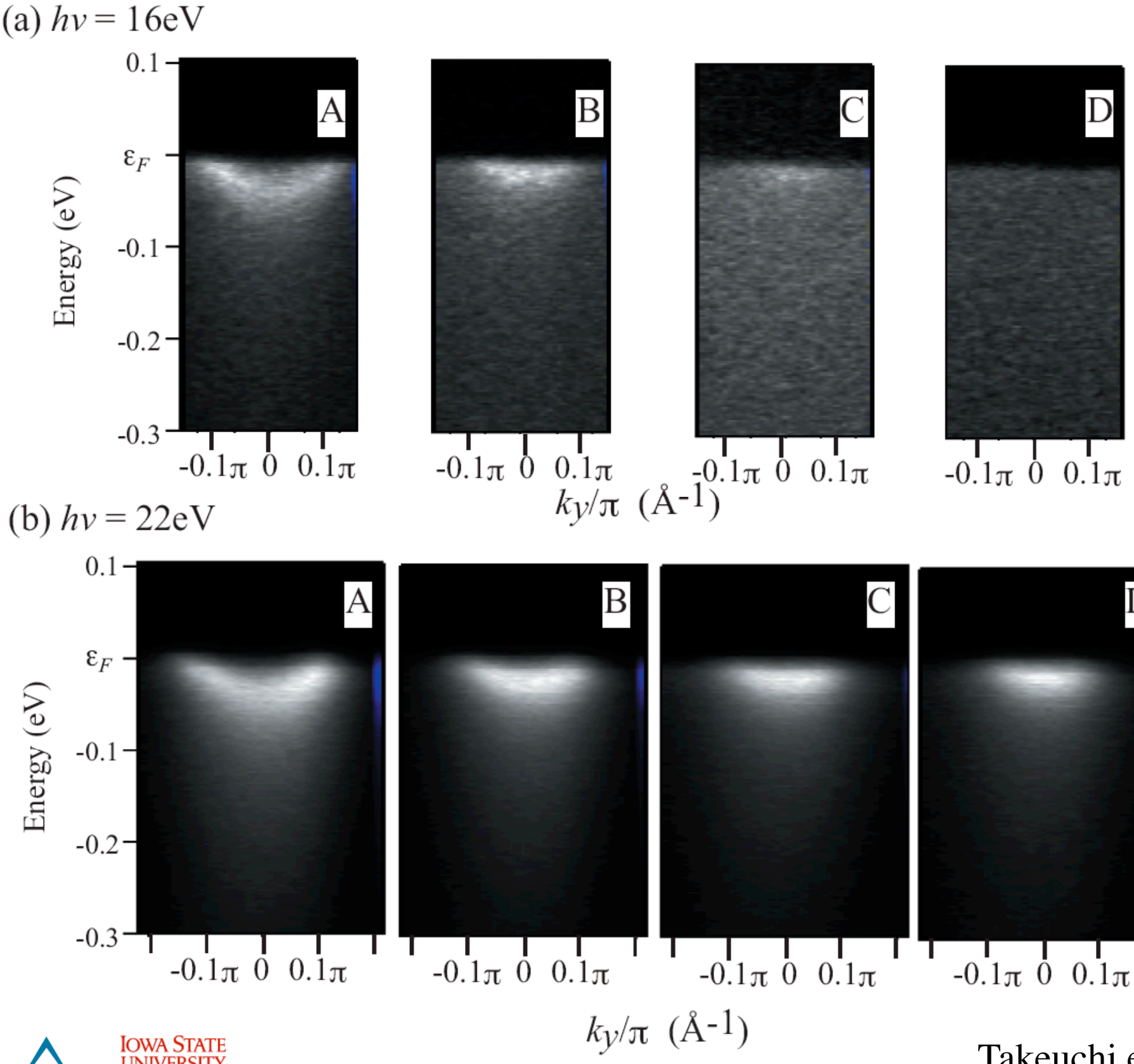
Kaminski et al. *Submitted*

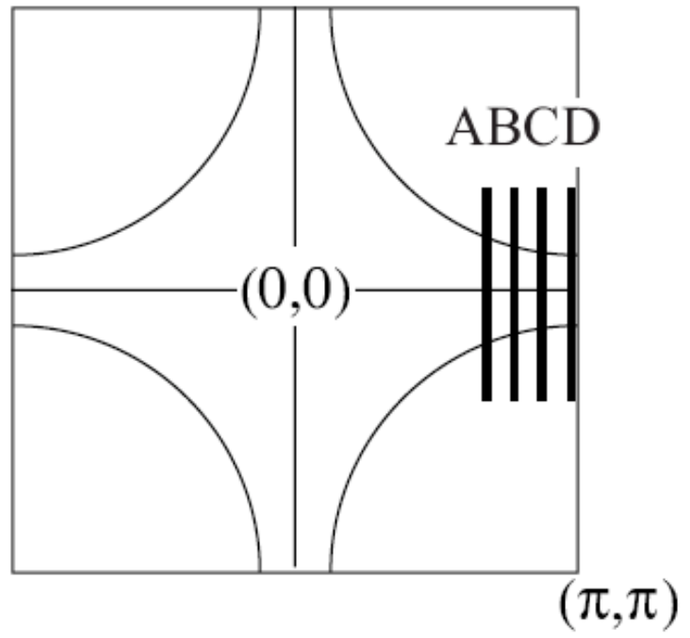
"Amplitude" of the collective mode from optics and ARPES



Hwang et al. *Nature* **427**, 714 (2004)

The topology of the Fermi surface of Bi2201





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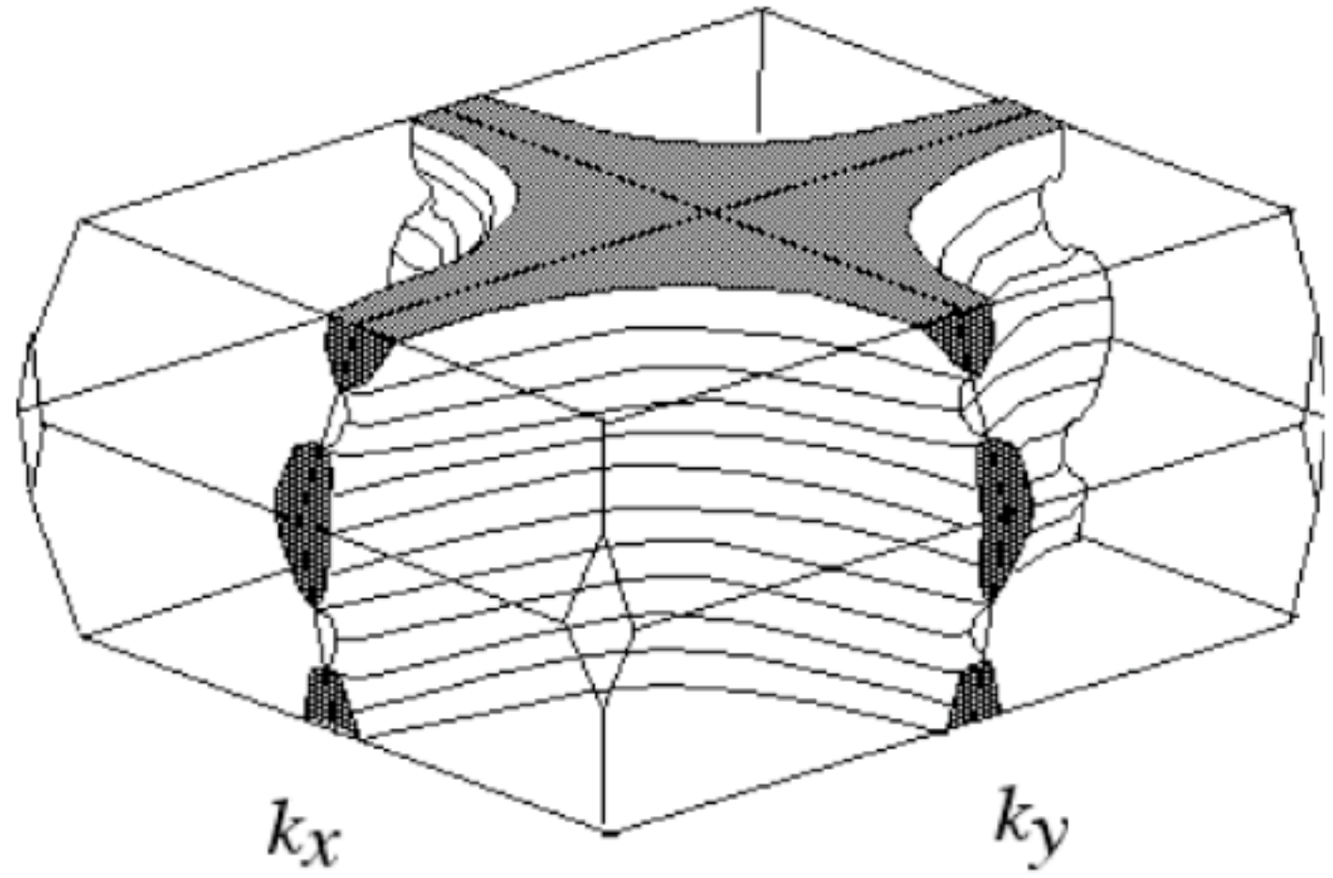
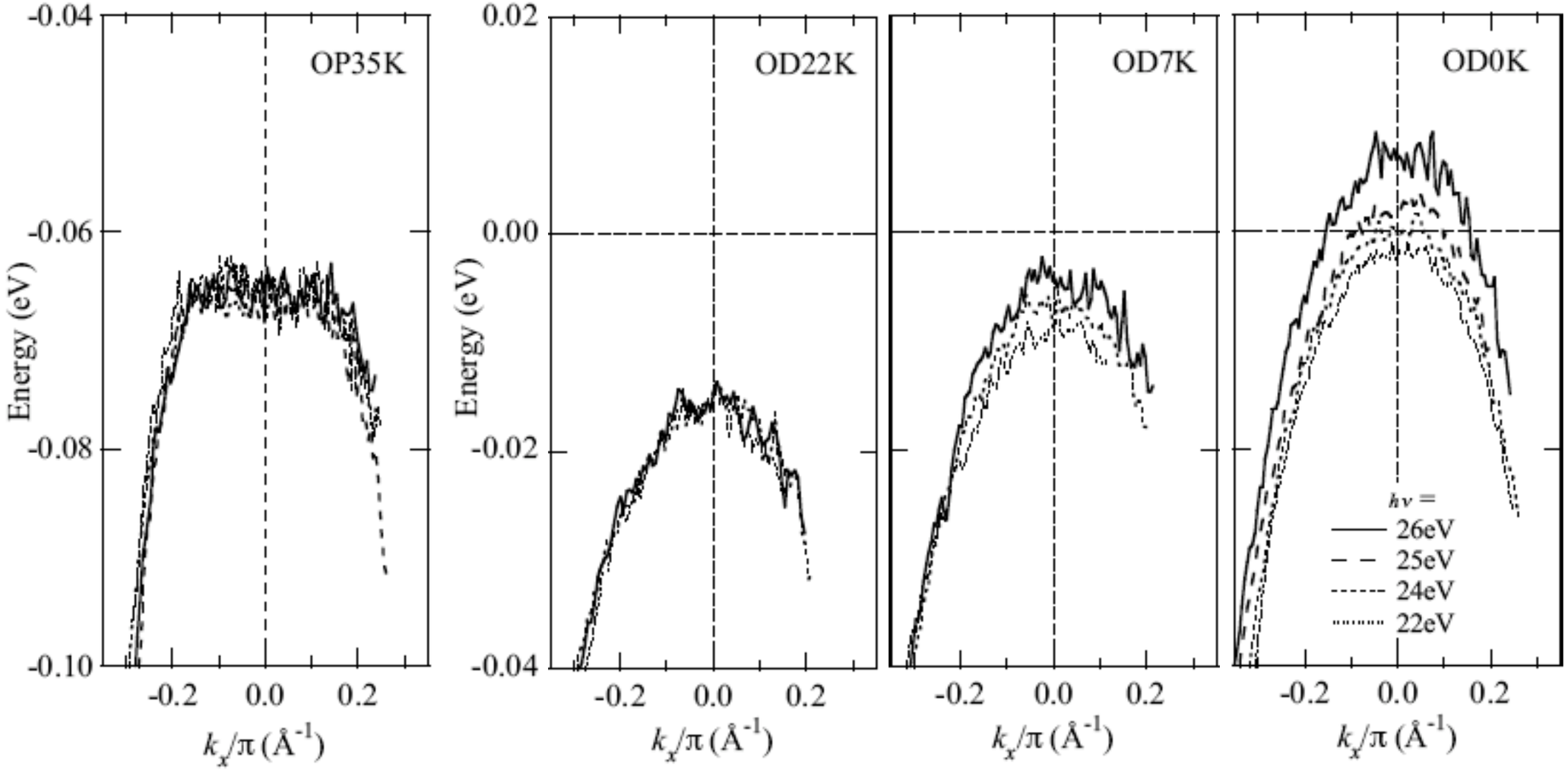
Takeuchi et al. *Submitted*

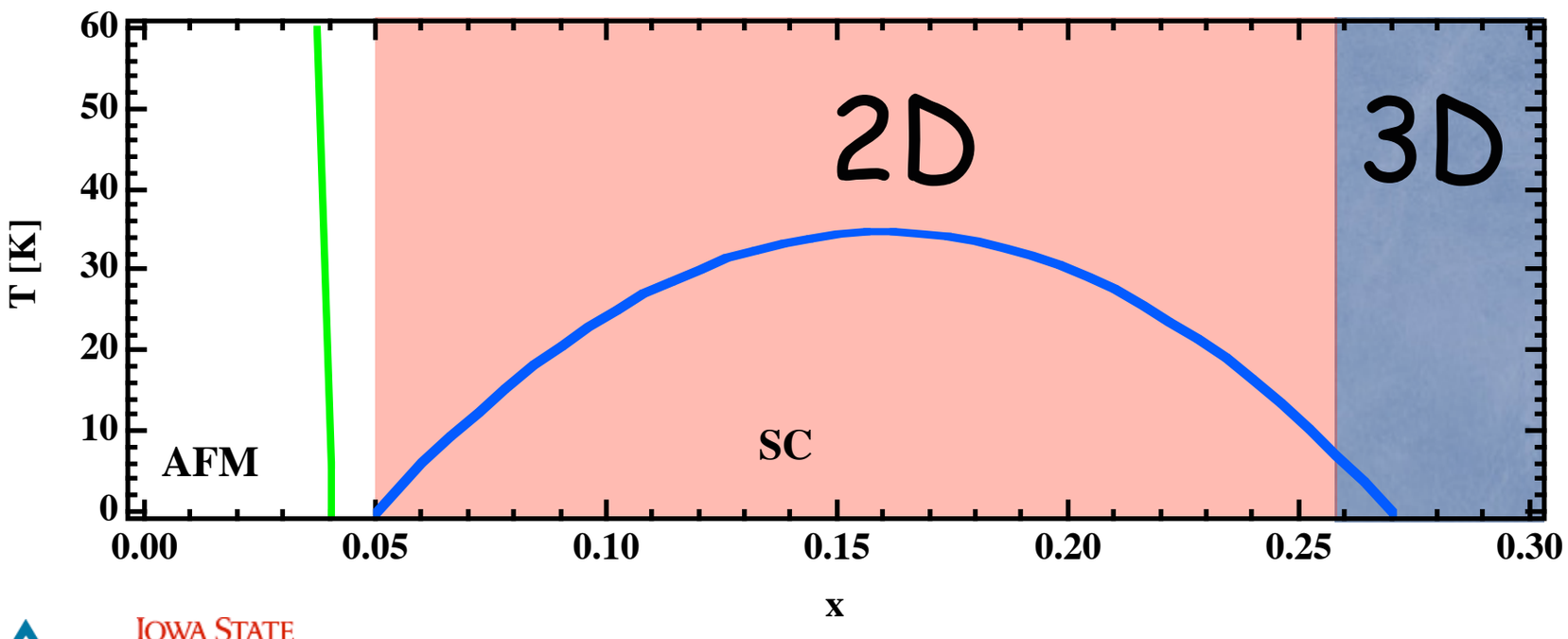
3D Fermi surface in overdoped Bi2201



k_x

Takeuchi et al. *Submitted*





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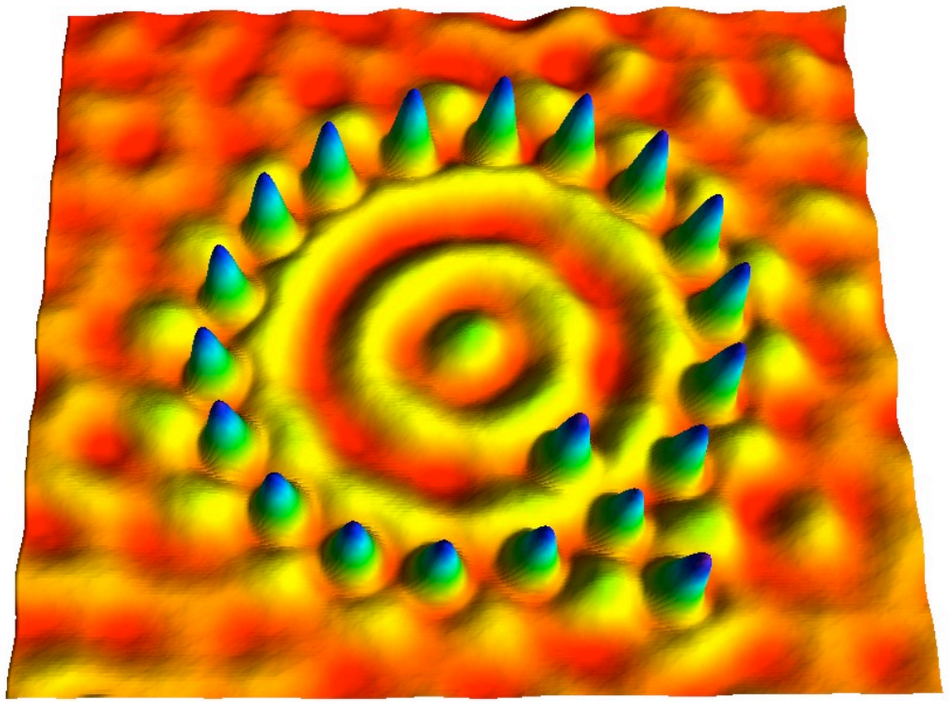
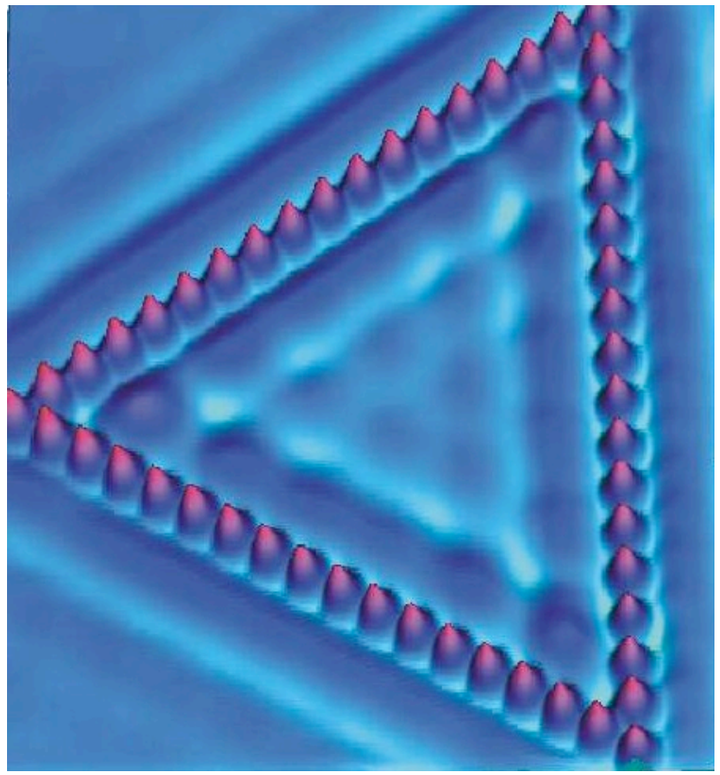
Takeuchi et al. *Submitted*

Scattering in traditional STM



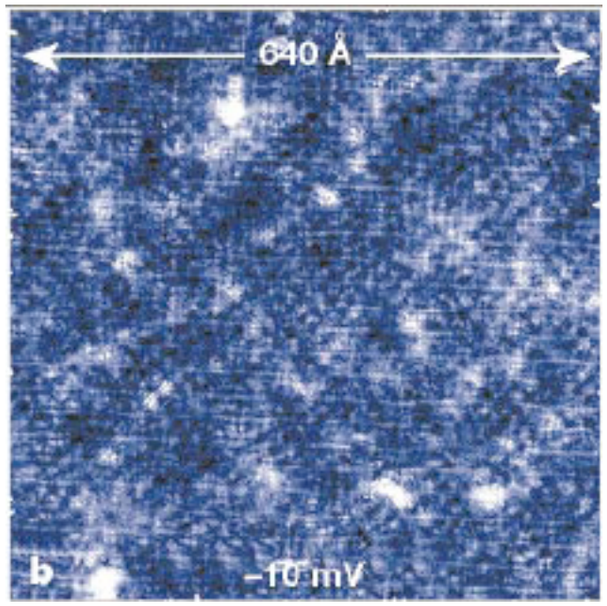
Cu on Cu(111)



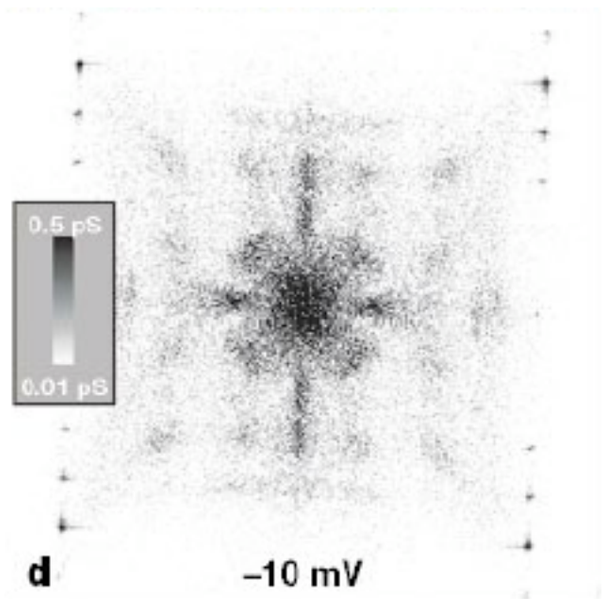
Ag on Ag(111)

SPECS website

FT STM



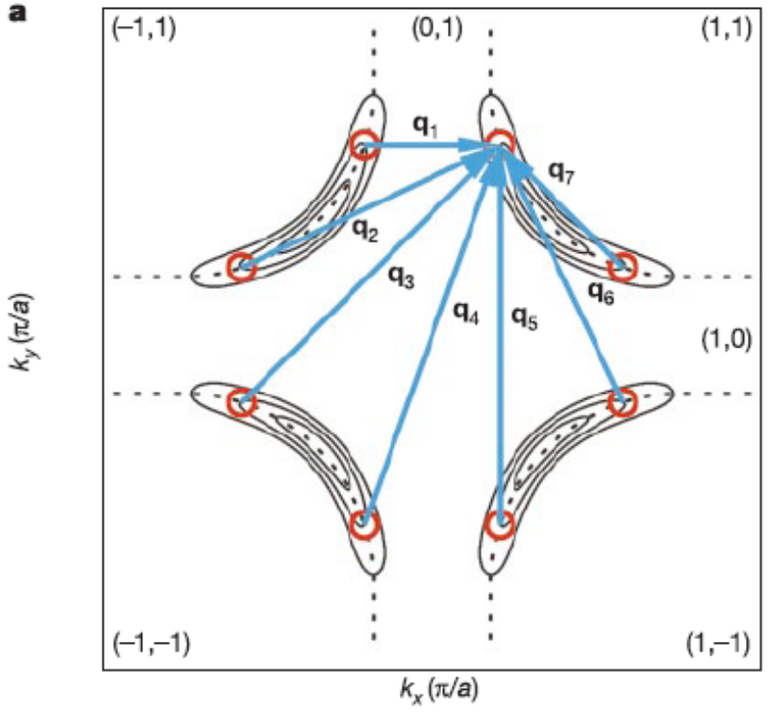
Fourier transform



J. E. Hoffman et al,
Science **295**, 466 (2002)

J. E. Hoffman et al,
Science **297**, 1148 (2002)

K. McElroy et al,
Nature **422**, 592 (2004)

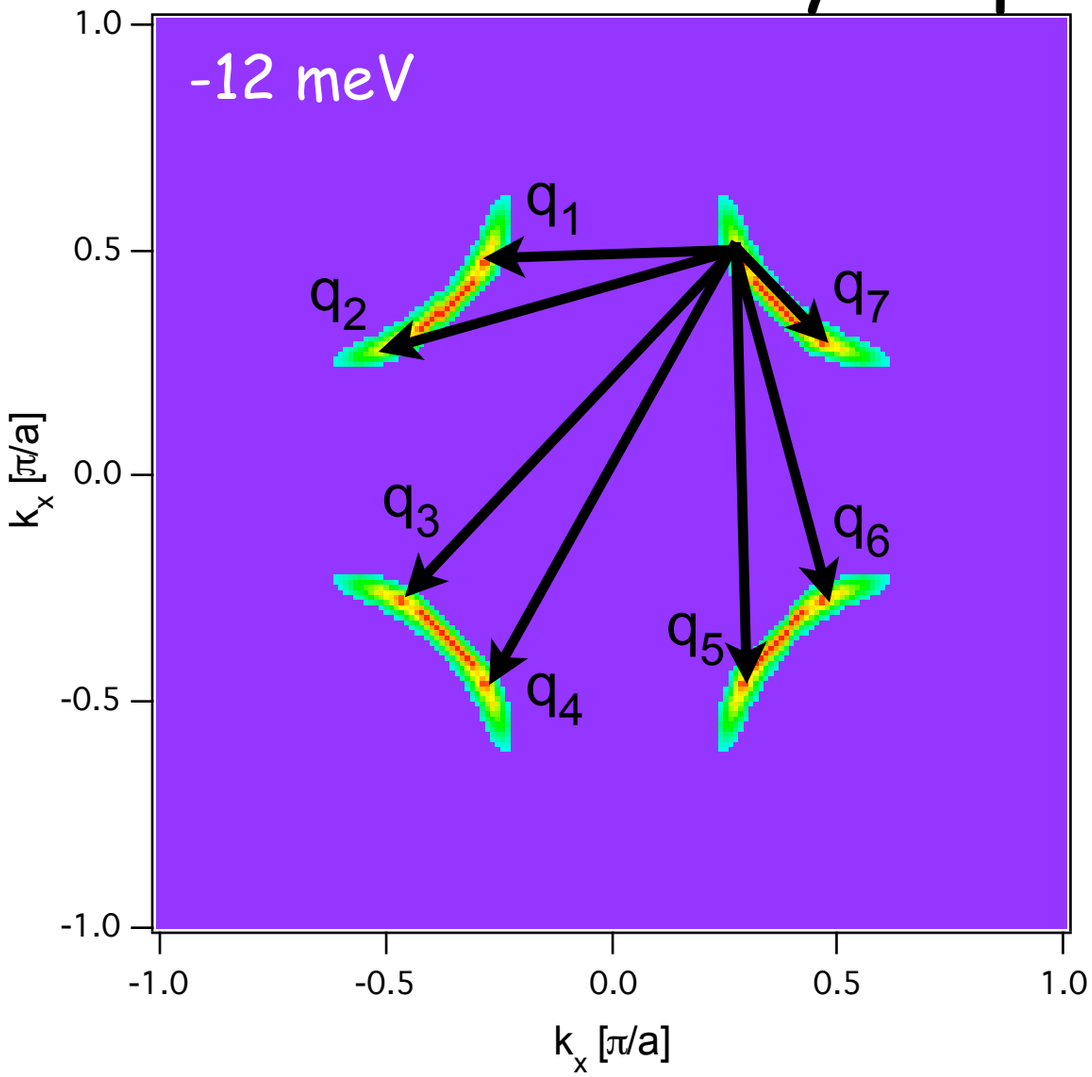


L. Capriotti et al,
PRB **68**, 014508 (2003)

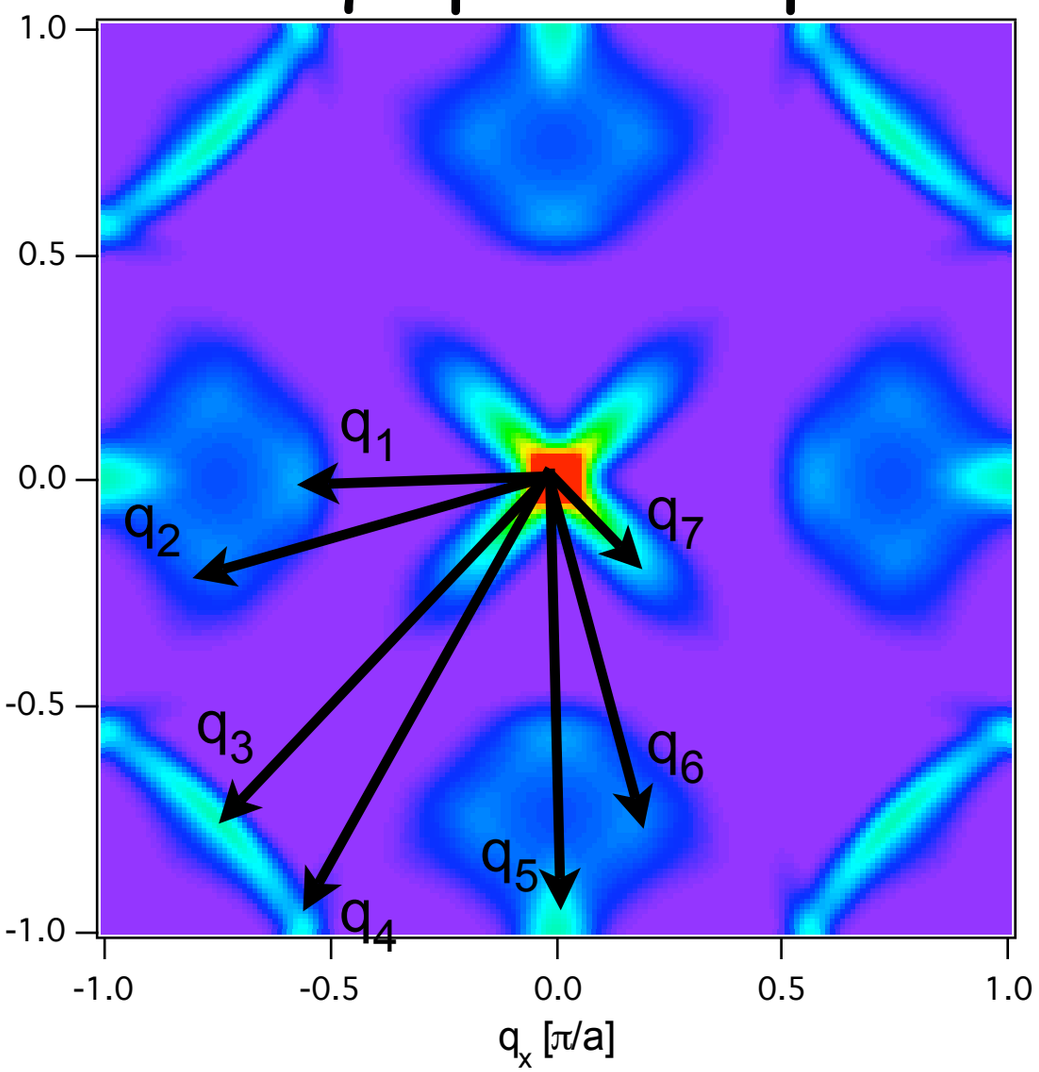
R. S. Markiewicz et al,
PRB **69**, 214517 (2004)

AutoCorrelated (AC) ARPES - ARPES data and q-space

ARPES intensity map

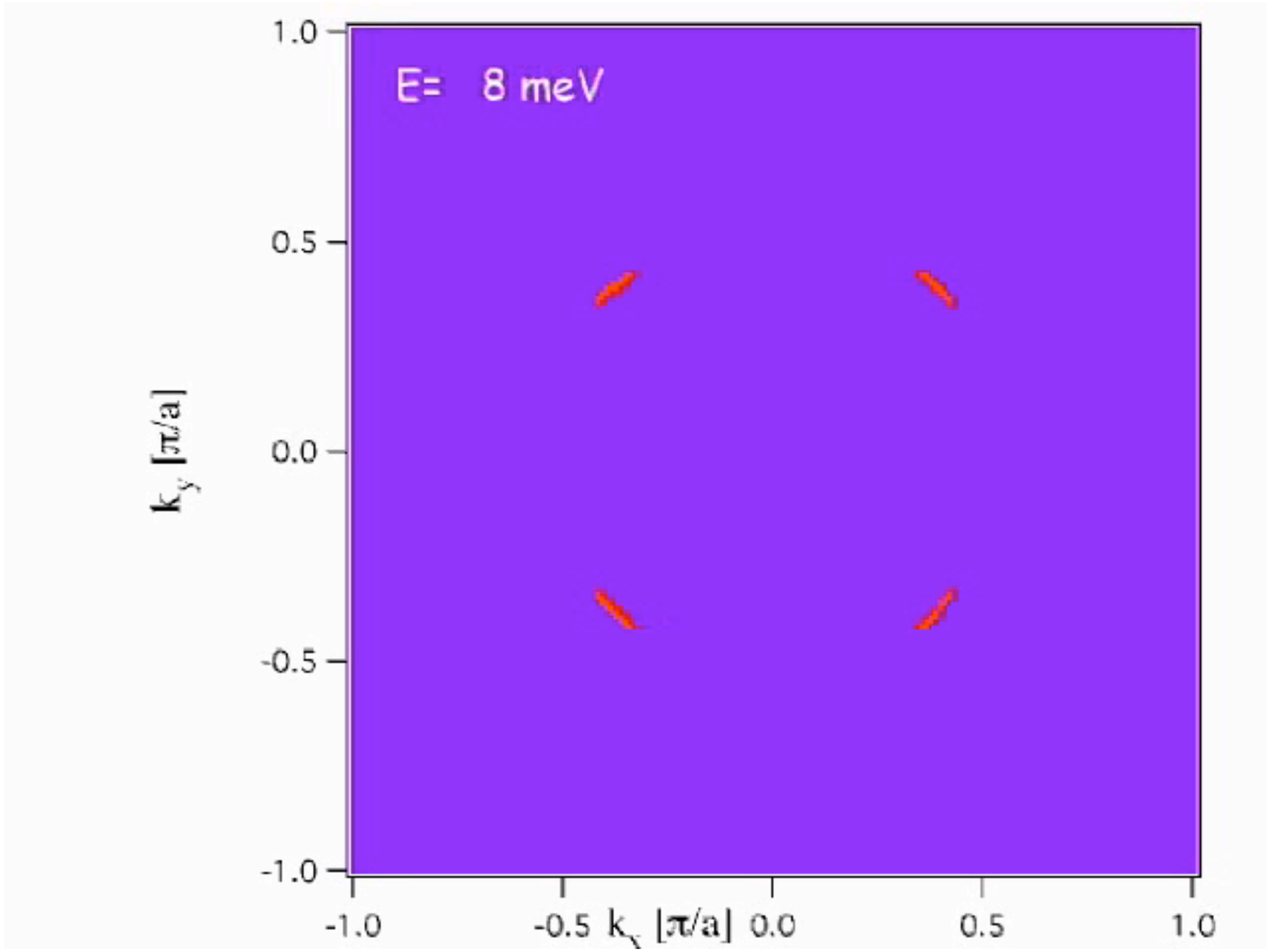


q-space map

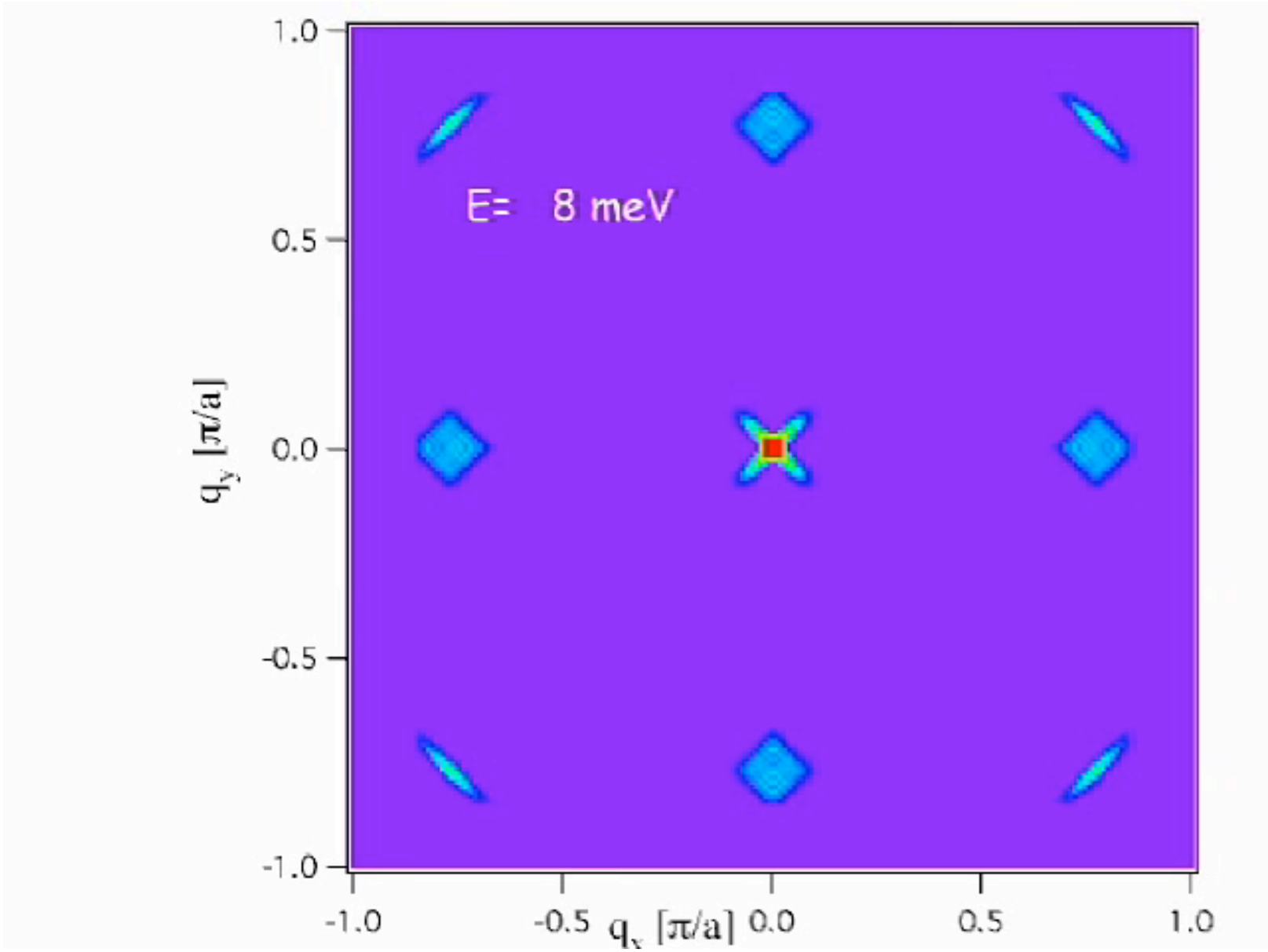


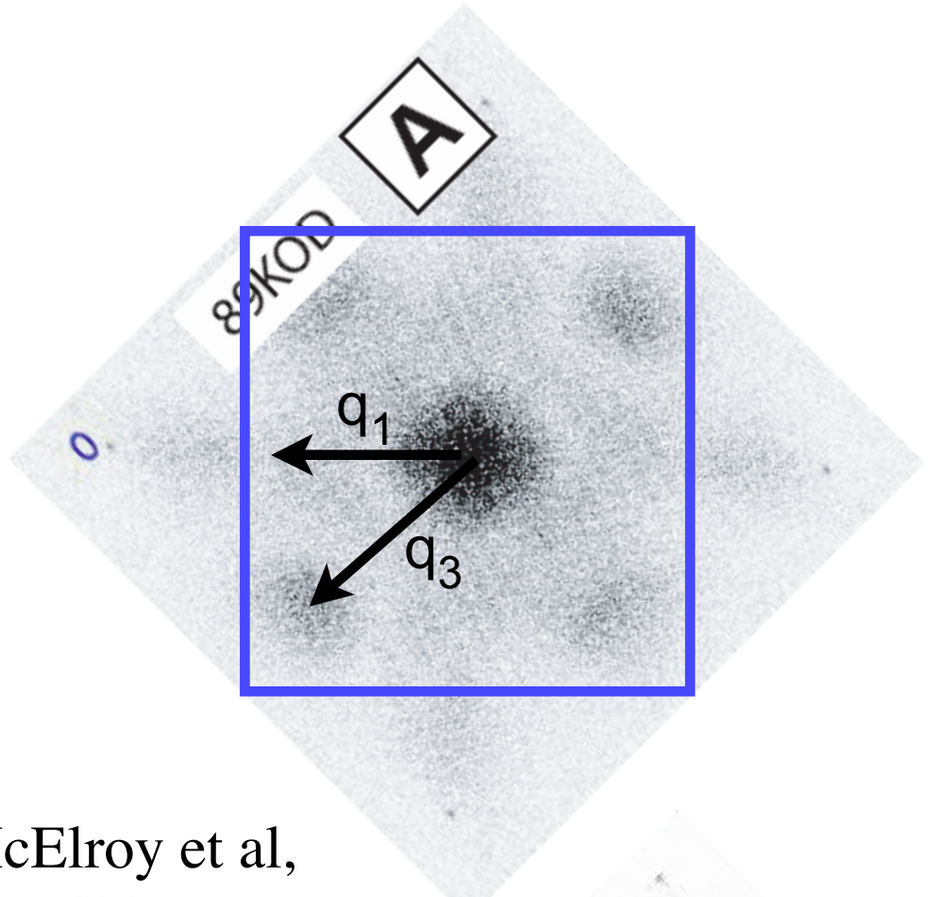
$$S(q,\omega=\omega_0)=\sum_{k_x,k_y} I(k,\omega)\; I(k+q,\omega)$$

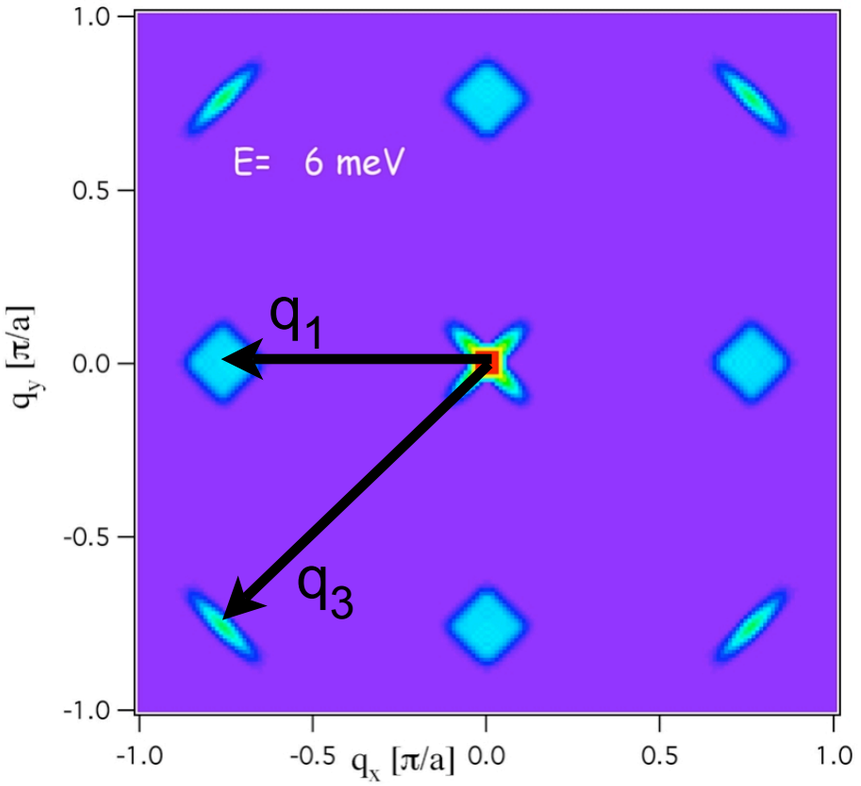
ARPES intensity maps



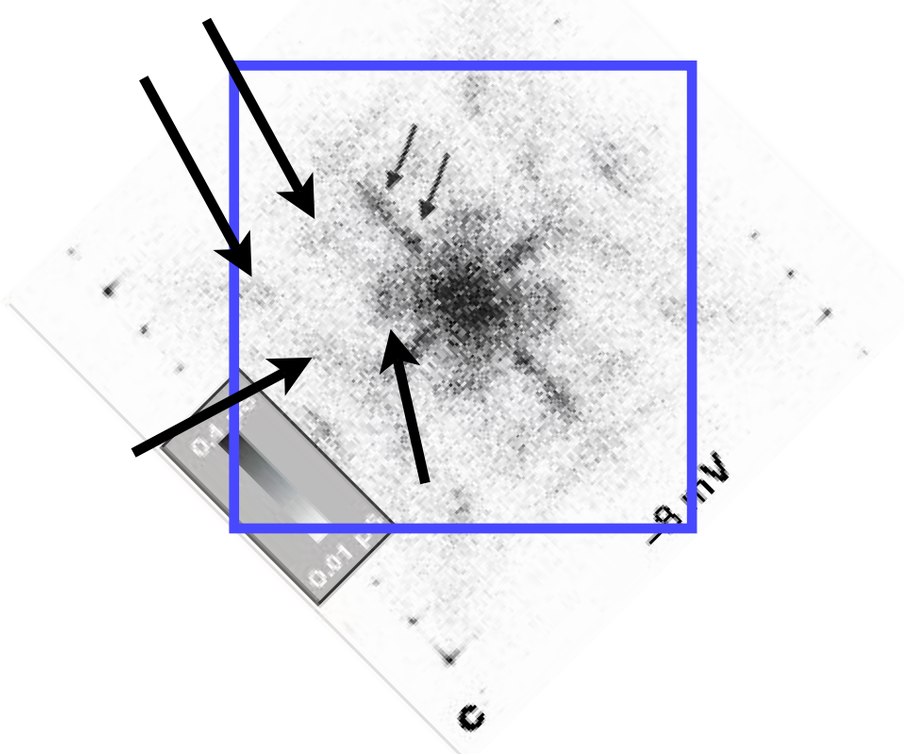
q-space

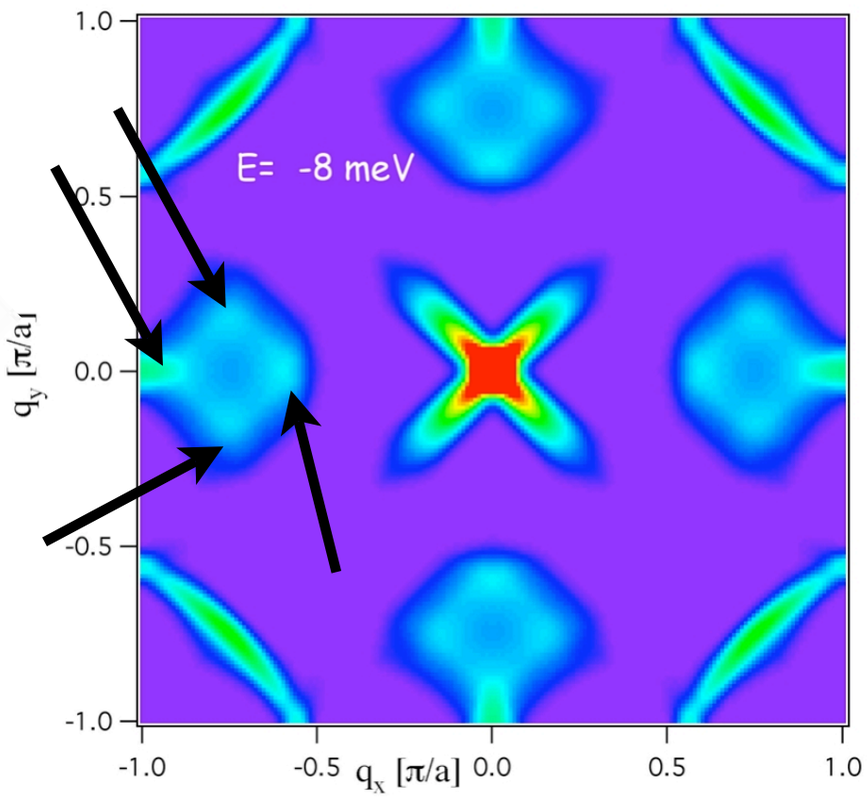






K. McElroy et al,
Nature **422**, 592 (2004)





Conclusions:

- all identified properties of the bosonic mode observed in ARPES are consistent with magnetic origin

- the topology of the Fermi surface changes from hole-like to electron-like on the overdoped side around Tc~65K in Bi2212

- a dimensional crossover from 2D to 3D electronic structure occurs within superconducting dome in single layer BSCO

- AutoCorrelated ARPES is a new tool to study scattering processes in solids