Фотоэмиссионный взгляд на низкоэнергетические электронные взаимодействия в сверхпроводящих купратах

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ARPES view of low energy electronic interactions in superconducting cuprates

Alexander Kordyuk

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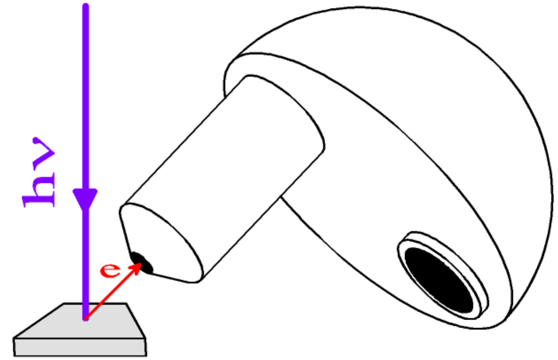
IMP Kiev, Ukraine

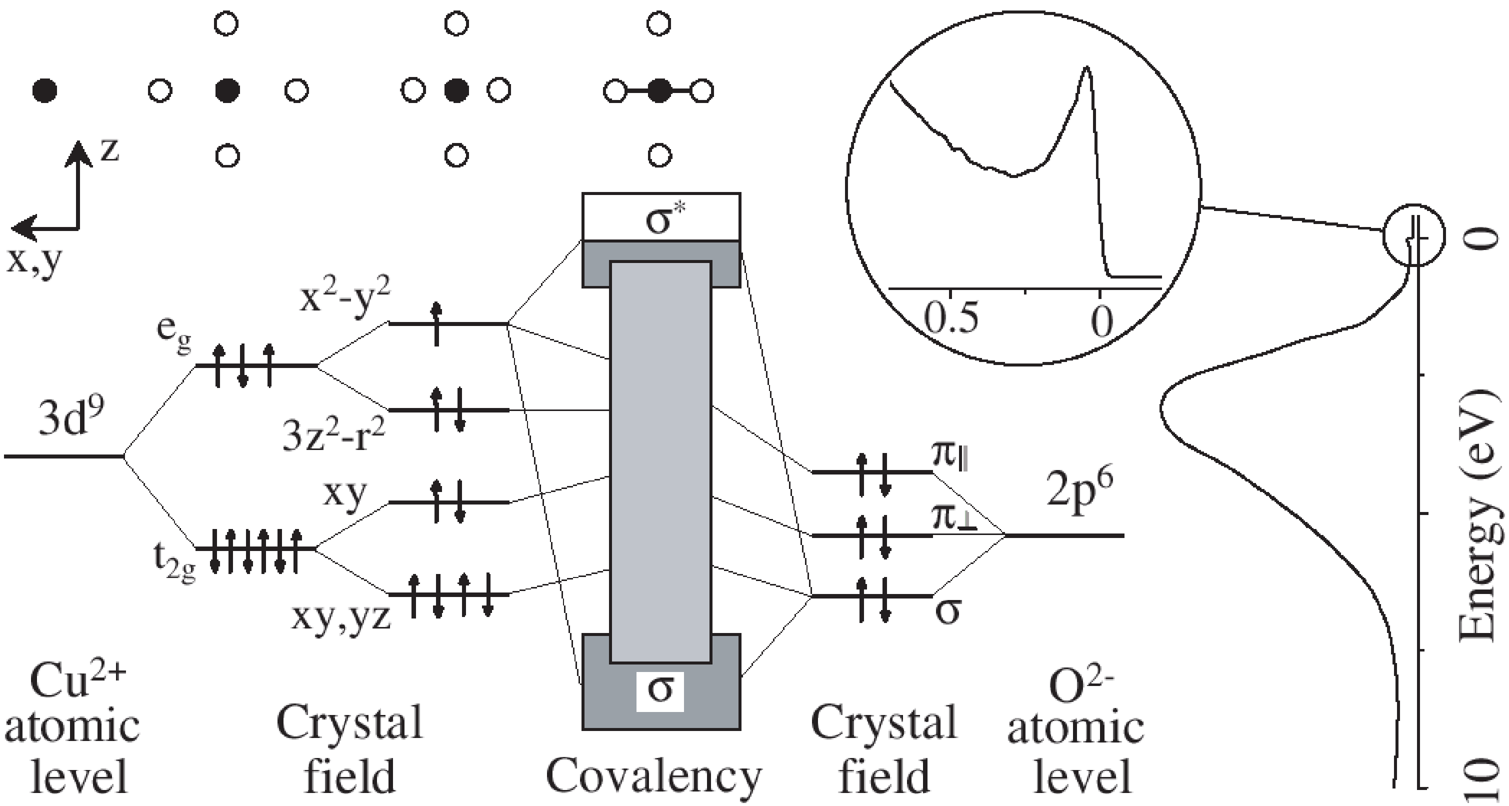
Navigation

Introduction to ARPES

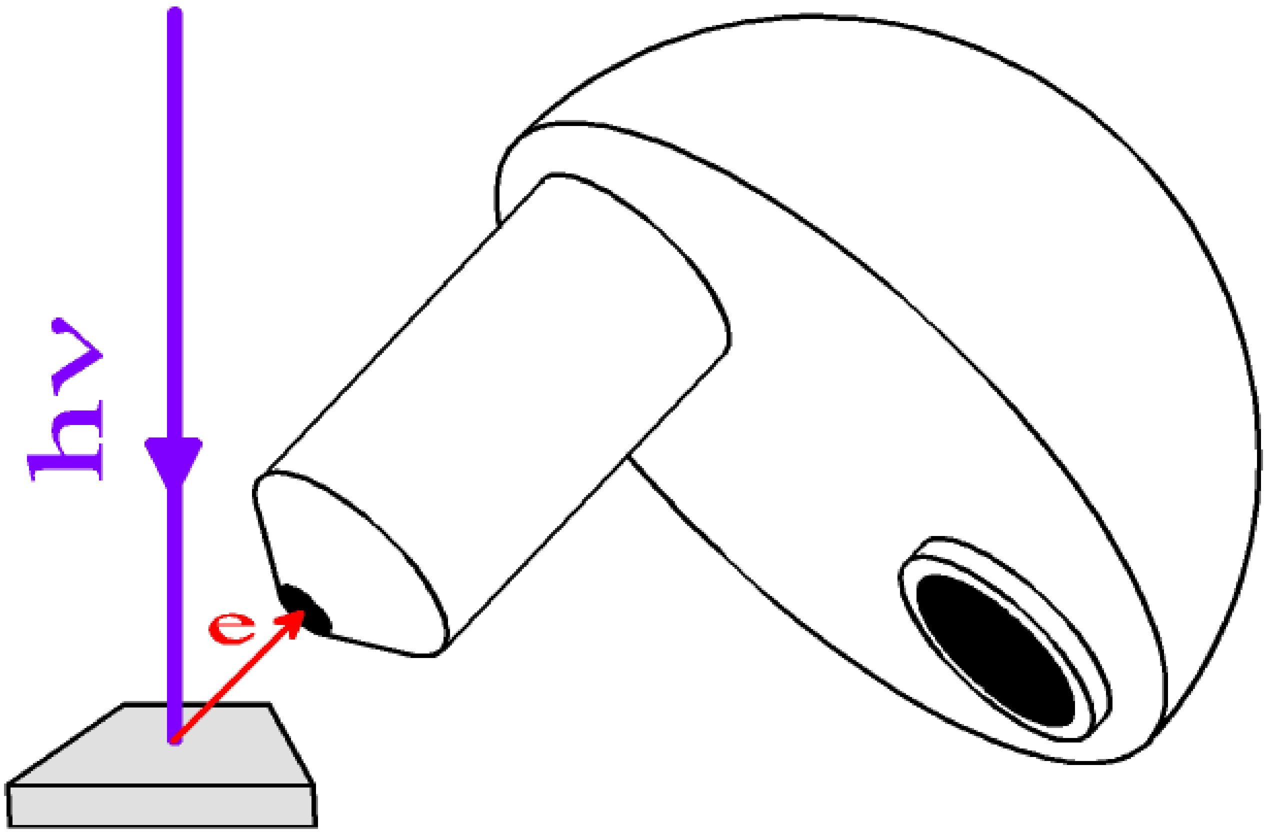
the most direct tool to explore the momentum-energy space of the electrons in solids

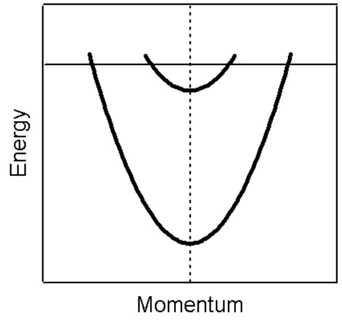
Photoemission Spectrum

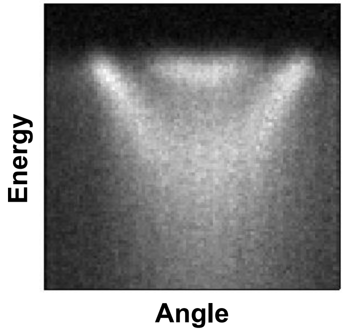




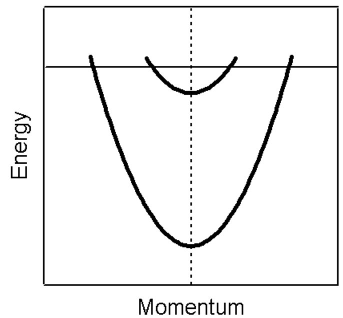
Angle-Resolved Photoemission (ARPES)

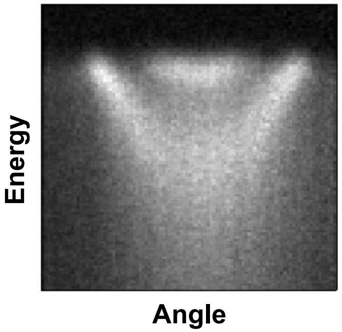


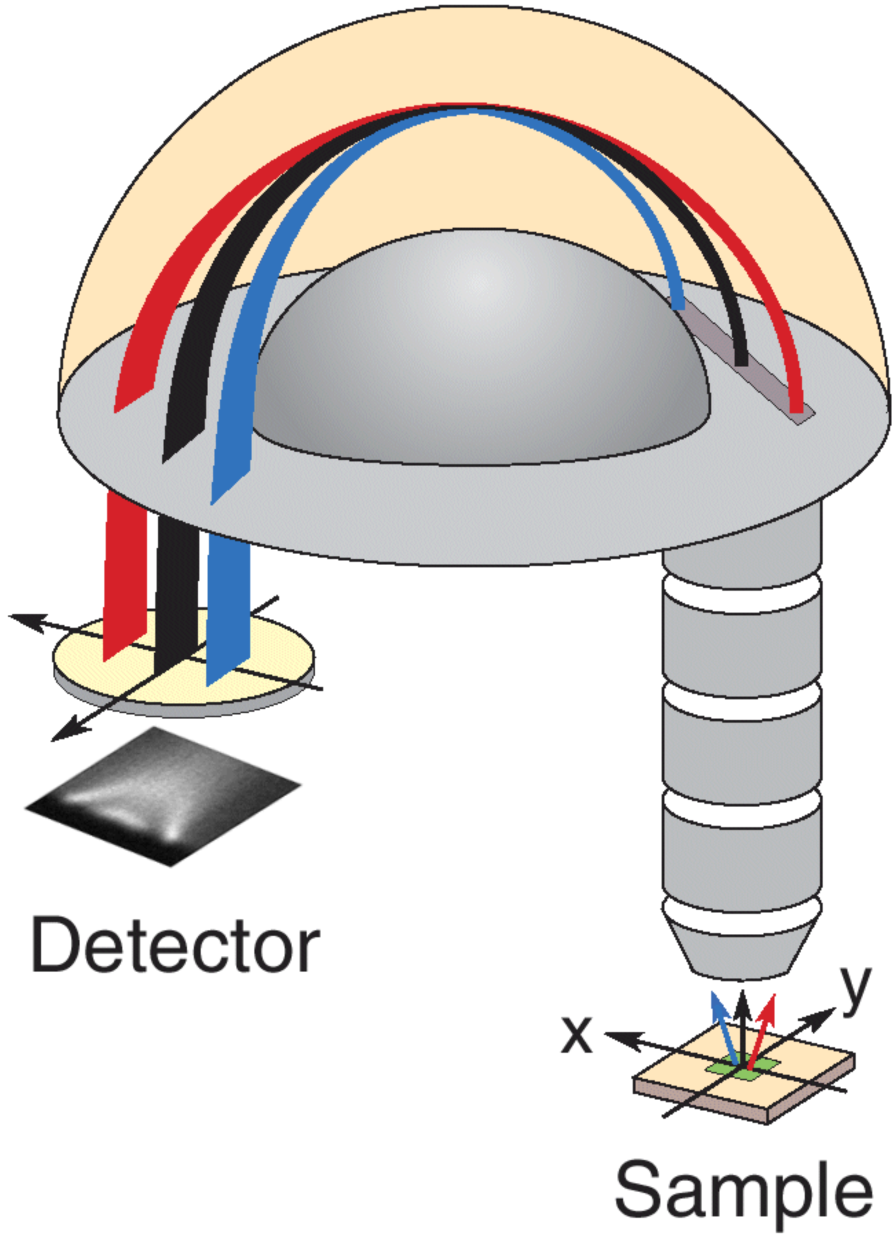




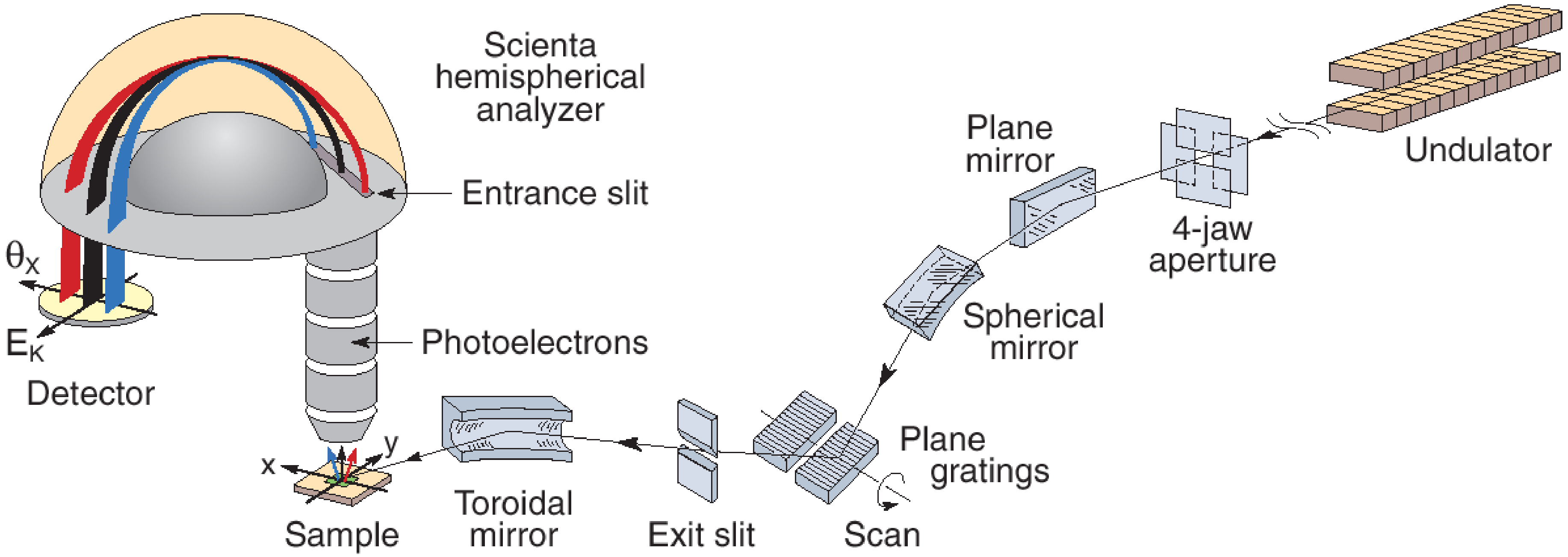
Angle Resolved Analyser





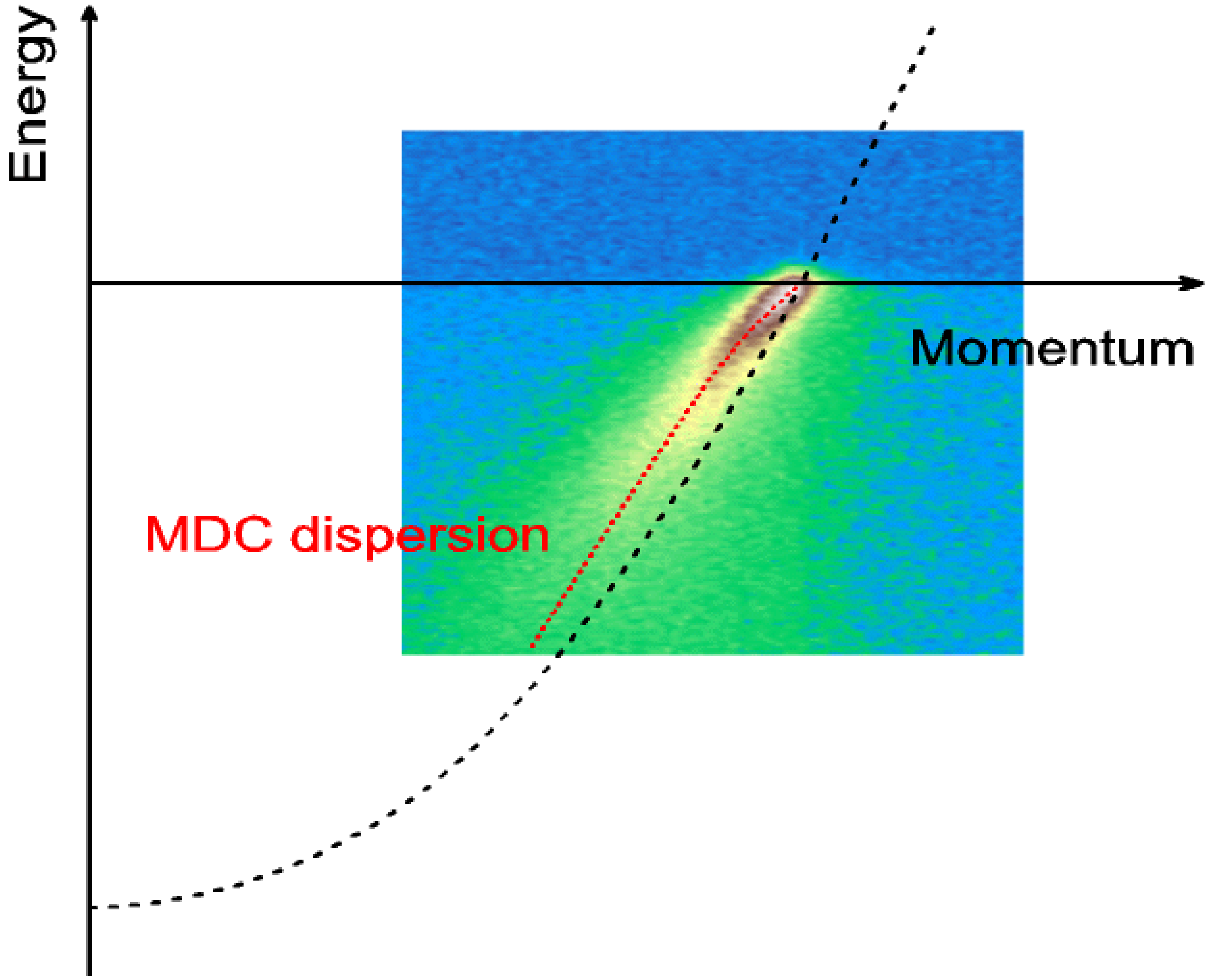


ARPES with Synchrotron Light



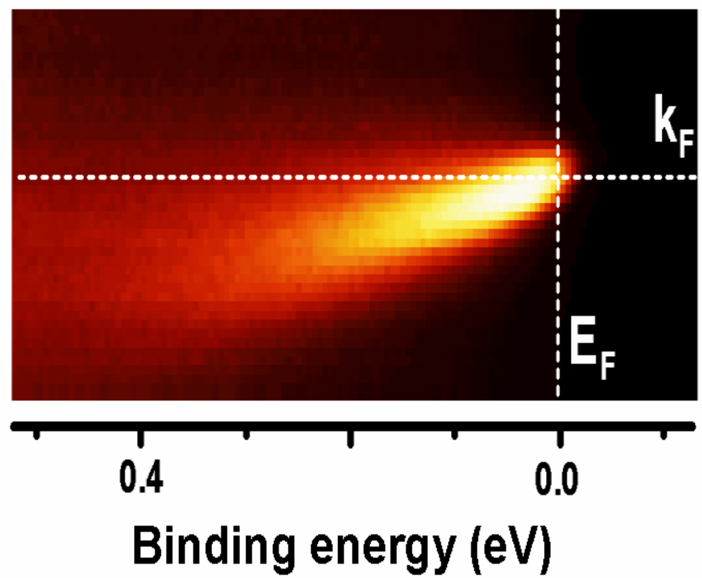
Damascelli *RMP* 2003

Basics: electron dispersion

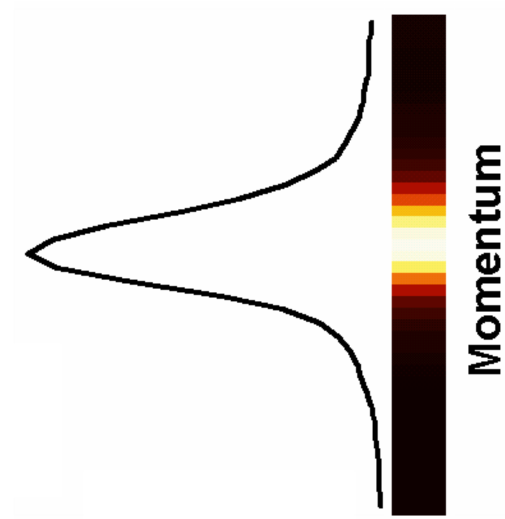


$$A(\mathbf{k},\omega)$$

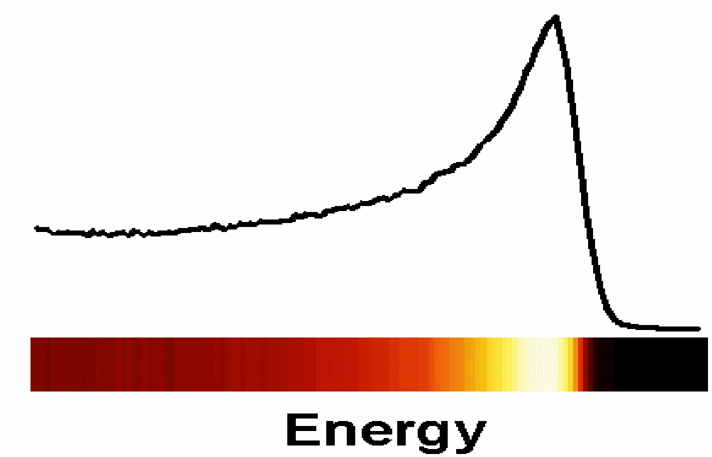
$I(k,\omega)$ - Energy Distribution Map



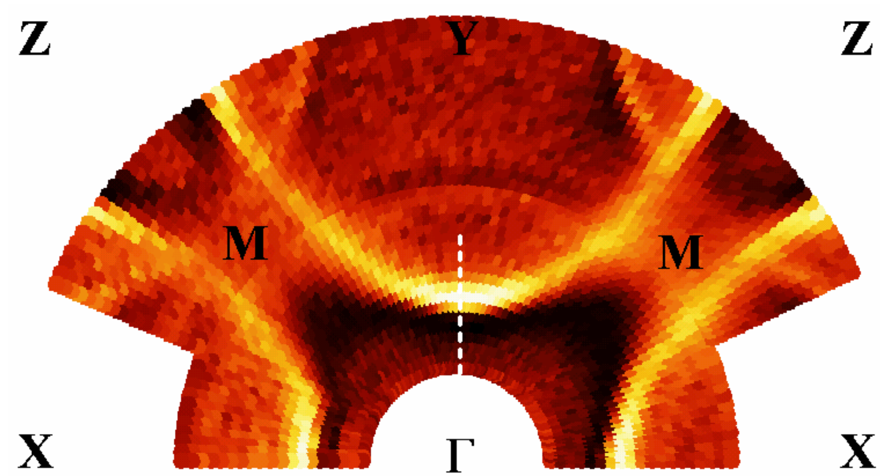
$I(k,\omega)$ - Momentum Distribution Curve



$I(k,\omega)$ - Energy Distribution Curve

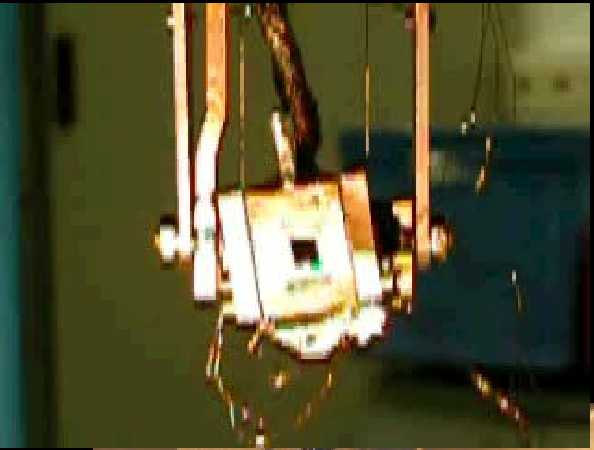


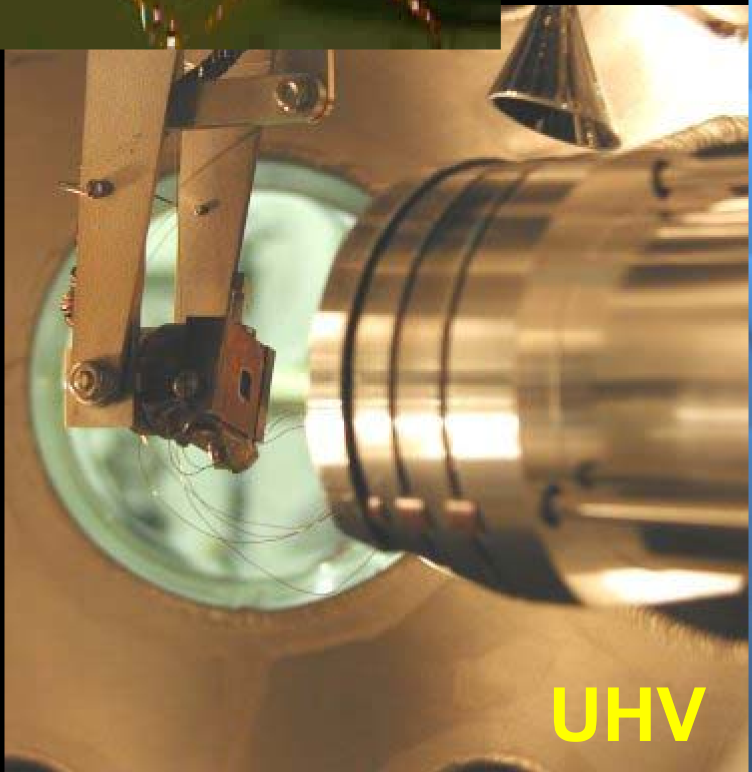
$I(k_x,k_y,\omega)$ - Momentum Distribution Map

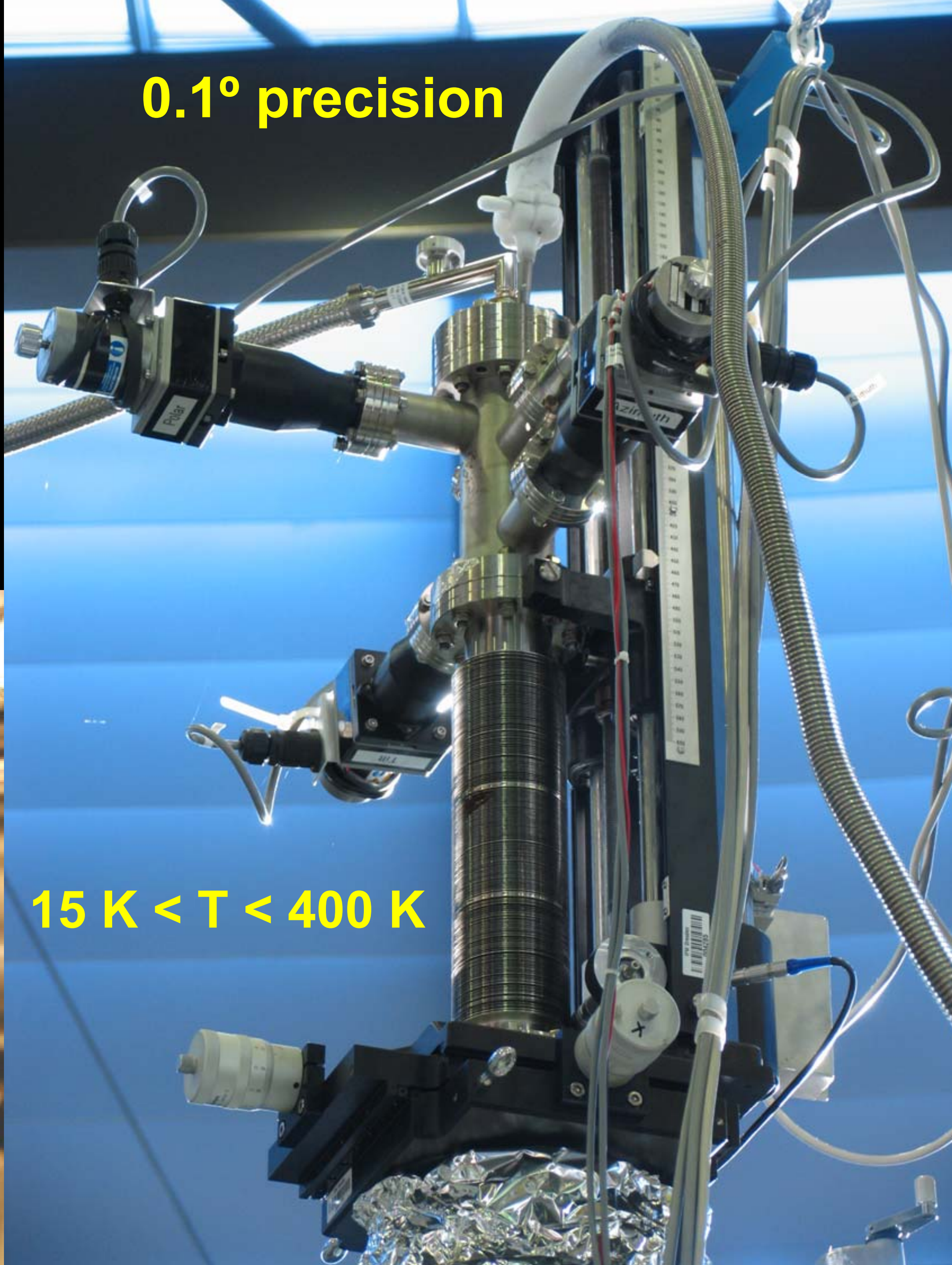


Borisenko *PRB* 2001

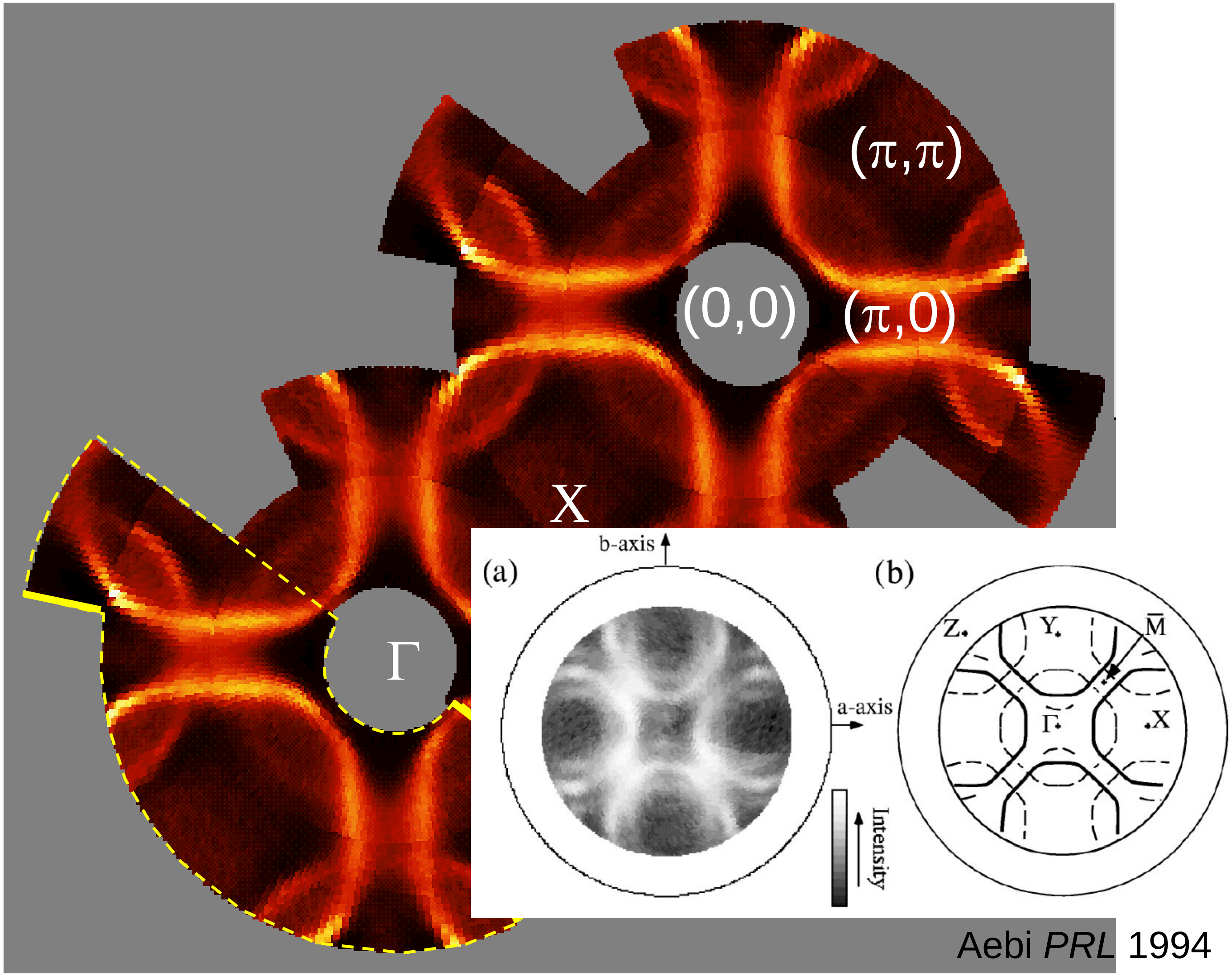
Precise Cryo-Manipulator





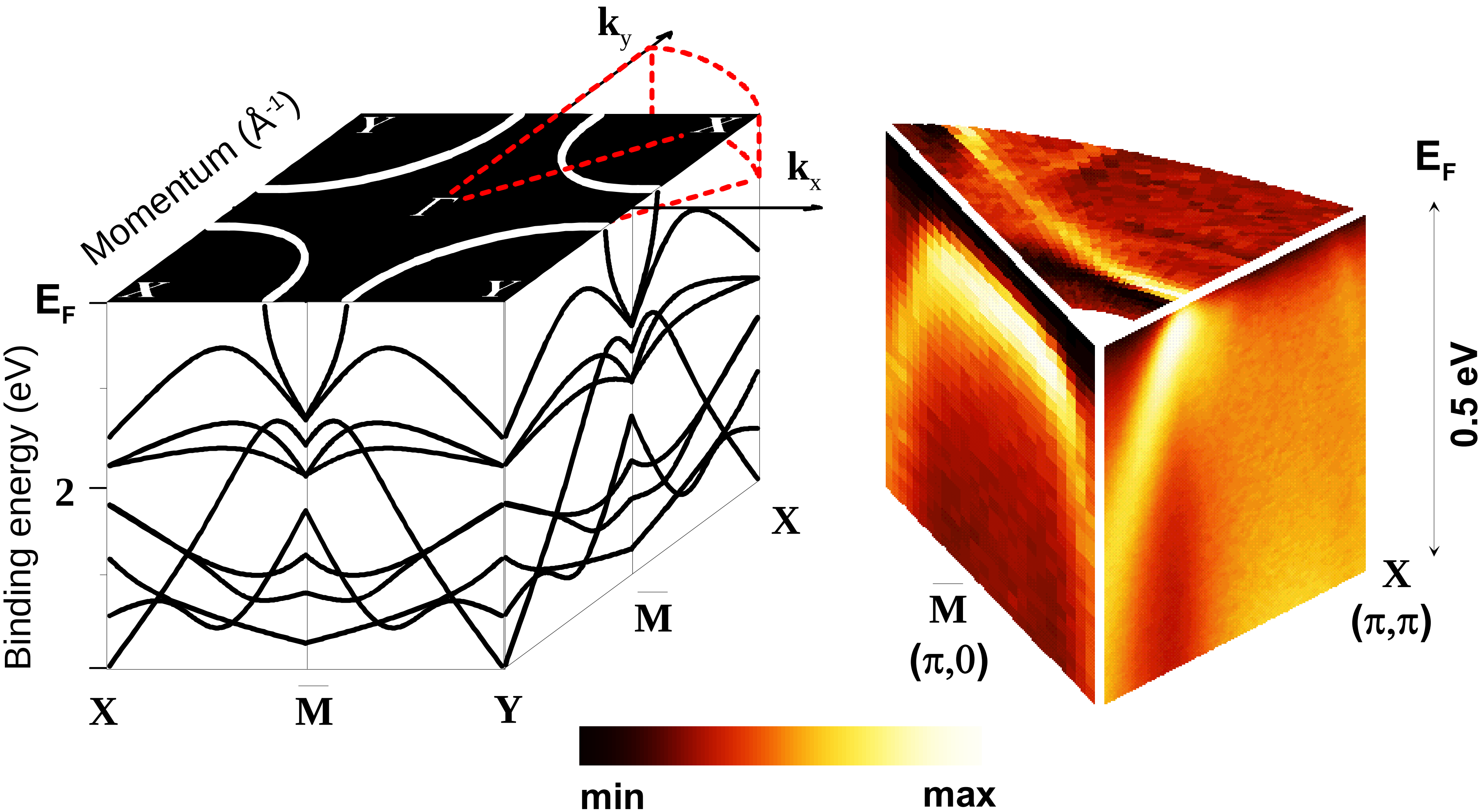


Fermi-surface map



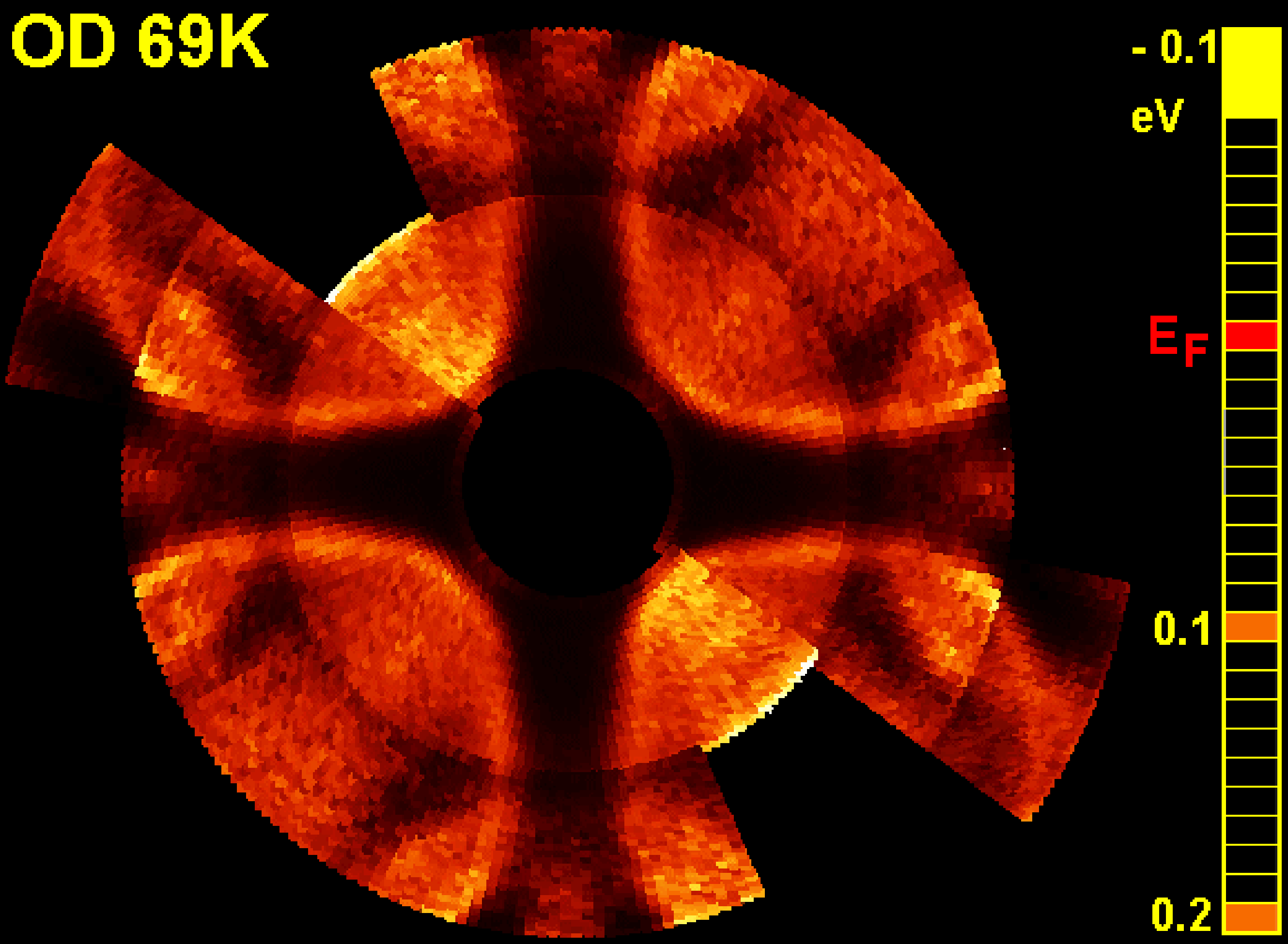
Aebi *PRL* 1994

Momentum-energy space



Borisenko *PRB* 2001

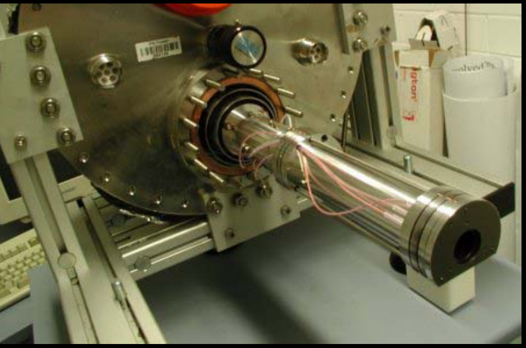
Momentum Distribution Map



300 K, 21.2 eV

Kordyuk 2000

Momentum-energy space explorer today



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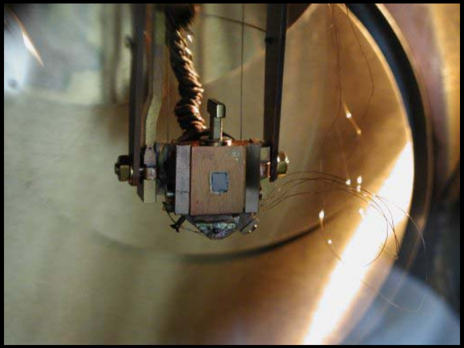

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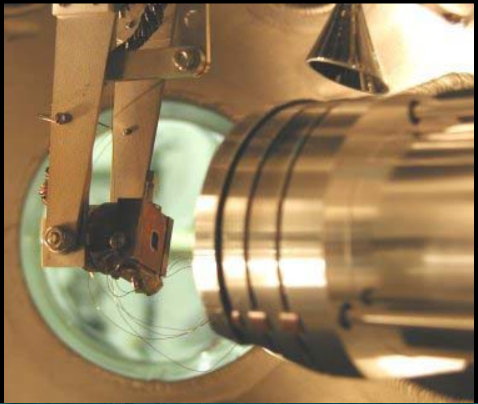

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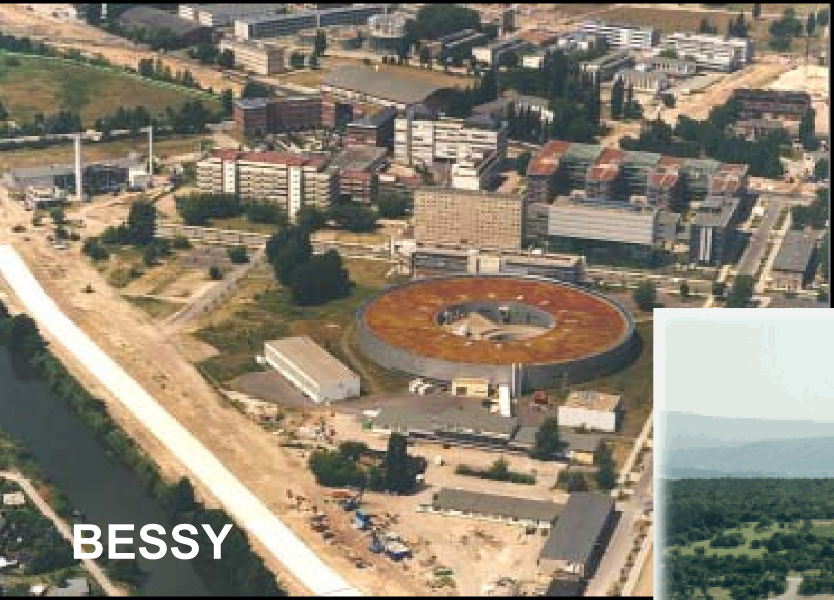
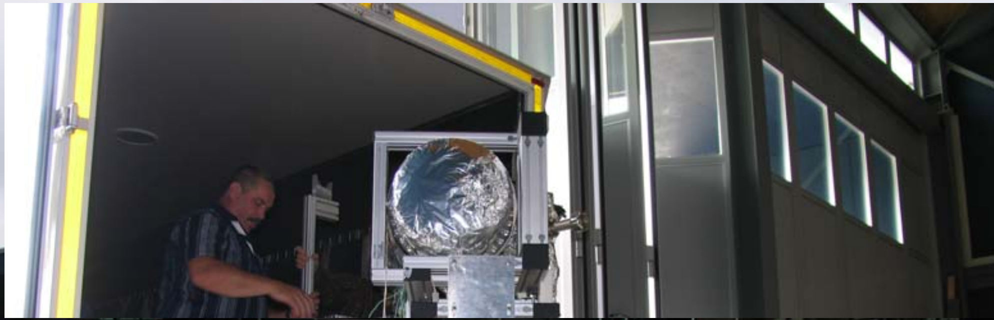
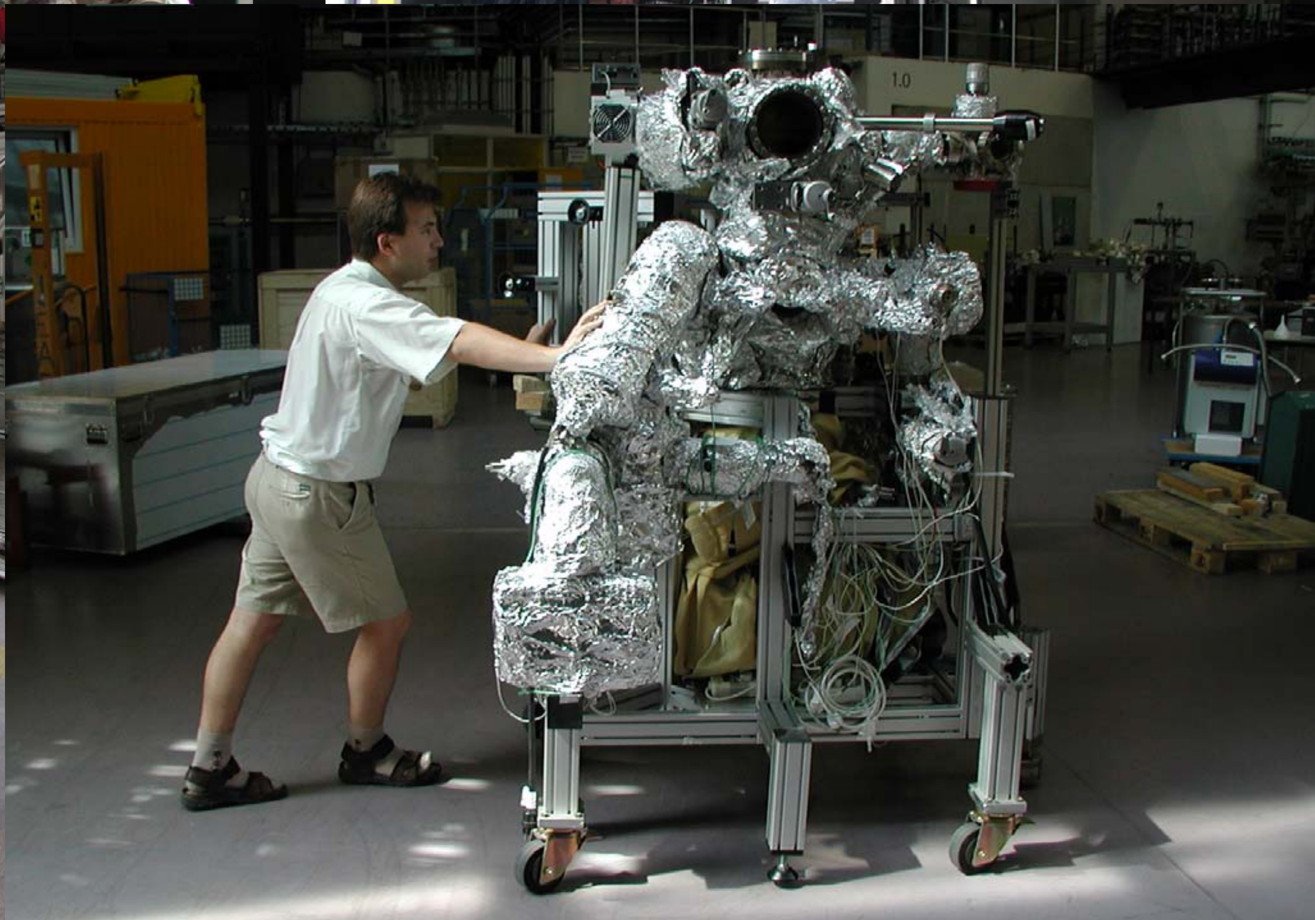


$h\nu$

more synchrotrons

...travelling chamber





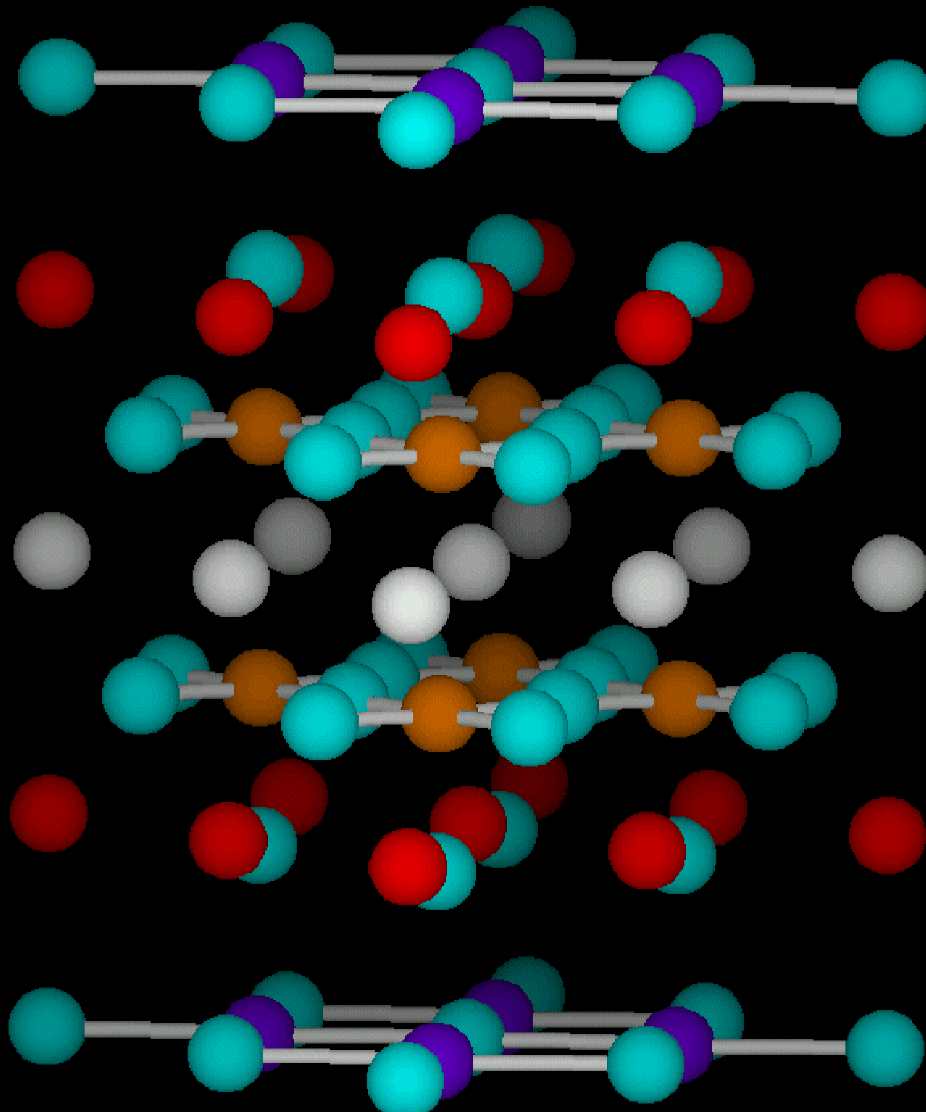
The advantages of our group

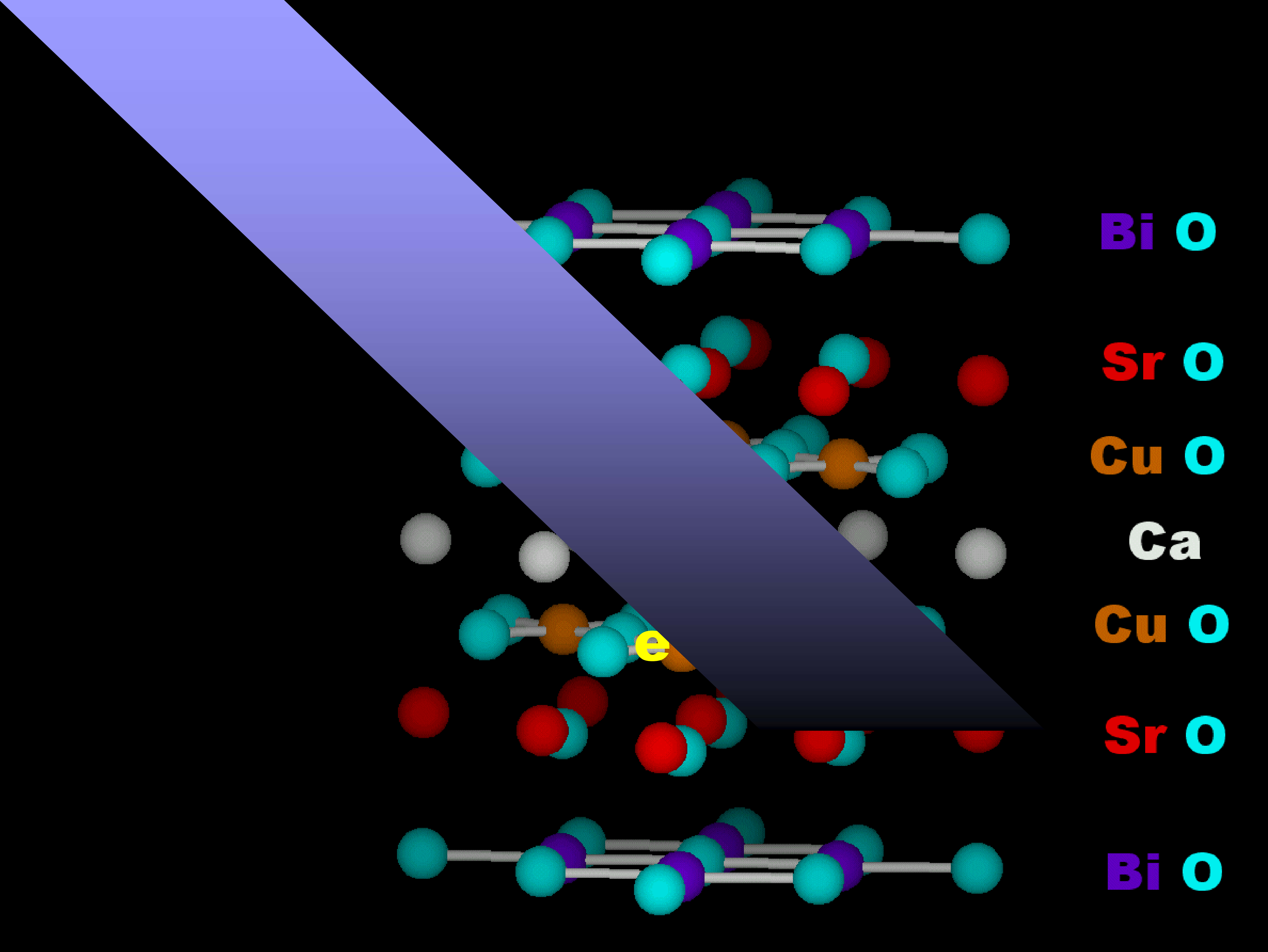
why Bi(Pb)-2212 is the best of the cuprates to be explored by ARPES

$Bi_2Sr_2CaCu_2O_{8+\delta}$

BSCCO

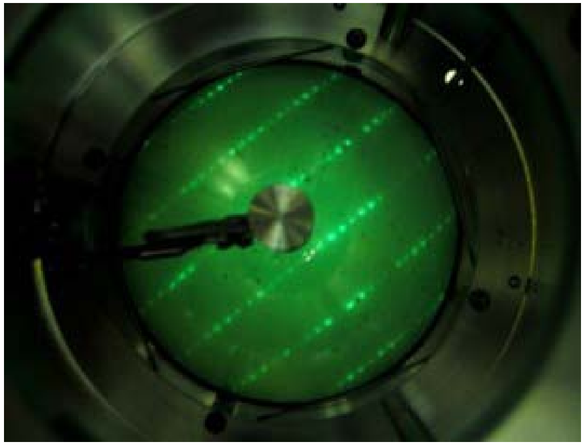
Bi-2212



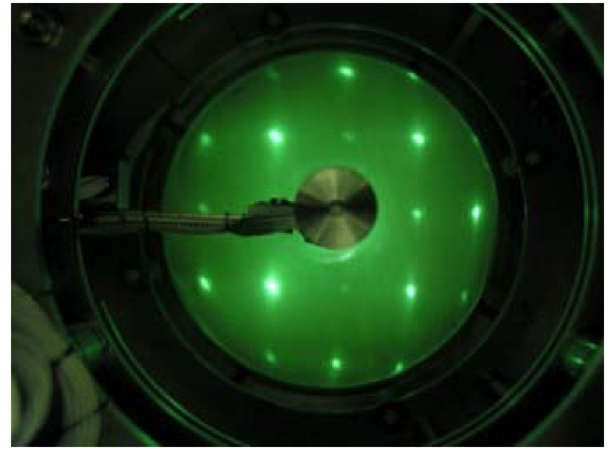


Bi O
Sr O
Cu O
Ca
Cu O
e
Sr O
Bi O

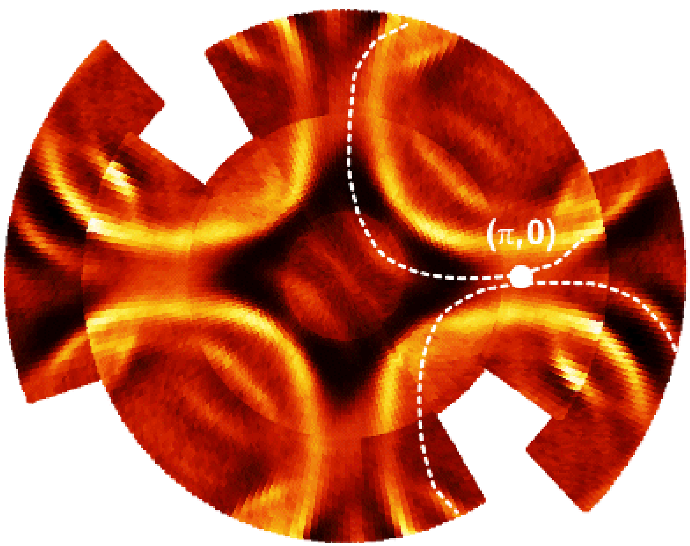
Pb or not Pb?

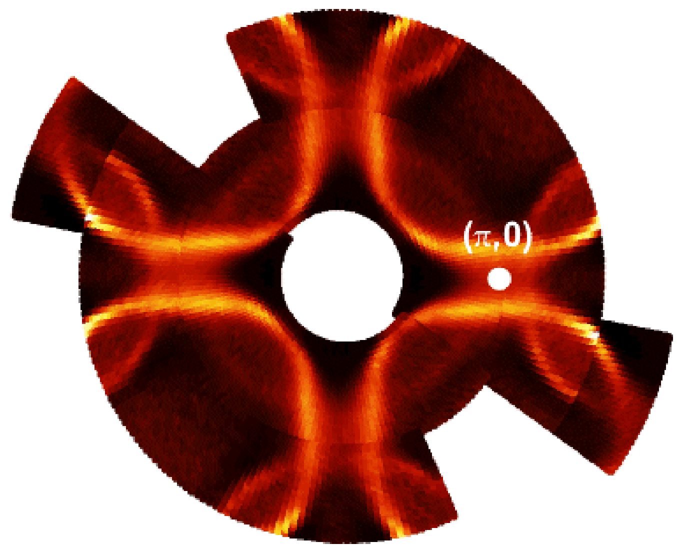


Bi2212



Pb-Bi2212

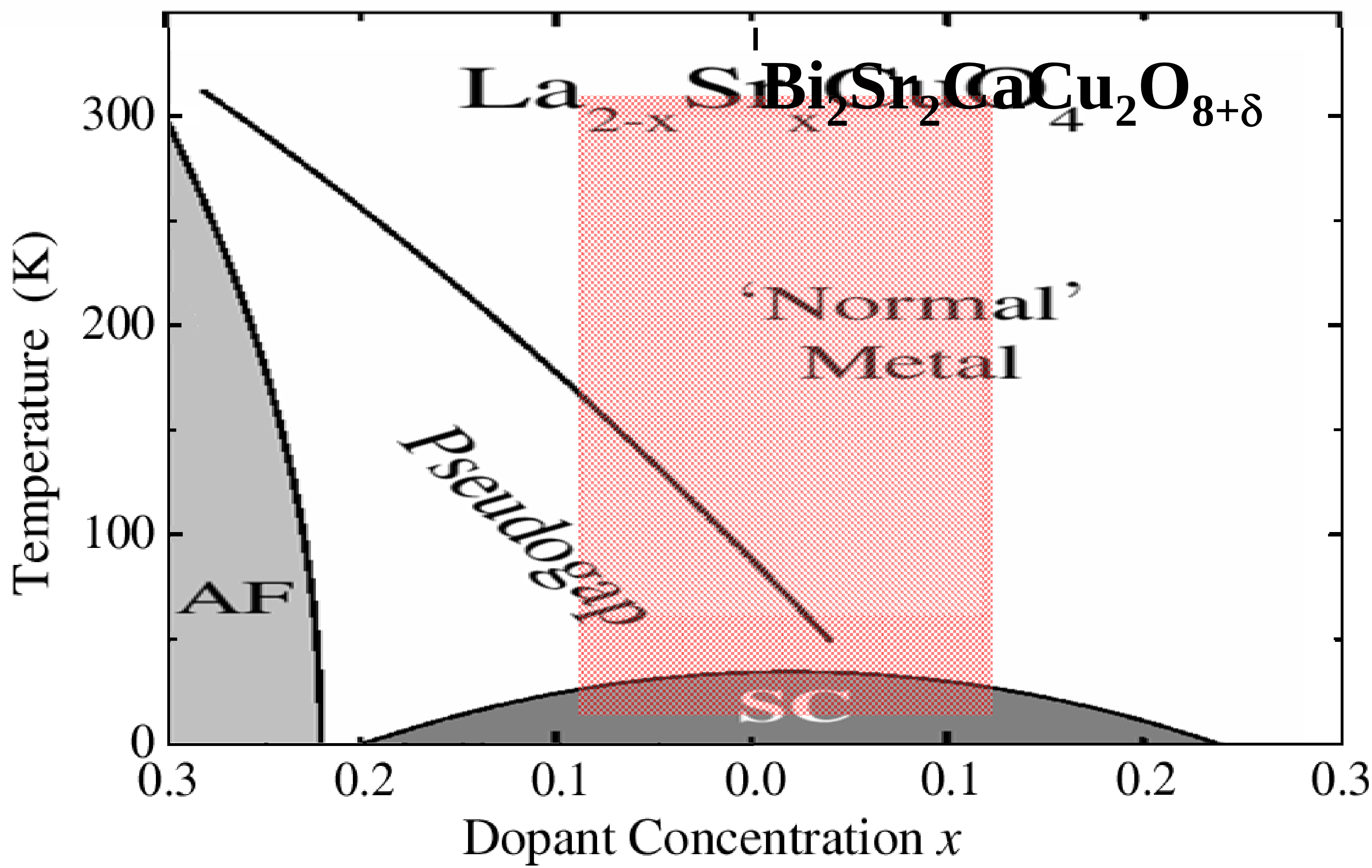




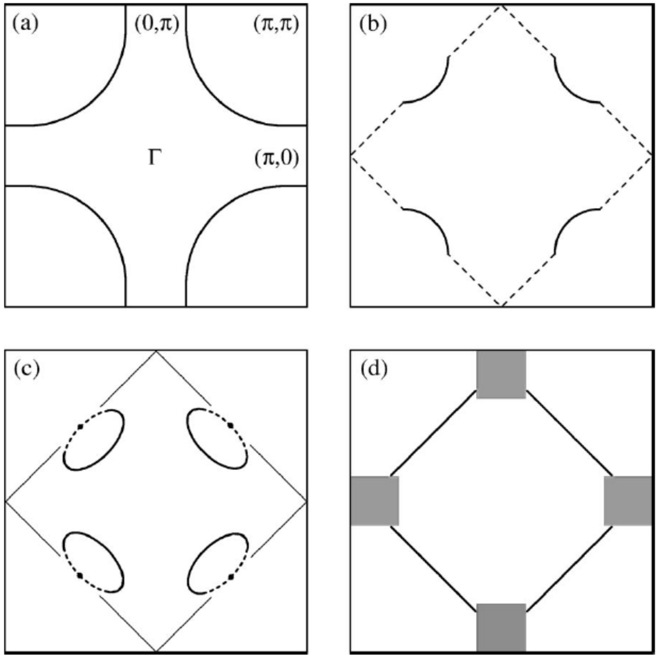
Introduction to HTSC physics

what ARPES said, what people believed it had been saying, and what we believe it is saying today

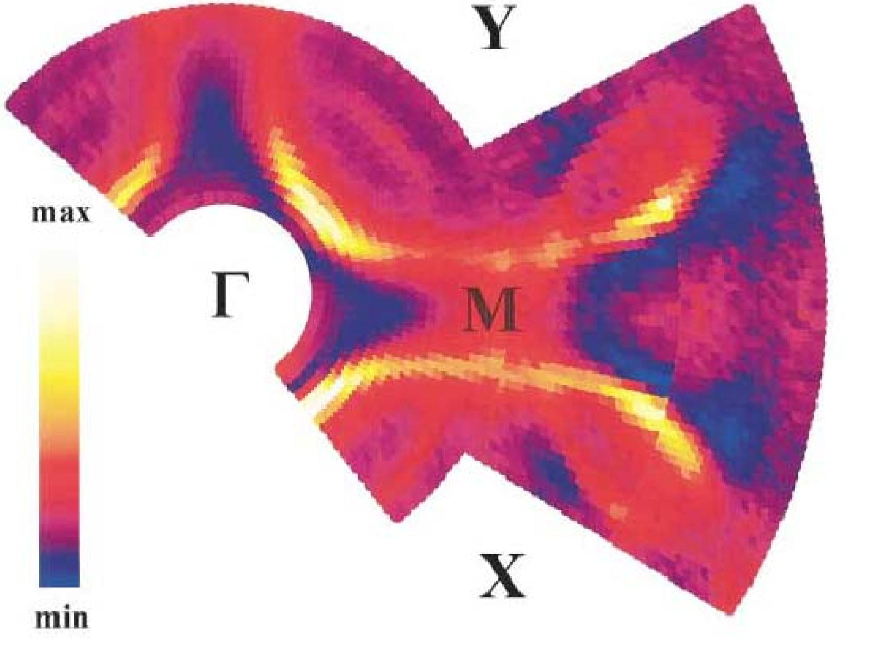
„Generic“ phase diagram of cuprates



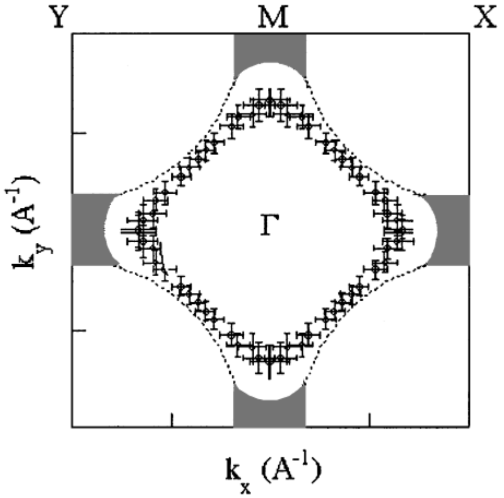
Fermi surface



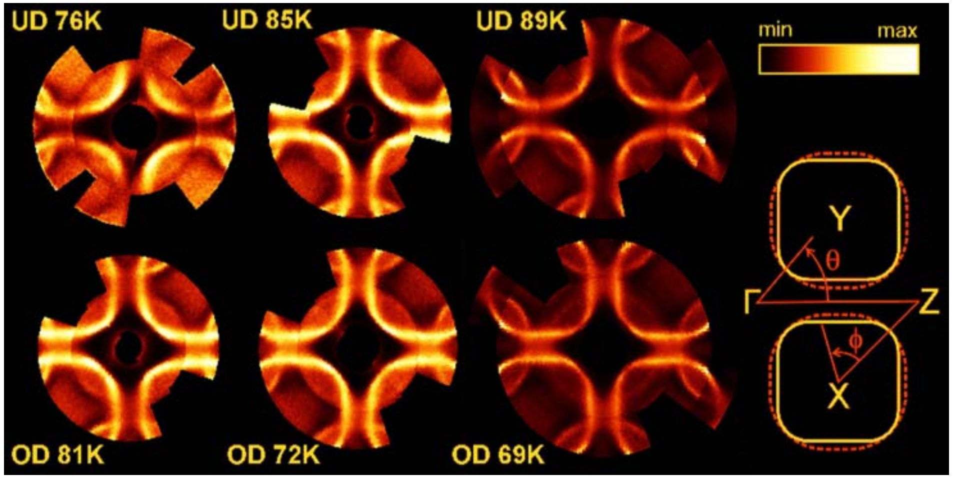
Damascelli *RMP* 2003



Borisenko *PRL* 2000



Bogdanov *PRL* 2000



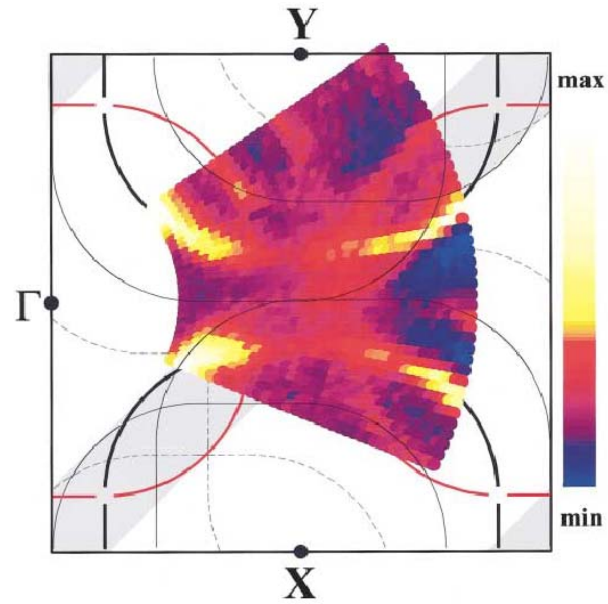
Kordyuk *PRB* 2002

Fermi surface:

Nature of the Shadow Band (SB)

Stripes

...



Borisenko *PRL* 2000

Peak-Dip-Hump

Unusual Dispersion and Line Shape of the Superconducting State Spectra of $Bi_2Sr_2CaCu_2O_{8+\delta}$

M. R. Norman,[1] H. Ding,[1,2] J. C. Campuzano,[1,2] T. Takeuchi,[1,3] M. Randeria,[4] T. Yokoya,[5] T. Takahashi,[5] T. Mochiku,[6] and K. Kadowaki[6,7]

[1]*Materials Sciences Division, Argonne National Laboratory, Argonne, Illinois 60439*

[2]*Department of Physics, University of Illinois at Chicago, Chicago, Illinois 60607*

[3]*Department of Crystalline Materials Scienc*

[4]*Tata Institute of Fundamental*

[5]*Department of Physics, Tohok*

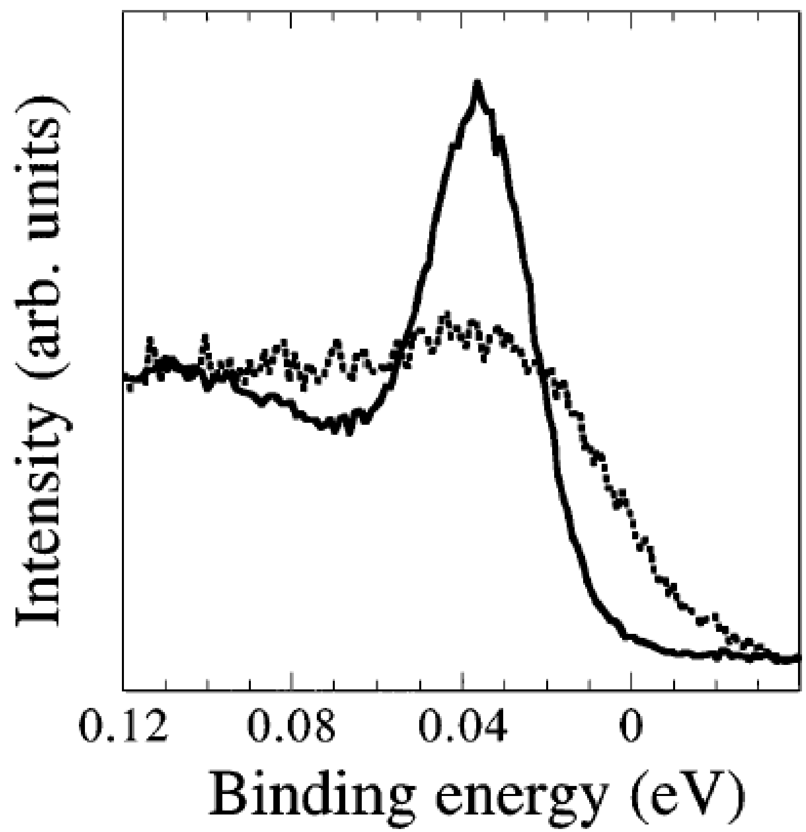
[6]*National Research Institute for Metai*

[7]*Institute of Materials Science, Univ*

(Received 18

Photoemission spectra of $Bi_2Sr_2CaCu_2O_{8+\delta}$ b of the zone: a sharp peak at low energy and a sharp peak persists at low energy even as one n significant dispersion which correlates well with features are naturally explained by the interaction below T_c, and speculate that the latter may be re [S0031-9007(97)04393-7]

PACS numbers: 74.25.Jb, 74.72.Hs, 79.60.Bm



Angle-resolved photoemission data on the quasi-two-dimensional high temperature superconductors can be interpreted in terms of the one-electron spectral function [1]. This implies that important information about the self-energy Σ, and how it changes from the normal to the superconducting (SC) state, can be obtained by analysis of the angle-resolved photoemission spectroscopy (ARPES)

Electronic Excitations in $Bi_2Sr_2CaCu_2O_8$: Fermi Surface, Dispersion, and Absence of Bilayer Splitting

H. Ding,[1,2] A. F. Bellman,[1,3] J. C. Campuzano,[1,2] M. Randeria,[1] M. R. Norman,[1] T. Yokoya,[4] T. Takahashi,[4]
H. Katayama-Yoshida,[4] T. Mochiku,[5] K. Kadowaki,[5] G. Jennings,[1] and G. P. Brivio[3]
[1]*Materials Sciences Division, Argonne National Laboratory, Argonne, Illinois 60439*
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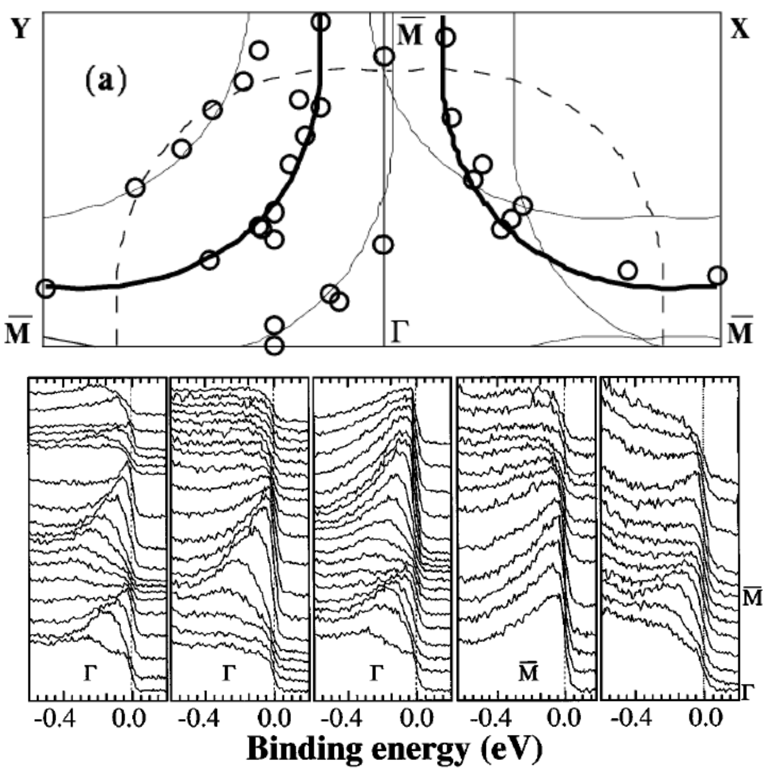
[3]*Dipartimento di Fisica, Universita di Milano, 20133 Milano, Italy*
[4]*Department of Physics, Tohoku University, 98*
[5]*National Research Institute for Metals, Sengen, Tsuk*



eceived 5 July 1995)

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ke band theory, the line
argue that the "dip feat
nany-body effects.

9.60.Bm

many explanation
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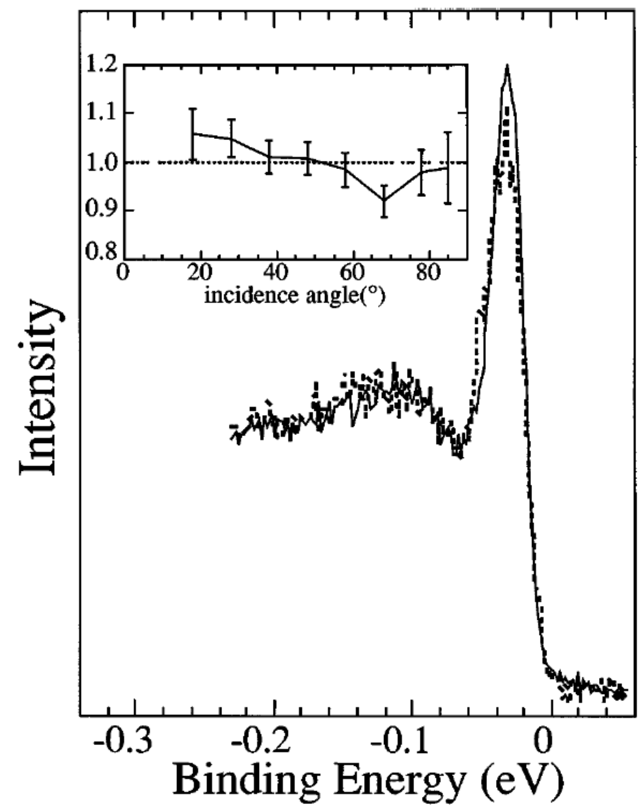
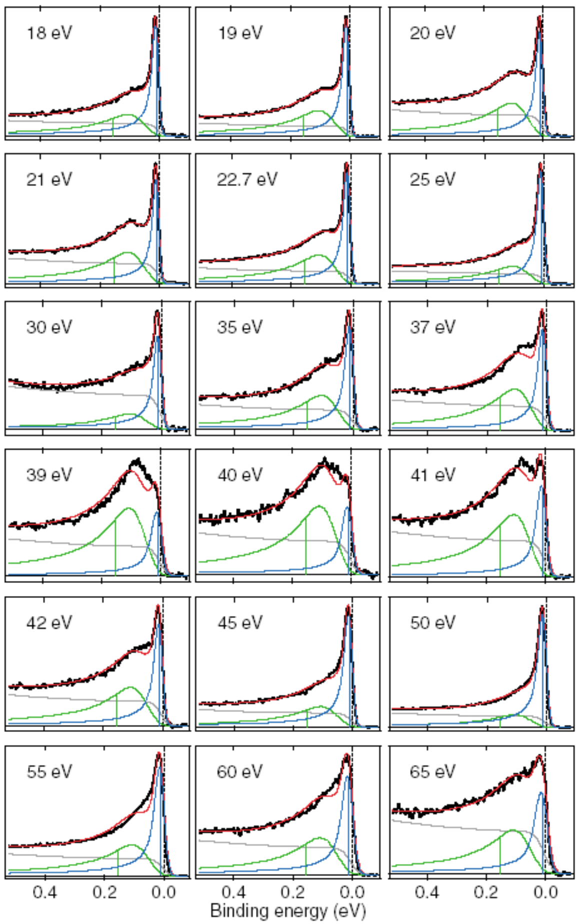


Origin of the Peak-Dip-Hump Line Shape in the Superconducting-State (π, 0) Photoemission Spectra of $Bi_2Sr_2CaCu_2O_8$

A. A. Kordyuk,[1,2] S. V. Borisenko,[1] T. K. Kim,[1] K. A. Nenkov,[1] M. Knupfer,[1]
J. Fink,[1] M. S. Golden,[3] H. Berger,[4] and R. Follath[5]



search, IFW Dresden, P.O. Box 270016, D-01171 Dresden, Germany
: of National Academy of Sciences of Ukraine, 03142 Kyiv, Ukraine
ute, University of Amsterdam, NL-1018 XE Amsterdam, The Netherlands
École Politechnique Féderale de Lausanne, CH-1015 Lausanne, Switzerland
›H, Albert-Einstein-Strasse 15, 12489 Berlin, Germany
ived 18 October 2001; published 30 July 2002)

ion measurements of the photon energy dependence of the $(\pi, 0)$ ission spectrum of the bilayer Bi high-temperature superconductors, we ›-hump line shape is dominated by a superposition of spectral features :tronic states which reside at different binding energies, but are each tical single-particle spectral functions. The previously identified bilayer-it: with the "superconducting" peak being due to the antibonding band, ed by its bonding bilayer-split counterpart.

003 PACS numbers: 74.25.Jb, 71.18.+y, 74.72.Hs, 79.60.–i

: excitations near l relevance to a he cuprate high-s it is here that its maximal mag-pling that causes rongly felt. Un-

the intensity of the "peak" and "hump" in the $(\pi, 0)$ spectrum, as well as the variation in the binding energy of the dip as a function of excitation energy, essentially exclude a scenario in which the peak, dip, and hump features in the superconducting state are dominated by a single-band spectral function. The data support a paradigm change in our interpretation of the PDH line shape, and

Signature of Superfluid Density in the Single-Particle Excitation Spectrum of $Bi_2Sr_2CaCu_2O_{8+\delta}$

D. L. Feng,[1*] D. H. Lu,[1] K. M. Shen,[1] C. Kim,[1] H. Eisaki,[1]
A. Damascelli,[1] R. Yoshizaki,[2] J.-i. Shimoyama,[3] K. Kishio,[3]
G. D. Gu,[4] S. Oh,[5] A. Andrus,[5] J. O'Dor
Z.-X. Shen[1*]

We report that the doping and temperature d
spectra near the Brillouin zone boundary of Bi_2
pected sensitivity to the superfluid density. In th
photoemission peak intensity as a function of dop
density and the condensation energy. As a funct
intensity shows an abrupt behavior near the supe
temperature where phase coherence sets in, rath
where the gap opens. This anomalous manifest
single-particle spectroscopy raises important que
anism of high-temperature superconductivity.

The collective nature of superconductivity manifests itself contrastingly in different techniques. Microwave and muon spin relaxation measurements are inherently sensitive to the collective motion of the condensate, whereas single-electron tunneling spectroscopy and photoemission mainly probe single-particle excitations of the

superflui
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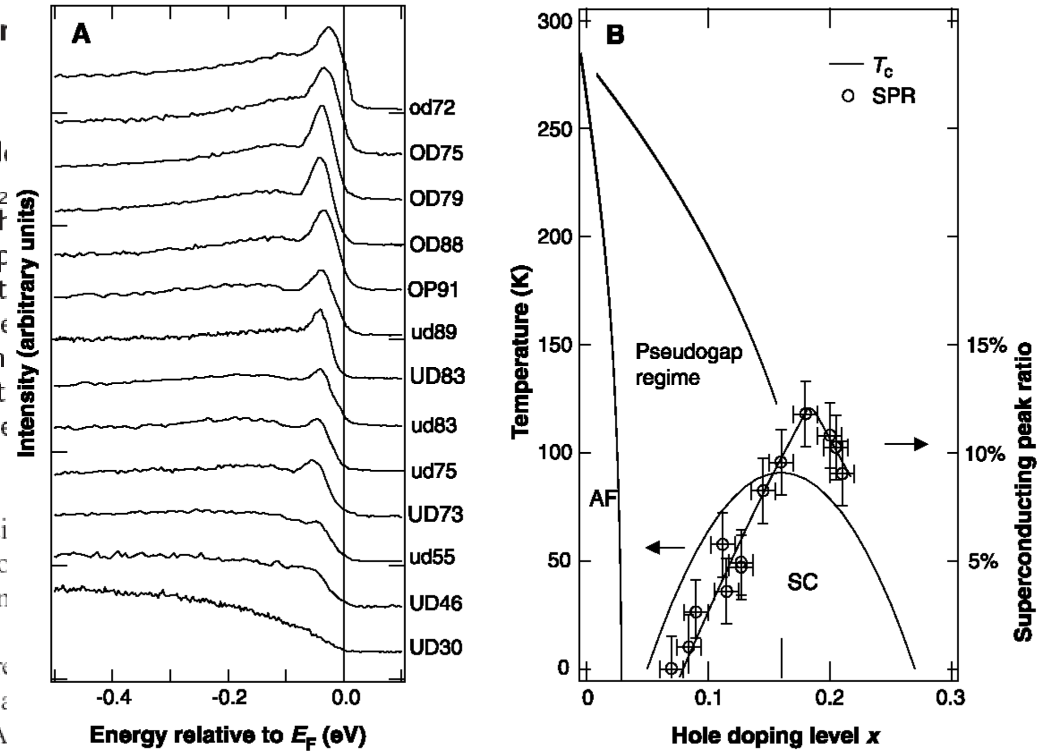
sation energy, both of which scale approximately with dopant x in the underdoped regime and saturate or even scale with $A - x$ in the overdoped regime (where A is a constant). The temperature dependence of this peak intensity also shows a resemblance to that of the superfluid density. More important, this peak intensity shows an abrupt behavior near T_c, where phase coherence sets in, rather than



Coherent Quasiparticle Weight and Its Connection to High-T_c Superconductivity from Angle-Resolved Photoemission

H. Ding,[1] J. R. Engelbrecht,[1] Z. Wang,[1] J. C. Campuzano,[2,3] S.-C. Wang,[1] H.-B. Yang,[1] R. Rogan,[1] T. Takahashi,[4] K. Kadowaki,[5] and D. G. Hinks[3]

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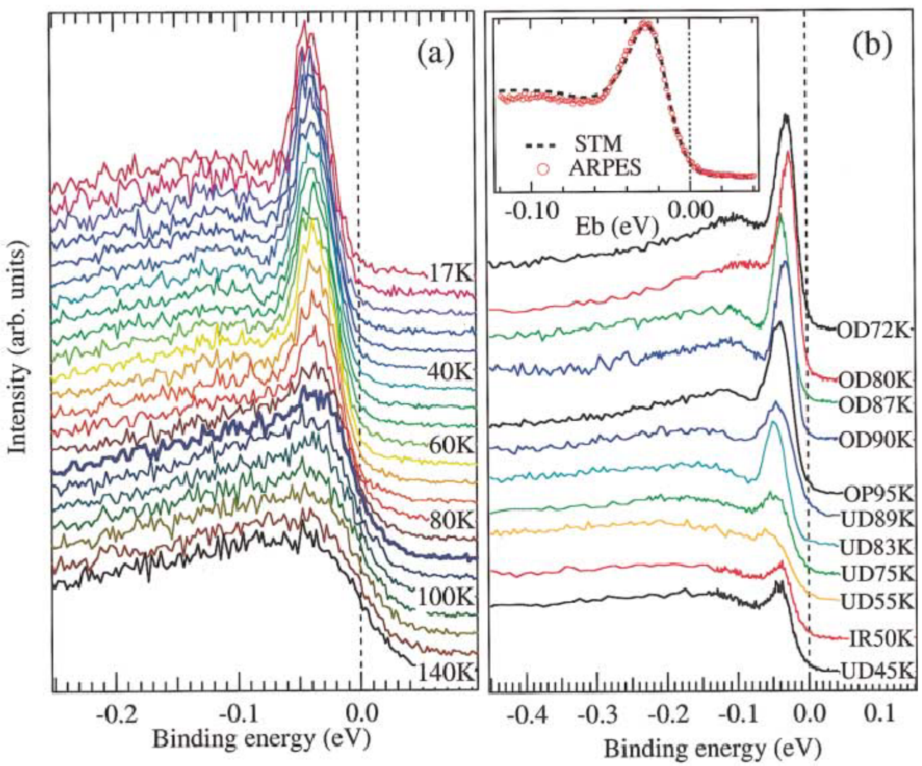
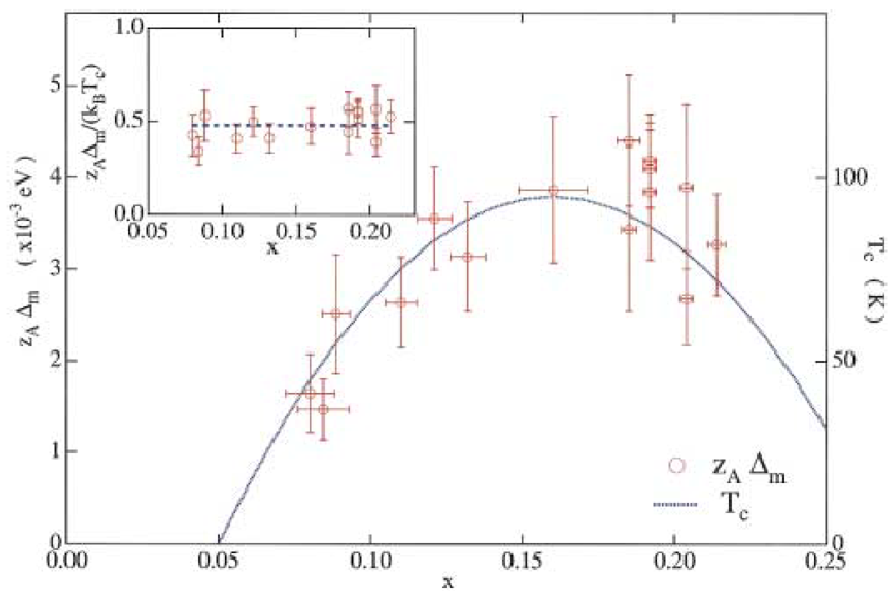
published 7 November 2001)



of the single-particle coherent weight, z_A, for high-T_c
ved photoemission. We find that at low temperatures



Quasiparticles?

Quasiparticles in the Superconducting State of $Bi_2Sr_2CaCu_2O_{8+\delta}$

A. Kaminski,[1,2] J. Mesot,[2] H. Fretwell,[1] J.C. Campuzano,[1,2] M.R. Norman,[2] M. Randeria,[3] H. Ding,[4] T. Sato,[5] T. Takahashi,[5] T. Mochiku,[6] K. Kadowaki,[7] and H. Hoechst[8]

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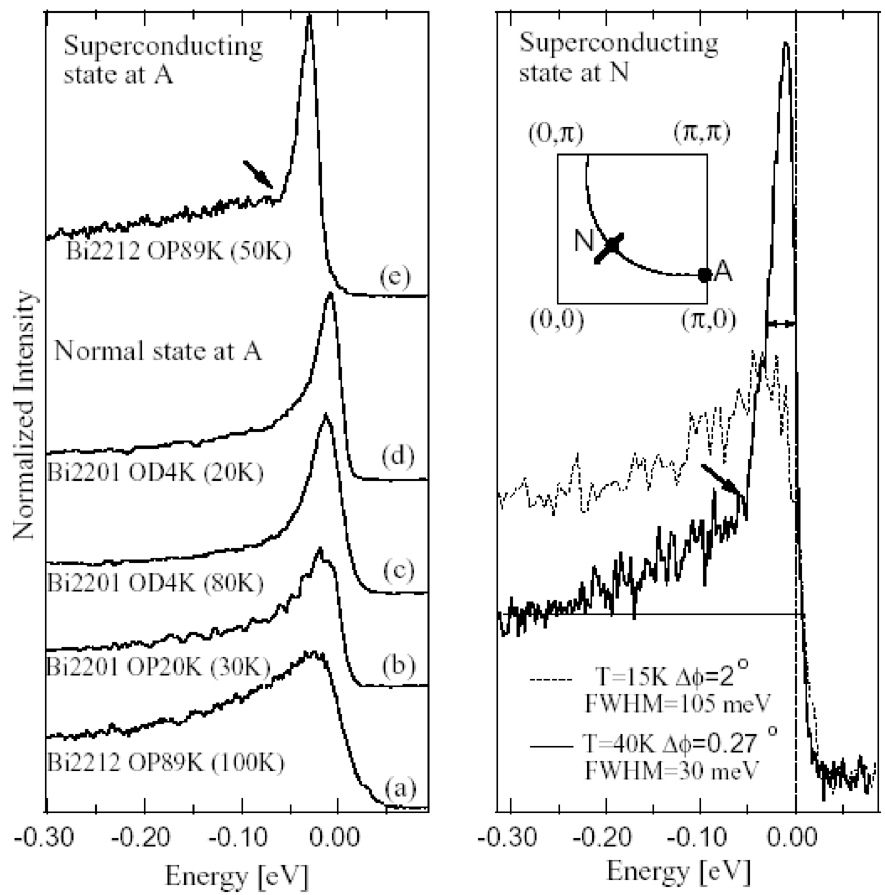
[5]*Department of Physics, Tohc*
[6]*National Research Institute for M*
[7]*Institute of Materials Science, U*
[8]*Synchrotron Radiation C*
(Received 27 April 1999; revis

Recent improvements in momentum resolutic
spectroscopy results on the spectra of Bi_2Sr_2(
there is a node in the superconducting gap. V
presence of true quasiparticles at all Fermi mon
normal state. The region of momentum space p
comparison of our results to conductivity meas

PACS numbers: 74.25.Jb, 71.18.+y, 74.72.Hs, 79.6



Landau's concept of the Fermi liquid [1] underlies mu
of our present theoretical understanding of electron dyna
ics in crystalline solids. Landau was able to demonstra
that, even though the electrons interact strongly with o
another, one can still describe the low temperature prope
ties of metals in terms of "quasiparticle" excitations, whi
are bare electrons dressed by the medium in which th

Momentum, Temperature, and Doping Dependence of Photoemission Lineshape and Implications for the Nature of the Pairing Potential in High-T_c Superconducting Materials

Z.-X. Shen[1] and J. R. Schrieffer[2]
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[2]*National High Magnetic Field Laboratory and Department of Physics, Florida State University, Tallahassee, Florida 32306*
(Received 27 September 1996)

The anomalous momentum and temperature dependence of the spectral lineshape in data from underdoped $Bi_2Sr_2CaCu_2O_{8+\delta}$ (Bi2212) indicates that the quasiparticles are strongly coupled to collective excitations centered near $\mathbf{Q} = (\pi, \pi)$. The doping dependence of the spectral lineshape and its correlation with the size of the superconducting gap indicate these collective excitations are

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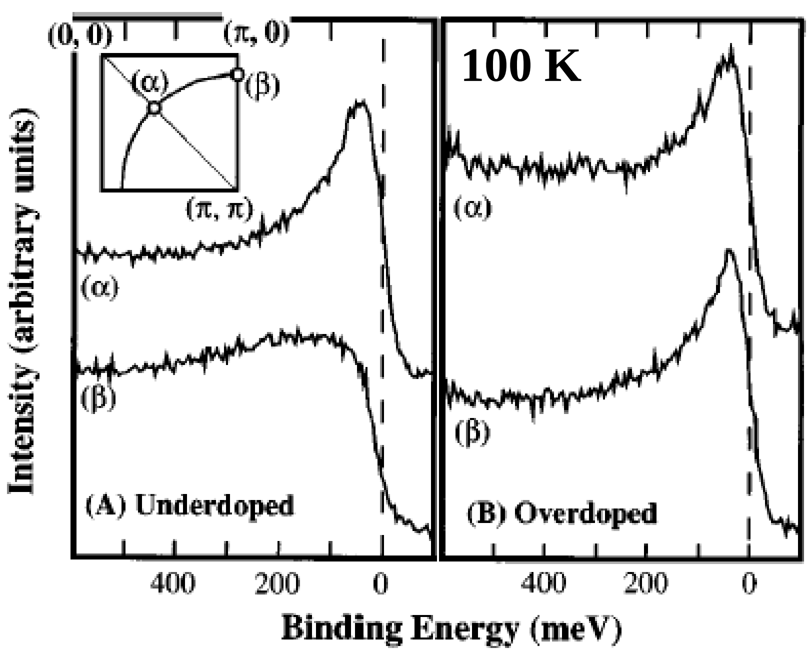

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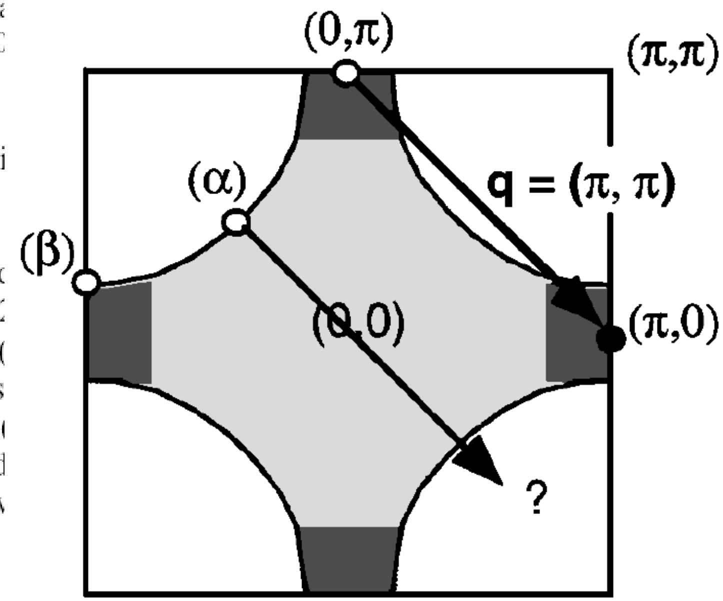


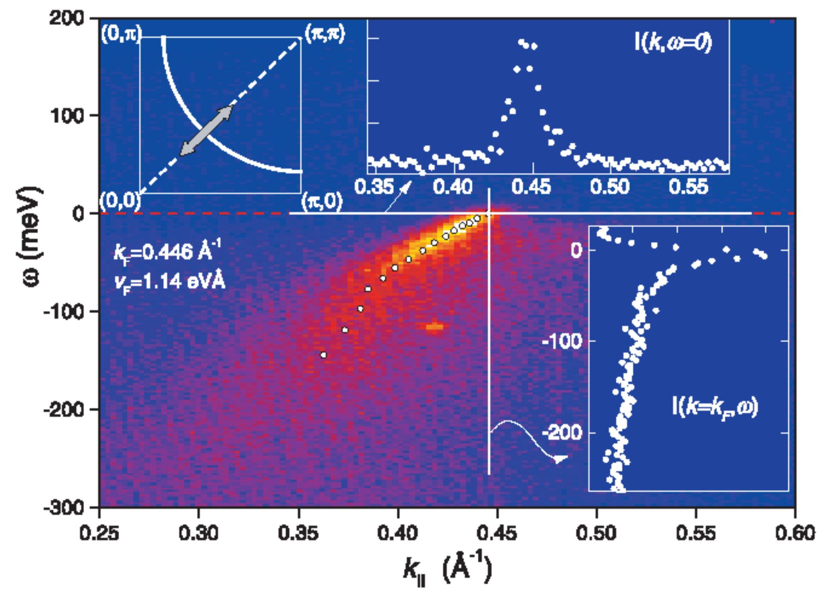
Evidence for MFL

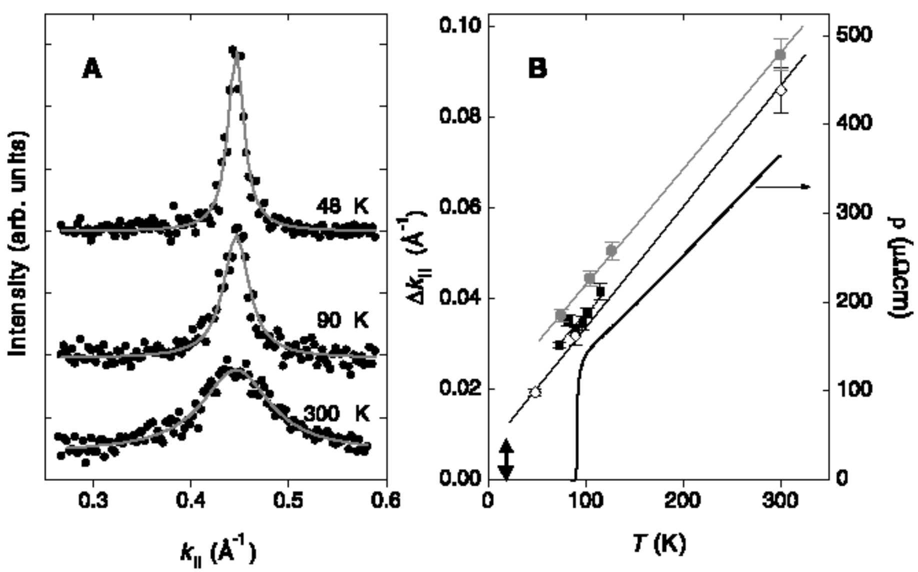
24 SEPTEMBER 1999 VOL 285 SCIENCE

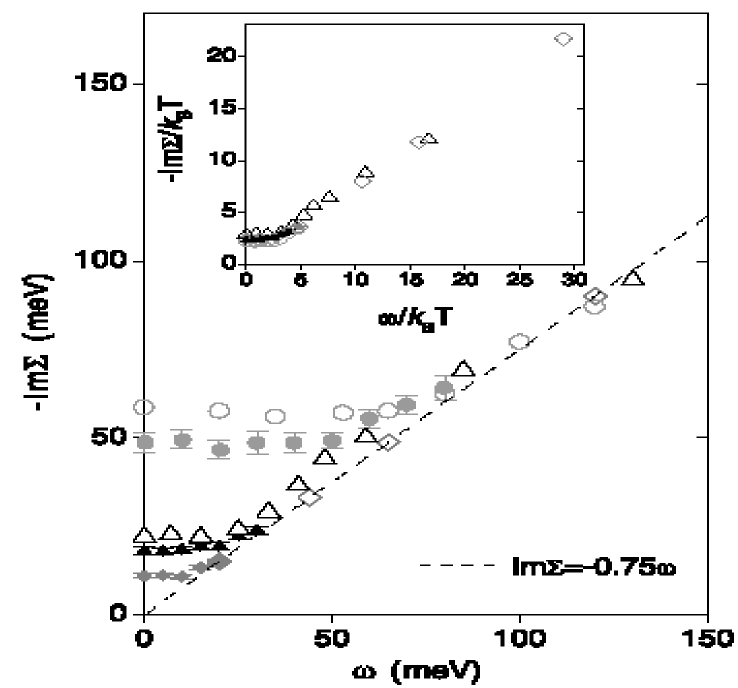
Evidence for Quantum Critical Behavior in the Optimally Doped Cuprate $Bi_2Sr_2CaCu_2O_{8+\delta}$

T. Valla,[1] A. V. Fedorov,[1] P. D. Johnson,[1] B. O. Wells,[1,4]
S. L. Hulbert,[2] Q. Li,[3] G. D. Gu,[5] N. Koshizuka[6]

The photoemission line shapes of the optimally doped cuprate $Bi_2Sr_2CaCu_2O_{8+\delta}$ were studied in the direction of a node in the superconducting order parameter by means of very high resolution photoemission spectroscopy. The peak width or inverse lifetime of the excitation displays a linear temperature dependence, independent of binding energy, for small energies, and a linear energy dependence, independent of temperature, for large binding energies. This behavior is unaffected by the superconducting transition, which is an indication that the nodal states play no role in the superconductivity. Temperature-dependent scaling suggests that the system displays quantum critical behavior.







Time reversal symmetry breaking?

PHYSICAL REVIEW B VOLUME 61, NUMBER 6 1 FEBRUARY 2000-II

Proposal for an experiment to test a theory of high-temperature superconductors

C. M. Varma
Bell Laboratories, Lucent Technologies, Murray Hill, New Jersey 07974

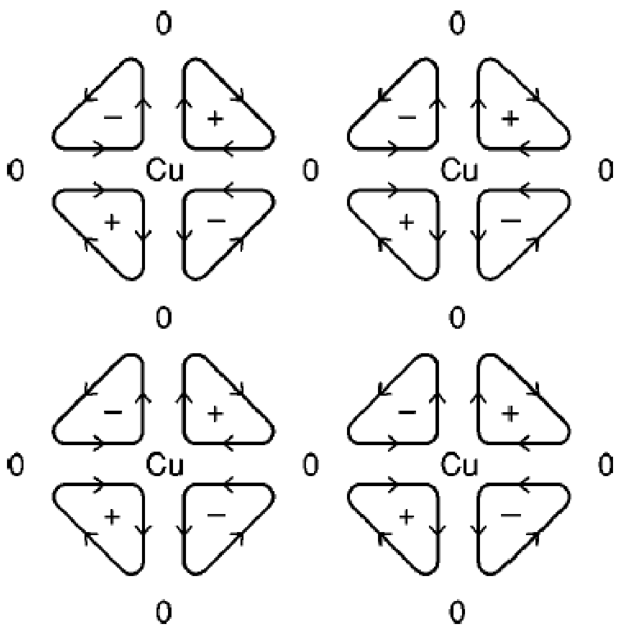
(Received 21 October 1999)

A theory for the phenomena observed in copper-oxide based high-temperature superconducting materials derives an elusive time-reversal and rotational symmetry-breaking order parameter for the observed pseudogap phase ending at a quantum-critical point near the composition for the highest T_c. An experiment is proposed to observe such a symmetry breaking. It is shown that angle-resolved photoemission yields a current density which is different for left and right circularly polarized photons. The magnitude of the effect and its momentum dependence is estimated. Barring the presence of domains of the predicted phase, an asymmetry of about 0.1 is predicted at low temperatures in moderately underdoped samples.

I. INTRODUCTION

Despite twelve years of intensive experimental and theoretical studies of copper-oxide based superconducting compounds,[1] no consensus about the fundamental physics or even about the minimum necessary Hamiltonian to describe the phenomena has emerged. One of the few theoretical ideas which has clearly survived experimental tests is that at den- Cu-O compounds is the symmetery in region II of the so-called pseudogap phase.

A systematic theory[5,6] starting with a general model for Cu-O compounds provides an answer to this question. Region II in Fig. 1 is derived to be a phase in which a fourfold pattern of current flows in the ground state in each unit cell as shown in Fig. 2. Time-reversal symmetry as well as rotational symmetry is broken but the product of the two is con- phase has been called the circulating-current Quantum fluctuations about this phase are ve MFL fluctuations, characteristic of region I. fluctuations promote "d" or generalized iring d



NATURE | VOL 416 | 11 APRIL 2002

Spontaneous breaking of time-reversal symmetry in the pseudogap state of a high-T_c superconductor

A. Kaminski*†, S. Rosenkranz*†, H. M. Fretwell‡, J. C. Campuzano*†, Z. Li§, H. Raffy§, W. G. Cullen†, H. You†, C. G. Olson||, C. M. Varma¶ & H. Höchst#

* *Department of Physics, University of Illinois at Chicago, Chicago, Illinois 60607, USA*
† *Materials Science Division, Argonne National Laboratory, Argonne, Illinois 60439, USA*
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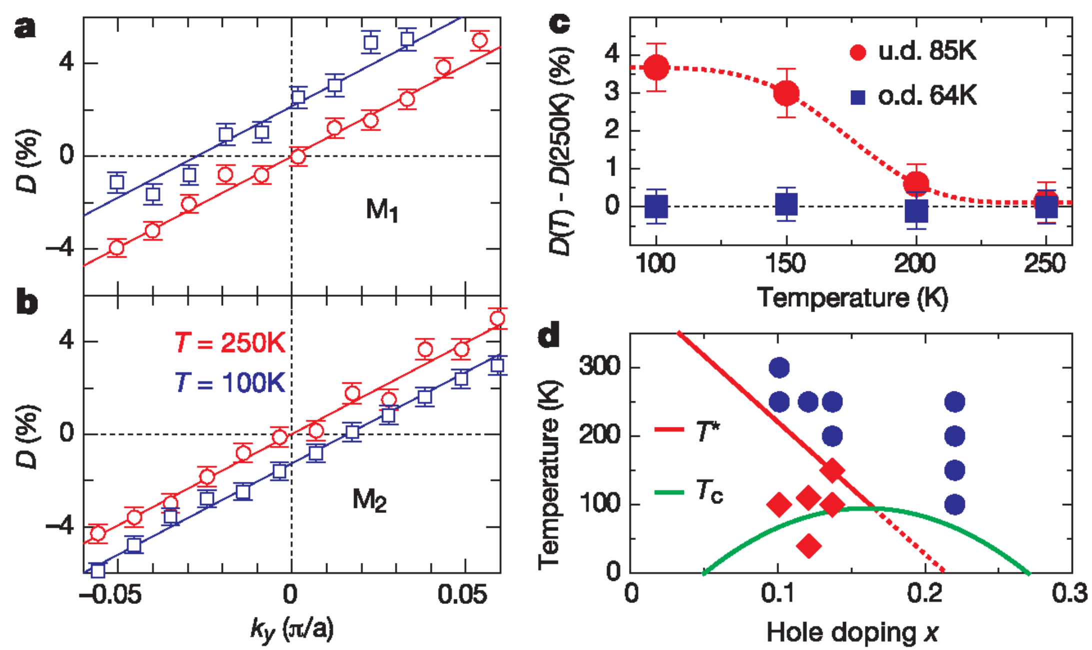
¶ *Bell Laboratories, Lucent Technologies, Murray Hill, New Jersey 07974, USA*
# *Synchrotron Radiation Center, Stoughton, Wisconsin 53589, USA*

A change in 'symmetry' is often observed when matter undergoes a phase transition—the symmetry is said to be spontaneously



Superconductors

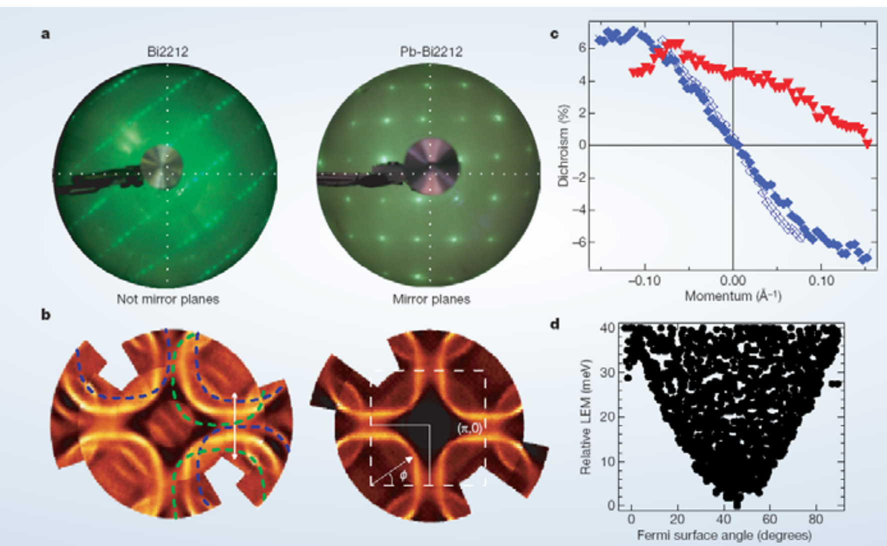
Time-reversal symmetry breaking?

Sergey V. Borisenko*, Alexander A. Kordyuk*†, Andreas Koitzsch*, Martin Knupfer*, Jörg Fink*, Helmuth Berger‡, Chengtian T. Lin§

Arising from: Kaminski, A. *et al.* *Nature* **416,** 610–613 (2002)

One of the mysteries of modern condensed-matter physics is the nature of the pseudogap state of the superconducting cuprates. Kaminski *et al.*[1] claim to have observed signatures of time-reversal symmetry breaking in the pseudogap regime in underdoped $Bi_2Sr_2CaCu_2O_{8+\delta}$ (Bi2212). Here we argue that the observed circular dichroism is due to the 5×1 superstructure replica of the electronic bands and therefore cannot be considered pristine Bi2212, the dichroic signal is nonzero in the Γ–(π,0) plane.

This result can readily be explained. The superstructure results in diffraction replicas of the electronic structure seen in the momentum-distribution map (Fig. 1b) as green and blue dashed curves. Because of the pronounced inequivalence of the matrix elements in the first and second Brillouin zones, the spectral weight of these replicas is always different near the (π,0) point.



VOLUME 92, NUMBER 20 PHYSICAL REVIEW LETTERS week ending 21 MAY 2004

Circular Dichroism in Angle-Resolved Photoemission Spectra of Under- and Overdoped Pb-Bi2212

S. V. Borisenko,[1] A. A. Kordyuk,[1,2] A. Koitzsch,[1] T. K. Kim,[1] K. A. Nenkov,[1] M. Knupfer,[1] J. Fink,[1] C. Grazioli,[3] S. Turchini,[3] and H. Berger[4]

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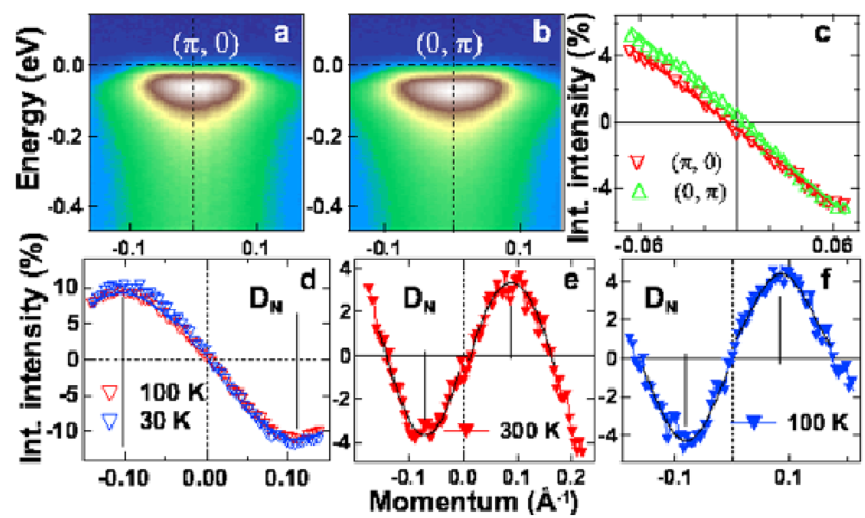
(Received 7 May 2003; published 19 May 2004)

We use angle-resolved photoemission with circularly polarized excitation to demonstrate that in the 5 × 1 superstructure-free $(Pb, Bi)_2Sr_2CaCu_2O_{8+\delta}$ (Pb-Bi2212) material there are no signatures of time-reversal symmetry breaking in the sense of the criteria developed earlier [Kaminski *et al.*, Nature (London) **416**, 610 (2002)]. The dichroic signal retains reflection antisymmetry as a function of temperature and doping and in all mirror planes, precisely defined by the experimental dispersion at low energies. The obtained results demonstrate that the signatures of time-reversal symmetry violation in pristine Bi2212, as determined by angle-resolved photoemission spectroscopy, are not a universal feature of all cuprate superconductors.

DOI: 10.1103/PhysRevLett.92.207001 PACS numbers: 74.25.Jb, 74.72.Hs, 79.60.–i

The variety of specific points, lines, and regions in the 'normal state" part of the phase diagram of the high-emperature superconductors clearly demonstrates not only its complexity but also the absence of its detailed understanding [1]. It is therefore important to realize which of them are really universal boundaries of particular phases and which just designate intermediate states with properties defined by the proximity to the well established phases such as superconductivity. A recent out on the systems with reduced interference of the temperature-sensitive structural modifications together with the development of an improved experimental methodology aiming at more precise and reliable investigation of circular dichroism effects in low energy photoemission would be of special interest today.

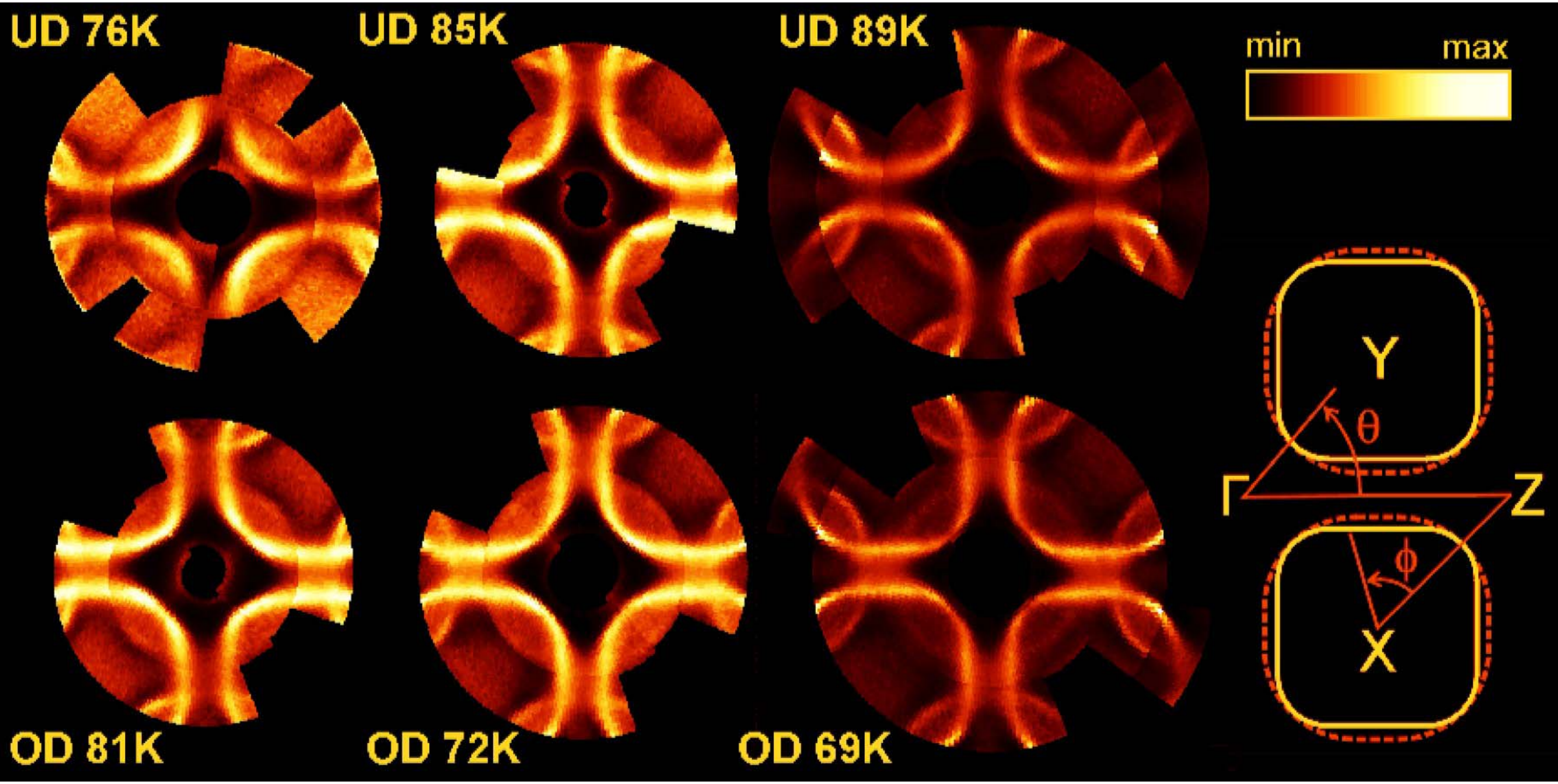
In this Letter we present the results of the ARPES investigation of the $(Pb, Bi)_2Sr_2CaCu_2O_{8+\delta}$ (Pb-Bi2212) cuprates known to have no 5 × 1 superstructure. We dem-



In what we believe today

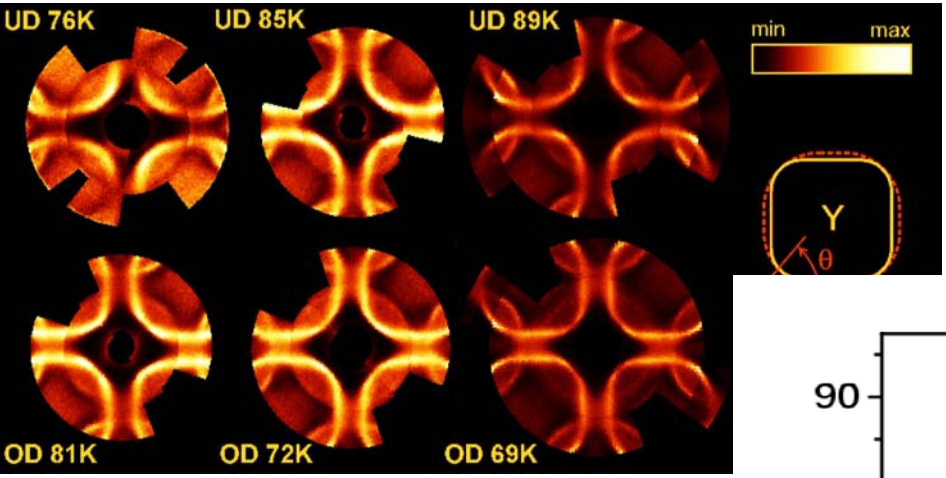
Electronic band structure

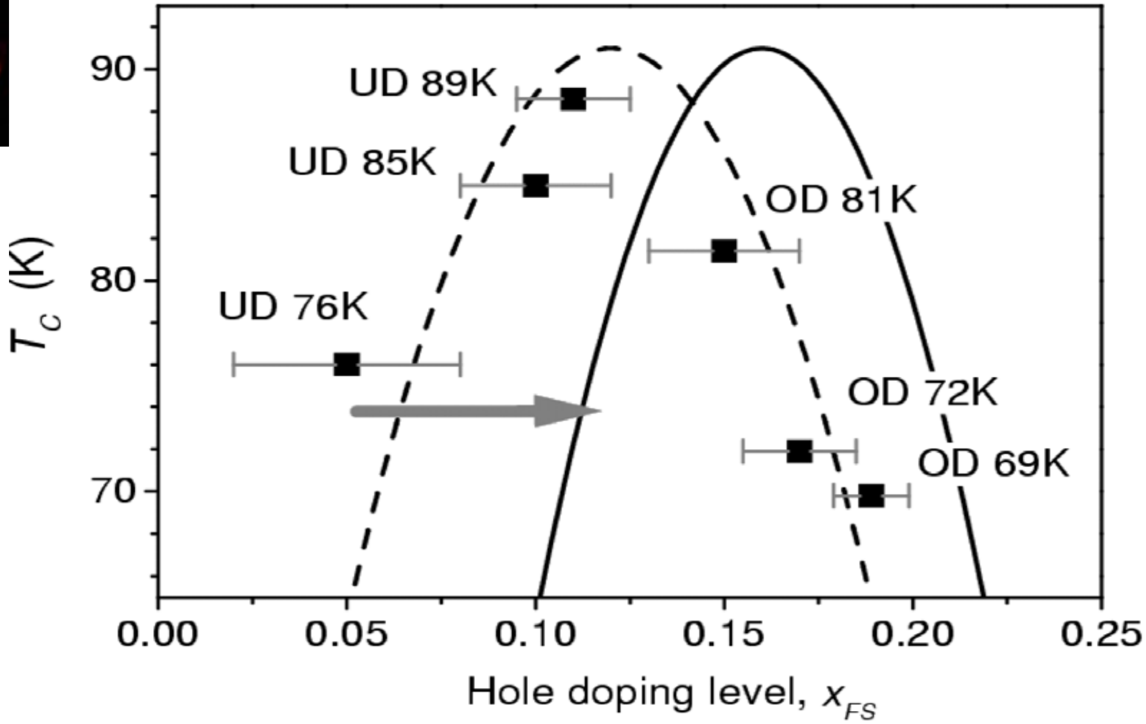
A set of superstructure-free Bi(Pb)-2212 in a wide doping range...



Kordyuk *PRB* 2002

A set of superstructure-free Bi(Pb)-2212 in a wide doping range with known doping level

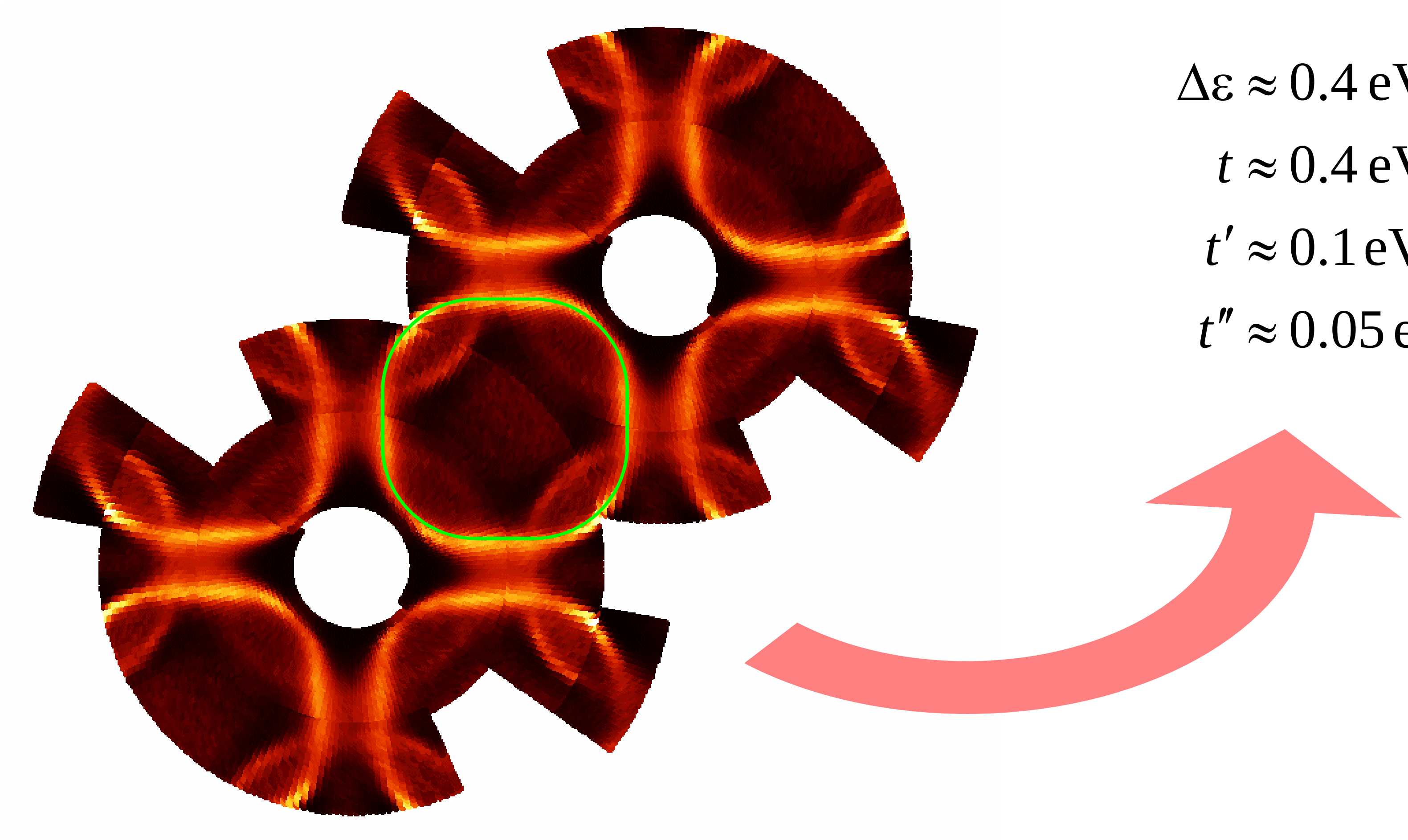




Kordyuk *PRB* 2002

Band structure: TBF

$$\varepsilon(k_x,k_y) = \Delta\varepsilon - 2t(\cos k_x + \cos k_y) + 4t'\cos k_x \cos k_y - 2t''(\cos 2k_x + \cos 2k_y)$$



$$\Delta\varepsilon \approx 0.4\,\mathrm{eV}$$

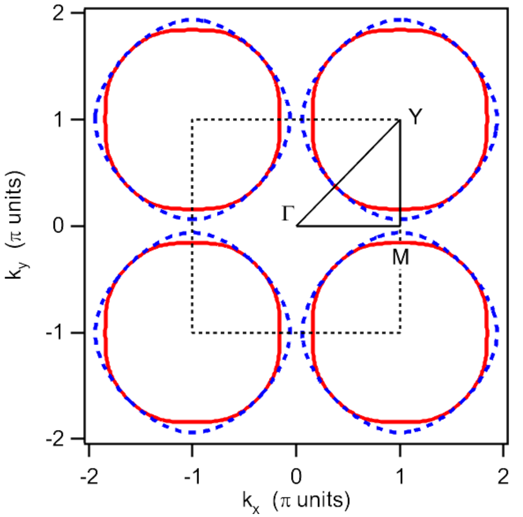
$$t \approx 0.4\,\mathrm{eV}$$

$$t' \approx 0.1\,\mathrm{eV}$$

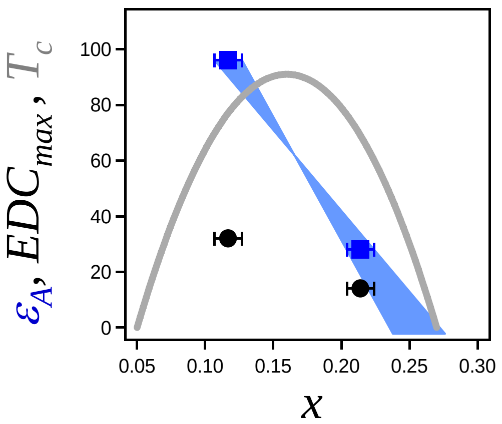
$$t'' \approx 0.05\,\mathrm{eV}$$

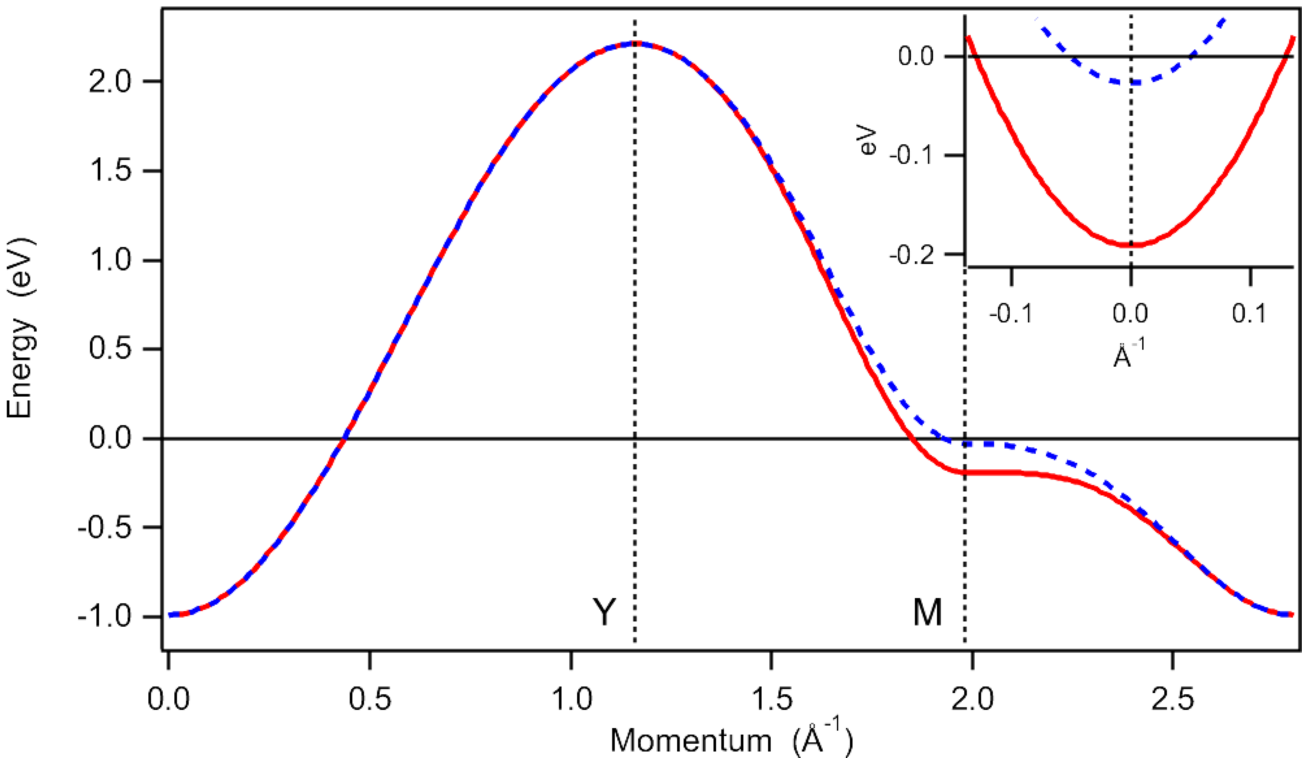
Kordyuk *PRB* 2003

Bare band structure



Sample	t (eV)	t' (eV)	t'' (eV)	$t_\perp$ (eV)	$\Delta\epsilon$ (eV)
OD 69 K	0.40	0.090	0.045	0.082	0.43
UD 77 K	0.39	0.078	0.039	0.082	0.29





Kordyuk *PRB* 2003

High precision Fermi surface mapping

OD
<Tc

OP
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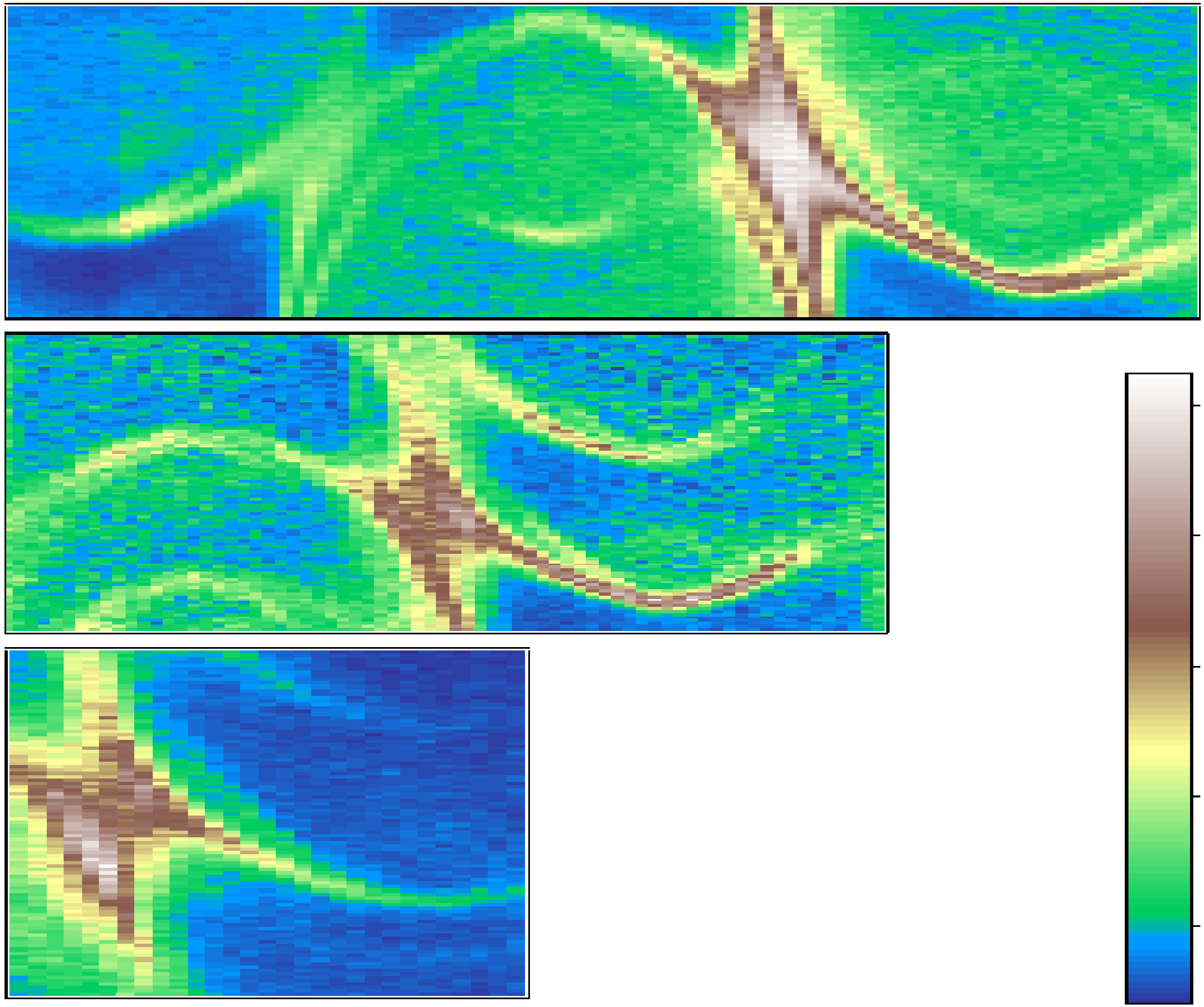
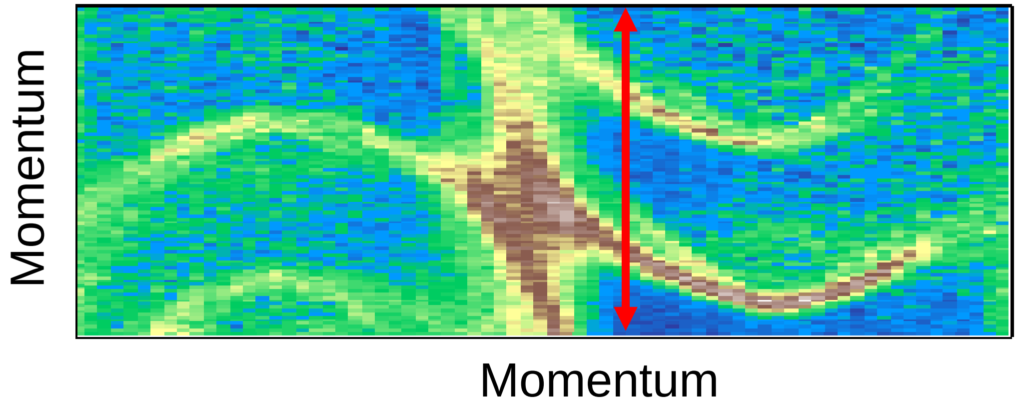
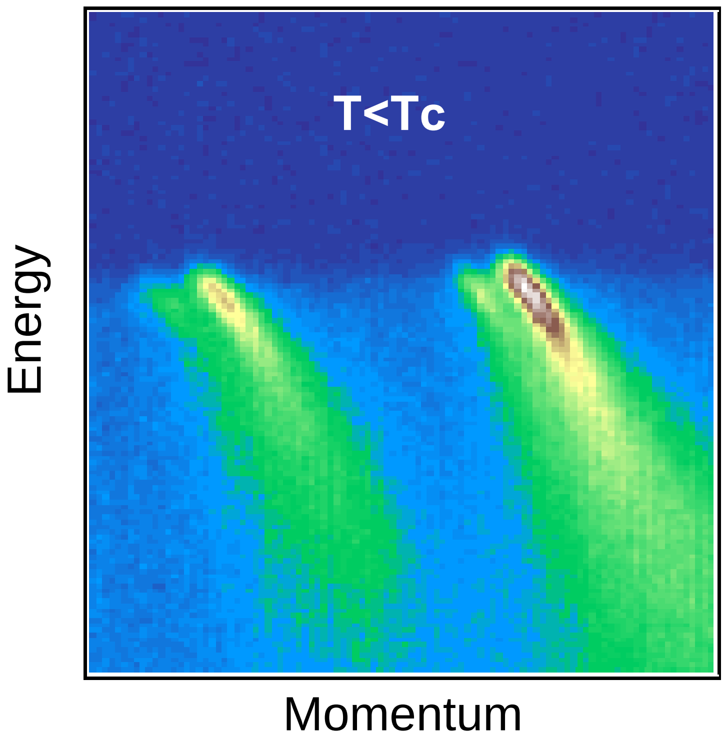
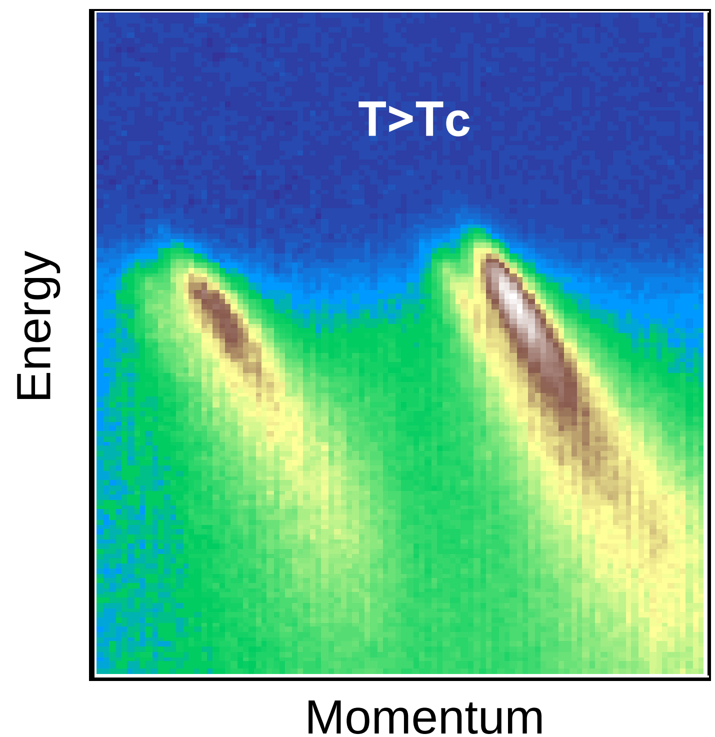
UD
<Tc



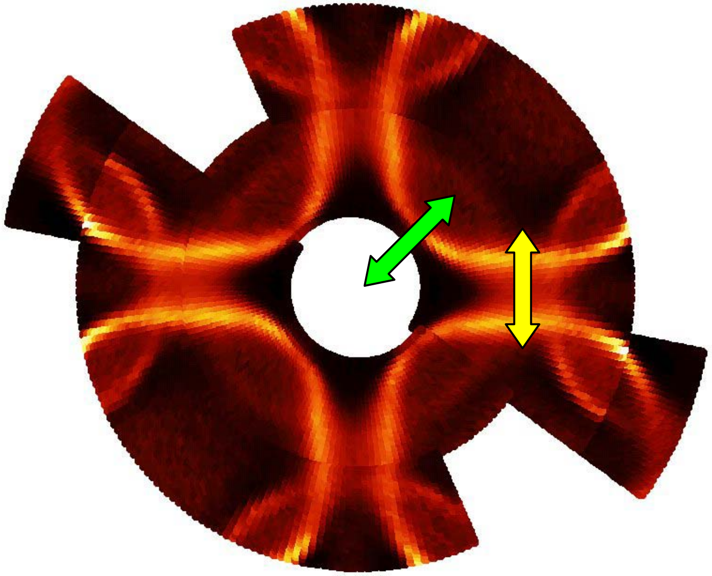
Bilayer splitting in OP Bi-2212 in normal state

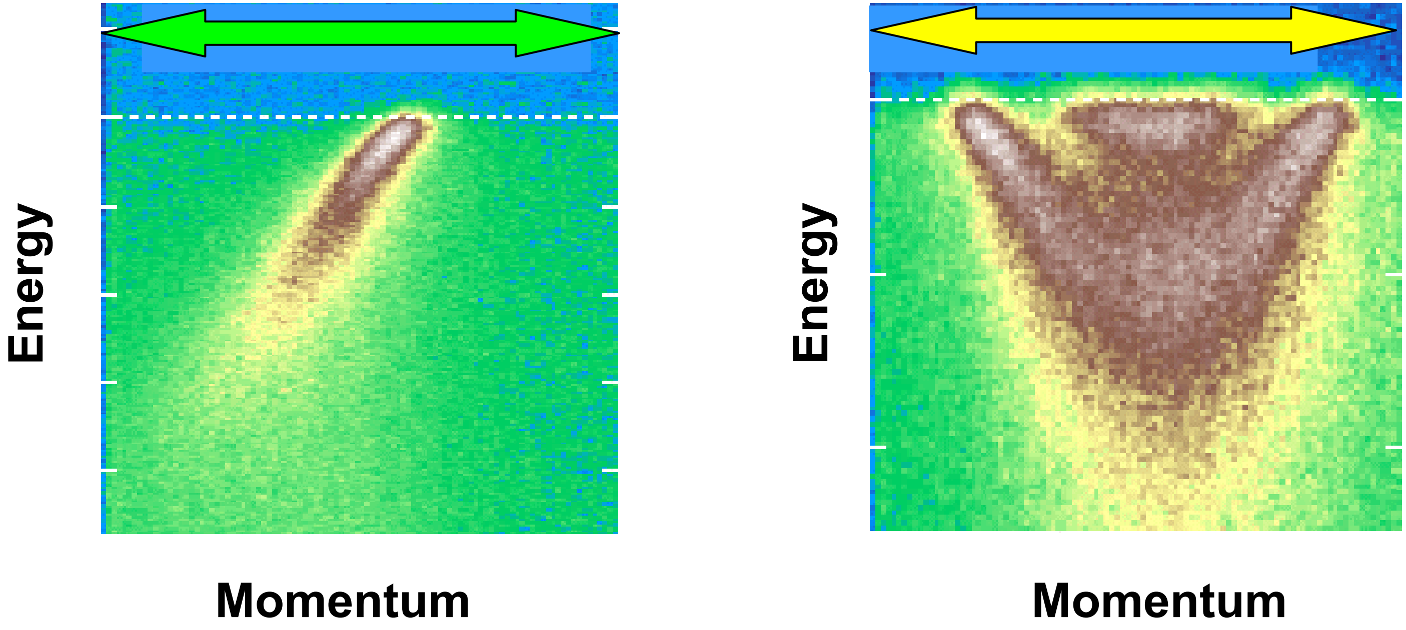




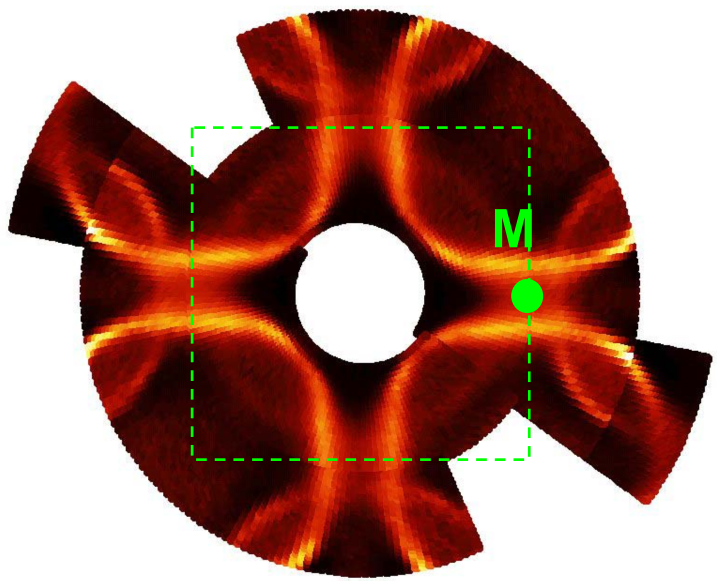


Key regions



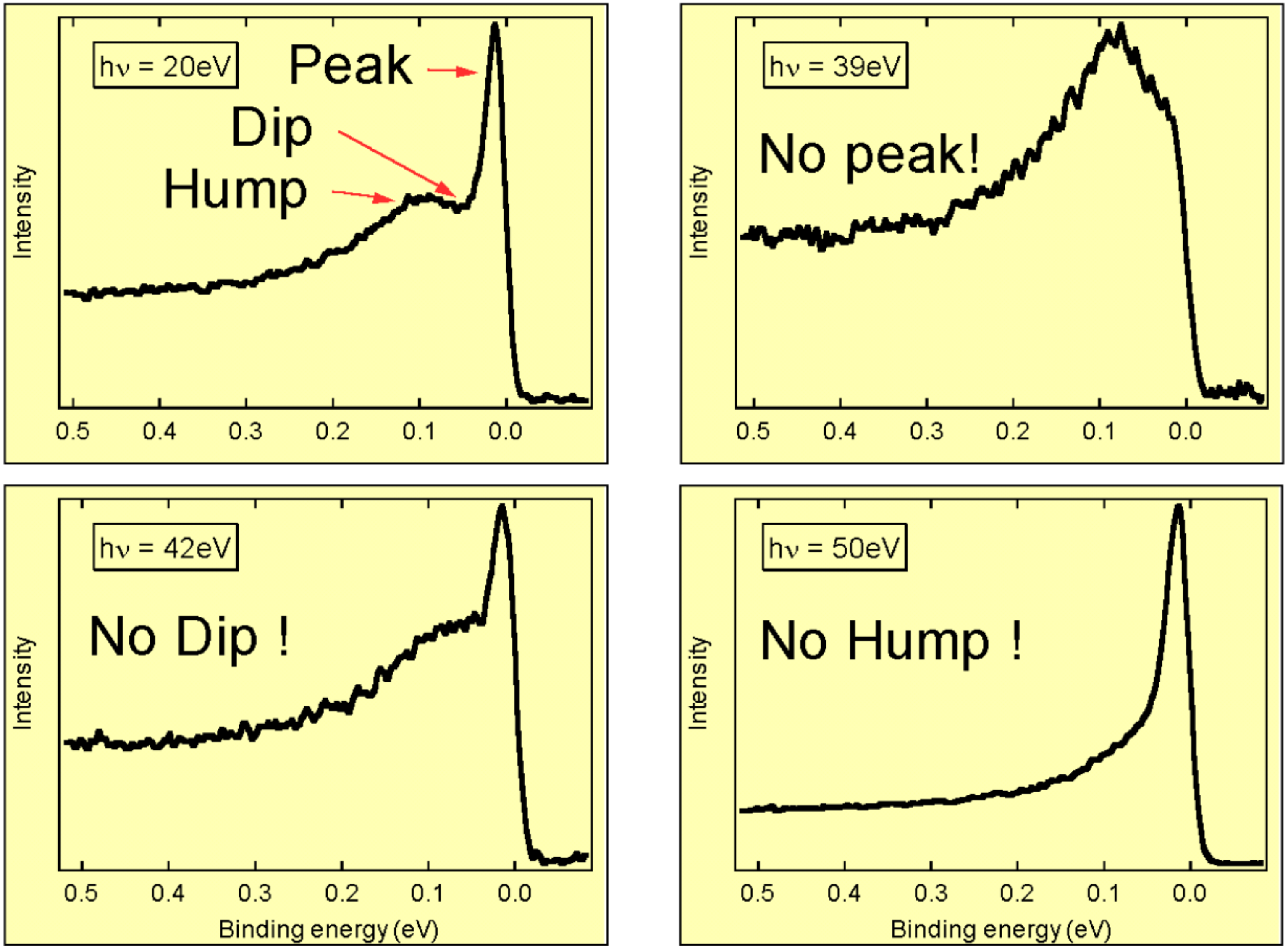


Saddle point



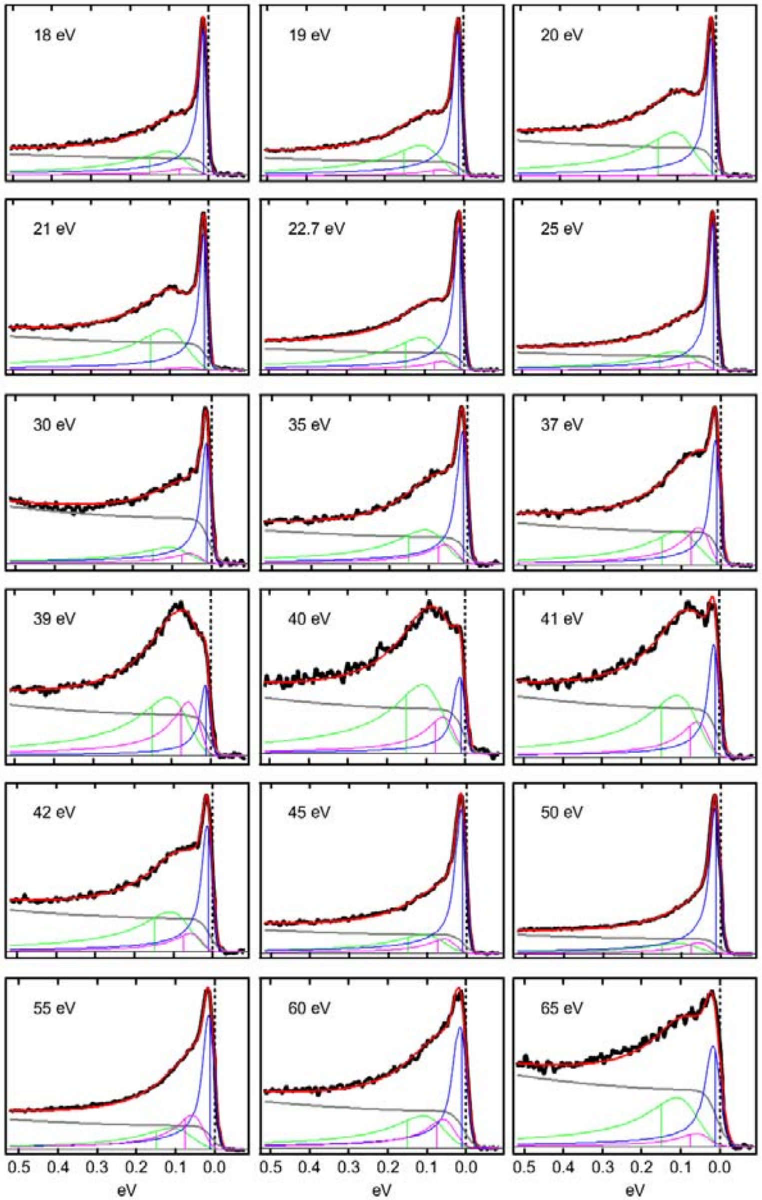
$(\pi,0)$

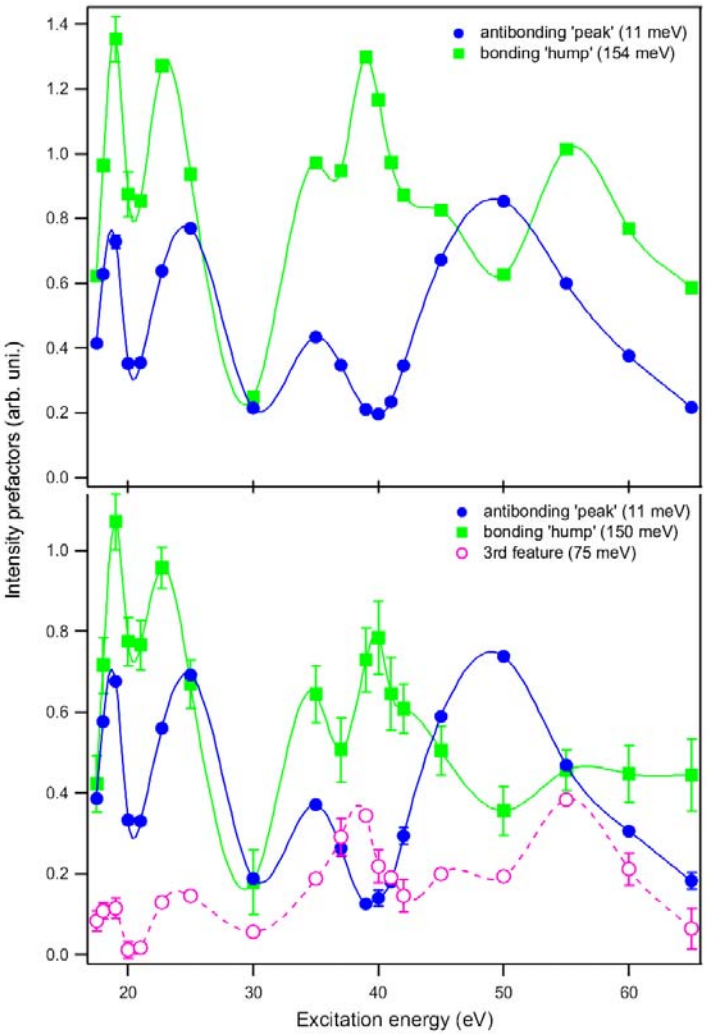
Excitation energy variation: PDH in OD



Kordyuk *PRL* 2002

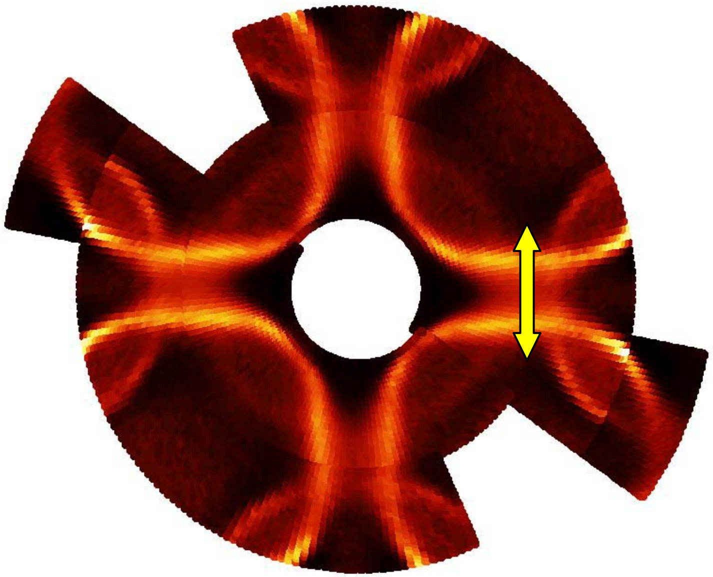
Excitation energy variation: PDH in OD



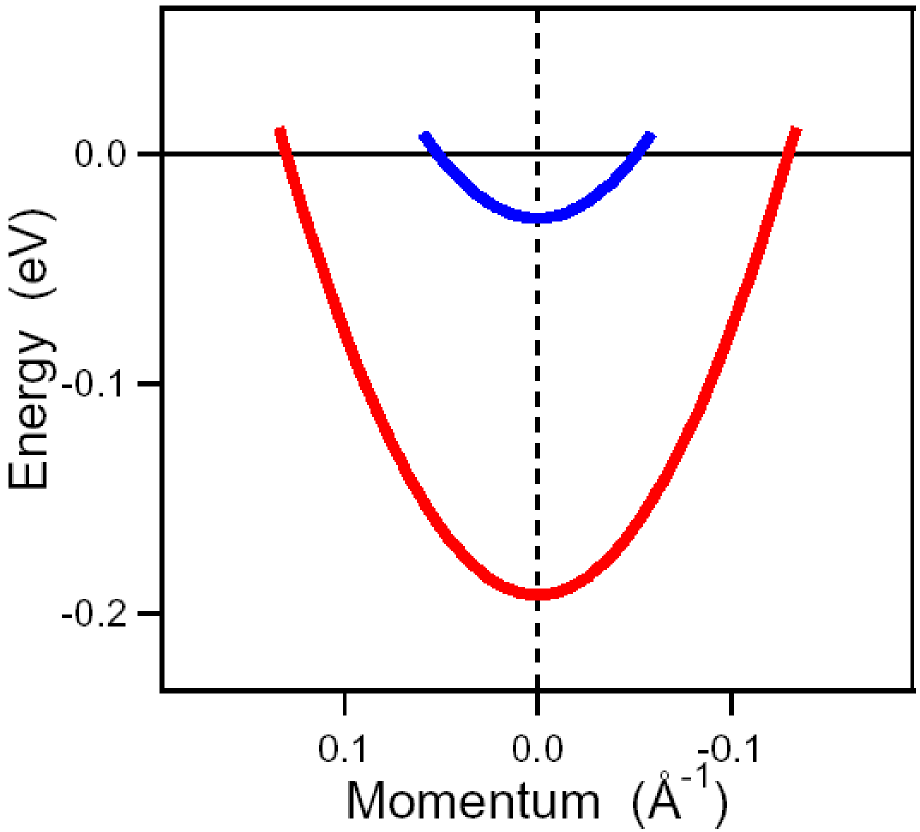


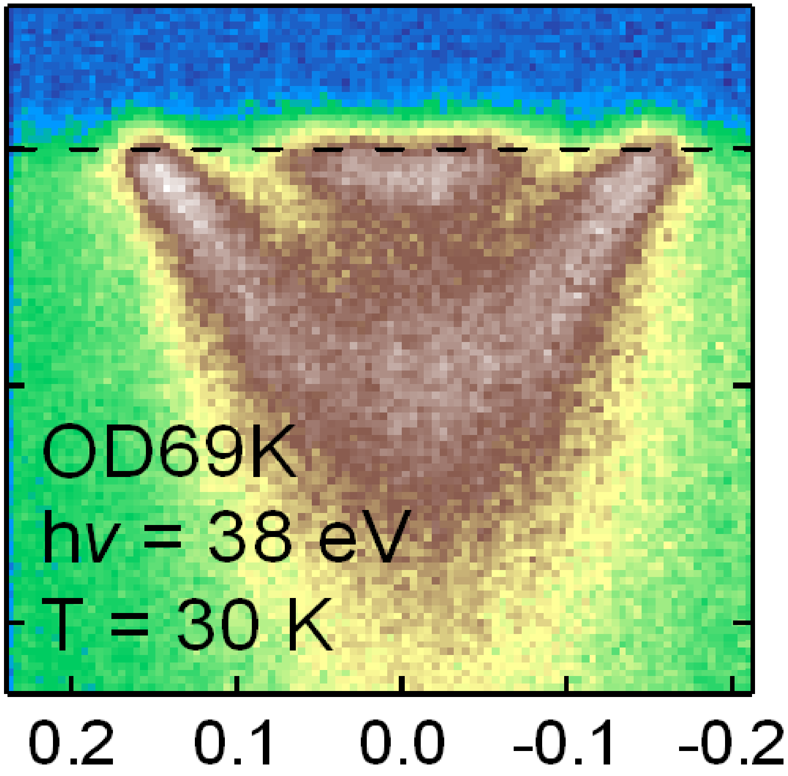
Kordyuk *PRL* 2002

Antinodal region (XMY)

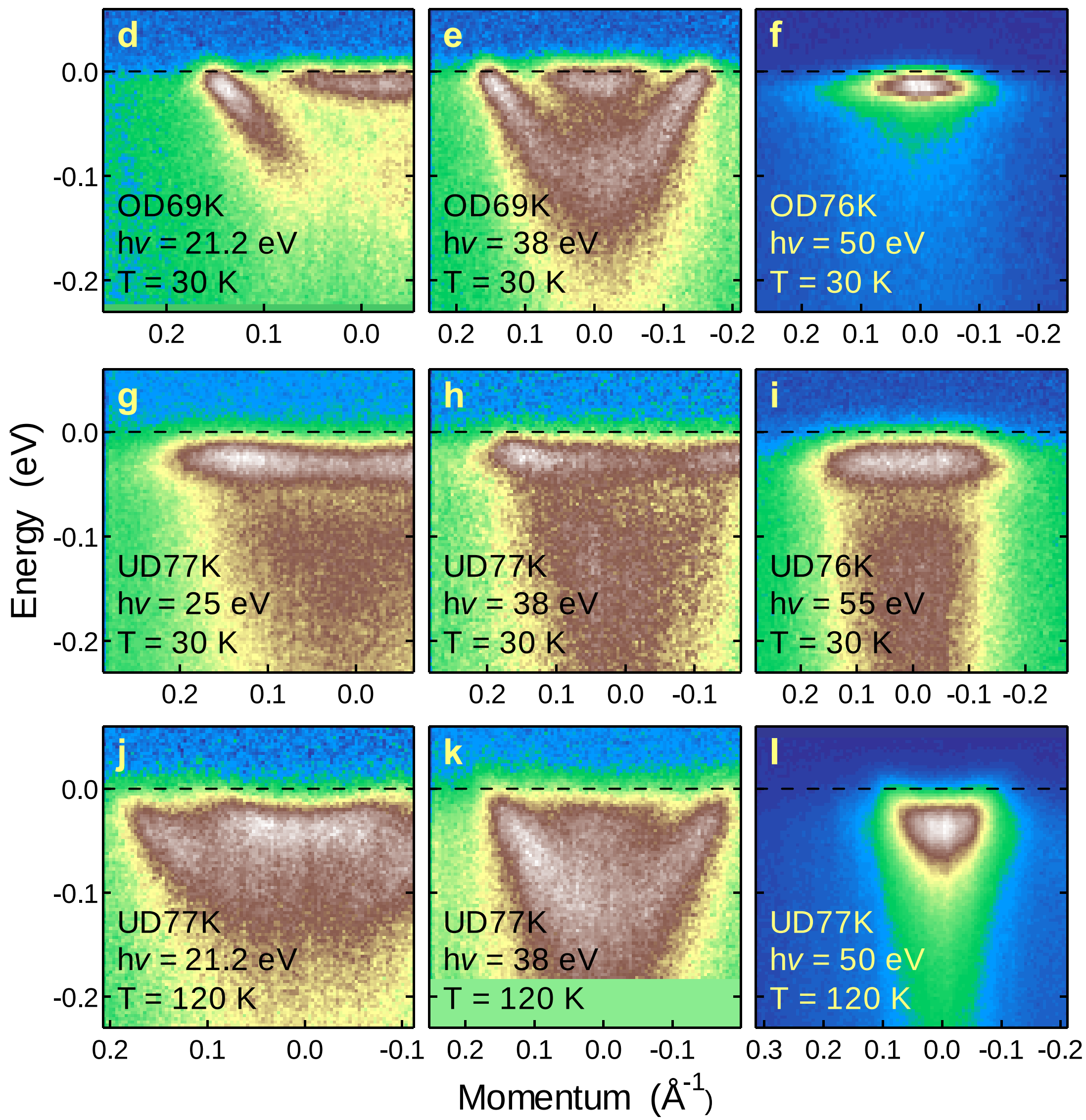


Antinodal or "XMY cut"



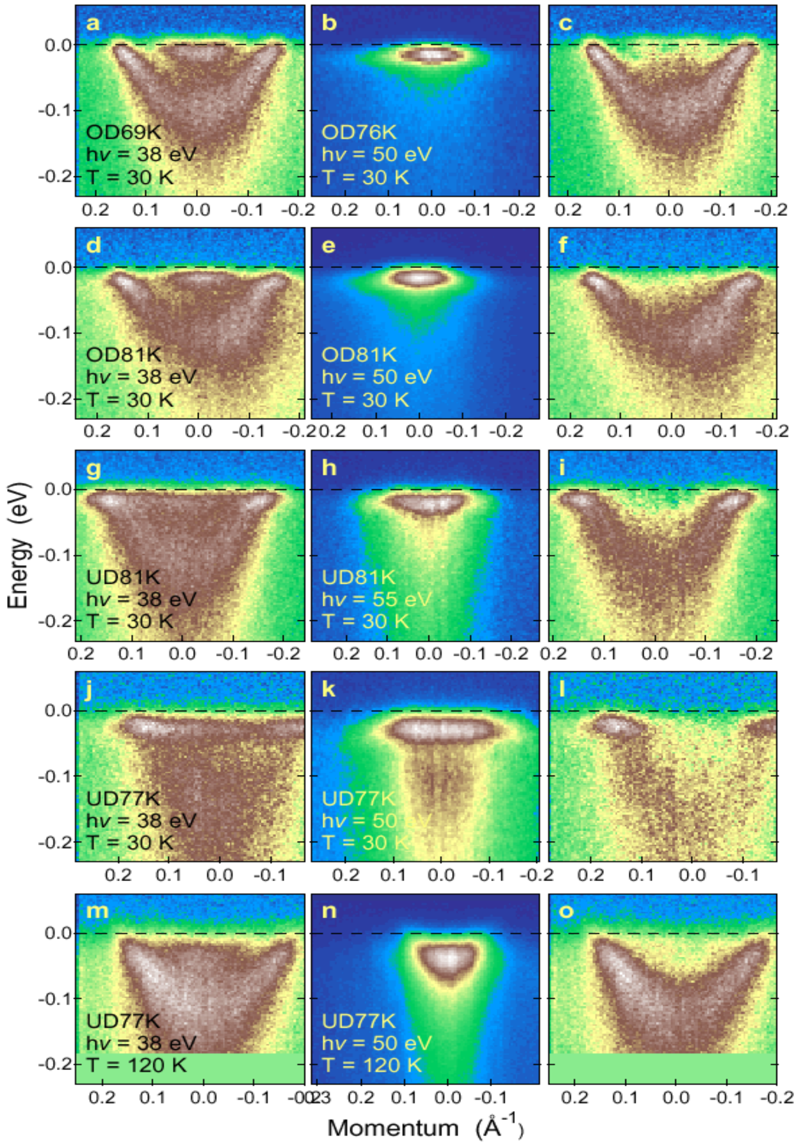


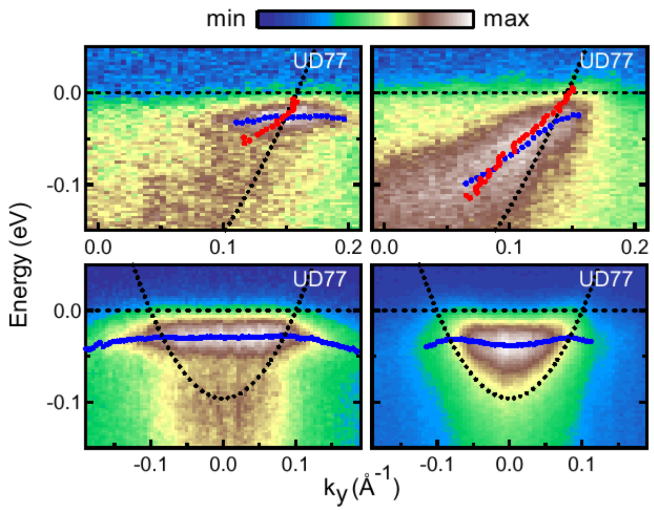
Interaction with a mode

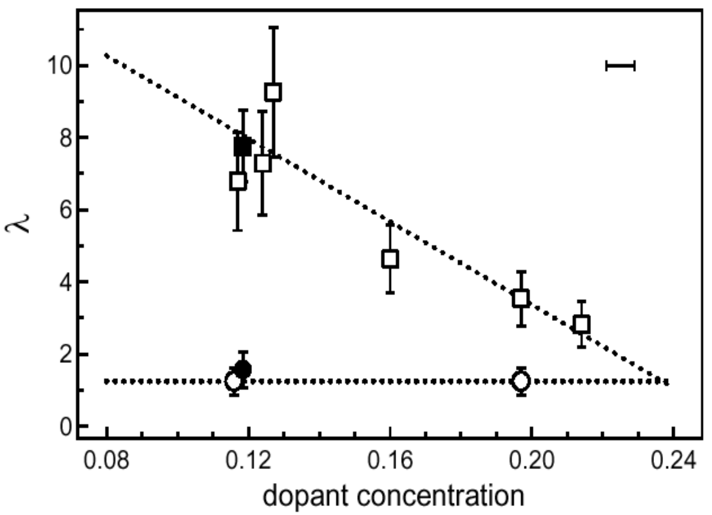


Borisenko *PRL* 2003

Interaction with a mode







Kim *PRL* 2003

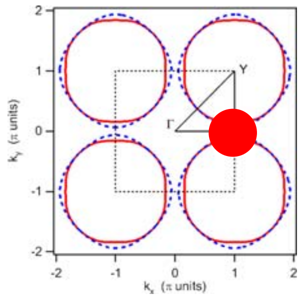
Antinodal electrons couple to …

Doping dependence: UD↑
OD↓

Temperature dependence: $<T_c$

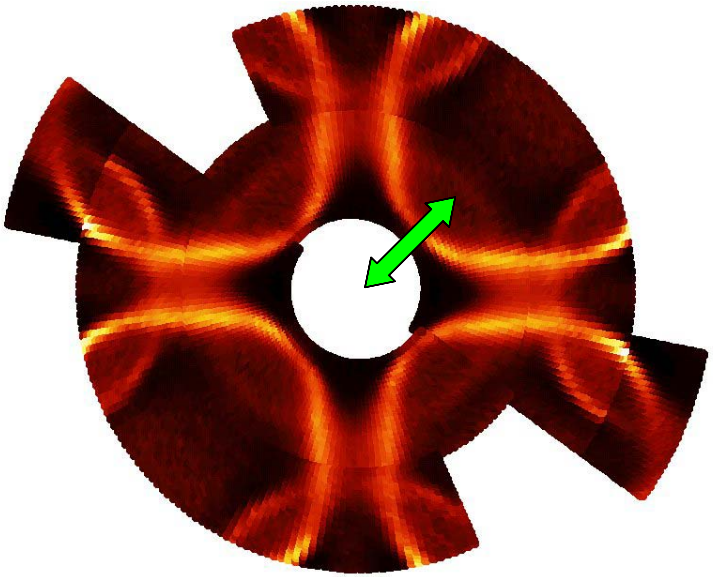
Energy ~ 40 meV

k-dependence:

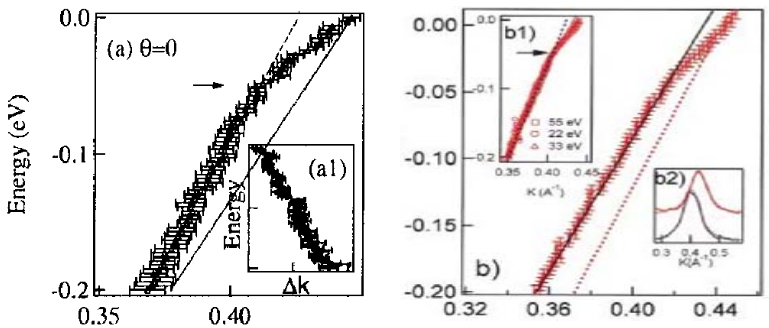


spin fluctuations

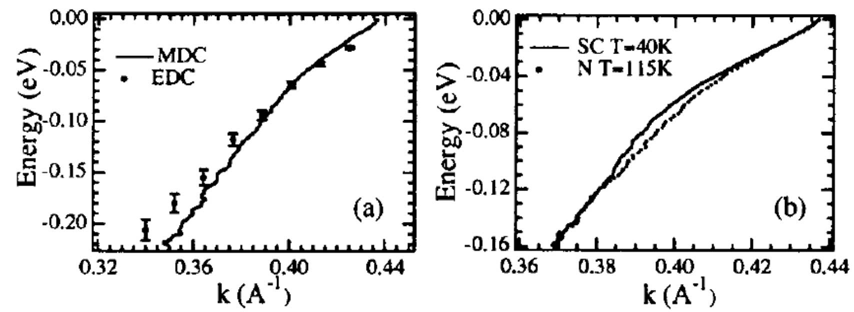
Nodal direction (GX)



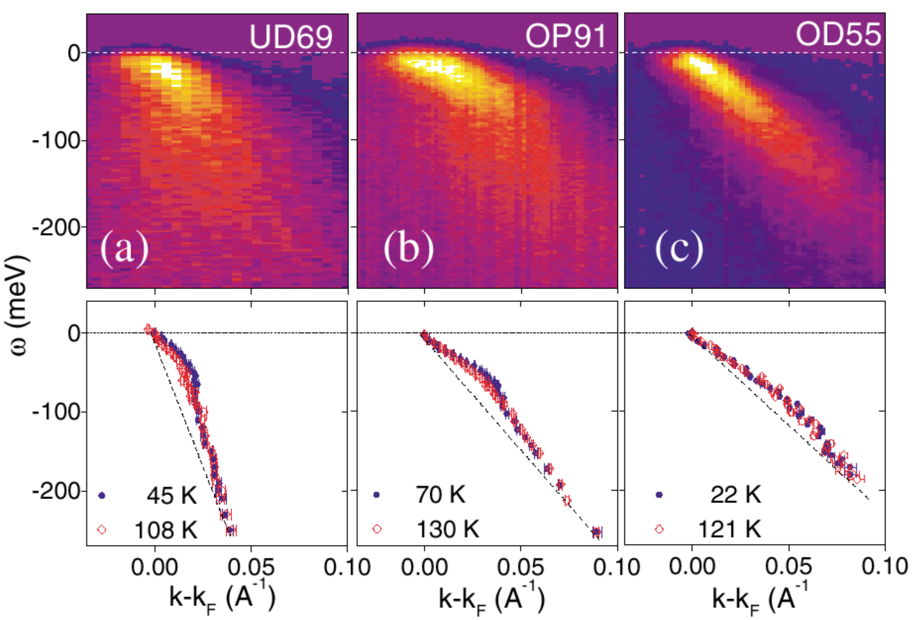
„Kinks“



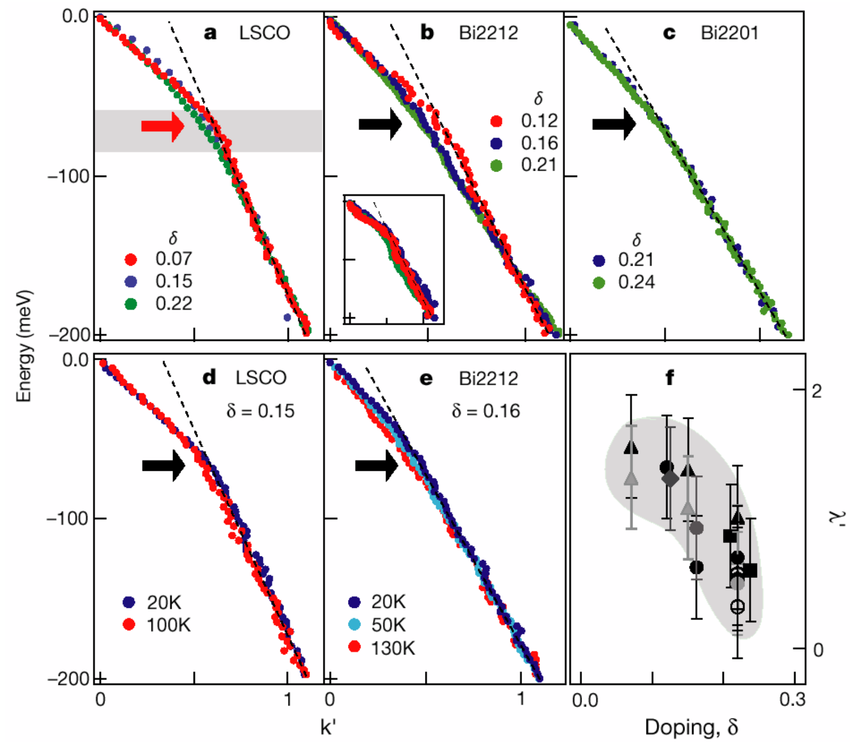
Bogdanov *PRL* 2000



Kaminski *PRL* 2001

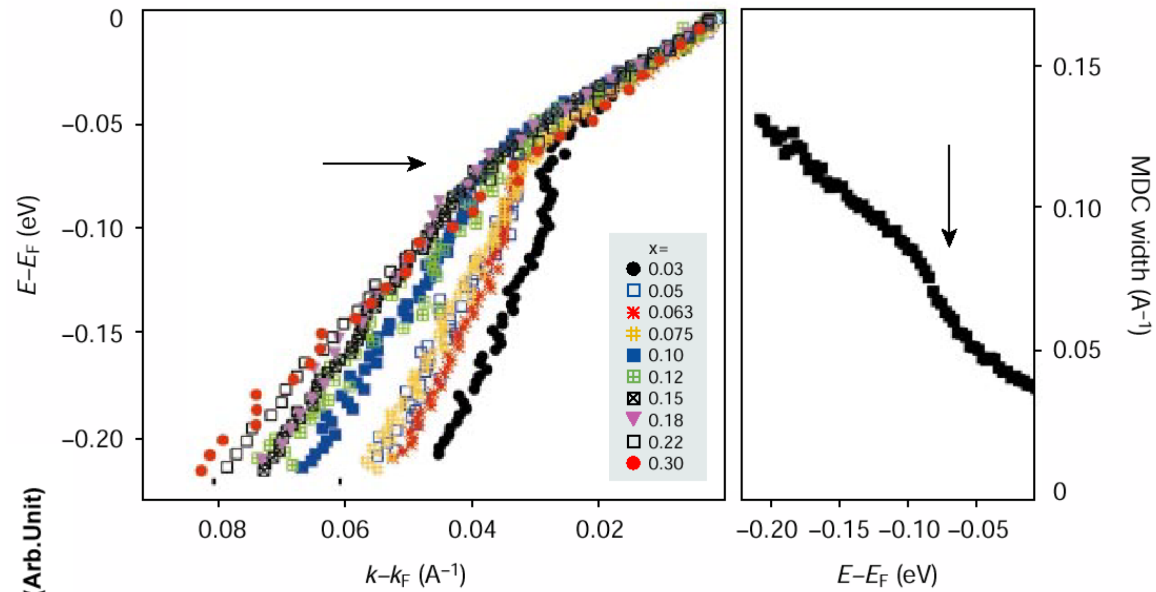


Johnson *PRL* 2001

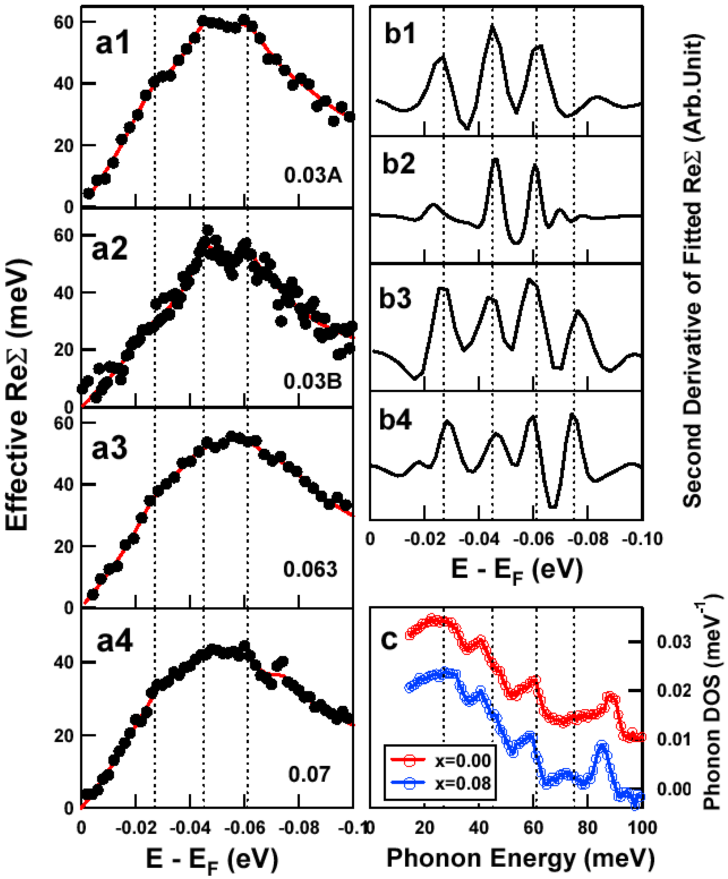


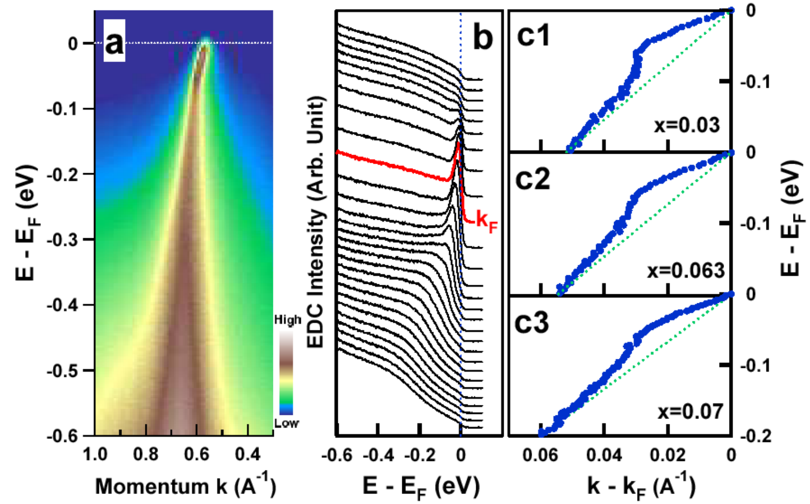
Lanzara *Nature* 2001

„Kinks“



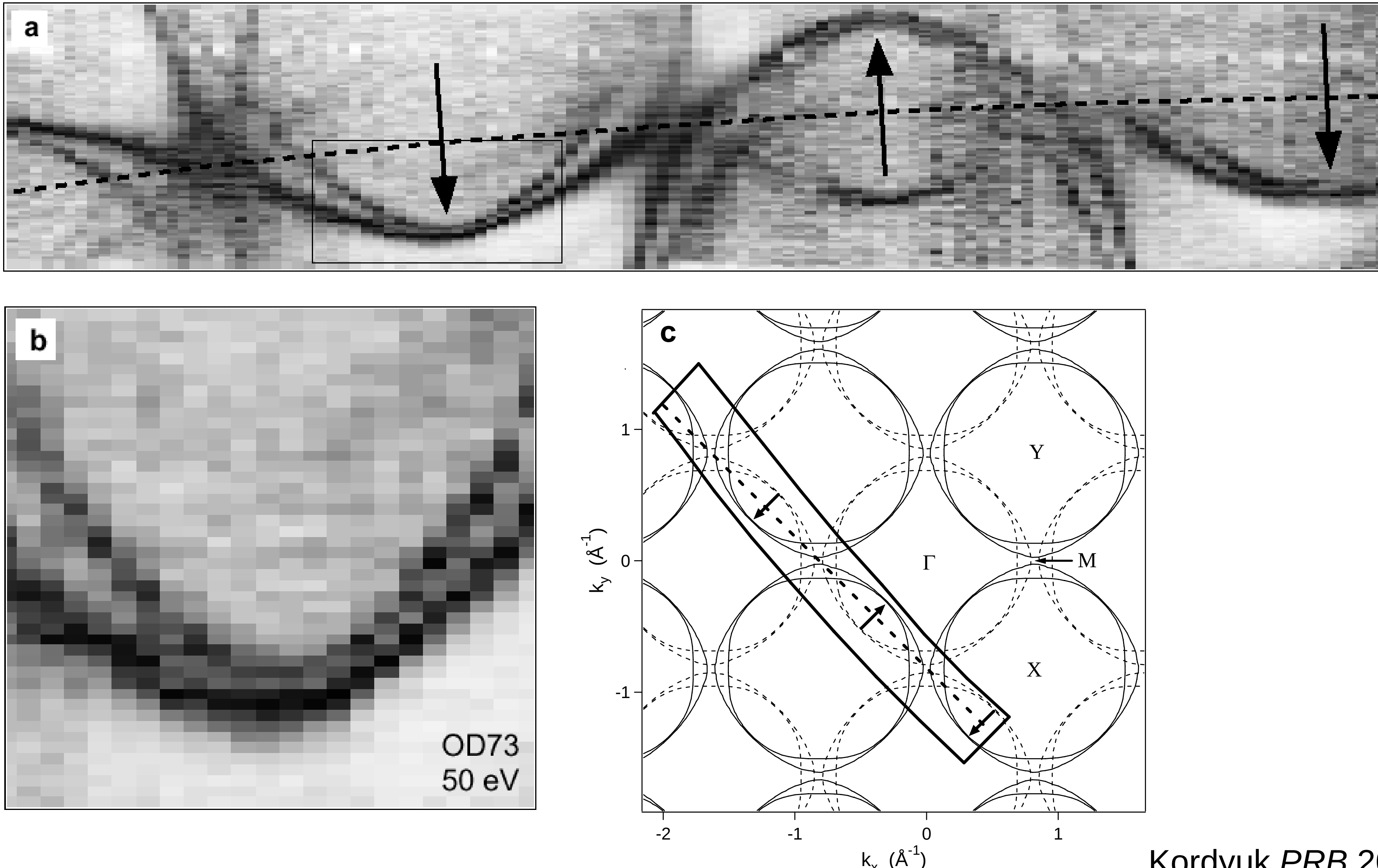
Zhou *Nature* 2003





Zhou *cond-mat* 2004

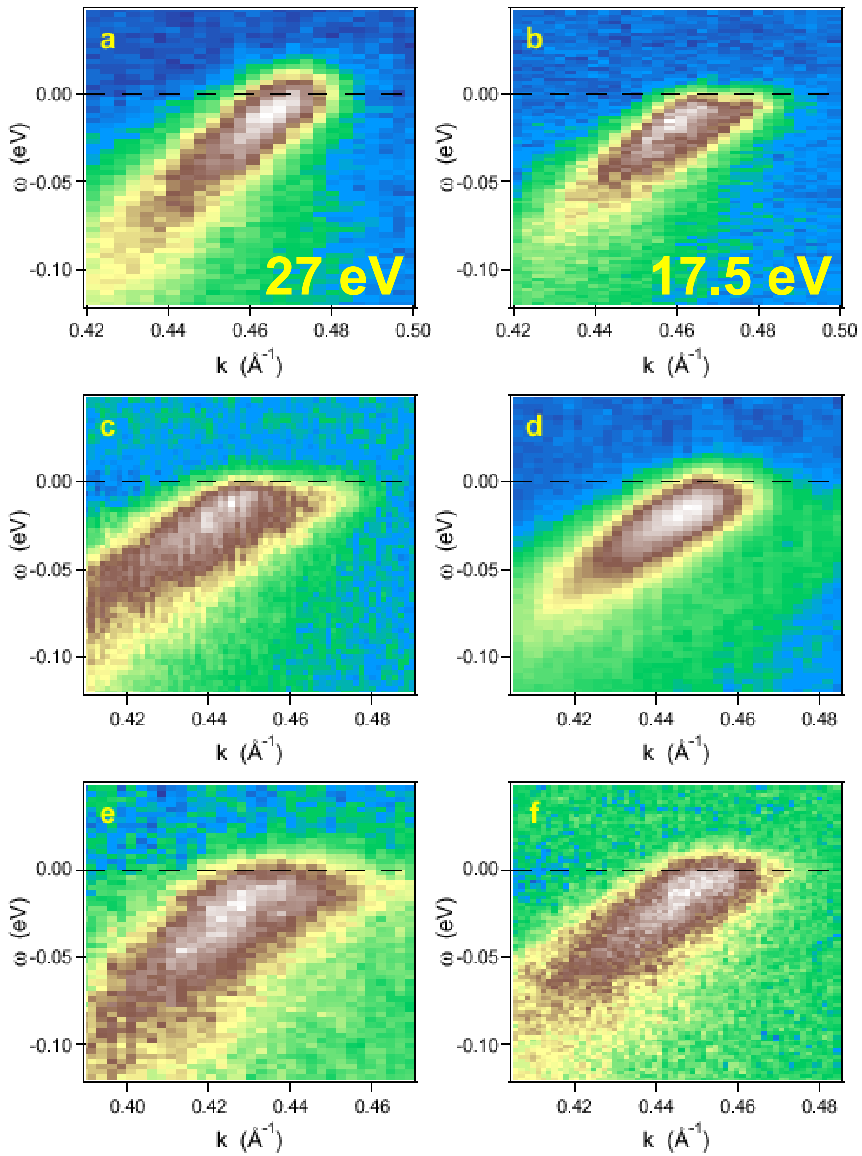
One complication: nodal splitting

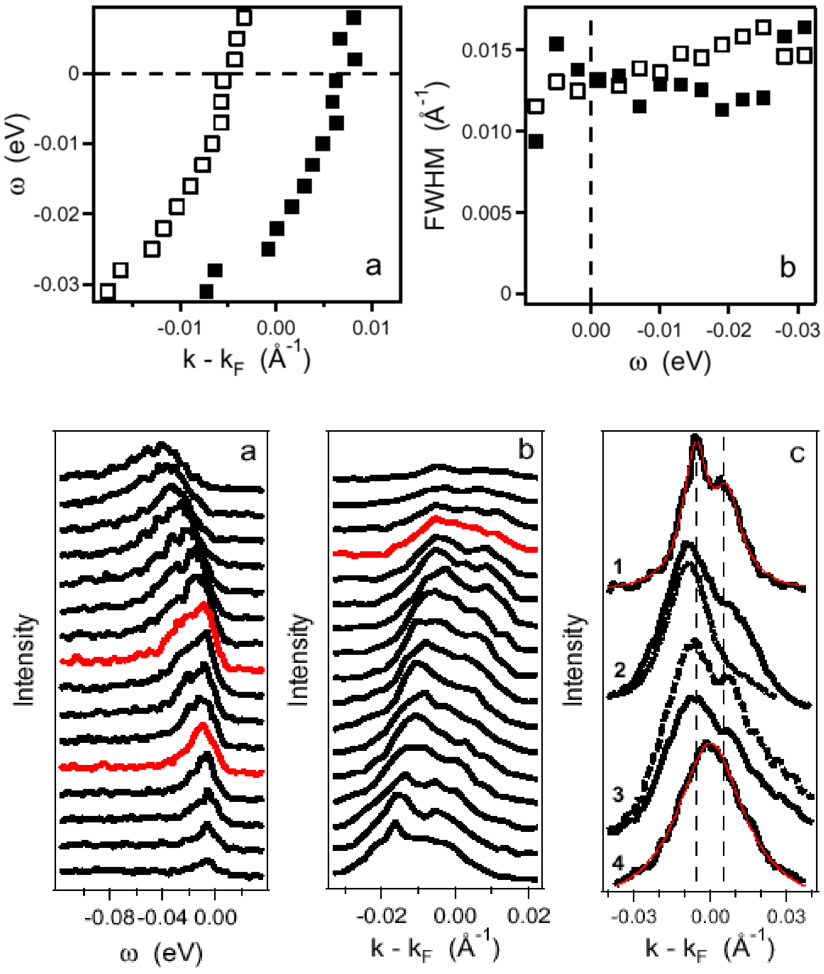


Kordyuk *PRB* 2004

Nodal splitting

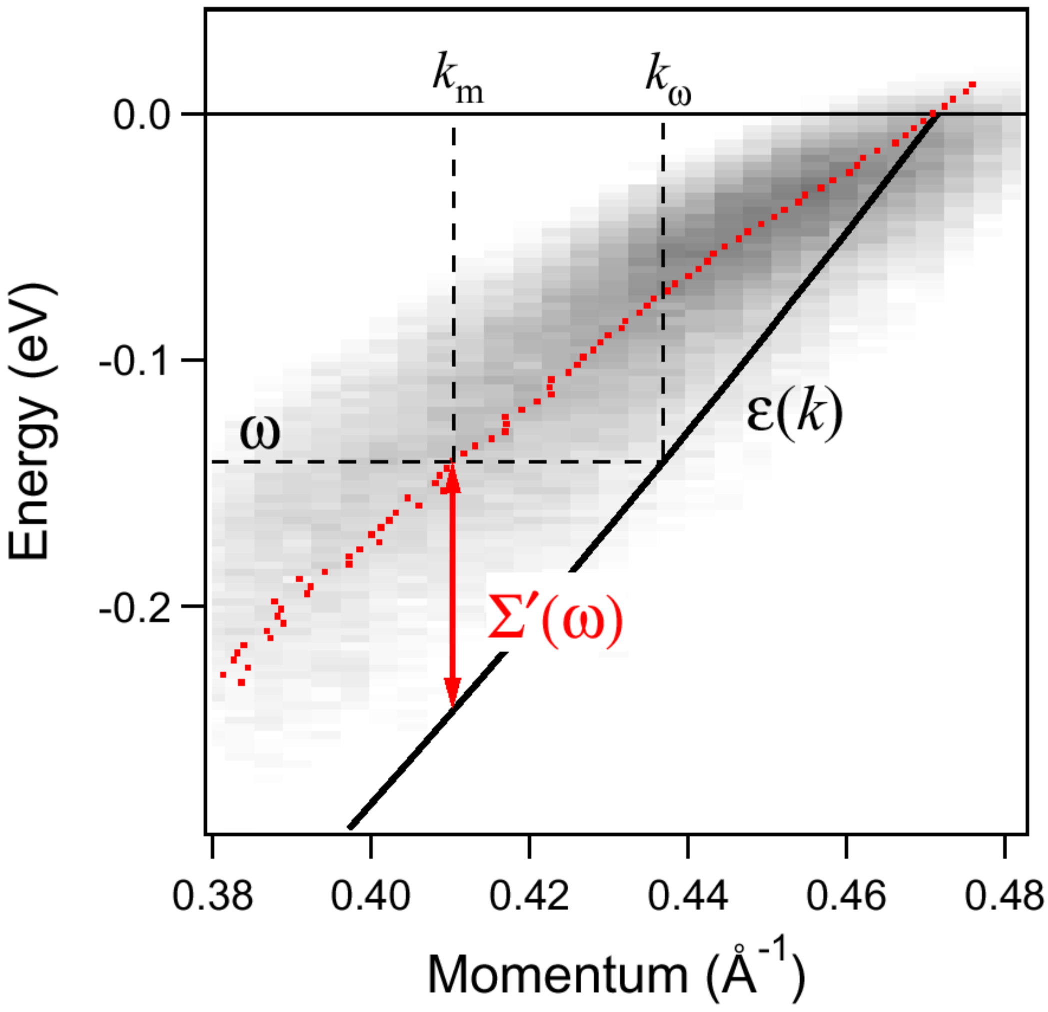
Δk = 0.012 1/Å
$\Delta\varepsilon$ = 50 meV (bare!)





Kordyuk *PRB* 2004

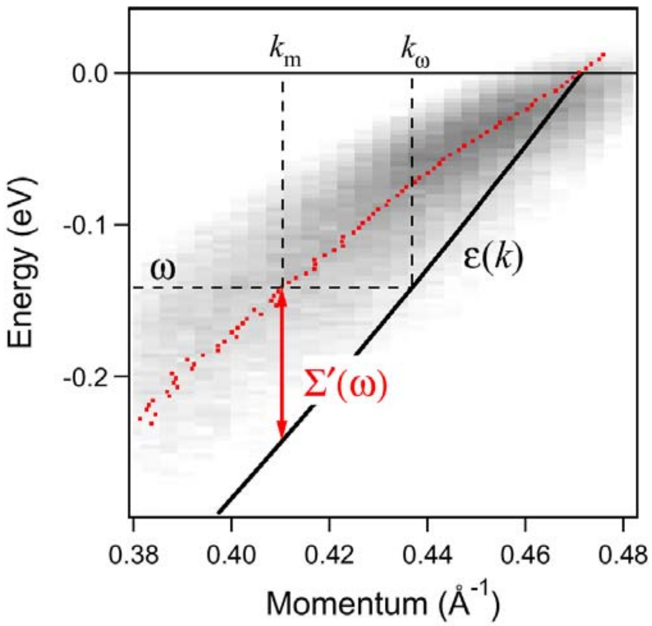
Bare dispersion



Kordyuk *cond-mat/0405696*

Self-energy approach

$$A(\omega, \mathbf{k}) = -\frac{1}{\pi}\frac{\Sigma''(\omega)}{(\omega - \varepsilon(\mathbf{k}) - \Sigma'(\omega))^2 + \Sigma''(\omega)^2}$$



$$\Sigma'(\omega) = \omega - \varepsilon(k_m)$$

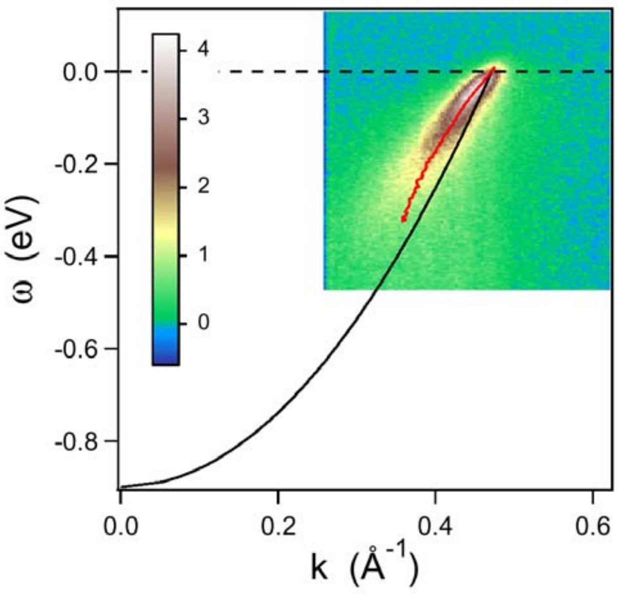
$$\Sigma''(\omega) = -v_F W(\omega)$$

Kordyuk *cond-mat/0405696*

Self-energy approach

$$\Sigma'(\omega) = \frac{v_F}{2}(k_m^2(\omega) - k_F^2) + \omega,$$

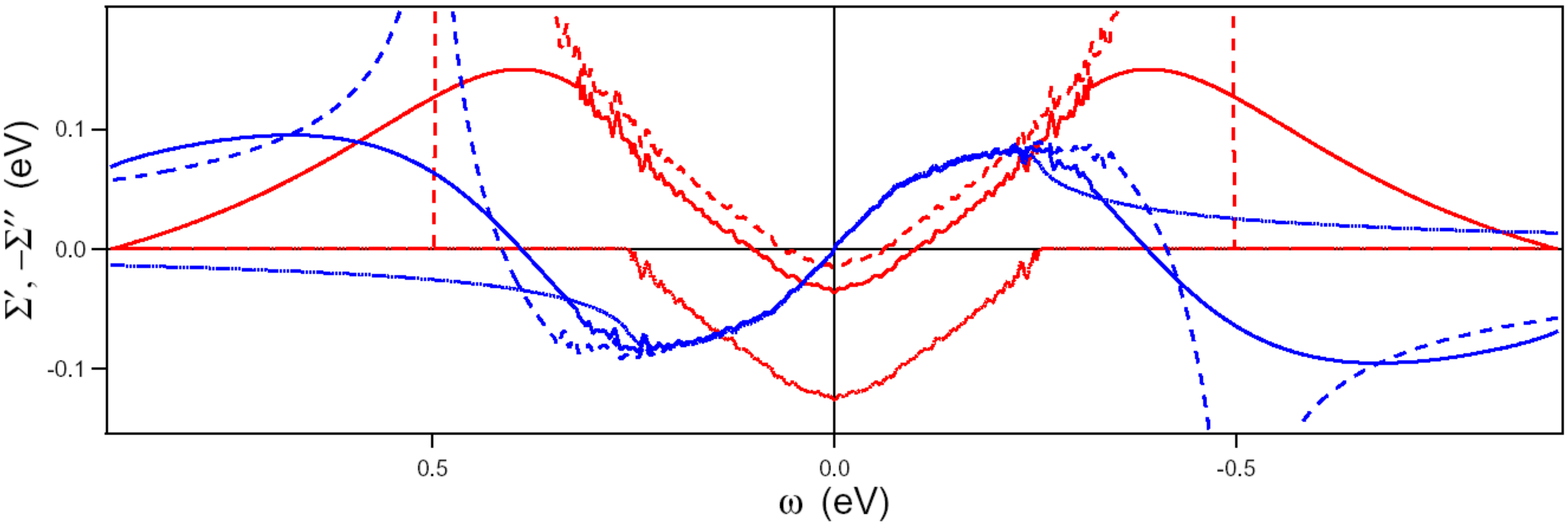
$$\Sigma''(\omega) = -v_F W(\omega)\sqrt{k_m^2(\omega) - W^2(\omega)}.$$

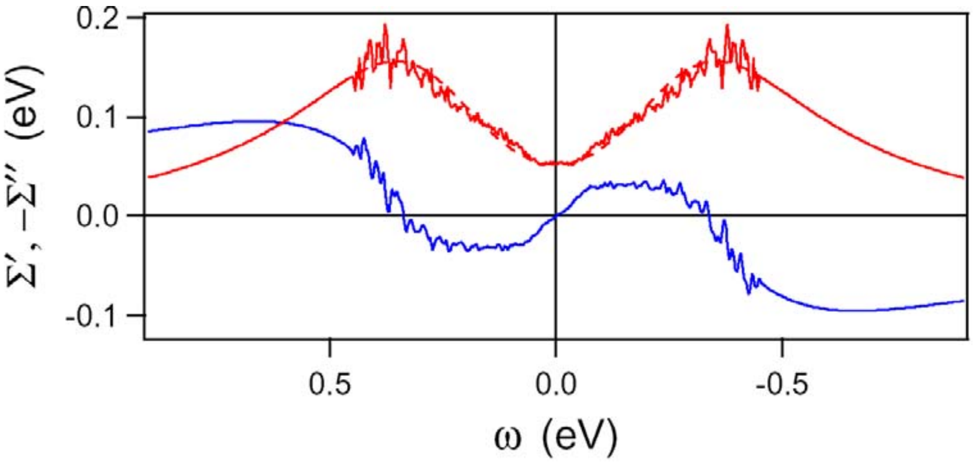


$$\Sigma'(\omega) = \mathrm{KK}\ \Sigma''(\omega)$$

Kordyuk *cond-mat/0405696*

Kramers-Kronig transform

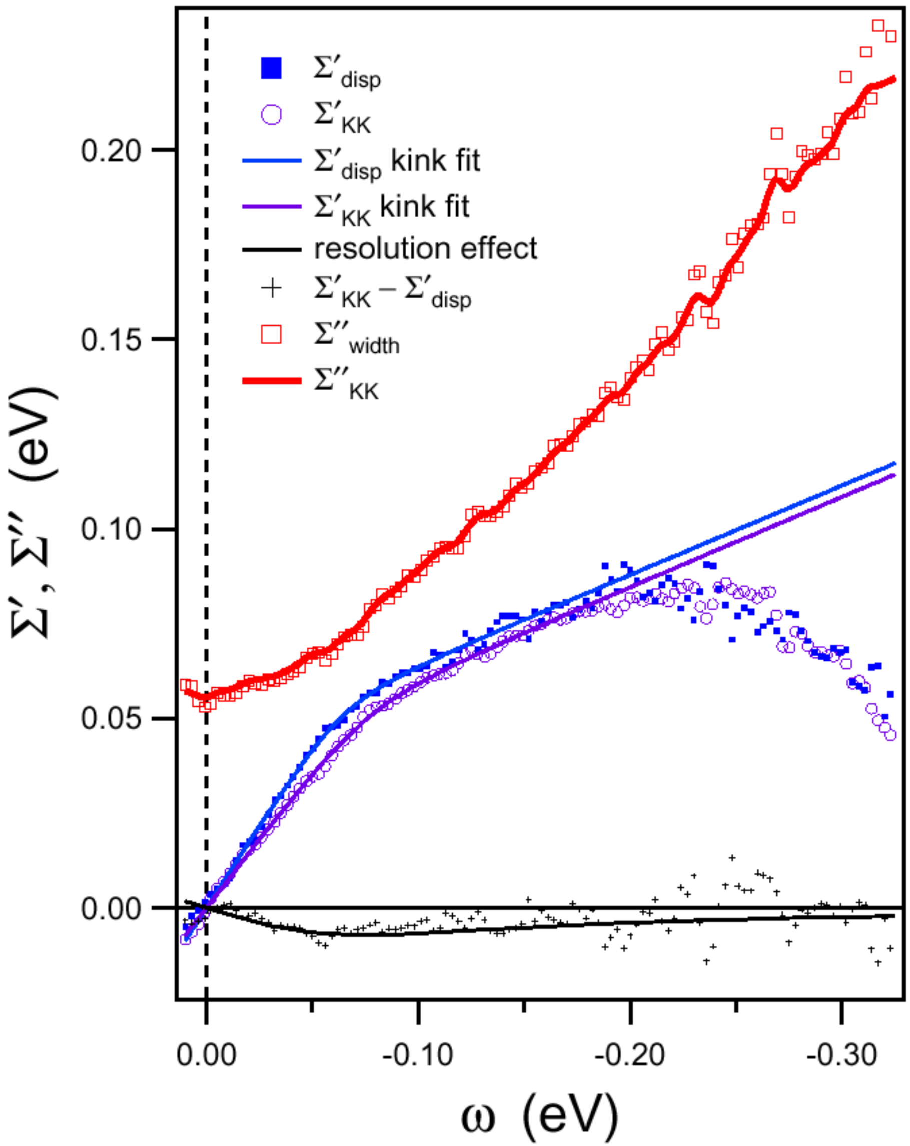


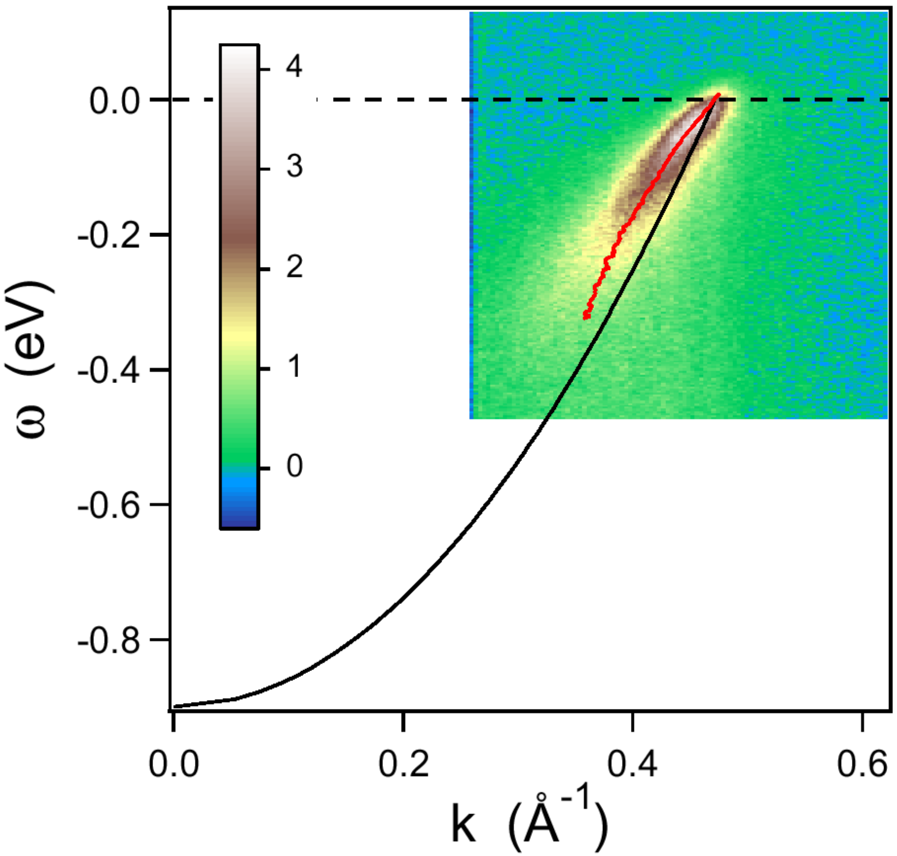


$\Sigma'(\omega) = \mathrm{KK}\ \Sigma''(\omega)$

Kordyuk *cond-mat/0409483*

Bare dispersion



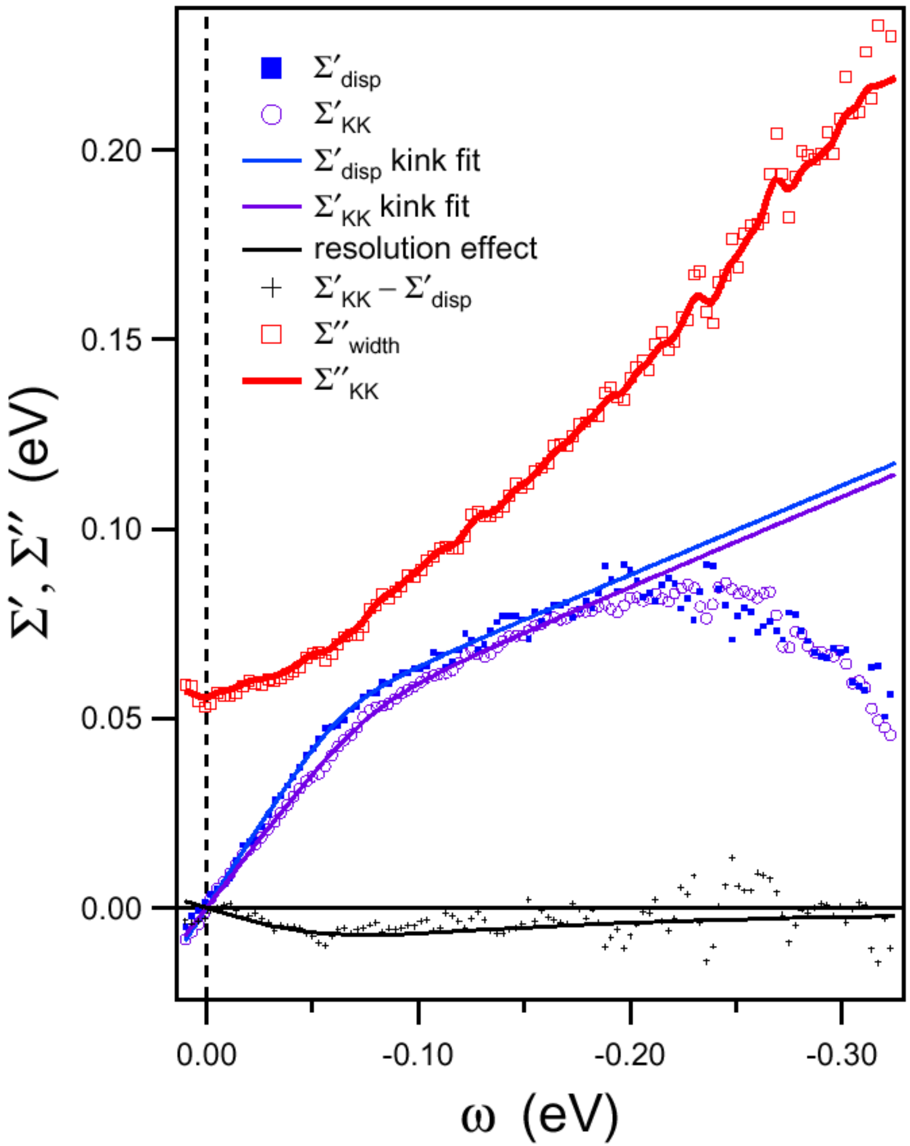


$$v_F = 3.82 \pm 0.17 \text{ eVÅ}$$

$$\lambda = 0.87 \pm 0.12$$

Kordyuk *cond-mat/0405696*

Bare dispersion



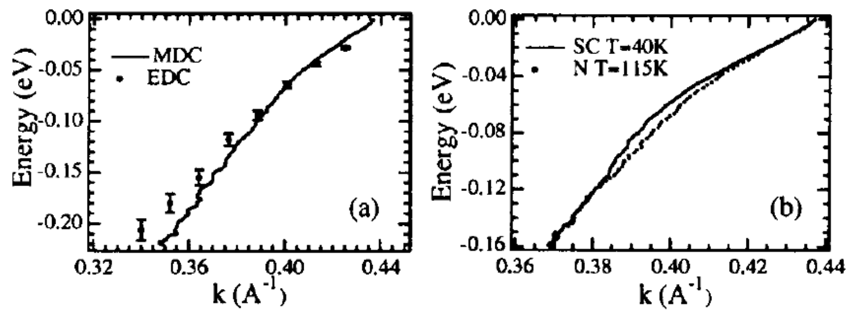
Self-consistency:
LDA + self-energy

Well defined quasi-particles

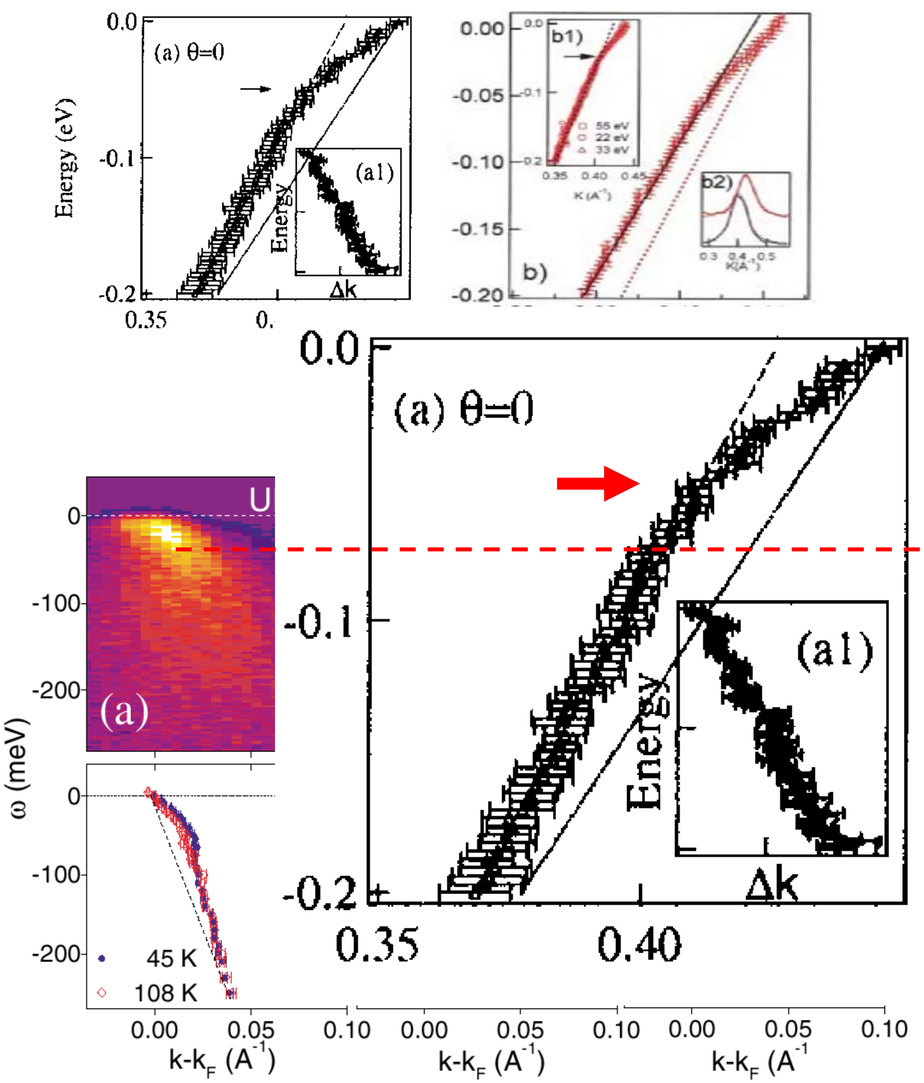
Kink phenomenology

Kordyuk *cond-mat/0405696*

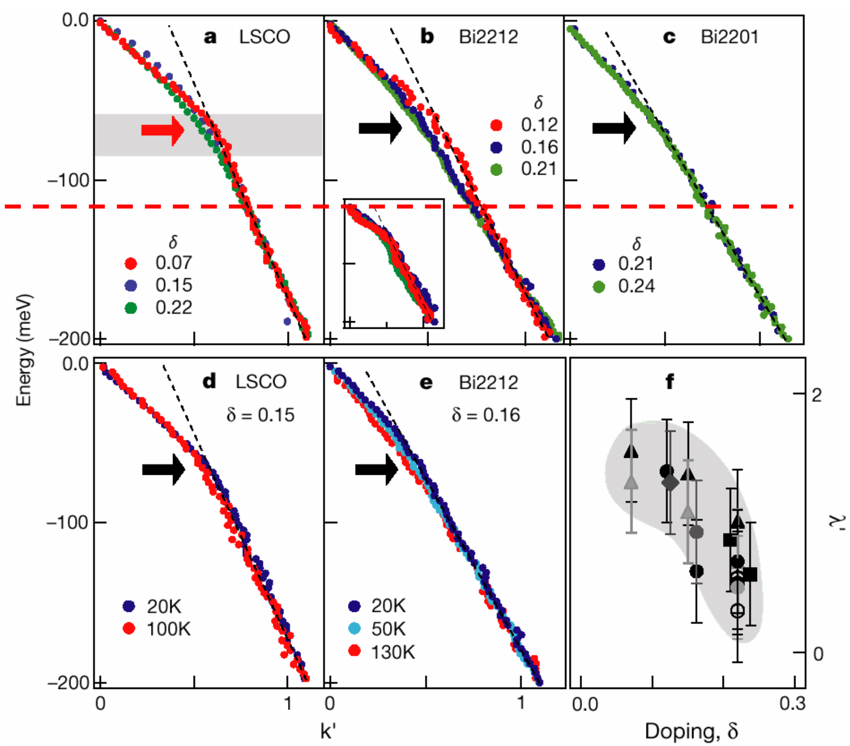
„Kinks“



Kaminski *PRL* 2001

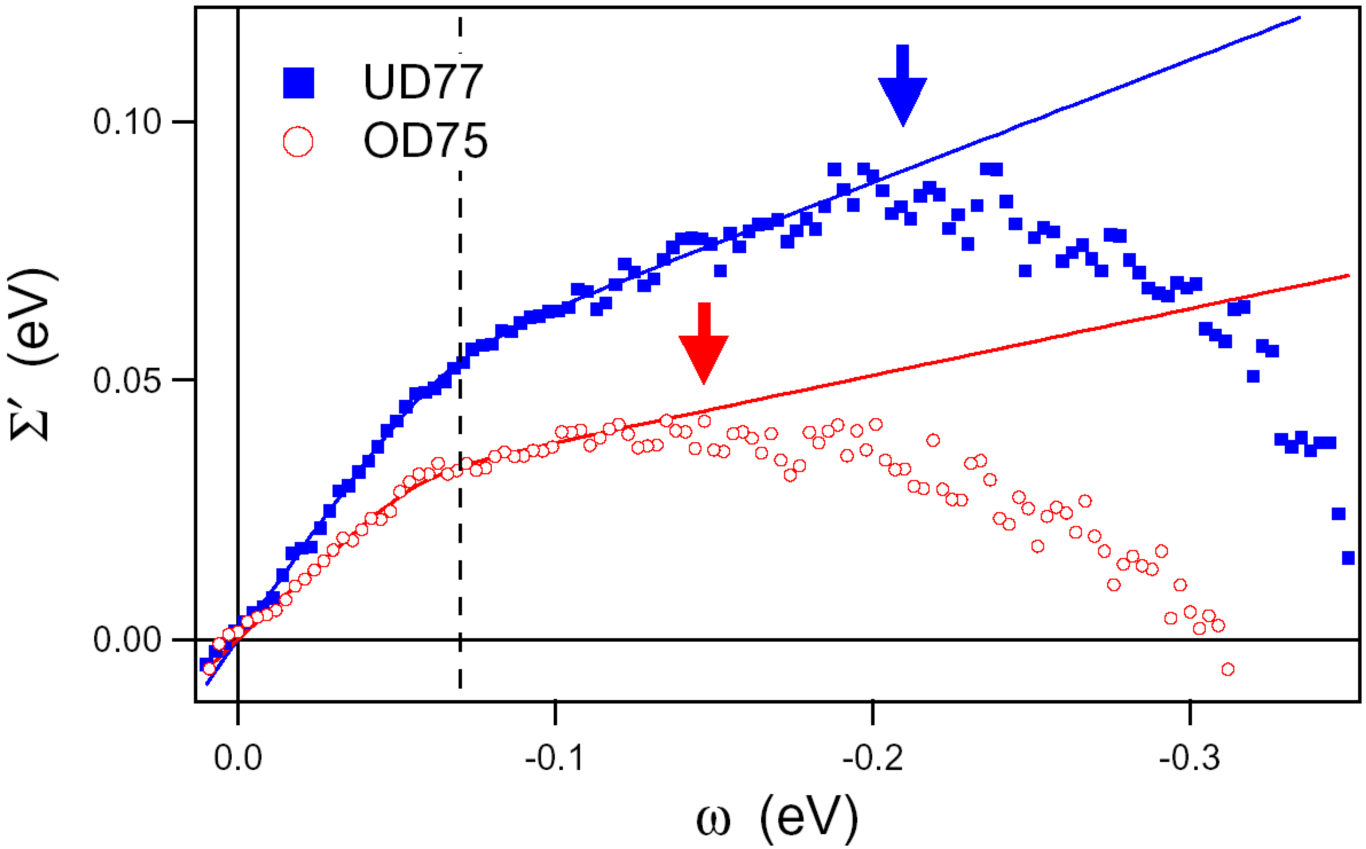


Johnson *PRL* 2001



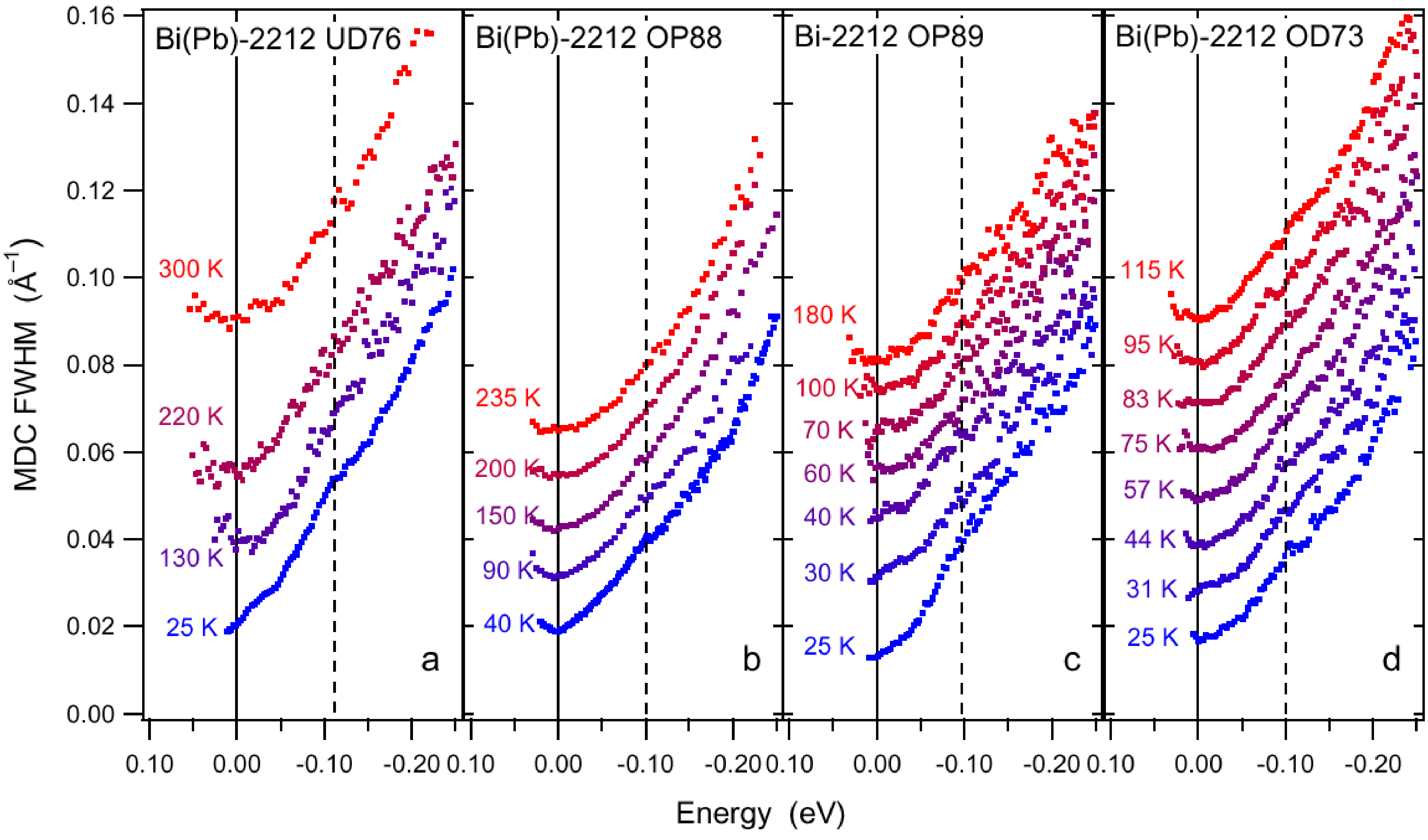
Lanzara *Nature* 2001

Phenomenology of the kink



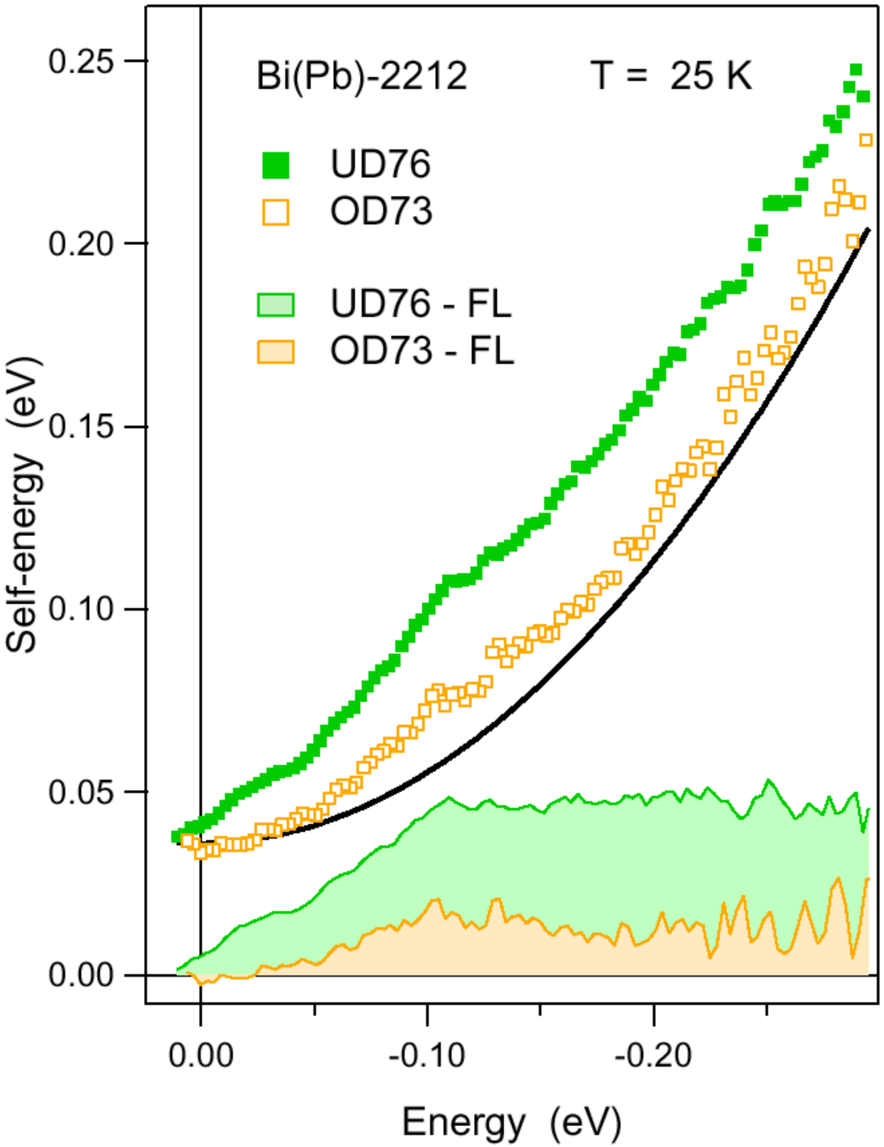
Kordyuk *cond-mat/0409483*

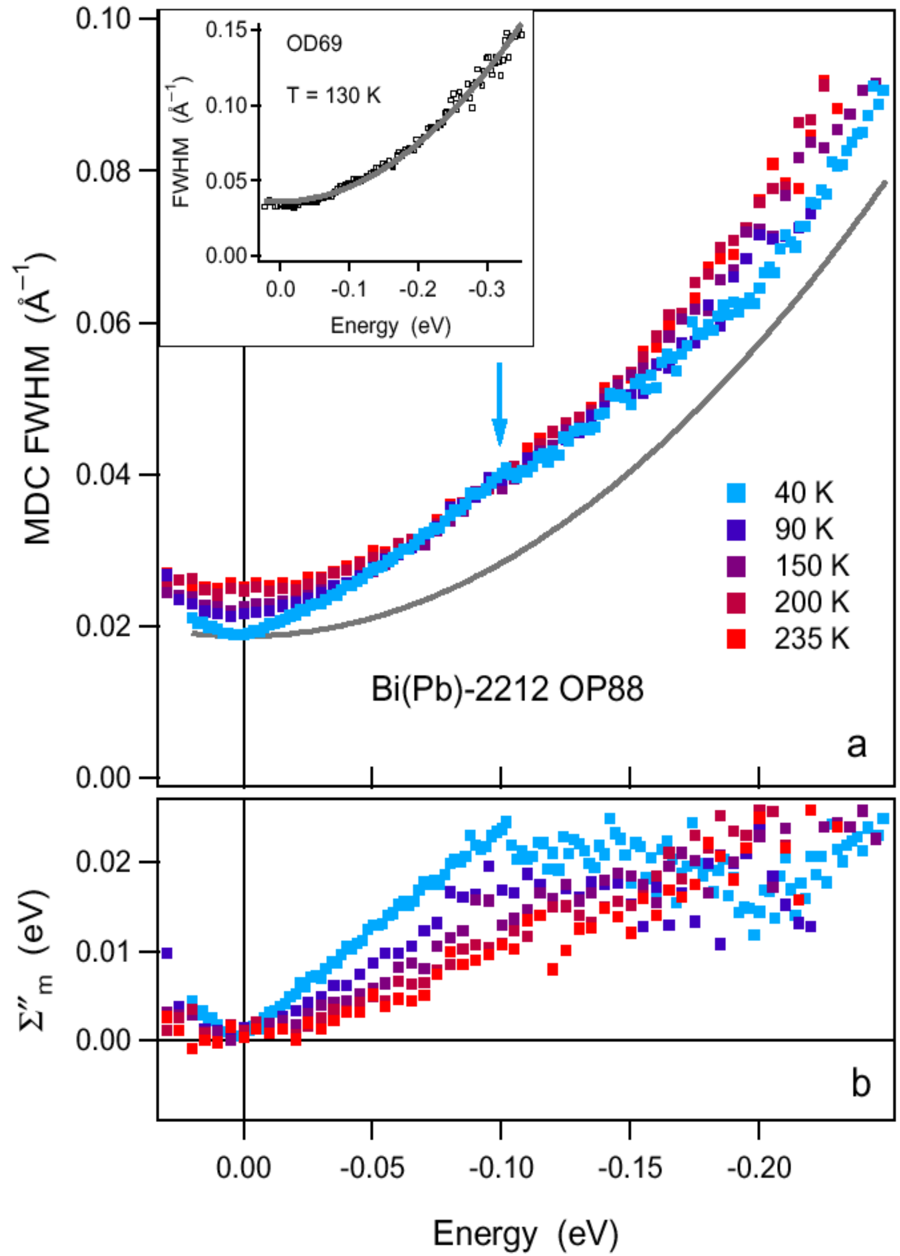
Scattering rate kink



Kordyuk *PRL* 2004

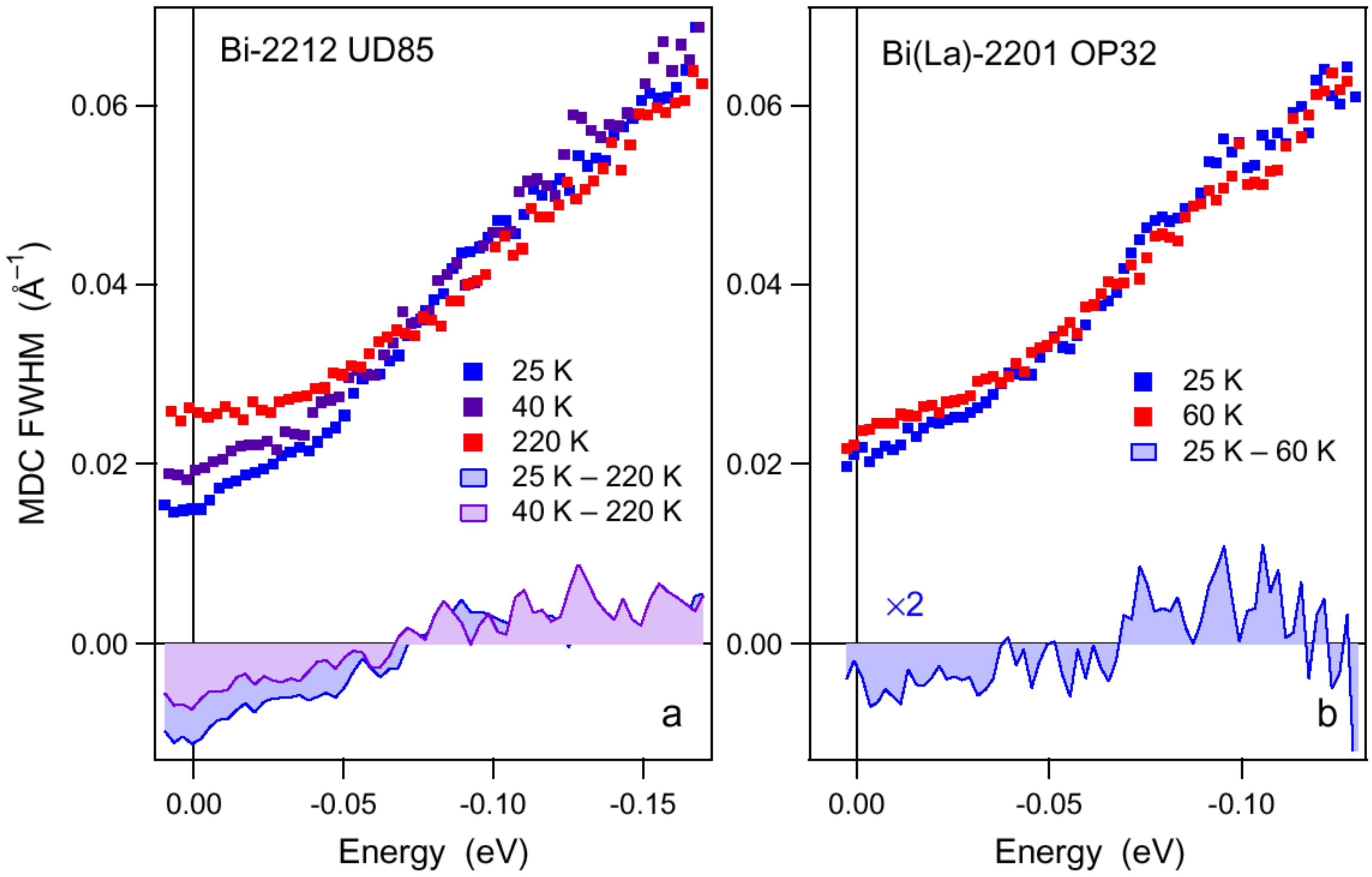
Scattering rate





Kordyuk *PRL* 2004

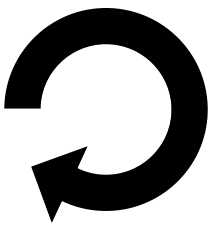
Scattering rate kink

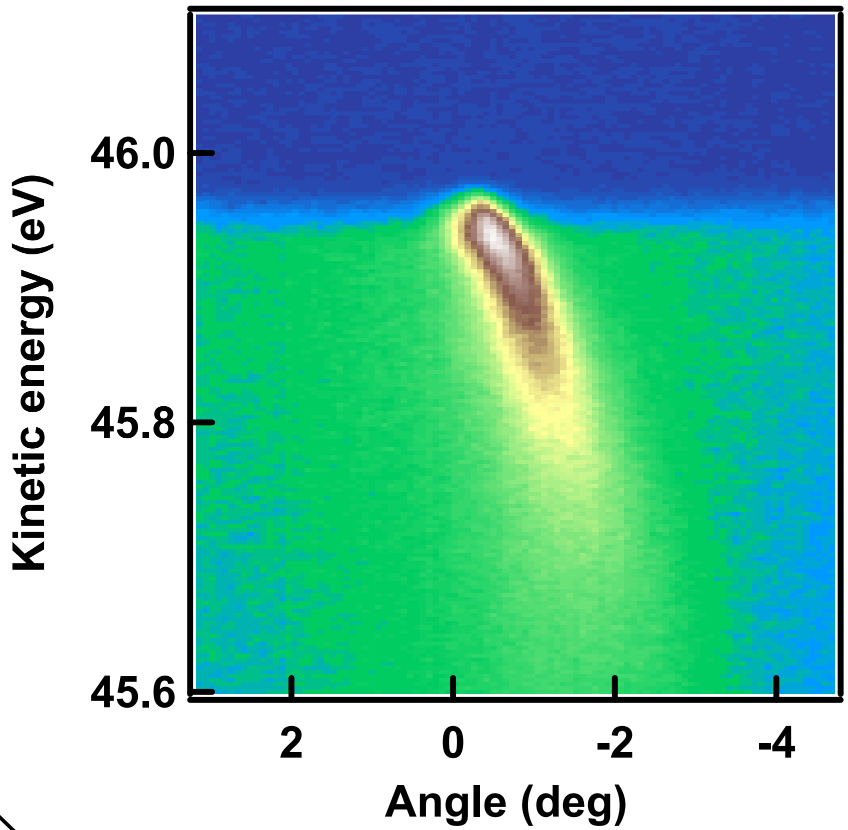


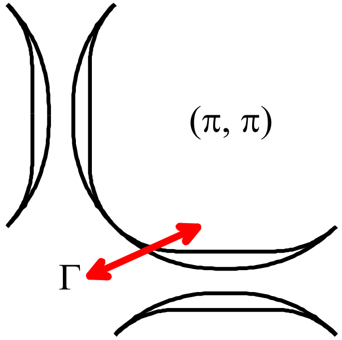
Kordyuk *PRL* 2004

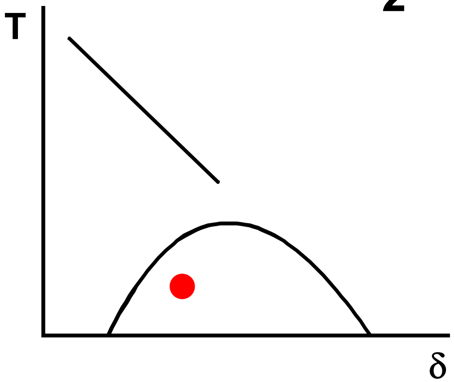
Parity

Circular dichroism in nodal region



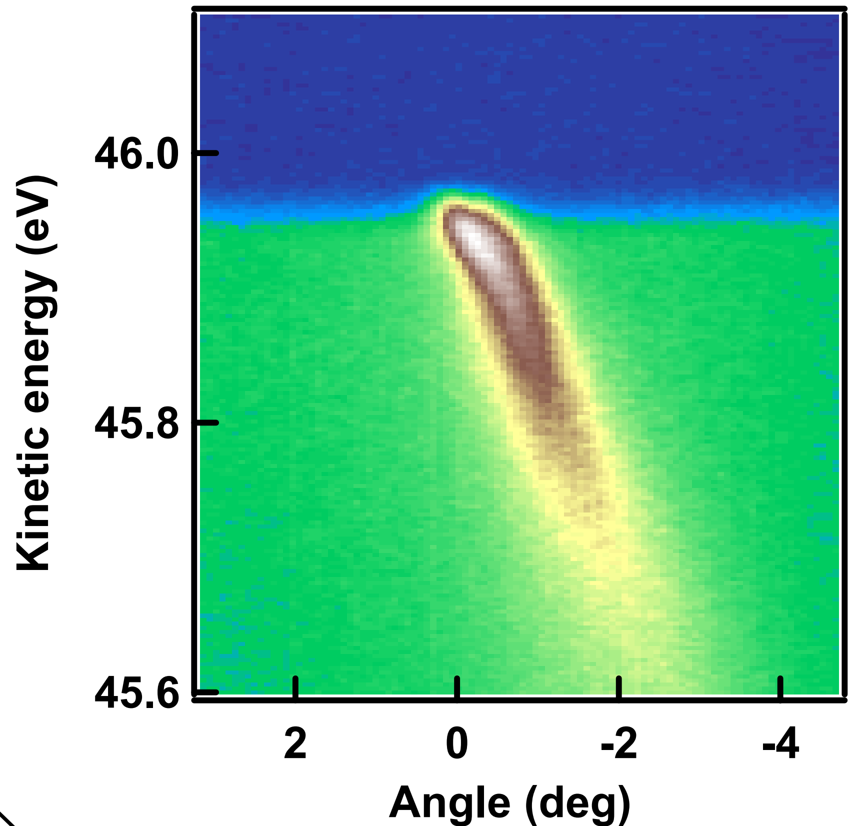


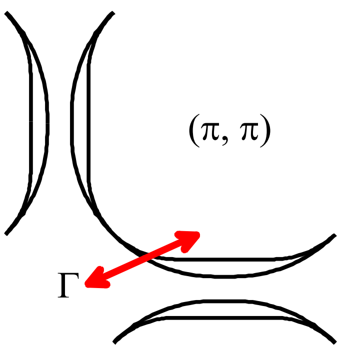


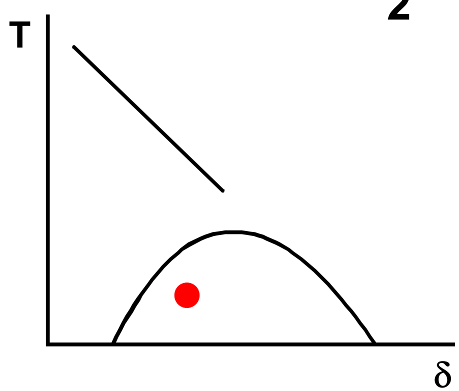


Borisenko 2004

Circular dichroism in nodal region

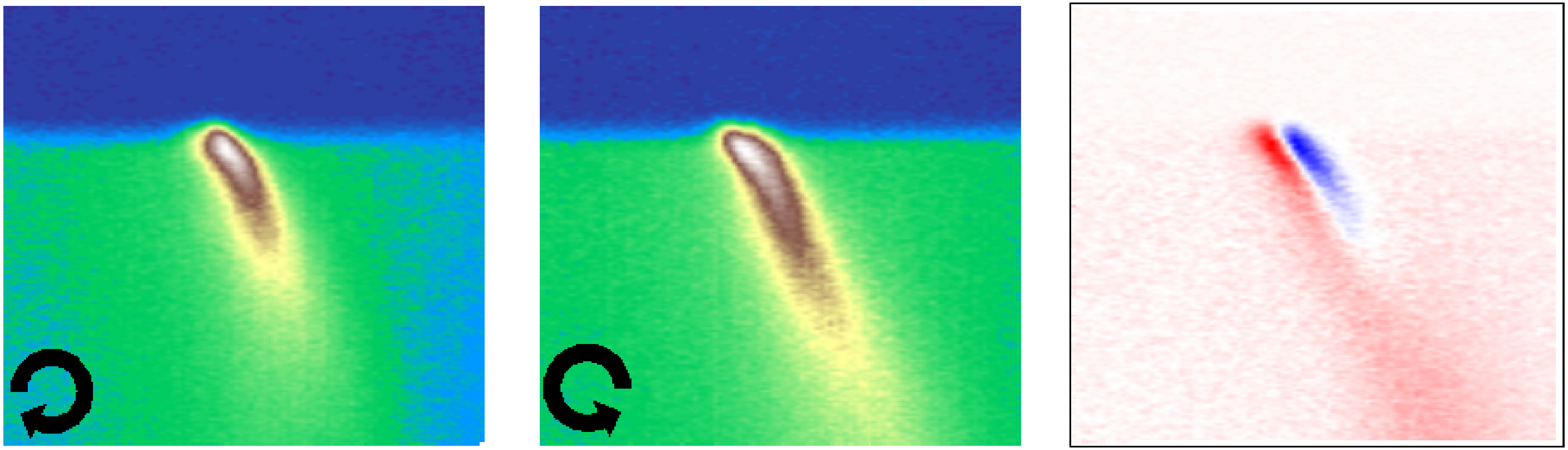


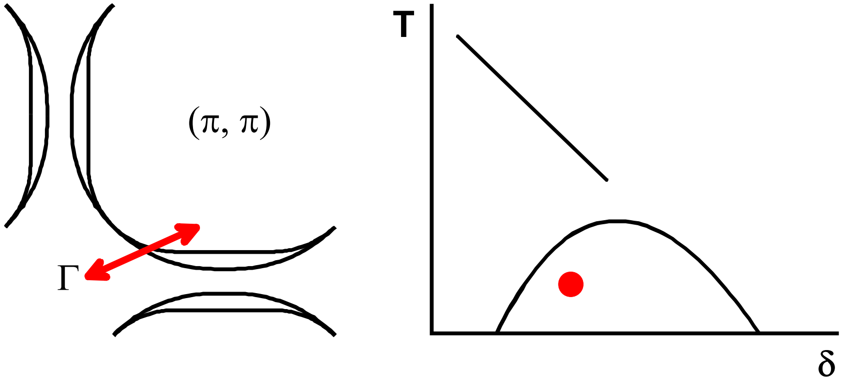




Borisenko 2004

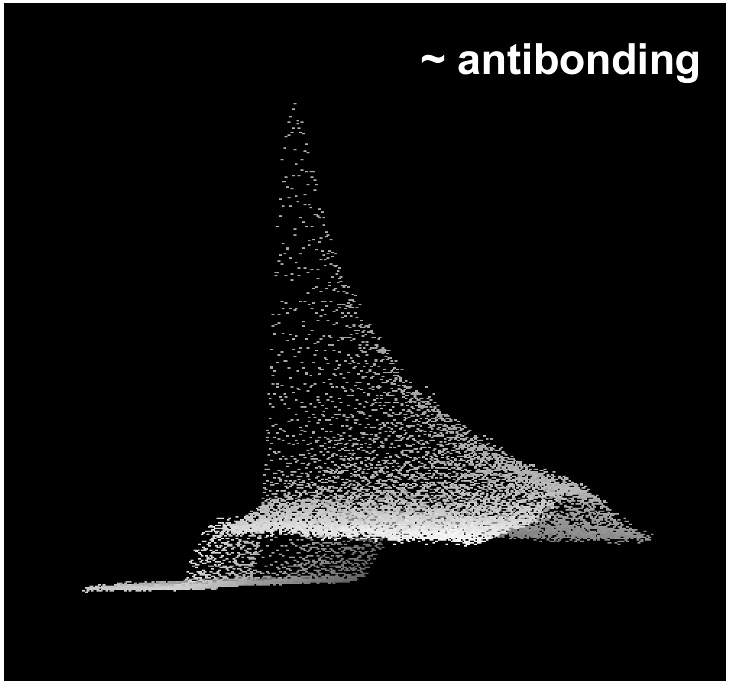
Circular dichroism in nodal region

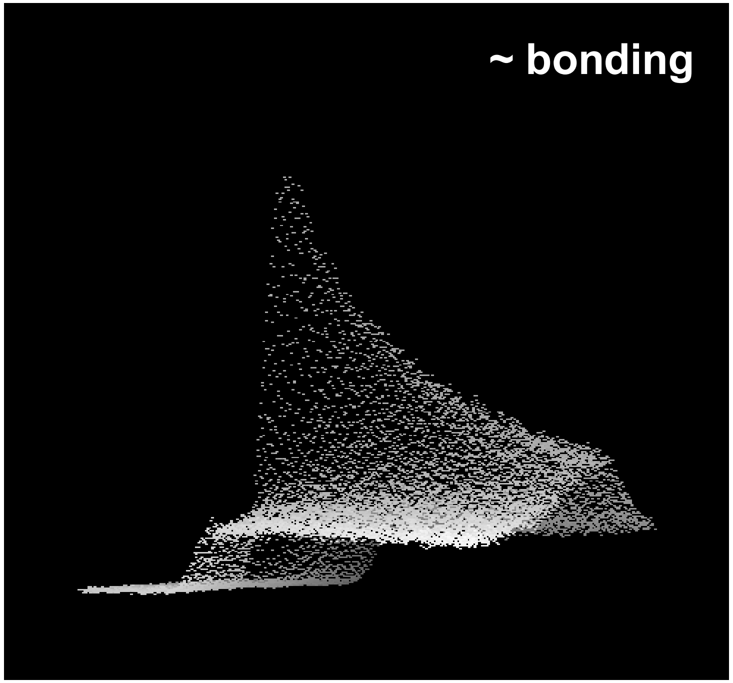


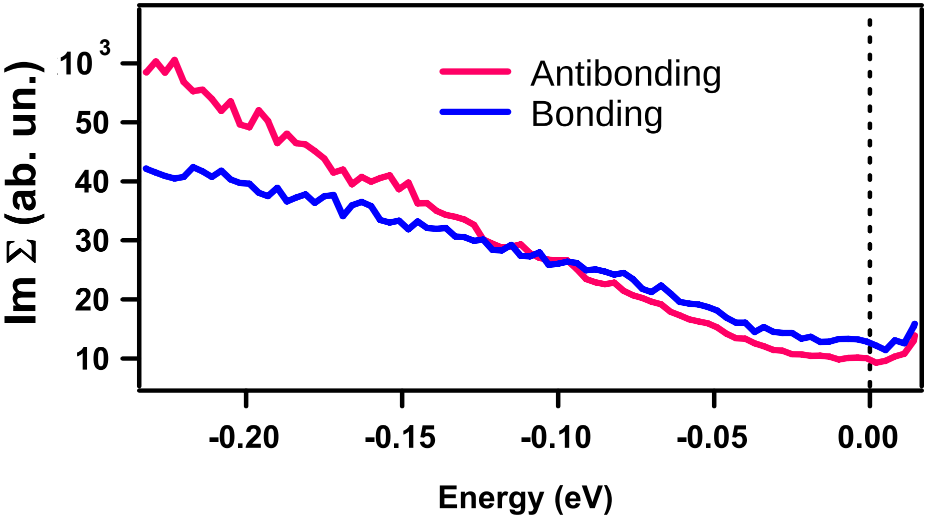


Borisenko 2004

Odd scattering







Borisenko 2004

Nodal electrons couple to …

Doping dependence: **UD↑**
OD↓

Temperature dependence:
< T_c for OD
< T* for UD

Parity: **odd boson**

spin fluctuations

Conclusions

- The spectral function analysis is applicable to the ARPES spectra from HTSC cuprates.
- Along the nodal direction well defined quasiparticles exist even for the underdoped Bi-2212 in the pseudogap state.
- Two channels in the scattering rate can be distinguished.
- The main doping independent contribution to the scattering can be well understood in terms of the conventional Fermi liquid model...
- ...while the additional doping dependent contribution has a magnetic origin.
- The magnetic contribution essentially increases with underdoping becoming dominant for the rest of the Brillouin zone and therefore determines the unusual properties of the cuprates in the superconducting and pseudo-gap phases.

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Sergey Borisenko

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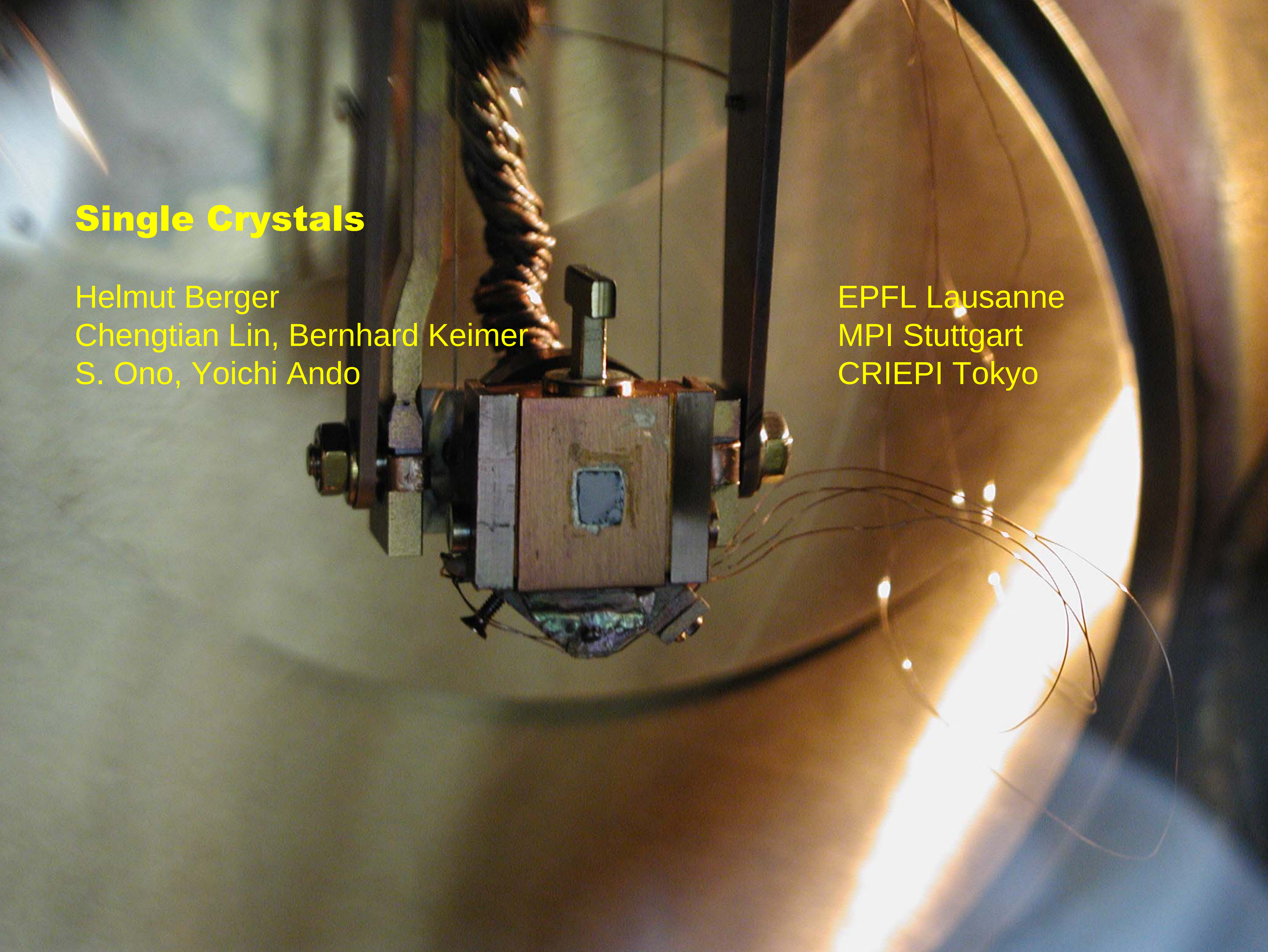
,

Single Crystals

Helmut Berger — EPFL Lausanne
Chengtian Lin, Bernhard Keimer — MPI Stuttgart
S. Ono, Yoichi Ando — CRIEPI Tokyo



Synchrotron Light

Rolf Follath	BESSY Berlin
Stefano Turchini, Cesare Grazioli	ELETTRA Trieste
Ming Shi, Luc Patthey	SLS Villigen


THE END