高分解能角度分解光電子分光による $Bi_2Sr_2CuO_{6+\delta}$ の電子構造の解明

(SRCとISSPの利用)

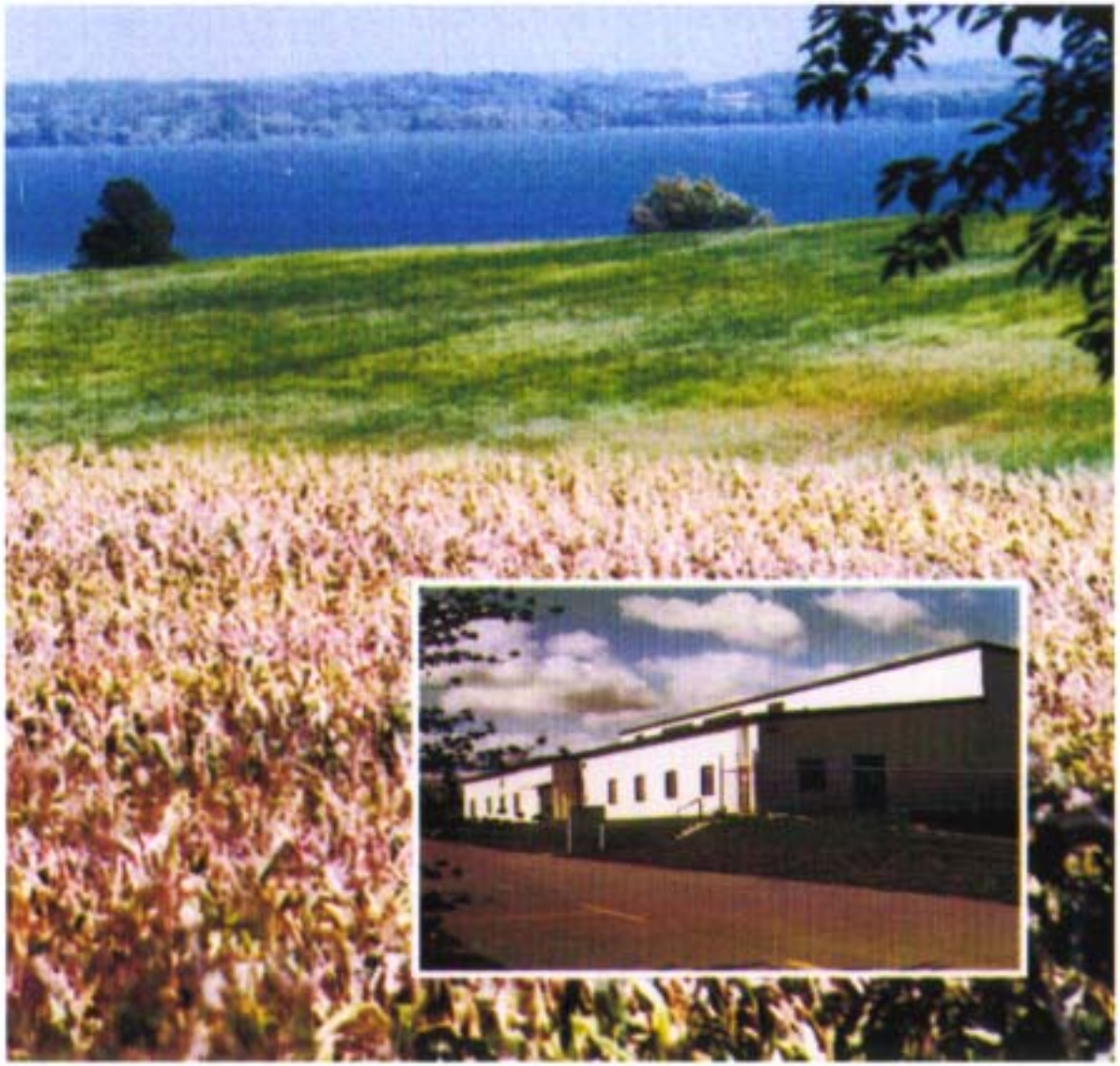
名古屋大学大学院工学研究科

竹 内 恒 博

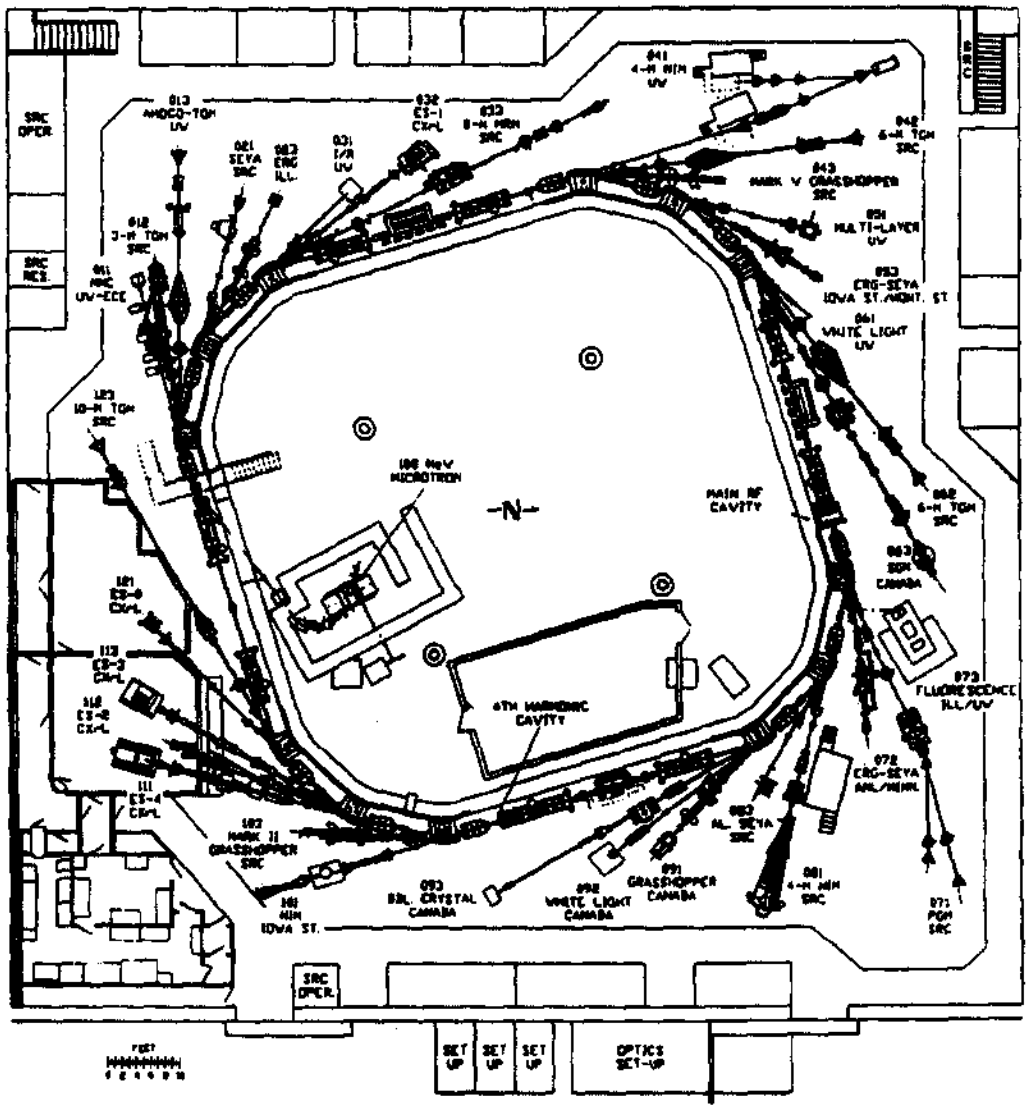
Today's Topics

1. SRC (4m NIM and U-NIM beam line)
2. Fermi surface topology of $Bi_2Sr_2CuO_{6+\delta}$
3. Qualitative analysis of the electron transport properties of $Bi_2Sr_2CuO_{6+\delta}$

The Synchrotron Radiation Center (University of Wisconsin - Madison)



Synchrotron Radiation Center (University of Wisconsin - Madison)



SRC

Energy : 800 MeV (1000 MeV)

Circumference : 88.9 m

Average Radios : 14.1 m

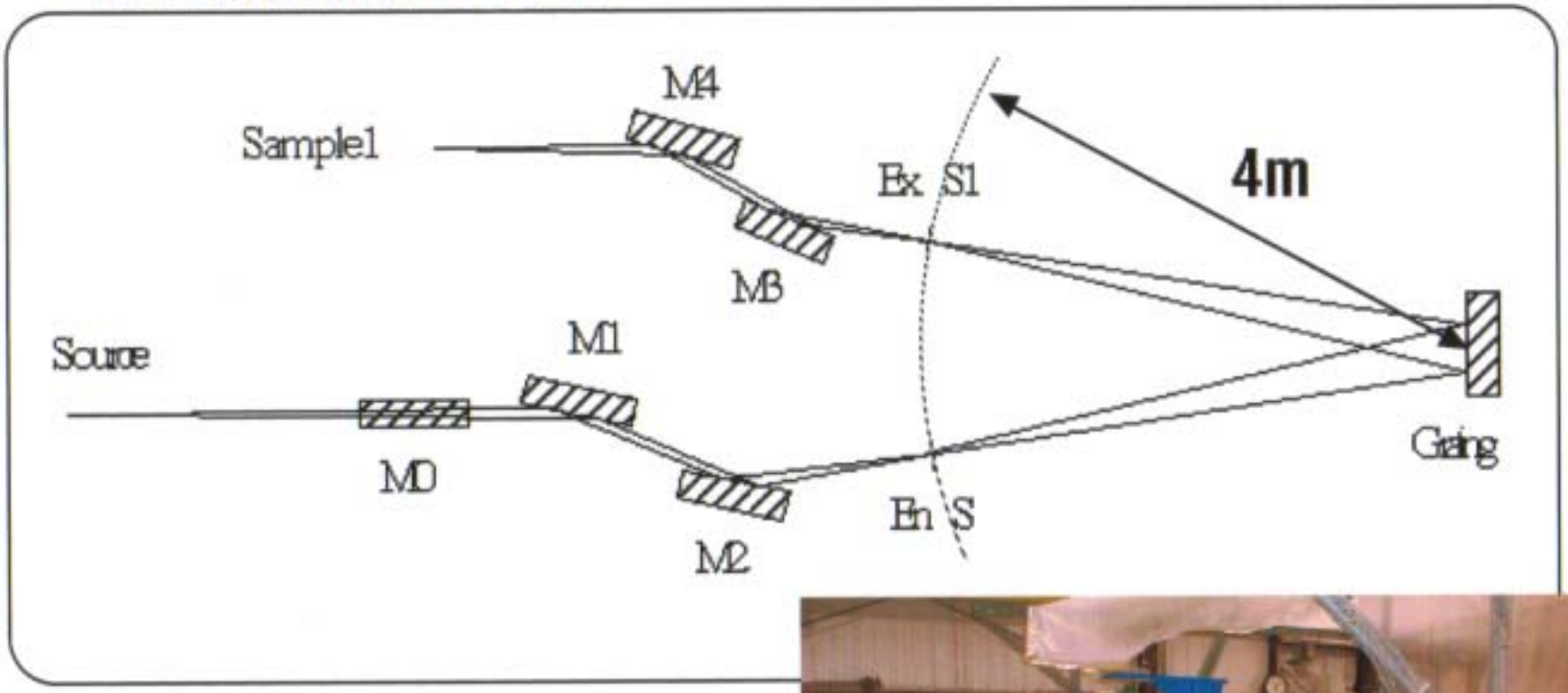
UVSOR

Energy : 750 MeV

Circumference : 53.2 m

Average Radios : 8.5 m

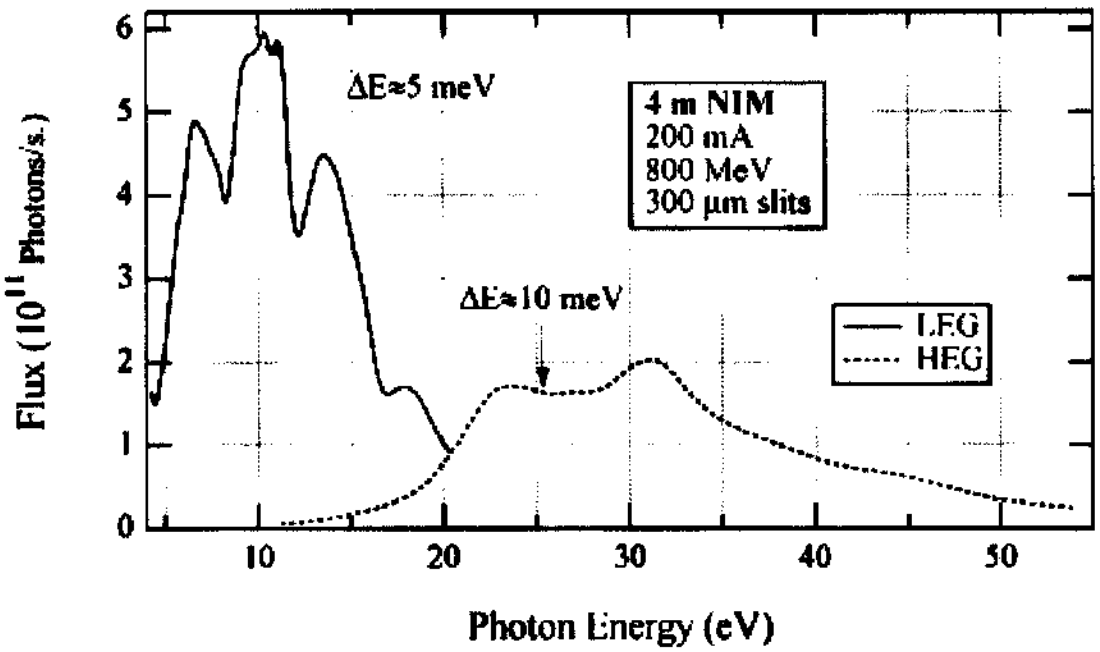
4mNIM and U-NIM



4m NIM

Energy Range : 4 - 60 eV

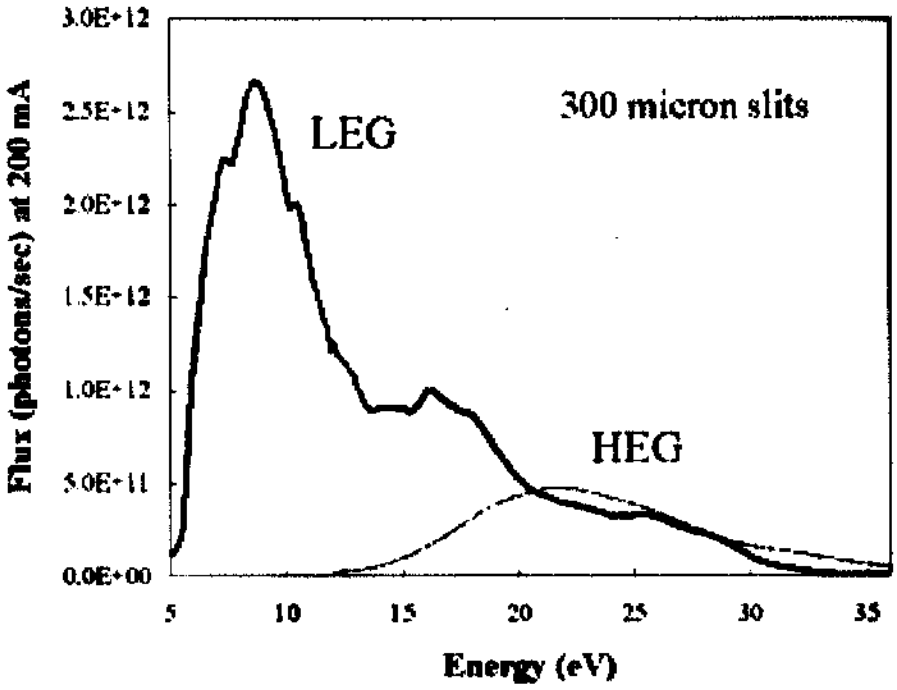
Flux : 1×10^{11} photons/s at 20eV

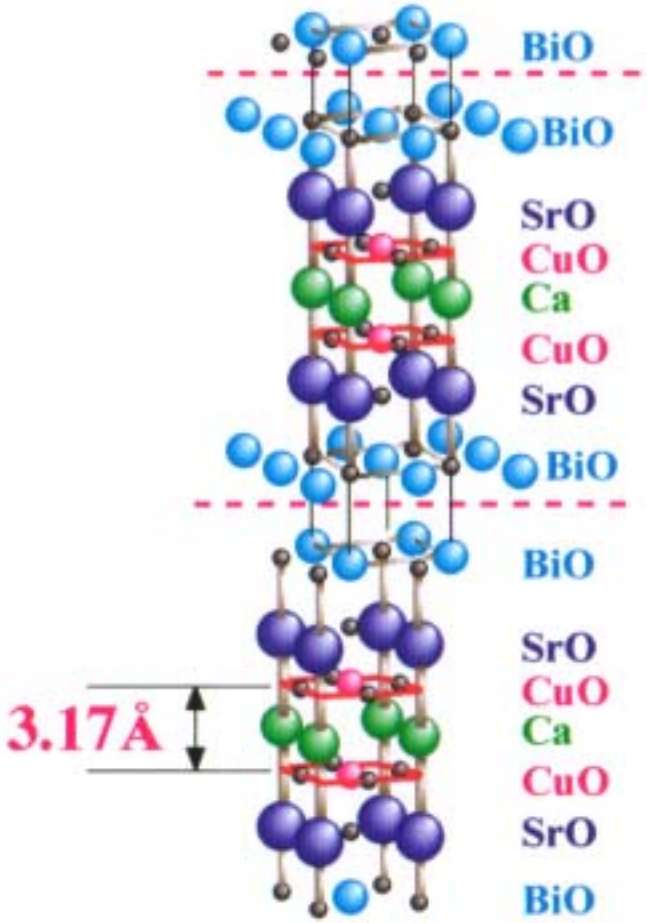


Undulator-NIM

Energy Range : 6 - 50 eV

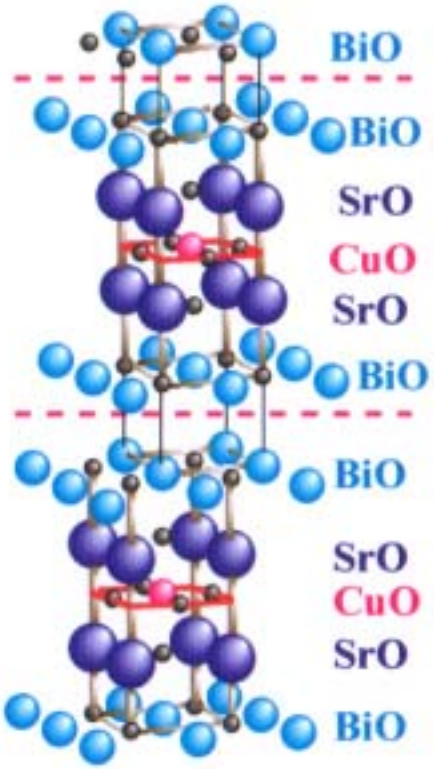
Flux : 5×10^{11} photons/s at 20eV





$Bi_2Sr_2CaCu_2O_{8+\delta}$

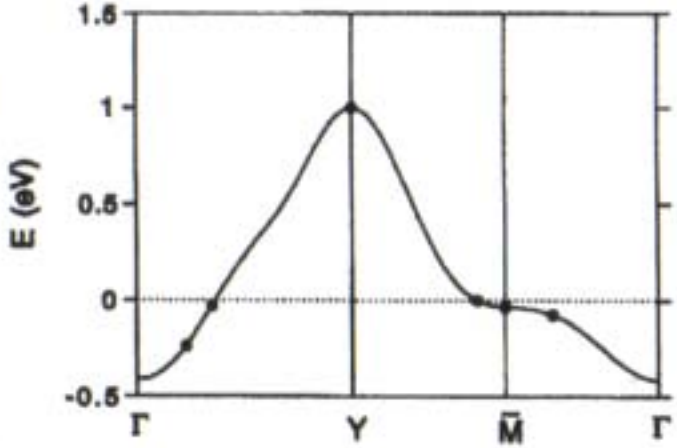
$T_{C\_opt.}$=92K

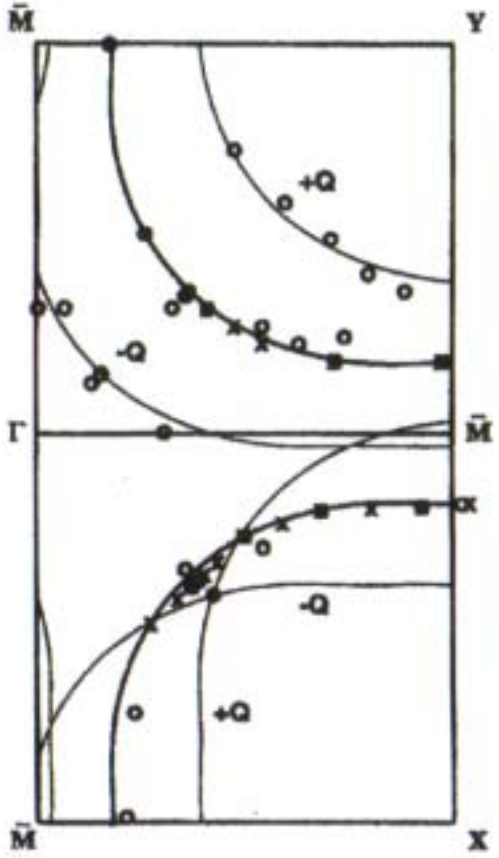


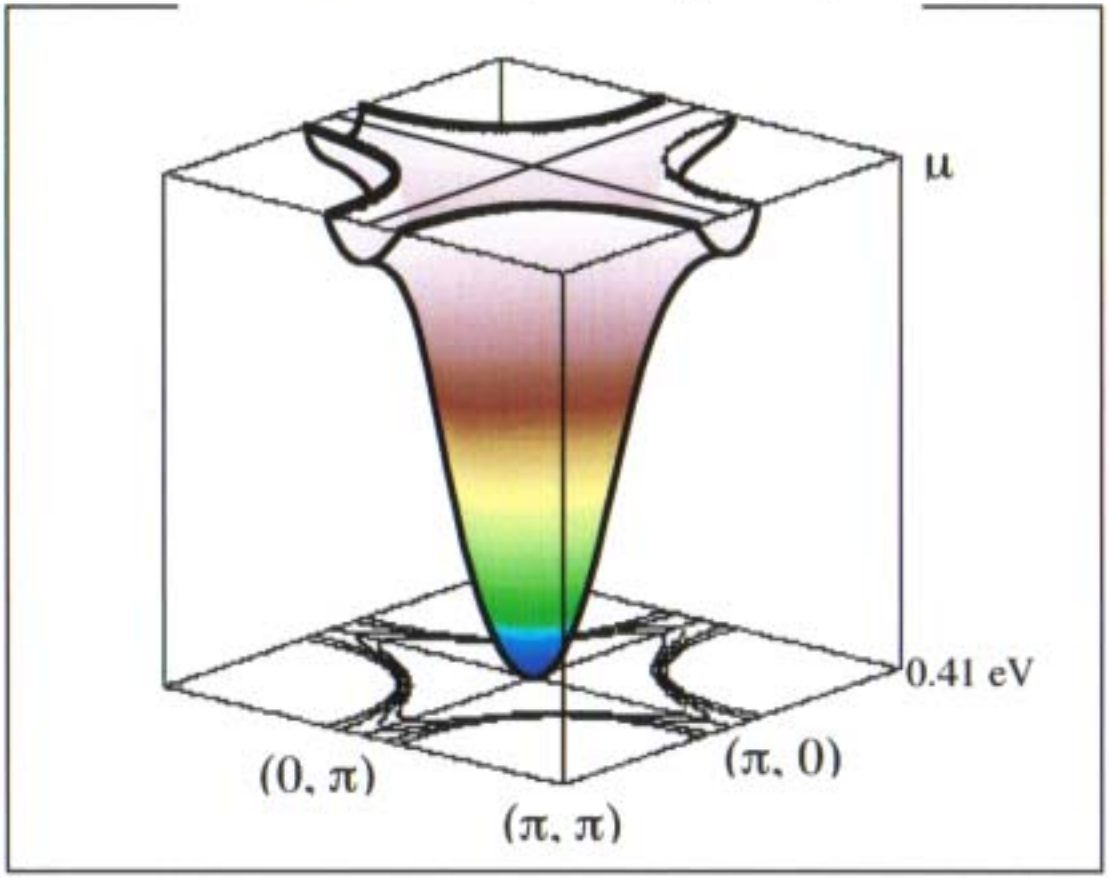
$Bi_2Sr_2CuO_{6+\delta}$

$T_{C\_opt.}$=36K

Electronic Structure of Bi2212 obtained by the tight-binding fit on the ARPES data







Norman *et al.*, PRB 52 (1995) 615.

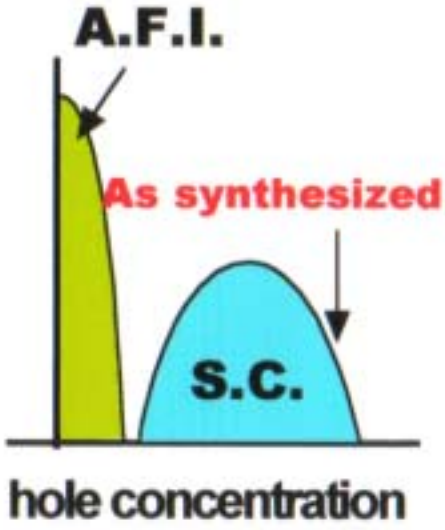
Experimental

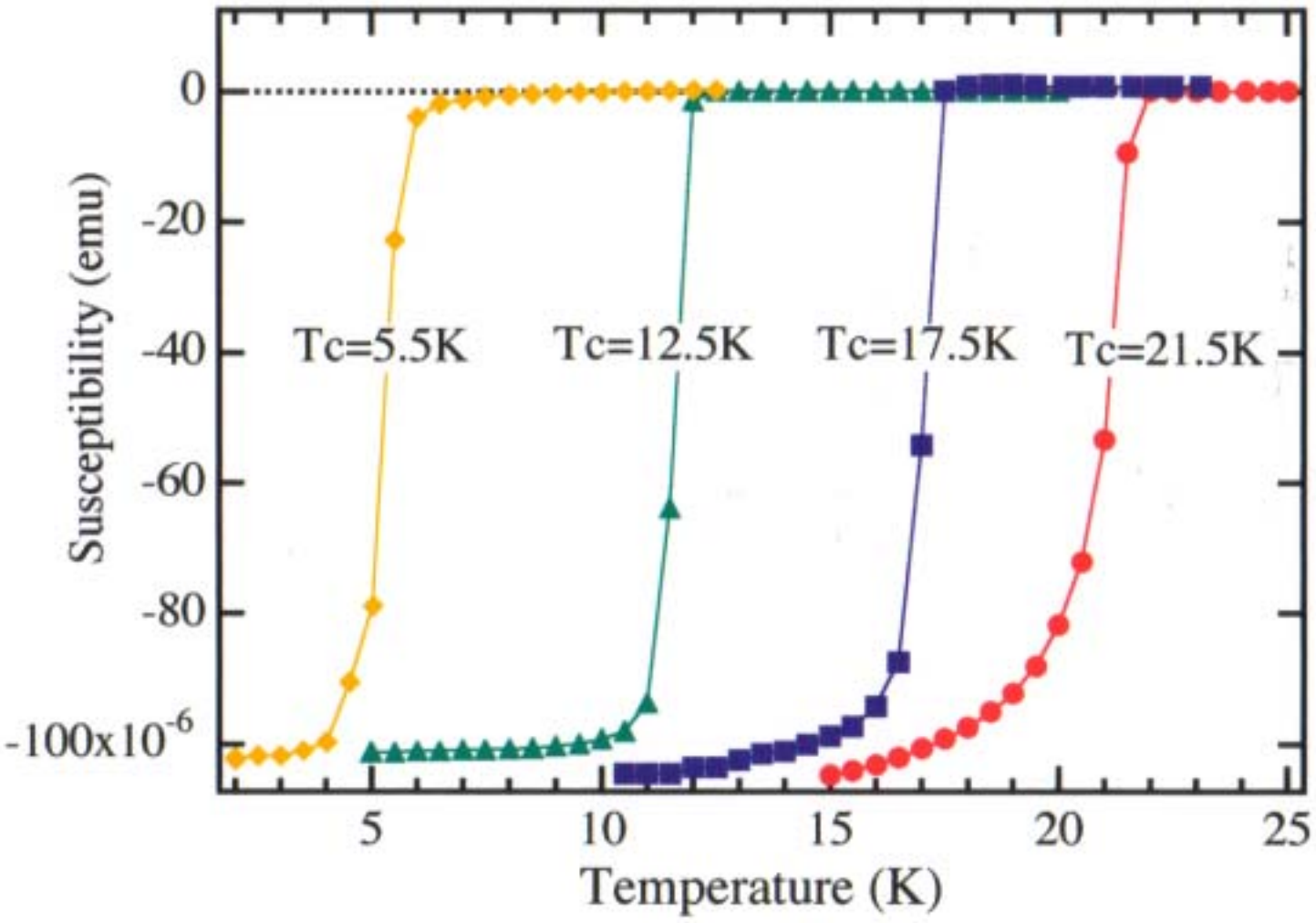
Sample Preparation

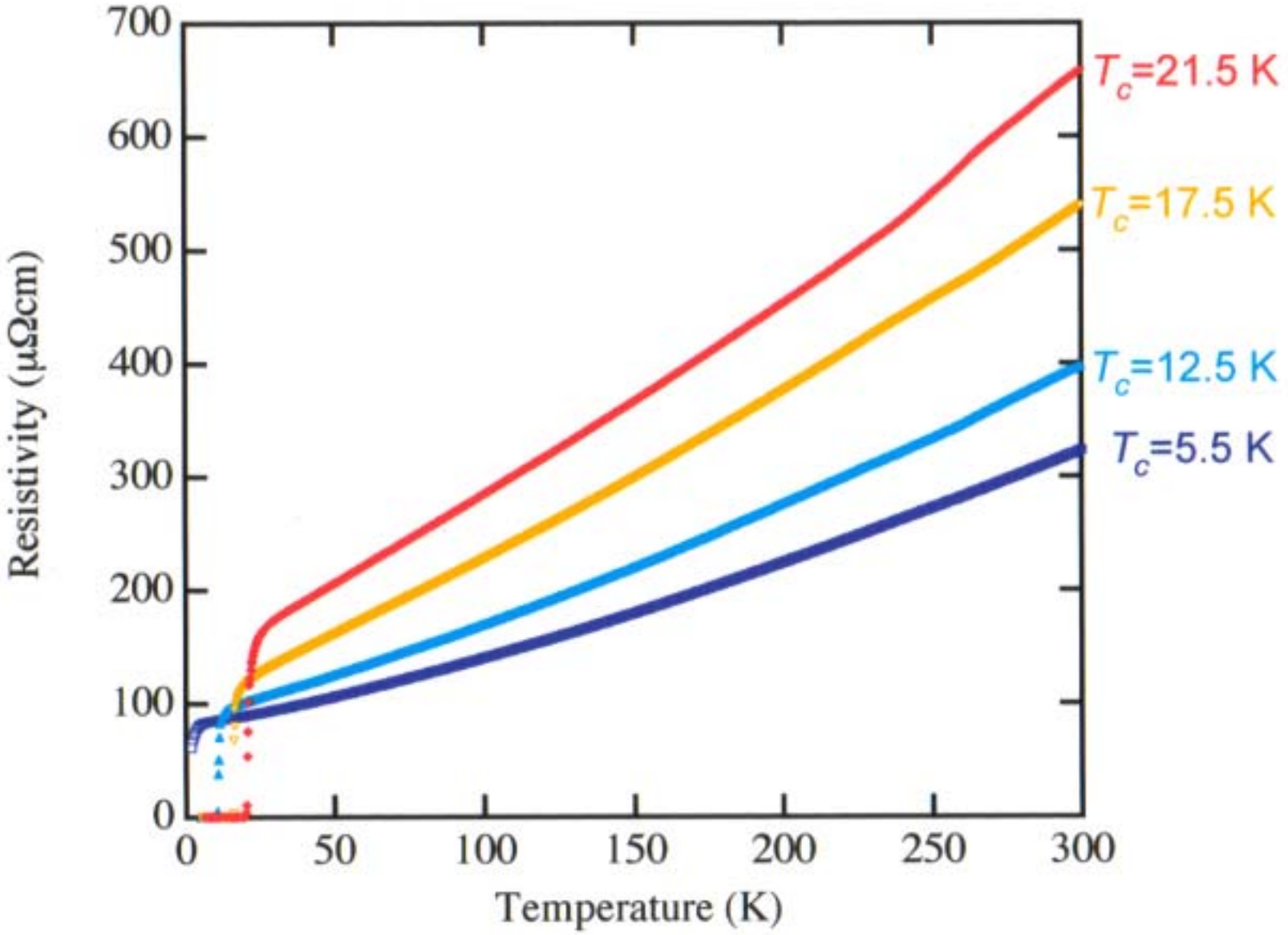
$(Bi,Pb)_{2.1}Sr_{1.9}CuO_{6+\delta}$ single crystals synthesized by a FZ furnace

Nominal composition	Bi : Pb : Sr : Cu = 1.74 : 0.38 : 1.88 : 1.0
Composition after synthesized	Bi : Pb : Sr : Cu = 1.83 : 0.34 : 1.91 : 1.0
	determined by ICP

As synthesized	T_c = 5 ~ 8 K
After oxygen annealing	T_c < 0.5K
After vacuum annealing	T_c = 10K ~ 24K




0
-20
-40
-60
-80
-100x10^-6
Susceptibility (emu)
Tc=5.5K
Tc=12.5K
Tc=17.5K
Tc=21.5K
5
10
15
20
25
Temperature (K)


700
600
500
400
300
200
100
0
Resistivity (μΩcm)
0
50
100
150
200
250
300
Temperature (K)
T_c=21.5 K
T_c=17.5 K
T_c=12.5 K
T_c=5.5 K

ARPES Measurement

★ISSP, The University of Tokyo

Analyzer SCIENTA SES2002
Photon source Gammadata VUV5010
(HeIα : 21.218eV)

Resolutions
Energy 5 meV (1.4 meV)
Angular 0.26° (0.1°)

★SRC, University of Wisconsin-Madison

Analyzer SCIENTA SES200
Photon source 16 ~ 28eV
Resolutions
Energy 15 meV
Angular 0.26° (0.1°)

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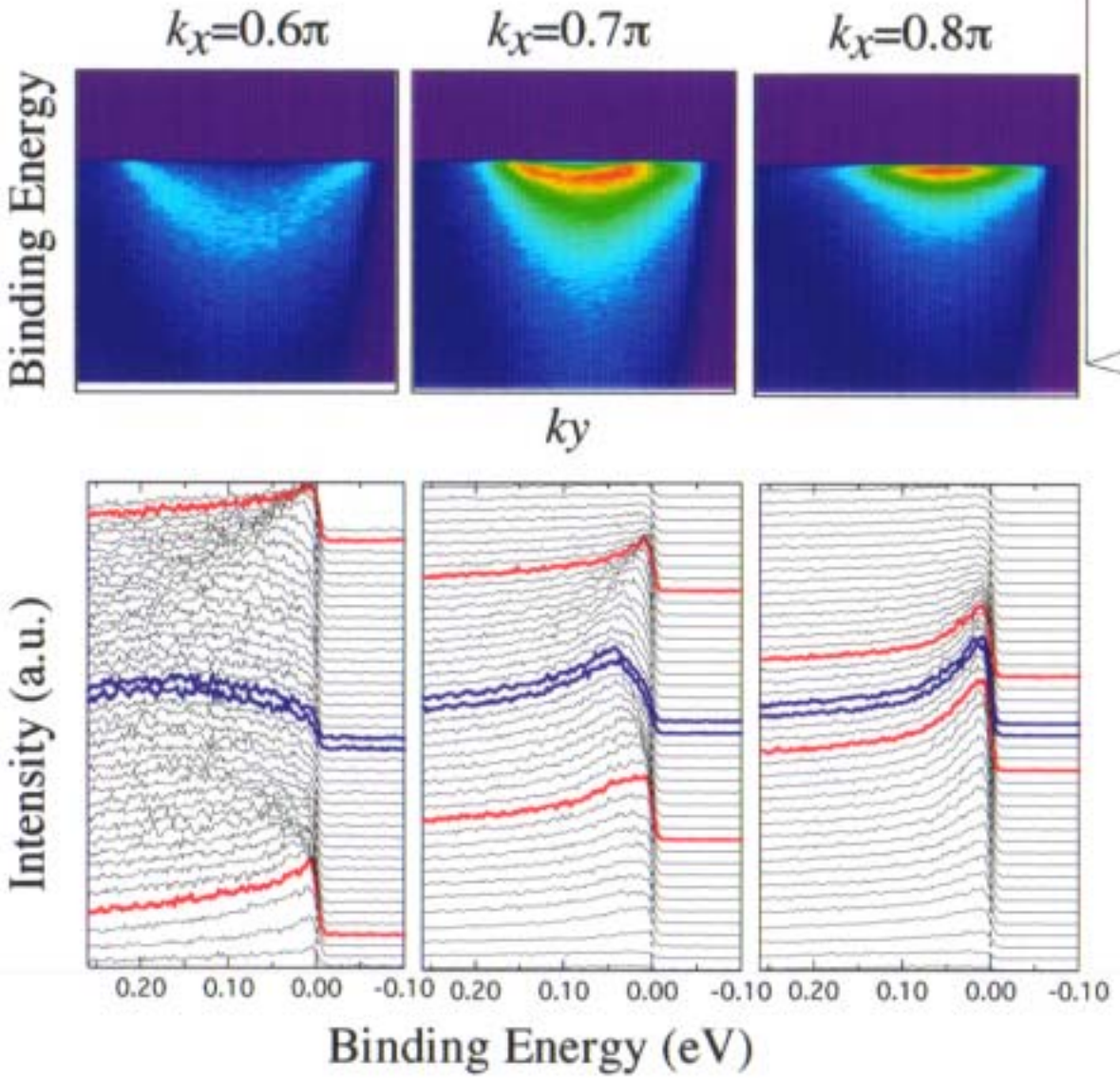
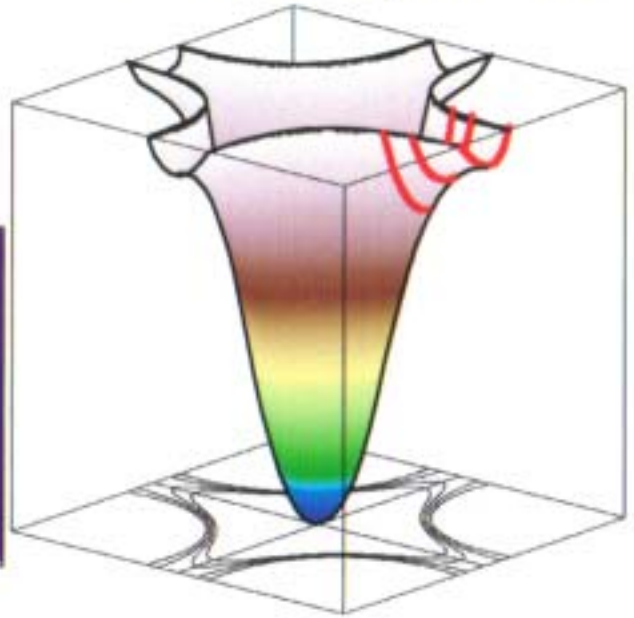
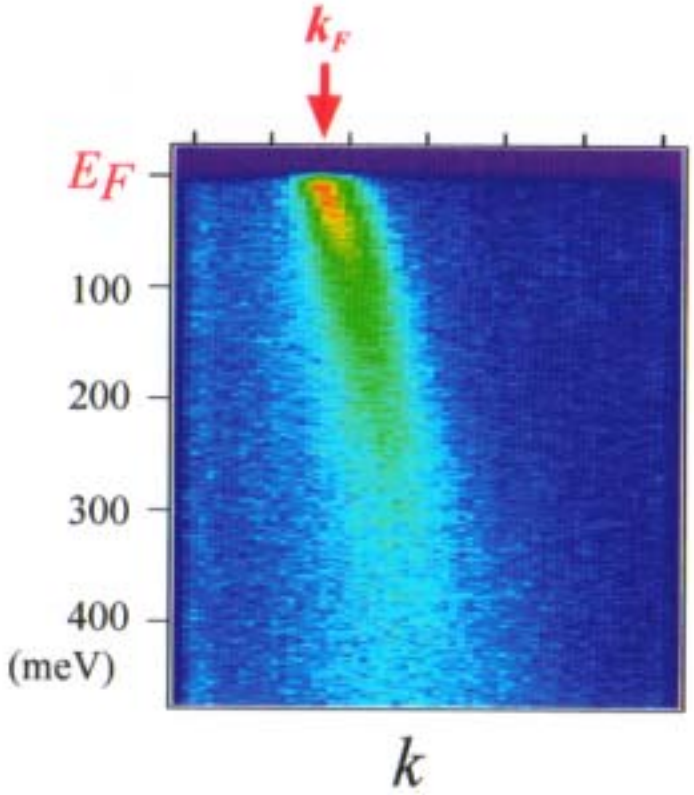
Energy Distribution Curves (EDC)

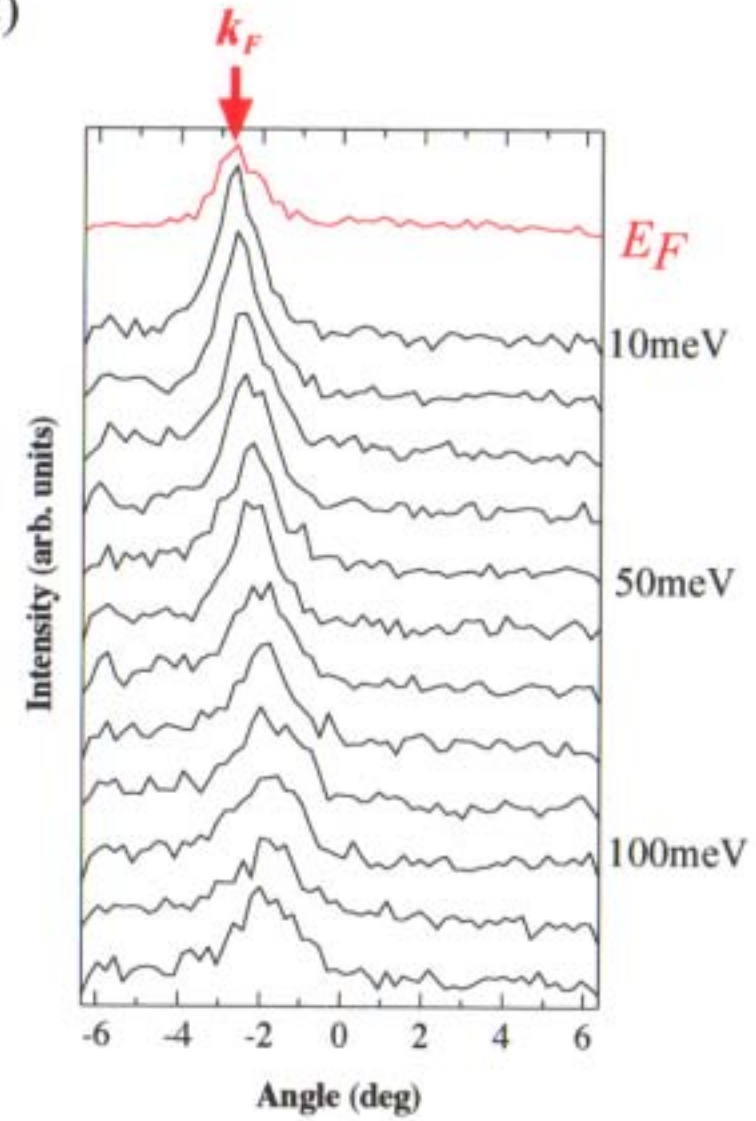




Tc ≤ 0.5 K
$h\nu$ = 21.218 eV
measured at ISSP

Momentum Distribution Curves (MDC)



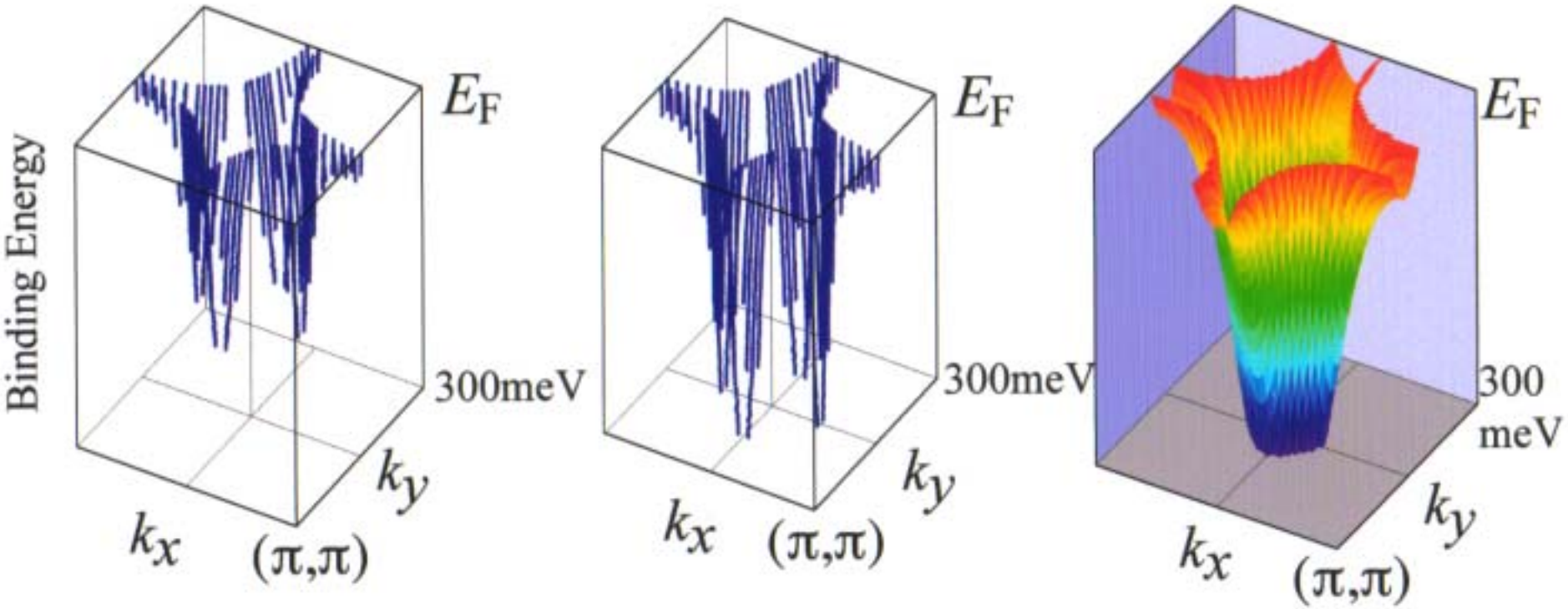


$Tc = 5K$

$h\nu = 21.218$ eV

measured at ISSP

Energy - Momentum dispersion



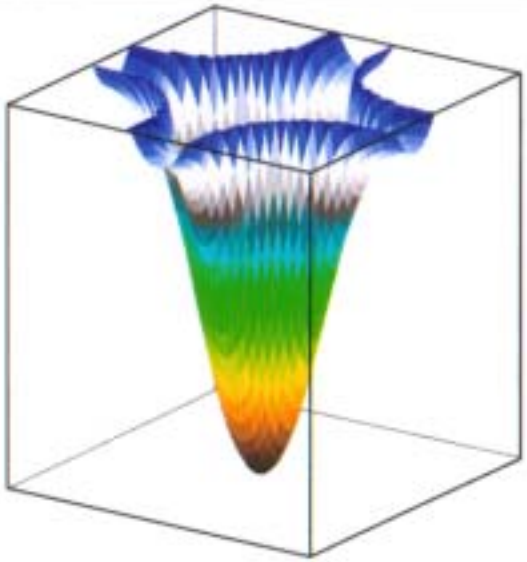
Tc = 5.5K

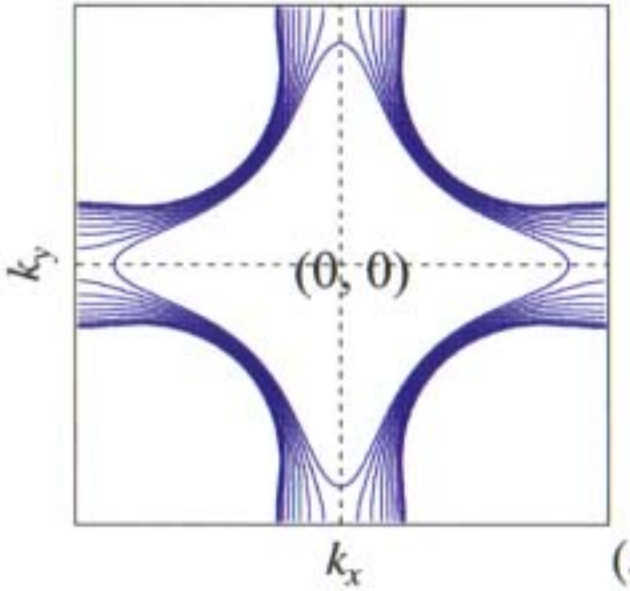
Tc = 17.5K

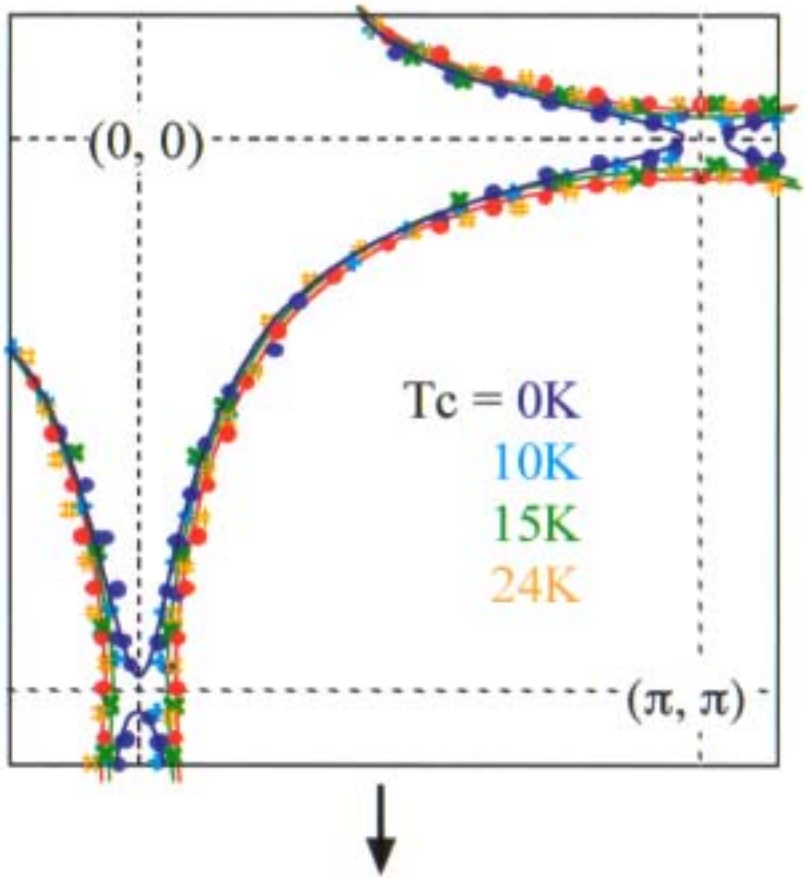
topology of Fermi surface
Fermi velocity
density of states

Fermi surface topology of the $Bi_2Sr_2CuO_{6+\delta}$ superconductor

Doping dependence of the FS

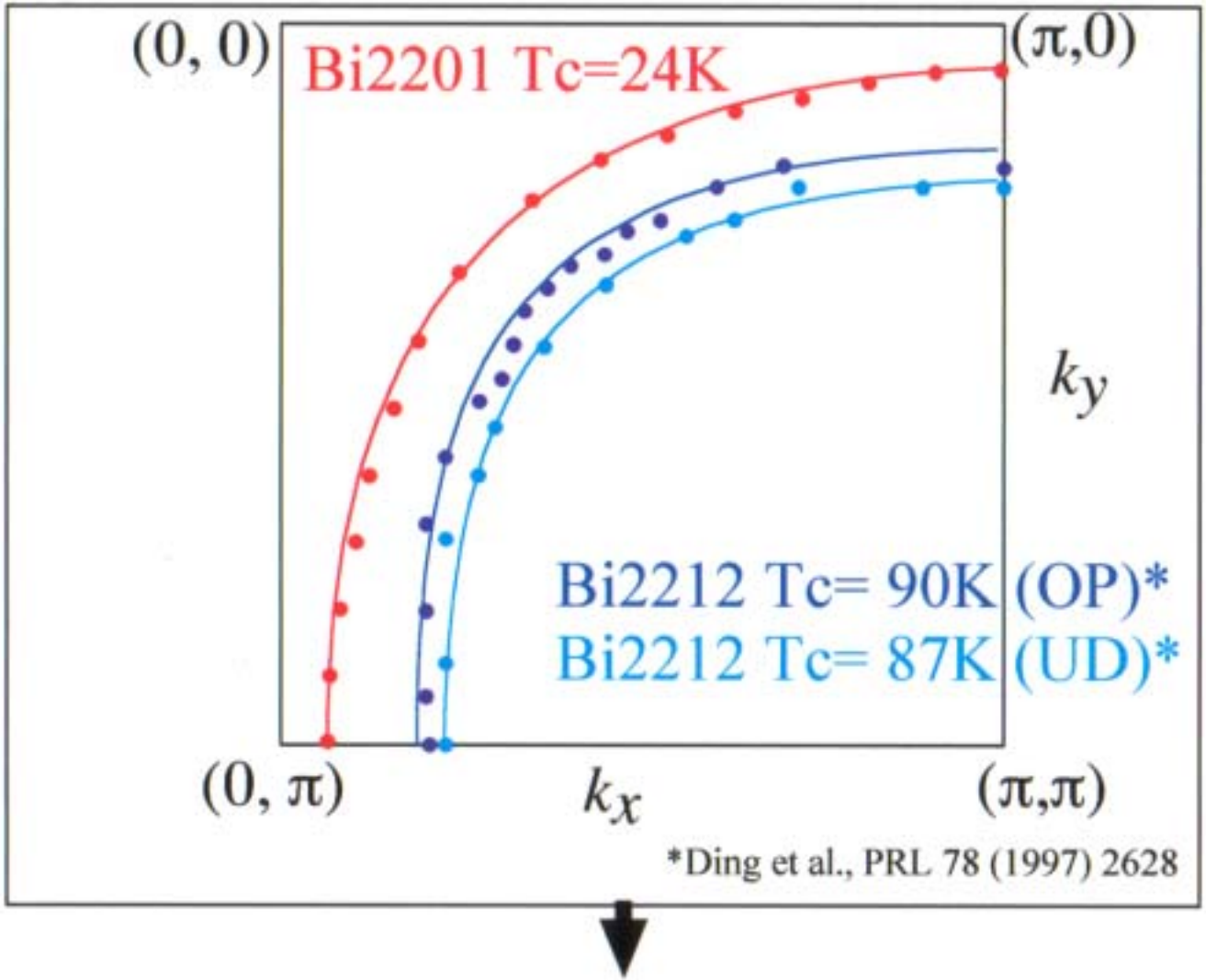




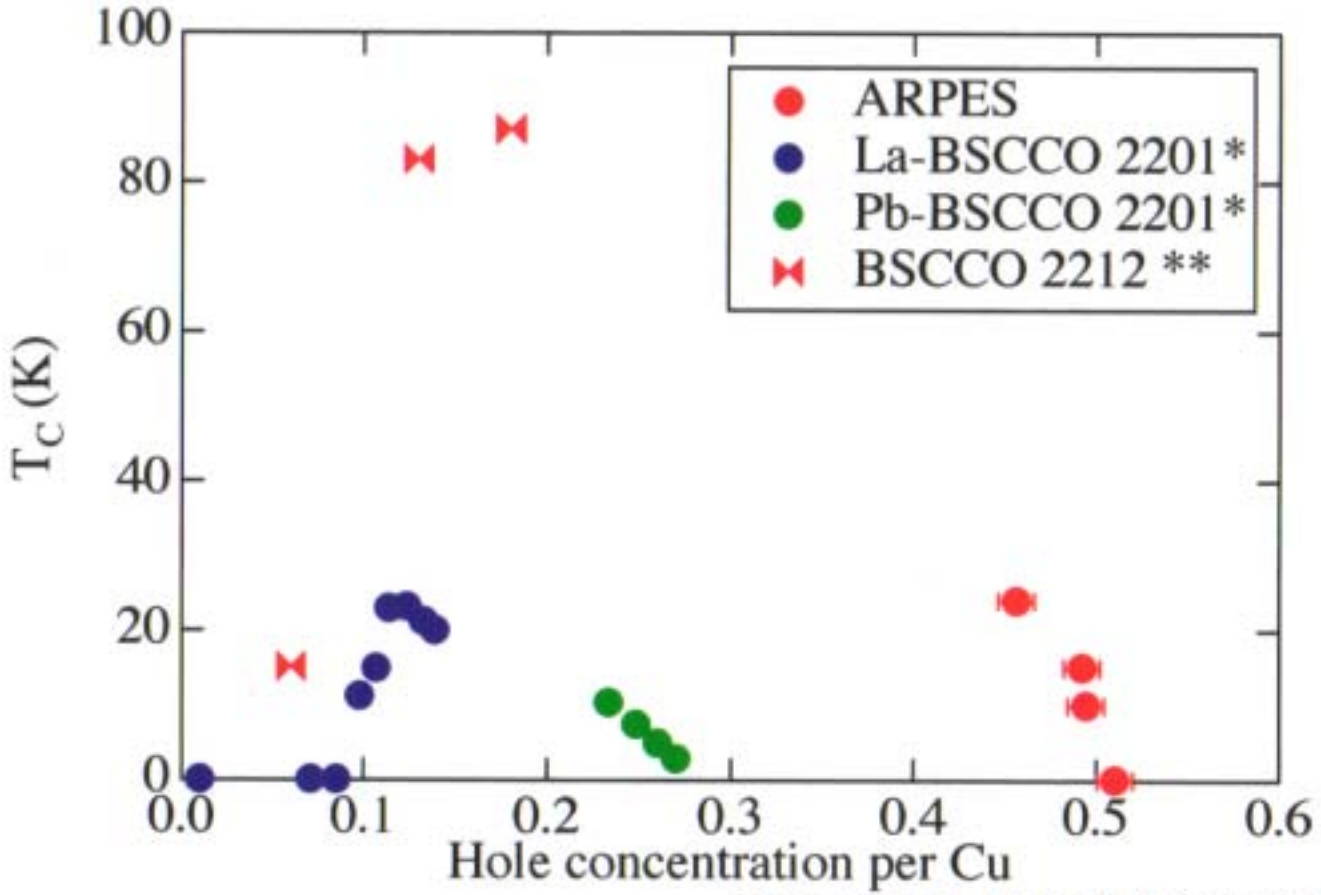


rigid band like

FS of Bi2201 and Bi2212

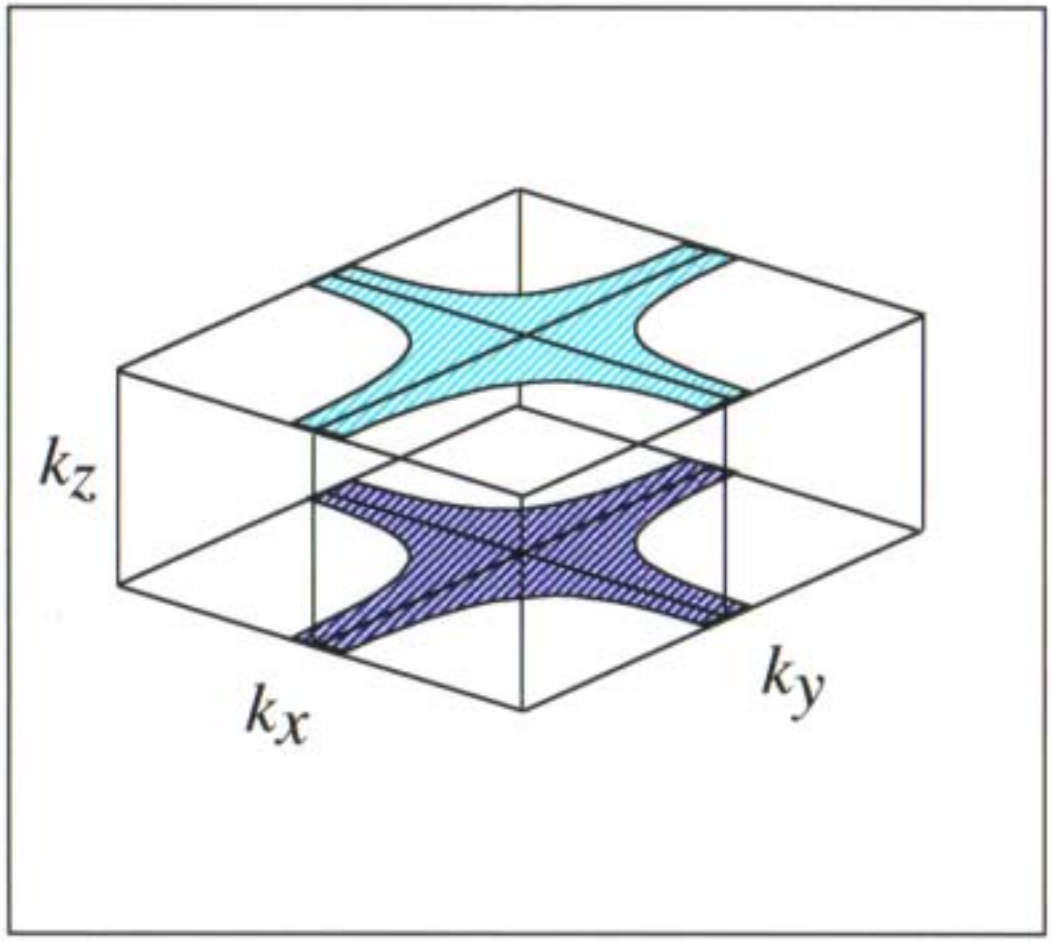


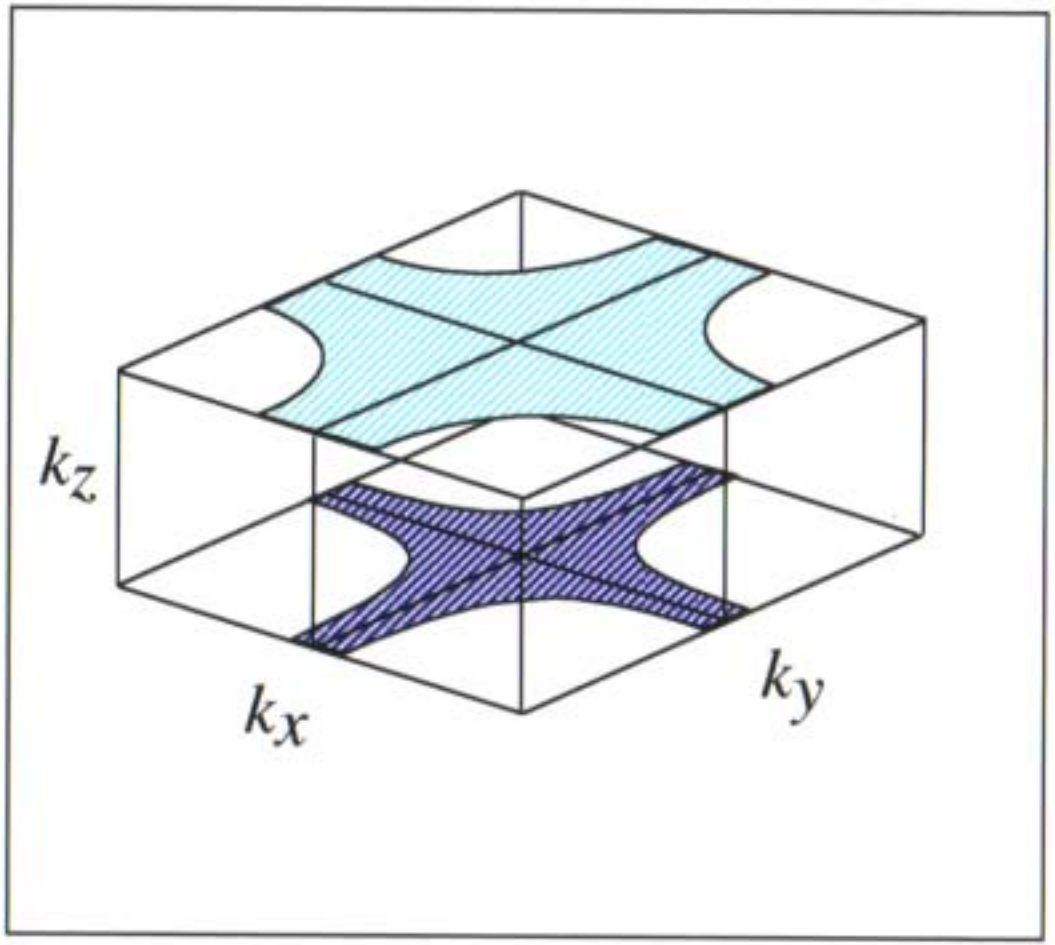
Extremely Large Hole-like Fermi Surface!!



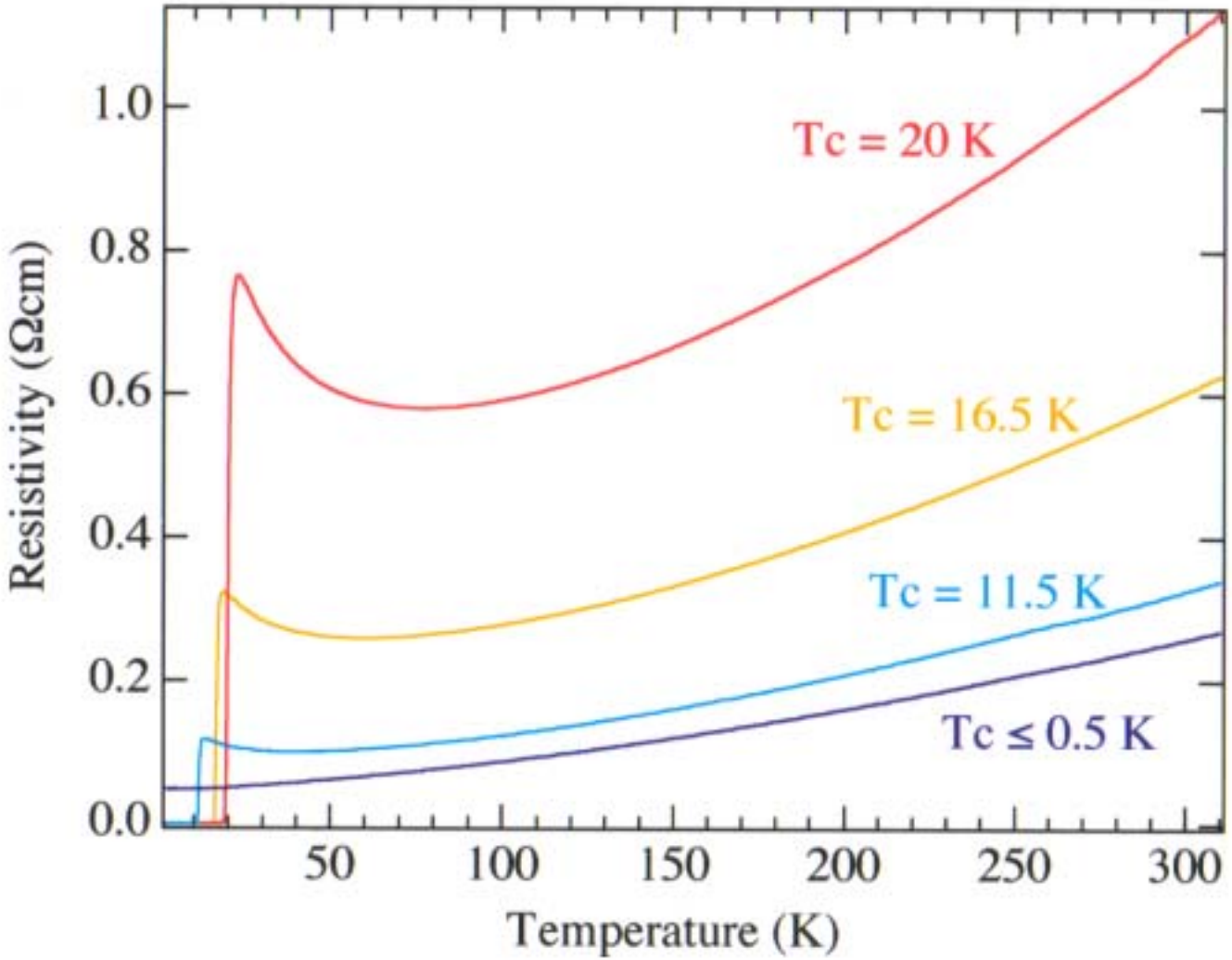
* Maeda et al., PRB 41 (1990) 6418.
**Ding et al., PRL 78 (1997) 2628.

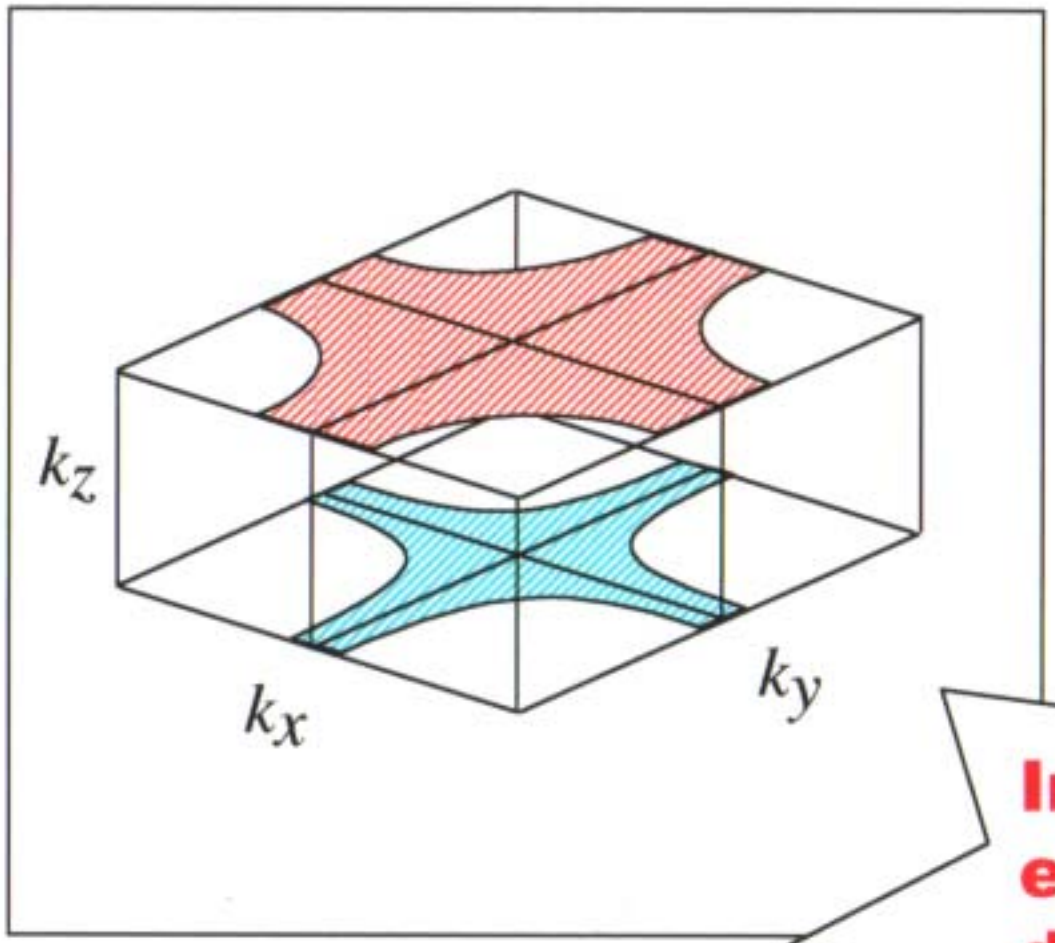
Heavily over-doped!!


k_z
k_x
k_y


k_z
k_x
k_y

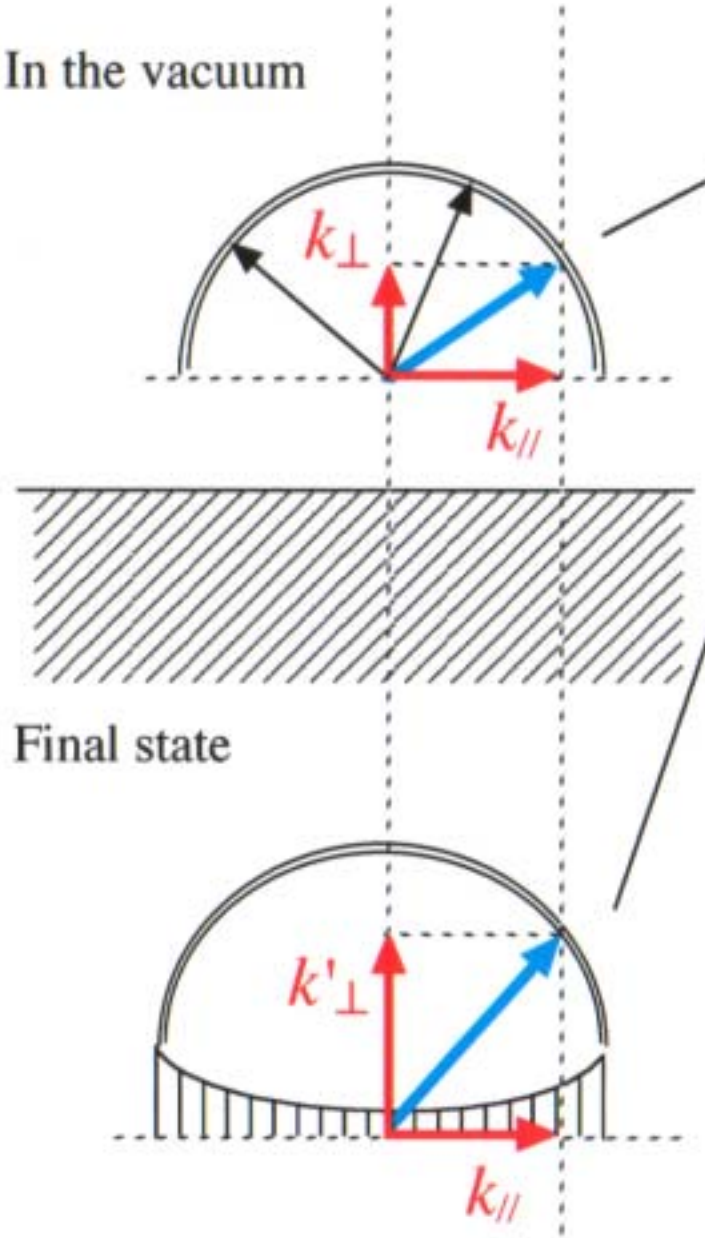
Resistivity along c-axis





dispersion along c-axis?

Incident photon energy dependence of the FS topology



$$E_{kin.} = \frac{\hbar^2}{2m}\left(k_\perp{}^2 + k_{//}{}^2\right)$$

$$E_{kin.} + W.F. = \frac{\hbar^2}{2m}\left(k'_\perp{}^2 + k_{//}{}^2\right)$$

(F.E.A. for the finial state)

$$k'_\perp = \sqrt{\frac{2m}{\hbar^2} \times W.F. + k_\perp{}^2}$$

k_z=0.5π → $h\nu$ = 16 eV : (π, 0, 12.67π)

k_z=0 → $h\nu$ = 18 eV : (π, 0, 13.82π)

k_z=0 → $h\nu$ = 22 eV : (π, 0, 16.03π)

k_z=π → $h\nu$ = 28 eV : (π, 0, 18.72π)

$Tc \leq 0.5K$

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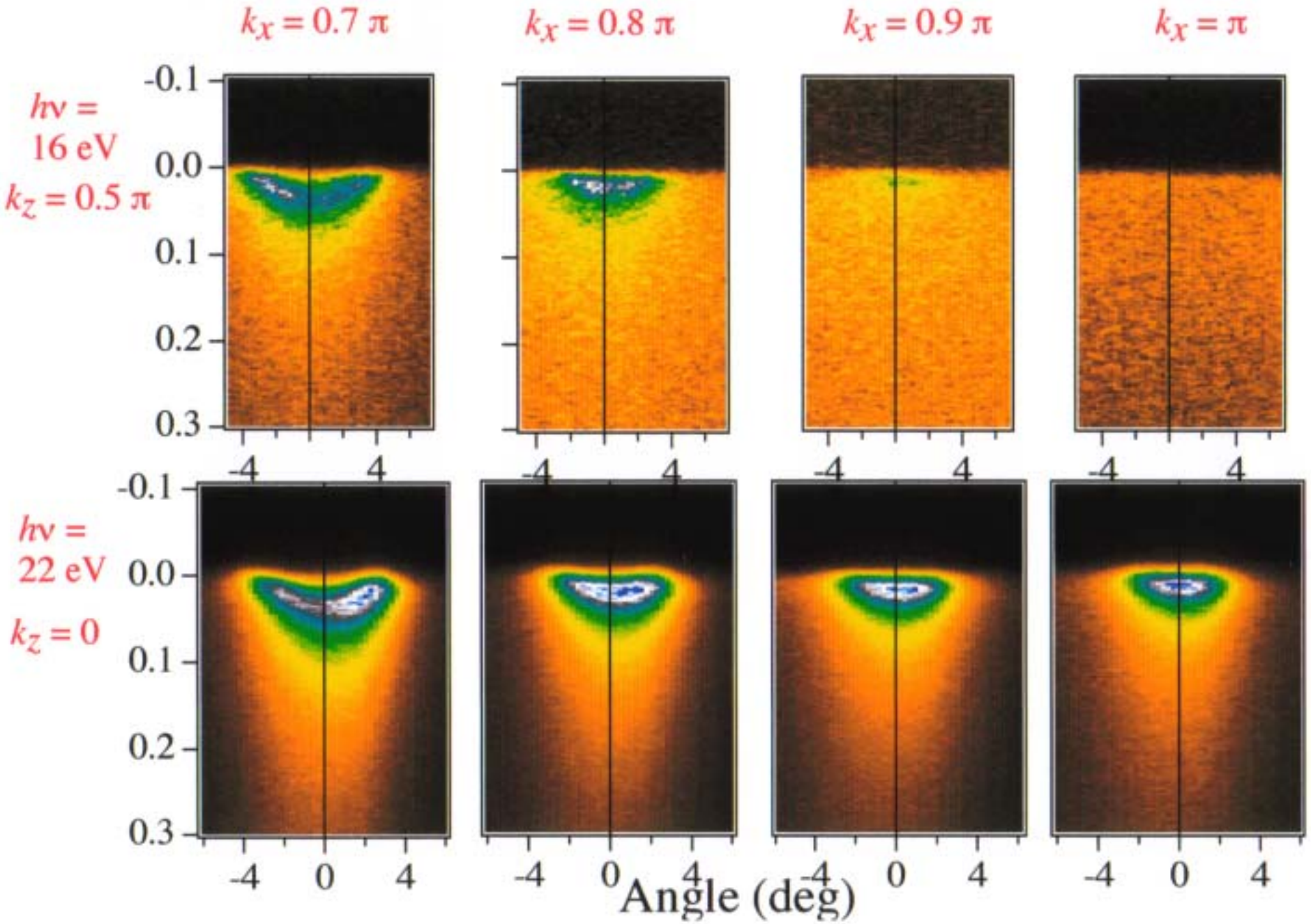
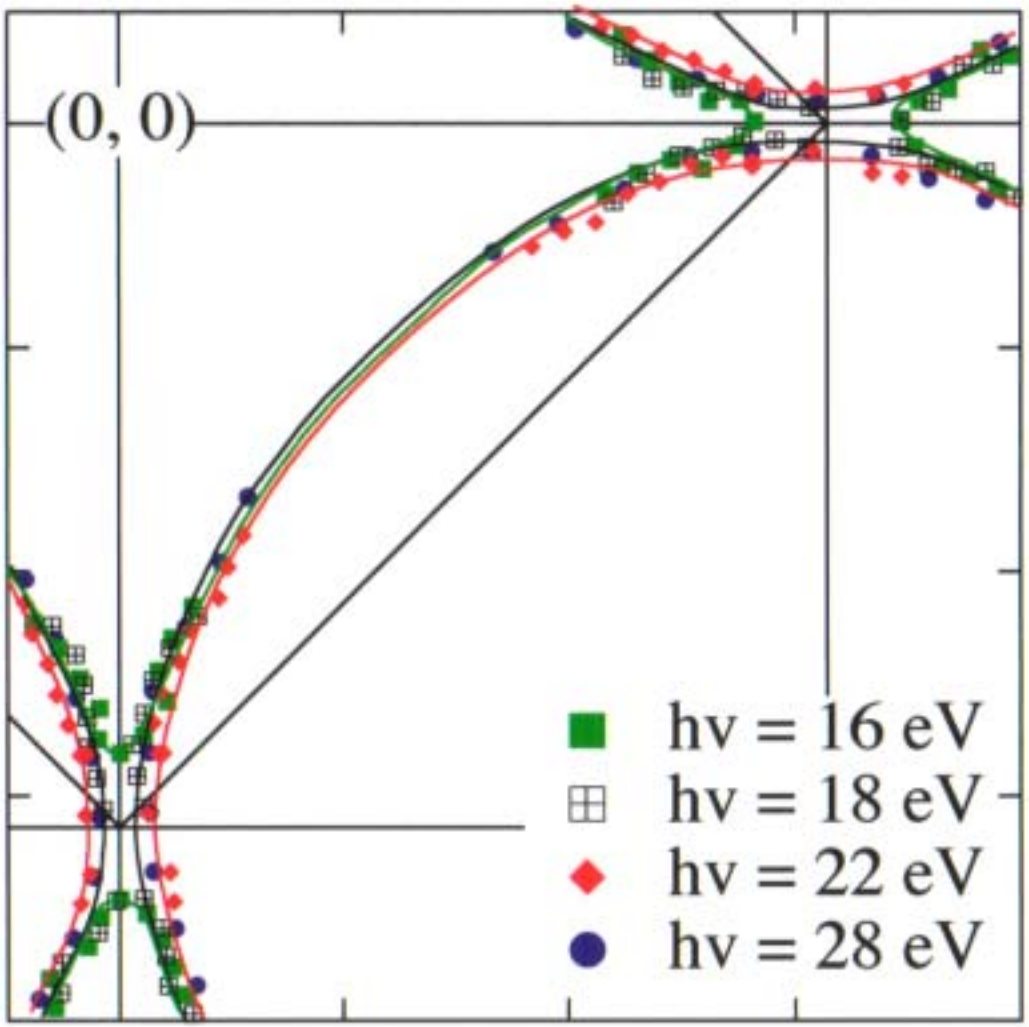


Tc≤0.5K
measured at SRC



$h\nu$ = 16 eV : (π, 0, 12.67π)

$h\nu$ = 18 eV : (π, 0, 13.82π)

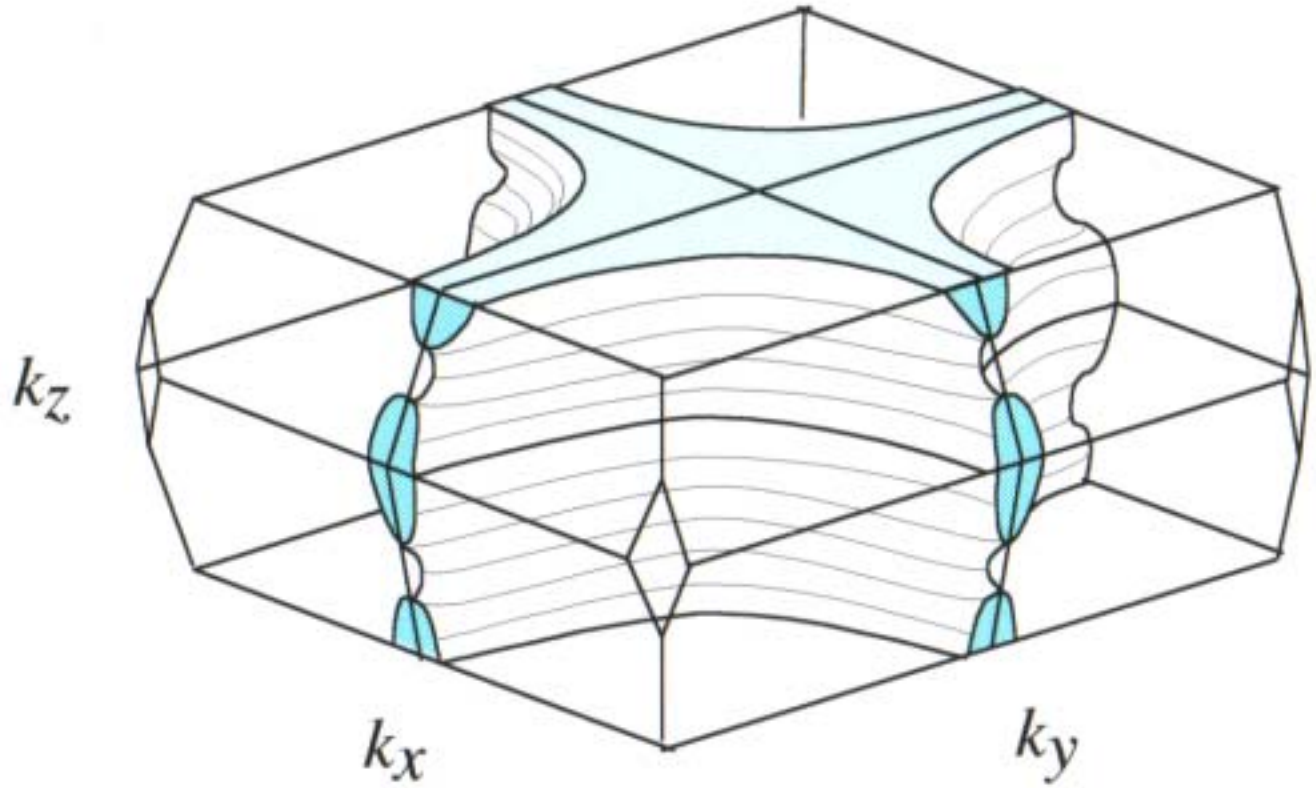
$h\nu$ = 22 eV : (π, 0, 16.03π)

$h\nu$ = 28 eV : (π, 0, 18.72π)

k_z=0, π
Hole-like FS

k_z=0.5π
Electron-like FS

FS of the heavily over-doped $Bi_2Sr_2CuO_{6+\delta}$ superconductor



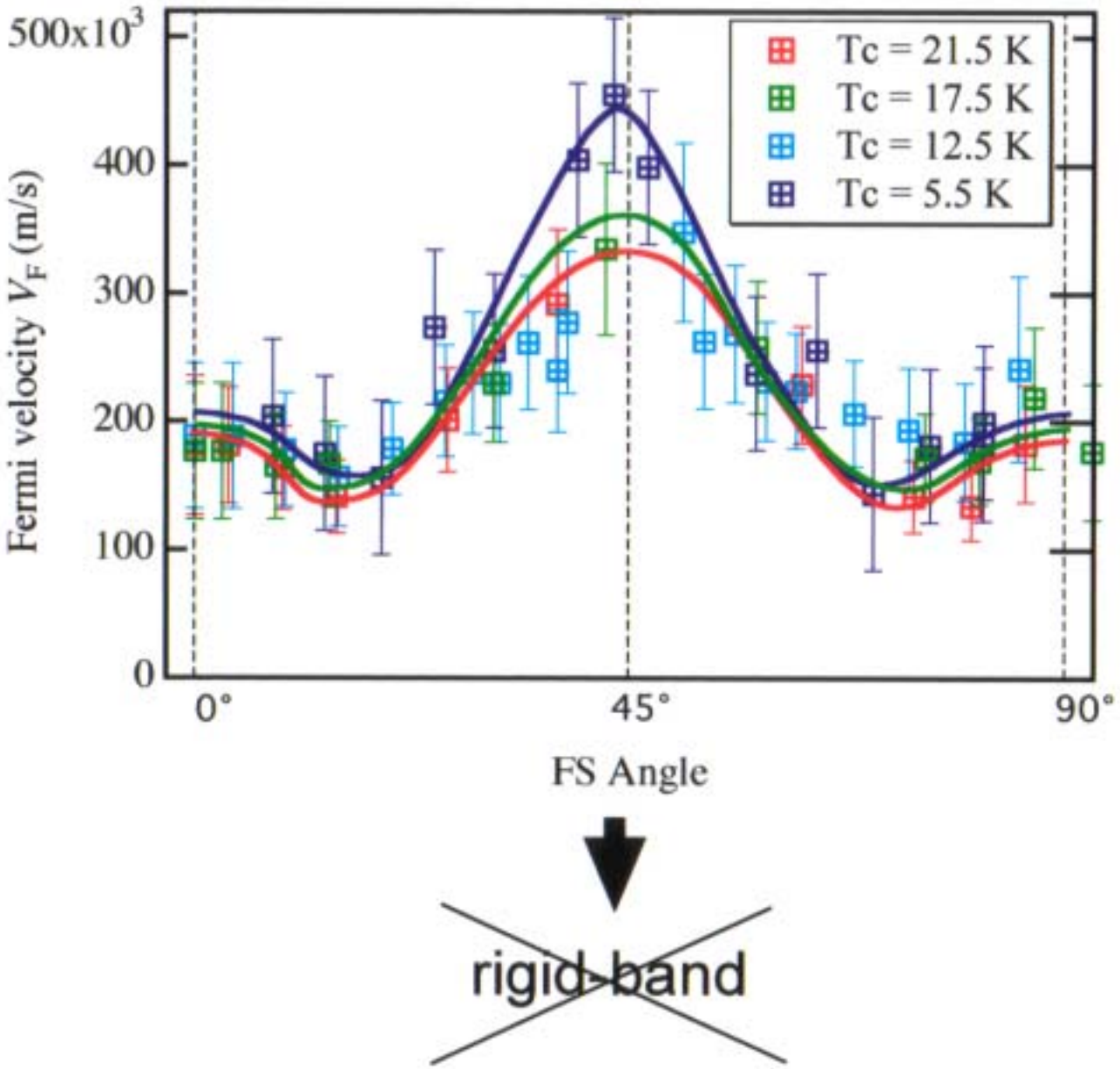
Summary for determination of the Fermi surface topology in the over-doped $(Bi,Pb)_2Sr_2CuO_{6+\delta}$ superconductor

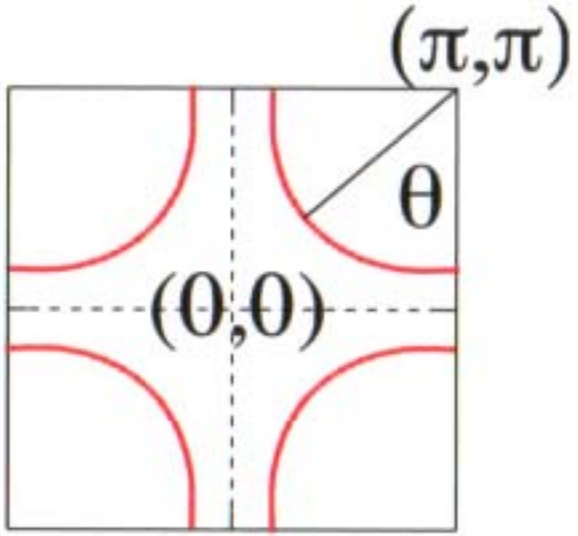
1. Rigid-band-like doping dependence
2. Extremely large carrier concentration
3. Presence of dispersive E-k relation along kz direction in the heavily over-doped sample

Qualitative evaluation of the electron transport properties of the $Bi_2Sr_2CuO_{6+\delta}$ superconductor using experimentally determined electronic structure

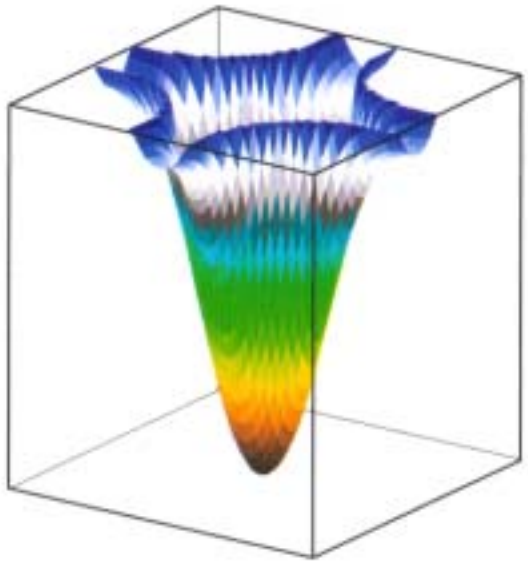
(1) Area of the Fermi Surface (carrier concentration)
(2) Fermi velocity

Quantitative evaluation of the relaxation time τ
from experimentally observed electrical resistivity


500x10^3
400
300
200
100
0
Fermi velocity V_F (m/s)
Tc = 21.5 K
Tc = 17.5 K
Tc = 12.5 K
Tc = 5.5 K
0°
45°
90°
FS Angle


(π,π)
θ
(0,0)

rigid-band



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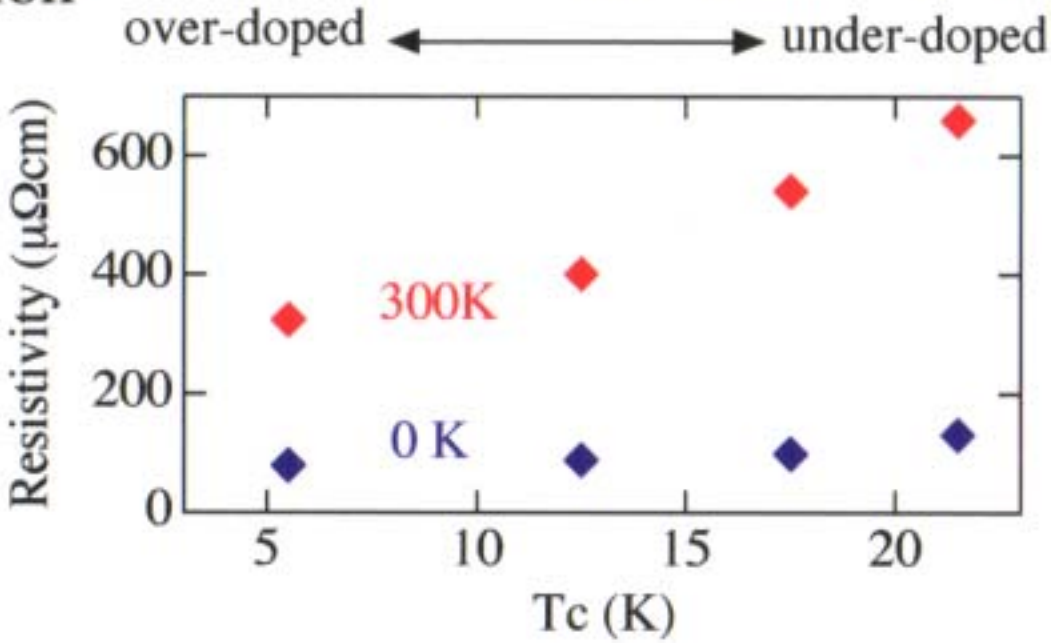
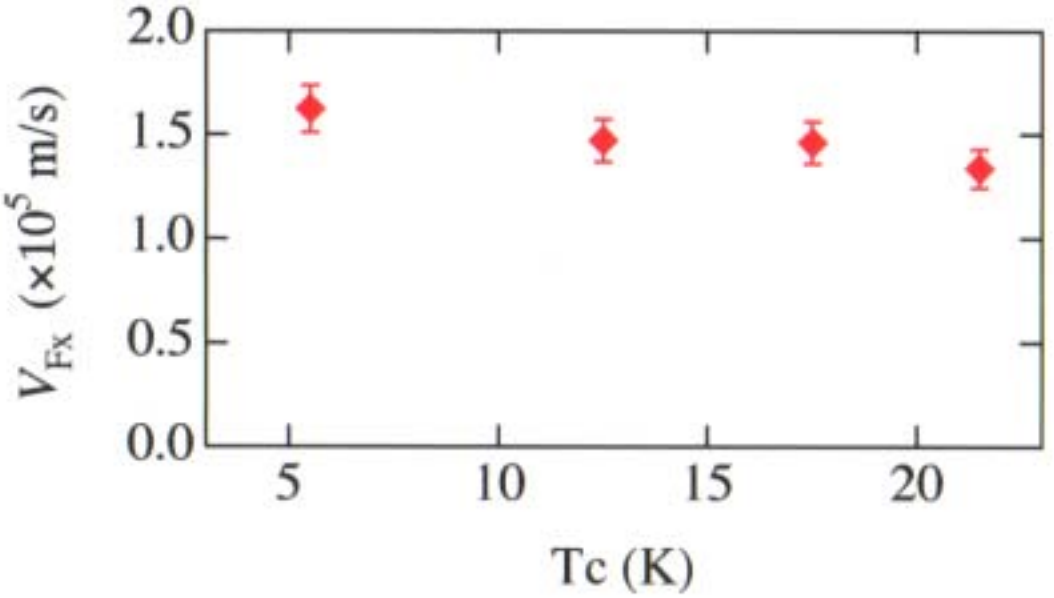
Boltzmann transport equation

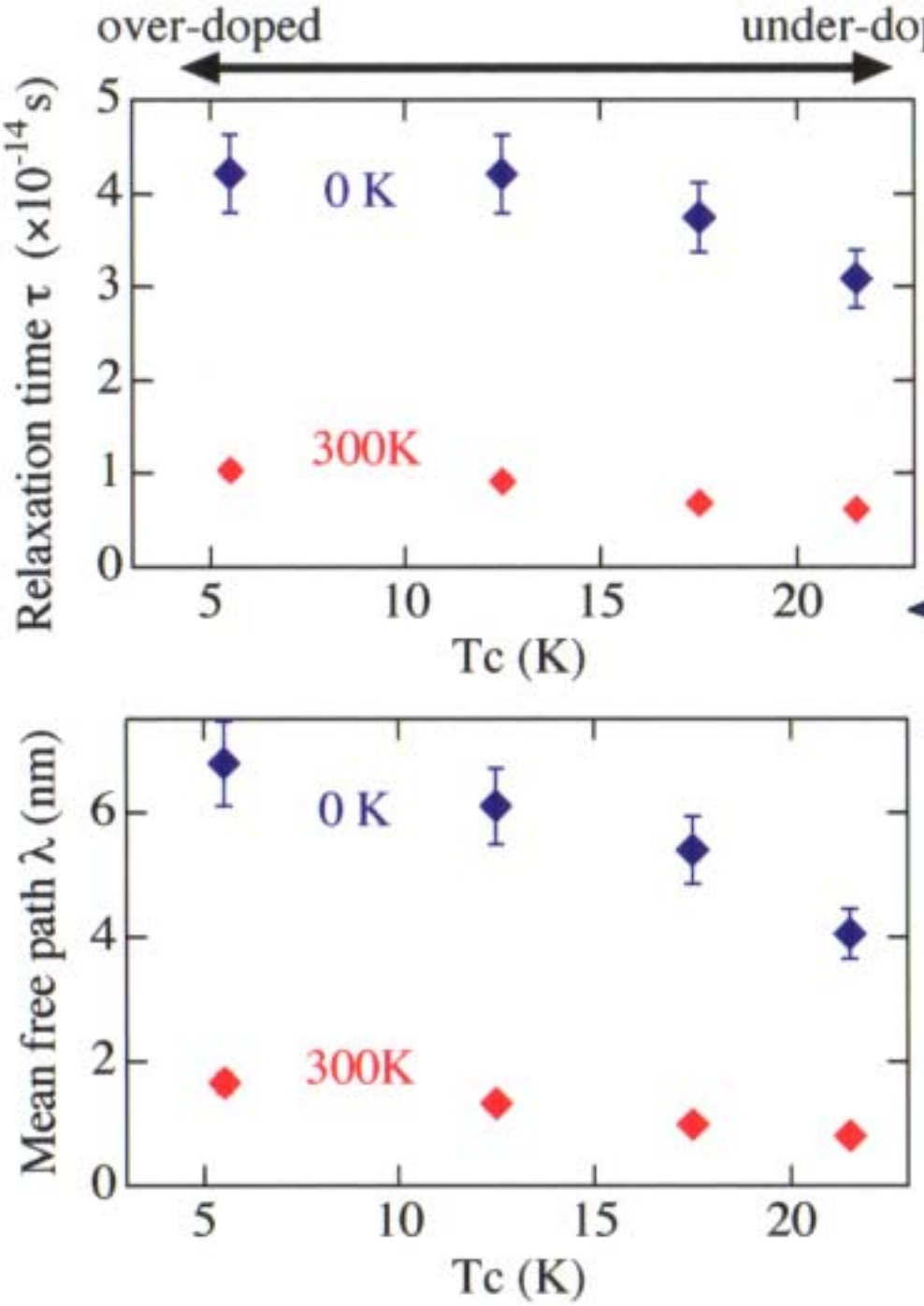
$$\sigma = \frac{1}{\rho} = \frac{e^2}{4\pi^3\hbar}\int \tau V_F \cos^2\theta dS$$

$$= \frac{S_F e^2 \tau V_F}{12\pi^3\hbar}$$

Relaxation time τ
and
Mean free path λ







Enhancement in the electron-electron scattering with decreasing carrier concentration!!

Summary

Mean free path and relaxation time in the BSSCO 2201 were successfully evaluated from the experimentally determined electronic structure with the measured electrical resistivity.

The enhancement in the electron interaction with decreasing carrier concentration is suggested.

In order to discuss in more details, high-resolution ARPES measurements with synchrotron radiation are strongly required.