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June 28-30, 2006

Recent Photoemission Results for the Electron-Doped High-Temperature Superconductors

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Collaborators

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K. Yamada, M. Fujita, T. Uefuji (*IMR, Tohoku Univ.*)

In this talk

1. Introduction

2. ARPES results for *e*-doped HTSC

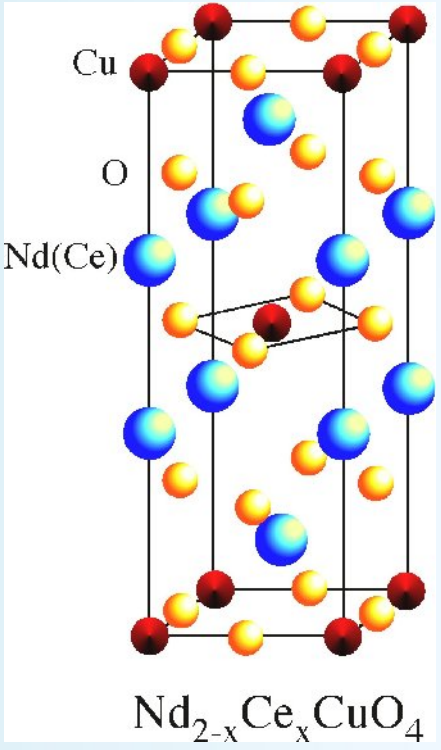
   i) Normal state

      Pseudogap and quasiparticle

   ii) Superconducting state

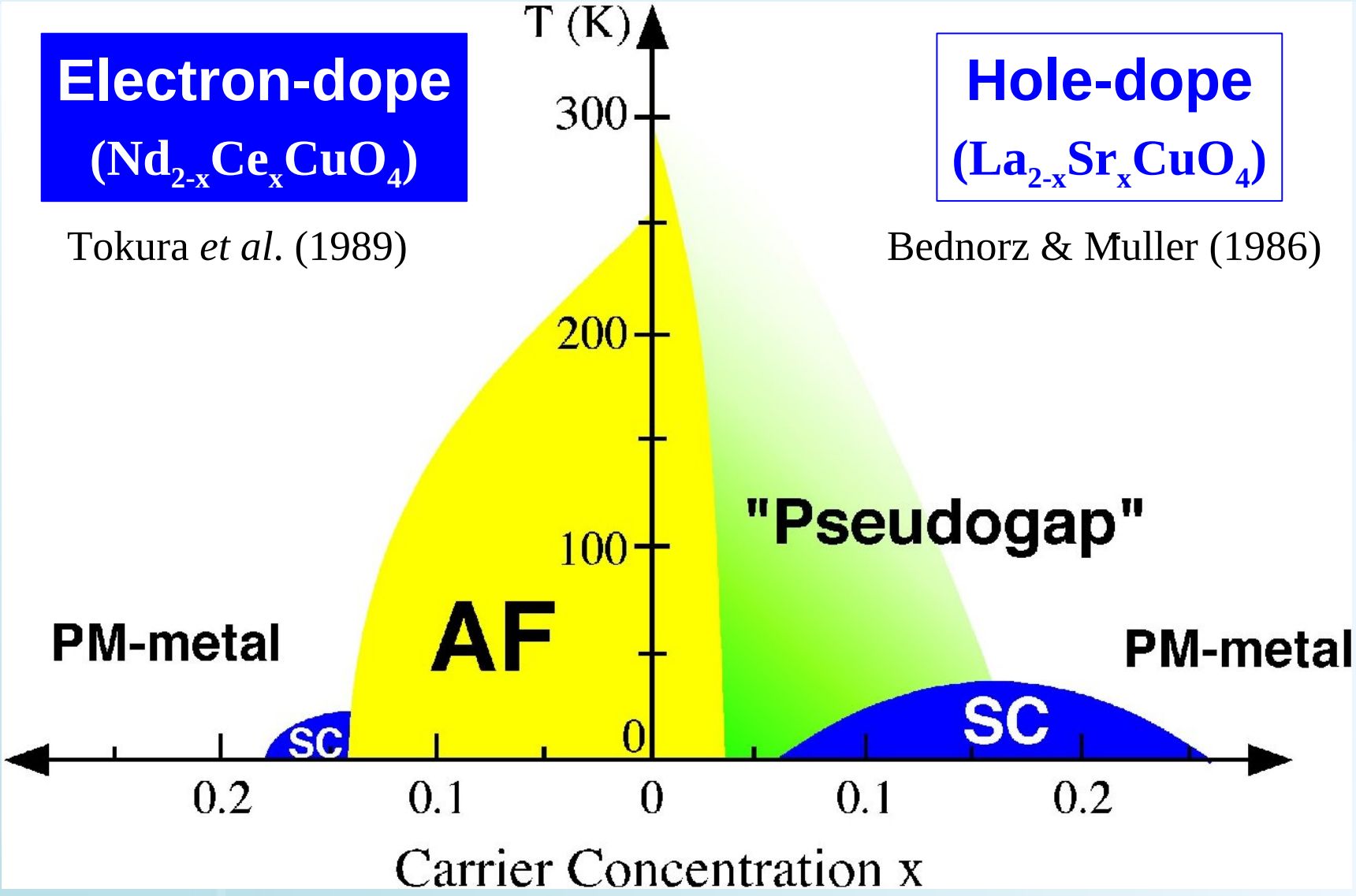
      Superconducting gap symmetry

3. Summary



Introduction

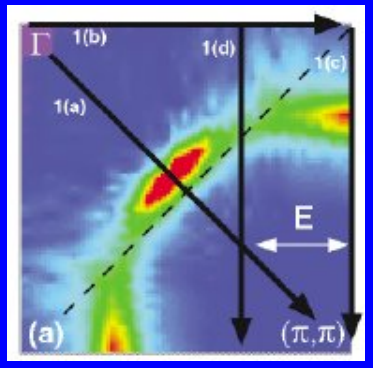
Phase diagram in HTSC



Key electronic structures in HTSC

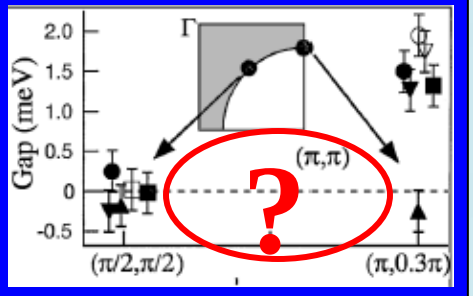
Electron-dope

Fermi surface

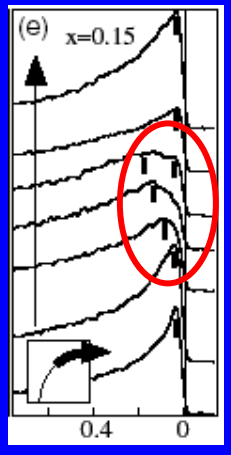


N.P. Armitage *et al*. 2001.

Gap symmetry

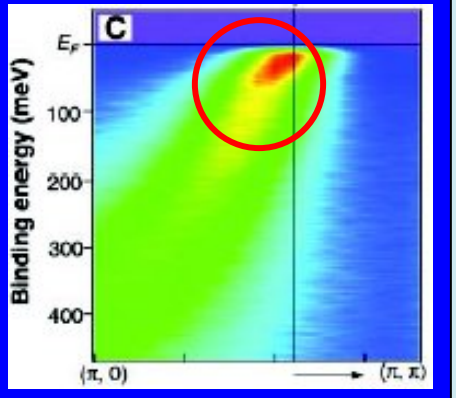


Pseudogap



N.P. Armitage *et al*. 2002.

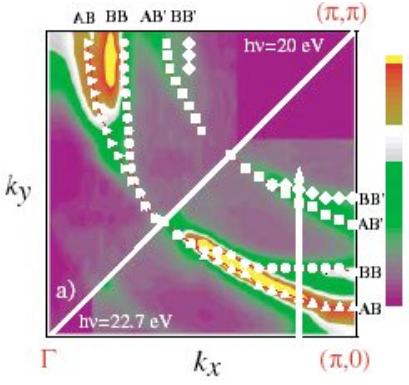
Quasiparticle



T. Sato *et al*. 2001.

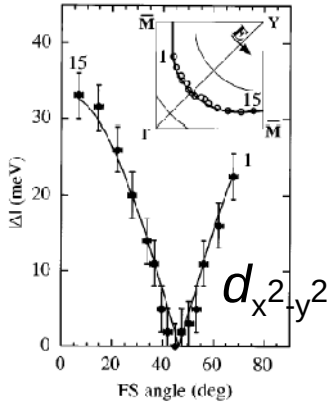
Hole-dope

Fermi surface



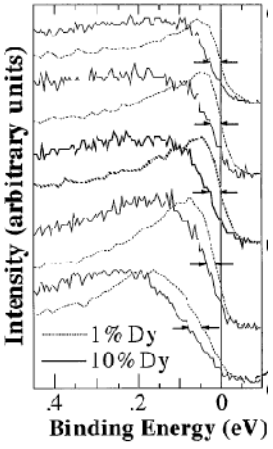
D.L. Feng *et al*. 2001.

Gap symmetry



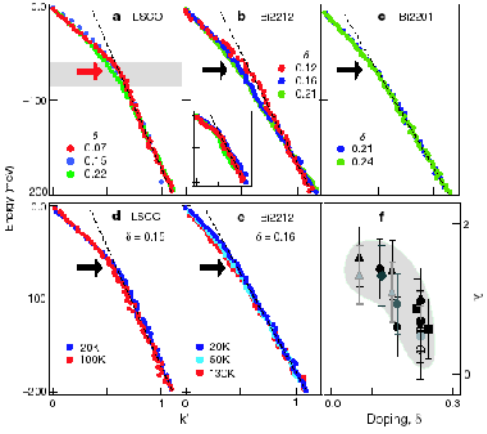
H. Ding *et al*. 1996.

Pseudogap



D.S. Marshall *et al*. 1996.

Quasiparticle



A. Lanzara *et al*. 2001.

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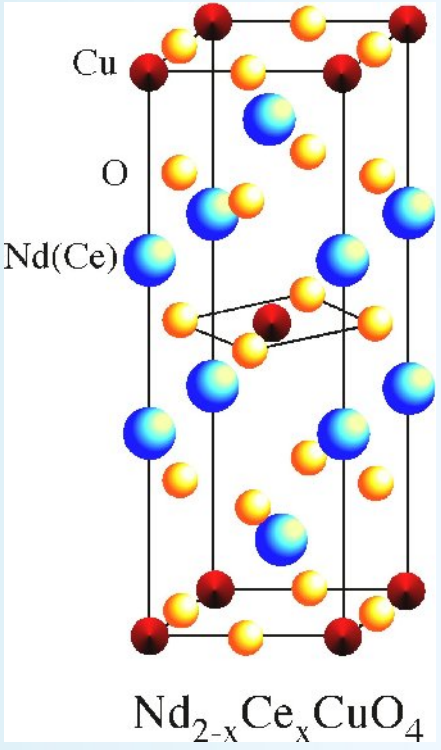
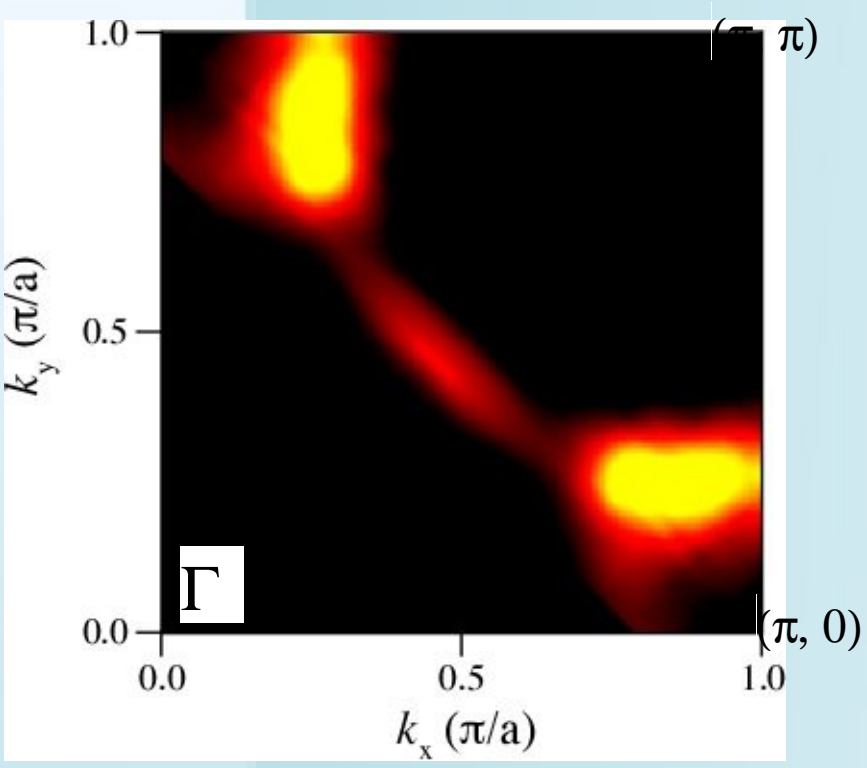
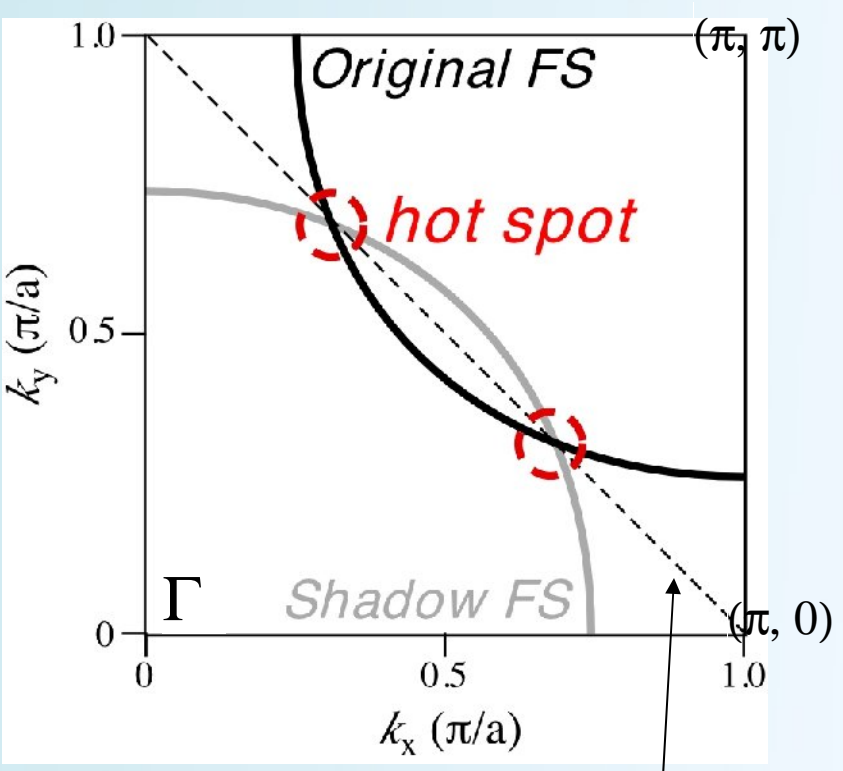


Near E_F ARPES intensity in $Nd_{1,87}Ce_{0.15}CuO_4$

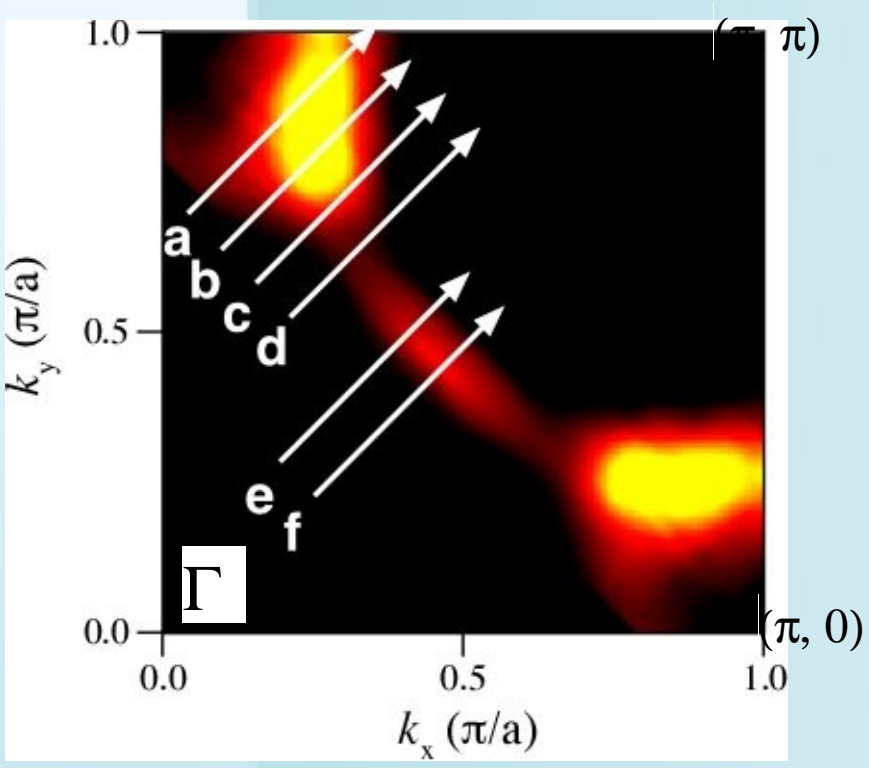


T = 30 K

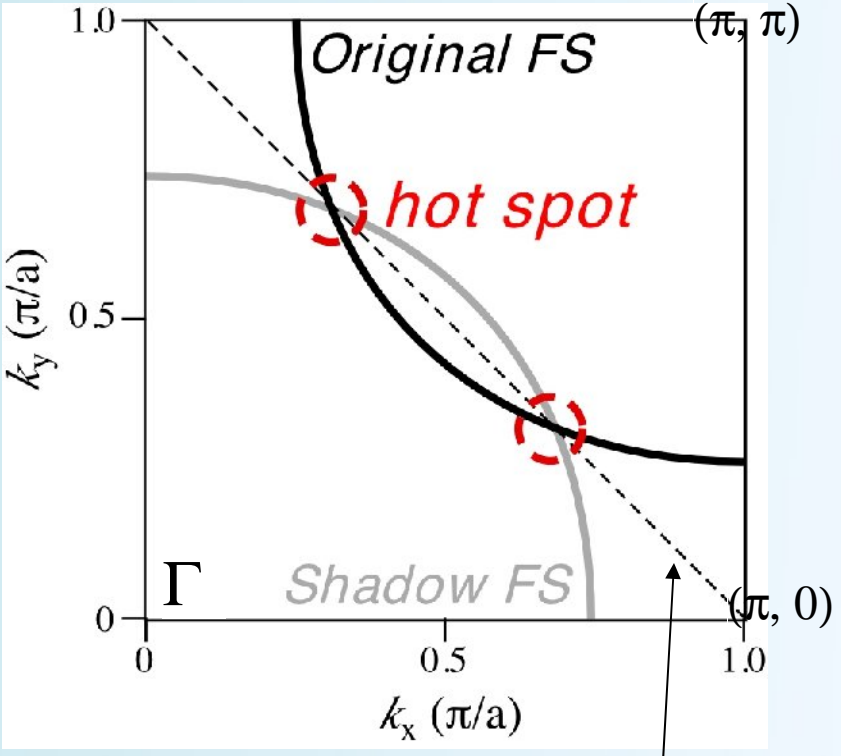


Magnetic zone boundary

Near E_F ARPES intensity in $Nd_{1,87}Ce_{0.15}CuO_4$



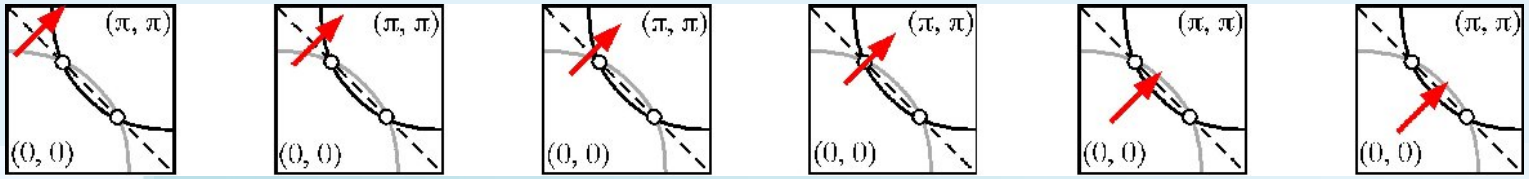
T = 30 K



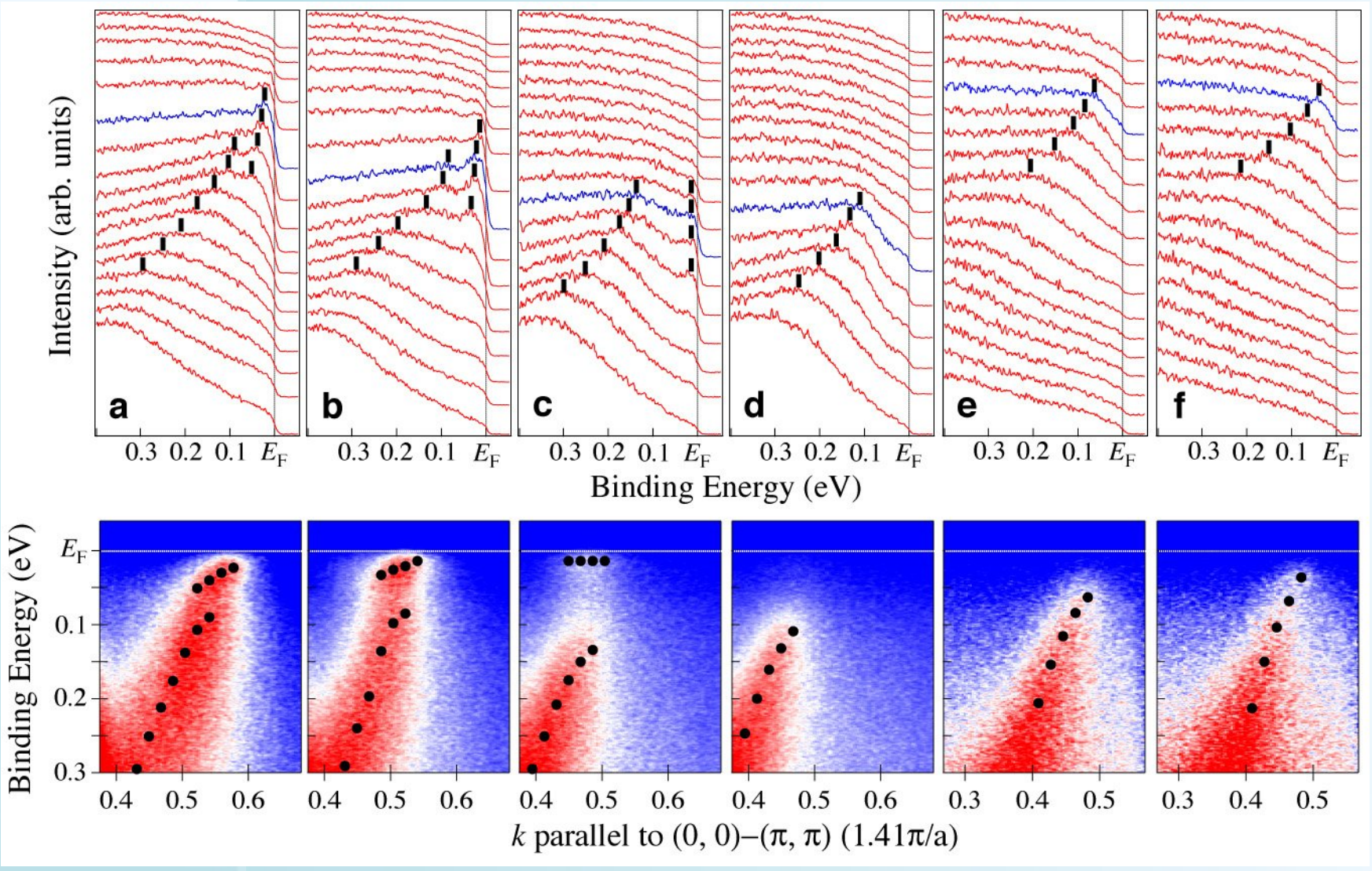
Magnetic zone boundary

Momentum dependence of ARPES spectra in NCCO (x= 0.13)

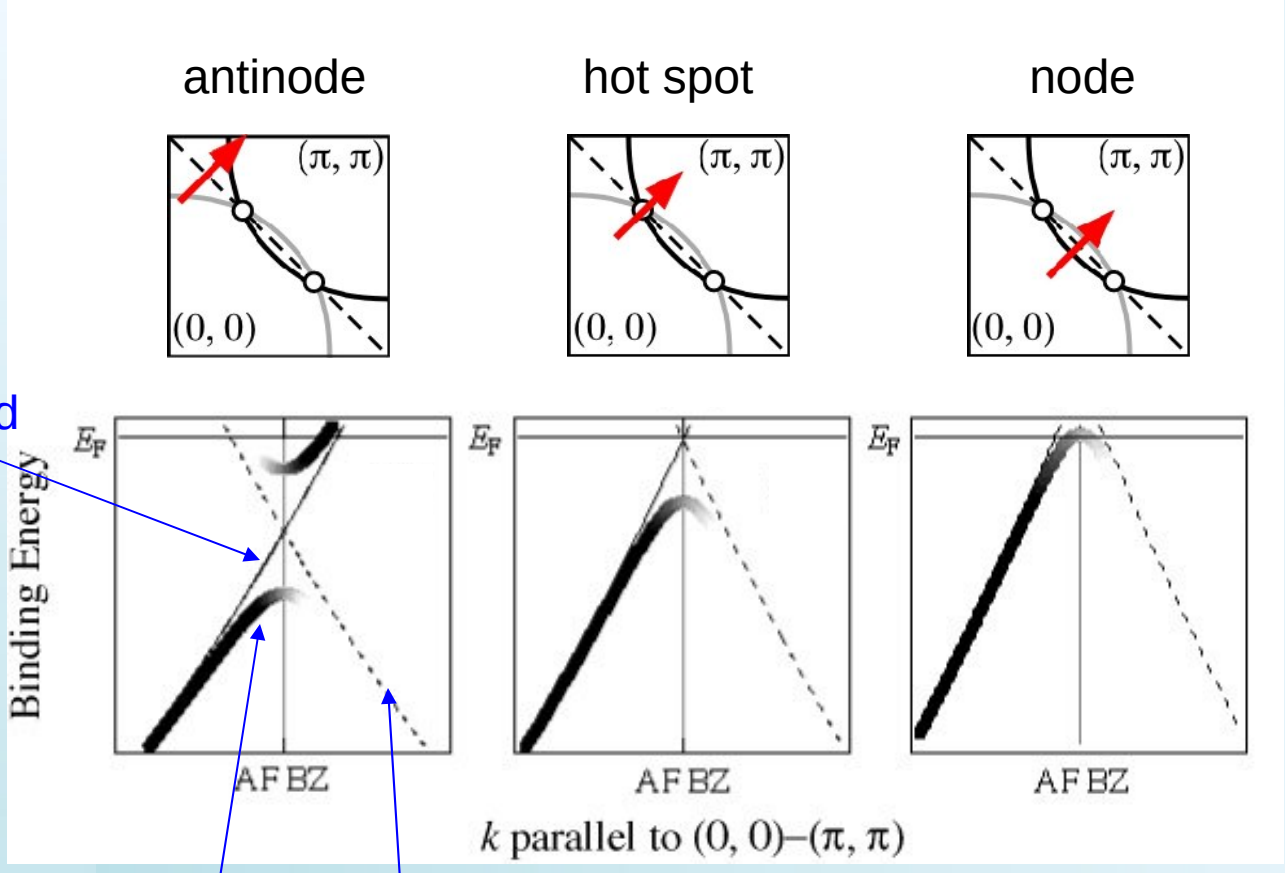
antinode



node



Modification of band dispersion by AF band-folding effect



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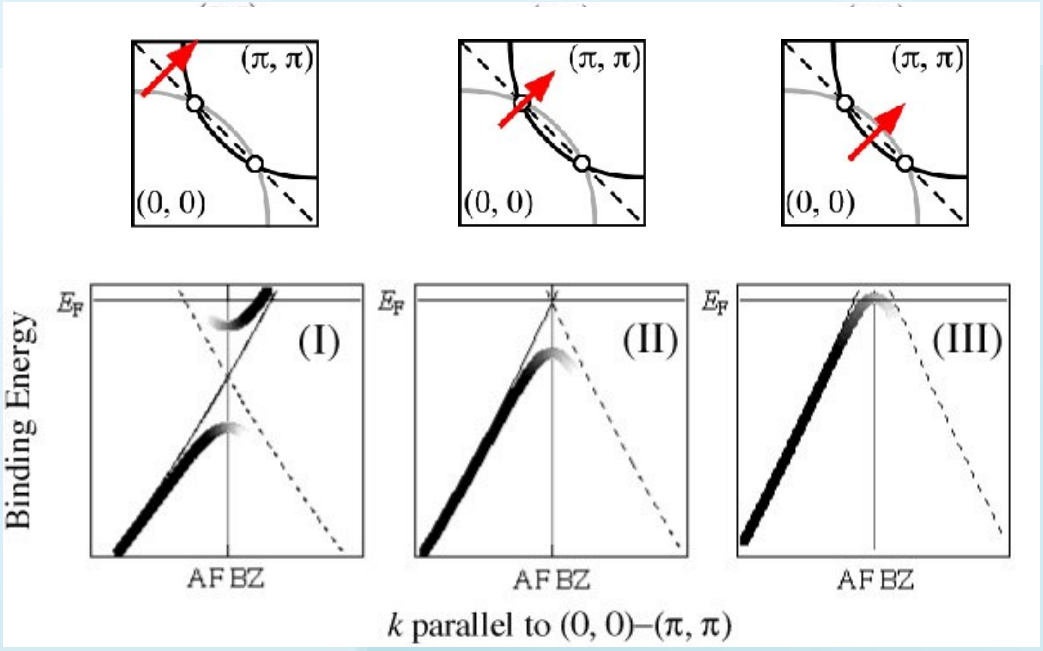


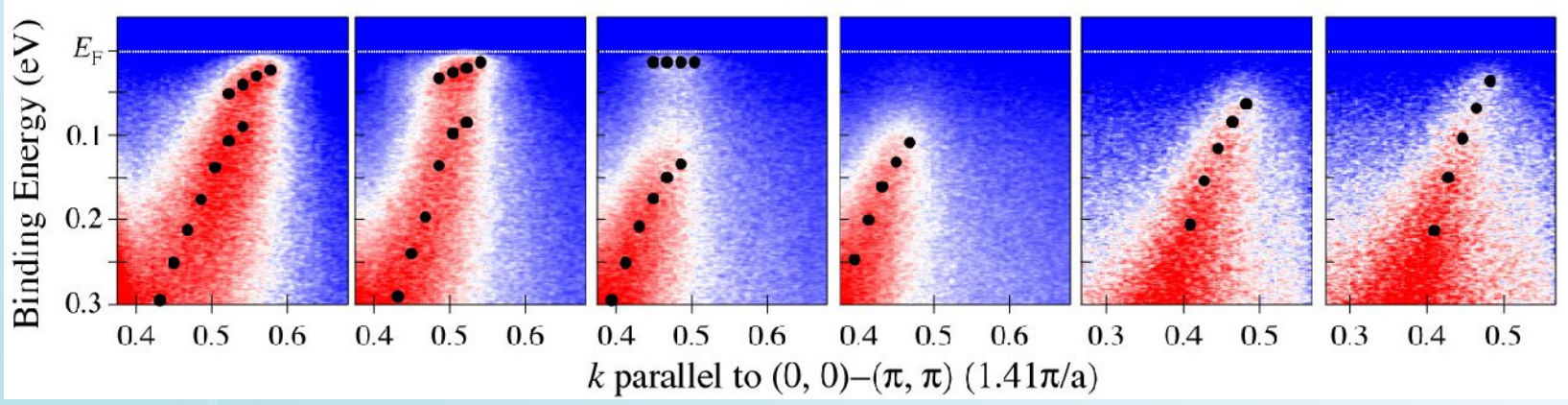
· QP is observed around $(\pi, 0)$

· QP mass increases
on approaching the hot spot

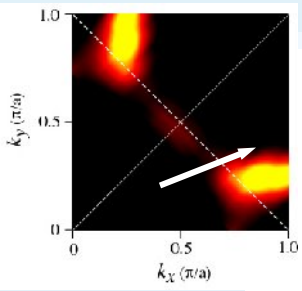
· QP intensity decreases
on approaching the hot spot

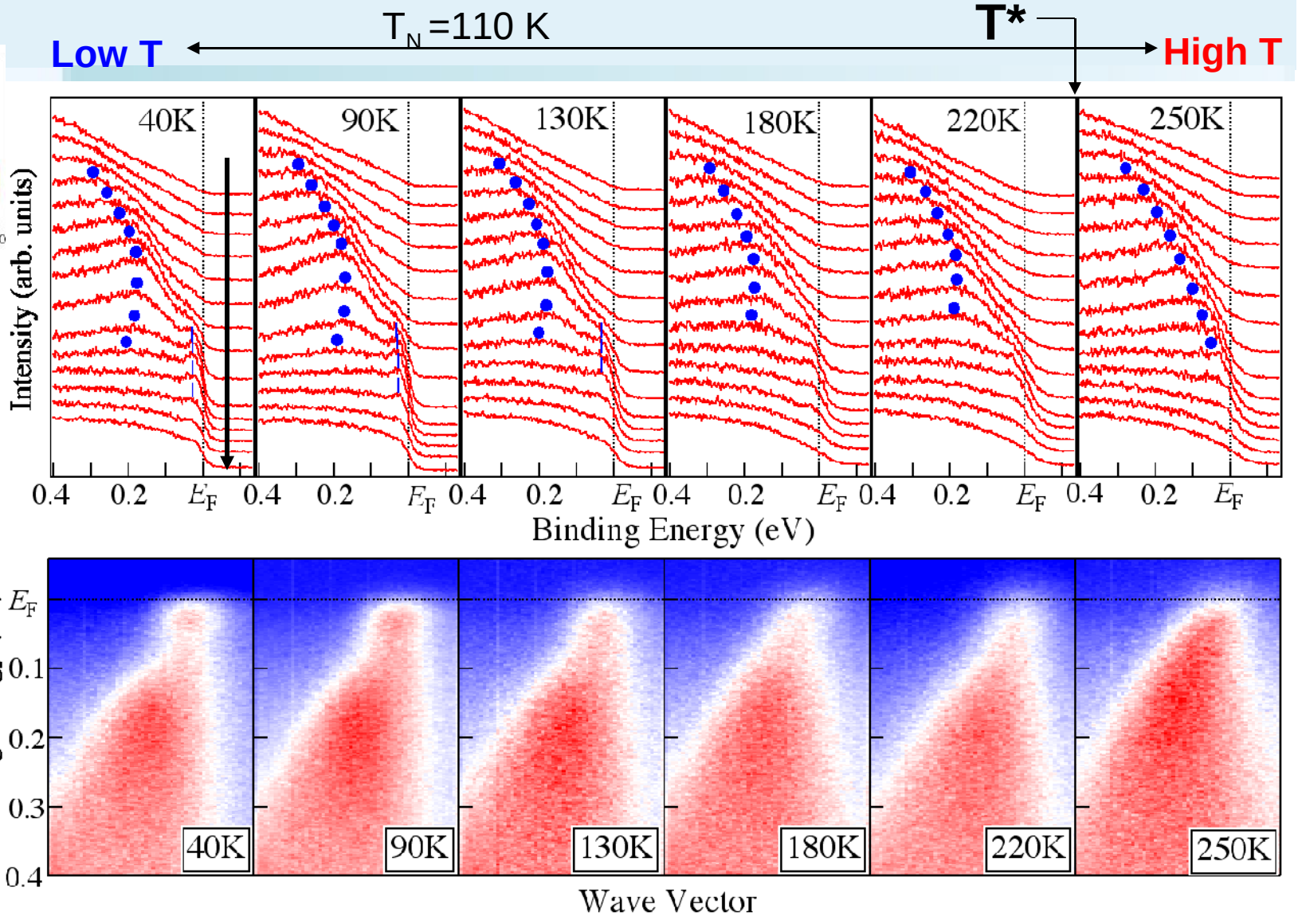
· Gap energy becomes small
on approaching the node

antinode ← hot spot → node



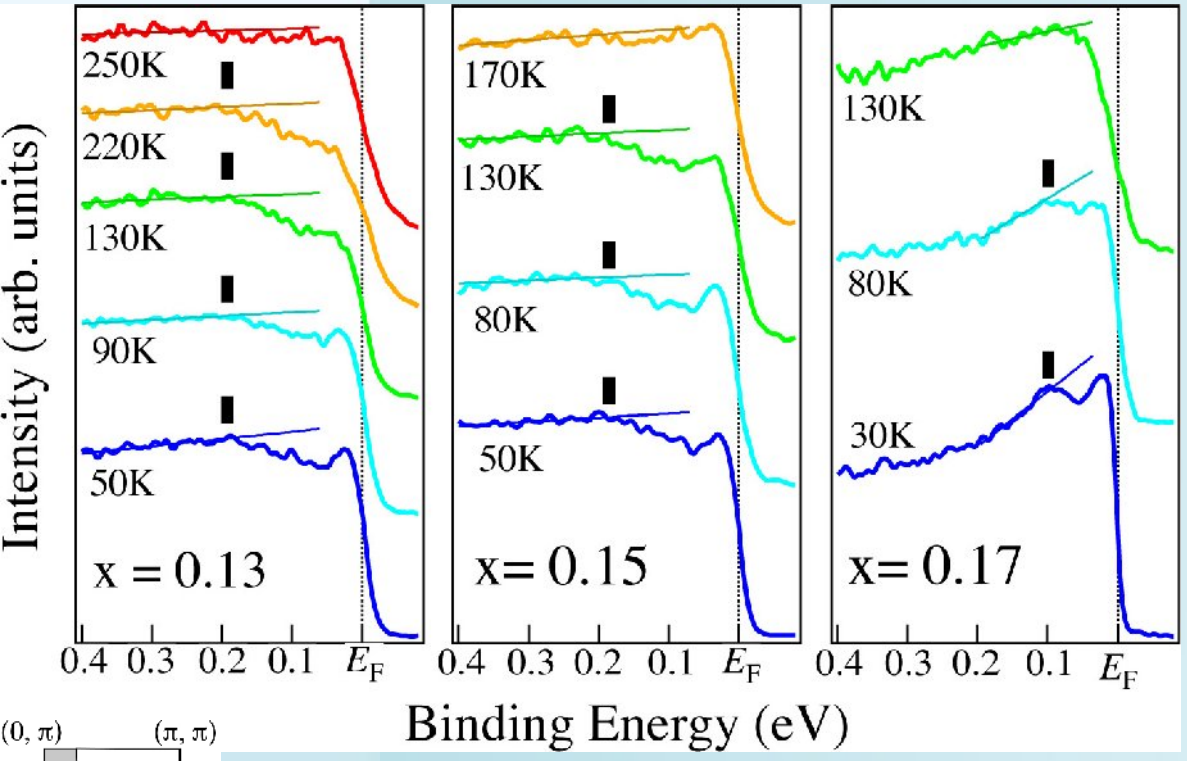
Temperature dependence of ARPES spectra in NCCO (x= 0.13)

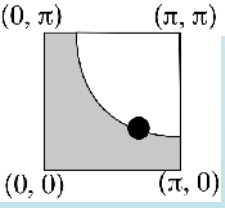


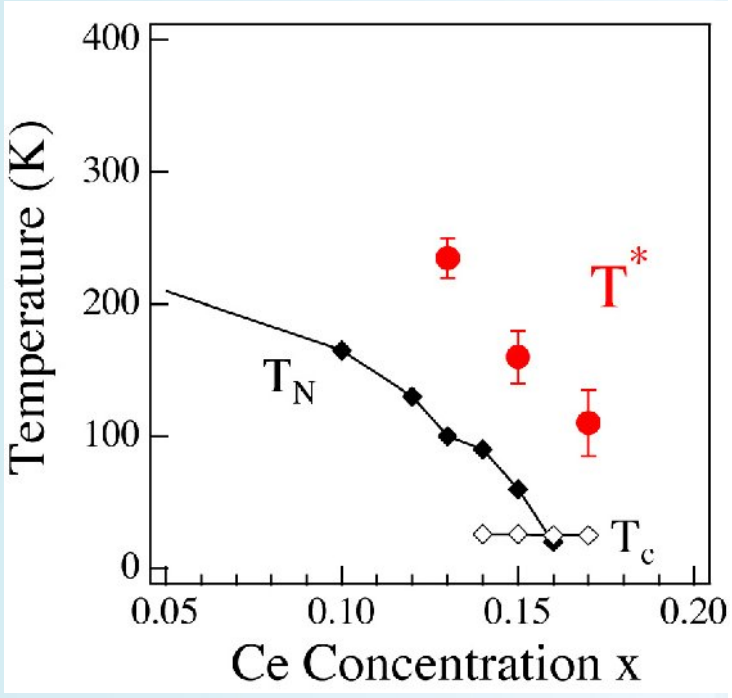


Doping dependence of T* in NCCO

k_F spectra







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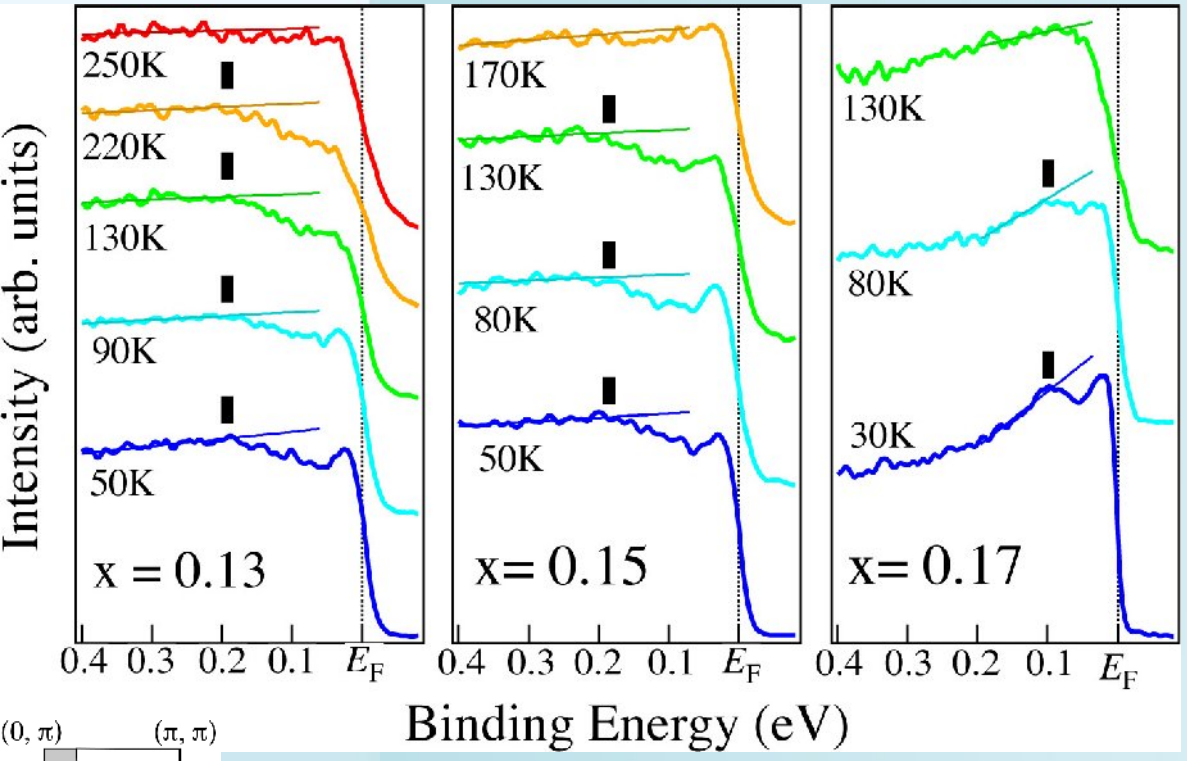
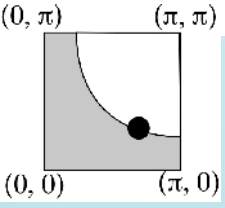
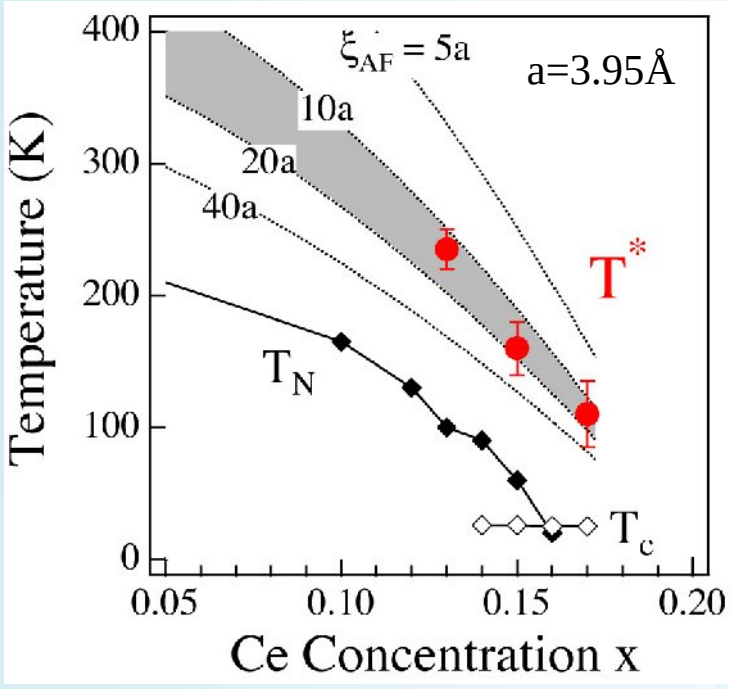


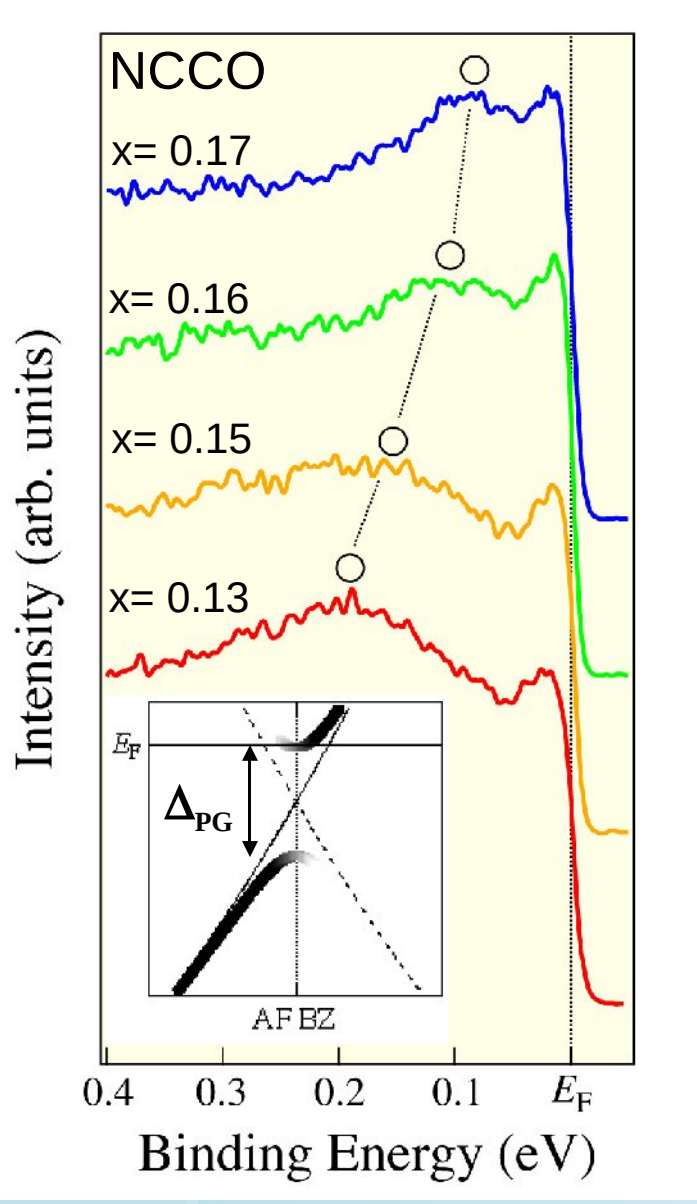


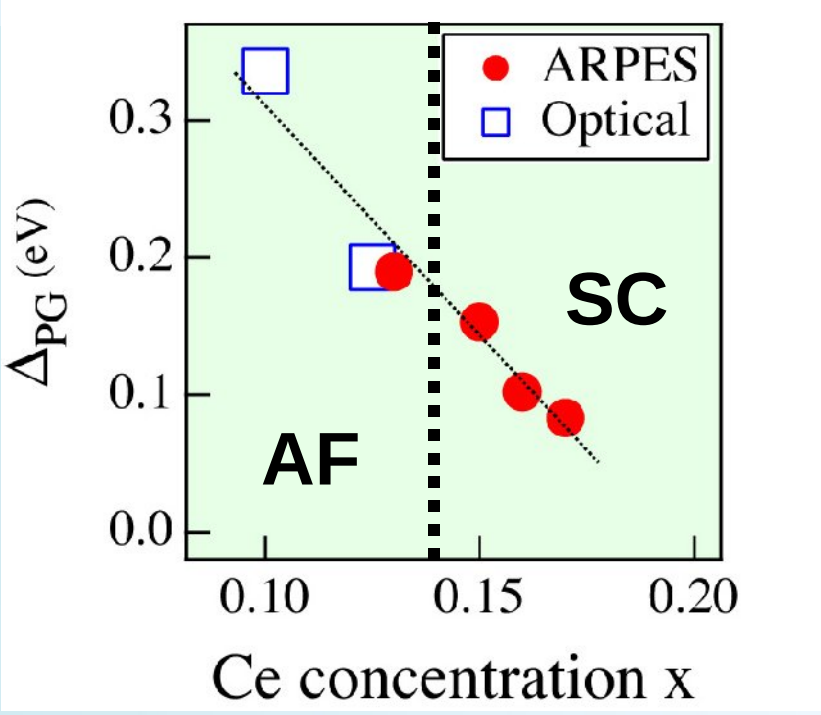


ξ_{AF} : Spin correlation length

P. K. Mang *et al.*, PRL (2004).

Doping dependence of pseudogap in NCCO





Y. Onose *et al.*, PRL 87, 217001 (2001).

-linear, $\tilde{\omega}$

-> J_{eff}

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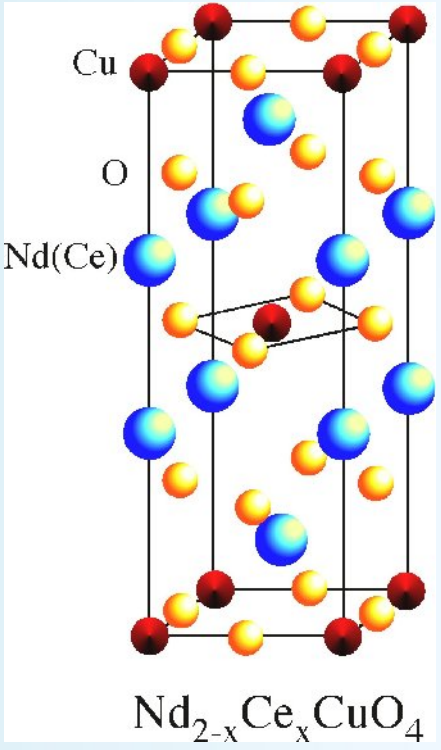
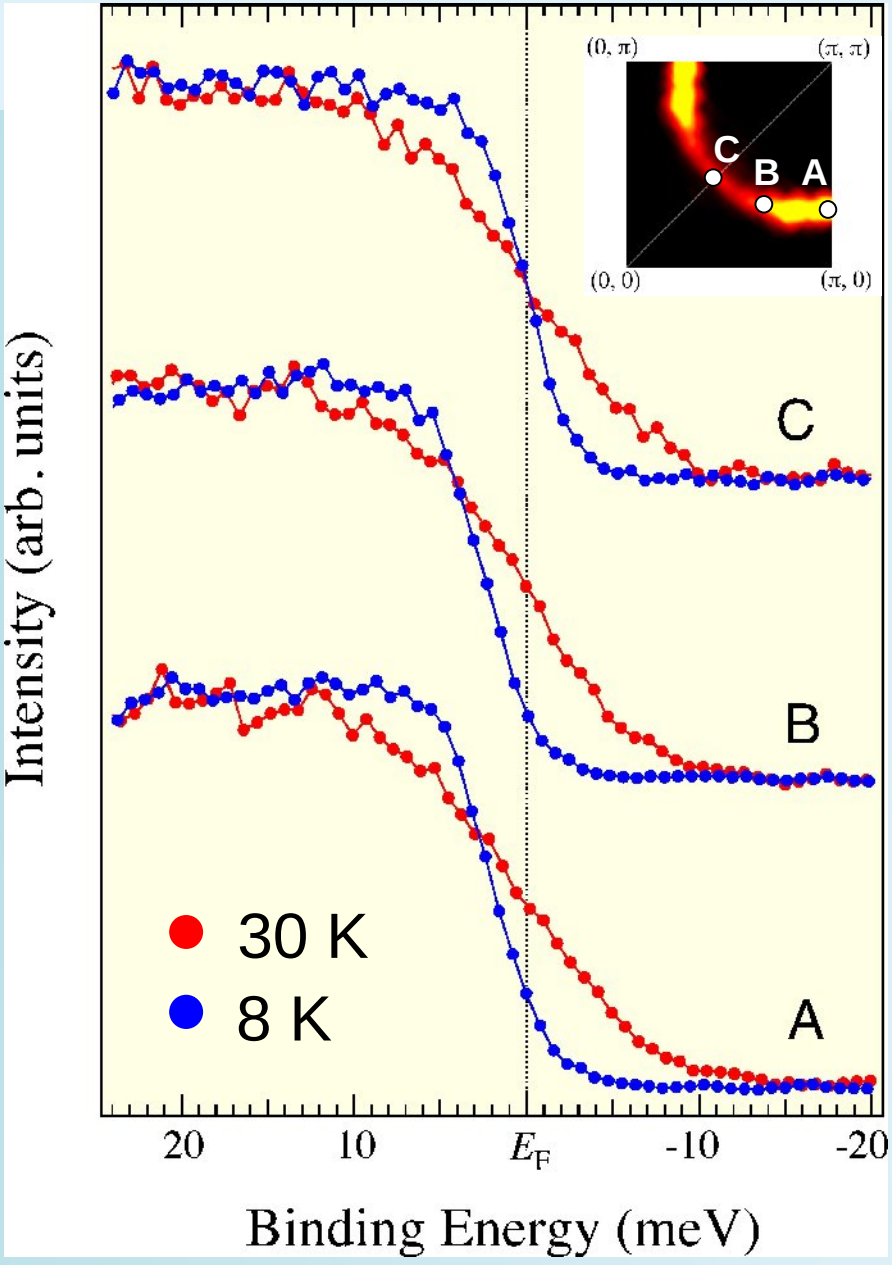


Superconducting gap in $Pr_{0.89}LaCe_{0.11}CuO_4$ (T_c= 26K)



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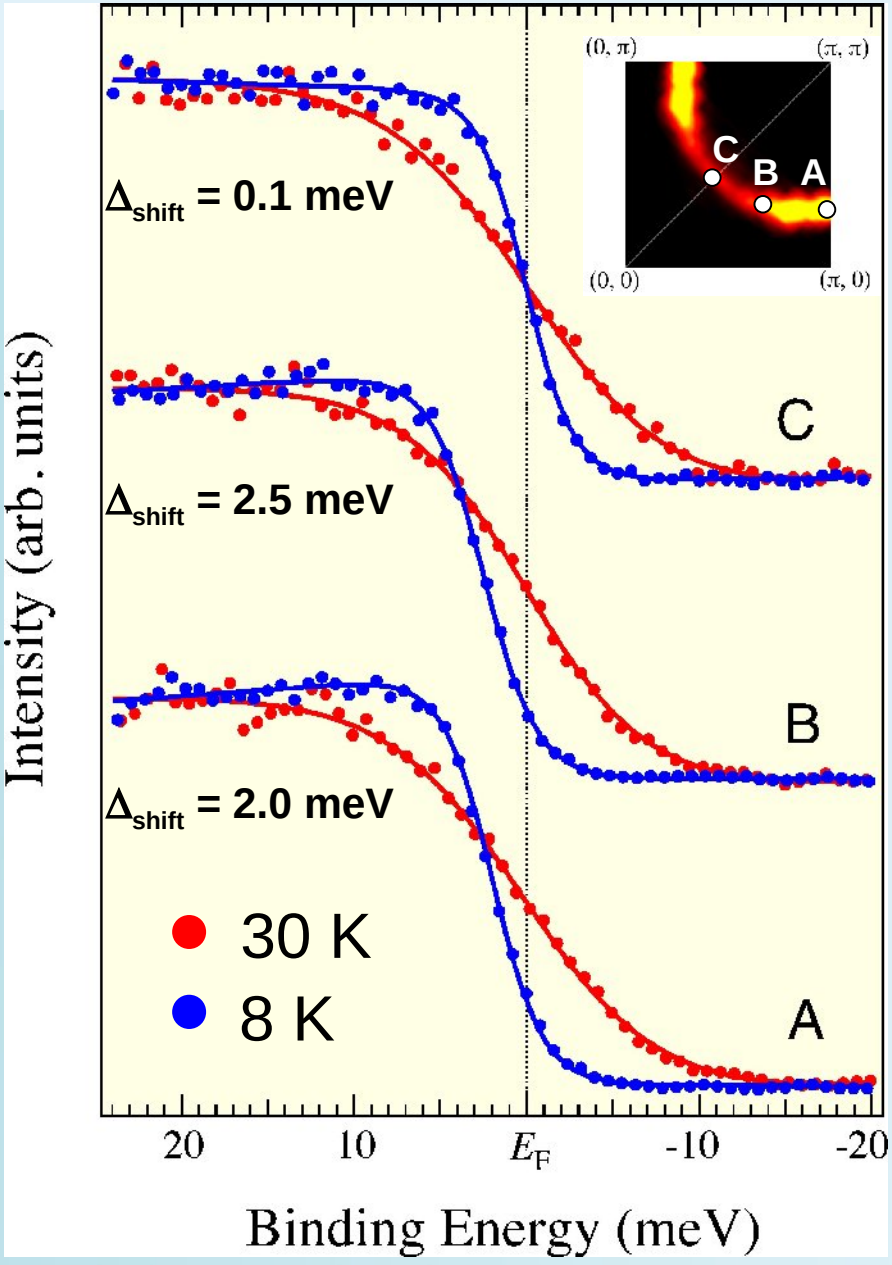
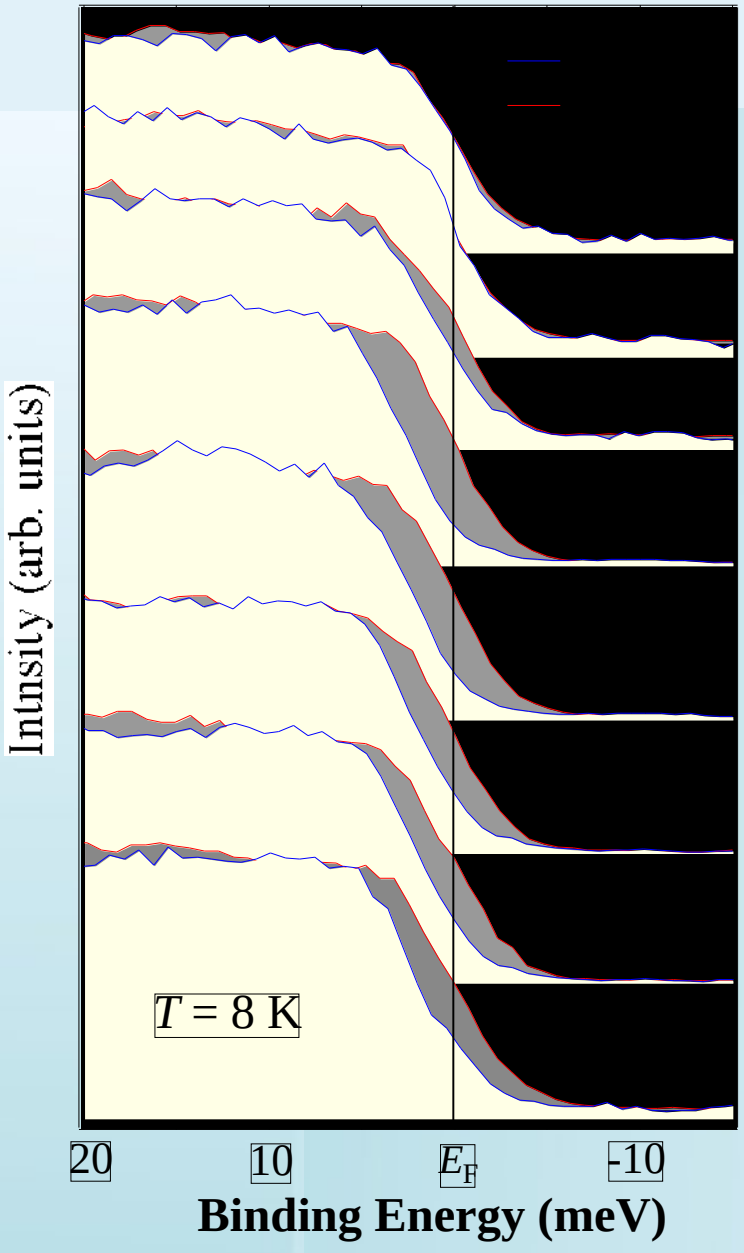
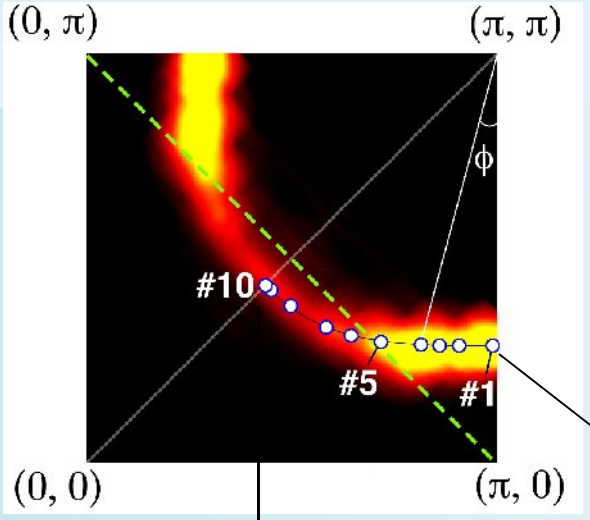


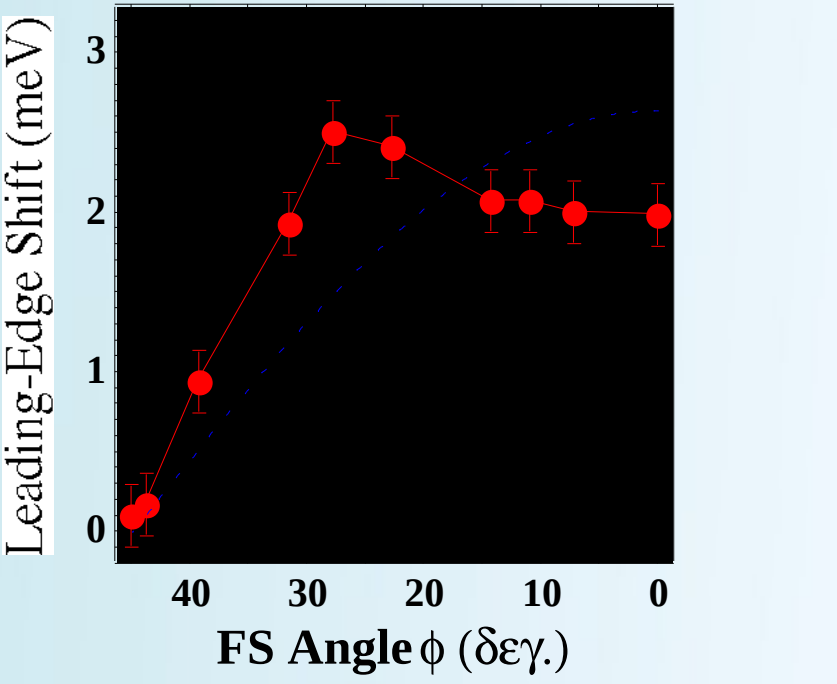
Momentum dependence of SC gap in PLCCO



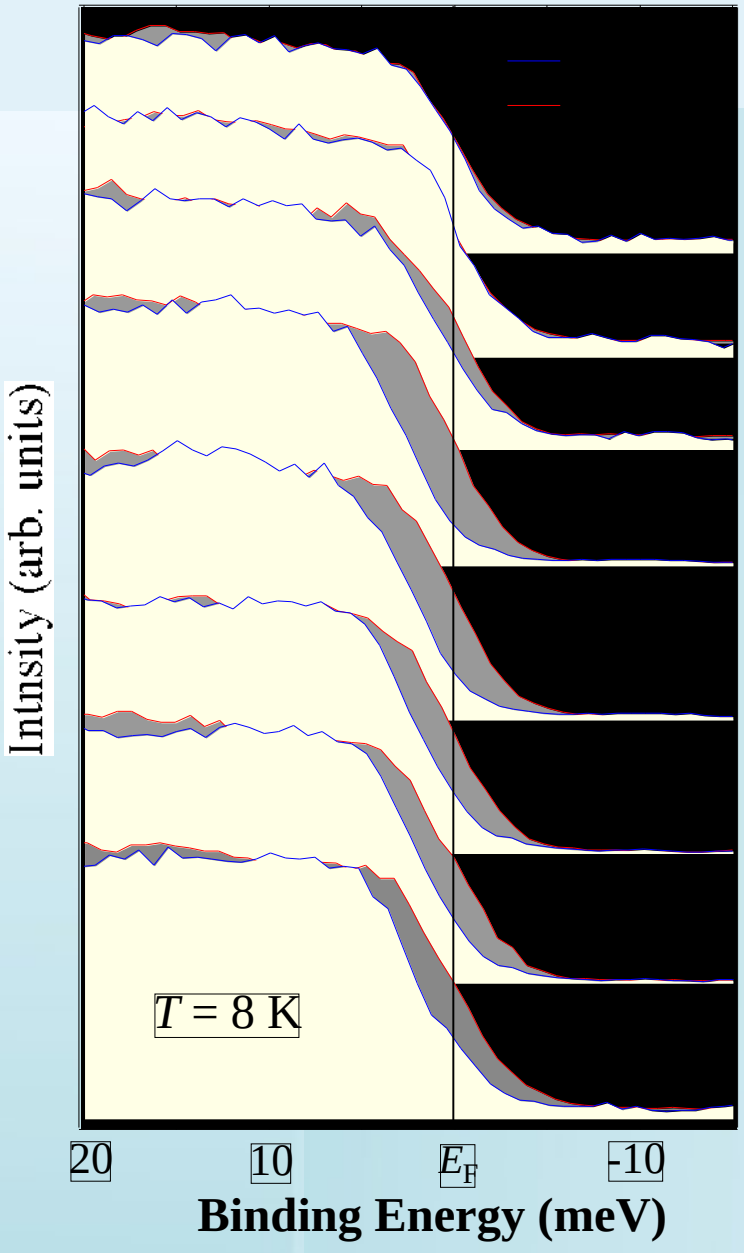


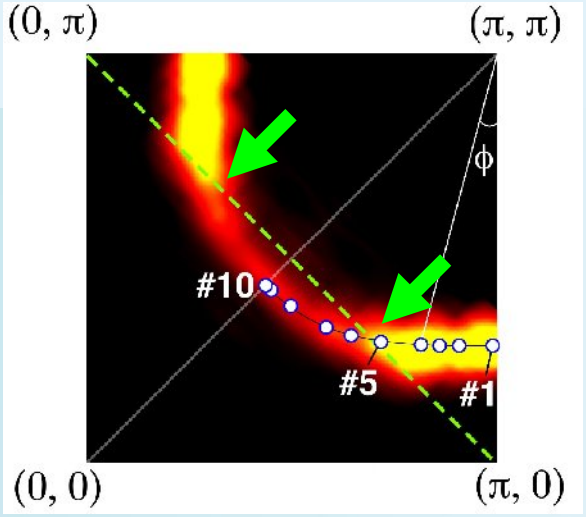
Node

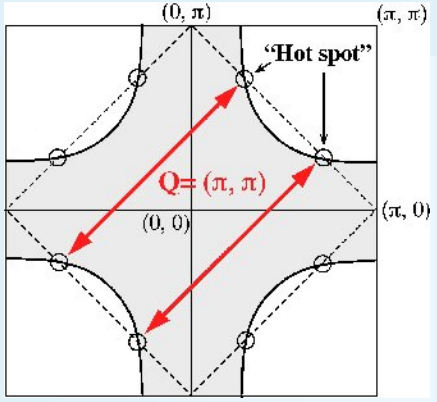
Antinode

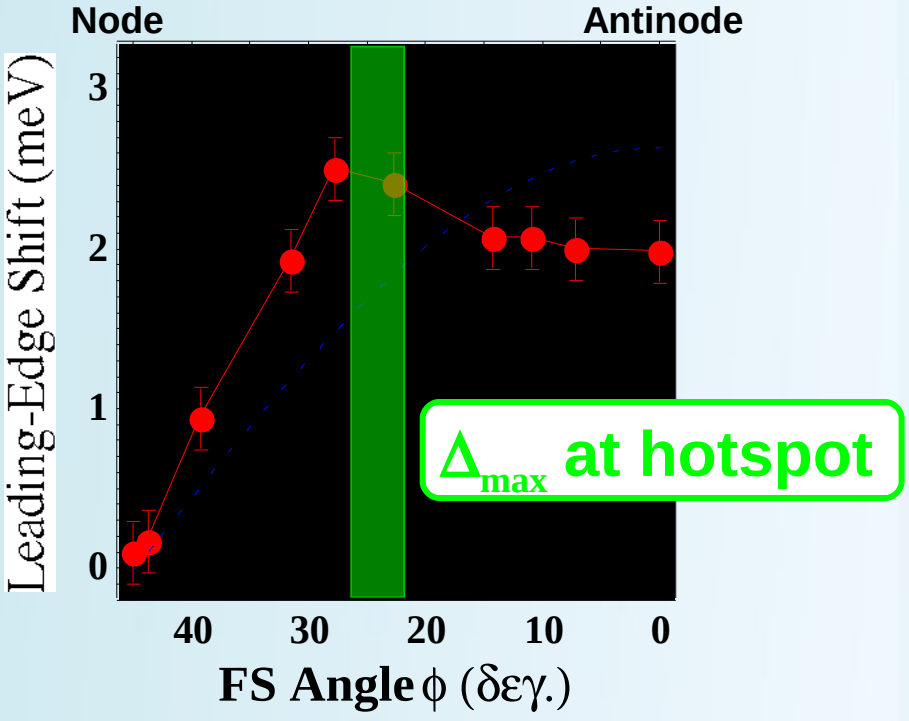


Momentum dependence of SC gap in PLCCO





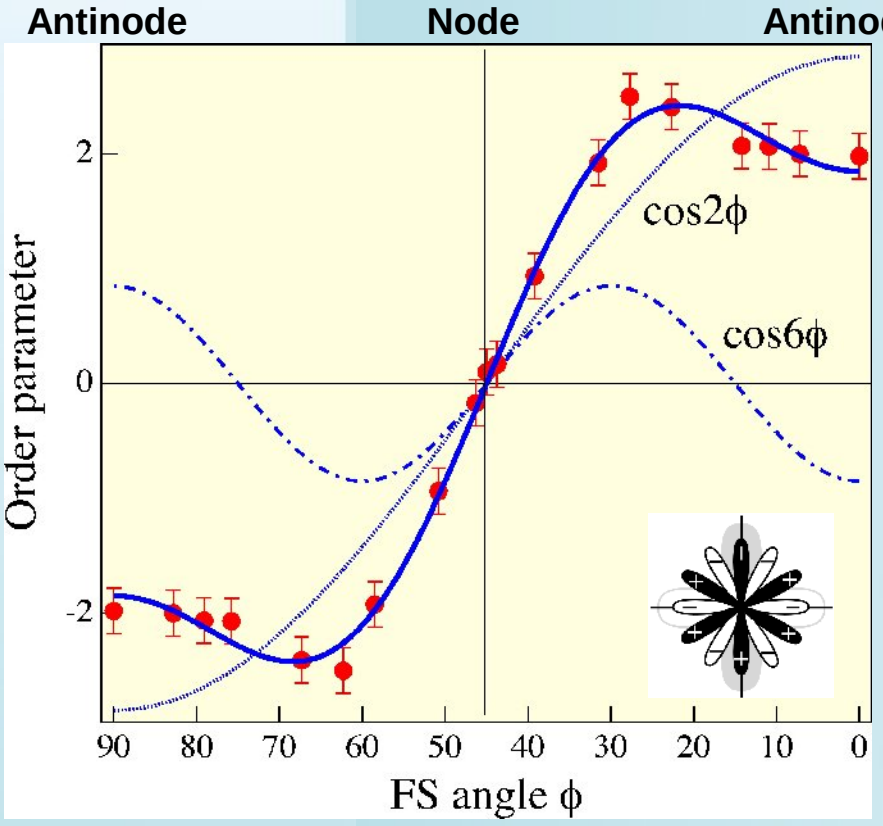




Numerical fitting of the superconducting gap

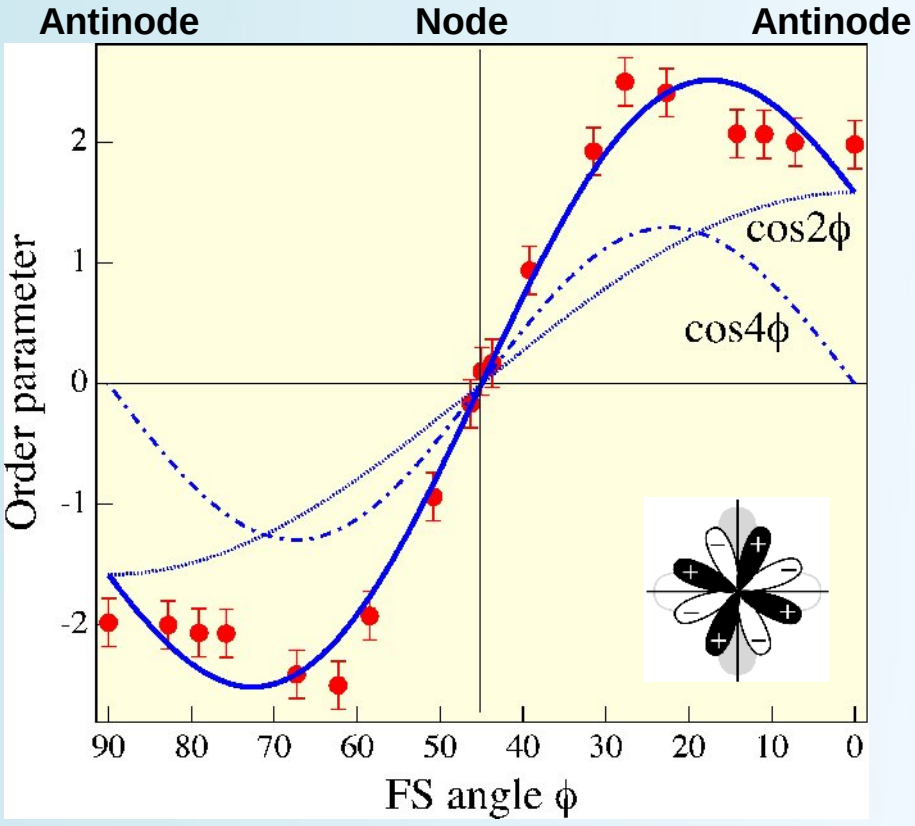
d + 2nd higher harmonic

$\Delta(\phi) = \Delta_0(A\cos2\phi + B\cos6\phi)$



d + *g* wave

$\Delta(\phi) = \Delta_0(A\cos2\phi + B\sin4\phi)$

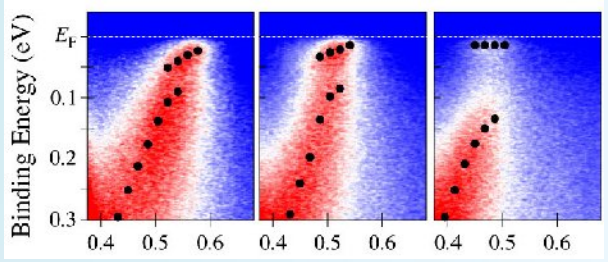


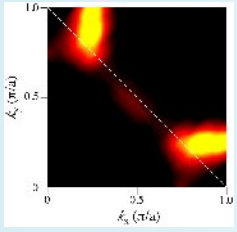
Summary

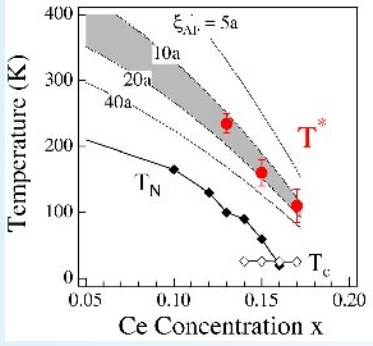
High-resolution ARPES in $Nd_{2-x}Ce_xCuO_4$ and $Pr_{1-x}LaCe_xCuO_4$

i) Normal state : pseudogap & quasiparticle

- Systematic variation of band dispersion
  explained by the AF band-folding effect
- Pseudogap temperature (T*)
  determined by the spin correlation length
- Linear doping dependence of Δ_{PG}







Magnetic excitation strongly couples to the electronic states near the Fermi level in electron-doped HTSCs

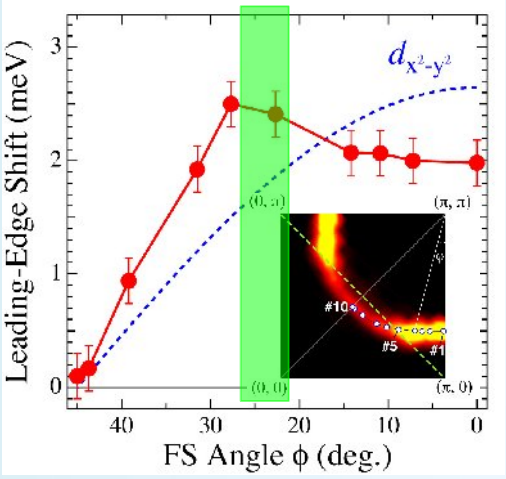
Summary

High-resolution ARPES in $Nd_{2-x}Ce_xCuO_4$ and $Pr_{1-x}LaCe_xCuO_4$

ii) Superconducting state : gap symmetry

- Nonmonotonic $d_{x^2-y^2}$

  Δ_{max} at the hot spot where the AF fluctuation most strongly couples to the electrons on the FS



Magnetic interaction plays an essential role in the pairing mechanism of electron-doped HTSCs

Experiments

Sample : $Nd_{2-x}Ce_xCuO_4$ (x = 0.13, T_N= 110 K)
(x = 0.15, T_c= 25 K)
(x = 0.16, T_c= 25 K)
(x = 0.17, T_c= 25 K)

$Pr_{2-x}LaCe_xCuO_4$ (x = 0.11, T_c= 26 K)

ARPES :

· Tohoku University

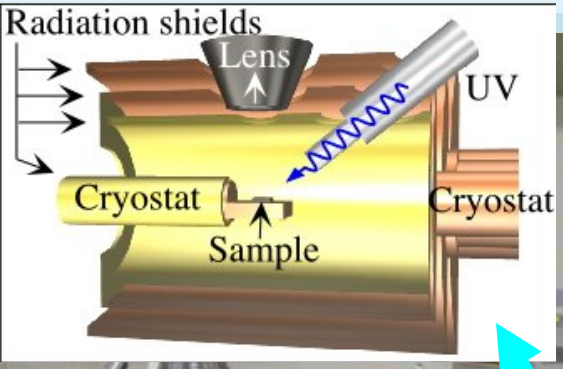
· Synchrotron Radiation Center at Wisconsin

Photon energy = 21.218 eV, 22 eV

Energy resolution = 5 -15 meV

Angular (momentum) resolution = 0.1° (0.007A^{-1})

Ultrahigh-resolution photoemission spectrometer at Tohoku University



Energy resolution: 1.3 meV
Angular resolution: ± 0.1°
Temperature: 3.2 K-
Pressure: 1.5×10^{-11} Torr

Hemispherical analyzer
SES2002

LEED Chamber

He lamp

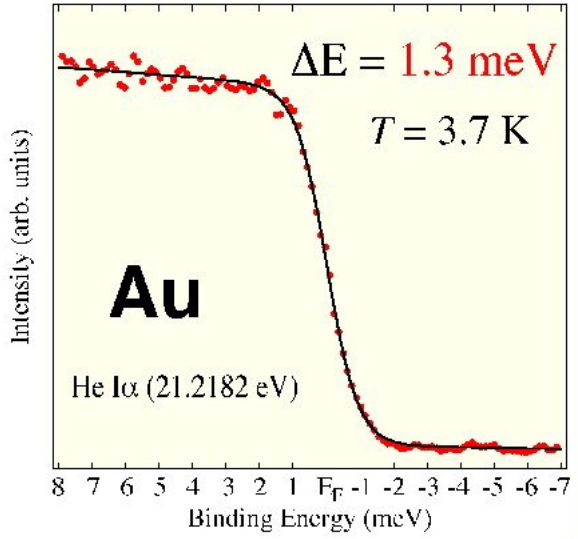
Preparation chamber

Monochromator

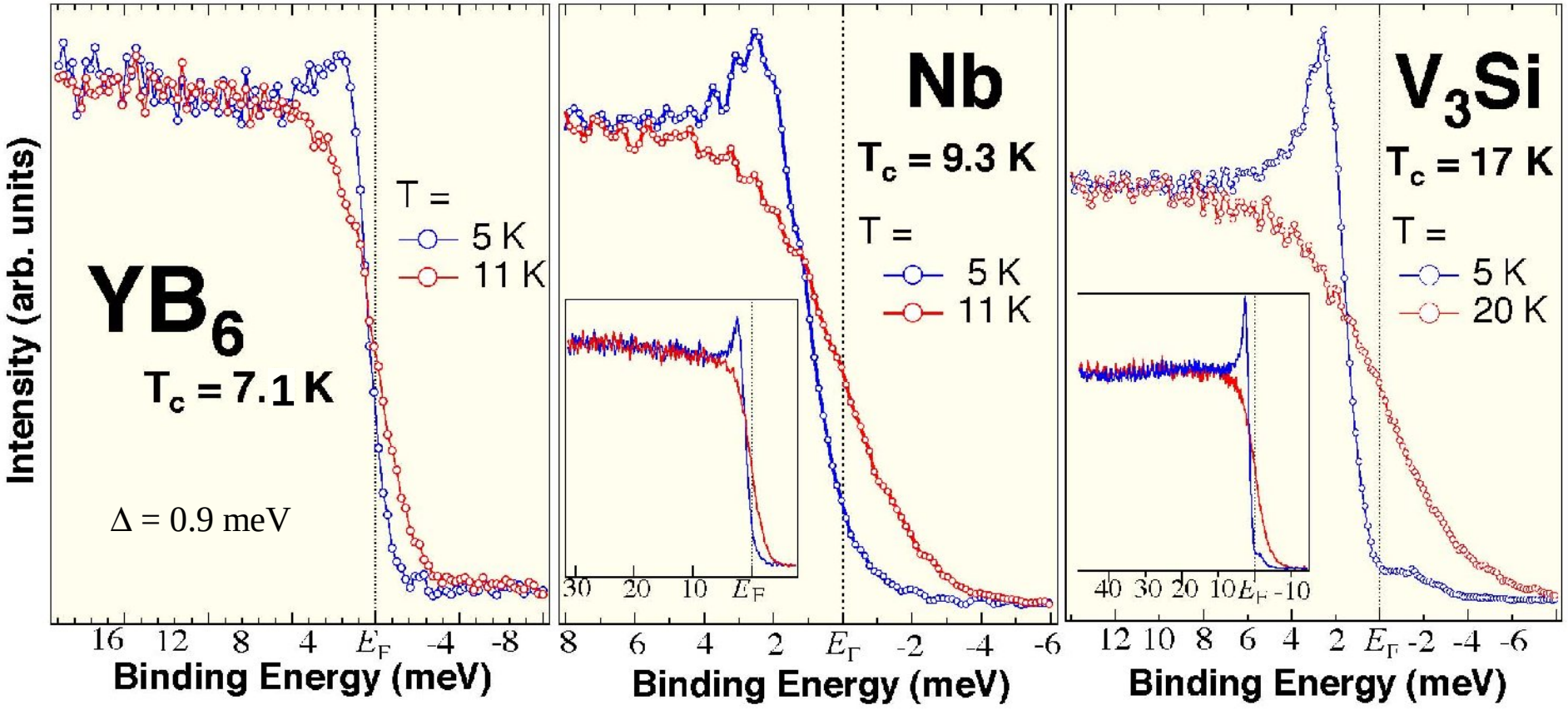
Manipulator

Main chamber

Pumping chamber



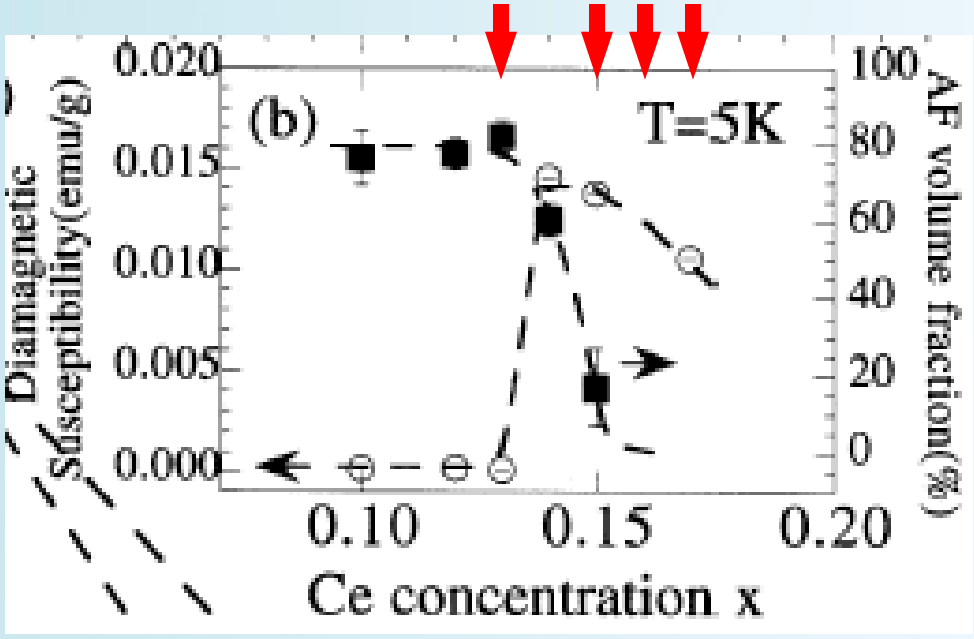
Superconducting gap in low-T_c superconductors



Samples for detailed doping dependence

$Nd_{2-x}Ce_xCuO_4$ (x= 0.13-0.17)

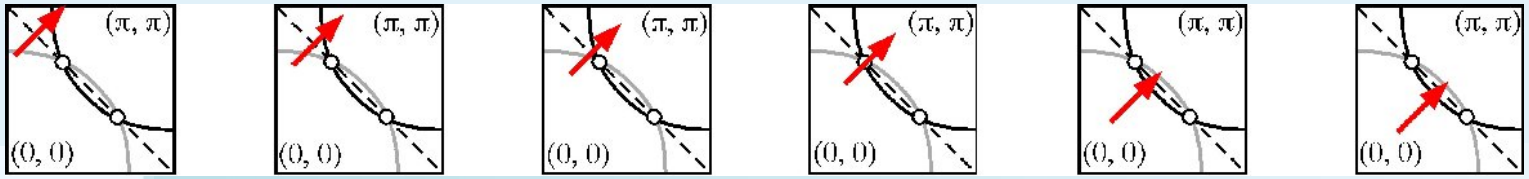
	T_N	T_c^{onset}
x= 0.13	110 K	——
x= 0.15	70 K	25 K
x= 0.16	——	25 K
x= 0.17	——	25 K



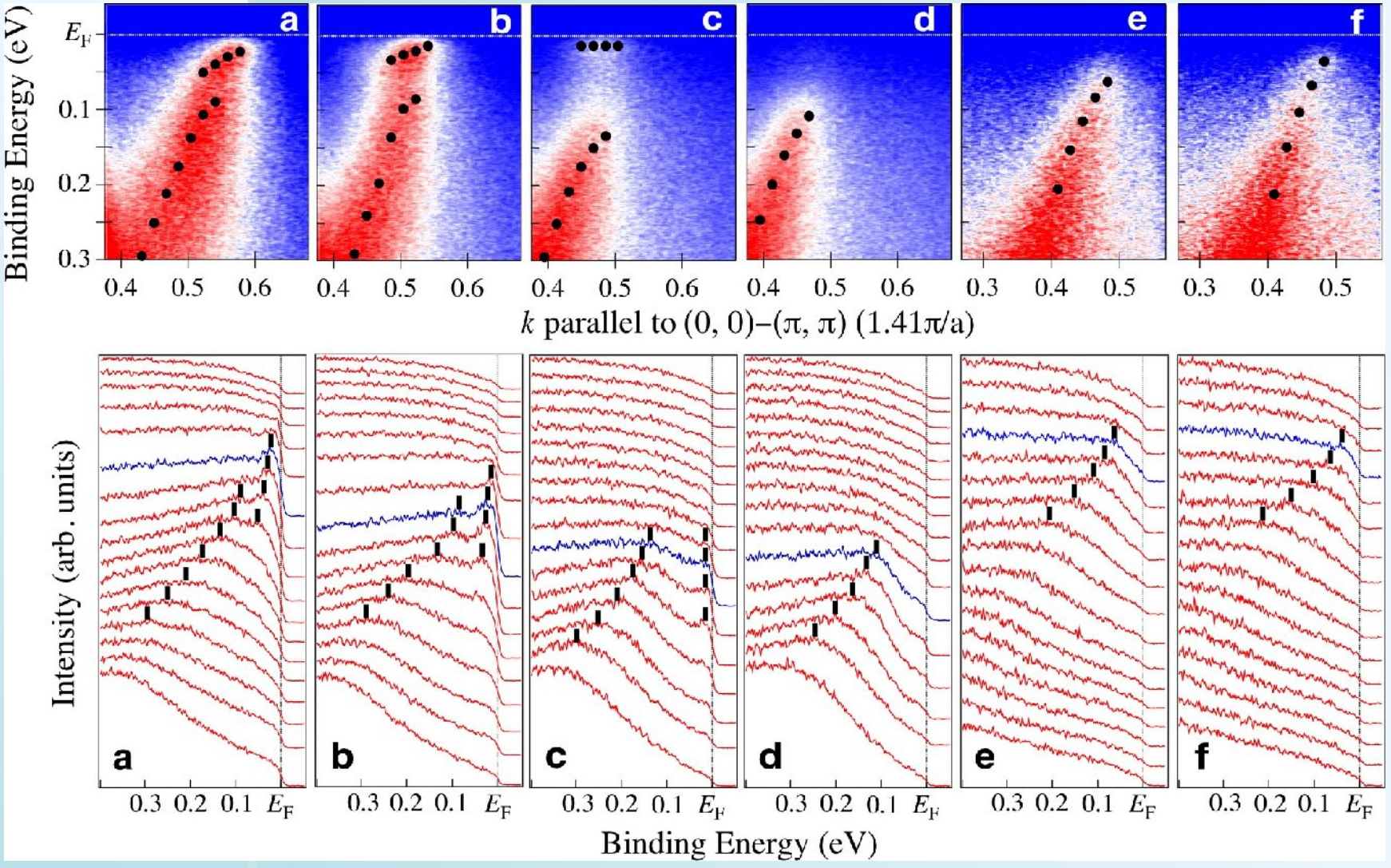
T. Uefuji *et al.*, Physica C 357-360, 208-211 (2001).

Momentum dependence of ARPES spectra in NCCO

antinode

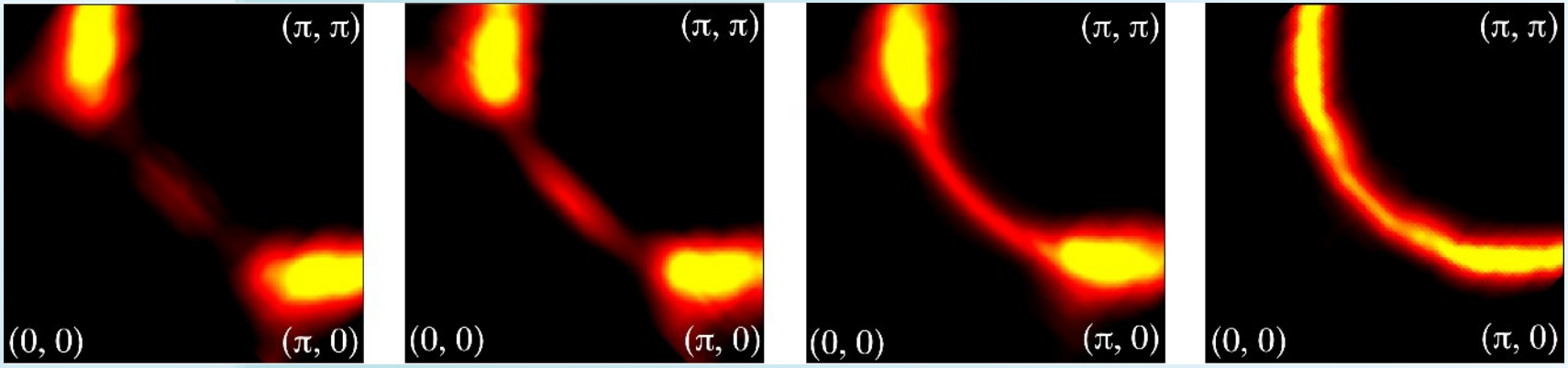


node



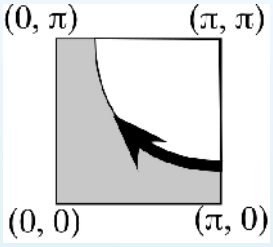
Doping dependence of the Fermi surface in NCCO

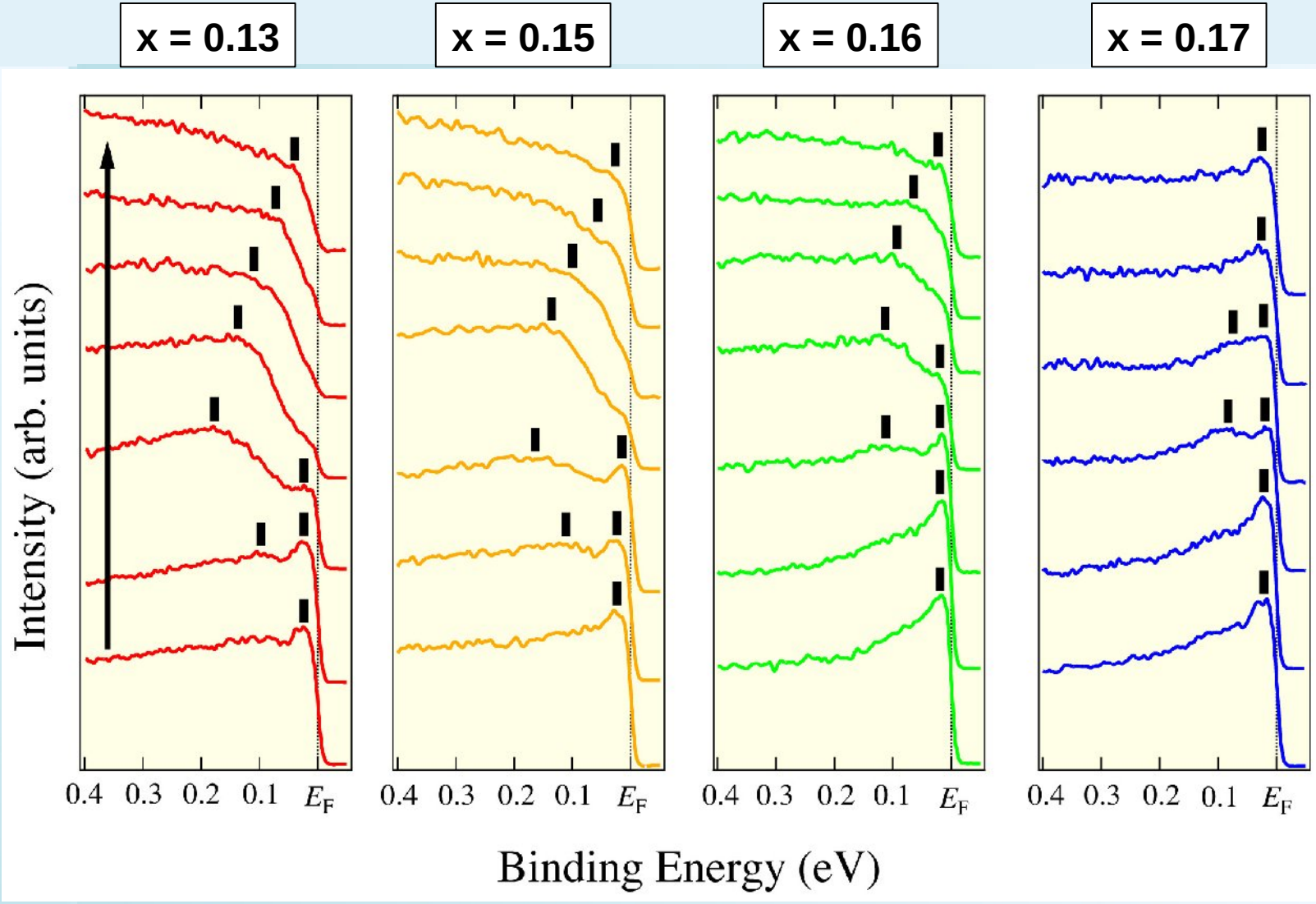
x = 0.13 x = 0.15 x = 0.16 x = 0.17



T= 30 K

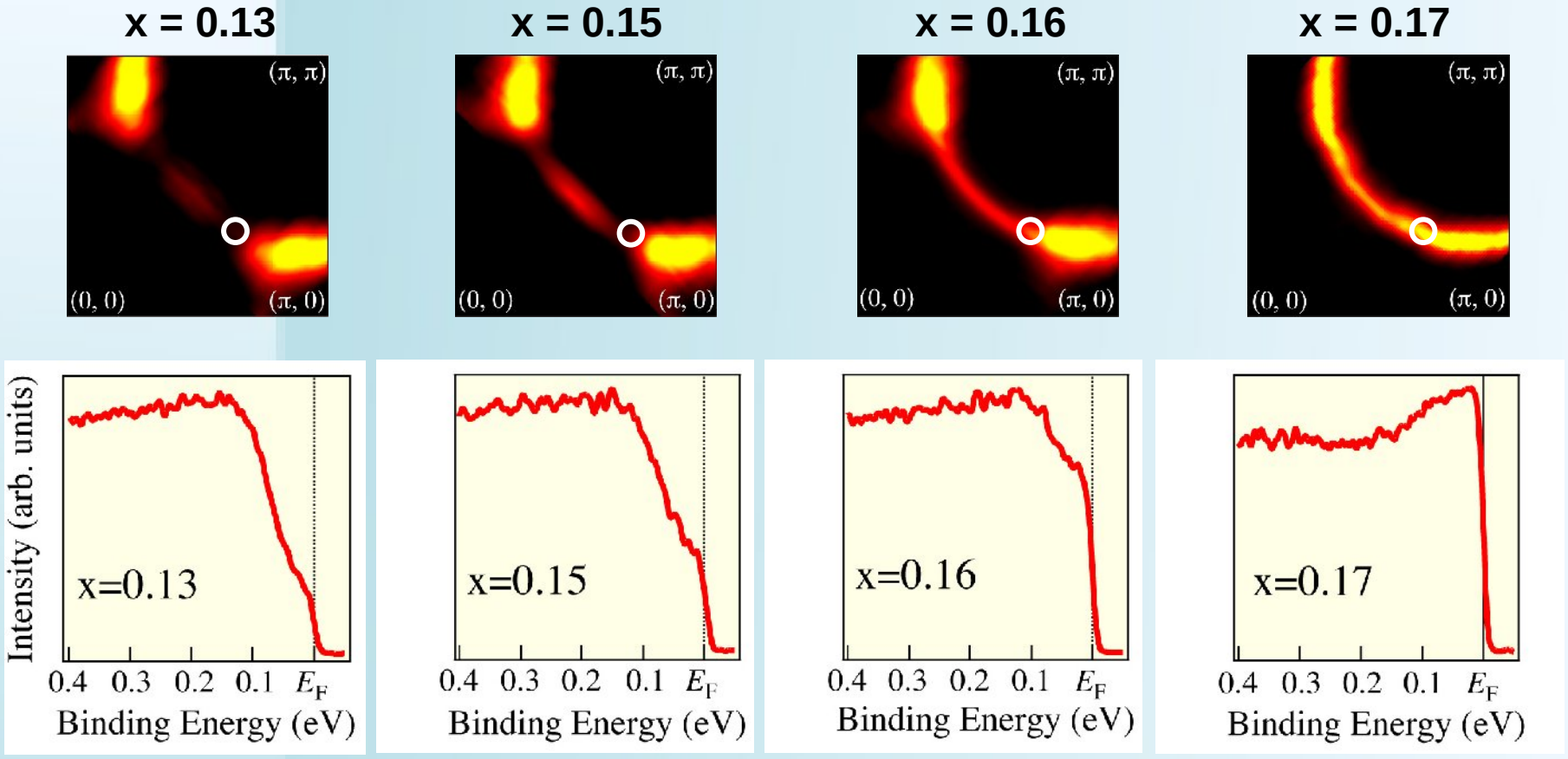
Doping dependence of ARPES spectra in NCCO



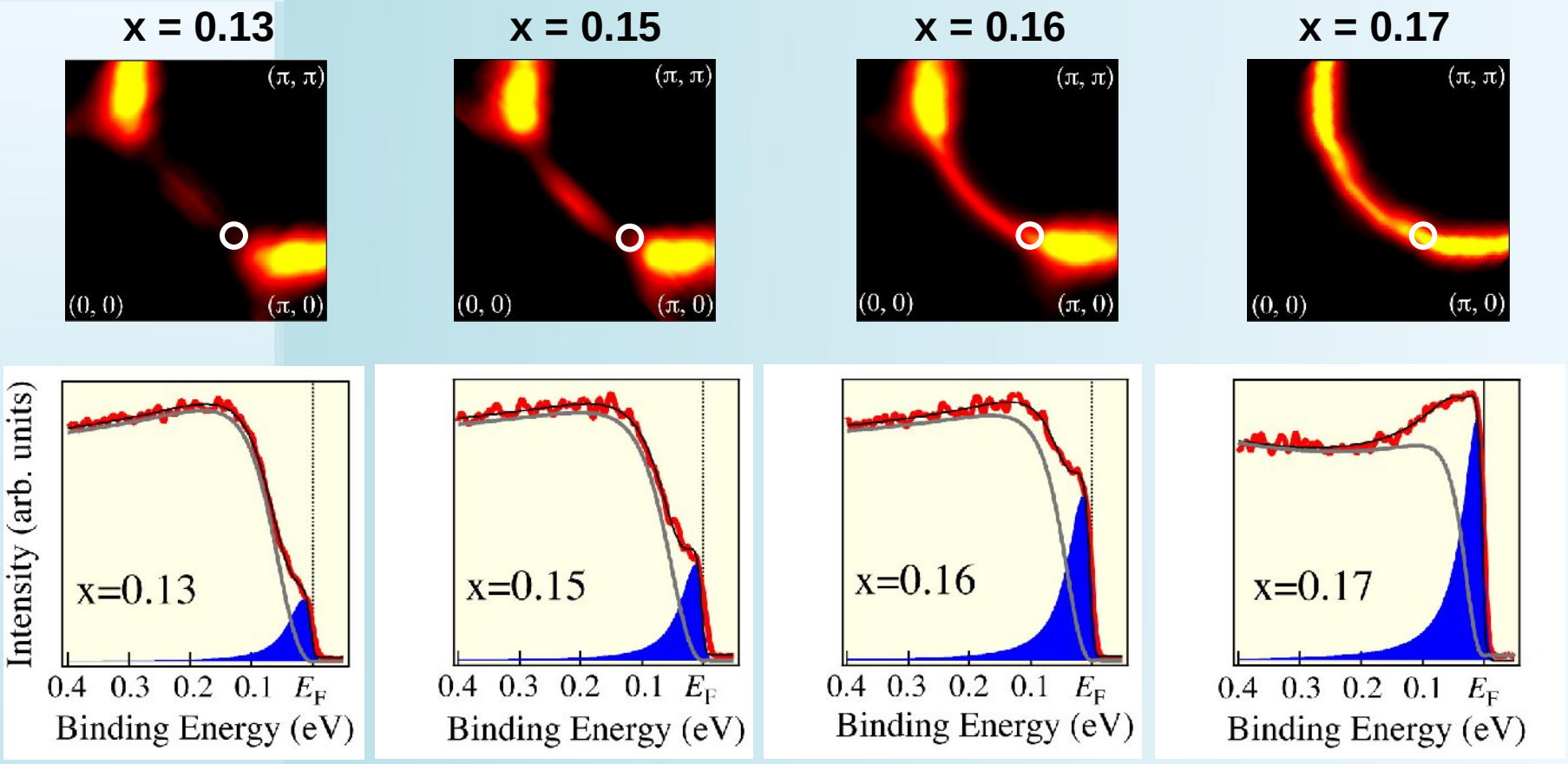


T= 30 K

Doping dependence of Fermi surface in NCCO



Doping dependence of Fermi surface in NCCO



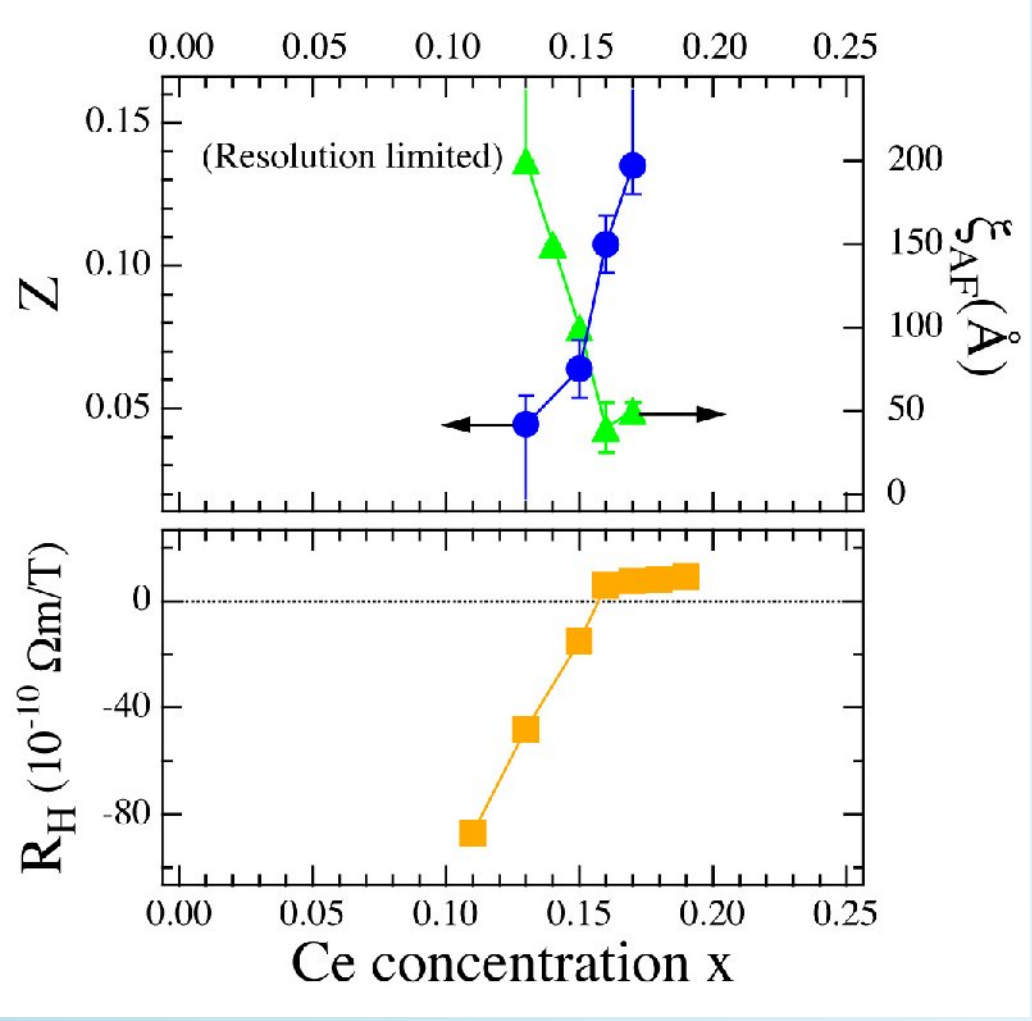
$Z \equiv$ in-gap spectral weight / total spectral weight [-0.4eV~E_F]

Doping dependence of in-gap spectral weight

In-gap weight

Hall coefficient

Y. Dagan *et al.*,
PRL (2004).

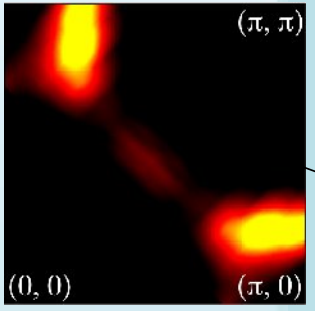


Spin correlation length

T. Uefuji *et al.*,
Physica C (2001).

Doping dependence of in-gap spectral weight

In-gap weight



Hall coefficient

Y. Dagan *et al.*,
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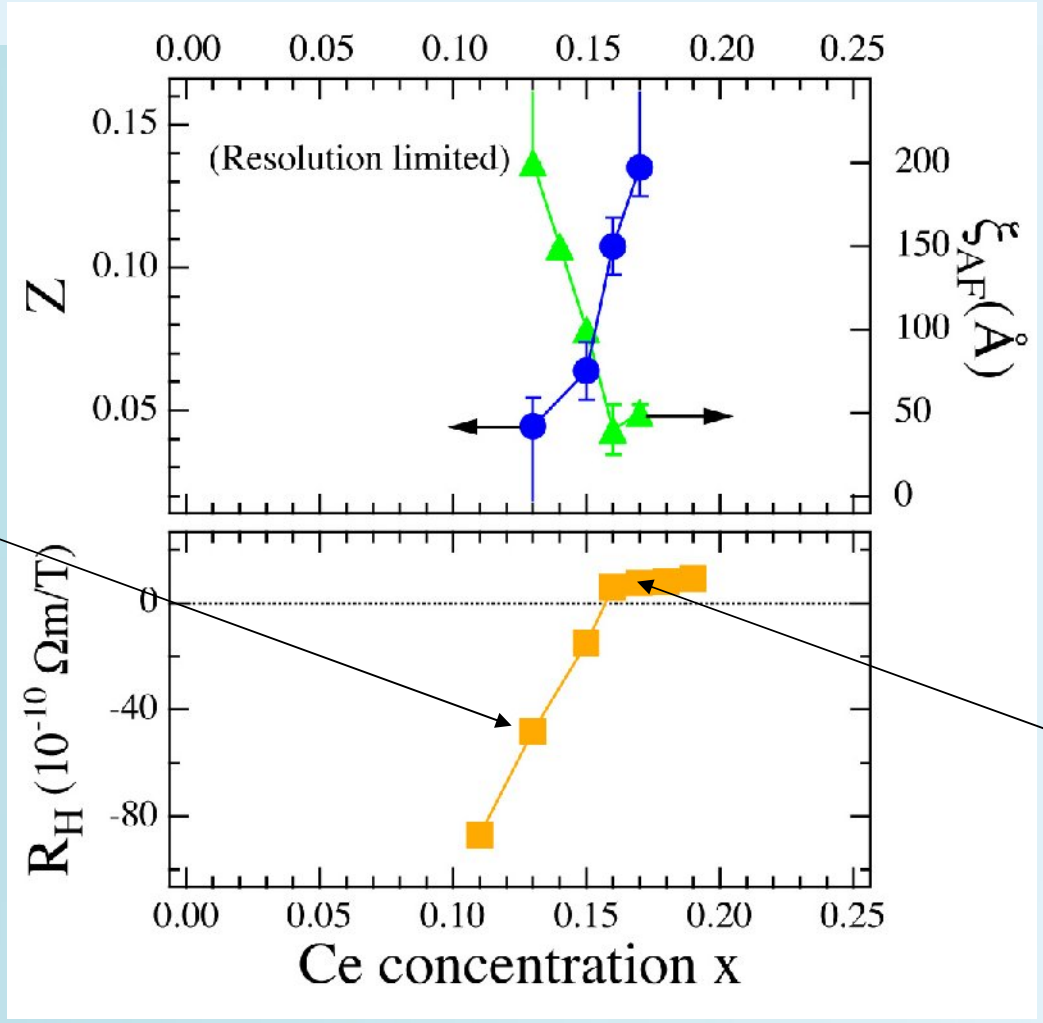
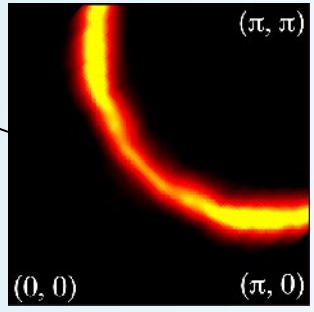


Spin correlation length

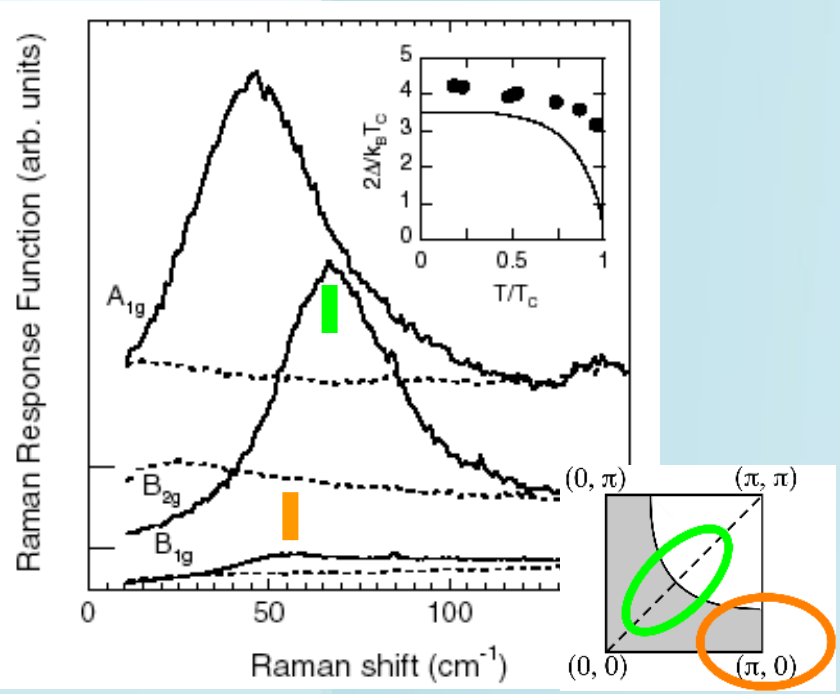
T. Uefuji *et al.*,
Physica C (2001).



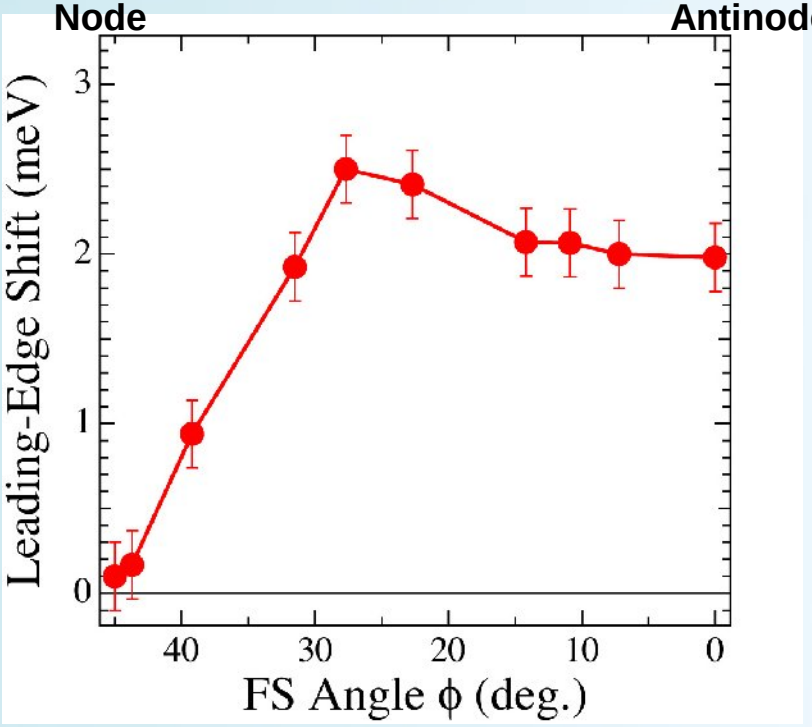
Anomalous transport properties in electron-doped HTSC
<----> pseudogap by spin correlation

Comparison with the Raman study

Raman



ARPES

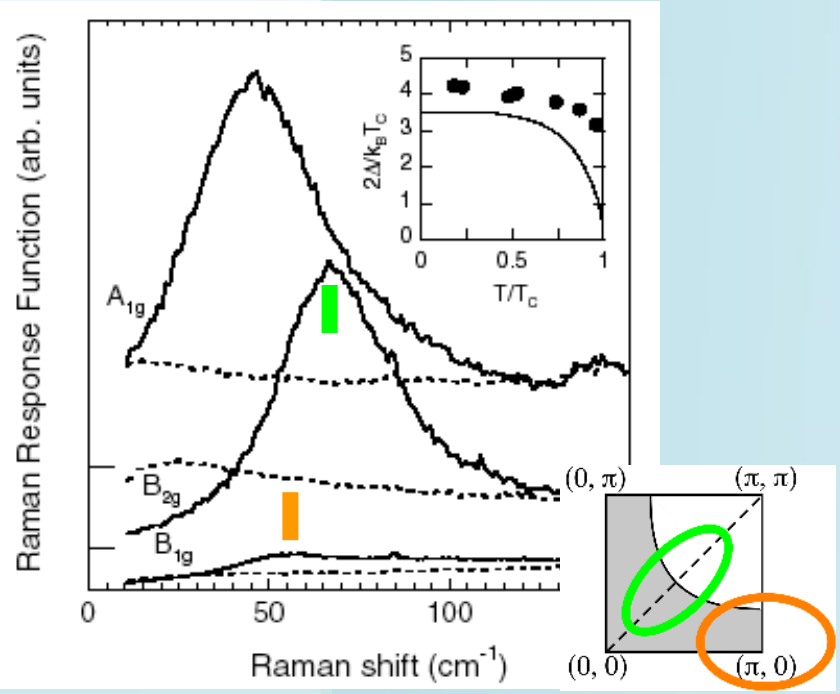


$\Delta_{B2g}/\Delta_{I} \sim 1.34$

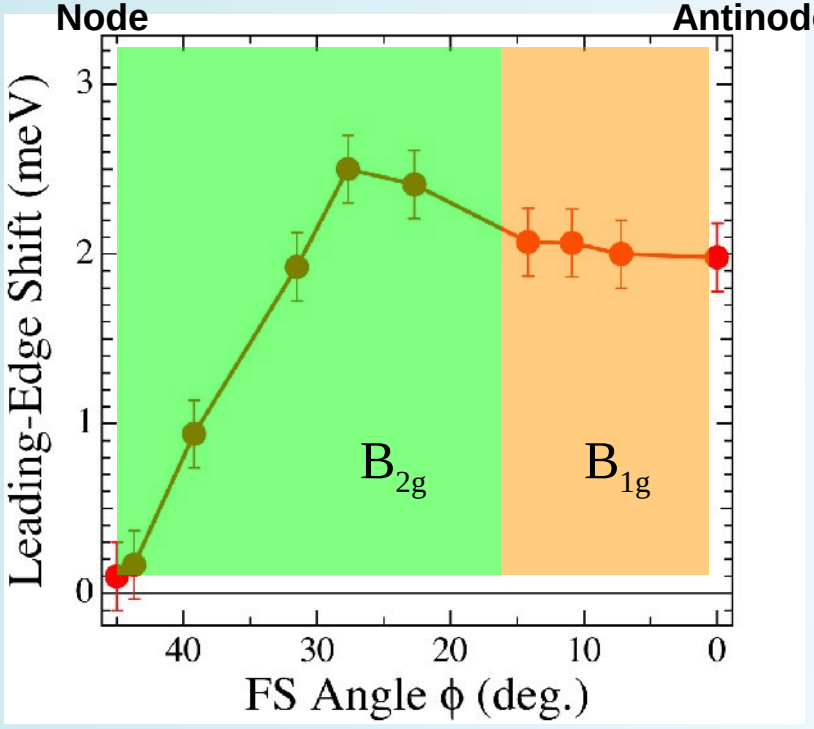
$\Delta_{\text{hot spot}}/\Delta_{\text{antinode}} \sim 1.3$

Comparison with the Raman study

Raman



ARPES



$\Delta_{B2g}/\Delta_{I} \sim 1.34$

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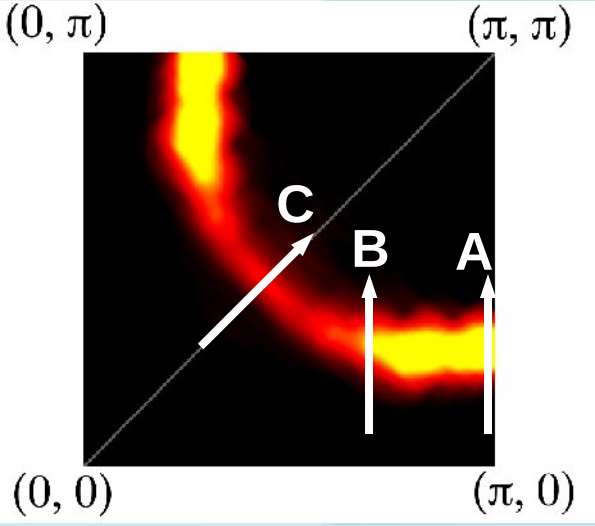
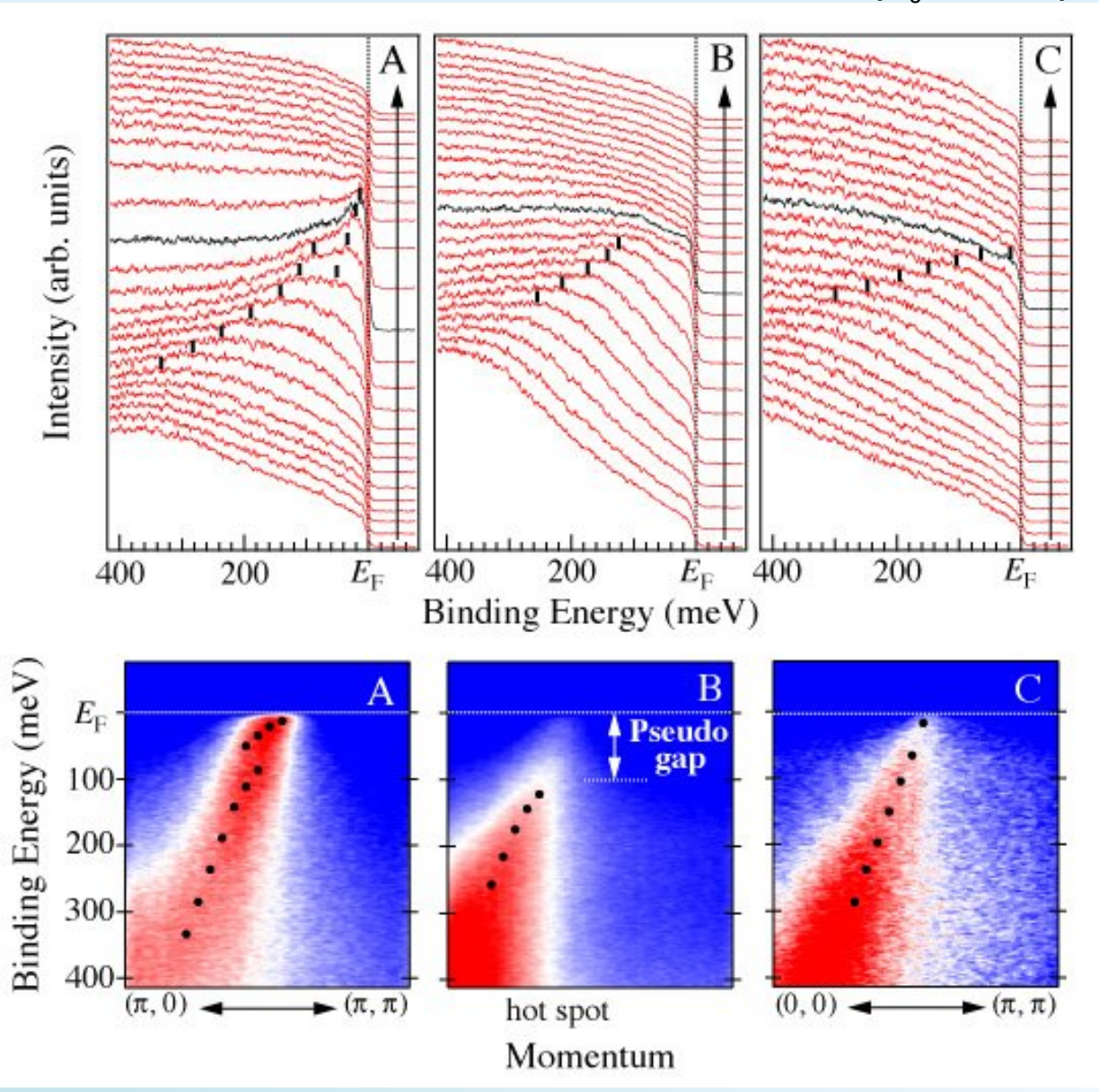
Fermi surface and band dispersion in $Pr_{0.89}LaCe_{0.11}CuO_4$

(T_c = 26 K)



T = 30 K



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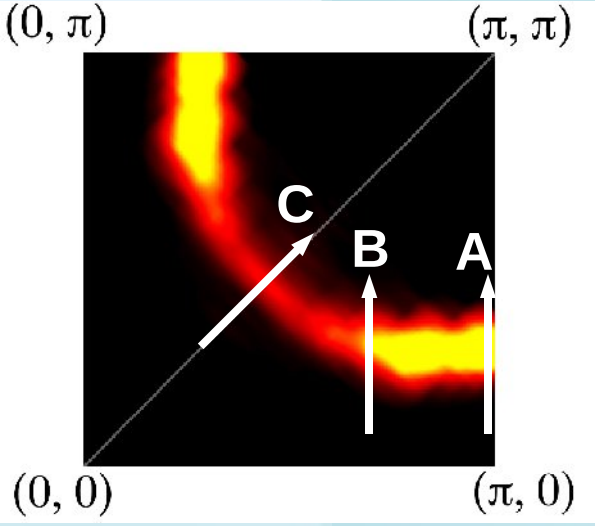
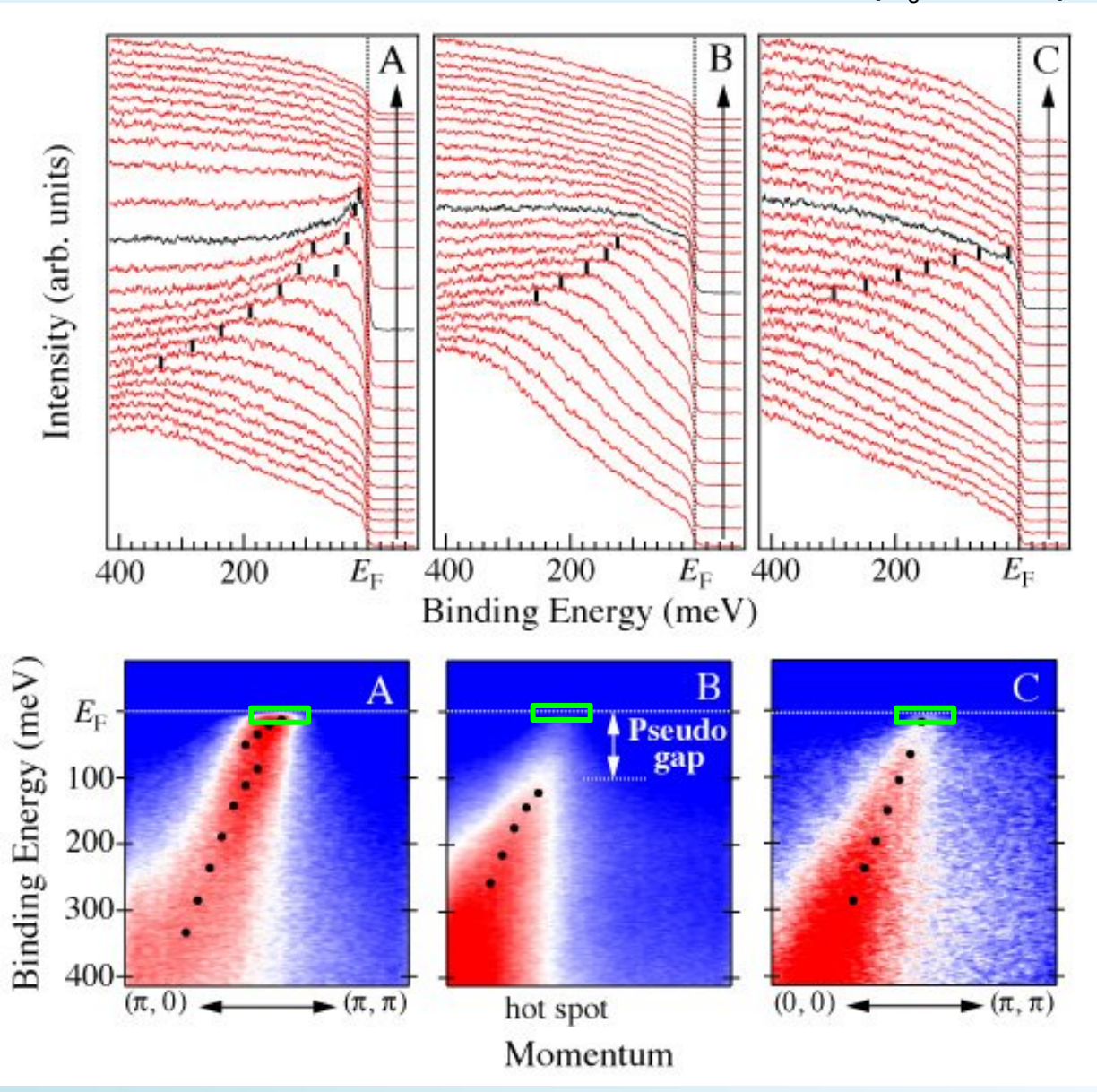
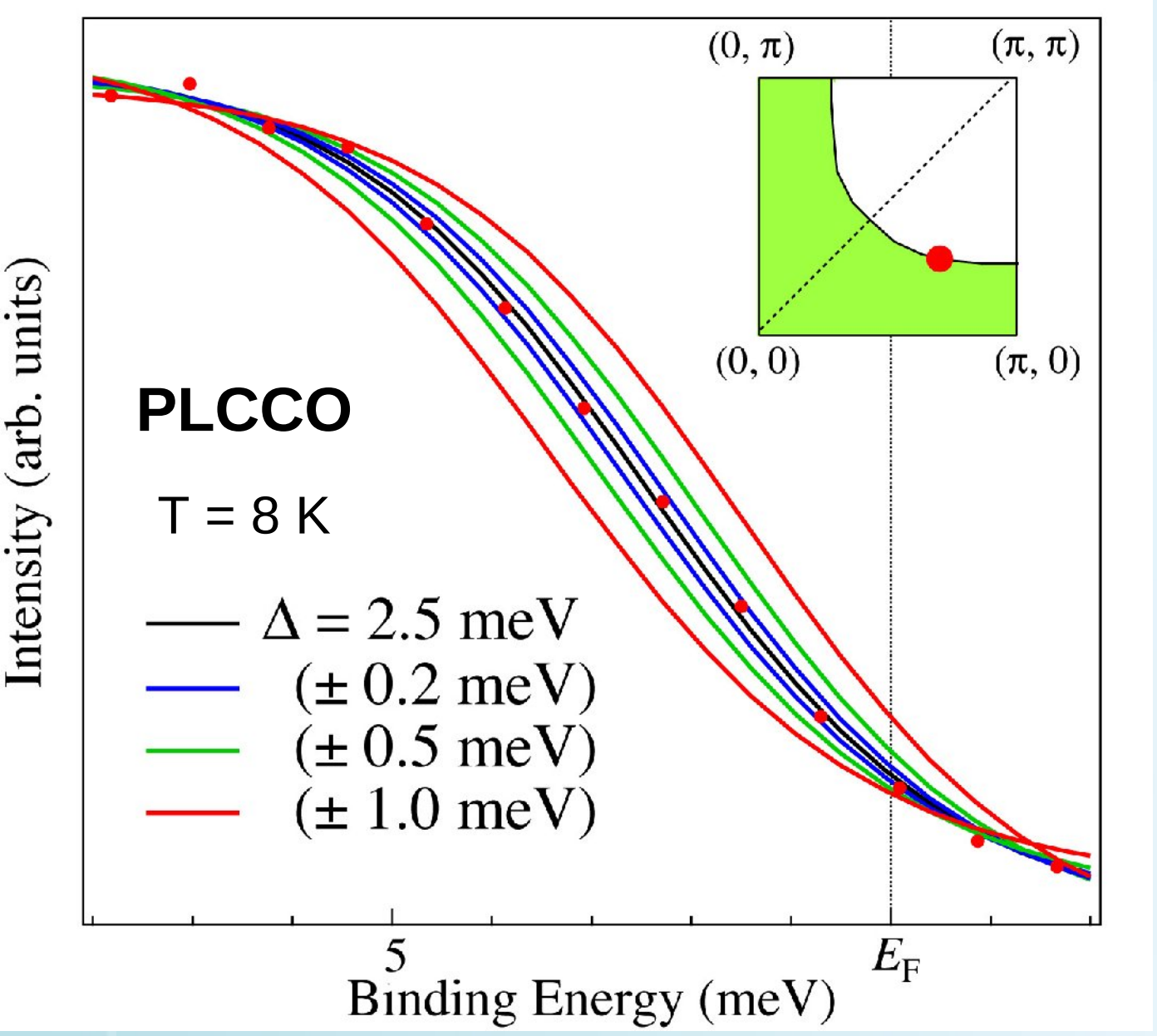
(T_c = 26 K)



T = 30 K

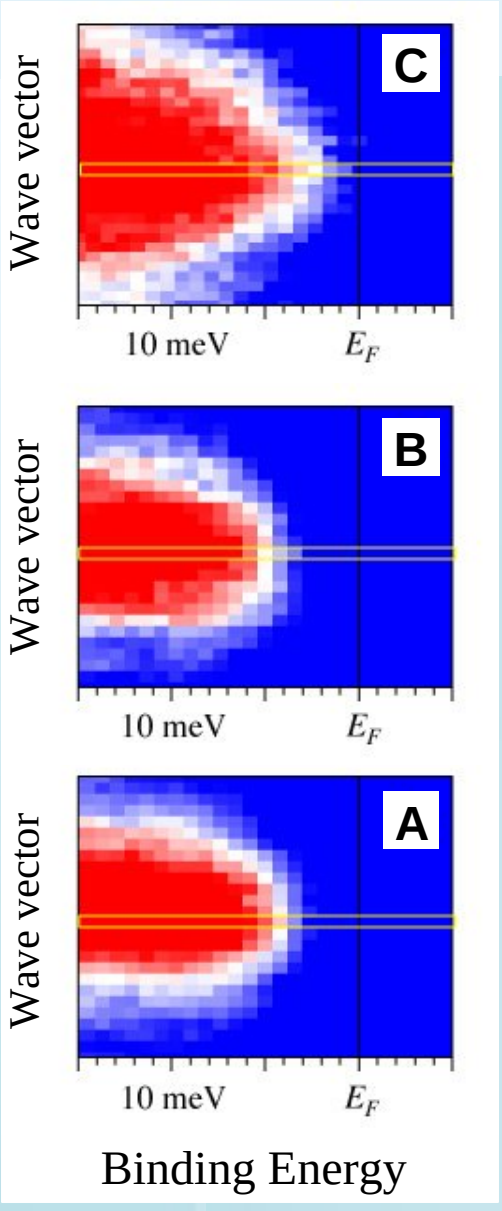


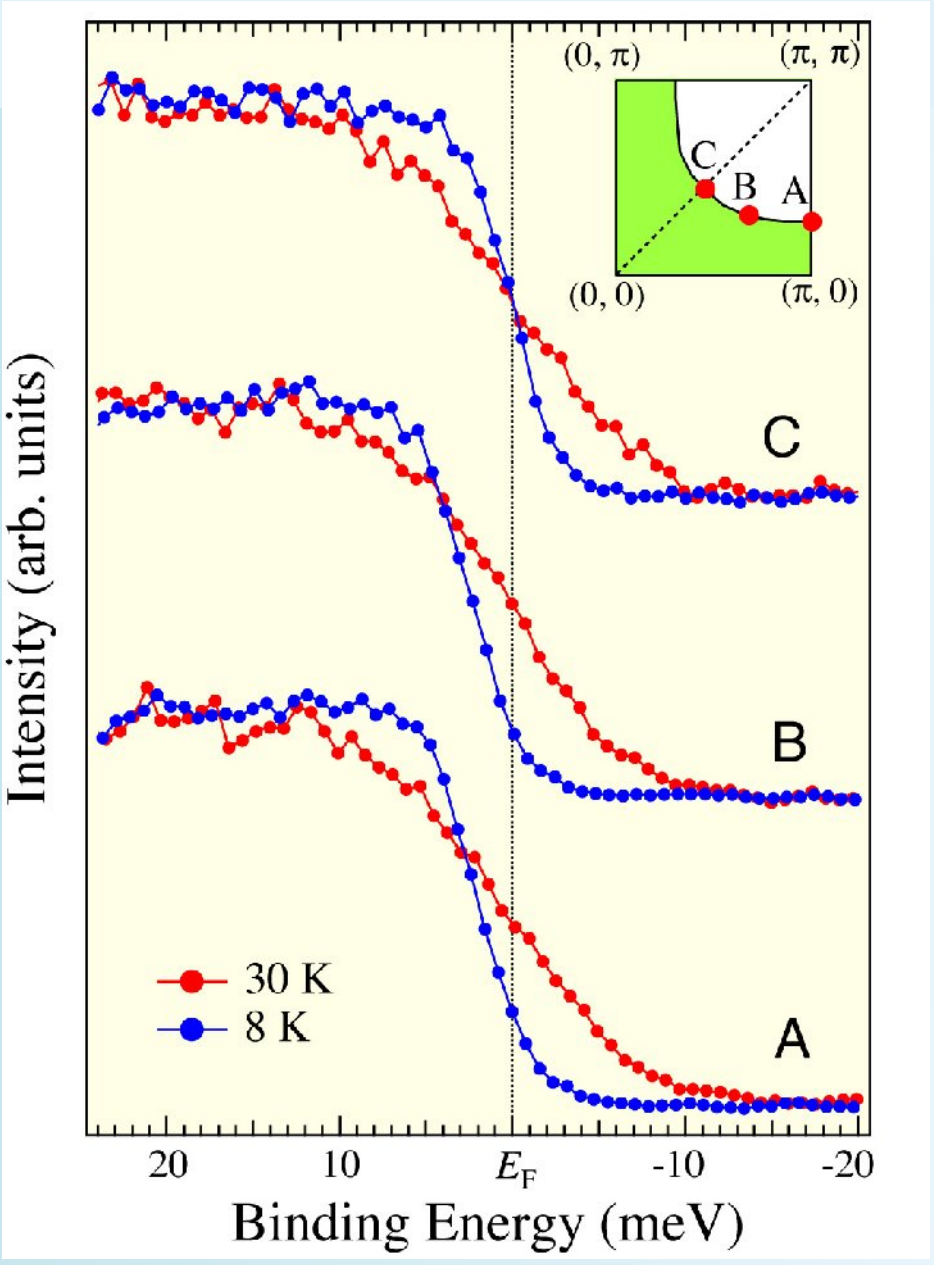
Numerical fitting of the ARPES spectrum in PLCCO



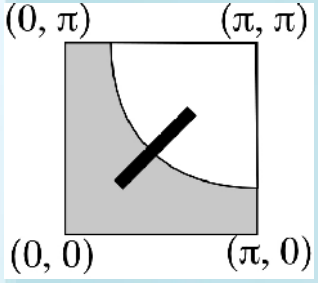
Superconducting gap in $Pr_{0.89}LaCe_{0.11}CuO_4$ (T_c= 26K)

Previous works

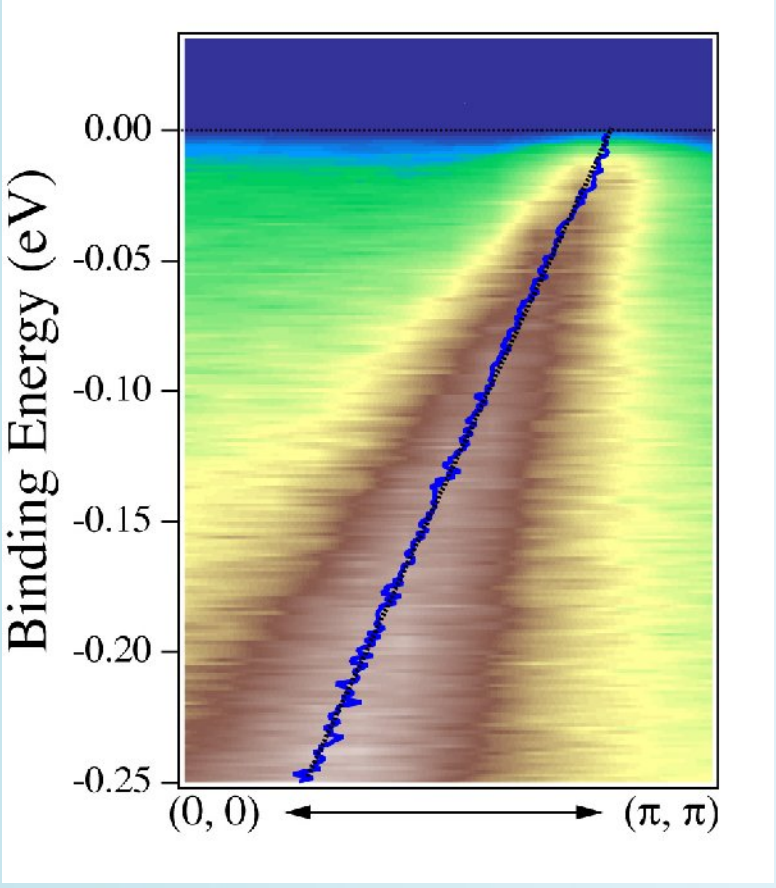




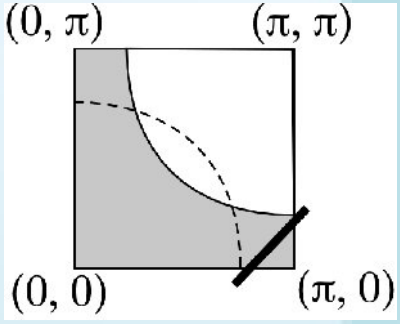
Nordal band direction in NCCO (x= 0.15)

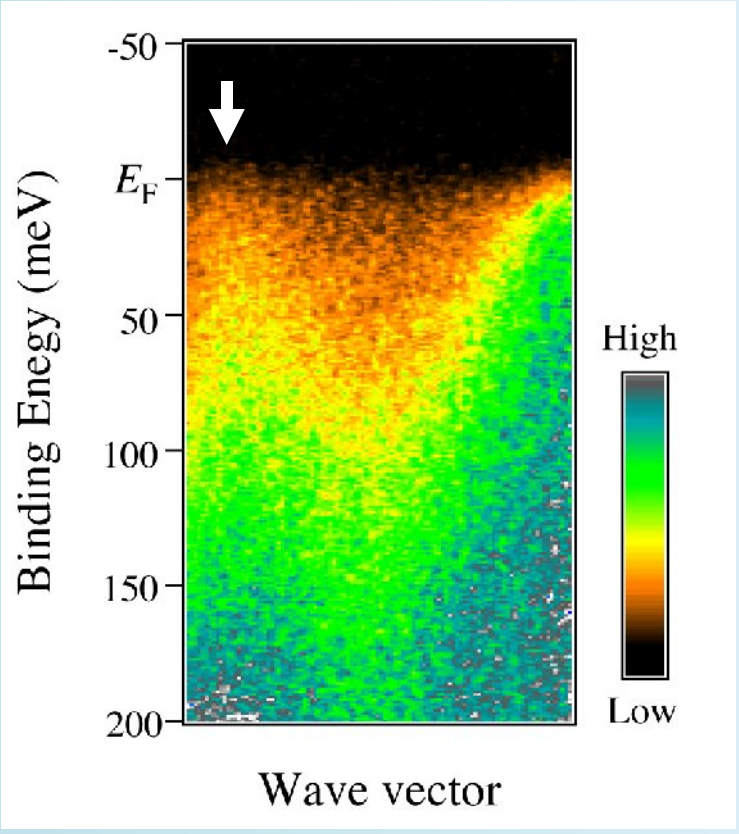


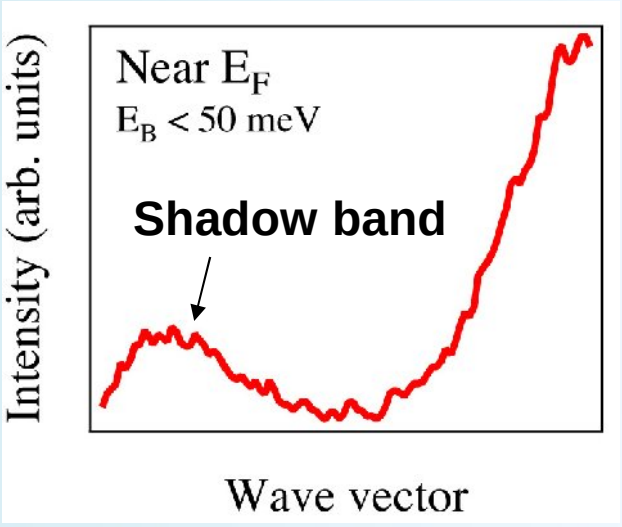
T = 10 K



Shadow band in NCCO





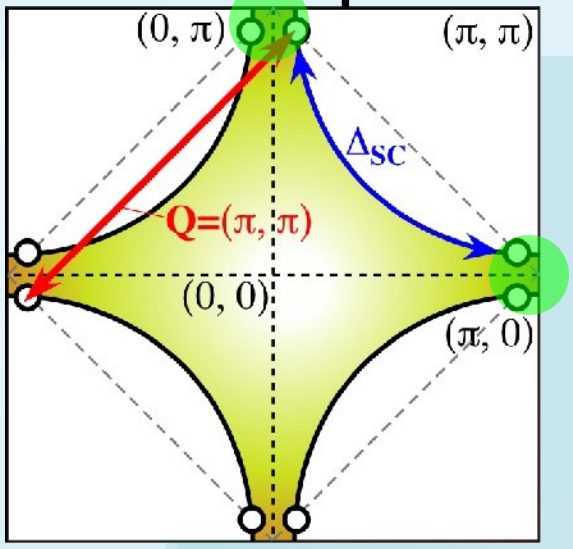


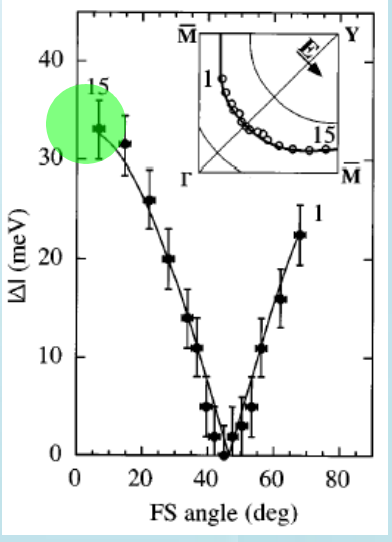
x = 0.13

T = 30 K

Superconducting gap symmetry in HTSCs

Hole-dope





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

Electron-dope