LETTERS

Impurity effects on electron–mode coupling in high-temperature superconductors

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Group 12

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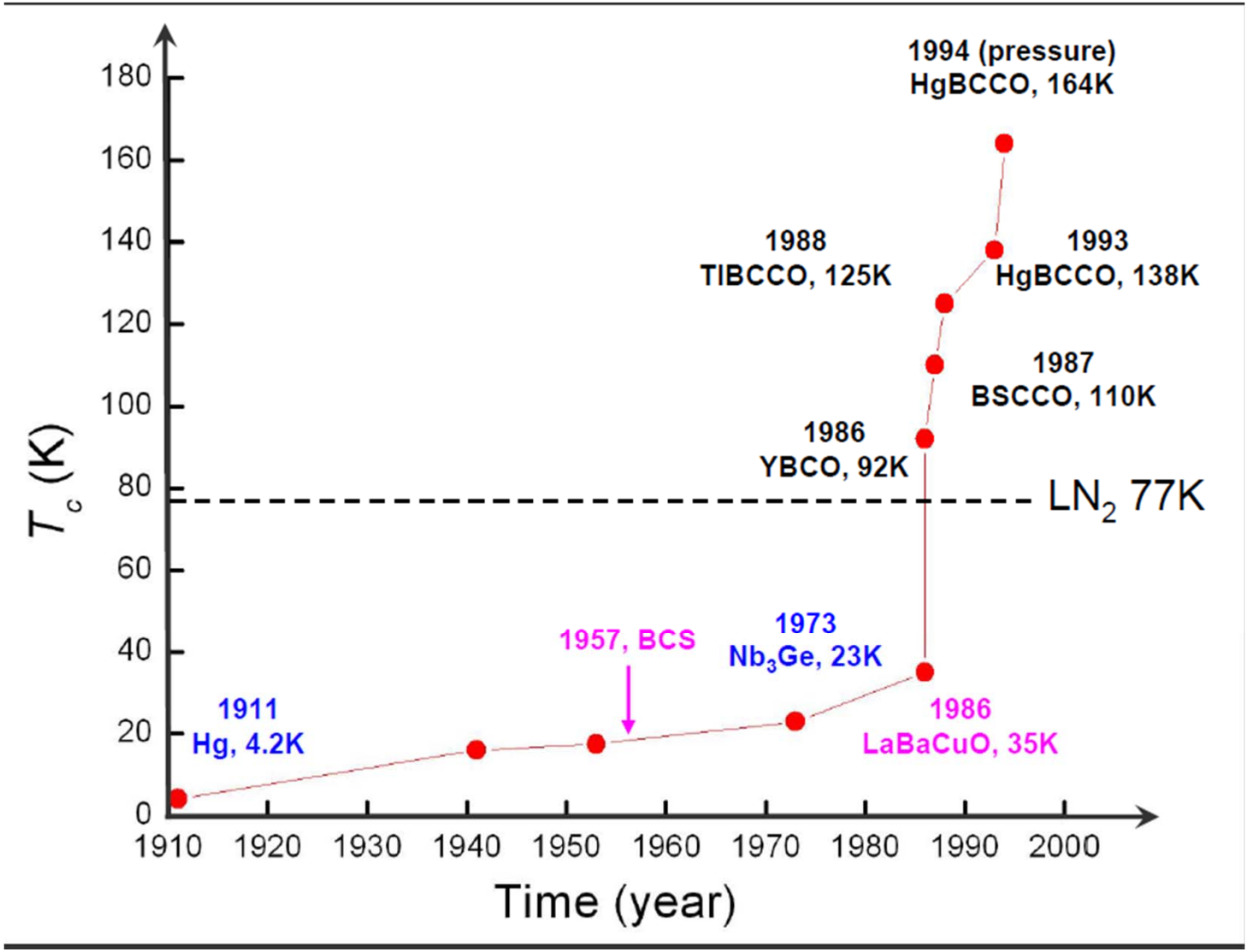
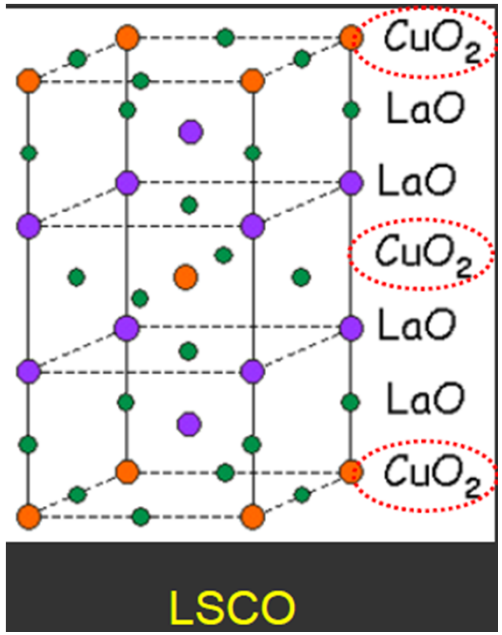
Outline

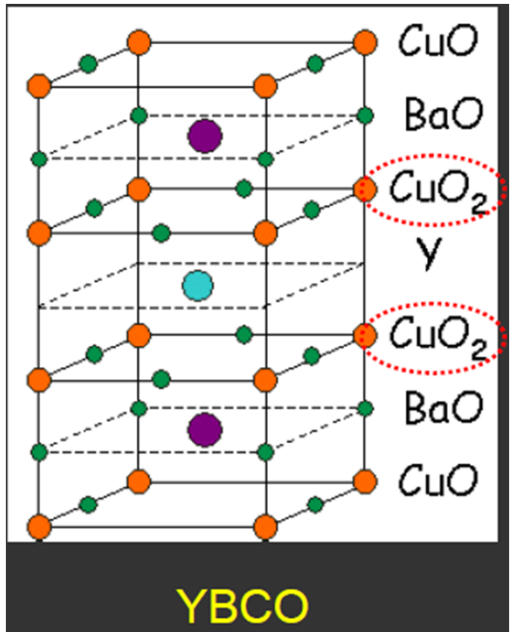
- Background Information
- Experimental Method
- Results
- Implications/Citation Report
- Critiques
- Summary

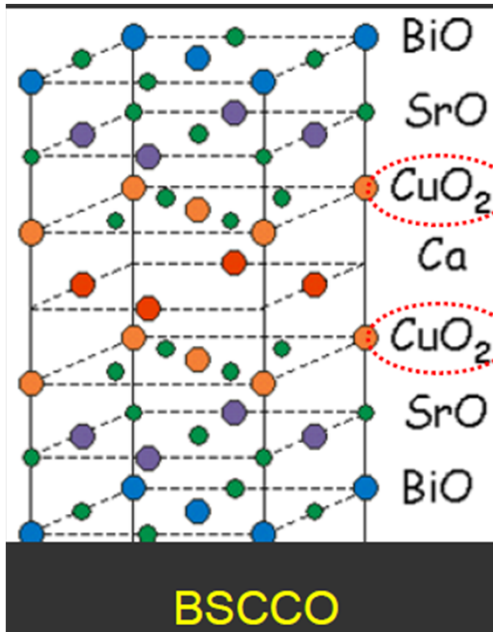
Superconducting transition temperatures have progressed over the years



Structure of high T_c superconductors





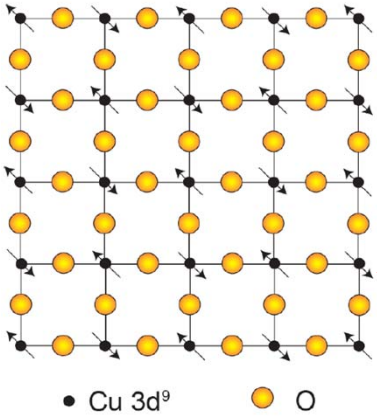


What is the common structural unit of all cuprates?

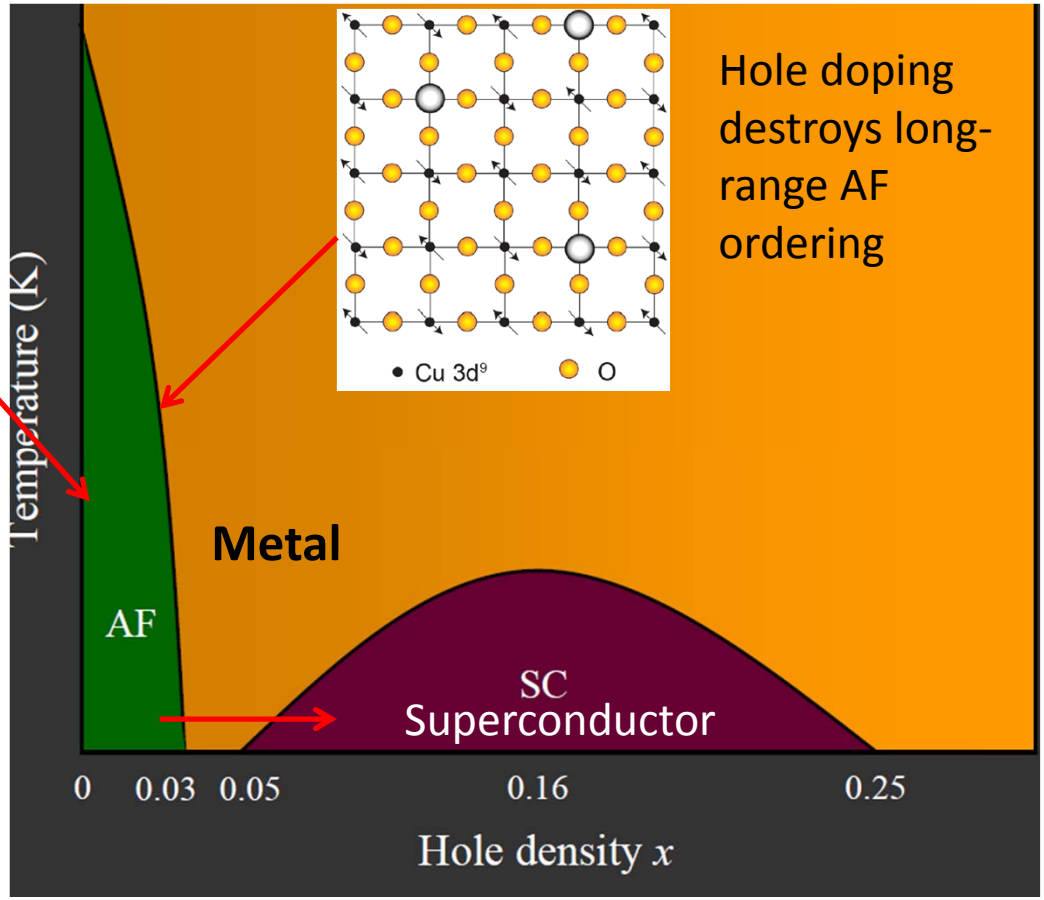
- The CuO_2 plane!
- The cuprates are complex quasi-2D copper oxides with the CuO_2 plane as the common structural unit.

High T_c compounds are doped Mott insulators

$La_{2-x}Sr_xCuO_4$



Parent compound is a Mott insulator with long range antiferromagnetic (AF) ordering

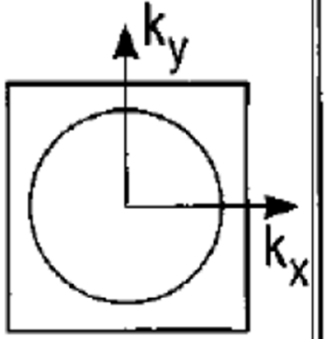
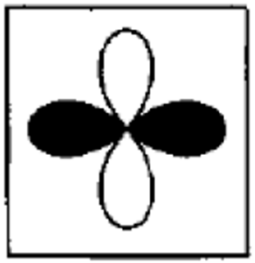


When sufficient carriers are added, the charge carriers will become mobile

The system will become a metal first, then a superconductor

s-wave vs. d-wave pairing

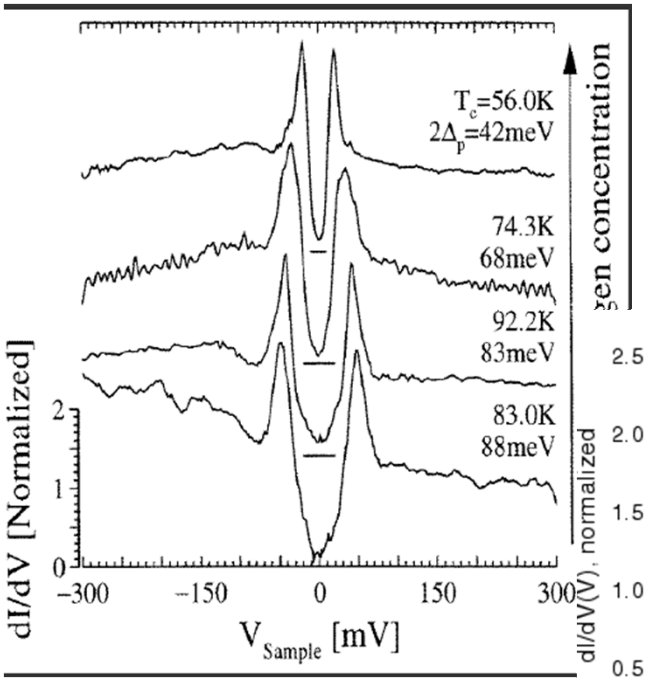
It was known quite early on that Cooper pairs in cuprates form spin singlet, so the spatial symmetry of Cooper pairs can only be s wave or d wave.

Wave function name	s-wave	$d_{x^2-y^2}$
Schematic representation of $\Delta(k)$ in B.Z.		

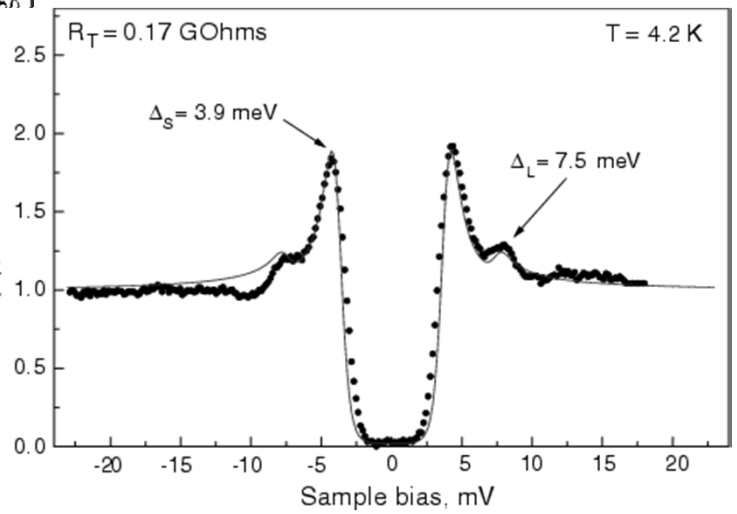
- s wave: $\Delta(k)$ = constant.
  The gap function is isotropic.
- d_{x2-y2} wave:
  $\Delta d_{x2-y2} = \Delta_0 (\cos k_x - \cos k_y)$
- $\Delta(k)$ is anisotropic.
- There are directions with zero gap (line nodes).
- The phase of $\Delta(k)$ changes.

There are many questions about the superconducting energy gap in high T_c superconductors

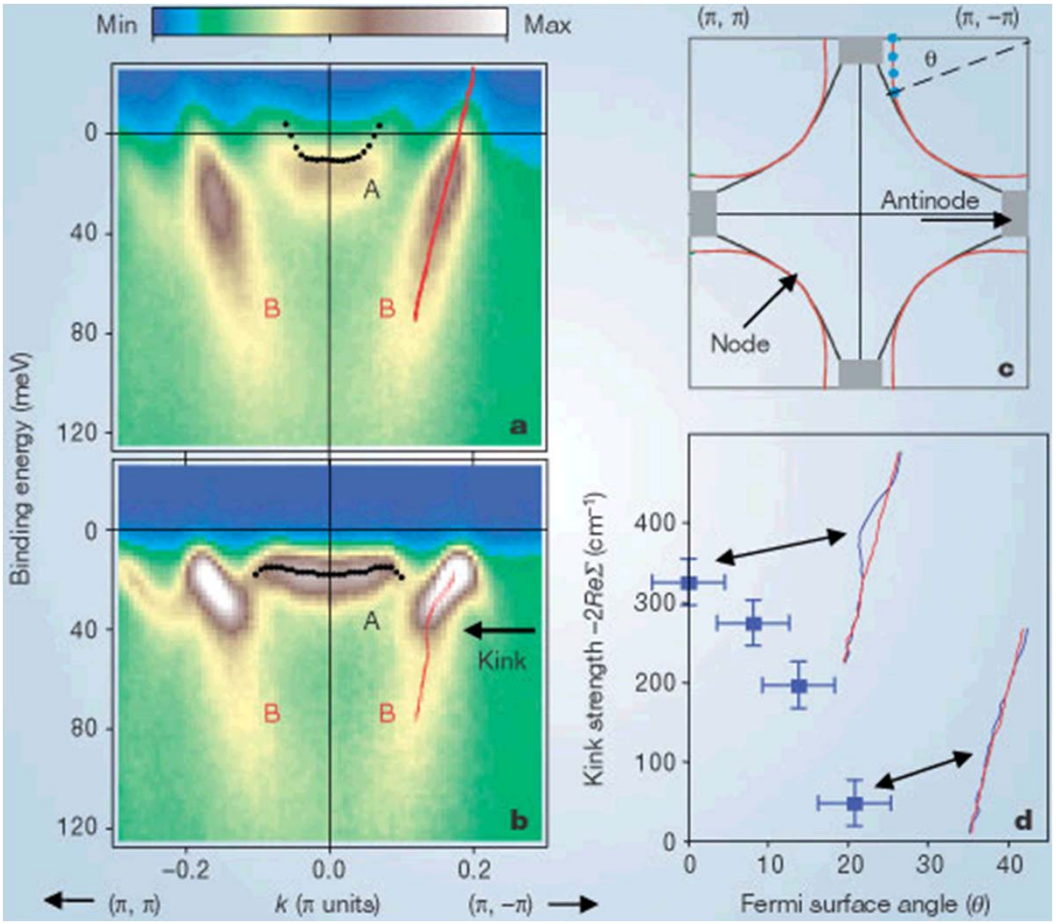
- Does the superconducting state have an energy gap? How big is it? What is its relation to the transition temperature T_c?
- How to measure this experimentally?
- Scanning tunneling spectroscopy at 4.2K on cleaved Bi-2212 crystals with different dopings



- The amplitude of the gap increases with decreasing hole density
- The ratio $2\Delta / kT_c$ ~10, much larger than the BCS



Kink in high T_c superconductor



What is a kink?

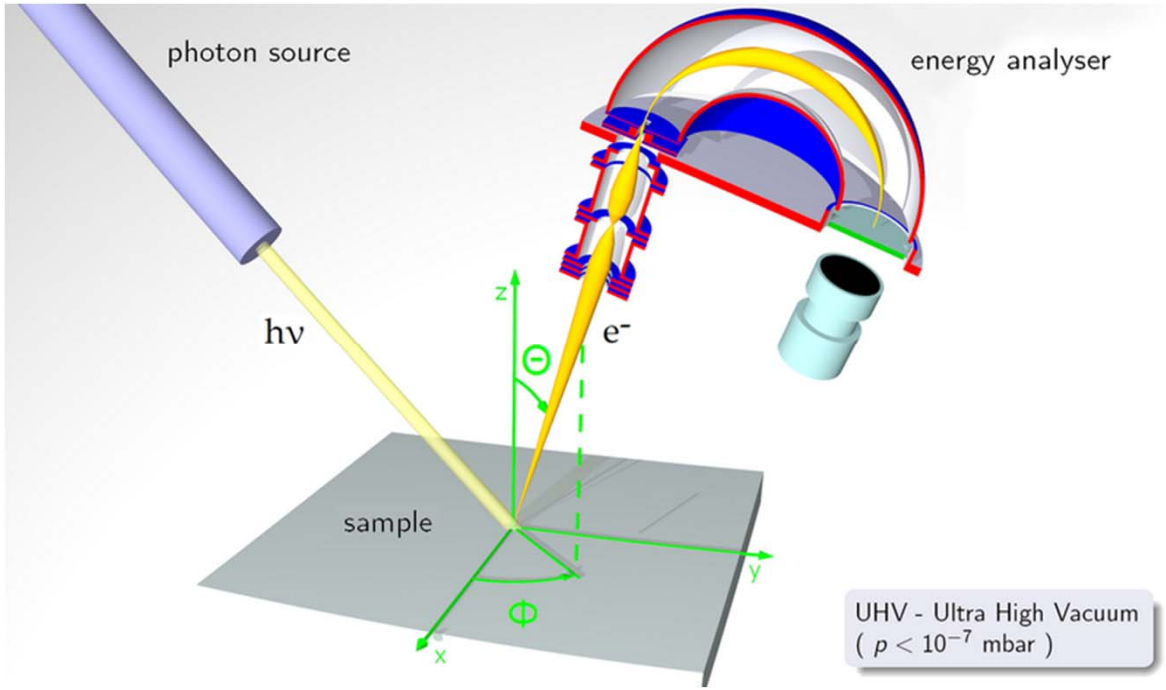
•Different velocity near the fermi surface

The origin of the kink?

•Electron-mode coupling?
•Electron-phonon interaction?

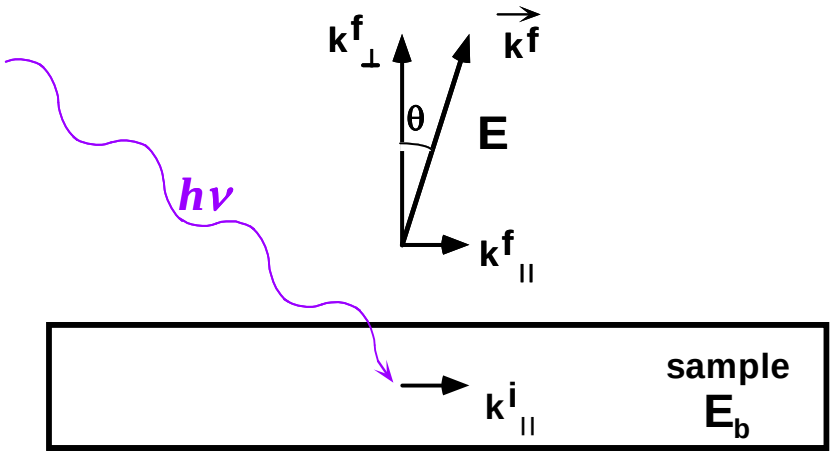
Experimental Methods

- Measurements: *High-resolution Angle-resolved Photoemission Spectroscopy (ARPES)*
- *Angle resolution*



Courtesy: Wikipedia.org

ARPES conveys information about electron dispersion (*E* vs. ***k***) and bandstructure



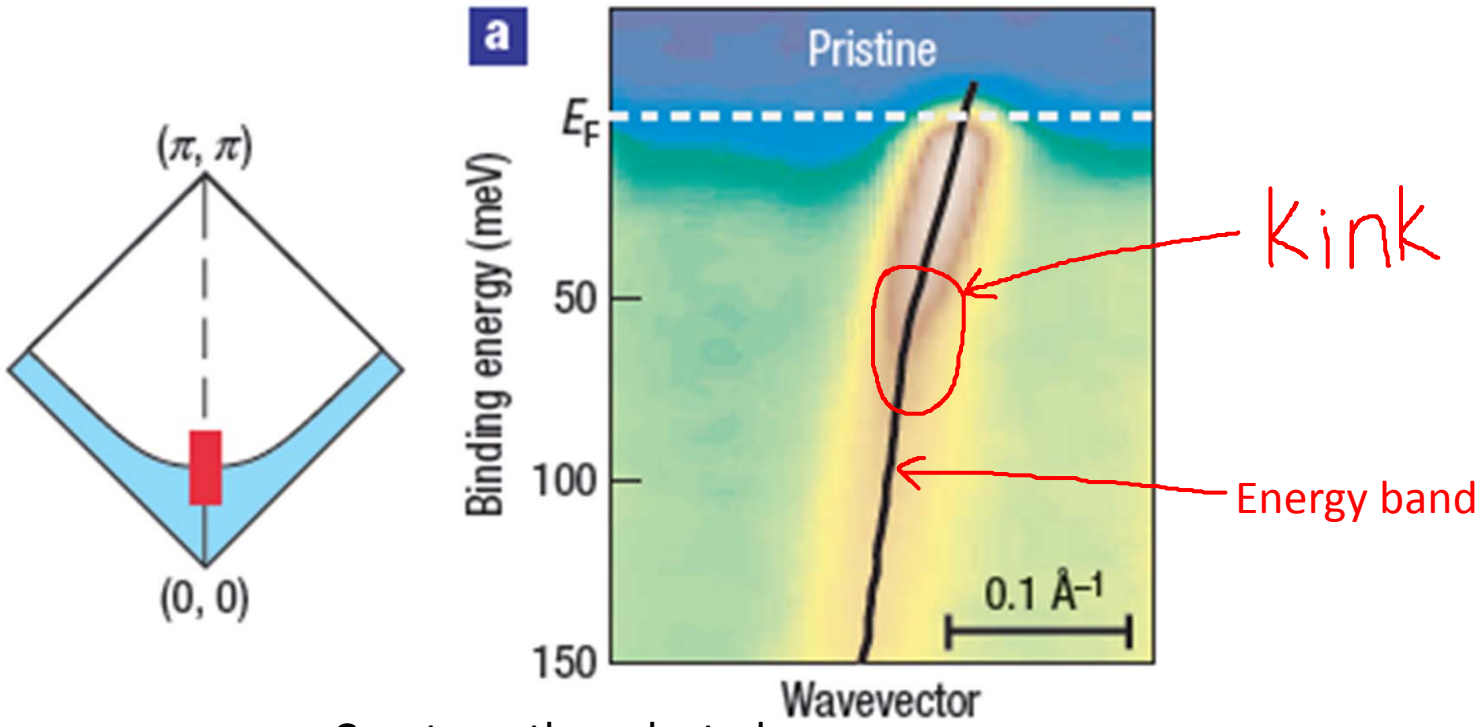
$$E = h\nu - W - E_b \qquad k^f_{||} = k^i_{||}$$

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

Courtesy: Ex7, IOP, CAS

ARPES outcome

- Band structure & kink



Courtesy: the selected paper

Experimental details of ARPES

- Photon Source: *He Ⅰα Resonance Line 21.218eV*
- Energy resolution: *7-12 meV*
- Angular resolution: *0.2°*
- Clean sample surface: *in situ cleaving of crystals in ultrahigh vacuum*

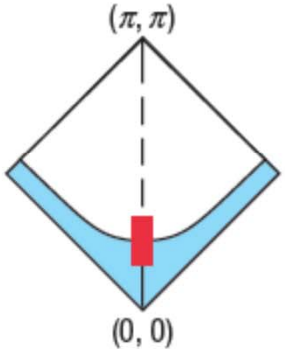
High resolution!

Primary Results

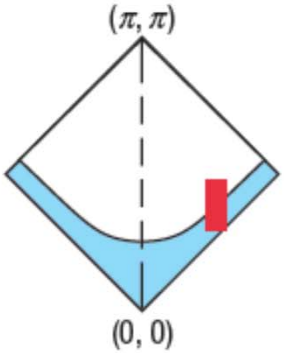
- Electron-mode coupling is distinguished from phonons as electron coupling method in high-T_c superconductors
  - Heavily dependent on the impurity element characteristics (Ni vs. Zn)
- Electron-mode coupling persists above T_c for Zn-substituted Bi-2122

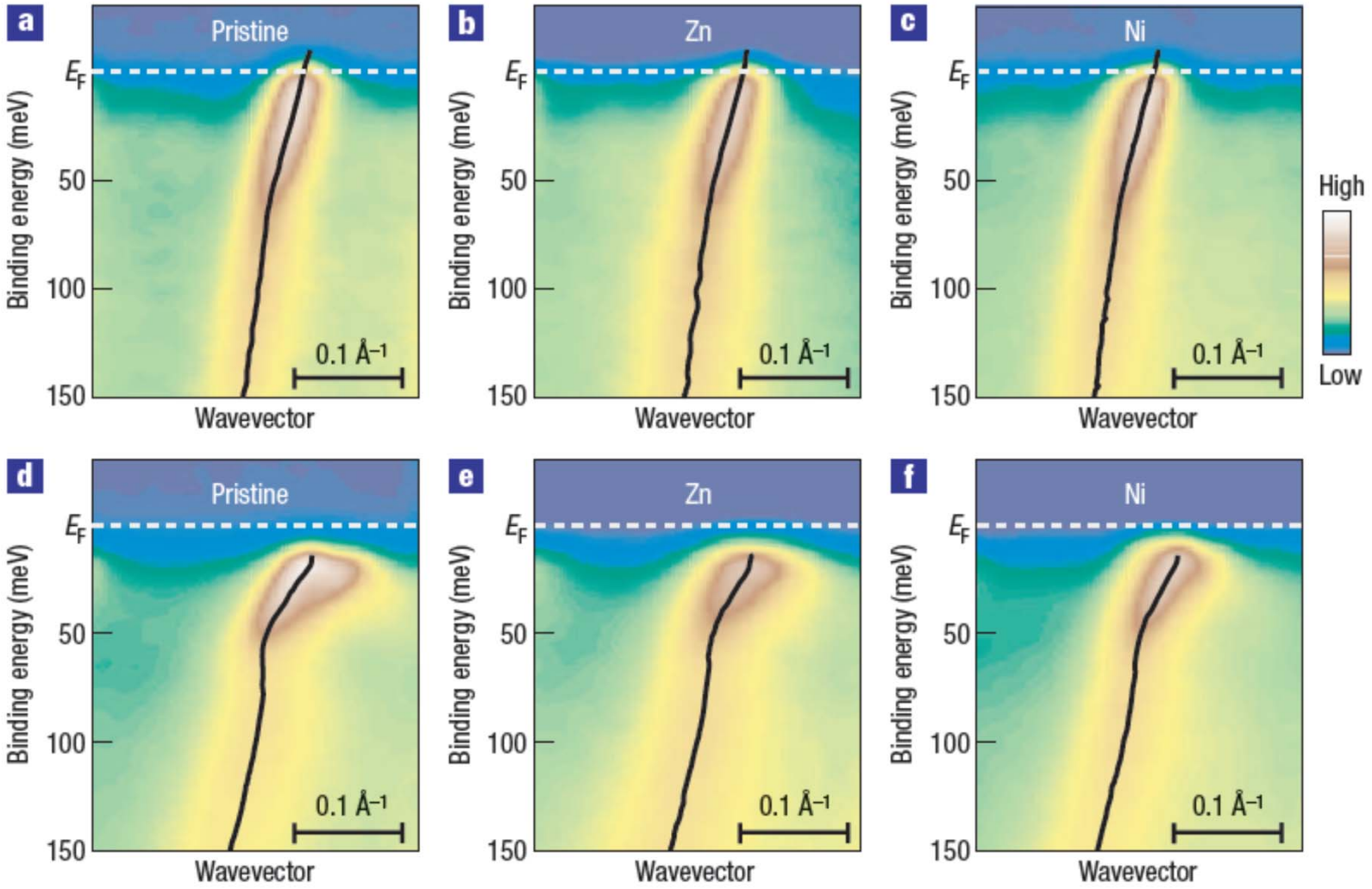
ARPES intensity plots for Bi-2122

Nodal Cut



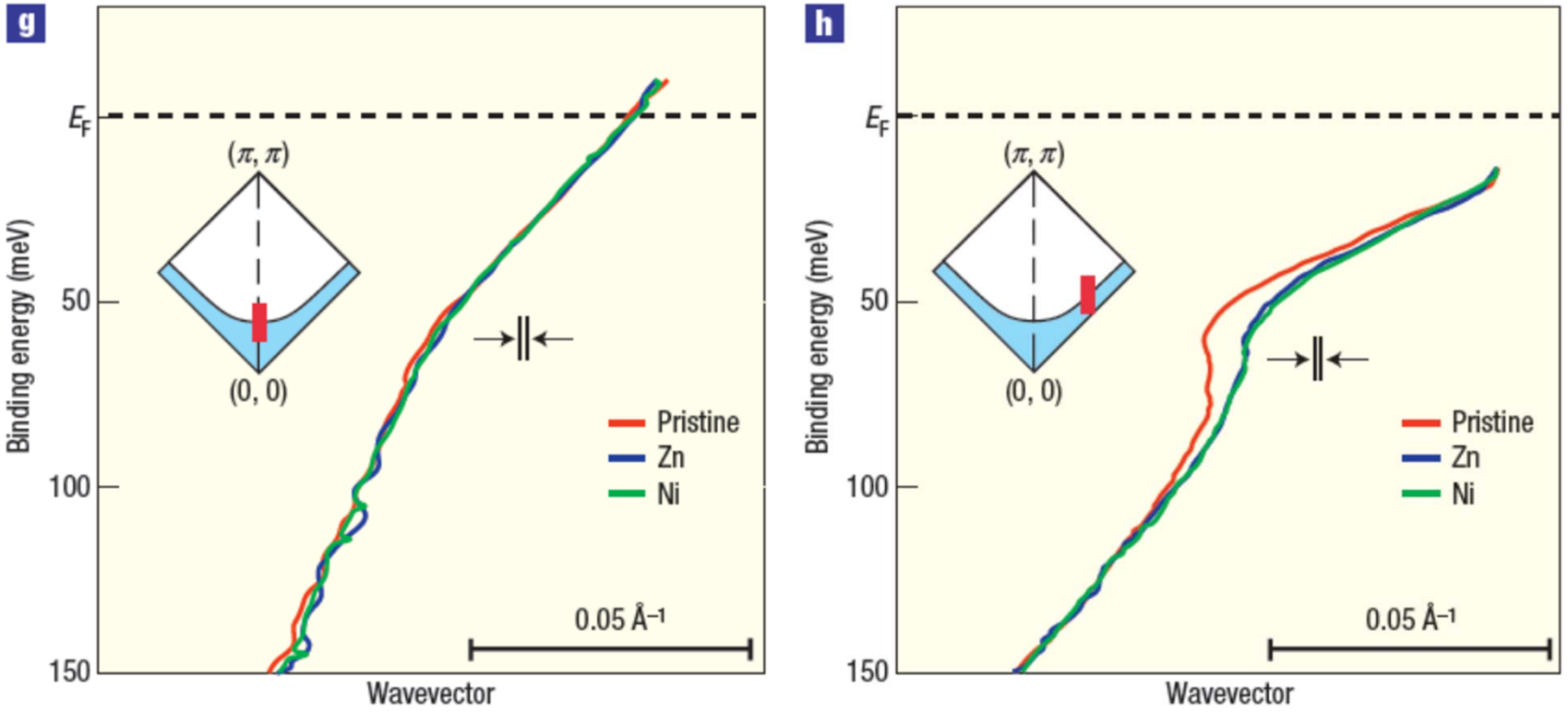
Off-Nodal Cut





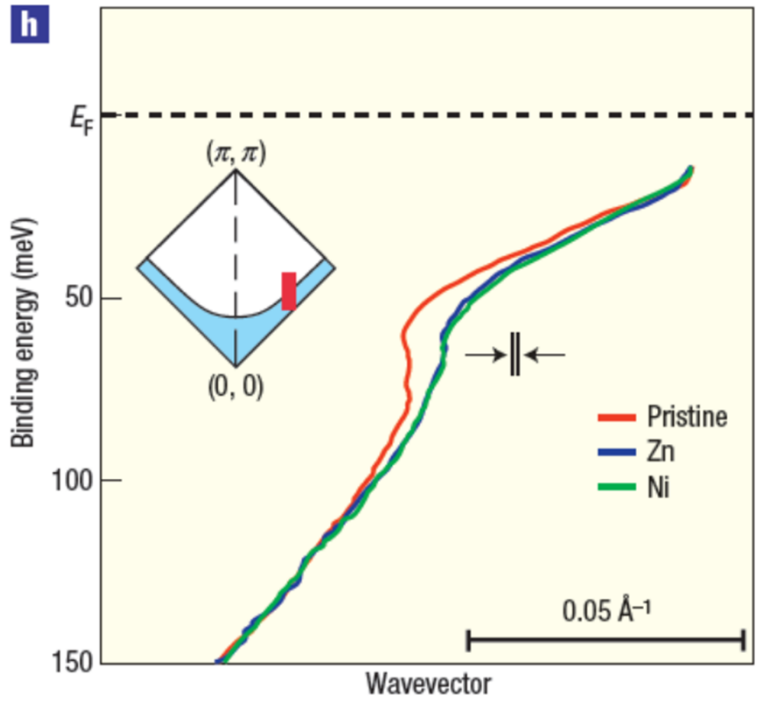
Comparative summary of MDCs for ARPES nodal and off-nodal intensity plots

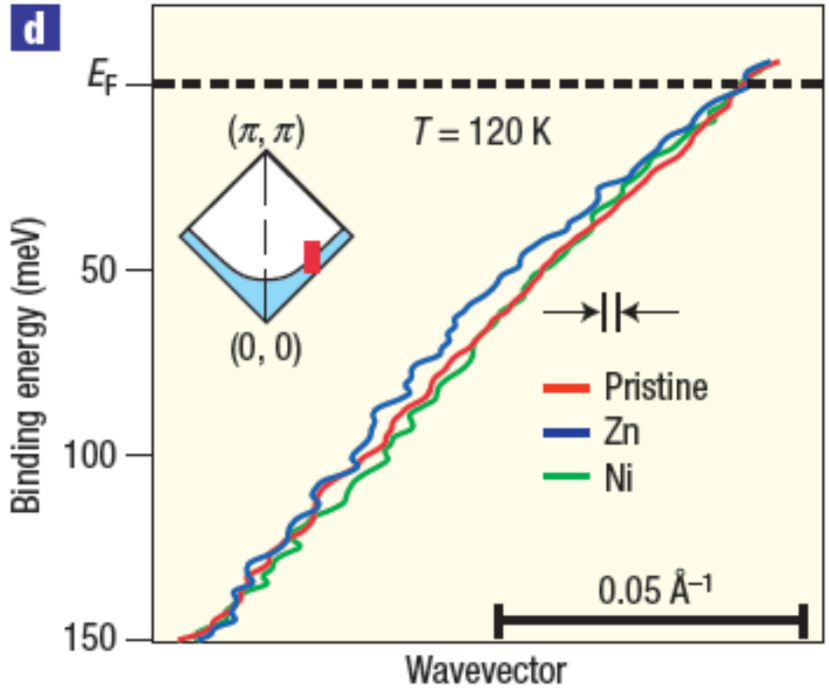
(black lines on previous slide)



Notice the reduction of the kink in the off-nodal cut [g]. This indicates the strength of the effect of the Zn and Ni substitutions in the cuprate.

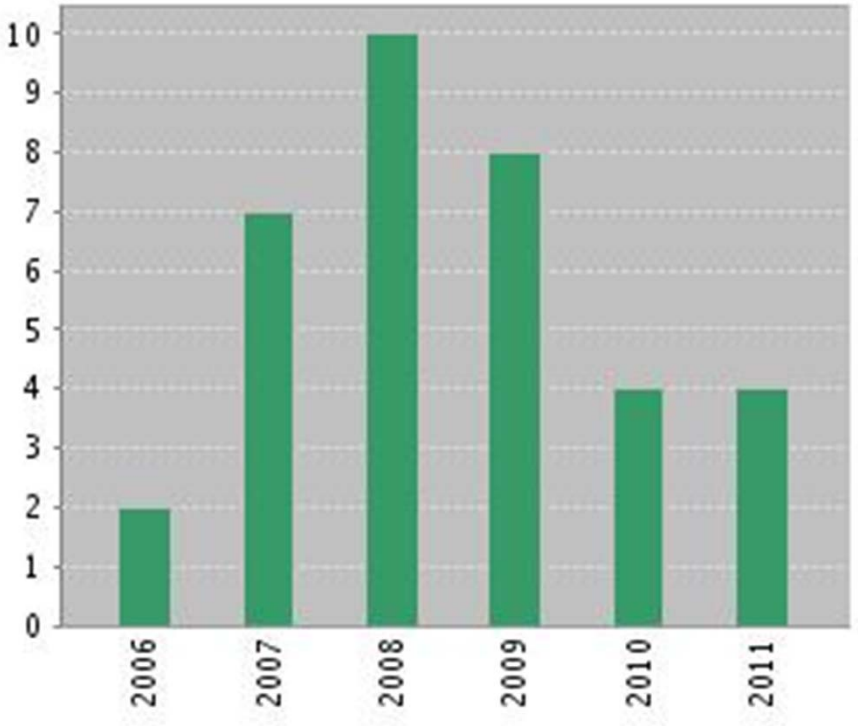
- Compare off-nodal cuts at T = 40K (left) and T = 120K (right).
  - Only Zn-substituted cuprate maintains kink above T_c
  - Indicates
    - (1) the importance of non-magnetic (Zn) vs. magnetic (Ni) substitution
    - (2) Strength of electron-mode coupling





Citation Report

- Number of citing articles: 36
- Journals: PRL, PRA, PRB, Nature
- Most discuss whether Cooper pairs bind from electron-phonon or magnetic excitations
- Debate still unresolved



Courtesy: Web of Knowledge

Article supporting electron-phonon coupling

PRL **101,** 157005 (2008) PHYSICAL REVIEW LETTERS week ending 10 OCTOBER 2008

Isotopic Fingerprint of Electron-Phonon Coupling in High-T_c Cuprates

H. Iwasawa,[1,2,*] J.F. Douglas,[3] K. Sato,[2,4] T. Masui,[5] Y. Yoshida,[2] Z. Sun,[3] H. Eisaki,[2] H. Bando,[2] A. Ino,[6] M. Arita,[7] K. Shimada,[7] H. Namatame,[7] M. Taniguchi,[6,7] S. Tajima,[5] S. Uchida,[8] T. Saitoh,[1] D. S. Dessau,[3] and Y. Aiura[2,7,+]

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Angle-resolved photoemission spectroscopy with low-energy tunable photons along the nodal direction of oxygen isotope substituted $Bi_2Sr_2CaCu_2O_{8+\delta}$ reveals a distinct oxygen isotope shift near the electron-boson coupling "kink" in the electronic dispersion. The magnitude (a few meV) and direction of the kink shift are as expected due to the measured isotopic shift of phonon frequency, and are also in agreement with theoretical expectations. This demonstrates the participation of the phonons as dominant players, as well as pinpointing the most relevant of the phonon branches.

Summary

- Performed ARPES measurements to determine the mechanism of superconductivity in high T_c cuprates
- CuO_2 superconductors were doped with Zn and Ni to determine the nature of the kink in ARPES data
- Kink remains for Zn cuprates, indicating the most probable cause is the electron-mode coupling
- Highly disputed: e-p or e-mode

Thanks for listening

Questions??