

What's pairing the electrons in high- T_c superconductors ?

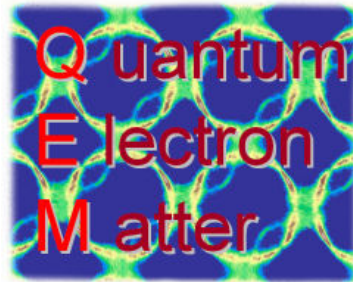
an opinion from k - space

Iman Santoso

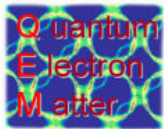
FOM-A11



FACULTEIT DER NATUURWETENSCHAPPEN, WISKUNDE EN INFORMATICA
VAN DER WAALS-ZEEMAN INSTITUTE



Acknowledgements



Quantum Electron Matter Group Van der Waals-Zeeman Institute, UvA

Sanne de Jong, Freek Masseur, **Yingkai Huang**, Anton Mans,
Wing Kiu Siu, Wim Koops, Ton Gortenmulder, Mark Golden



Support at SLS (Swiss Light Source)

Ming Shi, Luc Patthey



Support at BESSY

Rolf Follath, Patrick Bressler



Leibniz Institute
for Solid State and
Materials Research
Dresden

Sergey Borisenko
(loan of spectrometer)



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FOM (ILP, SICM), EU



● Introduction:

➡ high- T_C Superconductivity (cuprates)

➡ ARPES

➡ BSCCO, band structure, strategy

● Data:

➡ superconducting state

➡ normal state

● Conclusions and outlook

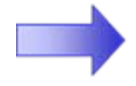
● what is the pairing glue ?



experimental access to electronic states vs.:



E



k



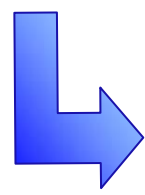
temperature



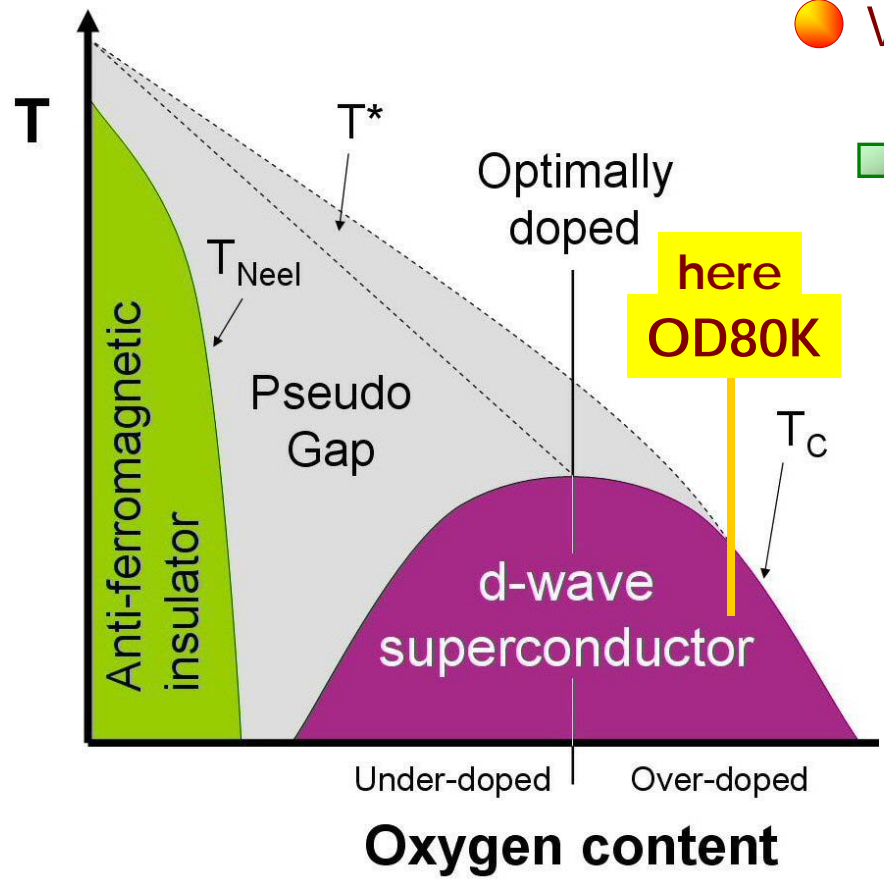
doping



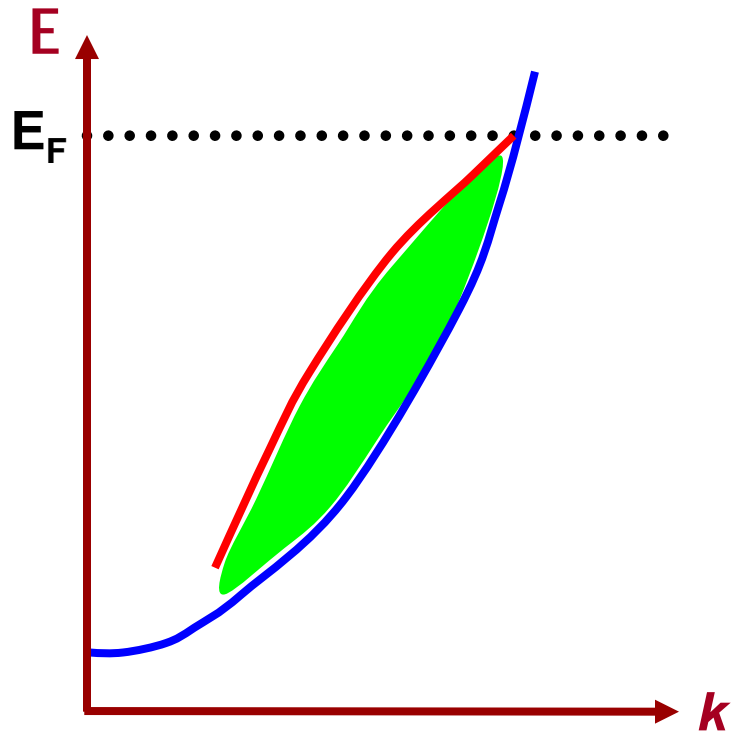
HTSC family



ARPES



Pic: XJ Zhou



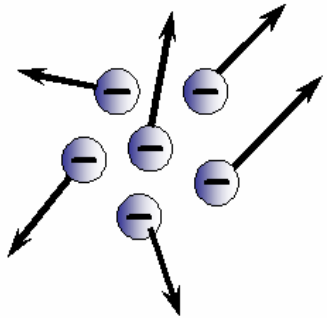
● **Free electrons:**
parabolic dispersion relation

● **Interacting electrons:**
- electron-electron
- electron-phonon
- electron-spin fluctuations

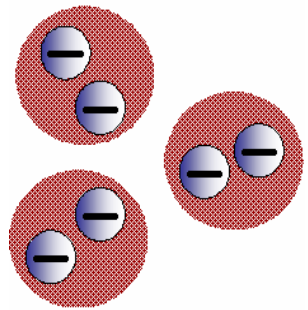
■ **Many body effects**

key to understanding superconductivity, CDW's etc....

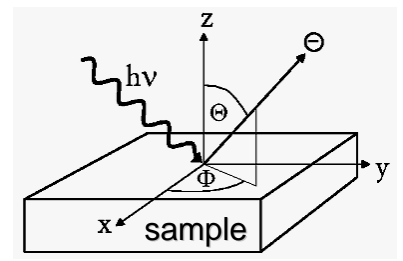
non-interacting



interacting



direct access
via **ARPES**



Introduction

What does photoemission measure ?

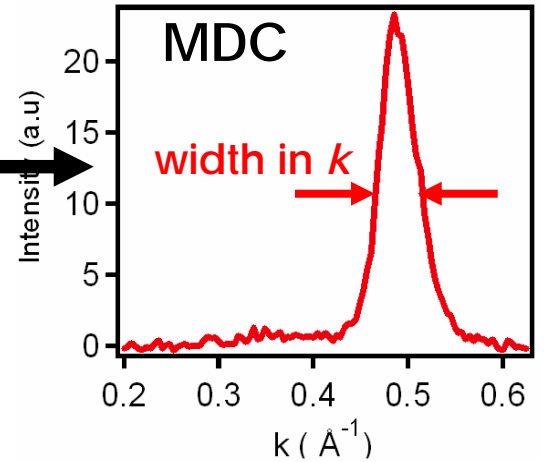
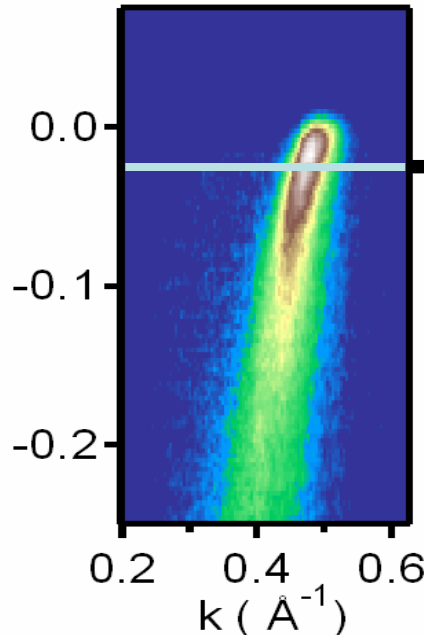
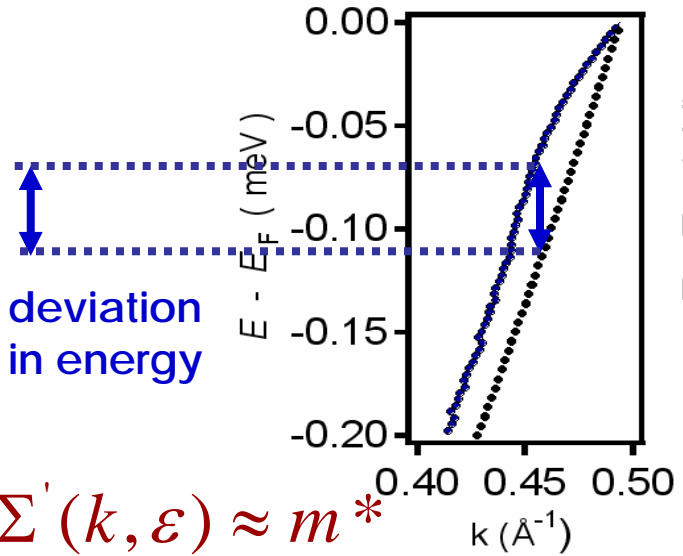
$$I \propto \sum_{f,i} \left| \langle f | \hat{p} \cdot \hat{A} | i \rangle \right|^2 A(k, \varepsilon) f(\varepsilon)$$

matrix element
↑
spectral function
Fermi function

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

self energy: imaginary part

self energy: real part



$\Sigma''(k, \omega) \approx$ quasiparticle scattering rate

Advantages:

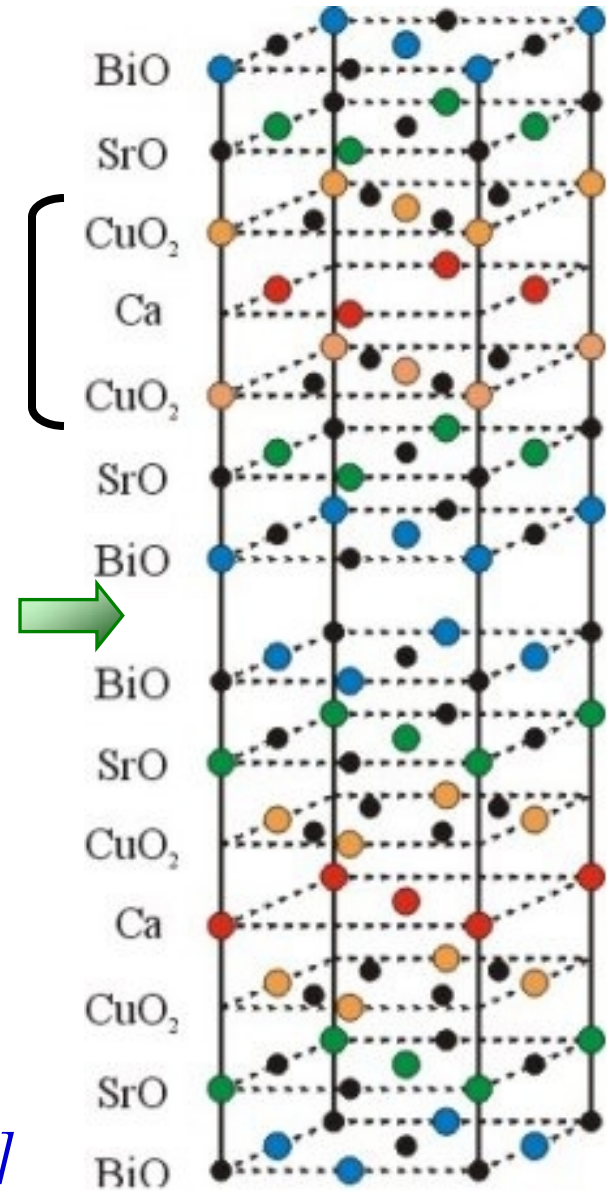
- high- T_c
- perfect cleavage surfaces
- practically no dispersion in k_{\perp}

Complications:

- BiO modulation (✓ Pb-doping)
- c-axis bilayer splitting
- ↳ do a good experiment
[have some tricks up your sleeve]

CuO₂
bilayer

cleaves
here



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➔ normal state

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- 2D Brillouin zone: Γ (0,0), $(\pi/a,0)$ and $(\pi/a,\pi/a)$

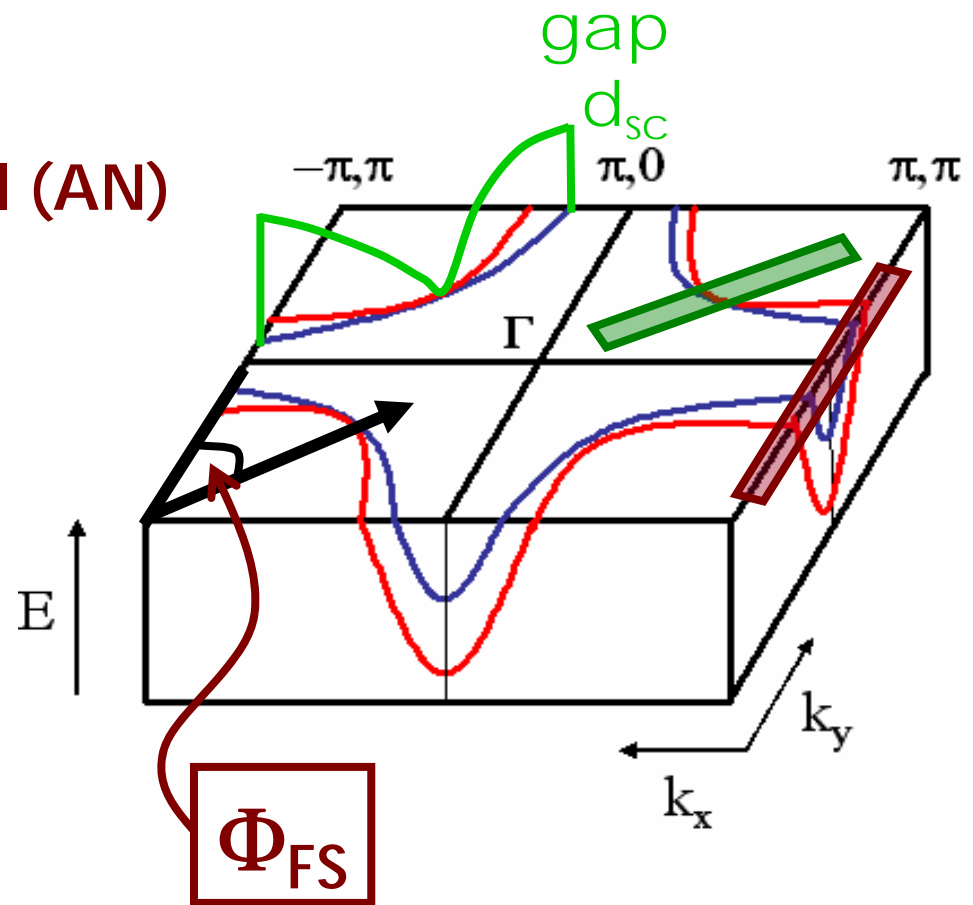
- c-axis bilayer splitting: antibonding and bonding
Fermi surfaces & bands

- nodal (N) and antinodal (AN) regions

- define Fermi surface angle Φ_{FS} :

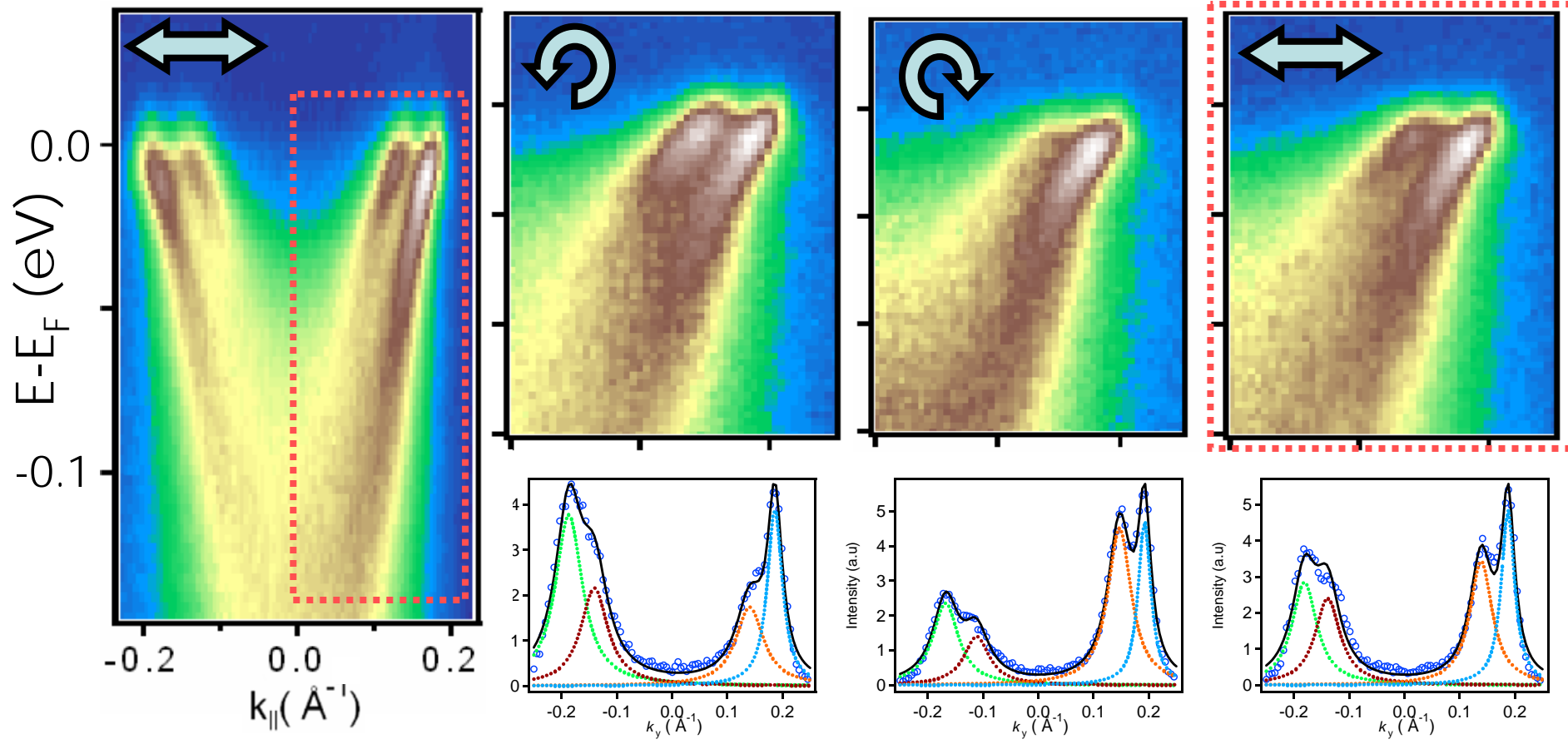
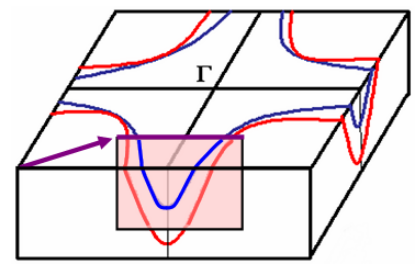
$$AN = 0^\circ$$

$$N = 45^\circ$$



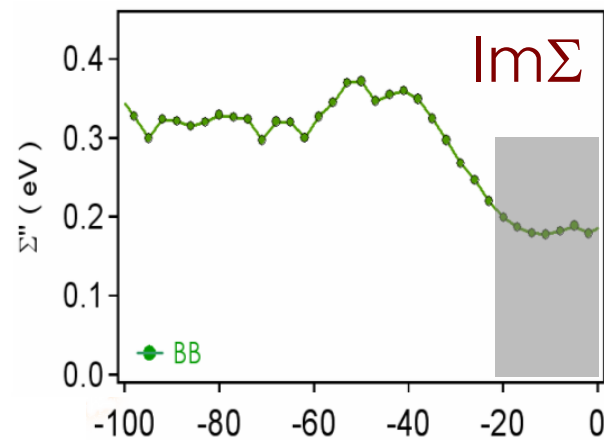
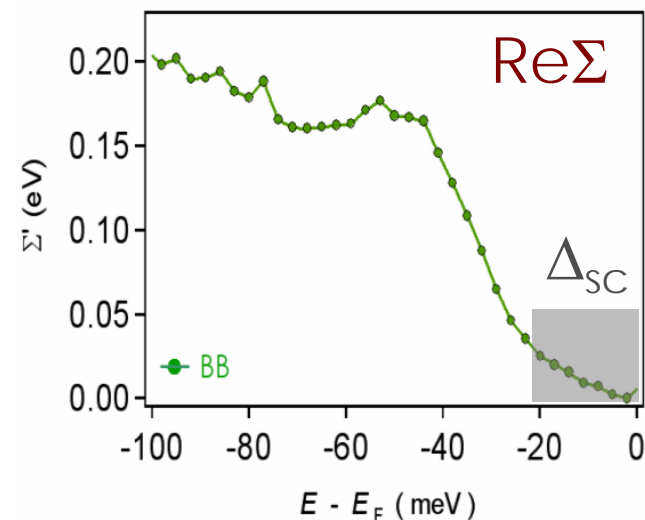
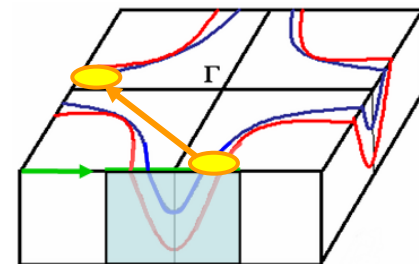
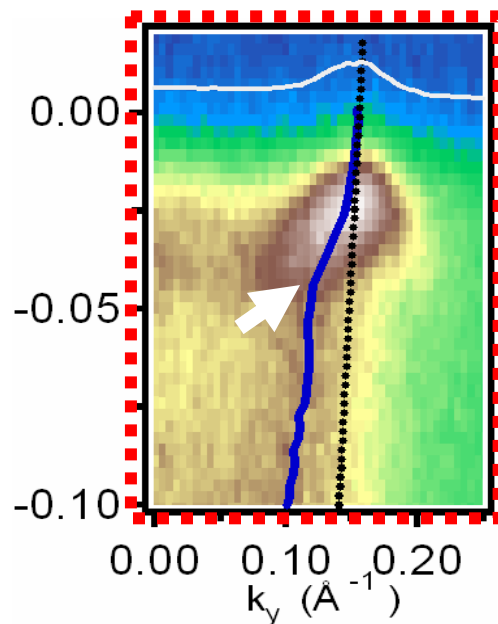
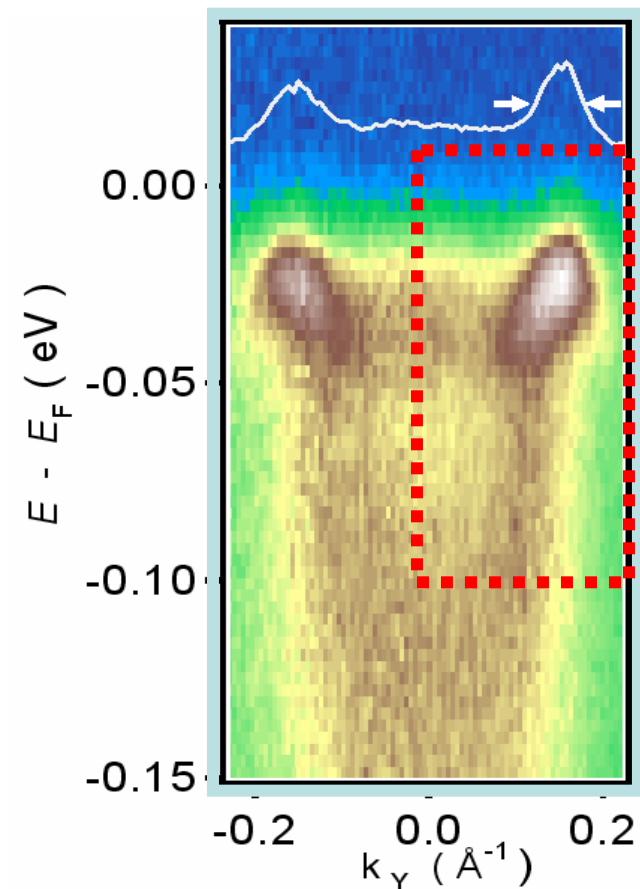
- variable polarisation of synchrotron radiation (LH, CL, CR)

→ multiple MDC's per Φ_{FS}

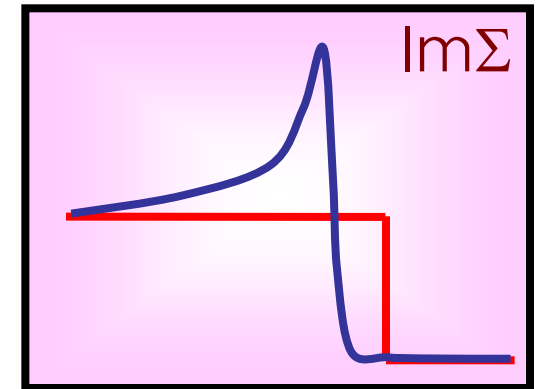
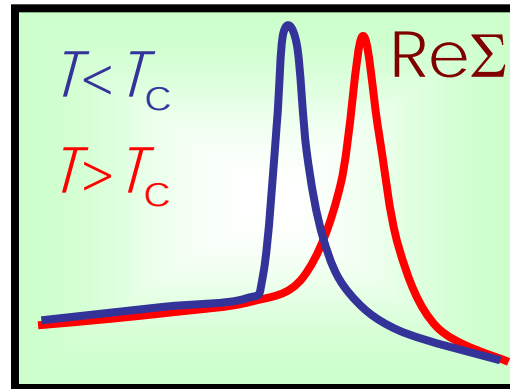
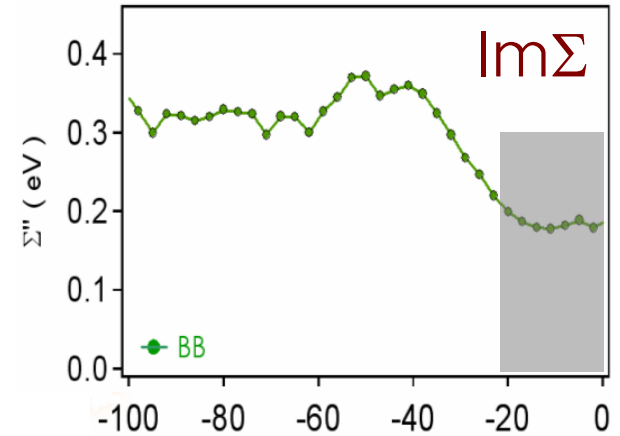
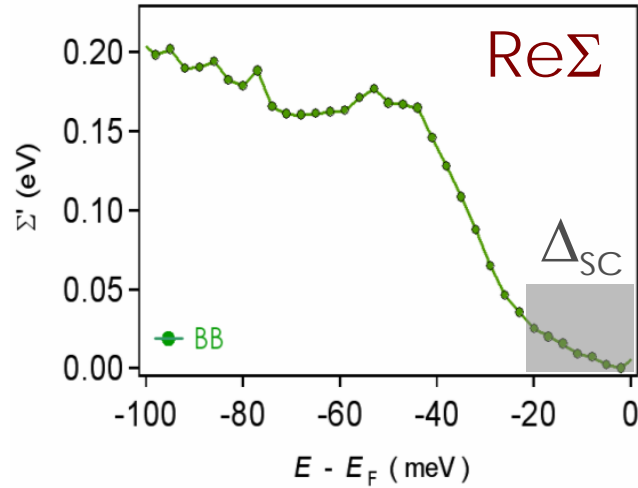
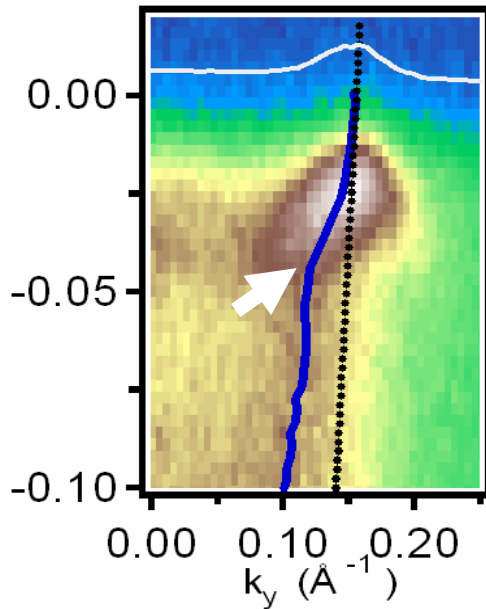


Data, $T < T_c$

Antinode: strong coupling to a bosonic mode



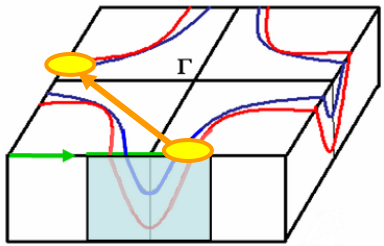
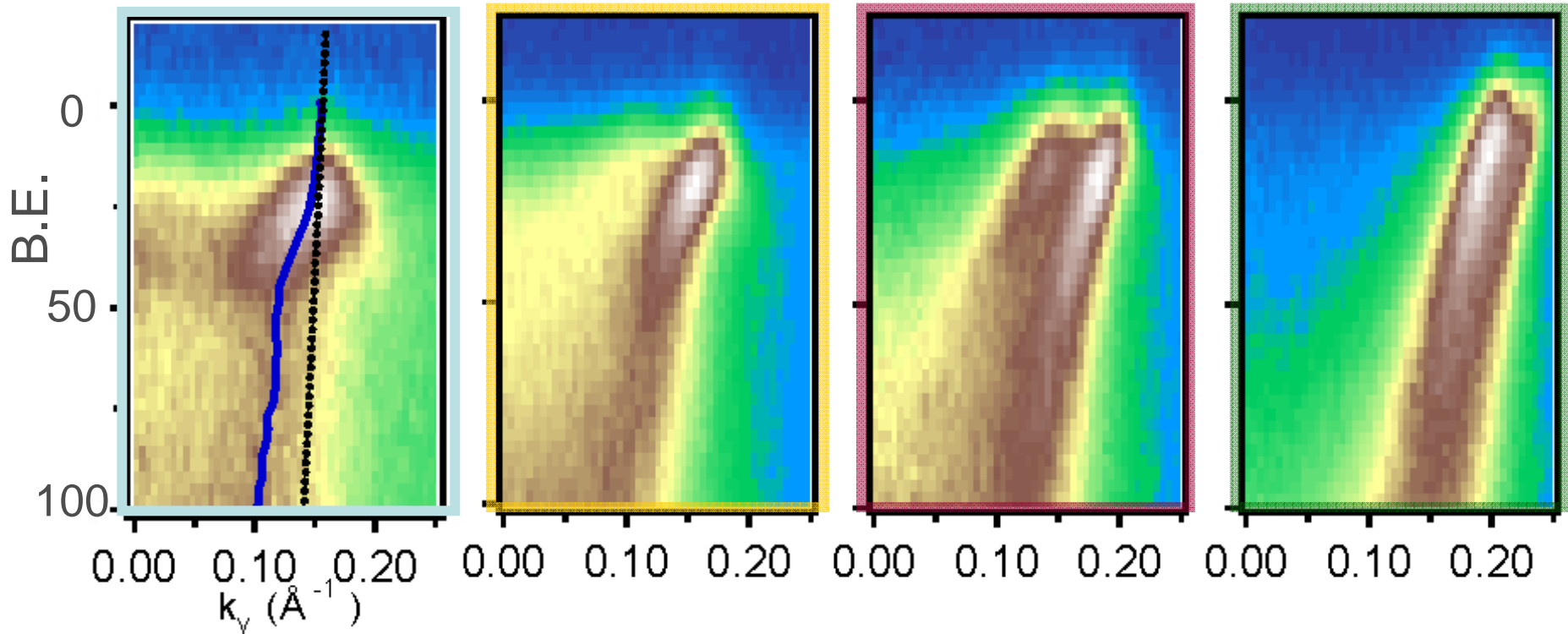
- ➔ large renormalisation
- ➔ sudden intensity drop coupled to maximum in Σ'' at 55meV



→ significant renormalisation at higher energies:
also contribution from a continuum

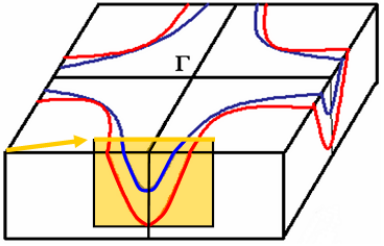
Data, $T < T_c$

towards node: coupling to mode reduces



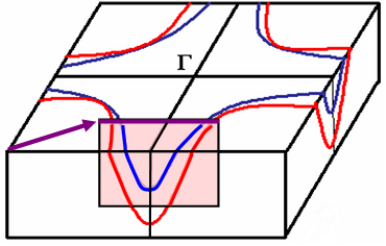
$\Phi_{FS} = 0$

$\Delta_{SC} \text{ (meV)} = 20$



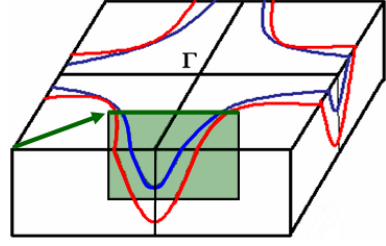
10

14



17

10

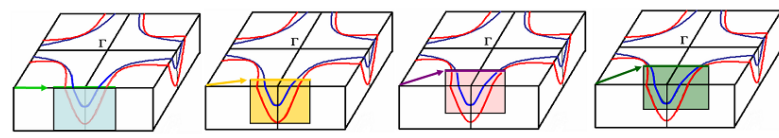
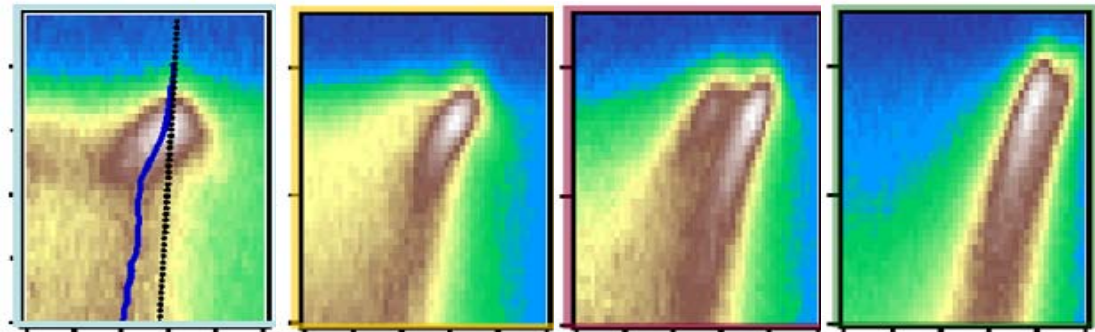


24

5

Data, $T < T_c$

towards node: coupling to mode reduces

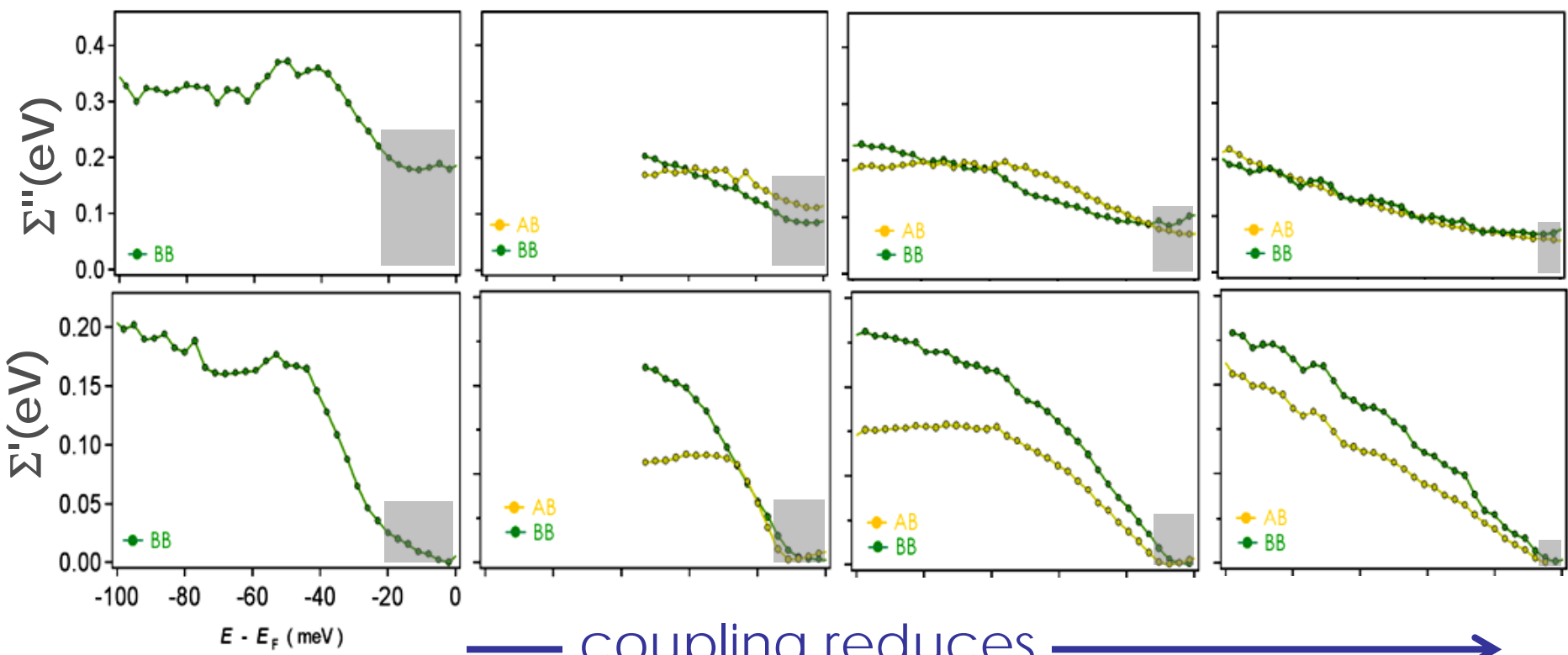


$\Phi_{FS} = 0$




10

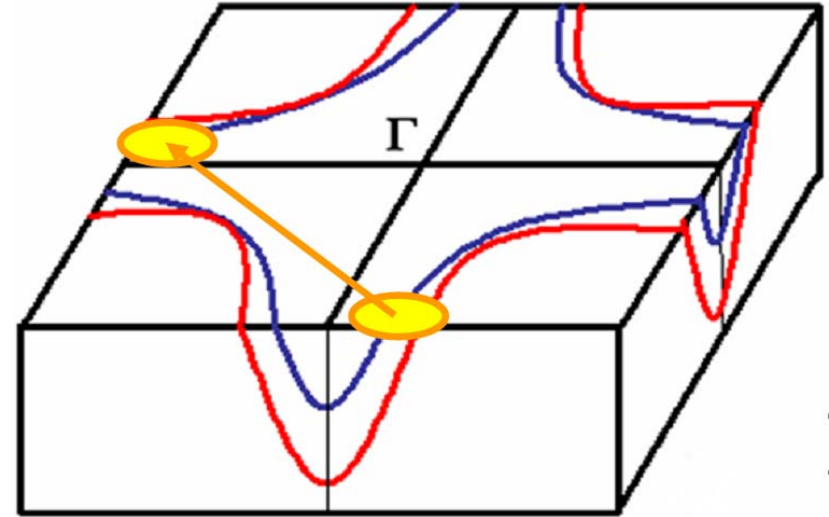
17

24

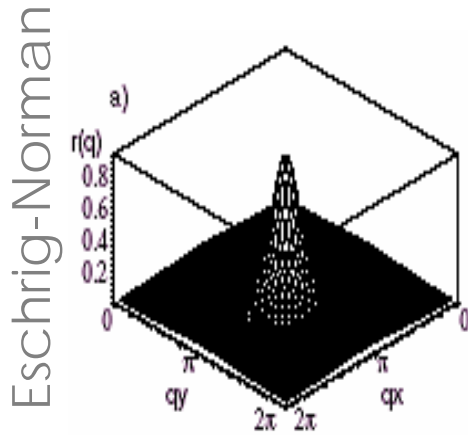


coupling reduces

 structure in self energy
 at $\Delta_{SC} + \Omega_{mode}$
 20 meV
 at AN
 Ω_{mode}
 30-35 meV

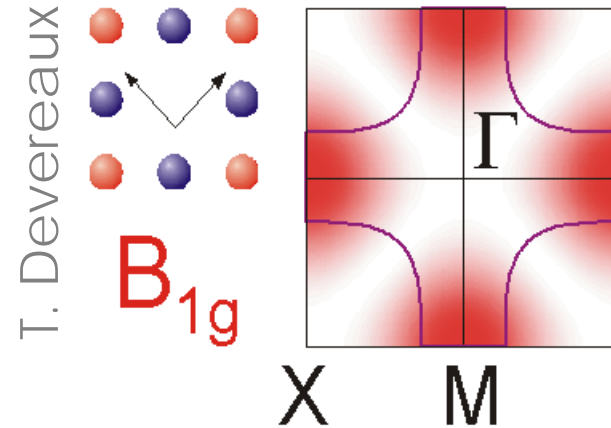


Spin-1 resonance mode



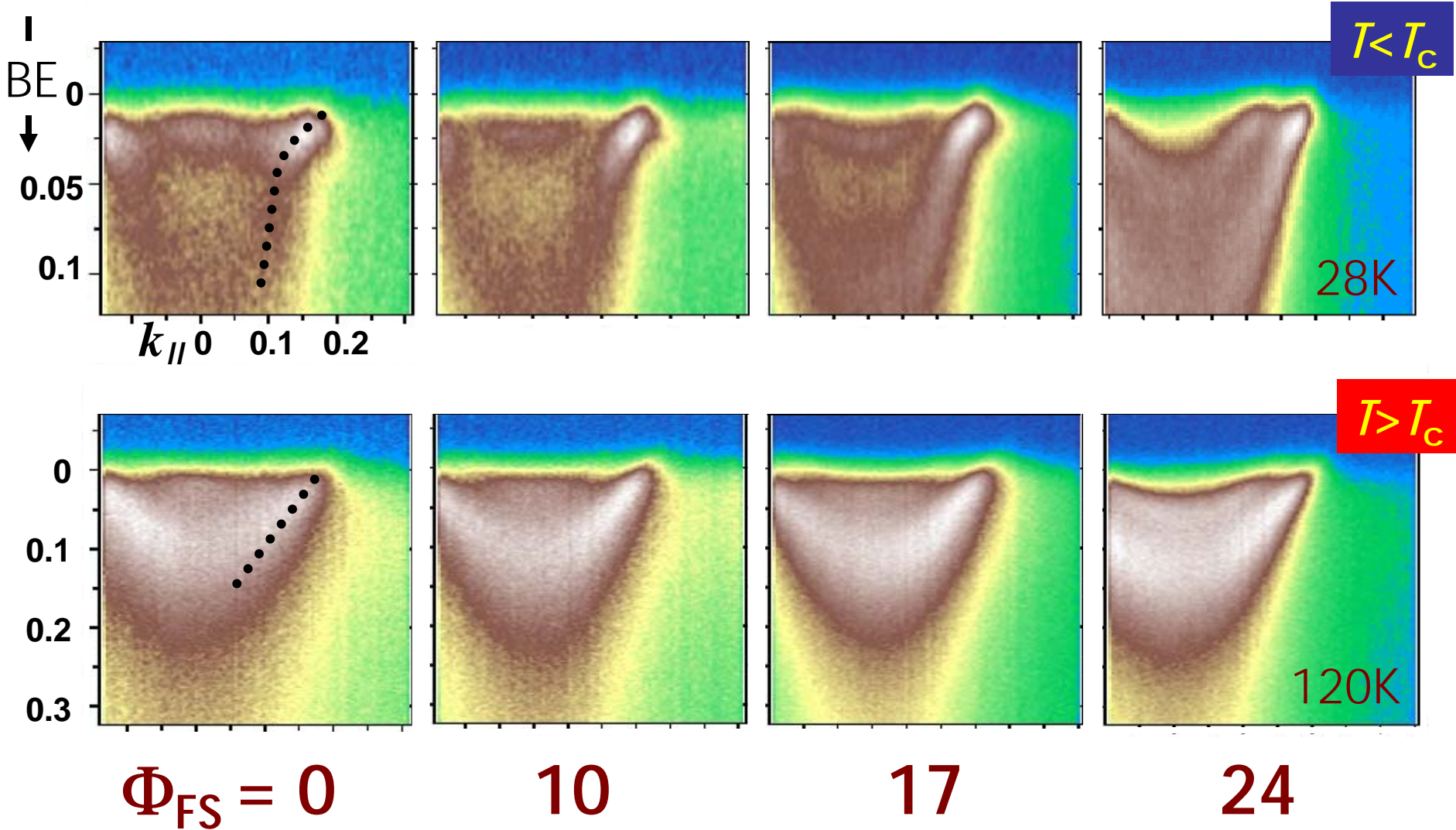
$\Omega_{mode} = 35\text{meV}$
 for OD80K
 Capogna et al.
 cond-mat
 0610869

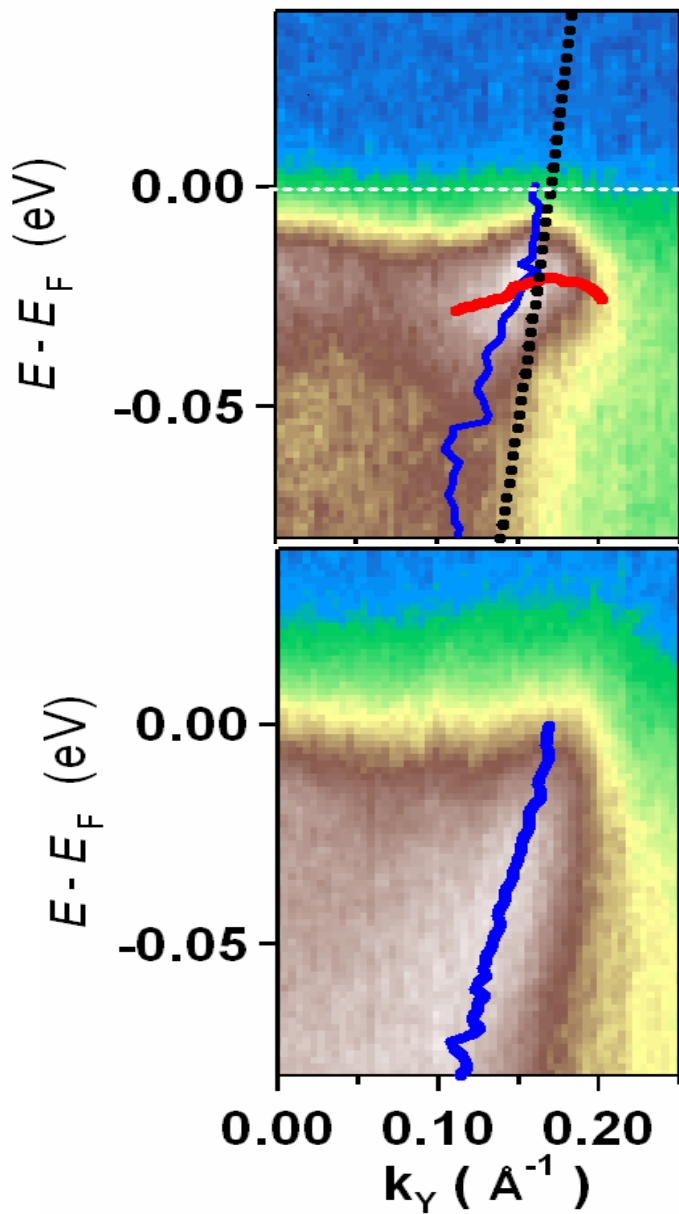
B_{1g} buckling phonon



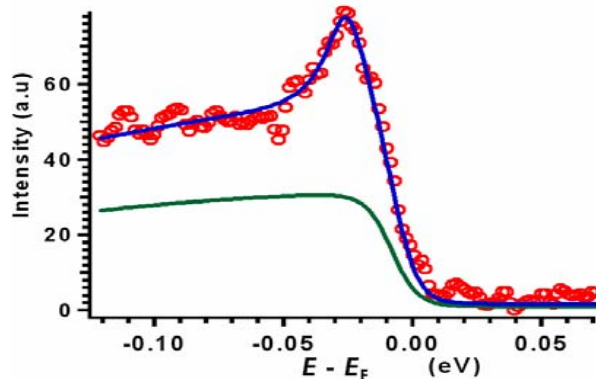
$\Omega_{mode} = 36\text{meV}$

● T-dependence (and doping dependence) holds key

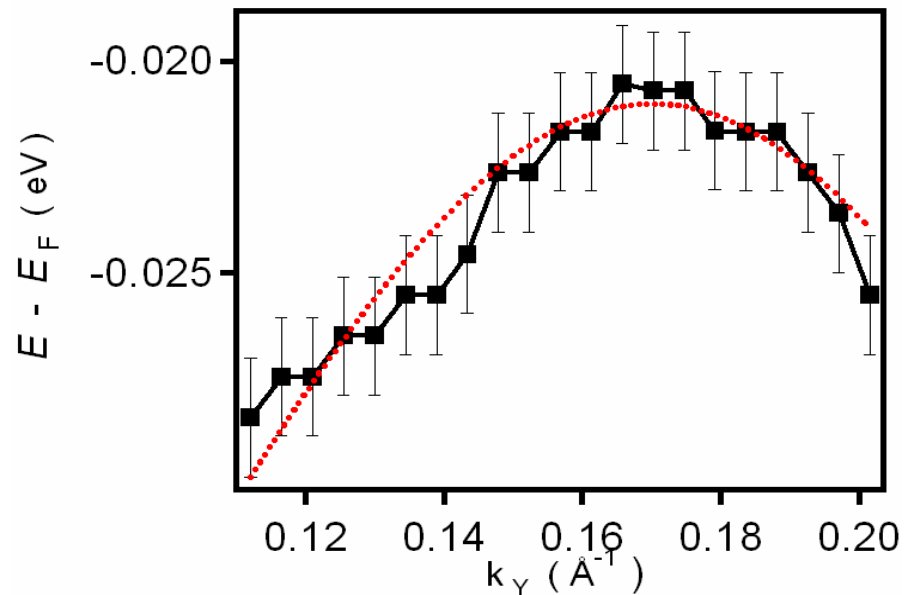




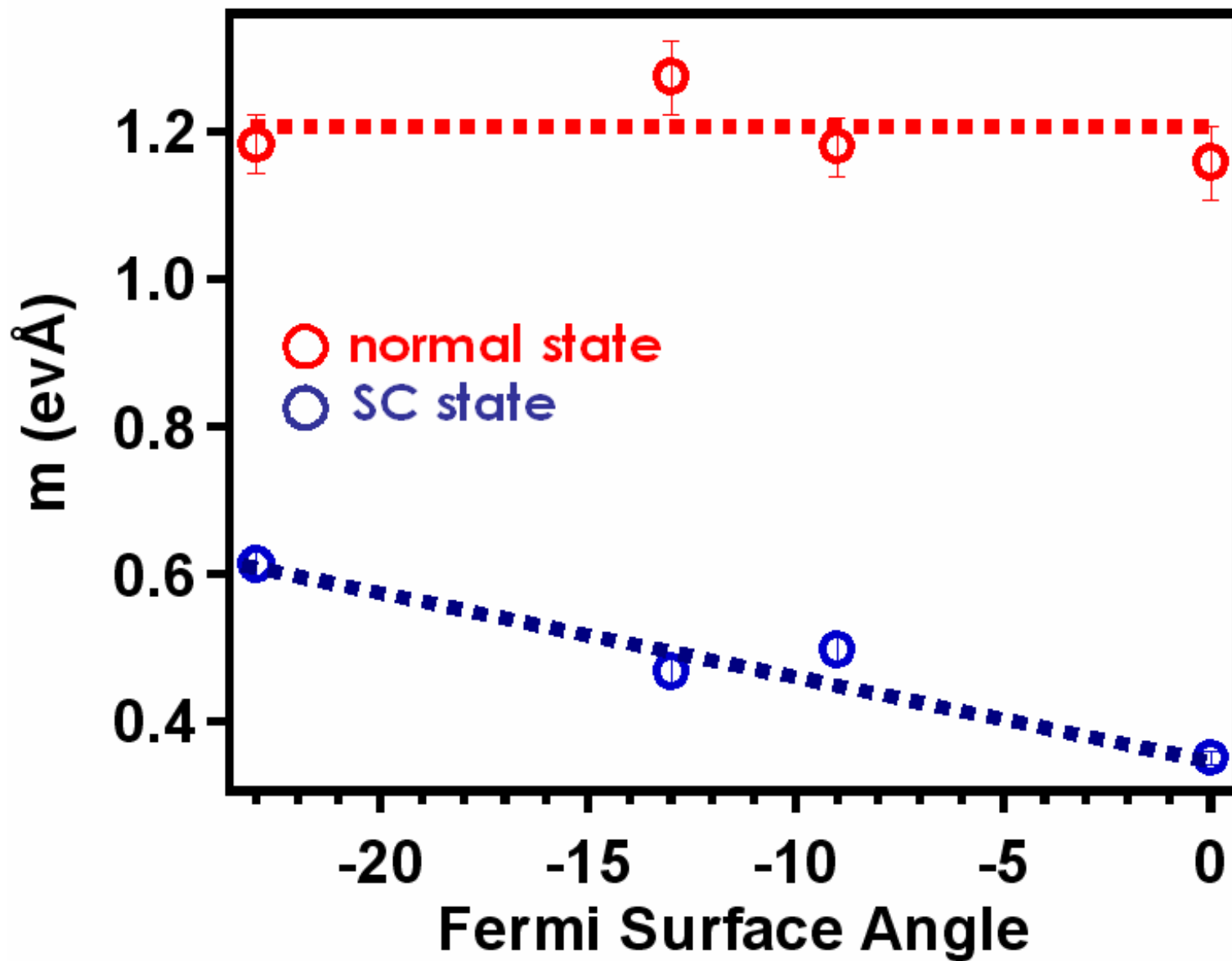
— EDC Dispersion



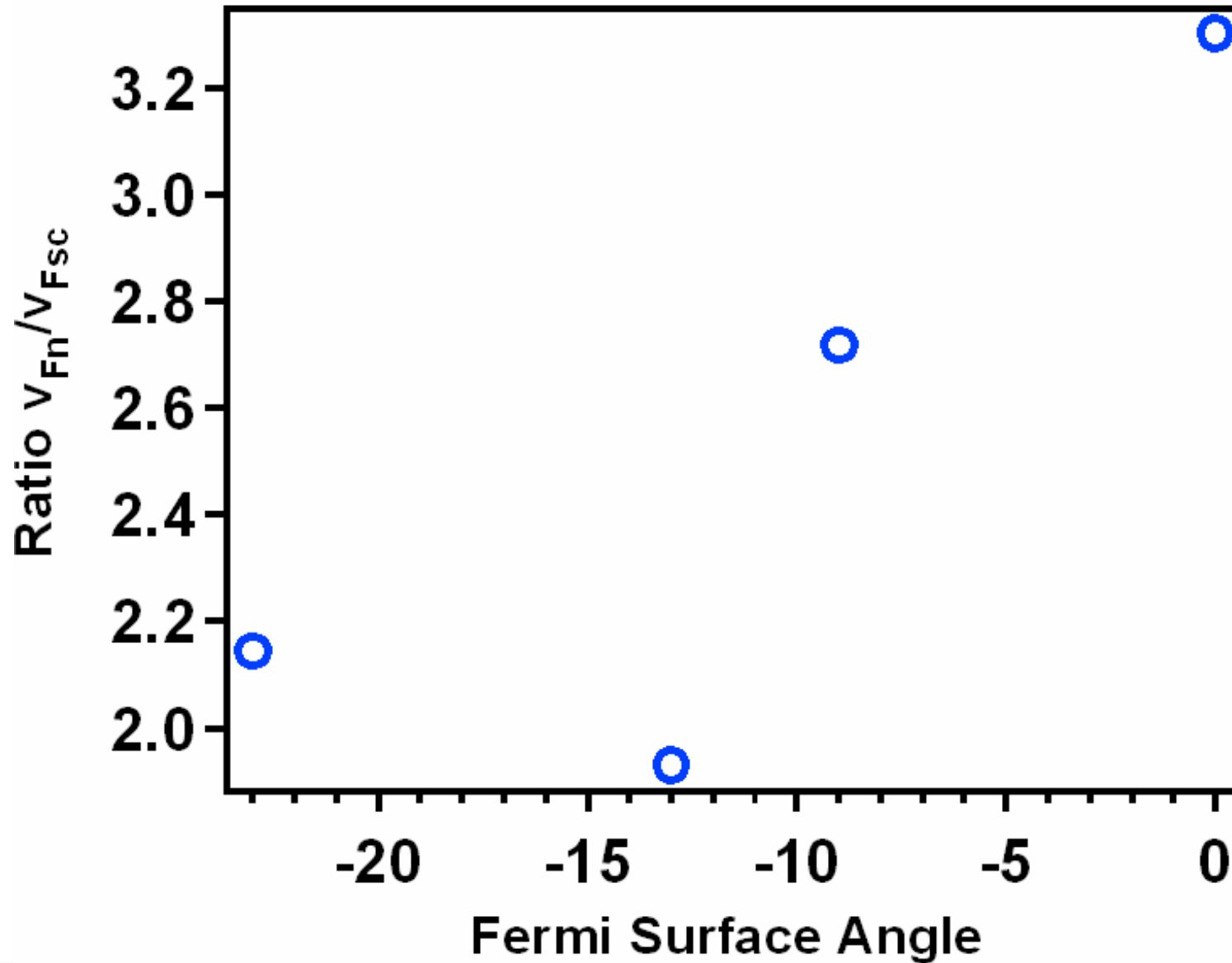
$$E(k) = \sqrt{m(k - k_F)^2 + \Delta^2} \quad \text{where} \quad m = \frac{v_F^0}{(1 + \lambda)}$$



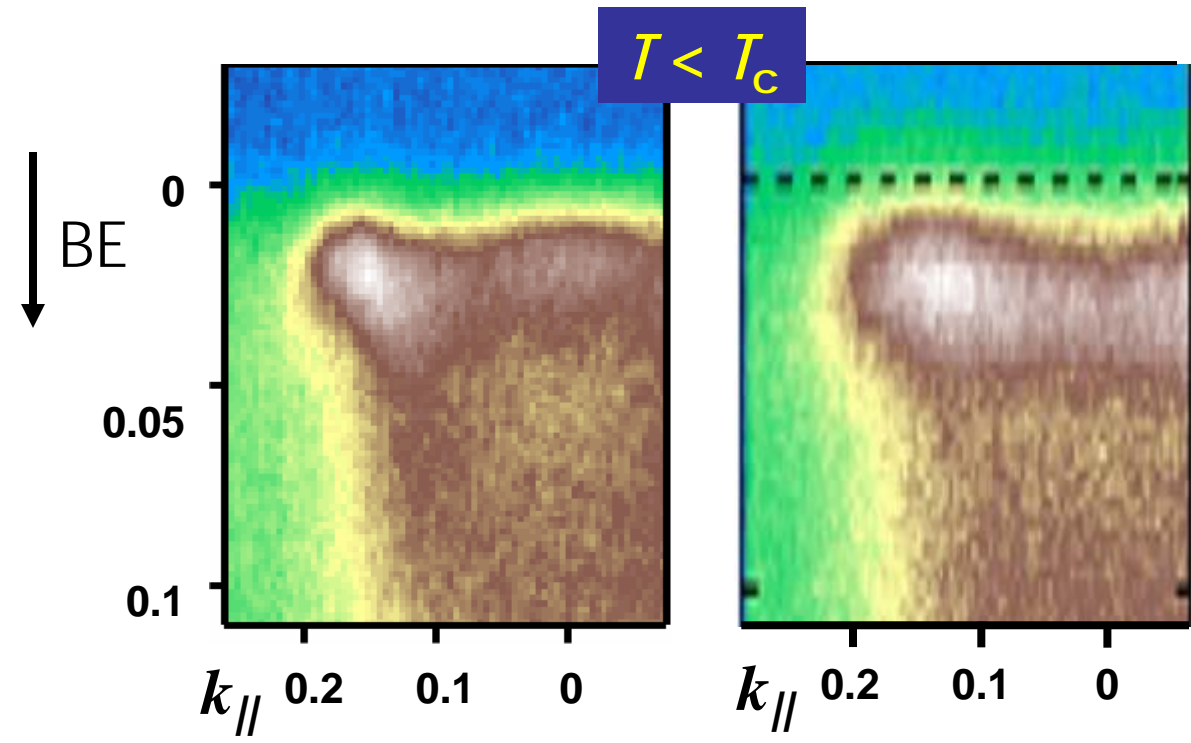
Bonding band



Bonding band



$$\Phi_{FS} = 0$$



PRL90, 207001 (2003)



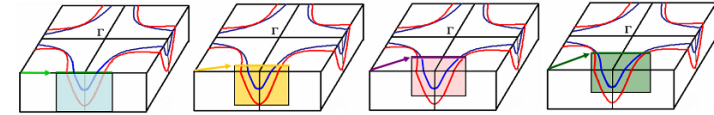
OD80K

UD77K

→ coupling ($T < T_c$) much stronger in UD systems

Conclusions and outlook

● Experiment:



high quality data → quantitative self energies in previously 'dark' FS area from AN towards node

● Conclusions:

strong coupling to bosonic mode (and continuum)

→ weakens as go away from antinode

→ disappears as go above T_c

→ coupling below T_c increases in UD regime



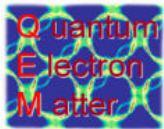
● Outlook

→ Kramers-Kronig consistency: $\text{Im}\Sigma \leftrightarrow \text{Re}\Sigma$

→ use ARPES Σ' , Σ'' → INS and Raman response

→ Y-doping of Pb-doped Bi2212 to access UD regime

Acknowledgements



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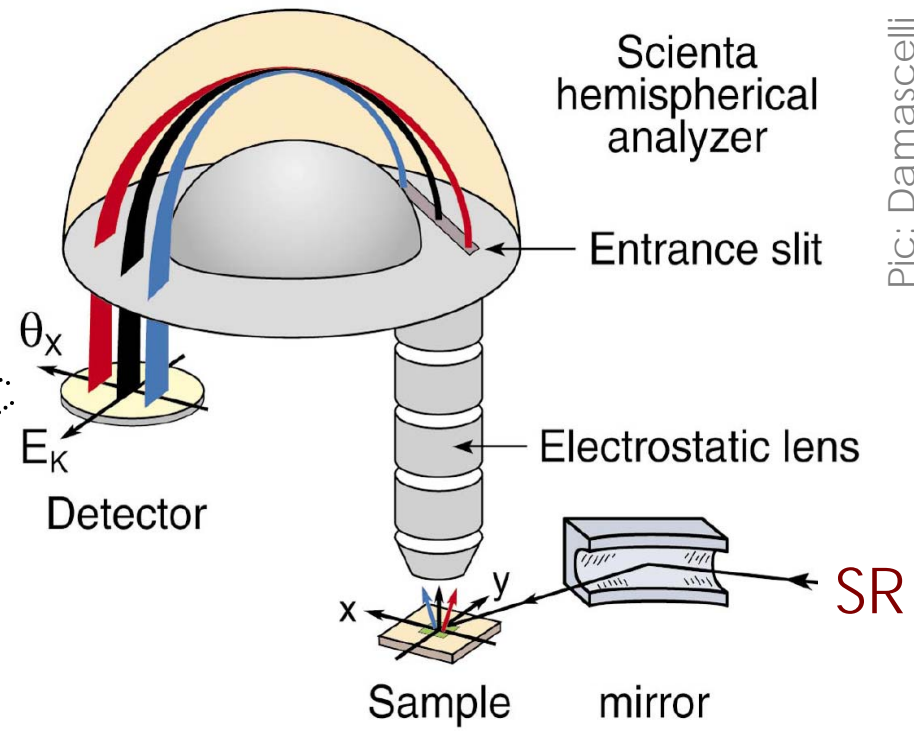
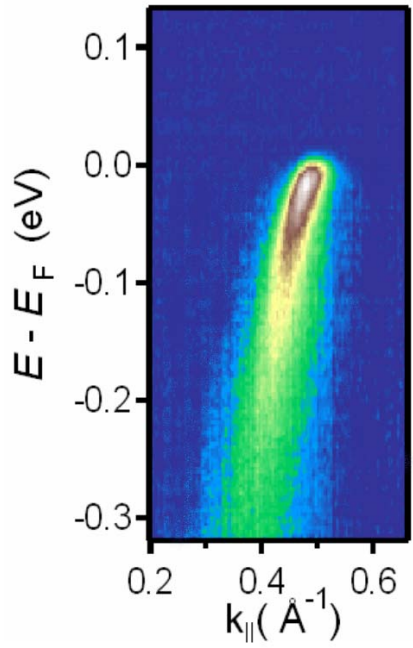


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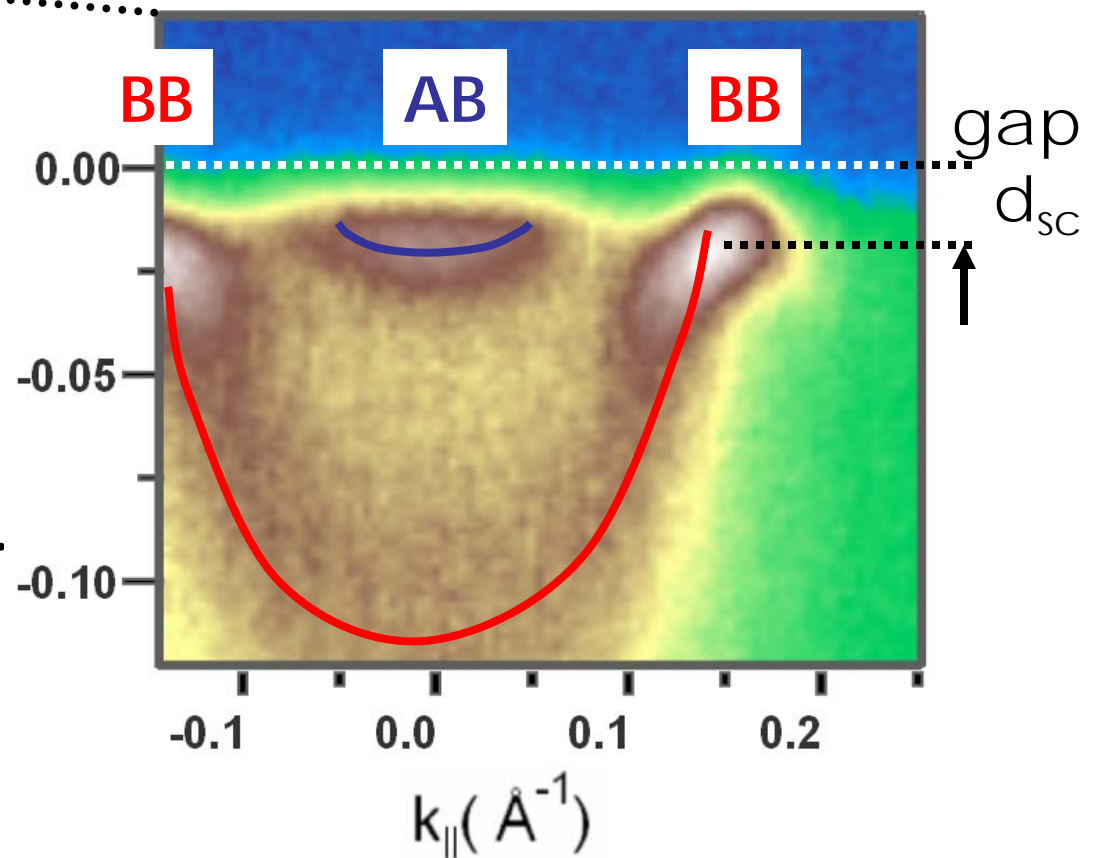
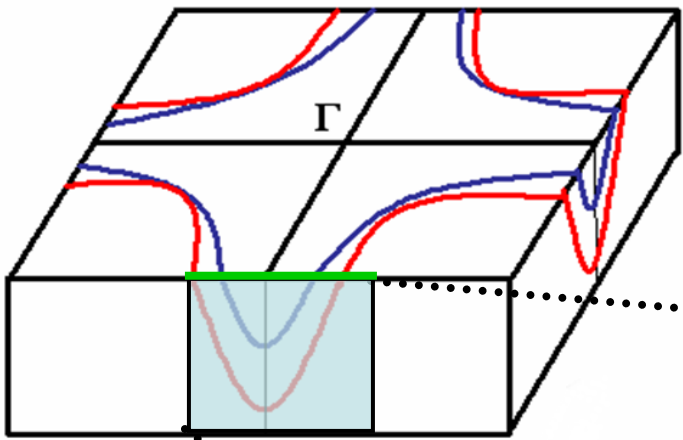
$$k_{||} = \sqrt{\frac{2mE_{kin}(eV)}{\hbar}} \sin\Theta$$



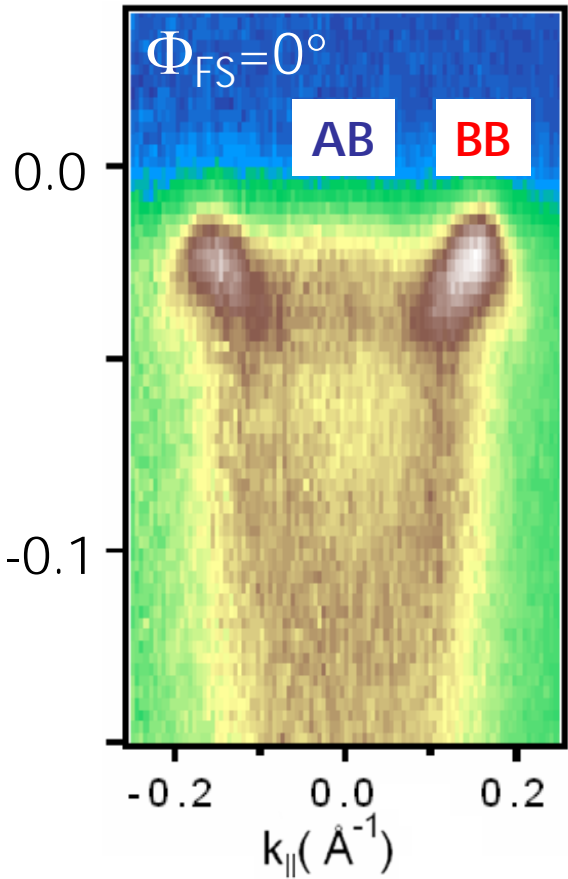
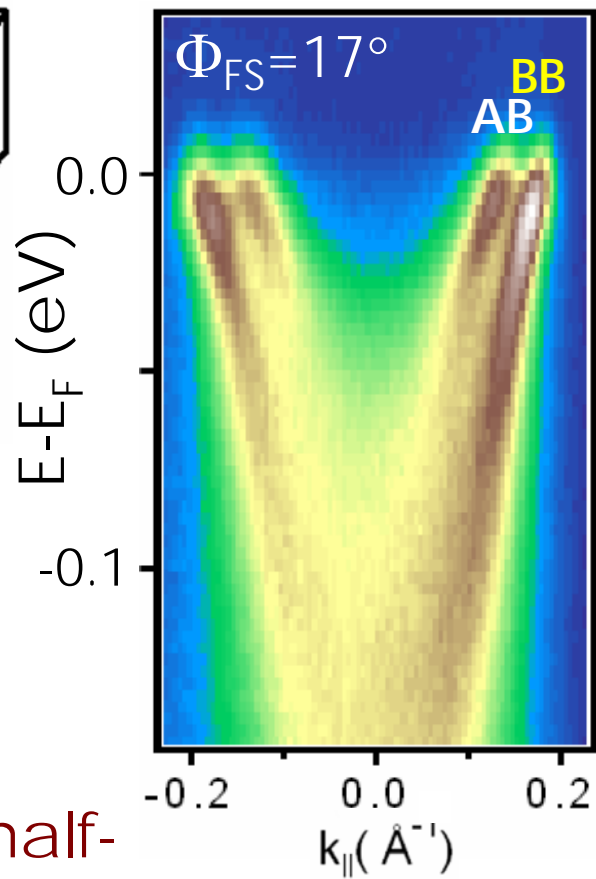
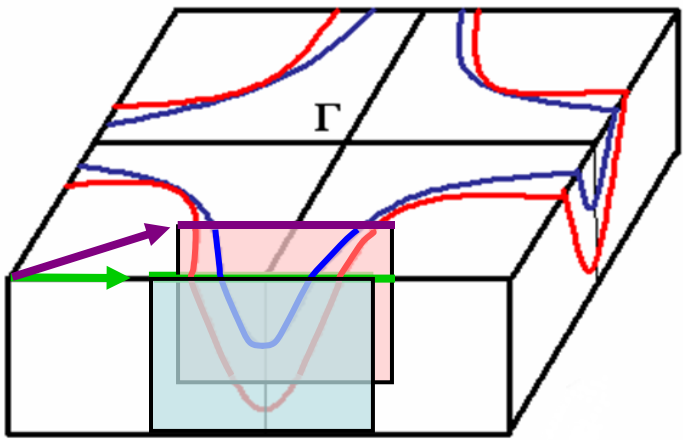
Pic: Damascelli

- photoelectric effect
- surface sensitive
- $k_{||}$ conserved

$$\Phi_{FS} = 0^\circ$$



● concentrate on the bonding band



● Experimental strategy:

→ special $h\nu$

→ cuts from AN to half-way to the node

→ variable polarisation of SR to 'multiply' data:

→ huge improvement in robustness of data fitting

