

*Fast and furious*The fate of quasiparticles at high temperature in  $\text{Sr}_2\text{RuO}_4$ 

Anna Tamai

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UNIVERSITÉ  
DE GENÈVE

## ARPES group



*Felix Baumberger*



*Andrew Hunter*



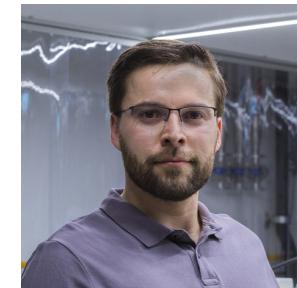
Sophie Beck



Antoine Georges



Jernej Mravlje

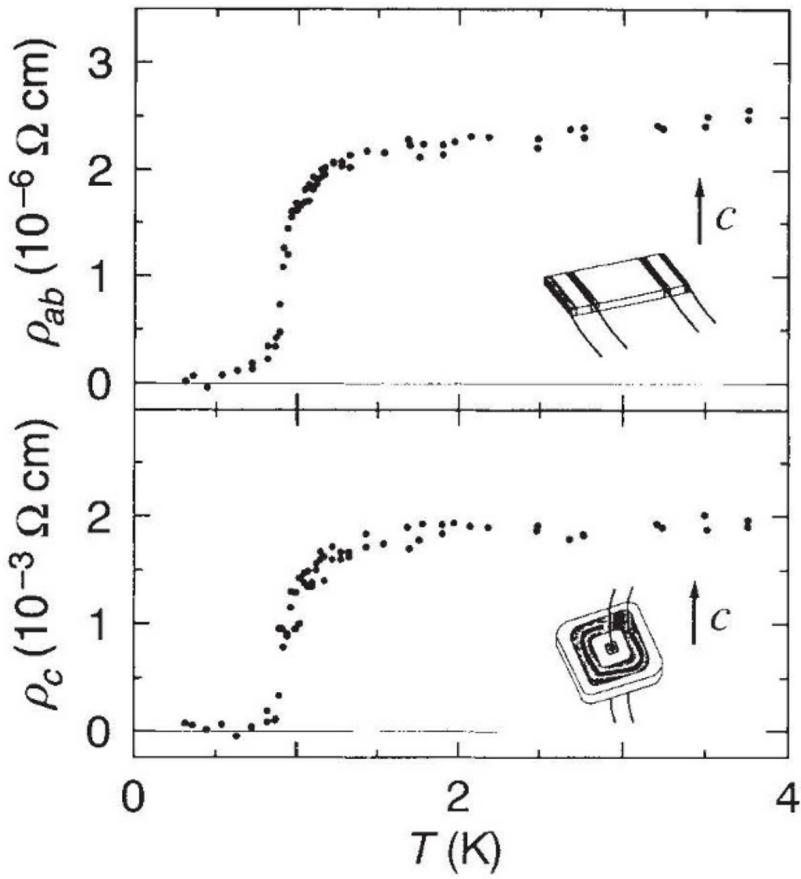
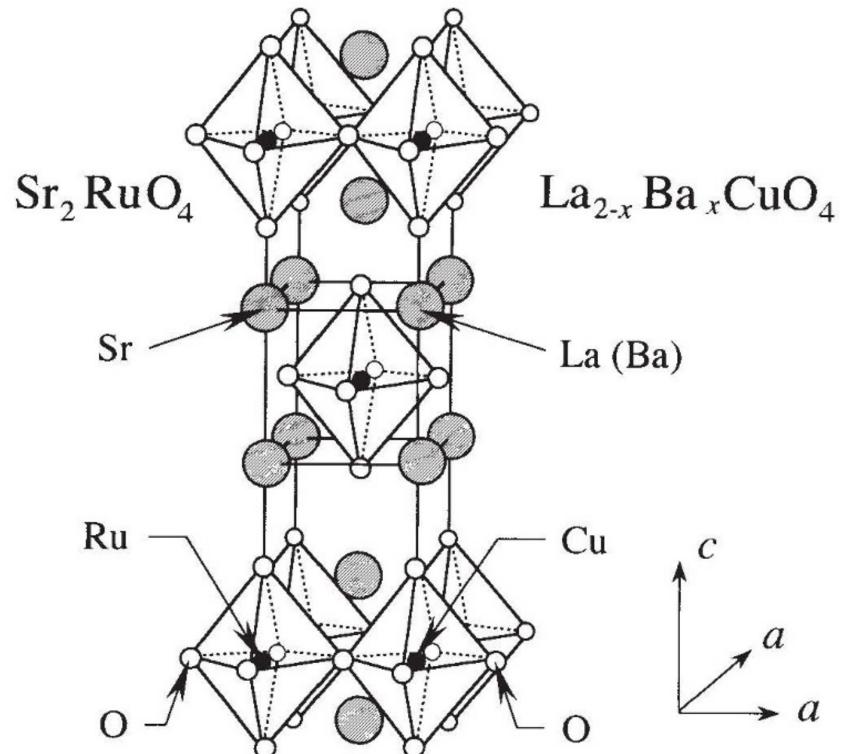


Carsten Putzke



Philip Moll

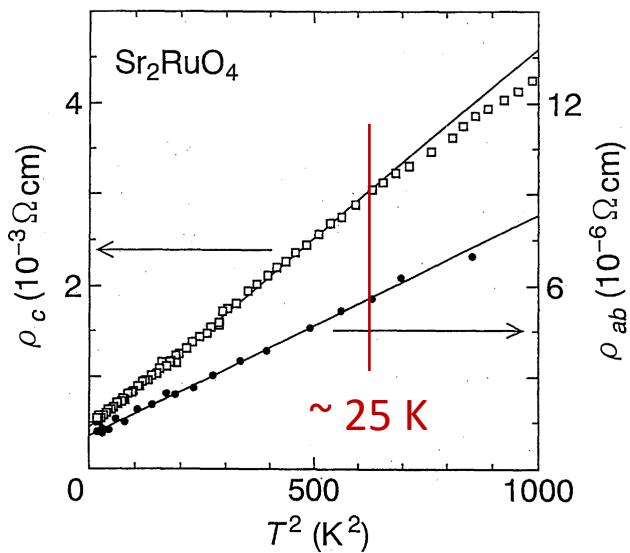
# Why $\text{Sr}_2\text{RuO}_4$ ?



Y. Maeno, Nature 1994

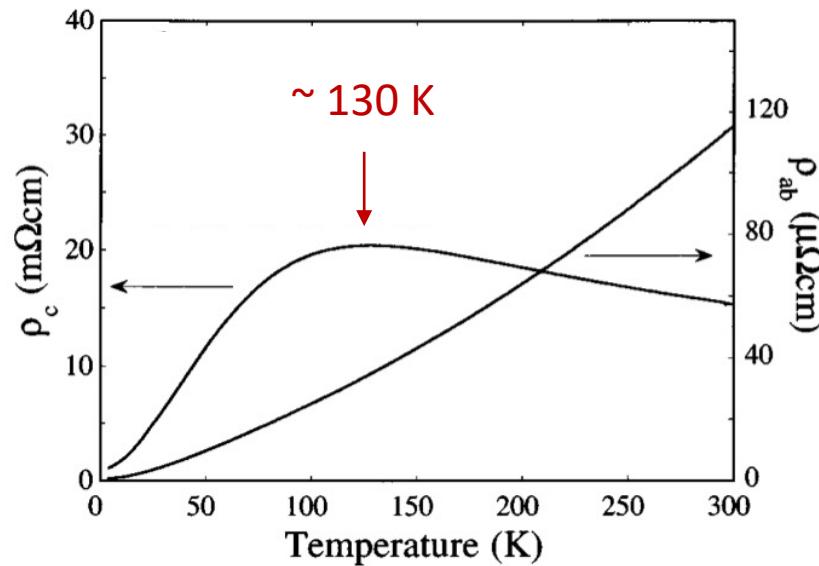
# $\text{Sr}_2\text{RuO}_4$ - resistivity

low - T



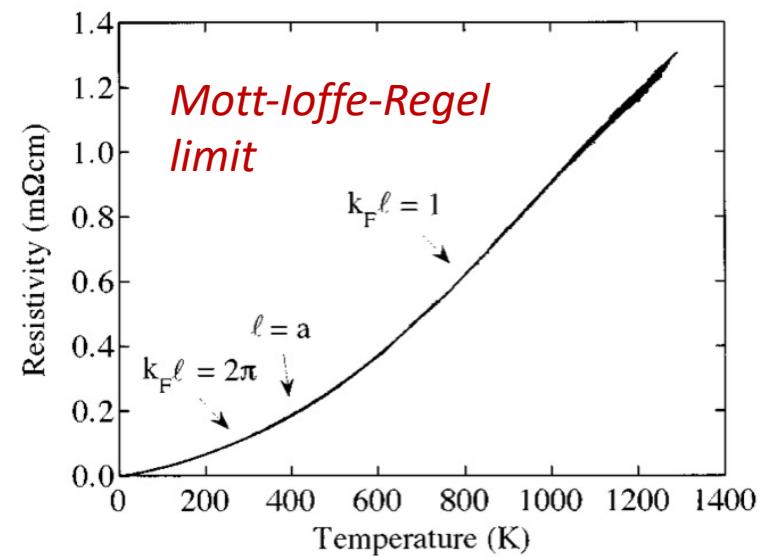
Y. Maeno, JPSJ 1997

c-axis crossover



N.E. Hussey, PRB 57, 5505 (1998)

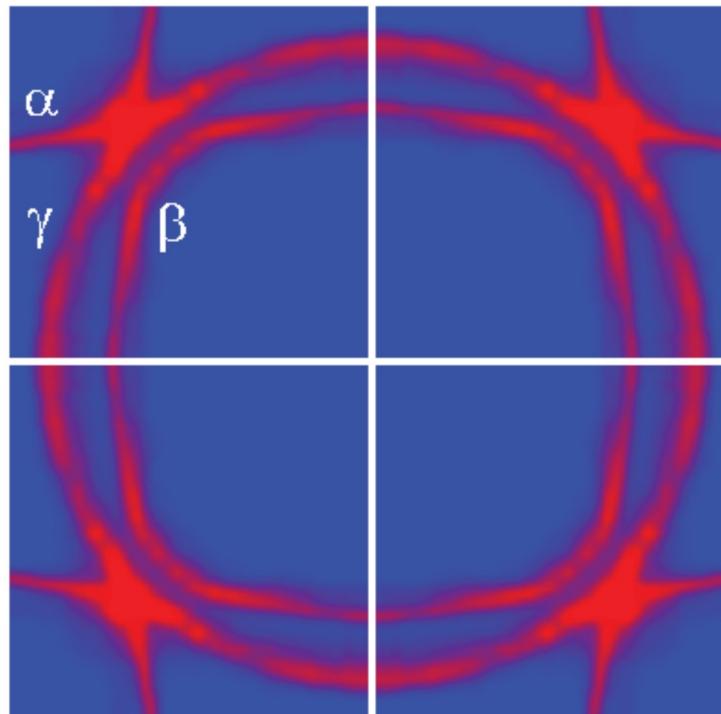
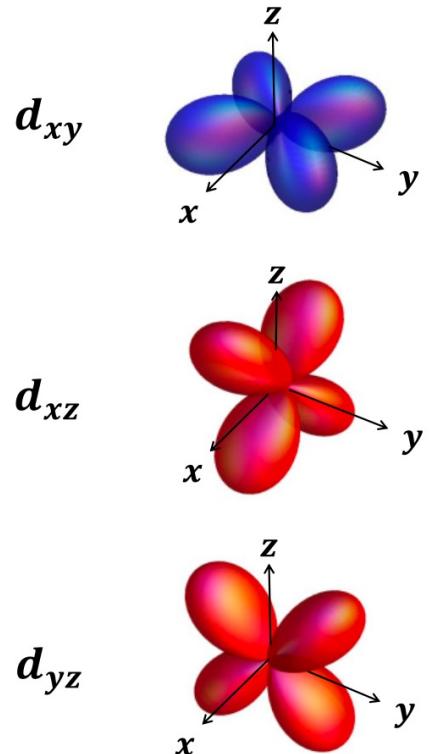
high - T



A. W. Tyler, PRB 58, R10107 (1998)

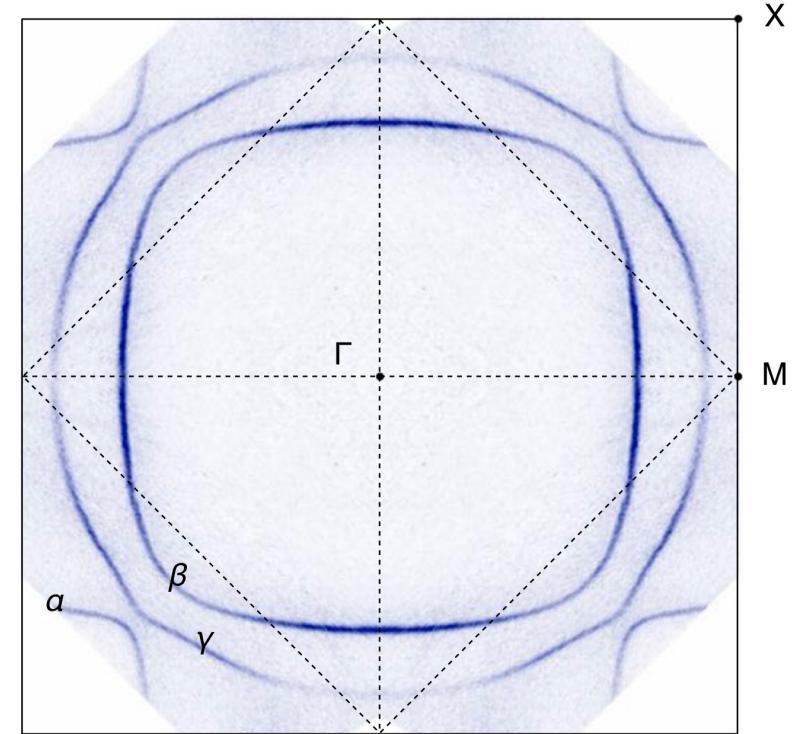
# Electronic structure

Ru<sup>4+</sup>: **4 4d el./Ru**



A. Damascelli et al., PRL 85, 5194 (2000)

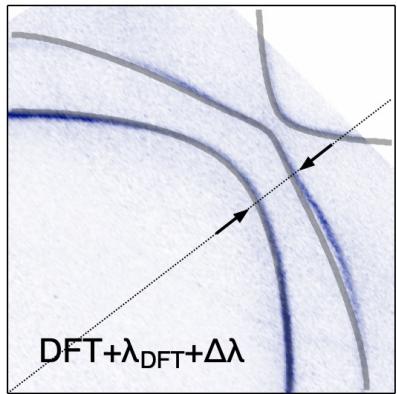
laser ARPES



A. Tamai, PRX 2019

# High-resolution laser ARPES on $\text{Sr}_2\text{RuO}_4$

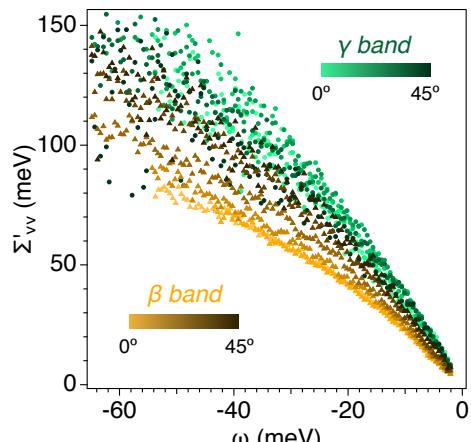
A. Tamai, PRX 9, 021048 (2019)



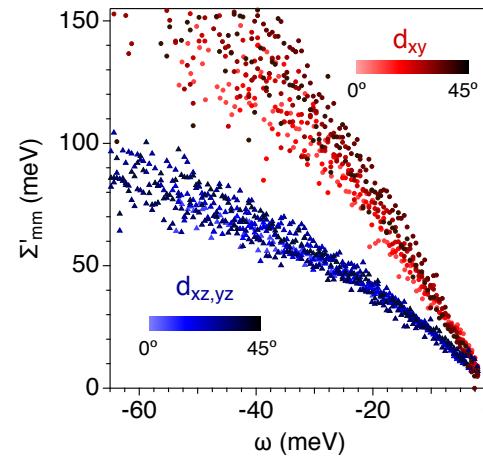
**Correlation induced enhancement of SOC**

$$\hat{H}^0 = \hat{H}^{\text{DFT}} + \hat{H}_{\lambda_{\text{DFT}}+\Delta\lambda}^{\text{SOC}}$$

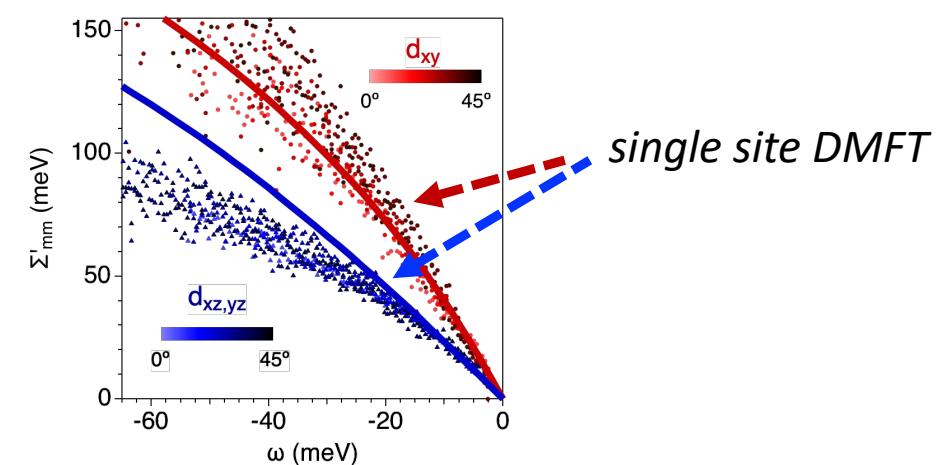
**Dominant role of local-interactions:**



*band basis*

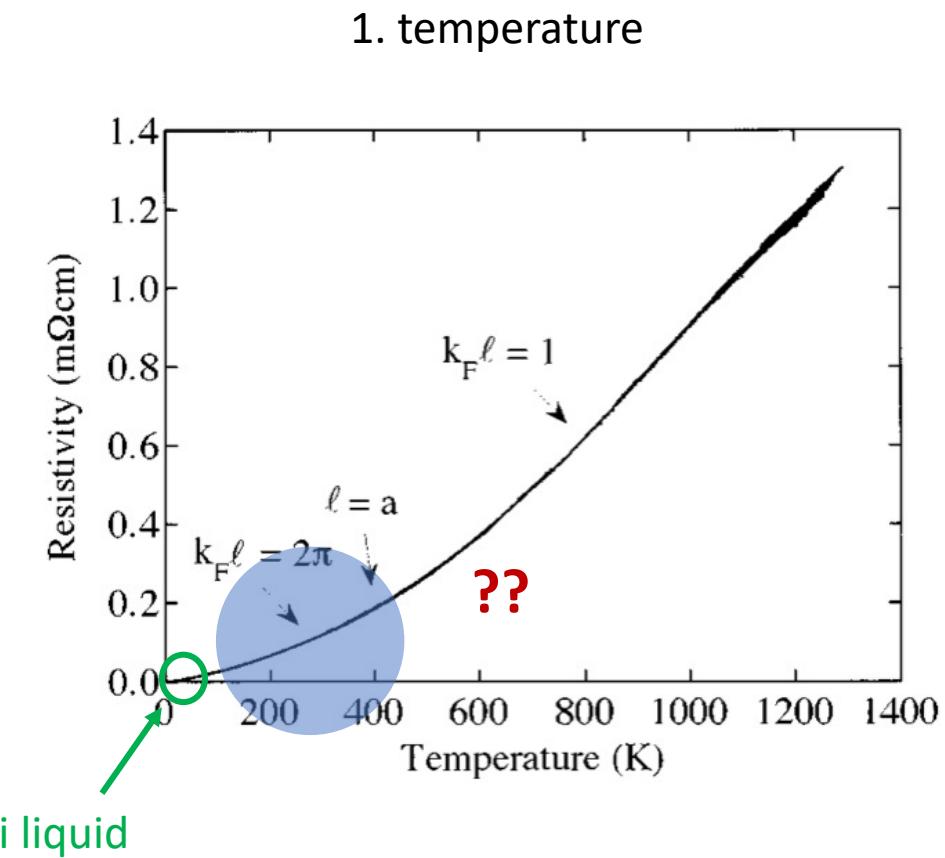


*orbital basis*

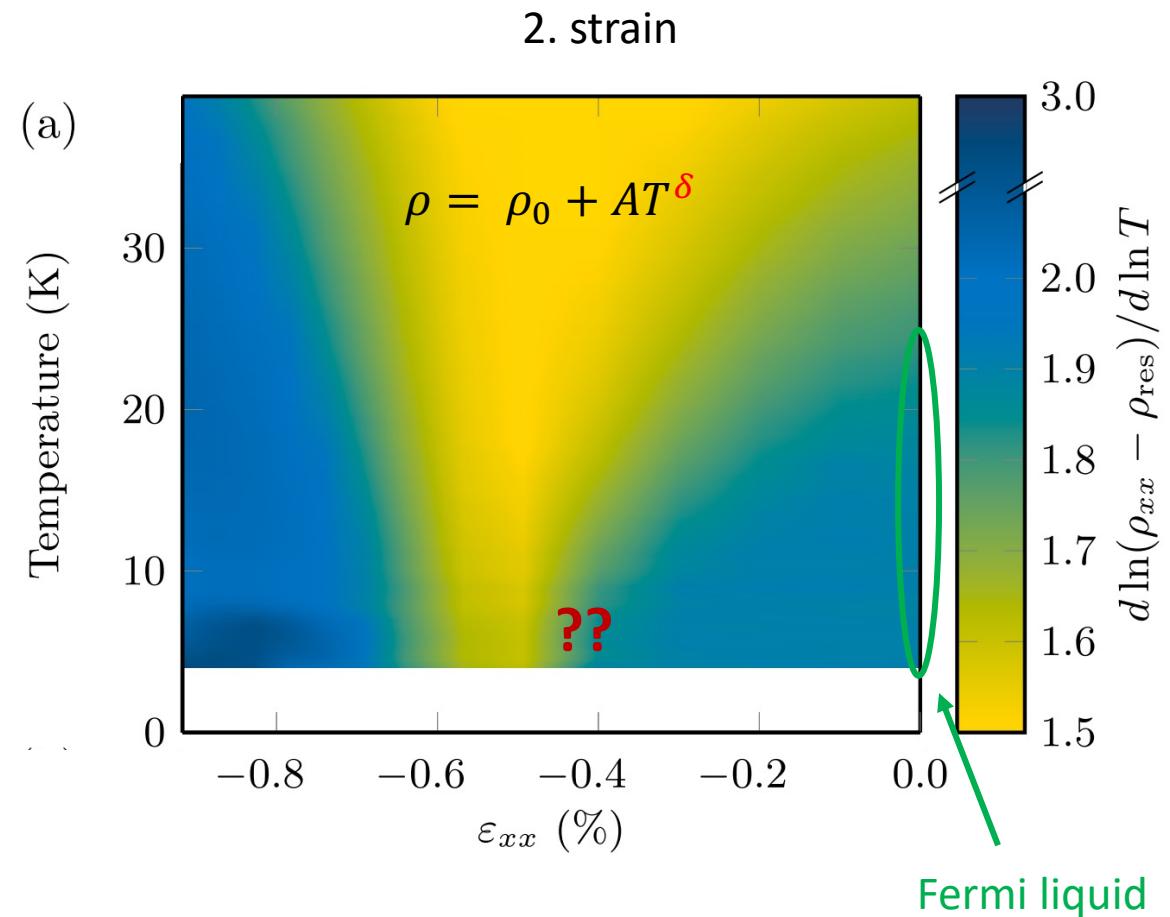


*single site DMFT*

# Menu of the talk



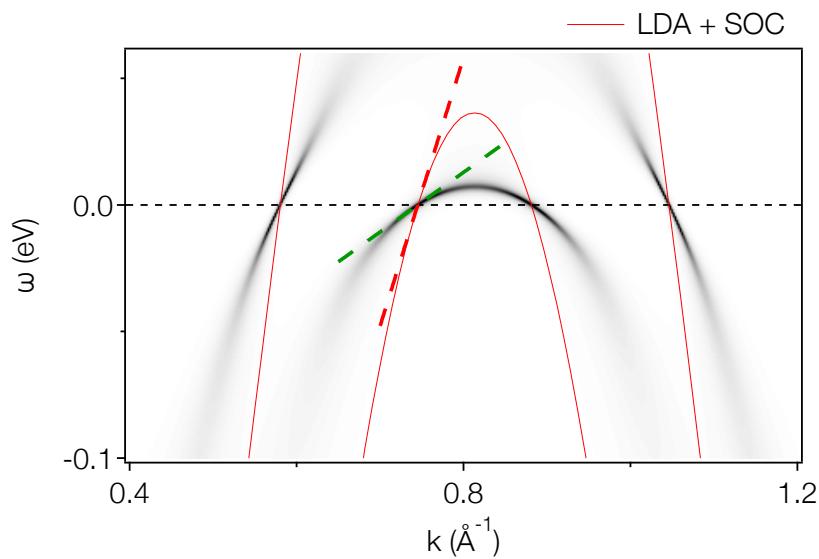
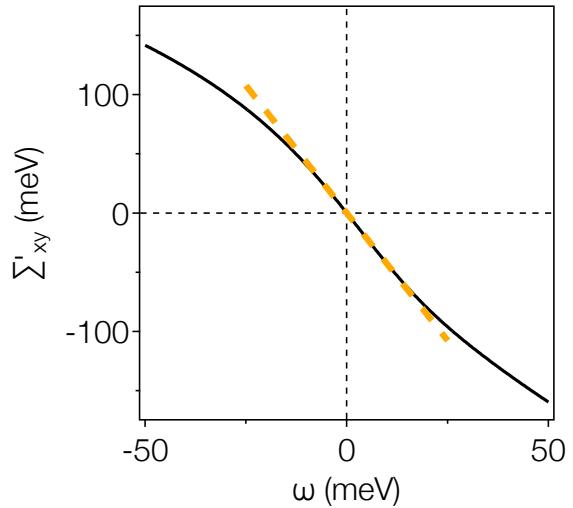
A. W. Tyler, PRB 58, R10107 (1998)



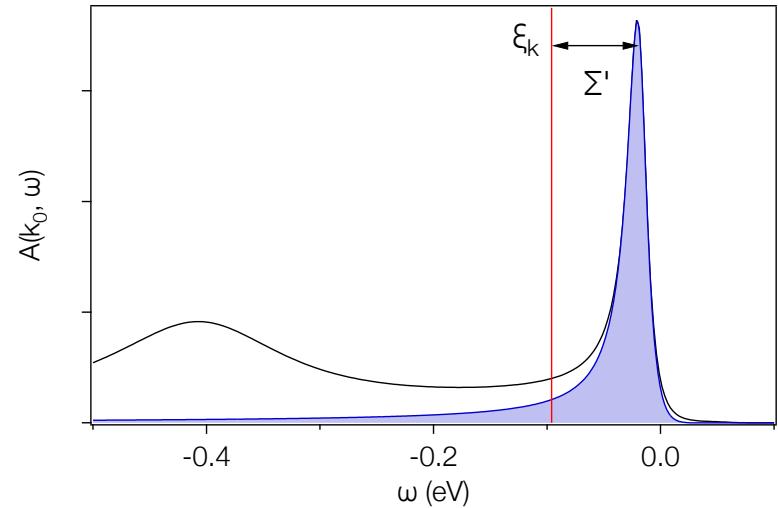
M. Barber, PRL 2018

# Quasiparticle residue: $Z$

*mass enhancement*



*spectral weight*

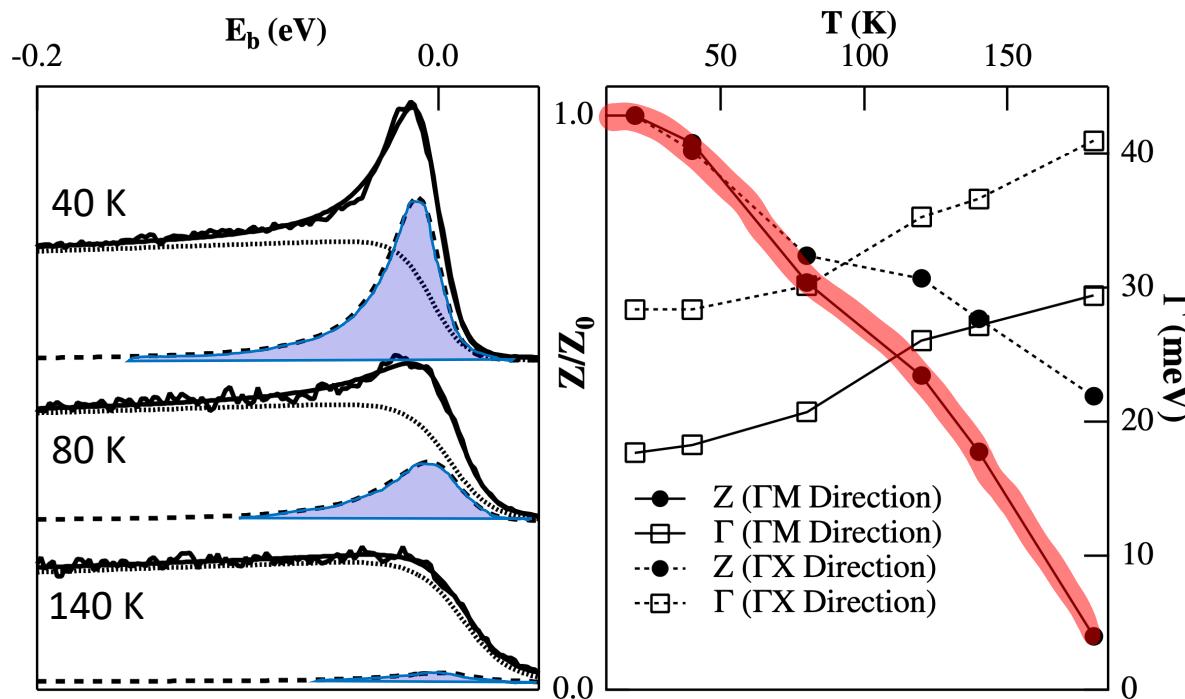


$$Z = \left( 1 - \left. \frac{\partial \Sigma'}{\partial \omega} \right|_{\omega=0} \right)^{-1}$$

$$Z = \frac{v_F^*}{v_0} = \frac{m_0}{m^*}$$

$$Z = \int A_{ch}(\omega) d\omega$$

# Temperature dependence - previous studies

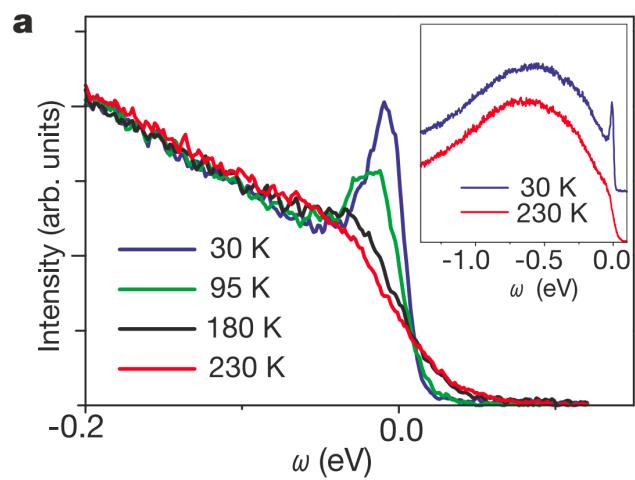


$\text{Sr}_2\text{RuO}_4$ , Wang et al. 2004 :

- QPs disappear near 130 K ( $\rho_c$  crossover)
- $Z \rightarrow 0$  around 200 K

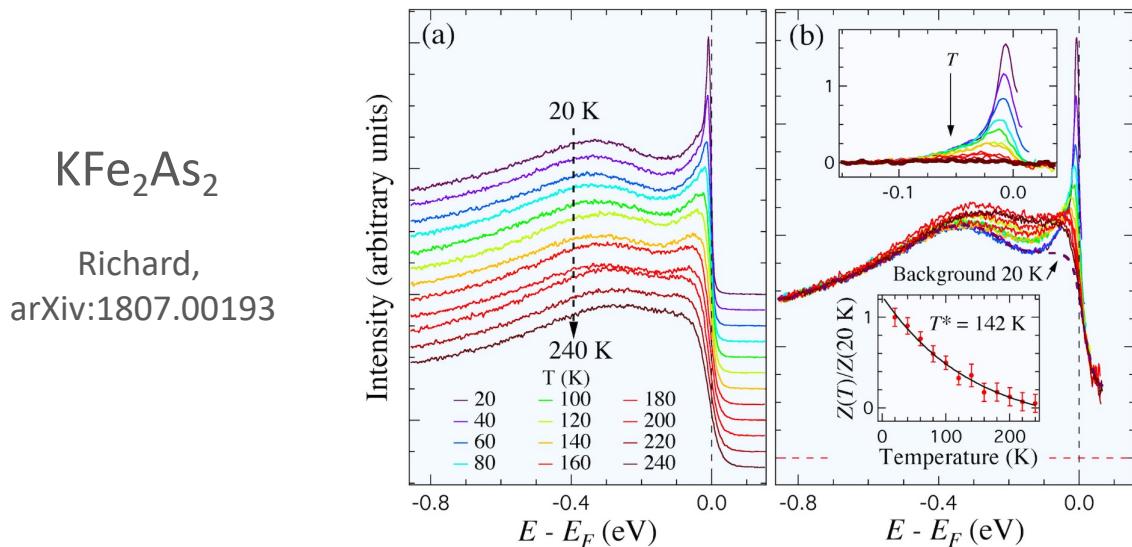
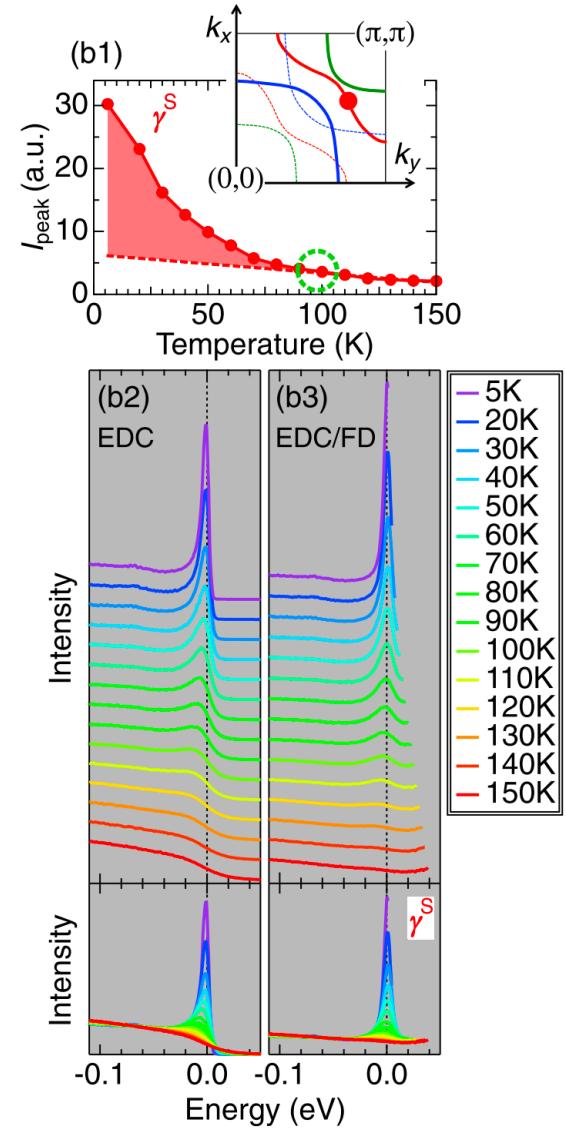
Wang, PRL 92, 137002 (2004)

# Temperature dependence - previous studies

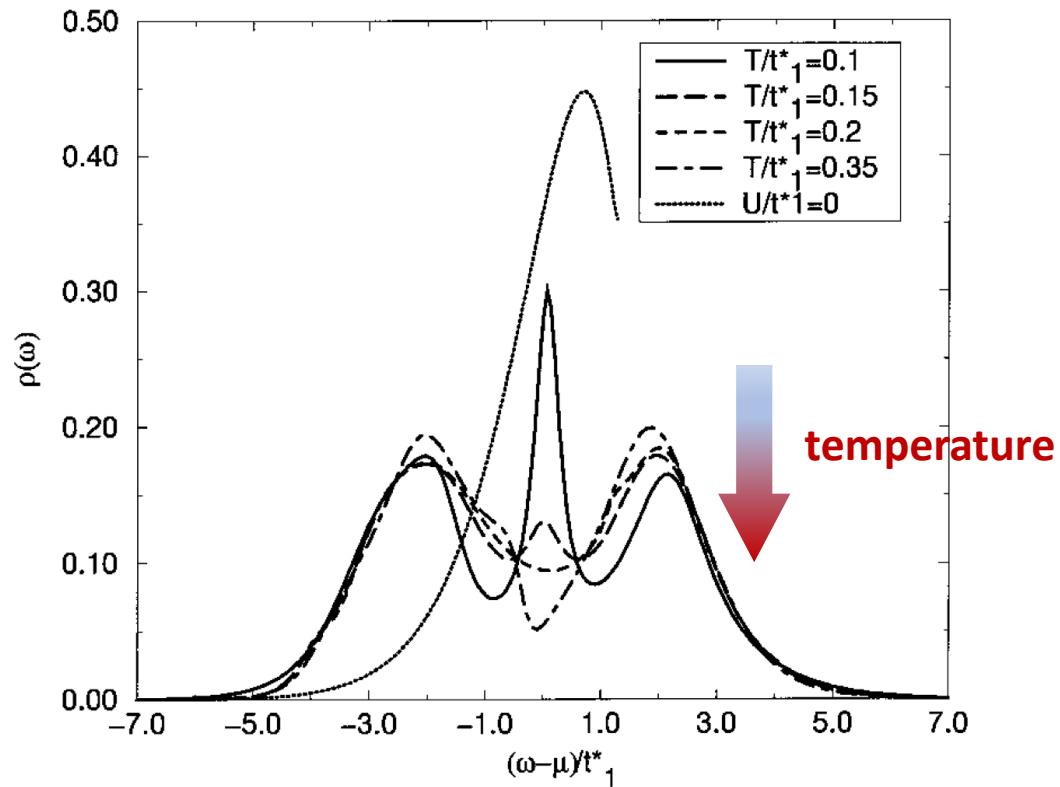


Cobaltates  
Valla,  
Nature 417 (2003)

$\text{Sr}_2\text{RuO}_4$   
Surface states  
Kondo,  
PRL 117, 247001 (2016)

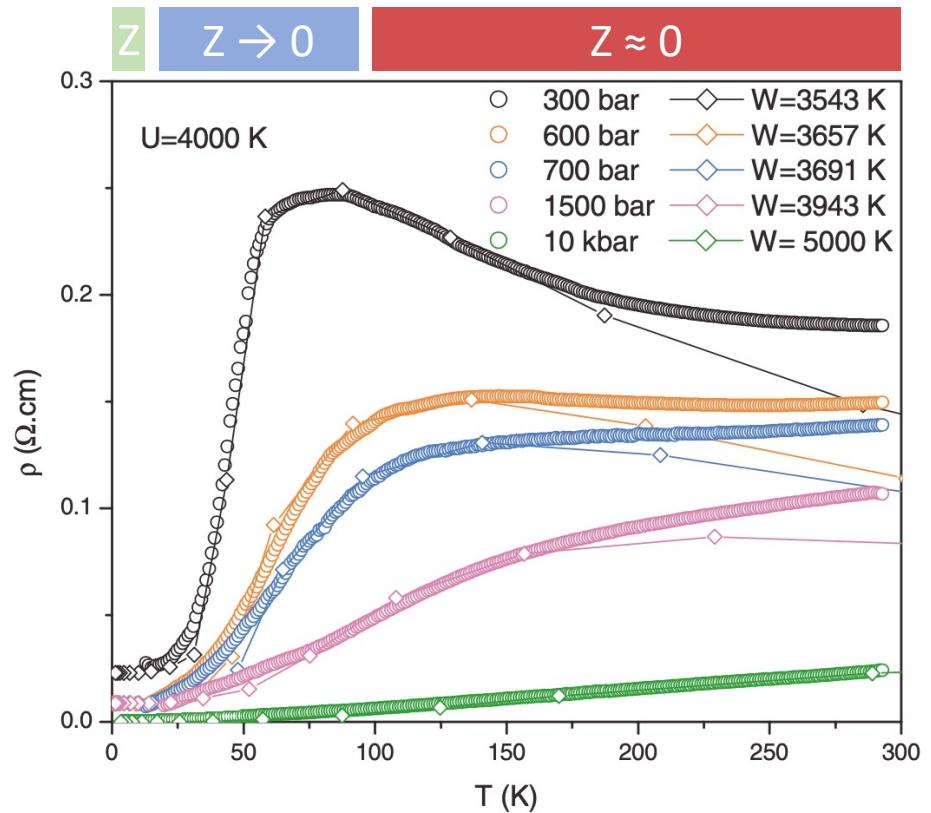


# Temperature dependence - previous studies



Half-filled Hubbard model, moderate U

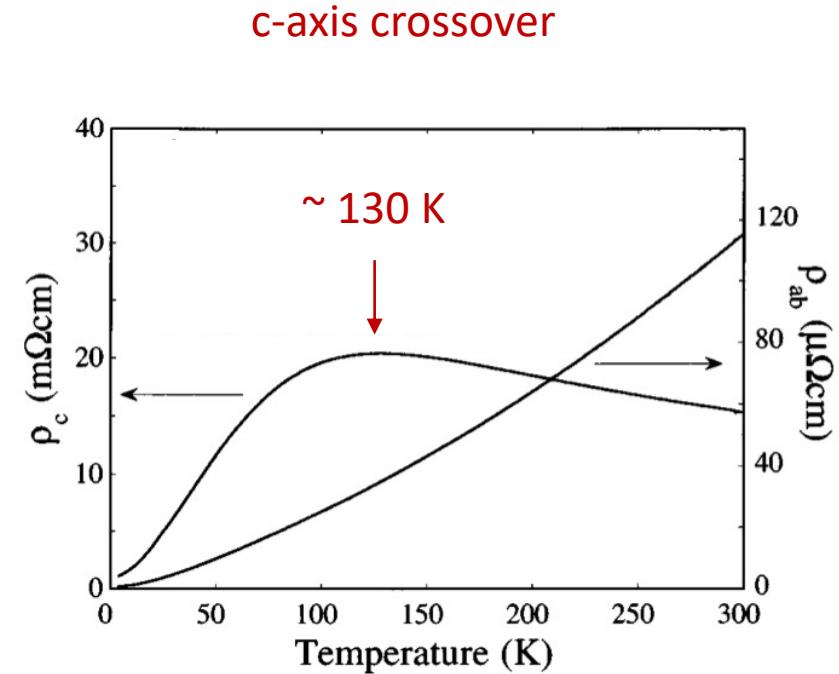
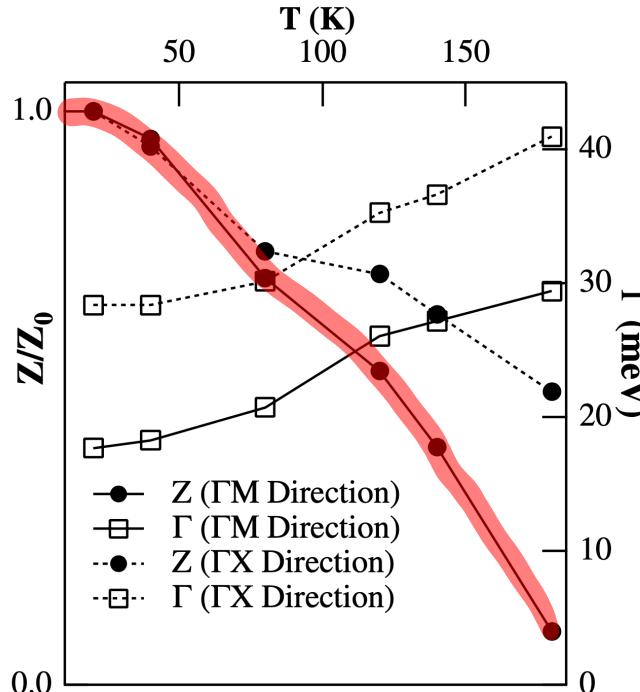
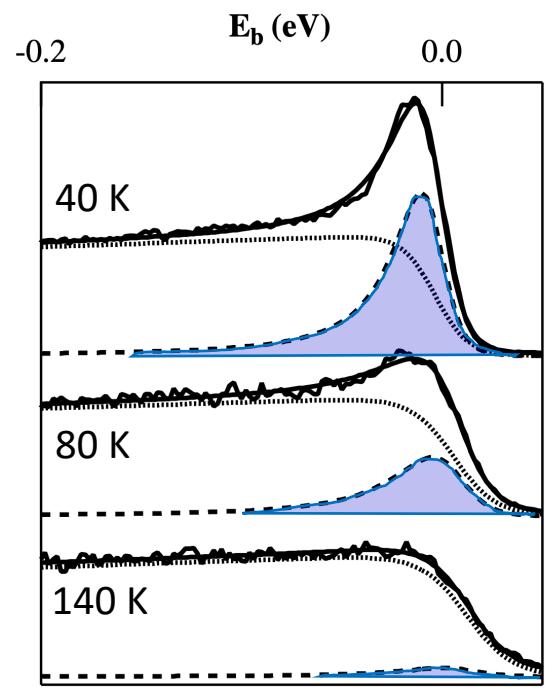
Merino and McKenzie, PRB 61 7996 (1999)



$\kappa$  - $(\text{BEDT-TTF})_2\text{Cu}[\text{N}(\text{CN})_2]\text{Cl}$

Limelette et al., PRL 91 016401 (2003)

# Temperature dependence - previous studies



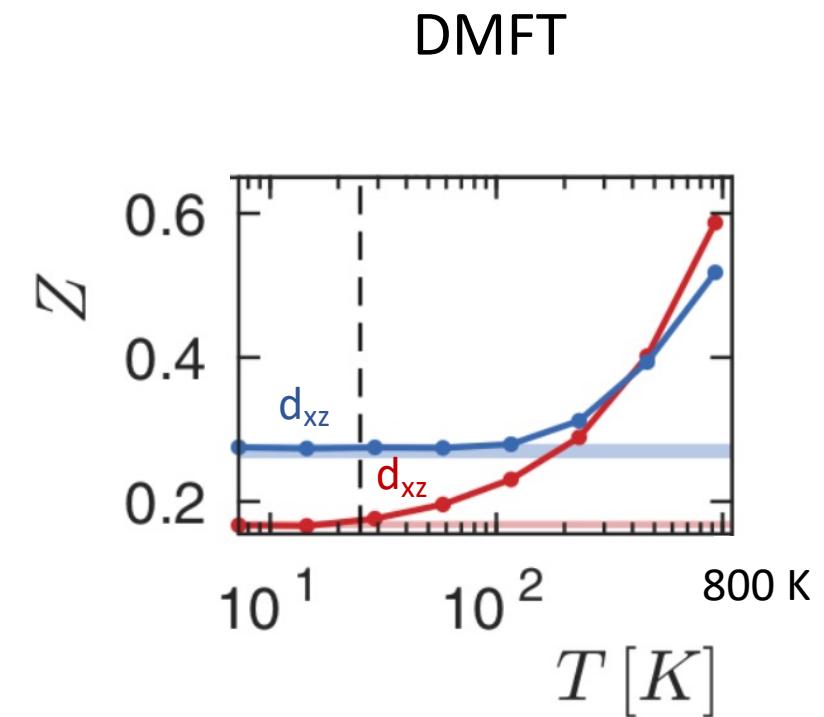
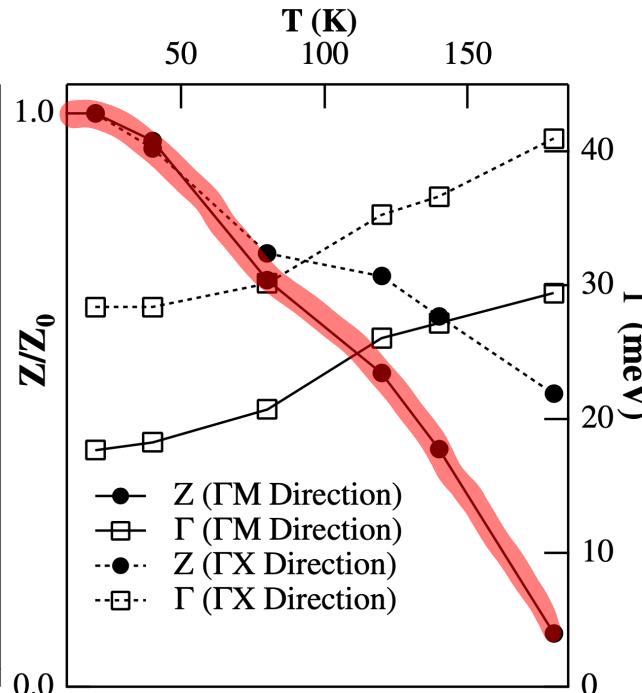
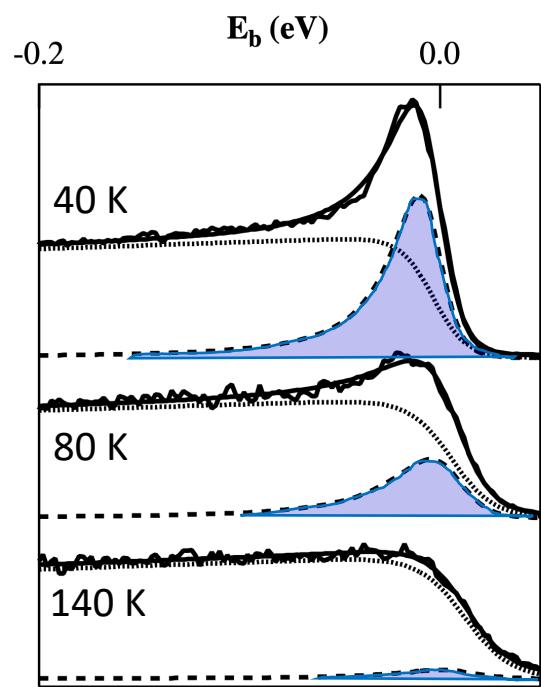
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N.E. Hussey, PRB 57, 5505 (1998)

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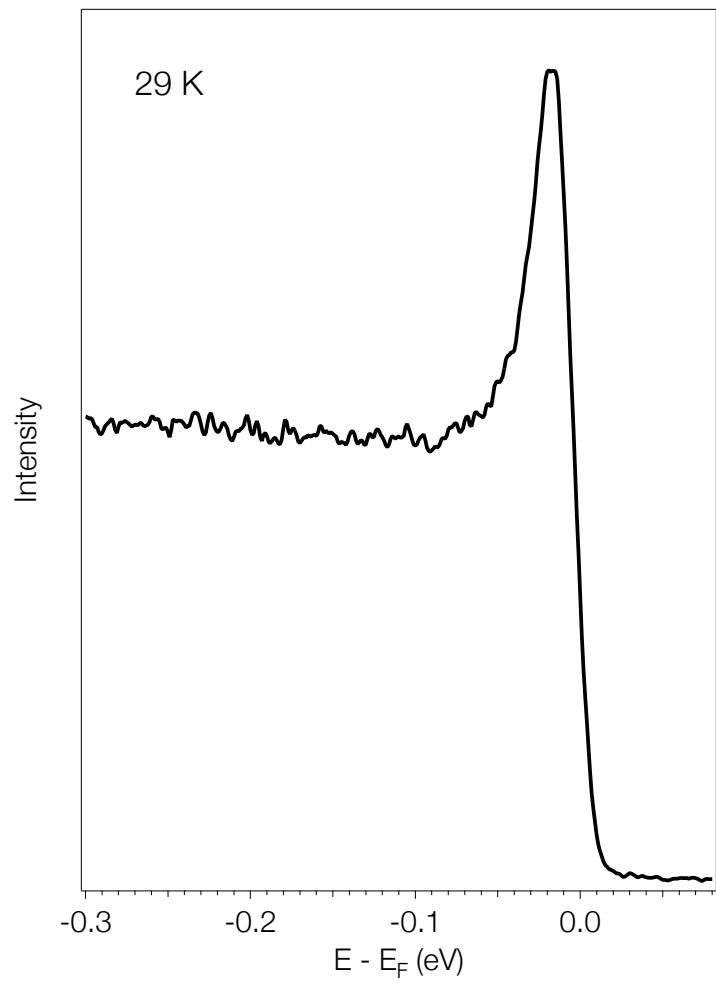
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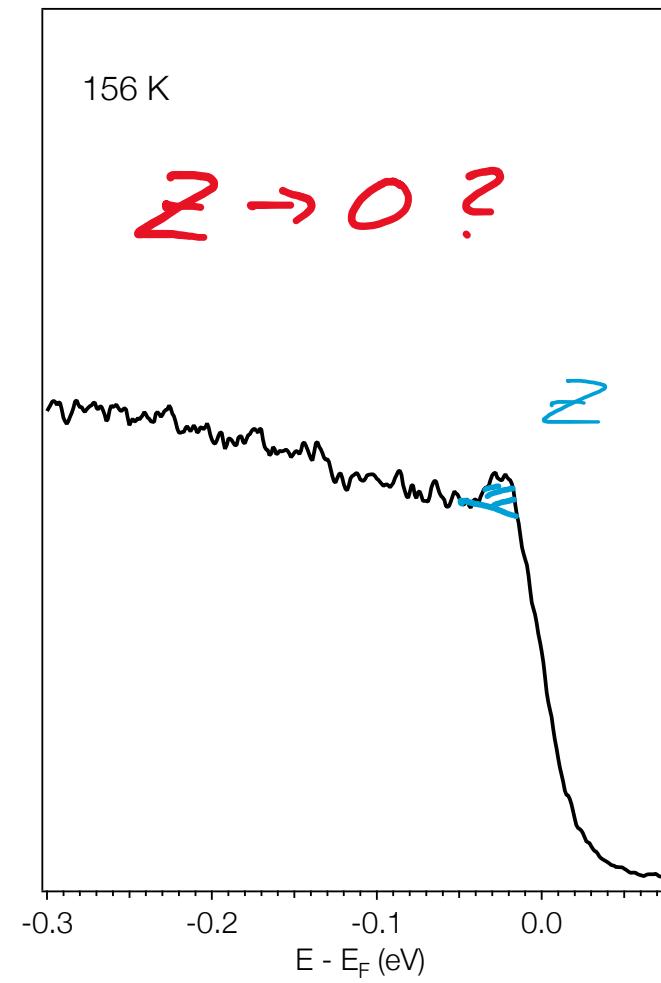
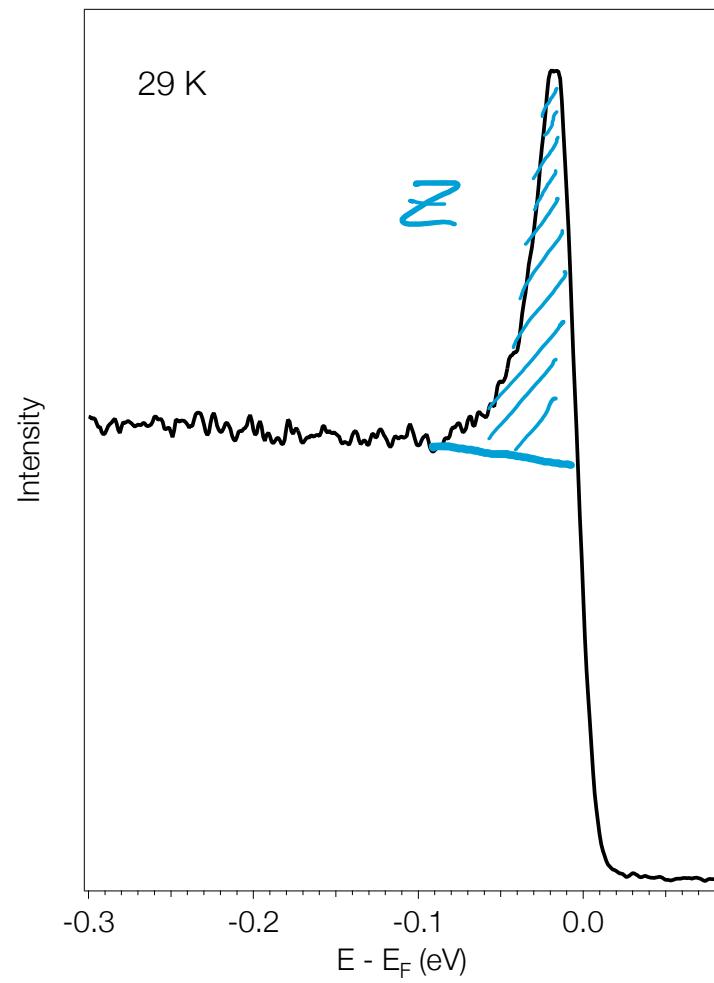
F. Kugler, PRL 124 16401 (2020)  
J. Mravlje, PRL 106 096401 (2011)

?

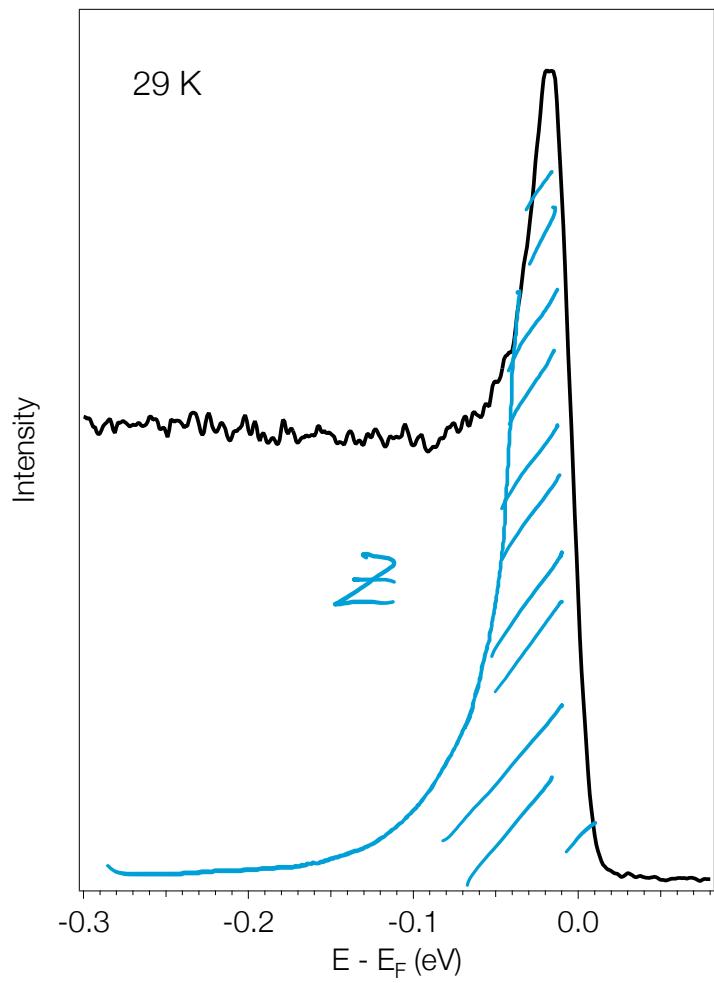
# New data



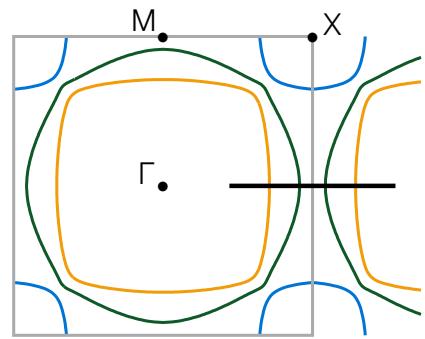
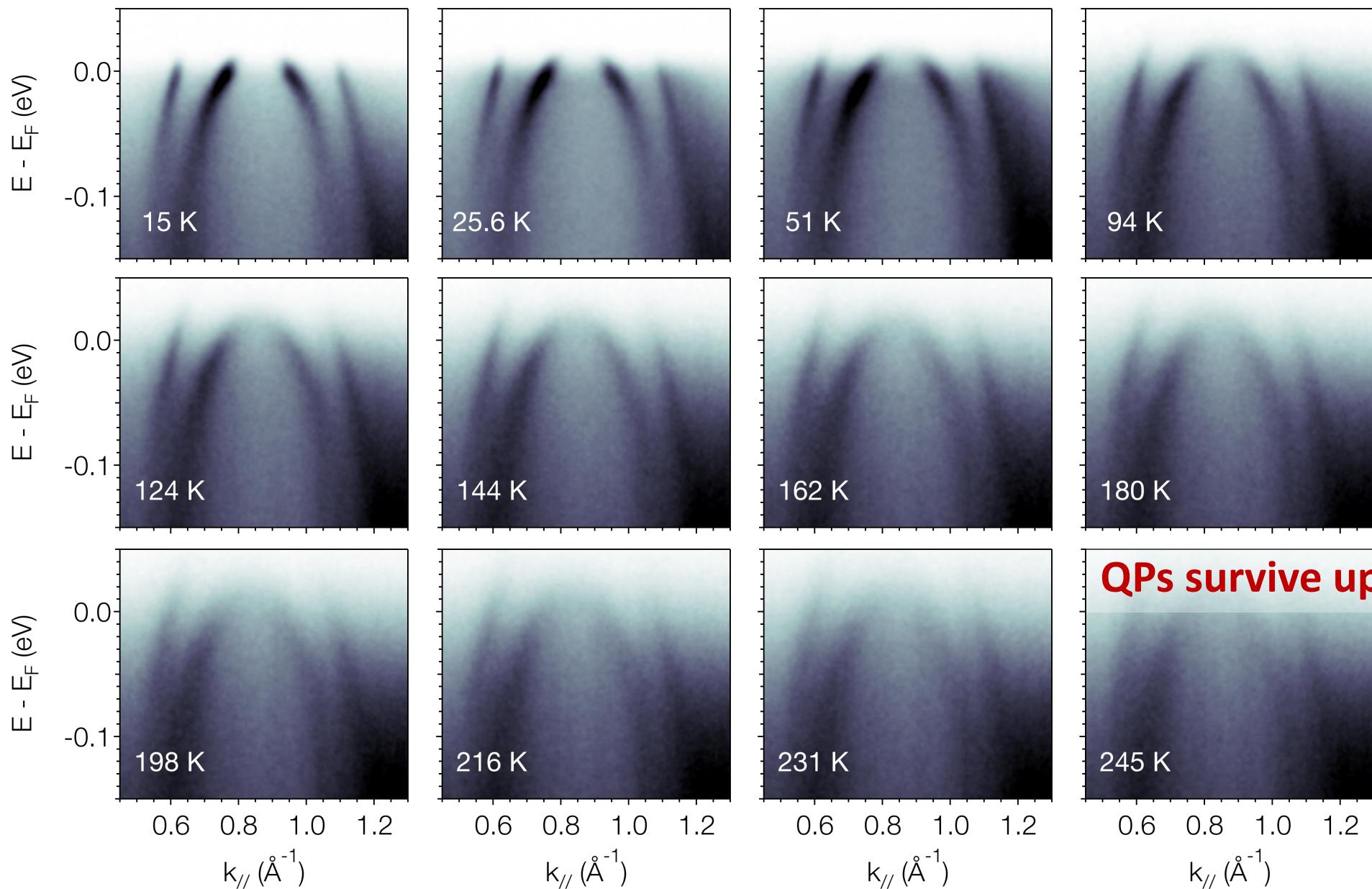
# Spectral weights



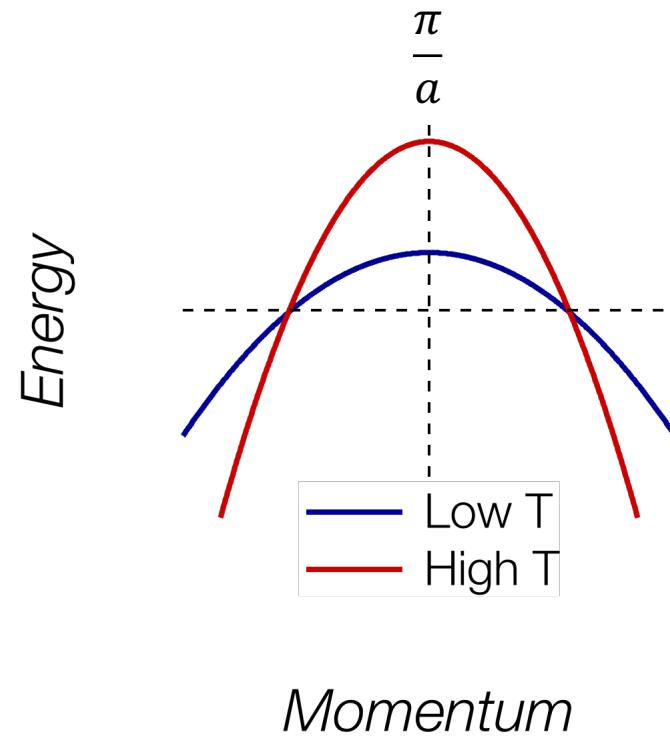
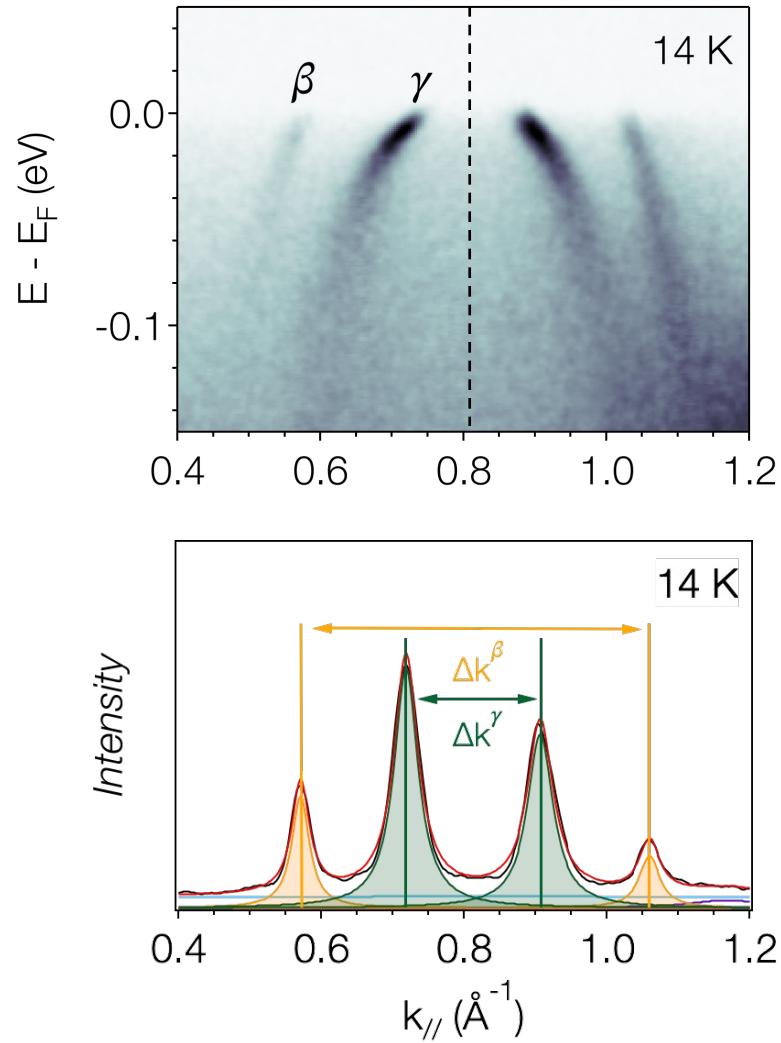
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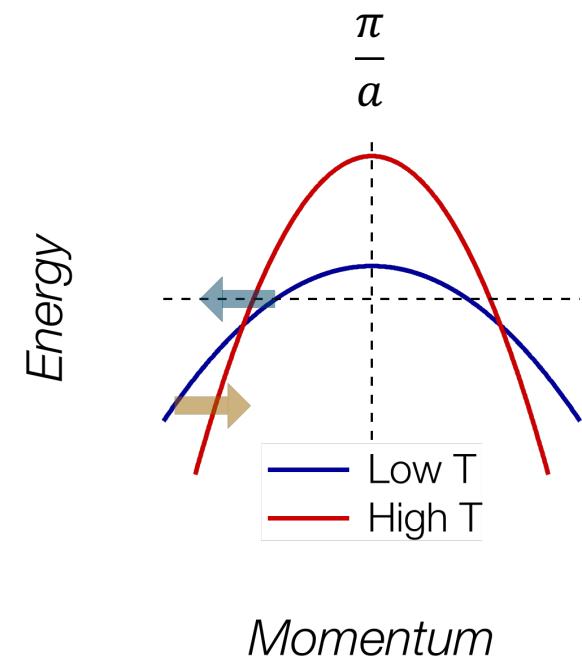
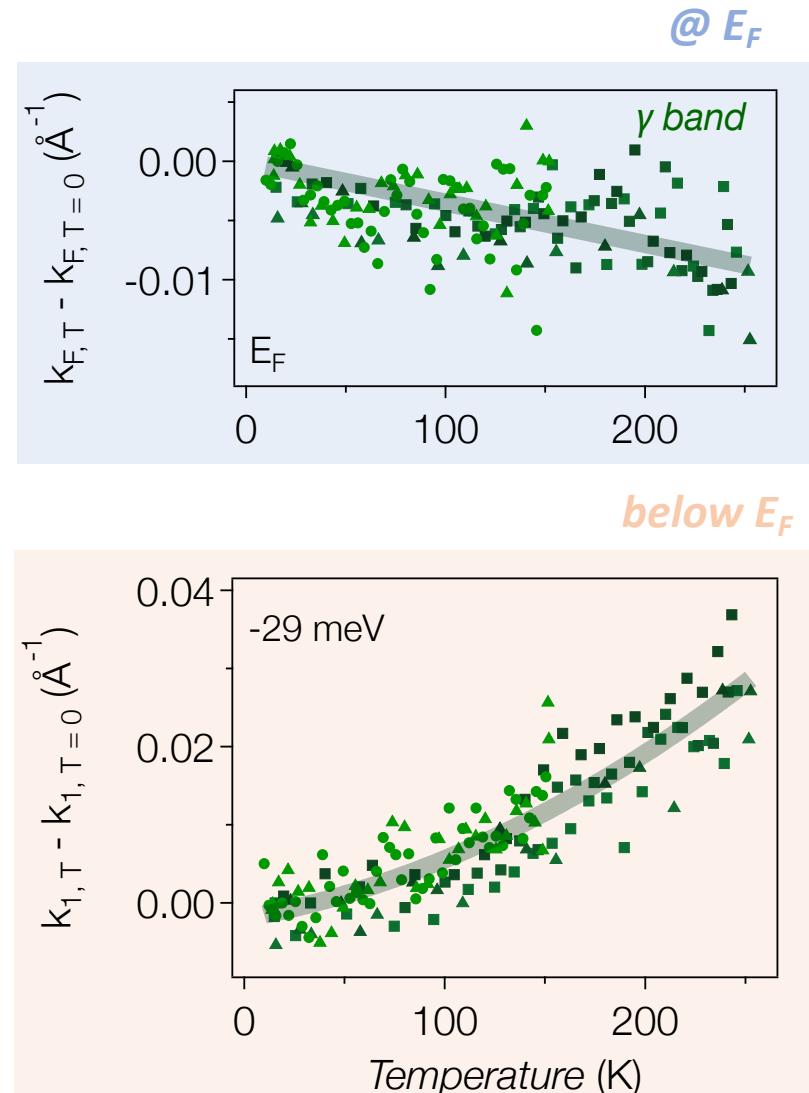
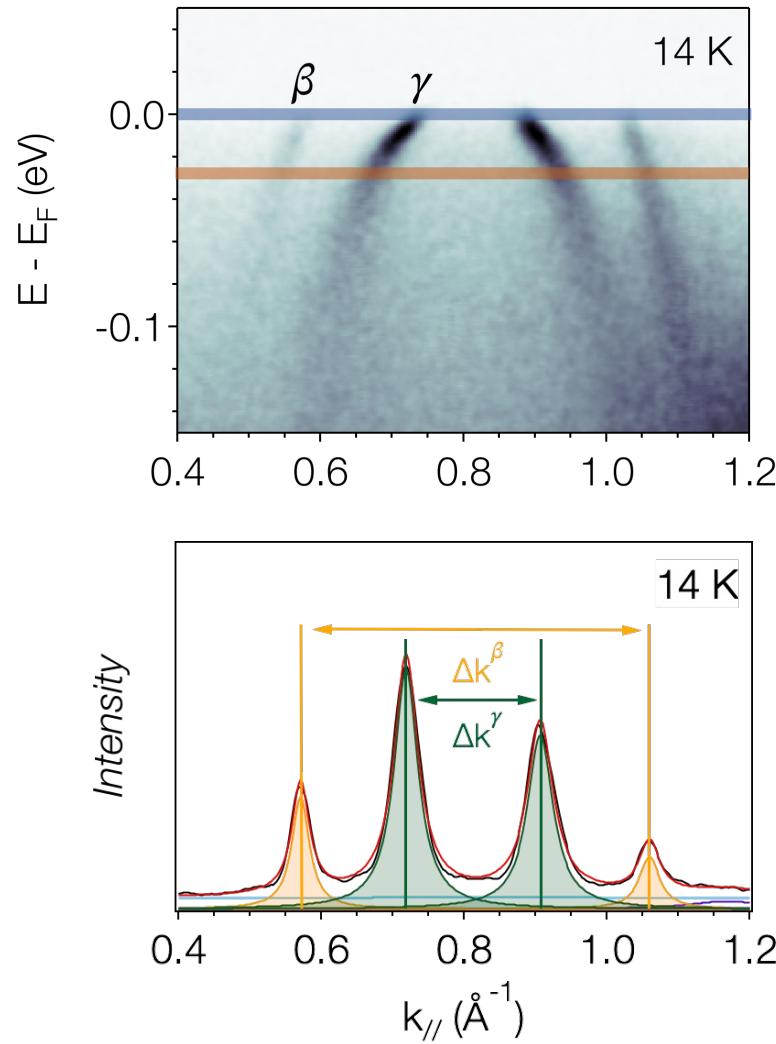
# Temperature dependent ARPES



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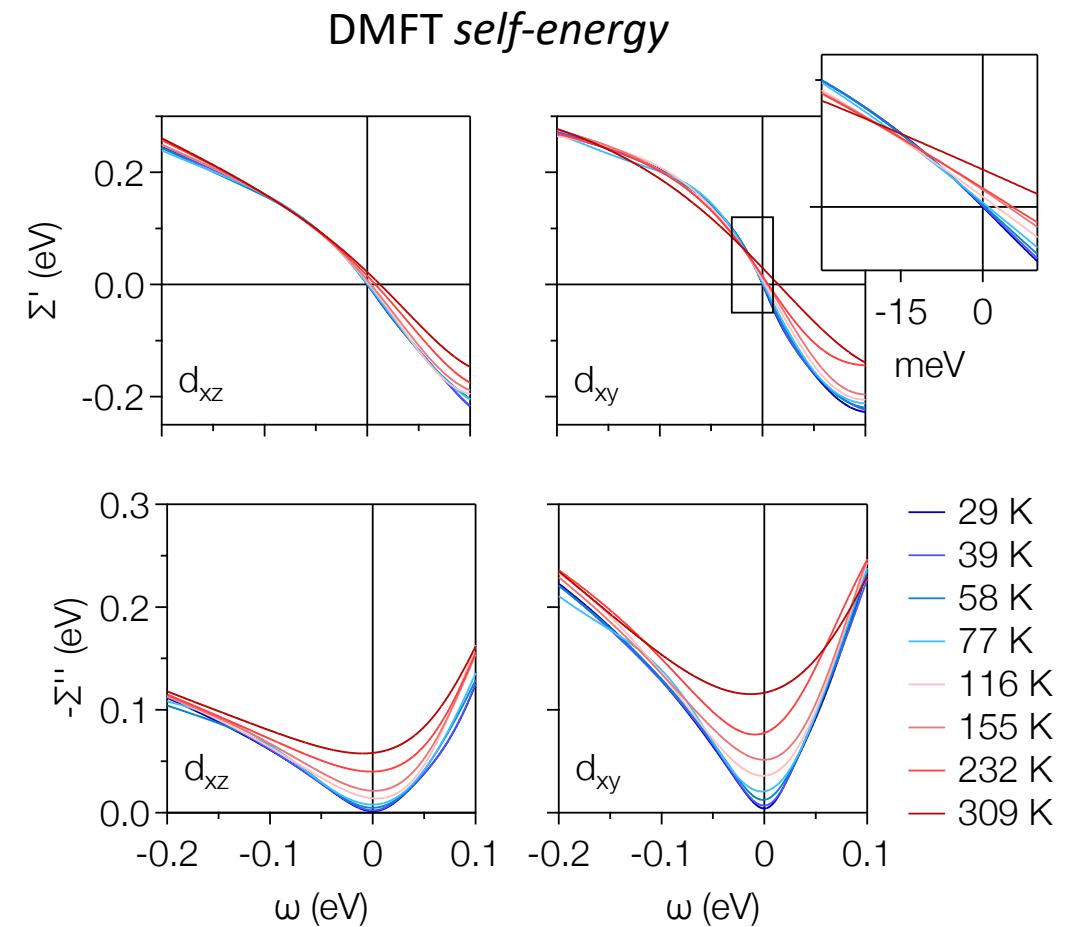
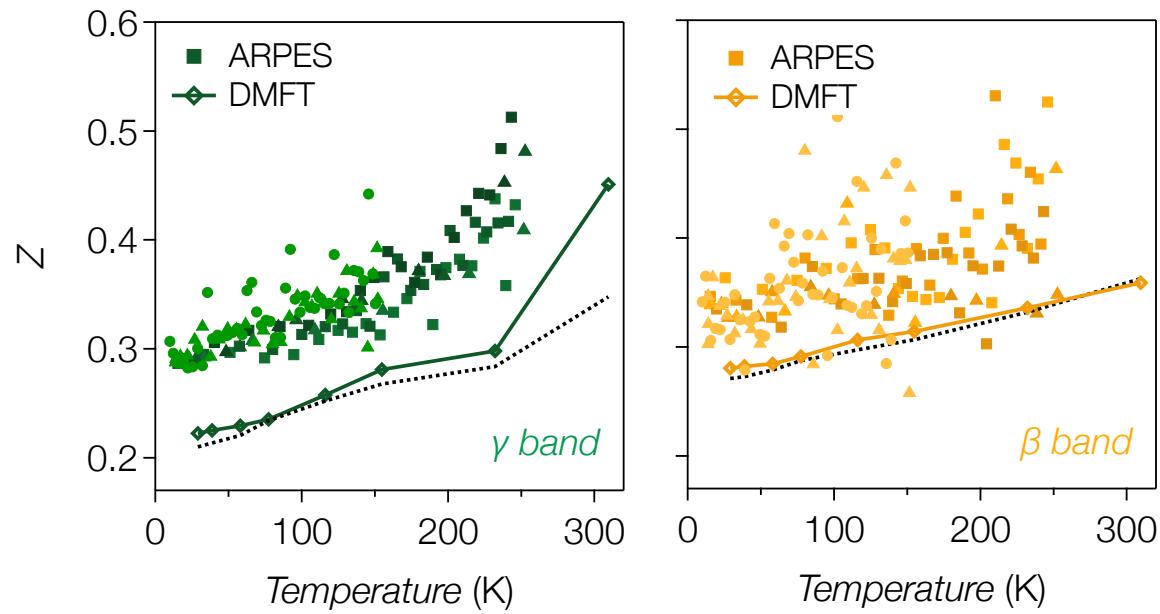


# Temperature dependent ARPES

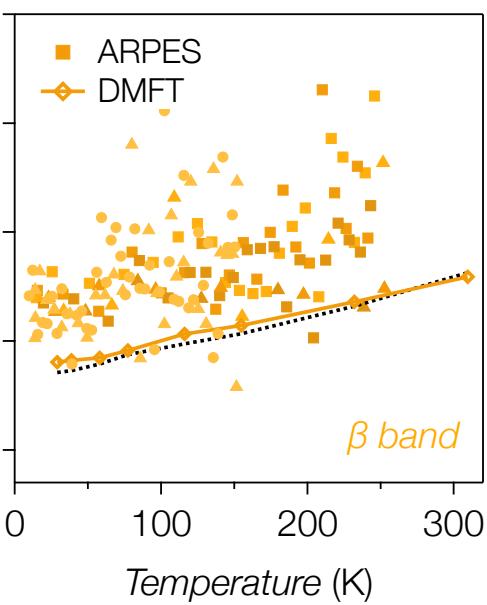
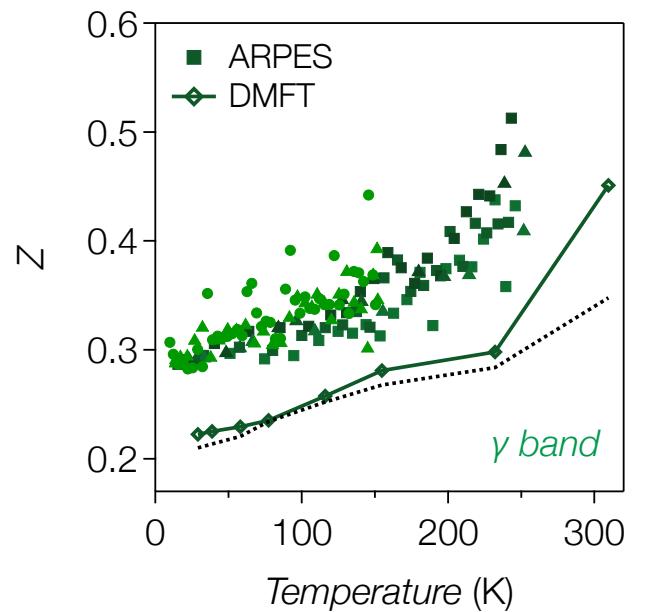


# QP residue $Z$

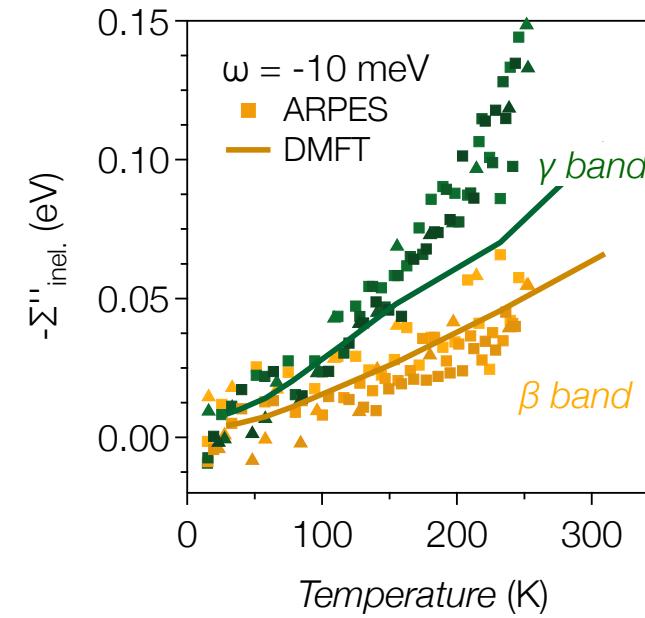
$$Z = \frac{v_F^*}{v_0} = \frac{m_0}{m^*}$$



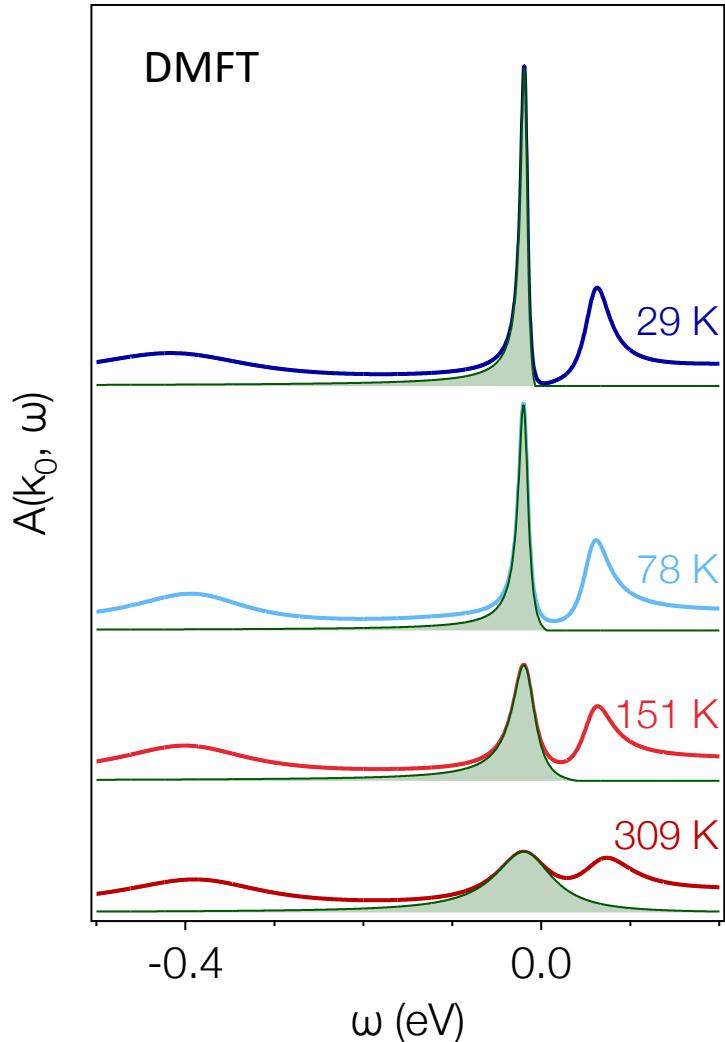
$$Z = \frac{v_F^*}{v_0} = \frac{m_0}{m^*}$$



## Imaginary part $\Sigma''$

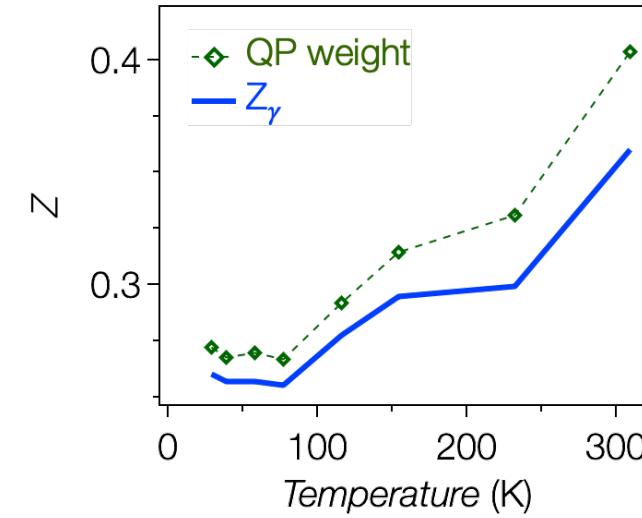


# Spectral weight vs temperature

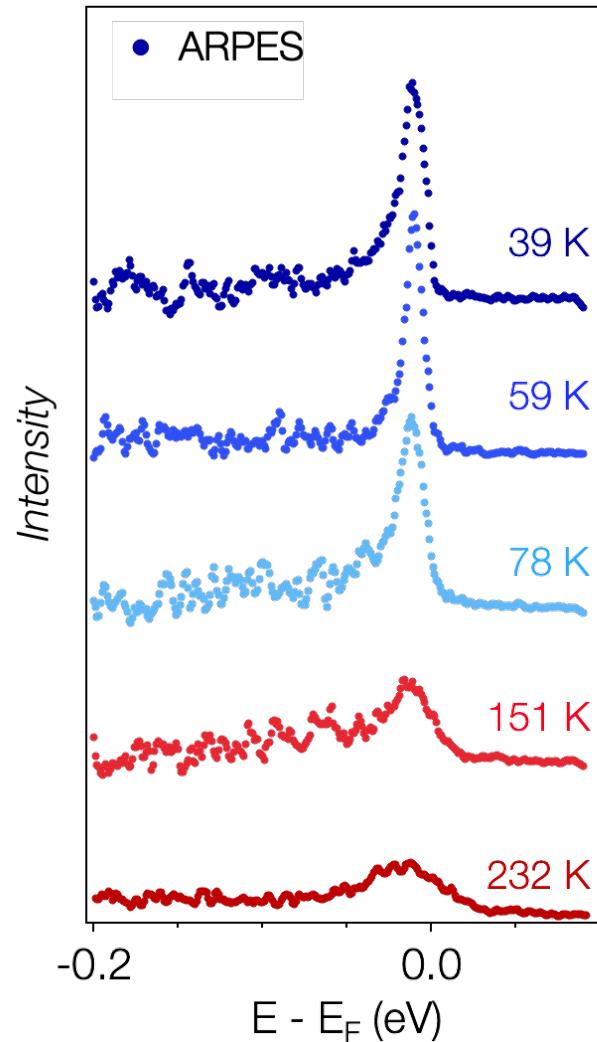
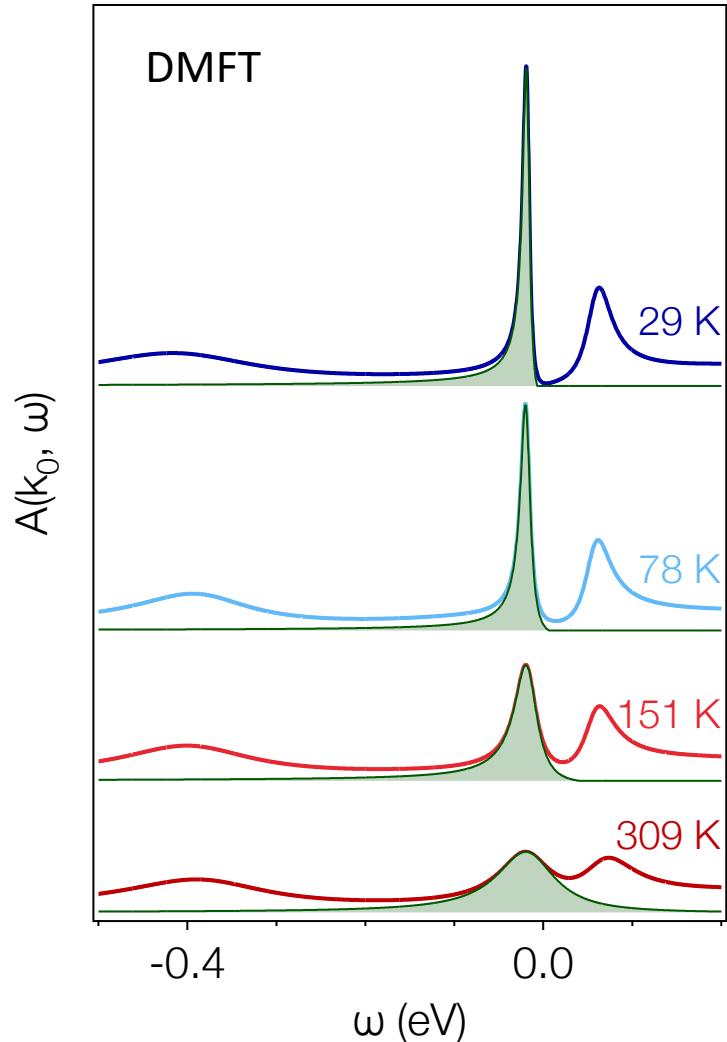


$$\text{QP weight} = \int A_{ch}(\omega) d\omega$$

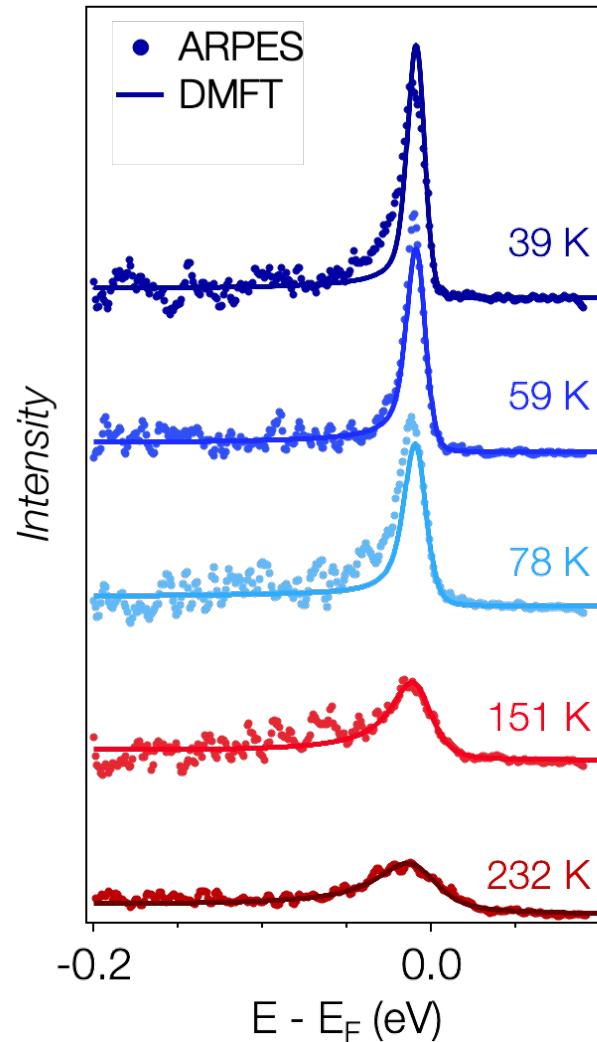
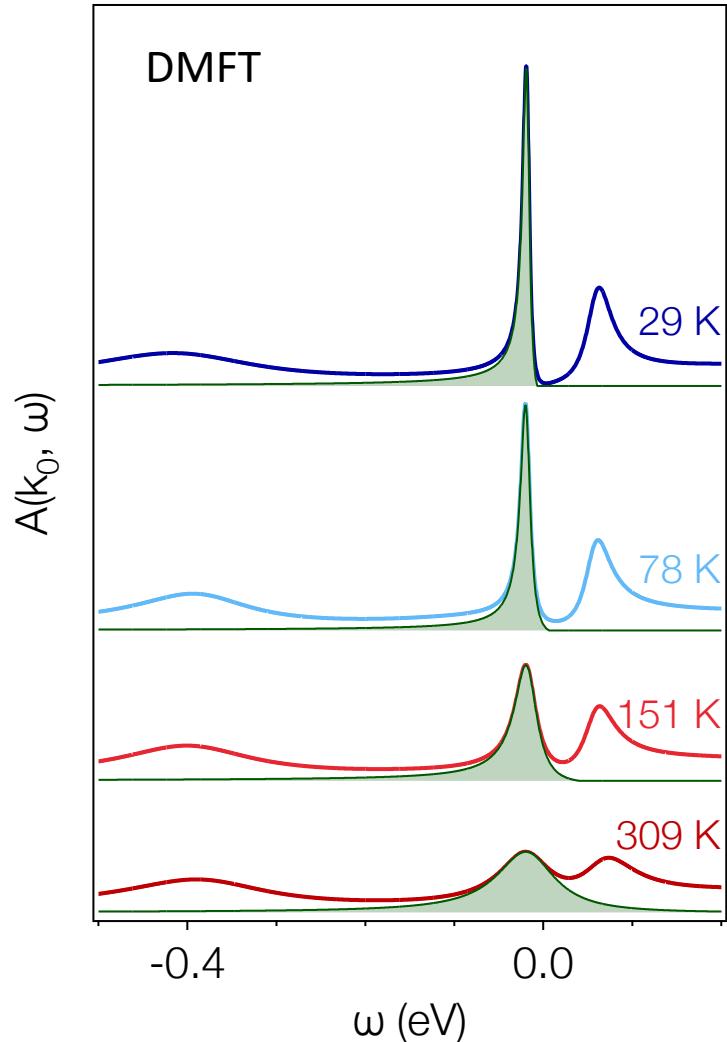
$$\frac{1}{Z_\gamma} = \sum_m \frac{1}{Z_m} |U_{m\nu}(\theta)|^2$$



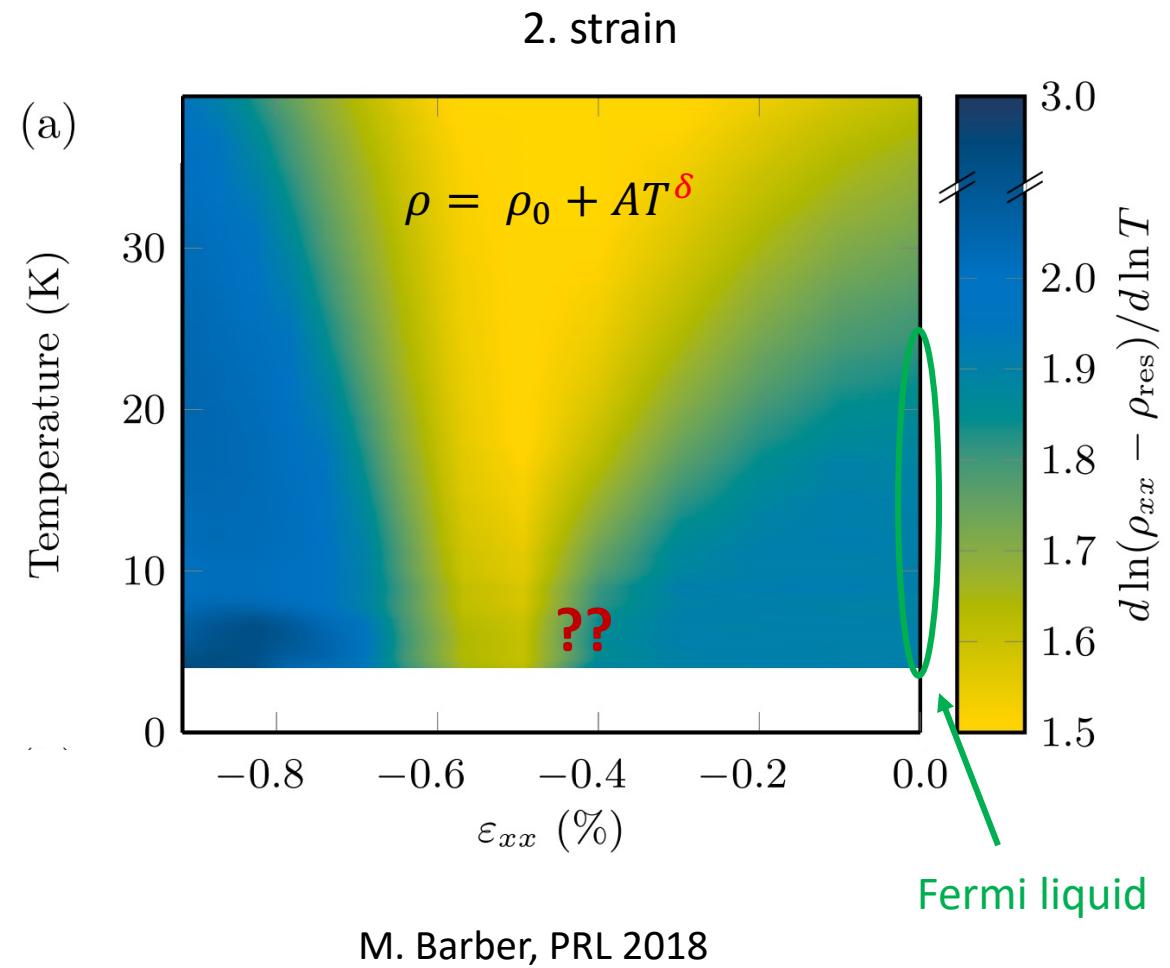
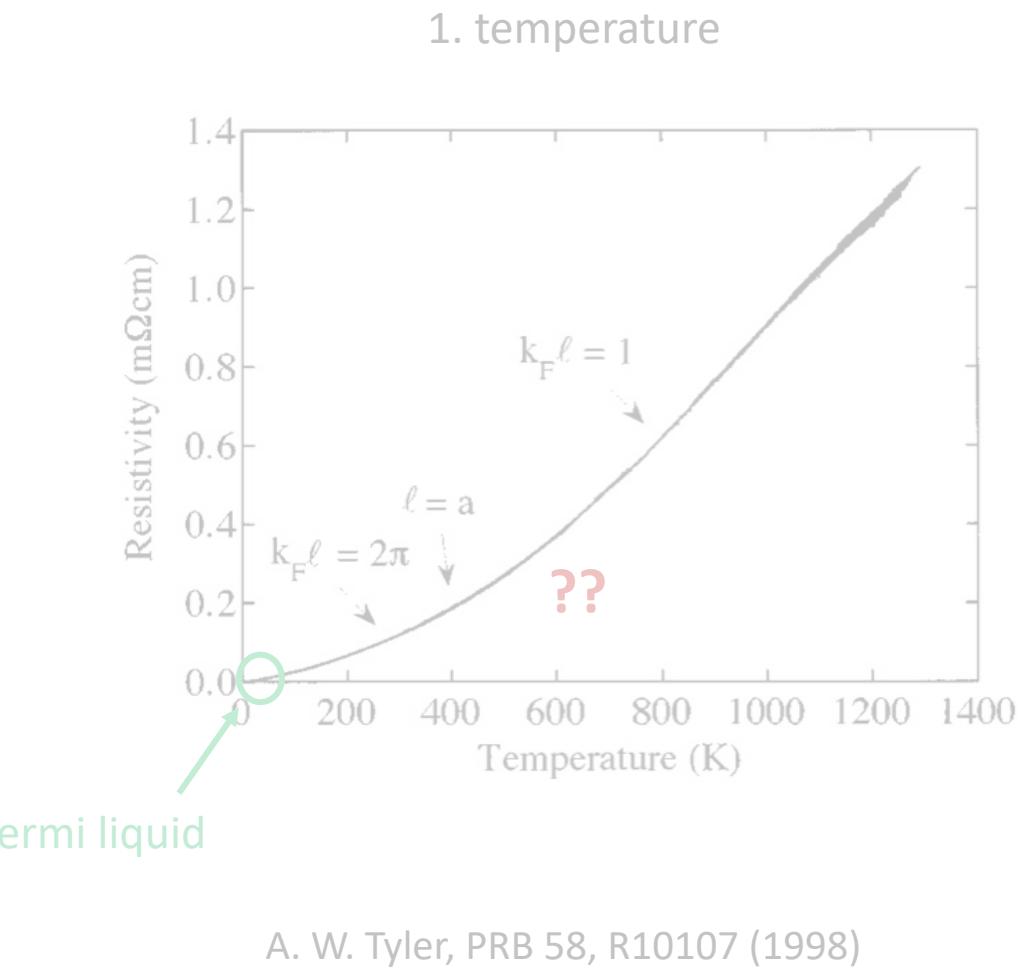
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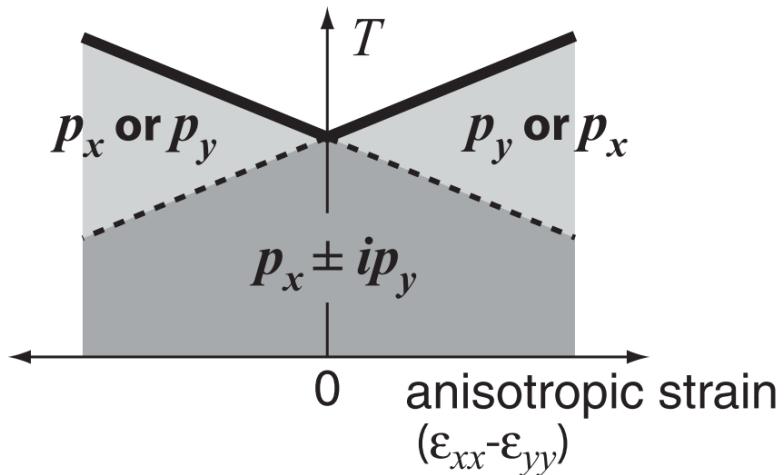
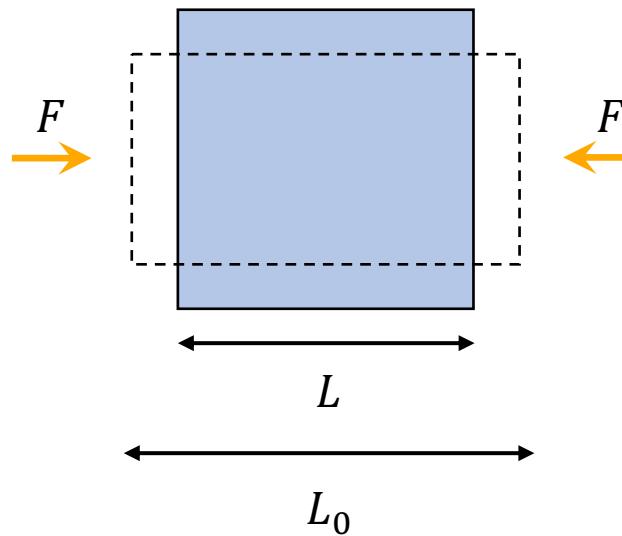


# Menu of the talk

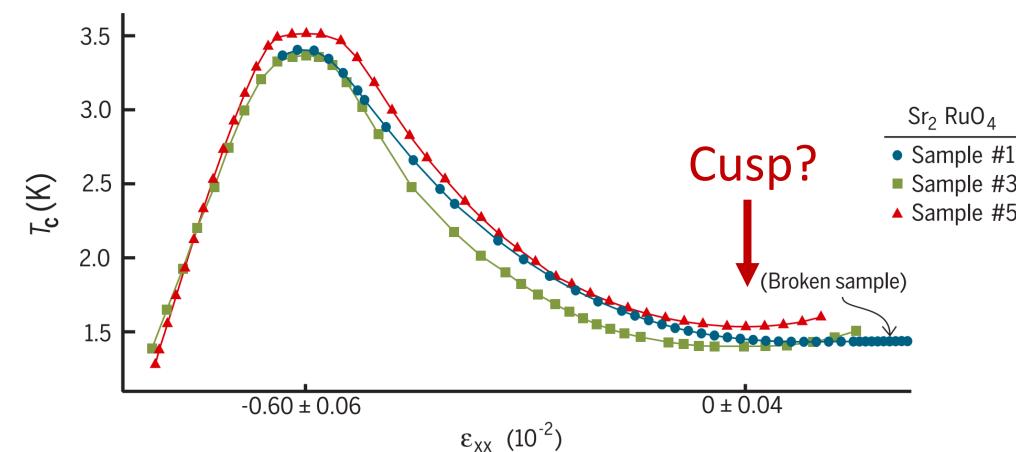


# $\text{Sr}_2\text{RuO}_4$ under uniaxial-strain

$$\varepsilon = \frac{L - L_0}{L_0}$$



C. Hicks, Science 2014

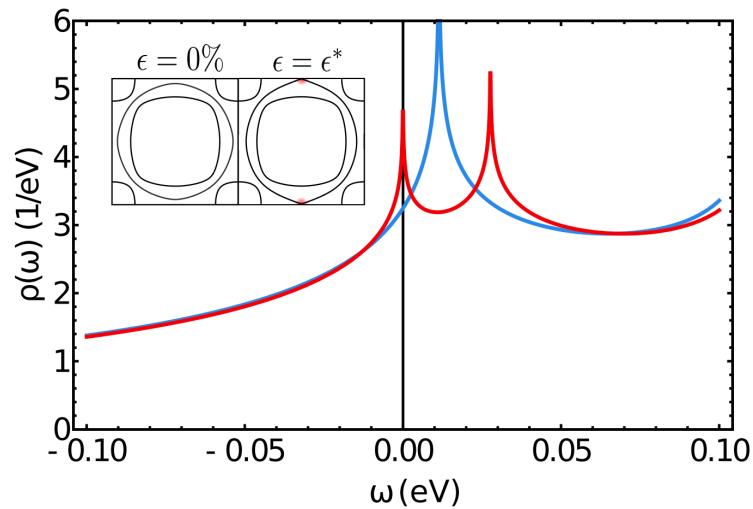


A. Steppke, Science 2017

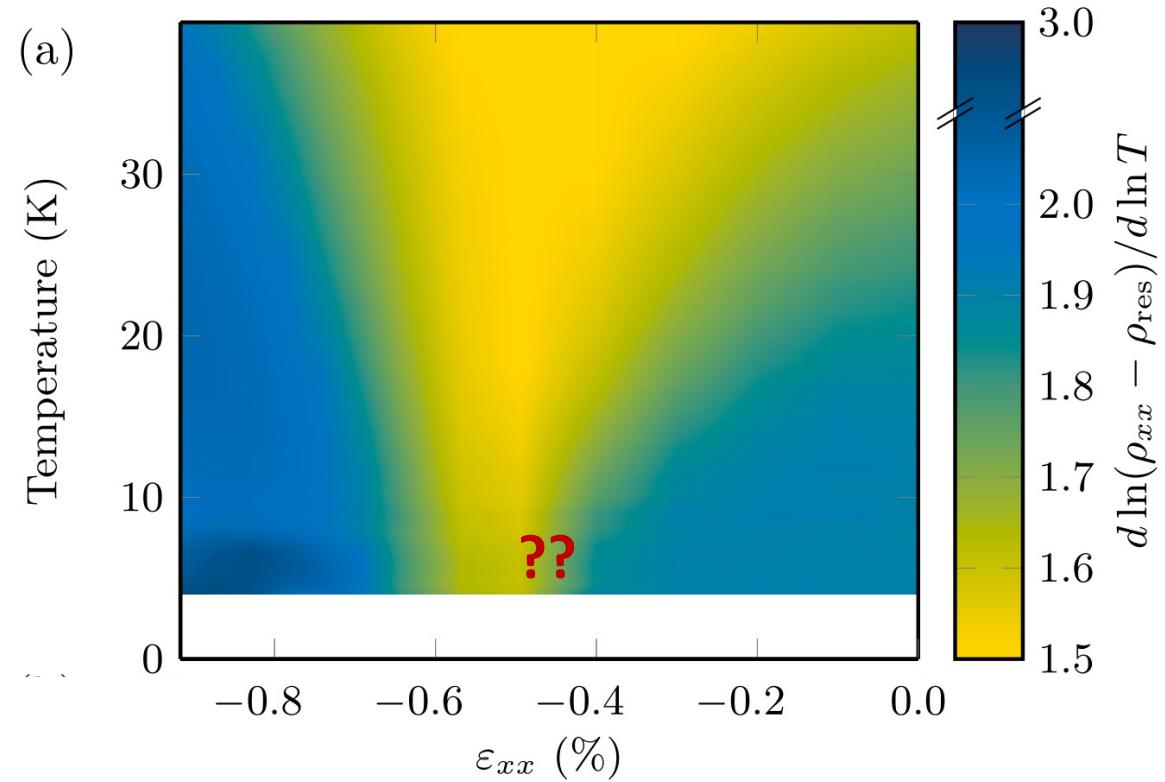
# $\text{Sr}_2\text{RuO}_4$ under uniaxial-strain

- Peaked  $T_c$  appears to coincide with non-FL
- vHs enhanced correlations?

V. Stangier,  
PRB 105 (2022)



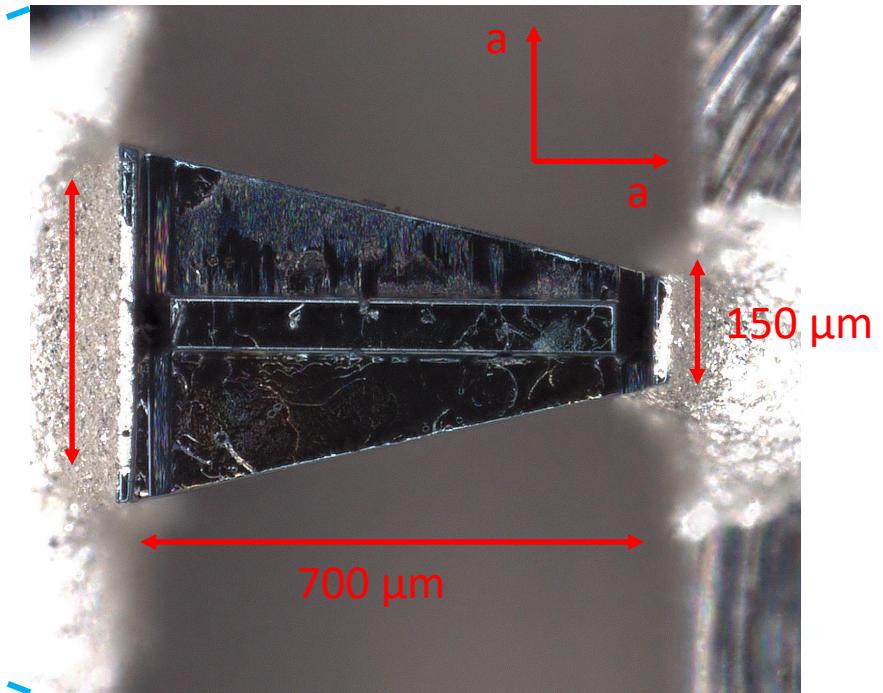
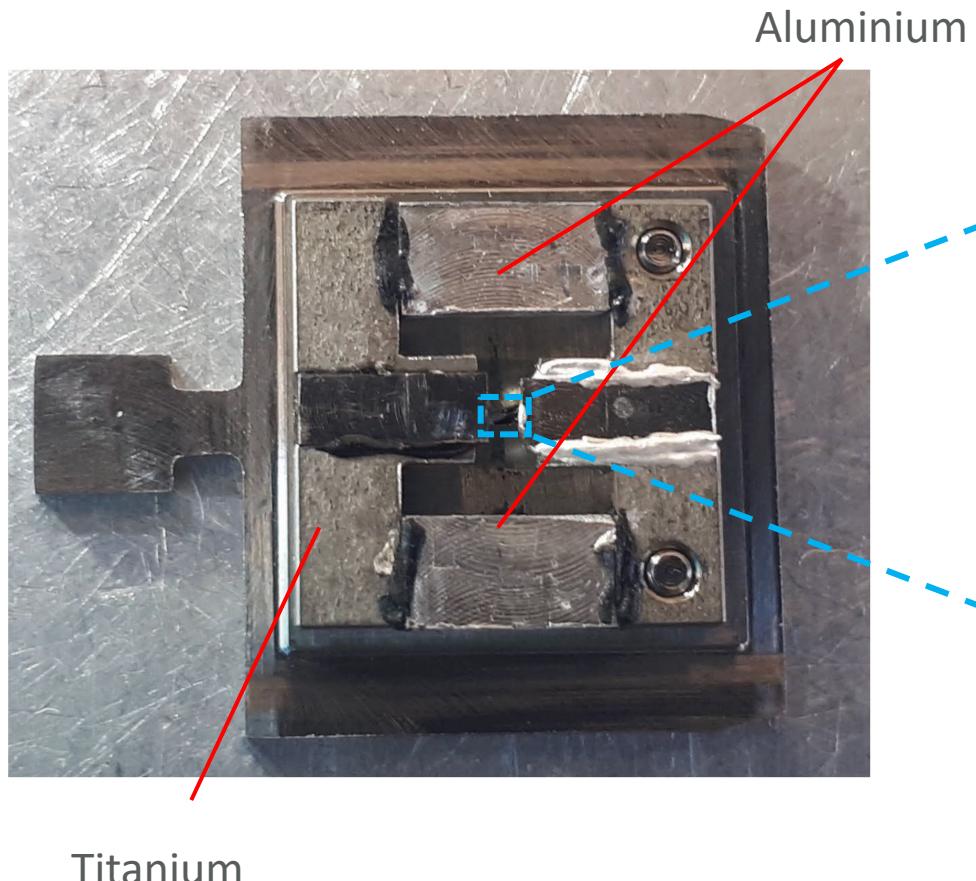
$$\rho = \rho_0 + AT^\delta$$



M. Barber, PRL 2018

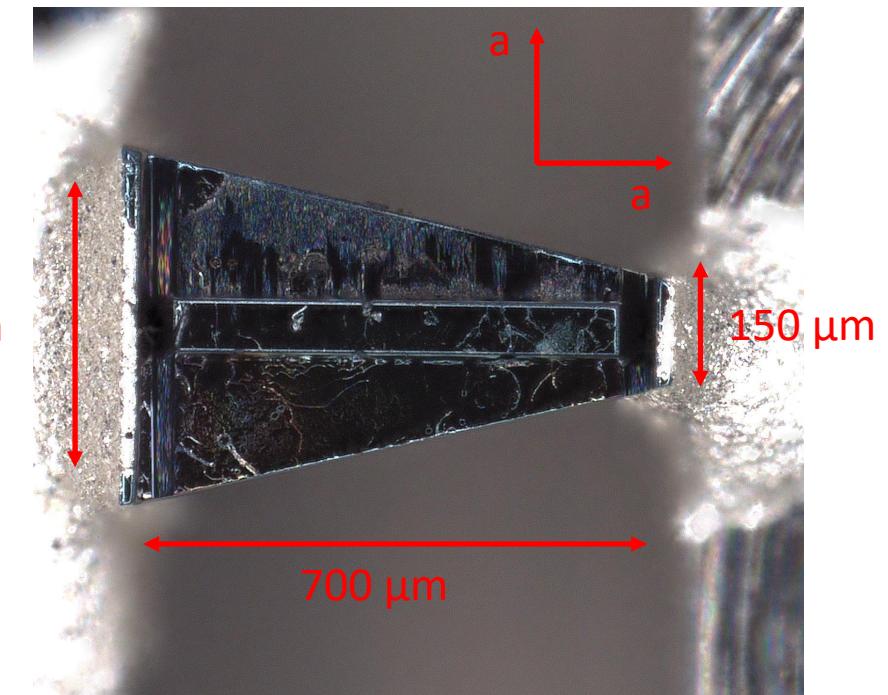
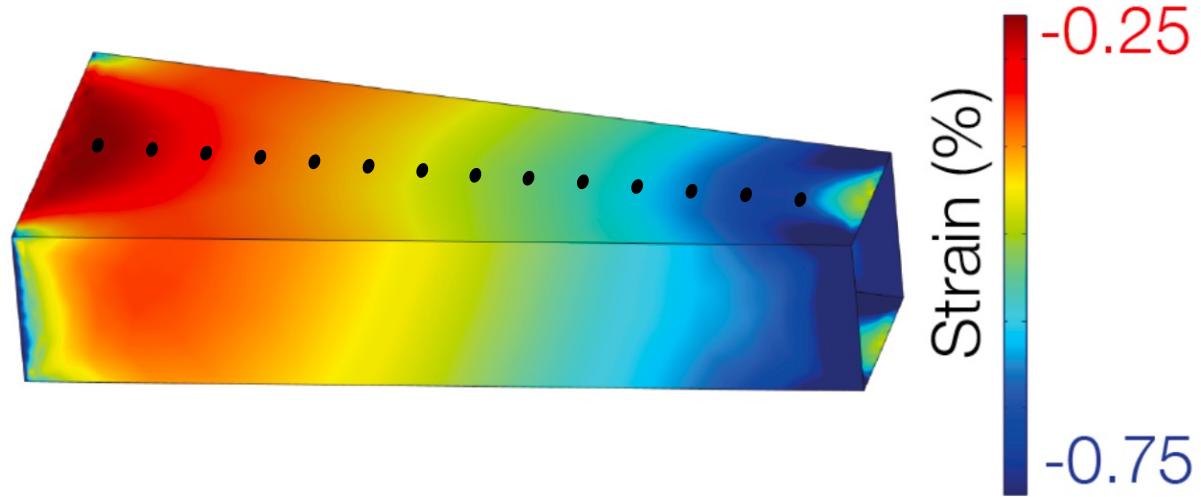
# Our new approach

$$\varepsilon = \frac{F}{A E_Y}$$

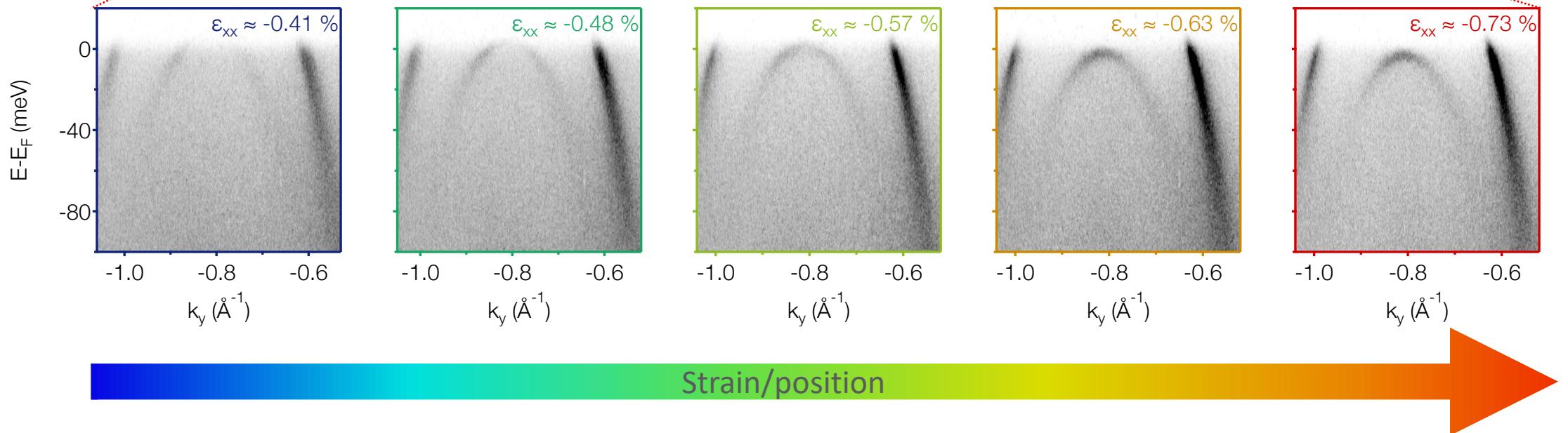
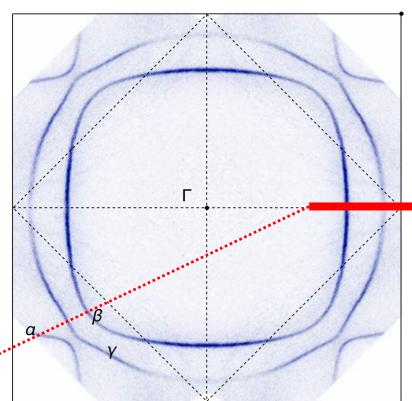
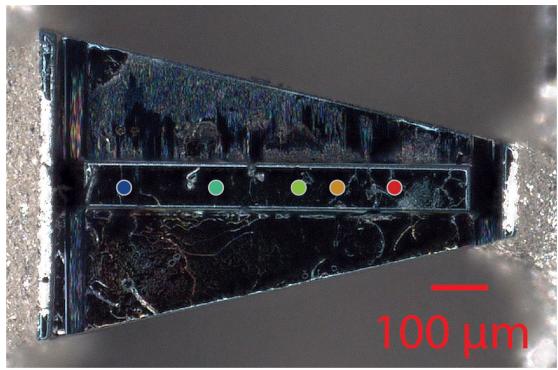


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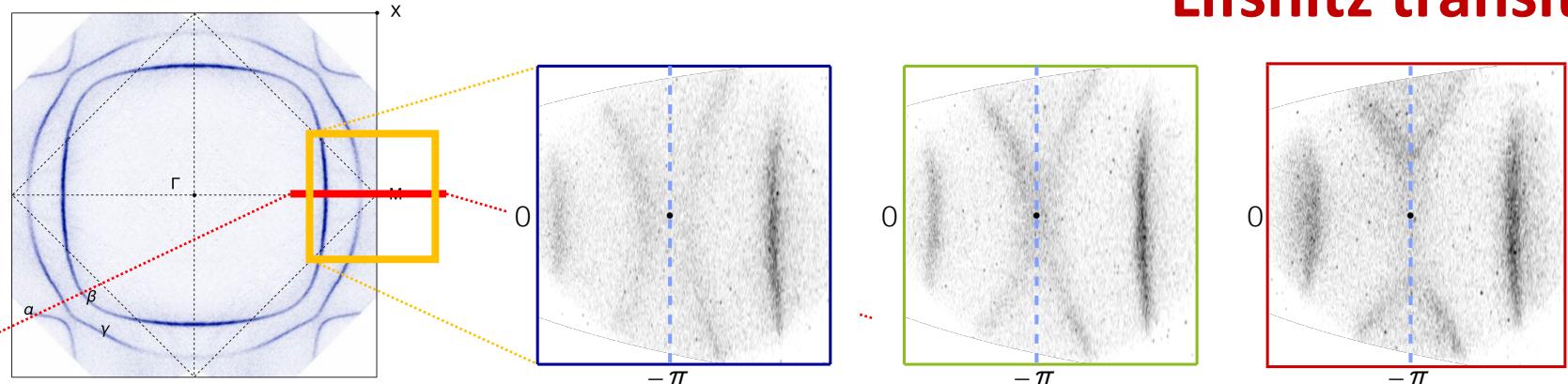
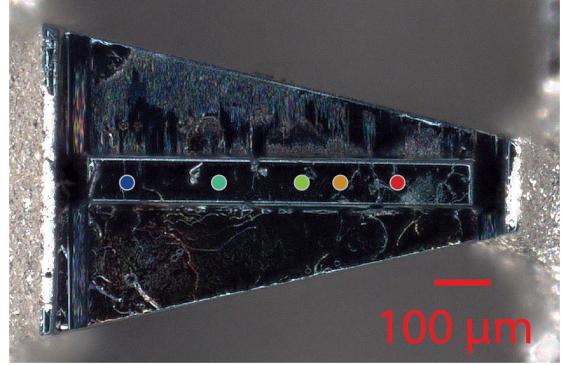
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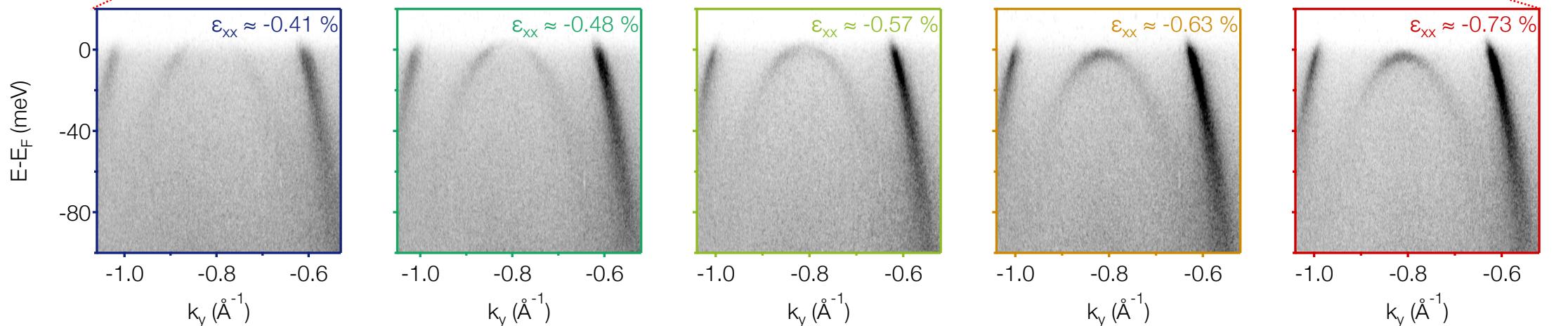
# Strain dependent ARPES



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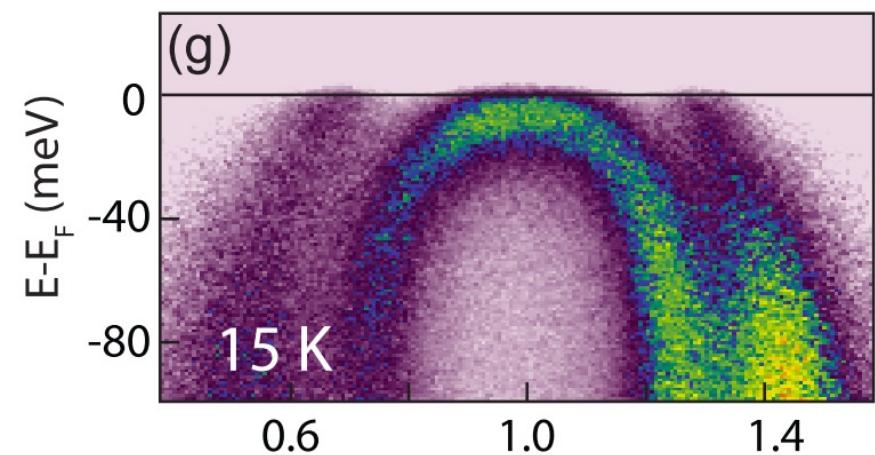


Lifshitz transition



Strain/position

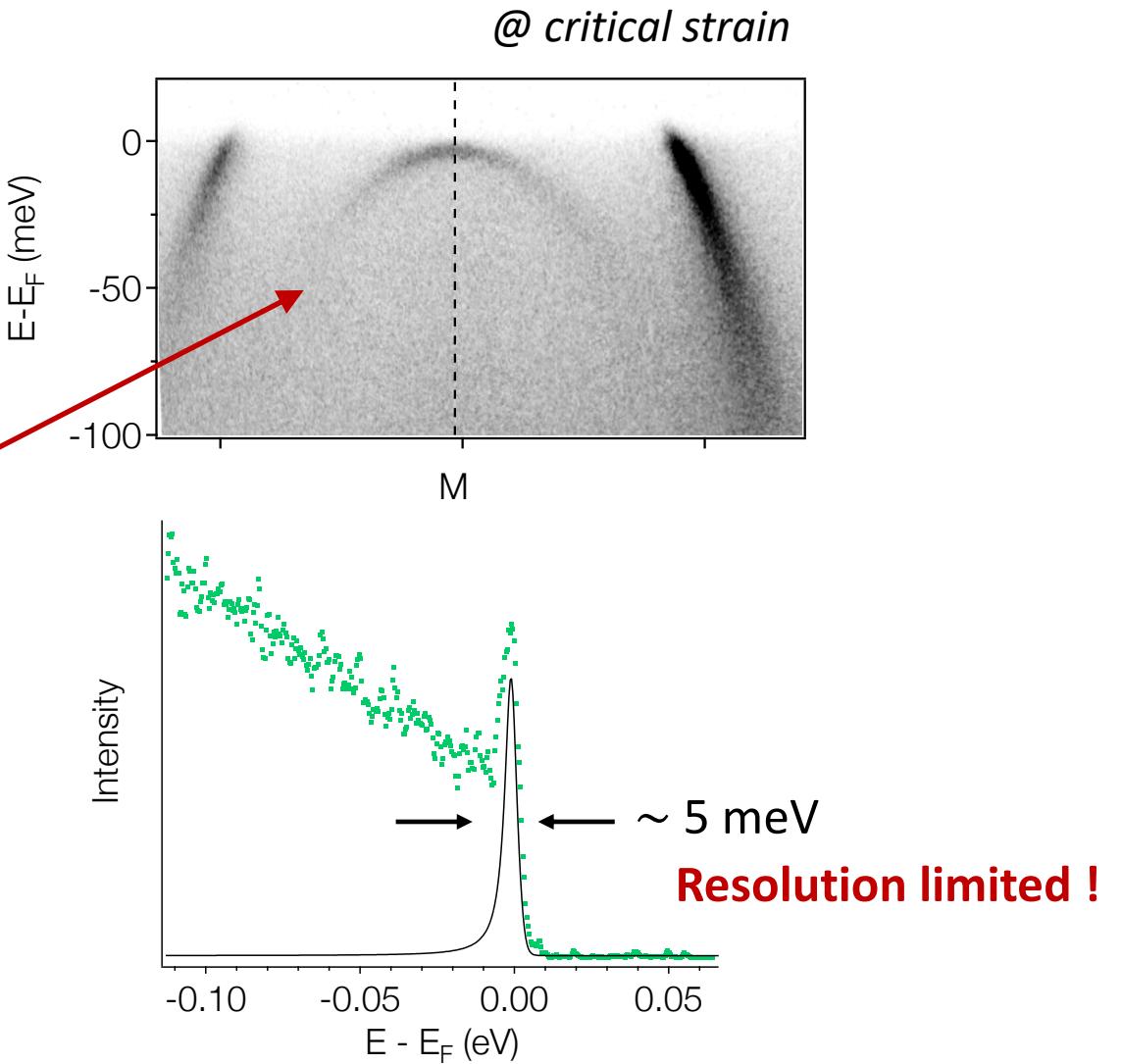
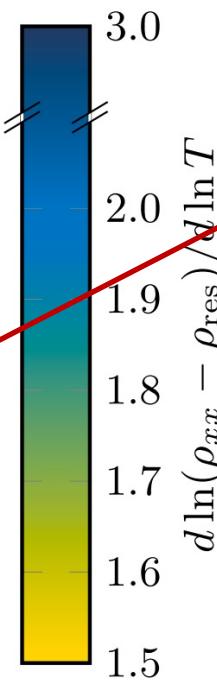
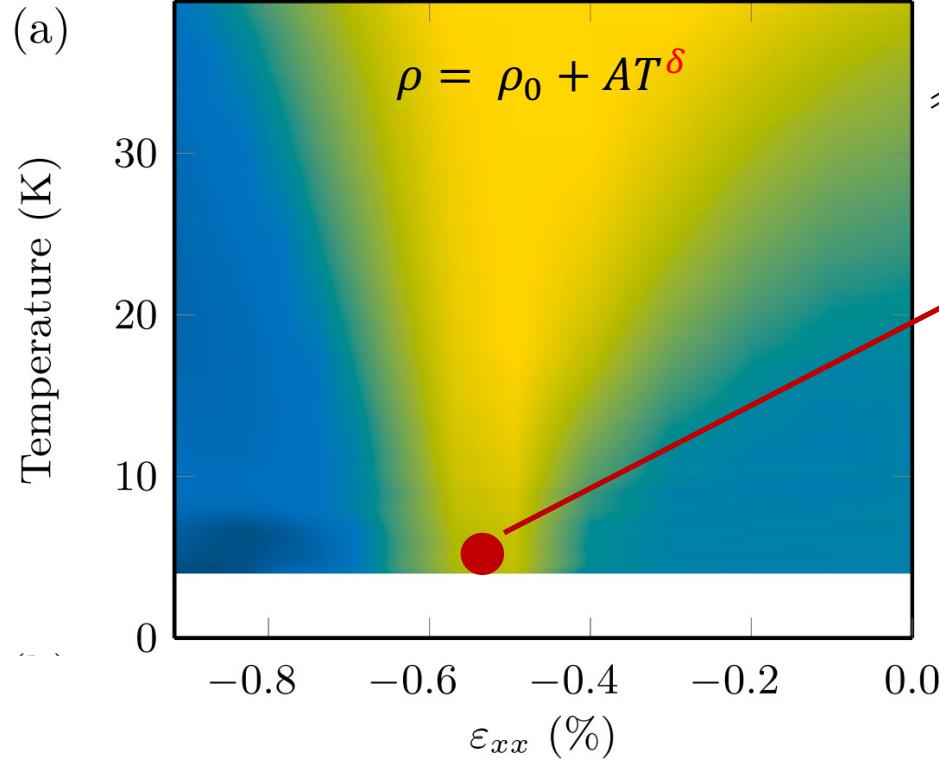
Epitaxially strained film



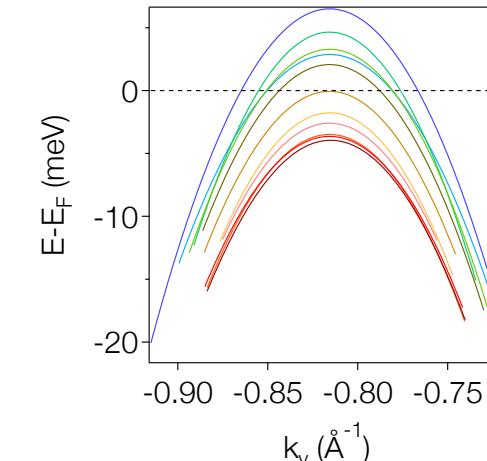
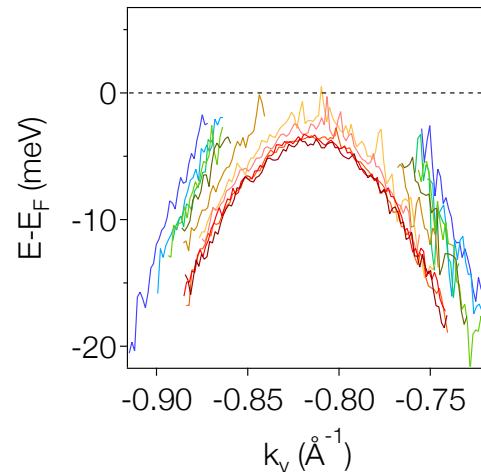
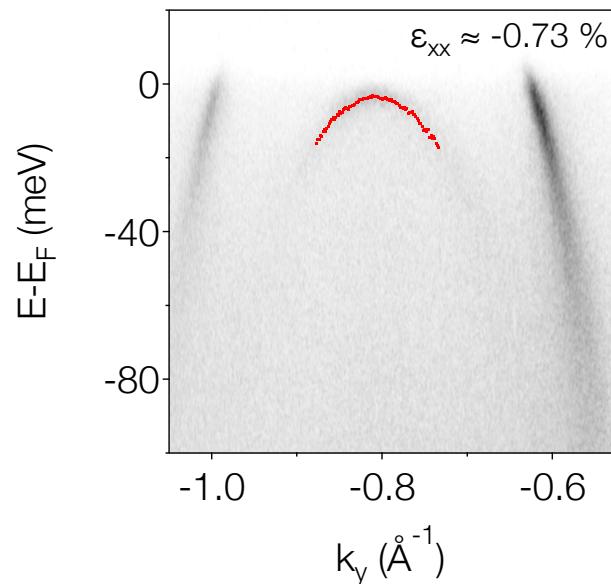
Conventional strain cell

FIB engineered crystal + laser source

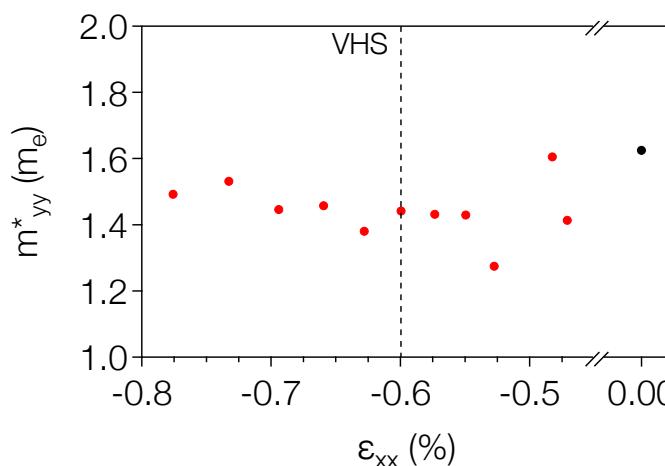
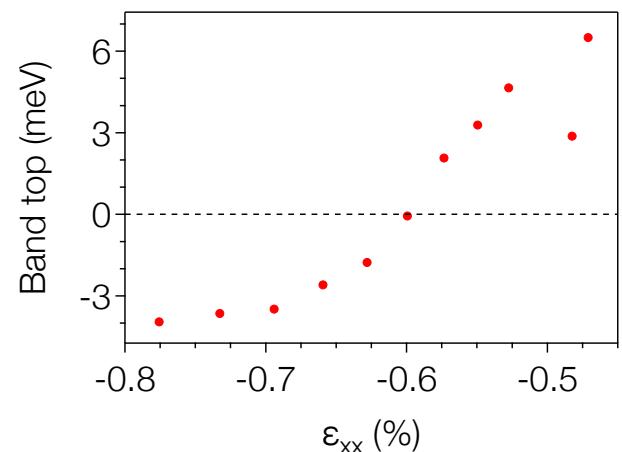
# Non-Fermi Liquid QPs



# QP dispersion



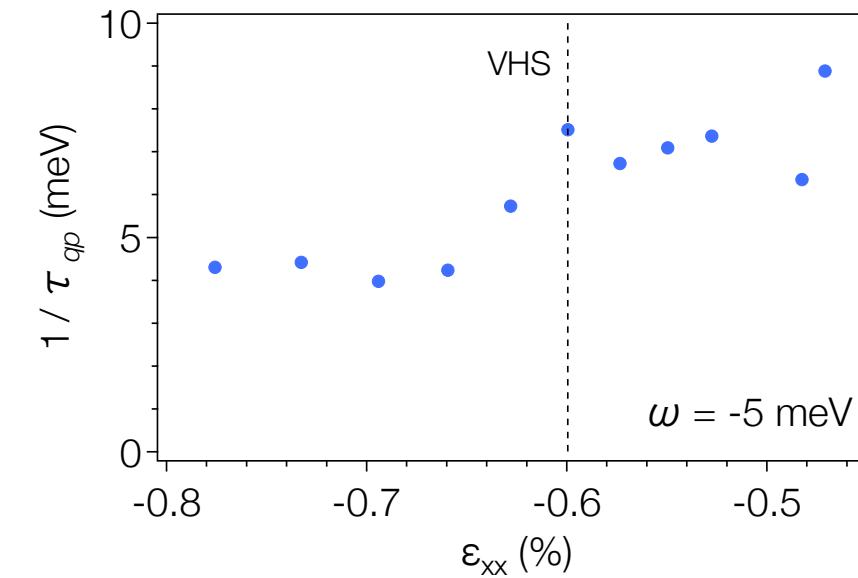
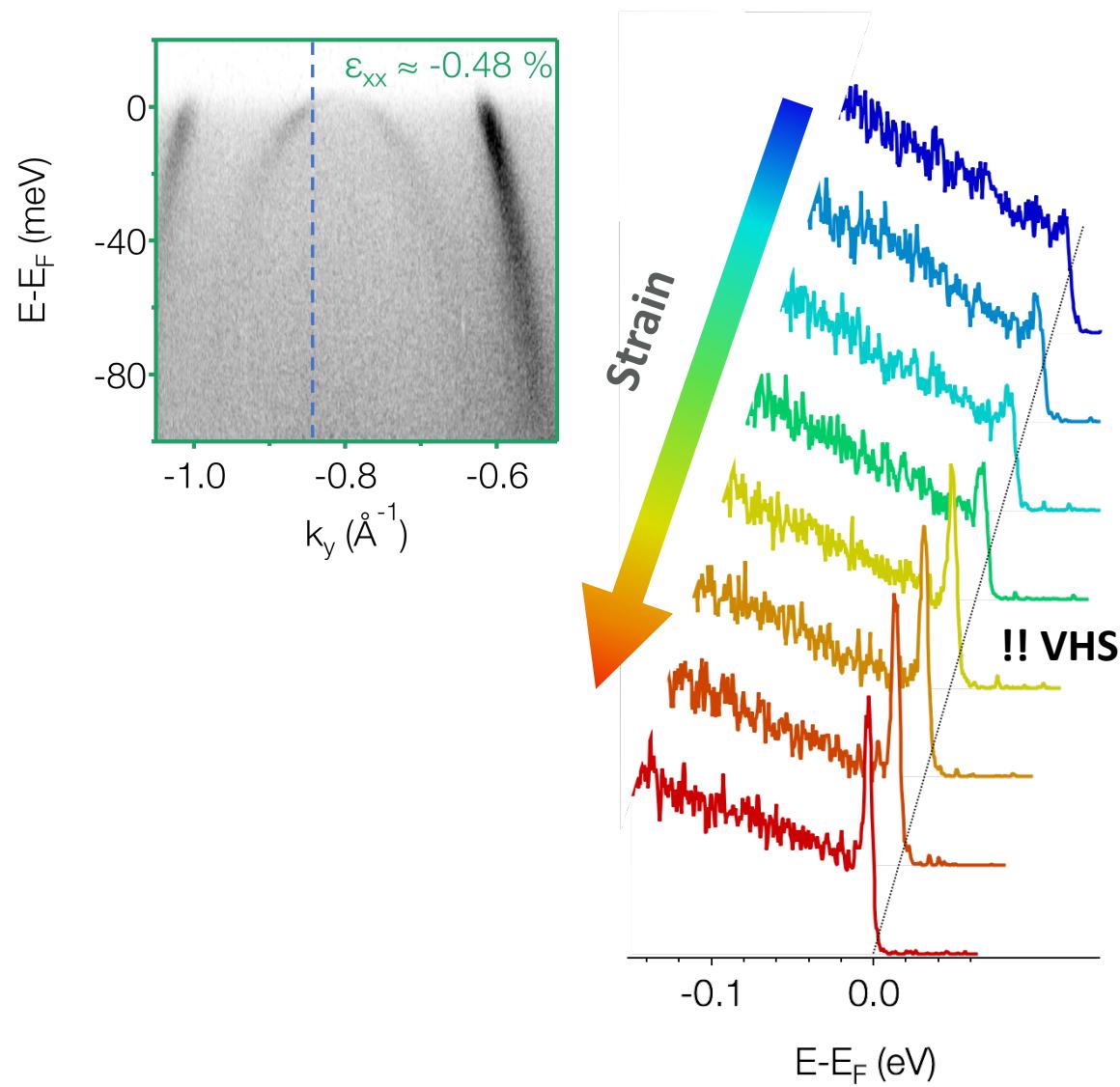
Strain/position  
↓



$$\frac{1}{Z} = \frac{m^*}{m_0} \approx 5$$

No strain dependence ?

# Linewidth analysis



**Scattering rate decreases**

see also P-Y Yang et al. arXiv:2302.07763  
*Hall coefficient*

# Conclusions



## Temperature dependence - *fast and furious QPs*:

- QP – like excitations in non-FL regime
- Dispersion:  $Z$  increases with  $T$  and lifetime decreases with temperature
- $\beta$  &  $\gamma$  sheets deflate with increasing  $T$
- Spectral weights unreliable

## Precision ARPES of $\text{Sr}_2\text{RuO}_4$ under strain

- Excitations remain QP-like
- Effect of vHs crossing on the scattering rate

