Δλ and κ/T: How they help us to determine the 3D gap structures

work by Vivek Mishra, Peter Hirschfeld, Siegfried Graser

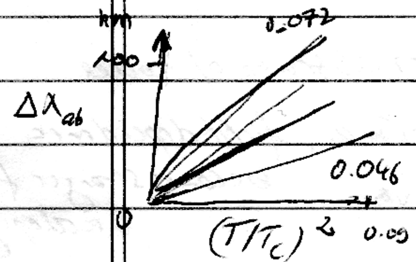
Δλ and κ/T: how they can help to determine the 3D gap structures

Work in progress by Vivek Mishra and Peter Hirschfeld

- Motivation
- 3D gap structures
- Thermal Conductivity and Penetration Depth

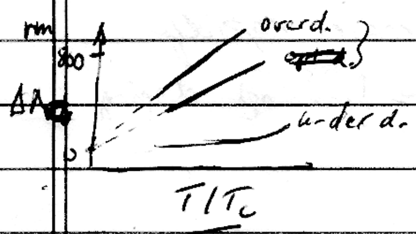
1) Motivation

- C. Martin et al. $Ba(Fe_{1-x}Ni_x)_2As_2$, penetration depth



$\Delta\lambda_{ab}(T) = a + bT^n$ ⇒ no nodes?

$1.5 < n < 2.2$ decreasing for overdoping — impurities?



⇒ nodes in overdoped samples

Question: if nodes exist they have to contribute to both the in-plane and c-axis penetration depth!!

But position of 3D nodal structures can enhance linear term in ~~out of plane~~ c-axis pen. depth.

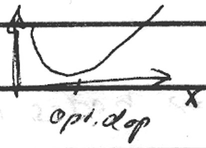
- Reid et al. $Ba(Fe_{1-x}Co_x)_2As_2$, c-axis heat transport

- heat transport: Interesting because probe down to very low $T \sim 50\,mK$

κ_{ab}: small or zero linear-T term for $H=0$ $\Rightarrow$ absence of nodes
but strong H-dependence $\Rightarrow$ deep minima, field dependence becomes stronger for overdoping!

κ_c: linear-T ~~dependence~~ term at low T $\Rightarrow$ nodal behavior

Anisotropy $(\kappa_c/\kappa_{c,N})/(\kappa_{ab}/\kappa_{ab,N})$



increases rapidly away from opt. doping

normalized anisotropy goes to 1 as a function of magnetic field!

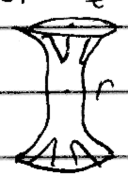
2.) 3D gap structures

Most Pnictides show fairly 2D gaps.
Depending on doping some materials (e.g. Ba-122) develop stronger 3D behaviour:

- ~~Model:~~ Hole pocket, mainly of d_{xz}/d_{yz} character, shows doping dependent warping close to Z

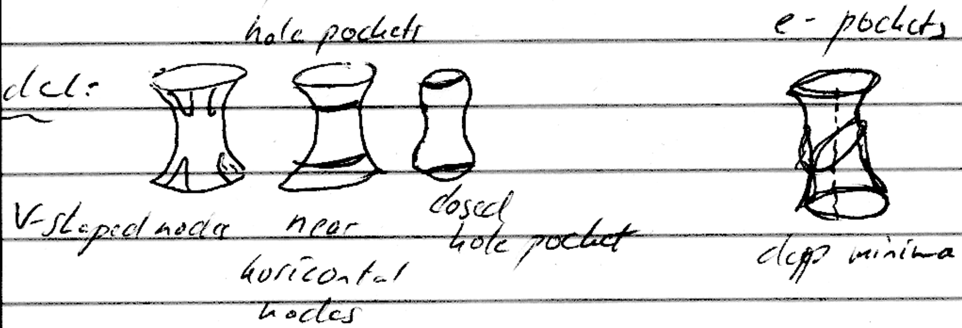
SRT + Microscopic Calculation

SF



Warping is related to hybridization with other orbitals ⇒ change of orbital character at $k_z = \pi$
⇒ ~~M~~ matrix elements in spin fluctuation calculations result in reduced pairing ⇒ ~~nodes~~ 3D nodes on the FS close to $k_z = \pi$! Similar conclusion by Kuroki et al. $BaFe_2(As_{1-x}P_x)_2$

Model:



3) - <u>Penetration depth:</u>

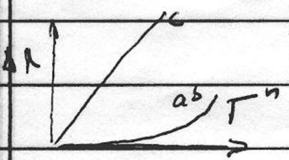
usual argument: T^2 for dirty supercond. due to in gap-states
lin. T for nodal supercond. (line nodes)

But: if imp. scattering dominates we should see T^2
behaviour in ab-plane and c-axis ~~pe~~ penetration depth

$$\frac{1}{\lambda_\alpha^2} \sim \sum_i n_i \int \frac{d\omega}{\pi} \left\langle \tanh\left(\frac{\omega}{2T}\right) (v_{F,\alpha})^2 \, \mathrm{Im}\left[\frac{\hat{\Delta}}{(\Delta^2-\omega^2)^{3/2}}\right] \right\rangle_{FS}$$

$\lambda_{0,\alpha}$ cannot be accessed (integration over all bands necessary)
$\Delta\lambda_\alpha \sim \lambda_{0,\alpha} F(T)$ T dependence can be calculated exactly

$\lambda_{0,c} \gg \lambda_{0,ab}$



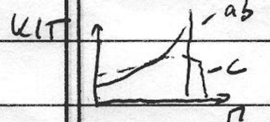
$n \approx 2-3$

We find: „crossover" with linear behavior due to nodes on hole sheets and quasilinear behavior due to qp excitations from deep minima on eletron sheets

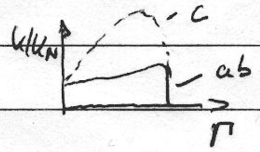
- <u>Thermal conductivity</u>

low T: κ/T depends on nodal phase space and on the direction of v_F at the nodes $\langle v_{F,ab}^{nodal} \rangle$; $\langle v_{F,c}^{nodal} \rangle$

we need: large $v_{F,c}$ component at the nodes $\Rightarrow$ large κ_c/T for $T \to 0$
$\Rightarrow$ horizontal nodes close to warping of FS $\Rightarrow$ large $(\kappa_c/T)/(\kappa_{ab}/T)$ anisotro



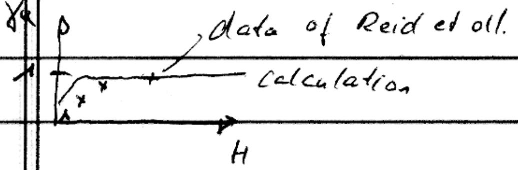
Scattering rate



interband scattering cannot explain strong anisotropy of <u>normalized</u> residual thermal conductivity: $(\kappa^a/\kappa_N^a)/(\kappa^c/\kappa_N^c) = 1$

Magnetic field dependence:

$$\chi_u^{-1} = \lim_{T \to 0} \frac{\kappa_a/\kappa_{a,N}}{\kappa_c/\kappa_{c,N}}$$



- Small fields: χ_u dominated by weak nodes on hole sheets!
- large fields: deep gap minima start to contribute and dominate due to larger phase space,

electron pockets more 2D => anisotropy vanis