D-wave density wave in $CeCoIn_5$ and high T_c cuprates

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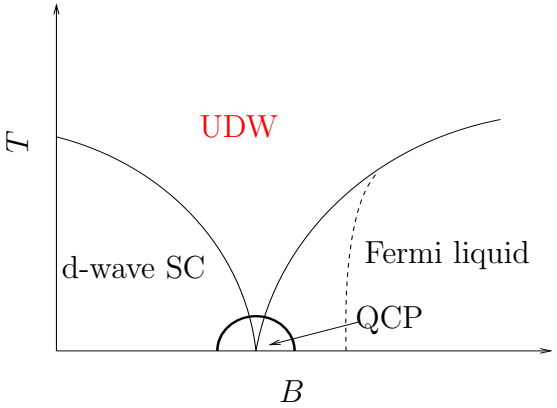
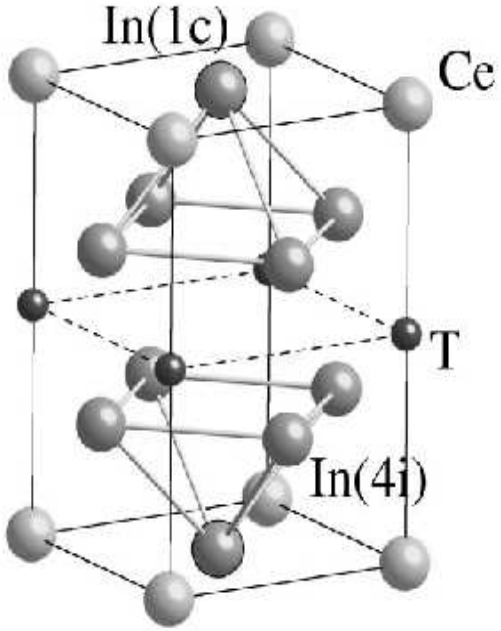
Outline:
- Properties of $CeCoIn_5$
- Landau levels in magnetic field
- Angular magnetoresistance, application to $CeCoIn_5$ and high T_c SC

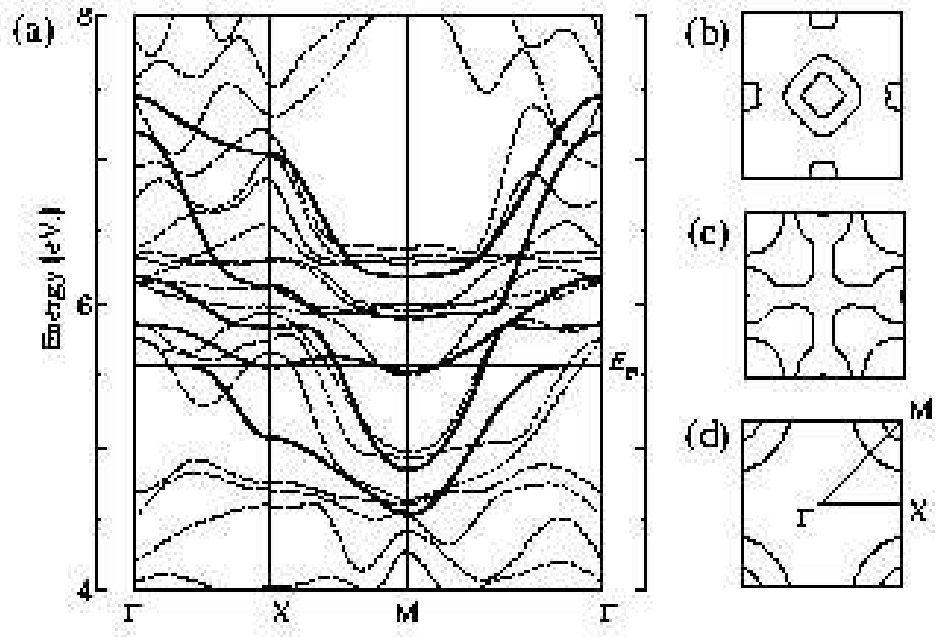
Properties of $CeCoIn_5$

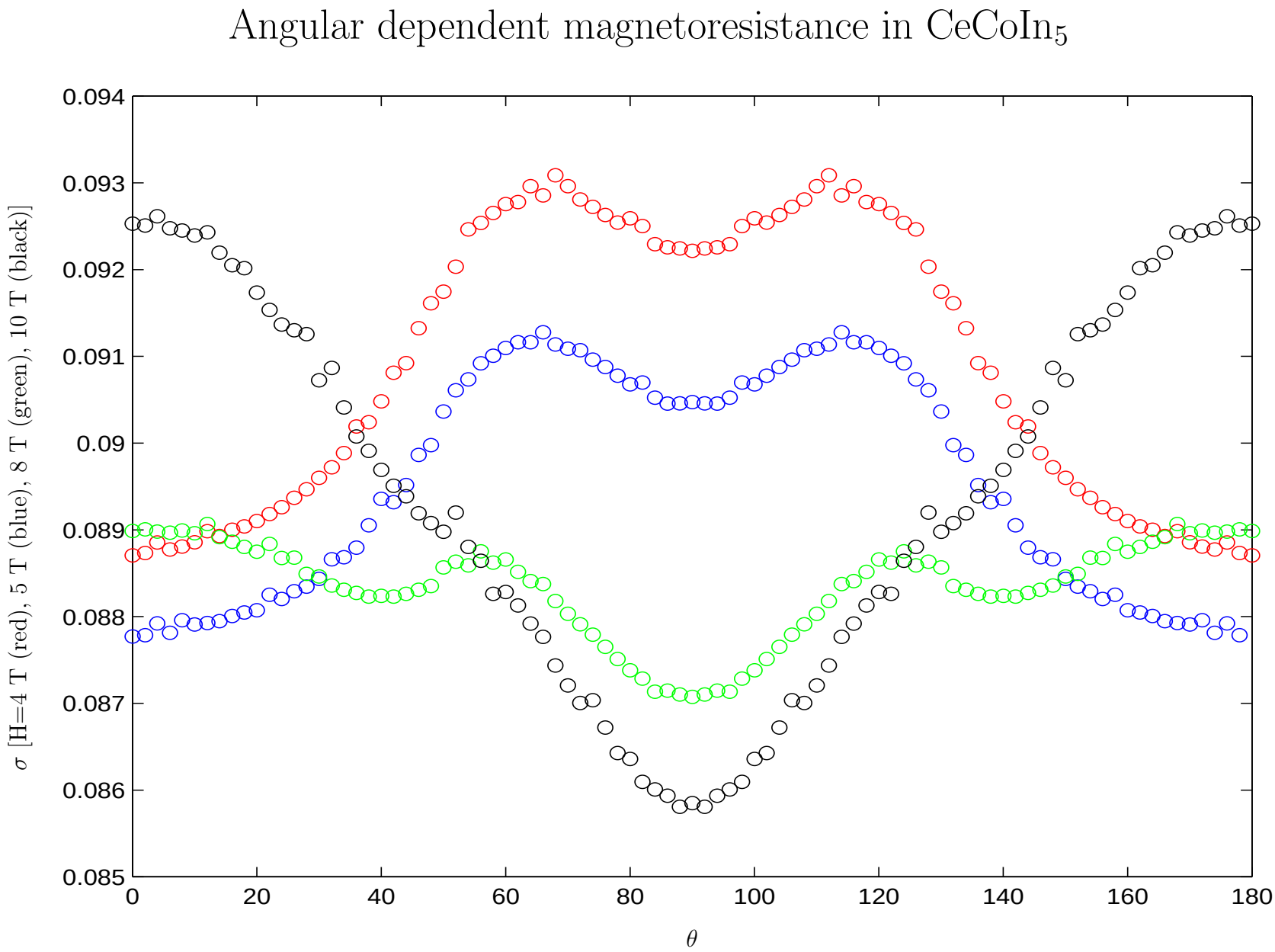
Similarities with high T_c superconductors:

- quasi-2-dimensional structure (tetragonal)
- d-wave SC
- proximity of AF
- presence of non-Fermi liquid phase

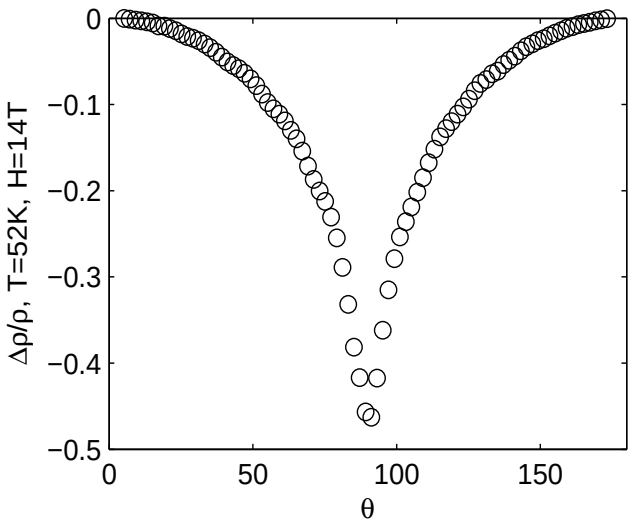


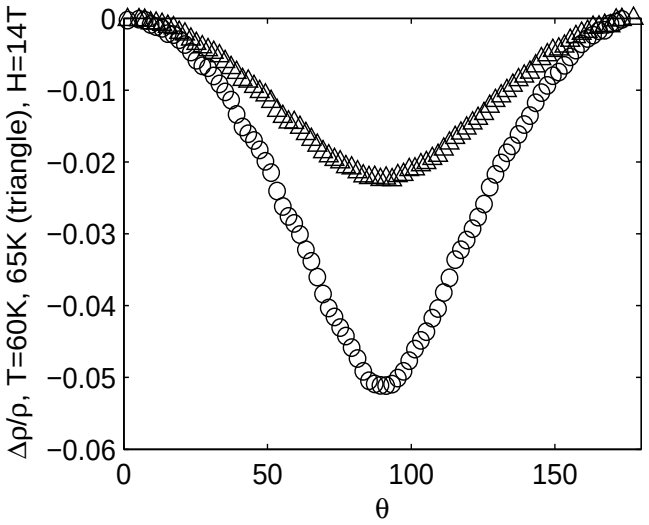


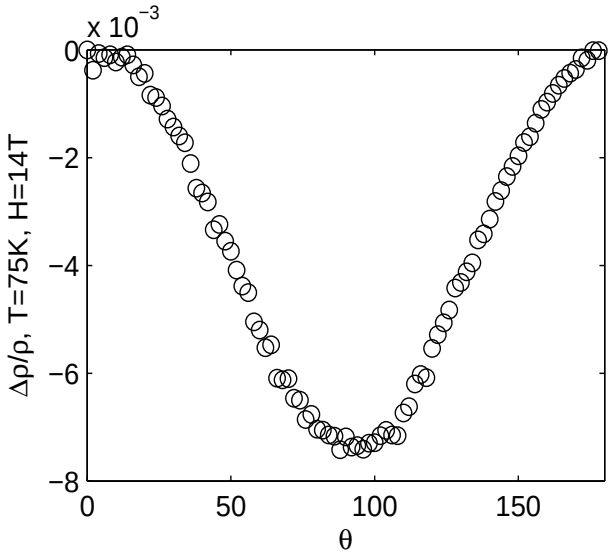


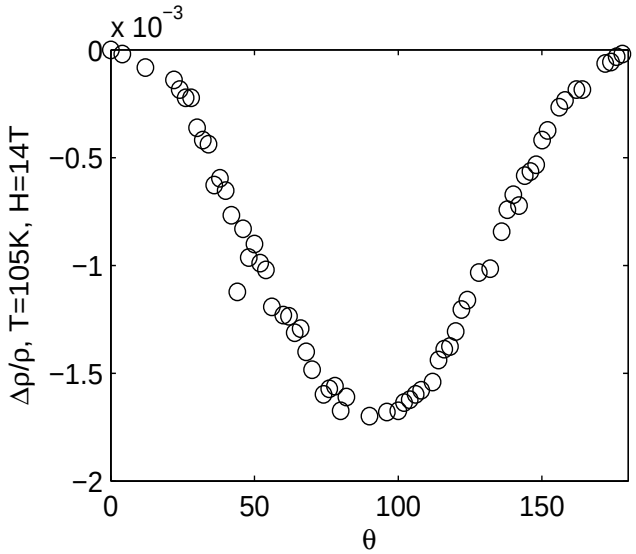

Angular dependent magnetoresistance in CeCoIn5
σ [H=4 T (red), 5 T (blue), 8 T (green), 10 T (black)]
θ
0.094
0.093
0.092
0.091
0.09
0.089
0.088
0.087
0.086
0.085
0
20
40
60
80
100
120
140
160
180

Angular dependent magnetoresistance in $Y_{1-x}Pr_xBa_2Cu_3O_7$ (x=0.32, T_{c0}=55 K)









UDW Hamiltonian:

$$H = \sum_{\mathbf{k},\sigma}{}' \left[\xi(\mathbf{k})(a^{+}_{\mathbf{k},\sigma} a_{\mathbf{k},\sigma} - a^{+}_{\mathbf{k}-\mathbf{Q},\sigma} a_{\mathbf{k}-\mathbf{Q},\sigma}) + \Delta(\mathbf{k},\sigma) a^{+}_{\mathbf{k},\sigma} a_{\mathbf{k}-\mathbf{Q},\sigma} + \overline{\Delta(\mathbf{k},\sigma)} a^{+}_{\mathbf{k}-\mathbf{Q},\sigma} a_{\mathbf{k},\sigma} \right].$$

$\langle a^{+}_{\mathbf{k},\sigma} a_{\mathbf{k}-\mathbf{Q},\sigma} \rangle \sim \Delta(\mathbf{k},\sigma)$: non-local interaction (on site and direct Coulomb, exchange, pair-hopping and bond-charge). The spectrum:

$$E_{\pm}(\mathbf{k},\sigma) = \frac{\xi(\mathbf{k}) + \xi(\mathbf{k}-\mathbf{Q})}{2} \pm \sqrt{\left(\frac{\xi(\mathbf{k}) - \xi(\mathbf{k}-\mathbf{Q})}{2} \right)^2 + |\Delta(\mathbf{k},\sigma)|^2}$$

wavevector dependent gap=unconventional, $\langle m(\mathbf{Q}) \rangle = 0$, $\langle n(\mathbf{Q}) \rangle = 0$, "hidden-order".

The thermodynamic properties are identical to that of d-wave SC.

Effect of magnetic field

1. Landau levels, continuum model:

$$H = \int d\mathbf{r} \sum_{n=1,2} \left(-iv\left[R_n^+\partial_x R_n - L_n^+\partial_x L_n\right] + iv_\perp(-1)^n\left[R_n^+\partial_y R_n - L_n^+\partial_y L_n\right] - i\Delta b\left[\exp(i\varphi)R_n^+\partial_y L_n + \exp(-i\varphi)L_n^+\partial_y R_n\right]\right)$$

$$\begin{bmatrix} -iv\partial_x - iv_\perp\partial_y + v_\perp exB\cos(\theta) & \Delta b\exp(i\varphi)(-i\partial_y + exB\cos(\theta)) \\ \Delta b\exp(-i\varphi)(-i\partial_y + exB\cos(\theta)) & iv\partial_x + iv_\perp\partial_y - v_\perp exB\cos(\theta) \end{bmatrix}\Psi = E\Psi$$

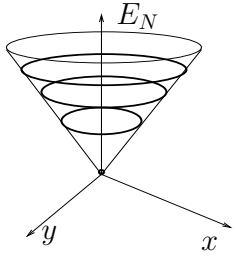
$$E\Psi = (-iv_a\partial_x\rho_3 + \Delta ceBx\cos(\theta)\rho_1)\Psi,$$

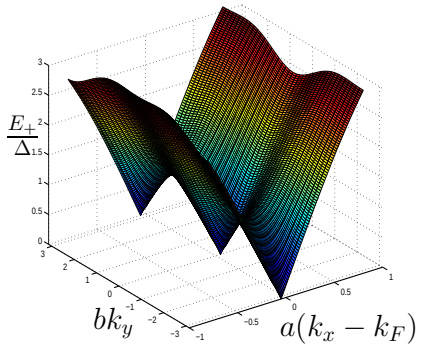
$$\Rightarrow E_n = \mu \pm \sqrt{2nv_a\Delta ce|B\cos(\theta)|}$$

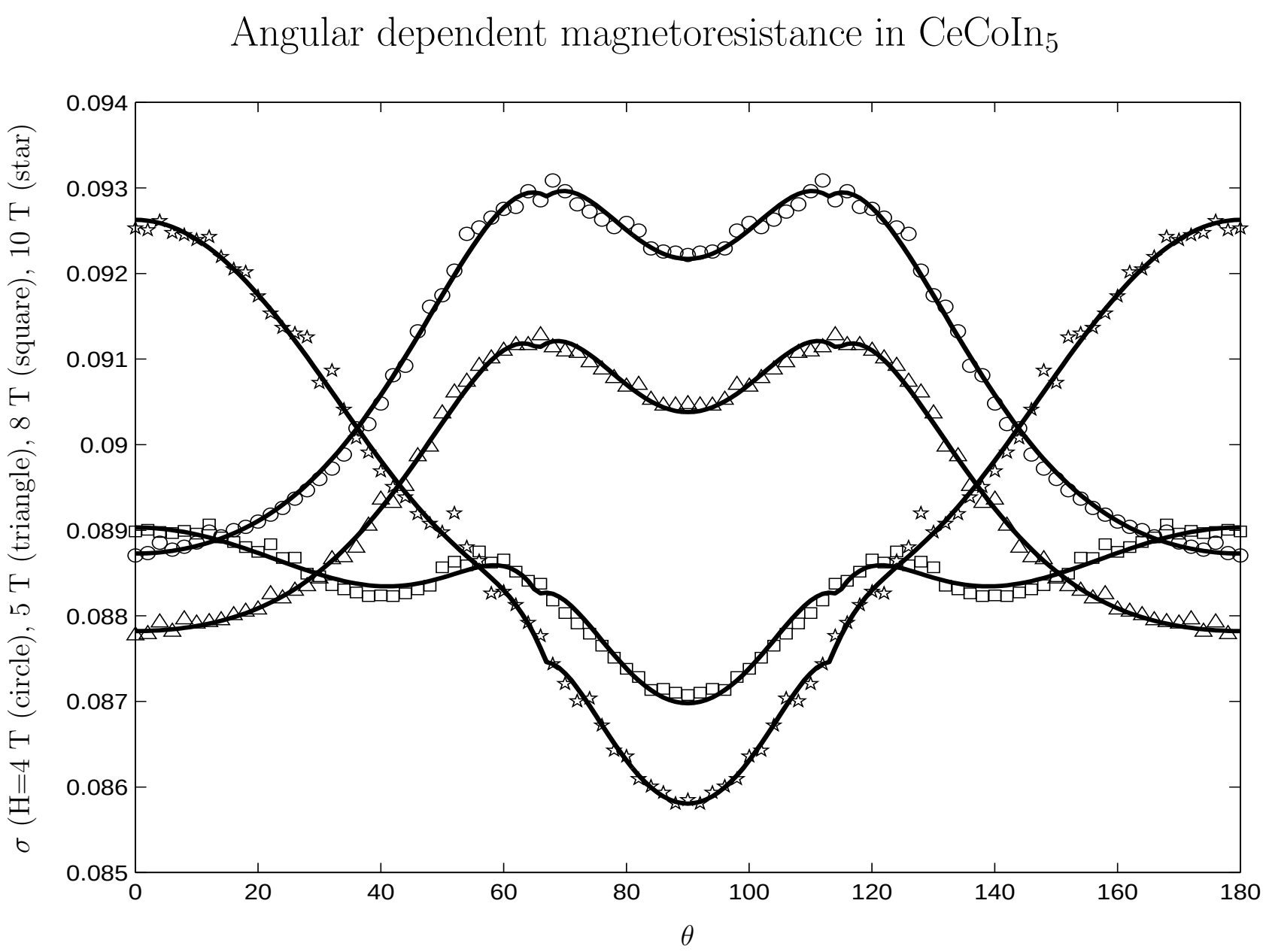
In quasi 2D: $E_n = \mu \pm \sqrt{2n\Delta ceB|v_a\cos(\theta) - v_\perp\sin(\theta)|}$

2. Conductivity:

$$\sigma = \sum_n \frac{\sigma_n}{\cosh^2(\beta E_n/2)},$$



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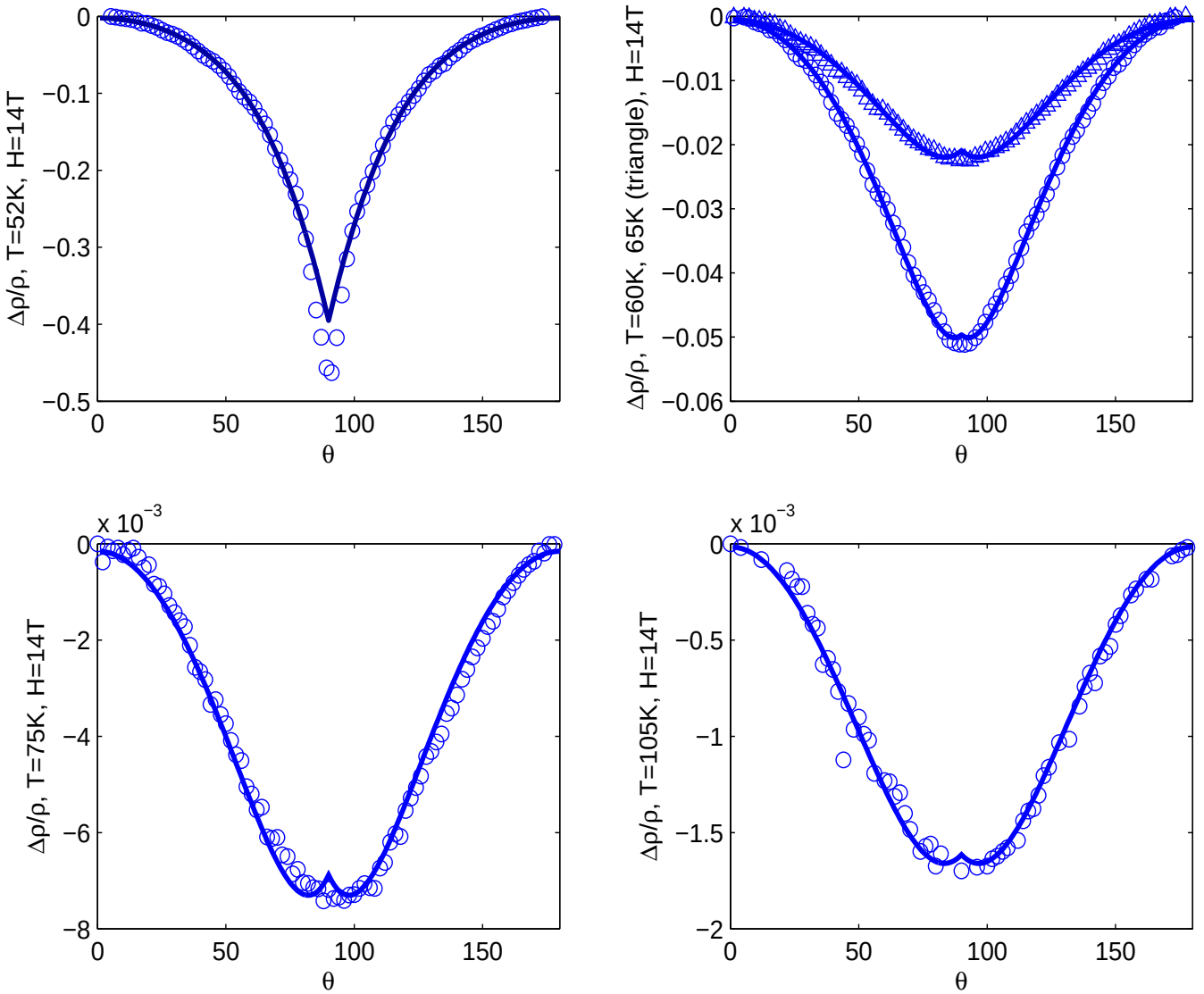

Conclusions

- non-local interactions
- transition is metal to metal instead of metal to insulator
- In magnetic field: Landau levels, particles living around nodes dominate the low-T high-H behaviour, gapped excitations
- The pseudogap (non-Fermi liquid) phase of $CeCoIn_5$ is well described by quasi 2D UDW
- The ADMR in pseudogap phase of high T_c is consistent with 2D UDW