Title: Field-induced thermal transport in BEC antiferromagnets

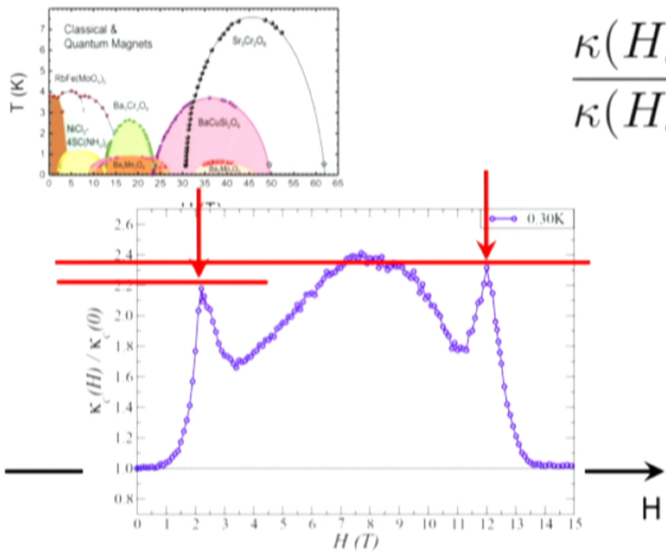
Date: Jan 08, 2013 03:30 PM

URL: http://pirsa.org/13010002

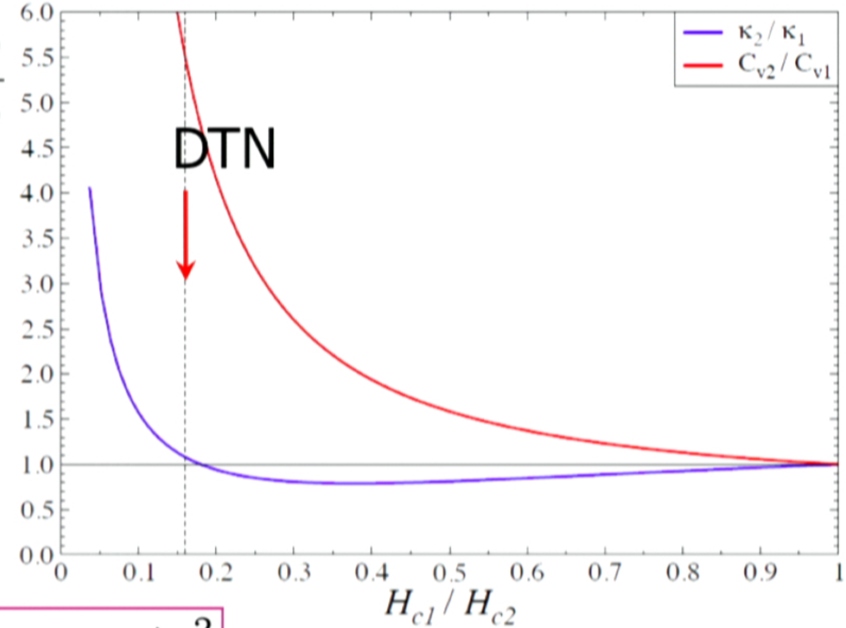
Abstract: Recent experiments in BEC quantum magnets exhibit a dramatic evolution of

the thermal conductivity of these materials in magnetic field. By considering various relaxation mechanisms of bosonic excitations in the vicinity of the BEC quantum-critical point at finite temperature we provide a detailed explanation of several unusual features of the data. We identify the leading impurity-scattering interaction and demonstrate that its renormalization due to quantum fluctuations of the paramagnetic state compensates the related mass renormalization effect. This explains the enigmatic absence of the asymmetry between the two critical points in the low-T thermal conductivity data, while such an asymmetry is prominent in many other physical quantities. The observed characteristic "migration" of the peak in thermal conductivity away from the transition points as a function of temperature is explained as due to a competition between an increase in the number of heat carriers and an enhancement of their mutual scattering. An important role of the three-boson scattering processes within the ordered phase of these systems is also discussed. Other qualitative and quantitative features of the experiment are clarified and the future directions are sketched.

thermal conductivity vs H_c's ratio



$$\frac{\kappa(H_{c2})}{\kappa(H_{c1})}$$



$$\frac{\kappa(H_{c2})}{\kappa(H_{c1})} \approx \left(\frac{m_2}{m_1}\right) \cdot \frac{1}{4} \left(1 + \left(\frac{m_1}{m_2}\right)^2\right)^2 \approx 1.1$$

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PRL **106**, 037203 (2011)

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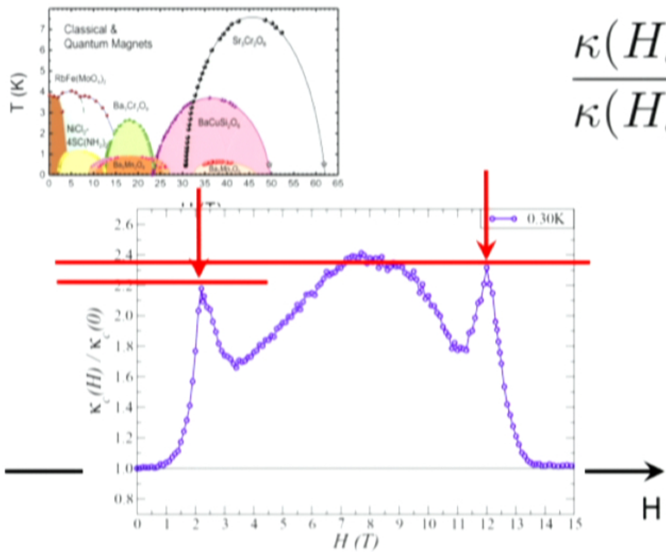

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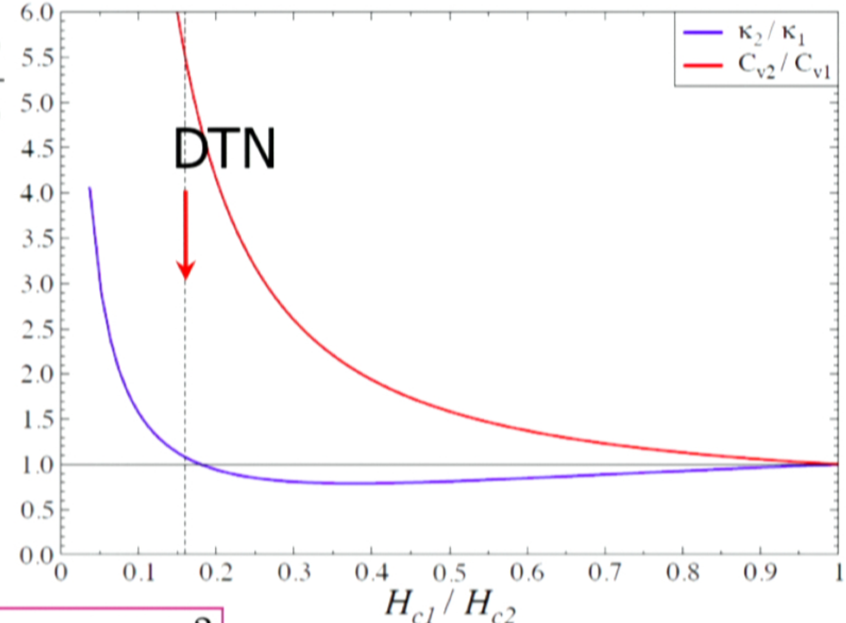

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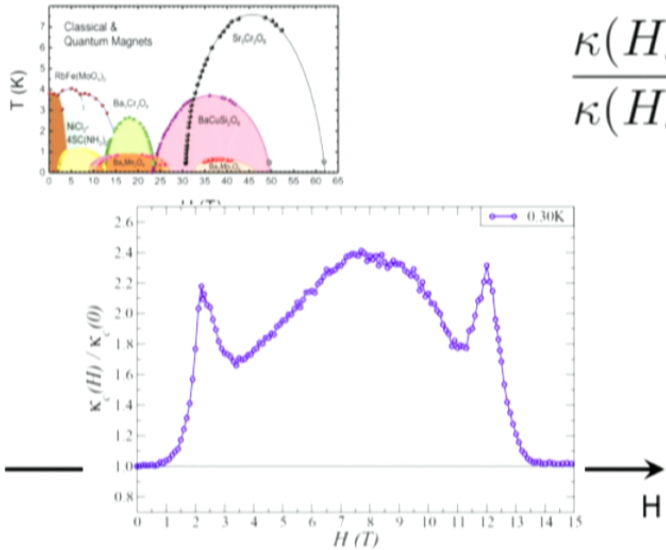
"no asymmetry" problem



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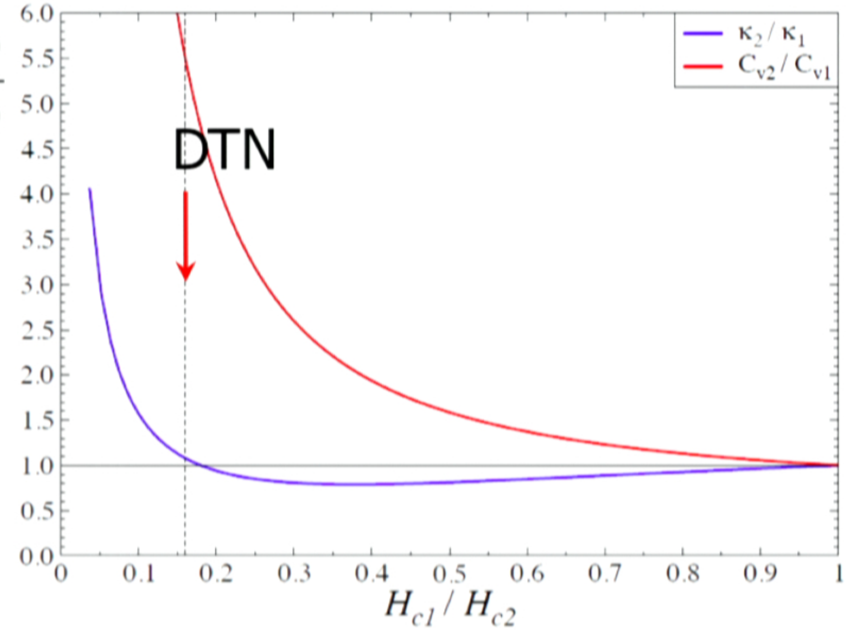
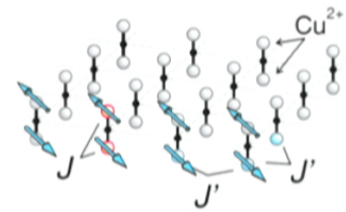


-- unless $H_{c1} << H_{c2}$, $\kappa_2 \approx \kappa_1$ for any BEC system at low enough T

-- valid for the **dimer-based systems** as well:

modulations of **intra-dimer** J lead to the same scattering as δD



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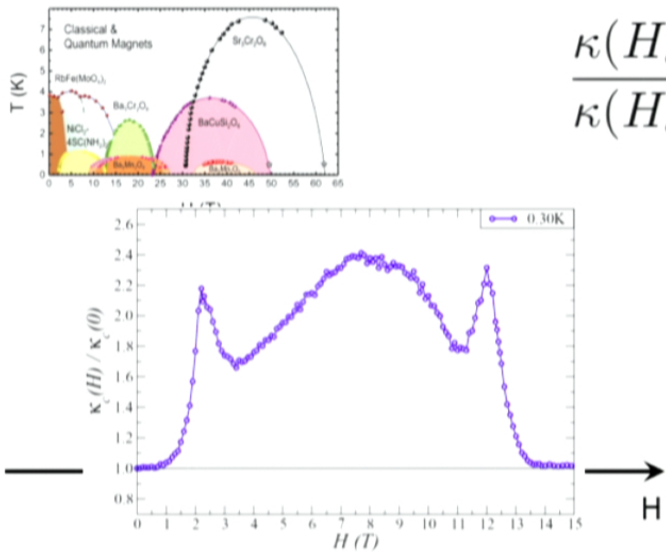

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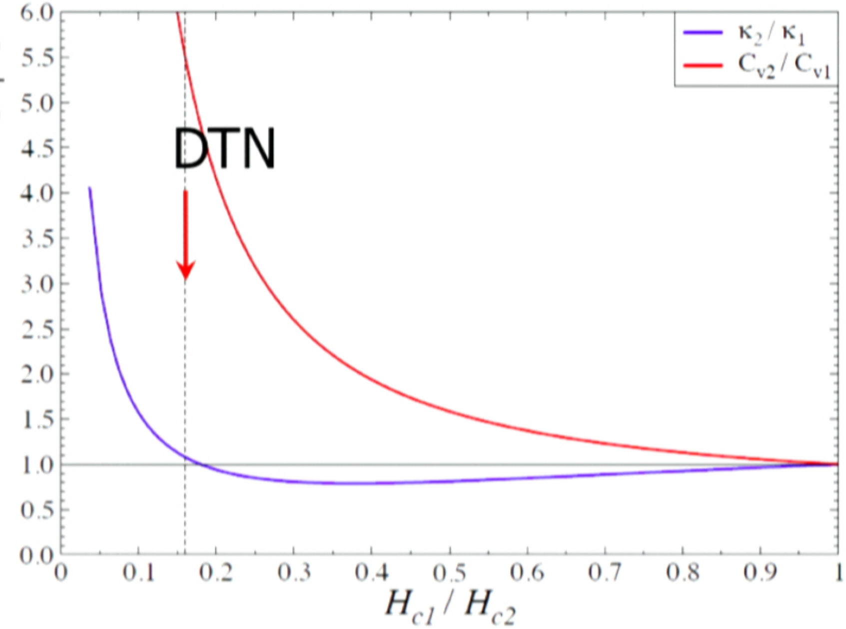

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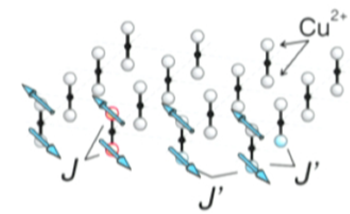
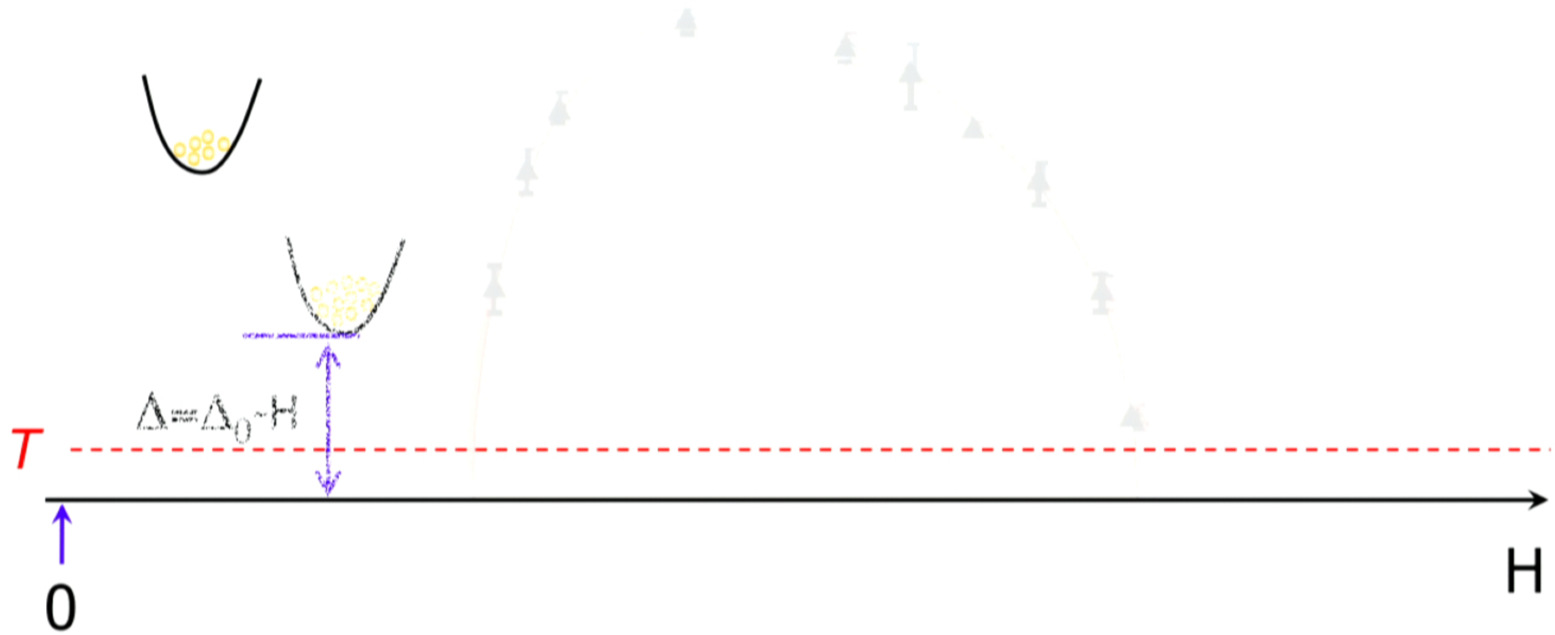


away from QCPs, dispersion, DOS



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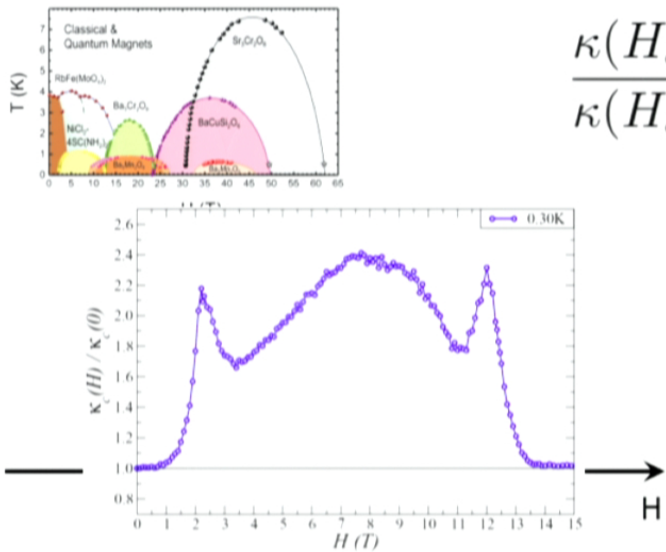

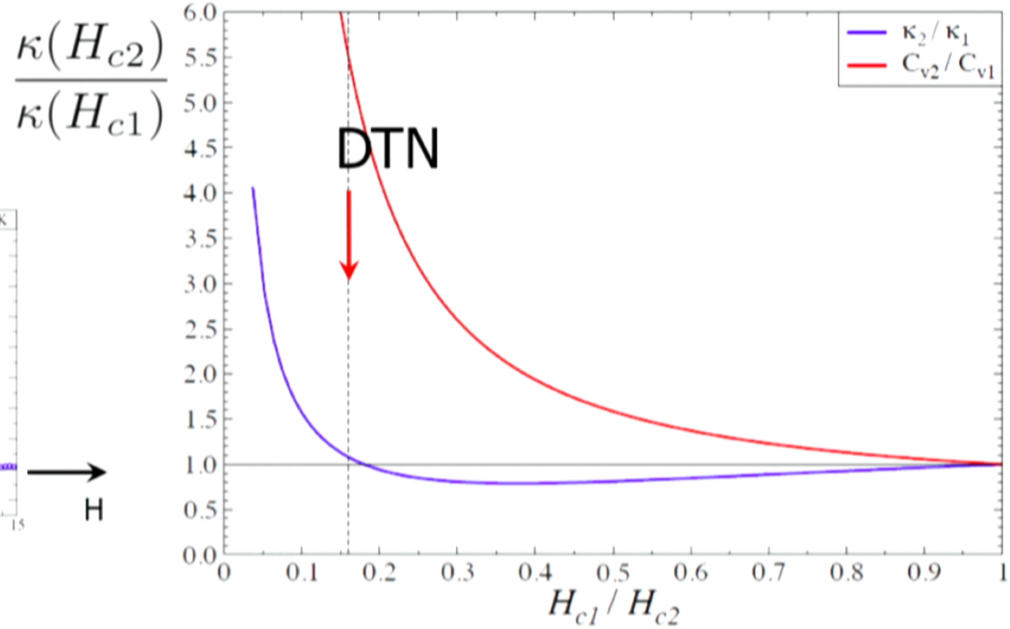

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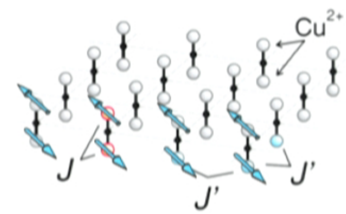

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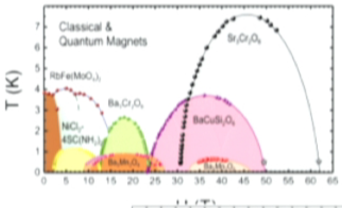

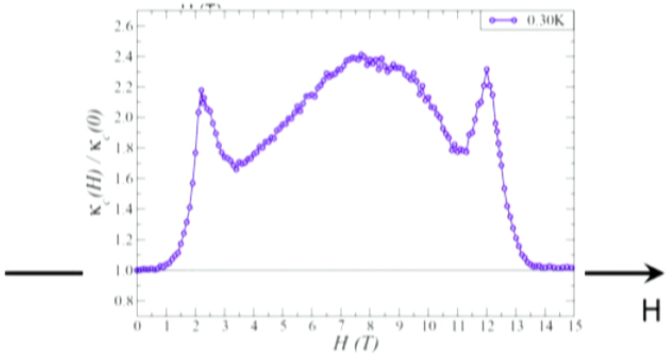

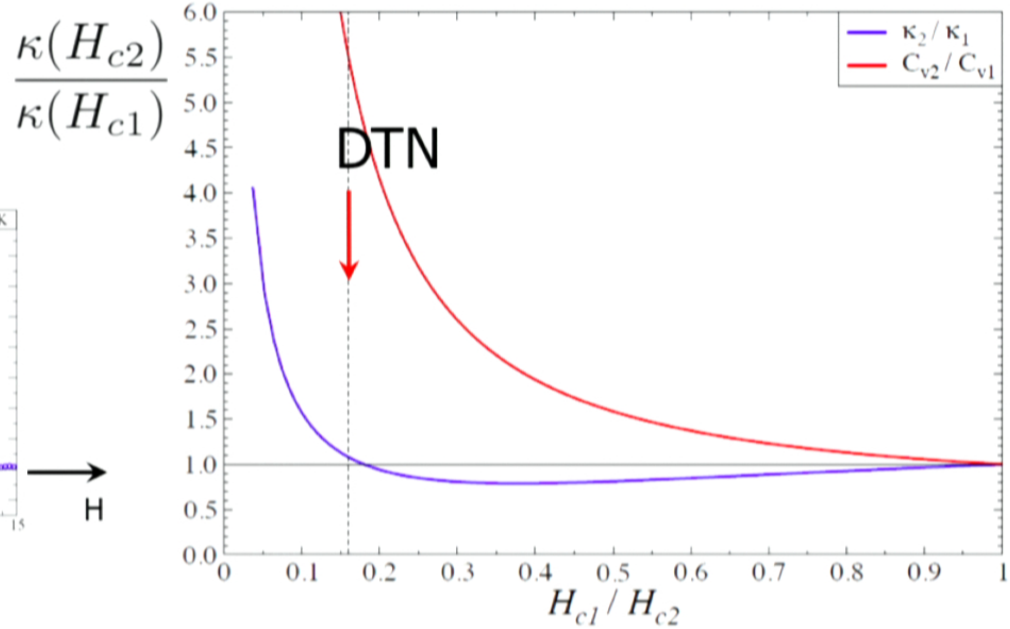

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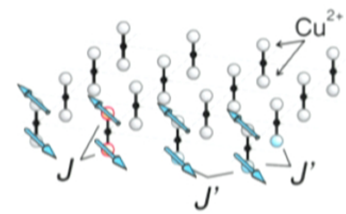

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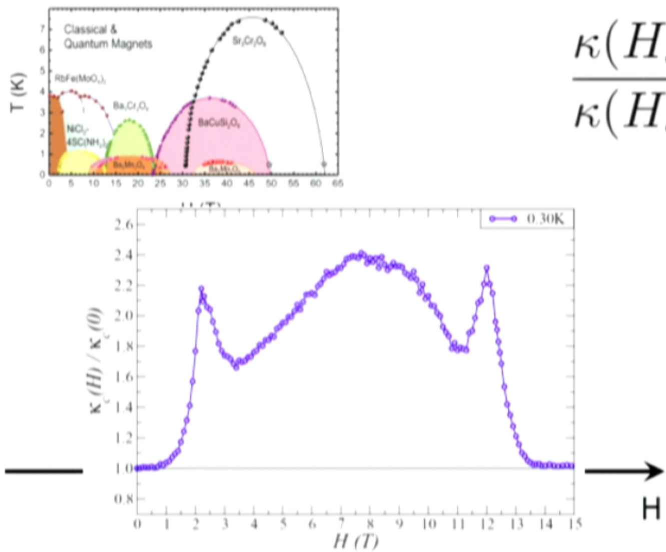

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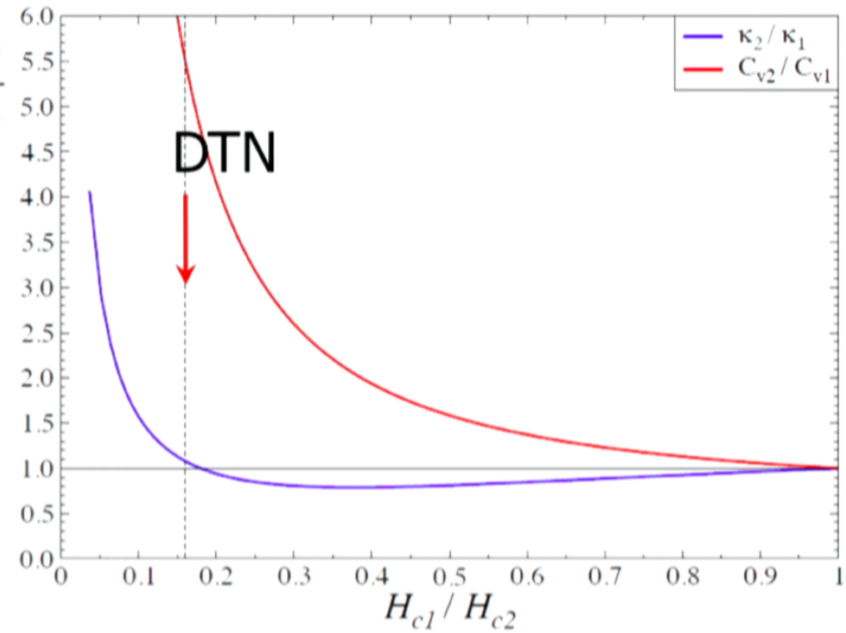

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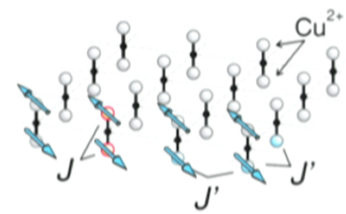

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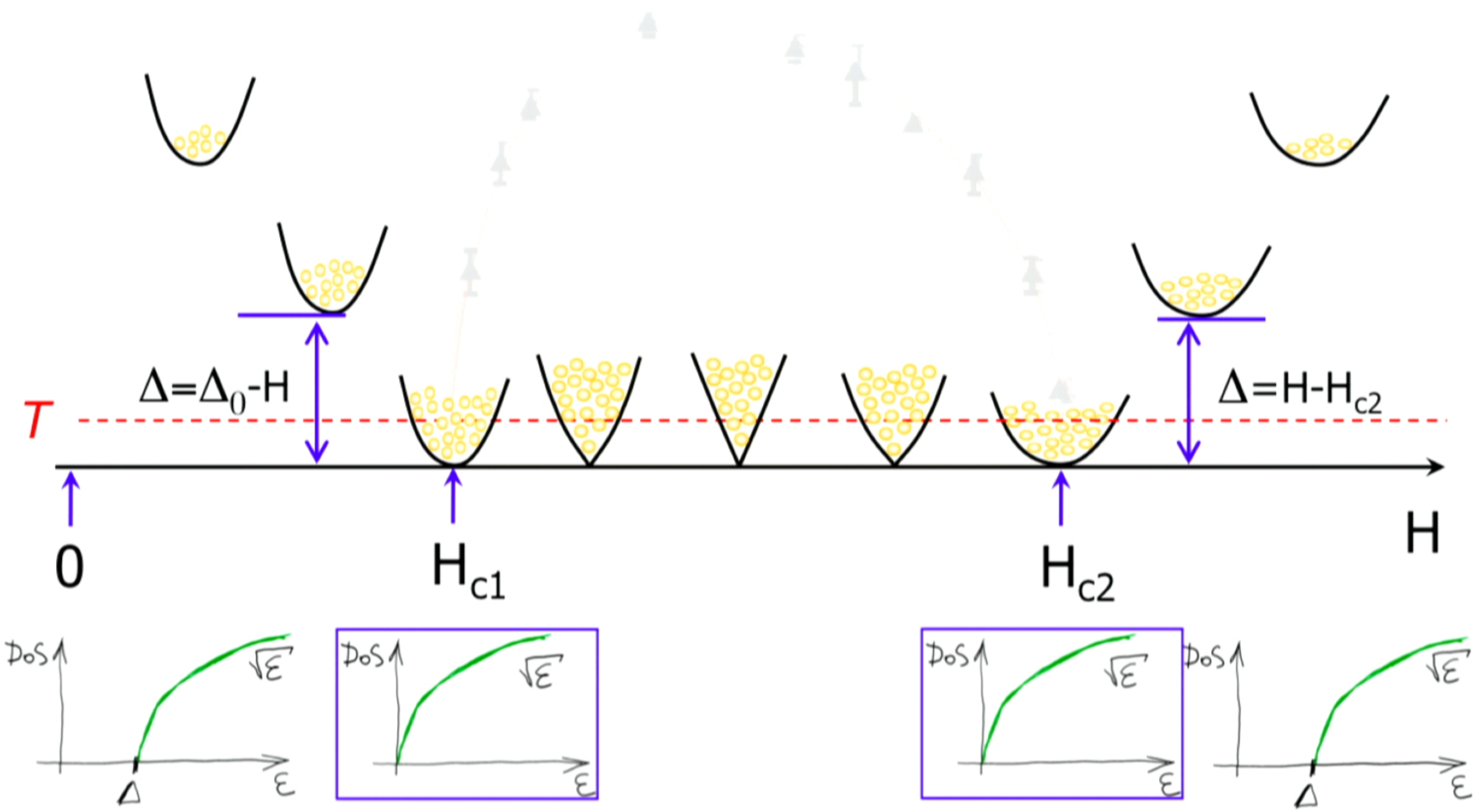
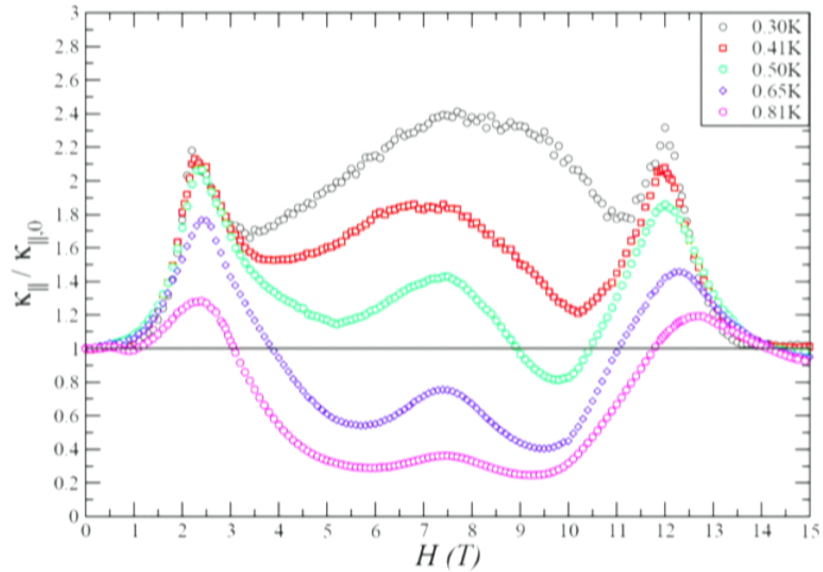


puzzles, III: minima

$$\kappa \propto \int_0^T k^2\, dk \cdot (\mathbf{v_k})^2 \cdot \tau_\mathbf{k}$$

puzzles, II: “peak migration” problem



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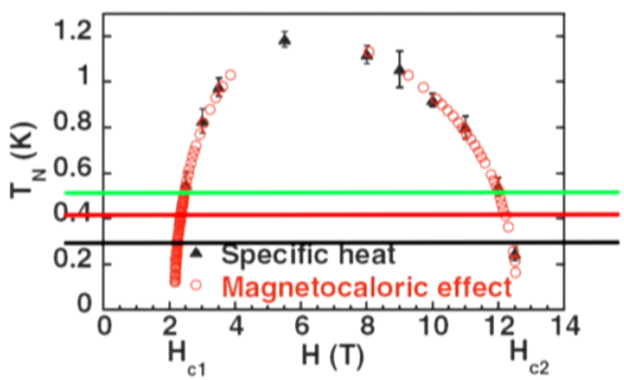
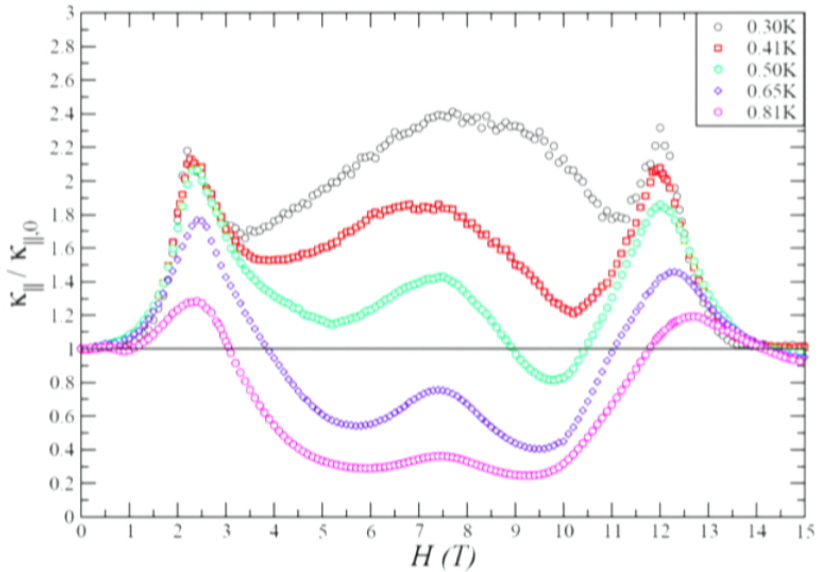
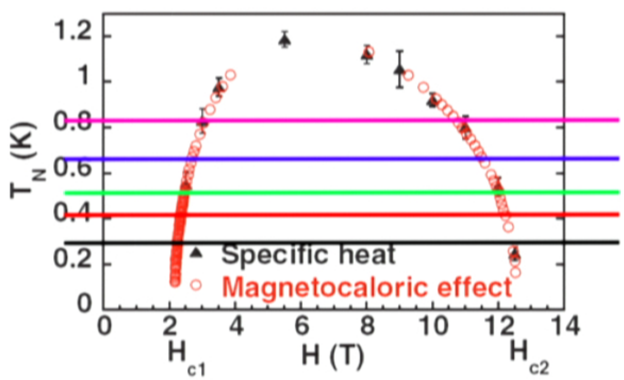
puzzles, II: “peak migration” problem

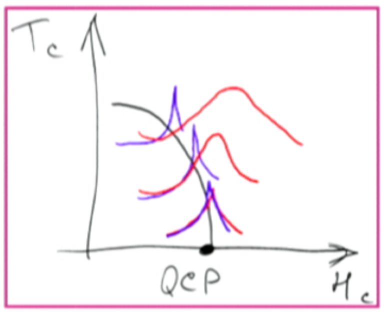


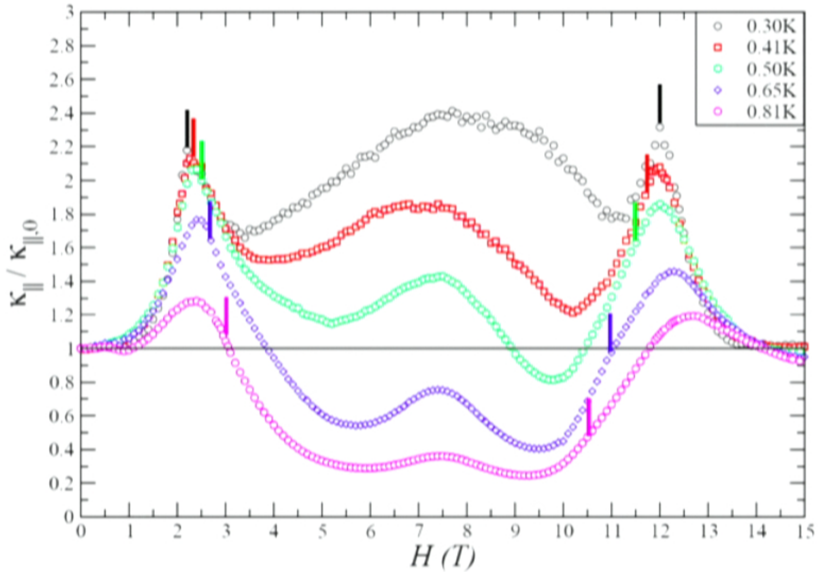


puzzles, II: "peak migration" problem

☑ peaks/maxima in κ "migrate" **away** from H_c's as T increases → ??







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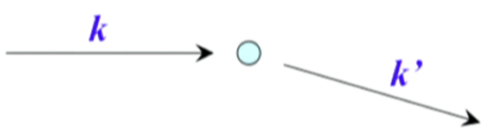
scatterings in the paramagnetic phase

☑ both b-b and impurity scattering are important for $\omega_{\mathbf{k}}=\Delta+k^2/2m$ band

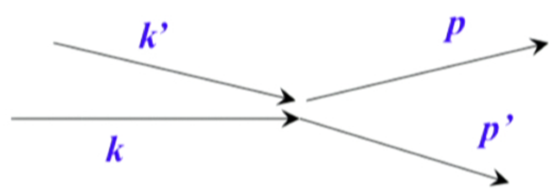
$$\mathcal{H} = \sum_{\mathbf{k}} (\varepsilon_{\mathbf{k}} - \mu_0)\, b^{\dagger}_{\mathbf{k}} b_{\mathbf{k}} + g_0 \sum_{\mathbf{k},\mathbf{1},\mathbf{2}} b^{\dagger}_{\mathbf{k}+\mathbf{2}-\mathbf{1}} b^{\dagger}_{\mathbf{1}} b_{\mathbf{2}} b_{\mathbf{k}}$$

$$\mathcal{H}^{D}_{\mathrm{imp}} = \delta D \sum_{\mathbf{i}} b^{\dagger}_{\mathbf{i}} b_{\mathbf{i}} = \delta D \sum_{\mathbf{k},\mathbf{k}'} e^{i\mathbf{R}_{\mathbf{i}}(\mathbf{k}-\mathbf{k}')}\, b^{\dagger}_{\mathbf{k}} b_{\mathbf{k}'}$$

☑ *impurity scattering:* $\boldsymbol{k \neq k'}$



☑ *b-b scattering:* $\boldsymbol{k + k' = p + p'}$



thermal conductivity, impurity only

$$\kappa \propto \int_0^\infty k^2 dk \cdot \frac{k^2}{m^2} \cdot \frac{\omega_{\mathbf{k}}^2}{T^2} \cdot \frac{e^{\omega_{\mathbf{k}}/T}}{(e^{\omega_{\mathbf{k}}/T} - 1)^2} \cdot \tau_{\mathbf{k}}$$

$$\omega_{\mathbf{k}} = \varepsilon_{\mathbf{k}} - \mu$$

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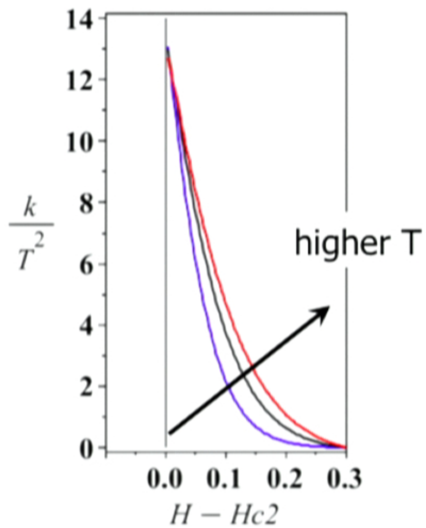

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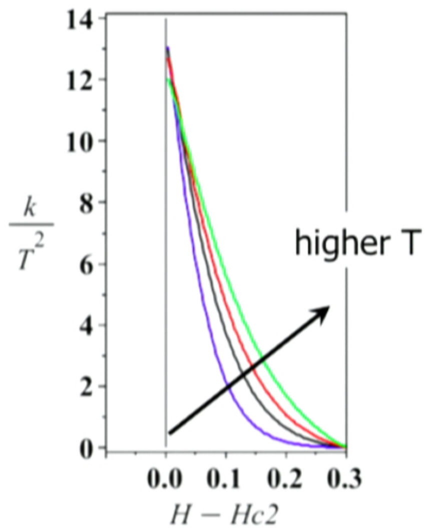
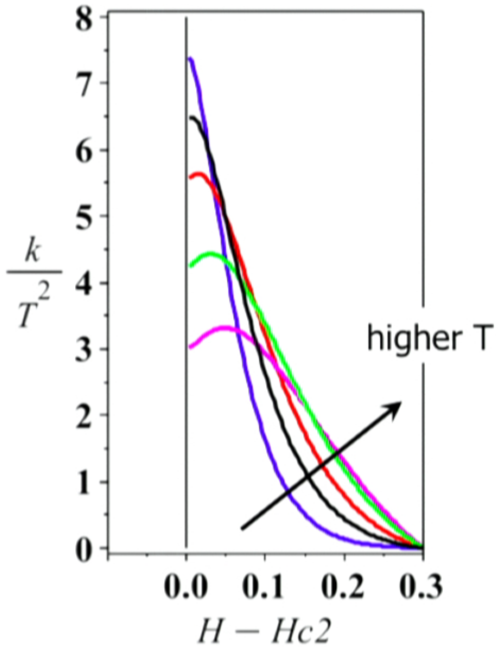
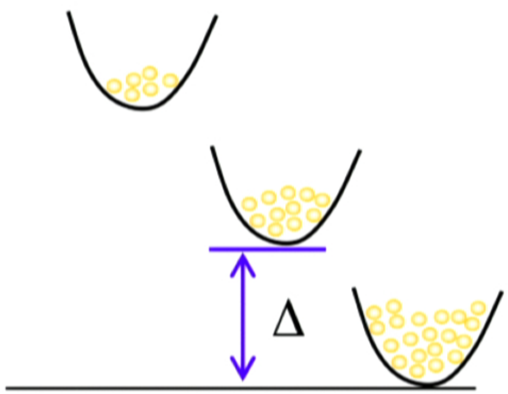


thermal conductivity, Goldilocks gap



- ☑ impurity and b-b together:
  - ☑ **"migrating" peaks!**
  - ☑ reason → bosons provide extra scattering



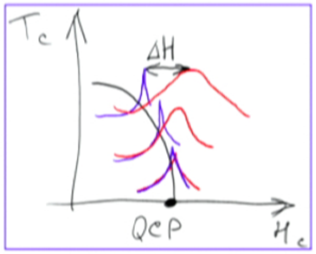
☑ more heat carriers, but also more scatterers
→ "optimal" gap

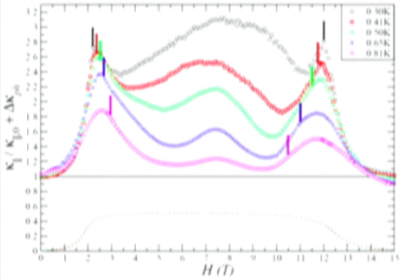
"peak migration" problem

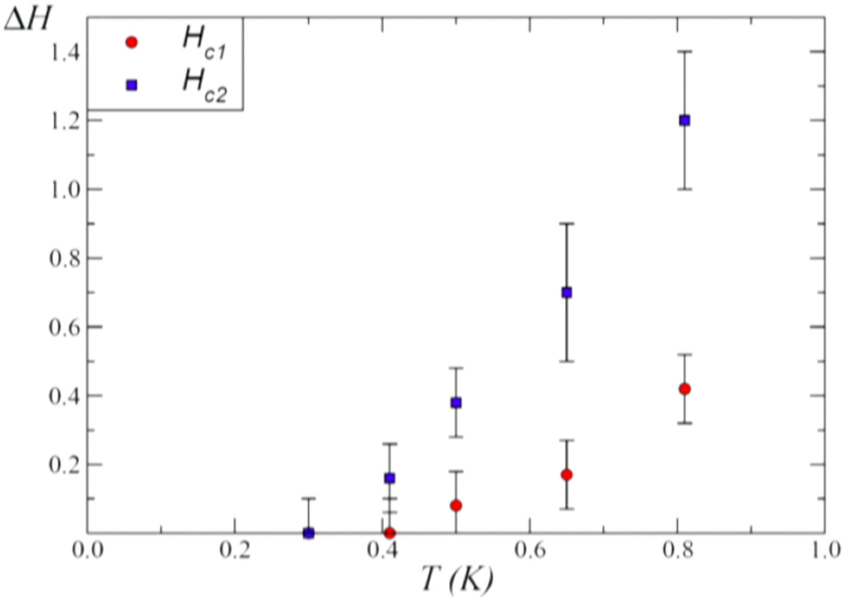
- ☑ what is "optimal" gap (optimal ΔH)?
- ☑ when the impurity and b-b mean-free paths are equal $\ell_{\text{imp}} \approx \ell_{bb}$ (only b-b part knows about the gap $\Delta=\Delta H$)

$$n_i \approx (mT)^{3/2} \, e^{-\Delta/T}$$

$$\Delta = T \cdot \ln\left(\frac{(mT)^{3/2}}{n_{\text{imp}}}\right)$$

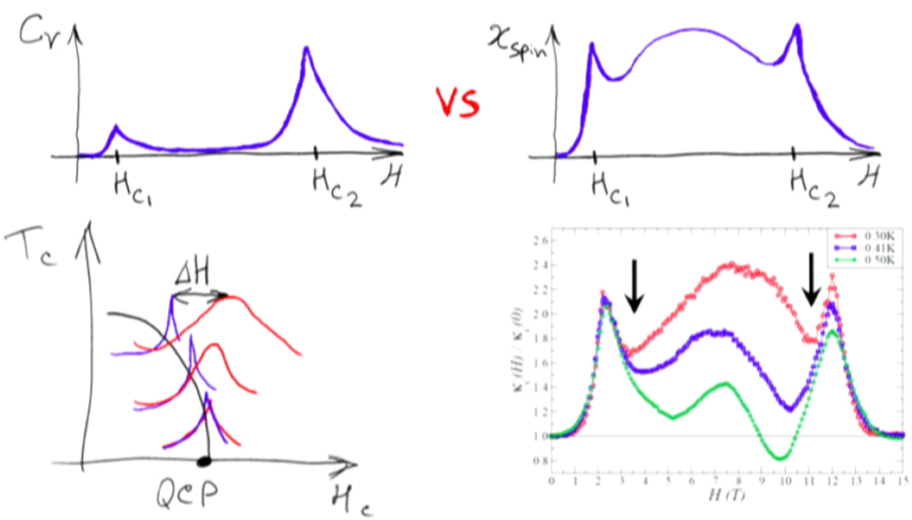






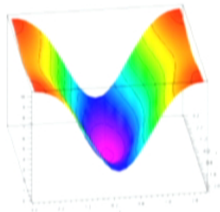
conclusions

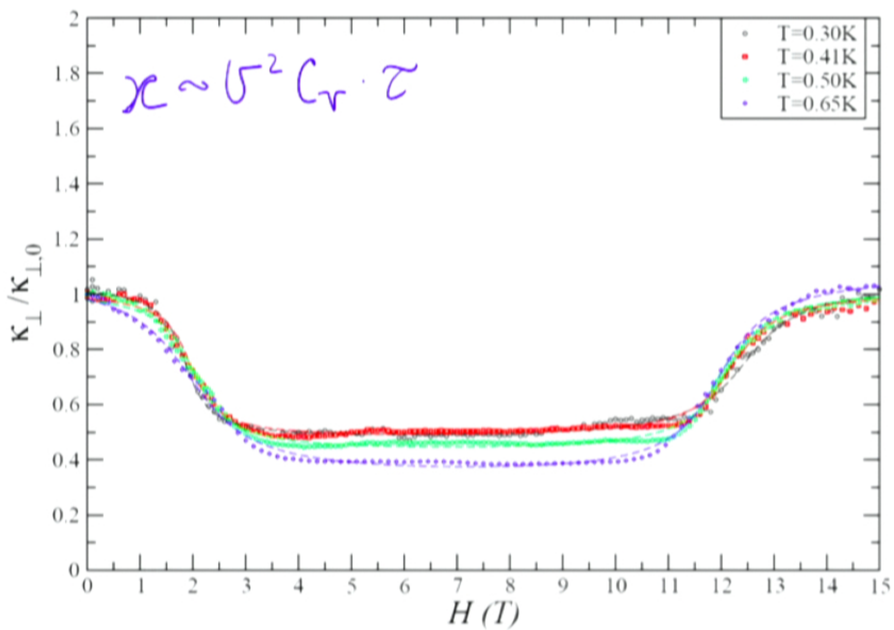
- clear field-induced thermal current by spins in DTN
  - "no asymmetry" – intriguing compensation of m, δD renorm.
  - "migrating peaks" – interplay of imp. and b-b, "Goldilocks gap"
  - "minima" in the ordered state – 3-boson decays
- experiments in other BEC's needed (clean and low T !!)
- more to come



analysis, II: "phonon addition"

- ☑ is this a "true" feature (possible off-set by the phonon scattering in the BEC phase)?
- ☑ anisotropic dispersion → no spin part in the "weak" direction – only phonon scattering





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analysis, II: "phonon addition"

☑ is the "migration" of the peaks away from H_c's a "true" feature?
YES