A theory of the underdoped cuprates

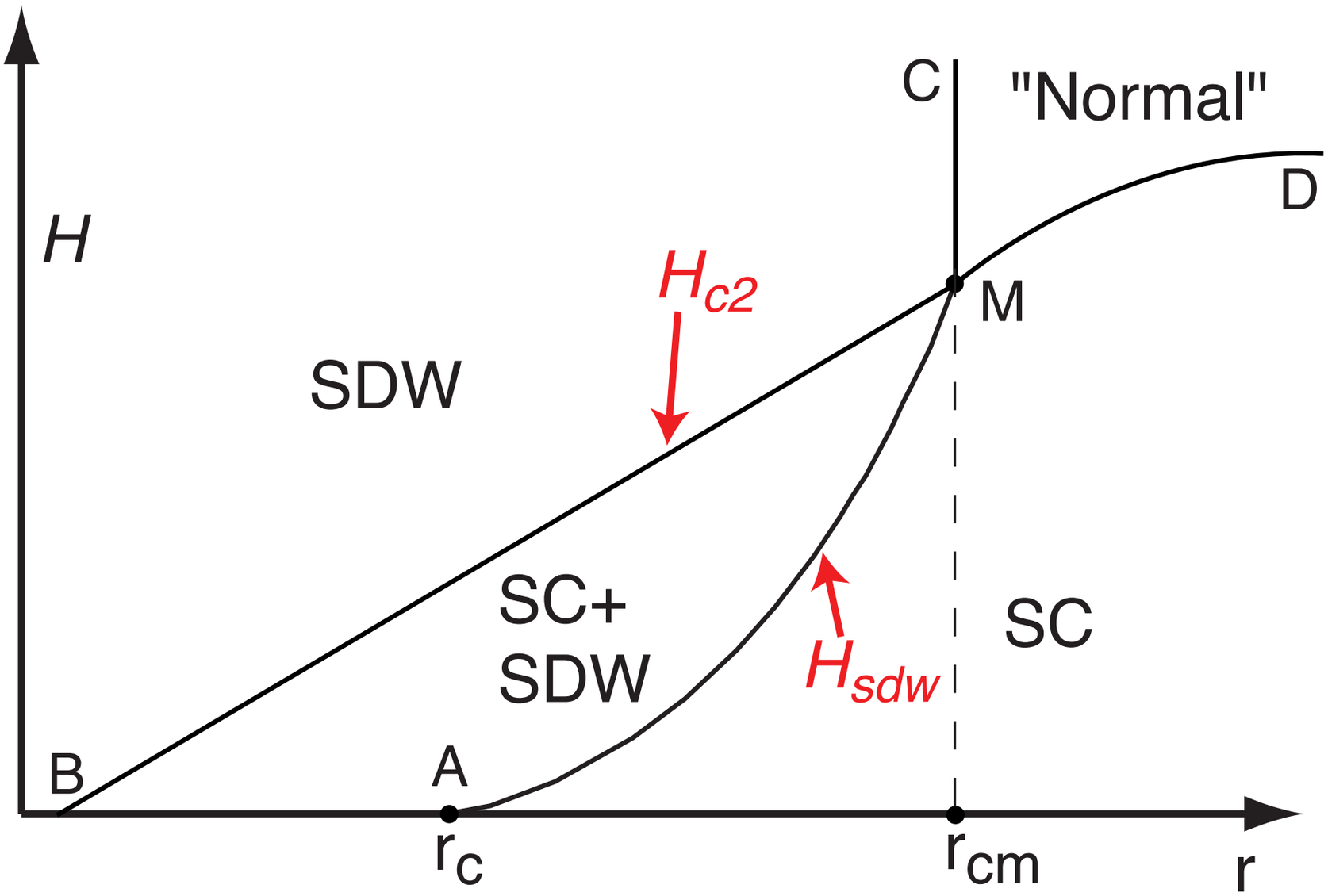
Destruction of Neel order in the cuprates by electron doping, R. K. Kaul, M. Metlitksi, S. Sachdev, and C. Xu, *Physical Review B* **78**, 045110 (2008).

Paired electron pockets in the underdoped cuprates, V. Galitski and S. Sachdev, *Physical Review B* **79**, 134512 (2009).

Competing orders in the underdoped cuprates, Eun Gook Moon and S. Sachdev, *to appear*

Phenomenological quantum theory of competing orders

Competition between superconductivity (SC) and spin-density wave (SDW) order



E. Demler, S. Sachdev and Y. Zhang, *Phys. Rev. Lett.* **87**, 067202 (2001).

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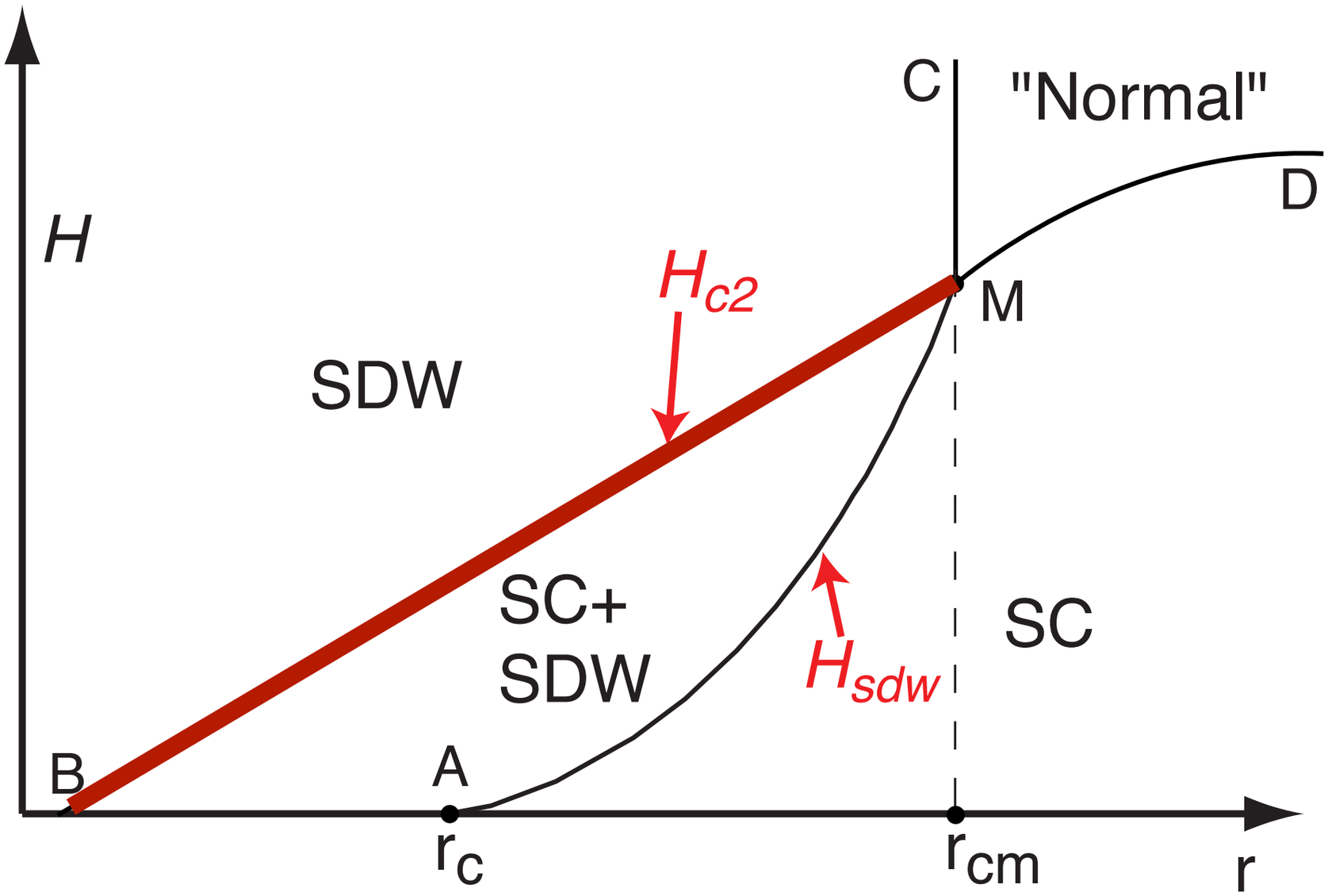

- Upper-critical field, H_{c2}, decreases as SDW is enhanced with decreasing doping (r)

E. Demler, S. Sachdev and Y. Zhang, *Phys. Rev. Lett.* **87**, 067202 (2001).

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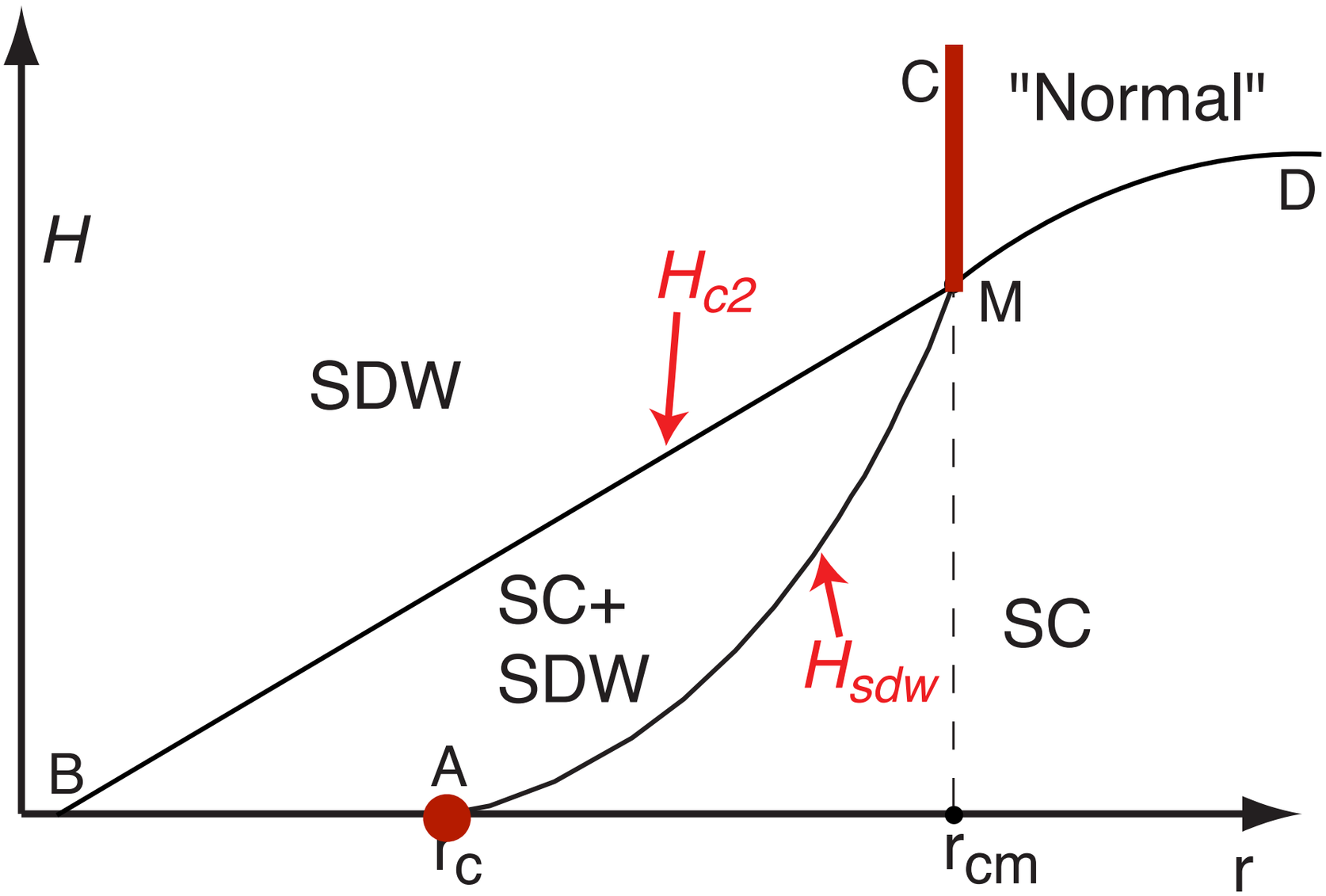

- SDW order is more stable in the metal than in the superconductor: $r_{cm} > r_c$.

E. Demler, S. Sachdev and Y. Zhang, *Phys. Rev. Lett.* **87**, 067202 (2001).

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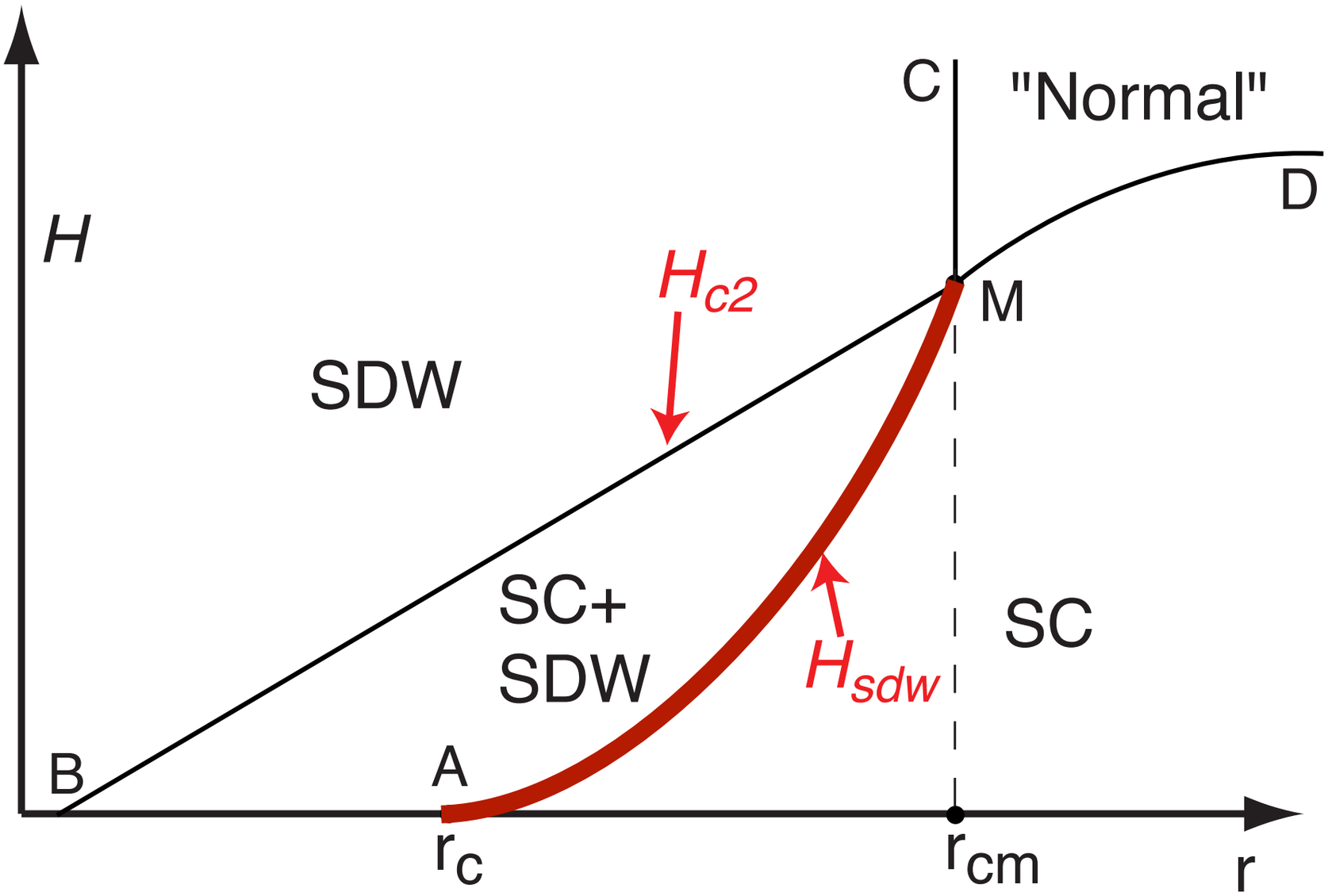

- For doping with $r_c < r < r_{cm}$, SDW order appears at a quantum phase transition at $H = H_{sdw} > 0$.

E. Demler, S. Sachdev and Y. Zhang, *Phys. Rev. Lett.* **87**, 067202 (2001).

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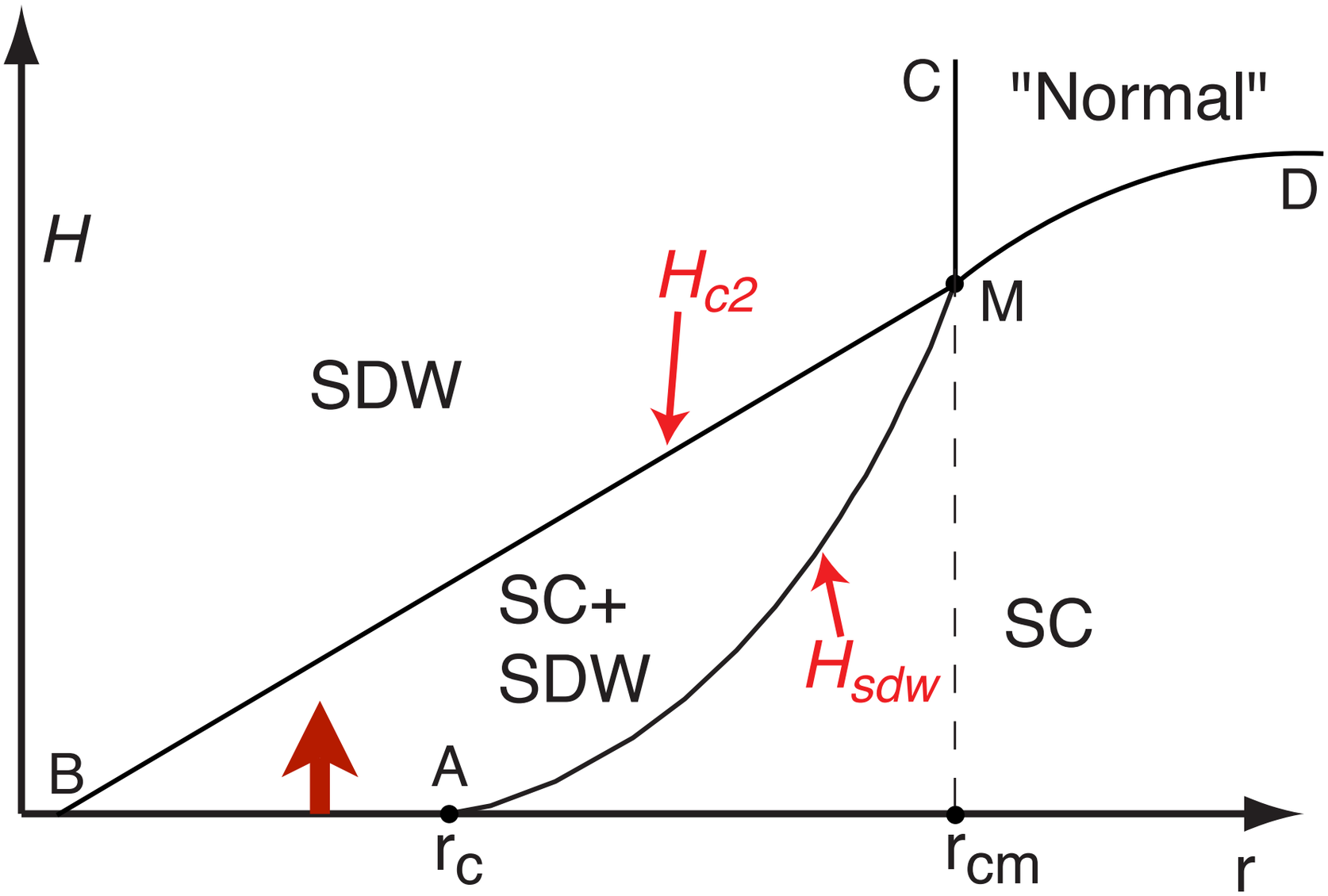

Neutron scattering on $La_{1.9}Sr_{0.1}CuO_4$

B. Lake *et al.*, *Nature* **415**, 299 (2002)

E. Demler, S. Sachdev and Y. Zhang, *Phys. Rev. Lett.* **87**, 067202 (2001).

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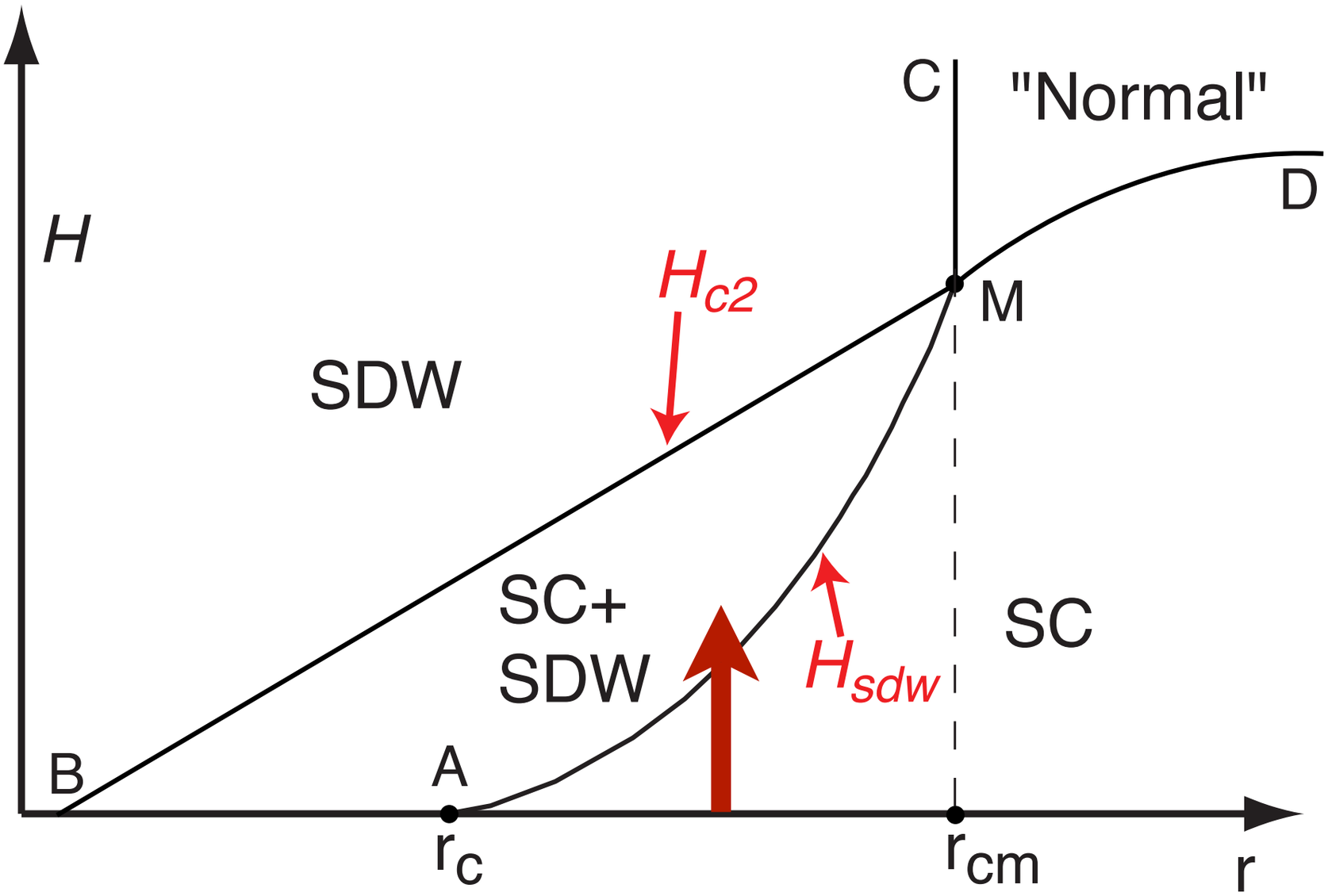

Neutron scattering on $La_{1.855}Sr_{0.145}CuO_4$
J. Chang *et al.*, arXiv:0902.1191

E. Demler, S. Sachdev and Y. Zhang, *Phys. Rev. Lett.* **87**, 067202 (2001).

Phenomenological quantum theory of competing orders

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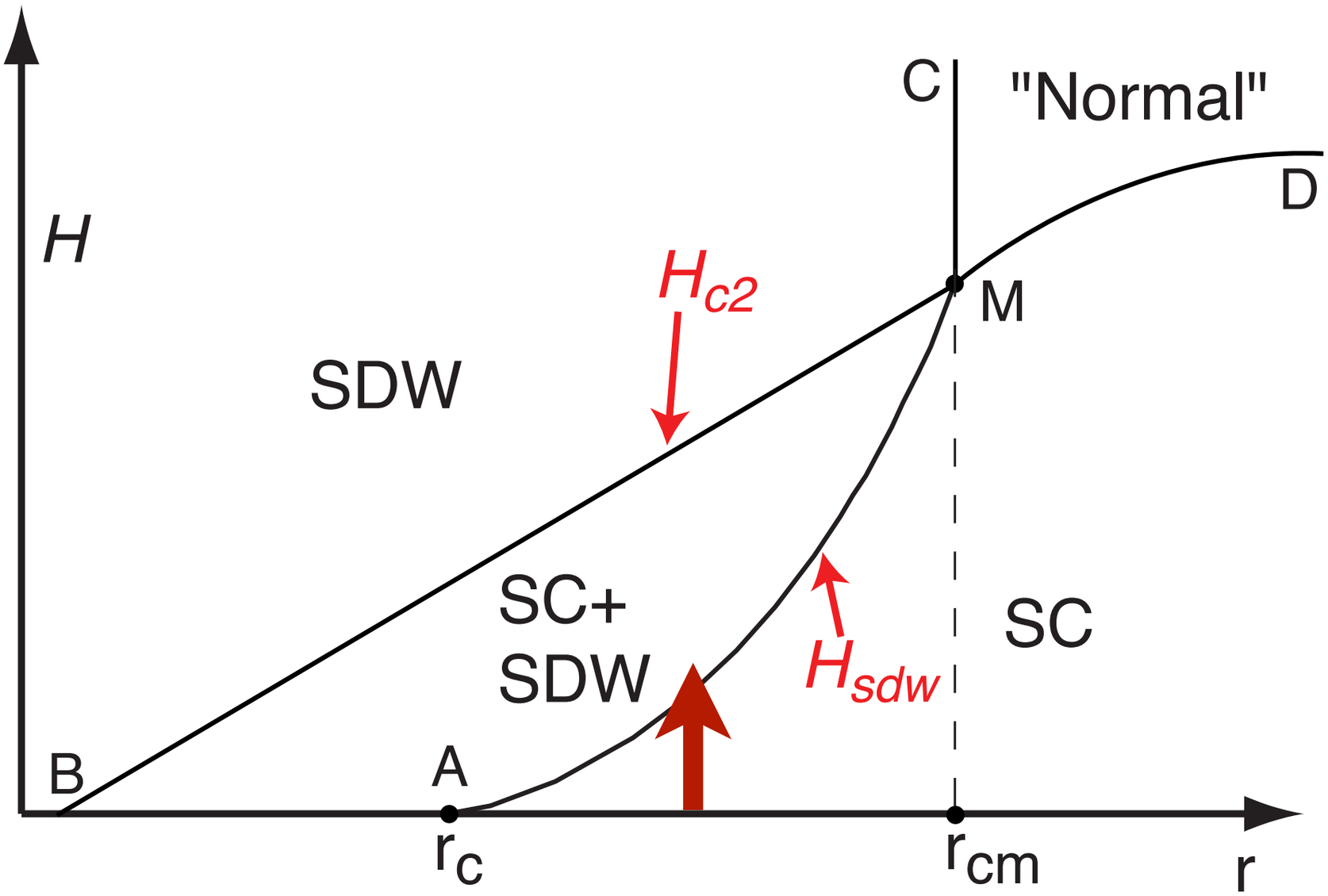

Neutron scattering on $YBa_2Cu_3O_{6.45}$
D. Haug *et al.*, arXiv:0902.3335

E. Demler, S. Sachdev and Y. Zhang, *Phys. Rev. Lett.* **87**, 067202 (2001).

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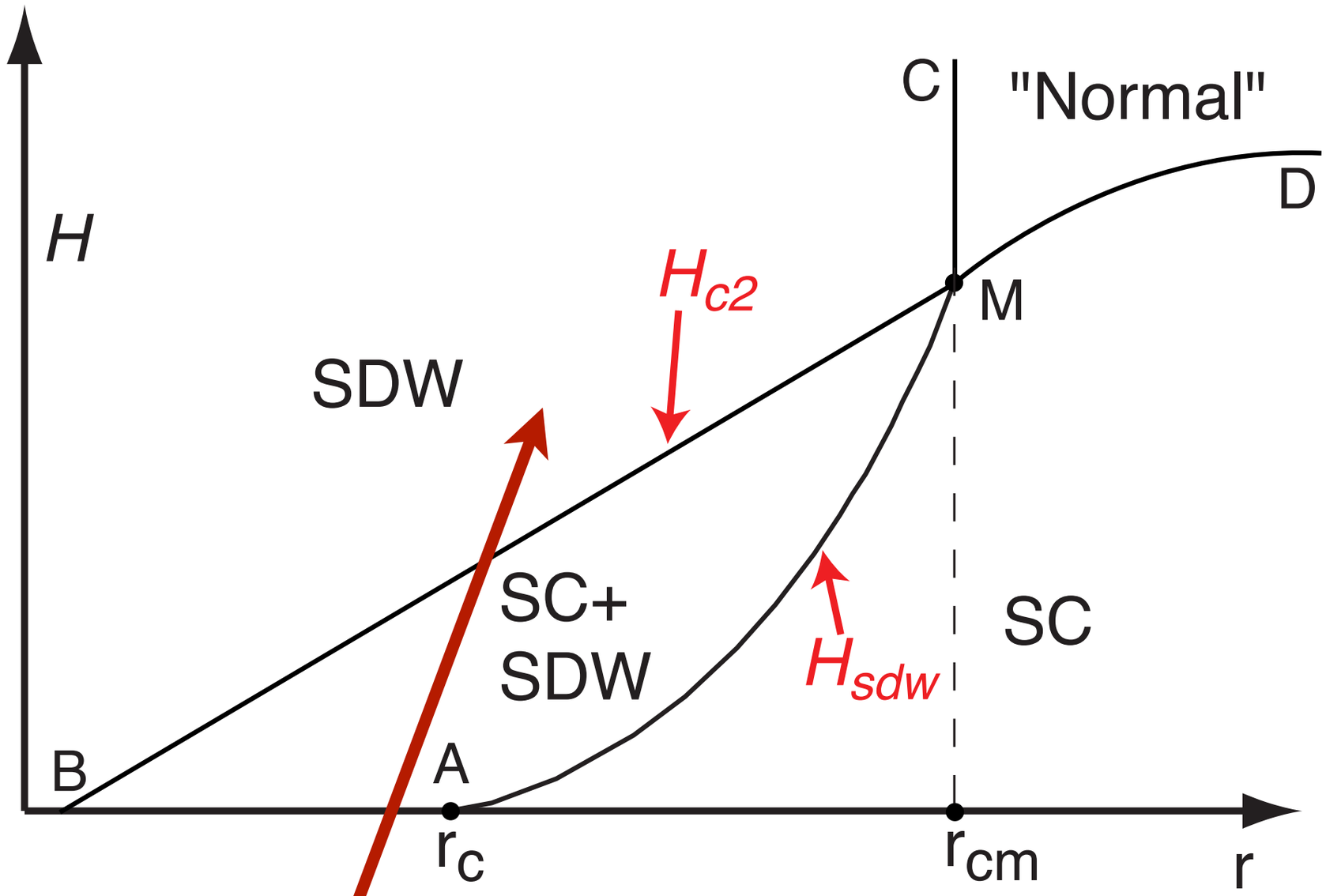
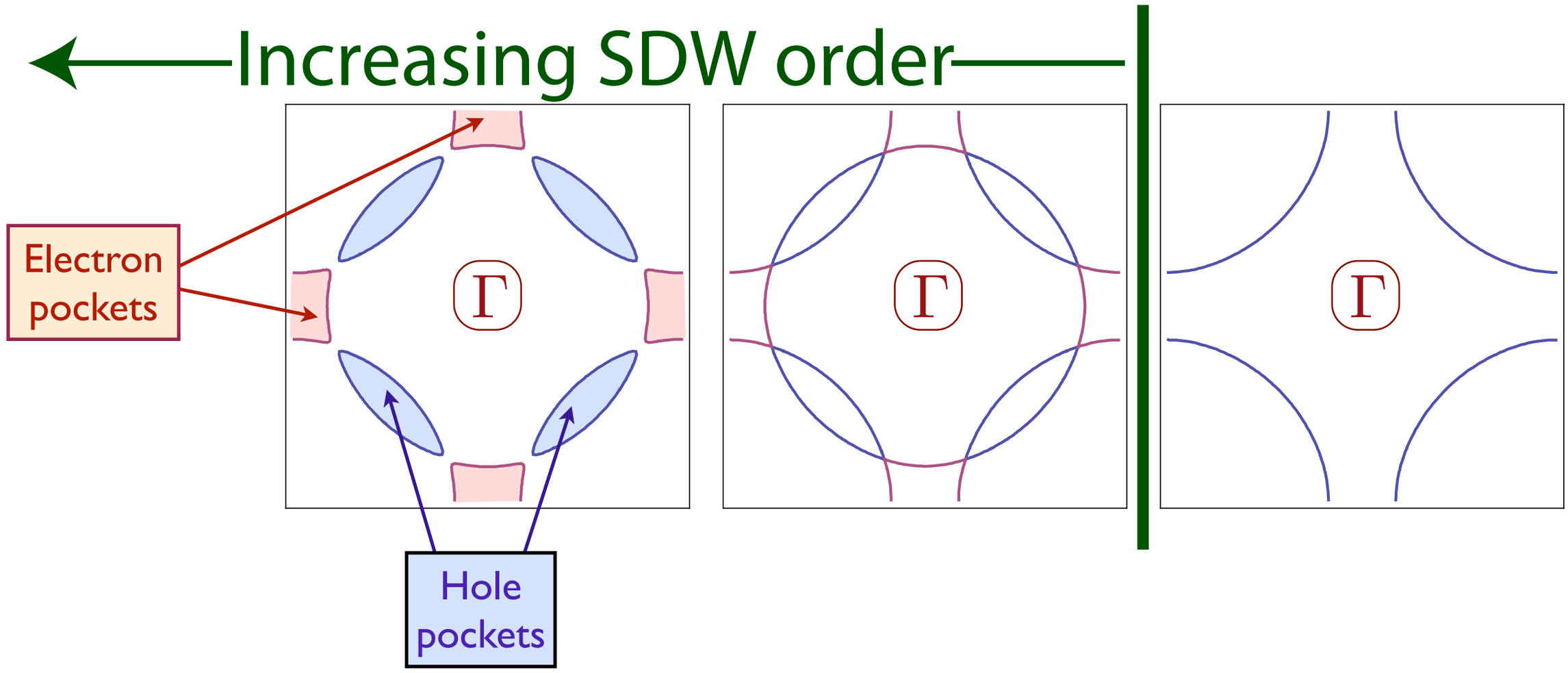


Quantum oscillations without Zeeman splitting

N. Doiron-Leyraud, C. Proust, D. LeBoeuf, J. Levallois, J.-B. Bonnemaison, R. Liang, D. A. Bonn, W. N. Hardy, and L. Taillefer, *Nature* **447**, 565 (2007)

Spin density wave theory in hole-doped cuprates



S. Sachdev, A. V. Chubukov, and A. Sokol, *Phys. Rev. B* **51**, 14874 (1995).
A.V. Chubukov and D. K. Morr, *Physics Reports* **288**, 355 (1997).

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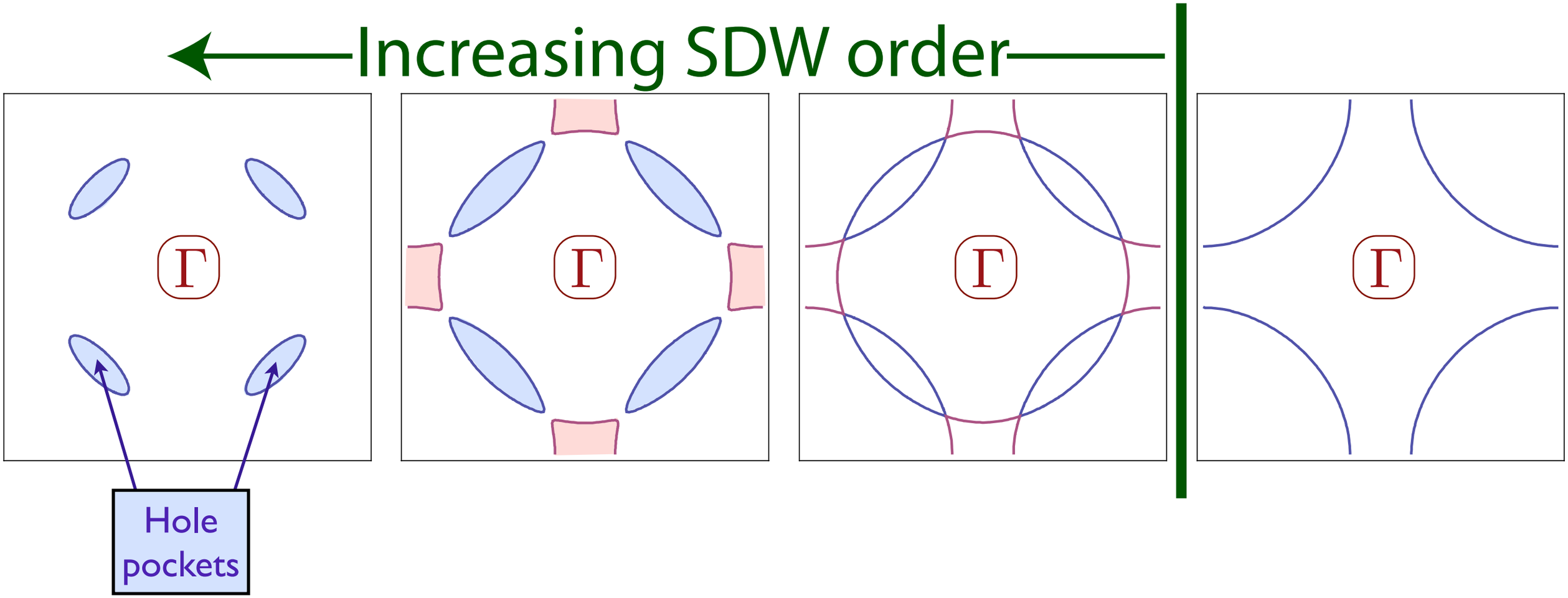

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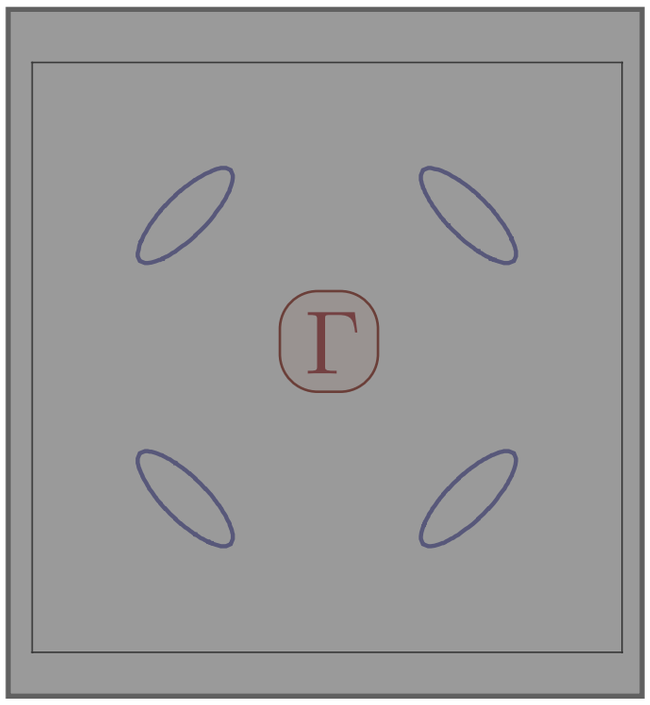
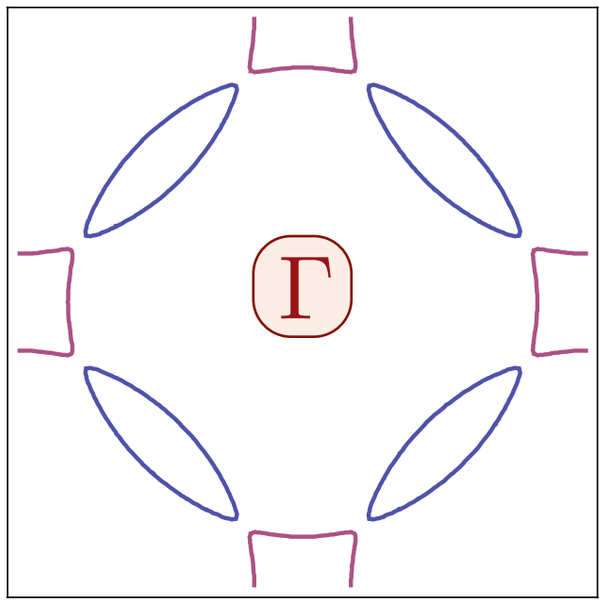
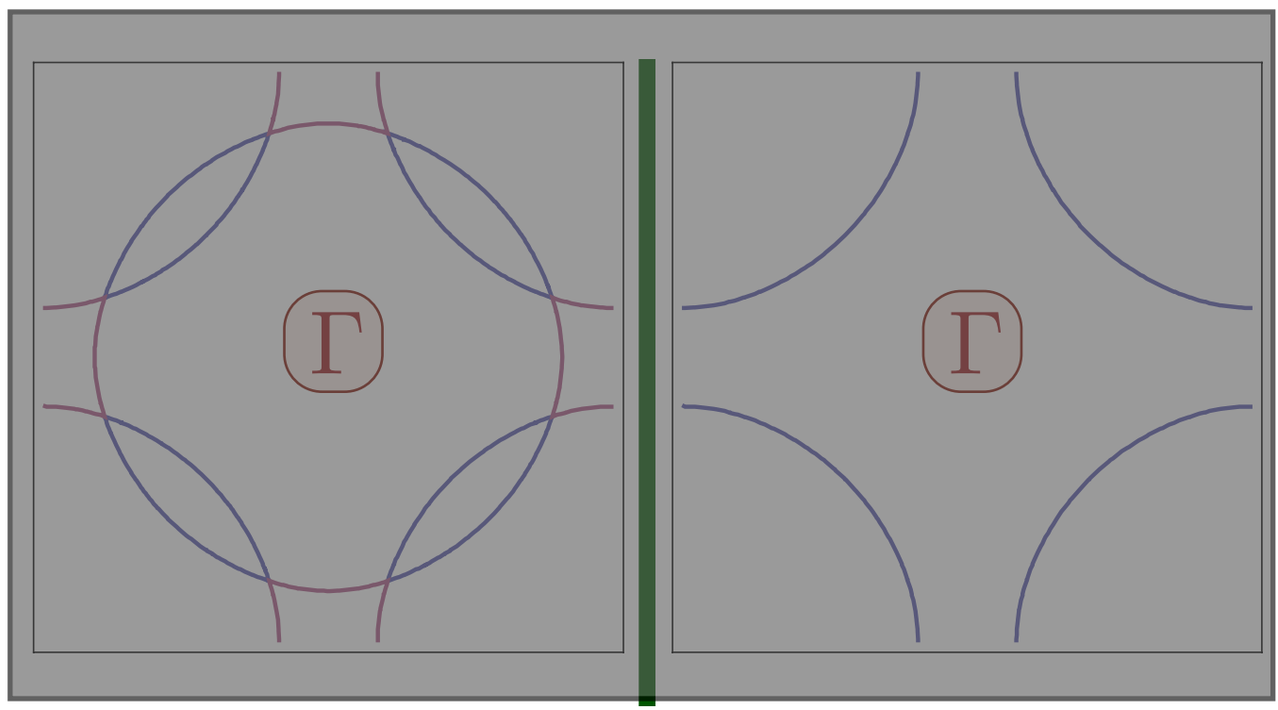
A.V. Chubukov and D. K. Morr, *Physics Reports* **288**, 355 (1997).

Fermi pockets in hole-doped cuprates

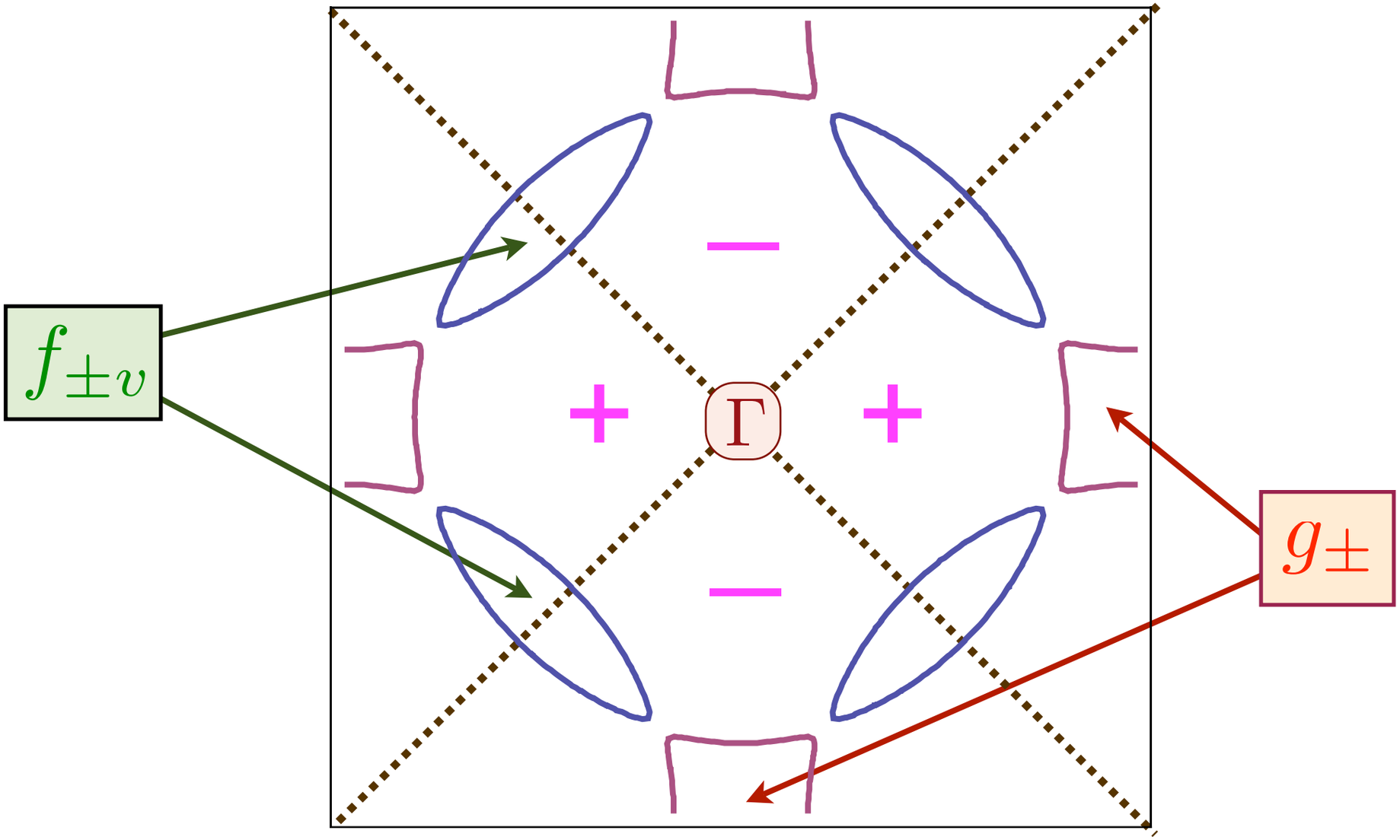






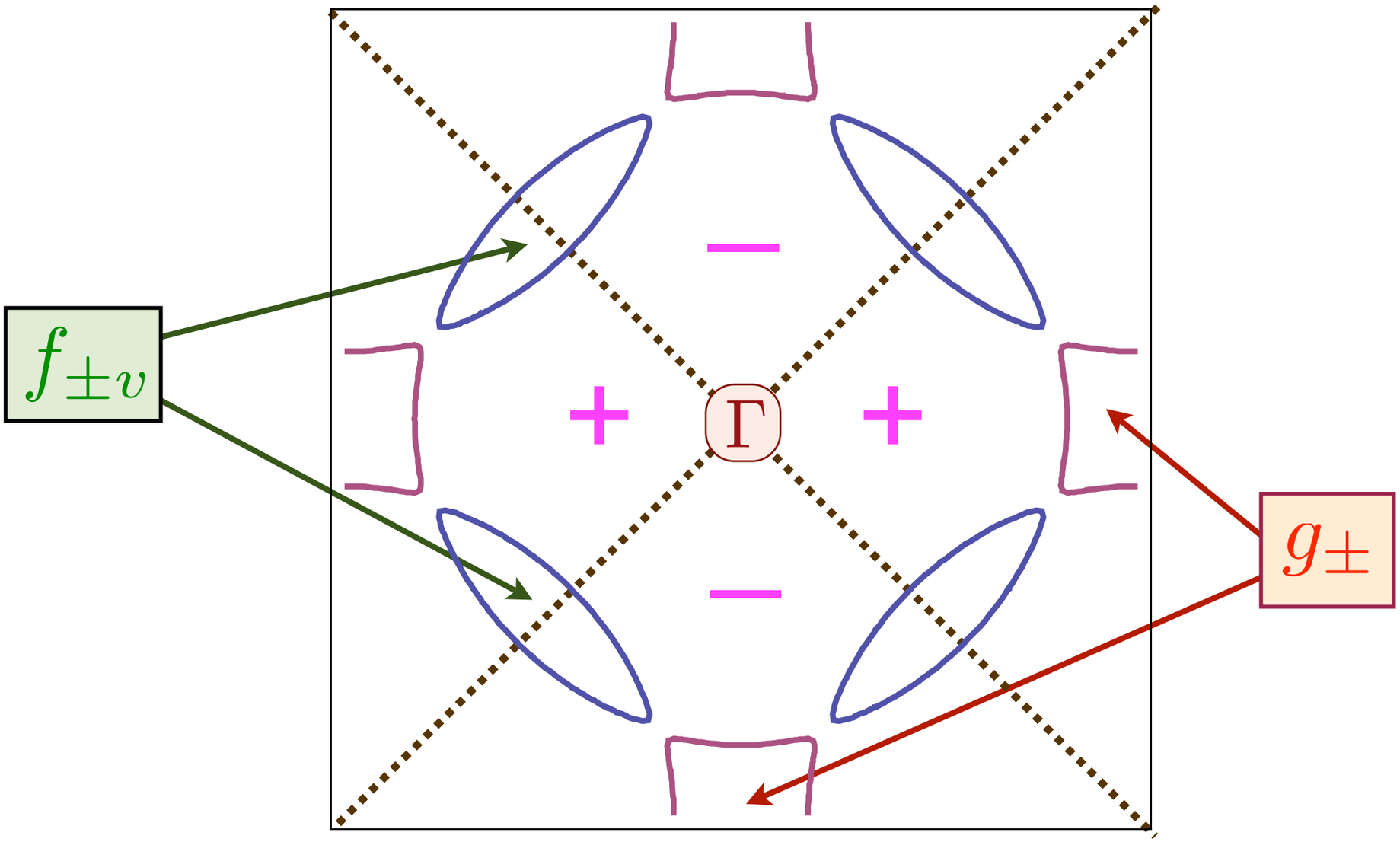
Begin with SDW ordered state, and focus on fluctuations in the *orientation* of the SDW order parameter $\vec{\varphi}$, by using a unit-length bosonic spinor z_α

$$\vec{\varphi} = z^*_\alpha \vec{\sigma}_{\alpha\beta} z_\beta$$



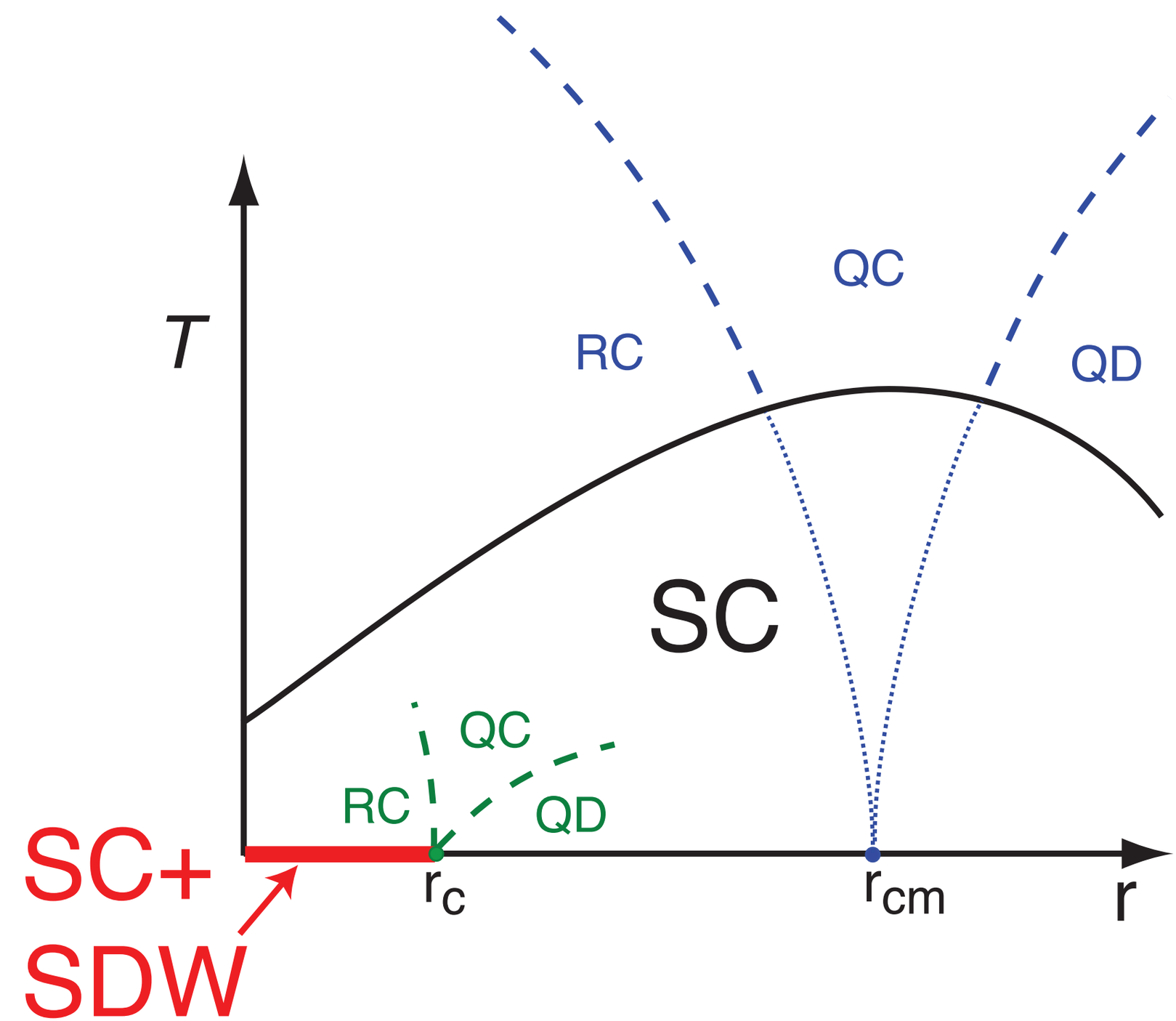
d-wave pairing of the electrons is associated with

- Strong s-wave pairing of $g_{\pm}$
- Weak p-wave pairing of $f_{\pm v}$.



Field-doping phase diagram has all the key features of the phenomenological theory of competing orders

Finite temperature "pseudogap"



- Because $r_{cm} > r_c$, for $T > T_c$ there is local SDW order which is disordered by thermal fluctuations.