Metal-Insulator Transition in Graphene

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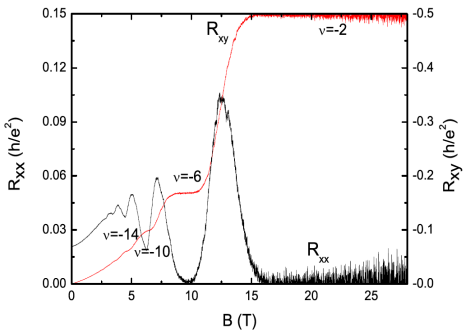

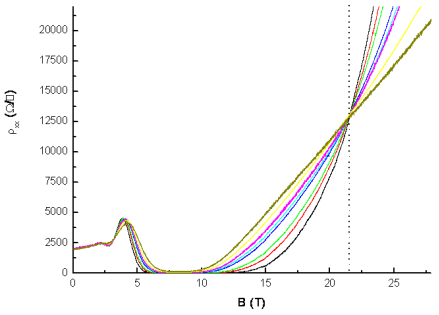

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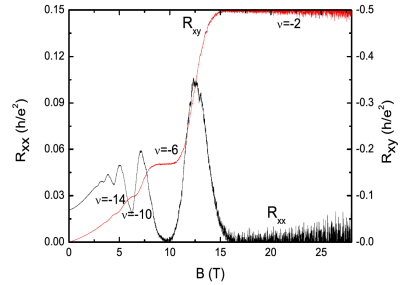
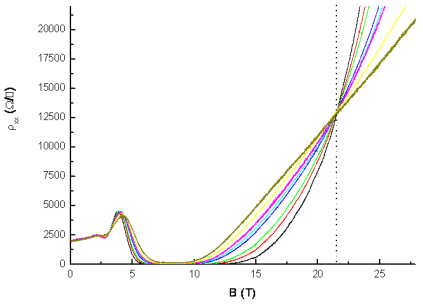


- **Quantum Hall regime in graphene**

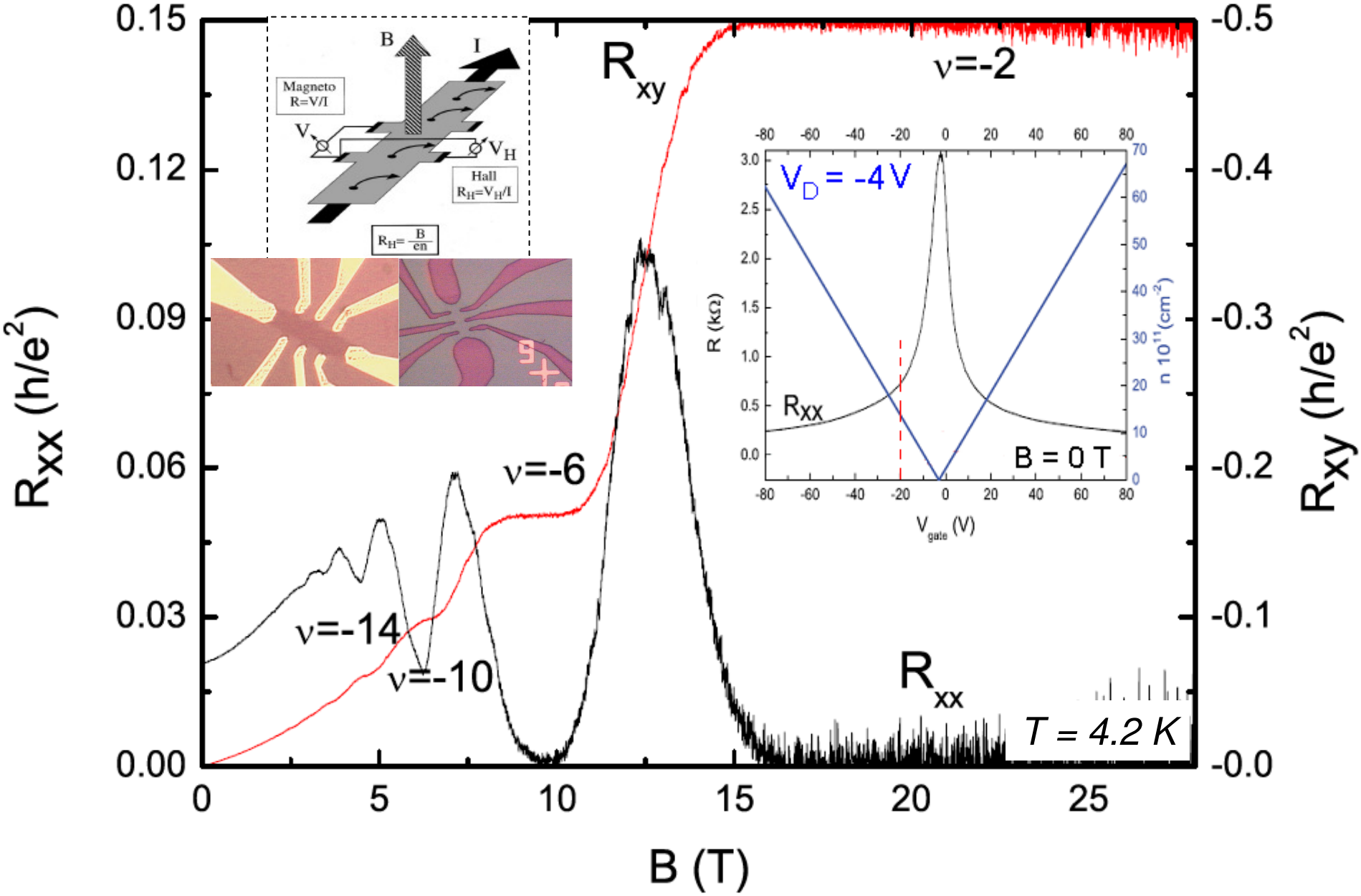
- **T-dependence of QHE in graphene: Metal–Insulator (MI) transition**



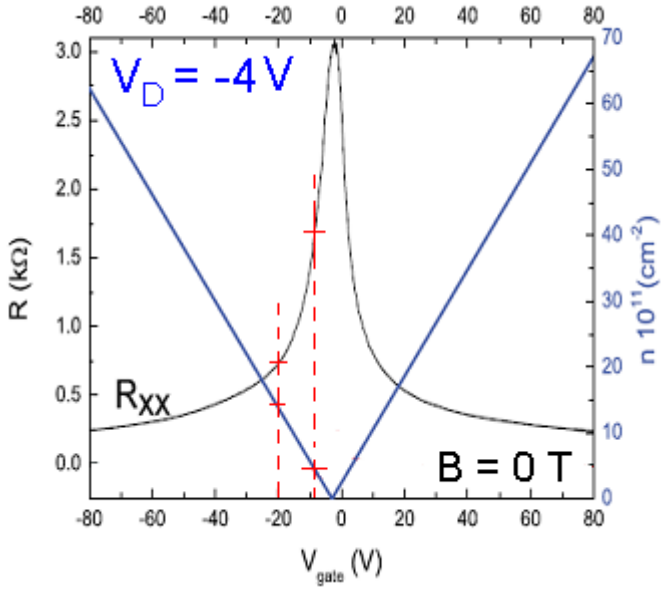
- **Scaling theory of QHE in 2DES: critical exponent of the MI quantum phase transition**

- **Conclusion: non-universality of MI transition**

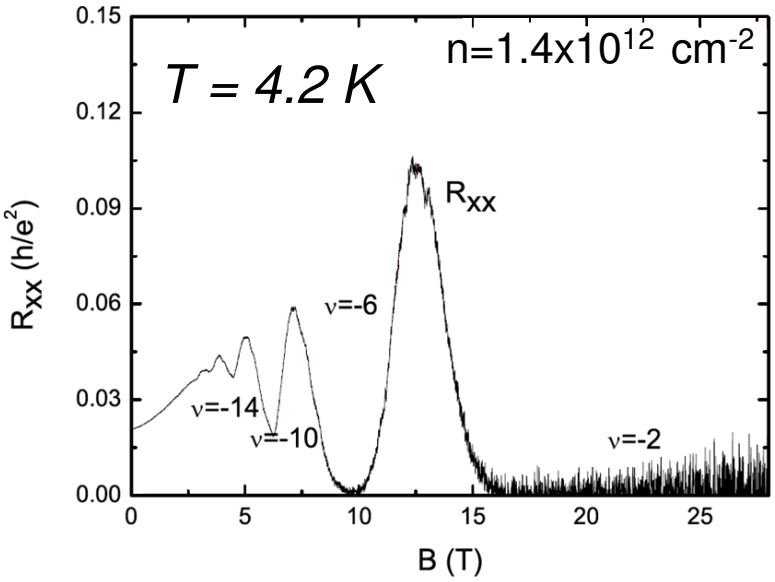
QHE in graphene



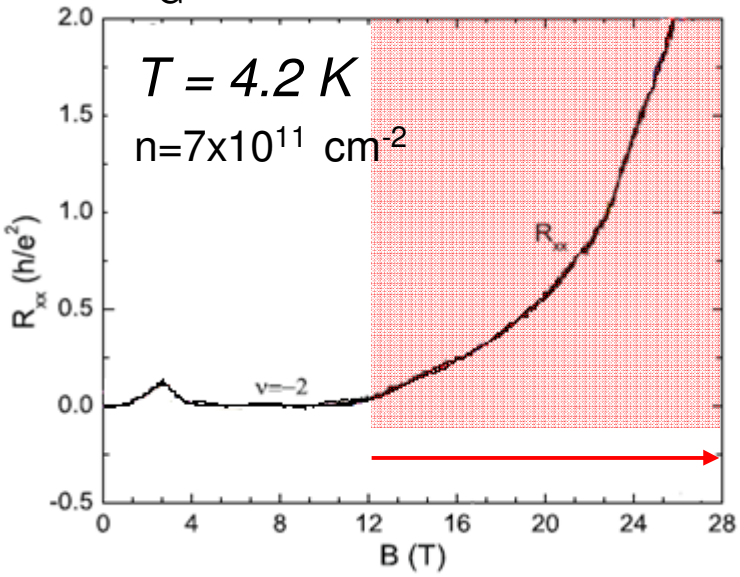
QHE in graphene



V_G=-20V "far" from CNP

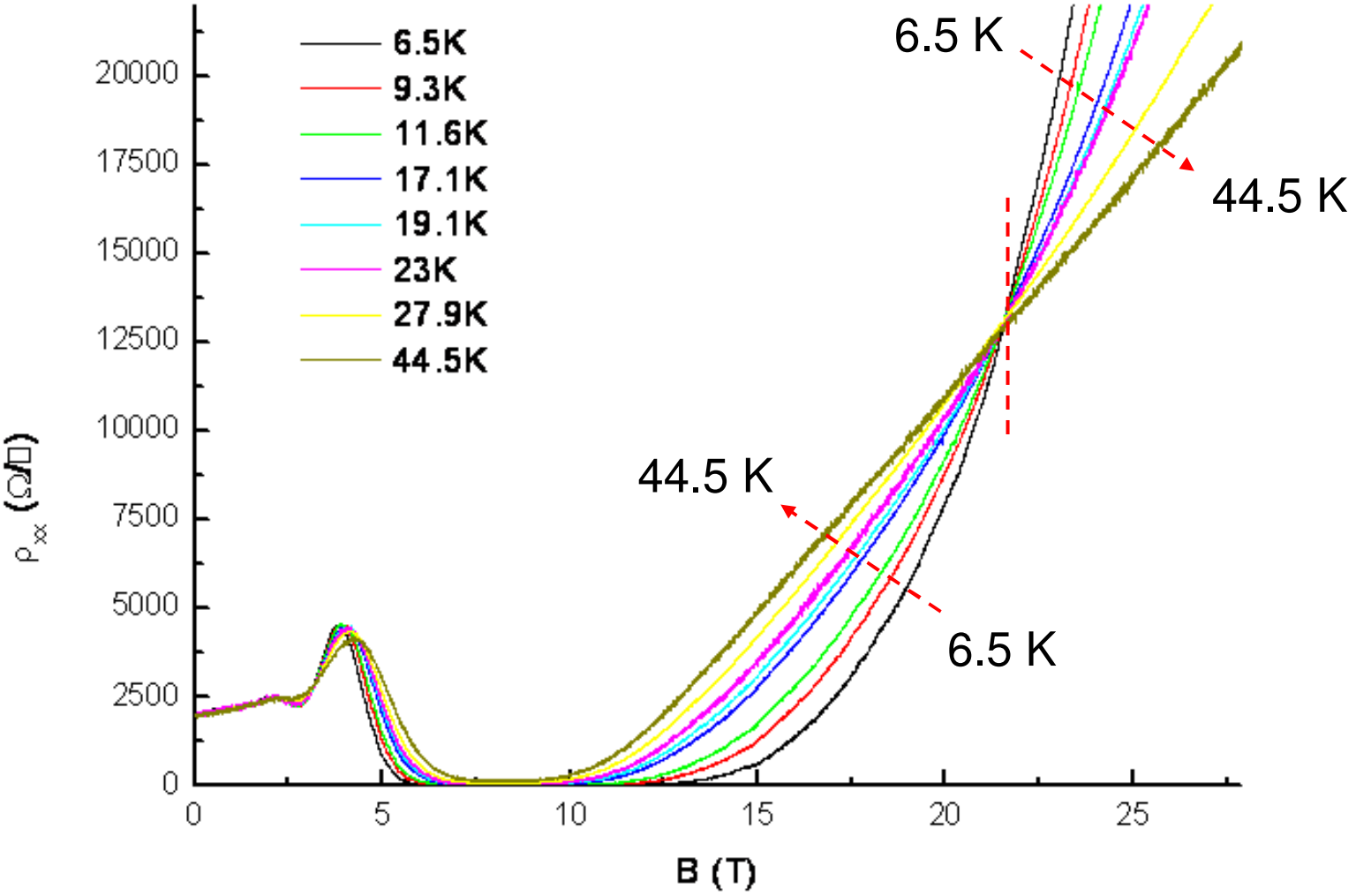


V_G=-8V "close" to CNP



T - dependence of QHE

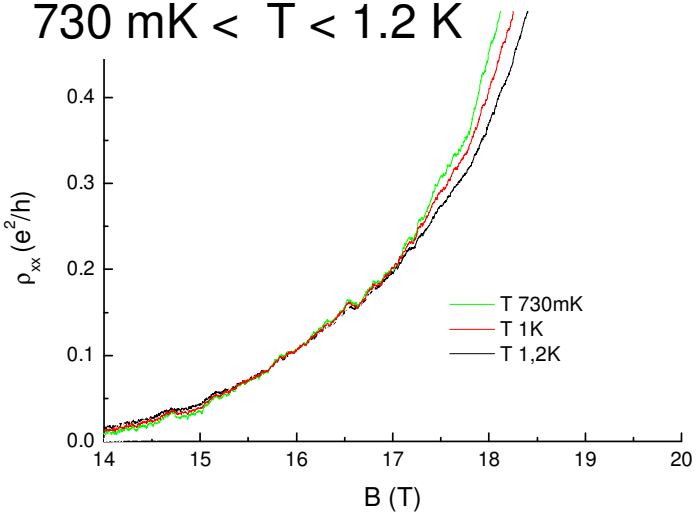
4V from CNP



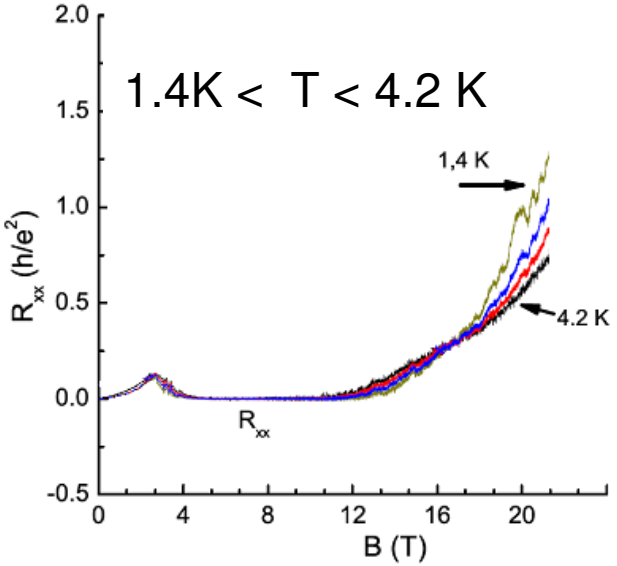
n=6.8x10^{11} cm^{-2}

T - dependence of QHE

730 mK < T < 1.2 K

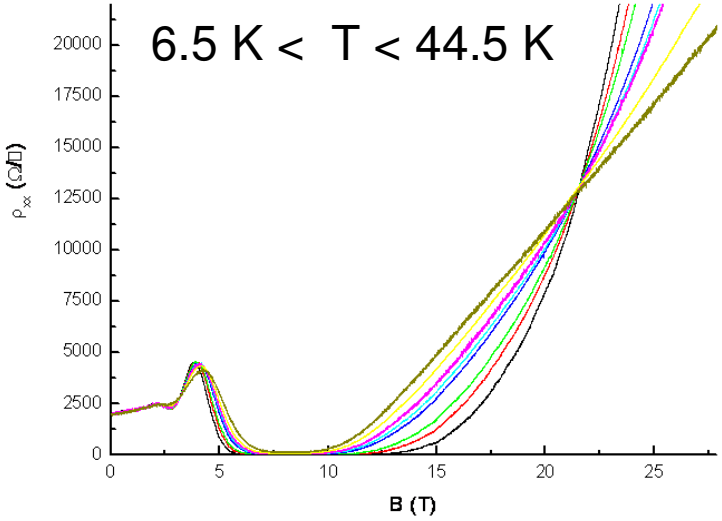


1.4K < T < 4.2 K



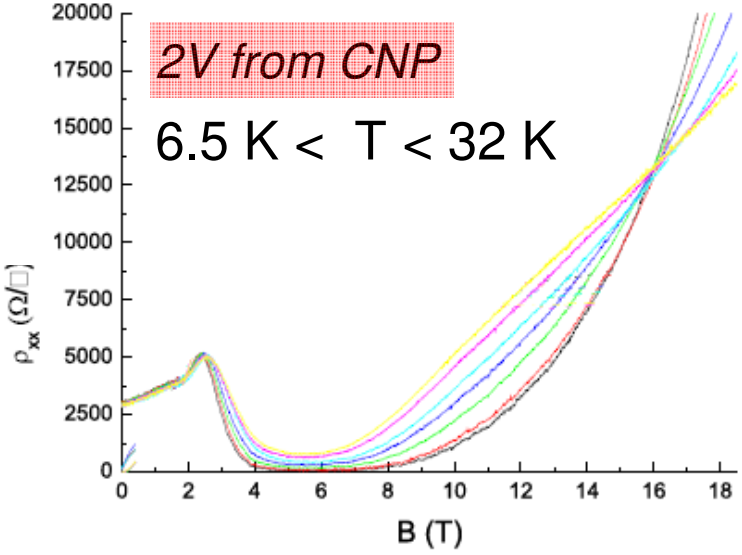
4V from CNP

6.5 K < T < 44.5 K

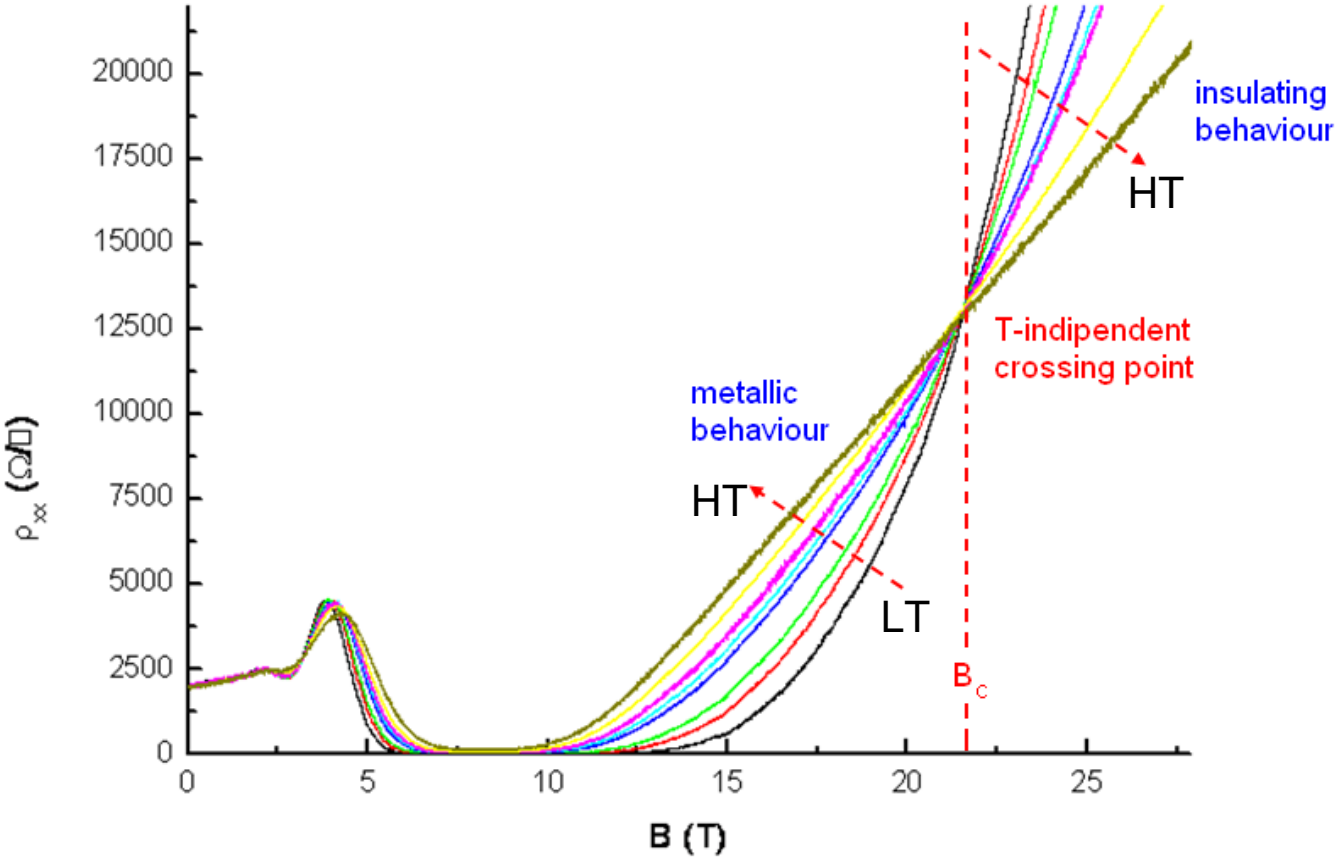


2V from CNP

6.5 K < T < 32 K



T - dependence of QHE

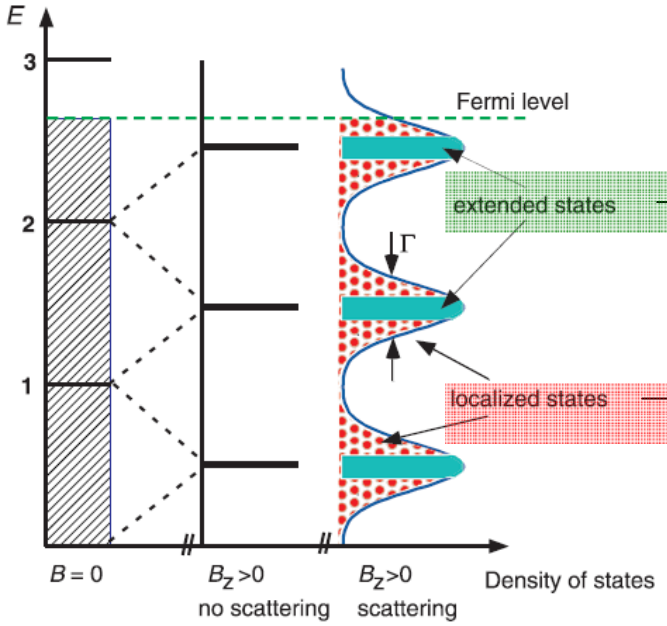


metallic state ⇨ ***insulating state***

Metal – Insulator Transition (MIT)

First observation on graphene

Metal-Insulator Quantum Phase Transition in 2DES



extended states → R_{xy} sharp rise & R_{xx} SdH peaks

localized states → R_{xy} plateaus & R_{xx} zero minima

Beyond the last plateau @ v = 2, the observed MIT takes place

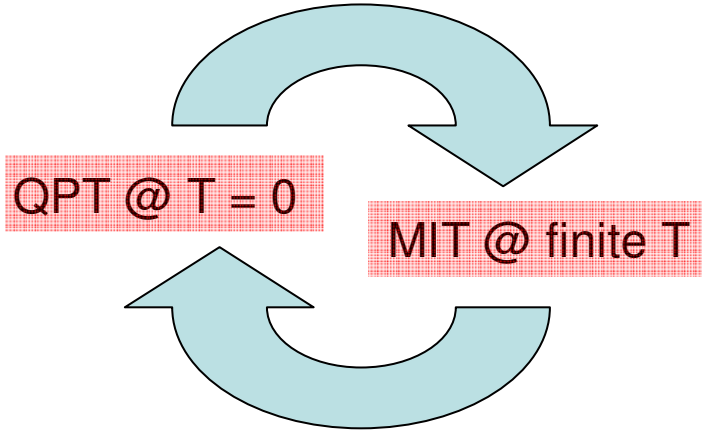
Nature of the MIT intimately related to localization lenght ξ of the wavefuncion, which for 2DES in the QH regime @ 0 K, obeys the law:

$$\zeta = (E - E_C)^{-\gamma}$$ → ***critical exponent***

which in turn defines a Quantum Phase Transition (QPT)

Wei HP et al PRL 61 1294 (1998); Hilke M et al 1998 Nature 395 675; Pruisken et al. SSC 137 (2006) 540

Scaling theory of QHE in 2DES
(Renormalization group theory applied to QH regime in 2DES)



T-dependence of experimentally accessible parameters R_{xx}, n_{2D} and B

$$R_{xx} = \exp[-\Delta\nu/\nu_0(T)] \qquad \Delta\nu = 1/B - 1/B_c$$

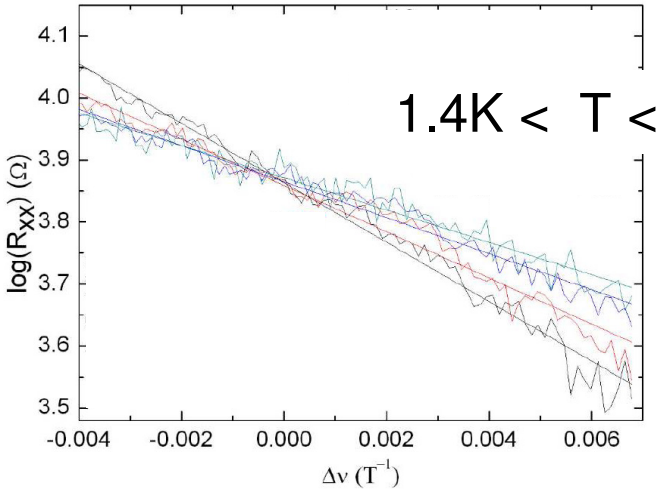
$$\nu_0 \propto T^{\kappa}$$ → *critical exponent*

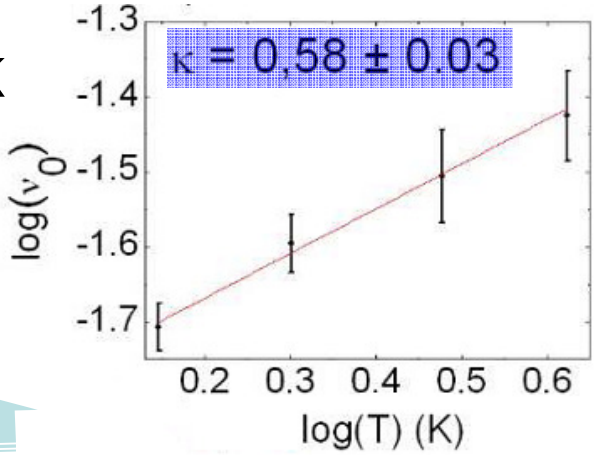
$$\mathrm{Log}(R_{xx}) = -\Delta\nu/\nu_0(T)$$

$$\mathrm{Log}(\nu_0) \propto k * \mathrm{Log}(T)$$

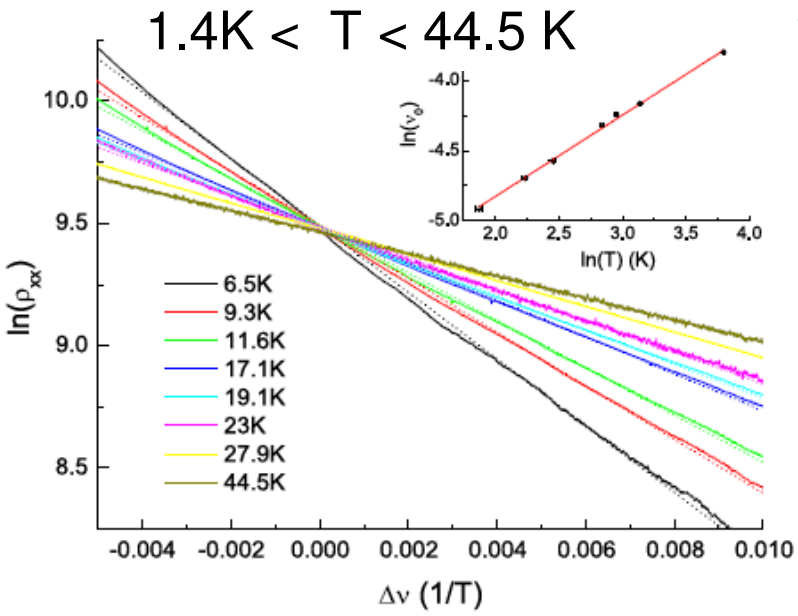
$\mathrm{Log}(R_{xx}) = -\Delta\nu/\nu_0(T)$

$\mathrm{Log}(v_0) \propto k * \mathrm{Log}(T)$





4V from CNP

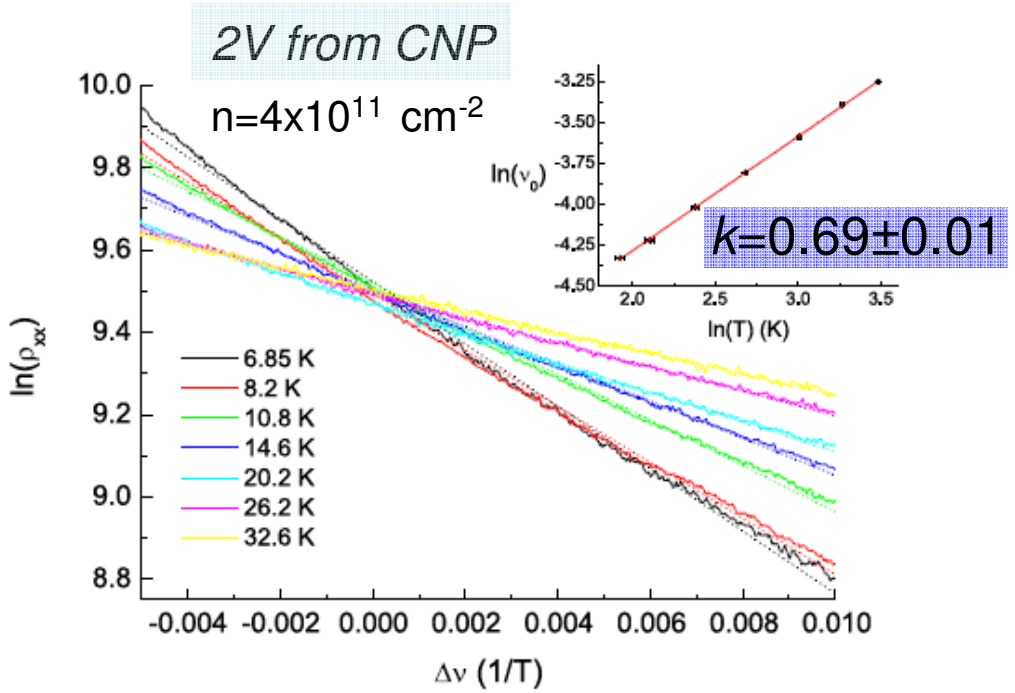


- ***Scaling model ok:***
  MIT transition in graphene
  QPT with critical exponent
  κ = 0.58 ± 0.03

- ***QPT robust! Observable up to 45 K***

- ***k_{2DES} ~ 0.57 ---- universality of the MI-QPT?***

Keeping the system even closer to the CNP …



… the critical exponent change to k = 0.7

MIT QPT non-universal

Amado et al NJP 12 (2010) 053004; Zhang et al PRL 105, 046804 (2010); Amado et al, in preparation

Conclusions

- Study of T-dependence of QHE in graphene evidences a MIT beyond the v=2 plateau
- MIT observable up to 40 K very robust
- Scaling theory of QHE identifies the MIT as a QPT with non-universal critical exponent

Thanks for your attention