
# Negative Magnetoresistance in High-Mobility Heterostructures


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**Dr. Lina Bockhorn** **Dr. Eddy Rugeramigabo**

**Shirin Hakim** **Asija Velieva**

**High-mobility samples:**
**Prof. Werner Wegscheider (Zürich)**
**Dr. Dieter Schuh (Regensburg)**

**Theory contributions:**
**Dr. Igor Gornyi (Karlsruhe)**
**Prof. Jesus Inarrea (Madrid)**

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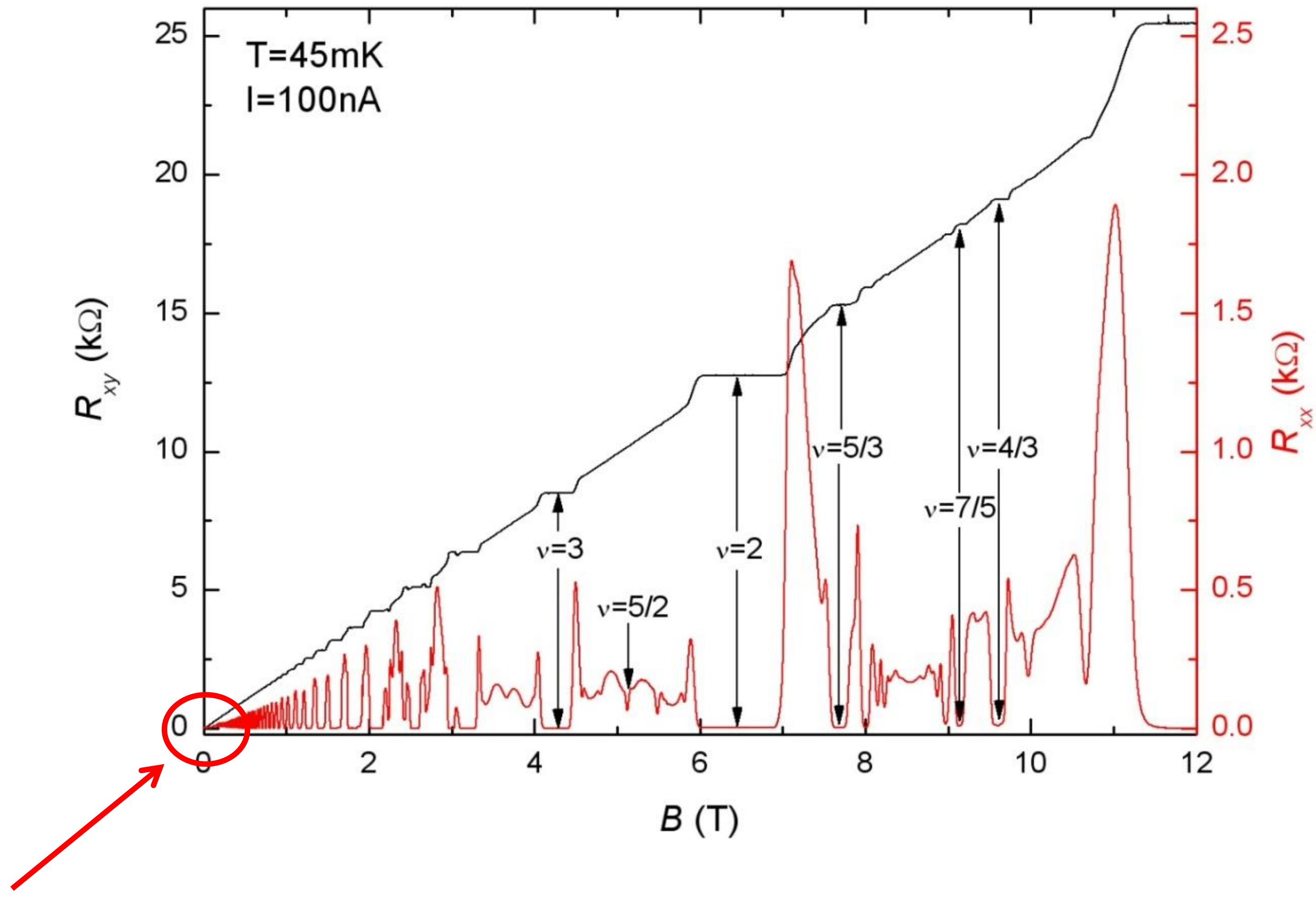
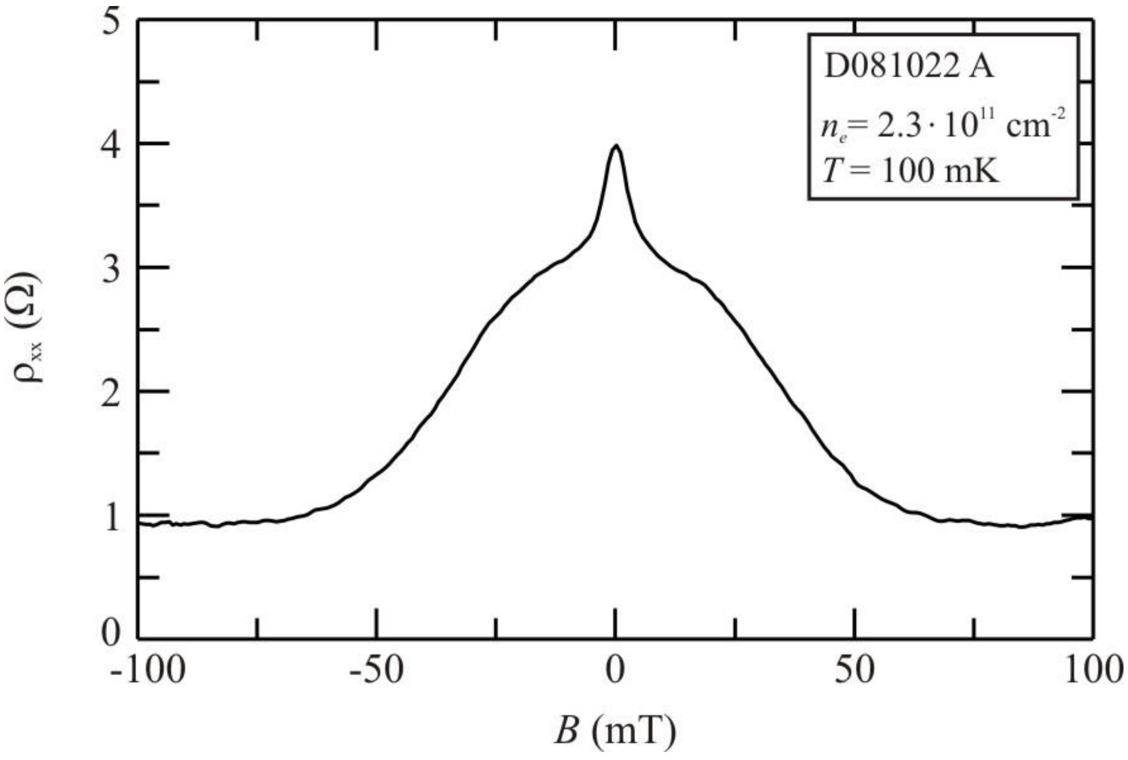
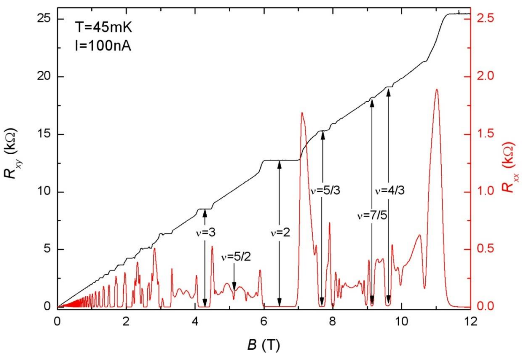

T=45mK
I=100nA
$R_{xy}$ (kΩ)
$R_{xx}$ (kΩ)
B (T)
ν=3
ν=5/2
ν=2
ν=5/3
ν=7/5
ν=4/3
0
5
10
15
20
25
0.0
0.5
1.0
1.5
2.0
2.5
0
2
4
6
8
10
12

# Magnetoresistance in High-Mobility Sample.




**Phys. Rev. B. 83, 113301 (2011)**

**apparently several groups had observed such strange magnetoresistance curves (e.g. Umansky et al. APL 71, 683 (1997), Dai et al. PRL (2010)), but no detailed investigations and no explanations**

**In the meantime several other experimental observations**

# Names for Negative Magnetoresistances

| | |
|---|---|
| L. Bockhorn, P. Barthold, D. Schuh, W. Wegscheider, and R. J. Haug, Phys. Rev. B 83, 113301 (2011). | huge |
| A. T. Hatke, M. A. Zudov, J. L. Reno, L. N. Pfeiffer, and K. W. West, Phys. Rev. B 85, 081304 (2012). | giant |
| R. G. Mani, A. Kriisa, and W. Wegscheider, Scientifc Reports 3, 2747 (2013). | giant |
| Q. Shi, P. D. Martin, Q. A. Ebner, M. A. Zudov, L. N. Pfeiffer, and K. W. West, Phys. Rev. B 89, 201301(R) (2014). | colossal |
| L. Bockhorn, I. V. Gornyi, D. Schuh, C. Reichl, W. Wegscheider, and R. J. Haug, Phys. Rev. B 90, 165434 (2014). | giant (rare) |
| Q. Shi, M. A. Zudov, L. N. Pfeiffer, and K. W. West, Phys. Rev. B 90, 201301 (2014). | colossal |
| L. Bockhorn, J. Inarrea, and R.J. Haug, arXiv 1504.00555 | huge |

# Overview

- **negative magnetoresistances**
- **magnetoresistance due to oval defects**
- **current-induced negative magnetoresistance**
- **size dependence**
- **conclusions**

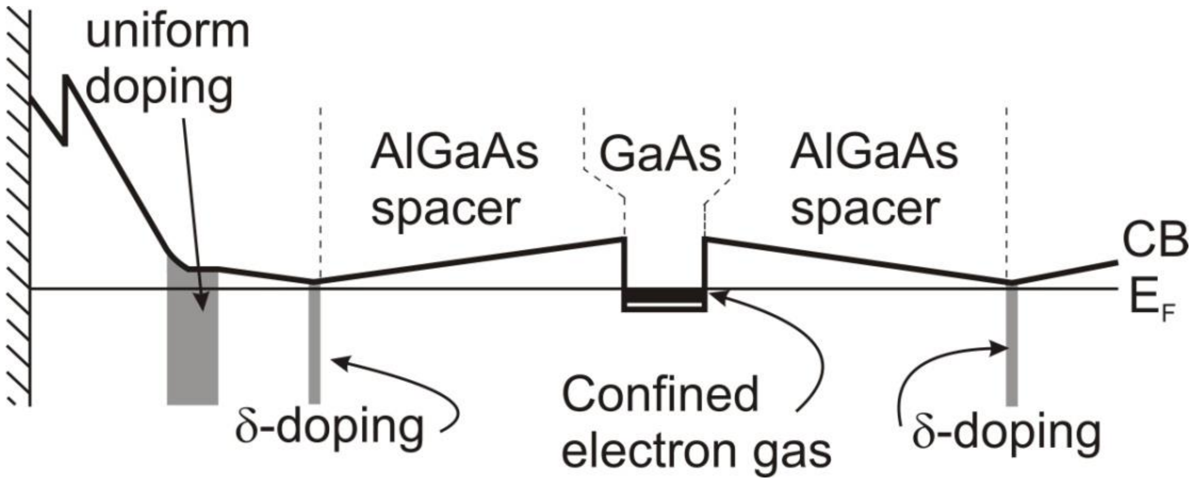
# Sample Structure

**GaAs/AlGaAs heterostructure:**

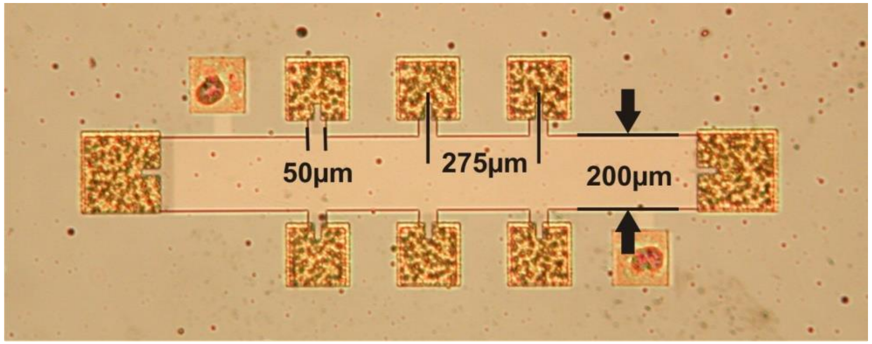
- **30 nm quantum well (QW)**
- **QW located 150 nm beneath the surface**
- **spacer width 70 nm**

**2DEG-Parameter :** $n_e = 3.2 \cdot 10^{11}\ \mathrm{cm^{-2}}$

$\mu_e = 11.9 \cdot 10^{6}\ \mathrm{cm^2/Vs}$

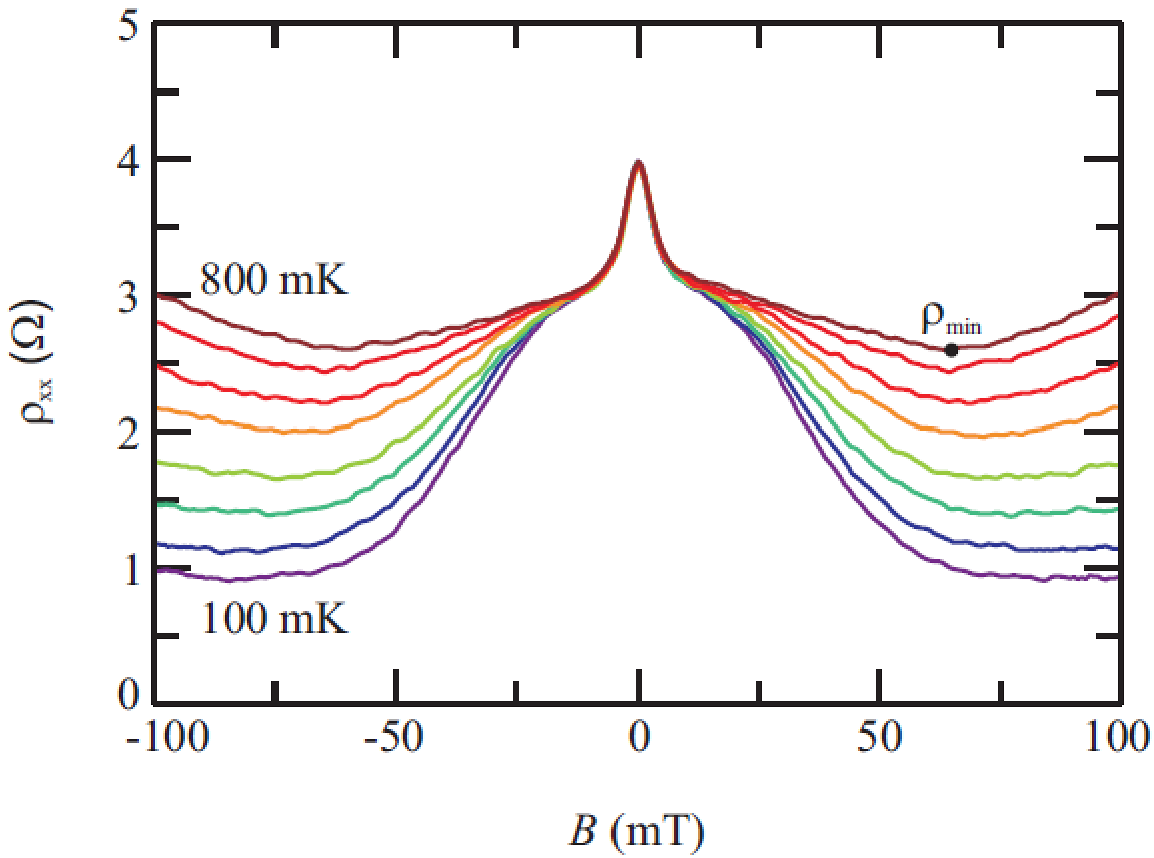


# Main Geometry

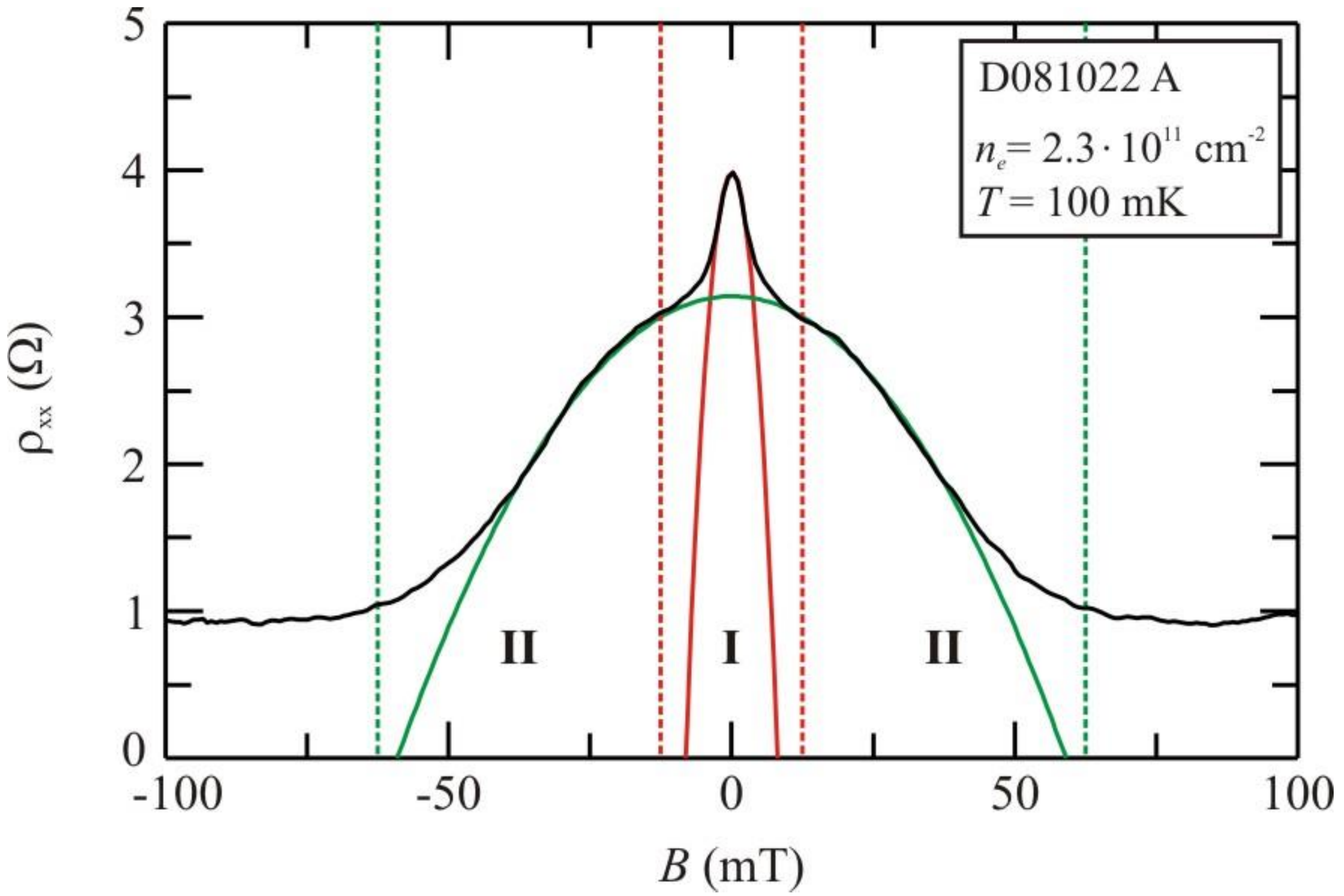



- Hall bars were defined by photolithography and wet etching
- $n_e$ and $\mu_e$ are manipulated by using a top gate
- Hall bar dimensions are in the range of the mean free path
- $n_e = 3.2 \cdot 10^{11}\ \mathrm{cm}^{-2}$
  $\mu_e = 11.9 \cdot 10^{6}\ \mathrm{cm}^2/\mathrm{Vs}$
  $\Lambda = 113\ \mu\mathrm{m}$

# Basic Facts: Temperature Dependence at Low Temperatures



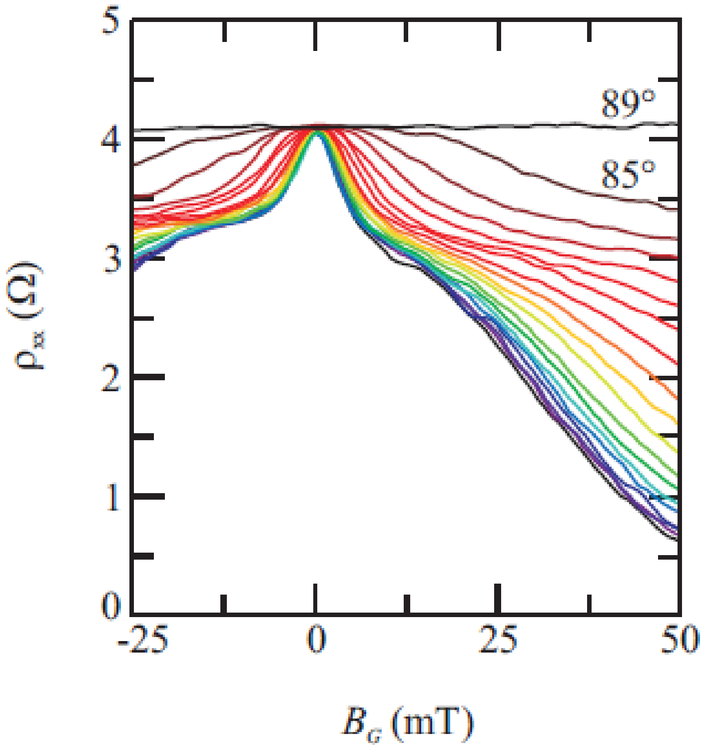
# Two Different Magnetoresistances



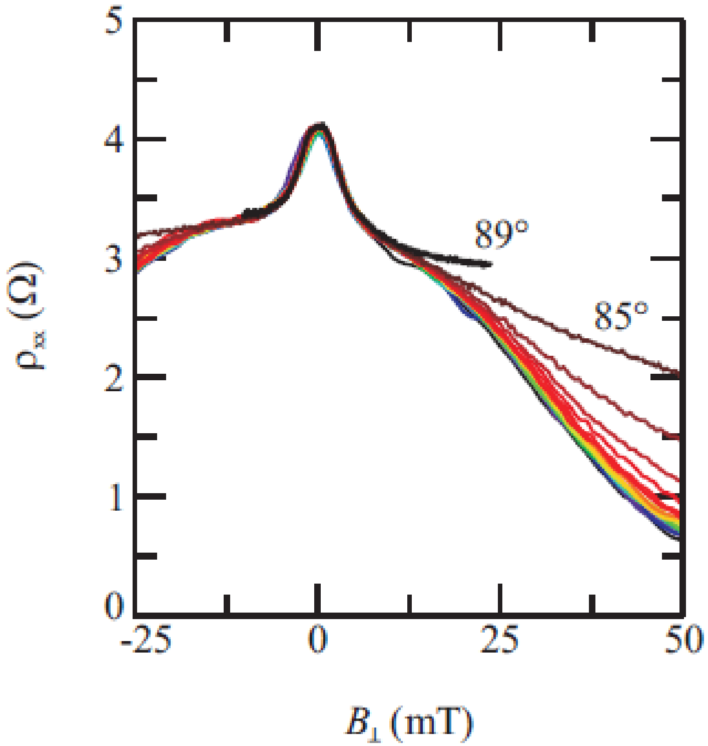

**both are parabolic in field**

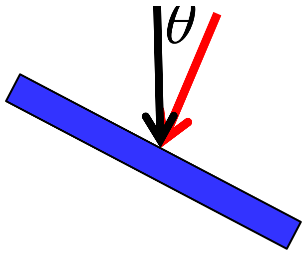
# Tilted Magnetic-Field Dependence

**total field**

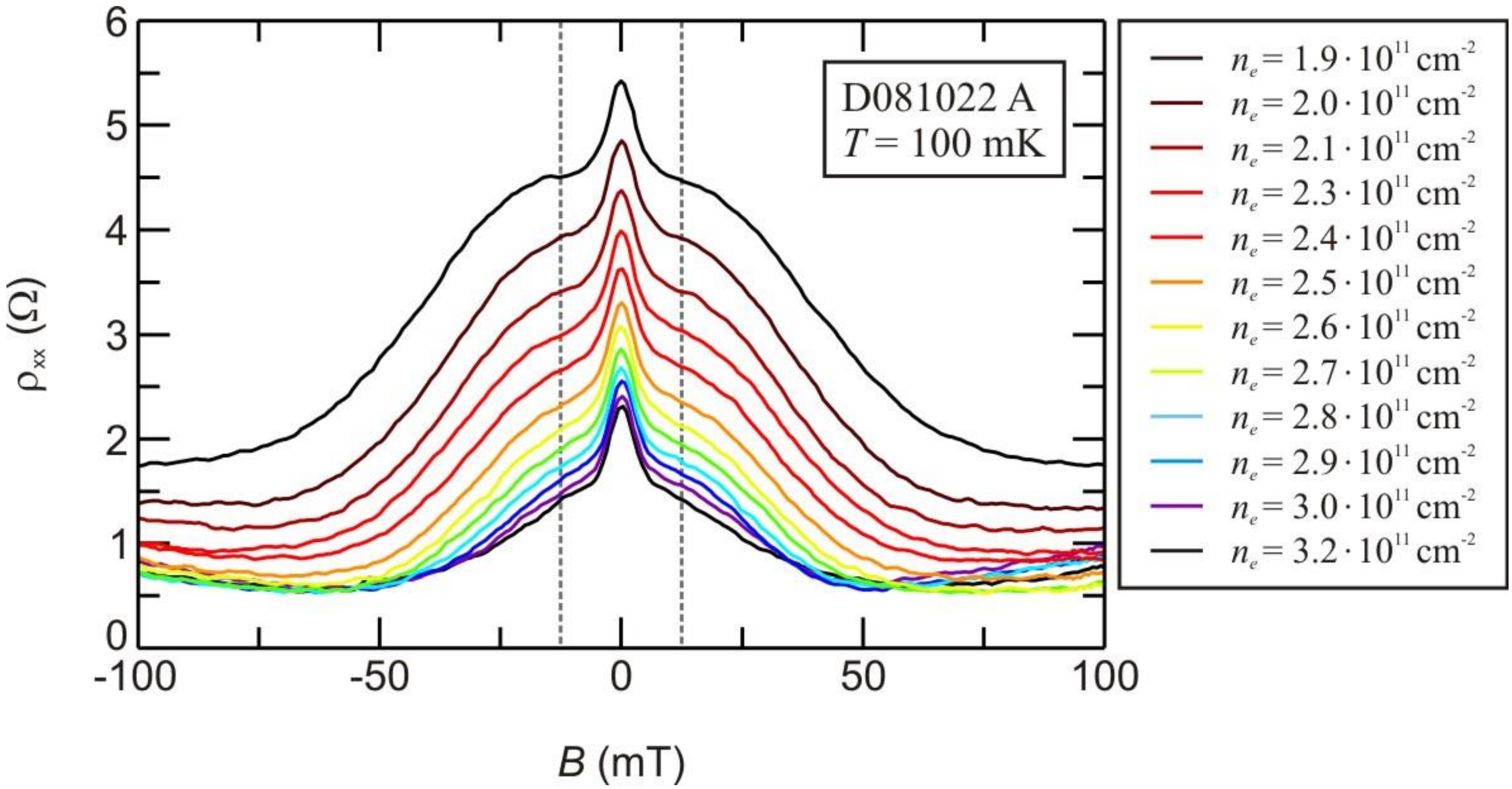



**perpendicular field**

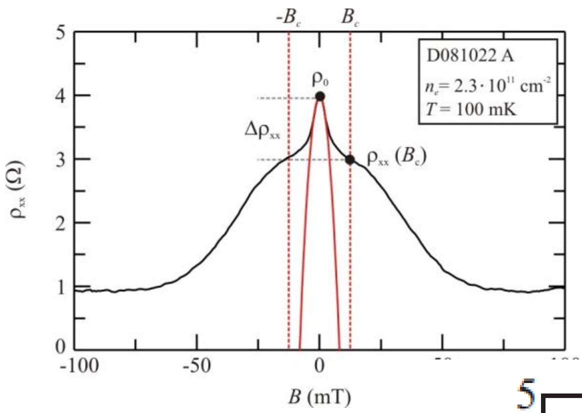


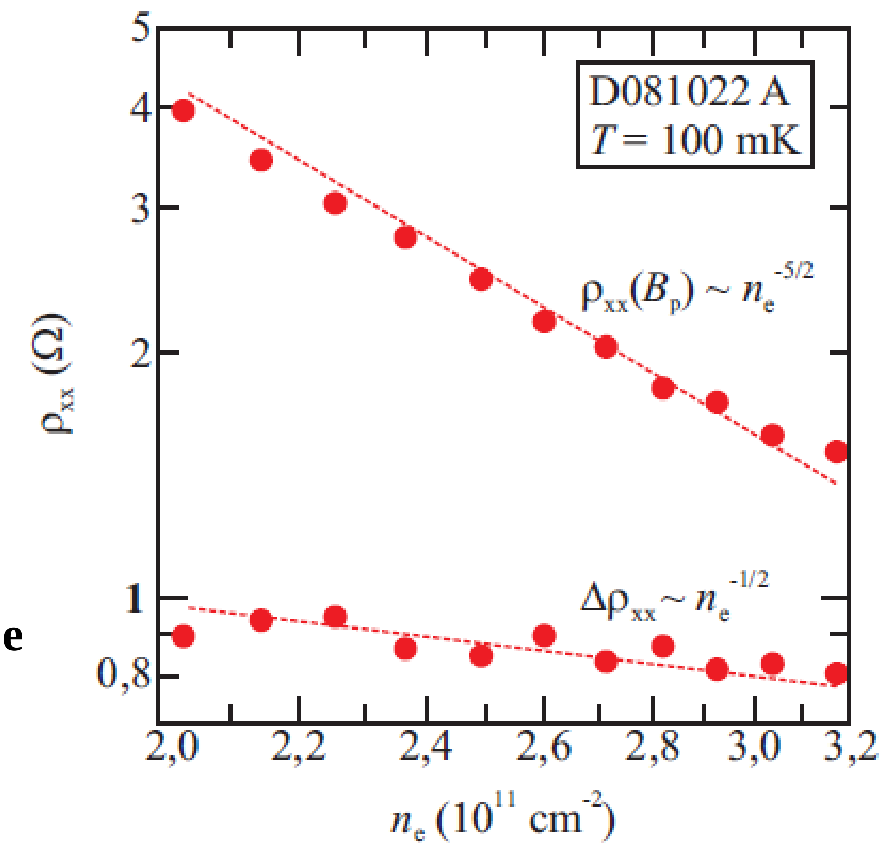
# Top Gate: Density Dependence



# Density Dependence of Resistances




magnetic field quenches different contributions to longitudinal resistance




**scattering from smooth disorder (remote ionized impurities)**

additional type of disorder

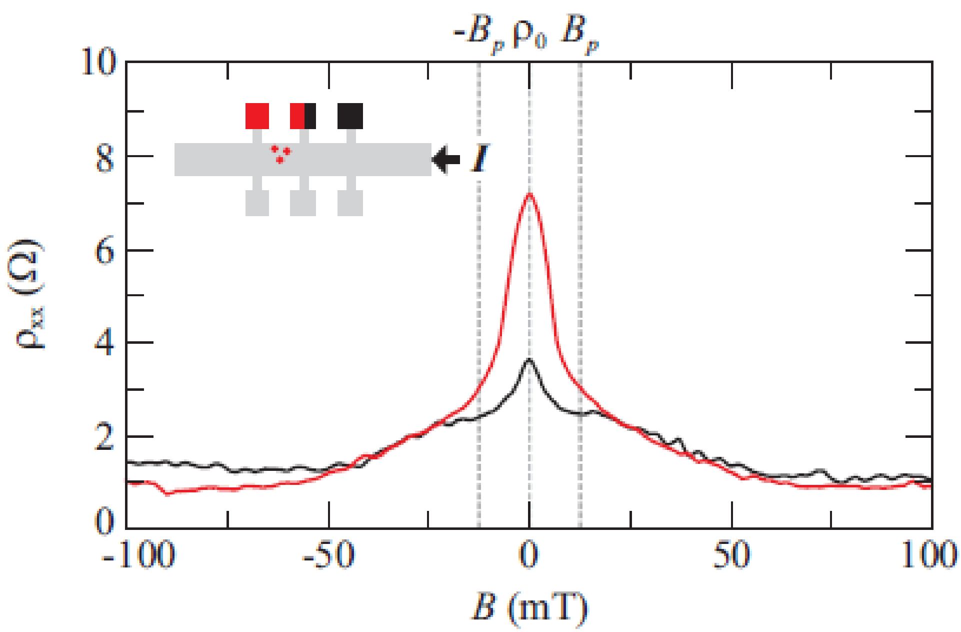
# Small Peak

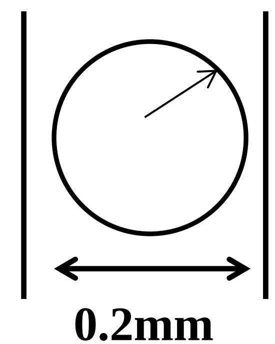
- temperature independent below 1 K
- depends only on perpendicular magnetic field: two dimensional

→ classical effect

e.g.
classical cyclotron radius
of 0.1mm
at 0.7mT
???

- not always small

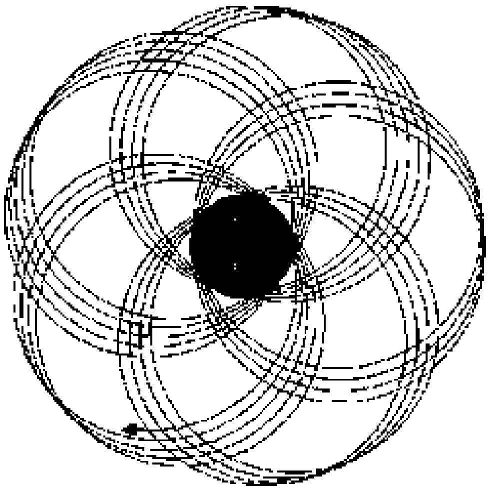


PHYSICAL REVIEW B, VOLUME 64, 205306

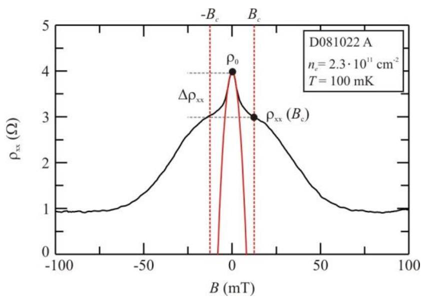
# Quasiclassical magnetotransport in a random array of antidots

D. G. Polyakov,[1,*] F. Evers,[1] A. D. Mirlin,[1,2,†] and P. Wölfle[1,2]



see also:
E.M. Baskin, L.I. Magarill, and M.V. Entin, Zh. Eksp. Teor. Fiz. 75, 723 (1978) [ Sov. Phys. JETP 48, 365 (1978)]; E.M. Baskin and M.V. Entin, Physica B 249-251, 805 (1998).

# Interplay of Strong Scatterers and Smooth Disorder: Classical Memory Effect




**situation for high-mobility structures**

$$\tau_S \sim \tau_L \qquad (\omega_0 \sim \omega_{perc})$$

$$\Delta\rho_{xx}/\rho_0 = -\frac{\omega_c^2}{\omega_0^2}$$

**$\tau_S$ transport scattering time for strong scatterers**

**$\tau_L$ transport scattering time for smooth disorder**

$$\frac{\rho_{xx}}{\rho_0} = 1 - \frac{\omega_c^2}{2\pi n_S v_F^2} f(x) \qquad x = \tau_S/\tau_L$$

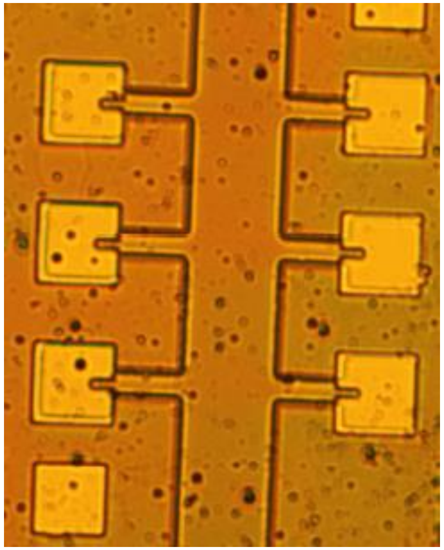
$$f(x) = \frac{2}{x+1}\int_0^\infty dq \, \frac{q\, J_1^2(q)}{x\, q^2 + 2[1 - J_0^2(q)]}$$

$$1\text{–}10 \cdot 10^4\, cm^{-2}$$

**very low density of strong scatterers**
**radius: 10 – 20 µm**

**L. Bockhorn et al.**
**Phys. Rev. B 90, 165434 (2014)**

# Sample Surfaces



macroscopic defects seen at the surface

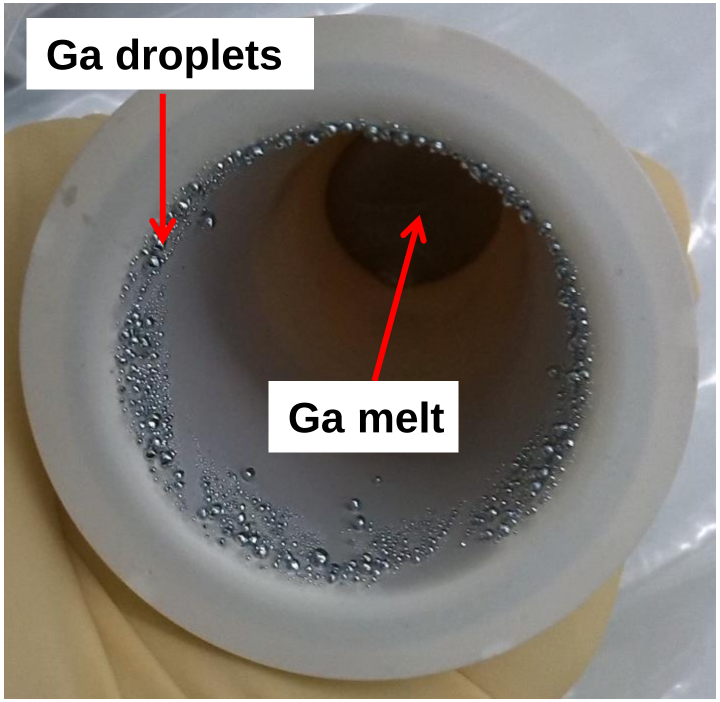
diameter: up to 40μm

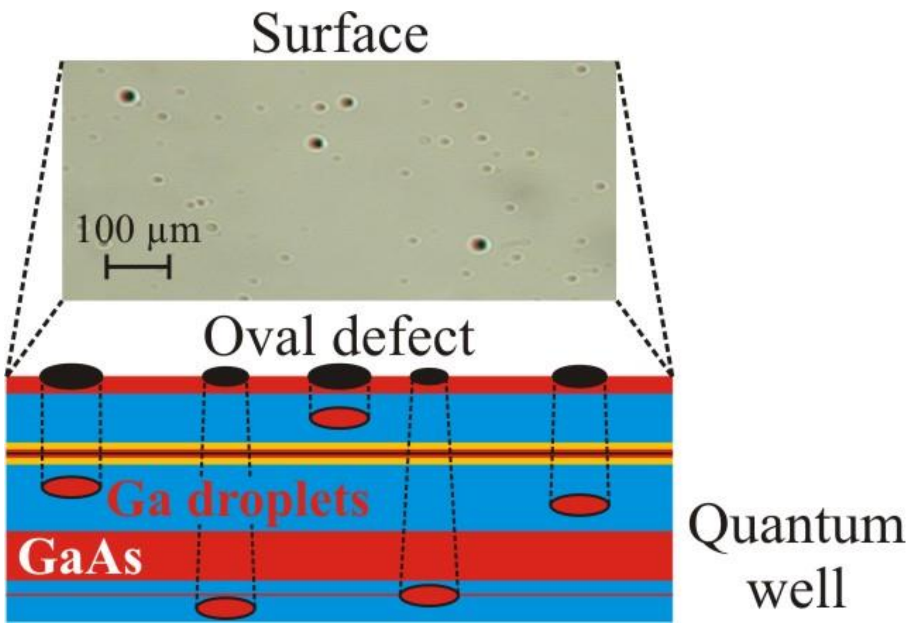
density: around $10^4$ cm$^{-2}$
→ inter-defect spacing: $d_{OD}$ ~ 90 μm

- **oval defects are always present!**

→ $l \sim d_{OD}$
→ μ ~ 1 x $10^7$ cm$^2$/Vs

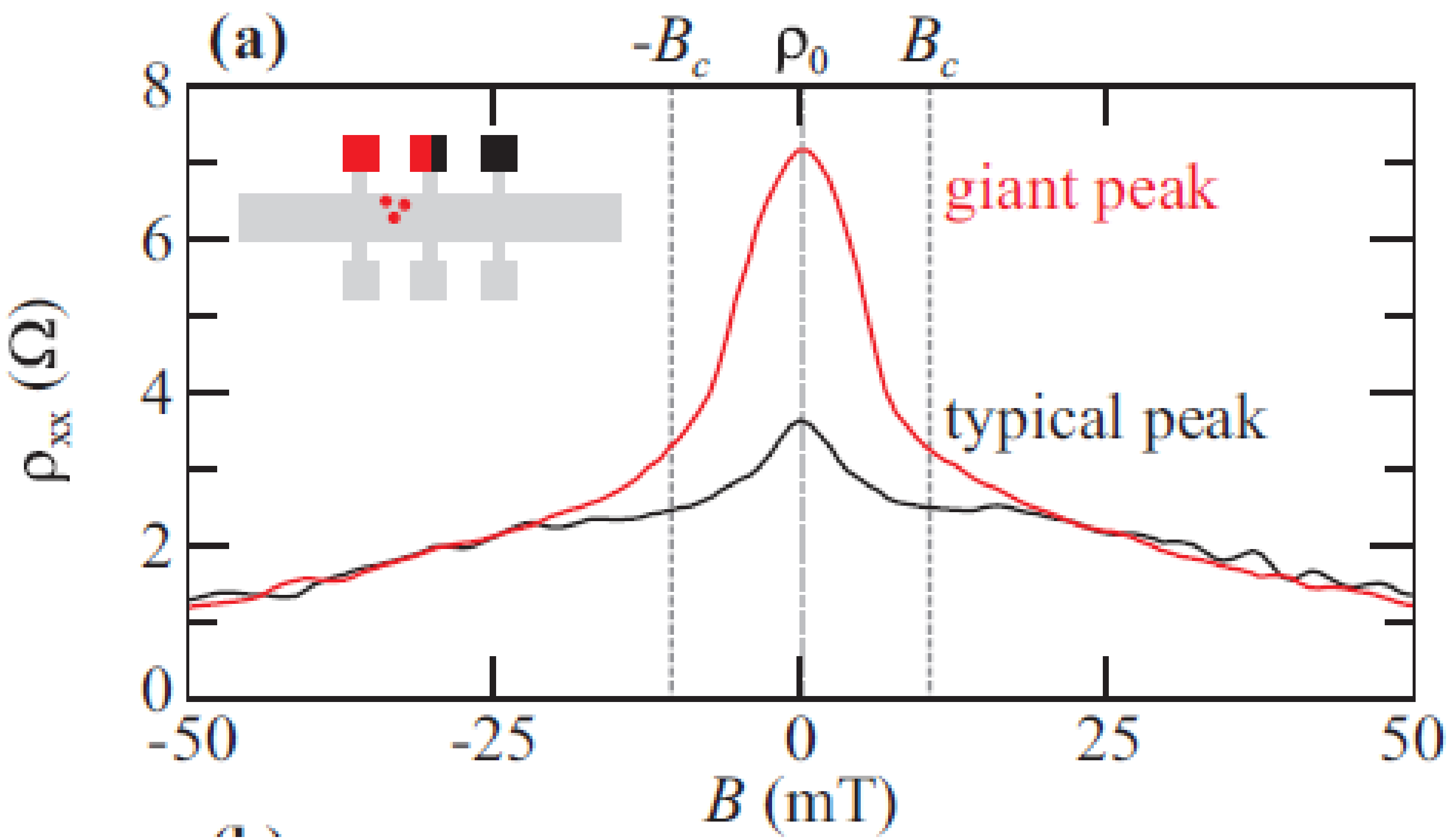
# Oval Defects in the Sample



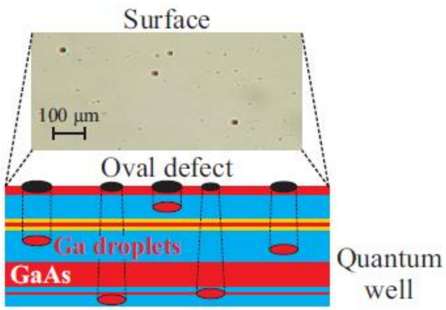




Y. G. Chai and R. Chow, Appl. Phys. Lett. **38**, 796 (1981).
G. D. Pettit, J. M. Woodall, S. L. Wright, P. D. Kirchner, and J. L. Freeouf, J. Vac. Sci. Technol. B **2**, 241 (1984).
K. Akimoto, M. Dohsen, M. Arai, and N. Watanabe, J. Cryst. Growth **73**, 117 (1985).
S.-L. Weng, Appl. Phys. Lett. **49**, 345 (1986).
M. Shinohara and T. Ito, J. Appl. Phys. **65**, 4260 (1989).

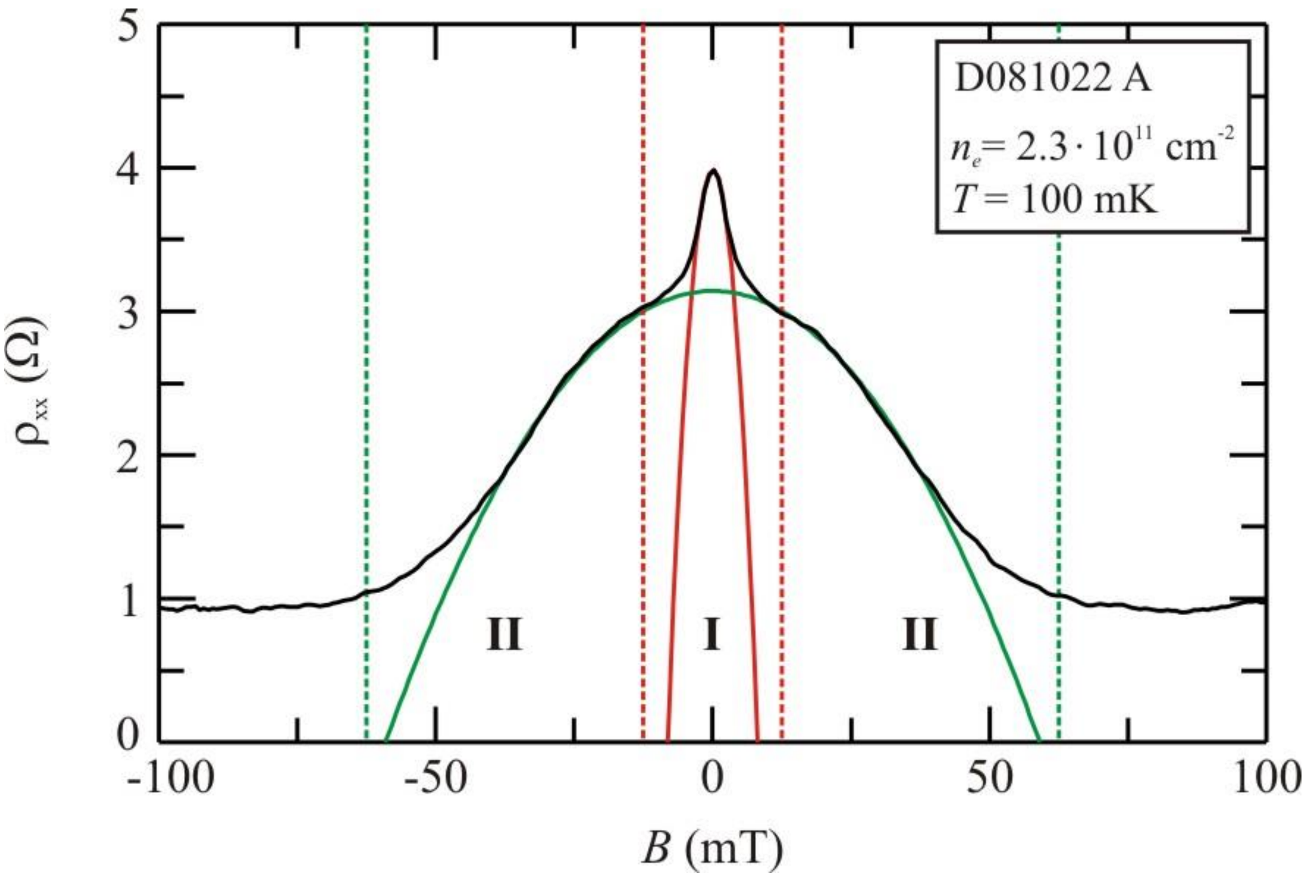
# Different Densities of Oval Defects = Different Peak Heights




**L. Bockhorn et al.**
**Phys. Rev. B 90, 165434 (2014)**



# Huge Peak

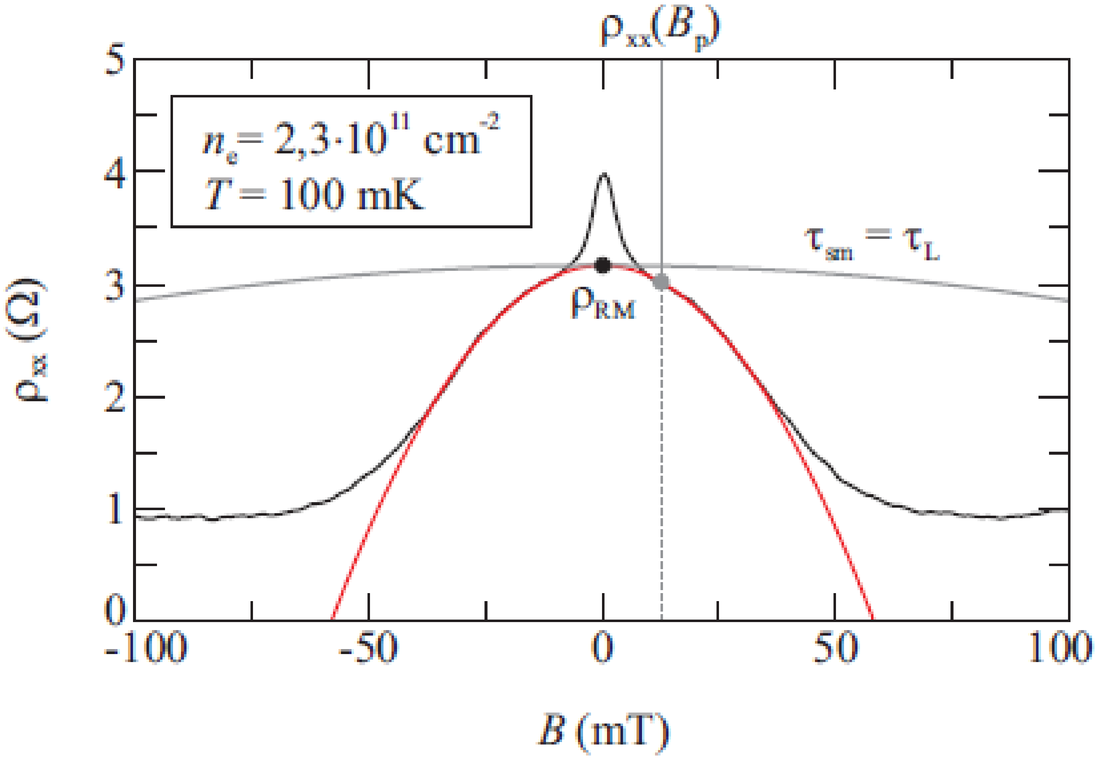



**temperature dependent, parallel field dependent**

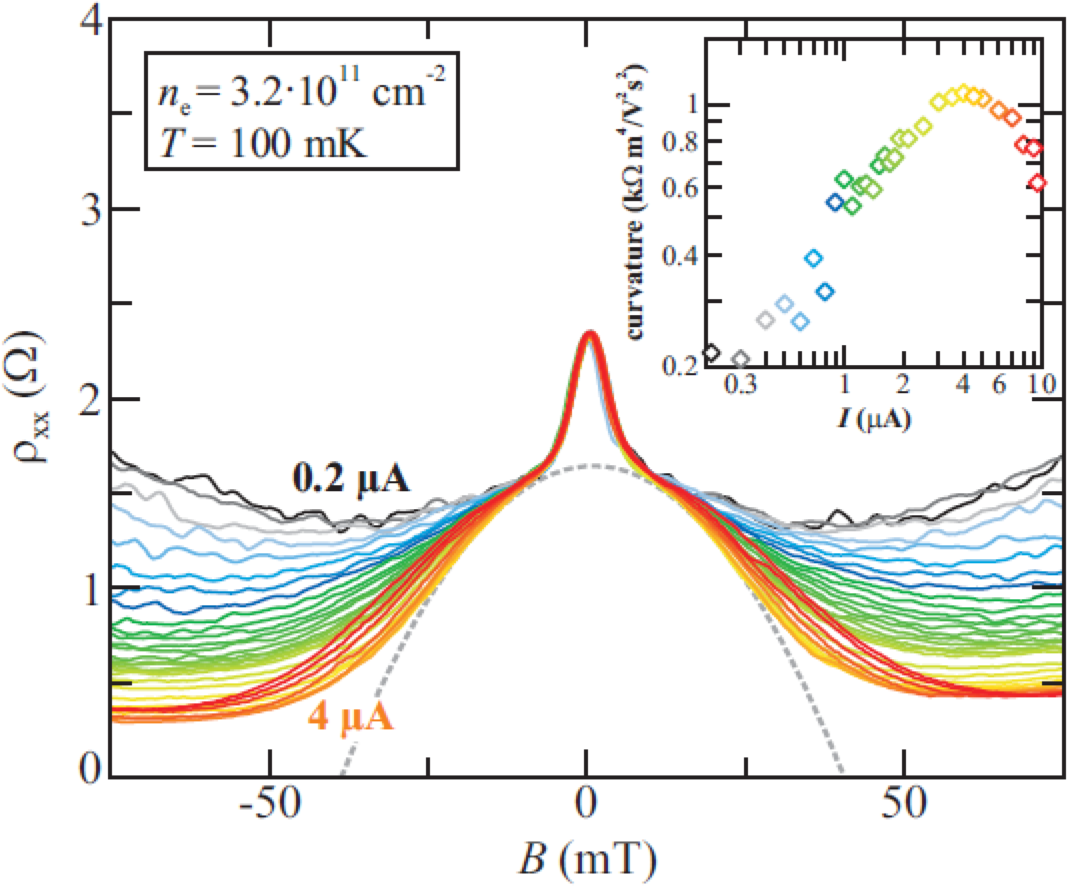
# Electron-Electron Interaction Correction in the Ballistic Regime

$$\rho_{xx} = \frac{1}{\sigma_0} + \frac{1}{\sigma_0^2}(\mu^2 B^2)\left[\delta\sigma_{xx}^{ee}(T)\right]^{-1}$$

I.V. Gornyi, A.D. Mirlin,
Phys. Rev. Lett. 90, 076801 (2003)



# Current-Induced Negative Magnetoresistance



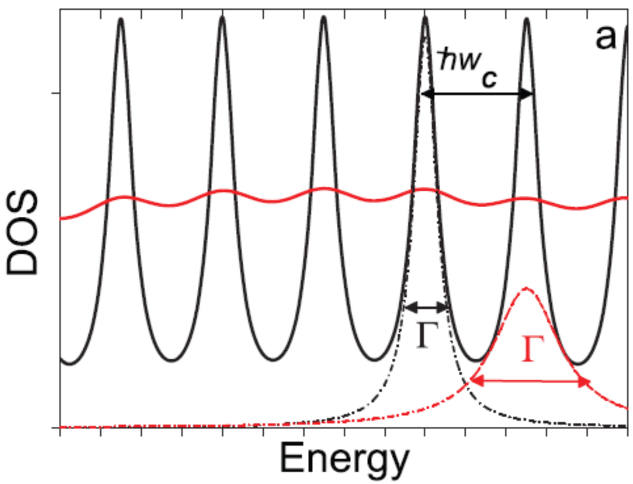

**arXiv 1504.00555**

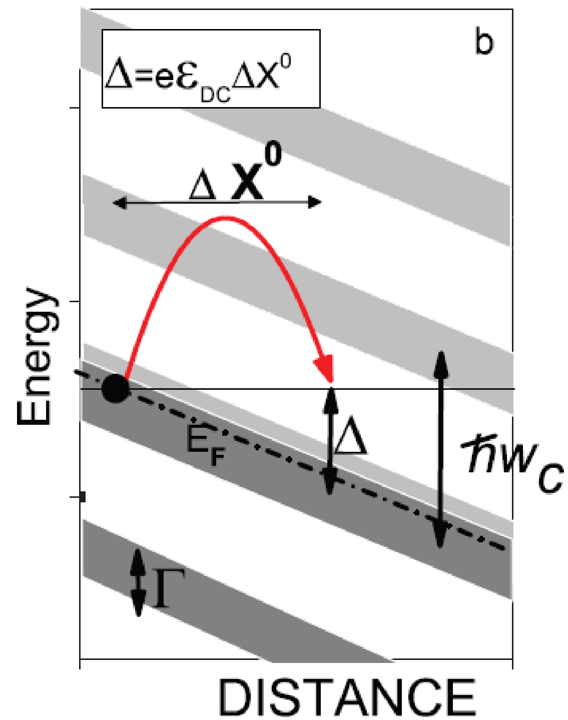
EPL, **106** (2014) 47005
doi: 10.1209/0295-5075/106/47005

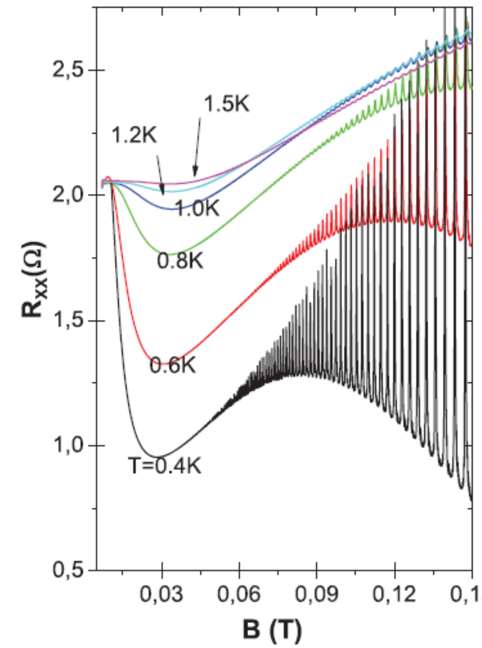
www.

# Theoretical model for negative giant magnetoresistance in ultrahigh-mobility 2D electron systems

J. Iñarrea

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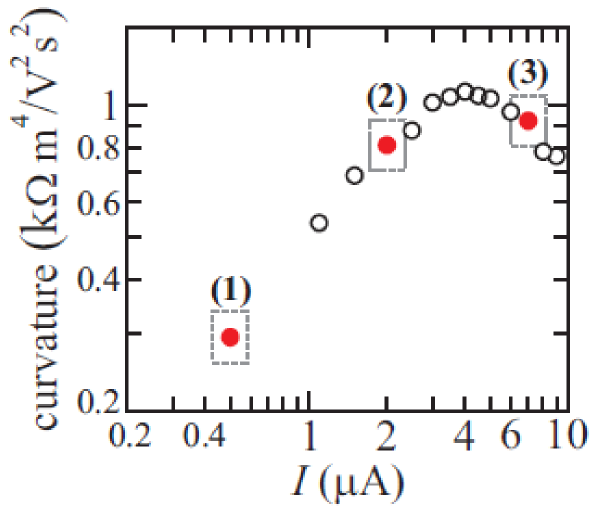
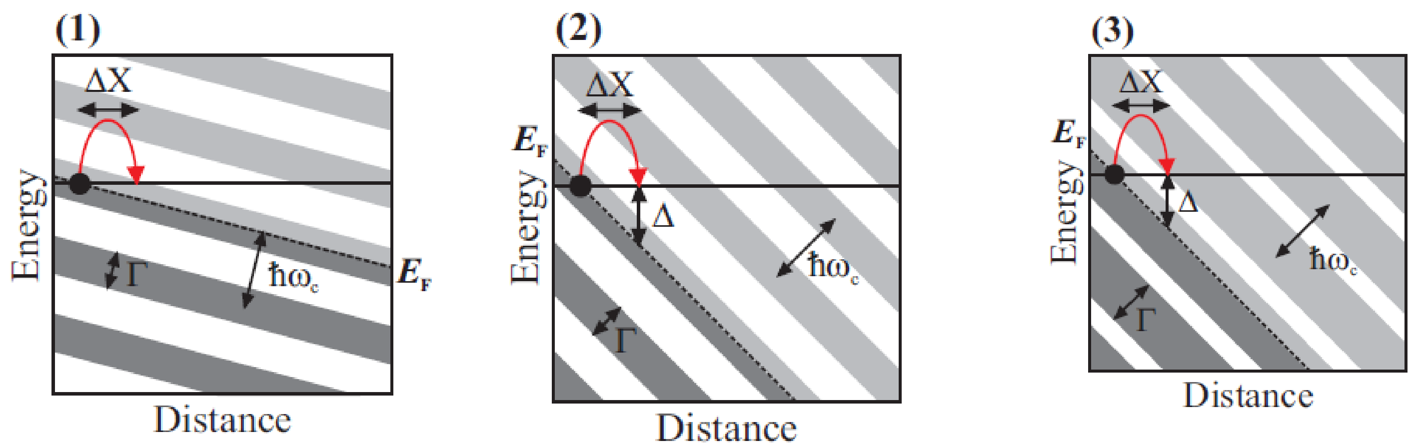
# Analogoue Explanation for Our Results

$$\varpi_c \tau = 1$$

**at B = 0.86mT**




**arXiv 1504.00555**

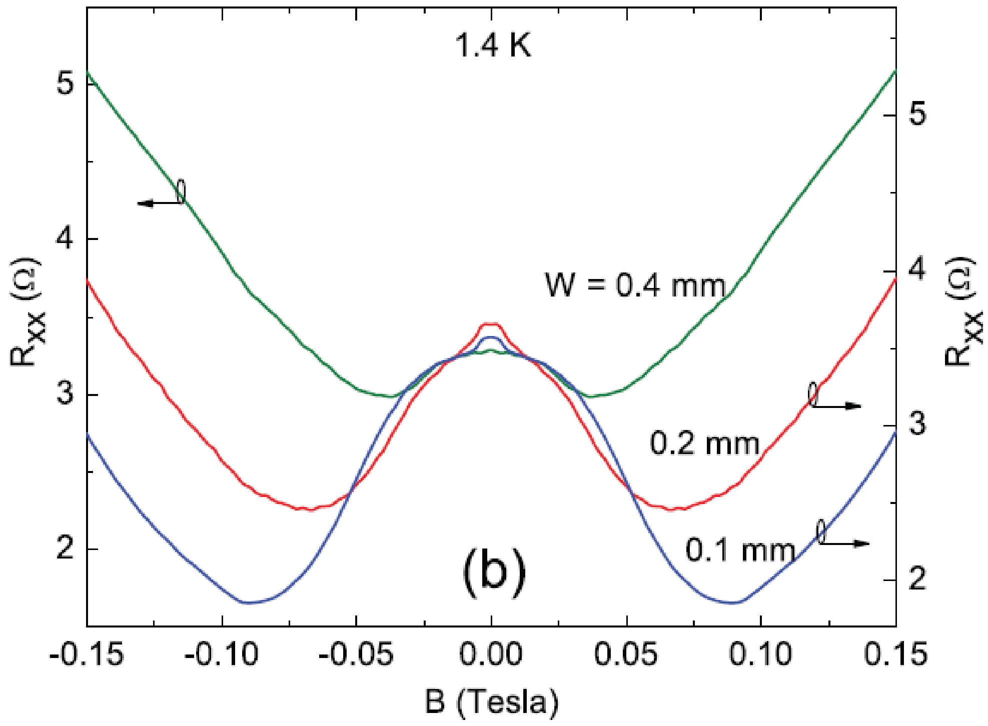
# Size Dependence?

L. Bockhorn, A. Hodaei, D. Schuh, W. Wegscheider, and
R. J. Haug, *J. Phys.: Conf. Ser.* **456**, 012003 (2013).

**presentation at high-magnetic field conference in Chamonix 2012**

**small peak is not geometry dependent, huge peak shows geometry dependence**

# Size Dependence




R. G. Mani[1], A. Kriisa[2] & W. Wegscheider[3]

SCIENTIFIC REPORTS | 3 : 2747 | DOI: 10.1038/srep02747

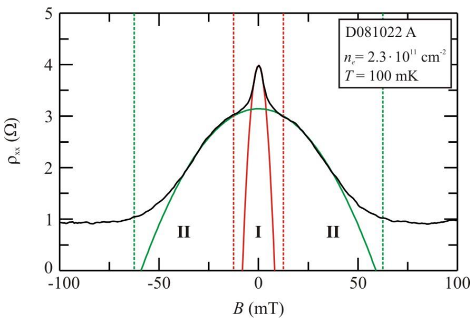
2013

# Conclusions

- **negative magnetoresistances in high-mobility 2DEGs**

- **small peak: classical effect due to scattering from oval defects**

- **huge peak: temperature dependent current induced**




- **size dependence?**