Insulating States in Quantum Wires

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Conductance Quantisation

Simple picture: Transmission and reflection of waves through a waveguide

Landauer's Formula

$$G = \frac{2e^2}{h} T$$

T - Transmission coefficient

Electron-Electron Interactions

2D and 3D - Well-defined Fermi surface - Fermi liquid theory works.

1D - No Fermi surface, Fermi liquid theory break down!

Exactly solvable model - **Luttinger model** Excitations - Bosonic

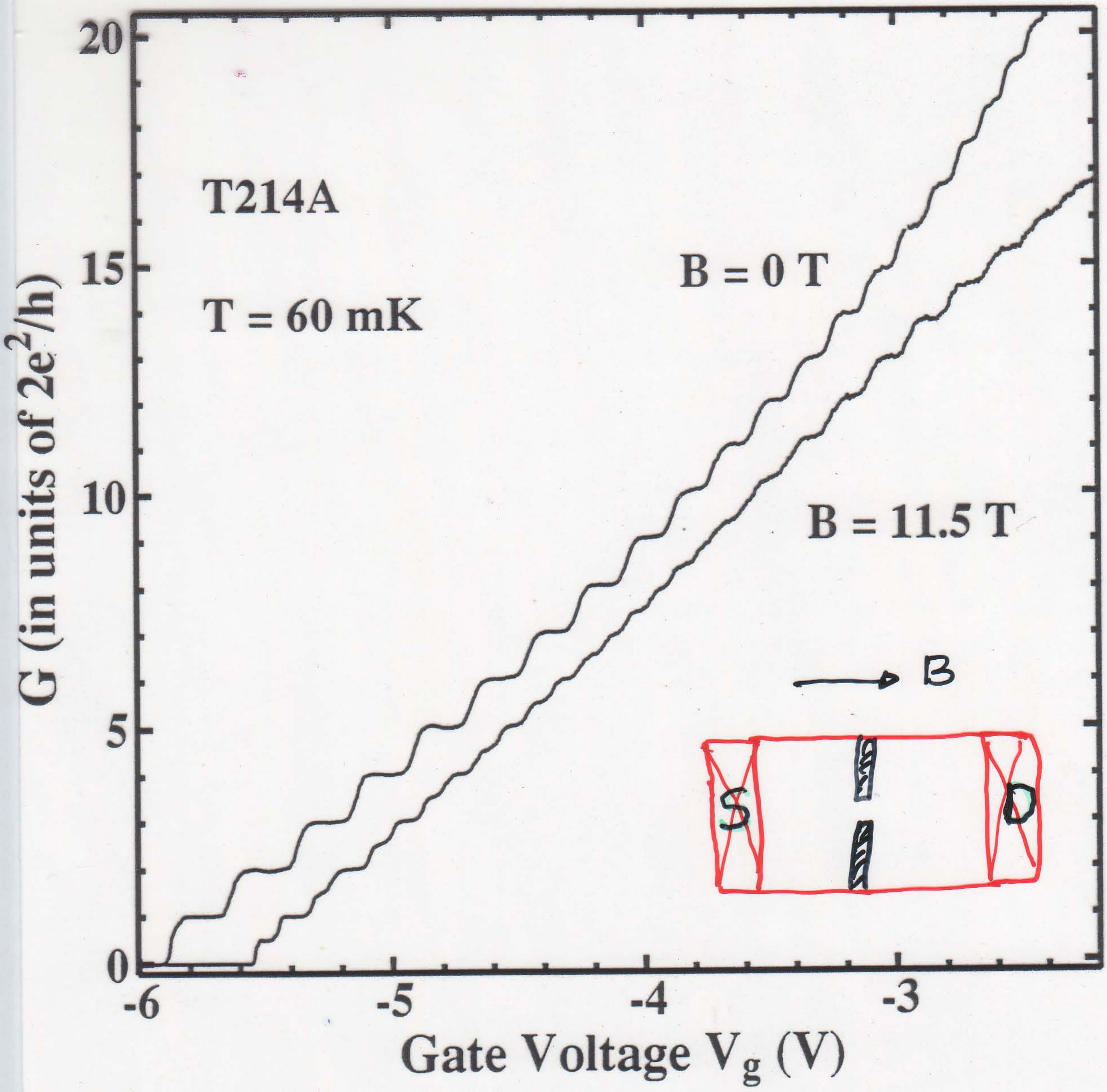
Coulomb interactions between electrons renormalise conductance to

$$G = \frac{2e^2}{h} K$$

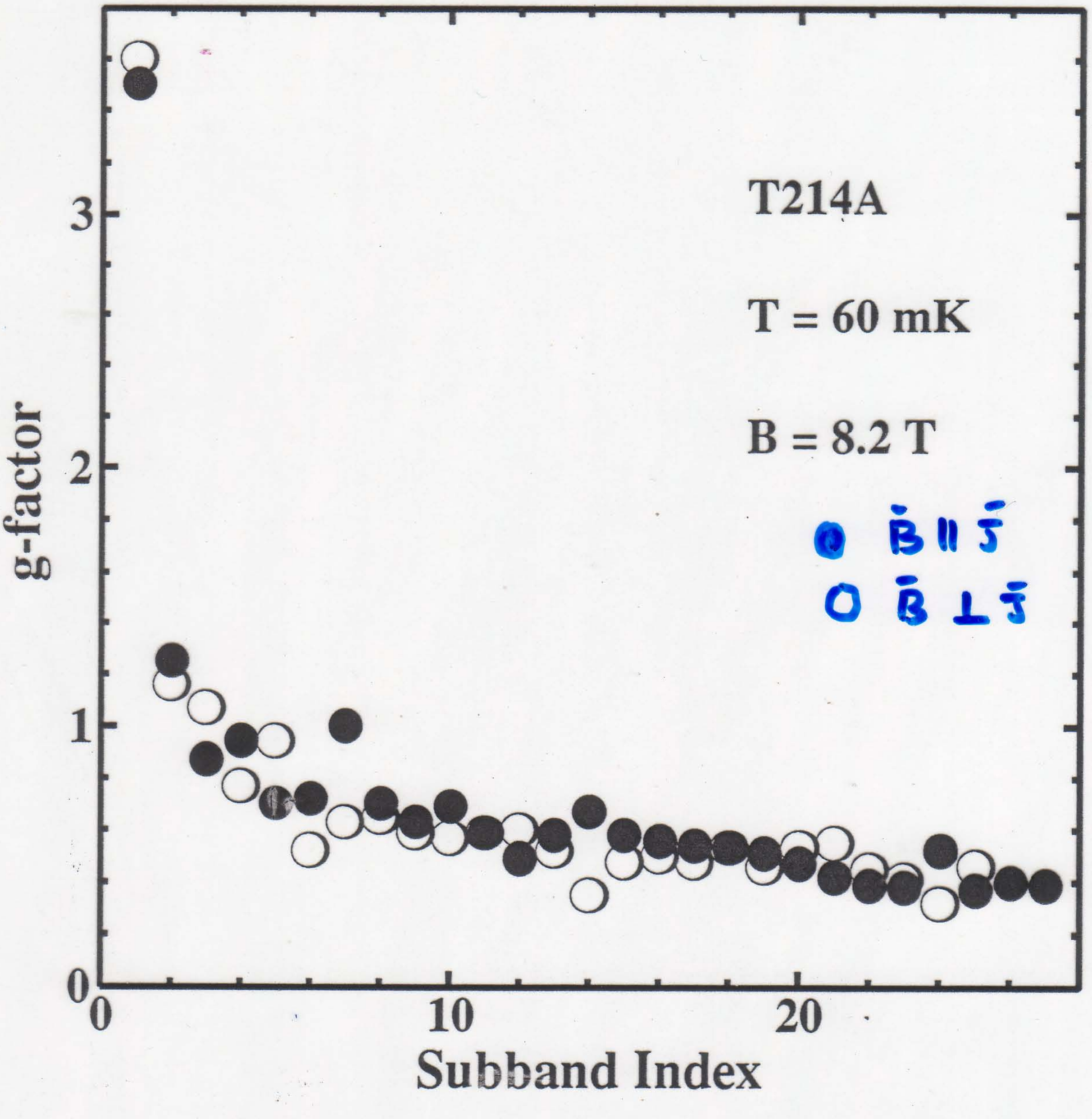
For repulsive Coulomb interaction, interaction parameter $K < 1$.

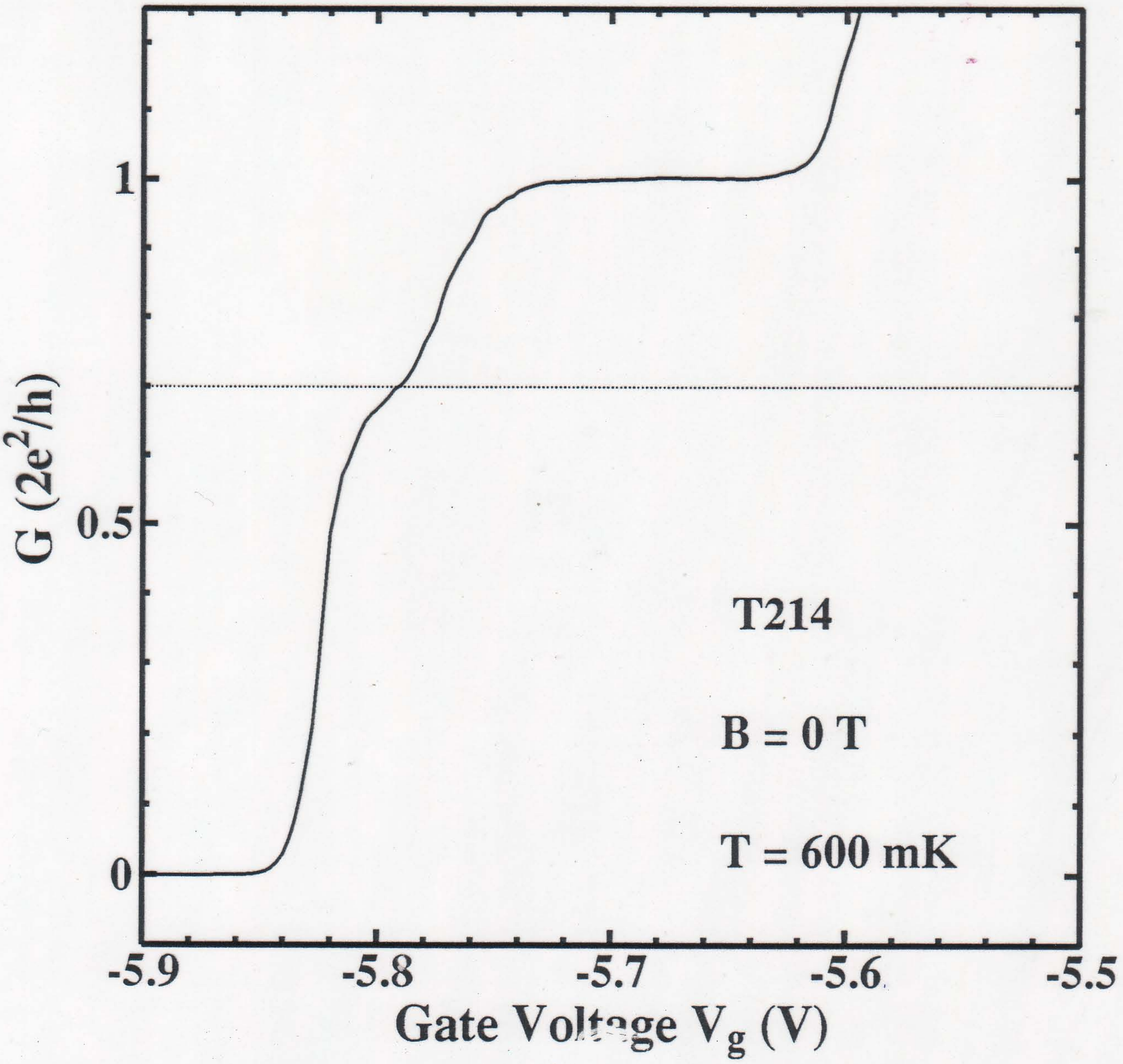
G follows power law temperature and voltage dependences.

Low density : $n \ll 1/\mathit{Bohr\ radius}$, **Wigner Crystal** results for long range Coulomb interactions.

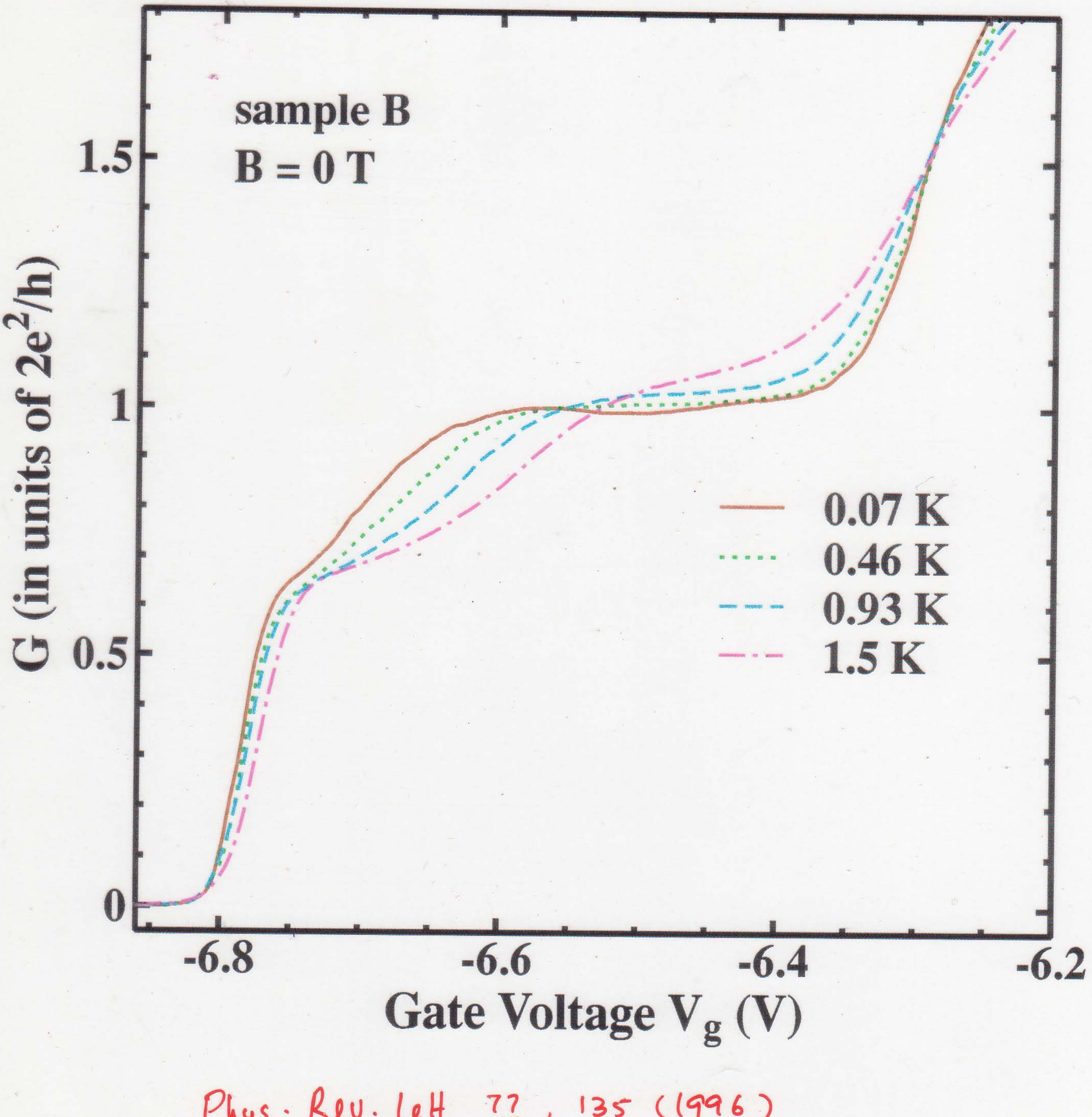

T214A
T = 60 mK
B = 0 T
B = 11.5 T
B
S
D
G (in units of 2e²/h)
0
5
10
15
20
-6
-5
-4
-3
Gate Voltage V_g (V)

$eV_{sd} = 2 g \mu_B \bar{B} \bar{S}$

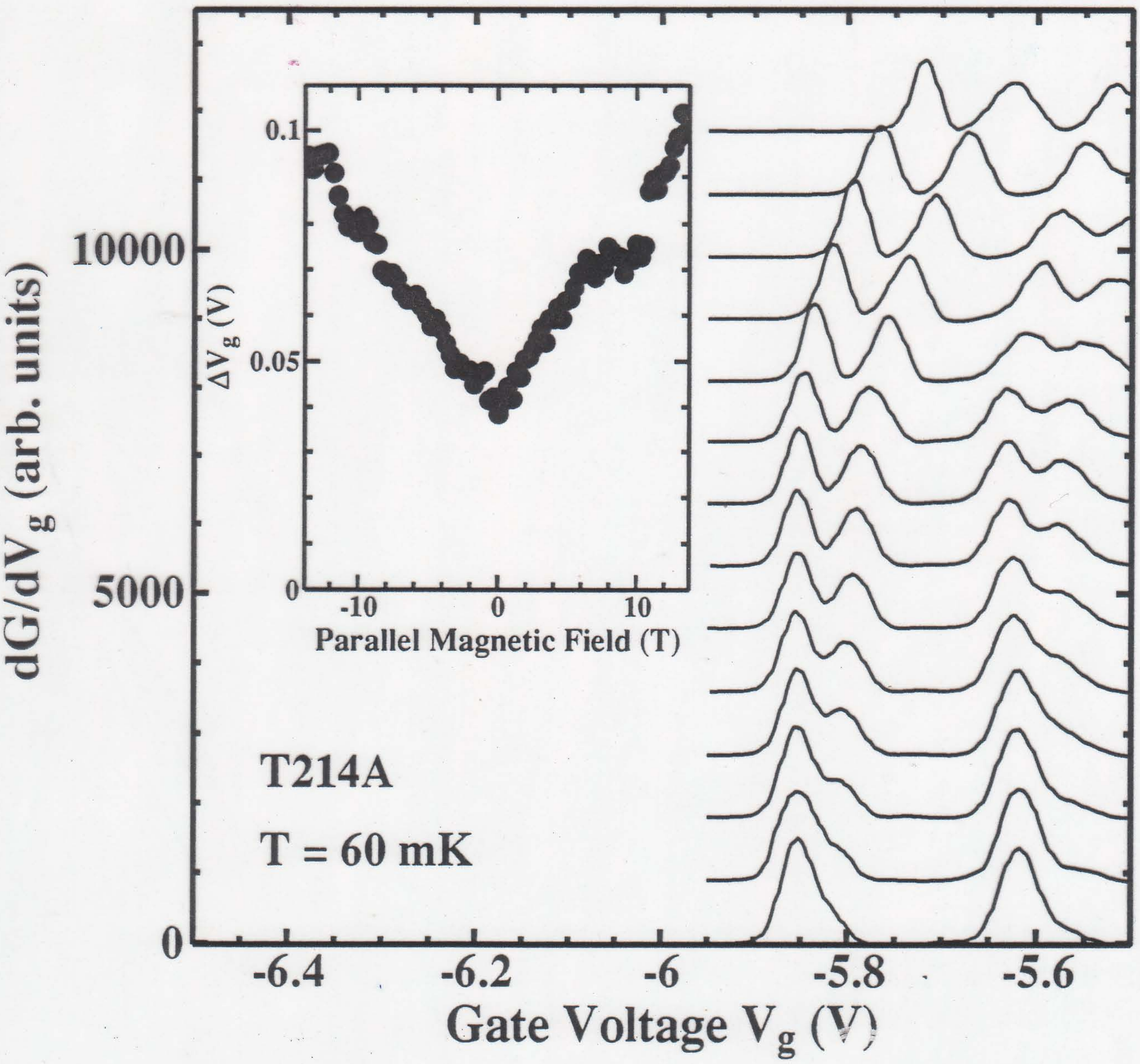



G (2e²/h)
1
0.5
0
-5.9
-5.8
-5.7
-5.6
-5.5
Gate Voltage Vg (V)
T214
B = 0 T
T = 600 mK

Temperature dependence of the structure at $0.7(2e^2/h)$ compared to the last quantised plateau



Phys. Rev. Lett 77, 135 (1996)


dG/dV_g (arb. units)
10000
5000
0
-6.4
-6.2
-6
-5.8
-5.6
Gate Voltage V_g (V)
T214A
T = 60 mK
0.1
0.05
0
ΔV_g (V)
-10
0
10
Parallel Magnetic Field (T)

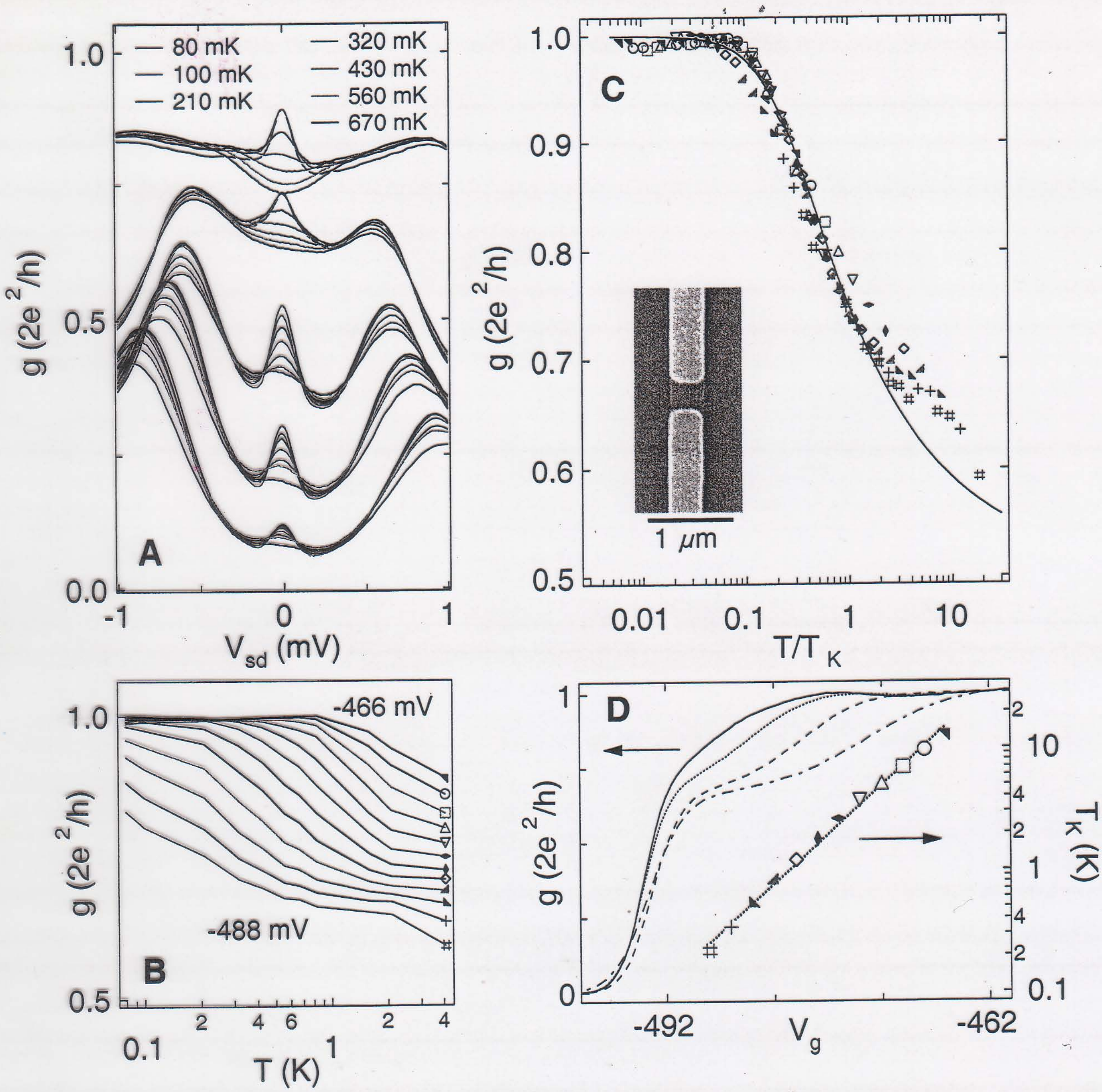
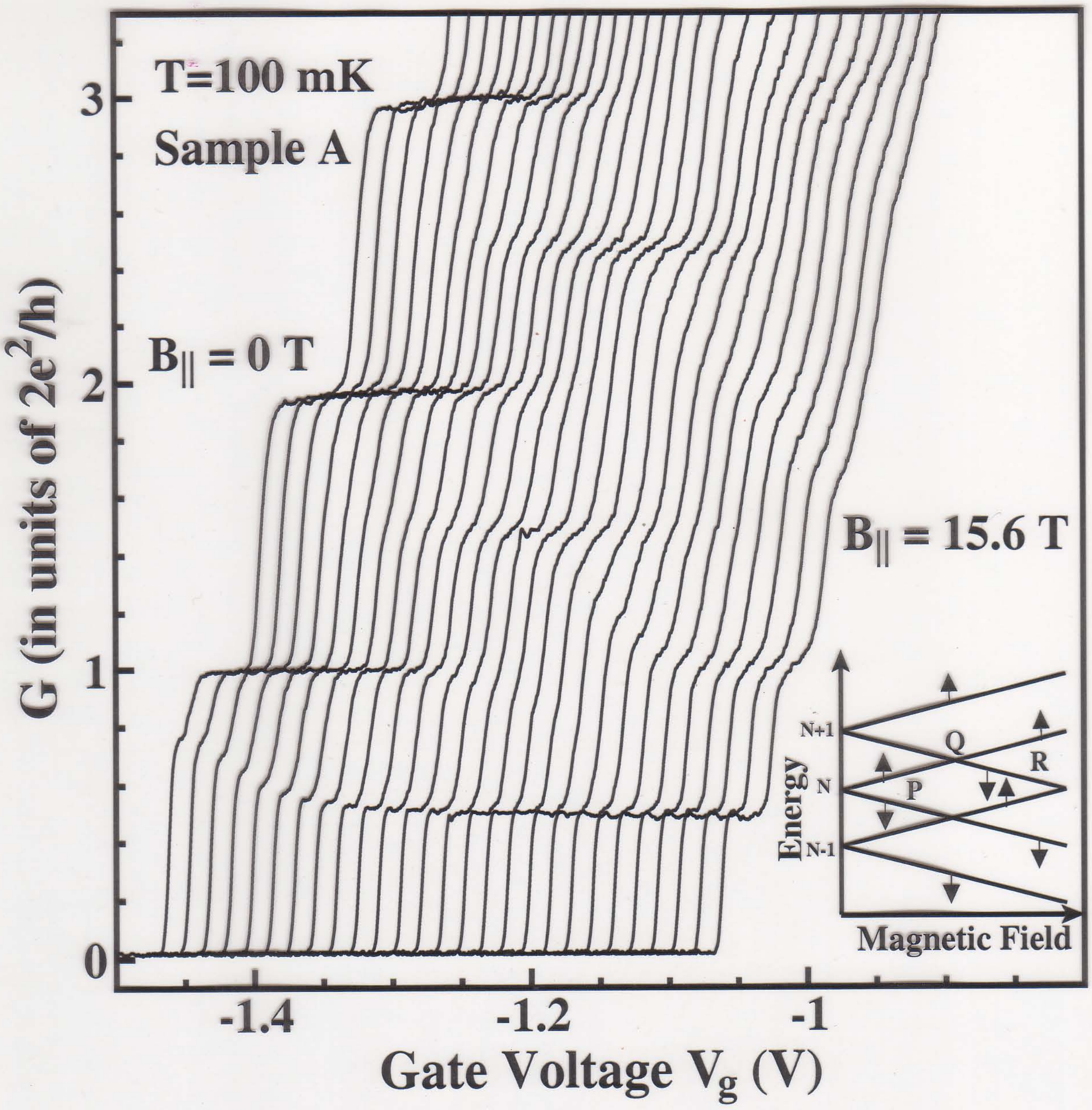


Figure 3
Cronenwett, et al.

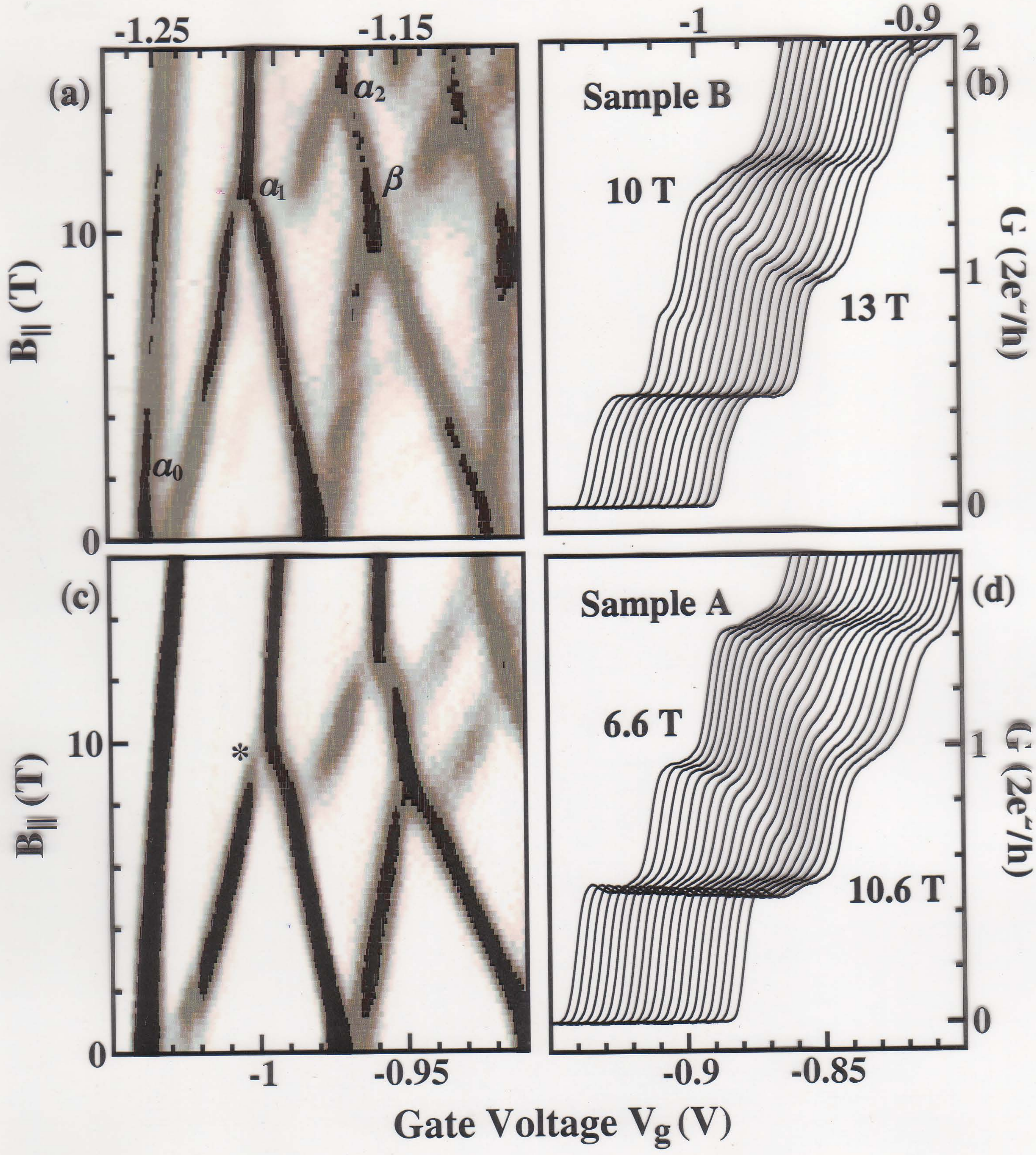
Phys. Rev. Lett. <u>88</u>, 226805 (2002)

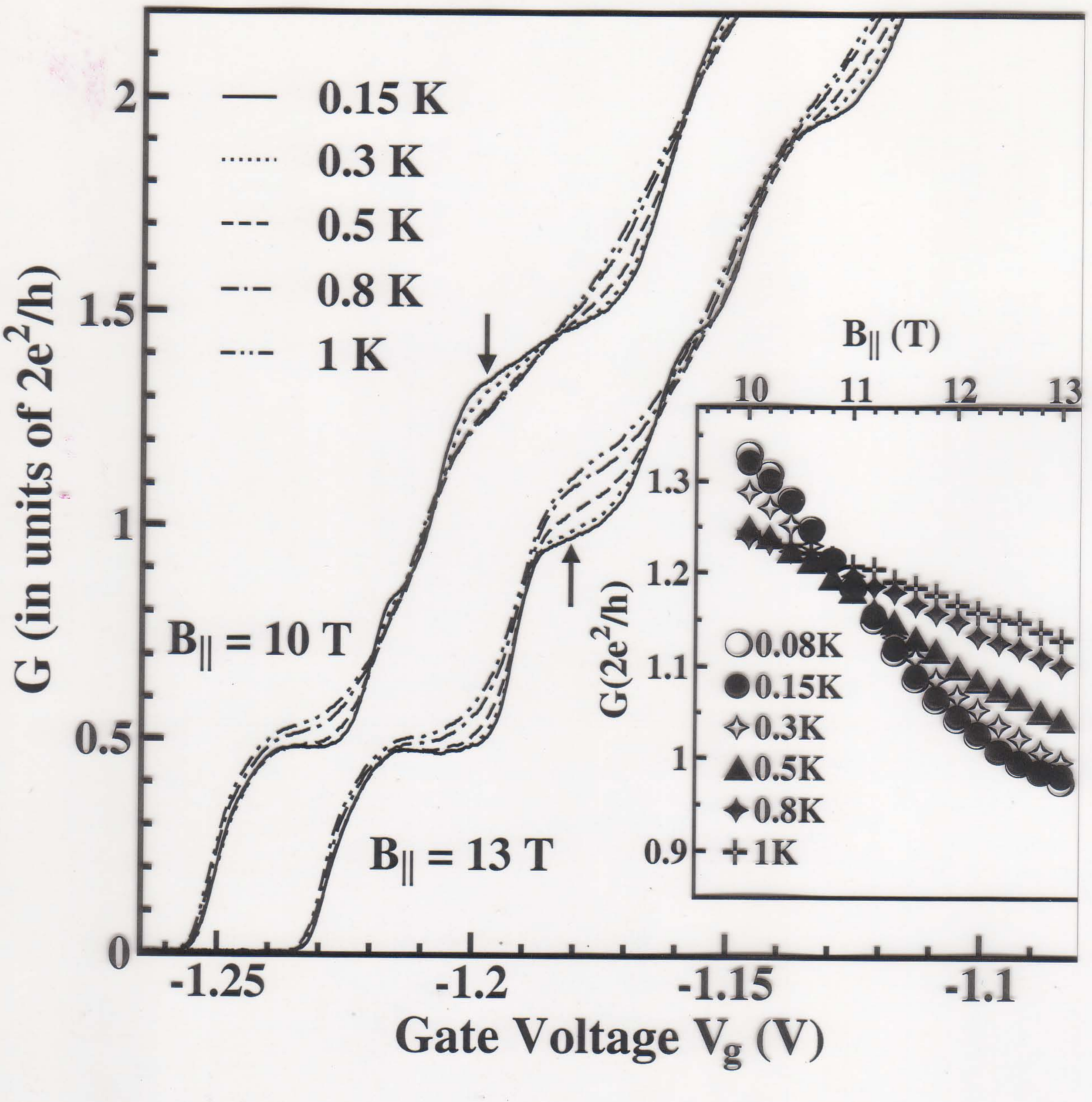
Zeeman splitting and crossing of energy levels



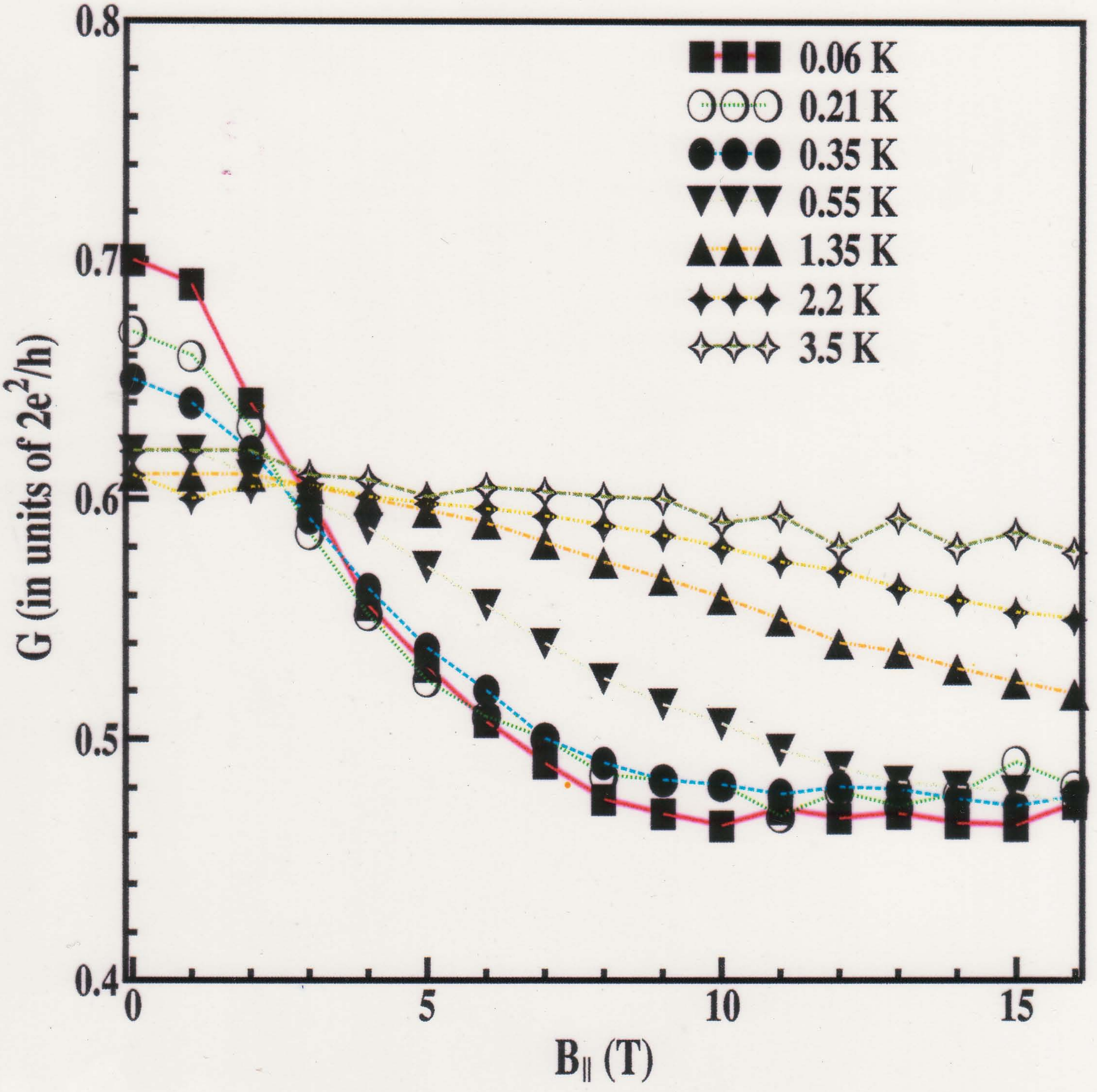
Phys. Rev. Lett. 91, 136404 (2003)

"0.7 analogues" at crossings of energy levels in B




G (in units of $2e^2/h$)
0.15 K
0.3 K
0.5 K
0.8 K
1 K
$B_{||}$ = 10 T
$B_{||}$ = 13 T
Gate Voltage V_g (V)
-1.25
-1.2
-1.15
-1.1
0
0.5
1
1.5
2
$B_{||}$ (T)
10
11
12
13
$G(2e^2/h)$
1.3
1.2
1.1
1
0.9
○0.08K
●0.15K
✧0.3K
▲0.5K
✦0.8K
+1K

Physica E, 12, 708 (2002)



K. J. Thomas, Ph.D Thesis (1997) University of Cambridge

Key Results:

① **0.7 Structure** – $G \sim 0.7\,(2e^2/h)$

$B_{\parallel}$ studies show evidence of spin polarisation. However, why $G \sim 0.5\,(2e^2/h)$ and why 0.7 structure strengthens with T unkonown!

② **Kondo piacture**: zero bias conductance peak at $G \sim 0 \rightarrow 2e^2/h$. Microscopic model, nevertheless Origin of magnetic moment unclear!

③ **0.7 Analogue**: spin effects at crossings of 1D levels in $B_{\parallel}$; Exchange effects.

Other interpretations:

For example,

Wigner crystal regime of transport.

Matveev: Phys. Rev. Lett. Vol. 92, 106801 (2004)

no spin polarisation.

* When $(n a_B)^{-1} \geq 1$ 1D WC results.

* Electron spins form an antiferromagneti Heisenberg chain with small coupling J.

* Finite current perturbs the spin chain, T-dependent corrections to resistence

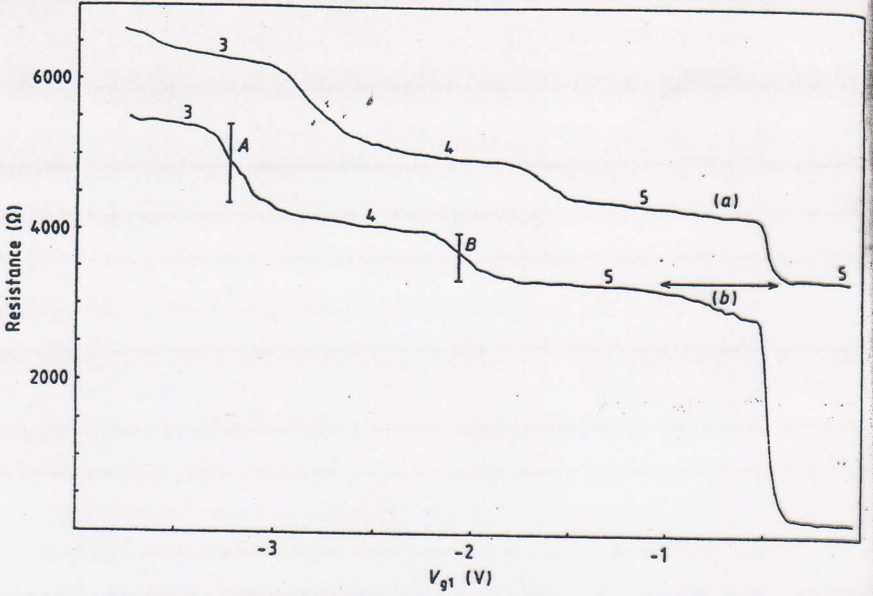


Figure 3. The device resistance is plotted as a function of V_{g1} for voltage V_{g2} (*a*) − 1 and (*b*) 0 V the numbers indicate the number of occupied sub-bands, and the vertical bars the corresponding steps in resistance as discussed in the text; $A = h/24e^2$ and $B = h/40e^2$. The horizontal line is a guide to illustrate the equivalence of the quantised value of resistance when a voltage of −1 V is applied to either gate independently.

In figure 4 we have removed this anomalous resistance to demonstrate fully that the preservation of the quantised structure when the electron transport through the two narrow constrictions is entirely ballistic. Plateau indices have again been marked on the diagram and the qualitative features discussed above are readily apparent. The quantised

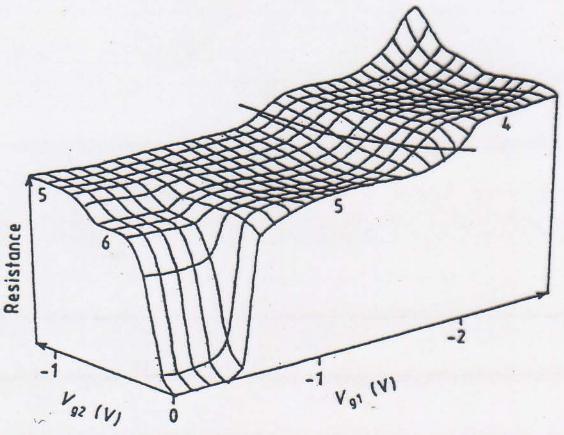


Figure 4. The channel resistance is plotted (in arbitrary units) in a three-dimensional representation as a function of the two applied gate voltages. The quantised nature of the resistance is clearly demonstrated and plateau indices are marked for clarity. The line connecting the points of inflection between plateaus 4 and 5 illustrates the perturbation due to the proximity of the gates as discussed in the text.

Wharam et al. (1991)

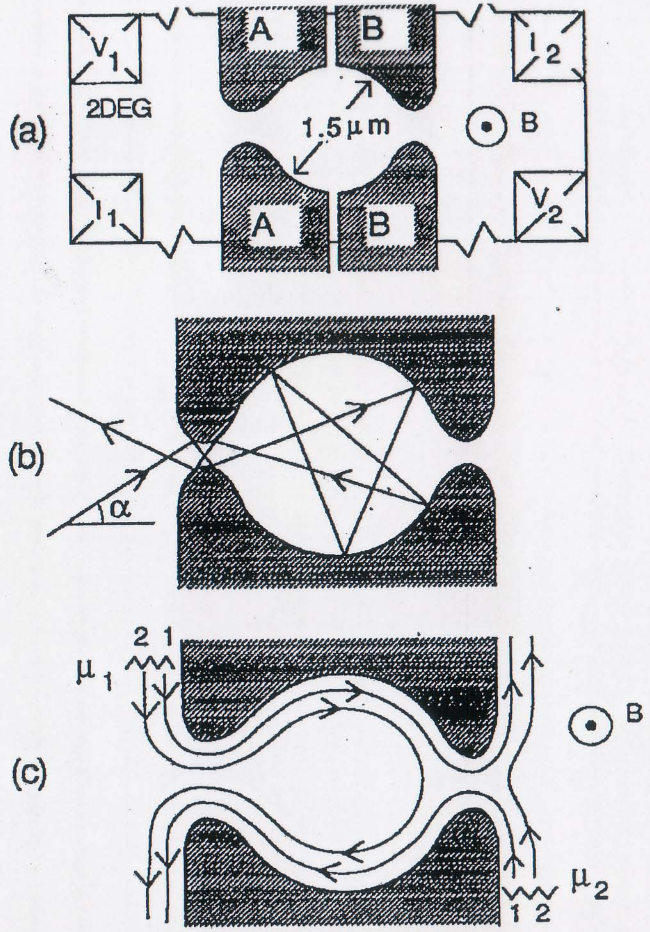


FIG. 1. (a) Schematic layout of the sample. Gate pairs *A* and *B* define two QPC's with a cavity in between. Current I_1, I_2, and voltage V_1, V_2 contacts are attached to the wide 2D EG regions. (b) Typical electron trajectory in the absence of a magnetic field, illustrating nonadiabatic transport. (c) Electron flow in edge channels along equipotential lines in a high magnetic field, illustrating adiabatic transport.

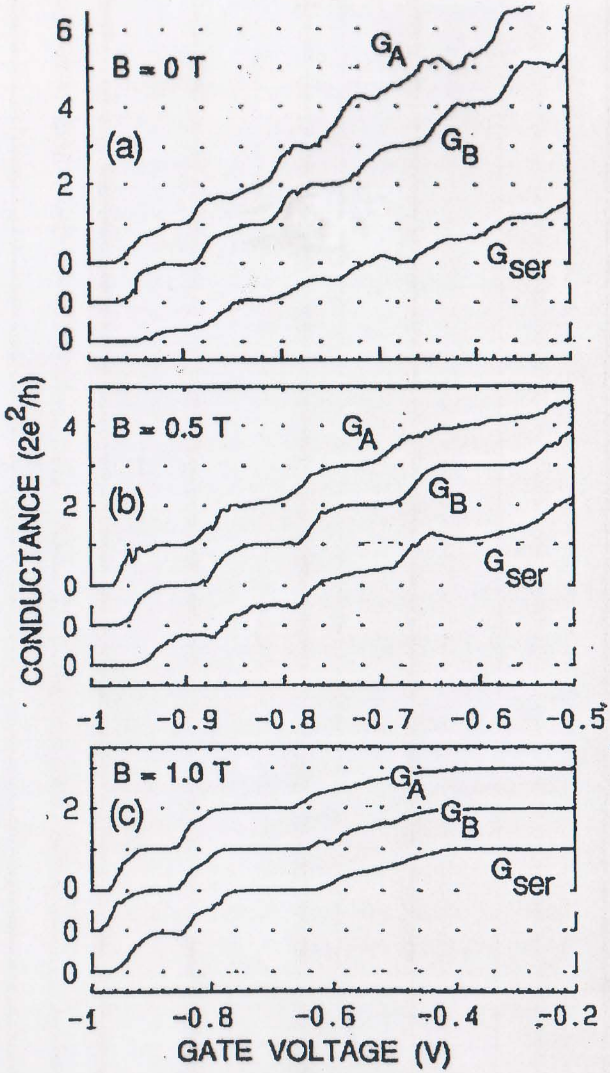
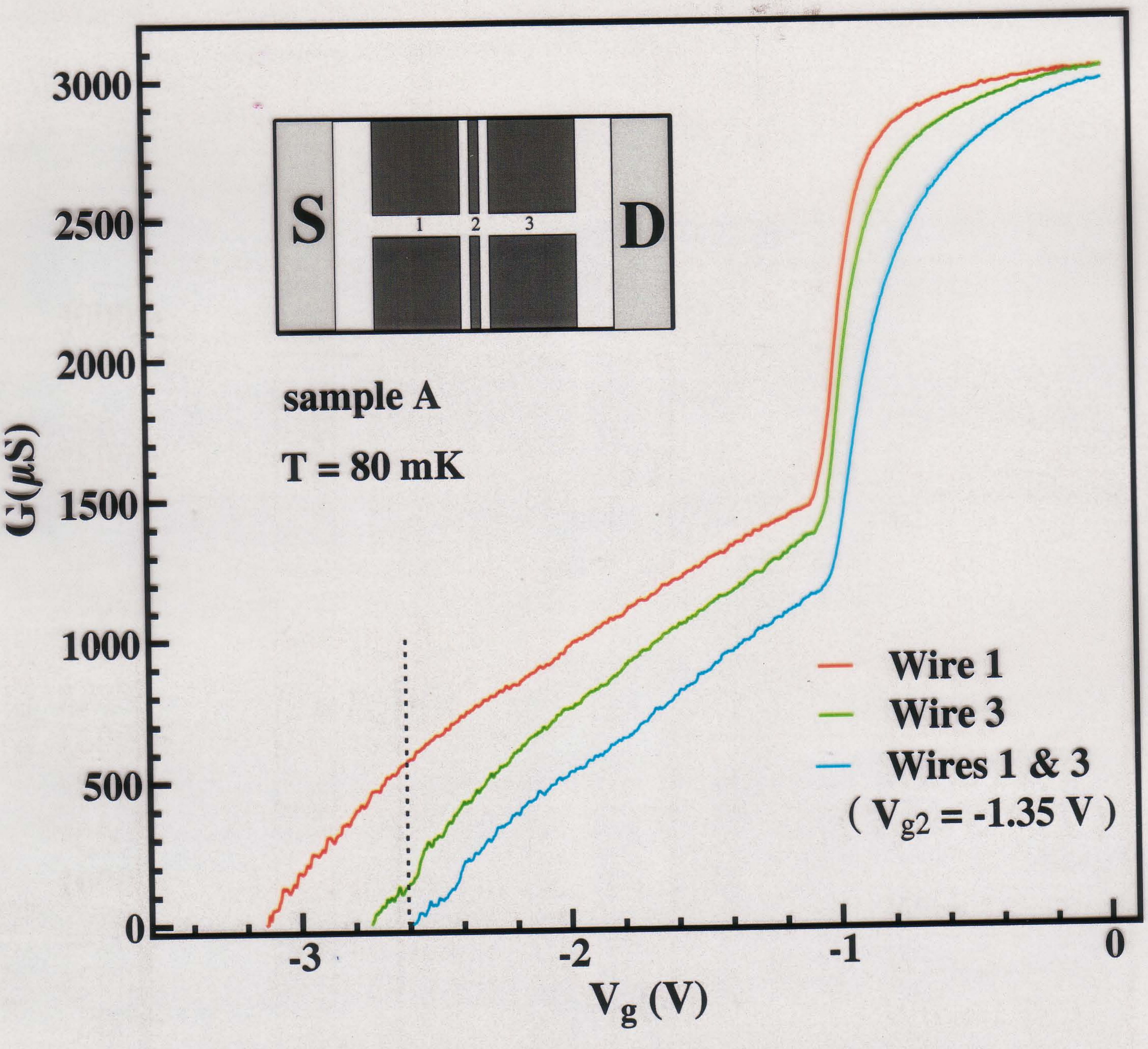


FIG. 2. Comparison between the conductances of the individual QPC's G_A and G_B and the conductance of the complete device G_{ser}, illustrating the transition from Ohmic transport at $B = 0$, to adiabatic transport at $B = 1.0$ T. The curves have been offset for clarity.

Kouwenhoven et al.

Gate Characteristics

Single and Series Wires



Honda , Tarucha et al.

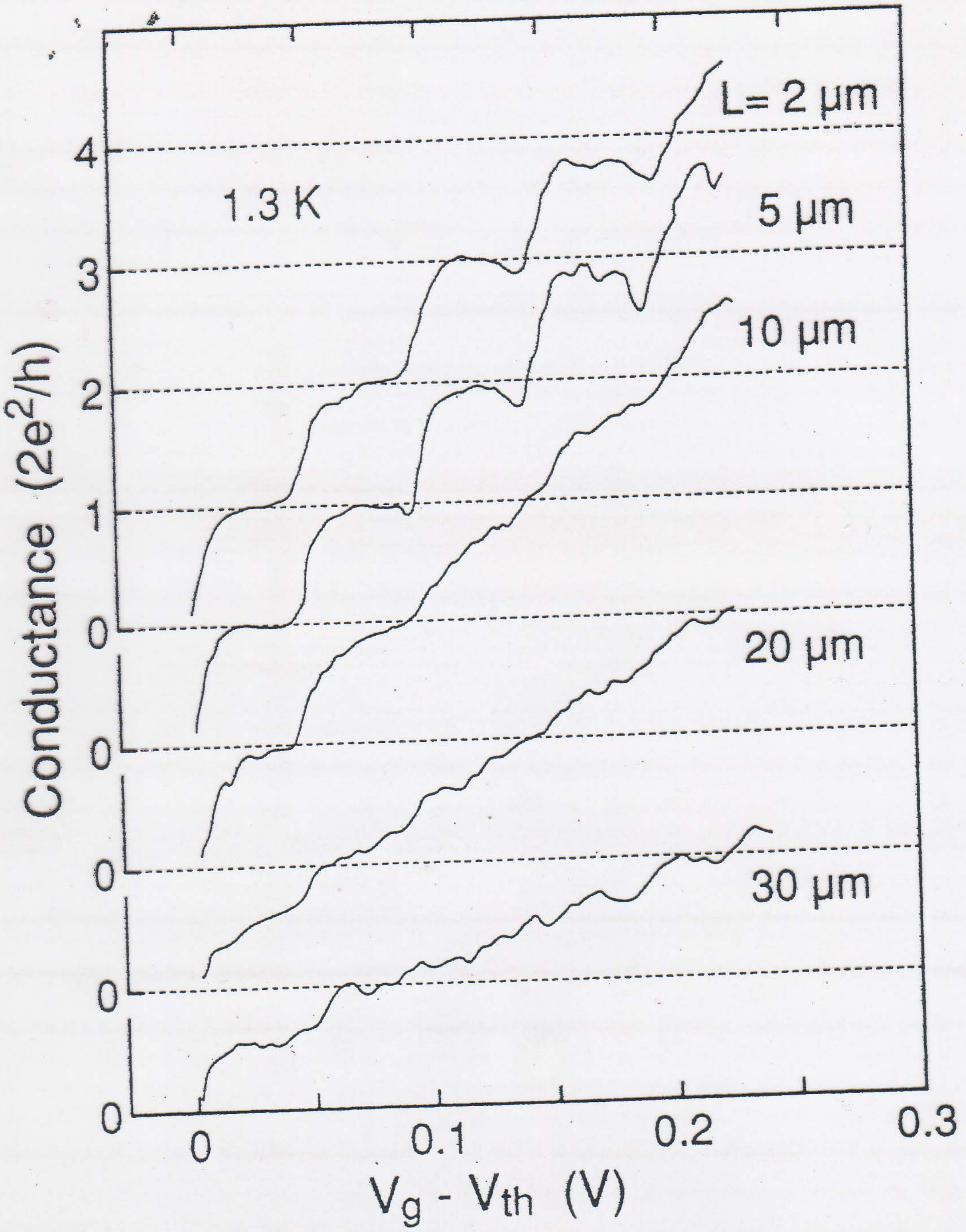


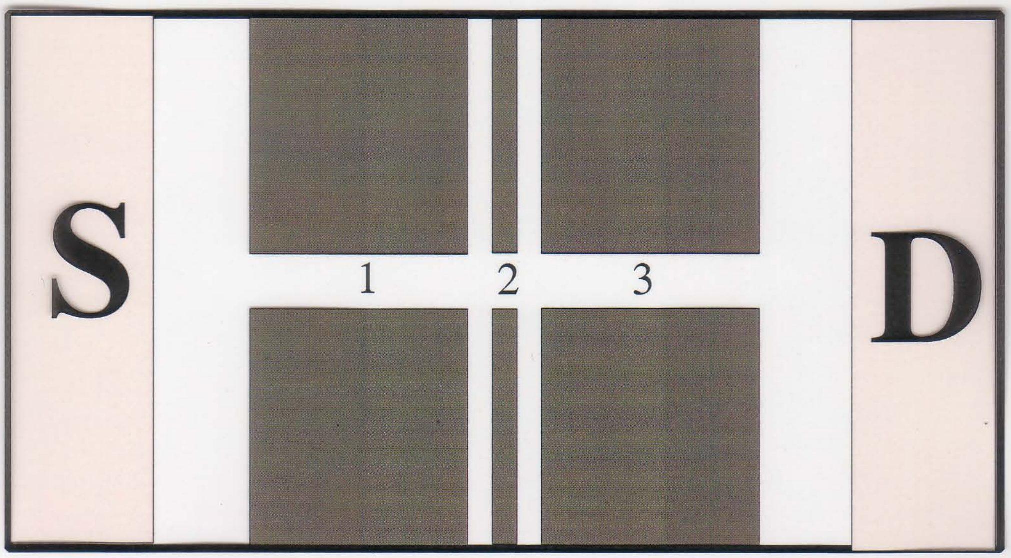
Fig. 3. Wire conductance as a function of effective gate voltage, $V_g - V_{th}$, at 1.3 K. The curves are offset for clarity.

Sample Parameters

Samples A and B

2D Carrier density $= 2.4 \times 10^{11}\ \text{cm}^{-2}$

2D Mobility $= 3.4 \times 10^{6}\ \text{cm}^{2}/\text{Vs}$



Wires 1 and 3

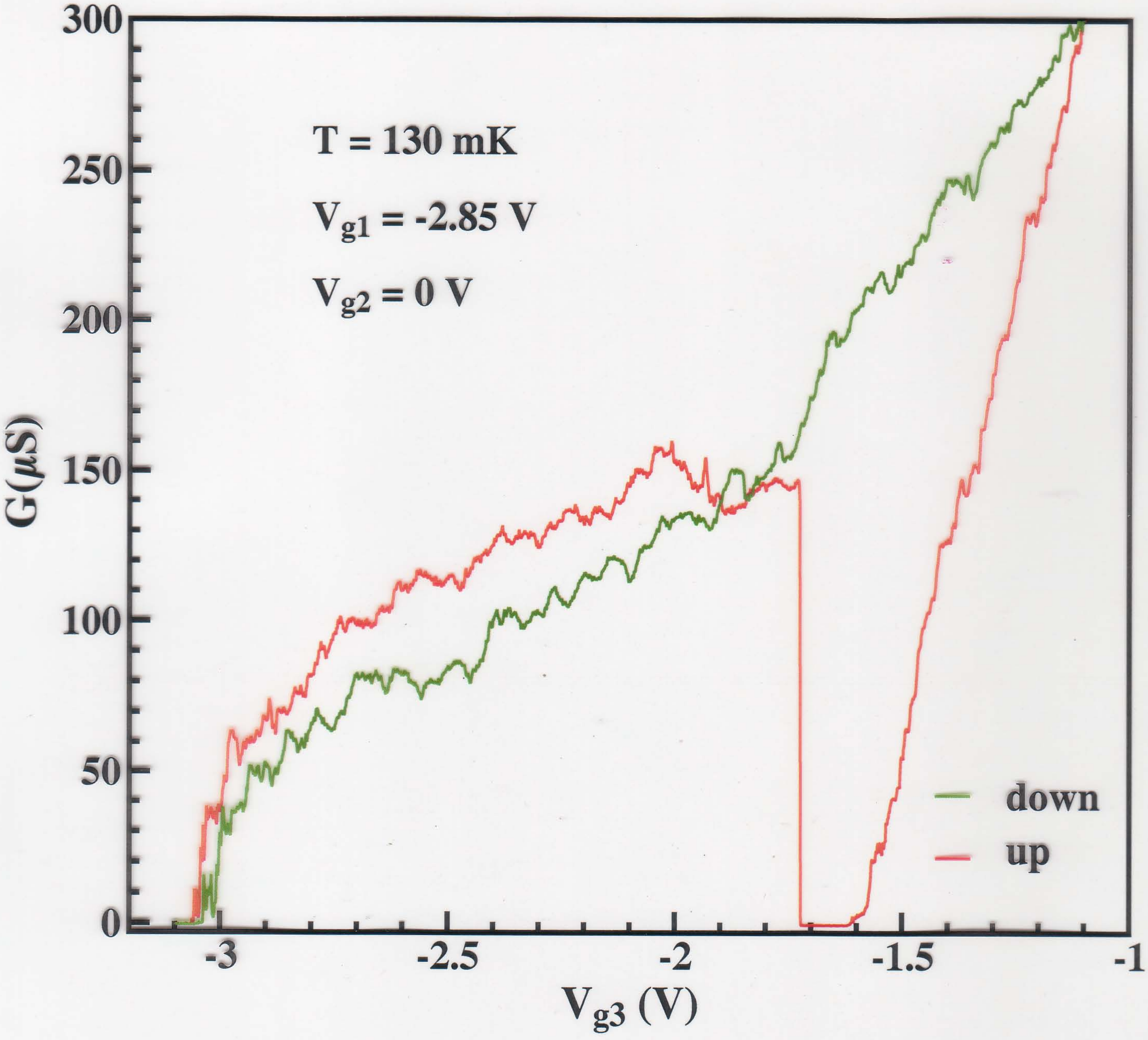
$L = 3\ \mu m$

Wire 2

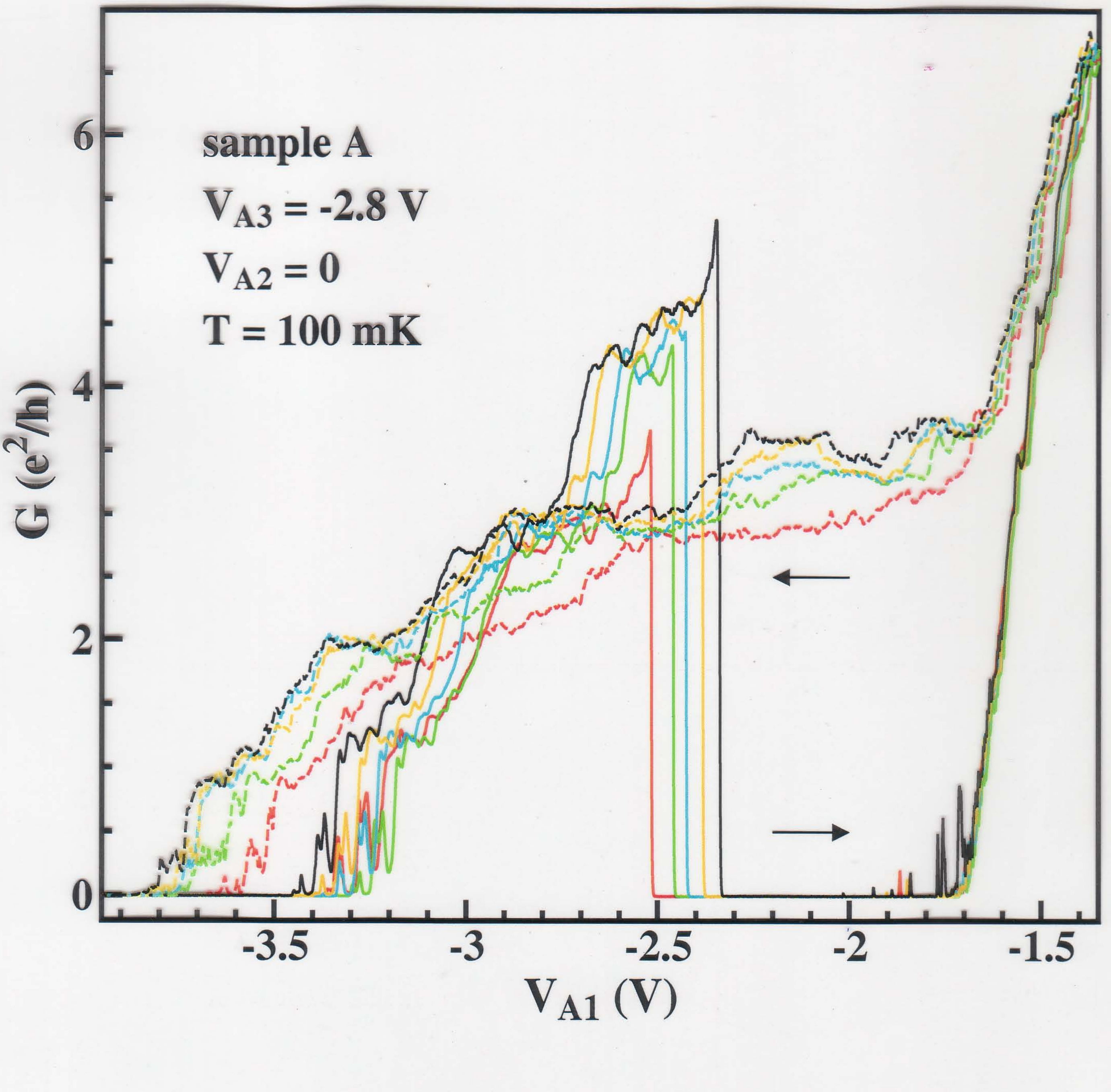
$L = 0.4\ \mu m$

All wires have a width of 1.2 μm
Separation between adjacent wires is 0.4 μm
2DEG is is 0.3 μm away from surface gates

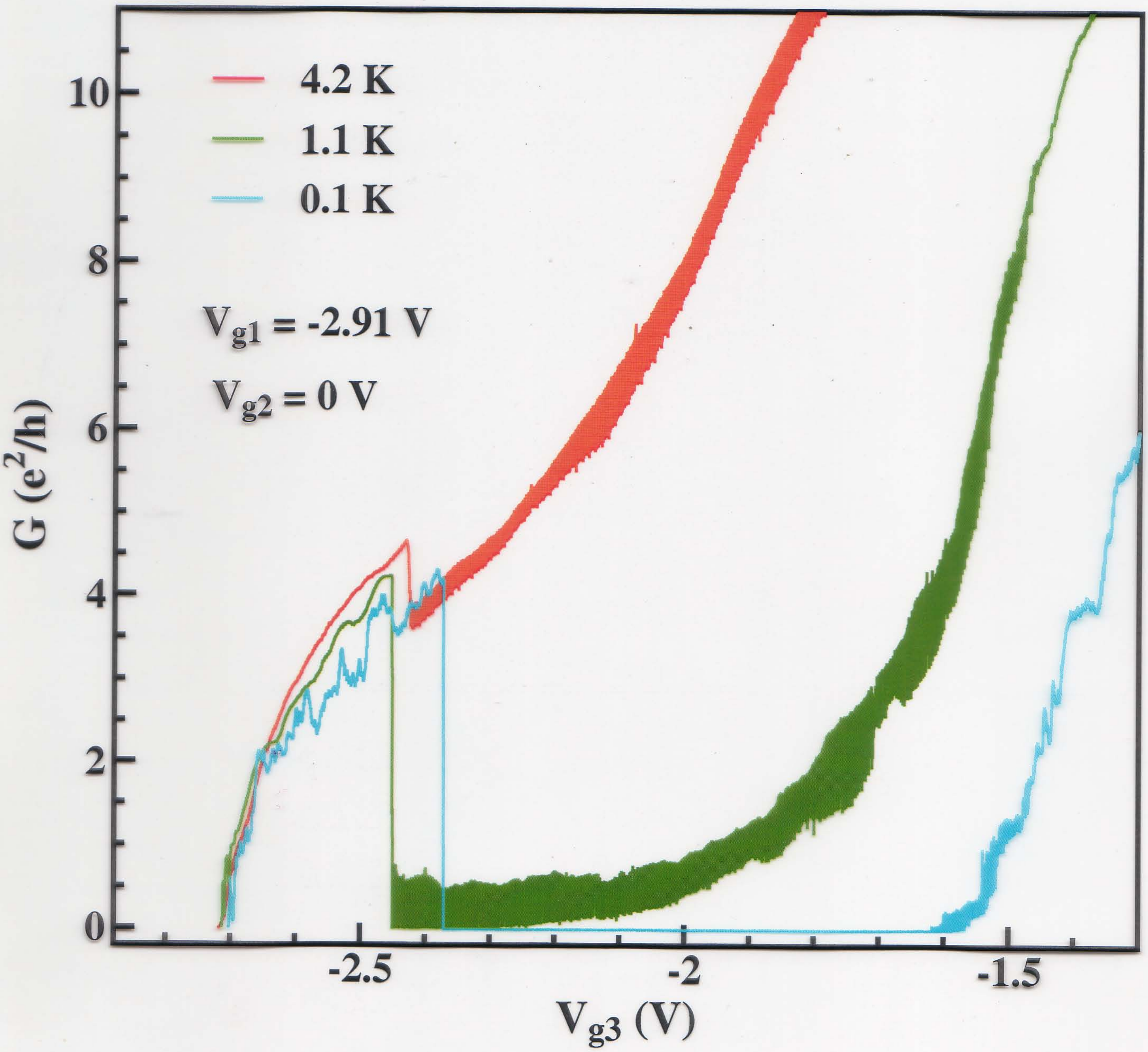
Conductance Collapse!



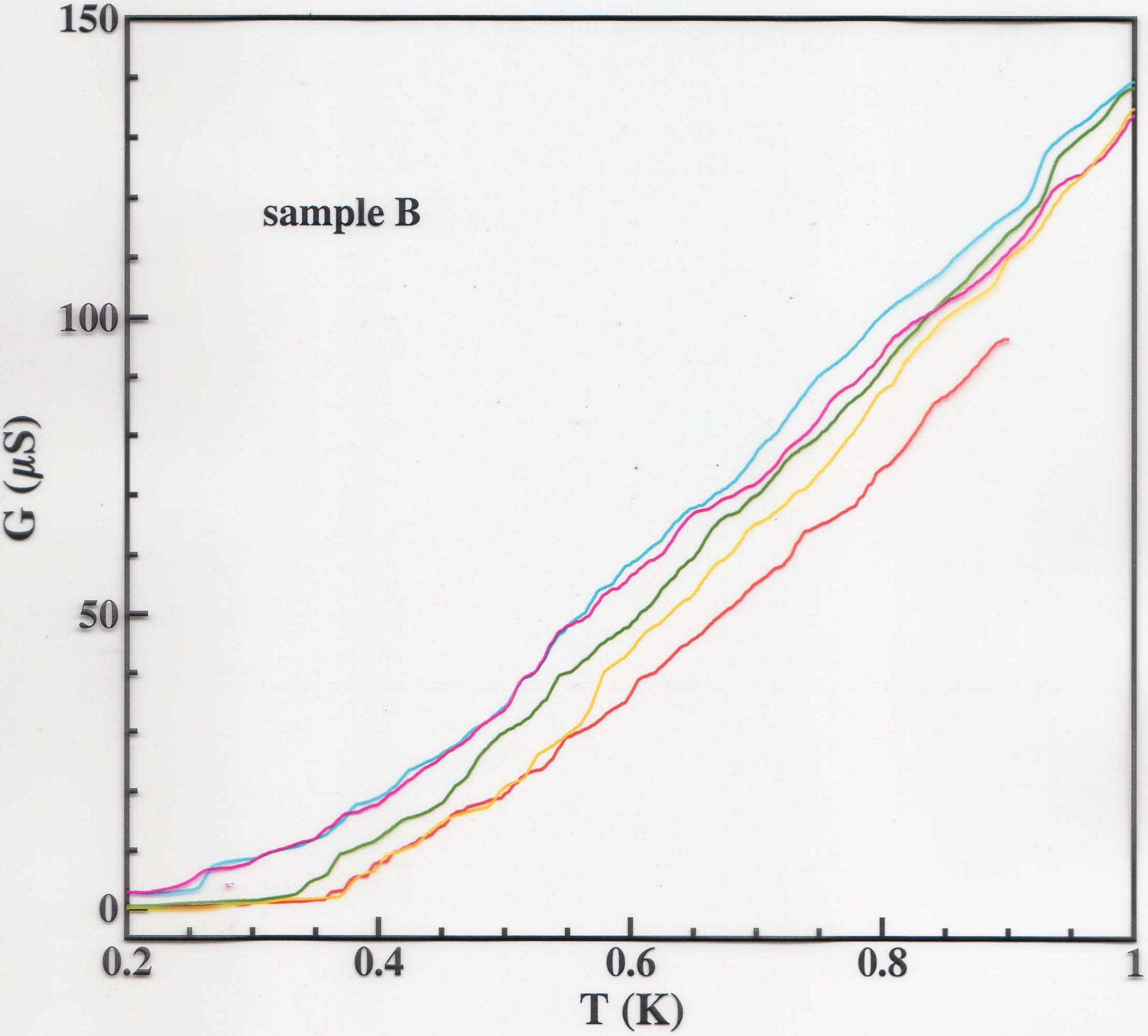
Reproducibility of Collapse in Gate Sweeps



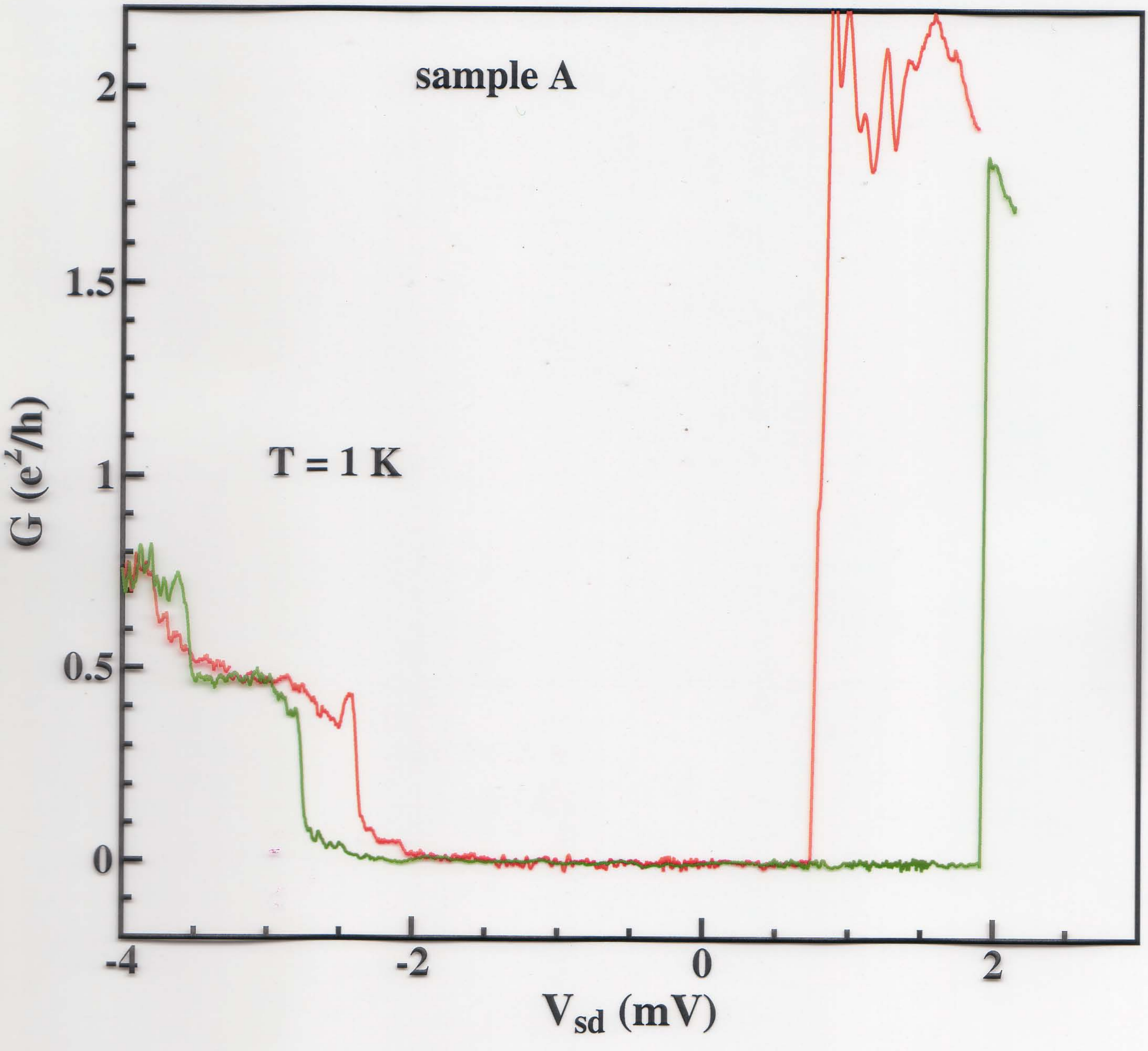
Conductance Collapse at Various T



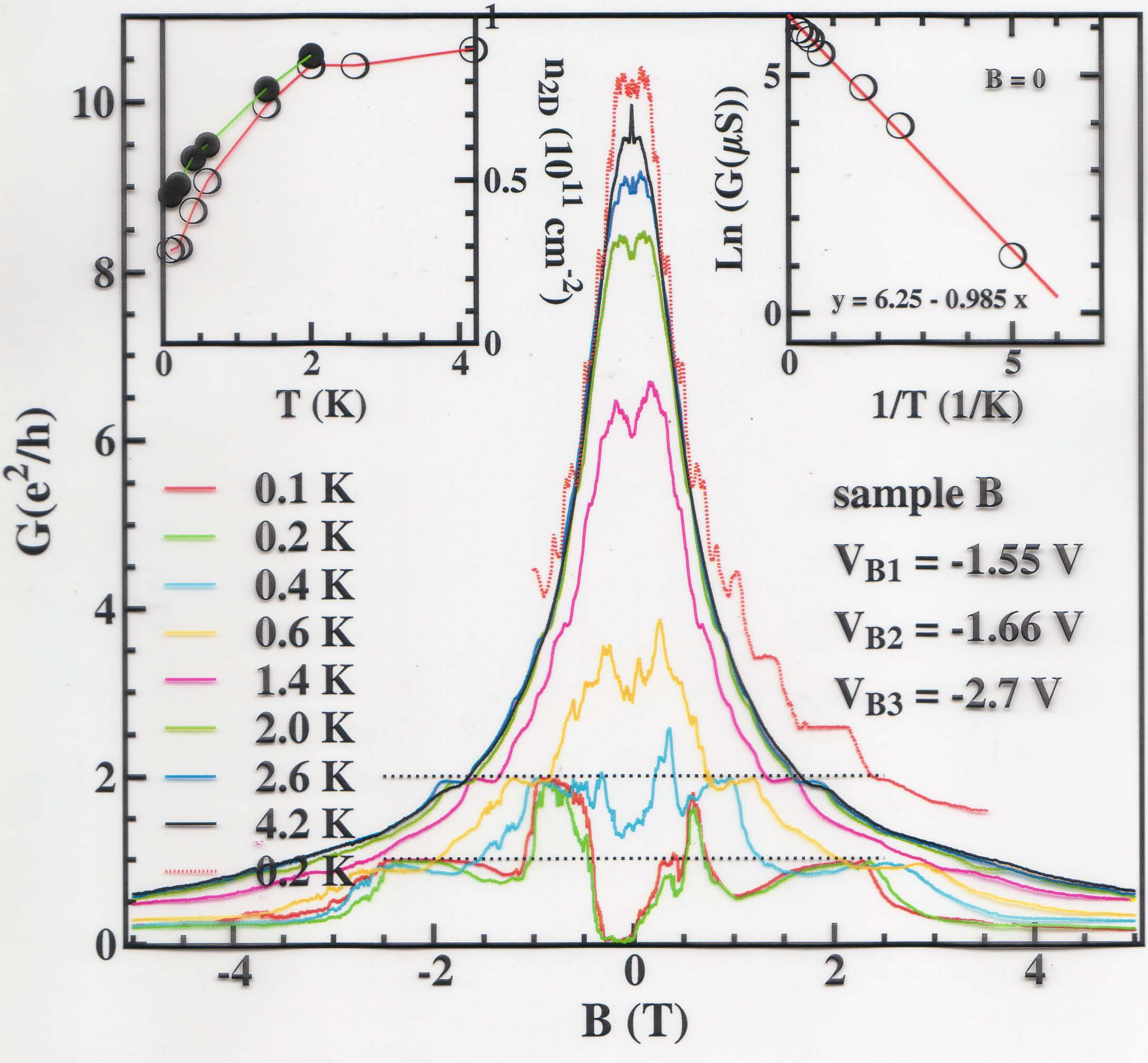
Reproducibility in Temperature Cycles



DC bias dependence



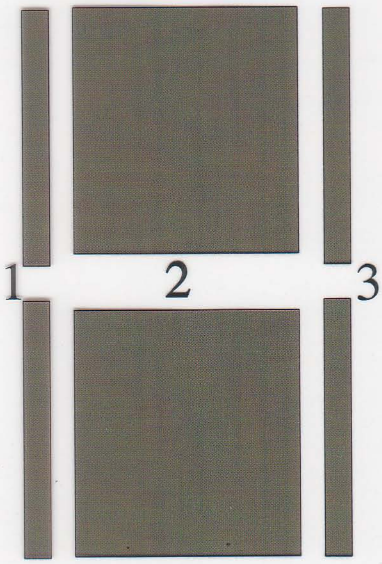
In a Perpendicular B Field...



Sample C

2D Carrier density = 3.3×10^{11} cm^{-2}

2D Mobility = 3.6×10^{6} cm^{2}/Vs



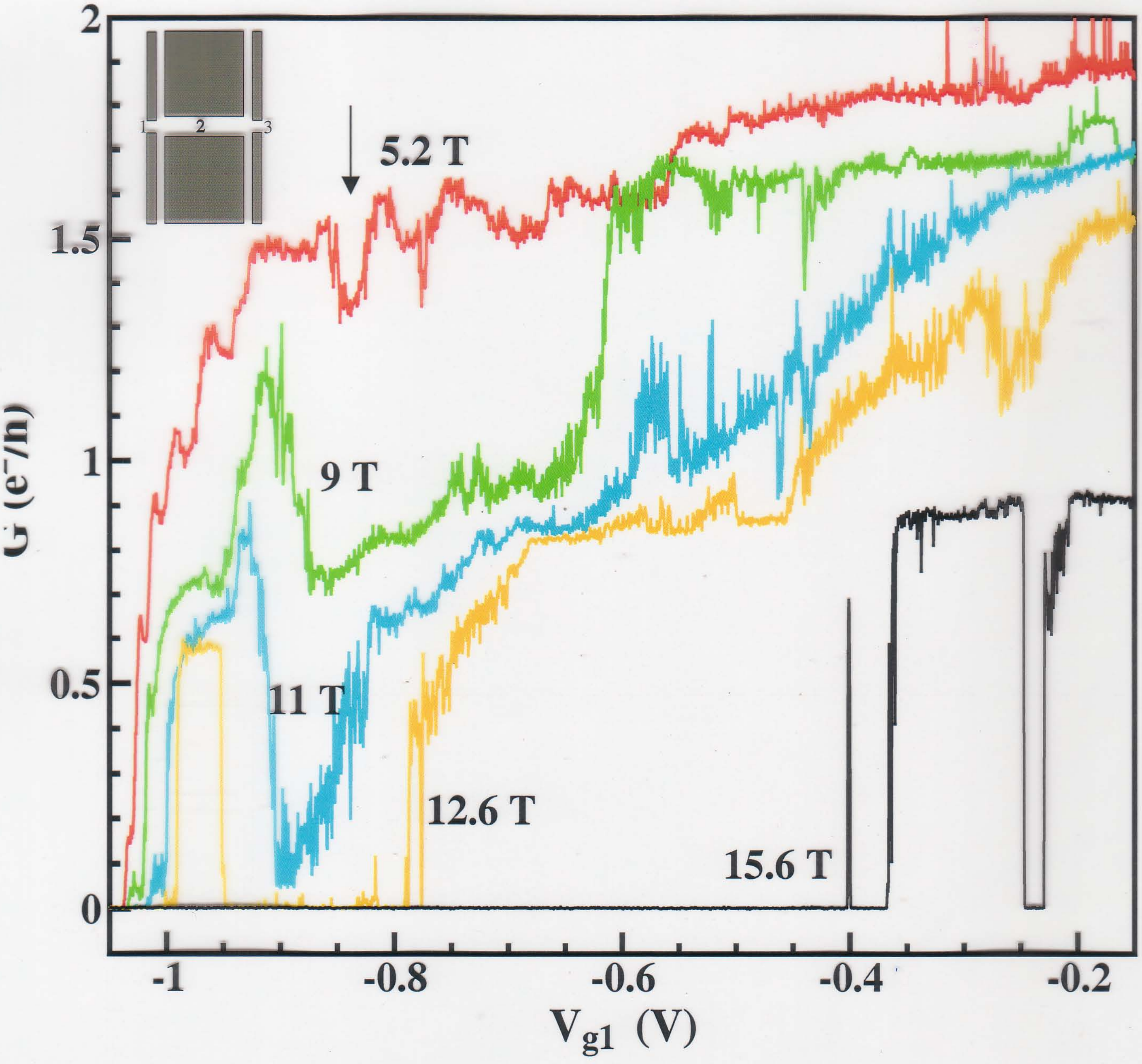
Wires 1 and 3	**Wire 2**
L = 0.3 μm	**L = 2 μm**
W = 0.4 μm	**W = 0.8 μm**

Separation between adjacent wires is 0.25 μm

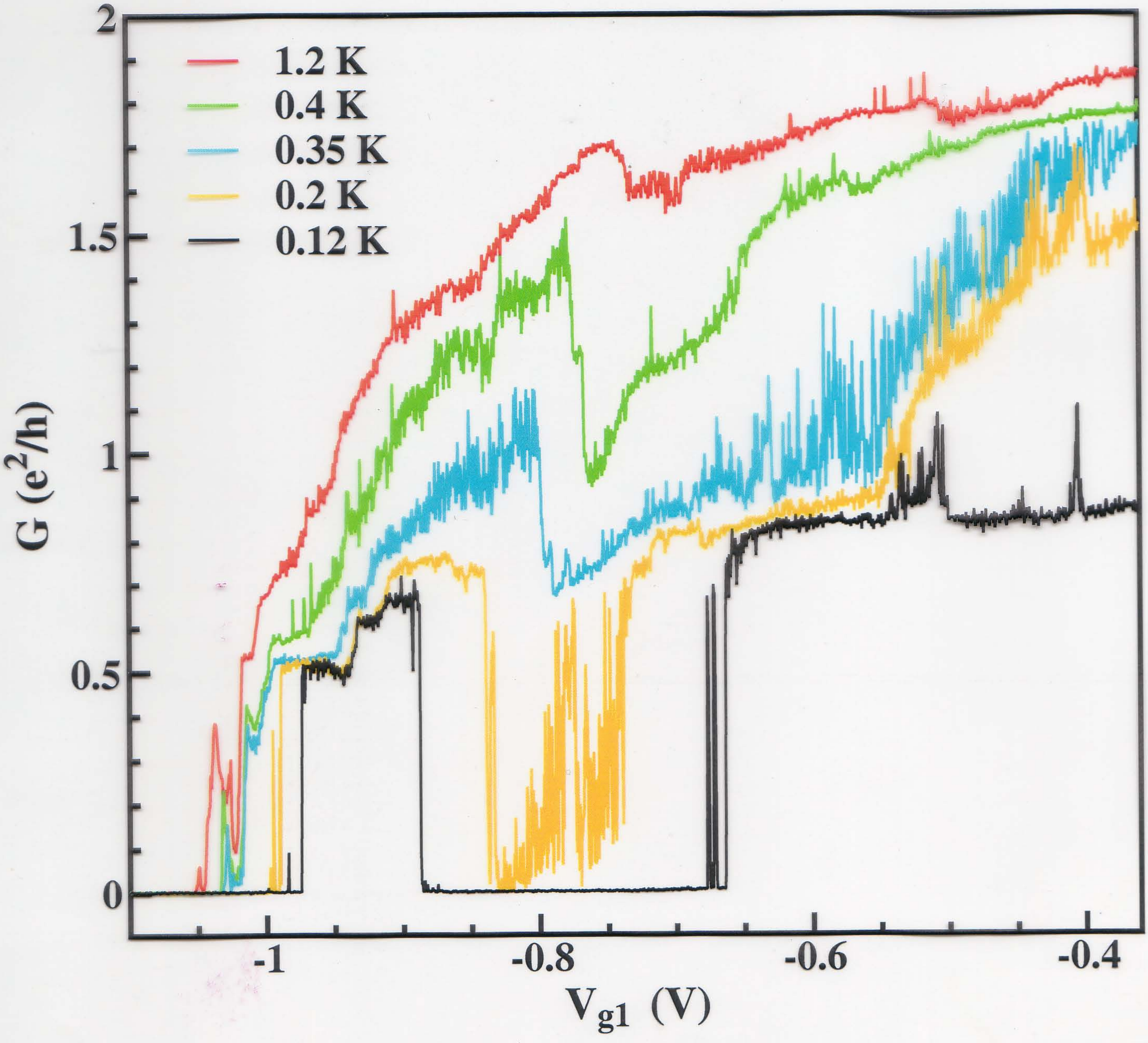
2DEG is 0.1 μm away from surface gates

Conductance Collapse Type 2

($B_{\parallel}$ -Induced)



Collapse Type 2: T Dependence



References:

Conductance collapse : J. Phys. C **16** (2004) L279

0.7 structure : Phys. Rev. Lett. **77** 135 (1996)

0.7 analogue : Phys. Rev. Lett. **91** 136404 (2003)

Zero bias peak -
Kondo pincture : Phys. Rev. Lett. **88**, 226805 (2002)

Summary

We have observed an unusual collapse in the conductance of 1D quantum wires.

Two types of collapse are observed, both of which have the defining feature of zero conductance in a gate voltage region where a finite conductance is expected.

The mechanism is unknown but may result from an inter-subband charge density wave or a 1D Wigner crystallization.

Further experimental and theoretical work are necessary to understand the phenomenon.