ELECTRON INTERACTIONS IN 1D

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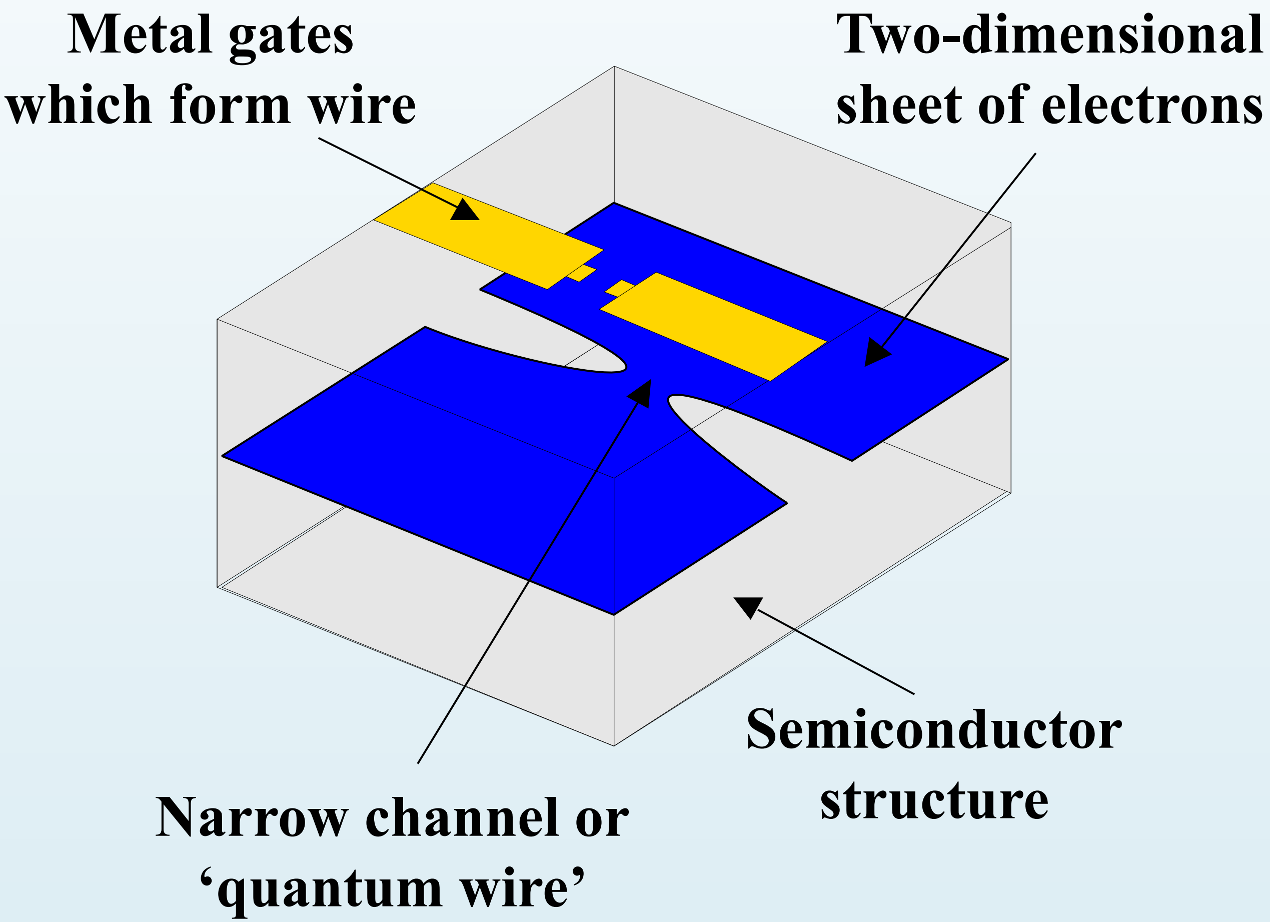
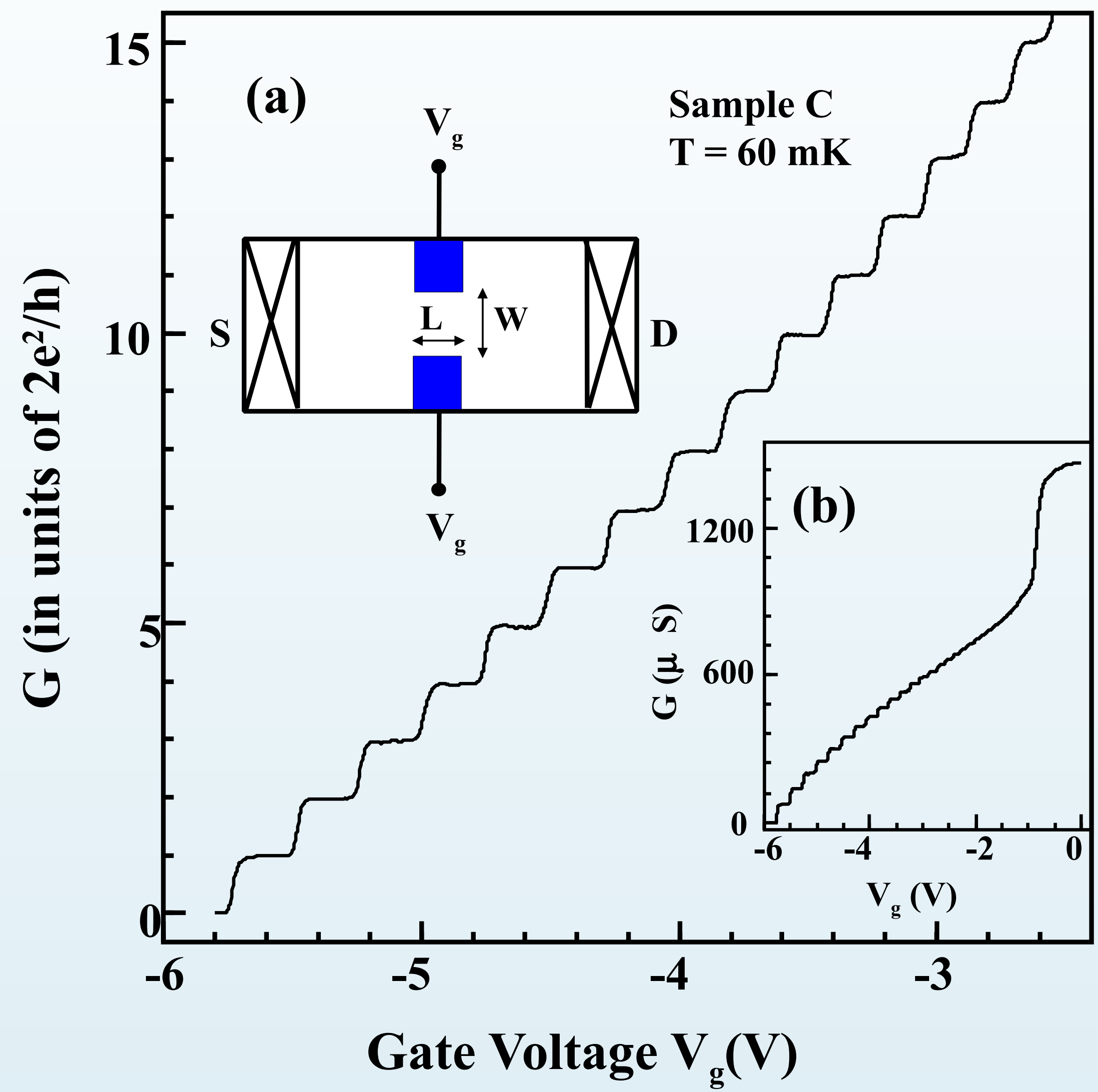
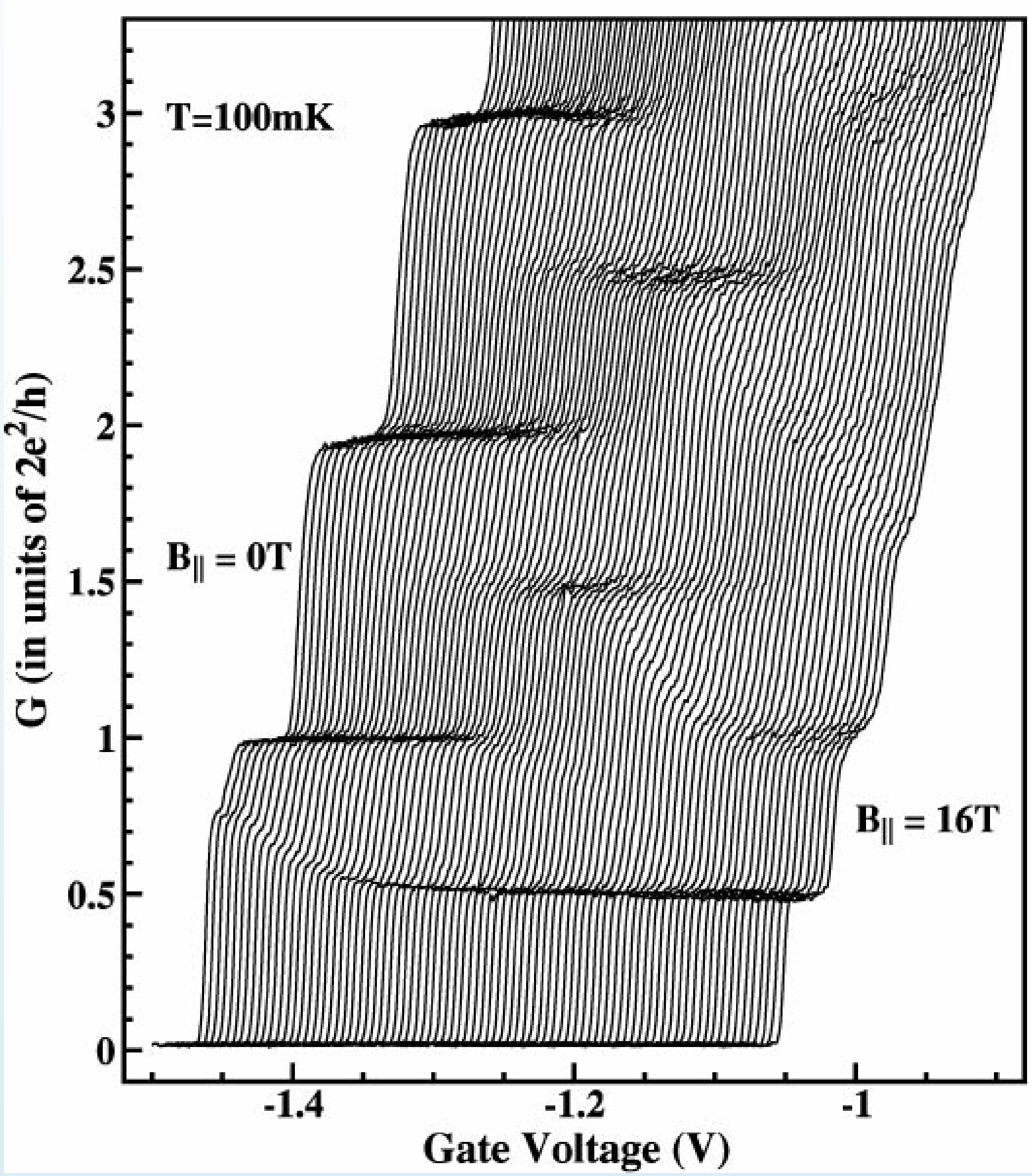
Forming the one-dimensional quantum wire



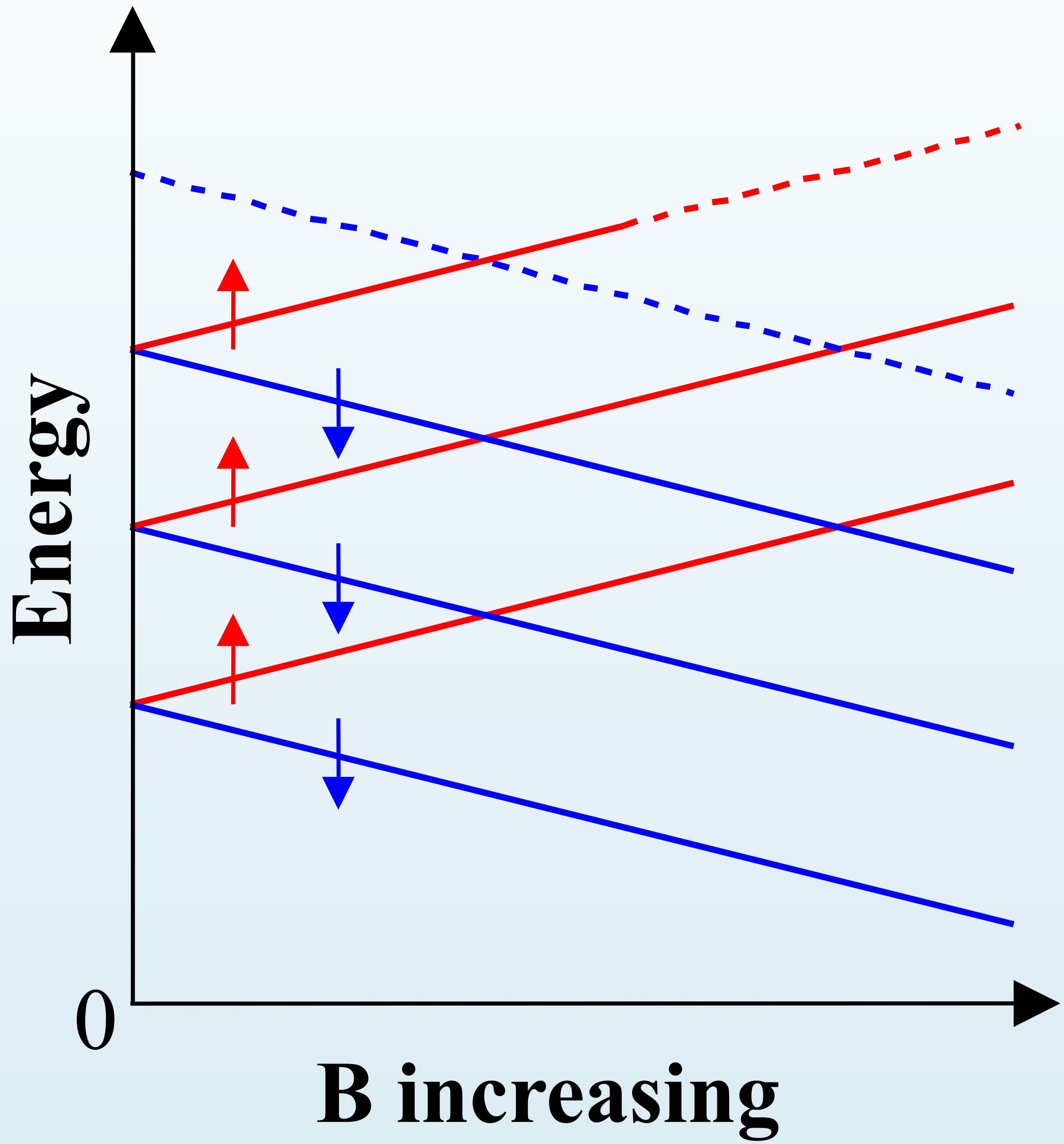


(a)
Sample C
T = 60 mK
V_g
S
L
W
D
V_g
G (in units of 2e²/h)
Gate Voltage V_g(V)
15
10
5
0
-6
-5
-4
-3
(b)
G (μ S)
1200
600
0
-6
-4
-2
0
V_g (V)

Conductance of a quantum wire in an in-plane parallel magnetic field



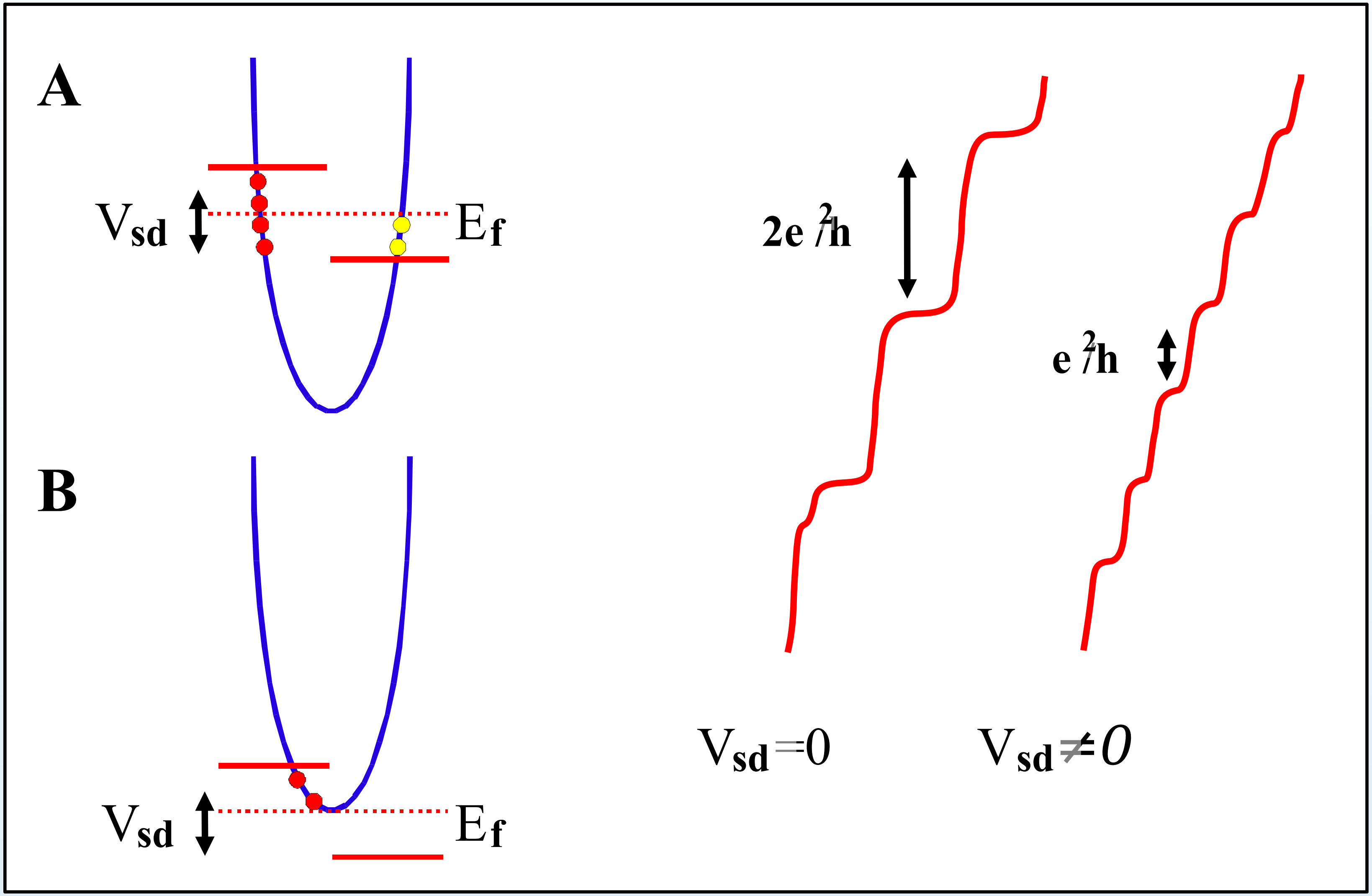
Energy of spin-polarised 1D 1D subbands



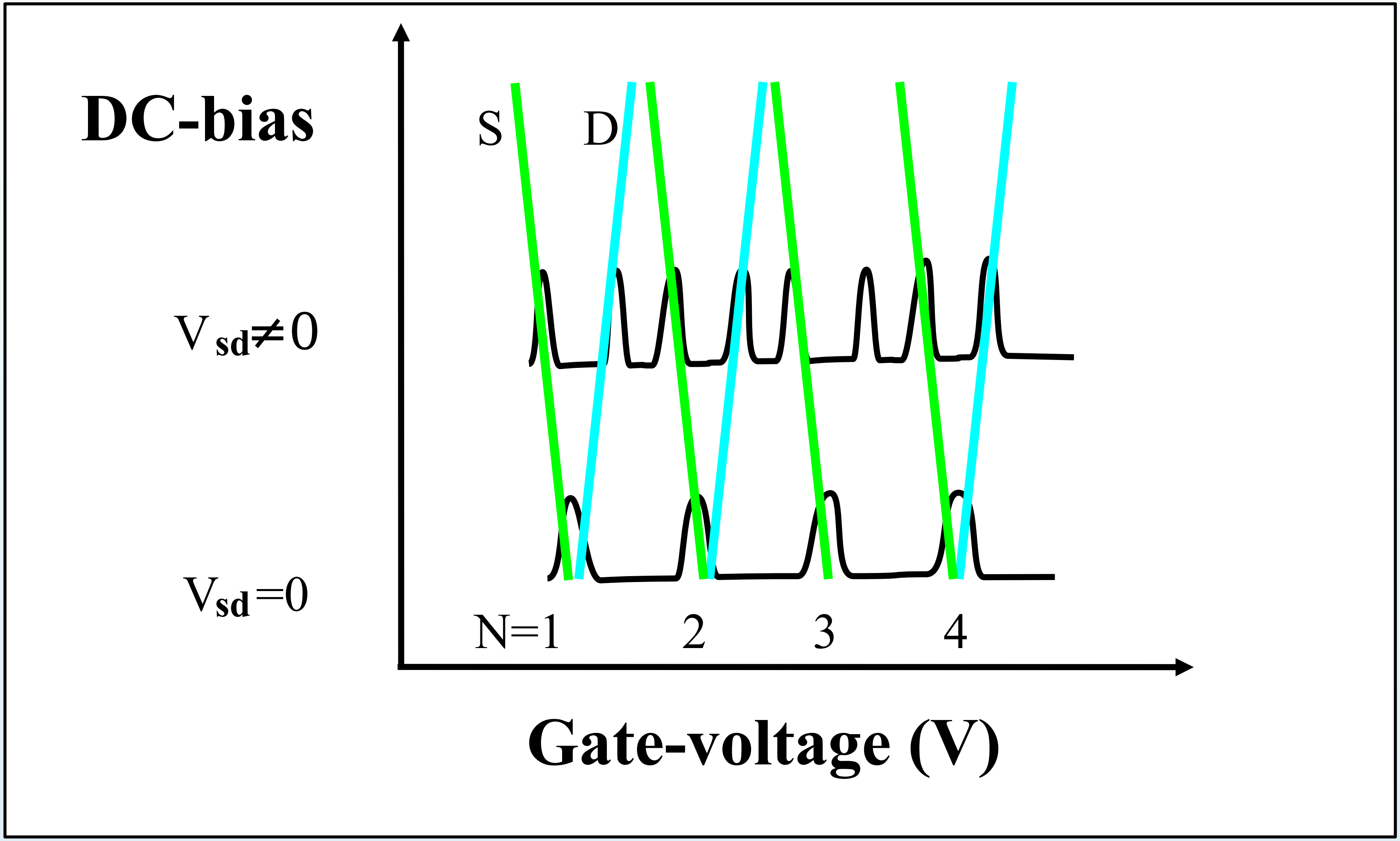
DC-bias measurements

- A powerful way of probing an energy spectrum.
- Can give information about a subband when it is partially populated.
- Useful for studying the restructuring of energy spectrum at crossings.

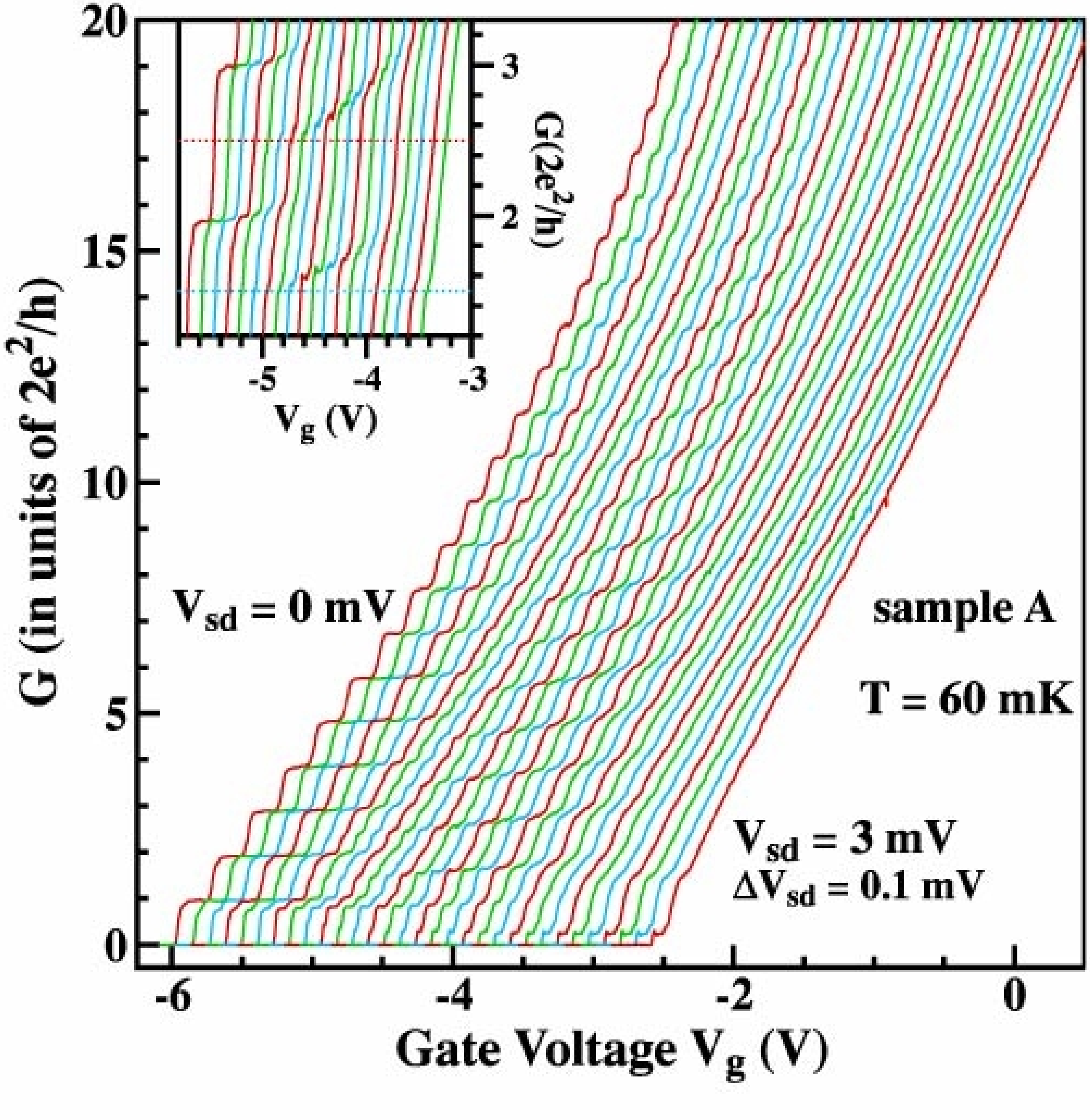
“Half-plateaux” caused by DC-bias



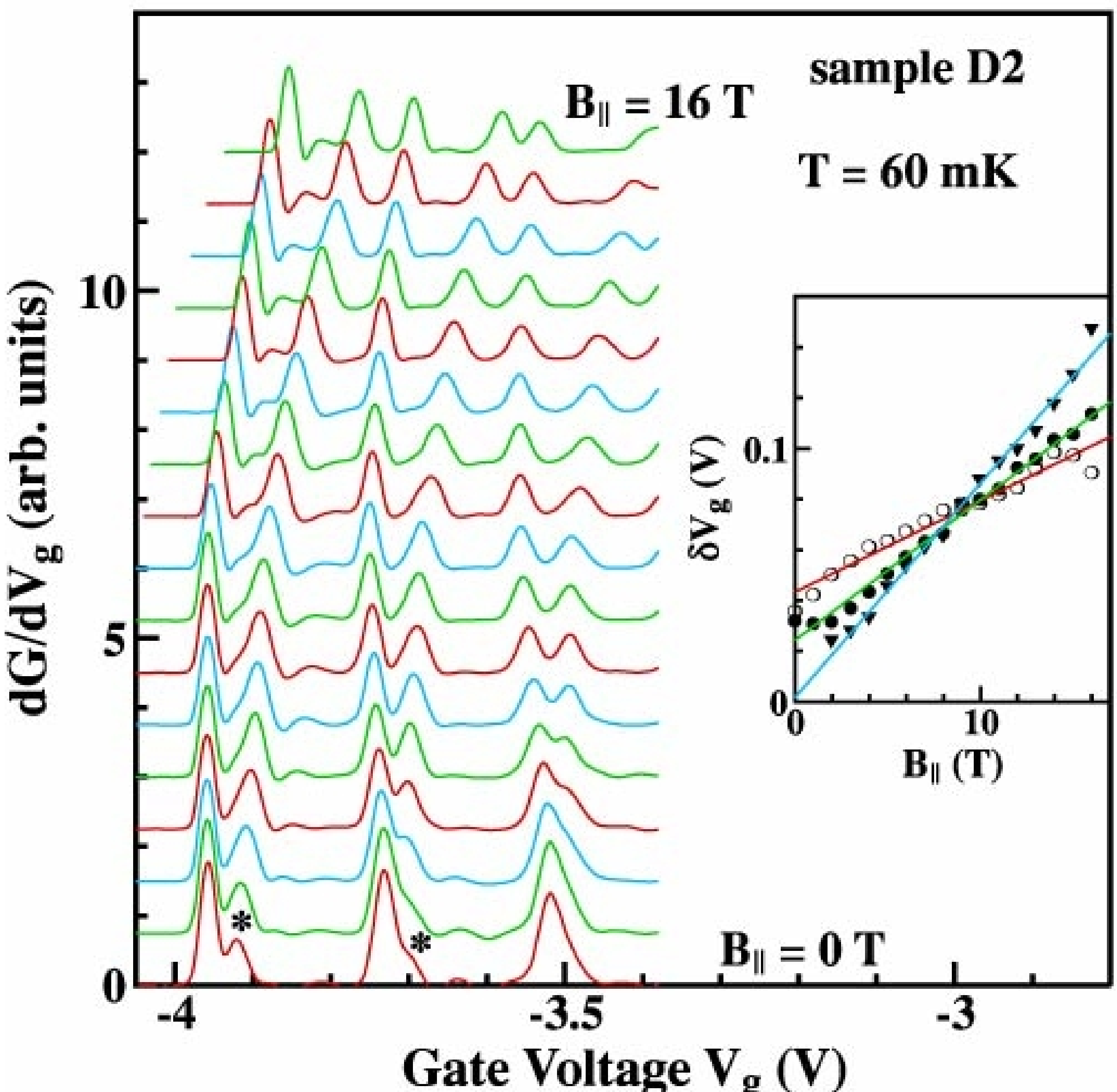
Peaks for each subband split into two



Half-Plateaus induced by a dc source-drain bias

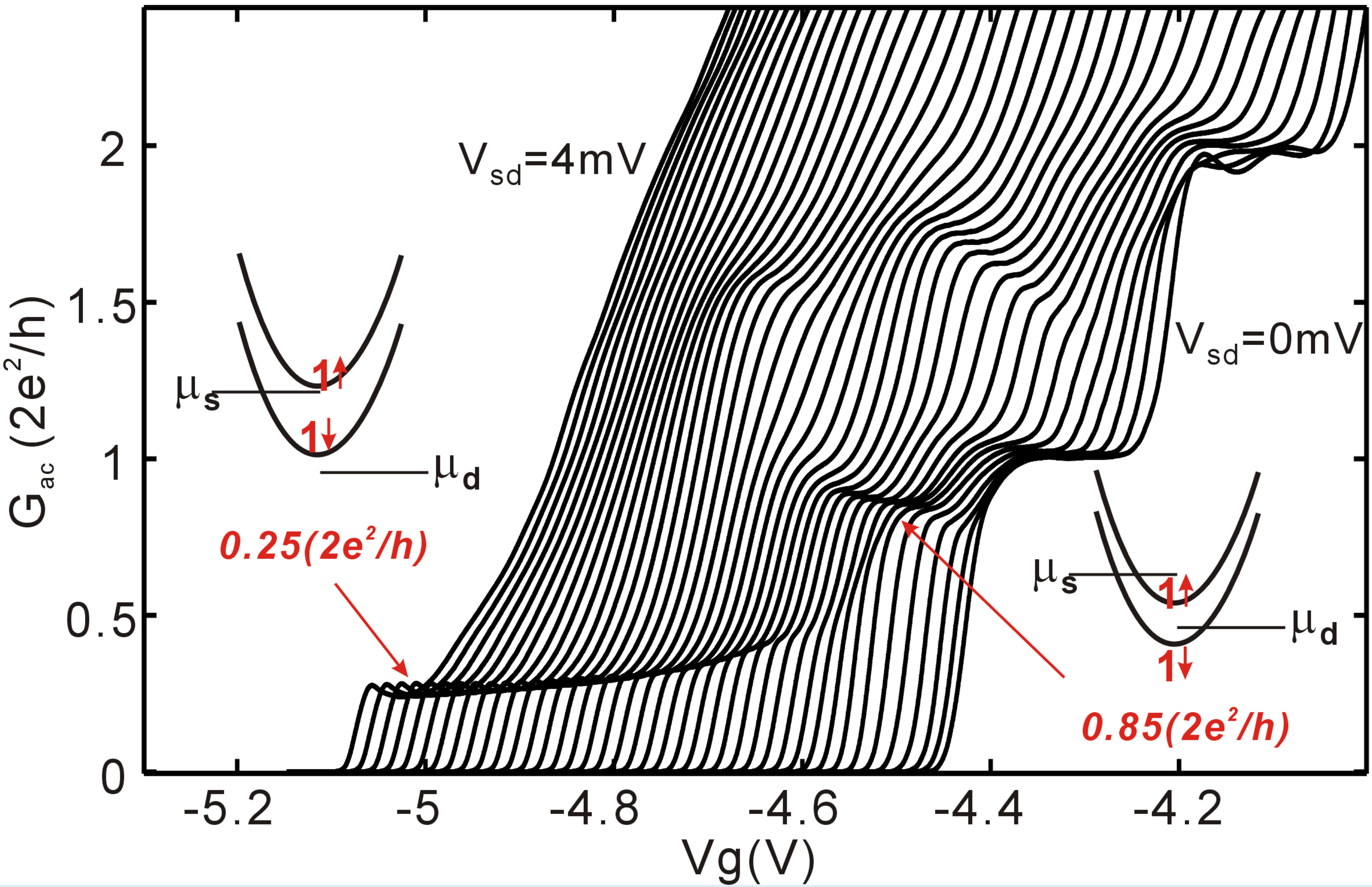


Splitting of the transconductance peaks in an in-plane magnetic field

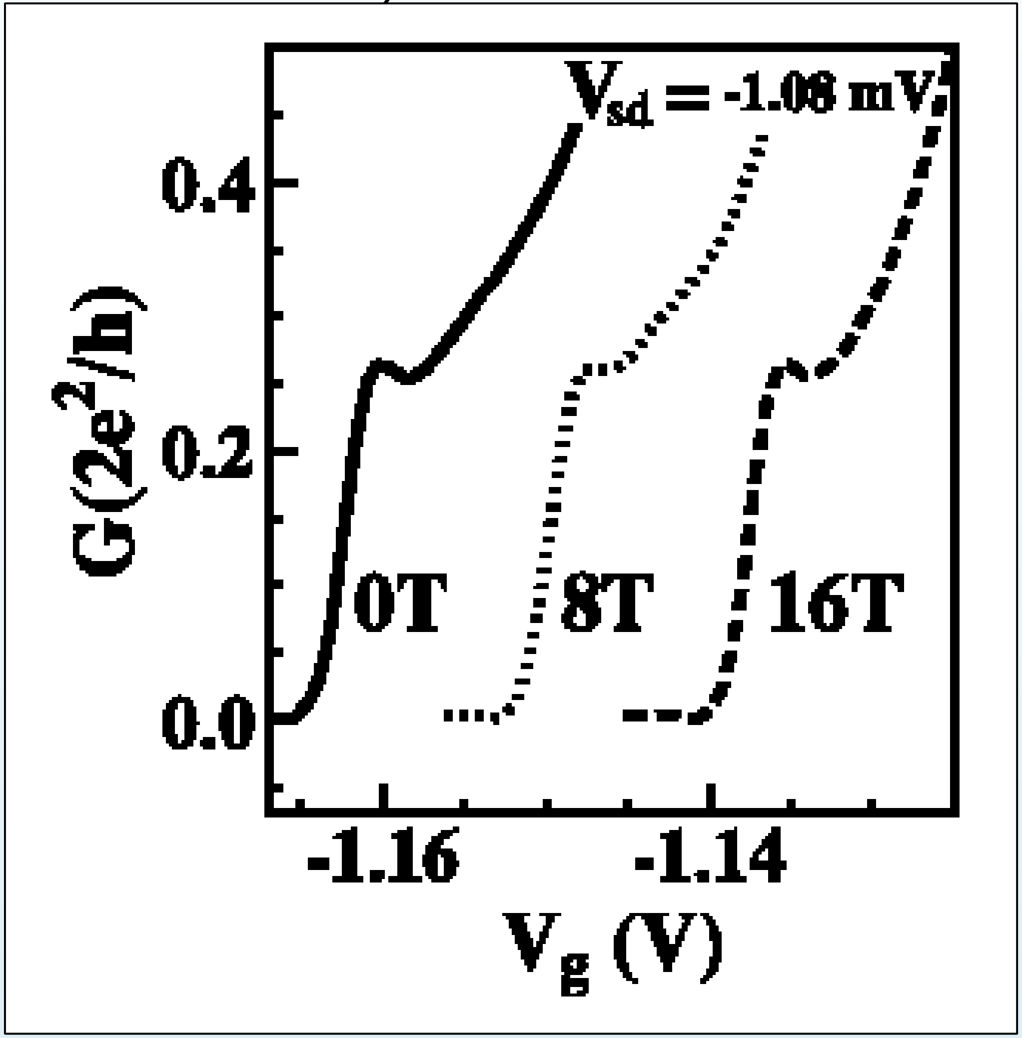


Preceding Results All Follow One-Electron Considerations

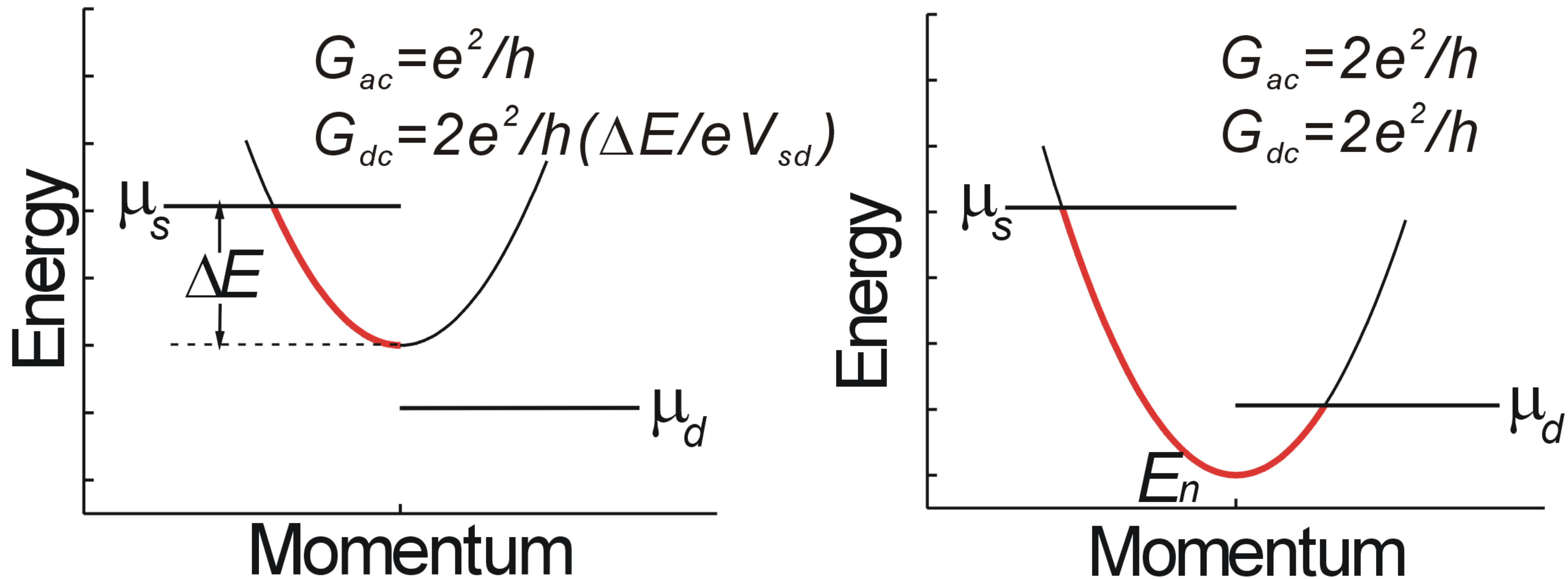
FORMATION OF 0.25, Chen, Graham, Thomas



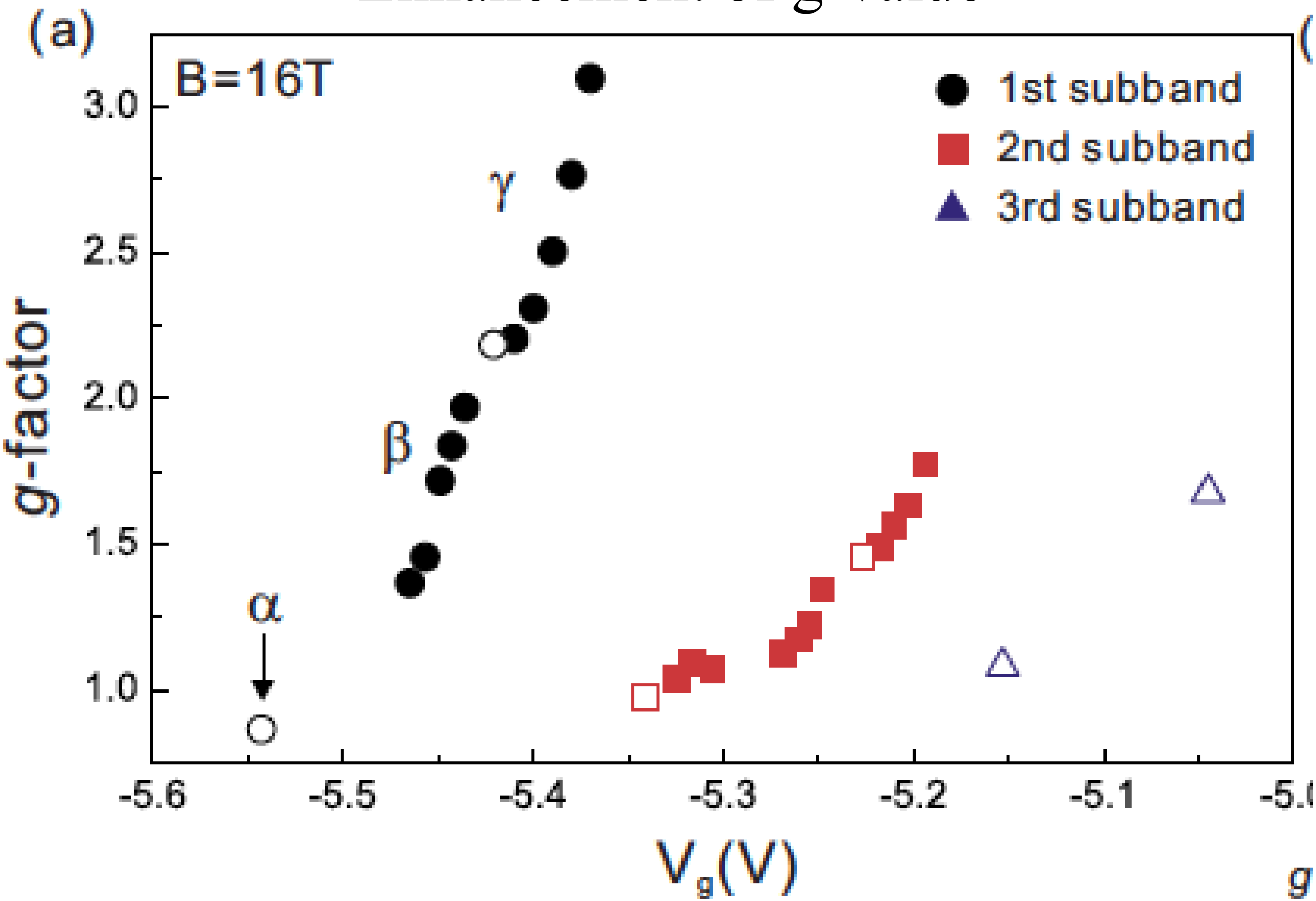
DC-bias '0.25' structure at B=0, 8 and 16T



DC Conductance allied to Differential Conductance G_{ac}



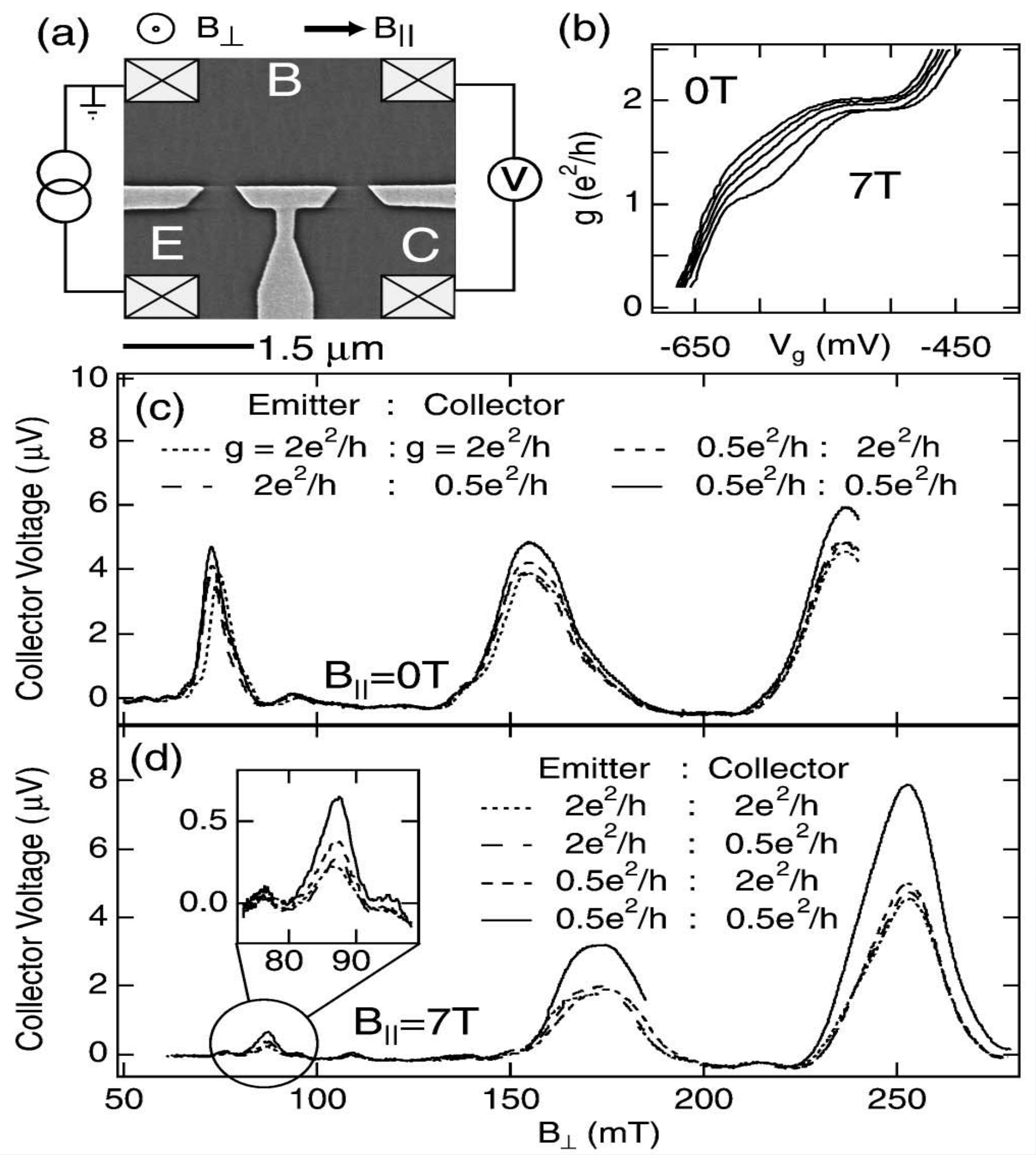
Enhancement of g Value



Consequences of Spin Polarisation – Spin Locking and Topological Features, Spin Lattices Controlled by Rashba Fields.

- <u>Electron Focusing</u>

Focusing – Potok, Marcus et al

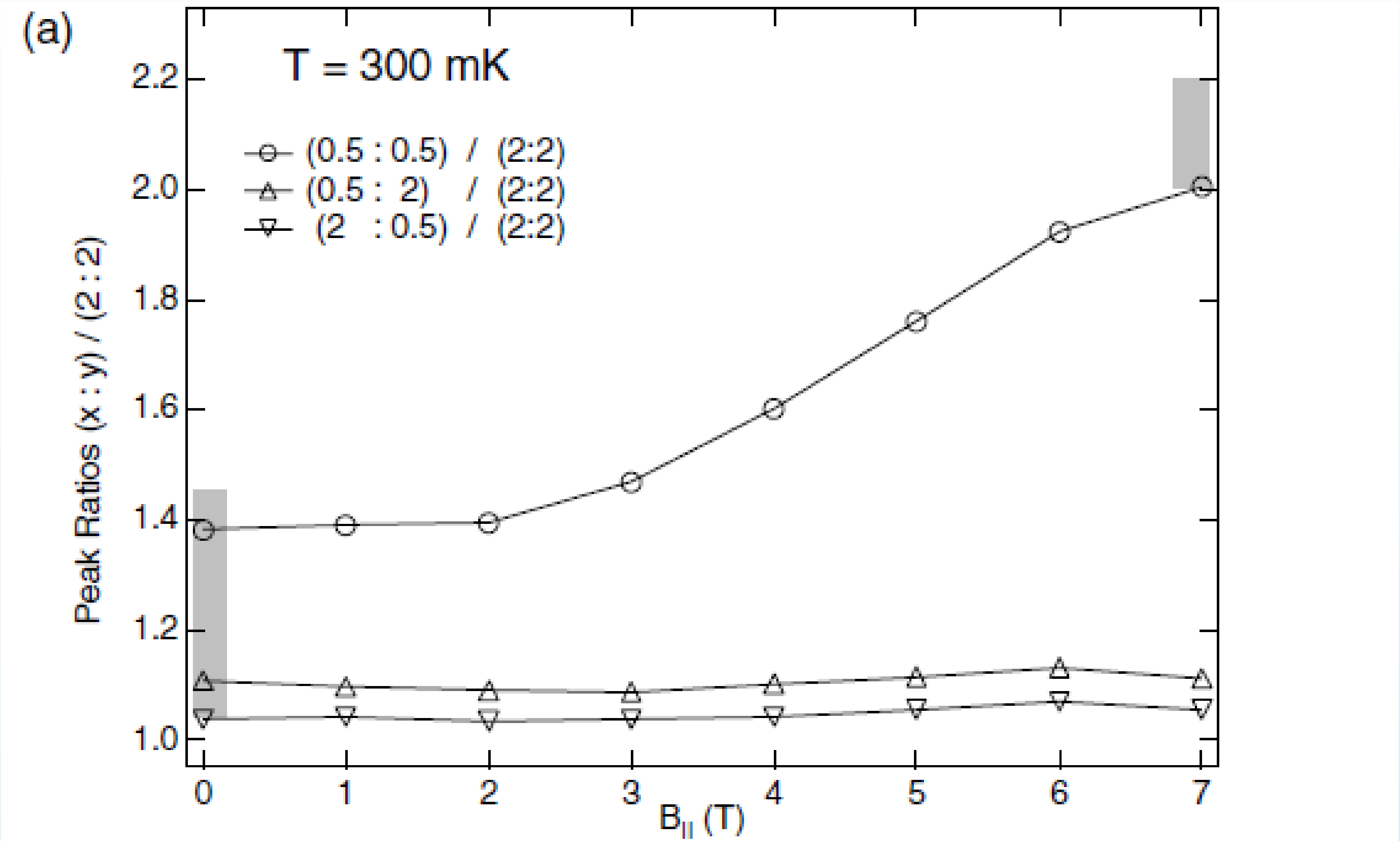


Collector Voltage for Different Settings When Spin Degeneracy is Lifted. Constant Current,I, is Injected

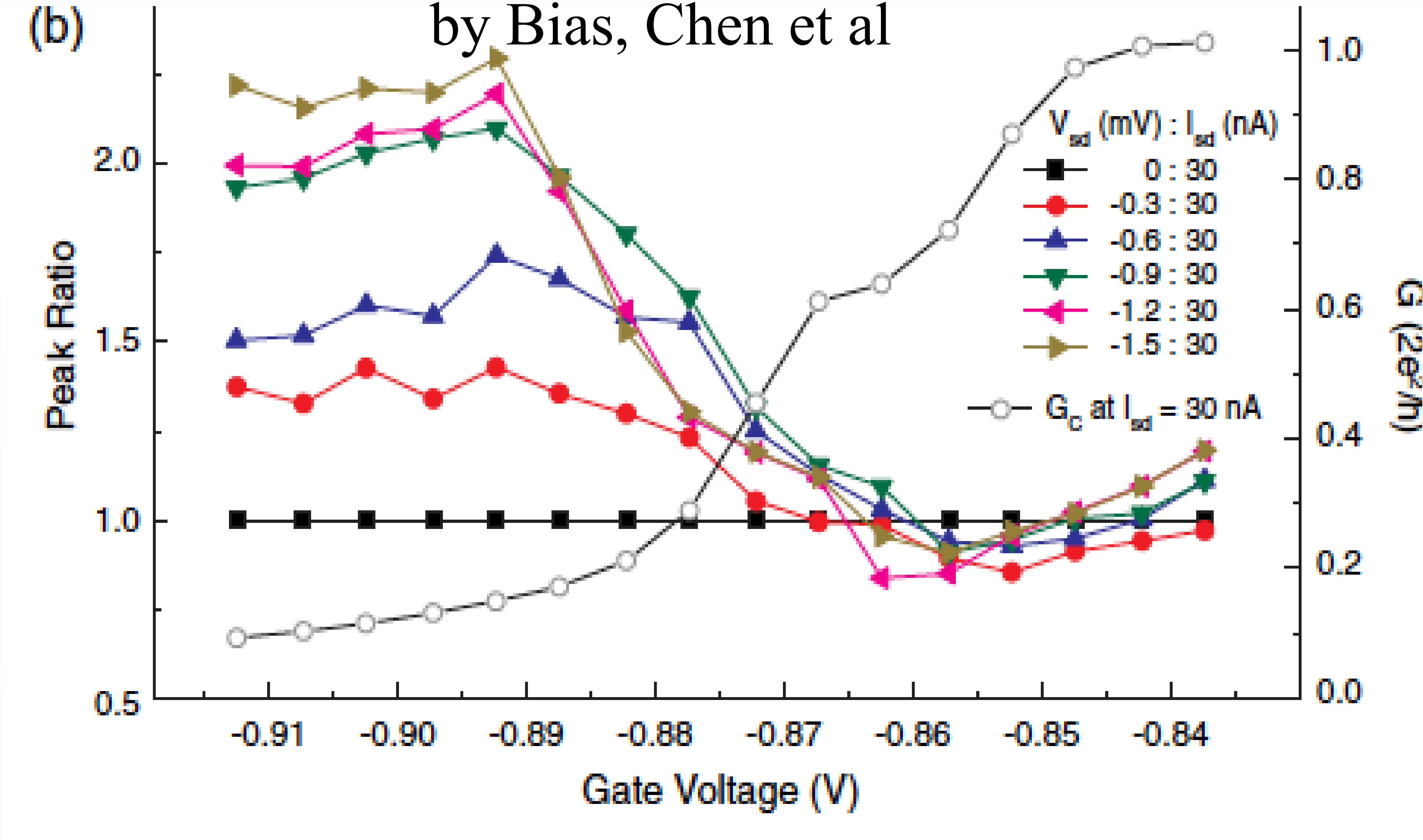
Emitter	Collector	Voltage
$2e^2/h$	$2e^2/h$	V
$2e^2/h$	e^2/h	V
e^2/h	$2e^2/h$	V
e^2/h	e^2/h	2V

Measured Voltage is a Constant Except When Both Emitter and Collector are Set to Spin Polarisation

Spin Detection – Potok, Marcus et al



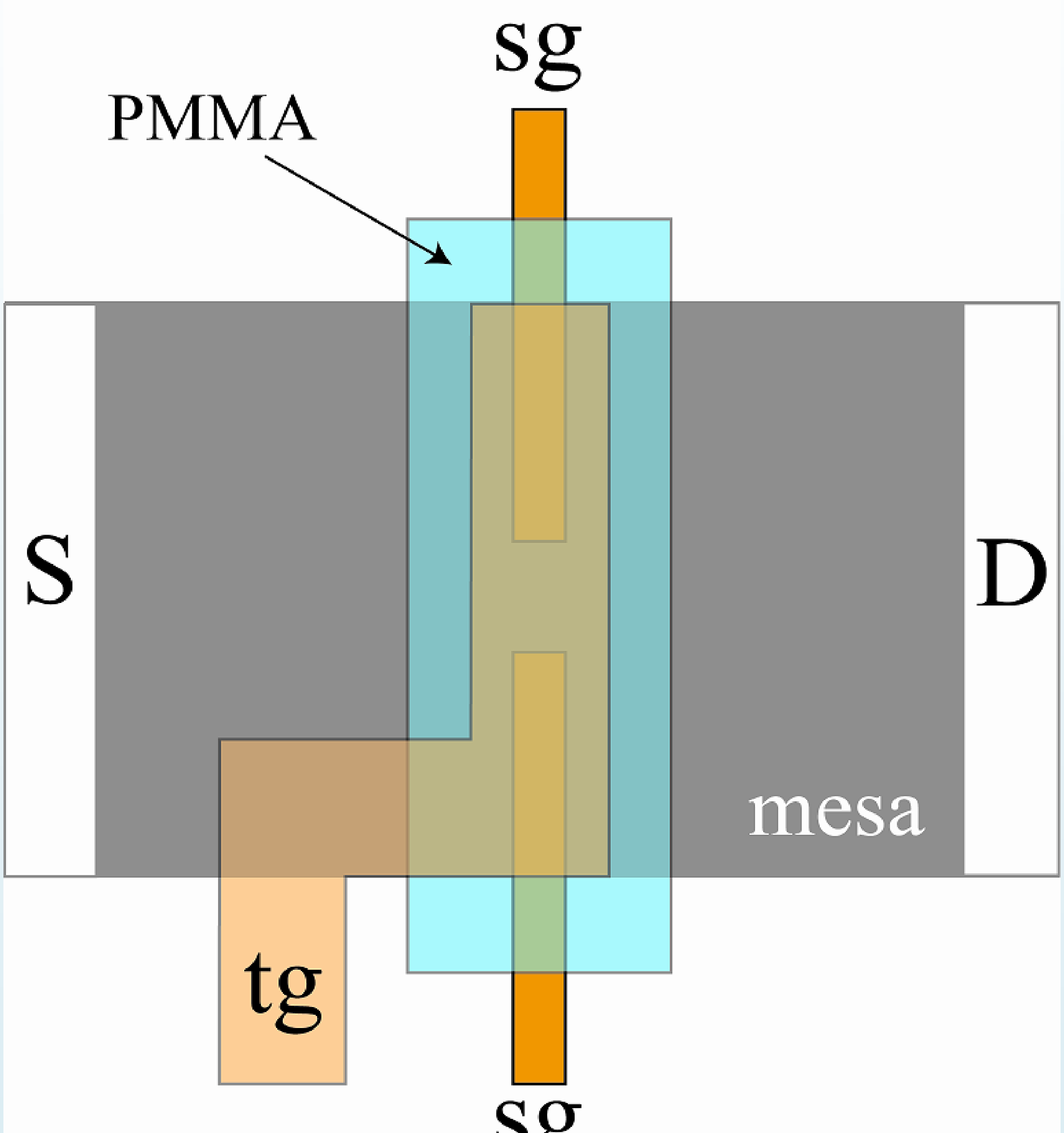
The Rise in the Ratio due to Spin Polarisation Induced by Bias, Chen et al



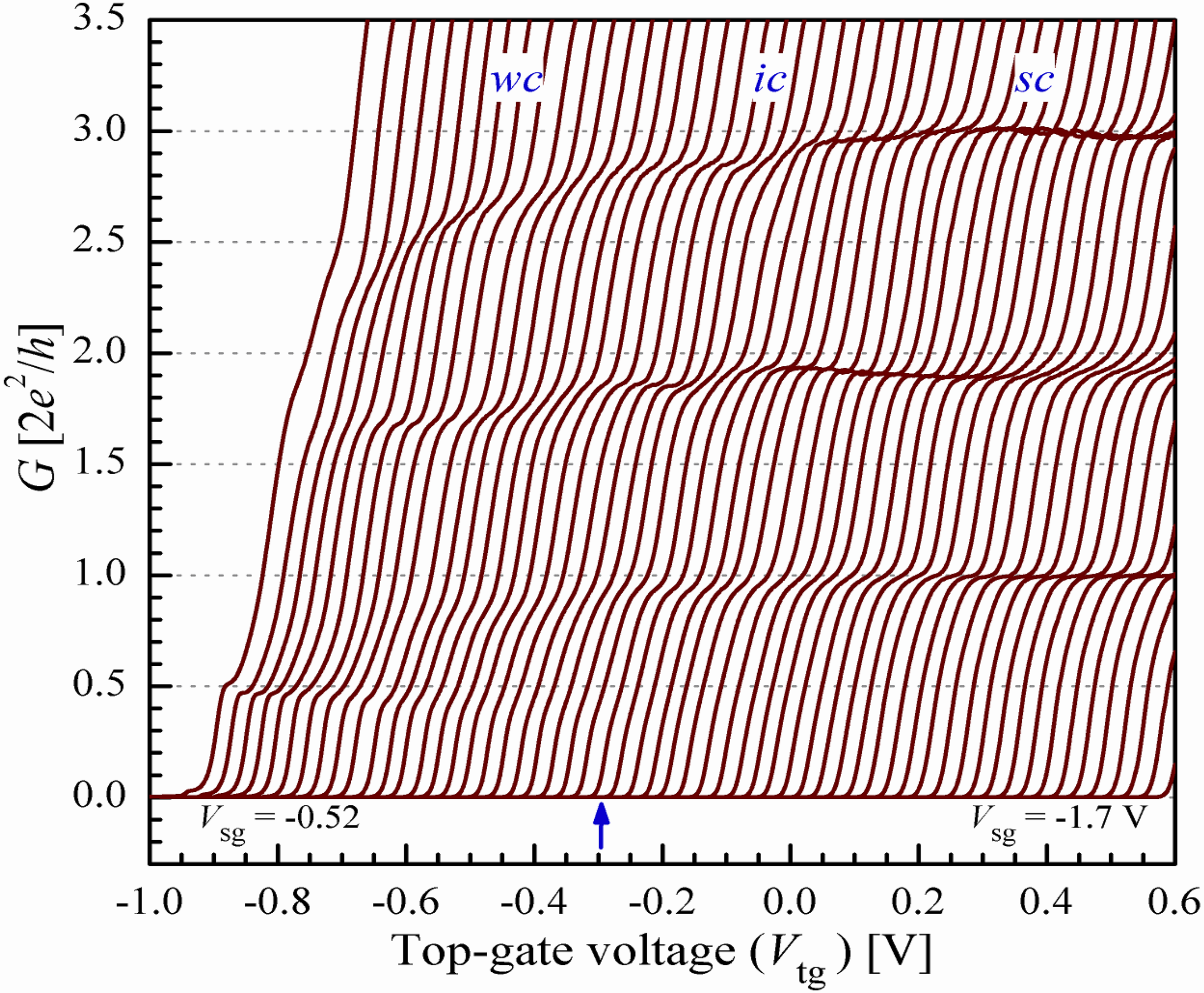
First Evidence of 1D Density of States by Berggren et al Due to Magneto-Electric Subbands Produced by Strong Confinement and Magnetic Field – Modified Shubnikov-de Haas.

Wide 1D Electron Gas, Energy Levels Dominated by Electron Interactions and Size Quantisation

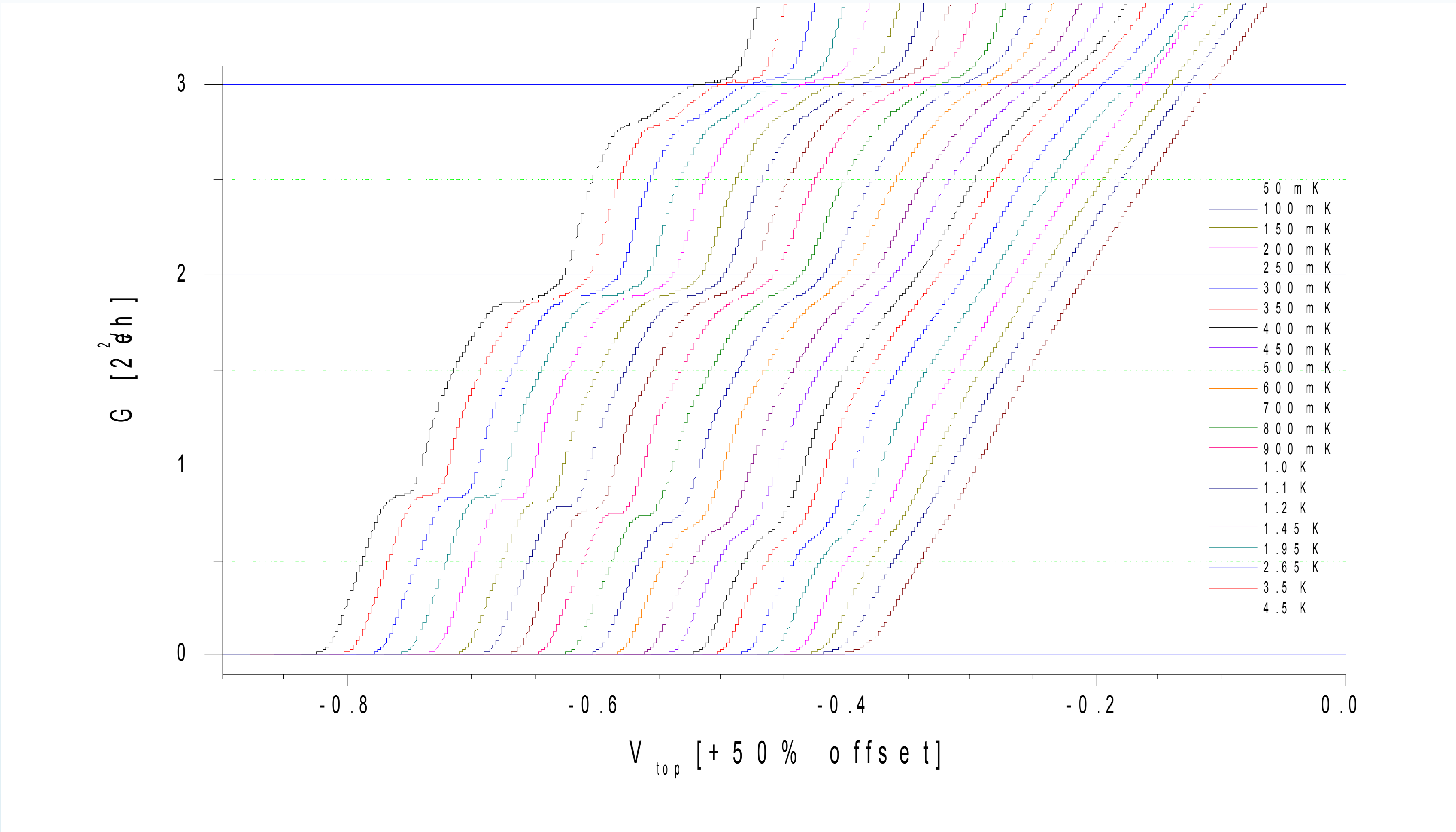
Control of carrier concentration and width



Transition to Spin Incoherent Regime at Low Density

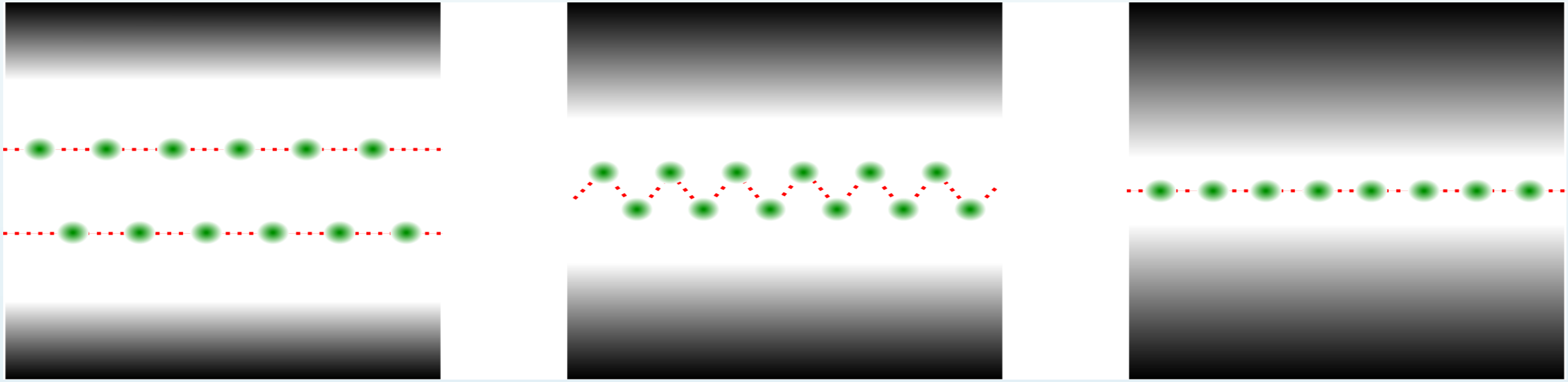


Incoherent to Coherent Transition of First Level

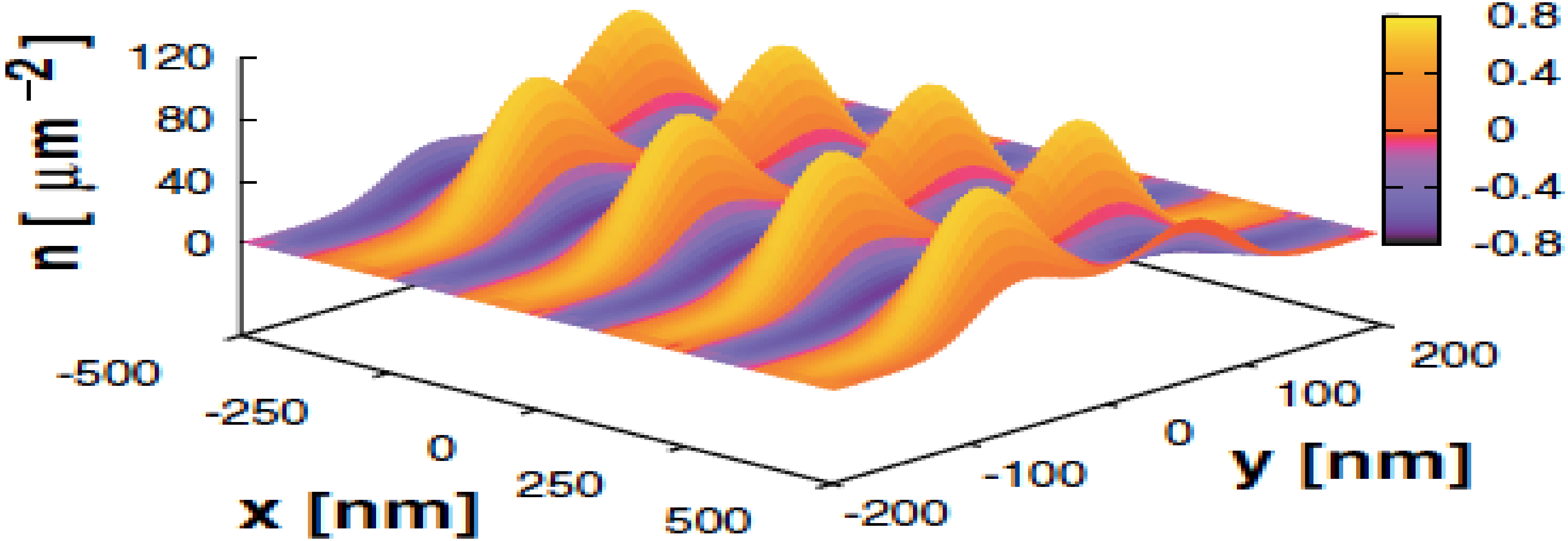


Plateau increases to near value of $2e^2/h$ as T drops from 3K to 0.05K

Formation of lattice due to interactions in weakly confined 1D channel, (Matveev, Meyer)



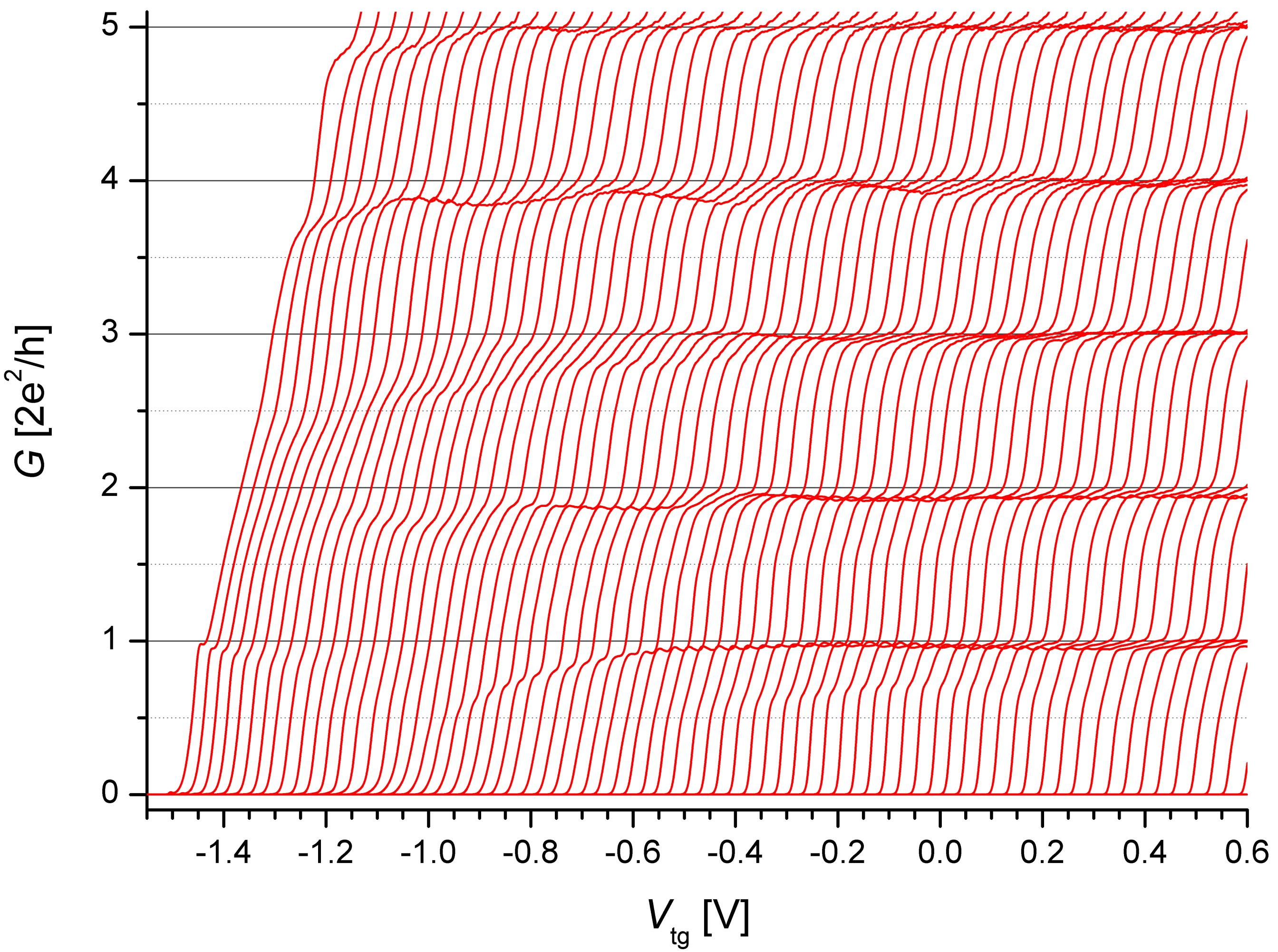
Double Zig-Zag
(Berggren and Yakimenko)



a)

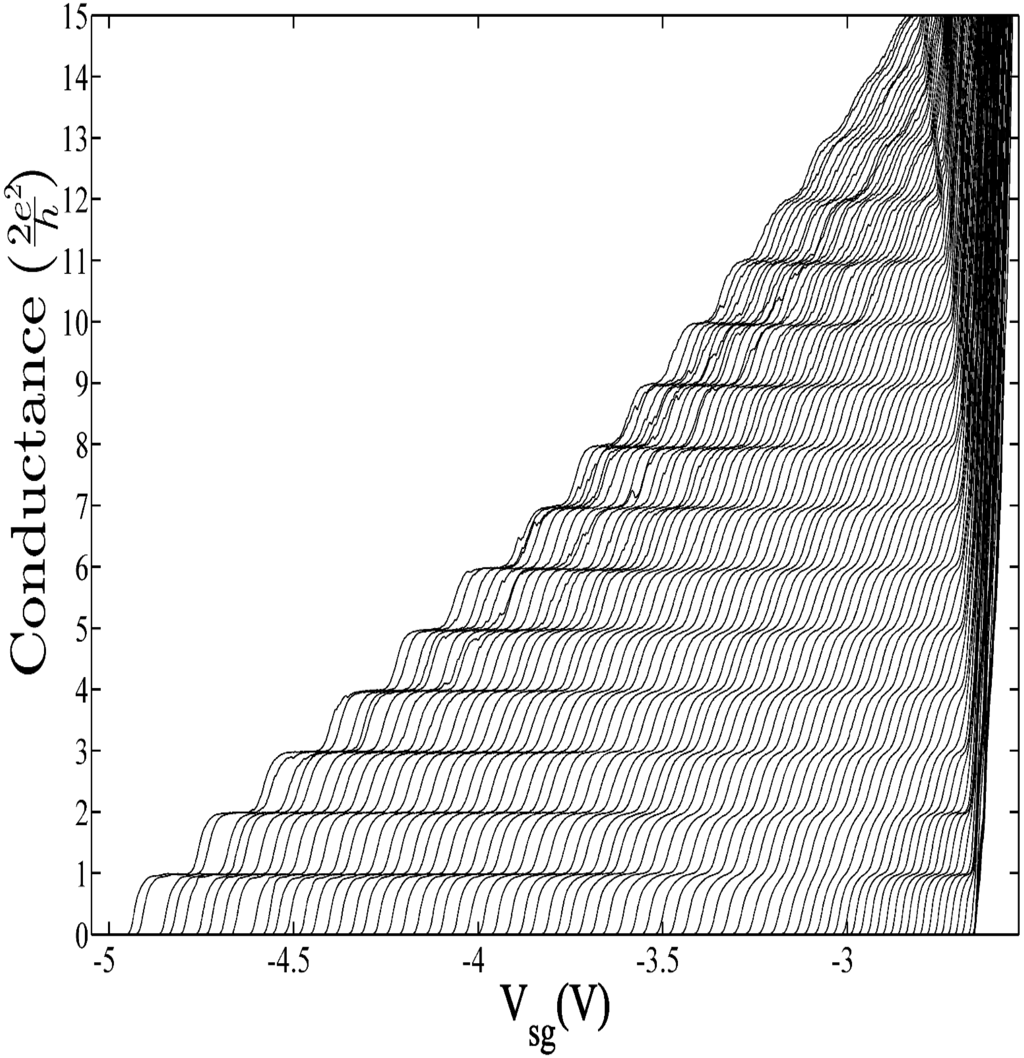
Formation of Incipient Wigner Lattice

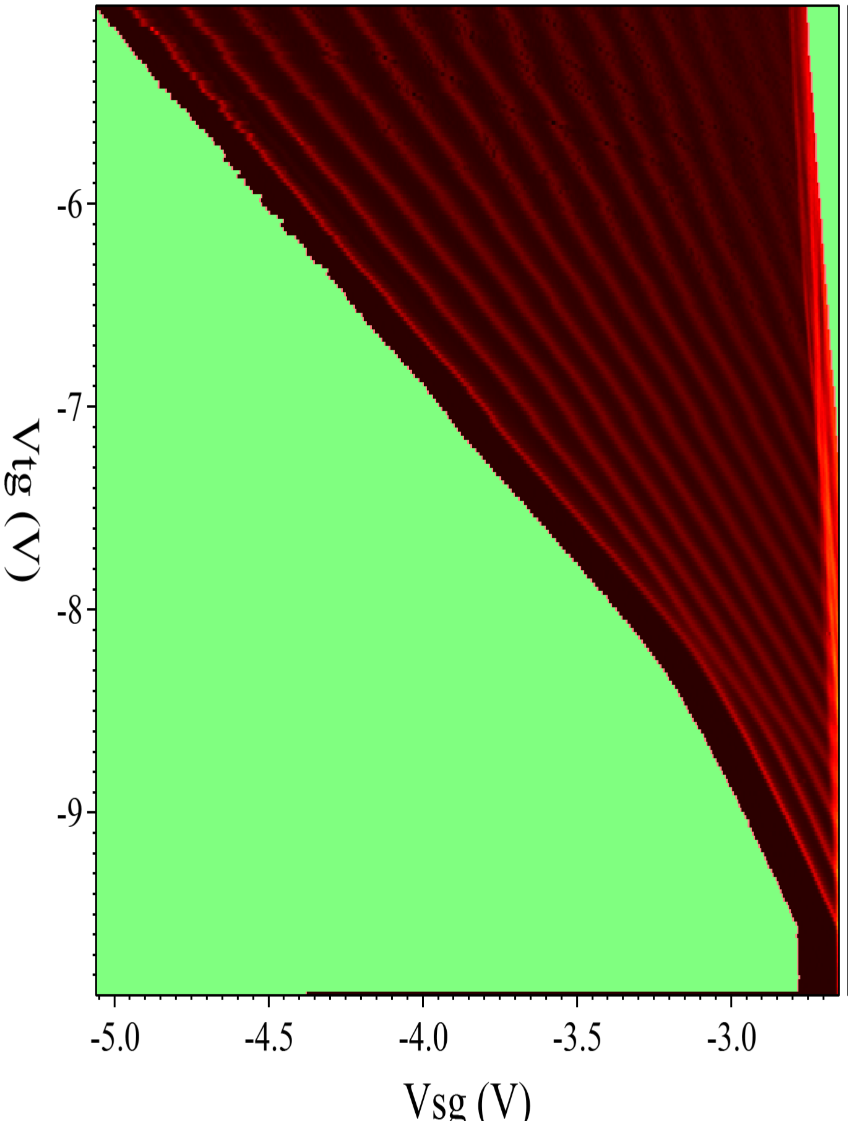
Weakly confined 1D. Right hand side is strong confinement and weakest is left.



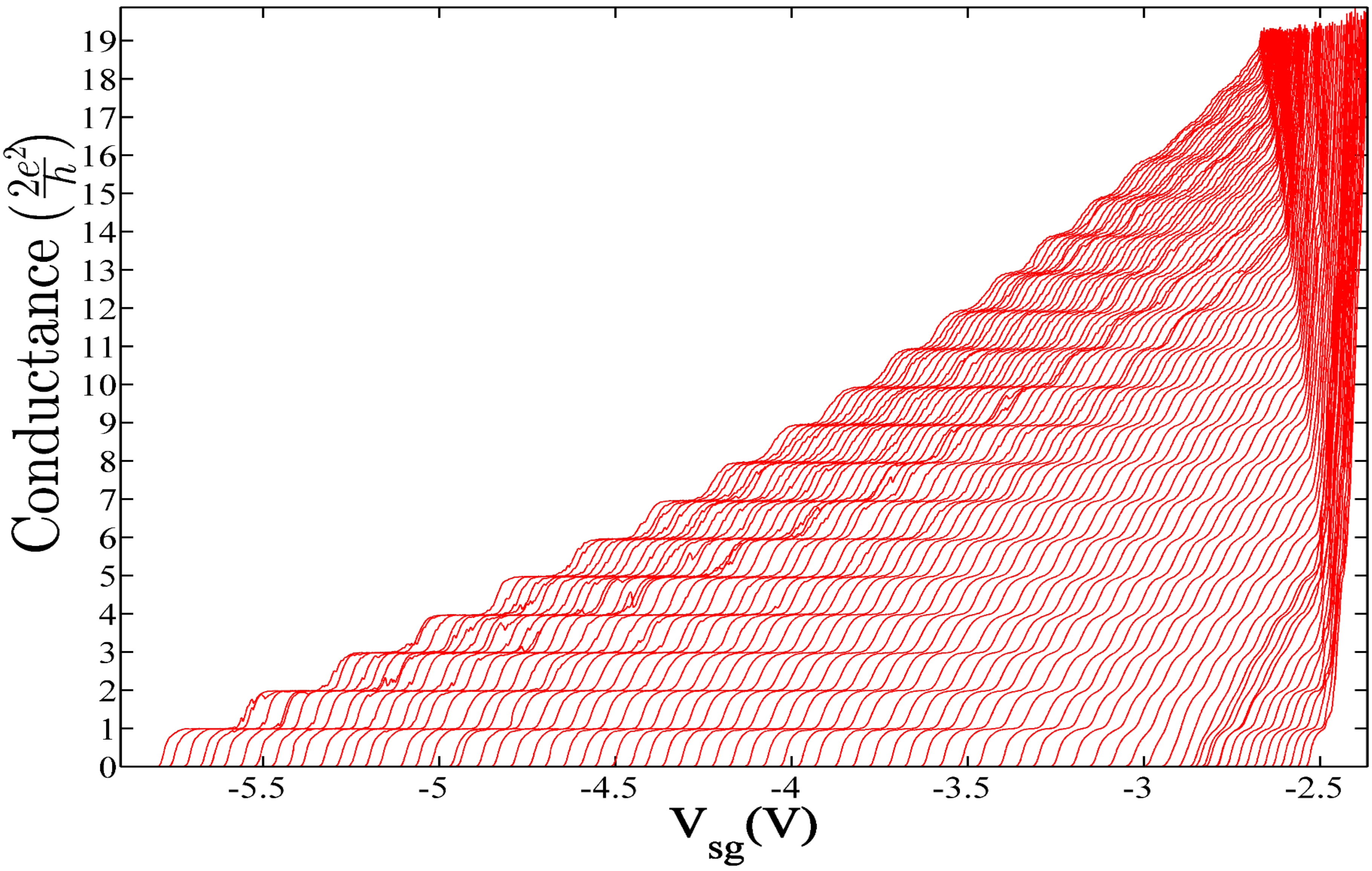
Characteristics Following a Constant Change in Carrier Concentration Induced by Top Gate – Inversion of the Ground State

An anti-crossing is observed in the behaviour of the lowest two energy levels.
The closeness of the curves following the anti-crossing arises from the increase in capacitance between the split gates and the electron gas which is now in a new ground state- the former first excited state.

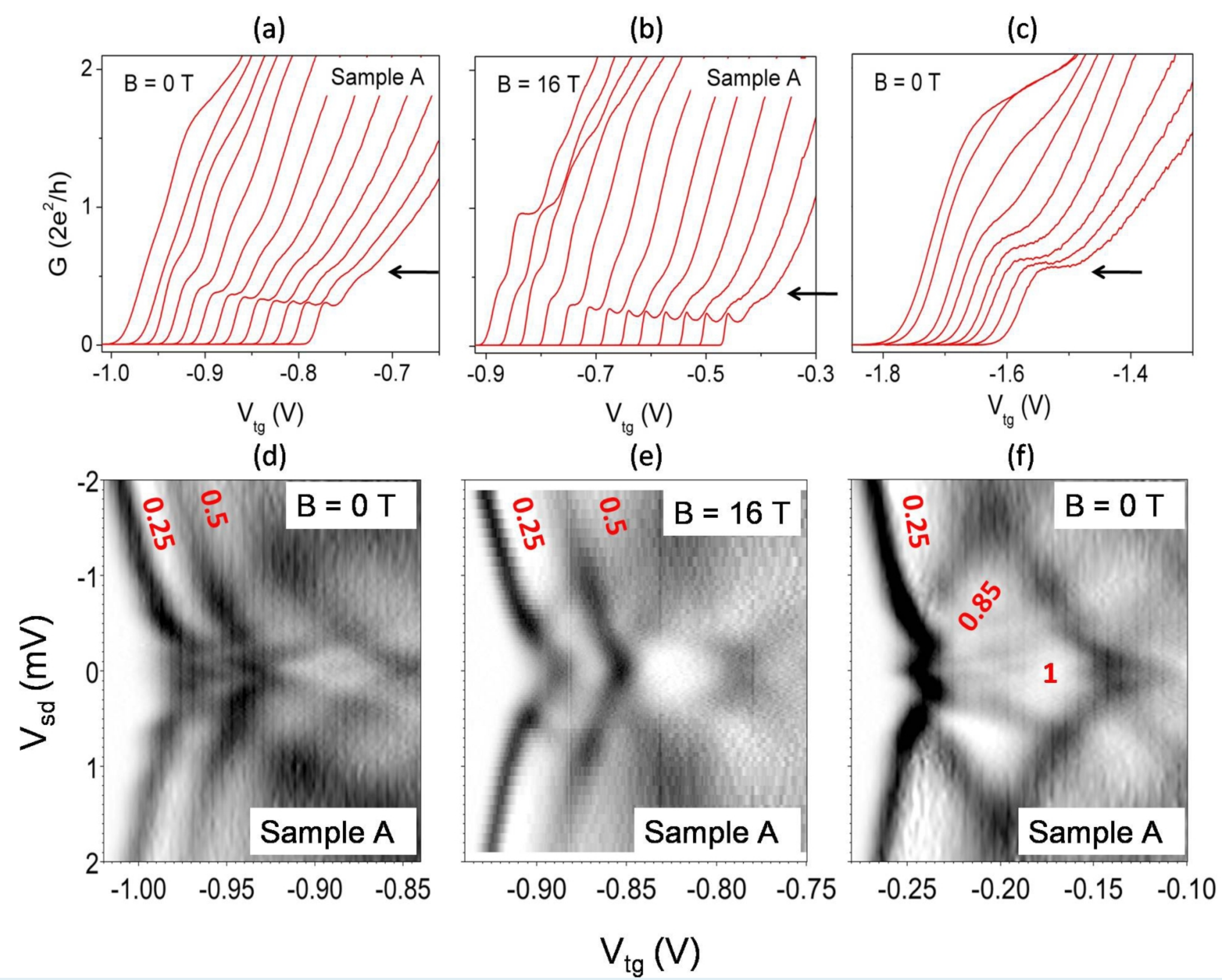




Ground State Wavefunction Observed By Split Gate Capacitance

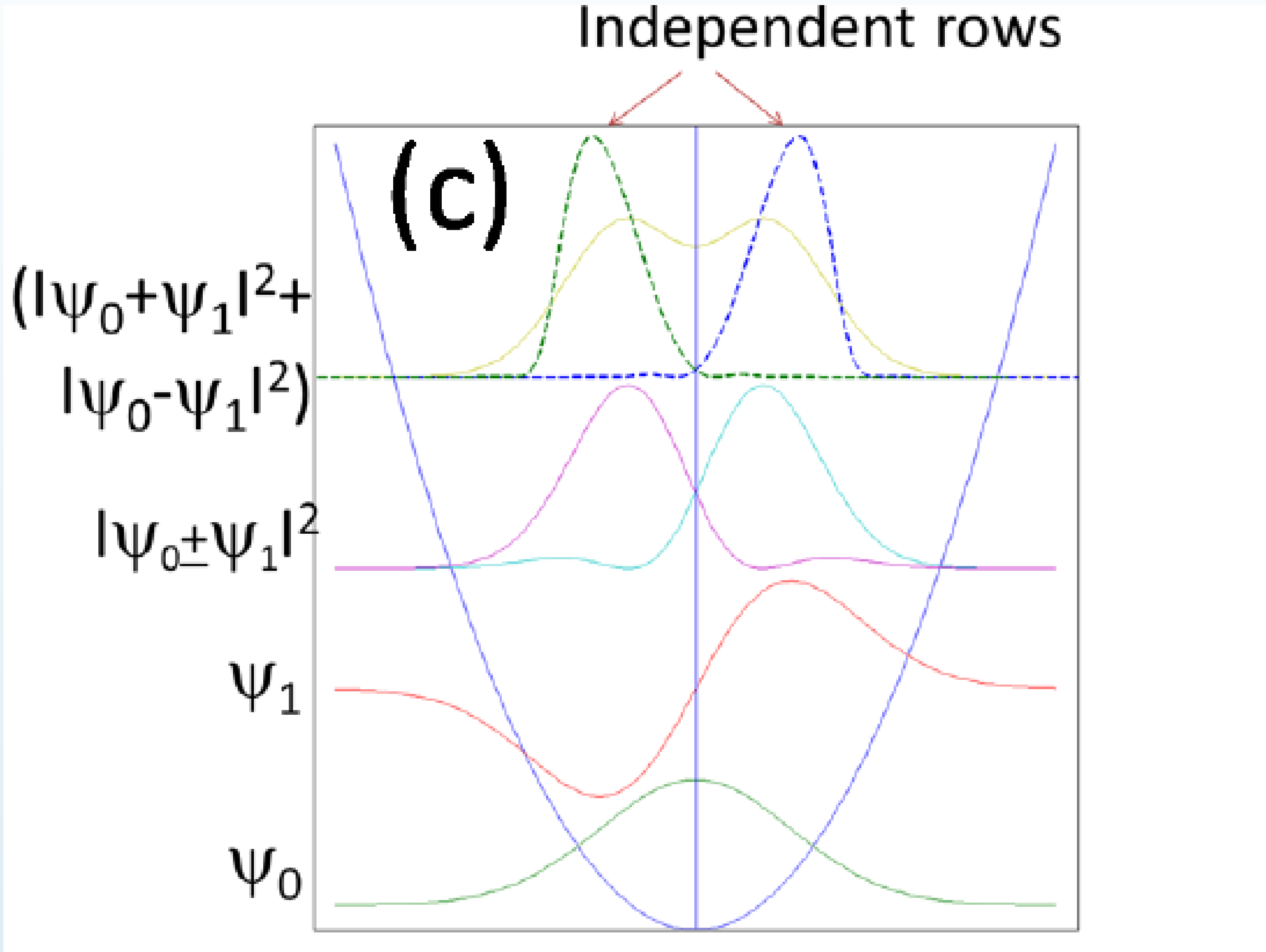


Coupling and Increasing Source-Drain Voltage

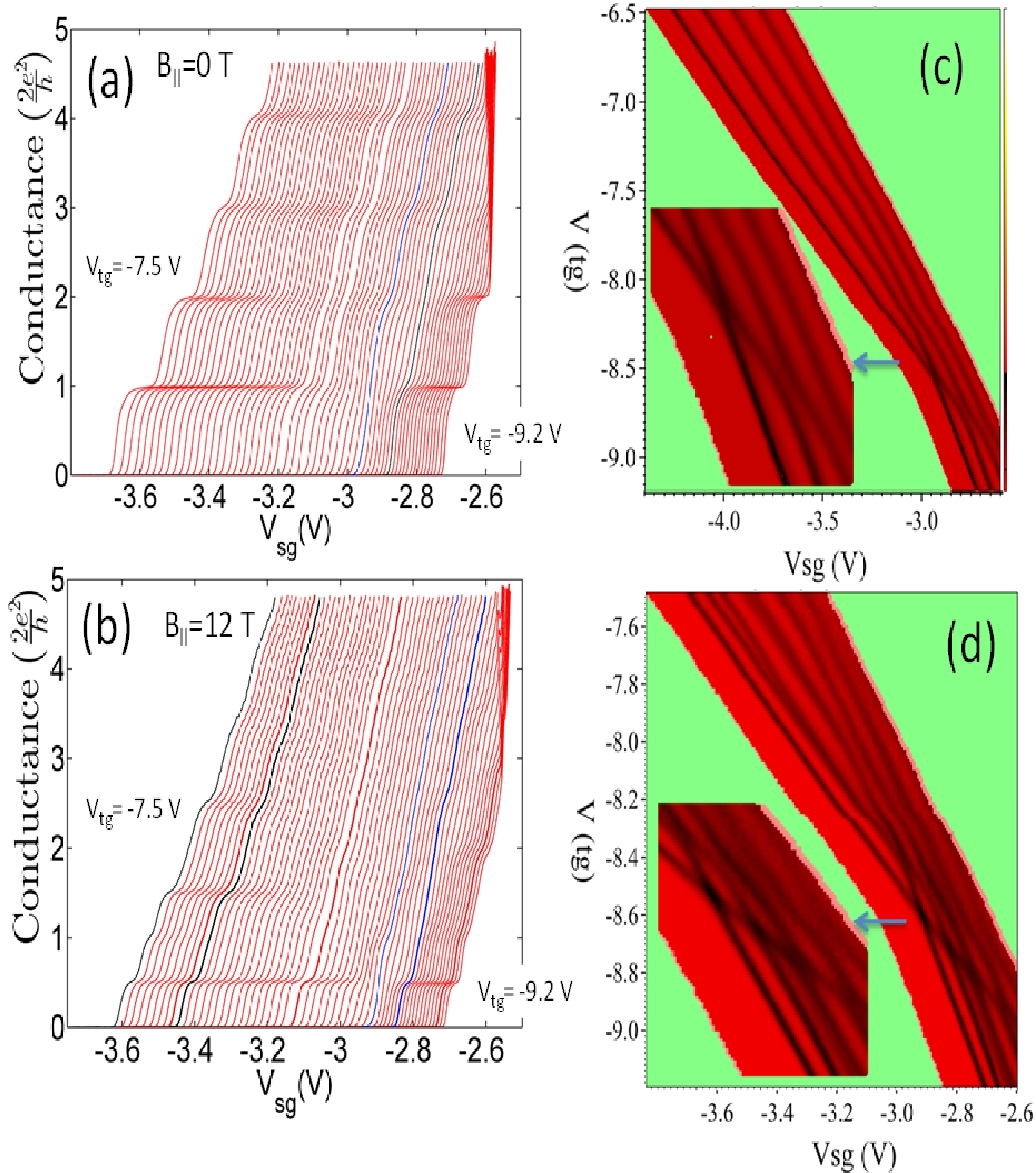


a),Anti-Crossed coupled rows; b) a) in 16T; c) 2 uncoupled rows; d) and e) gray scale plots of a) and b);f) single wire strongly confined showing typical absence of 0.5. Above traces moved along voltage axis for clarity.

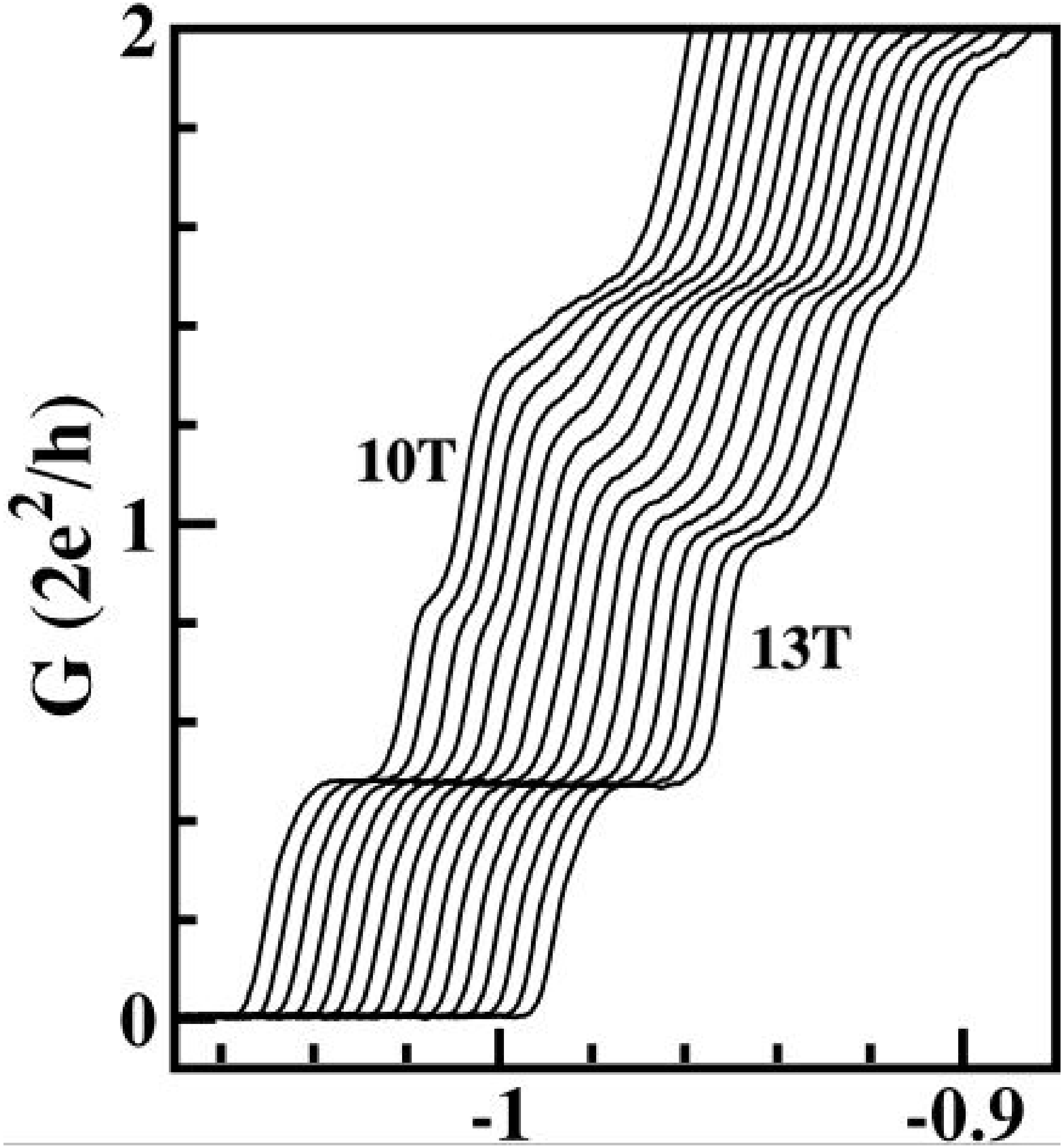
Wavefunction Hybridisation as Found Experimentally, There Will Be Distortion Due to Interaction



Increase in Carrier Concentration Results in a Crossing and Direct Jump to $4e^2/h$ Followed by Anti-Crossing for B=0 as Former Ground State Passes Through Higher Levels.
For B Parallel =12 Tesla Spins Split, Crossings Due to Opposite Spins and Complex Pattern as 2↓ Becomes New Ground State .

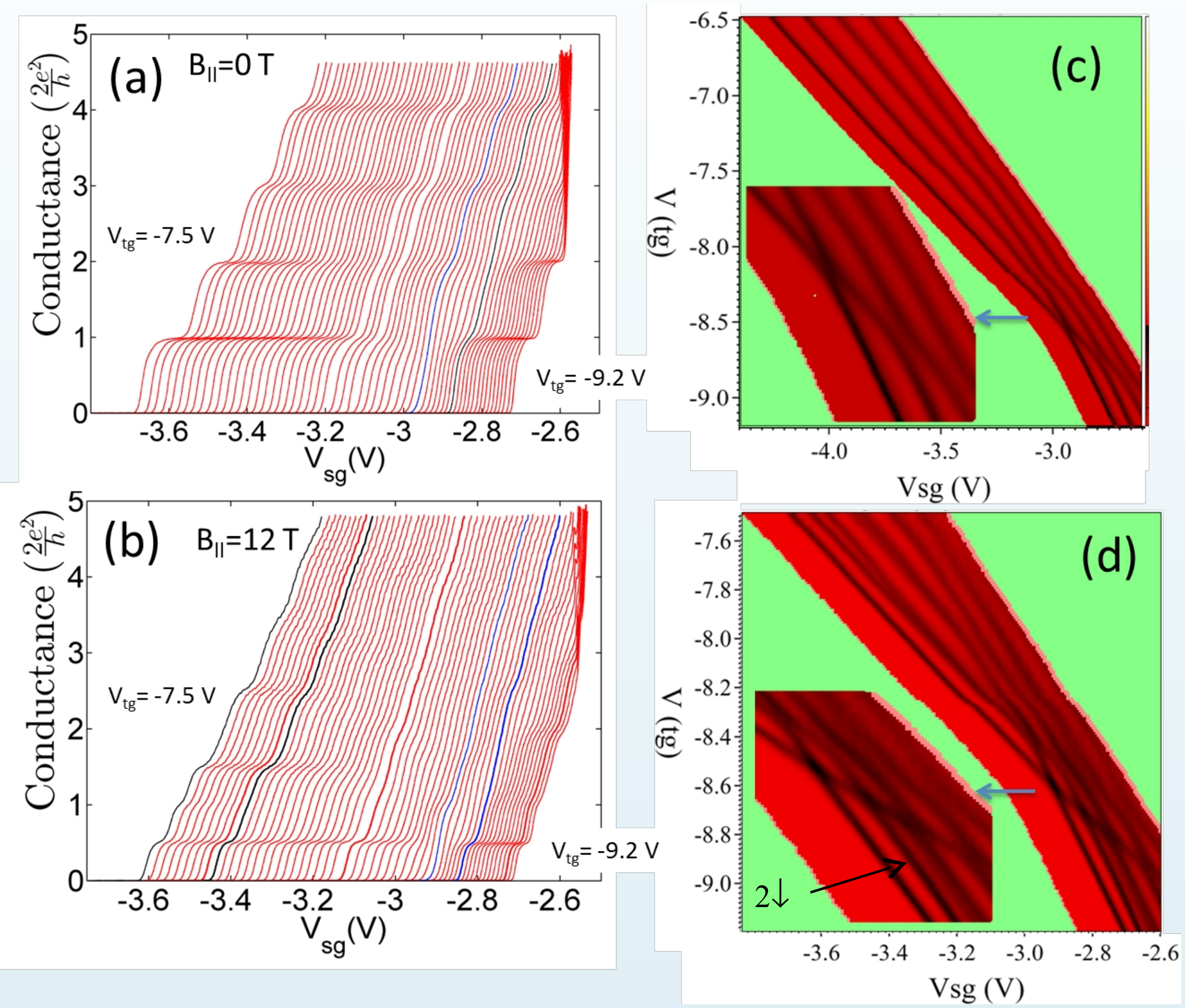


The 0.7 Analogue Structure



Effect of in-plane B on the double rows

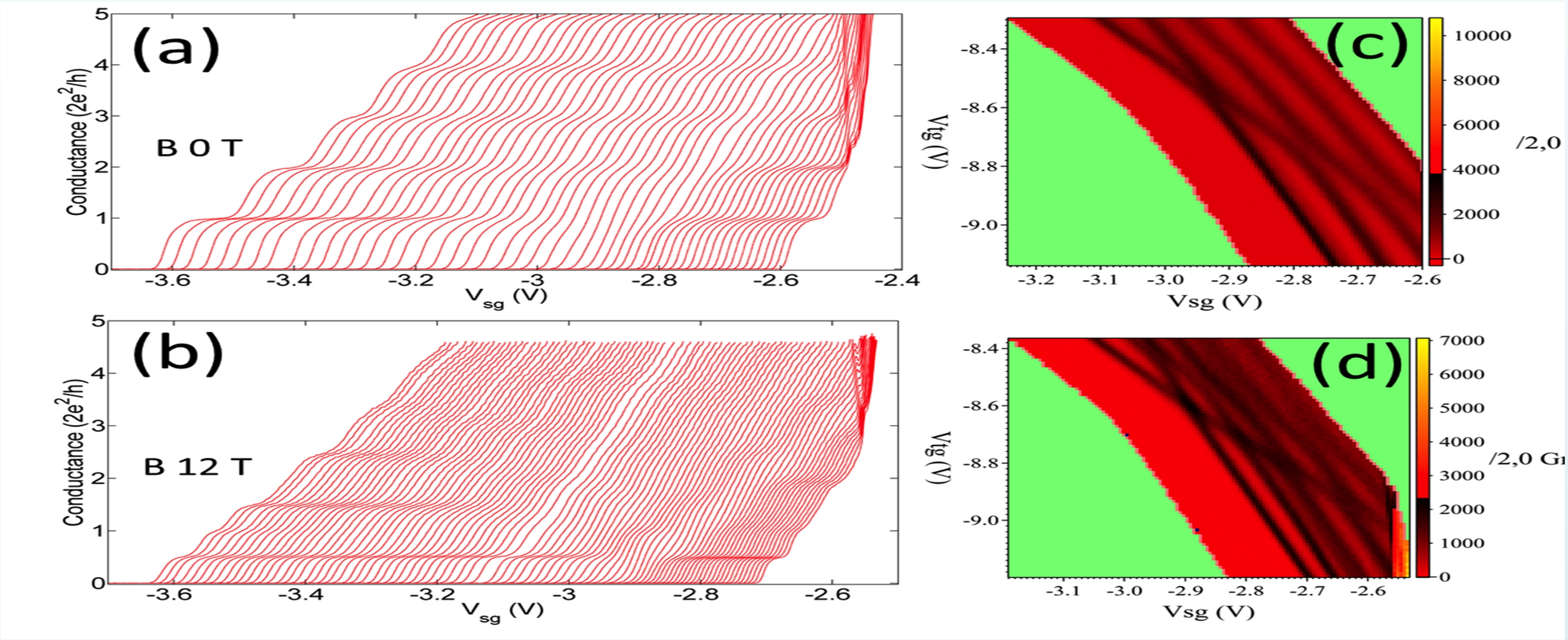
- **Wavefunction hybridisation and manipulation with in-plane B**



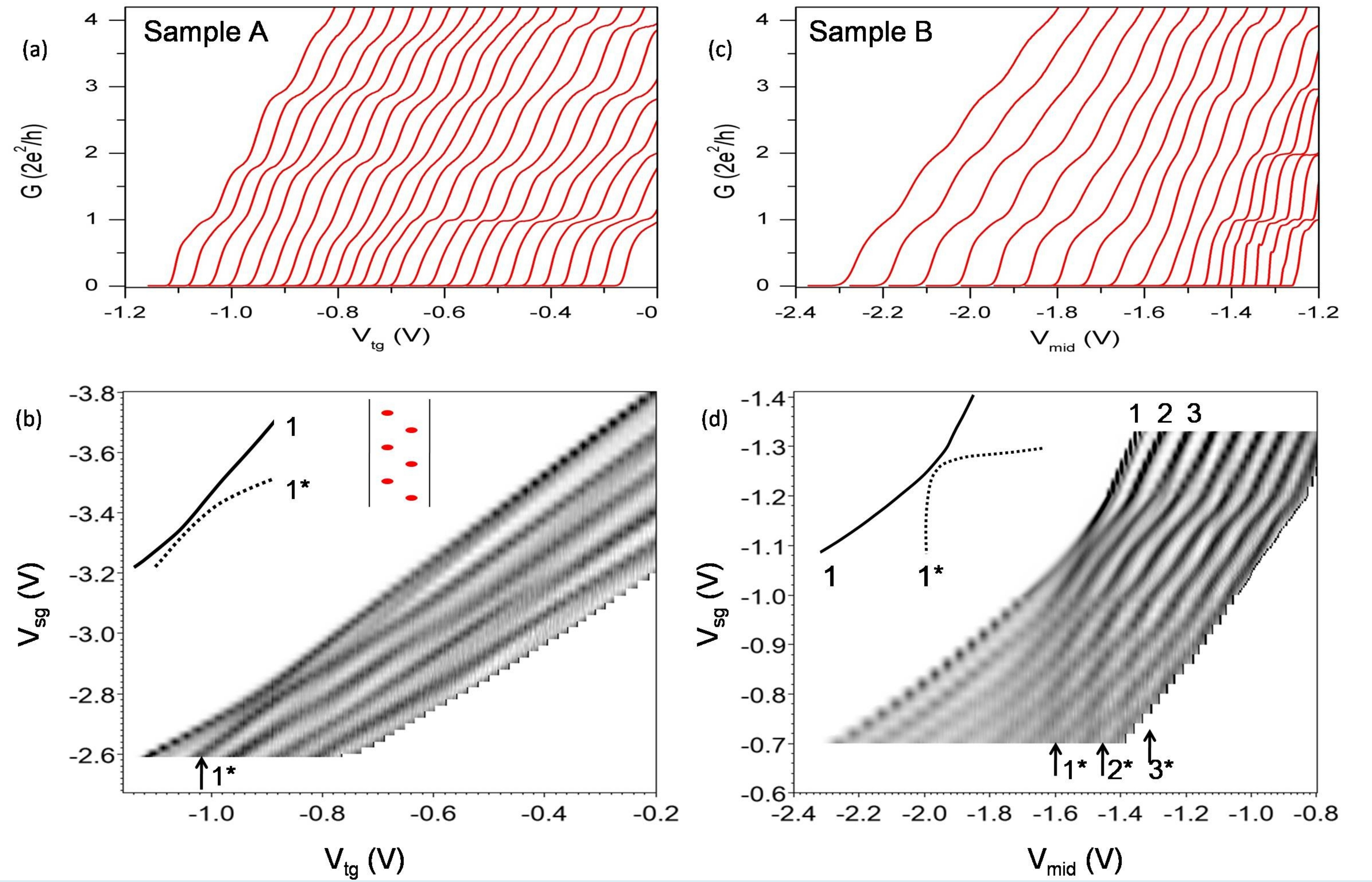
- ✓ As the confinement weakens, the 0-state passes through the 1-state giving rise to an anti-crossing and a jump to $4e^2/h$ as indicated in the 'blue' trace.
- ✓ Further weakening the confinement results in reintroduction of $2e^2/h$, and jump to $2e^2/h$, as 1-state being the new ground
- ✓ Application of 12T lifts spin-degeneracy and plateaus appear at ne^2/h.
- ✓ Widening the channel results in complex pattern of overlapping levels, the ground state crosses through the higher levels
- ✓ Reintroduction of e^2/h suggests the 2↓ dropping through many states to become the new ground state.

The 0-state passes through several levels during its trajectory as the confinement weakens, which indicates e-e interaction affects the ground state more significantly than the higher energy levels.

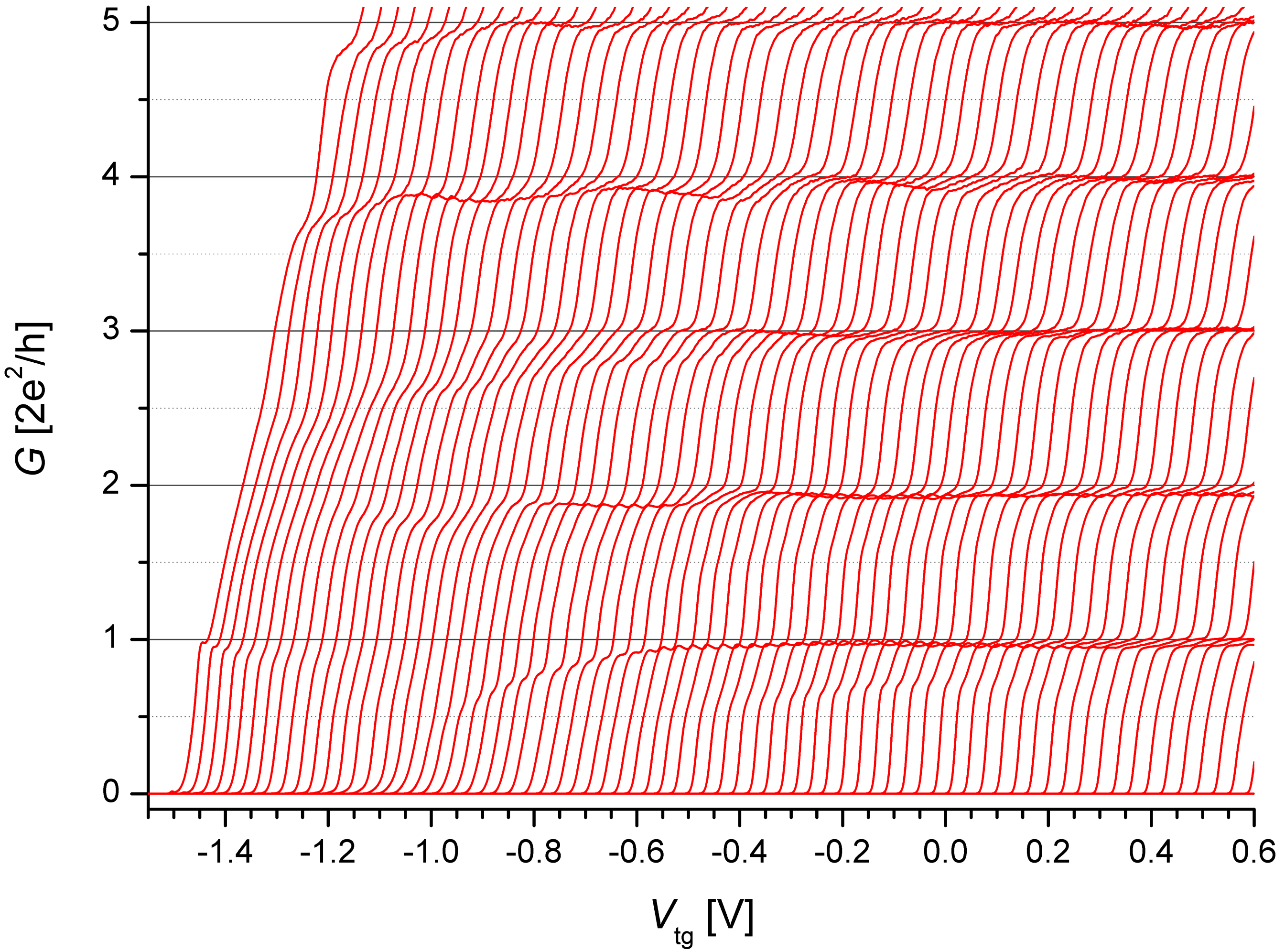
Examples of Row Formation and Movement of Energy Levels Within Channel



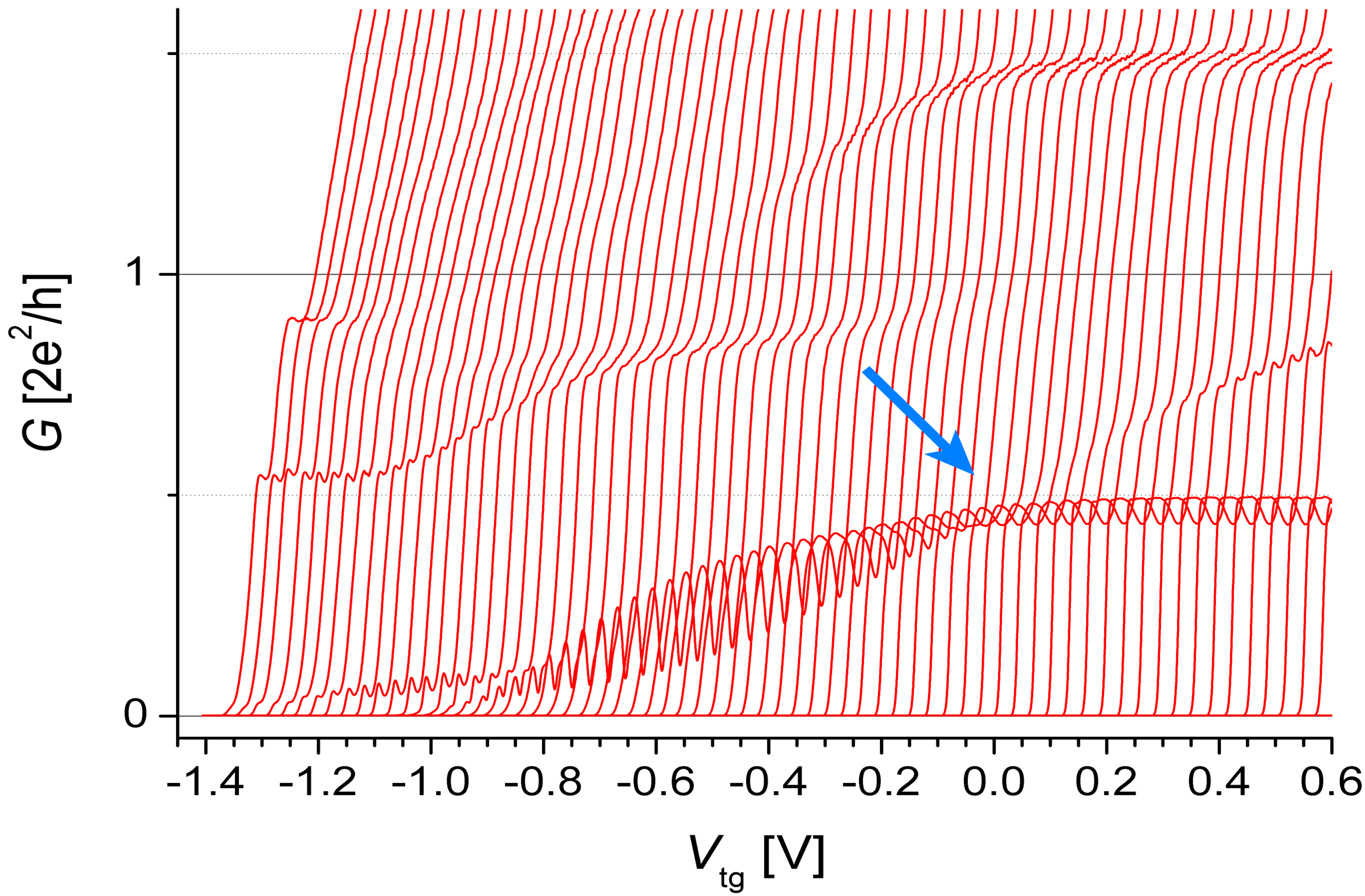
Wider Still- Evidence of Hybridisation of Rows, B=0



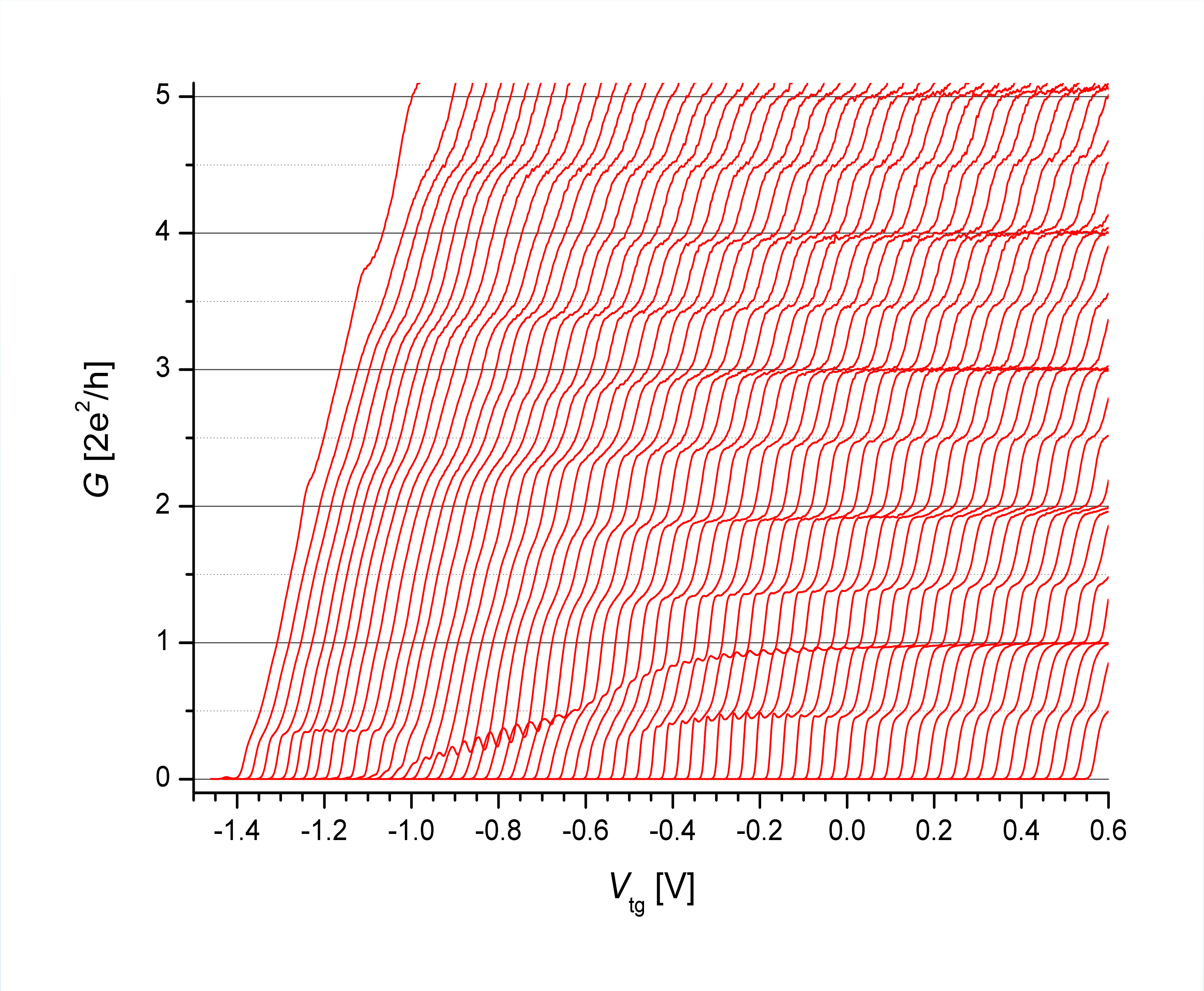
Weakly confined 1D. Right hand side is strong confinement and weakest is left.

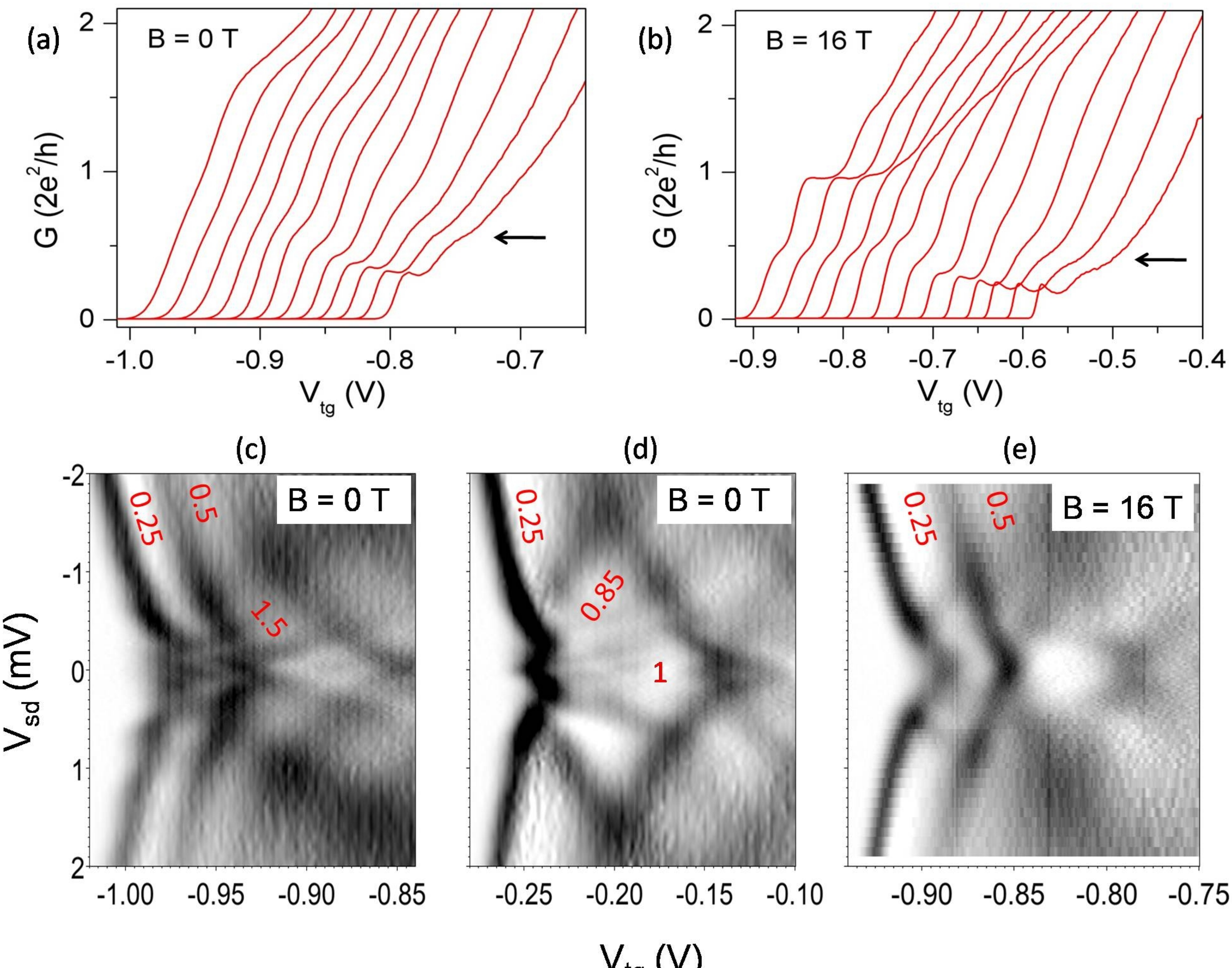


16 Tesla Field, strong confinement on right, weak-left

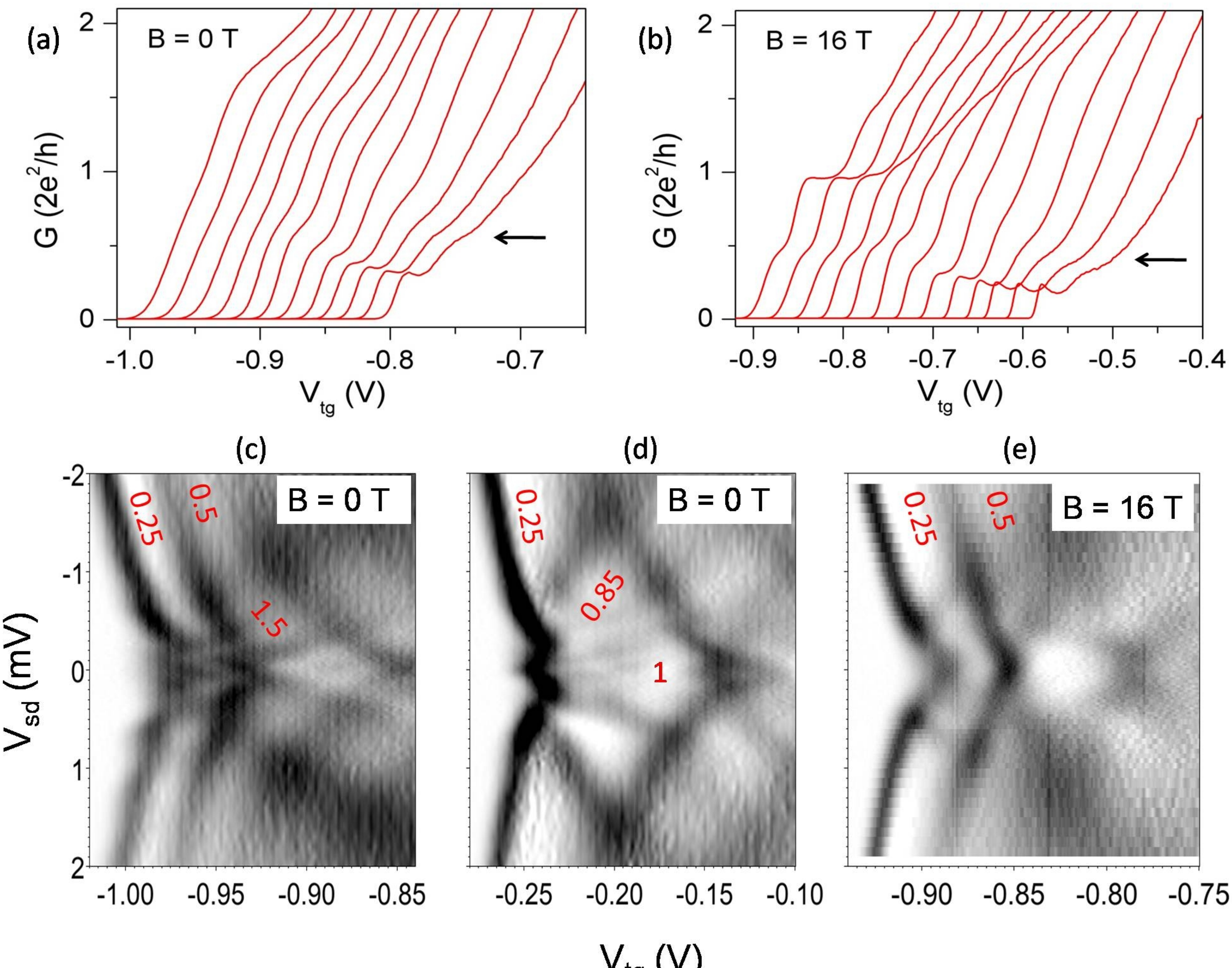


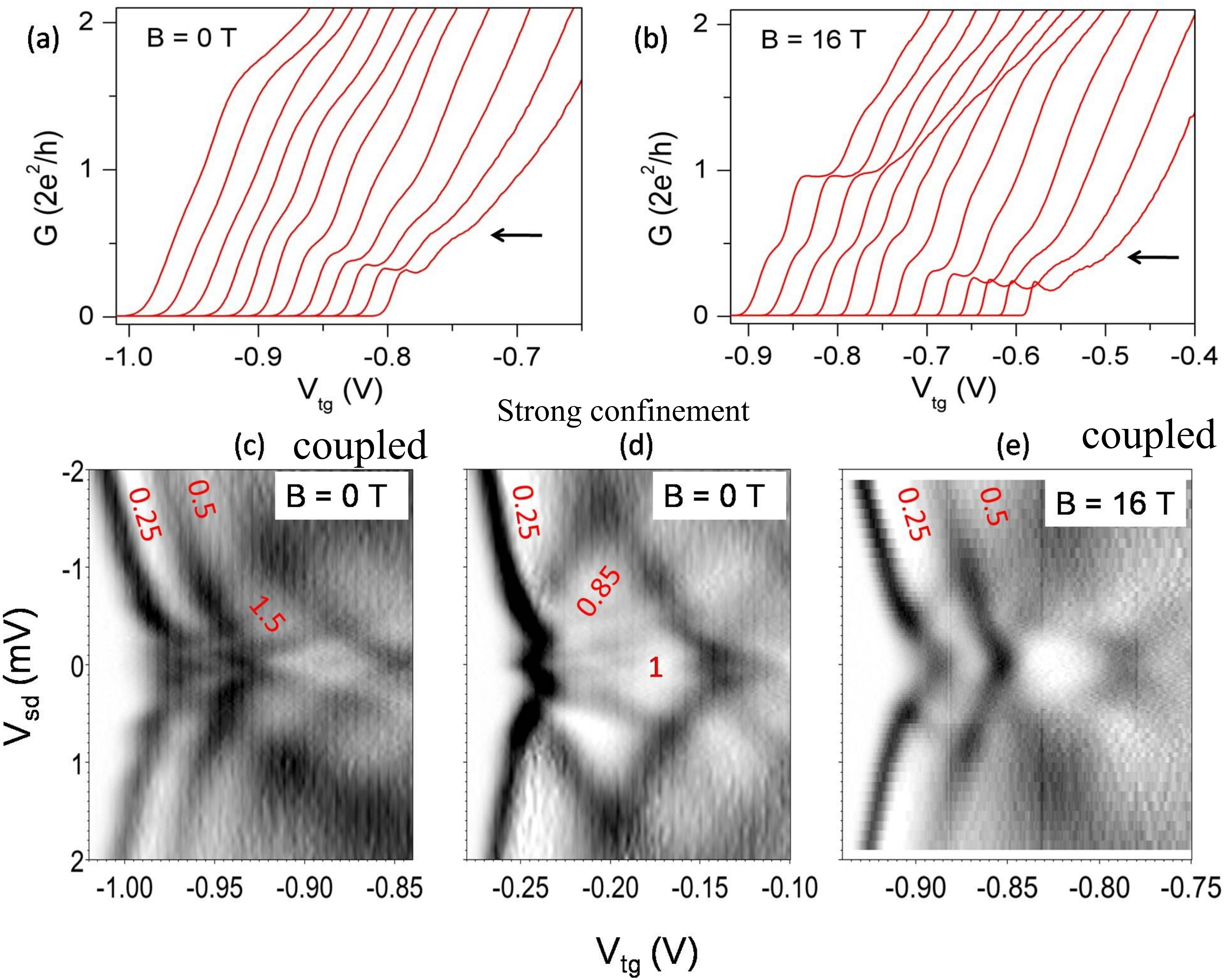
Effects of 7 Tesla Field on conductance, strong confinement on right, weak on left.





(a)
B = 0 T
G (2e²/h)
V_tg (V)
(b)
B = 16 T
(c)
B = 0 T
0.25
0.5
1.5
(d)
B = 0 T
0.25
0.85
1
(e)
B = 16 T
0.25
0.5
V_sd (mV)
V_tg (V)


(a)
B = 0 T
G (2e^2/h)
V_tg (V)
(b)
B = 16 T
G (2e^2/h)
V_tg (V)
(c)
B = 0 T
0.25
0.5
1.5
(d)
B = 0 T
0.25
0.85
1
(e)
B = 16 T
0.25
0.5
V_sd (mV)
V_tg (V)



(a)
B = 0 T
G (2e²/h)
V_tg (V)
(b)
B = 16 T
Strong confinement
(c)
coupled
(d)
(e)
coupled
B = 0 T
0.25
0.5
1.5
0.85
1
B = 16 T
V_sd (mV)
V_tg (V)

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Direction-resolved transport and possible many-body effects in one-dimensional thermopower

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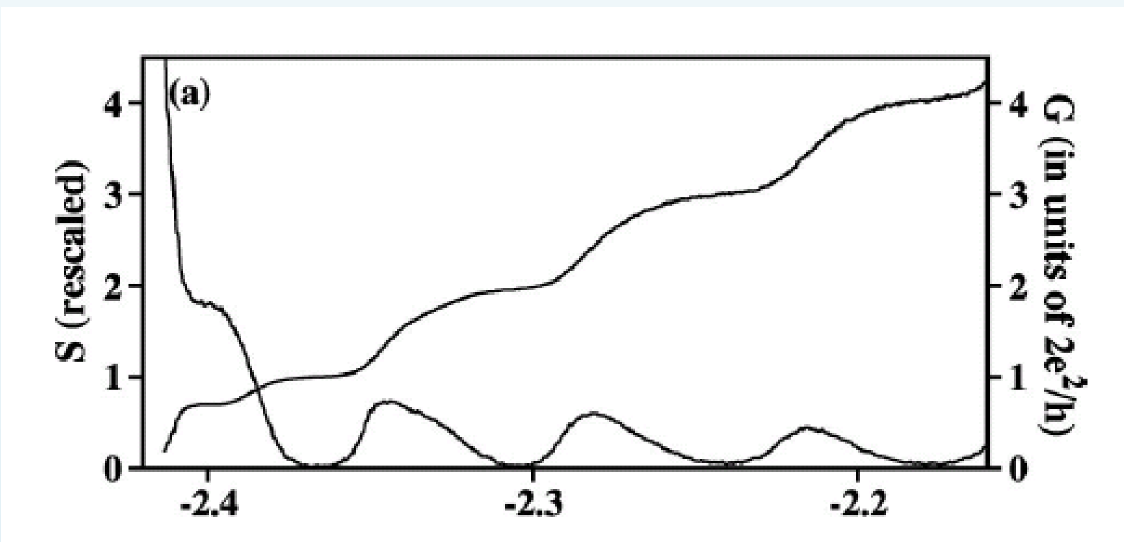
(Received 20 October 2000)

A single-particle theory due to Mott predicts a proportionality between the diffusion thermopower and the energy derivative of the logarithm of the conductance. Measurements of a ballistic 1D wire show that the Mott theory remains valid in the presence of a finite current, and that it leads to a direction-sensitive probe of electron transport. We observe an apparent violation of the Mott model at low electron densities, when there is a nonquantized plateau in the conductance at $0.7(2e^2/h)$. There is as yet no successful theoretical explanation of this so called *0.7 structure*, but the distinctive thermopower signature, which deviates from single-particle predictions, may provide the key to a better understanding.



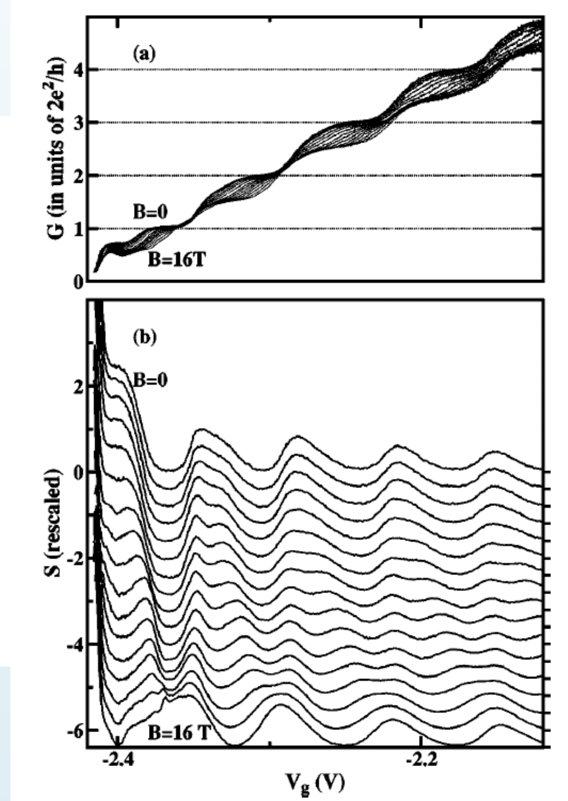
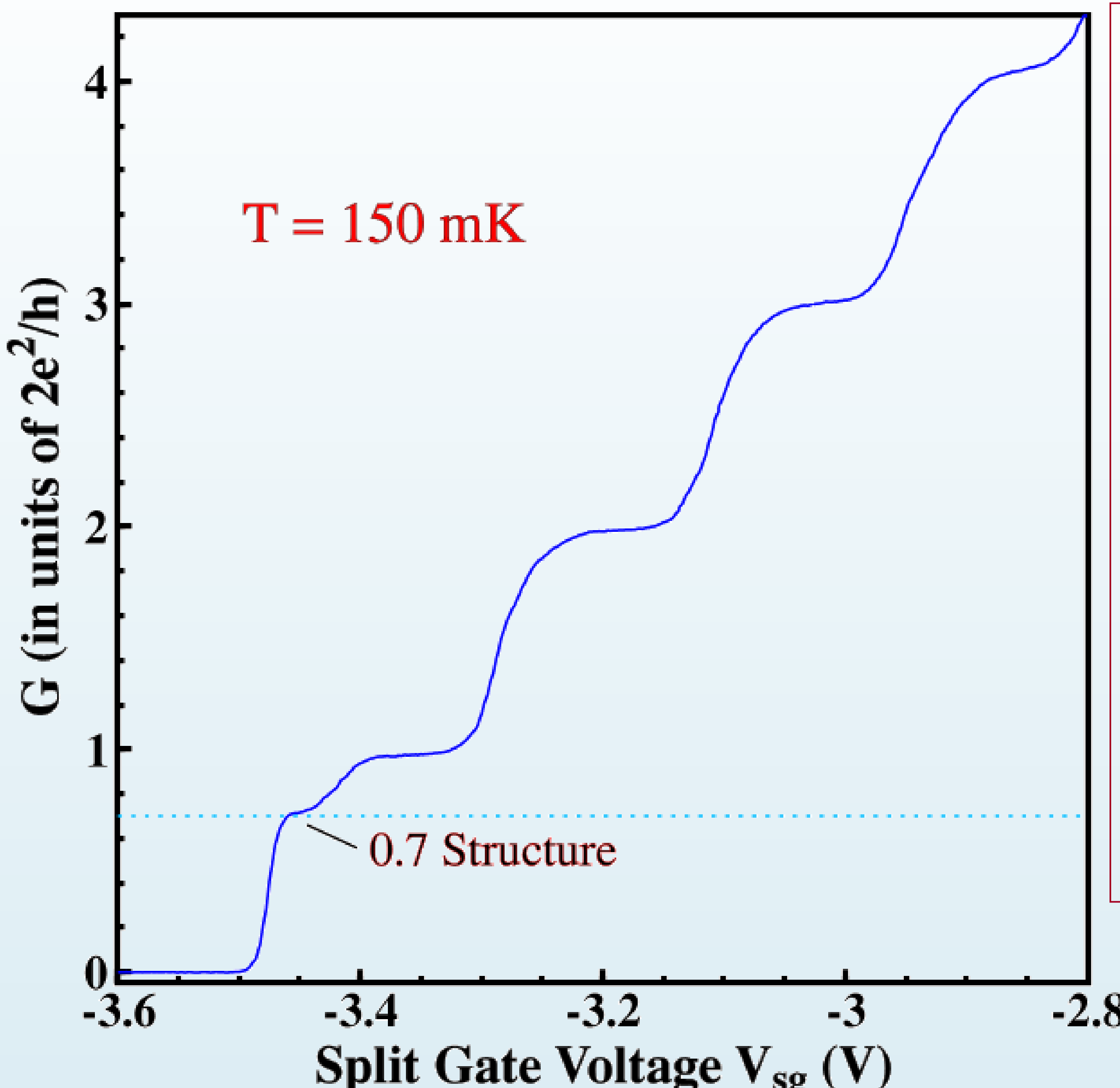


FIG. 4. (a) The conductance G and (b) thermopower S for sample C when the in-plane magnetic field $B_\parallel$ is incremented from 0 to 16 T in steps of 1 T. Lifting of spin degeneracy at high fields restores the zero in S that is predicted by single-particle theory [Eq. (1)]. The traces in (b) are offset vertically.

0.7 Structure in a Ballistic 1D Channel

Thomas et al., Phys Rev. Lett 77 (1996) 135



0.7 structure has been reported in :

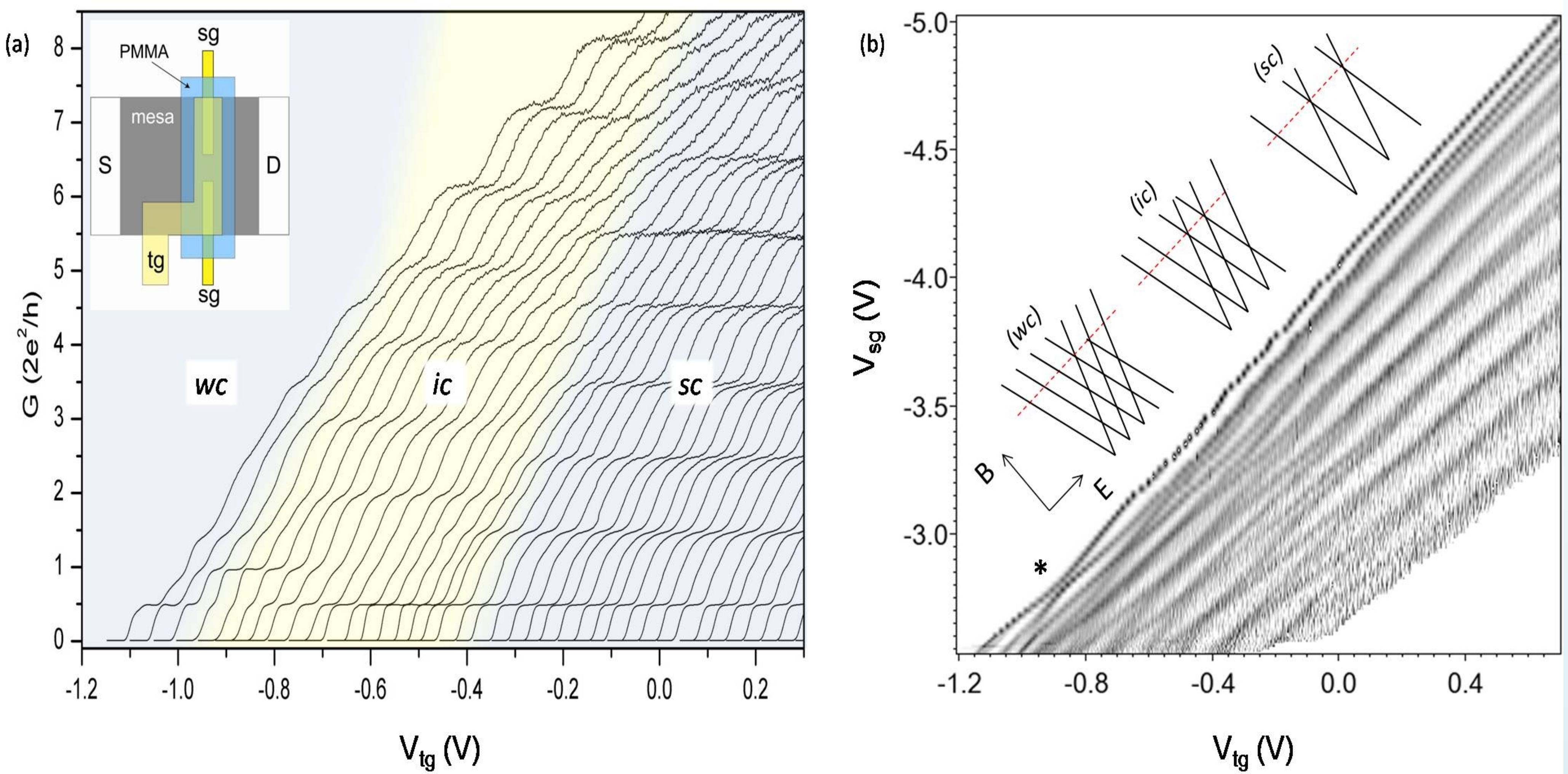
n-GaAs (Split-gates, Etched wires, AFM defined wires, Induced wires, Cleaved edge overgrowth wires, EEL wires)

p-GaAs

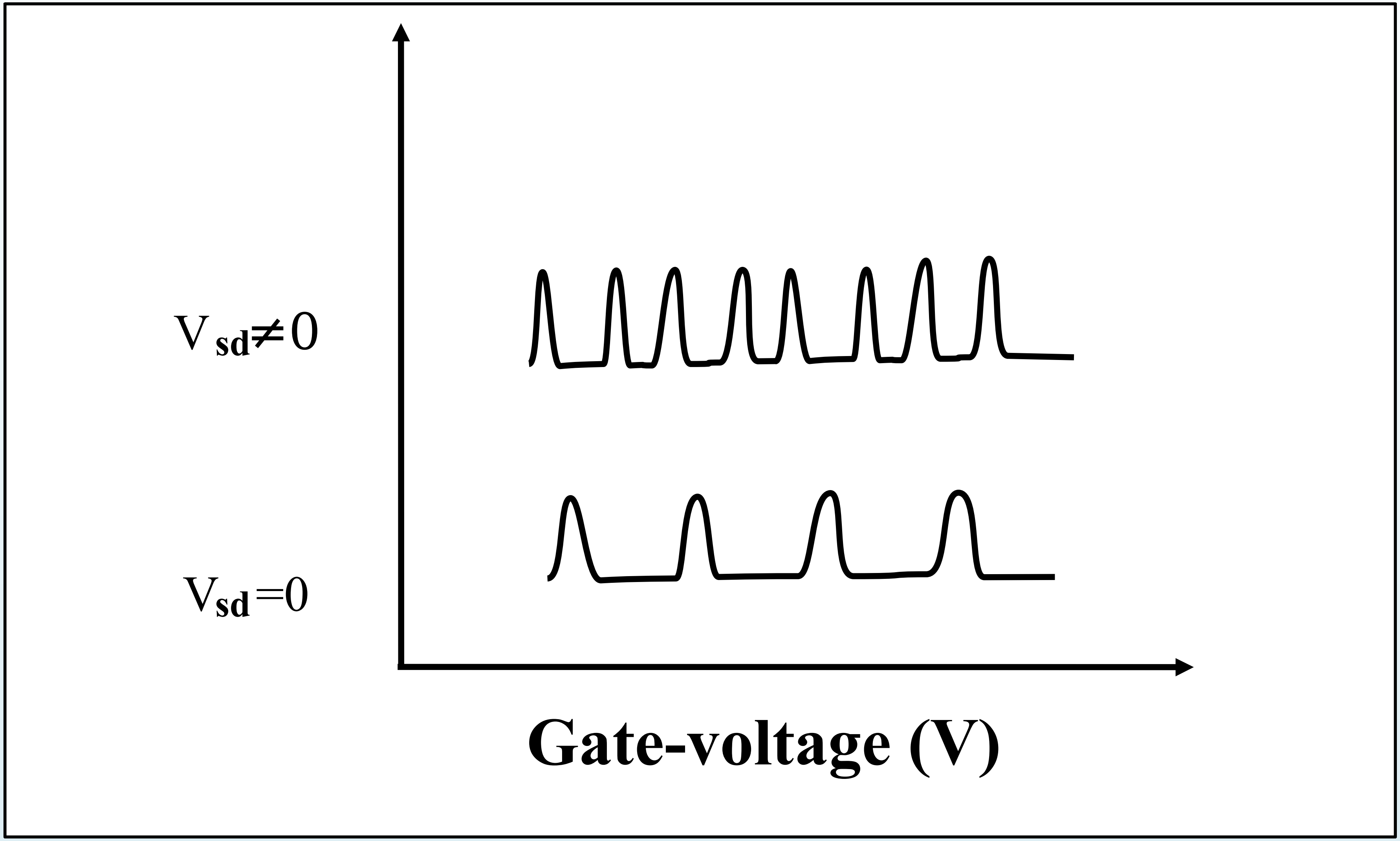
n-GaN

Si

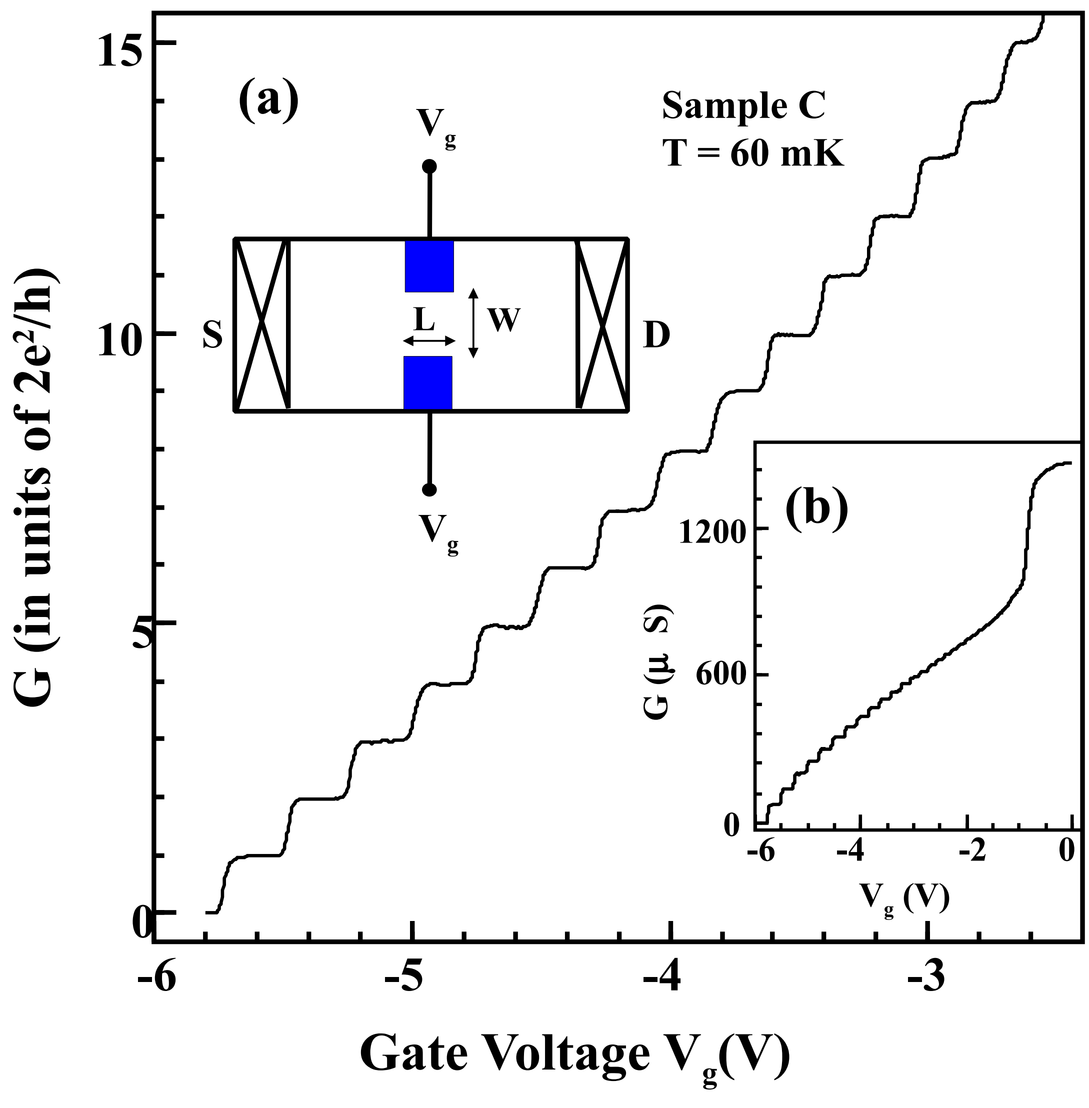
16 Tesla Parallel Field



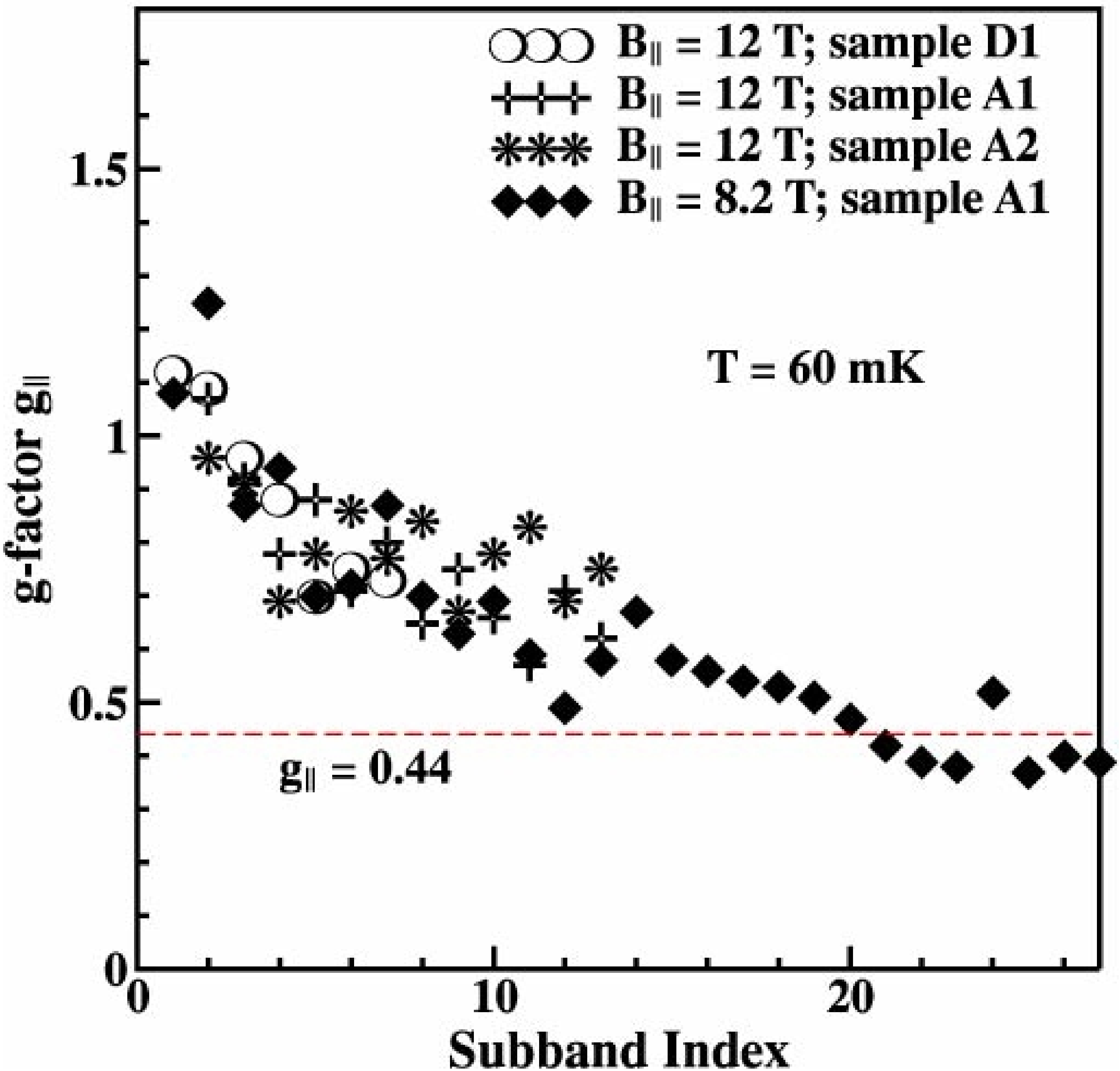
Plot dG/dVg as function of DC-bias and gate-voltage



Ballistic Quantisation



Enhancement of the g-factor in a 1D channel



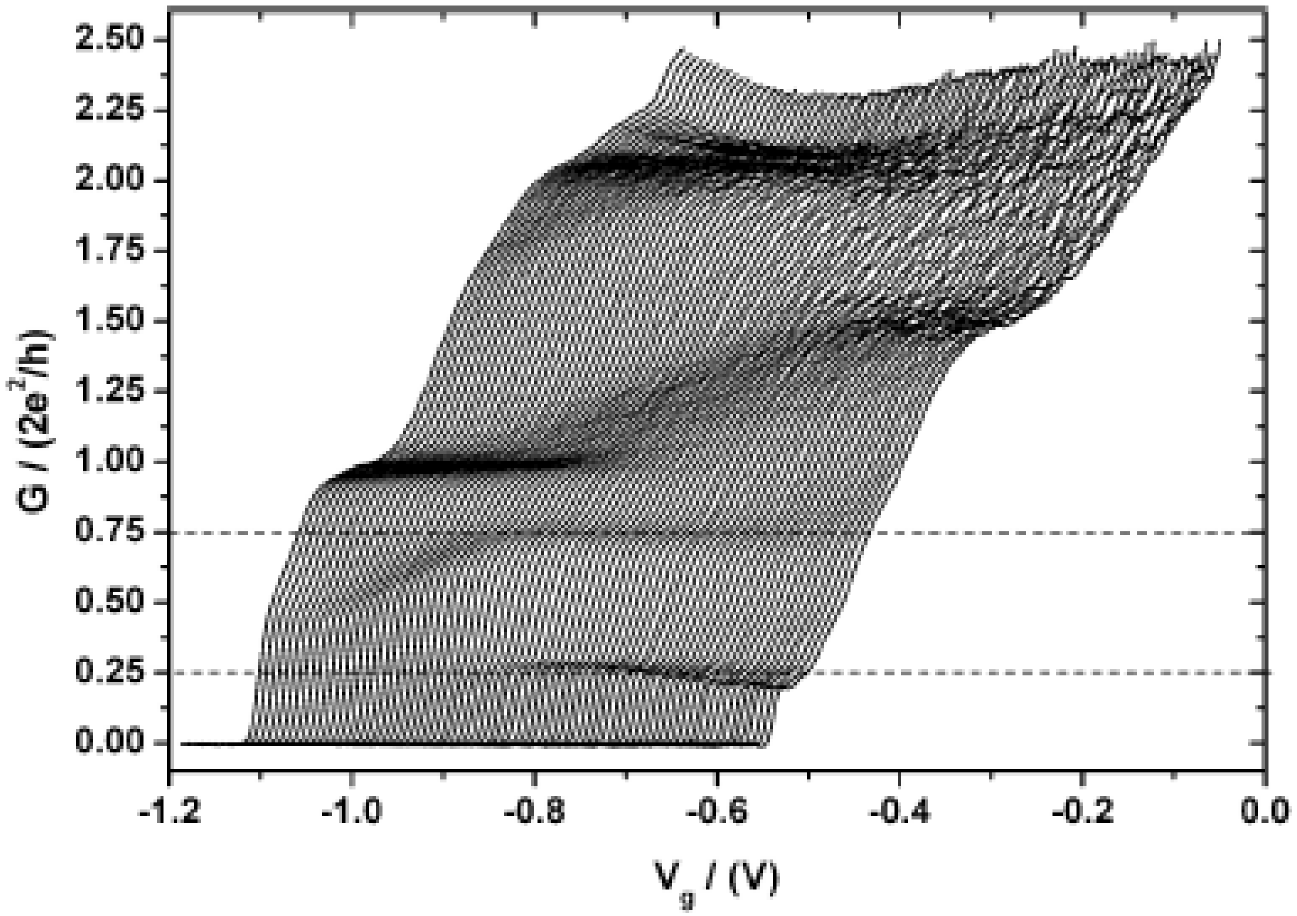
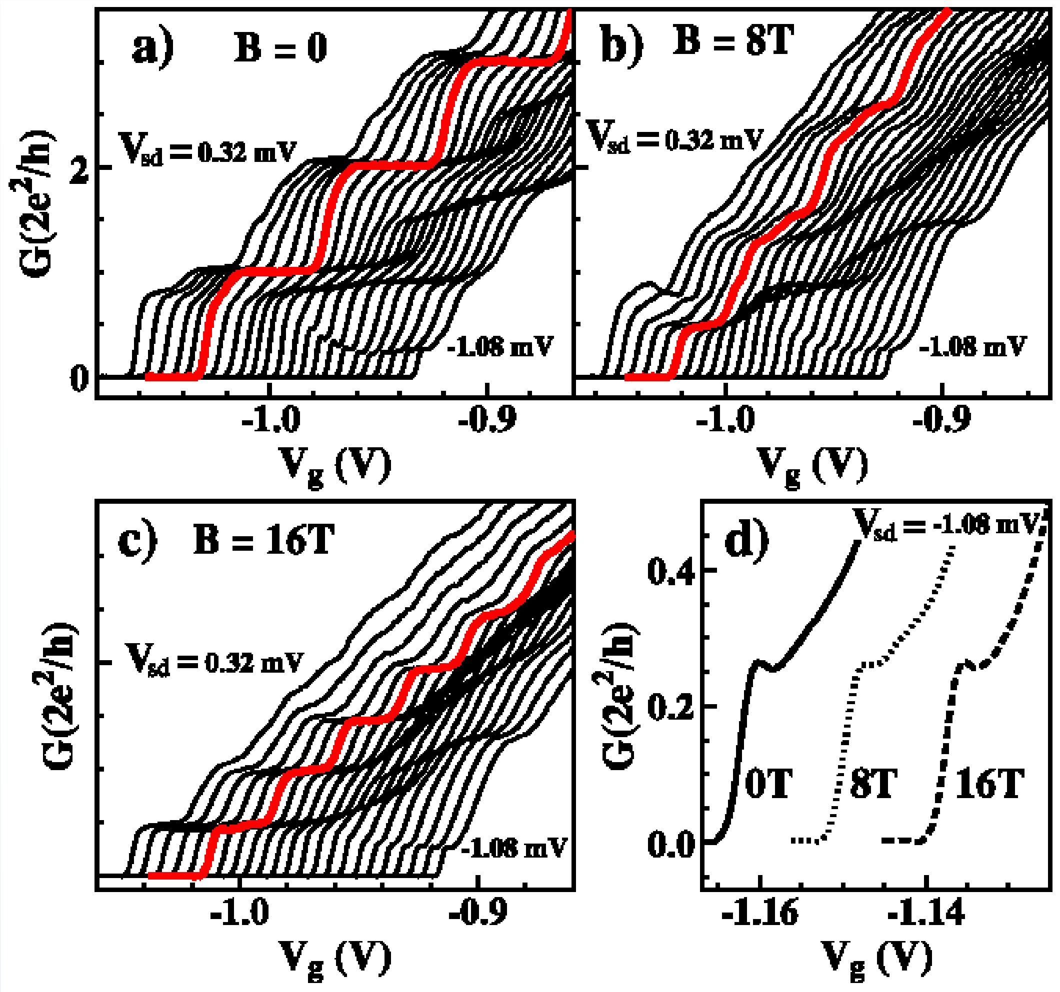
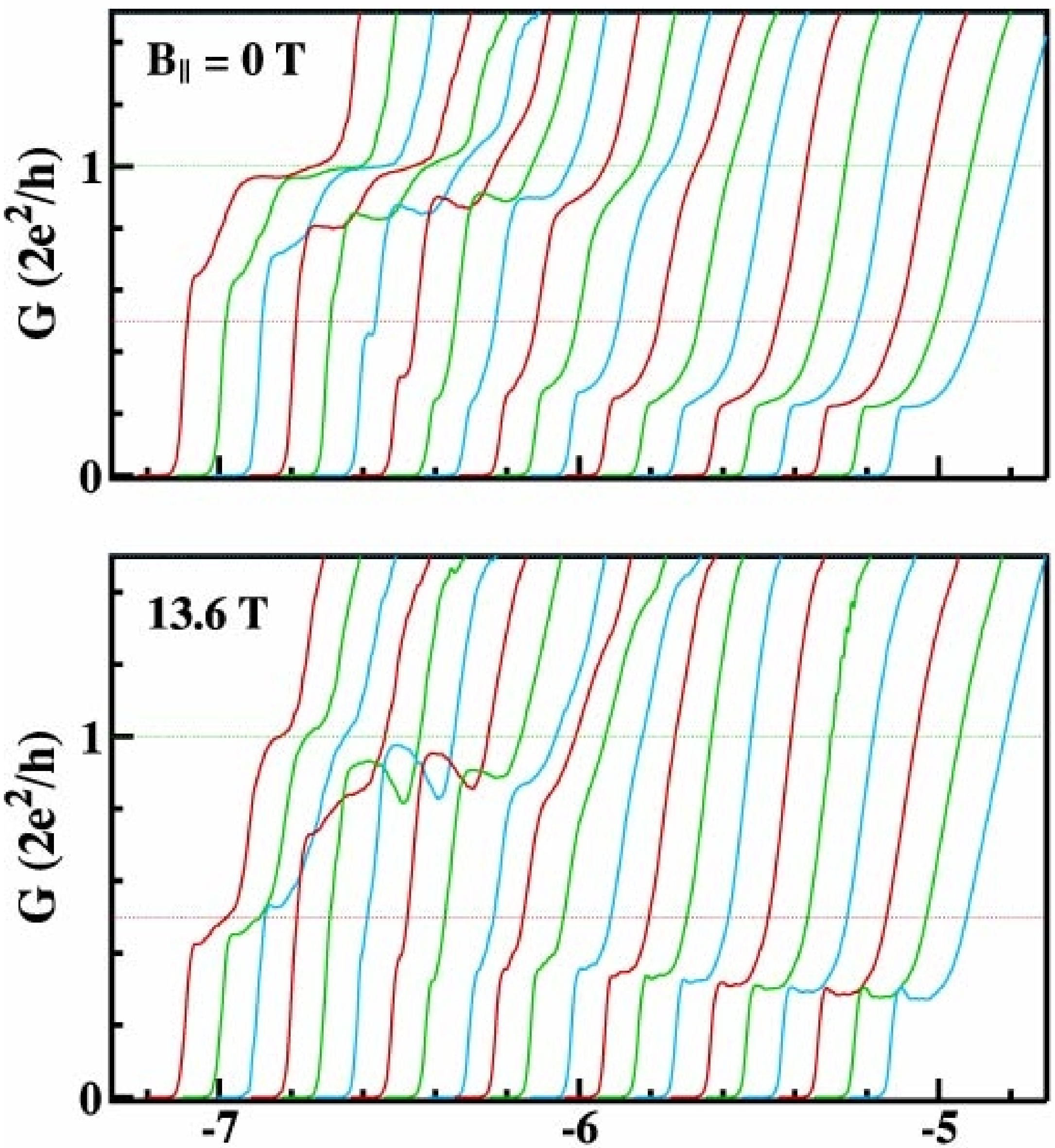


FIG. 3: Differential conductance of an $In_{0.75}Ga_{0.25}As$ quantum wire at $T = 1.5$K under a source-drain bias V_{sd}. From left to right, V_{sd} is increased from -0.1mV to +4.0mV (traces are laterally offset). Note the appearance of a $0.25(2e^2/h)$ and $0.75(2e^2/h)$ plateaux for the fist 1D subband, while only a $1.5(2e^2/h)$ plateau appears for the second subband.

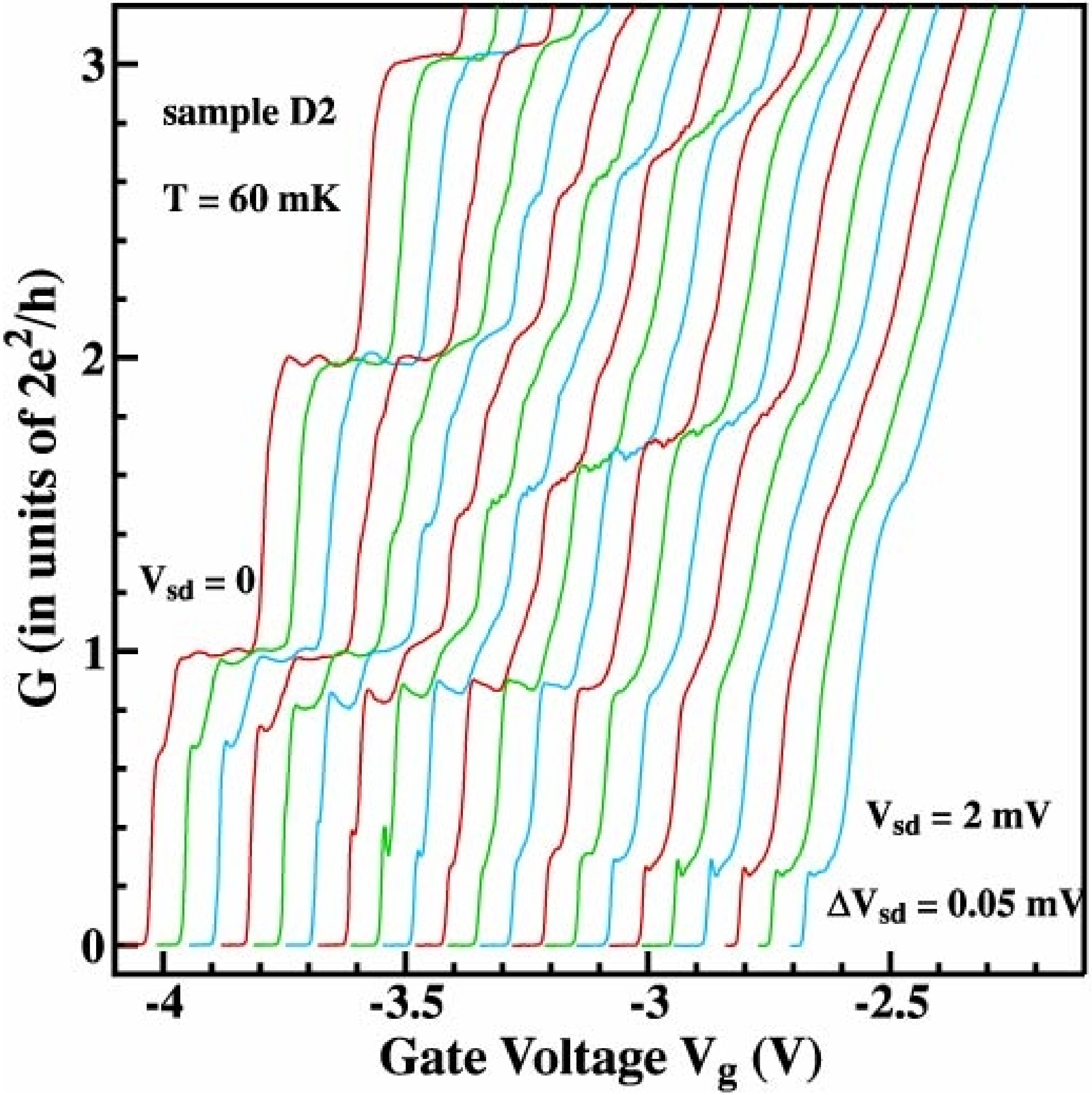
DC-bias data at B=0,8 and 16T



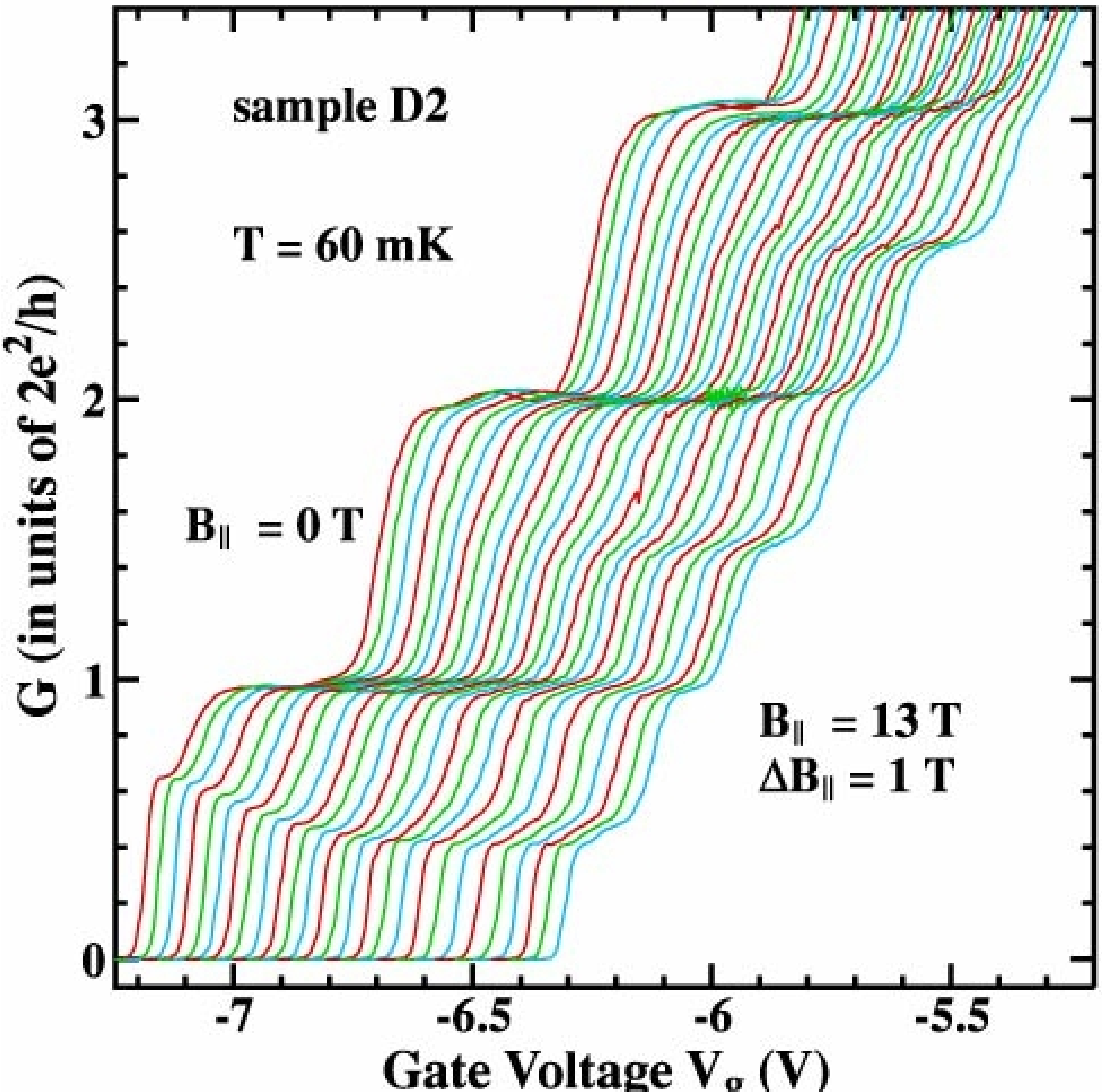
Effect of source-drain bias on the "0.7 structure" and the spin-split plateau



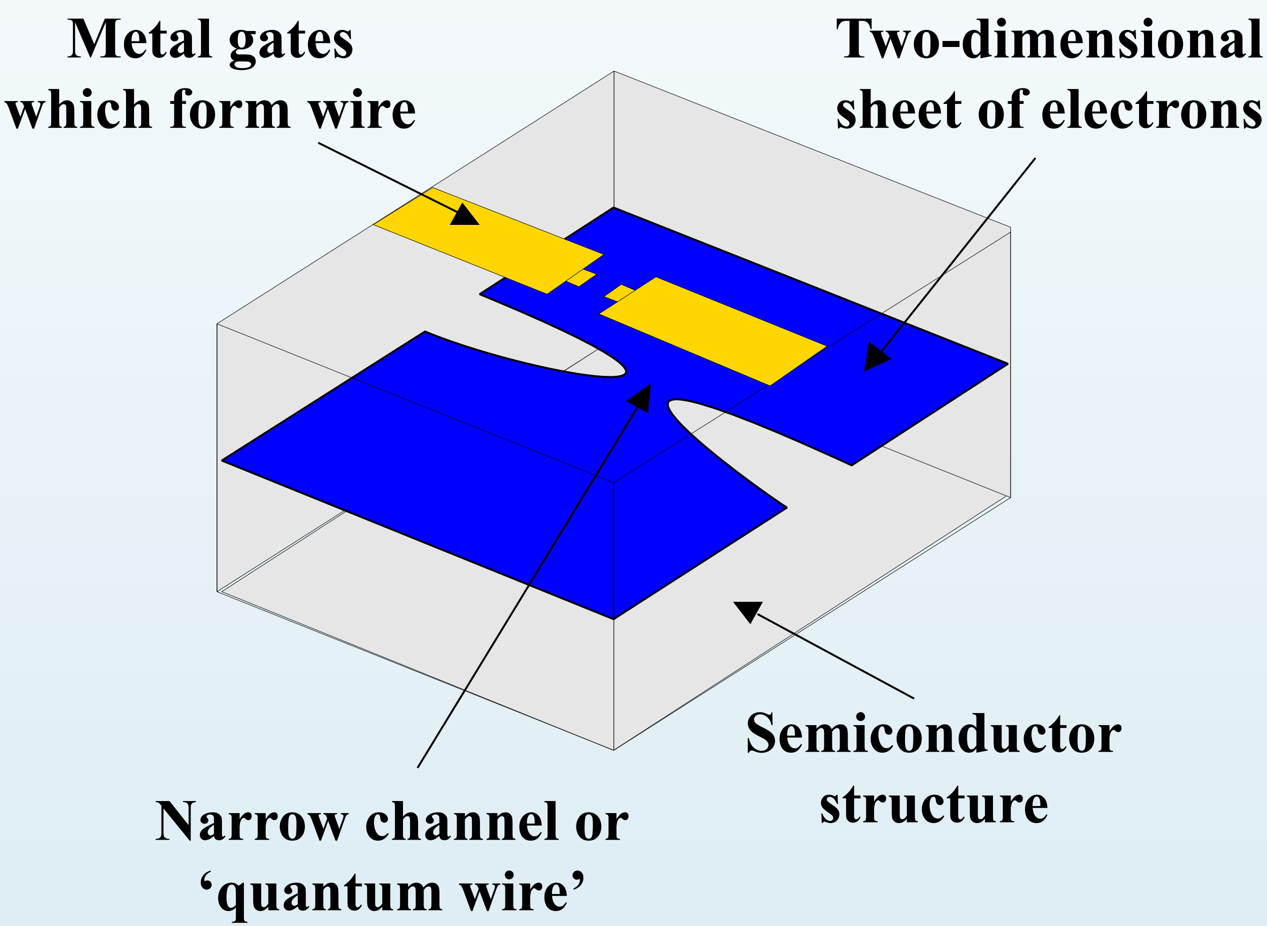
Evolution of the "0.7 structure" in a dc source-drain bias at zero magnetic field



The evolution of the "0.7 structure" into the spin-split plateau



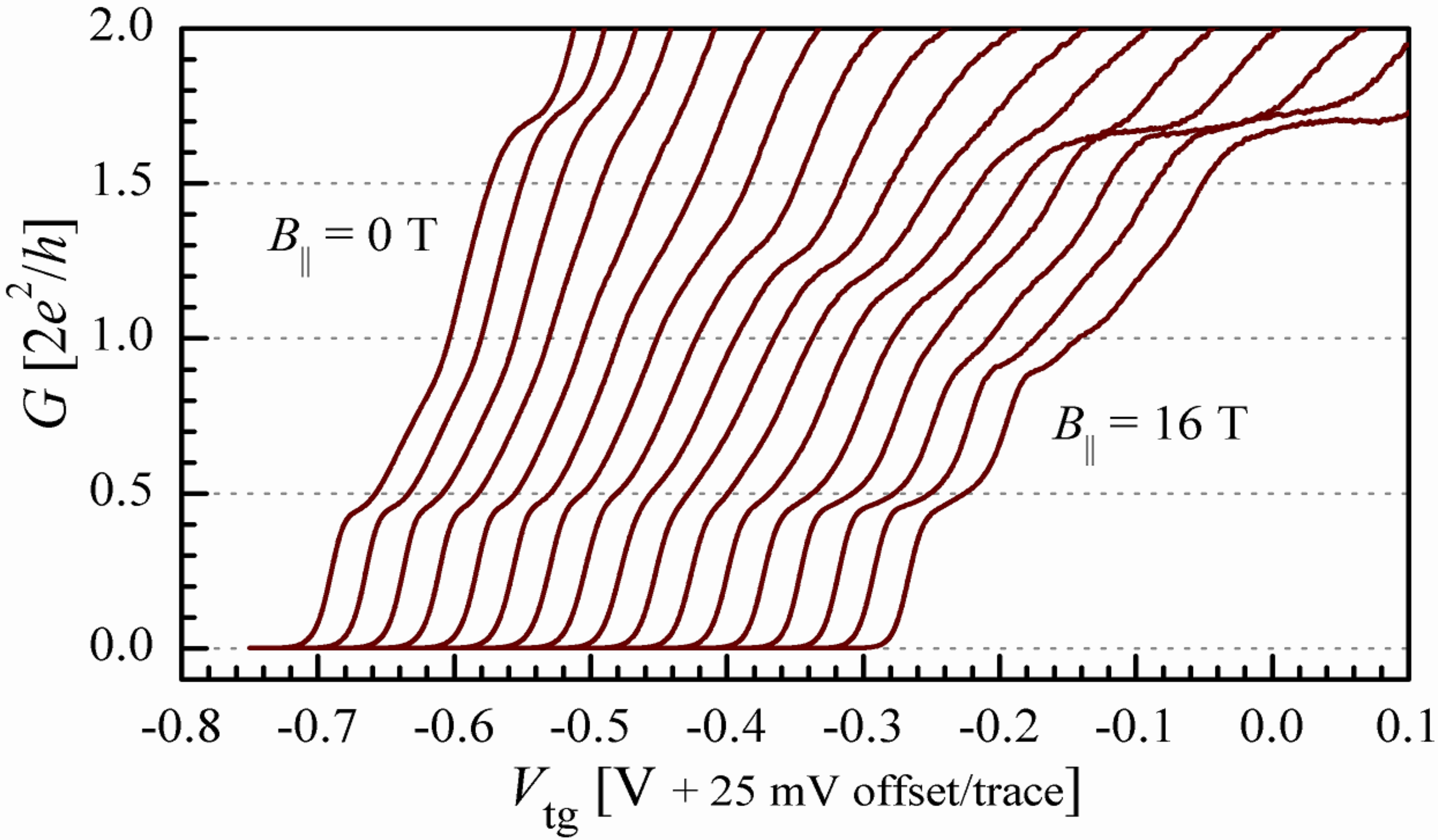
Forming the one-dimensional quantum wire



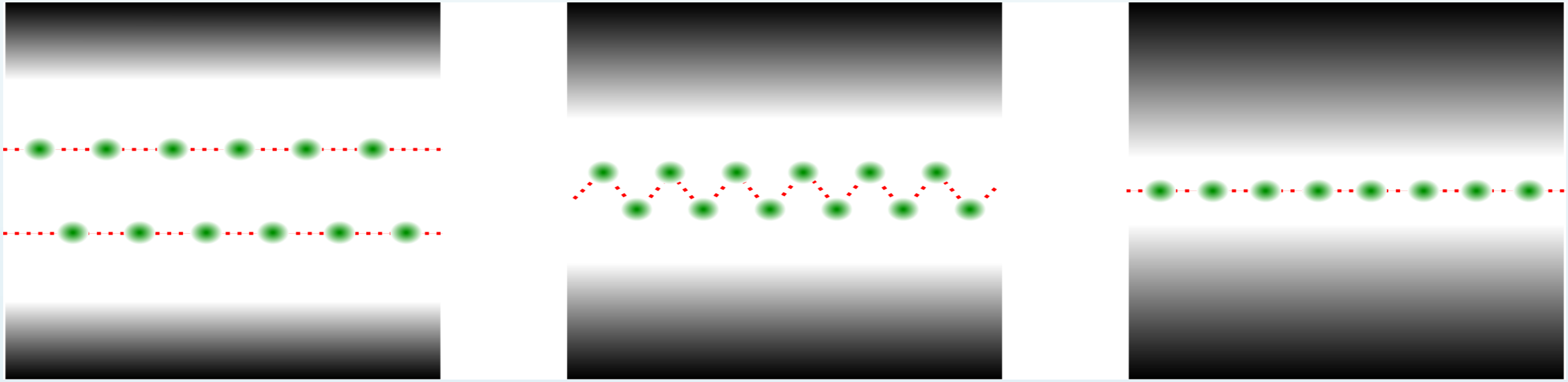
Level Crossing Behaviour

1. For low or zero source-drain bias, behaviour akin to a magnetic phase transition is observed when opposite spin levels approach.
2. At finite source drain bias it is possible to have opposite spin levels with only one direction of momentum. Then an anti-crossing is found.

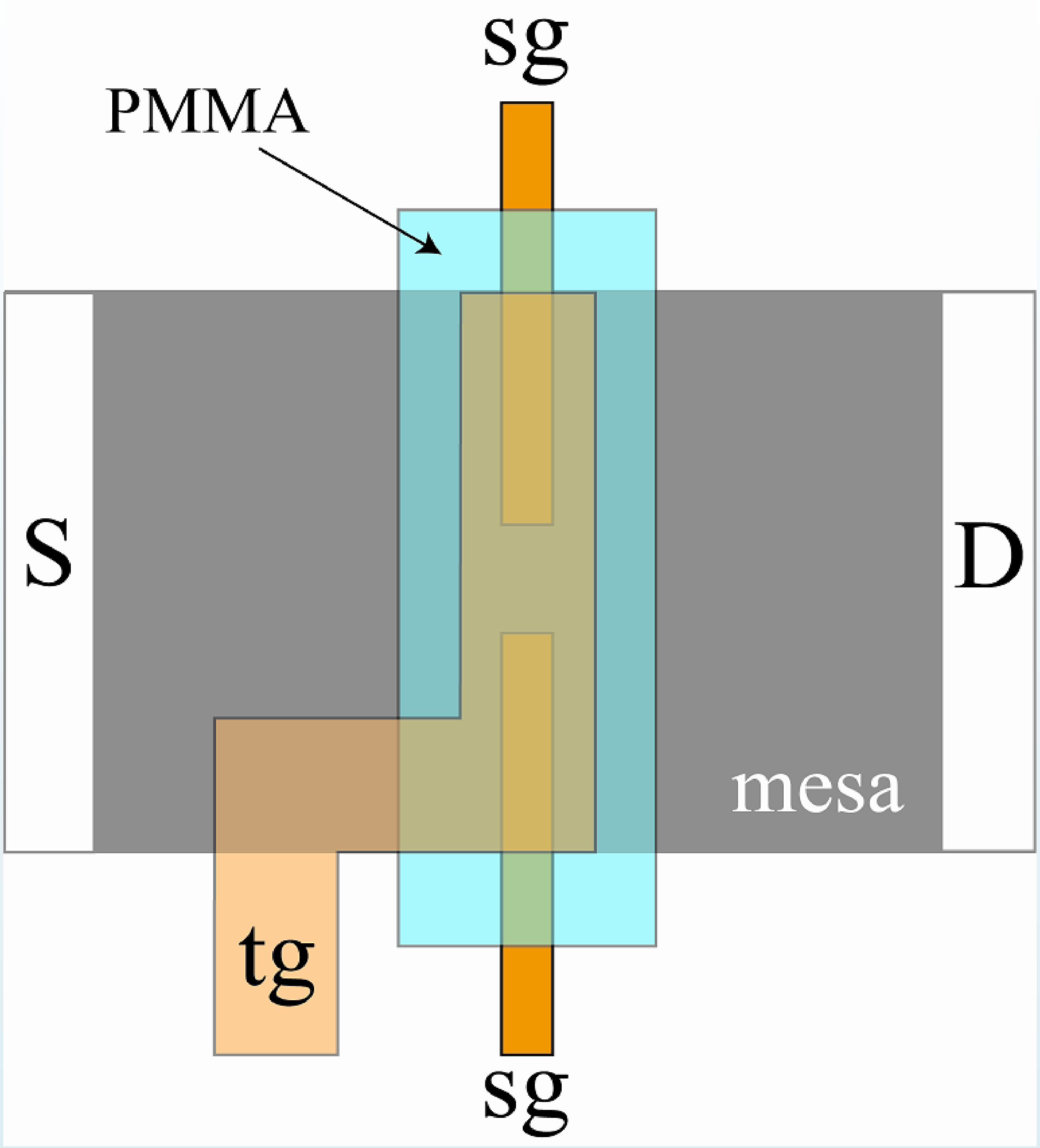
Spin Coherence Introduced by Magnetic Field



Formation of lattice due to interactions in weakly confined 1D channel

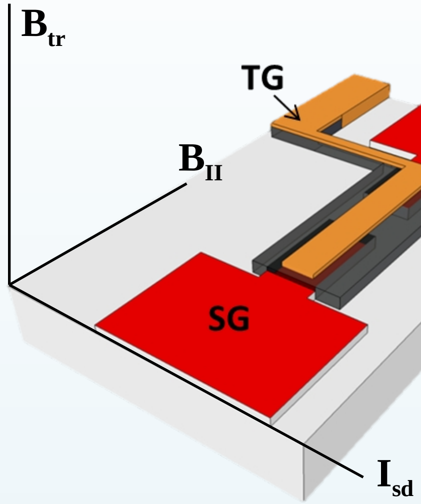


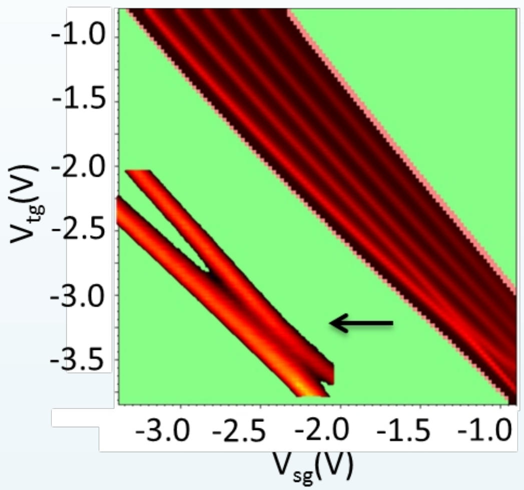
Control of carrier concentration and width

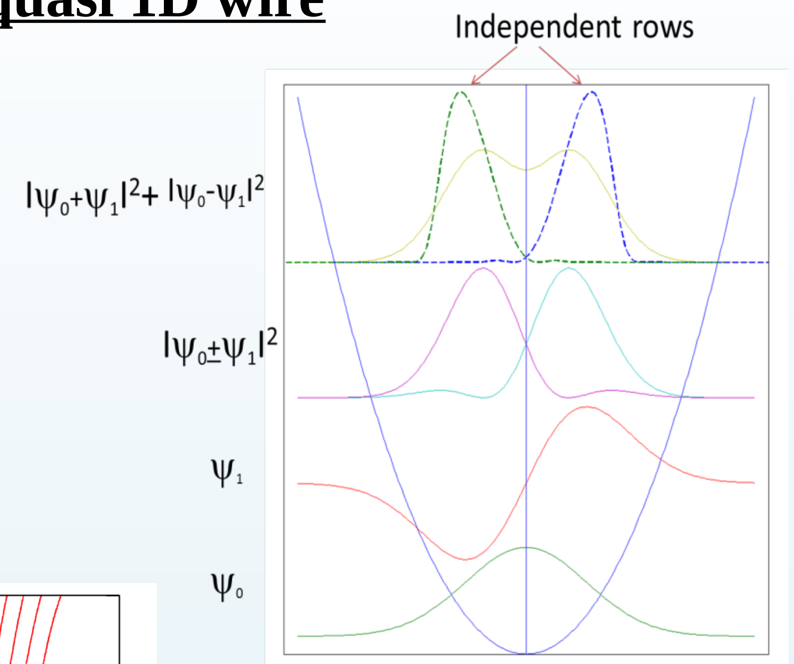


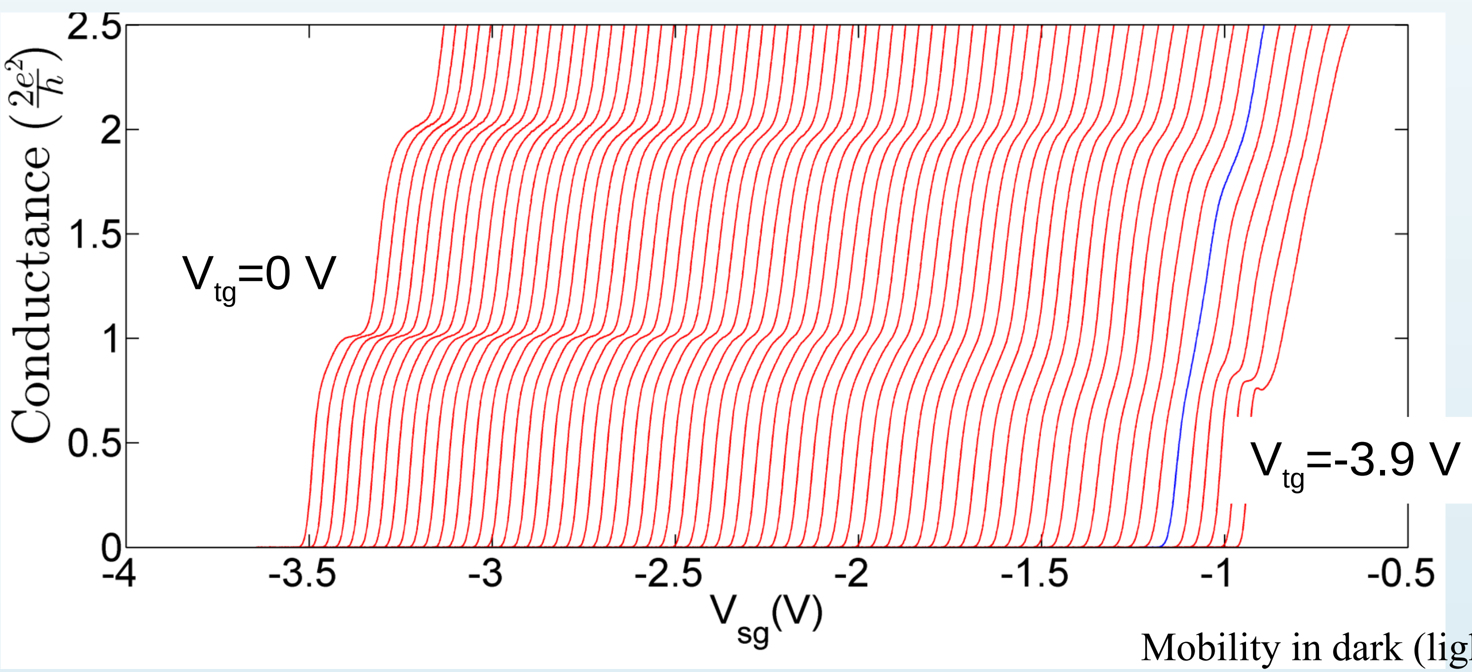
Double-rows in a quasi 1D wire

- **<u>Results on the optimisation of double rows in a quasi 1D wire</u>**









- Double rows in 10 different cool downs on different samples
- Always occurs in the weak confinement regime
- LED illumination helps in achieving double rows

Sample B, Batch-1 on Wafer W731

Mobility in dark (light) of 1.85×10^6 cm^2/Vs (3.1×10^6 cm^2/Vs) and electron density of 1.5×10^{11}cm^{-2} (2.6×10^{11}cm^{-2})

Sanjeev Kumar
Michael Pepper

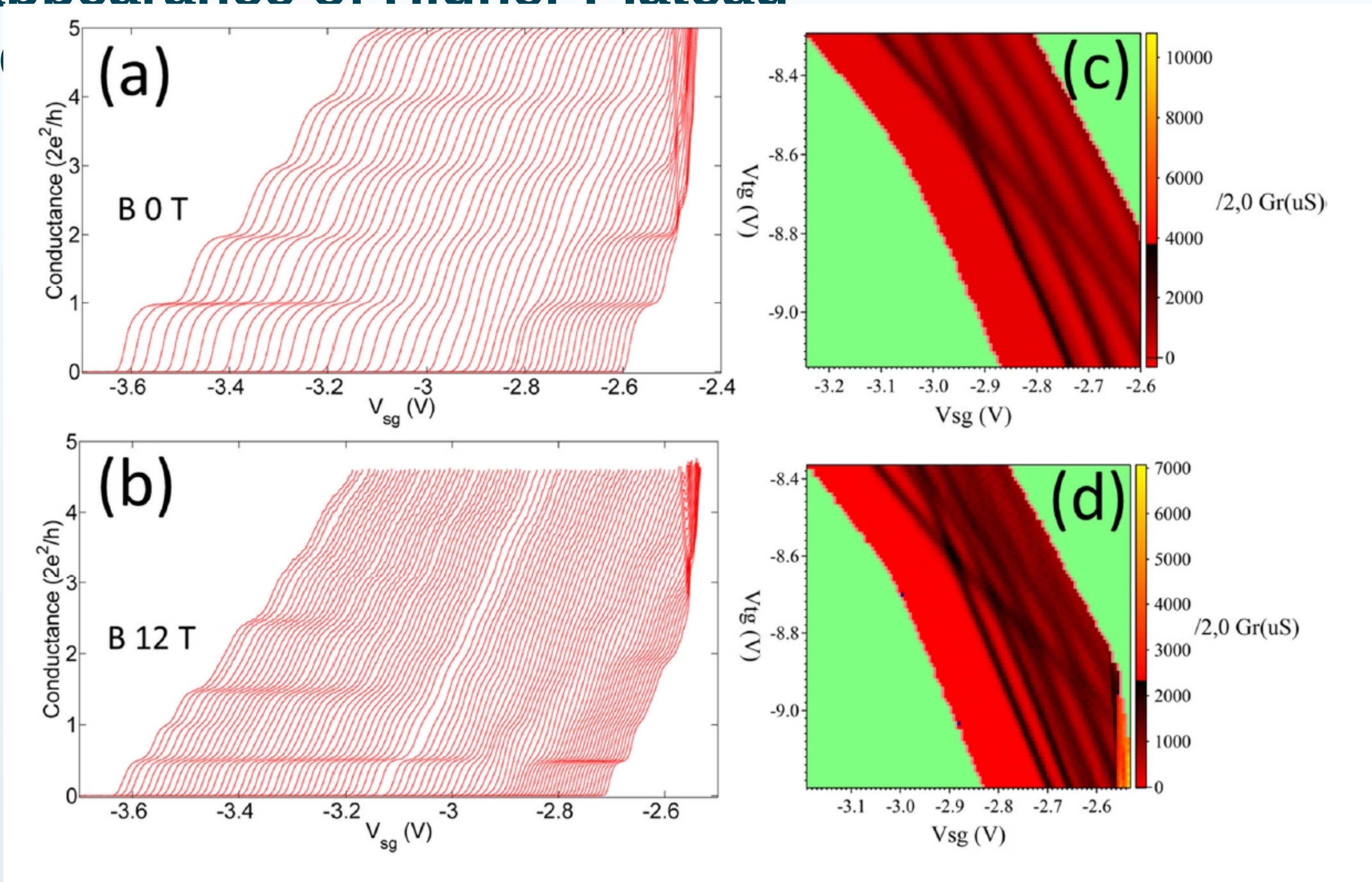
Incipient Wigner Lattice (IWL)

- ✓ At sufficiently low temperatures a one-dimensional line of electrons will attempt to maintain a periodic separation forming an antiferromagnetic Heisenberg spin chain. Recent theories of interacting 1D electrons have shown that when the confinement potential is sufficiently weak there will be a lateral rearrangement of the electrons to form a zig-zag array, with many possible spin phases depending on ring exchange interactions. Decreasing the electron confinement, or increasing the interaction, results in the electron repulsion breaking the array into two distinct rows, termed as IWL
- ✓ The IWL which arises as a result of a 1D-2D wavefunction transition is a dynamic self-organisation, unlike the static case in a quantum dot.

- **One of the objectives of the Programme Grant is to understand and optimise the formation of the IWL, and to use the IWL as a provider of entangled electrons.**
- **Attempt to block one of the rows using a bar gate to look for Mott Insulator**

Window of Ground State Splitting Into Two Followed by Disappearance of Higher Plateau

0 an

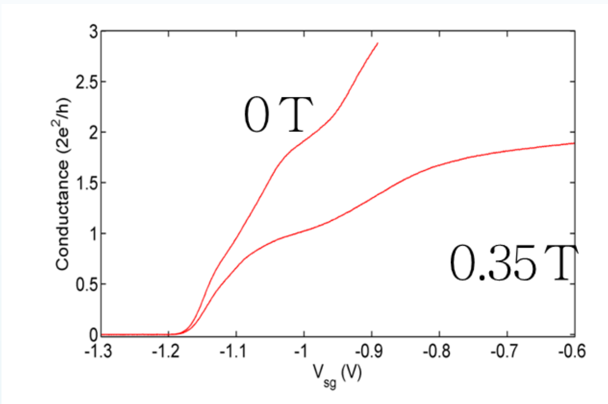


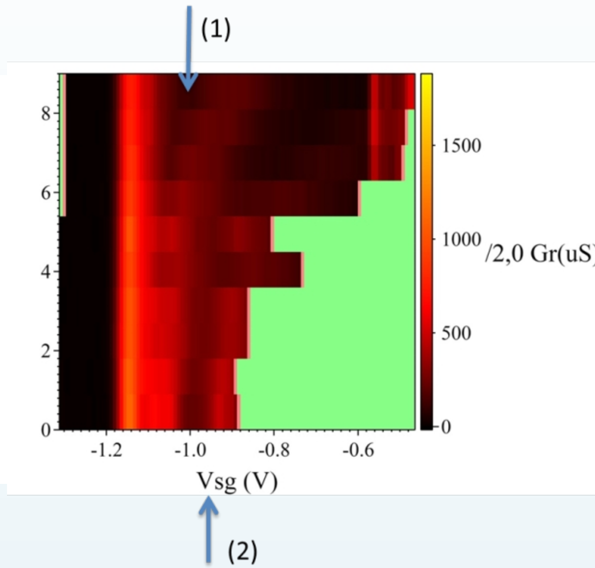
Nanoelectronic Based Quantum Physics:

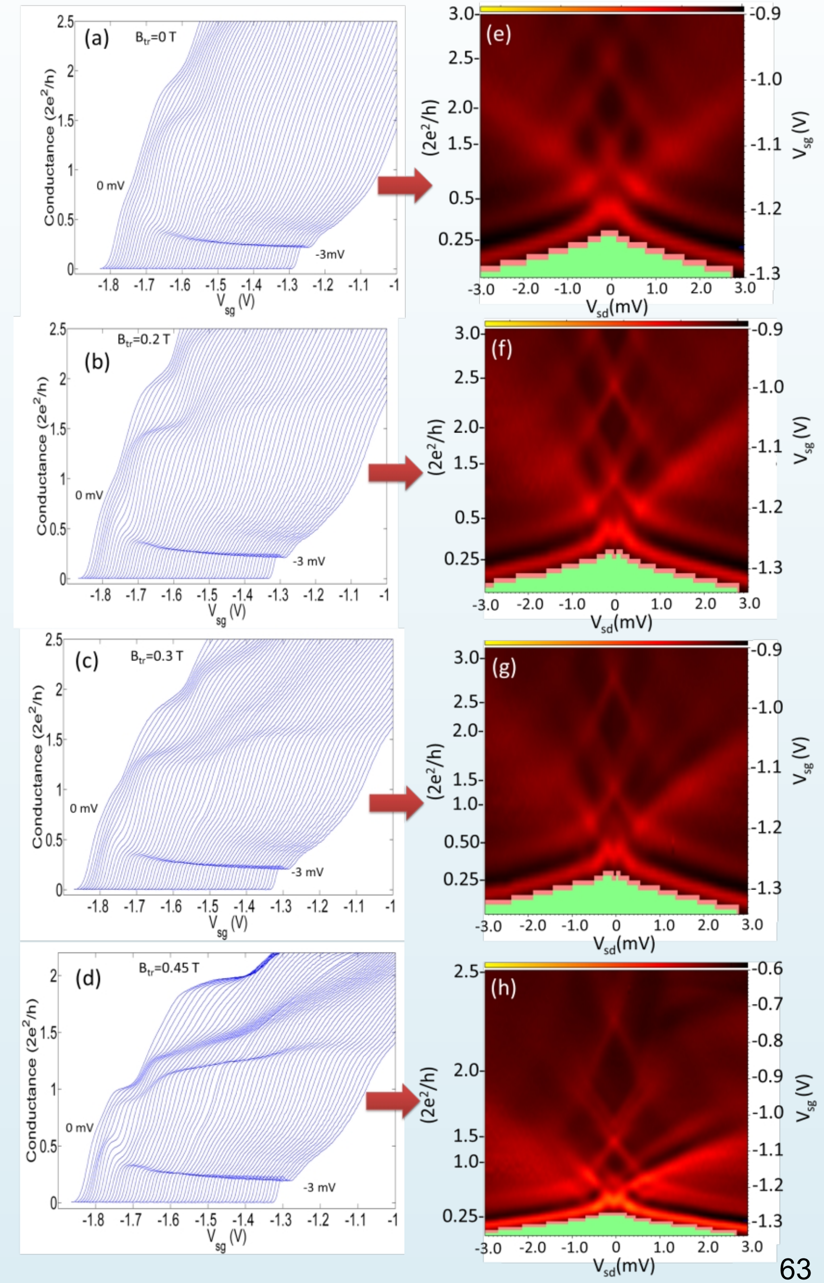
Technology and Applications

Inf uence of transverse B on double rows

- **<u>DC bias characteristics of the double rows and inf uence of transverse B (B_{tr})</u>**





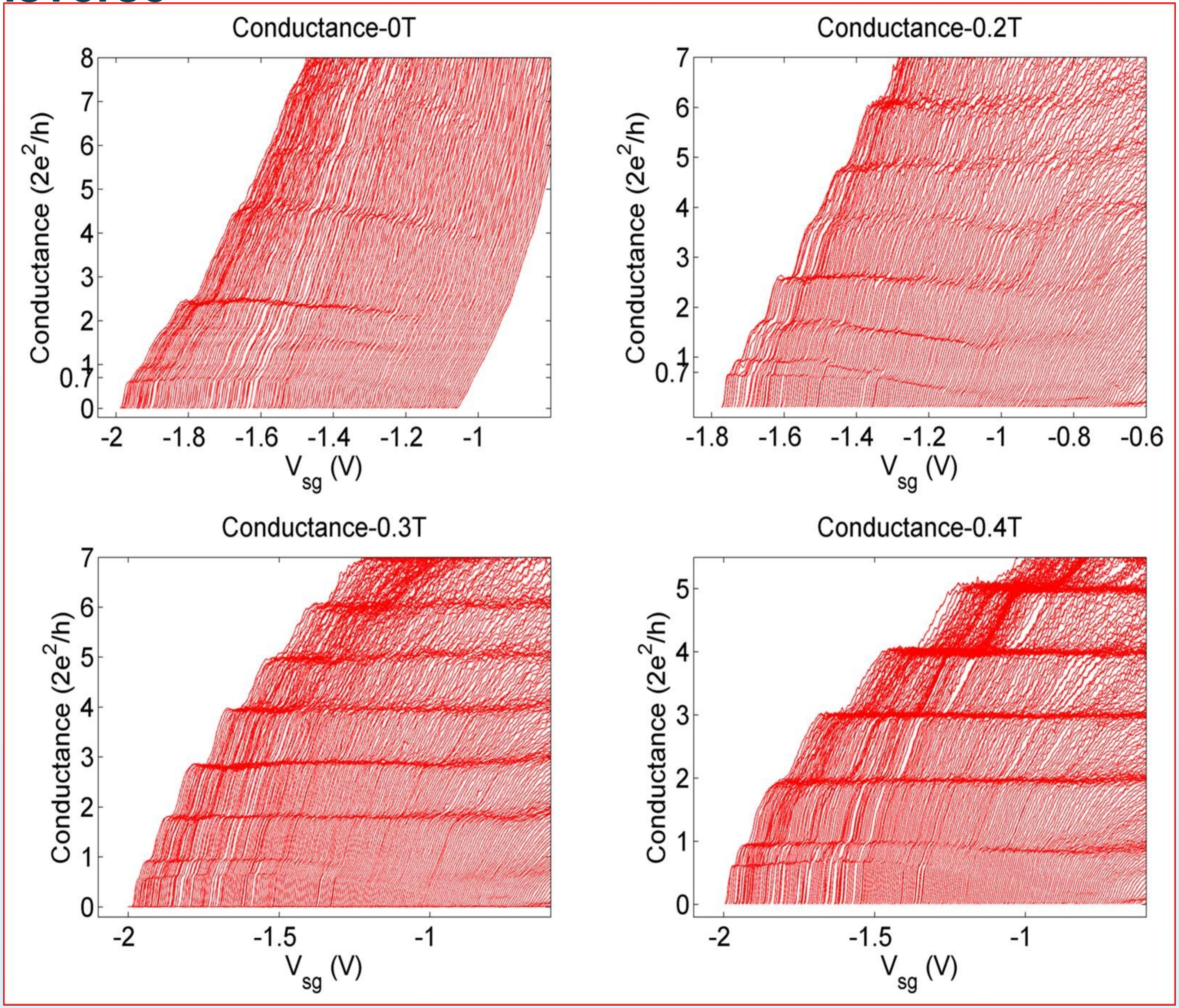


✓ (a)-(d) show plots of differential conductance characteristics for source-drain bias of 0 to -3 mV in the presence of B_{tr} of 0, 0.2, 0.3 and 0.45 T, respectively.; (e)-(h) represent greyscale plots of (a)-(d), respectively, red regions are the regions of conductance risers and black regions are of conductance plateaux.

✓ The coupling between the rows evident from the presence of $0.5(2e^2/h)$ in the strong dc-bias ((a) and (e)), smears out with an increase in small B_{tr} ((b)-(d) and (f)-(h)) where the structure at $0.25(2e^2/h)$ remains unaffected.

✓ Plateaux become broader and sharper due to the additional magnetic confinement and the suppression of backscattering.

Window of Enhanced Interactions Due to 0.3 Tesla Transverse

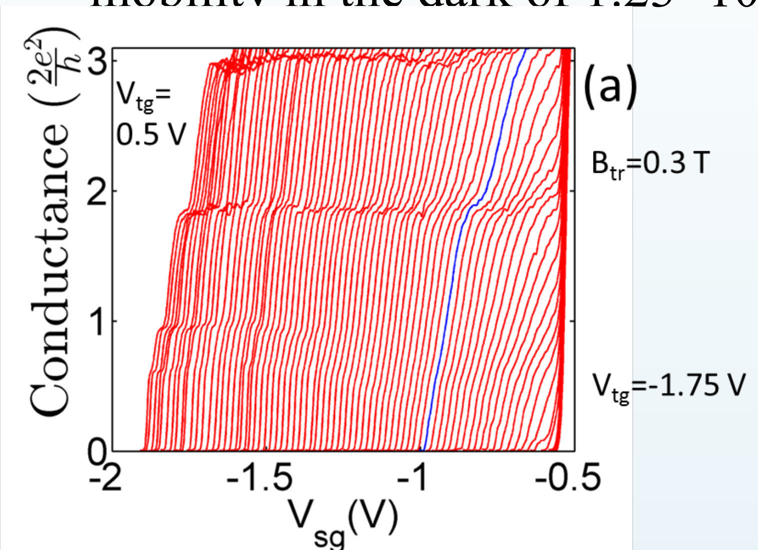


Nanoelectronic Based Quantum Physics: Technology and

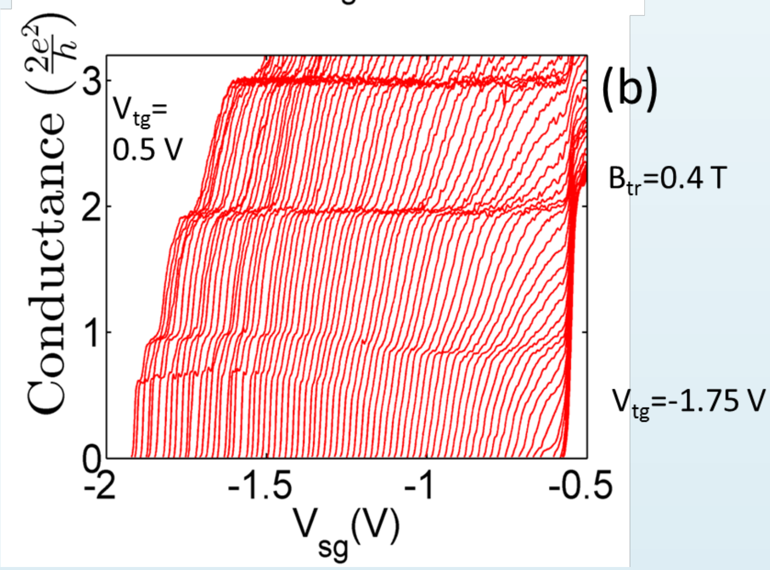
Double rows due to transverse Magnetic field

- **<u>Transverse B enhanced double rows</u>**

  - A low density device from a modulation doped GaAs/AlGaAs heterostructure with a mobility in the dark of 1.23×10^{6} cm^2/Vs and electron density of 4.5×10^{10}cm^{-2}

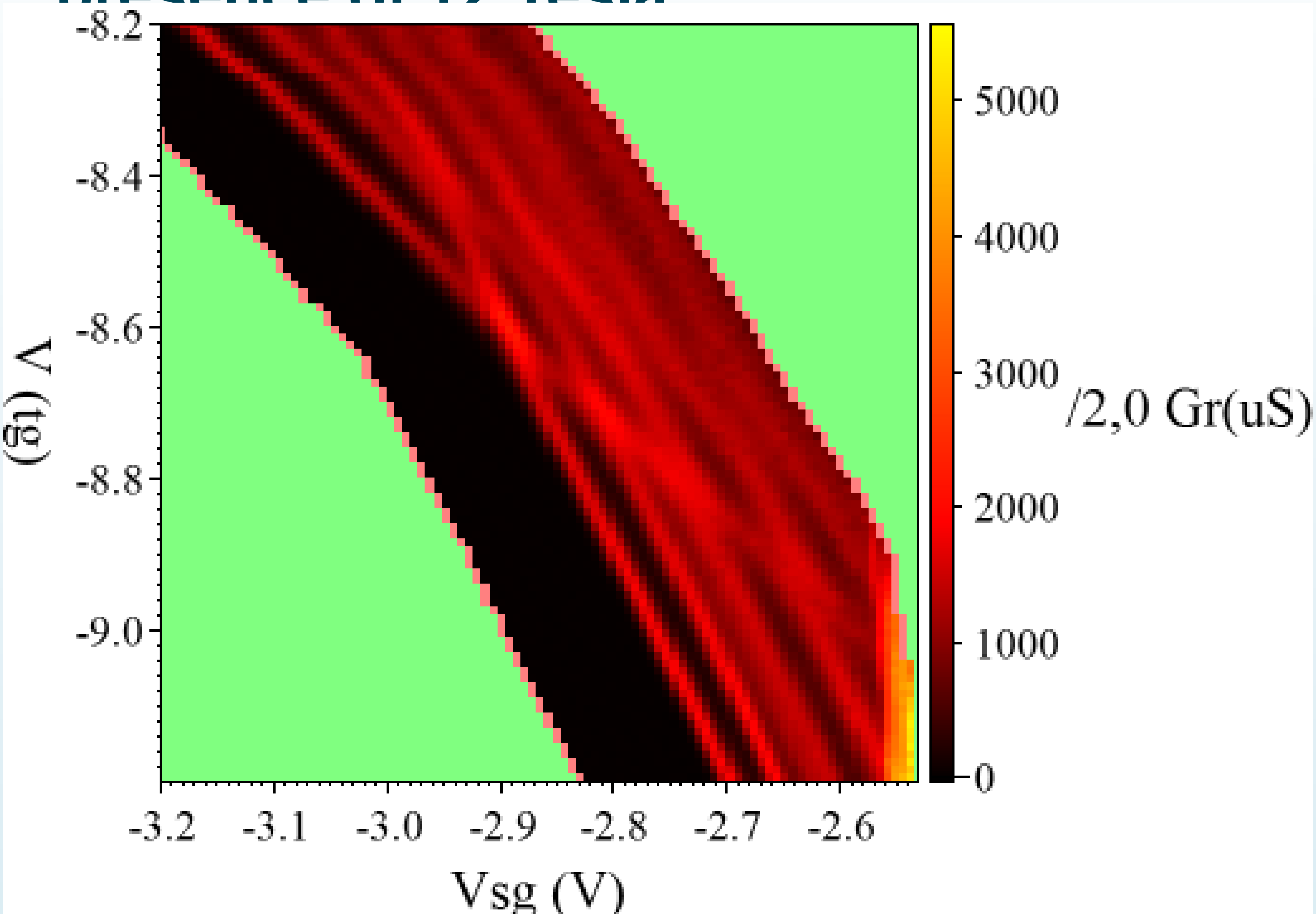


- ✓ In the absence of $B_{tr,}$ plateaux were not resolved very well
- ✓ Increase Btr helped resolving the plateaux
- ✓ At 0.3T, weakening the confinement resulted in smearing out of
- ✓ $2e^2/h$ and direct jump to $4e^2/h$ was observed
- ✓ Further increase in Btr to 0.4T removed double jump and standard plateaux are observed

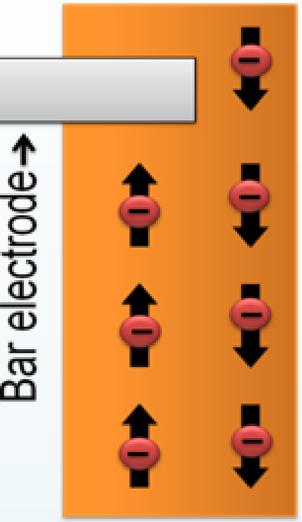


- ✓ Magnetic enhancement of double rows can not be attributed to spin effects as small fields has no effect on lifting spin degeneracy
- ✓ Therefore double row enhancement is attributed to a change in the confinement potential for small Btr such that cyclotron energy $\hbar\omega \ll E_0$, where E_0 is ground state confinement energy.
- ✓ If the increase in the electron-electron repulsion caused by the increasing confinement can exceed the energy difference between the 0- and 1-states, which is approximately the energy required for row formation, then double row will be created.
- ✓ At higher B_{tr},. The cycotron energy can be equal or exceed E_0, thus increasing the gap between E_0 and E1, so $2e^2/h$ reappears

Level Crossing in Weakly Confined 1D in presence of 12 Tesla



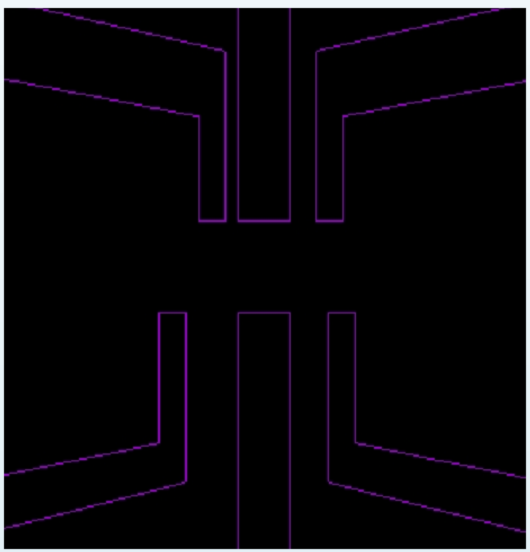
Blocking row experiments

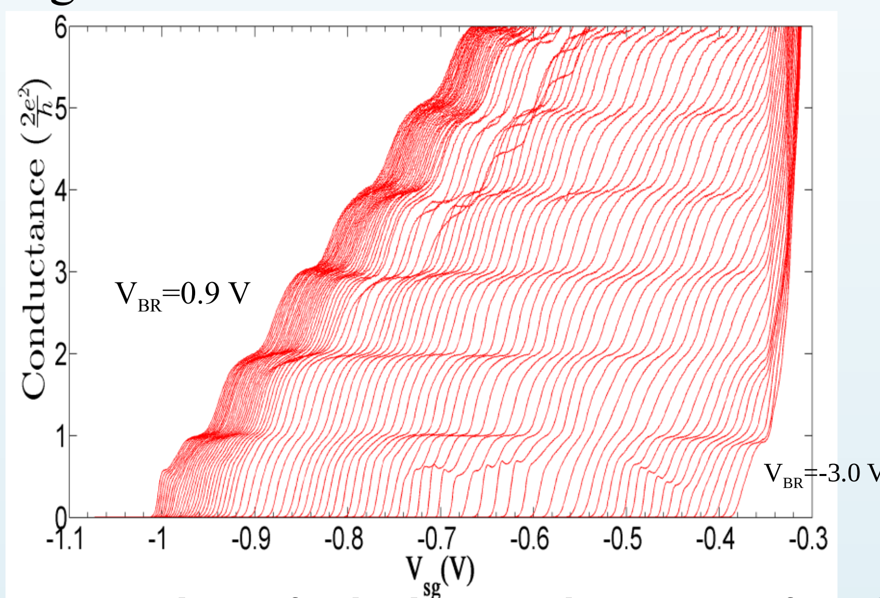


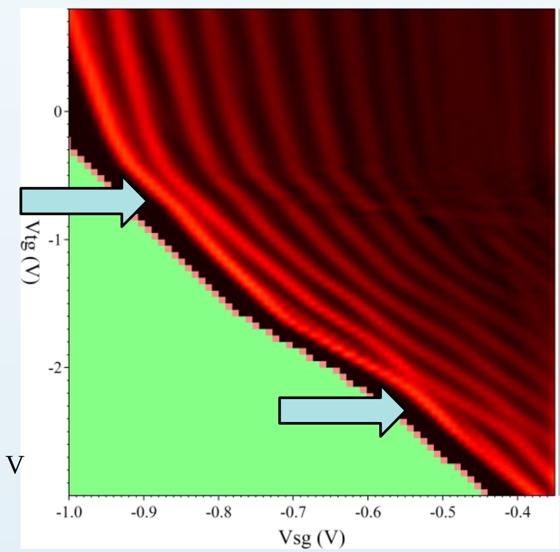
When a blocking gate is placed next to the double rows so that one row is localised and the other, which is free to move, is then trapped in the potential minima of the first row. As the carrier concentration in the rows is always equal so the Mott insulator may be studied as the separation is reduced.

Objective

To investigate theoretical suggestions that the effective electron charge is renormalised to take the value $e/(2)^{1/2}$, an example of charge fractionalisation in the absence of a magnetic field.







Device design, optmisation of the bar gate, separated from the split gate from 100-400nm.

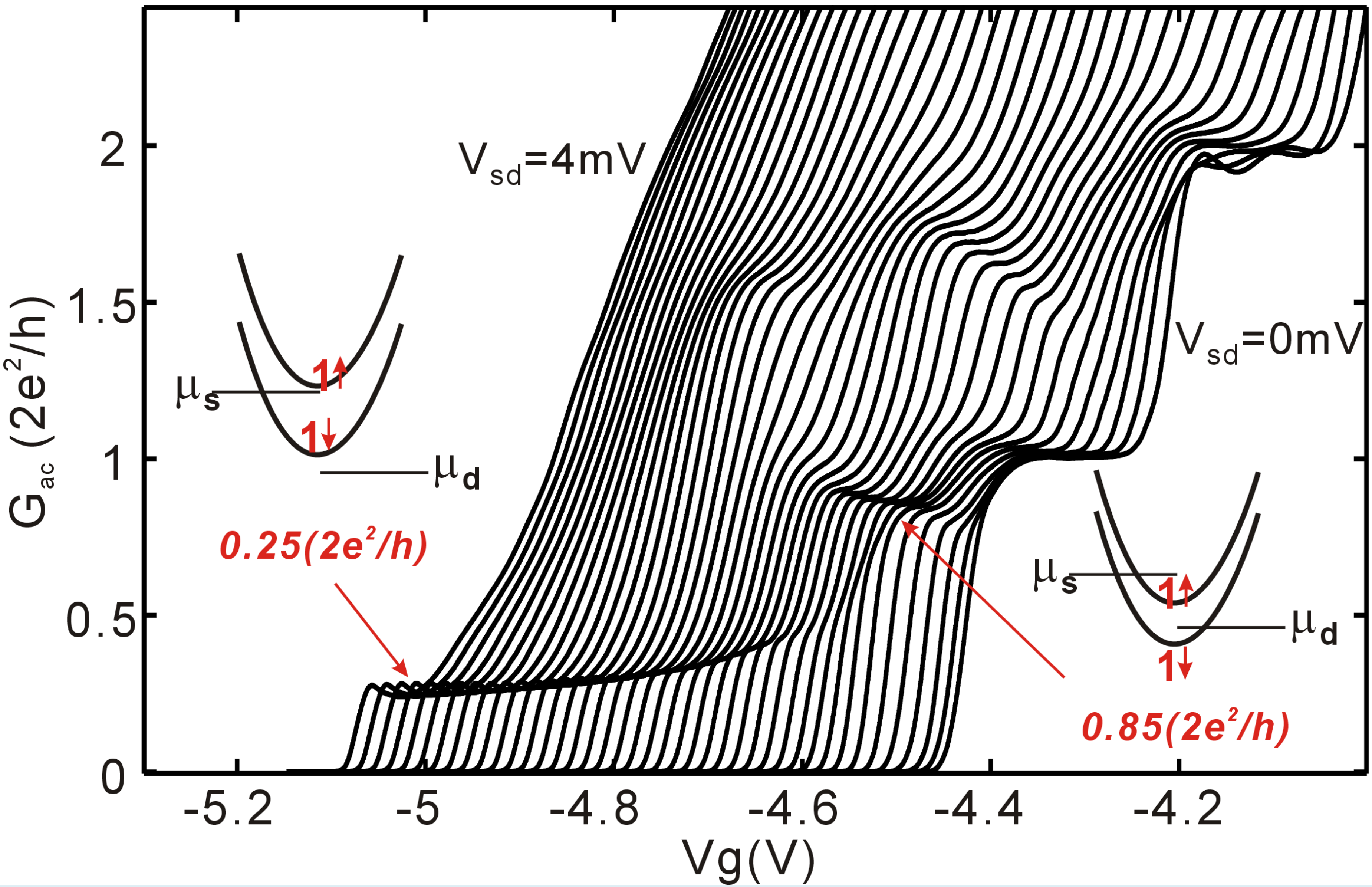
Results are for the device with BR 300nm from the edge of the split gate

Other results:

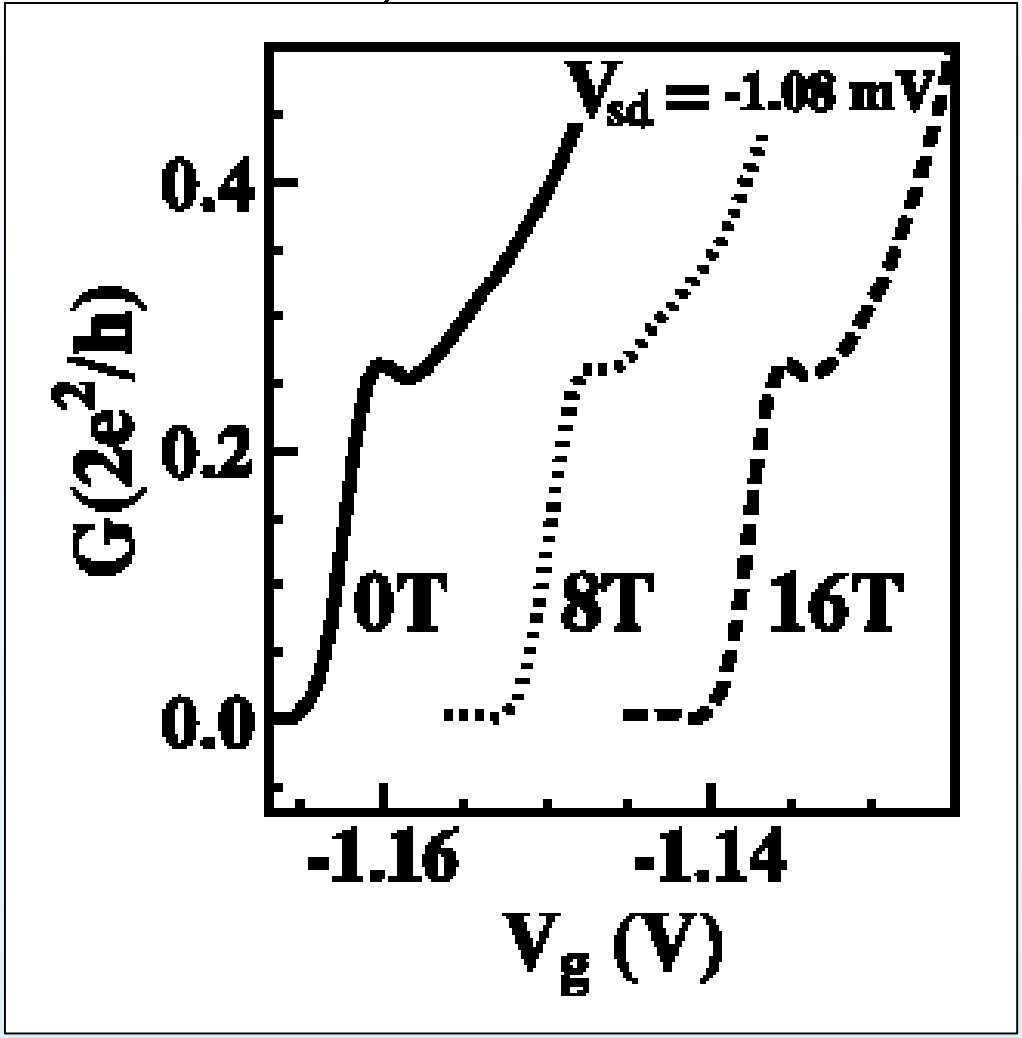
Swept B_{tr} at a f xed G of the split-gates for different bar gate voltage

Oscillations like A-B were observed, needs further measurements.

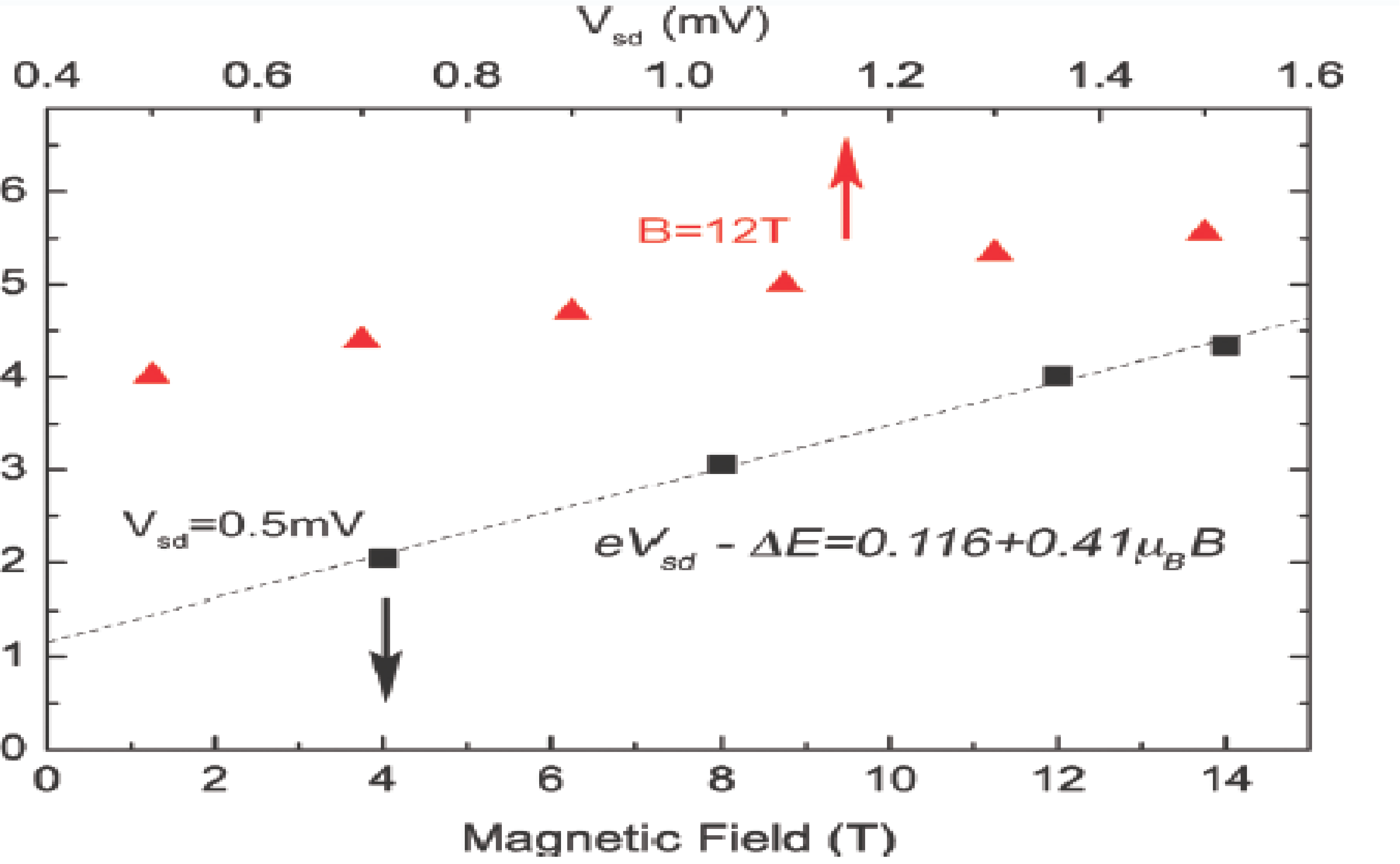
FORMATION OF 0.25, SPIN POLARISED STATE



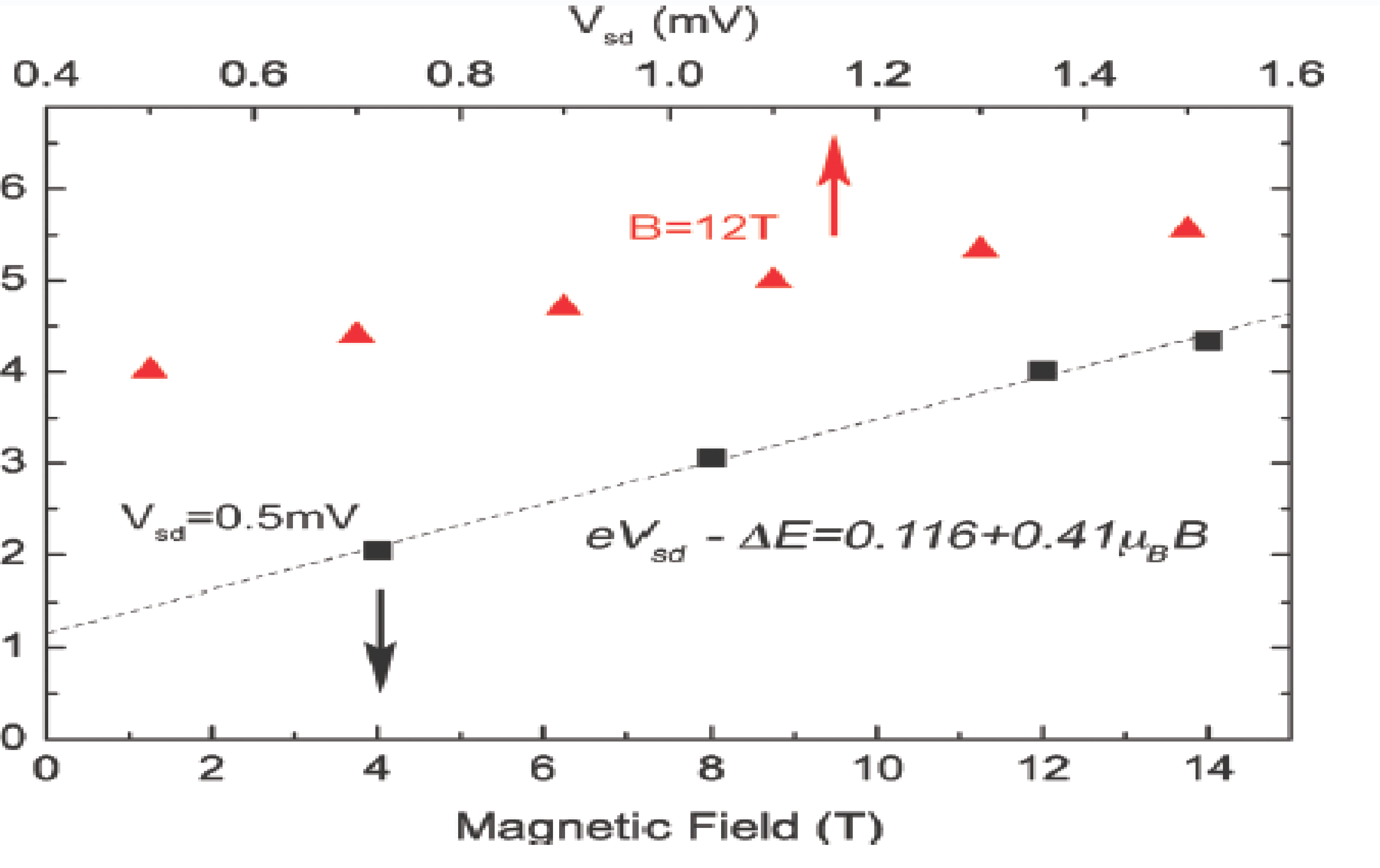
DC-bias '0.25' structure at B=0, 8 and 16T



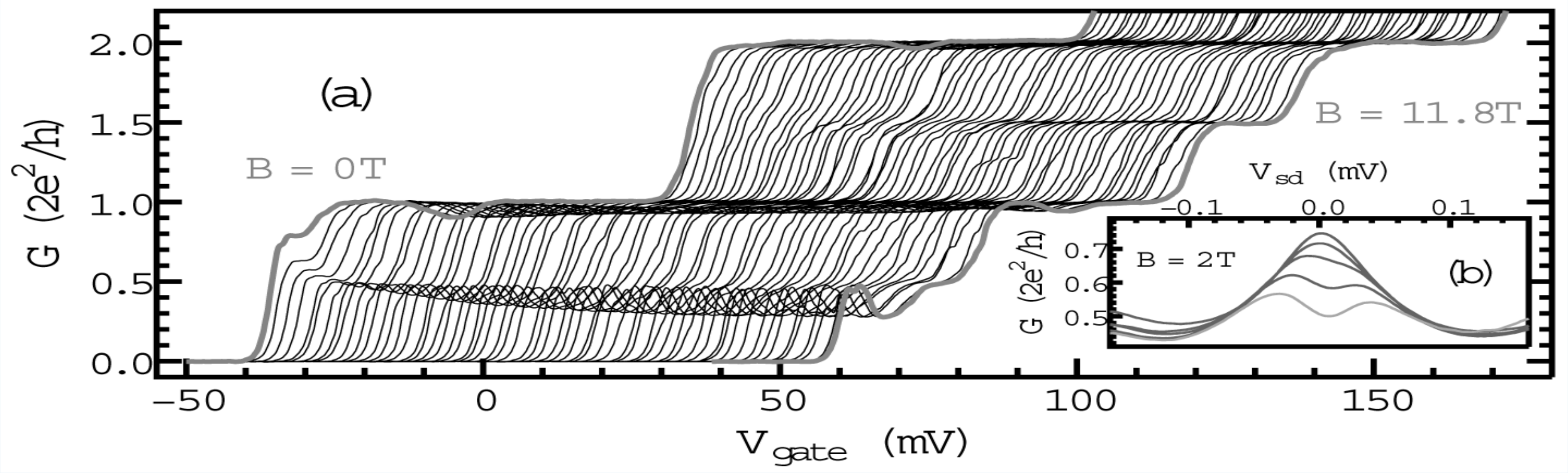
Enhancement of g Value



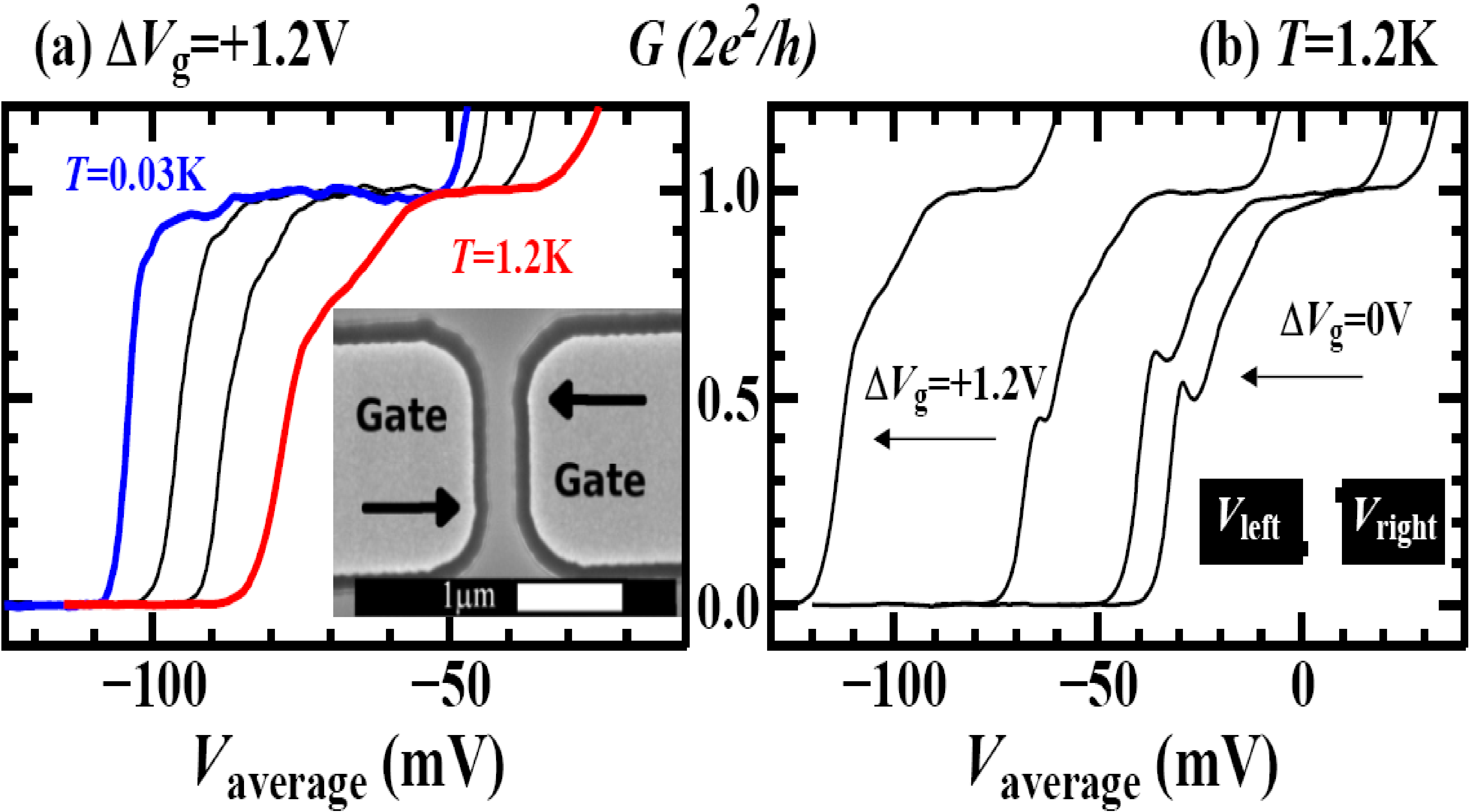
Enhancement of g Value



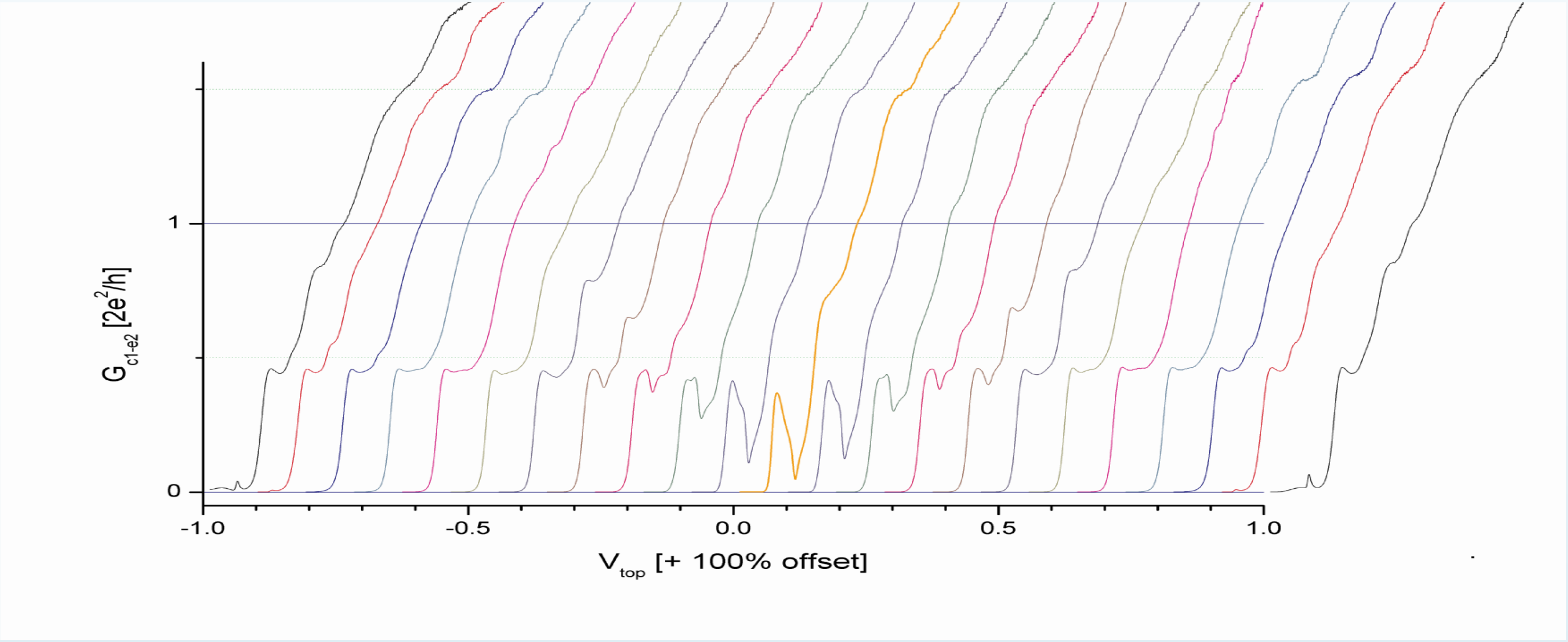
Magnetic Field Removal of Kondo Screening at 0.1K



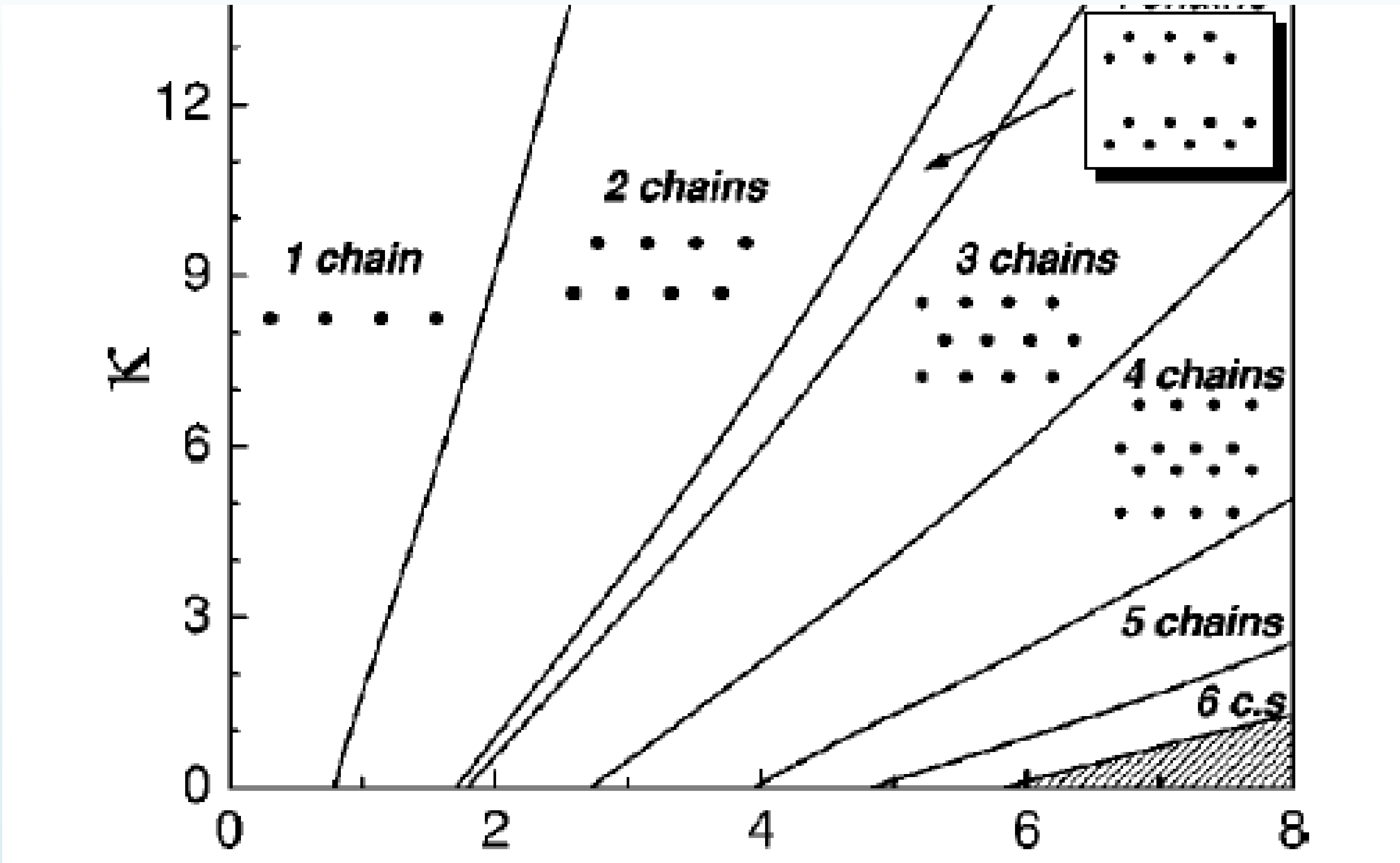
Conversion of a Channel to a Quasi-Dot



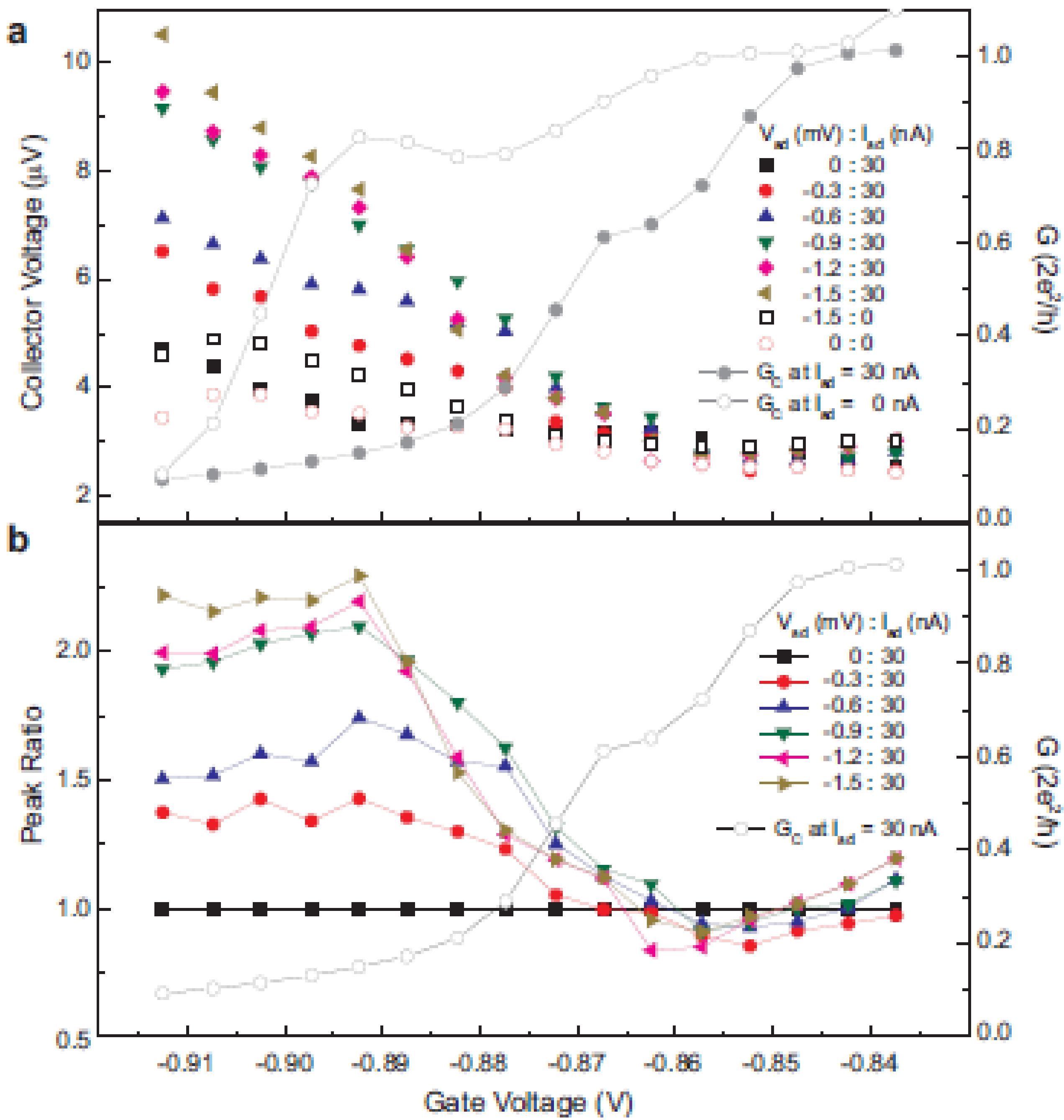
Increasing Offset Voltage Squeezes Electron Gas and Removes Beating



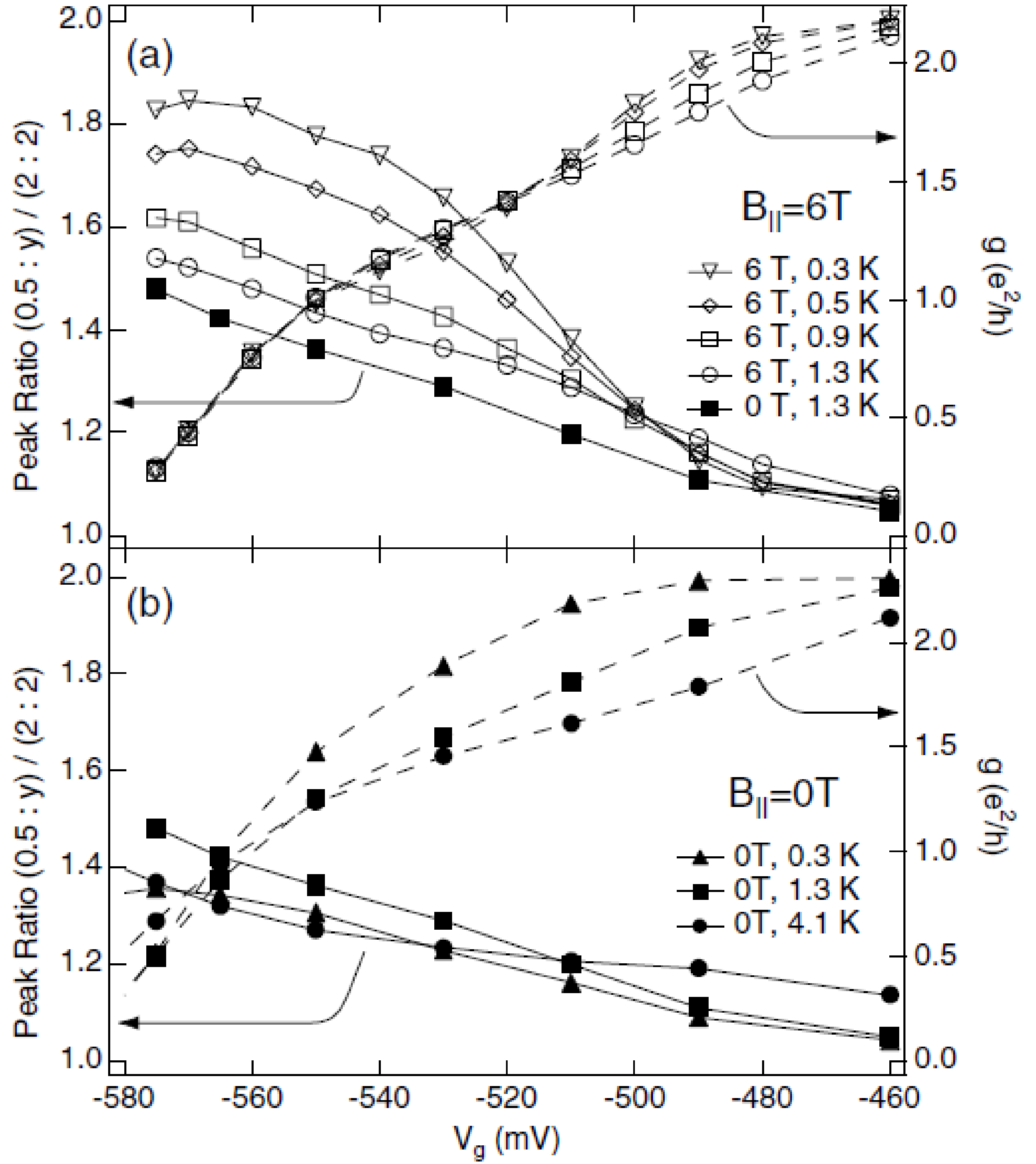
Classical Row Formation, Piacente et al



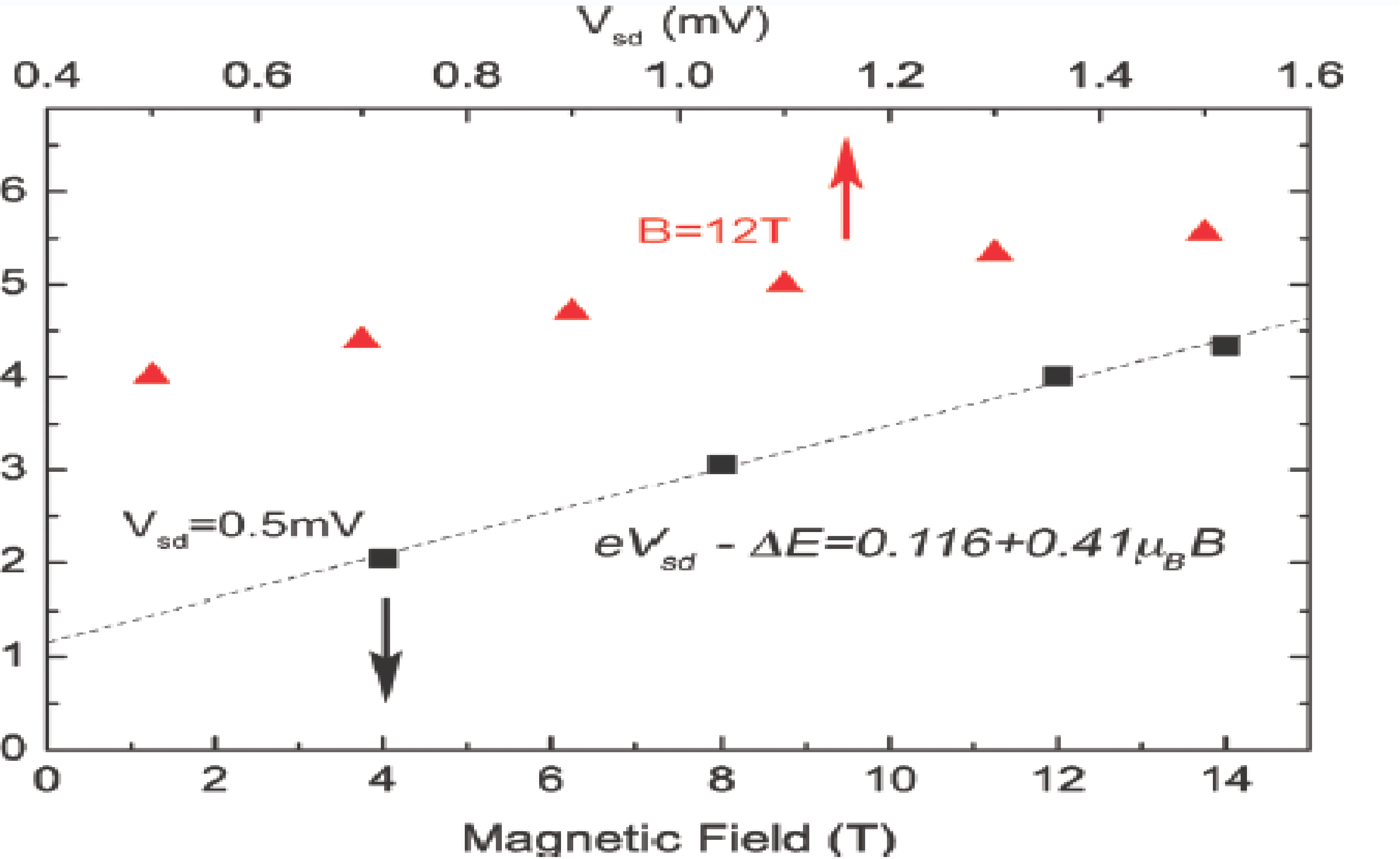
Chen et al, Voltage Induced Spin Polarisation, B=0

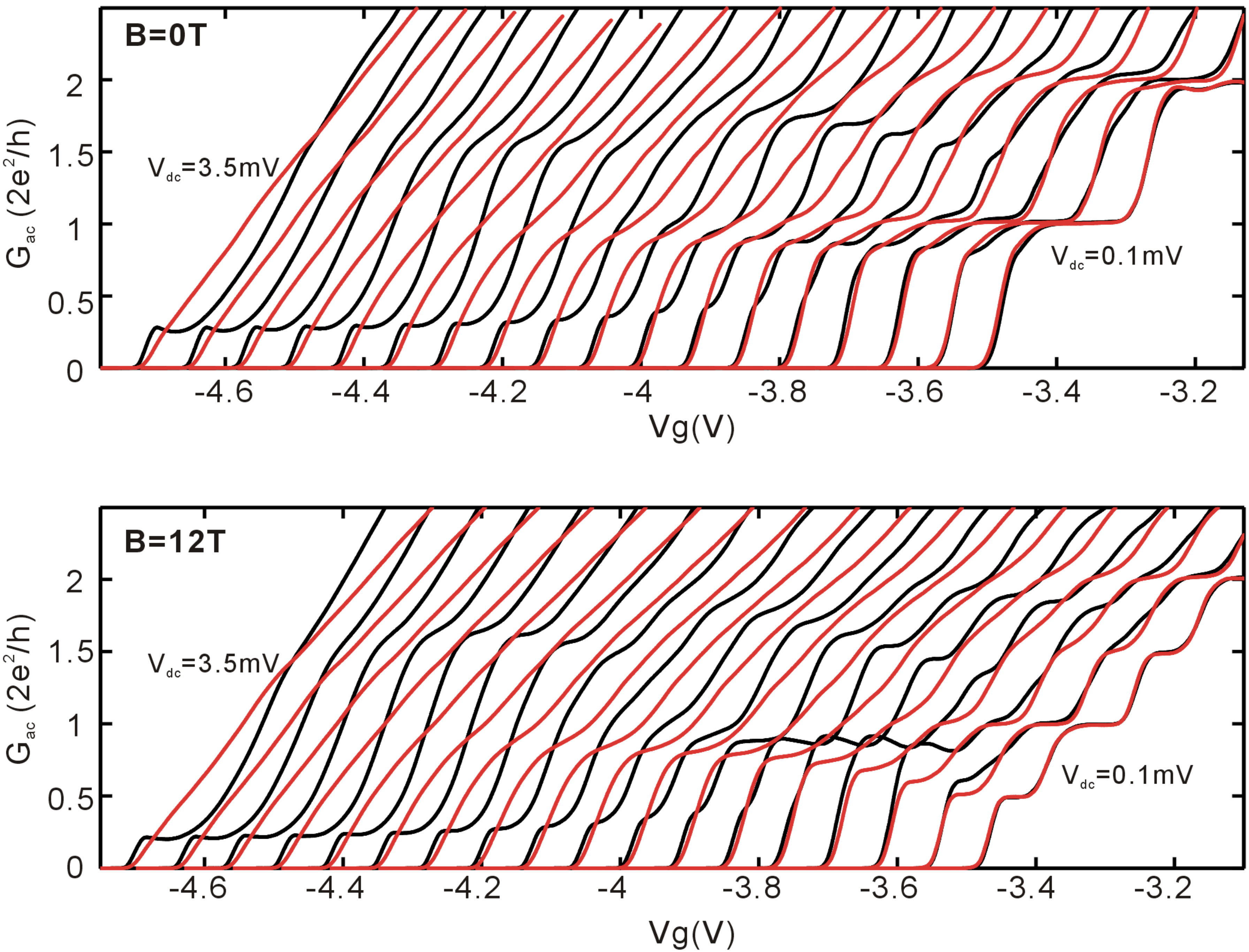


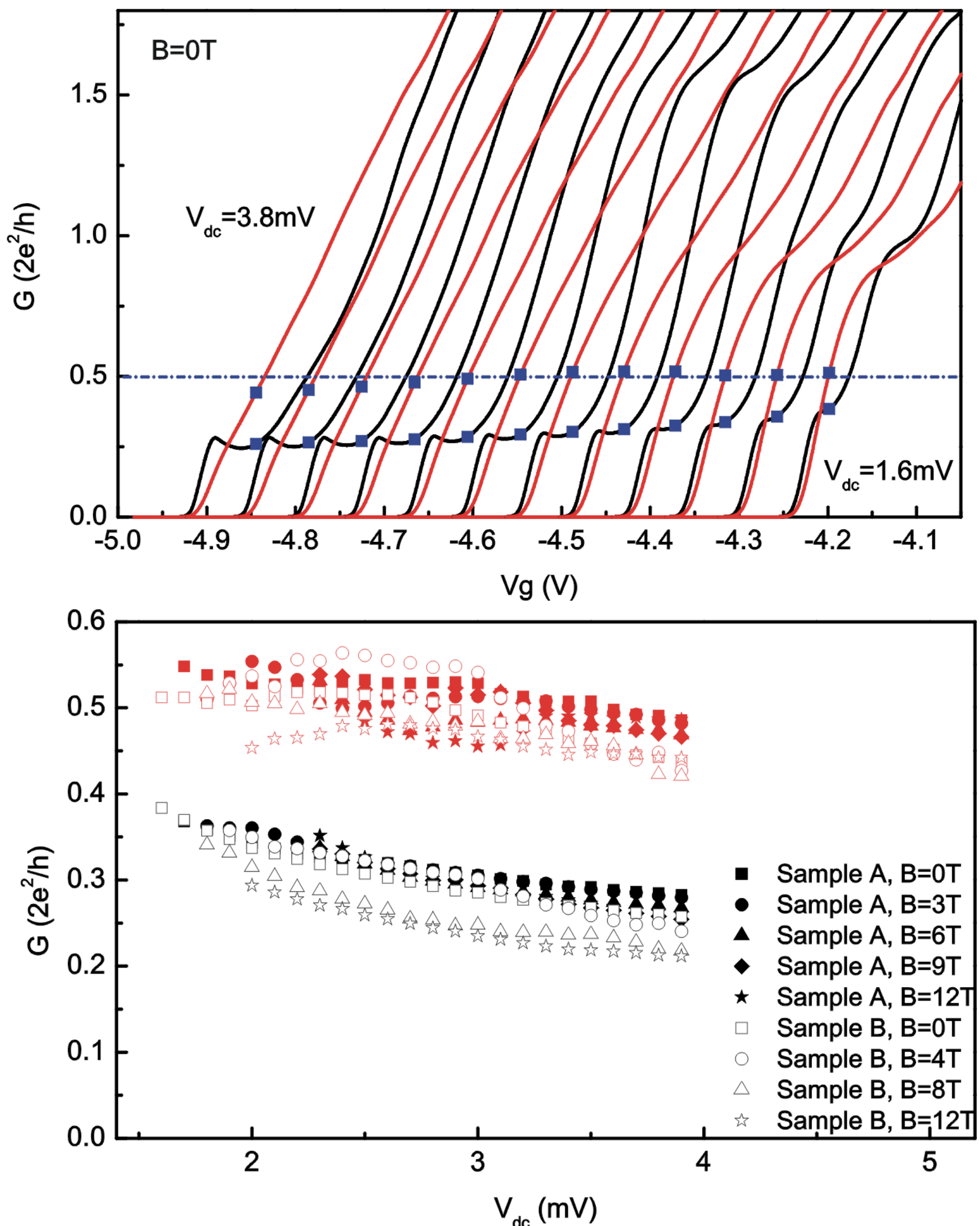
Growth of Spin Detection – Potok, Marcus et al



Enhancement of g Value




B=0T
V_{dc}=3.5mV
V_{dc}=0.1mV
G_{ac} ($2e^2/h$)
0
0.5
1
1.5
2
-4.6
-4.4
-4.2
-4
-3.8
-3.6
-3.4
-3.2
Vg(V)
B=12T
V_{dc}=3.5mV
V_{dc}=0.1mV
G_{ac} ($2e^2/h$)
0
0.5
1
1.5
2
-4.6
-4.4
-4.2
-4
-3.8
-3.6
-3.4
-3.2
Vg(V)



B=0T
V_{dc}=3.8mV
V_{dc}=1.6mV
G ($2e^2/h$)
0.0
0.5
1.0
1.5
-5.0
-4.9
-4.8
-4.7
-4.6
-4.5
-4.4
-4.3
-4.2
-4.1
Vg (V)
G ($2e^2/h$)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
2
3
4
5
V_{dc} (mV)
Sample A, B=0T
Sample A, B=3T
Sample A, B=6T
Sample A, B=9T
Sample A, B=12T
Sample B, B=0T
Sample B, B=4T
Sample B, B=8T
Sample B, B=12T