EUROSOI January 2014

Role of the Gate in Ballistic Nanowire SOI MOSFETs

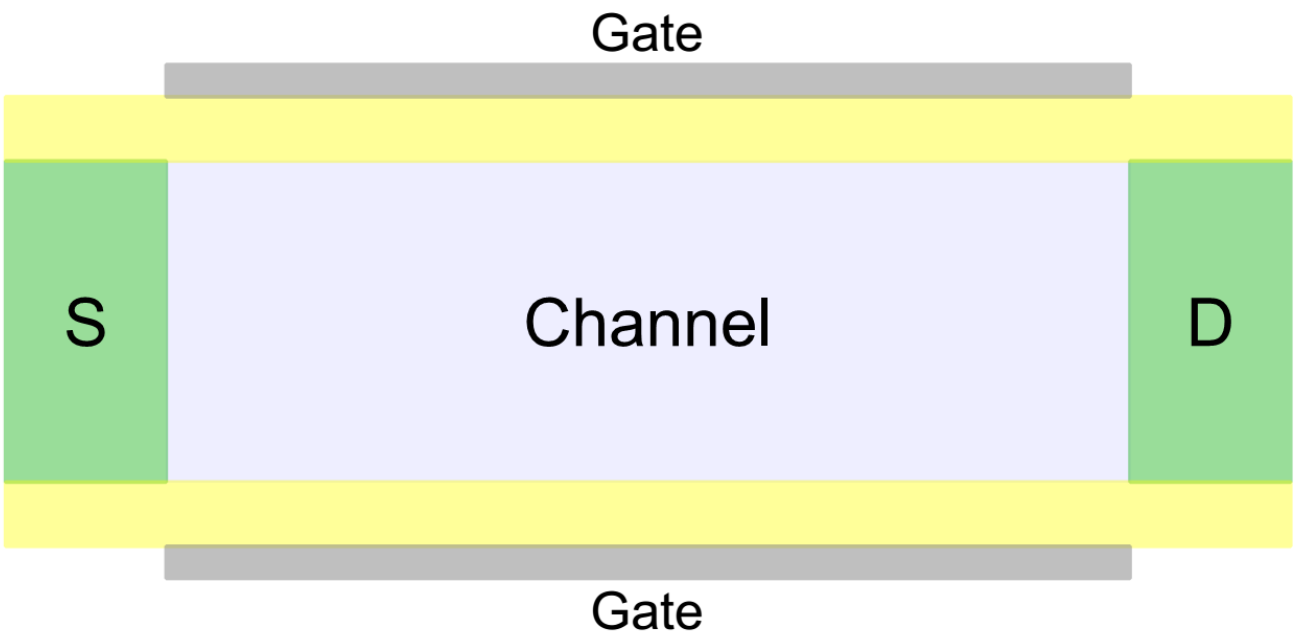
A. Mangla[1], J.-M. Sallese[1], C. Sampedro[2], F. Gamiz[2], C. Enz[1]

[1]École Polytechnique Fédérale de Lausanne (EPFL), Switzerland
[2]Universidad de Granada, Spain

anurag.mangla@epfl.ch

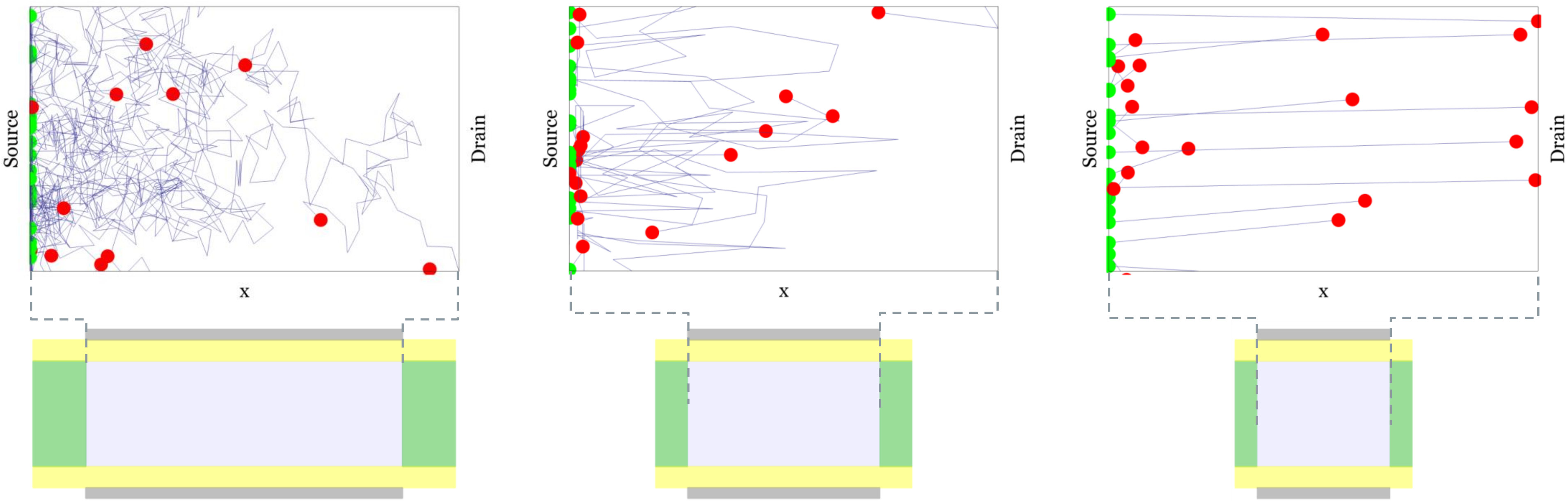
ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

Double-Gate Nanowire SOI MOSFET



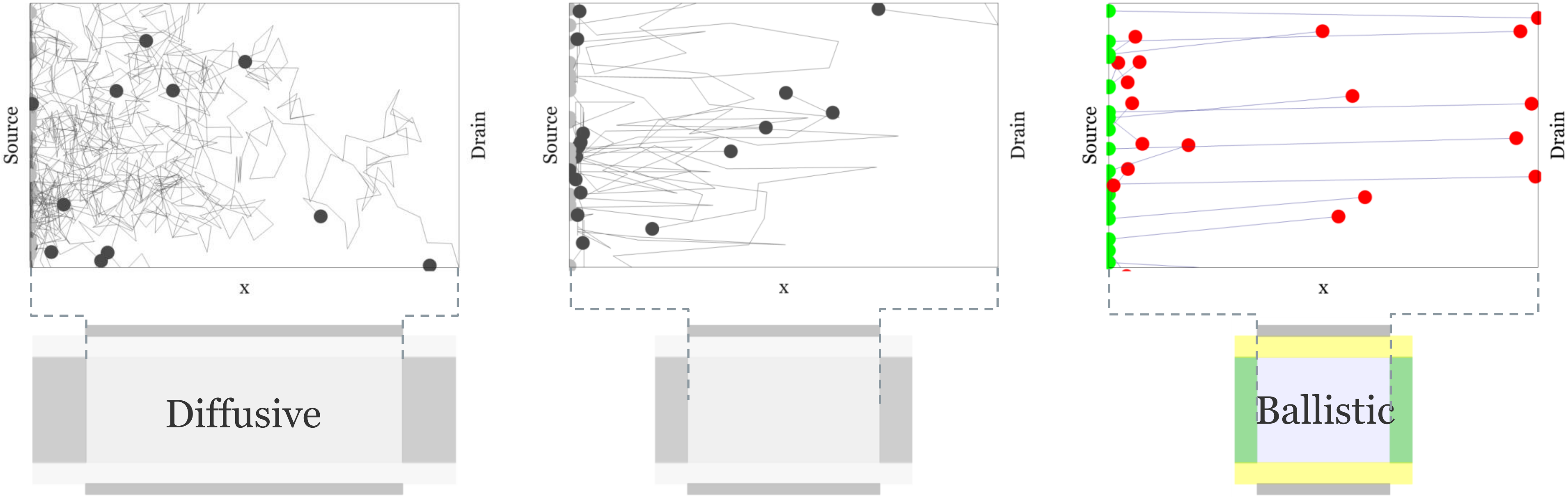
The picture inside the MOSFET

- A simplistic view of charge transport inside the MOSFET channel:



The picture inside the MOSFET

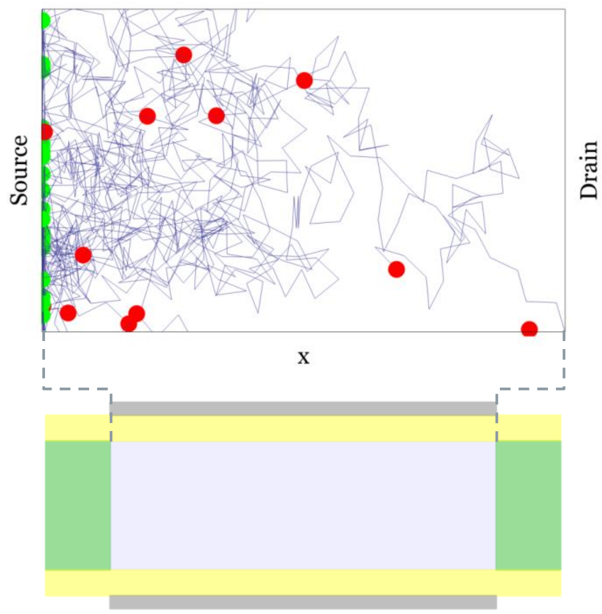
- A simplistic view of charge transport inside the MOSFET channel:



- Electrons travel across the channel **without scattering** in a ballistic MOSFET

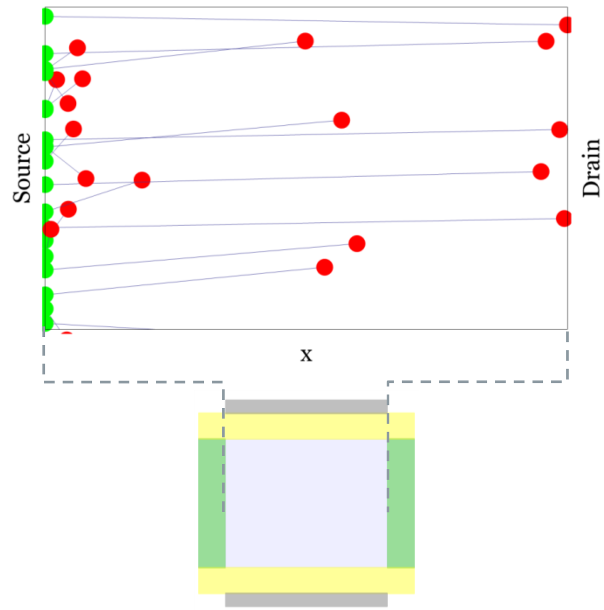
What role does the gate play?

- Diffusive:



  - Carrier population depends on **local channel potential** which is **function of gate voltage**

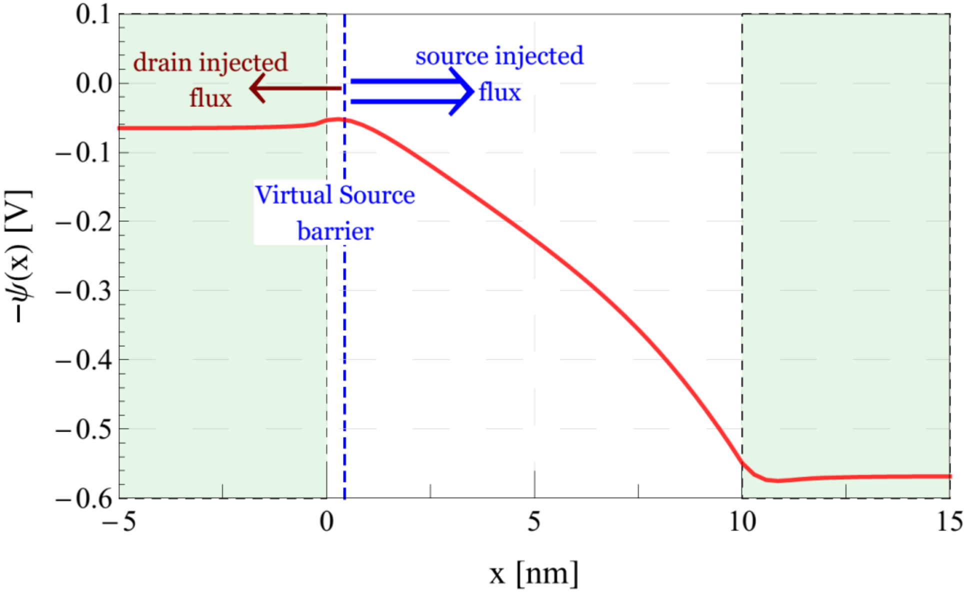
- Ballistic:



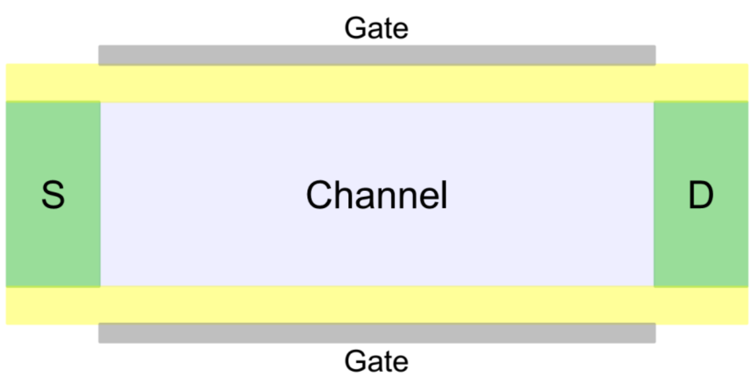
  - Carrier population is governed by **source** and **drain Fermi levels** and **NOT the local quasi-Fermi level**

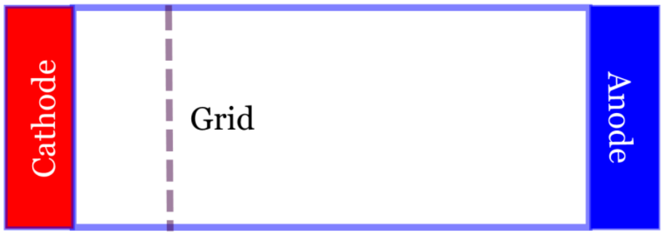
Ballistic MOSFET ≡ vacuum tube?

- The barrier model [Lundstrom]:



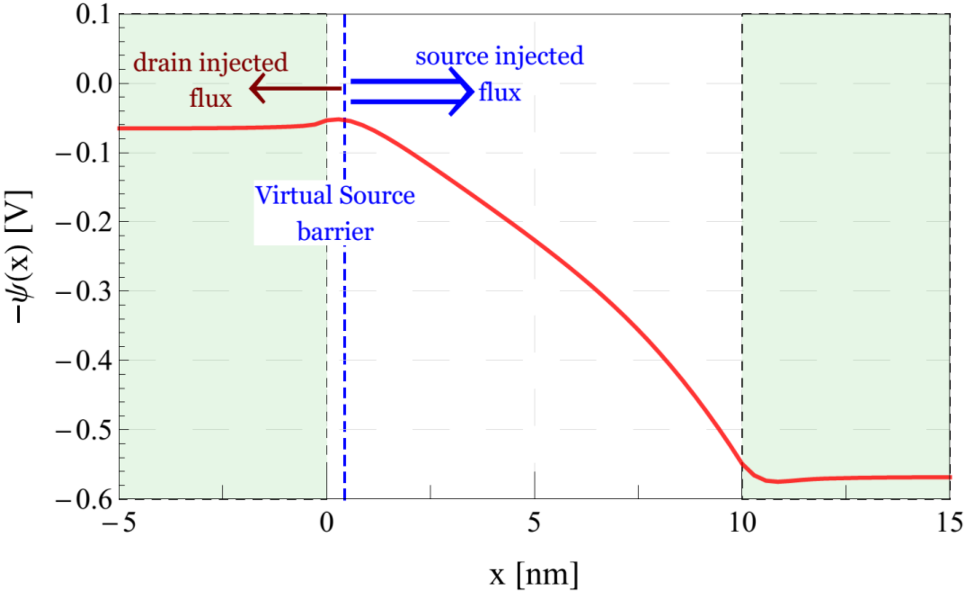
- Virtual Source barrier: potential bump which acts as the effective source of carriers
- The gate voltage V_G controls its height



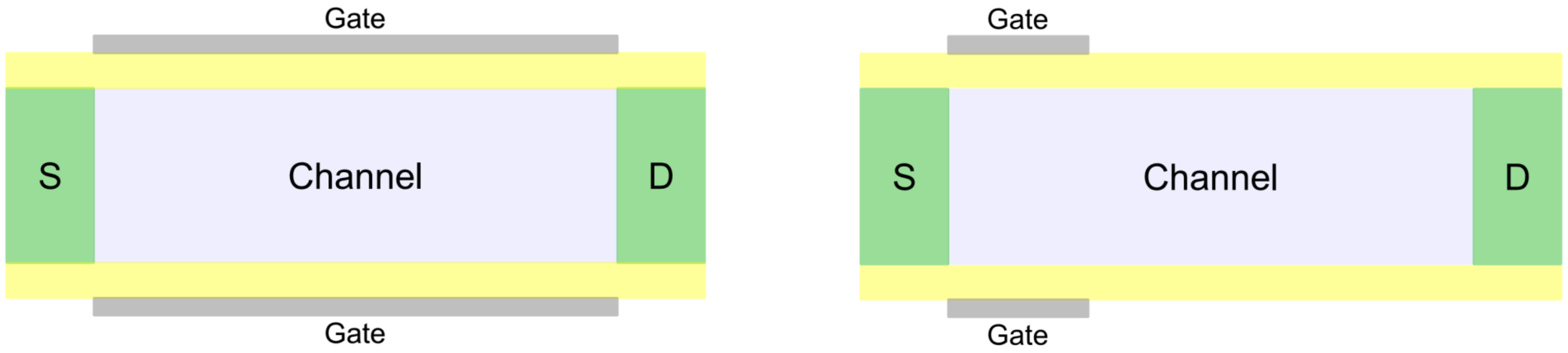


Ballistic MOSFET ≡ vacuum tube?

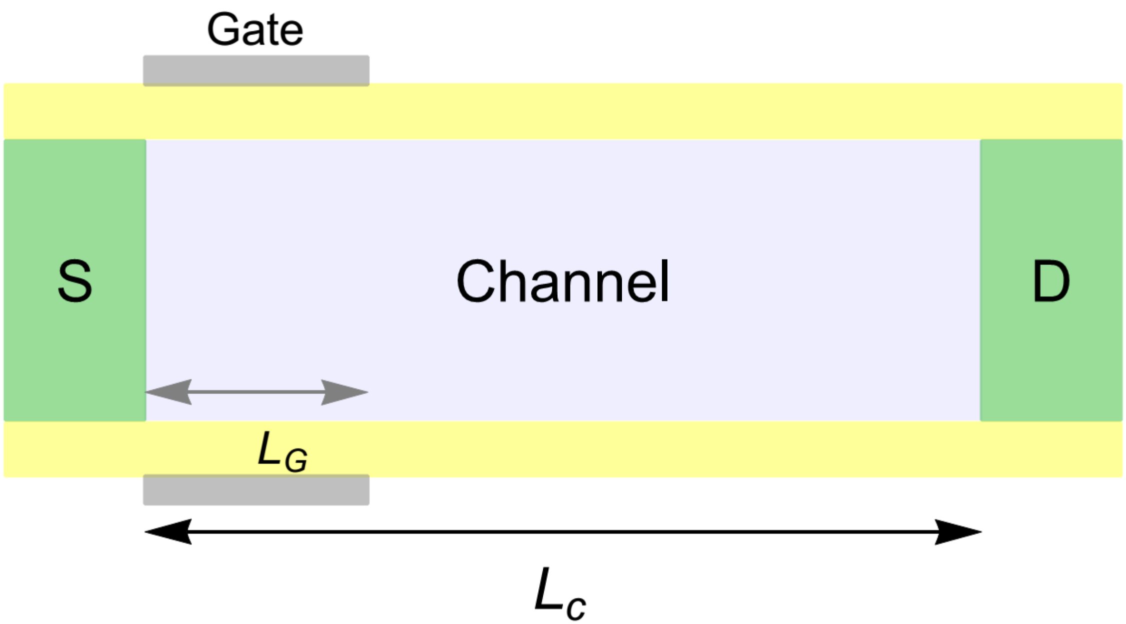
- The barrier model [Lundstrom]:



- Virtual Source barrier: potential bump which acts as the effective source of carriers
- The gate voltage V_G controls its height

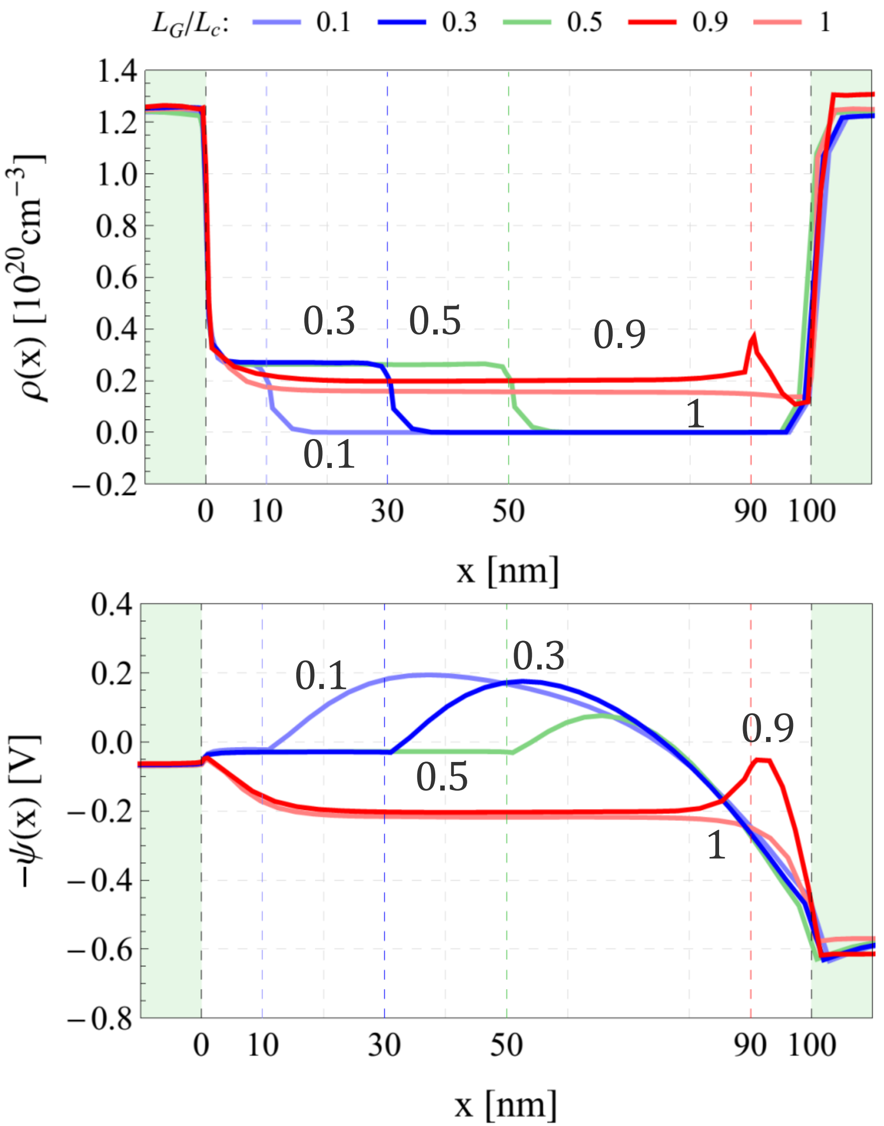


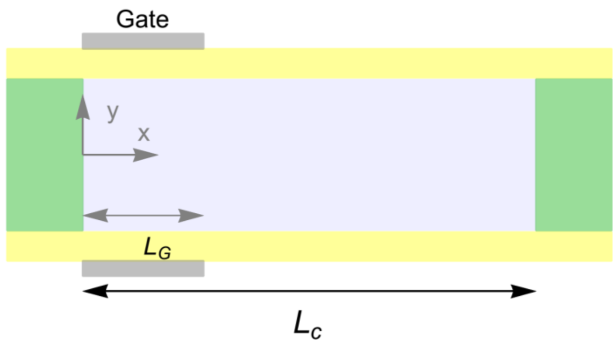
A ballistic MOSFET with *partial gates*



- L_c: Length of the channel between the source and drain junctions
- L_G: Length of the channel covered by the metal gate

Effect of gate length | Long channel ($L_c = 100$ nm)





- Poisson's equation:

$$\frac{\partial^2\psi(x,y)}{\partial x^2} + \underbrace{\frac{\partial^2\psi(x,y)}{\partial y^2}}_{\text{Gate}} = \frac{q\rho(x,y)}{\varepsilon_{Si}}$$

- In the **non-gated part**:

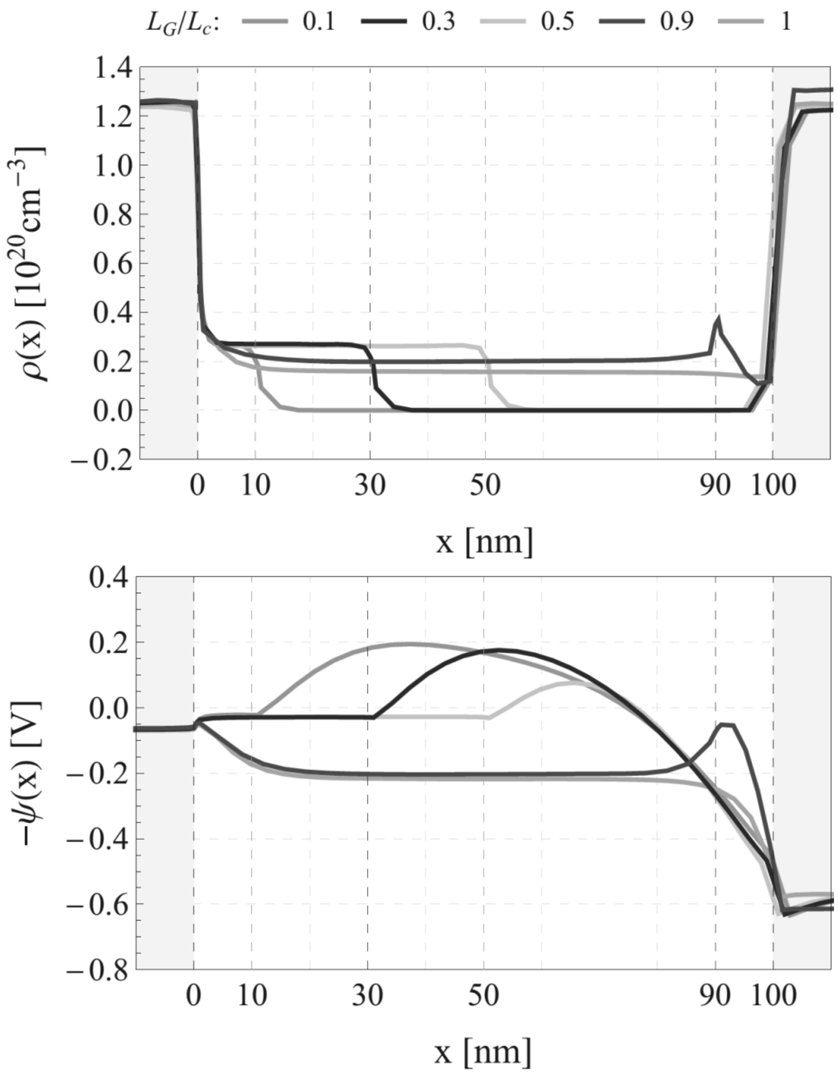
$$\frac{\partial^2\psi(x,y)}{\partial x^2} = \frac{q\rho(x,y)}{\varepsilon_{Si}}$$

$$\psi(x) = \frac{q\rho}{2\varepsilon_{Si}}x^2 + c_1 x + c_2$$

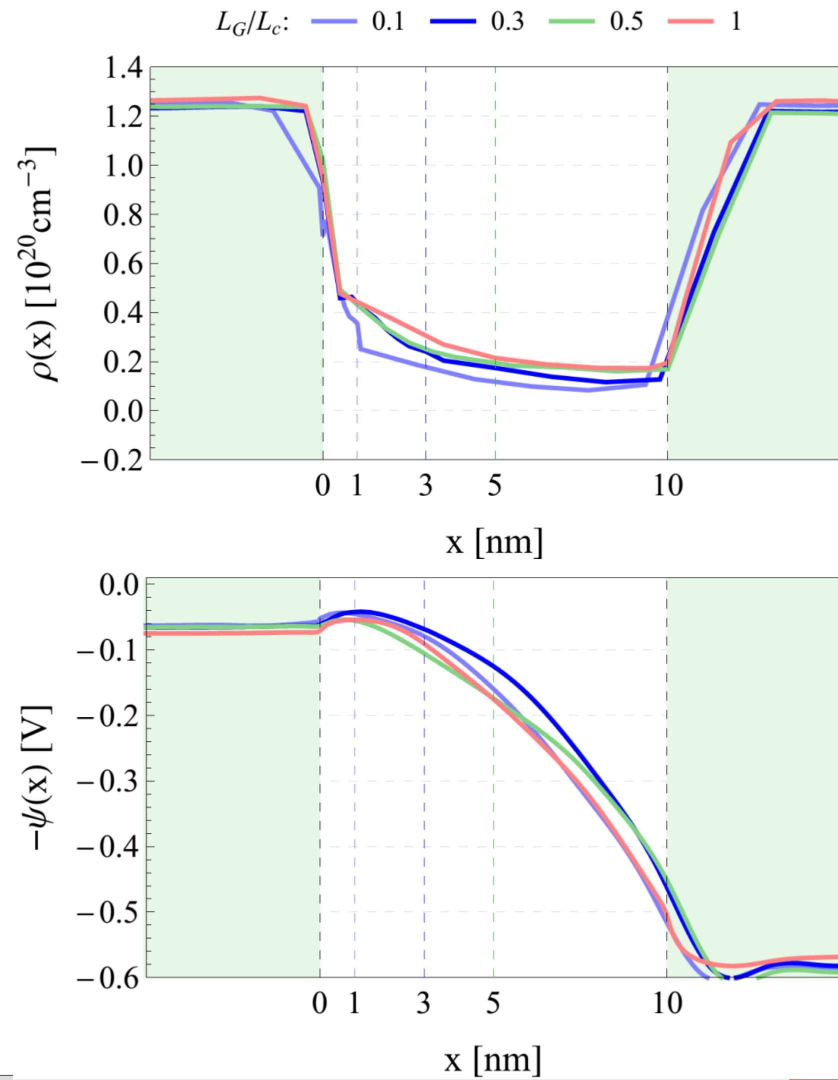
c_1, c_2: determined by V_D

Effect of gate length | Short channel ($L_c = 10$ nm)

- $L_c = 100$ nm

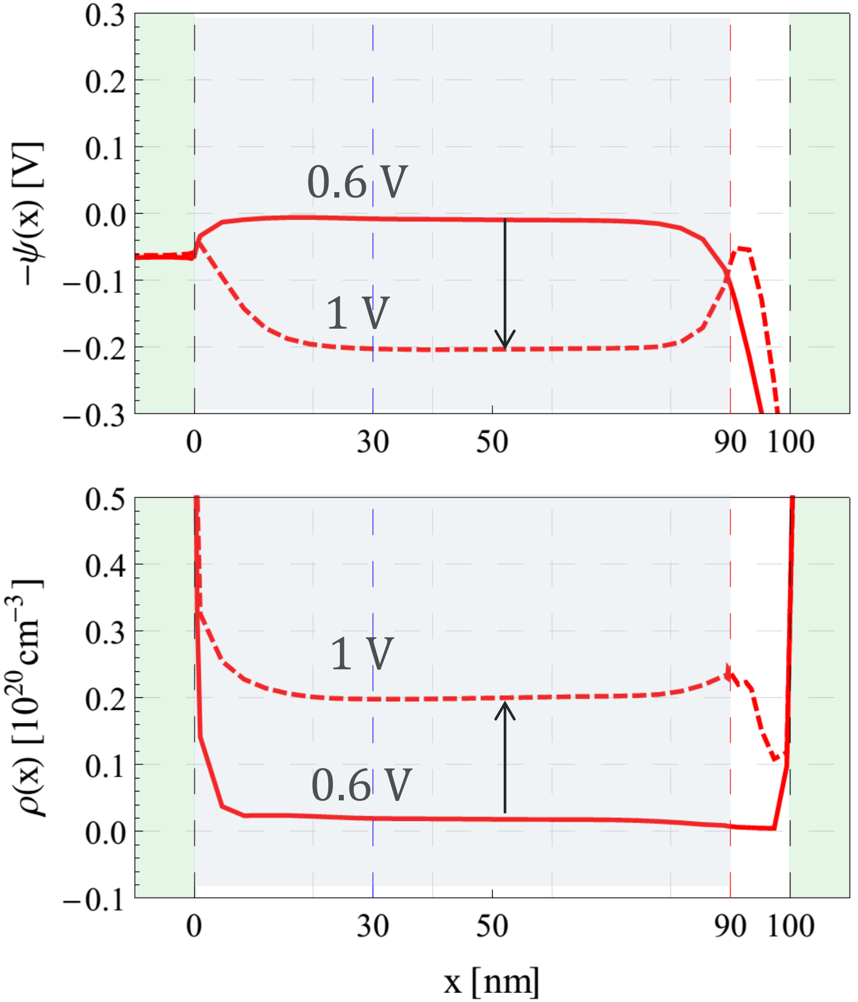


- $L_c = 10$ nm

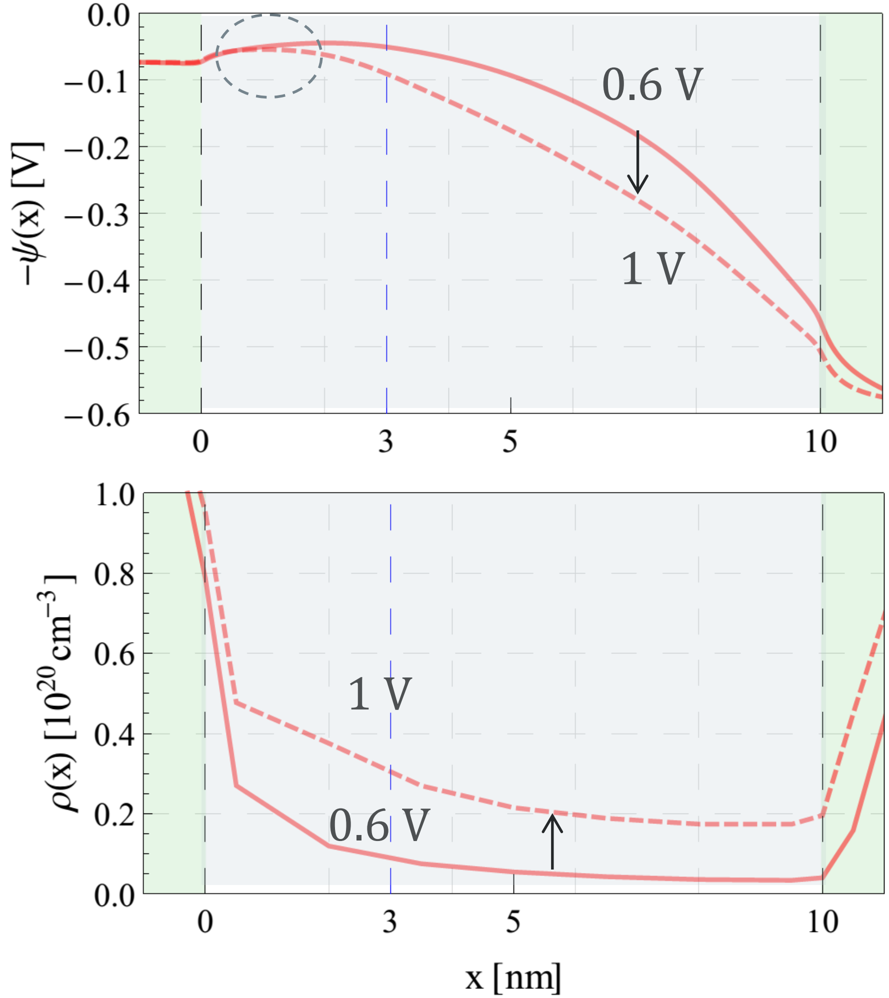


Effect of gate voltage | Long gate

- Channel length $L_c = 100$ nm

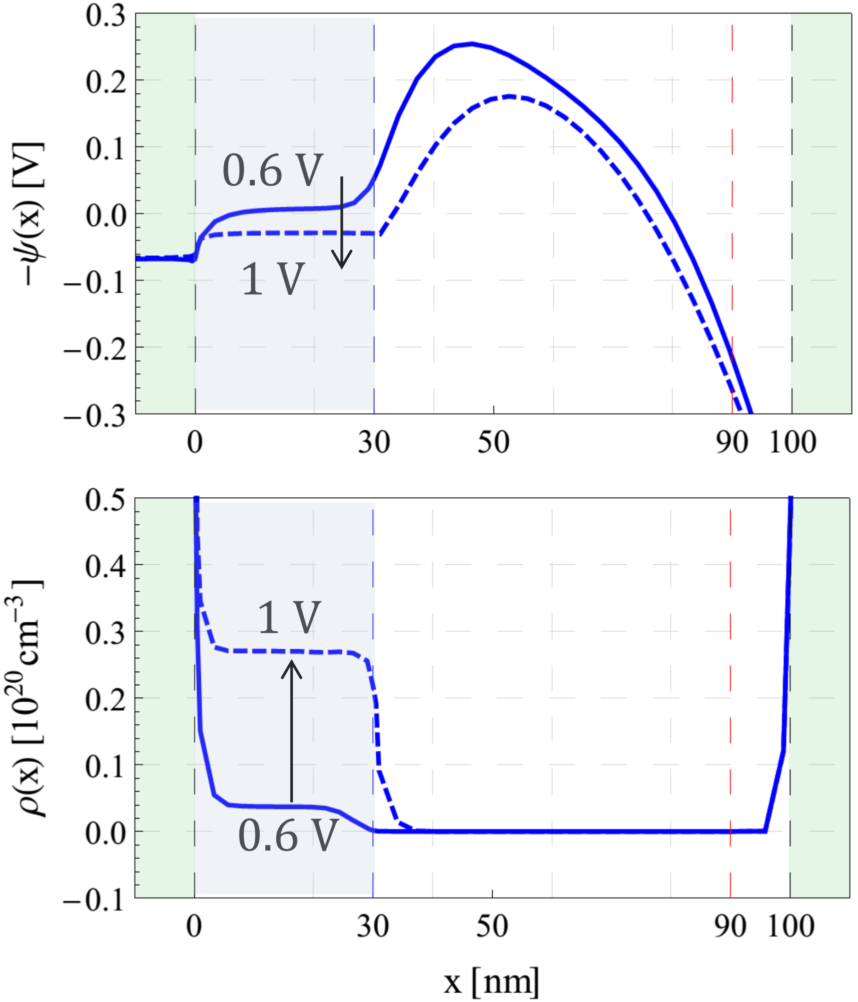


- Channel length $L_c = 10$ nm

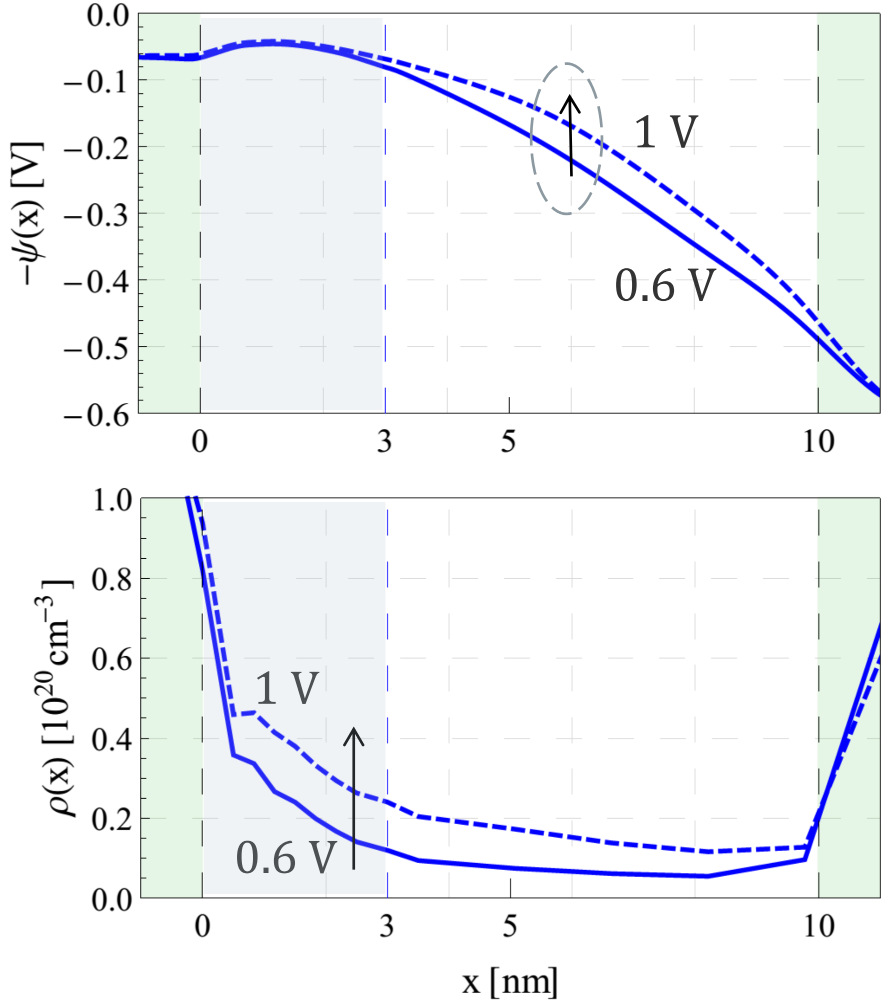


Effect of gate voltage | Short gate $(L_G/L_c = 0.3)$

- Channel length $L_c = 100$ nm

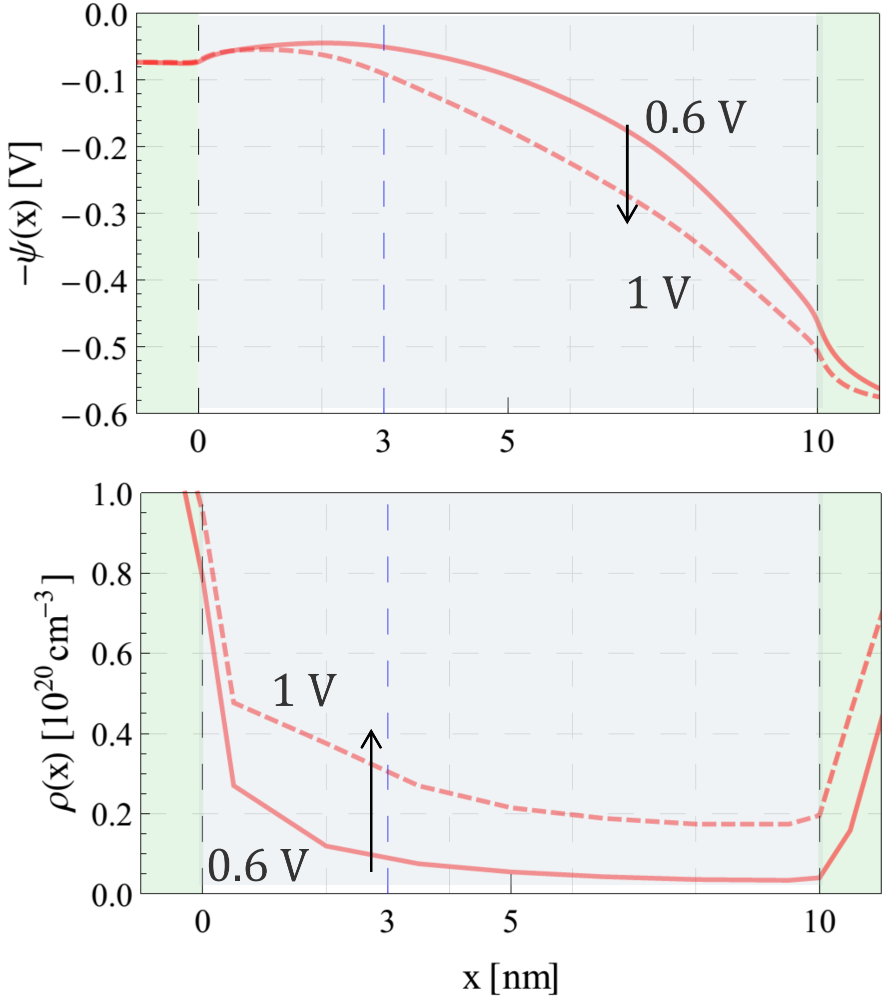


- Channel length $L_c = 10$ nm

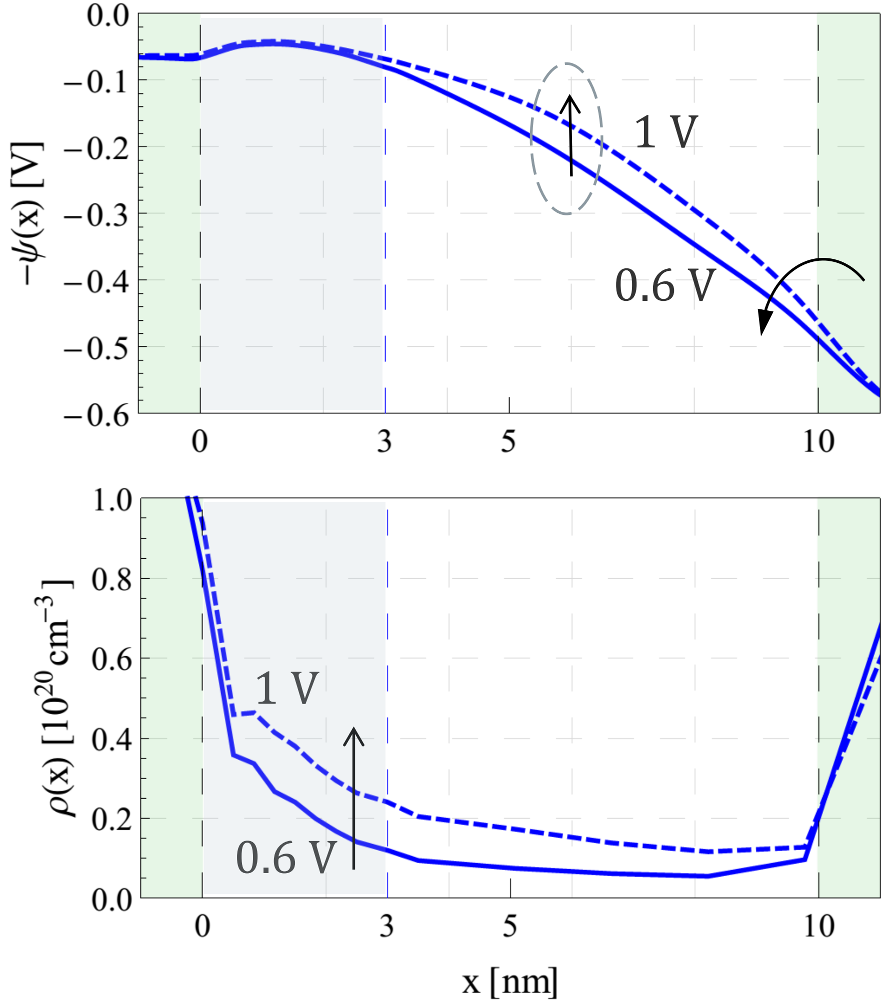


Effect of gate voltage | Channel length $L_c = 10$ nm

- Long gate



- Short gate



Effect of gate Voltage | Channel length $L_c = 10$ nm

- Poisson's equation:

$$\frac{\partial^2 \psi(x,y)}{\partial x^2} + \underbrace{\frac{\partial^2 \psi(x,y)}{\partial y^2}}_{\text{Gate}} = \frac{q\rho(x,y)}{\varepsilon_{Si}}$$

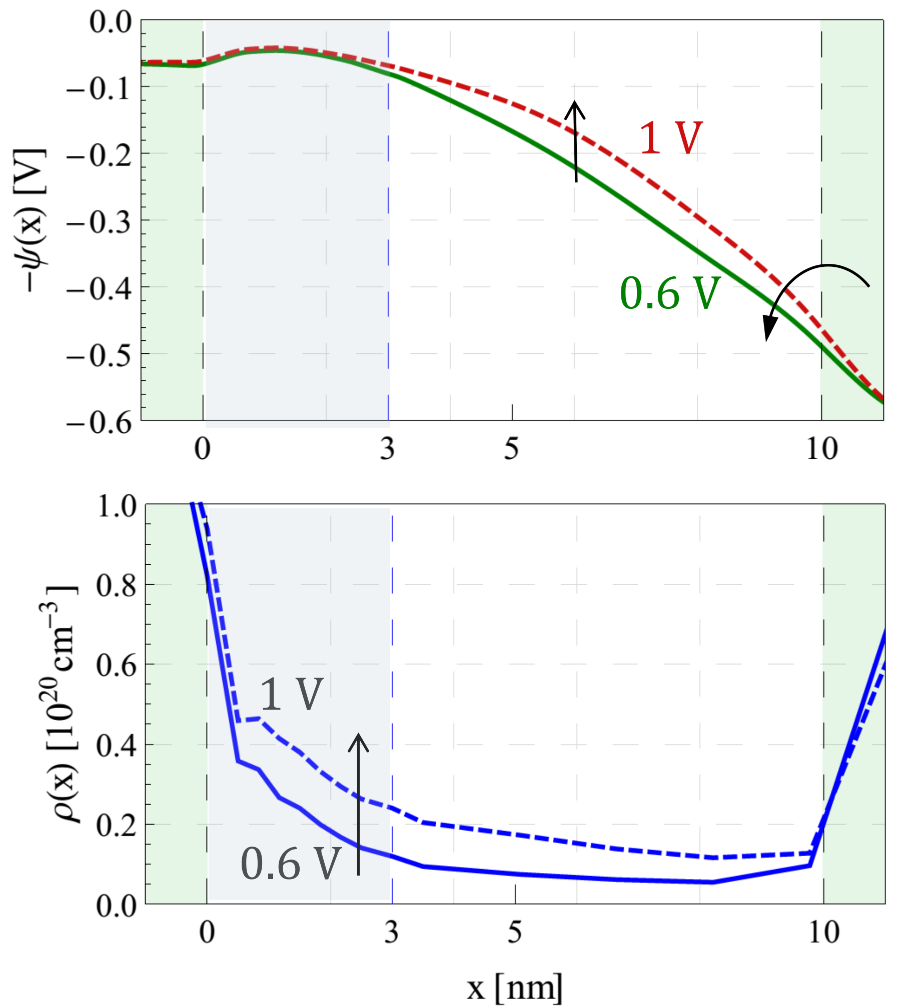
- In the **non-gated part**:

$$\frac{\partial^2 \psi(x,y)}{\partial x^2} = \frac{q\rho(x,y)}{\varepsilon_{Si}}$$

$$\psi(x) = \underbrace{\frac{q\rho}{2\varepsilon_{Si}}}_{\text{charge}} x^2 + \underset{V_D}{c_1 x} + c_2$$

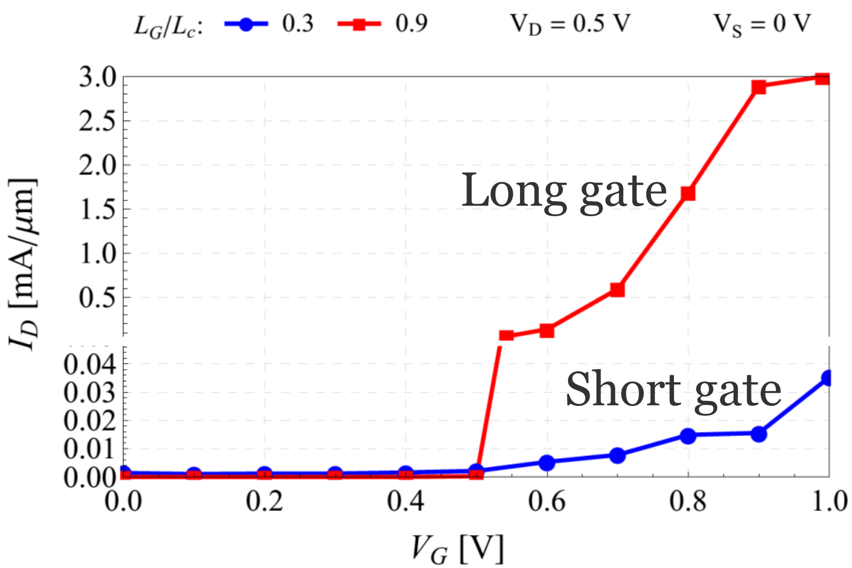
- Channel electrostatics **dominated by drain**, especially at low V_G

- Short gate



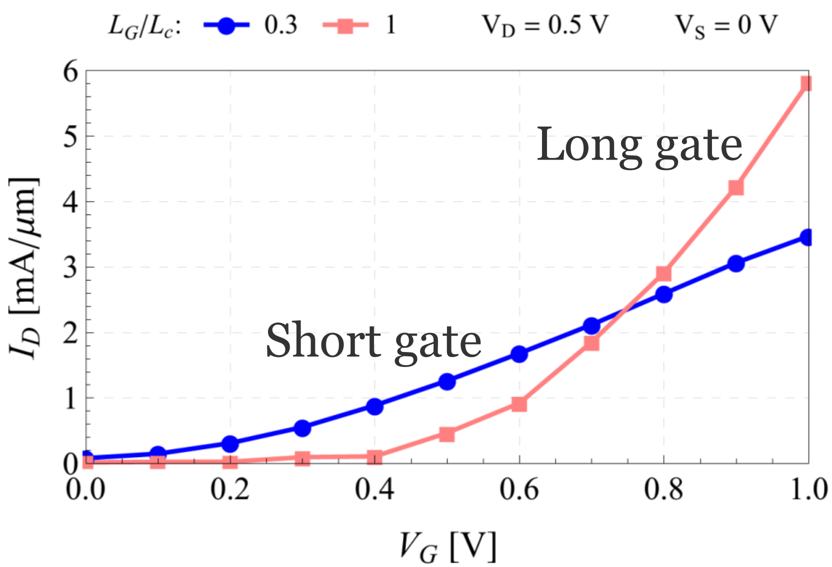
Ballistic drain current

- Channel length $L_c = 100$ nm



- Short gate current **two orders of magnitude less** than the long gate current

- Channel length $L_c = 10$ nm

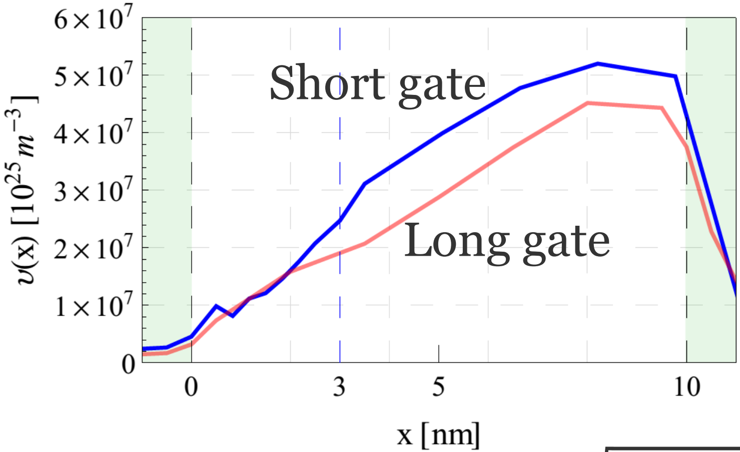


- Same order of magnitude in the short and long gate cases
- **Short gate current > long gate current at low voltages!**

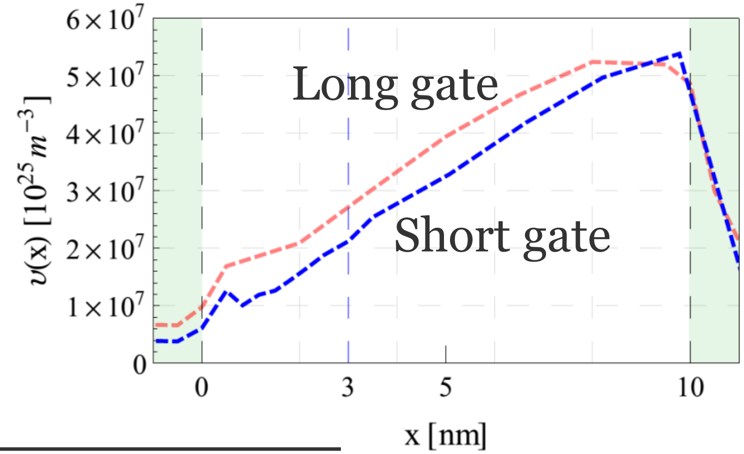
$$I_D = q\,\rho(x)\,\upsilon(x)$$

Ballistic carrier velocity | Channel length $L_c = 10$ nm

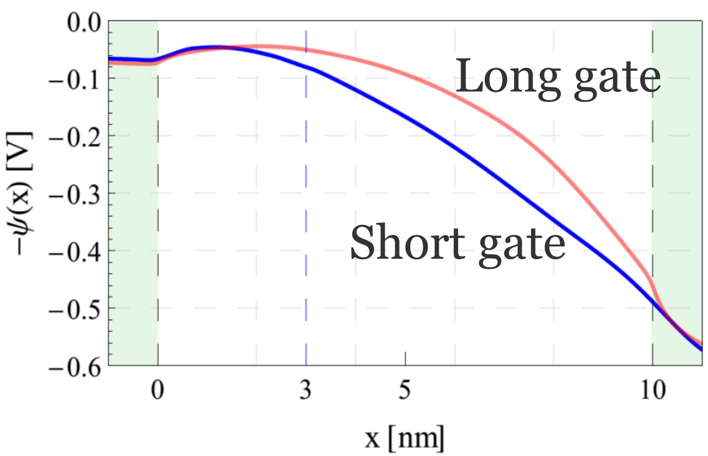
- $V_G = 0.6$ V $\qquad \upsilon(x)_{short} > \upsilon(x)_{long}$

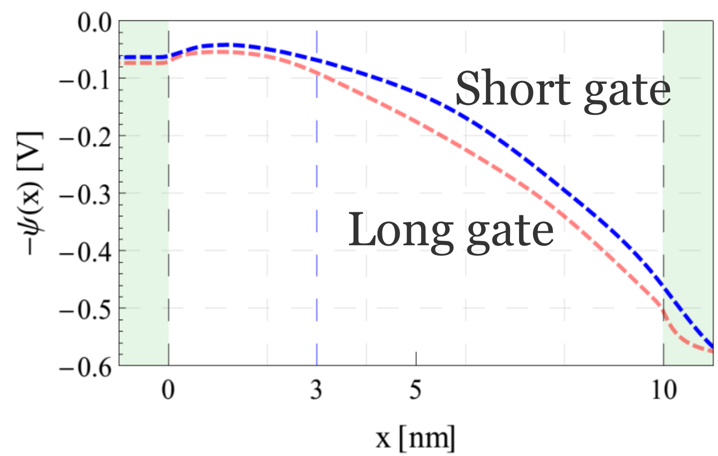


- $V_G = 1$ V $\qquad \upsilon(x)_{short} < \upsilon(x)_{long}$

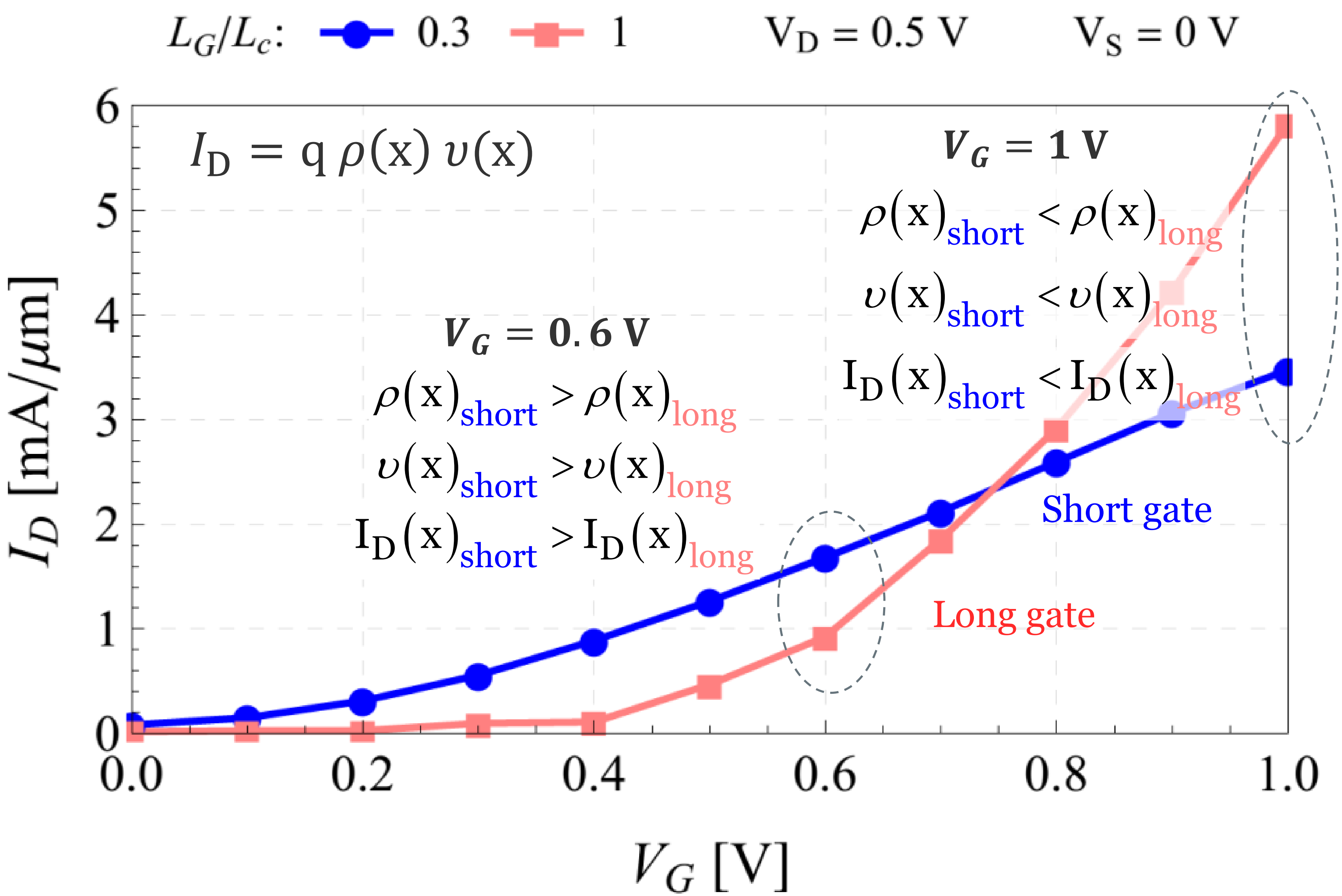


$$\boldsymbol{\upsilon}(\mathbf{x}) = \sqrt{-\frac{\mathbf{2q}}{\mathbf{m}}\left(\boldsymbol{\psi}(\mathbf{x}) - \boldsymbol{\psi}_{\mathbf{vs}}(\mathbf{x})\right) + \boldsymbol{\upsilon}_{\mathbf{vs}}(\mathbf{x})}$$



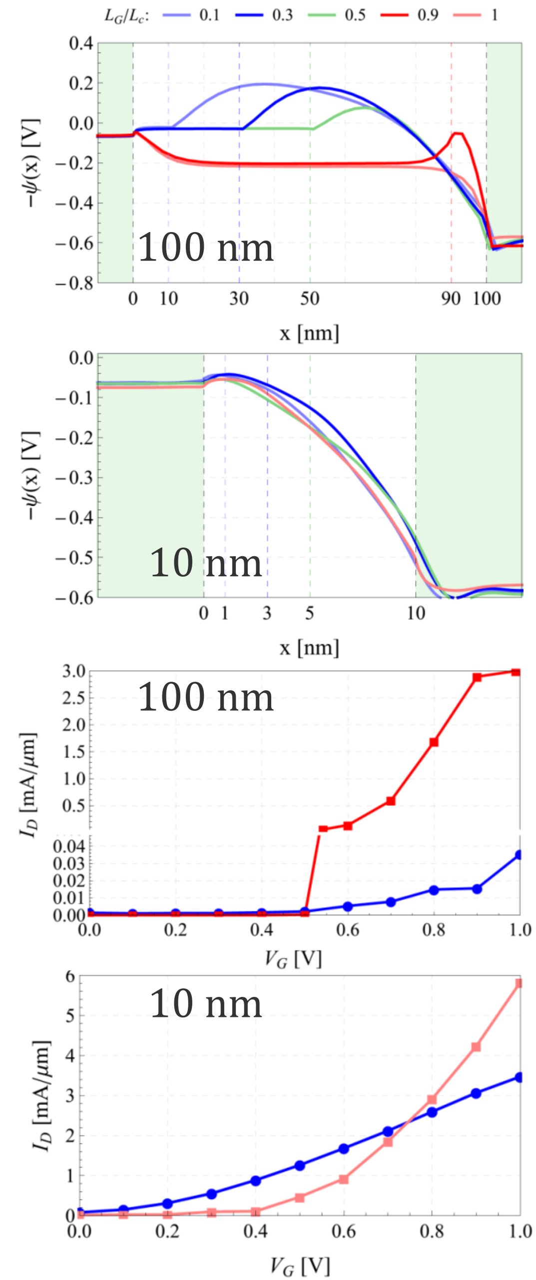


Ballistic drain current | Channel length $L_c = 10$ nm



Conclusions

- What role does the gate play?
  - 100 nm: The gate controls the electrostatics.
  - 10 nm: The drain dominates the electrostatics.
- Is a partial gate sufficient?
  - 100 nm: No, the drain current is diminished.
  - 10 nm: Same order of magnitude of drain current in the partial and full gate cases.
- Full gate is necessary to maintain current efficiency even in 10 nm ballistic devices.
- Drain current in ballistic devices is NOT independent of channel length.
- Perspectives: development of ballistic compact model including channel electrostatics.



EUROSOI January 2014

Role of the Gate in Ballistic Nanowire SOI MOSFETs

Questions?

A. Mangla[1], J.-M. Sallese[1], C. Sampedro[2], F. Gamiz[2], C. Enz[1]

[1]École Polytechnique Fédérale de Lausanne (EPFL), Switzerland
[2]Universidad de Granada, Spain

anurag.mangla@epfl.ch

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE