La simulation du courant et du bruit dans les composants quantiques: Méthode des trajectoires de Bohm pour l'étude des interactions entre les électrons

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I.- Introduction: *"La simulation du courant et du bruit dans les composants quantiques"*

II.- Our approach: *"Méthode des trajectoires de Bohm pour l'etude des interactions entre les électrons"*

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JOURNÉES "SIMULATION ET CARACTÉRISATION DES NANOCOMPOSANTS"

Universitat Autònoma de Barcelona

Outline of the talk:

I.- Introduction: ***"La simulation du courant et du bruit dans les composants quantiques"***

I.1.- From the "many-particle" to the "single-particle" Schrödinger equation.

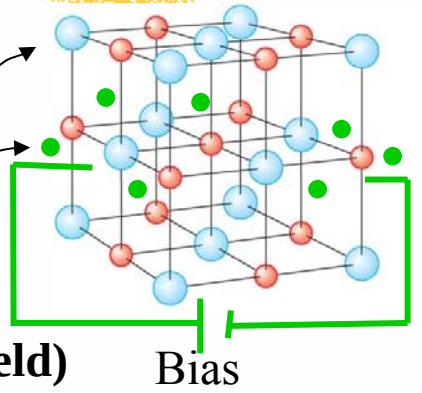
I.2.- The computation of DC/AC and noise current in quantum devices.

II.- Our approach: ***"Méthode des trajectoires de Bohm pour l'etude des interactions entre les électrons"***

I.1.- From the "many-particle" to the "single-particle" Schrödinger equation

Many-particle Schrödinger equation:

$$i\hbar \frac{\partial \Psi_T(\bar{r}_1, \bar{r}_2, ..., \bar{R}_1, \bar{R}_2, ..., t)}{\partial t} = \hat{H}_T \cdot \Psi_T(\bar{r}_1, \bar{r}_2, ..., \bar{R}_1, \bar{R}_2, ..., t)$$



Full Hamiltonian (spinless electrons, no magnetic field)

kinetic energy of the electrons

kinetic energy of the atoms

electron-electron coulomb interaction

$$\hat{H}_T = \left\{ \sum_k \left(-\frac{\hbar^2}{2m_0} \nabla_k^2 \right) + \sum_g \left(-\frac{\hbar^2}{2M_g} \nabla_g^2 \right) + \frac{1}{2} \sum_k \sum_{j \atop k \neq j} \frac{q^2}{4\pi\varepsilon\varepsilon_0 r_{kj}} \right.$$

$$\left. + U_0(\bar{R}_1, \bar{R}_2, \bar{R}_3, ...) + \sum_k U_C(\bar{r}_k, \bar{R}_1, \bar{R}_2, \bar{R}_3, ...) + \sum_k U_E(\bar{r}_k) + \sum_g U'_E(\bar{R}_g) \right\}$$

atom-atom coulomb interaction

electron-atom coulomb interaction

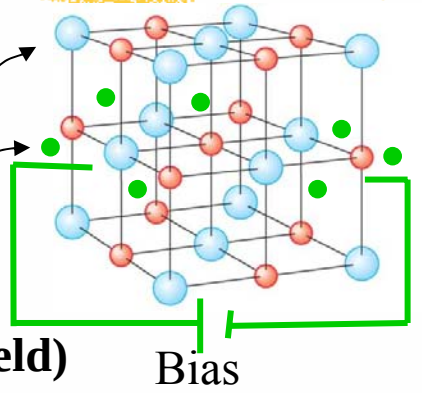
electron-potential due to external bias

atom potential due to external bias

I.1.- From the "many-particle" to the "single-particle" Schrödinger equation

Many-particle Schrödinger equation:

$$i\hbar \frac{\partial \Psi_T(\bar{r}_1, \bar{r}_2, ..., \bar{R}_1, \bar{R}_2, , ..., t)}{\partial t} = \hat{\mathrm{H}}_T \cdot \Psi_T(\bar{r}_1, \bar{r}_2, ..., \bar{R}_1, \bar{R}_2, ..., t)$$



Full Hamiltonian (spinless electrons, no magnetic field)

$$\hat{H}_T = \left\{ \sum_k \left(-\frac{\hbar^2}{2m_0} \nabla_k^2 \right) + \sum_g \left(-\frac{\hbar^2}{2M_g} \nabla_g^2 \right) + \frac{1}{2} \sum_k \sum_{j \atop k \neq j} \frac{q^2}{4\pi\varepsilon\varepsilon_0 r_{kj}} \right.$$

$$\left. + U_0(\bar{R}_1, \bar{R}_2, \bar{R}_3, ...) + \sum_k U_C(\bar{r}_k, \bar{R}_1, \bar{R}_2, \bar{R}_3, ...) + \sum_k U_E(\bar{r}_k) + \sum_g U'_E(\bar{R}_g) \right\}$$

Numerical viability of solving the many-particle Schrödinger equation ?

For a 3D system with N=100 electrons, L=100nm length (with Δx=0.1 nm)

nº of variables in 3D = $1000^{3N} \sim 10^{1000}$ variables **!!!!!!!**

I.1.- From the "many-particle" to the "single-particle" Schrödinger equation

1st approximation:

Born-Oppenheimer approximation (being the mass of the atoms much larger than the mass of electrons, we can assume they are always at rest at the electronic time scale).

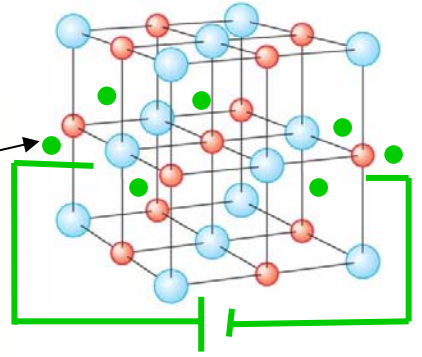
$$\hat{H}_T = \left\{ \sum_k \left(-\frac{\hbar^2}{2m_0} \nabla_k^2 \right) + \sum_g \left(-\frac{\hbar^2}{2M_g} \nabla_g^2 \right) + \frac{1}{2} \sum_k \sum_{j \atop k \neq j} \frac{q^2}{4\pi\varepsilon\varepsilon_0 r_{kj}} \right.$$

$$\left. + U_0(\bar{R}_1, \bar{R}_2, \bar{R}_3, \ldots) + \sum_k U_C(\bar{r}_k, \bar{R}_1, \bar{R}_2, \bar{R}_3, \ldots) + \sum_k U_E(\bar{r}_k) + \sum_g U_E(\bar{R}_g) \right\}$$

The suppressed terms can be included later, perturvativelly, as a phonon scattering.

Many-particle Schrodinger equation:

$$i\hbar \frac{\partial \Psi_T(\bar{r}_1, \bar{r}_2, \ldots, t)}{\partial t} = \hat{\mathrm{H}}_T \cdot \Psi_T(\bar{r}_1, \bar{r}_2, \ldots, t)$$



I.1.- From the "many-particle" to the "single-particle" Schrödinger equation

2nd approximation:

Effective-mass approximation (for infinite structures, only one band involved, and a parabolic dispersion, then, the atom-electron interaction is included into an "effective" value of the electron mass).

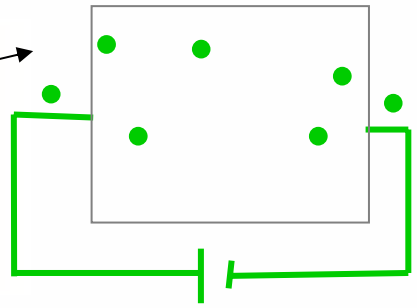
$$\hat{H} = \left\{ \sum_k \left(-\frac{\hbar^2}{2m_0^*}\nabla_k^2 \right) + \frac{1}{2}\sum_k \sum_{k\neq j} \sum_j \frac{q^2}{4\pi\varepsilon\varepsilon_0 r_{kj}} + \sum_k U_C(\bar{r}_k, \bar{R}_1, \bar{R}_2, \bar{R}_3, \ldots) + \sum_k U_E(\bar{r}_k) \right\}$$

This was an important simplification and it used to divide the study of a system of electrons between those involved in:

(i) Electron band-structure + (ii) Electron transport

Many-particle Schrödinger equation:

$$i\hbar \frac{\partial \Psi(\bar{r}_1, \bar{r}_2, \ldots, \bar{r}_N, t)}{\partial t} = \hat{\mathrm{H}} \cdot \Psi(\bar{r}_1, \bar{r}_2, \ldots, \bar{r}_N, t)$$



I.1.- From the "many-particle" to the "single-particle" Schrödinger equation

3rd approximation:

Mean-field approximation (the term of the Coulomb interaction among electrons is changed by an average potential)

$$\hat{H} = \left\{ \sum_k \left(-\frac{\hbar^2}{2m^*} \nabla_k^2 \right) + \cancel{\frac{1}{2} \sum_k \sum_{k \neq j} \frac{q^2}{4\pi\varepsilon\varepsilon_0 r_{kj}}} + \sum_k U_E(\bar{r}_k) \right\} = \sum_i H_i$$

$$\sum_k U_{coul}(\bar{r}_k)$$

The total Hamiltonian is just a sum of single-particle Hamiltonian. But there is still another source of correlation between electrons.

I.1.- From the "many-particle" to the "single-particle" Schrödinger equation

4th approximation:

For electrons, only antisymmetrical wave-functions are valid

$$i\hbar\frac{\partial\Psi(\bar{r}_1,\bar{r}_2,...,\bar{r}_N,t)}{\partial t}=\hat{\mathrm{H}}\cdot\Psi(\bar{r}_1,\bar{r}_2,...,\bar{r}_N,t) \Rightarrow \Psi(\vec{r}_1,\vec{r}_2,\vec{r}_3,..,t)=-\Psi(\vec{r}_2,\vec{r}_1,\vec{r}_3,..,t)$$

$$if \quad \vec{r}_1=\vec{r}_2=\vec{r}_o \Rightarrow \Psi(\vec{r}_o,\vec{r}_o,t)=-\Psi(\vec{r}_o,\vec{r}_o,t)$$

$$\Psi(\vec{r}_o,\vec{r}_o,t)=0$$

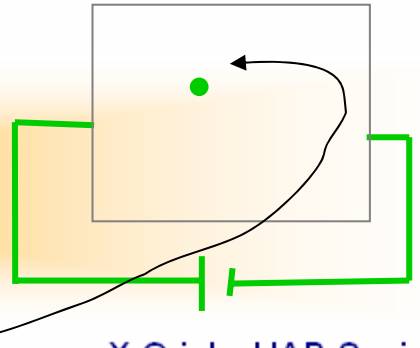
Pauli exclusion principle

No exchange-interaction (a multiplicative wave-function is assumed)

$$\Psi(\bar{r}_1,\bar{r}_2,\bar{r}_3,...\bar{r}_N,t)=\Psi_1(\bar{r}_1,t)\cdot\Psi_2(\bar{r}_2,t)\cdot\Psi_3(\bar{r}_3,t)..\cdot\Psi_N(\bar{r}_N,t)$$

Single-particle Schrödinger equation (no correlations):

$$i\hbar\frac{\partial\Psi_i(x,t)}{\partial t}=\hat{\mathrm{H}}_i\cdot\Psi_i(x,t)=\left\{-\frac{\hbar^2}{2\cdot m_x^*}\frac{\partial^2}{\partial x^2}+U_E(x)\right\}\Psi_i(x,t)$$



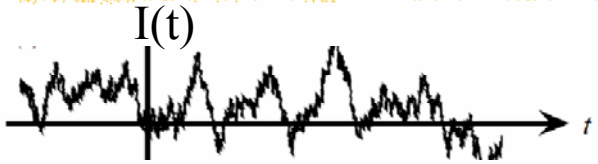
I.2.- The computation of DC/AC and noise in quantum devices

Computation of DC current in quantum systems

	Quantum function			Approximations				Name
	Schrö	Wigner	Green	Born-Oppen.	Effective-mass	Mean field	No exchange	
Transport	●			●	●	●	●	Landauer method
		●		Perturvative	●	●	●	Wigner distribution
			●	Perturvative	●	●	●	Non-Equil. Green Funct.
	●			Buttiker probes	●	●	Second quantization	Buttiker method
Band structure	●		●	Perturvative	Pseudo	●	●	k.p method
	●		●	Perturvative	Pseudo	●	●	Tight-binding method
	●		●	●	Ab initio	Ab initio	Ab intio	Dens Func Theory
			●	Perturvative	Ab intio	Ab initio	Ab initio	Time Dependent DFT

I.2.- The computation of DC/AC and noise in quantum devices

Quantum Noise:

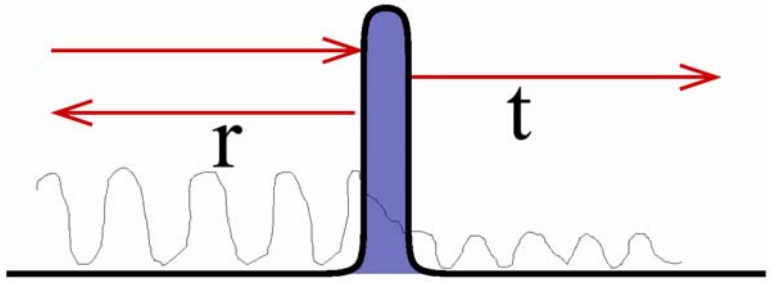


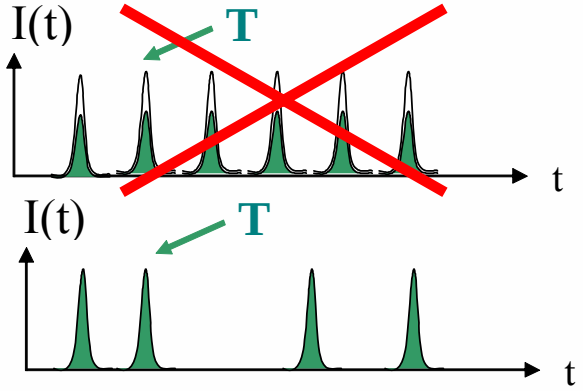
$$I(t) \qquad \Delta I(t) = I(t) - \bar{I} \qquad C_I(\tau) \qquad S_I(w)$$

fluctuations — Autocorrelation — Fourier transform

Example: Partition noise due to the tunneling probability

Binomial distribution **Noise=T(1-T)**





Electrons are transmitted or reflected, but not both !

The noise measured by the amperimeter takes into account the wave and the particle nature of electrons.

I.2.- The computation of DC/AC and noise in quantum devices

Computation of noise in quantum systems

Transport

Quantum function			Approximations				Name
Schrö	Wigner	Green	Born-Oppen.	Effective-mass	Mean field	No exchange	
●		●	Perturvative	●	●	Second quantization	Full counting statistics
		●	Perturvative	●	●	Second quantization	Non-equil. Green funct.
●			Buttiker probes	●	●	Second quantization	Buttiker method

Mixed techniques

Example, Once you know the Noise expression, for example, T(1-T), you compute T with approaches for DC current

I.2.- The computation of DC/AC and noise in quantum devices

Quantum high-frequency effects ("Driven Tunneling"):

Quasi-static approximation $U_E(x)$ $(\tau << 1/f)$ ⇩ Hamiltonian eigenstates: $\psi(x)$

High-frequency, $U_E(x,t)$ $(\tau \approx 1/f)$ ⇩ Wave packet: $\psi(x,t)$

electron transit time — **External oscillating frequency**

Displacement current (Maxwell equations):

The amperimeter measures the particle (conduction) current plus the displacement current !!

$$\vec{\nabla} \times \vec{H} = \vec{J}_c + \partial \vec{D} / \partial t \Rightarrow \vec{\nabla} \cdot \left(\vec{J}_c + \partial \vec{D} / \partial t \right) = 0$$

$$\vec{\nabla} \cdot \vec{D} = \rho \Rightarrow \text{Poisson equation}$$

Continuity equation ⇩

$$\partial \rho / \partial t + \vec{\nabla} \cdot \vec{J}_c = 0$$

A time-dependent self-consistent Schrödinger and Poisson solver !!

I.2.- The computation of DC/AC and noise in quantum devices

Computation of time-dependent current in quantum systems

Assume a quasi-static approximation
Computation of current with DC models and some capacitive coupling

Transport

Quantum function			Approximations				Name
Schrö	Wigner	Green	Born-Oppen.	Effective-mass	Mean field	No exchange	
●			●	●	●	●	Non-periodic potentials
	●	●	Perturvative	●	●	●	Wigner / Green funct.
●		●	Perturvative	●	●	Second quantization	Floquet theory

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II.- Our approach: ***"Méthode des trajectoires de Bohm pour l'étude des interactions entre les électrons"***

II.1.- Single-particle Bohm trajectories.

II.2.- Many-particle Bohm trajectories

II.3.- Our quantum Monte Carlo approach

II.4.- Numerical results

II.- Our approach: *"Méthode des trajectoires de Bohm pour l'étude des interactions entre les électrons"*

Most of the quantum electron transport in nanoelectronic devices is understood under a non-interacting (Fermi liquid) picture.

Our goal: Go beyond the non-interacting (Fermi liquid) pattern, to develop a formalism that introduces Coulomb and exchange interactions (correlations) among electrons.

Quantum function			Approximations				Name
Schor	Wigner	Green	Born-Oppen.	Effective-mass	Mean field	No exchange	
●			●	●	Exact.	Exact.	Many-particle Bohm traj.

We extract quantum trajectories from the Schrödinger equation

II.1.- Single-particle Bohm trajectories

A simple mathematical development

[D. Bohm, Phys. Rev, 1952]

$$i\hbar\frac{\partial\Psi(x,t)}{\partial t}=\left\{-\frac{\hbar^2}{2m^*}\frac{\partial^2}{\partial x^2}+U(x,t)\right\}\Psi(x,t)$$

Polar form

$$\Psi(x,t)=R(x,t)\cdot\exp(iS(x,t)/\hbar)$$

$$\frac{\partial S}{\partial t}+\frac{(\partial S/\partial x)^2}{2m^*}+U(x,t)+Q(x,t)=0$$

$$\frac{\partial R^2(x,t)}{\partial t}+\frac{\partial}{\partial x}\left(R^2(x,t)\cdot\frac{\partial S(x,t)/\partial x}{m^*}\right)=0$$

Quantum potential

$$Q(x,t)=-\frac{1}{R(x,t)}\left(\frac{\hbar^2\partial^2R(x,t)/\partial x^2}{2m^*}\right)$$

Current density

$$J(x,t)=R^2(x,t)\cdot\frac{\partial S(x,t)/\partial x}{m^*}$$

Hamilton-Jacobi equation

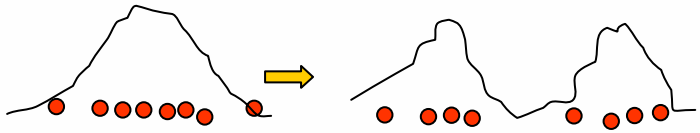
$$\frac{\partial S}{\partial t}+H(\partial S/\partial x,x,t)=0$$

Continuity equation

$$\frac{\partial R^2(x,t)}{\partial t}+\frac{\partial}{\partial x}\big(J(x,t)\big)=0$$

Newton-like equation

$$\frac{d^2x(t)}{dt^2}=-\frac{\partial}{\partial x}\big(U(x,t)+Q(x,t)\big)\Big|_{x=x(t)}$$



II.1.- Single-particle Bohm trajectories

Example: Plane wave $\Psi(x,t) \propto \exp(ik\cdot x)$ $\Rightarrow$ $v(x,t) = \frac{\hbar}{m}\cdot\frac{\partial(k\cdot x)}{\partial x} = \frac{\hbar k}{m}$

Example: double barrier

Equation of Motion:

$$\psi(x,t)$$

$$\Downarrow$$

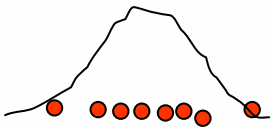
$$v(x,t) = \frac{1}{m}\frac{\partial S(x,t)}{\partial x}$$

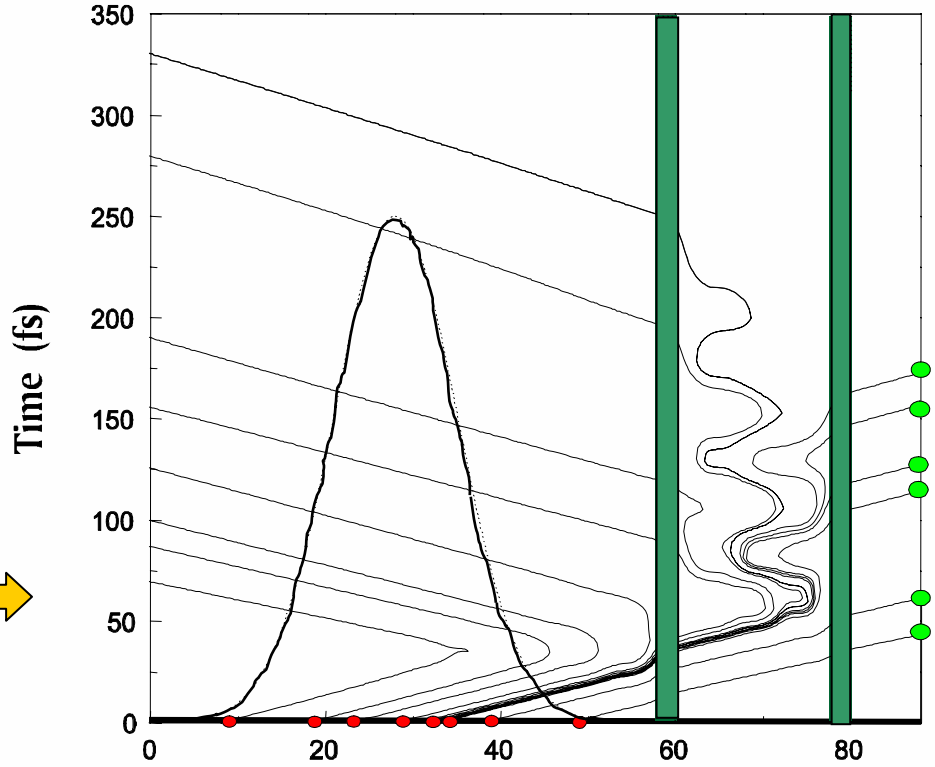
$$\Downarrow$$

$$x(t) = x(t_o) + \int_{t_o}^{t} v(x(t),t)\cdot dt$$

$\Uparrow$

Quantum uncertainty





Continuity equation:

$$\frac{\partial R^2(x,t)}{\partial t} + \frac{\partial}{\partial x}\left(J(x,t)\right) = 0$$

[X.Oriols *et al.* S.S.C. 1996]

II.2.- Many-particle Bohm trajectories

N particles in 3D space

$$i\hbar \frac{\partial \Psi(\vec{r}_1,...,\vec{r}_N,t)}{\partial t} = \left\{ \sum_{k=1}^{N} \left(-\frac{\hbar^2}{2m^*} \nabla_k^2 \right) + U(\vec{r}_1,...,\vec{r}_N,t) \right\} \Psi(\vec{r}_1,...,\vec{r}_N,t)$$

Polar form

$$\Psi(\vec{r}_1,...,\vec{r}_N,t) = R(\vec{r}_1,...,\vec{r}_N,t) \cdot \exp(iS(\vec{r}_1,...,\vec{r}_N,t)/\hbar)$$

Hamilton-Jacobi equation

$$\frac{\partial S(\vec{r}_1,...,\vec{r}_N,t)}{\partial t} + \sum_{k=1}^{N} \frac{(\nabla_k S)^2}{2m^*} + U(\vec{r}_1,...,\vec{r}_N,t) + Q(\vec{r}_1,...,\vec{r}_N,t) = 0$$

Continuity equation

$$\frac{\partial R^2(\vec{r}_1,...,\vec{r}_N,t)}{\partial t} + \sum_{k=1}^{N} \nabla_k \left(R^2(\vec{r}_1,...,\vec{r}_N,t) \cdot \nabla_k \frac{S(\vec{r}_1,...,\vec{r}_N,t)}{m^*} \right) = 0$$

$$\frac{d^2\vec{r}_i}{dt^2} = -\nabla_i \left(U(\vec{r}_1,....,\vec{r}_N,t) + Q(\vec{r}_1,....,\vec{r}_N,t) \right)\Big|_{\vec{r}_1=\vec{r}_1(t),....,\vec{r}_N=\vec{r}_N(t)}$$

$$\vdots$$

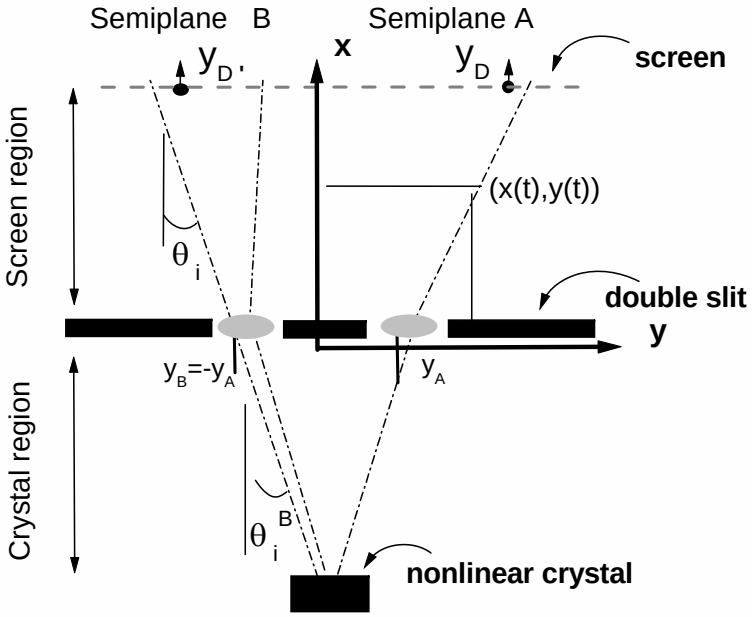
$$\vdots$$

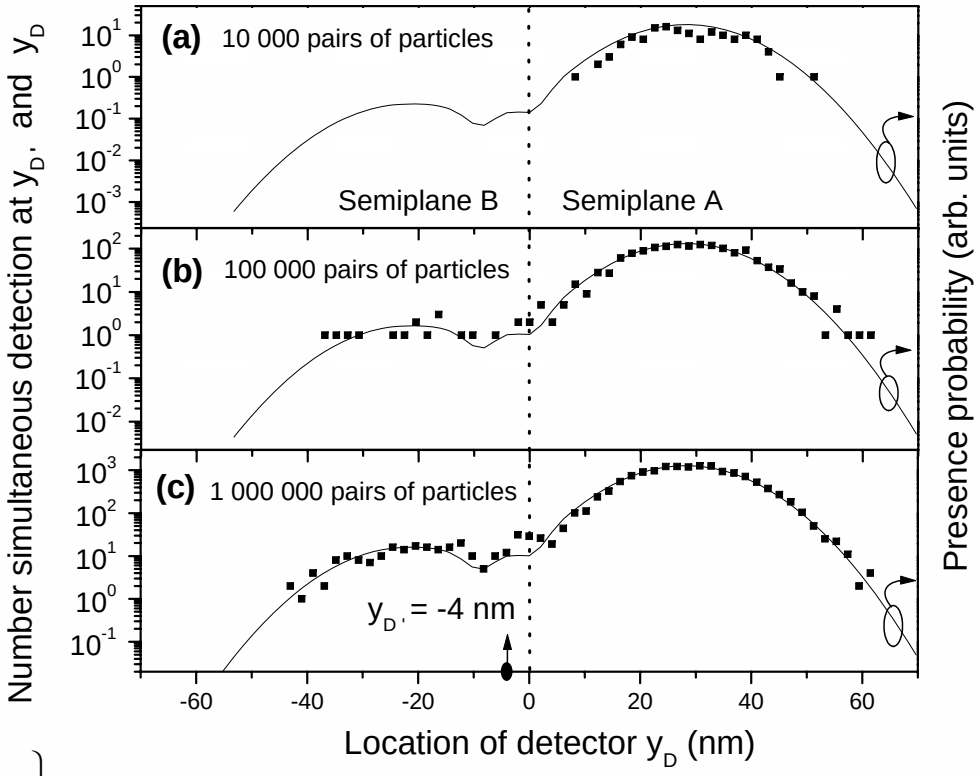
A system of N coupled equations

The wave function evolution (i.e the correlations among electrons) can be calculated using many-particle Bohm trajectories.

II.2.- Many-particle Bohm trajectories

Example: Two symmetric boson system



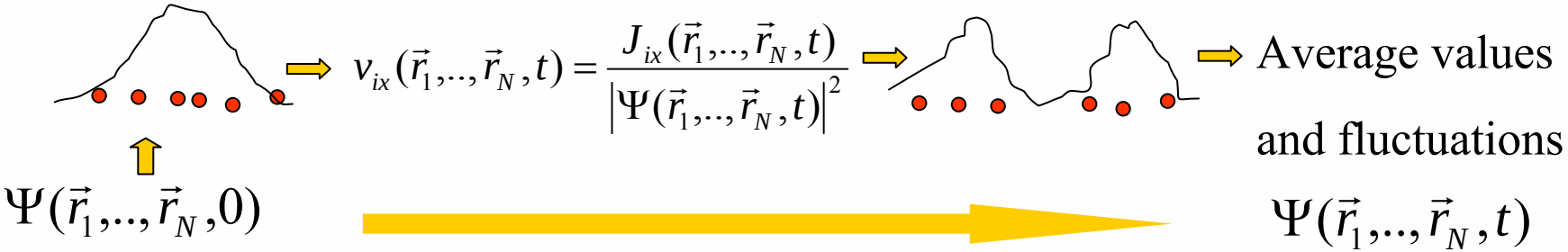


$$\Psi(x_1,x_2,y_1,y_2,t)=\frac{1}{\sqrt{2}}\left\{\begin{array}{l}\Psi_A(x_1,y_1,t)\cdot\Psi_B(x_2,y_2,t)\\+\Psi_A(x_2,y_2,t)\cdot\Psi_B(x_1,y_1,t)\end{array}\right\}$$

[X.Oriols, Phys. Rev A, 2005]

II.2.- Many-particle Bohm trajectories

Summary of Bohm trajectories



Main criticism against Bohm trajectories approach:

"…**In any case, the basic reason for not paying attention to the Bohm approach is not some sort of ideological rigidity, but much simpler…It is just that we are all too busy with our own work to spend time on something that doesn't seem likely to help us make progress with our real problems**".

Steven Weinberg (private comunication with Shelly Goldstein)

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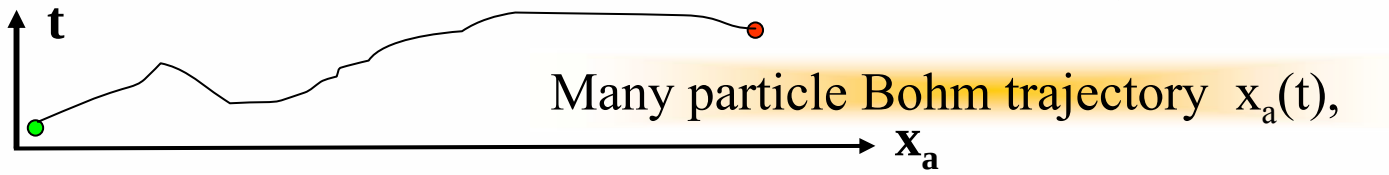
II.3.- Our Quantum Monte Carlo approach

$$i\hbar\frac{\partial\Psi(\vec{r}_1,\ldots,\vec{r}_N,t)}{\partial t}=\left\{\sum_{k=1}^{N}\left(-\frac{\hbar^2}{2m^*}\nabla_k^2\right)+\sum_{k=1}^{N}U_E(\vec{r}_k,t)+\frac{1}{2}\sum_{\substack{k=1\\k\neq j}}^{N}\sum_{j=1}^{N}\frac{q^2}{4\pi\varepsilon\varepsilon_0|\vec{r}_k-\vec{r}_j|}\right\}\Psi(\vec{r}_1,\ldots,\vec{r}_N,t)$$



Theorem: Many-particle Bohm trajectory from single-particle pseudo-Schrodinger equation

$$i\hbar\frac{\partial\Psi(\vec{r}_a,t)}{\partial t}=\left\{-\frac{\hbar^2}{2m^*}\nabla_a^2+U_E(\vec{r}_a,t)+\frac{1}{2}\sum_{\substack{k=1\\k\neq a}}^{N}\frac{q^2}{4\pi\varepsilon\varepsilon_0|\vec{r}_k(t)-\vec{r}_a|}+G(\vec{r}_a,\vec{r}_b(t),t)+i\cdot J(\vec{r}_a,\vec{r}_b(t),t)\right\}\Psi(\vec{r}_a,t)$$

DEMO: See X.Oriols, Phys. Rev Lett, 2007 (in press)

II.3.- Our Quantum Monte Carlo approach

▶ **Approximation**:

$$G(\vec{r}_a,\vec{r}_b(t),t) \approx G(\vec{r}_a(t),\vec{r}_b(t),t)$$

$$J(\vec{r}_a,\vec{r}_b(t),t) \approx J(\vec{r}_a(t),\vec{r}_b(t),t)$$

▶ **Thus, we can obtain many-particle Bohm trajectories by solving a system of N single-particle Schrödinger equations with time dependent potentials**

$$i\hbar\frac{\partial\Psi_1(\vec{r}_1,t)}{\partial t} = \left\{-\frac{\hbar^2}{2m^*}\nabla_1^2 + U_E(\vec{r}_1) + \sum_{k=2}^{N}\frac{q^2}{4\pi\varepsilon\varepsilon_0\left|\vec{r}_k(t)-\vec{r}_1\right|}\right\}\Psi_1(\vec{r}_1,t) \quad ; \quad \vec{r}_1(t) = \vec{r}_1(t_o) + \int_{t_o}^{t} dt \left.\frac{J_1(\vec{r}_1,t)}{|\Psi_1(\vec{r}_1,t)|^2}\right|_{\vec{r}_1=\vec{r}_1(t)}$$

(…..)

$$i\hbar\frac{\partial\Psi_N(\vec{r}_N,t)}{\partial t} = \left\{-\frac{\hbar^2}{2m^*}\nabla_N^2 + U_E(\vec{r}_N) + \sum_{k=1}^{N-1}\frac{q^2}{4\pi\varepsilon\varepsilon_0\left|\vec{r}_k(t)-\vec{r}_N\right|}\right\}\Psi_N(\vec{r}_N,t) \quad ; \quad \vec{r}_N(t) = \vec{r}_N(t_o) + \int_{t_o}^{t} dt \left.\frac{J_N(\vec{r}_N,t)}{|\Psi_N(\vec{r}_N,t)|^2}\right|_{\vec{r}_N=\vec{r}_N(t)}$$

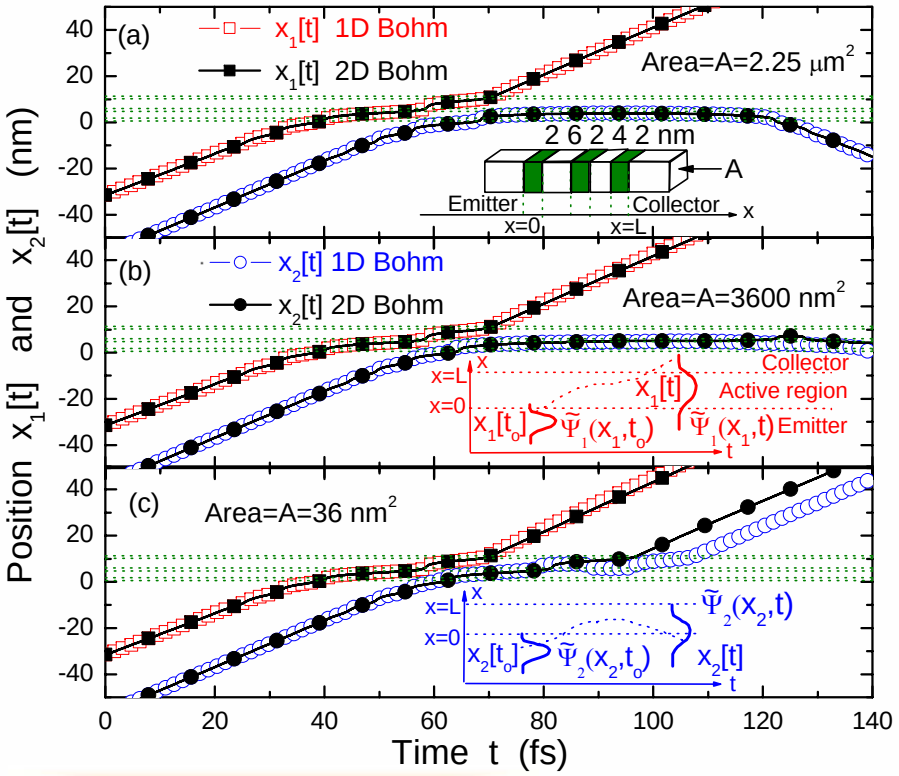
▶ **Numerical viability:** N=100 electrons, L=100nm length (with Δx=0.1 nm) in 1D

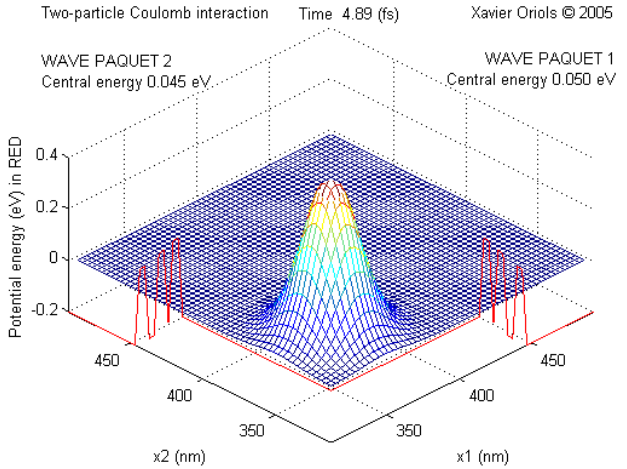
nº of variables = 1000·N = 100 000 variables

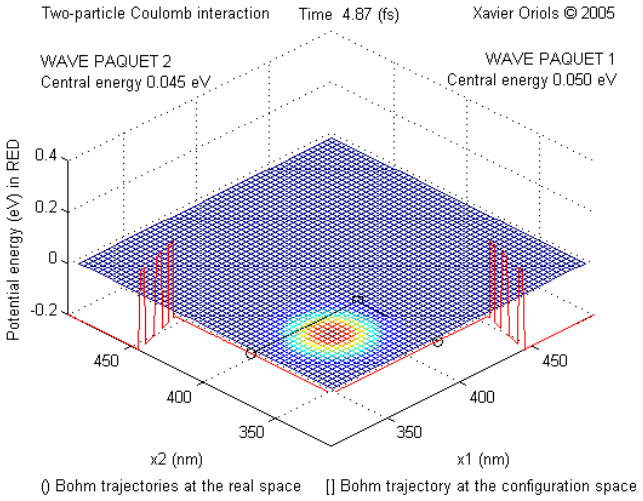
X.Oriols, Phys. Rev Lett, 2007 (in press)

II.3.- Our Quantum Monte Carlo approach

Example: two interacting particles







Electrostatic potential

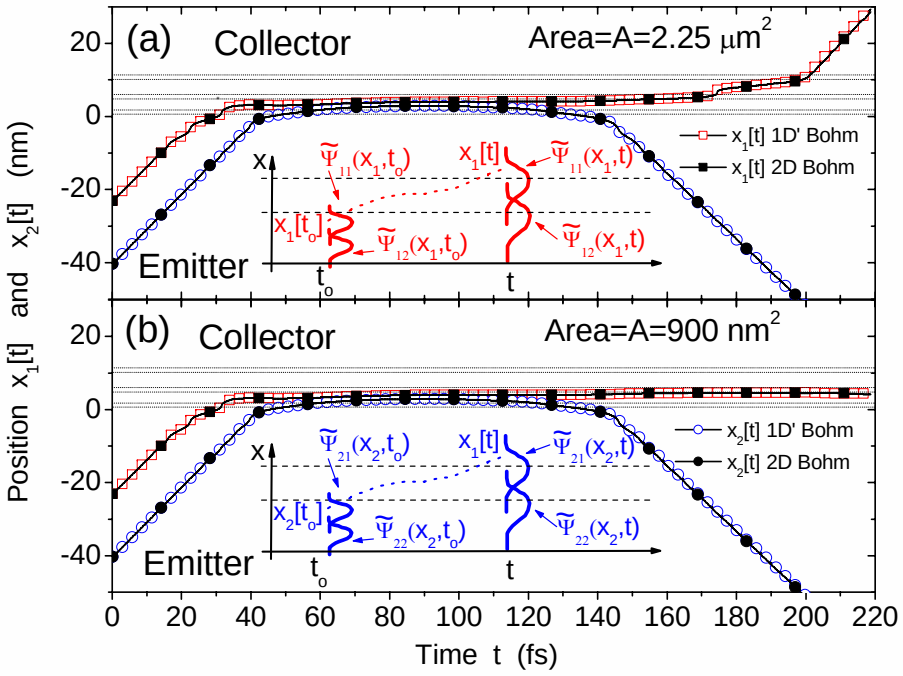
$$V(x_1,x_2)=U_E(x_1)+U_E(x_2)+\frac{q^2}{4\pi\varepsilon\varepsilon_0\cdot|r_1-r_2|}$$

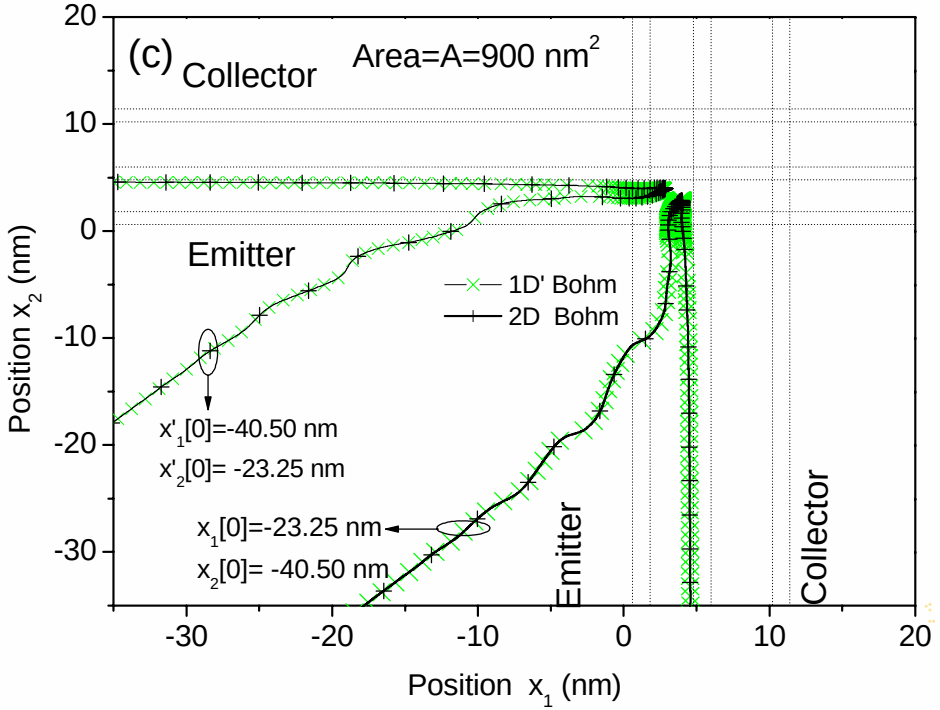
II.3.- Our Quantum Monte Carlo approach

Example: two (Coulomb and Exchange) interacting particles

Only antisymmetrical wave-functions are valid

What is the difference due to the Exchange interaction?





Observable results are identical when we interchange the initial position of electrons

Outline of the talk:

I.- Introduction: *"La simulation du courant et du bruit dans les composants quantiques"*

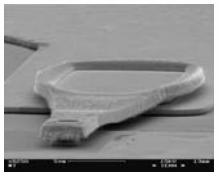
II.- Our approach: *"Méthode des trajectoires de Bohm pour l'étude des interactions entre les électrons"*

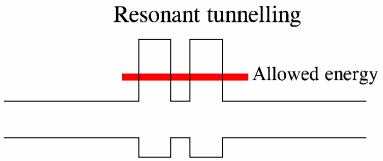
II.1.- Single-particle Bohm trajectories.
II.2.- Many-particle Bohm trajectories
II.3.- Our quantum Monte Carlo approach
II.4.- Numerical results
II.3.1.- Coulomb Blockade and resonant tunneling
II.3.2.- Current noise with Coulomb correlations
II.3.3.- AC conductance

II.3.1.- Numerical results: Coulomb Blockade and Resonant tunneling

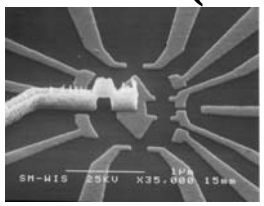
Double/triple barrier structure

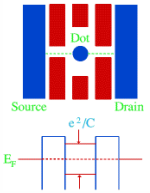
Resonant tunneling diode





Coulomb blockade (Single electrons)



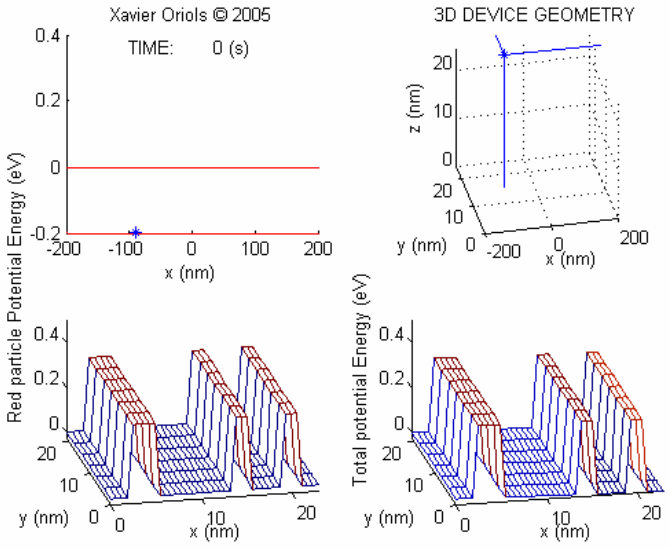


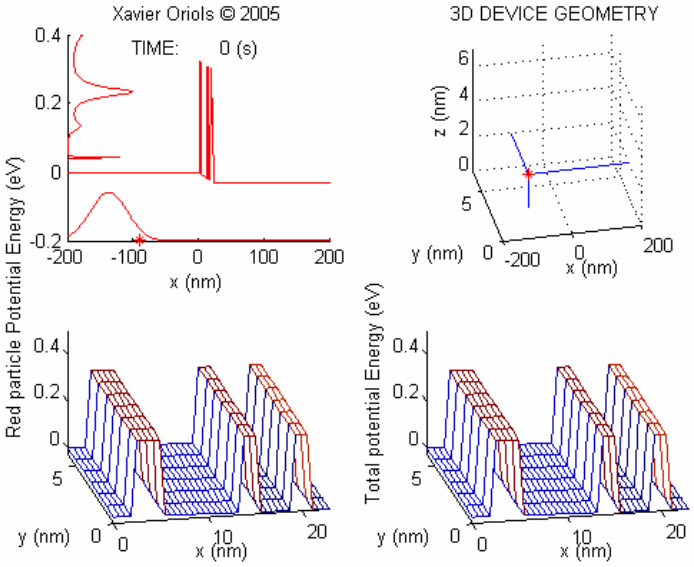
Example: Coulomb correlation as a function of the lateral area

Area=20 nm x 20 nm

Dimensions

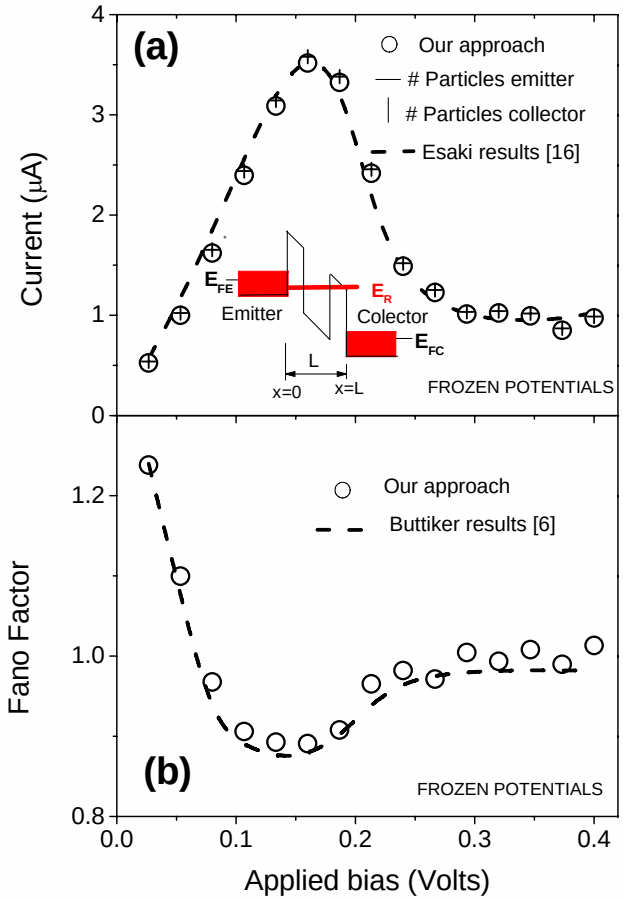
Area=6 nm x 6 nm

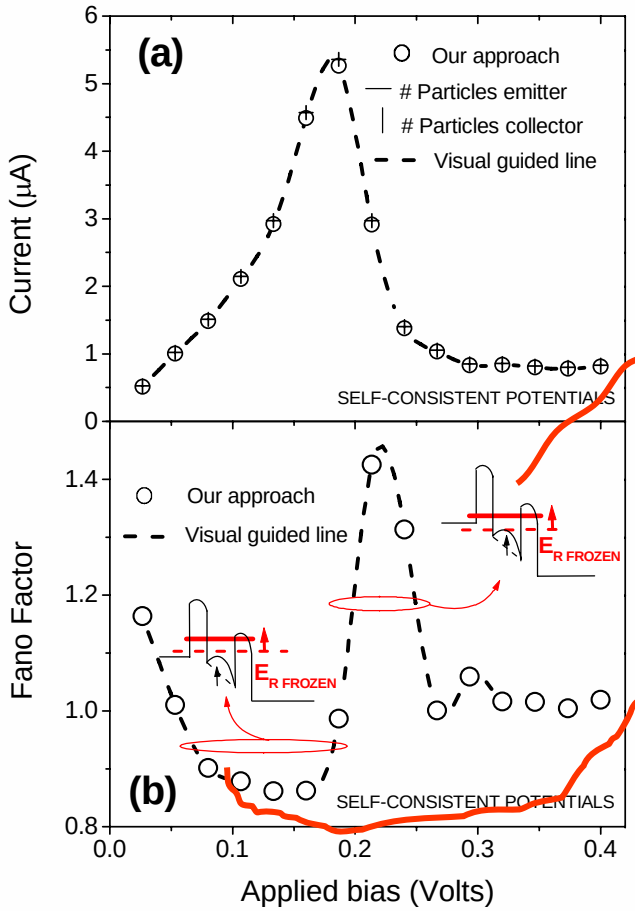




II.3.2.- Numerical results: Current noise with Coulomb correlations

Example: Effect of Coulomb correlation on current and noise for RTD





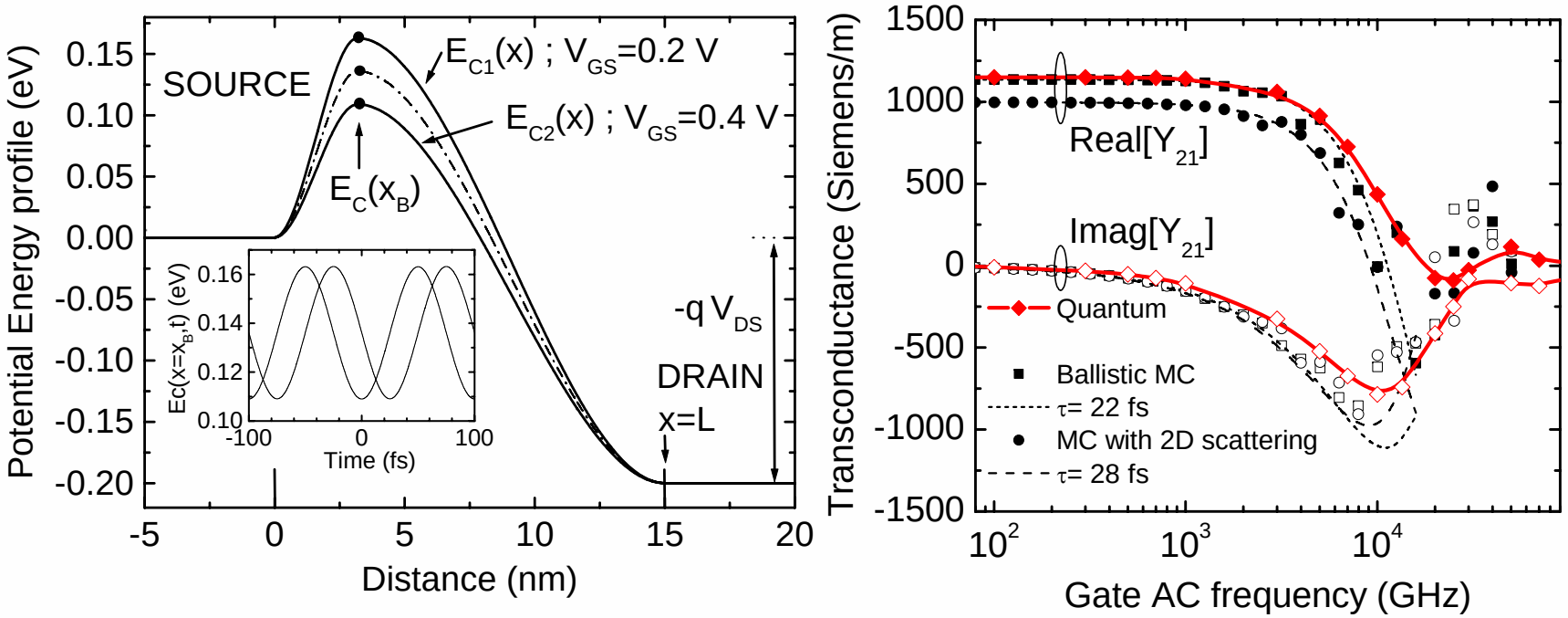
Bounching of electrons

Anti-bounching of electrons

[X.Oriols *et al.*, APL, 2004]

II.3.4.- Numerical results: AC conductance

Quantum-frequency limits for nanoscale Si MOSFET



[X.Oriols *et al.*, Phys. Rev B, (2005)]

[E. Fernandez-Diaz, A.Alarcon and X.Oriols *et al.*, IEEE TON, (2005)]

Summary:

- We have developed a quantum Monte Carlo formalism, based on Bohm trajectories, to study Coulomb and Exchange correlations in nanoscale devices.

- Our approach is accurate, **intuitive** and provides an **unified formalism** to study average current, instantaneous current and noise in different transport regimes, from resonant tunneling to Coulomb Blockade in nanoelectronic devices.

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