Y-junction splitting spin states of a moving quantum dot

Tuukka Hiltunen and Ari Harju

PRB 86, 121301 (R) (2012)

Motivation

- Development of a quantum computer
  - Transportation of information between different parts of the system.
    - Surface acoustic wave (SAW)
- Simulation of the SAW transfer of two interacting electrons through a Y-shaped junction.

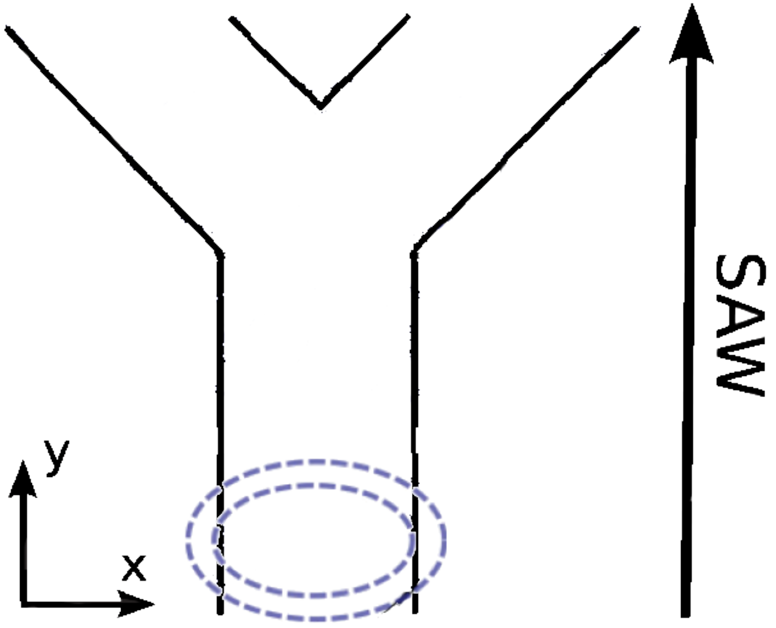
Hamiltonian

$$H(t) = \sum_{j=1}^{2} \left[-\frac{\hbar^2}{2m^*} \nabla_j^2 + V_{\text{ext}}(\mathbf{r}_j, t) \right] + V_{\text{int}}(\mathbf{r}_1, \mathbf{r}_2)$$

With Coulomb interaction V_{int} and

$$V_{\text{ext}}(\mathbf{r}_j, t) = \frac{1}{2} m^* \omega_0^2 \left(\alpha \min[|x_j - a(t)/2|^2, |x_j + a(t)/2|^2] + \beta y_j^2 \right) + D x_j$$

System



Detuning potential

$$V_{\text{ext}}(\mathbf{r}_j, t) = \cdots + Dx_j$$

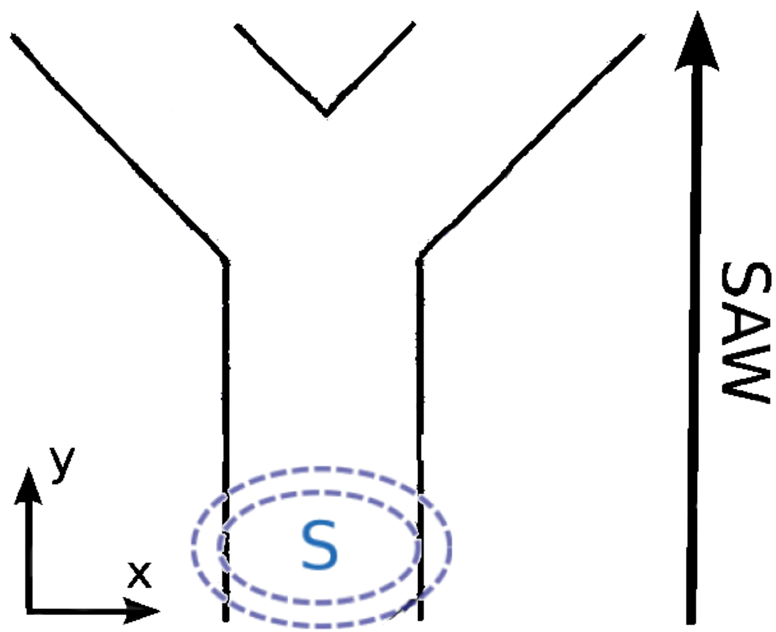
Detuning shifts potential values at the minima to

$$V_{D,\pm} = \pm\frac{aD}{2} - \frac{D^2}{2m^*\omega_0^2}$$

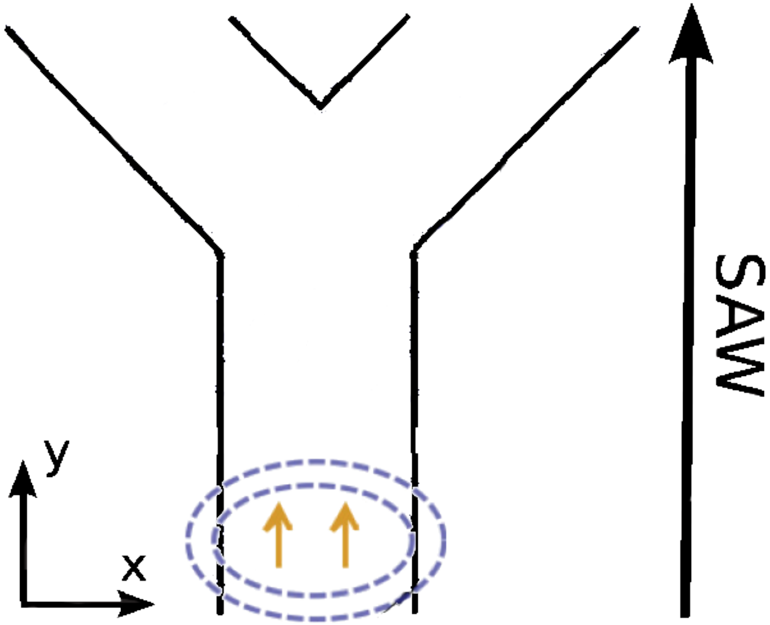
Thus

$$\Delta V = V_{D,+} - V_{D,-} = aD$$

System – Singlet



System – Triplet



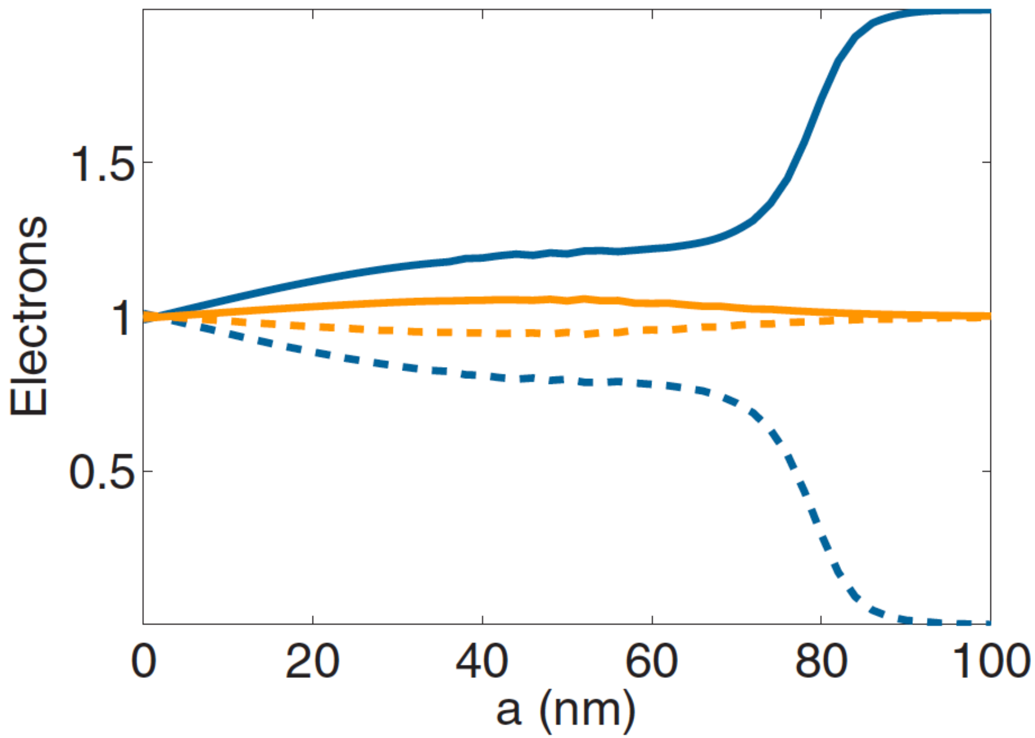
Simulation

- Ground state is computed by exact diagonalization.
- Fock-Darwin states are used as the one-particle basis.
- Time evolution of the system

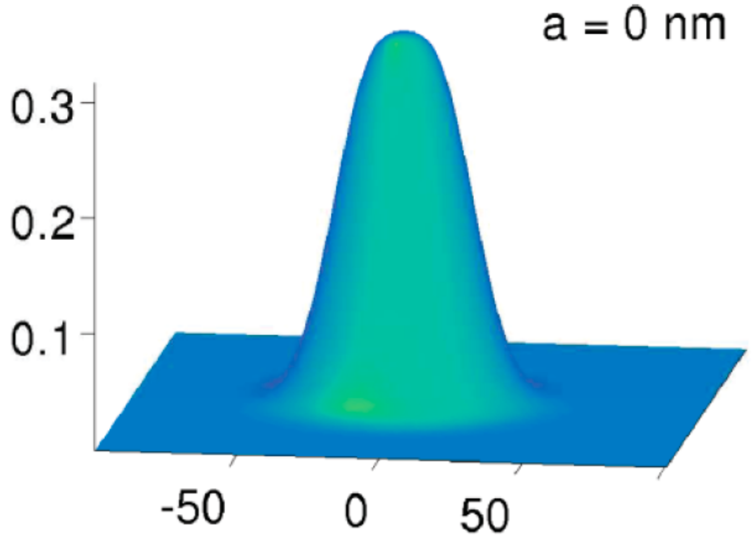
$$\psi(t+\Delta t) = \exp\left(-\frac{i}{\hbar}H(t)\Delta t\right)\psi(t)$$

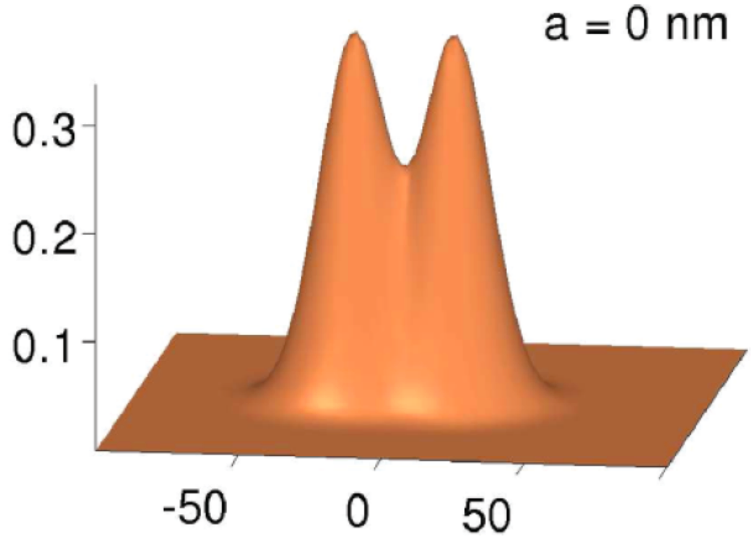
- Charge density is computed from the two-body wave function using the reduced one particle density matrix.

Number of electrons in the dots at detuning strength $D = 0.20 \times D_0$

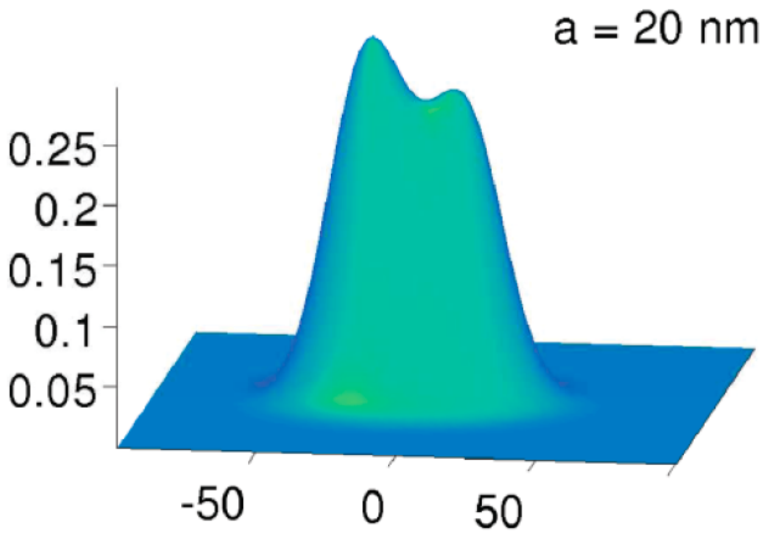


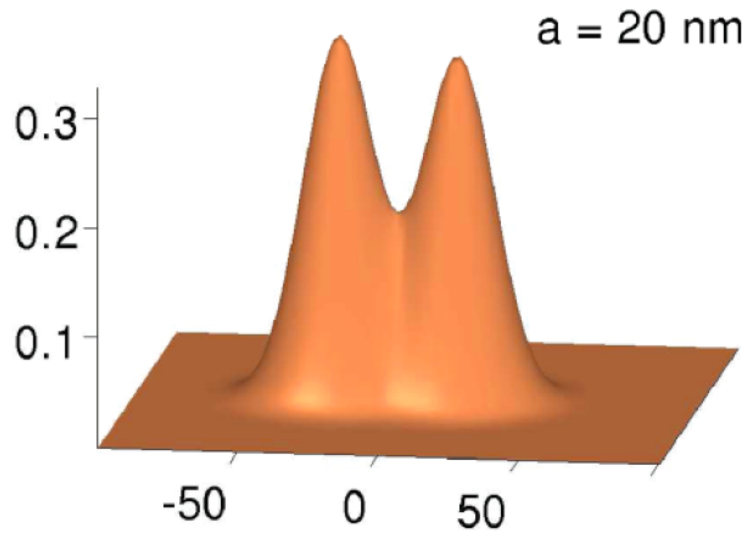
Evolution of the charge density at detuning strength $D = 0.20 \times D_0$



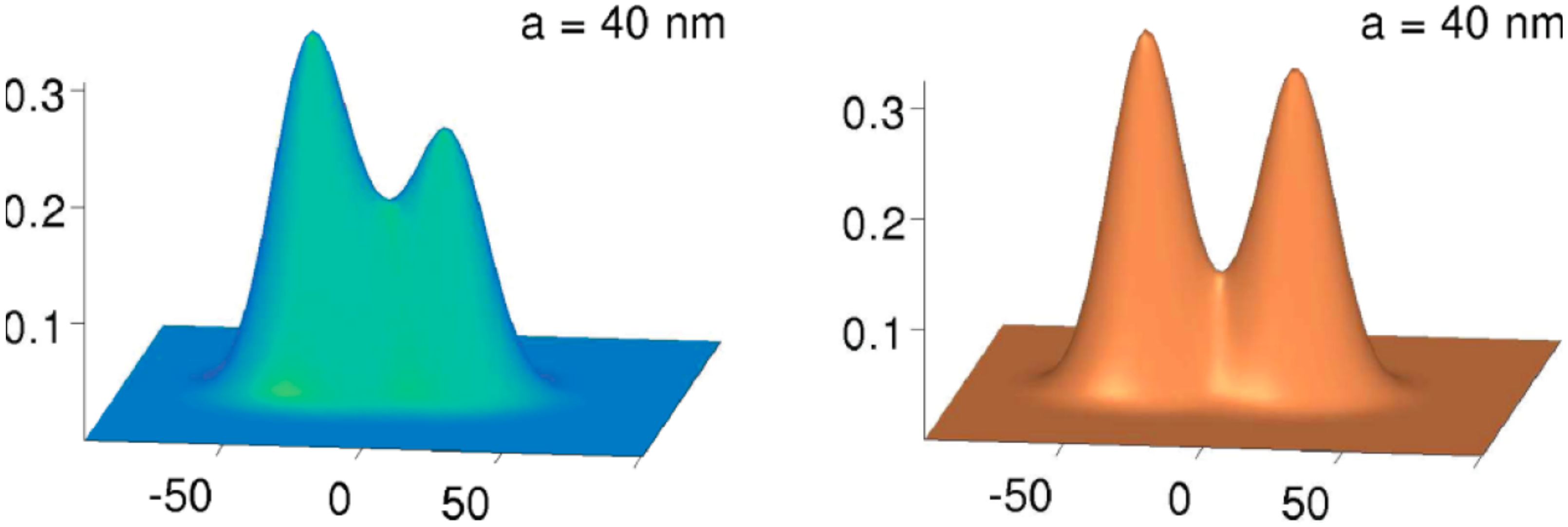


Evolution of the charge density at detuning strength $D = 0.20 \times D_0$

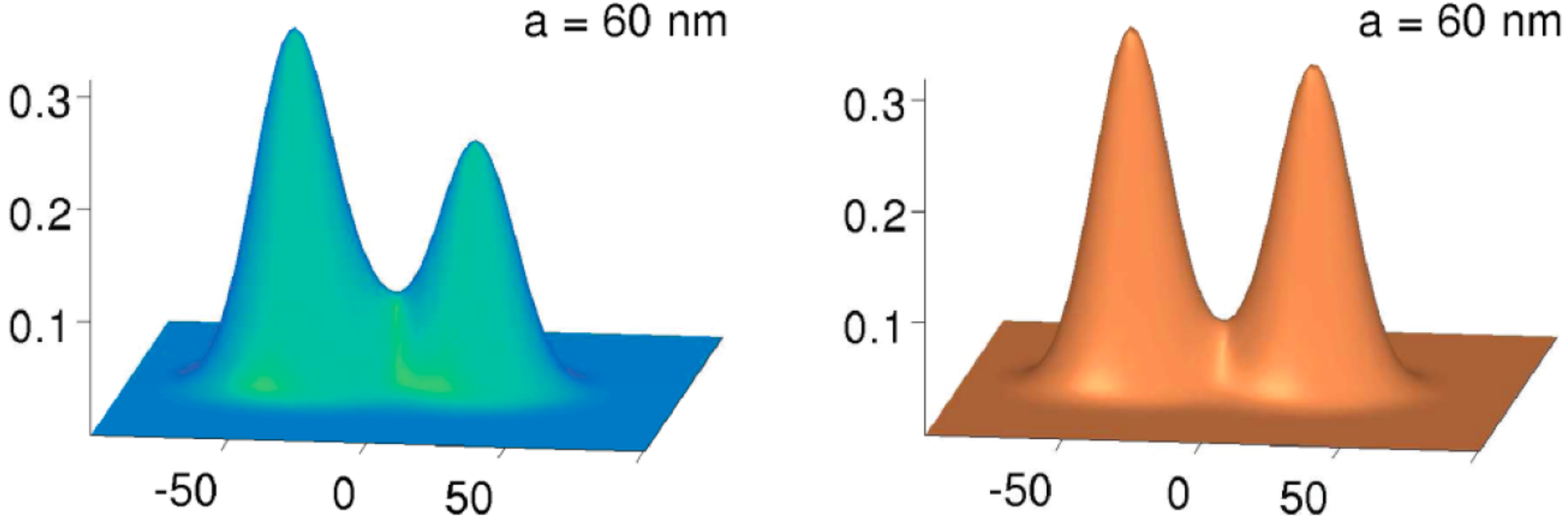




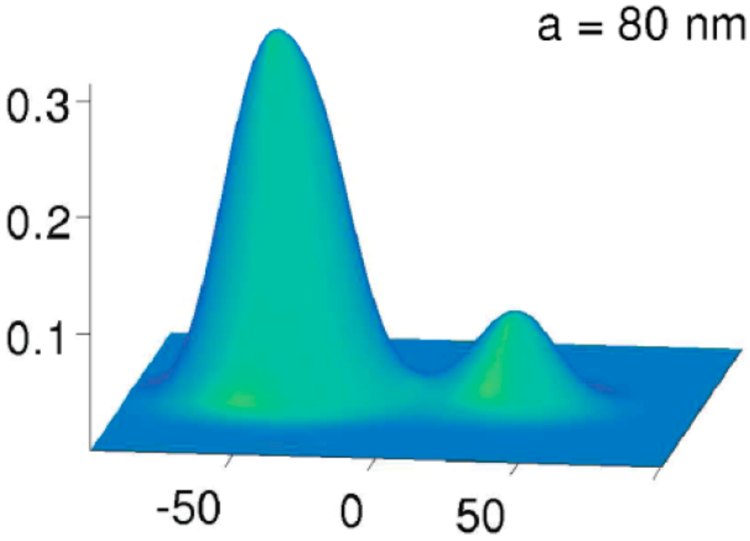
Evolution of the charge density at detuning strength $D = 0.20 \times D_0$

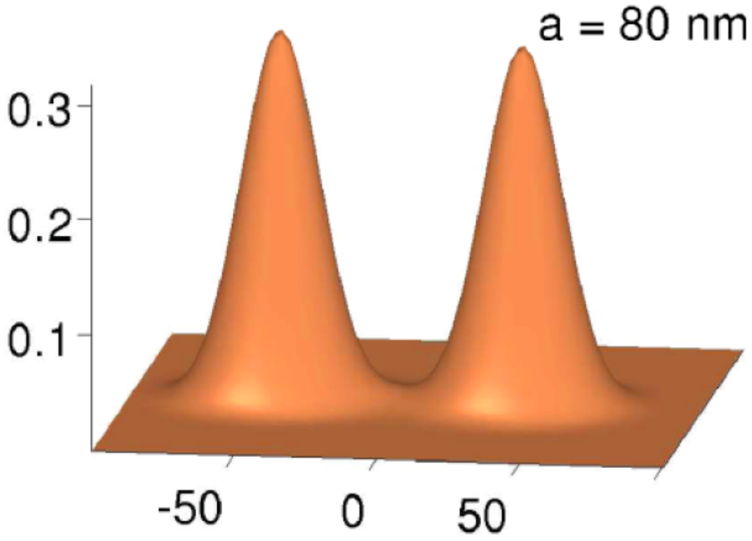


Evolution of the charge density at detuning strength $D = 0.20 \times D_0$

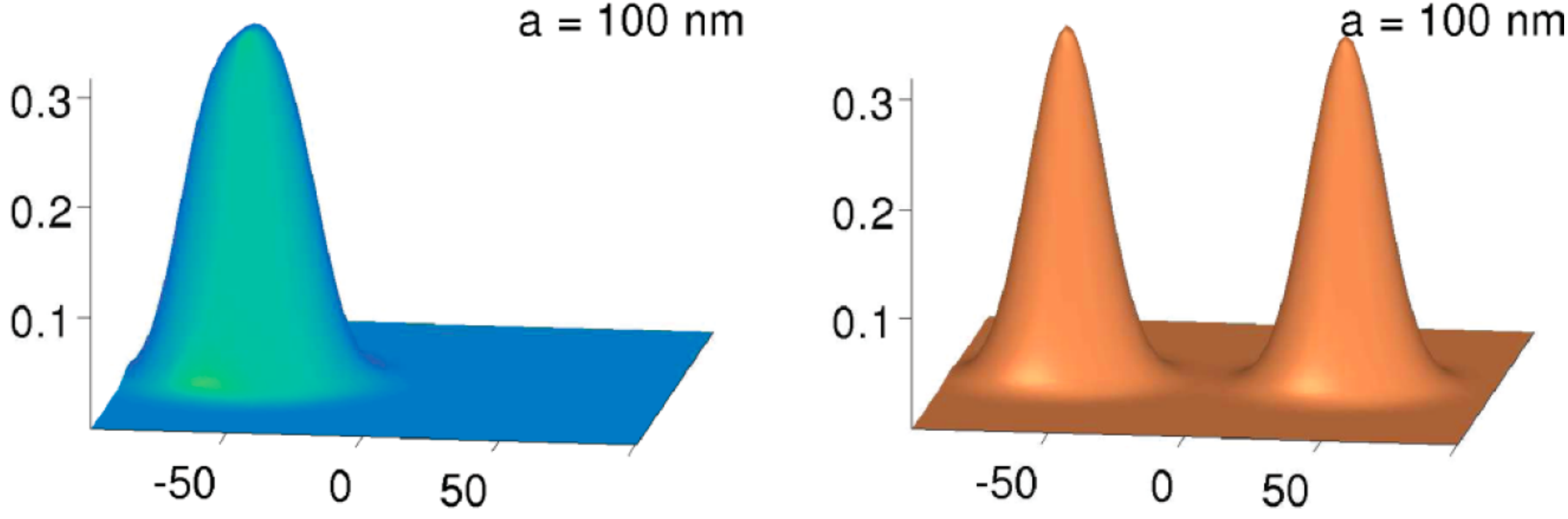


Evolution of the charge density at detuning strength $D = 0.20 \times D_0$

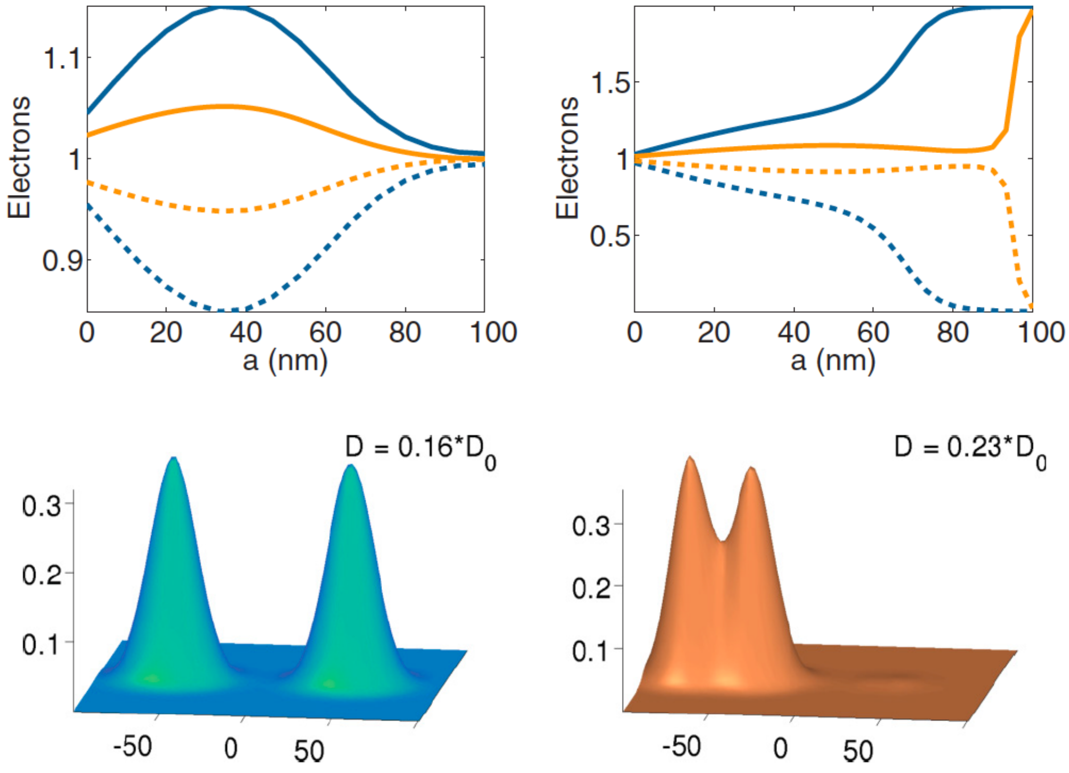




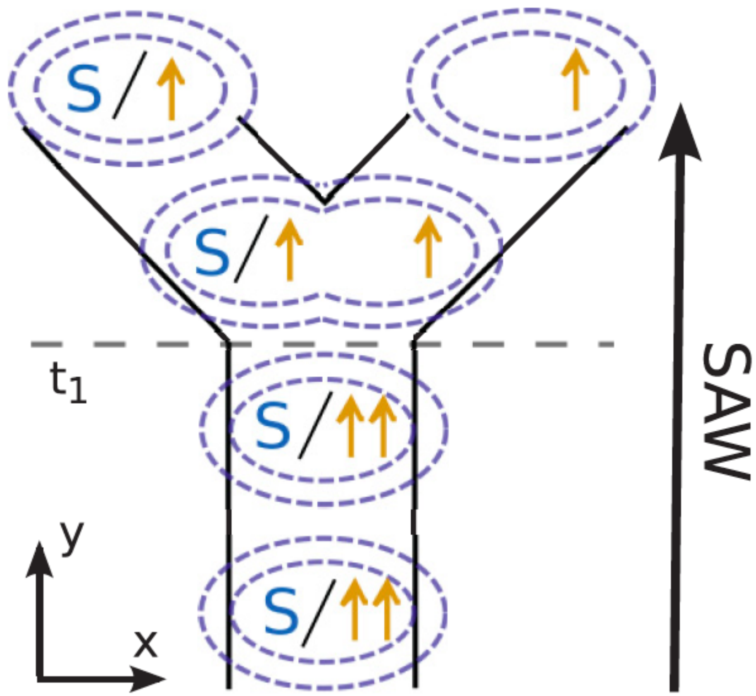
Evolution of the charge density at detuning strength $D = 0.20 \times D_0$



Effect of the detuning strength on the behavior of the system



Shape of the dot



$$V_{\mathrm{ext}}(\mathbf{r}_j, t) = \frac{1}{2} m^* \omega_0^2 \left(\alpha \min[|x_j - a(t)/2|^2, |x_j + a(t)/2|^2] + \beta y_j^2 \right) + D x_j$$

Conclusion

- They predict that a Y-shaped junction with an electrostatic detuning potential can be used to differentiate the two-body singlet and triplet states in SAW-induced electron transport.
- This phenomenon could be used in quantum information technology. For example, in quantum computing, it could allow measurement and control of two-electron qubits.