

# Chapter 3. Edge Structure Of A Quantum Dot In A Large Magnetic Field

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## 3.1 Project Description

### Sponsor

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Two years ago, Professor Raymond Ashoori demonstrated that it is possible to tunnel a single electron on and off a quantum dot and map out the energy level structures of the first five or ten electrons.<sup>1</sup> This experiment was also done in a magnetic field so that the spectrum can be monitored as the field is varied.<sup>2</sup> In the future, it is expected that the magnetic field can be increased so that one can enter the fractional quantum hall effect (FQHE) regime, i.e., when only the lowest Landau level is occupied. It is then important to theoretically study what is the expected behavior for the tunneling onto a quantum dot in the FQHE limit.

We addressed this problem two years ago, assuming that the electrons are confined by a rapidly varying potential. We found a strong suppression of the tunneling amplitude due to many-body effects, and novel features such as alternating strong and weak tunneling amplitude with increasing electron numbers in the case of the  $2/3$  filled Landau level.<sup>3</sup> However, in practice the con-

fining potential is produced by gates relatively far away, so that the confining potential is slowly varying. In the past year, we initiated a project to study the behavior of the edge of the quantum dot in the case of a slowly varying potential. It is important to understand the edge structure because tunneling occurs predominantly at the edge.

Traditionally, the FQHE is understood in terms of the Laughlin wavefunction, which describes an incompressible electron state at special filling factors. Recently, it has been suggested that a partially filled Landau level may be described by making a transformation to composite fermions.<sup>4</sup> This is achieved by attaching two magnetic field flux quanta to each electron. The theory explains several experimental observations, and its predictions were recently experimentally confirmed.

We use the composite fermion approach to study an experimentally relevant system where electrons are confined to a quantum wire or a quantum dot. We solve for the electron wavefunction by multiplying it with a Jastrow-like function. Figure 1 demonstrates the good agreement between our calculations and the results obtained from the Laughlin wavefunction by Rezayi and Haldane. However, their study was limited to simple fractions and few electron systems.

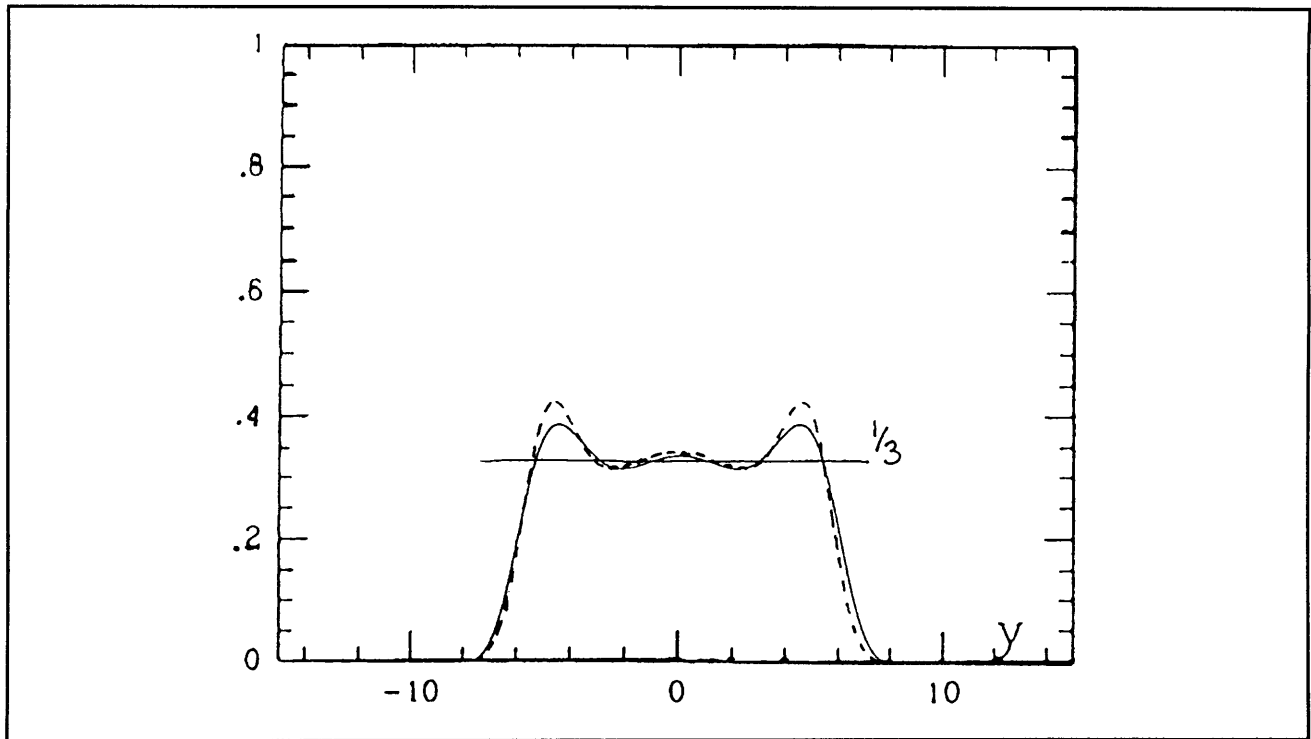
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<sup>1</sup> R.C. Ashoori et al., "Single-electron Capacitance Spectroscopy of Discrete Quantum Levels," *Phys. Rev. Lett.* 68: 3088 (1992).

<sup>2</sup> R.C. Ashoori et. al., "N-Electron Ground State Energies in a Quantum Dot in Magnetic Field," *Phys. Rev. Lett.* 71: 613 (1992).

<sup>3</sup> J. Kinaret, P.A. Lee, Y. Meir, X.G. Wen, and N. Wingreen, "Conductance Through a Quantum Dot in the Fractional Quantum Hall Regime," *Phys. Rev. B.* 45: 9484 (1992).

<sup>4</sup> B.I. Halperin, P.A. Lee, and N. Read, "Theory of the Half Filled Landau Level," *Phys. Rev. B* 47: 7312 (1993).



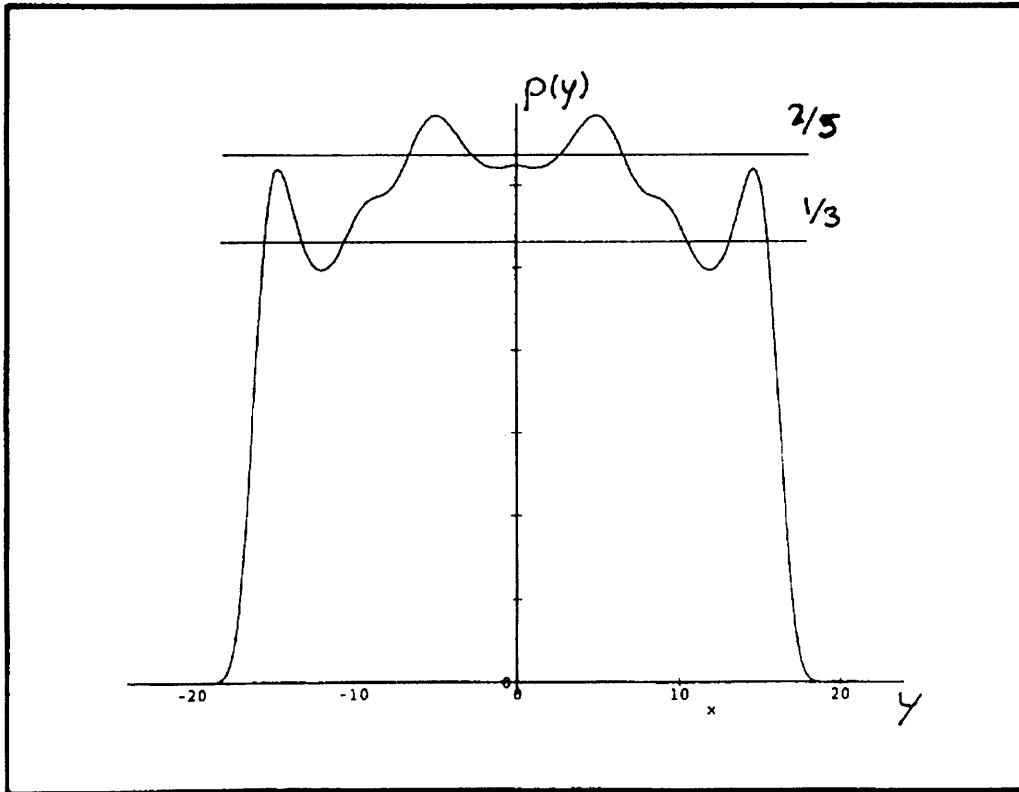
**Figure 1.** Density profile for the  $1/3$  quantum Hall state. Dashed line: Rezayi-Haldane calculations for the Laughlin wavefunction. Full line: Our composite fermion Hartree calculation. Length is measured in magnetic length units. Unit corresponds to a completely filled Landau level.

We are able to extend our calculations to other fractional states and greater number of electrons. This allows us to perform the first systematic study of the fractional edge states. We find that the fractional edge states can be described very naturally in the composite fermion representation as the integer edge states and the snake states. We can predict the number of fractional edge states formed in a given confinement scheme as well as the density distribution (see figure 2). These results are crucial for the explanation edge magnetoplasmon experiments in mesoscopic devices. The results are also the starting point for a theory of tunneling onto the quantum dot in the FQHE regime.

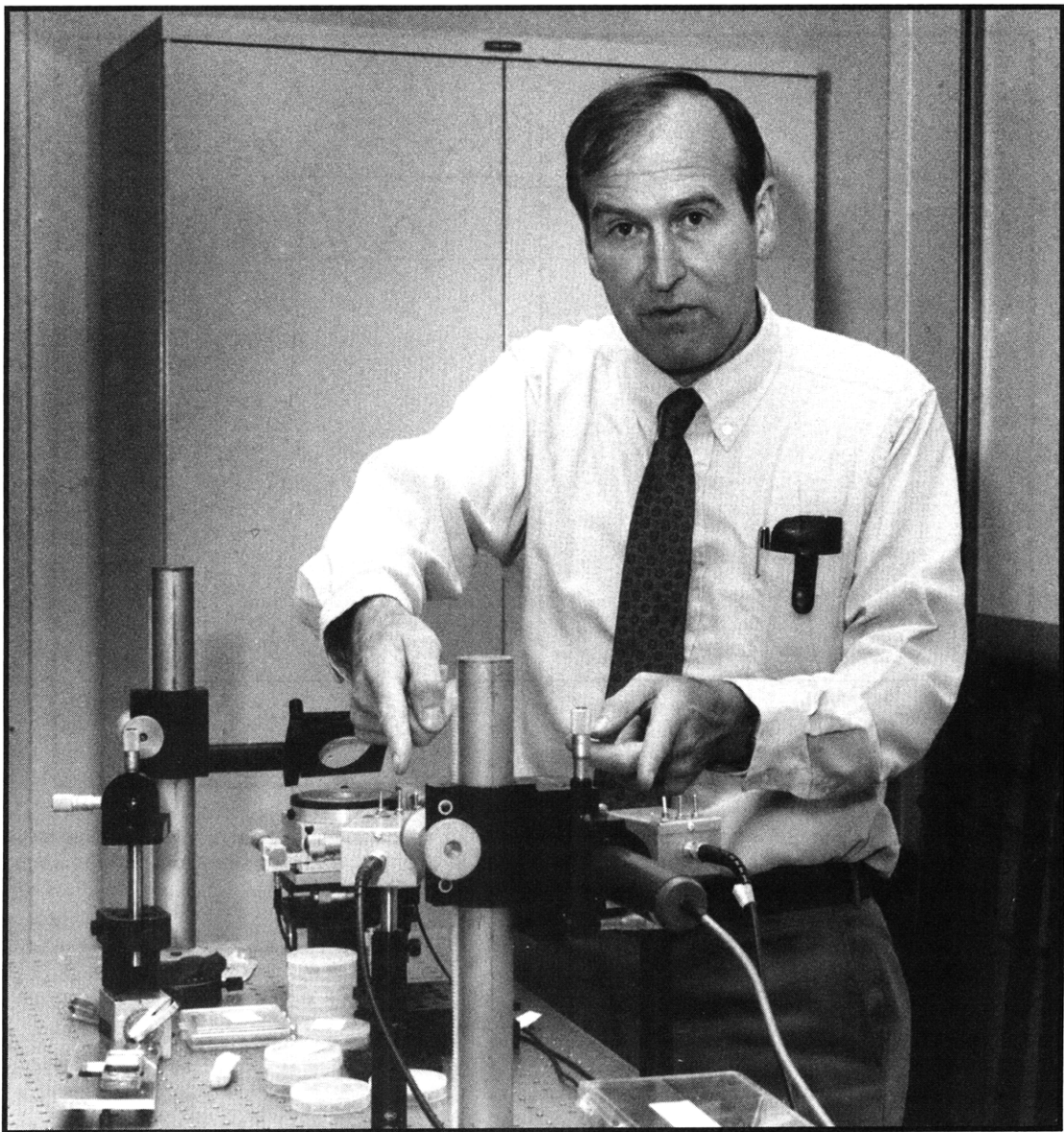
### 3.2 Publications

Lee, P.A. "Few Electron Nanostructures: A New Laboratory for Studying Strongly Correlated Systems." *Proceedings of the NATO Workshop, Noordevijk, the Netherlands, September 1992, Physica B* 189: 1 (1993).

Meir, Y., N. Wingreen, and P.A. Lee. "Low Temperature Transport Through a Quantum Dot: The Anderson Model Out of Equilibrium." *Phys. Rev. Lett.* 70: 2601 (1993).



**Figure 2.** Density profile for the  $2/5$  state (composite fermion Hartree calculation). Despite the ripples reflecting the density-density correlation function one can see that  $2/5$  state goes through a  $1/3$  state before entering the vacuum.



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