Probing the Structure of Integer Quantum Hall Edges with Momentum-Resolved Tunnel Spectroscopy

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We present measurements of momentum-resolved magneto-tunneling from a two-dimensional (2D) contact into integer quantum Hall edges and observe a feature at zero voltage bias which cannot be explained in a simple non-interacting particle picture of an integer quantum Hall edge. Using cleaved-edge overgrowth we create a device with two orthogonal quantum wells (QW-A and QW-B) separated by a T-shaped tunnel junction (Fig.1). A high magnetic field perpendicular to QW-A creates quantum Hall edge states close to the T-junction which are probed with QW-B acting as a tunnel contact. The high interface quality at the cleaved edge of the sample results in strict momentum conservation for tunneling charges along the barrier [1,2]. Resonances in the tunnel conductance correspond to coincidences of electronic states in the energy-momentum space between the two QW systems. Because the magnetic field is transverse to the tunnel current, the Lorentz force acting on the tunneling electrons shifts the dispersion in k-space and the voltage bias shifts the energy, allowing us to map out an entire E vs. k dispersion relation. We are able to resolve the dispersion of both the integer quantum Hall edge modes and the 2D Fermi surface (Fig.3).

We identify one feature that cannot be explained with a simple non-interacting edge picture. With the edge state dispersion reflecting the shape of the edge potential, we have a direct measure of the electrostatics in a quantum Hall edge. Electrostatic simulations of the device under negative bias quantitatively confirm the identification of conductance peaks with spin-unresolved Landau levels. Extrapolating this understanding to the zero bias conductance trace shows which peak corresponds to which filling factor. Momentum conservation yields van-Hove singularities in the tunneling density of states which, when broadened with a gaussian, account for the qualitative shape of the zero bias conductance trace. Fig. 2 shows the good agreement of our model with the experiment concerning positions and shape of the main resonance peaks. There is however an additional resonance in the shoulder of the lowest Landau level that is seen in all of the samples studied so far and which cannot be explained within our non-interacting edge state model. At zero bias we are probing electronic states at the Fermi energy, where correlation effects should play a role in the energetic structure at the edge either through the exchange enhanced spin-splitting (present also in the bulk), or through edge reconstruction induced by Coulomb interactions [3]. Either of these two effects is therefore a reasonable candidate for explaining this feature. An exchange enhanced spin gap would increase the separation of the edge modes of the two spin orientations. The peak offset would then be a measure of the exchange energy. In the edge-reconstruction model, the peak offset would define the Fermi momentum of the outermost Fermi-point of the reconstructed edge.

We will report on additional measurements with an in-plane magnetic field to investigate spin related effects.

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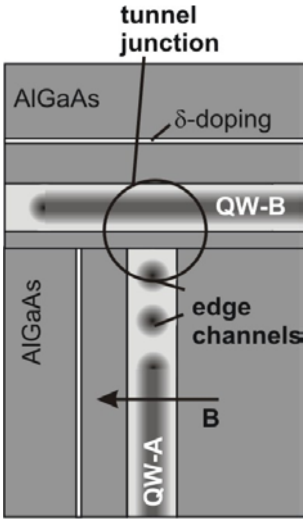

Figure 1: The samples are fabricated by cleaved edge overgrowth. Two quantum wells (QW-A and QW-B) are arranged in a T-shape. A magnetic field B creates quantum Hall edge states close to the tunnel barrier.

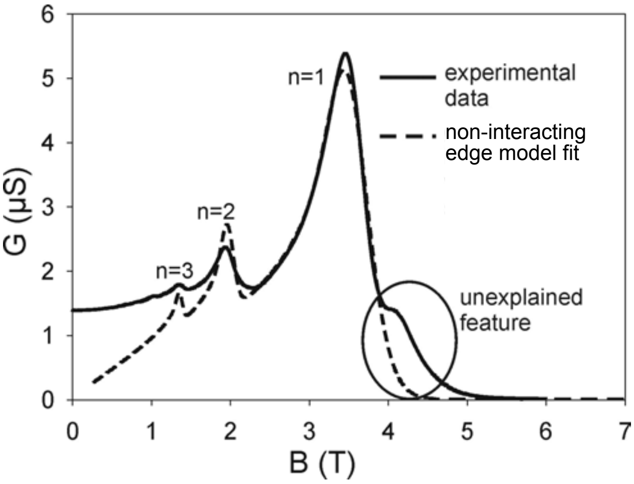

Figure 2: (Sample 1) Differential tunnel conductance at zero bias. Resonances due to tunneling into spin degenerate Landau levels are indexed, and explain of the main structure except for a secondary peak in the shoulder around 4.1 T.

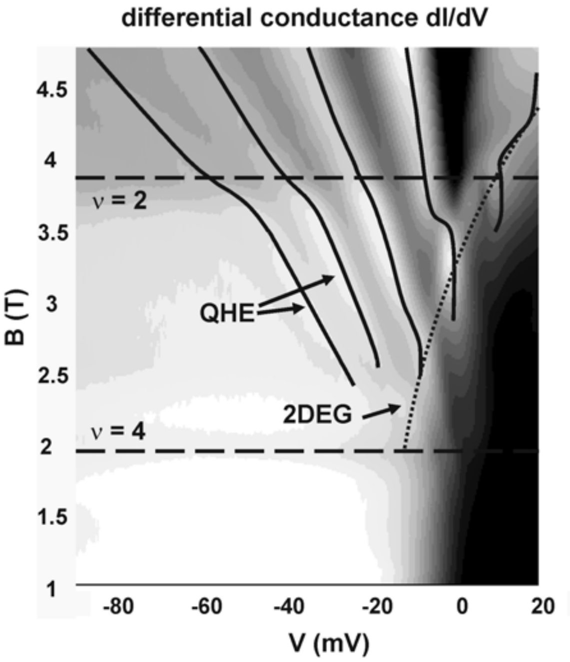

Figure 3: (Sample 2) Gray-scale plot of the differential tunnel conductance (light represents high and dark low conductance). Negative bias indicates tunneling of electrons into the quantum Hall edge. Solid lines indicate maxima in the tunnel conductance. In these resonance maxima we can identify the dispersion of the edge states of individual Ladau levels as well as the dispersion curve of the 2D tunnel contact (dotted line).