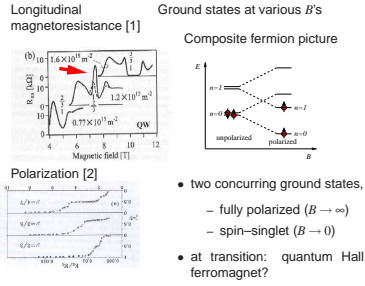# Spin structures in inhomogeneous fractional quantum Hall systems

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Fractional quantum Hall system, $\nu = 2/3$

Longitudinal magnetoresistance [1]

Ground states at various B's

Composite fermion picture

Polarization [2]

- two concurring ground states,
  - fully polarized ($B \to \infty$)
  - spin–singlet ($B \to 0$)
- at transition: quantum Hall ferromagnet?
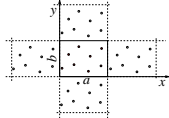

- scattering on domain walls ⇒ enhanced resistance?
- stable half–polarized state?

What happens at the transition?

Model

- rectangle + periodic boundary conditions with $N \approx 8$ electrons
- lowest Landau level
- exact diagonalization

Yoshioka, PRB **29**, 6833 (1984)
Zhang, Chakraborty, PRB **30**, 7320 (1984)

$$H = \frac{e^2}{4\pi\varepsilon} \sum_{i<j} \frac{1}{|r_i - r_j|} + g\mu_B B \sum_i \sigma_i^z + g\mu_B \sum_i B_z(x)\sigma_i^z + g\mu_B \sum_i B_x(x)\sigma_i^x$$

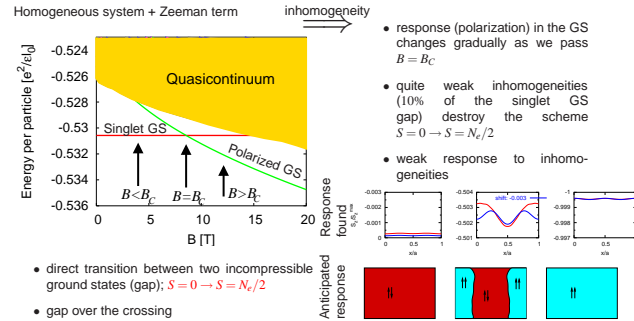Zeeman / spatially varying Zeeman / in-plane inhomogeneity

- (homogeneous) Zeeman term: brings the two incompressible ground states to degeneracy
- third term: attempt to enforce domains
- fourth term: mixing the two incompressible ground states (over the gap)

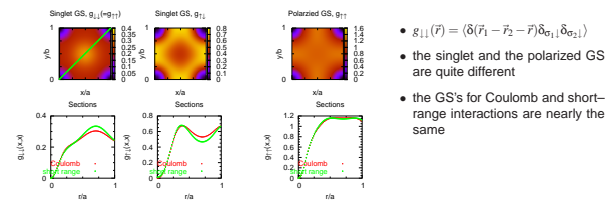### Profile of inhomogeneities
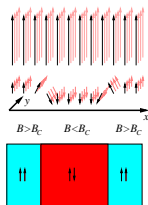
Additional magnetic field

- varying in the x direction
- constant along y
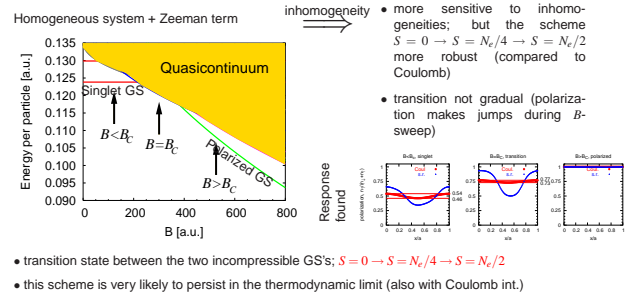- we expect it to support a domain structure (half of system polarized, half of system unpolarized)

Coulomb interaction: weak response

Homogeneous system + Zeeman term → inhomogeneity

- response (polarization) in the GS changes gradually as we pass $B = B_C$
- quite weak inhomogeneities (10% of the singlet GS gap) destroy the scheme $S = 0 \to S = N_e/2$
- weak response to inhomogeneities

- direct transition between two incompressible ground states (gap); $S = 0 \to S = N_e/2$
- gap over the crossing

Response found

Anticipated response

Spin-spin correlation functions for the incompressible ground states

Singlet GS, $g_{\downarrow\downarrow}(=g_{\uparrow\uparrow})$ Singlet GS, $g_{\uparrow\downarrow}$ Polarized GS, $g_{\uparrow\uparrow}$

- $g_{\downarrow\downarrow}(\vec{r}) = \langle \delta(\vec{r}_1 - \vec{r}_2 - \vec{r})\delta_{\sigma_1\downarrow}\delta_{\sigma_2\downarrow}\rangle$
- the singlet and the polarized GS are quite different
- the GS's for Coulomb and short–range interactions are nearly the same

Short–range interaction: stronger response

Homogeneous system + Zeeman term → inhomogeneity

- more sensitive to inhomogeneities; but the scheme $S = 0 \to S = N_e/4 \to S = N_e/2$ more robust (compared to Coulomb)
- transition not gradual (polarization makes jumps during B-sweep)

Response found

- transition state between the two incompressible GS's; $S = 0 \to S = N_e/4 \to S = N_e/2$
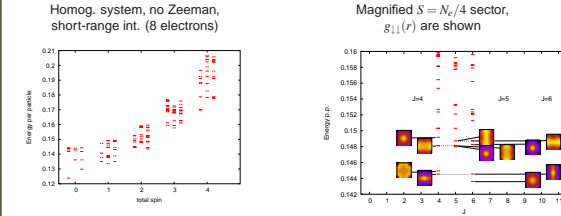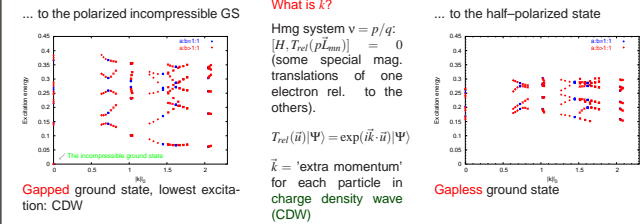- this scheme is very likely to persist in the thermodynamic limit (also with Coulomb int.)

Summary

Transition between $S = 0$ and $S = N_e/2$ at $\nu = 2/3$

- if only the two ground states (the spin–singlet one and the polarized one) cross, i.e. there is a gap over the GS in the transition point, no pronounced spin structures can be achieved by magnetic inhomogeneities
- in the thermodynamical limit there seems to be an exactly half–polarized and (probably) gapless state at the transition point

The half–polarized transient state (in 8 electron syst.)

- completely different from the two incompressible ground states
- it can be formed into a domain–like form by magnetic impurity of suitable form
- intrinsically, it seems to support stripe–like spin structures
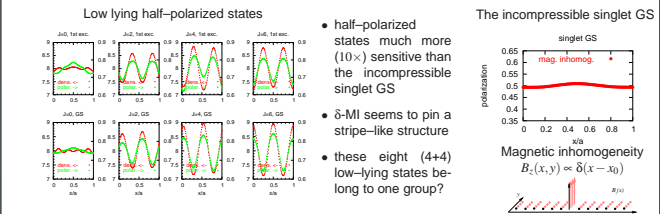
Half–polarized states ($S = N_e/4$)
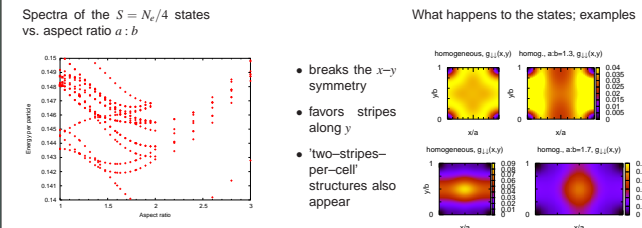
In homogeneous system without Zeeman energy

Homog. system, no Zeeman, short-range int. (8 electrons)

Magnified $S = N_e/4$ sector, $g_{\downarrow\downarrow}(r)$ are shown

The excitations, homogeneous system

What is $\vec{k}$?

... to the polarized incompressible GS

Hmg system $\nu = p/q$:
$[H, T_{rel}(p\tilde{L}_{mn})] = 0$ (some special mag. translations of one electron rel. to others).

$T_{rel}(\vec{u})|\Psi\rangle = \exp(i\vec{k}\cdot\vec{u})|\Psi\rangle$

$\vec{k} = $ 'extra momentum' for each particle in charge density wave (CDW)

... to the half–polarized state

Gapped ground state, lowest excitation: CDW

Gapless ground state

What are its intrinsic spin structures? Apply magnetic impurity $\propto \delta(x - x_0)$ ...

Low lying half–polarized states

- half–polarized states much more ($10\times$) sensitive than the incompressible singlet GS
- δ-MI seems to pin a stripe–like structure
- these eight (4+4) low–lying states belong to one group?

The incompressible singlet GS

Magnetic inhomogeneity $B_z(x,y) \propto \delta(x - x_0)$

Stretch the primitive cell along x in homogeneous system

Spectra of the $S = N_e/4$ states vs. aspect ratio $a : b$

- breaks the x–y symmetry
- favors stripes along y
- 'two–stripes–per–cell' structures also appear

What happens to the states; examples

References

[1] S. Kronmüller et al., *Phys. Rev. Lett.*, **81**, 2526 (1998), J. Smet et al., *Nature*, **415**, 281 (2002), S. Kraus et al., *Phys. Rev. Lett.*, **89**, 266801 (2002); Hashimoto et al., *Phys. Rev. Lett.*, **88**, 176601 (2002).

[2] I.V. Kukushkin et al., *Phys. Rev. Lett.*, **82**, 3665 (1999)

[3] D. Yoshioka, *Phys. Rev. B*, **29**, 6833 (1984); T. Chakraborty, *Surf. Sci.*, **229**, 16 (1990); E. Rezayi, *Phys. Rev. B*, **36**, 5454 (1987).