Spin flip excitations in fractional quantum Hall systems

Magnetoexcitons - IQHE

Filling factor 2: polarized and spin-singlet ground state

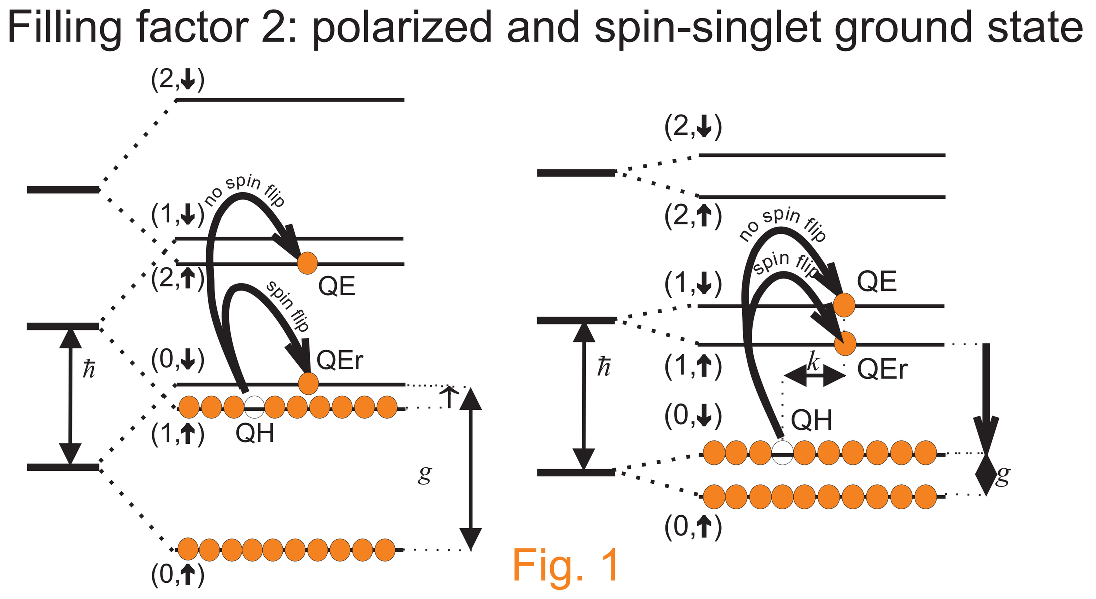
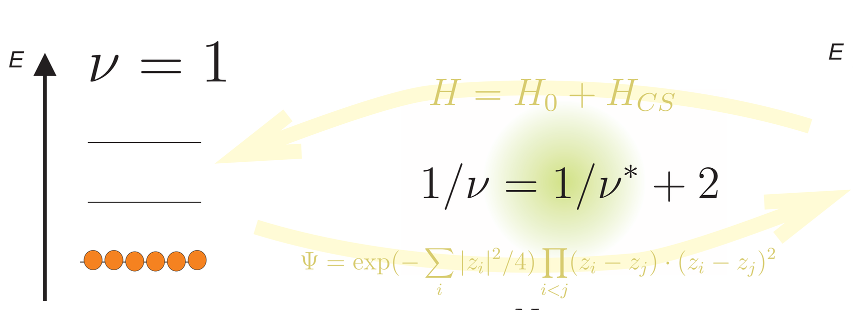


Fig. 1

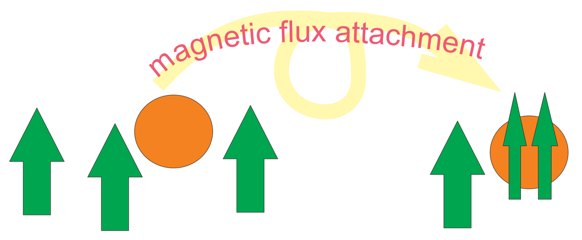
Idea: - zero resistance at =2 and zero temperature T
- magnetoexcitons occur at non-zero T
- electron-hole distance = current flows
- activated (non-zero) resistance determined by magnetoexcitons

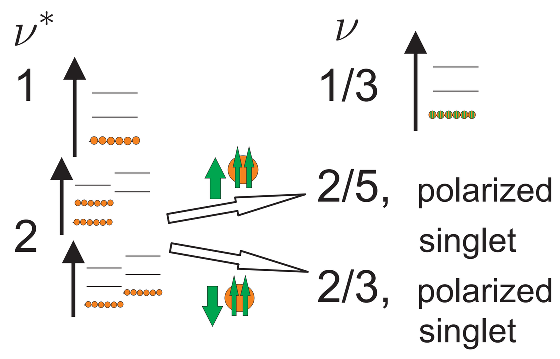
FQHE - composite fermion picture



filling factor $\nu = \frac{n}{eB/h} = \frac{N_e}{AB/(h/e)}$

Jain '89 and later [Phys. Rev. Lett. **71**, 153 (1993)]

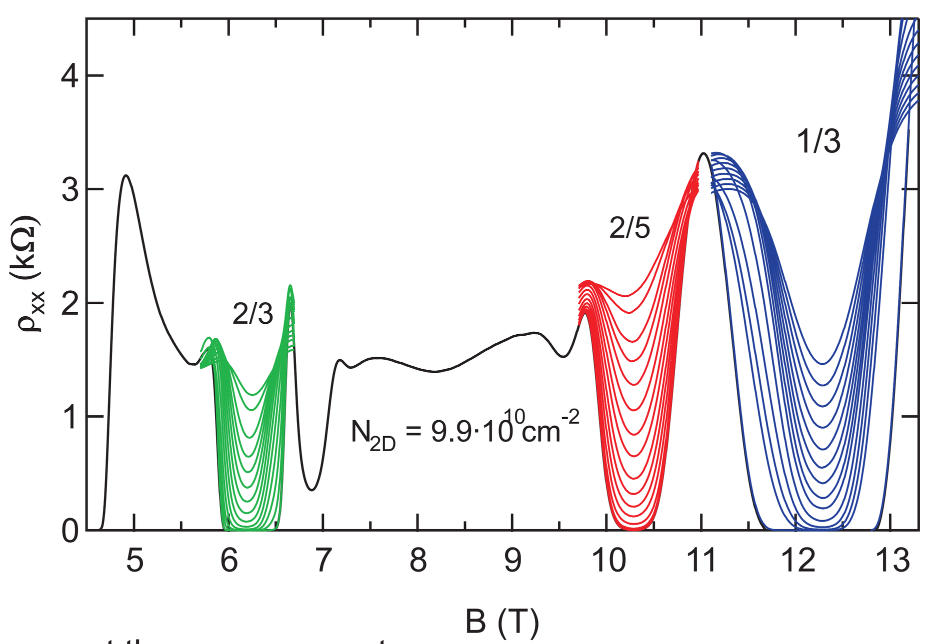




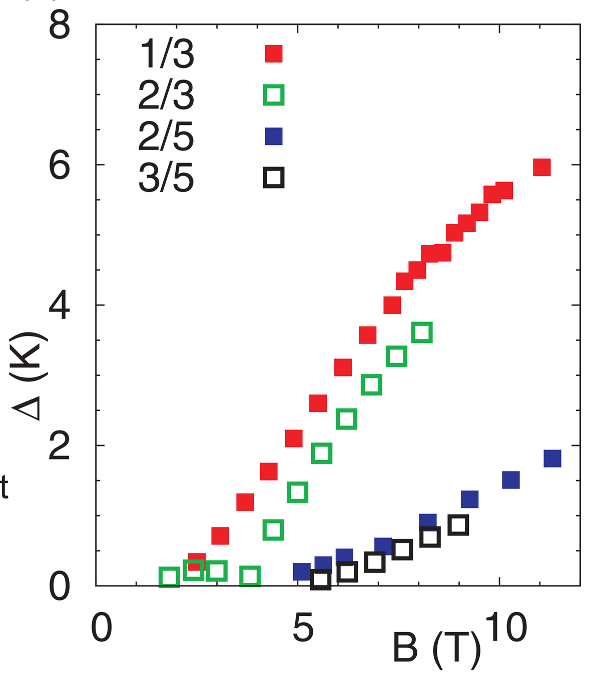
Observation...

...activated transport

$$R_{xx} = R_0 \exp(-E_a/kT)$$

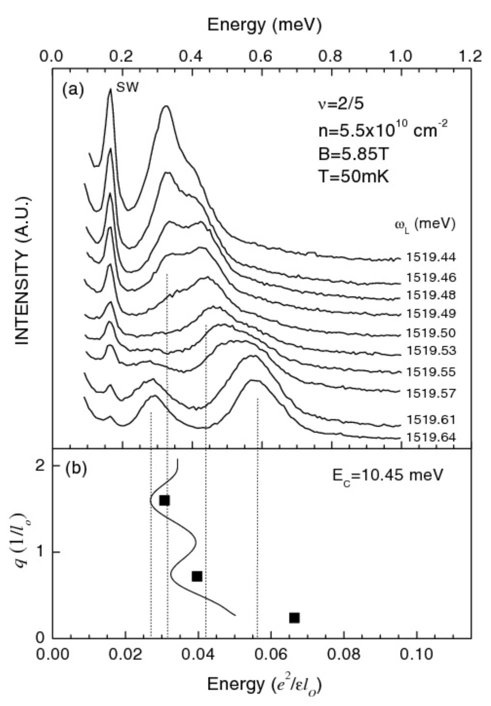


- repeat the measurement at other el. densities
- ...tuned by gate



... inelastic light scattering

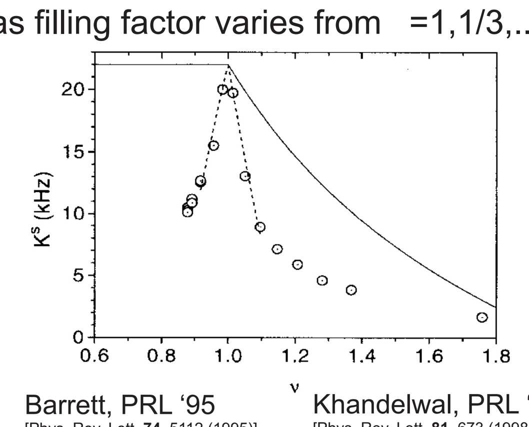
- single electron density
- different excitation than in transport



Pinczuk '01 [Phys. Rev. Lett. **86**, 2637 (2001)]

... depolarization via NMR

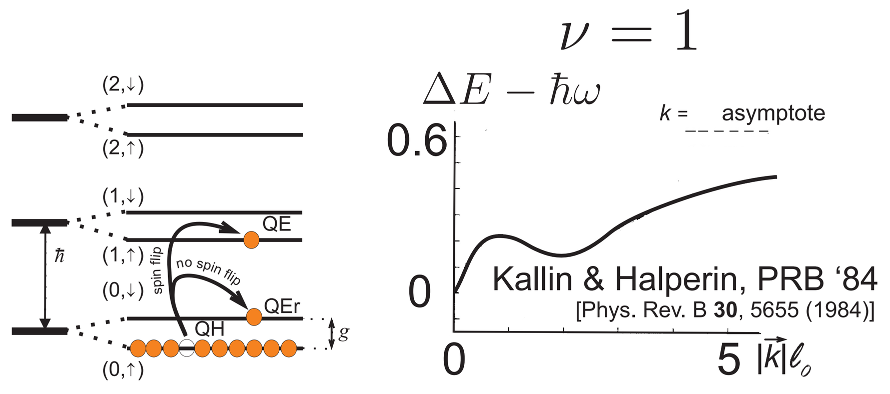
- ground state property
- as filling factor varies from =1,1/3,...

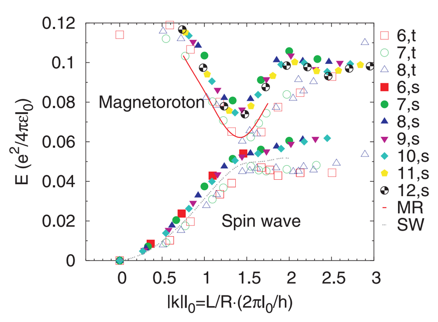


Barrett, PRL '95 [Phys. Rev. Lett. **74**, 5112 (1995)]

Khandelwal, PRL '98 [Phys. Rev. Lett. **81**, 673 (1998)]

Energies for magnetoexciton





Dethlefsen et al., PRB '06 [Phys. Rev. B **74**, 195324 (2006)]

CF filling factor 2: magnetoexcitons

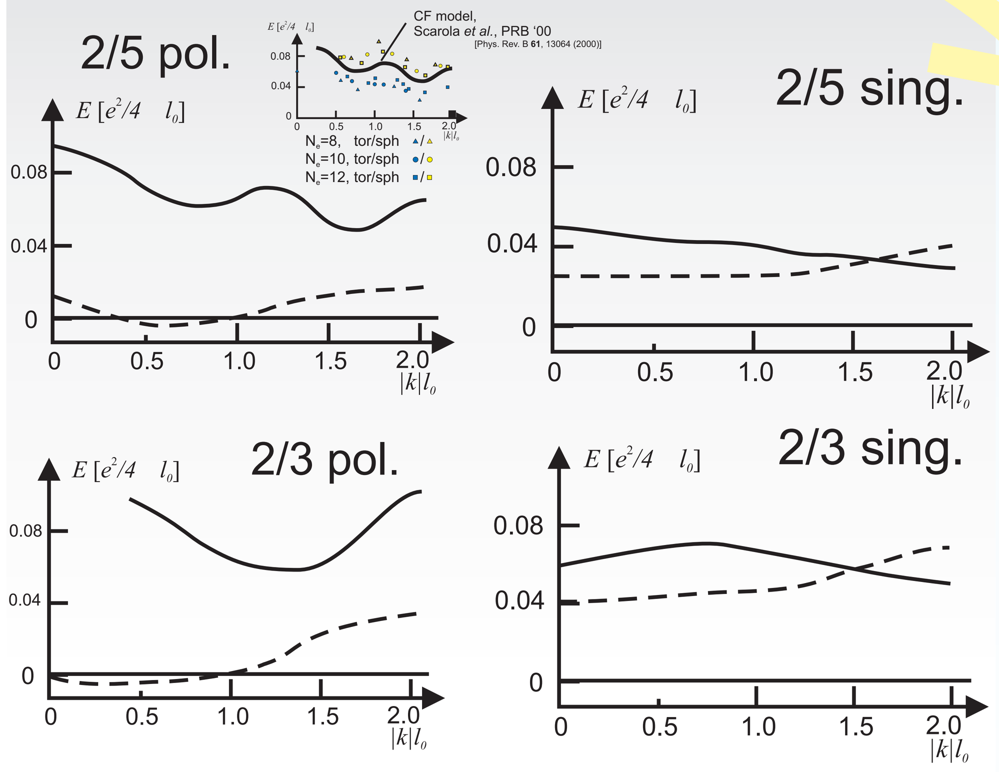
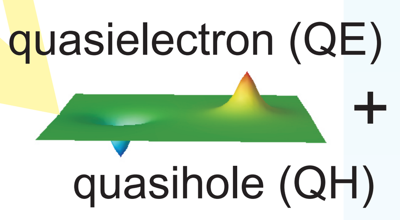
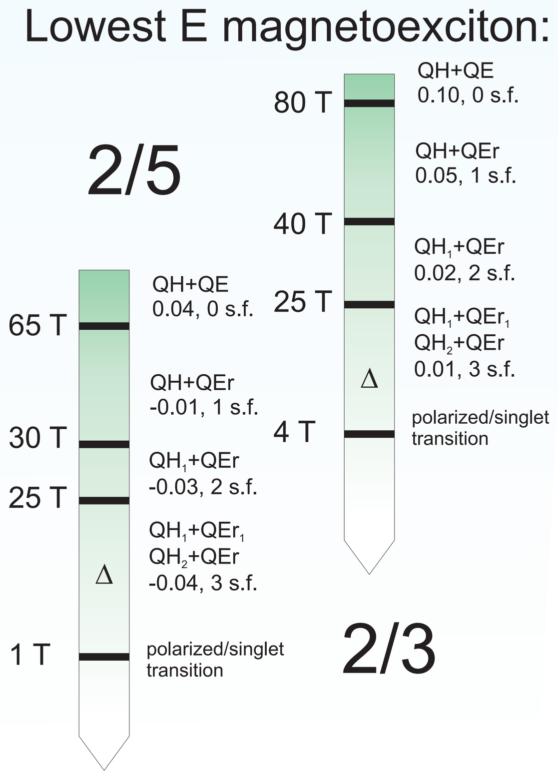


Fig. 2



Lowest E magnetoexciton:



Energies for spin-flips

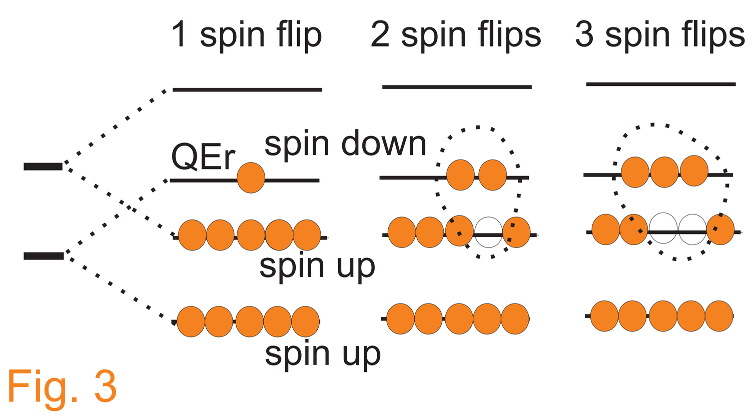
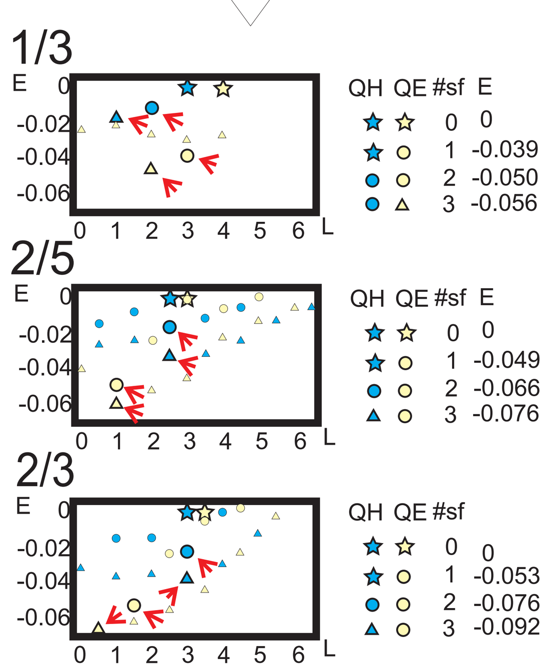


Fig. 3

Flipping spin of a quasiparticle

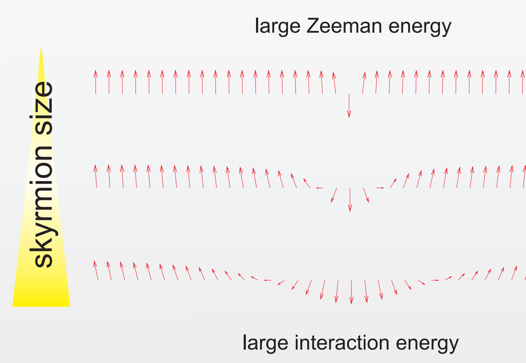
- costs Zeeman energy
- may reduce the interaction (Coulomb) energy

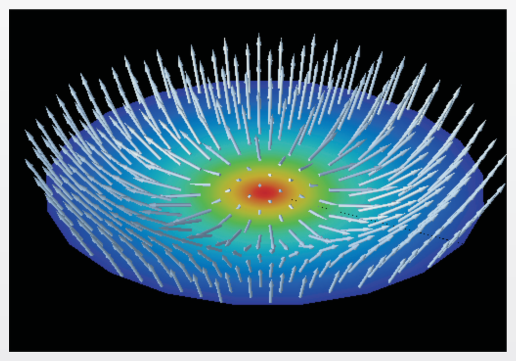


What are these states microscopicallyΔ

Skyrmions (spin textures) - = 1 or 1/3

only for Heisenberg ferromagnets (filling 1 or 1/3)





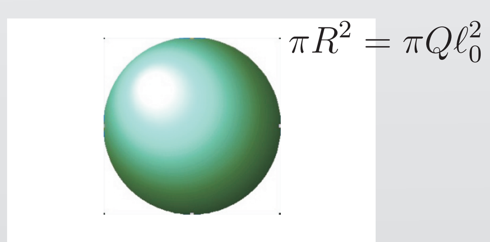
Sondhi et al., PRB '93 [Phys. Rev. B **47**, 16419 (1993)]

But what about 2/5, 2/3...Δ

Exact diagonalisation

- finite system
- N_m single-electron states
- N_e electrons
- $\binom{N_m}{N_e}$ many-body states (Slater det.'s) → finite

sphere



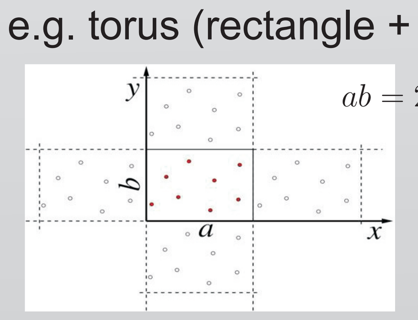
Haldane PRL '83 [Phys. Rev. Lett. **51**, 605 (1983)]

$$H = \frac{e^2}{4\pi\varepsilon\ell_0}\sum_{i<j}\frac{1}{|\vec{r}_i - \vec{r}_j|} + g\mu_B B\sum_i \sigma_i^z$$

magnetic length: $\ell_0 = \sqrt{\hbar/eB}$

energy units: $[e^2/4\pi\varepsilon\ell_0]$

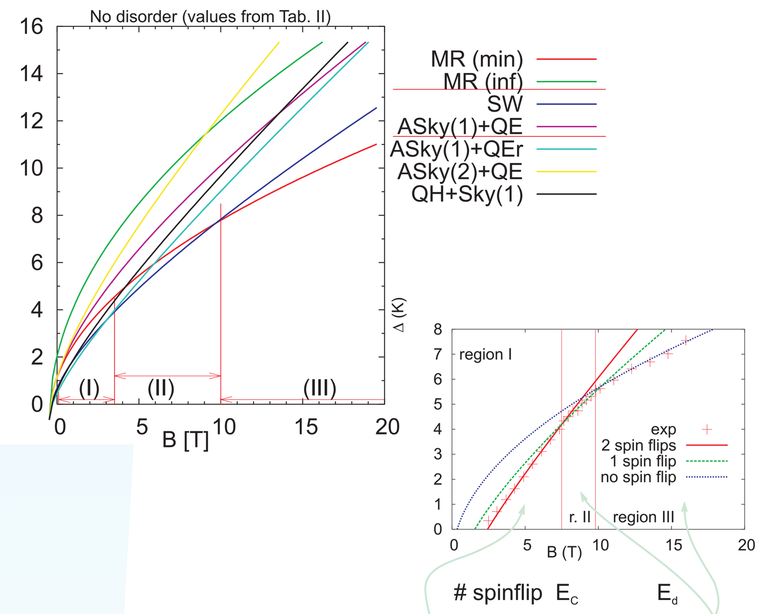
other possibilities: e.g. torus (rectangle + PBC)



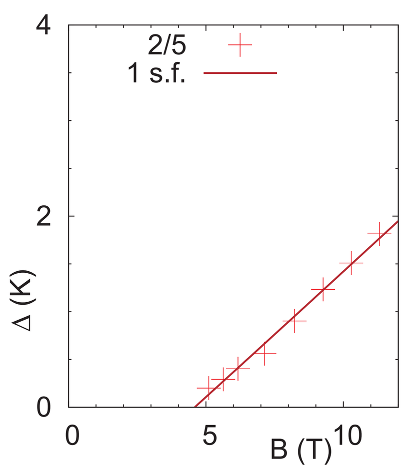
Yoshioka PRL '83 [Phys. Rev. B **29**, 6833 (1984)]

Gaps as a function of B: experiment analysis

$$\Delta\ [\mathrm{K}] = a \cdot \underbrace{50\sqrt{B\ [\mathrm{T}]}}_{e^2/4\pi\varepsilon\ell_0} + b \cdot 0.3\, B\ [\mathrm{T}] + E_d$$

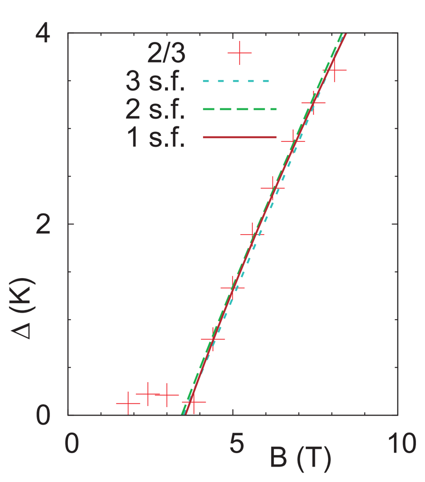


# spinflip	E_c	E_d
0	0.045	-1.5
1	0.033	-2.3
2	0.021	-2.8



Several alternatives...

# spinflip	E_c	E_d
0	0.029	-3.2
1	-0.001	-1.2
2	-0.030	0.9
3	-0.060	3.0



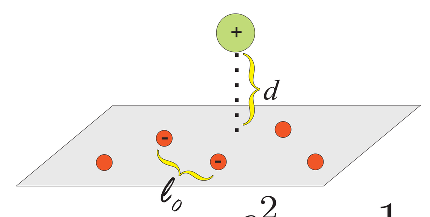
Several alternatives...

# spinflip	E_c	E_d
0	0.077	-7.5
1	0.052	-5.9
2	0.026	-4.4
3	0.001	-2.9

Microscopic model of disorder

impurity displaced by d

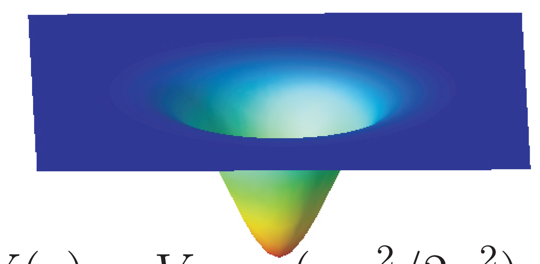
remote ionized donors



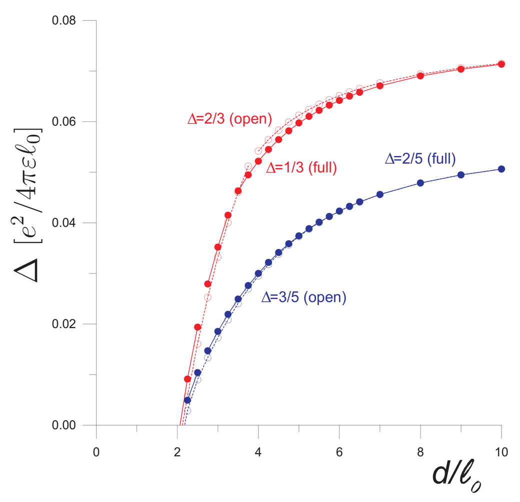
$$V(r) = \frac{e^2}{4\pi\varepsilon}\frac{1}{r^2 + d^2}$$

gaussian impurity

surface roughness

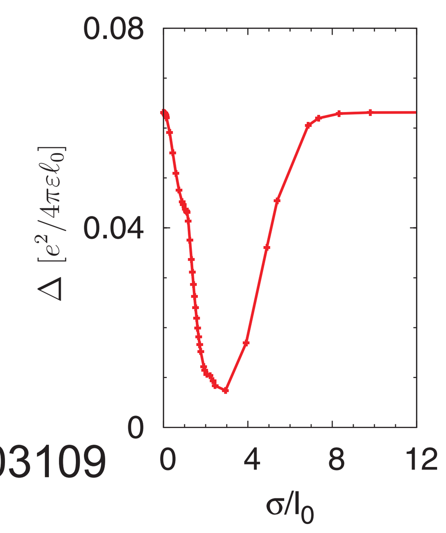


$$V(r) = V_0 \exp(-r^2/2\sigma^2)$$



General trend:

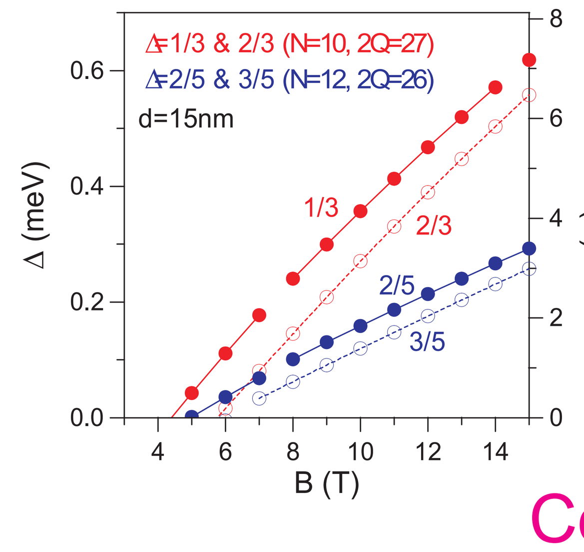
- as B decreases, so does d/ℓ_0 or ℓ_0 and finally the gap vanishes
- but gaps at 2/3 and 2/5 vanish at the same B

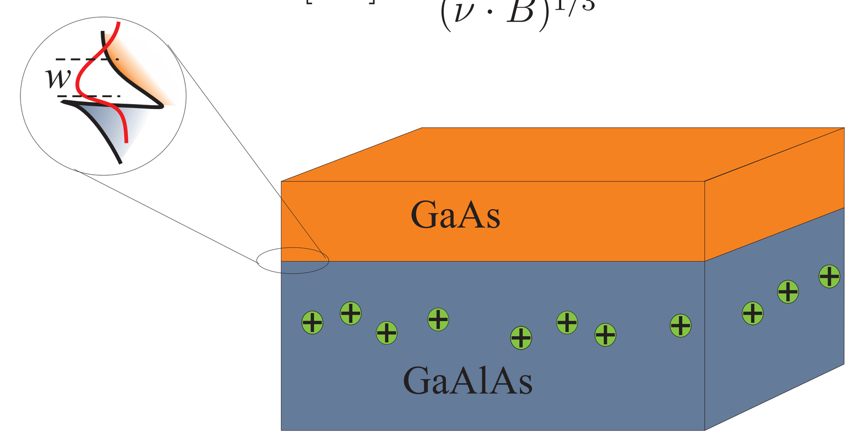


cond-mat/0703109

Improved: finite width

$$w\ [\mathrm{nm}] = \frac{30.0}{(\nu \cdot B)^{1/3}}$$





Conclusions

- lowest excitations contain spin flips not only for filling factor 1/3 but also 2/3, 2/5
  theory: more than one spin flip in a clean system (analogy of skyrmions at 1/3)
  experiment: spin flips possible but not their number uncertain
- simplified model of disorder: single charged impurity displaced by d from 2DEG
  single value of d can explain gap onsets at different filling factors
  finite width of the 2DEG has to be considered
  basic mechanism of gap collapse: comparing the magnetic length to some fixed disorder-related length scale

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