Wave Function and Emergent SU(2) Symmetry in $\nu_T = 1$ Quantum Hall Bilayer

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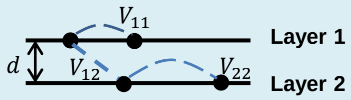
1) Bilayer Quantum Hall system in lowest Landau levels (LLLs):



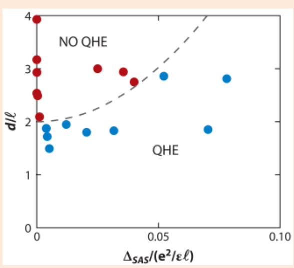
Layer distance d
Magnetic length $\ell = \sqrt{\hbar c/eB}$
Coulomb interaction

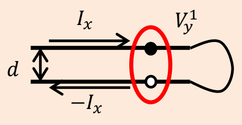
$$V_{11}(r) = V_{22}(r) = \frac{e^2}{\epsilon r}, \qquad V_{12}(r) = \frac{e^2}{\epsilon\sqrt{r^2+d^2}}$$

Interlayer hopping Δ_{SAS} (small, set to 0 hereafter)

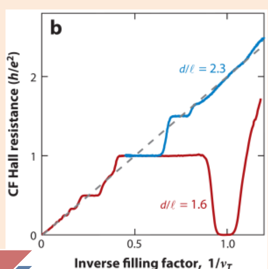
2) Exciton Condensate at $\nu_T = \frac{1}{2}+\frac{1}{2} = 1$

Hall conductance

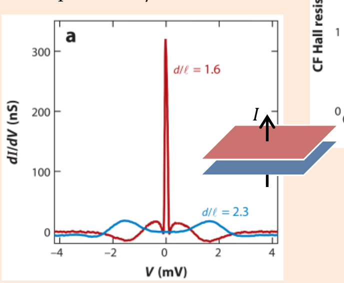




Counterflow current drives charge neutral excitons



Interlayer tunneling peak for $d/\ell < 1.8$



Counterflow Hall resistence vanishes for $d/\ell < 1.8$

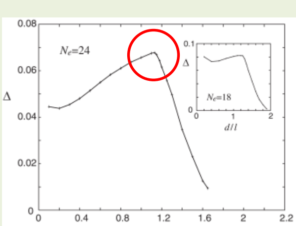
Eisenstein 2014

Via a PH transformation in LLL of layer 2, one has an exciton superfluid forms at $d/\ell < 1.8$,

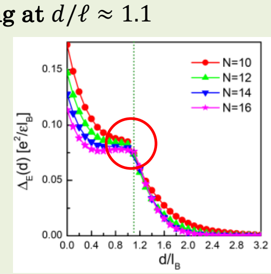
$$\langle c_1^\dagger(r)c_2(r)\rangle \neq 0\,.$$

Equivalently, by defining layer indices 1 & 2 as pseudospin ↑ & ↓, the superfluid can be viewed as an in-plane ferromagnet.

3) Charge gap level crossing at $d/\ell \approx 1.1$



DMRG, Shibata & Yoshioka 2006



ED, Zhu, Fu & Sheng 2017

Conjecture:
The level crossing is due to an emergent SU(2) symmetry.

4) An exact SU(2) symmetric point: $d/\ell = 0$

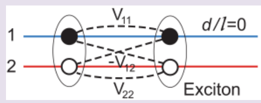
$V_{11}(r) = V_{22}(r) = V_{12}(r)$ indicates SU(2) pseudospin symmetry. The ground state is the **Halperin (111) state**:

$$\Psi_{111} = \mu(z,w)\prod_{i<j}^{N}(z_i-z_j)\prod_{k<l}^{M}(w_k-w_l)\prod_{i,k}^{N,M}(z_i-w_k)$$

After PH-transformation in LLL of layer 2, Ψ_{111} becomes

$$\Psi_0 = \det M_{ij}\,, \quad M_{ij} = e^{-\left(|z_i|^2+|w_j|^2-2z_iw_j^*\right)/4\ell^2} = e^{-|z_i-w_j|^2/4\ell^2+i\phi_{ij}}$$

Physical picture: condensate of free excitons



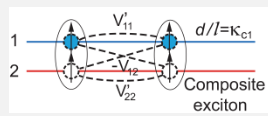
Free due to SU(2) symmetry:

$$V_E = V_{11} + V_{22} - 2V_{12} = 0$$

5) Emergent SU(2) symmetry of CBs at $d/\ell \approx 1.1$

Define a composite boson (CB) as an electron bound with an intralayer flux.

Interaction $V'_{ij}(r)$ between CBs:
$V'_{11}(r) < V_{11}(r)$ as screened by fluxes
$V'_{12}(r) \approx V_{12}(r)$ for interlayer CBs



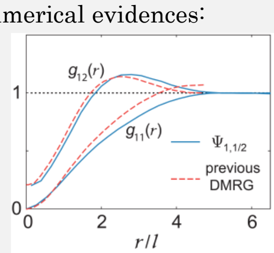
Conjecture: $V'_{11}(r) \approx V'_{12}(r)$ at $d/\ell \approx 1.1$.

This indicates formation of a condensate of free CB excitons.
A **trial wave function** in electron-hole basis:

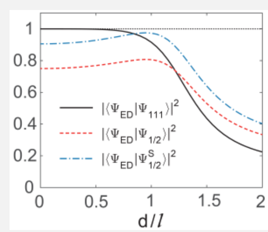
$$\Psi_{1,1/2} = \prod_{i<j}(z_i-z_j)(w_i^*-w_j^*)\,\mathrm{perm}\,M'_{ij}\,, \qquad \mathrm{perm}\,M_{ij} = \sum_\sigma\prod_i M_{i\sigma_i}$$

$$M'_{ij} = e^{-\left(|z_i|^2+|w_j|^2-z_iw_j^*\right)/4\ell^2} = \underbrace{e^{-|z_i-w_j|^2/8\ell^2}}_{\text{exciton}}\underbrace{{}^{-|z_i|^2/8\ell^2-|w_i|^2/8\ell^2+i\phi_{ij}}}_{\text{½ filling per layer}}$$

Numerical evidences:

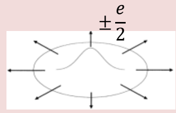


Correlation functions compared with DMRG at $d/\ell \approx 1.1$

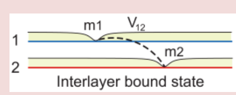


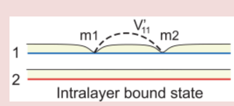
Overlap with ED (4-electron)

6) Possible crossing levels at $d/\ell \approx 1.1$: meron-antimeron bound states of total charge $\pm e$



A meron traps a half charge





Bound state (BS) energy: $V_{ij}(r)/4 + \eta\ln r$
Interlayer BS & intralayer BS becomes degenerate when $V'_{11} = V'_{12}$ (level crossing).

Discussion:

Free excitons at $d/\ell \approx 1.1$ possibly indicates a vanishing Goldstone mode velocity. Is it a phase transition point?

It suggests intralayer meron BS has lower energies at $d/\ell > 1.1$, and may play a key role in superfluid metal transition at $d/\ell \approx 1.8$.