Journal Club ;

Henok Weldeyesus, 01.07.2022

SCIENCE ADVANCES | RESEARCH ARTICLE

PHYSICS

Observing separate spin and charge Fermi seas in a strongly correlated one-dimensional conductor

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An electron is usually considered to have only one form of kinetic energy, but could it have more, for its spin and charge, by exciting other electrons? In one dimension (1D), the physics of interacting electrons is captured well at low energies by the Tomonaga-Luttinger model, yet little has been observed experimentally beyond this linear regime. Here, we report on measurements of many-body modes in 1D gated wires using tunneling spectroscopy. We observe two parabolic dispersions, indicative of separate Fermi seas at high energies, associated with spin and charge excitations, together with the emergence of two additional 1D "replica" modes that strengthen with decreasing wire length. The interaction strength is varied by changing the amount of 1D intersubband screening by more than 45%. Our findings not only demonstrate the existence of spin-charge separation in the whole energy band outside the low-energy limit of the Tomonaga-Luttinger model but also set a constraint on the validity of the newer nonlinear Tomonaga-Luttinger theory.

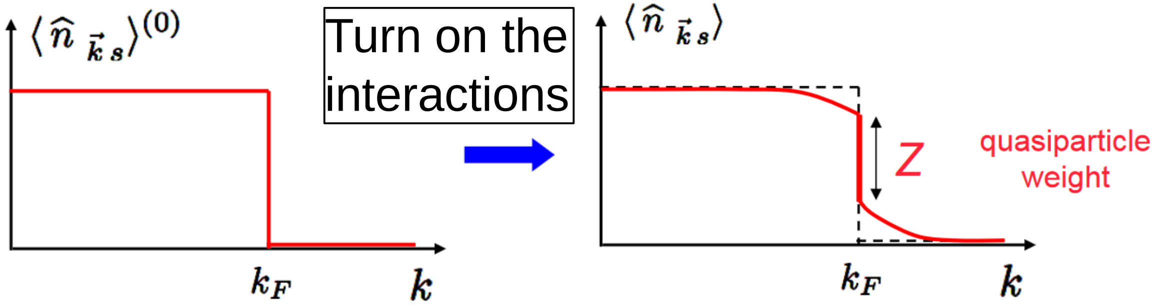
What to expect (Outline)

- Introduction:
  - Recap: Momentum resolved tunneling in 1d
  - Recap: Effects of strong interactions in 1d
  - Previous results

- This paper:
  - The new device
  - Measurements and results
    - “Replica” modes / two fermi seas
    - Screening of interactions

Fermi liquid theory

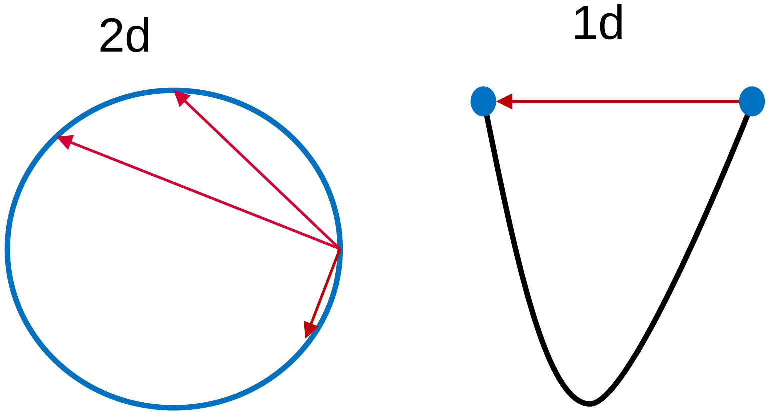
- Low temperature description of many metals
- Interacting electrons → non-interacting quasi particle excitations

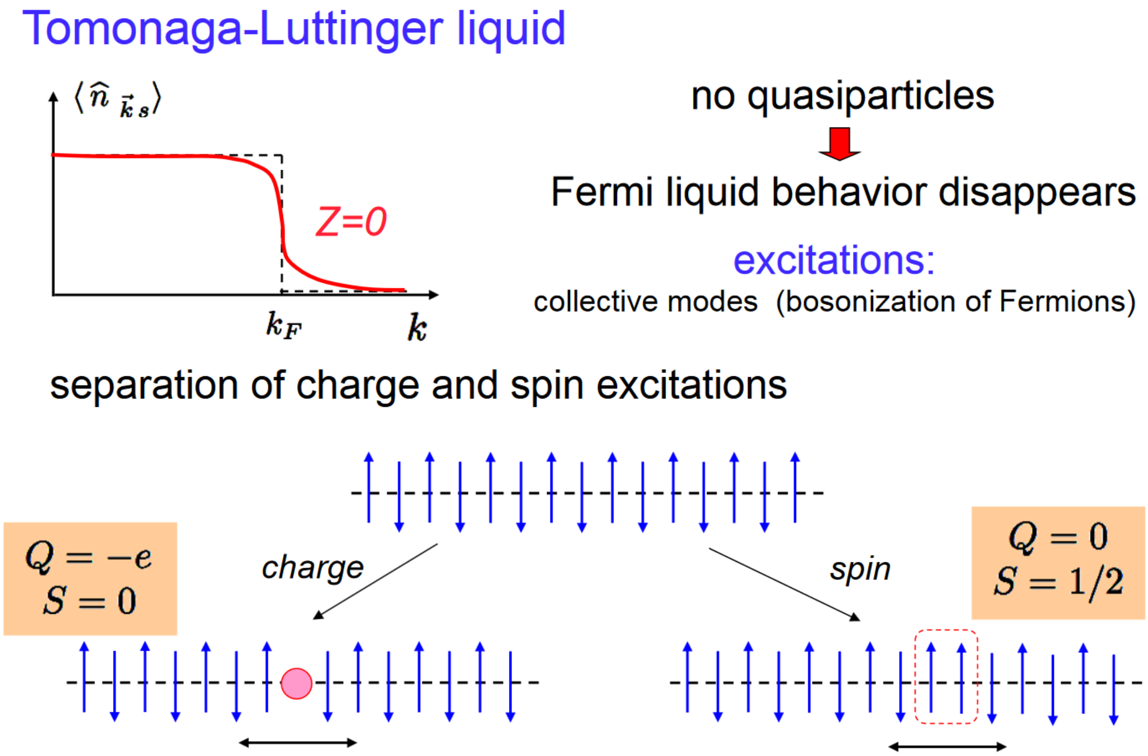


Lecture notes: Solid state theory Manfred Sigrist 2014

Breakdown of Fermi liquid theory in 1d

- Fermi liquid theory only works in 2d/3d

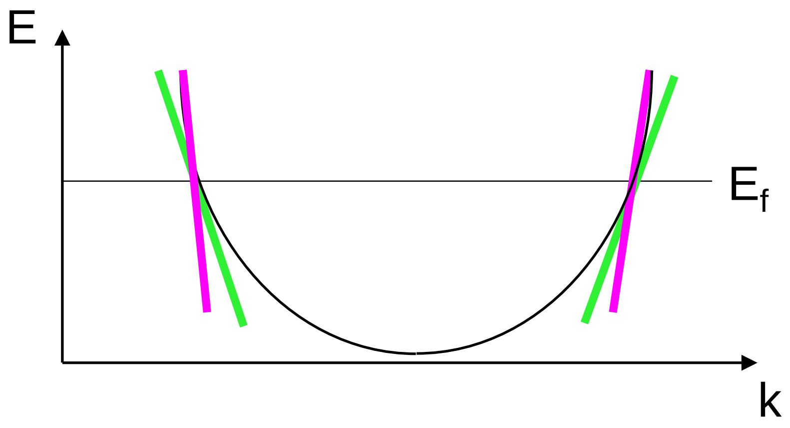




Lecture notes: Solid state theory Manfred Sigrist 2014

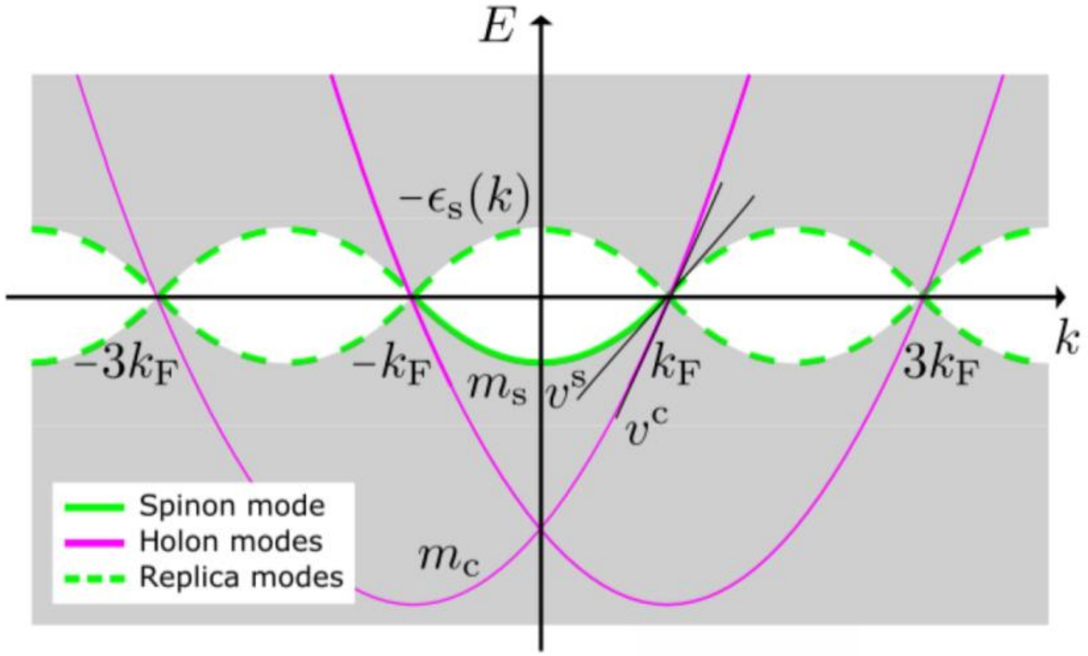
Lutinger Liquids

- Fermi liquid theory breaks down in 1d
- Correct model is Tomonaga luttinger liquid
  - At least at low energys
  - Dispersion is linearized around Fermi points
  - Two collective excitations (Spin-charge Separation)
    - Charge (Holon)
    - Spin (Spinon)



Effects of strong interactions in 1d
Beyond Luttinger-Liquids

- Luttinger liquid doenst include band curvature
- Only low energy description
- Excitations don’t decay
- High energy descriptions are currently investigated



Previous results

Hierarchy of Modes in an Interacting One-Dimensional System

O. Tsyplyatyev, A. J. Schofield, Y. Jin, M. Moreno, W. K. Tan, C. J. B. Ford, J. P. Griffiths, I. Farrer, G. A. C. Jones, and D. A. Ritchie

Phys. Rev. Lett. **114**, 196401 – Published 11 May 2015

Nature of the many-body excitations in a quantum wire: Theory and experiment

O. Tsyplyatyev, A. J. Schofield, Y. Jin, M. Moreno, W. K. Tan, A. S. Anirban, C. J. B. Ford, J. P. Griffiths, I. Farrer, G. A. C. Jones, and D. A. Ritchie

Phys. Rev. B **93**, 075147 – Published 24 February 2016

Momentum-dependent power law measured in an interacting quantum wire beyond the Luttinger limit

Y. Jin, O. Tsyplyatyev, M. Moreno, A. Anthore, W. K. Tan, J. P. Griffiths, I. Farrer, D. A. Ritchie, L. I. Glazman, A. J. Schofield & C. J. B. Ford

Nature Communications **10**, Article number: 2821 (2019) | Cite this article

1834 Accesses | **10** Citations | **1** Altmetric | Metrics

Nonlinear spectra of spinons and holons in short GaAs quantum wires

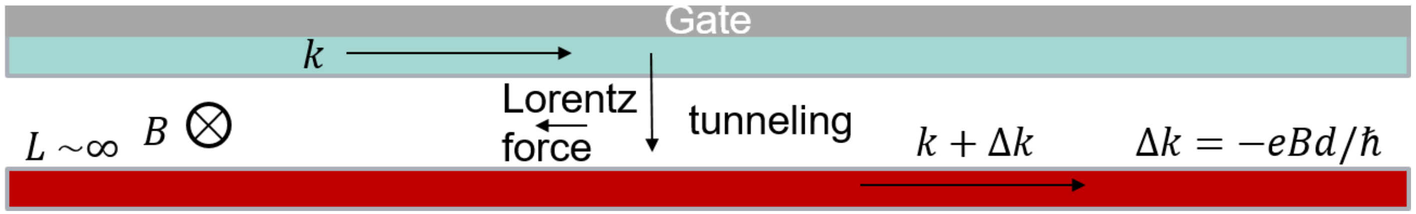
M Moreno, C. J. B. Ford, Y. Jin, J. P. Griffiths, I. Farrer, G. A. C. Jones, D. A. Ritchie, O. Tsyplyatyev & A. J. Schofield

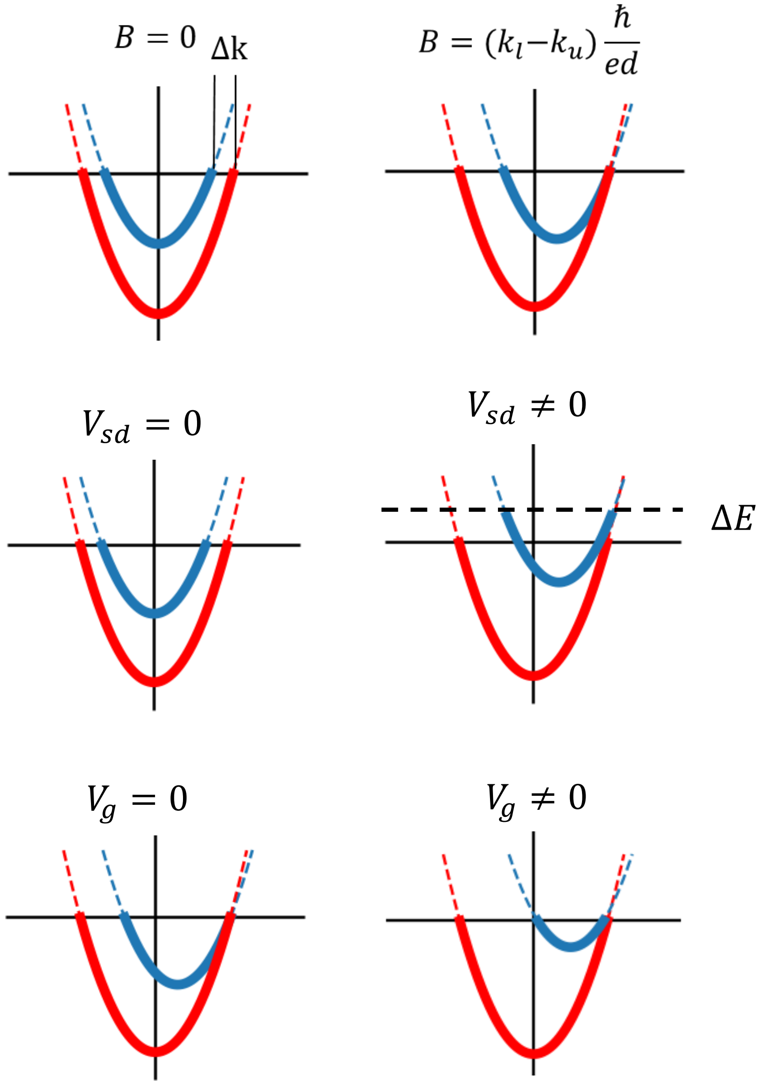
Nature Communications **7**, Article number: 12784 (2016) | Cite this article

3772 Accesses | **14** Citations | **89** Altmetric | Metrics

Recap: Momentum resolved tunneling in 1d

- <u>Magnetic field</u> ***B*** changes momentum of tunneling electrons
  - Shifts dispersions with respect to each other.
- <u>Bias voltage</u> $\boldsymbol{V_{sd}}$ shifts dispersions in energy by $\boldsymbol{eV_{sd}}$
- <u>Gate voltage</u> $\boldsymbol{V_g}$ tunes density
  - Changes $\boldsymbol{k_f}$
- Increased conductance when matching Fermi-points

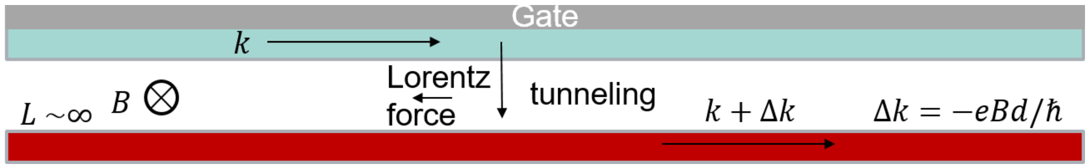


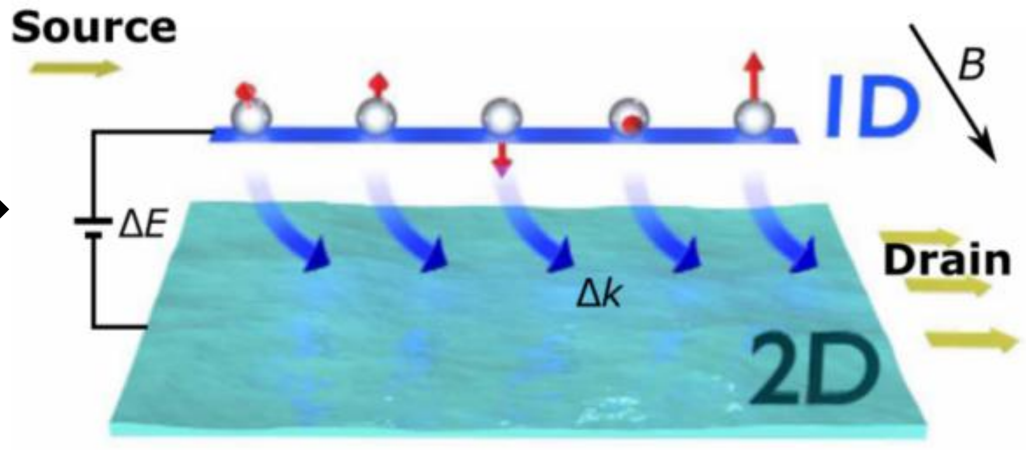


Recap: Momentum resolved tunneling in 1d

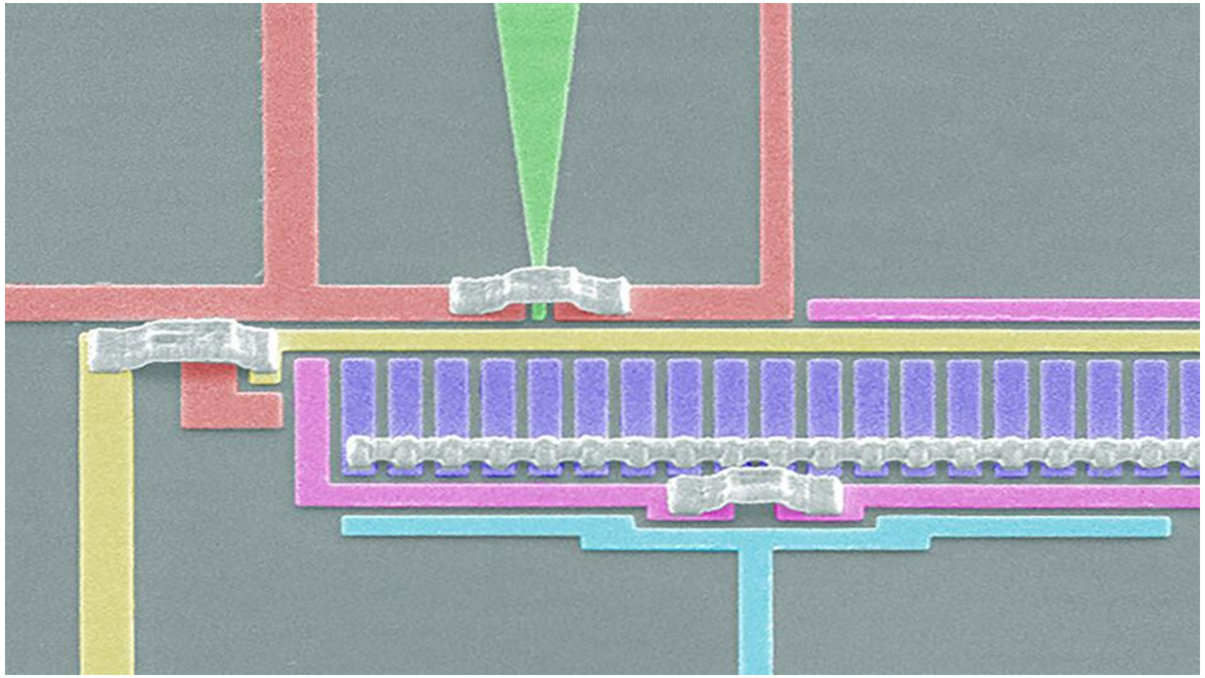
1D – 1D

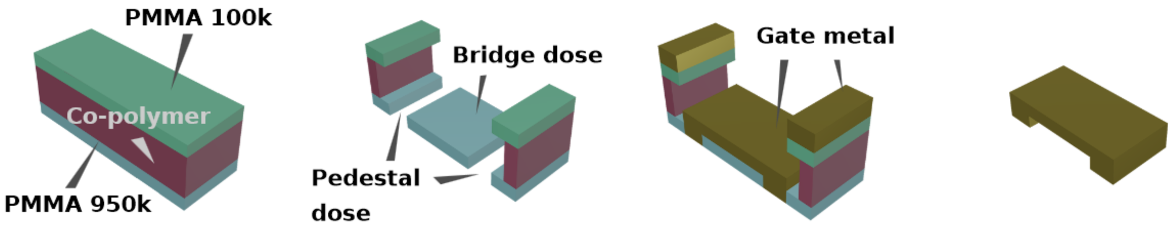
1D – 2D





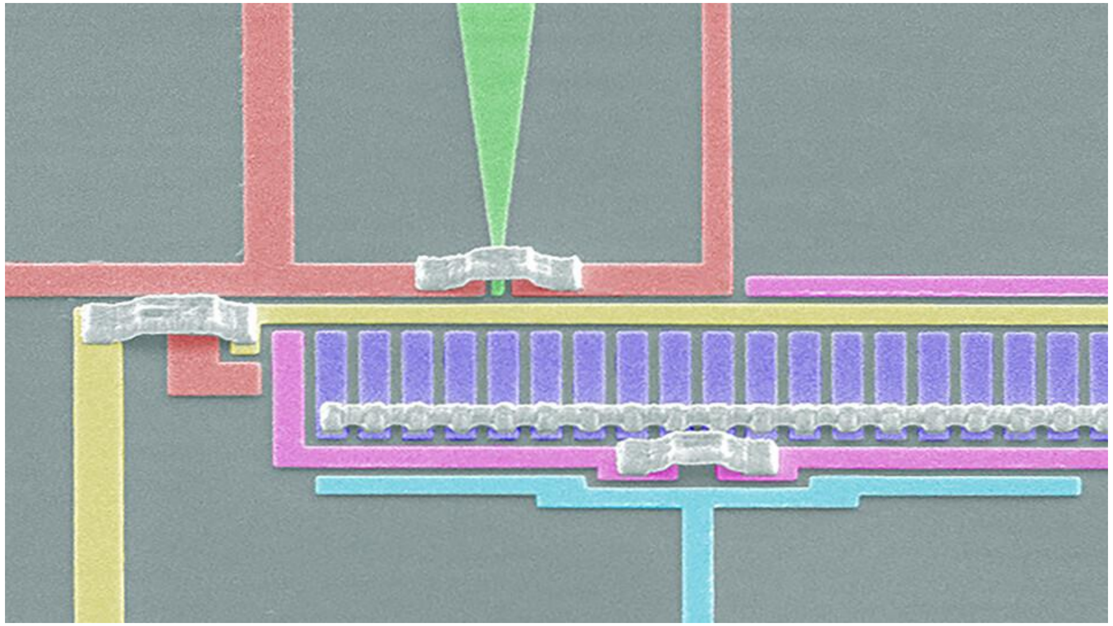
The device

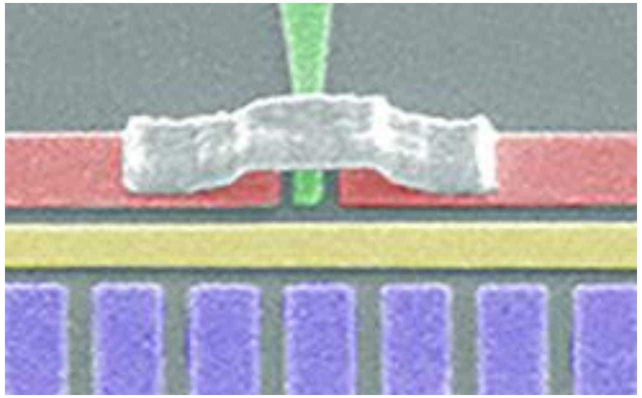


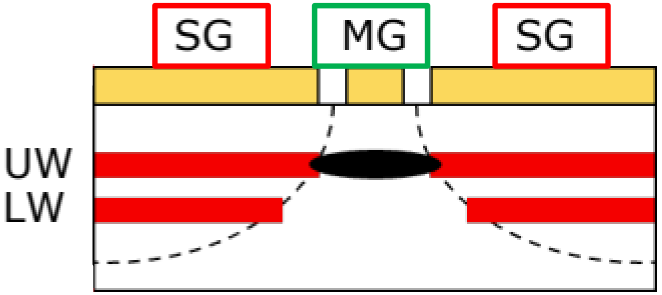

PMMA 100k
Co-polymer
PMMA 950k
Bridge dose
Pedestal dose
Gate metal

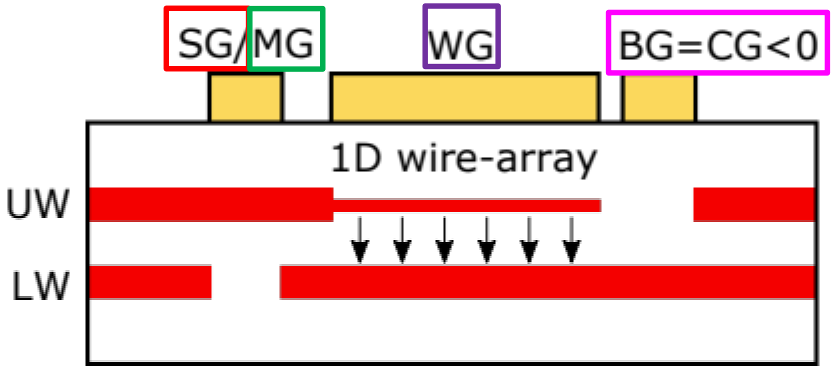
The device: Setup tunneling

Bias MG positive after pinching both upper and lower system to attract carriers in the upper system only

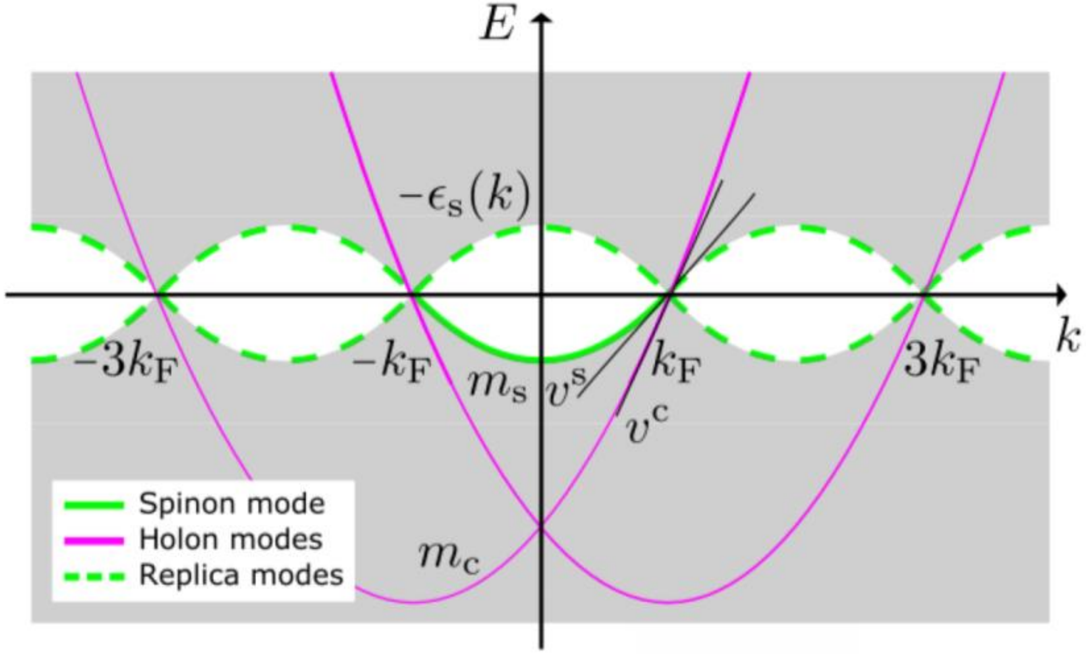


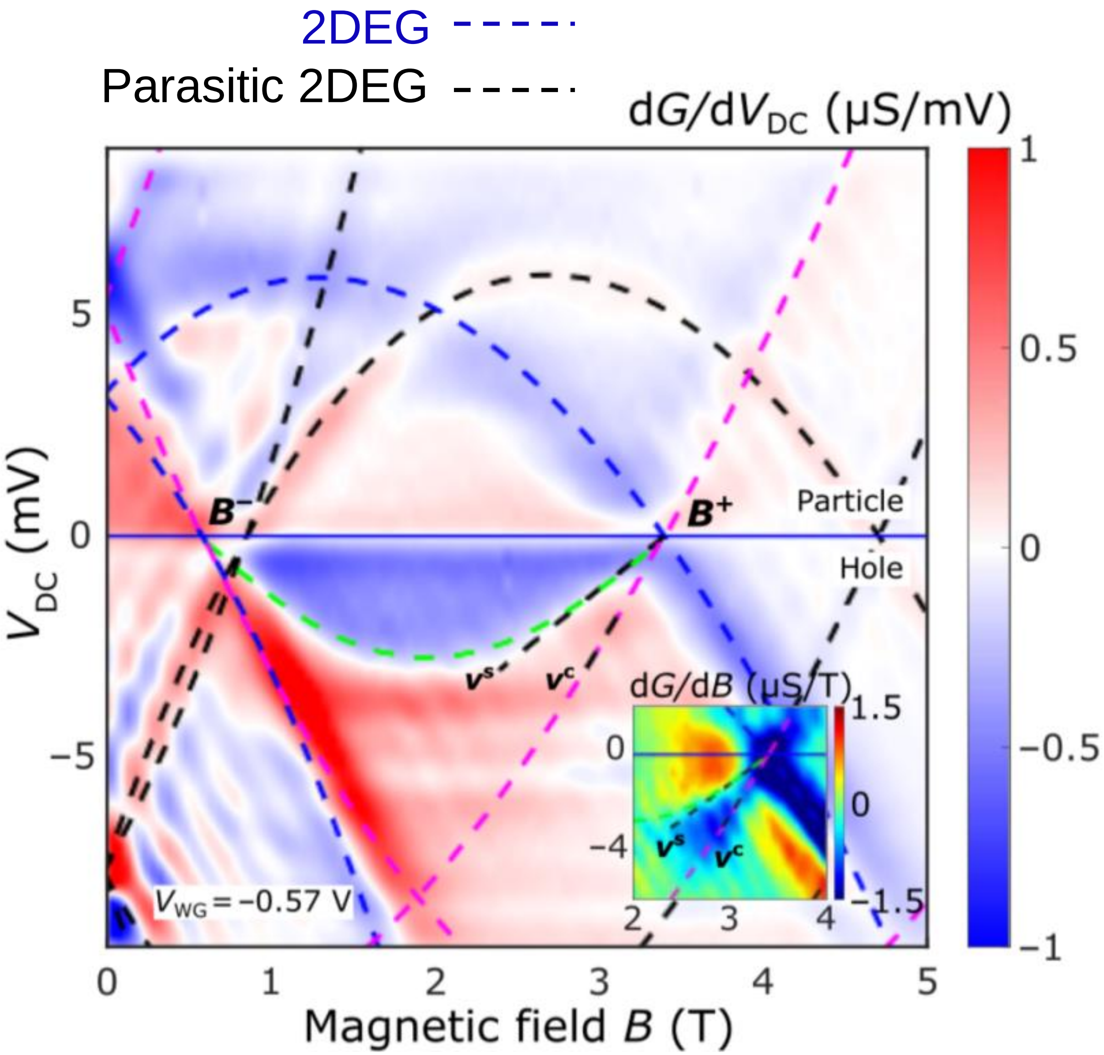






Measurements and results / “Replica” modes

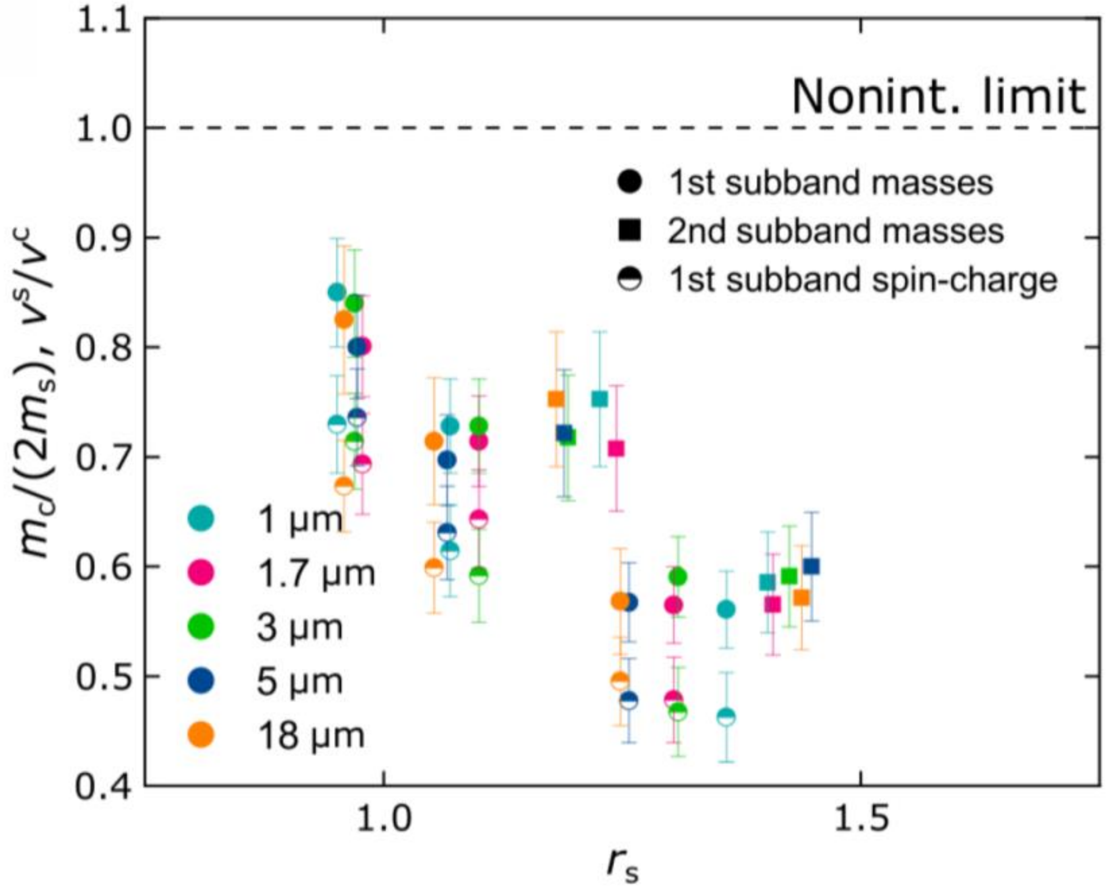




Measurements and results / interaction strength

- Masses extracted from parabolic fits.
- Velocities extracted from slope near $\boldsymbol{E_f}$
- $\boldsymbol{r_s}$ is varied by gatevoltage

Smaller means stronger interactions



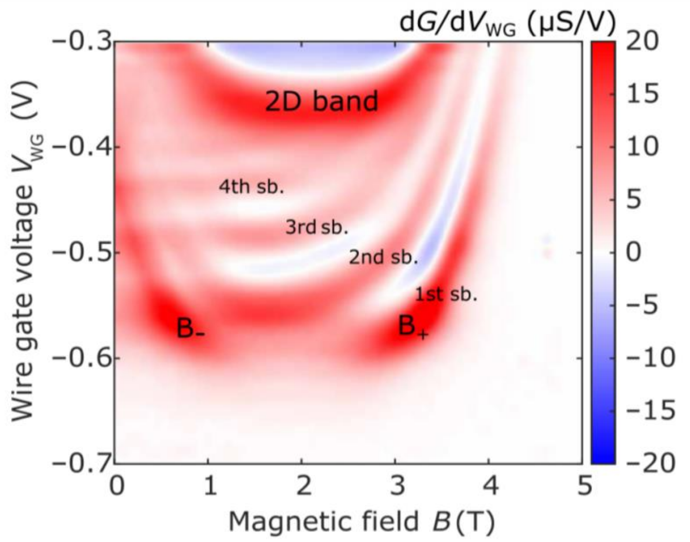
$r_s = 1/(2\,a_B'\,n_{1D})$

Measurements and results / Two fermi seas Screening of interactions

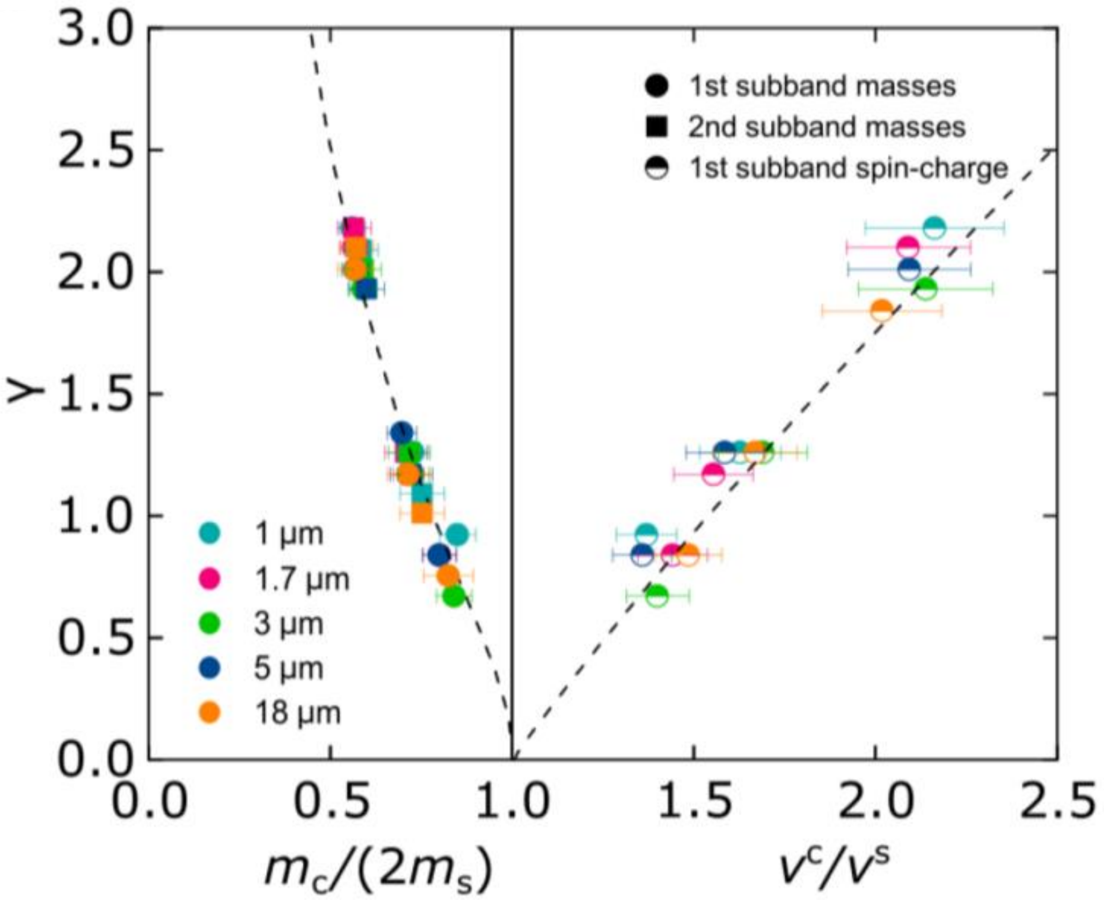
Hubbard Modell

$$\hat{H} = \underbrace{-t \sum_{i,\sigma} \left(\hat{c}^{\dagger}_{i,\sigma} \hat{c}_{i+1,\sigma} + \hat{c}^{\dagger}_{i+1,\sigma} \hat{c}_{i,\sigma} \right)}_{\text{Hopping term}} + \underbrace{U \sum_{i} \hat{n}_{i\uparrow} \hat{n}_{i\downarrow}}_{\text{Coulomb term}},$$

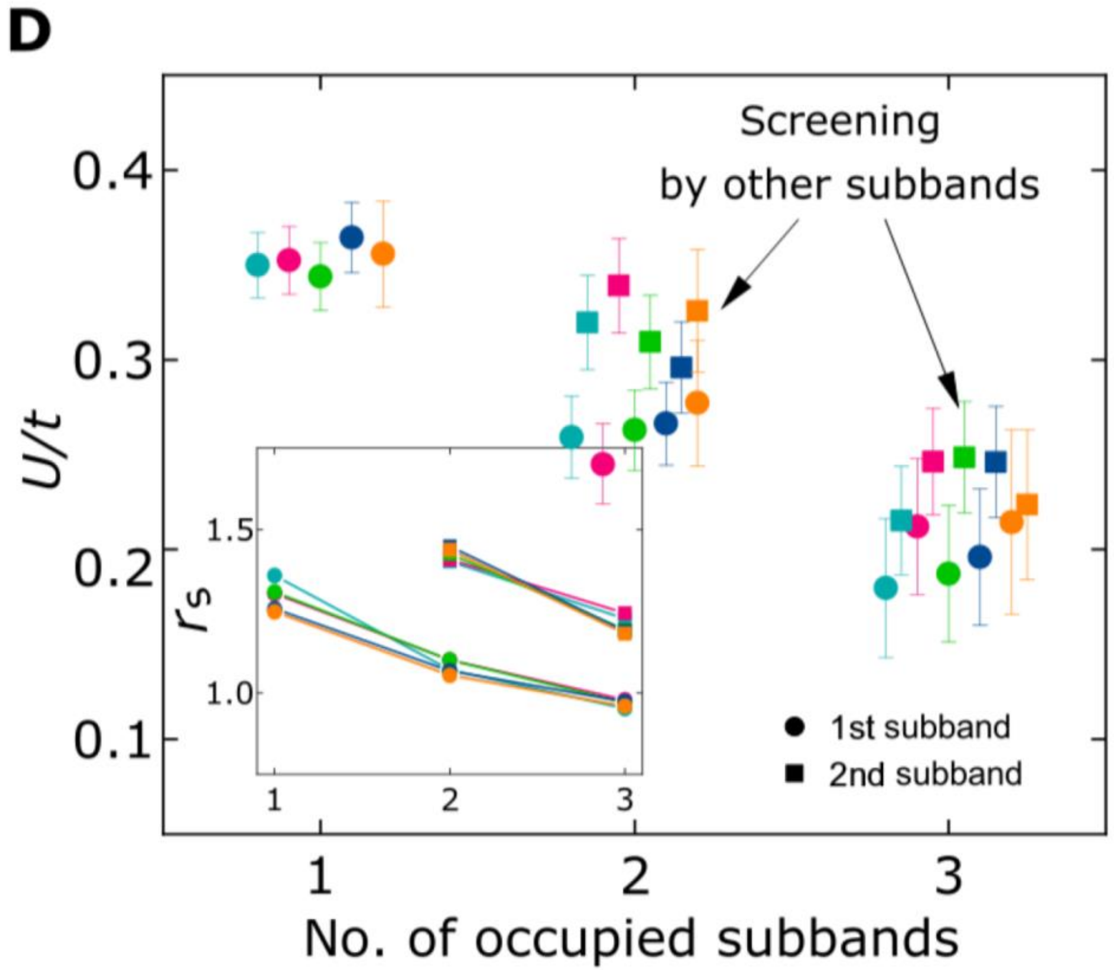
U/t → bigger means stronger interactions



$$\gamma = 0.032 \frac{\lambda_F}{a} \frac{U}{t}$$



Measurements and results / Two fermi seas Screening of interactions



Summary