Finanziato dall'Unione europea NextGenerationEU
Ministero dell'Università e della Ricerca
Italiadomani PIANO NAZIONALE DI RIPRESA E RESILIENZA
NQSTI National Quantum Science and Technology Institute

Towards superconducting correlations in the quantum Hall regime

Stefan Heun CNR-NANO

09/09/2024

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Matteo Pioldi

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Francesco Giazotto

iit @NEST ISTITUTO ITALIANO DI TECNOLOGIA

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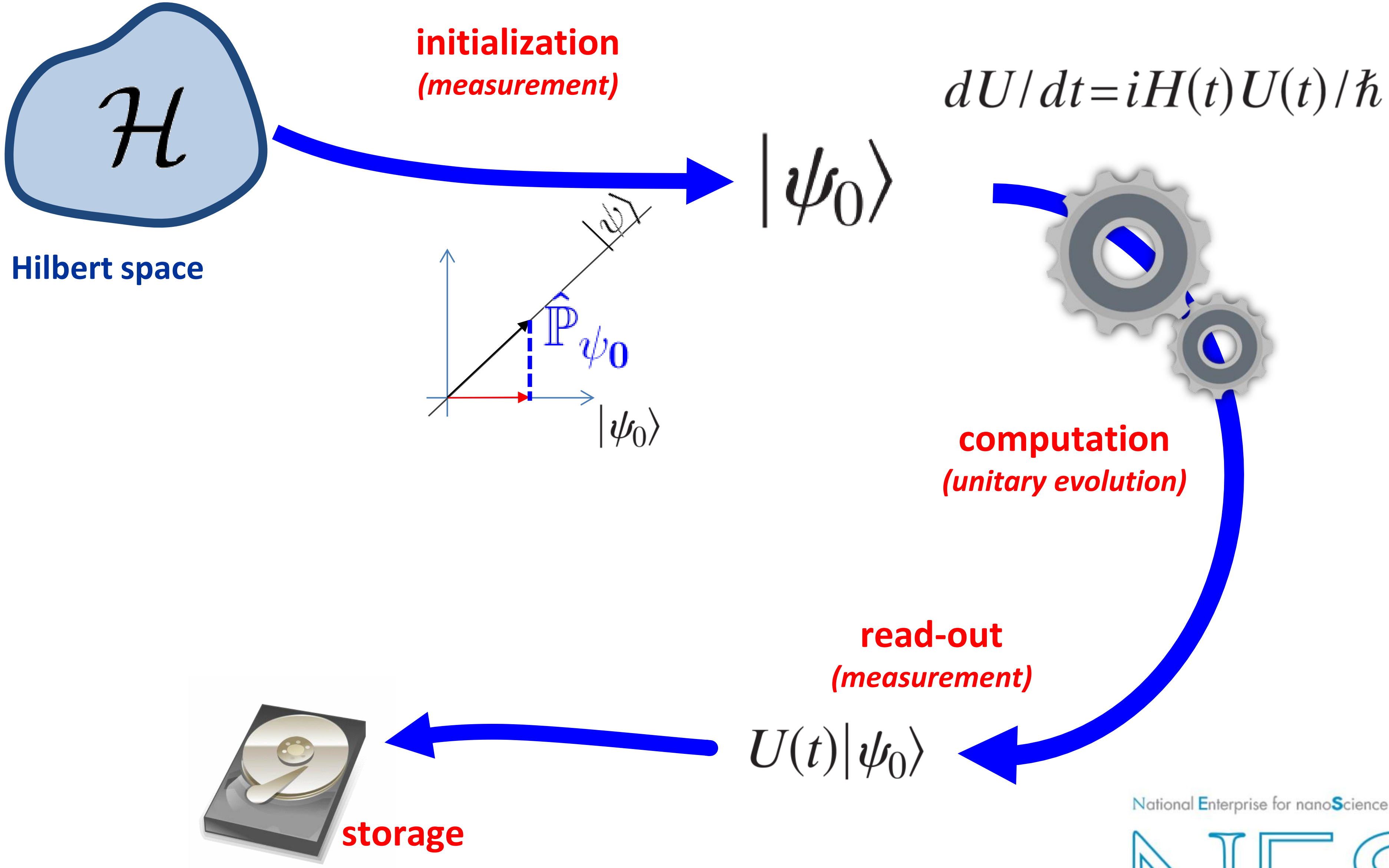
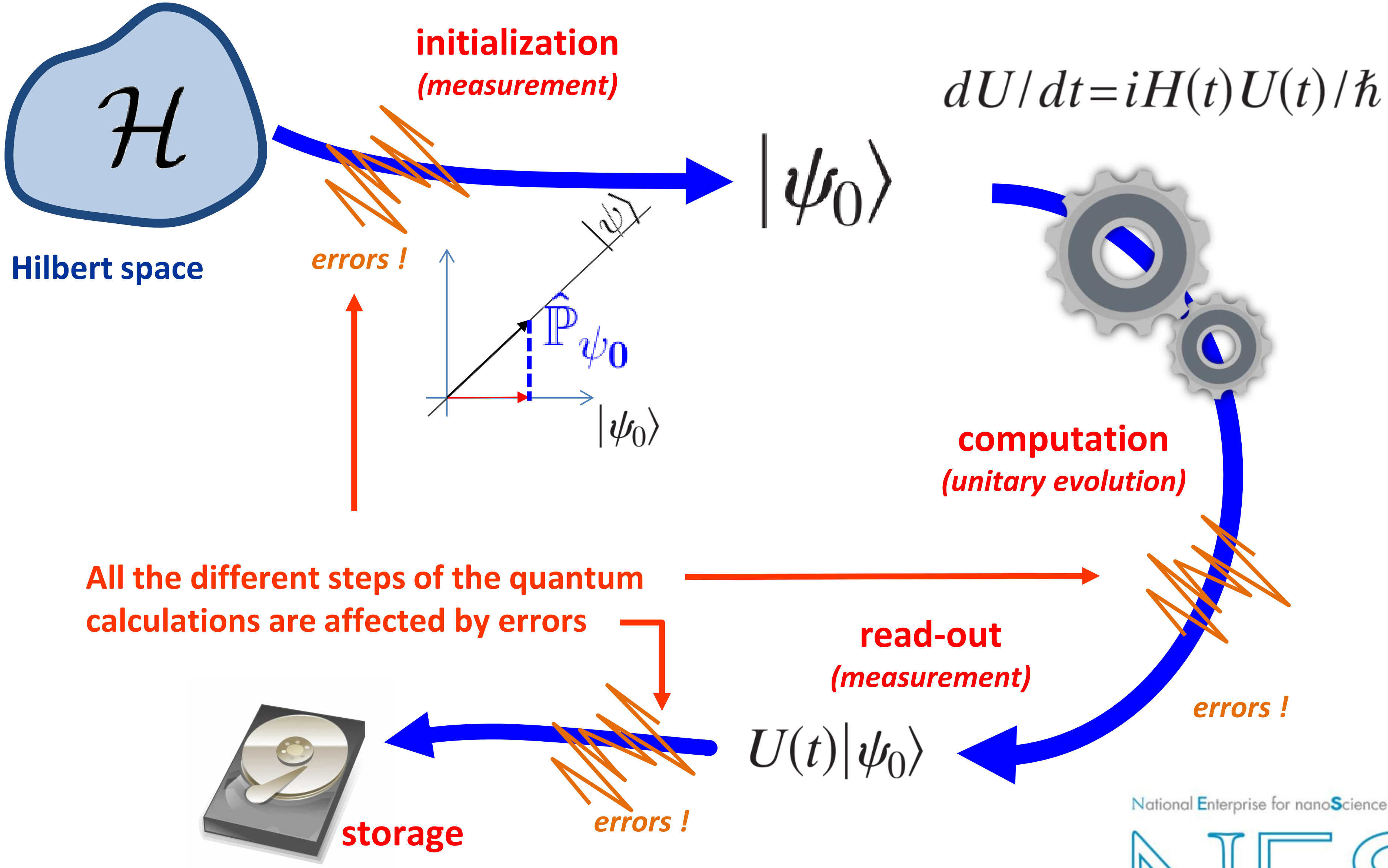
The road to quantum computing



The road to quantum computing



National Enterprise for nanoScience and nanoTechnology

Topological States of Matter

New states of Matter:

NEWS IN FOCUS

PHYSICS

Nobel for 2D exotic matter

Physics award goes to theorists who used topology to explain strange phenomena.

BY ELIZABETH GIBNEY AND DAVIDE CASTELVECCHI

David Thouless, Duncan Haldane and Michael Kosterlitz have won the 2016 Nobel Prize in Physics for their theoretical explanations of strange states of matter in 2D materials, known as topological phases.

The British-born trio's work in the 1970s and 1980s laid the foundations for predicting and explaining bizarre behaviours that experimentalists discovered at the surfaces of materials, and inside extremely thin layers. These include superconductivity — the ability to conduct without resistance — and magnetism in very thin materials. At the time, these mathematical theories were quite abstract, said Haldane in an

Physics prizewinners Michael Kosterlitz (left), David Thouless (centre) and Duncan Haldane (right).

Nature 538 (2016) 18

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Nobel for 2D exotic matter

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BY ELIZA
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Nat

PERSPECTIVE
PUBLISHED ONLINE: 25 OCTOBER 2017 | DOI: 10.1038/NMAT5012
nature materials

Topological states of condensed matter

Jing Wang[1,2]* and Shou-Cheng Zhang[3]*

Topological states of quantum matter have been investigated intensively in recent years in materials science and condensed matter physics. The field developed explosively largely because of the precise theoretical predictions, well-controlled materials processing, and novel characterization techniques. In this Perspective, we review recent progress in topological insulators, the quantum anomalous Hall effect, chiral topological superconductors, helical topological superconductors and Weyl semimetals.

Nat. Mater. 16 (2017) 1062

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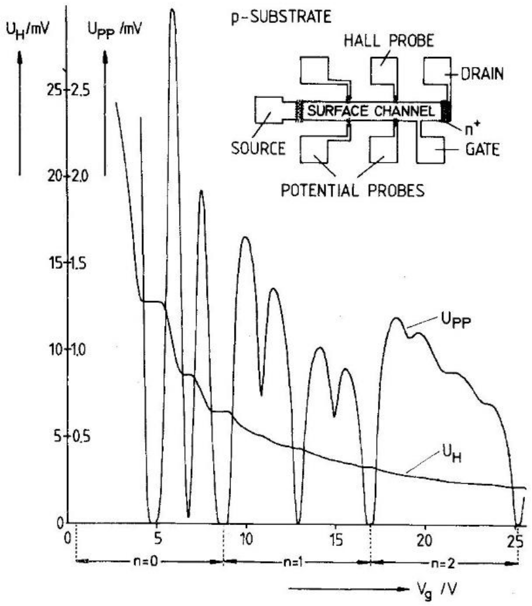
Quantum Hall Effect

VOLUME 45, NUMBER 6 PHYSICAL REVIEW LETTERS 11 AUGUST 1980

New Method for High-Accuracy Determination of the Fine-Structure Constant Based on Quantized Hall Resistance

K. v. Klitzing
Physikalisches Institut der Universität Würzburg, D-8700 Würzburg, Federal Republic of Germany, and Hochfeld-Magnetlabor des Max-Planck-Instituts für Festkörperforschung, F-38042 Grenoble, France



K. v. Klitzing et al., PRL 45 (1980) 494.

PHYSICAL REVIEW B VOLUME 38, NUMBER 14 15 NOVEMBER 1988-I

Absence of backscattering in the quantum Hall effect in multiprobe conductors

M. Büttiker
IBM Thomas J. Watson Research Center, P.O. Box 218, Yorktown Heights, New York 10598
(Received 21 March 1988)

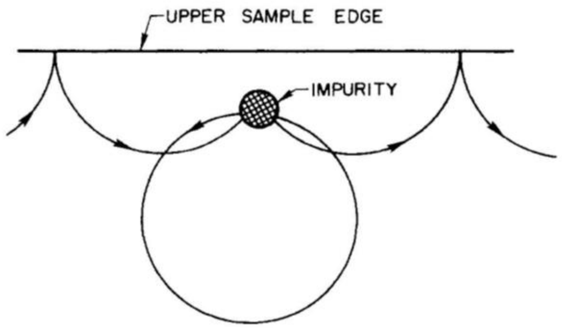


FIG. 4. Quasiclassical skipping orbits along the upper edge of the sample in presence of a localized impurity. In a high magnetic field backscattering over distances large compared to the cyclotron radius is suppressed.

M. Büttiker, PRB 38 (1988) 9375.

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Topological States of Matter

REVIEW

Topological Quantum Computation—From Basic Concepts to First Experiments

Ady Stern[1]* and Netanel H. Lindner[2,3]

Quantum computation requires controlled engineering of quantum states to perform tasks that go beyond those possible with classical computers. Topological quantum computation aims to achieve this goal by using non-Abelian quantum phases of matter. Such phases allow for quantum information to be stored and manipulated in a nonlocal manner, which protects it from imperfections in the implemented protocols and from interactions with the environment. Recently, substantial progress in this field has been made on both theoretical and experimental fronts. We review the basic concepts of non-Abelian phases and their topologically protected use in quantum information processing tasks. We discuss different possible realizations of these concepts in experimentally available solid-state systems, including systems hosting Majorana fermions, their recently proposed fractional counterparts, and non-Abelian quantum Hall states.

The principal obstacles on the road to quantum computing are noise and decoherence. By noise, we mean imperfections in the execution of the operations on the qubits (quantum bits). Decoherence arises when the quantum system that encodes the qubits becomes entangled with its environment, which is a bigger, uncontrolled system. There are two approaches to tackling these barriers. One is based on complete isolation of the computer from its environment, careful elimination of noise, and protocols for quantum correction of unavoidable errors. Enormous progress has been achieved in this direction in the past few years. The other approach, which is at the root of topological quantum computation, is very different. It uses a non-Abelian state of matter (*1–10*) to encode and manipulate quantum information in a nonlocal manner. This nonlocality endows the information with immunity to the effects of noise and decoherence (*2–6*).

Non-Abelian States of Matter

Several properties define a non-Abelian state of matter (*1*, *2*, *6–10*). It is a quantum system whose

[1]Department of Condensed Matter Physics, Weizmann Institute of Science, Rehovot 76100, Israel. [2]Institute of Quantum Information and Matter, California Institute of Technology, Pasadena, CA 91125, USA. [3]Department of Physics, California Institute of Technology, Pasadena, CA 91125, USA.

*To whom correspondence should be addressed. E-mail: adiel.stern@weizmann.ac.il

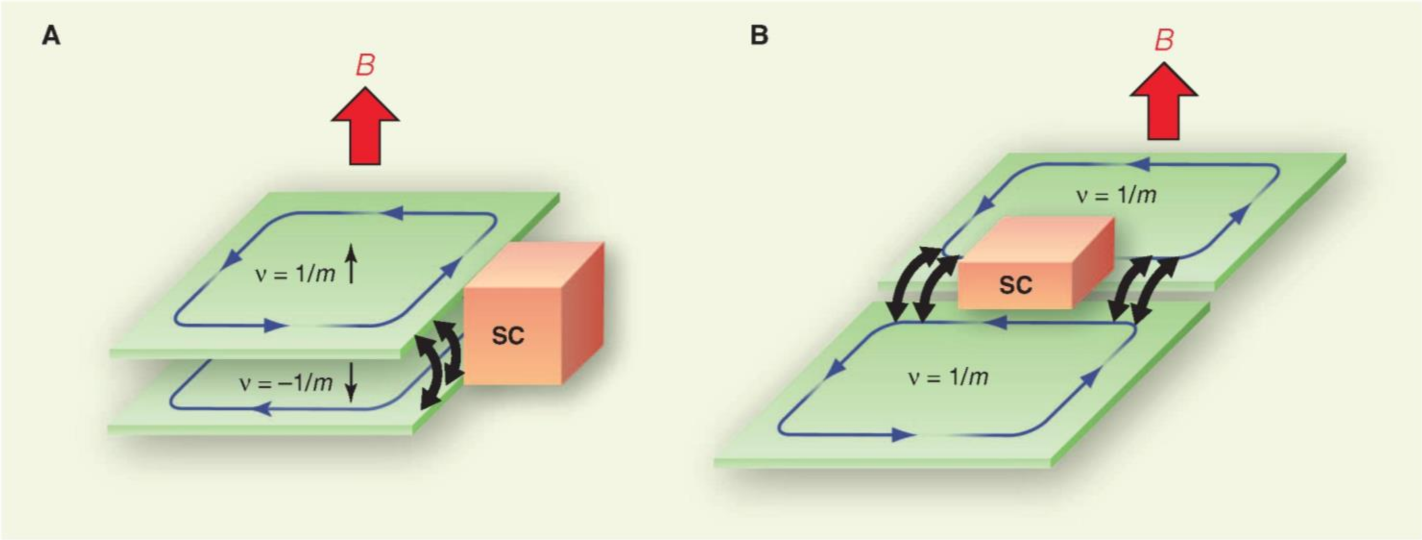
Topological States of Matter

REVIEW

Topological Quantum Computation—From Basic Concepts to First Experiments

Ady Stern[1*] and Netanel H. Lindner[2,3]

Promising platform: QH state in proximity to SC



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sics, Weizmann Institute
itute of Quantum Infor-
f Technology, Pasadena,
s, California Institute of

be addressed. E-mail:

State of the art

QH+SC hybrids

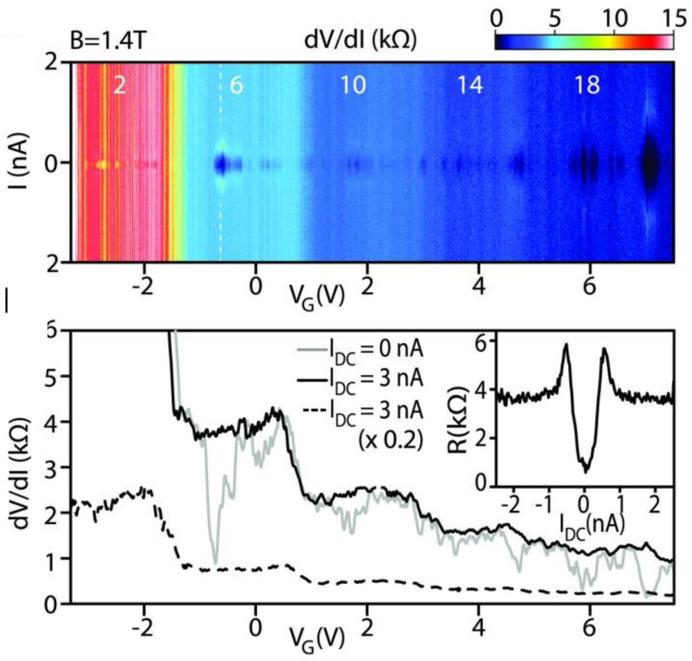
State of the art

Graphene-based QH+SC hybrids

- ultra-high carrier mobility
- barrier-free contacts with high-B_c materials

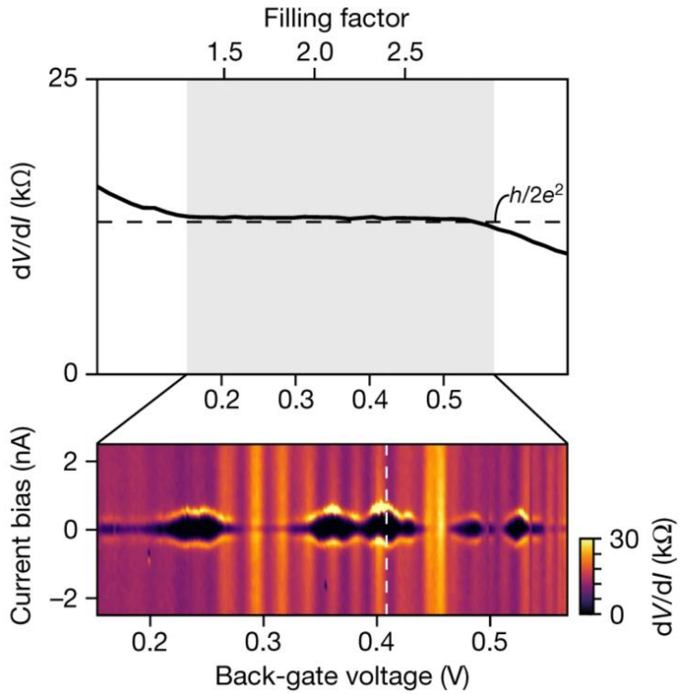
State of the art

MoRe - **SC pockets**



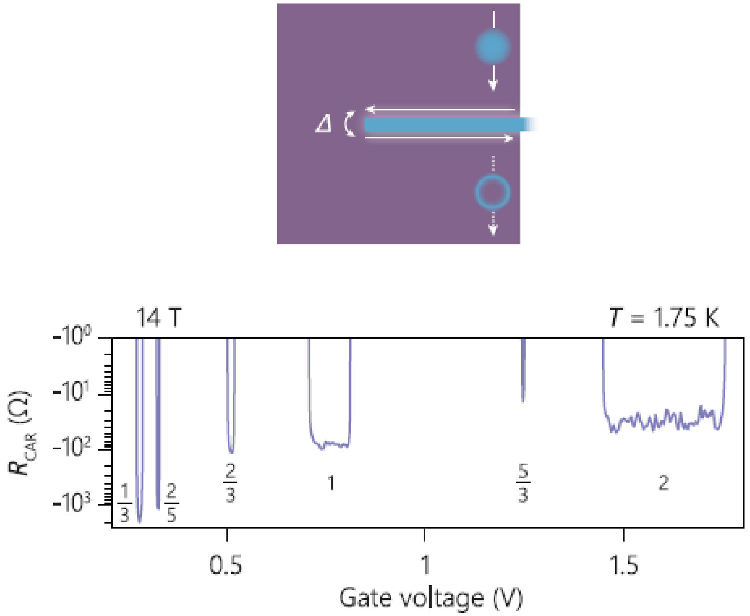
F. Amet *et al.*, Science **352**, 966–969 (2016)

MoGe - **chiral SC**



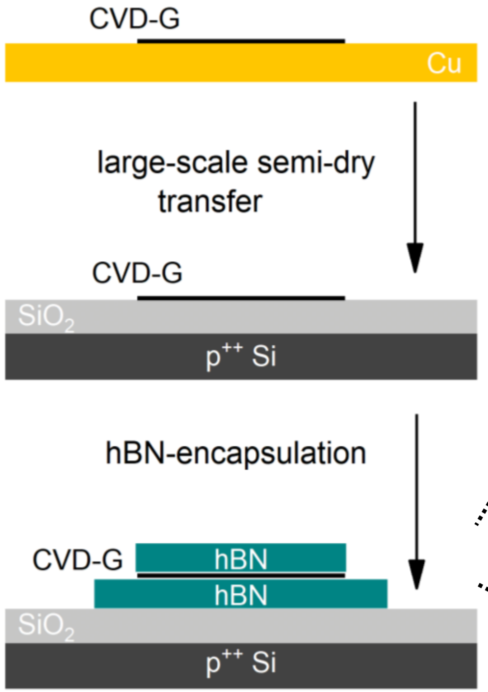
H. Vignaud *et al.,* Nature **624**, 545–550 (2023)

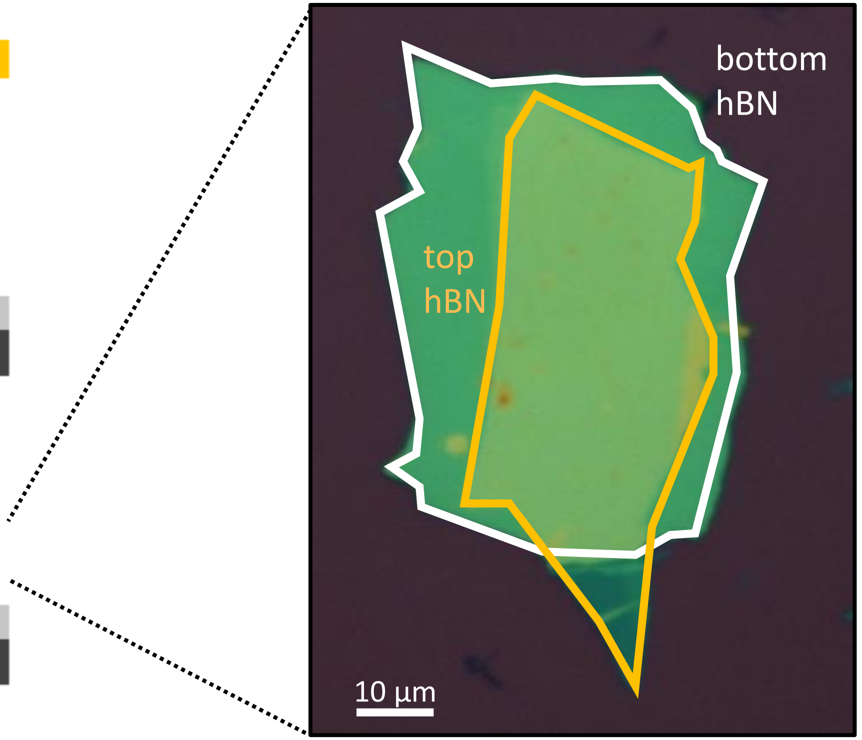
NbN - **Andreev reflection FQH**



G.-H. Lee et al., Nat. Phys. **13**, 693 – 698 (2017)
Ö. Gül *et al.*, *Phys. Rev. X* **12**, 021057 (2022)

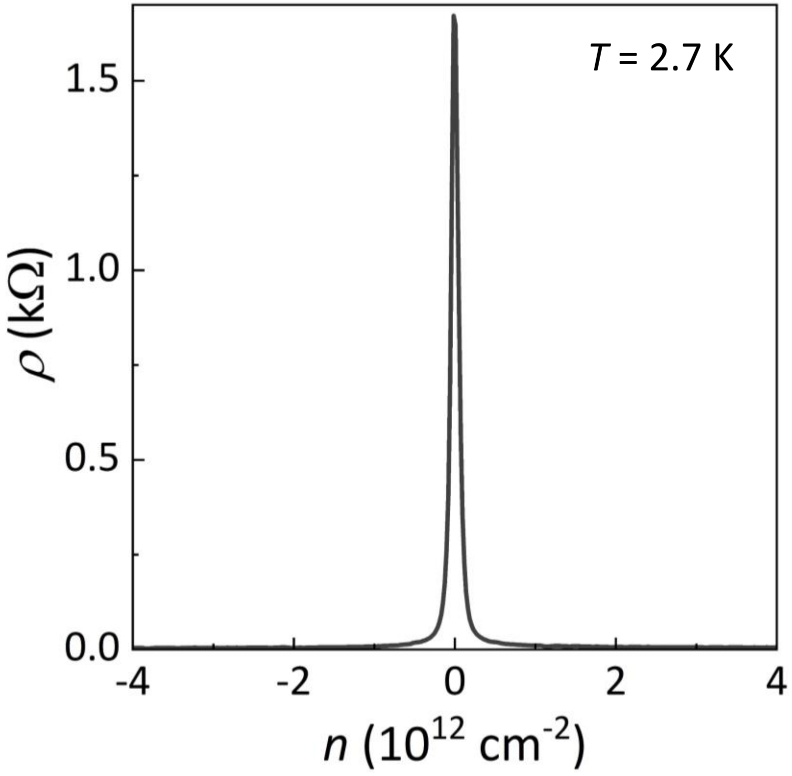
Results - Fabrication





S. Pezzini *et al.*, *2D Mater.* **7**, 041003 (2020)

A. Boschi, SP *et al.*, *in preparation*



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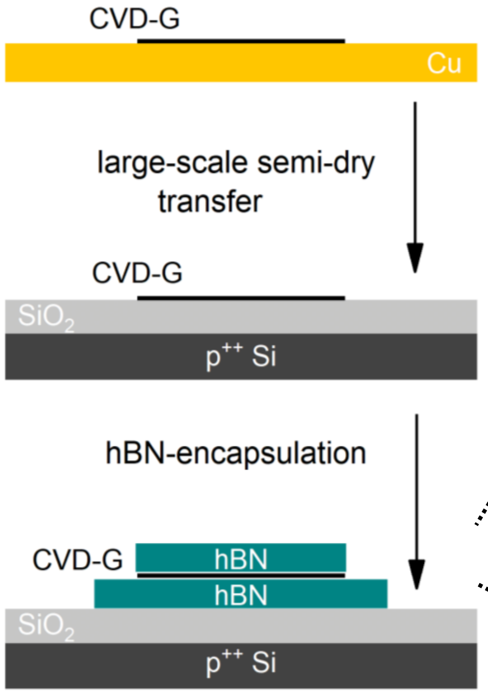

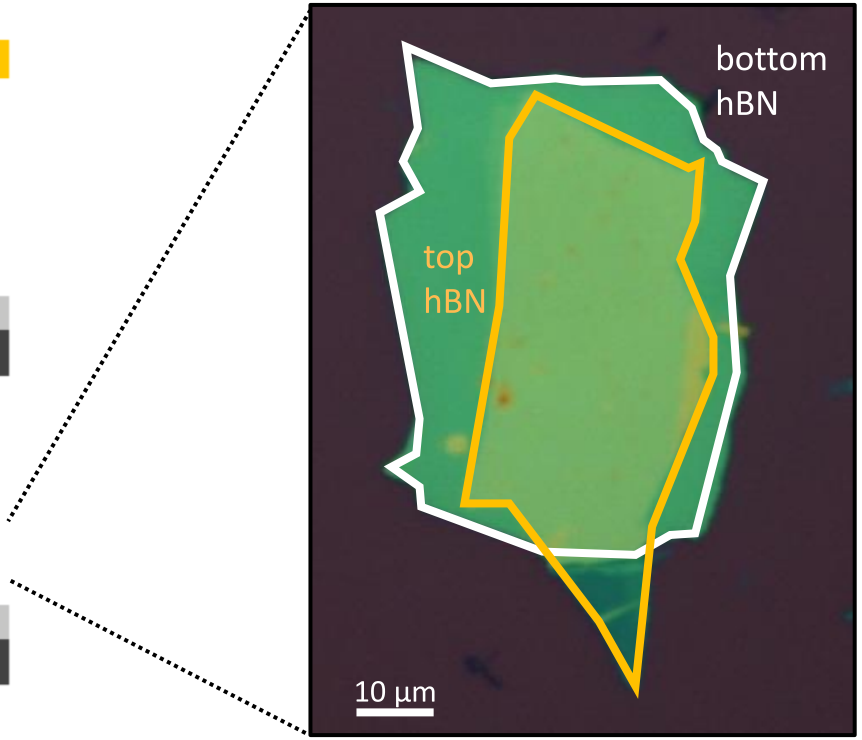

S. Pezzini *et al.*, *2D Mater.* **7**, 041003 (2020)

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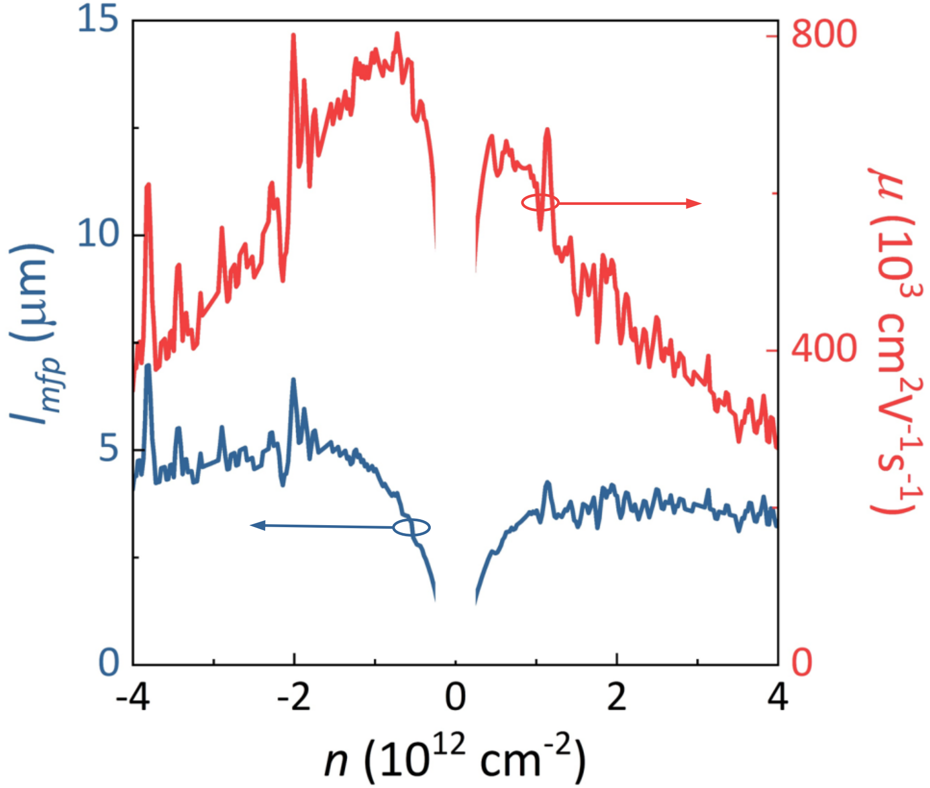
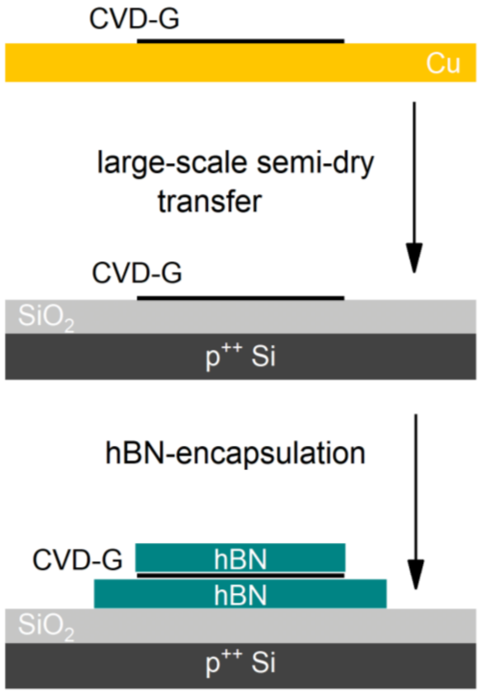
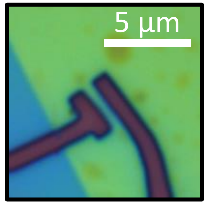


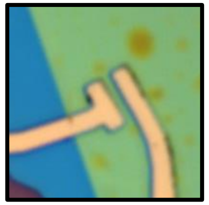
Results - Fabrication



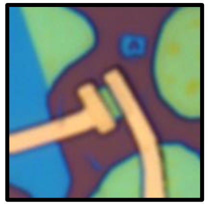
S. Pezzini *et al.*, *2D Mater.* **7**, 041003 (2020)



contact etching



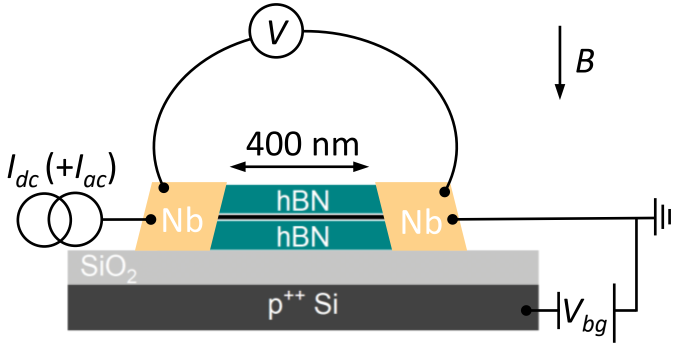
Nb sputtering



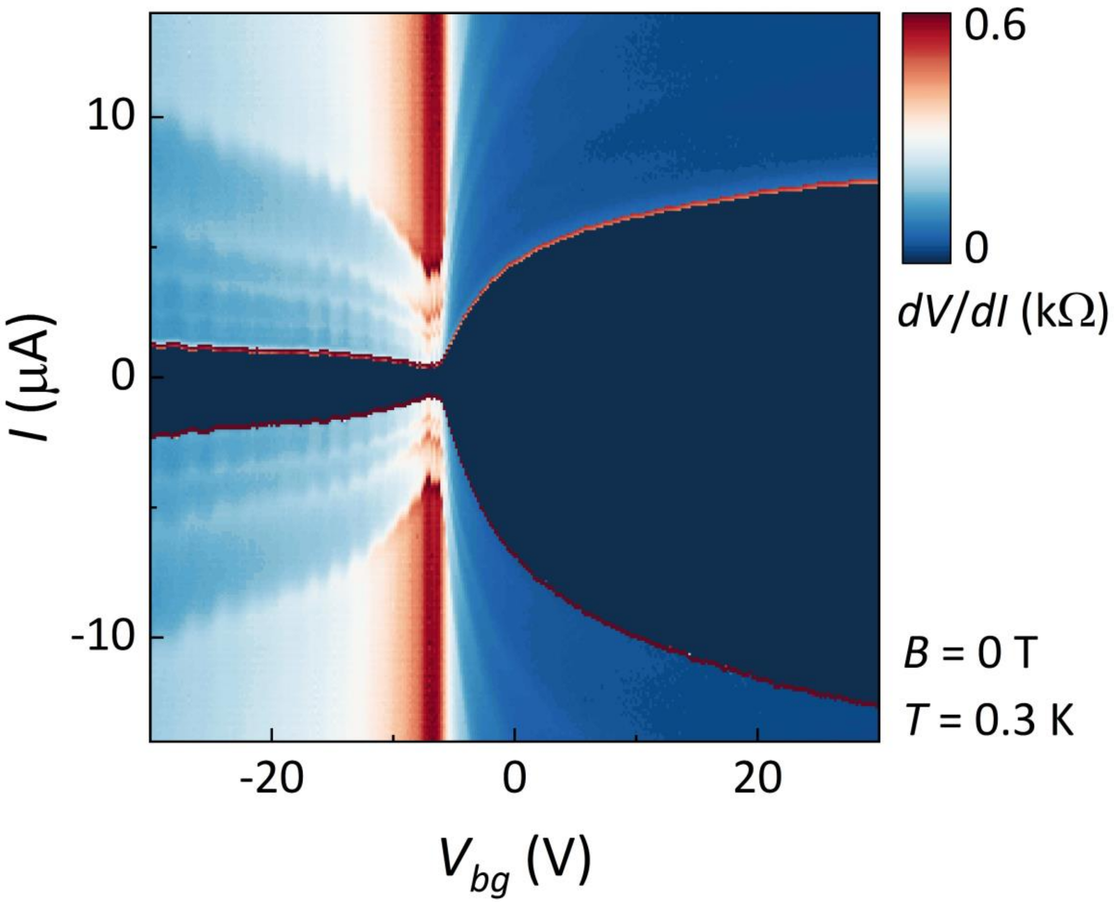
mesa etching

I. Villani *et al.*, *in preparation*

L. Wang *et al.*, *Science* **342**, 614-617 (2013)
M. Ben Shalom *et al.*, *Nat. Phys.* **12**, 318–322 (2016)



Results - induced superconductivity



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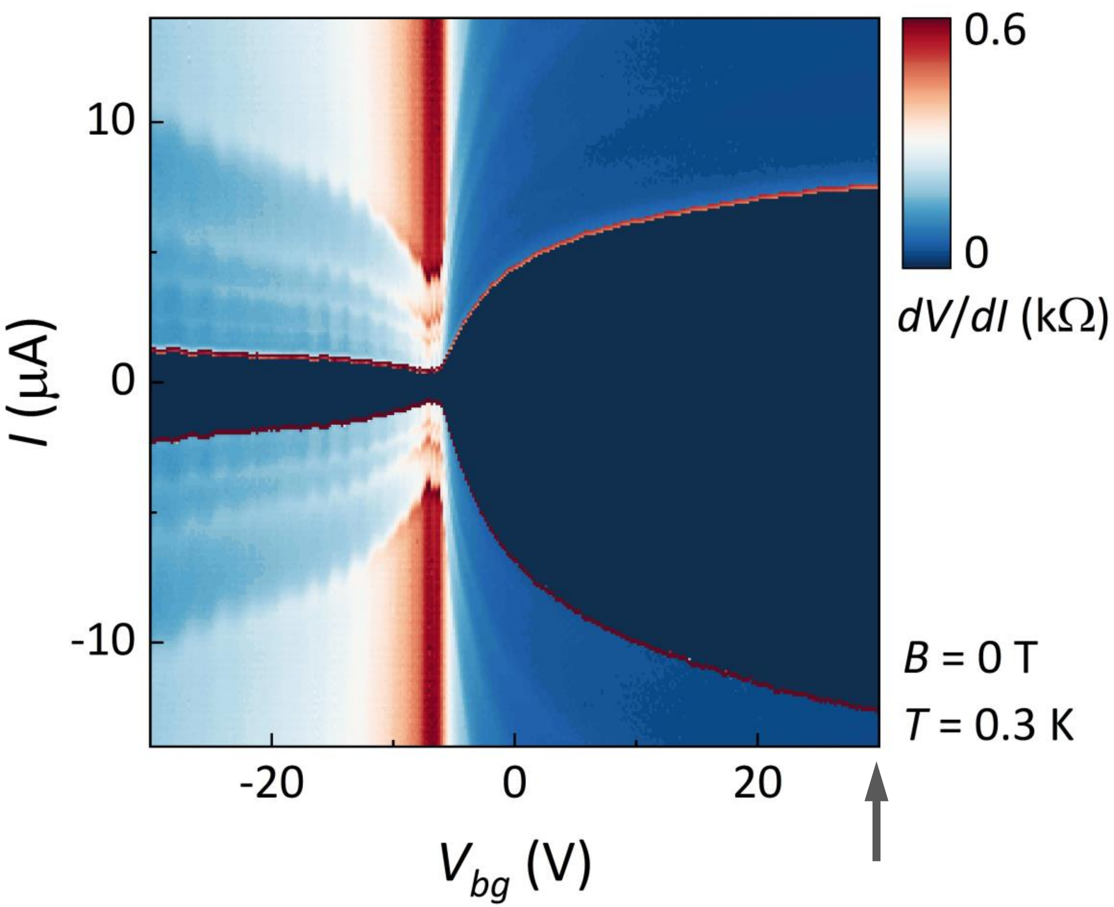
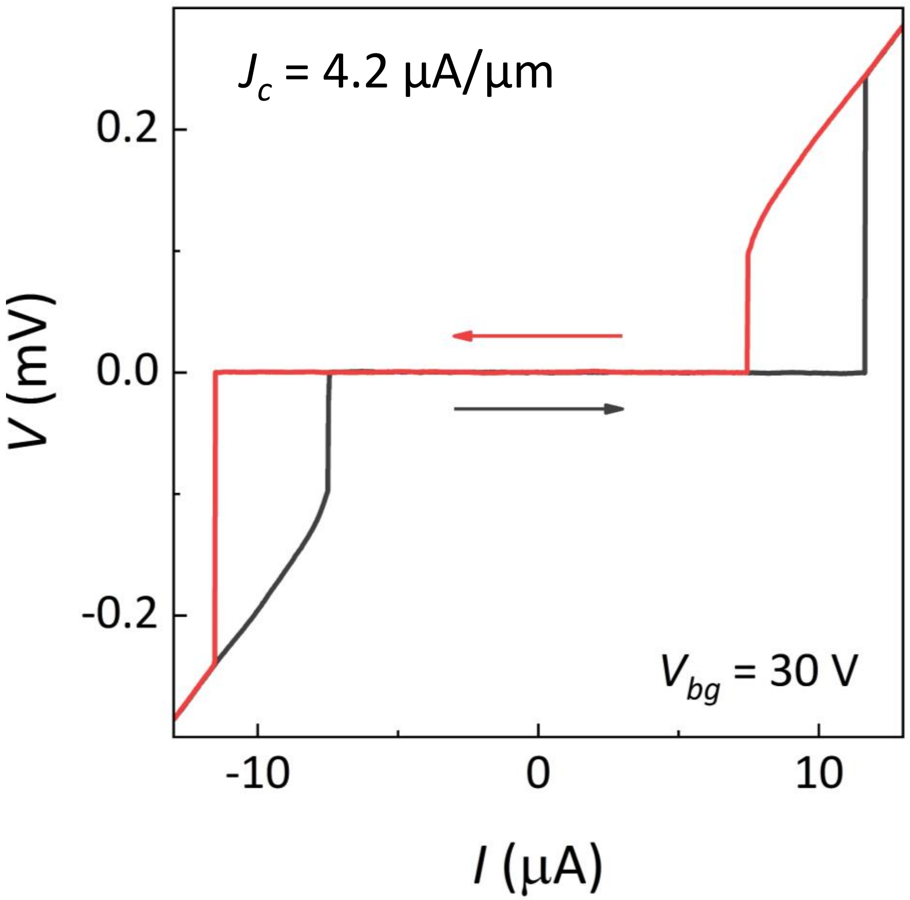
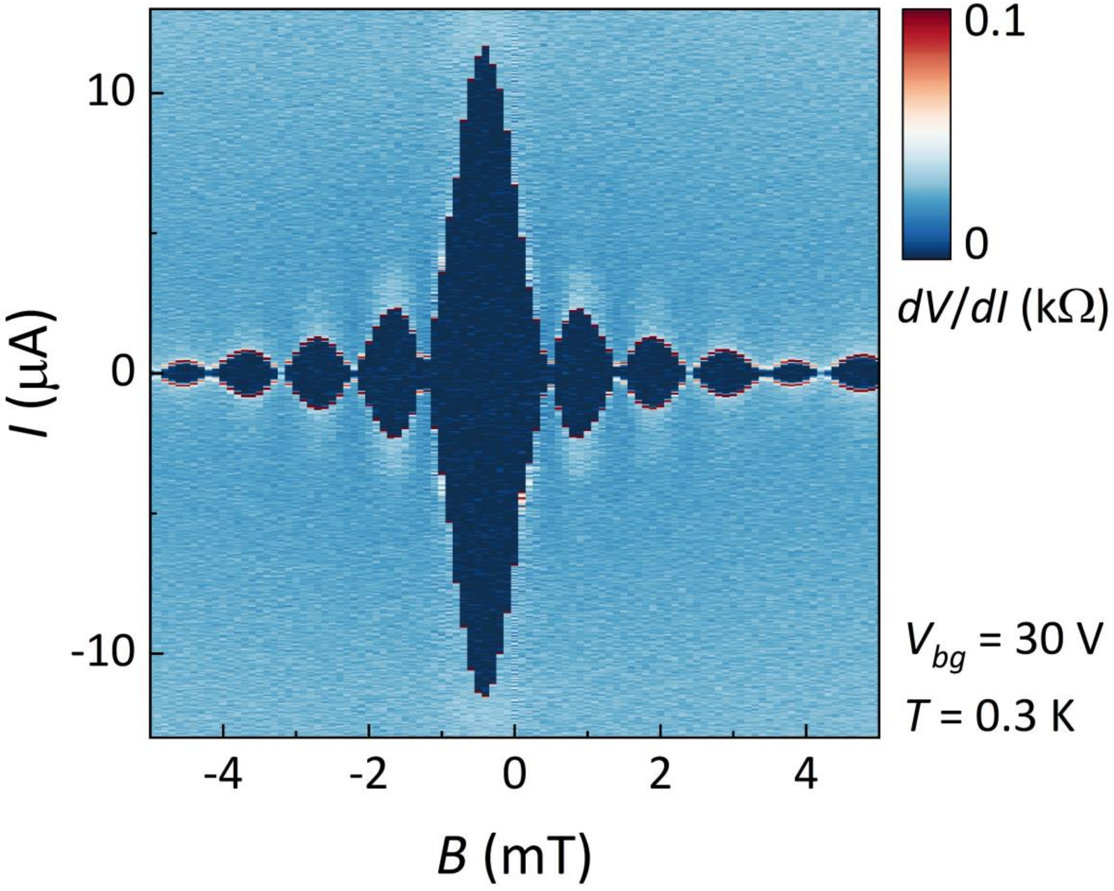




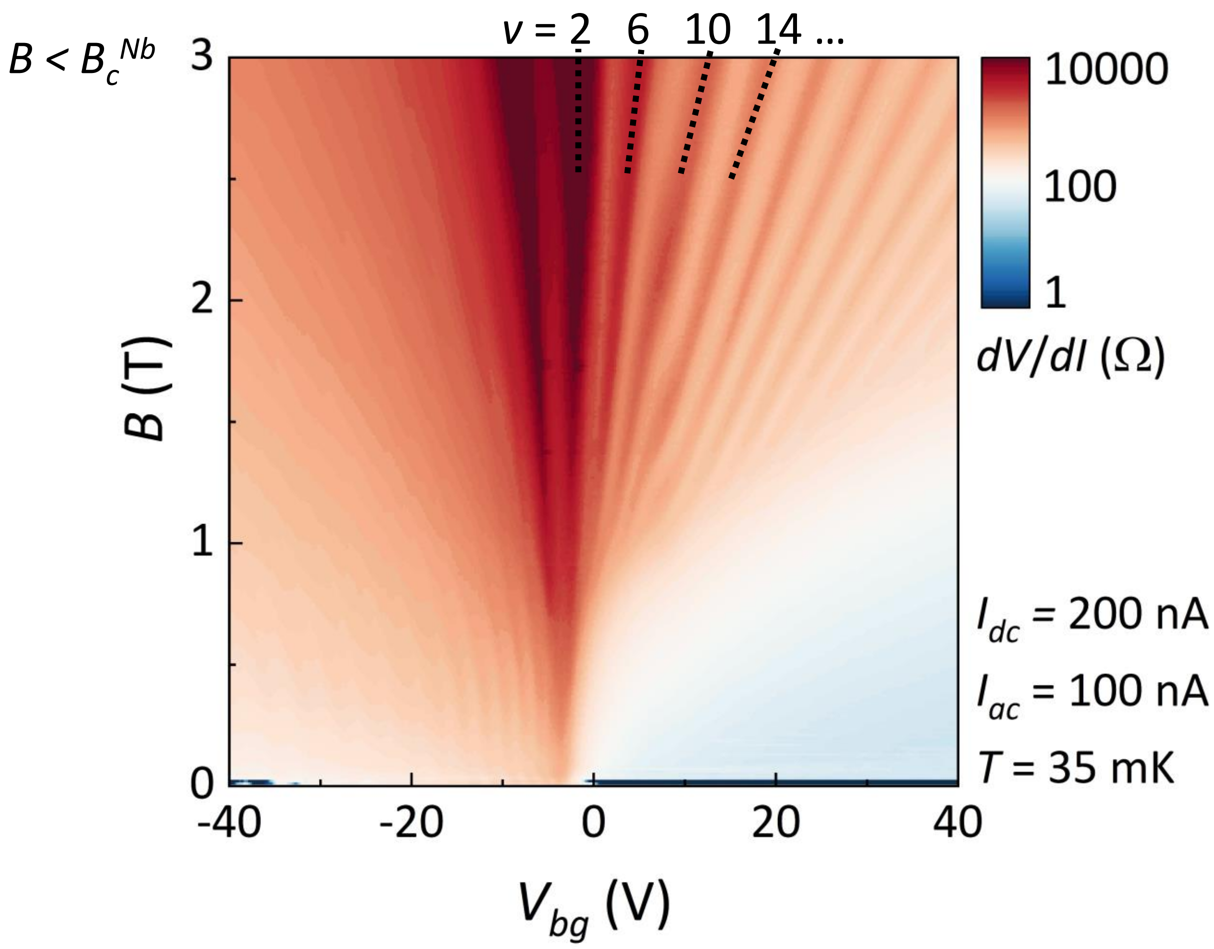
Results - superconductivity at low B



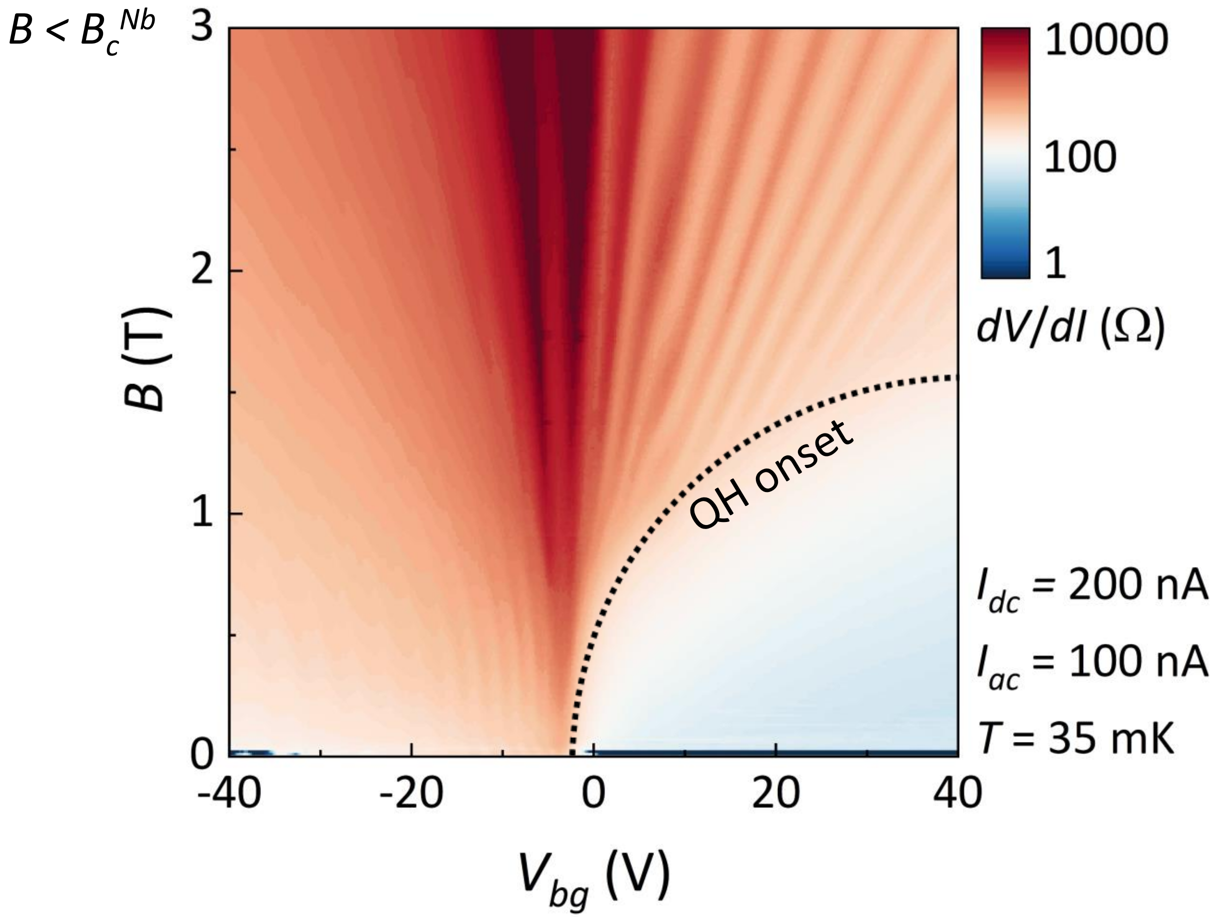
Fraunhofer interference pattern

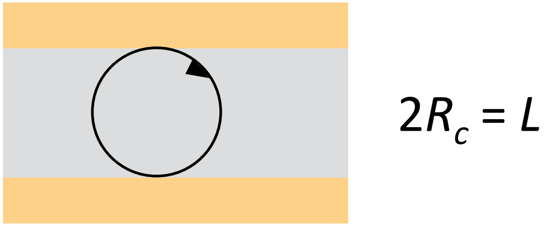
I_c quickly suppressed (?)

Results - normal state magneto-transport

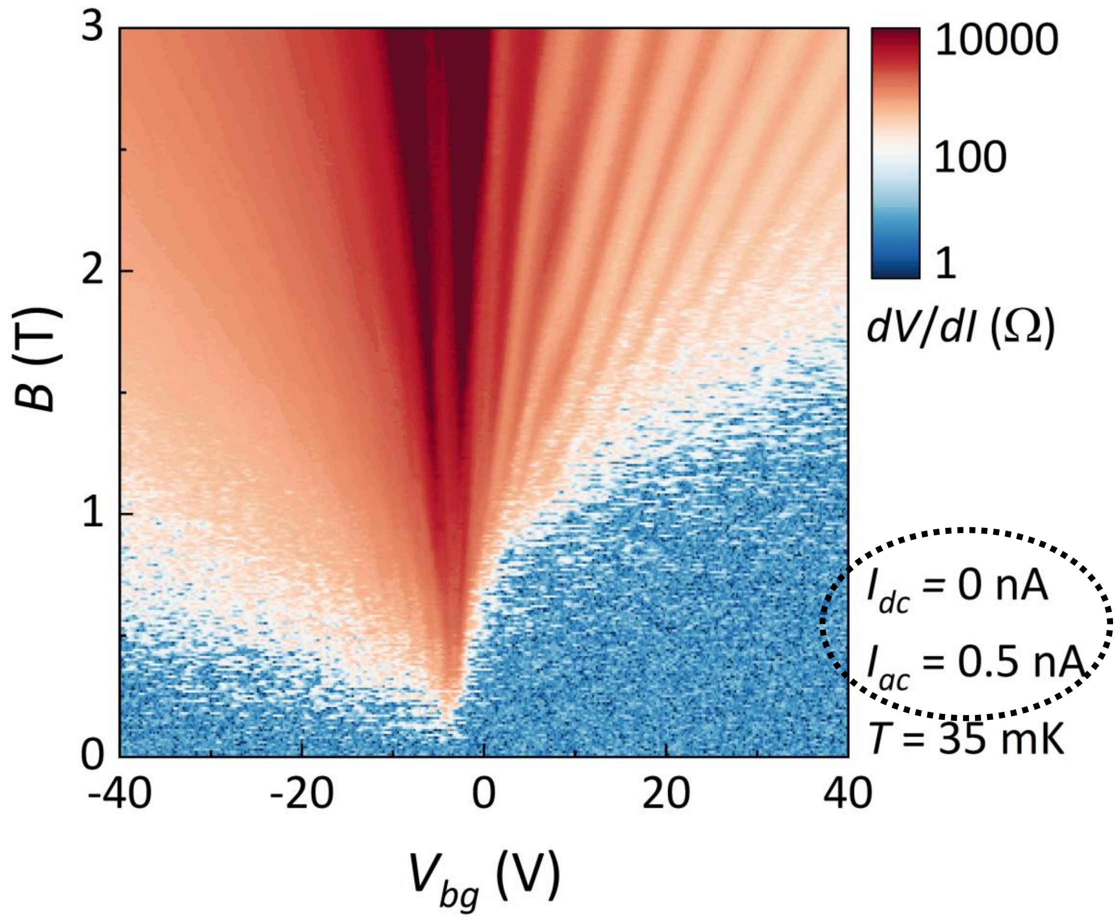


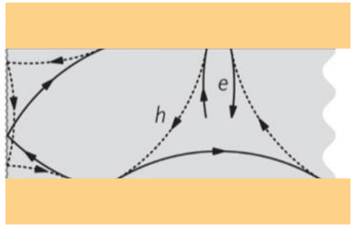
Results - normal state magneto-transport





Results - superconductivity at intermediate *B*

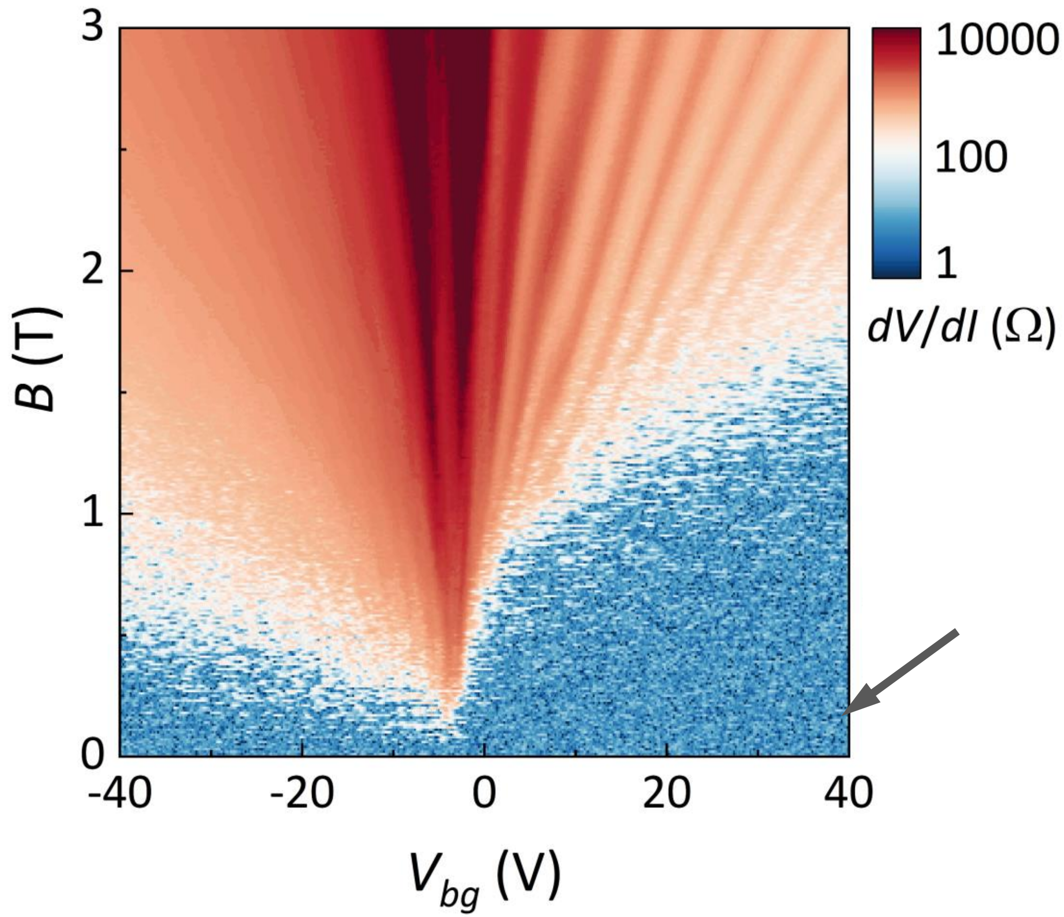


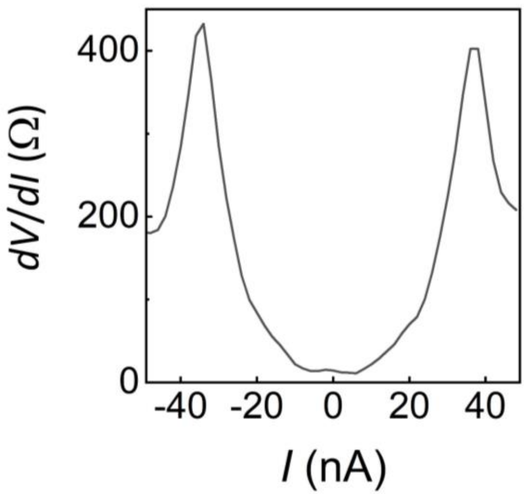


$2R_c > L$

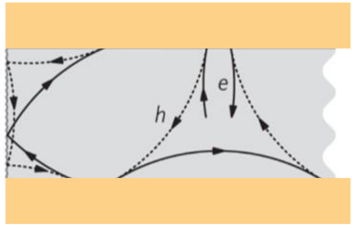
M. Ben Shalom *et al.*, *Nat. Phys.* **12**, 318–322 (2016)

Results - superconductivity at intermediate *B*





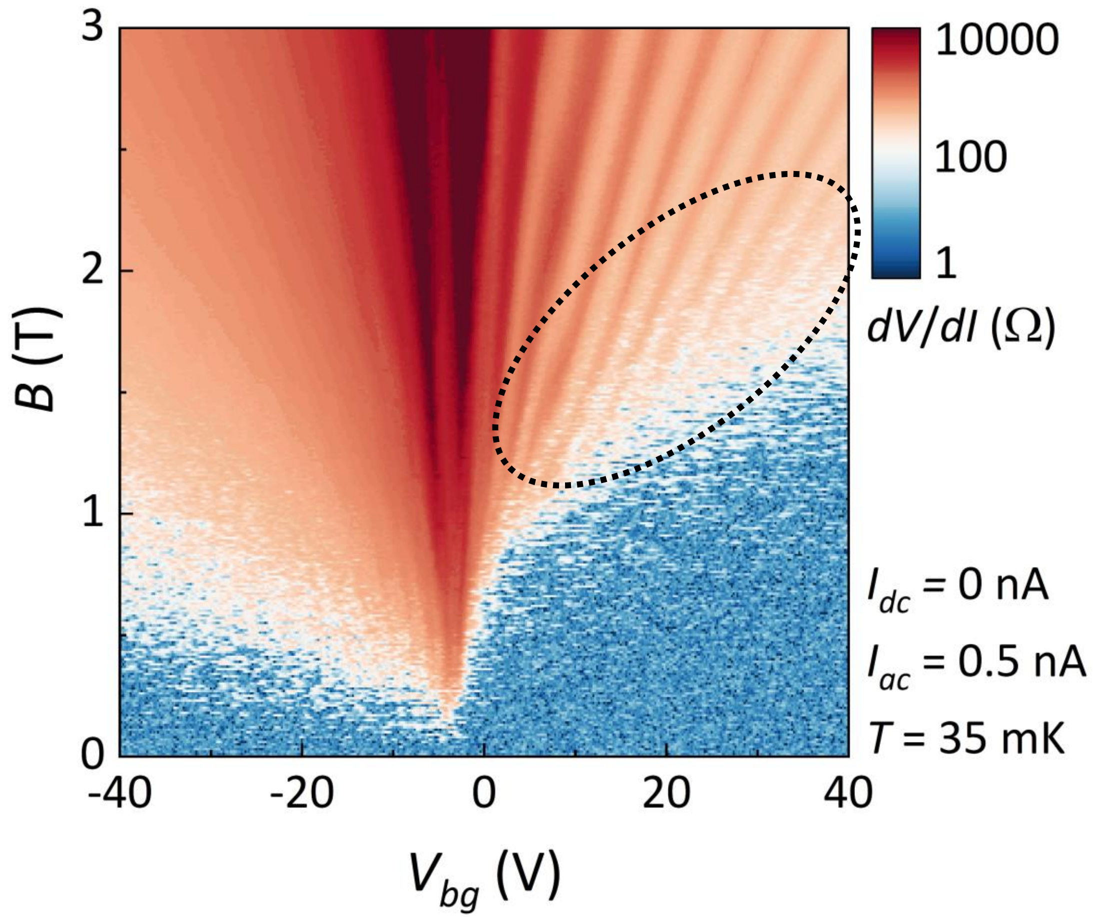
V_{bg} = 40 V
B ~140 mT

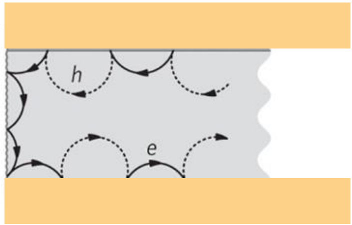


$2R_c > L$

M. Ben Shalom *et al.*, *Nat. Phys.* **12**, 318–322 (2016)

Results - superconductivity at high *B*





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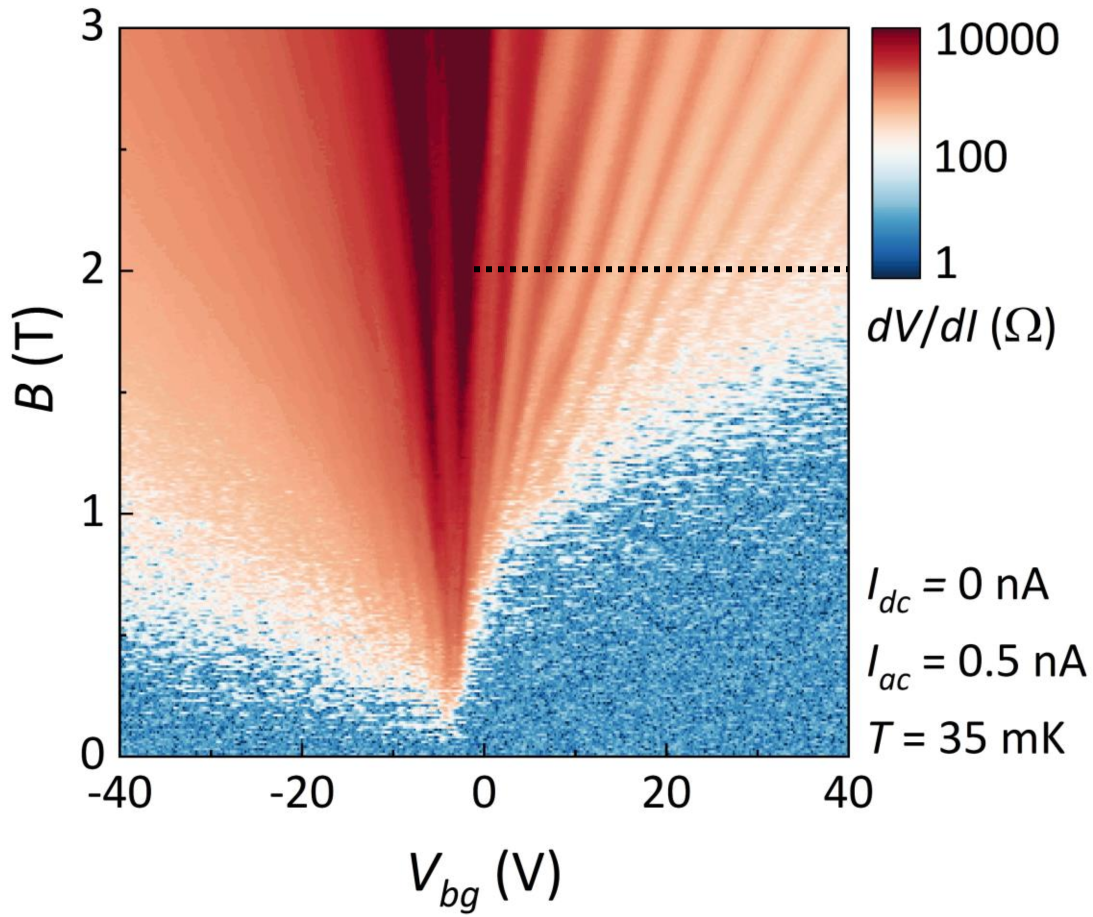
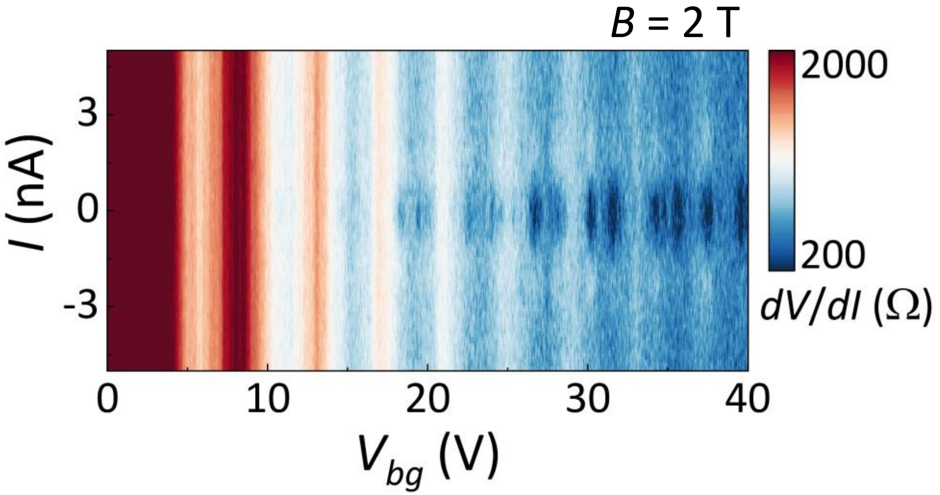
Results - superconductivity at high *B*





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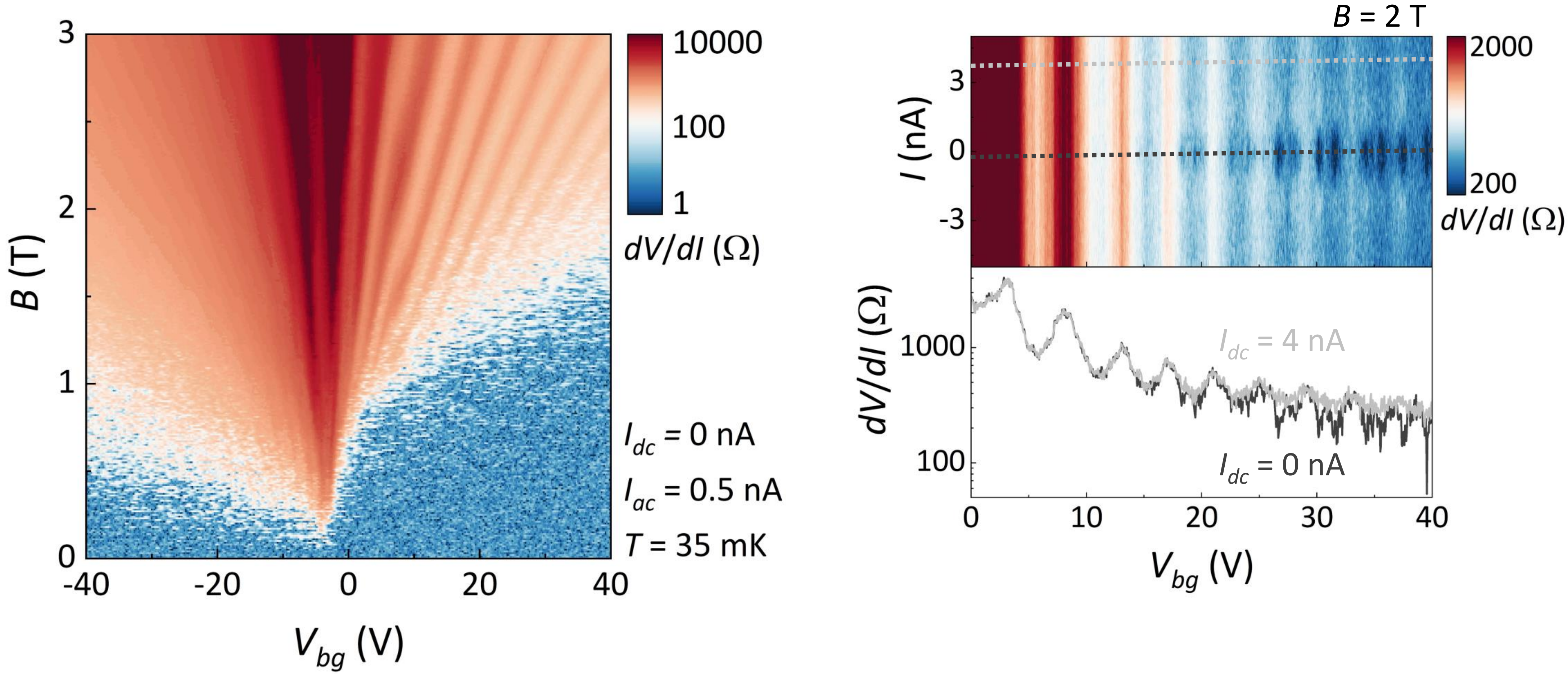
Results - superconductivity at high *B*



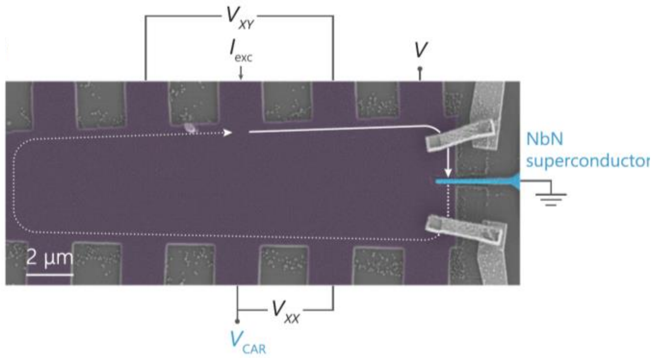
Summary & Outlook

- highly transparent graphene-Nb interfaces

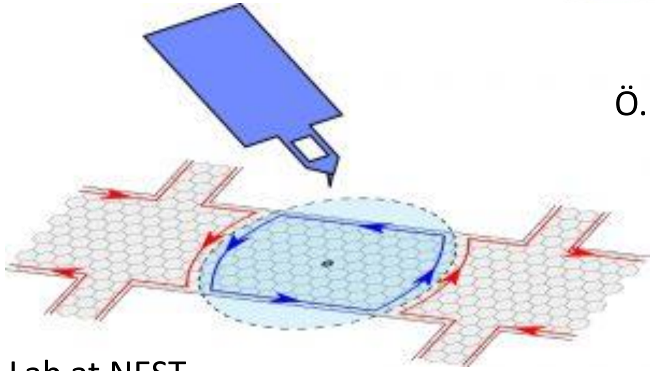
- SC in quantizing magnetic fields

Summary & Outlook

- highly transparent graphene-Nb interfaces
- SC in quantizing magnetic fields
- SC materials (**new sputtering**) and device geometry
- **new 10 mK dilution** and local probing



Ö. Gül *et al.*, *Phys. Rev. X* **12**, 021057 (2022)



SGM Lab at NEST

Thank you for your attention!

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