QUANTERA

ERA-NET Cofund in Quantum Technologies

Mid-term Strategic Conference

Granada, 13-14 November 2019

2D hybrid materials as a platform for topological quantum computing (Topoquant)

Werner Wegscheider

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731473.

Topoquant: employ topology for quantum computation

In most solid-state quantum computation implementations decehorence represents the major obstacle and vastly increases the number of physical qubits in order to achieve a certain number of logical qubits

in contrast:

Topological quantum computation encodes quantum information nonlocally by nucleating non-Abelian anyons separated by distances L, typically spanning the qubit device size. This nonlocality renders topological qubits exponentially immune to dephasing from *all* sources of classical noise on the scale of L

our platform to achieve Majorana-based topological qubits:

Highest-quality InAs and InSb-based systems combined with in-situ, epitaxially grown superconductor Al, that allow the integration of multiple Majorana wires

the consortium

Klaus Ensslin – ETH Zürich:

realization of nanostructures based on InAs and InSb quantum well systems; low-temperture magnetotransport investigations

Werner Wegscheider – ETH Zürich:

growth of high-mobility and gate-tunable 2DEGs in InAs and InSb; combination of these with epitaxial Al

Felix von Oppen – Freie Universität Berlin:

theory of electronic nanodevices and topological phases of matter, spec. of Majorana bound states in proximity-coupled superconductors

Fabrizio Nichele – (Univ. of Copenhagen, now IBM Zürich):

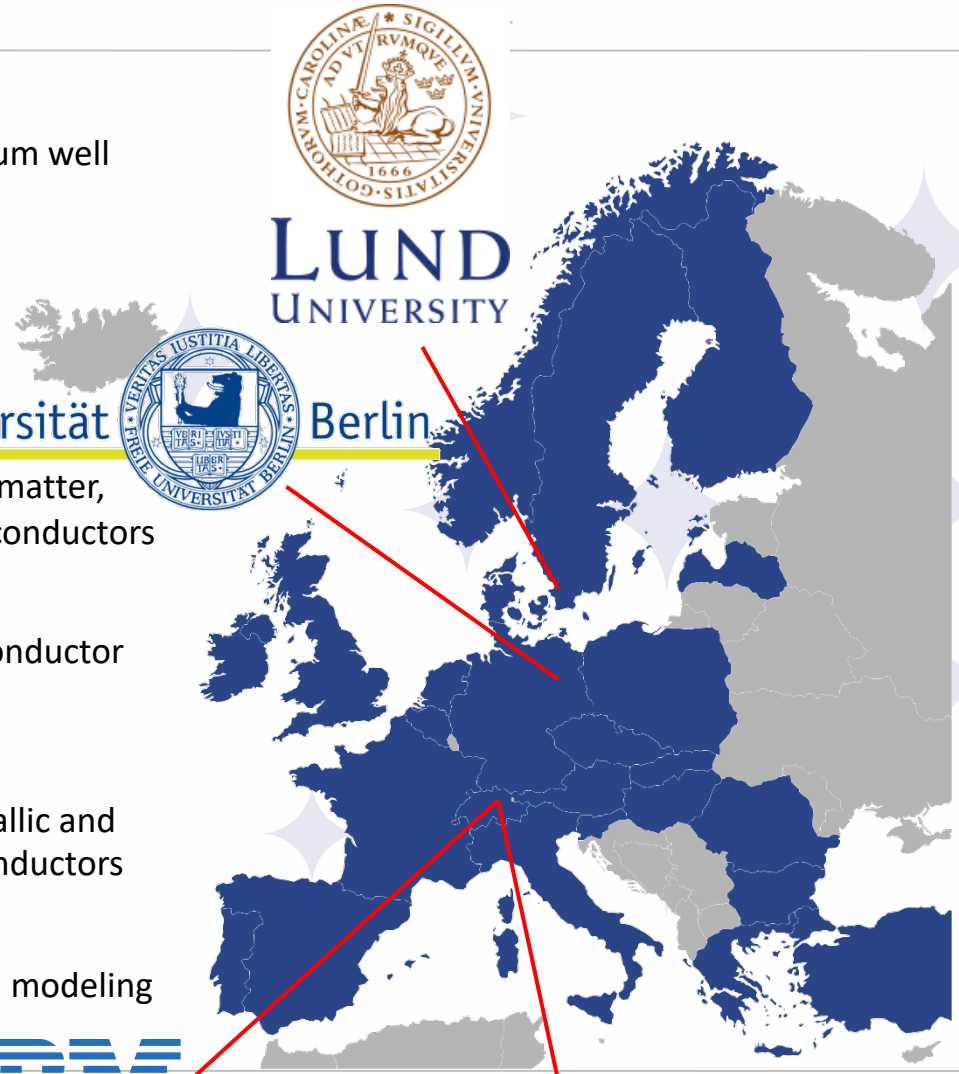
low-temperature measurements of semiconductor/superconductor hybrid nanostructures

Ville Maisi – Lund University:

performing real-time charge detection experiments on metallic and semiconductor systems as well as parity studies in superconductors

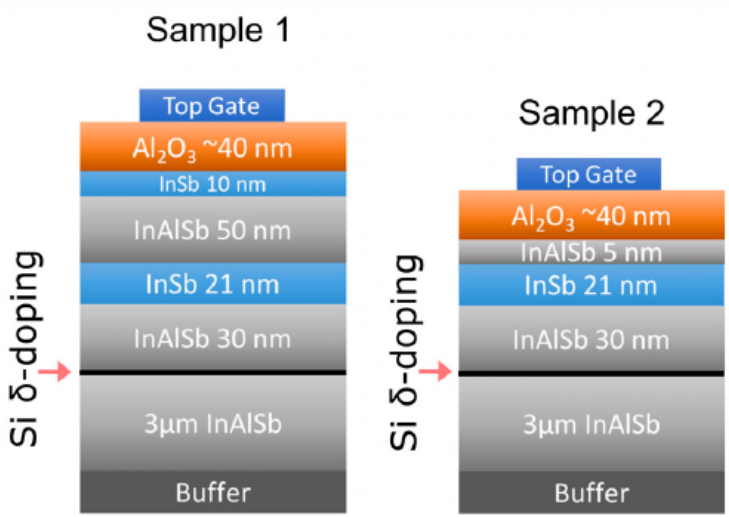
Martin Leijnse – Lund University:

carrying out quantum transport calculations and theoretical modeling of Majorana devices and qubits



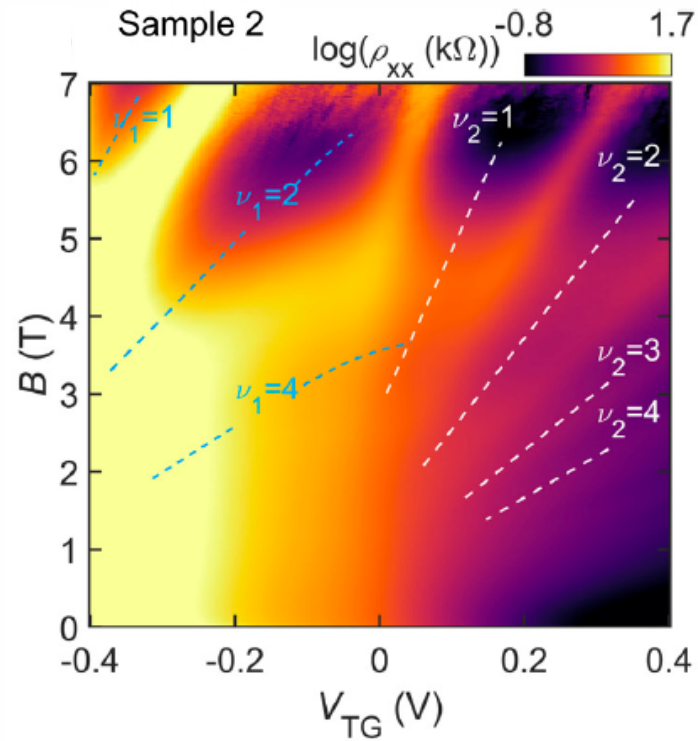
progress in InSb quantum well fabrication

Ensslin, Wegscheider (Zürich)



Properties	Sample 1	Sample 2
Upper barrier thickness	50 nm	5 nm
$\mu_{2(max)}$ [$cm^2 (V\ s)^{-1}$]	350 000	67 000
n_2($\times 10^{15}\ m^{-2}$)	0–3.5	0–3
m^*	0.020 m_0	0.019 ± 0.02 m_0

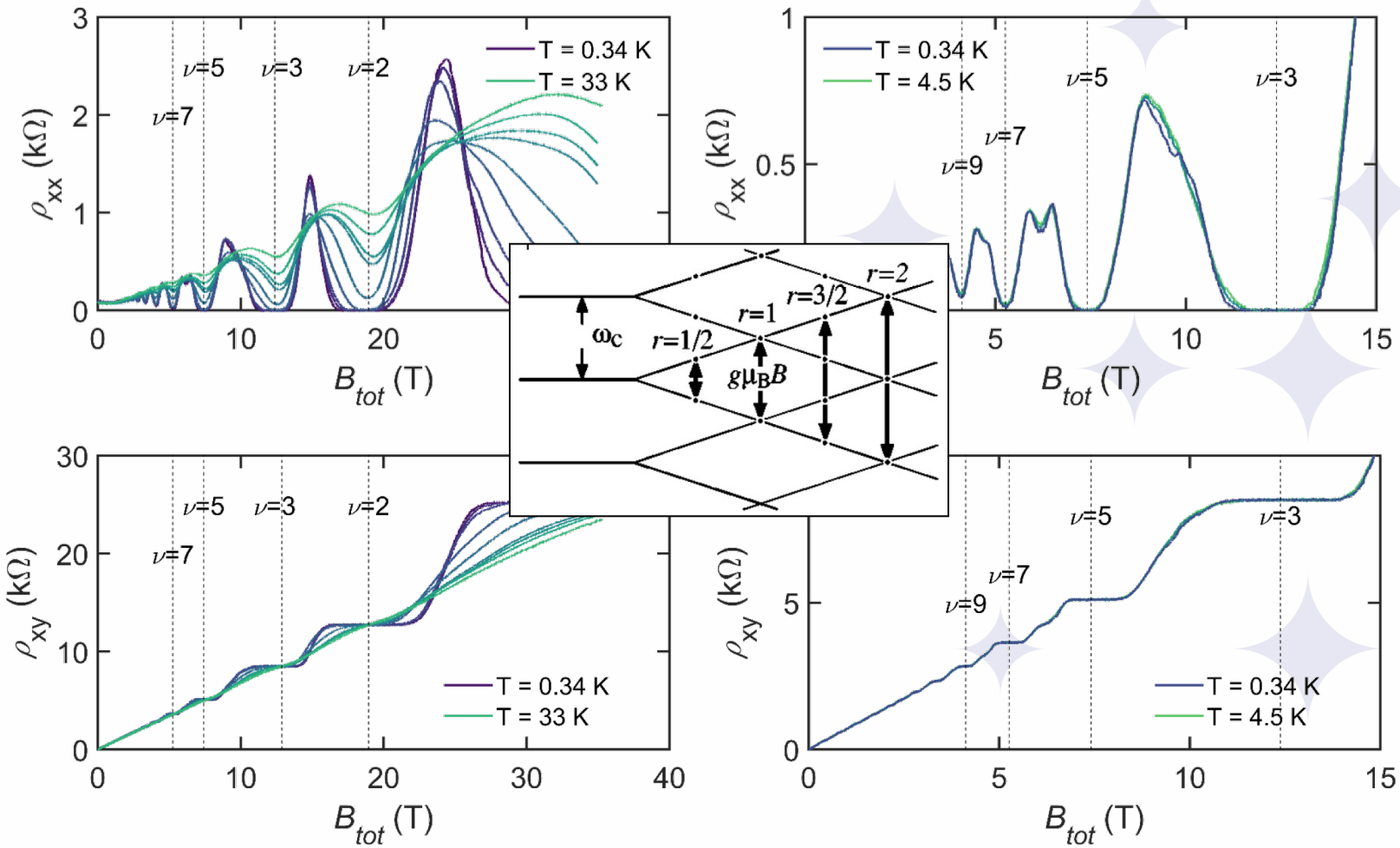
Phys. Rev. Mat. **2**, 054601 (2018).
Appl. Phys. Lett. **115**, 012101 (2019).



- record mobilities InSb quantum wells
- gating scheme developed that allows full depletion
- optimization of in-situ Al. deposition

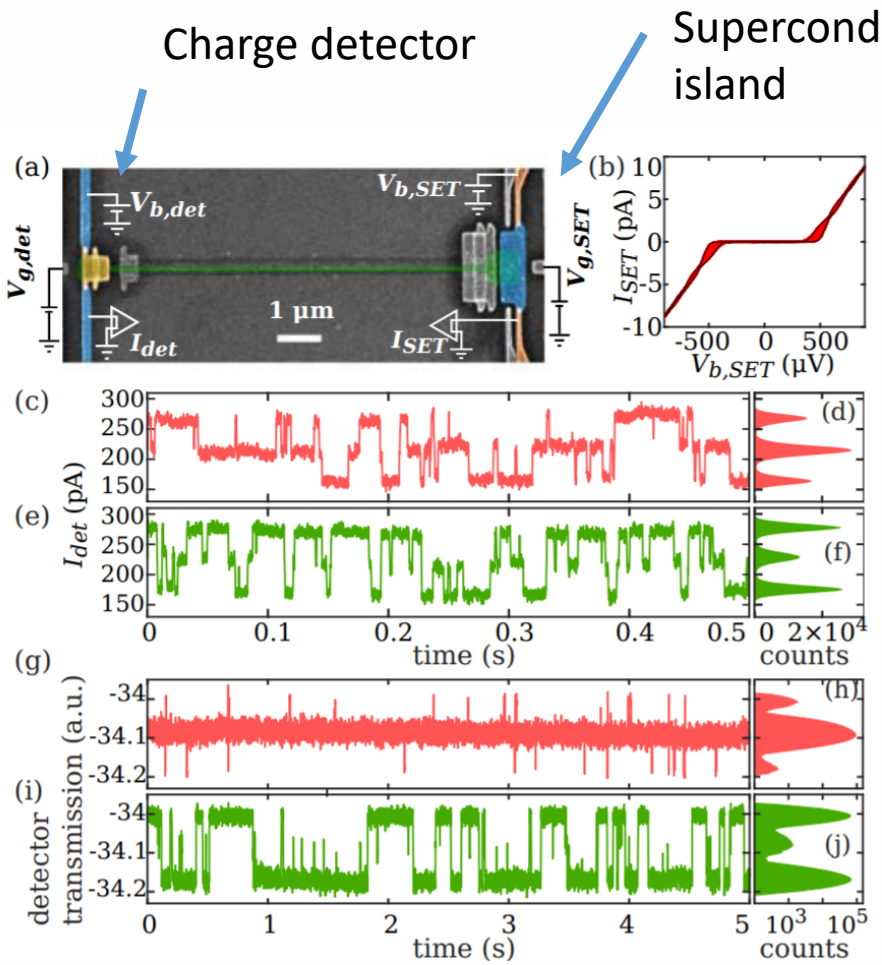
measurements at High-Field magnet lab (HFML, Nijmegen)

Ensslin, Wegscheider (Zürich)



detecting parity of a superconducting island

Maisi (Lund)



- real-time readout of parity of superconducting islands achieved
- we can suppress the spurious parity switching down to 10 Hz level yielding an upper limit of 100 ms for the coherence time determination and maintain the island free of quasiparticle excitations for 97 % of the time.
- parity is extremely fragile against readout backaction
- careful design and understanding of the backaction processes is critical

Phys. Rev. B **100**, 020502(R) (2019).

simulation of dynamics of Majorana qubit manipulation

Leijnse (Lund)

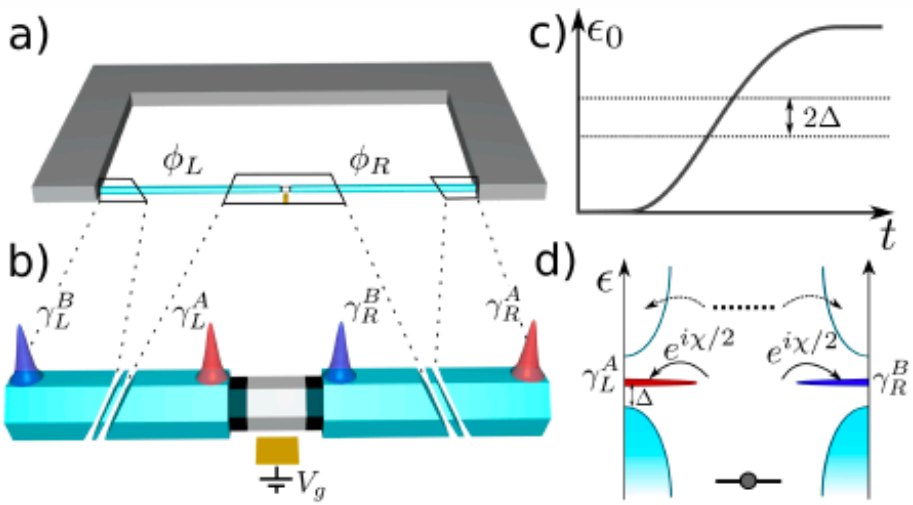


FIG. 1. a) Schematic representation of the device consisting of two long TS wires (blue) embedded into a superconducting loop. b) Enlarged representation of the ends of the wires, which host MBSs ($\gamma_{L,R}^{A,B}$), and the QD used for the operations. c) Time evolution of the QD energy level. d) Energy representation, where curved arrows represent the processes of the electron tunneling to the MBSs (solid lines) or to the continuum of states (dashed lines) during the manipulation of the QD level energy (thick horizontal line).

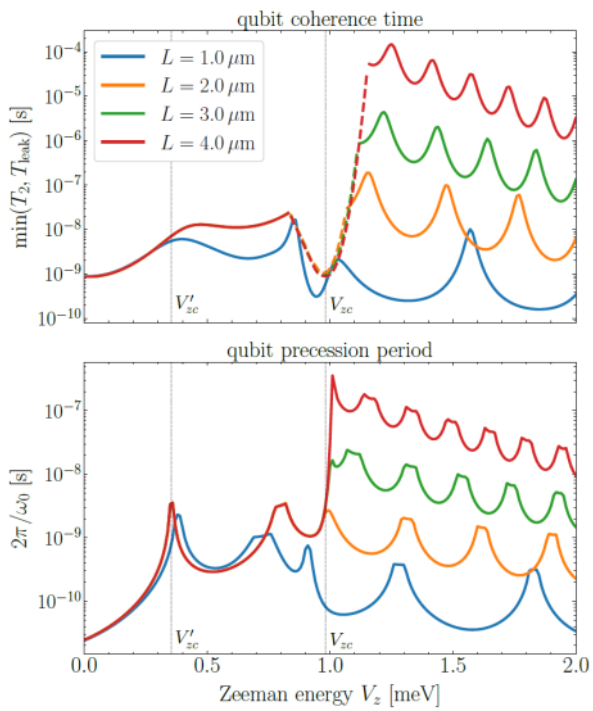
- analyze the efficiency and time scales of charge transfer operations from a quantum dot to two coupled topological superconductors
- developed formalism for, and numerical implementation of, T-matrix based calculations of cotunneling transport through superconducting islands with strong electron-electron interactions
- our results establish charge-transfer based operations as a realistic alternative to experimentally probe the non-abelian nature of MBSs.

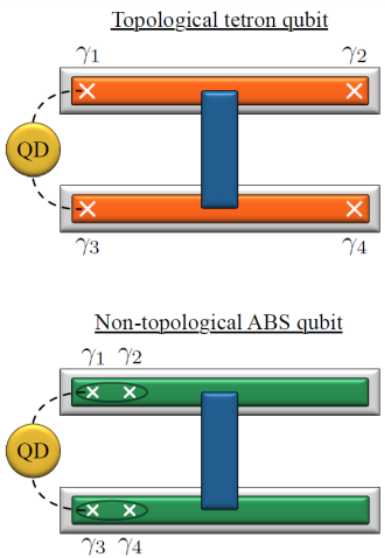
arXiv:1910.08420

simulations of coherence times of a noisy Majorana qubit

von Oppen (Berlin)

coherence times and precession period of a noisy Majorana qubit as function of magnetic field:





arxiv:1911.02582

Dephasing and leakage dynamics of noisy Majorana-based qubits: Topological versus Andreev

- propose simple Ramsey-like protocol to measure coherence times and precession periods (left Fig.)
- compare Majorana/Andreev qubits (right Fig.)
- suggest to use coherence time as signature of transition into the topologically protected regime
- theory of quantum-dot readout of Majorana box qubits (tetrons)

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