TT 31: Topology: Majorana Physics

Time: Wednesday 9:30–12:45 Location: HSZ 304

TT 31.1 Wed 9:30 HSZ 304

Photonic noise as a probe of Majorana bound states — •Lena Bittermann[1], Fernando Dominguez[1], and Patrik Recher[1,2] — [1]Institut für Mathematische Physik, Technische Universität Braunschweig, D-38106 Braunschweig, Germany — [2]Laboratory for Emerging Nanometrology Braunschweig, D-38106 Braunschweig, Germany

We propose a route to detect Majorana bound states (MBSs) by coupling a topological superconductor to a quantum dot (QD) in a pn-junction. Here, two MBSs are coherently coupled to electrons on the QD, which recombine with holes in situ to photons. Importantly, the polarization of the emitted photons provides direct information on the spin structure [1,2] and nonlocality [2,3] of the MBSs. Here, we focus on the shot noise of the emitted photons which allows to clearly distinguish the cases of well separated MBSs at zero energy from overlapping MBSs. In addition, we show that quasiparticle poisoning changes the shot noise from super-Poissonian to sub-Poissonian [4]. Furthermore, this setup can be extended by coupling a second QD close to the second MBS which gives rise to nonlocal shot noise correlations leading to additional signatures of MBSs.

[1] D. Sticlet, C. Bena, and P. Simon, PRL 108, 096802 (2012)
[2] E. Prada, R. Aguado, and P. San-Jose, PRB 96, 085418 (2017)
[3] A. Schuray, L. Weithofer, and P. Recher, PRB 96, 085417 (2017)
[4] L. Bittermann, C. De Beule, D. Frombach, and P. Recher, PRB 106, 075305 (2022)

TT 31.2 Wed 9:45 HSZ 304

Statistical Majorana bound state spectroscopy — •Alexander Ziesen[1], Alexander Altland[2], Reinhold Egger[3], and Fabian Hassler[1] — [1]JARA Institute for Quantum Information, RWTH Aachen University, Aachen, Germany — [2]Institut für Theoretische Physik, Universität zu Köln, Köln, Germany — [3]Institut für Theoretische Physik, Heinrich-Heine-Universität, Düsseldorf, Germany

Tunnel spectroscopy data for the detection of Majorana bound states (MBS) is often criticized for its proneness to misinterpretation of genuine MBS with low-lying Andreev bound states. Here, we suggest a protocol removing this ambiguity by extending single shot measurements to sequences performed at varying system parameters. We demonstrate how such sampling, which we argue requires only moderate effort for current experimental platforms, resolves the statistics of Andreev side lobes, thus providing compelling evidence for the presence or absence of a Majorana center peak.

TT 31.3 Wed 10:00 HSZ 304

Disentanglement, disorder lines, and Majorana edge states in a solvable quantum chain — Gennady Y. Chitov[1], •Karun Gadge[2,3], and Pavel N. Timonin[4] — [1]Département de Physique, Institut Quantique, Université de Sherbrooke, Sherbrooke, Québec J1K 2R1, Canada — [2]Institute for Theoretical Physics, Georg-August-University Göttingen, Friedrich-Hund-Platz 1, D-37077 Göttingen, Germany — [3]School of Basic Sciences, Indian Institute of Technology Mandi, Mandi 175005, India — [4]Rostov-on-Don, Russia

We study the exactly solvable one-dimensional model: the dimerized XY chain with uniform and staggered transverse fields, equivalent upon fermionization to the noninteracting dimerized Kitaev-Majorana chain with modulation. The criticality is controlled by the properties of zeros of model's partition function, analytically continued onto the complex wave numbers. In the ground state they become complex zeros of the spectrum of the Hamiltonian. The analysis of those roots yields the phase diagram which contains continuous quantum phase transitions and weaker singularities known as disorder lines (DLs) or modulation transitions. The salient property of zeros of the spectrum is that the ground state is shown to be separable (factorized), and the model is disentangled on a subset of the DLs. From analysis of those zeros we also find the Majorana edge states and their wave functions. Reference: PRB 106, 125146 (2022)

TT 31.4 Wed 10:15 HSZ 304

Unifying the theoretical description of Andreev, Majorana, quasi-Majorana bound states — •Pasquale Marra[1,2] and Angela Nigro[3] — [1]Graduate School of Mathematical Sciences, The University of Tokyo, 3-8-1 Komaba, Meguro, Tokyo 153-8914, Japan — [2]Department of Physics, and Research and Education Center for Natural Sciences, Keio University, 4-1-1 Hiyoshi, Yokohama, Kanagawa 223-8521, Japan — [3]Dipartimento di Fisica 'E. R. Caianiello', Università degli Studi di Salerno, 84084 Fisciano (Salerno), Italy

In one-dimensional topological superconductors systems, zero-energy Majorana edge modes localize at the domain walls between topologically distinct phases, similar to the case of Jackiw-Rebbi solitons, which are solutions of the Majorana-Dirac equation on an inhomogeneous background. On the other hand, topologically trivial Andreev states below the particle-hole gap can originate from disorder or spatial inhomogeneities. Distinguishing between Majorana and Andreev states is an ongoing challenge that generated intense debate in the scientific community. Indeed, there is a continuous crossover between topologically nontrivial Majorana and trivial Andreev states induced by smooth inhomogeneities, which can occur without closing the bulk gap. Here, we describe nontrivial Majorana and Andreev bound states induced by spatial inhomogeneities and disorder, Shockley states, and Jackiw-Rebbi solitons in a unifying framework, introducing a characteristic length scale that can unambiguously distinguish between different regimes.

TT 31.5 Wed 10:30 HSZ 304

Majorana zero modes in fermionic wires coupled by Aharonov-Bohm cages — •Niklas Tausendpfund[1,2], Sebastian Diehl[2], and Matteo Rizzi[1,2] — [1]Peter Grünberg Institut 8, Forschungszentrum Jülich, Germany — [2]Institute for Theoretical Physics, University of Cologne, Germany

We devise a number-conserving scheme for the realization of Majorana Zero Modes in an interacting fermionic ladder coupled by Aharonov-Bohm cages. The latter provide an efficient mechanism to cancel single-particle hopping by destructive interference. The crucial parity symmetry in each wire is thus encoded in the geometry of the setup, in particular, its translation invariance. A generic nearest-neighbor interaction generates the desired correlated hopping of pairs. We exhibit the presence of an extended topological region in parameter space, first in a simplified effective model via bosonization techniques, and subsequently in a larger parameter regime with matrix-product-states numerical simulations. We demonstrate the adiabatic connection to previous models, including exactly-solvable ones, and we briefly comment on possible experimental realizations in synthetic quantum platforms, like cold atomic samples.

TT 31.6 Wed 10:45 HSZ 304

Tunable coupling of quantum dots via Andreev bound states - towards a Kitaev chain — Chun-Xiao Liu, Guanzhong Wang, Tom Dvir, and •Michael Wimmer — Qutech and Kavli Institute for nanophysics, TU Delft, Niederlande

We show that the coupling between two quantum dots can be effectively mediated via Andreev bound states in a central superconducting segment. This gives rise to an effective superconducting and normal coupling between quantum dot states. Both coupling strengths can be independently controlled by changing the properties of the Andreev bound states, e.g. by a gate voltage. This allows to implement a Kitaev chain that can easily be tuned to a topological phase [1]. We will also discuss first experimental results implementing a two-site Kitaev chain [2, 3].

[1] arXiv:2203.00107
[2] arXiv:2205.03458
[3] arXiv:2206.08045

TT 31.7 Wed 11:00 HSZ 304

Odd-frequency pairing in Floquet topological superconductors — •Eslam S. Ahmed, Shun Tamura, and Yukio Tanaka — Department of Applied Physics, Nagoya University, Japan

Time-periodic (Floquet) Hamiltonians offer a unique and tunable way to engineer topological systems with intriguing edge modes. In particular, Floquet superconductors can possess multi-Majorana edge modes at energies $E = 0$ and $E = \pi$.

It is well-established that there is a direct relationship between odd-frequency Cooper pairing amplitudes and the topological invariants in the static superconductors. In our study, we discuss this relationship in the time-periodic regime.

We consider a Kitaev chain alternating in time between two different values for chemical potential. By tuning the time-periodicity of the alternating chemical potential, we show that the chain admits multiple zero and π energy Majorana modes at the edge of the chain. Furthermore, We show that odd-frequency Cooper pairing amplitude at the edge of the chain is correlated to the presence of Zero and π Majorana modes.

15 min. break

TT 31.8 Wed 11:30 HSZ 304

Phase diagram of an extended parafermion chain — Jurriaan Wouters[1], Fabian Hassler[2], Hosho Katsura[3], and •Dirk Schuricht[1] — [1]Institute for Theoretical Physics, Center for Extreme Matter and Emergent Phenomena, Utrecht University — [2]JARA-Institute for Quantum Information, RWTH Aachen University — [3]Department of Physics, Graduate School of Science, The University of Tokyo

We study the phase diagram of an extended parafermion chain, which, in addition to terms coupling parafermions on neighbouring sites, also possesses terms involving four sites. Via a Fradkin–Kadanoff transformation the parafermion chain is shown to be equivalent to the nonchiral $\mathbb{Z}_3$ axial next-nearest neighbour Potts model. We discuss a possible experimental realisation using hetero-nanostructures. The phase diagram contains several gapped phases, including a topological phase where the system possesses three (nearly) degenerate ground states, and a gapless Luttinger-liquid phase.

TT 31.9 Wed 11:45 HSZ 304

Interacting Majorana fermions — •Lukas Janssen[1] and Urban F. P. Seifert[2] — [1]Technische Universität Dresden, Dresden, Germany — [2]University of California, Santa Barbara, USA

I will present our study of models of interacting Majorana fermions with global SO(N) symmetry. The models can be understood as real counterparts of the SU(N) Hubbard-Heisenberg models and may be realized in Abrikosov vortex phases of topological superconductors, or in fractionalized phases of strongly frustrated spin-orbital magnets. I will describe the zero-temperature phase diagrams and discuss the natures of the occurring quantum phase transitions, with the help of mean-field, renormalization group, and quantum Monte Carlo approaches.

[1] L. Janssen and U. F. P. Seifert, Phys. Rev. B 105, 045120 (2022)

TT 31.10 Wed 12:00 HSZ 304

Multiplicative Majorana zero modes — •Adipta Pal — Max Plank Institute for the Physics of Complex Systems, Dresden, Germany

Topological qubits composed of unpaired Majorana zero-modes are under intense experimental and theoretical scrutiny in efforts to realize practical quantum computation schemes. In this work, we show the minimum four 'unpaired' Majorana zero-modes required for a topological qubit according to braiding schemes and control of entanglement for gate operations are inherent to multiplicative topological phases, which realize symmetry-protected tensor products—and maximally-entangled Bell states—of unpaired Majorana zero-modes known as multiplicative Majorana zero-modes. We introduce multiplicative Majorana zero-modes as topologically-protected boundary states of both one and two-dimensional multiplicative topological phases, using methods reliant on multiplicative topology to construct relevant Hamiltonians from the Kitaev chain model. We furthermore characterize topology in the bulk and on the boundary with established methods while also introducing techniques to overcome challenges in characterizing multiplicative topology. In the process, we explore the potential of these multiplicative topological phases for an alternative to braiding-based topological quantum computation schemes, in which gate operations are performed through topological phase transitions.

TT 31.11 Wed 12:15 HSZ 304

Controlling Majorana modes via Fulde-Ferrell-Larkin-Ovchinnikov phases in topological superconductors and superfluids — •Pasquale Marra[1,2], Daisuke Inotani[2], Takeshi Mizushima[3], and Muneto Nitta[2] — [1]Graduate School of Mathematical Sciences, The University of Tokyo, 3-8-1 Komaba, Meguro, Tokyo 153-8914, Japan — [2]Department of Physics, and Research and Education Center for Natural Sciences, Keio University, 4-1-1 Hiyoshi, Yokohama, Kanagawa 223-8521, Japan — [3]Department of Materials Engineering Science, Osaka University, Toyonaka, Osaka 560-8531, Japan

The next milestones in the route to topological quantum computation with Majorana modes are demonstrating their nonabelian braiding statistics and realizing Majorana-based topological qubits. To achieve this, most proposals require the manipulation of electric gates or magnetic fields in networks of proximitized semiconducting nanowires. Here, we focus on an alternative platform to obtain Majorana modes by employing inhomogeneous Fulde-Ferrell-Larkin-Ovchinnikov (FFLO) phases in topological superconductors and superfluids. The FFLO state spontaneously breaks translational symmetry, inducing a periodic and spatial modulation of the superconducting pairing. We explore the interplay between FFLO order, nontrivial topology, and emergent quantum-mechanical supersymmetry and consider possible routes to realize nonabelian braiding in these platforms.

TT 31.12 Wed 12:30 HSZ 304

Time-reversal invariant topological superconductor in the Coulomb blockade regime — •Steffen Bollmann[1], Elio König[1], and Jukka Väyrynen[2] — [1]Max Planck Institute for Solid State Research, Stuttgart — [2]Purdue University, West Lafayette, Indiana USA

Floating topological superconductors coupled to conduction electrons can realize unconventional O(N), Sp(2N), or multi-channel Kondo effects. Here, we introduce a new topological superconducting mesoscopic device, a time-reversal invariant version of the Majorana Cooper pair box in the Coulomb blockade regime. In this setup of Cartan-Altland-Zirnbauer class DIII, spinful Majorana zero modes appear at the edges of a topological triplet superconductor with fluctuating Cooper pair spin and charge. We study the Kondo effect in the limit of dominating charging energy and in the limit of both small and large spin fluctuations. Beyond its value in the context of exotic mesoscopic Kondo effects, our study sheds light on the intricate interplay of band topology and strong quantum fluctuations of non-Abelian order parameter fields.