TT 3: Topology: Quantum Hall Systems

Time: Monday 9:30–13:00 Location: H 2053

TT 3.1 Mon 9:30 H 2053

Current cross-correlations from an anyonic Mach-Zehnder interferometer — Sarthak Girdhar[1,2,3], Diksha Garg[2,3,4], •Thomas L. Schmidt[3], and Edvin G. Idrisov[3] — [1]Tata Institute of Fundamental Research, Bengaluru, India — [2]Indian Institute of Technology Bombay, Mumbai, India — [3]Department of Physics and Materials Science, University of Luxembourg, Luxembourg — [4]Bhabha Atomic Research Centre, Mumbai, India

Advances in hybrid mesoscopic devices have opened up new avenues for studying edge excitations in quantum Hall (QH) systems. Recent experimental breakthroughs have enabled the construction of anyonic colliders at both integer ($\nu = 2$) and fractional ($\nu = 1/3$) filling factors. Measurements of current cross-correlations and the generalized Fano factor at fractional fillings have demonstrated possible evidence of anyonic exclusion statistics for the constituent charge carriers. All these findings align with the theoretical predictions for the Laughlin state at $\nu = 1/3$.

In our work, we use the nonequilibrium bosonization technique to study the collision of two dilute beams of quasiparticles in chiral QH edge states at filling factors $\nu = 1/(2n+1)$ in a Mach-Zehnder interferometer. The presence of two QPCs acting as beam splitters has some very interesting consequences, e.g., a modulation of the ordinary Aharonov-Bohm oscillations with the length difference between the two beam splitters in the chiral channels. We calculate the tunneling current, its zero frequency noise and the cross-correlation between the currents after scattering.

TT 3.2 Mon 9:45 H 2053

Nonlocal thermoelectric detection of interaction and correlations in edge states — Alessandro Braggio[1], Matteo Carrega[2], •Björn Sothmann[3], and Rafael Sánchez[4] — [1]NEST, Istituto Nanoscienze-CNR and Scuola Normale Superiore, I-56127 Pisa, Italy — [2]SPIN-CNR, 16146 Genova, Italy — [3]Theoretische Physik, Universität Duisburg-Essen and CENIDE, D-47048 Duisburg, Germany — [4]Departamento de Física Teórica de la Materia Condensada, IFIMAC, and Instituto Nicolás Cabrera, Universidad Autónoma de Madrid, 28049 Madrid, Spain

We investigate nonequilibrium effects in the transport of interacting electrons in quantum conductors, proposing the nonlocal thermoelectric response as a direct indicator of the presence of interactions, nonthermal states and the effect of correlations. This is done by assuming a quantum Hall setup where two channels (connected to reservoirs at different temperatures) co-propagate for a finite distance, such that a thermoelectrical response is only expected if the electron-electron interaction mediates heat exchange between the channels. This way, the nonlocal Seebeck response measures the interaction strength. Considering zero-range interactions, we solve the charge and energy currents and noises of a non-equilibrium integrable interacting system, determining the universal interaction-dependent length scale of energy equilibration. Further, a setup with two controllable quantum point contacts allows thermoelectricity to monitor the interacting system thermalisation as well as the fundamental role of cross-correlations in the heat exchange at intermediate length scales.

TT 3.3 Mon 10:00 H 2053

Quantum Hall effect and current distribution in a 3D-topological insulator — •Stefan Hartl[1], Maximilian Kühn[2], Lukas Freund[2], Johannes Ziegler[1], Dmitriy Kozlov[1], Jürgen Weis[2], and Dieter Weiss[1] — [1]Universität Regensburg, Regensburg, Germany — [2]MPI für Festkörperforschung, Stuttgart, Germany

Strained 3D-HgTe, which is a strong topological insulator, exhibits a pronounced quantum Hall effect. This is despite the fact that the current is carried by electrons on the top and bottom surfaces as well as electrons in the bulk conduction band. Here we study the system by three experimental techniques: transport measurements, which include all charge carriers, magnetocapacitance which probes the topmost layer of charges, and Hall potential profile measurements using a scanning field-effect transistor to probe the current distribution in the quantum Hall regime. At small magnetic magnetic fields B, the carrier density reflected by the periodicity of the Shubnikov-de Haas and magnetocapacitance oscillations is strikingly different. This suggests the coexistence of different Landau fans for the three electron species. For large B, however, the capacitance and SdH oscillations reflect the same carrier density. This suggests that at sufficiently high B - due to the charge rearrangement - only one Landau fan survives. The current distribution in the quantum Hall regime shows that the Hall quantization results from the dissipationless Hall current flow in the incompressible bulk regions of the system, similar to the mechanism in conventional two-dimensional electron systems.

HgTe provided by N. Mikhailov and S. A. Dvoretsky, Novosibirsk.

TT 3.4 Mon 10:15 H 2053

Current distribution in the quantum Hall regime — •Serkan Sirt[1], Matthias Kamm[1], Afif Siddiki[2], Vladimir Umansky[3], and Stefan Ludwig[1] — [1]Paul-Drude-Inst. für Festkörperelektronik, Berlin — [2]Istanbul Atlas Univ., Turkey — [3]Weizmann Inst., Israel

The current distribution in the quantized Hall regime is of fundamental interest and important for applications. The widely appreciated Landauer-Büttiker picture (LBP) assumes chiral current flow along 1D, dissipation-less, compressible edge channels (EC). The screening theory [1] goes beyond the scope of the LBP by taking into account Coulomb interaction between electrons. It predicts dissipation-less current flow within incompressible strips (ICSs). The current-generating electric field is restricted to the Landau-gaped ICSs but fully screened elsewhere. As the magnetic field, B, is increased along a quantized Hall plateau, the ICSs move from the edge into the bulk of the Hall bar and thereby widen. Local potential measurements favor the screening theory [2] but direct current measurements are still missing.

Here, we present such direct current distribution measurements using a Hall bar including a small ohmic contact in its center, which does not disturb EC currents. Our measurements suggest EC current at the low B sides of the plateaus but clearly demonstrate bulk currents at higher B, while the Hall resistance remains quantized. Using multiterminal measurements, we further confirm that both, edge and bulk currents, are chiral.

[1] R.R.Gerhardts, Phys. Stat. Sol. (b), **245** (2008) 378
[2] E. Ahlswede et al., Physica B **298** (2001) 562

Invited Talk TT 3.5 Mon 10:30 H 2053

Topological Thermal Hall Conductance of Even Denominator Fractional States — •Moty Heiblum — Weizmann Institute of Science Rehovot 76100, Israel

The even denominator fractional quantum Hall (FQH) states $\nu = 5/2$ and $\nu = 7/2$, have been long predicted to host non-abelian quasiparticles. The presence of energy-carrying neutral modes cripples customary conductance measurements and thus motivates thermal transport measurements, which already proved to be sensitive to all energy-carrying modes. Each state has a different capacity to carry quanta of heat - as expressed by the so-called: 'central charge' - identifying the state's topological order. While the 'two-terminal' thermal conductance measurements identified the topological orders of abelian and non-abelian QH states, they are prone to partial thermal equilibration among counter-propagating modes. Here, we report a 'four-terminal' thermal Hall conductance measurement, which separately measures the heat carried by the downstream and upstream chiral modes. This measurement is insensitive to thermal equilibration among modes. We verify that the $\nu = 5/2$ and $\nu = 7/2$ states are non-abelian, supporting a single upstream Majorana mode, thus obeying the Particle-Hole Pfaffian topological order. While current numerical works predict a different central charge, this contribution should motivate further theoretical work.

15 min. break

TT 3.6 Mon 11:15 H 2053

Fractional quantum Hall states with variational Projected Entangled-Pair States: a study of the bosonic Harper-Hofstadter model — •Erik Lennart Weerda and Matteo Rizzi — University of Cologne, Cologne, Germany

An important class of model Hamiltonians for investigation of topological phases of matter consists of mobile, interacting particles on a lattice subject to a semi-classical gauge field, as exemplified by the bosonic Harper-Hofstadter model. A unique method for investigations of two-dimensional quantum systems are the infinite projected-entangled pair states (iPEPS), as they avoid spurious finite size effects that can alter the phase structure. However, due to no-go theorems in related cases this was often conjectured to be impossible in the past. In this letter, we show that upon variational optimization the infinite projected-entangled pair states can be used to this end, by identifying fractional Hall states in the bosonic Harper-Hofstadter model. The obtained states are characterized by showing exponential decay of bulk correlations, as dictated by a bulk gap, as well as chiral edge modes via the entanglement spectrum.

TT 3.7 Mon 11:30 H 2053

Quantum chaos in a quantum optical simulation of a topological insulator — •Jacquelin Luneau[1,2], Tommaso Roscilde[2], Benoit Douçot[3], and David Carpentier[2] — [1]Technical University of Munich, TUM School of Natural Sciences, Physics Department, 85748 Garching, Germany — [2]ENSL, CNRS, Laboratoire de Physique, F-69342 Lyon, France — [3]LPTHE, UMR 7589, CNRS and Sorbonne Université, 75252 Paris Cedex 05, France

We consider a simple setup of two bosonic modes strongly coupled to a two-level system. In a regime of topological coupling, the dynamics in the space of number of quanta simulates the dynamics of a particle in a Chern insulator submitted to a weak electric field [1]. This analogy enables us to group the eigenstates of the system in three distinct families lying at the same energy scales. The first two families are associated to the bulk of the topologically trivial and non-trivial domain, while the last family corresponds to the edge domain. The family associated to a non-trivial topology is chaotic, while the one associated to a trivial topology is not chaotic. We show that the quantum signatures of chaos of the topological family of eigenstates are non-standard, corresponding to a system at the limit of the domain of application of Random Matrix Theory [2].

[1] J. Luneau, B. Douçot, D. Carpentier, arXiv:2211.13502 (2022).
[2] J. Luneau, T. Roscilde, B. Douçot, D. Carpentier, to be submitted.

TT 3.8 Mon 11:45 H 2053

Topological Phase Transitions of Interacting Phases in Commensurate Magnetic Flux — •Axel Fünfhaus[1], Marius Möller[1], Thilo Kopp[2], and Roser Valentí[1] — [1]Goethe Uni Frankfurt, Frankfurt am Main, Germany — [2]University of Augsburg, Augsburg, Germany

Lattice Hamiltonians in external magnetic fields provide a non-trivial magnetic translation algebra which results in Lieb-Schultz-Mattis (LSM) type theorems. The LSM theorems impose constraints on the topology of the system, in particuar on its Hall conductivity, and exclude trivial band insulating phases depending on the filling factor. We examine these constraints by taking into account the role of interaction driven spontaneous symmetry breaking of translation symmetry. Using exact diagonalization, we identify phase transitions from Hall insulating to topologically trivial charge density wave states for various flux quantum ratios and filling factors. Our findings demonstrate the importance of "conventional" phase transitions in the study of topological phases as they may provide loopholes for properties otherwise protected by no-go LSM-type theorems.

TT 3.9 Mon 12:00 H 2053

New evidence for protected helical Andreev hinge modes in a bismuth nanoring Josephson junction — •Alexandre Bernard[1], Yang Peng[2], Alik Kasumov[1], Richard Deblock[1], Meydi Ferrier[1], Franck Fortuna[3], Yuval Oreg[4], Felix von Oppen[5], Hélène Bouchiat[1], and Sophie Guéron[1] — [1]Laboratoire de Physique des Solides, France — [2]California State University, USA — [3]Institut des Sciences Moléculaires d'Orsay, France — [4]Weizmann Institute of Science, Israel — [5]Dahlem Center for Complex Quantum Systems and Fachbereich Physik, Germany

Second-order topological insulators are characterized by helical, non-spin-degenerate one-dimensional states running along opposite crystal hinges with no backscattering [1]. Injecting superconducting pairs therefore entails splitting Cooper pairs into two families of helical Andreev states of opposite helicity, one at each hinge. Here we provide new evidence for such separation via the measurement and analysis of the switching supercurrent statistics of a crystalline nanoring of bismuth connected to superconducting electrodes. Using a phenomenological model of two helical Andreev hinge modes, we identify an 'odd' state in this long junction, and we find that pairs relax at a rate comparable to individual quasiparticles, in contrast to the much faster pair relaxation of non-topological systems [2].

The nanowire was made by Alik Kasumov, Vladimir Volkov and Yusif Kasumov in Chernogolovka.

[1] F. Schindler et al., Nat. Phys. 14 (2018) 918
[2] A. Bernard et al., Nat. Phys. 19 (2023) 358

TT 3.10 Mon 12:15 H 2053

Thermal robustness of the quantum spin Hall phase in monolayer WTe_2 from single-point first-principles simulations — •Antimo Marrazzo — Dipartimento di Fisica, Università di Trieste, Strada Costiera 11, Trieste I-34151, Italy

I will present first-principles simulations of the temperature effects on the electronic structure of monolayer 1T'-WTe_2 and consider the contributions of both thermal expansion and electron-phonon coupling [1]. First, I will show that thermal expansion is weak but tends to increase the indirect band gap. Then, I will discuss the effect of electron-phonon coupling on the band structure, which has been calculated with nonperturbative methods, observing a small reduction of the band inversion with increasing temperature. Notably, the topological phase and the presence of a finite gap are found to be particularly robust to thermal effects up to and above room temperature. Finally, I will introduce a single-point formula to calculate $\mathbb{Z}_2$ topological invariants in the supercell framework [2], where a single Hamiltonian diagonalisation is performed. Beyond disordered systems, our approach [2] is particularly useful to investigate the role of defects, to study topological alloys and in the context of *ab initio* molecular dynamics simulations at finite temperature.

[1] A. Marrazzo, Phys. Rev. Materials 7 (2023) L021201
2] R. Favata, A. Marrazzo, Electron. Struct. 5 (2023) 014005

TT 3.11 Mon 12:30 H 2053

Quantum kinetic equation and thermal conductivity tensor for bosons — •Léo Mangeolle[1,2,3], Lucile Savary[1,2], and Leon Balents[2] — [1]ENS de Lyon, CNRS, Laboratoire de Physique, 46 allée d'Italie, 69007 Lyon, France — [2]Kavli Institute for Theoretical Physics, University of California, Santa Barbara, CA 93106 — [3]Technical University of Munich, School of Natural Sciences, Physics Department, 85748 Garching, Germany

We obtain a systematic derivation of the semi-classical kinetic equation for neutral bosons from their full quantum kinetic equation. It incorporates the semi-classical topological dynamics of wavepackets in the form of geometric properties of the energy eigenstates, such as the Berry phases and curvatures, generalized to phase space. This makes it possible to treat inhomogeneous systems, including boundaries, textures, etc., in a compact and natural manner. We compute the associated observable quantities, such as energy and current densities, away from equilibrium. In particular, the thermal conductivity tensor, which describes the energy current induced by a temperature gradient, is exactly obtained. This provides a self-contained and exact derivation of the intrinsic thermal Hall effect of neutral bosons such as phonons and magnons, in agreement with Kubo formula results while being considerably more intuitive, and naturally avoiding subtleties associated with magnetization currents. I will eventually present a few calculations using the derived quantum kinetic equation: - the local thermal Hall current of topological magnons in a collinear antiferromagnet, - the energy density and local currents in a skyrmion lattice.

TT 3.12 Mon 12:45 H 2053

Correlated two-Leviton states in the fractional quantum Hall regime — Bruno Bertin-Johannet[1], Alexandre Popoff[2], •Flavio Ronetti[1], Jérôme Rech[1], Thibaut Jonckheere[1], Laurent Raymond[1], Benoît Grémaud[1], and Thierry Martin[1] — [1]Aix-Marseille Univ, Université de Toulon, CNRS, CPT, Marseille, France — [2]Collège de Tipaerui, BP4557- 98713 Papeete, Tahiti, French Polynesia

The on-demand generation of single- and few-electron states in mesoscopic systems has opened the way to the fascinating field of electron quantum optics (EQO), where individual fermionic quantum states are manipulated with methods borrowed from photonic quantum-optical experiments. In this framework, a train of Lorentzian voltage pulses represents one of the most reliable experimental protocol to inject coherent single-electronic states, known as Levitons, into ballistic channels of meso-scale devices. These fascinating results open up the possibility of investigating the dynamics of single-electron states in one-dimensional systems. Indeed, it is well known that, in contrast with photons, electronic systems are drastically affected by electron-electron correlations. In this talk, we focus on two-Leviton states injected in a single period with a time separation Δt. We propose that an effective interaction between the two Levitons is induced by the strongly-correlated background which can be tuned by this time delay Δt. Evidence for this interaction between single-elctron wave-packets can be found in some quantum transport measurement and we support this statement by analytical and numerical calculations.