Q 52: Quantum Gases: Fermions II

Time: Thursday 14:30–16:45 Location: P 204

Q 52.1 Thu 14:30 P 204

Observation of a dynamical topological phase transition — •Benno Rem[1], Nick Fläschner[1], Dominik Vogel[1], Matthias Tarnowski[1], Dirk-Sören Lühmann[1], Markus Heyl[2], Jan Budich[3], Ludwig Mathey[1], Klaus Sengstock[1], and Christof Weitenberg[1] — [1]ILP, ZOQ, CUI, Universität Hamburg — [2]Physik Department, TU München — [3]IQOQI, ITP, Universität Innsbruck

Topological phases are characterized by a non-local order and constitute a exotic form of matter. The paradigmatic Haldane model on a hexagonal lattices features topologically distinct phases characterized by the Chern number. Recently, quenches in such models have attracted particular attention and it was pointed out that while a Hall response builds up dynamically, the Chern number of the wave function cannot change across the quench. Instead the dynamical evolution will feature Fisher zeros in the Loschmidt amplitude, which give rise to what is called a dynamical phase transition. Here, we experimentally study this dynamical evolution using a time- and momentum-resolved state tomography for spin-polarized fermionic atoms in driven optical lattices [1]. At a critical time after a sudden quench, we observe the appearance, movement and annihilation of dynamical vortices in momentum space [2]. We identify them as the Fisher zeros, which signal the dynamical phase transition. Our results pave the way to a search of topological quantities in non-equilibrium dynamics.

[1] N. Fläschner, et al., Science 352, 1091 (2016)
[2] N. Fläschner, et al., arXiv:1608.05616 (2016)

Q 52.2 Thu 14:45 P 204

Synthetic Creutz-Hubbard Model: Interacting Topological Insulators with Ultracold Atoms — Johannes Jünemann[1,2], Angelo Piga[3], Shi-Ju Ran[3], Maciej Lewenstein[3,4], •Matteo Rizzi[1], and Alejandro Bermudez[5,6] — [1]Johannes Gutenberg-Universität, Mainz (Germany) — [2]MAINZ - Graduate School Materials Science in Mainz (Germany) — [3]ICFO-Institut de Ciencies Fotoniques, Castelldefels (Spain) — [4]ICREA-Institució Catalana de Recerca i Estudis Avançats, Barcelona (Spain) — [5]Swansea University (UK) — [6]Instituto de Física Fundamental, IFF-CSIC, Madrid (Spain)

Understanding the robustness of topological phases of matter in the presence of strong interactions, and synthesising novel strongly-correlated topological materials, lie among the most important challenges of modern theoretical and experimental physics. Here we present a complete theoretical analysis of the Creutz-Hubbard ladder, a paradigmatic model that provides a neat playground to address these challenges. We put special attention to the competition of exotic topological phases and orbital quantum magnetism in the regime of strong interactions and identify the universality class of the different phase transitions. These results are furthermore confirmed and extended by extensive numerical simulations and analysis of the entanglement properties. Moreover, we propose how to experimentally realize this model and test its phase diagram in a synthetic ladder, made of two internal states of ultracold fermionic atoms in a one-dimensional optical lattice. Our work paves the way towards quantum simulators of interacting topological insulators with cold atoms.

Q 52.3 Thu 15:00 P 204

One dimensional massless Lorentz Invariant Systems on Ring with magnetic Flux — •Manon Bischoff[1], Johannes Jünemann[1], Matteo Rizzi[1], and Marco Polini[2] — [1]JGU Mainz — [2]IIT Genua

The persistent current response of one dimensional (1D) electrons on a ring pierced by a magnetic flux has been longly studied in solid state setups. Little attention has been however devoted to systems with Dirac-cone dispersion at the Fermi-level, and the few available results are focused on the non-interacting case. Here we investigate the scaling of the current and its response with respect to system-size and interaction-strength in a (quasi-)1D Creutz ladder model with Hubbard interactions, as realisable in cold atomic setups. We present both analytical results based on bosonization and numerical results obtained using so-called binary tree-tensor networks. The current response behaves very similarly to the Drude weight of the 1D Hubbard model: it vanishes at exactly half-filling as soon as interactions are turned on (thus testifying a gap opening), while it stays finite and positive away from that (the system stays in the Luttinger liquid regime). This is instead in contrast with two dimensional massless Lorentz invariant systems, where the magnetic susceptibility (also the persistent current response to a piercing flux) away from half-filling is vanishing in the free case and interactions can induce a net negative response.

Q 52.4 Thu 15:15 P 204

Signatures of topological phases in ultracold fermionic ladders — •Andreas Haller[1], Leonardo Mazza[2], Matteo Rizzi[1], and Michele Burrello[3] — [1]Institute of Physics, Johannes Gutenberg University, 55099 Mainz, Germany — [2]Département de Physique, Ecole Normale Supérieur, 75005 Paris, France — [3]Niels Bohr Institute, University of Copenhagen, 2100 Copenhagen, Denmark

Inspired by the recent experimental advances in the study of ultracold atoms trapped in optical lattices, we consider models of ultracold fermions hopping in ladder geometries and subject to artificial magnetic fluxes.

In the presence and absence of interactions, we investigate the thermodynamic phases that can emerge in these simple, quasi-one-dimensional setups.

By applying the concept of resonances in chiral currents, we find a topological order parameter, distinguishing between trivial and quantum Hall (QH) phases.

We aim for evidence about fractional QH phases in ladders with short-range repulsive interactions: For both nearest and next-to-nearest neighbor interactions, tensor network simulations show not only the appearance of the expected $\nu = 1/3$ Laughlin-like states, but also of an exotic $\nu = 1/2$ phase.

Q 52.5 Thu 15:30 P 204

Topological order in finite-temperature Gaussian fermionic systems — •Lukas Wawer, Dominik Linzner, and Michael Fleischhauer — Fachbereich Physik und Forschungszentrum OPTIMAS, Technische Universität Kaiserslautern, 67663 Kaiserslautern, Deutschland

Since their discovery, topological states of matter have been praised for their fascinating and potentially useful properties as protected edge states or anyonic excitations. However, these features seem to vanish at finite temperature. Exploiting the equivalence of Zak (or Berry) phase and polarization we can classify topological order in finite-temperature systems by means of the many body polarization [1]. We show that topological order defined in this way survives at any finite temperature in Gaussian fermionic systems. On the one hand we consider a 1D model for symmetry protected topological order (Su-Schrieffer-Heeger model) and find that there is a quantized winding of the polarization for closed paths in parameter space. On the other hand we study a 2D model (Hofstadter-Hubbard model) with intrinsic topology and show that there is an integer change of polarization at any finite temperature if we go through the Brillouin zone. This change of polarization can be identified as the counterpart of the Chern number in closed 2D models. [1] D. Linzner, L. Wawer, F. Grusdt, and M. Fleischhauer, Phys. Rev. B 94, 201105(R) (2016)

Q 52.6 Thu 15:45 P 204

Versatile detection scheme for topological Bloch-state defects — •Marlon Nuske[1], Matthias Tarnowski[2,3], Nick Fläschner[2,3], Benno Rem[2,3], Dominik Vogel[2], Klaus Sengstock[1,2,3], Ludwig Mathey[1,2,3], and Christof Weitenberg[2,3] — [1]Zentrum für optische Quantentechnologien, Universität Hamburg, 22761 Hamburg, Germany — [2]Institut für Laserphysik, Universität Hamburg, 22761 Hamburg, Germany — [3]The Hamburg Centre for Ultrafast Imaging, 22761 Hamburg, Germany

The dynamics in solid state systems is not only governed by the band structure but also by topological defects of the Eigenstates. A paradigmatic example are the Dirac points in graphene. For this system with a two-atomic basis the linear dispersion relation at the Dirac points is accompanied by a vortex of the azimuthal phase of the Eigenstates. In a time-of-flight (ToF) expansion the Eigenstates interfere and the resulting signal contains information about the azimuthal phase. We present a versatile detection scheme that uses off-resonant lattice modulation to extract the azimuthal phase from the ToF signal. This detection scheme is applicable to a variety of two-band systems and can be extended to general multi-band systems.

Q 52.7 Thu 16:00 P 204

Measurement of the merging transition of Dirac points in a tunable optical lattice — •Matthias Tarnowski[1,3], Marlon Nuske[2], Nick Fläschner[1,3], Benno Rem[1,3], Dominik Vogel[1], Klaus Sengstock[1,2,3], Ludwig Mathey[1,2,3], and Christof Weitenberg[1,3] — [1]Institut für Laserphysik, Universität Hamburg, 22761 Hamburg, Germany — [2]Zentrum für optische Quantentechnologien, Universität Hamburg, 22761 Hamburg, Germany — [3]The Hamburg Centre for Ultrafast Imaging, 22761 Hamburg, Germany

Topological defects, such as Dirac points in graphene, and their resulting Berry phases play an important role, e.g. for the electronic dynamics in solid state crystals. Tunable quantum gas systems in optical lattices allow for deep and new insights into topological properties of quantum many-body systems. Here we discuss the experimental observation of the so-called merging transition of Dirac points in a tunable hexagonal optical lattice in a boron nitride configuration. We have developed a new method to fully map out the positions of the topological defects in a two-band model. Our measurements illustrate that topological defects are robust under change of lattice parameters and can only be destroyed by annihilation of two vortices with opposite winding.

Q 52.8 Thu 16:15 P 204

High-Precision Spectroscopy of Ultracold Fermions in a Honeycomb Lattice — •Nick Fläschner[1,2], Benno S. Rem[1,2], Matthias Tarnowski[1,2], Dominik Vogel[1], Christof Weitenberg[1,2], and Klaus Sengstock[1,2,3] — [1]ILP - Institut für Laserphysik, Hamburg, Deutschland — [2]The Hamburg Centre for Ultrafast Imaging, Hamburg, Deutschland — [3]ZOQ - Zentrum für Optische Quantentechnologien, Hamburg, Deutschland

Ultracold atoms in optical lattices with tunable geometry [1-4] can be employed to emulate various solid-state systems. For the understanding of such complex quantum systems, it is desirable to develop versatile spectroscopy methods. Here we demonstrate a high-precision multi-band spectroscopy in a honeycomb lattice using ultracold fermionic atoms. We determine both the fully momentum-resolved energy spectrum and the excitation probabilities, which reflect the symmetry of the eigenstates and e.g. the Dirac cones in the system. Our results provide an ideal starting point for the investigation of interacting systems.

[1] Becker et al., New J. Phys. 12, 065025 (2010)
[2] Soltan-Panahi et al., Nat. Phys. 7, 434-440 (2011)
[2] Taruell et al., Nature 483, 302-305 (2012)
[3] Fläschner/Rem et al., Science 352, 1091-1094 (2016)

Q 52.9 Thu 16:30 P 204

Exact Quantum Field Mappings Between Different Experiments on Quantum Gases — •Etienne Wamba[1,2], Axel Pelster[1], and James R. Anglin[1] — [1]State Research Center OPTIMAS and Fachbereich Physik, Technische Universität Kaiserslautern, 67663 Kaiserslautern, Germany — [2]International Center for Theoretical Physics, 34151 Trieste, Italy

Experiments on trapped quantum gases can probe challenging regimes of quantum many-body dynamics, where strong interactions or nonequilibrium states prevent exact solutions. Here we present a different kind of exact result, which applies even in the absence of actual solutions: a class of space-time mappings of different experiments onto each other [1]. Since our result is an identity relating second-quantized field operators in the Heisenberg picture of quantum mechanics, it is extremely general; it applies to arbitrary measurements on any mixtures of Bose or Fermi gases, in arbitrary initial states. It represents a strong prediction of quantum field theory which can be tested in current laboratories, and whose practical applications include perfect simulation of interesting experiments with other experiments which may be easier to perform.

[1] Phys. Rev. A **94**, 043628 (2016)