Q 21: Quantengase: Optische Gitter 1

Time: Tuesday 10:30–12:30 Location: V53.01

Q 21.1 Tue 10:30 V53.01

Observation of Correlated Particle-Hole Pairs and String Order in Low-Dimensional Mott Insulators — •Manuel Endres[1], Marc Cheneau[1], Takeshi Fukuhara[1], Christof Weitenberg[1], Peter Schauss[1], Christian Gross[1], Leonardo Mazza[1], Mari Carmen Banuls[1], Lode Pollet[2], Immanuel Bloch[1], and Stefan Kuhr[3] — [1]Max-Planck-Institut für Quantenoptik, Garching — [2]Theoretische Physik, ETH Zurich — [3]University of Strathclyde, SUPA, Glasgow

Quantum phases of matter are characterized by the underlying correlations of the many-body system. Although this is typically captured by a local order parameter, it has been shown that a broad class of many-body systems possesses a hidden non-local order. In the case of bosonic Mott insulators, the ground state properties are governed by quantum fluctuations in the form of correlated particle-hole pairs that lead to the emergence of a non-local string order in one dimension. Using high-resolution imaging of low-dimensional quantum gases in an optical lattice, we directly detect these pairs with single-site and single-particle sensitivity and observe string order in the one-dimensional case.

Q 21.2 Tue 10:45 V53.01

Dynamics of ultracold fermions in higher lattice orbitals — •Nick Fläschner, Jannes Heinze, Jasper Simon Krauser, Sören Götze, Christoph Becker, and Klaus Sengstock — Universität Hamburg, Institut für Laser-Physik, Luruper Chaussee 149, 22761 Hamburg, Germany

Due to the analogy to electrons in crystals, ultracold fermions in optical lattices are ideally suited to simulate solid-state systems. These are often characterized by their dynamical response to an external perturbation, e.g. charge transport in electric fields. To compare both situations, it is highly interesting to investigate the dynamical properties of ultracold fermions in optical lattices. For this, we prepare spin-polarized fermions in a shallow 1D-lattice, excite a small fraction to the third band using lattice amplitude modulation and thus create particle-hole pairs with a well-defined momentum [1]. We observe the time evolution of the particle-hole pair in momentum space which reveals an oscillatory behavior. The oscillation frequency is dependent on the initial momentum of the excitations, the trapping frequency of the harmonic confinement and the lattice depth. We compare our data to a single-particle quantum model yielding very good quantitative agreement. Our findings will allow us to investigate the dynamical properties of interacting Fermi spin-mixtures as well as transport properties of fermionic quantum gases in higher bands.

[1] J. Heinze et al., PRL 107, 135303 (2011)

Q 21.3 Tue 11:00 V53.01

Klein-Tunneling of a Quasirelativistic Bose-Einstein Condensate in an Optical Lattice — •Christopher Grossert[1], Tobias Salger[1], Sebastian Kling[1], Dirk Witthaut[2], and Martin Weitz[1] — [1]Institut für Angewandte Physik, D- 53115 Bonn — [2]Max-Planck-Institute for Dynamics and Self-Organization, D-37073 Göttingen

A proof-of-principle experiment simulating effects predicted by relativistic wave equations with ultracold atoms in a bichromatic optical lattice that allows for a tailoring of the dispersion relation is reported [1]. In this lattice, for specific choices of the relativistic phases and amplitudes of the lattice harmonics the dispersion relation in the region between the first and the second excited band becomes linear, as known for ultrarelativistic particles. We have shown that the dynamics can be described by an effective one-dimensional Dirac equation [2].

We experimentally observe the analog of Klein-Tunneling, the penetration of relativistic particles through a potential barrier without the exponential damping that is characteristic for nonrelativistic quantum tunneling [3]. Both linear (relativistic) and quadratic (nonrelativistic) dispersion relations are investigated, and significant barrier transmission is only observed for the relativistic case.

[1] T. Salger et al.: Phys. Rev. Lett. **107** 240401 (2011)
[2] D. Witthaut et al.: Phys. Rev. A **84** 033601 (2011)
[3] O. Klein: Z.Physik **53** 127 (1929)

Q 21.4 Tue 11:15 V53.01

Optical lattice based quantum simulators for relativistic field theories — •Nikodem Szpak and Ralf Schützhold — Fakultät für Physik, Universität Duisburg- Essen

We show how (discretized) relativistic field theories emerge from the low energy regime of optical lattice systems loaded with ultra-cold atoms. In particular, we demonstrate a general mechanism of mass generation on the lattice and the apearance of pseudo-relativistic energy-momentum relation for quasi-particles, known for several particular systems. Our goal is to present the underlying mechanisms from a unified perspective, applicable for general Hubbard-like Hamiltonian systems, including also crystalline materials like graphene. We complete by giving examples in different geometric settings.

[1] N. Szpak and R. Schützhold, Phys. Rev. A 84, 050101(R) (2011)

Q 21.5 Tue 11:30 V53.01

Creating, moving and merging Dirac points with a Fermi gas in a tunable honeycomb lattice — •Gregor Jotzu, Leticia Tarruell, Daniel Greif, Thomas Uehlinger, and Tilman Esslinger — Institute for Quantum Electronics, ETH Zurich, 8093 Zurich, Switzerland

We report on the creation of Dirac points with adjustable properties in a tunable honeycomb optical lattice. Using momentum-resolved interband transitions, we observe a minimum band gap inside the Brillouin zone at the position of the Dirac points. We exploit the unique tunability of our lattice potential to adjust the effective mass of the Dirac fermions by breaking the inversion symmetry of the lattice. Moreover, changing the lattice anisotropy allows us to move the position of the Dirac points inside the Brillouin zone. When increasing the anisotropy beyond a critical limit, the two Dirac points merge and annihilate each other. We map out this topological transition in lattice parameter space and find excellent agreement with ab initio calculations. Our results pave the way to model materials where Berry phases and the topology of the band structure play a crucial role. Furthermore, they provide the possibility to explore many-body phases resulting from the interplay of complex lattice geometries with interactions.

Q 21.6 Tue 11:45 V53.01

Observation of inter-band dynamics in a tunable hexagonal lattice — •Malte Weinberg, Juliette Simonet, Christina Staarmann, Julian Struck, Christoph Ölschläger, Patrick Windpassinger, and Klaus Sengstock — Institut für Laserphysik, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg

Hexagonal lattices have recently attracted a lot of attention in the condensed matter community and beyond. Upon other intriguing features, their unique band structure exhibits Dirac cones at the corners of the Brillouin zone of the two lowest energy bands.

Here, we report on the experimental observation of quasi momentum-resolved inter-band dynamics of ultracold bosons between the two lowest Bloch bands (s- and p-band) of a hexagonal optical lattice with tunable band structure.

Due to the spin-dependency of the lattice potential [1], a rotation of the magnetic quantization axis and the choice of the atomic spin state allow for an in-situ manipulation of the lattice structure from hexagonal to triangular geometry. It is thus possible to modify the band structure and open a gap at the Dirac cones. The loading of atoms into the excited band is achieved by a microwave transition between different spin states which in certain cases is only allowed as a result of interaction effects. We observe the time-dependent population of quasi momenta, revealing a striking influence of the existence of Dirac cones on the dynamics of atoms in the first two energy bands.

[1] P. Soltan-Panahi et al., Nature Physics 7, 434-440 (2011)

Q 21.7 Tue 12:00 V53.01

Sauter-Schwinger like tunneling in tilted Bose-Hubbard lattices — Friedemann Queisser[2], •Patrick Navez[1], and Ralf Schützhold[2] — [1]Institut für Theoretische Physik, Technische Universität Dresden, 01062 Dresden, Germany — [2]Fakultät für Physik, Universität Duisburg-Essen, Lotharstrasse 1, 47057 Duisburg, Germany

We study the Mott phase of the Bose-Hubbard model on a tilted lattice. In the limit of large coordination numbers Z (i.e,. tunneling partners), we establish a hierarchy of correlations via a $1/Z$-expansion. On the (Gutzwiller) mean-field level, the tilt has no effect – but quantum fluctuations entail particle-hole pair creation via tunneling. For small potential gradients (long-wavelength limit), we derive a quantitative analogy to the Sauter-Schwinger effect, i.e., electron-positron pair creation out of the vacuum by an electric field. For large tilts, we obtain resonant tunneling reminiscent of Bloch oscillations.

References: arXiv:1107.3730v1, Phys. Rev. A **82**, 063603 (2010)

Q 21.8 Tue 12:15 V53.01

Tunneling dynamics of ultracold bosons in tilted optical lattices — •Konstantin Krutitsky[1], Patrick Navez[2], Friedemann Queisser[1], and Ralf Schützhold[1] — [1]Fakultät für Physik, Universität Duisburg-Essen, Lotharstrasse 1, 47057 Duisburg, Germany — [2]Institut für Theoretische Physik, Technische Universität Dresden, 01062 Dresden, Germany

We present the results of our investigation of ultracold bosons in tilted optical lattices by means of exact numerical diagonalization. Starting in the ground state, we calculate the probability for creating a particle-hole excitation in the Mott-insulator phase after the tilt is smoothly switched on and off again. For very short time scales, we obtain dynamical particle-hole creation, and for intermediate time scales, the particle-hole pairs are produced via tunneling in rather good agreement with the analytical predictions. Finally, if the time dependence is very slow (such that the excitations have enough time to propagate through the whole lattice), finite-size effects start to play a role, and eventually, the pair creation probability goes to zero in the adiabatic regime.

References: arXiv:1107.3730v1, Phys. Rev. A **82**, 063603 (2010)