Q 4: Quantum gases (Fermions) I

Time: Monday 11:00–13:00 Location: e214

Q 4.1 Mon 11:00 e214

Simulationg the Mott insulator using attractive interaction — •Chun Fai Chan, Marcell Gall, Nicola Wurz, Jens Samland, and Michael Köhl — Physikalisches Institut, University of Bonn, Bonn, Germany

We investigate the particle-hole symmetry of the two-dimensional Hubbard model under a particle-hole transformation using ultracold fermionic potassium-40 confined in optical lattices. By experimentally probing the density and spin sectors of the Hubbard models with both repulsive and attractive interactions, we demonstrate a direct mapping between relevant observables. In addition, we observe a Mott-like, spin-incompressible phase in our realization of the spin-imbalanced attractive Hubbard model. Our results present a novel approach to quantum simulation by giving access to strongly-correlated phases of matter through an experimental mapping to easier detectable observables.

Q 4.2 Mon 11:15 e214

Dark state dynamics in dissipative Fermi gases — •Lukas Freystatzky[1,2] and Ludwig Mathey[1,2] — [1]Zentrum für Optische Quantentechnologien, Universität Hamburg, Hamburg, Germany — [2]The Hamburg Centre for Ultrafast Imaging, Hamburg, Germany

Inspired by recent experiments in ultracold Ytterbium gases, reported by Sponsele *et.al., Quantum Science and Technology* **4**, 014002 (2019), we investigate the dynamics of the dissipative 1D Fermi-Hubbard model.

The dynamics is governed by the coherent evolution due to the Hamiltonian as well as an inelastic scattering process leading to two particle losses. We model this system with a Master equation formalism, for small system sizes. We expand these studies to larger system sizes by using a quantum Jump algorithm.

In our model we find dark states, i.e. eigenstates of the Hamiltonian that do not couple to the dissipative term. Depending on the initial state the system can be driven into different dark states with distinct properties. For example, a spin balanced initial state decays into highly correlated Dicke states.

Other initial states give rise to dark states with non-trivial dynamics, as we report in this presentation.

Q 4.3 Mon 11:30 e214

Detecting topology in interacting fermionic wires via post-quench observables — Andreas Haller[1], Pietro Massignan[2,3], and •Matteo Rizzi[4,5] — [1]Institute of Physics, Johannes Gutenberg University, D-55099 Mainz, Germany — [2]Departament de Fìsica, Universitat Politècnica de Catalunya, Campus Nord B4-B5, 08034 Barcelona, Spain — [3]ICFO – Institut de Ciencies Fotoniques, The Barcelona Institute of Science and Technology, 08860 Castelldefels (Barcelona), Spain — [4]Forschungszentrum Jülich, Institute of Quantum Control, Peter Grünberg Institut (PGI-8), 52425 Jülich, Germany — [5]Institute for Theoretical Physics, University of Cologne, D-50937 Köln, Germany

We exploit a simple observable called "mean chiral displacement" (MCD) for interacting fermionic wires and study numerically the interacting Su-Schrieffer-Heeger (SSH) chain by means of matrix product state calculations. In particular, we propose to study the time-evolution of a simple local quench which relates the MCD to the many-body topological invariant of the Hamiltonian for weakly-correlated interacting models. We study both a short-range correlated and a long-correlated model exhibiting topological/trivial insulators and a (trivial) symmetry breaking phase, and we link the behavior of the MCD to all three phases. We provide an experimental blueprint to obtain the long-range correlated model hosting all three phases.

Q 4.4 Mon 11:45 e214

Observing the Few-Body Precursor of a Higgs Mode — •Luca Bayha, Marvin Holten, Keerthan Subramanian, Ralf Klemt, Philipp Preiss, and Selim Jochim — Physics Institute, Heidelberg University, Germany

The competition between two scales gives rise to rich physics. For example, the finite size of mesoscopic systems results in single particle gaps and shell structures, well known from nuclear and atomic physics. Here I will present our progress on realizing such mesoscopic systems with ultracold fermions. We can prepare closed shells of up to 12 fermions in the ground state of a two dimensional trap. With the help of a Feshbach resonance we tune the interactions from a single–particle gap regime to a pairing regime. For filled shells there is a minimal required attraction for pairing to overcome the single–particle gap.

In the thermodynamic limit, the onset of pairing with increasing interaction gives rise to a quantum phase transition into the superfluid state. This is accompanied by an undamped Higgs mode. Remarkably, we observe a precursor of this mode already in the mesoscopic system consisting of six fermions. The lowest monopole excitation shows mode softening as function of the interaction strength. The non-monotonicity is the few body analogue of the gap closing at the phase transition. By measuring the atom number distribution of the excitation, we can show that it is a pair excitation as expected for the Higgs mode, since the order parameter is the pair density.

Q 4.5 Mon 12:00 e214

Slow quench in dilute attractively interacting Fermi gases: Emergence of preformed pairs — •Johannes Kombe, Jean-Sébastien Bernier, Michael Köhl, and Corinna Kollath — Physikalisches Institut, University of Bonn, Nussallee 12, 53115 Bonn, Germany

We investigate the non-equilibrium behaviour of dilute attractively interacting Fermi gases subject to slow ramps of their internal interaction strength, identifying three different dynamical regimes as a function of ramp duration. We demonstrate that, via slow quenches, one can dynamically tune the coherence between pairs, and thus control the magnitude of the superconducting order parameter. In fact, we show that one can even engineer a non-equilibrium state made of preformed pairs.

Q 4.6 Mon 12:15 e214

Assembling a Strongly Correlated Fermi Superfluid one Atom at a Time — •Marvin Holten, Luca Bayha, Keerthan Subramanian, Carl Heintze, Philipp Preiss, and Selim Jochim — Physics Institute, University of Heidelberg, Germany

Strong correlations between Fermions lie at the heart of many open questions concerning quantum matter that remain unresolved to this day. Examples are quark gluon plasmas, strange metals or high temperature superconductors. Effective descriptions of such systems in terms of weakly interacting constituents are unknown and the strong fermionic correlations must be considered.

In our experiment, we take a novel approach to study a strongly interacting two-dimensional Fermi superfluid by starting from very small systems, prepared deterministically in the ground state. We find evidence for the presence of a few body precursor of the superfluid phase transition and study its dependence on particle number. In this talk, I present first results obtained by applying a time-of-flight imaging technique, both spin and single particle resolved, to this system. This enables us to extract arbitrary N-body correlations of our many-body state. First measurements reveal strong high-order momentum correlations even between identical, non-interacting, Fermions. These manifest due to Pauli's principle, leading to particular geometric arrangements of trapped Fermions also referred to as Pauli Crystals.

We plan to extend these measurements to both interacting systems and larger particle numbers in the future to tackle the issue of the pairing mechanism in strongly interacting Fermi gases.

Q 4.7 Mon 12:30 e214

Unsupervised Machine Learning of Topological Phase Transitions from Experimental Data — •Niklas Käming[1], Benno Rem[1,2], Matthias Tarnowski[1,2], Luca Asteria[1], Nick Fläschner[1], Christoph Becker[1,3], Klaus Sengstock[1,2,3], and Christof Weitenberg[1,2] — [1]ILP - Institut für Laserphysik, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany — [2]The Hamburg Centre for Ultrafast Imaging, Luruper Chaussee 149, 22761 Hamburg, Germany — [3]ZOQ - Zentrum für Optische Quantentechnologien, Universität Hambur g, Luruper Chaussee 149, 22761 Hamburg, Germany

Machine learning techniques such as artificial neural networks are currently revolutionizing many technological areas and have also proven successful in quantum physics applications. Here we apply unsupervised learning techniques such as deep convolutional autoencoders to identify phase transition from experimental data. We map out the complete two-dimensional topological phase diagram of the Haldane model with an unsupervised learning scheme applied to experimental momentum space density images of ultracold quantum gases. Our work points the way to experimentally explore unknown complex phase diagrams without prior knowledge of the underlying theoretical structure.

Q 4.8 Mon 12:45 e214

Experimental Quantum State Reconstruction of Few-Fermion Systems via Neural Networks — •Laurin Fischer[1], Marcel Neugebauer[1], Martin Gärttner[2], Philipp Preiss[1], Matthias Weidemüller[1], and Selim Jochim[1] — [1]Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg — [2]Kirchhoff-Institut für Physik, Universität Heidelberg, Im Neuenheimer Feld 227, 69120 Heidelberg

For reconstructing the state of a many-body quantum system, the number of required measurements typically scales exponentially with the system size. Machine learning techniques based on generative models have emerged in recent years as an intriguing tool to tackle this challenge. To this end, an artificial neural network is trained to encode the probability distribution of an informationally complete measurement via unsupervised learning.
This approach has been established through numerical simulations of spin models, showing promising scaling of computational resources. In order to investigate the practical feasibility of these methods, we aim to apply them to realistic experimental settings.
In this talk, we demonstrate a successful neural-network state representation of a system of few fermionic ^6Li atoms in a double-well potential of optical tweezers. The training data is generated by measurements of in-situ populations in real space and correlation measurements in momentum-space, allowing us to benchmark this approach against more conventional techniques of state reconstruction, such as maximum likelihood.