Q 12: Quantum Effects

Time: Monday 14:00–16:00 Location: f442

Q 12.1 Mon 14:00 f442

Exploring complex graphs using 3D quantum walks of correlated photon pairs — •Max Ehrhardt[1], Robert Keil[2], Lukas Maczewsky[1], Matthias Heinrich[1], and Alexander Szameit[1] — [1]Institut für Physik, Universität Rostock, Albert-Einstein-Str. 23-24, 18059 Rostock, Germany — [2]Universität Innsbruck, Institut für Experimentalphysik, Technikerstr. 25d, 6020 Innsbruck, Austria

The complexity of graphs fundamentally constrains the applicative potential of quantum walks in quantum search algorithms, as well as the study of graph theory problems and biochemical energy transport. Currently, the experimental implementation of such graphs is limited to two dimensions for more than a single walker. We harness the hybrid interaction of spatial degrees of freedom and coupling between the polarization states of single photons to implement quantum walks on 3D graphs in waveguide circuits for the first time. In order to illustrate the functional capabilities of our approach, we demonstrate that polarization forms a synthetic space in a single waveguide, and successively upgrade this system to the third dimension. In addition to experimentally exploring 3D graphs with two correlated photons, we also present a new approach to the implementation of negative coupling coefficients as well as the observation of fermionic statistics with two bosonic quantum walkers.

Q 12.2 Mon 14:15 f442

Partial distinguishability in systems of identical particles — •Gabriel Dufour, Eric Brunner, Christoph Dittel, and Andreas Buchleitner — Physikalisches Institut, Albert-Ludwigs-Universität Freiburg

A complete description of bosonic and fermionic many-body systems should include degrees of freedom which could, in principle, allow to distinguish the particles. Indeed, the existence of such "labels" leads to the degradation of many-particle interference in the dynamical degrees of freedom. We show how partial distinguishability can be described in terms of entanglement between dynamical and label degrees of freedom and relate the coherences of the reduced state of the dynamical degrees of freedom with the interference contributions to expectation values of many-body observables.

Q 12.3 Mon 14:30 f442

Are photons really bosons? — •Chris Müller[1], Konrad Tschernig[2], Malte Smoor[1], Tim Kroh[1], Armando Perez-Leija[2], Kurt Busch[1,2], and Oliver Benson[1] — [1]Humboldt-Universität zu Berlin, Germany — [2]Max-Born-Institut, Germany

Quantum electrodynamics introduces photons as bosons, that means their joint wavefunction is symmetric under particle exchange. So far the bosonic nature of photons has been demonstrated only indirectly, e.g. by observing photon bunching in the Hong-Ou-Mandel effect [1]. It would be highly interesting to measure the exchange phase ϕ directly, which should be zero for bosons and π for fermions. Another possibility is the exotic anyon, where the exchange phase can have values different from 0 or π. Protocols for measuring the exchange phase using massive particles, have been recently proposed [3].

Here, we present a novel joint theoretical and experimental approach to measure the exchange phase of photons directly. Our setup consists of two coupled Mach-Zehnder interferometers fed by indistinguishable photon pairs generated in a cavity-enhanced parametric down-conversion source [4]. We will show our first results of measuring the exchange phase of photons and discuss the sensitivity for potential deviations from the expected value of zero.

[1] C. K. Hong et al., Physical Review Letters 59, 2044, 1987
[2] C. F. Roos et al., Physical Review Letters 119, 160401, 2017
[3] A. Ahlrichs et al., Applied Physics Letter 108, 021111, 2016

Q 12.4 Mon 14:45 f442

Extracting particle distinguishability from imperfect suppressions in many-particle interference — •Michael Minke, Christoph Dittel, and Andreas Buchleitner — Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder Str. 3, 79104 Freiburg, Federal Republic of Germany

The Deviations from perfect suppression of the coincident output event in the two-particle Hong-Ou-Mandel experiment are indicative of some degree of mutual distinguishability between both particles. While Hong-Ou-Mandel-type suppression has been generalised to many perfectly indistinguishable particles, it remained unknown to date whether finite detection probabilities of output events which are suppressed in an ideal scenario likewise reveal information on the particles' distinguishability. Here we show that, in the evolution of four partially distinguishable particles on the two dimensional hypercube graph (or on a four-mode Sylvester interferometer), violations of suppression laws allow us to draw conclusions on the mutual distinguishability of all four constituents.

Q 12.5 Mon 15:00 f442

Quantum light: wave or particle? — •Syamsundar De, Jan Sperling, Thomas Nitsche, Johannes Tiedau, Sonja Barkhofen, Benjamin Brecht, and Christine Silberhorn — Integrated Quantum Optics, Paderborn University, Warburger Strasse 100, 33098 Paderborn, Germany

Wave-particle dualism is commonly interpreted as that the quantum objects exhibit either particle- or wave-like behavior. In this study, we challenge this usual notion of wave-particle duality by experimentally showing that neither the wave nor the particle picture can successfully describe our observations. We introduce correlation-based criteria that allow us to simultaneously and quantitatively assess wave and particle properties. It turns out that the measured correlations in our experiment using squeezed light are indeed incompatible with the predictions for waves and particles, simultaneously falsifying these two classical notions in a single quantum system. Besides, we establish a connection between our correlation-based criteria with the complementary notions of quantum coherence, linked with either the quantum-optical nonclassicality or the encoding capability of quantum information in particles. Additionally, we apply our methodology to certify the nonclassicality of coherent states, which are traditionally treated as classical light.

Q 12.6 Mon 15:15 f442

Biphoton interference of terahertz and visible light — •Mirco Kutas[1,2], Björn Haase[1,2], Patricia Bickert[1], Felix Riexinger[1,2], Daniel Molter[1], and Georg von Freymann[1,2] — [1]Fraunhofer Institute for Industrial Mathematics (ITWM), Fraunhofer-Platz 1, 67663 Kaiserslautern — [2]Department of Physics and Research Center OPTIMAS, Technische Universität Kaiserslautern (TUK), 67663 Kaiserslautern

We present our latest developments in the detection of terahertz radiation using visible light [Kutas *et al.*, arXiv:1909.06855, (2019)]. It bases on a quantum optical technique to detect radiation by transferring photon properties via biphoton correlation into another and better detectable spectral range [Lemos *et al.*, *Nature* **512**, 409-412 (2014)]. Only one photon of a correlated pair interacts with the sample, whereas solely its associated partner is detected, having never interacted with the sample. This concept is especially interesting for terahertz radiation, as detection in this frequency range is still technically complex. In our experiments the correlated photon pairs are created in a nonlinear crystal either due to spontaneous parametric down-conversion or conversion of thermal photons [Haase *et al.*, Opt. Express **27**, 7458-7468 (2019)]. Detecting the interference of the visible photons, we are able to perform layer thickness measurements with terahertz radiation.

Q 12.7 Mon 15:30 f442

Nonlinear terahertz interferometry with visible photons — •Björn Haase[1,2], Mirco Kutas[1,2], Felix Riexinger[1,2], Patricia Bickert[1], Daniel Molter[1], and Georg von Freymann[1,2] — [1]Fraunhofer Institute for Industrial Mathematics (ITWM), Fraunhofer-Platz 1, 67663 Kaiserslautern — [2]Department of Physics and Research Center OPTIMAS, Technische Universität Kaiserslautern (TUK), 67663 Kaiserslautern

Nowadays, it is still technically challenging to detect terahertz radiation, although many different applications have been developed in the past. Based on the indistinguishability of correlated biphoton pairs, created by spontaneous parametric down-conversion (SPDC) due to vacuum fluctuations in a nonlinear crystal, Lemos *et al.* showed the possibility to transfer properties of photons in one spectral range into another range, for which better cameras exist [Lemos *et al.*, *Nature* **512**, 409-412, (2014)].

Recently, we demonstrated this concept in the strongly frequency non-degenerated regime with pairs of photons in the terahertz and visible spectral range [Kutas *et al.*, arXiv:1909.06855, (2019)]. This concept enables us to determine sample properties in the terahertz frequency range using cameras that are sensitive only for visible light. Inspired by these studies, we present results of an alternative approach of this concept, by seeding the nonlinear interaction with phase-unlocked pulsed terahertz photons [Haase *et al.*, 44$^{\text{th}}$ IRMMW-THz, Paris (2019)]. Because of an increased signal-to-noise ratio, this will facilitate us to reduce the required measurement time significantly.

Q 12.8 Mon 15:45 f442

A Compact Laser System for Quantum Gas Experiments in BECCAL on the ISS — •Victoria Henderson[1,2], Ahmad Bawamia[2], Jean-Pierre Marburger[3], André Wenzlawski[3], Andreas Wicht[2], Patrick Windpassinger[3], Markus Krutzik[1,2], Achim Peters[1,2], and The BECCAL Team[1,2,3,4,5,6,7] — [1]HU Berlin — [2]Ferdinand-Braun-Institut, Berlin — [3]JGU, Mainz — [4]LU Hannover — [5]ZARM, Bremen — [6]DLR, Bremen — [7]Universität Ulm

BECCAL (BEC - Cold Atom Laboratory) is a multi-user quantum gas experiment designed to be operated on the ISS. It is a collaboration between DLR and NASA, built upon a heritage of sounding rocket and drop tower experiments as well as NASA's Cold Atom Lab. It will enable the exploration of fundamental physics with Rb and K BECs in microgravity, facilitated by prolonged timescales and ultra-low energy scales compared to those achievable on Earth.

The ambitious functionality of BECCAL presents a unique challenge for laser system design, especially in terms of the stringent size weight and power limitations. To meet this we combine micro-integrated diode lasers (from FBH) with Zerodur boards of miniaturized free-space optics (from JGU), all connected via fibre optics. These technologies have proven their reliability in many qualification tests. We will present the current design of the BECCAL laser system, alongside the requirements, concepts and heritage that has formed it.

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