TUE 9: Quantum Physics in Strong Fields: Contributed Session to Symposium

Time: Tuesday 14:15–16:15 Location: ZHG101

TUE 9.1 Tue 14:15 ZHG101

LUXE: a high-precision experiment to study non-perturbative QED in electron-laser and photon-laser collisions — •Tom Blackburn — Department of Physics, University of Gothenburg, 41296 Gothenburg, Sweden

The Laser Und XFEL Experiment (LUXE), in planning at DESY Hamburg, is intended to study quantum electrodynamics (QED) in strong electromagnetic fields, and in particular the transition from perturbative to non-perturbative. In the non-perturbative regime, electron-positron pairs tunnel out of the vacuum in a manner akin to the Schwinger process. The experiment will make precision measurements of the photon and positron rates in collisions between a high-intensity laser pulse and the 16.5 GeV electron beam of the European XFEL, or the high-energy secondary photons it produces. This talk will provide an overview and update on the work of the LUXE collaboration, as the experiment moves towards implementation.

TUE 9.2 Tue 14:30 ZHG101

The Quantum Superluminality of Tunnel-ionization — •Ossama Kullie[1] and Igor Ivanov[2] — [1]Department of Mathematics and Natural Sciences. University of Kassel, 34132 Kassel, Germany. — [2]Department of Fundamental and Theoretical Physics, Australian National University, Australia

Tunneling is one of the most interesting phenomena in quantum physics. In our tunnel-ionization model [1, 2, 3], we have shown that the time-delay of the adiabatic and nonadiabatic tunnel-ionization determines the barrier time-delay in a good agreement with the attoclock measurement and that it corresponds to the dwell time and the interaction time. In the present work, we show that the barrier time-delay for H-like atoms with a large nuclear charge can be superluminal (quantum superluminality), which can be experimentally validated using the attoclock scheme. Furthermore, we accompany our model with the numerical integration of time-dependent Schödinger equation (NTTDSE), where we expect good agreement with our model as in earlier work [2]. We investigate the quantum superluminality for the different experimental calibrations (adiabatic and nonadiabatic tunnel-ionization) of the attoclock [4] and discuss its interpretation. [1] O. Kullie, J. Phyis. Commun. 9, 015003, (2025). [2] O. Kullie and I. Ivanov, Annals of Physics 464, 169648 (2024). [3] O. Kullie, Annals of Physics 389, 333 (2018). [4] O. Kullie and I. A. Ivanov, Quantum superluminality of Tunnel-Ionization. In preparation.

TUE 9.3 Tue 14:45 ZHG101

Theoretical strong-field quantum physics in Dresden: An Overview — •Christian Kohlfürst — Helmholtz-Zentrum Dresden-Rossendorf, Bautzner Landstraße 400, 01328 Dresden, Germany

We provide an overview of the research area of strong-field quantum electrodynamics, focusing particularly on the topics covered by the Strong-Field research group within the Institute of Theoretical Physics at the Helmholtz-Zentrum Dresden Rossendorf. Special emphasis is placed on non-equilibrium quantum dynamics and the scattering of light by light.

TUE 9.4 Tue 15:00 ZHG101

Femtosecond and attosecond correlations in multi-electron pulses — •Rudolf Haindl[1,2], Valerio Di Giulio[1,2], Armin Feist[1,2], and Claus Ropers[1,2] — [1]Max Planck Institute for Multidisciplinary Sciences, Göttingen, Germany — [2]4th Physical Institute, University of Göttingen, Göttingen, Germany

Correlations between electrons are at the core of numerous phenomena in atomic, molecular, and solid-state physics. In femtosecond electron emission from nanoscale field emitters, Coulomb interactions result in structured few-electron states with strong correlations in energy [1,2], transverse momentum [2], and time[3].

In this contribution [4], we combine femtosecond-gated, event-based detection with inelastic electron-light scattering to directly map the photoelectron phase-space distribution of two-electron states. Our experiments demonstrate a bimodal structure in longitudinal phase space, with distinct contributions from interparticle interaction and dispersion. Moreover, we theoretically reveal that global phase modulation coherently shapes the few-electron phase-space distribution to exhibit attosecond temporal correlations. This controlled phasing of few-electron states leads to a multi-electron quantum walk and can be harnessed to produce tailored excitations and super-radiance via two-electron energy post-selection.

[1] R. Haindl et al., *Nat. Phys.* **19**, 1410-1417 (2023).
[2] S. Meier et al., *Nat. Phys.* **19**, 1402-1409 (2023).
[3] J. Kuttruff et al., *Sci. Adv.* **10**, eadl6543 (2024).
[4] R. Haindl et al., *arXiv*, arXiv:2412.11929 (2024).

TUE 9.5 Tue 15:15 ZHG101

Quantum simulation of strong field phenomena and curved spaces in deformed optical lattices — •Nikodem Szpak — Faculty of Physics, University of Duisburg-Essen

Low energy excitations in specially designed optical lattice systems can behave like relativistic particles. Inhomogeneous perturbations of these lattices can give rise to effective coupling to artificial electromagnetic fields and curvature. We give a review of interesting strong field phenomena, like spontaneous pair creation or graviational lensing, still not accessible in direct experiments, which can be simulated with cold atoms in finite size optical lattices.

TUE 9.6 Tue 15:30 ZHG101

Scattering matrix approach to dynamical Sauter-Schwinger process: vortex- vs. spiral structures — •Mateusz Majczak, Katarzyna Krajewska, Jerzy Kamiński, and Adam Bechler — Institute of Theoretical Physics, Faculty of Physics, University of Warsaw, Pasteura 5, 02-093 Warsaw, Poland

The dynamical Sauter-Schwinger mechanism of electron-positron (e^-e^+) pair creation by electric field pulses is considered using the S-matrix approach and reduction formulas. They lead to the development of framework that treats the external electric field to all orders and is based on the solutions of the Dirac equation with the so-called Feynman- or anti-Feynman boundary conditions. The asymptotic properties of those solutions are linked to the electron and positron spin(helicity)-resolved probability amplitudes. Most importantly, the corresponding spin- or helicity-resolved distributions, when summed over spin or helicity configurations, reproduce the momentum distributions of created particles calculated with other methods that are typically used in this context, such as the DHW function approach. In contrast to those approaches, however, the S-matrix method provides the information about the phase of the probability amplitude of e^-e^+ pair creation. Therefore, it allows one to study the vortex- and spiral structures in momentum distributions of produced particles. As it follows from our numerical studies, a momentum spiral is created as a result of the vortex-antivortex annihilation. Moreover, as we show, in order to observe such annihilation one has to drive the pair creation with electric field pulses of the time reversal symmetry.

TUE 9.7 Tue 15:45 ZHG101

Vortex Structures and Spin Effects in Dynamical Schwinger Process — •Wojciech Smialek[1], Mateusz Majczak[1], Adam Bechler[1], Jerzy Kamiński[1], Carsten Müller[2], and Katarzyna Krajewska[1] — [1]Institute of Theoretical Physics, Faculty of Physics, University of Warsaw, Poland — [2]Institut für Theoretische Physik I, Heinrich-Heine-Universität Düsseldorf, Germany

The dynamical Schwinger effect offers a unique opportunity to probe the nonperturbative regime of QFT under controlled conditions. While the spectra and yields of particles created in this process have been studied in great detail, the currently dominant tools for nonperturbative analysis of this process within QED do not allow for a full examination of the spin properties of the created pairs.

In order to study the angular momentum effects in the dynamical Schwinger process, we present a novel S-matrix-based formalism that grants access to the full information about the state of the created pairs through spin-resolved probability amplitudes. This formalism has been adapted to Dirac and Klein-Gordon fields to provide further insight into spin effects.

Our numerical analysis reveals the occurrence of vortical phase singularities in the complex probability amplitude of spinor and scalar pairs when the QED vacuum is exposed to a circularly polarized electric field. The occurrence of phase vortices is linked to a nonvanishing orbital angular momentum carried by the particles, and as we show, the structure of vortices for fermionic and bosonic pairs complies with the principle of angular momentum conservation.

TUE 9.8 Tue 16:00 ZHG101

Photon-graviton conversion in a magnetic field — •Naser Ahmadiniaz — Helmholtz Zentrum Dresden Rossendorf, Dresden, Germany

In this talk, I will first give a brief overview of the worldline formalism, a first-quantized approach to quantum field theory that streamlines the computation of scattering amplitudes in gauge theory and gravity. This method is particularly well suited to incorporating background fields non-perturbatively and reveals the underlying geometric structure of amplitudes. The main focus will be on photon–graviton conversion in an external magnetic field. While this process is typically studied at tree level, one-loop corrections due to scalar and spinor fields have also been computed. Unlike the tree-level result, the one-loop amplitude exhibits a dependence on the photon polarization, leading to vacuum dichroism. I will present a worldline-based derivation of this one-loop effect and show how the formalism naturally captures the emergence of dichroism. Furthermore, I will discuss the role of a previously neglected tadpole contribution. Although such diagrams often vanish in conventional treatments, we find that in this context the tadpole gives a finite contribution to the amplitude that must be included to obtain a complete result.