WPC Theoretical Physics Symposium 2025

Interdisciplinary centre for theoretical physics

Report of Contributions

https://indico.desy.de/e/47240

Contribution ID: **1** Type: **not specified**

Opening and Welcome

Wednesday 14 May 2025 10:00 (15 minutes)

Presenter: SCHOMERUS, Volker (T (Theorie))

Contribution ID: **28** Type: **not specified**

Festive Colloquium on the Occasion of Prof. Alexander Lichtenstein's 70th Birthday - for detailed information visit the event page: https://indico.desy.de/event/47388/

Friday 16 May 2025 14:00 (3 hours)

Please visit the Festive Colloquium webpage (https://indico.desy.de/event/47388/) for all information, including registration.

Contribution ID: **29** Type: **not specified**

Superconductivity: past, present and future

Wednesday 14 May 2025 10:15 (40 minutes)

Superconductivity, the ability to carry electrical current without any resistance whatsoever, is perhaps the longest known example of a quantal order—defined by an order parameter, the phase of the electronic wave function, that does not have a classical analogue. While the problem of classifying superconducting states is largely solved, the question of mechanism remains in many respects open. We believe we understand the origin of superconductivity in "conventional"materials such as mercury, the compound where the phenomenon was first observed, but recent decades have seen a remarkable series of discoveries of new families of compounds, in which superconductivity coexists with, and may well be derived from, a wide range of novel physics including Kondo-renormalized heavy fermion materials, Mott insulators, quantum magnets, and fractional Chern and other topological states. In this talk I will present via a few examples recent progress and open questions related to understanding the evident diversity of mechanisms, and raise questions related to using this understanding to design new materials with even higher transition temperatures.

Presenter: MILLIS, Andrew (Columbia University, Flatiron Institute)

Contribution ID: **30** Type: **not specified**

Challenges ahead in atomic, molecular, and nuclear few-body physics

Friday 16 May 2025 09:40 (40 minutes)

In ultracold atomic physics and in nuclear physics, the interactions are often very close to the regime of universality, with near-infinite scattering lengths. Using a variety of tools, such as correlated Gaussian basis set expansions, effective field theory, and Monte Carlo methods, significant progress has been achieved during the past decade to compute bound state properties and in some cases resonance positions and widths. But the description of collision processes, e.g. for systems with 5-10 atoms or nucleons, has lagged far behind and has far less quantitative capability. This is especially problematic for processes where the initial or final state of the system has 3 or more particles or composites in the continuum. I will discuss some such problems, and broaden out the discussion to discuss the collisional electronic structure problem as well, for electron collisions and photo-processes involving increasingly complex molecules and even heavy atoms.

Presenter: GREENE, Chris H. (Purdue University)

Contribution ID: **31** Type: **not specified**

Gravity is Different –Counterexamples to the Wilsonian Paradigm of Low Energy Effective Theory

Wednesday 14 May 2025 11:15 (40 minutes)

The physical world is hierarchical. Kenneth Wilson mathematically formulated this idea in the language of effective theory. For each energy scale, there is a set of laws called an effective theory that describes physical phenomena at that scale, and we can be ignorant of more fundamental laws at higher energies. For example, the pion theory is an effective theory of QCD; we do not need to know details of QCD to discuss pion physics at energies far below the QCD scale. The basic assumption is that, as long as an effective theory satisfies consistency conditions that are evident at the applicable scale, it can be derived from a more fundamental and mathematically consistent theory at higher scales. In this talk, I will show that this assumption is false with gravity by presenting several counterexamples. These are conditions that any gravitational effective theory must satisfy, but which are not obvious from low-energy considerations alone.

Presenter: OOGURI, Hirosi (Caltech & Kavli IPMU, Tokyo)

Contribution ID: **32** Type: **not specified**

Engineering gravity via conformal field theory

Wednesday 14 May 2025 11:55 (40 minutes)

Holography posits a radical way to quantify gravitational physics. It claims that all information of a gravitational theory in a region of space can be encoded by a quantum field theory at the boundary of this region. Here I will discuss quantum gravity from this perspective. We will see how one can engineer - i.e., design and build - gravity through this relationship, using possible quantum theories on the boundary as materials for the undertaking. I will discuss how overcoming the challenging obstacles to this engineering task is paramount for deciphering mysterious properties of black holes and understanding fundamental aspects of quantum gravity.

Presenter: CASTRO, Alejandra (U of Cambridge)

Contribution ID: **33** Type: **not specified**

Energy conversion at the nanoscale: exploiting non-thermal resources

Wednesday 14 May 2025 14:00 (40 minutes)

Nanoscale engines are becoming increasingly common, manifested for example in on-chip processors that transduce energy and particles between reservoirs to perform tasks like cooling. However, when compared to macroscopic energy-transducing engines, quantum thermoelectric devices might operate on time and length scales where their environmental energy reservoirs cannot be accurately described by well-defined thermal distributions. As a result, the reservoirs are not characterized by a specific temperature or chemical potential. Furthermore, due to this time and spatial miniaturization, fluctuations in the resulting energy and particle flows become significant.

Instead of conforming to a thermal picture, we propose to use the non-thermal nature to create devices which are potentially more efficient and precise than their thermal counterparts.
In response to these challenges, we aim to investigate the energy and particle transduction of a prototype thermoelectric device operating between a non-thermal and thermal reservoir. Assuming ideal coherent quantum transfer, particle and energy flows will be examined using scattering theory.

First, by addressing specific tasks such as efficiently cooling a reservoir with minimal resources, we will propose and define performance metrics to achieve these objectives. In the presence of a non-thermal environment, the traditional categorization of energy into heat and work is no longer applicable. Consequently, we will quantify the non-thermal resources required to accomplish the task through entropy currents and the provided non-equilibrium free energy.

Second, we will optimize these metrics based on defined tasks such as cooling power for reservoir cooling and/or minimizing particle current noise during task execution by designing optimal particle transmission between the reservoirs. The proposed procedure leads to a transmission filter between the reservoirs determined by the shape of the non-thermal distribution.

These procedures serve as an initial exploration into characterizing and utilizing non-thermal resources, which may encourage a broader discussion on the use of non-standard resources to accomplish unconventional tasks in various fields of physics and nanoscience.

Presenter: KIRCHBERG, Henning (Chalmers U)

Contribution ID: **35** Type: **not specified**

Frustrations and complexity in classical and quantum spin systems

Wednesday 14 May 2025 14:40 (40 minutes)

The origin of complexity remains one of the most important and, at the same time, the most controversial scientific problems. Earlier attempts were based on theory of dynamical systems but did not lead to a satisfactory solution of the problem. I believe that a deeper understanding is possible based on a recent development of statistical physics, combining it with relevant ideas from evolutionary biology and machine learning.

Using patterns in magnetic materials as the main example, I discuss some general problems such as a formal definition of pattern complexity, self-induced spin glassiness due to competing interactions as a way to interpret chaotic patterns, and complexity of frustrated quantum spin systems studied via generalization properties of neural networks used to find the ground state.

Presenter: KATSNELSON, Mikhail (Radboud U Nijmegen)

Contribution ID: **37** Type: **not specified**

What we know and don't (yet) know about the Two-Dimensional Hubbard Model

Thursday 15 May 2025 11:00 (40 minutes)

The Hubbard model is a paradigm of the 'strong correlation problem', with relevance to high-Tc superconductors and ultra-cold atoms in optical lattices. Key aspects of its physics in two dimensions can now be established beyond doubt, thanks to the development of controlled and accurate computational methods working in synergy (such as quantum embedding, tensor networks, various flavors of quantum Monte Carlo and, recently, neural quantum states). I will review some of these recent developments in this presentation and highlight the questions that remain to be answered.

Presenter: GEORGES, Antoine (Collège de France, Paris & Flatiron Inst., New York)

Contribution ID: **38** Type: **not specified**

Lighting up superconductivity

Thursday 15 May 2025 11:40 (40 minutes)

We will discuss recent experiments in the pseudogap phase of the high Tc cuprate YBCO that have been interpreted as the light induced Meissner effect. A special feature of these materials is a bilayer structure with a large difference of Josephson couplings within the bilayers and between them. Motivated by this hierarchy of scales, we introduce a model that consists of bilayers of copper-oxygen planes with a local superconducting phase that persists up to the pseudo-gap temperature at equilibrium. Under pumping, the time evolution of the relative phase in the bilayers is described by a driven sine-Gordon equation. We will argue that the experimentally observed phenomena can be explained by a new type of dynamical instability in the sine-Gordon model triggered by the strong terahertz pump pulse. This interpretation suggests that these experiments reveal strong superconducting correlations in the pseudogap state but do not require photoinduced superconductivity.

Presenter: DEMLER, Eugene (ETH Zurich)

Contribution ID: **39** Type: **not specified**

Matching Effective Field Theories to the Large Hadron Collider

Thursday 15 May 2025 09:00 (40 minutes)

Effective Field Theory (EFT) gives a universal language to parameterize the effects of heavy particles at low energies in an expansion in powers of E/M, where E is the experimental energy scale and M is the mass of the heavy particle. The most general corrections to the Standard Model can be fully classified, and searches for the effects of these corrections can be performed. However, constraints on the truncated EFT unavoidably depend on the prior assumptions about the size of neglected higher order terms. This is not just an “in principle” issue: conventional EFT searches at the CERN Large Hadron Collider (LHC) can give incorrect results, namely they “rule out” new physics that is actually present in the data. This talk will describe a proposal for incorporating physically meaningful prior assumptions into these searches. We show that this method is practical, avoids the problems of conventional EFT searches, and gives sensible results that can be meaningfully compared with UV models.

Presenter: LUTY, Markus (U of California, Davis)

Contribution ID: **40** Type: **not specified**

The Detection Challenge of the Cosmic Neutrino Background and Other Relics

Thursday 15 May 2025 09:40 (40 minutes)

The cosmic microwave background—the relic light from the Big Bang—has transformed cosmology into a precision science. Its lesser-known counterpart, the cosmic neutrino background, is another remnant from the early universe, dating back to when the cosmos was just a fraction of a second old. Although a direct laboratory detection remains beyond our current reach, discovering this background would mark a milestone of profound significance. In this talk, I will argue that building a relic neutrino telescope is, at its core, a challenge in quantum metrology. I will explore how tackling this problem may open new avenues for detecting other cosmic relics, including dark matter.

Presenter: ARVANITAKI, Asimina (Perimeter Institute)

Contribution ID: **42** Type: **not specified**

Challenges in attochemistry and its theoretical description

Thursday 15 May 2025 16:30 (40 minutes)

The absorption of light excites the electrons of a molecule. As a result, the distribution of electrons and thus the reactivity of the molecule in these electronically excited states differ significantly from the ones in the ground state. Thanks to this conceptually simple yet complex process, photochemistry has considerably broadened the spectrum of possible reactions, as compared to thermal chemistry. Yet, photochemical reactions are limited by the nature and finite number of electronic excited states in molecules. Because of the time-energy uncertainty principle, attosecond and sub-femtosecond pulses have a large spectral width and therefore populate several electronic excited states in a simultaneous and coherent manner; this is called an "electronic wavepacket". By interference, the electronic distribution of a wavepacket is not the simple average of the individual electronic distributions of the different states: an electronic wavepacket is a new type of initial electronic state, with a new nature. What would be the reactivity of a molecule in this new electronic state? With the technological advances of attoscience, the concept of attochemical control, also called "charge-directed reactivity"has been demonstrated experimentally and theoretically mostly on diatomic. Although highly challenging, extending this to chemical reactions in polyatomic molecules is the ambitious goal of attochemistry. In this presentation, we will discuss the outstanding challenges in the field of attochemistry, and in particular its theoretical description.

Presenter: VACHER, Morgane (Nantes U)

Contribution ID: **43** Type: **not specified**

Challenges in Conformal Bootstrap

Thursday 15 May 2025 14:40 (40 minutes)

The conformal bootstrap program has emerged as one of the most powerful non-perturbative tools for studying critical phenomena in quantum and statistical field theories. By exploiting the symmetries and consistency conditions of conformal field theory (CFT), such as crossing symmetry and unitarity, this approach enables the determination of scaling dimensions and operator product expansion (OPE) coefficients without relying on perturbation theory or a Lagrangian description. In this talk, I will focus on future challenges to move beyond the landmark results obtained for the 3D Ising model and O(N) vector models, and to digest the obtained numerical results into analytic understanding of higher-dimensional CFTs.

Presenter: RYCHKOV, Slava (IHES, Bures-sur-Yvette)

Contribution ID: **44** Type: **not specified**

Entropic Order

Thursday 15 May 2025 14:00 (40 minutes)

Ordered phases of matter, such as solids, ferromagnets, superfluids, or quantum topological order, typically only exist at low temperatures. Upending the conventional wisdom, we present explicit local models in which all such phases persist to arbitrarily high temperature. The physical mechanism is that order in one degree of freedom can enable many more to freely fluctuate, leading to "entropic order", whereby typical high energy states are ordered! Interacting bosons can lead to entropic order at any temperature, avoiding existing no-go theorems on long-range order or entanglement at high temperature. We also show how we can obtain superconductors at very high temperature using these ideas.
We explain the connection to the no-hair theorem for large Black Holes. We emphasize a few critical open questions about these unconventional models.

Presenter: KOMARGODSKI, Zohar (SCGP Stony Brook)

Contribution ID: **45** Type: **not specified**

Polaritonic Chemistry: Challenges & Opportunities

Friday 16 May 2025 11:00 (40 minutes)

Polaritons are hybrid light-matter states that form when material excitations strongly interact with "trapped or confined light", such as in optical cavities or plasmonic nanostructures. While the physics community has studied polaritonic phenomena with atoms and inorganic semiconductors for several decades, significant interest in molecular polaritons has only emerged over the past decade. This interest was sparked by experiments demonstrating the possibility to manipulate the chemistry of molecules via polariton formation, giving rise to the field of polaritonic chemistry. Molecular polaritons offer opportunities to modify both thermal and excited-state processes, depending on whether the molecular excitation coupled to the cavity photon is vibrational or electronic. Despite the potential of polaritonic chemistry to make an impact in areas such as catalysis or optoelectronics, many fundamental questions remain unanswered. Progress in the field is currently hampered by a lack of understanding of key experimental observations. Additionally, unlike atoms, molecules have a very rich internal structure, which significantly complicates the theoretical modeling of the coupled light-matter system. In this talk, I will provide an overview of this emerging field, highlighting both the challenges it faces and the opportunities that lie ahead.

Presenter: CLIMENT, Clàudia (U de Barcelona)

Contribution ID: **47** Type: **not specified**

Strong-field physics meets quantum optics

Friday 16 May 2025 11:40 (40 minutes)

There has been recent experimental evidence demonstrating quantum optical signatures in nonperturbative, extremely nonlinear optical processes such as high-order harmonic generation (HHG). These results came as a surprise, as typically, quantum optics deals with single or few-photon states; light states with increasing photon numbers behave more and more classically. Strong-field physics commonly deals with extremely high photon numbers (>1013-1016 photons per shot). With a conversion efficiency of about 10-5 - 10-9 for HHG, bright photon states in very different energy(and frequency) ranges could be obtained. The theoretical foundation to describe these intuitively orthogonal physical disciplines is still in its infancy. Fundamental questions on the origin of the nonclassicality of the observed quantum signatures remain open –which role does the measurement process play? What it the role of the generation medium/material, e.g., why do many-particle matter systems with fast and efficient decoherence processes still enable quantum characteristics of the emitted light? How can we characterize such many-photon quantum light states? Can we increase the "quantumness"of the generated harmonics? And how can we theoretically and numerically describe these processes? In this talk, I will give an overview over the state of the art of this very new field at the intersection of two previously disjunct fields of physics and provide first ideas how to approach some of the challenges.

Presenter: GRÄFE, Stefanie (FSU Jena)

Contribution ID: **48** Type: **not specified**

Some Challenges of Quantum Theory Applied to Chemistry and Materials Science

Thursday 15 May 2025 15:50 (40 minutes)

We have strived for a general understanding of complex general chemical problems in the last 25 years. This endeavor has led my group to touch upon various situations that point to unsolved problems of quantum chemistry. In this talk, I will present a compilation of these problems that will lead us from relativistic quantum chemistry to electronic structure theory and reaction chemistry, up to quantum dynamics.

Presenter: REIHER, Markus (ETH Zürich)

Contribution ID: **49** Type: **not specified**

Are black holes natural?

Wednesday 14 May 2025 15:50 (40 minutes)

Four-dimensional black holes are know not to deform under weak static perturbations, i.e., they have a vanishing polarizability. This constitutes a sort of classical naturalness problem. I will present a solution to this problem, which shows that this surprising fact remains true for arbitrarily large perturbations. I will end commenting on our ability to test this results in observations and questioning its quantum fate.

Presenter: PARRA-MARTINEZ, Julio (IHES)

Contribution ID: **50** Type: **not specified**

Monitoring elementary molecular events and conical intersections by ultrafast X-ray pulses, quantum light, and optical cavities

Friday 16 May 2025 09:00 (40 minutes)

Employing quantum light in nonlinear multidimensional spectroscopy is opening up many exciting opportunities to enhance the signal-to-noise ratio, improve the combined temporal, spatial, and spectral resolutions, and simplify nonlinear optical signals by selecting desired transition pathways in second and third order signals. We show how photoelectron signals generated by time-energy entangled photon pairs can monitor ultrafast excited state dynamics of molecules with high joint spectral and temporal resolutions, not subjected to the Fourier uncertainty limitation of classical light. Two-entangled-photon absorption scales linearly with the pump intensity, allowing the study of fragile biological samples with low photon fluxes, and quantum interferometry can enhance the signals. Optical cavities provide another means for controlling the photophysics of molecules by making use of strong light–matter coupling without employing strong external laser pulses. A quantum dynamical study of charge migration in molecules in an optical cavity demonstrates how to trigger and manipulate charge migration pathways that are originally inactivated or suppressed in the bare molecule.

Novel X-ray pulse sources from free-electron lasers and high-harmonic generation setups enable the monitoring of elementary events molecular such as the ultrafast passage through conical intersections on unprecedented temporal, spatial and energetic scales. The attosecond duration of X-ray pulses, their large bandwidth, and the atomic selectivity of core X-ray excitations offer new windows into photochemical processes. We show how the Orbital Angular Momentum of twisted X-ray light can be leveraged to detect vibronic coherences and time evolving chirality emerging at conical intersections due to the bifurcation of molecular wavepackets.

Due to formatting limitations, only part of the abstract is shown here. Please refer to the attached PDF for the full version including images

Presenter: MUKAMEL, Shaul (University of California, Irvine)

Contribution ID: **51** Type: **not specified**

Tales from the Stellar Graveyard: How Dead Stars Reveal New Physics

Wednesday 14 May 2025 16:30 (40 minutes)

Axions, hypothetical particles born in QCD and long suspected to help make up dark matter, are usually thought to slip through the universe unnoticed. But when matter is squeezed to the extreme densities found in white dwarfs and neutron stars, these "invisible"particles can leave unmistakable fingerprints. I will sketch how the ultra dense interiors of such stellar remnants reshape axion behavior, alter the balance of forces inside the star, and drive energy loss processes that ripple out to supernovae and beyond. By treating the cosmos's most compact objects as natural laboratories, we gain new ways to test axion ideas, complementing lasers, traps, and colliders on Earth. The talk will outline this new frontier and its implications for dark matter searches and dense matter theory.

Presenter: WEILER, Andreas (TUM)

Contribution ID: **56** Type: **not specified**

About local and non-local correlations - A brief history of the electronic structure problem in correlated electron materials

Friday 16 May 2025 14:00 (1 hour)

Photon Science Colloquium

Presenter: BIERMANN, Silke (Ecole Polytechnique)

Contribution ID: **57** Type: **not specified**

Quantum Impurity Solvers: Recent Advances

Friday 16 May 2025 15:00 (30 minutes)

Quantum impurity problems first appeared in the treatment of magnetic atoms embedded in metals, and now act as auxiliary objects within the dynamical mean field theory of correlated materials. Among Prof. Lichtenstein's many notable contributions to our current understanding of the physics of materials are his seminal work in developing Monte Carlo techniques for simulating impurity models. Yet, in many regimes and for many observables, simulations of this type remain either infeasible or extremely expensive. Here, I will discuss prospects for addressing this challenge by combining Inchworm Monte Carlo techniques with some mathematical technologies that have recently drawn attention in physics, such as tensor train cross-interpolation and pole representations

Presenter: COHEN, Guy (Tel Aviv University)

Contribution ID: **58** Type: **not specified**

Enantio-sensitive spin-orientation locking and spin vortices induced by geometric fields in chiral molecules

Friday 16 May 2025 16:00 (30 minutes)

Presenter: SMIRNOVA, Olga (Max Born Institut, Berlin)

Contribution ID: **59** Type: **not specified**

What does it tell us when curves cross?

Friday 16 May 2025 16:30 (30 minutes)

In physics and chemistry it is often observed that the curves of a physical quantity f(x,p) cross at one or more points, when plotted as a function of x for different values of the parameter p. Sometimes these crossing points are confined to a remarkably narrow region, or are even located at a single point, called "isosbestic point". For example, crossing points are found in the curves of the heat capacity C(T,X) of many correlated materials, with X as the pressure or the magnetic field, and of the Hubbard model, with X as the interaction U, but also in the Raman response chi"(omega,T) and many other quantities. I will explain that crossing points provide valuable information about the system in which they occur.

Presenter: VOLLHARDT, Dieter (Universität Augsburg)