Physics in Intense Fields (PIF22)

Monday, 29 August 2022 - Friday, 2 September 2022

Book of Abstracts

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Prospects for Vacuum Birefringence and Coulomb-assisted Birefringence with HiBEF at EuXFEL/HED

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Abstract to be confirmed

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Experimental demonstration of all-optical nonlinear Compton scattering using a multi-petawatt laser

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Progress in laser wakefield acceleration (LWFA) has led to the production of a multi-GeV electron beam from a cm-length plasma. Such beams are collocated together with high intensity laser pulses at petawatt (PW) laser facilities, allowing the study of laser-electron collisions in all-optical setups. This configuration opens up the possibility to test strong-field quantum electrodynamics (SFQED), in order to understand the behavior of charged particles under the influence of a strong laser field. In particular, experiments on nonlinear Compton scattering can reveal nonlinear features in high-energy gamma-ray emission spectra.

We present the measurement of high-energy gamma-ray beams generated from nonlinear Compton scattering experiments at the CoReLS 4PW facility. The gamma beams were produced during the collision of LWFA-accelerated electrons (E<3.5 GeV) and an ultrashort laser pulse (25fs) of intensity $I \approx 4 \times 10^{20}$ W/cm2, achieving a quantum nonlinearity parameter $\chi \approx 0.4-0.5$. The unprecedented properties of the gamma beams required the development of a novel detection technique based on a pixelated LYSO scintillation detector. Using this detection method, we observed broad gamma-ray spectra that can be parametrized by a critical energy >150 MeV, extending over hundreds of MeV. The beams have a low divergence (≈1 mrad), small source size and ultrashort duration, thus exhibiting an ultrahigh brilliance. Such high energy gamma beams open up new research possibilities in fundamental physics and nuclear photonics.

Experiment / **39**

Strong field QED in crystals

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Utilizing the relativistic invariance of the parameter $\chi = \gamma E/E_0$, ultrarelativistic particles in strong crystalline fields of the order 10^{11} V/cm enable investigations of processes in fields of the order the QED critical field $E_0 = m^2c^3$/eħ=1.32·10^{16} V/cm (with a corresponding magnetic field of B_0=4.41·10^9 T) in the particle rest frame. In the framework of the CERN NA63 experiment we have obtained

experimental results on e.g. quantum synchrotron radiation emission, coherent pairs, radiation reaction and recently trident production in such fields. An overview of results from the CERN NA63 experiment is presented.

Gravity and curved space / 45

SUSY in the Sky with Gravitons

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The quest of the perturbative post-Minkowskian study of the gravitational two body problem has recently seen advances upon employing quantum field theory techniques. I report on a novel approach based on a worldline quantum field theory that provides an efficient way to study the classical scattering of two massive objects (black holes, neutron stars or stars) in GR.

We are able to directly compute the emitted Bremsstrahlung, deflection and spin kick of such an event. The inclusion of spin degrees of freedom of the scattered massive bodies leads to a hidden N=2 supersymmetry on the worldline.

Gravity and curved space / 46

QED as a toy model for gravitational scattering

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The techniques of scattering amplitudes in quantum field theory have been applied successfully to the description of black hole scattering in recent years. In this talk, I will analyze three instances where QED can be used to great advantage as a toy model (or building block) of the gravity case.

Astrophysics and Cosmology / 54

Testing Strong-Field QED with X-ray Polarization

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We argue that measurements of X-ray polarization using the recently launched Imaging X-ray Polarimetry Explorer will answer many open questions about magnetars in particular the physical state of their surfaces, whether vacuum birefringence exists, and the nature of the hard X-ray emission from these objects. We outline the capabilities of the instrument, specific models and the results of simulations and observations for the magnetar 4U 0142+61.

Astrophysics and Cosmology / 31

On the role of QED processes in astrophysics of compact objects

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In this talk I will review the role of QED effects in magnetospheres of astrophysical compact objects, black holes and neutron stars. I will focus on the dynamics of electron-positron pair discharges in large unscreened electric fields, as well as on magnetic reconnection with strong radiative cooling and pair production. Finally, I will highlight observable emission signatures of these fundamental plasma processes.

Strong Field QED / 44

Resurgence of the Gradient Expansion for Intense Fields

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A major computational challenge in the physics of intense fields is the ability to do reliable non-perturbative computations for fields that are both strong and have large gradients. In this talk I discuss the use of ideas from resurgence to make precise resummations and analytic continuations into the intense field regime beginning with modest amounts of perturbative weak-field information. The main idea is illustrated with an example of the Schwinger effect in an intense inhomogeneous field.

Strong Field QED / 28

Colliding laser pulses: From Sauter-Schwinger to Breit-Wheeler

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We study electron-positron pair creation induced by the field of two colliding (transversal and linearly polarized) laser pulses ranging from the Sauter-Schwinger regime at small laser frequencies to the Breit-Wheeler regime at large photon energies.

On the basis of a generalized WKB approach, we find that the pair creation rate along the symmetry axis (where one would expect the maximum contribution) displays the same exponential dependence as for a purely time-dependent electric field. The pre-factor in front of this exponential contains the corrections due to focusing or de-focusing effects induced by the spatially inhomogeneous magnetic field. Through this new method, we can thus not only reproduce particle production rates within a purely time-dependent toy model approach but also analyze the distortions the magnetic field creates with respect to the particle momentum spectrum as well as the total yield.

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Pair production in colliding laser pulses: Computational Aspects

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We discuss spatially- and temporally-resolved, non-perturbative pair production in colliding, linearly polarized laser pulses on the basis of two numerical approaches; a generalized WKB approach culminating in solving a modified Riccati equation and large-scale simulations based on the Dirac-Heisenberg-Wigner formalism.

We discuss how Dirac-Heisenberg-Wigner (quantum kinetic theory) as well as the numerical WKB formalism allow us to numerically observe the transition from the Sauter-Schwinger regime at arbitrarily small laser frequencies to the Breit-Wheeler regime at large photon energies and highlight the qualitative agreements of both approaches.

In particular, we demonstrate that our new, advanced scheme vastly improves the predictions given by the Locally-Constant-Field-Approximation (LCFA) in the context of the overall pair production yield. In particular, in the regime of light-light interactions of more than 25 keV energy.

Strong Field QED / 23

Radiation Reaction: Reduction of Order, Runaways, Resummation, Resurgence

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There is a renewed interest in the physics of radiation reaction (RR), largely driven by high-power laser systems where particles are subject to RR forces at least as strong as the Lorentz force. The Lorentz-Abraham Dirac (LAD) equation of motion with RR has, however, unphysical runaway solutions. The Landau-Lifshitz (LL) equation obtained from the Lorentz-Abraham-Dirac equation through 'reduction of order' is free of these.

We show how LL is the first in a divergent series of approximations that, after resummation, eliminate runaway solutions at all orders. Using Borel plane and transseries analysis we explain why this is, and show that a non-perturbative formulation of reduction of order can retain runaway solutions.

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Photon merging in the collision of two laser pulses

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The quantum vacuum nonlinearity allows for the effect of laser photon merging in the collision of two (or more) laser beams. As the merged photons origin from a manifestly inelastic process, their energy differs significantly from the background photons of the driving lasers, making them accessible for experiments. However, the number of merged photons is typically considered to be very small. In this talk, results on the emission characteristics of the merged signal photons will be presented, demonstrating that the availability of just two laser beams is sufficient to achieve a sizable signal in experiments with state-of-the-art technology.

Strong Field QED / 19

Worldline approach to the off-shell four-photon amplitudes

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The most general QED four-photon amplitude that has been computed, so far, is the one with two photons on-shell and two off-shell. The generalization of this work to a fully off-shell calculation is presently still lacking. Here we present the result of such a calculation, although still with at least one of the legs taken in the low-energy limit, unifying the scalar and spinor QED cases. Despite the finiteness of these amplitudes we keep them in D dimensions to make them useful as building blocks for higher-loop amplitudes in dimensional regularization. The worldline representation is used together with an integration-by-parts procedure that leads, already at the integrand level, to compact expressions that are term-by-term gauge invariant and free of spurious ultraviolet divergences. We clarify the relation between this tensor basis and one used by Costantini, De Tollis and Pistoni.

For the case where one of the photons is in the low energy limit, we express the result in terms of generalized hypergeometric functions and their derivatives. For the case with two low-energy photons we obtain more general formulas than in previous works and we write this result in terms of the hypergeometric function 2F1. As a check on this latter result, we match the special case where k1 = −k2 with the known results for the scalar and spinor QED photon propagators in a constant external field. We also use it for a rederivation of the 2-loop scalar and spinor QED beta functions. Furthermore, we compute the Delbrück cross section at low energies for scalar and spinor QED.

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Worldline master formulas for dressed electron propagator in constant external fields

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The standard formalism for calculating the S-matrix in quantum field theory is based on path integrals over field configurations, and can be formulated as a diagrammatic perturbative method. Alternative to this approach is the Worldline formalism, based on first-quantized relativistic point particle path integrals. Recently, a novel representation of the fermion propagator dressed with an arbitrary number of photons was developed based on this formalism.

In this talk, I will present an extension of this work that includes a constant external electromagnetic field. The resulting Bern-Kosower type representation of the fermion propagator, dressed with a constant field in addition to N scattering photons, reduces all spin-related algebra to a minimum. Using this representation I will show, as a simple application, how to recover the relativistic Landau levels.

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Coulomb-assisted quantum vacuum birefringence

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In this talk, we consider the scattering of an x-ray free-electron laser (XFEL) beam on the superposition of a strong magnetic field B_{ext} with the Coulomb field E_{ext} of a nucleus with charge number Z. In contrast to Delbrück scattering (Coulomb field only), the magnetic field B_{ext} introduces an asymmetry (i.e., polarization dependence) and renders the effective interaction volume quite large, while the nuclear Coulomb field facilitates a significant momentum transfer Δk.

For a field strength of $B_{\text{ext}} = 10^6$ T (corresponding to an intensity of order 10^{22} W/cm^2) and an XFEL frequency of 24 keV, we find a differential cross section dσ/dΩ~10−25 $Z^2/(\Delta k)^2$ in the forward direction for one nucleus. Thus, this effect might be observable in the near future at facilities such as the Helmholtz International Beamline for Extreme Fields at the European XFEL.

Strong Field QED / 30

A unifying approach to strong fields

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Strong fields are ubiquitous in physics, occurring on scales from quarks to the entire universe, and encompassing all fundamental interactions. Insights gained from one area of strong field physics can be of great value in other areas. This is (relatively) straightforward with vector and scalar forces, but the very different nature of gravity can make it hard to translate results from one arena to the other.

However, the special case of dynamics in a conformally flat spacetime is formally equivalent to the interaction with a scalar field in a flat background. This equivalence provides a "Rosetta Stone", enabling us to discuss gauge fields and gravity in the same language. In this talk, we introduce this approach, and use it to discuss the characterisation of "strong fields", and some of the important phenomena they induce.

Gravity and curved space / 47

From Amplitudes to Strong Fields and back again

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Over the last 30 years, there has been intensive work and incredible progress in our understanding of perturbative scattering amplitudes in gauge theory and gravity, but so far these advances have not addressed strong background fields. In this talk, I will try to convince you that there is actually an un-tapped wealth of connections between the amplitudes and strong field communities, which could lead to surprising advances in both.

Gravity and curved space / 16

Electrodynamics as toy model for binary gravitational dynamics at high orders

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Quantum Electrodynamics (QED) serves as a useful toy model for classical observables in gravitational two-body systems with reduced complexity due to the linearity of QED. We investigate scattering observables in scalar QED at the sixth order in the charges (two-loop order) in a classical regime analogous to the post-Minkowskian expansion in General Relativity. We use modern methods to compute scattering amplitudes and their classical limits to extract the scattering dynamics of relativistic charged bodies in both conservative and dissipative sectors.

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Quantum kinetic theory and collisional contributions to shear induced polarization

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We derive a quantum kinetic theory for QED based on Kadanoff-Baym equation [1]. It generalizes the well-known classical kinetic theory to the polarized case, with spin polarization entering in the next order of gradient expansion. We also discuss generalization to QCD. We use this framework to study polarization of probe massive fermion in QED plasma with shear [2]. We find new collisional contributions to shear induced polarization coming from self-energy and gauge link respectively. The new contributions are parametrically the same as the one considered so far in the literature. They can lead to modest suppression of the shear induced polarization in phenomenological studies.

[1] Shu Lin, "Quantum kinetic theory for quantum electrodynamics", Physical Review D 105 (2022) 7, 076017
[2] Shu Lin and Ziyue Wang, "Shear induced polarization: Collisional contributions", arXiv:2206.12573

Strong Field QED / 21

Euler-Heisenberg Lagrangian with axial gauge

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The Euler-Heisenberg Lagrangian is discussed in homogeneous electromagnetic fields with a constant axial gauge coupling, to one-loop order. Two special configurations, namely a magnetic field with chiral chemical potential as well as an electric field with spatial axial gauge, are argued to possess an exact eigenspectrum, whose sum leads to a defining Lagrangian.

In the case of an electric field, it is shown that the addition of a spatial axial gauge leads to an enhancement of pair production. The imaginary part of the Lagrangian is also examined using the worldline formalism where it is demonstrated the axial gauge acts as a negative mass shift for helicity aligned eigenstates, leading to the enhancement. Finally, the massless case is discussed, whose form is exact at one-loop by virtue of the Fujikawa method.

Strong Field QED / 22

Beam focus and longitudinal polarization influence on electron spin dynamics in counterpropagating laser beams

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In recent years, the sole light-based interaction with the spin of a free electron (polarization and spin detection) has been discussed for the case of electron diffraction in counterpropagating laser beams [1,2]. The quantum dynamics of the electron in such a standing light wave of the so-called Kapitza-Dirac effect [3,4] is commonly solved for the approximation of two counterpropagating plane wave laser beams. In our recent work [5], we investigate the effect of beam waist corrections to the plane-wave ansatz on the quantum dynamics of the electron and its spin by a perturbative approach.

We particularly pay attention on the influence of a small longitudinal polarization component in Coulomb gauge, which would be zero when simply averaged along the transverse direction of the laser beam. We conclude in our study that the longitudinal polarization component and transverse field inhomogenieties from beam focussing have no significant influence in the regime of XFEL beams, but may play a role for optical fields.

[1] Phys. Rev. Lett. 118, 070403 (2017).
[2] Phys. Rev. A 102, 033106 (2020).
[3] Math. Proc. Cambridge Philos. Soc. 29, 297 (1933).
[4] Nature (London) 413, 142 (2001).
[5] Phys. Rev. A 105, 053123 (2022).

Gravity and curved space / 48

The On-Shell Highway to Classical Physics

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The KMOC approach is a formalism that expresses classical observables on flat backgrounds in terms of quantum scattering amplitudes. After a first review, I will show two generalizations of the original framework by extending its range of application to classical wave physics and observables on a curved background. Using these, I will prove how to compute the bending of light and waveforms using on-shell amplitudes from coherent states. The talk will conclude with the derivation of non-trivial classical phenomena such as memory effects using only amplitudes on a curved background.

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High-energy limit of quantum and classical wave scattering observables

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We study the space of quantum and classical observables for the radiation emitted by a scalar moving in gauge and gravitational plane-wave backgrounds. We explore the structure of new localised observables such as the momentum and angular momentum flow, as well as their global analogues. We observe that classical observables exhibit a power-law divergence in QED and a logarithmic divergence in general relativity (GR), even when radiation reaction is included, and show that these can only be resolved in the full quantum theory.

Strong Field QED / 10

Highly Radiating Charged Particles in a Strong Electromagnetic Field

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There is a famous $\alpha\chi^{2/3} \sim 1$ problem of a perturbation theory for QED in a strong electromagnetic field. It leads to the situation when radiation losses of highly energetic electrons in a sufficiently high intensity electromagnetic wave cannot be calculated reliably in the frame of the perturbation theory because of divergence of its series at $\alpha\chi^{2/3} \sim 1$. We consider the latter problem trying to avoid as possible using of the perturbation theory. We argue that the leading order term of asymptotic expression for the rate of radiation losses of an electron with its energy tending to infinity coincides with the leading order of the asymptotics obtained in the 1st order of the perturbation theory. The analogous statement can be made for electron-positron pairs production by a high energetic gamma-photons in a strong electromagnetic wave. These results provide possibilities to draw a self-consistent conclusion about invariant masses of electrons and photons in a strong electromagnetic field when their energies tend to infinity. We explain why these results can hardly (if possible) be obtained in the frame of a regular perturbation theory.

Strong Field QED / 2

Acceleration of spin-polarized proton beams from a dual-laser pulse scheme

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The acceleration of spin-polarized particle beams from laser-plasma interaction has gained a lot of interest in recent years due to the availability of high-intensity lasers and their applications for investigating strong-field phenomena. In particular, probing the nuclear structure of protons and neutrons requires polarized particle beams [1]. In this talk, we will present a setup consisting of two laser pulses with anti-parallel polarization propagating side-by-side through a near-critical density target [2]. In contrast to magnetic vortex acceleration, an additional proton filament in the space between the two pulses is formed and ejected at the end of the plasma target. Our particle-in-cell simulations show that the spatial separation of the two laser pulses leads to better spin polarization while still delivering good angular spread.

[1] M. Büscher et al., doi:10.1017/hpl.2020.35, High Power Laser Sci (2020)
[2] L. Reichwein et al., arXiv:2201.11534v2 (2022)

Strong Field QED / 3

QED Effects at Grazing Incidence on Solid-State-Targets

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New laser facilities will reach intensities of 10^{23}W cm^{-2}. This advance enables novel experimental setups in the study of laser-plasma interaction. In these setups with extreme fields quantum electrodynamic (QED) effects like photon emission via non-linear Compton scattering and Breit-Wheeler pair production become important.

We study high-intensity lasers grazing the surface of a solid-state target by two-dimensional particle-in-cell simulations with QED effects included. The two laser beams collide at the target surface at a grazing angle. Due to the fields near the target surface electrons are extracted and accelerated. Finally, the extracted electrons collide with the counter-propagating laser, which triggers many QED effects and leads to a QED cascade under a sufficient laser intensity. Here, the processes are studied for various laser intensities and angles of incidence and finally compared to a seeded vacuum cascade. Our results show that the proposed target can yield many order of magnitude more secondary particles and develop a QED cascade at lower laser intensities than the seeded vacuum alone.

Strong Field QED / 25

Generation and acceleration of linear Breit-Wheeler positrons in ultra-intense laser plasma interactions

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Creation of electrons and positrons via binary photon collisions, i.e. the linear Breit-Wheeler (BW) process, is a basic prediction of quantum electrodynamics, but it is yet to be observed in the laboratory. Motivated by experimental capabilities of newly constructed laser facilities and by recent developments in target fabrication, we have performed PIC simulations supplemented by a post-processing algorithm that have shown that over 10^7 linear BW pairs can be produced by a single laser pulse [New J. Phys. 23, 115005 (2021)] and over 10^8 linear BW pairs can be produced by two colliding laser pulses [Comm. Phys. 4, 139 (2021)] propagating inside a structured plasma channel. The simulations use an experimentally achievable laser intensity in the range of 10^{22} W/cm^2. We have also found that the pair yield from the linear BW process dominates over the yield from the nonlinear BW and Bethe-Heitler processes [Phys. Plasmas, 29, 053105 (2022)].

In order to assesses the dynamics of the linear BW positrons, we have recently developed a first-ever fully kinetic code for predictive simulations of the linear BW pair creation in high-intensity laser-matter interactions and the subsequent positron acceleration. Using this new tool, we found that the linear BW pairs created in both setups can form collimated positron beams with a narrow divergence angle and energy in the GeV range. Our results suggest feasible experimental setups for the observation of the linear BW process in the laboratory and for generation of collimated energetic positron beams. Our findings also indicate that one should no longer automatically assume that the yield of the linear BW process is inferior to the yield from the nonlinear BW process, so the linear BW process must be included when considering ultra-intense laser plasma interactions.

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LUXE: A new experiment to study non-perturbative QED in e^--laser and γ-laser collisions.

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The LUXE experiment (Laser Und XFEL Experiment) is a new experiment in planning at DESY Hamburg using the electron beam of the European XFEL. At LUXE, the aim is to study collisions between a high-intensity optical laser and up to 16.5 GeV electrons from the Eu.XFEL electron beam, or, alternatively, high-energy secondary photons. The physics objectives of LUXE are to measure processes of Quantum Electrodynamics (QED) at the strong-field frontier, where QED is non-perturbative. This manifests itself in the creation of physical electron-positron pairs from the QED vacuum. LUXE intends to measure the positron production rate in a new physics regime at an unprecedented laser intensity. Additionally, the high-intensity Compton photon beam of LUXE can be used to search for physics beyond the Standard Model.

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High-field QED in the laboratory: current status and near-term opportunities

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The fast-paced advance in the high-power laser technology has recently allowed reaching focussed intensities exceeding 10^{21} Wcm^{-2}, with realistic plans to reach $> 10^{23}$ Wcm^{-2} in near-term largescale laser facilities worldwide. While these intensities are still orders of magnitude lower than those needed to produce an electron-positron pair from the vacuum, this limitation can be overcome by focussing the laser pulse onto an ultra-relativistic electron beam. In this case, the electric field in the rest frame of the electron is relativistically boosted by its Lorentz factor. As an example, a 1 GeV electron beam interacting with a laser focussed intensity of 10^{21} Wcm^{-2} will experience, in its own rest frame, an electric field of the order of 20% of the Schwinger field. GeV-scale electron beams suitable for these experiments can be provided either by laser-wakefield or radio-frequency accelerations.

At these unique field intensities, a plethora of exotic processes can be triggered and studied, including highly non-linear Compton scattering, quantum radiation reaction, and Breit-Wheeler pair production. Detailed experimental characterisation of these phenomena will not only advance our fundamental understanding of this branch of fundamental physics but will also be instrumental for astrophysics, cosmology, and plasma physics. An international collaboration led by UK scientists has recently performed the first experiments in this area at the Rutherford Appleton Laboratory, unveiling quantum signatures of radiation reaction [1,2]. Several other campaigns at different world-class physics laboratories, including the E-320 experiment at SLAC [3], the LUXE experiment at the Eu-XFEL [4], and experiments at the Extreme Light Infrastructure and the Astra-Gemini laser, are currently in their preparation stage and aim at pushing our experimental capabilities even beyond the Schwinger field.

In this talk, an overview of the current status and near-term opportunities in this area of physics will be given, with a particular focus on the experimental challenges in studying this fascinating area of physics.

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New and old physics in the interaction of a radiating electron with the extreme electromagnetic field

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We show that an all-optical configuration of the laser-electron collision in the λ^3 configuration based on 10 PW-class lasers presents a viable platform for reaching the range of parameters where a perturbative QED in strong external electromagnetic field breaks. This case is contingently referred to as a case of the non-perturbative QED, and this range of parameters is the intriguing goal from an experimental point of view because of a possible manifestation of a new physics of the interaction of a highly radiating particle with a strong electromagnetic field. We show that the strong-field region can be reached by electrons having initial energy higher than 50 GeV. Our theoretical considerations are in agreement with three-dimensional particle-in-cell simulations. While increasing of the electron energy raises the number of electrons experiencing the strong-field region, the observable signature of photon emission radiative correction in the strong field is expected to fade out when the electron energy surpasses the optimal value. This threshold of electron energy is identified and the parameters for achieving the non-perturbative limit of QED are provided.

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Optimal photon polarization toward the observation of the nonlinear Breit-Wheeler pair production

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We investigate the optimization of photon polarization to increase the yield of Breit-Wheeler pair production in arbitrarily polarized plane wave backgrounds. We show that the optimized photon polarization can improve the positron yield by more than 20% compared to the unpolarized case, in the intensity regime of current laser-particle experiments.

The seed photon optimal polarization results from the polarization coupling with the polarization of the laser pulse. Compact expressions of the coupling coefficients in both the perturbative and nonperturbative regimes are given. Because of the evident difference in the coupling coefficients for the linear and circular polarization components, the seed photon optimal polarization state in an elliptically polarized laser background deviates considerably from the orthogonal state of the laser polarization.

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Particle-beam scattering from strong-field QED

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We consider the scattering of probe particles on an ultraboosted beam of charge, in the case that the fields of the beam are strong and must be treated nonperturbatively.

We show that the fields of the ultraboosted beam act as stochastic plane waves-scattering amplitudes (of elastic scattering, nonlinear Compton and nonlinear Breit-Wheeler) are obtained without approximation by averaging plane wave scattering amplitudes over all possible plane wave parameters.

The relevant plane waves are ultrashort and, as such, scattering on ultraboosted beams does not exhibit the conjectured strong-field behavior of QED based on the locally constant field approximation.

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Nonlinear Compton scattering in time-dependent electric fields: LCFA and beyond

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The locally constant crossed field approximation (LCFA) is a powerful tool for studies of various strong field QED phenomena. It is common that numerical codes for simulating strong laser-matter interaction rely on LCFA for taking into account QED effects, and therefore it is crucial to establish the limits of applicability of the approximation and develop possible extensions.

We explore LCFA in detail for photon emission by a spinless particle in a strong time-dependent electric field. This kind of electromagnetic field is of particular interest, because it models the electric antinode of a standing electromagnetic wave, which is the beneficial configuration for QED cascade generation. It is worth emphasizing that a time-dependent electric field is not crossed in contrast to the comprehensively studied case of a plane wave.

We develop an approach for calculating the photon emission probability rate in a generic time-dependent electric field. It allows one to establish the LCFA applicability range, and calculate the first and higher-order corrections to it. We test LCFA and such corrections against the numerically calculated probability rates.

Astrophysics and Cosmology / 6

Kinetic model of pair cascades in pulsar polar caps

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Time-dependent discharges of electron-positron pairs have recently been proposed as a primary ingredient to explain the nature of pulsar radio emission, a long-standing open problem in high-energy astrophysics. During these discharges - positive feedback loops of gamma-ray photon emission via curvature radiation by TeV electrons and positrons and pair production - the plasma self-consistently develops inductive waves that couple to electromagnetic modes capable of escaping the pulsar dense plasma.

However, a full kinetic model that could predict the growth rate of the cascade, the screening time, and the subsequent emissions is still lacking. First, we show how the kinetic equations can be used to provide such predictions in two setups: (i) uniform electric field and a more realistic vacuum-gap space-time dependent electric field. We show also that the full QED differential probability rates can be approximated by a heuristic rate for photon emission and pair creation. All analytical results are illustrated with particle-in-cell simulations performed with OSIRIS. Second, these results are used to interpret new multidimensional simulations including an ab initio description of the Quantum Electrodynamics (QED) effects responsible for hard photon emission and pair production in pair discharges. It is shown that the electromagnetic modes generated during pair discharges present direct imprints of QED and plasma kinetic effects in properties (e.g. frequency, polarisation and Poynting flux angular distribution) that are consistent with observations.

Astrophysics and Cosmology / 20

Vacuum and in-medium polarization phenomena in strong magnetic fields

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We discuss the fermion-antifermion polarization phenomena in strong magnetic fields that can be realized in heavy-ion collisions, laser fields, and neutron stars. We elaborate on its effects on birefringence when a photon is traversing the magnetic-field region [1].

The medium effects can drastically change the vacuum birefringence due to the Pauli blocking effect and the medium-specific contribution known as the Landau damping. We also discuss the axial charge generation when a perturbative electric field is applied on top of the strong magnetic fields, leading to a non-zero divergence of the axial-vector current [2]. For massive fermions, the medium contribution can be as large as the vacuum contribution known as the chiral anomaly.

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[2] Koichi Hattori and Kazunori Itakura, "In-medium polarization tensor in strong magnetic fields (II): Axial Ward identity at finite temperature and density," 2205.06411 [hep-ph].

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Baryogenesis from axion inflation

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In inflation models driven by an axion-like particle the inflaton may have a Chern-Simons coupling to the Standard Model (SM) $\mathrm{U}(1)_Y$. In this talk we show that this setup is a highly predictive baryogenesis model without further ingredients other than the SM and the inflaton (and the origin of neutrino mass). During inflation this Chern-Simons coupling sources a dual production of the SM chiral fermions and maximally helical $\mathrm{U}(1)_Y$ gauge fields associated with the SM chiral anomaly equation ala Schwinger effect. We will discuss the possibility where the anomalous transport of these primordial chiral asymmetries and the helical $\mathrm{U}(1)_Y$ gauge fields after inflation gives rise to the present baryon asymmetry.

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QCD in a strong magnetic background

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Strong magnetic fields show up in various context in high-energy physics such as heavy-ion collisions, compact stars, and the early universe. Thus it is of interest to understand the behavior of strongly interacting matter in such extreme conditions. In this talk, I will give an overview of some of the progress that has been made over the past decade. In particular, I will discuss the phenomenon of (inverse) magnetic catalysis which is the increase (decrease) of the chiral condensate as the magnetic field increases.

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Strongly interacting matter in intense electromagnetic fields

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Strong electromagnetic fields, as they arise in high-energy heavy-ion collisions, in the interior of magnetars and potentially during the evolution of the early universe, have a significant impact on the physics of quarks and gluons. First-principles lattice simulations of this non-perturbative system have revealed a highly nontrivial response to the background fields and a corresponding phase diagram with a rich structure.

In this talk, I will briefly recapitulate the recent lattice findings regarding magnetic fields and also discuss the impact of electric fields. In the latter case, even the simplest setting of a hot electron gas yields a surprising result.

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Pair production of phonons in Bose-Einstein condensates with curved and expanding acoustic metric

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The large-scale structure of our Universe is seen as a result of quantum field fluctuations amplified by the evolution of space-time itself. Quantum fields in curved spacetimes have many tantalizing theoretical properties, for example particles being produced by the time-dependence of the geometry. I will describe how quantum fields in geometries with spacetime curvature and different cosmologies can be quantum-simulated with Bose-Einstein condensates in specifically designed trapping potentials and with time-dependent interaction strengths. New analytical results for relativistic scalar fields in cosmologies with 2+1 spacetime dimensions will be compared with recent experimental results.

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The role of the chiral anomaly in polarized DIS

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I'll discuss the role of the triangle anomaly in polarized deep inelastic scattering (DIS) employing a worldline formalism. I'll demonstrate that the structure function $g_1(x_B, Q^2)$ measured in polarized DIS, as well as its first moment which defines the proton's helicity $\Sigma(Q^2)$, is dominated by the chiral anomaly in both Bjorken ($Q^2 \to \infty$) and Regge ($x_B \to 0$) asymptotics. I'll show that in both asymptotics the structure function is identically controlled by the triangle anomaly, which has an infrared pole in the forward scattering limit. The cancellation of this pole involves a subtle interplay of perturbative and nonperturbative physics that is deeply related to the $U_A(1)$ problem in QCD.

In the worldline formulation of quantum field theory, the triangle anomaly arises from the imaginary part of the worldline effective action. I'll show explicitly how a Wess-Zumino-Witten term coupling the topological charge density to a primordial isosinglet $\bar{\eta}$ arises in this framework. I'll demonstrate the fundamental role played by this contribution both in topological mass generation of the η' and in the cancellation of the infrared pole arising from the triangle anomaly in the proton's helicity $\Sigma(Q^2)$. I will introduce an axion-like effective action for g_1 at small x_B that follows from the cancellation of the infrared pole in the matrix element of the anomaly. It describes the interplay between gluon saturation and the topology of the QCD vacuum. In this context I'll outline the role of "over-the-barrier" sphaleron-like transitions in spin diffusion at small x_B. Such topological transitions can be measured in polarized DIS at a future Electron-Ion Collider.

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Nonlinear Compton scattering and nonlinear Breit-Wheeler pair production including the damping of particle states

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In the presence of an electromagnetic background plane-wave field, electron, positron, and photon states are not stable, because electrons and positrons emit photons and photons decay into electron-positron pairs. This decay of the particle states leads to an exponential damping term in the probabilities of single nonlinear Compton scattering and nonlinear Breit-Wheeler pair production [1]. We present analytical and numerical results on the probabilities of nonlinear Compton scattering and nonlinear Breit-Wheeler pair production including the particle states'decay within the locally-constant field approximation [2]. First, the probabilities and some of their asymptotic values are computed analytically. Then, several plots of the total and differential probabilities for different pulse lengths and for different spin and polarization quantum numbers are shown. We stress that it is crucial to take into account the damping of the states in order for the probabilities to stay always below unity and we show that the damping factors also scale with the intensity and pulse duration of the background field. In the case of nonlinear Compton scattering we show numerically that the total probability behaves like a Poissonian distribution for sufficiently low initial electron energies such that the photon recoil is negligible.

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Strong Field QED / 29

The effect of radiative corrections on electron propagation and photon emission in a strong constant crossed field

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Accounting for loop radiative corrections, such as photon polarization and electron mass operators, become essential as the strength of the external field reaches the limit of ~1600 Sauter-Schwinger fields in the reference frame of a particle, namely, $\alpha\chi^{2/3} \sim 1$ where χ denotes the (dimensionless) field. It is sufficient to consider just 1-loop corrections below the limit $\alpha\chi^{2/3} < 1$. In the first part of this talk, we analyze the modification of the free electron propagation in a strong constant crossed field by the 1-loop mass correction.

At $\alpha\chi^{2/3} > 1$, any scattering problem requires a summation of loop radiative corrections to all orders. According to the Ritus-Narozhny conjecture, the leading order corrections are given by combining the 1-loop photon polarization operators with the bare photon lines, and (fortunately) appear to be summable. However, in effect, such dressed 'photons' obtain a dynamical mass depending on χ. Unless χ is small, they are violently unstable. This makes formulation of the photon emission probability quite intricate. We briefly review this issue and the possible ways to resolve it in the second part of the talk.

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Dyson - Schwinger equations in scalar electrodynamics

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Quantum electrodynamics (QED) is a theory of the interacting fermionic electron-positron and electromagnetic fields. However, it may be expedient to isolate or neglect contributions of spin effects. Also, there do exist charged scalar particles. Therefore, it is worth studying a scalar version of QED as well. At first glance, such a theory should be simpler due to the absence of spin degrees of freedom. However, it turns out that due to gauge invariance it contains an extra interaction (bare vertex) as compared to the standard fermionic QED.

Amongs the most important QED equations are the Dyson-Schwinger (DS) equations, establishing a relationship between the exact (i.e. dressed by radiative corrections) propagators and vertices. In particular, they are used to construct nonperturbative methods based on partial resummations of the perturbative series. We obtain analogs of the DS equations for scalar QED in an external electromagnetic field and discuss a diagrammatic interpretation of the corresponding mass and polarization operators. We use functional integration techniques, which are especially convenient to derive and analyze general properties and relations.

In this approach the main object is a generating functional, which is an amplitude of vacuum-vacuum transition in the presence of classical sources. It generates the full set of Green functions and obeys functional equations called the quantum equations of motion. The DS equations are obtained by taking extra variational derivatives of these equations with respect to sources after expressing the result in terms of the exact propagators and vertices. After that we set scalar sources to zero but allow the presence of an external electromagnetic field, leaving the corresponding source unconstrained. The resulting equations have a much more bulky structure than in standard QED. In particular, in the presence of an external field,the mass operator contains the contribution of an exact three-photon vertex (see Fig. 1), which was not pointed out previously in the literature.

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Experimental demonstration of all-optical nonlinear Compton scattering using a multi-petawatt laser

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TBA

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Abstract to be confirmed

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TBA

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TBA

Abstract to be confirmed

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Aspects of the strong-field Breit-Wheeler process in a tightly focused laser pulse

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Experimental efforts toward the detection of the nonperturbative strong-field regime of the Breit-Wheeler pair creation process plan to combine incoherent sources of GeV γ quanta and the coherent fields of tightly focussed optical laser pulses. This endeavour calls for a theoretical understanding of how the pair yields depend on the applied laser field profile. We provide estimates for the number of produced pairs in a setup where the high-energy radiation is generated via bremsstrahlung. Attention is paid to the role of the transversal and longitudinal focussing of the laser field, along with the incorporation of a Gaussian pulse envelope. We compare our results with predictions from plane-wave models and determine the parameters of focused laser pulses which maximize the pair yield at fixed pulse energy.