Workshop summary:
Advanced QED methods for future accelerators

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Abstract. The talks presented at the workshop “Advanced QED methods for future accelerators” are briefly summarised. They focused on the theoretical description of Intense Field QED (IFQED), the calculation and simulation of IFQED processes and other IFQED applications.

1. Introduction
The workshop “Advanced QED methods for future accelerators” had essentially two aims. One was to gain a firmer understanding of available QED techniques necessary for describing processes in the extreme environments expected during bunch-bunch collisions at future high-luminosity TeV-scale electron-positron accelerators. The other was to gain an analogous understanding in connection with the extreme environments created by high-intensity laser beams. Urgent further attention must be given to the impact of quantum effects on the design of such machines and systems. This workshop was dedicated to reviewing the formalisms for describing these radiative processes and the methods of calculation in the strong-field environments. It was jointly sponsored by the Cockcroft Institute of Accelerator Science and Technology, UK, and the Institute for Particle Physics Phenomenology, University of Durham, UK, and it was a workshop of the series of mini-workshops of the Beam Dynamics Group of ICFA, the International Committee for Future Accelerators. The organisers hope that this workshop was the first in a series and plan a second workshop of this kind in 2010.

In the following, the talks presented at the workshop will be briefly summarised. The methods introduced to describe Intense Field QED (IFQED) phenomena include the quasiclassical operator method of Baier and Katkov and the semiclassical method of Nikishov and Ritus, based on the Furry representation. IFQED calculations for intense laser-light fields were presented as well as the implementation of IFQED processes in computer simulations for high energy accelerators. Further applications include experiments with strong fields and recycled accelerator parts, lepton pair creation in strong laser fields, strong field QED effects in crystals and geometric and ultrarelativistic methods.

2. Intense Field QED methods
Intense-field phenomena can be befittingly described on the quantum mechanical level within the Furry or bound-interaction representation [1], and in [2] an introduction to this approach was given. The Furry representation is a variant of the interaction representation intermediate
between the Heisenberg and Dirac representations. In this representation the effects of the external field are included in the wave functions and the eigenstates describe a bound system instead of a free particle system. Hence the commutation relations, the gauge transformations and the charge conjugation operation on the electron propagator have to be adapted accordingly and the contributions of self-closed diagrams in the vacuum polarization have to be included.

In [3] an introduction to the quasiclassical operator method of Baier and Katkov [4] is given and it describes recent developments for the application of this method to pair creation processes by a photon in an external field and for radiation processes in oriented crystals. Furthermore, applications for the description of the superposition of a plane wave and a constant field, radiation processes occurring during beam-beam interaction at linear colliders and the description of inhomogeneous fields are reviewed.

In contribution [5] the derivation of the transition rate of the beamstrahlung process is reviewed, comparing the quasiclassical operator method with the semi-classical method of Nikishov and Ritus [6, 7] which uses the Furry representation. The former assumes a classical interaction between the electron and the external field, but a quantum interaction to produce the radiated photon and it is only expected to be valid if the electron is ultra-relativistic before and after the photon emission. The latter is a full calculation within the usual S-matrix theory. Here, there are no kinematic approximations and radiative corrections within the Furry representation have to be included.

3. IFQED calculations

Intense laser light is an important tool for probing the quantum vacuum and other QED effects at high fields. Related IFQED calculations were presented in several talks at the workshop. For example, the QED vacuum can be analysed using light-by-light diffraction [8] whereas other related phenomena of QED in strong light fields include photon merging in light-proton collisions [9], photon splitting in a laser-light field [10], Delbrück scattering in combined Coulomb and laser-light fields [11], laser-light-assisted bremsstrahlung [12] and laser-light-induced channelling of electron positron pairs [13, 14].

In this context, contribution [15] describes Compton scattering at high intensities occurring in collisions of an electron beam with a high-power laser beam. After an overview of this process the expected intensity signatures of the emitted photons are reviewed [16]. Current and planned laser facilities which could be utilised are listed, e.g. the Vulcan facility [17] and the Extreme Light Infrastructure (ELI) project [18], as well as planned experiments at Daresbury laboratory and Forschungszentrum Dresden-Rossendorf.

4. Simulation of IFQED processes in colliders

Contribution [19] reviews the implementation of depolarization effects in the computer code GUINEA-PIG++ [20] which simulates aspects of the beam-beam interaction. In particular, spin-dynamical effects like precession and spin-flip have been included and compared with the implementation in CAIN [21]. Some differences occur which are assumed to arise from a different choice of the coordinate systems: in CAIN the z-direction is the direction of the incoming particle whereas GUINEA-PIG++ uses a fixed z-direction. Despite these differences good overall agreement is found for the main beam-parameter sets of the ILC.

A further talk summarised the implementation and limitations of IFQED processes in CAIN and contained suggestions for improving these, focusing especially on second order pair-production processes. The Volkov solutions for these pair-production processes were discussed as well as the two vertex auxiliary functions and the Volkov propagator poles. Results of recent simulations using CAIN can be found in [22].
5. IFQED applications
Contribution [23] explains how low energy experiments employing intense laser beams or strong electric and magnetic fields can be used to search for phenomena beyond the Standard Model, focusing on models with minicharged particles and hidden photons. This can be achieved with dark current experiments in accelerator cavities (AC/DC experiments), by testing Coulomb's law with Cavendish-type experiments, with light-shining-through-a-wall experiments including tunnelling phenomena of the third kind and with laser-beam polarization experiments. Examples for this kind of experiment include the ALPS experiment at DESY and an experiment to search for hidden-sector photons at Daresbury laboratory using an ILC superconducting RF cavity.

Another talk focused on possibilities for lepton pair creation in strong laser-light fields. For example, in laser-driven colliders [24] muon pair production from positronium atoms can be probed [25]. Pair production can also occur, via absorption of multiple photons, when a beam of relativistic particles collides with a pulse of laser light [26]. Free pair creation in laser light-nucleus collisions [27] is also possible. For these, petawatt lasers or UV/X-ray lasers (e.g. DESY FLASH) and ion accelerators at CERN or GSI could be utilised. Pair creation can also take place in counter-propagating laser beams which create standing electromagnetic waves where pronounced magnetic-field effects occur [28].

In contribution [29] the connection between IFQED effects in crystals [30] and in beamstrahlung is presented. Experiments carried out with crystals can be used to support beamstrahlung calculations for future linear colliders. The results of experimental studies of quantum suppression of synchrotron radiation, coherent pairs and the trident process confirm the validity of the theory in the strong field regime.

In a further talk geometric and ultrarelativistic methods for accelerator physics were introduced. In the ultrarelativistic approach the nonlinear system of partial differential equations which describes the particles in a beam is replaced by a hierarchy of linear equations. Examples for the ultrarelativistic expansion for a cold fluid, for a single charged particle [31] and of the Maxwell-Vlasov equations [32] were presented.

6. Summary
The workshop “Advanced QED methods for future accelerators” provided reviews of the quasiclassical operator method of Baier and Katkov and the semi-classical method of Nikishov and Ritus, which is based on the Furry representation.

In anticipation of future high-luminosity electron-positron accelerators at the TeV-scale, the implementation of IFQED processes in the simulation of the beam-beam interaction in the codes GUINEA-PIG++ and CAIN was summarised.

For the application of IFQED in intense laser-light fields several different calculations and related ongoing and planned experiments were described, including vacuum polarization effects in intense laser-light fields, IFQED effects in Compton scattering and lepton pair creation in strong laser-light fields. Further talks reviewed strong fields in recycled accelerator parts as a laboratory for fundamental physics, experiments on strong field QED in crystals and geometric and ultrarelativistic methods for accelerator physics.

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