EXHILP 2019

3rd Conference on Extremely High Intensity Laser Physics

September 3-6, 2019 Stanford

About ExHILP 2019

The third Extremely High Intensity Laser Physics Conference (ExHILP 2019) is hosted by the PULSE Instituteand Department of Applied Physics at Stanford University and co-organized by Lawrence Berkeley National Laboratory. The conference combines theory, experiment and simulations of laser-matter and laser-vacuum interactions at the highest intensities. This year ExHILP is focusing on Strong Field Quantum Electrodynamics (SFQED) with applications to astrophysics and cosmology, high-luminosity colliders and physics beyond the standard model. Experiments will include PW-class laser interactions in plasmas, ultra-relativistic particle and high energy photon beams. Previous conferences were hosted in Heidelberg (2015) and Lisbon (2017).

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September 3-6, 2019

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INVITED SPEAKER

TUTORIAL/PLENARY TALKS:

- Roger Blandford (Astrophysical Motivations, KIPAC/SLAC)
- Antonino Di Piazza (Strong-Field QED: Theory, MPIK Heidelberg)
- Felix Karbstein (Helmholtz-Institut Jena)
- Stuart Mangles (Strong-Field QED: Experiments, Imperial College London)
- Mattias Marklund (Strong-Field QED: Simulations, Chalmers University of Technology)
- Michael Peskin (Beamstrahlung/Linear Collider, SLAC/Stanford)

TOPICAL TALKS:

- Andrei Beloborodov (Columbia)
- Tom Blackburn (University of Gothenburg)
- Alex Chen (Princeton University)
- Qiang Chen (Nebraska-Lincoln)
- Fabrizio Del Gaudio (Técnico Lisboa)
- Dario Del Sorbo (SLAC/Stanford)
- Eric Esarey (BELLA/Berkeley)
- Mickael Grech (École Polytechnique)
- Mark Hogan (SLAC/Stanford)
- Ben King (Plymouth University)
- James Koga (Kansai Photon Science Institute)
- Georg Korn (ELI Beamlines)
- Felix Mackenroth (Max Planck Institute for the Physics of Complex Systems)
- Chang Hee Nam (Center for Relativistic Laser Science)
- Adam Noble (Strathclyde)
- Claudio Pellegrini (UCLA/SLAC)
- Ralf Schützhold (Helmholtz-Zentrum Dresden-Rossendorf)
- Daniel Seipt (University of Michigan)
- Ulrik Uggerhøj (Aarhus)
- Vitaly Yakimenko (SLAC/Stanford)

TUESDAY (SEP 3)

8:00	**Registration**
8:30	**Welcome**

Strong-field QED (SFQED) Theory Session Chair:

8:45	**Antonino Di Piazza** (Max-Planck-Institut für Kernphysik) *Theory of Strong-Field QED in Intense Laser Fields*
9:45	**Break**
10:00	**Ben King** (University of Plymouth) *Improved local approximation for nonlinear Breit-Wheeler pair creation and short pulse effects on photon polarisation in nonlinear Compton scattering*
10:20	**Tom Blackburn** (University of Gothenburg) *Benchmarking and Improving Semiclassical Approaches to Strong-Field QED*
10:40	**Alexander Macleod** (University of Plymouth) *Two particle scattering in strong-field QED*
10:55	**Erez Raicher** (Max-Planck-Institut für Kernphysik) *Momentum-dependent effective mass in a rotating electric field*
11:10	**Break**
11:25	**Felix Mackenroth** (Max-Planck-Institut für Physik komplexer Systeme) *Nonlinear Compton scattering of an ultraintense laser pulse in a plasma*
11:45	**Daniel Seipt** (University of Michigan) *Ultrafast Polarization of an Electron Beam in an Intense Bi-chromatic Laser Field*
12:05	**Yue-Yue Chen** (Max-Planck-Institut für Kernphysik) *Polarized positron beams via intense two-color laser pulses*
12:20	**Lunch**

Laser-based SFQED Experiments Chair:

14:00	**Stuart Mangles** (Imperial College London) *Exploring QED in laser-plasma experiments*
14:45	**Break**
15:00	**Qiang Chen** (Nebraska-Lincoln) *Extremely high-order multiphoton Thomson scattering*
15:20	**Chang Hee Nam** (Institute for Basic Science) *Experimental Approach for strong field QED processes with a multi-PW Laser*
15:40	**Georg Korn** (ELI Beamlines) *High intensity lasers and high field program at ELI Beamlines*
16:00	**Posters & Light Dinner**

WEDNESDAY (SEP 4)

8:30	**Coffee and Snacks**

Numerical Simulations (QED-PIC and related) Chair:

8:45	**Mattias Marklund** (Chalmers University of Technology) *Simulations of strong field-matter interactions*
9:30	**Break**
9:50	**Mickael Grech** (École Polytechnique) *Recent developments around the Apollon laser & SMILEI projects*
10:10	**David Burton** (Lancaster University) *Quantum Backreaction in Laser-Driven Plasma*
10:25	**Robbie Watt** (Imperial College London) *Numerical Modelling of Breit-Wheeler Detection Experiments*
10:40	**Yutong He** (University of California, San Diego) *Enhanced gamma-ray emission in structured targets irradiated by counter-propagating laser pulses*
10:55	**Break**
11:15	**Martin Jirka** (ELI-Beamlines/Czech Technical University in Prague) *Direct laser acceleration in radiation-dominated regime*
11:30	**Evgeny Gelfer** (ELI Beamlines) *Radiation Induced Acceleration of Ions*

Crystal-based SFQED Experiments Chair:

11:45	**Ulrik Uggerhøj** (Aarhus) *Testing radiation reaction by means of GeV e± in crystals*
12:05	**Tobias Wistisen** (Max-Planck-Institut für Kernphysik) *Quantum radiation reaction beyond the local constant field approximation*
12:20	**Lunch**

Beam-Beam Interactions (future linear collider) Chair:

14:00	**Michael Peskin** (SLAC/Stanford) *Extreme Fields and Lasers for Elementary Particle Physics*
14:45	**Break**
15:00	**Vitaly Yakimenko** (SLAC/Stanford) *Concept for a Fully Non-perturbative QED Collider*
15:20	**Fabrizio Del Gaudio** (Técnico Lisboa) *Bright γ rays source and nonlinear Breit-Wheeler pairs in the collision of high density particle beams*
15:40	**Dario Del Sorbo** (SLAC National Accelerator Laboratory) *Probing electron-positron QED cascades in the collision of tightly focused lepton beams*
16:00	**Break**

LINAC/XFEL-based SFQED Experiments Chair:

16:20	**Claudio Pellegrini** (UCLA/SLAC) *Very Large Power density and High Field QED with X-ray FELs*
16:40	**Ishay Pomerantz** (Tel Aviv University) *The LUXE Experiment: probing strong-field QED at the EU.XFEL*
16:55	**Sebastian Meuren** (SLAC/Stanford) *Probing Strong-field QED at FACET-II (SLAC E-320)*

THURSDAY (SEP 5)

8:30	**Coffee and Snacks**

Strong Fields in Astrophysics Chair:

8:45	**Roger Blandford** (KIPAC/SLAC) *Cosmic Laboratories*
9:45	**Break**
10:05	**Andrei Beloborodov** (Columbia) *Magnetic Energy Release in Magnetars*
10:25	**Alexander Chen** (Princeton University) *Self-consistent Global Simulations of Pair Discharge in Neutron Star Magnetospheres*
10:45	**Break**

Light-Light Interaction (Euler-Heisenberg and related) Chair:

10:55	**Felix Karbstein** (Helmholtz-Institut Jena) *All-optical probes of vacuum polarization effects*
11:40	**Break**
12:00	**Adam Noble** (University of Strathclyde) *Cherenkov Radiation from the Quantum Vacuum*
12:20	**Hedvika Kadlecova** (ELI–Beamlines) *Born–Infeld electromagnetic shock waves in the Quantum Vacuum*
12:35	**Wendell Hill, III** (University of Maryland) *Precision measurements of the quantum vacuum at the petawatt level*
12:50	**Lunch**

Schwinger Pair Production Chair:

14:30	**Ralf Schützhold** (Helmholtz-Zentrum Dresden-Rossendorf) *Dynamically assisted tunneling: from the Sauter-Schwinger effect to nuclear fusion*
14:50	**Chul Min Kim** (Center for Relativistic Laser Science) *Phase-integral Formulation of Dynamically Assisted Schwinger Pair Production*
15:05	**Greger Torgrimsson** (Friedrich-Schiller-Universität Jena) *Perturbative approach to nonperturbative pair production*
15:20	**Christian Kohlfürst** (Helmholtz-Zentrum Dresden-Rossendorf) *Spin-states in multiphoton pair production for circularly polarized light*
15:35	**Break**
15:55	**Tae Moon Jeong** (ELI-Beamlines) *Spherically-focused Ultrastrong Electromagnetic Field for Electron-Positron Pair Production*
16:10	**Charles Su** (Illinois State University) *Optimal supercritical potentials for the electron-positron pair-creation rate*
16:25	**Christian Schubert** (Universidad Autónoma del Estado de México) *Fermionic Schwinger pair creation*
16:40	**Break**

Community Activities Chair:

16:55	**Phil Bucksbaum** (SLAC/Stanford) *Building the SFQED community*
17:10	**Stepan Bulanov** (BELLA/Berkeley) *Physics of plasmas in extreme fields*
18:00	**Barbecue**

FRIDAY (SEP 6)

8:30	**Coffee and Snacks**
Wakefield Acceleration and Future Facilities	Chair:
8:45	**Eric Esarey** (Lawrence Berkeley National Laboratory) *High Intensity Laser Experiments at the BELLA Center*
9:05	**Mark Hogan** (SLAC/Stanford) *Plasma Wakefield Acceleration and Extreme Beams at FACET-II*
9:25	**James Koga** (Kansai Photon Science Institute) *Using Relativistic Flying Mirrors for High Field Science*
9:45	**Break**
10:00	**Liangliang Ji** (Shanghai Institute of Optics and Fine Mechanics) *Relativistic polarized electron generation via plasma wakefield acceleration*
10:15	**Hans Rinderknecht** (University of Rochester) *Frontiers in physics enabled by EP OPAL: a multibeam ultra-intense laser user facility*
Numerical Approaches (Lattice QED and related)	Chair:
10:30	**Yuan Shi** (Lawrence Livermore National Laboratory) *What can we learn from solving classical field equations?*
10:45	**Qingzheng Lyu** (Max-Planck-Institut für Kernphysik) *The Computational-QFT Approach in QED Processes with Strong Laser Fields*
11:00	**Break**
Beyond Standard Model Physics	Chair:
11:15	**Ou Labun** (University of Texas, Austin) *Toward BSM physics with lasers: precision modeling and statistical methods for theory-experiment comparison*
11:30	**Lance Labun** (University of Texas, Austin) *What do we need to discover the Unruh effect in laser experiment?*
11:45	**Hartmut Ruhl** (Ludwig-Maximilians-University of Munich) *2D spacetime manifolds, radiation reaction, emergent inertia*
12:00	**Summary**
12:30	**Lunch**

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THALES	

EXHILP 2019

Contributed Talks

Theory of Strong-Field QED in Intense Laser Fields

A. Di Piazza[1, *]

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The talk will be devoted to a pedagogical introduction to the theoretical methods employed in QED in order to study processes occurring in the presence of intense background electromagnetic fields [1, 2]. After a general introduction on when and how background electromagnetic fields have to be taken into account exactly in the calculations of quantum probabilities, I will focus on the case of background laser fields [3, 4]. I will cover general subjects including the Furry picture and the local constant field approximation. In the last part of the talk I will briefly report on the recent efforts [5–7] on how to enter the so-called non-perturbative regime of strong-field QED at high energies [8–13].

[1] V. B. Berestetskii, E. M. Lifshitz, and L. P. Pitaevskii, Quantum Electrodynamics (Elsevier-Butterworth-Heinemann, Oxford, 1982).
[2] E. S. Fradkin, D. M. Gitman, and Sh. M. Shvartsman, Quantum Electrodynamics with Unstable Vacuum (Springer, Berlin, 1991).
[3] V. I. Ritus, J. Sov. Laser Res. **6**, 497 (1985).
[4] A. Di Piazza, C. Müller, K. Z. Hatsagortsyan, and C. H. Keitel, Rev. Mod. Phys. **84**, 1177 (2012).
[5] T. G. Blackburn, A. Ilderton, M. Marklund, and C. P. Ridgers, New J. Phys. **21**, 053040 (2019).
[6] C. Baumann, E. N. Nerush, A. Pukhov, and I. Y. Kostyukov, arXiv:1811.03990 (2018).
[7] V. Yakimenko, S. Meuren, F. Del Gaudio, C. Baumann, A. M. Fedotov, F. Fiuza, T. Grismayer, M. J. Hogan, A. Pukhov, L. O. Silva, and G. White, Phys. Rev. Lett. **122**, 190404 (2019)
[8] V. I. Ritus, Sov. Phys. JETP **30**, 1181 (1970).
[9] N. B. Narozhny, Phys. Rev. D **20**, 1313 (1979).
[10] N. B. Narozhny, Phys. Rev. D **21**, 1176 (1980).
[11] A. M. Fedotov, J. Phys.: Conf. Ser. 826, 012027 (2017).
[12] T. Podszus and A. Di Piazza, Phys. Rev. D **99**, 076004 (2019).
[13] A. Ilderton, Phys. Rev. D **99**, 085002 (2019).

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Improved local approximation for nonlinear Breit-Wheeler pair creation and short pulse effects on photon polarisation in nonlinear Compton scattering

B. King,[1,*] N. V. Elkina,[2] and H. Hu[3]

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A challenge to upcoming experiments that plan to collide a particle beam with laser pulses of moderate intensity, is how to correctly incorporate quantum effects into simulation frameworks. Using a uniform approach, we extend the widely-used locally constant field approximation (LCFA) to derive the rate of nonlinear Breit-Wheeler pair creation. By benchmarking with analytical results and numerical integration of photon-seeded pair creation in finite laser pulses, we show that our extended approach remains valid at smaller values of the intensity parameter than the standard LCFA.

There has been recent interest in using polarised rates for nonlinear Compton scattering to generate high-energy electron beams of a higher spin polarisation degree. This has been most often studied in the context of numerical simulations, which rely upon the integrated LCFA. However, it is known that in the low-lightfront-momentum, and angular parts of the emitted spectrum, one can find features beyond the LCFA when the laser background chosen is a short enough pulse. Here, we investigate what new features are brought in the polarisation of the emitted photon, keeping the electron unpolarised.

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Benchmarking and Improving Semiclassical Approaches to Strong-Field QED

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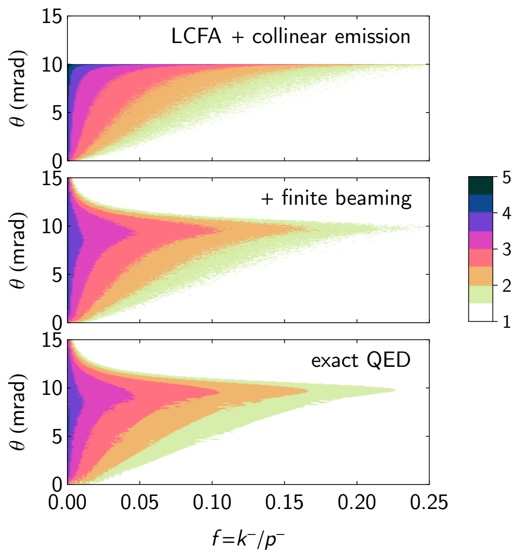

FIG. 1. Probability density ($\log_{10}$-scaled) that an electron in a circularly polarized laser pulse with $a_0 = 10$ emits a photon with lightfront momentum transfer $f \simeq \omega'/(\gamma m)$ and angle θ: as predicted by (upper) the standard numerical approach, (middle) our improved method and (lower) exact QED.

The recoil associated with photon emission is key to the dynamics of ultrarelativistic electrons in strong electromagnetic fields, as are found in high-intensity laser-matter interactions and astrophysical environments such as neutron star magnetospheres. When the energy of the photon becomes comparable to that of the electron, it is necessary to use quantum electrodynamics (QED) to describe the dynamics accurately.

However, computing the appropriate scattering matrix element from strong-field QED is not generally possible due to multiparticle effects and the complex structure of the electromagnetic fields. Therefore these interactions are treated semiclassically, coupling probabilistic emission events to classical electrodynamics using rates calculated in the locally constant field approximation. This framework underpins the PIC simulations used to study how next-generation lasers could be used as high-energy photon and particle-beam sources.

Our recent work provides comprehensive benchmarking of this approach against the exact QED calculation for nonlinear Compton scattering of electrons in an intense laser pulse [1]. We find agreement at the percentage level between the photon spectra, as well as between the models' predictions of absorption from the background field, for normalized amplitudes $a_0 > 5$. The error is largest for low- to moderate-energy photons, as their number is overestimated [2] and their angles of emission are underestimated. We discuss how adding the finite beaming of the radiation improves the accuracy of the standard numerical method [3] (see Figure 1), and its relation to recent work that targets interference effects [4, 5].

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[1] T. G. Blackburn, D. Seipt, S. S. Bulanov and M. Marklund. Benchmarking semiclassical approaches to strong-field QED: Nonlinear Compton scattering in intense laser pulses. *Phys. Plasmas* **25**, 083108, 2018.
[2] C. N. Harvey, A. Ilderton and B. King. Testing numerical implementations of strong-field electrodynamics. *Phys. Rev. A* **91**, 013822, 2015.
[3] T. G. Blackburn, D. Seipt, S. S. Bulanov and M. Marklund. Radiation beaming in the quantum regime. arXiv:1904.07745 [physics.plasm-ph]
[4] A. Di Piazza, M. Tamburini, S. Meuren and C. H. Keitel. Implementing nonlinear Compton scattering beyond the local-constant-field approximation. *Phys. Rev. A* **98**, 012134, 2018.
[5] A. Ilderton, B. King and D. Seipt. Extended locally constant field approximation for nonlinear Compton scattering . *Phys. Rev. A* **99**, 042121, 2019.

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Two particle scattering in strong-field QED

A. Ilderton,[1] B. King,[1] A. J. Macleod,[1,*] and S. Tang[1]
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The most commonly studied strong-field QED processes are those with a single initial particle (Nonlinear Compton and Breit Wheeler, trident, etc). However, future experimental efforts will typically involve highly energetic, dense particle bunches in which processes with multiple particles in the initial state become important. We study here strong-field processes in which two seed particles interact together with a high-intensity laser pulse. We derive analytic results for various processes, finding subtle differences between these and those involving only a single seed particle. We also describe the extensions required to the locally-constant field approximation to accommodate two-seed processes in numerical simulations.

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Momentum-dependent effective mass in a rotating electric field

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It is shown that a particle in a rotating electric field acquires an effective mass which depends on its momentum absolute value as well as on its direction with respect to the field plane. The impact of this phenomenon on the non-linear Breit-Wheeler and non-linear Compton processes is investigated. In the first case, the threshold for pair production by a gamma photon in the presence of the field varies according to the photon propagation direction. Furthermore, this effect may be inferred from the harmonics structure of the outcoming pair spectrum. In the second case, the field-induced emission of a photon by an electron bears signatures of the effective mass. Varying the energy of the incoming electron allows for a measurement of the momentum dependence of the effective mass. Two corresponding experimental set-ups are suggested.

Nonlinear Compton scattering of an ultraintense laser pulse in a plasma

Felix Mackenroth[1,2], Naveen Kumar[2], Norman Neitz[2], and Christoph H. Keitel[2]

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[2] *Max-Planck-Institut für Kernphysik*

Laser pulses travelling through a plasma can feature group velocities significantly differing from the speed of light in vacuum. This modifies the well-known Volkov states of an electron inside a strong laser-field from the vacuum case and, consequently, all quantum electrodynamical effects triggered by the electron. Here we present an in-depth study of the basic process of photon emission by an electron scattered from an intense short laser pulse inside a plasma, labelled nonlinear Compton scattering, based on modified Volkov solutions derived from first principles. Consequences of the nonlinear, plasma-dressed laser dispersion on the Compton spectra of emitted photons and implications for high-intensity laser-plasma experiments are pointed out. From a quantitative numerical evaluation we find the plasma to effectively suppress emission of low-frequency photons, whereas the emission of high-frequency photons is enhanced. The emission's angular distribution, on the other hand, is found to remain qualitatively unchanged with respect to the vacuum case.

Ultrafast Polarization of an Electron Beam in an Intense Bi-chromatic Laser Field

Daniel Seipt,[1,*] Dario Del Sorbo,[2] Christopher P. Ridgers,[3] and Alec G. R. Thomas[1]

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Recent high-intensity laser-plasma experiments provided evidence for quantum radiation reaction effects due to hard photon emission. In this talk I will discuss the radiative spin-polarization of the electrons as a manifestation of quantum radiation reaction affecting the spin-dynamics [1, 2]. It is demonstrated that radiative polarization of high-energy electron beams can be achieved in collisions with bi-chromatic laser pulses, by employing both a Boltzmann kinetic approach and a Monte-Carlo algorithm within the quasi-classical approximation of intense field QED [3]. I will present simulations for a near-term experimentally feasible scenario of a 8 GeV electron beam scattering from a 1 PW laser pulse. Aspects of spin dependent radiation reaction are also discussed, with spin polarization leading to a measurable splitting of the energies of spin-up and spin-down electrons.

[1] D. Seipt, D. Del Sorbo, C. P. Ridgers, and A. G. R. Thomas. Theory of Radiative Electron Polarization in Strong Laser Fields. *Phys. Rev. A* **98**, 023417 (2018).
[2] D. Seipt and A. G. R. Thomas. A Frenet-Serret Interpretation of Particle Dynamics in High-Intensity Laser Fields. *Plasma Phys. Control. Fusion* **61**, 074005 (2019).
[3] D. Seipt, D. Del Sorbo, C. P. Ridgers, and A. G. R. Thomas. Ultrafast Polarization of an Electron Beam in an Intense Bi-chromatic Laser Field. arXiv:1904.1203.

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Polarized positron beams via intense two-color laser pulses

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Generation of ultrarelativistic polarized positrons during interaction of an ultrarelativistic electron beam with a counterpropagating two-color petawatt laser pulse is investigated theoretically [1]. Our Monte Carlo simulation based on a semi-classical model [2], incorporates photon emissions and pair productions, using spin-resolved quantum probabilities in the local constant field approximation, and describes the polarization of electrons and positrons for the pair production and photon emission processes, as well as the classical spin precession in-between. The main reason for the polarization is shown to be the spin-asymmetry of the pair production process in strong external fields, combined with the asymmetry of the two-color laser field. Employing a feasible scenario, we show that highly polarized positron beams, with a polarization degree of $\zeta \approx 60\%$, can be produced in a femtosecond time scale, with a small angular divergence, ~ 74 mrad, and high density $\sim 10^{14}$ cm^{-3}. The laser-driven positron source, along with laser wakefield acceleration, may pave the way to small scale facilities for high energy physics studies.

[1] Y.-Y. Chen, P.-L. He, R. Shaisultanov, K. Z. Hatsagortsyan and C. H. Keitel. Polarized positron beams via intense two-color laser pulses. arXiv:1904.04110.

[2] Y.-Y. Chen, J.-X. Li, K. Z. Hatsagortsyan and C. H. Keitel. γ-Ray Beams with Large Orbital Angular Momentum via Nonlinear Compton Scattering with Radiation Reaction. *Phys. Rev. Lett.* **121**, 074801, 2018.

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Exploring QED in laser-plasma experiments

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Today's lasers are now approaching the intensities needed to explore a range of processes which can only be described by the theory of quantum electrodynamics. Key processes that are, in principal, observable with current and near-term laser systems include quantum radiation reaction in the collision of a high-energy electron beam and a high-intensity laser pulse, and the creation of electron-positron pairs through photon-photon collisions.

I will discuss some of the experimental progress that has been made in these areas, the challenges that we face, and the methods we are adopting to overcome them. I will focus on the 2018 experimental results on radiation reaction in laser-electron beam collisions [1, 2] and I will report on the ongoing analysis and prospects of an experiment at the Gemini laser facility in the UK, which aims to observe the Breit-Wheeler process, $\gamma\gamma \rightarrow e^+e^-$, [3] for the first time in a scheme based on that proposed by Pike et al., [4]

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[1] J. M. Cole *et al.,* Experimental Evidence of Radiation Reaction in the Collision of a High-Intensity Laser Pulse with a Laser-Wakefield Accelerated Electron Beam *Phys. Rev. X* **8**, 011020, 2018.

[2] K. Poder *et al.,* Experimental Signatures of the Quantum Nature of Radiation Reaction in the Field of an Ultraintense Laser. *Phys. Rev. X* **8**, 031004, 2018.

[3] G. Breit, and John A. Wheeler, Collision of two light quanta. *Phys. Rev.* **46**, 1087–1091, 1934.

[4] O. .J. Pike, F. MacKenroth, E. G. Hill, and S. .J. Rose, A photon-photon collider in a vacuum hohlraum. *Nature Phot.* **8**, 434–436, 2014.

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Polarized positron beams via intense two-color laser pulses

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Generation of ultrarelativistic polarized positrons during interaction of an ultrarelativistic electron beam with a counterpropagating two-color petawatt laser pulse is investigated theoretically [1]. Our Monte Carlo simulation based on a semi-classical model [2], incorporates photon emissions and pair productions, using spin-resolved quantum probabilities in the local constant field approximation, and describes the polarization of electrons and positrons for the pair production and photon emission processes, as well as the classical spin precession in-between. The main reason for the polarization is shown to be the spin-asymmetry of the pair production process in strong external fields, combined with the asymmetry of the two-color laser field. Employing a feasible scenario, we show that highly polarized positron beams, with a polarization degree of $\zeta \approx 60\%$, can be produced in a femtosecond time scale, with a small angular divergence, ~ 74 mrad, and high density $\sim 10^{14}$ cm^{-3}. The laser-driven positron source, along with laser wakefield acceleration, may pave the way to small scale facilities for high energy physics studies.

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Experimental Approach for strong field QED processes with a multi-PW Laser

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Compton scattering between an ultrarelativistic electron beam with an ultrahigh intensity laser can offer an opportunity to explore strong field QED effects. At the Center for Relativistic Laser Science (CoReLS) of Institute for Basic Science we have developed a 20 fs, 4 PW Ti:Sapphire laser by upgrading one of two PW laser beamlines [1] and operated the multi-PW laser for the investigations of strong field physics since 2017. We recently achieved a laser intensity of 5×10^{22} W/cm^2 by focusing a wavefront-controlled 3 PW laser pulse with an f/1.6 off-axis parabolic mirror [2]. In the Compton backscattering between a GeV electron beam with an ultrahigh intensity laser, the energy is transferred from a relativistic electron to a laser photon, converting the low energy laser photon into a gamma ray, which offers an oppotunity to observe strong field QED processes, such as nonlinear Compton scattering, radiation reaction, and pair production. At CoReLS the production of GeV electrons using the laser wakefield acceleration (LWFA) scheme has been studied with its PW lasers. Using a dual gas jet target the generation of multi-GeV electron beams was successfully demonstrated [3]. By controlling the LWFA process with chirped PW laser pulses, stable 2 GeV electron beams were produced from a 1-cm He gas cell when driven with positively chirped laser pulses [4]. In addition, the generation of high charge multi-GeV electron beams from a He gas cell with the multi-PW laser has been tested by implementing an ionization injection scheme. We are preparing for nonlinear Compton scattering experiments from the interaction of a GeV electron beam and a PW laser. The radiation reaction effect in the quantum regime will be also examined in the interaction. Furthermore, we plan to exploit the Breit-Wheeler pair production from the interaction of Compton gamma-rays and photons of an ultrahigh intensity laser. The experimental exploration of nonlinear Compton scattering using a multi-PW laser will thus allow the opportunity to investigate QED effects in photon-particle and photon-photon interactions.

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High intensity lasers and high field program at ELI Beamlines

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In this talk we will be discussing the actual status of the ELI Beamline facilities including the first user actions started recently using different lasers.
Actually two laser sources are being used for experimental commissioning. The L1 laser a 1 kHz and 50 mJ with 15fs pulse duration and a contrast exceeding 10^{11} and the L3 HAPLS (High Power PW Laser System) with 1 PW, 10 Hz capabilities.
The L4 -10 PW laser has delivered over 1.5 kJ of energy in full CPA mode and it the compressor is actually assembled and prepared for 10 PW operation (150fs, 1.5 kJ) at enhanced repetition rates of up 1 shot per minute. L4 will also be able to provide enhanced repetition rate amplified shaped ns pulses for shock compression investigations at 1.5 kJ level having a PW level laser beamline synchronized with it.
The high intensity interaction commissioning experiments include particle acceleration of protons and electrons as well as neutron generation and first high intensity plasma Physics experiments. The actual lay- out of different experimental areas will be described including the possibility to do high intensity laser collision experiments with laser wake-field accelerated electrons allowing to enter nonlinear QED regimes of interaction. The high intensity research program and user opportunities will be described.

Simulations of strong field-matter interactions

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Strong field physics, in particular associated with lasers, has led to a number of interesting applications, such as compact radiation and electron sources. The interaction between analytics, simulations, and experiments has led to the successful development of new and powerful codes, and these are utilized on a daily basis for developing new experiments, investigating currently inaccessible experimental domains, and interpreting experimental data. A brief overview of such simulations tools, and their foundations, will be given in this talk. Moreover, we are currently approaching field strengths where we have less control on the error bounds on some of our analytical calculations. Since this is a basis also for our numerical tools, with consequences for experimental design and interpretation, I will try to discuss some of the upcoming possibilities and challenges.

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Recent developments around the Apollon laser & SMILEI projects

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The Apollon laser [1, 2] is now operational at the 1PW level (30J in 20fs). An ongoing upgrade will allow to reach the multi-PW level in the months to come, and the first experiments are about to start. In this talk, I will briefly review the latest advances on the Apollon laser as well as the first, forthcoming experiments. I will then present the latest developments made in the open-source, collaborative PIC code SMILEI [3]. There, I will focus on recent developments of a dynamic/adaptive vectorization strategy [4] to address the latest supercomputer architectures, as well as on the QED modules that have been developed in SMILEI to address strong field physics processes. A particular attention will be paid to the merging algorithm that has been implemented, and builds up on the merging approach initially proposed by Vranic & Grismayer [5]. I will present both, the code developments and recent advances we have made - both on the simulation & theory sides - in treating QED cascades in a rotating electric field.

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[3] Derouillat et al., *SMILEI: A collaborative, open-source, multi-purpose particle-in-cell code for plasma simulation*, Computer Physics Communications **222**, 351 (2018)

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Quantum Backreaction in Laser-Driven Plasma

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We will present our new approach [1] for investigating quantum effects in laser-driven plasma. Unlike the modelling strategies underpinning particle-in-cell codes that include the effects of quantum electrodynamics, our new field theory incorporates multi-particle effects from the outset. Our approach is based on the path-integral quantisation of a classical bi-scalar field theory describing the behaviour of a laser pulse propagating through an underdense plasma. Results established in the context of quantum field theory on curved spacetime [2] are used to derive a non-linear, non-local, effective field theory that describes the evolution of the laser-driven plasma due to quantum fluctuations. We will discuss the physical implications of our new theory, and identify parameter regimes in which the quantum fluctuations are expected to play a significant role.

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Numerical Modelling of Breit-Wheeler Detection Experiments

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The Breit-Wheeler process is the annihilation of two (linear) or more (nonlinear) photons to produce an electron positron pair. The process is important in explaining astrophysical phenomena, however, very little experimental evidence exists. To date, only a single experiment has directly observed the nonlinear Breit-Wheeler process during a campaign at the Stanford Linear Accelerator Center (SLAC) in 1997 [1]. The linear Breit-Wheeler process on the other hand has never been directly observed in the laboratory.

With the advancement of ultra-high intensity laser technology, interest in carrying out Breit-Wheeler detection experiments has increased. However, using current laser facilities, these experiments are expected to have a low signal to noise ratio. Therefore, detailed numerical modelling is vital for both pre-experiment optimisation and post-experiment inference.

In this talk I will present the development of a new QED process package which has been integrated into the code Geant4. This allows signal to noise ratio calculations of laser based QED experiments to be preformed within a single framework. I will also discuss how machine learning techniques can be used to improve the efficiency of these calculations.

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Enhanced gamma-ray emission in structured targets irradiated by counter-propagating laser pulses

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Previous simulation research by our group has shown that an over-dense channel target irradiated by a PW-class high-intensity laser pulse ($I \approx 5 \times 10^{22}$ W/cm^2) is an efficient source of collimated multi-MeV gamma-ray beams [1]. We have performed an incident power and channel density scan and found that the conversion efficiency of the laser energy into a beam of gamma-rays (5° opening angle) can be significantly increased without increasing the laser intensity by utilizing channels with an optimal density [2]. The conversion efficiency into multi-MeV photons increases roughly linearly with the incident laser power P, as we increase P from 1 PW to 4 PW while keeping the laser peak intensity fixed at 5×10^{22} W/cm^2. The increase in closely connected to enhanced direct laser acceleration assisted by a strong laser-driven magnetic field [3].

The newly-constructed laser facilities, such as ELI Beamlines, will enable experiments not only at high incident power, but also with multiple laser pulses instead of just one. Motivated by this experimental capability, we have considered a setup where a structured target with an embedded relativistically transparent channel is irradiated by two counter-propagating laser pulses. Using 2D particle-in-cell simulations, we found that the laser energy conversion rate into multi-MeV photons is significantly increased due to head-on collision between laser-accelerated electrons and a counter-propagating laser. Such increase is notable even when the lasers are injected with inclined angles of up to 8 degrees. This setup allows us to achieve remarkably high values of the quantum parameter $\chi_e > 1.0$ at only $I \approx 5 \times 10^{22}$ W/cm^2, so it can serve as a platform for studies of the quantum radiation reaction.

The photon emission in our setup has a distinctive feature: it occurs in a static magnetic field with a strong gradient. We have examined that applicability of the Monte Carlo method for photon generation that uses the synchrotron cross-section in a constant magnetic field [4] and found that the magnetic field gradient can have an unexpected effect on the emitted photon spectrum. An analytical calculation employing the retarded potential shows that the photon spectrum can be significantly enhanced due to a strong magnetic field gradient for certain observation angles. The impacted part of the spectrum is below the critical frequency.

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Direct laser acceleration in radiation-dominated regime

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In the interaction of an intense laser pulse with an underdense plasma channel, electrons can be accelerated to very high energies due to the betatron resonance. The acceleration in this setup strongly depends on the laser pulse and plasma channel parameters, as well as on the local initial conditions.

We studied the direct laser acceleration within a plasma channel using the parameters of the upcoming generation of 10 PW-class lasers, i.e. in the regime where radiation reaction comes into play and significantly alters the electron dynamics. Radiation reaction can be beneficial for the acceleration process, as it allows for radiative electron trapping and changes the onset of betatron resonance at very high laser intensities. However, it also gives an upper bound for the maximum attainable electron energy. We show that even with radiation reaction, it is still possible to obtain multi-GeV electrons in a single-stage acceleration within a 0.5 mm-long channel provided that the optimal initial conditions are satisfied. We present those conditions in a form of explicit analytical scaling laws that can be applied to guide the future electron acceleration experiments.

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Radiation Induced Acceleration of Ions

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Most of the proposed mechanisms for laser ion acceleration are based on irradiating overdense targets [1] and imply that increase of ions energy requires the respectively high laser intensity. If the latter is high enough, the impact of the radiation friction (RF) on electron motion may become substantial [2]. This may result in a stronger dragging of the electrons and thus in an essential enhancement of a charge separating field driving the ion acceleration [3, 4]. However, in the previous simulations (see, e.g., [5]) taking RF into account led to quite minor corrections to the ions spectra. It was natural, as a strong laser pulse could not penetrate deeply into an opaque target, hence only a minority of the electrons could ever probe a strong field region to experience the RF force.

Here we consider laser ion acceleration in a transparent thin foil demonstrating that in such a case RF can indeed crucially change the plasma dynamics strongly enhancing the ion acceleration. We develop an analytical model, derive the ion energy scalings and validate them by extensive 1D and 2D PIC simulations, see Fig. 1. Finally, the transition from classical to quantum regime of RF in such a setup is discussed.

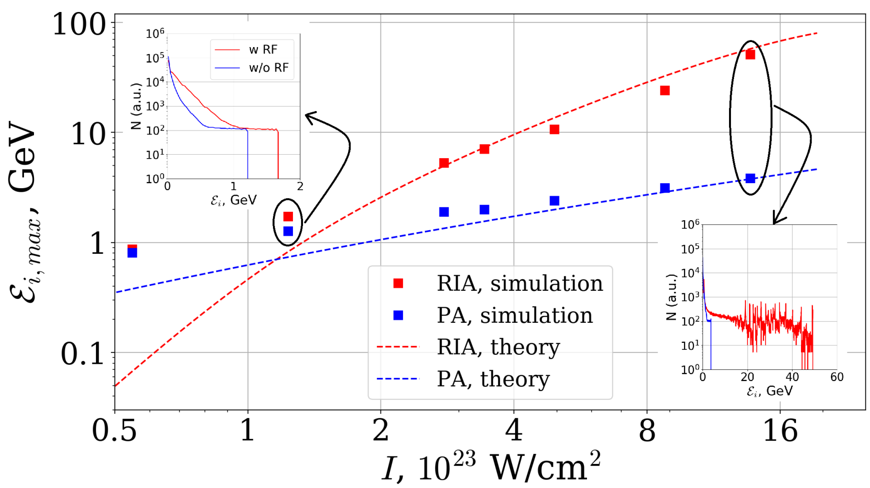

FIG. 1. Maximal ion energy (insets: ion spectra) at $t = 3$ps vs laser intensity (linear polarization) from 1D simulation with (RIA) and without (PA) RF taken into account. FWHM pulse duration 30 fs, foil density $n_0 = 5n_c$ and thickness $d = \lambda = 1\mu$m.

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Testing radiation reaction by means of GeV $e^{\pm}$ in crystals

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In the restframe of a GeV electron, the electric field $\mathcal{E} \simeq 10^{11} - 10^{13}$ V/m (depending on orientation and material) inside a single crystal reaches a magnitude of the order of the QED critical field $\mathcal{E}_0 = m^2c^3/\hbar e \simeq 1.32 \times 10^{18}$ V/m [1]. The quantum nonlinearity/strong field parameter χ for the crystal case becomes $\chi \simeq \gamma\mathcal{E}/\mathcal{E}_0$, where γ is the Lorentz factor. In the past, NA63 (and NA43) has used crystals providing values of $0.01 \lesssim \chi \lesssim 7$ to investigate, for example, quantum corrections to synchrotron radiation [2], pair- and trident creation [3, 4] and the rôle of spin in strong field radiation processes [5]. Following the realization that radiation reaction would be possible to address by means of crystals [6], NA63 launched a series of experiments on this starting with [7].

If the radiation reaction is to be treated classically in a perturbation approach, as e.g. used to derive the Landau-Lifshitz equation, then $\chi\alpha \ll 1$, with $\alpha = e^2/\hbar c \simeq 1/137$ and the ratio of damping force to external force is given by $\eta = \gamma\chi\alpha$ [8, p. 212]. For experimental investigations of radiation reaction approaching the classical regime, i.e. for $\chi \ll 1$, it is thus necessary to have large Lorentz-factors, $\gamma \gg 1$ for the magnitude of the radiation dampening force to be appreciable in comparison with the Lorentz force.

In the framework of the CERN NA63 experiment we have used $\gamma \simeq 10^5$ electrons and positrons in diamond and silicon crystals to address the phenomenon of radiation reaction.

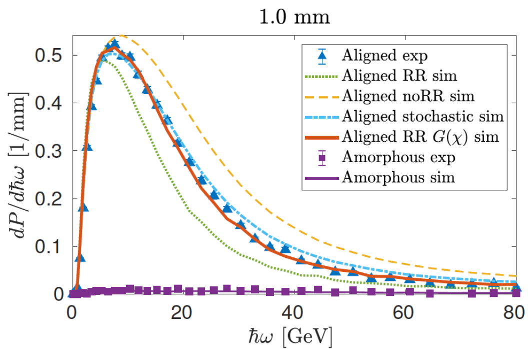

FIG. 1. An example of the emission spectrum comparison between data and theories for 80 GeV electrons penetrating a 1 mm thick diamond crystal aligned with angles 2–4 times the critical (Lindhard) angle to the ⟨100⟩ axis.

In Figure 1 is shown an example of measurements performed at CERN in 2018 [9], compared to models including and excluding the radiation reaction, as will be specified in the presentation.

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Quantum radiation reaction beyond the local constant field approximation

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When an electron or positron hits a crystal target with a small angle of incidence with respect to a crystal axis or plane, it experiences a strong electromagnetic field. If the particle energy is high enough, one can reach the QED critical (Schwinger) field $E_{\rm cr} = m^2c^3/(\hbar e) \approx 1.3 \times 10^{18}$ V/m in the rest frame of the particle. Quantum radiation reaction is the emission of multiple photons in this regime. In [1] we investigated this using a positron beam with 180 GeV directed along crystalline axis. The radiation emission process could then be approximated as if taking place in a constant field, in each moment of time, often called the local constant field approximation (LCFA). While this approximation was decent, we also saw that for low energies of emitted photons, the approximation was not great. With this in mind, a new theoretical model based on a semiclassical approach for calculating radiation emission in the quantum regime beyond the use of the LCFA was devised. We have shown how the semiclassical approach under the circumstances of the experiment produces the correct spectra for channeling radiation [2, 3]. In 2017 an experiment was carried out at the CERN H4 beamline with 50 GeV positrons entering the crystal along a crystalline plane, which is a regime where quantum effects are still significant, but which is more sensitive to deviations from the LCFA. We measured 5 different settings of crystal thickness and particle beam parameters, and compare the experimentally measured photon emission spectra to the LCFA model, and the new theoretical model, which we denote the quantum stochastic model (QSM). In figure (1) one of the measurements is shown. It is seen that the new approach is in convincing agreement with the data, while the LCFA is in disagreement [4].

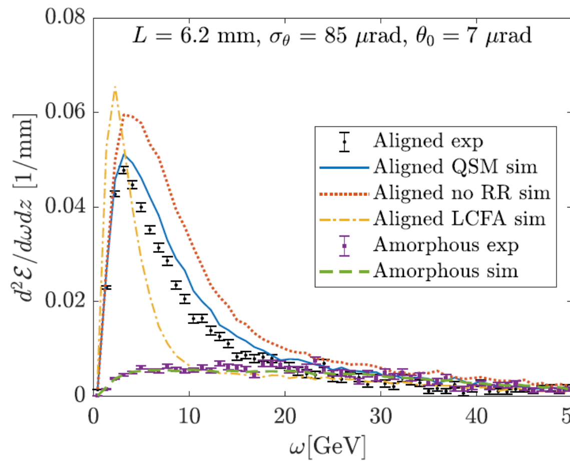

FIG. 1. A figure with the experimental data compared to the different theoretical models for one of the crystal thicknesses.

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Extreme Fields and Lasers for Elementary Particle Physics

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The future of elementary particle physics is uncertain, but many of the possibilities for future facilities now being discussed involve high-power lasers and extreme electromagnetic fields. In this talk, I will review the various aspects of this subject. I will begin with a discussion of the goals of particle accelerators for the next generation beyond the facilities now under discussion. I will then briefly review the physics of high-energy e+e- bunch collisions, including "beamstrahlung" and high-energy photon radiation. Following this, I will discuss laser-driven accelerators and extremely high-energy photon-photon collisions.

Concept for a Fully Non-perturbative QED Collider

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Bright γ rays source and nonlinear Breit-Wheeler pairs in the collision of high density particle beams

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The emission of beamstrahlung radiation and the consequent creation of electron-positron pairs is known to occur at the interaction point of particle colliders. Until now, these two effects have been regarded as detrimental in experiments as they reduce the available energy for the target collisions and produce background noise on detectors.

On the contrary, we envisage a novel potential for these detrimental effects to produce energetic radiation and to probe quantum electrodynamics beyond the state of the art experiments [1].

We consider tightly focused and compressed beams (spot size $\sim \mu$m, and current $\sim 100s$ of kA), thus of high collective field $100s$ of MGauss, at moderate energy $10s$ of GeV. Such beams can collide in the quantum regime, where the electromagnetic field measured in one beam frame of reference approaches the Schwinger limit $\eta = E^*/E_{\text{Schwinger}} \sim 1$. In this regime up to 10% of the beam energy is converted in highly collimated γ-rays (peak brilliance $\sim 10^{26}$ ph/s mm^2 mrad^2 0.1%BW) which on their turn decay producing up to 10^5 electron-positron pairs, in the same beam collective field. Our estimates are confirmed by full scale self-consistent QED-PIC simulations performed with QED-OSIRIS [2] and exceed by few orders of magnitude the predictions of previous works [3].

Our results show that beamstrahlung radiation provides a highly collimated γ rays source with unprecedented brilliance. Furthermore, the high yield of nonlinear Breit-Wheeler pairs suggests beam-beam collisions as viable alternative to beam-laser setups for studying QED effects close to the Schwinger limit.

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Probing electron-positron QED cascades in the collision of tightly focused lepton beams

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Recently, there has been a significant effort in assessing the possibility to study QED pair cascades in the laboratory by using ultra-intense laser fields [1, 2]. We will show that the collision of tightly focused 10 GeV-class electron-positron beams can also be used to study QED cascades in the laboratory and benchmark theoretical and numerical models. In the moderate disruptive regime ($0.5 < D < 5$), the beams can be strongly compressed during their interaction, leading to very large magnetic field amplification (up to ~ 100 times) and to a QED cascade that reaches a multiplicity of 10. We will present a detailed QED-PIC study of the beam-beam cascades. Furthermore, we will show analytically that in the beam-beam case, the cascade rate is faster than exponential, and will compare this model with the numerical results, showing overall good agreement.

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Very Large Power density and High Field QED with X-ray FELs

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We review and discuss the possibility offered by X-ray free electron lasers (FELs) to reach power density in the range of 10^21 nto 10^23 W/cm^2 in the laboratory and the applications to the study of High Field QED , sscattering the radiation on a highly relativistic electron beam coexisting with the FEL, in experiments on radiation reaction, electron positron pairs production. We consider also the possibility of studying high field photon-photon scattering.

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The LUXE Experiment: probing strong-field QED at the EU.XFEL

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We present the LUXE experiment which plans on using the European XFEL electron beam in Hamburg, Germany, with an energy of $14 - 17.5$ GeV and a high intensity optical laser to study non-perturbative QED phenomena. The main focus of the experiment will be the measurement of the rate of laser assisted electron-positron pair production in collisions of high energy photons with an intense laser beam (the non-linear Breit-Wheeler process), and non-linear Compton scattering in electron-laser interaction. It is envisaged to use a strongly focussed optical laser with an intensity of up to 2×10^{20} W/cm^2, so that values of $a_0 = \xi \lesssim 7$ will be reached for the intensity parameter, and for the polarizability parameter $\chi \lesssim 1.4$ are expected. The design of the experimental setup, detector systems requirements and simulation results will be presented and discussed.

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Probing Strong-field QED at FACET-II (SLAC E-320)

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Nonperturbative QED effects associated with the so-called critical (Schwinger) field will be explored at SLAC by colliding the $7-13\,\text{GeV}$ FACET-II electron beam with $10\,\text{TW}$-class laser pulses [1, 2]. More precisely, the quantum parameter $\chi = E^*/E_{\text{cr}}$ will become of order unity in those collisions. It measures the magnitude of the electromagnetic field E^* in the electron rest frame in units of $E_{\text{cr}} = m^2c^3/(\hbar e) \approx 1.3\times 10^{18}\,\text{V/m}$. In the regime $\chi \gtrsim 1$ the QED vacuum becomes unstable with respect to electron-positron pair production and photon emission disrupts classical trajectories [3].

The first experiment which probed nonlinear effects in electron-laser collisions was the seminal SLAC E-144 [4–6]. In comparison with E-144 the upcoming E-320 will probe nonlinear Compton scattering and electron-positron pair production in the so-called tunneling regime, where the inverse Keldysh parameter $a_0 = eE/(m\omega c)$ is large (E and ω denote the peak field strength and central angular frequency of the laser, respectively). Already with the baseline design ($\chi \sim 1$, $a_0 \gg 1$) E-320 will be able to observe vacuum breakdown in locally constant fields, highly nonperturbative Compton scattering, the breakdown of the so-called local-constant field approximation (LCFA) used in numerical codes, and clear signatures of quantum radiation reaction, e.g., stochasticity and thus a breakdown of the classical Landau-Lifshitz (LL) description [1].

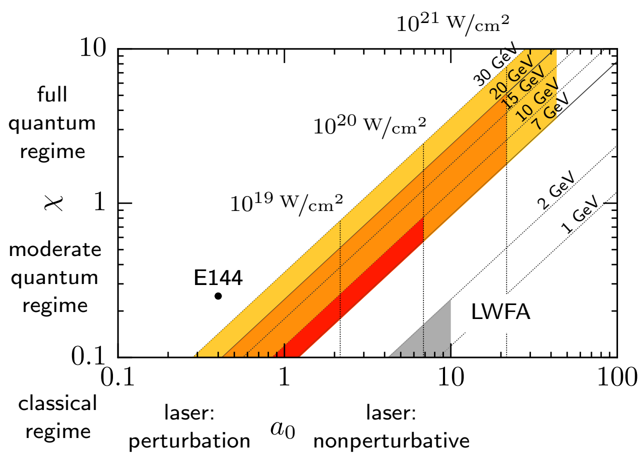

FIG. 1. Parameters which are, in principle, achievable at SLAC/FACET-II. Electron energies $20-30\,\text{GeV}$ are obtainable either by combining two thirds of the SLAC linac or by employing a PWFA afterburner at FACET-II.

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Cosmic Laboratories

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Observations of cosmic sources frequently exhibit physics under conditions that are quite extreme in relation to what could ever be explored in a terrestrial laboratory. Understanding these sources can require, applying secure physics in new locales, attempting to infer completely new and, otherwise, unknowable, physics from astronomical and cosmological measurements and planning to connect future observations with future experiments. Examples of all three types of investigation will be given drawing on: Ultra High Energy Cosmic Rays, Early Universe Cosmology, Active Galactic Nuclei, Gamma-Ray Bursts/Repeaters and Fast Radio Bursts.

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Magnetic Energy Release in Magnetars

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Observations of magnetars show that their stored magnetic energy is capable of getting out of the neutron star, dissipating in its magnetosphere, and producing explosions. Most spectacular events are X-ray bursts and giant gamma-ray flares that release up to 10^{46} erg in a fraction of a second, generating enormous heat density and electron-positron plasma. Dissipation results from magnetic reconnection and turbulence cascades; recent MHD simulations show how these processes can operate in magnetars. However, the dissipation picture on a microscopic level is not established, and current efforts aim at understanding the plasma kinetics in ultra-strong magnetic fields. Besides injecting heat and pair plasma in the magnetosphere, giant flares also launch ultra-relativistic blast waves into the magnetar wind. These blast waves may produce the recently discovered cosmological Fast Radio Bursts.

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Self-consistent Global Simulations of Pair Discharge in Neutron Star Magnetospheres

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Neutron stars are surrounded by dense magnetospheres with nontrivial magnetic field structure. They are sources of multi-band emission from radio waves to very high energy gamma-rays. Their ultra strong magnetic field and rapid spin make it easy to create $e^{\pm}$ pairs through nonlinear QED effects. The structure of the magnetosphere, the mechanism of pair production and particle acceleration in the magnetosphere, and how magnetic energy is converted to kinetic energy is a complex problem that only recently has started to be addressed fully from first principles simulations. In this talk I will describe how global Particle-in-Cell (PIC) simulations have been used to help us better understand the magnetosphere of neutron stars. In particular, I will show how rotation-powered pulsars self-consistently supply the plasma in the magnetosphere through the QED pair creation process. I will also show how this process can dissipate energy in the twisted magnetosphere of magnetars, producing the observed X-ray emission.

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All-optical probes of vacuum polarization effects

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In this talk, I focus on the vacuum of quantum electrodynamics (QED) and discuss the status and perspectives of all-optical probes of quantum vacuum nonlinearities. I in particular argue that, due to our quantitative theoretical understanding of the underlying fundamental physics processes in the parameter regime accessible by state-of-the-art and near-future high-intensity laser facilities, all-optical probes have the potential to allow for precision probes of vacuum polarization effects. After recalling the theoretical concepts their study is based on, I review prominent all-optical probes discussed in the literature. In a next step, I detail our recent activities aiming at providing solid, quantitative predictions for precision experiments of QED vacuum nonlinearities at the high-intensity frontier.

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Cherenkov Radiation from the Quantum Vacuum

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A charged particle moving through a medium emits Cherenkov radiation when its velocity exceeds the phase velocity of light in that medium. In vacuum, light is usually assumed to move at the universal speed c, and causality arguments appear to preclude Cherenkov radiation. However, under the influence of strong electric and magnetic fields, quantum fluctuations can become polarised, turning the vacuum into an exotic medium with a pair of anisotropic refractive indices. This allows sufficiently energetic particles to emit Cherenkov radiation even when travelling in vacuum [1].

In this talk we discuss the physical origins of Vacuum Cherenkov Radiation (VCR), and how its properties can be determined. We consider astrophysical situations where VCR can dominate over other radiation mechanisms, and explore prospects for studying it with high power lasers.

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Born–Infeld electromagnetic shock waves in the Quantum Vacuum

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We investigate two counter-propagating electromagnetic waves in the vacuum within the framework of the Born-Infeld theory [1] in quantum electrodynamics. We obtain a new solution for electromagnetic shocks in Born–Infeld vacuum and investigate the properties of the solution, the wave steepening and subsequent generation of higher order harmonics and electromagnetic shock wave formation. We derive the non–linear field equations and we demonstrate that they decouple in general and can be solved exactly. We solve the non–linear field equations assuming the solution in a form of a Riemann wave. We compare the results in Born–Infeld theory to the previous results obtained in the Heisenberg–Euler approximation [2, 3]. We discuss whether the two theories, Born–Infeld and the Heisenberg-Euler formalism, can be distinguished in an experiment [4].

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Precision measurements of the quantum vacuum at the petawatt level

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Petawatt-class lasers of short duration supporting rep rates of order 1 Hz are propelling us closer to the threshold for a host of novel investigations. Measuring the coupling constant for the Lagrangian responsible for the lowest order, nonlinear 4-photon processes is one example, which, for example, will allow new fundamental tests of quantum electrodynamics (QED). Mediating nonlinear photon-photon scattering with ultra-intense fields will complement ongoing measurements of vacuum birefriengence in strong magnetic fields (e.g., [1]). While the birefriengence investigations do not yet have the sensitivity to resolve the Euler-Heisenberg, so-called QED, prediction, Fig. 1 shows that a 100 PW pulse should be sufficient to distinguish the QED coupling constant from that of the Born-Infield, as well as other models based on modification of the Standard Model of particle physics. The sensitivity scales as the square root of the number of shots – 10^4 shots at 1 PW puts one in the parameter space of a single 100 PW shot. Colocating petawatt lasers with a high-energy linac will extend the field of research to the non-perturbative regime of strong-field QED.

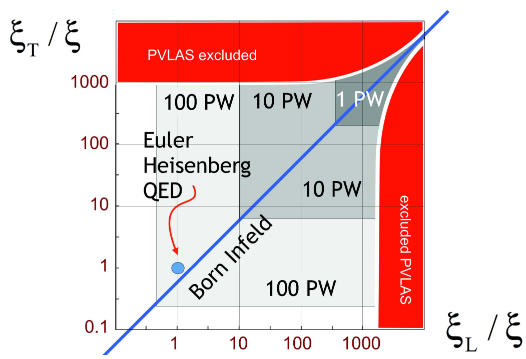

FIG. 1. Single-shot sensitivity parameter spaced normalized to the QED prediction, $\xi_L/\xi_T = 1$ (blue point) for the longitudinal (ξ_L) and transverse (ξ_T) coupling constants, taken from [2]. The blue line corresponds to the Born-Infeld theory and the shaded red region is the parameter space excluded by PVLAS 2014 data.

Higher statistics, enabled by acquiring hundreds to thousands of shots per day, will allow new paradigms to be adopted for strong-field experiments with 1 to 10 PW lasers. Specifically, *precision* measurements will be possible, as a function of intensity and other parameters. Precision acquisition will require a means for direct assessment of the pulse in the focus on every shot. Scattering experiments will further require a sufficiently low particle density in the focus to minimize noise from unwanted *real*-particle scattering. The future looks bright, but a number of technical hurdles must be surmounted. In this presentation we will discuss viable techniques for real-time characterization of the pulse as well as creating and monitoring the density of *real* particles in the focal volume. Preliminary experimental results will also be presented.

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Dynamically assisted tunneling: from the Sauter-Schwinger effect to nuclear fusion

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Even tough tunneling is usually taught in the first course on quantum mechanics, our understanding is still far from complete — especially for time-dependent potential barriers, where the tunneling probability can be strongly enhanced. This enhancement mechanism is analyzed for the Sauter-Schwinger effect and it is discussed whether and when it could also apply to nuclear fusion.

Phase-integral Formulation of Dynamically Assisted Schwinger Pair Production

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Dynamically assisted Schwinger pair production refers to the pair production in the combined field of a strong constant or locally constant electric field and a weak oscillating one [1]. The presence of the weak oscillating field enhances pair production so that the requirements on the experimental condition can be substantially lowered. To obtain analytically the pair production rate in such condition, we apply the phase-integral method [2] to the WKB solution of the mode-decomposed Klein-Gordon equation [3]. The resulting formula, expressed as a power series in the strength of the weak field, is consistent at least at lowest orders with the formulas obtained by more complicated formalisms [4, 5]. The enhancement effect is analyzed by using the plots of the production rate including higher-order contributions, and the parameter range for validity is specified.

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Perturbative approach to nonperturbative pair production

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It is very difficult to reach the intensities required for spontaneous, pure Schwinger pair production, but various non-spontaneous pair-production processes can occur at much lower intensities while still sharing the nonperturbative nature of the Schwinger mechanism. One way to enhance the probability is to add a second coherent field, which is weaker but with higher frequency. Previous approaches treated both the strong and the weak field together, either numerically or analytically with WKB or worldline instanton methods. In [1, 2] we showed that it is not only possible but also useful in practice to instead treat the weak field perturbatively. In fact, this allows us to obtain improved analytical approximations. This approach also tells us which frequency components give the dominant contribution, which is important to know for future experiments.

We have recently shown [3] that the same methods can be applied to Schwinger pair production in a background of thermal photons (which replaces the weak, high-frequency field). In the thermal case the expansion parameter is the fine-structure constant. The zeroth order gives pure Schwinger pair production and the higher orders give an exponentially enhanced probability due to the absorption of thermal photons. We have found that the dominant contribution comes already from the second order, i.e. from the absorption of two thermal photons. Apart from recovering the exponential part of the probability, which was previously obtained with very different methods, our approach allows us for the first time to obtain the pre-exponential part. In this case it turns out to be particularly important, because it scales as α^2 and is hence very small, so the exponential enhancement of the probability first has to compensate for the small prefactor before it can give something that is much larger than the zeroth order. So, the "Keldysh" parameter $\gamma = \frac{\text{temperature}}{\text{field strength}}$ has to be larger than what the exponential part alone would suggest. However, our result also shows that for larger γ the probability quite quickly converges to purely perturbative Breit-Wheeler pair production (i.e. by two thermal photons without any electric field). Thus, γ has to be above a threshold for significant enhancement of the probability, but cannot be too large if one wants nonperturbative pair production.

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Spin-states in multiphoton pair production for circularly polarized light

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Photoelectron angular distributions (PAD) are often used in chemistry and atomic physics in order to study, e.g., ionization spectra [1]. We consider multiphoton pair production [2] as the relativistic analogue to atomic ionization. In this context, we expand the concept of PAD to the strong-field QED regime.

We have devoted a recent work [3] to study the photoelectron angular distributions with respect to angular momentum transfer [1] for multiphoton pair production in rotating fields. As it is the angular particle distribution that carries the information regarding the dynamics of the creation process, we could identify the individual contribution of each spin state. To be more specific, we were able to decompose the angular distribution function into a parallel and an anti-parallel contribution based upon the spin alignment of the particle-antiparticle pair under consideration, cf. Fig. 1.

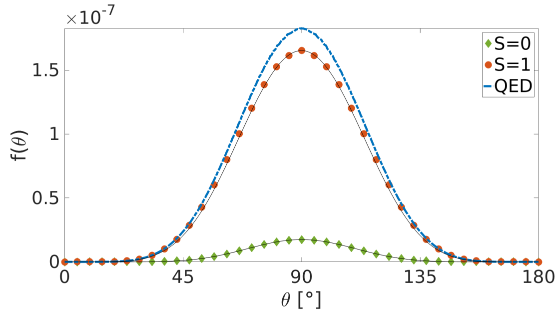

FIG. 1. Photoelectron angular momentum $f(\theta)$ for a 4-photon pair production process as a function of the angle between the fields' propagation direction and the particle's ejection direction. The total yield for electron-positron pair production (dashed blue curve) is given by the sum of a state with parallel spin alignment (orange circles) and a state of orthogonal alignment (green diamonds).

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Spherically-focused Ultrastrong Electromagnetic Field for Electron-Positron Pair Production

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As the peak intensity of the femtosecond high power laser pulse approaches to ~10^{24} W/cm^2 or even higher, much attention has been paid to physical phenomenon, such as light-light scattering and electron-positron pair production, associated with the nonlinear quantum electrodynamics under an ultra-strong electromagnetic field. A fascinating scheme using counter-propagating or multiple laser beams [1] is frequently considered to reduce the required laser power for the nonlinear quantum phenomenon. Although a full description of electric- and magnetic-fields under the 4π-spherical focusing condition has been developed based on the dipole pulse theory [2], it is still interesting to develop mathematical expressions to describe electric- and magnetic-fields based on the diffraction optic theory. Such expressions make it possible to relate the incoming laser power directly to the focused laser intensity and to estimate the focused intensity and its distribution.

In this presentation, we show the mathematical expressions describing electric- and magnetic-field distributions, which are developed through the diffraction optics theory under the 4π-spherical focusing condition. The electric- and magnetic-fields under the 4π-spherical focusing condition are expressed as a superposition of spherical Bessel functions multiplied by Legendre functions. The FWHM volume of the focused intensity is reduced to ~$\lambda^3/20$ under the 4π-spherical focusing condition, and the peak intensity reaches 10^{27} W/cm^2 with a 100 PW laser pulse through the relationship of $E_p = (k/4)\sqrt{2\pi P_L / c\varepsilon_0}$. Here, k is the wavenumber, P_L the laser power, c light speed, and ε_0 the permittivity. The Poincaré invariants and the electron-positron production rate are also derived from the explicit field expressions. The calculation shows that a first event of e-p pair production can be observed when focusing a ~ 36 TW TM mode EM wave reflected by the spherical relativistic flying mirror [3,4].

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Optimal supercritical potentials for the electron-positron pair-creation rate

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We examine the steady-state electron-positron pair-creation rate for supercritical electric potentials with arbitrary spatial dependence. The numerical optimization algorithms predict that the set of external fields that can maximize the production rate for positrons with a given energy take nontrivial spatial shapes. We explain the underlying physical mechanisms based on a simple analytical model that exploits resonances among the negative energy eigenstates of the Dirac Hamiltonian. The results are rather encouraging from an experimental perspective as they suggest that one does not require unachievable infinitely large fields to maximize the possible pair-creation yield. In fact, in many cases smaller electric fields lead surprisingly to larger yields for given energy ranges. This work has been supported by the NSF.

TITLE: Fermionic Schwinger pair creation

Authors: Naser Ahmadiniaz, Sang Pyo Kim, Christian Schubert

Abstract: We extend to the fermionic case some results previously obtained by two of the authors on scalar Schwinger pair creation in a purely time-dependent field. In particular, we show how to generalize the description of the dynamics in terms of the Gelfand-Dikii equation to include spin, and we find a fermionic counterpart to a previously constructed family of "solitonic" fields that can be tuned so as not to pair-create for a given momentum. While spin can often be neglected in Schwinger pair creation, solitonic fields provide an unusual example where pair creation can depend on spin in an essential way.

Building the SFQED community

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Physics of plasmas in extreme fields

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High Intensity Laser Experiments at the BELLA Center

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The Berkeley Laboratory Laser Accelerator (BELLA) Center at LBNL is exploring the physics and applications of laser-driven plasma-based accelerators (LPAs) using the BELLA PW laser (40 J, 35 fs, 1 Hz). Laser-driven plasma-based electron and ion accelerators are capable of generating ultra-high accelerating gradients, several orders of magnitude larger than conventional accelerators. These high gradients offer the potential for extremely compact devices delivering high energy particles. Applications being pursued at the BELLA Center include the long-term development of LPA-based high energy lepton colliders and near-term development of LPA-based light sources and compact LPAs for biology and medicine.

Recent experimental results at the BELLA Center will be presented. This includes the generation of electron beams up to 8 GeV energy gain per stage [1], multistage coupling at low energy, and implementation of an all-plasma-based proton beamline for radiobiology with results from a first study using normal and radioresistant prostate cancer cells at ultra-high (FLASH) dose rates. Also discussed will be improvements to the BELLA PW laser, including implementation of a second beamline for the multi-GeV staging of LPAs and a short focal length beamline for experiments at ultra-high intensity.

The work was supported by the U.S. Department of Energy Office of Science Offices of High Energy Physics and Fusion Energy Sciences, under Contract No. DE-AC02-05CH11231.

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Using Relativistic Flying Mirrors for High Field Science

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Recently, peak intensities of 10^{22} W/cm^2 at KPSI [1, 2] and 5.5×10^{22} W/cm^2 at GIST [3] have been achieved. Higher intensities could be reached with 10 petwatt (PW) [4–6] and future 100 PW [7] lasers. Such laser systems make available regimes of strong radiation damping [8–11] and bright and clean multi-GeV gamma rays for fundamental studies in nuclear and quark-gluon physics [12]. Relativistic flying mirrors (RFM) could be used to realize even higher intensities (see [13] and references cited therein). We have shown that even laser pulses at nearly relativistic intensities can be reflected from the RFM and can generate relativistically upshifted harmonics [14, 15]. Since RFM are generated by ultra-high power lasers propagating in plasma, the combination of the relativistically upshifted light, ultrahigh intensity lasers and high energy electron beams represents a unique platform to perform fundamental physics experiments. We will present the possibilities and prospects for them.

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Plasma Wakefield Acceleration and Extreme Beams at FACET-II

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Discussions at this workshop will highlight the physics opportunities enabled by the combination of high-energy beams and intense laser pulses. FACET-II is a new National User Facility at SLAC National Accelerator Laboratory scheduled to begin operating in 2020. A photoinjector in a configuration similar to that of LCLS will enable FACET-II to investigate acceleration and beam quality preservation utilizing beams with an emittance two-orders of magnitude lower than what was routinely available at FACET. Plasma based experiments will investigate boosting beam energies by 10s of GeV in meter-scale plasmas and generating new classes of beams for future X-ray FELs. The status of the facility and expected initial experimental program will be discussed in the context of ExHILP.

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Relativistic polarized electron generation via plasma wakefield acceleration

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Spin-polarized electron beams are extensively used for spin-dependent high energy physics and material science and lately for spin-dependent dyniamcs at extreme laser intensities. Here we propose a new approach based on wakefield acceleration in plasma for generating high-energy polarized electron beams. We first designed a set-up capable of providing 100% pre-polarized electron targets. We found the restrictions to preserve the electron beam polarization in the pre-polarized plasma for beam-driven wakefield and further proposed to use a vortex laser beam to resolve the depolarization issue of injected electrons in laser-driven wakefield acceleration (see Fig. 1). The theoretical predictions for PWFA and LWFA to generate relativistic polarized electron beams are confirmed in full three-dimensional particle-in-cell simulations incorporating spin dynamics (the Thomas-Bargmann Michel Telegdi equation), where the latter preserves the electron spin polarity by more than 80% at high beam charge and flux. The proposed method releases the limit on beam flux for polarized electron acceleration and promises more than an order of magnitude boost in peak flux, as compared to ordinary Gaussian beams [1]. These results suggest a promising table-top all-optical method to produce energetic polarized electron beams. The possibility of utilizing this approach for spin-dependent phenomina in the strong-field QED regime will also be discussed [2].

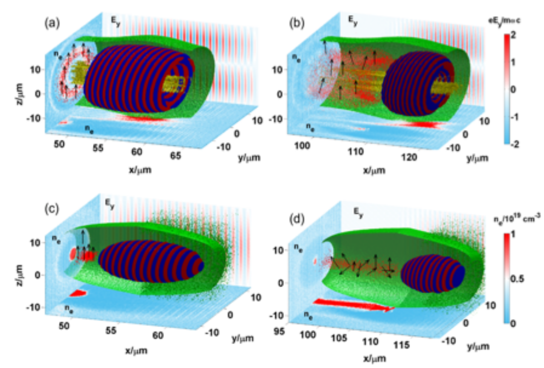

FIG. 1. Electron density and laser field distributions (iso-surface) for the vortex laser (a) & (b) and for the Gaussian laser (c) & (d). The black arrows denote the electron spin directions. Due to the unique vortex structure, the electron spin orientations are well preserved, corresponding to 80% purity of polarzation, which is not possible for the ordinary Gaussian laser beams.

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Frontiers in physics enabled by EP OPAL: a multibeam ultra-intense laser user facility

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Substantial opportunities for breakthrough science are within reach of a proposed laser user facility featuring multiple ultra-intense ($> 10^{23}$ W/cm^2) beamlines, including high-energy and high-energy-density physics, astrophysics, nuclear physics, materials science, and planetary science. Such a facility is currently proposed by using an existing long-pulse beamline of the OMEGA EP laser[1] to pump two optical parametric amplifier lines. Each OPAL beamline is seeded by an ultrabroadband front end, amplified to ∼600 J, and compressed to 20 fs, resulting in a power per beam of 30 PW, three times higher than competing capabilities. The remaining OMEGA EP beamlines are frequency-tripled and delivered to the target chamber for target preconditioning.

We present the results of recent community workshops discussing scientific requirements and research opportunities for this facility in the fields of high-energy-density physics; ultrahigh field science; relativistic plasma physics; nuclear physics; and x-ray, gamma, electron, ion, and neutron sources. Bright, subpicosecond broadband betatron x-ray sources will expand the range of macroscopic (e.g., radiography) and microscopic (extended x-ray absorption fine structure) experiments for dynamically driven materials at atomic pressures. Tunable 10- to 100-keV sources will offer improved time resolution for diffraction measurements of phase-transition kinetics and Thomson-scattering measurements of material state. In the frame of relativistic (GeV-class) electron beams, high-intensity laser pulses will exceed the Schwinger limit and probe particle radiation and reaction physics in the quantum dominated regime.[2] All-optical experiments will perform studies of vacuum birefringence.[3] Intense laser pulses will offer the prospect of prolific electron-positron jet production via a variety of mechanisms to study the physics of gamma-ray bursts and other astrophysical phenomena[4] and lead to the development of trapped pair plasmas for basic research.[5] High energy and control of pulse shape and duration will enable the systematic study of ion acceleration physics, potentially leading to GeV-class proton beams[6] for isochoric heating and bright spallation neutron sources.[7] An overview of the proposed research facility and the scientific requirements to perform this research will be presented. This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0003856, the University of Rochester, and the New York State Energy Research and Development Authority.

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The Computational-QFT Approach in QED Processes with Strong Laser Fields

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The standard QED calculation of the processes in a strong background laser field crucially depends on the exact solution of the Dirac equation in the presence of the field. Unfortunately, to solve the Dirac equation in a general background field exactly and analytically is technically impossible.

In order to overcome this difficulty, we can go from calculating the transition amplitude between different field states to calculating the expectation value of the operator for the corresponding physical quantities. Since all of the operators for physical observables can be expanded in terms of the field operators, the remaining question is to get the time-space dependence of the field operator in the laser field. By numerically solving the single-particle wave equation within the laser, we can obtain the field operator as a function of space and time and then the corresponding physical quantities as well.

As this new method is not only restricted for QED processes and can be used in all QFT calculation, it is called Computational-QFT approach. This approach can also give a full time-space resolution to theQED process in strong fields, which is not possible for the traditional calculations where only the asymptotic behavior at $t \to \pm\infty$ can be described. Besides, this approach is intrinsically non-perturbative, which gives us a new way to study some non-perturbative process like the Schwinger effect.

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Toward BSM physics with lasers: precision modeling and statistical methods for theory-experiment comparison

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June 18, 2019

Abstract

High-intensity laser experiments are expected to create particle beams and achieve energies capable of testing astrophysics, standard model physics and hypotheses beyond in addition to strong-field quantum and classical theory. Discovering new physics, whether quantum radiation corrections or BSM particles, will require greater control of measurements and the ability to use data to quantitatively discriminate between alternative theories. The statistical and phenomenological methods to exclude or discover new processes are thoroughly developed in particle physics, but laser-plasma experiments will also involve irreducible uncertainties in modeling the interaction because of shot-to-shot variation in initial conditions and the impossibility of reconstructing individual events. Therefore, we must also introduce statistical and phenomenological methods to determine parameters of the laser-plasma interaction as precisely as possible. We propose a unified framework to increase the accuracy of models of the laser-plasma interaction and provide error-controlled predictions that allow discriminating between theories of the dynamics. We demonstrate the necessity of this framework by showing how omitted parameters and incomplete measurements admit multiple theory explanations for the same experimental data. We start with an example in the single-particle limit how measured distributions of the scattered particles allow us to constrain unmeasured parameters of the laser and demonstrate how rigorous statistical methods can enable discovery according particle physics standards.

What do we need to discover the Unruh effect in laser experiment?

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July 31, 2019

Abstract

In an effort to understand particle production by black holes, Unruh noticed that a detector undergoing constant acceleration displays a thermal distribution of excitations. Unruh thus suggested an approach to construct laboratory tests of the formulation of quantum theory in curved spacetime. Recognizing the ability of high intensity lasers to achieve the highest accelerations, several groups have proposed laser-based experiments to verify the Unruh effect under controlled conditions. In this talk, I will review the theory and discuss predictions and prospects for discovering the Unruh effect in laser experiments. For example, Chen and Schutzhold suggest looking for radiation on the acceleration axis, where Larmor radiation should vanish identically. I discuss the precision required to discover this or other predicted signals of the Unruh effect in laser experiments.

2D spacetime manifolds, radiation reaction, emergent inertia

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2D manifolds in spacetime are considered as elementary physics entities. They represent an alternative approach to the concept of worldlines. In particular, assuming that spacetime is essentially 2D the concept of radiation reaction derived from it is void of the classical singularities and ambiguities present in a 1D world. Closely linked to the postulated 2D structure of spacetime is the concept of emergent inertia. In addition, radiation reactive Bargman equations can be obtained in the same context. Details are discussed in the presentation.

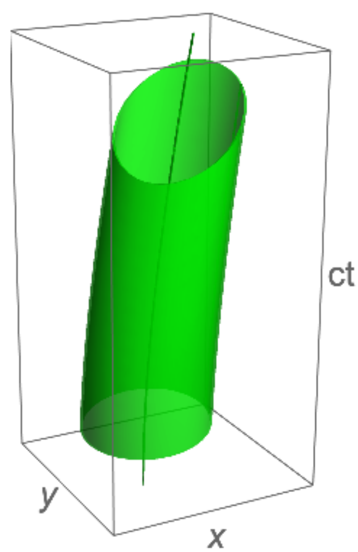

FIG. 1. 2D manifold in spacetime representing elementary physics entities.

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EXHILP 2019

Posters

Towards realistic simulations of QED cascades: Non-ideal laser and electron seeding effects

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QED cascades are complex avalanche processes of hard photon and electron-positron pair creation driven by ultra-strong electromagnetic fields. They play a fundamental role in astrophysical environments such as the magnetosphere of pulsars, rendering an earth-based implementation with intense lasers attractive. A number of analytical and numerical studies has been performed to investigate the onset and development of QED cascades as a function of the laser intensity in the collision of two counter-propagating laser pulses [1]. However, it has been recently demonstrated that the onset of QED cascades is also strongly influenced by the shape of the laser pulses, such as the laser pulse waist radius [2], even at intensities around 10^{26} W/cm^2. Following these earlier findings, in our recent work [3] we have investigated the effect on the onset of QED cascades of: (a) the laser pulse duration, (b) the presence of a relative delay for the peak of the laser pulses to reach the focus, (c) the existence of a mismatch between the laser focal axis of the two laser pulses. This is especially important as, in realistic laboratory conditions, fluctuations may arise in the temporal and point stability of the lasers.

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Radiation reaction and Breit-Wheeler processes in Breakout-Afterburner regime

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Laser-accelerated ion beams have a multitude of applications with a particularly interesting one being hadron therapy, essential for cancer treatment. Breakout-Afterburner (BOA) [1] is one of the high-performance laser-driven-ion acceleration mechanisms capable of accelerating ions to relatively higher values with the same intensities of the laser. In this scenario an initially overdense, ultrathin target (with a width comparable to the laser skindepth) turns transparent to the incoming laser pulse due to lowering of the density by the expanding plasma and increase in the value of critical density by the relativistic motion of the electron (relativistically induced transparency). This leads to a phase of extreme ion acceleration which continues to exist until the electron density of the expanding target becomes classically underdense. Buneman instability between streaming electrons and ions results in electrostatic mode structure, that is found to be instrumental in transferring the laser energy to ions via laser-induced electronic drifts. In relatively thick targets ($\sim 10's$ of microns) where hole-boring and shock acceleration dominate, a reduction in the ion-energy is observed in the ultra-relativistic regime [2]. We show using 2D PIC simulations that in the ultra-relativistic BOA regime with thin targets, radiation reaction and Breit-Wheeler pair production can also improve the acceleration of fully ionized Carbon ions driven by an ultra-intense linearly-polarised laser pulse [3].

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Investigating pair production by the nonlinear Breit-Wheeler process in high intensity laser experiments

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June 2019

One of the most fundamental processes of strong field quantum electrodynamics (QED) involves the interaction of a highly energetic gamma photon with multiple optical photons – typically a high intensity laser field. This process is called the nonlinear Breit Wheeler process and it has been studied for the first time in the SLAC E144 experiment. With the increasing laser power of high power laser systems, experiments can now investigate the non-perturbative and quasi-static regime of this process and test physics models of strong field QED. We developed an experimental setup at the Astra-Gemini Laser at the Rutherford Appleton Laboratory for the investigation of the nonlinear Breit-Wheeler process. In this setup, laser-accelerated electrons of $1\,GeV$ are converted into a gamma-ray beam by bremsstrahlung. The gamma ray beam then interacts with a high intensity laser pulse creating electron positron pairs. The pairs are separated with a magnetic chicane setup which is designed to minimize background events. The pair detection scheme, the background assessment and the operation of single particle detectors are discussed.

The QED four-photon amplitudes off-shell

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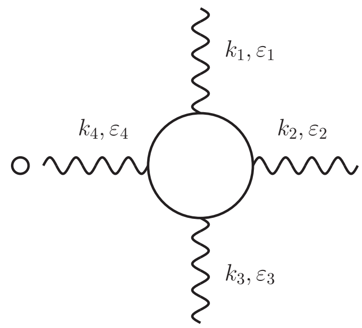

FIG. 1. One-loop four-photon diagram with one low-energy leg (photon with a circle).

The most general case of the QED four-photon amplitude that has been computed, so far, is the one with two photons on-shell and two off-shell [1]. 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 (FIG. 1), unifying the scalar and spinor QED cases. Despite of 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 [2, 3] 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 the one used in [1]. 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 [4]. 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 ${}_2F_1$. As a check on this latter result, we match the special case where $k_1 = k_2$ 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.

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Single Particle Detection System for the Strong-Field QED Experiment at FACET-II

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Predictions of strong-field quantum electrodynamics (SFQED) models have been widely studied [1]. Examples of physical processes studied in the SFQED framework are radiation reaction and electron-positron pair creation (trident and Breit-Wheeler process). Experiments demonstrating SFQED effects have already been performed, for example, the SLAC E-144 [2] and, recently, at the Rutherford Appleton Laboratory [3]. However, the new proposed experiment at FACET-II will explore a regime of interaction where the perturbative treatment of a strong electromagnetic (laser) field breaks down, i.e., the electrons start to interact coherently with many photons.

Here, we present a detection system using fast scintillators and ultra fast gated cameras capable of diagnose and track single positrons hits with reduced background noise for the upcoming SFQED experiment at FACET-II. The detection of single positrons demonstrates that the pair creation effect predicted by the SFQED theory occurred at the point of interaction between the high-energy electron beam (13 GeV) and high-intensity laser ($116.3 \times 10^{18}\,\mathrm{W\,cm^{-2}}$). Moreover, we discuss the spatial resolution and energy range of the proposed detection system.

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Controlling Transverse Instabilities in Light-Sail Ion Acceleration

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In the interaction with an ultra-thin solid-density foil, a super-intense laser pulse can, in principle, transfer almost all of its laser energy to the target ions, hence making it possible to produce dense, energetic (several MeV/u), quasi-monoenergetic ion beams [1]. These aspects make radiation pressure acceleration in the light-sail regime a promising acceleration mechanism for several important applications such as ion beam therapy. However, the onset of Rayleigh-Taylor-like transverse instabilities [2] deform the target, thus deteriorating the quality of the ion spectrum. In this work, we investigate the optimal laser and target parameters that suppress the detrimental effect of transverse instabilities and hence improve the ion spectrum. Simple analytical modeling is supported by multidimensional particle-in-cell simulations.

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The Virtual Axion in the BW Experiment

1 Abstract

A recent experiment on the Gemini laser facility at the Rutherford Appleton Laboratory collided intense beams of high-energy photons (∼500 MeV) with a dense X-ray field (∼1.5 keV) to investigate the final QED process involving photons which has not been directly observed, the Breit-Wheeler process. The BW process has been well studied in QED, so we are exploring how to use the results of these experiments to investigate how processes involving particles beyond the Standard Model, e.g., the axion, affect the expected results. We have calculated the cross-sections of two possible axion-involved processes in the experiment using effective field theory and will discuss how the effective mass value of the axion, the coupling parameter, and the significance of the cross-sections compare with the BW process. We can use these results to predict departures from the expected BW pair-production rate in the experiment and aim to use these and the experimental analysis to exclude some of the axion models.