European XFEL Joint Theory Seminar

Thursday, 28 May 2026, 16:00 – 17:00 CET

European XFEL, Auditorium / Lighthouse (XHV)

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Dark-field Concept for the Measurement of Weak Quantum Vacuum Signals

Modern physics views the vacuum not as the absence of everything, but as a highly non-trivial quantum state characterized by the omnipresence of vacuum fluctuations. It encodes information about the full particle content of the underlying microscopic theory in the form of virtual processes. Because electromagnetic fields couple to charges, vacuum fluctuations of charged particles are predicted to give rise to nonlinear self-couplings of electromagnetic fields. These couplings inherently modify Maxwell's linear theory of classical electrodynamics and — at least in principle — invalidate the superposition principle. At the same time, for the field strengths reached by macroscopic electromagnetic fields currently available in the laboratory the quantum vacuum nonlinearities induced by Standard Model particles are very small, with the leading correction governed by quantum electrodynamics (QED). For these reasons, this fundamental tenet, anticipated 90 years ago in the seminal theoretical work of Heisenberg and Euler [1], has remained experimentally challenging and is yet to be tested in the laboratory.

Because of their brilliance and a favorable frequency scaling X-ray free-electron lasers (XFELs) constitute a particularly promising probe. However, the effect is very small even when probing a tightly focused high-intensity laser field with XFEL radiation. Achieving a sufficiently good signal-to-background separation is key to its first successful detection in a controlled laboratory experiment. To master this challenge, several years ago we have proposed a dark-field detection concept [2] that was later successfully validated in a proof-of-principle experiment at the HED/HIBEF instrument of the European XFEL [3]. In this talk, I will introduce and explain the dark-field concept, provide predictions for the attainable signals and discuss the status and perspectives of this approach for the measurement of light-by-light scattering signals in a dedicated experiment within the BIREF@HIBEF Collaboration [4].

[1] W. Heisenberg, H. Euler, Z. Physik 98,714–732 (1936); [2] F. Karbstein, D. Ullmann, E. A. Mosman, M. Zepf, Phys. Rev. Lett. 129(6), 061802 (2022); [3] M. Šmíd, et al, Phys. Rev. A 112 (6), 063512 (2025); [4] N. Ahmadiniaz, et al., High Power Laser Science and Engineering 13, e7 (2025).

Host: Ruslan Kurta

Virtual participation (via Zoom):

https://xfel.zoom.us/j/63148539246?pwd=gEXX0wUiRNKi49KlvLDqcISVn8O311.1
Meeting ID: 631 4853 9246
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