The DeLLight Project : Slowing down the light in vacuum with intense laser pulses

Ali Aras[1], Adrien E. Kraych[1], Xavier Sarazin[1], François Couchot[1]

[1]IJCLab, Universite Paris-Saclay, CNRS/IN2P3, 91405 Orsay, France
ali.aras@ijclab.in2p3.fr

In classical electrodynamics, Maxwell's equations in vacuum are linear. This implies that the permittivity ϵ_0 and permeability μ_0, thereby the speed of light (c), are universal constants. In contrast, Quantum Electrodynamics (QED) introduces the concept of a dynamic vacuum, where virtual particle-antiparticle pairs are continually created and annihilated. These quantum fluctuations lead to non-linear coupling of electromagnetic fields [1,2], resulting in the decrease of the speed of light in vacuum (i.e. an increase of the vacuum optical refractive index) when vacuum is stressed by intense external electromagnetic fields. The DeLLight (Deflection of Light by Light) experiment [3-5] aims to observe this effect using intense, ultra-short laser pulses provided by the LASERIX facility (2.5 J per pulse, 40 fs, 10 Hz repetition rate) at IJCLab (Paris-Saclay University). The experimental approach involves measuring the refraction of a low-intensity probe laser pulse as it traverses the optical index gradient in the vacuum induced by an external intense pump laser pulse. Considering the deflection in the vacuum is exceedingly small and difficult to measure directly, it is amplified using a Sagnac interferometer. The amplified deflection is then detected in the interfering signal at the dark output.

With a pump pulse energy E = 2.5 J and minimum waist sizes of the probe and pump beams at focus in the interaction area $w_0 = W_0 = 5$ μm, the expected signal is about 15 pm [3]. Given the spatial resolution to define the position of the interference intensity profile $\sigma_y = 15$ nm (corresponding to the ultimate shot noise of available CCD cameras), the expected QED deflection signal can be observed at a 5σ confidence level with about one month of collected data.

In this talk, I will discuss the critical experimental parameters that limit the sensitivity of the interferometer, namely the extinction factor and the spatial resolution, and I will present the performance and sensitivity achieved with the current DeLLight interferometer [4]. Afterward, I will present the results of the first interferometric measurements of light-by-light deflection in air, induced by the non-linear optical Kerr effect, using a low-intensity pump of only a few μJ [5]. These results demonstrate and validate the DeLLight interferometric performance.

Références

1. W. Heisenberg and H. Euler, "Folgerungen aus der diracschen theorie des positrons", Zeitschrift fur Physik 98, 714 (1936).
2. J. Schwinger, On gauge invariance and vacuum polarization, Physical Review 82, 664 (1951).
3. S. Robertson, A. Mailliet, X. Sarazin, F. Couchot, E. Baynard, J. Demailly, M. Pittman, A. Djannati-Ataı, S. Kazamias, and M. Urban, Experiment to observe an optically induced change of the vacuum index, Physical Review A 103, 023524 (2021)
4. A.M. Mailliet et al. "Performance of a Sagnac interferometer to observe vacuum optical nonlinearity", Physical Review A 109, 043526 (2024)
5. A. Kraych et al. "Interferometric measurement of the deflection of light by light in air", Physical Review A 053510 (2024)