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## Measuring vacuum magnetic birefringence with static high-field superconducting magnets

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For many years the PVLAS collaboration has been working on trying to measure vacuum magnetic birefringence using optical techniques. That electrodynamics in vacuum is non-linear was predicted in 1935 [H. Euler and B. Kockel, *Naturwiss.*, 23, 246 (1935)] and the first experimental proposal to detect the leading nonlinear effect, namely vacuum magnetic birefringence closely related to light-by-light elastic scattering, dates back to the early eighties at CERN following an idea by E. Iacopini and E. Zavattini [*Phys. Lett. B*, 85, 151 (1979)]. A lot of progress has been made since but the goal still needs to be reached. Recently Turolla et al. [Monthly Notices of the Royal Astronomical Society, Volume 465, Issue 1, 11 February 2017, Pages 492–500] have indirectly inferred evidence of vacuum magnetic birefringence from the observation of a neutron star and ATLAS has directly observed  $\gamma\text{--}\gamma$  interactions at high energies [*Nature Physics* 13, 852–858 (2017)]. A direct observation at low energies is still lacking.

At present the PVLAS collaboration has reached an experimental value for the relevant parameter  $\frac{\Delta n}{3B^2}$  to be compared with  $A_e$  describing the non linear behaviour of electrodynamics in vacuum of  $\frac{\Delta n^{(PVLAS)}}{3B^2} = (6 \pm 9) \times 10^{-24} \text{ T}^{-2}$  to be compared with the theoretical predicted value of  $A_e = 1.32 \times 10^{-24} \text{ T}^{-2}$ . Although the measured value is approaching the goal it was obtained with an integration of  $5 \times 10^6 \text{ s}$  and is at present limited by wideband noise and not systematic effects. Further integration does not seem to be the best approach.

The sensitivity of the PVLAS apparatus is far from being shot-noise limited with a wideband contribution which still needs to be understood and is under investigation. Past and present experiments using the same, or a similar, approach also suffer from a similar problem. As can be seen in the attached figure the birefringence noise of our and other experiments seems to lay on a power curve and diminishes with frequency.

So the two main ingredients are for an experiment aiming at measuring directly vacuum magnetic birefringence using light are: high modulation frequency of the signal and a high value for the integral  $\int B^2 dl$ . Typical values today are  $\int B^2 dl \approx 10 - 20 \text{ T}^2\text{m}$  at frequencies of the order of tens of Hertz.

Very high values of  $\int B^2 dl \approx 1000 - 5000 \text{ T}^2\text{m}$  can be obtained with accelerator superconducting magnets like the HERA magnets and the ones in LHC. The problem is to modulate the effect at a reasonably high frequency. In the past, rotating the polarisation of the light entering the polarimeter has been proposed by OSQAR but difficulties have been encountered, e.g. mirror birefringence. A new possible technique, published in 2016 [*Eur. Phys. J. C* (2016) 76:294] and still to be tested, proposes the insertion of two synchronously rotating half-wave plates inside the Fabry-Perot cavity (with therefore a relatively low finesse of  $\approx 10^3$ ) each one on either side of the magnetic field so as to have a rotating polarisation *only* in the static magnetic field but *not* on the mirrors of the cavity.

This idea, with its possible drawbacks, will be presented thinking on the lines of using an LHC magnet at CERN.

[Experimental birefringence sensitivities of experiments designed to measure vacuum magnetic birefringence. The continuous line is a fit resulting in a power law  $S_{\Delta n} = f^k$  with  $k = -0.78$ ]. 1

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