Research Matters Sc

Investigating the quantum vacuum: the PVLAS experiment

Quantum Electrodynamics (QED) predicts that if a linearly polarised light beam is propagated through a transverse magnetic field in a vacuum, the light polarisation state will change from linear to elliptical [1]. This effect is identical to the Cotton-Mouton effect in gases; the quantum vacuum behaves like a gas, exhibiting magnetic birefringence. The PVLAS Collaboration at the Legnaro National Laboratory of I.N.F.N, Italy, is trying to measure this physical effect, for the first time, by conducting experimental studies of the quantum vacuum using an optical ellipsometer and an Oxford Instruments 5200 Hall Effect Magnetometer.

The effect can be interpreted as a photon-photon scattering process. It is a crucial test of a QED theoretical prediction, ranking in importance with the classic QED experimental tests, such as the measurement of the Lamb-shift in hydrogen and of the *g-2* factor of leptons. This latest work at PVLAS may also shed light on the production of neutral, near-massless particles resulting from a two-photon interaction (the axion is an example of this class of particles), all of which are candidate constituents of the dark matter known to fill our universe [2,3].

The magnetic birefringence effect in the quantum vacuum is proportional both to the square of the field intensity and to the length of the optical path in the field region. Several technological challenges must therefore be met in the PVLAS apparatus in order to obtain an intense field over the large distances required.

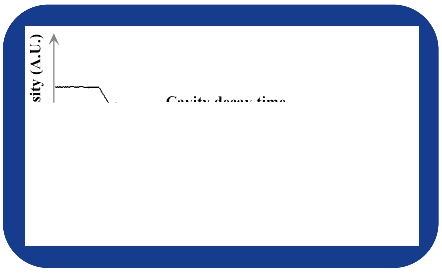

Fig. 1. Decay curve of the light intensity transmitted by the Fabry-Perot resonator when the light input is switched off.

A 1 m long superconducting dipole magnet, designed at CERN for PVLAS and capable of reaching a field of 8.8 T, is placed vertically within a custom designed warm bore cryostat [4]. The optical path is increased by means of a high-finesse Fabry-Perot resonator, which accumulates light within the magnetic region. This resonator is a 6.4 m long cavity based on two high-reflectivity supermirrors, which is held at resonance by an electro-optic feedback loop acting on a Nd:YAG laser, locking its wavelength (1064 nm) to the instantaneous cavity length [5,6].

Figure 1 shows a typical decay curve (time constant 860 μs) obtained when observing the light intensity transmitted by the cavity once the light input is turned off. This results in a finesse of 126,000, a Q factor of 1.6×10^{12}, and a total optical path of 126 km. Even under these conditions, the expected ellipticity is extremely small, of the order of 10^{-11}, and can only be detected by the introduction of a time variation, which enables the application of heterodyne techniques. The required modulation is obtained by rotating the 4000 kg cryostat about its vertical axis on a large turntable, at frequencies up to 1 Hz. During rotation, the superconducting coils are short-circuited so that the magnet operates in persistent current mode. A 9 m high granite tower is built around the rotating cryostat assembly to support the cavity and isolate it mechanically from the turntable, as shown in figure 2.

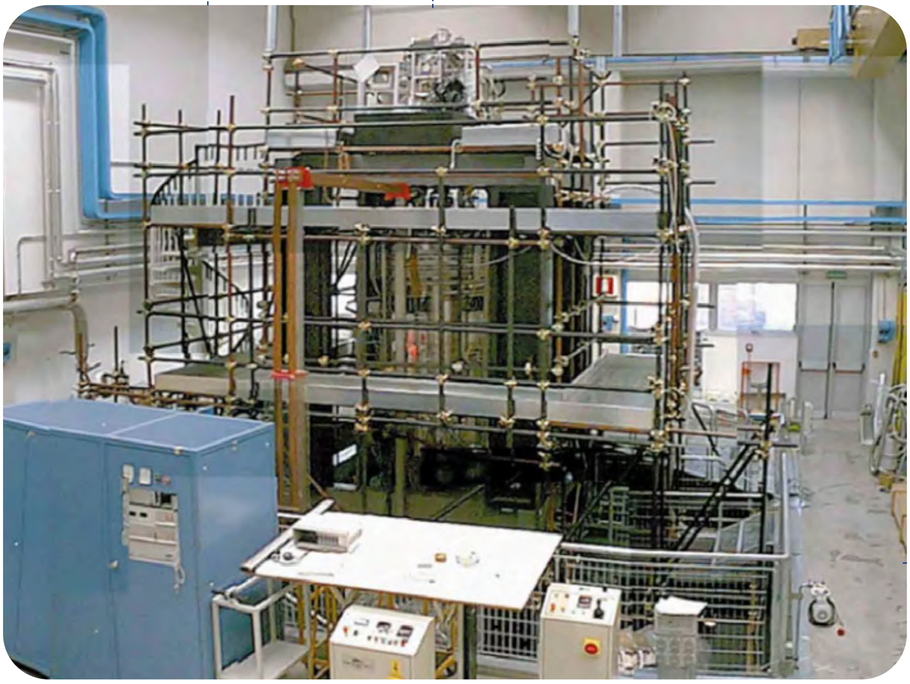

Fig. 2. View of the granite tower supporting the optics. The tower is 9 m high starting from below floor level and the rotating cryostat is visible inside it. The resonator mirrors are located at the bottom and top of the tower.