The OSQAR Experiment at CERN: From Photon Science to sub-eV Particle/Astroparticle Physics

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The OSQAR Experiment at CERN to probe Quantum Electro Dynamic and Astroparticle Physics

1. Measurement of the Vacuum Magnetic Birefringence Effect
2. Search for Axion-like-Particles
3. Experimental Setup
4. Results
5. Conclusions and outlook

OSQAR - Laser-based Particle Physics experiments for :

1st Goal:

* Optical Search of QED vacuum magnetic birefringence

Measurement of the VMB down to the level predicted by QED

A challenge for optical metrology

⇒ superconducting high-field magnet, optical cavity & …

…new results are guaranteed

2st Goal:

* Search for Axions and Axion-like-Particles (ALPs)

Axions and photon Regeneration (OSQAR) - “2-in-1” experiment.

A collaboration between ten European Institutes and CERN.

Measurement of VMD Effect :

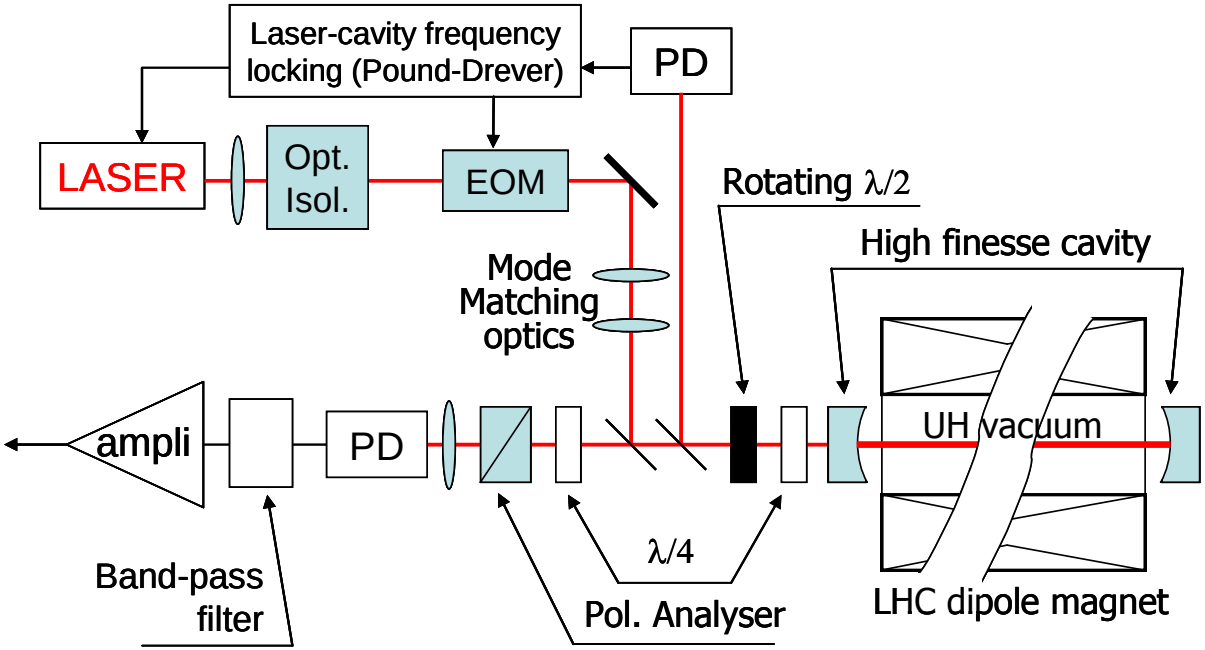
W. Heisenberg and E.Euler (1935): Consequences of Dirac's Theory of the Positron. Prediction of

* ***The Vacuum Magnetic Birefringence (VMB)***
* **The effective Lagrangian for photons in QED has nonlinear terms**
* **VMB from the QED Theory: Euler-Heisenberg Lagrangian,**
  i.e. Taylor expansion of gauge and Lorentz invariants
* **Leads to E^2 and B^2 dependent changes in the tensors of permittivity & permeability of the vacuum**
* **Vacuum magnetic "anomaly" of the refraction index:**

$$\Delta n = 4.0 \times 10\uparrow\text{-}24\ B\uparrow 2$$

Very small effect: 2nd order correction to the Lagrangian, i.e. $O(a^3)$, gives a Δn correction of 1.45% with respect to the dominant term

VMB & Linear Dichroism measurements for Axion Search: *Principle & Proposed Optical Scheme*

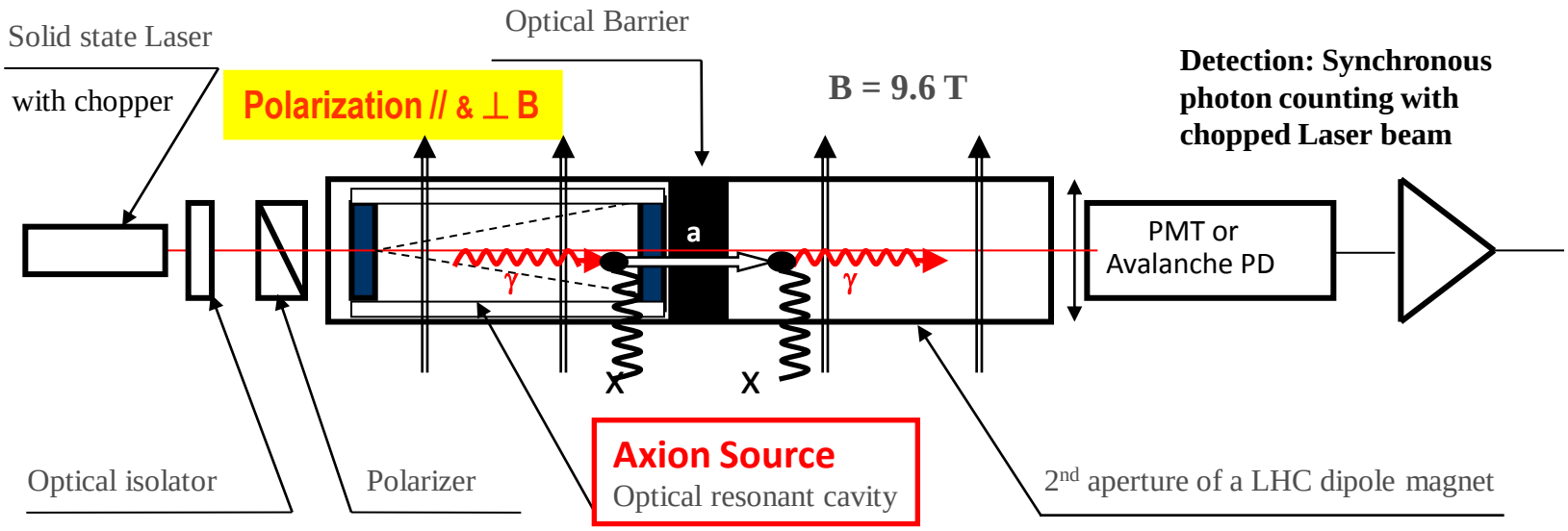


Search for Axion-like-Particles

* Peccei-Quinn solution to the strong CP problem:
**Introduce global anomalous chiral U(1)PQ symmetry, spontaneously broken by the vacuum expectation value of a complex scalar
** Generic prediction for axion coupling and masses
Coupling to photons
** Axion-Like-Particles (ALPs) predicted by many BSM scenarios, e.g. string theory
** Axions with global anomalous PQ symmetries generic in string compactifications
** ALPs are the only non-SUSY candidates for cold dark matter
** Search for AXIONS via "light shining through the wall" experiments
** Linearly polarized laser beam in vacuum along a transverse magnetic field and optical wall in the beam pipe.

Direct Axion/ALP Search Experiment

Photon Regeneration



Nd-YAG laser: Power P = 0.1 – 10
λ = 1064 nm

Optical cavity: F = 10^4-10^5, l = 7 m
Detection part: L = 7 m

Expectations: Improvement / the present reference result of Cameron et al. Phys. Rev. D47 (1993) 3707
~ R x 10^7 with 1 magnet & 100 W

Experimental setup

Different setups for the two OSQAR goals:

1st Goal: VMB measurement setup

2st Goal: Axion search setup

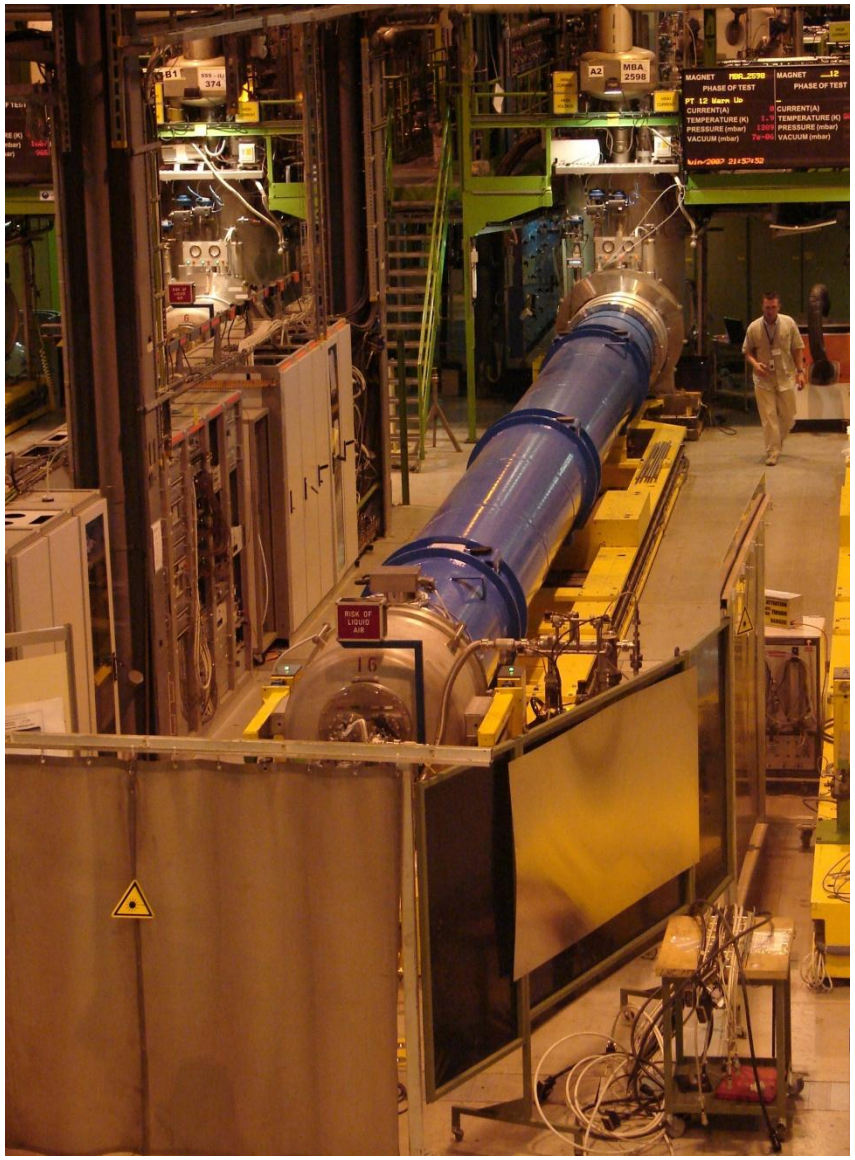
*** Re-use at least 2 benches of the existing test infrastructure for LHC superconducting magnets**

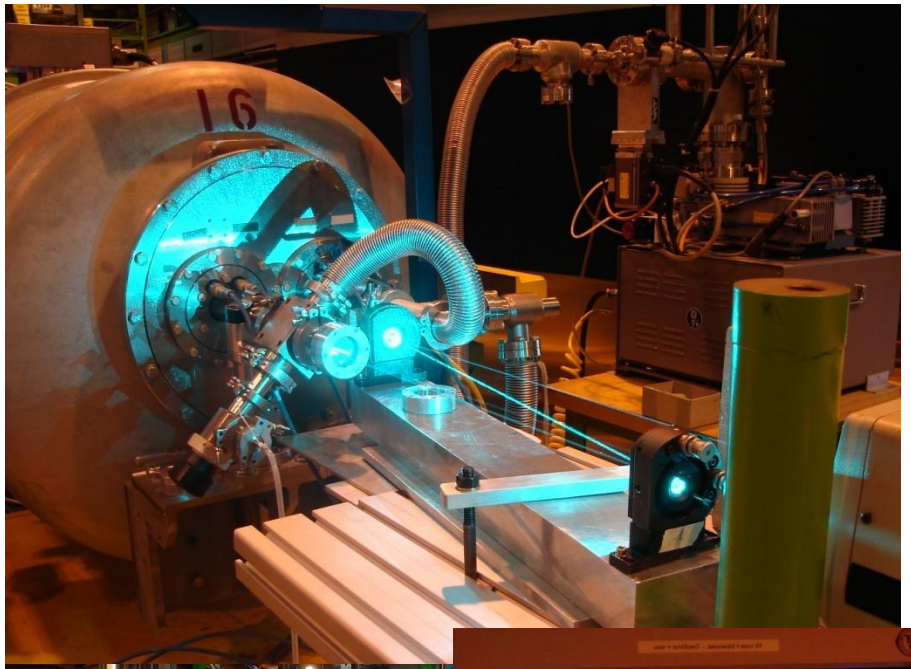
*** Use of Class-4 laser Ar+ (488 & 514 nm)**
R&D with R_{max} output coupler (> 99.55 %)

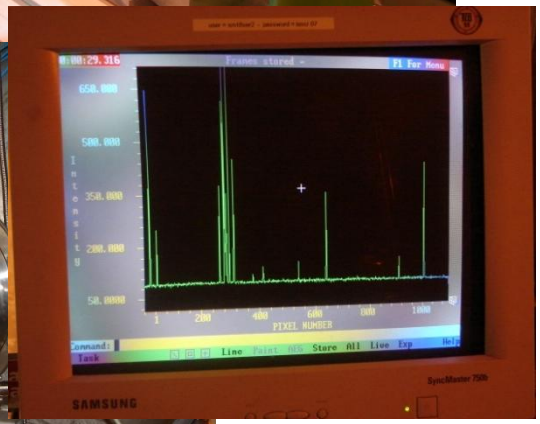
*** Mirror integration inside the LHC magnet aperture with a Z-fold cavity (*alternative with a linear one)***

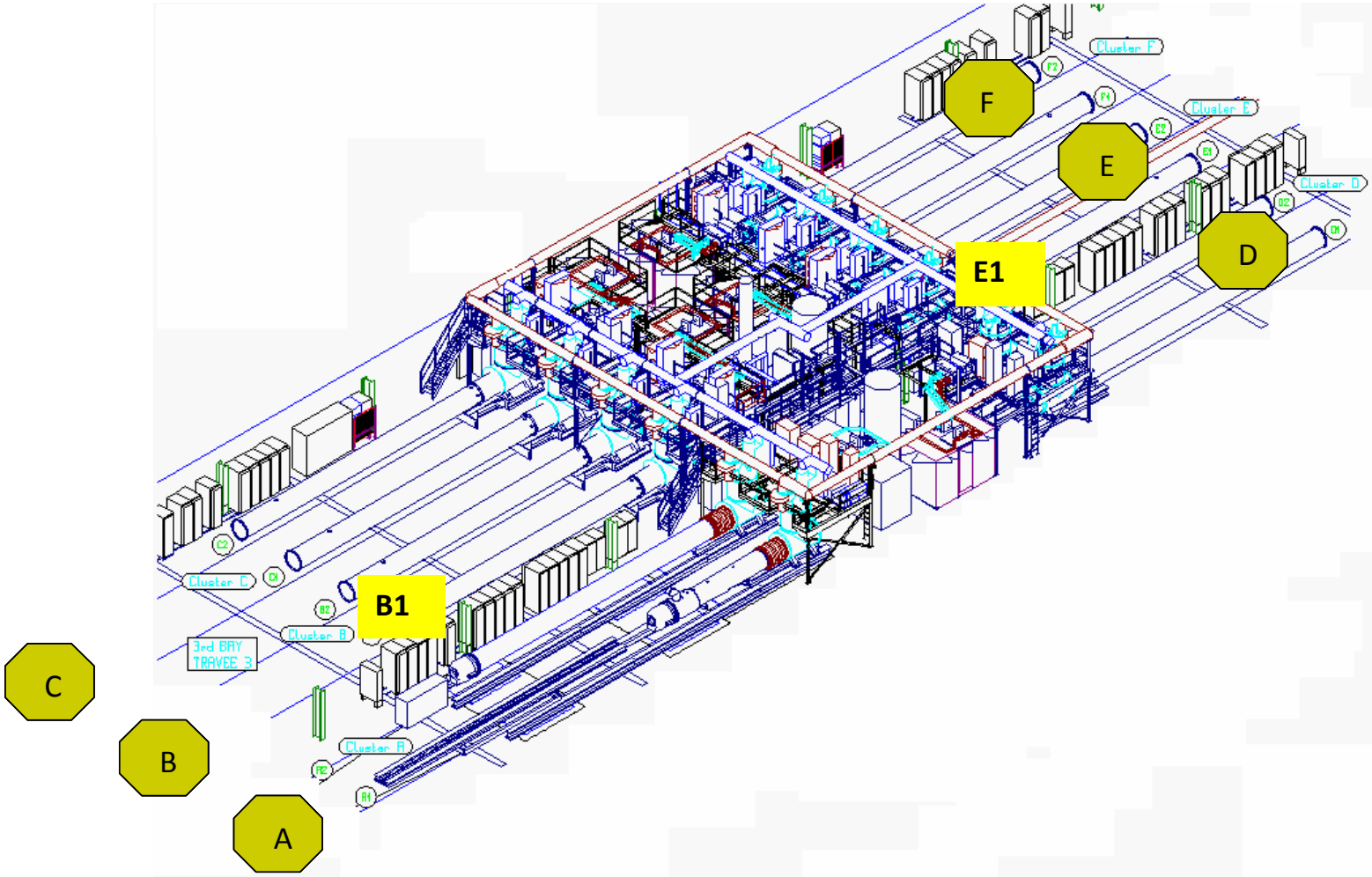
*** For Axion/ALP searches: Photon detection with a LN_2 cooled CCD Camera of Princeton Instrument, 1100 pixels of 5 mm height densely packed over 27 mm, QE ≈ 50%, DC/pix ≈ 0.1/mn**

Experiment with the 18 W Ar+ laser & N_2 gas








F
E
D
E1
B1
C
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A
Cluster F
Cluster E
Cluster D
Cluster C
Cluster B
Cluster A
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TRAVEE 3

Results

2007 Pilot run: Photon regeneration setup

* **Use only one LHC Dipole Magnet**
* **18 W Ar+ laser**
* **Polarization || to magnetic field**
* **Measurements also done with N_2 gas**

No signal found in expected region

Conclusion and outlook

Photon regeneration Experiment

Preliminary Phase to check PVLAS results; 1 dipole with/without gas (done)

Phase-1: 2 dipoles, CW laser beam, extra & intra cavity to improve BFRT results (2010)

Phase-2: 2 dipoles, CW laser beam & High Finesse FP cavity (2011-2012)

Phase-3: more than 2 dipoles to be competitive with CAST results

"n-1 Experiment" i.e. VMB & Linear Dichroism-

Phase-1&2 : Measurements of QED prediction in $O(\alpha^2)$ & $O(\alpha^3)$ respectively within 1 dipole (2012 & 2014)

OSQAR Collaboration, CERN

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