Laser Experiments to Search for Axion-like Particles

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Light Shining Through a Wall

Assuming 5T magnet, the PVLAS "signal", and 532nm laser light

\[ \mathcal{L}_{\text{int}} = -\frac{1}{4M} F_{\mu\nu} F^{\mu\nu} = \frac{\phi}{M} (\vec{E} \cdot \vec{E} - \vec{B} \cdot \vec{B}) \]

\[ \mathcal{L}_{\text{int}} = -\frac{1}{4M} F_{\mu\nu} \tilde{F}^{\mu\nu} = \frac{\phi}{M} (\vec{E} \cdot \vec{B}) \]

\[ P_{\text{regen}} = \frac{16 B_1^2 B_2^2 \omega^4}{M^4 m_\phi^8} \sin^2 \left( \frac{m_\phi^2 L_1}{4\omega} \right) \cdot \sin^2 \left( \frac{m_\phi^2 L_2}{4\omega} \right) \]

\[ P_{\text{GammaV}}^{\text{regen}} = (3.9 \times 10^{-21}) \times \frac{(B_1/5 \text{ T})^2 (B_2/5 \text{ T})^2 (\omega/2.33 \text{ eV})^4}{(M/4 \times 10^5 \text{ GeV})^4 (m_\phi/1.2 \times 10^{-3} \text{ eV})^8} \times \sin^2 \left( \frac{\pi}{2} \frac{(m_\phi/1.2 \times 10^{-3} \text{ eV})^2 (L_1/2.0 \text{ m})}{(\omega/2.33 \text{ eV})} \right) \sin^2 \left( \frac{\pi}{2} \frac{(m_\phi/1.2 \times 10^{-3} \text{ eV})^2 (L_2/2.0 \text{ m})}{(\omega/2.33 \text{ eV})} \right) \]
GammeV Apparatus

GammeV was located on a test stand at Fermilab’s Magnet Test Facility. Two shifts/day of cryogenic operations were supported.

- Laser box
- Tevatron magnet
- Vacuum port
- Cryogenic magnet feed can
- Cryogenic magnet return can
- Cryogenic magnet return can
- Vacuum tube connected to plunger
- PMT box
- PMT box
World-wide effort to probe $g_{\alpha\gamma\gamma} \sim 10^{-7} \text{ GeV}^{-1}$

GammeV @CERN
PRL 100, 080402 (2008)

ALPS @DESY
PLB 689, 149 (2010)

OSQAR @CERN
PRD 78, 092003 (2008)
Note: with N$_2$ gas

LIPSS @JLab
PRL 101, 120401(2008)
scalar only

BMV @France
pseudoscalar only
Final results: PRD 78, 032013 (2008)
REAPR: Future LSW

Resonantly enhanced axion-photon regeneration

Production cavity:
High finesse amplifies forward moving photons $\times \mathcal{F}$

Regeneration cavity:
Resonant enhancement provides another power of $\mathcal{F}$

Prob(regeneration):
Linearly:
magnetic field length $\frac{1}{4}$ - root:
0-bkgd int time finesse factor: $\mathcal{F}$

$\mathcal{F}$ factor of $10^5$

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Strawperson optical design

- Use two lasers.
- **Laser 1** injects power into generation cavity
- **Laser 2** is offset locked to **Laser 1**
- Offset frequency $\Omega = \text{integer} \times \text{FSR of the cavities}$
- Regeneration cavity is PDH locked to **Laser 2**
- **Laser 2** used for heterodyne readout of signal in regeneration cavity

G. Mueller (D. Tanner, Univ of FL, DOE Intensity Frontier Workshop)
Possible reach

Baseline design with BL=180 Tesla-meters, with F=3 \(10^5\), P=10W, Integration time T=30 days.
ALPS-II at DESY

Any Light Particle Search (axion-like and low mass hidden $\gamma$'s)

DESY: ALPS-IIa and ALPS-IIb have been approved with ALPS-IIc with HERA magnets targeted for 2017.

US: R&D proposal for optical bench is in preparation. Long baseline cavity work with the holometer. Discussions to use Tevatron magnets but no specific plans.

CERN: Long standing effort, OSQAR, continues as well.
Holometer at Fermilab

Build two nested 40m interferometers to test for possible holographic noise - a Planck scale jitter in space time.
Holometer at Fermilab

Build two nested 40m interferometers to test for possible holographic noise – a Planck scale jitter in space time.
Some additional points

- We will hear about a re-arrangement of the GammeV apparatus to search for chameleons and the axion-like searches described also have sensitivity to low mass hidden photons.

- There have been other cavity based ideas to look for interactions with DM particles or make use of high magnetic field gradients to look for new particles. These ideas have not been realized in practical experiments, but ideas should continue.

- The photon is a particle too! Even a small laser can produce more photons than electron or proton accelerator. Advanced optical detection techniques can be utilized. The photon is a special particle with the potential to connect to hidden $U(1)$'s or extremely high energy mass scales.