Study of the discovery potential of next generation LSW experiments

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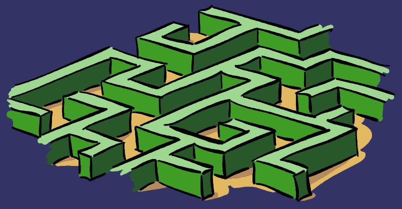
Outline

- WISPs intro.
- Current bounds, (Axion-light particles)
- Laboratory experiments: Photon-regeneration experiments (LSW).
- Next generation of experiments.
- Conclusions.



Weakly Interacting Sub-eV Particles

- WISPs appear naturally in many extensions of the Standard Model.
- Hidden sectors: light particles weakly coupled with the visible sector. Among others:

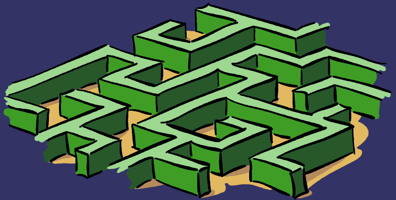
AXIONS[1] HIDDEN U(1)'s MINI-CHARGED

$$\mathcal{L}_{int} = g_{a\gamma\gamma} a F_{\mu\nu} \tilde{F}^{\mu\nu}$$

$$\mathcal{L}_{mix} = \frac{1}{2} \chi F_{\mu\nu} B^{\mu\nu}$$

$$Q_{MCP} = \frac{e_h}{e} \chi$$

Nice introduction from I. Antoniadis, J. Jaeckel



1 Peccei- Quinn (1977), Wilczek (1978), Weinberg (1977)
2 Holdom (1985)

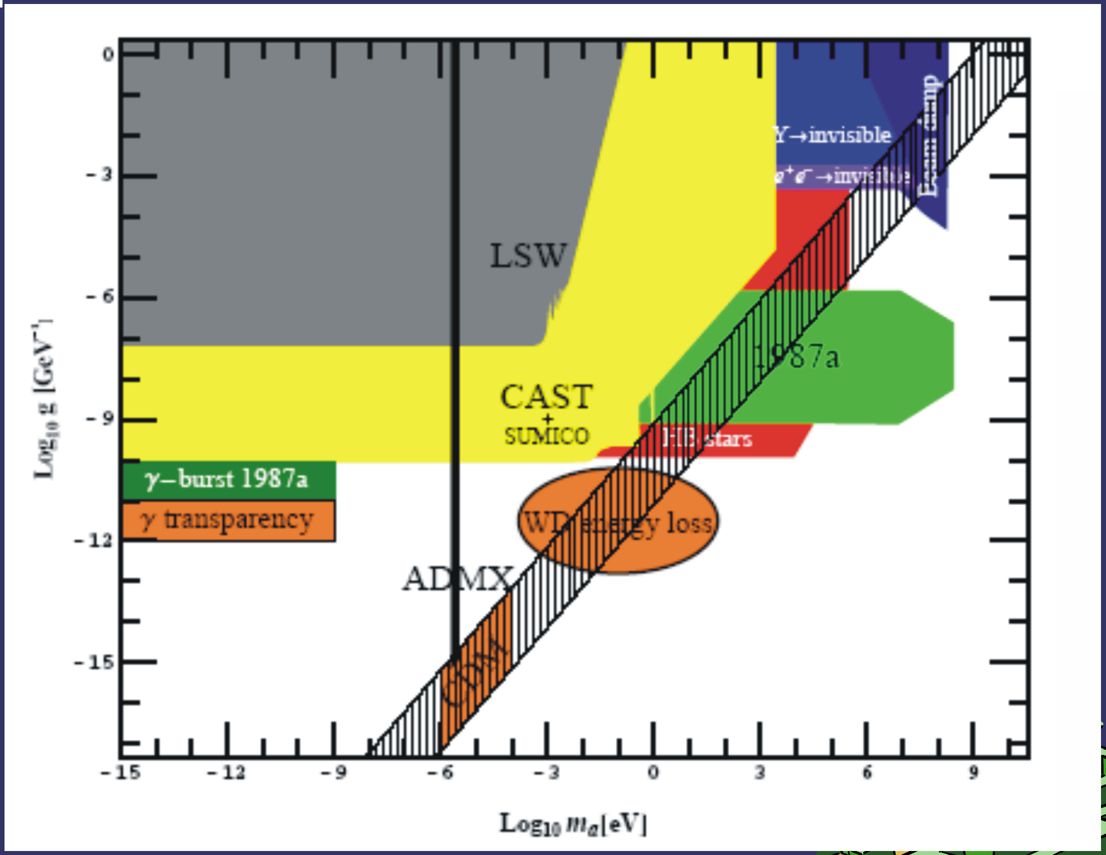
Where to search?

Fortunately, our universe is big factory of WISPs: Several Astrophysical experiments constraint axion-like particles (ALPs).

Hints from puzzling Astrophysical observations:

- Cosmic photon oscillation Into ALPs in random magnetic fields in galaxy Clusters $m_\phi \le 10^{-12}$ eV. [1] ?

- Transparency of the Universe due high energy $\gamma \rightarrow \phi$ conversion[2]. (talk from M. Roncadelli)



[1] Burrage et al (2009)

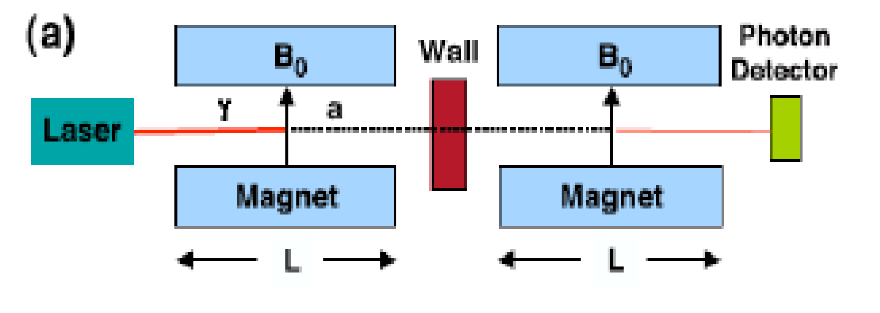
[2] A. De Angelis et al (2007)

Boom of Laboratory Experiments

2005 -2007: PVLAS OBSERVATION – RETRACTION of vacuum birefringence and dichroism in laser polarization experiments.

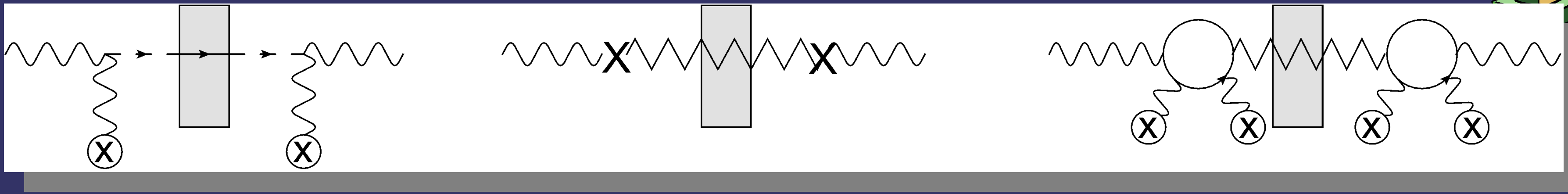
Prompt a boom of theoretical research (WISPs) and more importantly: optical precision experiments, in particular photon regeneration experiments

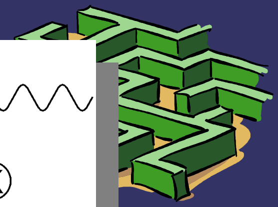
Via Primakoff effect we expect to detect regenerated photons after the wall



PRL 98, 172002 (2007)

Sensitive:





Light Shining through a wall

Advantages: Sensible to ALPs, Hidden U(1)'s and MCPs, relatively simple.

Disadvantage: Lose of coherence for higher masses.

At first order in (g B L):

$$P_{\gamma\to a} = \frac{(g_{a\gamma\gamma} B \cdot L \cdot \omega)^2}{|k_a|^2} |F(q)|^2$$

$$q = |k_\gamma - k_a| \sim \frac{m^2}{2\omega}$$

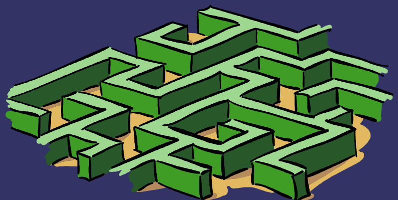
Strong B xL dependence!

$$F(q) = \frac{1}{L}\int_0^L e^{iqz}dz = \frac{2}{qL}\sin\left(\frac{qL}{2}\right)$$

Raffelt & Stodolsky (1988)

Van Bibber et al (1987)

Probability peaks for F(q) $\to$ 1 ⇨ q $\to$ 0



Maximal sensibility for small masses.

LSW bounds $m_\phi < 10^{-3}$ eV, $g_{\phi\gamma\gamma} \lesssim 7 \times 10^{-8}$ ALPS Collaboration

Next Generation of LSW experiments

Technological and Theoretical improvements are needed!

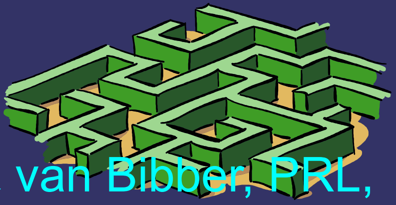
Resonant Enhanced FP Cavities: Probability of conversion enhanced by [2] $\frac{\mathcal{F}_\gamma \mathcal{F}_a}{\pi^2}$, $\mathcal{F}$: Finesse of the cavity

Actual Finesse achivable 10^4 - 10^5

Powerful laser and detector technology → 150 kW laser power
Detector efficiency

Reciclyng of superconducting dipole magnets (HERA, TEVATRON, LHC).

Improve B x L!!!!!!



2) Hoogeveen & Ziegenhagen, Nucl. Phys B 358 (1991); Sikivie, Tanner & van Bibber, PRL, 98 (2007)

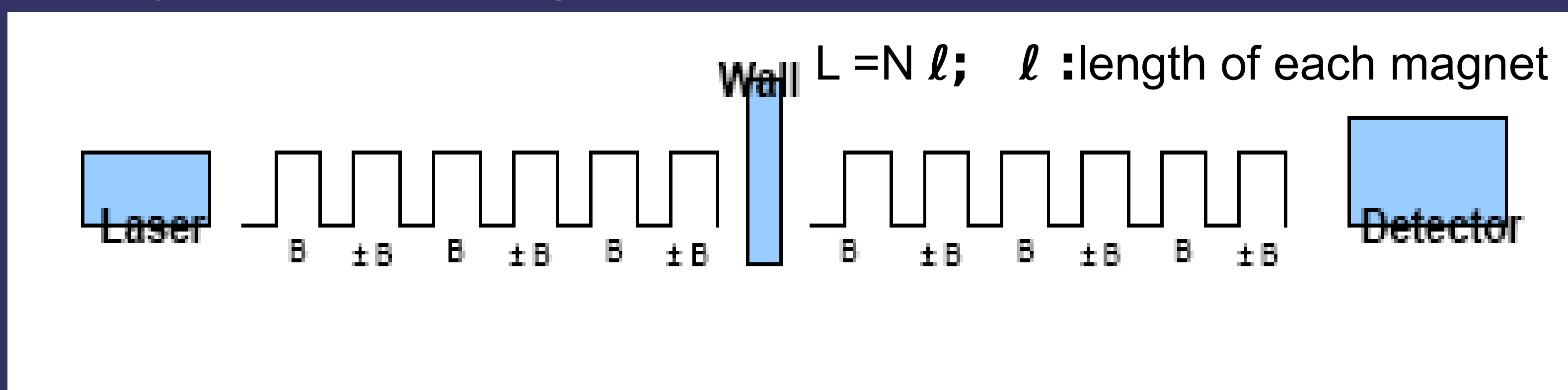
Second Generation of LSW experiments

1 Magnet → Several magnets Phase shift plates → Jaeckel & Ringwald (2007)

Van Bibber, wiggler configuration

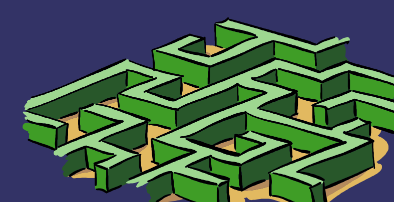
Peak the form factor for $q \neq 0$

Most likely, next generation of LSW experiments will be composed of N equally spaced magnets with a natural separation in between



We can decompose the form factor:

$$\int_0^L dx' e^{iqx'} = \int_0^l dx' e^{iqx'} + \int_{l+\Delta}^{2l+\Delta} dx' e^{iqx'} + ... + \int_{(N-1)(l+\Delta)}^{l+(N-1)(l+\Delta)} dx' e^{iqx'},$$



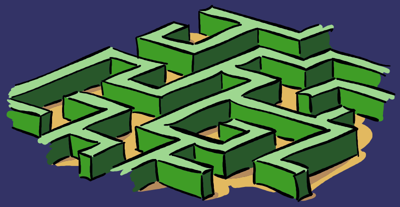
For the normal non-alternating configuration
Works like we were adding a phase of q∆ for each magnet

$$F(q) = \int_0^{\ell} dx\ e^{iqx} + \int_{\ell}^{2\ell} dx\ e^{iq(x+\Delta)} + ... + \int_{(N-1)\ell}^{N\ell} dx\ e^{iq(x+(N-1)\Delta)}$$

$$F(q) = \sum_{s=0}^{N-1} \int_{s\ell}^{(s+1)\ell} dx\ \exp\left[iq\left(x + s\Delta\right)\right]$$

See : “Extending the reach of axion-photon regeneration experiments towards larger masses with PSP” Jaeckel & Ringwald, PLB(2007).

As with PSP, we are able to scan a wide region of ALPs masses verying the gaps between the magnets



Without introducing extra losses!

PSP !!

As a result, we obtain modified form factors:

Normal N-magnets configuration:

$$F(q) = \frac{2}{qL}\sin\left(\frac{qL}{2N}\right)\frac{\sin\left(\frac{qN}{2}\left(\frac{L}{N}+\Delta\right)\right)}{\sin\left(\frac{q}{2}\left(\frac{L}{N}+\Delta\right)\right)}.$$

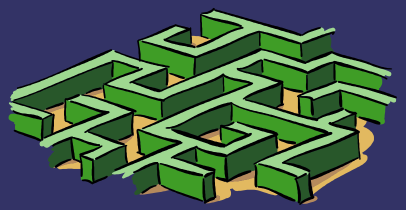
Alternating magnets of n subgroups:

$$F(q) = \begin{cases} \frac{2q}{L}\sin\left(\frac{qL}{2N}\right)\frac{\sin\left(\frac{qN}{2}(L/N+\Delta)\right)}{\sin\left(\frac{q}{2}(L/N+\Delta)\right)}\tan\left(\frac{qN}{2n}\left(\frac{L}{N}+\Delta\right)\right), & n \text{ even} \\ \frac{2q}{L}\sin\left(\frac{qL}{2N}\right)\frac{\cos\left(\frac{qN}{2}(L/N+\Delta)\right)}{\sin\left(\frac{q}{2}(L/N+\Delta)\right)}\tan\left(\frac{qN}{2n}\left(\frac{L}{N}+\Delta\right)\right), & n \text{ odd} \end{cases}$$

Maximizing the form factor, we can improve the sensibility for a certain mass range:

Example, Normal

$$\frac{qL}{2N}\left(1+\frac{N\Delta}{L}\right) = k\pi,$$



Prospects for ALPs

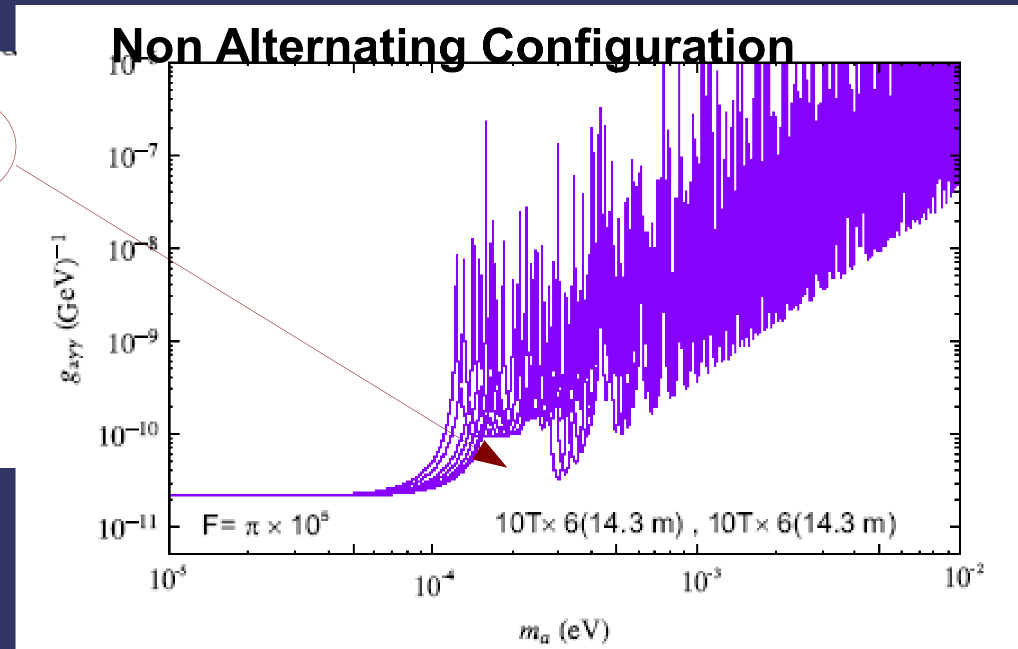
6+6 configuration LHC

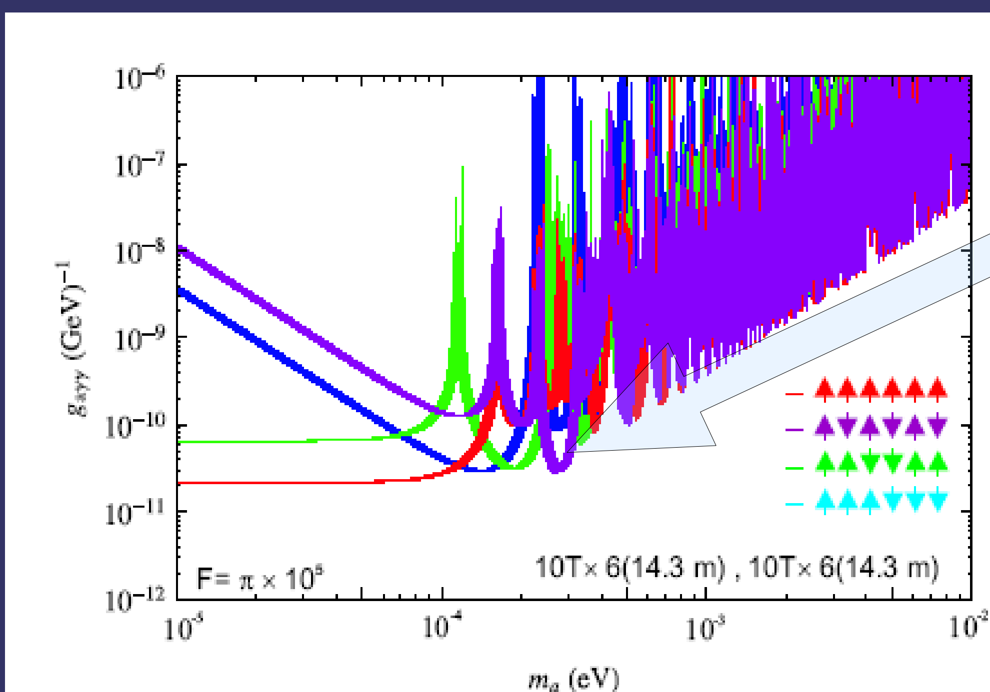
+

Res. Cavities, Laser Power Detector ....

$g^{min}_{\phi\gamma\gamma} \lesssim 3 \times 10^{-11}$

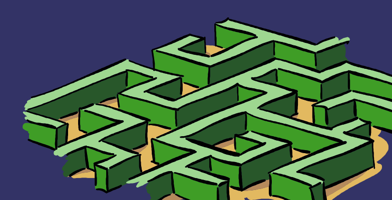
$m_\phi \times 10^{-4}$ eV	Δ (m)
3	15.4
3.2	11.8
3.5	7.5
3.7	5.23
3.9	3.3
4.1	1.6





Δ (m)
3.83
3.30
2.8
2.33
1.89
1.47
1.08

Alternating configurations help to fill the region of small masses



Conclusions

- We have derived the corrected form factors for the next generation of LSW experiments.
- According to the goals of the individual experiment, an appropriate gap between the magnets should be selected, or at least taken into account for realistic predictions.
- Restrictions: Cavity size, aperture of the magnets. Available magnets allow cavities of the order of 100-150 m.
- New experimental ideas to “exploit” the gaps?
- Also in MCPs, Chameleons?