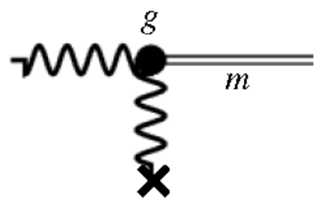
Ultra-light Particles beyond the Standard Model:

Laboratory Experiments

A Landscape

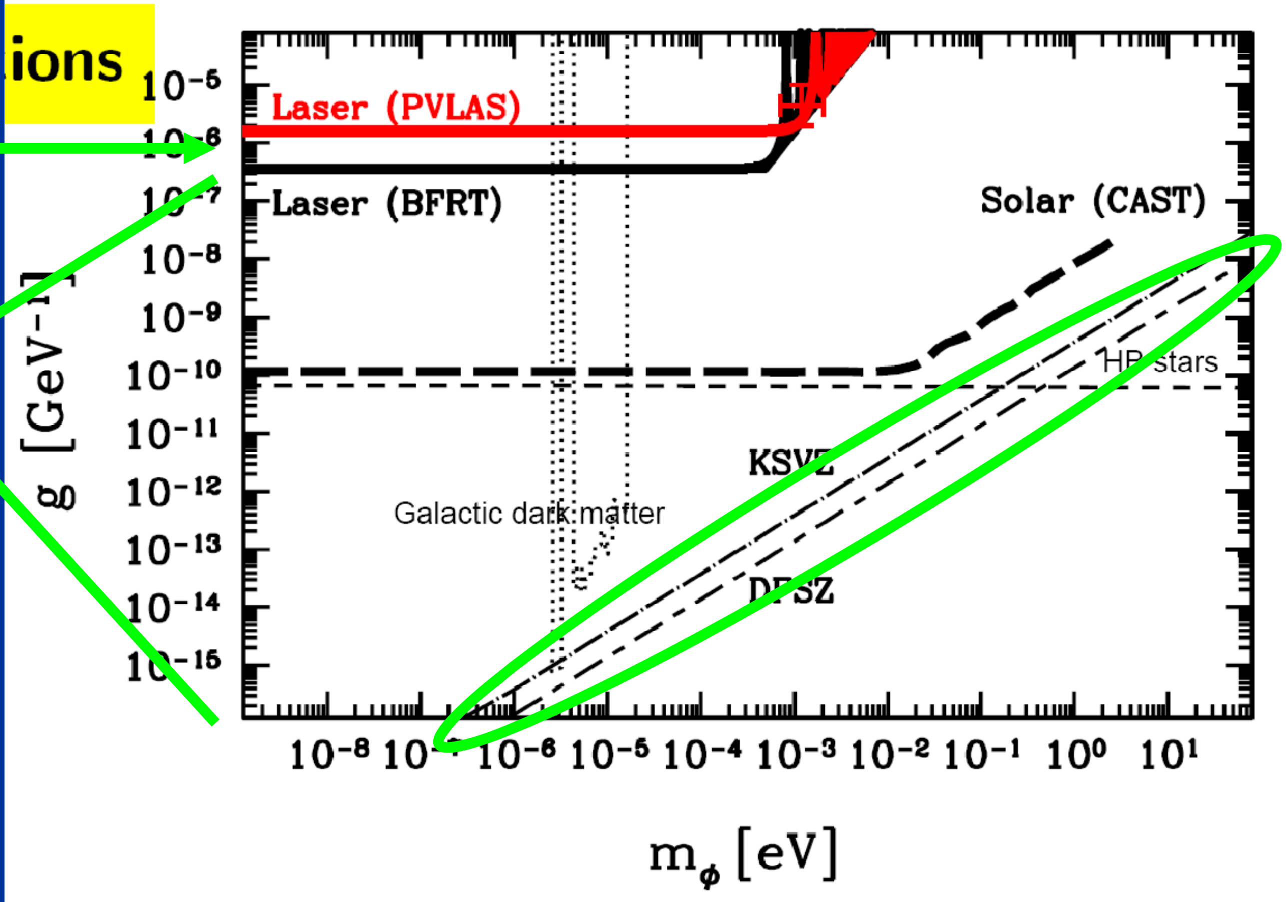
related to scalar and pseudoscalar WISPs



today's lab. limits

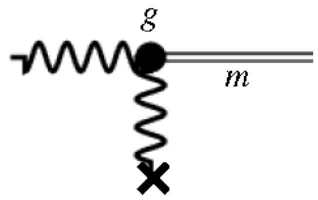
terra incognita

a promised continent:
the QCD axion



A Landscape

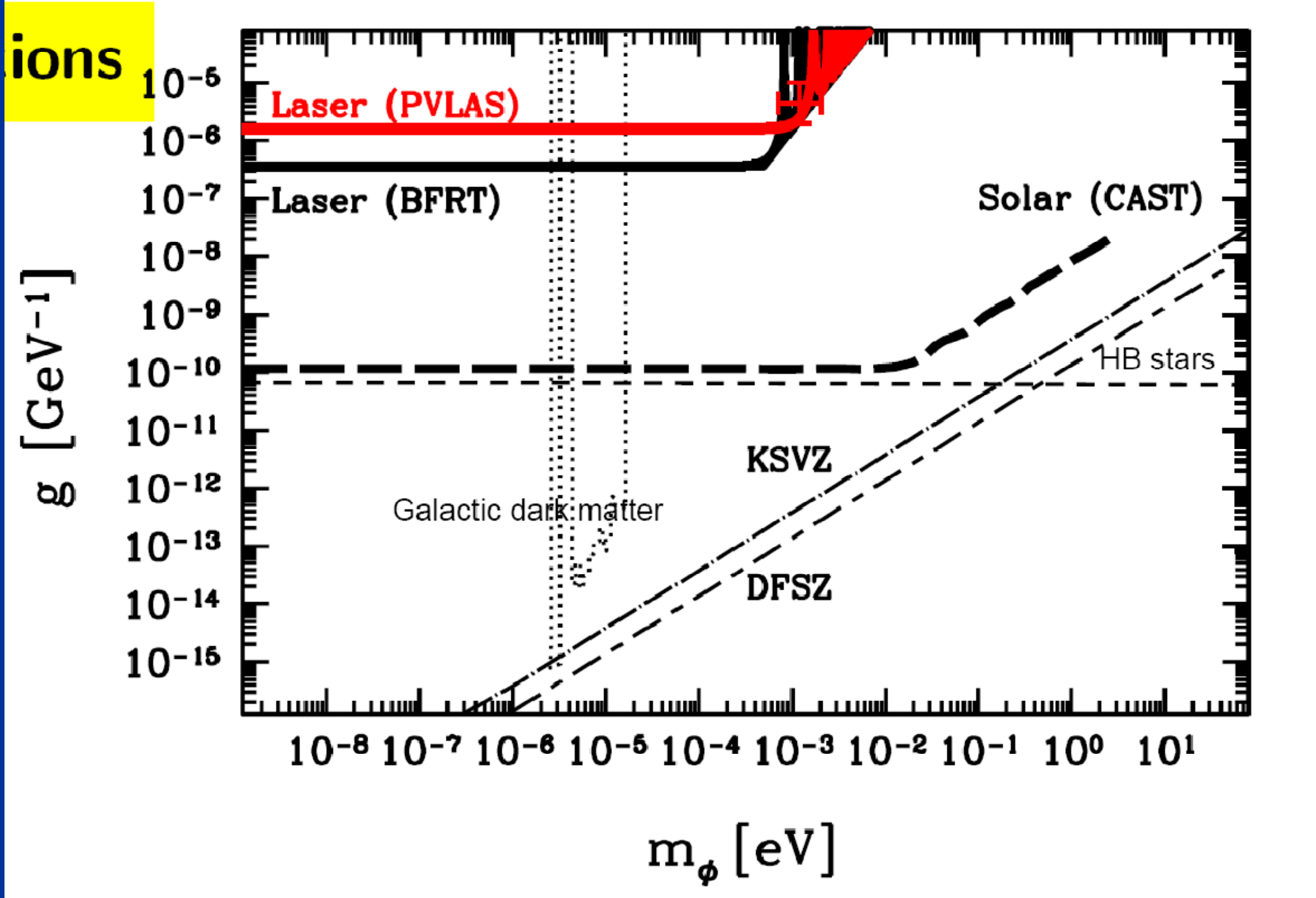
related to scalar and pseudoscalar WISPs



Scales of new physics

TeV

PeV



How to explore this landscape?

Low Energy Photon Colliders

Interactions involving multiple photons:

- Interaction of intense laser light with strong electromagnetic fields.
- Schwinger pair production.

- Oscillation effects.

Low Energy Photon Colliders

Interactions involving multiple photons:

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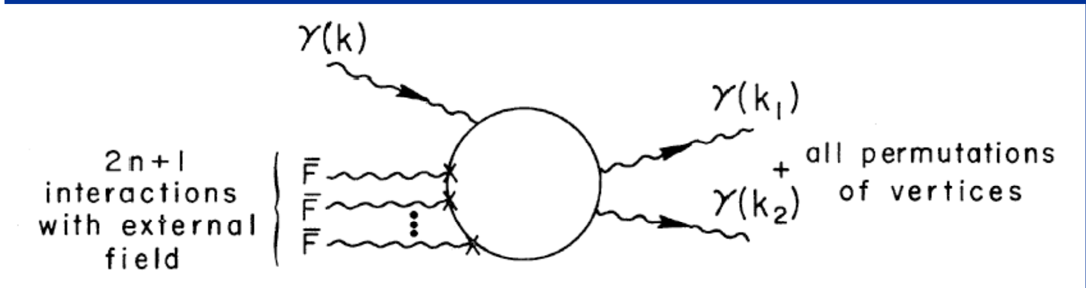
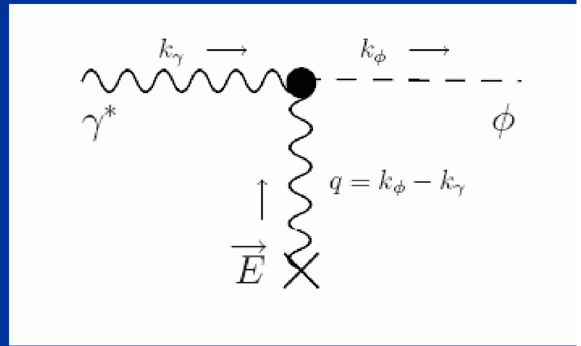
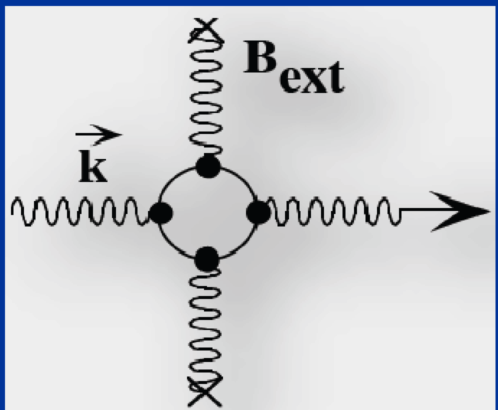
New Physics may interfere with QED!

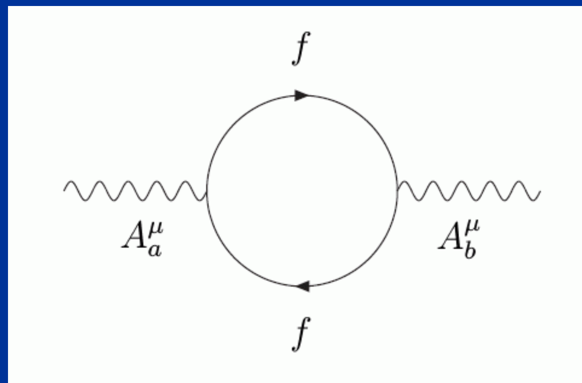
Rotation:





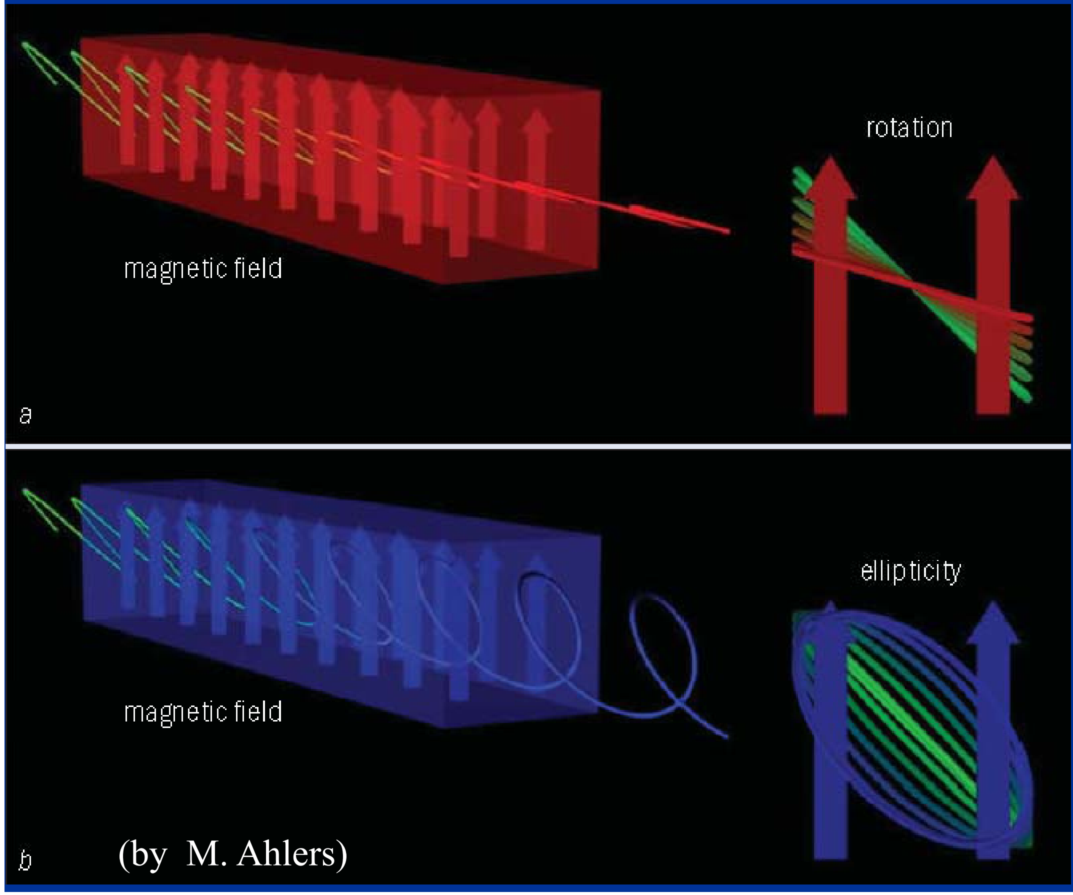
Ellipticity:





Indirect WISP Search

Change of laser light polarization passing a magnetic field



(by M. Ahlers)

rotation:
dichroism due to
real WISP production

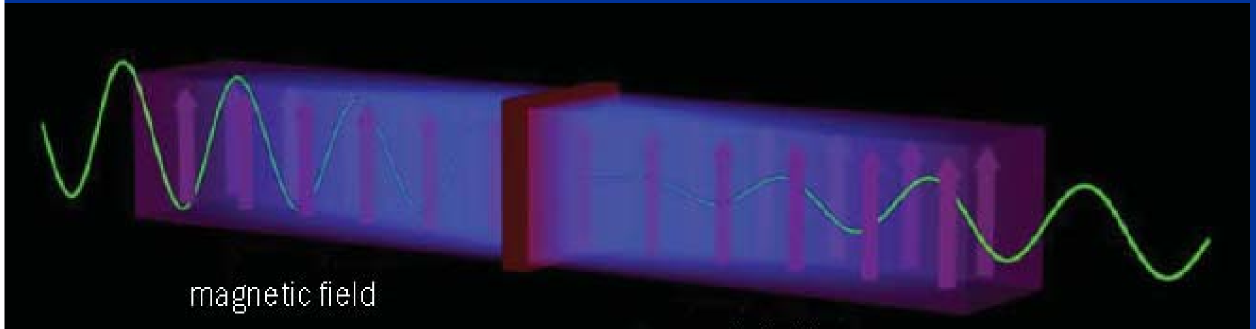
ellipticity:
birefringence due to
virtual WISP production

Indirect WISP Search Experiments

- Q&A in Taiwan
  - ongoing, sensitivity comparable to PVLAS
- BMV at Toulouse (France)
  - starting, aiming for QED prediction of ellipticity due to e^+e^- loop
  - also direct search experiments
- OSQAR at CERN (using two LHC dipoles)
  - starting, aiming also for QED-ellipticity
  - also direct search experiments

Direct WISP Search

"Light shining through a wall" (LSW) or "photon regeneration" experiments.



(by M. Ahlers)

- cross-check of indirect searches,
- more simple determination of properties of new particles,
- access to WISPs not detectable in indirect searches.

LSW Experiments

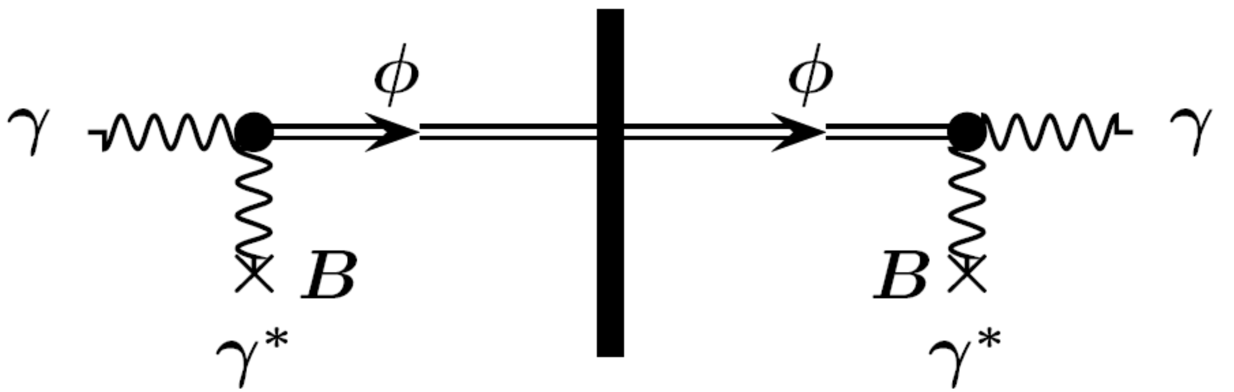
- BFRT at Brookhaven National Laboratory, finished in 1993
  – limits on existence of WISPs
- BMV at Toulouse (France)
  – ongoing, limits published
- GammeV at Fermilab
  – ongoing, limits published
  – most sensitive limits on WISPs
- LIPSS at Jefferson Lab. (USA)
  – ongoing, preliminary results

LSW Experiments

- PVLAS at INFN Legnaro (Italy) ?
- OSQAR at CERN (using two LHC dipoles)
  – ongoing, preliminary results
- ALPS at DESY

Brief Introduction to Photon Regeneration Experiments

Light shining through a wall



Skivie 1983, Ansel'm 1985, Van Bibber et al. 1987

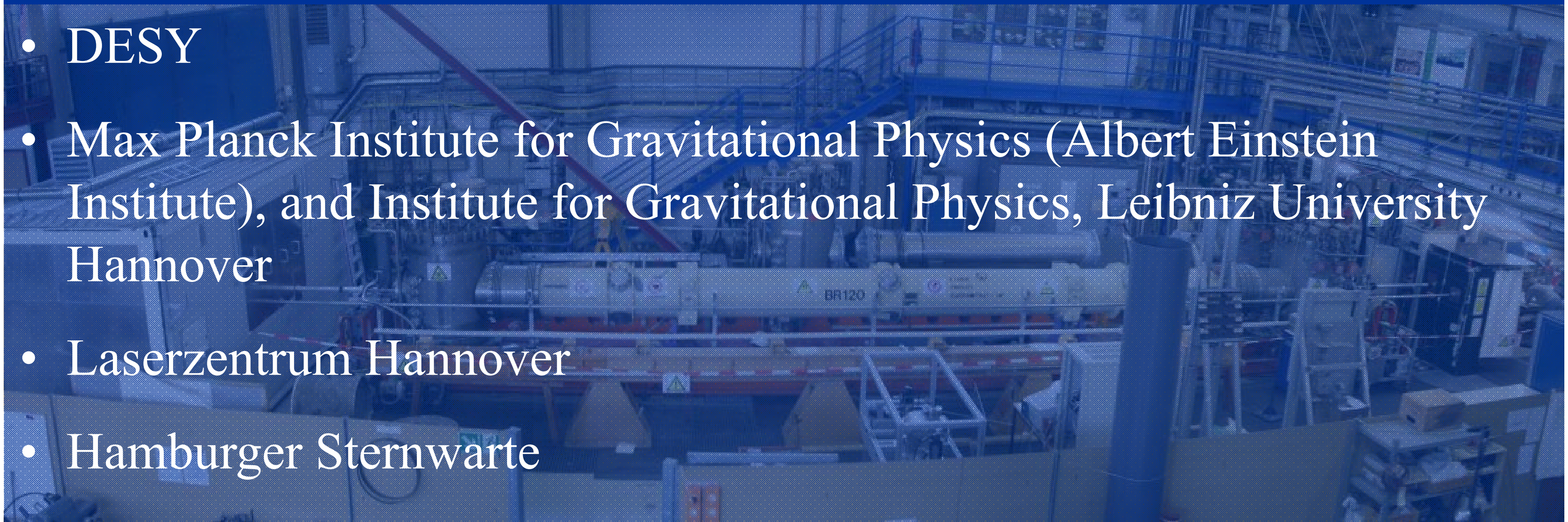
The ALPS Project

Axion-Like Particle Search @ DESY

A photon regeneration experiment

The ALPS Project

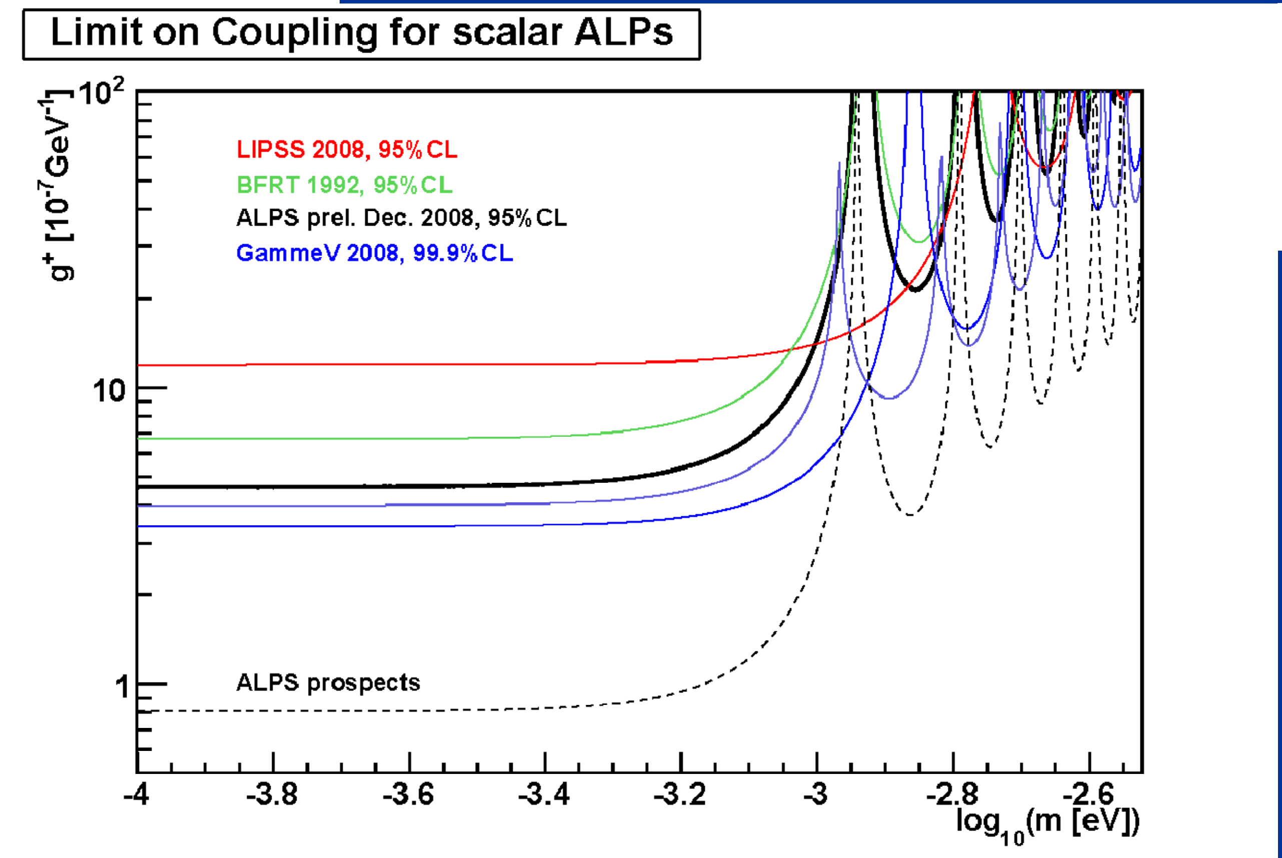
Axion-Like Particle Search @ DESY

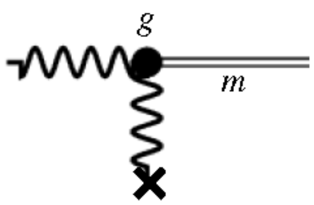


- DESY
- Max Planck Institute for Gravitational Physics (Albert Einstein Institute), and Institute for Gravitational Physics, Leibniz University Hannover
- Laserzentrum Hannover
- Hamburger Sternwarte

A photon regeneration experiment

ALPS Sensitivity





Successful and stable operation of a cavity in the generation part!

Future Prospects of direct WISP Searches

- Increase sensitivity for lower couplings
- Extend mass range to higher values.

Towards lower Couplings

<u>"Brute force" approach:</u>

- Laser (power + optical cavity)
- Magnet (field strength + length)
- Detector sensitivity

Towards lower Couplings

Laser (flux of incoming photons) in tight magnet bore:

- ALPS at present: 0.7 W 532 nm,
  cavity with power built up of 40 — 0.03 kW
- ALPS prospects: 10 W 532 nm (enhanced LIGO),
  cavity with power built up of 500 — 5 kW
- ALPS "dream": 100 W 532 nm (advanced LIGO),
  cavity with power built up of 1000 — 100 kW
- OSQAR proposal: 1kW 1064 nm (Nd-YAG),
  cavity with power built up of 10.000 — 10,000 kW

(http://axion-wimp2007.desy.de/e30/e126/talk_Siemko.pdf)

Laser: 100 kW seems to be possible, MW real challenge!

Towards lower Couplings

Magnet (interaction probability):

- ALPS at present: ½ + ½ HERA dipole,
  B=5.2 T, l=4.2 m 22 Tm
- OSQAR proposal: 1+1 LHC, dipoles
  B=9.7 T, l=14.3 m 139 Tm
- “dream”: 2+2 dLHC dipoles (or 4+4 LHC dipoles),
  B=20 T, l=30m 600 Tm

Magnet: $B \cdot l$ up to $\approx 25 \cdot (B \cdot l)_{ALPS}$ possible?

Towards lower Couplings

Detector sensitivity:

- ALPS at present: SBIG-402 40 mHz
- ALPS near future: PIXIS 1024:B 4 mHz

- "kind-of-limit": radioactivity, CR in 20·20 μm^2 signal region at ALPS about 0.02 mHz
  - may be reached with TES (single photon counting) for example.

Detector sensitivity: increase by factor of 200 in future?

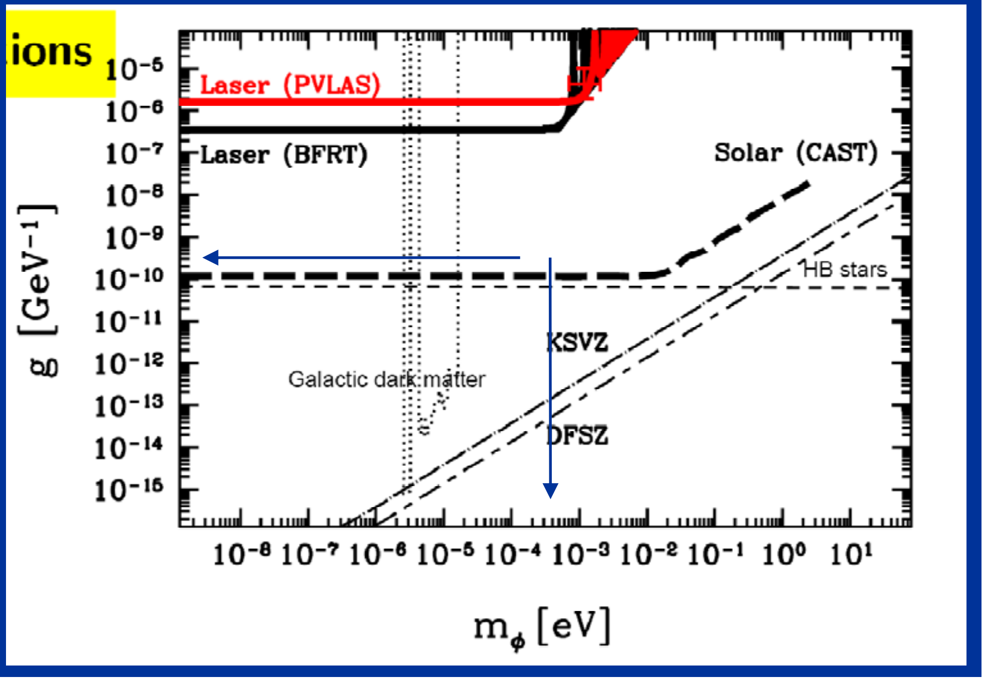
Towards lower Couplings

Relative to ALPS in summer '09 aiming for $g=10^{-7}GeV^{-1}$:

- Laser (power + optical cavity): 100
- Magnet (field strength + length): 25
- Detector sensitivity: 200

Physics:

$$g = 2\cdot(Bl)^{-1}\cdot(P_{\gamma\to\phi\to\gamma})^{-4}$$
$$= g_{ALPS}\cdot(25)^{-1}\cdot(100\cdot200)^{-4}$$
$$= g_{ALPS} / 300$$
$$\approx 3\cdot10^{-10}GeV^{-1}$$



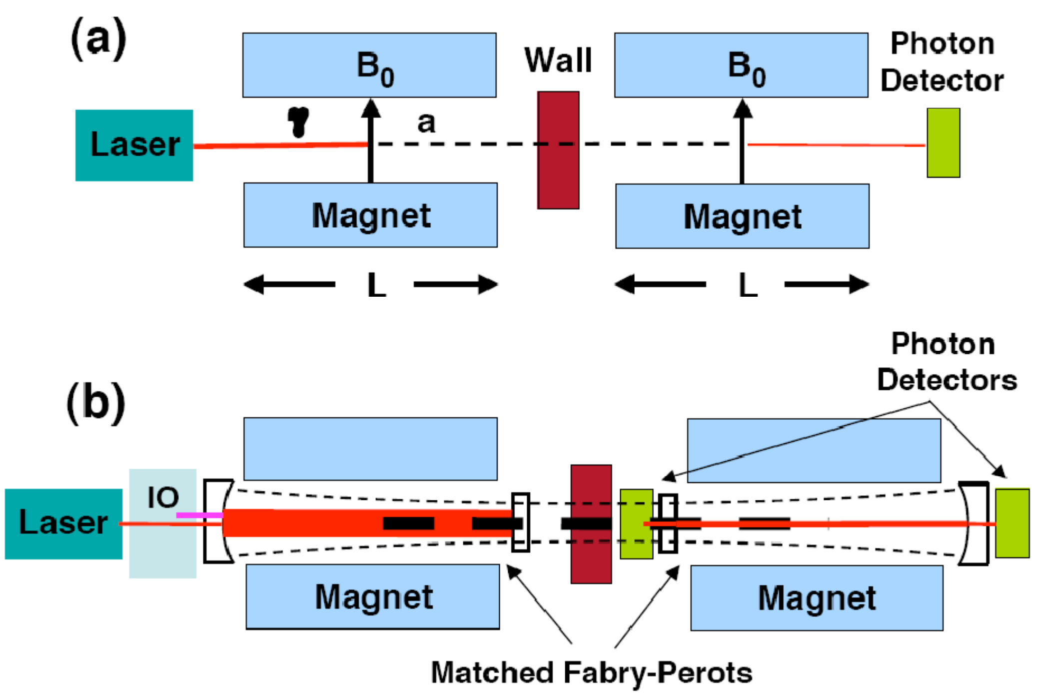
Towards lower Couplings

Ingenuity in addition to "brute force":

"Resonantly enhanced Axion-Photon Regeneration"

P. Sikivie, D.B. Tanner , Karl van Bibber. Phys.Rev.Lett.98:172002,2007.

(also F. Hoogeveen, T. Ziegenhagen, DESY-90-165, Nucl.Phys.B358)



Optical cavity also for the regeneration of photons from WISPs!

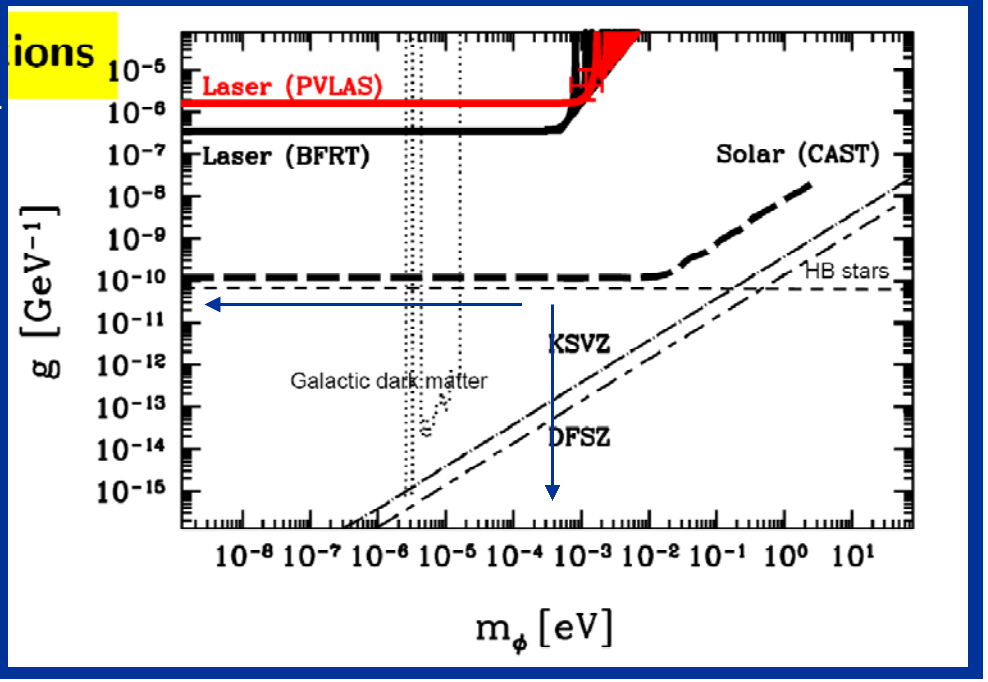
Increase power output by finesse of cavity:
10^4 seems to be possible.

Towards lower Couplings

With resonantly enhanced photon regeneration using a 10^4 optical cavity:

Physics:

$$g = 2\cdot(Bl)^{-1}\cdot(P_{\gamma\to\phi\to\gamma})^{-4}$$
$$= g_{ALPS}\cdot(25)^{-1}\cdot(20{,}000\cdot 10^4)^{-4}$$
$$= g_{ALPS}\;/\;3{,}000$$
$$\approx 3\cdot 10^{-11}\,GeV^{-1}$$



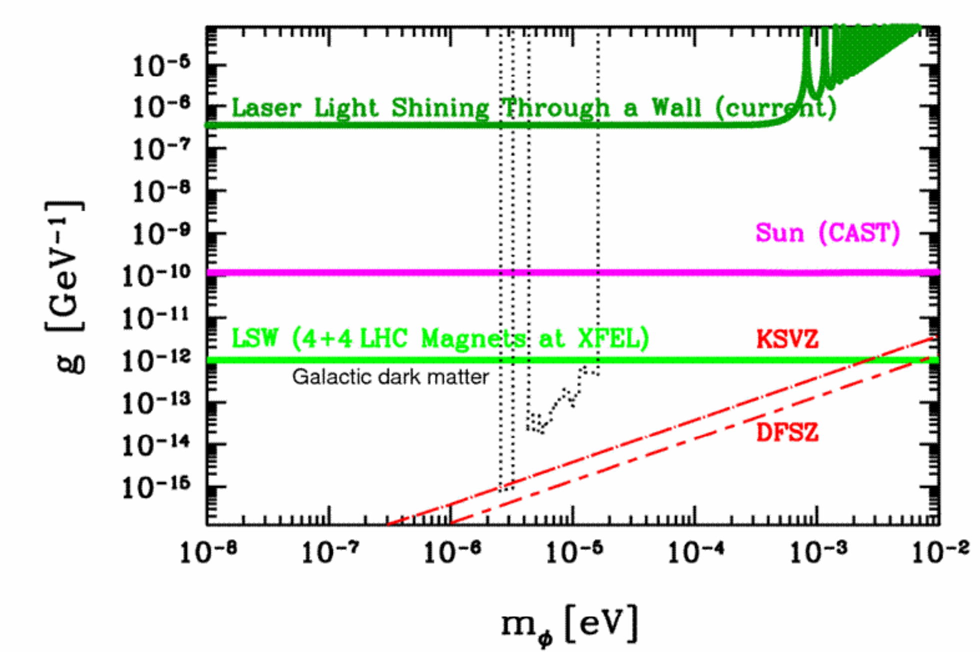
Within a decade limits from astrophysics might be surpassed.

Towards higher Masses

Big science (again):

With about one year of beam time at the XFEL and an installation of 4+4 LHC dipoles axions with masses above 1 meV could be probed.

- Advantage:
  detection of keV γ "easy".
- Challenge:
  how to convince the internat. XFEL-GmbH?



Low Energy Photon Colliders

Interactions involving multiple photons:

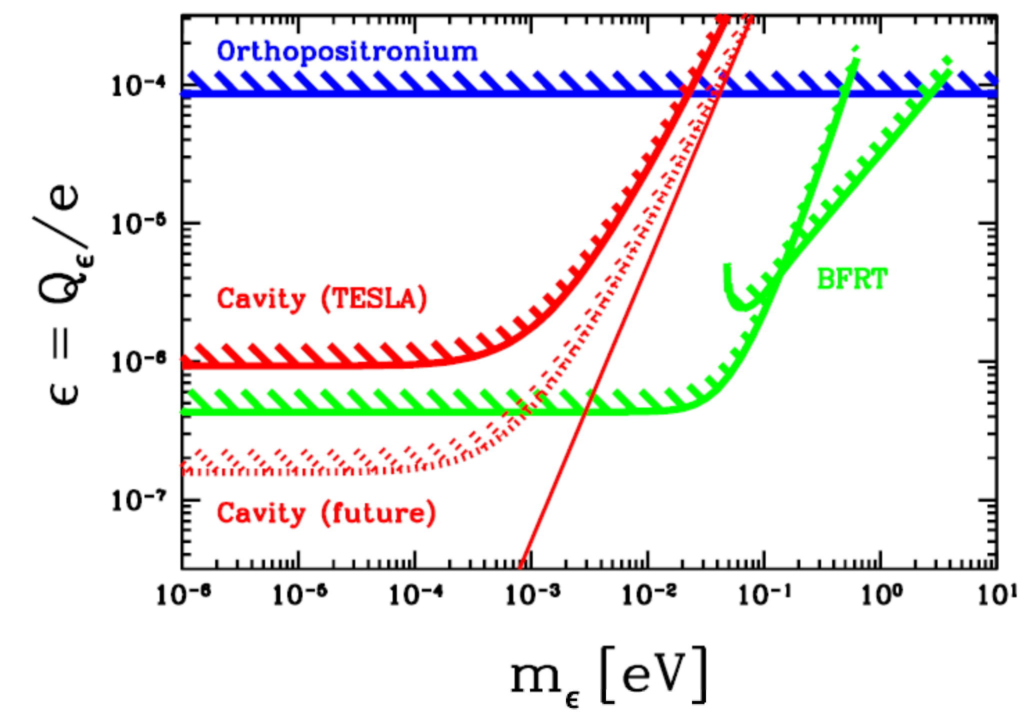
- Interaction of intense laser light with strong electromagnetic fields.
- Schwinger pair production.
- Oscillation effects.

Schwinger Pair Production

If field strength $E > m^2/\varepsilon e$: spontaneous pair production!

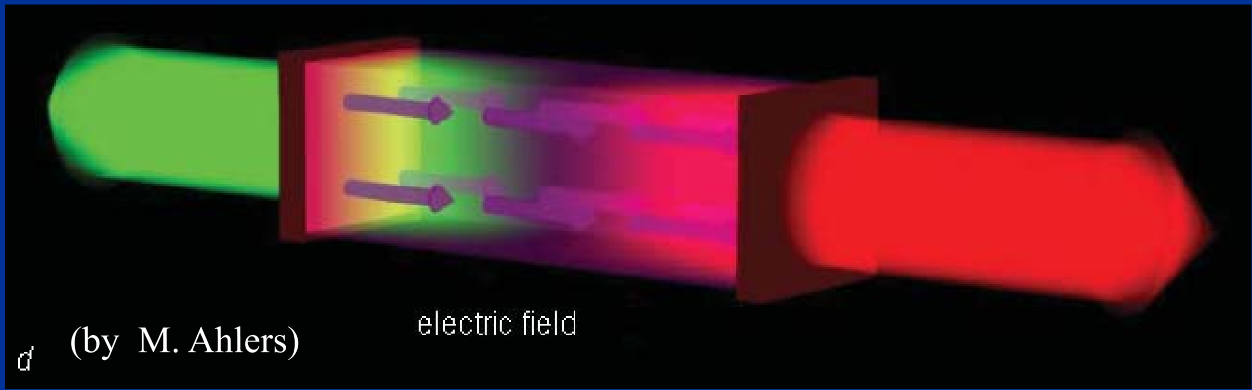
- for electron/positron: $E > 10^{18}$ V/m
- for MCP with $\varepsilon = 10^{-6}$, m=1meV: $E > 5$ MV/m

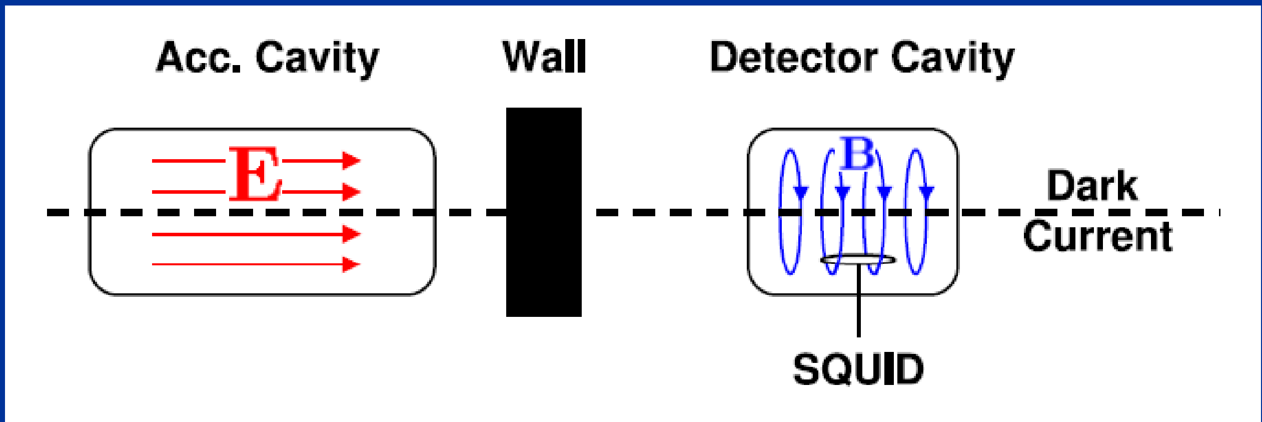
Accelerator Cavities as a probe of millicharged particles, H. Gies, J. Jaeckel, A. Ringwald, Europhys. Lett. 76(5), 794 (2006)



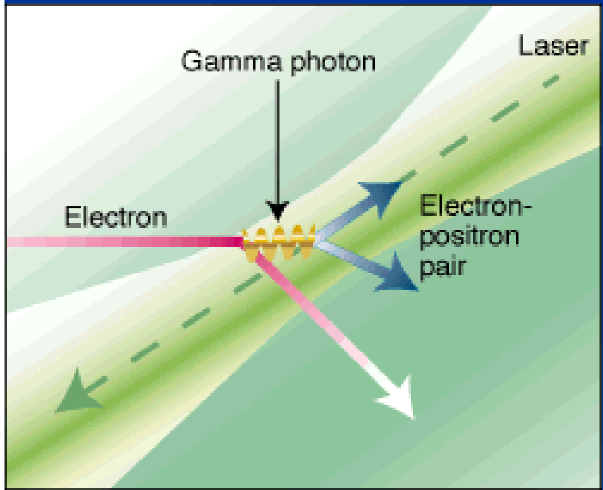
Schwinger Pair Production

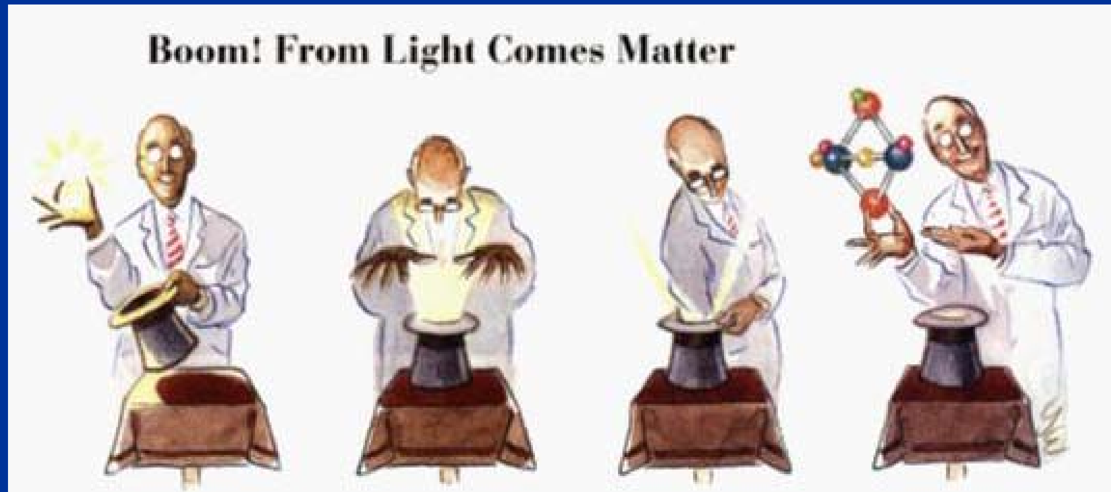
"Current flowing through a wall" experiments.





Schwinger Pair Production





http://www.slac.stanford.edu/exp/e144/e144.html

Repeat the SLAC E-144 experiments at XFEL to probe QED in the non-linear regime?

First discussions with G. Carugno and G. Ruoso have started.

Low Energy Photon Colliders

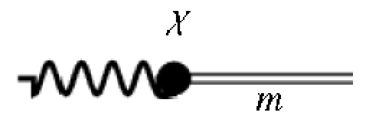
Interactions involving multiple photons:

- Interaction of intense laser light with strong electromagnetic fields.
- Schwinger pair production.

- Oscillation effects.

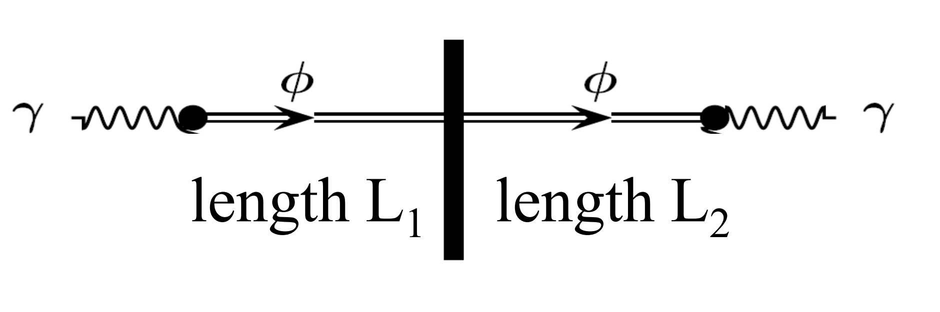
Search for massive Photons

"Light shining through a wall" without external fields:



(like neutrino oscillations).

Principle of an experiment:

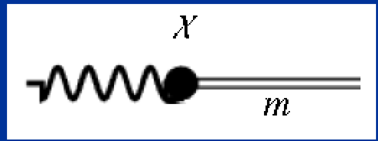


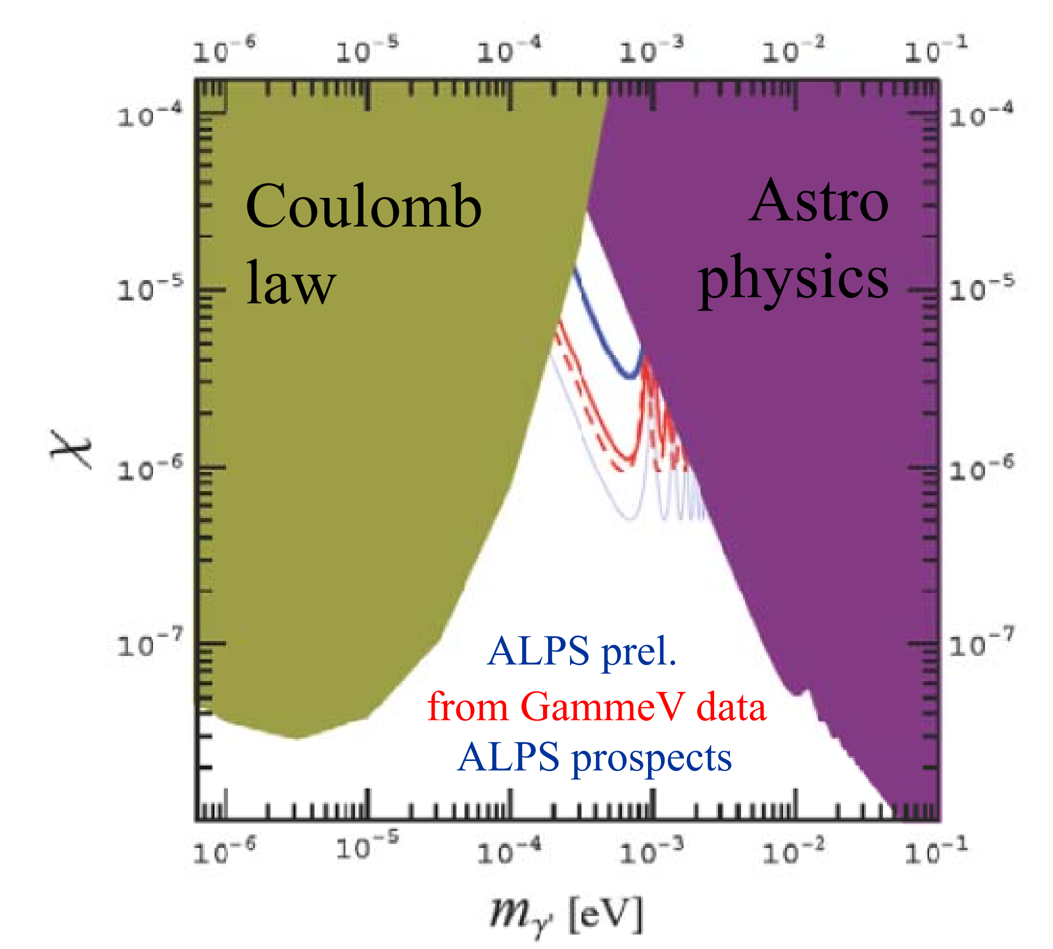
Experimental requirements very similar to searches for axion-likes, but:
- no magnetic field,
- UHV conditions.

$P_{reconv.} = 16\chi^4 \cdot [\sin(qL_1/2) \cdot \sin(qL_2/2)]^2$ (kinetic mixing)

Preliminary ALPS Sensitivity

95% CL limits for massive hidden sector γ





Only laboratory experiments searching for massive hidden sector γ might close the gap in the meV mass region!

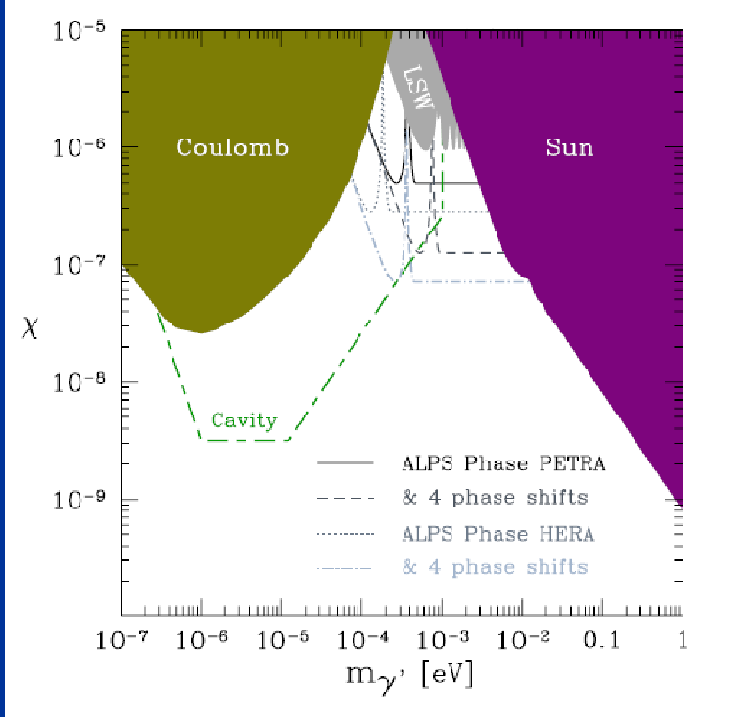
Future Prospects

Searches for massive hidden sector photons benefit from the laser and detector developments sketched above.

Different mass regions may be probed by different lengths (L_1 and L_2) of the vacuum tubes.

Laser experiments explore the hidden sector,
M. Ahlers, H. Gies, J. Jaeckel,
J. Redondo, A. Ringwald,
Phys. Rev. D 77 (2008) 095001

Phase "PETRA": $L_1 = L_2 = 40$m
Phase "HERA": $L_1 = L_2 = 170$m

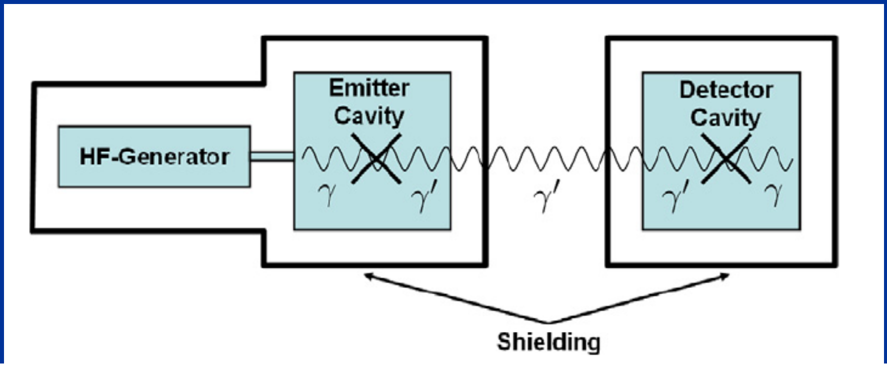


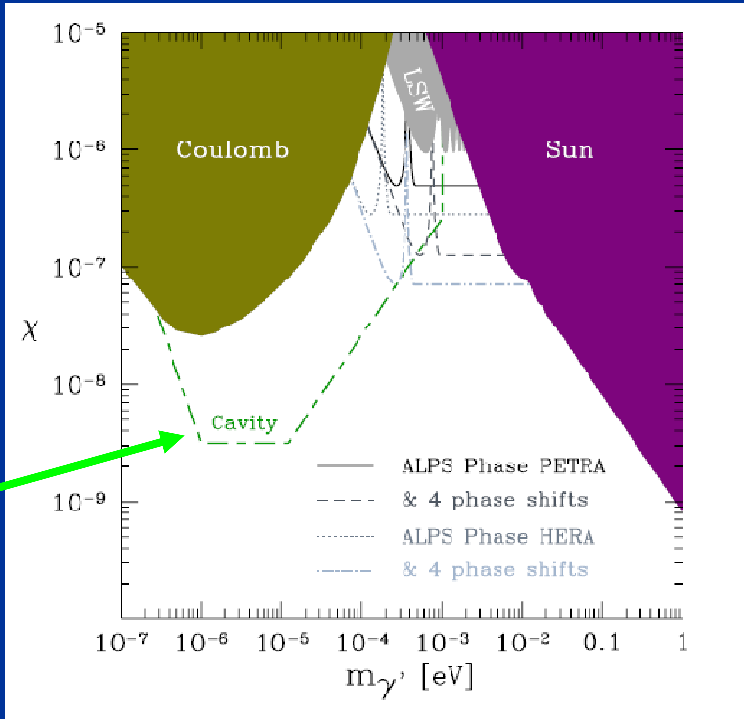
Future Prospects

Searches for massive hidden sector photons benefit from the laser and detector developments sketched above.

Different mass regions may be probed also by different technologies.

A Cavity Experiment to Search for Hidden Sector Photons, J. Jaeckel, A. Ringwald, Phys. Lett. B659 (2008) 509





Two Cavity Test Stands @ DESY

- Two adjacent test stands,
- well shielded,
- perfectly matched for WISP searches.

Summary

- Searching for WISPs in the laboratory is necessary to complement astrophysics experiments.
- There is a wealth of different experimental approaches.
- Microwave cavities might be minicharged particle factories.
- The sensitivity of future experiments will likely surpass present day limits from astrophysics.
- Finding the QCD axion remains a challenging target.

- The typical size of WISP direct search experiments are perfectly matched to laboratories like DESY / CERN.

A WISP Future at DESY?

The laboratory's interest:

- small scale particle physics experiments on site
- exploit possibilities of new light sources (PETRA III, FLASH, XFEL) for particle physics.
- help developing the research field further (theory).

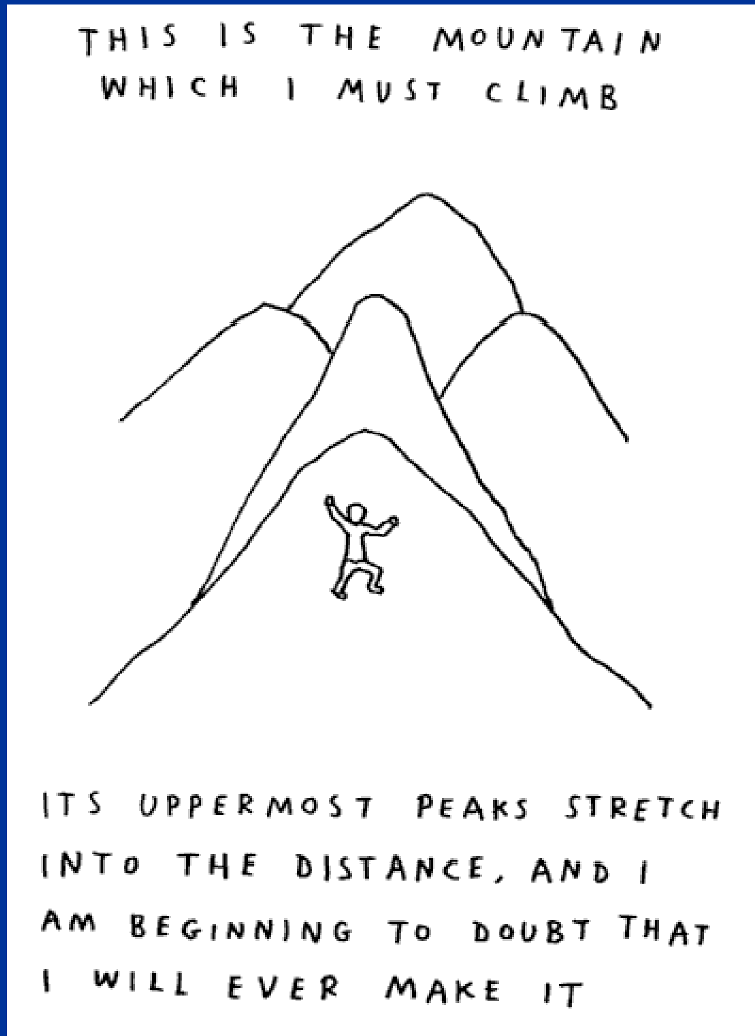
A WISP Future at DESY?

Resources:

- Rather limited at present, therefore participation in external experiments unlikely at present.
- The situation will be reviewed in autumn 2009 depending
  – on results achieved at ALPS,
  – on the outcome of the strategic Helmholtz review in spring 2009 for the funding period 2010 to 2014.

Collaboration very welcome!

It might look challenging …



… but surprises might be close!