WISP Searches at Synchrotron Sources

Exploring Possibilities

Axel Lindner,

in collaboration with
Philippe Brax, Konstantin Zioutas

HELMHOLTZ
ASSOCIATION

DESY

The next 20 Minutes

> Motivation

- Recent developments in former particle physics laboratories
- An experiment at ESRF

> Formulas, Tools and Assumptions

> Some Results

- Hidden Photons
- Axion-like Particles
- Miscellaneous

> Summary

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Motivation I: DESY in Hamburg

Motivation II

- Up to now LSW experiments in the laboratory have mainly used optical photons in the eV range.
  - This limits the accessible maximal WISP-masses.
  - Do keV photons offer totally new possibilities for experiments?
- PRL **105,** 250405 (2010) PHYSICAL REVIEW LETTERS week ending 17 DECEMBER 2010

  Photon Regeneration Experiment for Axion Search Using X-Rays

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  [1]*Laboratoire National des Champs Magnétiques Intenses (UPR 3228, CNRS-INSA-UJF-UPS), F-31400 Toulouse Cedex, France, EU*

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  (Received 16 August 2010; published 16 December 2010)

  In this Letter we describe our novel photon regeneration experiment for the axionlike particle search using an x-ray beam with photon energy of 50.2 and 90.7 keV, two superconducting magnets of 3 T, and a Ge detector with a high quantum efficiency. A counting rate of regenerated photons compatible with zero has been measured. The corresponding limits on the pseudoscalar axionlike particle–two-photon coupling constant is obtained as a function of the particle mass. Our setup widens the energy window of purely terrestrial experiments devoted to the axionlike particle search by coupling to two photons. It also opens a new domain of experimental investigation of photon propagation in magnetic fields.

  See presentation by R. Battesti this afternoon!

- Could one do better (in principle)?

DESY

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Formulas (1)

- Conversion probability photon ↔ hidden photon:

$$P = \chi^2 \times \frac{{m_{HP}}^4}{E^2 q^2} \times \sin^2\left({}^{qL}/{}_2\right)$$

  - χ: kinetic mixing hidden photon ↔ photon.
  - *E*: photon energy
  - *L* = length
  - $q = n \times E - \sqrt{E^2 - {m_{HP}}^2}$ with refractive index *n*.

Formulas (2)

- Conversion probability photon $\leftrightarrow$ ALP:

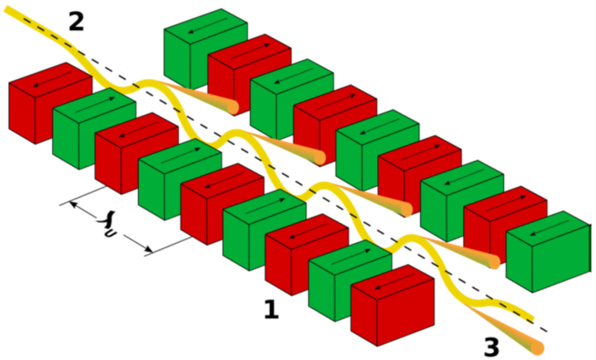
$$P = 0.25 \times \frac{E^2}{\sqrt{E^2 - m_{ALP}{}^2}} \times (gLB)^2 \times F^2$$

  - *g*: coupling ALP $\leftrightarrow$ 2 photons.
  - *B*: magnetic field strength.
  - *L*: magnetic field length.
  - *E*: photon energy.
  - $q = n \times E - \sqrt{E^2 - m_{ALP}{}^2}$ with refractive index *n*.
  - *F*: $\sin(0.5qL)/(0.5qL) \times \tan\left({}^{0.5qL}/_{nPol}\right)$ *nPol* even,
    $\cos(0.5qL)/(0.5qL) \times \tan\left({}^{0.5qL}/_{nPol}\right)$ *nPol* odd.
  - *nPol*: number of alternating dipoles (assuming equal distribution, no gaps).

- For more elaborated calculations see:
  Phys. Rev. D 82, 115018 (2010), "Optimizing light-shining-through-a-wall experiments for axion and other weakly interacting slim particle searches",
  Paola Arias, Joerg Jaeckel2, Javier Redondo, Andreas Ringwald.

Tools: Insertion Devices

- Electron or positron bunches circulate in a synchrotron.
- These bunches produce X-rays by wiggling around in a magnetic field:



http://en.wikipedia.org/wiki/Insertion_device

- Characteristics:
  - Short flashes of light (44 ps at PETRA III).
  - Large intervals between flashes (192 ns at PETRA III).
  - Different photon polarizations possible.

Tools: Insertion Devices

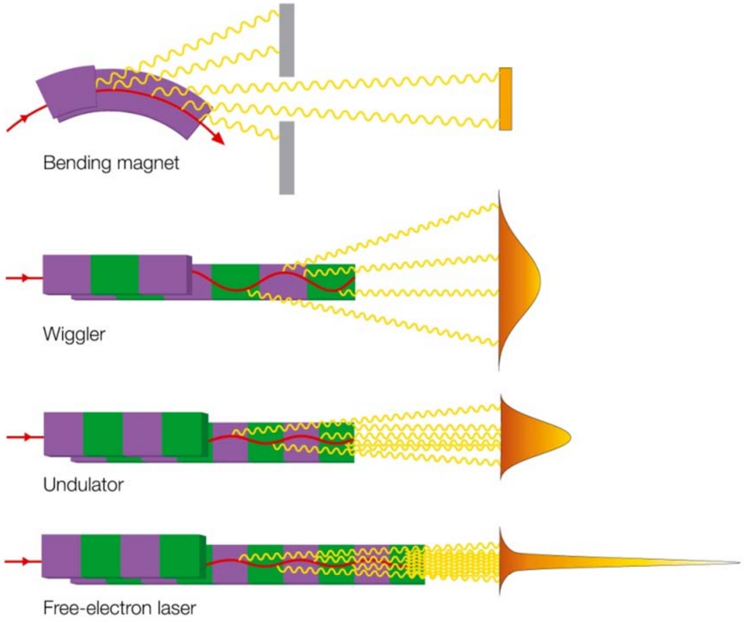
> Wigglers:
Periode and strength of B-field not tuned to radiation wavelength, corresponds to a series of bending magnets.

  - Broad wavelength spectrum.
  - Power proportional to nPol (number of dipole magnets).

> Undulators:
Radiation produced by a particle bunch interferes constructively with the motion of other bunches.

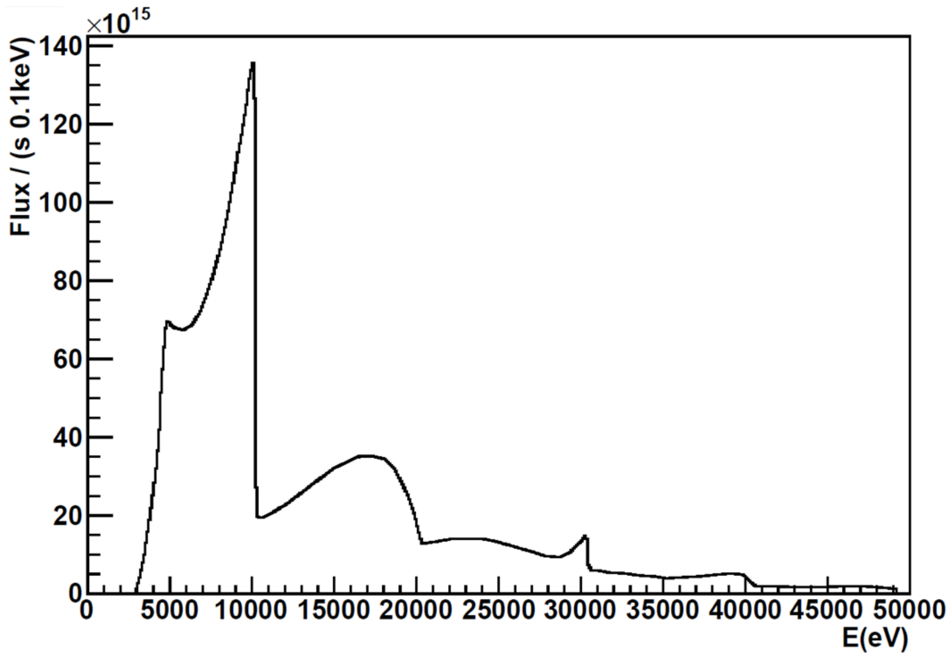
  - Small bandwidth..
  - Power proportional to $nPol^2$.

Tools: Insertion Devices



(Toy) Parameters of the Radiation

- Pulse length: 44 ps
- Interval: 192 ns
- Beam diameter: 1 cm^2 at 40 m behind the undulator
- Flux: 10^{19} photons per second ("a realizable dream")
- Energy Spectrum:

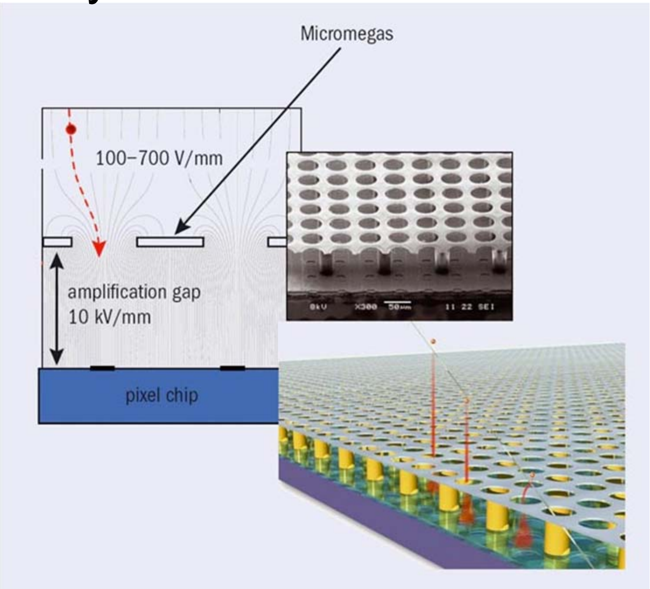


Spectrum tunable in principle to any photon energy
(courtesy of W. Drube, DESY).

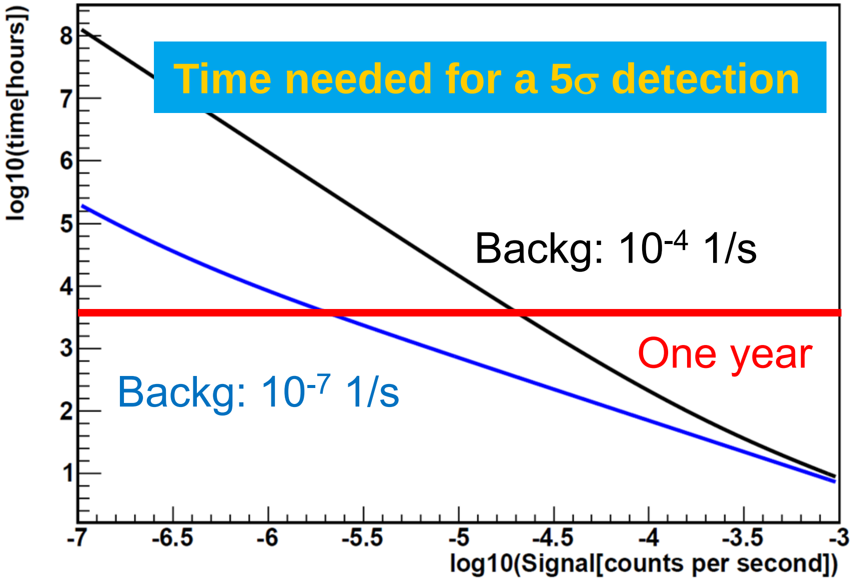
Detector Assumptions

See talks by T. Dafne and I. Irastorza

- Efficiency close to 100%.
- Background counts 10^{-4} per second.
- Trigger-able.
  - Background reduces to about 10^{-7} counts per second with the pulse structure given above.



http://cerncourier.com/cws/article/cern/41011



One could imagine to be sensitive to signal rates above <u>10^{-6} counts per second</u> (reconversion probability 10^{-25}).

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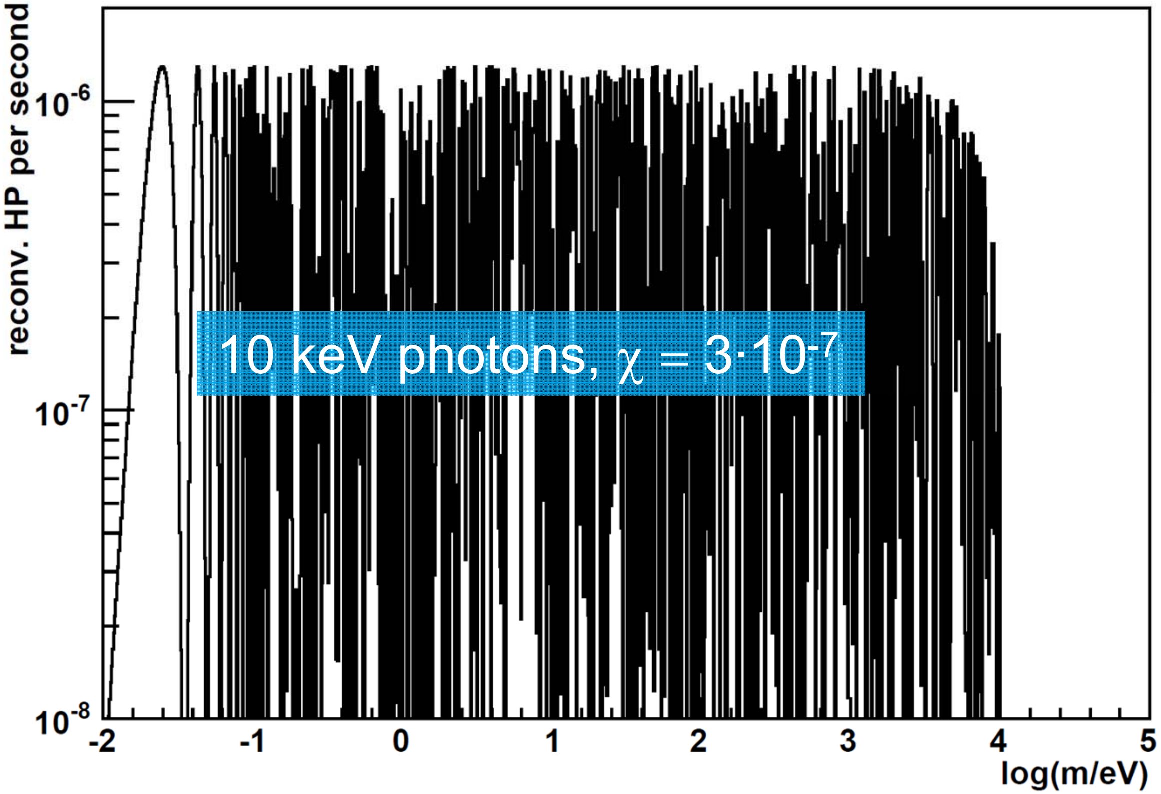
Search for Hidden Photons

> Set-up: two 20 m long vacuum tubes separated by a wall.



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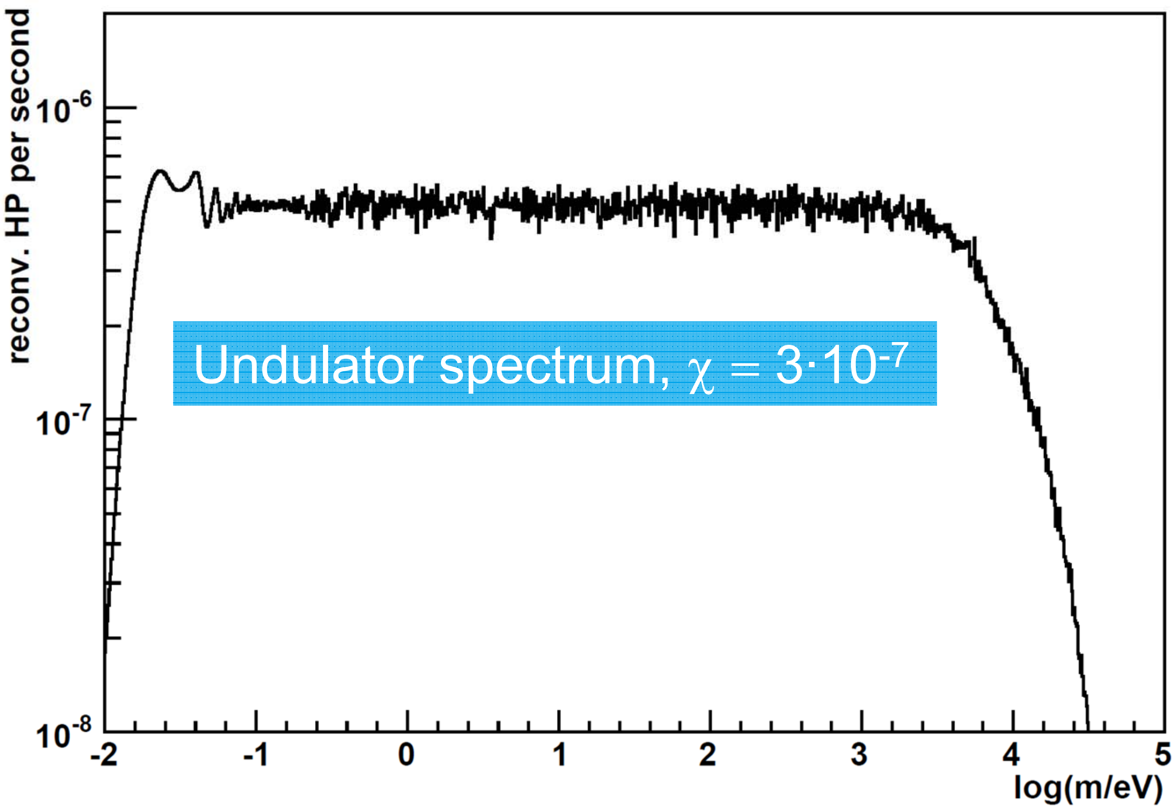

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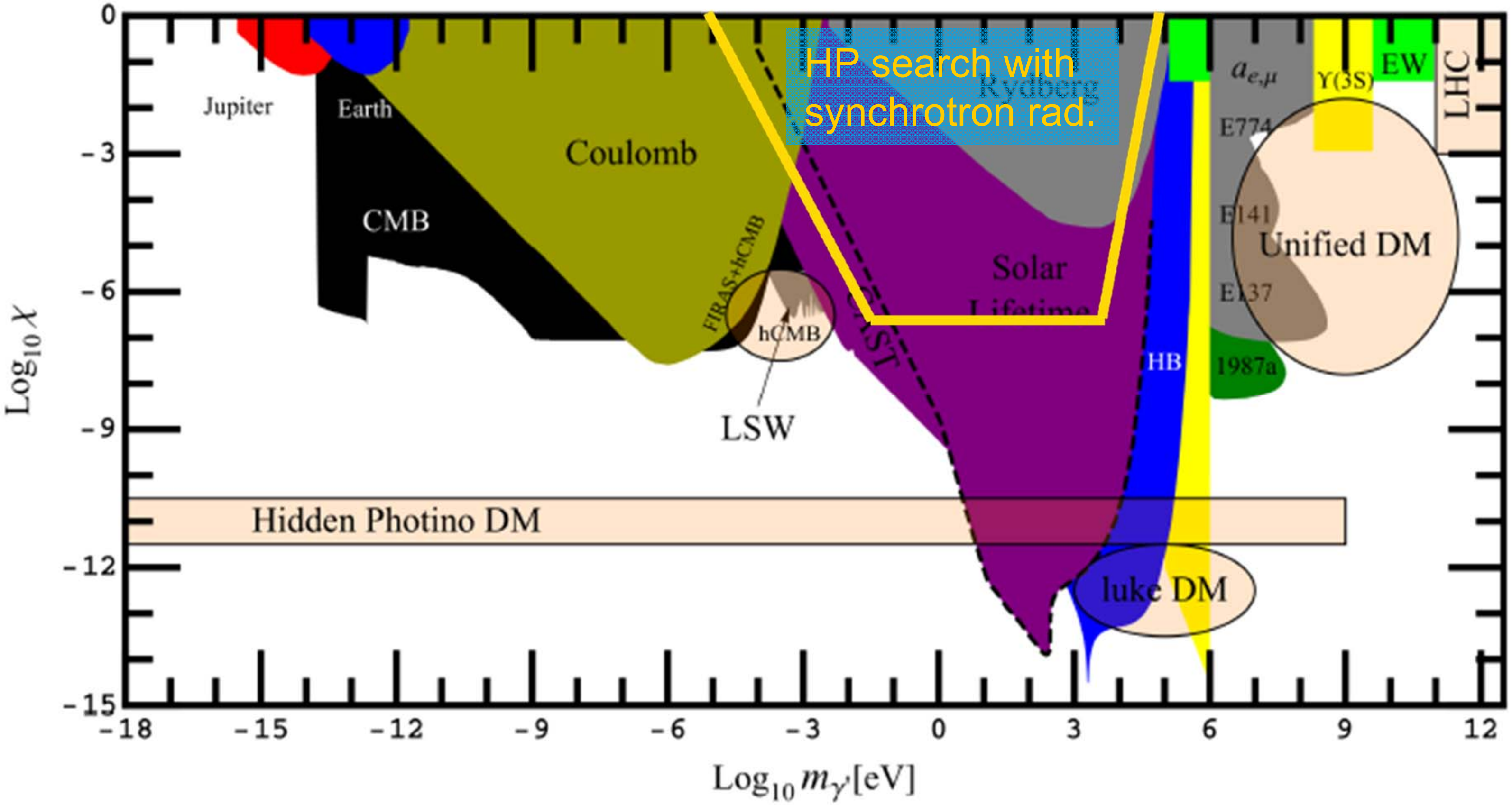
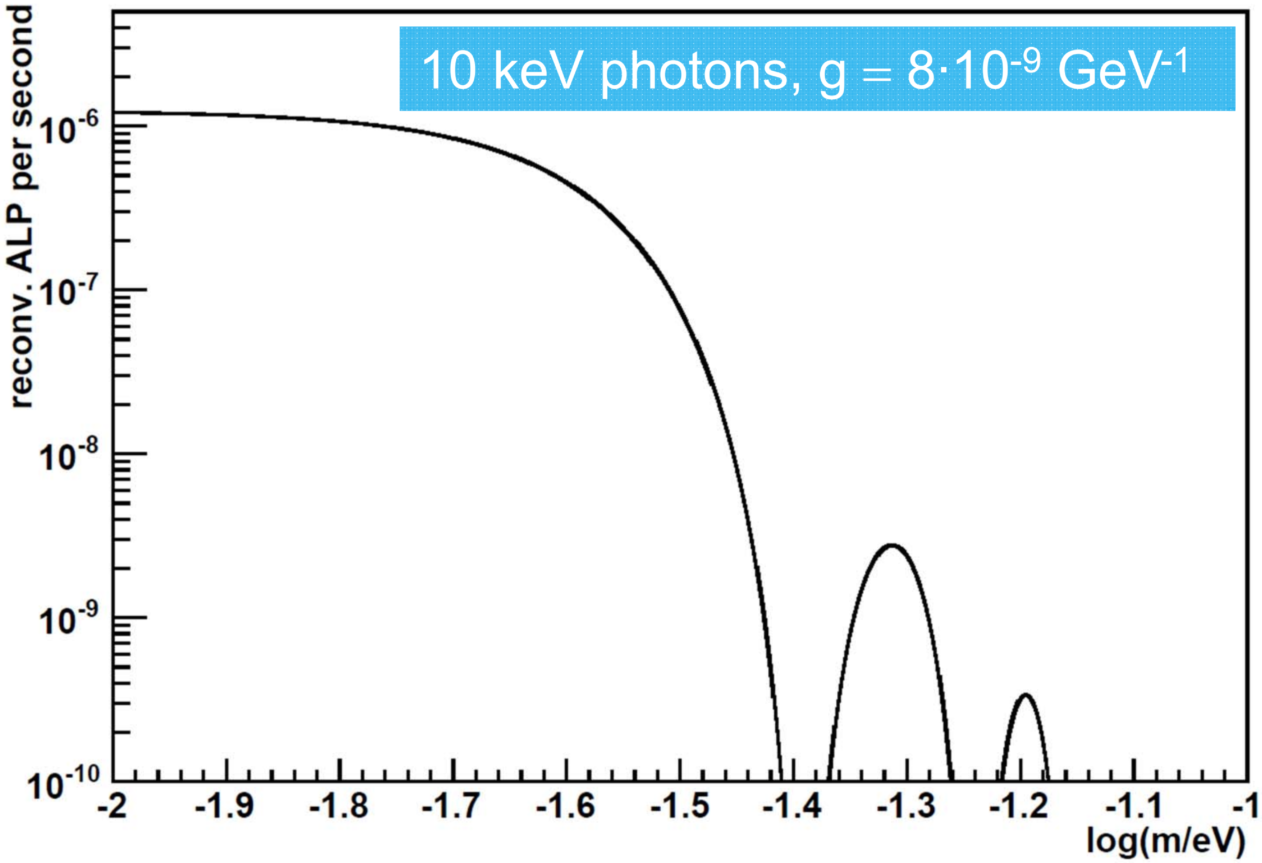


J. Jaeckel and A. Ringwald, arXiv:1002.0329 [hep-ph].

> Probes astrophysics results in the laboratory.

Search for Axion-like Particles

> Set-up: two CAST-like dipoles separated by a wall with
> L = 15 m, B = 10 T



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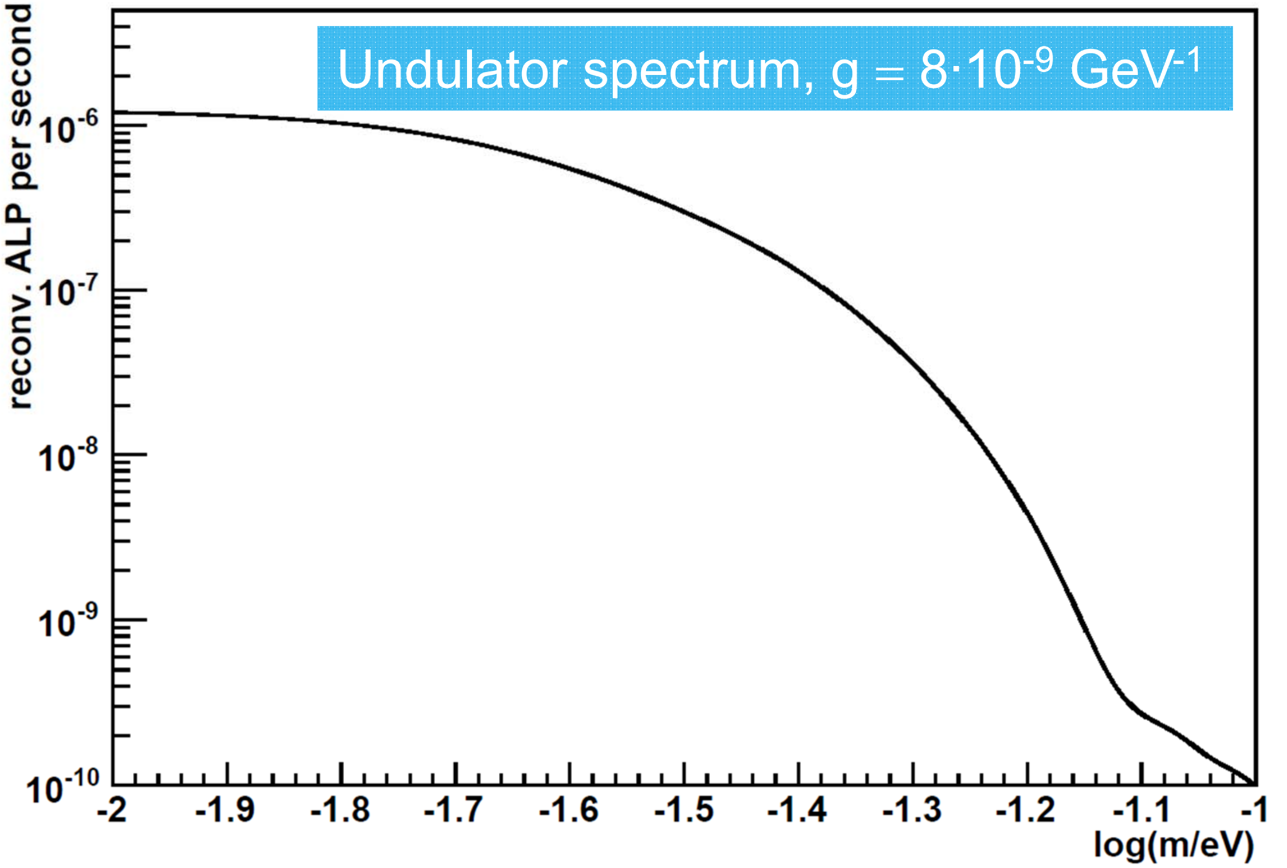

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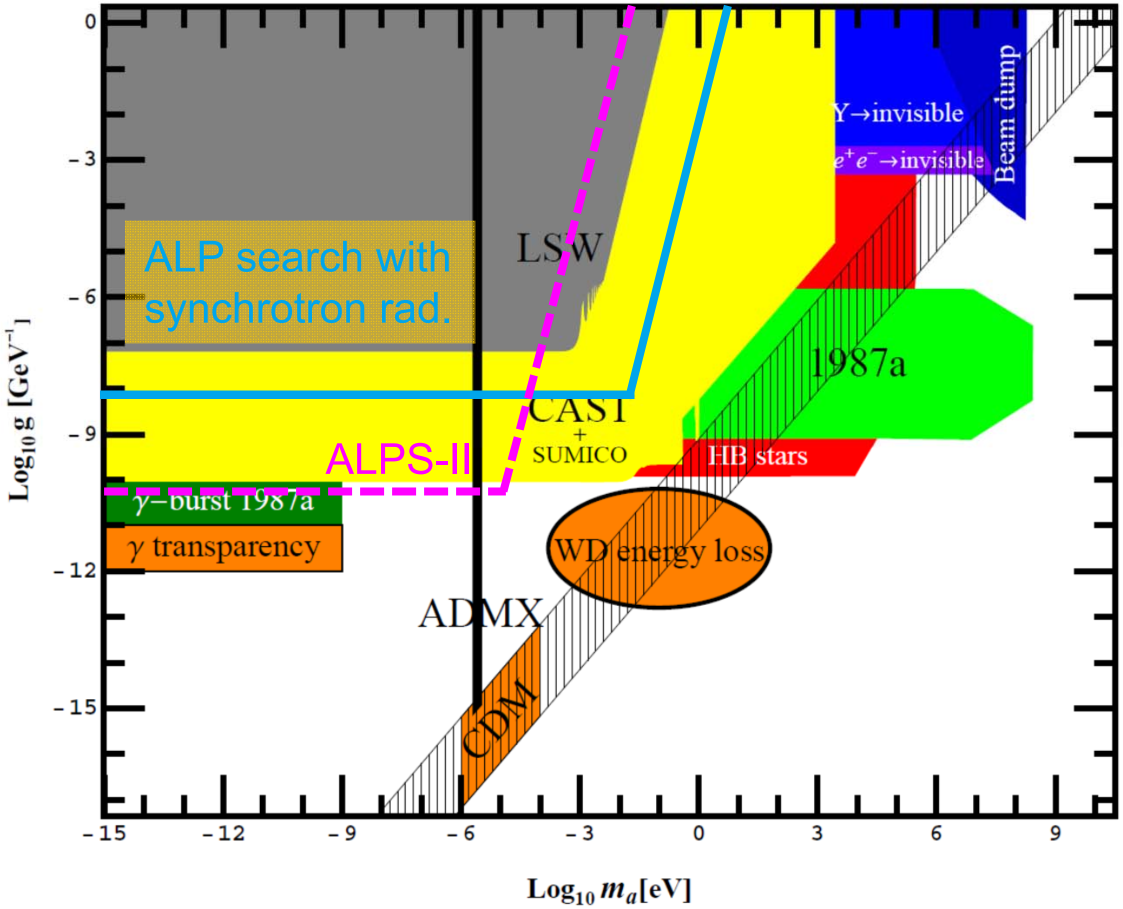


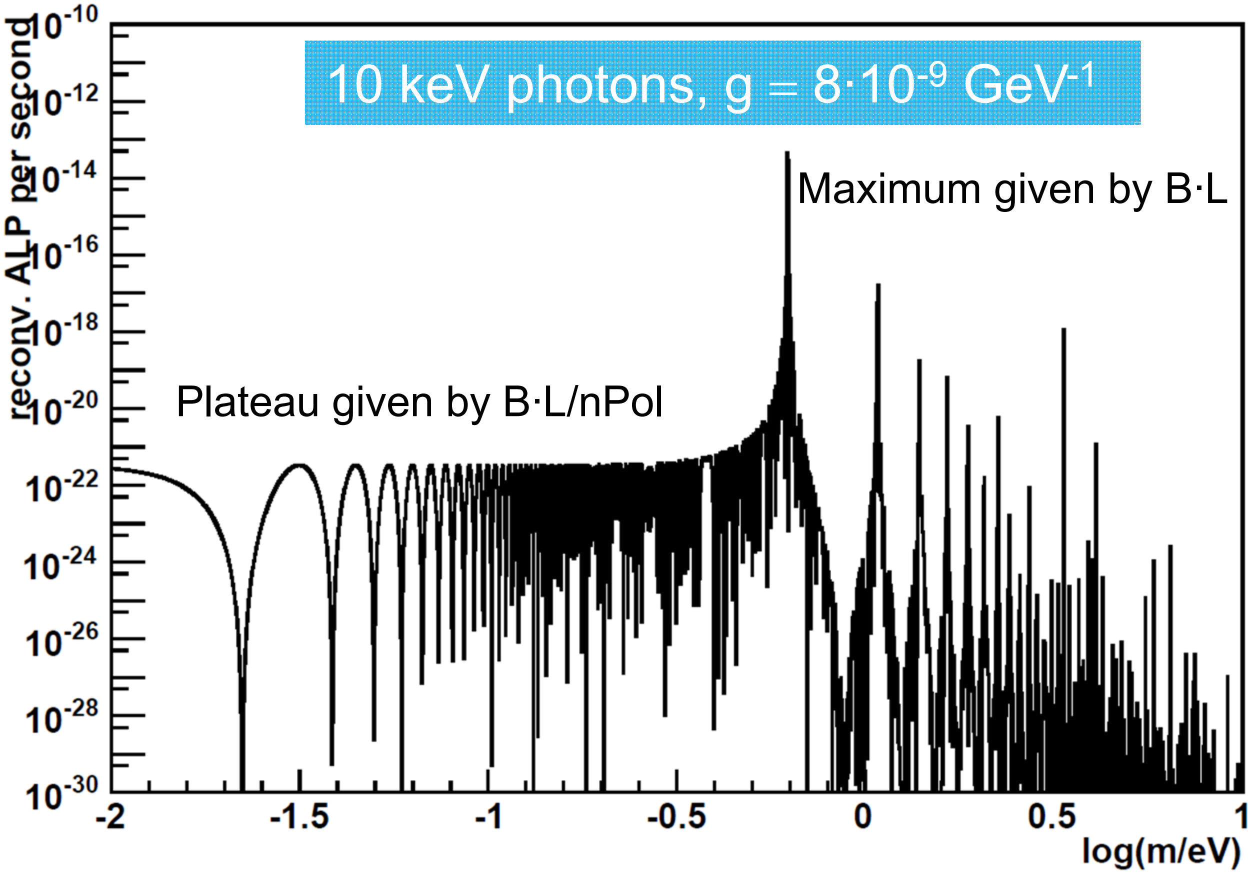
J. Jaeckel and A. Ringwald, arXiv:1002.0329 [hep-ph].

Not competitive, but probes some of the astrophysics results in the laboratory.

See also:
R. Rabadan, A. Ringwald, K. Sigurdson, *Photon Regeneration from Pseudoscalars at X-ray Laser Facilities*, *hep-ph/0511103*, Phys. Rev. Lett. 96 (2006) 110407.

Search for Axion-like Particles

> Set-up: undulator magnet in generation and regeneration part,
L = 25 m, B = 0.6 T, nPol = 781 (like SPring-8 undulator).



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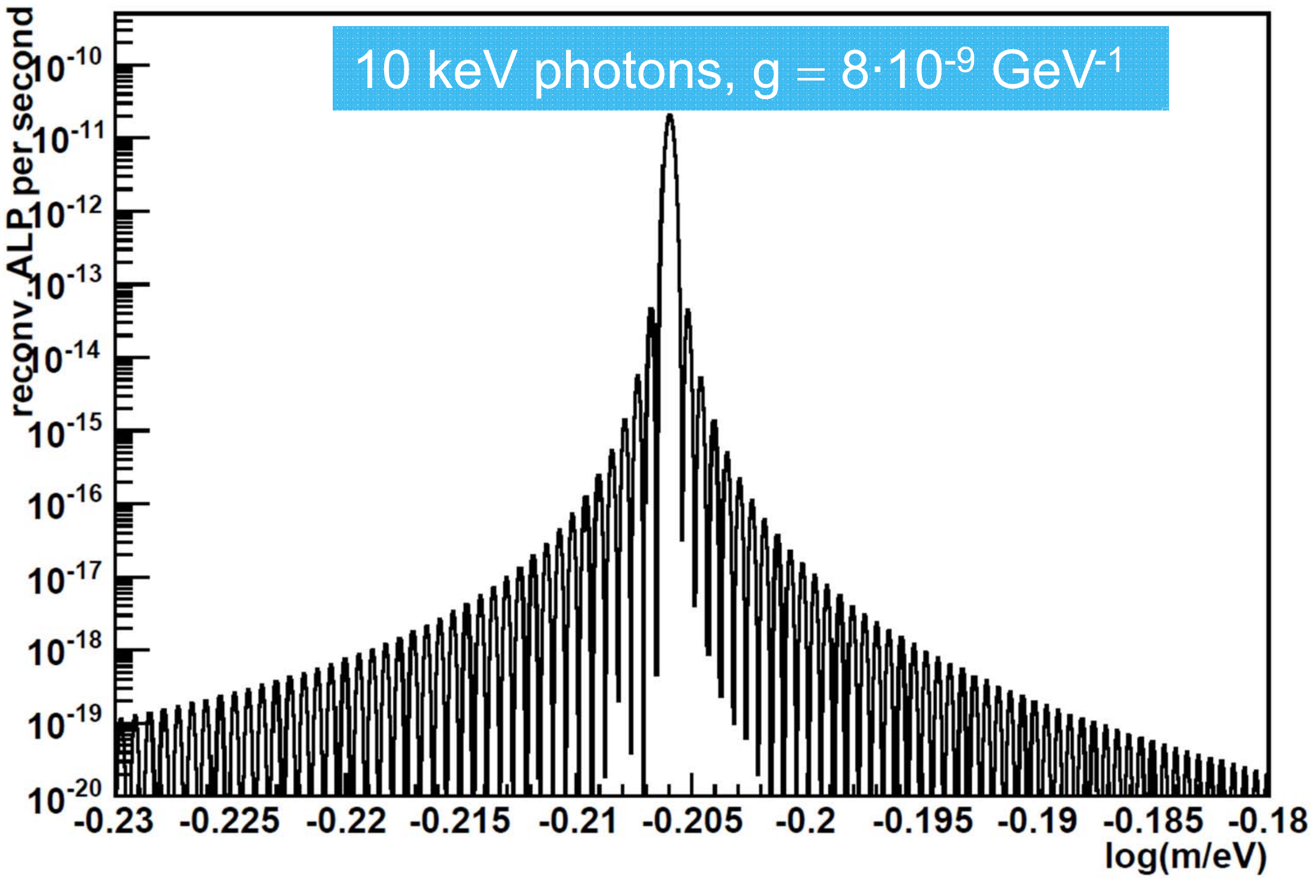

Sensitive only to "discrete" masses for $g \approx 10^{-7}$ GeV^{-1}, maximum sensitivity given by B·L (small compared to a LHC-dipole).

Search for Axion-like Particles

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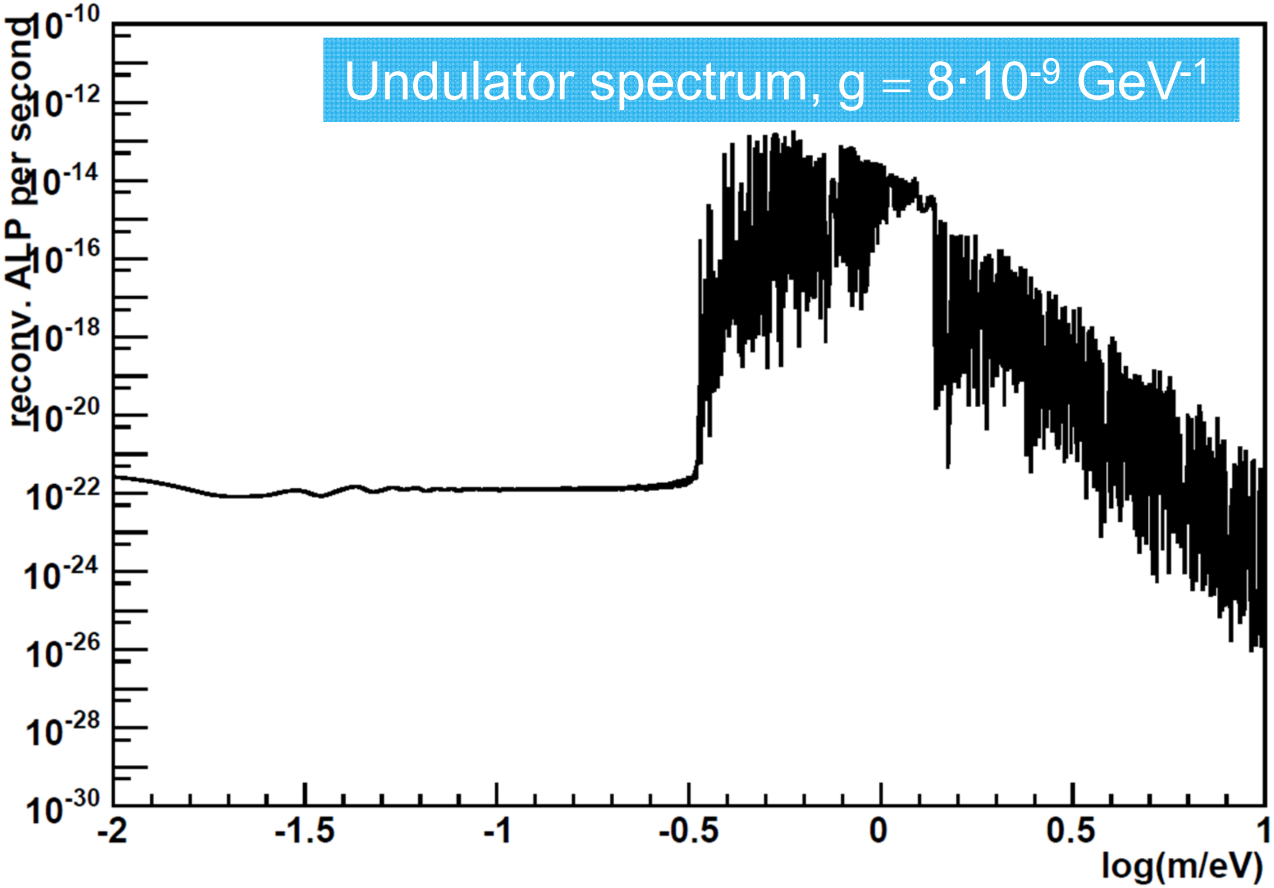
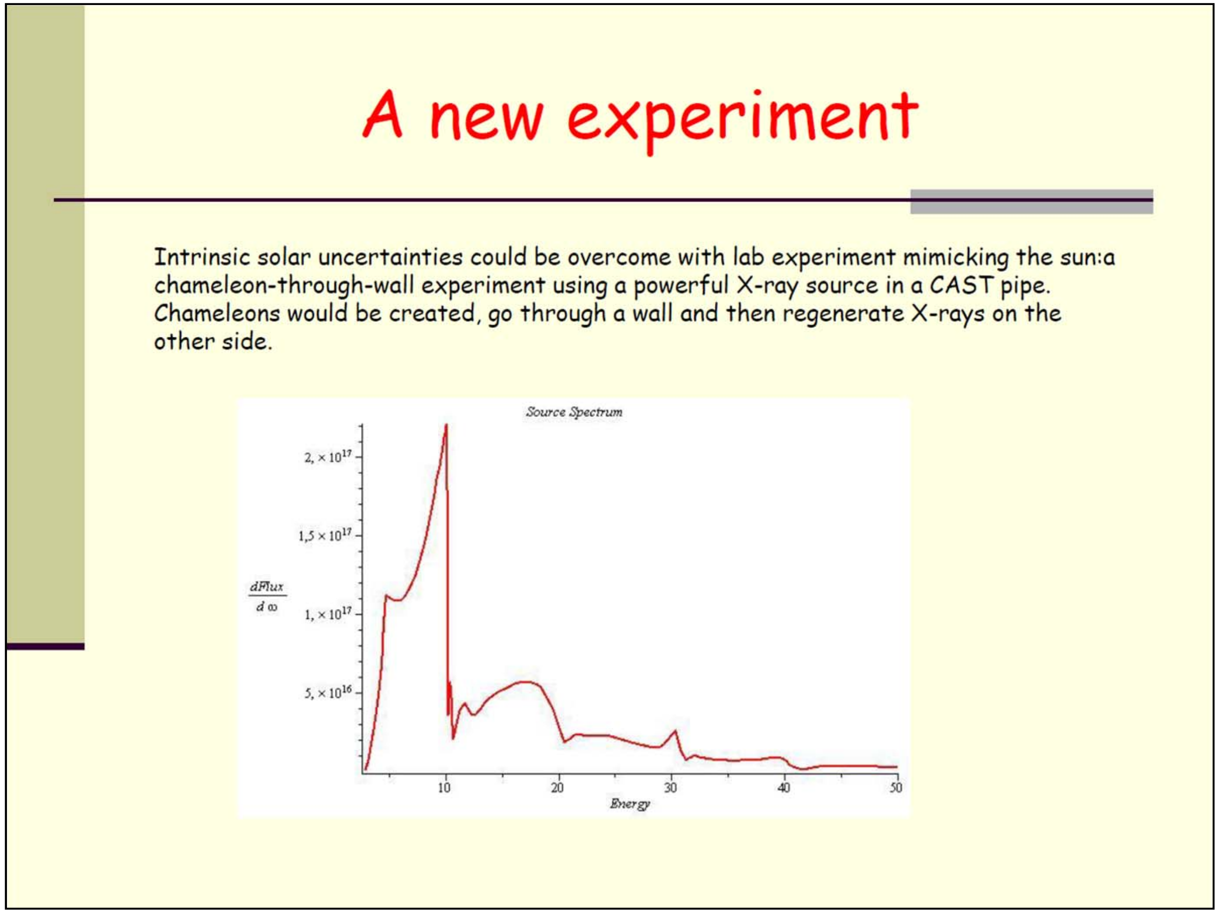


Could probe $g \approx 3\cdot 10^{-7}$ GeV^{-1}, hard to imagine a meaningful application.

Reminder: LSW with Chameleons

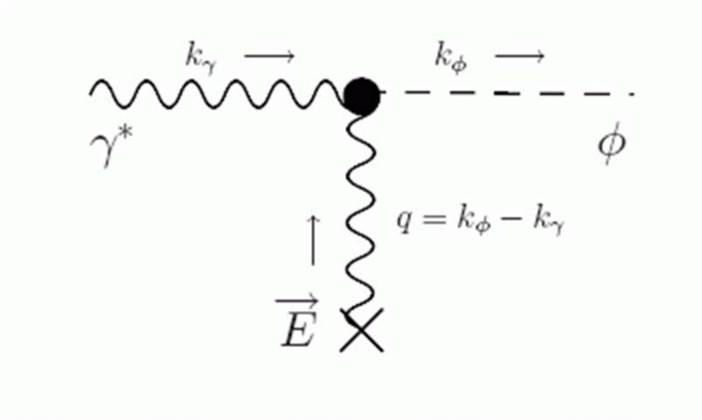
> See talk by P. Brax:
  keV Chameleons could make it through a wall!



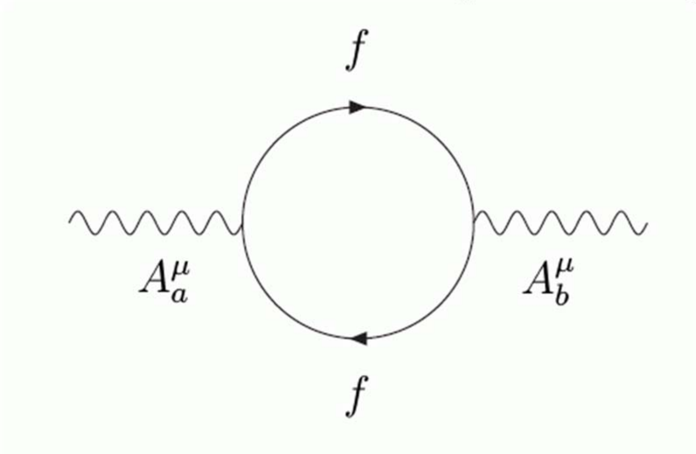
Possibility to probe Dark Energy in the laboratory?

New indirect WISP Searches?

Rotation = $g^2 \cdot (B \cdot \omega \cdot m_a^{-2})^2 \cdot \sin^2(m_a^2 l / 4\omega)$



Ellipticity = $g^2 \cdot (B \cdot \omega \cdot m_a^{-2})^2 \cdot ½ \cdot [m_a^2 l / 2\omega - \sin^2(m_a^2 l / 2\omega)]$



New indirect WISP Searches?

- Both effects are proportional to ω^2:
increase by a factor of 10^8 for 10 keV compared to optical light.
- New possibilities due to better polarization of SR radiation?

B. Marx et al., Optics Communications 284 (2011) 915–918

We report on the measurement of the highest purity of polarization of X-rays to date. The measurements are performed by combining a brilliant undulator source with an X-ray polarimeter. The polarimeter is composed of a polarizer and an analyzer, each based on four reflections at channel-cut crystals with a Bragg angle very close to 45°. Experiments were performed at three different X-ray energies, using different Bragg reflections: Si(400) at 6457.0 eV, Si(444) at 11,183.8 eV, and Si(800) at 12,914.0 eV. At 6 keV a polarization purity of 1.5×10^{-9} is achieved. This is an improvement by more than two orders of magnitude as compared to previously reported values. The polarization purity decreases slightly for shorter X-ray wavelengths. The sensitivity of the polarimeter is discussed with respect to a proposed experiment that aims at the detection of the birefringence of vacuum induced by super-strong laser fields.

Summary

> Light-Shining-through-Walls with Synchrotron Radiation:
  - Hidden photon: tests parameter regions probed by astrophysics only.
  - ALP: only relatively small additional parameter region accessible.
  - Chameleons: interesting, new approach to probe for Dark Energy in the laboratory.

> Polarization studies:
  - New possibilities with advance in polarization purity for X-rays?

> Reminder: K. Baker's talk on search for dark stuff at Jefferson Lab

> New ideas for new opportunities welcome!
  - PETRA III extensions at DESY under construction.
  - Beamlines at the European XFEL & at FLASH II under construction.