Axion-Like Particle Search

Prospects and Status of the ALPS Experiment

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DESY PRC Open Session

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Motivation – Design – Status

The Nutshell

ALPS ...

... is an acronym for Axion-Like Particle Search

... is a collaboration between DESY, Laser Zentrum Hannover e.V. and Hamburger Sternwarte

... is planned to test the interpretation of recent experimental results in terms of new very light bosons (axion-like particles)

Axions (or axion-like particles) ...

... have initially been proposed to explain the strong CP problem

... are (light) weakly interacting (pseudo-) scalars

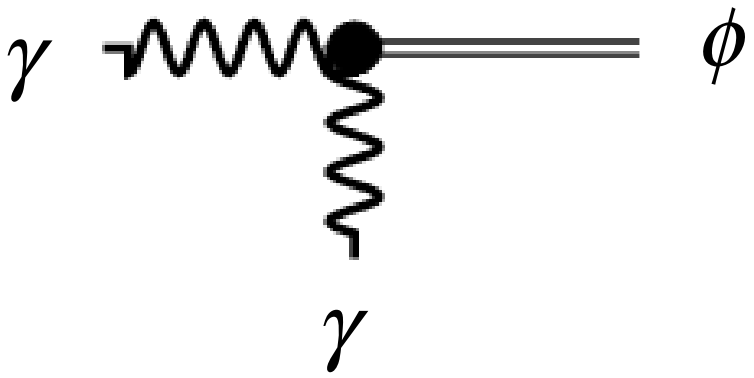
... naturally occure in string theories

... are possible candidates for dark matter

... have an (effective) coupling to photons

ALPs in the Laboratory

Quantitative description by effective Lagrangian from
QED $\oplus$ light boson $\oplus$ γ-γ-ϕ vertex

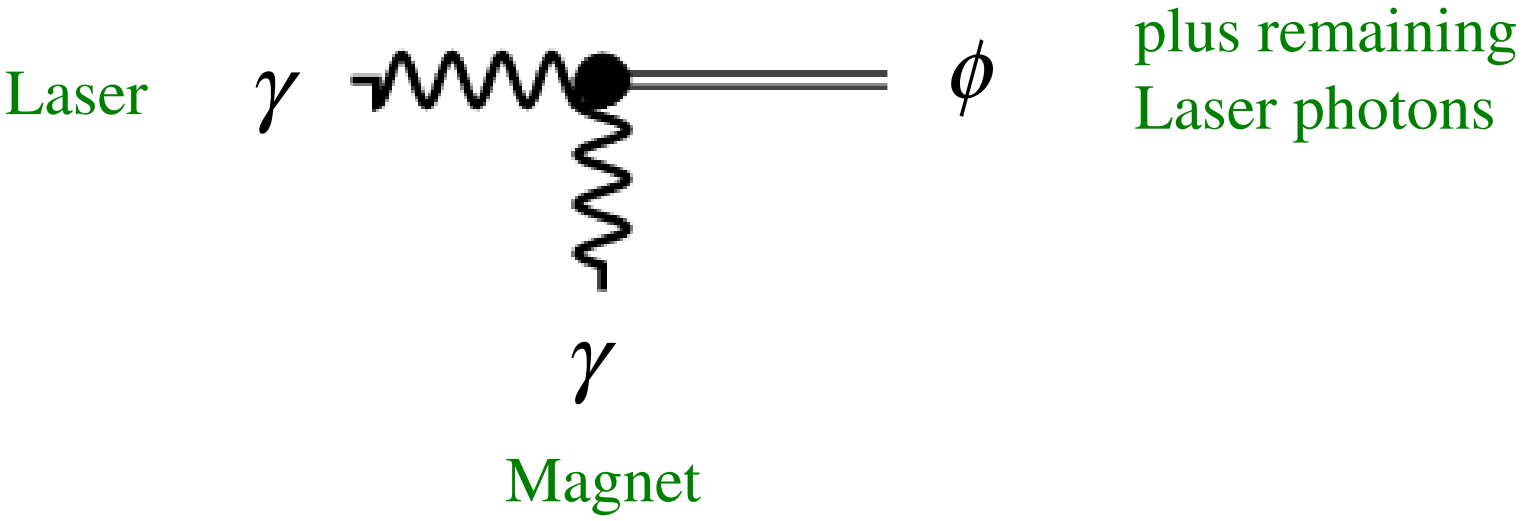


Model independent description with two free parameters:
ALP mass m_ϕ and γ-γ-ϕ coupling g

ALPs in the Laboratory

Photon-to-ALP conversion – polarization-dependent attenuation

$\Rightarrow$ apparent rotation of (linear) polarization axis

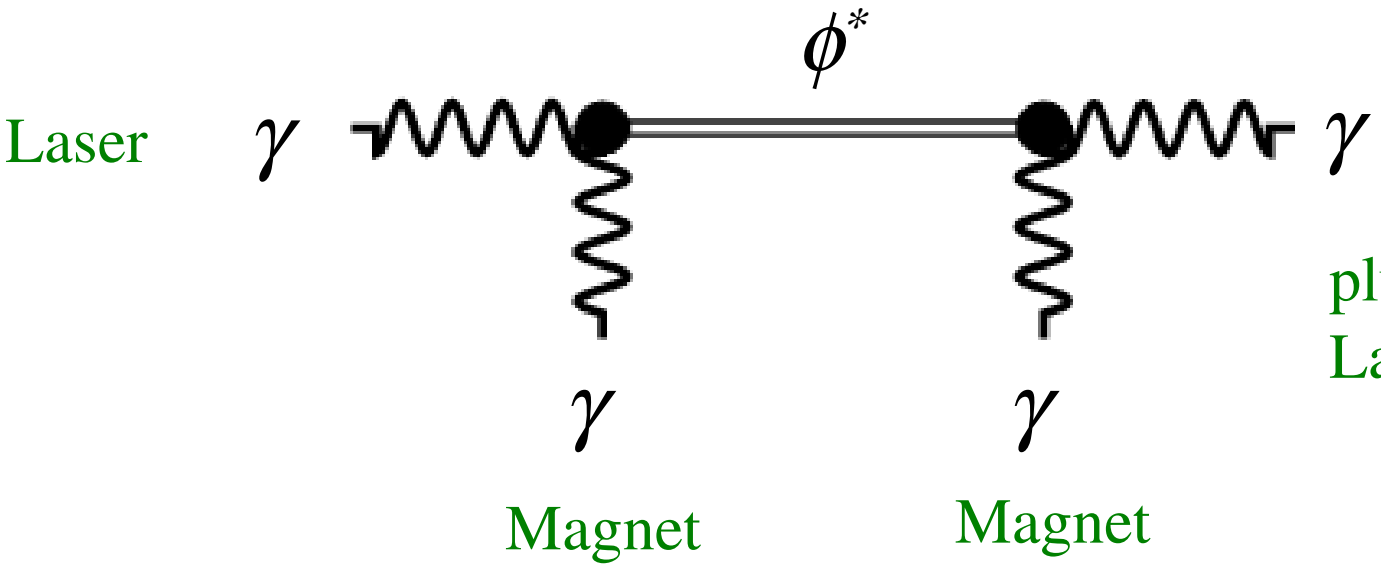


Observation reported by PVLAS, exclusion limits from BFRT

ALPs in the Laboratory

Propagator corrections – polarization-dependent deceleration

$\Rightarrow$ arising ellipticity from linear polarization



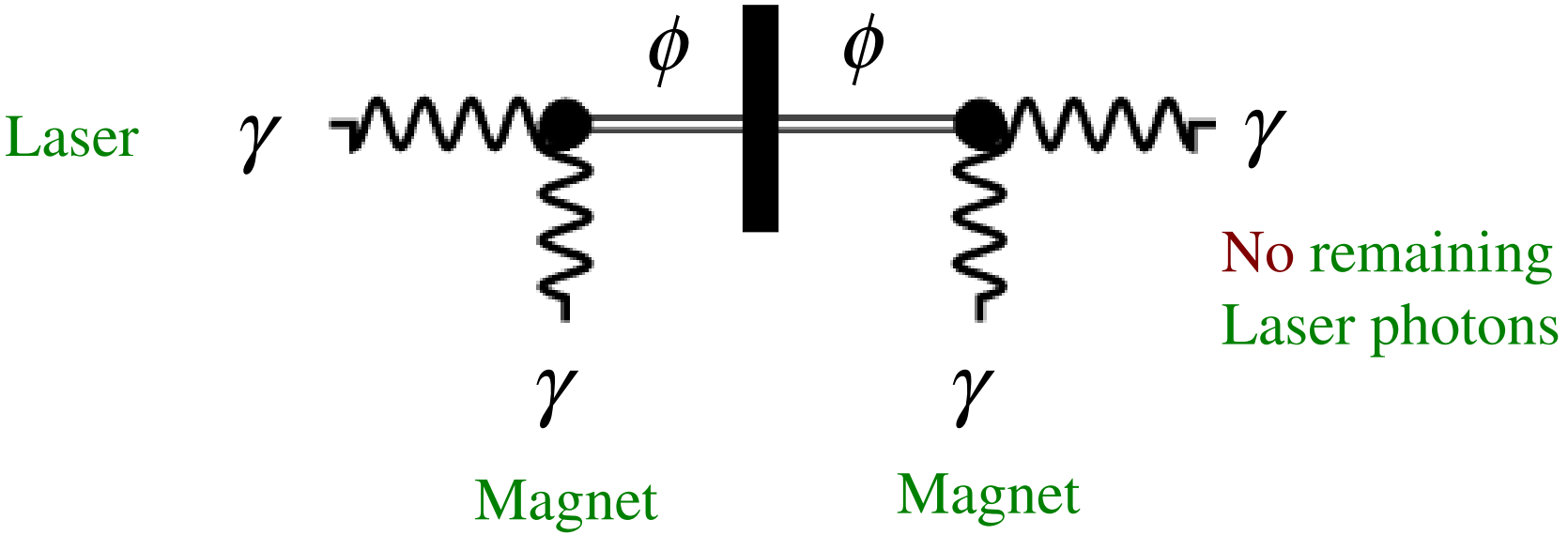
plus non-reacting
Laser photons

Exclusion limits from BFRT

ALPs in the Laboratory

Photon-ALP-photon conversion – light shining through a wall

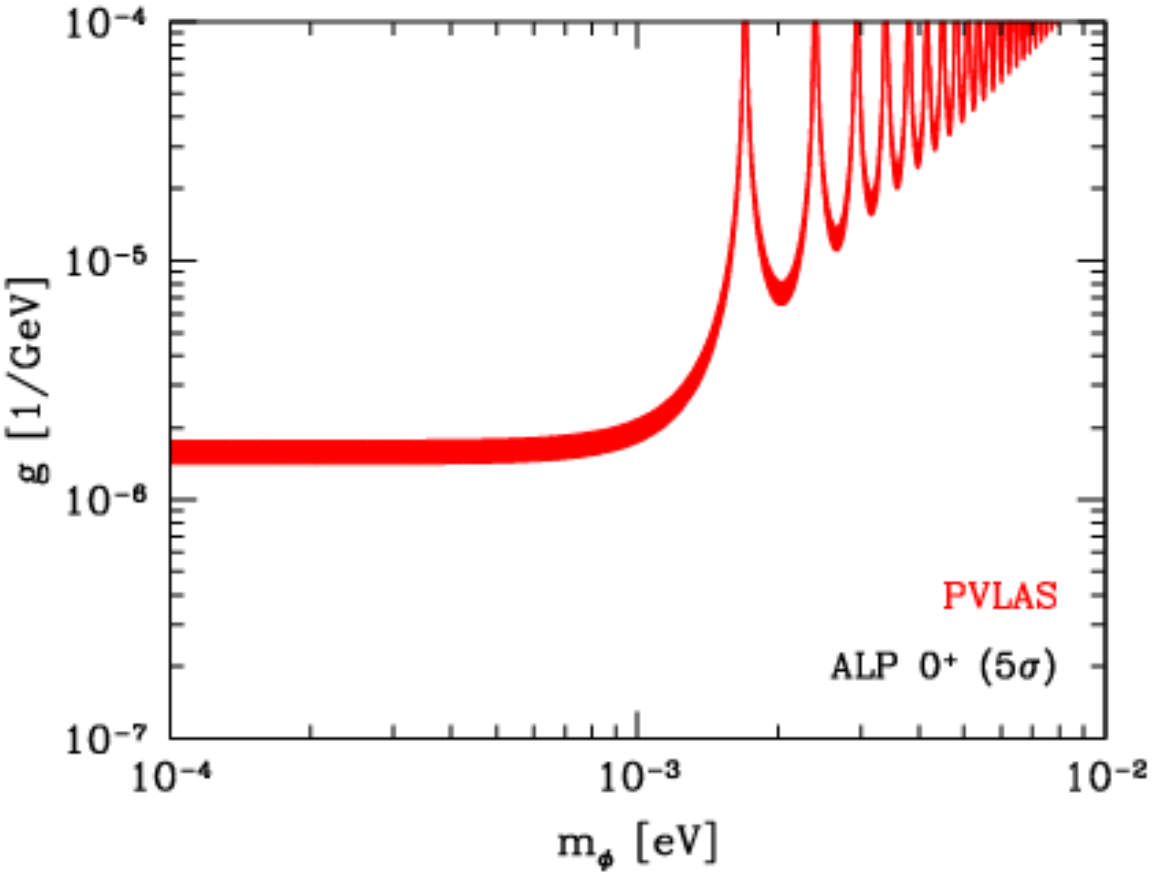
$\Rightarrow$ direct ALP detection in <u>regeneration</u> only



Exclusion limits from BFRT, process at ALPS

Experimental Situation

PVLAS observes polarization rotation, which can be interpreted as photon-to-ALP conversion



Experimental Situation

PVLAS observes polarization rotation, which can be interpreted as photon-to-ALP conversion with allowed band in m_ϕ-g plane

BFRT places limits from the observation of
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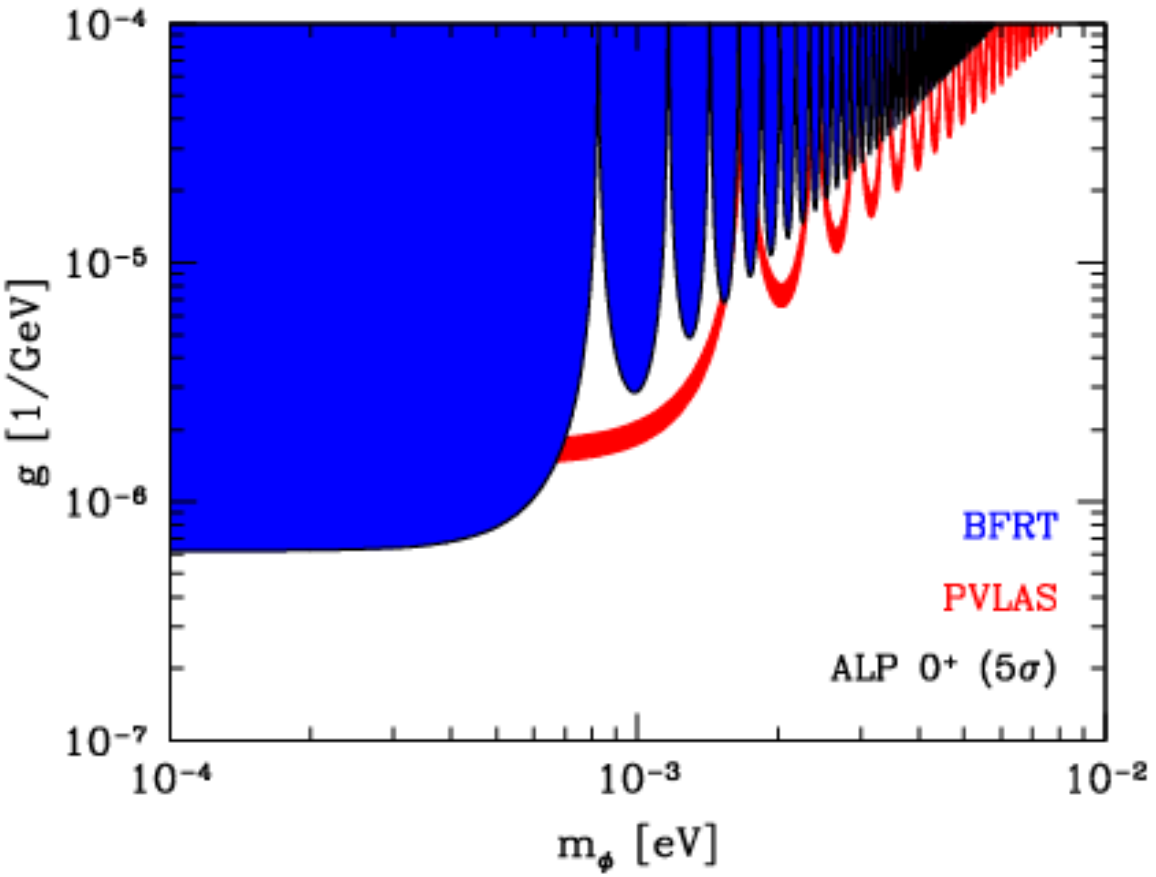

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- no rotation
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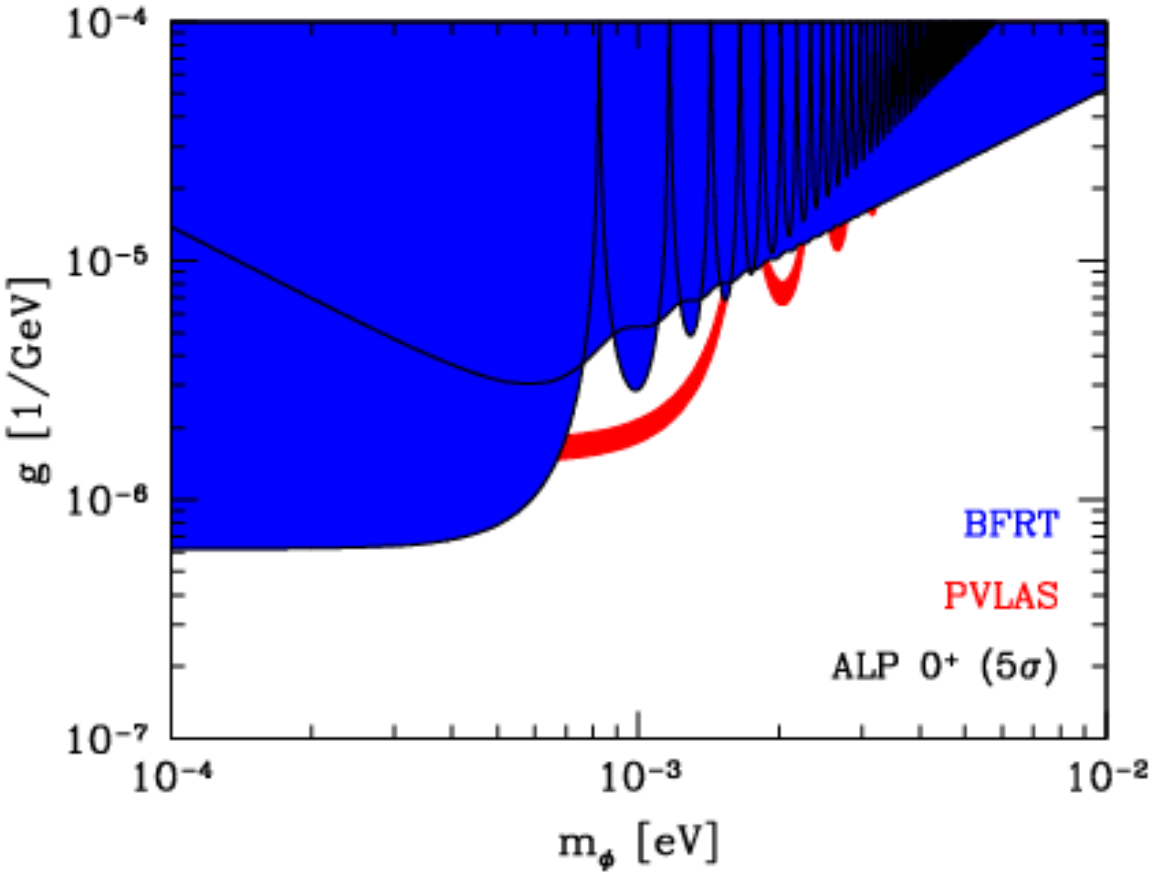

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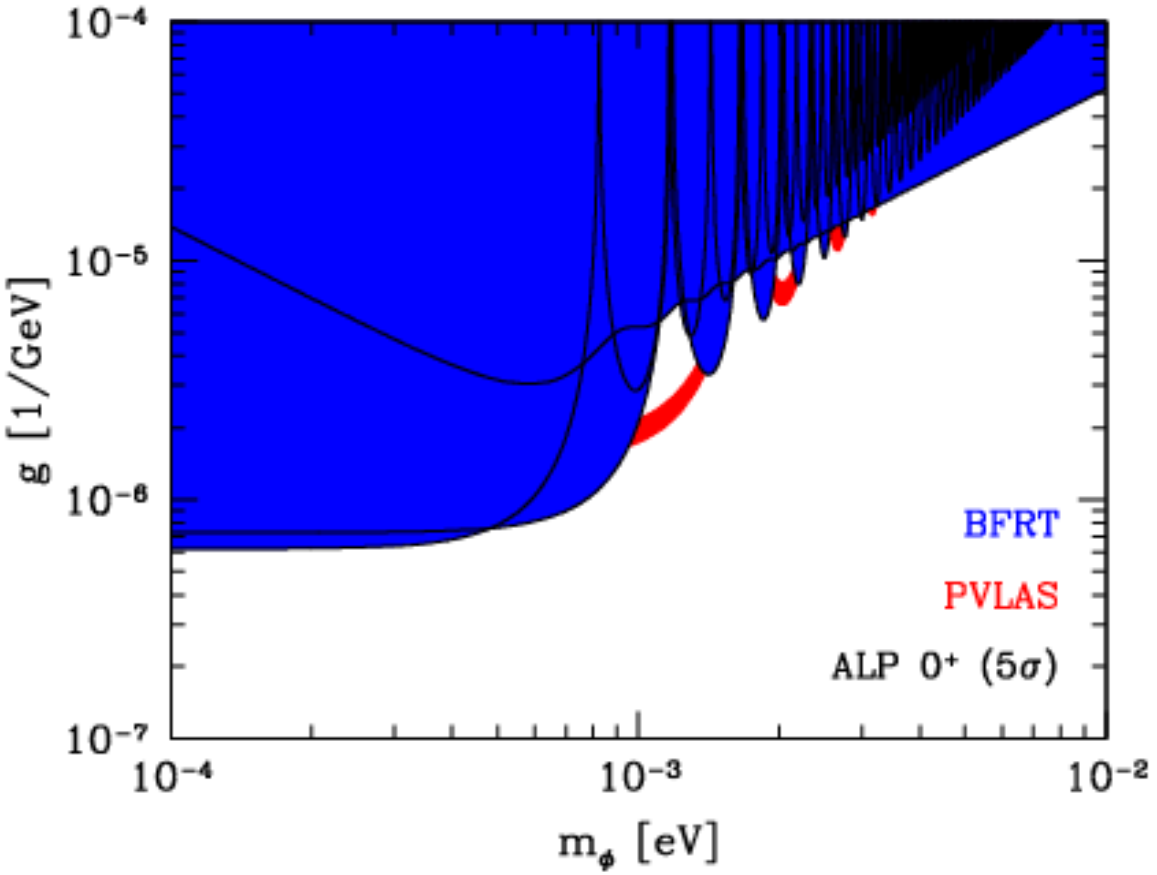

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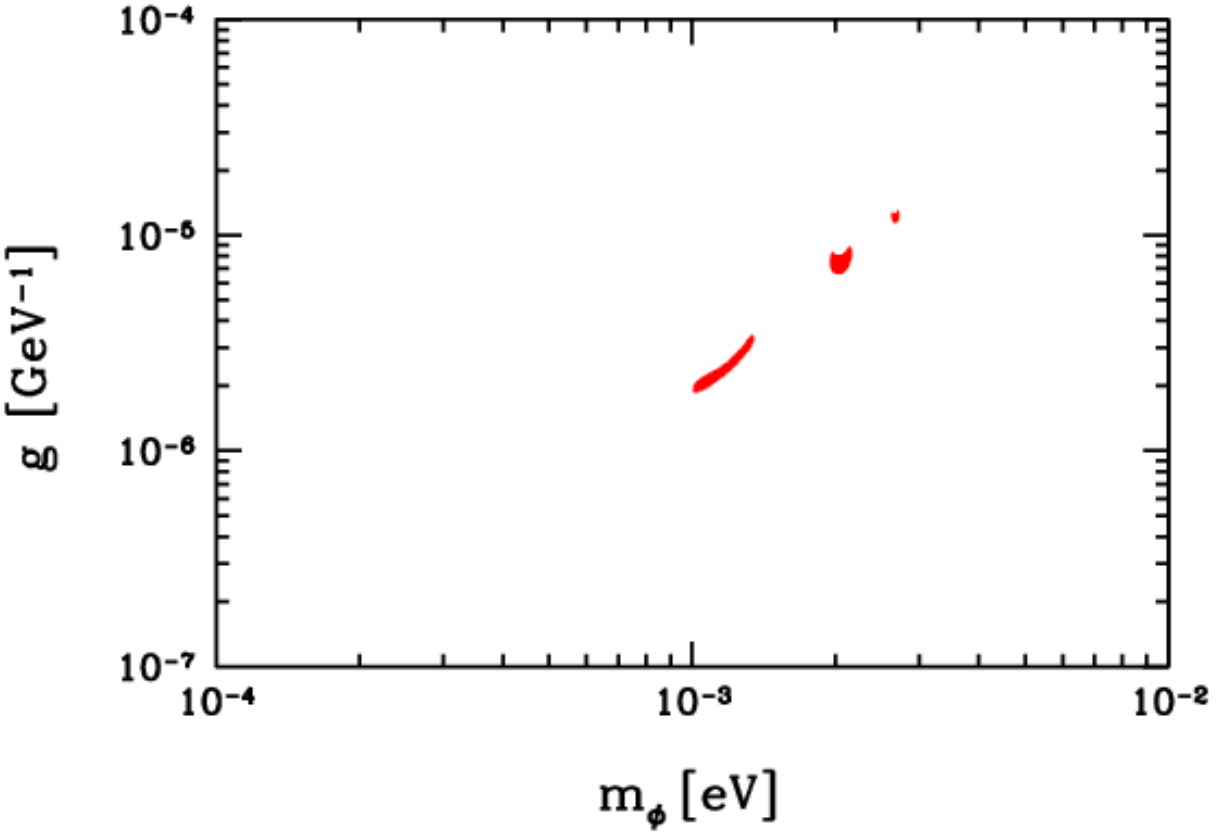
Combination exhibits three allowed regions in parameter space, which ALPS will explore



ALPS Setup

ALPS is planned around a spare HERA proton dipole magnet

$\phi - \gamma$ conversion region

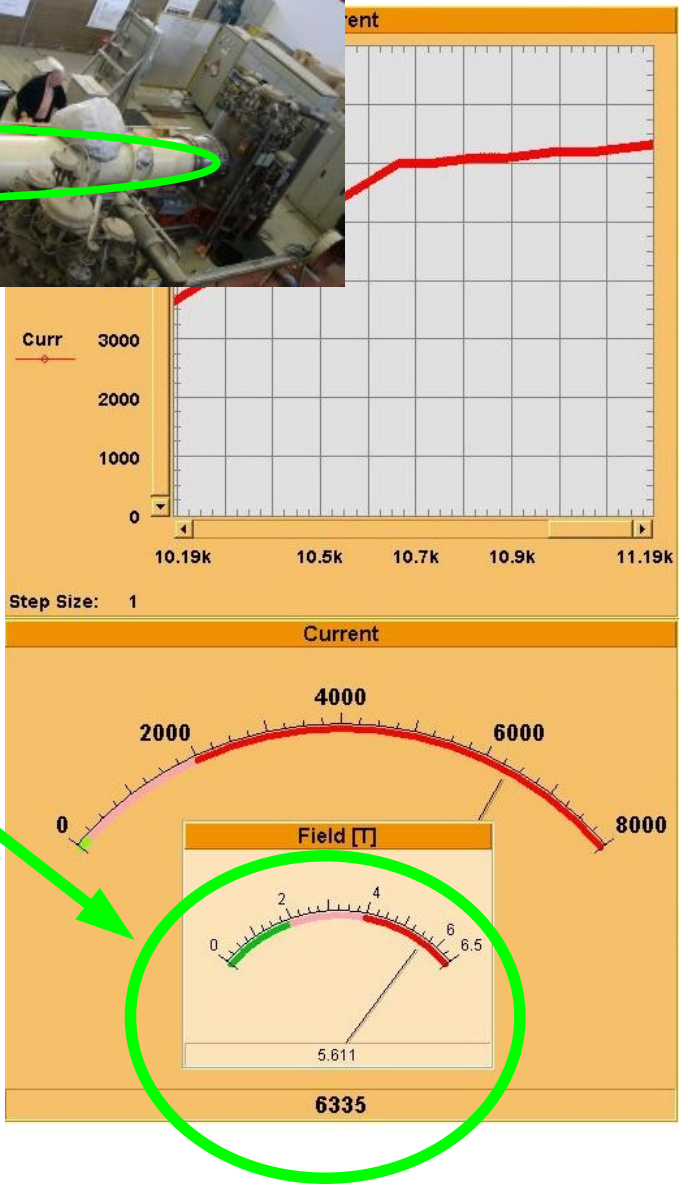
$\gamma - \phi$ conversion region

Detektor

Barrier

Laser

ALPS Setup



Magnet:

- HERA spare dipole BR120 in Bld. 55
- Fully connected and operational
- Reached 5.6 T at 6335 A during test operation last September

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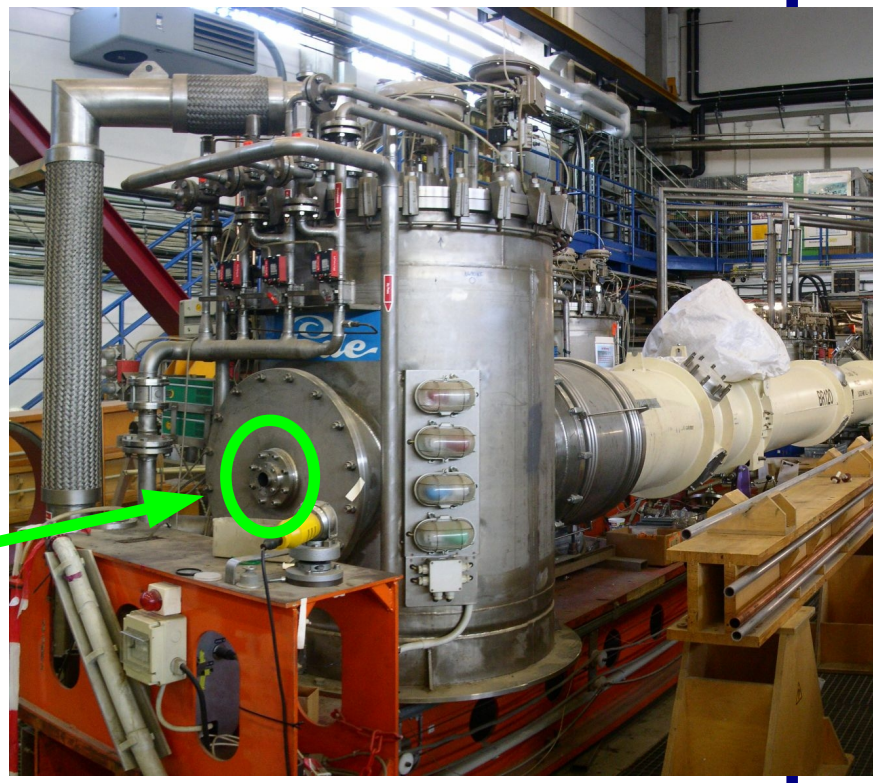
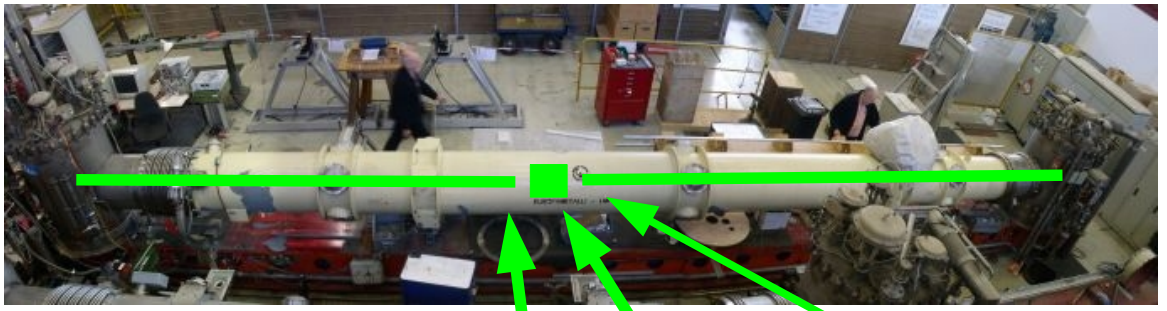
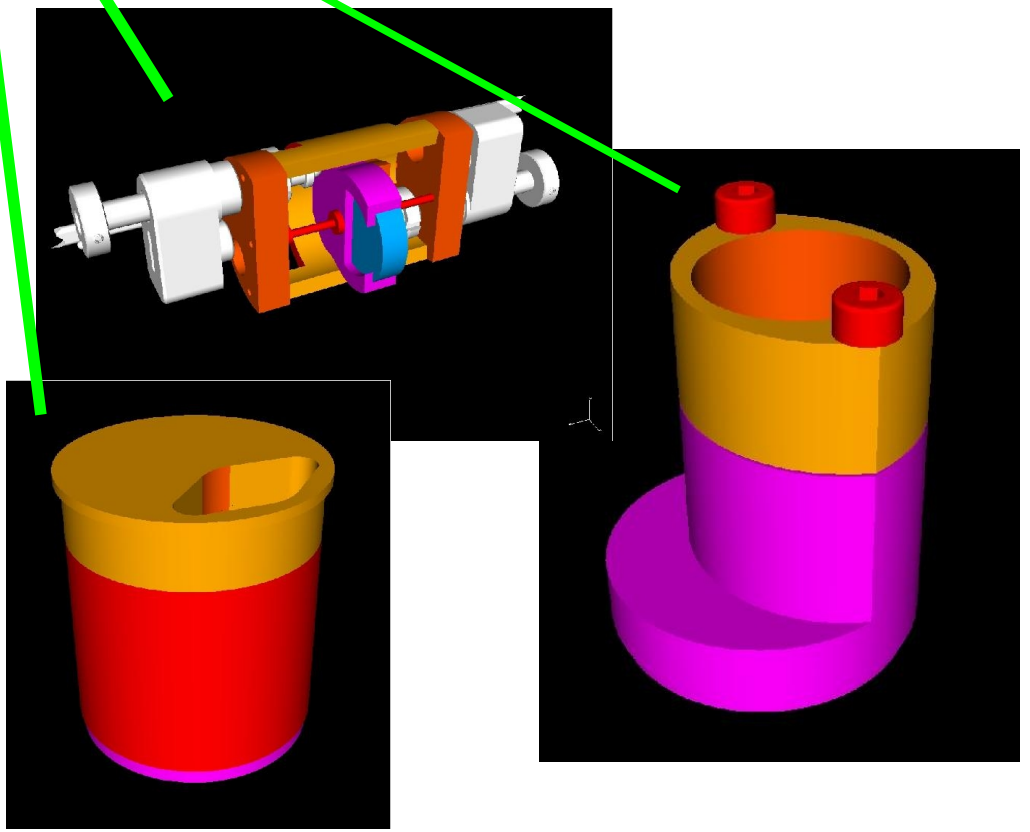


- Equipped with warm Ti-tube, which will host the ALPS magnet insert unit

ALPS Setup

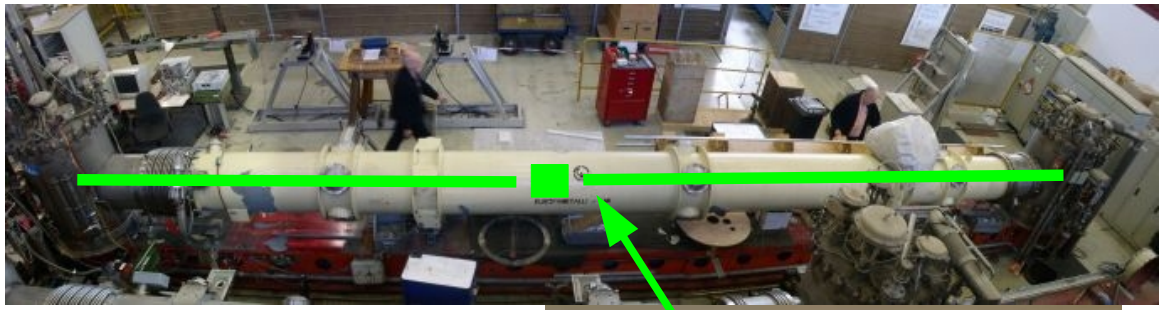




Magnet Insert Unit:

- Vacuum tubes on either side
- CAD designs of parts inside the magnet are ready

ALPS Setup



Magnet Insert Unit:

- Vacuum tubes on either side
- CAD designs of parts inside the magnet are ready

- First components crafted
- Vacuum tests successful

ALPS Setup

Laser:

- Will be hosted in hermetic container
- Civil engineering ongoing

- Pulsed laser with 532nm and 40W under construction at LZH
- Complete system expected at DESY end of June

ALPS Setup

Detector:

Start-up configuration:

- Astronomy CCD camera
- Plug-and-play USB connection
- 1 Hz noise rate (specifications)
- Sensitive to <1 Hz signal rate or regeneration probability of 10^{-20} with foreseen laser and less than 20 min exposure

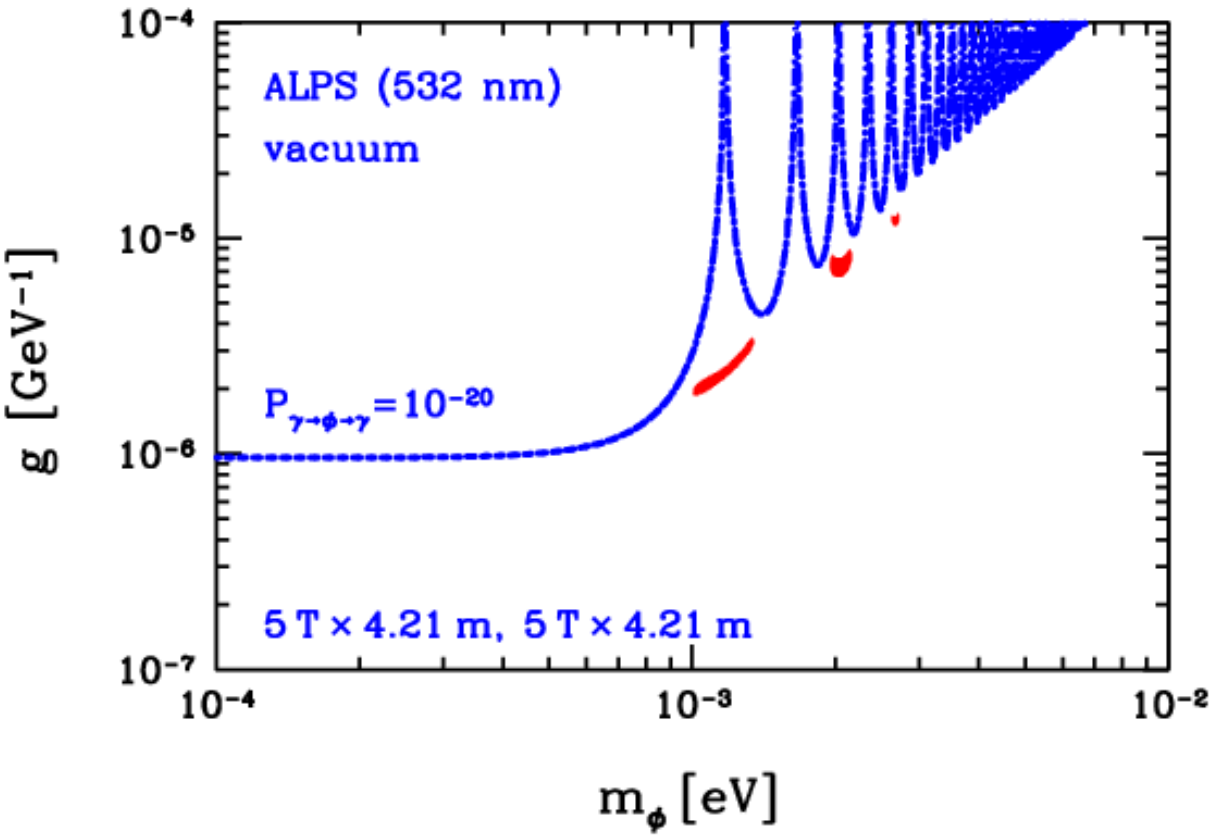
ALPS Sensitivity

Reconversion probability with in ideal magnet:

$$P = \left(\frac{g B}{q} \sin \frac{qL}{2} \right)^4 \qquad q = \frac{m_\phi^2}{2 E_\gamma}$$

Optimal sensitivity for given B and L for vanishing ALP mass

Generic setup cannot explore parameters allowed by PVLAS+BFRT



ALPS Sensitivity

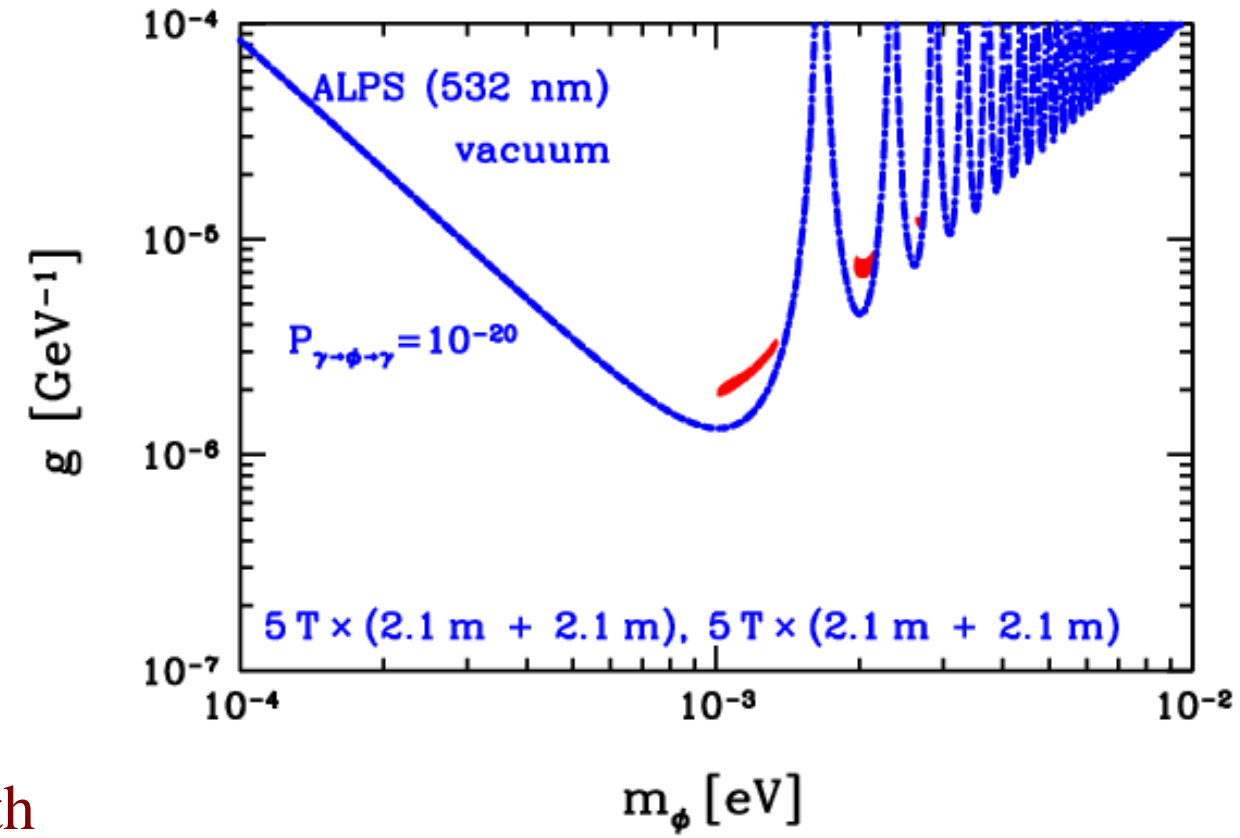
Reconversion probability with one phase shift per region:

$$P = \left(\frac{g B}{q} \sin \frac{qL}{2} \tan \frac{qL}{4} \right)^4$$

Shifting photon phase inside conversion regions introduces additional term

Best sensitivity now at non-zero q / m_ϕ

Sensitive to PVLAS+BFRT with one shift by π after half of conversion path



ALPS Potentials

ALPS ...

... is sensitive to discover or exclude the axion-like particle possibly explaining the PVLAS+BFRT anomaly

... design is influenced by foreseen systematical checks: laser injector, detector side of vacuum tubes, modularity

... will allow to measure the mass of this particle by scanning the refraction index n with low pressure gas, which changes

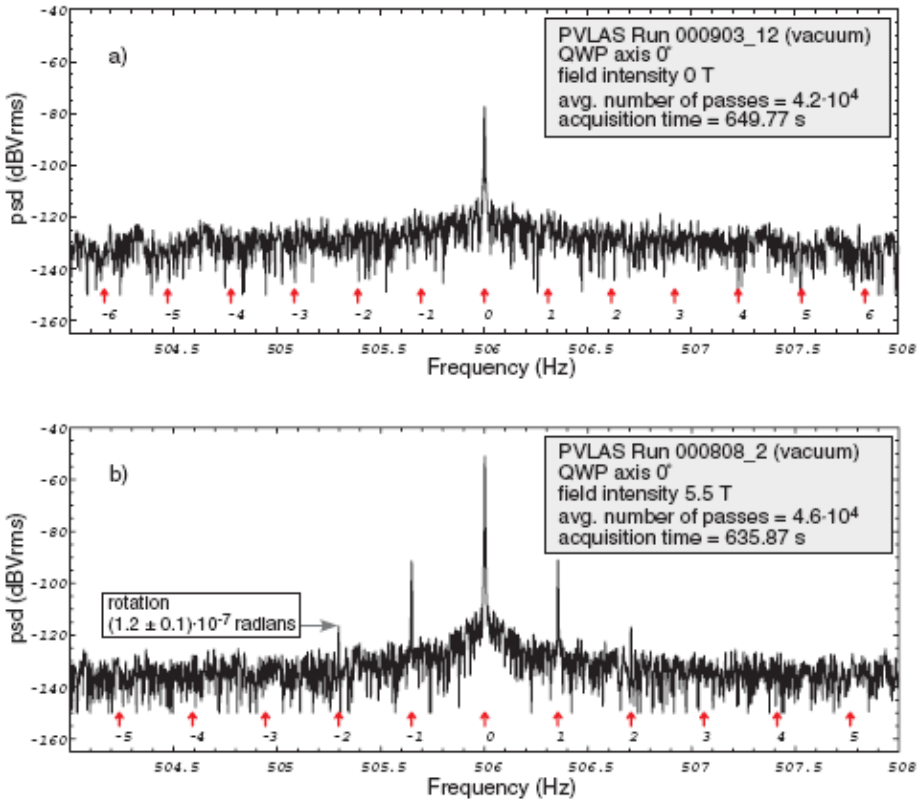
$$q = \frac{m_\phi^2}{2E_\gamma} + 2(n-1)E_\gamma$$

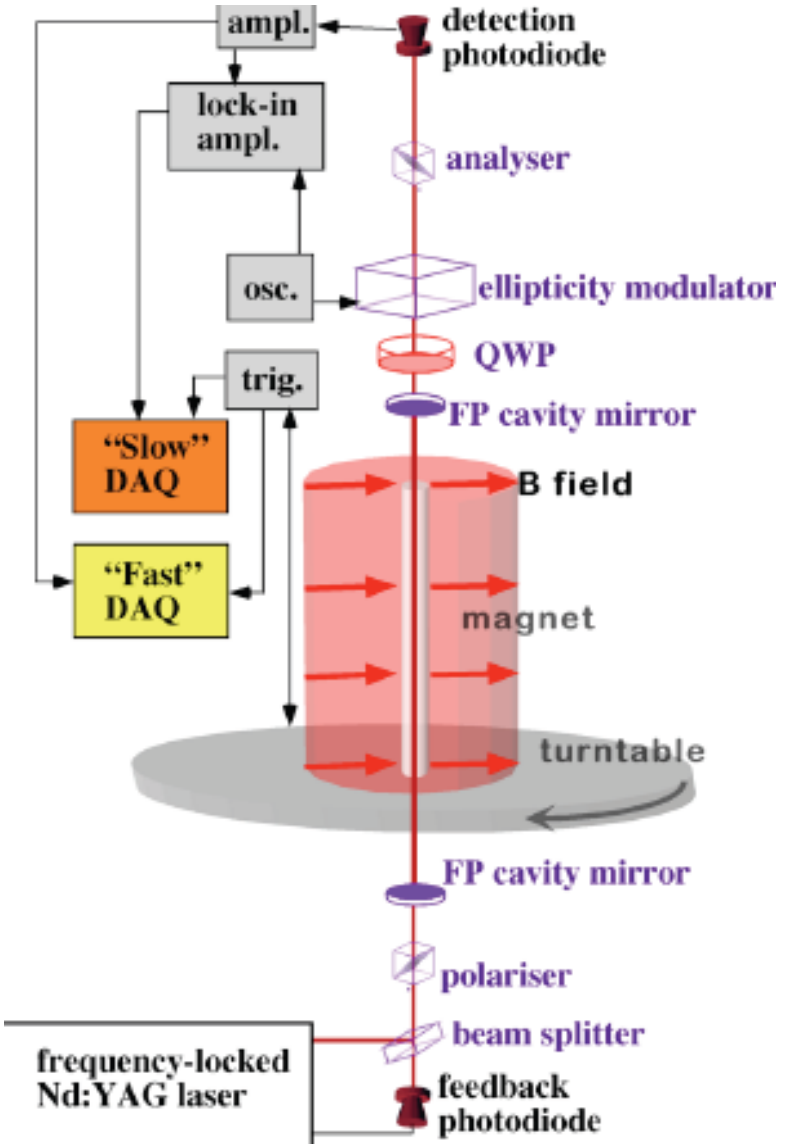
... data can be used to set limits on the existence of para-photons (studies are ongoing to quantify the expected reach)

... is not sensitive to pair-production of milli-charged particles, another interpretation of the PVLAS+BFRT anomaly

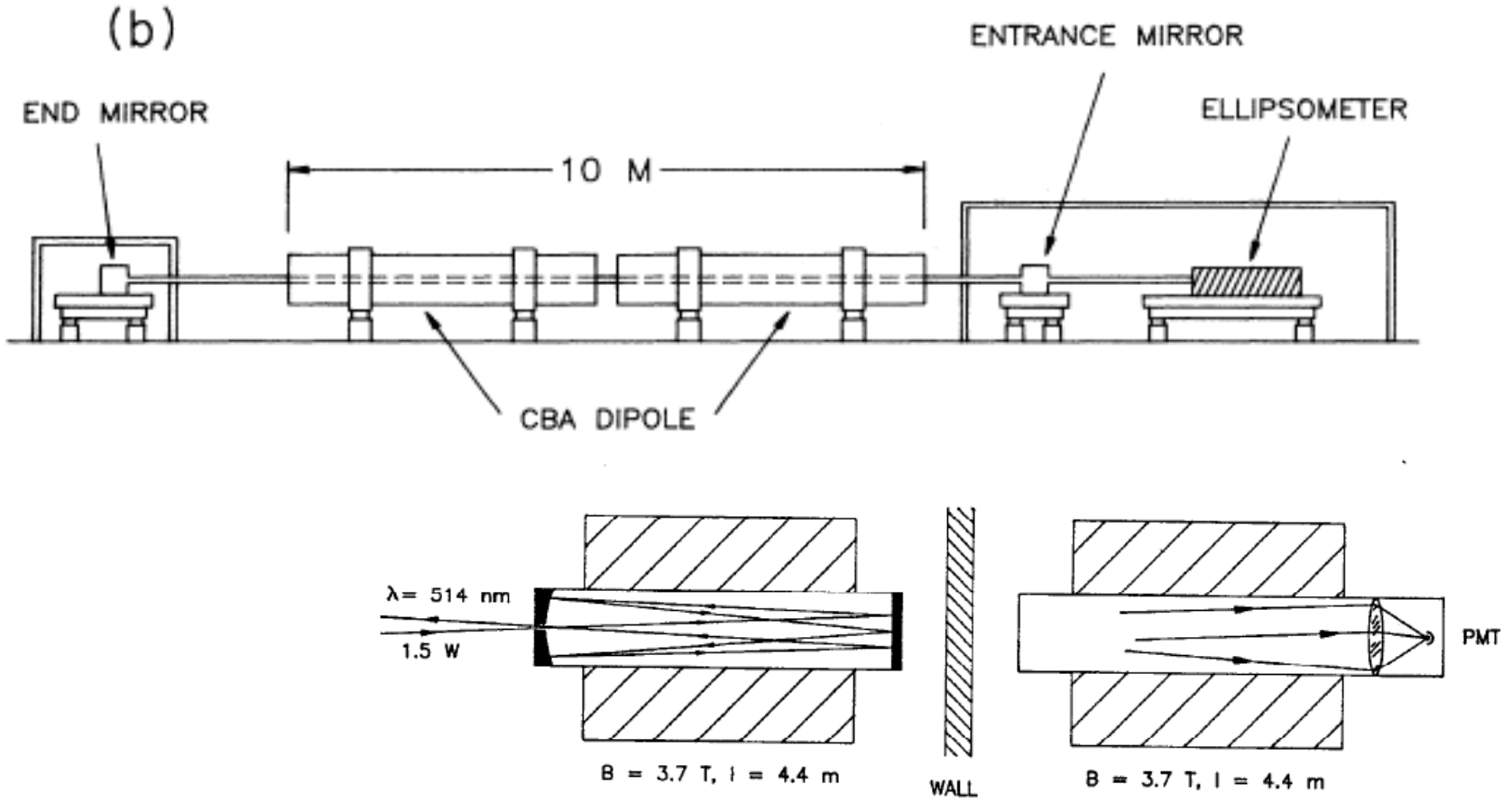
Backup

Polarizzazione del Vuoto con LASer

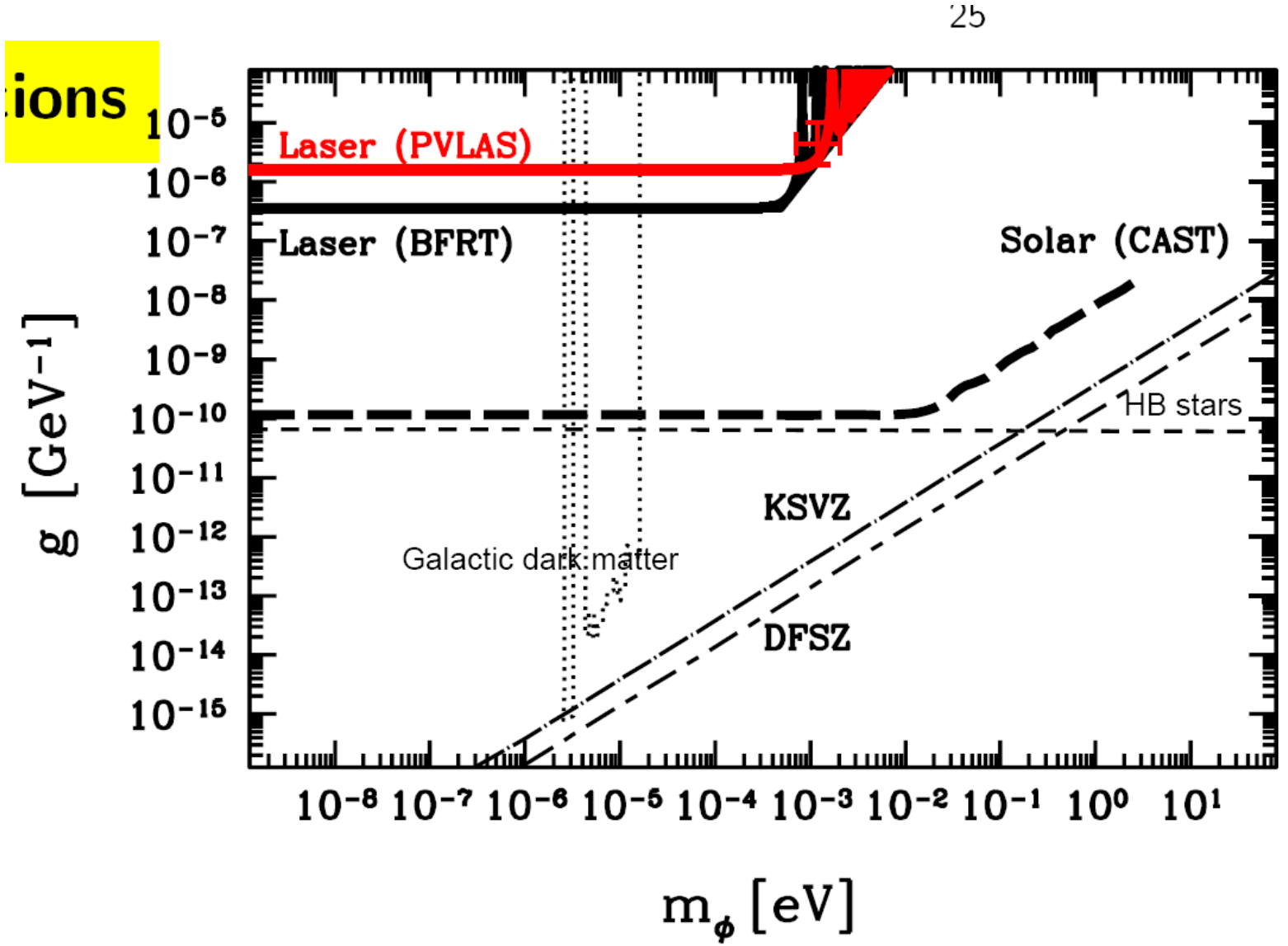




Brookhaven – Fermilab – Rochester – Trieste

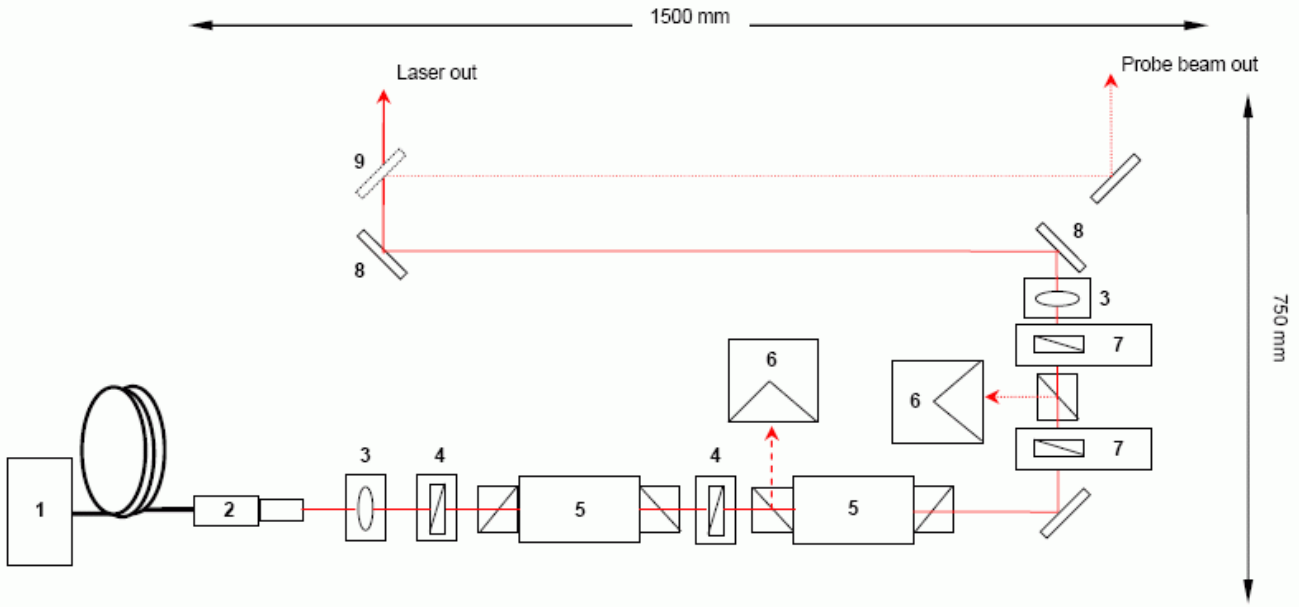


Cosmological Axion Limits



Laser Injection System

Schematic Laser Setup – LZH



1 IPG laser – 19"-rack
2 IPG fiber connector (QBH compatible)
3 Lens holder
4 λ/2 - waveplate holder
5 Faraday isolator
6 1.5 kW power meter
7 Motorized λ/2 - waveplate holder
8 Piezo-electric transducer mirror
9 AR-coated substrate – probe beam

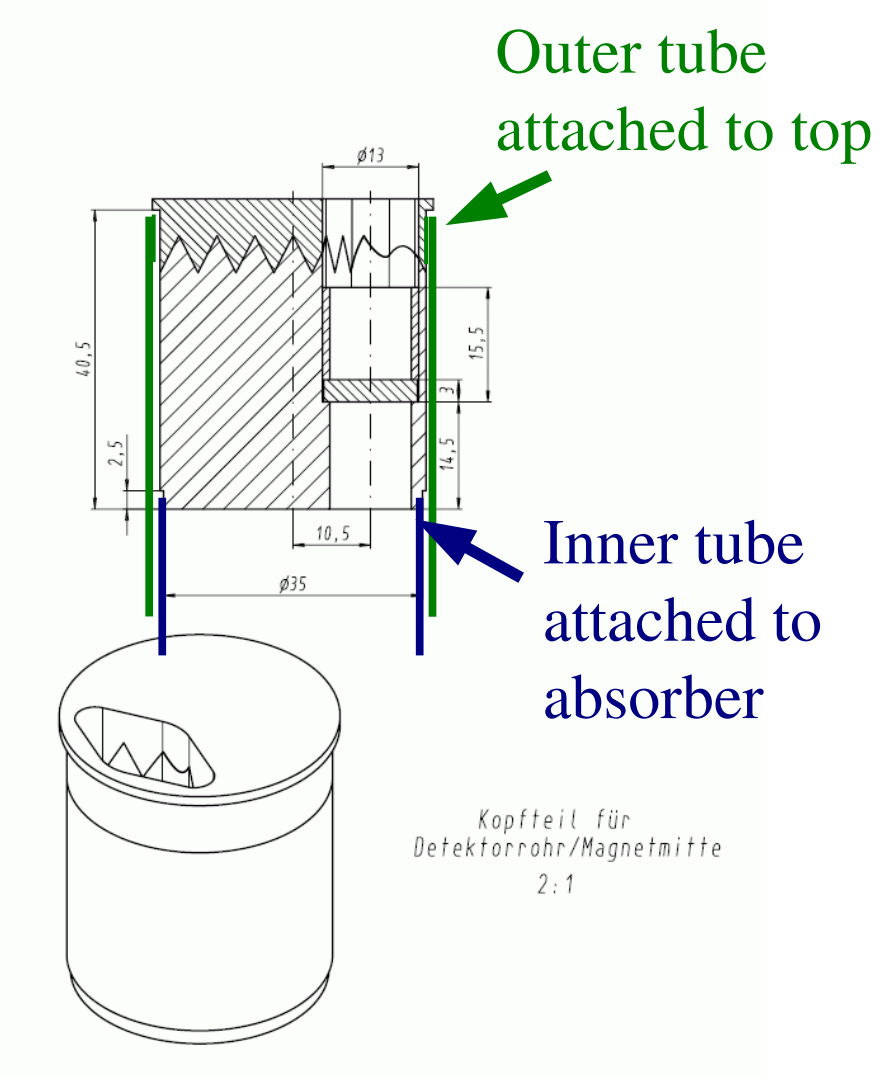
M. Hildebrandt 10.01.07

Laser – Detector Alignment

Vacuum system on detector side consists of two concentric tubes

Turning inner tube changes between two configurations:

- Open line-of-side allows laser-detector-alignment with light transmitted through mirror
- Closed window for physics measurements



Changes of Conversion Length

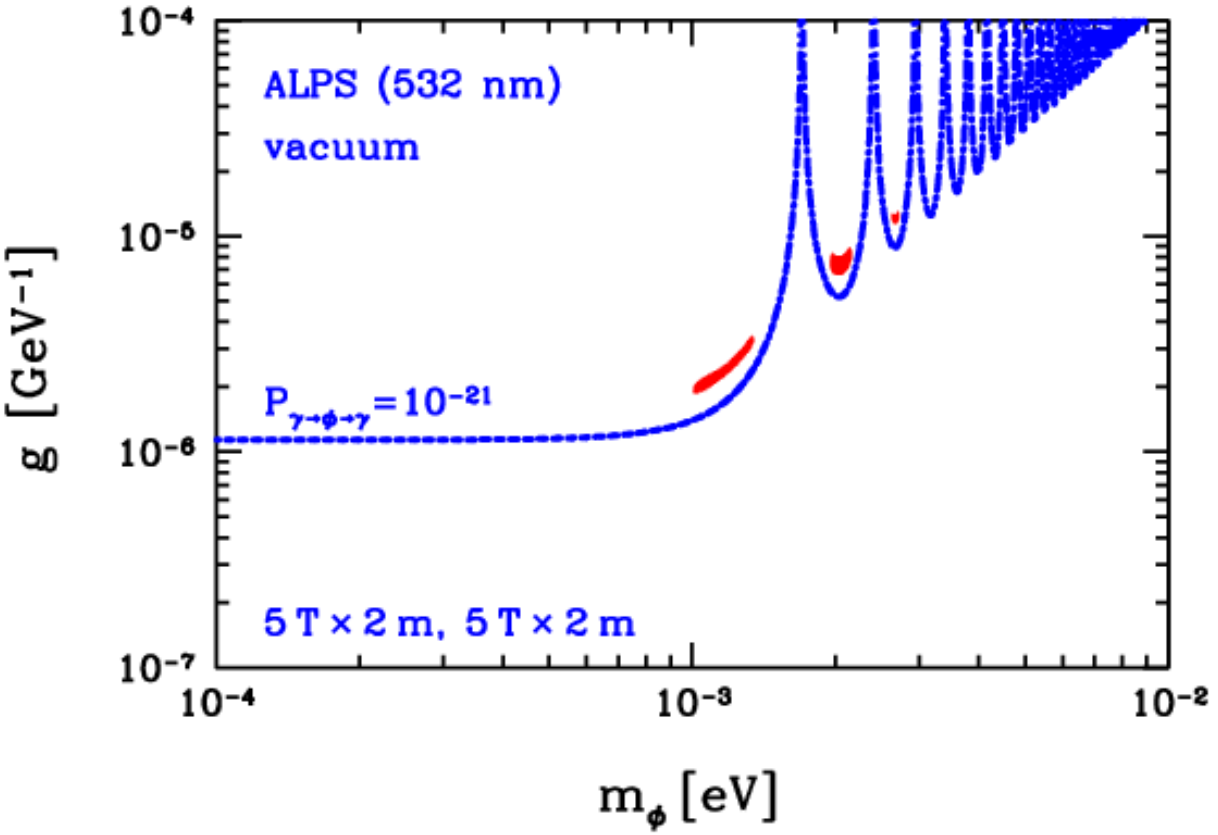
Reconversion probability with in ideal magnet:

$$P = \left(\frac{g B}{q} \sin \frac{qL}{2} \right)^4 \qquad q = \frac{m_\phi^2}{2 E_\gamma}$$

Optimize rate by tuning $qL/2$ to multiples of π

Optimal length at PVLAS+BFRT masses is 2 m on either side

Exploration requires one order of magnitude better sensitivity
⇒ low noise detector



Phase Shifts

sin $qL/2$ term results from incoherence of ALP and photon waves

Refractive material accelerates phase velocity of photon wave, allowing to phase-match both waves