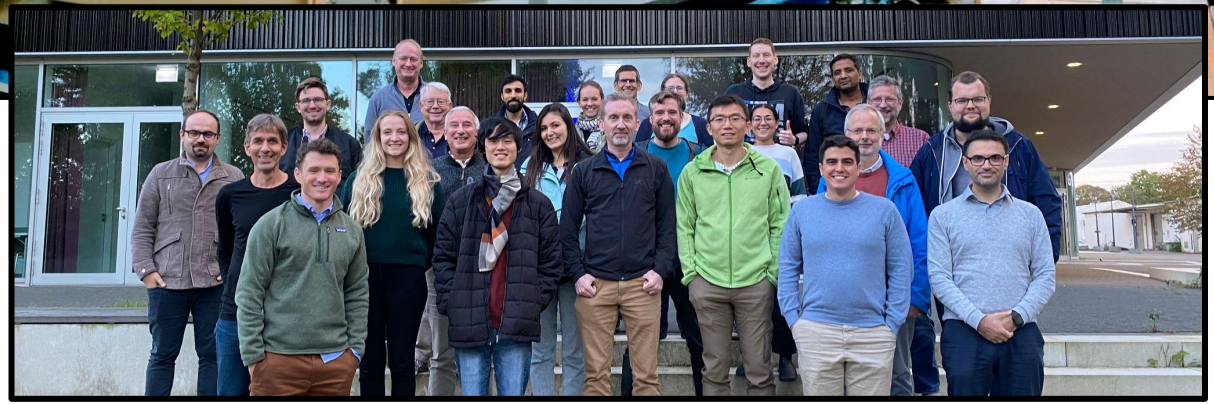
The ALPS II Experiment:
Status and Outlook



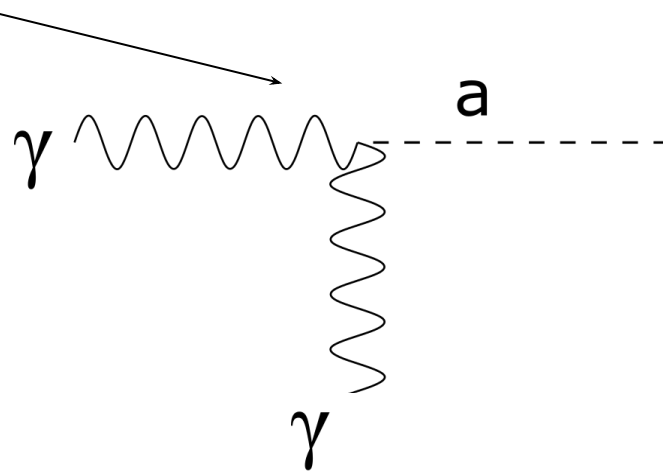
Daniel Brotherton
(University of Florida)
on behalf of the ALPS Collaboration

Nov. 2024 DESY PRC Open Session

Any Light Particle Search II

Axion-photon coupling:

$$\mathcal{L} = g_{a\gamma\gamma}\, a F_{\mu\nu} F^{\mu\nu}$$



Light-Shining-Through-a-Wall

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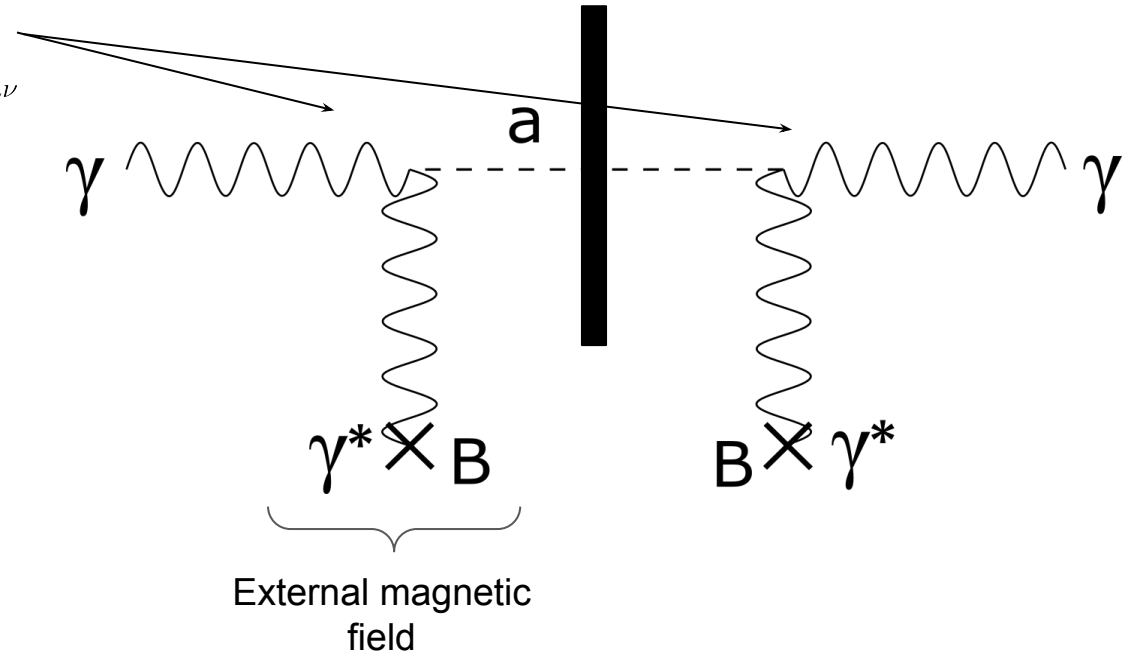

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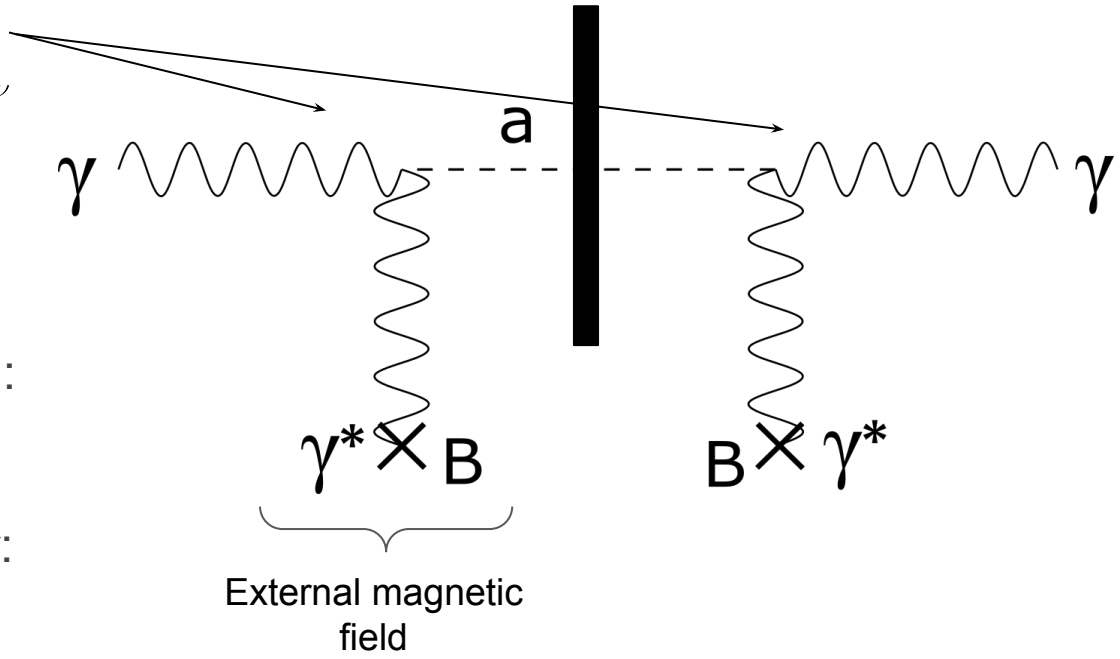

Scalar search:
E ⊥ B

Pseudoscalar:
E || B

Light-Shining-Through-a-Wall

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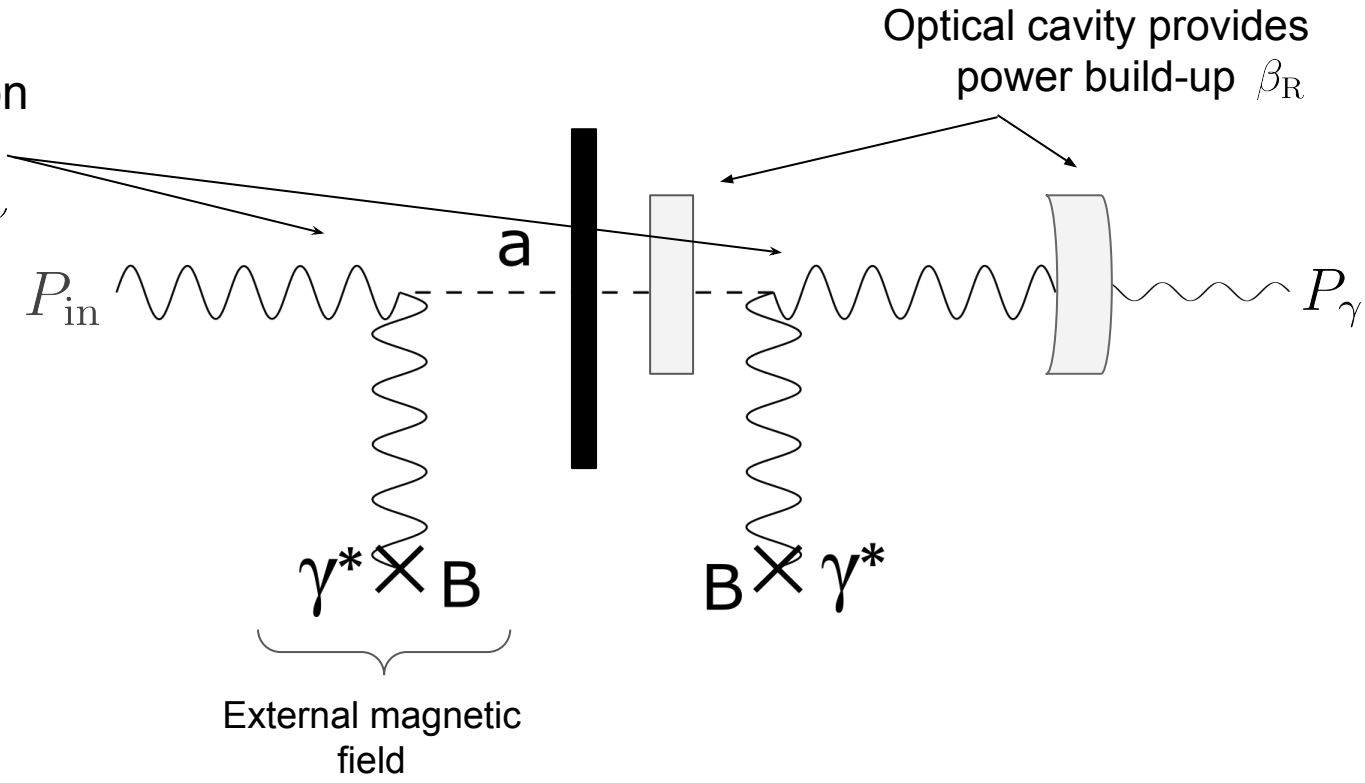

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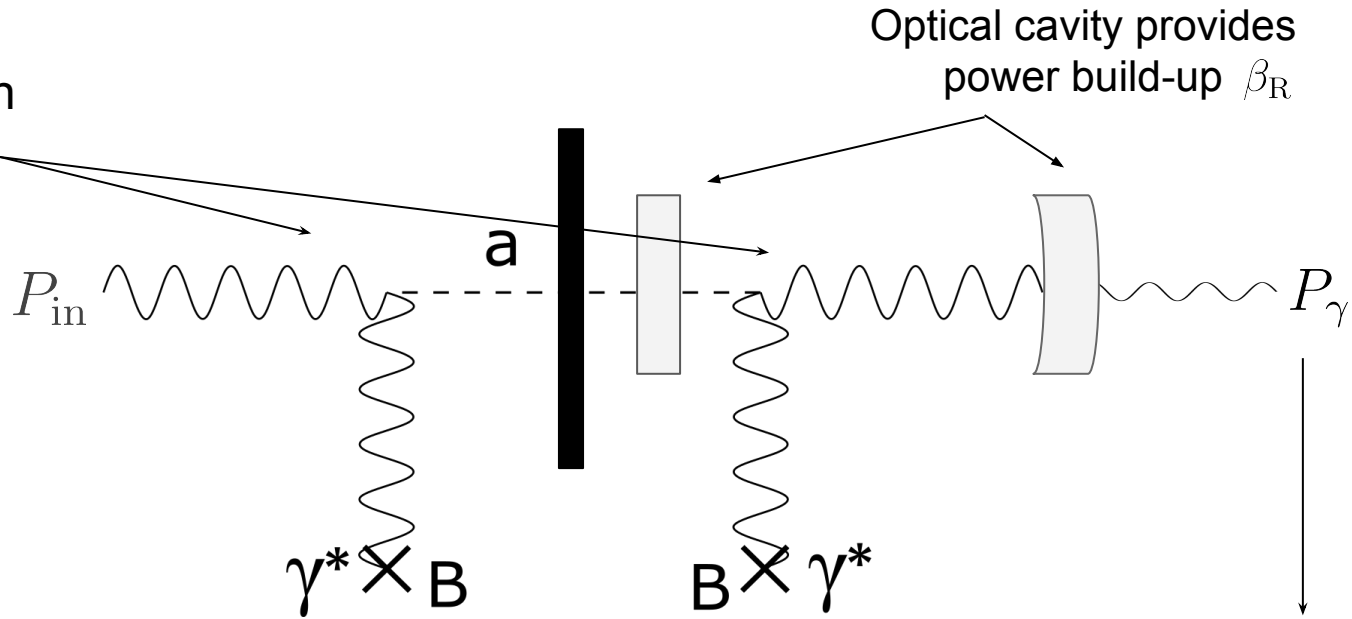
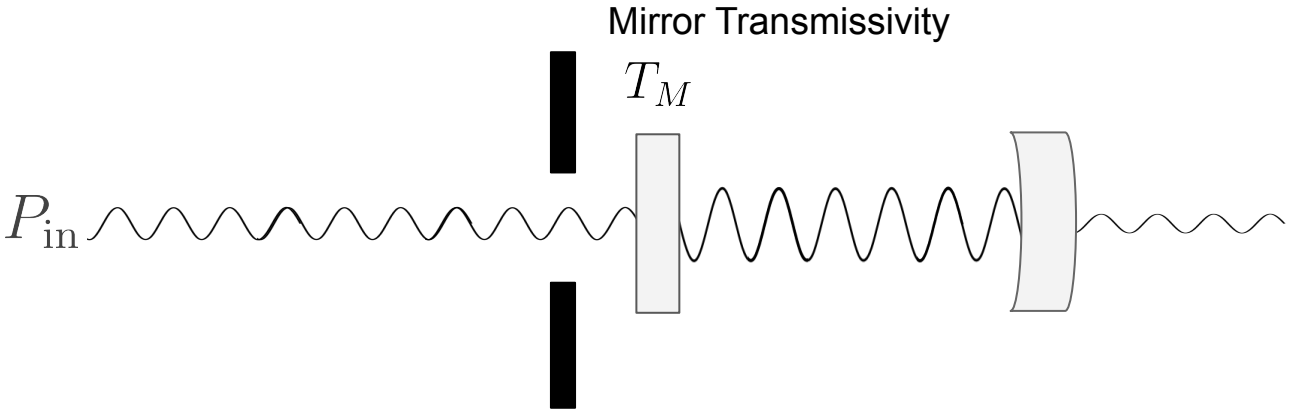


$$P_\gamma = \left(\frac{1}{2} g_{a\gamma\gamma} B L\right)^4 P_{\mathrm{in}}\, \eta\, \beta_{\mathrm{R}}$$

Calibration via “Open Shutter” Measurements

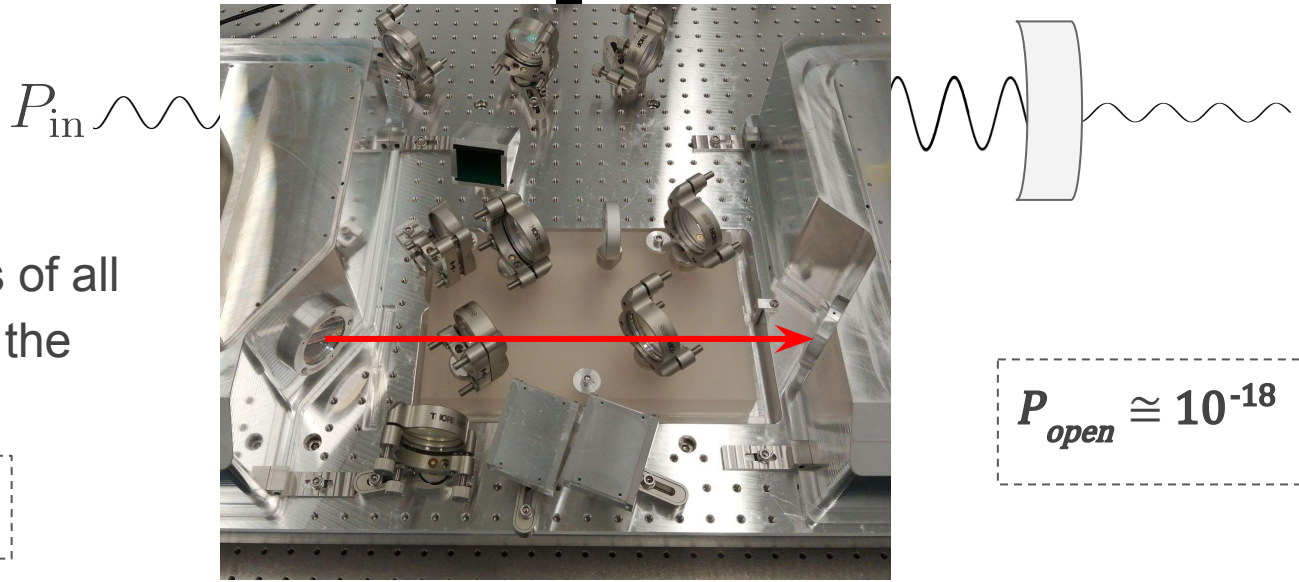


$$P_{\mathrm{open}} = P_{\mathrm{in}}\, T_{\mathrm{M}}\, \eta \beta_{\mathrm{R}}$$

Calibration via “Open Shutter” Measurements

Mirror Transmissivity

T_M

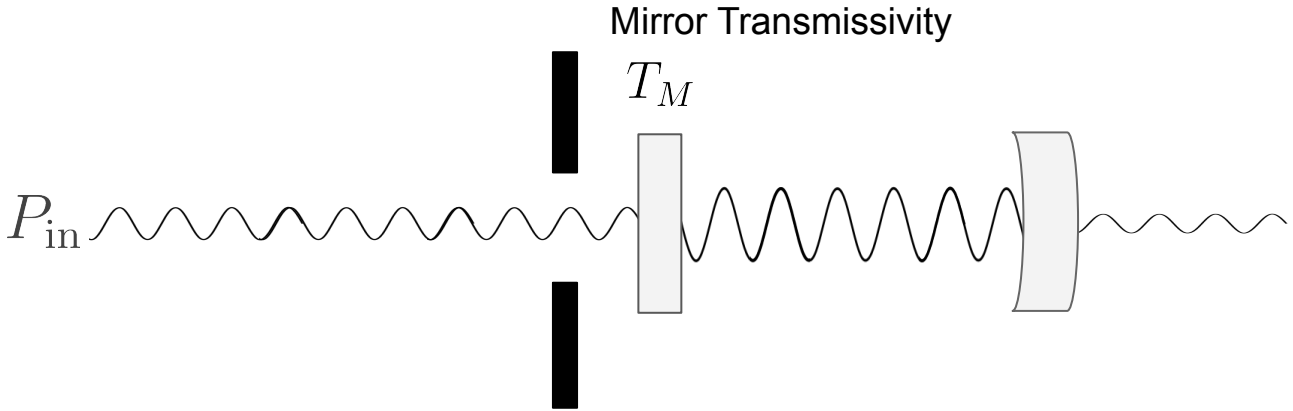


In reality, $\boldsymbol{T_M}$ is of all the mirrors on the optical axis!

$$\boldsymbol{T_M = 9 \times 10^{-23}}$$

$$\boldsymbol{P_{open} \cong 10^{-18}} \text{ Watts}$$

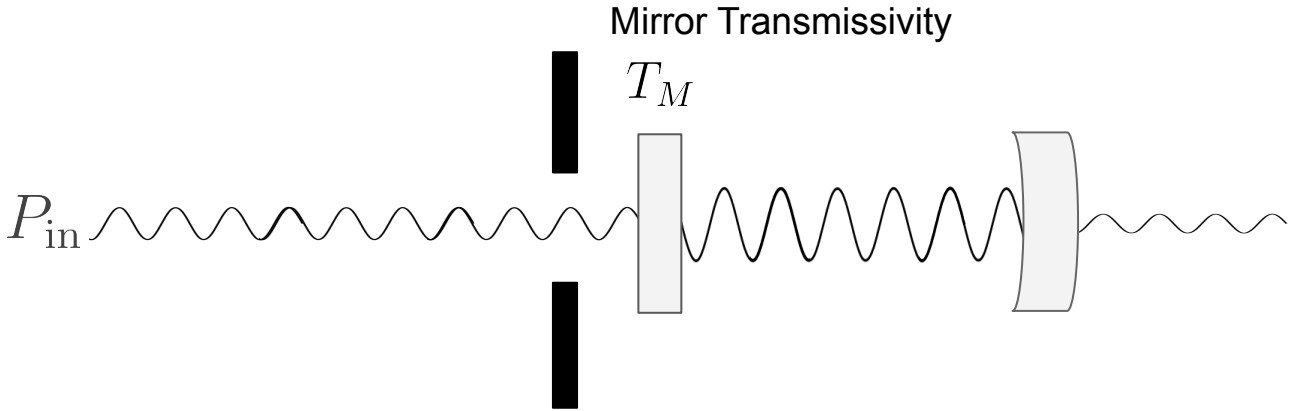
Calibration via “Open Shutter” Measurements



shutter closed
vs.
shutter open

$$\begin{cases} P_\gamma = \left(\frac{1}{2} g_{a\gamma\gamma} B L\right)^4 P_{\mathrm{in}}\, \eta\, \beta_{\mathrm{R}} \\ P_{\mathrm{open}} = P_{\mathrm{in}}\, T_{\mathrm{M}}\, \eta \beta_{\mathrm{R}} \end{cases}$$

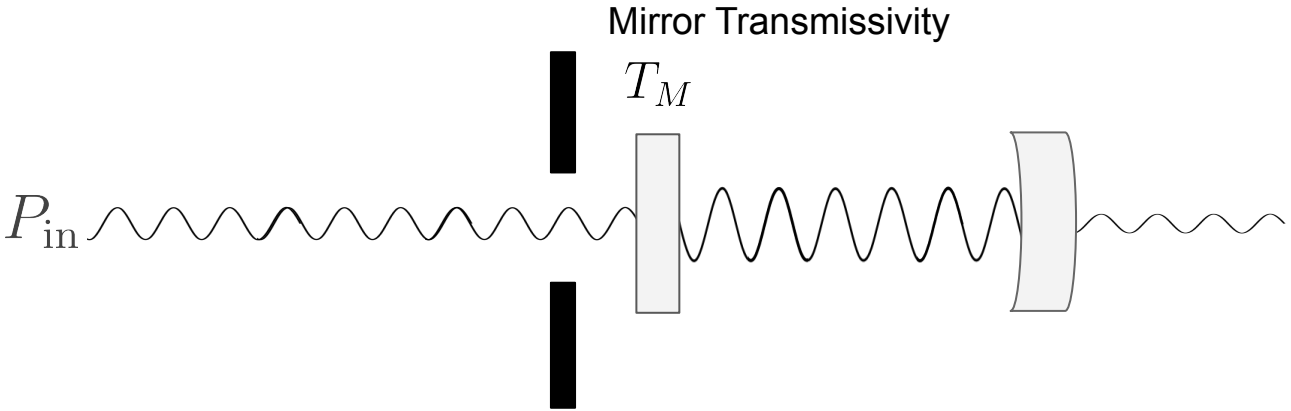
Calibration via “Open Shutter” Measurements



Ratio:

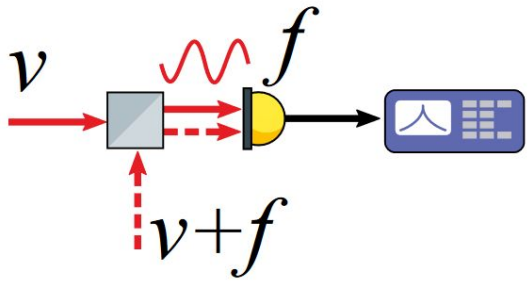
$$\frac{P_\gamma = \left(\frac{1}{2} g_{a\gamma\gamma} B L\right)^4 \cancel{P_{\mathrm{in}}\, \eta\, \beta_{\mathrm{R}}}}{P_{\mathrm{open}} = \cancel{P_{\mathrm{in}}}\, T_{\mathrm{M}}\, \cancel{\eta\, \beta_{\mathrm{R}}}}$$

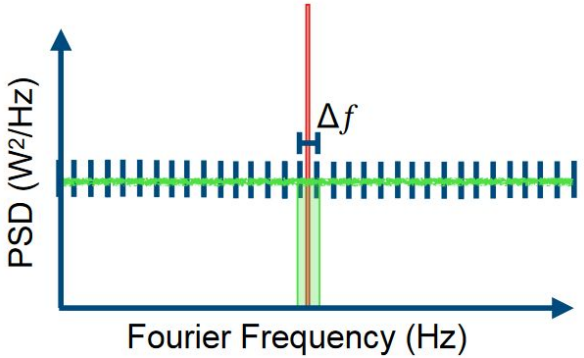
Calibration via “Open Shutter” Measurements



$$g_{a\gamma\gamma} = \left(\frac{P_\gamma}{P_{\mathrm{open}}} T_{\mathrm{M}} \right)^{1/4} \frac{2}{BL}$$

Detection with Heterodyne Interferometry





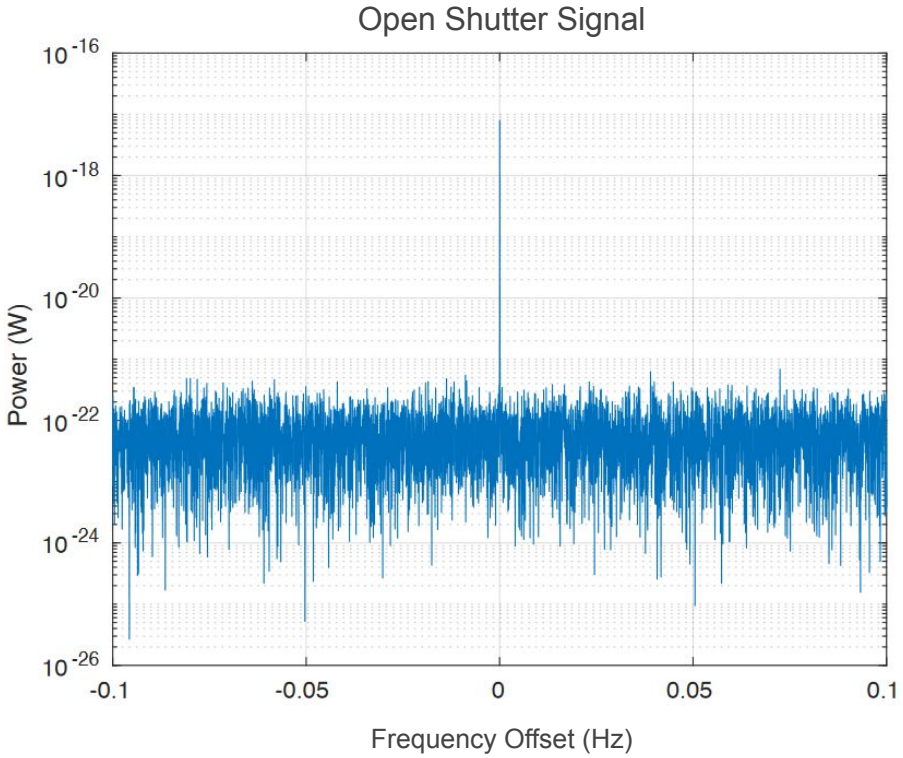
Interfere the regenerated EM field with a strong “local oscillator” field

Creates a beatnote at the difference frequency

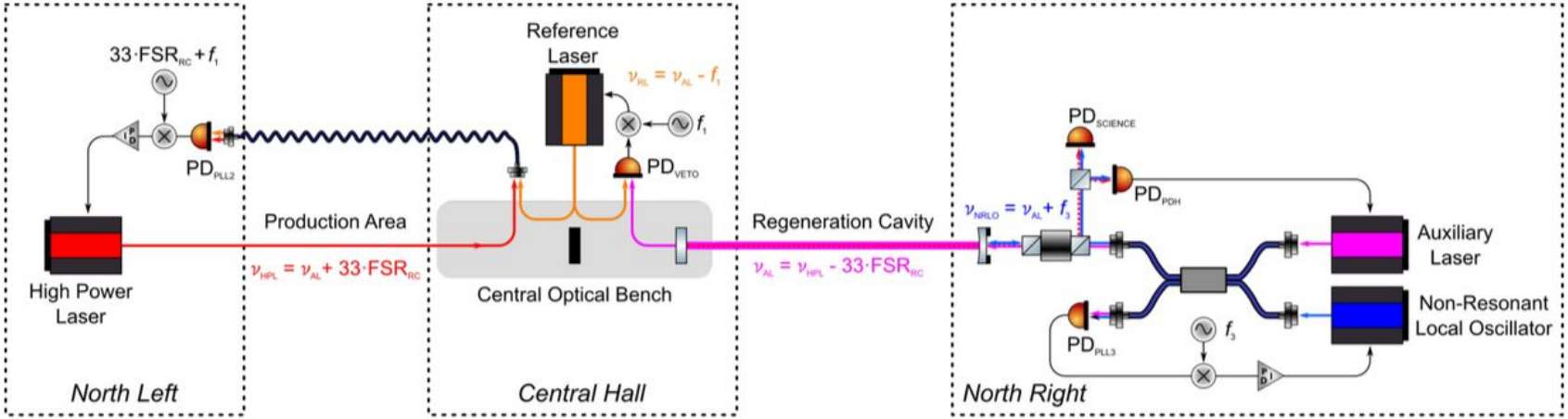
$$\left|\sqrt{P_\gamma}e^{i2\pi\nu t}+\sqrt{P_{\mathrm{LO}}}e^{i2\pi(\nu+f)t+i\Delta\phi}\right|^2 = P_\gamma + P_{\mathrm{LO}} + 2\sqrt{P_\gamma P_{\mathrm{LO}}}\cos(2\pi f\, t+\Delta\phi)$$

Detection with Heterodyne Interferometry

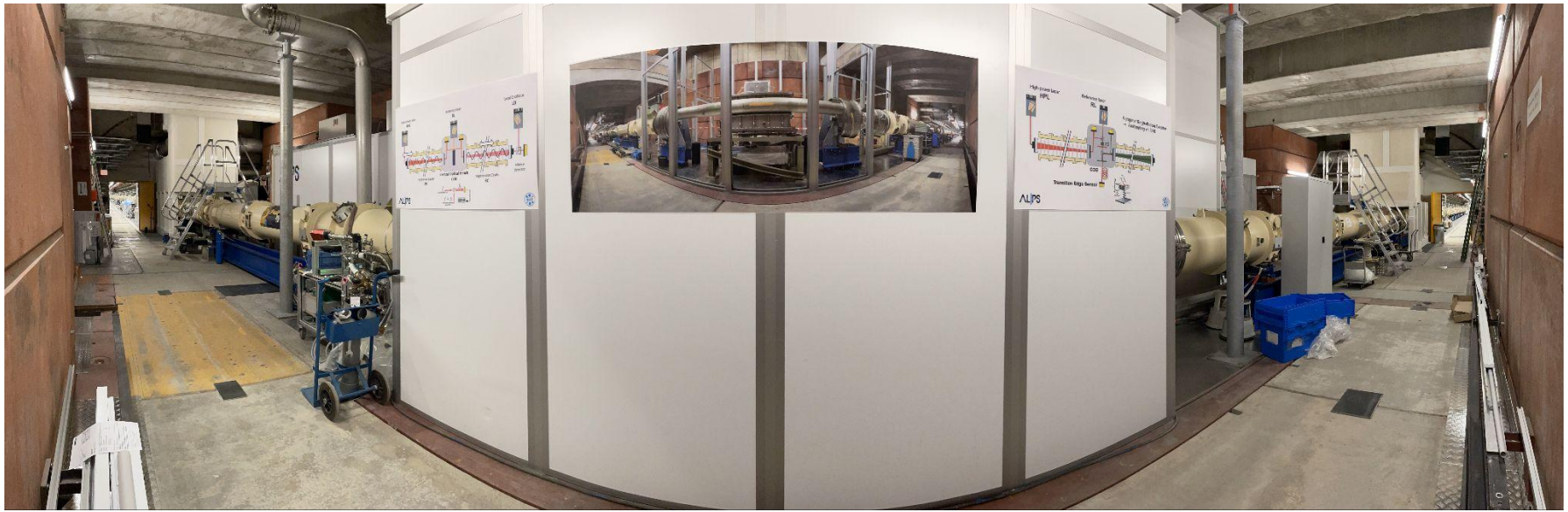
- Signal expected in a single frequency bin
- For integration times of ~1 million seconds, requires control of laser frequencies to the μHz level
- Frequencies defined to tens of nHz



Frequency Control System



Must stabilize laser frequencies *without* introducing backgrounds!

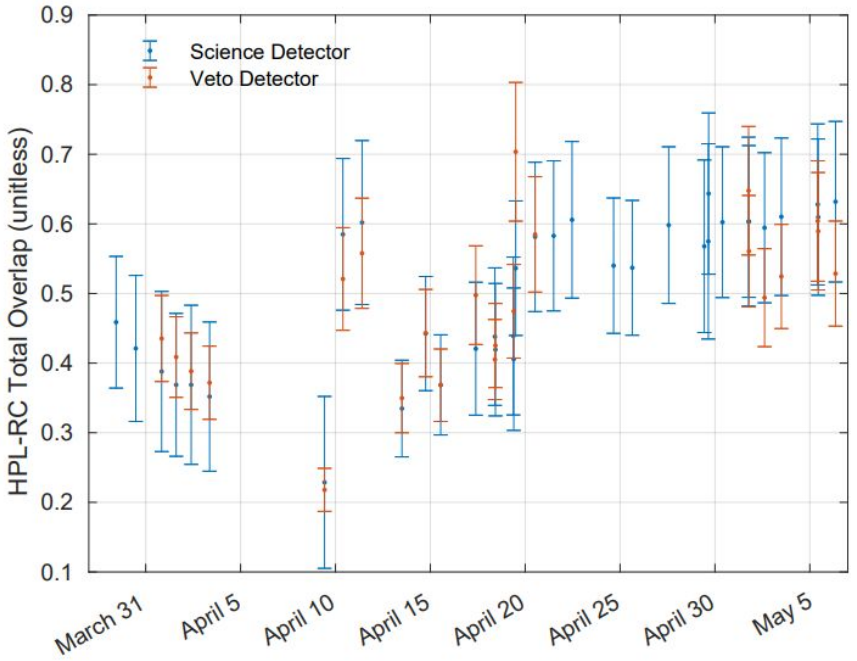


Current Status

Conclusion of the Initial Science Campaign

- Scalar run: early-mid February
- Pseudo-scalar run: April-May
- Total coupling η measured during open shutter periods
    - Maintained ~50% across each run, demonstrating frequency control

(Pseudoscalar Run)

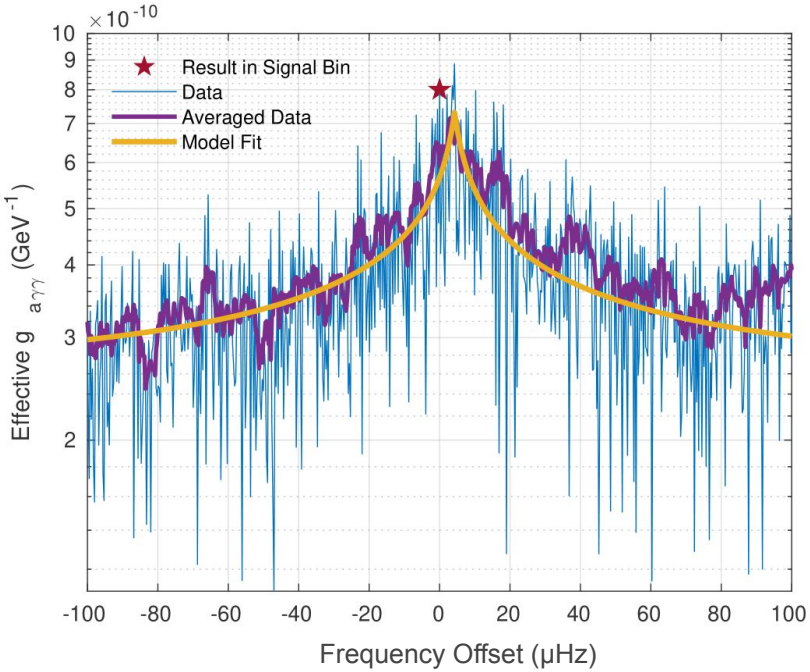


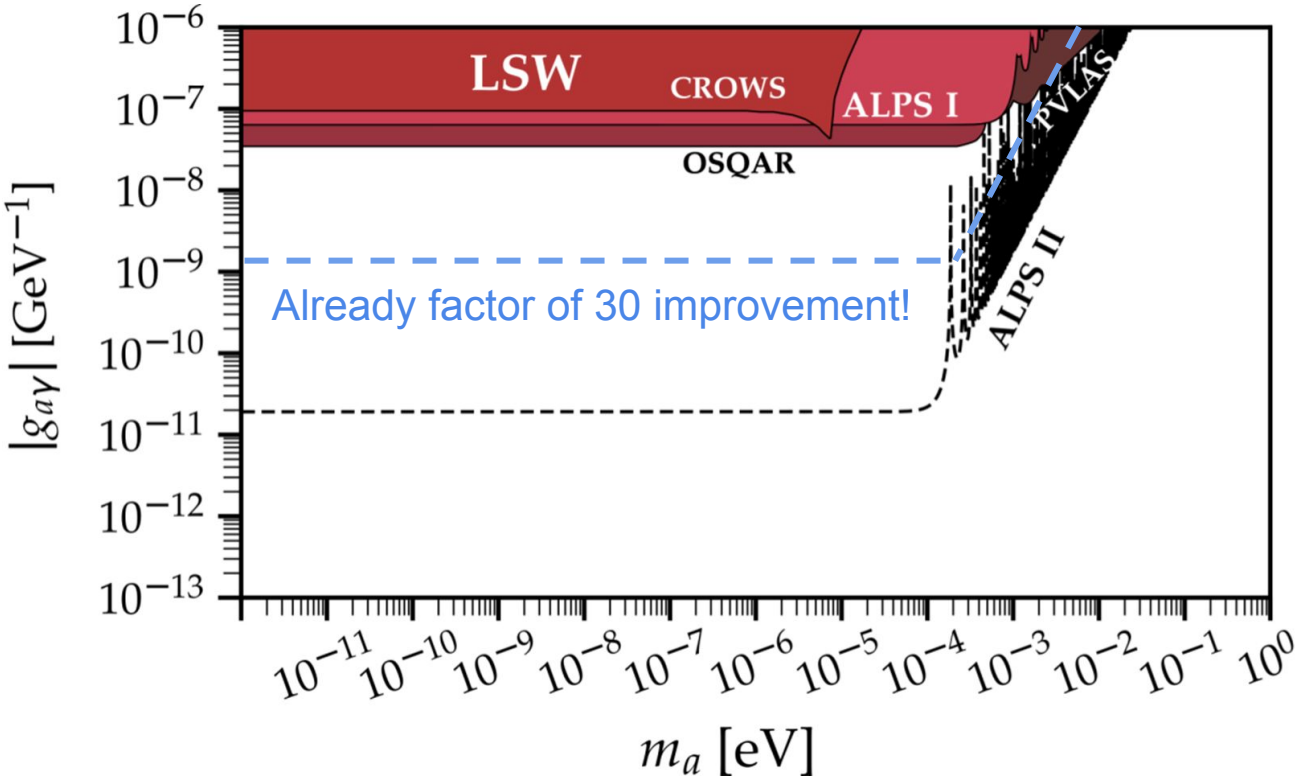
Results

- Limited by stray-light in frequencies near the signal bin (< 100 uHz offset)
- Methods developed to estimate the expected background
  - sets 95% C.L. exclusion limits:

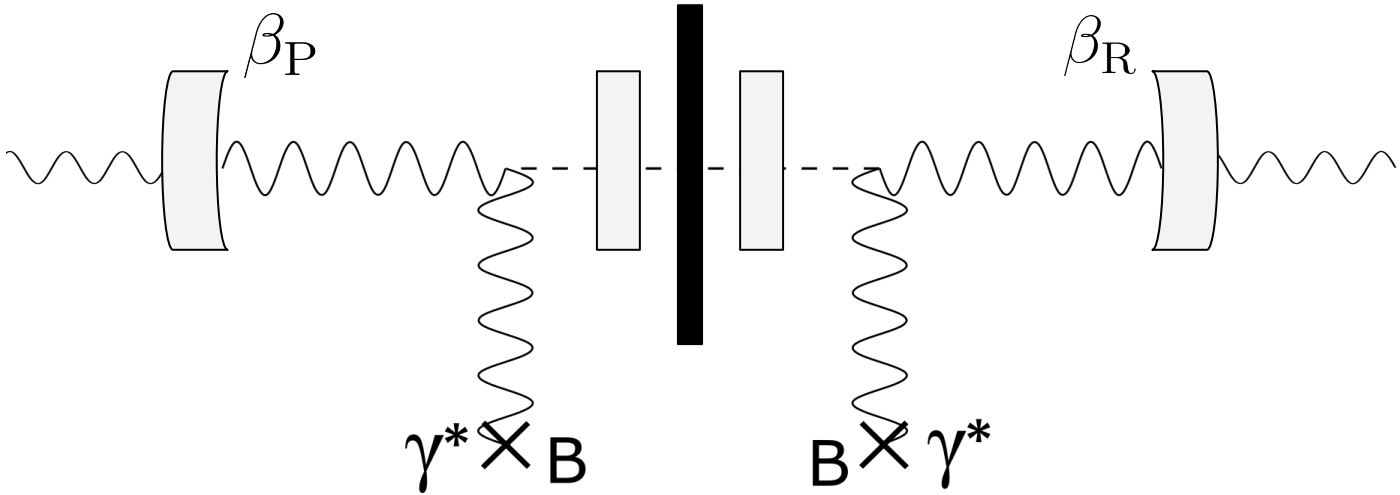
Scalar	**Pseudoscalar**
1.6×10^{-9} GeV^{-1}	1.3×10^{-9} GeV^{-1}

- Stray-light and noise reducing measures are underway




LSW
CROWS
ALPS I
OSQAR
PVLAS
ALPS II
Already factor of 30 improvement!
$|g_{a\gamma}|$ [GeV^{-1}]
m_a [eV]
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}
10^{-11} 10^{-10} 10^{-9} 10^{-8} 10^{-7} 10^{-6} 10^{-5} 10^{-4} 10^{-3} 10^{-2} 10^{-1} 10^{0}

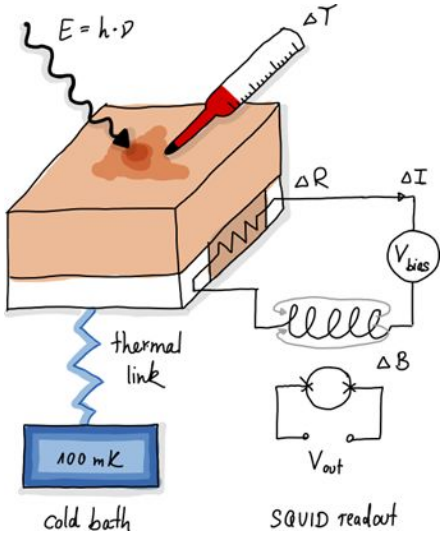
Next Steps: Production Cavity



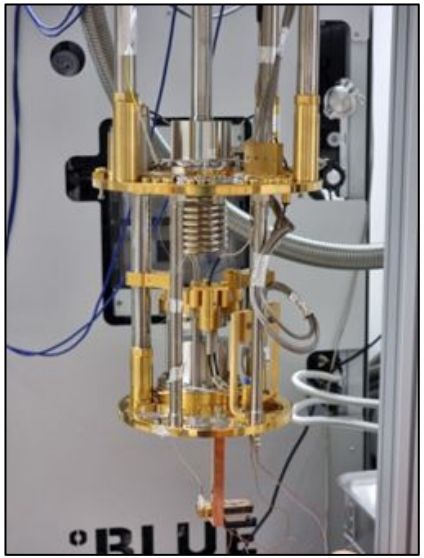
$$P_\gamma = \left(\frac{1}{2} g_{a\gamma\gamma} B L\right)^4 \cdot P_{\mathrm{in}} \cdot \eta \beta_{\mathrm{P}} \beta_{\mathrm{R}}$$

Next Steps: Transition-Edge Sensor

- confirmation of signals seen in Heterodyne
- completely different systematics
- development with already significant progress

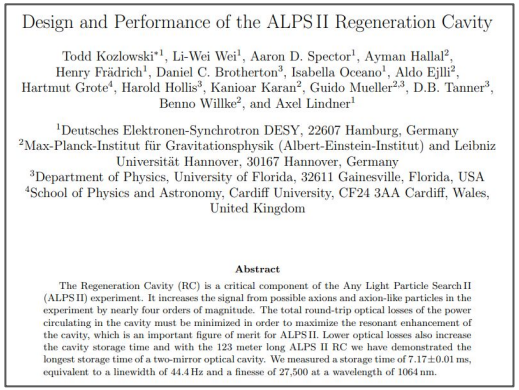


Sketch courtesy of
Katharina-Sophie Isleif



Summary

- First science runs and their analysis done, papers in preparation
- New limits, ×30 in sensitivity, $\times 10^6$ better signal-to-noise
- Forthcoming commissioning & runs with the Production Cavity
- ALPS II paving the way for future experiments!



Design and Performance of the ALPS II Regeneration Cavity

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[2]Max-Planck-Institut für Gravitationsphysik (Albert-Einstein-Institut) and Leibniz Universität Hannover, 30167 Hannover, Germany
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Abstract

The Regeneration Cavity (RC) is a critical component of the Any Light Particle Search II (ALPS II) experiment. It increases the signal from possible axions and axion-like particles in the experiment by nearly four orders of magnitude. The total round-trip optical losses of the power circulating in the cavity must be minimized in order to maximize the resonant enhancement of the cavity, which is an important figure of merit for ALPS II. Lower optical losses also increase the cavity storage time and with the 123 meter long ALPS II RC we have demonstrated the longest storage time of a two-mirror optical cavity. We measured a storage time of 7.17±0.01 ms, equivalent to a linewidth of 44.4 Hz and a finesse of 27,500 at a wavelength of 1064 nm.

https://arxiv.org/abs/2408.13218