Heterodyne detection in ALPS II

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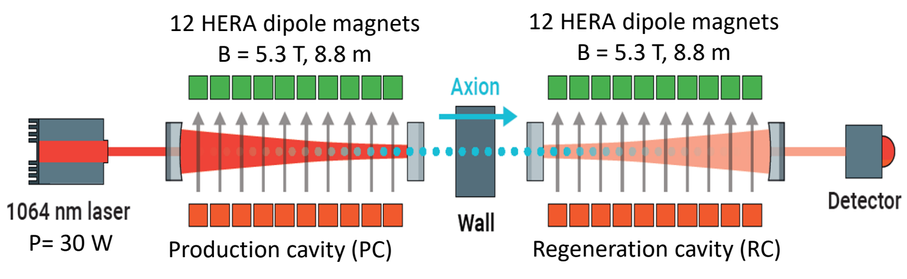
ALPS II: LSW with optical cavities

Light-shining-through-a-wall technique and resonant regeneration

Mode-matched optical cavities in the magnetic field regions



Power build-up: 5,000
(150 kW circulating power)

Finesse: 120,000

Production Cavity (PC):
increase circulating power before wall

Regeneration Cavity (RC):
resonantly enhances reconversion probability of ALPs into photons

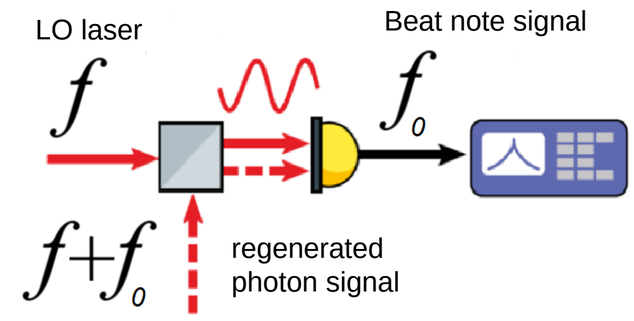
Number of regenerated photons:

$$N_S = \eta^2 N_{PC} \frac{\mathcal{F}_{RC}}{\pi} \frac{1}{16} (g_{\alpha\gamma} B L)^4$$

A FEW PHOTONS PER WEEK!

Heterodyne detection

- Local oscillator laser is phase locked to PC circulating field
- Interfere regenerated field with a much stronger LO laser field
- Beat note carries information on photon rate of the regenerated signal



$$\left| \sqrt{\bar{P}_{LO}} e^{i(2\pi f t + \phi_1)} + \sqrt{\bar{P}_{weak}} e^{i[2\pi(f+f_0)t + \phi_2]} \right|^2 =$$

$$\bar{P}_{LO} + \bar{P}_{weak} + 2\sqrt{\bar{P}_{LO}\bar{P}_{weak}} \cos(2\pi f_0 t + \Delta\phi)$$

- Signal coherently sums over time
- Noise averages out
- Can reach shot noise limit
- Excellent energy resolution

Requirements

ALPS II:

- PC circulating field must be resonant in the RC
- Light Tightness: Isolate the RC area from any light from PC (below 10^{-24} W)

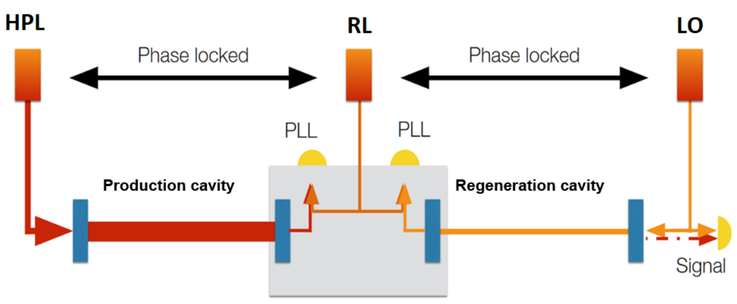
150 kW circulating power in PC. Need strong suppression between end stations field

Additional requirement for HET:

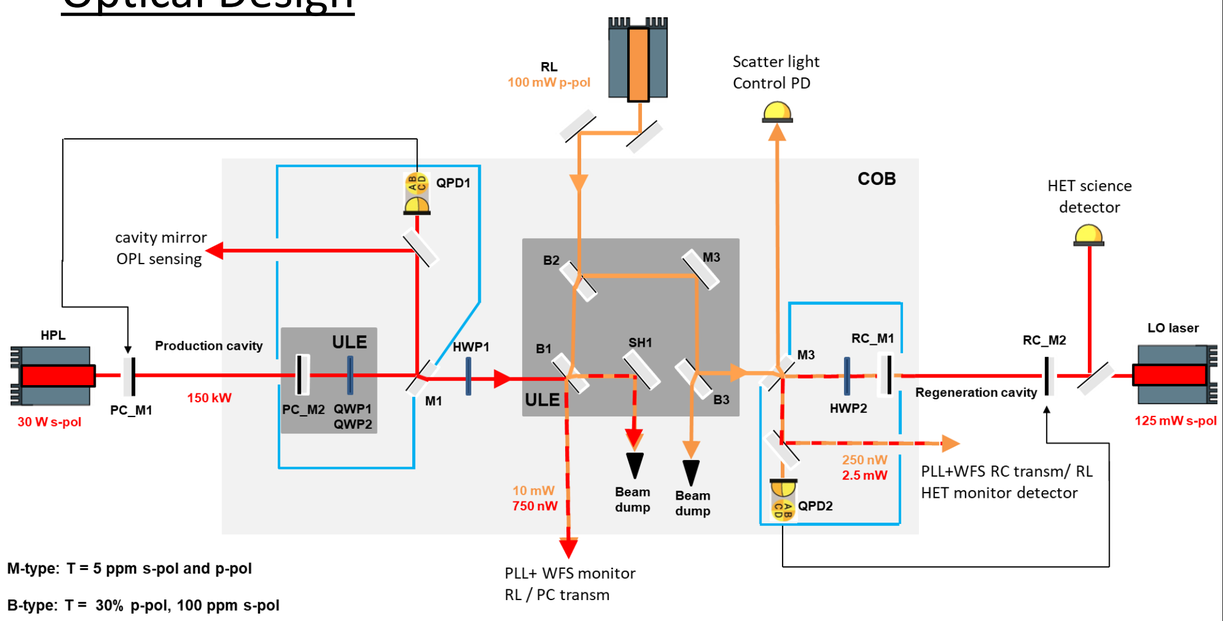
- Phase change between the regenerated photon field and the LO laser < 0.1 cycles over ~2 weeks

Maintain phase coherence without light contamination from production cavity!!

Use another laser (RL) and Phase Lock Loops (PLLs) between lasers



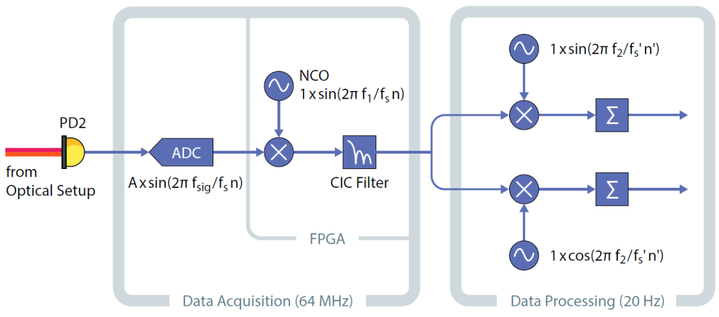
Optical Design



Control and Alignment Loops

- PLL: RL is phase locked to RC transmission, PC transmission is phase locked to RL
- WFS: RL is aligned on RC transmission, Overlap between RL and PC transmission serves as an overall alignment check
- QPD1, QPD2 for cavity axes alignment
- Interferometer senses OPL changes in the substrate of the PC end mirror

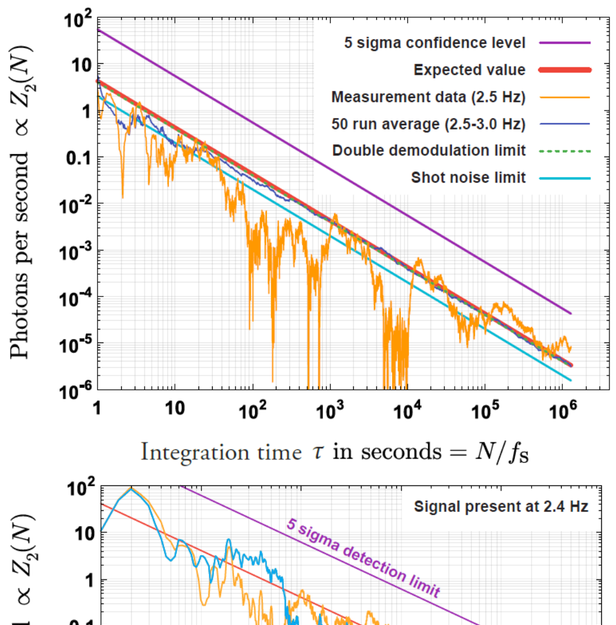
Digital Demodulation



- First demodulation stage occurs in FPGA
- I/Q demodulation in post-processing at 20 Hz

Noise floor

- No beatnote signal. P_{LO} = 5 mW on shotnoise limited photodiode
- Measurement agrees with the theoretical limit for shot noise
- No spurious signal after 19 days of integration time
- Integrated noise floor below 2 x 10^{-24} W (equivalent to about 10^{-5} photons/s)

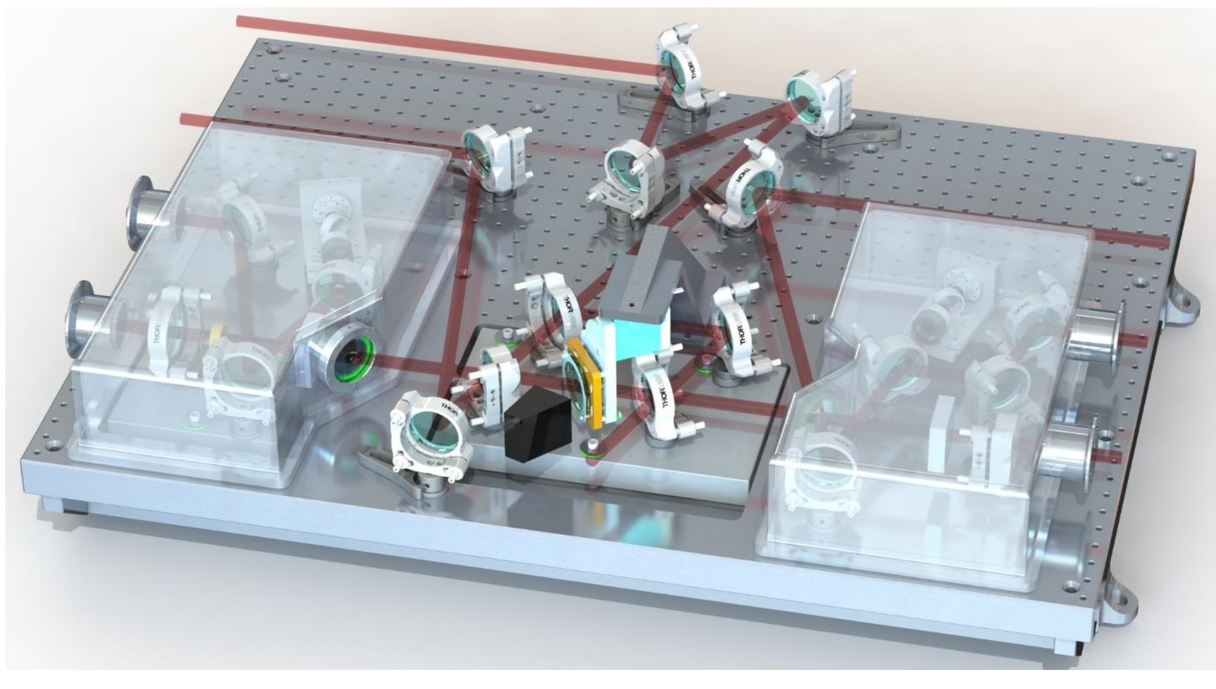


Test signal

- Signal power = 6.3 x 10^{-21} W (equivalent to 3.39e-2 photons/s)
- Measurement = 6.4 x 10^{-21} W (3.33e-2 photons/s) after 3 days integration time with 5σ confidence
- Demodulating at a different frequency, signal is not detected

[Z. Bush et al., **PRD 99** 022001 (2019)]

Central Breadboard Design



- Key optical components on Ultra Low Expansion (ULE) glass
- Low drift mirror mounts for alignment stability

Giuseppe Messineo, Ayman Hallal, Todd Kozlowski, D. B. Tanner and Guido Mueller, **15th PATRAS Workshop on Axions, WIMPs and WISPs**, (3 – 7 June 2019), Freiburg