Heterodyne detection in ALPS II

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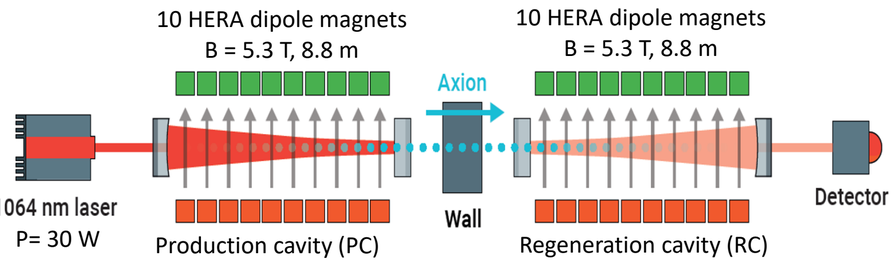
ALPS II: LSW with optical cavities

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

Mode-matched optical resonators 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 (increases flux of ALPs through the wall)

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

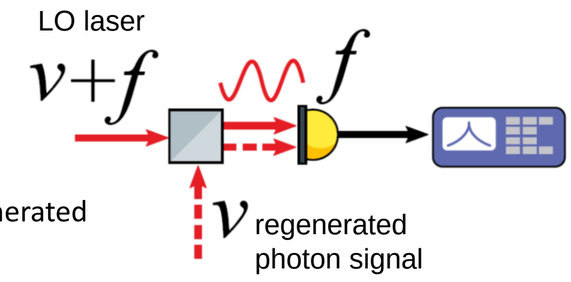
Number of regenerated photons:

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

NEED DETECTOR SENSITIVE TO PHOTON LEVELS AS LOW AS A FEW PHOTONS PER WEEK!

Heterodyne detection

- Local oscillator laser is phase locked to PC circulating field
- Regenerated photons are coherent with PC circulating field



⇨ Measure beat note between regenerated photon signal and LO laser field

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

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

AC term carries information on photon rate of the regenerated signal

PHASE SENSITIVE DETECTION
Noise sums incoherently, signal coherently sums over time

Requirements

General for ALPS II:

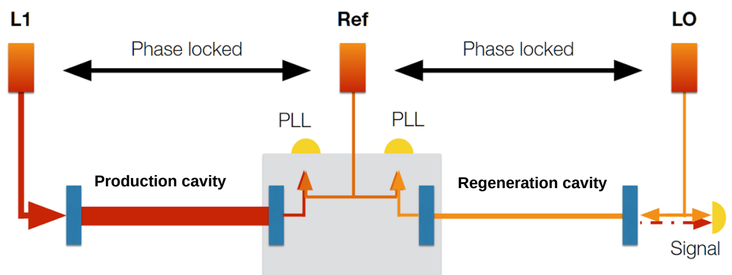
- RC resonant with the PC circulating field
- Light Tightness (no light from PC side can reach RC side): 150 kW circulating power in PC. Need strong suppression between end stations field

Additional requirement for HET:

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

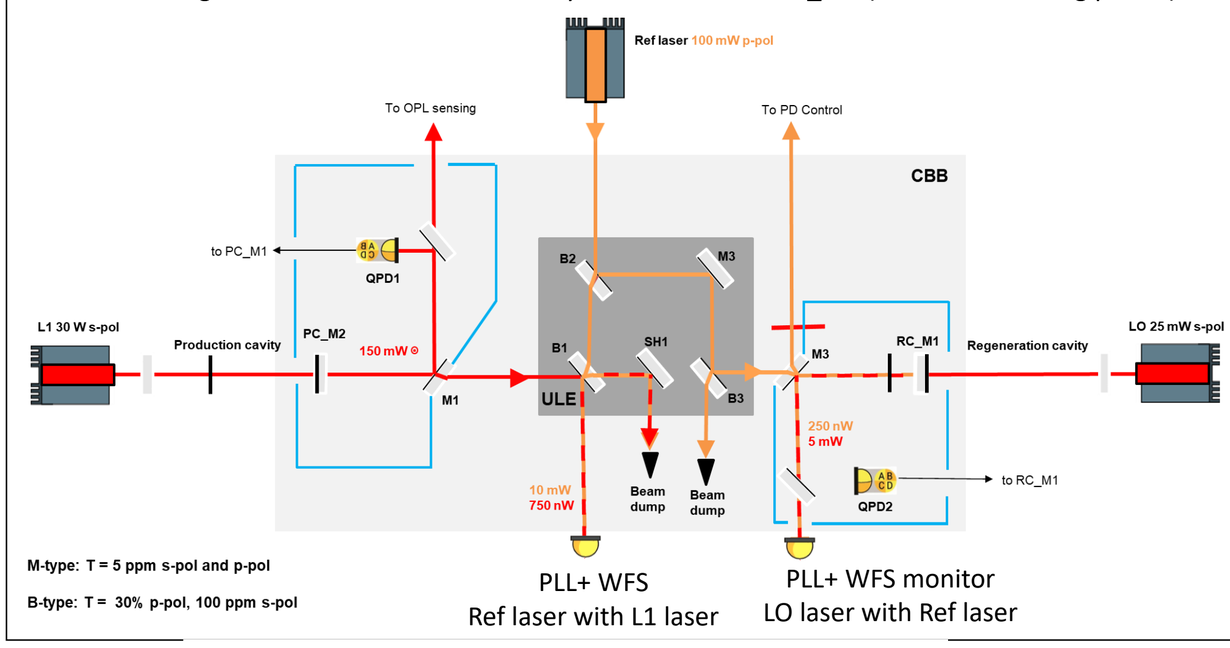
Must transfer phase information between cavities without light contamination from production cavity!

SOLUTION:
Use another laser (REF) and Phase Lock Loops (PLLs) between lasers

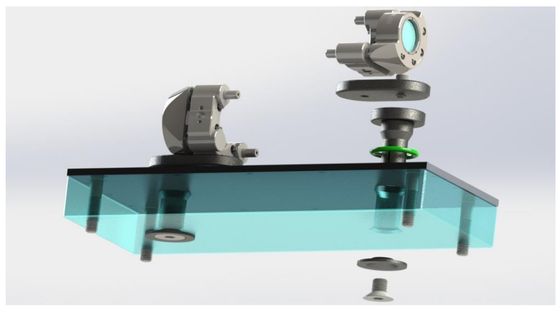


Optical bench design

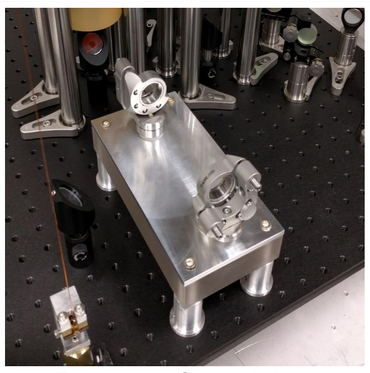
- QPD1, QPD2 for cavity axes alignment
- OPL sensing for thermal effects in the cavity mirror substrate PC_M2 (150 kW circulating power)



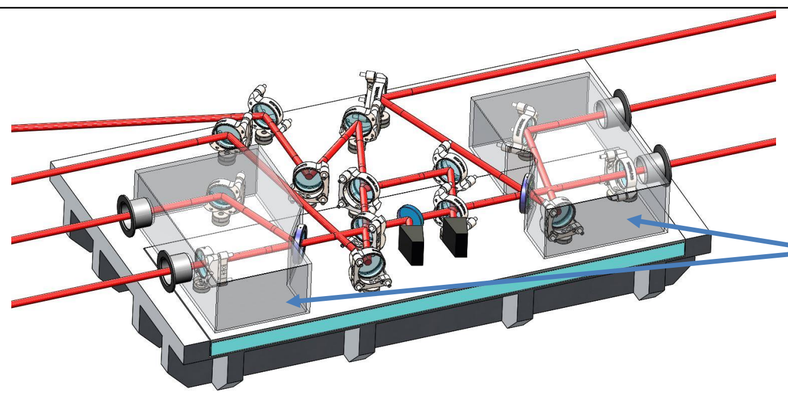
Central Breadboard stability



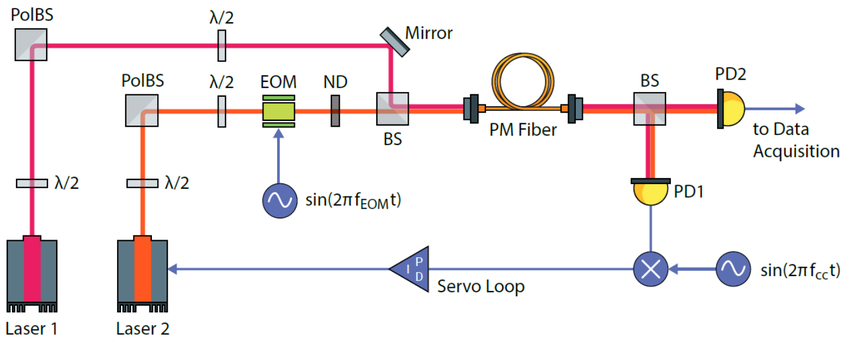
- Key optical components on Ultra Low Expansion (ULE) glass
- Low drift mirror mounts for alignment stability



Prototype for stability measurements

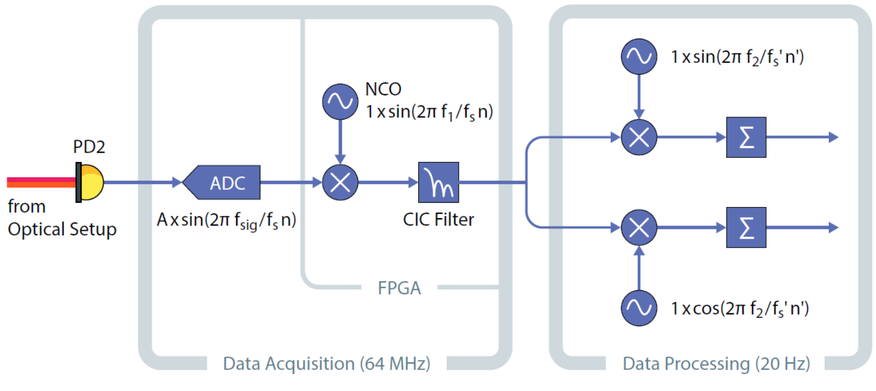


Optical Testbed for HET detector



- Phase Lock Loop keeps beat note frequencies fixed
- EOM used to phase modulate Laser 2
- Attenuate sidebands (SB) and measure beat note between SB and LO

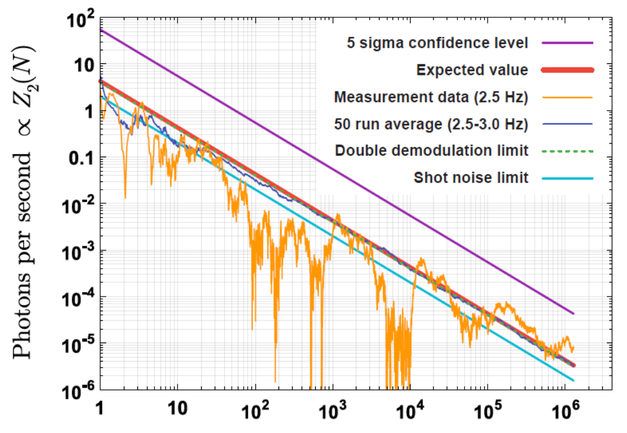
Digital Demodulation



- First demodulation stage occurs on processing card
- I/Q demodulation in post-processing at low (~Hz) frequency signal

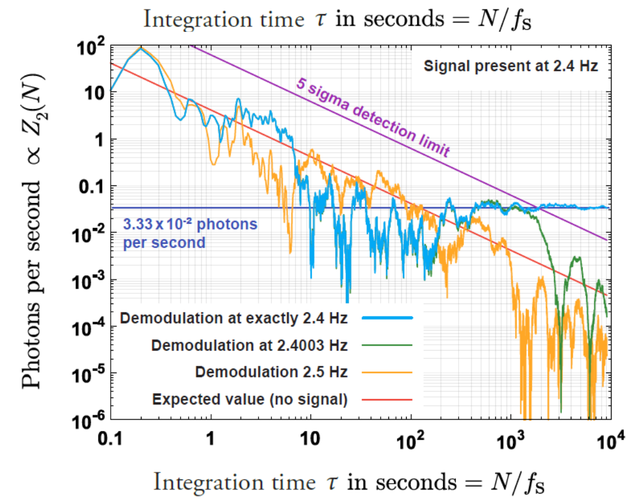
Noise floor measurements

- No beatnote signal. P_{LO} = 5 mW on photodiode (shot noise limited)
- Measurement agrees with the theoretical limit for shot noise
- No spurious signal after 19 days of integration time
- Equivalent dark count rate of 10^{-6} photons/s



Test signal

- Modulation depth of EOM set to produce a sideband with equivalent rate of 3.39e-2 photons per second
- Measure 3.33e-2 photons per second after 3 days integration time with 5 sigma confidence



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