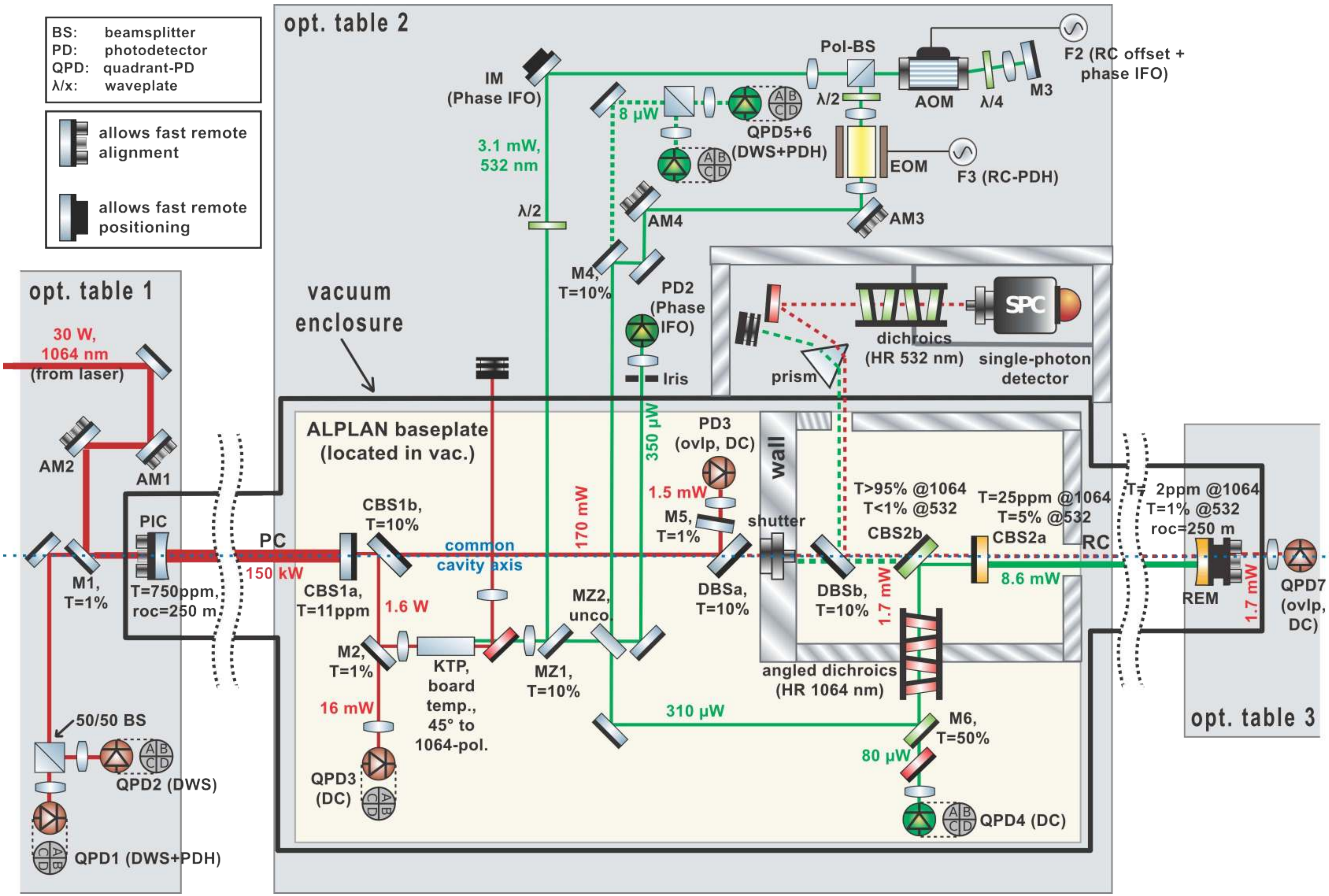
Problems with ALPS II

Analysis of the possible showstoppers for the current baseline design and alternate design concept

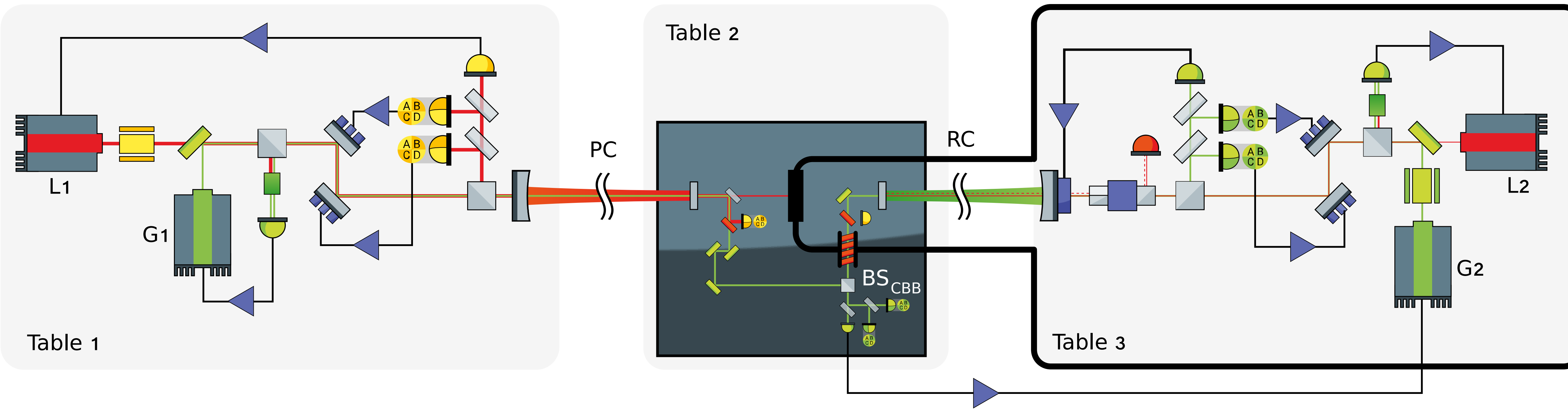
ALPSII Baseline Design



Problems

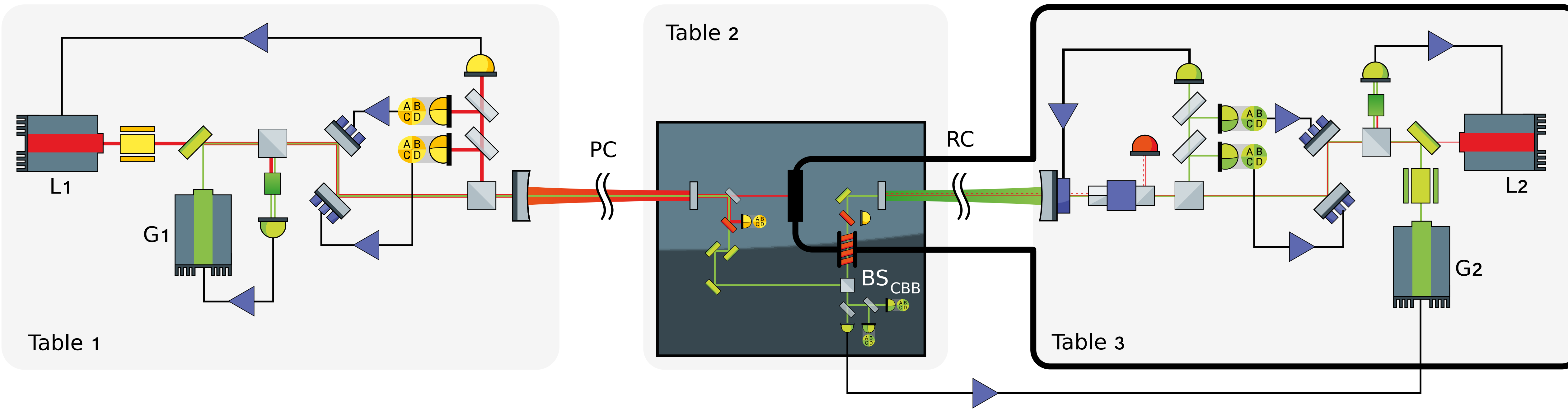
- PC must be locked to work with RC
  - with high power
- Frequency doubling on the ALPLAN
  - PC Eigenmode location restricted by SHG crystal
  - KTP required
  - Increased complexity of ALPLAN
- Detection on Table 2
  - Output to detector orthogonal to beam axis
  - Light tightness
- Direct path from PC to RC
- Optics on Table 2
- Heterodyne requires ULE CBB

Alternative Setup



- L1 frequency locked to PC
- G1 phase locked to L1 on table1
- G2 phase locked to G1 on CBB
- RC length locked to G2
- L2 phase locked to G2

Requirements



- Requirements:
  - RC length must be to wishing 1.4 Hz of the IR field circulating within the PC
  - Relative phase noise between local oscillator for heterodyne and the IR field circulating inside PC must not change by more than 0.01 cycles

Problems

- (1) Changes in effective of point reflection (EPF)
  - (a) phase noise between the local oscillator and measurement signal,
  - (b) detuning of the cavity from the PC IR circulating field
- (2) Offset phase locking two lasers and propagating them through cavities will lead to length noise in the cavities coupling to relative phase noise between the circulating fields of the two lasers
- (3) Phase locking G1 to L1 before the cavity will lead to relative phase noise between G1 and the IR field circulating inside the PC

Problem 1a

- Phase change in cavity circulating field due to length detuning given by:

$$\Delta\phi_{\text{cycles}}(\Delta L, \lambda) = \frac{2\mathscr{F}}{\pi}\frac{\Delta L}{\lambda}$$

- Change in EPF due to mirror coating thermal expansion

$$\Delta L = l\alpha\Delta T$$

- Use α=1e-6m/Km, ℓ=5e-6m, $\mathscr{F}$=120,000, λ=1064nm

- Temperature RMS stability must be better that 0.026 K to meet the 0.01 cycle requirement for heterodyne

Problem 1b

- Length detuning for IR due to change in effective reflection point for green, cavity length change:

$$\Delta L = l\alpha\Delta T$$

- Change in resonance frequency for IR:

$$\Delta\nu = \nu\frac{\Delta L}{L}$$

- Use α=1e-6 m/Km, ℓ=5e-6 m, L = 100 m, λ=1064 nm, ν=3e14 Hz
- Temperature RMS stability must be better that 0.09 K to meet the 1.4 Hz requirement for dual resonance

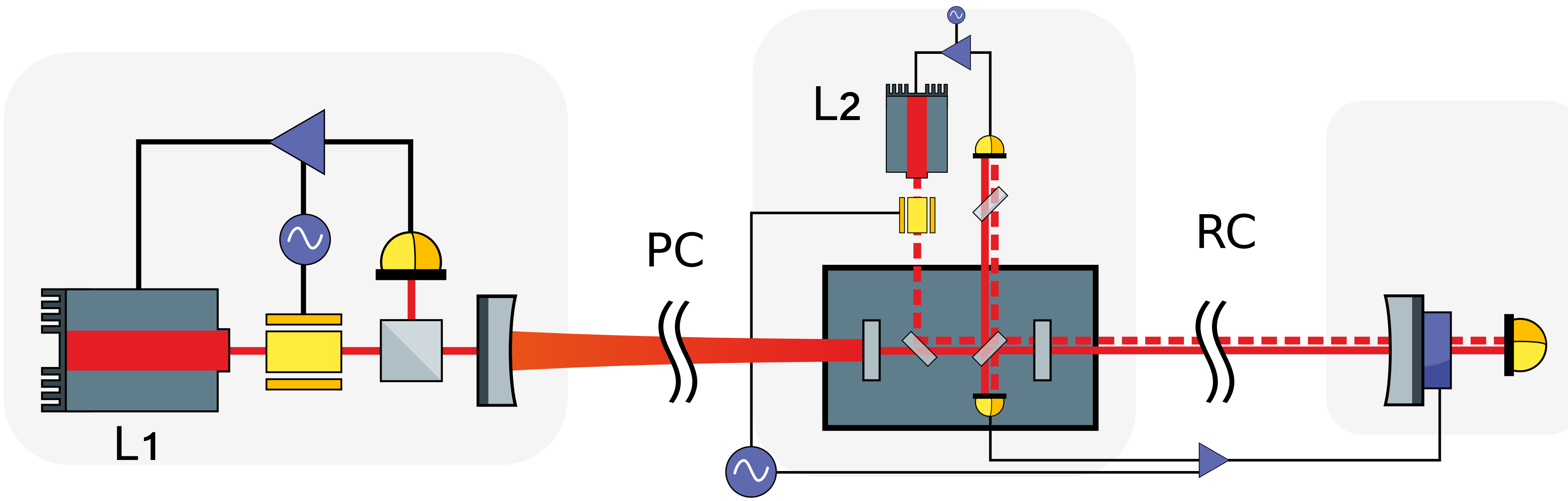
Problem 1a and 1b

- Possible problem for TES and Heterodyne
- EPF must be measured
  - Can be done with dichroic lock (mid-April)
  - Can be specified?
- Total coating thickness ~10μm
  - EPF < 1μm significantly relaxes requirements
- For heterodyne ΔEPF < 0.13pm
- For TES ΔEPF < 0.46pm

Problem 1a and 1b

- Possible solution:
  - Phase lock G1 to L1 after PC
  - Maintain resonance of L2
    - At low freq. off-load length lock error signal
      - Detune green
    - Also offset oscillator of PLL between G1 and L2
- Requirements:
  - PLL between G1 and G2 better than 5 µcycles
  - G2 L2 PLL offset frequency controlled to 0.5 Hz

Problem 2



- Lasers in PLL with offset frequency of n·FSR_{RC}
- Cavity lengths differ by m·$\lambda_{L1}/2$
- RC length lock tracks length of PC
  - FSR_{RC} changes
  - PLL offset frequency no longer correct
  - L1 detuned from RC

Problem 2

- Effect can be canceled for PC RC frequency noise

$$\Delta L_{PC}^{\mathrm{RMS}} \lesssim \frac{93\,\mathrm{\mu m}}{n - m - \frac{mn}{N}}$$

  - Absolute length of RC must be tuned
  - Modulate PC length monitor LO resonance

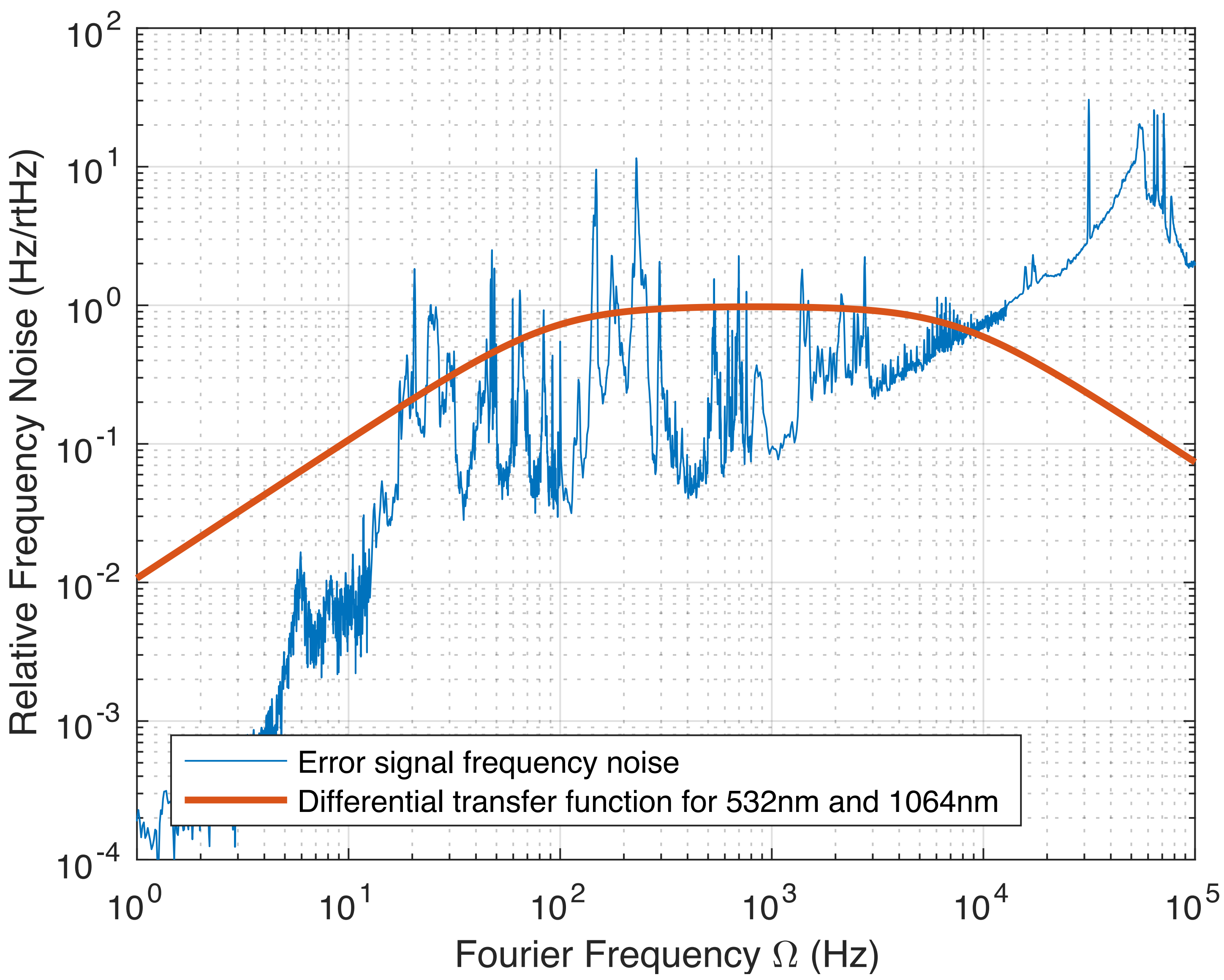
- Does not cancel for Local oscillator phase noise

$$\Delta L_{PC}^{\mathrm{RMS}} < \frac{13\,\mathrm{\mu m}}{n}$$

- PC length stability must be better than 13 um/n
  - Long term length stability must be measured
  - At low freq. could stabilize PC with external length reference

Problem 3

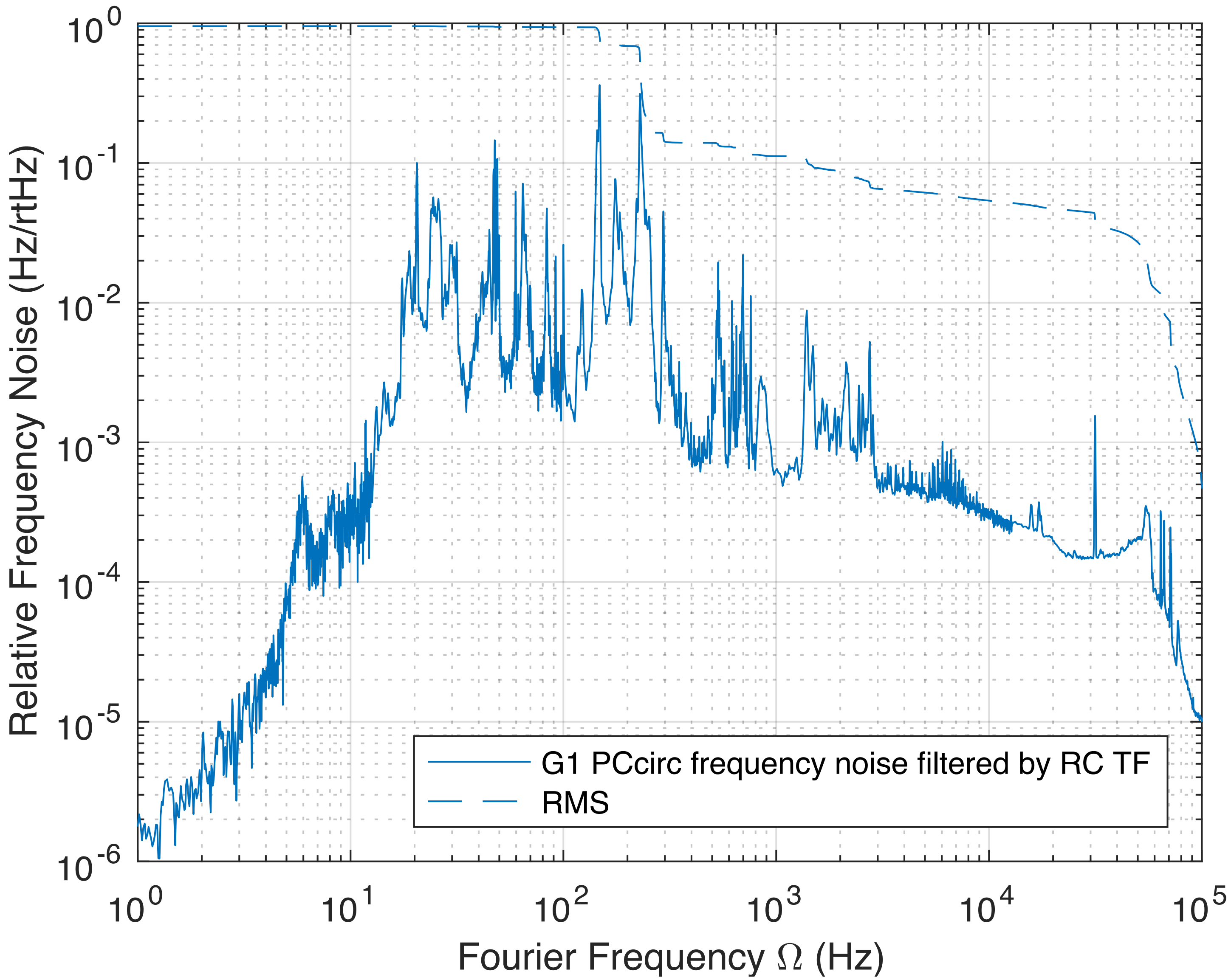
- L1 and G1 locked before PC
- G1 has error point noise from PC frequency lock



- Error point measurement of frequency lock for ALPSIIa PC
- For ALPSIIc length noise to frequency noise coupling will be reduced by longer length
- Filter by the differential transfer function for green and IR
- Filter by the RC pole

Problem 3

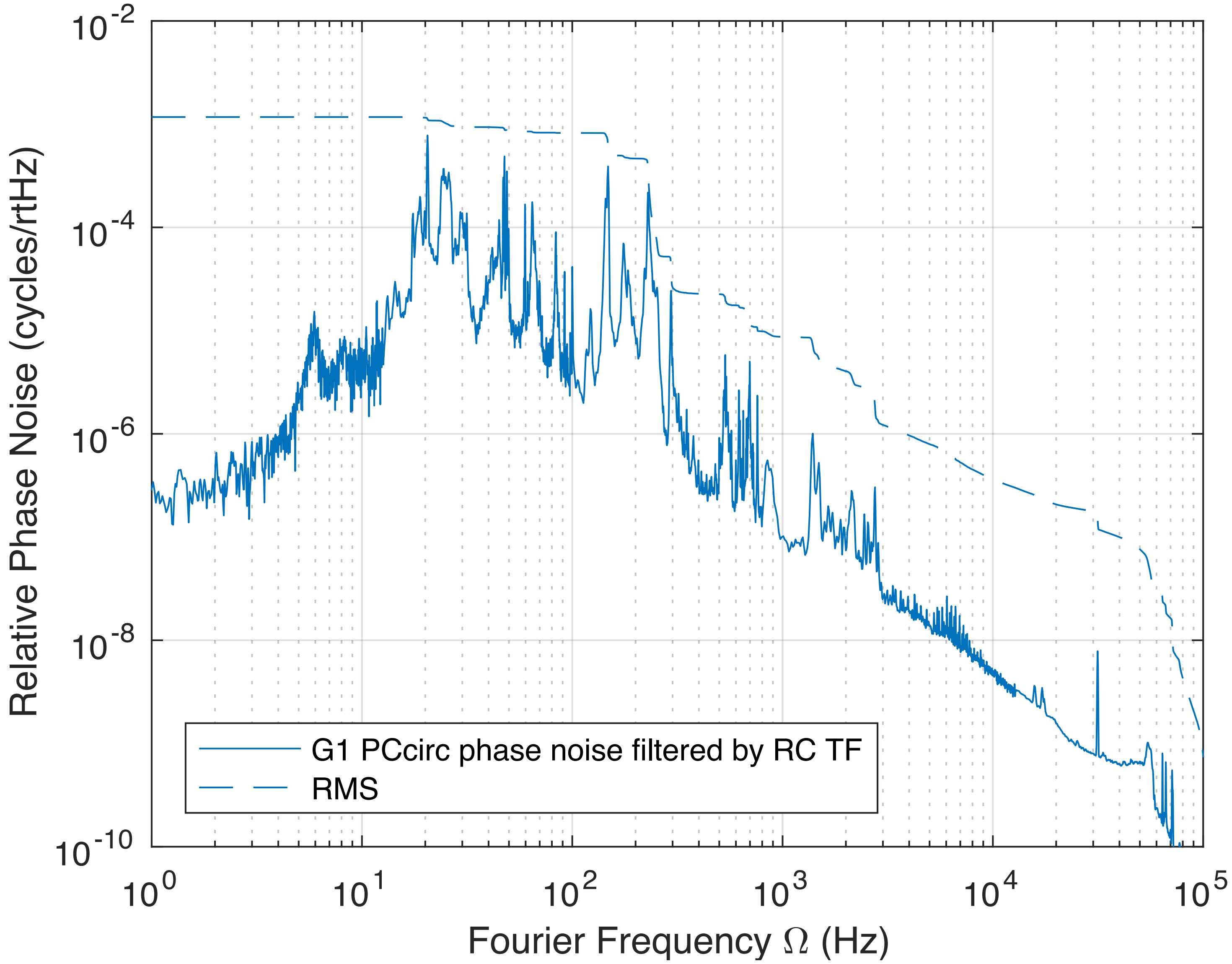
- Error signal after filtering
- Frequency dif. between PCcirc and RC resonance



- RMS is 0.95 Hz
- Requirement is 1.4 Hz
- Noise due mostly to seismic noise
  - Reduced coupling to ALPSIIc

Problem 3

- Frequency noise converted to phase noise
- G1 has error point noise from PC frequency lock

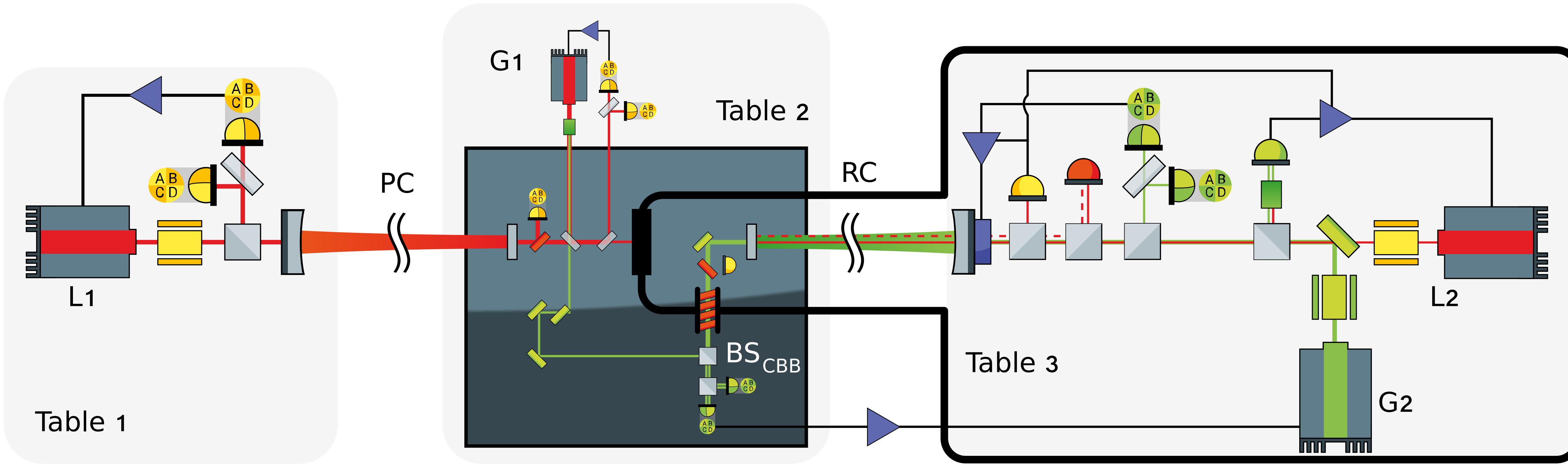


- Error point measurement of frequency lock for ALPSIIa PC converted to phase
- For ALPSIIc length noise to frequency noise coupling will be lower
- RMS phase noise: 0.001 cycles

Summary

- Problems 1a 1b appear to be possible showstoppers for TES and heterodyne
  - Difference in effective point of reflection must be investigated
  - Could be measured with dichroic lock of RC
- Problem 2 may require absolute RC length tuning
  - May require external length reference for PC
- Problem 3 likely not a showstopper according to our current analysis
- Impact of noise in PLL must be more rigorously evaluated

Possible Solution



- Modulate sidebands on L2 and monitor resonance of IR with the RC
  - Slow feedback to the length lock error signal to maintain IR resonance
    - Fixes problem 1b (only for heterodyne)
  - Slow feedback to VCO used for G2 PLL to account for phase shift of G2 being detuned from the cavity resonance and maintain L2 phase with respect to G1
    - Fixes problem 1a
- External length reference for PC