Constructing mode mismatch error signals at 2 µm in an 80 meter suspended Silicon coupled cavity

J.V. van Heijningen[1,†], V. Jaberian Hamedan[1], L. Toms-Hardman[1], C. Zhao[1]
[1]OzGrav, University of Western Australia, 35 Stirling Hwy, Crawley WA 6009, Australia
[†] joris.vanheijningen@uwa.edu.au

OzGrav
ARC Centre of Excellence for Gravitational Wave Discovery

THE UNIVERSITY OF WESTERN AUSTRALIA

Abstract

Minimising any optical losses in a gravitational wave detector is important if advanced techniques, such as squeezing or the white light cavity, are to be fruitful. Mode mismatch is a source of optical loss and so we need error signals to control it to a minimum. We present an optical experiment that will ultimately be used in the 80 meter suspended Silicon coupled cavity. A table-top experiment is under construction and early simple cavity simulations yield the error signals we need.

Mode mismatch

When input beam waist position and/or size are not matched to those of the cavity, we speak of mode mismatch (see Fig. 1).

- Independent error signals for these types of mismatch can be extracted by heterodyne detection of cylindrical modes [1].
- Position and size mismatch have a different effect on the content of the reflected beam as [2]

$$E_{\text{pos}} \propto \left[\Psi_0 + \boldsymbol{i}\,\frac{b}{2kw_0^2}(\Psi_0+\Psi_2)\right]$$

$$E_{\text{size}} \propto \left[\Psi_0 + \frac{\Delta w}{2w_0}\Psi_2\right],$$

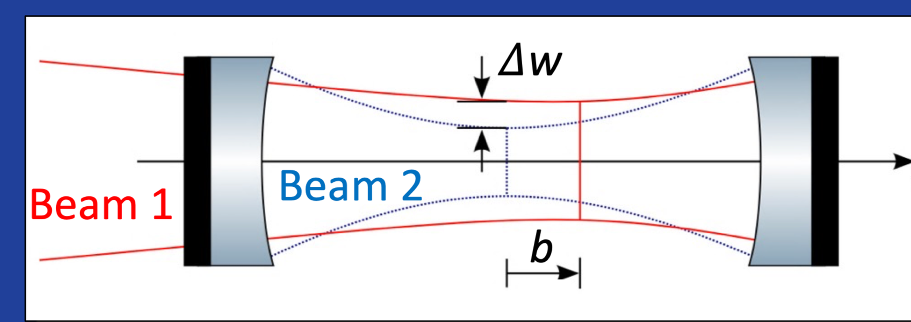
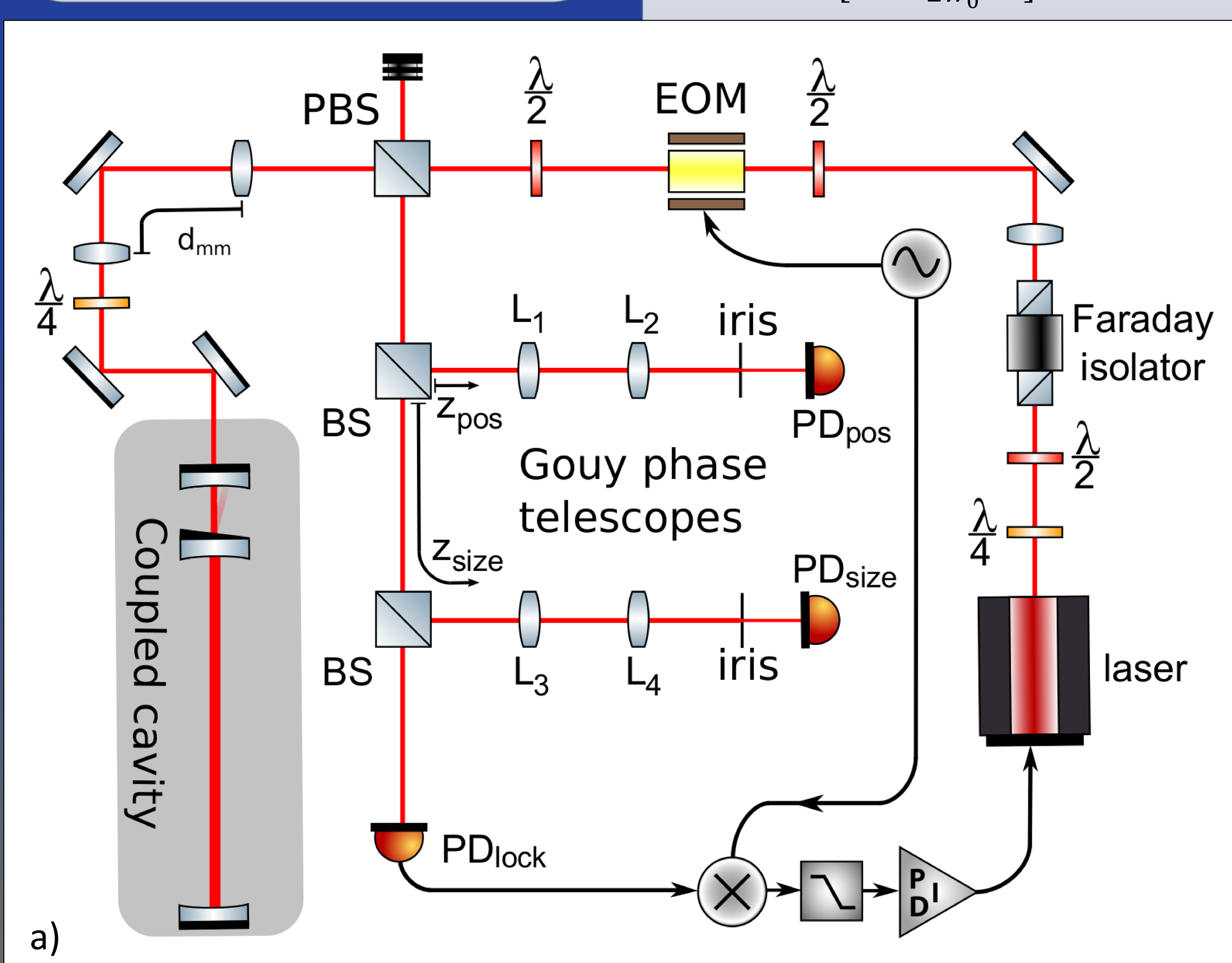


Figure 1: Position and size mismatch of the waist of input beam 1 to the waist of cavity eigenmode beam 2. Adapted from Ref. [3].

where $\Psi_{0,2}$ represents the fundamental and second order mode, $k = 2\pi/\lambda$ and w_0 the nominal cavity eigenmode waist.



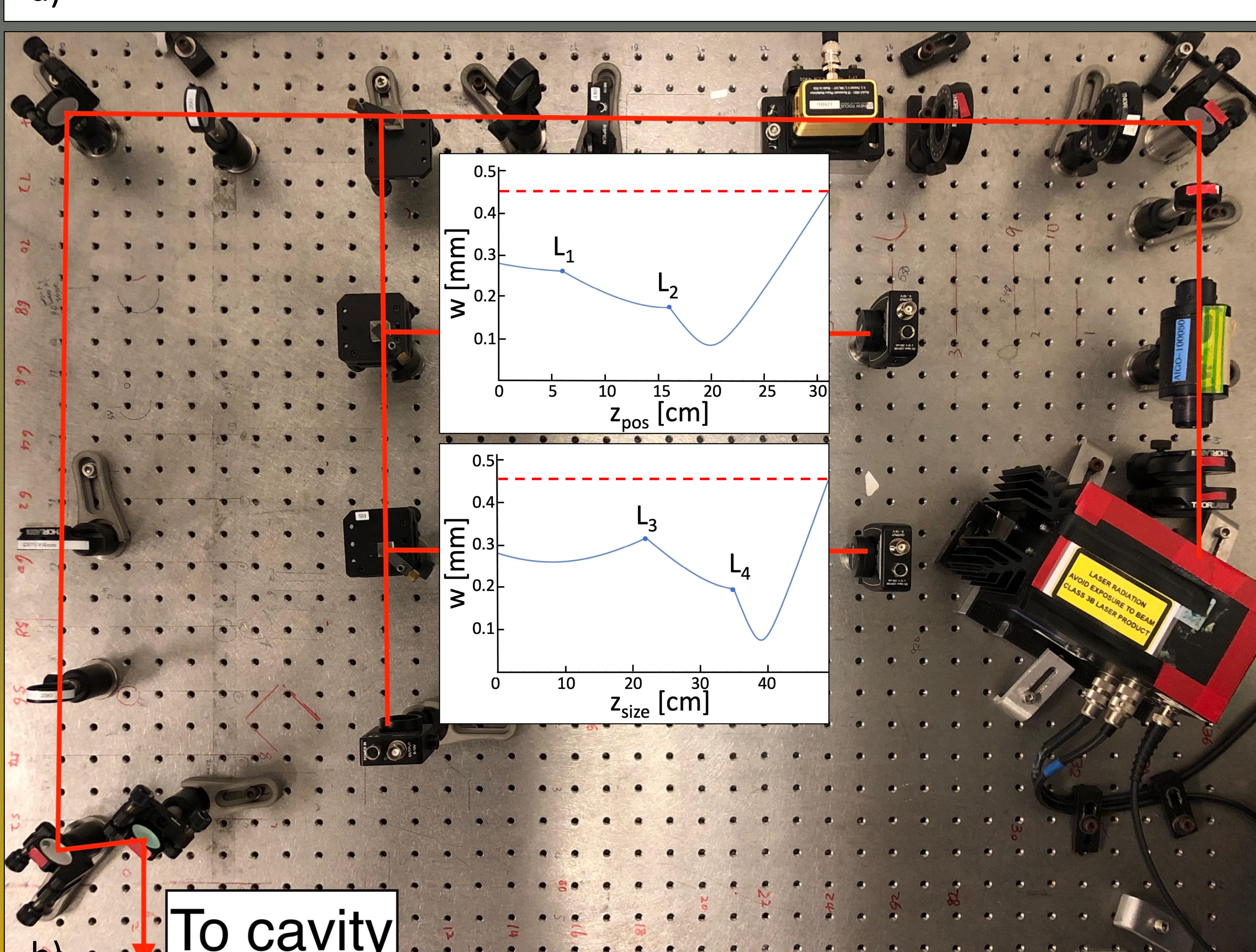
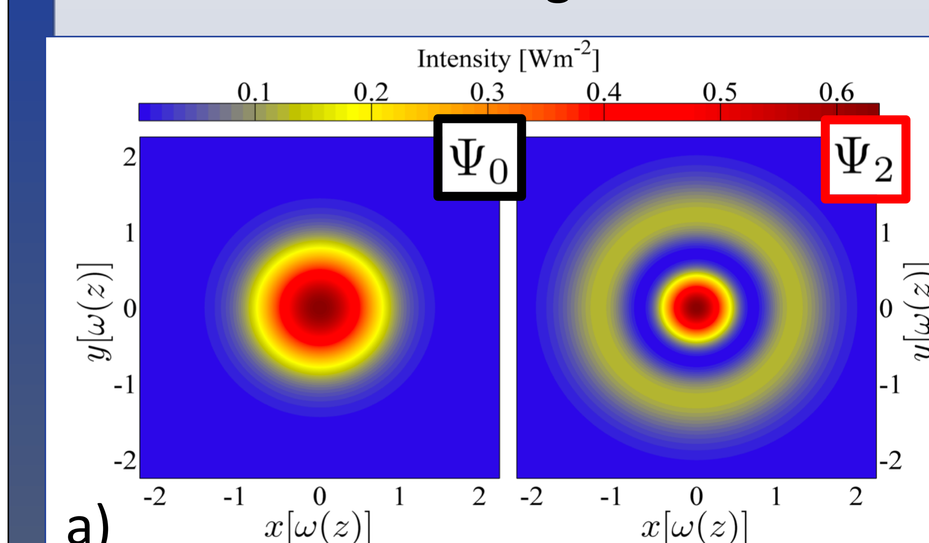


Figure 2: a) Optical set-up to generate mismatch error signals interrogating the coupled cavity. Not shown are mixers and low-pass filters from PD_{pos} and PD_{size}. b) Photograph of the set-up, with insets showing both telescope designs yielding a 0.9 mm spot at the iris.

Error signals

In Fig. 2 the optical set-up to extract the error signals is shown.

- The irises at the 2 photodiodes (PDs) are required to extract the signals (see Fig. 3).
- Telescopes provide an in-phase or 90° difference in accumulated Gouy phase between Ψ_0 and Ψ_2 to extract both signals.



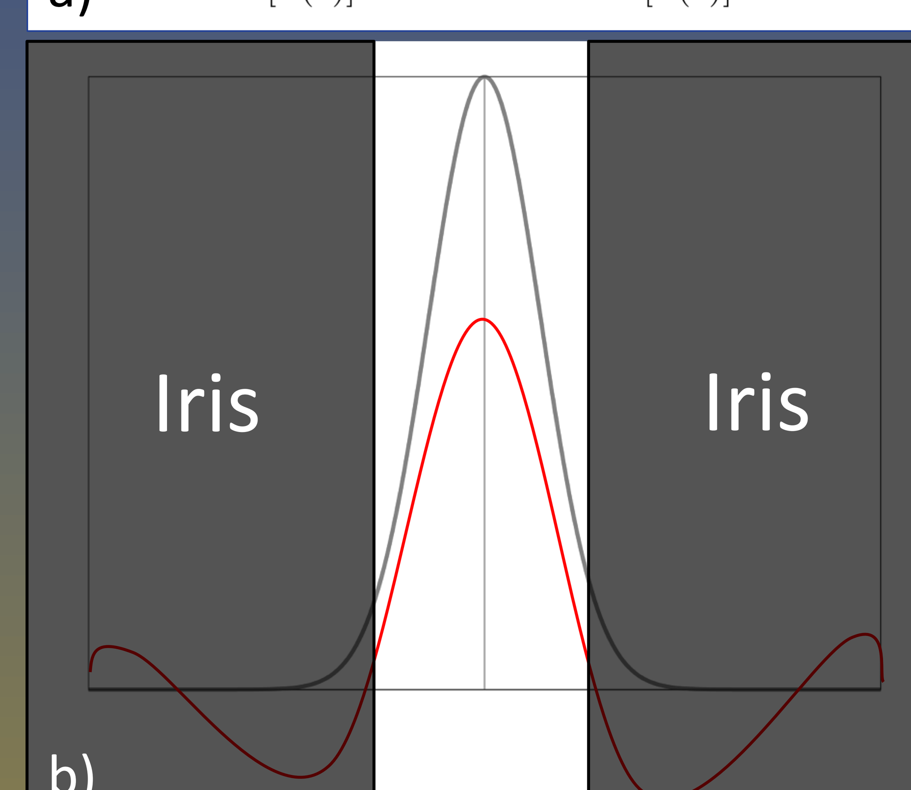


Figure 3: a) Transverse profile of the fundamental mode Ψ_0 and higher order mode Ψ_2. Adapted from Ref. [3]. b) Use of iris to shield the PD from out-of-phase parts of Ψ_2.

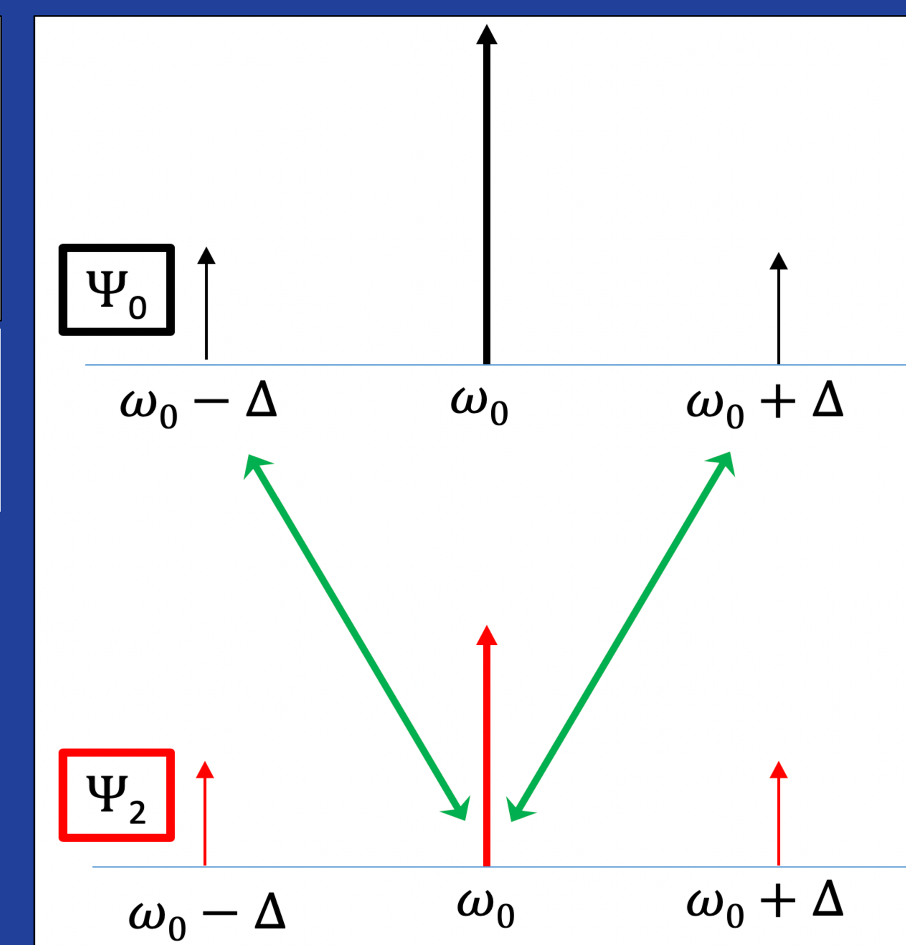


Figure 4: Carrier and EOM induced sidebands of the fundamental mode Ψ_0 and higher order mode Ψ_2. We use the beat signal between modes indicated by green arrows.

- Error signals are obtained by a demodulation of the beat signal of the sidebands of Ψ_0 with the carrier of Ψ_2 (see Fig. 4).
- Finesse [4] simulations show it is possible by changing d_{mm}, *i.e.* creating a mismatch (see Fig. 5).

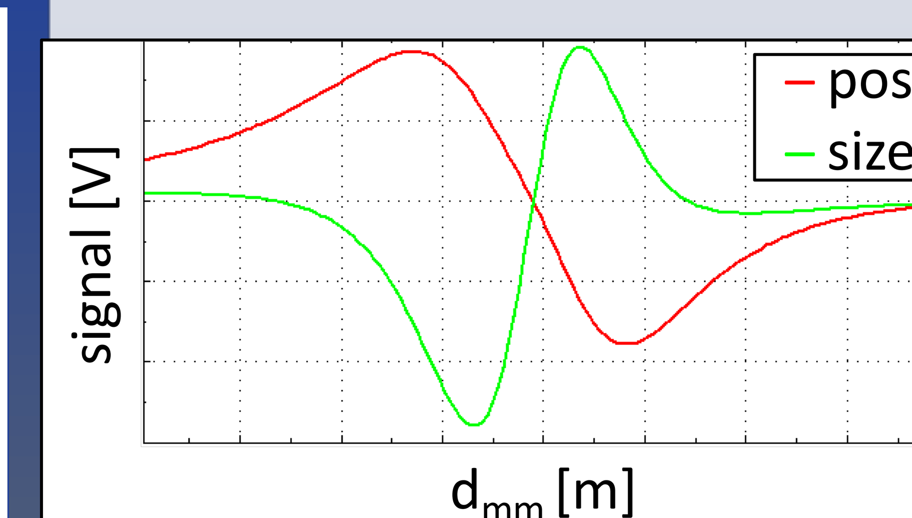


Figure 5: Preliminary simulation results, in which, by varying d_{mm} (see Fig. 2a), a mode mismatch is intentionally created.

Conclusion

The presented optical technique will be used in the coupled cavity (under construction, see Fig. 6). Experience with 2 µm laser light is vital for future detectors such as Einstein Telescope.

References

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[3] J. Miller and M. Evans, Optics Lett., Vol. 39, pp. 2495-2498 (2014)
[4] Finesse simulation software, http://www.gwoptics.org/finesse/

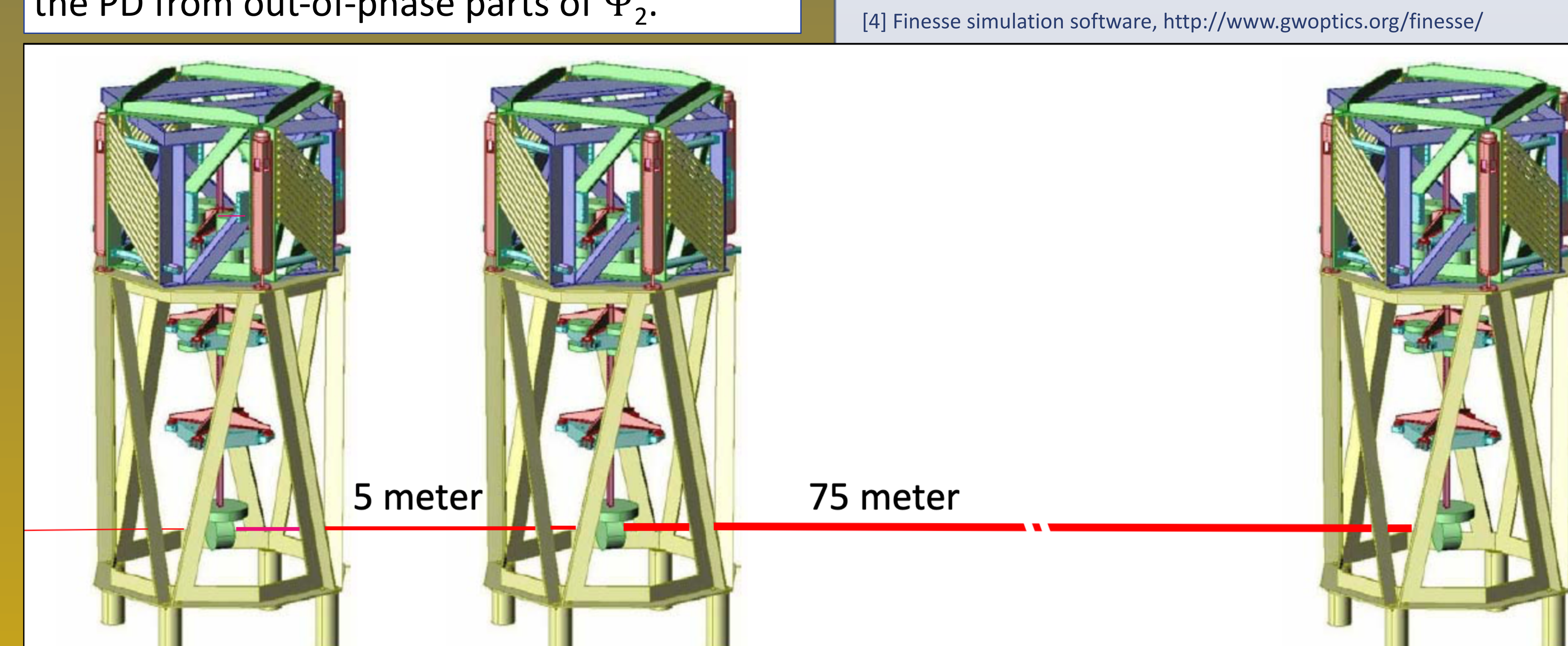

Figure 6: Conceptual overview of the Gingin South Arm coupled cavity. The test masses are made of Silicon (⌀ 100 mm) and 2 µm laser light is used. The isolators, test masses and a similar set-up as shown in Fig. 2 will be constructed at our High Optical Power Test Facility.