A direct mode mismatch sensing scheme between the recycling cavities and the arms

2023 GWADW

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Talk Summary

During this talk, I will attempt to convince you:

i. Losses need to be improved if we are to achieve 10dB of squeezing with high power operation.

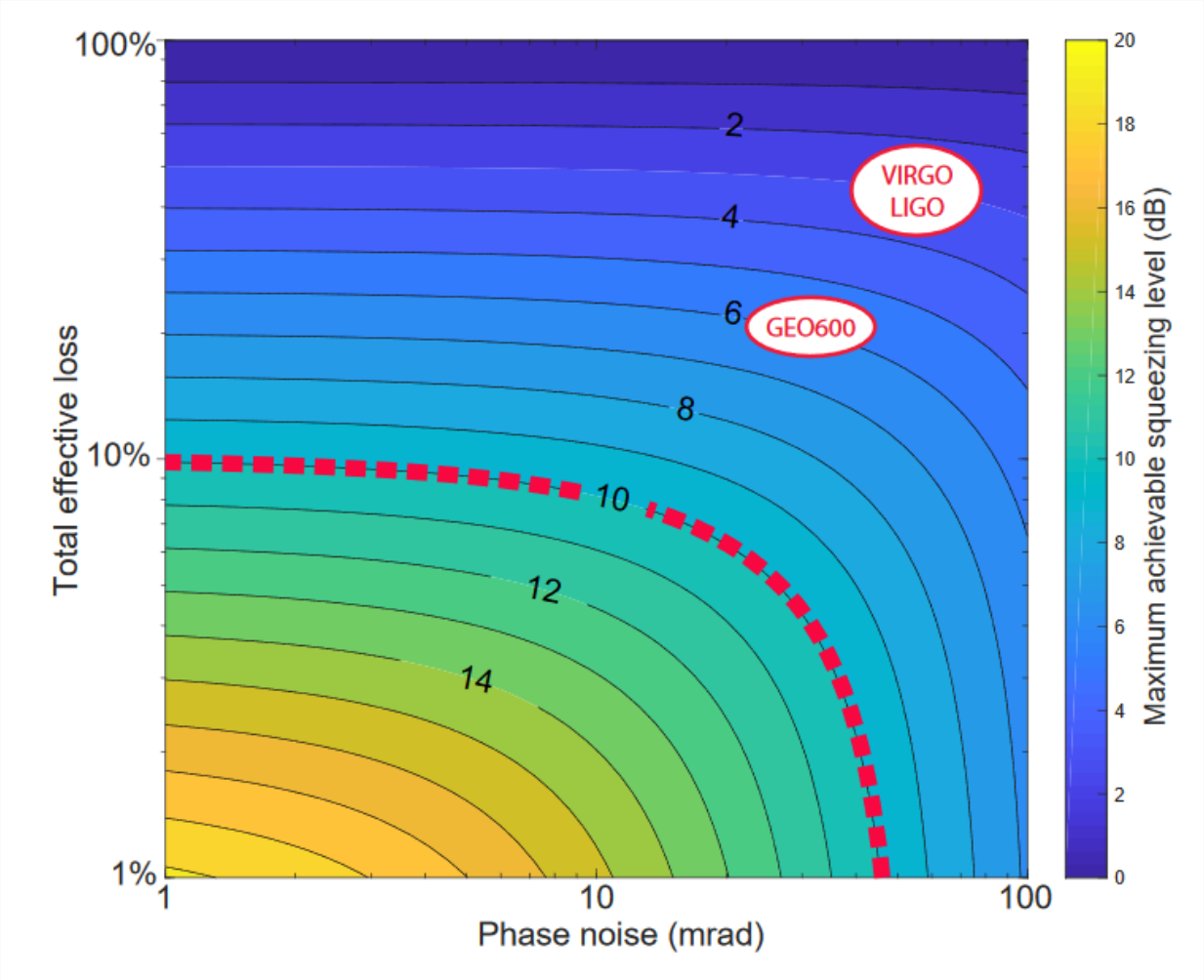
ii. Mode mismatch loss, is an important source of loss with interesting effects

iii. More power ∴ commensurately more difficult mode matching problem **in the core interferometer**

iv. I present a direct measure of mismatch

v. Which **may** complement phase camera development / MODAN / CC Pole / PRC gain signals.

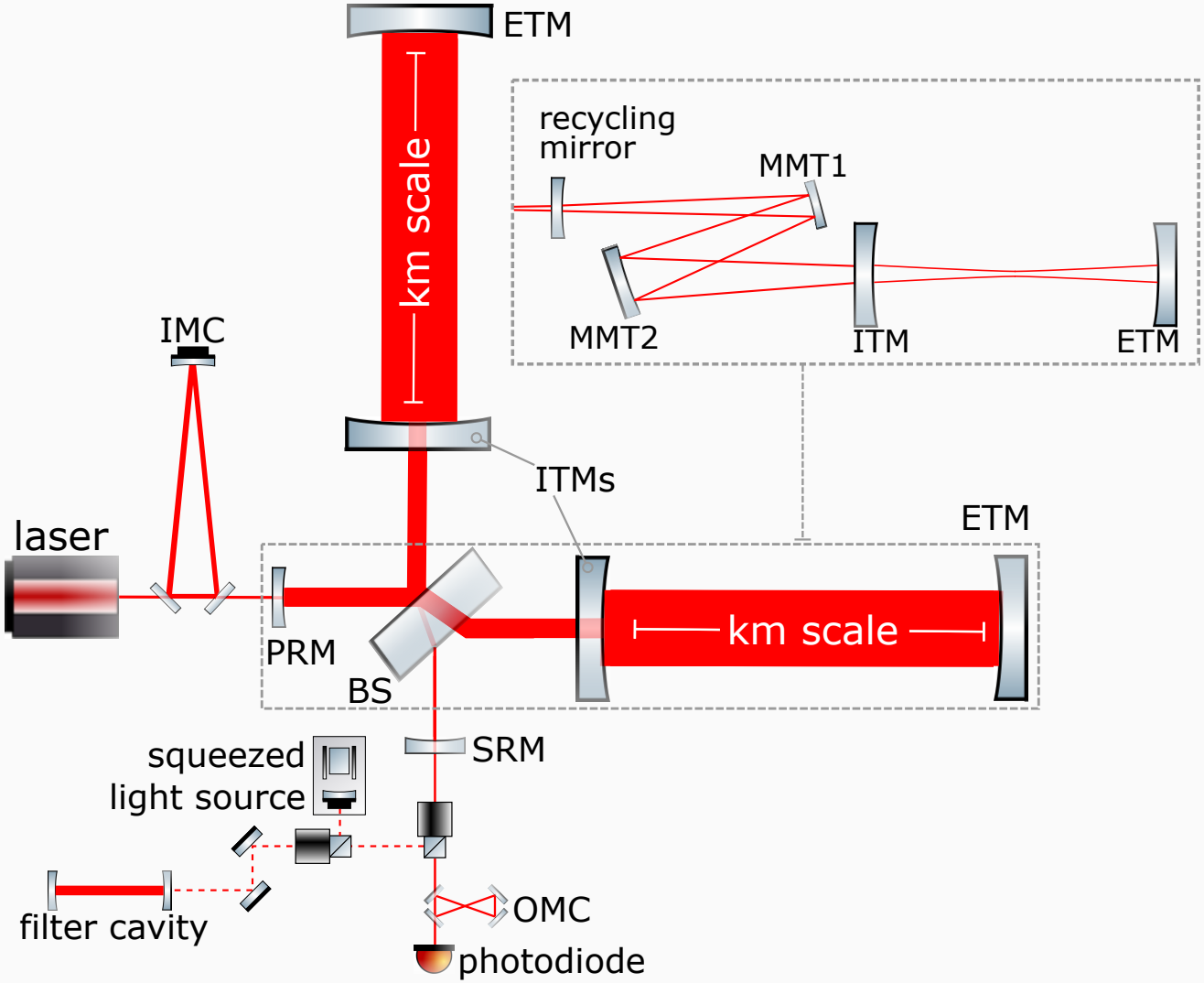
Introduction



Loss / Phase noise Landscape for 3G Detectors

Reproduced from Fig 6.6 in ET Steering Committee Editorial Team (Sept. 2020). *Einstein Telescope design report update 2020*.

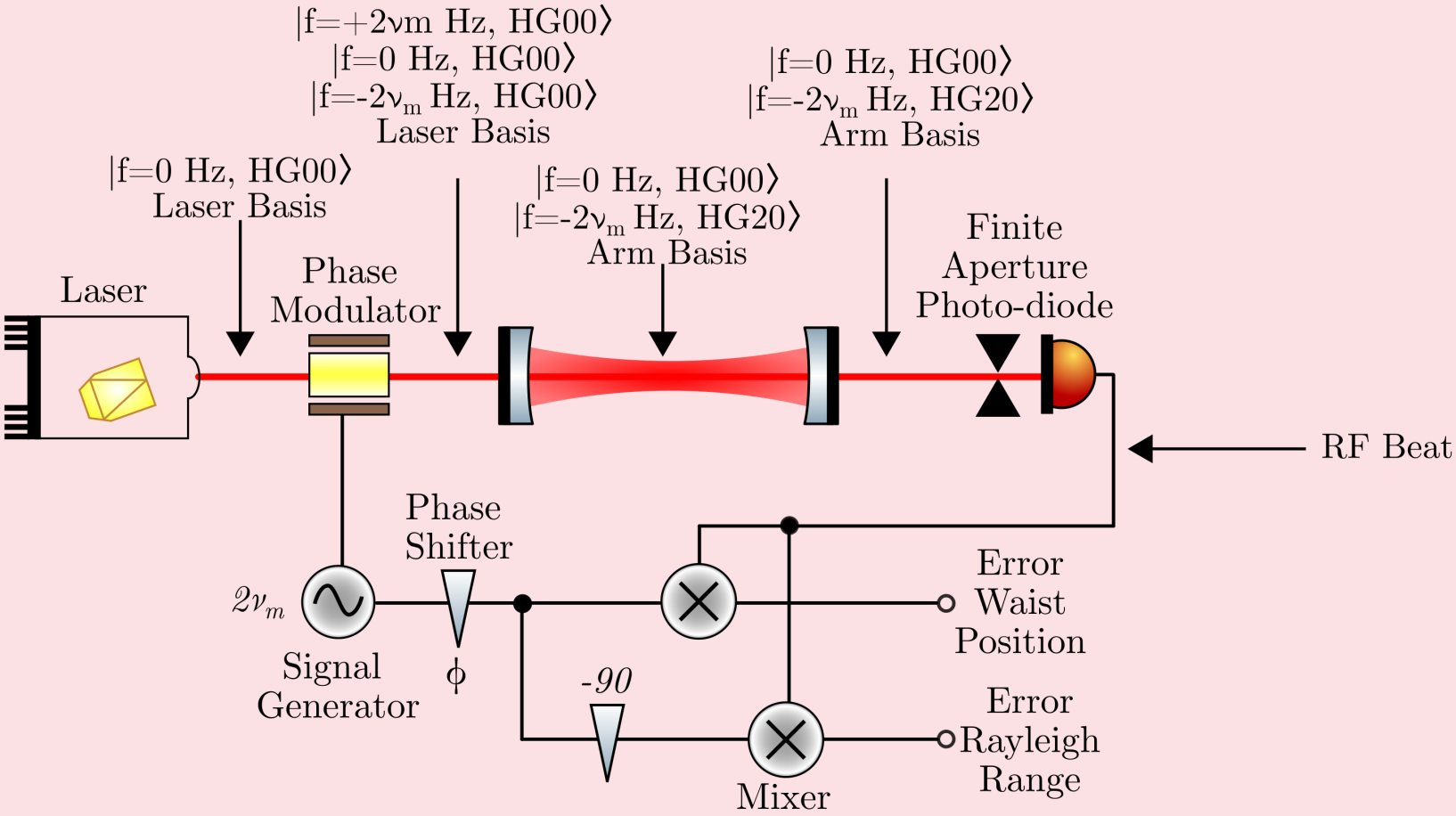
Einstein Telescope Collaboration. URL: `https://apps.et-gw.eu/tds/ql/?c=15418`



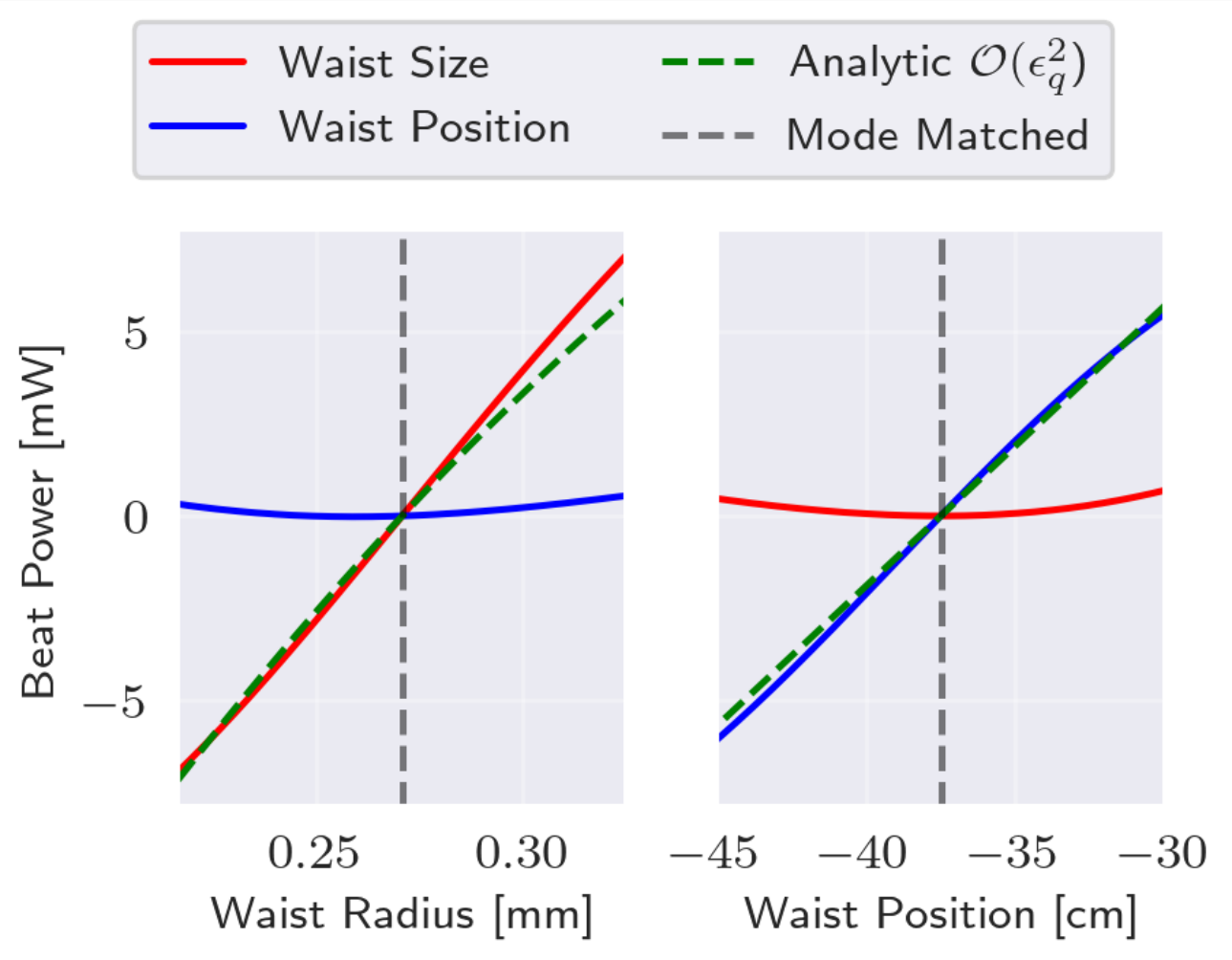
Overview of spatial eigenmodes in a typical advanced GW detector

Courtesy vanHeijningen. Reproduced from Goodwin-Jones et. al, Eigenmode Mismatch Sensing in Quantum Enhanced Interferometers: A Review and Recommendations for a New Generation, In Prep.

Simple Cavity Example



$$k_{0020} \approx \frac{\sqrt{2}(i\Delta_z - \Delta_{zR})}{4\overline{z_R}} + \mathcal{O}(\Delta_z^2, \Delta_{zR}^2), \tag{1}$$

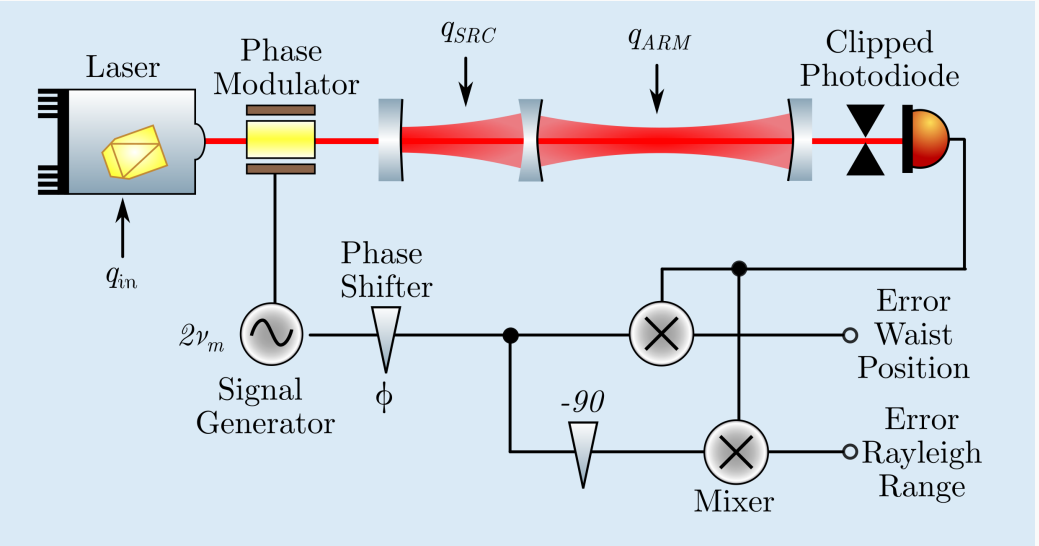


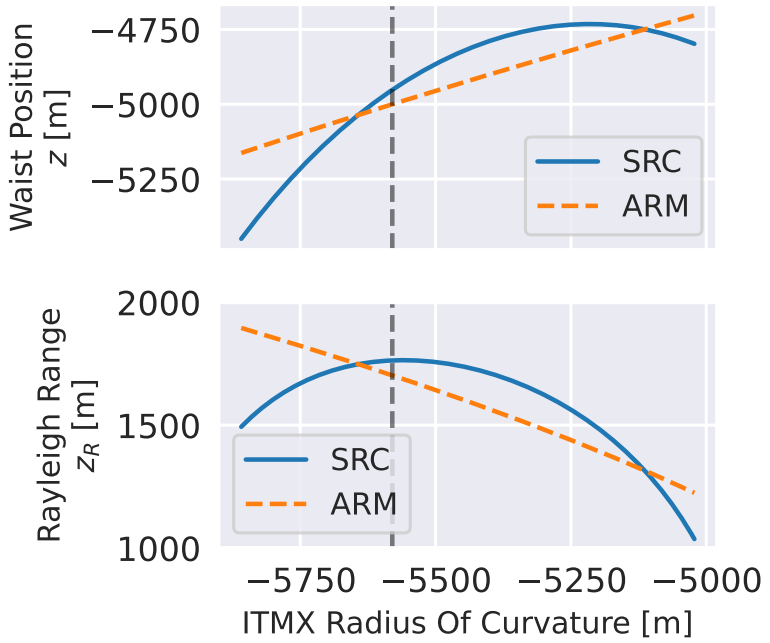
$$k_{0020} \approx \frac{\sqrt{2}(i\Delta_z - \Delta_{zR})}{4\overline{z_R}} + \mathcal{O}(\Delta_z^2, \Delta_{zR}^2), \qquad \text{(1 Repeated)}$$

Coupled Cavity Example

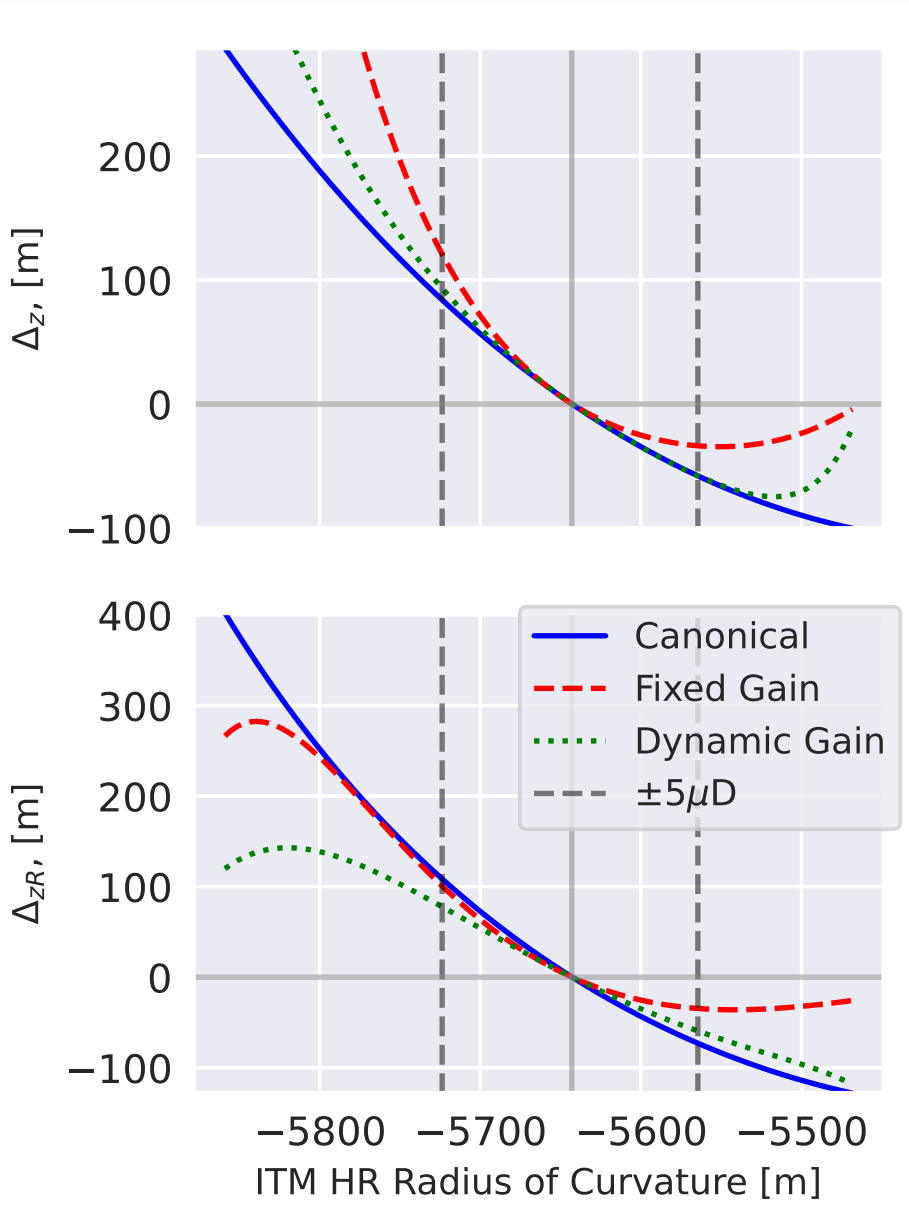
Assumptions

- Input/Output optics are mode matched
- 2nd Order Arm mode seperation frequency $\ll$ HWHM Recycling cavity





Note - Can't generate pure waist size / waist position mismatch



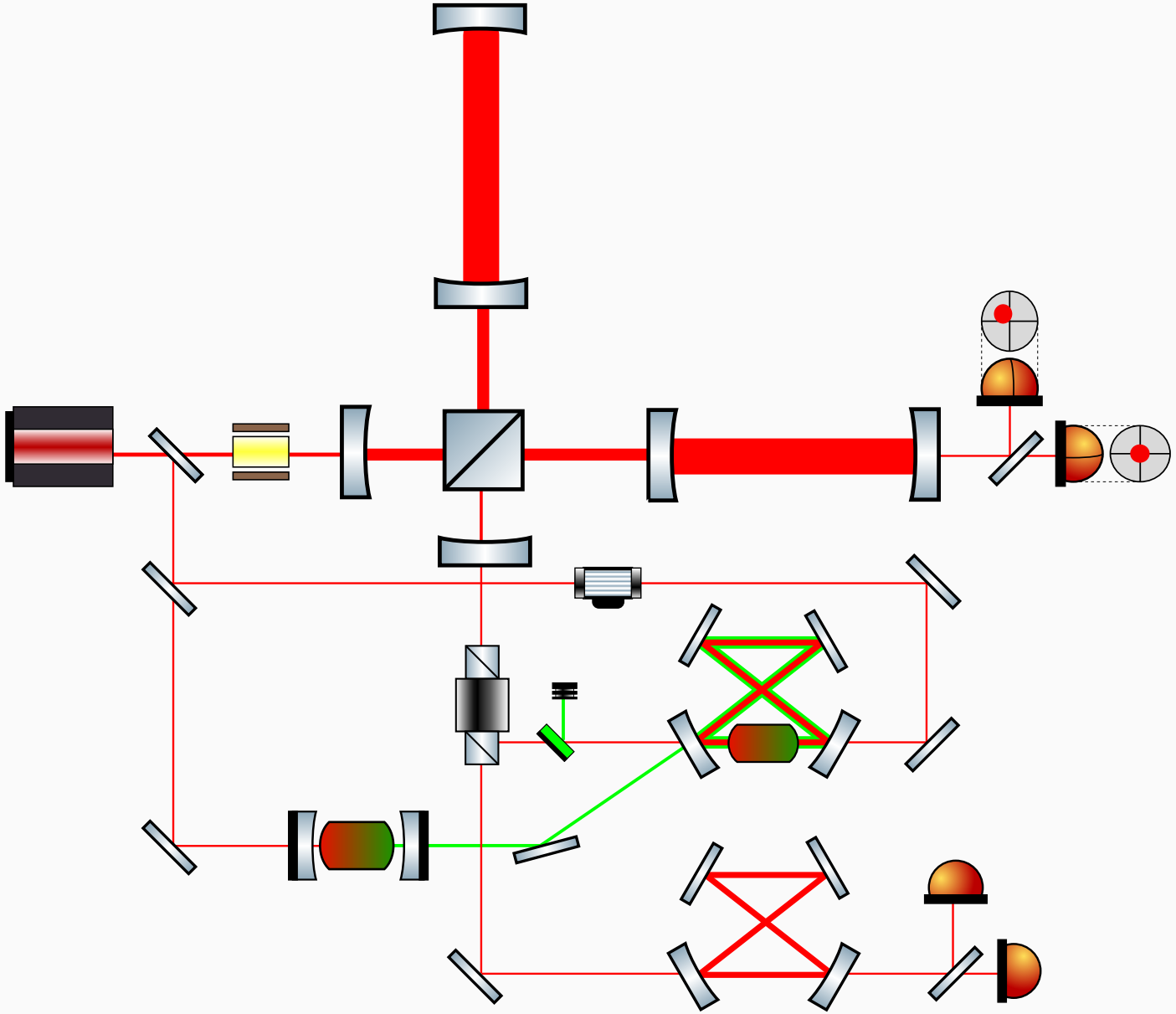
An early preprint is available on Research Square / DCC

`https://www.researchsquare.com/article/rs-2872352/v1`

`https://dcc.ligo.org/LIGO-P2300010`

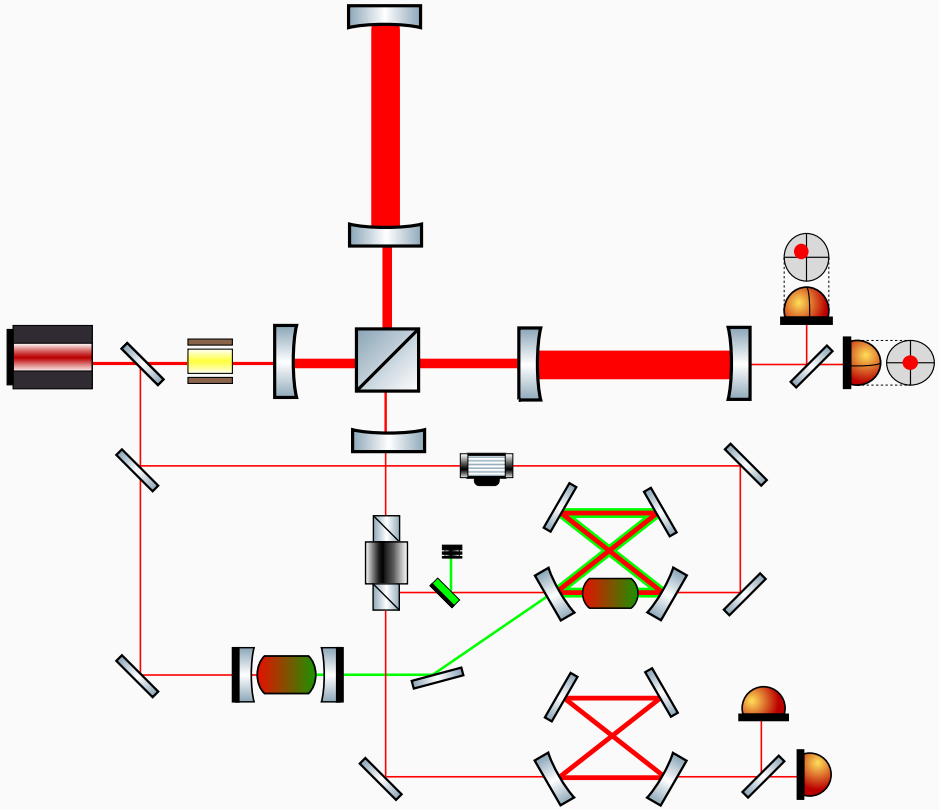
Link to paper

LLO Test



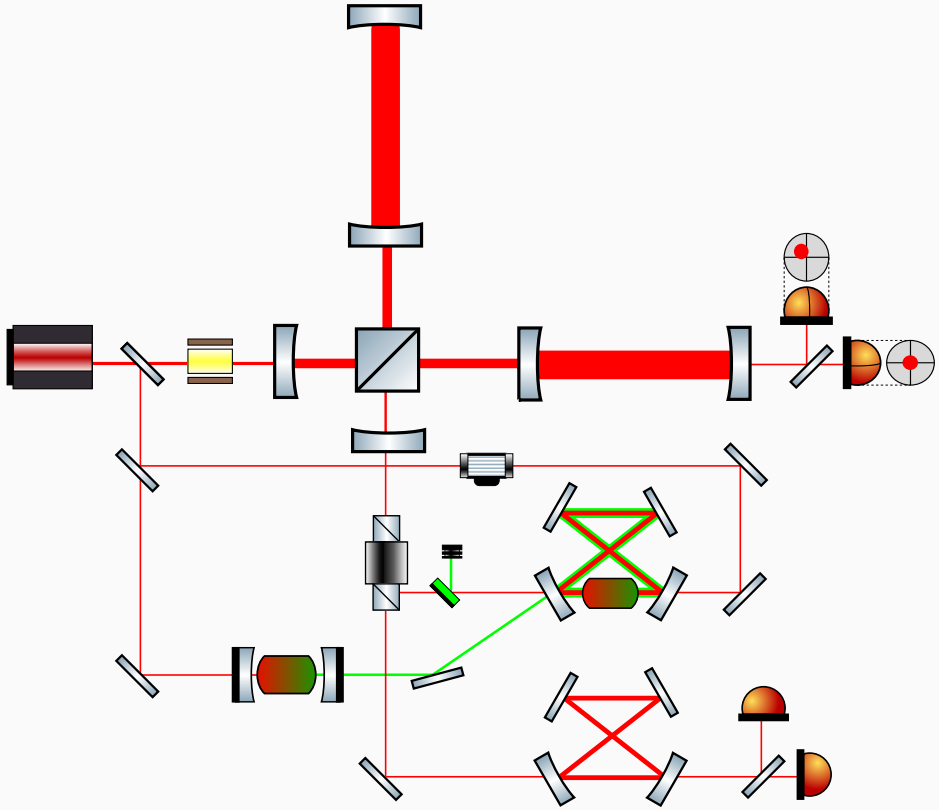
Simplified Optical Layout

- AOM excites a side band at 10 kHz once combined in OPO
- $|\text{HG00, 0}\rangle \rightarrow$ $|\text{HG00, 0}\rangle + |\text{HG00, 10 kHz}\rangle$
- Mismatches on OPO$\rightarrow$XARM path scatter light into HG20
- $|\text{HG00, 10kHz}\rangle \rightarrow$ $|\text{HG20, 10 kHz}\rangle$



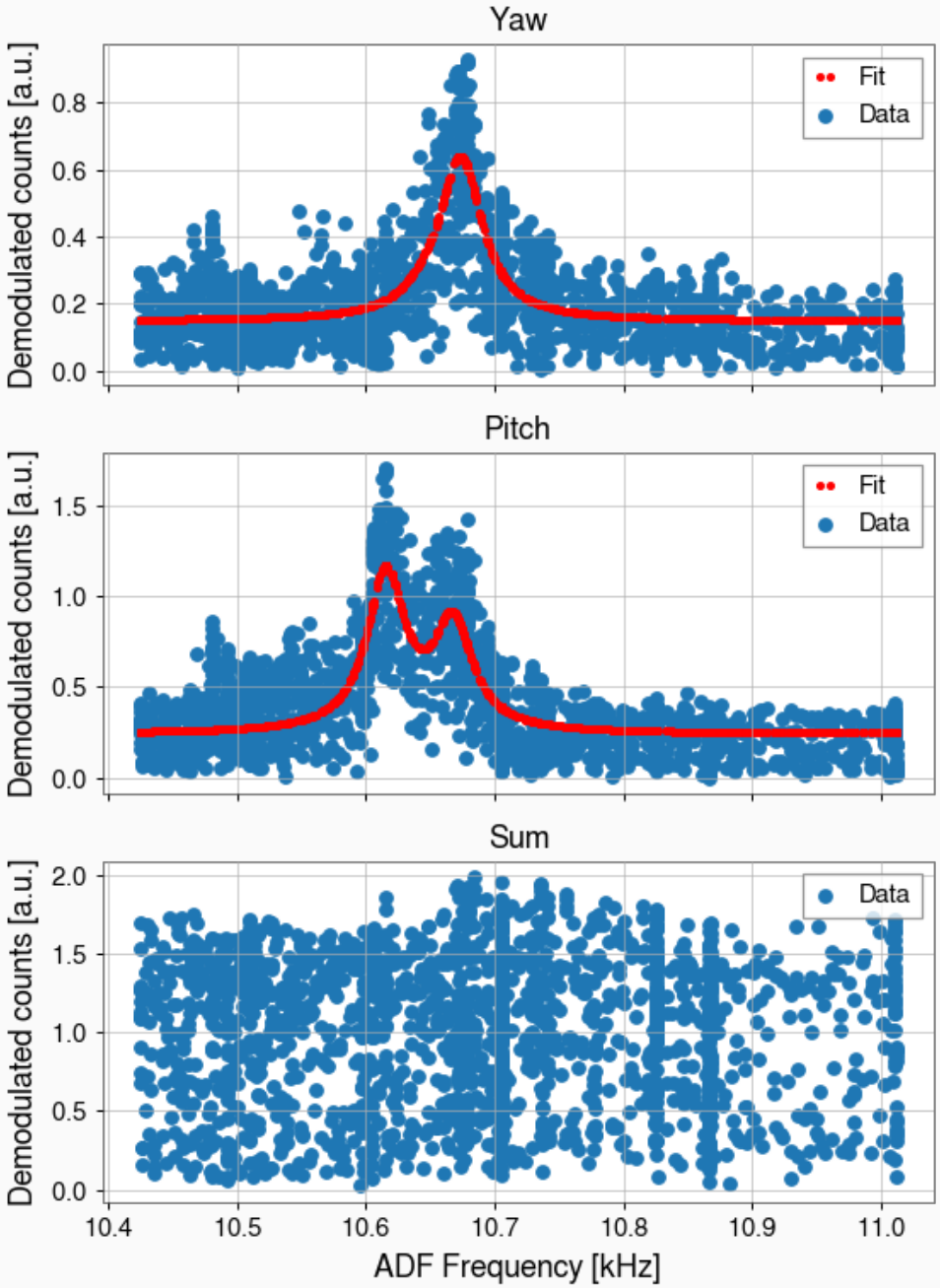
Simplified Optical Layout

- XARM filters non resonant modes
- In-loop QPD keeps transmission bench centered
- Out of loop, offset QPD mixes the HG20 and HG00 fields
- The ratio of the HG20 power and HG00 power is then the mode mismatch.



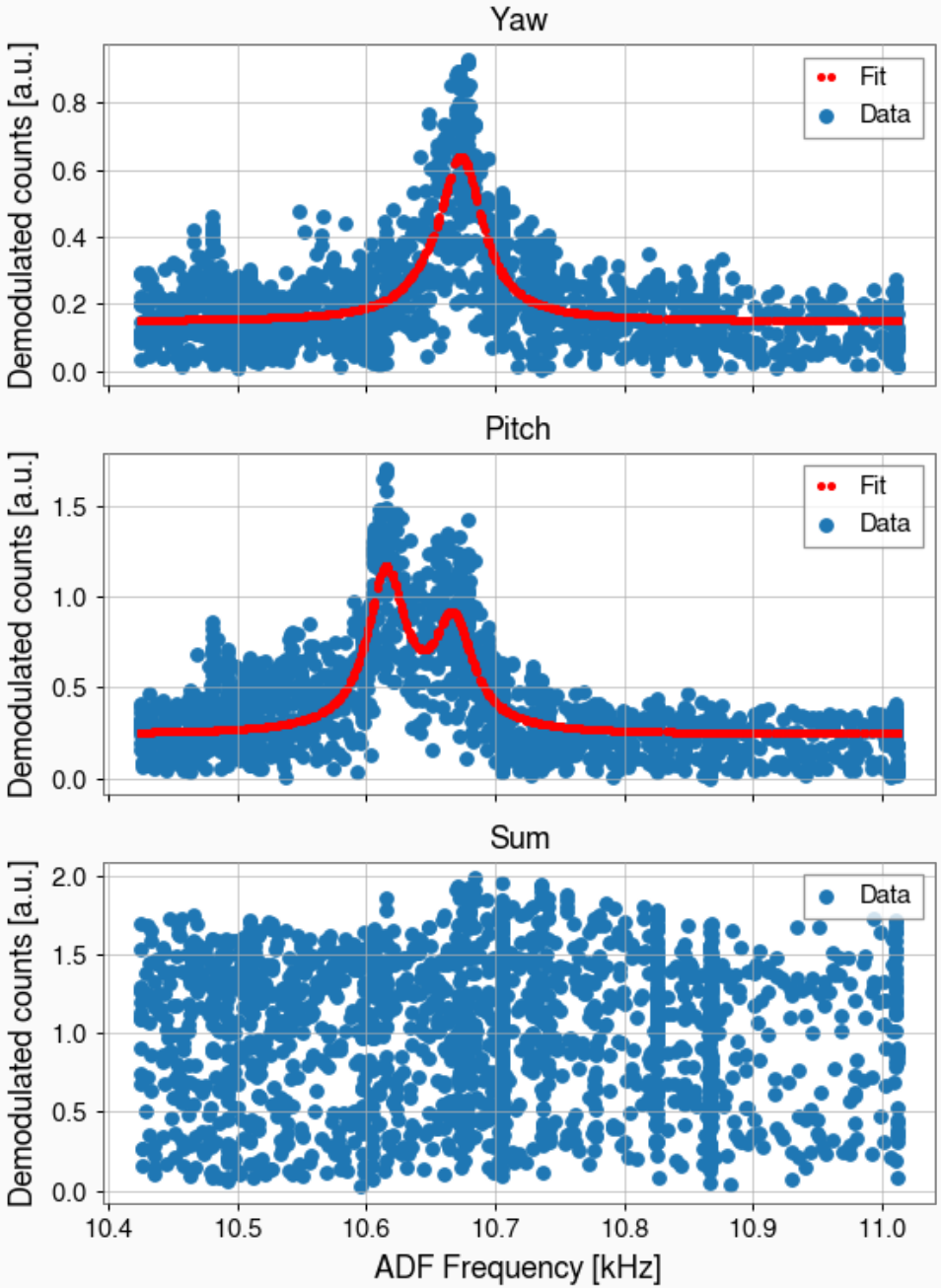
Simplified Optical Layout

- Each dot is 1s of integration time
- One mode shows up in "Yaw"
- Two modes show up in "Pitch"



- Assuming this is HG20 and HG02 cavity implies cavity 'g' factors of 0.8152 and 0.8135.
- Assuming all astigmatism is on the ITM implies a RoC of 1949.48 ± 0.04 and 1951.56 ± 0.04 m for the vertical and horizontal.

See LLO aLOG 61000.

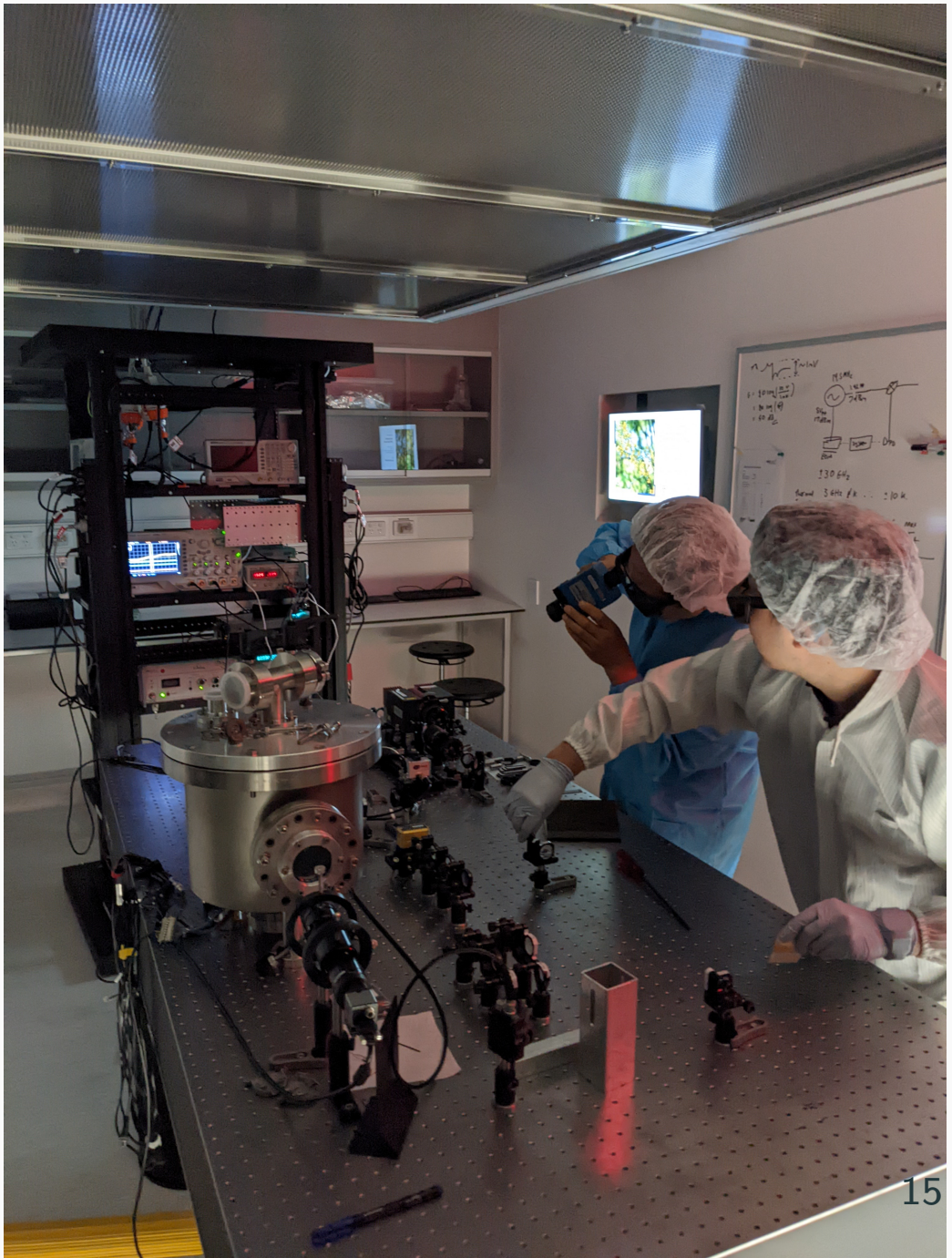


Caveats

- Establishing power in the ADF was difficult
- Used -15 dBm (to AOM amplifier), instead of nominal -60 dBm.
- Cannot use ADF CDS models as at 16 kSa / sec.

Further Work

- Closed loop active mode matching demonstration ongoing at UWA
- Suspended demonstration with T-SAMS ongoing at Gingin.



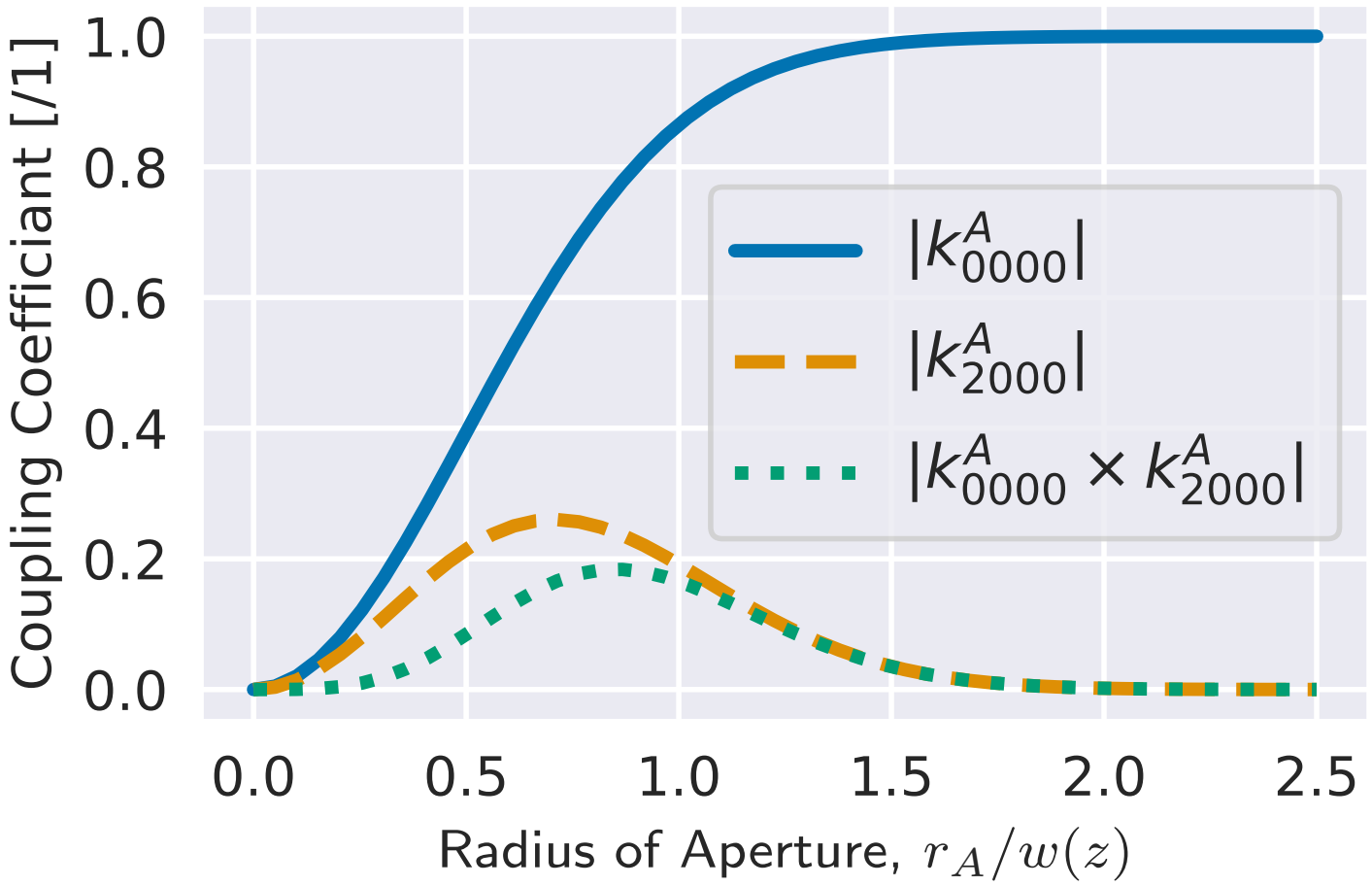
Conclusions

Talk Summary

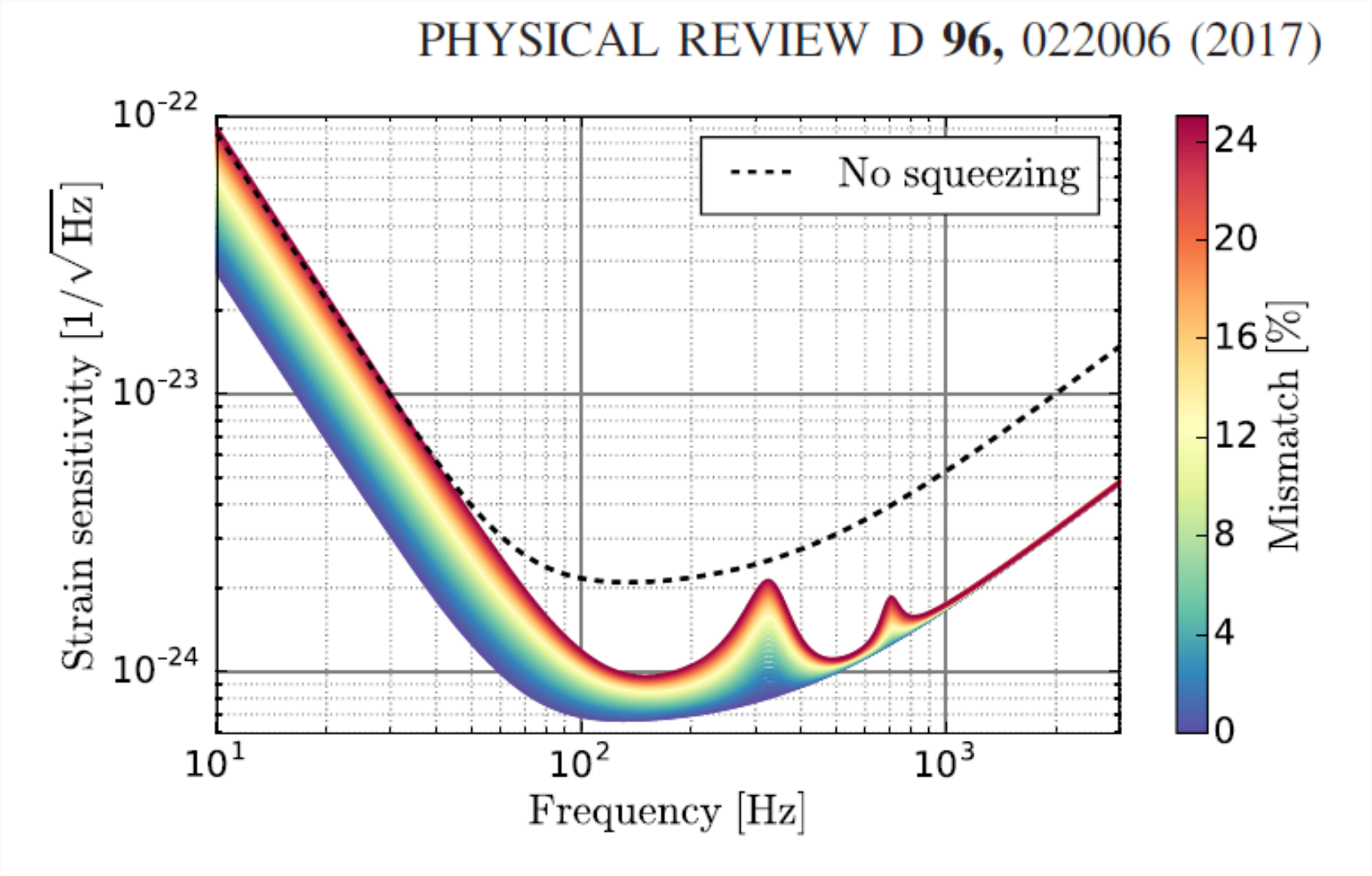
Conclusions

i. More power ∴ commensurately more difficult mode matching problem **in the core interferometer**
ii. I presented a direct measure of mismatch.
iii. Demonstration at LLO generally positive.
iv. Work is ongoing to develop the technique.

Appendix



$$k^A_{2,0,0,0} = -e^{i\gamma_{2,0,0,0}}\sqrt{2}(r/w(z))^2 \exp(-2(r/w(z))^2), \quad (2)$$



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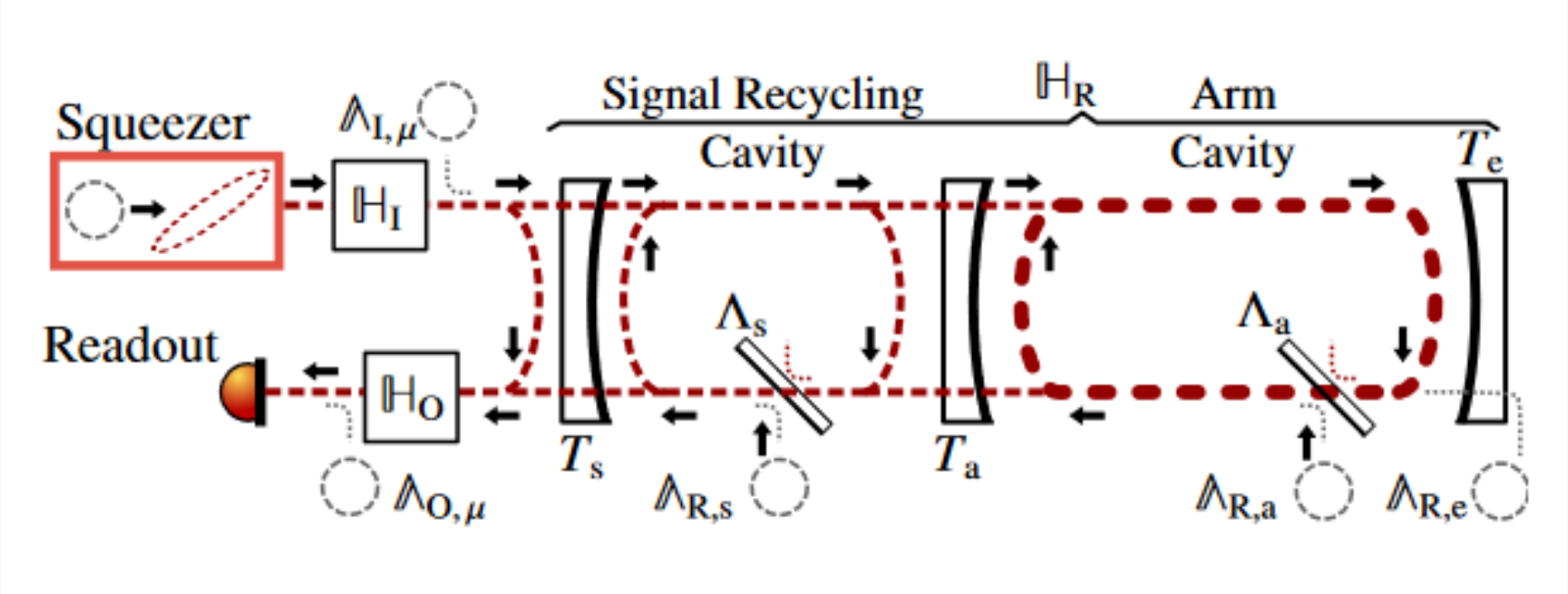

Reproduced from L McCuller et al. (Sept. 2021). "LIGO's quantum response to squeezed states". In: *Phys. Rev. D* 104 (6), p. 062006. DOI: 10.1103/PhysRevD.104.062006. URL: https://link.aps.org/doi/10.1103/PhysRevD.104.062006

References i

- Töyrä, Daniel et al. (July 2017). "Multi-spatial-mode effects in squeezed-light-enhanced interferometric gravitational wave detectors". In: *Phys. Rev. D* 96 (2), p. 022006. DOI: 10.1103/PhysRevD.96.022006. URL: https://link.aps.org/doi/10.1103/PhysRevD.96.022006.
- ET Steering Committee Editorial Team (Sept. 2020). *Einstein Telescope design report update 2020*. Einstein Telescope Collaboration. URL: https://apps.et-gw.eu/tds/ql/?c=15418.

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McCuller, L et al. (Sept. 2021). "LIGO's quantum response to squeezed states". In: *Phys. Rev. D* 104 (6), p. 062006. DOI: 10.1103/PhysRevD.104.062006. URL: https://link.aps.org/doi/10.1103/PhysRevD.104.062006.