Homodyne Detector Characterization

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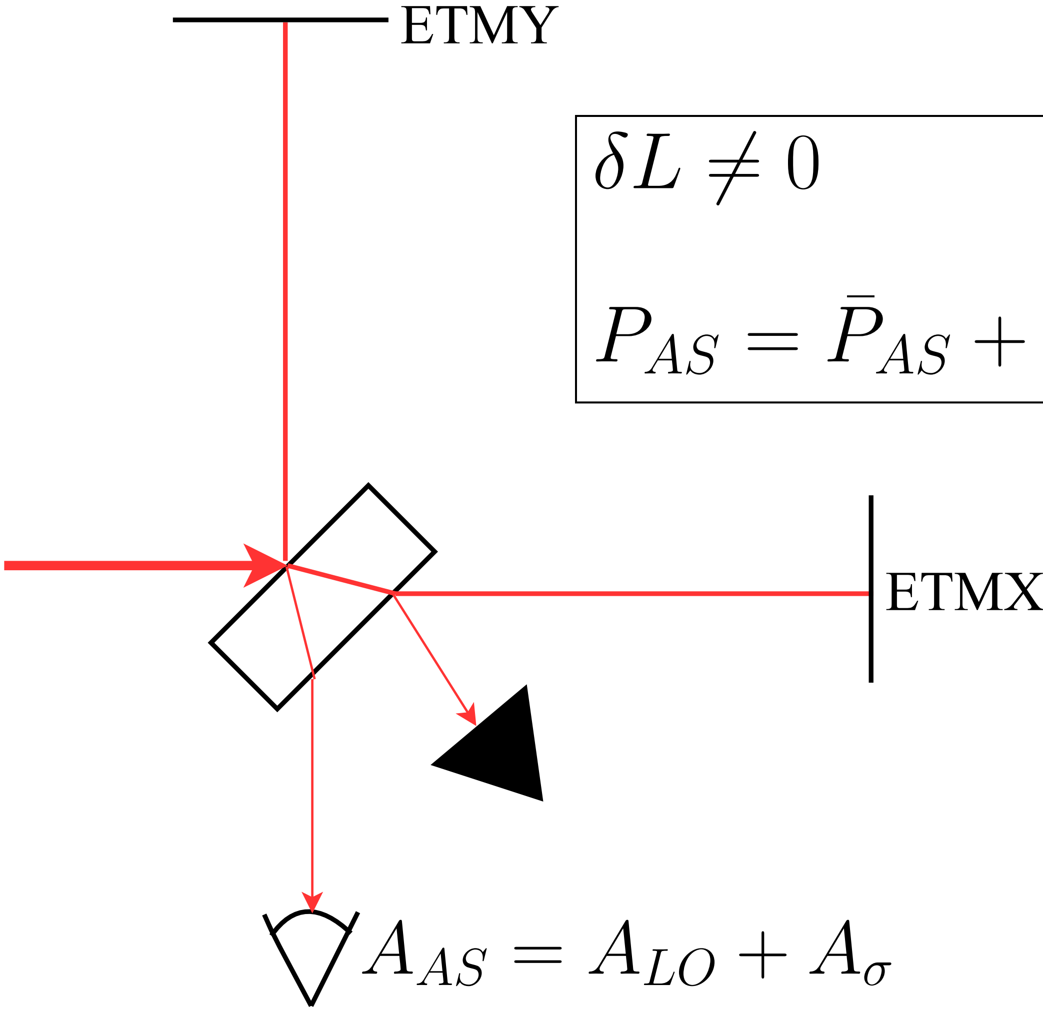
LIGO-T1500287-v1

Outline

- DC Readout
- Balanced Homodyne Readout
- Instrumental Setup
- Performance
- Conclusions

DC Readout

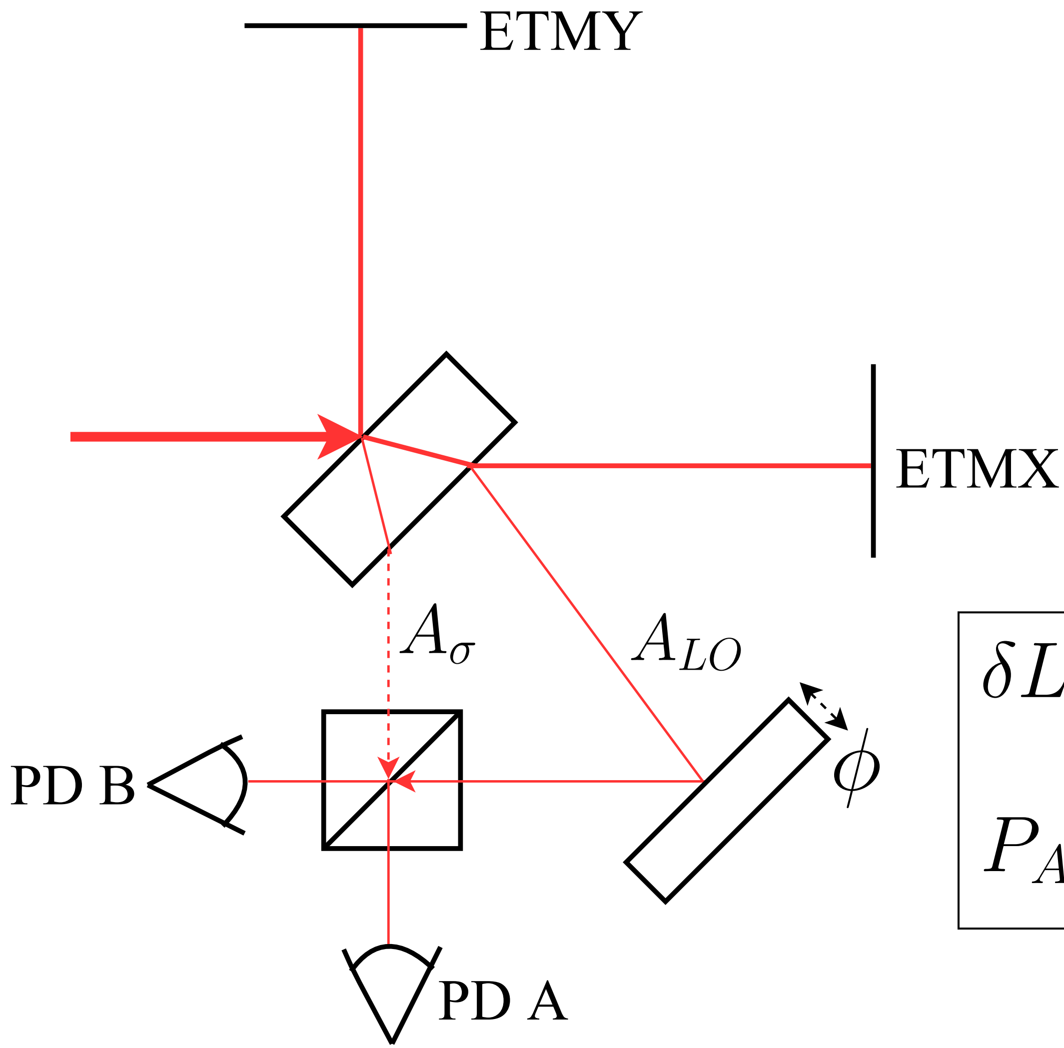


$$\delta L \neq 0$$

$$P_{AS} = \bar{P}_{AS} + 2Re(\bar{A}_{LO}(A_\sigma + \epsilon \bar{A}_{LO})^*)$$

$$A_{AS} = A_{LO} + A_\sigma$$

Balanced Homodyne Readout



$$\delta L = 0$$

$$P_A - P_B = 2Re(e^{i\phi}\bar{A}_{LO}A_\sigma^*)$$

Balanced Homodyne Readout

- Insensitive to power noise on the LO
- Output not dominated by power from arm offset
- Homodyne phase can be tuned to optimize the sensitivity
- Facilitates the measurement of sub-quantum noise with squeezing

BHR Sub-quantum Noise

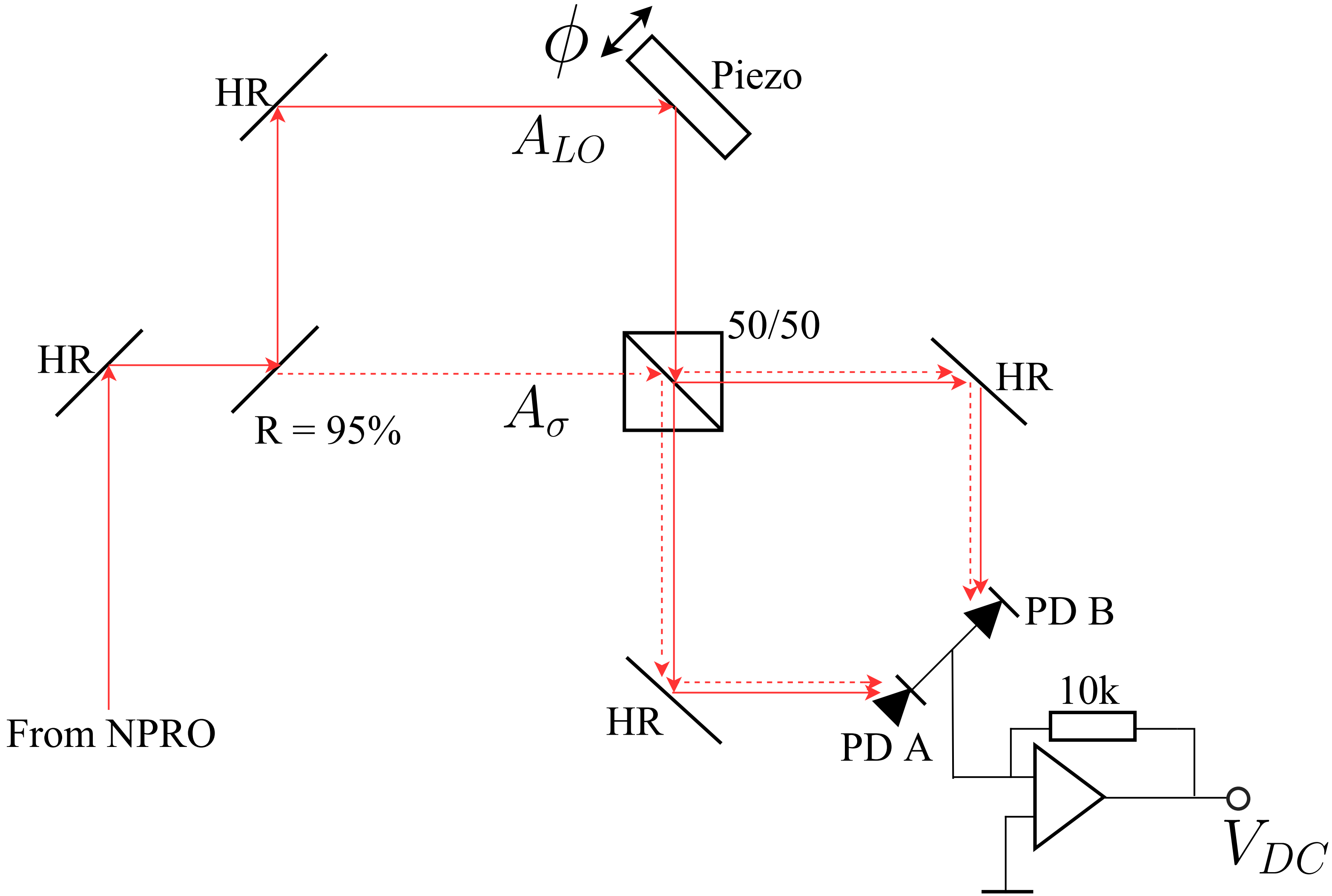
- Squeezing allows the measurement of sub-quantum noise
- Quantum noise must exceed electronics noise to be measured

$$\frac{R}{\alpha F_{sqz}}\sqrt{2\epsilon P} \geq \sqrt{4k_B T R}$$

$$\sqrt{R} \geq \alpha F_{sqz}\sqrt{\frac{2k_B T}{\epsilon P}}$$

- A larger resistor is desirable
- In BHR, current subtraction occurs before signal readout, so a larger resistor can be used without the need to support high voltage (10 kΩ vs. 400 Ω in DCR)

Balanced Homodyne Detector



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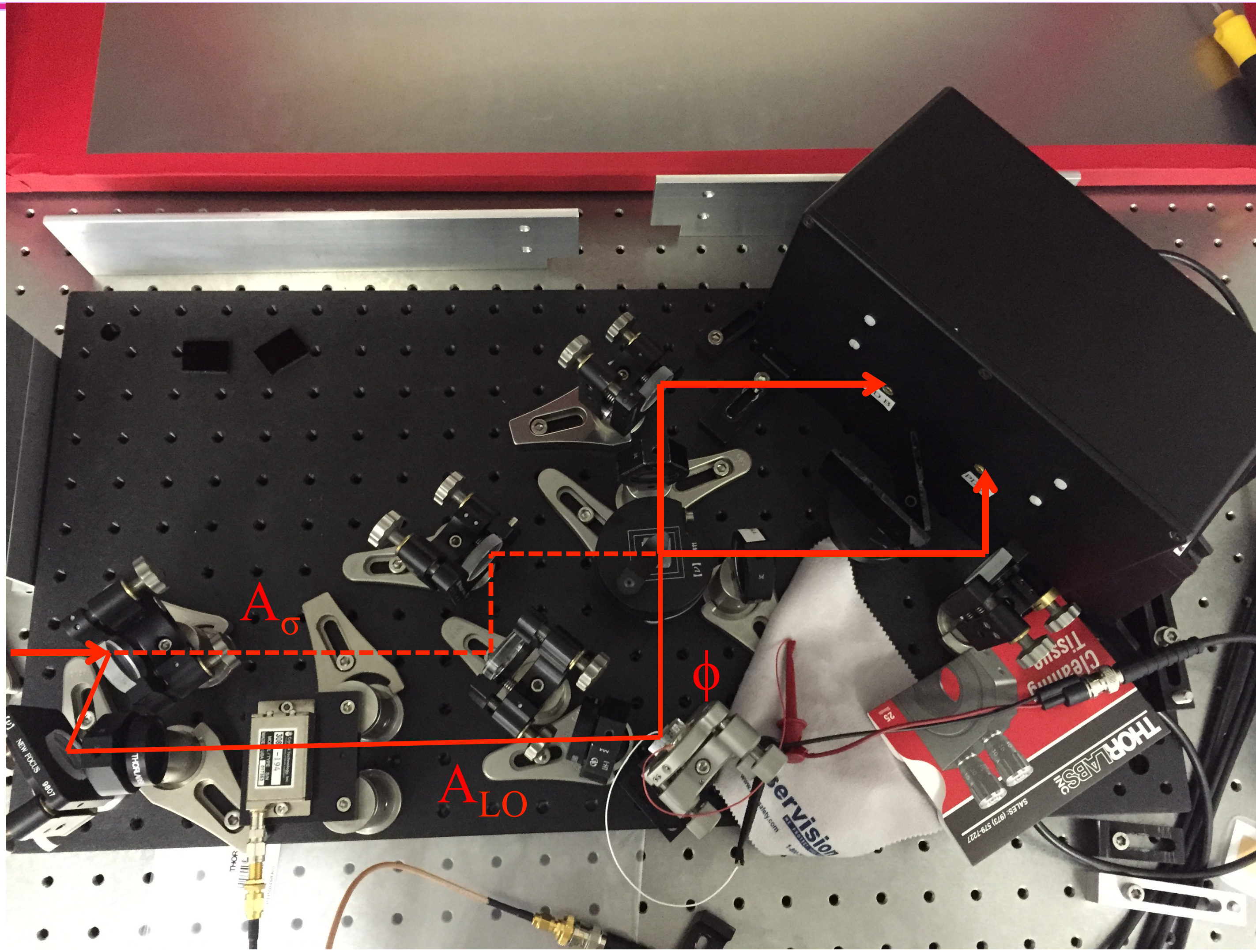
Balanced Homodyne Detector



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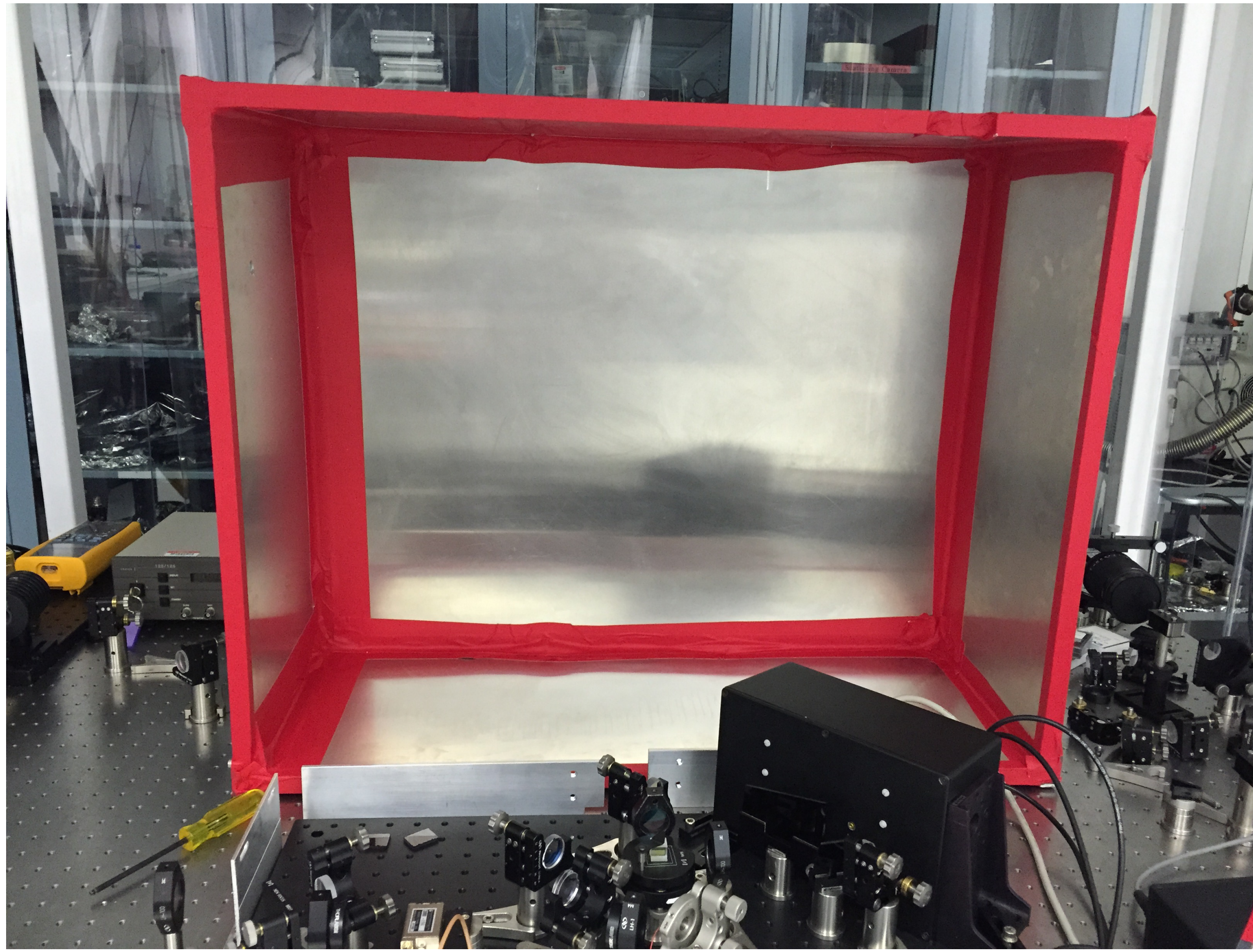
Acoustic Isolation

- Aluminum and foam box
- 20 dB isolation



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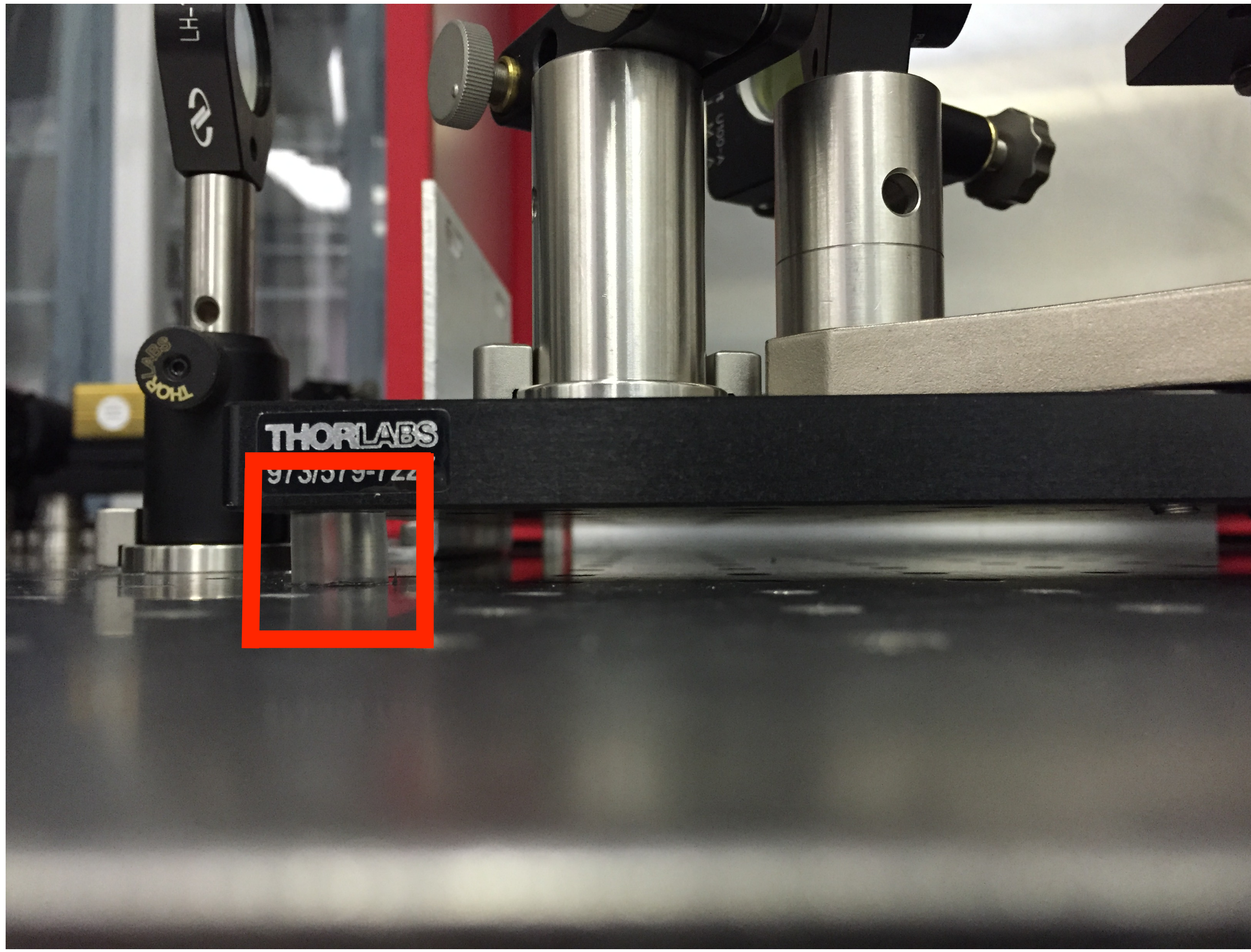
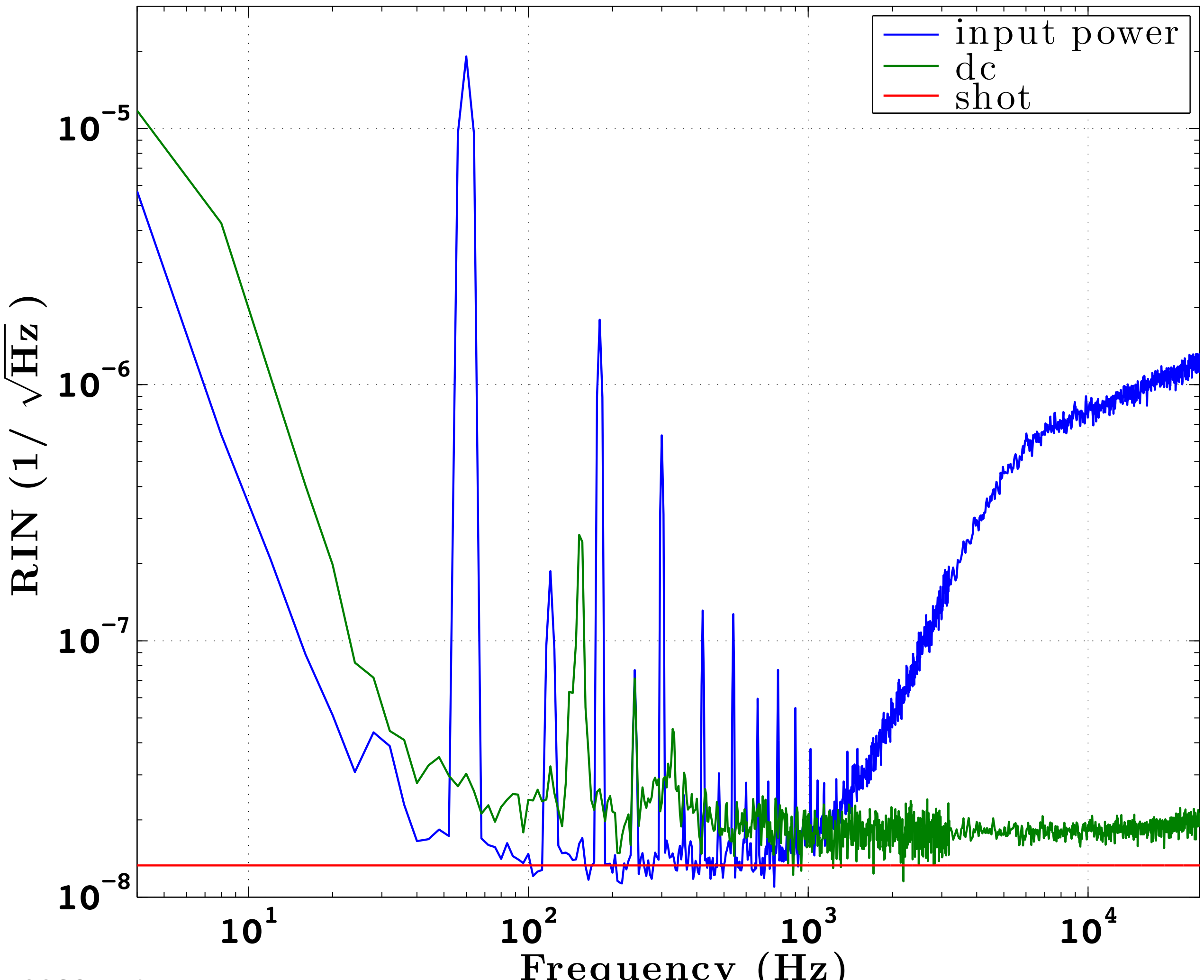
Vibration Isolation

- Silicon rubber feet



LO Noise Cancellation in BHD



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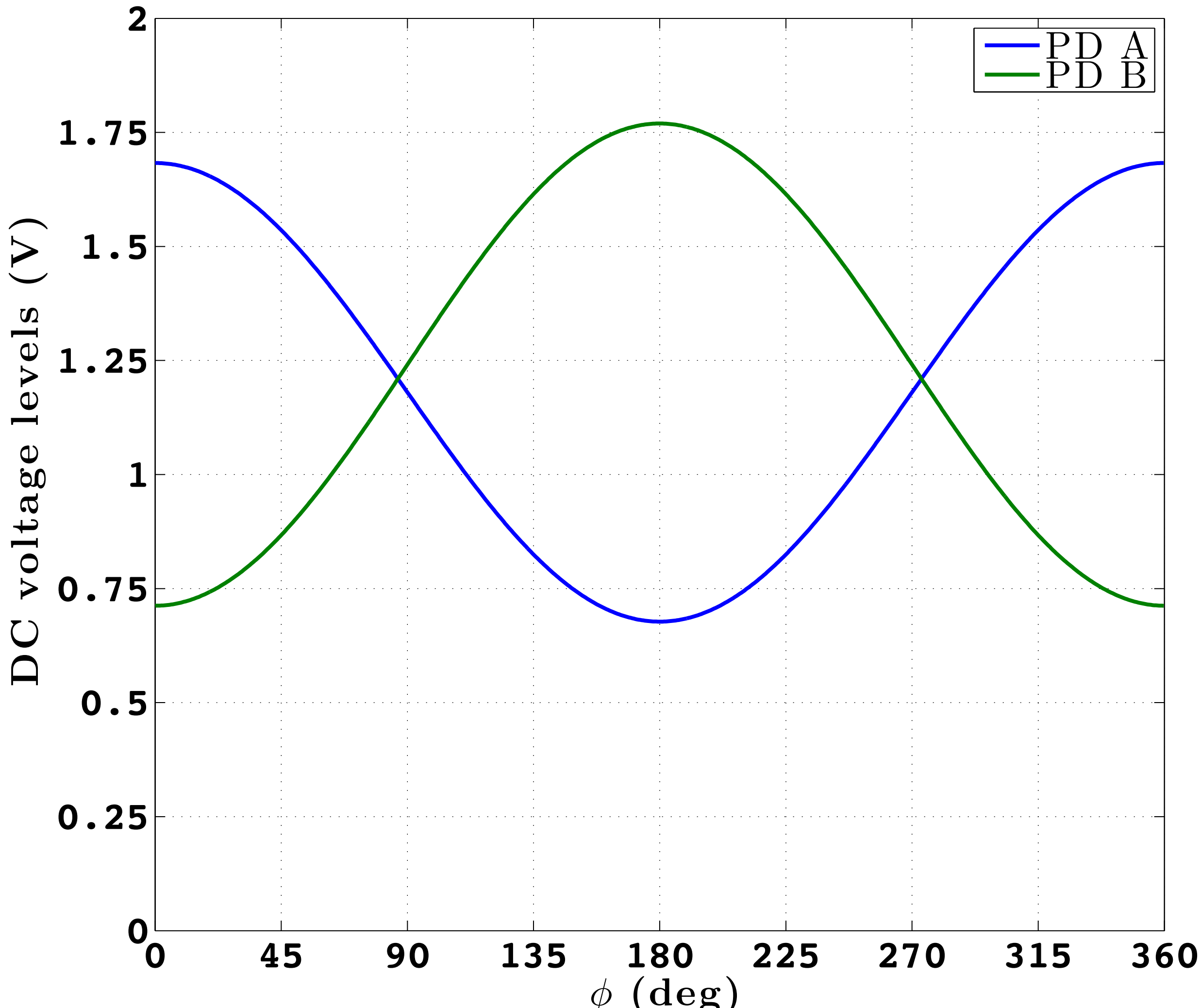
Controlling the Homodyne Phase

- Homodyne phase, ϕ, was initially controlled by individual PD voltage

$$V_A = \frac{e\eta_A R}{2h\nu}(P_{LO} + P_\sigma + 2\sqrt{P_{LO}P_\sigma}\cos\phi)$$

$$V_B = \frac{e\eta_B R}{2h\nu}(P_{LO} + P_\sigma - 2\sqrt{P_{LO}P_\sigma}\cos\phi)$$

Controlling the Homodyne Phase



Noise Variance

- Difference current noise variance depends on quadrature of operation

$$\delta i_{DC}^2 = 4P_{LO}\delta X^2_{-\phi,\sigma} + 4P_\sigma \delta X^2_{\phi,LO}$$

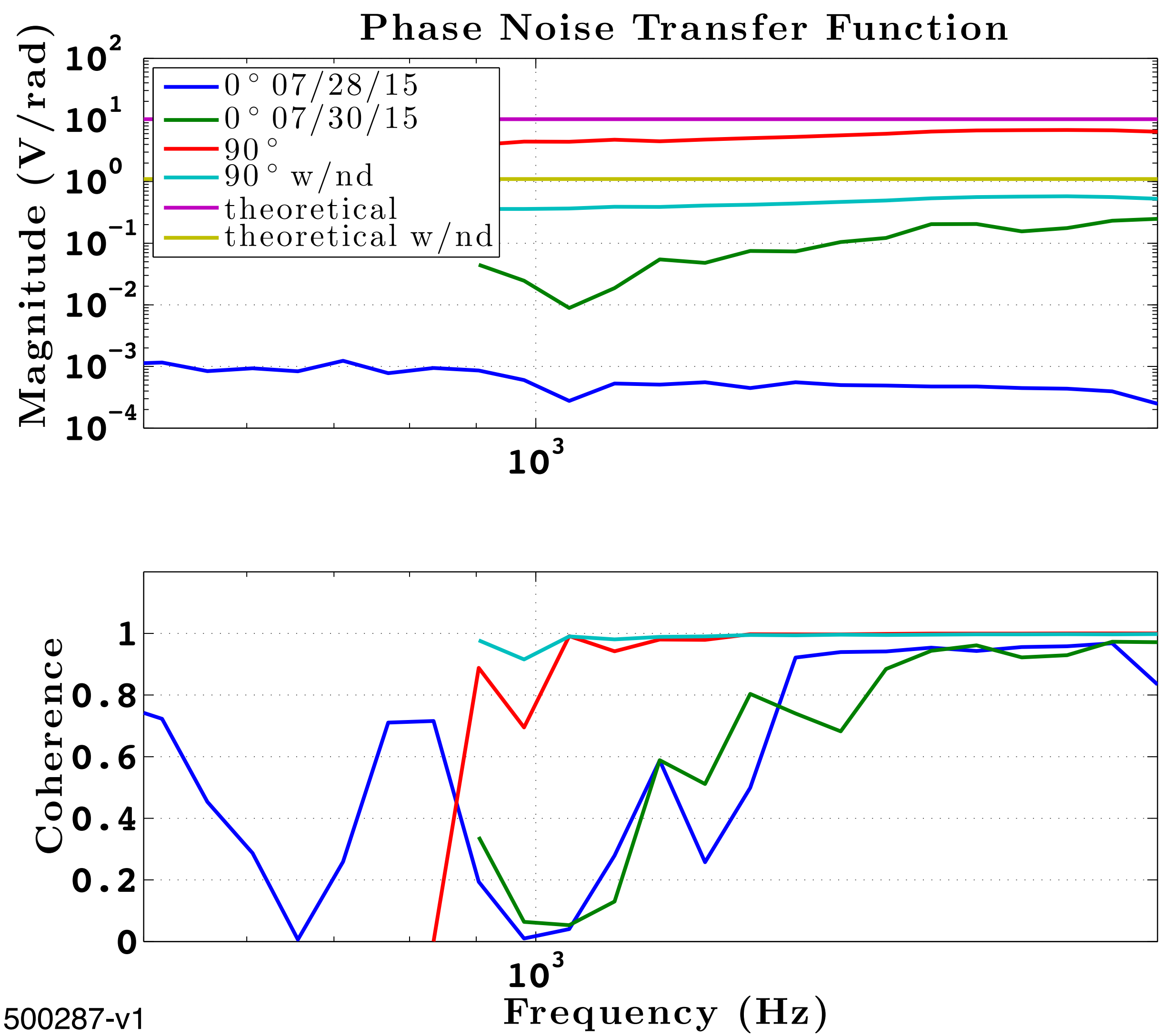
$$\phi = 90^\circ,$$
$$\delta i_{DC} \approx 2\sqrt{P_\sigma}\delta X_{2,LO}$$

$$\phi = 0^\circ,$$
$$\delta i_{DC} \approx 2\sqrt{P_\sigma}\delta X_{1,LO}$$

LO Phase Noise

- Phase noise was injected into LO path by driving the piezo mirror
- Output noise was measured in both the amplitude and phase quadratures
- ND filter was added to signal path to verify noise variance scaling with P_σ

LO Phase Noise



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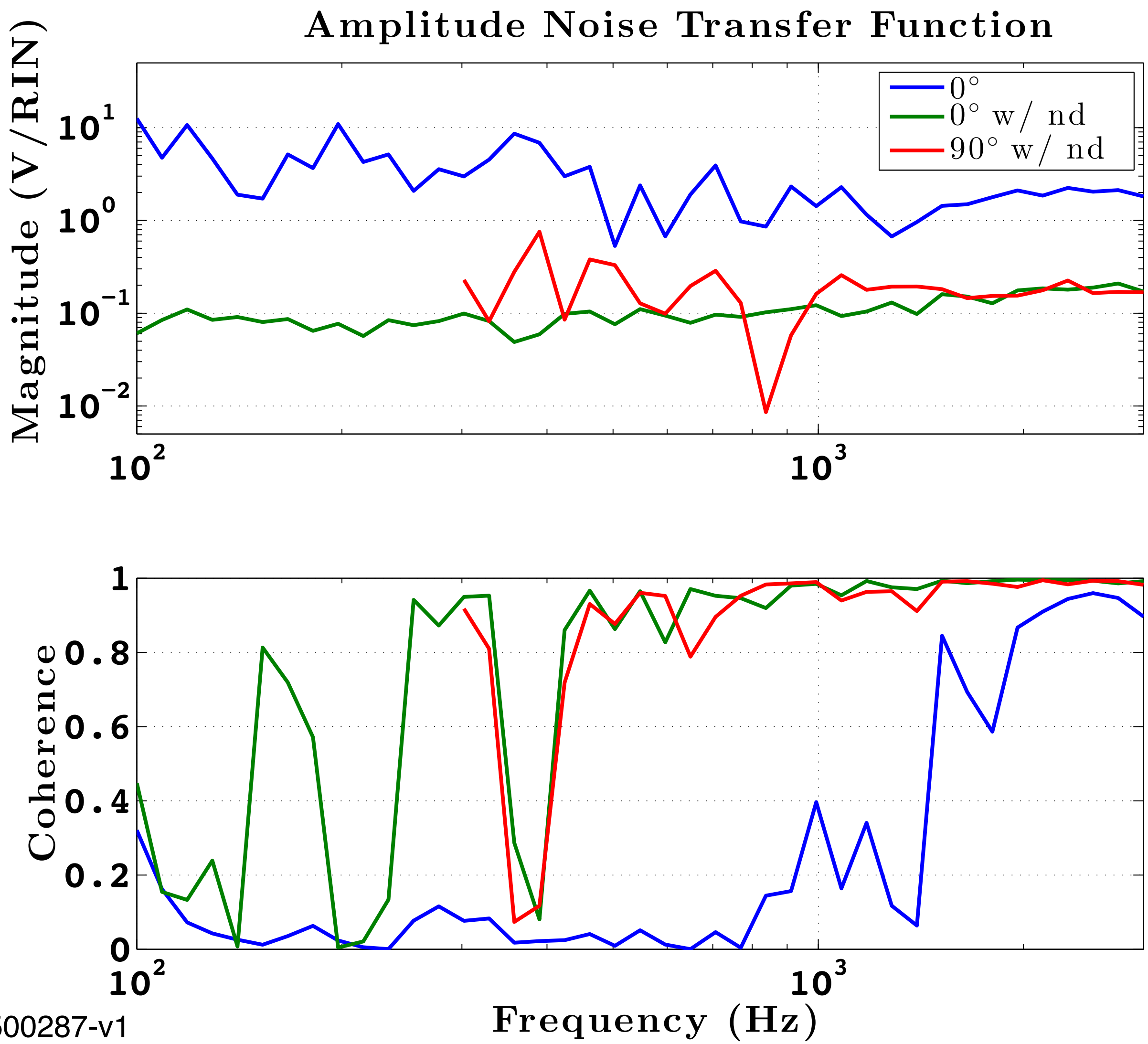
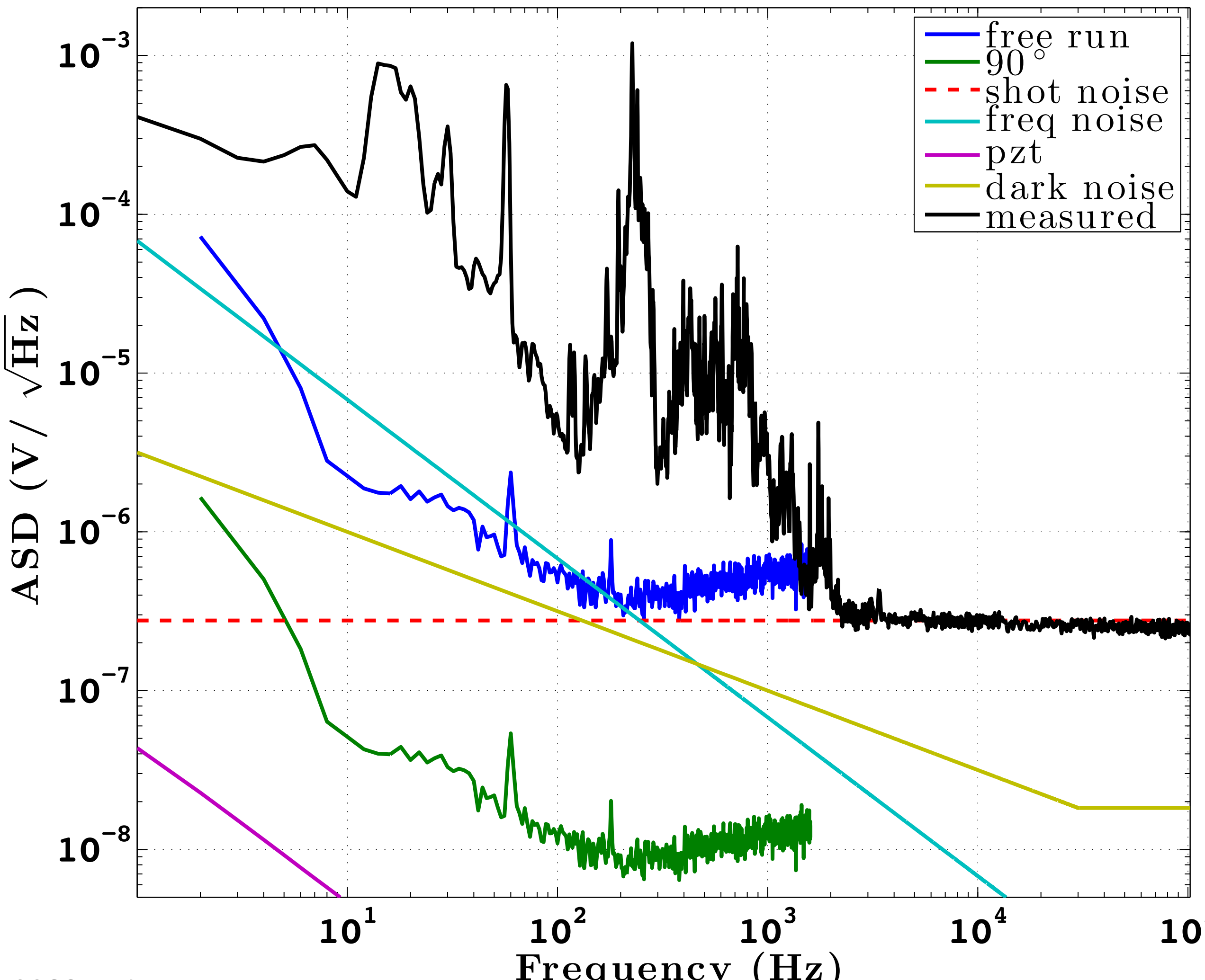
LO Amplitude Noise

- Amplitude noise was injected into LO path by driving an AOM
- Output noise was measured in both the amplitude and phase quadratures
- ND filter was added to signal path to verify noise variance scaling with P_σ
- Did not see what we expected

LO Amplitude Noise



Noise Budget



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Conclusions

- Reached shot noise over 1 kHz
  - Well below free-running power noise in this range
  - Hoped to reach shot noise at all frequencies
- Dominated by acoustic noise at low frequencies
  - Operating this detection scheme in air is difficult

Future Efforts

- Use RF modulation instead of PD voltages to servo the homodyne phase
- Characterize the detector’s response to LO amplitude modulation
- Locate and catch all scatter

Acknowledgments

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- Fellow SURF, Stephen

References

- Fritschel, et al. ‘Balanced Homodyne Readout for Quantum Limited Gravitational Wave Detectors’. *Opt. Express* 22.4: 4224.
- Steinlechner, et al. ‘Local-Oscillator Noise Coupling in Balanced Homodyne Readout for Advanced Gravitational Wave Detectors’. SUPA, School of Physics and Astronomy, The University of Glasgow, Glasgow, UK.

Questions?