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Low frequency precision sensor experiments at UWA

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The University of Western Australia

GWADW | 22.05.2019

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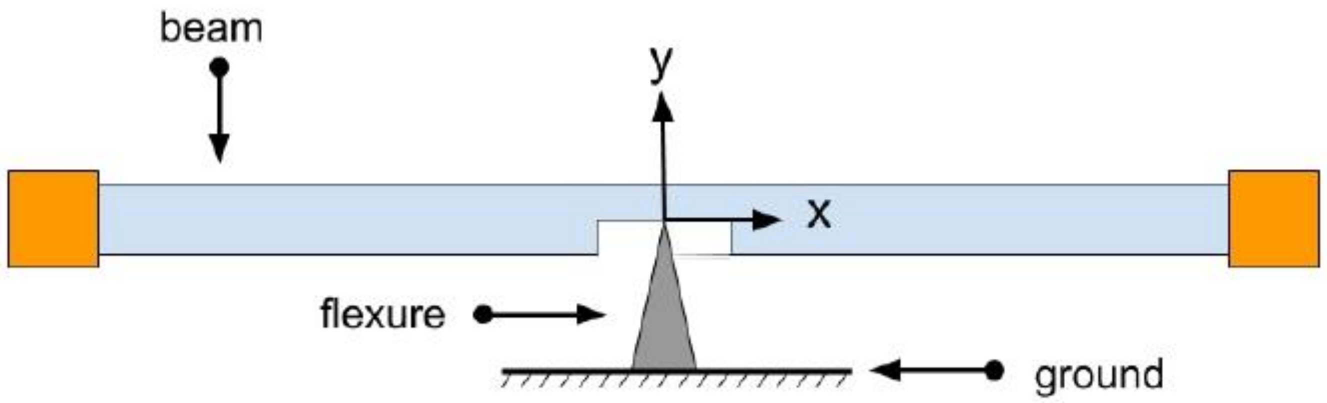
Contents

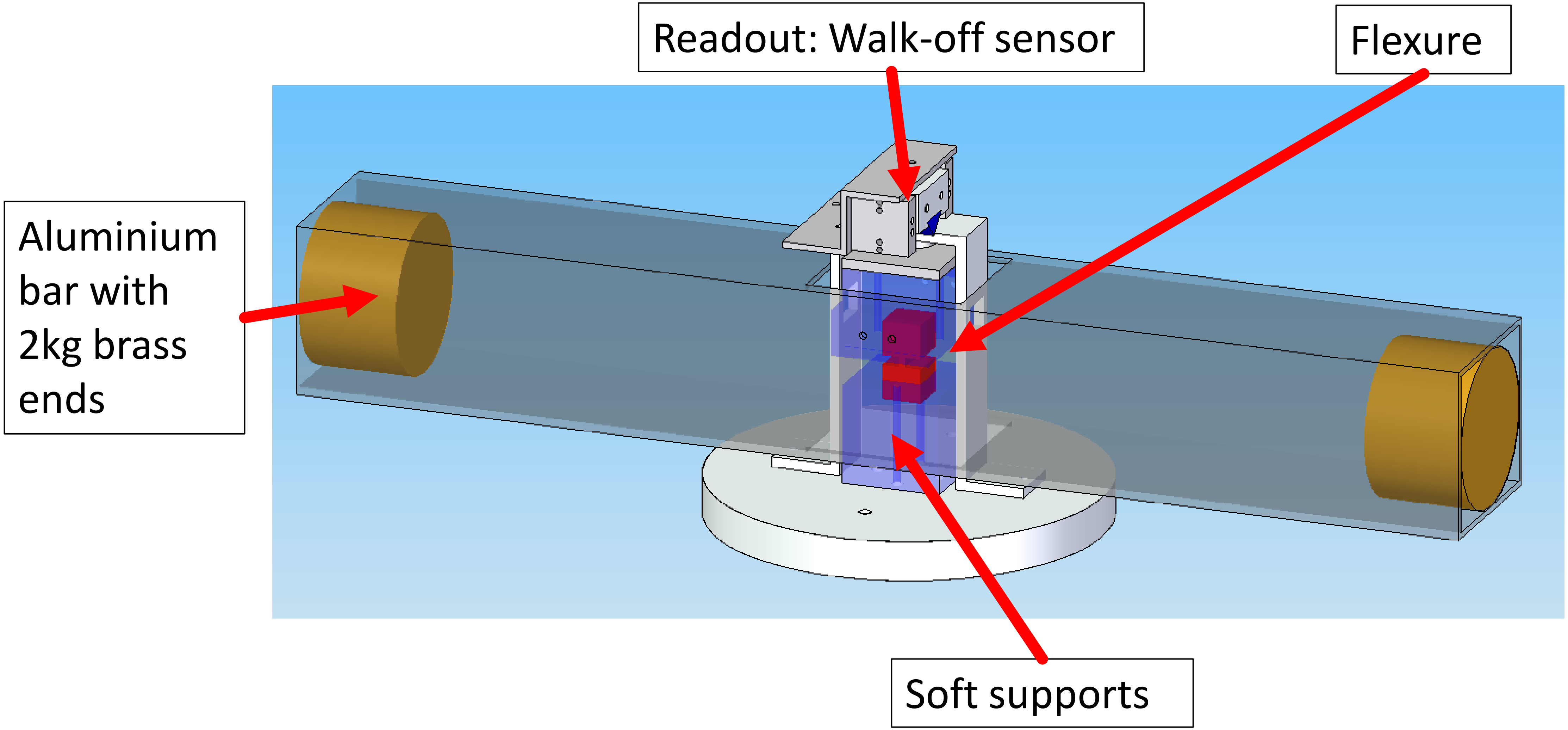
- Advanced Low Frequency Rotational Accelerometer ALFRA
- Cryogenic accelerometer with an interferometric readout

ALFRA goals

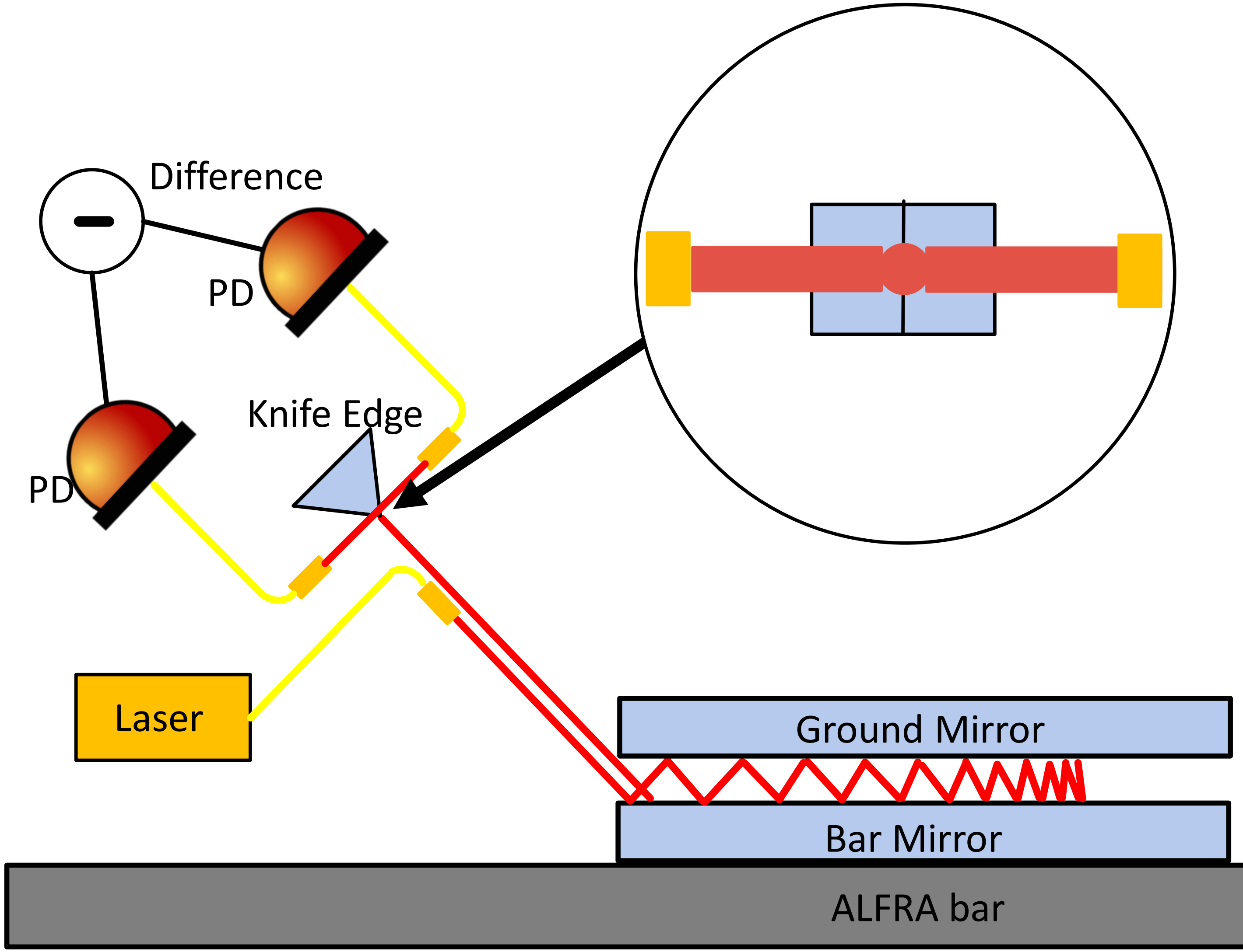
- A balance beam style rotation sensor
- Capable of horizontal and vertical mounting
- Low resonant frequency – 10mHz
- Sensitivity of nano radians or below at 10mHz and above
- Compact



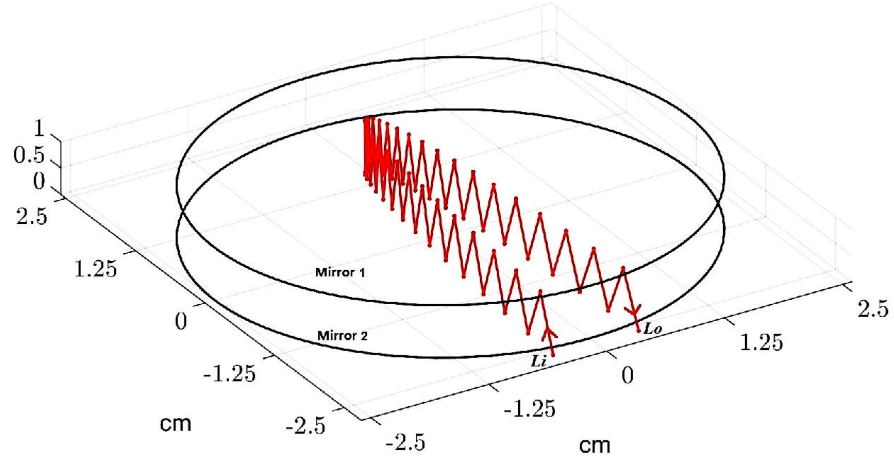
Overview: Conceptual design



Optical readout: Walk-off sensor

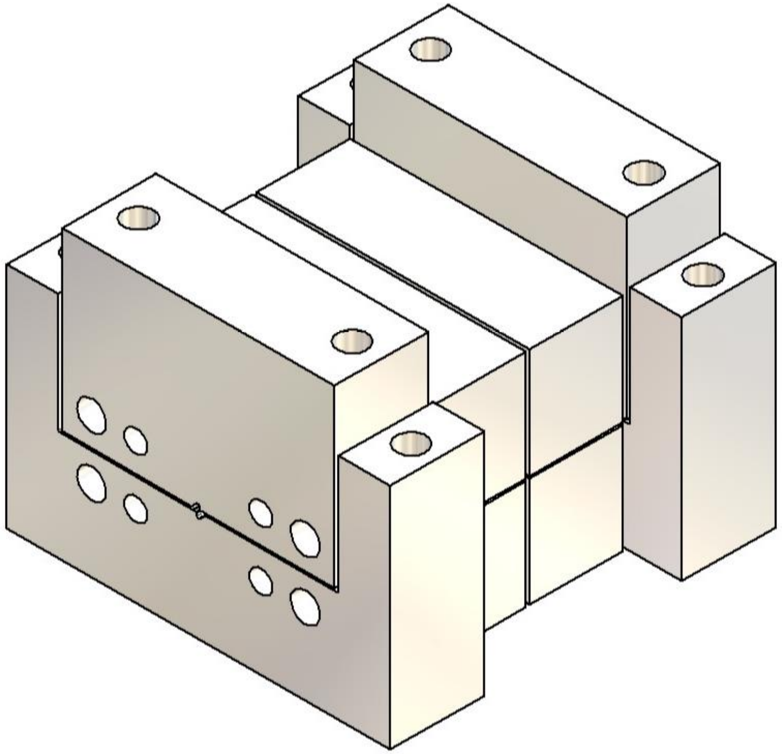


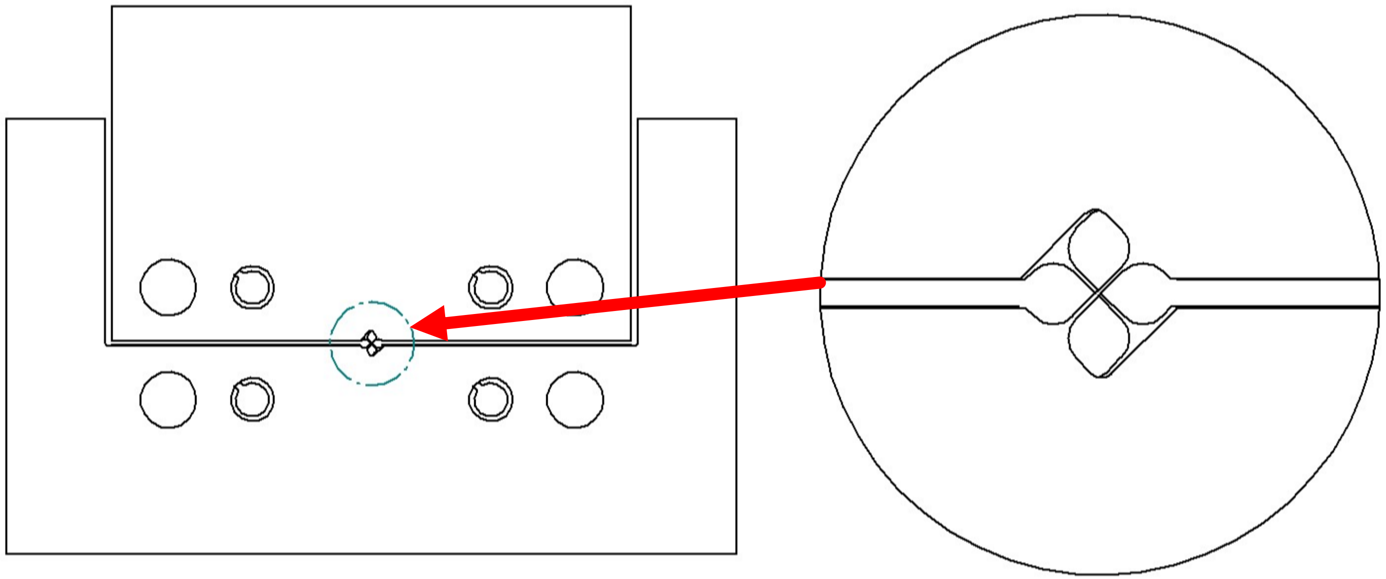
- Laser bounces between two mirrors in parabolic shape
- Angle change between mirrors can be detected by laser position change on a knife edge
- The bounces amplify the angular sensitivity



Cross flexure design

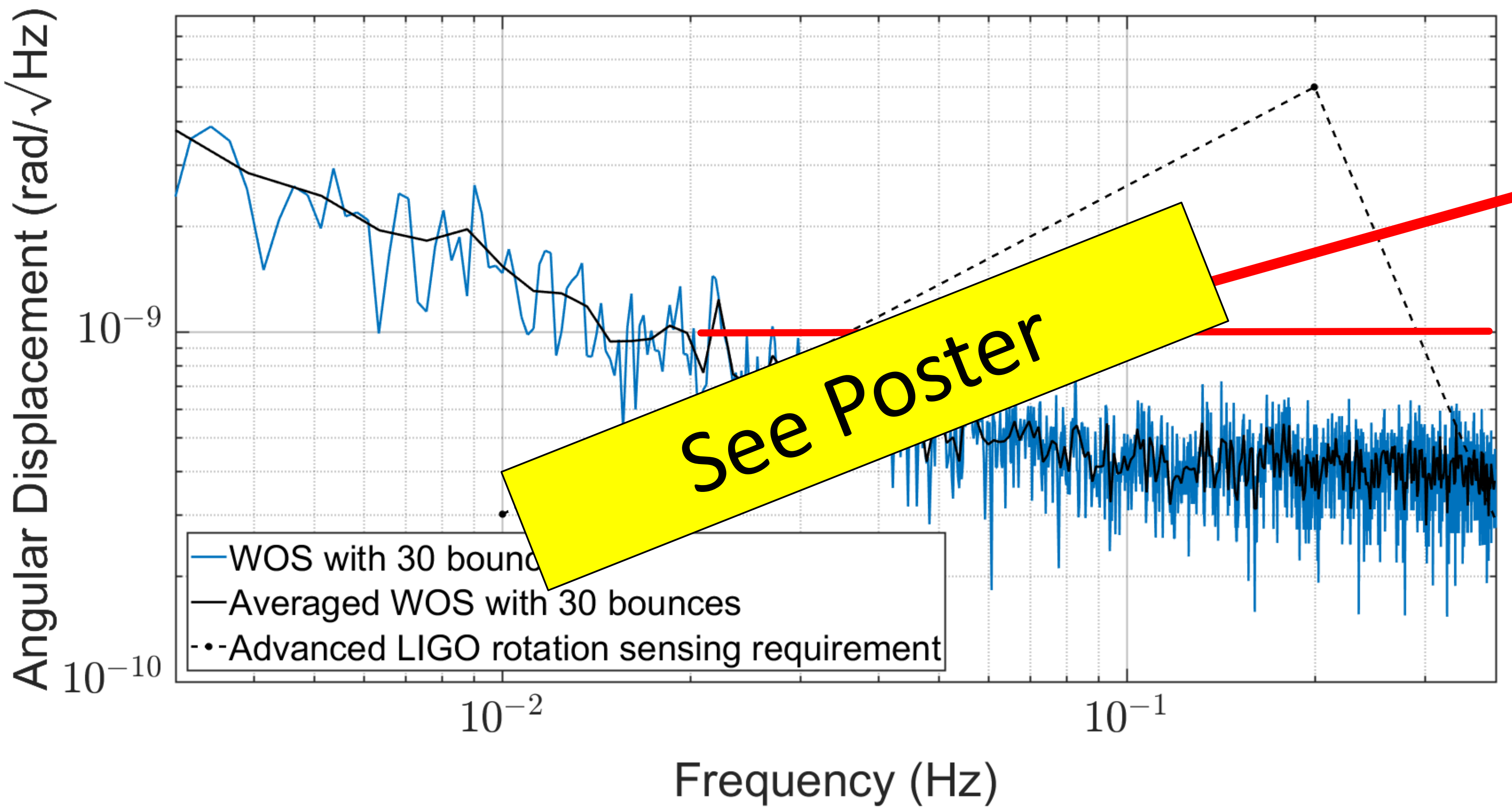
- 4 identical 45 degree aluminium flexures, 2 flipped





- Creates a cross flexure for vertical and horizontal mounting
- 10um thick, 200um long
- To meet goal of 10mHz resonant frequency
- Future plan to use amorphous metal

Sensitivity: Walk-off sensor not in air



Currently at nano radians sensitivity above 20mHz

J. J. McCann et al., Rev. Sci. 90, 045005 (2019)

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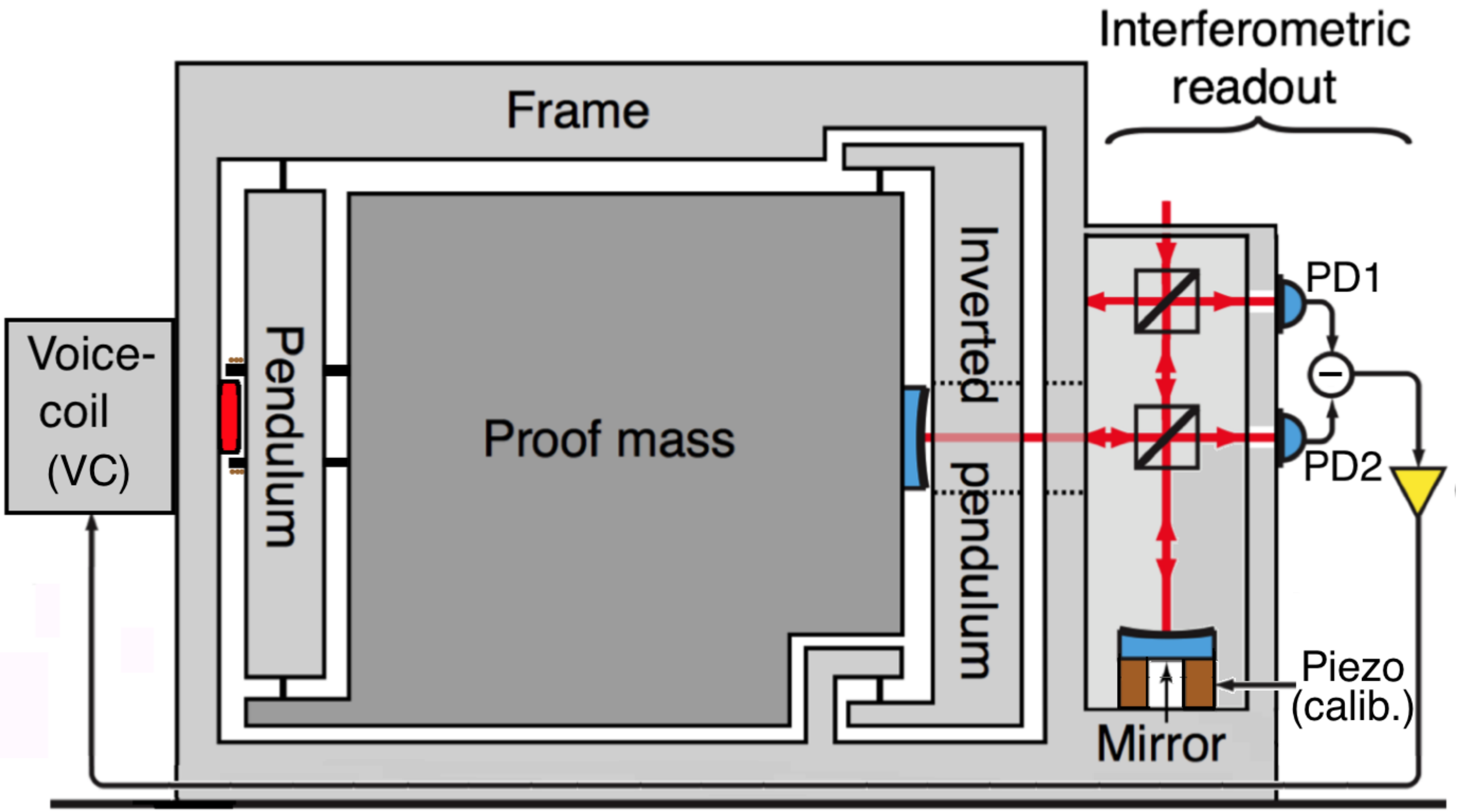
Accelerometer with an interferometric readout

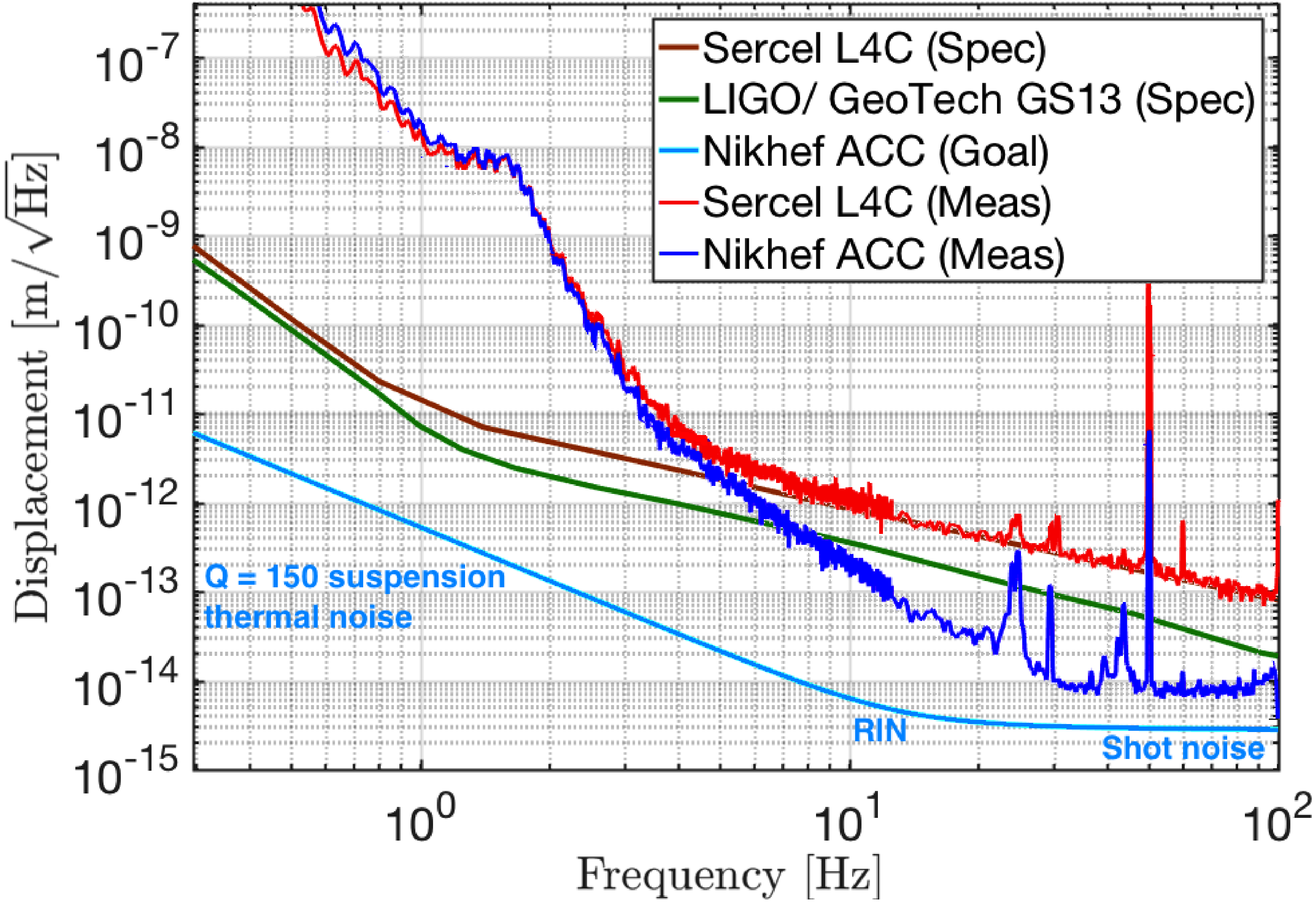


- Read out both arms, match and subtract to reject common mode noise
- Actuator coil attached to proof mass, 50 µm wires run to frame
- Control loop *locks* the proof mass. Output is in the control signal

A. Bertolini et al., NIM A, 556, pp 616-623 (2006)

M.B. Gray et al., Opt.Quant.Electron., 31, pp 571-582 (1999)

Sensitivity in vacuum on suspended bench



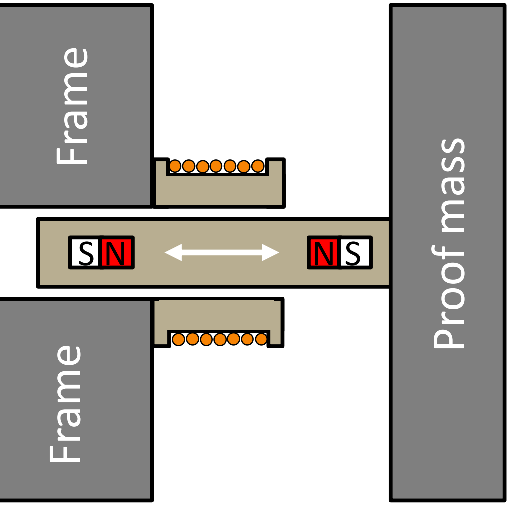
J.V. van Heijningen et al., IEEE SAS proc., pp 76-80 (2018)

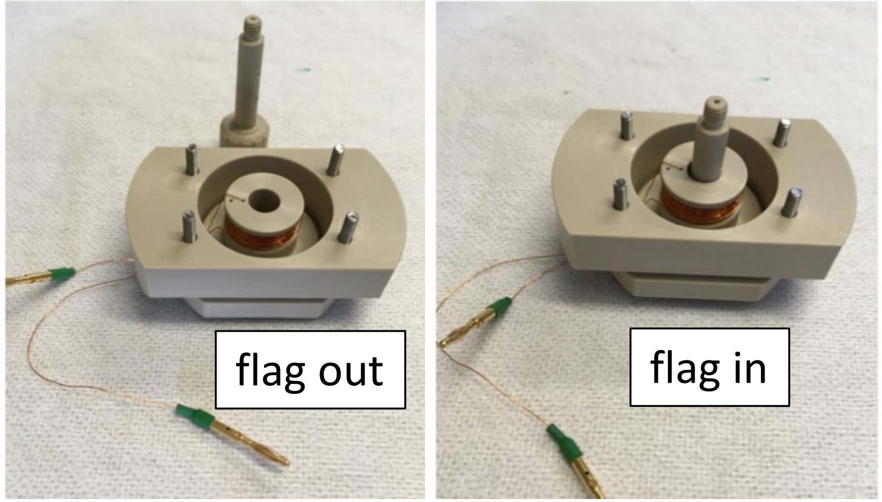
- Measurement done at MultiSAS prototype at Nikhef

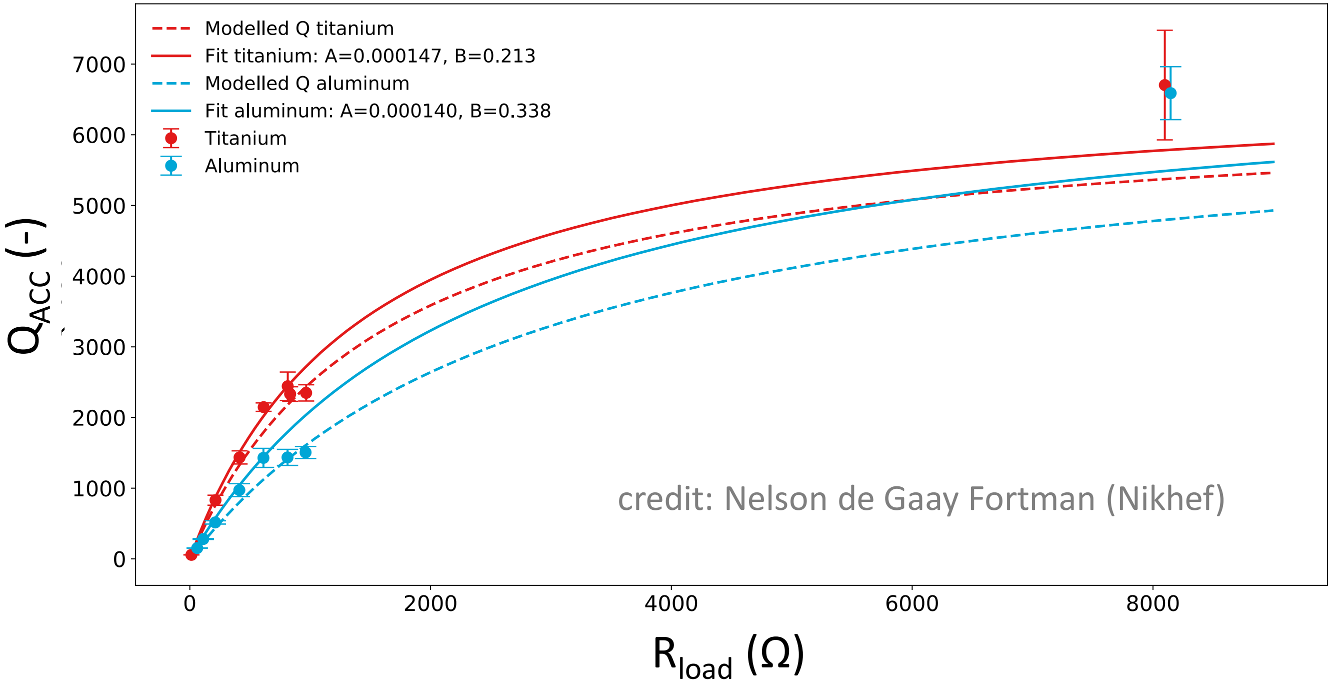
J.V. van Heijningen et al. CQG **36** 075007 (2019)

- Noise between 3-30 Hz not understood
- 8 fm/√Hz observed sensitivity from 30 Hz onwards

Improvements of Q by changing actuator design

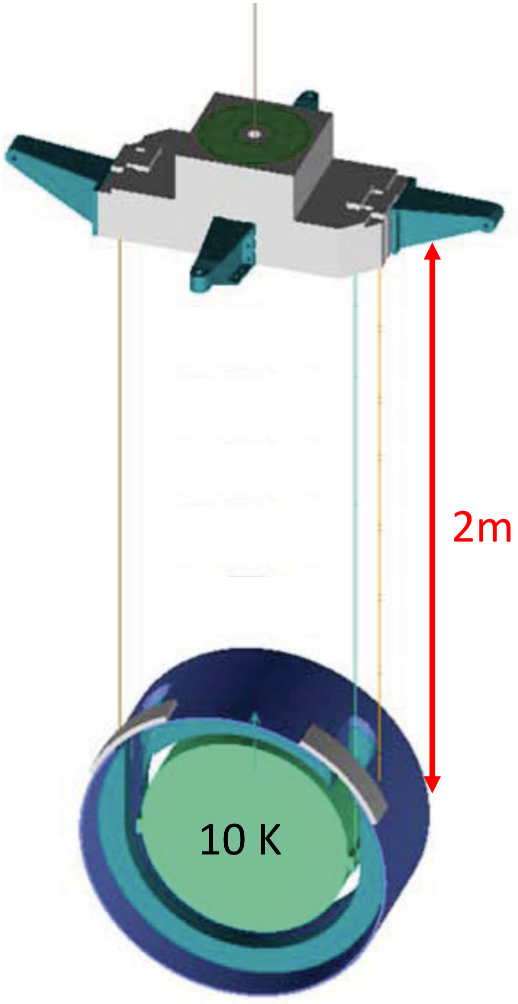






- Actuator components *swapped*: coil attached to frame and magnet(s) to proof mass
- Use of two magnets with opposite polarity orientation (see cartoon) reduces coupling from stray magnetic field to proof mass
- Ringdown measurements performed at Nikhef (using shadow sensor instead of ITF readout) show an increase of Q_{ACC} which would lower thermal noise

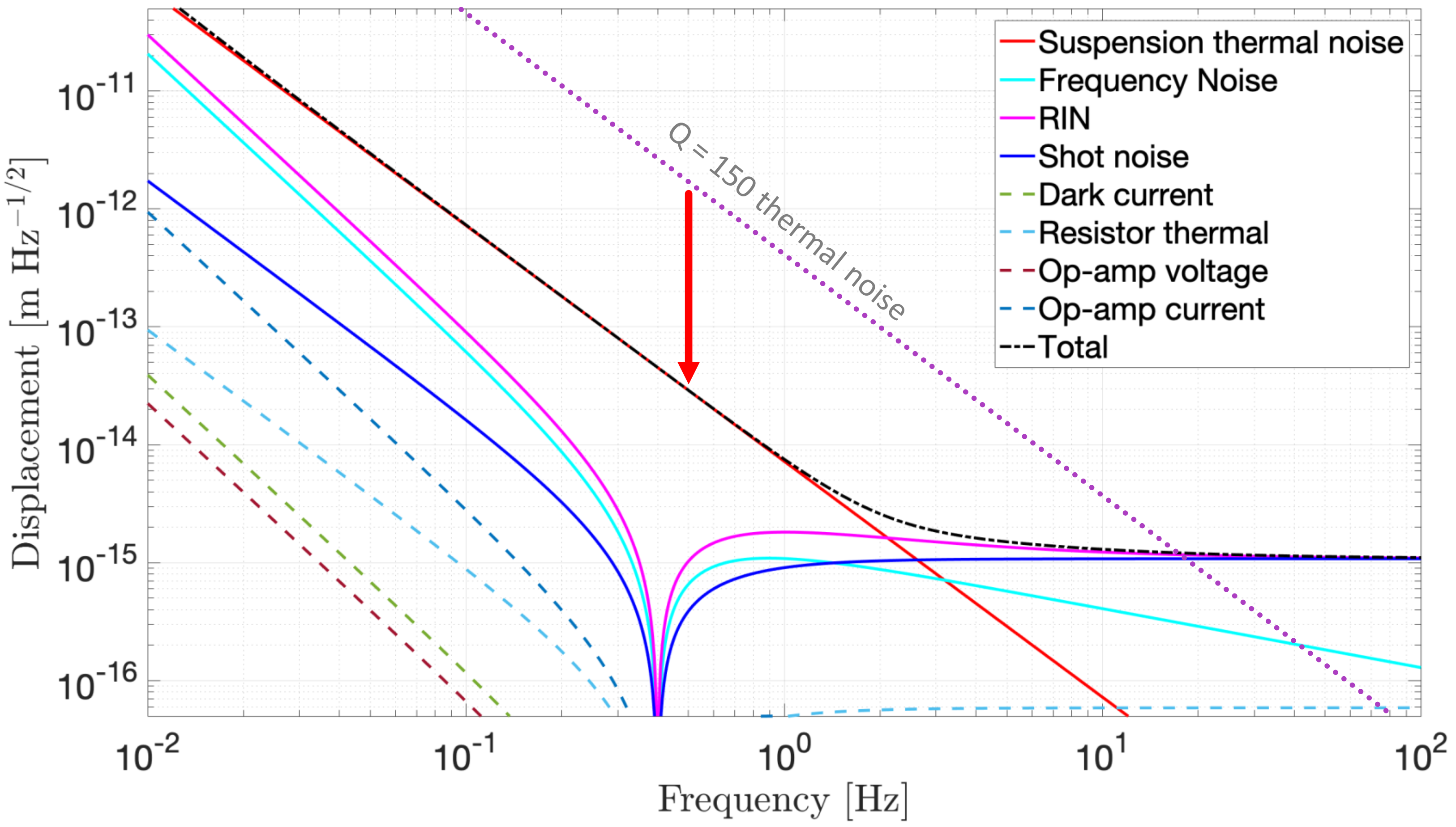
Exploiting the low temperature on the PUM



adapted from ET CDS

- In ET-LF, the TMs are kept at 10 K, so the temperature of the penultimate mass (PUM) is lower than that
- Idea: make the accelerometer out of Niobium, which is superconducting at T < 9.2 K and intrinsic high-Q
- We expect Q_{ACC} to increase even more as Eddy current effects diminish; $Q_{ACC} = 10^4$ is assumed in noise budget on next slide
- The sensor, placed on the PUM, allows for precise monitoring of the (vibrational) impact of cryogenics

Noise budget of the proposed accelerometer



Parameter	Value	Unit
Proof mass	0.85	kg
Leg mass	80	g
Leg length	7.1	cm
Natural frequency	0.4	Hz
Quality factor	1×10^4	-
Frequency noise [30]	$500 \cdot f^{-1/2}$	Hz Hz$^{-1/2}$
Static differential arm length	0.5	mm
Injected power	50	mW
Wavelength	1550	nm
Temperature	< 9.2	K
Opamp voltage noise	4.0	nV Hz$^{-1/2}$
Opamp current noise	2.2	fA Hz$^{-1/2}$
Feedback resistor	20	kΩ
Diode responsivity	1.04	A/W
Diode dark current	50	nA

Thermal noise level is about 50 times lower

Summary

Advanced Low Frequency Rotational Accelerometer ALFRA

- Balance beam style detector
- WOS sensor optical readout with nano radian sensitivity
- 10um thin cross flexure allowing vertical and horizontal mounting

Cryogenic accelerometer with an interferometric readout

- Room temperature results of 8fm/rt(Hz) from 30Hz
- Actuator improvements made to reduce coupling to stray magnetic fields which increases Q
- Idea for reducing eddy current effects by exploiting cryogenics in 3G detectors


THANK YOU
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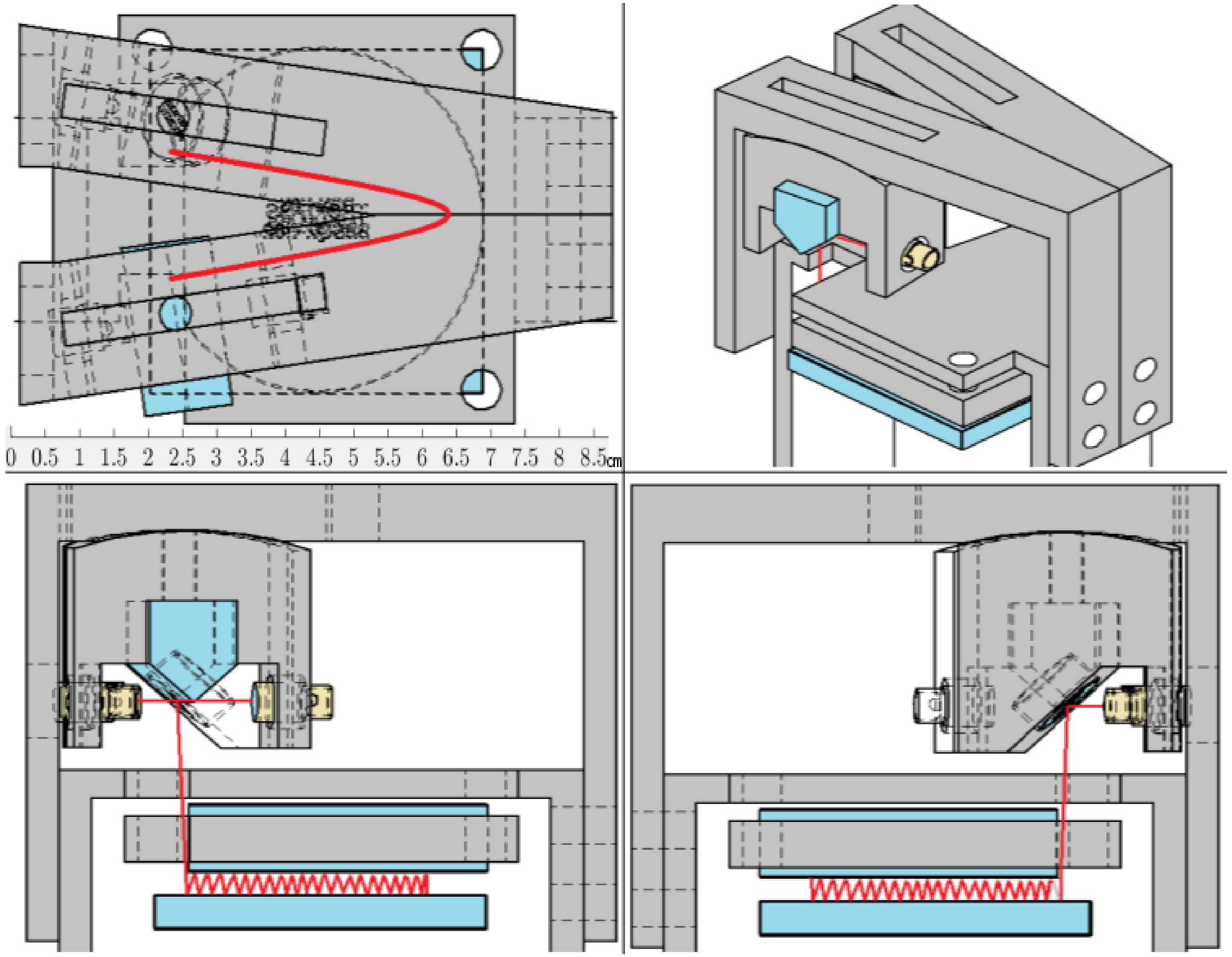
Vacuum and WOS

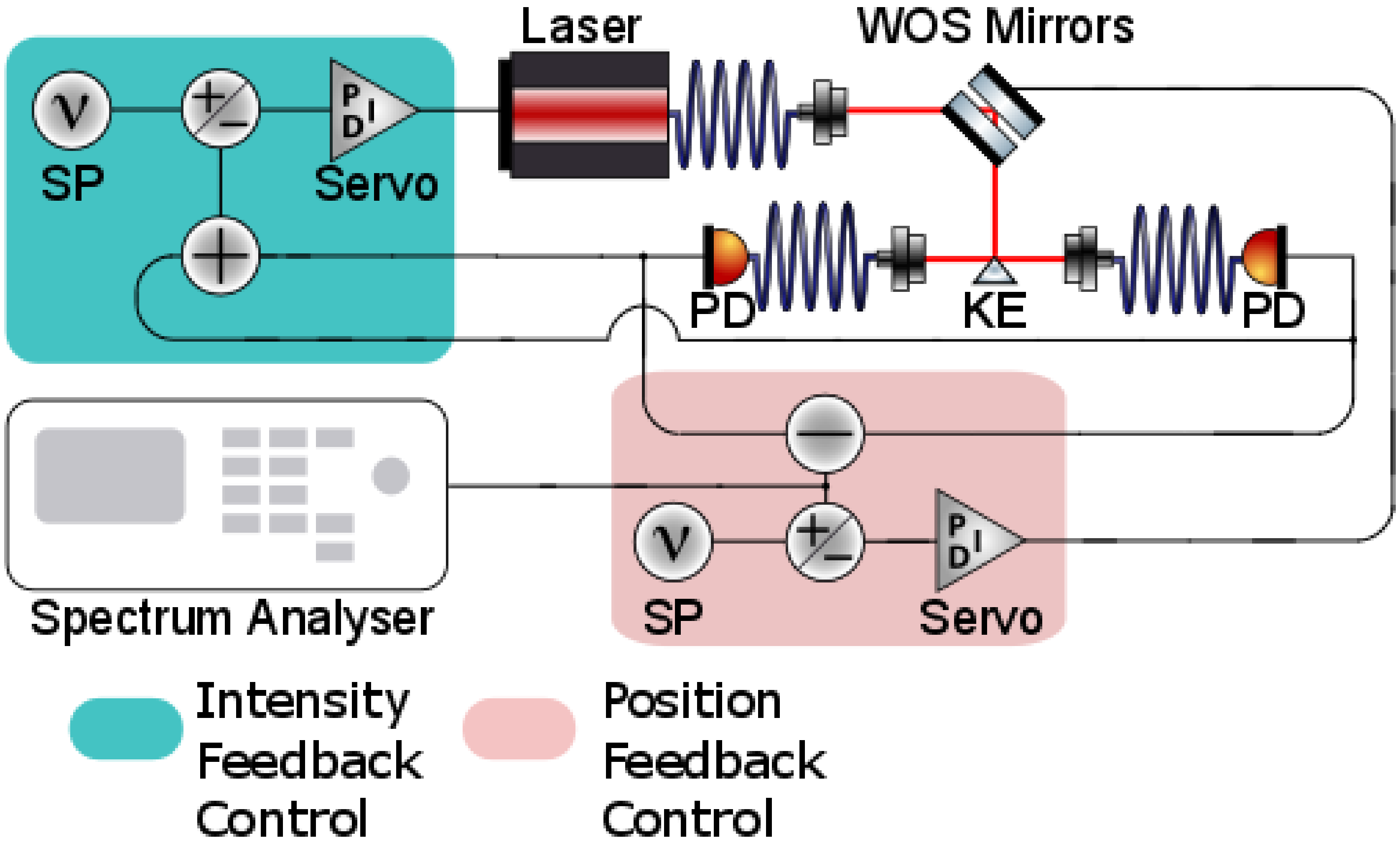
Vacuum

- Flexures to be cut this week
- Bar components to be machined in January

WOS Mechanical Design



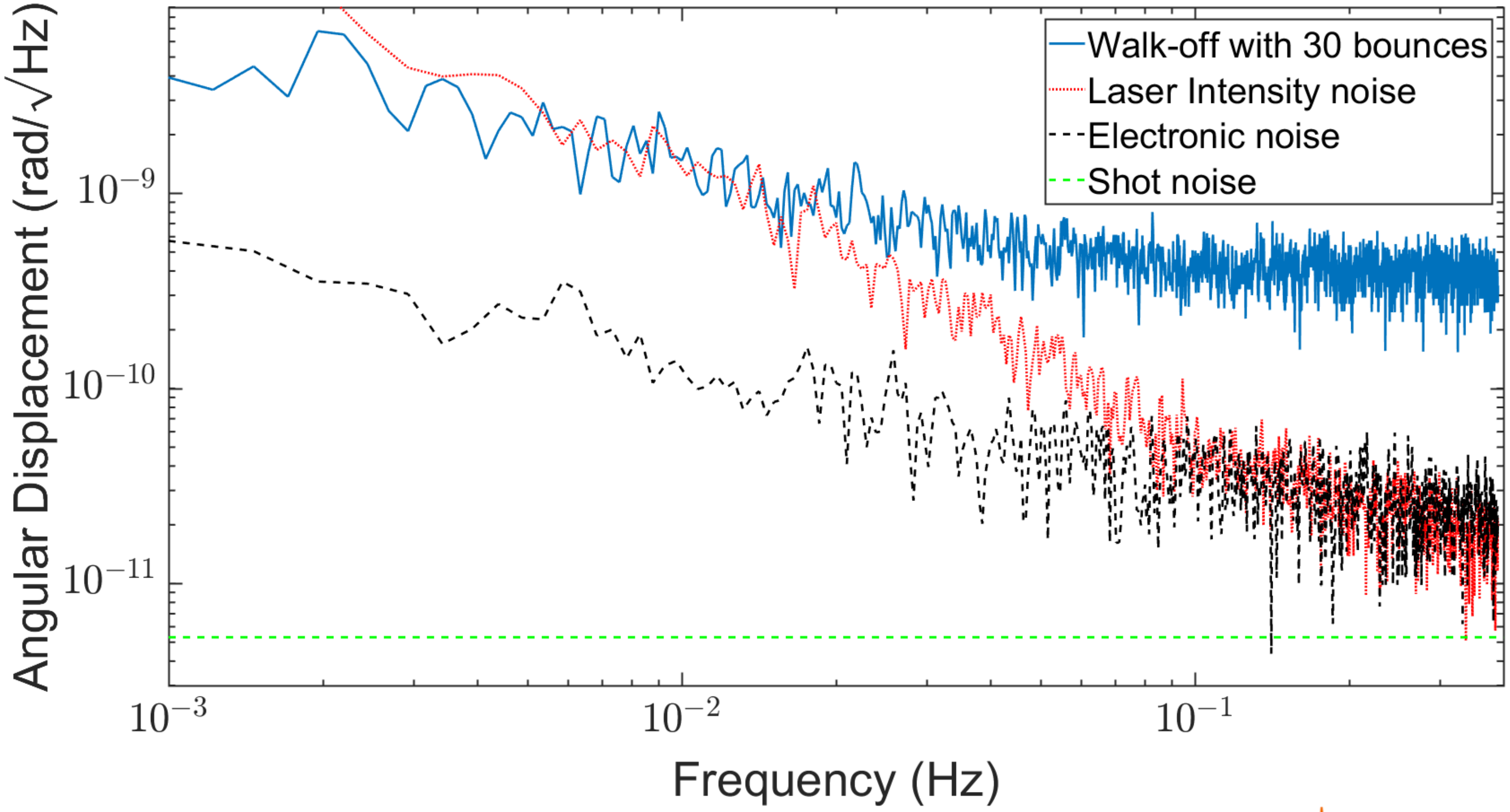
WOS Improvements



- Laser intensity feedback
- Position feedback to provide greatest common mode rejection

WOS Results (Not in Vacuum)

- Still limited by laser intensity
- Move to vacuum



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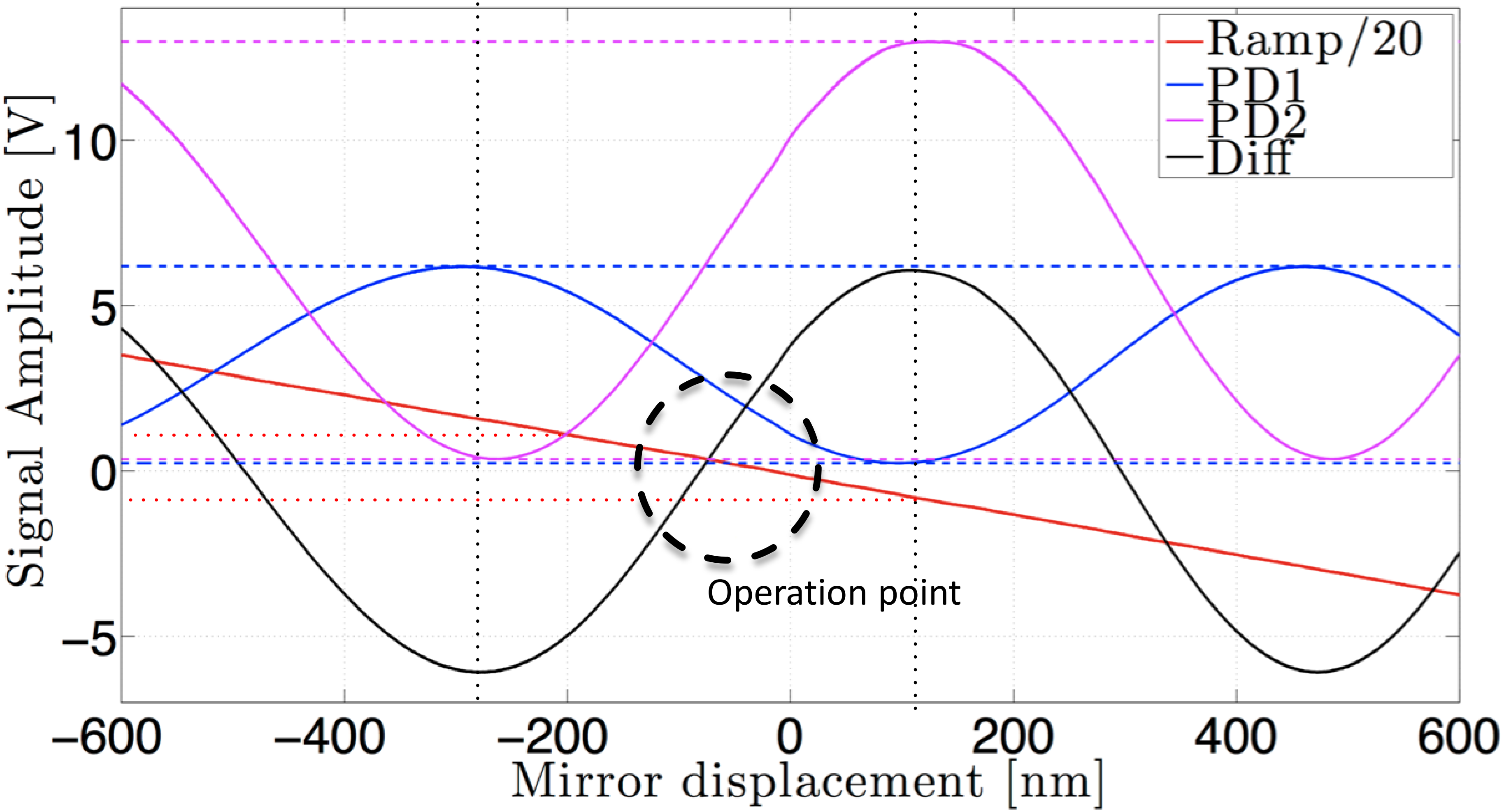
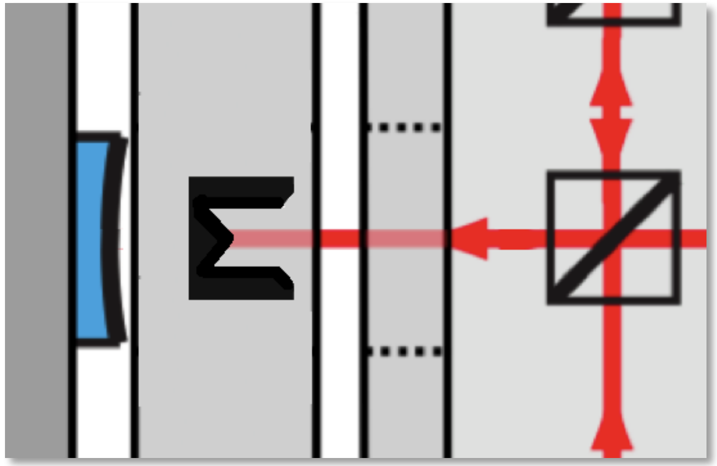
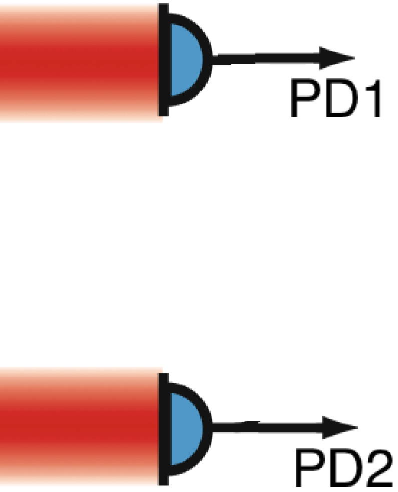
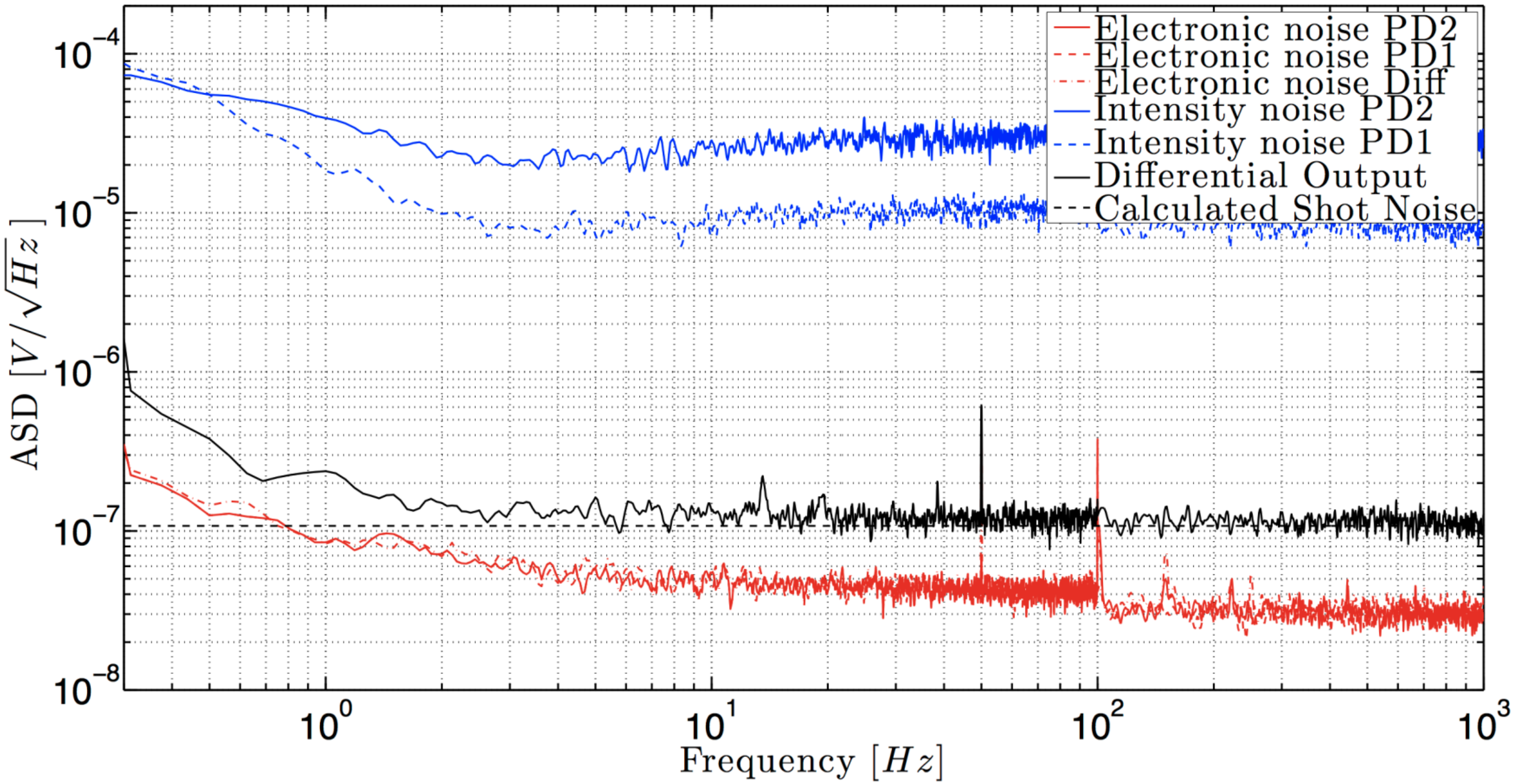
How we calibrate the interferometric readout



Shot noise limited from 5 Hz onwards?

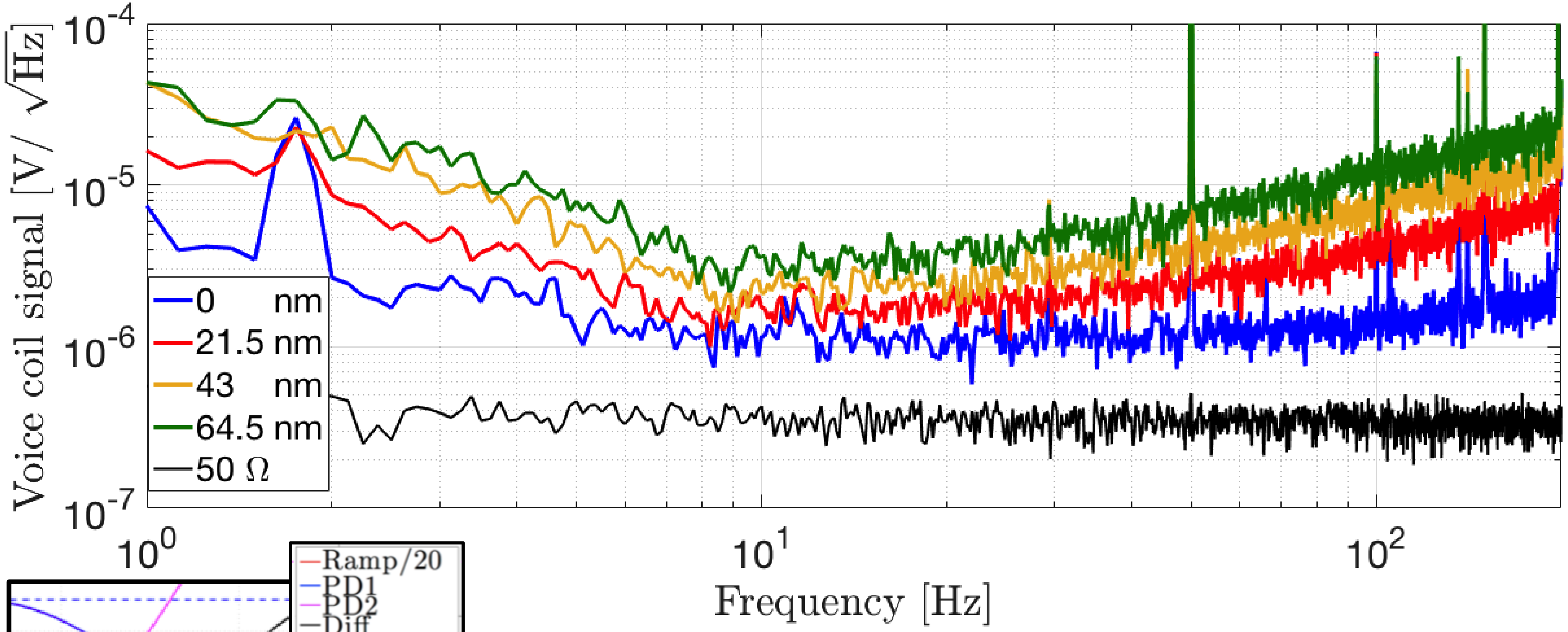


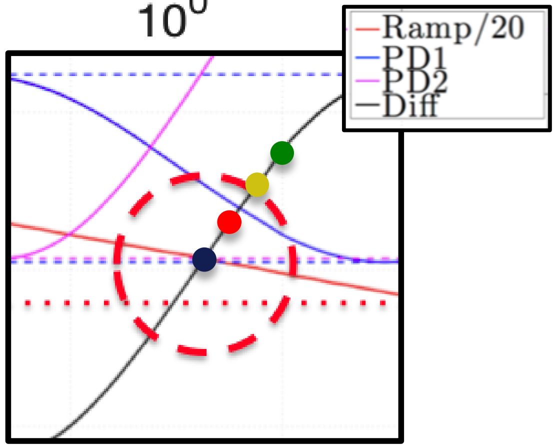




Measurement done without interference, one interferometer arm blocked

Changing lock point in loop worsens shot noise





Let the loop lock on 0, 1, 2 or 3 Volt

Measurement with locked mass and PZT locking