Speedmeter topologies for future gravitational wave detectors

B. Barr

for the Glasgow interferometry group

GR21, July 2016 LIGO-G1601482

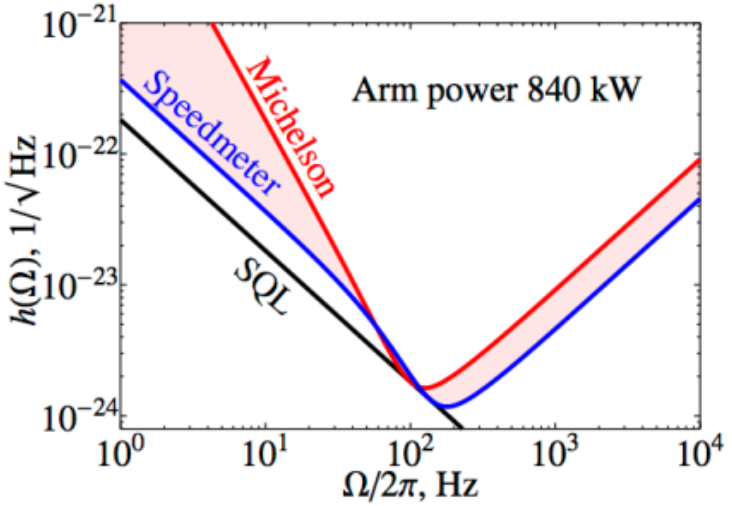
Overview

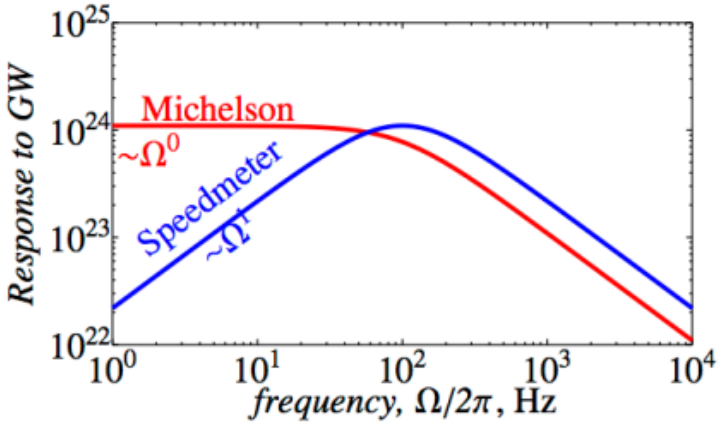
- **Why speedmeters?**
  - **Back action noise reduction**

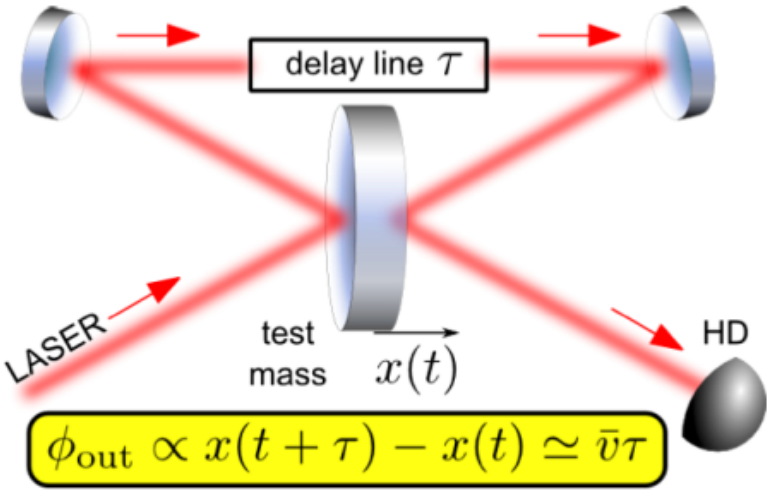
- **The Glasgow ERC Speedmeter experiment**
  - **Concept**
  - **Implementation**

- **Future speedmeters**
  - **Polarisation**
  - **Sloshing**

Starting point







- Back- action reduction: RP force of two reflections cancel each other, but with delay τ:

$$\hat{F}_{\text{b.a.}}(\Omega) \simeq -i\Omega\tau \frac{2\bar{P}_{\text{pulse}}}{c},$$

- The benefit: Much better QN sensitivity at low frequencies than Michelson;
- The price to pay: Response of speed meter wanes linearly with frequency as it goes to DC, i.e. response $\propto \Omega\tau$.

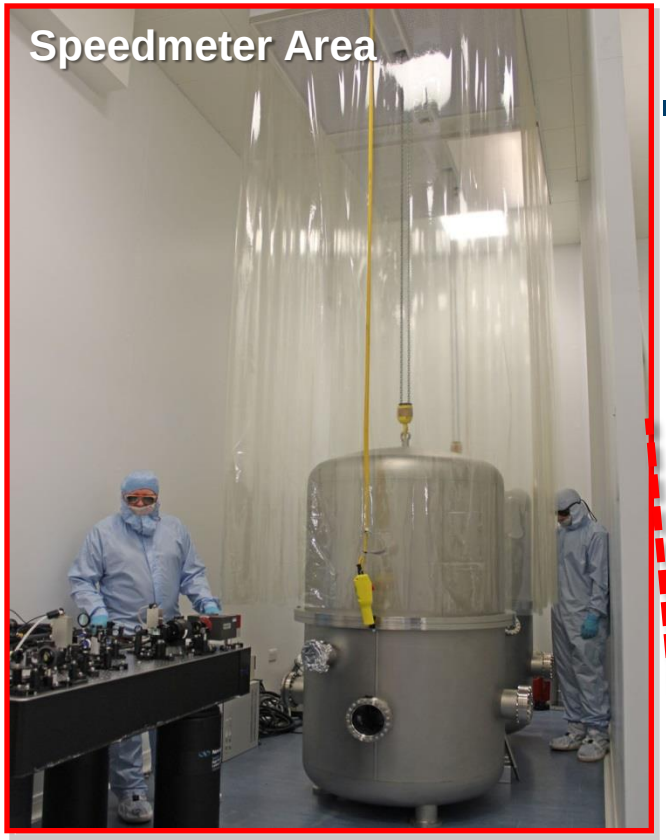
Overview

- **Why speedmeters?**
  - **Back action noise reduction**

- **The Glasgow ERC Speedmeter experiment**
  - **Concept**
  - **Implementation**

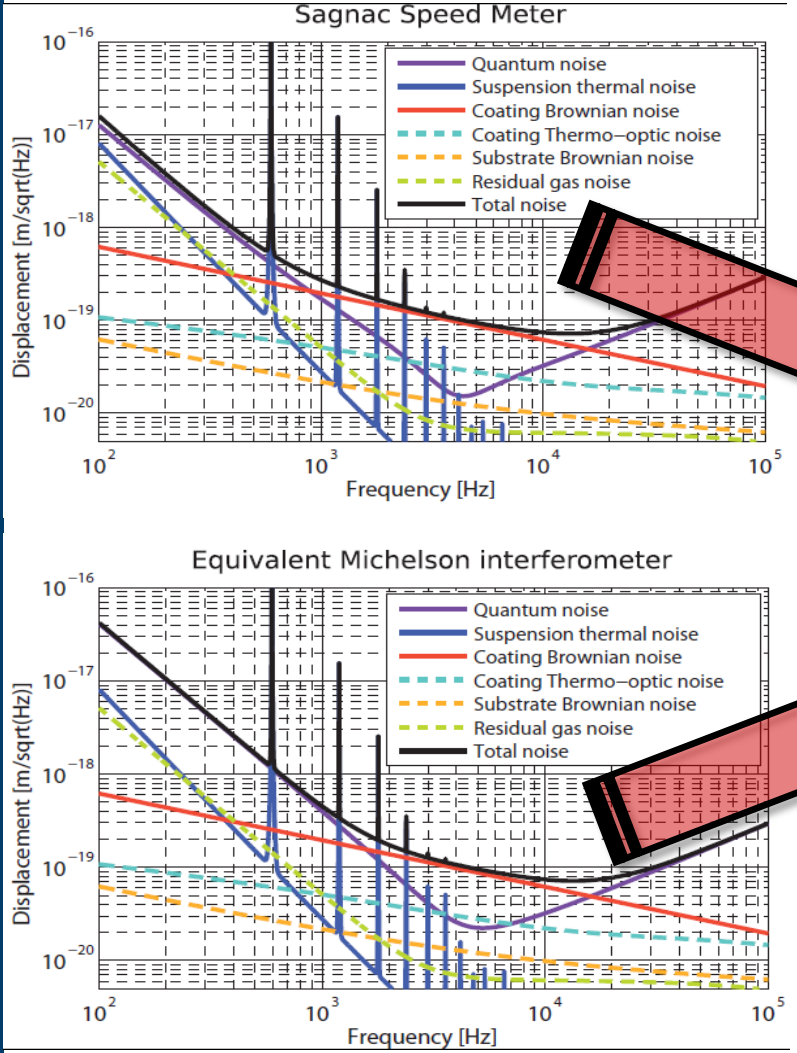
- **Future speedmeters**
  - **Polarisation**
  - **Sloshing**

Glasgow speedmeter - proof of principle

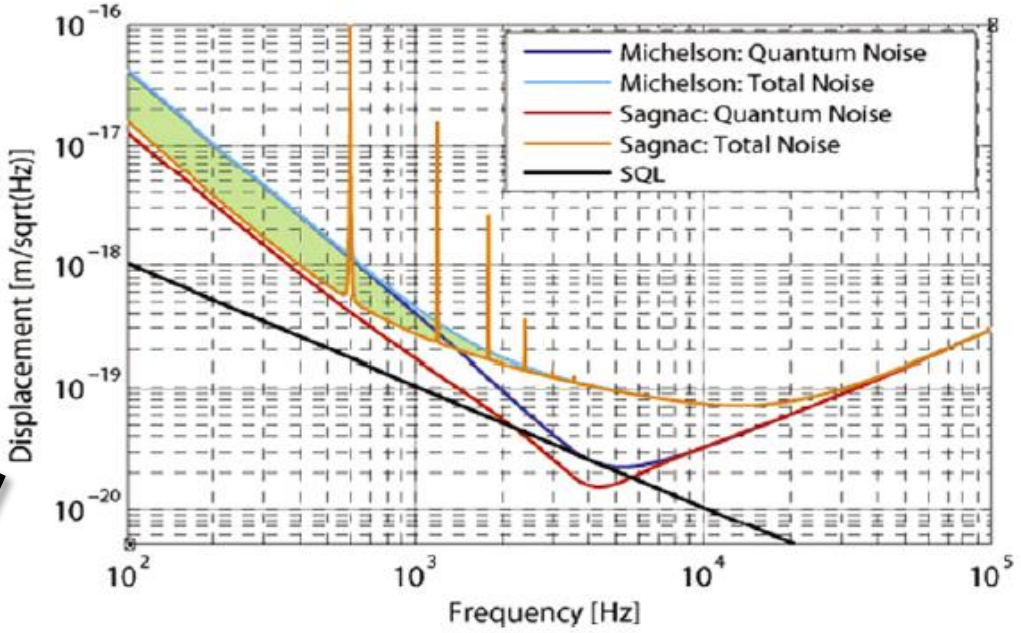


- **The Glasgow speedmeter experiment is an ERC funded project with three major goals:**
  - **Create an ultra-low noise speed meter testbed which is dominated by quantum radiation pressure noise**
  - **Demonstrate the reduced back-action noise of the Sagnac topology**
  - **Explore speedmeter technology for future GW detectors**

Sensitivity Goal



About 3x better quantum noise limited sensitivity between 100Hz and 1kHz.

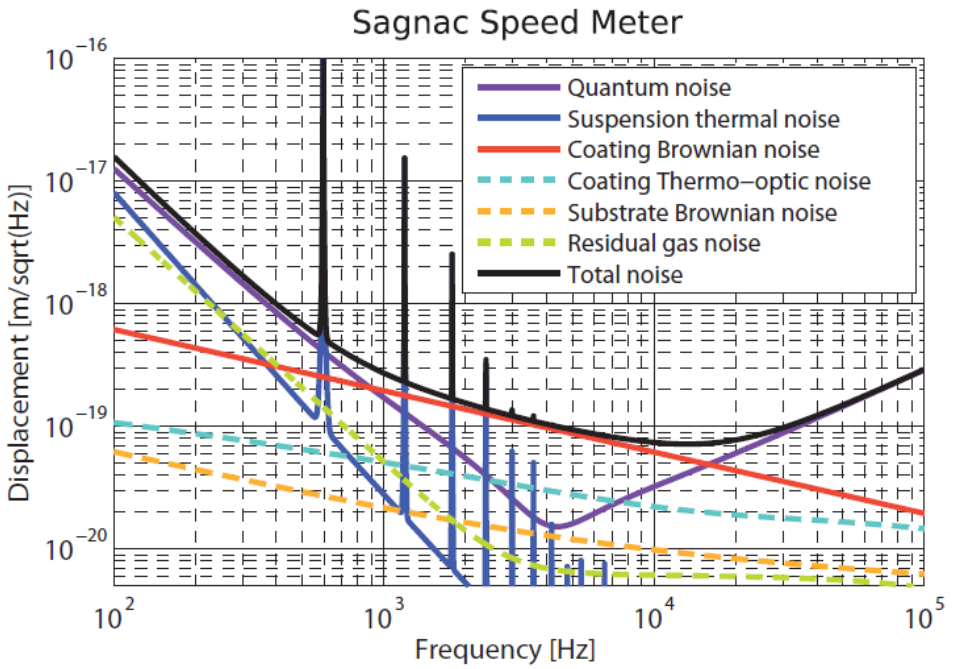


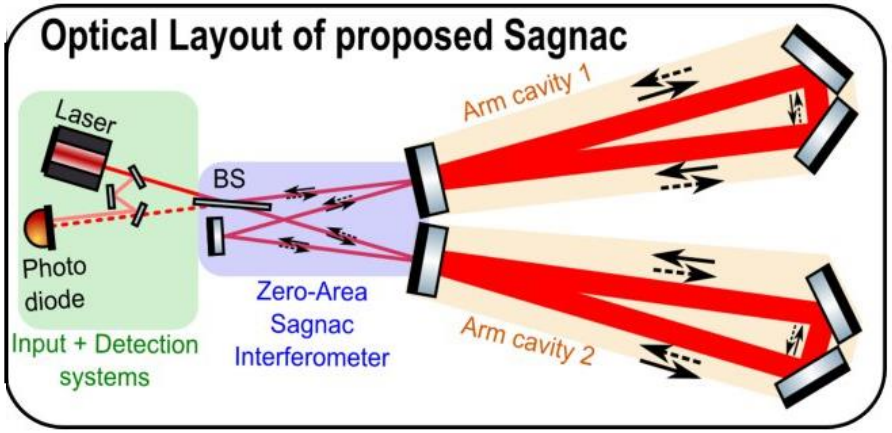
(Assuming that MI is well understood, so won't actually build one but go straight for a Sagnac)

Conceptual approach

- In-vacuum operation, passive multi-stage seismic pre-isolation
- Triangular arm cavities with monolithically suspended mirrors
- One gram input mirrors, 100g end mirrors
- Approx. 4kW of intra-cavity power
- 2.8m cavity round trip length, 20ppm – 30ppm loss per round trip
- Large laser beam spots to reduce coating Brownian thermal noise
- In-vacuum suspended balanced homodyne detector

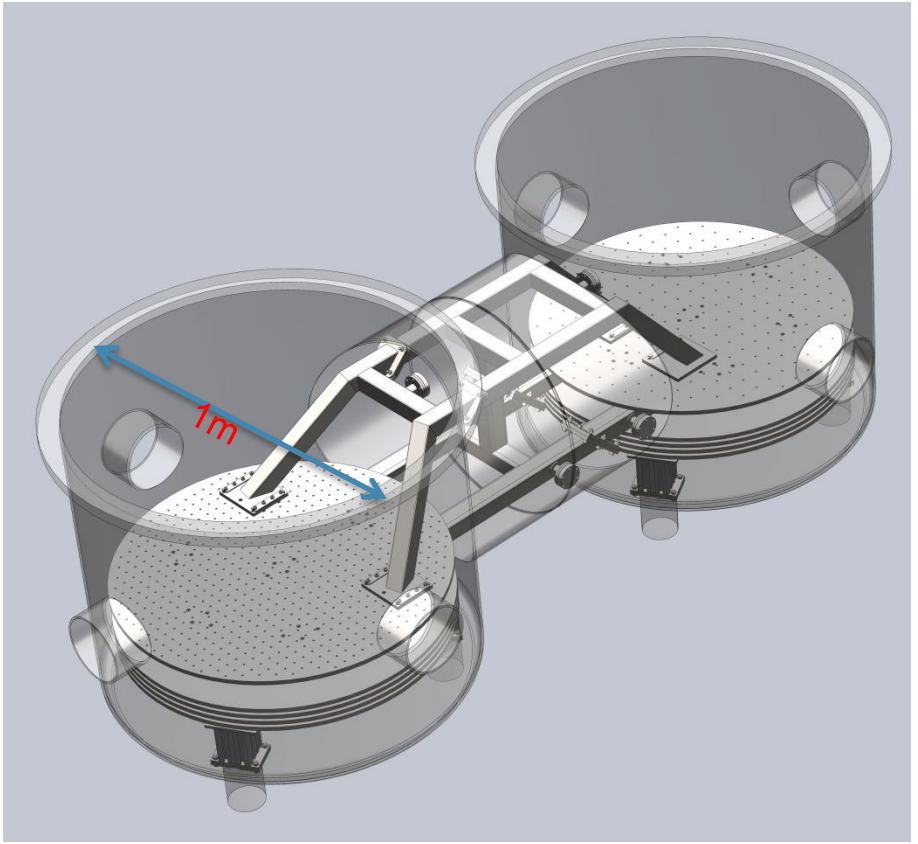
Target displacement sensitivity: better than 10^{-18} m/sqrt(Hz) at 1kHz

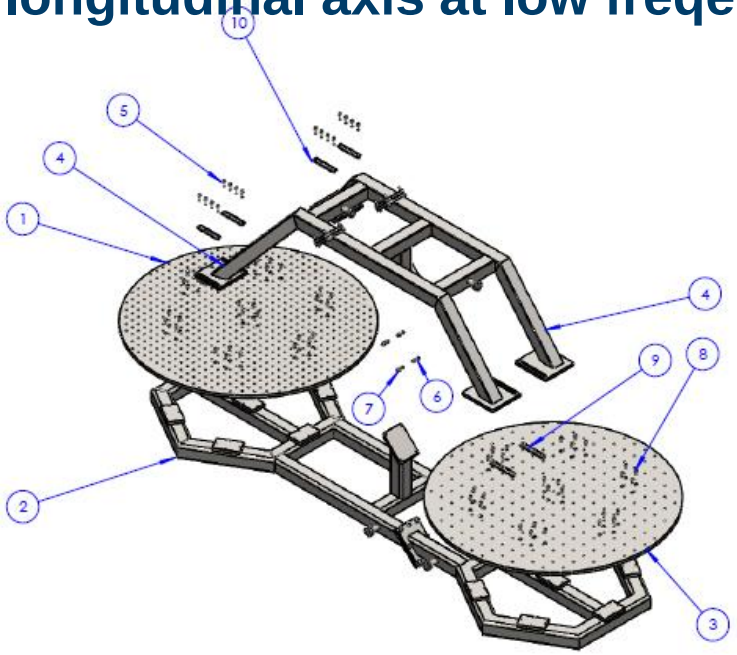


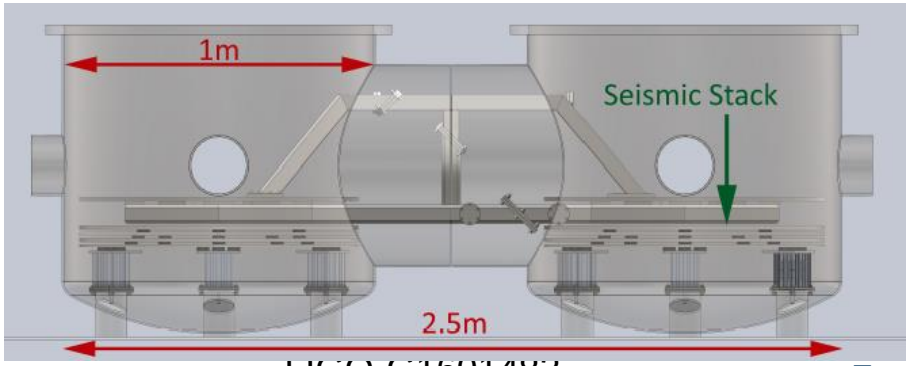


Infrastructure

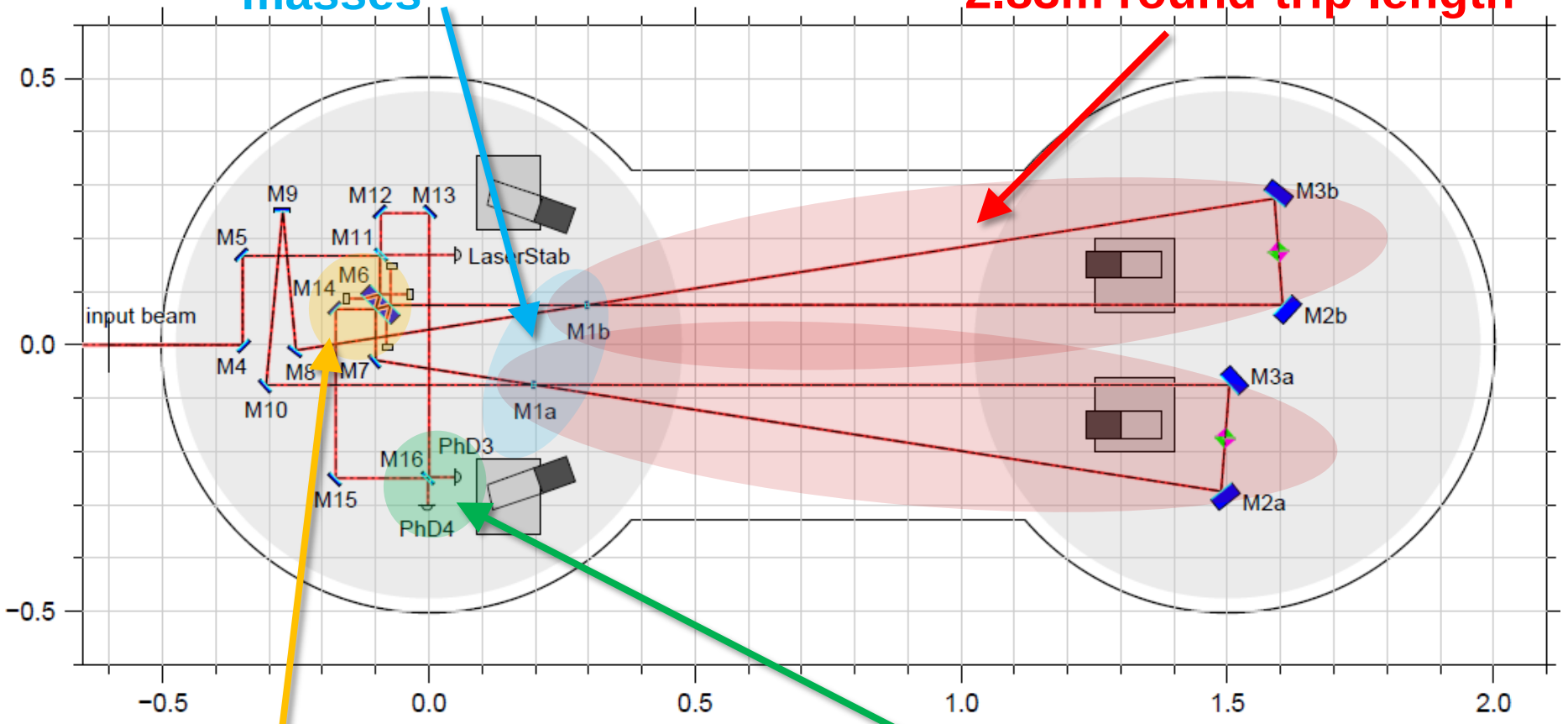
- **Two GEO600-style vacuum chambers**
- **Four layer seismic isolation stack: fluorel springs + 60kg stainless discs**
- **Custom-made circular optical breadboards**
- **Stiffening with a truss structure, to ensure rigid motion along the longitudinal axis at low freqencies**



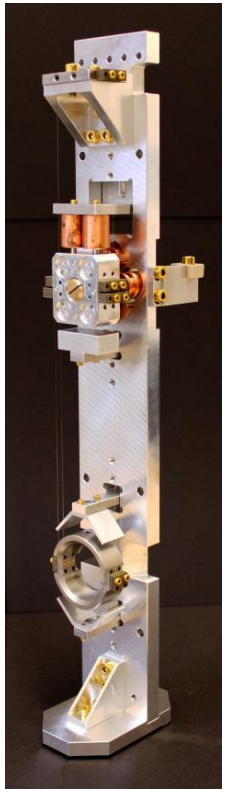




Optical layout

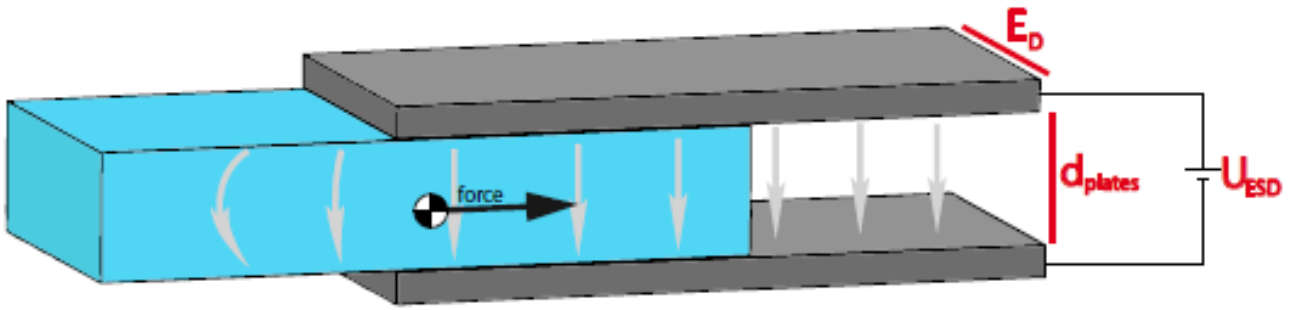


Suspension design



- **Auxiliary suspension design complete**
  - Steering optics with coil/magnet actuators at upper mass
  - Two pendulum stages, steel wires; no vertical stage
- **Arm cavity end mirror suspensions**
  - Triple pendulum stages with all-monolithic final stage
  - Design based on AEI 10m SQL IFO suspensions
  - ESD for fast actuation – tests underway
- **Small input mirror suspensions**
  - Monolithic multi-stage design
  - Scaled down version of 100g suspensions
- **Main BS suspension**
  - Large substrate to get access to secondary beams
  - Limited space requires elegant support structure

Plate capacitor ESD's



OPEN ACCESS
IOP Publishing
Classical and Quantum Gravity
Class. Quantum Grav. 32 (2015) 175021 (11pp)
doi:10.1088/0264-9381/32/17/175021

New design of electrostatic mirror actuators for application in high-precision interferometry

H Wittel[1], S Hild[2], G Bergmann[1], K Danzmann[1] and K A Strain[1,2]

[1] Max-Planck-Institute for Gravitational Physics and Leibniz Universität Hannover, D-30167 Hannover, Germany
[2] SUPA, School of Physics and Astronomy, The University of Glasgow, Glasgow, G12 8QQ, UK

E-mail: Holger.Wittel@aei.mpg.de

Received 17 November 2014, revised 1 July 2015
Accepted for publication 22 July 2015
Published 19 August 2015

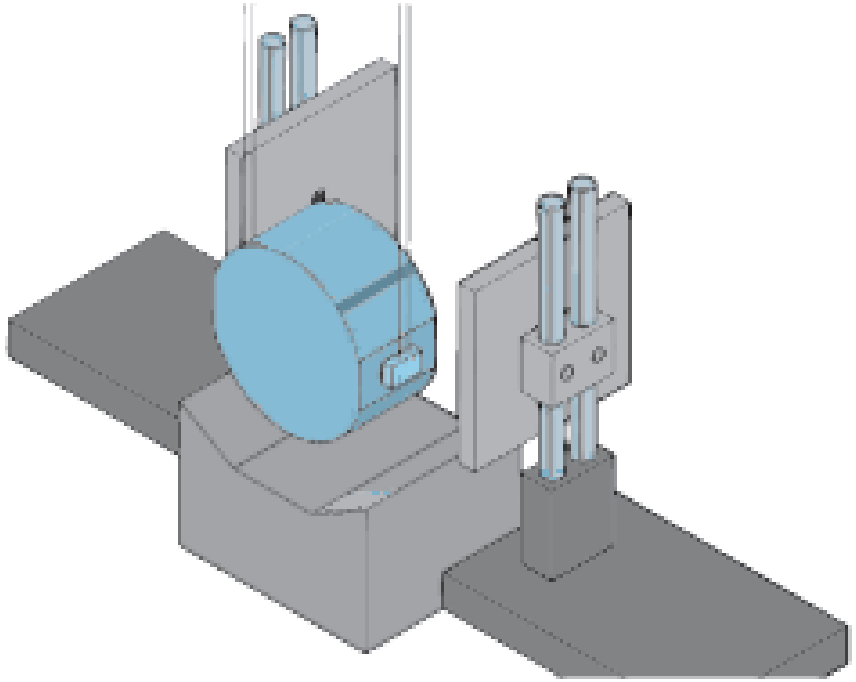
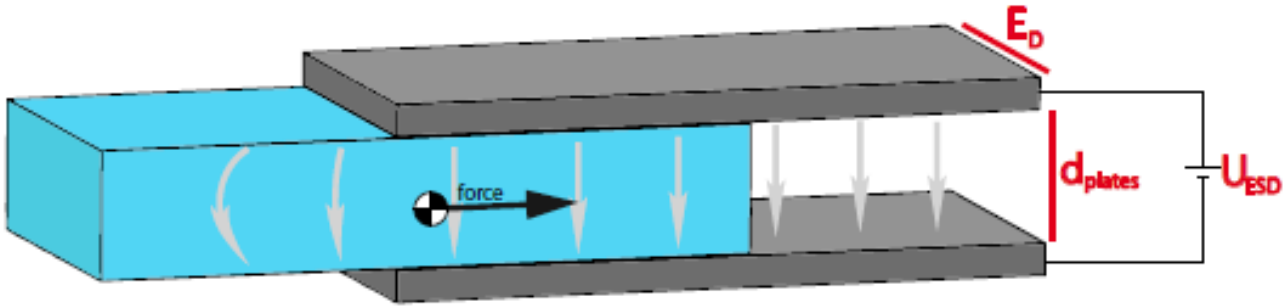


Plate capacitor ESD's



OPEN ACCESS
IOP Publishing
Classical and Quantum Gravity
Class. Quantum Grav. 32 (2015) 175021 (11pp)
doi:10.1088/0264-9381/32/17/175021

New design of electrostatic mirror actuators for application in high-precision interferometry

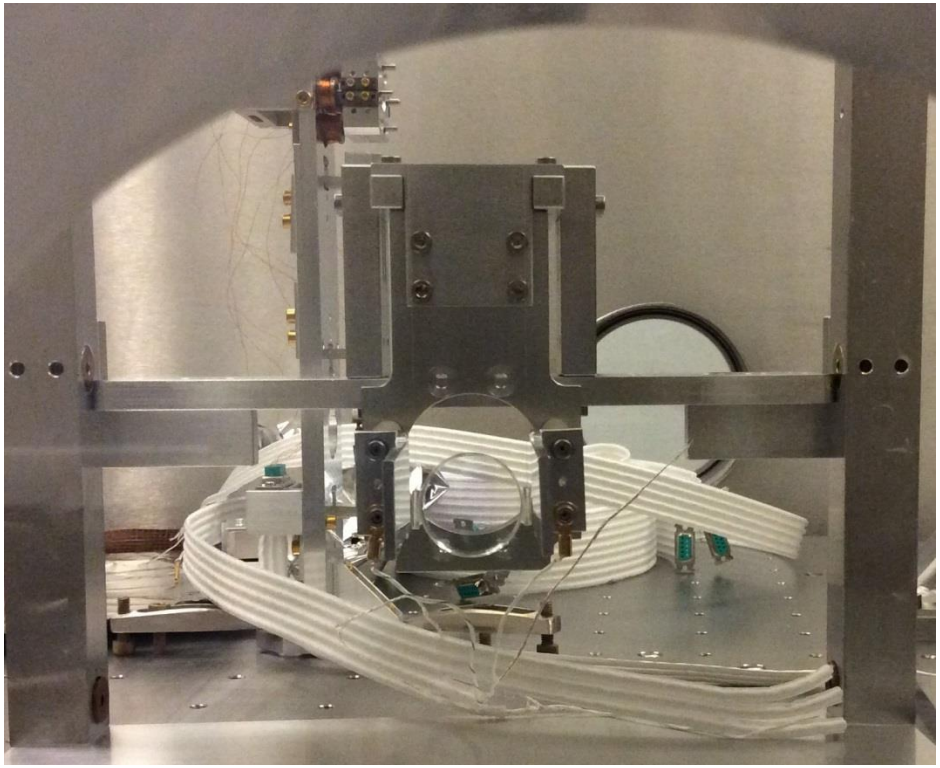
H Wittel[1], S Hild[2], G Bergmann[1], K Danzmann[1] and K A Strain[1,2]

[1] Max-Planck-Institute for Gravitational Physics and Leibniz Universität Hannover, D-30167 Hannover, Germany
[2] SUPA, School of Physics and Astronomy, The University of Glasgow, Glasgow, G12 8QQ, UK

E-mail: Holger.Wittel@aei.mpg.de

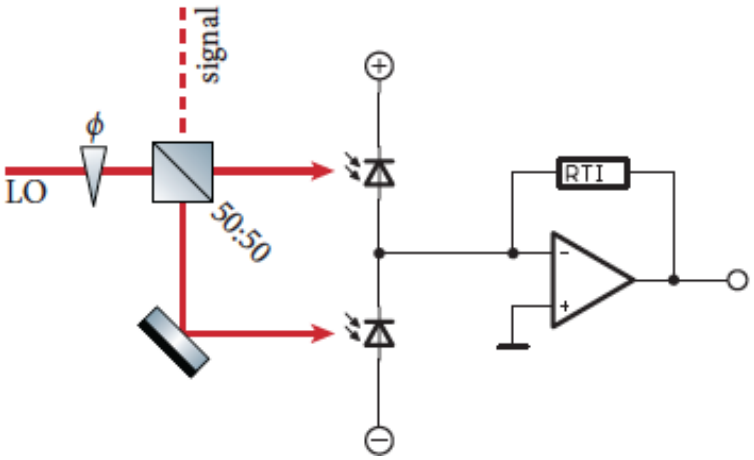
Received 17 November 2014, revised 1 July 2015
Accepted for publication 22 July 2015
Published 19 August 2015

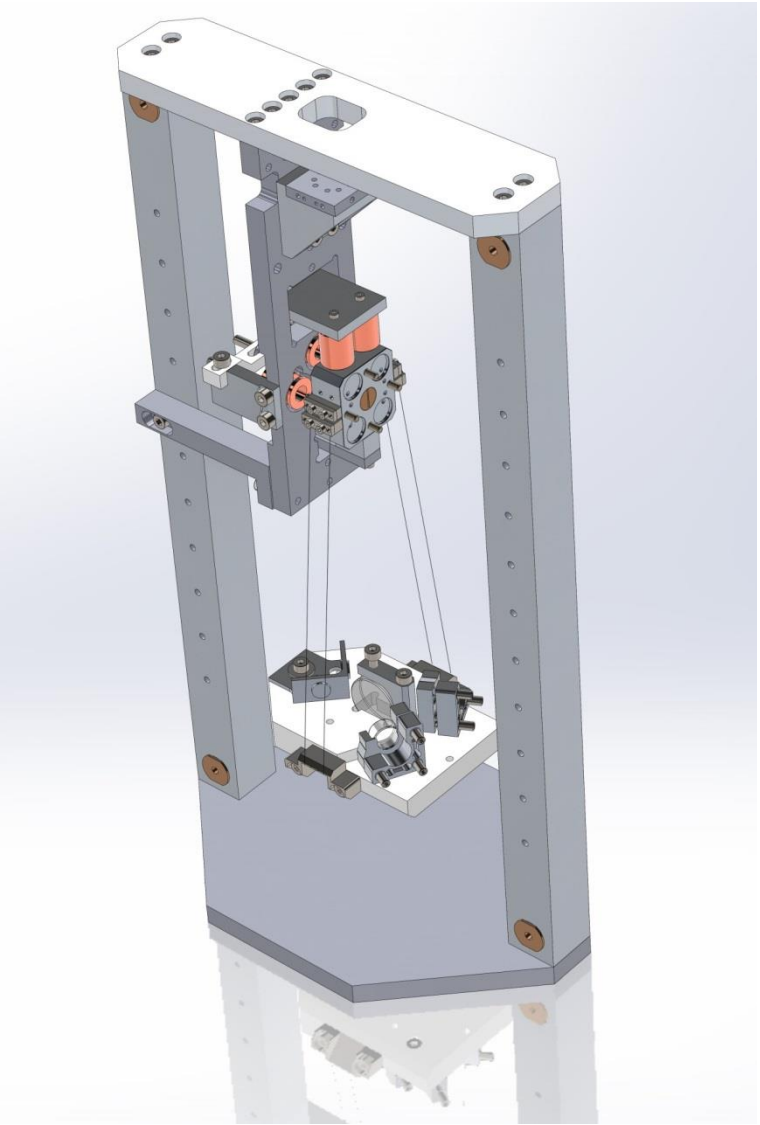
CrossMark



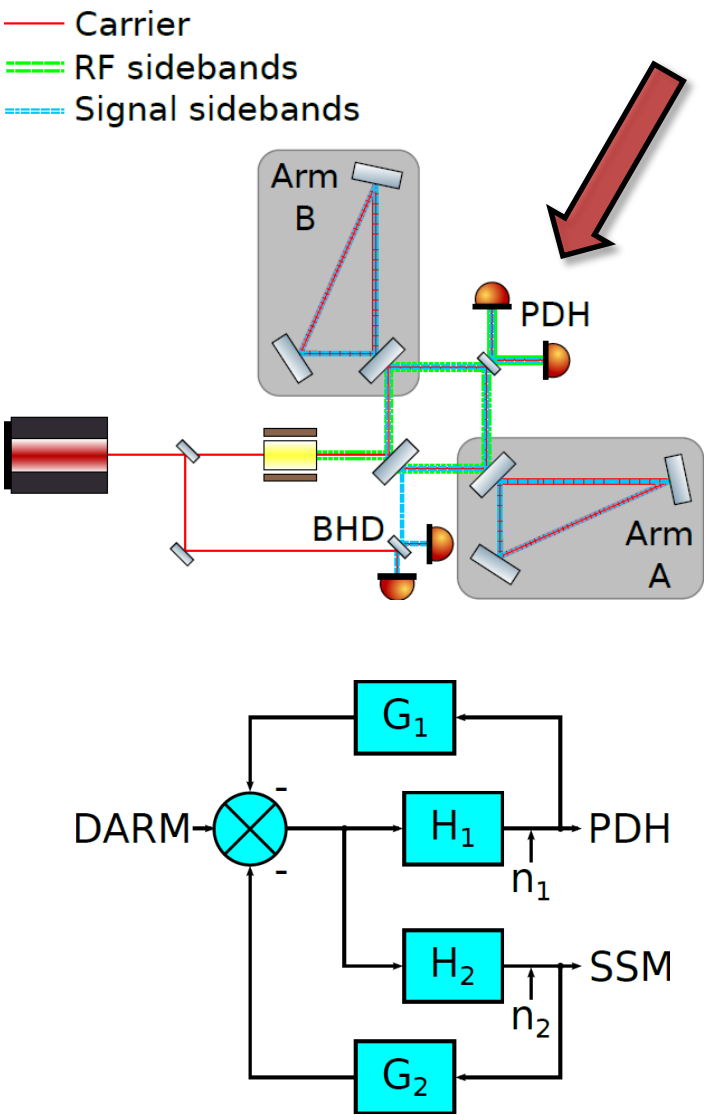
Balanced homodyne readout

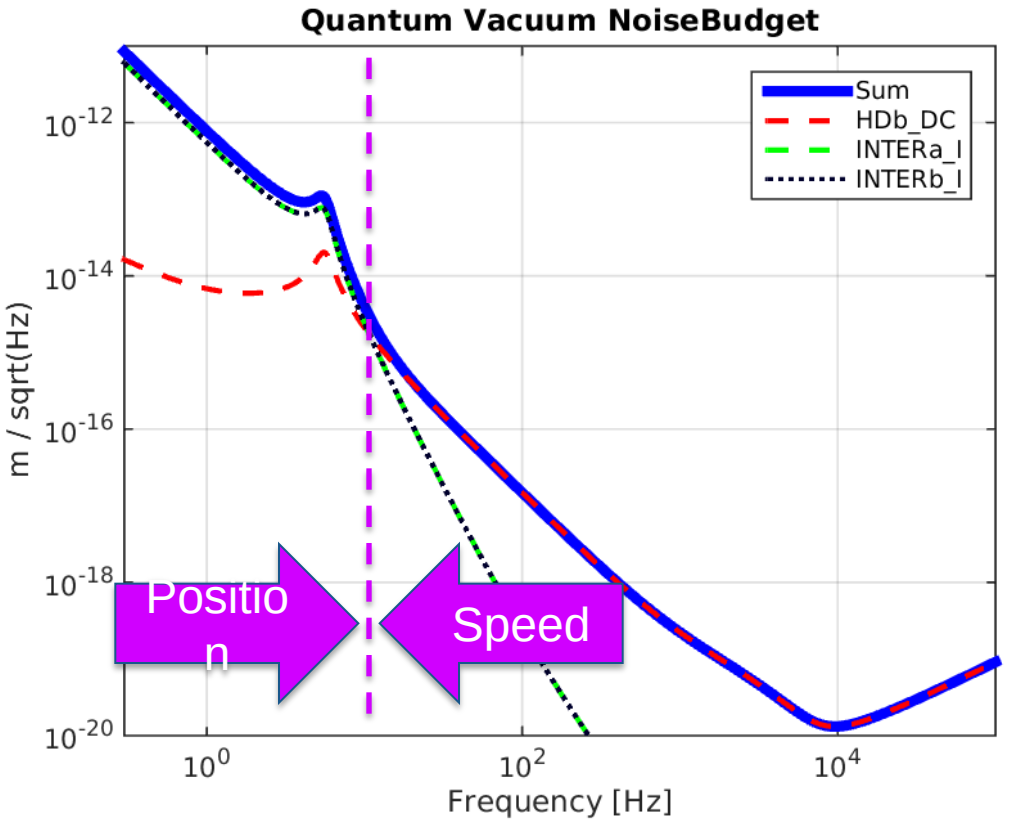
- **DC readout won‘t work, need external LO**
- **Selecting the right quadrature angle is essential**
- **Well established tool in bench-top quantum optics experiments, less so in suspended interferometers ...**
- **Investigated coupling of LO noise to BHD signal and HOM suppression**





Sensing and control

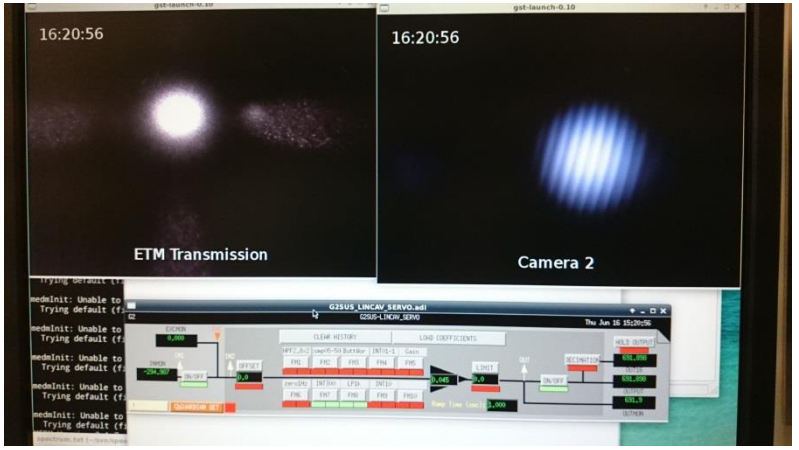




Full details: arXiv:1603.07756 [gr-qc]

Everything else…

- **Too many things to cover here**
  - **Laser stabilisation (amplitude, frequency, mode-cleaning)**
  - **Modelling (effects of asymmetries from beamsplitter, arm cavity power mismatch, etc)**
  - **Analysis of ring cavity mirror surface scattering (non-normal incidence beams allow scatter back along the beam path – mixing of CW and CCW beams, micro-roughness measurement and analysis)**
  - **Environment monitoring (seismic, temperature, humidity, etc)**
  - **Digital control system (CDS) already being used for locking**
  - **Length and angular control studies**
  - **10 micron suspension fibres**
  - **Blade spring tests**
  - **Etc etc etc…**



Overview

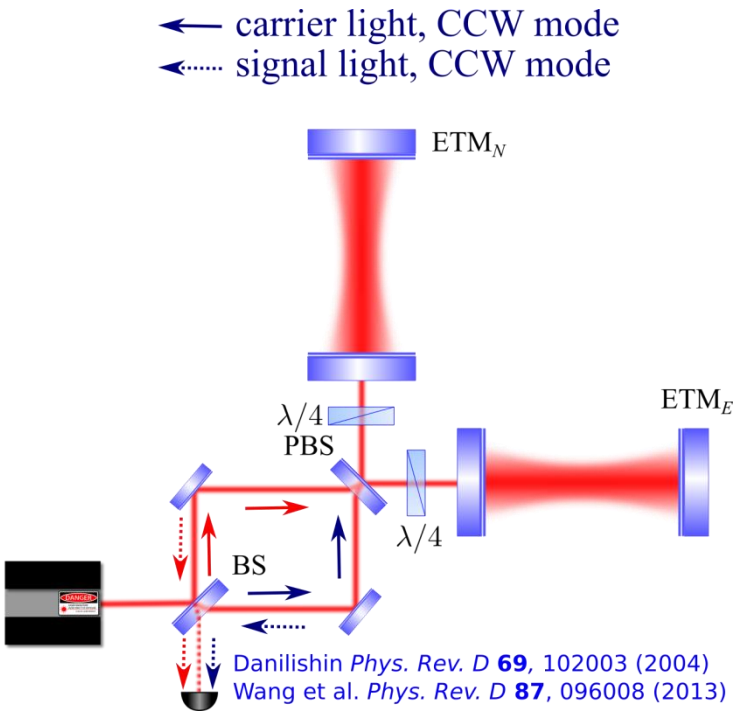
- **Why speedmeters?**
  - **Back action noise reduction**

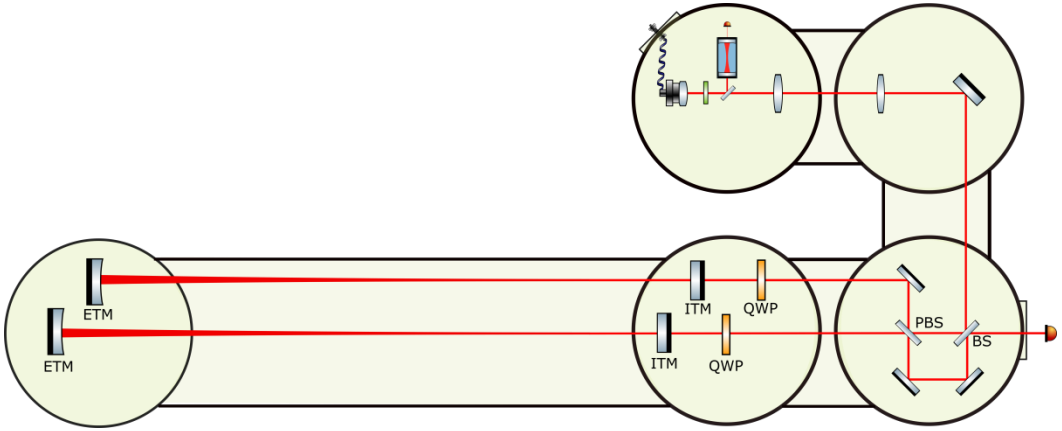
- **The Glasgow ERC Speedmeter experiment**
  - **Concept**
  - **Implementation**

- **Future speedmeters**
  - **Polarisation**
  - **Sloshing**

Polarisation Sagnac

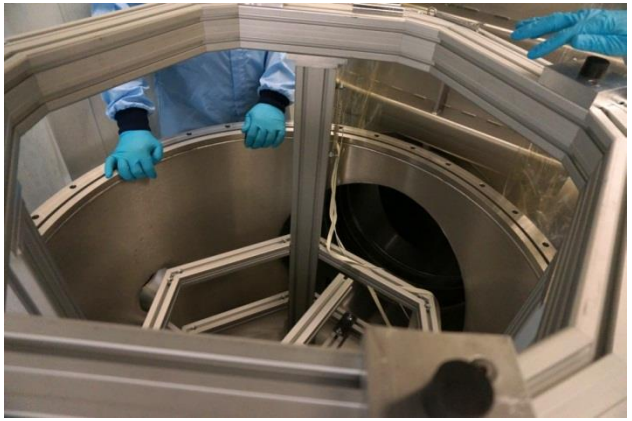
- **Simple first stage - proof of principle**
  - **Characterise polarisation optics – thin film polarisers, QWP's**
  - **Completely upgrade our vacuum and suspension system**
  - **Changing wavelength to 1550nm**
  - **Begin with single arm test – inform full Sagnac later…**

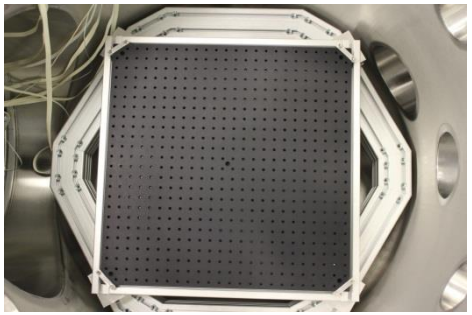


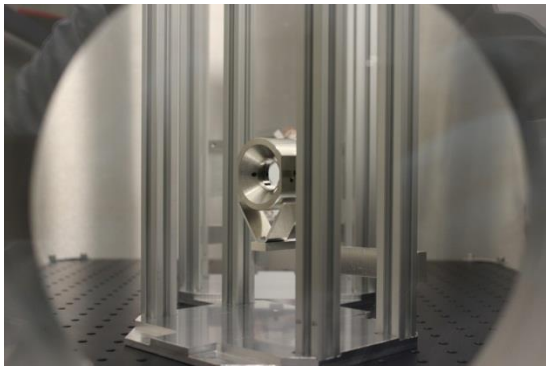


System upgrade

- **Major reconfiguration of our system:**
  - **Removed all the suspensions and infrastructure from inside the vacuum system and replaced them with new designs.**
  - **Redesigned for flexibility and ease of operation.**

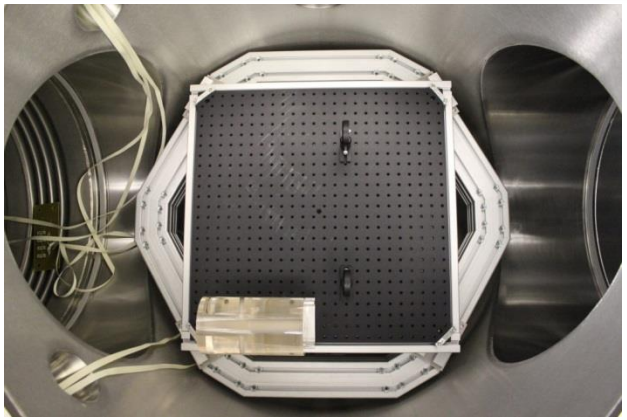


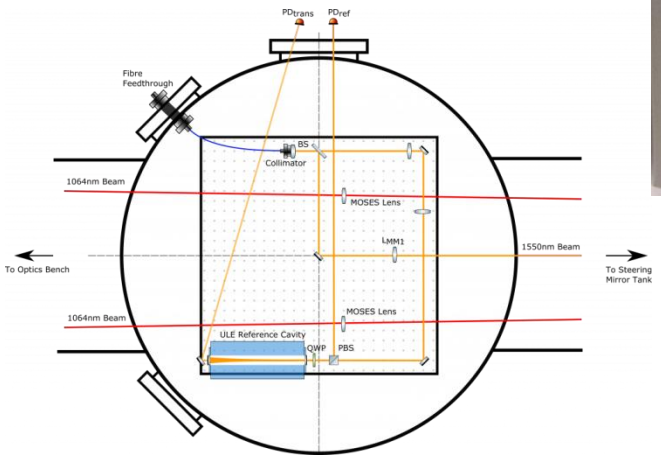


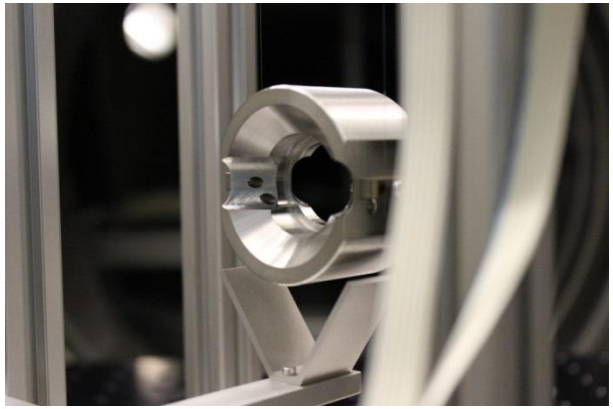


Early days…

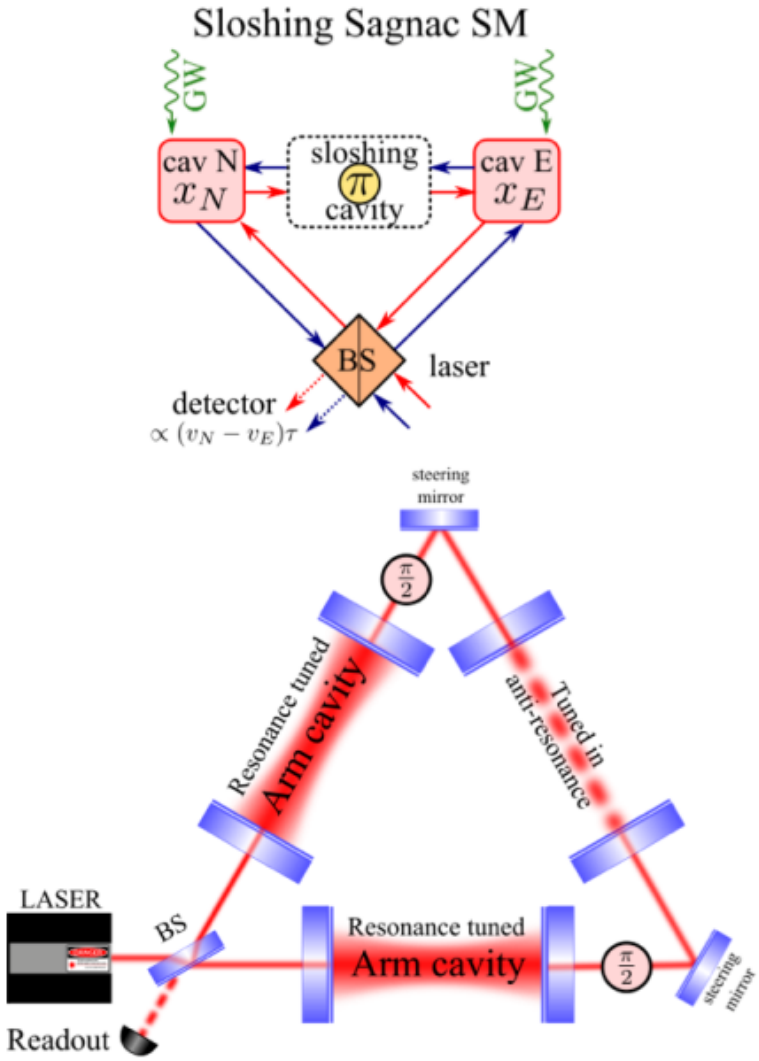
- **Putting it all together**
  - **Suspensions built, controlled and in place**
  - **1550nm laser stabilisation and amplification characterisation (now!)**





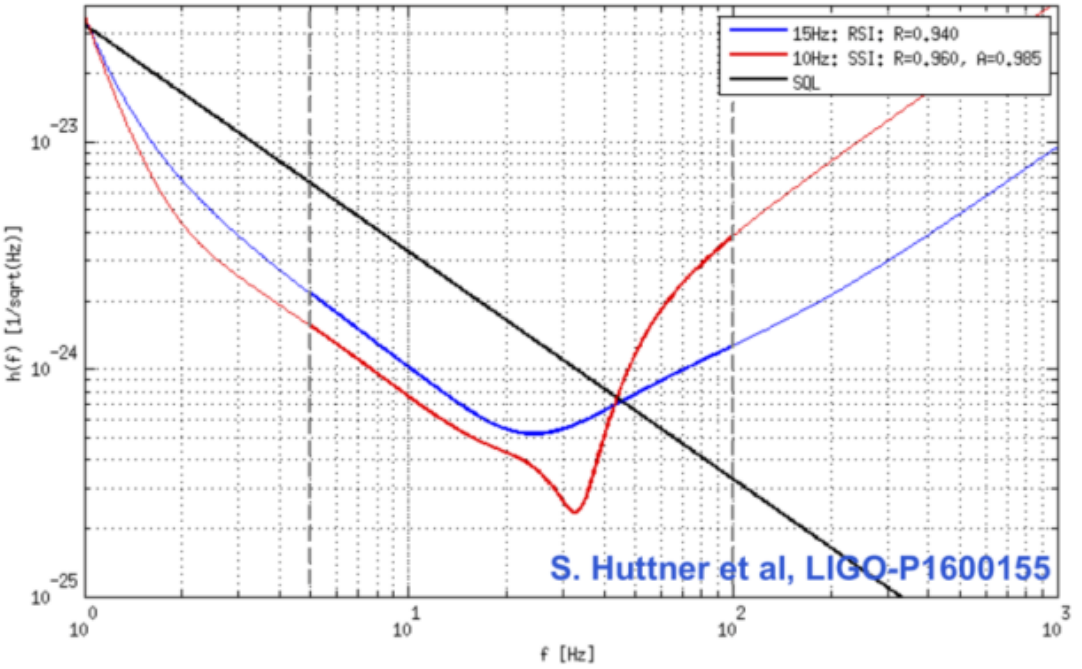


Sloshing Sagnac



Sloshing Sagnac ≡ Sloshing Speed Meter

1. Sloshing cavity (AR-tuned) between the arms;
2. Linear cavities & fits the ET layout;
3. Reduced ETM reflectivity ⇒ 2.2 times lower coating TN.



End

Thanks for listening!