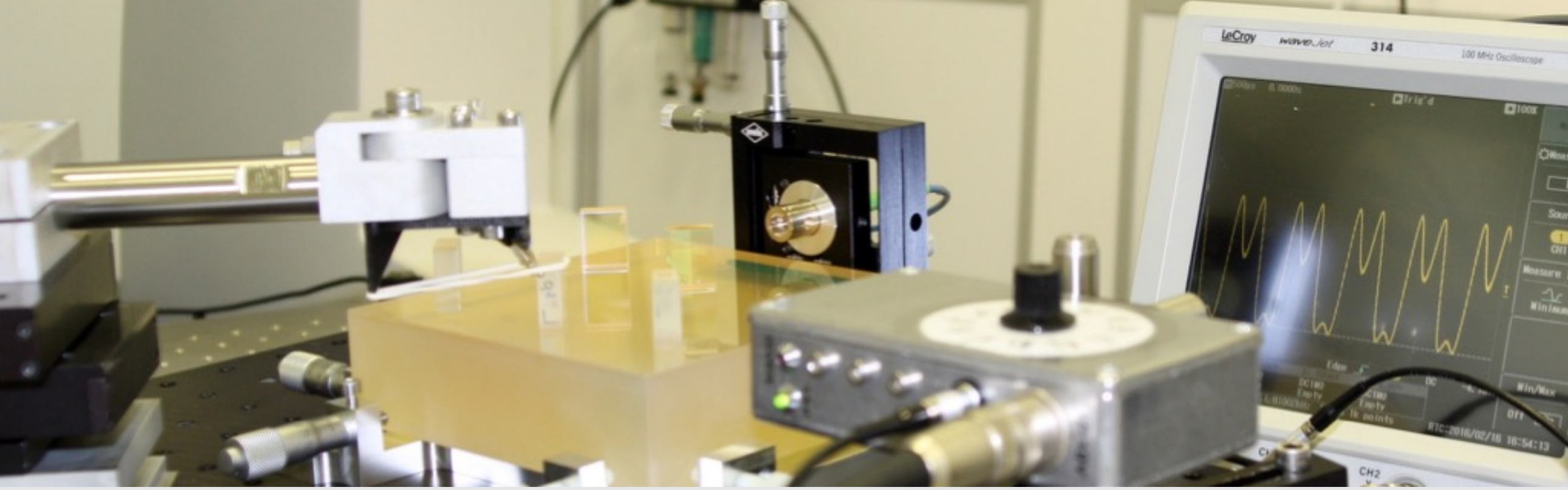


Upscalable optical test mass readout via deep frequency modulation interferometry

12th Edoardo Amaldi Conference on Gravitational Waves
July 9-14, 2017

Katharina-Sophie Isleif





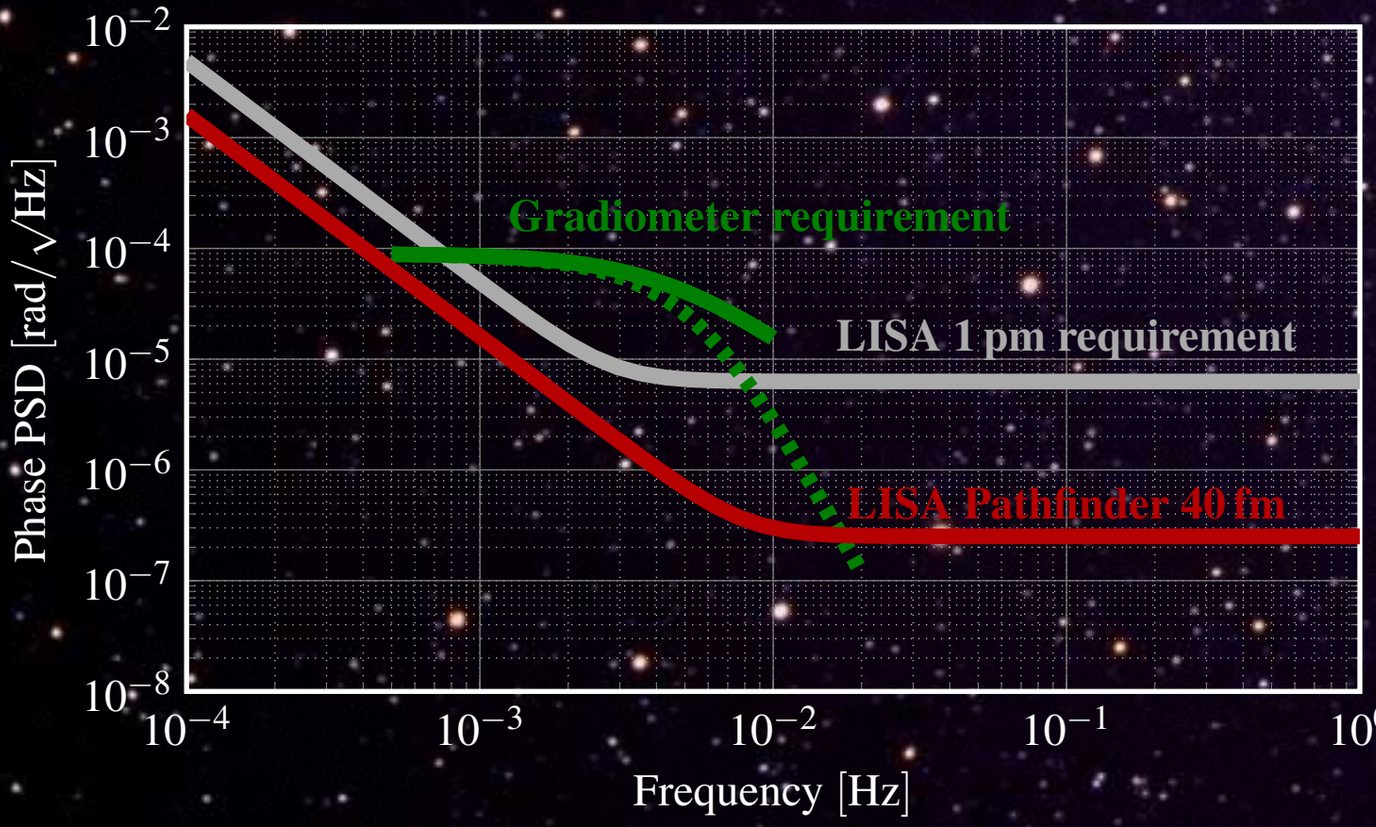


?
?

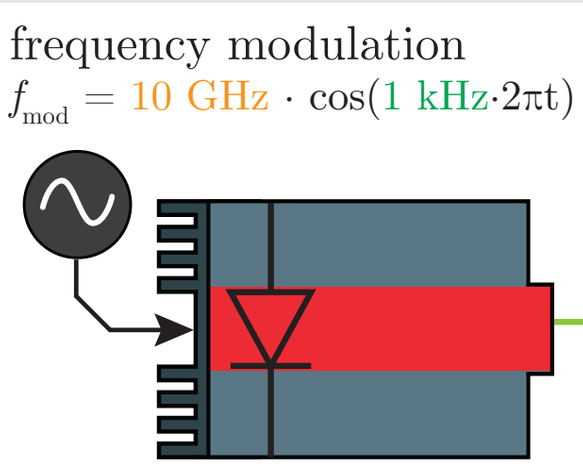
K. Danzmann, O. Gerberding, F. Guzmán Cervantes, G. Heinzel, V. Huarcaya, K.-S. Isleif, M. Mehmet, T.S. Schwarze, C. Vorndamme, Q. Wang

Motivation

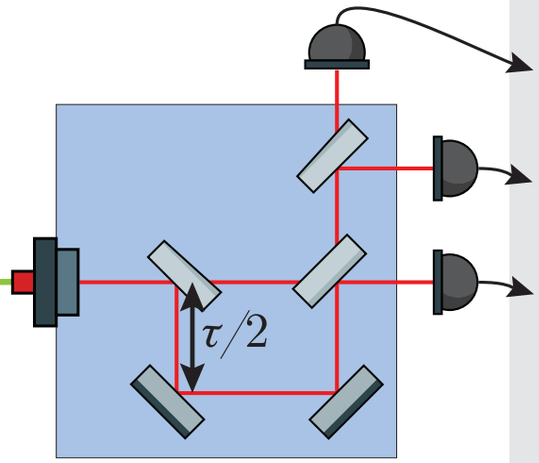
- Multiple test masses for future gravimetry (>6)
- all DoF for each test mass (>36 DoF)



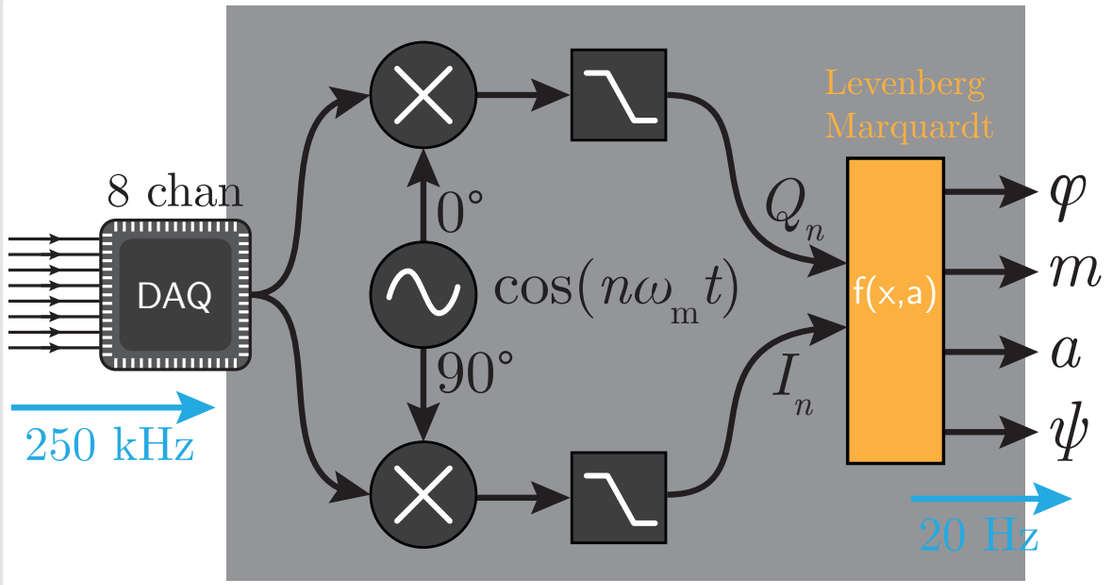
Deep Frequency Modulation Interferometry



deeply frequency tunable laser source

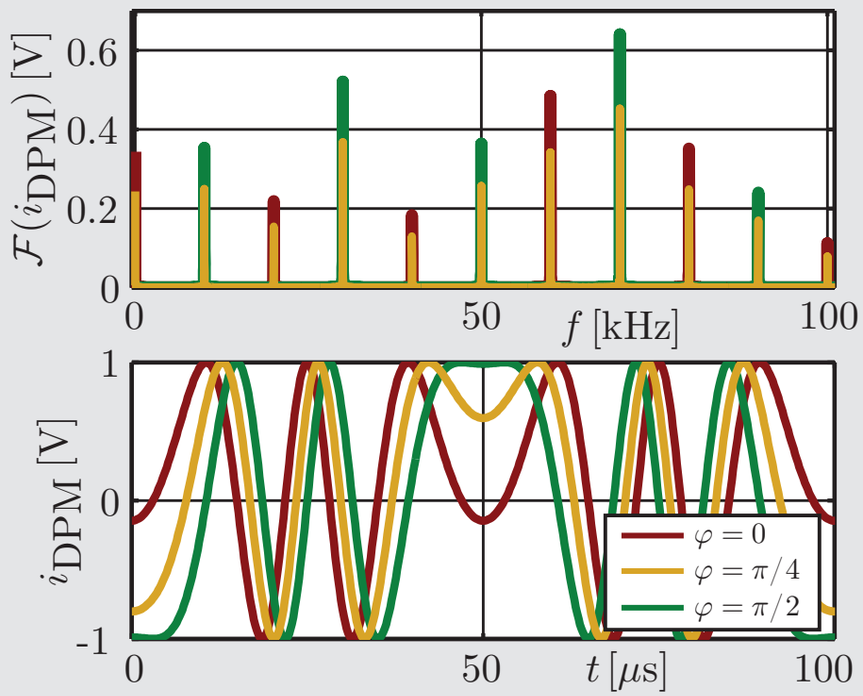


unequal arm length interferometer

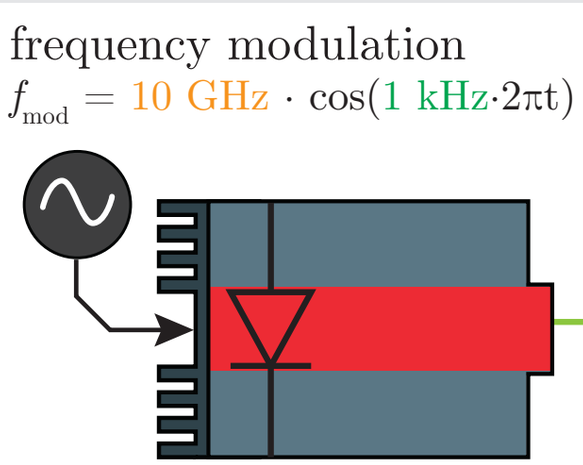


SW phasemeter with fit algorithm

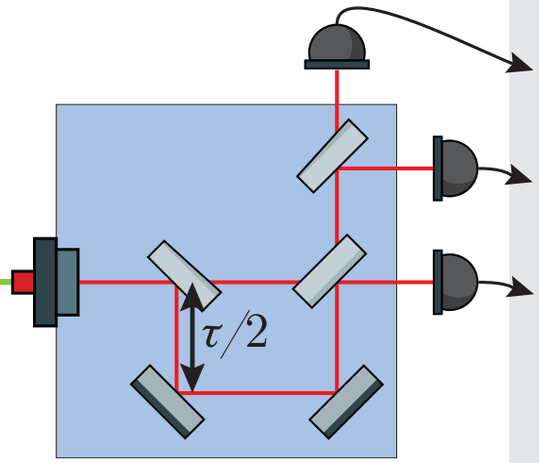
- deep **frequency modulated** laser + **unequal arm length** interferometer
  - ➡ *quasi-heterodyne* signal
- **fit algorithm** extracts desired information
  - ➡ optical amplitude *a*, optical phase φ
  - ➡ modulation depth *m*, modulation phase ψ



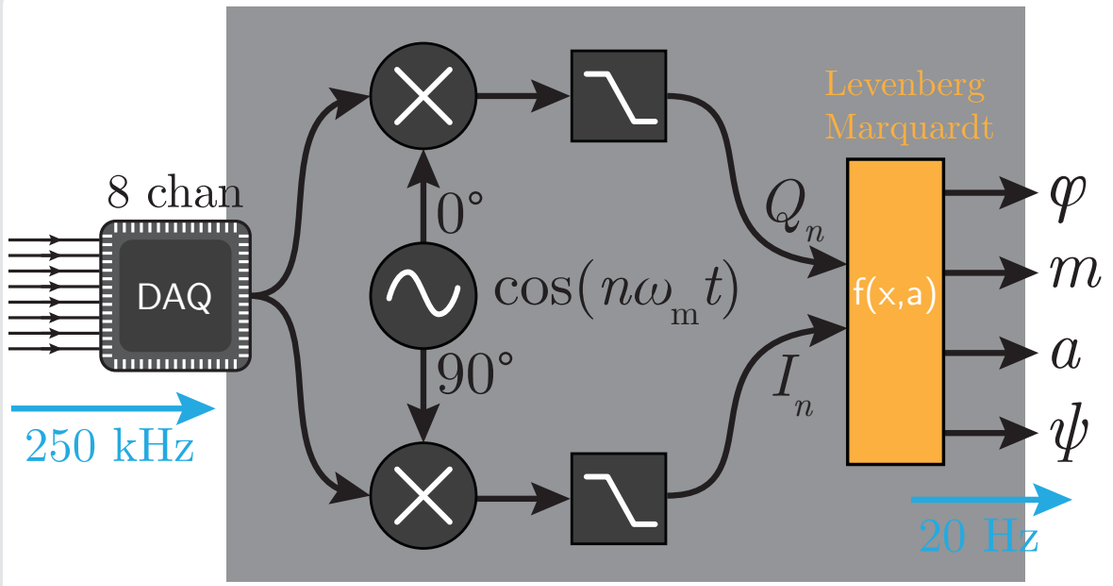
Deep Frequency Modulation Interferometry



deeply frequency tunable laser source



unequal arm length interferometer



SW phasemeter with fit algorithm

- advantages
  - compact optical set-ups
  - single laser beam per interferometer
  - kHz beat note (QPDs are available)
  - one single laser source
  - potentially absolute distance measurements:

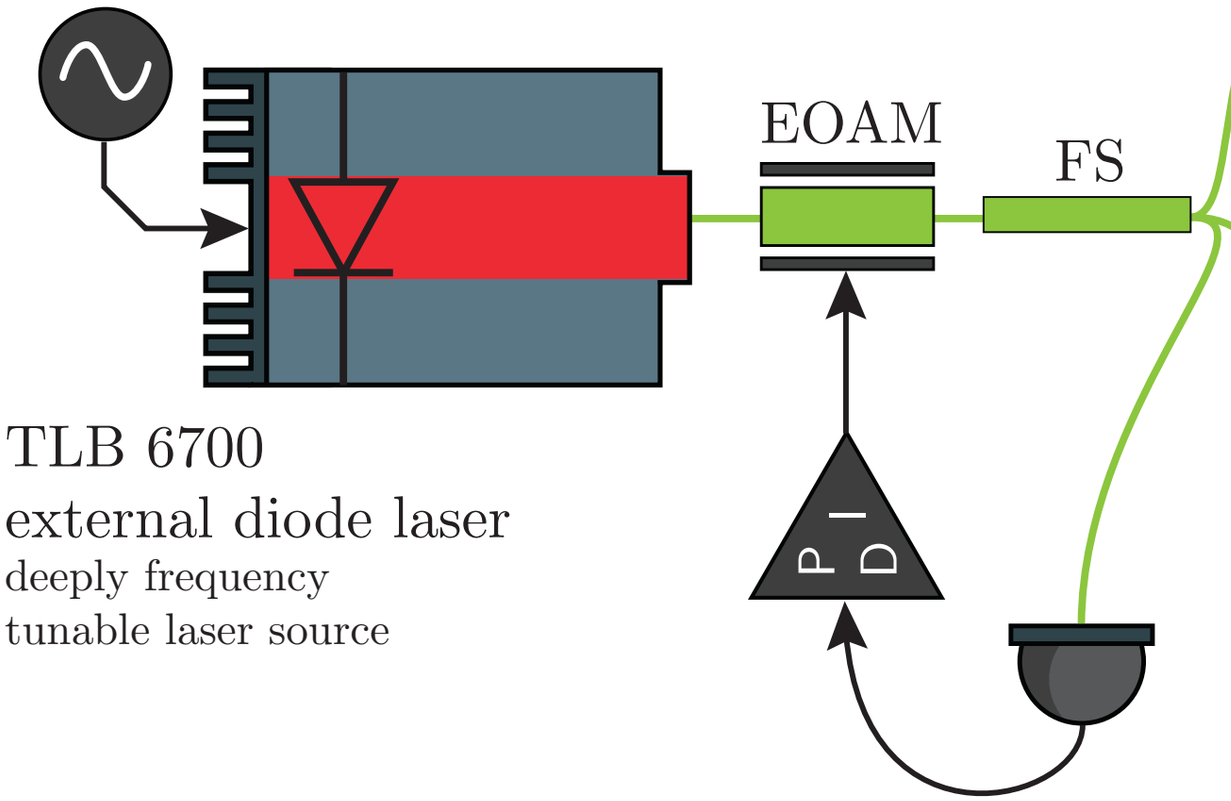
$$m = 2\pi \Delta f \tau$$

- challenges:
  - deeply tunable laser source (several GHz with kHz rate)
  - sophisticated readout algorithm
  - laser frequency noise
  - other (non-linear) noise coupling due to the strong modulation

First experimental demonstration

frequency modulation

$f_{\mathrm{mod}} = 10\ \mathrm{GHz} \cdot \cos(1\ \mathrm{kHz} \cdot 2\pi t)$



TLB 6700

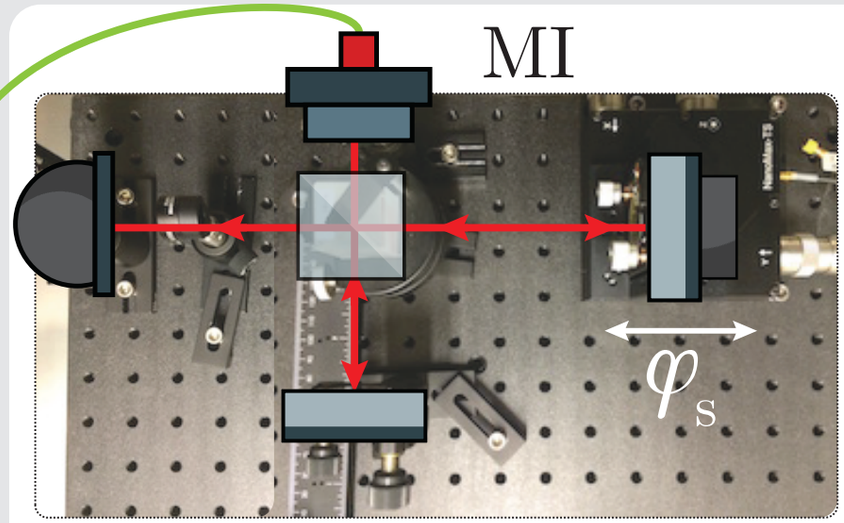
external diode laser

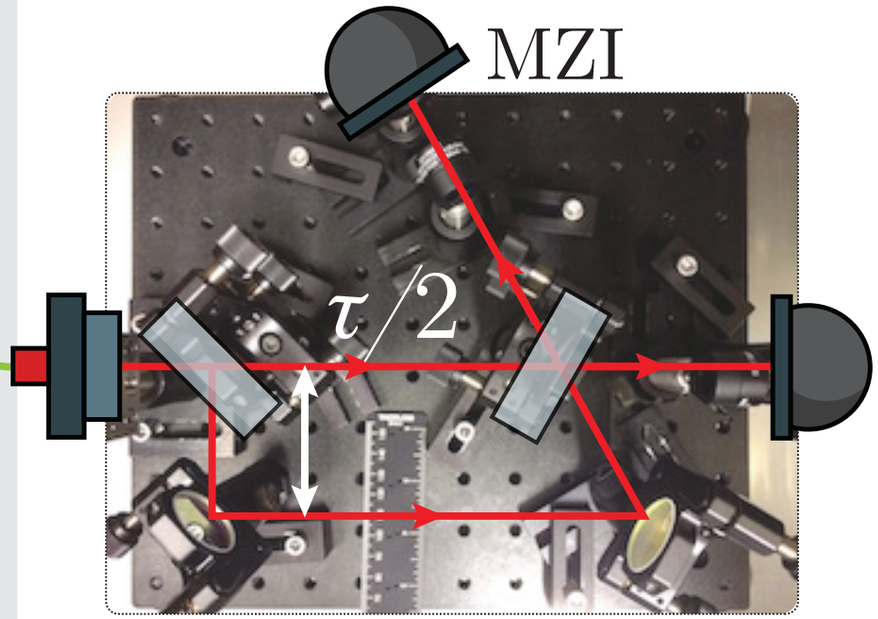
deeply frequency

tunable laser source

laser preparation with

amplitude stabilisation

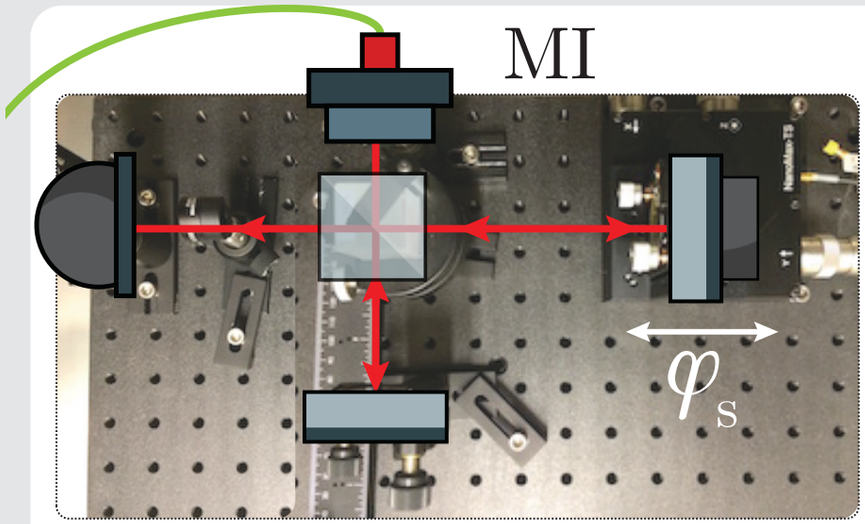


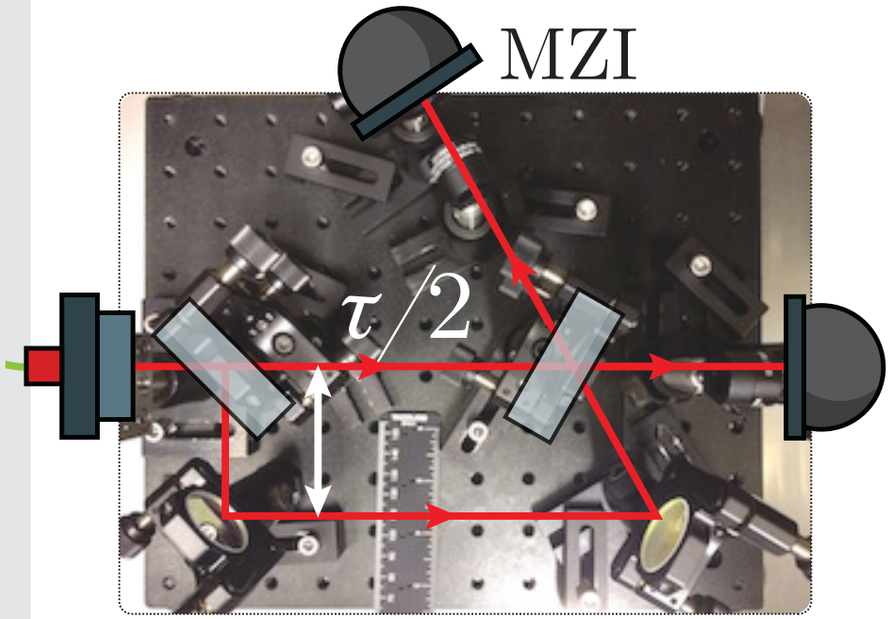


unequal arm length

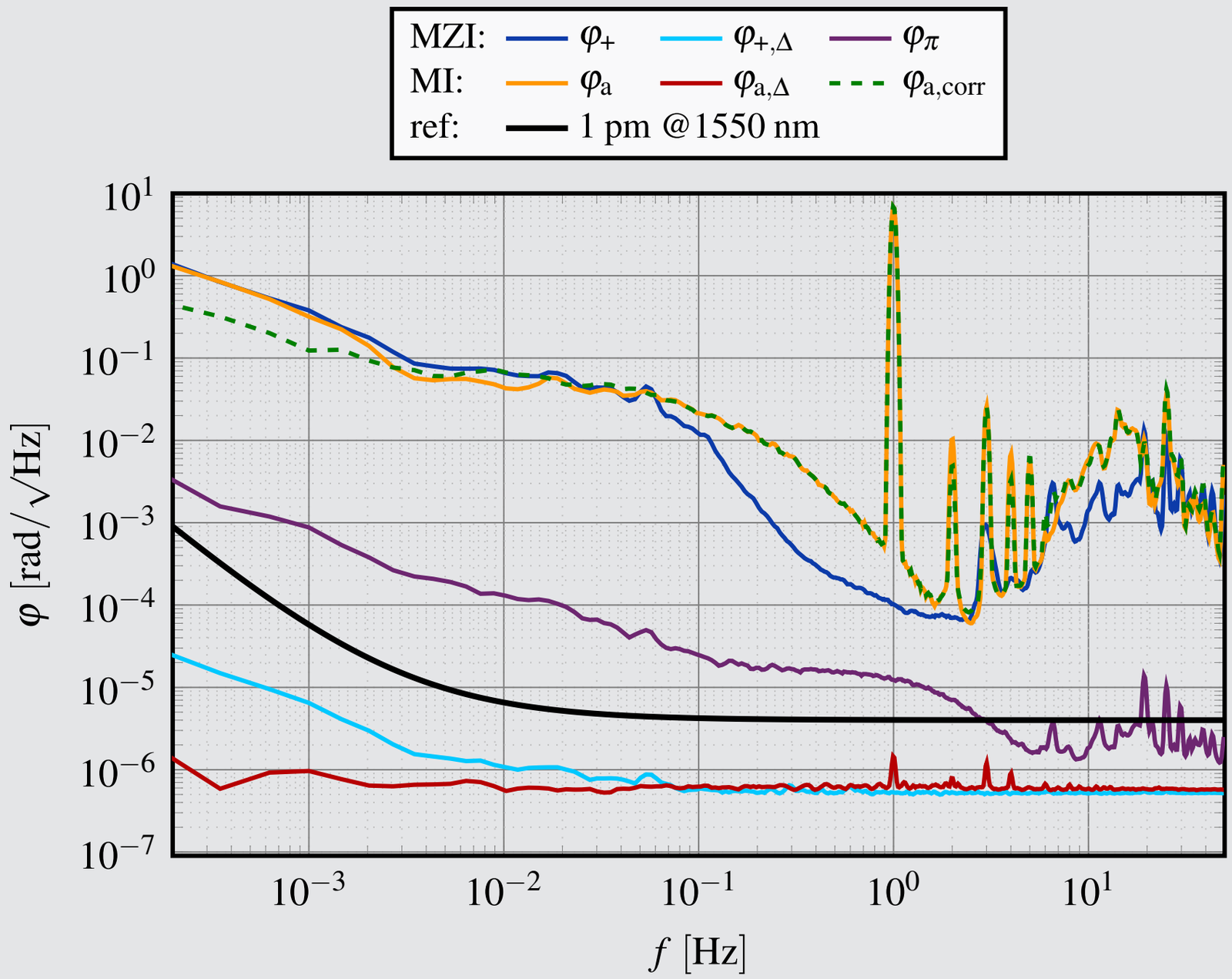
interferometer

First experimental demonstration

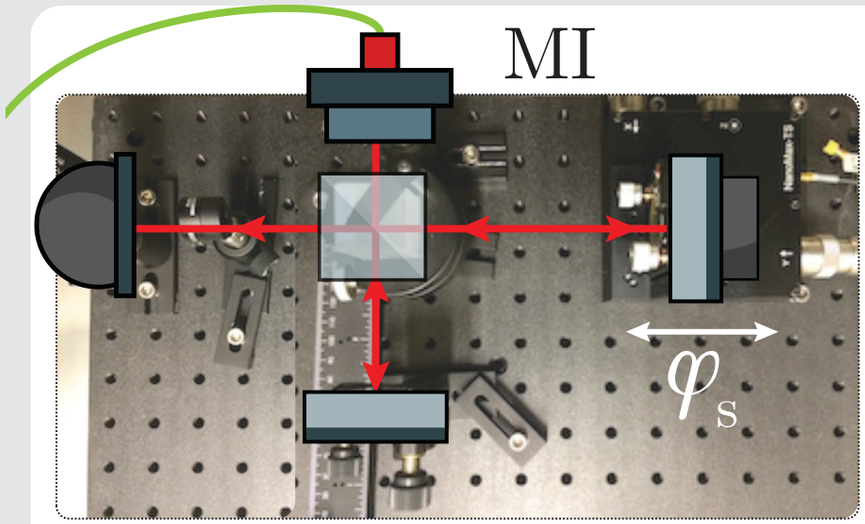


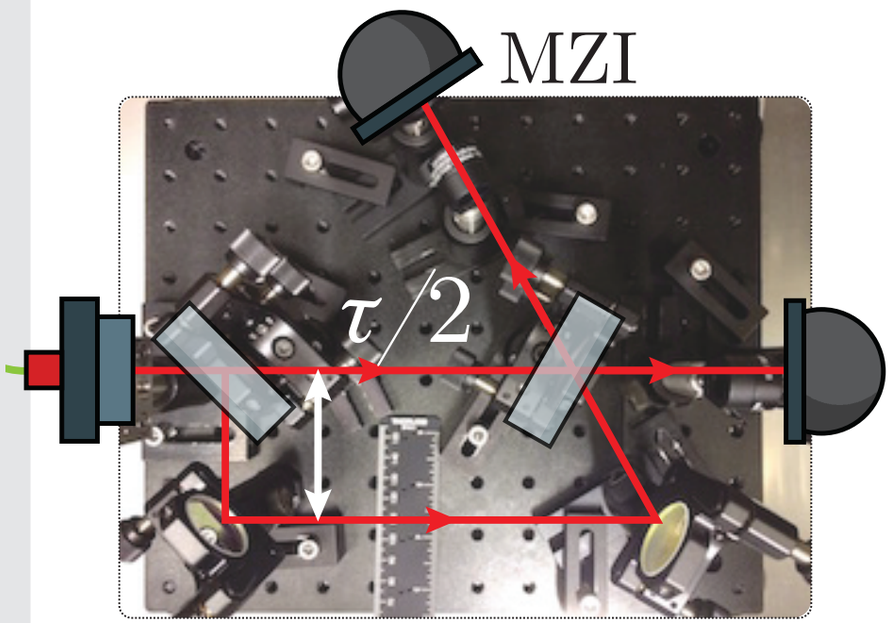


unequal arm length interferometer



First experimental demonstration





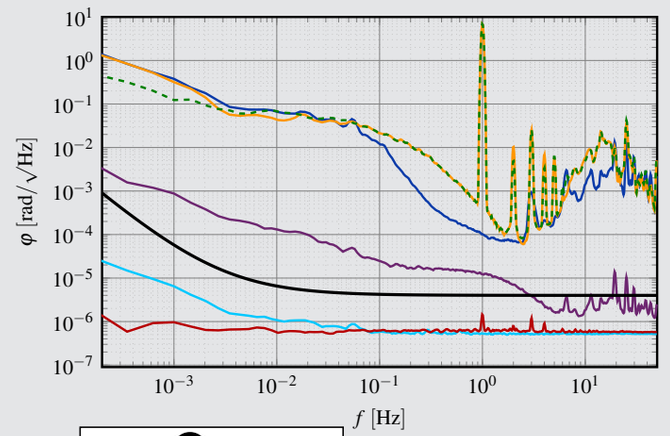
unequal arm length interferometer

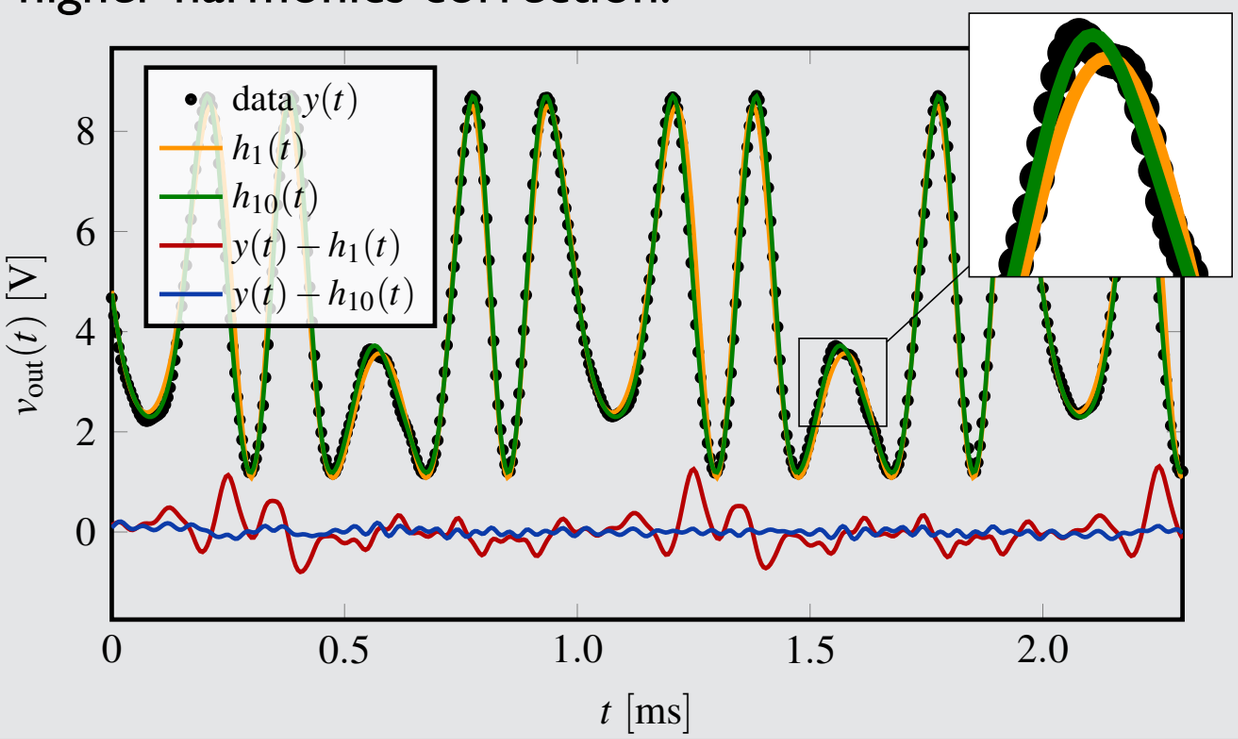
- displacement sensitivity between phase measure of 2 photodetectors monitoring the same optical signal:

$$250\,\mathrm{pm}/\sqrt{\mathrm{Hz}} \quad @ \quad 1\,\mathrm{mHz}$$

without yet applying:

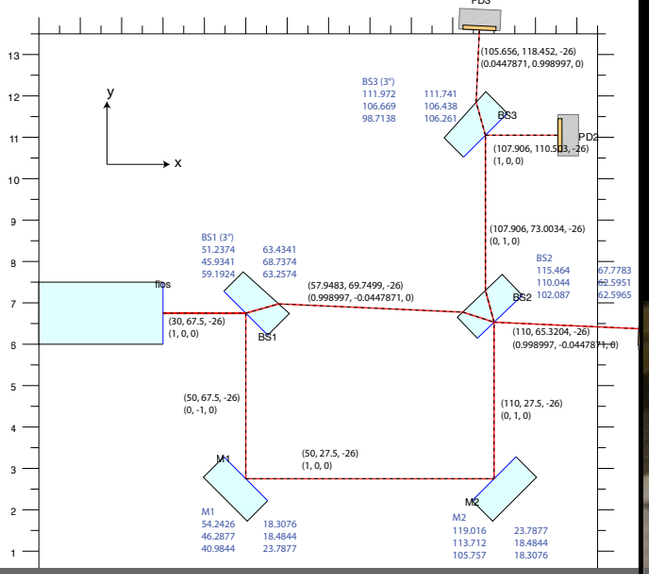
- temperature stabilization (no vacuum)
- stray light suppression
- clean polarization
- higher harmonics correction:



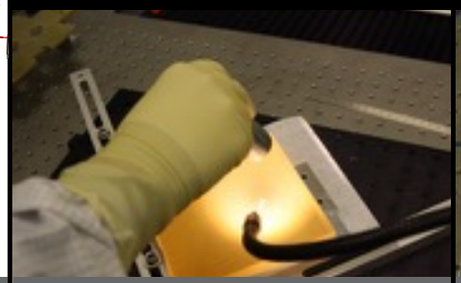


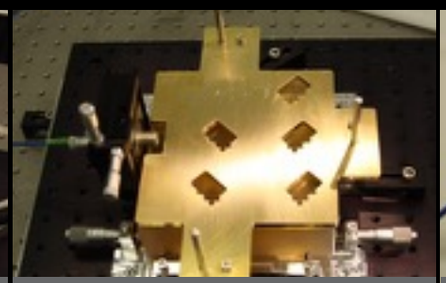
Opt. Express **24**, 1676-1684 (2016)
https://www.osapublishing.org/oe/abstract.cfm?URI=oe-24-2-1676

Quasi-monolithic Mach Zehnder Reference

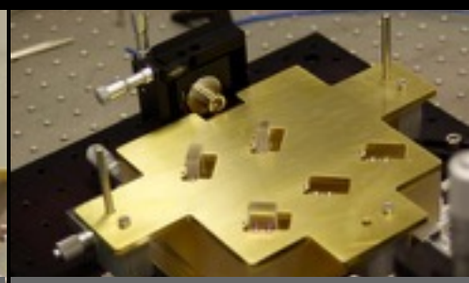


IfoCAD simulation


clean room


template installation


template aligned to beam


template glueing

UV glue: EMIUV Optocast 3553- LV-UTF

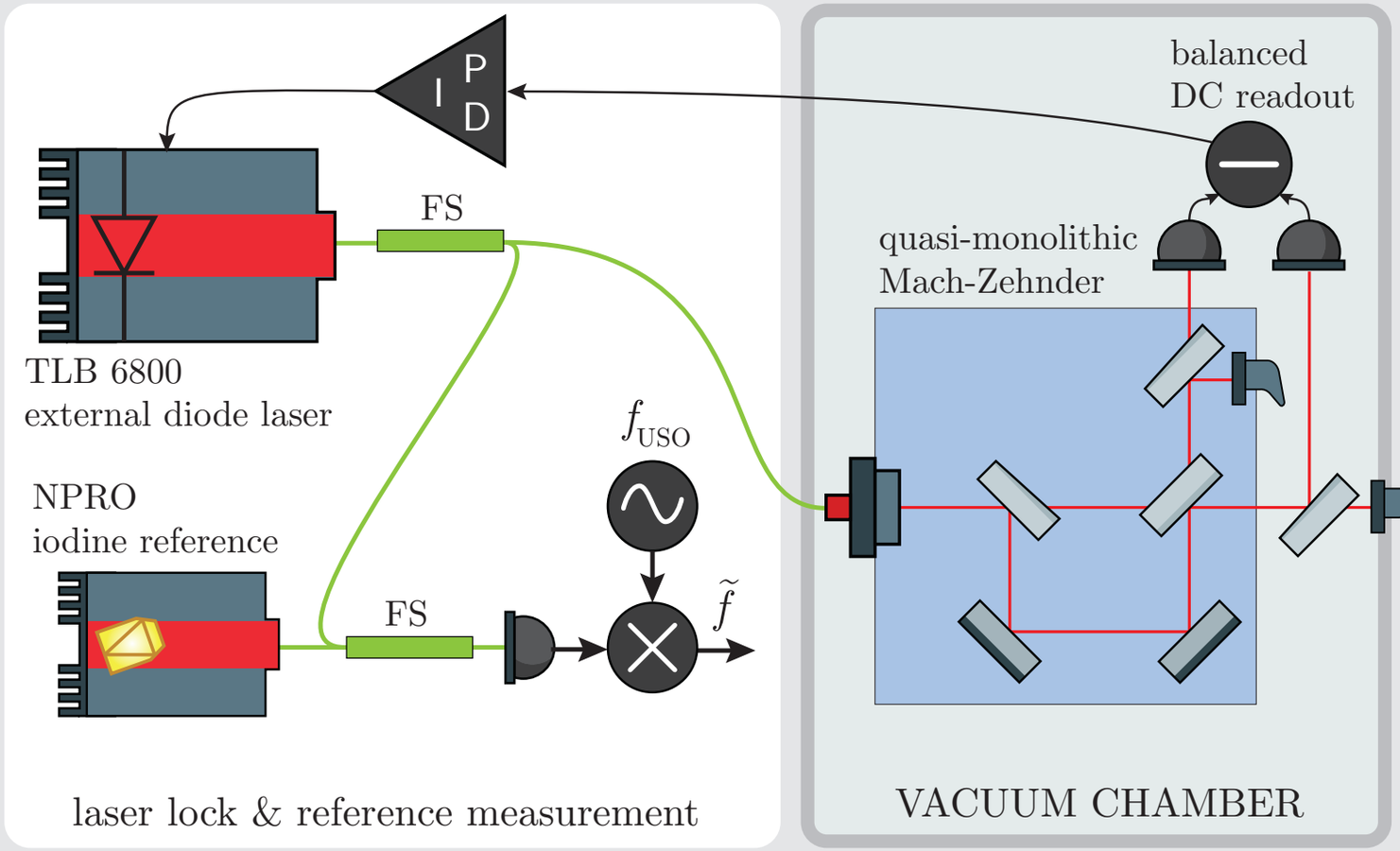
Clearceram Ohara CCZ-HS, CTE 0.1e-7 / K

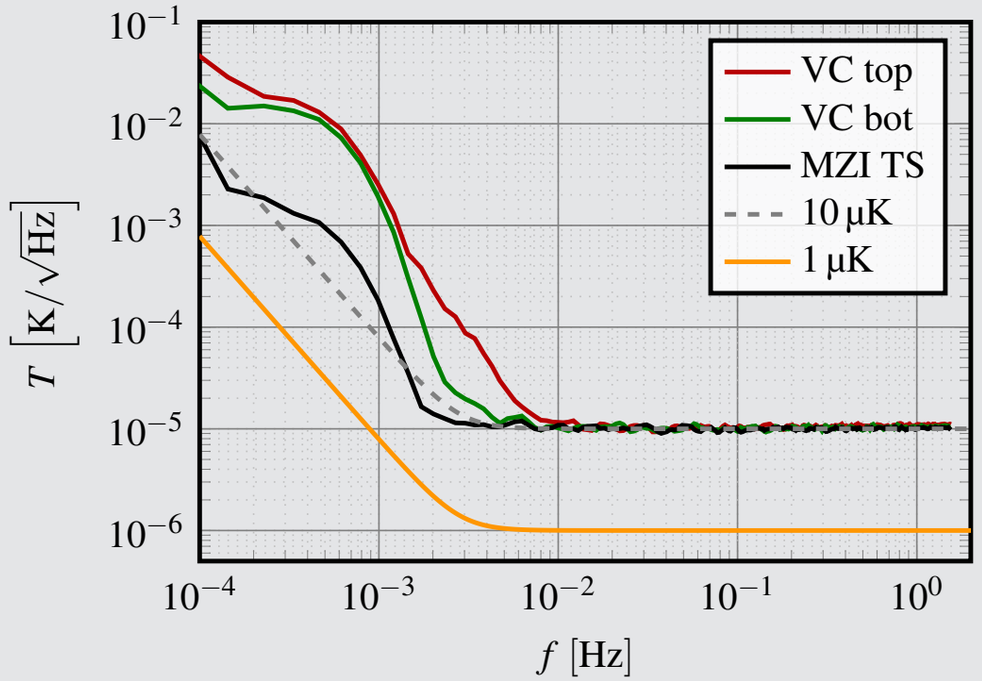
alignment of critical component (recombining beamsplitter) with *pointing fingers*
contrast before and after cure: > 90%

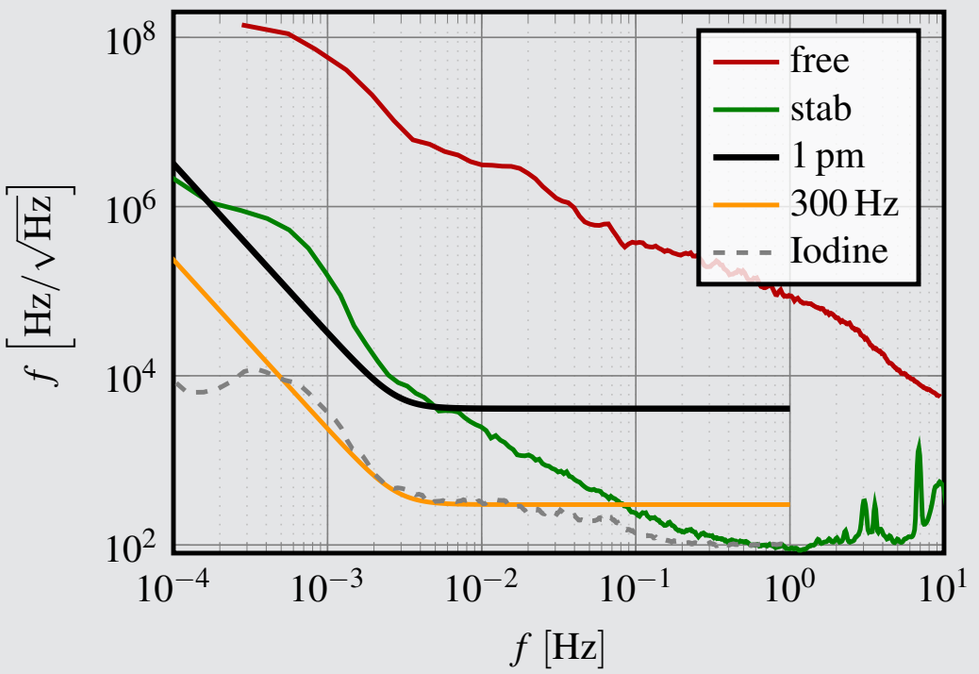
MZI as Frequency Reference

Frequency stability measurement:

- potentially limited by stray light from photodiodes/ polariser/lenses…
- reference Mach Zehnder shows 1pm stability at 5mHz
- temperature oscillation frequency: ca. 1h







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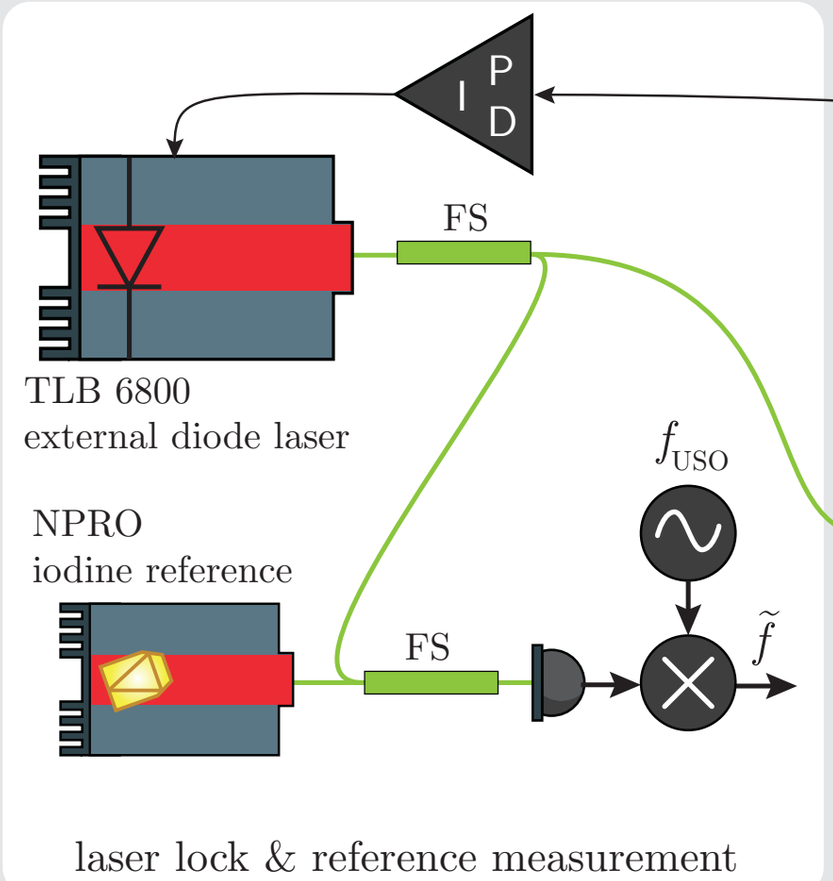
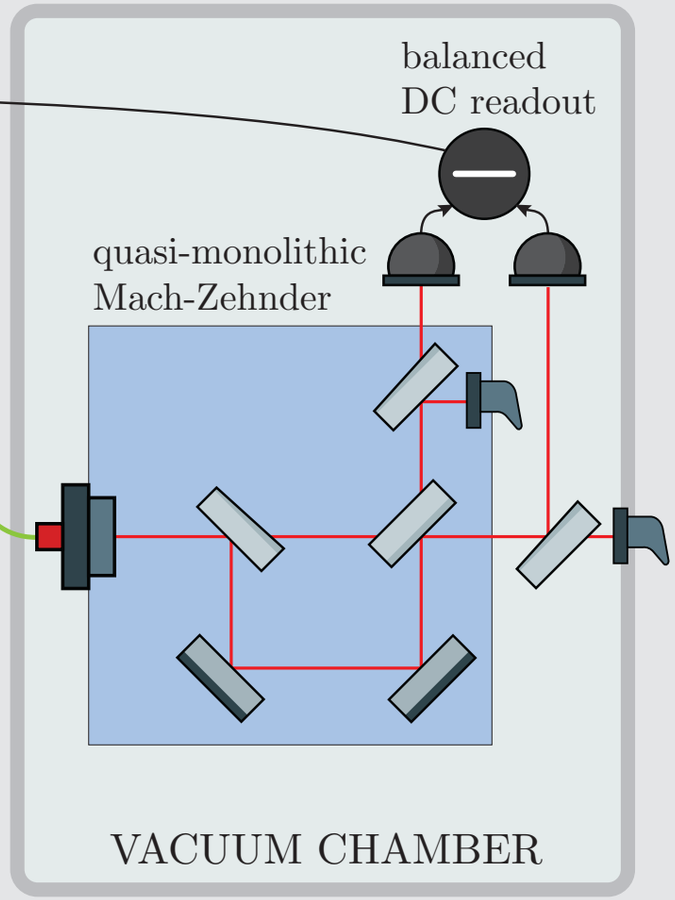
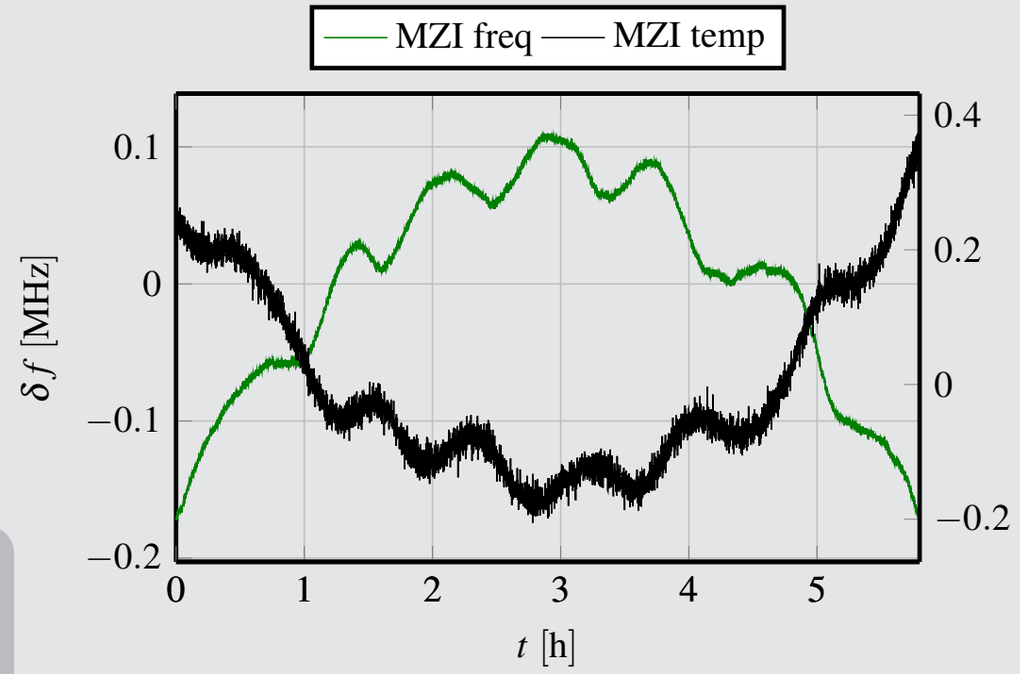
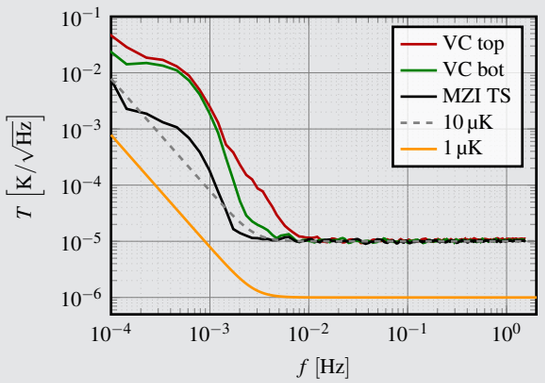
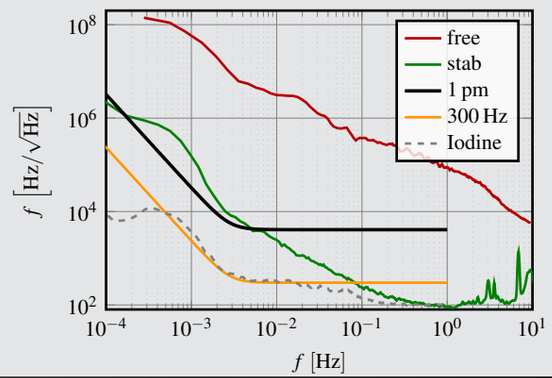






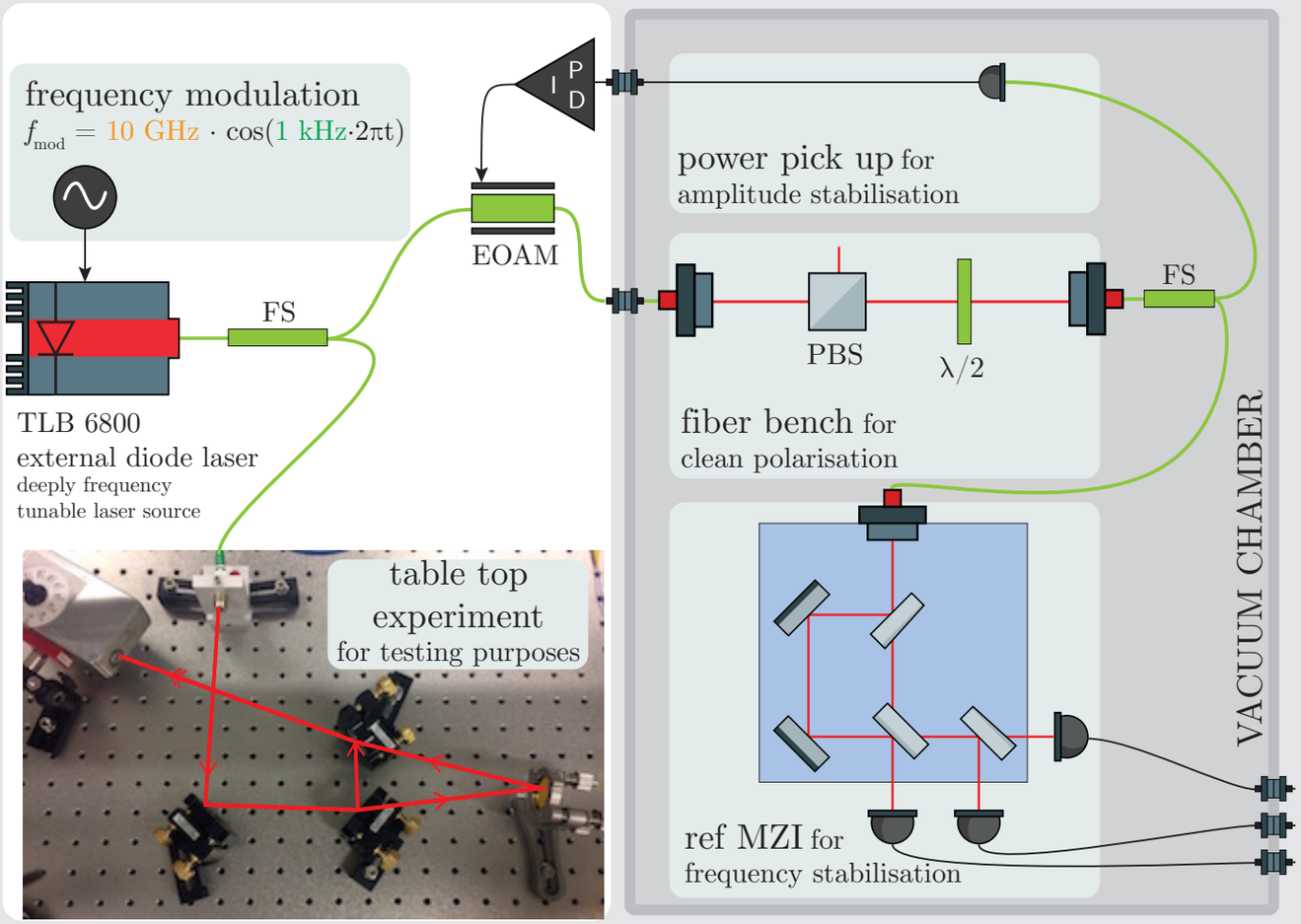


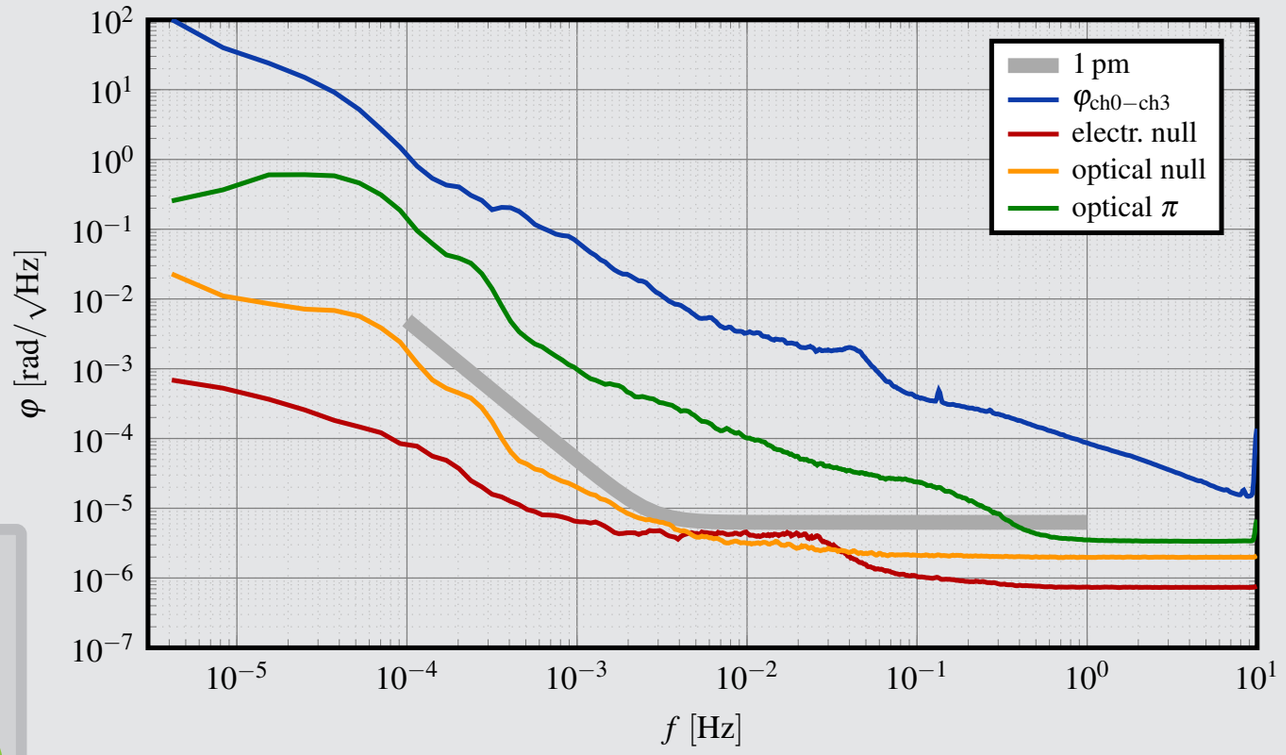


Phys. Rev. App. **7** (2017), Nr. 2, 24027.
DOI: https://doi.org/10.1103/PhysRevApplied.7.024027

Current Performance Status

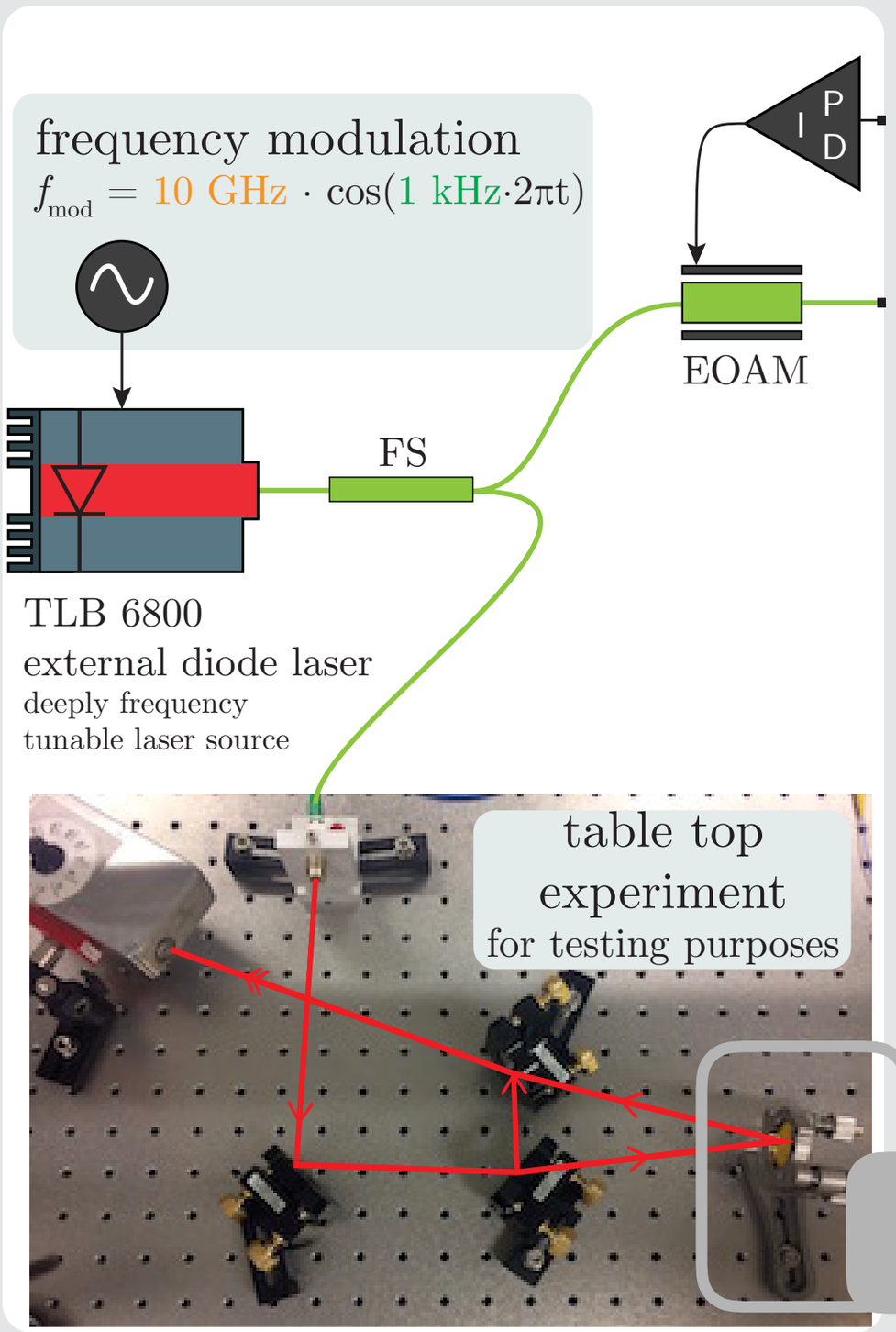
- stable MZI in vacuum chamber with thermal shielding
- amplitude stabilizations via EOAM and diode current





- white noise floor: polarization & amplitude fluctuations
- stray light shoulder: ghost beam & polarization influence
- temperature oscillations
- other high frequency coupling

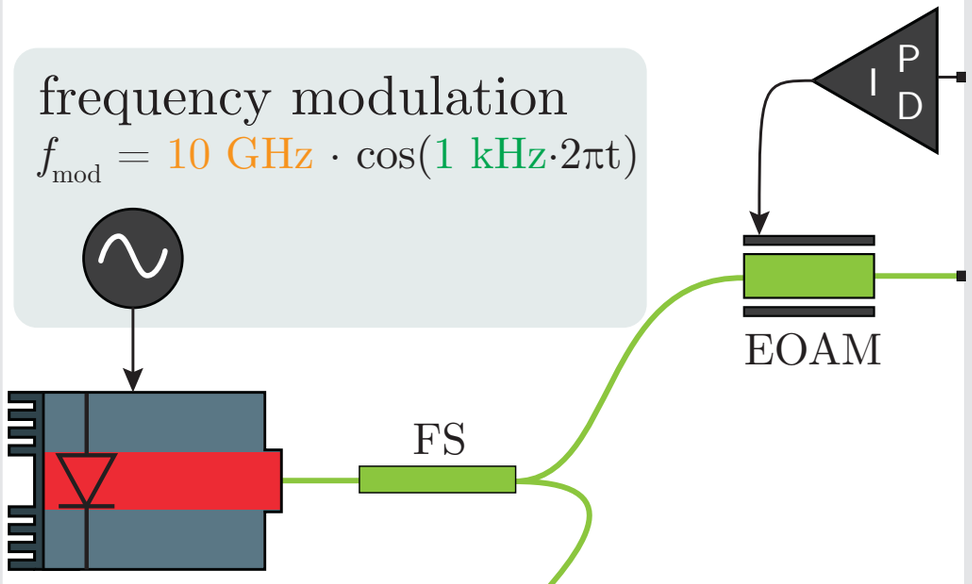
Towards optical test mass readout



Towards optical test mass readout

frequency modulation

$f_{\mathrm{mod}} = 10\ \mathrm{GHz} \cdot \cos(1\ \mathrm{kHz} \cdot 2\pi t)$



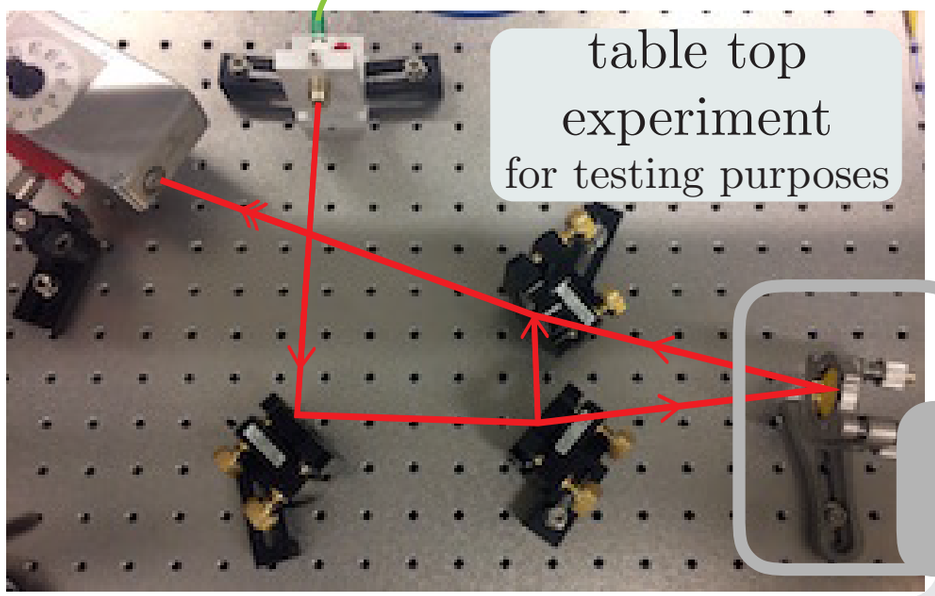
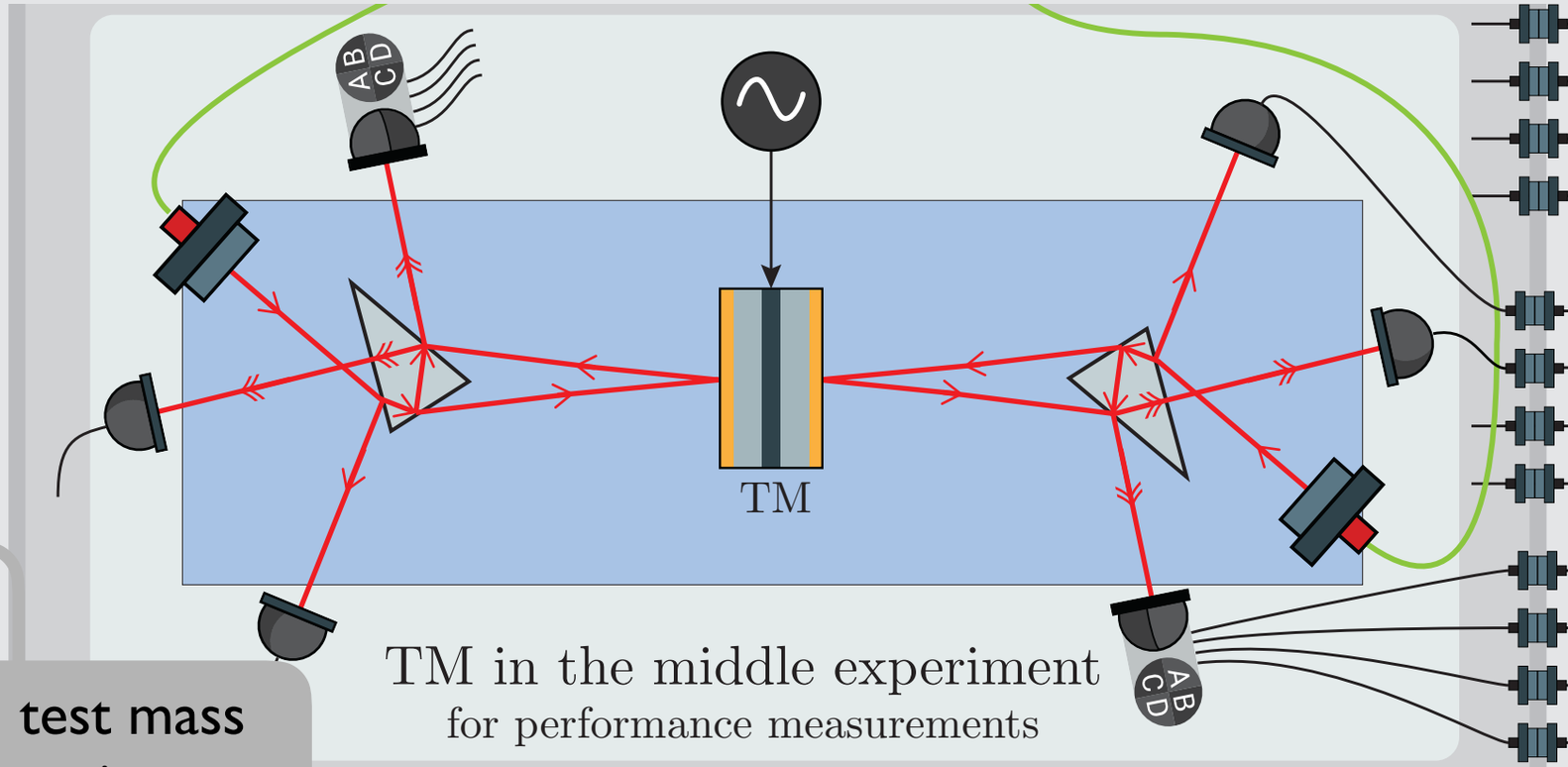


table top experiment
for testing purposes

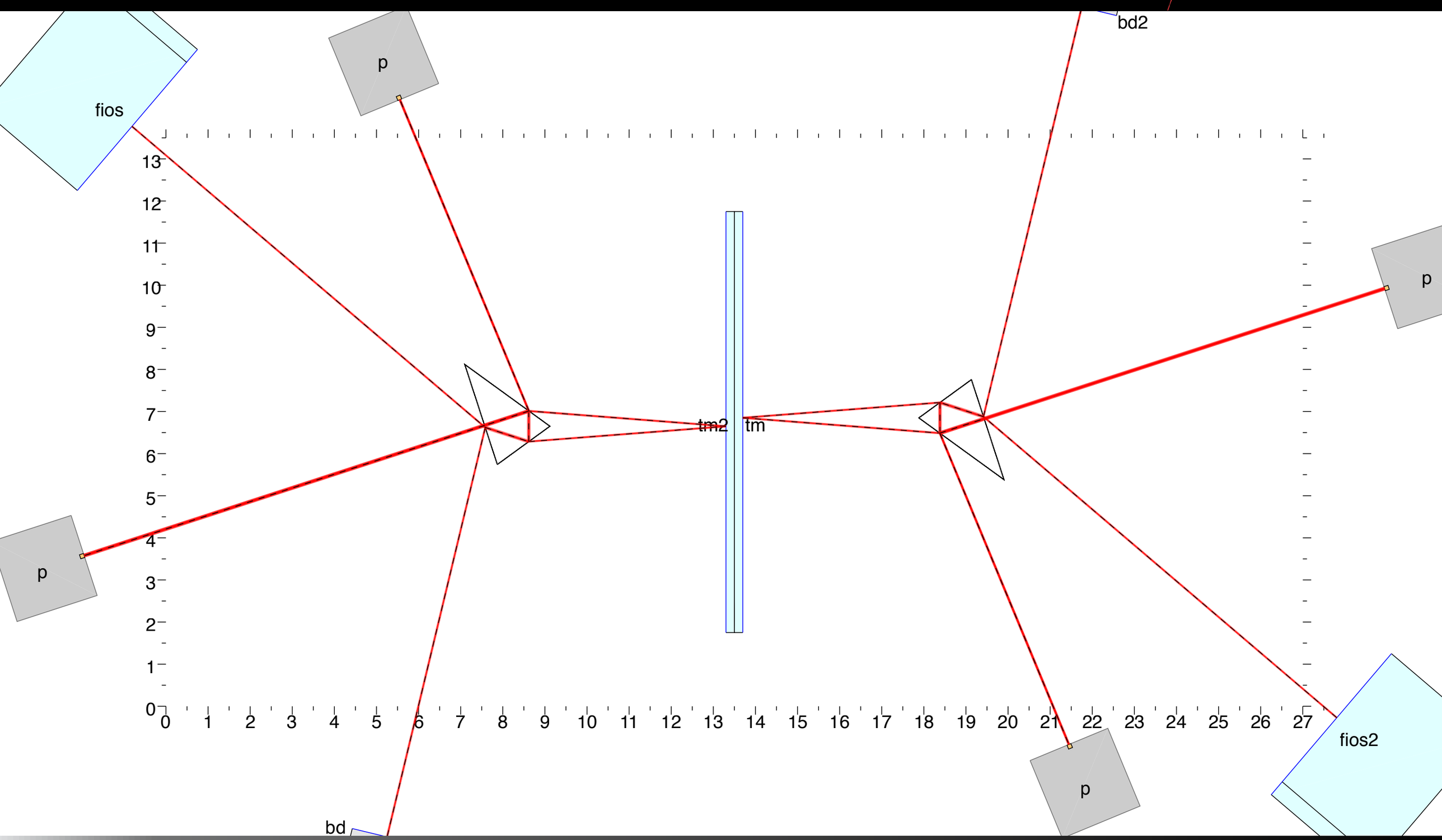
test mass mirror



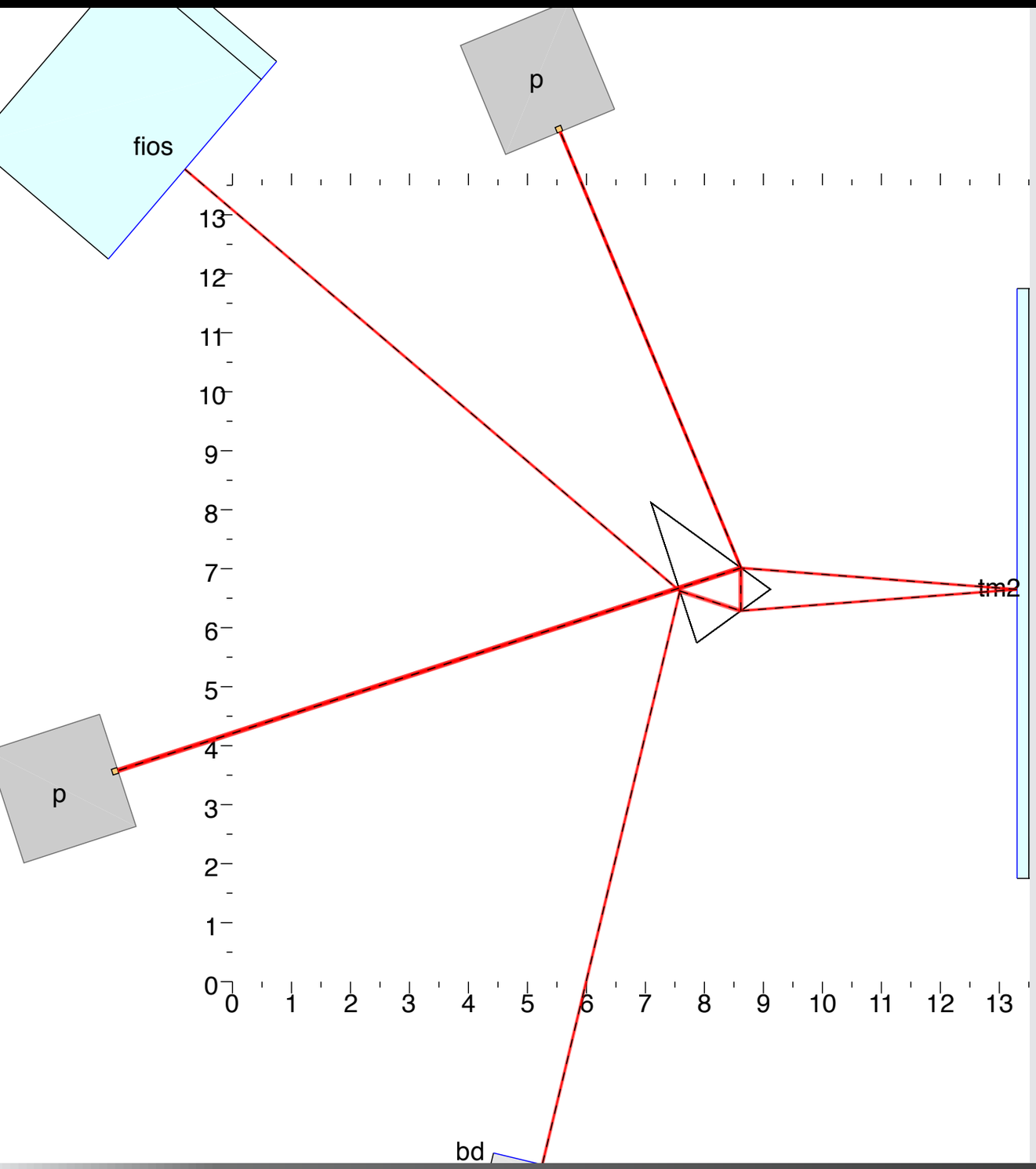
TM in the middle experiment
for performance measurements

VACUUM CHAMBER

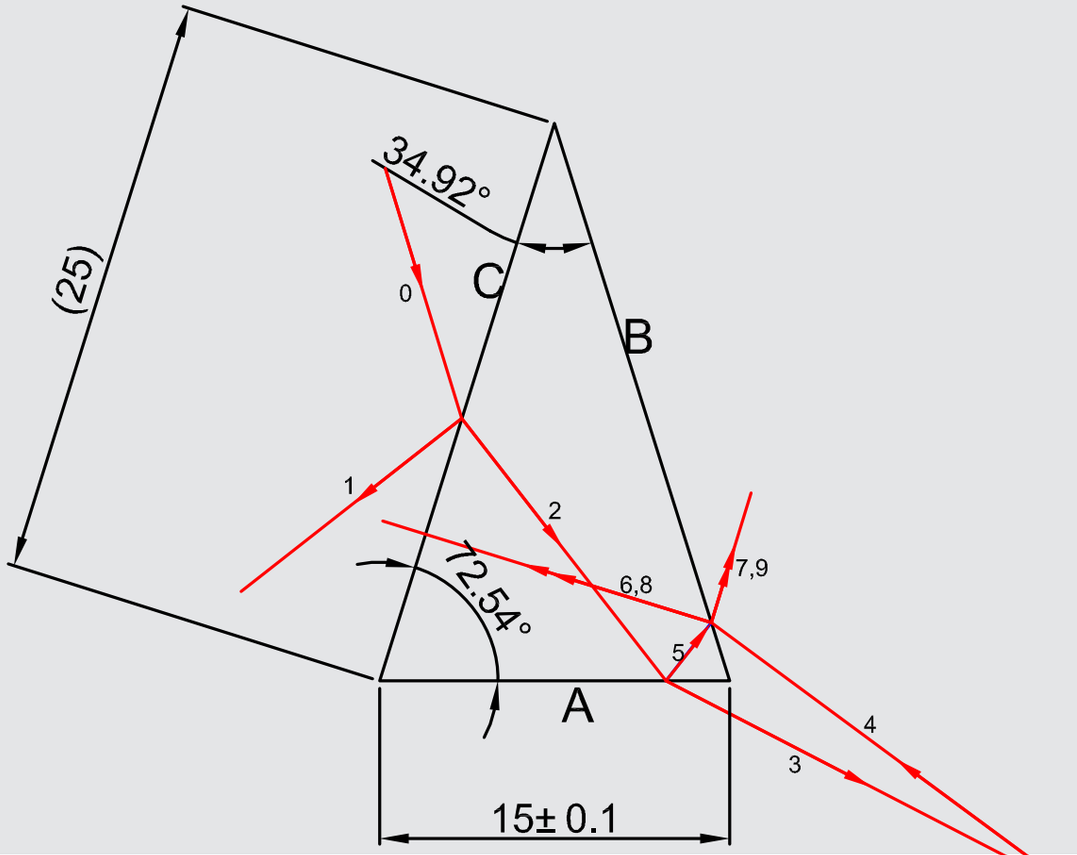
Towards optical test mass readout



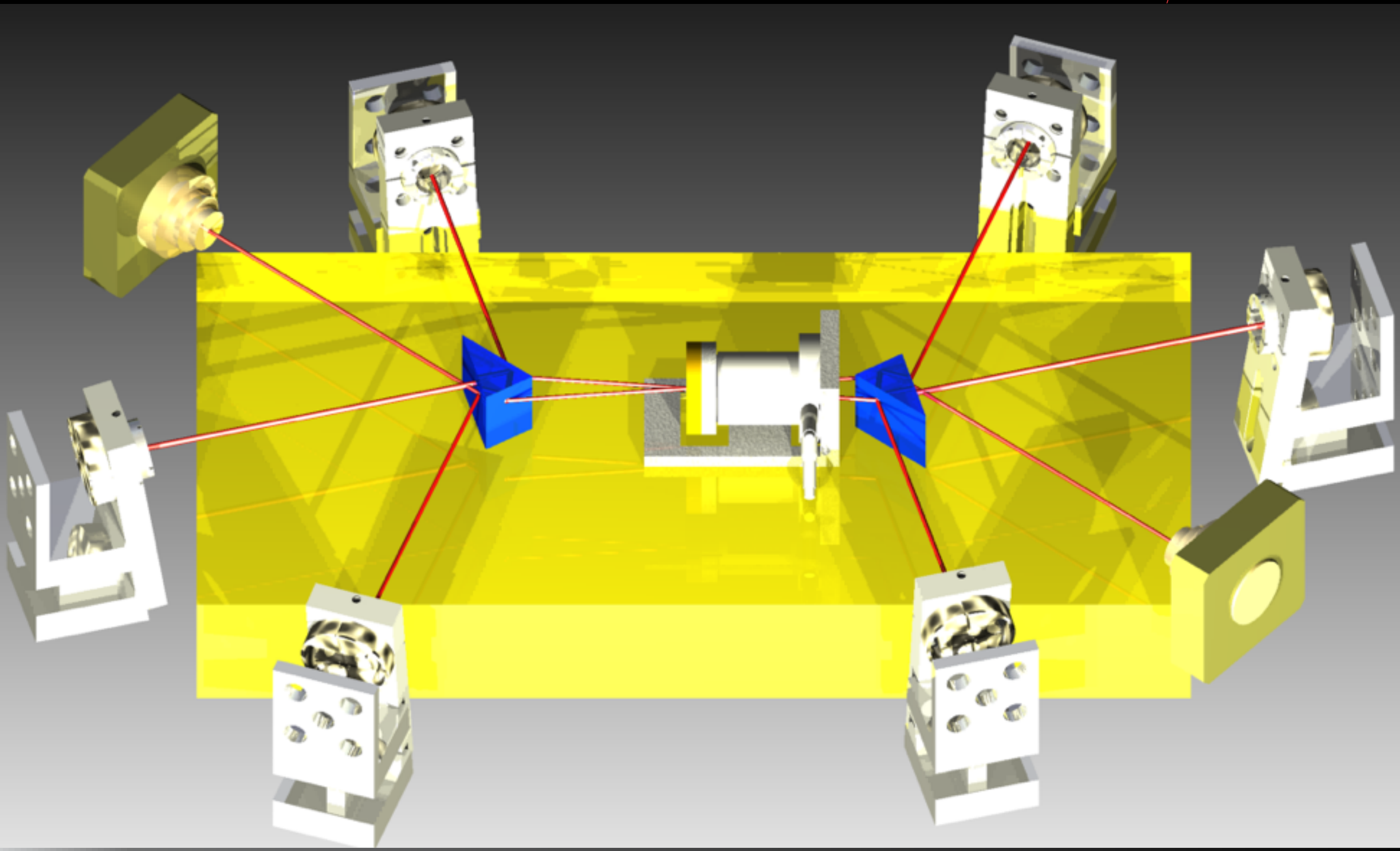
Towards optical test mass readout



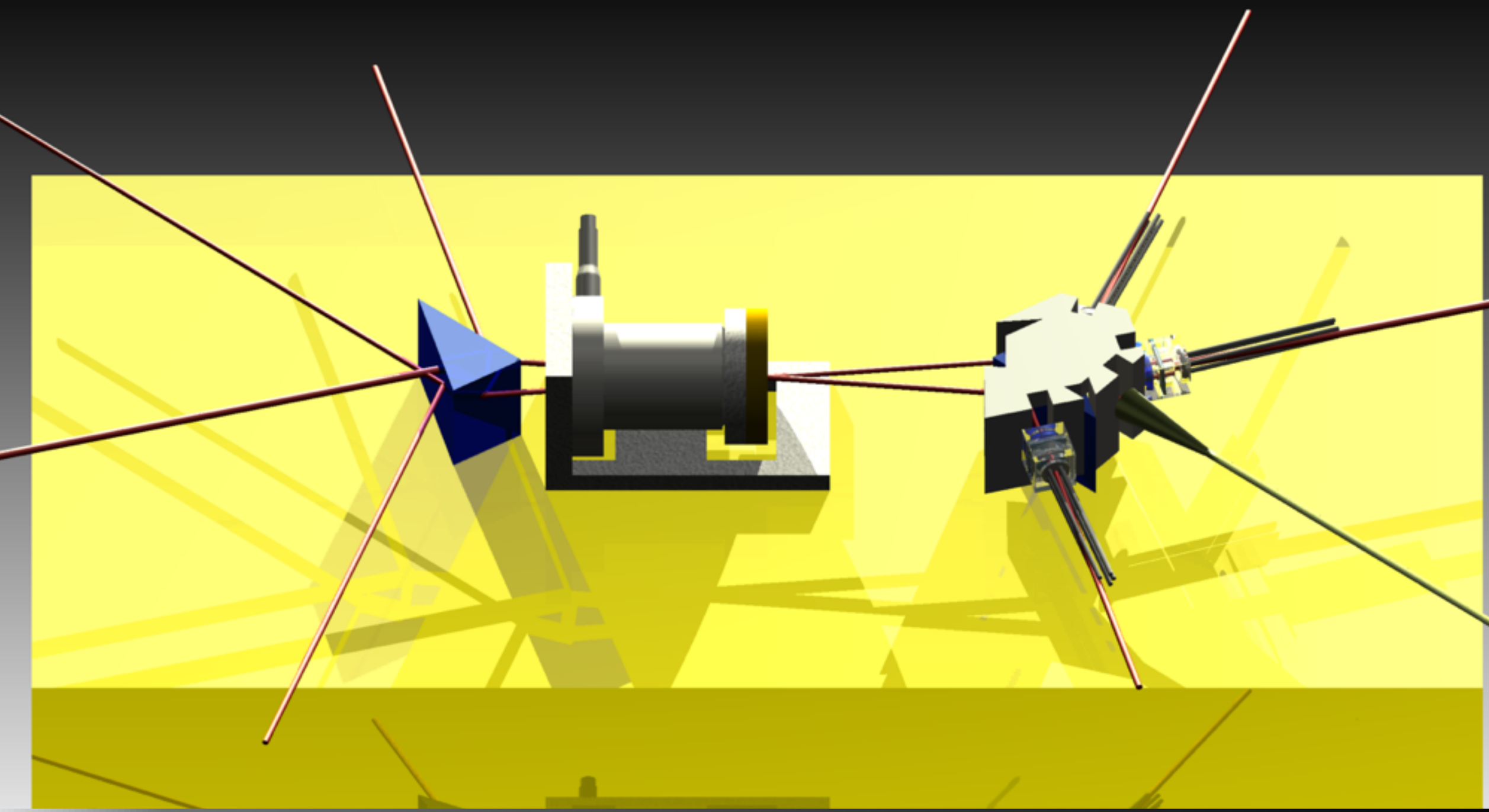
- Complete MZI Ifo within a single optical component, only 25x25x15 mm^3
- variable distance to TM in dependence on the Prism design
- no ghost beams due to reflections except for surface C under an angle



Towards optical test mass readout



First concept for Optical Heads



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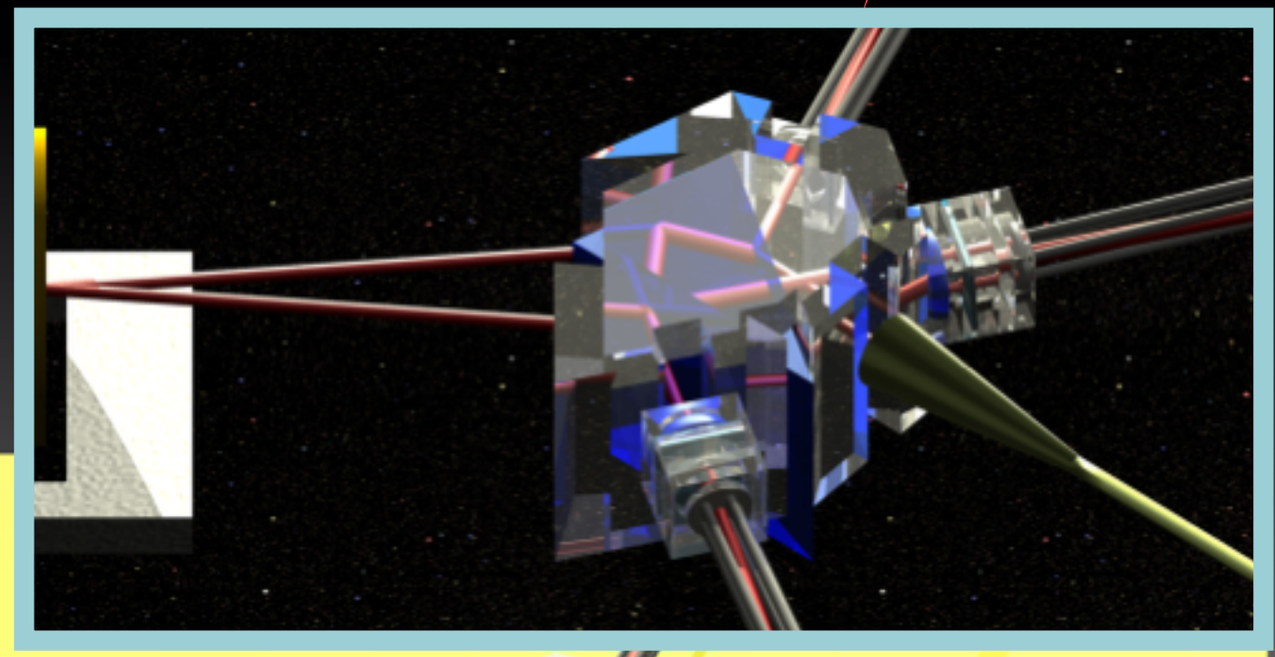
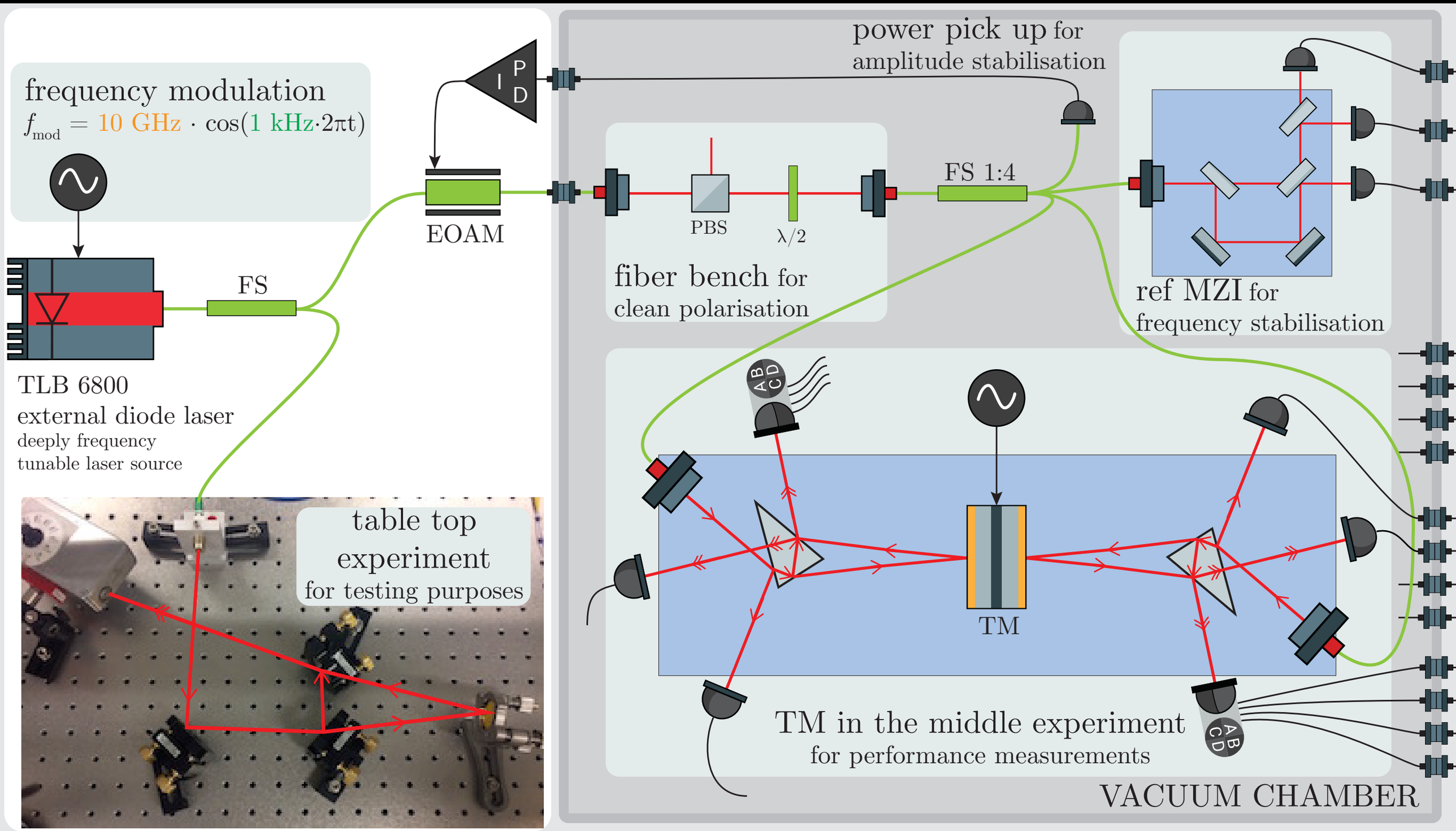
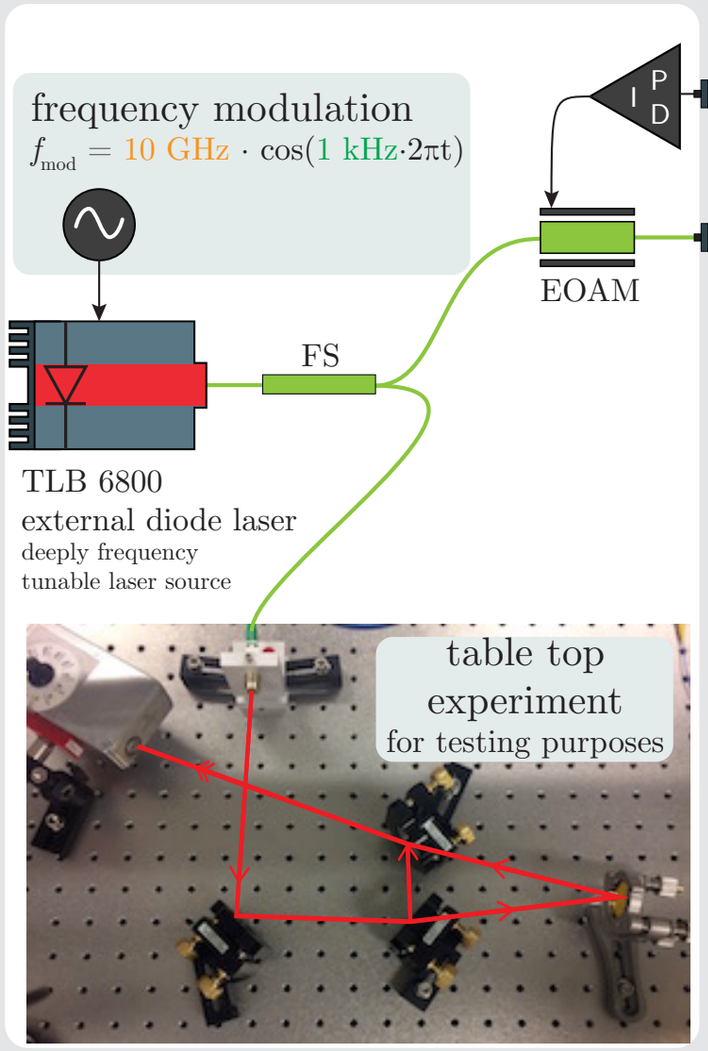


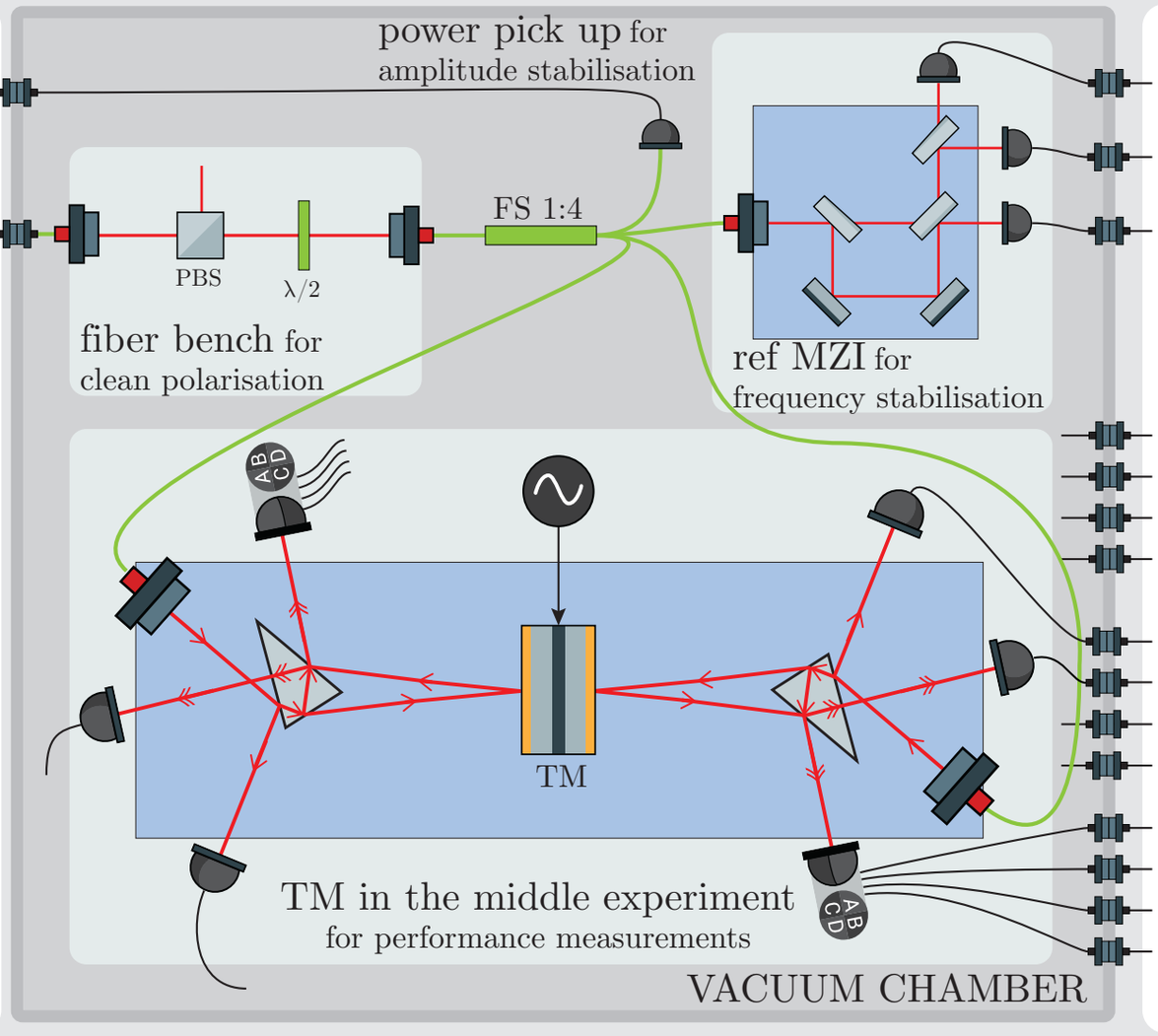
Outlook & Next steps

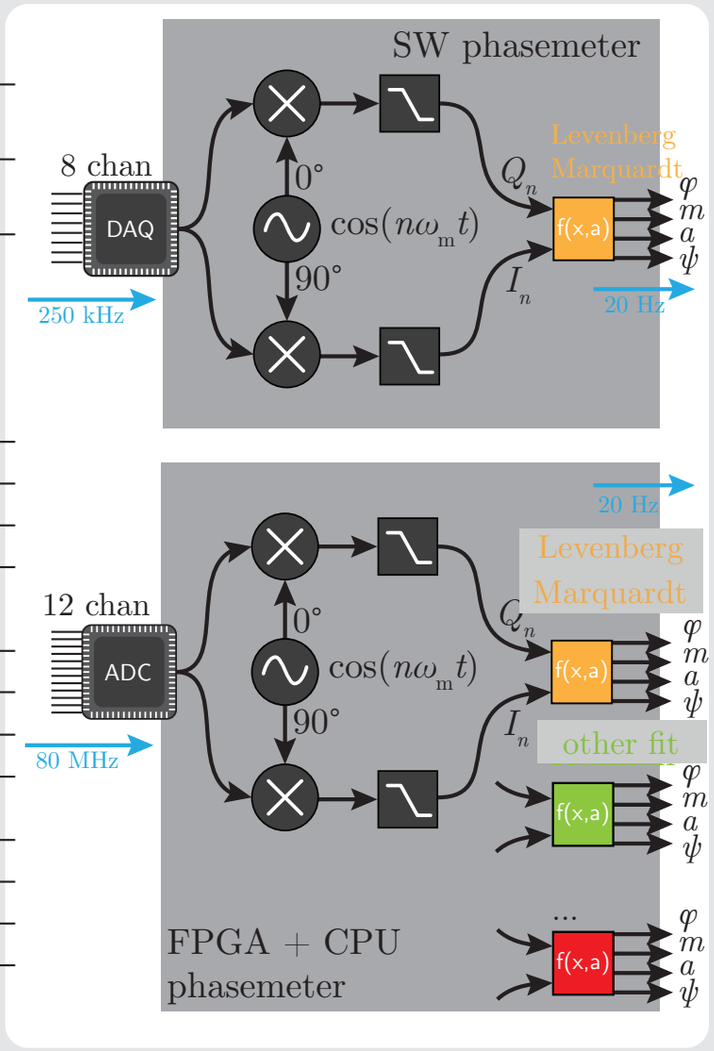


Outlook & Next steps

- Prisms are ordered
- Glueing of the TM in the middle exp.
- Freq. reference or stabilisation investigation
- Additional noise hunting of stray light (ghost beam, polarization)
- Test of different fit algorithm implemented on the Phasemeter

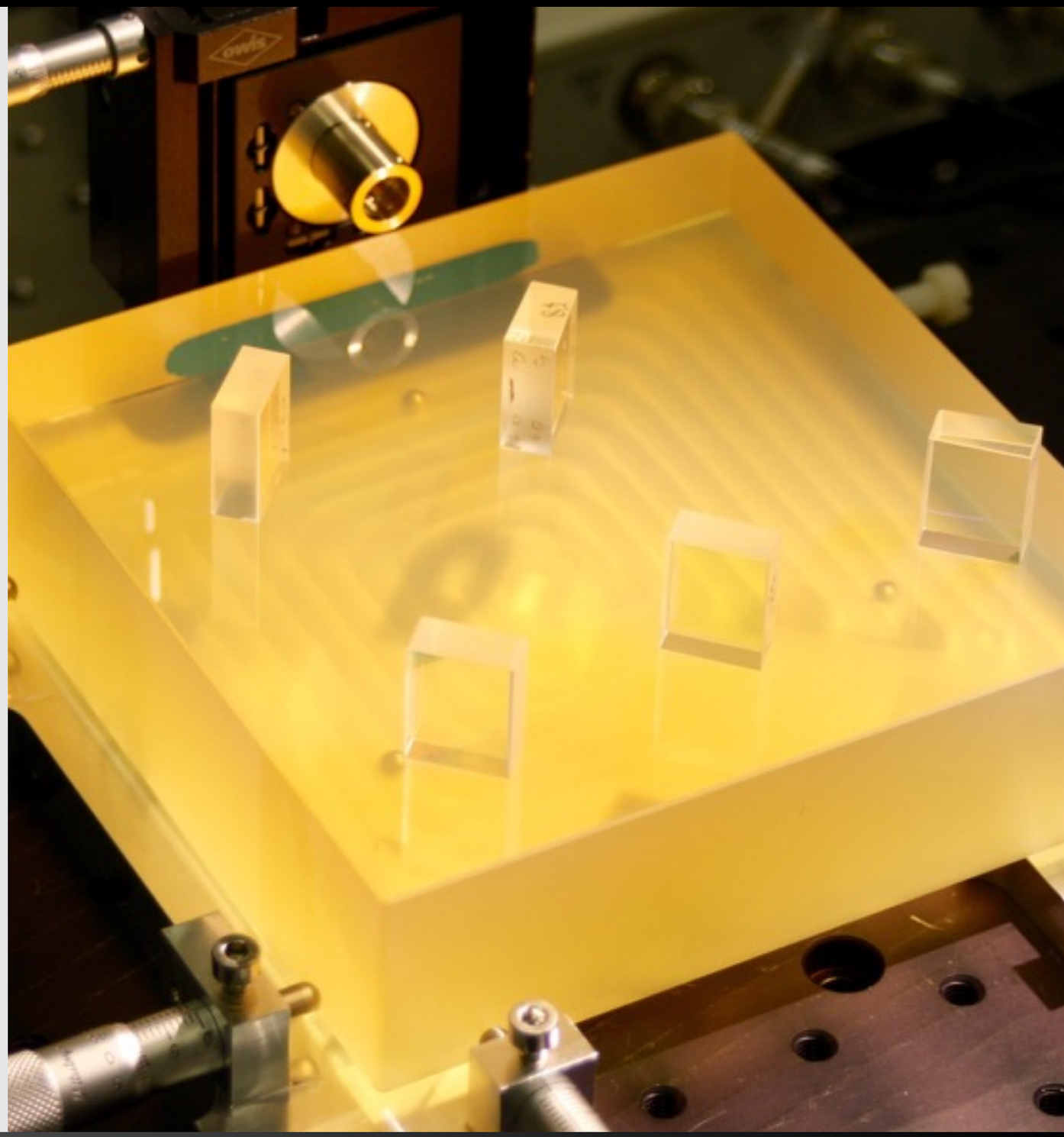






Conclusion

- **DFM Performance:**
  - approaching the 1pm displacement sensitivity
- **Suitable Frequency Reference for LISA:**
  - investigation via balanced DC readout & the unequal arm length MZI
- **Miniaturized optical heads:**
  - Multi-DoF test mass readout via Prisms and DFM seems very promising



Thank you for your attention

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  - approaching the 1pm displacement sensitivity
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