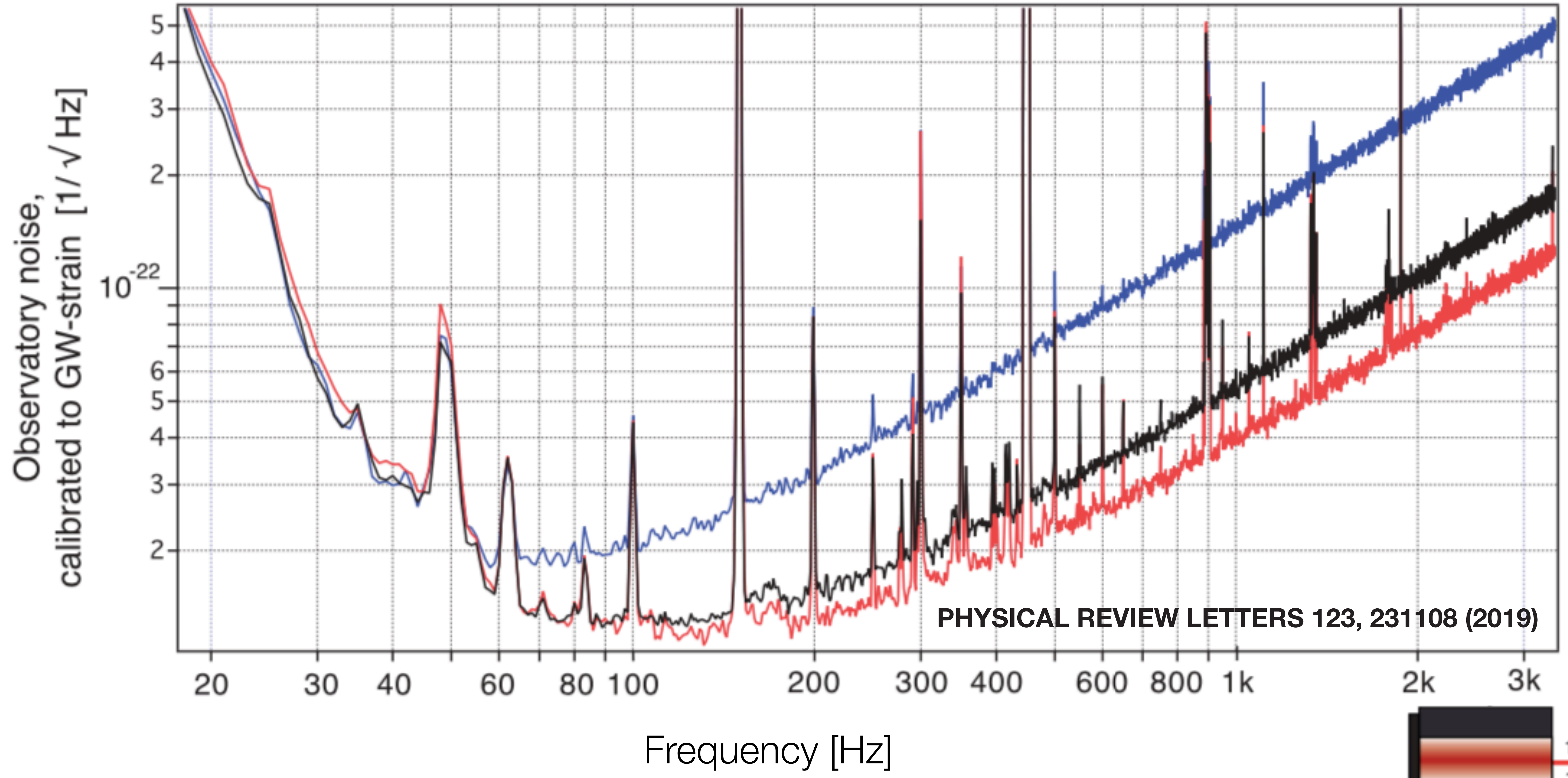
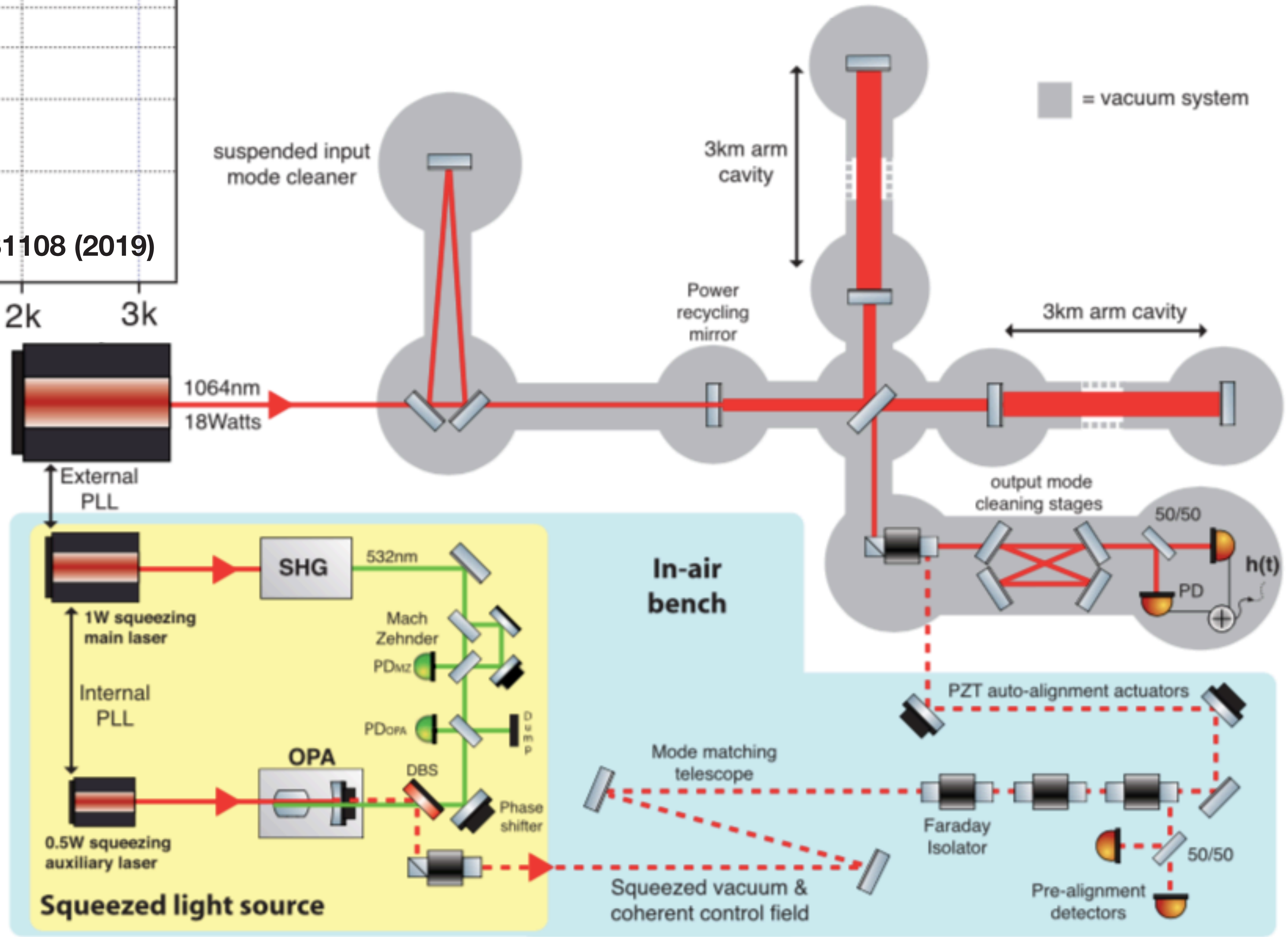
Frequency dependent squeezing for AdVirgo+

E. Capocasa on behalf of Virgo QNR team

ILANCE workshop 15th April 2022

AdVirgo Frequency independent squeezing in O3

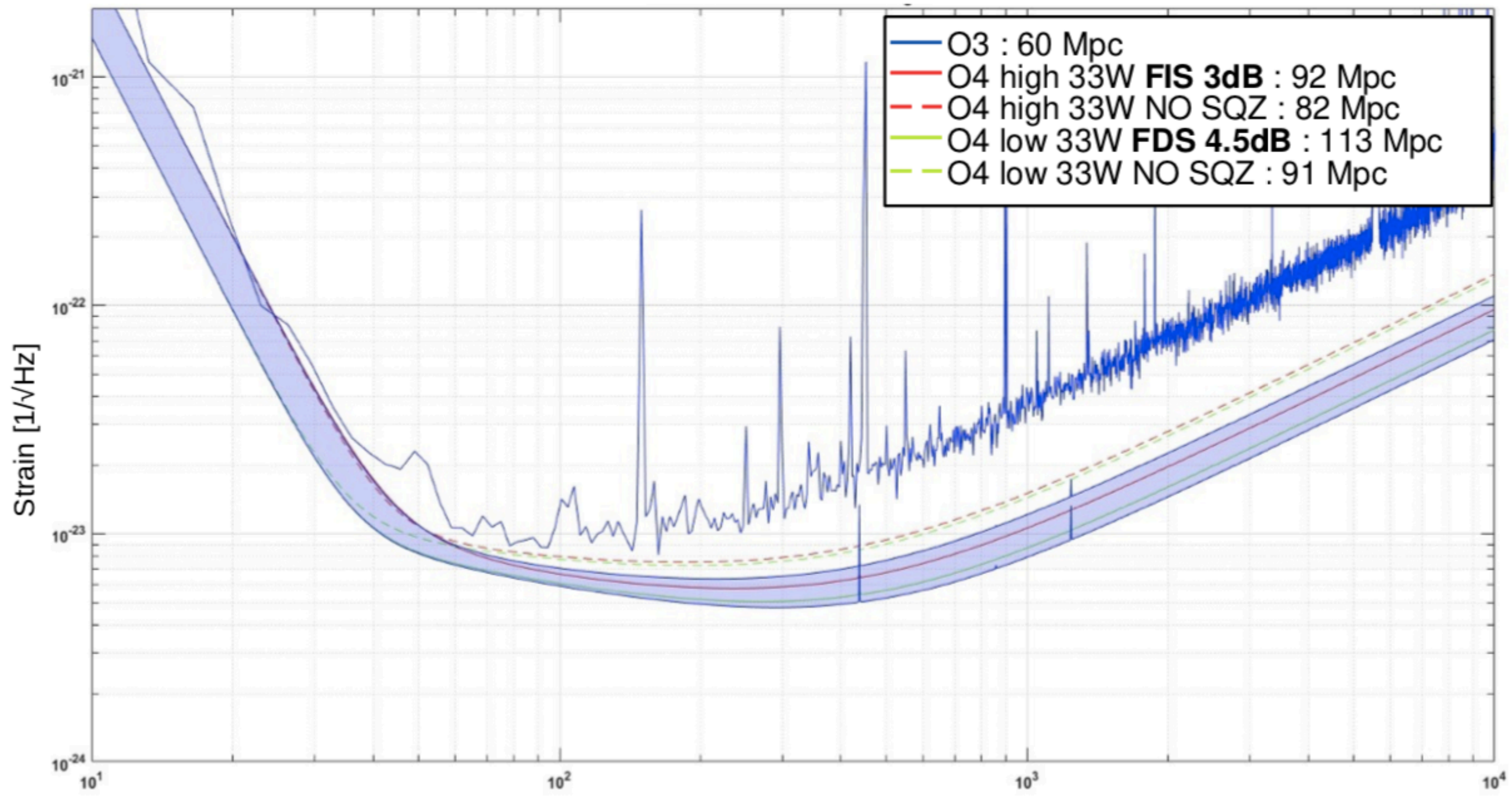


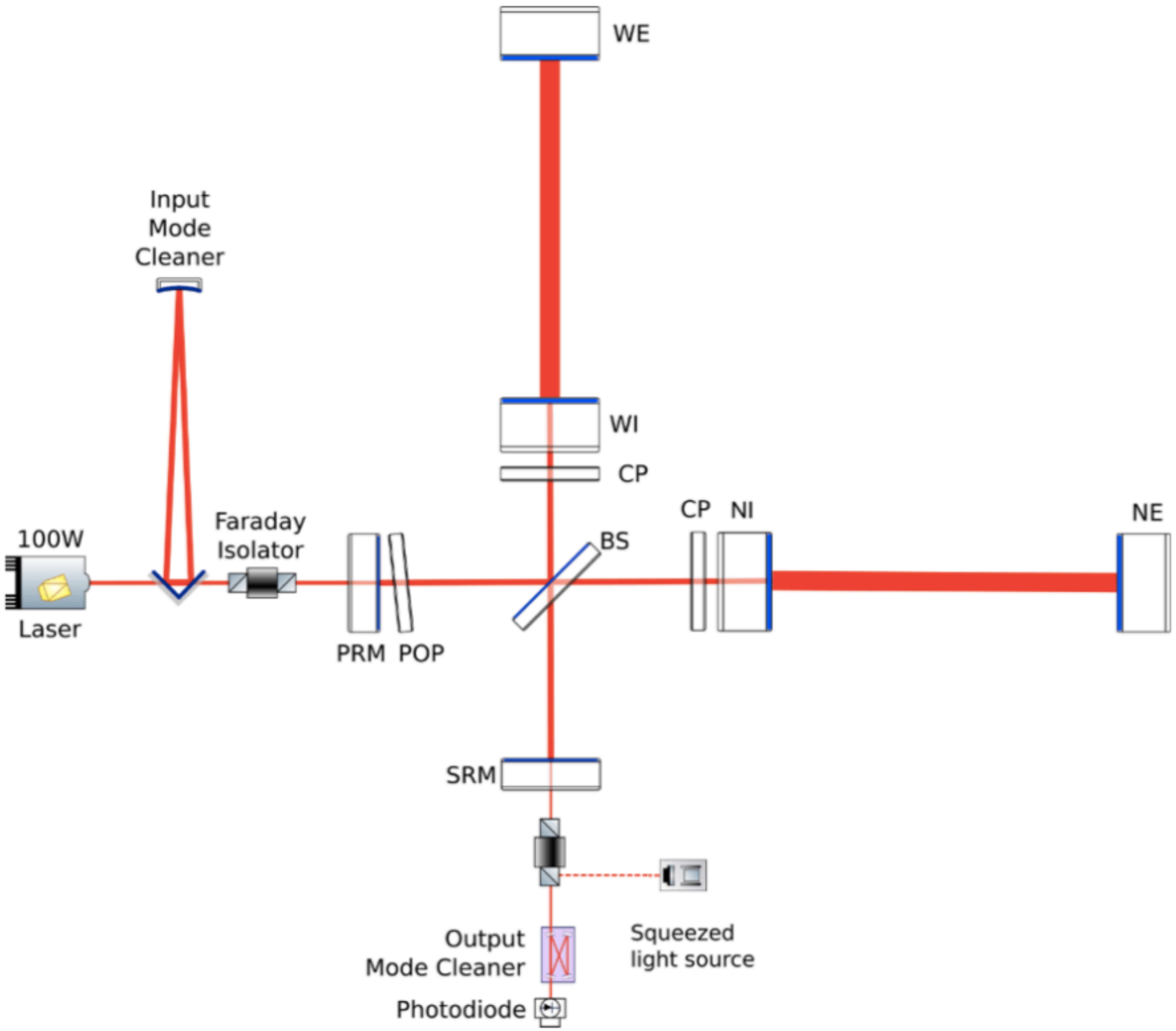


- ~ 3dB quantum noise reduction
- Evidence of increased radiation pressure (Phys. Rev. Lett. **125**, 131101)

AdVirgo+ frequency dependent squeezing for O4

- 285 m filter cavity for squeezing ellipse rotation
- Goal: broadband quantum noise reduction





AdVirgo+ frequency dependent squeezing for O4

- 285 m filter cavity for squeezing ellipse rotation
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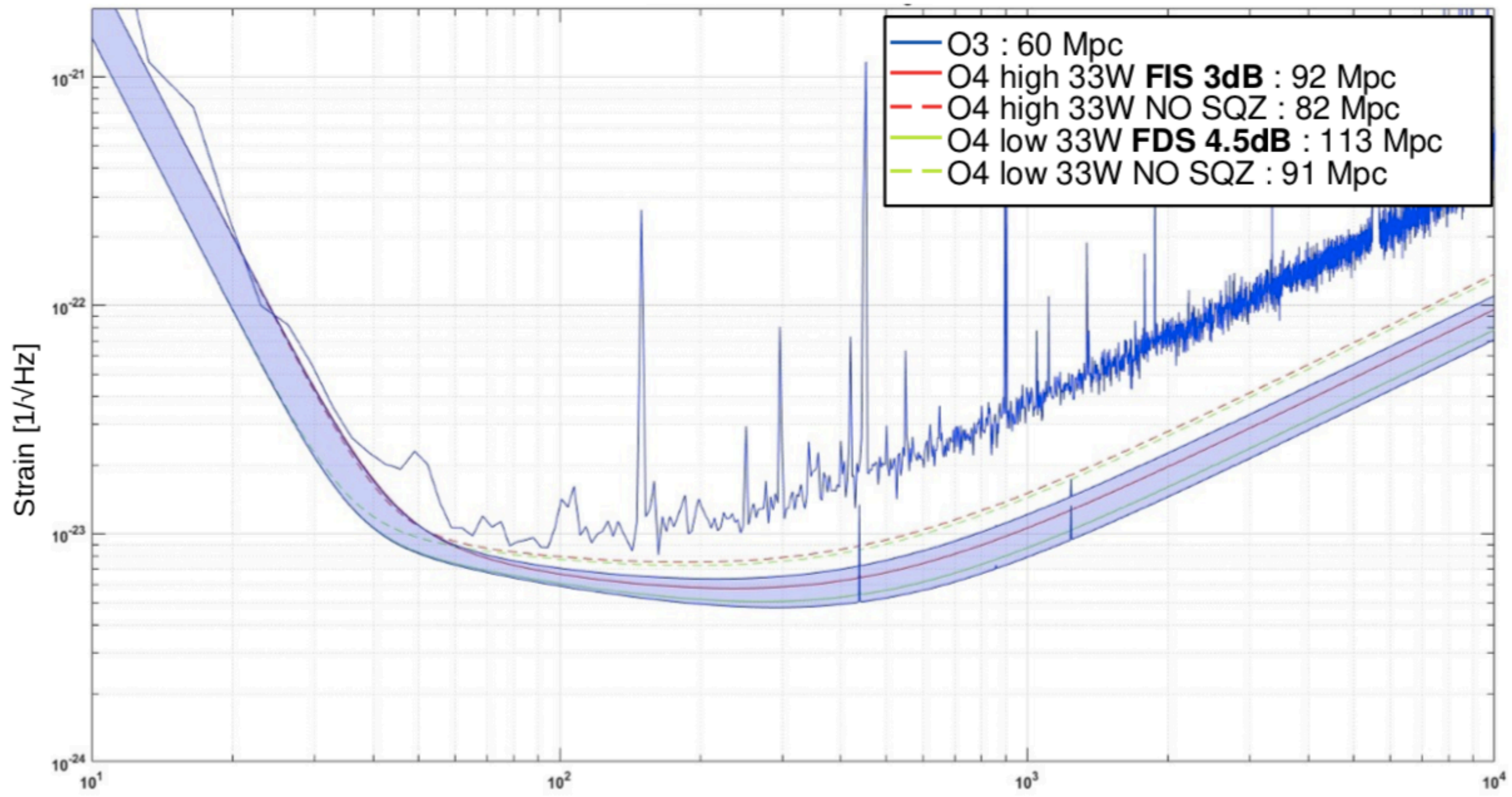
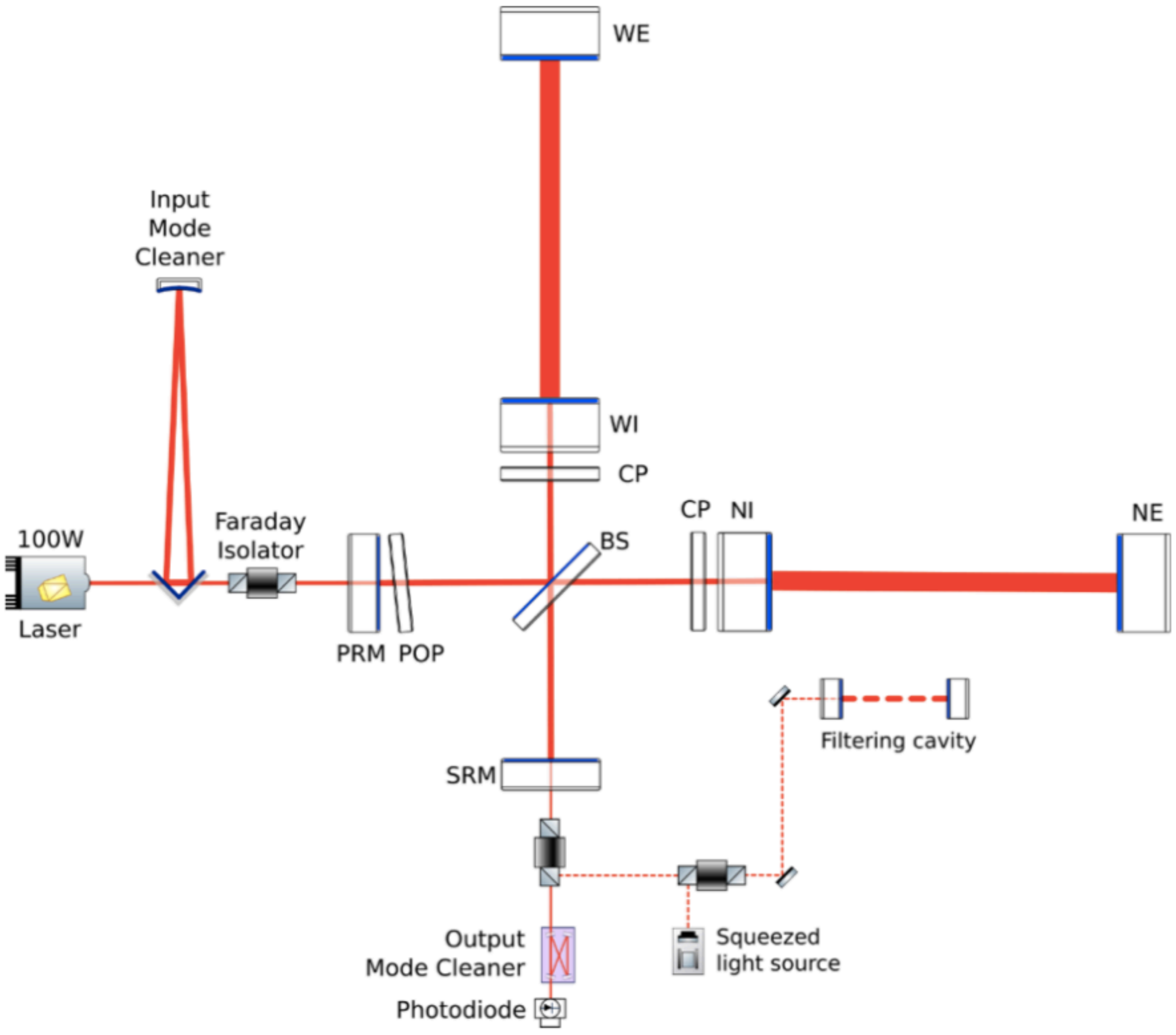
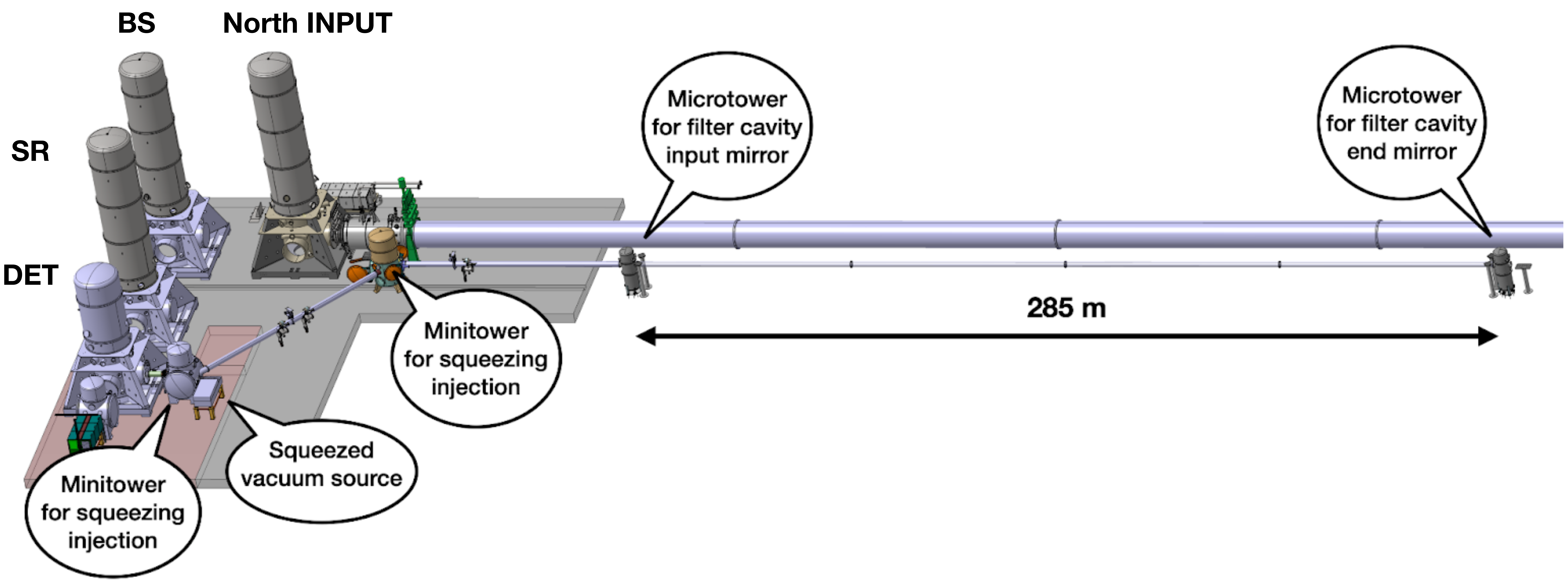
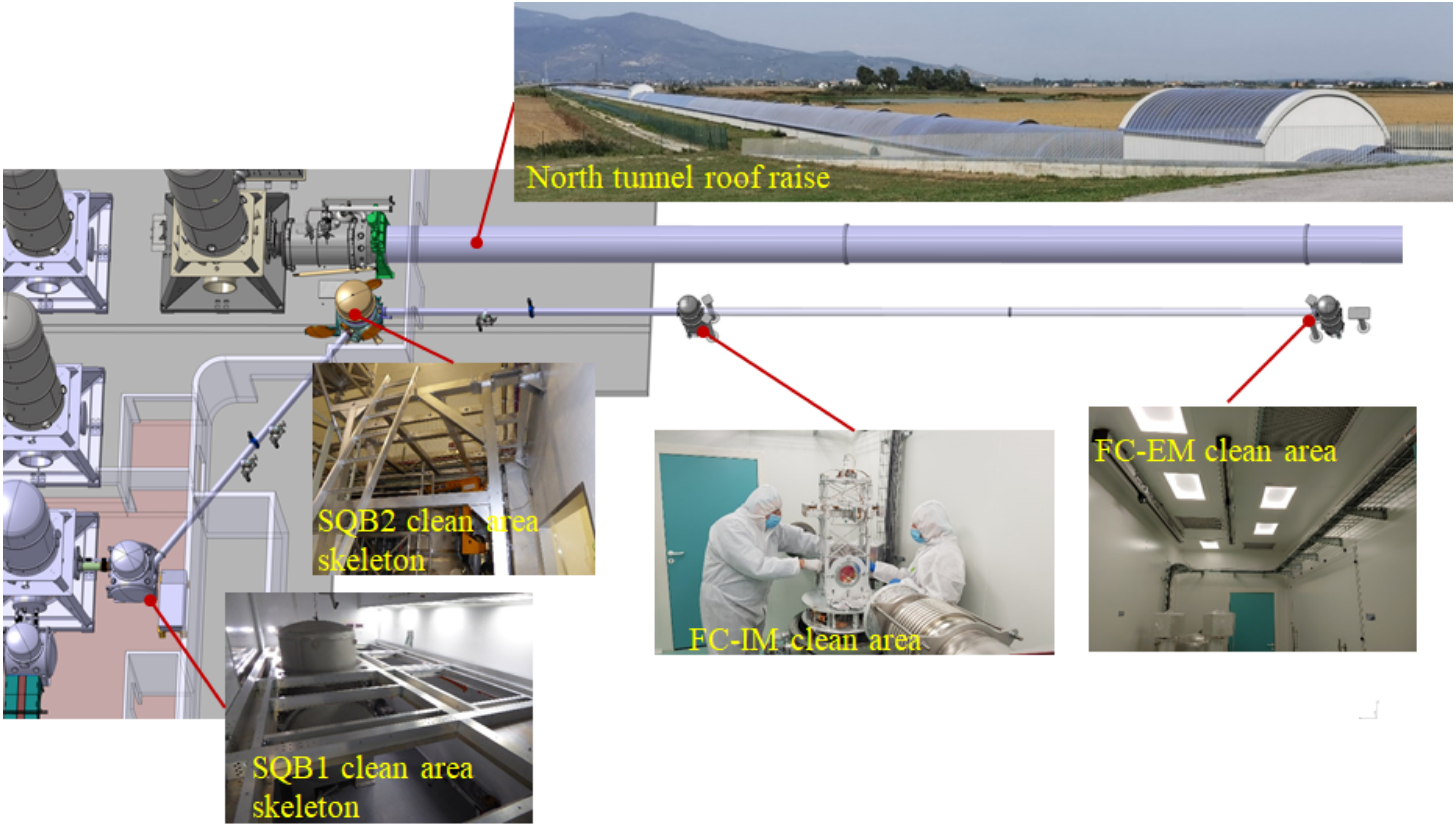




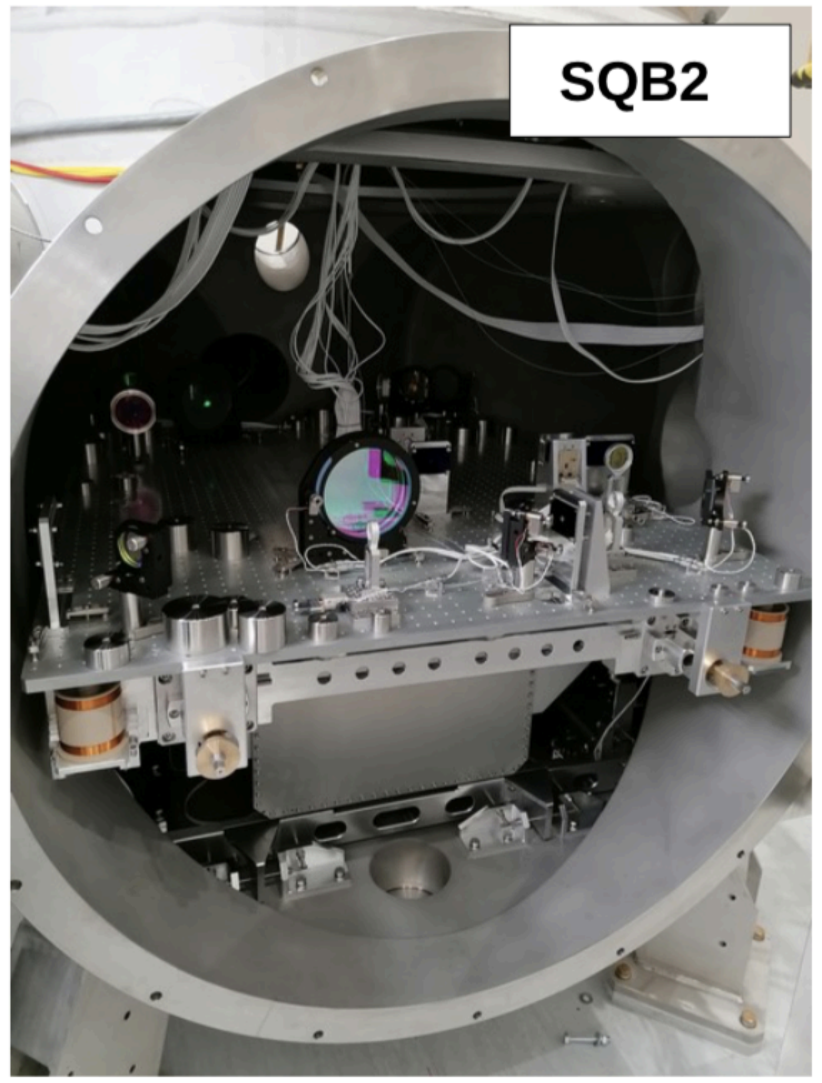
Quantum noise reduction (QNR) system overview

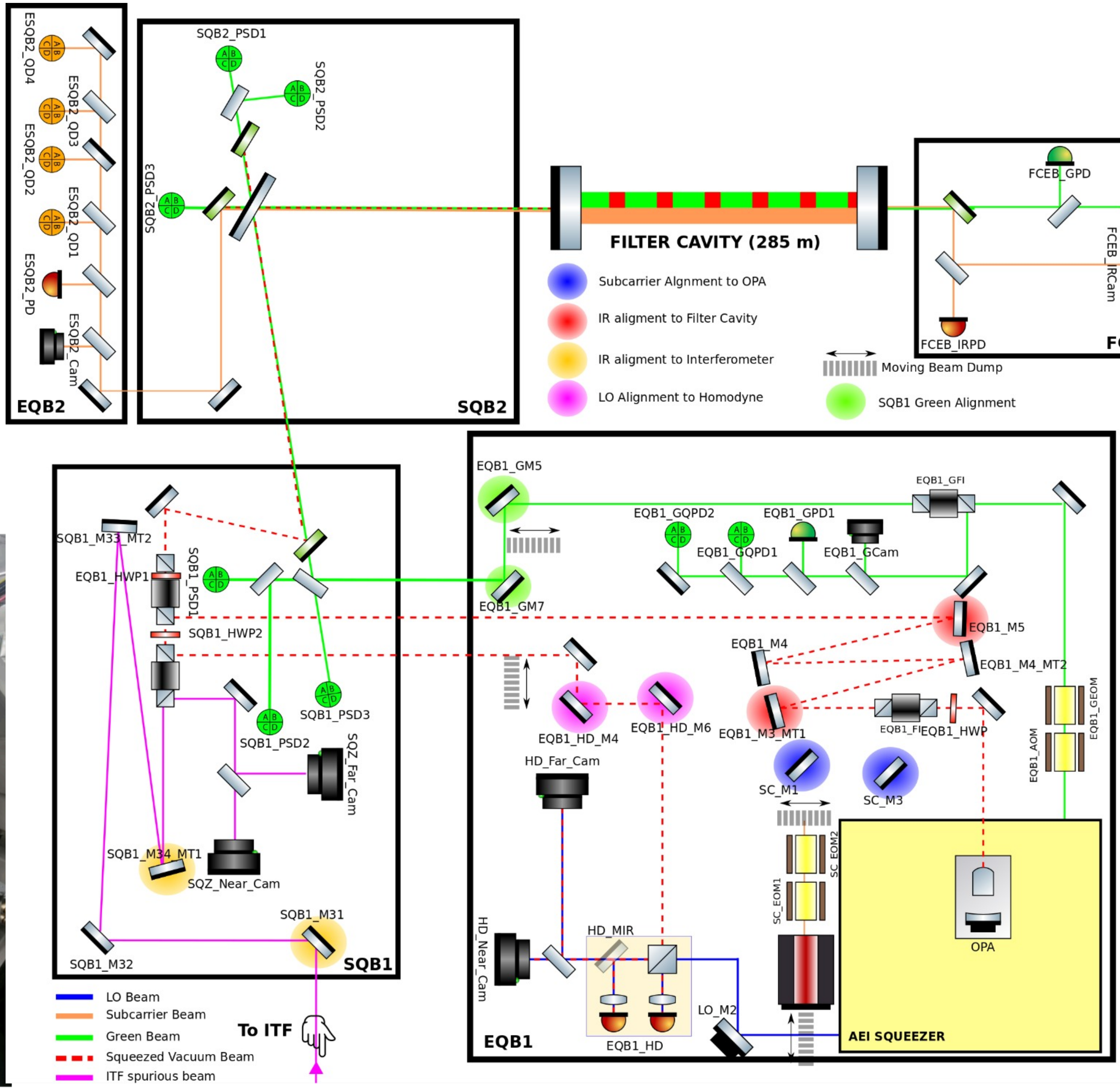


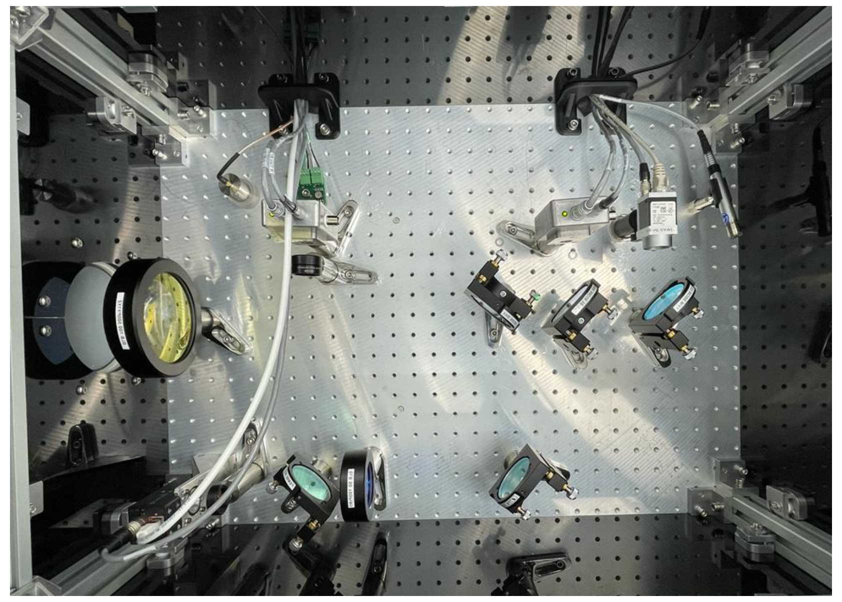
Infrastructural work completed in December 2020

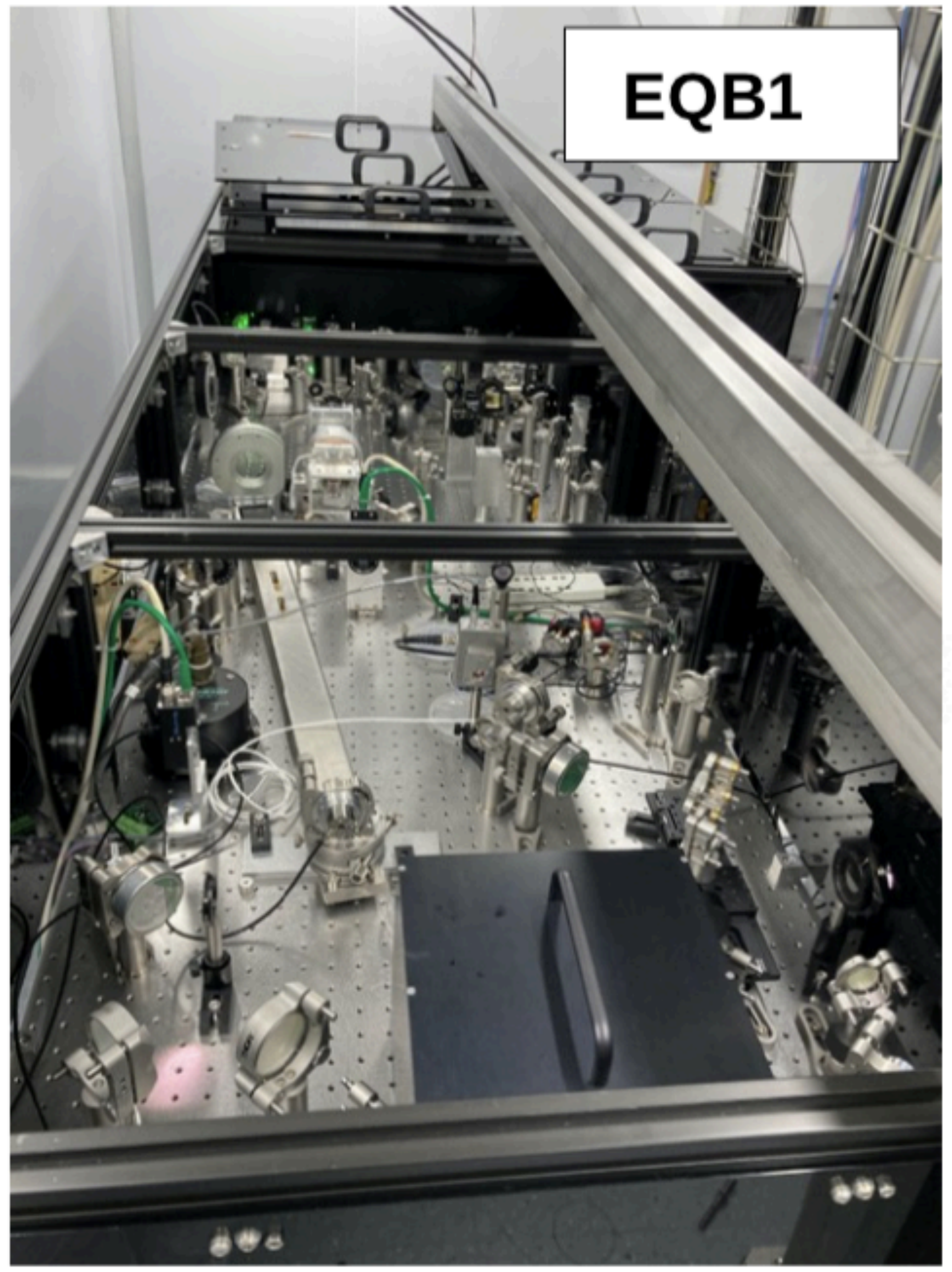


Quantum noise reduction (QNR) system overview



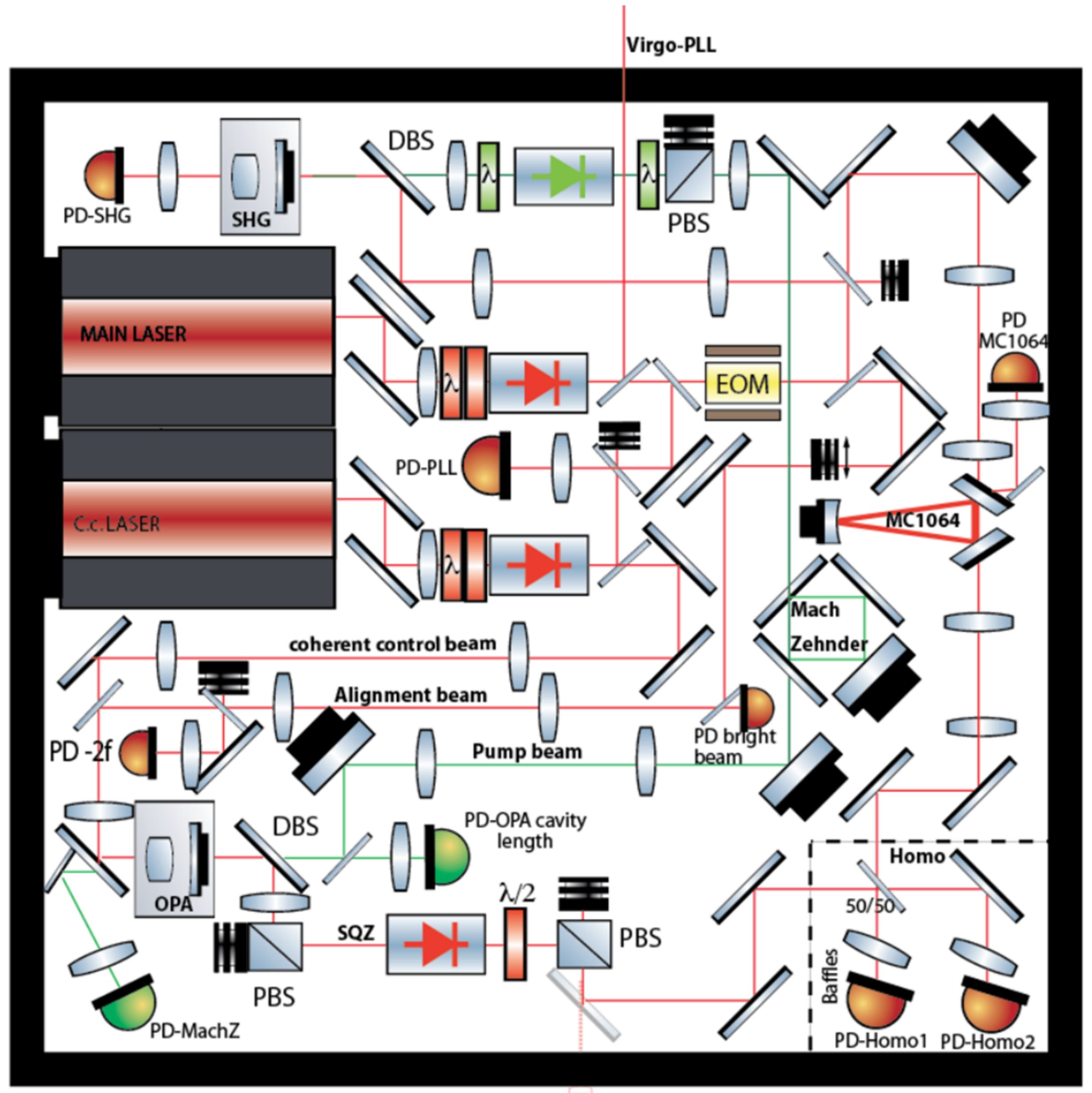


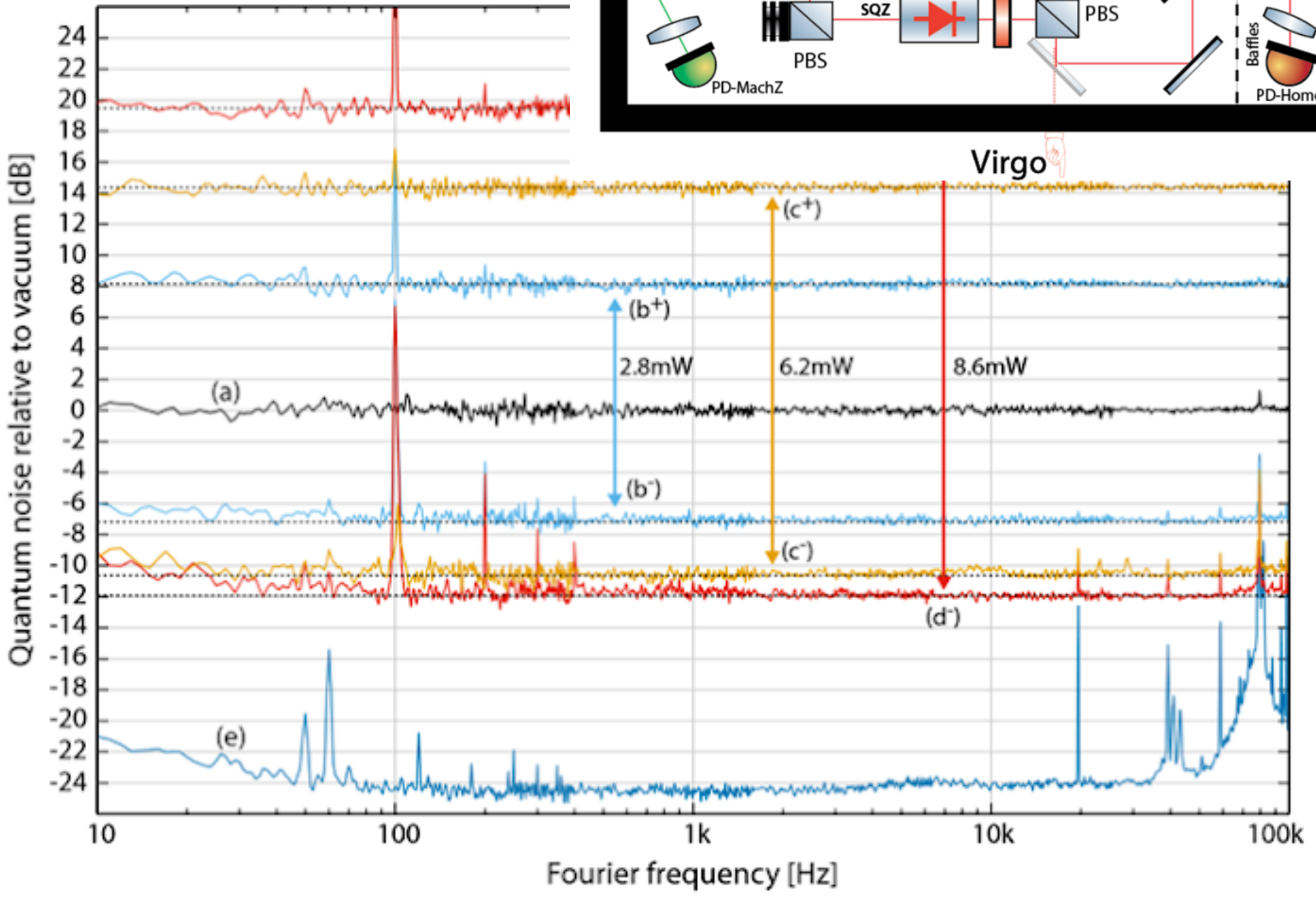




Squeezed vacuum source

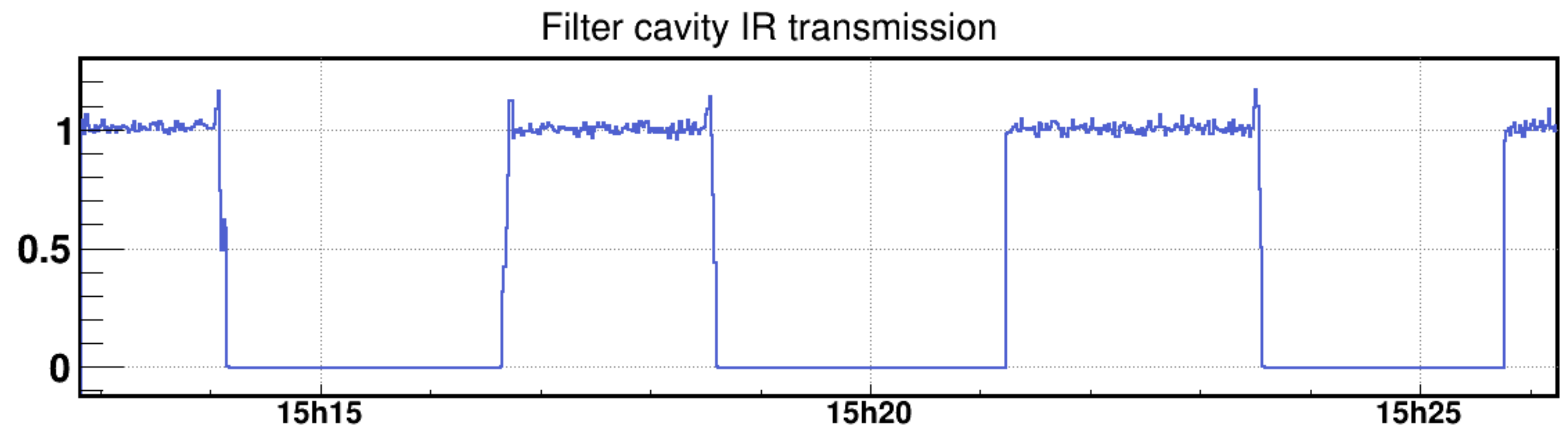
- Source developed by AEI installed on site in January 2018 (for O3 run)
- Up to 14 dB of squeezing produced in the audio bandwidth
- Very low phase noise: 3 mrad
- Size: 1m^2, duty cycle: ~100%
- Minor modification for FDS in October 2020

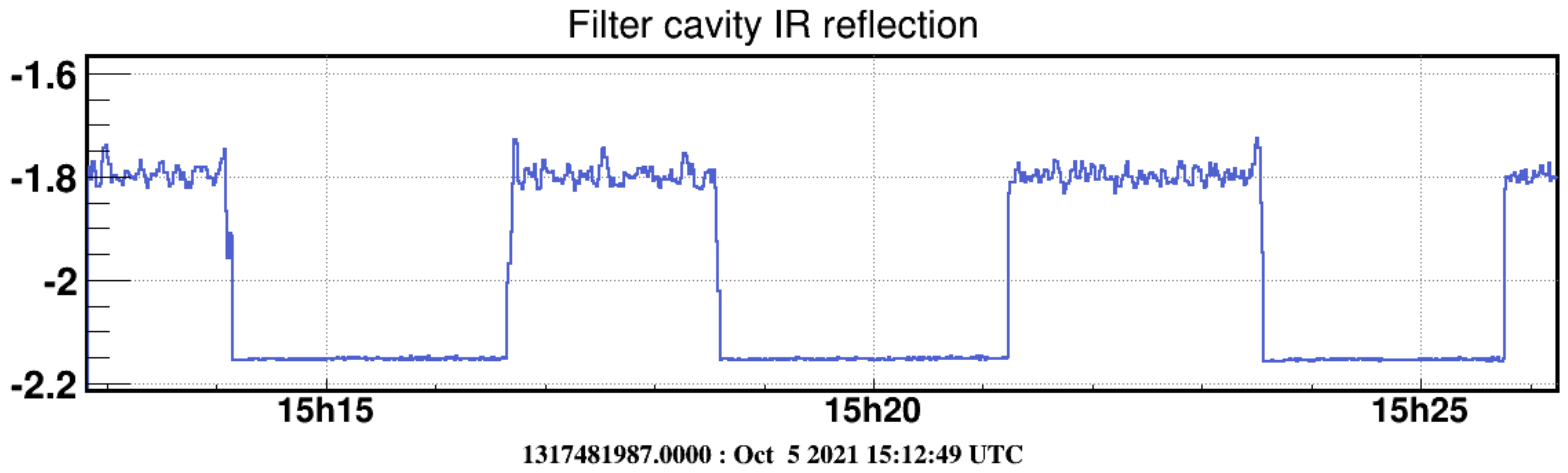


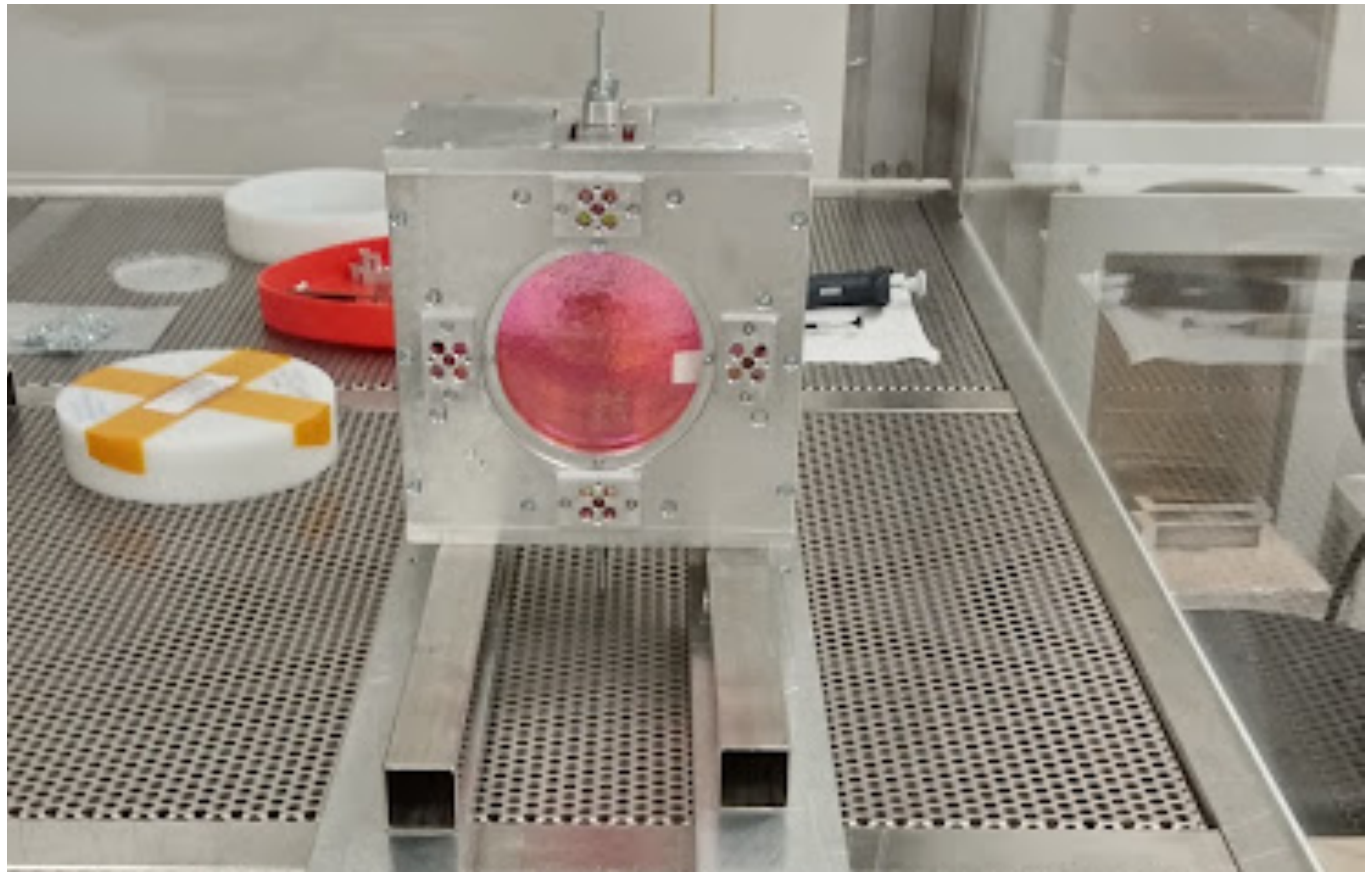


Filter cavity mirrors and round trip losses

- Diameter: 15 cm, Radius of curvature ~ 558 m
- Flatness: ~0.6 nm RMS ⌀ 50 mm
- Dichroic coating
  - IR finesse ~11000
  - GR finesse ~100



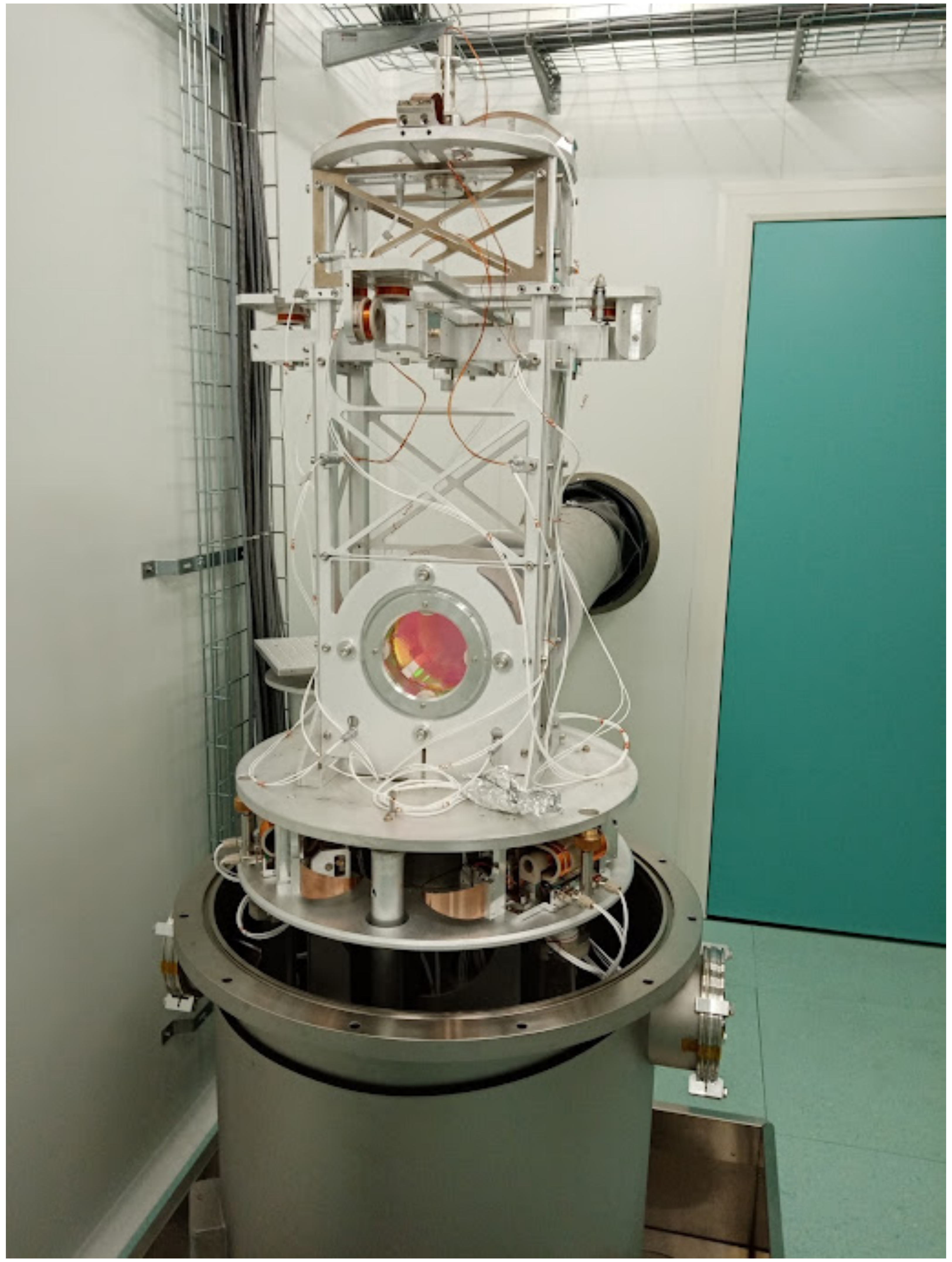




Measured round-trip losses: ~ 30 ppm

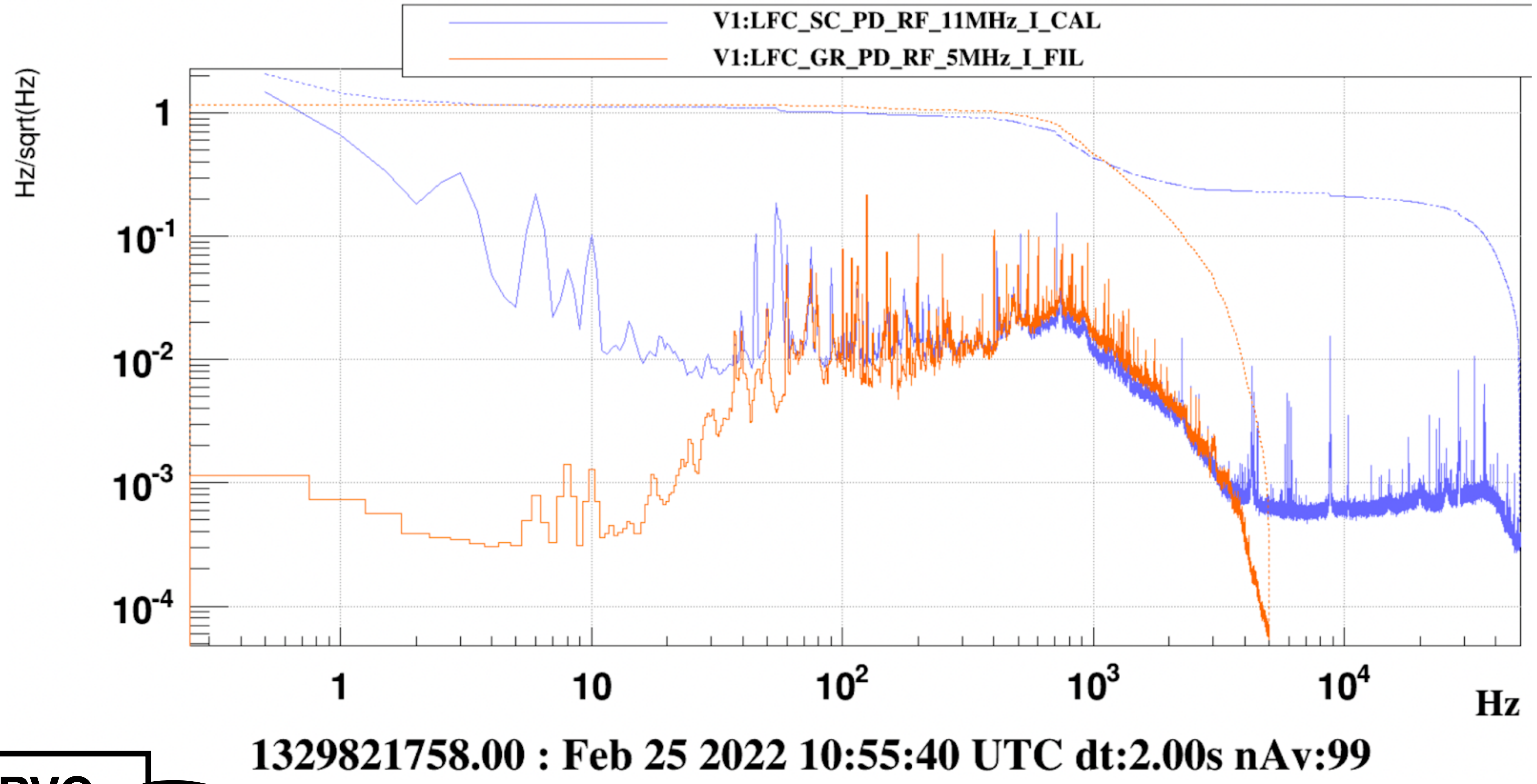
Filter cavity suspensions

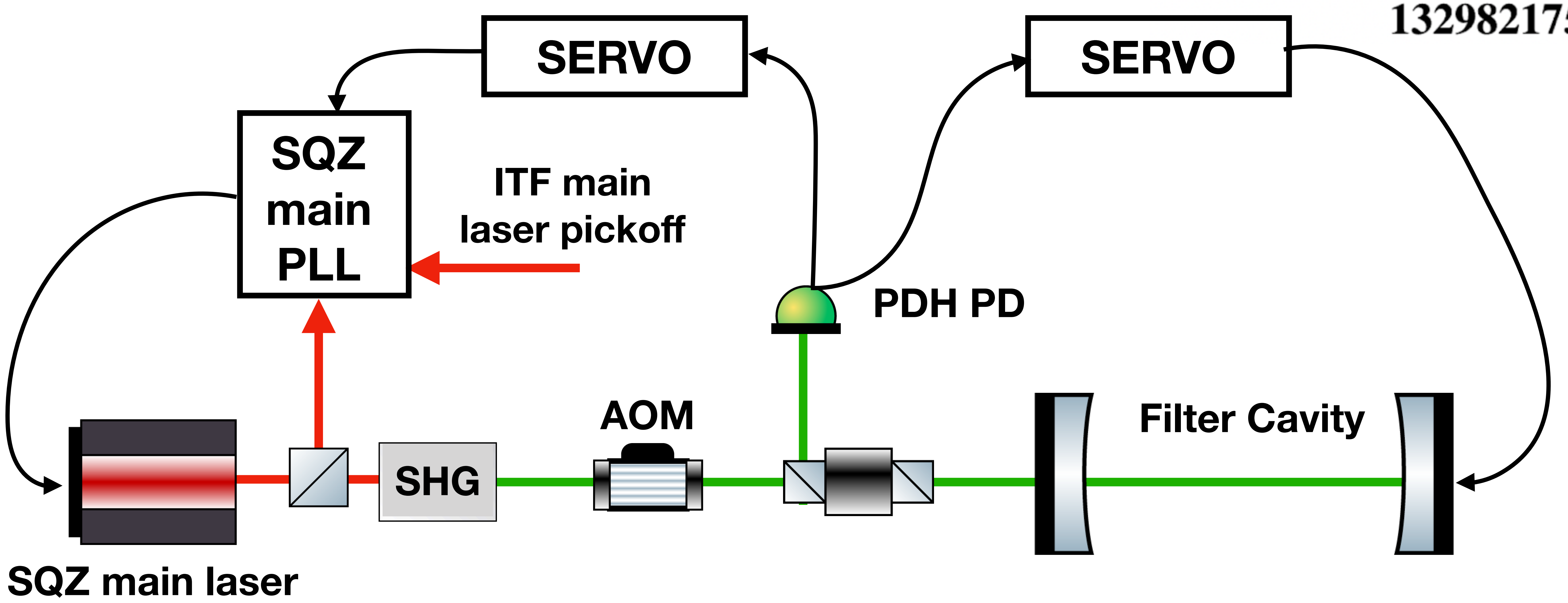
- New suspensions: double pendulum sitting on inverted pendulum bench
- Optical levers on the marionette (Tx, Ty, Tz) and on the mirror (Tx, Ty)
- Mirror residual motion below 1urad



Filter cavity longitudinal control with green beam

- Feedback to FC mirror up to 10 Hz
- Feedback to laser frequency up to ~900Hz
  (added later to suppress noise in the ~100 Hz region)
- Residual length noise ~1 Hz

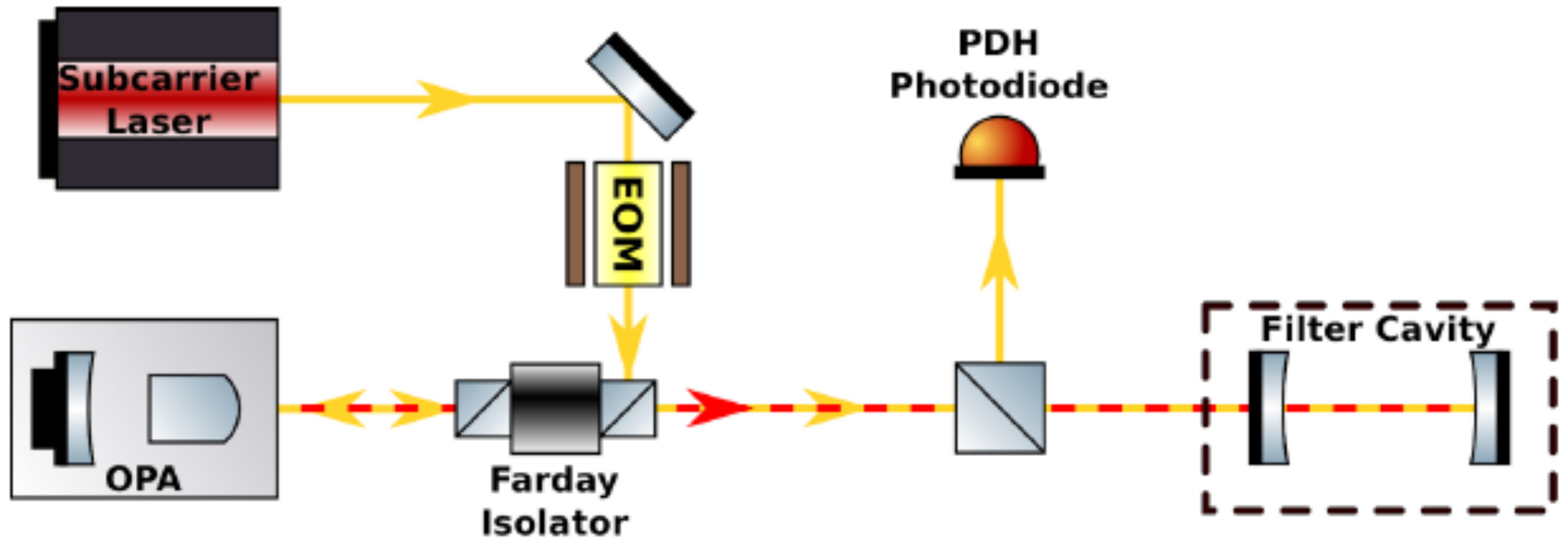


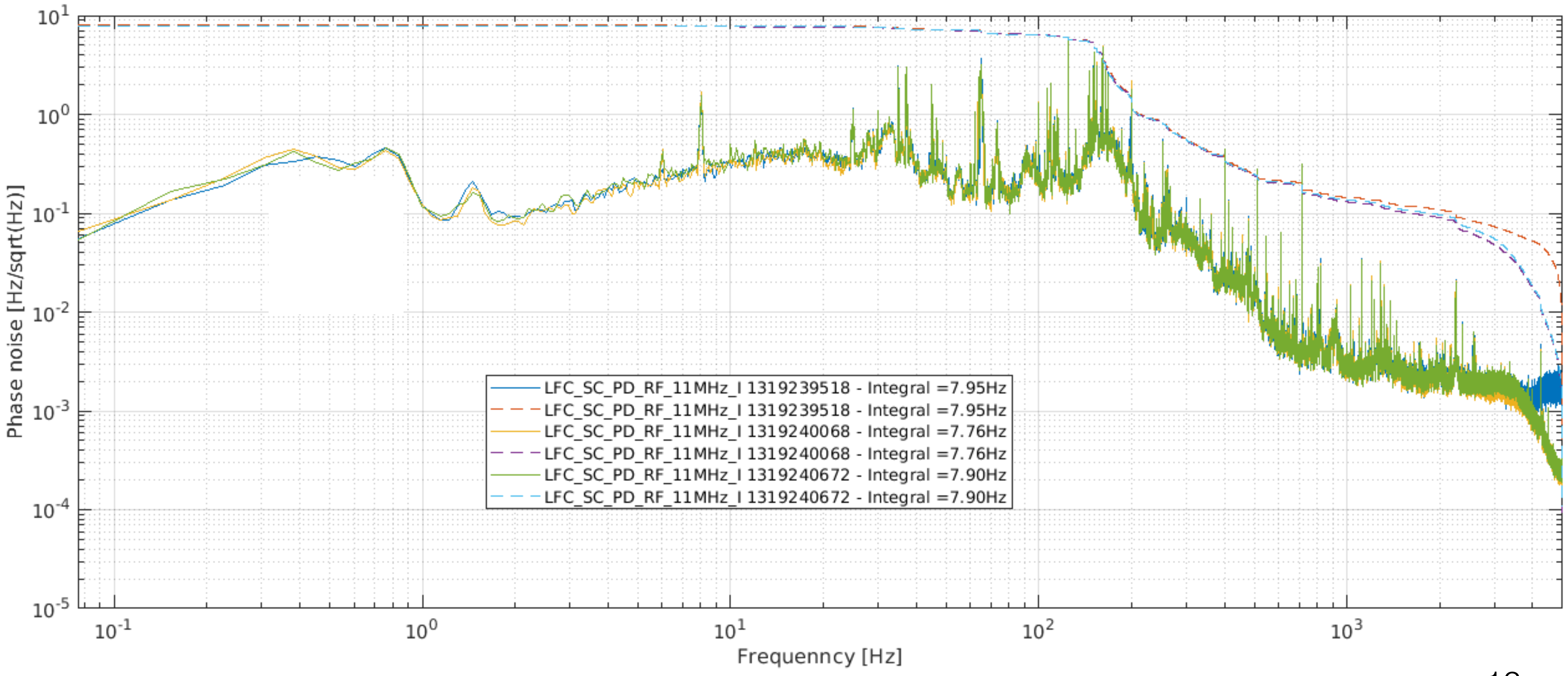


- Working fine in standalone
- To be tested with ITF

Filter cavity longitudinal control with IR (subcarrier)

- Subcarrier laser offset with a PLL by 1.2 GHz wrt the squeezer main laser
- Tune AOM on the green path to find the co-resonance condition between IR and GR in the filter cavity
- Hand-off the lock from Green PDH signal to SubCarrier error signal (0.1% pick off in reflection from FC)
- **Only tested with feedback to mirrors (UGF <100). Residual rms 8 Hz**
- **Cannot be used for standalone FDS characterisation**



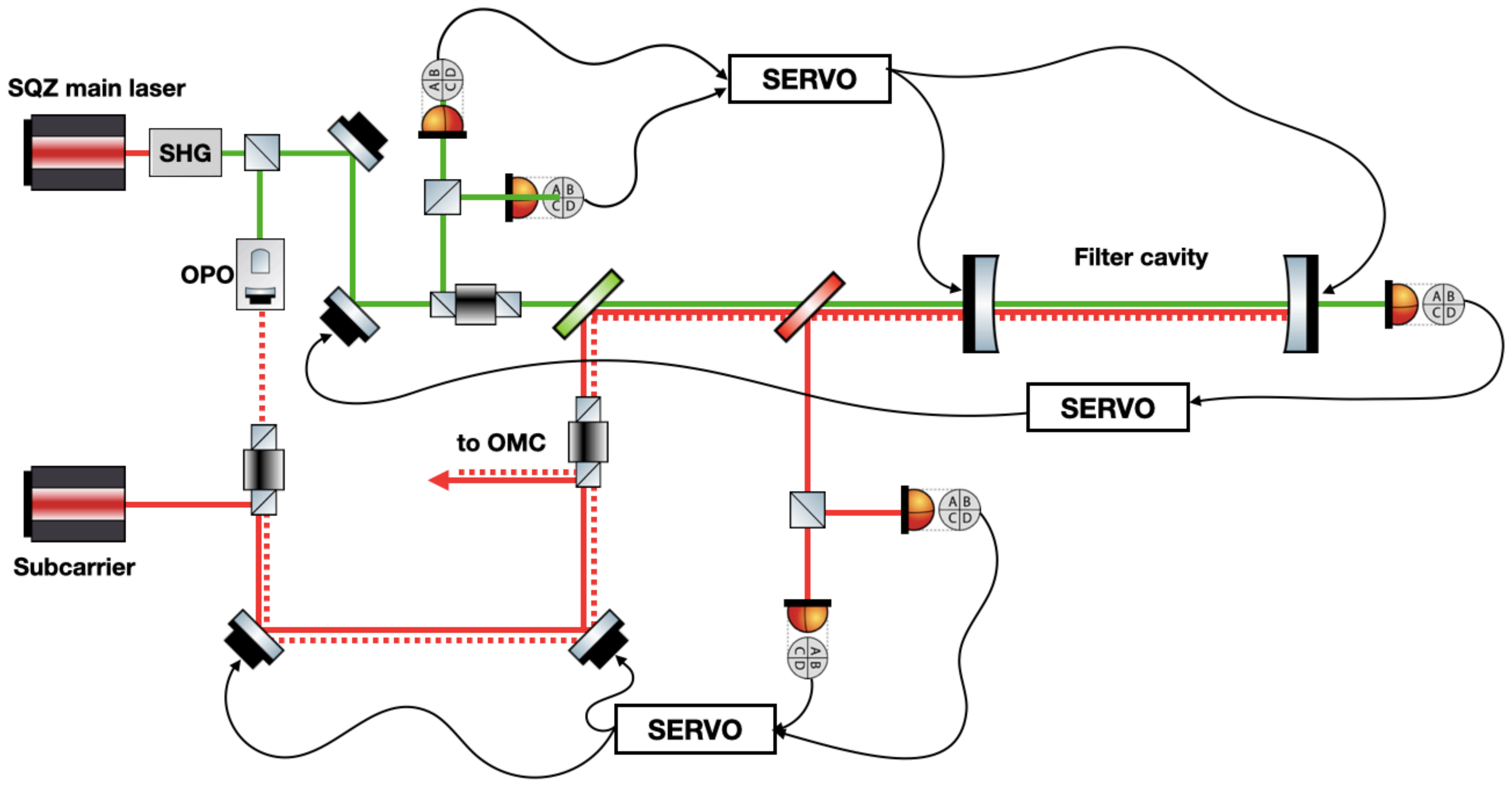


Filter cavity angular control

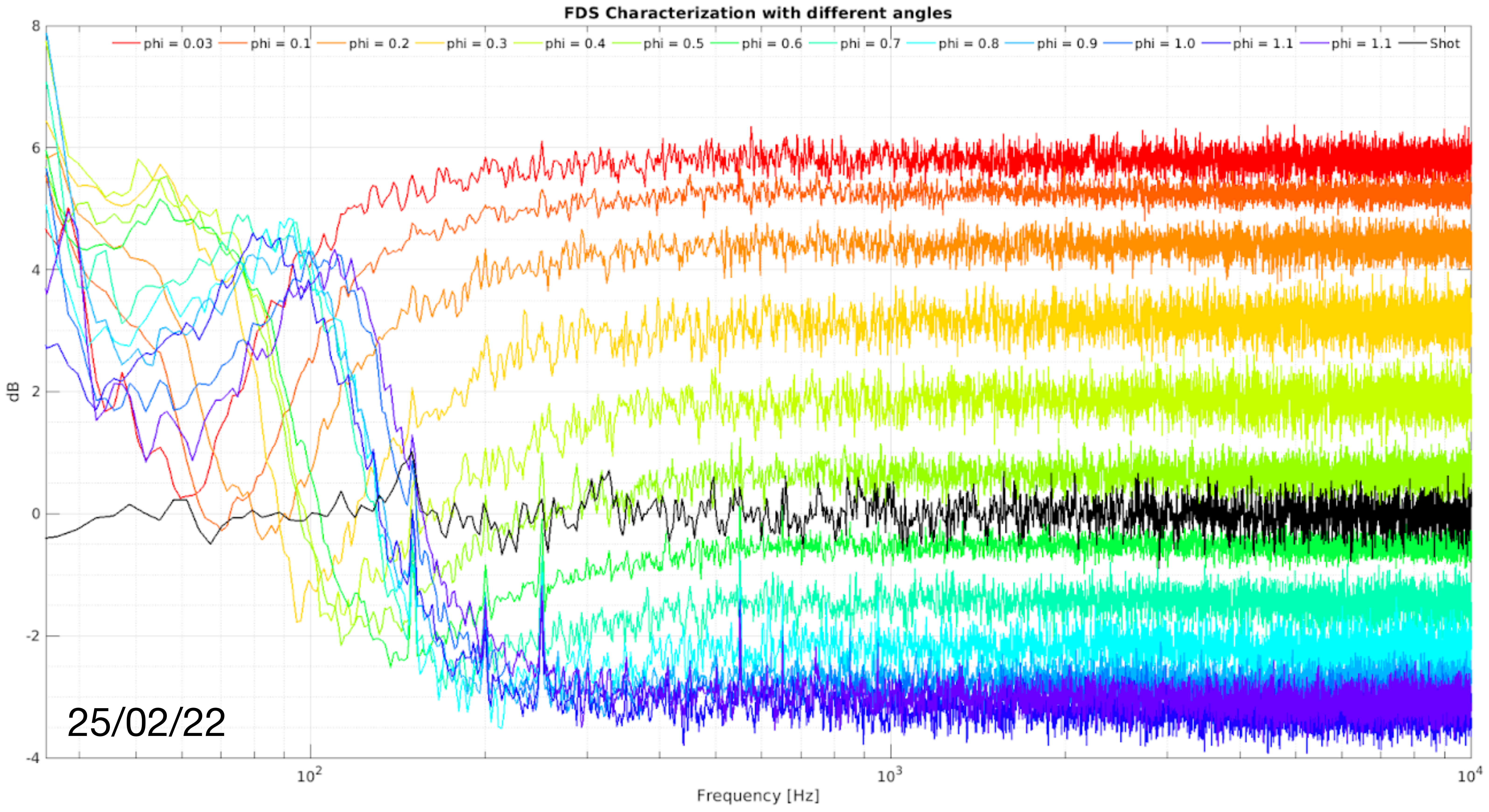
- First implemented on green beam with dithering line
  - On cavity mirrors -> beam centering
  - On steering mirrors -> maximizing axis overlap

→

- Recently AA with WFS implemented
  - WFS on reflected green beam to align the cavity on green
  - WFS on reflected IR beam to align IR into the cavity
  - Point loop implementation on going

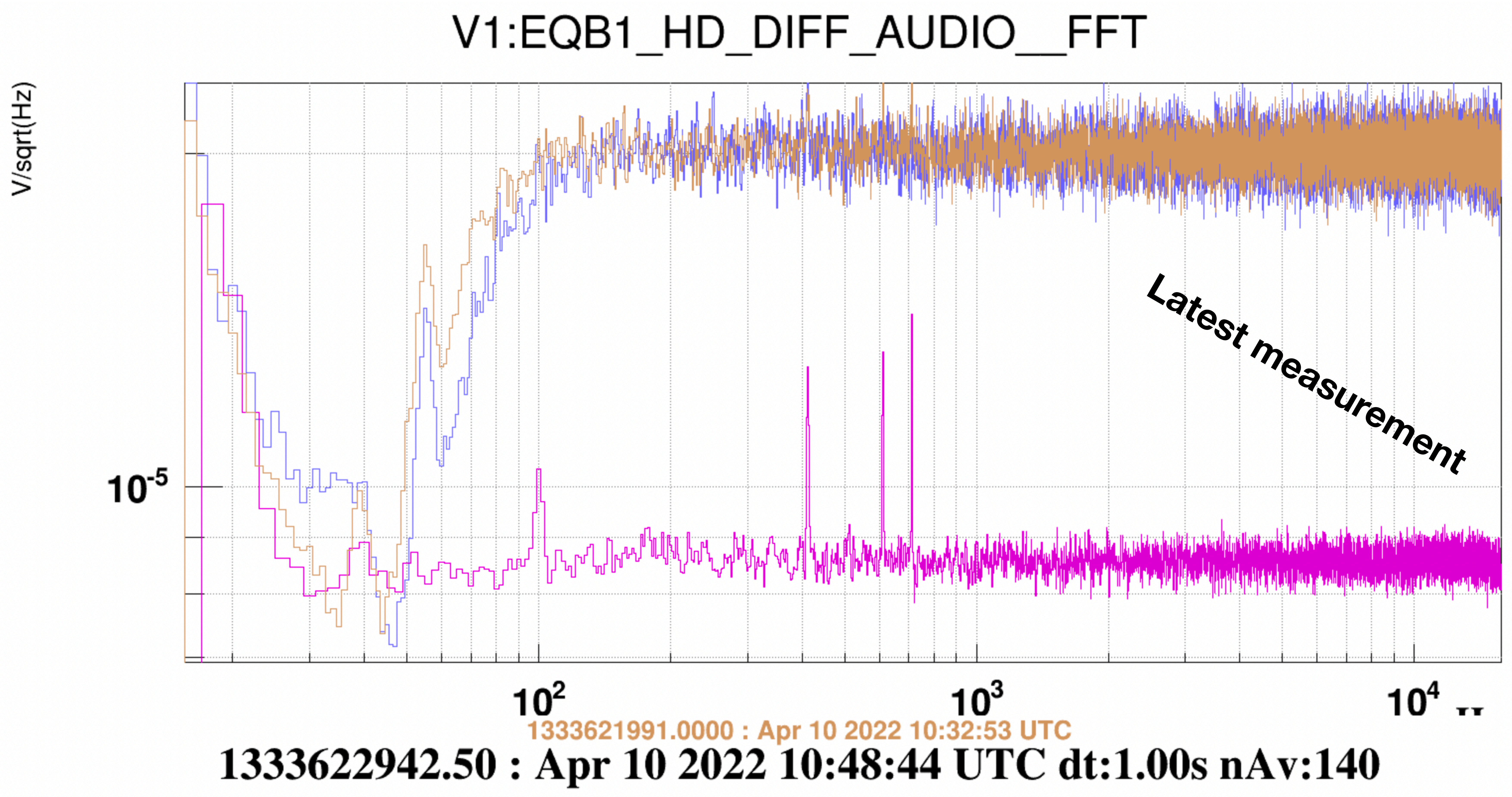


Frequency dependent squeezing measurement



- Ellipse rotation at ~50Hz -> shot noise level at low frequency
- Excess of losses (~35%) -> sub optimal alignment conditions
- Detuning stability to be better characterised

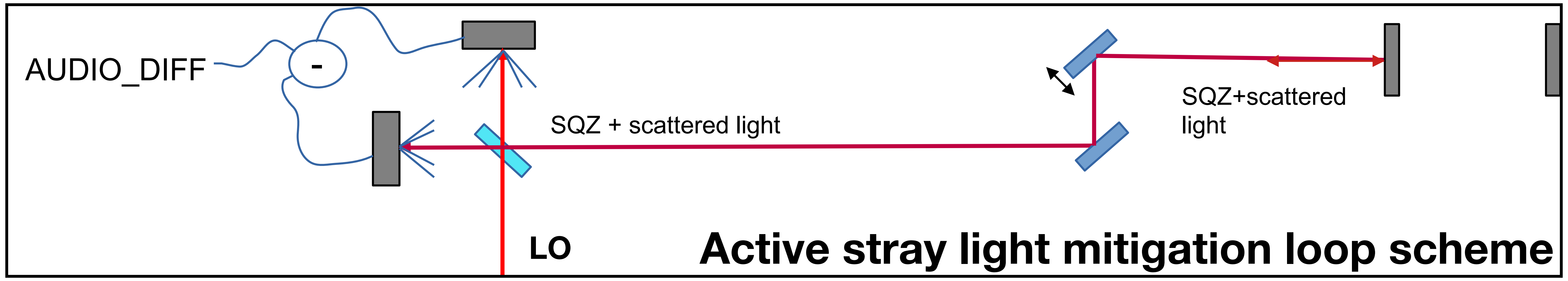
Frequency dependent squeezing measurement

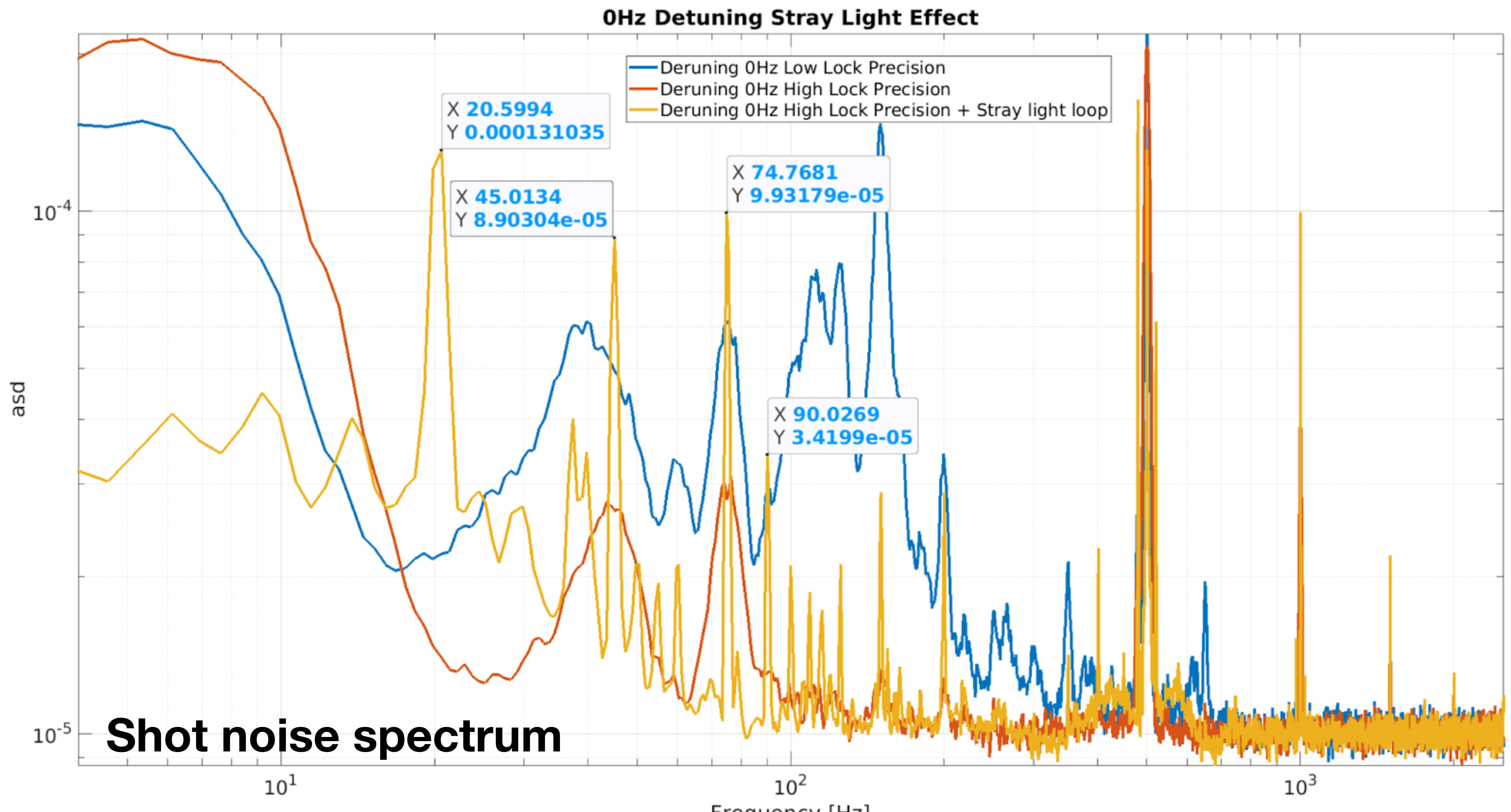


- Ellipse rotation at ~40Hz -> below shot noise level at low frequency
- Estimated losses 17%

Scattered light contamination

- Evidence of local oscillator scattered light by Homodyne PD
- Effect reduced with the locking precision improvement and active stray light mitigation





- Note that local oscillator will be switched off during SQZ injection in ITF

Summary and next steps

- Frequency dependent squeezing for AdVirgo+ commissioning is well advanced
    - Ellipse rotation measured at ~50 Hz
- Further optimisation of standalone FDS system:
    - Automatic alignment finalisation
    - Detuning and stability characterisation
    - Scattered light mitigation
    - Longitudinal control improvement
    - Repeat FDS measurement with optimal conditions
- Preparation and commissioning of SQZ injection into ITF

Perspectives

- Quantum noise reduction plans are currently relying on filter cavity technology for O5, post O5 and even 3rd generation detectors

- Main effort will be devoted to the optimisation of this technique
    - Loss reduction
    - Phase noise and scattered light mitigation
    - Optimized design and control strategies

KAGRA/Virgo collaboration within FDS activities

- FDS demonstration at Tama: joint work of KAGRA and Virgo members
- Visits and exchange periods: hopefully more frequent after covid emergency resolution

PHYSICAL REVIEW LETTERS **124,** 171101 (2020)

Editors' Suggestion   Featured in Physics

Frequency-Dependent Squeezed Vacuum Source for Broadband Quantum Noise Reduction in Advanced Gravitational-Wave Detectors

Yuhang Zhao,[1,2] Naoki Aritomi,[3] Eleonora Capocasa,[1,*] Matteo Leonardi,[1,†] Marc Eisenmann,[4] Yuefan Guo,[5] Eleonora Polini,[4] Akihiro Tomura,[6] Koji Arai,[7] Yoichi Aso,[1] Yao-Chin Huang,[8] Ray-Kuang Lee,[8] Harald Lück,[9] Osamu Miyakawa,[10] Pierre Prat,[11] Ayaka Shoda,[1] Matteo Tacca,[5] Ryutaro Takahashi,[1] Henning Vahlbruch,[9] Marco Vardaro,[5,12,13] Chien-Ming Wu,[8] Matteo Barsuglia,[11] and Raffaele Flaminio[4,1]

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[7]*LIGO, California Institute of Te*
[8]*Institute of Photonics Technologies, N*
[9]*Institut für Gravitationsphysik, Leibniz Universi (Albert-Einstein-Institut), Ca*
[10]*Institute for Cosmic Ray Research (IC Kamioka-cho, Hi*
[11]*Université de Paris, CNRS, Astro*
[12]*Institute for High-Energy Physics, University of A*
[13]*Università di Padova, Dipartimen*

PHYSICAL REVIEW D **98,** 022010 (2018)

Measurement of optical losses in a high-finesse 300 m filter cavity for broadband quantum noise reduction in gravitational-wave detectors

Eleonora Capocasa,[1,2,*] Yuefan Guo,[3] Marc Eisenmann,[4] Yuhang Zhao,[1,5] Akihiro Tomura,[6] Koji Arai,[7] Yoichi Aso,[1] Manuel Marchiò,[1] Laurent Pinard,[8] Pierre Prat,[2] Kentaro Somiya,[9] Roman Schnabel,[10] Matteo Tacca,[11] Ryutaro Takahashi,[1] Daisuke Tatsumi,[1] Matteo Leonardi,[1] Matteo Barsuglia,[2] and Raffaele Flaminio[4,1]

Accepted Paper

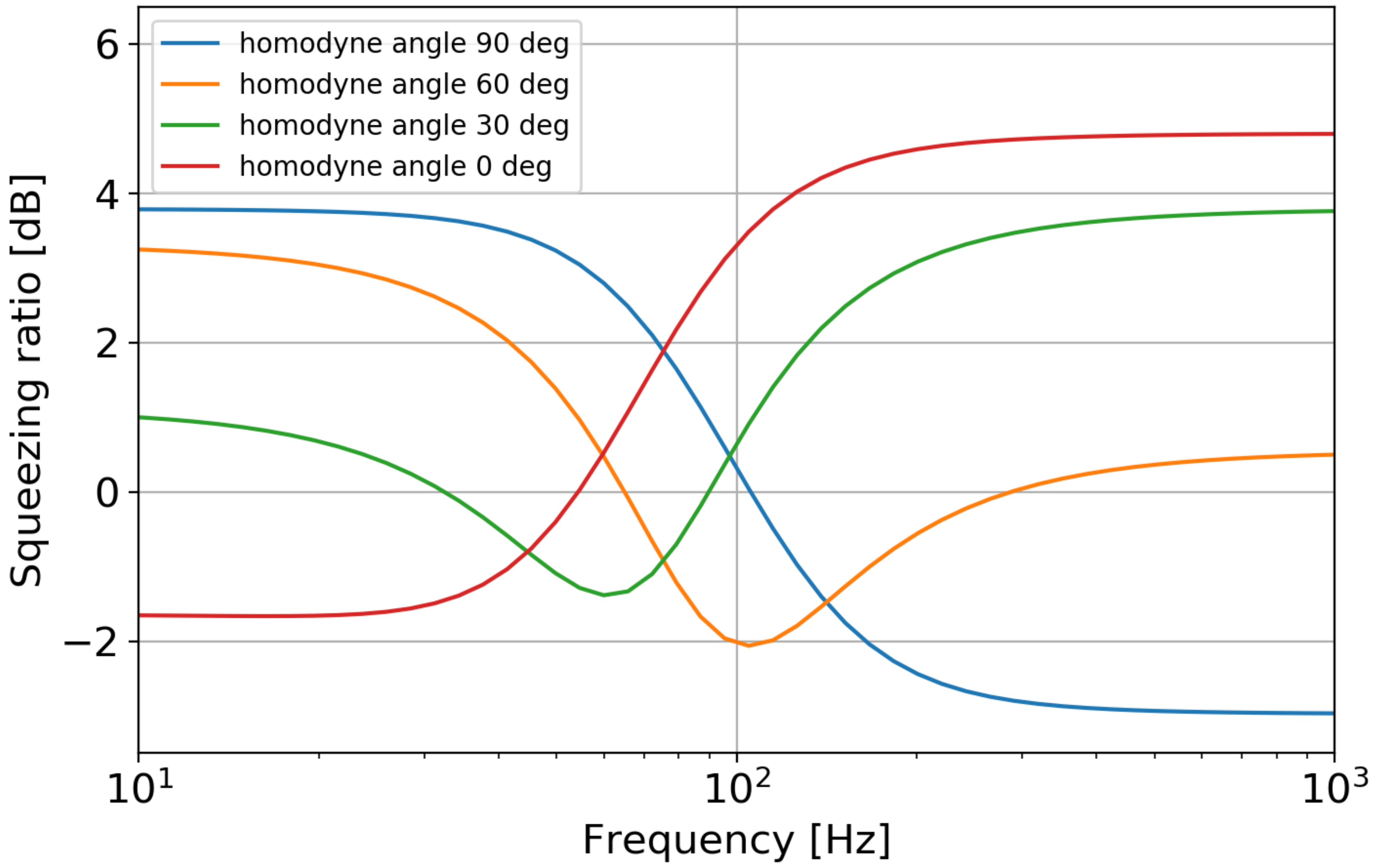
Improving the stability of frequency-dependent squeezing with bichromatic control of filter cavity length, alignment, and incident beam pointing

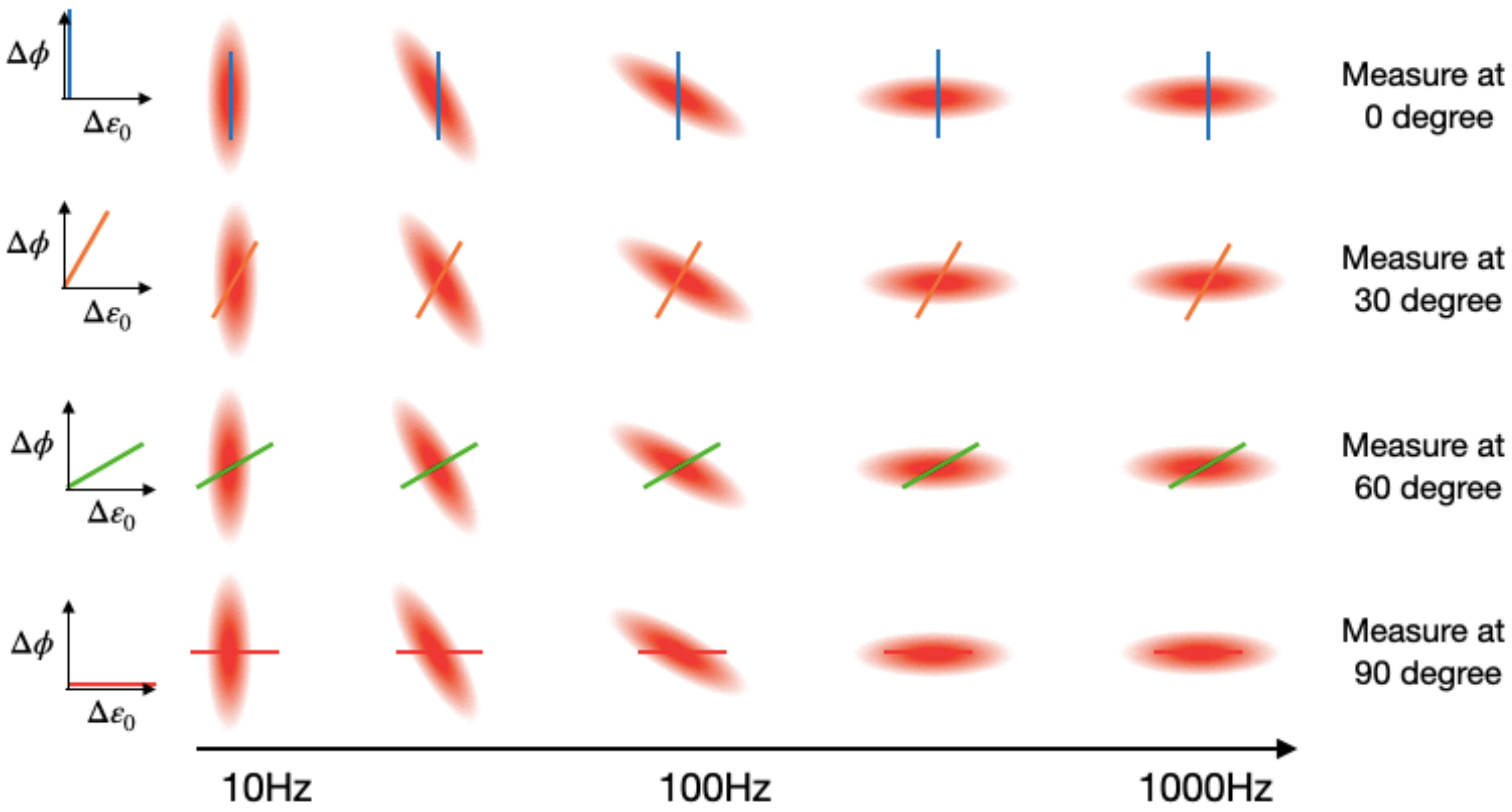
Phys. Rev. D

Yuhang Zhao, Eleonora Capocasa, Marc Eisenmann, Naoki Aritomi, Michael Page, Yuefan Guo, Eleonora Polini, Koji Arai, Yoichi Aso, Martin van Beuzekom, Yao-Chin Huang, Ray-Kuang Lee, Harald Lück, Osamu Miyakawa, Pierre Prat, Ayaka Shoda, Matteo Tacca, Ryutaro Takahashi, Henning Vahlbruch, Marco Vardaro, Chien-Ming Wu, Matteo Leonardi, Matteo Barsuglia, and Raffaele Flaminio

Accepted 1 March 2022

Backup


homodyne angle 90 deg
homodyne angle 60 deg
homodyne angle 30 deg
homodyne angle 0 deg
Squeezing ratio [dB]
Frequency [Hz]
6
4
2
0
−2
10^1
10^2
10^3


$\Delta\phi$
$\Delta\varepsilon_0$
Measure at 0 degree
Measure at 30 degree
Measure at 60 degree
Measure at 90 degree
10Hz
100Hz
1000Hz