Status of frequency-dependent squeezing for Advanced Virgo Plus

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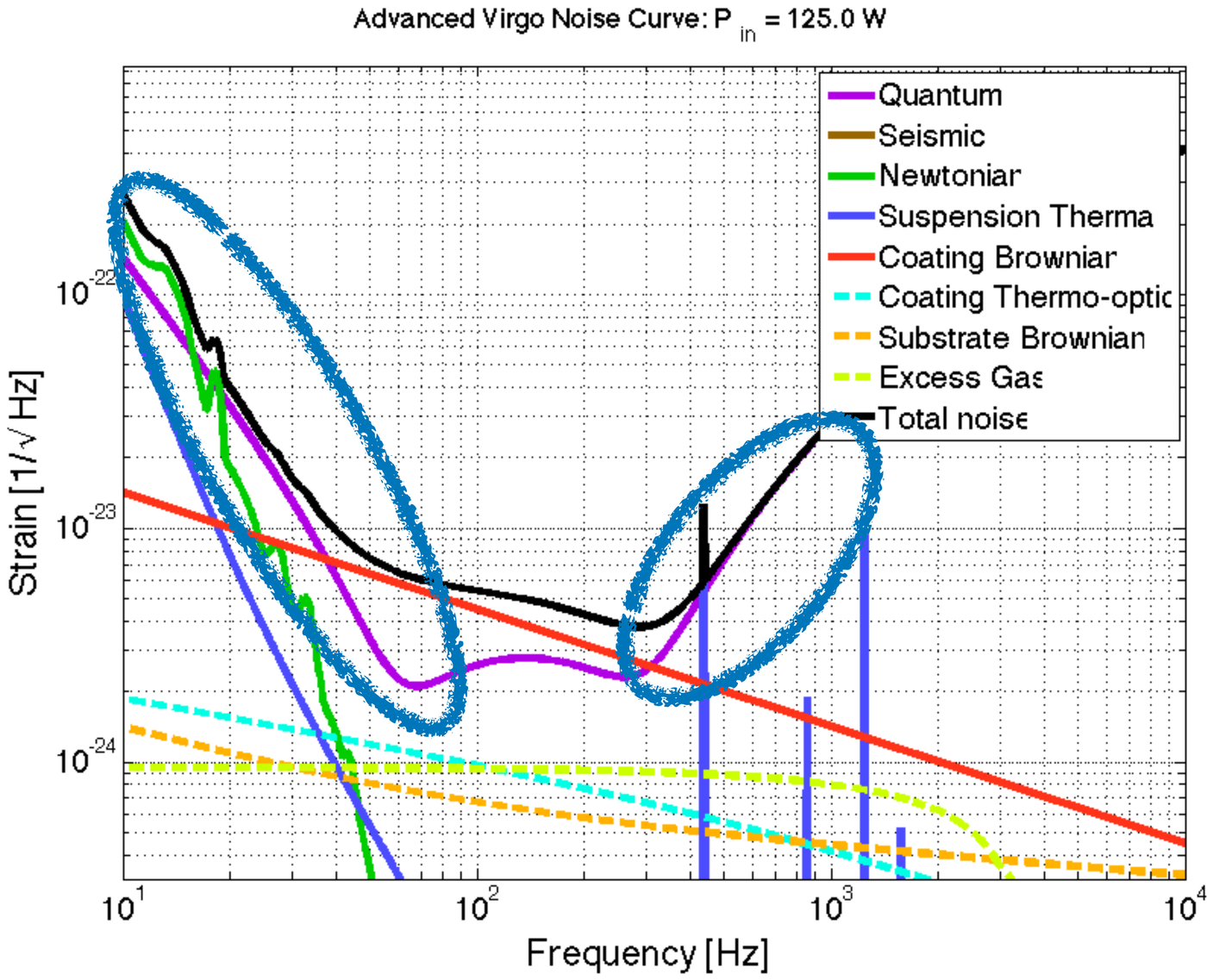
NVV SAF, Lunteren, 04-11-2022

Motivation

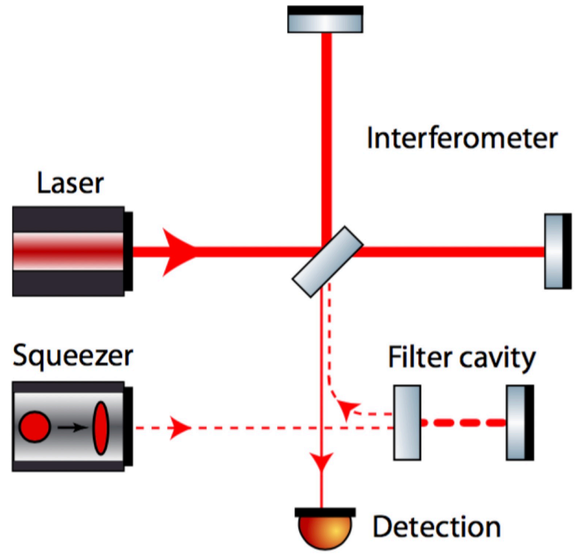


Quantum noise limits the sensitivity

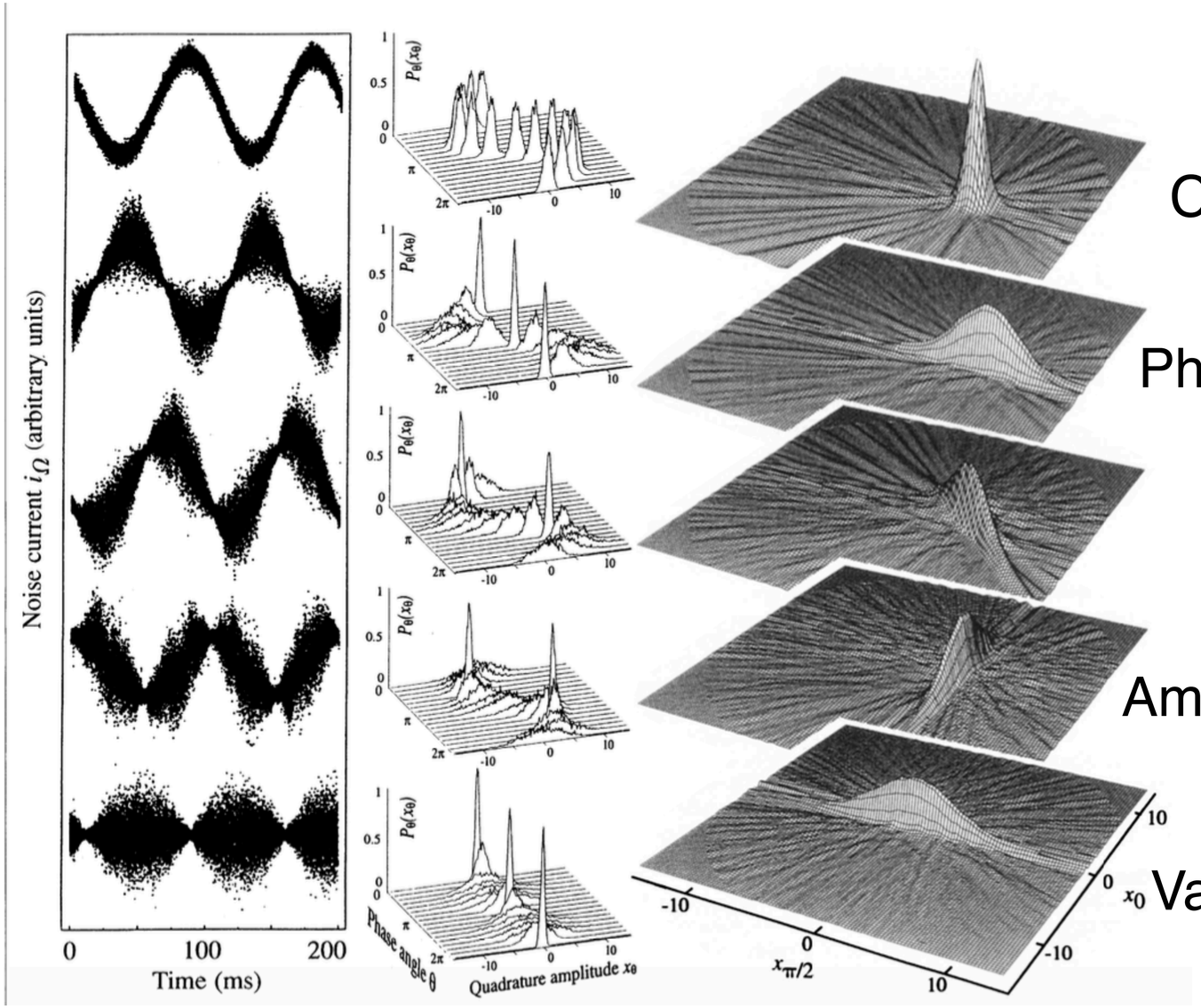
Shot noise + radiation pressure noise

In high + low frequency region

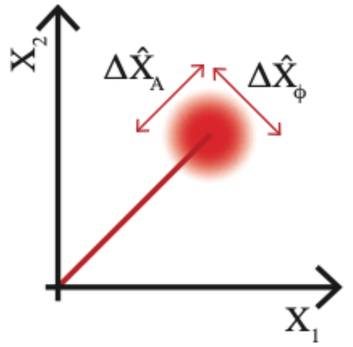
Frequency dependent squeezing



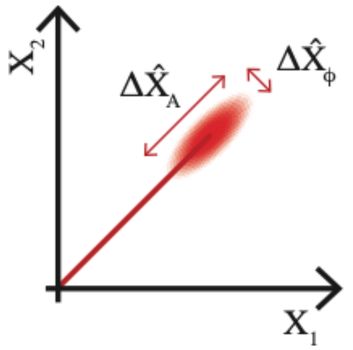
What is squeezed state?



Coherent state

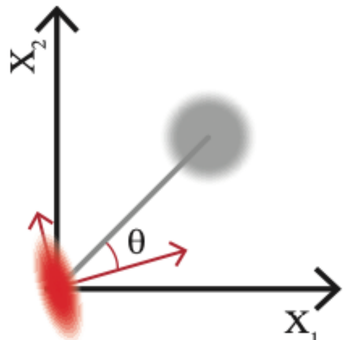


Phase squeezed state



Amplitude squeezed state

Vacuum squeezed state

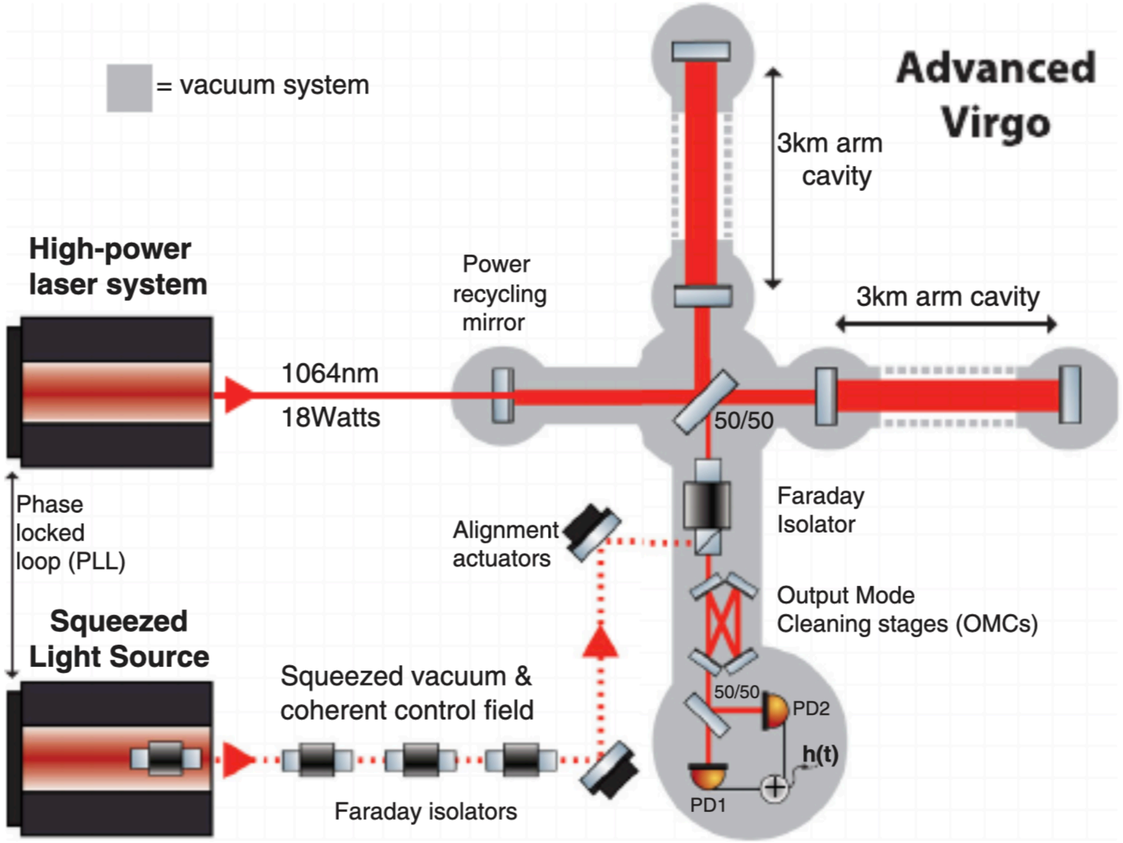


Contents

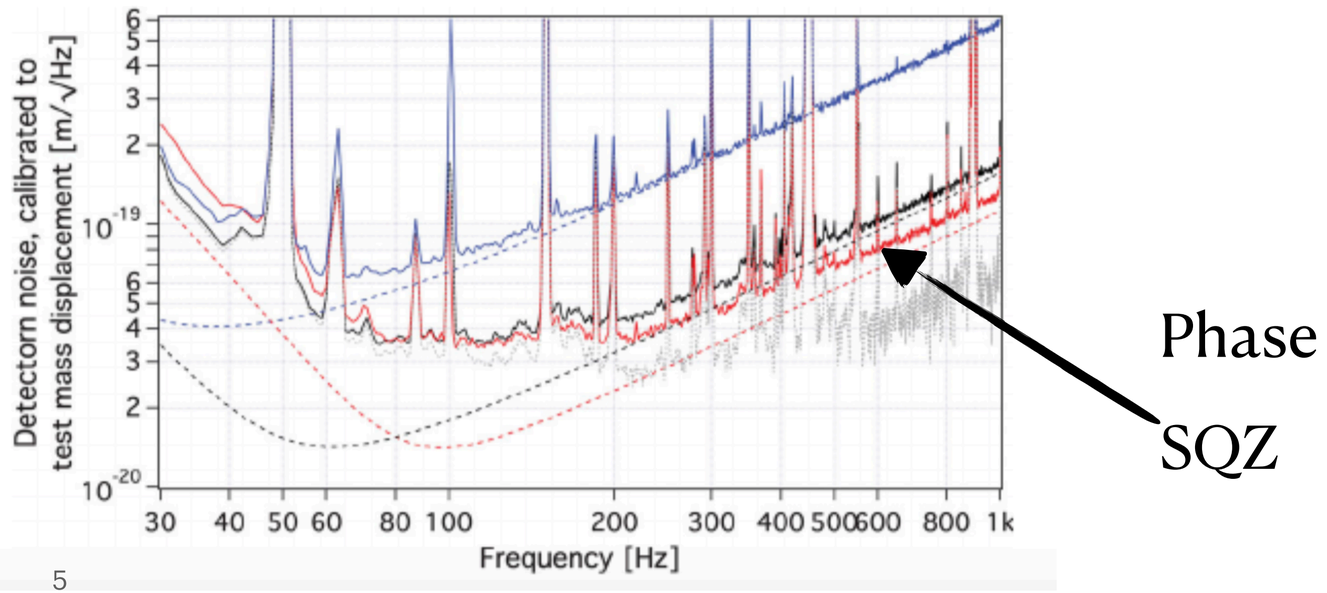
- Overview of the quantum noise reduction system
- Timeline of the milestones
- Frequency dependent squeezing measurement
- Next steps

From FIS to FDS

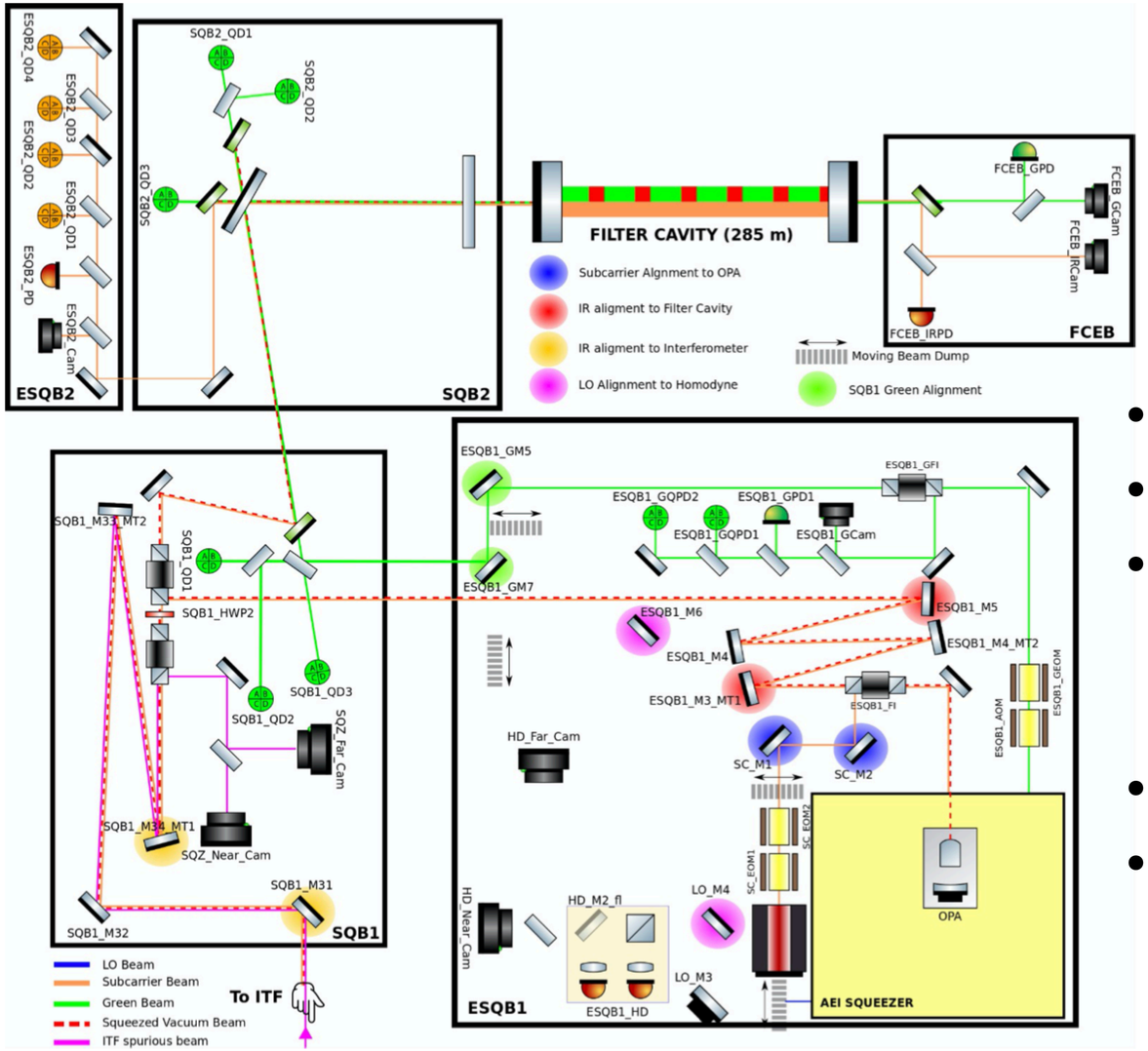
Frequency independent squeezing & frequency dependent squeezing

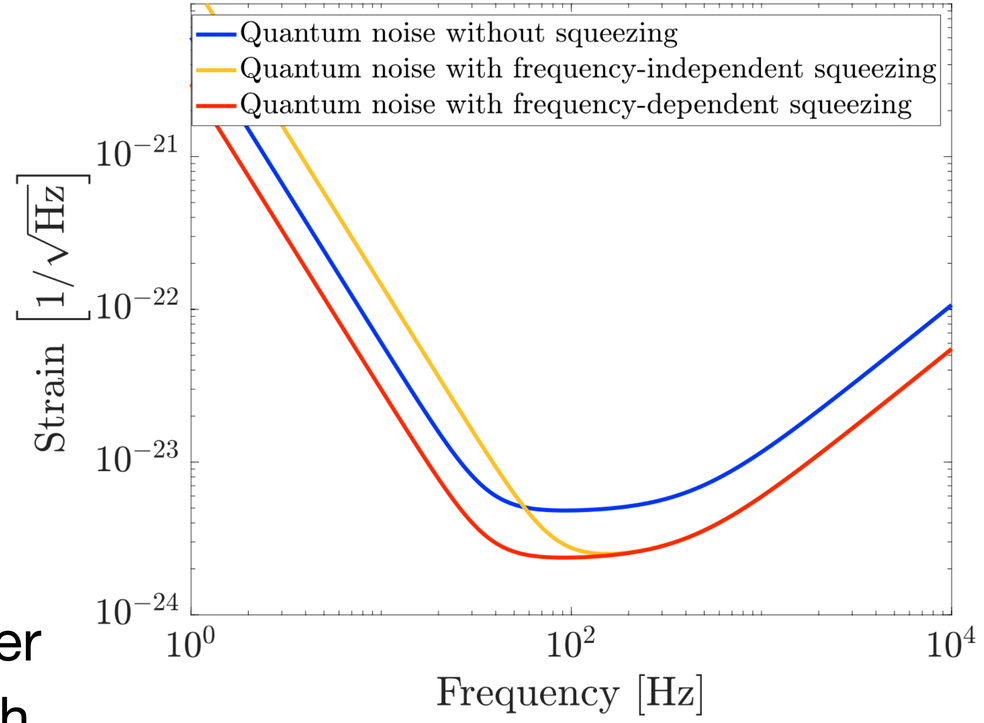


Frequency independent squeezing has been implemented for Virgo O3 run. In the low-frequency region, we started to see the effect of the radiation pressure noise.

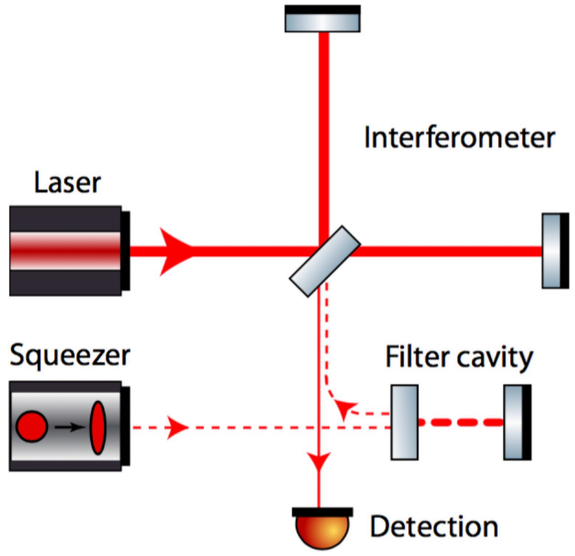


Overview of the system

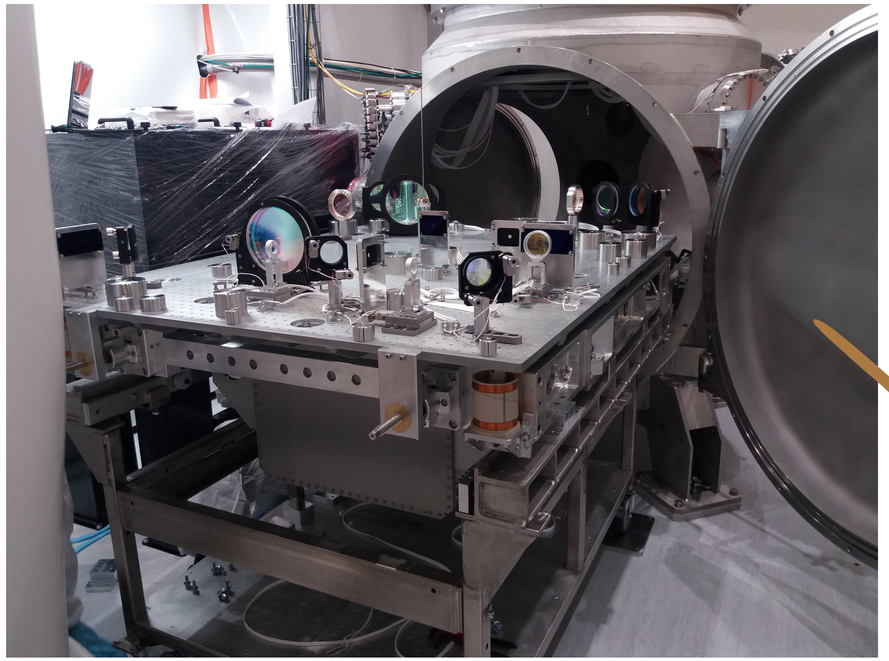


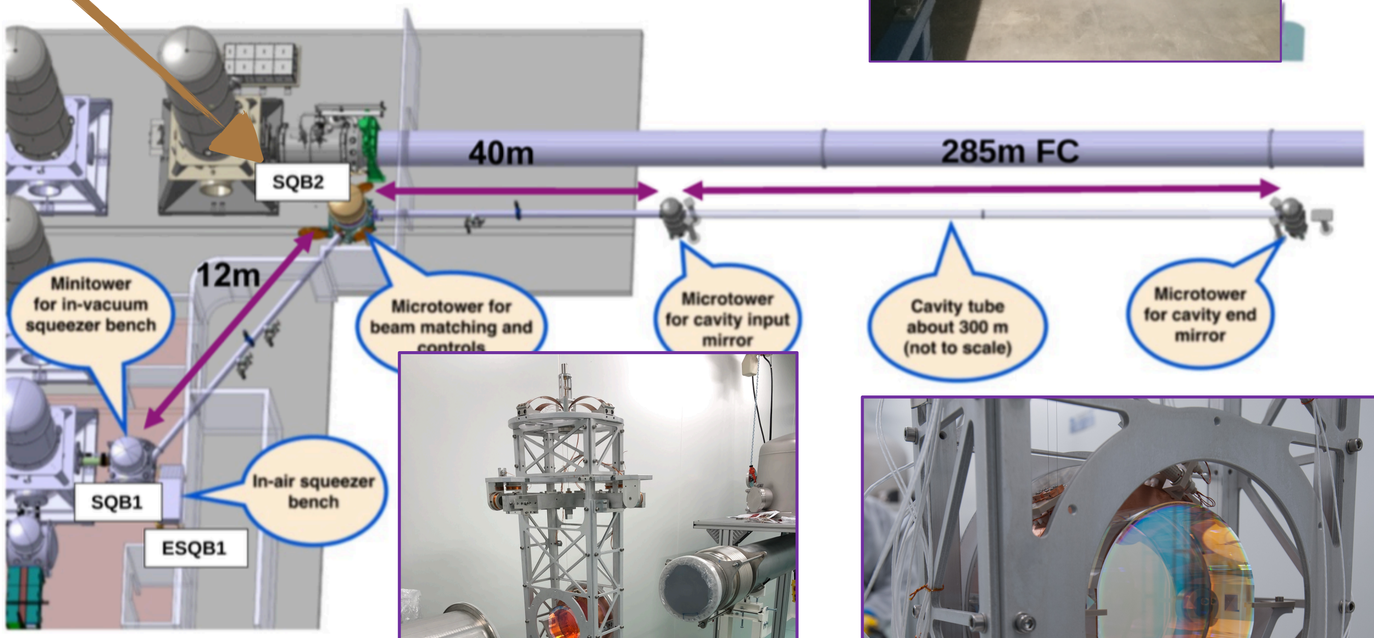


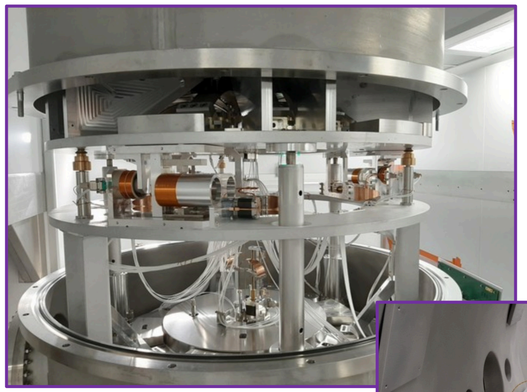
- AEI squeezer
- EQB1 bench
- Suspended benches
  - SQB1
  - SQB2
- EQB2 bench
- Filter cavity

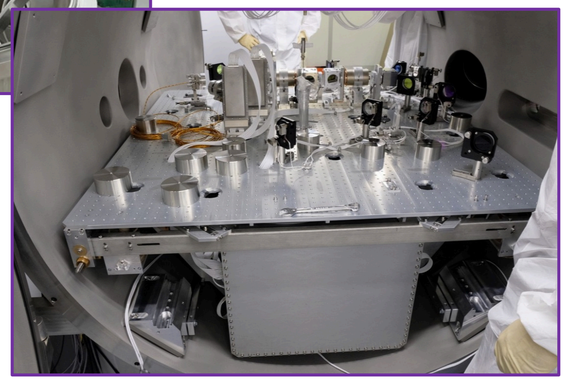


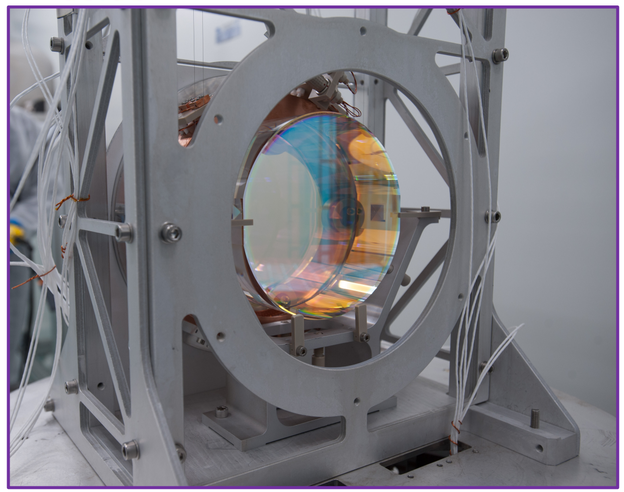
Overview



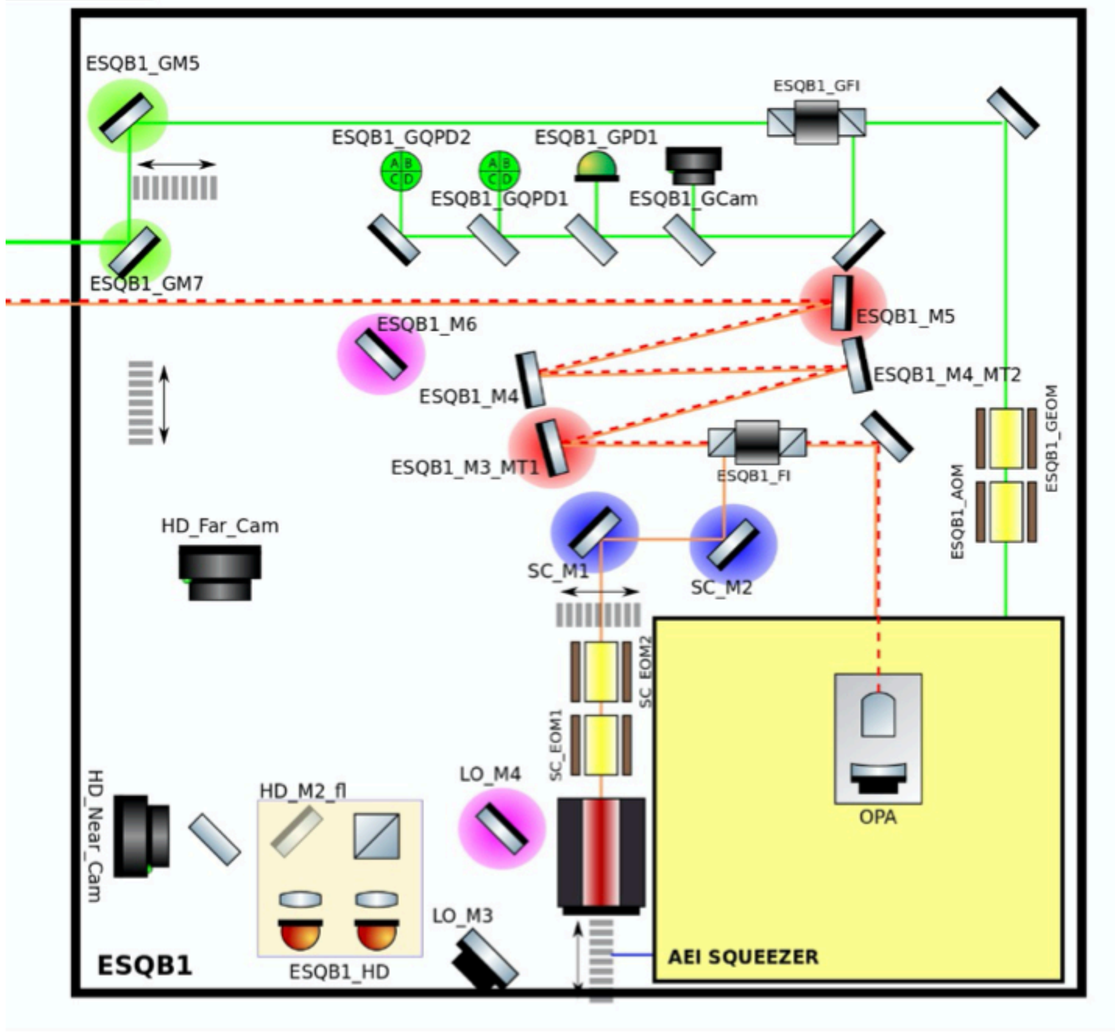

SQB2
40m
285m FC
12m
Minitower for in-vacuum squeezer bench
Microtower for beam matching and controls
Microtower for cavity input mirror
Cavity tube about 300 m (not to scale)
Microtower for cavity end mirror
SQB1
In-air squeezer bench
ESQB1

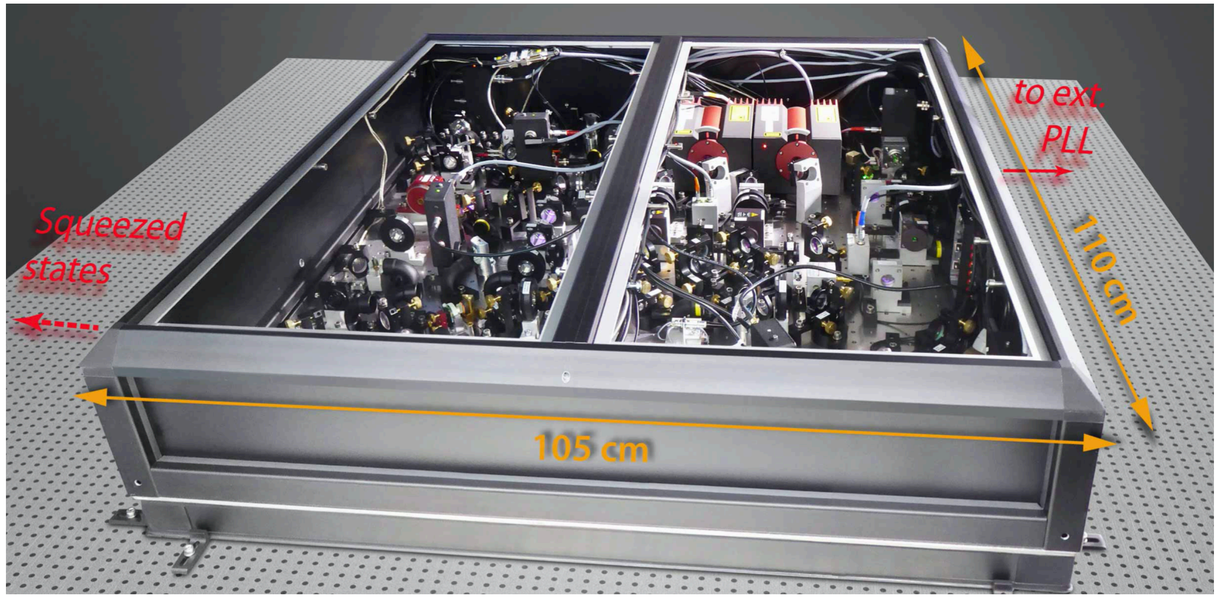






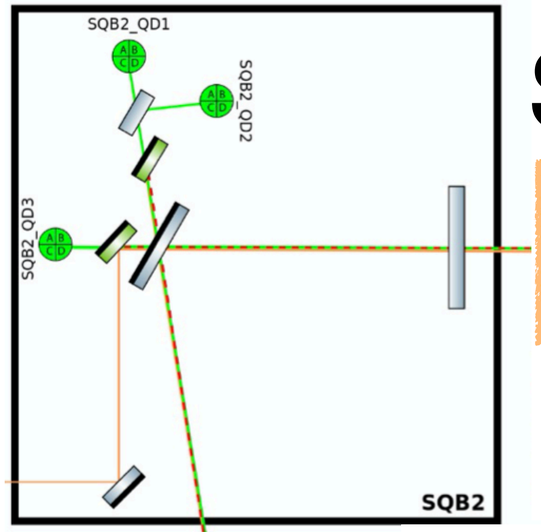
In air squeezing bench



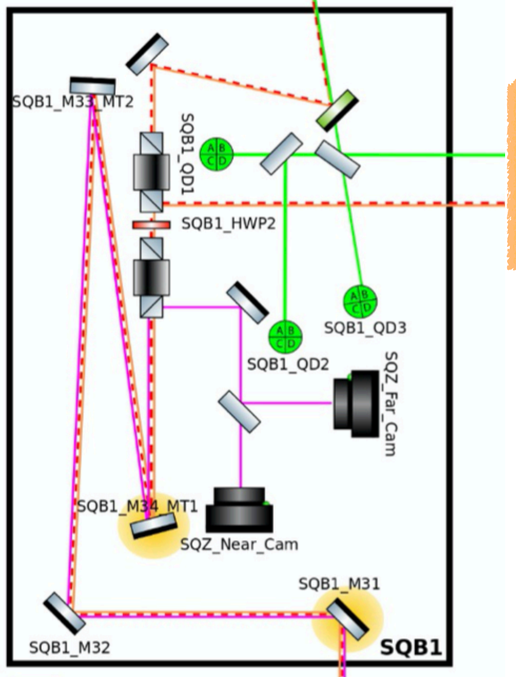


- Squeezer: green beam, bright alignment beam(BAB), squeezing beam, local oscillator beam
- EQB1:
  - **S**ub **C**arrier beam source(IR)
  - External Homodyne detector
  - Mode-matching telescopes

Suspended benches

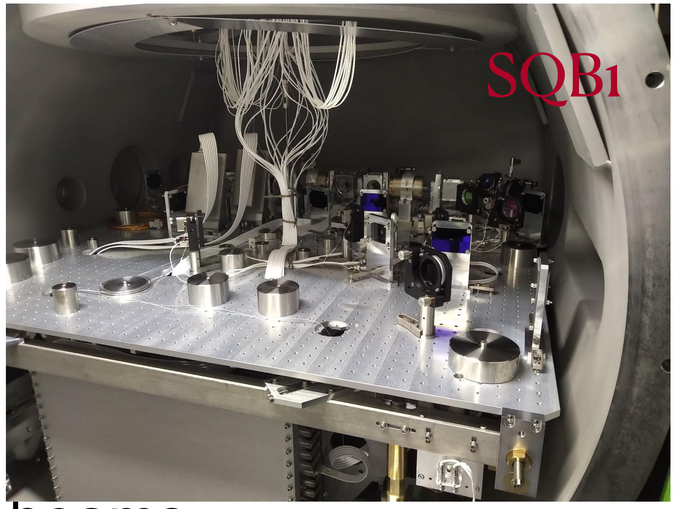


Filter cavity



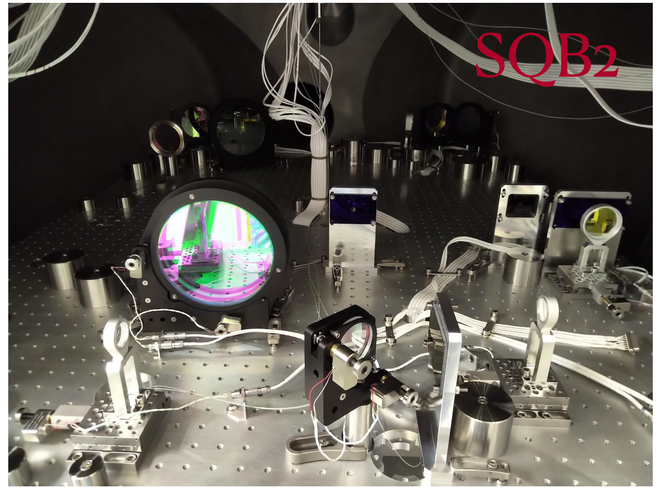
In air Squeezer

ITF

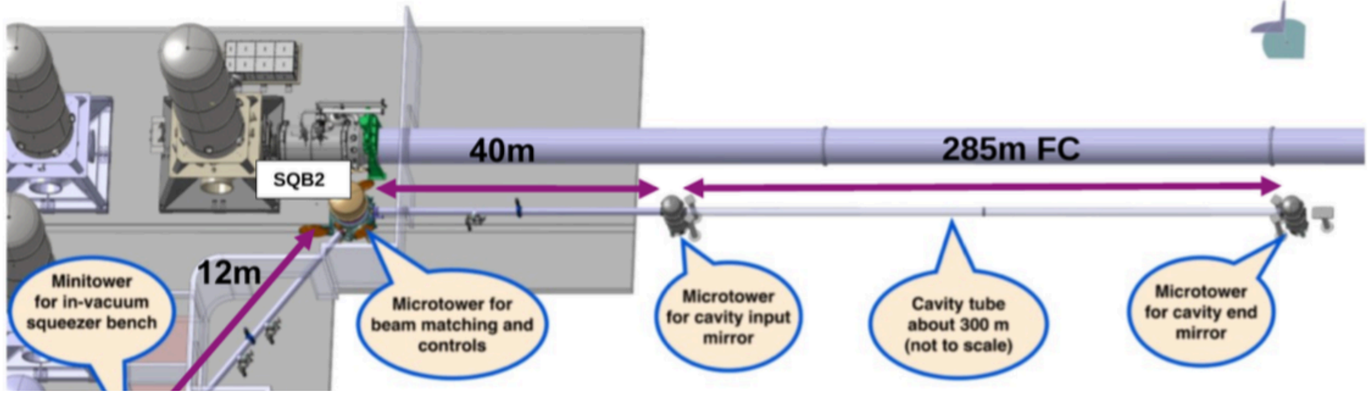


Used for :

- Overlap green and IR beams
- Mode matching telescopes
- Control bench position wrt beams using PSDs
- Sending FIS to filter cavity
- Sending FDS to ITF

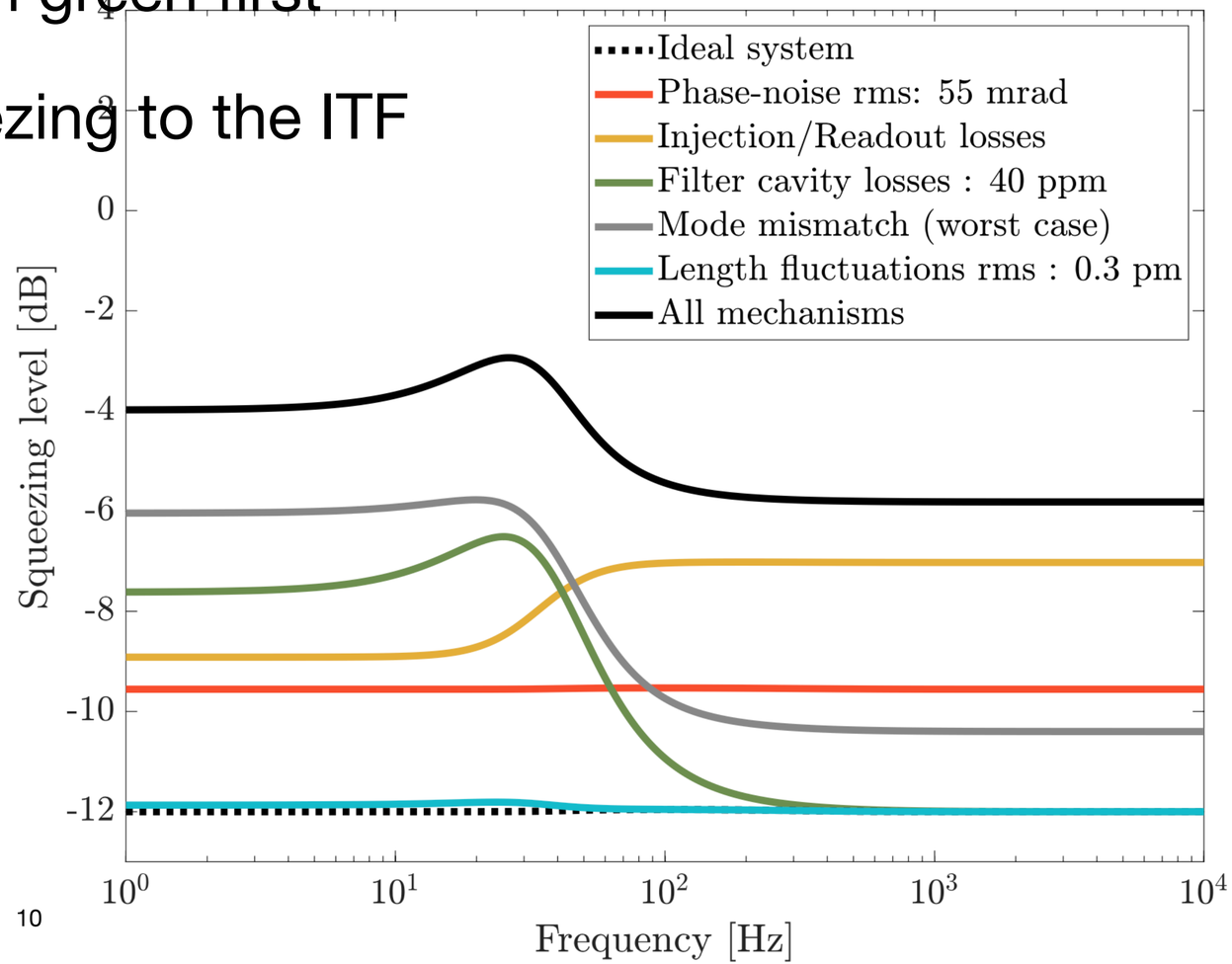


Filter cavity

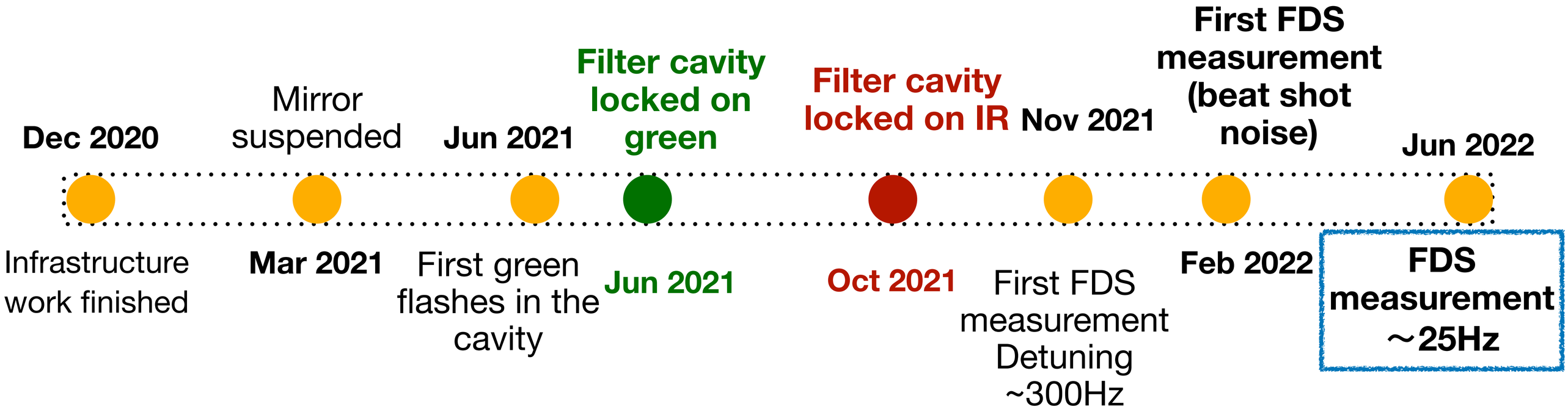


- Coating for both green and IR
- Low finesse with green ——> lock with green first
- Lock with SC beam when inject squeezing to the ITF

Cavity length	285m
FSR	526kHz
Mirror mass	3.5kg
Finesse for green	117
Finesse for IR	11114



Milestones

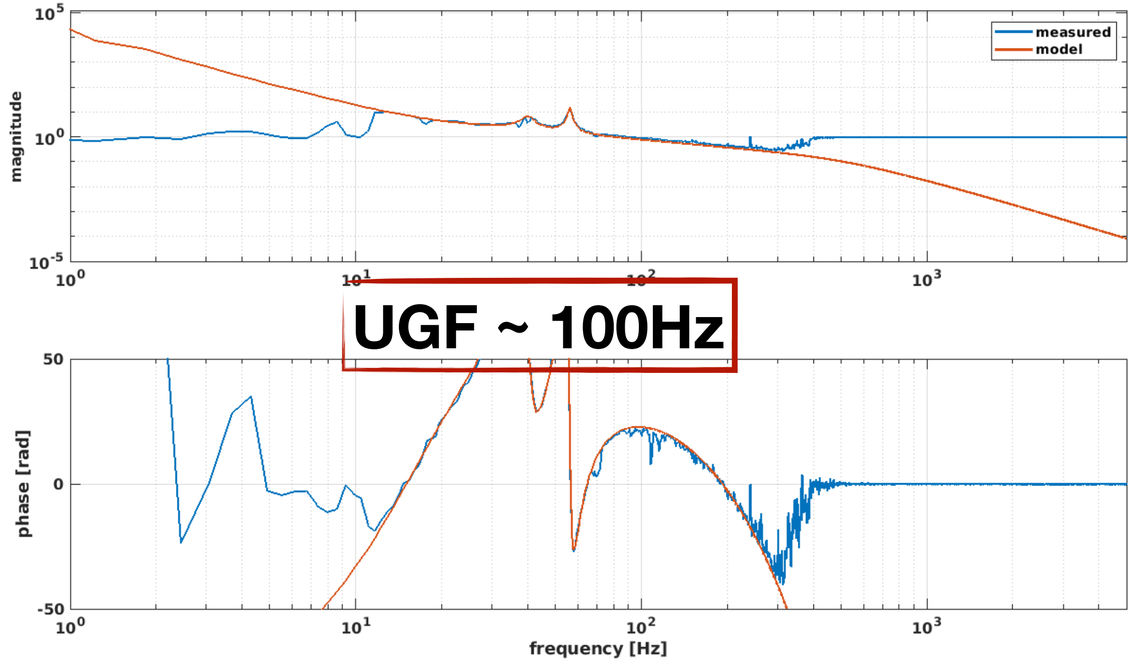

Dec 2020
Infrastructure work finished
Mirror suspended
Mar 2021
Jun 2021
First green flashes in the cavity
Filter cavity locked on green
Jun 2021
Filter cavity locked on IR
Oct 2021
Nov 2021
First FDS measurement Detuning ~300Hz
First FDS measurement (beat shot noise)
Feb 2022
Jun 2022
FDS measurement ~25Hz

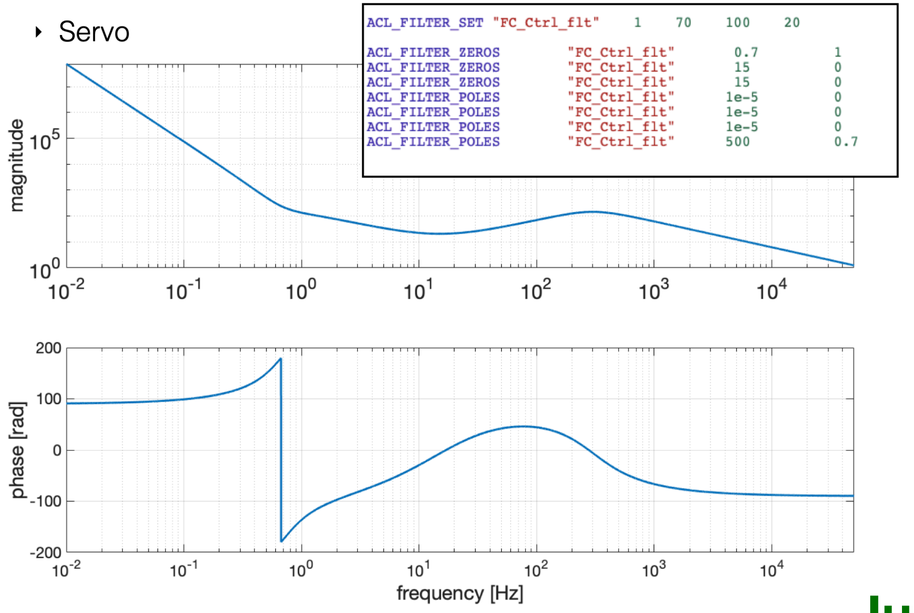
Milestones

Filter cavity locked on green

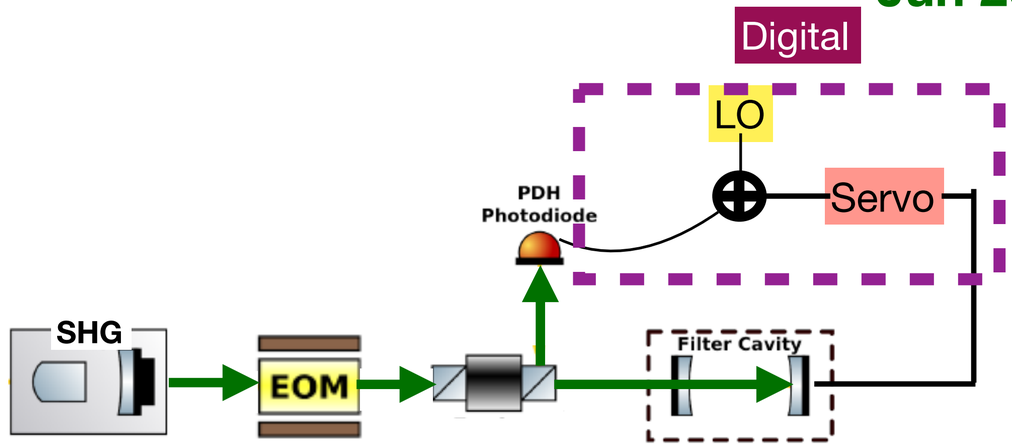
Optical gain + cavity pole | Photodiode | Servo | Coil | Pendulum

$$G_{OL}\left[\frac{V}{V}\right] = G_{cav}\cdot G_{opt}\left[\frac{W}{m}\right]\cdot G_{PD}\left[\frac{V}{W}\right]\cdot G_{servo}\left[\frac{V}{V}\right]\cdot G_{coil}\left[\frac{N}{V}\right]\cdot G_{pen}\left[\frac{m}{N}\right]$$





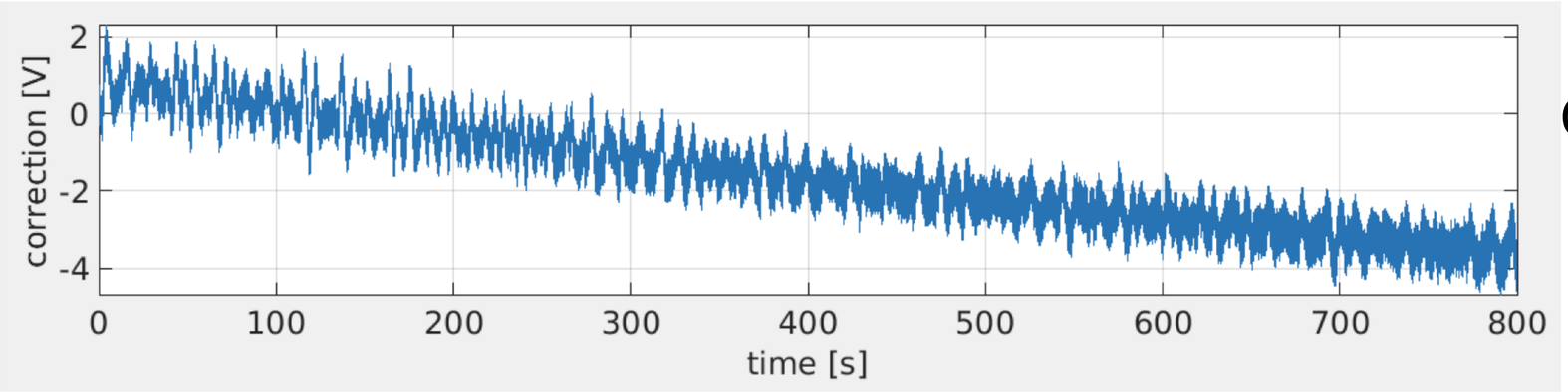
Jun 2021



- Locking not stable
- Bandwidth limited by delay

Milestones

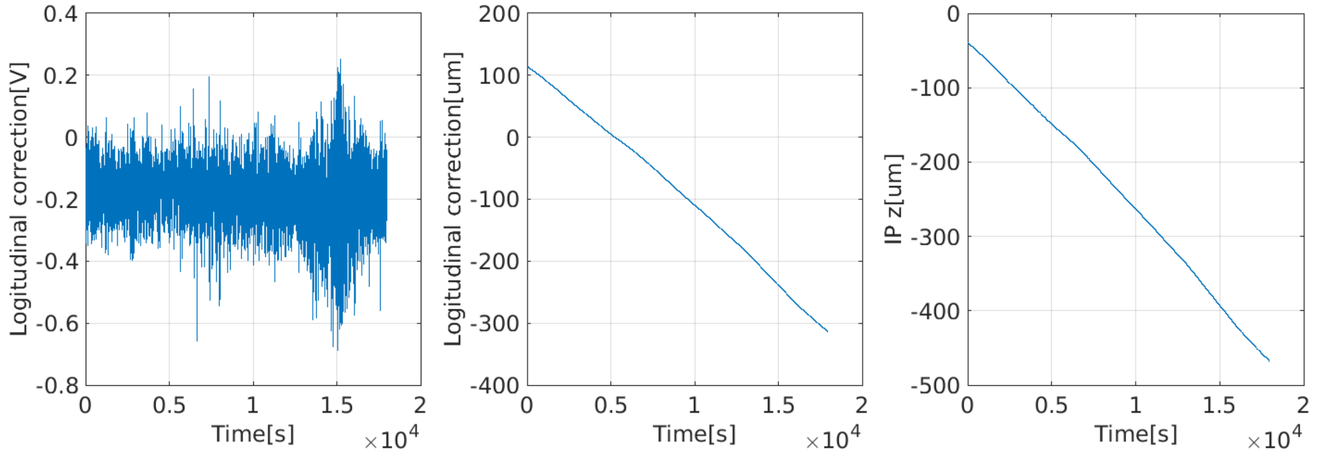
Improve locking stability



Correction signal long term drift

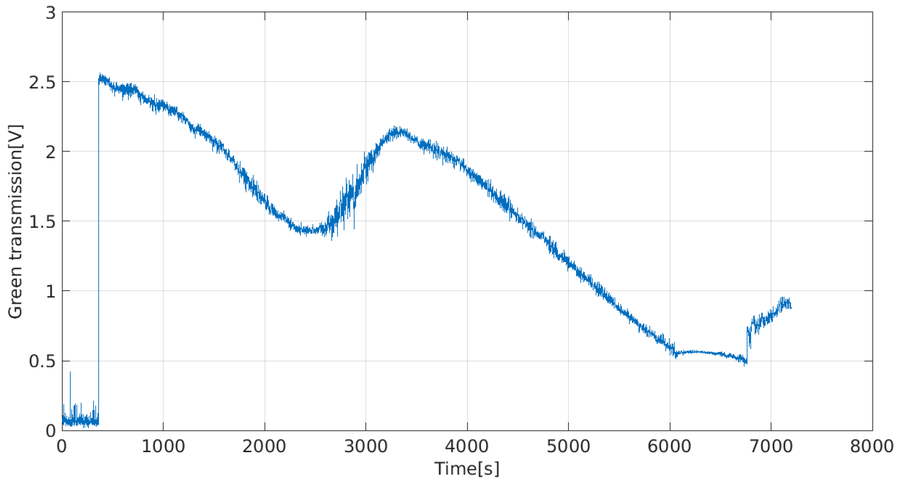
Actuator saturation

Longitudinal correction signal has been low passed and sent to the Inverted Pendulum



Milestones

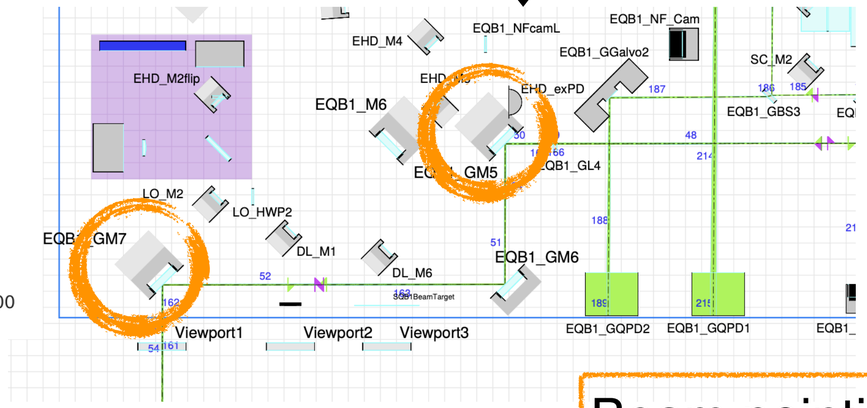
Improve locking stability



Temperature change

Cavity alignment drift

Different frequency lines

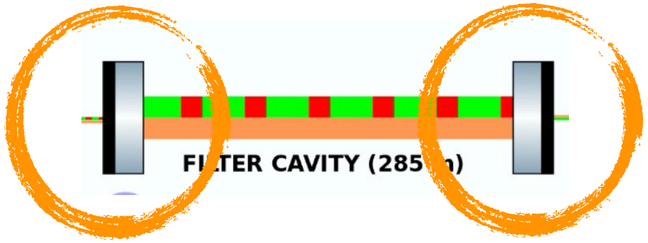


Error signals

Green transmission signal

Demod

Beam pointing control



Longitudinal PDH signal

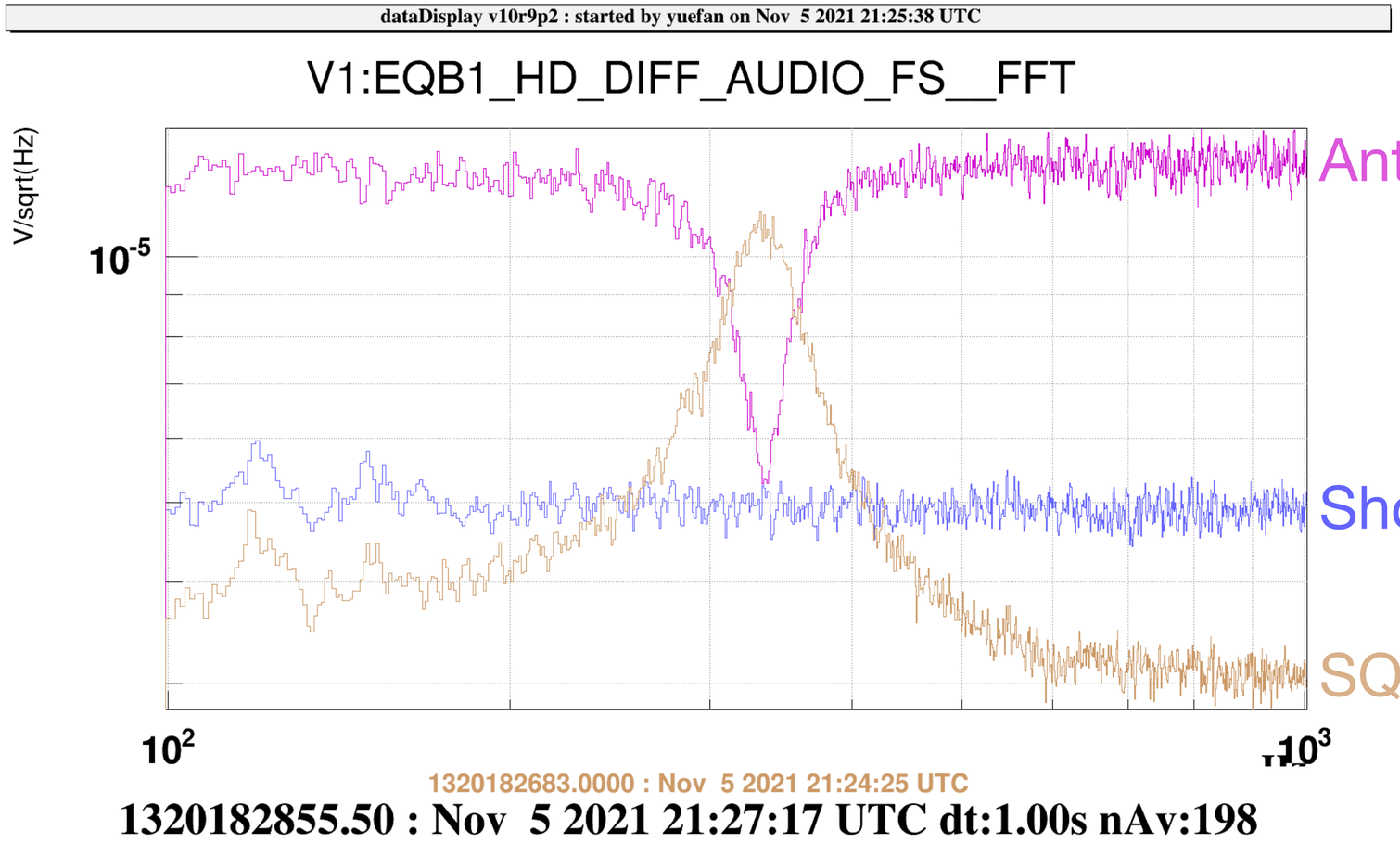
Demod

Drift control

Milestones

First FDS measurement

- Detuning frequency > 300Hz
- Didn’t reach shot noise

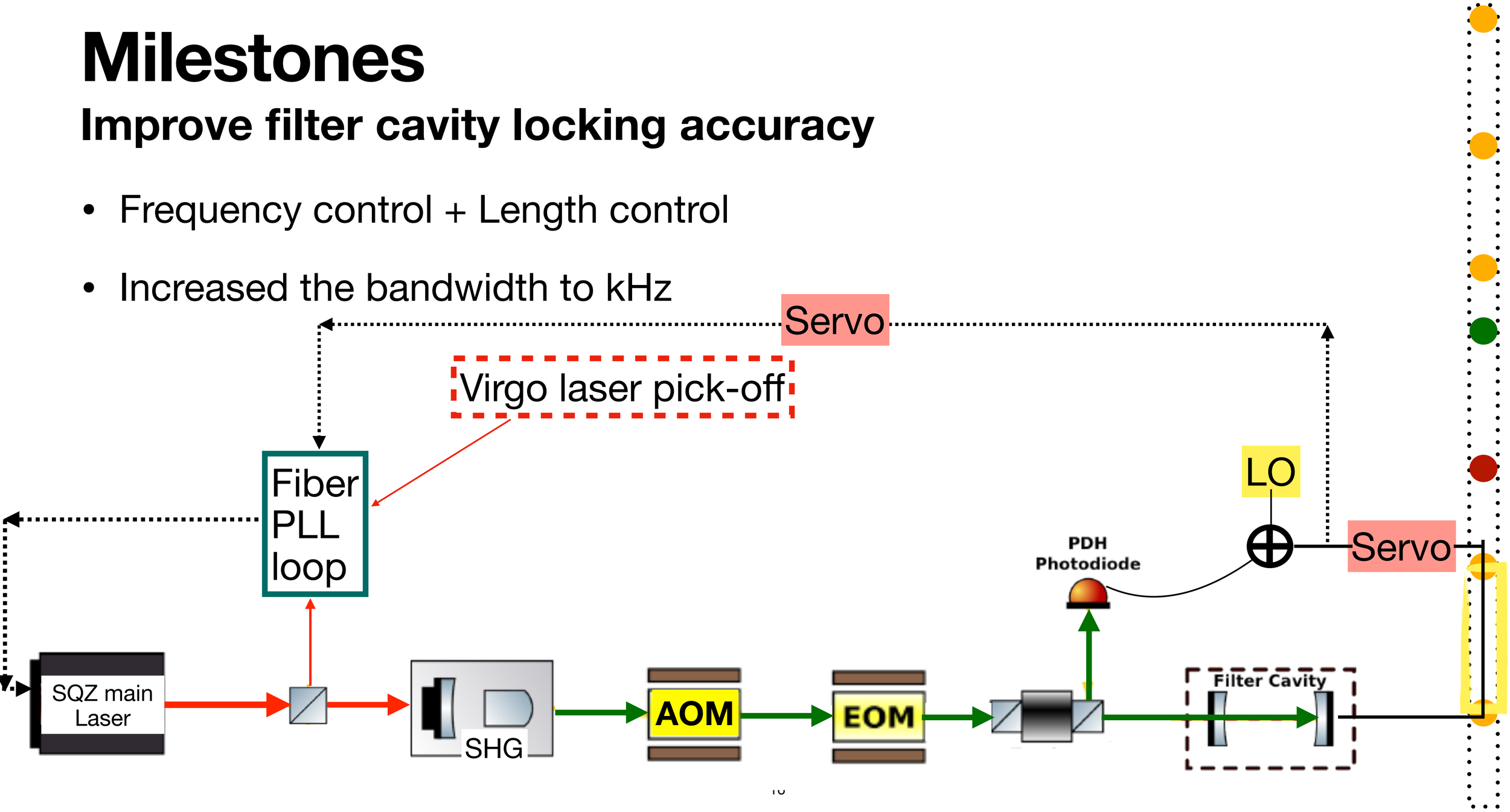


Nov 2021

Milestones

Improve filter cavity locking accuracy

- Frequency control + Length control
- Increased the bandwidth to kHz



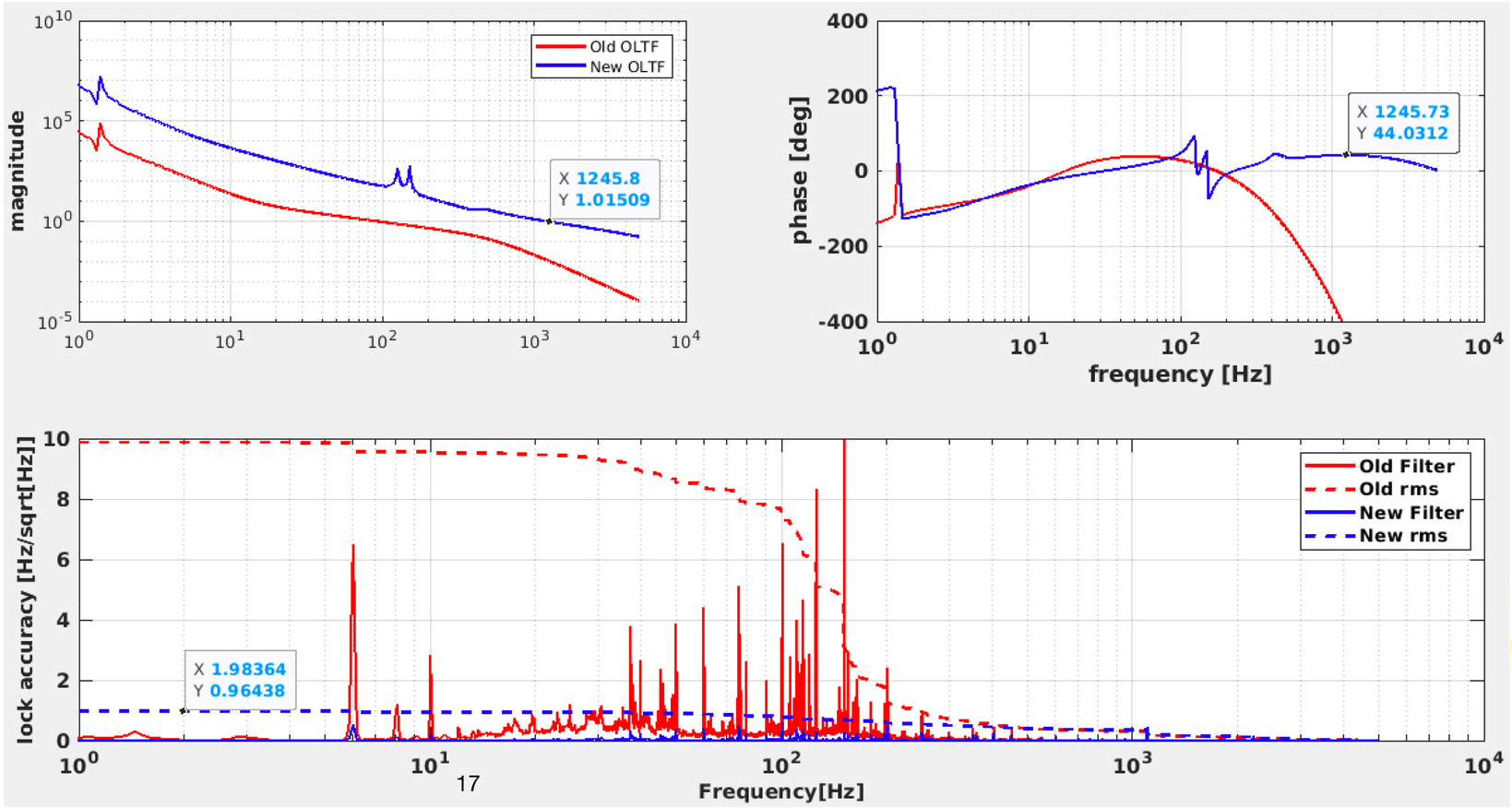
Milestones

Improve filter cavity locking accuracy

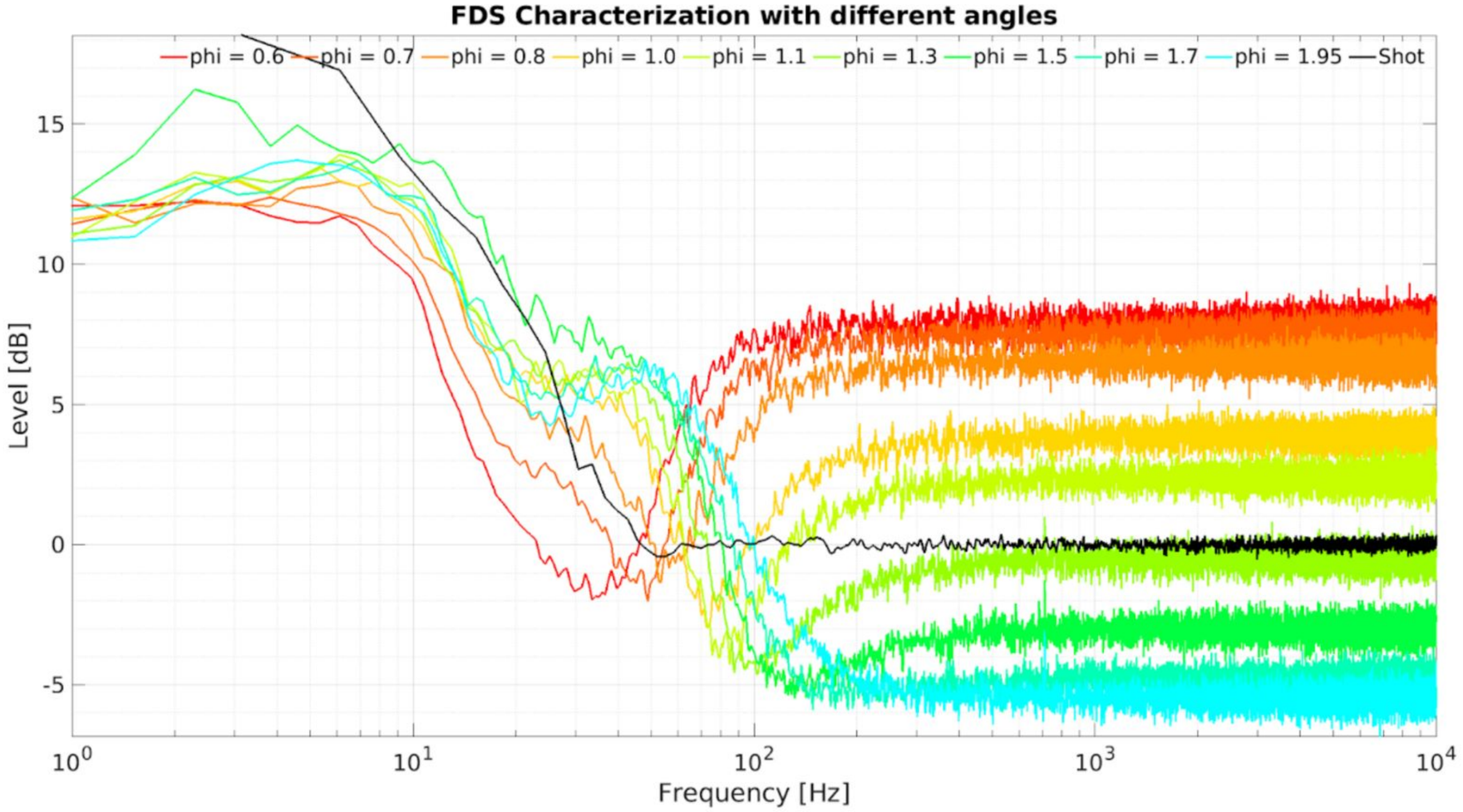
- Frequency control + Length control
- Increased the bandwidth to kHz
- Lock accuracy <**1Hz**

Only length control

Length + frequency control



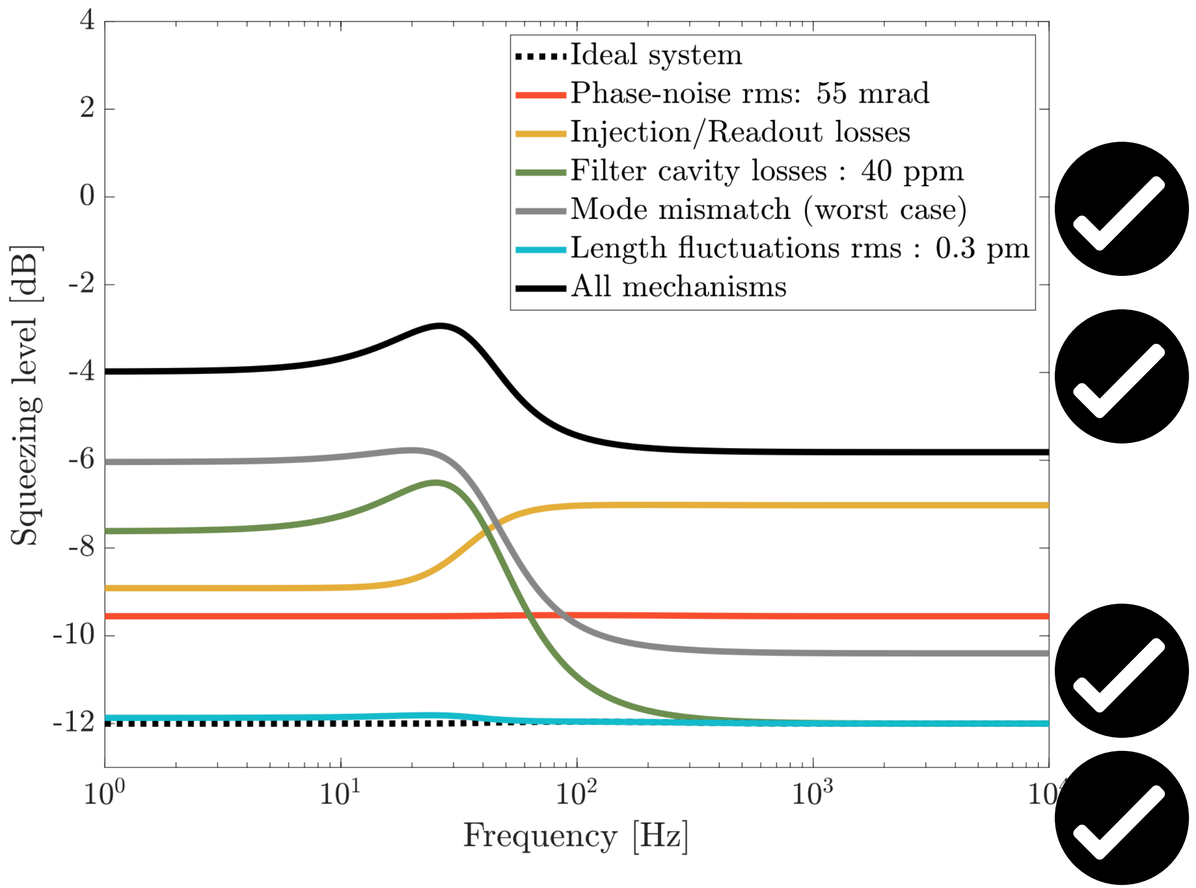
Frequency dependent squeezing measurement



- After improved FC locking accuracy
- Detuning 25Hz
- Characterization from Homodyne angle 0.55rad to 2.05rad in **~30min**
- 2dB sqz in low frequency
- 5dB sqz in high frequency

*Homodyne angle is a relative value

Frequency dependent squeezing degradation



	Obtained	Expected
Phase noise	31mrad	20~60mrad
Losses	12%	12%
Filter cavity Round trip losses	81ppm	40ppm
Mode mismatching	2%	2%
Filter cavity length fluctuations	1Hz	<1Hz

System long term stability test on going

Next steps

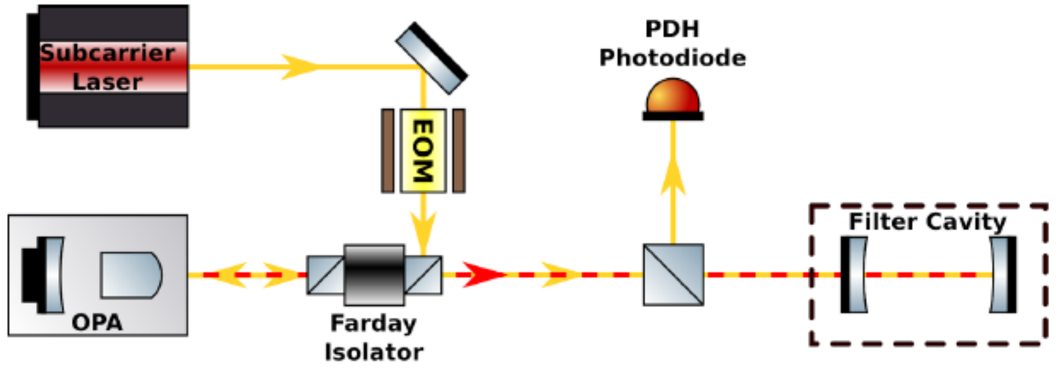
- Prepare the injection path towards the ITF
- Injection of FIS/FDS to the ITF

Backup

Sub carrier

Choice of the frequency shift: **1.26 GHz**

- Resonance in the filter cavity
- Detuning at 25 Hz
- No-interference with coherent control beam (4 MHz shifted wrt main laser)
- Completely reflected by the ITF Output Mode CleanerÂ
- Negligible impact with the interferometer controls



Lock of the Filter cavity on IR Beam (subcarrier Laser)

- The subcarrier laser must be offsetted with a PLL by 1.2 GHz wrt the Squeezer Main Laser
- Tune the Green AOM modulation frequency to find the co-resonance condition between IR and GR in the filter cavity
- Pass the lock of the filter cavity from Green PDH error signal to IR PDH error signal
- Close the automatic alignment loop of the IR on the filter cavity