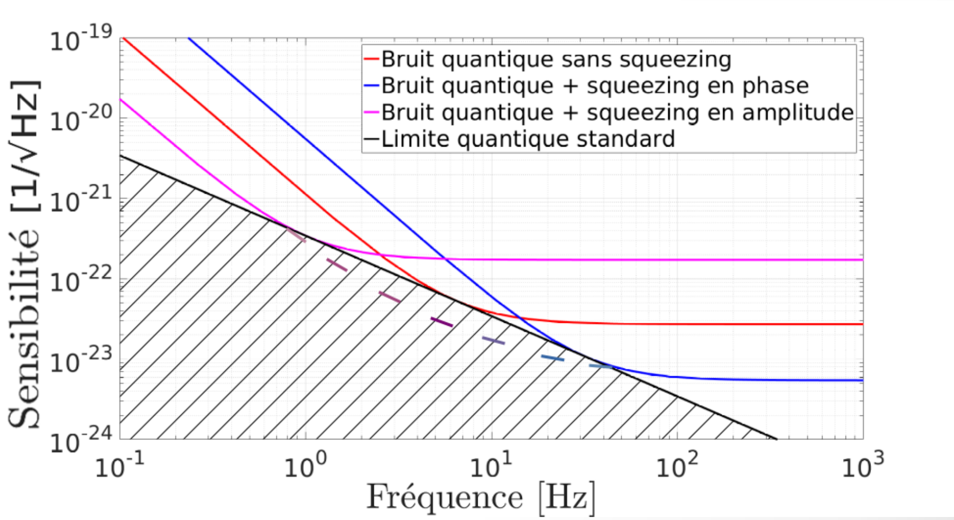
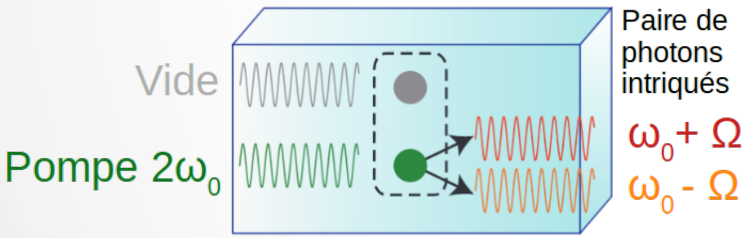
In-vacuum squeezer for Advanced Virgo+ and plans at CALVA

Nicolas Leroy et Angélique Lartaux – IJCLab

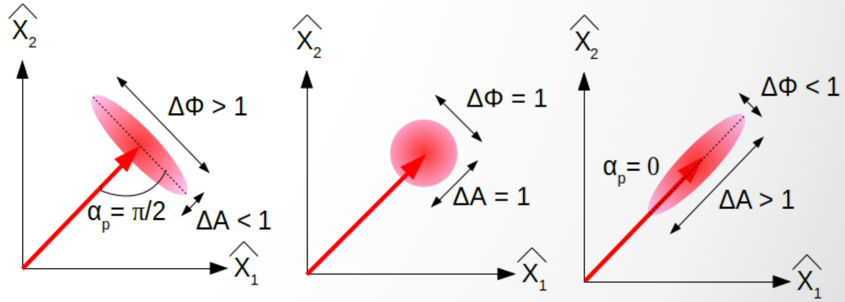
Quantum noise

- Low frequency : fluctuation of of the radiation pressure
- High frequency : shot noise
- Using non linear effect to squeezed light state



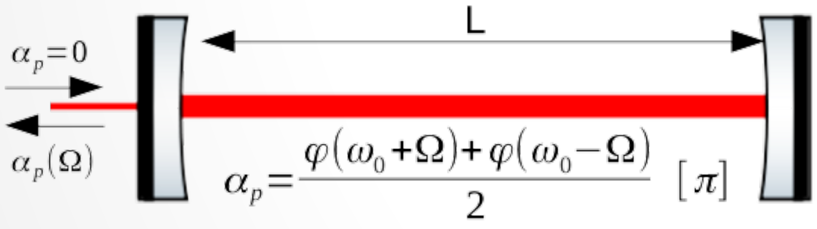


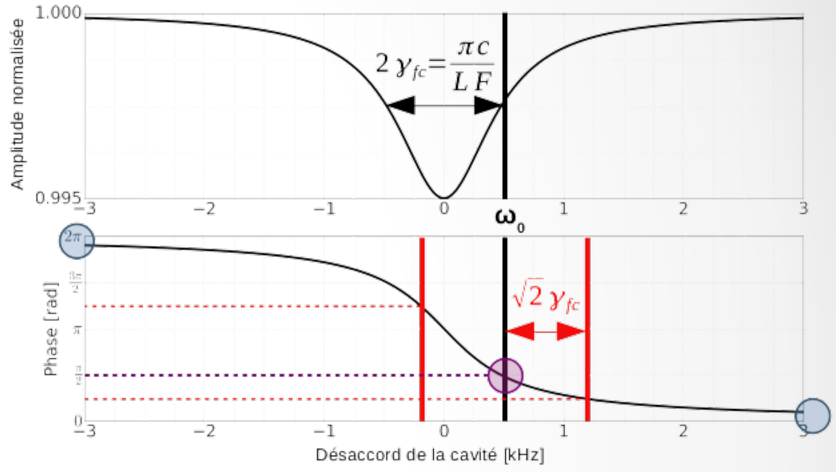
$$\alpha_p = \frac{\varphi(\omega_0+\Omega)+\varphi(\omega_0-\Omega)}{2} \quad [\pi]$$

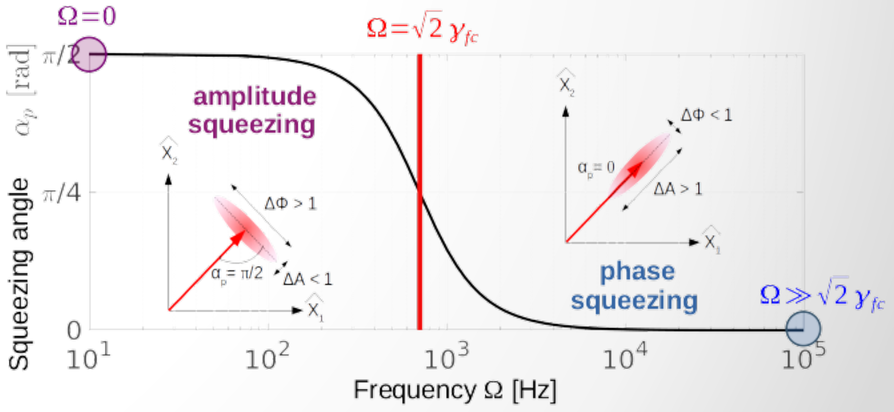


Frequency dependent squeezing

- Add a filtering cavity
- Intricated photons with different frequency will have a different phase shift in reflection
- It is then possible to have phase shift of Pi/2 at low frequency
- Flip frequency (a_p = pi/4) depends on cavity length and finesse







Why going for an in-vacuum squeezer ?

- Any loss in the system will degrade the squeezing level
  - With a typical 10 dB of squeezing achieved at the squeezer level only 3 dB (record is 6 dB) are measured in the interferometers
- From past experience :
  - Diffuse light – can be reduced with seismic isolation
  - Environmental noise : acoustic, ...

Exsqueez project

Exsqueez is an ANR funded project conducted by 4 laboratories:

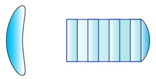
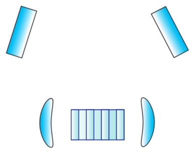
ANR ExSqueez LKB IJCLab Irène Joliot-Curie Laboratoire de Physique des 2 Infinis iP2i LES 2 INFINIS LYON LAPP

Goal: Demonstrate under vacuum frequency dependent squeezing (FDS) in the prospect of the Advanced Virgo detector O5 run.

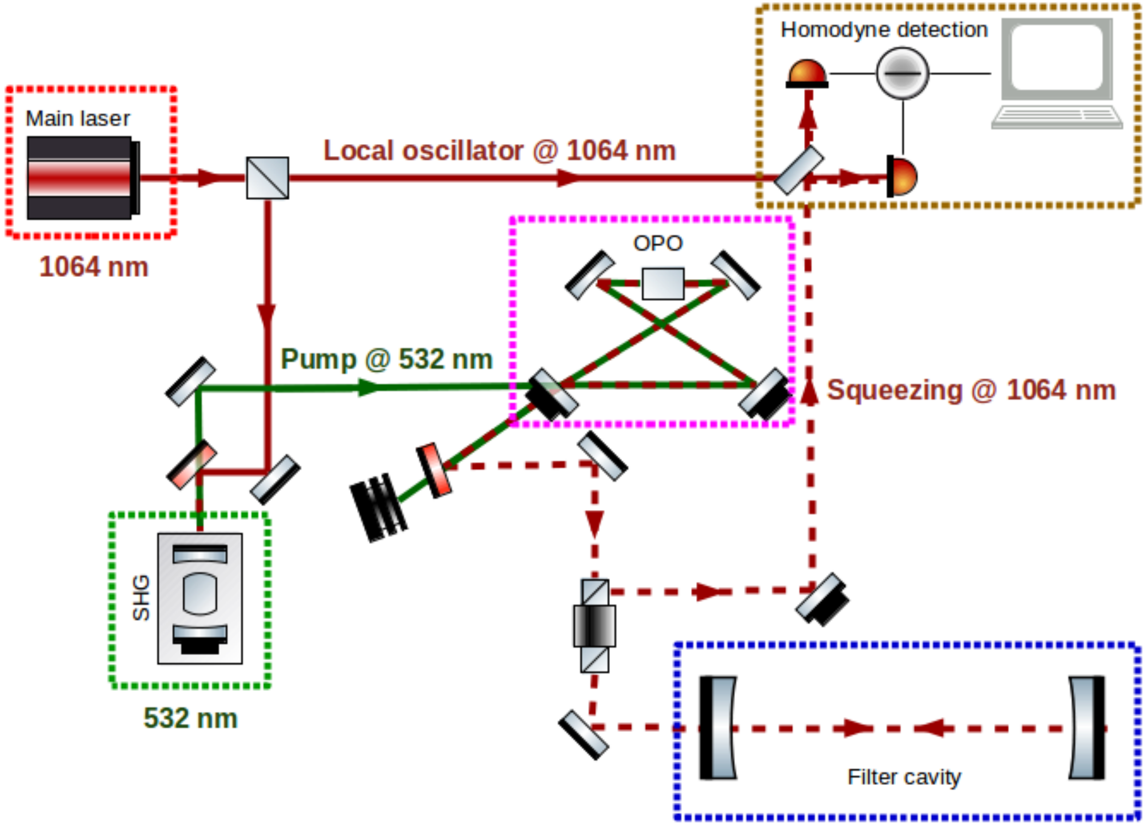
- Squeezing source from LKB
- Existing 50-m filter cavity on the CALVA facility at IJCLab
- Optics coatings from IP2I/LMA
- Electronics from LAPP in the Virgo standards

Need to associate labs from INP and IN2P3

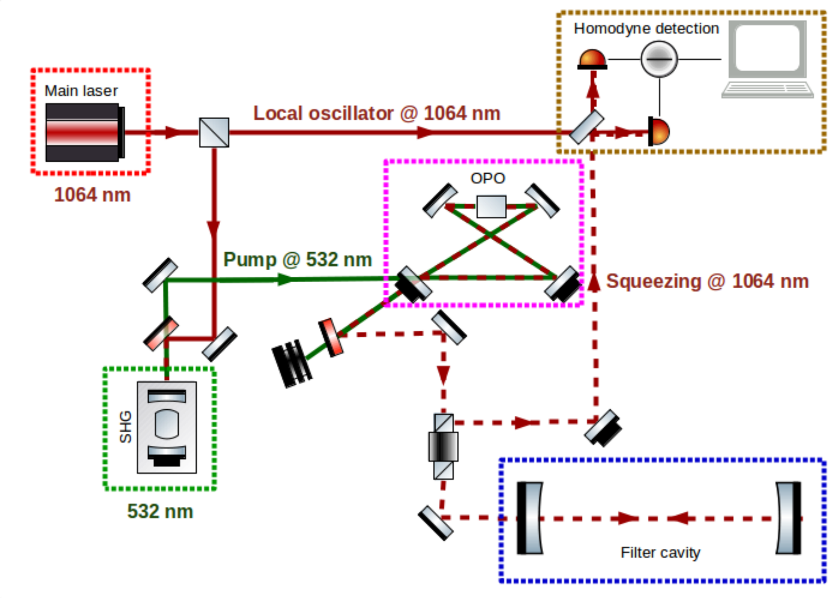
Squeezers

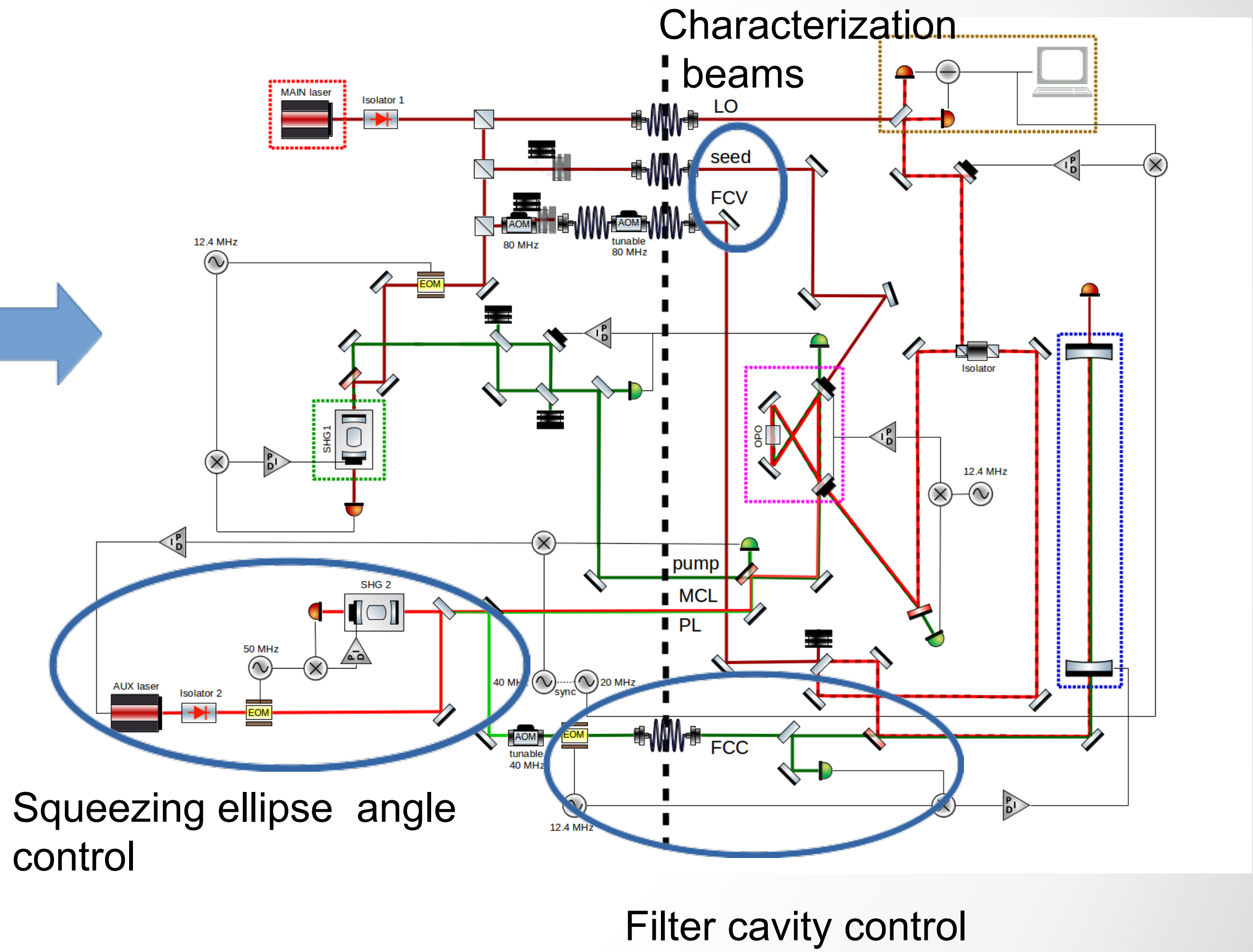
	Environment	OPO cavity design	Filter cavity
Advanced Virgo (O4)	In-air	Hemilithic 	285 m
Exsqueez	Under vacuum	Bow-Tie 	50 m

Simplified scheme



Simplify scheme

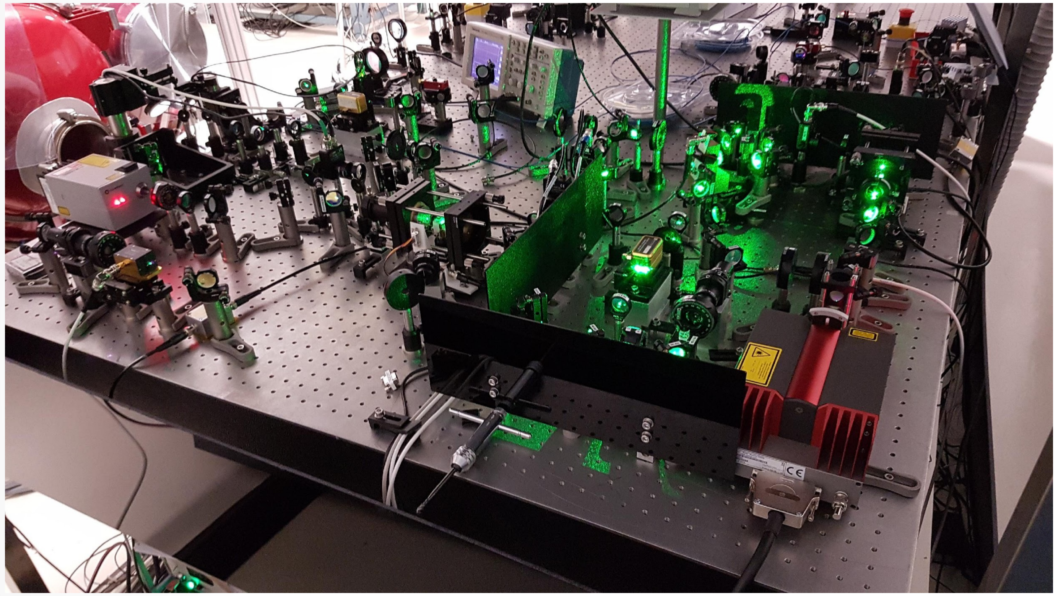




- 7 beams generated on the in-air laser preparation bench and sent to the in-vacuum bench
- 2 IR laser
- 2 Second Harmonic Generators (SHG) to produce green beams

Laser bench

Mach-Zehnder for pump power control



Frequency doubler 200 mW at 532nm
(pump beam)

Main laser, 2W at 1064nm:
- to generate pump beam
- Local oscillator beam
- Seed beam
- Filter Cavity Verification beam

Auxiliary laser, 500 mW at 1064nm:
- Modified Coherent Locking beam
- to generate Filter Cavity Control beam

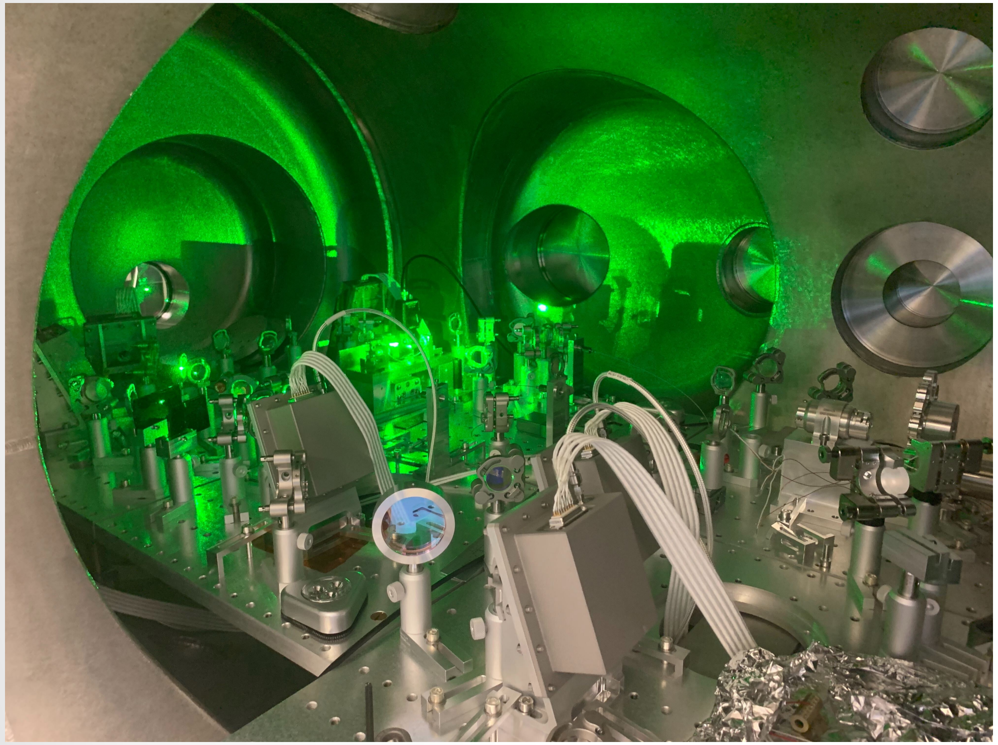
Frequency doubler 50mW at 532nm
(Filter Cavity Control beam)

In vacuum bench

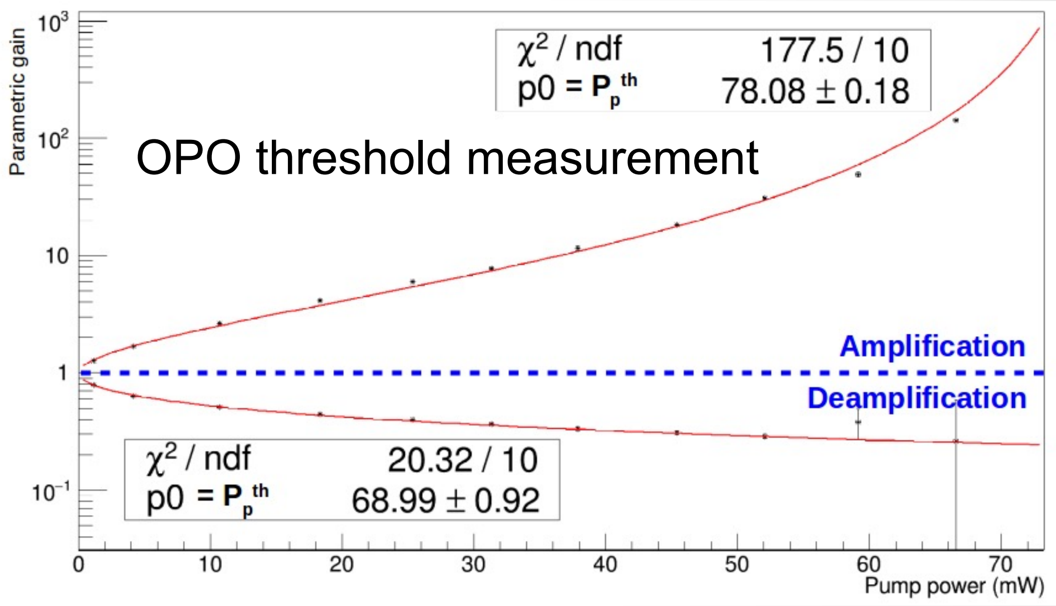
~ 10^{-6} – 10^{-7} mbar

OPO

Faraday Isolator



Homodyne detection

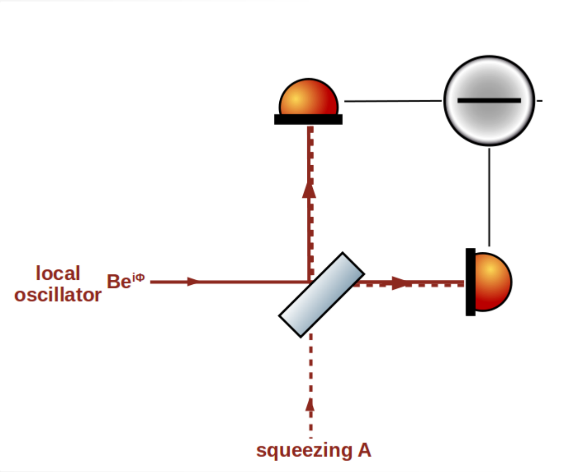


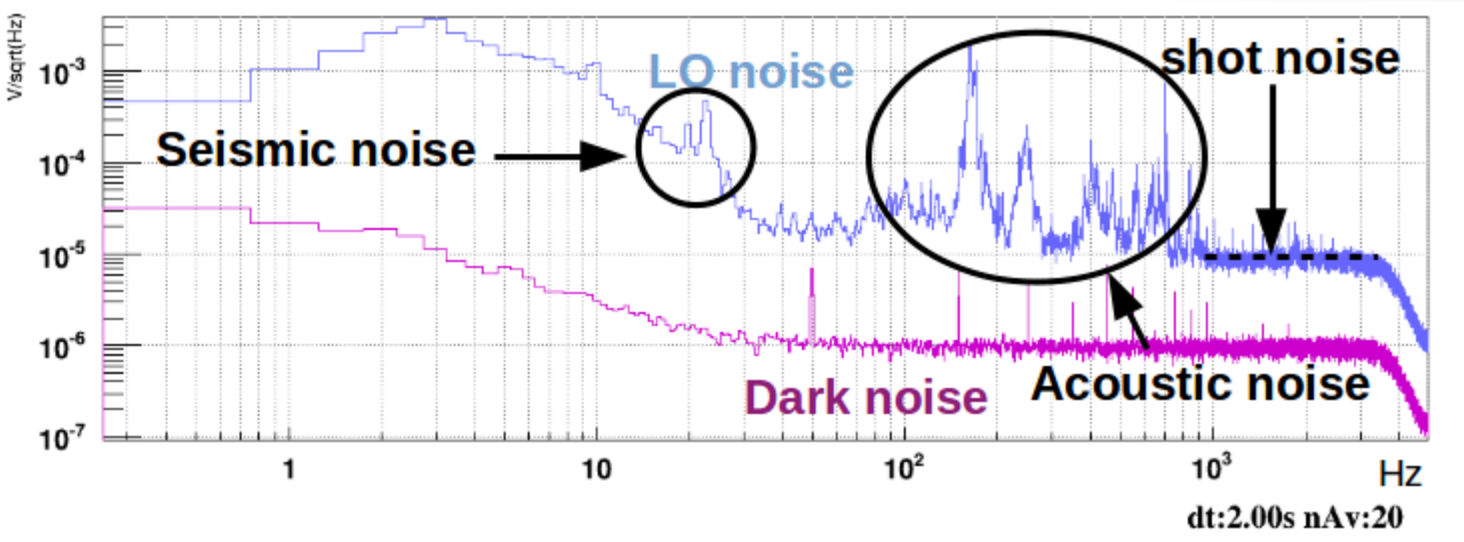
=> This bench is completed for in-air FIS

=> few more steps for in-vacuum FDS

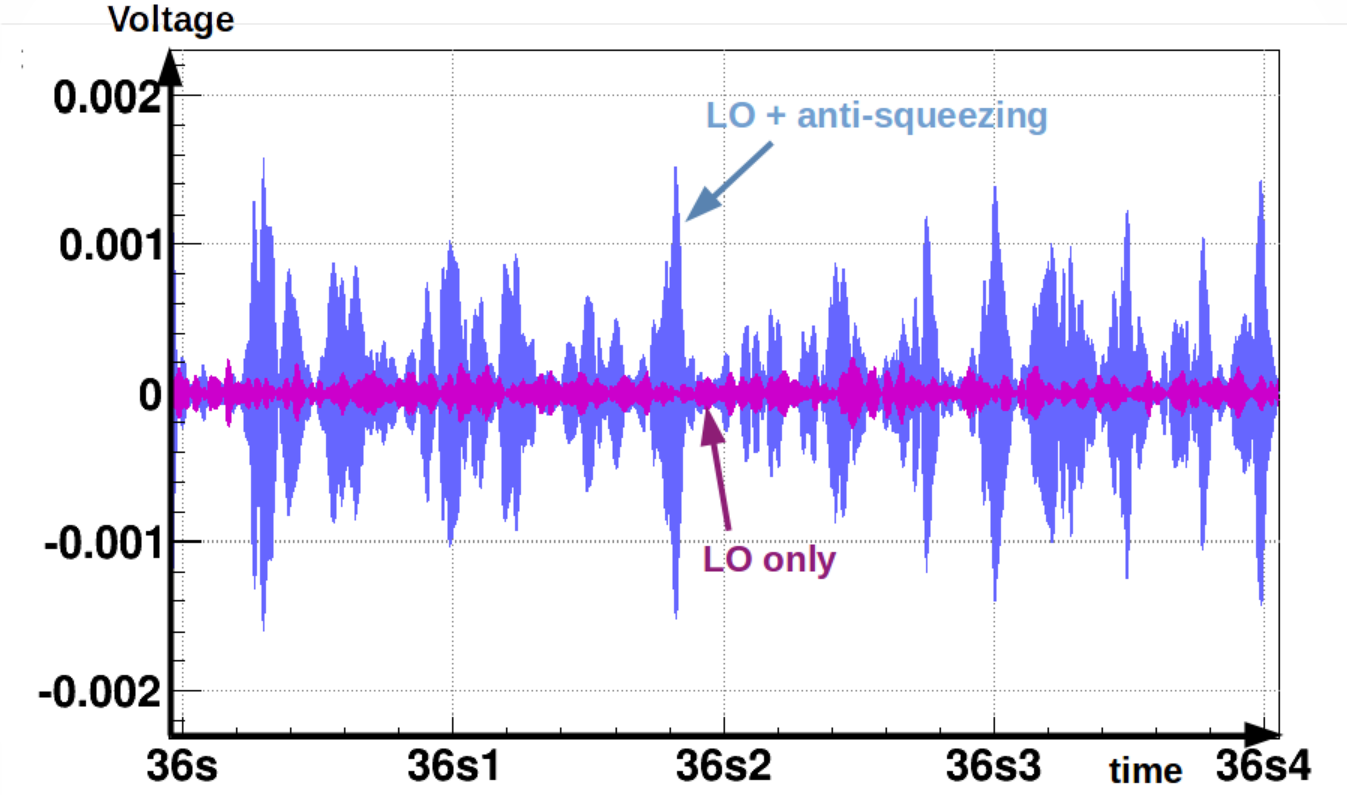
Environment under vacuum

- Squeezing measurement via homodyne detection to amplify low power squeezing signal with higher power local oscillator
- Homodyne detection noise measured => acoustic noise in the audio band (between 100 Hz and 1 kHz)

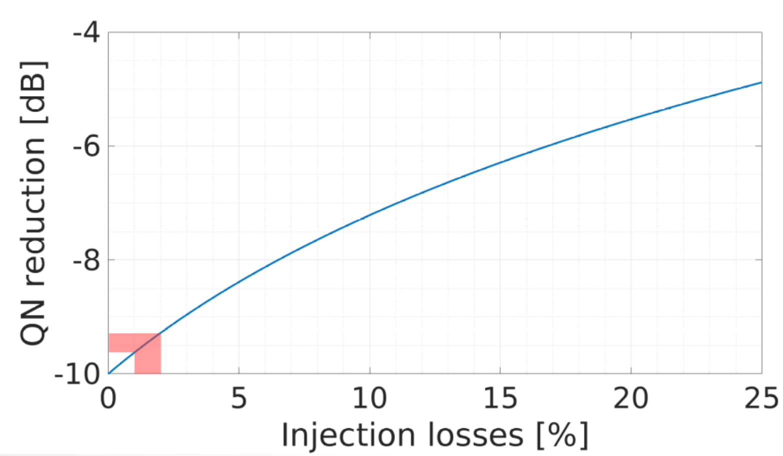


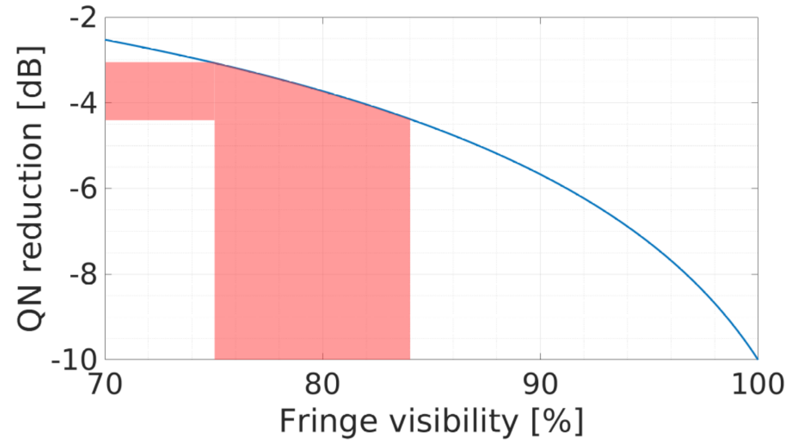


Frequency independent anti-squeezing

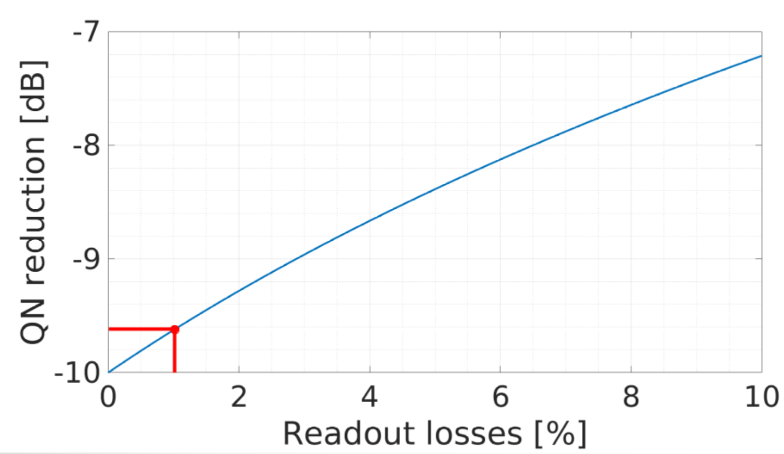


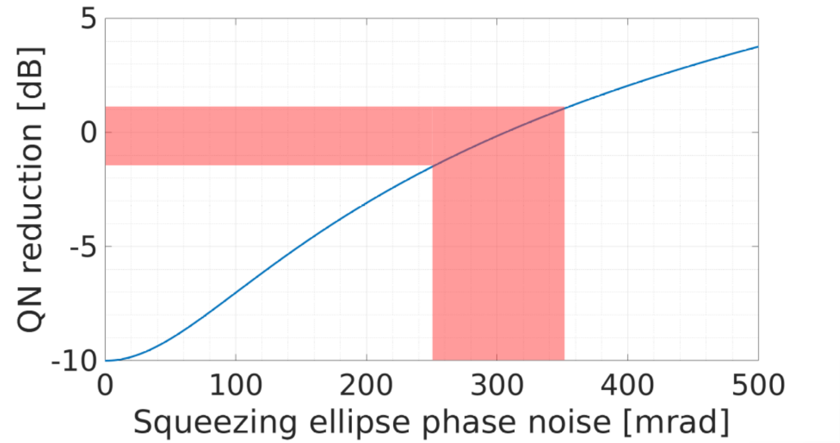
First characterization





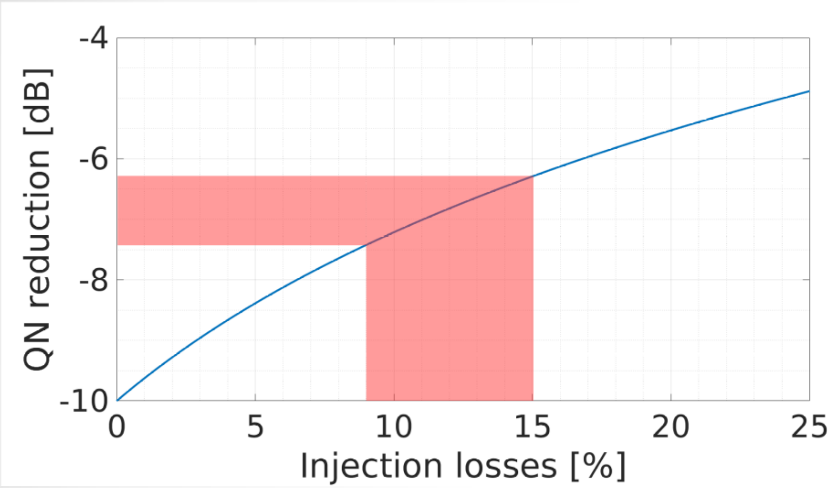
Squeezing matching to the LO
=> under improvement

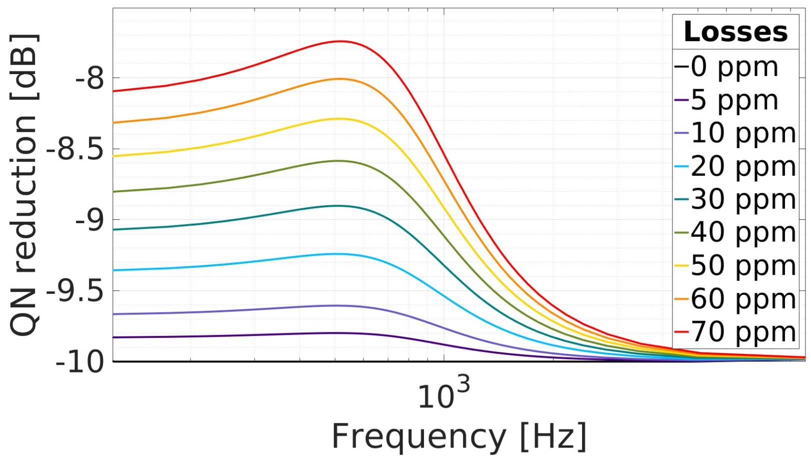


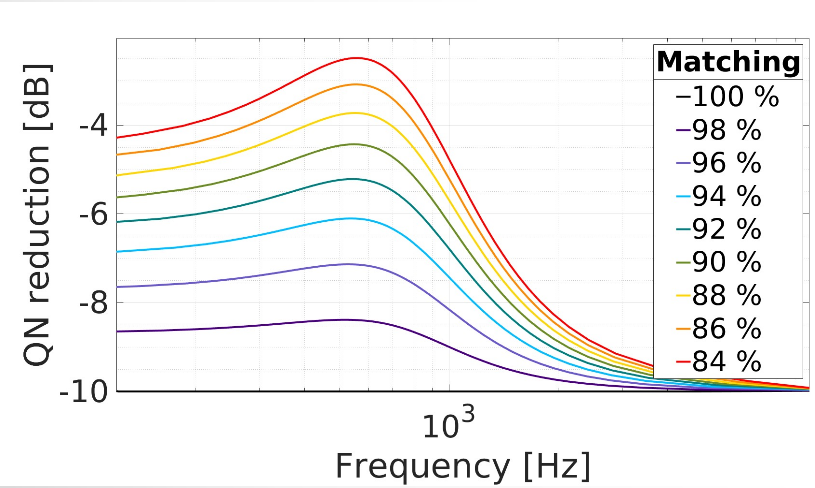


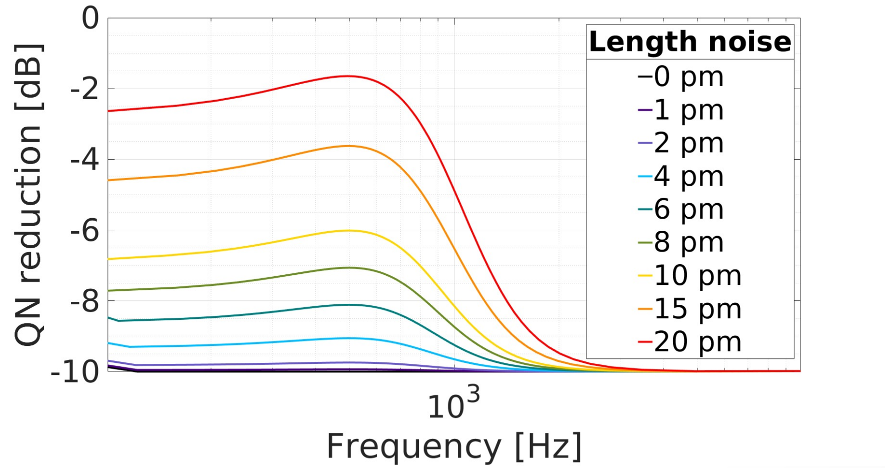
Residual squeezing ellipse jitter too high
=> under improvement

Frequency dependent losses









- More injection losses

- New frequency dependent losses linked to the filter cavity
  => reduce FDS level at low frequencies
  => need to be carefully controlled

Filter cavity

- Advanced Virgo: 285 m to obtain a corner frequency of ~ 35 Hz

- Exsqueez: existing 50 m suspended cavity on the CALVA facility mirrors coating to obtain a finesse 3000 @ 1064 nm => ~700 Hz corner frequency

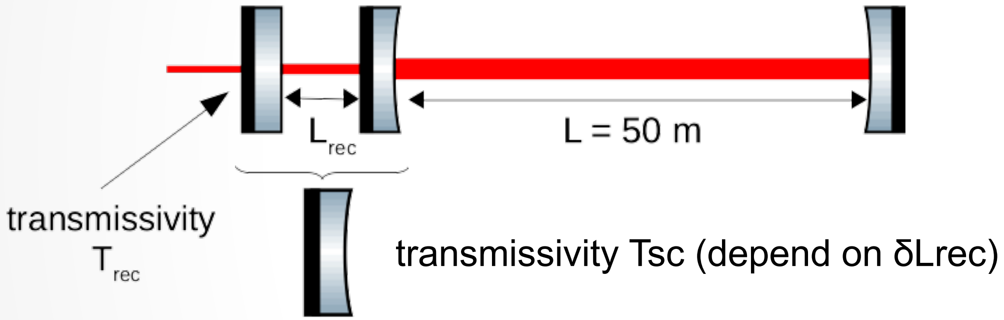
$$\Omega_{SQL} \simeq \frac{8}{c}\sqrt{\frac{P_{arm}\,\omega_0}{m T_{arm}}} \quad \Rightarrow \quad \gamma_{fc} = \frac{2\pi\Omega_{SQL}}{\sqrt{2}} \quad \Rightarrow \quad \gamma_{fc} = \frac{\pi c}{2 L_{fc} F}$$

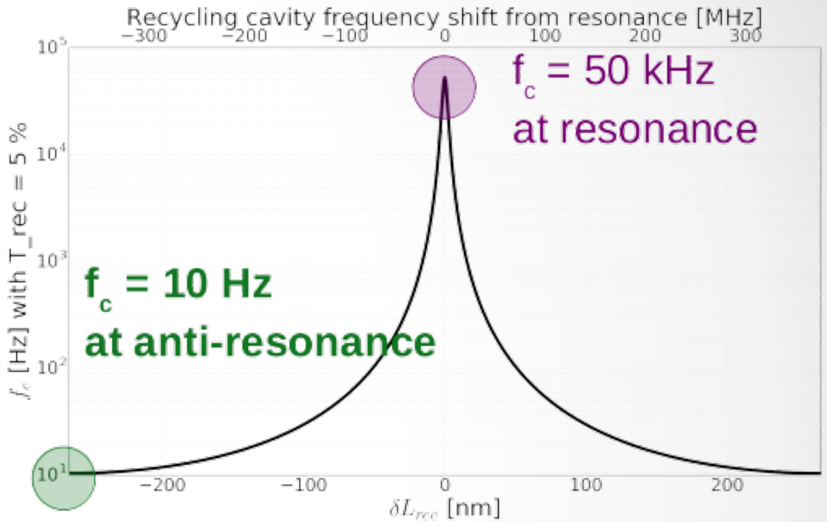
Not very flexible once length and finesse (mirror coating) have been fixed

- QFilter: variable finesse filter cavity to lower down the corner frequency and adjust it

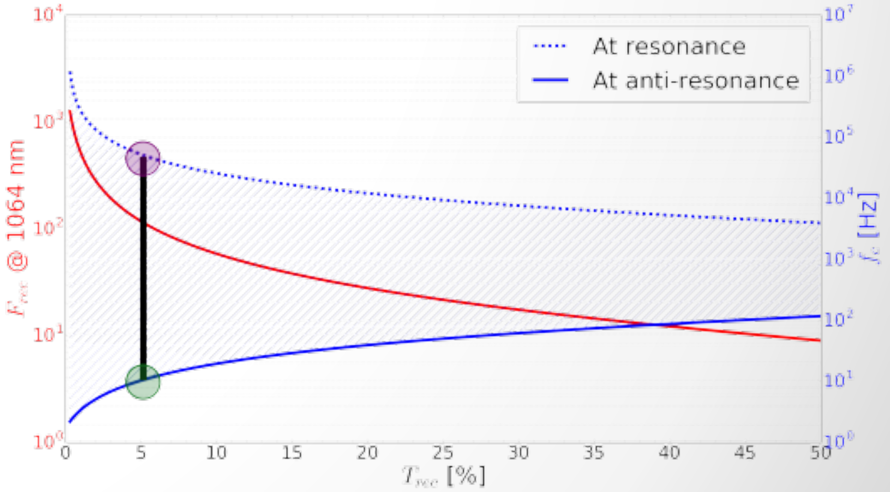
QFilter

- Add short cavity (Lrec ~ 20 cm) in front of the long filter cavity





- Simulation on-going to determine the optimal parameters for the coupled cavity (reflectivities, mirrors radius of curvature, etc.)



Conclusions

- First set-up installed for in-air frequency independent squeezing (FIS) characterization => need improvement of the squeezing angle lock
- Next step, put the system under vacuum => check the effect on acoustic noise and squeezing level
- Then we will send the FIS to the filter cavity to measure FDS with ~ 700 Hz corner frequency
- Finally we will add a short cavity to lower down and adjust the corner frequency by adjusting the filter cavity finesse
- We will study the possibility for an in-vacuum squeezing source for O5 run (2024)
- New filter cavity design could be useful for post O5 or Einstein Telescope