Status of the Frequency Dependent Squeezing Experiment @ TAMA

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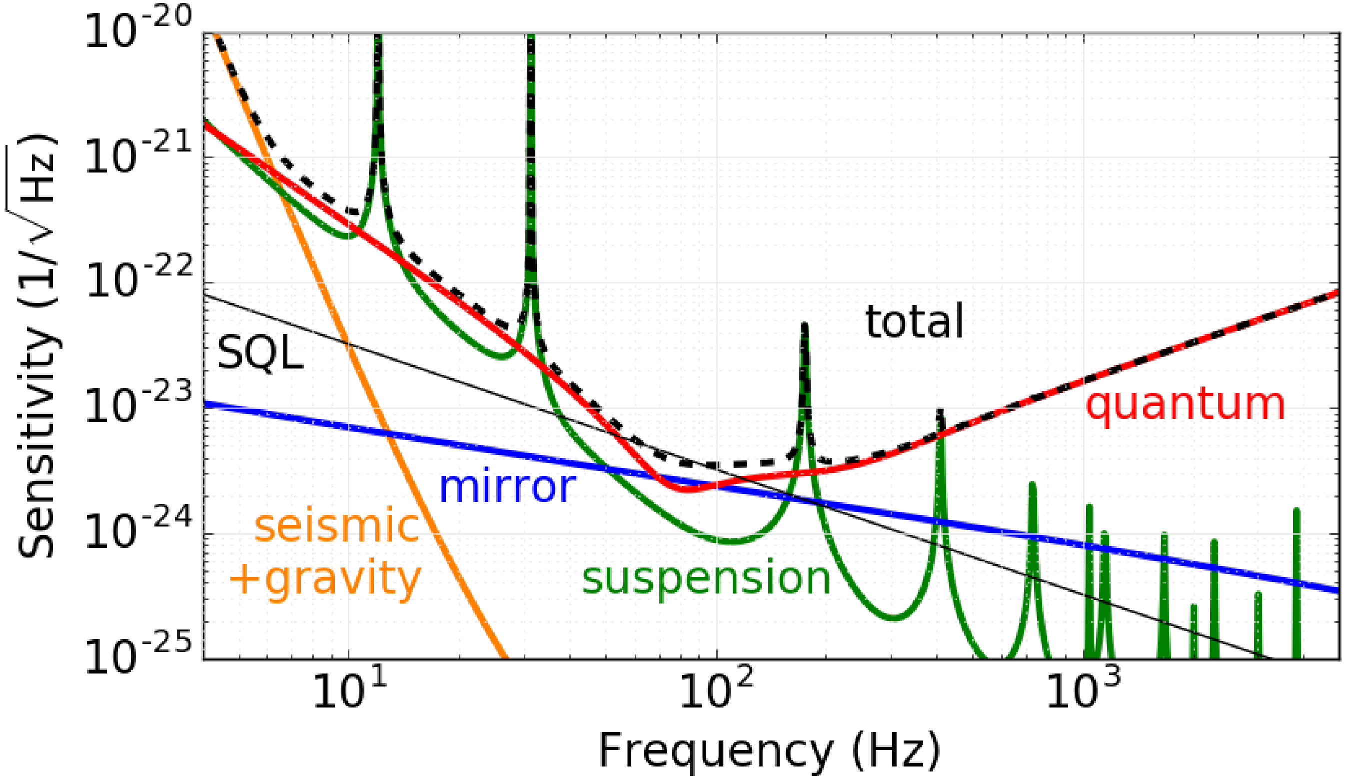
Motivations

- Quantum noise will limit the sensitivity of next generation GW detectors over a large part of the frequency band
- Even more true for cryogenic detectors as KAGRA with reduced thermal noise
- Shot noise can be reduced by increasing the laser power
  - More difficult to do in a cryogenic interferometer
  - Squeezing for risk reduction

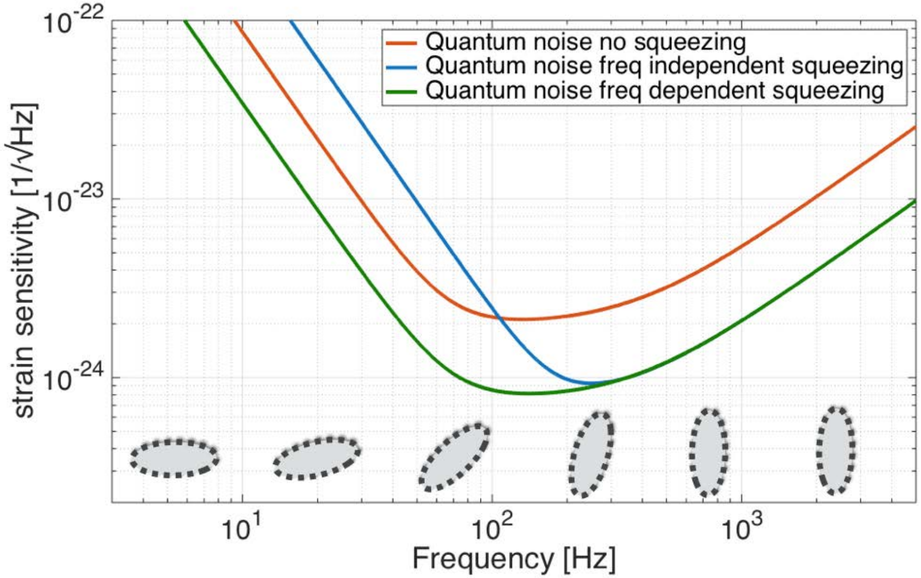


Frequency dependent squeezing

- Need for frequency dependent squeezing in the 100 Hz region
- Frequency dependent squeezing already achieved in the MHz region [1] and in the kHz region [2]

  [1] S. Chelkowsky et al., Phys. Rev. A 71, 2005

  [2] E. Oelker et al., Phys. Rev. Lett. 116, 2016



Study for KAGRA

- Study of impact of frequency dependent squeezing on KAGRA sensitivity
  - 9 dB vacuum squeezed source
  - 300 m filter cavity with 80 ppm round trip losses

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Estimation of losses in a 300 m filter cavity and quantum noise reduction in the KAGRA gravitational-wave detector

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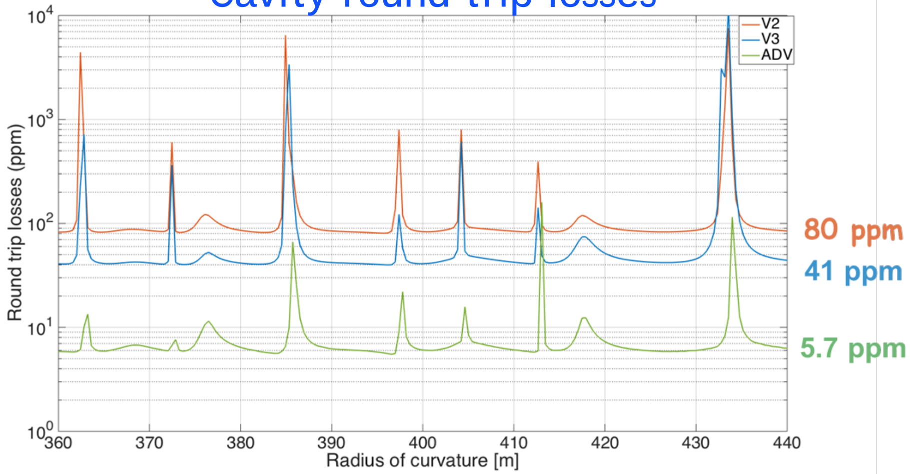
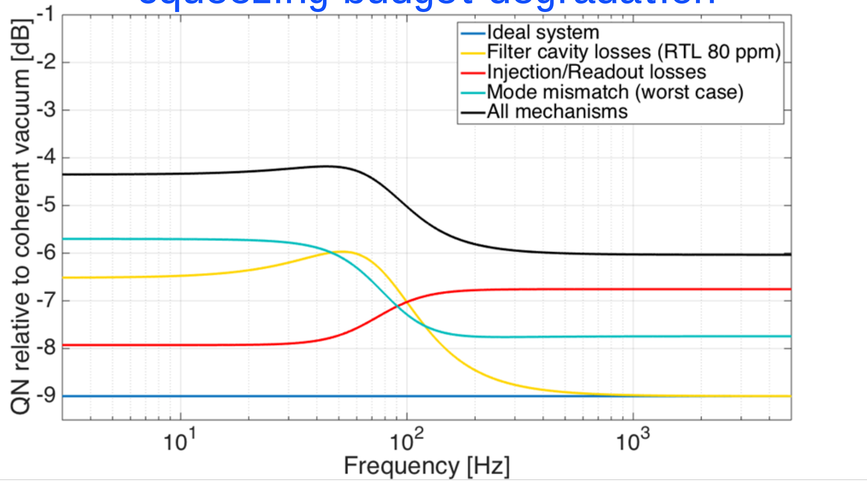
Study for KAGRA

- Filter cavity design study with realistic mirrors
  - 9 dB of squeezing
  - cavity length 300 m
  - RTL 80 ppm

Cavity round trip losses



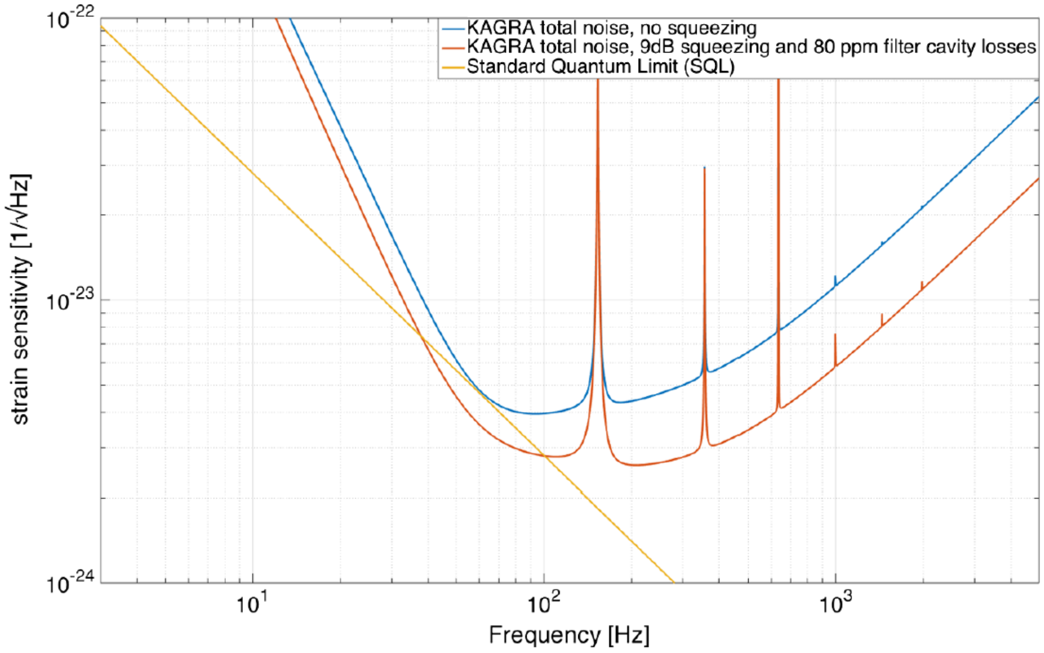
Squeezing budget degradation



		RMS [nm]	RMS [nm]	RMS [nm]
diameter[m]	0.05	1.23	1.36	0.27
diameter[m]	0.01	0.81	0.53	0.18

Study for KAGRA

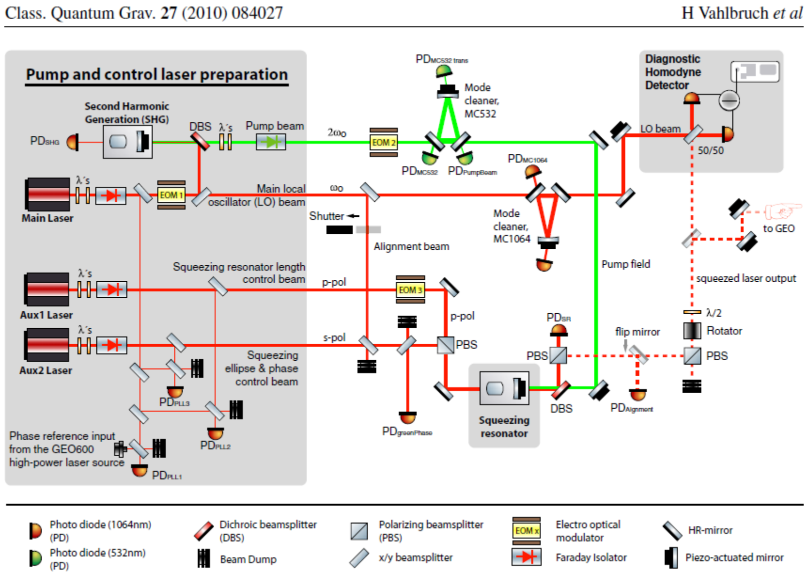
- Study of impact of frequency dependent squeezing on KAGRA sensitivity
  - ◆ 9 dB vacuum squeezed source
  - ◆ 300 m filter cavity with 80 ppm round trip losses



- Use of squeezing also allow reducing the required laser power
  - ◆ Can be very important for a cryogenic detector

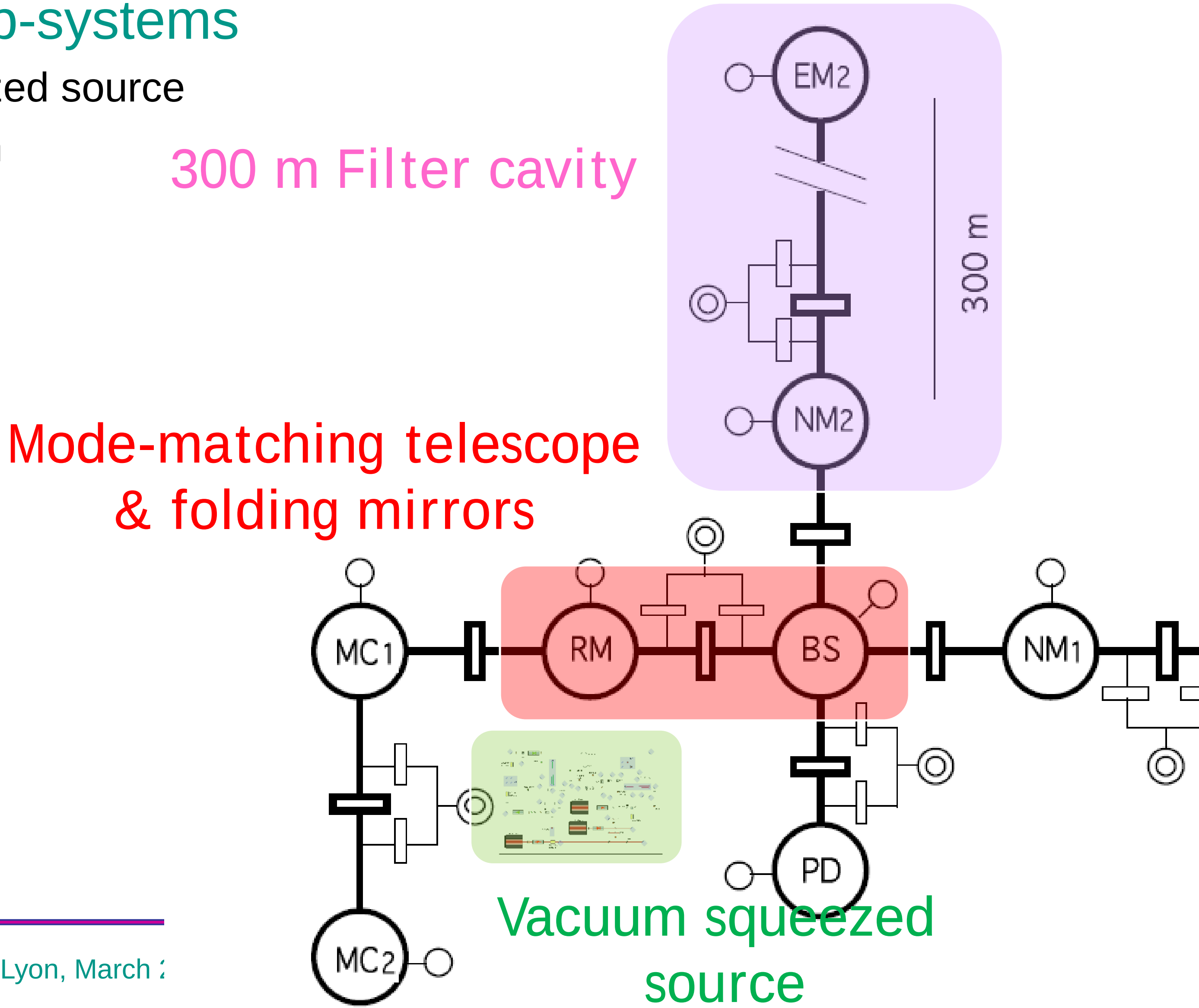
Proposal

- Proposal to JSPS
  - “Development of frequency dependent squeezing for next generation GW detectors”
- Main ingredients
  - Use of TAMA 300 infrastructure
  - Use of GEO-like vacuum squeezed source
- Approved by JSPS in 2015



Experiment lay-out

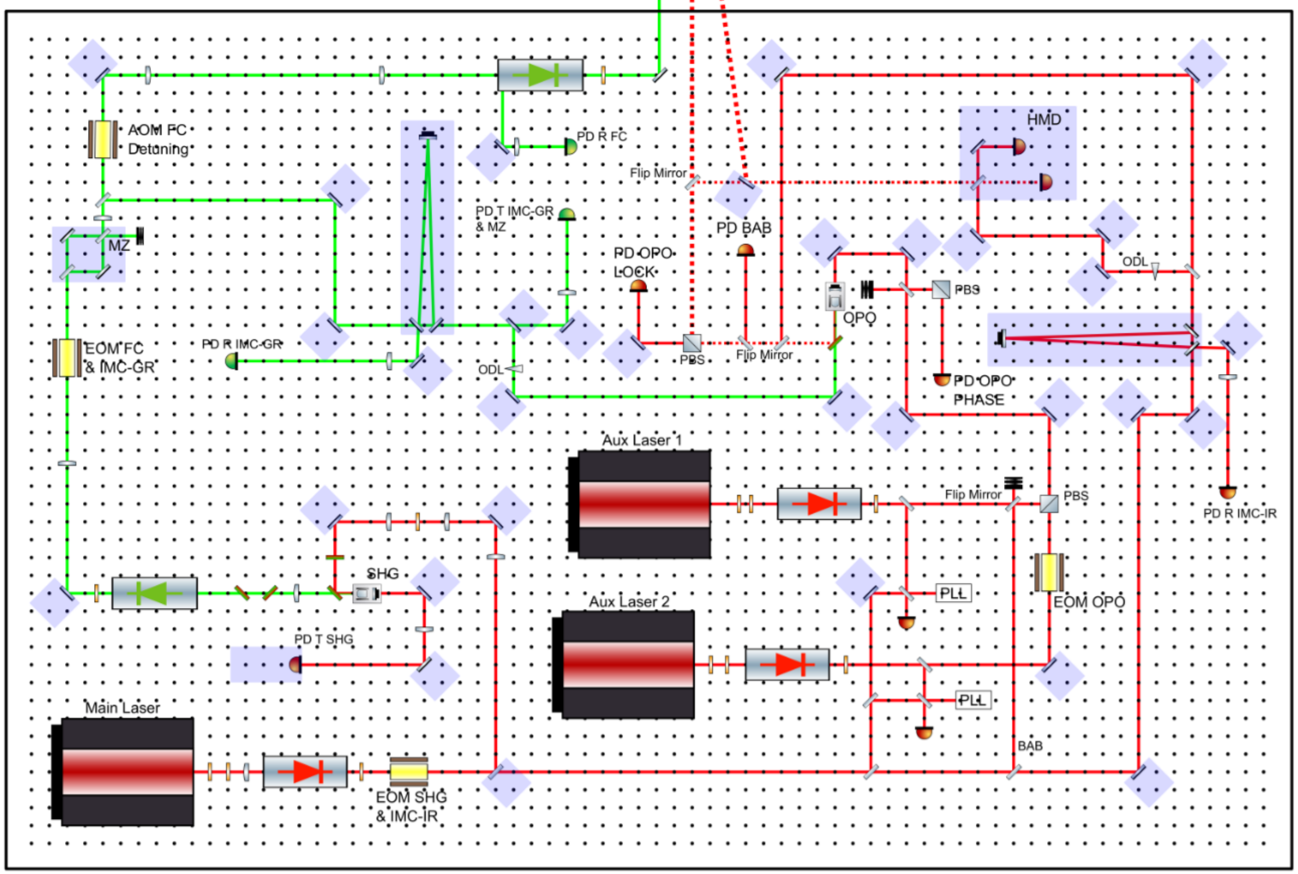
- Three main sub-systems
  - Vacuum squeezed source
  - Injection system
  - Filter cavity



Vacuum squeezed source

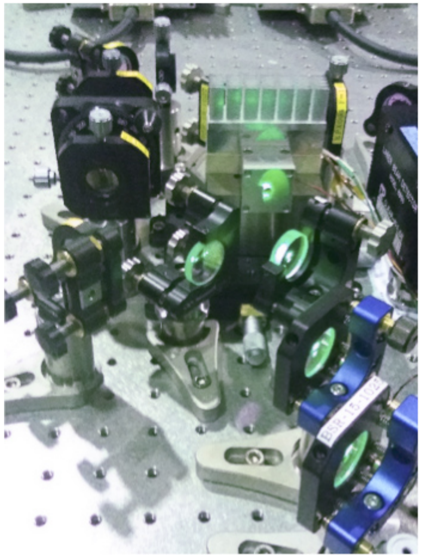
- Design inspired from GEO

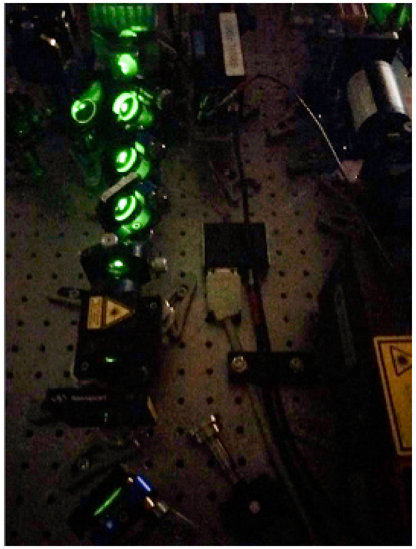
to the filter cavity

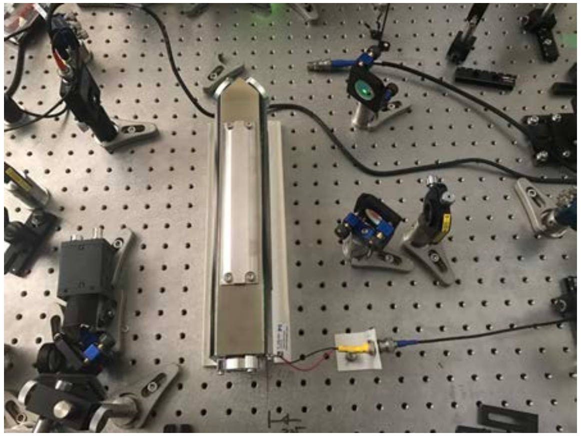


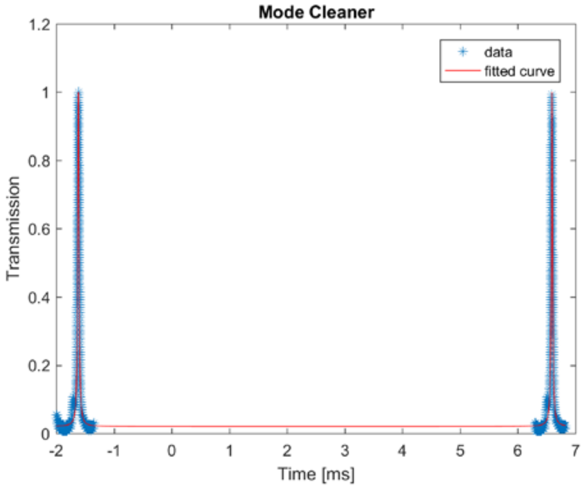
Vacuum squeezed source status

- Main laser
  - 2 W, acquired and installed
- Second harmonic generator
  - Designed, built and operated
- Green mode-cleaner
  - Design from Padova
  - Built, optical test done
- Mach-Zender
  - Designed
  - Parts acquired



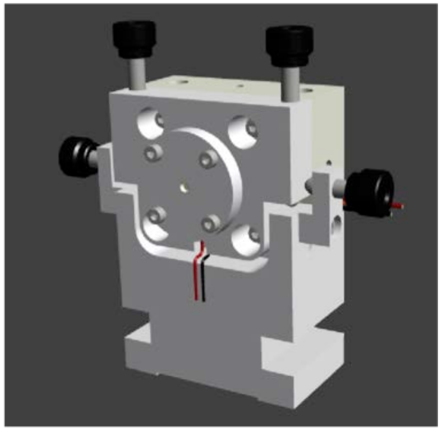


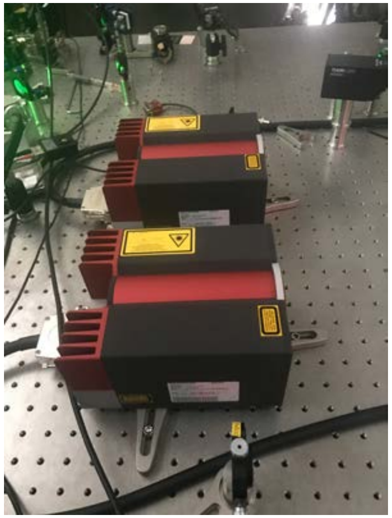




Vacuum squeezed source status

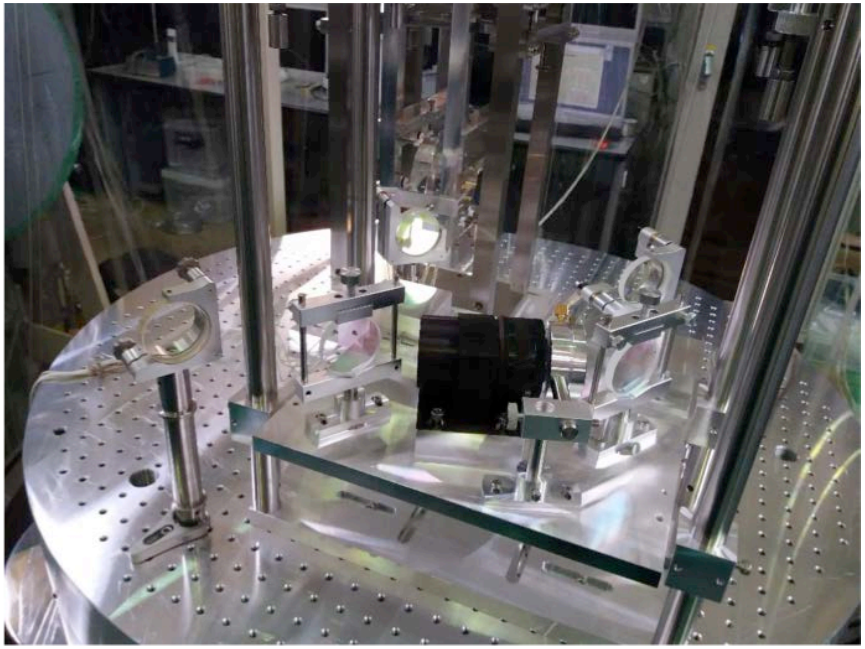
- OPO
  - PPKTP crystal
  - Revisited GEO design
  - Built, all parts available
- IR mode-cleaner
  - Design from Padova
  - Built and optically tested
- Auxiliary lasers & PLL's
  - Acquired
- Homodyne detector
  - High QE Photodiodes available
  - Electronics to be done

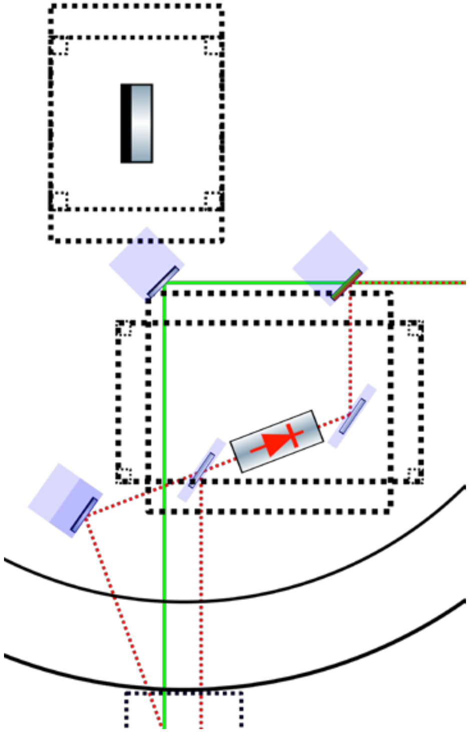




Injection system

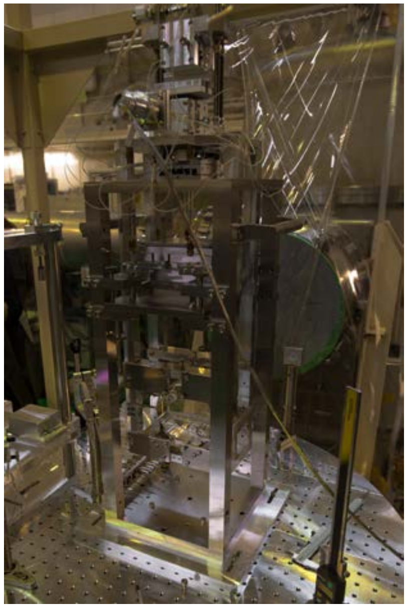
- Use of TAMA Faraday isolator
- Green and IR beams recombined in the vacuum system

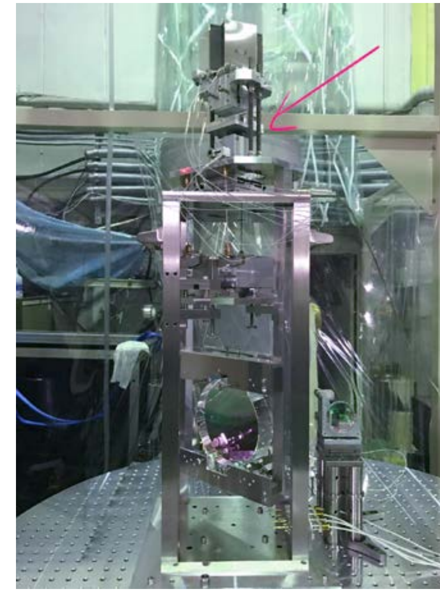


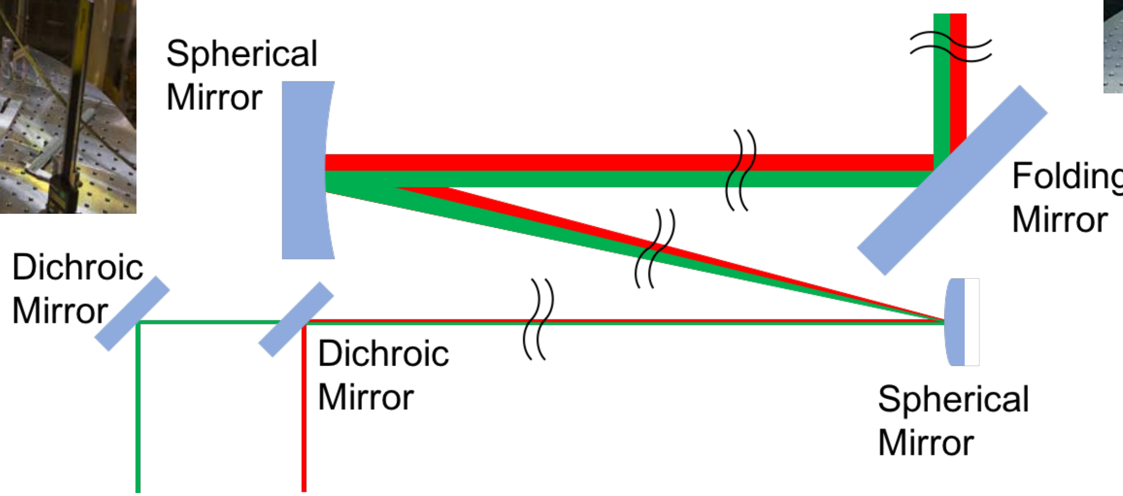


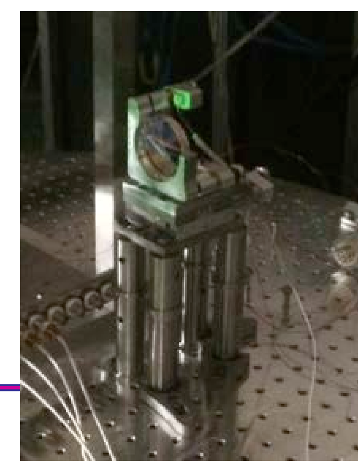
Injection system

- Dichroic mode-matching telescope



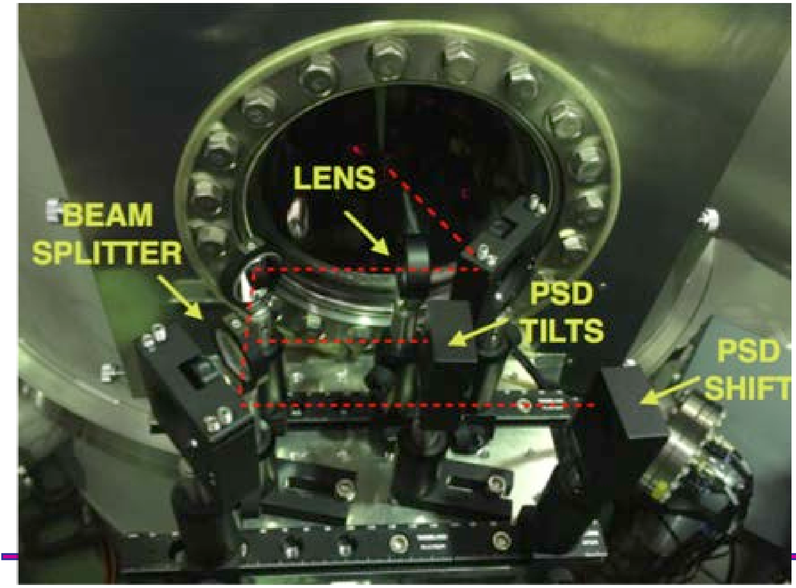






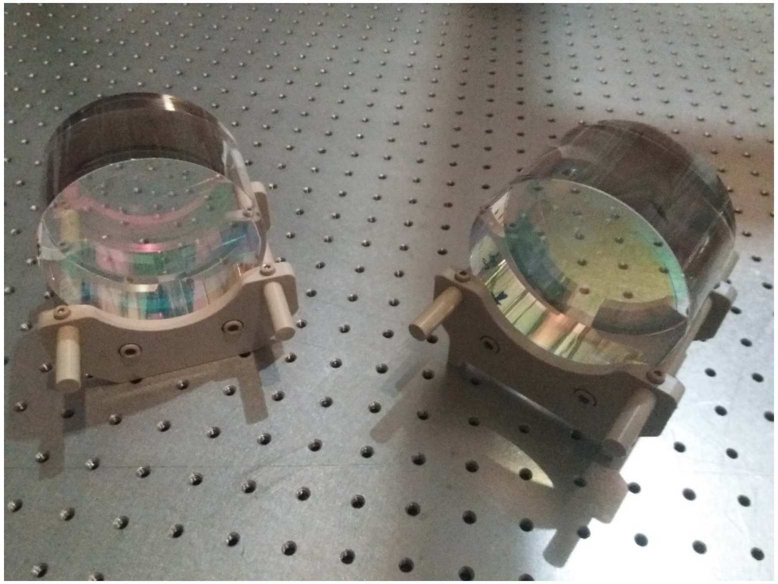
Filter cavity mirror suspensions

- Use of TAMA vibration isolation system
  - Stacks
- Use of TAMA double pendulums
- Virgo-like local position controls
- Status
  - Done



Filter cavity mirrors

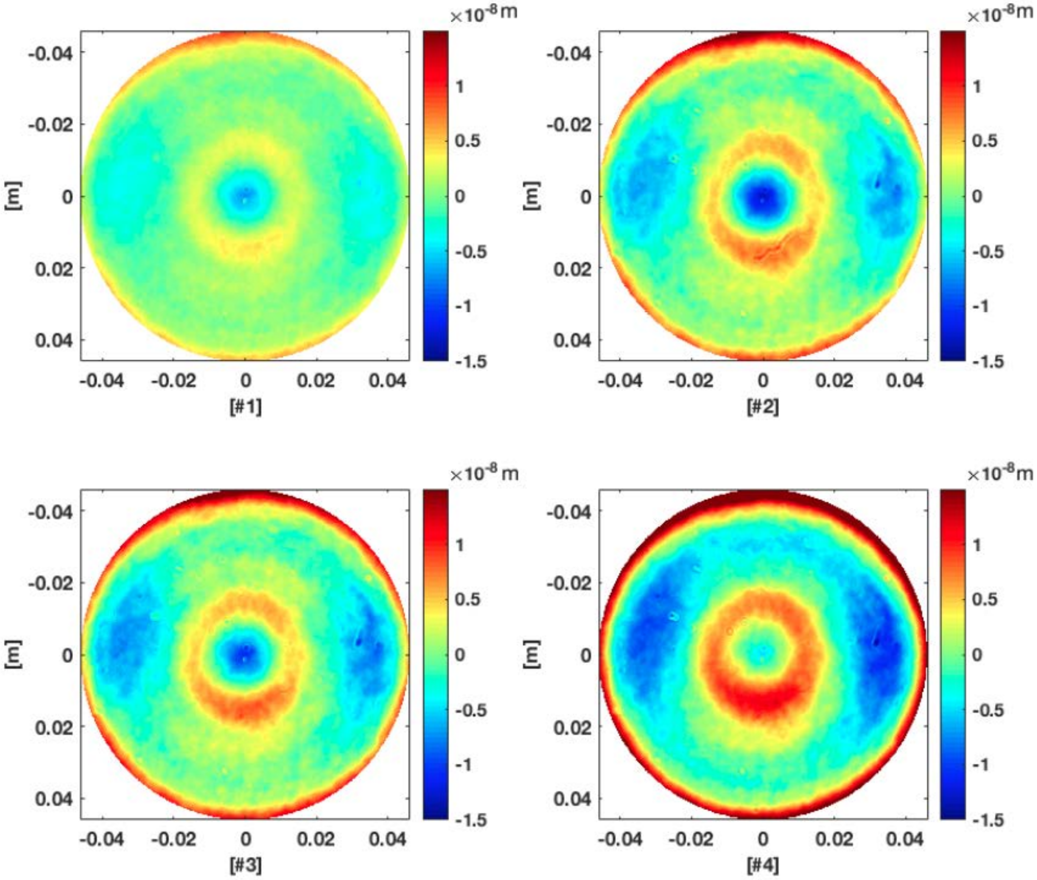
- TAMA size mirrors (10 cm diameter, 6 cm thick)
- Beam radius ~ 1 cm
- Finesse ~ 4500
- Dichroic coatings (green beam used for cavity control)
- Status: mirrors polished (@Coastline) and coated (@LMA)
  - 4 mirrors produced



Filter cavity mirrors

- Mirror performances
  - Initial-Virgo quality mirrors

	diameter 0.05 m		diameter 0.02 m	
Mirror	RMS (nm)	PV (nm)	RMS (nm)	PV (nm)
#1	1.96	11.5	0.52	3.28
#2	2.09	12.2	0.52	3.28
#3	1.5	8.3	0.48	3.36
#4	1.94	14.8	0.48	3.28



Filter cavity expected losses

- Mirrors performances
  - Initial-Virgo quality mirrors
  - Expected round trip losses: 40 ppm

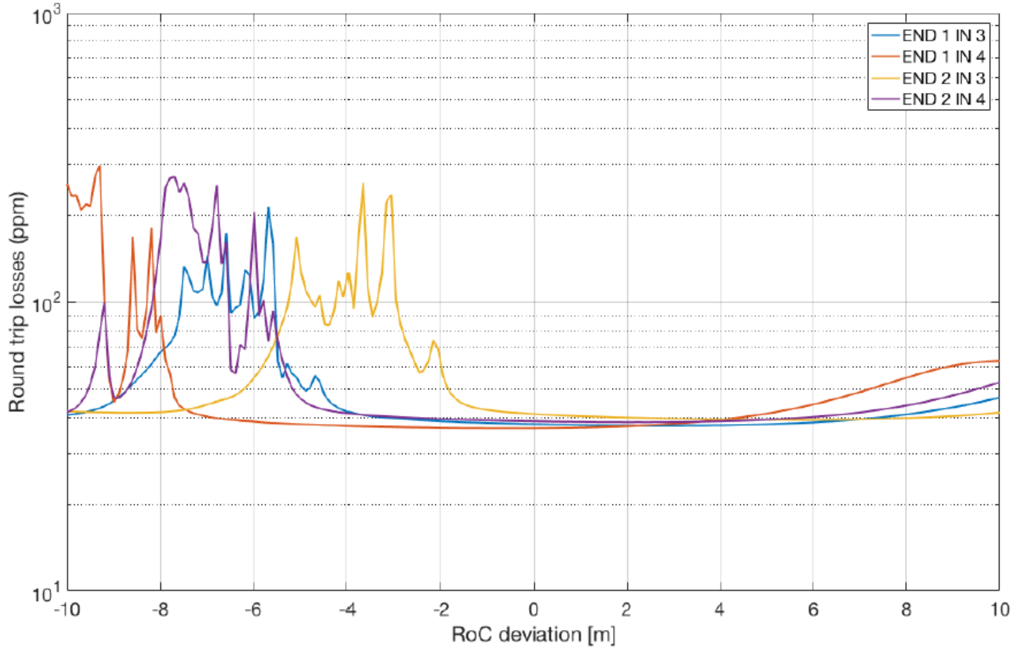
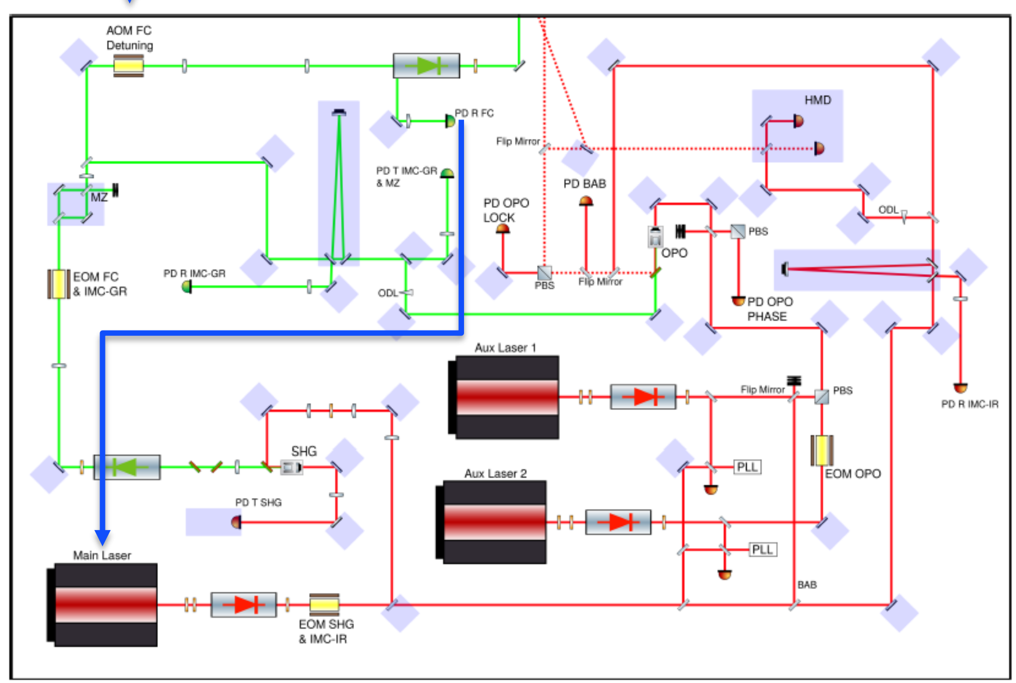


Figure 9.23: Round trip losses for different combination of filter cavity mirrors as a function of the deviation from the measured RoC.

From: E. Capocasa, PhD thesis (2017)

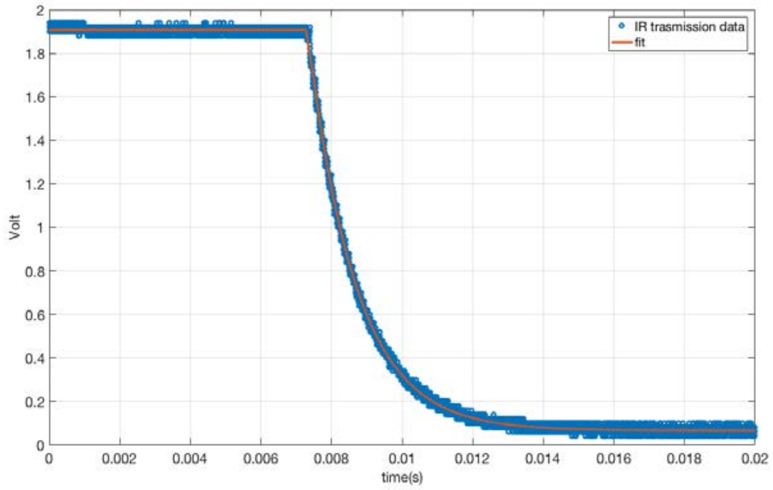
Filter cavity locking

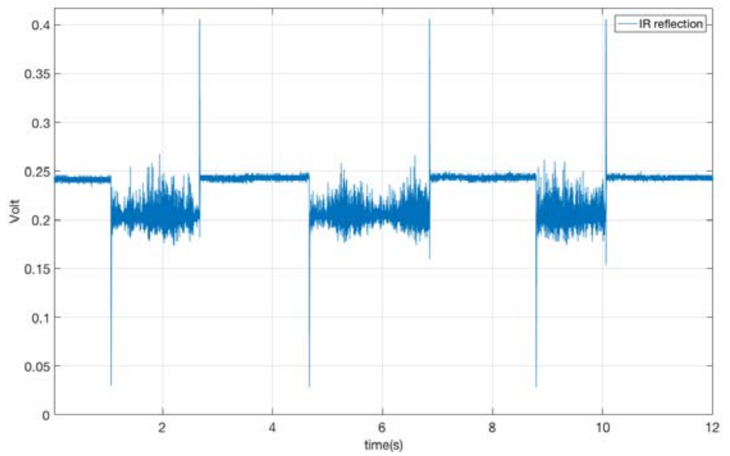
- Inspired from MIT, support from APC
  - ◆ Main laser locked to cavity length using the green beam from the SHG
    - » Pound-Drever signal sent to laser PZT
    - » 10 kHz bandwidth
  - ◆ IR beam detuning adjusted with AOM on green beam
    - » So far manual adjustment
- Status
  - ◆ Done
- Results
  - ◆ Locking accuracy
    - » ~150 Hz on green
    - » ~5 Hz on IR



Filter cavity matching and losses

- Cavity aligned and locked on both beams
- Cavity performances measured recently
- Best mode-matching: 95%
- IR decay time: 2.7 ms (preliminary)
- Round trip losses: 60 ± 20 ppm (preliminary)





Conclusions and perspective

- Status of the experiment
  - Vacuum squeezed source: under construction
  - Injection system: 1st version done
  - Filter cavity: built, aligned and locked
- Next steps
  - Cavity automatic alignment
  - Assembly and operation of the vacuum squeezed source
  - Preparation of the homodyne detector
  - Upgrade of control system
- Ideal testbed to learn about frequency dependent squeezing and to prepare its implementation in advanced detectors
- Collaboration with ANR Ex-Squeez and CALVA is possible
  - Obvious synergies available