



Haute école du paysage, d'ingénierie
et d'architecture de Genève



UNIVERSITÉ
DE GENÈVE



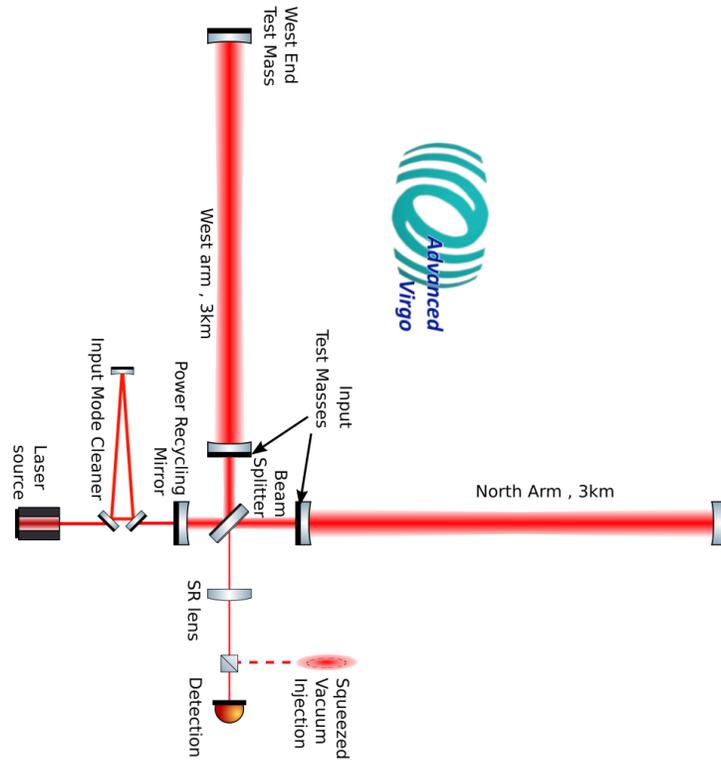
Upgrades to the detection optical benches of Virgo in preparation for the next observing run O5

Gravitational Waves and Detection Technologies –
PAS Rome meeting 2026

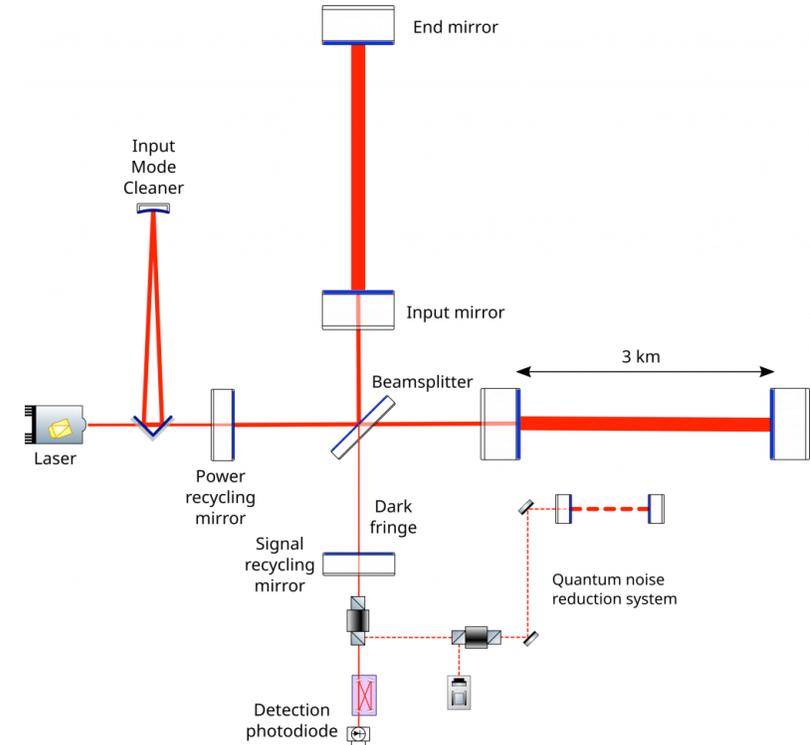
A. Daumas on behalf of the DET subsystem team



Past and present optical configurations of Virgo



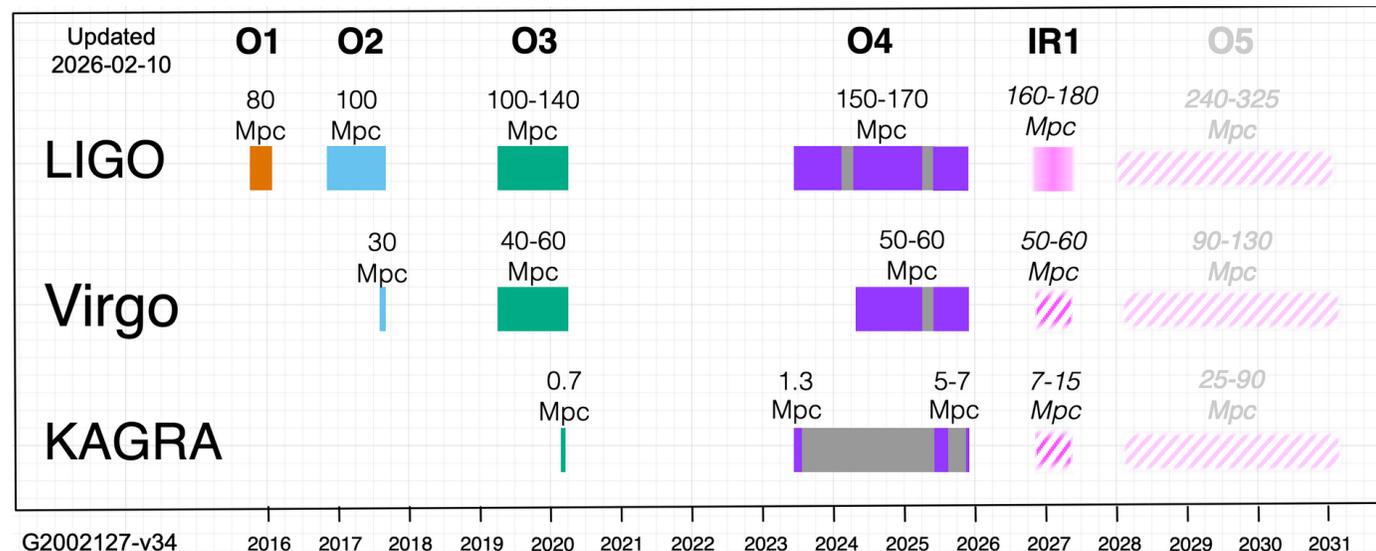
During O3: Power-recycled FPMI with marginally stable PRC



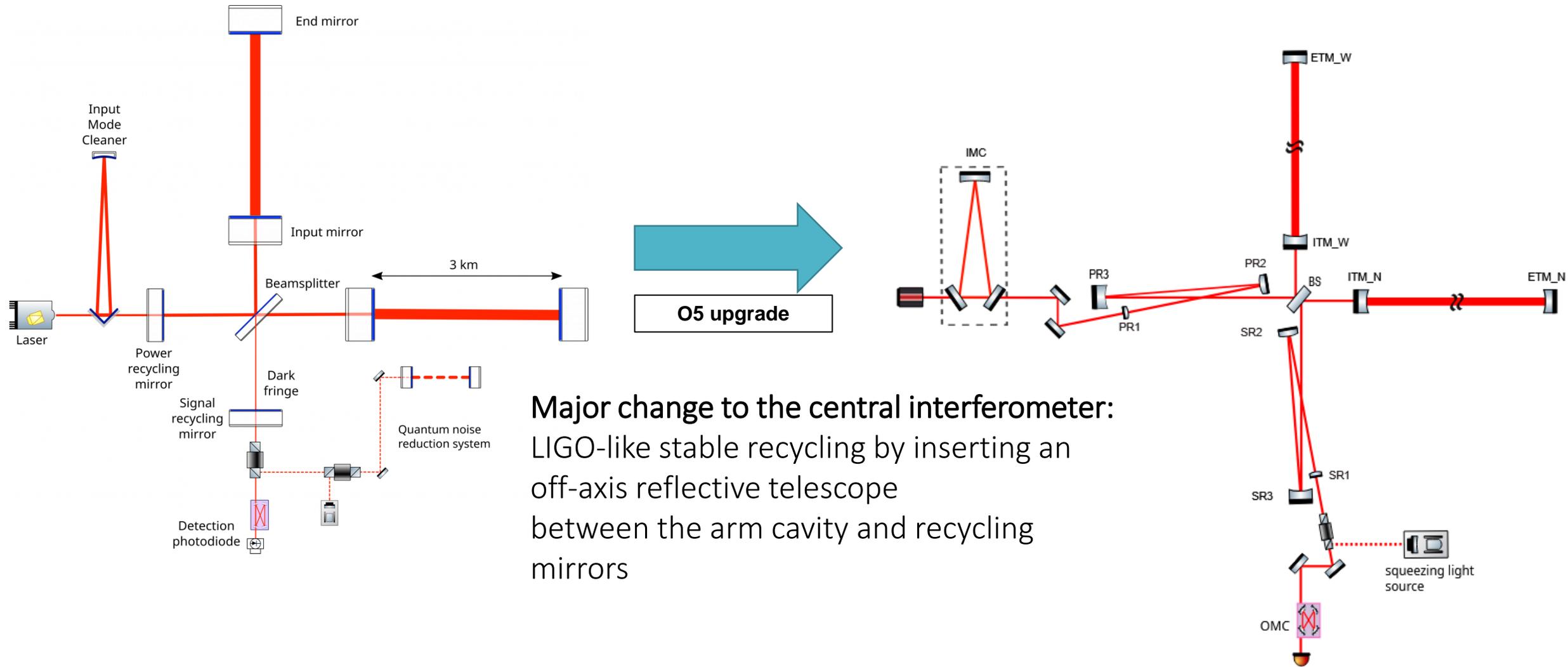
During O4: Dual-recycled FPMI with marginally stable PRC and SRC

Past and present optical configurations of Virgo

- Marginally stable recycling cavities (especially Signal Recycling) -> **Major negative impact** on the sensitivity and on the control of the interferometer, requiring a misaligned SR and limited input power in order to be operated.
- Stable recycling cavities achieved by **increasing the length of the recycling cavities** and accumulating Gouy phase to avoid HOM resonance.



Stable recycling cavity upgrade

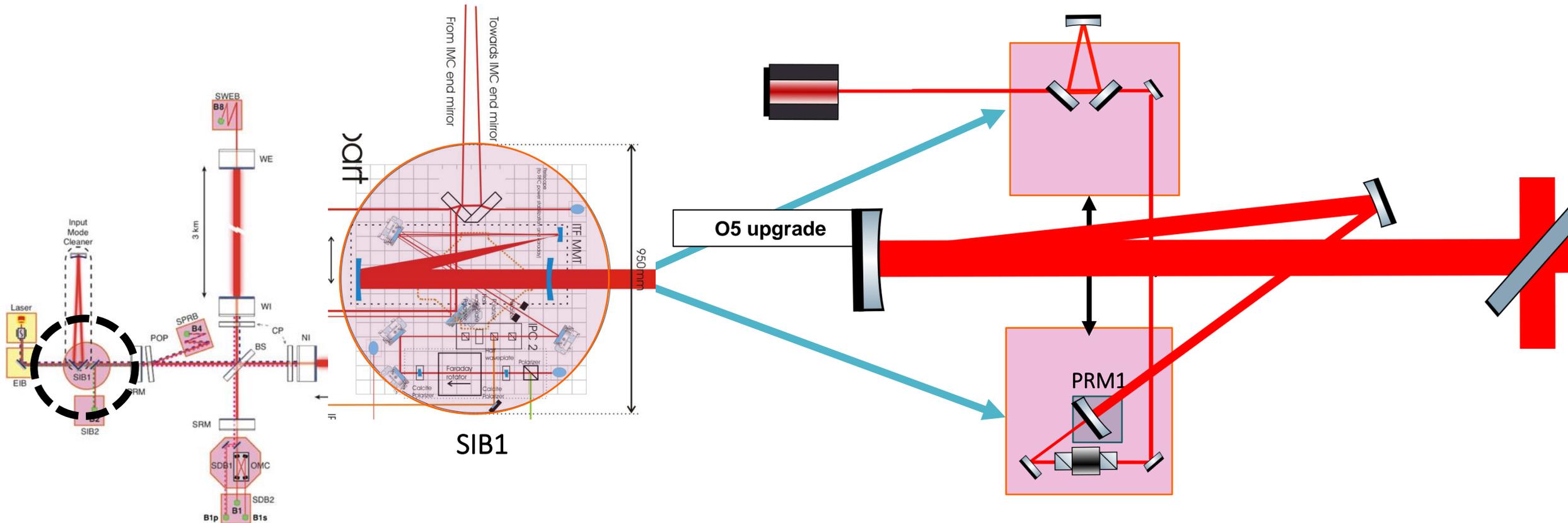


Major change to the central interferometer:
LIGO-like stable recycling by inserting an off-axis reflective telescope between the arm cavity and recycling mirrors

Impact on auxiliary benches

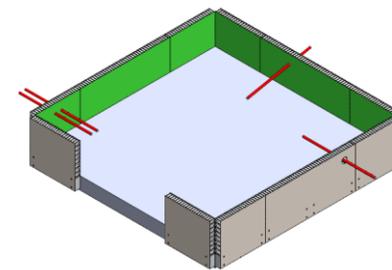
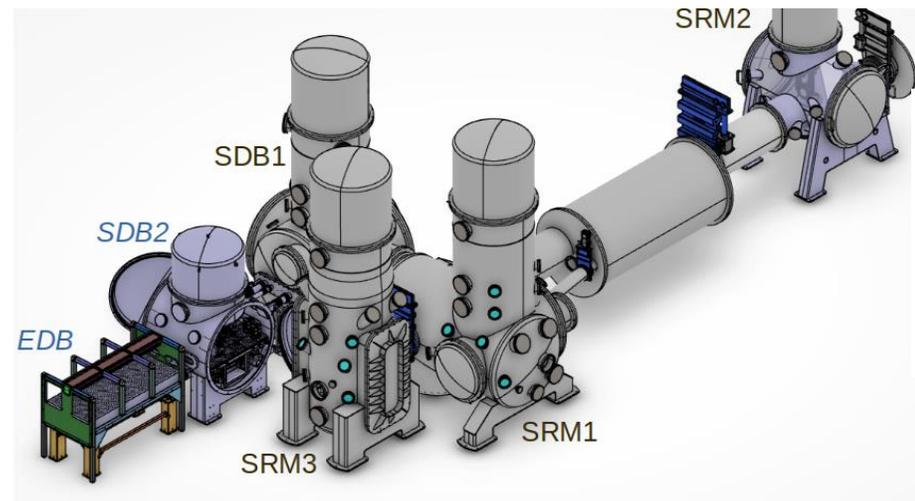
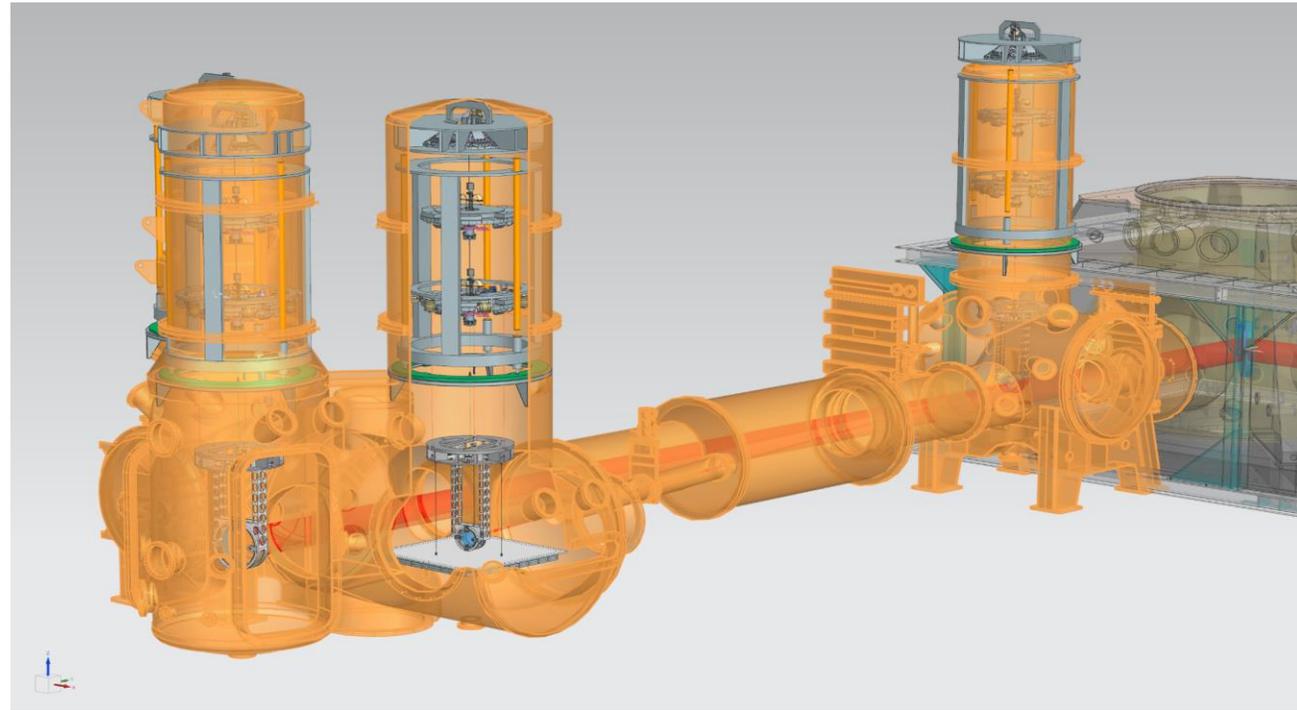
Consequence on injection and detection

- Space constrains : benches must be separated to let the beam pass
- Example with injection : SIB1 -> separated in 2 benches

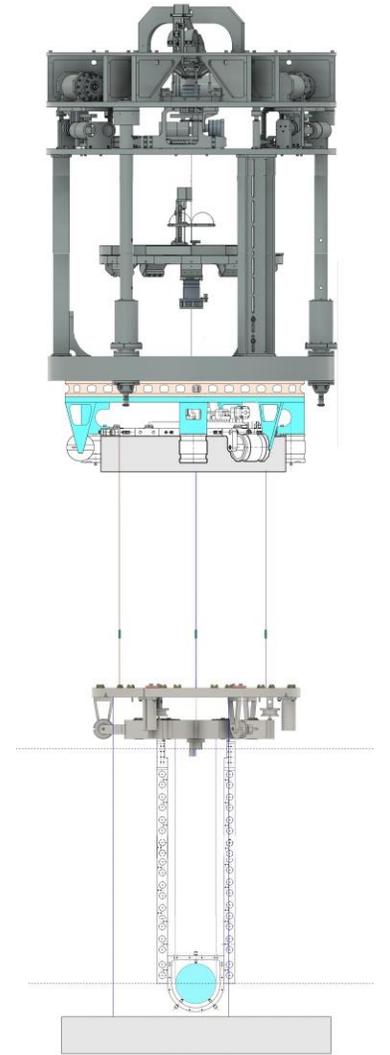


Impact on suspensions and vacuum

- New type of suspension with the auxiliary bench suspended to the same suspension stage as the RM1
- Major infrastructure works in order to remove and install the new vacuum chambers, and have bigger clean rooms



Suspensions for the RM1 mirrors and benches, baffles around the bench



Adaptation of detection chain

Dark fringe and B5 (control beam) detection path:

- Bench hosting SRM1 mirror, Faraday Isolator -> Signal Recycling Bench (SRB)
- Bench hosting the OMC -> SDB1
- Reshuffling needed on existing SDB2 bench

Pick-off signal

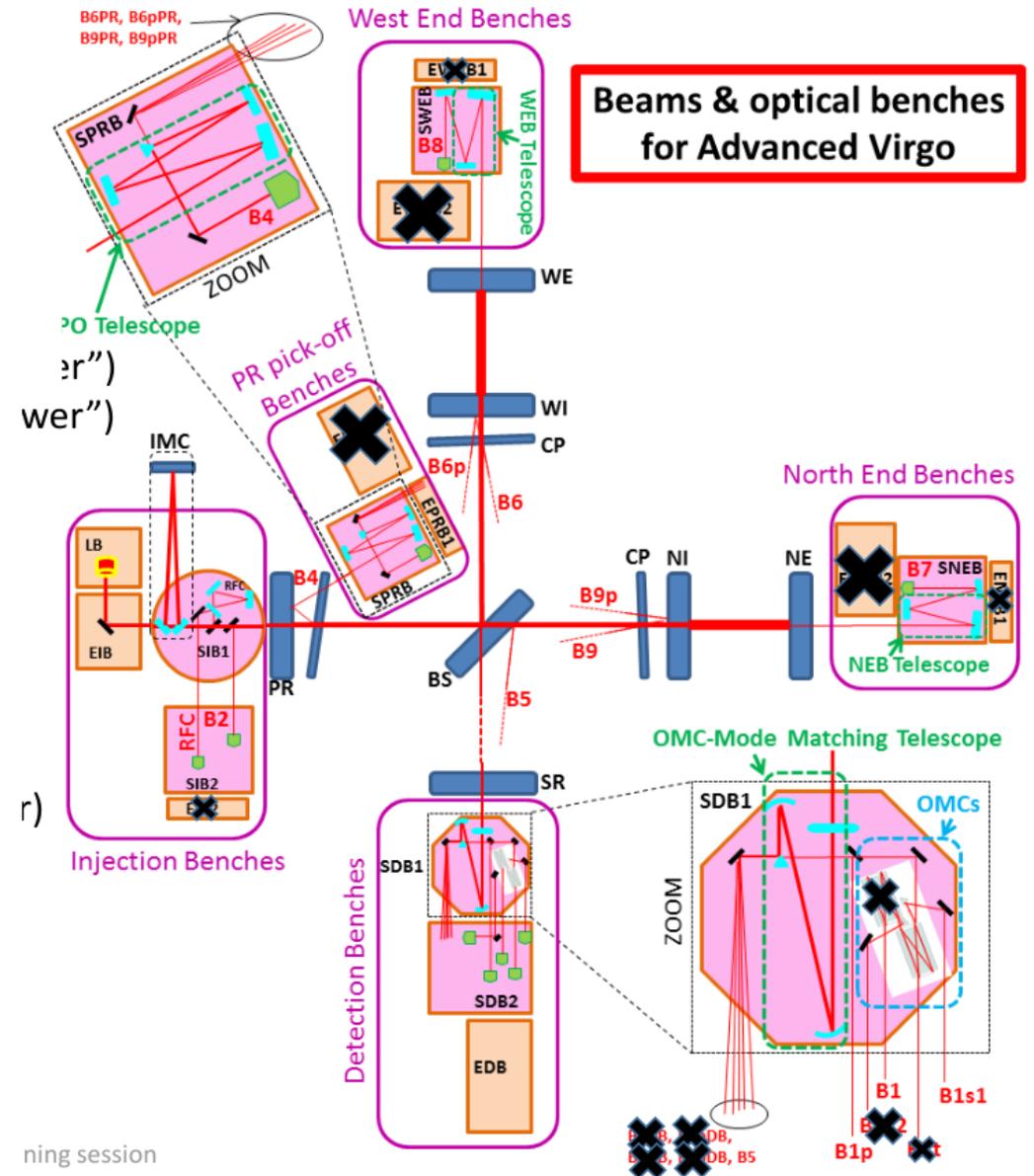
- Extraction of B4 beam in transmission of PRM2 mirror: SPOB bench optical design to be adapted
- IPC on B4 for lock acquisition at low power (photodiodes close to saturation during lock acquisition currently)

End benches

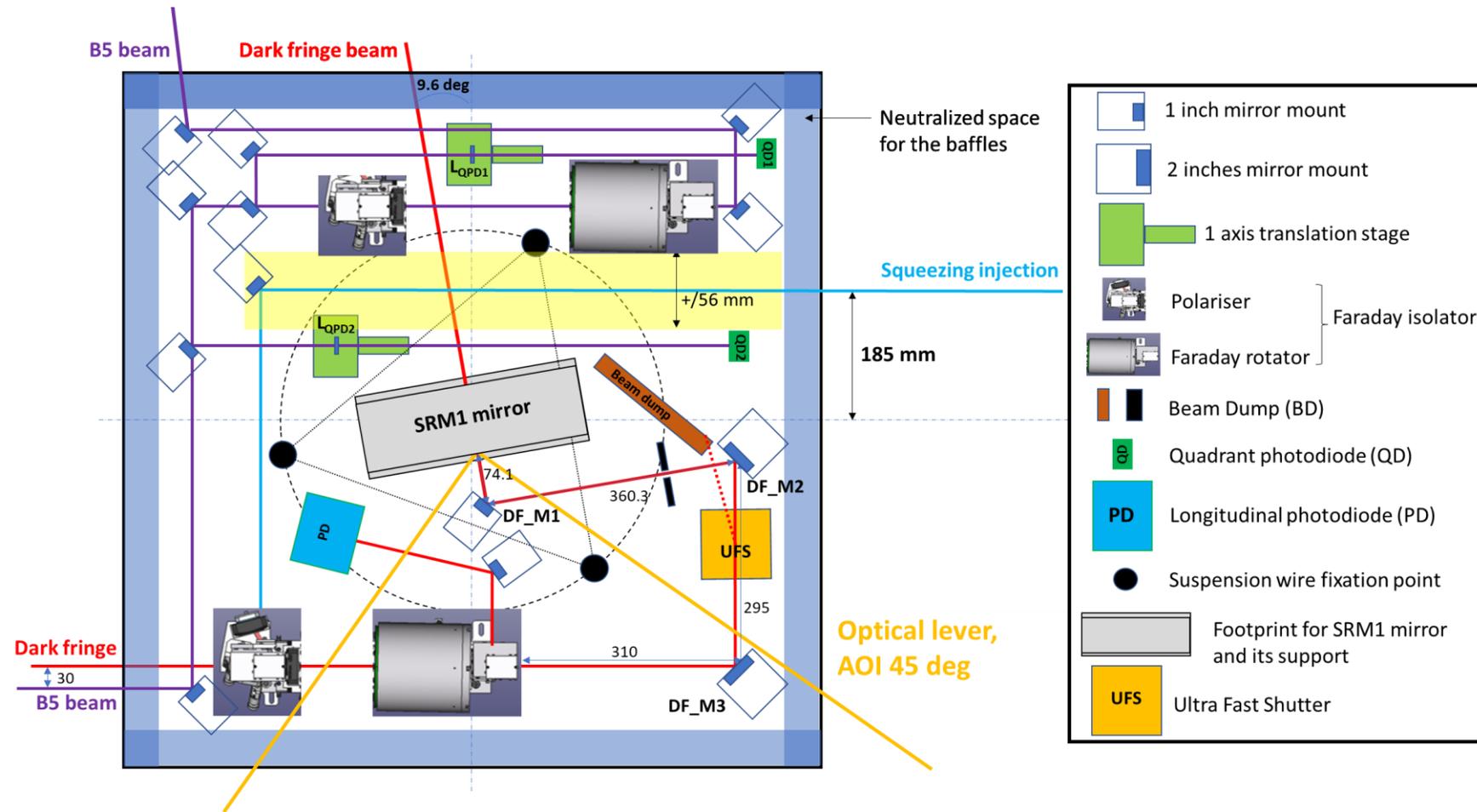
- No change to the test masses -> only scattered light reduction (DC quadrant photodiodes with low scattering for high power operations)

Electronics and aging components

- Picomotor driver multiplexing boards for the new and current benches
- Updated cameras for the monitoring of laser beams



New detection bench SRB

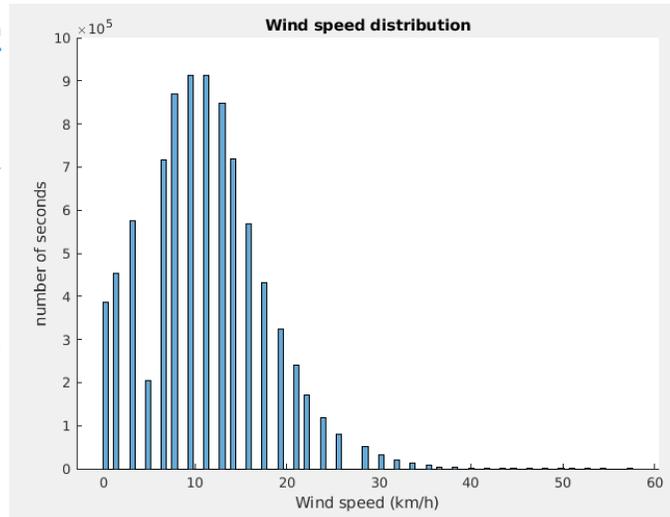
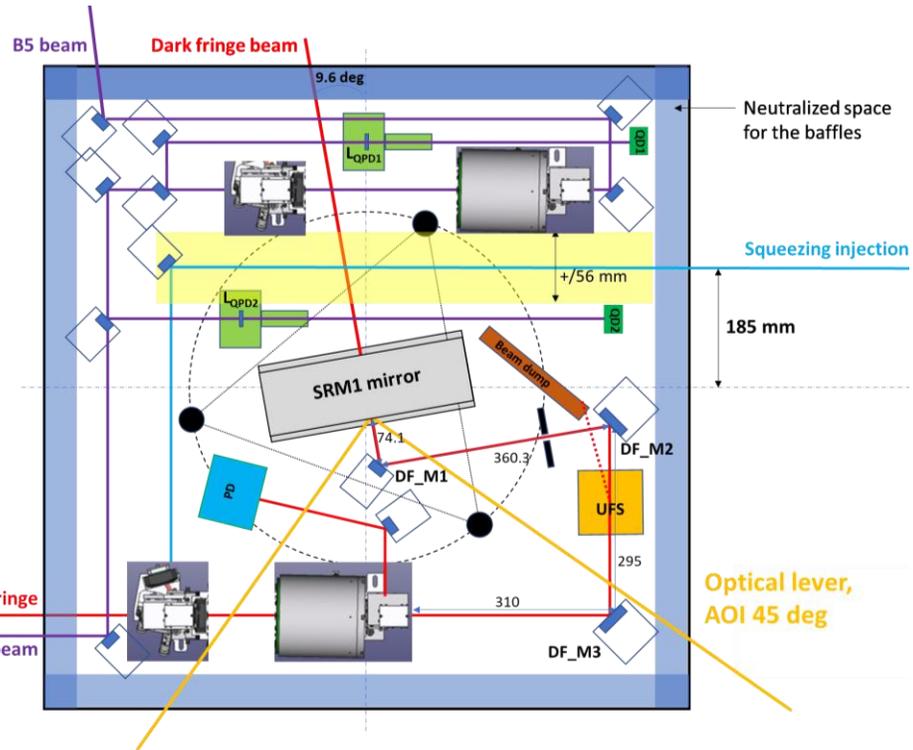
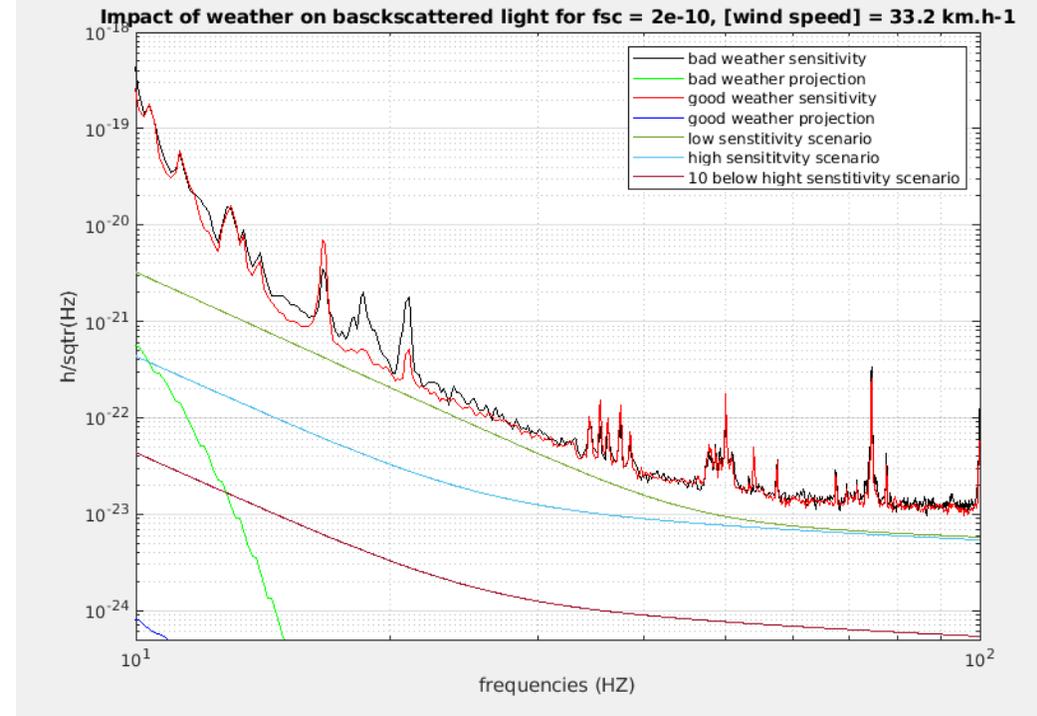


Main functions:

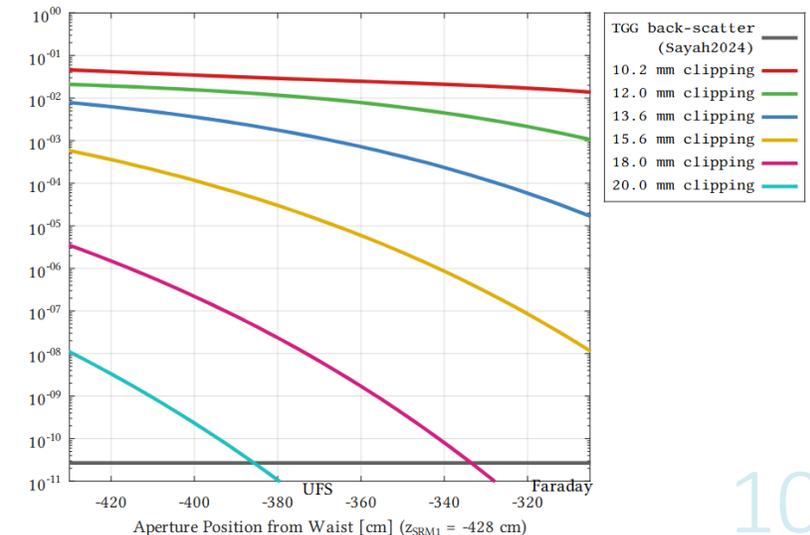
- Hosts SRM1 mirror and its suspension
- Hosts Output Faraday Isolator
- Extraction of dark fringe beam containing GW information and control beams
- Injection of squeezing through FI
- Hosts the fast shutter
- Interfaced with SDB1 for the OMC mode-matching telescope

Optical design of SRB

- Adaptable design to recycling cavity length to compensate for SRMs radius of curvature tolerancing errors known later in the project
- Scattered light budget to avoid deteriorating the sensitivity and losses budget to preserve the squeezing and dark fringe beams



Fractional Power: (Aperture Clipping vs Poistion) and (TGG Back Scatter)
 $L_{SRC} = 37.9$ m; $ROC_{SRM3} = 22.6$ m; X-waist = 763.3 μ m; Alignment Offset 1mm in x; 0mm in y



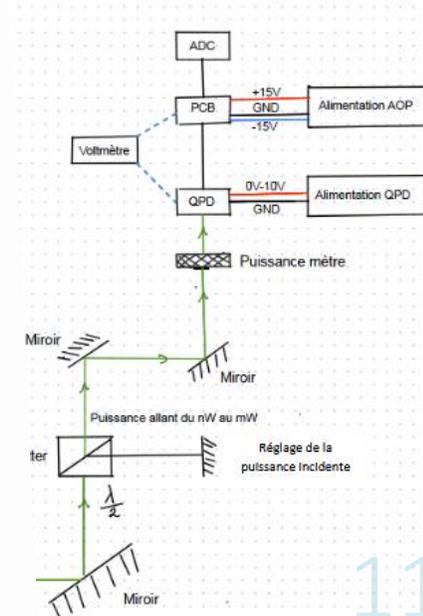
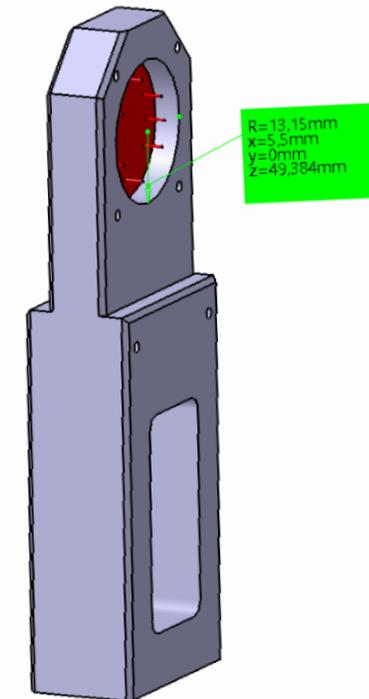
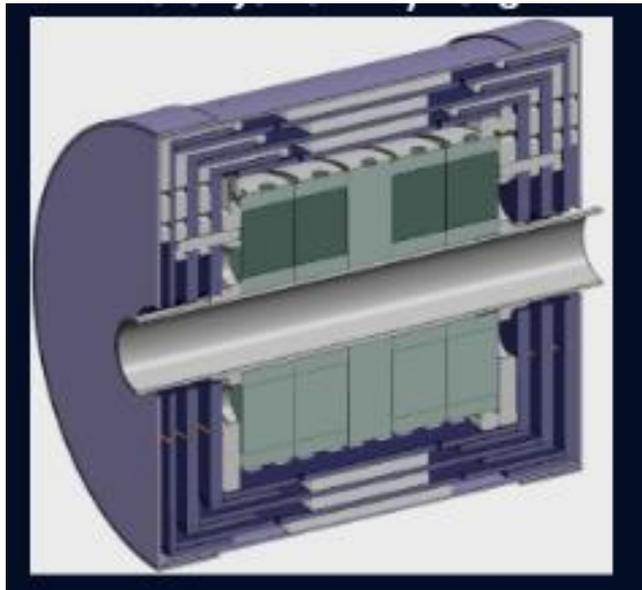
Upgrade of components

- Dark fringe and B5 control beam Faraday isolators

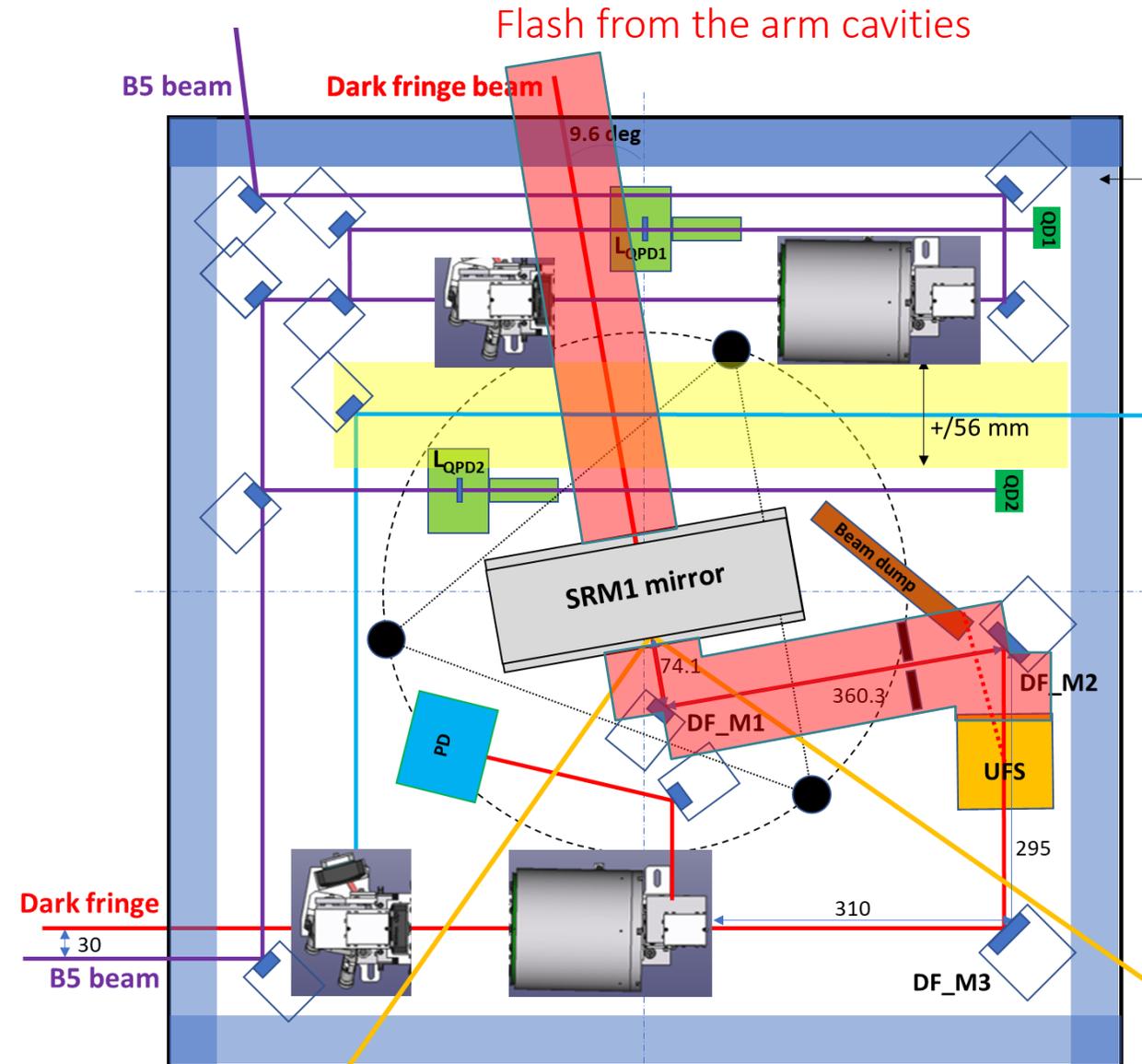
- DC Quadrant photodiodes

- o Similar FI design for both
- o Simulations, design, machining, assembly and validation by LPC Caen (Faraday and shields), optical design and tests at EGO
- o Full chain of design by LPC-EGO : avoiding issues due to characterizing a commercial magnet

- o Previous photodiodes: 20+ years old and not enough for both benches
- o Good SNRs for lock acquisition control signals



Interferometer unlocking



Why:

- ITF unlock -> stored energy in the Fabry Perot cavity will exit through the dark fringe port
- Elements in the detection chain (photodiodes, polarizers, OMC) are not made to withstand high power -> **very strong risk of damaging components**

Requirements for O5:

- Max expected optical power arriving on the bench: 20 kW (max 450 kW for 80W input power)
- 1ms closing time on shutter time from power deposited on PDs

Interferometer unlocking

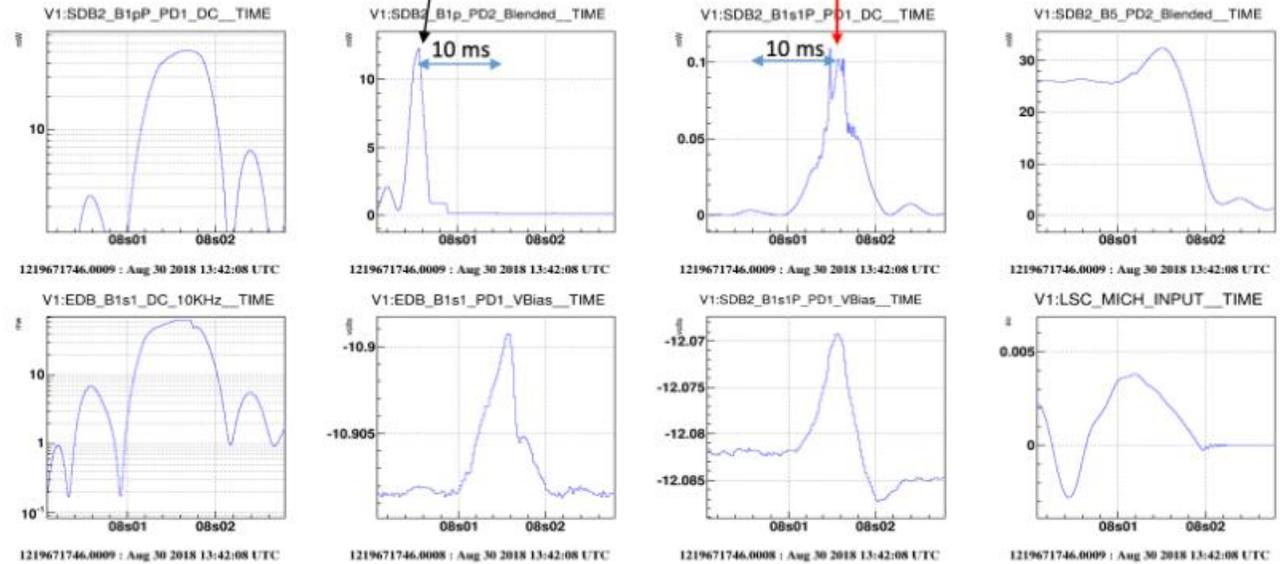
OMC damaged in 2018 in a flash:

- Flash power density: 3 GW/m^2 on OMC entrance
- Estimated power of 1 kW at the entrance of the detection bench

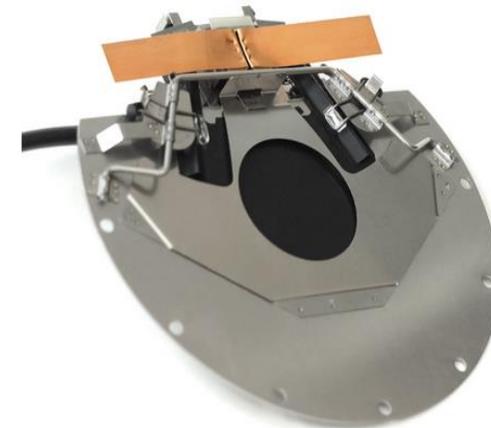
Current « slow » shutter

- In O3 : shutter damaged after 3 years of operation -> mechanical deformation induced by powerful flashes
- In front of OMC: small beam, other components not protected
- 10 ms shutter time : not possible for O5

B1p PD2 shutter closing



- Stable SRC: even shorter discharge time (0.4ms) compared to the current marginally stable cavity (0.9ms)
- Trigger: LSC_DARM error signal, not power elevation of dark fringe beam



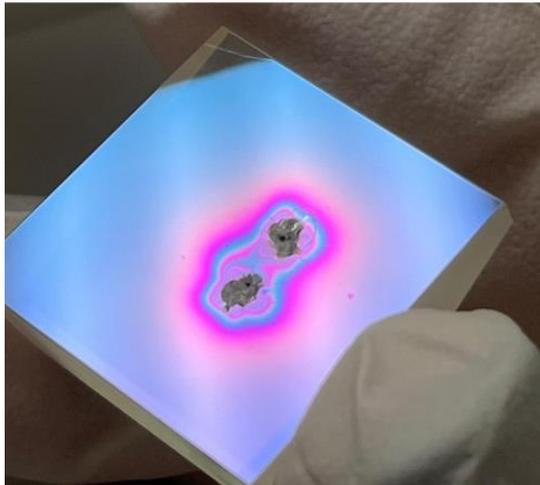
Commercial shutter from Uniblitz VS25 with beryllium copper blades with silver coating

Ultra Fast Shutter

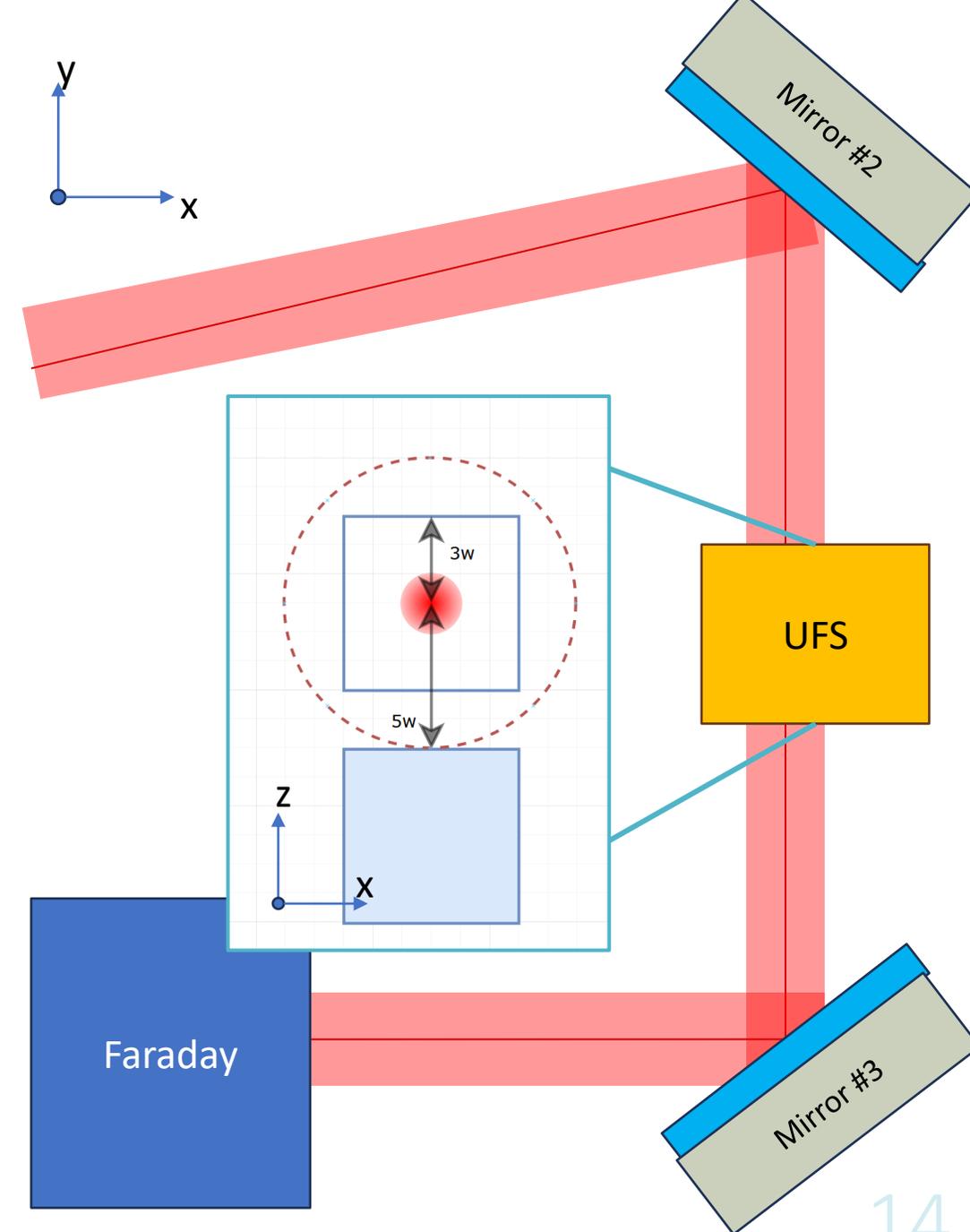
Development of a new Ultra Fast Shutter

- Shutter before the Faraday isolator to protect all downstream optics
- Long range of motion in order to have a clear aperture not cutting the beam at 5w
- Stringent requirements:

acceleration of 16mm in 1 to 2 ms ($32\,000\text{m/s}^2$), custom power source to be installed on the bench directly



LIGO output FI polarizer:
damage in 2024



Ultra Fast Shutter

Development of a new Ultra Fast Shutter

- Iterative design and prototyping

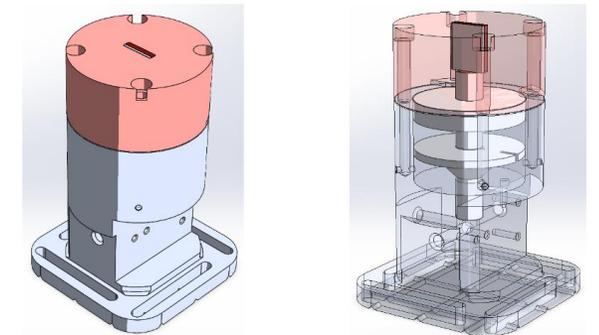
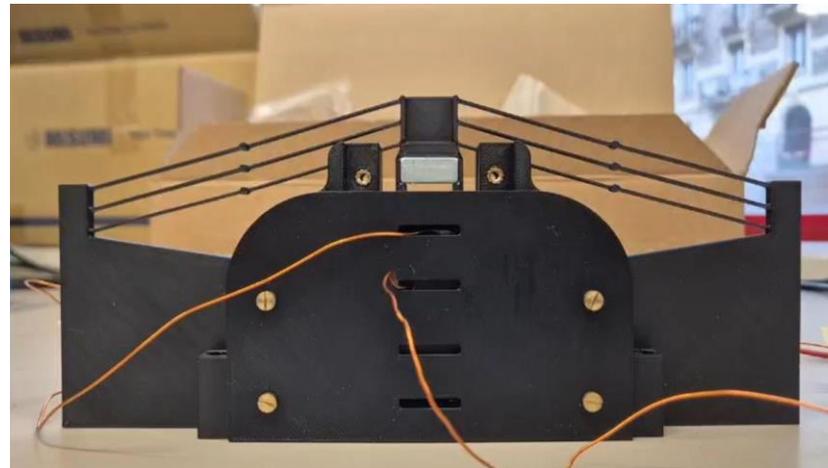
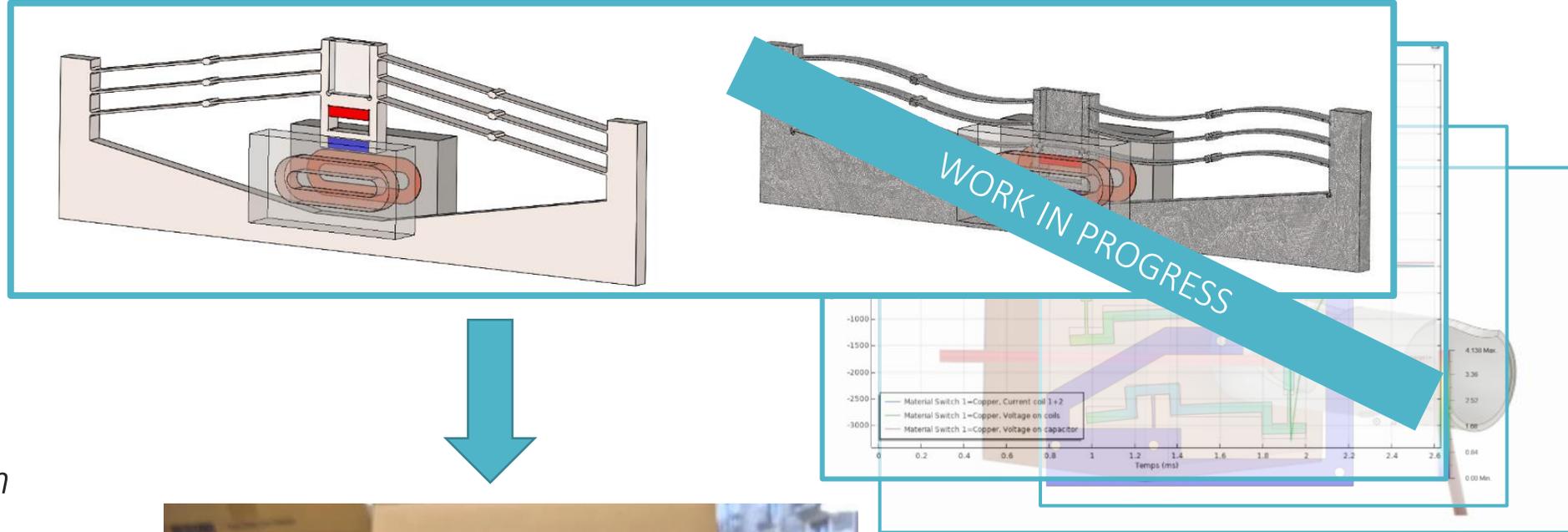
Currently explored: Moving magnet with bistable mechanism

- LIGO developing a new shutter

Discussion and feedback with LIGO colleagues

- Development in-kind from Switzerland (University of Geneva/HEPIA)

with help from Subatech/APC/LAPP (IN2P3-CNRS)



LIGO new shutter

Conclusion

Stable recycling cavity upgrade

- Necessary upgrade of the optical configuration of the central interferometer
- Impact on the detection subsystem

Redesign of optical layout, reshuffling of existing benches, upgrades of components

Signal Recycling Bench

- First bench in the detection chain

Optomechanical design of the whole bench at the interface of many Virgo subsystems and the rest of the detection chain (OSD/RCS/PAY/VAC/SLC/SQZ/ISC/INF)

- New bench suspended underneath the Signal Recycling Mirror

Integration procedures and contamination risks

- New components on the bench: QPDs, Faraday Isolators, Ultra Fast Shutter

Design, simulations, prototyping, assembly, integration and testing