A new Instrumented Baffle for Advanced Virgo

Mario Martínez

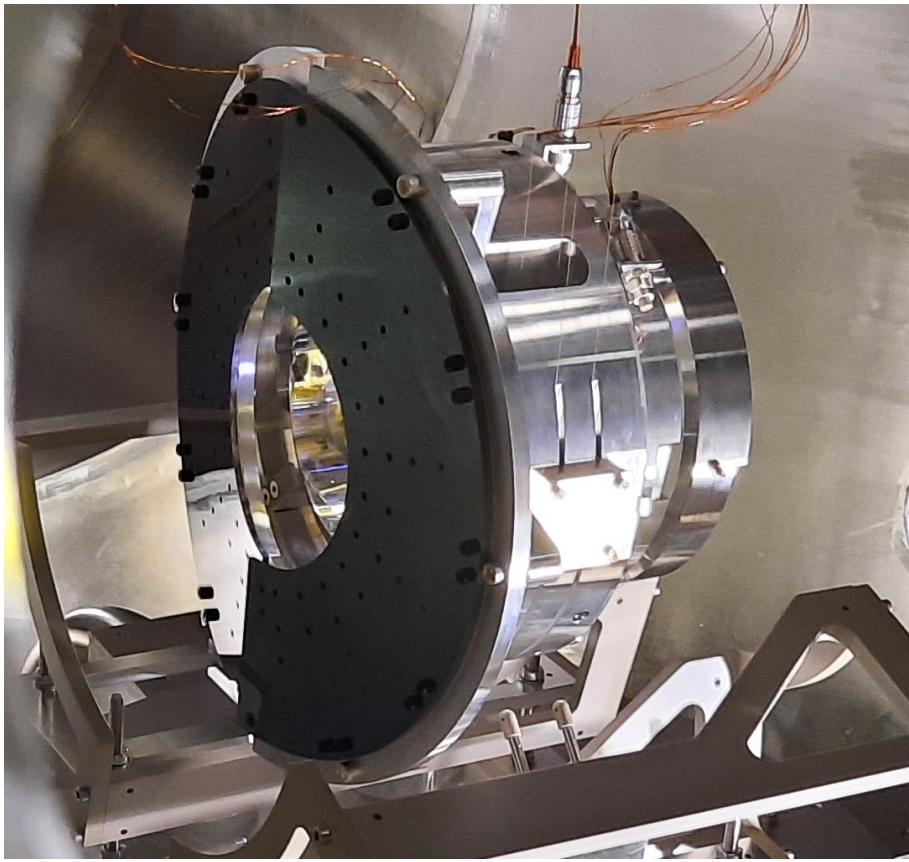
On behalf of the Virgo Collaboration

Virtual Iberian GW Meeting 2021

Outline

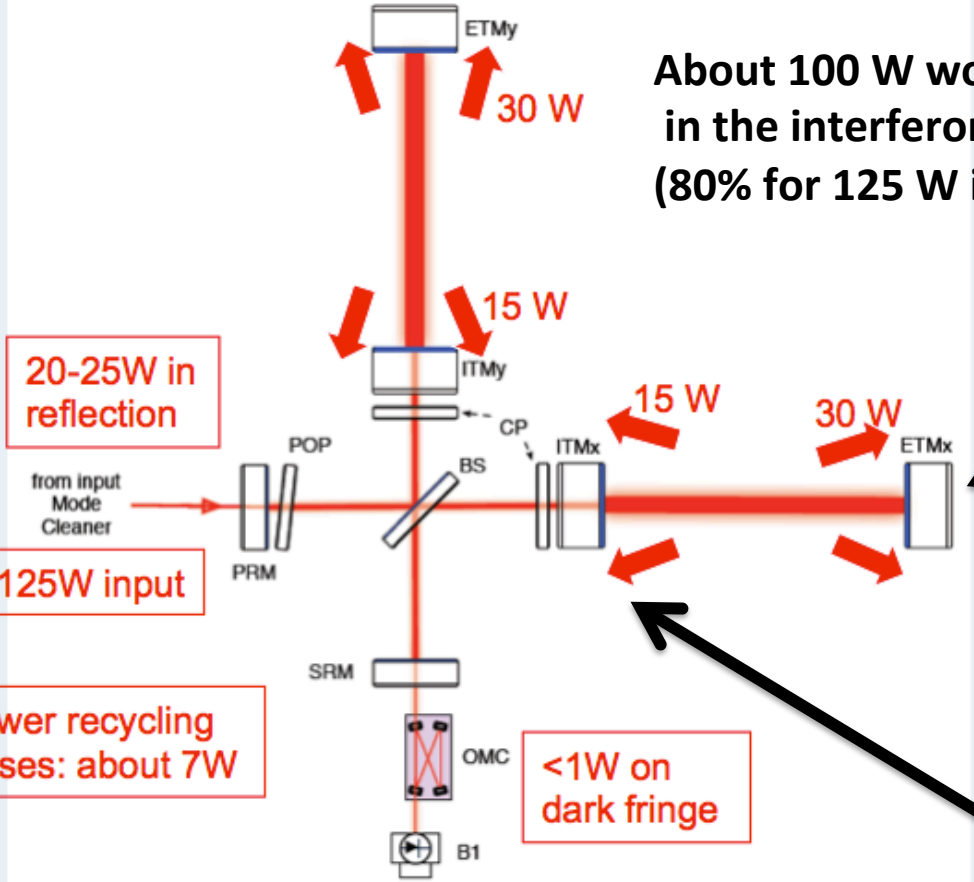
- Stray Light @ Virgo
- Instrumented baffle
- Installation
- Performance, first results
- Phase II

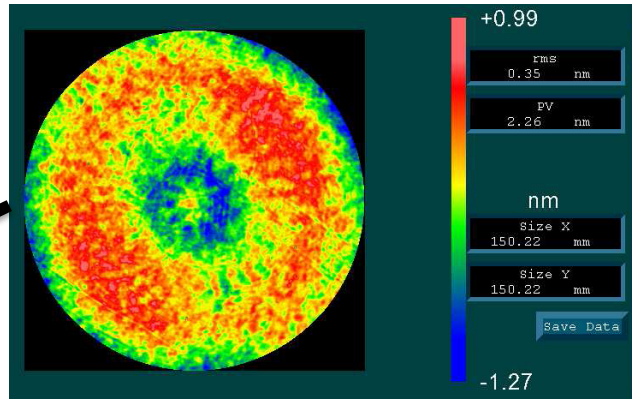
- Final notes
- AoB

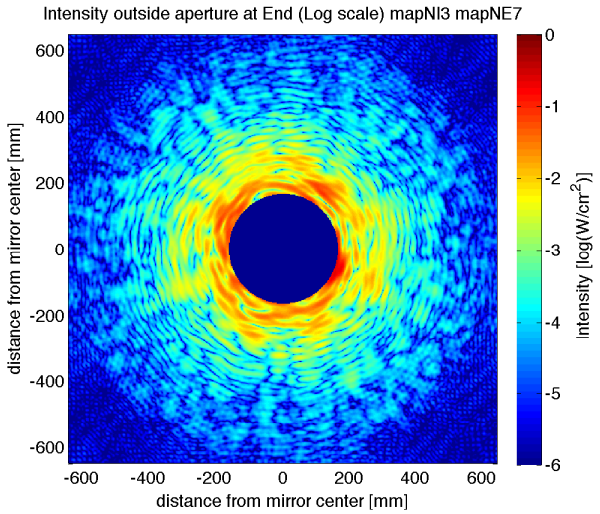


Layout and Stray Light

About 100 W would be diffused light in the interferometer (80% for 125 W input)







- Most of the light at small angles close to the mirrors

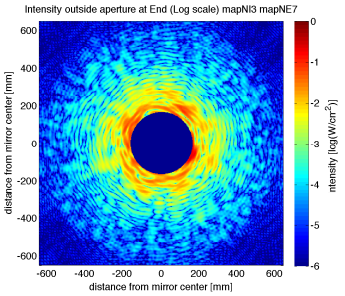
→ Dictated by the mirror maps/defects

- Larger angles going to core-optics/cryo stations
- Scattered light in long tube much smaller

→ but can kill the GW signal if not mitigated.

Layout and Stray Light

VIR-0055A-13



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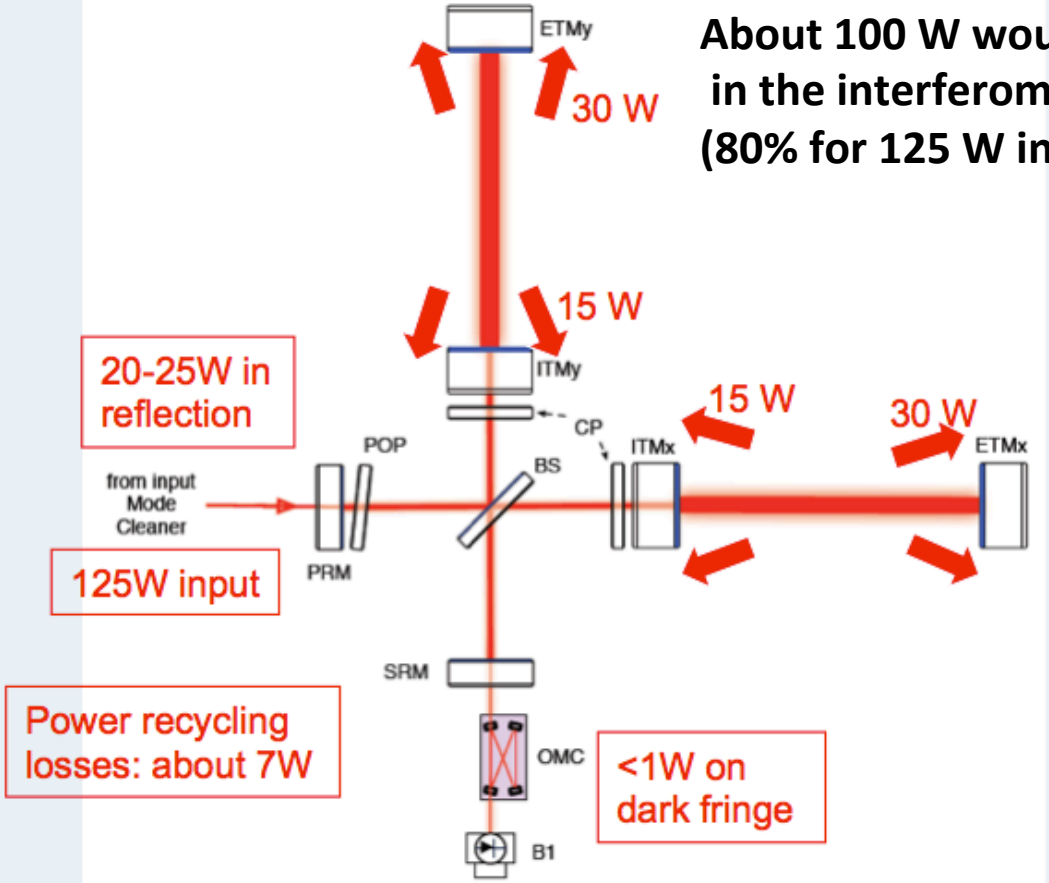

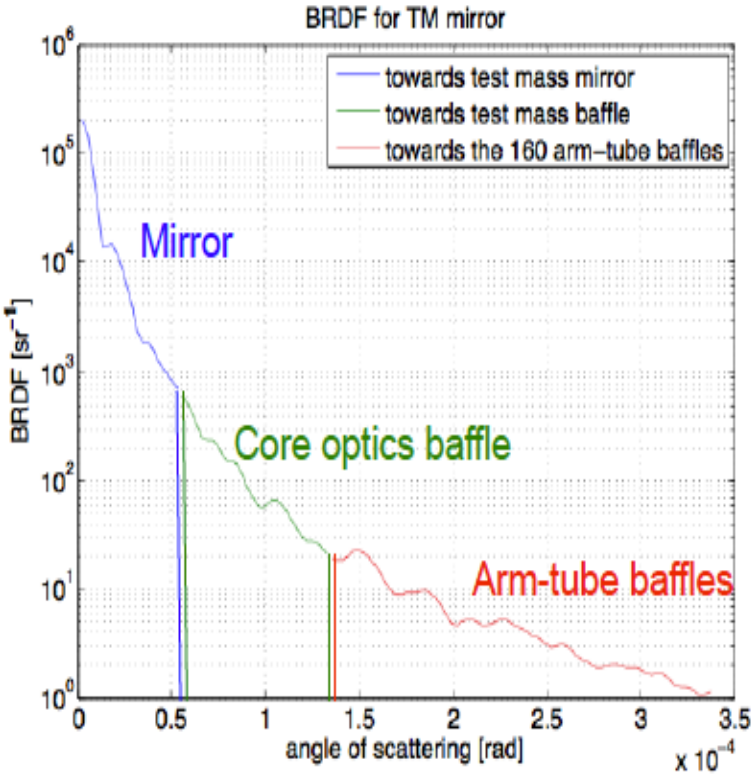

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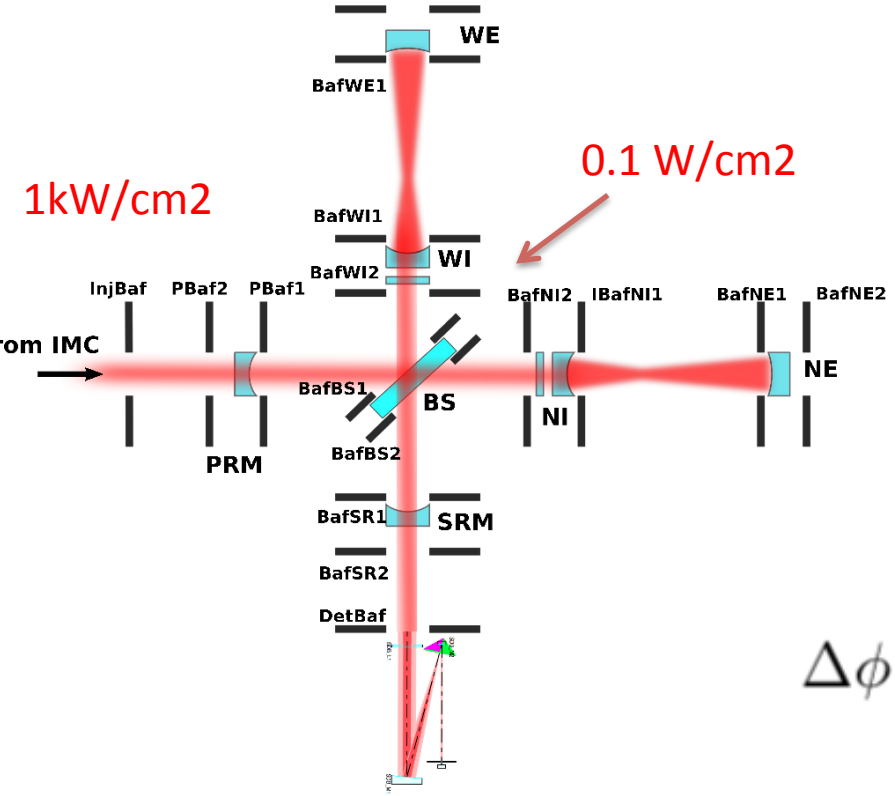
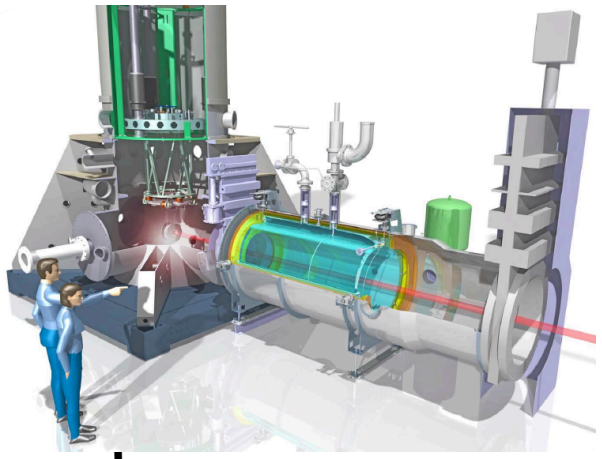
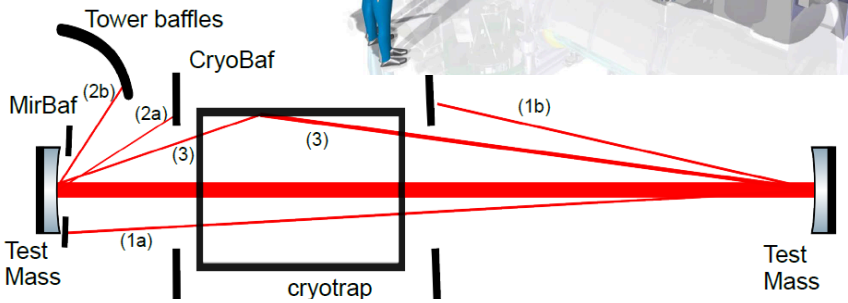
→ but can kill the GW signal if not mitigated.

A re-coupling of 10^{-24} W/W enough to destroy the expected GW signal

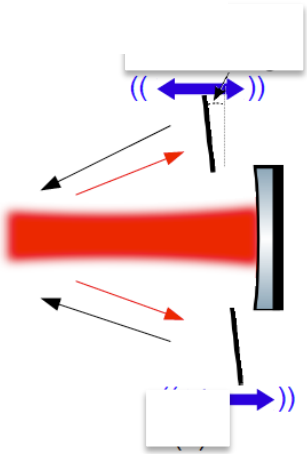
Needs for baffles







$$\Delta\phi = \frac{4\pi}{\lambda} x(f) \sqrt{P_{\mathrm{re-coupled}}}$$



ITF is full of passive baffles (AR coated) to eliminate the diffused light across (99.5%)

No real control/monitoring on where light goes

A re-coupling of 10^{-24} W/W enough to destroy the expected GW signal

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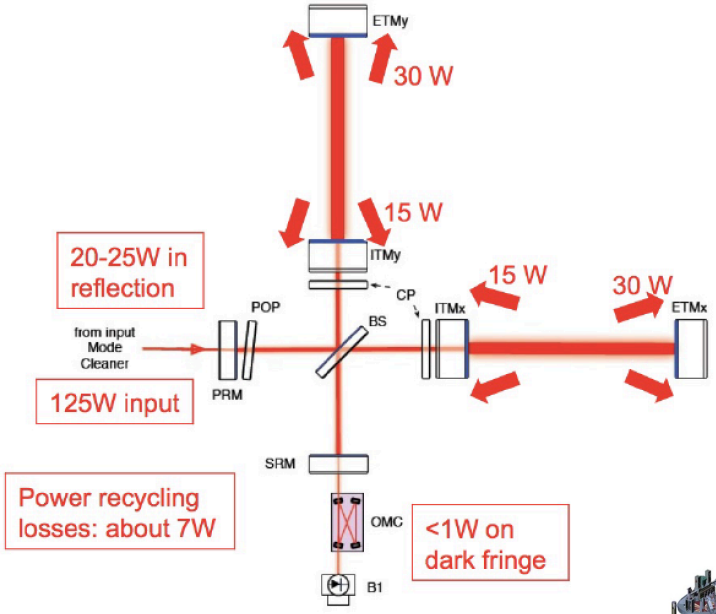
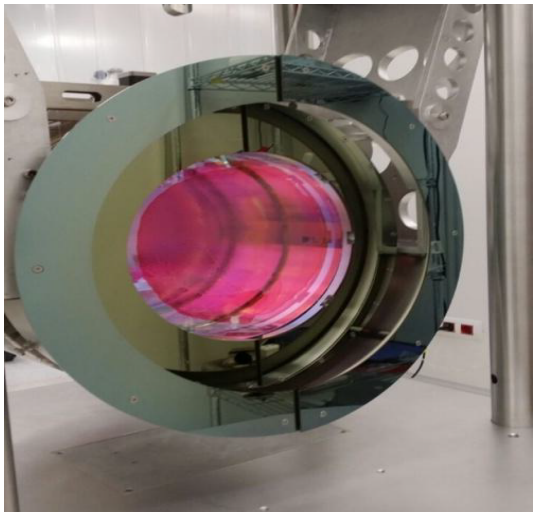
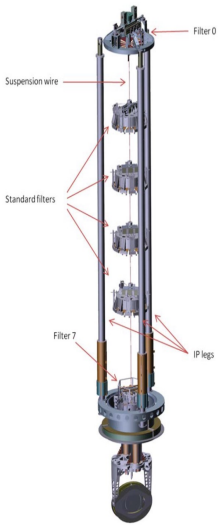
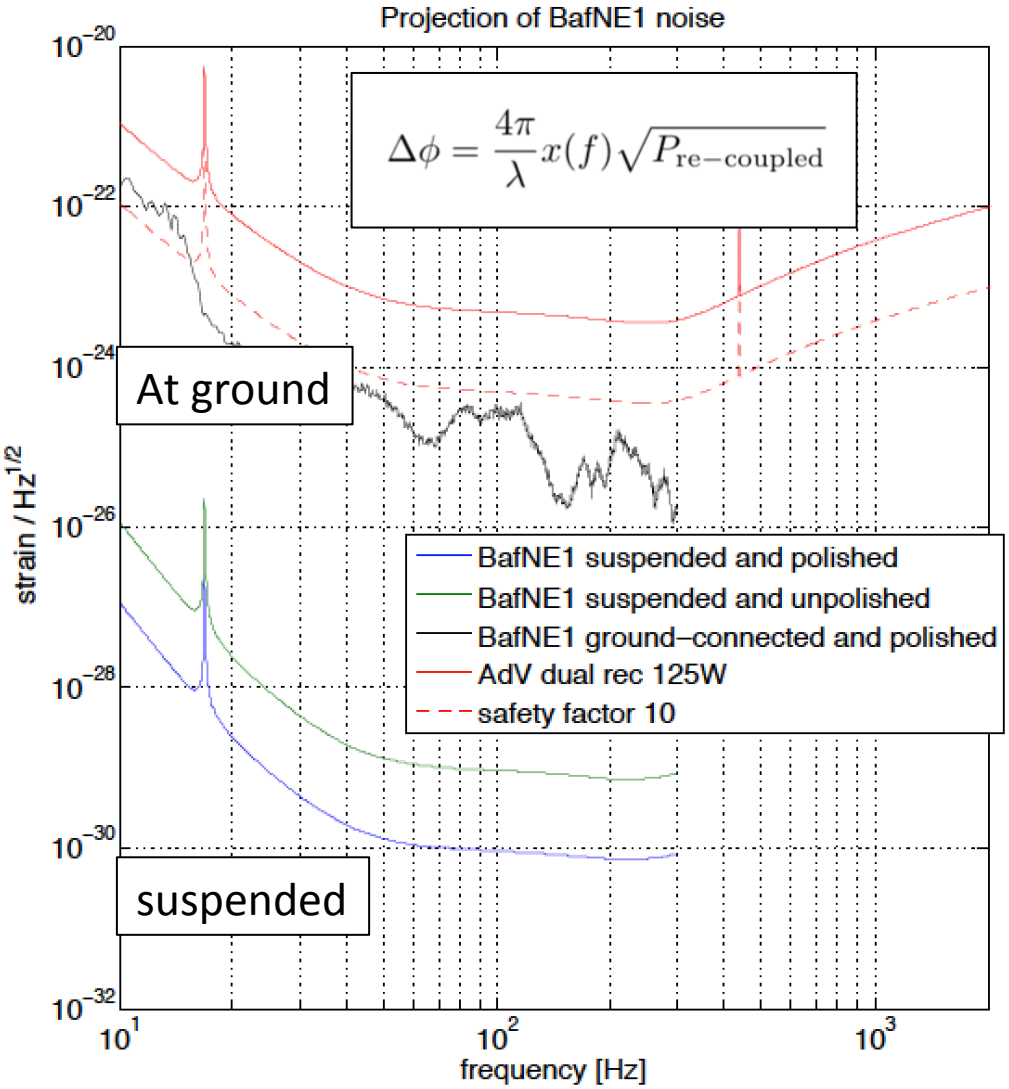
Baffles @ core optics





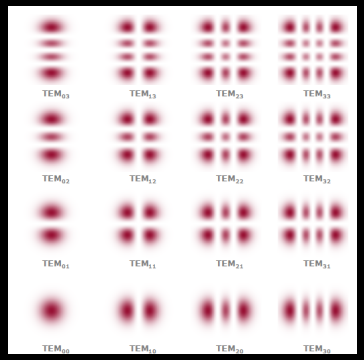


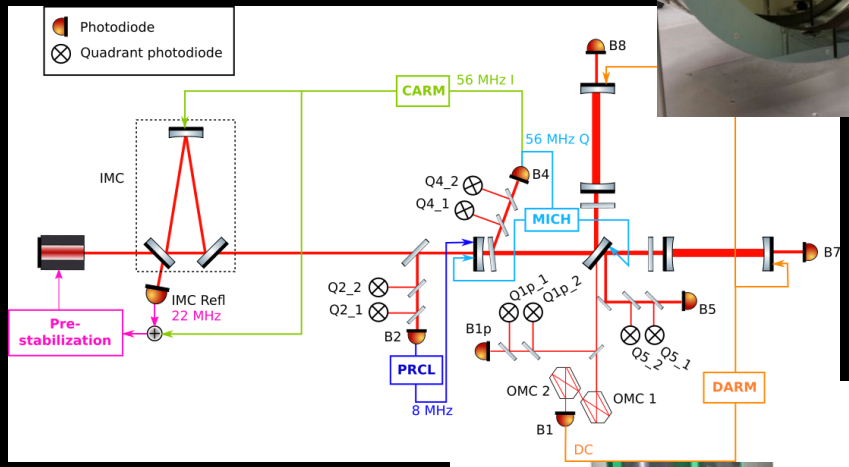


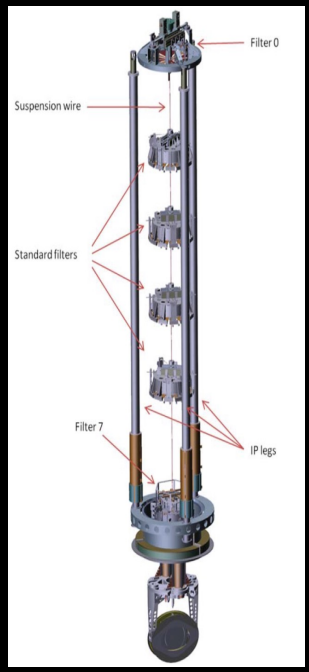
Baffles surrounding core optics needs to be suspended to preserve the sensitivity at low frequencies

Use case for smart baffle

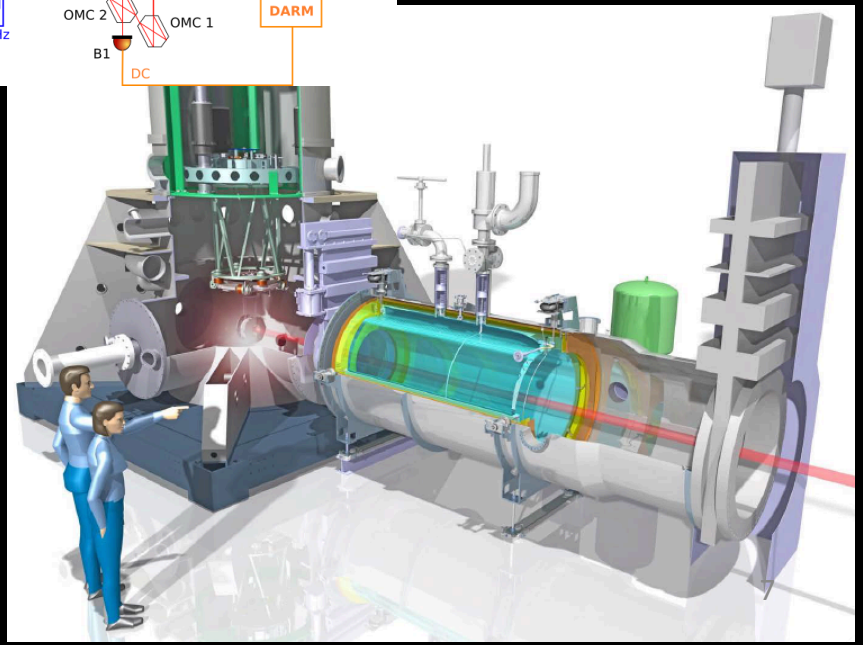
- Efficient alignment of ITF → maximize sensitivity
- Dynamic mapping of mirror surfaces
- Monitoring of developing laser high modes
- Correlate with ITF glitches



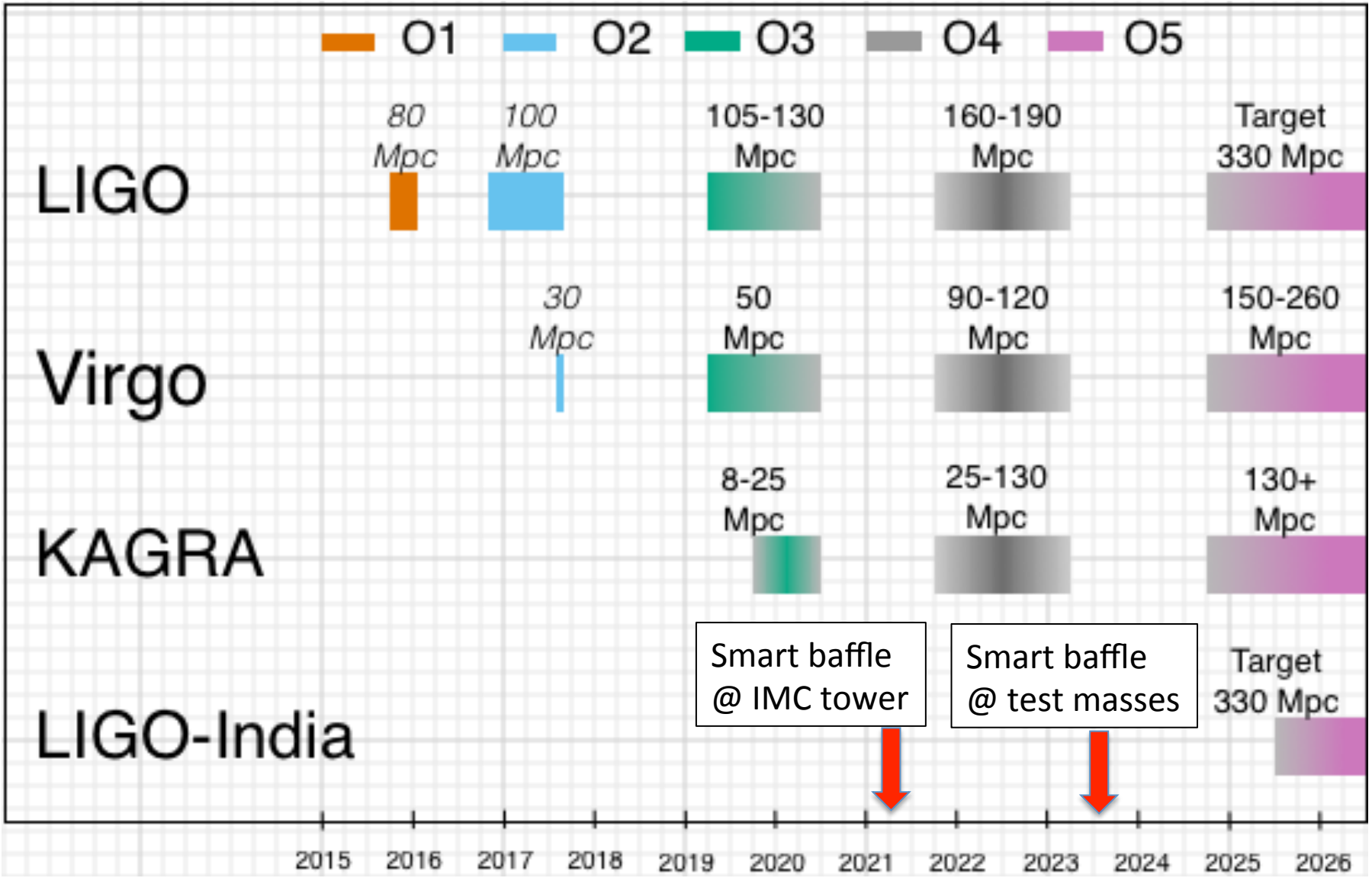




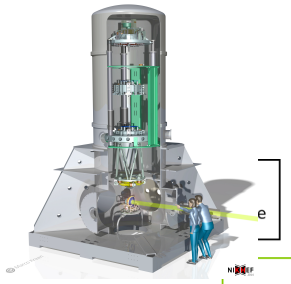
- Sensors on 1064 nm (IR)
- UHV (10^{-9} mbar)
- No active cooling possible
- Solid against baked out (100 C)
- Reflectivity less than 0.5%
- Total scattering under control
- Limited RO cabling → wireless RO
- Negligible induced EM noise near mirrors
- ……

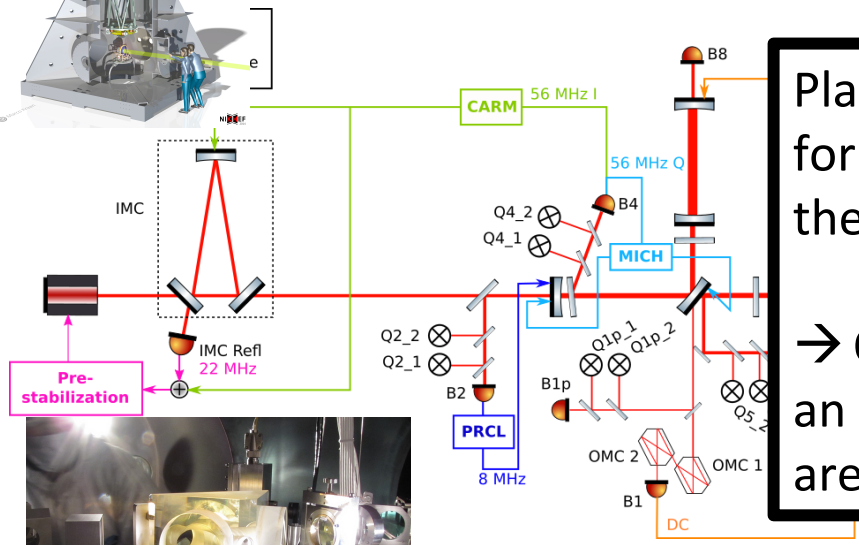


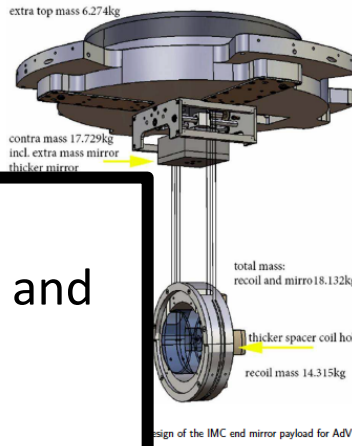
LVK Schedule



Baffle in IMC

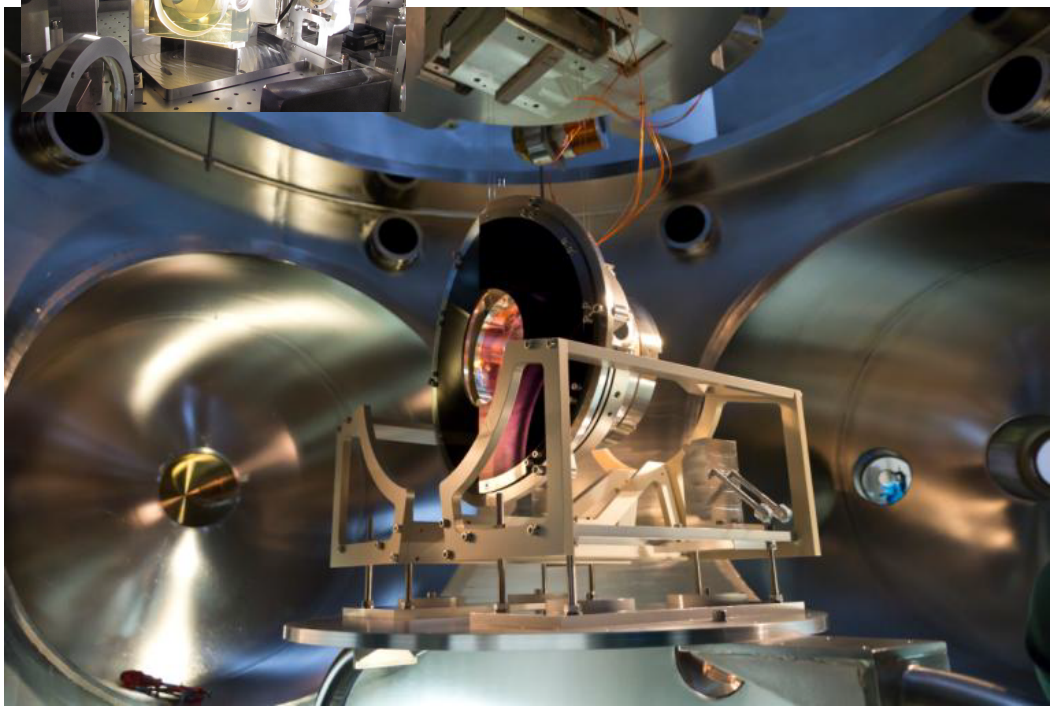


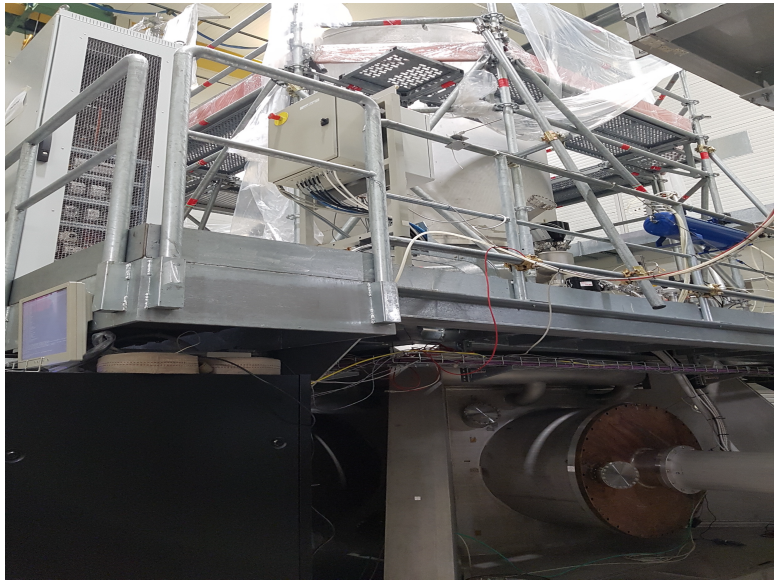




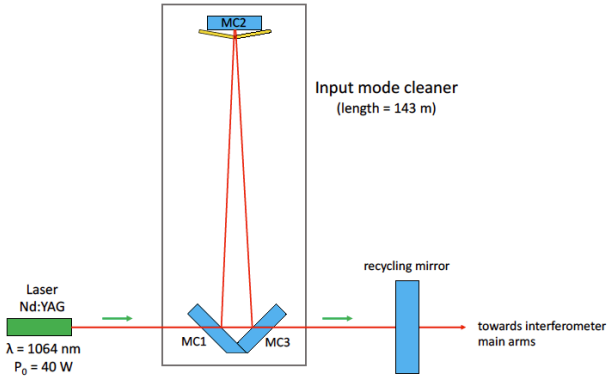
Plan to redesign the payload
for the Input Mode Cleaner mirror and
the installation of new mirror

→ Opportunity to integrate
an instrumented baffle in a suspended
area to demonstrate the feasibility





Simulations

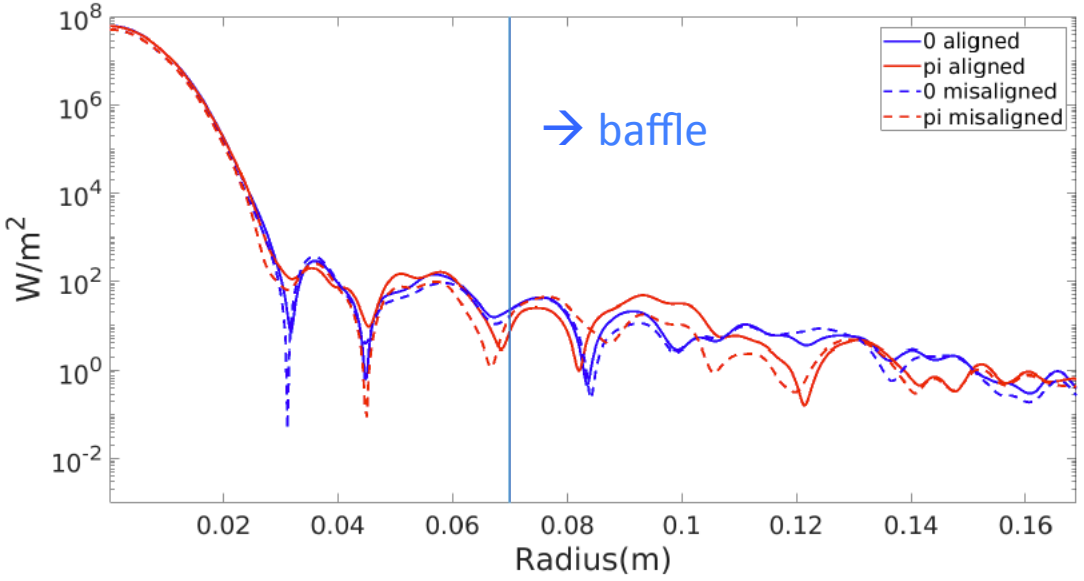


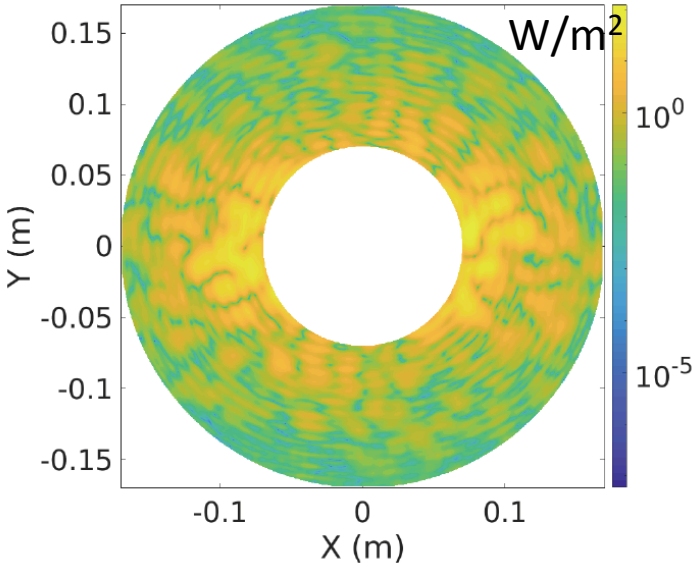
Simulations were used to optimize the sensor layout and determine the level of light power to be exposed to

We performed also studies on miss-aligned cavities

Scenarios	Mirror + baffle	Baffle	Photodiode
Resonance	1.35 x 10^4 W	0.20 W	3.2 x 10^{-3} W
Misaligned (10 μrad)	1.19x 10^4 W	0.17 W	3.0 x 10^{-3} W
Extremely misaligned	-	-	2.1x 10^{-2} W
Mechanical drift	390 W	-	130 (for 10 ms)

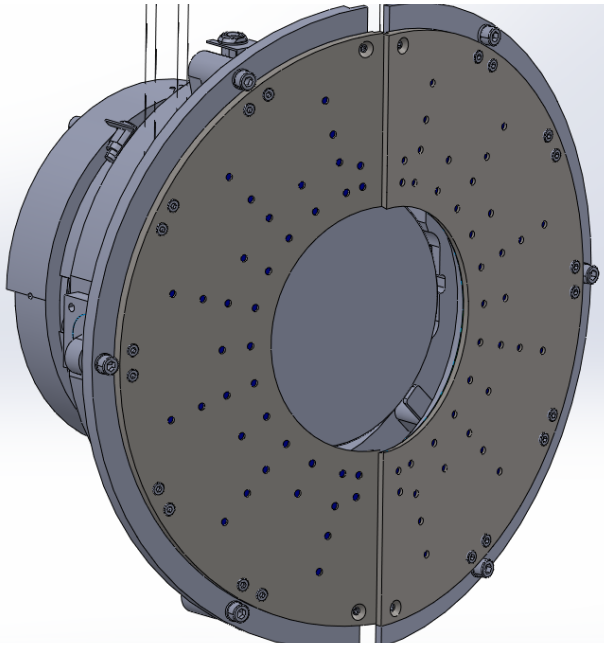
We are not repeating the simulations with the new mirror

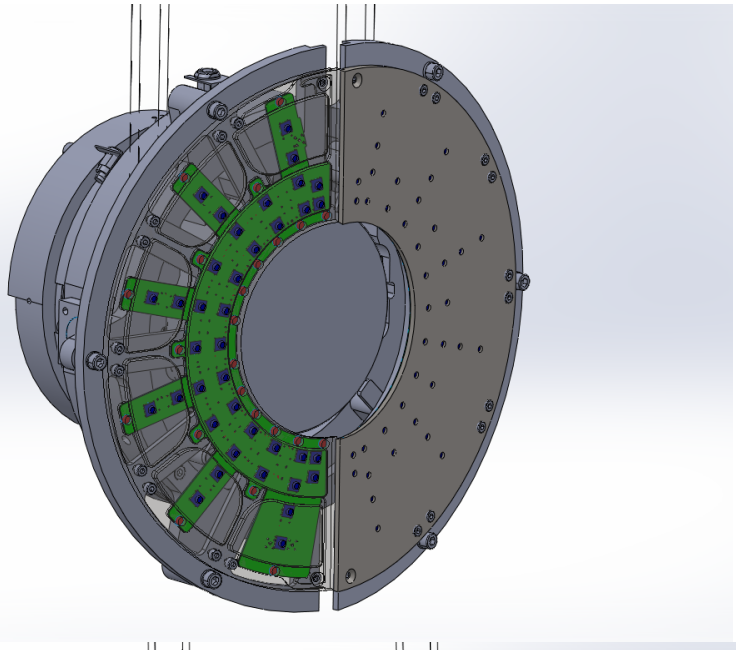




A. Romero-Rodríguez et al, 2021, Class. Quantum Grav. 38 045002

Conceptual Design





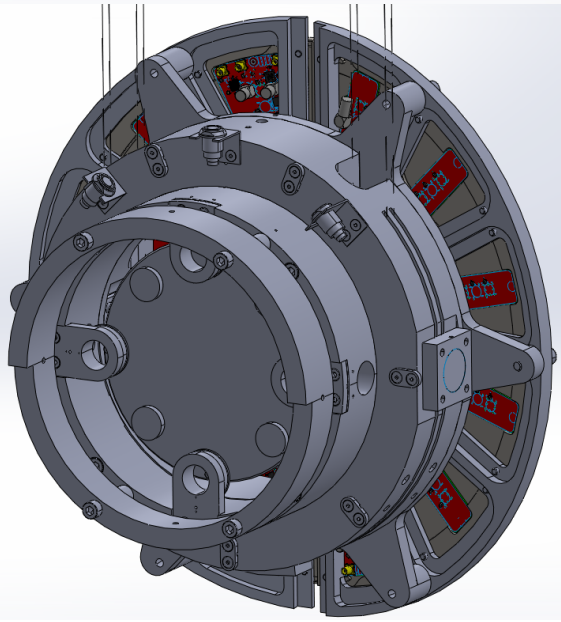


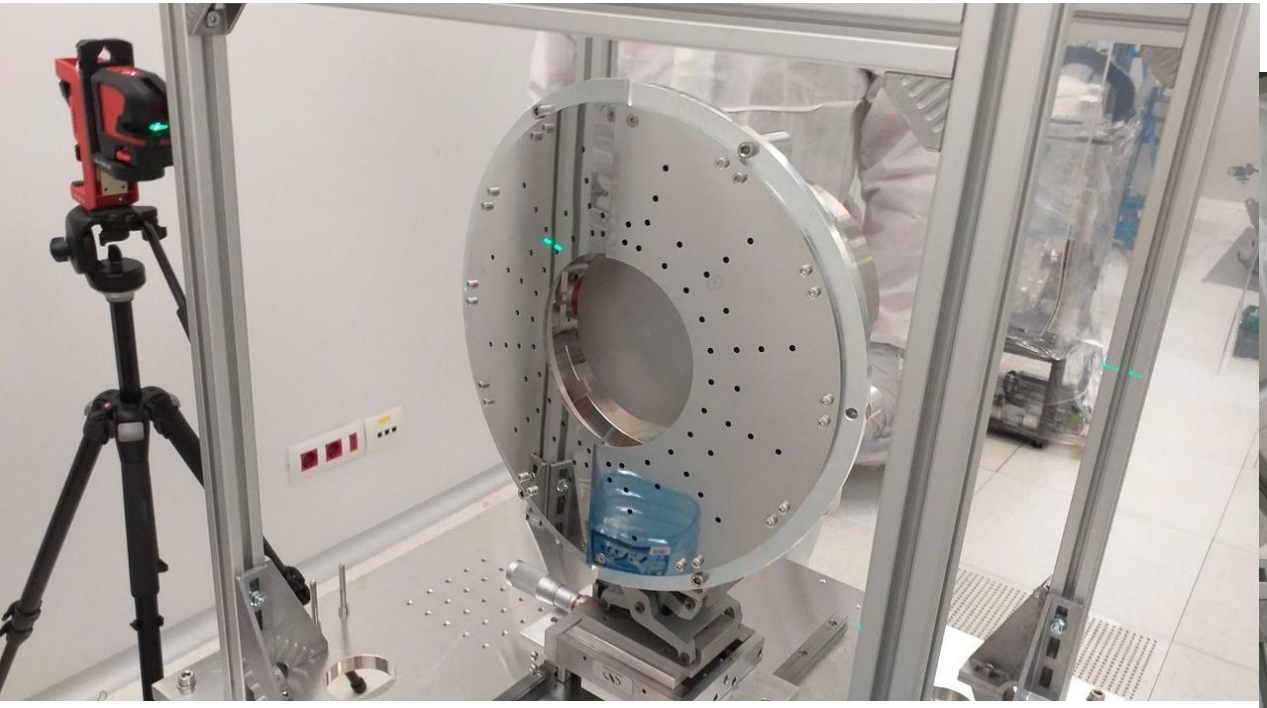
Photo-sensors located behind plate

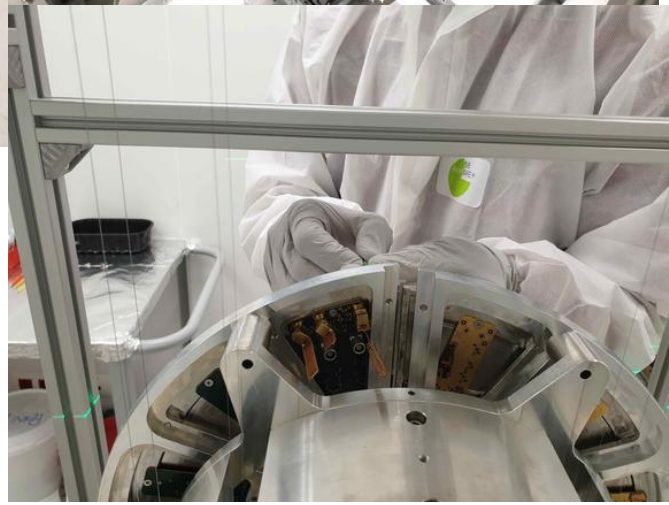
- Number of sensors 76 (38 in each 1/2 baffle)
- Sensors mounted in large PCBs
- Sensors active area 0.49 cm2
- Light reaches sensors through conical (12º) holes of 4 mm of diameter (in the polished side)

→ Avoid scattering in edges and hide PCB from light

→ Knife like edges in holes and inner aperture

First Integration test @ EGO

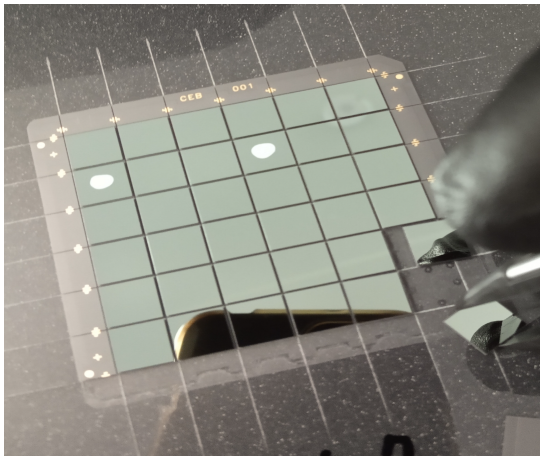


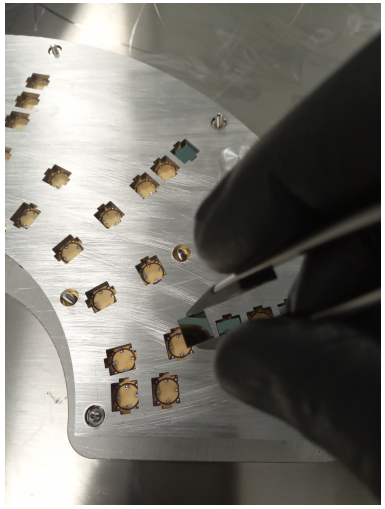


A first (successful) integration test with the
new IMC payload took place in October 2020

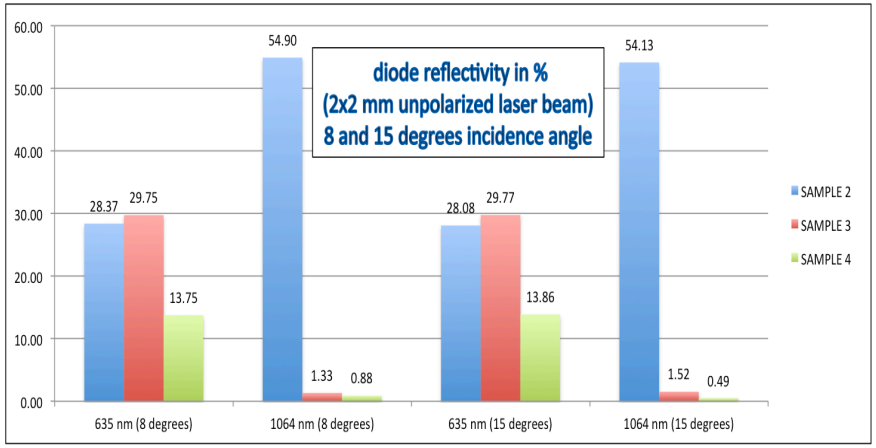
→ Indicated the perfect balance of the mechanics
→ Certified the integration with electronics and connections
→ Indicated the real integration @ vacuum tower would be smooth

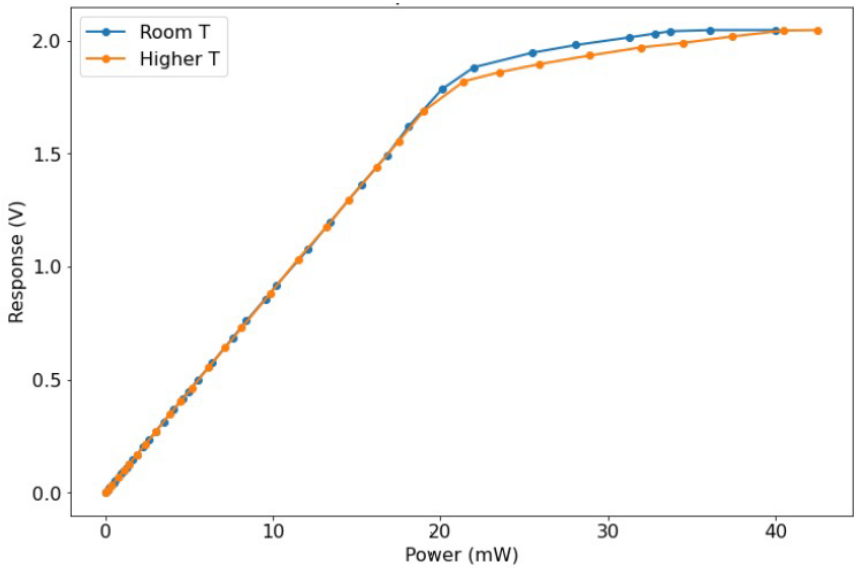
New Hamamatsu Sensors





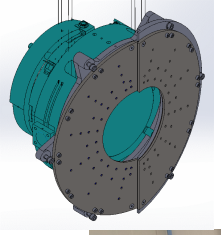
Dimensions	7.37 x 7.37 mm^2
Sensitive area	6.97 x 6.97 mm^2
Operation temperature	-40 to 100 °C
Power dissipation	50 mW
Optical coating	Anti-reflective (1.8%)
Photosensitivity	600 mA/W

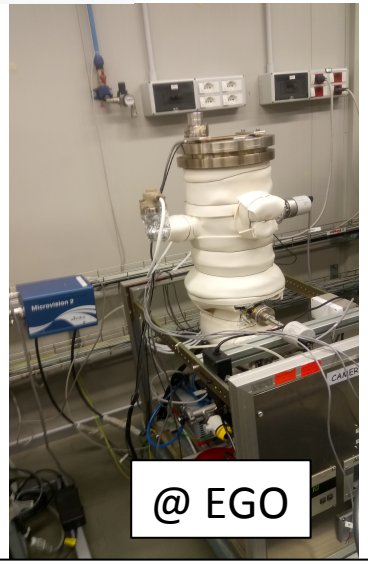


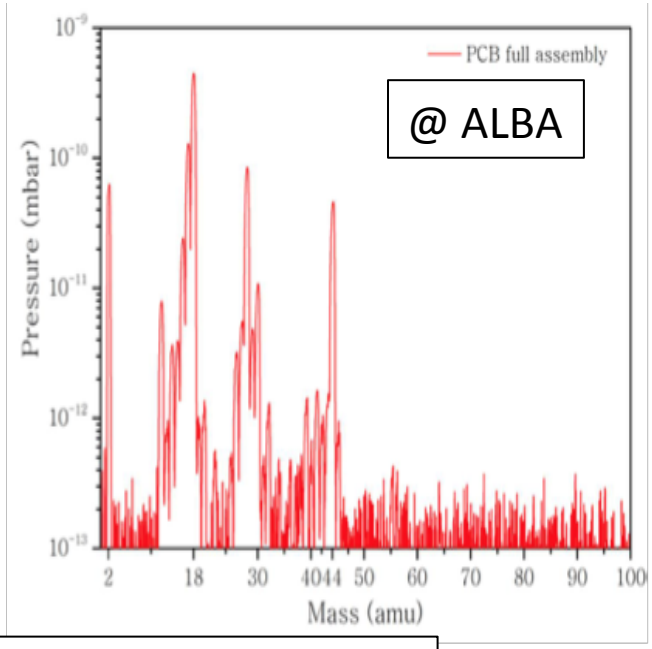


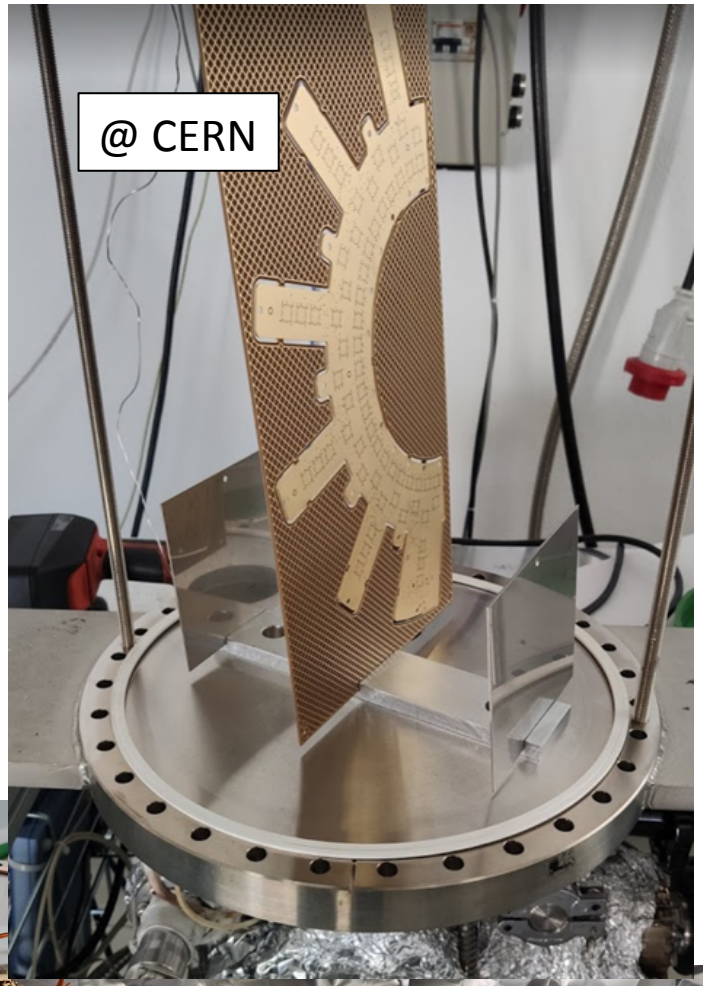
Thanks to 2-years long R&D with Hamamatsu we developed Si-based sensors
UHV compatible and with a reflectivity of about 1.2% - 1.8% reflectivity (v3 sensors)
→ First attempts to reduce to < 1 % led to non-linearity and slower sensors (v4 sensors)

Vacuum Tests







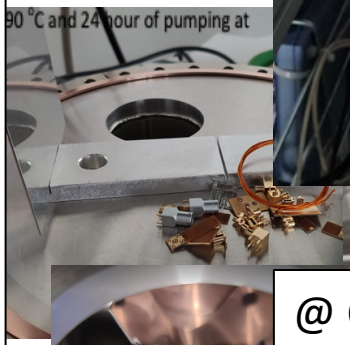


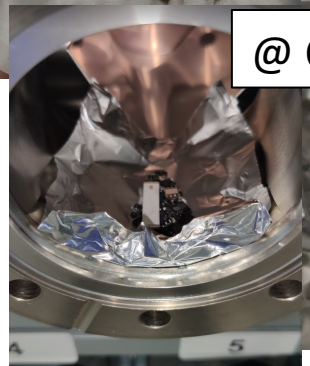
First test at ALBA and EGO satisfactory

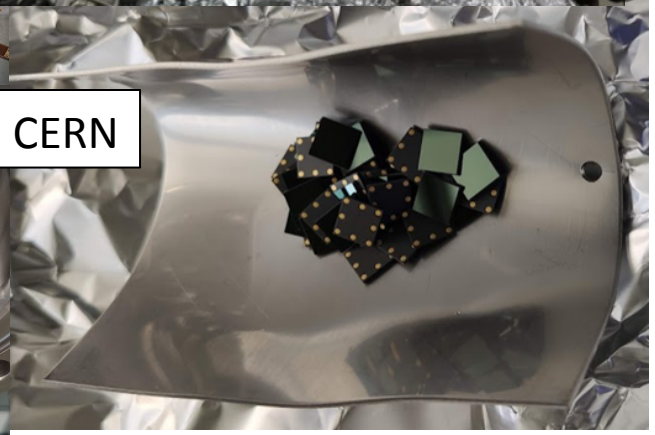
Intense collaboration with
CERN Vacuum Department
led to a stringent certification

Outgassing after 100C@24h -48h
bake out: in the range 10^{-7} – 10^{-9} mbar l/s

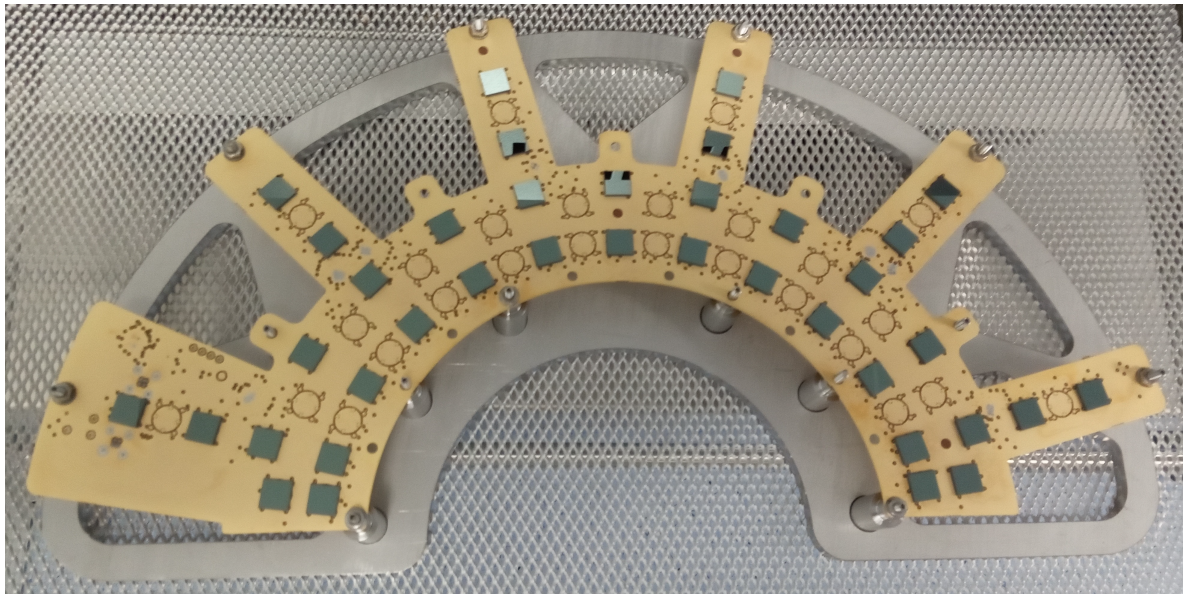
Tests with fully powered electronics
→ Very good heat dissipation (golden PCBs)

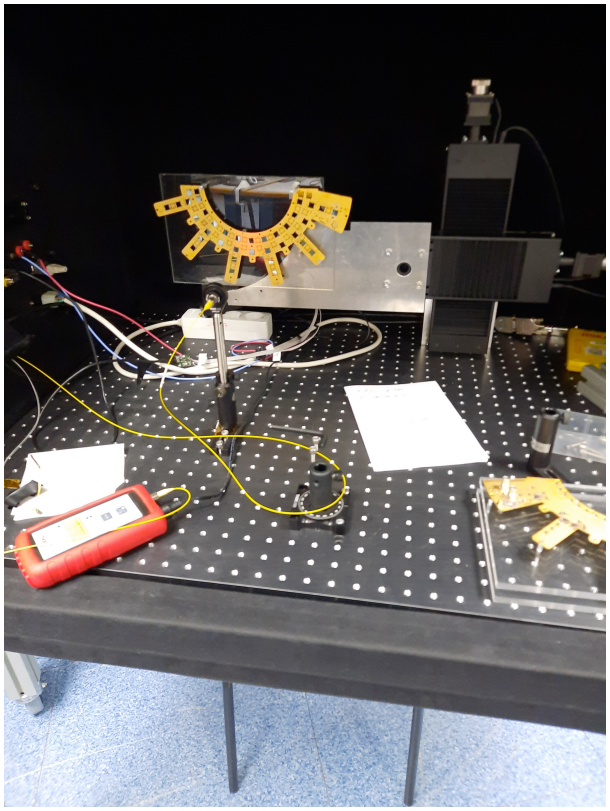


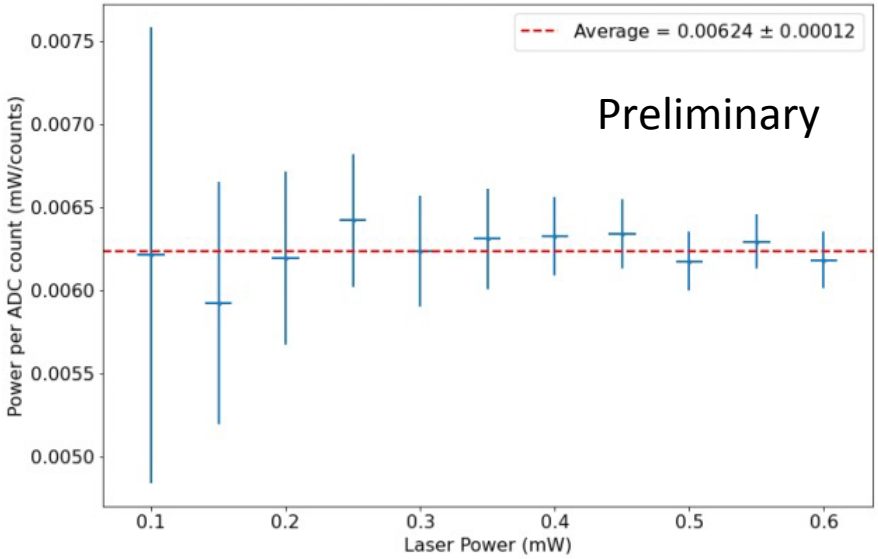




Front End Calibration





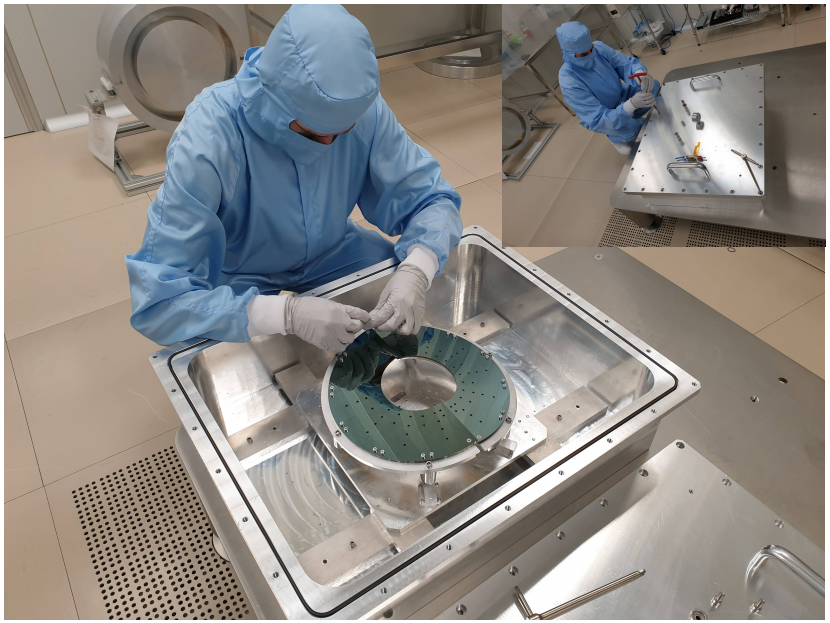


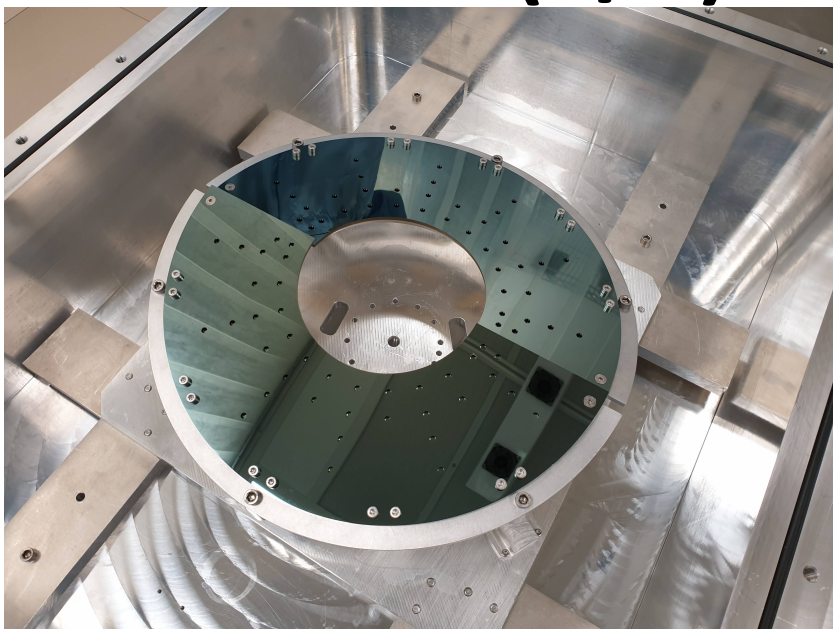
Ongoing campaign to obtain a precise absolute calibration of the baffle signals

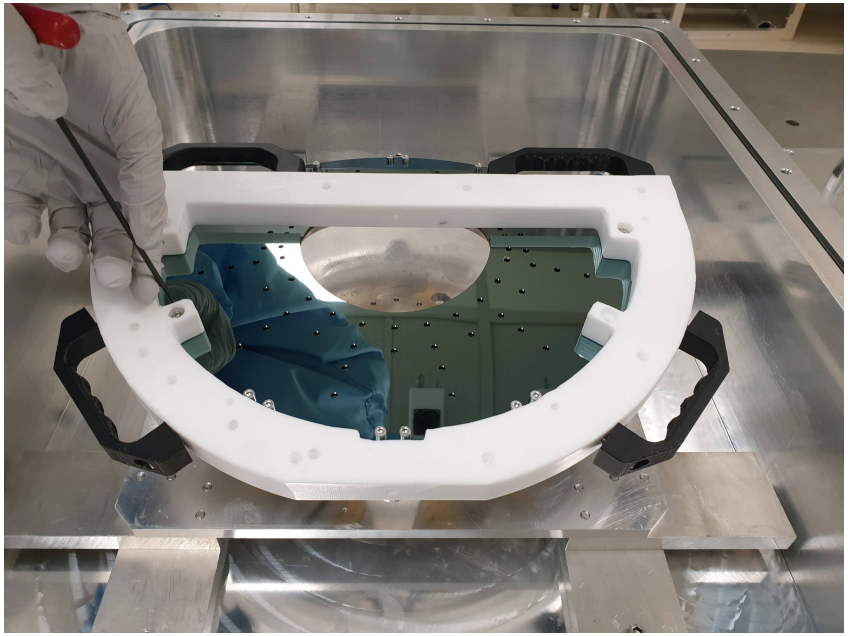
→ Inter-calibration at the level of < 2%

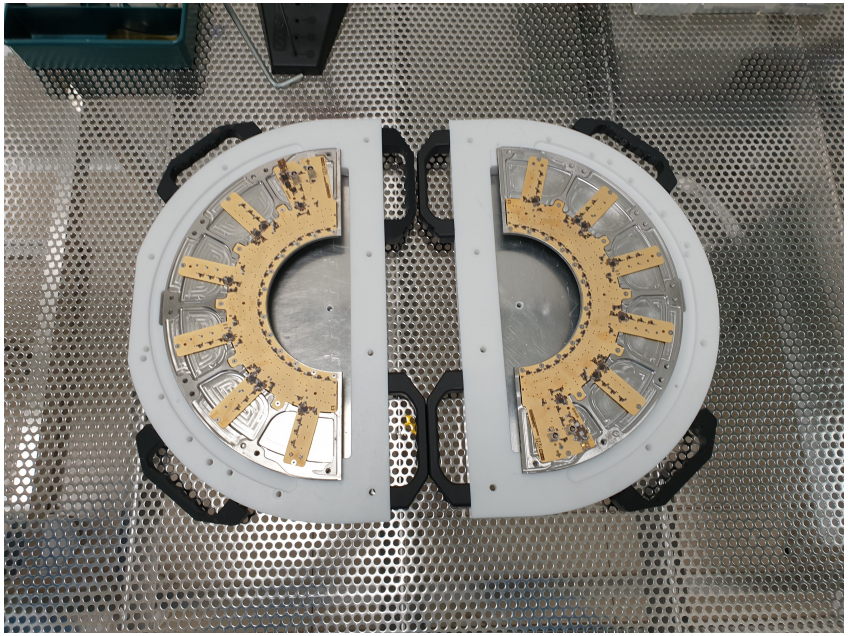
→ First absolute calibration at the < 5% level:
ADC count → 6.2 μW +/- 0.2 μW

Installation @ IMC end mirror (1/2)

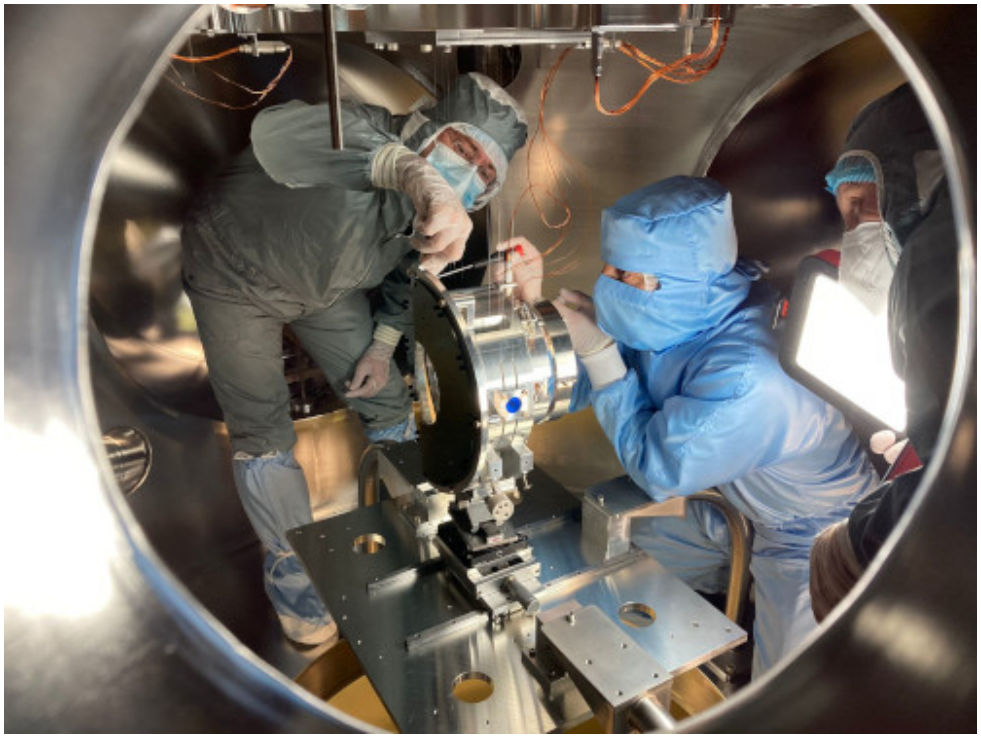


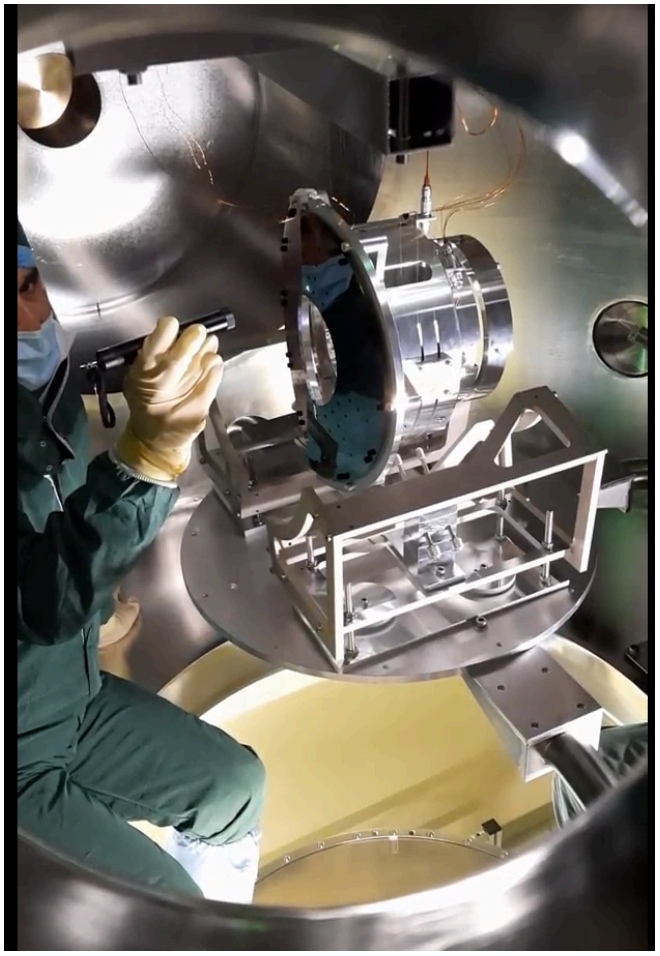


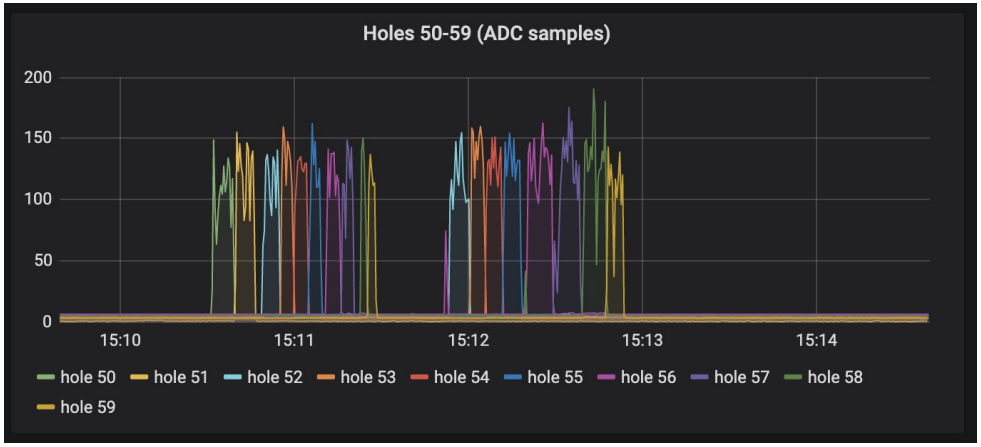




Installation @ IMC end mirror (2/2)

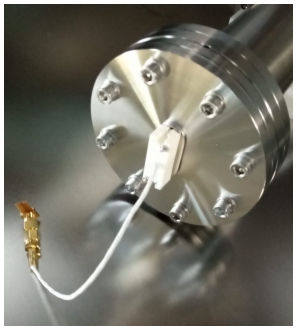




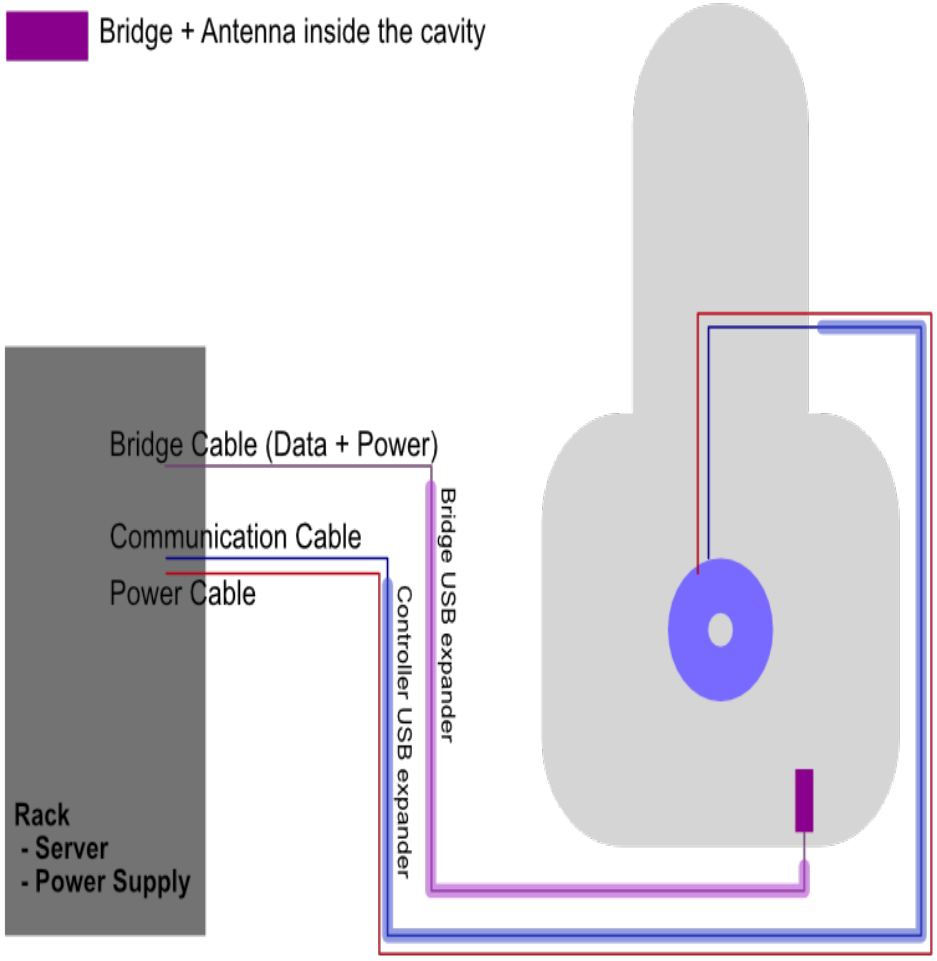


After a delicate installation the integrity of the detector was checked in situ (with a visible laser) before closing the tower and restoring the vacuum.

Commissioning

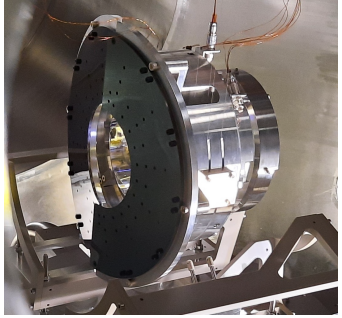


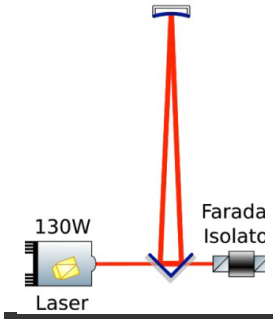
- The IMC baffle has been taking data for more than a month at EGO without observing any effect on the IMC cavity performance
- Injection of wireless signal does not affect the IMC feedback loops
- Temperature stable @ max 27 C
- Running serial readout mode @ 2Hz (→ nominally would reach 10 Hz) now integrating over 500 ms
- Wireless readout yet to be commissioned

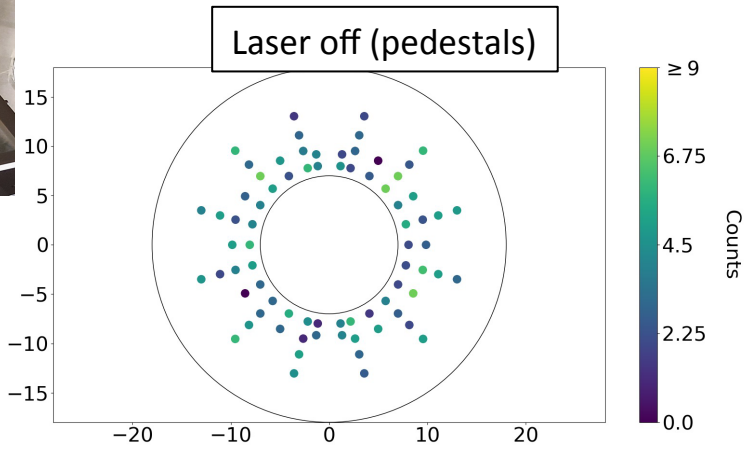


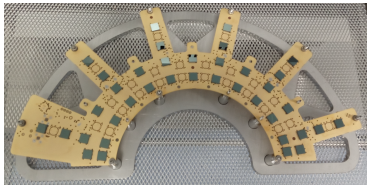
Plan to run the system in O4 (more than one year from now)

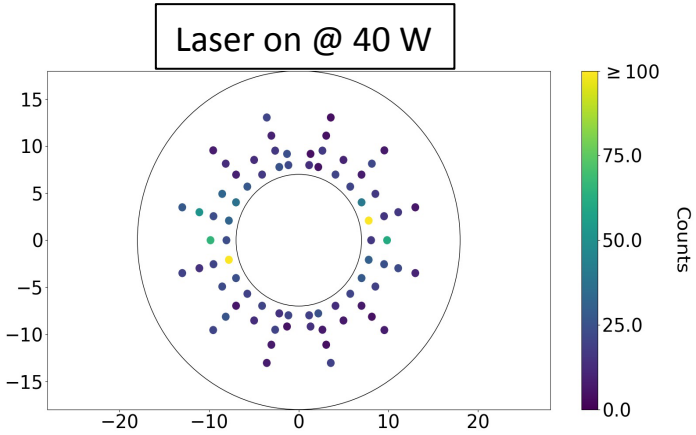
Performance

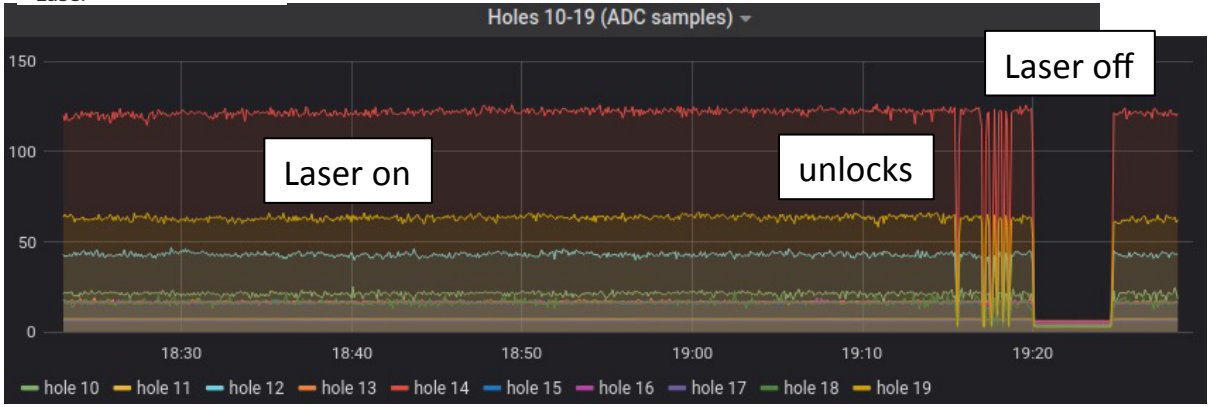








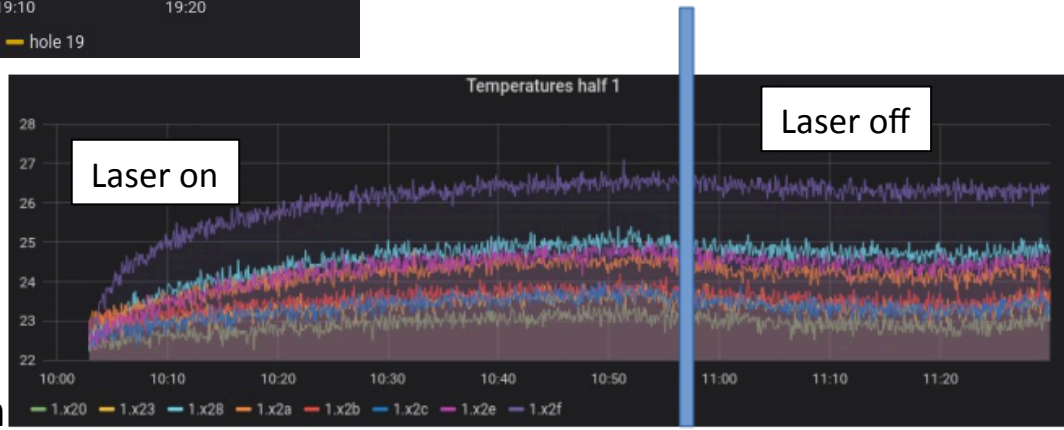


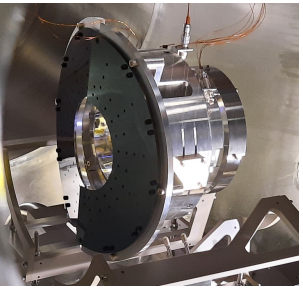


Very quiet detector with laser off
Very stable response with laser on

Able to see glitches
(temporarily unlocks of cavity)

Good thermal behavior in UHV
→ PCBs working with 2V
→ Golden PCB dissipates heat
→ Never beyond 27 C
→ Good for longevity and
for the mirror/suspension preservation





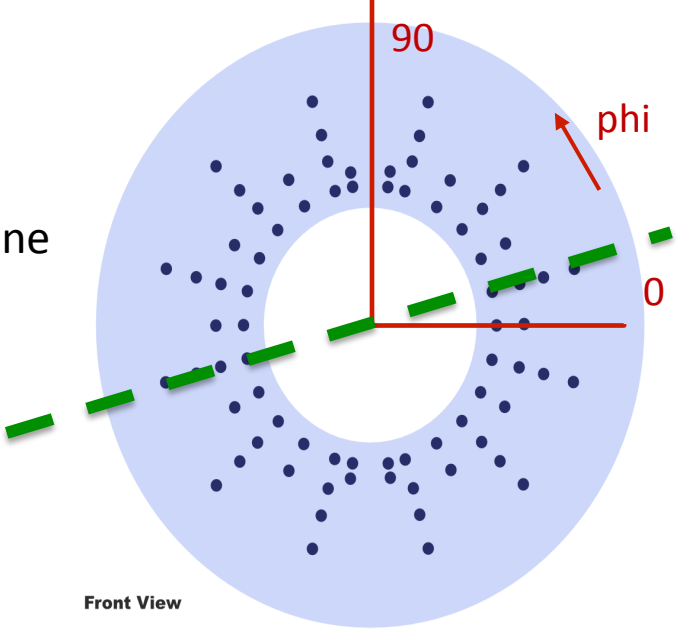
First results

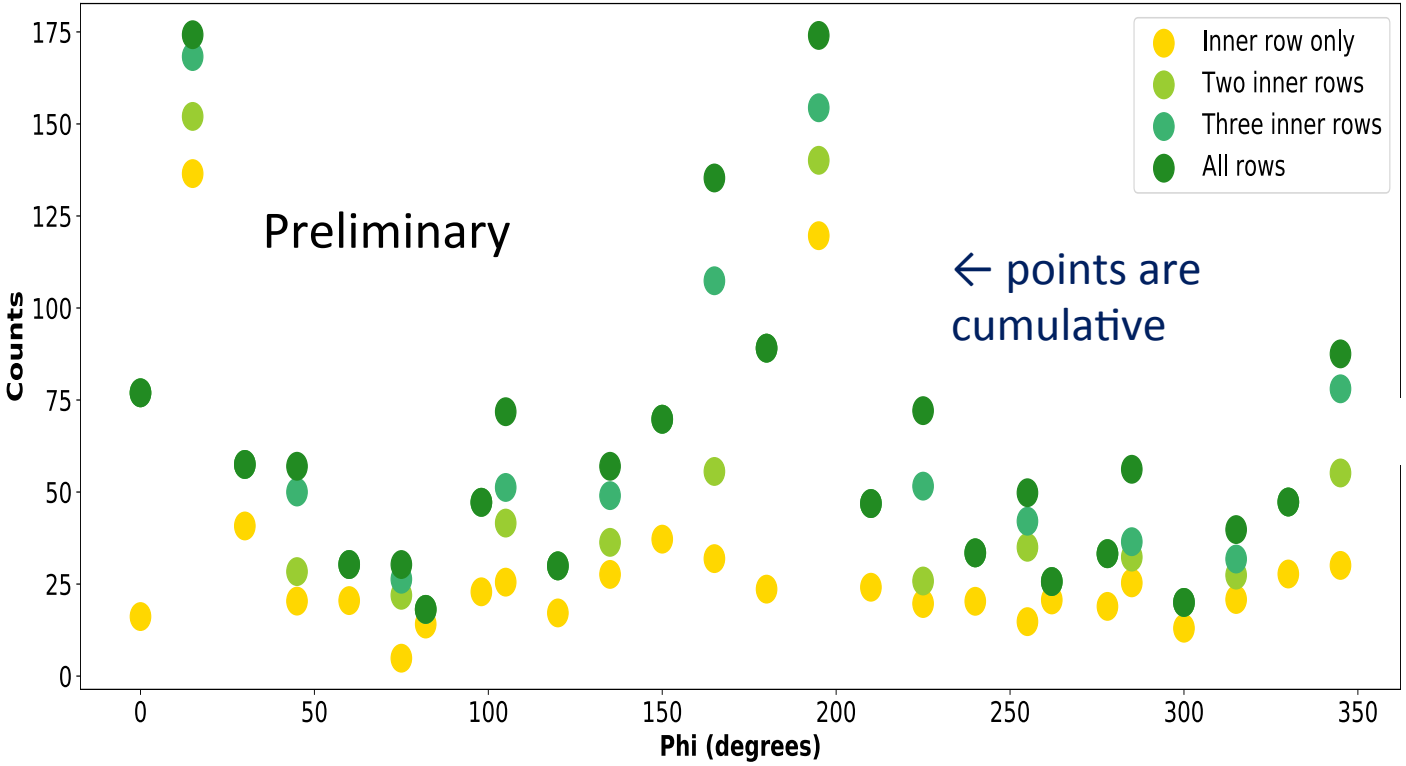
The triangular shape of the IMC cavity translates into light concentrated in the X-Z plane

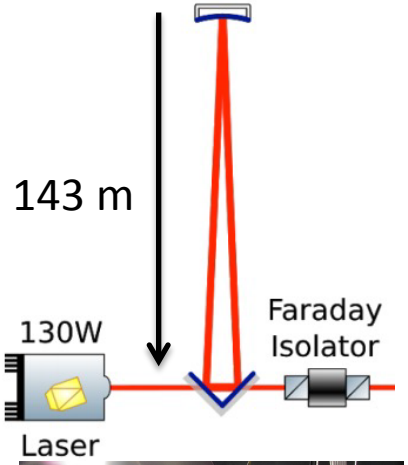
The fist data indicates a tilted phi distribution pointing to a potential miss-alignment of the dihedron cavity w.r.t to the end mirror

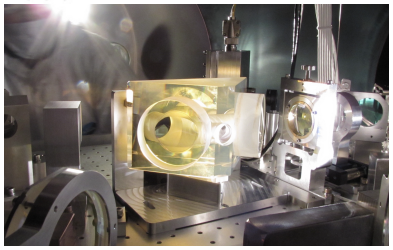
→ Needs to be confirmed with more data

→ Ongoing simulations with new mirror map



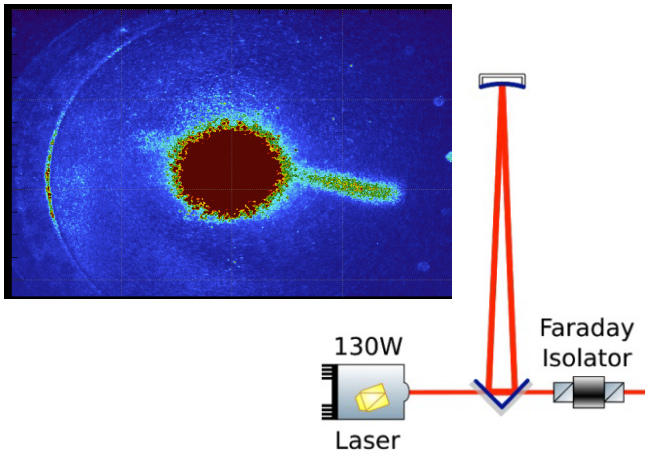


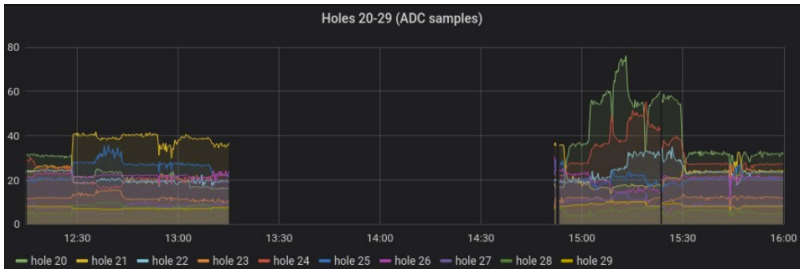


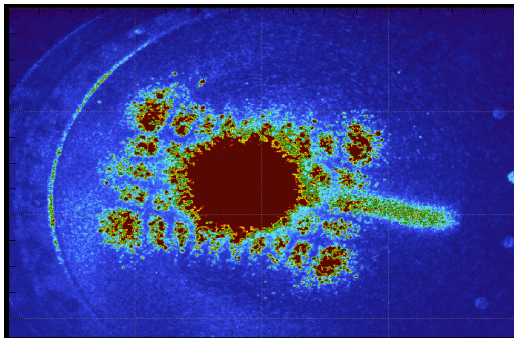


Miss-alignments

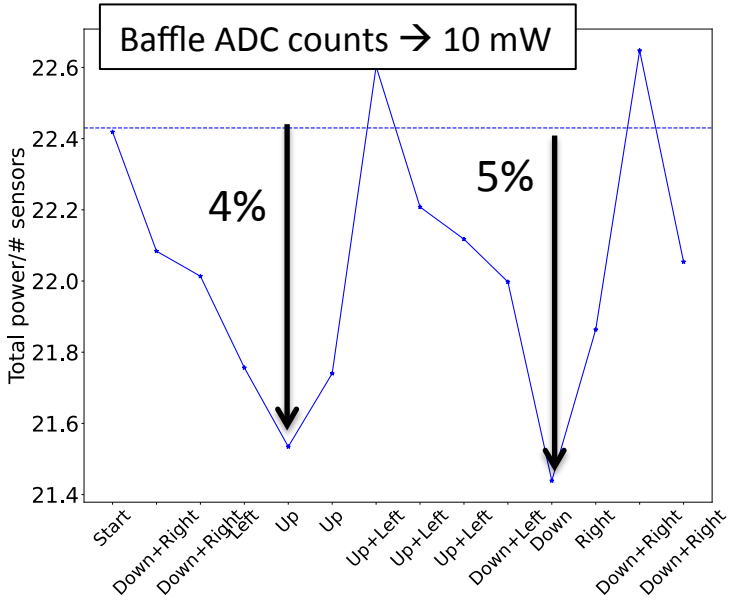
- Special run was taken with miss-aligned IMC cavity (ad hoc) to show the sensitivity of the instrumented baffle to the status of the cavity.

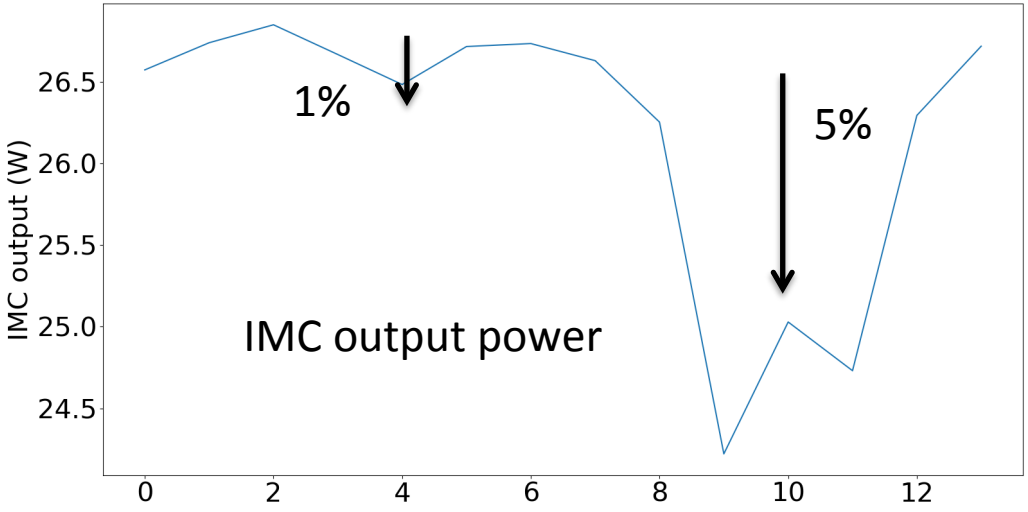




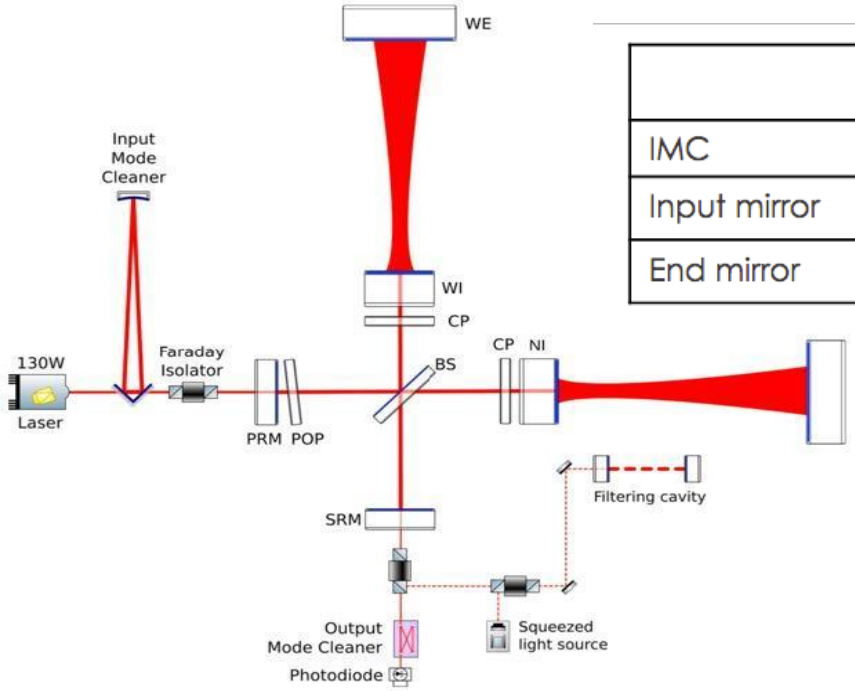


- The baffle demonstrates sensitivity to the situation of the cavity and the development of HOMs.



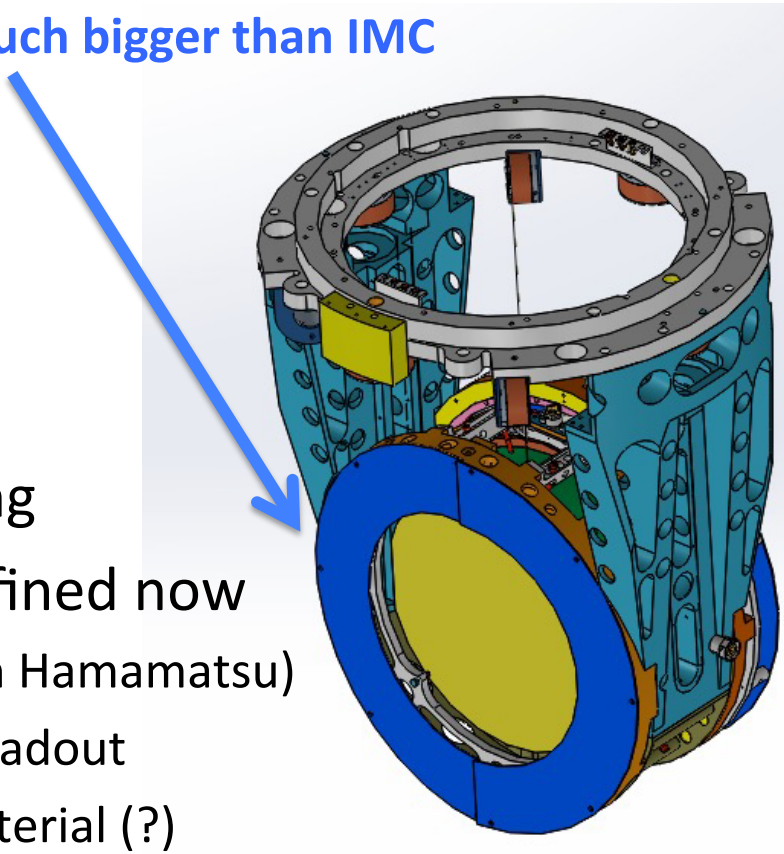


End Mirror Baffles



	Ø (cm)	Baffle inner Ø (cm)	Baffle outer Ø (cm)
IMC	14	14	35
Input mirror	35	33	80
End mirror	55	52	80

Much bigger than IMC



- New large mirrors (100kg) for O5
- Completely new payload and baffling
- New instrumented baffles being defined now
  - O(200) sensors v5 (being explored with Hamamatsu)
  - New DAQ at 1kHz / serial + wireless readout
  - Further Improvements on polished material (?)
    (considering ultra polished Nickel coating instead of SSTL+AR)

Final notes

The installation of the first instrumented baffle in Virgo has demonstrated that active monitoring of the stray light at the core optics of interferometers is feasible.

It is being operated at Virgo with no impact in the interferometer.

It will provide precious data to calibrate simulations and to improve the understanding of the stray light inside the experiment.

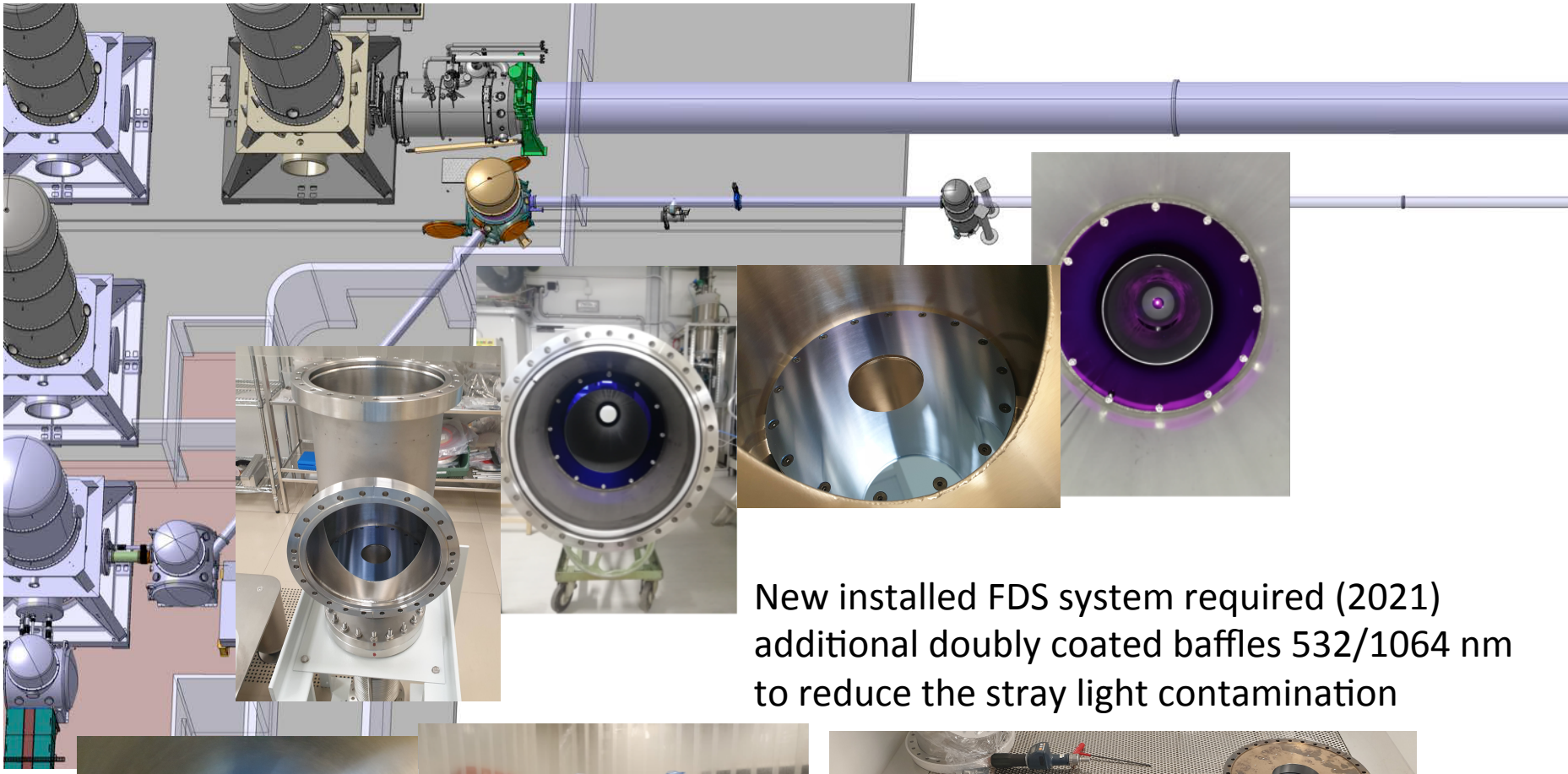
Instrumented baffles at the main arms offer extra handles on alignment, optimization/operation of the Fabry-Perot cavities, developing mirror defects, and correlation with glitches.

Thanks for your attention

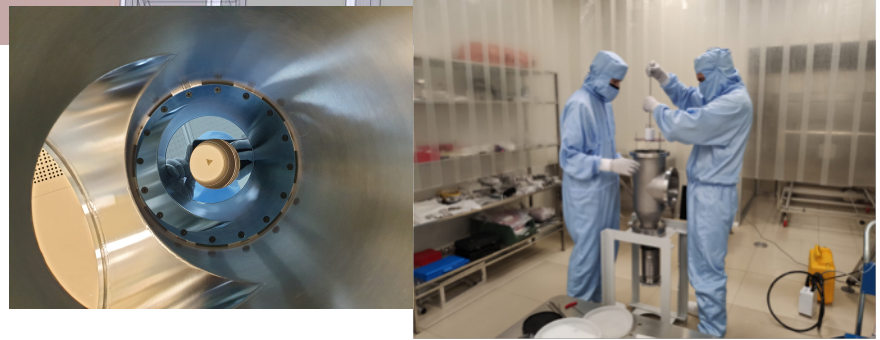
Very busy two years ahead of us to build the new devices

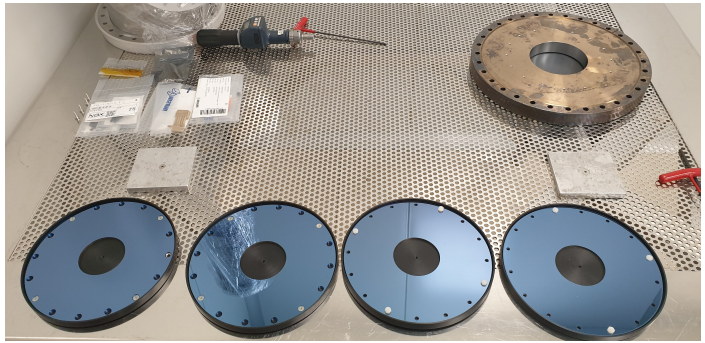
Other baffles

Frequency Dependent Squeezing



New installed FDS system required (2021)
additional doubly coated baffles 532/1064 nm
to reduce the stray light contamination





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Computing

One of 12 Tier-1 LHC data processing centers, only one in Spain fully Integrated in the GW computing grid

~20 PB on disk, ~20 PB on tape

Core Hours by Facility

	total
SURFsara	2.317 Mil
INFN-T1	2.014 Mil
Nebraska-CMS	1.861 Mil
Georgia Tech	1.419 Mil
PIC	1.200 Mil
NIKHEF-ELPROD	1.196 Mil
LIGO_US_LSU_SuperMIC	1.143 Mil
RAL-LCG2	1.072 Mil
MWT2 ATLAS UC	841 K

GPU Wall Hours by Facility

	total
LIGO-CIT-CE	85.1 K
Crane	30.8 K
SDSC-PRP	29.2 K
LIGO_US_LSU_QB2	25.9 K
LIGO-WA-CE	22.9 K
pic	7.46 K
ND - CAML_GPU	469
ND - CMS_GPU	81

Providing 7% of total LVC CPU last year
Providing 4% of total LVC GPU last year

Future enlargement subject to funding

IFAE