ACTIVE MONITORING OF STRAY LIGHT AT ADVANCED VIRGO: NEW INSTRUMENTED BAFFLES.

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on behalf of the IFAE group

12TH IBERIAN GRAVITATIONAL WAVES MEETING

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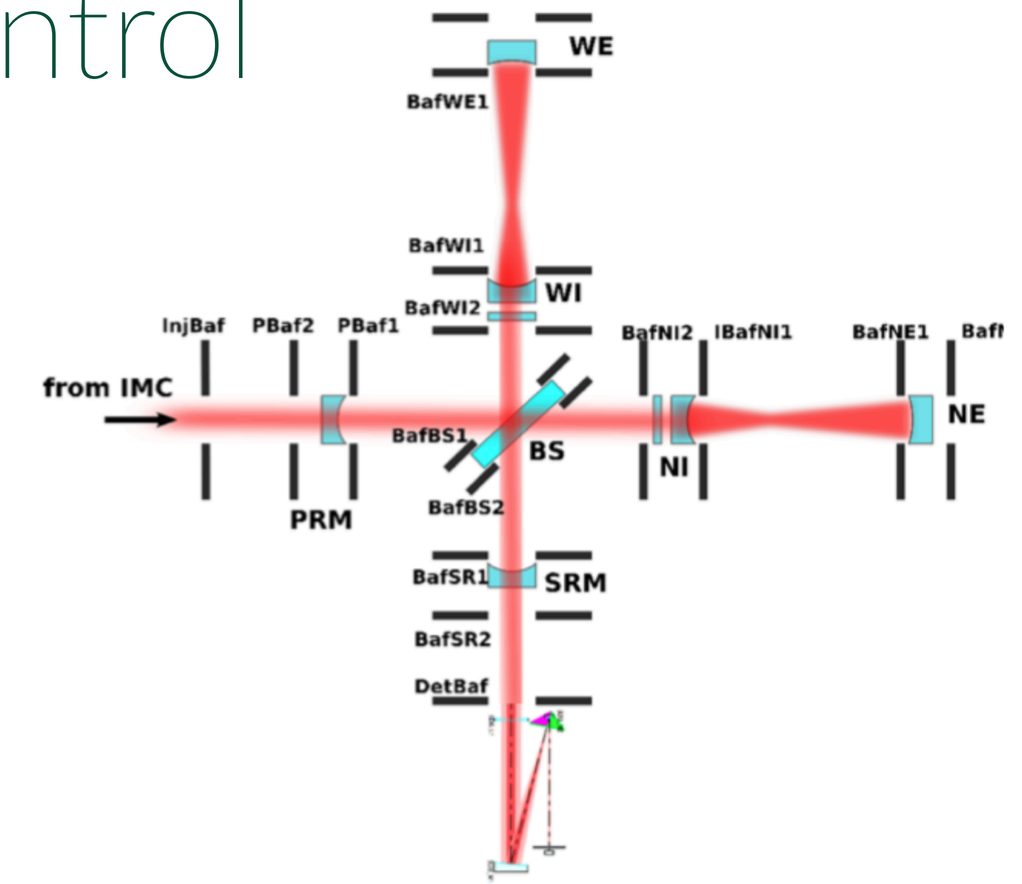
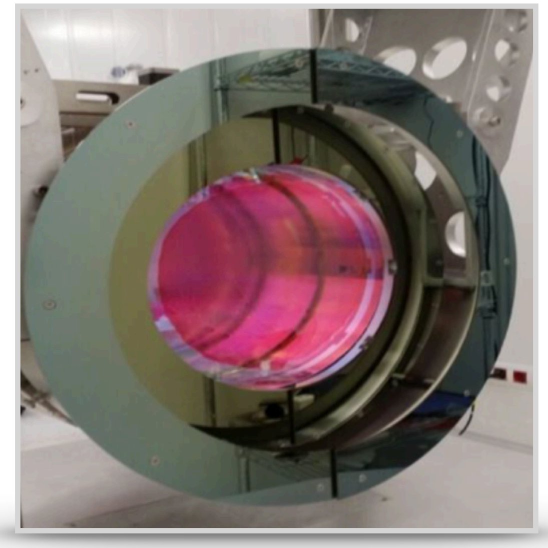
Stray Light Control

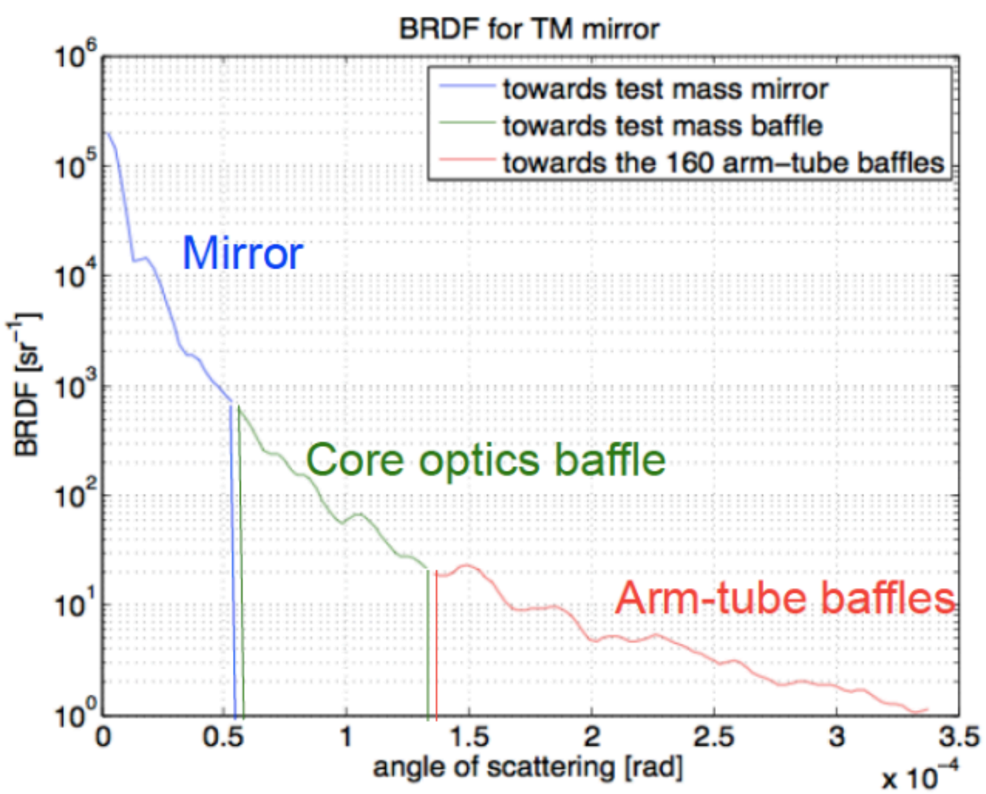


- Scattered light is a source of noise that limits the sensitivity for a large range of frequencies in the sensitivity band.
- Large fraction (70%) of light in interferometer lost in the form of stray light.
- The main sources of stray light are hard to identify and its consequences are difficult to mitigate.

- Solution to eliminate the diffused light: passive (AR coated) baffle installed in AdV.
  - No control/monitor of the distribution of light close to the mirrors.



Stray Light Control



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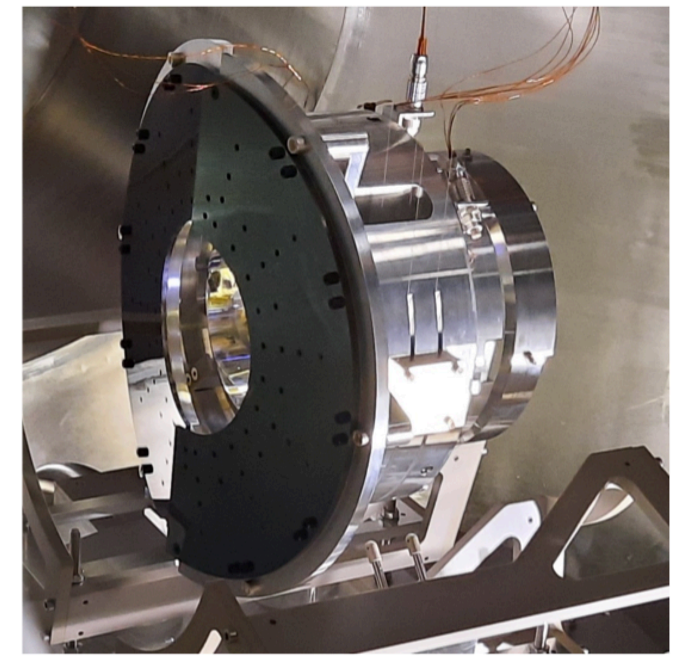
Stray light can occur at various places:

- Laser beam diffraction,
- Scattering on surfaces and in substrate of optics:
  - At small angles goes from the mirror surface to the opposite mirror,
  - At mid angles goes to core optics/cryo stations,
  - At larger angles in arm tubes.
- Stray light introduces noise which might severely impede detection of GW or be erroneously identified as a GW event.

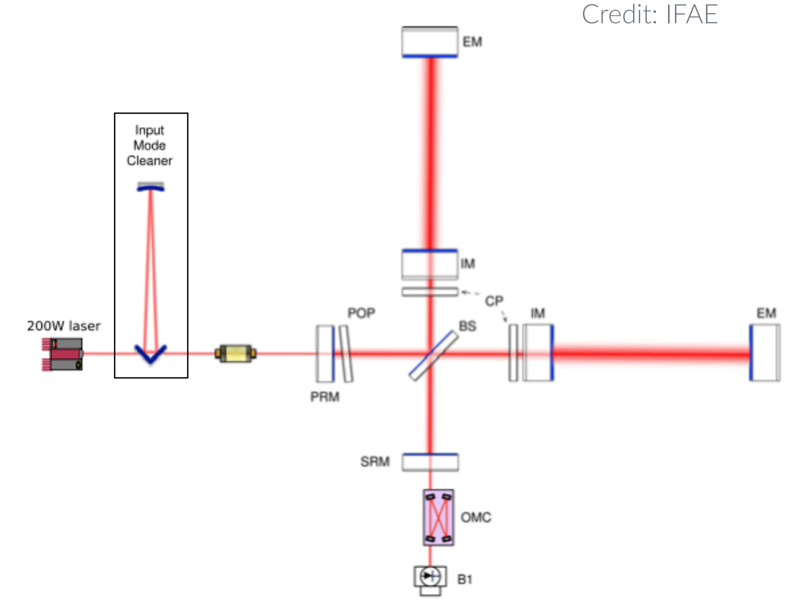
April 2021 upgrade: implementation of instrumented baffle surrounding the suspended end mirror of the Virgo's input mode cleaner cavity.

Why an Instrumented Baffle?

- More **efficient alignment and fine-tune** of the parameters of the interferometer during commissioning phase after shutdown period,
- **Monitor small-angle scattered light** from the mirrors in the cavity:
  - **Dynamic mapping of mirror surface and defects** (ageing and/or contamination)
- Detect higher-order laser modes,
- Establish correlation with interferometer glitches.



Credit: IFAE



The new active baffle with sensors will serve as a **demonstrator of the technology for its future implementation in the main arms** of the interferometer, surrounding the main mirrors.
It will also be **relevant for both 2G upgrades and 3G new projects.**

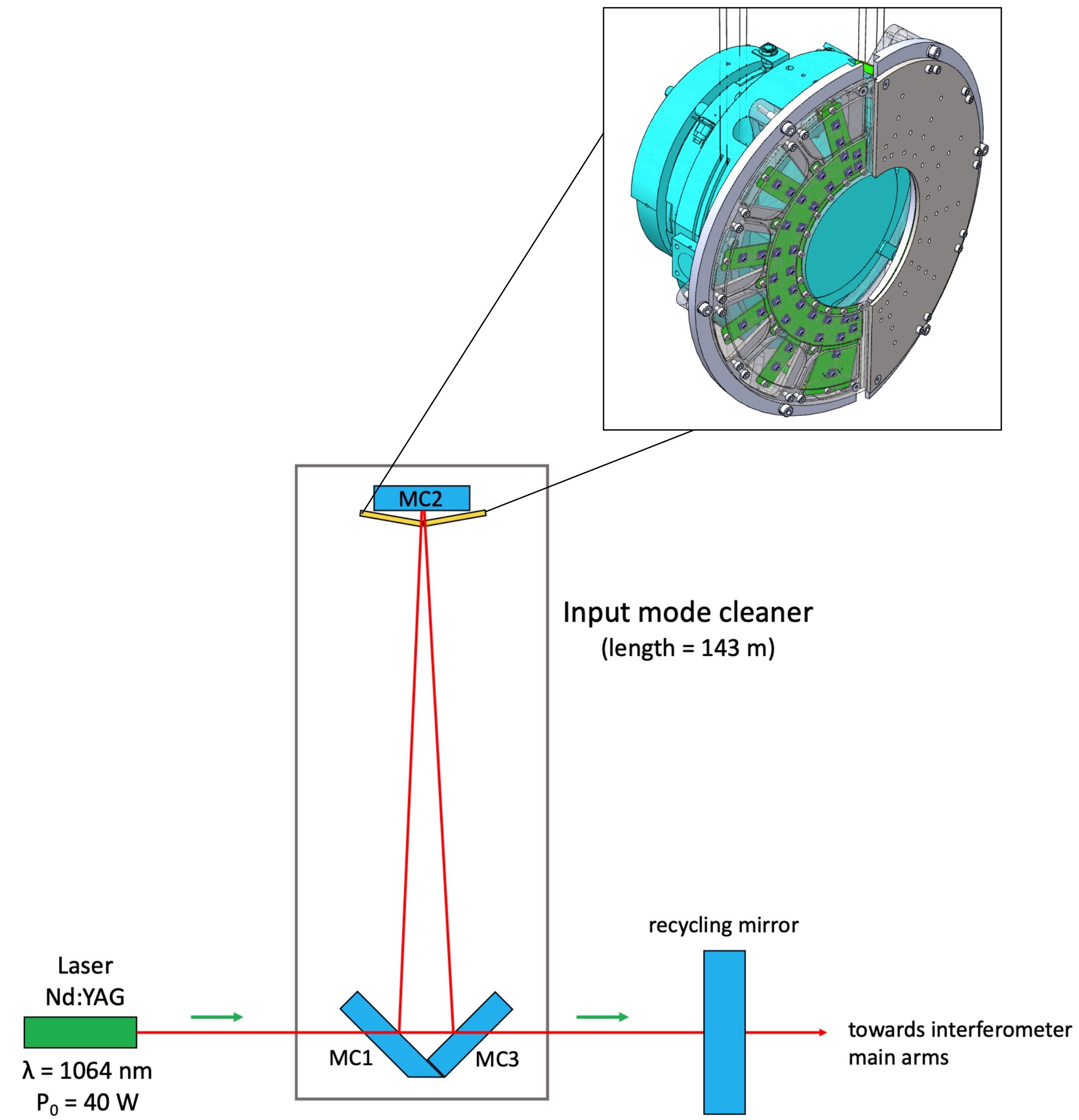
The Design

During Phase I upgrade, the input mode cleaner (IMC) end-mirror and payload were replaced.

This motivated the replacement of the passive baffle by a new instrumented one.

The IMC cavity

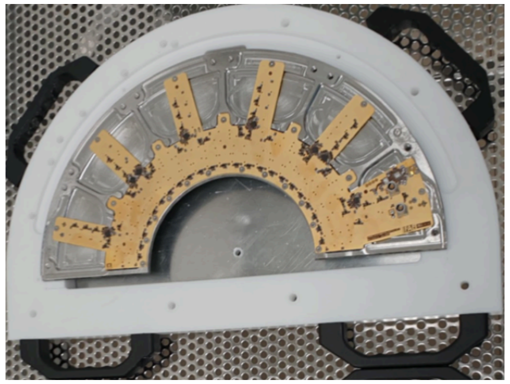
- In-vacuum triangular cavity with suspended optics, used for modal and frequency filtering of the laser beam before entering the interferometer.
  - MC2: end-mirror, radius of curvature of 187 m.
  - MC1: input mirror.
  - MC3: output mirror.

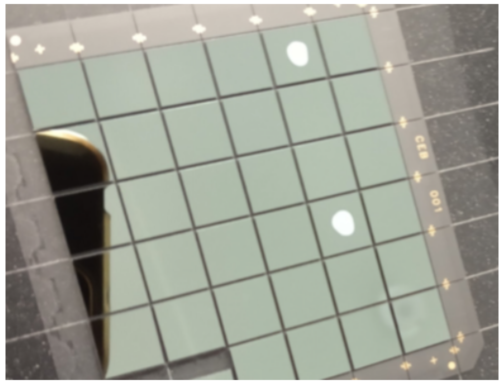


The Design

- Conical (12°) holes of 4 mm of diameter in the polished side,
- 76 photosensors mounted on two large gold-plated polyamide-based PCBs,
- Sensors active area 0.49 cm^2
- Sensor signals are processed by 16 ADCs.
- Each ADC is instrumented with a temperature sensor, leading to 16 separate readings.

All the elements in the baffle are certified for ultra-high vacuum (UHV) conditions.



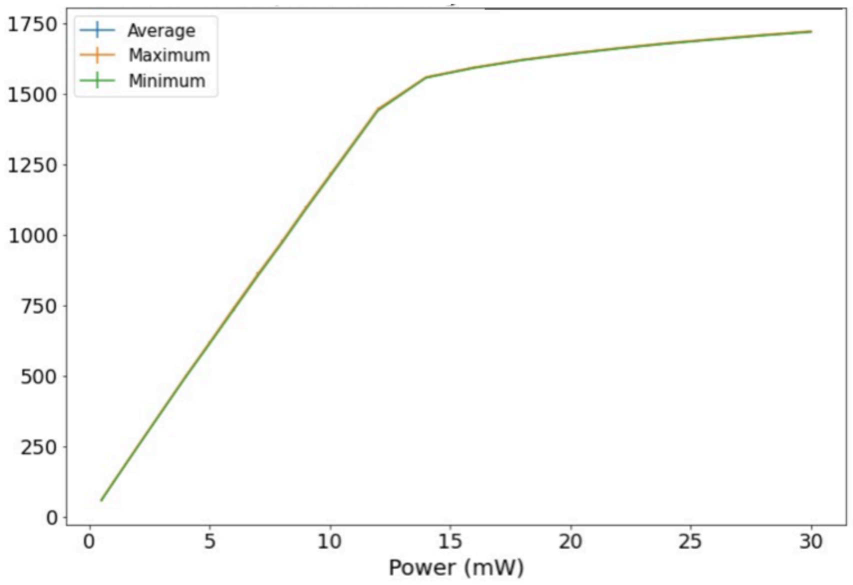


Credit: IFAE

CALIBRATION OF THE PHOTOSENSORS

Calibration of the photosensors indicates a good linearity in the response for the whole range of interest and a less than 3% sensor-to-sensor variation.

$$Calibration\ factor = 4.60 \pm 0.15\ \mu W/count$$

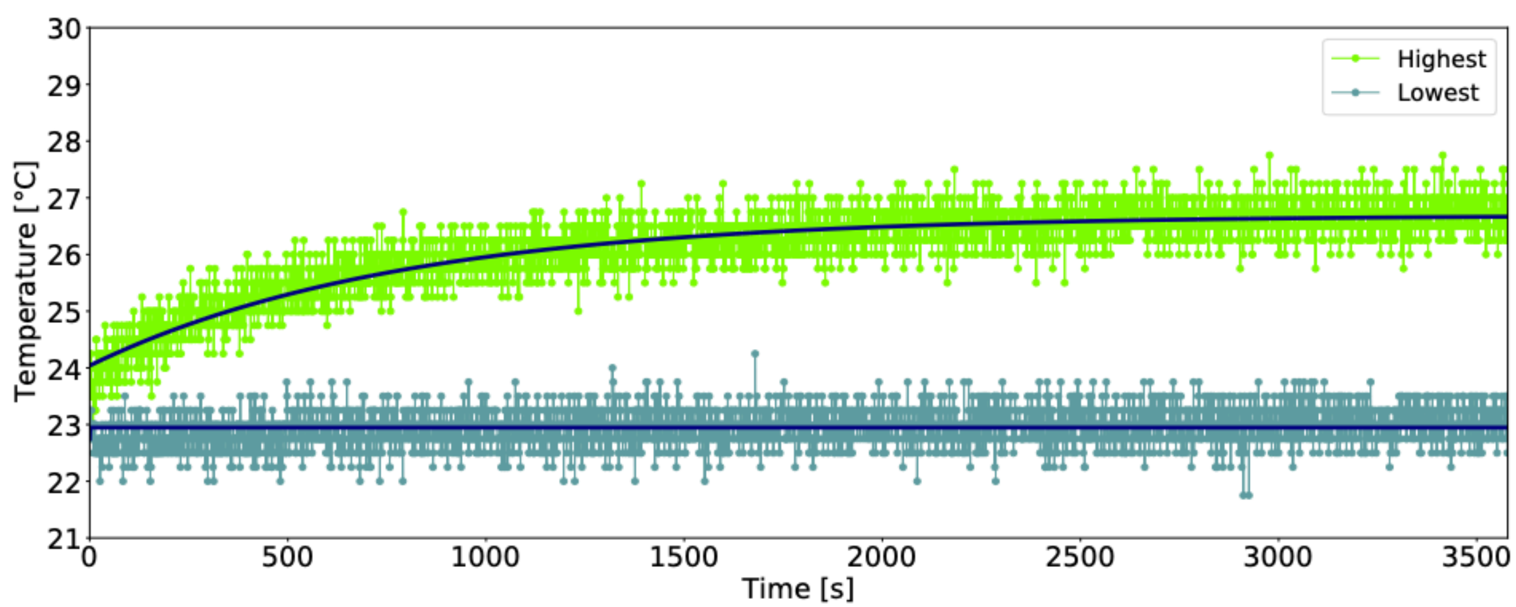


Credit: Alba Romero Rodriguez

FRONT-END ELECTRONICS OVERHEATING CONTROL

The suspended baffle operates at room temperature and under UHV conditions.

No cooling system due to limitations dictated by the suspension.



No overheating is observed thanks to:

- Moderate operating voltage,
- Efficient heat dissipation of the gold-plated PCB,
- Careful design of the mechanical couplings with the stainless steal structure.

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DATA ACQUISITION

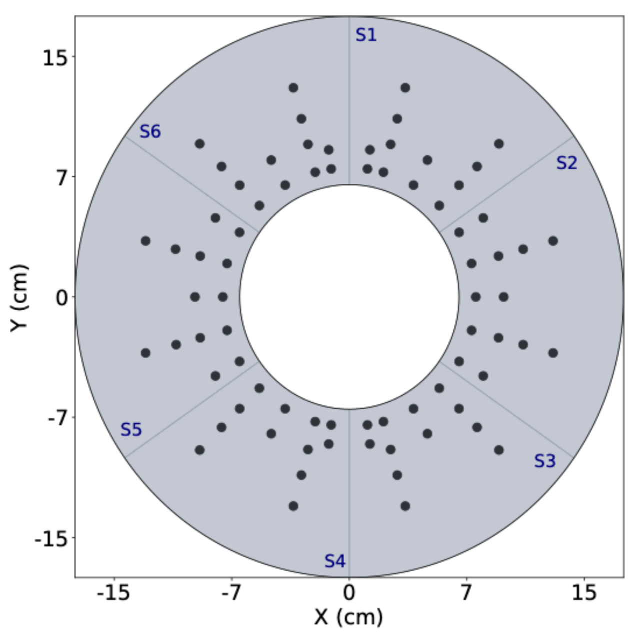
Data saved:

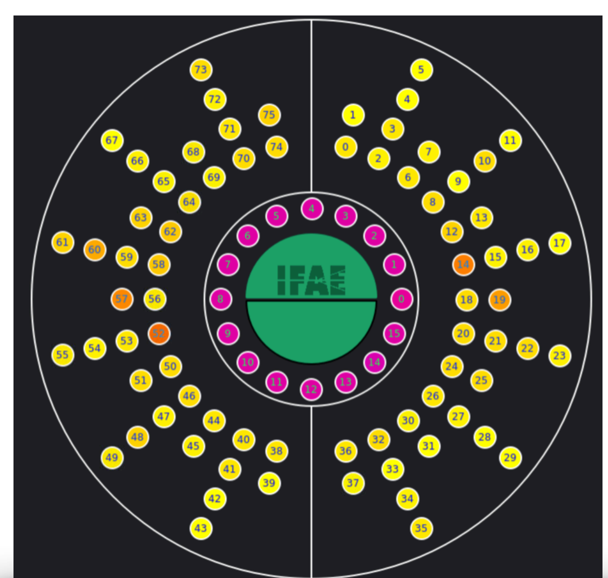
- Temperature sensors
- ADC counts
- Power supply information

Data from the Baffle is accessible through:

- CSV files on IFAE servers.
- Grafana database on IFAE servers.
- Virgo DAQ: sensor and temperature channels.

Creation of a Graphical User Interface (GUI) to interact with the baffle and see the results in real time.
The GUI is able to produce plots so to visualize the data in real time, control the electronics, power supply, log files.





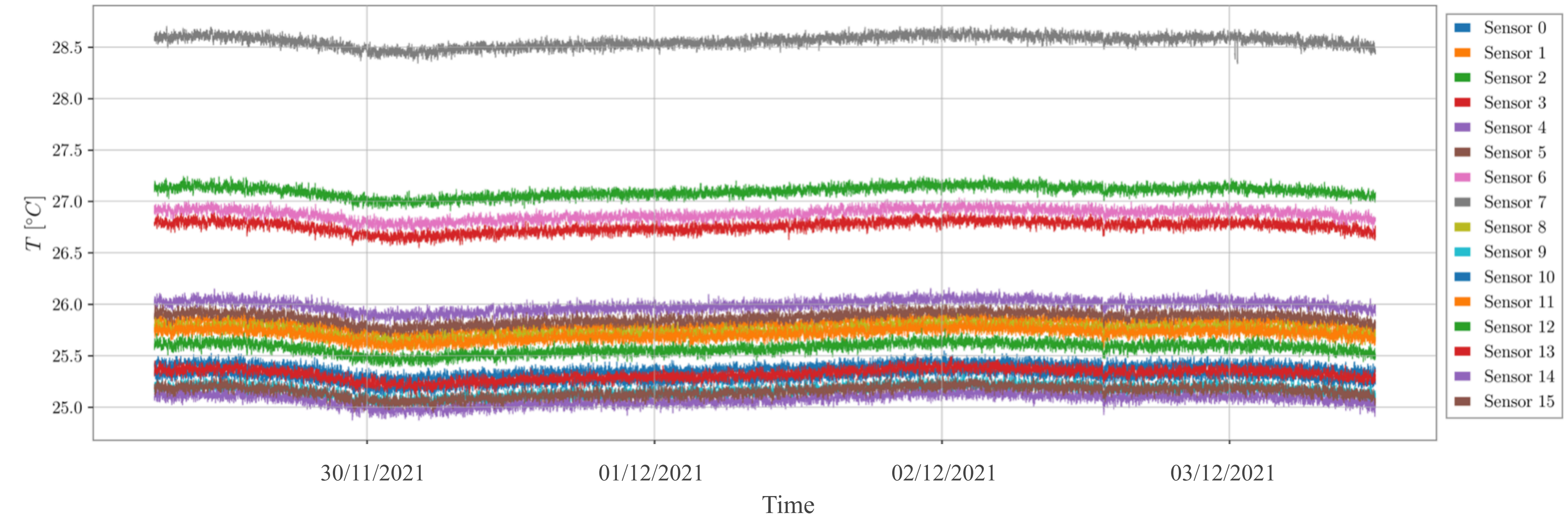
Switch on/off by click.

16 Temperature sensors.

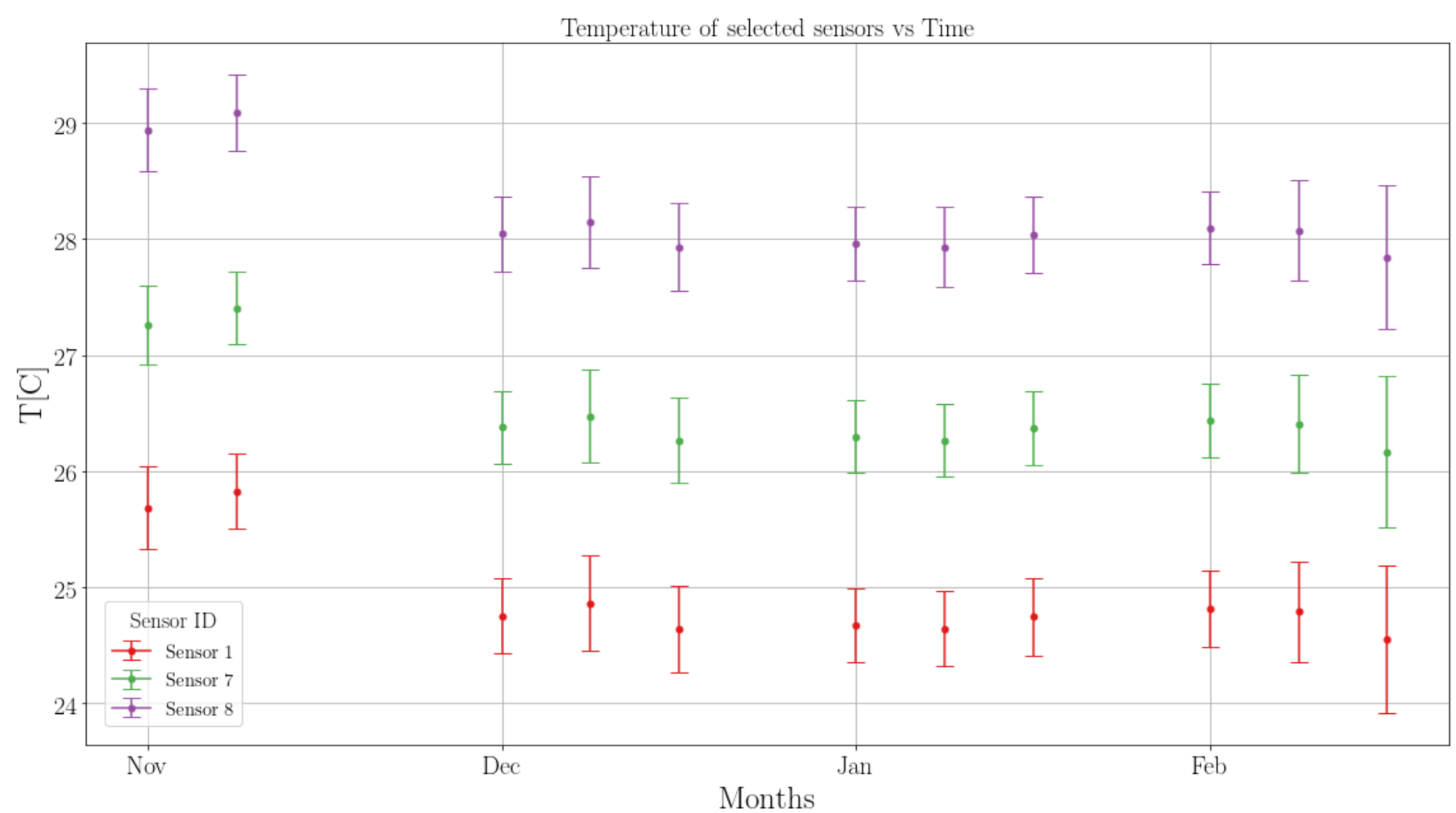
76 Photodiodes: Color $\propto$ ADC counts.

DATA MONITORING

- IMC baffle operates 24/7 and *weekly* analysis of its data shows stable behaviour.



- Long term analysis of its data shows stable behaviour.



Temperature sensors behaviour closest to the RO electronics: never goes beyond 30°C.

BAFFLE PERFORMANCE

Simulations were used to optimise the layout of the sensors in the baffle, and determine the light exposure of the photodiodes, in order to define mitigation strategies for preserving the detector integrity.

Simulations are done using the Stationary Interferometer Simulation (SIS) software: it calculates the stationary state field in an optical system.

It includes:

- IMC data,
- Mirrors:
  - Size,
  - Location,
  - Reflectivity,
- Apertures of the baffles in front of the mirror,
- Surface maps of the mirrors.
- Baffle:
  - Dimensions and its geometrical location surrounding the end-mirror, where the field is evaluated.
  - Results are still accurate given the fact that the amount of light illuminating the baffle is very small.

BAFFLE PERFORMANCE

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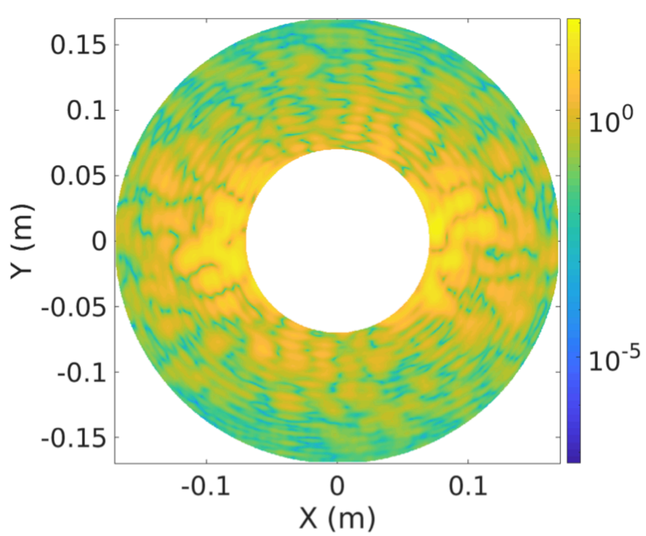
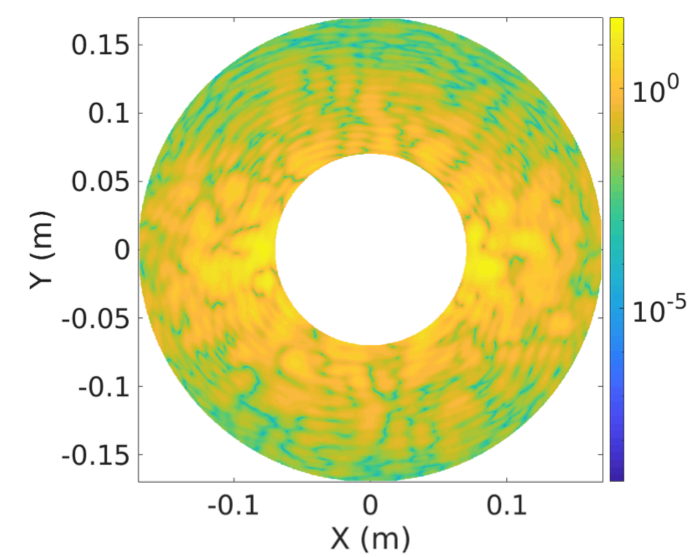
Aligned IMC



Misaligned IMC



The region in the baffle with the maximum light exposure is located in the horizontal axis near the right inner edge of the baffle.

Tilt of the end-mirror with respect to its nominal position:

- Vertical displacement of the beam position.

Cavity is still in resonance.
The power decreases with increasing tilt.

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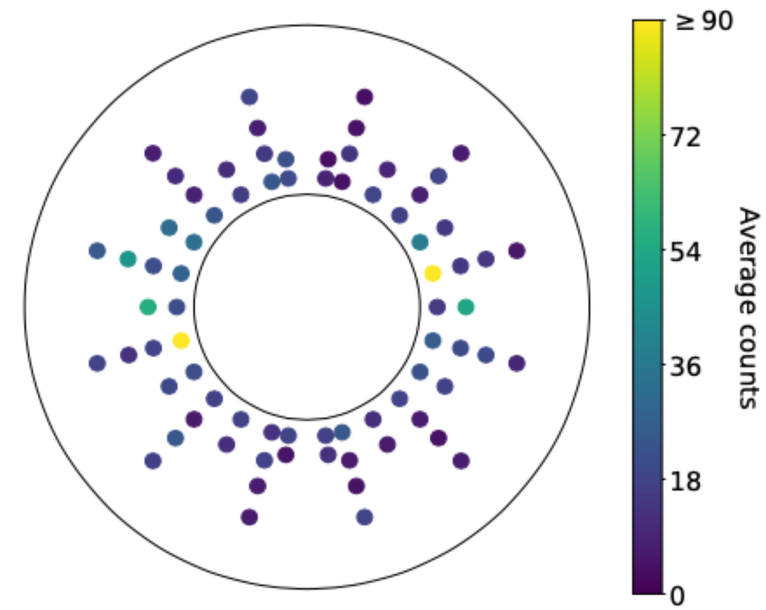
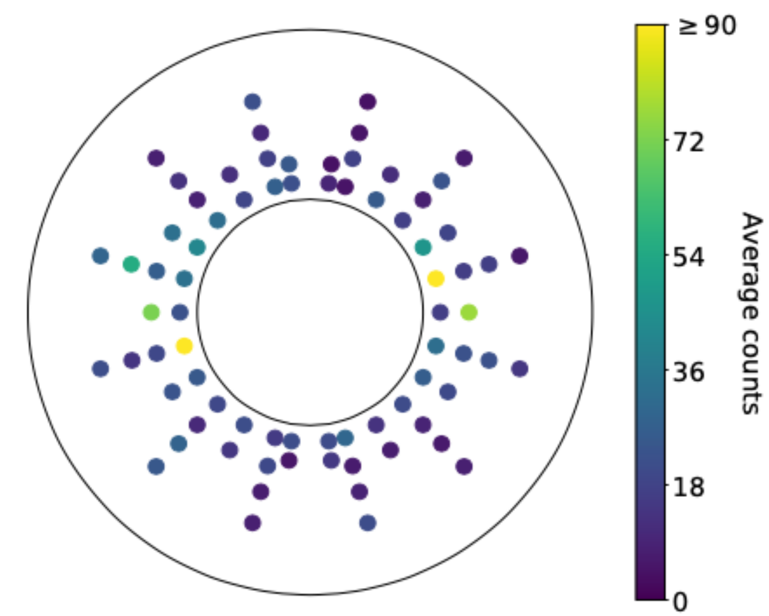
BAFFLE PERFORMANCE

- Concentration of signals at low radius with more than 100 counts registered by the sensors.
- More power is present in the half baffle at x<0.
- Power is concentrated in a plane tilted by ~ 15° in the ϕ direction with respect to the nominal x-y plane of the triangular cavity.

- Baffle is sensible to the status of the cavity, it can detect:
  - Appearance of laser higher order modes,
  - Momentary unlocks as they lead to the absence of circulating light in the cavity, resulting in an abrupt decrease in baffle signals.

ADC counts





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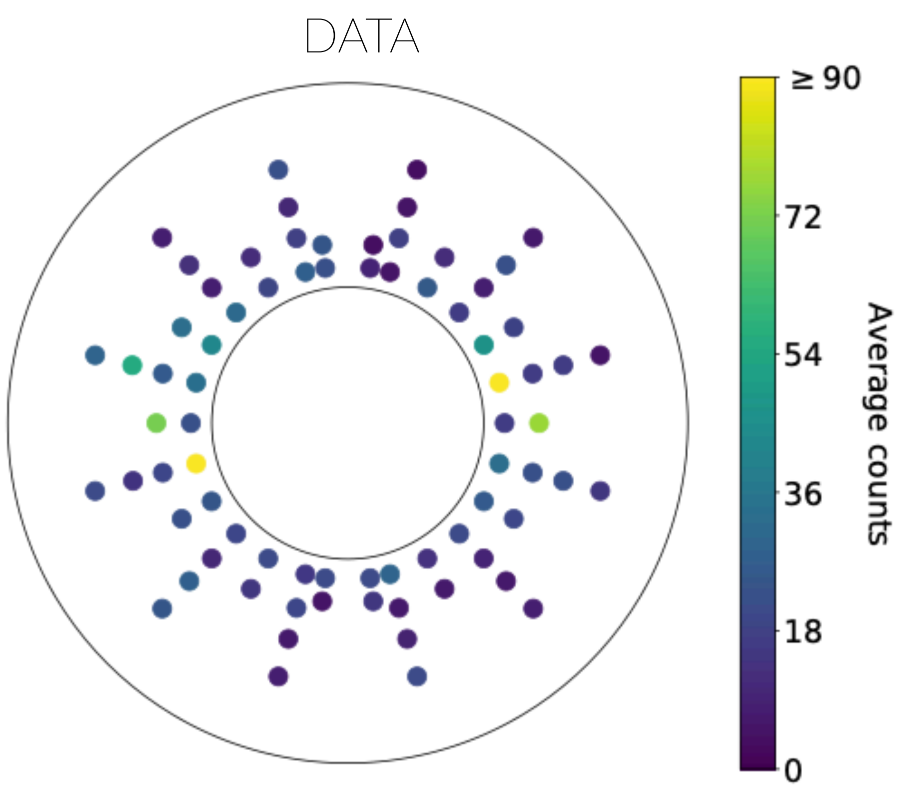
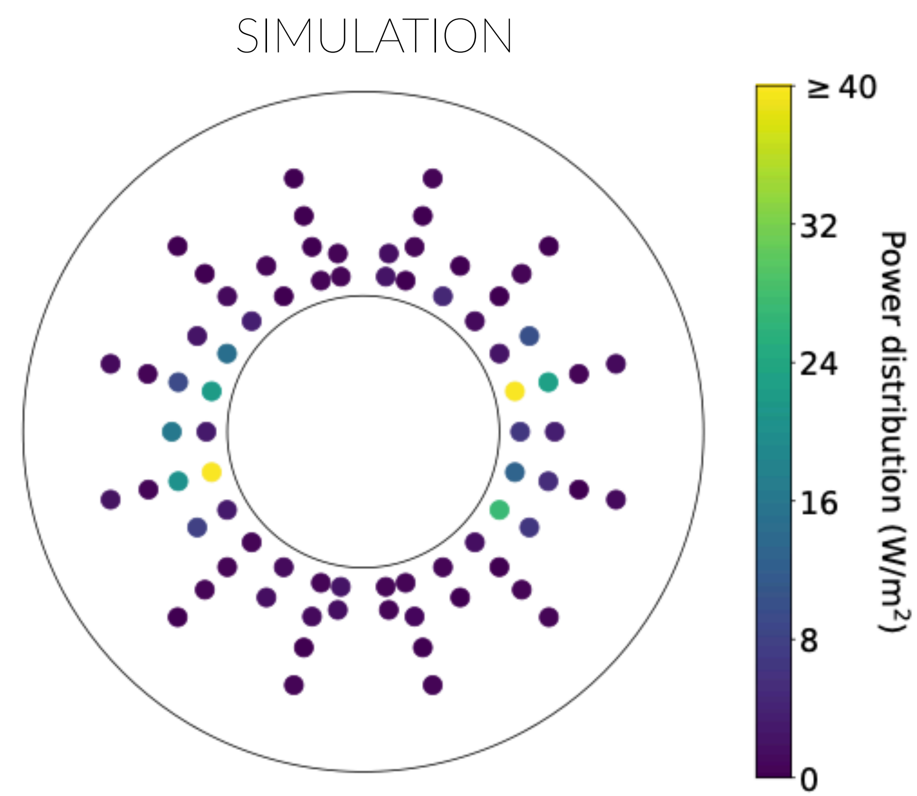
CALIBRATED DATA VS OPTICAL SIMULATIONS INSIDE THE IMC CAVITY





Simulated using SIS with the following assumptions:

- Nom. input laser power: 28.5 ± 0.1 W.
- No thermal effects in the mirrors induced by the laser.

Tilt of 15 degree in data is present also in the simulation.

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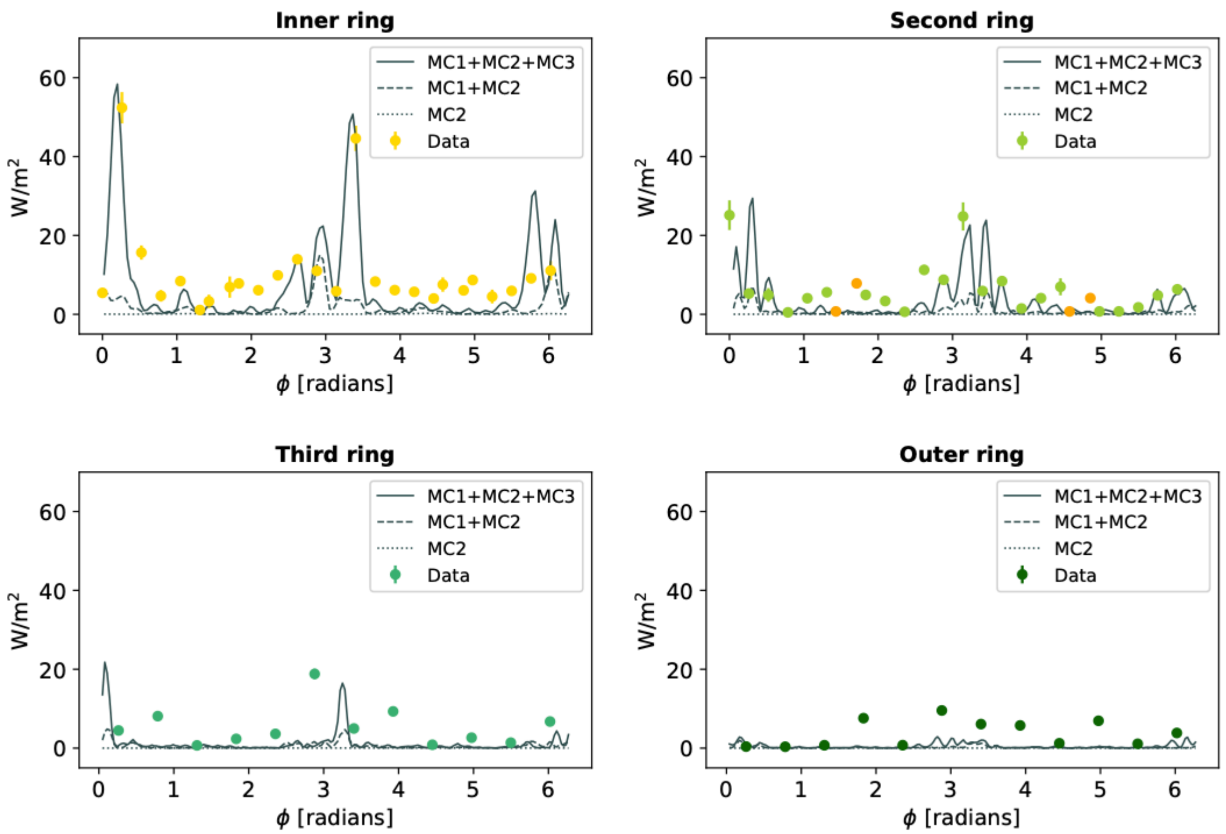
CALIBRATED DATA VS OPTICAL SIMULATIONS INSIDE THE IMC CAVITY

Measured differential distribution of the power intensity in the baffle.



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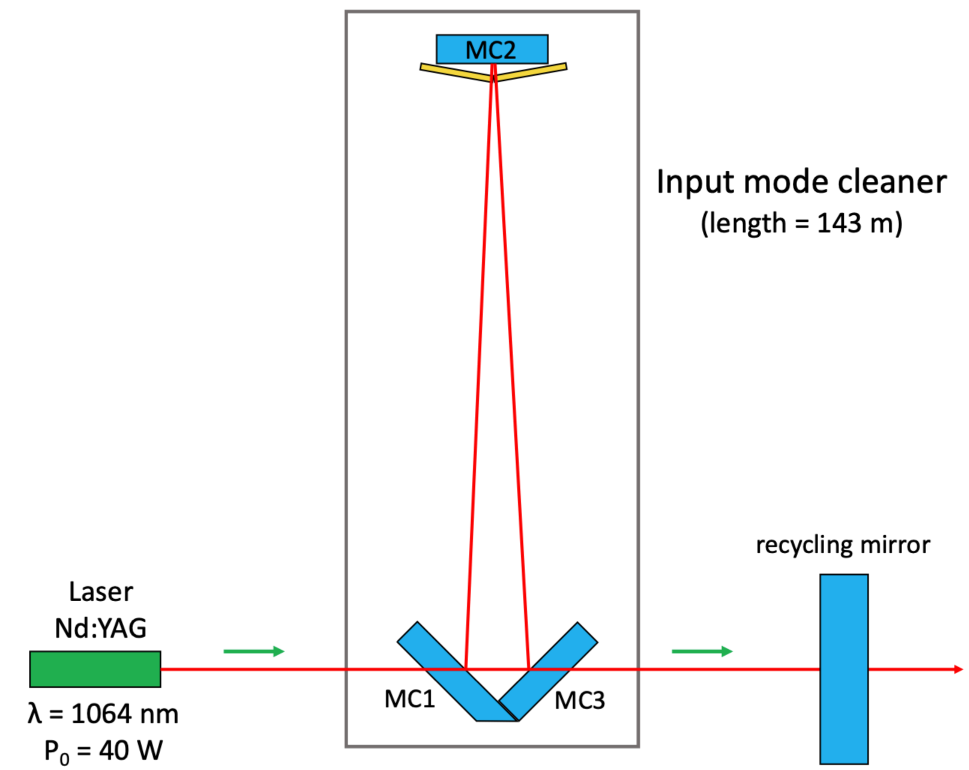


arXiv:2008.13740v2

Simulations provide approximate description of the data:

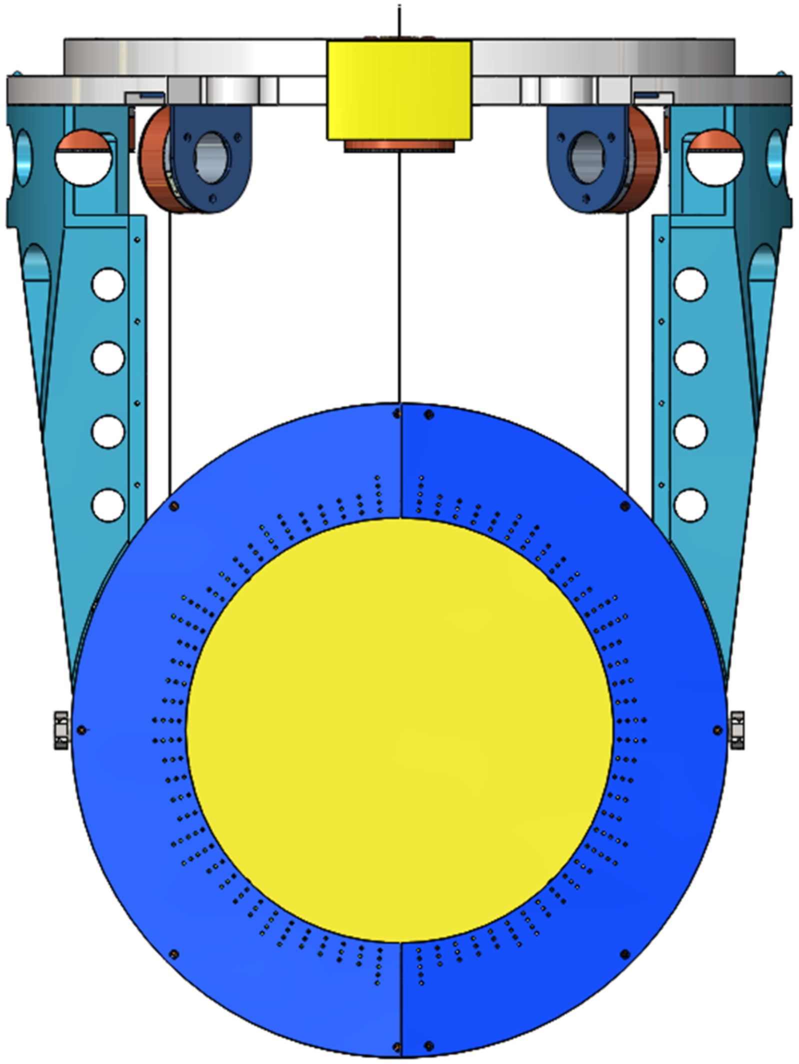
- Measured tilt in ϕ could be dominated by the details of the mirror surface maps.
- Without including mirror surface map information, simulations show no ϕ dependence.

Simulation's output highly dependent on mirror maps.

More accurate mirror surface maps could result in more accurate simulations.

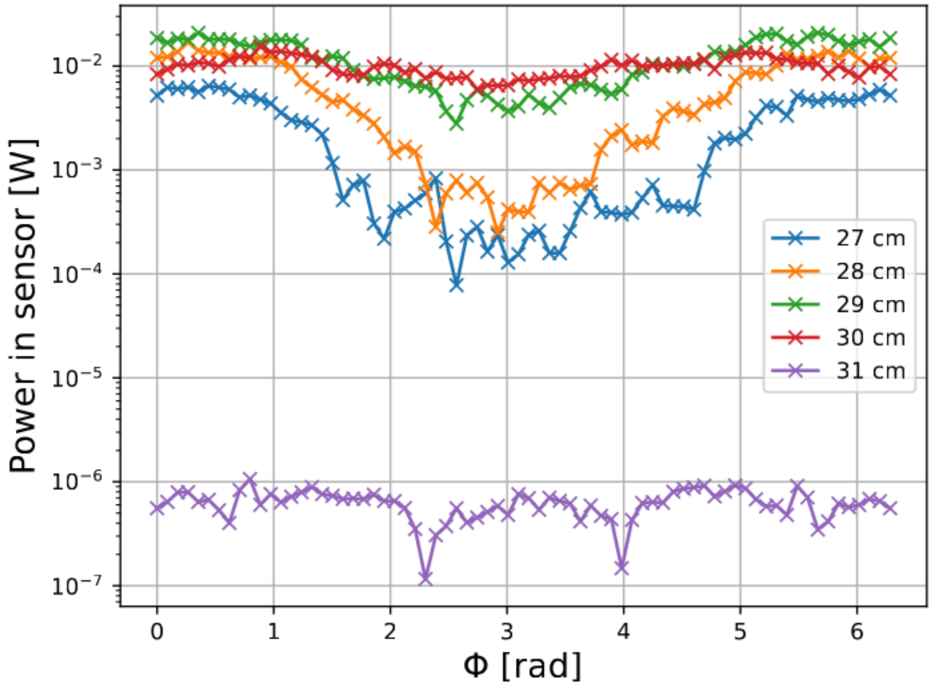
INSTRUMENTED BAFFLE IN PHASE II OF ADVANCED VIRGO

- Instrumented baffles are being constructed to be installed around the end mirrors in the main arms.
- Optical simulations of the light distribution in the detector's main cavities have been conducted to assess:
  - The ability of the sensors to effectively monitor misalignment and defects on the mirrors' surface.
  - Investigations have been done for:
    - Nominal conditions
    - Misaligned cavity
    - In presence of point absorber



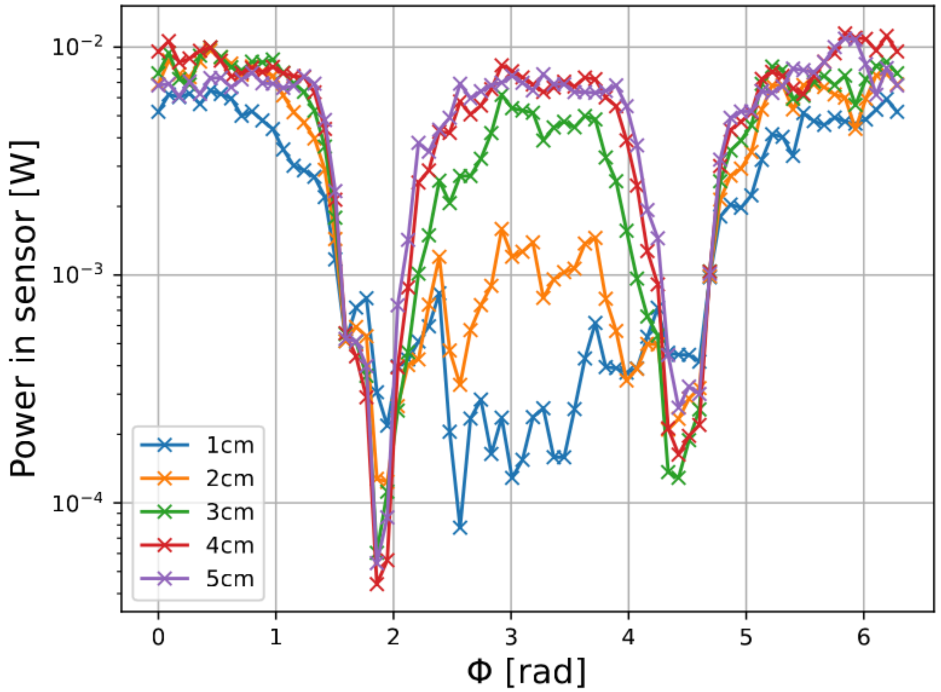
NOMINAL CONDITIONS

- Simulation of the power distribution with:
  - Expected parameters of the interferometer,
  - Appropriate mirror-maps,
  - Inclusion of cryo-baffle effect.
- Results indicate the range of light deposited in the baffle to optimise the sensor layout and operating points.



POINT ABSORBERS

- If point absorbers are present in mirror, the cavity will be out of the optimal operating conditions.
- Simulation of the FP cavity adding point absorber at different positions.
  - Point absorbers typical value for the current LIGO configuration is ~10mW: it increases linearly with the laser input power.
    - For O5 we choose 50mW.



EGO EUROPEAN GRAVITATIONAL OBSERVATORY

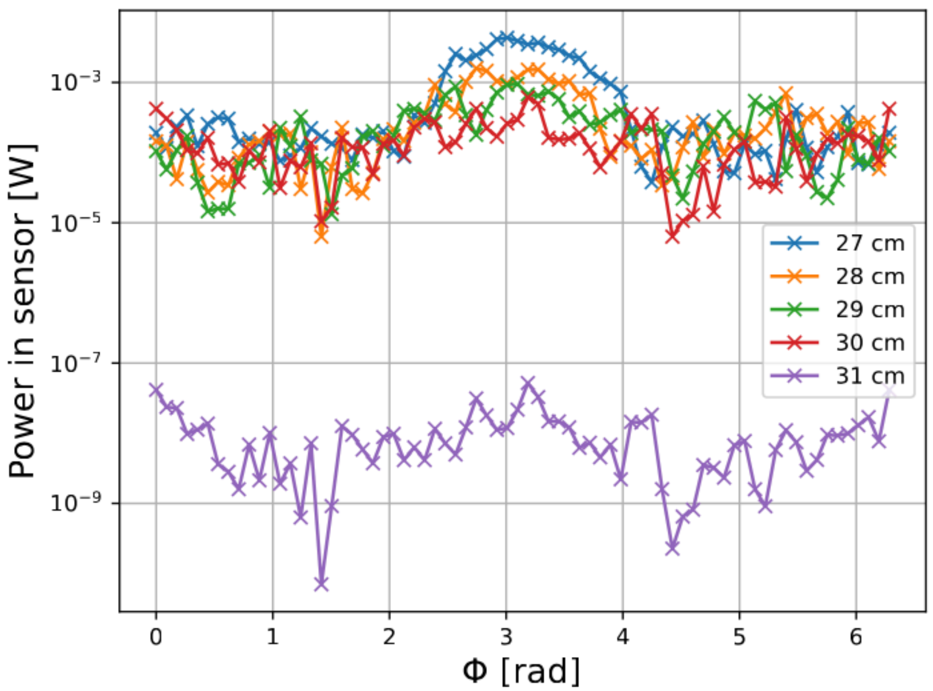
IFAE Institut de Física d'Altes Energies

EXCELENCIA SEVERO OCHOA

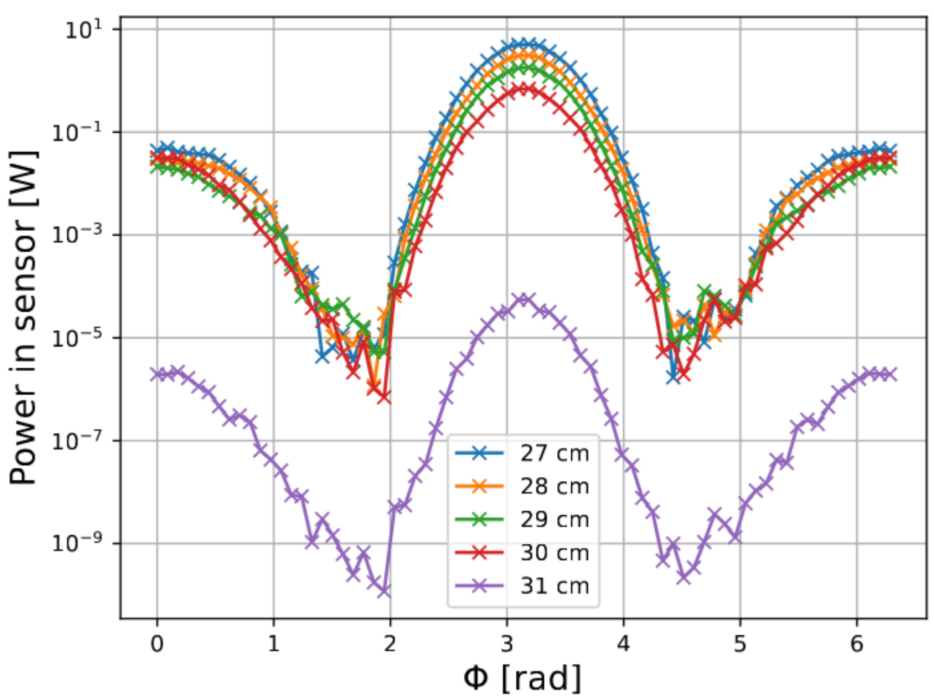
BIST Barcelona Institute of Science and Technology

MISALIGNED CAVITY

Misalignment = 3 x 10-7



Misalignment = 8 x 10-7

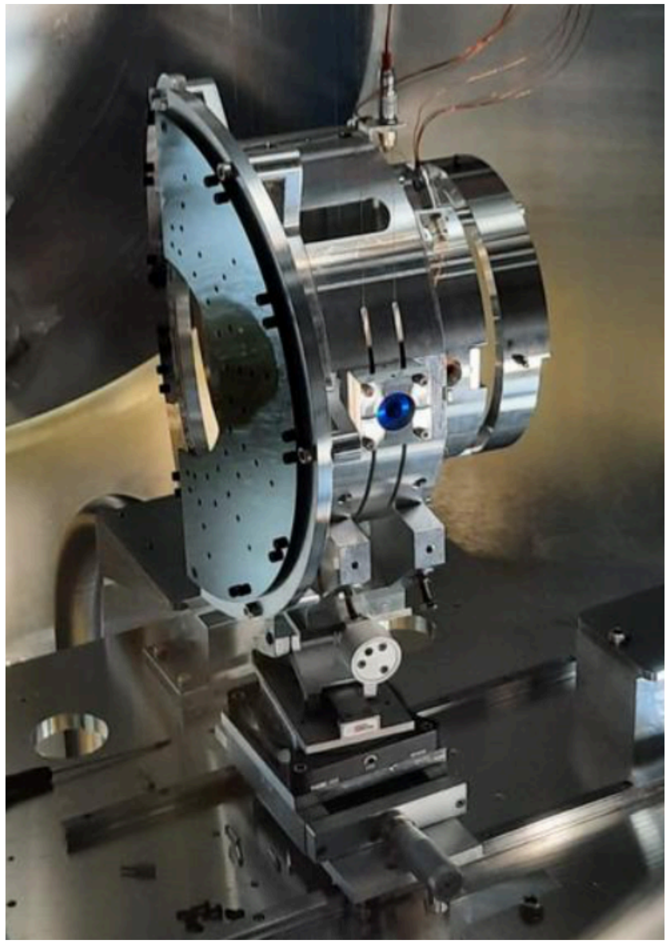


Credit: Adrian Macquet

- Simulations results show that the instrumented baffle could be used as a pre-alignment tool.
- Each ring of photodiodes is sensitive to the presence of misalignment.
- Different response for each ring:
  - Simulations are needed to tune the dynamic range for which the sensors must be calibrated to be sensitive enough to misalignments.

CONCLUSIONS

- Stray light is a persistent source of noise in the interferometer which hinders the sensitivity of the instrument and it is difficult to mitigate.
- IFAE has designed, built and installed an **instrumented baffle in front of IMC end-mirror** to:
  - Monitor small-angle scattered light,
  - Acquire data to calibrate simulations describing the light propagation inside the experiment.
- The instrumented baffle is a**cquiring data 24/7** since last year and its **behaviour is stable.** For a more user friendly operation a GUI has been created and deployed.
- Optical simulations need **better mirror maps** to describe the data more accurately, although they already give a **good approximate description** of the measured data.
- The instrumented baffle will provide **additional tools for alignment and optical cavity monitoring** in the next generation of gravitational wave detectors.



Credit: IFAE