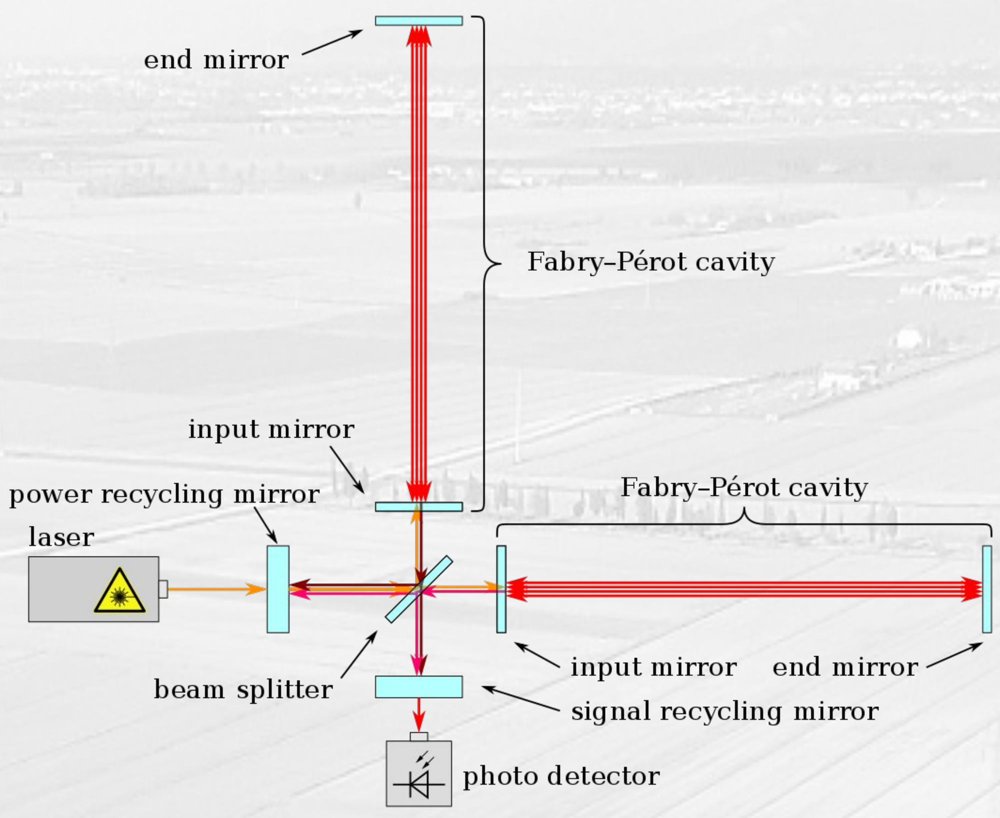
Charge Monitoring of Test Masses in Gravitational Waves Interferometers

Federico Armato[1,2] Andrea Chincarini[1,2]

[1]University of Genova [2]INFN Genova

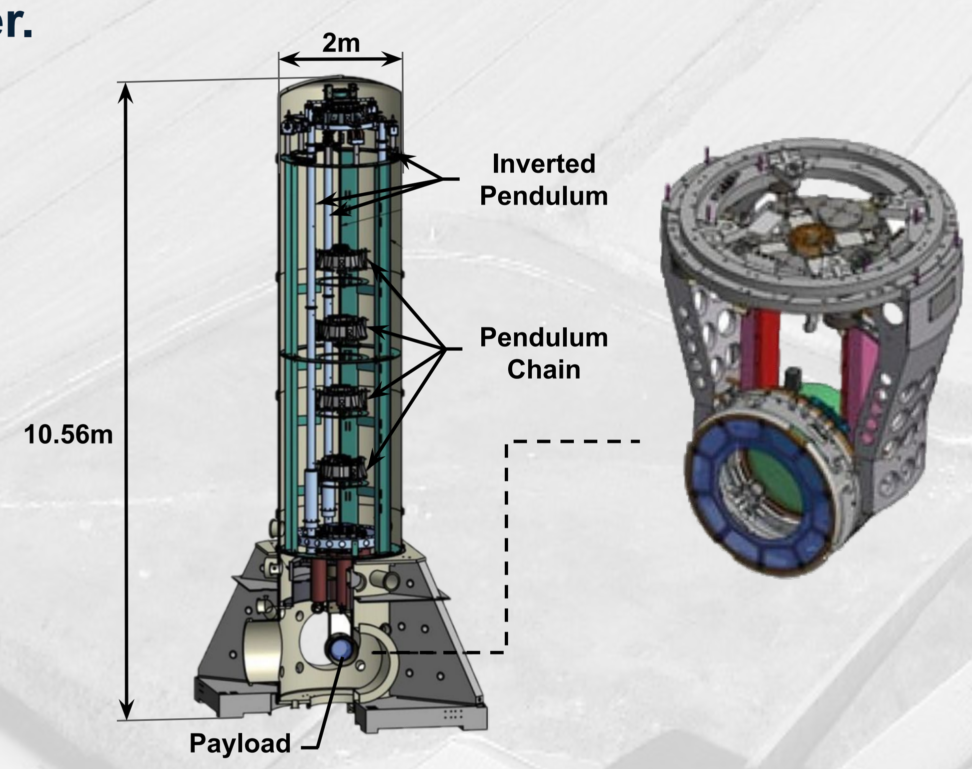
Introduction

The sensitivity of gravitational waves (GWs) detectors is influenced by multiple sources of noise. One such source arises from the charge deposition on the test mass (TM) [1], which interacts with the surrounding electrical fields, introducing an undesired non-gravitational force on the test mass.
In particular, in Virgo, at the end of O3 preparation phase, it was discovered that TMs exhibited electrical charging, with surface density on the order of several tens of pC/cm^2 [2].



Strategy

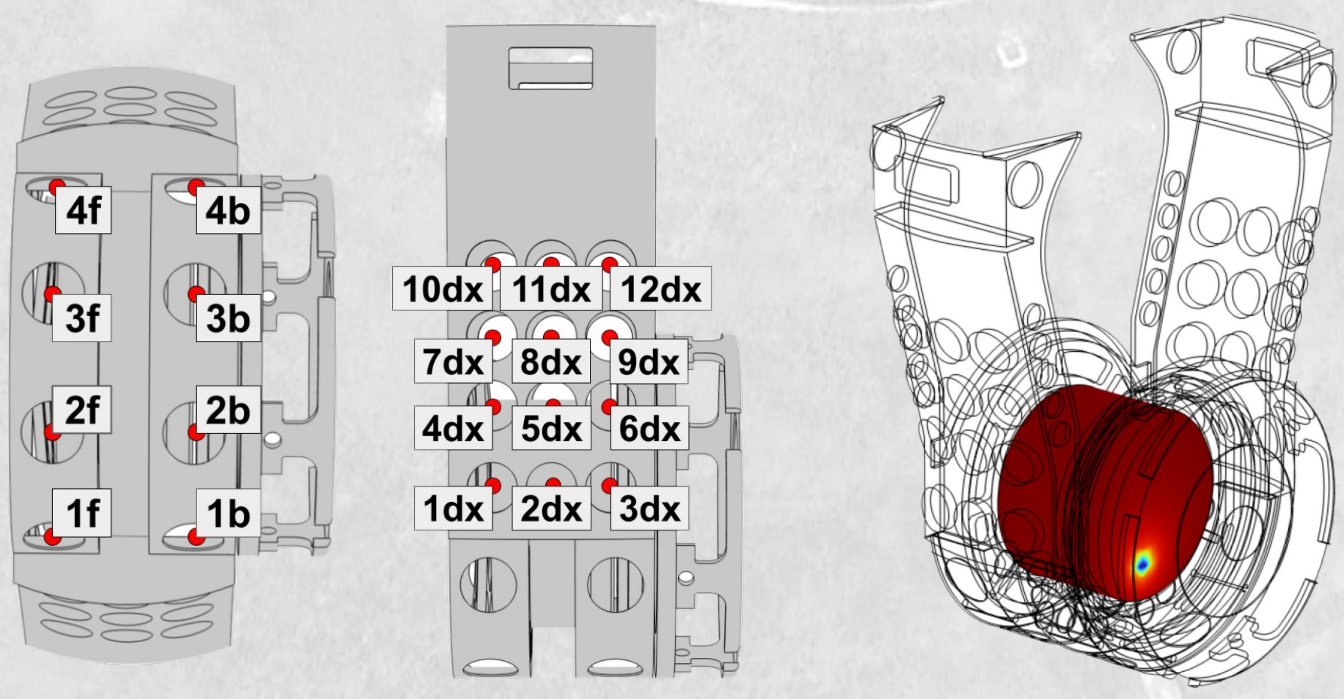
In our analysis we considered the Test Mass (TM) and the payload (PAY), the last stage of the TM suspension, located in the lower part of the tower.



Simulations enabled us to determine the field generated by charge distributions on the test mass.
Our objective was to solve the reverse process, that is to ascertain the charge distribution on the TM given the electrical fields measured in an arbitrary set of coordinates outside the TM.
To reach this goal we employed neural networks (NNs) trained on the simulations.

Implementation

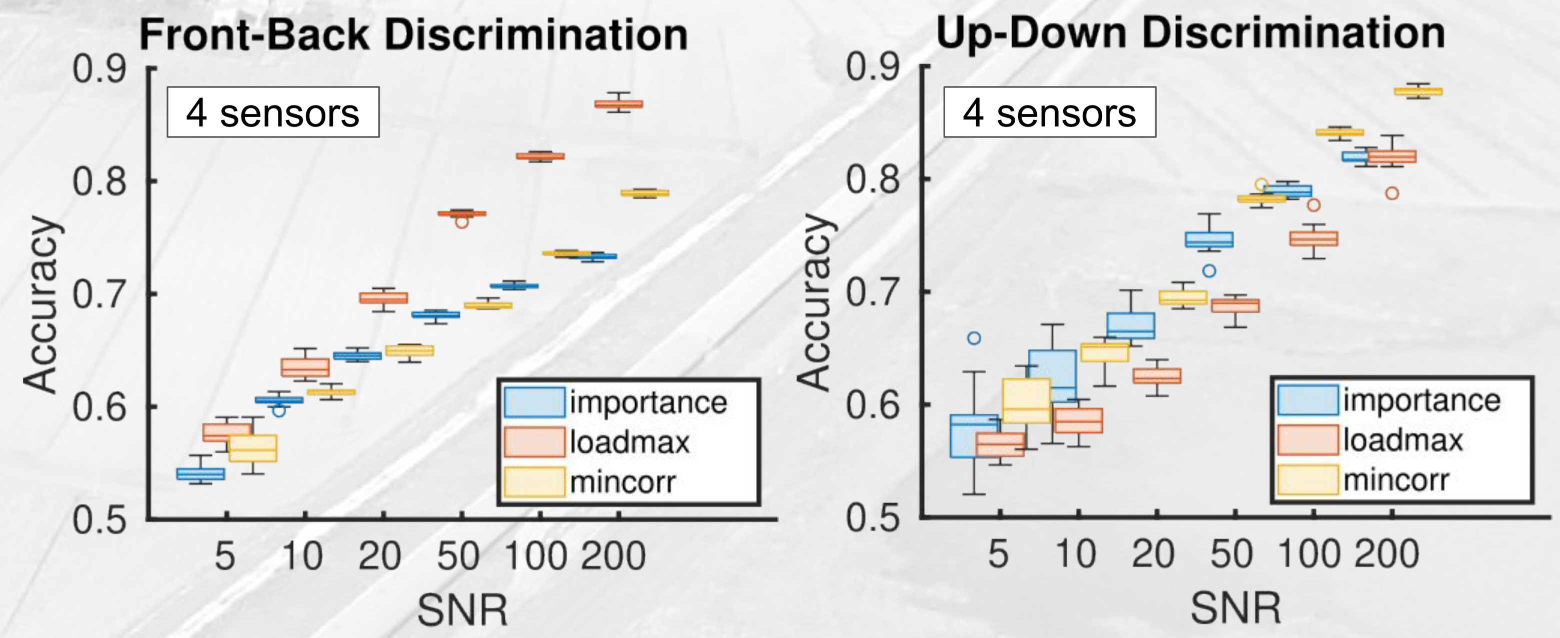
We explored 32 sensor locations candidates on the PAY and we simulated more than 100,000 different Gaussian distributions on the TM, where we had the flexibility to choose the parameters: intensity, standard deviation and position.



Selection Criteria

The significant constraints on the sensing coordinates, coupled with the heightened sensitivity of the interferometer, underscored the imperative for adopting minimally invasive solutions.
To maximize the information while minimizing the number of sensors, we implemented sensor selection criteria:

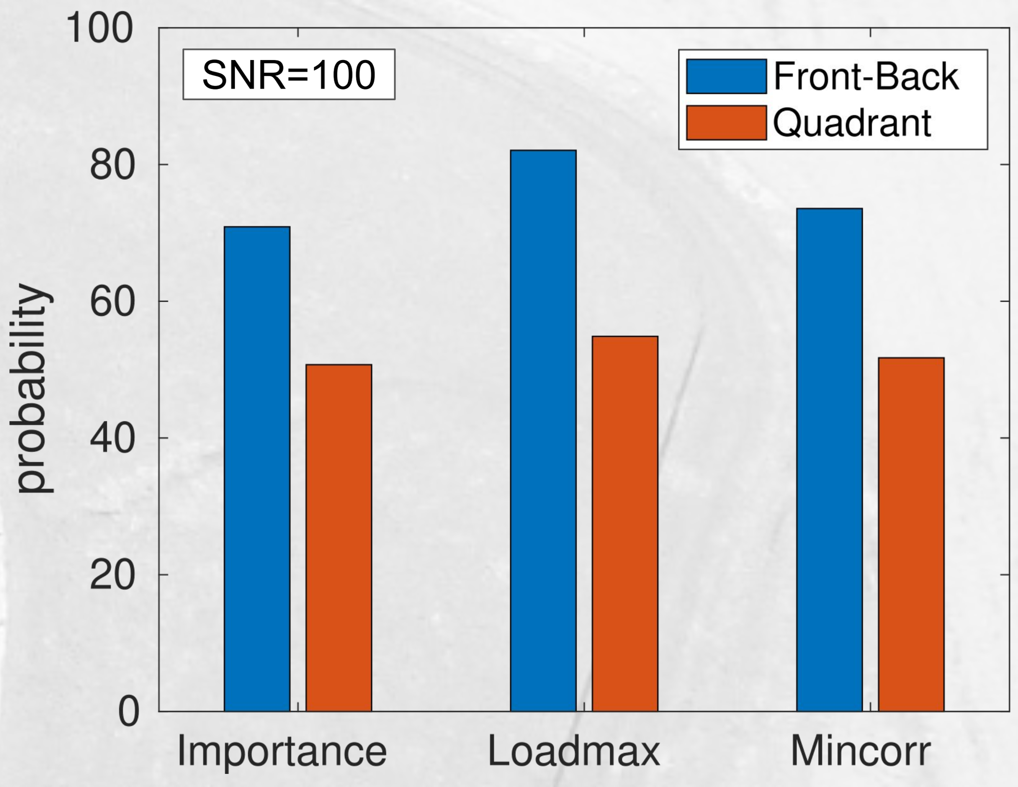
- Importance Method: Sensors are ranked according to their contribution to the Principal Components (PCs) weighted on their percentage of variance explanation.
- Loadmax Method: In selecting the first sensor, we prioritize the one that contributes the most to the first PC. For the second sensor, priority is given to the one that contributes the most to the second PC, and so on.
- Mincorr Method: We choose the first sensor based on the Importance criterion. The second sensor chosen is the least correlated, followed by selecting the third sensor as the least correlated with the previous two, and so forth.



Results

As a practical example, let us consider the situation in which we have only four sensors and we want to understand where locate them in order to get the best result.

To make this choice, we have to understand which physical quantity is the most significant to infer, which is strongly linked to the discharging method we want to employ.
Suppose, for instance, that we want to employ a high-vacuum electron gun and therefore the charge position is the most relevant information.



Comparing the results got by following the different selection criteria, it is clear how the Loadmax method is the most efficient in determining charge location, since it is the best both in face discrimination (82% of success) and quarter identification (55% of success).

References

[1] D. Ugolini et al. Charging Issues in LIGO. In 30th International Cosmic Ray Conference, volume 3, pages 1283–1288, 7 2007.
[2] I. Fiori et al. The hunt for environmental noise in virgo during the third observing run. Galaxies, 8(4), 2020.

farmato@ge.infn.it