

» INTERVIEW**BEYOND THE HIGGS BOSON
WITH THE CMS COLLABORATION**

Interview with Roberto Carlin, INFN researcher and professor of physics at the University of Padua, spokesperson for the international CMS (Compact Muon Solenoid) collaboration at CERN since 2018.

Since September 2018, Roberto Carlin has led the around 5,400 people - scientists, engineers, and technicians from all over the world - engaged in the CMS collaboration. The latter is one of the four big experiments of CERN's LHC accelerator and was key to the Higgs boson discovery, along with ATLAS, in 2012. Since 2018, in addition to characterising the particles produced in the LHC, especially the Higgs boson, the collaboration has been dedicated to the development of the experiment upgrade. This is being done in view of the next, post-LHC phase, which will see the start of the High Luminosity LHC (HiLumi LHC) in 2027, the high-luminosity successor to the accelerator, which is currently in development.

Weighing 14 tonnes, measuring 21 metres in length and 15 in diameter, CMS represents, together with ATLAS, one of the two big general purpose experiments dedicated to studying all the events produced in the collisions between the proton beams in LHC. The detector, which is cylindrical, is located at a depth of 100 metres along the LHC path and has a structure of concentric layers that enables the identification and measurement of the physical characteristics of the different particles produced: from the very accurate measurement of the traces of charged particles observed in the innermost part of the detector; to the measurement of their energy in the surrounding calorimeters; to the identification of the more evasive particles, the muons, detected in the outermost layer of the detector.

Roberto Carlin started his scientific work in the early 1980s at CERN and at the INFN Frascati National Laboratories, later spending a long period in the DESY laboratory in Hamburg, where he worked on the ZEUS experiment, for which he was vice-spokesperson. Member of CMS since 2005, he contributed to the installation and starting-up of the muon detector, and to the management of the first phases of data acquisition. He was, in addition, coordinator of the CMS trigger and vice-spokesperson for the collaboration. Elected spokesperson in September 2018, Roberto Carlin will complete his term in August 2020.

From its inception, in 2008, the performance of the LHC has increased to the point of placing an unprecedented challenge before the experiments, in terms of the quantity of data produced by the

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LHC collisions. How have you approached this?

It's true, LHC is much higher-performing than expected, both in terms of luminosity and in terms of efficiency, and it is an excellent thing because it provides experiments with a huge amount of data, but also great challenges. The peak luminosity, which determines the number of collisions in each moment, is, by now, more than double compared to the project figure, with the result that, in any event, we find 50 simultaneous collisions on average between protons: a quantity of signals to sort out that would, a few years ago, have been considered prohibitive. CMS ended last year with a significant set of updates, the so-called phase 1 upgrade that has involved numerous detectors, including the vertex detector, the key for identifying simultaneous interactions and the system for selecting events, essential for "separating the wheat from the chaff". In addition, the computers and data analysis algorithms are continuously updated, using more and more machine learning techniques. These continuous updates enable us to confront new challenges, but are also very useful for keeping up vital detector development work, and a community of experts capable of best exploiting them and of preparing for even more difficult future challenges like the HiLumi LHC.

What were the most interesting results and what were the difficulties encountered in these last two years?

Since the beginning of my term as spokesperson, CMS has submitted almost 190 articles to international journals (more than 1,000 in total). It would be truly difficult to choose one without being unfair to the others. What is most impressive is the variety of subjects treated, from accurate measurements of the physics of the beauty quark, or the top quark, and, of course, of the Higgs boson, to the numerous studies of physics beyond the Standard Model, as well as an intense programme of researching heavy ion collisions. The transition from a phase of first observations (the obvious example being that of the Higgs boson in 2012) to one of accurate measurements is evident, especially in the field opened by the discovery of the Higgs boson. The difficulties relate especially to the overlapping of very different activities: the analysis of the huge amount of data acquired; the updating of the detector during the machine stoppage period; the preparations for the imminent third run; and, above all, the preparations for the high luminosity upgrade. A separate conversation involves the difficulties recently linked to the crisis due to the spread of the CoViD-19 pandemic. CMS is a community spread across all the continents that is already used to working remotely, and this has helped a lot during the lockdown. Now we are gradually restarting, with a lot of precaution, work in person, in particular that linked to the upgrade and to the preparation for the next data acquisition, certainly not helped by international travel restrictions.

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The LHC will start up again in May 2021, after the conclusion of the preparations for its third run, which will last until the end of 2024. What should we expect from CMS?

In reality, because of the delays caused by CoViD-19, LHC will start up again at the beginning of 2022. Not only will we have updated detectors, some of these already prepared for the so-called “phase 2 of HiLumi LHC”, but we are preparing new ideas and techniques for the selection and analysis of data, which will allow us to significantly increase the field of studies and their accuracy. Accurate measurements are one of the possible avenues for identifying potential deviations from the predictions of the Standard Model and, thus, new physics. Such measurements will be enabled by the vast range of statistics from available data, but will need very careful calibration of the equipment and refined analysis techniques. At the same time, we will continue to look for direct evidence of new phenomena, seeking, as is our duty, in all possible corners. For example, we will look for medium-long life particles with new techniques, particles that can produce signals that are very distant from the interaction point between the beams. It is a very interesting phase for the experiments, in which we’re moving from “looking for the needle in the haystack” - the Higgs boson in our case - to “there’s something in the haystack, even if we don’t know what it is, so let’s try to find it”.

Your election as spokesperson for the CMS collaboration was another confirmation of the excellence of Italian physics at CERN. At the time of your nomination, three of the four big LHC experiments were led by Italians. What is this leadership owed to?

The school of Italian physics has a great tradition, students who come out of Italian universities are second to none. We have a research body, INFN, which works so well that it is often taken as an example internationally. Our physicists are in the position, and have the skills, to participate in a decisive manner, throughout the world, in projects for constructing accelerators and detectors and in their use for advancing our knowledge. The results are evident. It’s definitely important that this leadership, not only at the very highest levels, is maintained, providing our excellent young people with opportunities to start and develop a career.

The collaboration involves around 5400 people - including physicists, engineers, and technicians - coming from various institutions and countries. How do you manage such a numerous and culturally diverse team?

It’s a question I’m often asked, including during the numerous protocol visits that we host at CMS. What is most amazing is, beyond diversity, the fact that it is a true collaboration: each institution directly contributes with its technical and scientific staff and financing. The construction of the detector is

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also shared, with components manufactured throughout the world and assembled, at the end, in the experimental cave. It would seem like a recipe for disaster, but it actually functions very well, because everyone is involved in first person, finding space in a shared project, which is continually discussed and has a very clear aim: the advancement of science. The management is tasked with creating consensus around priorities, bringing any criticalities to light so that they are resolved, and ensuring that proposals for innovation find fertile ground, to ensure CMS is always at the frontier of science and technology.

In terms of diversity, how would you judge the gender balance within the collaboration?

We are talking about it a lot, not just in terms of gender but all kinds of diversity that compose the richness of a great collaboration. CMS has set up a diversity office that is working on highlighting problems and unconscious bias that can impact the contribution and expectations of people belonging to minorities. The percentage of women at CMS is growing over time, going from approximately 12% in 2006 to approximately 18% today, if you count physicists who already have a doctorate, a little higher if you also include students. Certainly, it's not enough, although in line with the general number of women in physics. It is important that there are enough role models, and, in fact, the proportion of women in management has also grown: it has been about 25% in recent years. ■