Newsletter Interview

MOST ACCURATE MEASUREMENT OF W BOSON MASS, CDF'S LATEST RESULT I Interview with Giorgio Chiarelli and Giorgio Bellettini

Interview with Giorgio Chiarelli, INFN researcher and co-spokesperson of the CDF collaboration, and Giorgio Bellettini, professor emeritus at the University of Pisa, among the promoters of the CDF project and the first non-US spokesperson.

One of the richest, longest and most steady evidence of the Italian contribution to the history of particle physics is certainly represented by the case of the W boson, one of the two mediating bosons of the electroweak force. Since the formulation of the first theoretical hypothesis on its existence to its first experimental observation, the history of the W boson speaks, indeed, Italian. This history has its roots in the work carried out by Enrico Fermi and the "Ragazzi di via Panisperna" in the 1930s and was crowned in 1984 with the contribution of Carlo Rubbia, who was awarded the Nobel Prize for Physics for the discovery of this particle. A story that continues to be characterized by the Italian colours, as demonstrated by the publication in the journal Science, on April 8, of the last long-awaited paper by the international collaboration of the Collider Detector at Fermilab (CDF) experiment, in which Italy participates with INFN. This paper, which also won the cover of the prestigious scientific journal, shows the results on the most accurate measurement ever of the value of the mass of the W boson, obtained by analysing the entire data set acquired by CDF from 2001 to 2011. Besides representing the latest success of Italian physics in the study of electroweak force, the result, in tension with theoretical predictions, could also indicate the existence of physical phenomena still unknown, which would open the way to a physics beyond the Standard Model.

CDF, in the course of a over thirty-years long career, has also been the protagonist of another fundamental result, the discovery in 1995 of the quark top. It has also seen and continues to see the fundamental contribution of INFN, one of the founding members of the collaboration and responsible for the funding and the implementation of a substantial part of the components of the detector, which ceased its activities in 2011. Also demonstrating the leading role played by INFN were the four non-US researchers who took turns in leading the experiment, all of whom came from the ranks of the institute. Among them, Giorgio Chiarelli, researcher at the INFN Pisa division and today co-spokesperson of the CDF collaboration, and Giorgio Bellettini, one of the founders of the CDF project in the late 1970s, and the first non-US CDF spokesperson.

Giorgio Chiarelli, what was the process that led to this latest CDF result?

The measurement is based on an analysis of events (proton-antiproton collisions) collected during run 2 of the Tevatron from 2001 to 2011. The data analysis required a lot of time, effort and care by the researchers of the collaboration for several reasons: the first is related to the fact that this result is the final work of the experiment on the mass of the W boson, one of the fundamental parameters of the standard model; the second is related to the increasing understanding, acquired over the years, of the operation of our detector: this allowed us to correct many instrumental effects, and to progressively reduce various uncertainties associated with the measurement of the mass of W. To give an idea, compared to 2012, when a first result related to the analysis of approximately a quarter of the data collected by the experiment was published, we have improved the accuracy of the measurement by a factor of two. A result that, in addition to the analysis work, also stems from input from the theoretical physics field. This accuracy is the result of the amount of data available (nearly four million W candidates) but also of much work and ingenuity of the researchers.

Why is it so important to improve the accuracy of the W boson mass value?

This measurement is of great importance in particle physics because the value of the mass of W is related to the mass of two other fundamental particles of the Standard Model, the Higgs Boson, which this year in July will celebrate the tenth anniversary of its discovery at CERN, and the top quark, identified by CDF and the analogous experiment at Fermilab D0 in 1995. These quantities, along with others, can be used to calculate relationships predicted by the Standard Model. Since the masses of the Higgs boson and the top quark are known, it is in fact possible to verify and check if there is a discrepancy between the theoretical predictions and the experimental measurements concerning the W boson, as highlighted by CDF in this latest result. If we think that this is far from the world around us, it is only an apparent distance: we are talking of the fundamental elements of the matter we know, and the forces that act between them. "Weak" interactions, of which the W boson is one of the mediators, are responsible for the processes that happen in our Sun.

What methods were used to avoid errors in the data-analysis?

To be sure that the analysis instruments used to carry out the measurement were not subject to bias, which could cause the results to tend towards values that were also unconsciously preferred or desired, an efficient analysis method was used. This method requires to close the final results in a “black box”, through a shift (unknown to all) from the central value of the mass of W. When, over a year ago, we opened our box we were surprised. We knew that the measurement would be very accurate and we were confident of the result, but once we determined the tension with the Standard Model we went back over our steps to see if there were any errors, which, however, were not found. Ensuring the integrity of the analysis process was one of the main activities I worked on with the other spokesperson of the collaboration, David Toback. An additional layer of control of results was also ensured by checks performed by reviewers selected from within the collaboration. Now our result is available to the scientific community.

What kind of repercussions will this result have?

The measurement indicates the need for theoretical and experimental physicists to go back to the work bench to further verify the analyses of the data used so far and to understand whether there is a need to improve and extend the current theory. The first, and obvious, implication is to repeat the measurement in the near future. As already mentioned, CDF ended its activity over ten years ago, but there are other more recent experiments, for example those hosted at the Large Hadron Collider at CERN, or future ones, that will confirm or disprove our result, and verify (or otherwise) the presence of new physics. Moreover, and here the word must ask to our theoretical colleagues, our result might suggest verifiable (or falsifiable) extensions of the Standard Model also in other measurable physical processes. We believe our measurement indicates a tension with the current Standard Model description, but science only develops in doubt and uncertainty, which are always the beacon of our work, subject to constant critical review.

How did INFN contribute to this latest success of CDF?

As a founding partner of the collaboration, INFN never faltered in its support of the experiment. Through the INFN, Italy provided a decisive contribution in the design, development and improvement phases of the detector, during the thirty-year history of CDF, in which several generations of Italian physicists and many students took part, carrying out their PhD thesis and their first experiences within the collaboration. Regarding this last measure, INFN not only contributed thanks to the data analysis work carried out by its researchers, but it also played a supporting role thanks to the CNAF of Bologna, where a copy of the CDF data was kept.

Giorgio Bellettini, can you tell us when and how the CDF collaboration came about?

INFN was one of the founding members of CDF, whose foundation dates back to the autumn of '79. In that year, during an international conference at Fermilab, the "Lepton-Photon Conference", some Fermilab physicists presented a new initiative, which consisted of transforming the main ring of the Tevatron accelerator into a proton-antiproton collider. The proposal was considered very bold because at the time the hadronic collider scene was dominated by CERN, which had already been working for years on collisions between opposing beams in the Super Proton Synchrotron (SPS). In the end, however, we decided that we would collaborate with an Italian group in the design and construction of a new detector to be installed on the nascent US collider. A few months later I was again at Fermilab, with the heads of the laboratory and of the Department of Energy, to propose and confirm our membership. Notwithstanding some initial perplexities, the project was finally approved at the beginning of 1980. In the same here, two important groups that would have worked on the implementation of CDF were created in the INFN Frascati National Laboratoris, where I worked, and in Pisa. CDF, can be hence be considered to all intents and purposes an Italian-American-Japanese activity, as demonstrated by the flags of the three countries positioned since 1985 above the head of the detector.

What were CDF's major achievements prior to ceasing operations in 2011?

In general, and especially for Italy, CDF was a very successful experiment. The most notable achievement was undoubtedly the discovery, in 1995, of the top quark, whose mass was measured very accurately in various ways, selecting different decay channels. However, the experiment was also responsible for the measurement of many phenomena of interest at the time, such as the production of strange baryons, containing the beauty quark, and the oscillations of their decay products. The new measurement of the mass of W is the result of the most recent period of activity of the Collaboration, which, thanks to the use of the entire data set acquired and to the refinement of systematic corrections, allowed to obtain the result published recently on Science, which were characterised by a very small error and exceptional accuracy. This result sets a value of the mass of W that deviates significantly from the prediction of the Standard Model, suggesting the possible presence of phenomena which have not yet been understood .

What types of technologies allowed CDF to maintain such high performance over its 30-year history?

CDF was a jewel of high technology: due to the extreme precision of its vertex tracer and central tracer, the component that detected the charged secondary particles and measured their momentum over much of the solid angle, and to the high spatial and energy resolution of its projective cell calorimeter, which measured the angular distribution of the energy flux carried by the secondary particles. The central tracer chamber of the experiment, for example, allowed us to distinguish in fine detail the superposition of traces of the different jets that distinguishes the final states of production of the W boson, allowing us to study them. A further famous improvement, the Silicon Vertex Detector, using conductive electrodes printed on silicon platelets, was also able to measure the point of origin of the events and the structure of events around their point of origin with an accuracy of a fraction of a millimetre. The combination of these factors allowed a clean separation of W production events and accurate measurement of their mass. All these aspects thus contributed to the acquisition of quality data and the exceptional reduction of systematic errors in this measurement.

How did INFN contribute to the creation and successes of CDF and how did its participation change over time?

CDF was a largely Italian experiment, to which INFN contributed in all aspects. Indeed, INFN physicists held leadership positions both in the design work of CDF and in the implementation phase of many of the detector components: the small-angle spectrometers - which operated at a lower resolution, but allowed the total cross section and elastic scattering of particles to be measured -, the silicon tracer, the trigger electronics that signalled the presence of secondary vertices to the production, the gigantic hadronic calorimeter with protective towers and the muon detectors. In this regard, I remember that in 1982, during the transfer of the hardware of the experiment from Italy to the United States, all the components we had built filled five ship containers. We also collaborated on the development of the central chamber of CDF and also on the entire trigger electronics of the experiment. Finally, I would like to underline the role of INFN in the conception and implementation of the Silicon Vertex Detector. This instrument employed an absolutely innovative technology that remains one of the main Italian contributions to CDF.

Making good use of their contribution to the construction of the detector, the INFN physicists worked on many of the main data analysis projects of the experiment. In addition to the groups of Frascati and Pisa, the INFN groups of the Divisions of Padua and Bologna, which joined the collaboration in 1990 and 1992, respectively, and subsequently of Rome and Trieste, also contributed to this effort.