Il Colle di Galileo

Understanding the TeV Scale through LHC Data, Dark Matter and Other Experiments

GGI, Florence
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Abstract. The workshop focused on new data from the LHC after the completion of its initial 7 TeV run, providing an opportunity to interpret the results and to plan for the future 14 TeV run. Particular attention was paid to the first serious indications for the discovery of a Higgs boson at a mass of 125 GeV. In addition to hearing from LHC experimentalists, attention was also given to input from experimenters at the Tevatron, as well as to the direct and indirect detection of dark matter, flavor physics, and other related searches. The main characteristic of the workshop was the close collaboration and intensive debate between theorists and experimentalists. The workshop also hosted a conference, jointly with the Johns Hopkins Series, on October 16/19, 2012.

Keywords. LHC results, Fermi scale, Interplay with Dark Matter and flavor physics.

Scientific Motivations

The Large Hadron Collider is, for the first time, thoroughly exploring the Fermi scale, i.e. the scale associated with the range of weak interactions or with the masses of their mediators, the W and the Z bosons. Although achieving this goal will require the extension of the energy of the collisions to the scheduled 14 TeV and the collection of a sufficient amount of data, the conference came after the completion of the initial 7 TeV run, and indeed also including some inverse femtobarns data at 8 TeV, due to an excellent performance of the accelerator.

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There are several key questions that the experimental investigation of the Fermi scale is intended to clarify. The first is the existence or non-existence of the/a Higgs boson, which is crucial to an understanding of the different range of the weak versus the electromagnetic interactions or the problem of ElectroWeak Symmetry Breaking (EWSB). The Standard Model (SM) of particle physics predicts the presence of a single Higgs boson as the only particle still missing in the full spectrum of the theory. Several precision measurements, mostly (but not only) of certain properties of the W and Z bosons, give an indirect determination of the Higgs boson mass around 100 GeV. This is true if these measurements are interpreted within the SM. The other major task of the LHC, assuming that the existence of the Higgs boson is established, is to understand its nature. The largely prevailing view among particle physicists is that the Higgs boson will have to be accompanied by other particles/phenomena within the Fermi scale, the discovery of which ought to be within reach of the LHC experiments. Such new phenomena are not included in the SM and are for this reason referred to as Beyond Standard Model (BSM) physics. There is no absolute consensus on what such BSM physics will be. Nevertheless the relatively dominant ideas are based on the view that the SM will have to be extended to include a new approximate symmetry relating bosons to fermions, called "supersymmetry", or that the Higgs boson will turn out to be a composite particle produced by some new strong interaction acting somewhat above the Fermi scale.

A variety of experiments over the last decade have shown that the Cabibbo Kobayashi Maskawa (CKM) picture of flavor physics, i.e. the physics that underlies the difference between the three generations, or replicas, of quarks and leptons, as incorporated in the flavor sector of the SM, is fundamentally at work. Yet the level of these tests is not the same as for the gauge sector of the SM. Furthermore the flavor sector of the SM is where most of the free parameters enter, leaving unexplained the strongly hierarchical spectrum of quarks and leptons or the strength of the communication between the different generations. A further task of the LHC is to see whether flavor physics is related to the problem of EWSB or not.

A third subject motivating the workshop is the nature of Dark Matter, interpreted as particles of some new kind. Based on the current understanding of particle physics and of cosmology, there are in fact reasons pointing to the Fermi scale as an interesting mass range for such hypothetical new particles too. This leads to an interesting interplay between the searches for DM particles in the halo of our galaxy, either "directly" or "indirectly", and the possible production of such new particles in the collisions at the LHC.

The workshop

Needless to say, the workshop was dominated by the discussions about the first serious indications for the discovery of a Higgs boson at a mass of 125 GeV, announced on July 4, 2012 by the two major LHC experiments, ATLAS and CMS.

These discussions included: i) the robustness of the signals collected at the time of the workshop; ii) the details of the results in the different decay channels of the putative Higgs boson; iii) the perspectives for further measurements; iv) the theoretical implications of mass and coupling measurements.

This last point in particular bears on the issue of the BSM physics that is expected to accompany the Higgs boson itself, as mentioned above. The searches for signs of such new physics, negative so far, were described and discussed at length during the workshop, from both an experimental and a theoretical point of view. In the case of supersymmetry the importance of looking at the signs of the partners of the top and of the gluon emerged and was clearly underlined. In the case of the composite Higgs boson, the signs of its putative pseudo-Goldstone nature were discussed. From this discussion it clearly emerged that the measured value of the mass of the Higgs boson calls for a perturbative value of its effective coupling to the fermionic composite top partners expected in this picture. This in turn has an impact on the flavor signals implied by the same picture, as searched for example in another of the LHC experiments, LHCb, so called because of its focus on the physics of the b-quark.

As mentioned above, the interplay between "direct" and LHC searches for DM was at the center of several talks/discussions. The existence of a 125 GeV Higgs boson implies that its exchange between a Dark Matter particle and the nucleus should produce a signal in one of the ultrasensitive DM detectors that are currently active in the direct searches, such as, for example, the XENON100 detector or its foreseen extension. This is true if the mass of the DM particle is indeed in the 100 GeV range. This, however, has not prevented people from entertaining the possibility that the mass of the DM particles could be lower, in the GeV range or even less. If that were the case, different strategies for their detection would have to be devised. First steps in this direction too were made at the workshop.

The workshop lasted for a total of 8 weeks (excluding the conference which will be described separately). During this period about 80 scientists from different physics institutions worldwide discussed and collaborated on the topics of the workshop. The full list of participants is reported on the workshop website. At least 30 participants per week were present in the institute at all times. During this period a morning talk took place almost every day, and occasionally afternoon sessions were also organized. These morning talks were characterized by their informal atmosphere with no strict respect of the time allocated when the discussions so demanded. The cross-talk between experimentalists and theorists was a significant feature of the entire workshop.

The conference

During the week of October 16/19 a conference took place bringing together leading theorists and experimentalists working on Higgs physics, Beyond the Stand-

ard Model and Dark Matter. There were a total of 20 talks of 50 minutes each. The conference was structured around the various themes covered by the program. The talks are listed below, grouped according to topic, although with obvious overlaps between different topics.

Higgs Physics

Vivek Sharma - Higgs Searches (CMS)
Giovanni Punzi - Tevatron Results on Higgs and MW
Roberto Contino - Modified couplings for a light composite Higgs
Alex Pomarol - Implications of a 125 GeV Composite Higgs
John Gunion - Multiple Higgs models and the 125 GeV state: an NMSSM perspective
Charalampos Anastasiou - The Higgs boson from its discovery to precision phenomenology
W.J. Murray - Higgs Searches (ATLAS)
Slava Rychkov - Oblique Corrections from Light Composite Higgs
Riccardo Rattazzi – Flavor, Naturalness & the Tops in Composite Higgs

Beyond the Standard Model and Flavour Physics

Alexander Tapper - New Physics Searches (CMS)
Frederic Teubert - Status of indirect searches for New Physics in Flavour Physics at the LHC
Gilad Perez - The status of alignment at the LHC12
Gennaro Corcella - Supersymmetric contributions to Z' decays
Cigdem Issever - Searches for Supersymmetry and Other New Physics at ATLAS
Lawrence Hall - Where is SUSY?
Yasunory Nomura - Spread Supersymmetry

Dark Matter

Tomer Volansky - Going beyond the WIMP: First direct detection limits on Sub-GeV dark matter
Neal Weiner - Higgs and DM Signals of Nearby Strong Dynamics
Bruno Serfass - The Status of Dark Matter Searches via Direct Detection