Il Colle di Galileo

GGI Workshop Beyond the Standard Model after the first run of the LHC

Dates: 20-05-2013 to 12-07-2013

Organizers:
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Summary. The first run of the Large Hadron Collider (LHC) was completed by the end of 2012. It amazingly unveiled the mystery of electroweak symmetry breaking by discovering the Higgs scalar particle. Our workshop discussed the status of theoretical ideas and their comparison with the first LHC run, starting from the experimental data, followed by theoretical models and their ultraviolet completion. The purpose was to bring together leading Beyond the Standard Model researchers, field and string theory experts with a key interest in comparing various Beyond the Standard Model ideas with the existing LHC data. This stimulated an intense and fruitful interaction between these communities in the excellent environment provided by the Galileo Galilei Institute.

Keywords. Physics Beyond the Standard Model, LHC physics

Scientific motivation

In Particle Physics theories with new symmetries and interactions have been proposed which predict the existence of new particles at energies above the electroweak scale, in the TeV range, or equivalently at distance scales of order 10–18 m

ISSN 2281-7727 (print)
ISSN 2281-9711 (online)

DOI: 10.13128/Colle_Galileo-14648
www.fupress.com/cdg

or smaller. These new theoretical frameworks are motivated by long-standing mysteries which still await an explanation.

These include:

- The large separation between the electroweak scale (W, Z gauge boson masses) and the quantum gravity or Planck scale
- The fermion mass hierarchy between the neutrino, the electron and top-quark masses
- The dark matter that seems to constitute most of the gravitating matter in the Universe
- The acceleration of our Universe that requires a new dark energy component
- The generation of the matter-antimatter asymmetry in the Universe
- The flatness and the temperature anisotropies of the observable Universe related to the hypothetical exponential inflationary stage after the Big-Bang
- The strong CP problem in strong interactions

In recent years, new experimental data have become available: the Large Hadron Collider at CERN began taking data in 2010, the Planck satellite has mapped the sky and various direct and indirect dark matter experiments have searched for the missing gravitating matter in our Universe. Comparison with the predictions of theoretical models from a complementary viewpoint (particle physics, cosmology and dark matter), has become possible but requires the combination of different tools and a broader expertise. Thus collaboration and meetings between researchers with different expertise has become more important than ever.

With the advent of the Large Hadron Collider we have entered an exciting new era. In 2012 the LHC discovered the missing building block of the Standard Model, responsible for the generation of the weak interaction scale and elementary particle masses, the Higgs boson. There are also good theoretical arguments suggesting that the LHC should also be able to probe the new physics responsible for the quantum stability of the Higgs mechanism. The last decade or so was characterized by rapid theoretical progress in understanding the possible nature of the new stabilizing physics: low-energy supersymmetry, technicolor, large extra dimensions, little Higgs, dark weakly-coupled sectors etc. Some of the most penetrating ideas put forward established a connection between the world of particle phenomenology at TeV energies and seemingly remote fundamental concepts such as string theory, holography, quantum gravity and extra dimensions. These ideas have opened up remarkable new horizons in theory, and they have given an obvious new meaning to the LHC. In 2013 the Planck satellite also released the latest data which seem to confirm with greater accuracy the predictions of the inflationary paradigm, which constrains inflationary models and provides more accurate information on the dark matter and dark energy content. The data of the dark matter experiments, such as FERMI, AMS and more recently LUX, have been intensively analyzed leading to further constraints on theoretical models.

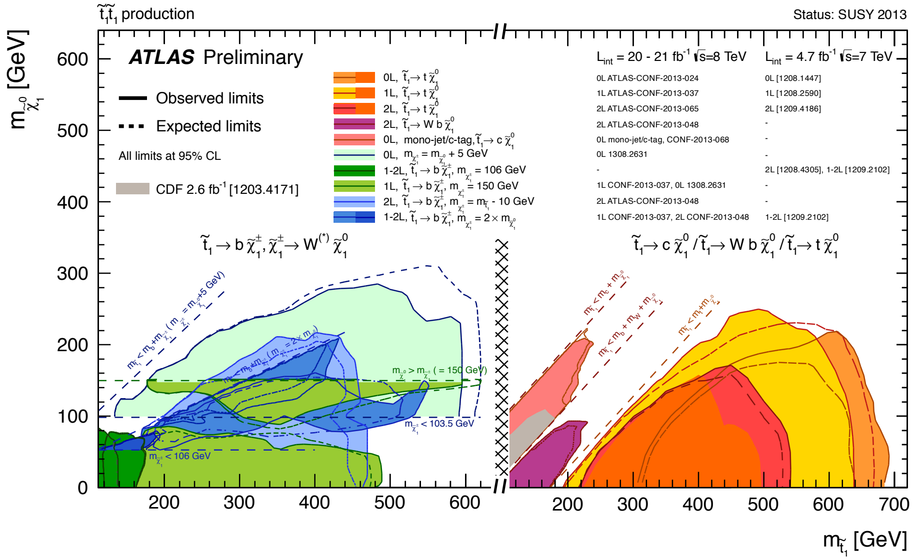

Fig. 1. Results presented by G. Villadoro at the topical conference. Shown here are constraints on natural supersymmetric models, in which stops are light, from the recent LHC data. The plots are in the plane stop mass versus the neutralino LSP mass.

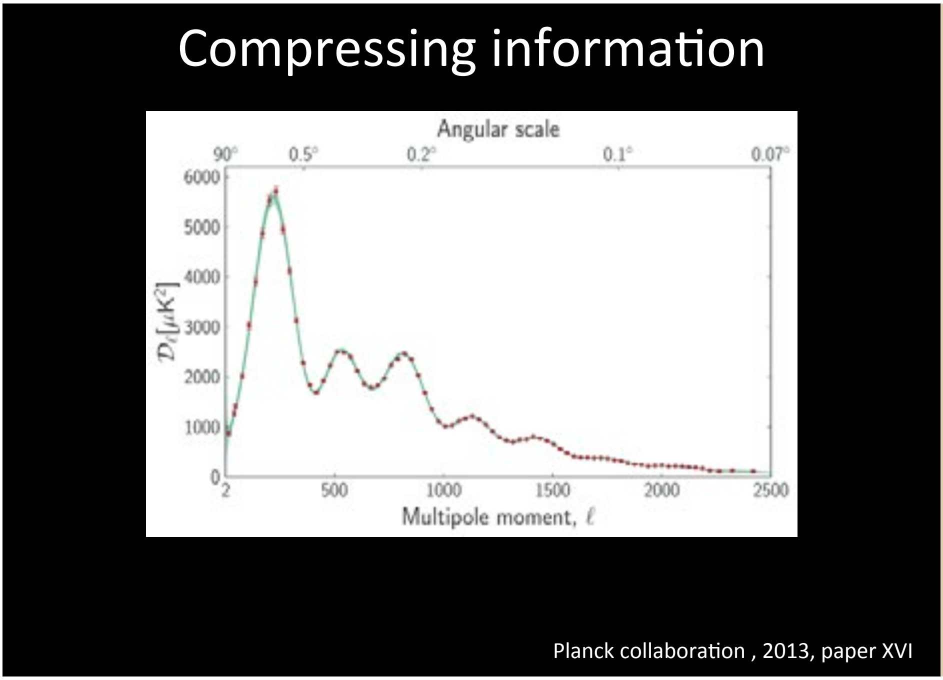

Fig. 2. Results presented by L. Verde. Angular distribution of contribution of cosmological fluctuations to the multipole coefficients of the cosmic microwave background temperature, from the recent 2013 Planck data.

At the end of 2012 LHC ended its first run. Some of the best-motivated Beyond the Standard Model theories, in particular supersymmetry and extra dimensional models, were constrained in much of their parameter space. The simplest supersymmetric models with moderate fine-tuning were seriously constrained and non-minimal, non-standard supersymmetric spectra became more natural than before. Other popular SM extensions were subject to stringent tests: universal extra dimensional models (UED), Randall-Sundrum holographic-like models and their avatars, TeV strings/strong gravity models, models with additional gauge bosons (Z') in their simplest realizations, models where the Higgs is a pseudo-Nambu-Goldstone boson, and dark matter models with a Higgs portal. The constraints coming from the complementarity with direct and indirect dark matter searches have played an important role in further restricting the theoretical models and their testable parameter space regions.

The GGI workshop

Our weekly workshop schedule included two advanced seminars every week on Mondays and Wednesdays, and one seminar of general interest to participants on Fridays. This included a lecture series for students on BSM topics: The State of Supersymmetry after Run I of the LHC, Conformal Field Theories for Physics Beyond the Standard Model and Composite Higgs: Principles and Applications. In total, there were 47 seminars by theorists and 3 experimental talks reporting on the latest data. We also organized a three-day conference at the end of our workshop in order to summarize the main results and promising directions to be followed up. The participants at the workshop were leading experts at world level, established researchers, doctoral and postdoctoral fellows in the fields of physics Beyond the Standard Model, LHC physics, cosmology and dark matter.

The main topics discussed during the workshop included:

- Electroweak symmetry breaking : elementary or composite Higgs?
- Strongly-coupled and holographic models
- Low energy supersymmetric models and supersymmetry breaking
- Non-standard supersymmetric spectra at the LHC
- Extra U(1)s and TeV scale new physics models
- Complementarity between LHC and dark matter searches
- Possible connections of TeV scale physics with cosmology and string theory

The total number of participants was around 80. The interactions and numerous discussions led to a significant number of collaborations, some of which were initiated during our workshop. Among the new results reported in our workshop were:

- An analysis of composite Higgs models
- Quantifying naturalness in supersymmetric models

- Proposals of flavor non-universal models of gauge mediation
- Cosmological Planck data versus ultra-light axions
- Overview of new LHC experimental results concerning the Higgs boson and searches for new physics
- Collider and indirect detection dark matter signals from couplings to low-energy hidden sectors

These results suggest that natural models of the Higgs boson are becoming more constrained to the point where some amount of fine-tuning may now be inevitable. In addition results from dark matter searches suggest that we may have to rethink what constitutes the dark matter of the universe. This is pushing the current theoretical models in unforeseen directions. Nevertheless new particles could still appear in the next round of experiments and in particular we eagerly await Run II of the LHC starting in 2015.