LHC - Heaven and Earth Colliding

No matter if we look out in space or inside matter the world's constituents remain the same. With the imminent start of the Large Hadron Collider (LHC), the world's most powerful particle accelerator, we enter into a new area of particle physics. Any new discoveries could also be beneficial to the areas of astrophysics and cosmology, shedding light on our common understanding of the universe.

Quest and Questions

The goal of the LHC experiments is to answer some of the most fundamental questions in particle physics: What is the origin of mass, why are there three families of particles, do the fundamental interactions unify and what is the mechanism of electroweak symmetry breaking and CP violation? Other important questions are if there could be new physics like Supersymmetry beyond the well-tested Standard Model or if extra dimensions exist. At the same time astrophysicists and cosmologists look for answers to some of their yet unanswered questions: what is dark matter and dark energy, what is the origin of the matter dominance in the universe (baryogenesis), is inflation the right mechanism for universe uniformity, how are the galaxies and large scale structures formed and what is the origin of cosmic rays?

Looking more closely to these questions it becomes apparent that they are closely linked. The unification of the forces in particle physics could be understood by studying what happened shortly after the Big Bang. CP violation is a necessary condition for baryogenesis, which produced the matter-antimatter asymmetry in the universe. New models for particle physics beyond the standard model, like Supersymmetry, provide several new particles, which could be dark matter candidates. Recent physics research has brought the micro- and macro-cosmos closer together.

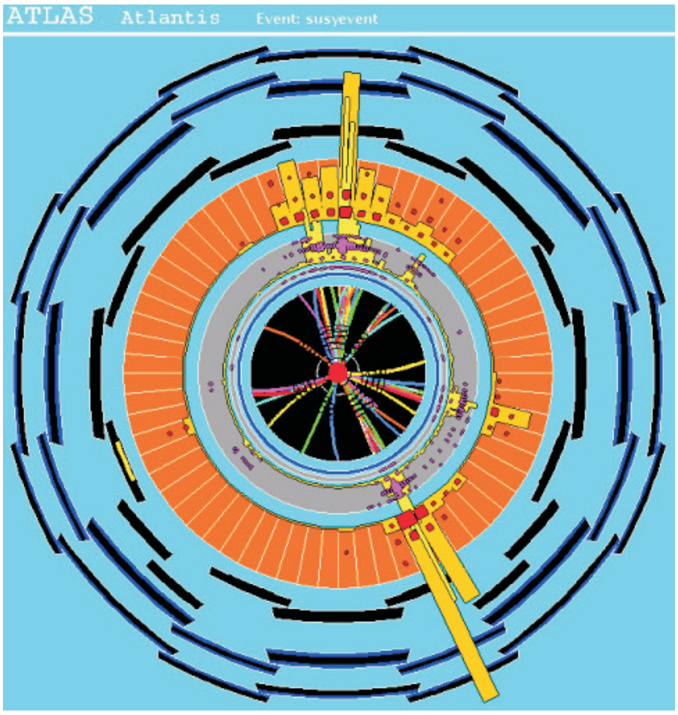

Fig.1 : A LHC collision as seen by the ATLAS experiment. In this event a pair of supersymmetric particles were produced, which decayed to six jets of particles, two muons with opposite signs and missing transverse energy.

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The Universe in Our Laboratory

The LHC is built at the European Centre of Particle Physics (CERN) in Geneva, Switzerland. This 27 km accelerator ring will provide proton-proton collisions at a centre-of-mass energy of 14 TeV as well as heavy-ion collisions. This corresponds to energy regions similar to conditions shortly after the big bang, never before explored in a laboratory on earth.

Four large-scale detectors are built at the four collision points around the ring. ATLAS and CMS will search for a large range of new physics signals, whereas ALICE and LHCb are dedicated to the studies of quark-gluon plasma and b-physics. In addition to these large scale experiments, TOTEM, MoEDAL and LHCf will respectively measure the proton-proton cross section, search for the magnetic monopole and study forward particle emission relevant for a better understanding of Ultra High Energy Cosmic Ray (UHECR) interactions.

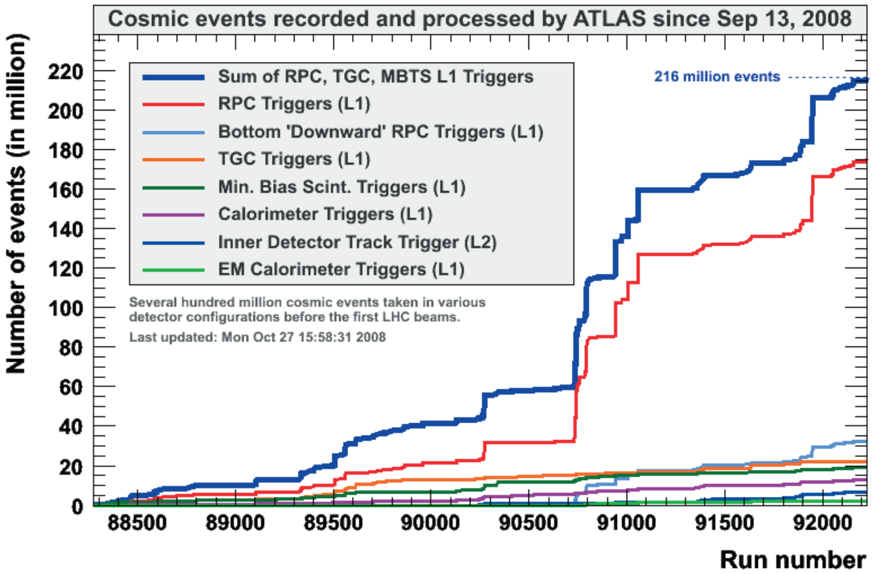

Fig. 2: Cosmic events already recorded by the ATLAS detector at LHC. Several hundred million cosmic events have been recorded in various detector configurations before the first LHC beams.

Constraints from Space

One of the most interesting searches at LHC will be the search for supersymmetric particles (See Fig. 1), which could provide one of the dark matter candidates accounting for ~23 % of the mass of our universe. Some of the most stringent criteria for these searches have come from astrophysics. The most famous example is the COBE and the later WMAP experiment, the first supporting the big bang theory itself and the latter measuring to an extreme precision the fluctuation in the cosmic microwave background radiation. Both experiments have contributed to significantly constrain the dark matter content in the universe, which limits the possible supersymmetric models researched by particle physics experiments.

Another very strong example where data from astrophysics have had fundamental impact on physics made with accelerators is provided by the discovery of neutrino oscillations made by the Sudbury Neutrino Observatory and Super-Kamiokande. The evidence for neutrinos masses suggests that the Standard Model needs to be extended.

Cosmic rays have been and still are a source of natural collisions on Earth and have been extensively studied by several experiments. One of the most recent ones, PAMELA, flying at a 350 - 610 km altitude has already provided valuable measurement of the particle fluxes, even reporting in November 2008 an excess of galactic positrons, which could be resulting from annihilating dark matter. If this is indeed a hint of dark matter, and not some other effect, it could constrain the dark matter interpretation just before LHC starts.

Light in the Dark

The main LHC program, the proton-proton collision and the study of high-pT events, is designed to search for hints or discoveries of physics beyond the Standard Model. In the best case, LHC may be the first experiment to produce dark matter candidates, which would be a revolutionary discovery both for particle physics as well as astrophysics. If the dark matter candidates prove to be from the supersymmetric model it may be possible for the LHC experiments to determine which of the SUSY models could be the right one as well as the Lightest Supersymmetric Particle (LSP) detection rate and its mass.

Some more speculative extensions of the Standard Model suggest that mini-black holes could be produced at LHC as well, indicating the existence of extra dimensions. They are not normal black holes but microscopic objects, which, although they could be produced at a rate as high as 1 Hz, would immediately decay by Hawking radiation into very high multiplicity events. However, if mini-black holes exist, cosmic ray observatories like Auger would most probably already observe them before LHC starts.

Already heavily used by the LHC experiments to calibrate and align the detectors, cosmic ray data is another source of interesting data. The LHC detectors are expected to collect an unprecedented amount of cosmic data from underground accelerator experiments (see Fig. 2). In addition, the collisions at LHC will permit the study of conditions which corresponds to collisions between a cosmic ray and a stationary proton of ~ 10^{17} eV. Recent cosmic ray experiments show a wide range of anomalies, which could be due to new physics.

Conclusions

As the first data from LHC approaches, the first collisions are expected in 2009, particle physicists are eager for any new astrophysics results and look forward with enthusiasm to a close collaboration with astrophysicists and cosmologists. It is fascinating that in space, on the surface of the Earth or hundreds of meters buried underground, we are all looking for the same answers to one of the most fundamental questions in physics: How on Earth was the universe created?

Further reading

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