Low-energy probes of new physics

Organized by Martin Jung (TU Munich), Peter Fierlinger (TU Munich) and Susan Gardner (Univ. of Kentucky).

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Astrometric observations reveal that most of the energy content of the universe is of unknown form and thus provides a compelling case for the existence of physics beyond the standard model of particle physics (SM). The discovery of the Higgs Boson at the Large Hadron Collider (LHC) completed the particle spectrum of the SM. However, there is much that remains unexplained. The biggest questions include what forces prevalent at the Big Bang produced a matter- dominated universe. Further questions deal with dark matter and dark energy. The answers lie in "new physics", that is, new particles and forces that have measurable effects, which can be investigated in laboratory experiments, either at high-energy colliders or through sensitive or precise measurements in low-energy systems. Advances in technology for low-energy experiments together with further data at 13 TeV from the LHC have provided a new environment, requiring a reassessment of the focus of the field. The scientific program covered the theory and experiment of a wide range of low-energy searches for new physics that provide unique and complementary information to accelerator-based searches, independent of potential discoveries at the LHC and future colliders.

This scientific program brought together the proponents of major low-energy experimental efforts to discuss the techniques, challenges, and progress. The major topics were slow-neutron physics, searches for time-reversal symmetry breaking electric dipole moments (EDMs), exotic effects such as light "axion-like" particles, parity violation, fundamental muon physics, and precision tests of SM radiative corrections. Theoretical participants included phenomenologists with expertise in calculations of particle-physics and QCD effects in specific systems such as nuclei, atoms, and molecules. The aim was to compare and combine techniques, address specific crucial questions for the experiments and to analyze the impact of existing and proposed experiments on the theoretical picture.

While the SM is extremely successful in describing phenomena at vastly different energy scales, it is known to be incomplete. In particular, the observational evidence for dark matter and energy and the amount of the matter-antimatter asymmetry in the universe cannot be addressed within the SM. Possible extensions to the SM predict new phenomena at all energy scales. Low-energy precision experiments are complementary to searches at the LHC. For example, very weakly coupled light particles such as axions would not be observed at a high-energy collider. Signals of new physics at short range may be revealed by precision measurements in systems such as slow neutrons, atoms, and muons, where the sensitivity is due to a combination of the coupling strength and energy scale of the new phenomena. Interpreting low-energy measurements provides insights into the nature of new phenomena. Strong upper limits or determinations for specific combinations of model parameters could be combined with direct measurements of new particles to set the structure of the new sector. Since each measurement is subject to physics from different energy scales, the MITP event strengthened the links between the communities involved. Techniques were discussed which so far have been only marginally treated to maximize the potential of greatly increased experimental sensitivities.

The main motivation of this scientific program was to strengthen the links between the communities and groups involved in different low- energy tests and to add new expertise and techniques from usually disparate fields in order to realize and interpret measurements of greatly increased precision, also to intensify the understanding of the interplay between all experiments on a theoretical basis. The scientific program covered the theoretical and experimental developments and status in a variety of fields, including the following high topics. In neutron decay and advances in neutron methods for fundamental measurements, new experiments with 10-100 times improved sensitivity are on track, probing the 10-100 TeV scale. One of the major experiments is the Munich-based PER experiment by strong international activities. There are a variety of new EDM searches either underway or already producing results: 100-times more sensitive measurements using neutrons and protons are currently developed, with new synergetic effort that lead for larger-than-customary collaborations. Atomic EDM experiments have advanced enormously in their technology in the very recent past and have an important potential for discovery in the coming years, also motivating the development of new approaches for theory. Quantum phenomena in slow neutrons, i.e. gravitationally bound states of neutrons, are a new concept which is evolving into a precision technique, notably to search for light "axion-like" or "chameleon" particles, but also other exotics. Parity violation in atomic systems (APV) provides the most precise measurement of the Weinberg angle near zero momentum transfer, which becomes a window to new physics when compared to higher-energy measurements. Efforts to measure with even higher precision require new experimental techniques, for example cold atoms as well as new efforts in theory. New experiments to measure rare decay modes of the muon, like the $\mu \to 3e$ and $\mu \to e$ conversion, are currently being realized with sensitivities reaching into the PeV scale. The discrepancy between the precision measurement of the anomalous magnetic moment of the muon and its SM prediction including QED, weak and QCD contributions is an intriguing laboratory signal for new physics. A new measurement will improve the experimental precision and provide a better assessment of systematic errors. At the same time advances in theory, in particular regarding strong-interaction contributions, are crucial to interpreting the results.

Each experiment can establish new physics, but it cannot determine its precise form so that the interpretation of results is complex. Therefore, the following problems in theory were analyzed in this scientific program: (i) the calculation of parameters on different scales, e.g. QCD, nuclear and atomic levels, which are often separated due to the different communities. (ii) placing phenomenological constraints on the parameter space for preferred new-physics scenarios by combining new experimental results, given the new boundaries of two years of high-energy data from LHC.

Due to the increasing scale of size and costs of the next generation of experiments, the identification of synergies is a key for advancing our measurements. In this scientific program this issue was also addressed. For example, laser techniques and the control and generation of small magnetic fields have advanced tremendously in the last years. Searches for the proton EDM using particle beams, measuring neutron and atom EDMs, and using trapped particles for precision QED tests employing table-top techniques started. In the discussions, the exchange of knowledge and ideas between the previously rather disjunctive communities achieved a significant potential for synergies.