Foreword

Nearly four hundred theorists and experimentalists gathered at DESY Hamburg in June 2002 at "The 10th International Conference on Supersymmetry and Unification of Fundamental Interactions" (SUSY02). In this week-long meeting new theoretical ideas, thorough analyzes of experimental data and exciting expectations for physics at the Large Hadron Collider (LHC) and the proposed TeV range electron-positron linear colliders were presented.

A lively and exciting atmosphere prevailed with participants exchanging standard and not-so-standard views on the evolution of particle physics. The excitement has its roots in the fascinating prospects of addressing fundamental problems of physics in the new generation of accelerators, justifying hopes of finding the long-awaited breakthroughs to solve many outstanding questions.

... *Waiting for SUSY*

On the experimental side, the conference marked the transition from the experiments completed at LEP, HERA, the Tevatron, and the SLC colliders to those at Tevatron-Run2 and HERA-II, and to preparations for physics at future collider facilities.

Experiments at LEP have covered a large range of parameter space in the Higgs sector of the minimal supersymmetric extension of the Standard Model (MSSM). The experiments seem to have ruled out one of two parameter ranges singled out previously by theoretical arguments, the small $\tan\beta$ region. However the large $\tan\beta$ region was not fully covered by LEP and remains of great interest for forthcoming Higgs searches at the Tevatron. On the other hand, strong support for a light Higgs boson as predicted by supersymmetric theories, can be derived from the theoretical interpretation of precision data at LEP and the SLC.

LHC experiments will be able to establish or rule out the existence of a light Higgs boson within a few years – in nearly all conceivable theoretical scenarios. Once discovered, the profile of this fundamental particle can be studied experimentally at a linear collider with very high precision to establish the Higgs mechanism for generating the masses of standard particles.

The search for genuine supersymmetric particles has been carried out by the LEP experiments in an equally clear way. In its higher energy phase of running, LEP set lower limits on the masses of the scalar partners of leptons close to the beam energy of 100 GeV. Similar limits have been achieved for the fermionic partners of W bosons, while the lightest supersymmetric particle has been constrained to a mass range above 50 GeV, albeit in a model-dependent way. The masses of squarks and gluinos on the other hand have been raised by Tevatron analyzes to a range of more than 200 GeV. This result is complemented by constraints on the stop mass in R-parity violating theories at HERA.

The discovery range for SUSY will be extended by LHC to values up to about 3 TeV, leaving little room in parameter space for supersymmetric particles to hide. Further ahead, the properties of such particles could be measured to parts-per-mil accuracy in the several hundred GeV mass range electron-positron colliders. This allows to determine the fundamental parameters in supersymmetric theories very precisely. All these results and expectations are based on theoretical high-precision calculations of the properties of SUSY particles and their production cross sections.

Other sources of information on supersymmetric scenarios, including the CP-violating sector, are offered by precision measurements at lower energies. B-decays and other rare decays are affected by supersymmetric particles through virtual loop effects. The fact that observations presently seem to be in agreement with the Standard Model, does not rule out the potential intervention of supersymmetric particles. Errors are still too large to draw definite conclusions in multi-dimensional SUSY parameter space on flavor physics.

By the same token, the small discrepancy between the measurement of the anomalous muon magnetic moment and the predictions of the Standard Model is compatible with wide areas of supersymmetric parameter space. New insight might soon be obtained from experiments studying lepton flavor-violating processes such as radiative muon decays into electrons. The recent observation of neutrino oscillations has prompted new interest in the search for such phenomena in the charged lepton sector, with the novel conversion processes enhanced by virtual SUSY contributions.

... Giving Mass and Energy to the Universe

The observation of cold dark matter in the Universe has long been speculated to be related to supersymmetry. If, as in many scenarios, the lightest supersymmetric particle is stable it would be a perfect candidate for this new kind of matter. Signals of such particles which account for most of the mass of the Universe, may be identified in dedicated search experiments or in astrophysics experiments.

Cosmological problems are an excellent test ground for physics at very high energy scales. Baryogenesis - crucial for our own existence - may be explained by supersymmetry mechanisms if stop and Higgs masses are tightly constrained, barely above the present experimental exclusion limits. A completely different picture emerges in the leptogenesis scenario where decays of Majorana neutrinos with masses close to the grand unification scale are the source for the observed asymmetry of matter and antimatter in the Universe.

Cosmological scenarios can cause problems for supersymmetric models. However, in detailed analyzes these often appear less severe. Recent data on energy fluctuations in the cosmic microwave background and measurements of the deceleration parameter via the Hubble diagram of Type I A Supernovae suggest a positive cosmological constant. From a theoretical point of view more than puzzling, these results have prompted suggestions that brane-world models may offer alternative scenarios for the cosmology of the early Universe.

... Connecting to the Planck Scale

The most compelling argument in support of supersymmetric extensions of the Standard Model is the unification of the three different gauge couplings – electromagnetic, weak and strong – at the percent level at a scale near 10^{16} GeV. After extrapolation over more than fourteen orders of magnitude in energy, the three couplings meet in a tiny area with accuracy much better than expected in many scenarios. This surprisingly successful prediction cannot be matched easily in alternative theories.

Although certain aspects of minimal versions are sometimes problematic, such as too rapid proton decay, even conventional supersymmetric grand unified theories are still in agreement with data. Moreover, the quark and lepton mass textures may have their origin at these scales. Higher dimensions offer additional freedom in building models and thus are more flexible in removing stumbling blocks of traditional grand unified theories. While they shed new light on questions of supersymmetry breaking, these models address also the doublet-triplet splitting of the Higgs field. Aspects of electroweak symmetry breaking may also be related to higher dimensions.

Studying the phenomenological aspects of supersymmetric theories in string theory has been improved by extending the powerful techniques of mirror symmetry to theories with only $N = 1$ supersymmetry. Furthermore, string theory can also be exploited to explore strongly coupled gauge theories, such as quantum chromodynamics, by means of the so-called AdS/CFT correspondence between string and field theory.

If supersymmetry is realized in Nature, experiments at a linear collider would be ideal instruments for determining the properties of new particles with very high precision. This is a necessary prerequisite for reconstructing the fundamental supersymmetric theory at the scale where supersymmetry breaking is localized. If the supersymmetry parameters are transmitted at this scale from a hidden world to our visible eigen-world by gravitational interactions, these machines can be used as powerful telescopes to a domain where particle physics and gravity are linked – a fascinating vision for the future.

... Living in Higher Dimensions

The idea of the Standard Model being localized on a four-dimensional brane that is embedded in a higher dimensional space-time, can be formulated in string theories. Models have been developed where constructions of this type are carried out explicitly. Phenomenological aspects of extra dimensions at around the TeV scale are important for experiments at the next generation of particle accelerators. An exciting signal for such a scenario realized in nature, would be the observation of radiation of black holes from high-energy particle collisions.

It is likely that also the structure of 4-dimensional space-time is modified at ultra-short distances. A particularly interesting aspect of this modification is potential non-commutativity of space (and time). Measurements of the x- and y-coordinates of an event would affect each other in a way similar to the position and momentum measurements in standard quantum mechanics, albeit with the interference being characterized by a very small-scale parameter. Such an idea can be developed within string theory, while similar ideas can also be developed from a field-theoretical point of view.

Additional strongly coupled gauge groups at energy scales of order TeV could have a significant impact on the pattern of electroweak symmetry breaking and the Higgs sector. This possibility is also suggested by reducing elegant theoretical structures in higher dimensions to the standard 3+1 space-time dimensions.

The physics program discussed at the conference focused on the innermost structures of the microcosm, for matter as well as space-time, but it found them deeply connected with the structure of the Universe at large - the final step of ultimate unification.

The First DESY Heinrich-Hertz Lecture on Physics "Quest for Unification"

At SUSY02, DESY launched a new series of annual lectures with the goal of conveying the fascination of particle physics to a wider audience at the university and in the city of Hamburg. Edward Witten of the Institute for Advanced Study at Princeton presented the first DESY Heinrich Hertz Lecture on Physics.

DESY Director General, Albrecht Wagner, introduced the series with a description of Hertz's great achievements in experiment as well as theory. Born 1857 in the city of Hamburg into a wealthy family of merchants, Heinrich Hertz developed an outstanding talent for physics quite early in life. After becoming Professor of Physics at the Karlsruhe Polytechnicum in 1886, he carried out one of the most important experiments of the 19th century – demonstrating the existence of electromagnetic waves. This proved Maxwell's theory in which electricity and magnetism are unified to electromagnetism, to be right.

Edward Witten's lecture covered the "Quest for Unification" in modern physics. He described the steps and arguments leading from the Standard Model of particle physics to grand unified theories at energy scales of order 10^{16} GeV. Straightforward extrapolation of highly precise experimental data on the three gauge couplings strongly suggests that at this scale electromagnetic, weak and strong interactions merge to a single unified interaction.

However the evolution of the couplings of the individual interactions approach a single point accurately only if the Standard Model is extended to a supersymmetric theory. This may also open the door for unifying the genuine particle physics interactions with gravity. This last step – one of the central goals of physics – may require the expansion of our 4-dimensional space-time world to a world of higher dimensions as required by superstring theories.

Forthcoming experiments at the LHC and future linear colliders will determine the truth or otherwise of these exciting ideas. Positive evidence would provide a comprehensive picture of matter and forces in nature – the "ultimate unification" sought after by the most eminent theorists in history.

Technical Note

Video recordings of the plenary talks delivered to the conference and ps files of the transparencies and the contributions to these proceedings are available on `http://www.desy.de/SUSY02/`.

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Chairmen of the Organizing Committee