J. Geiss, the ISSI Executive Director (on the right) and R. von Steiger.

international space activities needed better integration.

The ISSI essentially reinforces international and multidisciplinary aspects by complementing major national and university institutes catering for space science. It also provides Switzerland, a significant ESA contributor, with an institution of international standing on which to focus activities and public awareness. Consequently, ESA, the Swiss federal government, Swiss industry, and local authorities support the Institute. The foreseen budget ceiling is some 2 MECU covering a permanent staff of 12-15, temporary support for visiting scientists at all stages in their careers and facilities close to the Bern University's science faculties.

The ISSI will concentrate initially on solar-system sciences where the need for an interdisciplinary institute was vividly demonstrated by the first ISSI Workshop (see above) at which significant progress was made in tackling major outstanding issues concerning evidence for a weak, as opposed to strong, shock at the heliopause and the concentration of hydrogen in the heliosphere. Hydrogen is the main constituent so it is largely responsible for the heliosphere's pressure and hence the heliosphere's interaction with the interstellar medium.

ISSI's integrating activities focus on so-called Principle Investigator (PI)-type missions where a locally financed team led by a PI is responsible for the construction, operation and output of an instrument aboard a spacecraft. At the other extreme one has observer-type missions where an agency operates a space facility on behalf of users. PIs and their teams naturally enjoy certain benefits such as the right to first discovery, privileged use of data for two years, *etc.* The ISSI will not jeopardise these privileges but instead bring teams together across missions in such areas as the Sun-Earth relationship, heliosphere and cometary research, and the physics of solar and space plasma, where there are links to astrophysics, astronomy and earth observation.

Professor Geiss feels that it is too early to even guess at the ISSI's future interests since the IACG has yet decide its future orientation and role. The International Solar-Terrestrial Programme (IASTP) is expected to run for at least a decade, by which time it should be clear if the ISSI will turn more towards astronomy or towards planetary research, notably lunar and Earth-oriented aspects.

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HIGH-ENERGY PHYSICS

Seeking a Comprehensive Understanding

P.M. Zerwas from DESY, Hamburg, reports on the latest results presented at the *1995 International Europhysics Conference on High-Energy Physics* (Brussels, 27 July – 2 August 1995).

High-energy physics is presently split into two streams namely, the ever increasing experimental evidence supporting the Standard Model, and preparations for experiments at the TeV-energy scale, where the model is expected to be embedded in a more comprehensive theory. This duality was truly reflected in talks at the *1995 International Europhysics Conference on High-Energy Physics,* which provided an excellent overview of new results in particle physics.

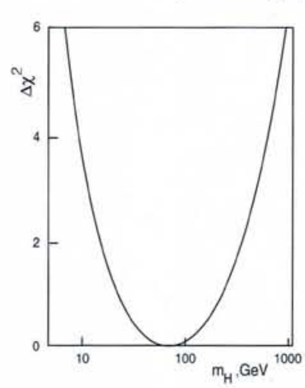
The Standard Model

The Standard Model (SM) of particle physics consists of "matter particles", "forces" and the "Higgs mechanism".

• **Matter particles**. Leptons and quarks organize themselves into three families of identical structure. Each family consists of a pair of neutrinos and charged leptons, and a pair of charge +2/3 and –1/3 quarks. These particles are pointlike at the present scale of experimental resolution. In fact, DESY's HERA and CERN's LEP have set upper limits of less than 10^{-17} cm on the radii of these particles. The heaviest of the quarks, the top quark, has recently been discovered at the Tevatron in the USA (A. Menzione) with a mass $m_t = 176 \pm 11$ GeV which corresponds approximately to the mass of the gold atom.

Although the top quark was proven to exist as the isospin partner of the b quark a long time ago, the successful prediction of the top mass from electroweak data is one of the triumphs of high-precision experimentation in particle physics and quantum field theory (W. Hollik). Since the number of (nearly massless) neutrinos has been determined to be three in invisible Z-decays, the ensemble of matter particles with the texture of the SM is now complete.

Whether **charge-parity** (CP) violation is realised in Nature through a complex mixing between quarks of different families is one of the SM's outstanding problems. While all observed phenomena in the K-$\bar{K}$ complex are compatible with this hypothesis, the *experimentum crucis* will be the observation of CP-violation in the B-$\bar{B}$ complex (R. Aleksan). This problem can be tackled by observing the difference of the time evolution of B and $\bar{B}$ beams in the $J/\psi K_S$-decay mode. Two asymmetric e^+e^- colliders will be built (at SLAC in the USA and at KEK in Japan) to solve the problem. They are in a race, however, with HERA-B, a dedicated experiment at DESY in which the HERA proton beam will collide with a fixed nuclear target to produce B/$\bar{B}$ mesons (experiments begin in 1998/9).



The mass of the Higgs particle as estimated using today's data. A fairly small Higgs mass of order 70 GeV is preferred, with a large error, however, stretching the mass range up to 600 GeV.

• **Forces** are built-up in the SM by the exchange of gauge particles associated with a SU(2) x U(1) symmetry in the electroweak sector, and with a SU(3) symmetry in the strong sector. Many properties of the gauge particles in the electroweak sector, the photon and the W^{+-}/Z bosons, are already known very accurately, notably masses, lifetimes and couplings to leptons and quarks (A. Olchevski, G. Rahal-Callot, S. Komamiya, J.M. Gerard).

LEP has determined the mass of the Z boson with unprecedented precision (M_Z = 91188.4 ± 2.2 MeV). The measurement of the W boson mass is steadily improving. A new quality will be reached shortly at CERN's upgraded LEP2 collider (collisions, at 130 GeV, were observed for the first time on 31 October) where the residual error will presumably be reduced to less than 30 MeV. The non-ablian symmetries predict the form of the self-interactions of the gauge bosons, or equivalently, the magnetic dipole moments and the electric quadrupole moments of the gauge particles. Present experiments at the Tevatron only slightly constrain these static electroweak parameters. LEP2 will improve the situation significantly by restricting anomalous components to less than about 0.2. CERN's LHC $p\bar{p}$ collider will be needed and, even better, future e^+e^- linear colliders, to perform high-precision tests of the non-ablian symmetries in the electroweak sector at a ≤ 0.01 level.

Quantum chromodynamics (QCD) is the microscopic theory of the strong interactions. It is based on quarks and gluons which have been established in the 1970s by the observation of three-jet events at DESY's PETRA storage ring. After isolating the gluon self-couplings in the four-jet distribution of hadronic Z decays at LEP, the main problem which remains to be solved in QCD is the high-precision determination of the **QCD coupling** and unambiguous evidence for asymptotic freedom which makes the strong coupling weak at high energies. Presently, the experimental values extracted from hadronic

Z-decays and from deep inelastic lepton-nucleon scattering cluster at two different points. Although not contradicting each other statistically speaking, this annoying discrepancy needs resolution. New insight can be obtained in the near future from high-statistics results at HERA, where deviations from scaling of the proton structure function provide a theoretically clean method to measure the QCD coupling. Lattice analyses of the hadron mass spectra will be a great help once the computing capacity is at hand.

The unexpected/expected increase of the **proton structure function** at small x (x is the fraction of the nucleon momentum carried by the struck quark in ep collisions) has been consolidated in recent HERA experiments (F. Eisele). While at small momentum transfer Q^2, the soft pomeron exchange is the proper mechanism to build up the photon-proton cross-section (A. Levy), the theoretical interpretation of the proton structure function is not clear at medium Q^2 (A. Mueller). While the rise of the proton structure function at small x was theoretically predicted two decades ago, it can be accounted for in the classical evolution approach only by starting the quark-gluon avalanche at very small Q^2. Ladders made up of gluons, exchanged between photon and proton, can be interpreted as a novel hard pomeron (BFKL pomeron) to describe the data equally well. Which picture is correct? A wealth of additional observables and final-state effects must be explored in high-statistics analyses for a generally accepted solution.

Light has recently been shed on the permanent **confinement of quarks** from an unexpected angle (E. Verlinde). In the analysis of a $N=2$ supersymmetric extension of SU(2) QCD, the vacuum structure of these theories as well as the spectrum of the stable particles could be determined exactly. By breaking the symmetry down to $N=1$, it was proved that confinement is realised through the condensation of monopoles, in analogy to the condensation of Cooper pairs in Type-II superconductors. Thin Meissner lines transporting the flux between the colour charges give rise to the confining linear growth of the potential energy between quarks.

• **Higgs mechanism**. In this mechanism, masses are generated for the fundamental particles, leptons, quarks and gauge bosons, through the interaction with a scalar field extending over all space and time. The mechanism manifests itself through the existence of a physical scalar particle, the Higgs boson. It assures that the theory remains valid up to very high energies with all particles interacting weakly with each other.

The alternative mechanism for breaking the SU(2) x U(1) symmetry down to the electromagnetic U(1) symmetry introduces new strong interactions at the TeV scale to circumvent the violation of unitary at very high energies. Technicolour theories are the only theories in which this idea has been formulated quantitatively. The most straightforward realizations of such theories, however, are not compatible with the electroweak high-precision data from LEP, and rather baroque formulations are needed to enforce agreement with the data. The sole alternative to the Higgs mechanism known at the present time therefore generally meets with much scepticism.

The only unknown in the SM Higgs sector is the mass m_H of the Higgs boson. All couplings are fixed so that accurate production and decay rates can be predicted. Since the Higgs particle affects the quantum corrections of the electroweak processes, the mass can be estimated from the electroweak data. However, the sensitivity, being only logarithmic, is weak. Nevertheless, the data (see figure) prefer a fairly small m_H of order 70 GeV, with a large error, however, stretching the mass range up to 600 GeV.

High-energy physics has succeeded in providing a clear picture of matter at very small distances, and in revealing the basic laws of Nature in the microcosm. However, the picture is still incomplete and new aspects must be studied at higher energies before a truly unified theory of matter may be formulated. New phenomena have been discovered in the past by exploiting various experimental methods. But, there is no alternative to skillful laboratory experiments at high-energy accelerators which ensure a deep and comprehensive understanding (D. Perkins, Oxford).

The Higgs particle has been searched for directly at LEP1 in Z-decays. From the non-observation of the signal, a lower limit of $m_H > 65.2$ GeV has been set (J.F. Grivaz). LEP2 will have a monopoly for searching Higgs particles. Through Higgs-strahlung the particle will be accessible up to a mass of 100 GeV. The LHC can continue the search for this particle over the entire mass range of < 700 GeV in the SM. However, these experiments are very difficult in the intermediate mass range below the $Z\bar{Z}$ decay threshold. This domain is covered by e^+e^- linear colliders in an ideal way. Moreover, these machines offer the opportunity to reconstruct the complete profile of the Higgs.

Beyond the Standard Model

The SM extends down to distances of order 10^{-16} cm. However, by incorporating *ad hoc* many fundamental physical parameters, couplings and masses, but not offering a theoretical interpretation of their specific values, it is incomplete. And last but not least, gravity is not built in. There are few experimental glimpses of the physics beyond the SM.

• **Partial Z-decay widths**. Measurements at LEP of the partial Z-decay widths to bottom (b) and charm (c) quark pairs are several standard deviations away from SM expectations. Virtual loops of supersymmetric particles could reduce R_b a little, but they do not affect R_c. Theorists are puzzled by these discrepancies and, so far, cannot offer a compelling explanation. The experimental analyses are difficult, requiring a clean discrimination of b from c quark decays. The surplus of b decays and the deficit of c decays cancel each other partially in the sum of the two modes, provoking nagging questions.

• **Neutrino mass**. Neutrinos are endowed with vanishing masses in the canonical form of the SM. However, the deficit of the solar neutrino flux gives strong support to the existence of oscillations between massive neutrinos. In a variety of experiments (D. Wark), the deficit was determined to be close to 50% and the solar model underlying the analysis has been dismissed as the source of the deficit. Results from underground laboratory experiments on neutrino oscillations may soon provide *prima facie* evidence for non-

The 1995 International Europhysics Conference on High-Energy Physics attracted almost 700 participants from 38 countries. It was held on a common campus of the two host universities, the Université Libre de Bruxelles and the Vrije Universteit Brussel, and was mainly organized at the administrative and logistical level by the scientific, administrative and technical staff of Brussel's Inter-University Institute for High Energies — a joint institute of the two universities to which physicists from the University of Antwerp are strongly associated. Moreover, all of the Belgian universities involved in particle physics provided secretarial help. The commitment of the local organizing committee and staff allowed for a relatively modest budget that could be covered by registration fees and by institutional and industrial sponsorship. Some 26 participants benefited from grants funded mainly by the European Community and the International Science Foundation.

The conference generated several parallel activities, including three pre-conference exhibits several months before the conference to representatives of the press and Belgian's scientific, industrial and political world. The exhibits, which covered CERN, particle physics in Belgium and the Solvay physics congresses and the birth of modern physics, were very successful and well-received by the press. Industrial and book exhibitions also took place during the conference itself. These activities, but especially the conference, helped focus the attention of not only Belgian's science and political authorities but also the public at large on particle physics.

The winners of the 1995 High-Energy and Particle Physics Prize of EPS were presented with the award at the opening ceremony of the 1995 International Europhysics Conference on High-Energy Physics. From left to right, G. Wolf, B.H. Wiik, P. Söding, and S.L. Wu.

zero neutrino masses. Moreover, massive neutrinos may account for the hot dark matter component of the Universe (V. Berezinsky).

• **Supersymmetry**. The electroweak symmetry breaking is presumably the most suitable launching pad for theoretical extrapolations into the area beyond the SM. If the Higgs boson is light, say less than about 200 GeV, the theory can be extended up to the scale of grand unification at 10^{16} GeV while keeping all particles weakly interacting. This provides the basis for renormalizing the electroweak mixing angle $\sin^2\Theta_W$ from the symmetry value of 3/8 down to a value close to 0.2 at low energies. In such a scenario, however, the light Higgs mass can only be stabilized if the theory is formulated in a supersymmetric frame, associating fermions with all fundamental bosons and *vice versa*. This extended particle spectrum can account quantitatively for the observed electoweak mixing angle $\sin^2\Theta_W = 0.23143 \pm 0.00028$ — a value that was in fact predicted more than a decade ago in supersymmetric theories.

If supersymmetry is realised in Nature, it may become evident in the LEP2 experiments (F. Zwirner) since much of the supersymmetric Higgs parameter space can be explored at LEP2. In addition, the supersymmetric partners of the W bosons may be light enough to be produced at LEP2. If the scalar quarks or gluinos are light, they may be detected at the Tevatron. So the coming years could reveal experimentally a new form of matter!

The complete particle spectrum of supersymmetric theories can be explored at LHC and next-generation e^+e^- linear colliders. While the coloured squarks and gluinos can be discovered at the LHC (if they are too heavy to be discovered at the Tevatron), the non-coloured states, supersymmetric partners of the weakly interacting gauge/Higgs bosons and leptons, are easy to discover at future e^+e^- colliders. Moreover, these machines will enable us to explore the structure of the supersymmetric theory, rooted at energy scales as far away as the Planck scale. The lightest stable supersymmetric particle may form the cold component of dark matter in the Universe. Novel experiments are being built-up to search for these particles (B. Sadoulet).

Supersymmetry may also be an important step for developing a quantum theory of gravity. This problem appears to be solved in string theories which reduce to quantum field theories in the local limit.

The New Generation of Colliders

Many ideas have been advanced recently suggesting that qualitatively new physical phenomena may be expected in the TeV energy range (L. Maiani). To explore this new domain, it will be necessary to operate both $p\bar{p}$ and e^+e^- colliders at TeV energies. Physics programmes are complementary so coverage of the TeV energy scale is assured.

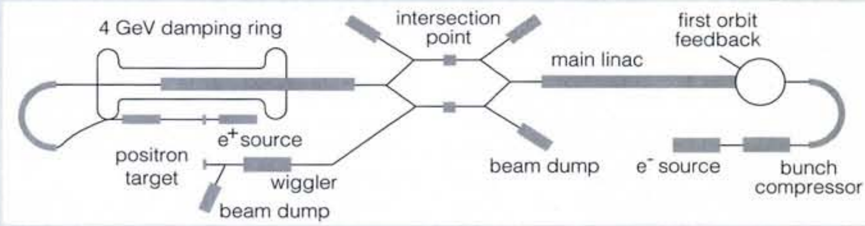
• **LHC $p\bar{p}$ collider**: will start operation at CERN in 2004 with an energy of at least 10 TeV, but hopefully already with the final energy of 14 TeV (C.H. Llewellyn-Smith). The luminosity is expected to rise quickly within a few years to the design value (10^{34} cm^{-2} s^{-1}).

The ATLAS and CMS general-purpose detectors will search for Higgs particles, supersymmetric matter and many other novel phenomena. The high particle flux requires many new ideas for building these detectors (B. Dolgoshein). A dedicated LHC-B experiment would give a 10-fold increase in sensitivity to CP-violation in the B sector. Operating LHC in the heavy-ion mode may give final proof for the formation of a quark-gluon plasma at high temperatures in QCD (I. Tserruya). The ALICE detector will look for an ensemble of phenomena that are expected to signal the transition from the QCD confinement phase to the plasma phase. Finally, high-energy electron-proton processes may eventually be studied by colliding the LHC proton beam with the LEP electron beam.

• **e^+e^- linear colliders**: design studies for the construction of e^+e^- linear colliders are underway at several laboratories. They are aiming at proposals within three to four years for the construction of such machines (D. Burke). Several technologies can be used including, among others, high-gradient conventional (KEK/SLAC) and superconducting techniques (TESLA, international collaboration based at DESY; see insert). Such a collider would be realised in several phases, with a total energy of 500 GeV in the first phase to cover top physics, the intermediate-mass Higgs sector and medium-energy supersymmetry. By increasing the power of klystrons and RF cavities, the energy could then be raised gradually to 1 TeV. In the last phase, which may require a longer accelerator, a final energy of 1.5 to 2 TeV is expected, allowing the detailed study of the high-mass Higgs sector, the complete supersymmetric particle spectrum and the underlying structure of this theory, possible strong interactions of W bosons at high energy, *etc.*

Physics programmes require a luminosity of several 10^{33} cm^{-2} s^{-1} at 500 GeV, increasing quadratically with the energy. This level can only be reached by colliding electron and positron bunches of very small transverse size. A bunch size of less than 60 nm has already been reached at SLAC's Final Focus Test Bed. This is sufficient for operating a collider based on low-frequency machines like TESLA, while high-frequency machines require another order of magnitude reduction of the transverse size. Besides the e^+e^--collision mode, the accelerator can be operated as an e^-e^-, $\gamma\gamma$ or $e^-\gamma$ collider. Applications of high-energy linear colliders outside particle physics are also under study (see insert).

Novel Applications of High-Energy Linear Colliders



A schematic illustration of the TESLA e^+e^- linear collider. A future linear collider not only offers operation as a e^+e^- collider but may also serve important areas of research other than particle physics. The possibility of using the linear electron accelerator part of a future e^+e^- collider for nuclear physics experiments is being discussed by the Nuclear Physics European Coordination Committee (NuPECC). Another exciting application for which the superconducting RF cavity approach being developed by DESY's TESLA collaboration, is particularly suited, involves the construction of a very powerful free-electron laser. High-energy electron bunches are passed through a magnetic undulator to generate coherent photon beams will allow microscopic resolutions at the sub-Ångstrom level. Single atoms deep inside molecules or crystals could be observed, and many novel applications suggest themselves in areas ranging from materials sciences to biology.