in the past. This effect is ascribed to *dark energy* which accelerates the expansion.

Dark matter and dark energy are just convenient names used by astronomers when speaking of the large velocities seen in the motion of visible matter in the universe. It is the great challenge for present astronomy and physics to understand the *true physical nature* of dark matter and dark energy.

Finally some conclusions. The entire universe has *probably a finite volume*, being slightly curved through the presence of visible and dark matter, and of dark energy. The universe will *probably expand forever* and will do so *faster and faster* because of the presence of dark energy.

Acknowledgements

The author is very grateful to Ulrich Bastian, Leif Hansen, Aase Høg, Bo Jacoby, Igor Novikov, and Kristian Pedersen for discussions and many useful comments on style and content of previous versions of this article.

About the author

Erik Høg, Copenhagen University Observatory, has been involved in the European efforts in space astrometry since the earliest studies in the 1970s. In 1999 he received "The Director of Science Medal, *for outstanding contribution to the science programme*" of the European Space Agency

Bibliography

Dreyer, J.L.E. 1953, *A History of Astronomy from Thales to Kepler*, Dover Publications, Inc.

Pedersen, Olaf 1992, *The Book of Nature*, Vatican Observatory Publications

Pedersen, Olaf 1993, *Early Physics and Astronomy, A Historical Introduction*, Cambridge University Press

Stephenson, Bruce 1994, *The Music of the Heavens, Kepler's Harmonic Astronomy*, Princeton University Press

Van Helden, Albert 1985, *Measuring the Universe, Cosmic Dimensions from Aristarchus to Halley*, The University of Chicago Press

WMAP 2003, *Wilkinson Microwave Anisotropy Probe*, http://map.gsfc.nasa.gov

Particle physics from the Earth and from the sky

Daniel Treille, CERN, Geneva, Switzerland

Recent results in particle physics offer a good balance between the news "coming from the Earth", namely results from the various colliders, and news "coming from the sky", concerning solar and atmospheric neutrinos, astroparticle programmes, searches for dark matter, cosmic microwave background (CMB), cosmology, etc.

In the light of this information, gathered in particular from the 2003 Summer Conferences (EPS in Aachen, Lepton-Photon in Fermilab), an account of the status of our field is given. It will appear in two parts, corresponding approximately to the division between the Earth and the sky. The first one covers the Electroweak Theory, ideas beyond the Standard Model, Quantum Chromodynamics (QCD), Beauty and heavy ion physics.

Electroweak Theory

The Electroweak Theory (EWT), together with Quantum Chromodynamics (QCD), modern version of the strong interaction, builds the Standard Model (SM) of Particle Physics [1]. The EWT is a fully computable theory. All EW measurable quantities, called "observables", as for instance the properties of the various Z^0 decay modes, can be predicted with great accuracy and compared to measurements. Each of them allows in particular to determine the Weak Mixing Angle, i.e. the parameter of the 2×2 unitary matrix which transforms the two abstract neutral bosons of the EWT into the two neutral physical states, photon and Z^0. The internal consistency of the EWT implies that all values of the Weak Mixing Angle obtained should coincide. In terms of the standard Big Bang model, the breaking of the EW symmetry, namely the time at which known elementary particles got their mass, presumably through the Higgs mechanism*, occured at about 10^{-11}s after the Big Bang.

The e^+e^- high-energy colliders LEP at CERN and SLC (SLAC Linear Collider) have delivered their quasi-final results. Their contribution to the validation of the EWT has been invaluable. However, besides celebrating this great success, it is worth considering the few areas of obscurity left and discussing how one can hope to improve the precision measurements in the future.

It is amusing to remember what was expected from LEP, for instance at the time of the meeting held in Aachen, in the same place as the 2003 EPS Conference, in 1986. In nearly all domains the quality and accuracy of the final results of Z^0 and $W^\pm$ physics* have been much better than foreseen, in particular due to the progress made during the last decade on detectors (microvertex devices allowing a clean tag of beauty particles, by revealing their long lifetime (flight path) of about 1 picosecond (few mm), luminometers providing a very accurate absolute normalization of the various processes, etc), on methods (such as how to determine the number of neutrinos from the Z^0 properties, ...) and on the mastering of theoretical calculations.

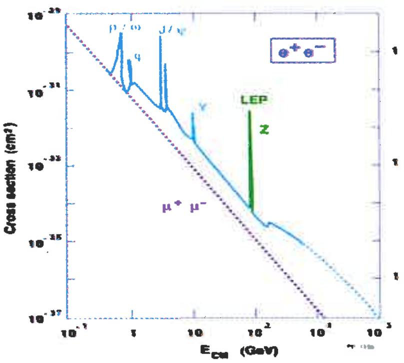
Figure 1 and its legend recall what is the scenery of e^+e^- collisions. Sitting on the huge Z^0 resonance, LEP recorded about 18 millions Z^0 events and SLC about half a million only, but with the strong bonus of a large polarization of the incident electrons and better conditions for beauty tagging. From this large amount of data, many observables were measured, often with an accuracy of one per mil or better. Later, LEP200 measured e^+e^- interactions at higher center-of-mass energies, up to 206 GeV: it recorded about 40K W pair events and set quite strong lower mass limits on the Higgs boson and Supersymmetric Particles.

If one summarizes the whole set of available EW measurements (LEP/SLC and others) by performing a global fit [2], one finds that the SM accounts for the data in a satisfactory but nevertheless imperfect way: the probability of the fit is only 4.5%.

The measurement lying furthest from the average is that of the weak mixing angle by the NuTeV experiment in Fermilab [3], which scatters neutrinos and antineutrinos on target nuclei. Before invoking new physics, the possible "standard" causes of such a disagreement were carefully investigated: unexpected features of the quark distribution inside nucleons are the most likely culprits. If this measurement is excluded from the fit, the probability becomes 27.5%, a reassuring number.

The other noticeable disagreement concerns the two most precise electroweak measurements, namely the spin asymmetry A_{LR} at SLC, i.e. the relative change of rate of Z^0 production in e^+e^- collisions

Article available at http://www.europhysicsnews.org or http://dx.doi.org/10.1051/epn:2004304



▲ Fig. 1: The scenery of e^+e^- collisions as a function of energy. LEP1 was "sitting" on the huge Z^0 resonance. Beauty factories exploit the Υ(4S) resonance located in the family of Υ beauty-antibeauty resonances near 10 GeV. The J/ψ is the lowest charm quark-antiquark bound state near 3 GeV. (*Fig. courtesy U. Almaldi.*)

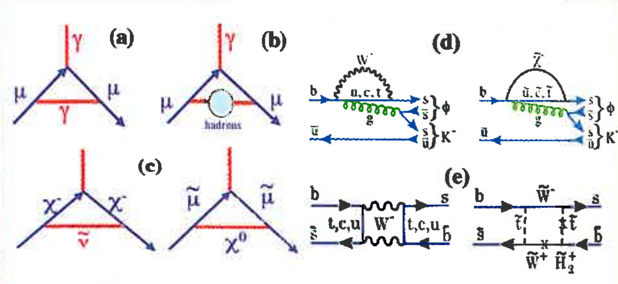
when one flips the electron helicity (i.e. the component of its spin along the direction of motion), and the forward-backward asymmetry of beauty production on the Z^0 at LEP, $A_{FB}{}^b$, i.e. the manifestation of the violation of particle-antiparticle conjugation C (and of parity P) in $e^+e^- \rightarrow Z^0 \rightarrow$beauty-antibeauty, which give values of the weak mixing angle differing by 2.7 standard deviation with no hint of an explanation, neither instrumental nor theoretical.

An ambiguity which is not yet removed concerns the theoretical interpretation of the muon g-2 measurement [4] obtained in Brookhaven with an experimental accuracy of ~ 5 10^{-7}. The slight departure of the muon g factor, relating the magnetic moment to the spin, from its canonical value of 2 (i.e. the value given by the Dirac equation describing pointlike relativistic fermions) is due to the fact that the electromagnetic interaction of a muon and a photon is perturbed by the exchange of one (or more) additional photon(s) (figure 2a). After correction of a small error, the theoretical frame is sound. However, the tiny hadronic contribution (figure 2b) to this quantity expected in the SM, which reflects the probability that the additional photon fluctuates into a light hadronic system, differs, depending on the way it is estimated. To obtain its value one has to resort to subsidiary experimental data. Using for this purpose the hadronic decays of the tau* (plus a set of assumptions) leads to a relatively fair agreement between theory and experiment (the latter larger than the former by 1.4 σ. However using hadronic production in low energy e^+e^- collisions leads to an excess of experiment over expectation which according to the most recent analyses [5] amounts to 2.7 σ. The situation may still change with the advent of data from the B Factories in SLAC and in KEK (Japan) and from KLOE in Frascati. This residual discrepancy is all the more unfortunate given that the g-2 observable is potentially a powerful telltale sign of new physics, in particular Supersymmetry [1], since new particles can contribute to the perturbation as virtual states (figure 2c). While a significant excess of the measured value over theory could point to an appetizing window for the masses of some supersymmetric particles, good agreement could on the contrary eventually turn into a noticeable constraint on the minimal value of their masses.

A low energy measurement which "returned to the ranks" is that of atomic parity violation (APV). APV [6] occurs because in an atom the electrons and the nucleus interact not only by photon exchange but also by Z^0 (and its possible recurrences at higher mass $Z^{0'}$) exchange. Alkali atoms, having a single outer electron, are the only ones that lead to tractable atomic calculations. Due to recent refinements of some theoretical estimates, there is presently a good agreement between the expectation and the 0.6% accurate measurement on cesium made in Boulder in 1997. The APV measurement does not weight much in the EW fit. However, a remarkable result for such a small sized experiment is that the lower mass limit it sets on a potential Z' (600-800 GeV) is quite competitive with those of LEP or Tevatron. However, to stay so in the face of future LHC data, the APV measurement should reach ~ 1‰ or so. The possibility of a programme using francium, the next alkali atom, much more sensitive but radioactive, is sometimes mentioned.

It is worth underlining here the promises of another set of low energy measurements concerning Electric Dipole Moments (EDM), in particular of the neutron. For particles to have a permanent EDM the forces concerned must violate the invariance under time reversal T (and therefore under CP*), and the SM expectations are out of reach, far below existing and foreseeable limits. But various scenarios beyond the SM may lead to strong enhancements. Very sophisticated methods involving ultra cold neutrons are under study and may bring an improvement of two orders of magnitude on the present neutron EDM upper limit. Limits on the muon EDM, as a by-product of the g-2 measurement, and on the electron EDM, through measurements made on various atoms, in particular Hg, are likely to improve as well. If no positive evidence is found, these limits will in particular become a major constraint for Supersymmetry.

Let us finally quote a potential problem concerning the unitarity of the Cabbibo-Kobayashi-Maskawa (CKM) matrix[7], and more precisely its first row. The CKM matrix gives the relationship between the quarks seen as mass and as flavour eigenstates. Unitarity just means that when one "rotates" from one base to the other the probability has to be conserved. The CKM matrix is a 3x3 unitary matrix, entirely defined in terms of four real parameters. It gives a concise description of all that we know at present about the weak interactions of quarks. The first row of the matrix concerns essentially the u⇔d and the u⇔s (Cabbibo angle) transitions and the fact that their moduli squared do not add exactly to unity could indicate that the value of the Cabibbo angle is slightly underestimated. Actually, after including recent results, like the data of E865, at Brookhaven Alternate Gradient Synchrotron, on the decay $K \rightarrow \pi e \nu$, the remaining deficit relative to unity amounts only to ~1.8 σ and is not a big worry



▲ Fig. 2: Examples of loop diagrams
(a) The lowest order diagram contributing to g-2.
(b) The hadronic contribution to g-2.
(c) SUSY particles in the loops as a possible contribution to g-2.
(d) Penguin diagrams (SM and SUSY) contributing to one B decay mode. The ressemblance to a penguin is a matter of taste.
(e) The loop diagrams responsible for beauty-antibeauty oscillation.

The message from LEP

In spite of the few open questions quoted above, the first message of LEP/SLC is therefore the quality of the agreement of the SM, or more exactly of its neutral current (i.e. Z^0) sector with data. Any theory attempting to go beyond the SM (see below) must therefore mimic it closely and offer very similar predictions of the various EW observables. Most interestingly, because of the extreme accuracy of the measurements, the agreement has been demonstrated at the quantum loop-level. Before expanding this last point, let us remark that the situation is less precise for the charged current sector of the SM. As for its scalar (Higgs or equivalent) sector, still largely untested, it will need the CERN Large Hadron Collider (LHC) to be explored.

In a given process, particles, even if they are too heavy to be produced as "real" particles, can nevertheless intervene as "virtual" states and slightly influence the process. Figure 2 presents a variety of such loop diagrams. Accurate measurements on a process can thus yield information on these virtual particles. At LEP the "missing pieces" of the SM were the top quark, too heavy to be pair produced but whose existence was never in doubt, and the Higgs boson, not yet observed directly at present. As G.Altarelli put it, LEP physicists were in the situation of a bush hunter, his ear to the ground, trying to hear the pace of a tiger (the Higgs) while an elephant (the top) was rampaging around.

It is well known that Z^0 physics at LEP gave a rather accurate "indirect" estimate of the top quark mass (presently $171.5^{+11.9}_{-9.4}$ GeV), in very good agreement with the value that later the Tevatron measured "directly" by producing the top, presently 174.3 ± 5.1 GeV (figure 3a). Once the "large" effect of the elephant-top on the relevant electroweak observables was well under control, one could search for the tiny effect expected from the tiger-Higgs boson, which in the SM is assumed to be the only missing piece.

Ignoring the disagreements quoted above, essentially that existing between A_{LR} and A_{FB}^b, and considering only the mean values, one can thus deduce, in the strict frame of the SM, the preferred mass region for the Higgs boson (remembering that the information concerns the logarithm of its mass):

$M_h = 91^{+58}_{-37}$ GeV, and $m_h < 219$ GeV at 95% CL (figure 3b).

Taken alone, the A_{LR} observable would give for the boson mass a range between about 15 and 80 GeV, while the observable A_{FB}^b would give it between about 200 and 700 GeV. The W mass value (the world average is 80.426 ± 0.034 GeV) indicates also a Higgs mass region on the low side.

Let us remark that the SLC measurement seems to contradict the lower limit of 114.2 GeV set on the Higgs mass by the direct Higgs search* at LEP200, as well as the indication for an effect near 115 GeV which is presently at the 1.7 σ level. However the problem would be less acute if the top mass was a few GeV, say one standard deviation, higher than one states presently, a possibility that a reanalysis by the Tevatron [8] experiment D0 of its Run I data might suggest. If it were so the limit on m_h would be raised from 219 to ~280 GeV. For this reason, and many other good ones, a precise determination of the top mass is "devoutly to be wished". The Tevatron will reduce the uncertainty to ~2.5-3 GeV, per experiment and with an integrated luminosity of $2 fb^{-1}$ (i.e. providing 2 events for a process having a cross-section of a femtobarn, i.e. 10^{-39} cm^2). The LHC should reach an uncertainty of ~1-2 GeV, while a Linear Collider will do about ten times better.

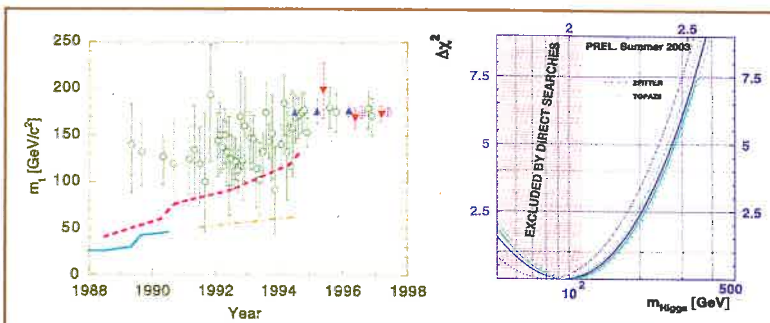
The other key message of LEP/SLC is thus the indication of a light Higgs boson. Is this the truth, or could it be an illusion? Clearly if one quits the frame of the SM by introducing new physics, it is quite possible to invent "conspiracies", i.e. interference of amplitudes of different processes, by which a heavy Higgs boson has its effect on electroweak observables compensated by something else, like new particles or extradimensions of space. However, these solutions are more or less artificial: it is thus reasonable to focus on the simplest scenario and to test in priority the assumption of a light boson by obtaining direct evidence for it.

Beyond the standard model

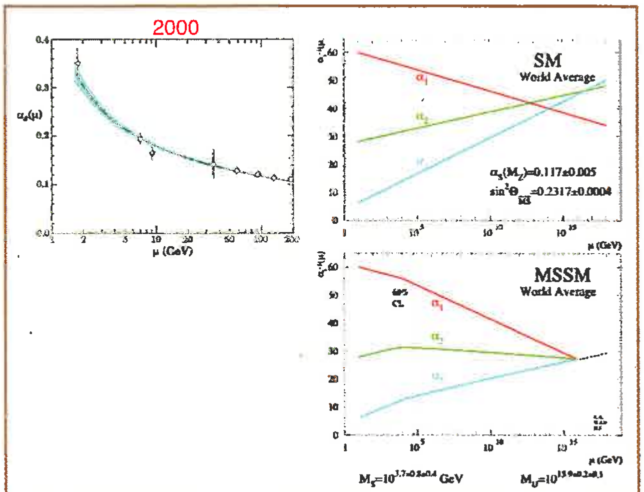
Exhaustive reviews of the direct searches for new physics at colliders, updating the existing limits, have been given. Unfortunately, besides the D_{sJ} particles* found by the Beauty Factories [9] and the Pentaquarks [10]*, no discovery has showed up at the high-energy frontier.

Nevertheless the motivations pushing to go beyond the SM are still present and more compelling than ever. The main one is the Hierarchy Problem that can be stated as follows. Gravity exists and defines a very high energy scale, the Planck scale* (~10^{19} GeV) at which the gravitational force becomes strong. In the SM all other masses, in particular the Higgs mass, should be irredeemably pulled towards this high scale by the radiative effects already quoted. Something more is needed to guarantee the stability of low-mass scales. Traditionally the routes leading beyond the SM either call for new levels of structure and/or new forces, as Technicolour (TC) [11] does, or involve more symmetry among the players of the theory, as in the case of Supersymmetry (SUSY) [1,12], in which SM particles and their "superpartners", i.e. the new particles of opposite spin-statistics (a boson as partner of a SM fermion and vice-versa) that SUSY introduces, conspire to solve the Hierarchy Problem.

TC breaks the EW symmetry in an appealing way, very reminiscent of the way the electromagnetic one is broken by supraconductivity (which, crudely speaking, gives a mass to the photon). However TC meets serious problems in passing the tests of electroweak measurements, because it harms too much the predictions. On the other hand SUSY, which has a more discrete effect in this respect, keeps its eminent merits and remains the most frequented and even crowded route. In this context another important result [13] derived from the LEP data is the quasi-perfect convergence near 10^{16} GeV of the electromagnetic, weak and strong coupling "constants" in the frame of SUSY, the so-called Supersymmetric Grand Unification (SGU) (figure 4b). This "running" of coupling constants with the energy scale is another consequence of the quantum nature of the theory: it is due to the effect of virtual particles appearing in the loop diagrams. The presence of



▲ Fig. 3: *Left:* The top mass from indirect LEP measurements (open circles) and from the direct Tevatron measurements (colour triangles).
Right: The preferred region for the SM Higgs mass (near the bottom of the χ^2 curve) deduced from electroweak measurements.



▲ **Fig. 4:** *Left*: The evolution of the strong coupling constant with the energy scale. *Right*: The convergence of the SM coupling constants, approximate in the SM (upper figure), exact in SUSY (lower figure). One should distinguish this smooth running of couplings from the evolution of the intensity of the interaction with the energy scale, depending on the mass of the exchanged boson.

superpartners explains why the "running speed" is different in SUSY and in the SM.

SUSY is certainly a broken symmetry as no partner of known particles with opposite spin-parity exists with the same mass. These partners are assumed to be heavy, but not too much (few hundred GeV to few TeV) as otherwise SUSY would no longer cure the hierarchy problem. Furthermore the convergence of couplings quoted above requires that the superpartners appear at relatively low mass, say 1 to 10 TeV.

With the diversity of the possible SUSY breaking mechanisms*, this theory presents a complex phenomenology with many different possible mass spectra for the supersymmetric particles. Its minimal version however offers a golden test: it predicts a very light Higgs boson, i.e. <130 GeV in full generality (for m_{top}=175 GeV), and <126 GeV once SUSY is broken, as it has to be, and in particular in all versions of Supergravity[14] presently considered as the reference points for future searches. This is a mass window that LEP, with 80 additional (i.e. 30% more) superconducting accelerating cavities and the magnificent performances of the accelerating field finally reached, could have explored and which stays as the first objective of future programmes. If SUSY represents the truth, the LHC, or maybe, with much luck and considerable improvements, the Tevatron, will discover it by observing, besides the light Higgs boson, some supersymmetric particles. But a Linear Collider will be needed to complete its metrology in the mass domain it will give access to.

However, quite interesting new roads have appeared in recent years.

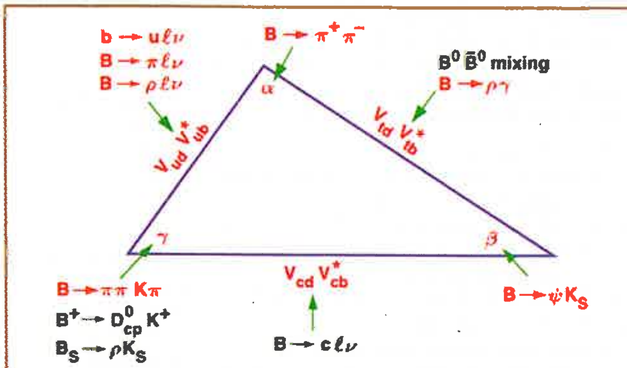
One, the Little Higgs scenario, leaving aside the Big Hierarchy problem (the one we introduced above) for the time being, tackles first the Small Hierarchy one, namely the fact that LEP announces a light Higgs boson while it pushes beyond several TeV the scale of any new physics (except SUSY which can still be "behind the door"): again the Higgs mass should be pulled to this high scale and the fact that it is not calls for efficient cancellation mechanisms to be at work. Keen to do without SUSY, this model, by an algebraic tour de force, manages to realize the compensations needed by inventing new particles, a Z', a W', a new quark, etc., at the mass scale of few TeV. The existing EW measurements put however the model under a severe tension. True or not, this theory has the merit to reinvigorate the LHC phenomenology by introducing new particles into the game and in particular insisting on quantitative tests concerning their decay modes.

The other new route postulates the existence, so far uncontradicted, of extra dimensions of space (ED), large enough to generate visible effects at future experiments. The general idea of an ED, due to Kaluza and Klein, is rather old (around 1919). The Superstring Theory requires EDs since it is consistent only in 9 or 10 spatial dimensions. For long, however, these EDs were thought to be "curled up" (compactified) at the Planck scale, until it was realized that things could be different. Several versions are presently put forward [15]. With substantial differences between them, they all predict Kaluza-Klein recurrences of the graviton or some of the SM particles, i.e. new states which can be produced if their mass is at the TeV scale or below, or that may change the rate of SM processes through their effect as virtual particles.

Such an eventuality, which has to be fully explored, would be an extraordinary chance for LHC and its prospective study also contributes an agreeable diversification of its phenomenology. However, before dreaming too much, it is important to appreciate correctly the existing limits, drawn either from accelerators or from astrophysics. For the ADD scenario, one should also consider the impact of dedicated tests of Newtonian gravity at small scale [16], which, besides micro-mechanical experiments, use sophisticated methods involving Ultra Cold Neutrons and maybe in the future Bose-Einstein Condensates, which build interesting bridges between particle physics and other sectors of physics.

Moreover, it is still a rather natural attitude to assume that extra dimensions, if they play a role, would do so at much higher energy scales, for instance the one of Grand Unification (GU). Many studies follow that path and analyse what one or more extra dimensions bring to the already very successful theories of Supersymmetric GU. This complements the class of studies which, to the symmetry group of GU, add other ones (a new U(1), a new SU(3), etc.) whose role is to deal in particular with the mystery of the triplication of families (i.e. the existence of the electron, muon and tau families).

The hope is that these attempts, performed from "bottom to top", i.e. from low towards high energies, and those, from "top to bottom", of Superstrings [17] will meet one day and guide each other.



▲ **Fig. 5:** The "d-b" Unitary Triangle. Adding to zero three complex numbers like $V_{ud}V_{ub}^*$, etc. naturally lead to draw a triangle. We indicate which B decay modes give access to its angles and sides. V_{ij} is the element of the CKM matrix connecting the flavour eigenstate quark i to the mass eigenstate quark j.

Quantum Chromodynamics (QCD)

QCD is the modern version of the strong interaction. The numerous experimental successes of QCD [18], besides its natural simplicity (a single parameter, the strong coupling "constant", if one forgets the quark masses), make it an exemplary theory. Most of the sectors of particle physics feed QCD and need it. QCD is both turned towards the domain of very high energies, where it exhibits "asymptotic freedom"*, and towards the low energy hadronic world, where its strong coupling at large distance leads to confinement of quarks and gluons. This evolution with the energy scale has been very clearly demonstrated in the past decade (figure 4a). All QCD aspects, from perturbative to non-perturbative, are actively studied and essential to extract correctly the physics of other sectors, EW measurements, beauty physics, heavy ions, etc. Nevertheless it is clear that all of them still need much progress, in particular to meet the requirements of future experimental programmes.

The QCD lattice simulations* built upon the basic principles of the theory, have become fundamental tools, well established and vital to many fields. The progress achieved is greatly due to that of the computing means, but also to the improvements of the algorithms and methods.

One of the few dark points concerning QCD seemed to be an excess of the production of beauty quark-antiquark pairs in various types of collisions compared to the predictions of the theory. However, new data and refined theoretical expectations show that the problem seems to be fading away.

The values of the single parameter of QCD, its coupling constant, extrapolated to the energy scale of the Z^0 mass, $\alpha_S(M_Z)$, obtained from very different sectors, are now well coherent. The uncertainty on this quantity, after having considerably decreased, is now stabilizing. Its absolute value, 0.118 ± 0.003, is in very good agreement with what is required by the most elaborate versions of Supersymmetric Grand Unification, including the effects appearing at the Grand Unification scale.

The nucleon structure and the distributions of the quarks and gluons inside it are better and better known and understood, especially thanks to HERA and in particular at the very small values of the fractional momentum x carried by the constituents, a crucial region since it will govern the production cross-sections at LHC.

However, when the spin intervenes, our understanding of nucleons is still poor. It is not yet clear how the spin of a nucleon is shared between its constituents. One is thus expecting from future polarization programs [19], in particular polarized proton-proton collisions in the RHIC collider at Brookhaven, a number of clarifications, in particular concerning the gluon helicity distribution, by measuring processes at transverse momenta large enough for the perturbative and computable version of QCD to apply.

It is important to underline that much remains to be done in matters of QCD if one wants to enter the CERN Large Hadron Collider (LHC) [20] era in optimal conditions, namely with a good mastery of the SM prediction for the many different topologies that searches will explore. Indeed before claiming for a discovery one

LEXICON

Asymptotic Freedom, Infrared Slavery: picturesque ways to express the consequences of the running of the strong coupling with the energy scale. At large energies (small distances) the coupling goes asymptotically to zero and the quarks inside the nucleon react as free particles when they are hit. But, at large separations (low energy or "infrared" limit) the coupling becomes strong and its effect guarantees the confinement of quarks and gluons.

CKM Matrix: in the SM the quark mass eigenstates are not the same as the weak eigenstates, and the matrix relating these bases was defined for six quarks, and given an explicit parameterization by Kobayashi and Maskawa, generalizing the four quark case described by a single parameter, the Cabibbo angle. The mixing is expressed in terms of a 3×3 unitary matrix operating on the charge −1/3 quark mass eigenstates d, s and b. The elements are the V_{ij} quoted in the text. Their values are determined by the weak decays of the relevant quarks (i.e. V_{cb} from beauty semileptonic decay into charm) and by neutrino scattering.

CP: symmetries represent a crucial aspect of particle physics. The invariance of the physical law under spatial mirror symmetry P is maximally violated by the Weak Interaction. The CP symmetry, product of P and of the charge conjugation C which interchanges particle and antiparticle, is also violated by the Weak Interaction, a fact which is a decisive one concerning our own existence, i.e. the matter-antimatter asymmetry in the Universe. Since the CPT symmetry is a sacred one in our present vision of the physical world (and is experimentally found to be exact), the time reversal symmetry T has to be violated as well by the Weak Interaction (and is indeed found to be so).

D_{sJ} Particles: these are narrow states of masses 2317 and 2460 MeV, discovered at the B-factories. They are likely to be P-wave levels of the D_S meson system (charmed and strange) but the surprise came from their mass, lower than expected.

Higgs Mechanism: the hypothetical mechanism by which the elementary particles and in particular the Z^0 and W get their mass by interacting with a field, the Higgs field. This is analogous to the case of supraconductivity: in a supraconductor one can say that by interacting with the field of Cooper pairs the photon gets a mass m and cannot penetrate the supraconductor by more than m^{-1} (Meissner effect). But this is just an analogy. In the SM the Higgs boson is an elementary Lorentz-scalar field. To fulfil its role, the Higgs field must be a complex doublet in an abstract space called the Weak Isospace.

Higgs Search: the direct search for the Higgs boson at LEP looked for the boson production in association with a Z^0 boson, $e^+e^- \to h^0Z^0$. The mass reach at LEP2 was therefore approximately the ultimate available center-of-mass energy minus the Z mass (i.e. 115 GeV for the 206 GeV of LEP200). A Higgs boson of such masses decays mostly into beauty-antibeauty, hence the vital role of the b-tagging technique in this search.

Lattice QCD: at the scale of the hadronic world, say 1 GeV, the QCD coupling constant is of order unity and perturbative methods fail. Lattice QCD which is QCD formulated on a discrete Euclidian space time grid provides a non-perturbative tool for calculating the hadronic spectrum, etc, from first principles. The discreteness of the grid acts as a non-perturbative regularization scheme.

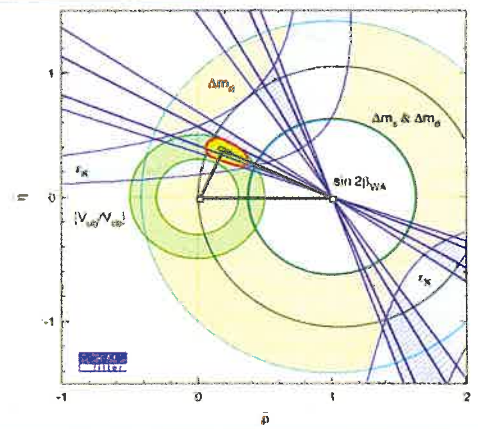
Pentaquarks: the present interpretation of newly discovered light narrow baryon resonances with a manifestly non-standard content of quarks. Diquark states may be involved in building them. This discovery is very interesting and under active study but probably does not call for any revolutionary revision of QCD.

Planck Scale: the energy scale at which the gravitational interaction between individual particles, negligible at present scales, becomes as strong as the other (unified) interactions. At that scale the theory must then incorporate gravitation, neglected in the SM. The problem is that, until the advent of String Theory, the theory of gravity, Einstein's General relativity, and Quantum Theory were not compatible.

SUSY Breaking Mechanisms: one does not know exactly how this occurs, but one can "parameterize this ignorance" within a few scenarios. The general idea is that the breaking occurs at high energy scale in a "hidden sector," and that the breaking is transmitted to the observable world by a "messenger." In the much studied case of SUGRA, the messenger is simply gravity.

Tau: the tau, discovered in 1974, is the charged lepton of the third (and last) family. Its mass is 1.777 GeV and its lifetime 0.291 ps. LEP and other programmes have shown that, besides its heaviness, the tau is "standard" and a mere recurrence of the electron and muon. Being standard it can be considered as a "laboratory": for instance its decay modes into light hadrons are a precious source of information on low energy hadronic physics.

Z^0, $W^\pm$: the neutral and charged quanta of the Weak Interaction. Discovered at CERN in 1983. Studied in detail at LEP 1 and 2, respectively. Masses: 91.1875 (21) and 80.426 (34) GeV, respectively. The Z mass was so accurately measured at LEP ($2.3\ 10^{-5}$) that it became one of the three basic entries of the SM, from which all other quantities are computable at first order. The Z and W decay into fermion-antifermion pairs, with branching ratios accurately predicted by the SM.



▲ Fig. 6: The tip (yellow) of the Unitary Triangle as determined from LEP, K physics, etc. The blue cones give the value of its angle β directly measured at B Factories.

should be confident with the estimate of the SM background. This remark is particularly true for the indispensable Monte Carlo programs needed to simulate the expected observations.

Heavy flavours

We recall that, in the jargon of particle physics, this corresponds to the physics of heavy quarks of the second, strangeness and charm, and especially third (beauty and top) generations. The heaviness of these quarks offers a simplified approach to the spectroscopy of hadrons containing them. Concerning the few symbols used below, B denotes a beauty meson (a beauty quark and a light antiquark, or vice-versa), while B_S is a meson containing beauty and strangeness. We recall that the ϕ is a narrow strange-antistrange bound state, while the J/ψ is the equivalent for charm. K_S (K_L) is the short (long)-lived neutral strange meson.

The progress of heavy flavour physics, especially of beauty physics is impressive. One must first underline the remarkable performances of the e^+e^- Beauty Factories, PEPB (detector BaBaR) at SLAC, and in particular KEKB (detector BELLE) in Japan, the first machine to deliver a luminosity of 10^{34} $cm^{-2}s^{-1}$ (the luminosity, multiplied by the cross-section of a given process, gives the rate of corresponding events). These colliders sit on the Upsilon(4S) resonance shown in figure 1, decaying into beauty meson-antimeson pairs.

In the study of the CKM matrix* defined above, the highlight is the determination of the so-called Unitarity Triangle [7]. In the SM, the unitarity of the CKM matrix, expressed in a graphical way, leads to the figure of a triangle, one for each of its rows and columns. This is because one of its four parameters is a non-zero phase, so that the CKM matrix is complex. Among the 6 unitarity relations, the "d-b" one, $V_{ud}V_{ub}^*+V_{cd}V_{cb}^*+V_{td}V_{tb}^*=0$, is particularly interesting because the three sides of the corresponding triangle (figure 5) have similar sizes. The length of its sides and its angles can be extracted from various measurements in the field of heavy flavour physics, and in particular of beauty physics. With enough of these measurements one can build this triangle in different ways: thus one can check that the result is unique, and, first of all, that one is indeed dealing with a triangle and not a more complicated situation that theories beyond the SM may announce.

It is clear that a very successful first round of experiments has been accomplished [21,7]. The direct measurement at Beauty Factories of one of the angles (called β or ϕ_1, depending on the continent…) via the theoretically very clean mode $B \rightarrow J/\psi\, K_S$ is in excellent agreement with the determination of the tip of the Triangle through the measurement of its sides made during the past decade at LEP and elsewhere, from B and K physics results (figure 6). This is another major success of the SM. However, revealing new phenomena through B physics calls for a still much better accuracy.

The roadmap, concerning the second round of measurements, defines an ambitious programme, involving many different decay modes of beauty and extremely demanding from the experimental (luminosity needed, control of systematics, etc.) as well as from the theory side: the hadronic uncertainties must be controlled, since the b quark under study is irredeemably confined inside beauty mesons, and one must obtain a reliable estimate of the contribution from loop diagrams complicating the process, the famous "penguins" (figure 2d), which represent both an embarrassing "pollution" and a promise, since it is in their loops that new physics, like Supersymmetry, could appear.

The kaon rare modes [22] also allow one to build another Unitarity Triangle through $K^+ \rightarrow \pi^+\nu\nu$, $K_L \rightarrow \mu\mu$, $K_L \rightarrow \pi^0\nu\nu$, $\pi^0e^+e^-$, etc. Several recent results and the promise offered by future experiments like CKM in Fermilab go in the right direction.

Finally, the muon rare modes are equally promising and the expected performances very impressive indeed: $\mu \rightarrow e\gamma$ with a sensitivity per event of 10^{-14} at PSI, conversion μe in nuclei at 2 10^{-17} in MECO at BNL.

Heavy ions

In the Big Bang model the transition from free quarks to hadrons occurred at a few microseconds. High energy heavy ions collisions are under study, to find evidence for the reverse step, i.e. the fusion of nucleons into a quark–gluon plasma (quagma) [23].

Fresh results are coming from the RHIC collider in Brookhaven, concerning Au-Au collisions up to 200 A GeV and have brought a few "surprises" concerning the properties of the hot and dense medium thus produced. The quote expresses the fact that some of them were actually predicted long ago.

The chemical freeze-out (at which the identity of the particles is fixed) occurs at 175 MeV (the Hagedorn temperature [24]), as at the CERN SPS, but the medium is now nearly baryon-free. The kinetic freeze-out (at which their kinematics is fixed) happens near 100 MeV. The medium undergoes an explosive expansion at a speed of 0.6 c, and shows a strong anisotropy of transverse flux, suggesting a hydrodynamic expansion due to very strong pressure gradients developing early in the history of the collision. Remarkably, the collision zone is opaque to fast quarks and gluons and this has a strong impact on hard phenomena: suppression of hadrons produced at large p_T, jet "quenching", i.e. the decrease of their rate of production, phenomena which are not observed in control collisions D-Au. Several questions concerning the Hanbury-Brown-Twiss (HBT) correlations (a concept borrowed from astronomy), e.g. the size of the collision zone, or the fate of charm in this opaque medium, etc. have still to be clarified.

However the most prominent signatures which could reveal a quark-gluon plasma are not yet available from RHIC and it is from the CERN Super Proton Synchrotron that results are still coming. In particular, the experiment NA45 confirms that the excess of low mass e^+e^- pairs, m_{ee}>0.2 GeV, implies a modification of the ρ resonance in the dense medium, probably linked to its baryonic density. The suppression of the production of the J/ψ, the lowest bound state of charm and anticharm, which could signal its fusion in the quagma [25], is confirmed by the analyses of NA50 and keeps all its interest. Unfortunately no unique prediction of this effect exists for RHIC and LHC. Data are needed: the next ones should come from PHENIX at RHIC and from NA60 at the CERN SPS.

Acknowledgements

I would like to thank several colleagues for their reading and suggestions, in particular L. Pape, P. Janot, R. Barate and I. Timmermans.

About the author

Daniel Treille is a senior physicist at CERN and a former spokesman of the DELPHI experiment.

References

[1] G. Kane, in *Scientific American*, June 2003, for a brief reminder of the SM and Supersymmetry Basics can be found in H. Georgi, *Scientific American*, April 80, p 104, G. t'Hooft, ibid., June 80, p 104

[2] All EW results are those provided by the LEP EW Group

[3] *CERN Courier*, Jan-Feb 02, article 6, p7

[4] F.J.M. Farley, *Europhysics News*, (2001) Vol. 32 No.5, *CERN Courier* Jan-Feb. 2004, article 2. The last g-2 result is from hep-ex/0401008

[5] M. Davier *et al.*, *Eur.Phys.J.*C 31, 503 (2003), S. Ghozzi and F. Jegerlehner, hep-ex/0310181

[6] M.A. Bouchiat, L. Pottier, *Scientific American*, June 1984

[7] Y. Karyotakis, G. Hamel de Monchenault, *Europhysics News*, (2002) Vol. 33 No.3

[8] J.F. Grivaz, *Europhysics News*, (2003) Vol. 34, No. 1

[9] *CERN Courier*, June 03, article 2, p6, July-Aug 03, article 6, p8, Sept 03, article 6, p9

[10] *CERN Courier*, Sept 03, article 1, p5, and a review by R. Jaffe and F. Wilczek, hep-ph/0401034

[11] K. Lane, Two lectures on Technicolour, hep-ph/0202255

[12] *CERN Courier*, Dec. 2000, article 19
CERN Courier, Jan-Feb. 2002, article 15

[13] *CERN Courier*, March 1991, article 1

[14] *CERN Courier*, Sept 02, article 17, ibid. Sept 03, article 17

[15] P. Binetruy, *Europhysics News*, (2002) Vol.33 No.2
Scientific American, August 2000,
CERN Courier, March 2000, article 6

[16] *CERN Courier*, vol.43, n06, article 15 by I.Antoniadis

[17] B. Greene, The elegant Universe,
H. Haber and G. Kane, Scientific American, April 83, p56,
M. Green, *Scientific American*, Sept. 86, page 44,
CERN Courier, April 99, article 11

[18] F. Wilczek, QCD made simple, *Physics Today*, Aug. 2000,
CERN Courier, April 03, article 15

[19] *CERN Courier*, Jan-Feb. 2002, article 16,
HERA with polarized e: *CERN Courier*, April 03, article 1, p5, HERMES: *CERN Courier*, Nov 01, article 18,
COMPASS: *CERN Courier*, Sept. 99, article 19,
RHIC: *CERN Courier*, April 02, p8, Jan-Feb 03

[20] *CERN Courier*, Jan-Feb 03, article 1, July-Aug 03, article 2

[21] *CERN Courier*, April 01, article 15, may 2002, article 2, see also reference 7

[22] KTeV: *CERN Courier*, April 99, article 2, July-Aug. 2001, article 1,
E787: *CERN Courier*, March 2002, article 2, p4
KLOE: *CERN Courier*, Sept. 99, article 23
NA48: *CERN Courier*, Sept. 99, article 2, July-Aug. 2001, article 1

[23] *Europhysics News*, (2000) Vol. 31, No. 3,
CERN Courier, Oct. 2002, article 13

[24] *CERN Courier*, Sept. 03, article 18

[25] *CERN Courier*, May 1999, article 7

Physics in daily life: Hear, hear...

L.J.F. Hermans, Leiden University, The Netherlands

Even a tiny cricket can make a lot of noise, without having to "refuel" every other minute. It illustrates what we physicists have known all along: Audible sound waves carry very little energy. Or, if you wish: the human ear is pretty sensitive—if the sound waves are in the right frequency range, of course.

How exactly our ears respond to sound waves has been sorted out by our biophysical and medical colleagues, and is illustrated by the familiar isophone plots that many of us remember from the textbooks. They are reproduced here for convenience. Each isophone curve represents sound that seems to be equally loud for the average person.

The figure reminds us that the human ear is not only rather sensitive, but that it also has an astonishingly large range: 12 orders of magnitude around 1 kHz. This is, in a way, a crazy result, if we think of noise pollution. It means that if we experience noise loud enough to reach the threshold of pain, and we assume a $1/r^2$ decay of the sound intensity, we would have to increase the distance from the source by a factor of 10^6 to get rid of the noise. Or, if we stand at 10 m from the source, we would have to walk away some 10 000 km.

Illustration by Wiebke Drenckhan

All this assumes that the attenuation can be neglected, since we have been taught that sound wave propagation is an adiabatic process. Obviously, real life isn't that simple. There are several dissipative terms. For example, think of the irreversible heat leaks between the compressed and the expanded areas: the classical absorption coefficient is proportional to the frequency squared, which makes distant thunder rumble. Then there is attenuation by obstacles. There is the curvature of the earth. There is the curvature of the sound waves themselves, usually away from the earth due to the vertical temperature gradient. Without loss terms like these, forget a solid sleep.

A second feature worth noticing is the shape of the curves. Whereas the pain threshold is relatively flat, the threshold of hearing increases steeply with decreasing frequency. If we turn our audio amplifier from a high to a low volume, we tend to loose the lowest frequencies. The "loudness" control is supposed to compensate for this.

Finally, it is interesting to notice the magnitude of the sound intensity. How much sound energy do we produce when we speak? Let us assume that the listener hears us speak at an average sound level of 60 dB, which corresponds to 10^{-6} W/m^2 as seen from the right-hand vertical scale. Assuming that the listener is at 2 m, the sound energy is smeared out over some 10 m^2. This means that we produce, typically, 10^{-5} W of sound energy when we talk. That is very little indeed. During our whole life, even if we talk day and night and we get to live 100 years, we will not talk more than 10^6 hours. With the above 10^{-5} W, this means a total of 10 Wh. Even with a relatively high price of 50 Eurocents/kWh, this boils down to less than one cent for life-long speaking. Cheap talk, so to speak.