Eur Phys J C **33**, s01, s181–s188 (2004)
Digital Object Identifier (DOI) 10.1140/epjcd/s2003-03-021-9

EPJ C direct
electronic only

Concluding talk

D. Treille

CERN, Geneva, Switzerland

Received: 29 October 2003 / Accepted: 9 December 2003 /

Abstract. I give my personal account of the conference in simple terms.

1 Introduction

Let me summarize in simple terms my own account of the EPS Conference. Although most informative talks were given in the parallel sessions, I will mostly refer to plenary ones. I will also mention a few points which in my opinion could have been emphasized more.

It was a stimulating meeting, well started by several important and sympathetic events:

- a very tonic talk of M.Koshiba, Nobel Prize 2002, on the birth of neutrino astrophysics
- the celebration of QCD, an exemplary gauge theory, exhibiting the remarkable property of asymptotic freedom whose "inventors" , D. Gross, D. Politzer and F. Wilczek, received the EPS Prize of Particle Physics
- the attribution of other EPS prizes to N.Arkani-Hamed (Gribov Medal), G. Unal (Prize of the Young Physicist), R. Landua and N. Tracas (Outreach Prize).

The conference offered a good balance between the news coming from colliders (tail of LEP production, results from Tevatron and HERA progressing towards the second phase of their data taking, heavy ions results coming from RHIC and the SPS, Beauty Factories in full swing, "terrestrial" neutrino physics, progress and prospective of LHC, future e^+e^- colliders, etc.) and results "coming from the sky", concerning the cosmic microwave background (CMB), the searches for dark matter, astroparticle programmes, etc.

2 Electroweak theory

P. Wells, from CERN, presented the quasi-final results of the LEP/SLC era and showed what they have contributed to the electroweak theory; she pointed out the remaining areas of obscurity and discussed how one can expect 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 in 1987. One will notice that in nearly all domains the quality and accuracy of the final results of Z^0 and W physics were much better than foreseen, in particular due to the progress made during the last decade with detectors (microvertices allowing a clean tag of beauty, luminometers providing a very accurate absolute normalization,..), methods (such as how to determine the number of neutrinos) and the mastering of theoretical calculations.

If one summarizes the whole set of available electroweak measurements (LEP/SLC and others) by performing a global fit (G.Quast), one finds that the Standard Model (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 the one of the weak mixing angle by the NuTeV experiment at Fermilab, which scatters neutrinos and antineutrinos on target nuclei. If this measurement is excluded from the fit, the probability becomes 27.5%, a reassuring value. Before invoking new physics, the possible causes of such a disagreement were carefully investigated: an isospin violation in the parton distributions of the target and especially a charge asymmetry concerning the strange sea at large reduced fractional momentum, x, are the most likely culprits.

The other noticeable disagreement concerns unfortunately the two most precise electroweak measurements, namely the spin asymmetry A_{LR} at SLC, i.e.the relative change in rate of Z^0 production when the electron helicity is flipped, and the forward-backward asymmetry of beauty production on the Z^0 at LEP, i.e.the manifestation of the violation of particle-antiparticle conjugation C (and of parity P) in $e^+e^- \to Z^0 \to$beauty-antibeauty, ${A_{FB}}^b$, which give values of the weak mixing angle differing by 2.9σ, 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 obtained in Brookhaven with an experimental accuracy of $\sim 7\ 10^{-7}$. The slight departure of the muon g factor, relating the magnetic moment to the spin, from its canonical Dirac value of 2 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). After correction of a small error the theoretical frame is sound. However, the hadronic contribution 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 leads to a fair agreement between theory and experiment. By contrast, using hadronic production in low energy e^+e^- collisions leads to an excess of experiment over expectation which amounts to $\sim 2.5\sigma$, according to T.Teubner in Aachen, a result that should still evolve, in particular with future hadronic data from e^+e^-, either directly measured (CMD-2, SND, BES, CLEO-c) or obtained through radiative return (KLOE, BABAR, BELLE). It is all the more unfortunate given that the g-2 observable is potentially a powerful telltale sign of new physics, in particular Supersymmetry, since new particles can contribute to the perturbation as virtual states. While a significant excess of the measured value over theory could point to an appetizing window for the masses of some supersymmetric particles, a 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 the one of atomic parity violation (APV). APV occurs because the electrons and nucleus in an atom interact not only by photon exchange but also by Z^0 (and its possible recurrences 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. A remarkable result for such a small sized experiment, the lower mass limit it sets on a potential Z' (600-800 GeV) is quite competitive with those of LEP or the Tevatron. However, to stay so in the face of LHC data, the APV measurement should reach ~ 1 per mille 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 T (and CP) invariance, and the SM expectations are out of reach. 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 to the present upper limit on the neutron's EDM. If no positive evidence is found, this limit will in particular become a major embarrassment for Supersymmetry.

Let us finally quote a potential problem concerning the unitarity of the Cabibbo-Kobayashi-Maskawa (CKM) matrix, and more precisely its first line. The CKM matrix gives the relationship between the quarks seen as mass and as flavour eigenstates. Unitarity simply means that when one rotates from one base to the other the probability has to be conserved. The first line 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 AGS, on the decay $K \to \pi e \nu$, the remaining deficit relative to unity amounts only to $\sim 1.8\sigma$ and is not a big worry. A reanalysis of semileptonic hyperon decays seem also to improve things.

3 The message from LEP

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. Accurate measurements on a process can thus yield information on these virtual particles. 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 fair agreement with the value that later the Tevatron measured "directly" by producing the top. Once the "large" effect of the top on the relevant electroweak observables is well under control, one can search for the tiny one expected from the Higgs boson, which in the SM is assumed to be the only missing piece.

Ignoring the disagreements quoted above, essentially the one 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):

$$m_h = 91\ ^{+58}_{-37}\ \text{GeV, and } m_h \leq 219\ \text{GeV at 95\% CL.}$$

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

We should note that the SLC measurement seems to contradict the lower limit of 114.4 GeV set on the Higgs mass by its direct 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 higher than is currently quoted, a possibility that a reanalysis of D0 Run I data might suggest. 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 2fb^{-1}). The LHC should reach an uncertainty of ~1-2 GeV, while a linear collider will do about ten times better.

The 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", by which a heavy Higgs boson has its effect on electroweak observables compensated by something else, like new particles or extra-dimensions of space. However, these solutions are more or less artificial: it is thus reasonable to focus on the simplest scenario and to test as a priority the assumption of a light boson.

4 Beyond the standard model

A. Quadt gave an exhaustive review of the direct searches for new physics at colliders and updated the existing limits. Unfortunately, besides the D_{sJ} particles found by the Beauty Factories (discussed in Aachen by S.Stone and in the mini-review of F.C.Porter) and the pentaquarks (discussed in a special talk by F.Wilczek), no discovery has shown up at the high energy frontier.

Nevertheless the motivations to go beyond the SM are still present and more compelling than ever. The main one is the hierarchy problem. 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. 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 does, or involve more symmetry among the players of the theory, as in the case of Supersymmetry (SUSY), in which SM particles and their superpartners conspire to solve the hierarchy problem.

Technicolour breaks the EW symmetry in an appealing way, very reminiscent of the way supraconductivity breaks the electromagnetic symmetry. However it meets serious problems in passing the tests of electroweak measurements. Supersymmetry, widely discussed in Aachen, keeps its eminent merits and remains the most frequented and even crowded route. In this context another important result 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 Supersymmetry, the so-called Supersymmetric Grand Unification (SGU).

SUSY is certainly a broken symmetry as no partner of known particles 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.

With the diversity of its possible breaking mechanisms, SUSY presents a complex phenomenology with many different possible mass spectra for the supersymmetric particles. However its minimal version offers a golden test: it predicts a very light Higgs boson, i.e. $\leq$130 GeV in full generality (for m_{top}=175 GeV), and $\leq$126 GeV once SUSY is broken, as it has to be, and in all versions of Supergravity presently considered as the reference points for future searches. This is a mass window that LEP, with the magnificent performances of the accelerating field finally reached and 80 additional superconducting cavities (i.e. 30% more), 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 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 appeared in recent years and were described in Aachen by L.Hall and F.Feruglio.

One, the Little Higgs scenario, leaving aside the Big Hierarchy problem 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 all 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 does not seem to be the case 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. True or not, this theory has the merit to reinvigorate the LHC phenomenology (H.E.Logan, E.Ros) by introducing new particles in the game and in particular insisting on quantitative tests concerning their decay modes.

The other new route postulates the existence, so far uncontradicted, of new dimensions of space, large enough to generate visible effects at future experiments. As discussed also by Antoniadis and Mele, several versions are put forward. One of them, the Arkani-Hamed-Dimopoulos-Dvali (ADD) scenario, considers "big" extradimensions (possibly up to 100 micron size) accessible only to gravity. Gravity seems weak compared to the other forces because it is diluted in more dimensions, the effective Planck scale may be much lower than usually thought, possibly close at hand, and the hierarchy problem is thus eliminated or, rather, reformulated. Other versions postulate the existence of extra dimensions at the scale of TeV^{-1}, which are also accessible to the SM particles: in particular the so-called Universal one has a most interesting phenomenology, with a new conserved quantity, the Kaluza-Klein (KK) number, and offers as the lightest of its new particles a stable and invisible one, much as in the case of R-conserving SUSY. Finally one should mention the "warped" scenario of Randall-Sundrum. All versions, with however substantial differences between them, predict KK recurrences of the graviton (ADD) or of some of the SM particles, 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 naturally to be fully explored, would be an extraordinary chance for LHC and its prospective study also contributes to agreeably diversify its phenomenology. However, before dreaming too much, it is important, as recalled in Aachen, 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, which, besides micro-mechanical experiments, may in the future use sophisticated methods involving Bose-Einstein condensates (hep-ph/0306168) or ultra cold neutrons(hep-ph/0301145).

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 GU. Many studies described in Aachen follow that path and analyse what one or more extra dimensions bring to the already very successful theories of Supersymmetric Grand Unification. This complements the class of studies which, to the symmetry group of GU, add other ones (U(1), SU(3), etc..) whose role is to deal with the flavour problem, and first with the mystery of the triplication of families.

The hope is that these attempts, performed from “bottom to top”, and those, from “top to bottom” of Superstrings, as described in Aachen by J.Barbon, will meet one day and guide each other.

5 QCD

The numerous experimental successes of QCD which, besides its natural simplicity (a single parameter, if one forgets the quark masses), makes it an exemplary theory, have been described by P.Schleper. 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 leads to confinement. All its aspects, from perturbative to non-perturbative, are actively studied and essential to extract correctly the physics of other sectors, electroweak 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.

P. Hernandez showed that the lattice simulations (i.e. QCD treated on a lattice of points approximating space-time) built upon the basic principles of the theory, became fundamental tools, well established and vital to many fields. She described the progress achieved, greatly due to those 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 beauty produced in various types of collisions compared to the predictions. However, new analyses and refined theoretical expectations could indicate that the problem is getting less severe at HERA and the Tevatron. But LEP γ-γ data are still puzzling.

The values of the single parameter of QCD, $\alpha_S(\mathrm{M}_Z)$, 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±0.0027, is in very good agreement with what is required by the most elaborate versions of SGU, including the effects appearing at the GU scale.

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

However, when the spin intervenes, our understanding of hadrons is still poor. Besides HERA , HERMES, COMPASS,.., one is thus expecting from the polarization program of RHIC a number of clarifications, in particular concerning the gluon helicity distribution, by measuring hard 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 LHC era in optimal conditions, namely with a good mastery of the SM prediction for the many different topologies that searches will explore. This remark is particularly true for the indispensable Monte Carlo programs

.

6 Heavy flavours

S. Stone, H.Yamamoto and T.Mannel described in great detail the impressive progress of heavy flavour physics, in particular of beauty physics. One must first underline the remarkable performances of the Beauty Factories, in particular of KEKB, the first machine to deliver a luminosity of $10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$.

In the study of the CKM matrix the highlight is the determination of the so-called Unitarity Triangle. In the SM, the unitarity of the CKM matrix, expressed in a graphical way, leads to the figure of a triangle because a single non-zero phase (a complex coupling) is present. The length of its sides and its angles can be extracted from various measurements in the field of heavy flavour physics, in particular beauty. With enough of these, one can build the triangle in different ways and 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 announce.

It is clear that a very successful first round of experiments has been accomplished. 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 $\mathrm{B}\rightarrow \mathrm{J}/\Psi \mathrm{K}_S$ 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. This is another important success of the SM. However, revealing new 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 is unfortunately prisoner of hadrons, and one must obtain a reliable estimate of the contribution from loop diagrams complicating the process, the famous pingouins, which represent both an embarrassing pollution and a promise, since it is in their loops that new physics could appear.

More generally, in searching for new physics, the interest rests on rare modes and phenomena. For beauty, after the first successes (measurement of β, control of b$\to$sγ), the next crucial tests will concern its semileptonic modes B$\to$(X$_S$, K*, K) l^+l^-. Other channels to be closely watched are $B \to \phi K_S$ (BELLE sees a 3.5 σ disagreement with the SM, not confirmed by BABAR) and $B_S \to \mu\mu$. The measurement of the mixing in the $B^0{}_S$ sector, which may have been a close miss at LEP, is also eagerly waited for, but one may have to wait, given the slow rise of the Tevatron luminosity. The impact of B_S studies and thus of B physics at Tevatron and LHC, which will produce B_S abundantly, is therefore manifest.

The kaon rare modes allow also in principle to build a Unitarity Triangle through $K^+ \to \pi^+ \nu\nu$, $K_L \to \mu\mu$, $K_L \to \pi^0 \nu\nu$, $\pi^0 e^+ e^-$, etc The results of KTeV, E787, KLOE and NA48, in particular NA48 recent observation of the mode $K_S \to \pi^0 e^+ e^-$, and the promises 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: $\mu \to e\gamma$ with a sensitivity per event of 10^{-14} at PSI, μe conversion in nuclei at 2 10^{-17} in MECO at BNL.

7 Heavy ions

S. Mioduszewski has reviewed with realism the results coming from the RHIC collider in Brookhaven, concerning Au-Au collisions up to 200 A GeV and the “surprises” (some of which were predicted long ago) they brought concerning the properties of the hot and dense medium thus produced.

The chemical freeze-out (at which the identity of the particles is fixed) occurs at 175 MeV (a value reminiscent of the Hagedorn temperature), 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 an hydrodynamic expansion due to very strong pressure gradients developing early in the history of the collision. Remarkably, the collision zone is opaque to fast partons and this has a strong impact on hard phenomena: suppression of hadrons produced at large p_T, jet quenching, phenomena which are not observed in control collisions D-Au. Several questions concerning the Hanbury-Brown-Twiss (HBT) correlations, e.g. the size of the collision zone, or the fate of charm in this opaque medium, etc have still to be be clarified.

However the most prominent signatures which could reveal a quark-gluon plasma are not yet available from RHIC and it is from SPS that results are still coming (NA45, NA49, NA50, NA57). In particular, NA45 confirms that the excess of low mass e^+e^- pairs, $m_{ee} \geq 0.2$ GeV, implies a modification of the ρ in the dense medium, probably linked to its baryonic density. The J/ψ suppression, confirmed by the analyses of NA50, 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 CERN.

8 Neutrinos

H. Murayama and K. Lesko shared the review of neutrino physics. It is clear that in this domain the time is truly revolutionary. After the triumph of SuperKamiokande (SK), the recent ones of K2K, SNO and KAMLAND have strengthened our knowledge of solar and atmospheric oscillations (C.Giunti). The main open question is whether there exists a fourth neutrino, of sterile nature, as suggested by LSND, but strongly disfavoured by the other results. The MiniBoone experiment in Fermilab will settle the matter in the coming years.

The big unknown is now the magnitude of the third mixing angle θ_{13}. Its value will tell if the ultimate stage of neutrino physics, namely the measurement of CP violation in this sector, is accessible or not (F.Terranova). Its measurement implies the one of the $\nu_e \to \nu_\mu$ oscillation. The answer will likely come from an oscillation experiment involving an accelerator ν_μ beam and a long baseline, as the JHF-SF programme in Japan, which could start in 2007. Other possibilities, more or less futuristic and problematic, are under consideration: an experiment involving several exchangeable detectors in the immediate vicinity ($\sim$1 km) of a nuclear reactor, or the use of a giant TPC surrounding a hyper-intense tritium source. See also the method proposed in hep-ph/0305152. Potential physics at ν factories, in the long term future, was reviewed by P. Huber.

Oscillations only give access to mass differences. To know their absolute values and determine the properties of the neutrino mass spectrum (is it degenerate or hierarchical, normal or inverted?) one must consider the β-decay of tritium which, through its end point, gives access to m_{ν_e} (present limit at 2.2 eV from Mainz and Troitsk, future one near 0.2 eV from KATRIN) and the neutrinoless double beta decay ($0\nu\beta\beta$). The existence of the latter would imply that the neutrino mass is of the Majorana type and give access to the $|m_{ee}|$ element of the mass matrix. NEMO3 is presently starting and should settle the open question of an effect put forward by Heidelberg-Moscow. Later CUORE (starting as CUORICINO), GENIUS, EXO, COBRA,.. may gain a good order of magnitude and become sensitive to the neutrino masses, at least in the case of an inverted hierarchy.

Interesting news have come from cosmology. Concerning the power spectrum of the CMB, one knows that the presence of relativistic neutrinos suppresses the growth of fluctuations at small angular scales. A combination of the results of the satellite programme WMAP and of the galactic survey 2dFGRS seems to indicate that $\Sigma m_{\nu_i} \leq$ 0.71 eV. This limit implies that the heaviest neutrino mass is in the bracket $0.03 \leq m_3 \leq 0.24$ eV (95% CL). The upper limit corresponds to the degenerate case, the lower one to a lower value of the atmospheric mass difference.

However in Aachen S.Hannestad called for some caution by underlining the role of the priors, etc.. on the numerical value of the limits one can extract from the WMAP et al result.

The Z-bursts scenario assumes that ultra-high energy neutrinos (10^{22} eV) may collide with fossile target neutrinos, producing a Z^0. This could eventually explain the existence (which has still to be confirmed) of extremely energetic cosmic rays, beyond the GKZ limit, and which seem thus to be exempt from an attenuation due to their collision with background photons. However this scenario requires to explain in turn the origin of such energetic neutrinos, and it would favour the degenerate solution for the neutrino masses, which is not the one preferred by theory.

Besides the proof that the SM is incomplete, what can we expect from the knowledge of the parameters, masses and mixings, which govern neutrino physics (F. Vissani)?

One would like to know whether neutrinos are Dirac or Majorana particles and from which energy scale their masses originate. Is it from the typical SUSY scale in relation with a breaking of R-parity? One prefers actually an origin linked to a much higher scale, via a seesaw mechanism implying the existence at that scale of a heavy right-handed neutrino. Let us recall that for instance the SO(10) GU symmetry group readily accomodates such a neutrino, another good reason to consider seriously the possibility of supersymmetric GU. This faith clearly calls for a still more sensitive exploration of proton stability, and one can only wish that, if giant detectors are conceived for future neutrino experiments, their ability to detect proton decay is seriously considered as well.

The results on neutrino properties should guide us in the quest of a theory of flavour. Present results have already filled a full churchyard of models. In the neutrino world, is there anarchy, as if the parameters had been drawn at random, or hierarchy, governed by an underlying law? In the latter case which type of "texture" are we dealing with? Is the flavour symmetry abelian or non-abelian? Unfortunately it is not guaranteed that the light will shine.

Does that information tell us something about our "genealogy", namely baryogenesis (W.Rodejohann)? One knows that electroweak baryogenesis, envisaged in the frame of SUSY, is already severely constrained and will be falsified if one does not find a light Higgs boson, close to the present limit, and a light stop quark. Remarkably there seems to exist a viable scheme of leptogenesis finding its origin in the properties of right-handed neutrinos at very high mass scale, and which explains the existing baryon asymmetry, for masses of the usual neutrinos in the ballpark 10^{-3} to 0.1 eV, as observed. That such a scenario turns out to be possible is a most interesting information; however to prove that this mechanism is the right one may turn out to be difficult if not impossible.

9 Astroparticles

Astroparticle physics, partly covered by S.Schael, is a vast domain, concerning now all types of particles and whose goal is to get information on their properties, but even more to get from them some information on cosmological objects or events. The number of such non-accelerator programmes, if one includes the recent past and the near future, amounts to about 160.

The enigma of ultra high energy cosmic rays, beyond the GKZ cut-off, is still open. Even their existence has to be demonstrated, since the present experiments cannot settle the issue. The AUGER programme, thanks to its two independent and concurrent techniques, should bring the answer and perhaps tell about their nature.

The main objective of Gamma Astronomy is to fill the gap between low energies (a few GeV, the domain of satellites, like EGRET in the past and GLAST in the future) and large ones (few hundred GeV, the threshold of ground detectors up to now). This region can in particular bring information about the distribution of the infrared background. But these detectors have the aptitude to tackle many other subjects, like the identification of the nature of gamma ray bursts (likely to be associated with supernovae) and the indirect search of WIMPS through their annihilation products. Preliminary results from HESS and the imminent start of MAGIC were reported.

Astrophysics of high energy neutrinos, detected either by atmospheric Cerenkov telescopes (AUGER, in its initial phase, EUSO, under study,..), or by subice (AMANDA, ICECUBE) and submarine (ANTARES, NESTOR) experiments, is certainly a fascinating possibility. Neutrinos, free from absorption, should map the topology of the far universe in its high energy manifestations. If their interaction cross-section is larger than the SM prediction, it is equally interesting. However the proof of principle has still to be given and no detection of HE neutrinos of extra-terrestrial origin has been reported so far.

Finally the search for gravitational waves is also in an exciting phase. Besides studies concerning pulsars, both the bar detectors, operating in coincidence (EXPLORER, AURIGA, NAUTILUS,..) and the large interferometers, presently under commissioning, LIGO, VIRGO, TAMA, could, in the years to come, open a new method of exploration of the universe.

As for cold dark matter, whose contribution to the content of the universe has been accurately determined by WMAP (29±4%), its search is in full swing. Concerning its baryonic part (4.4±0.4%, of which only a tenth corresponds to visible stars), the possibility that it could be mostly due to dark objects like failed stars is now excluded. Gas and dust may be the answer.

For non baryonic dark matter, the neutralino and the axion are still the favoured candidates, although newcomers have appeared, like the lightest Kaluza-Klein recurrence of a universal extradimensional theory, which is a stable particle.

The CAST experiment at CERN has given preliminary results which already improve the existing limits on the existence of solar axions with masses below 0.1 eV.

Concerning the neutralinos and more generally the WIMPS, fossile weakly interacting particles, the DAMA experiment at LNGS, exploiting about 100 kg of NaI crystals, continues to present, with one more year of data, a result suggesting a seasonal variation of its counting rate, for a very low threshold, as one could expect from a halo of fossile neutralinos. An unidentified systematic effect is not excluded and it would be important to confirm this observation in an independent manner. Neither CDMS nor EDELWEISS (which utilize both ionization and phonons as discrimination) confirm it, and at first sight they seem to exclude the mass and cross-section regions corresponding to the DAMA effect. However this conclusion has to be considered with caution, given in particular the very low threshold used by DAMA, as well as the potential role of spin-dependent interactions.

The WIMP detectors, present and to come, use generally two independent discrimination methods. One can hope to gain up to three orders of magnitude on the sensitivity with the experiments of second (CDMS2, EDELWEISS2, ZEPLIN2, CRESST2) and third (GENIUS, ZEPLIN4, CRYOARRAY, XENON) generation. Besides the cross-section of the WIMP-nucleon interaction, one needs assumptions about the local density and the velocity distribution of WIMPS in the halo. Comparing the expected sensitivities to the predicted values of the cross-section in SUSY's various incarnations (L.Roskowski), the conclusion is that, even if one limits oneself to the case of SUGRA, this type of searches, although it can bring eventually a positive evidence, is unable to falsify the theory.

A similar conclusion can be drawn concerning the indirect search methods in which one tries to identify an excess of positrons or gammas (monochromatic or as a continuum) due to the annihilation of fossil WIMPS, a signal that a group of Karlsruhe claims to have observed, as reported by W. de Boer. The actors of the game, after HEAT, EGRET,.. are PAMELA, AMS and the gamma astronomy detectors quoted above.

10 CMBR

A striking result from the year 2003, well illustrated in Aachen by S.Schael, is the measurement by the satellite WMAP of the power spectrum of the microwave background with a much better accuracy than the previous programmes like ARCHEOPS or BOOMERANG. It covers angular scales going from ∼90 degrees (multipole $\ell \sim 3.5$) to ∼0.25 degree (multipole ∼750). WMAP measures also the spectrum of the correlation between polarization and temperature. From the position (in ℓ) and the respective heights of the observed peaks, a large number of parameters of the universe have been extracted with an impressive accuracy. The flatness of the universe seems to be proven without ambiguity. As for the fraction of dark energy (of matter) Ω_Λ (Ω_m), WMAP alone gives the range 0.5 - 0.8 (0.58 - 0.14) (2σ). Evidence found for an early reionization period is most interesting result as well. The only potential anomaly reported could be a lack of power at large angular scale (the smallest multipoles) but in this particular region the cosmic variance is large and the conclusions not very significant.

One remembers that in the inflation model the CMBR spectrum is the result, observed at decoupling time (namely 350000 years after Big Bang), of Gaussian nearly scale-invariant fluctuations produced during the inflation period. The peaks and troughs of the power spectrum are due to the later competition between the gravitational potential and pressure gradients.

As V. Mukhanov underlined, one can say that after WMAP two of the three major predictions of inflation are confirmed: the flatness of the universe, linked to the superluminal expansion, and the existence of density perturbations corresponding to a quasi scale-invariant spectrum (inflation actually predicts a slight deviation from invariance which still needs experimental confirmation). The third prediction, the existence of gravitational waves originating from inflation, is out of reach of the interferometers, including LISA. Relevant information can however come from the programmes able to measure the CMBR polarization, in particular WMAP itself and, later on, PLANCK.

On the contrary the various models of inflation on the market are still rather unconstrained by the present data and the nature of the inflaton stays as a deep mystery.

11 Instrumentation

D. Fournier from LAL, Orsay gave an interesting review of the most innovative aspects of instrumentation. One should underline the extreme variety of the set-up used, from table-top experiments to gigantic detectors (AMANDA, EUSO, LISA,..), from very quiet environments (NEMO, bolometers,..) to extreme irradiation rates (LHC,..), with frequently conditions of a quasi-inaccessibility of the experiment.

He described the progresses made in the domains of tracking and tagging of short lifetimes, as well as in calorimetry, in particular for LHC, but underlined the sectors which can still be improved in the future, with adequate R/D programmes. He illustrated the bright carrier of RICH identification in various domains of physics, the special roles that TPC will continue to play,.. The creativity in matter of detectors for non accelerator physics (dark matter search, CMBR,..), in particular cryogenic ones, is also remarkable. All these breakthroughs could happen because a long and vigorous R/D activity was carried out, for instance concerning the LHC detectors, and its continuation is a key of the future of our field. If for instance one wants to push later the LHC luminosity to $10^{35}\mathrm{cm}^{-2}\mathrm{s}^{-1}$, it is imperative to pursue R/D studies aiming at improving its trackers, vertex detectors and electronics.

Obviously, as D.Stickland illustrated, this must be accompanied by a mutation of the computing means and of the distribution of information on a worldwide scale: this is what the GRID enterprise is aiming at.

12 Machines

Naturally a large part of the conference was devoted to the machines, present and future, through an afternoon round table in which the directors of the main laboratories described their programmes, and by the comprehensive review of M. Tigner.

One must recognize that some upgrades, like the Phase II of the Tevatron and HERA are happening slower than expected, with however promises of interesting results in the years to come. Other colliders like the Beauty Factories have reached rapidly their nominal performances. The near future is clearly dominated by the LHC which should start in 2007. It is commonplace but important to recall the magnitude and the difficulty of the enterprise, for the machine as well as for its detectors, the vital importance of its success and the enormous potential of physics it offers.

Given the timescale that a new project implies, it is crucial to plan the longer term future. The choice of an e^+e^- linear collider, which should complement the LHC by offering the accuracy of its measurements, is unanimous. There too, the enterprise is difficult and requires massive R/D programmes undertaken since many years. M. Tigner clearly presented the various options and the status of their R/D and identified the problems which are essentially solved and those which still need further work. B.Foster described the ongoing procedure which should lead to judicious choices and to an optimal organization, in a context which can only be worldwide.

M. Tigner also launched a vibrant call for more implication of the physicists in the R/D of acceleration physics, on potential projects, like muon-based facilities, as well as on new principles, like laser-plasma devices, etc... One can only subscribe to this call since what is at stake is the future of our field.

I have been honoured and pleased to give this concluding talk and I warmly thank the organizers for their outstanding efficiency and kindness.