HADRONIC PHYSICS WITH ELECTRONS BEYOND 10 GEV^{*}

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ABSTRACT

Concluding talk to the Dourdan workshop, this review discussed the new style of work which is emerging in the European nuclear physics community. It is based on the increasing use of large facilities serving a wide user community. The potential of a high-energy, high-duty-cycle and high-intensity electron machine is addressed. This was the facility in focus at Dourdan.

^{*} Concluding talk, Dourdan workshop on Hadronic physics with electrons beyond 10 GeV. Dourdan, 8-12 October 1990 to be published with the proceedings in Nuclear Physics.

1. INTRODUCTION

This workshop, which brought together over 200 participants, has been a very lively happening, with many review talks and much discussion. At stake is the future of a domain of research which, in Europe, could organize itself around a new large facility, namely a high-intensity, high-duty-cycle electron accelerator, reaching beyond 10 GeV.

This is the energy domain first accessed by the initial SLAC research programme which led to the discovery of a point-like structure inside the proton. These point-like scatterers, carrying the proton charge, were later identified with the quarks, but everything started with the discovery of the scaling property in 1968, and its interpretation in terms of point-like constituents [1]. This was the discovery of a new layer in the structure of the matter.

The main purpose of the new facility under discussion at the workshop is to explore in depth the domain opened by this prominent finding with the new benefit of a *high-duty-cycle* and a *high intensity*, so that coincidence experiments could be performed with good precision. This is not possible with the high-energy lepton beams (electrons, muons and neutrinos) which are now available at high-energy machines, and in particular at CERN. Their pulsed nature forbids most of the coincidence experiments which one would wish to do in order to understand in depth the processes which are at work when quarks recoil.

This is even more challenging to the nuclear physics community because the quark structure of the proton has a direct relevance to the behaviour of nuclear matter at short distances. Indeed, the EMC effect [2] stands as a witness to the fact that quarks in nuclei do not behave just as quarks in free nucleons. Measuring the properties of the scattered lepton provides information on the distribution of the point-like scatterers met by the impinging particle through photon exchange at large Q^2 and with a large energy transfer. This, however, hardly provides any clues about what happens to the recoiling quarks or antiquarks and does not give enough information on the processes through which the shattered system eventually transforms into the hadrons which are produced in the collision.

It is the challenge of these complicated hadronization mechanisms, about which we have not much knowledge at present, which motivates investigating further deep inelastic electron scattering with new equipment, new insight and new people with new ideas.

Since it is also the quark structure of nucleons and nuclei which is at stake, the question has to be addressed with the most appropriate experimental strategy. This

automatically calls for high energies, typically in excess of 10 GeV, so that processes at large enough momentum transfer squared (Q^2) can be observed with sizeable enough rates. The high intensity complements the energy for access to processes with cross-sections that decrease rapidly with increasing Q^2 . The high duty cycle is also a prerequisite for detailed correlation studies, analyzing the properties of the hadrons which are produced as the electron is scattered.

It is clear that the present design energy (4 GeV) of the new large facility with high intensity and full duty cycle (100 %), which is presently being built in the United States, CEBAF, to come into operation in 1994, is not enough to explore the quark structure of nucleons and nuclei.

If Europe plans a new big step forward in that direction, since its present and new machines (MAMI-B, NIKHEP, ELSA) will be largely superseded by CEBAF in 1995, it now seems clear that one should not try to duplicate CEBAF but consider directly an energy range extending beyond 10 GeV, where quark effects become clearly visible. Indeed CEBAF is also presently considering its possible extension to 16 and maybe 20 GeV [3].

The case for such a project is at the origin of this meeting. The priority set should correspond to a European choice. The cost, but mainly the constituency required for the full exploitation of such a machine, calls for a European venture. Such a machine would indeed require 300 to 400 users, whilst even a major European country could provide only about a third of that number. This would of course also be the case for a machine of the CEBAF type !

The Dourdan meeting will therefore be recognized to have had a historic character as the first one in which the nuclear physics community in Europe first discussed together the type of facility which they would like to build together.

This is of course only the beginning of an iteration procedure involving experimentalists, theorists and machine physicists, but it seems to be a very good start. This was an important meeting during which a sizeable fraction of the European nuclear physics community, together with colleagues from afar, and colleagues from particle physics also, considered in some detail a particular physics option. The corresponding facility, with a high energy (15-25 GeV) to set a scale after discussions in Dourdan, and high-duty cycle (close to 100 %), may look at first sight like a *bona fide* "high-energy" machine.

This may explain why a good number of high energy physicists contributed to this workshop and why one of them was even asked to give the concluding talk !

I am indeed a particle theorist. This is a statement and I do not know whether or not it should be considered as an apology [4]. Nevertheless, it should be taken as self-evident that :

It is for the nuclear physics community to define what should be its next promising tools.

It is clear that its increasing understanding of nuclear structure leads it now to probe the quark structure of nucleons and nuclei, beyond the nucleon structure of the nucleus, and this drives it automatically to higher energies in order to increase the resolution achieved.

However the new "high-energy" machine to be built should be defined according to its research goals and not necessarily optimized in such a way that it could also please the particle physics community.

The long-range priorities of the high-energy physics community are indeed now clear. In Europe it is the construction of the LHC, a 16 TeV proton-proton collider to be built alongside LEP in the LEP tunnel. This is the tool to study constituent interactions in the TeV range. One also hears mentioned the construction of a $b - \bar{b}$ factory, a τ -charm factory, a "Super Lear" $\bar{p}$ storage ring ... as other machines which could also be seriously considered, funding and constituency permitting. Particle physicists, as a community, have their interests, their own priorities and this does not include a high-duty-cycle machine in the energy range considered.

This machine should therefore be justified in the framework of the nuclear physics community's goals and culture. It is indeed a very powerful instrument to probe the structure of nuclear (and hadronic) matter with a resolution better than 0.1 fermi. Is it what a good fraction of the nuclear physicists are after primarily ? This is the key point.

2. THE DEEP STRUCTURE OF NUCLEAR MATTER

Electron machines have had a brilliant past in the exploration of nuclear structure. Many prominent results have originated from the Saclay ALS and other machines [5]. While the ALS is now outdated, other machines, with full duty cycles (MAMI-B, BATES, NIKHEF, ELSA), are presently starting, or soon to start. They will continue this exploration of nucleon and nuclear structure with continuous beams in the 1 GeV range. In the near future, CEBAF will follow with its 4 GeV beam. There is therefore a very promising near future for studying hadronic degrees of freedom in nuclear matter.

Nevertheless, when it comes to partonic (quark and gluon) degrees of freedom, a higher energy is definitely required. There is of course still much to do in the near future with muon beams at CERN and electron beams at PEP and HERA. However, and as previously said, a detailed exploration calls for coincidence experiments. In that case, a high intensity and a high duty cycle are required. This is the case for a new machine. One has then to improve significantly on past and future anticipated results. The option discussed looks promising. The enthusiasm felt throughout the workshop is most encouraging. Yet much effort is still needed before a project can materialize [6].

The first question is of course the physics case. I shall not discuss it again in technical terms here. There have been summary talks which have beautifully summarized the present situation [7]. K. Rith has reviewed the case for "From nuclei to nucleus". P. Mulders has covered that "From nucleons to quarks". The questions related to electroweak processes have been discussed by F. Scheck and finally F. Close has covered the question "From quarks to hadrons". The machine part has been summarized by J. L. Faure and the long and lively discussion which followed his talk is a most encouraging forerunner of the fruitful exchange which should take place at the next workshop, when machine designs and experimental plans can be confronted.

From these summary reports, it is clear that there is a good case for a machine which could cover the 15 to 25 GeV range with a 100 % duty cycle. Such a machine seems feasible but then comes the question of funding, which has not yet been addressed directly.

There is no need to summarize these excellent summaries and I have therefore to carry the discussion at a more general level.

The first question which one may face is : "Why is the future of nuclear physics with quarks and gluons ?"

One may of course say that the study of nuclei, which was the clear domain of nuclear physics thirty years ago, has evolved into the study of nuclear matter. It is similar to a shift from Botany to plant Biology, the latter developing after the former. The study of nuclear matter has already much developed. One has indeed now reached a level of understanding where a purely hadronic description is not enough. It may then seem natural that nuclear physicists are therefore turning their attention to the deep quark gluon structure of matter.

However, more than a question of particles under study, there is a question of culture.

Particle physicists look for elementary processes. They are after new grounds and try to avoid as much as possible the complexity of composite systems. If free quarks were available, they would love to use them as projectiles, leaving aside the fact that they are the constituents of the proton. Indeed, in present collider experiments, they almost use them as such.

Nuclear physicists on the other hand seem no to be deterred by the complexity of composite systems. They crave the challenge of finding simple and clear features in apparently highly complex situations.

Hadrons, not to speak of nuclei, are composite systems which appear in a very complicated QCD vacuum. The vacuum indeed behaves in much the same way as a medium, as discussed by G. 't Hooft in the opening lecture. This apparent complexity of the vacuum, of the nucleon and of the nucleus is a great challenge which appeals to the nuclear physicist. Indeed, whilst in physics we often simplify situations to the limit, it is in the hope of finding that the laws of simple things can be built up into the laws of complicated things.

It is then natural that nuclear physics brings itself to bear on these complicated issues, even though some may refer to them as known but only poorly explored questions in particle physics. Indeed the development of a large overlap between nuclear and particles physics is one of the striking phenomena of present day physics. Many fundamental questions have been left unanswered and call for a new and thorough investigation.

3. PARTICLE AND NUCLEAR PHYSICS. CONVERGENCE AND PERSPECTIVES

At present, one witnesses a great ecumenical spirit after the great schism of the late fifties. The last great common venture was the analysis of the V-A structure of the weak interaction. This was in 56-59 ! Since then the two fields have split apart with their own problems and their own series of conferences.

A big change has, however, been happening over the past 5 years or so, and many nuclear physicists are now working on high-energy facilities, often in the framework of mixed teams involving particle and nuclear physicists.

During this period, about 500 nuclear physicists have become full users of the CERN facilities, besides the 500 others, who had long been and still are busy with the exploitation of Isolde, now in its third development stage.

They are present in the relativistic heavy ion programme, but also with the muon programme where the NMC experiment has been "taken over" by nuclear physicists. They are also found in great numbers in the present LEAR experiments.

At the same time, if one looks at the United States, the two pillars of the present and future nuclear physics programme supported by NSAC are CEBAF and RHIC. Not so long ago such machines would have been considered as bona fide particle physics facilities. Yet they are the natural followers of machines such as the ALS, MAMI-B, Bates, on the one hand, or GANIL, SIS, on the other hand. KAONS would also have been considered a high-energy machine not so long ago and there are indeed many nuclear physicists busy with the AGS studying rare decay modes.

Future nuclear physics may thus a priori look like the continuation of high-energy physics of the recent past. This is, however, misleading and misses an important point already alluded to and developed later. The nuclear physics approach is indeed very different from the particle physicist's first exploratory spirit.

This is why particle and nuclear physicists differ in their presently-preferred options despite the fact that they all are, to some extent, after the quark structure of matter [8].

Realizing this cultural rift was one of my main experiences during the audit of nuclear physics in France with which I was associated in 1989 [9]. It is this audit which actually brought me to Dourdan. The conclusions reached and spelled out in our report are similar to those arrived at by the German audit [10] and those which seem to prevail at the European level [11].

Nuclear physics has now lost much of its once specific character, namely the study of stable nuclei. It has, however, not lost its style of research, with its focusing on the study in depth of a composite system presenting challenging problems. It deserves to continue along this most important line but the tools now needed are such that the community has to organise itself at the European level.

Let us look at this in a more explicit way. At the time of the schism between nuclear and particle physics, in the late fifties, nuclear physics focused itself on the study of nuclei considered as assemblies of nucleons. The typical excitation energies required were relatively low, less than 10 MeV. At the same time, particle physics was defining itself in terms of the study of the proton structure. The proton was indeed known to have a size. It could be excited into many resonance states. It was but one member of an extending family of hadrons. The energy required (in the center of mass) was well over 100 MeV. The split was complete by the early sixties. This is about the time when I started to work in physics. I had to choose and went to the

for this session, T. Ericson, is among the few who managed to stay successfully in both camps !

In the eighties, however, one witnessed a remarkable convergence.

- (i) Nuclear physics goes from nucleons to quarks in its study of nuclear matter (EMC, NMC);
- (ii) Nuclear physics shifts from nuclear structure to hadronic structure (LEAR, Saturne 2);
- (iii) The new state of nuclear matter, which Nuclear physicists long searched for, beyond the point where the hard core of the nuclear force could be overcome, is now recognized as the quark gluon plasma. Many nuclear physicists address this question with relativistic heavy ions together with particle physics.

At the same time, nuclear physicists started to use their specific experimental skills tackling problems which originated from particle physics. One may quote.

- (i) The study of rare (or "forbidden") decay modes (AGS, pion factories);
- (ii) The study of neutrino oscillations (using powerful nuclear reactors);
- (iii) The study of neutrino astronomy and the search for dark matter (Underground experiments).

Nuclear physics has to some extent lost its specific character. Despite the fact that many nuclear physicists are still studying highly deformed nuclei and nuclei with neutron content which put them at the limit of stability, the motivations there often came from astrophysics. But, when it comes to nuclear matter, particle physics questions came readily into play.

However, nuclear physics has not lost its style of work. It is basically concerned with the detailed study of composite systems.

Indeed, despite this clear convergence in the themes of research, a deeper cultural separation remains.

Particle physicists are in search of simplicity. They look for "new physics". They like simple yet not trivial objects. They are after energy to increase the resolution and probe hitherto unknown ground.

Nuclear physicists seem on the other hand to like the challenge offered by composite systems. They work very hard to find simplicity in the midst of a priori quite complicated situations. They are after the detailed understanding of complex systems. For them, intensity and duty cycle may be more important than sheer energy.

Both approaches follow from different and specific interests and both deserve drive and support.

Particle physicists have been after higher and higher energy. This quickly required large facilities exploited by a large community of external users. In Europe this quickly led to an international organization, CERN, and to a lesser extent DESY, now serving almost the whole European particle physics community (altogether about 90% of the particle physicists in Western Europe) and a sizeable fraction of the world-wide community.

The recent overwhelming development of colliders and their requiring large and sophisticated detectors right from the start has increased the relative initial investment for the detectors (0,4 for LEP). This brings in an "adiabatic" way the concept of a World Machine, a world-wide community of physicists constructing and exploiting the detectors installed on a big but still regional facility.

During the past 30 years, nuclear physics has been after refining the understanding of the dynamics of nuclei [9,10]. It went from nucleons in a mean field to the study of π 's and Δ 's in nuclei. It went from the study of stable nuclei to that of exotic and highly deformed nuclei. It went from the study of nuclei to that of nuclear matter. It reached the limit of a purely hadronic description of nuclear matter.

Institute machines have been replaced by National facilities. This step is however now not enough. Machine such as GANIL, Saturne-2, SIS at GSI have to rely on a large number of foreign users. The next step has to be international from the start. Even when one considers the many new institute-based tandems, their use now calls for international ambulatory detectors (Eurogamma).

There is another important cultural difference to mention at this stage.

Particle physicists insist on big jumps in energy. They are after new ground and a new machine should typically correspond to an order of magnitude increase in available energy. The Livingston plot bears witness to that [12]. The constituency and the funding required for a new high-energy facility are indeed such that there is no room for many new facilities within a decade ! Any new step has therefore to be quite sizeable in order to be justified.

Nuclear physicists on the other hand have so far preferred to proceed through overlapping steps so that they could extend and eventually modify their proven techniques, methods and models from one energy range to the next.

This should have been one of the reasons for proposing to repeat in Europe the 4 GeV (CEBAF) step, before going higher in energy, as first favoured by some members

of the community [9,10].

However, in view of the funding and of the constituency needed for *any* new step now, this style has to change. Granting the fact that there will not be many facilities built during the next decade, one has to optimize the steps made. The recent history of the relativistic ion programme shows that this cultural bias can be successfully overcome.

In particle physics, the cooperative effort needed has led to a concentration of means which is much larger in Europe than in the United States. This was clearly at the origin of the big European successes of the eighties. There is now optimism, but one should keep in mind the prevailing gloom of the mid-seventies following the great success of SPEAR and the start of the Fermilab machine much ahead of the SPS.

In nuclear physics there has been so far a much greater dispersion of means than it is now the case in the United States. Despite a higher global budget for many years, Europe finds itself in a mood of frustration while the United States is building CEBAF and should soon start RHIC.

Even in the framework of a probably decreasing global European budget in nuclear physics, there is still room for promising new ventures. However, this now requires a European organization and much cooperation when it comes to the preparation, the funding and the exploitation of any new big facility.

4. THE QUARK STRUCTURE OF MATTER

At present, the very important meeting ground between particle and nuclear physics is the quark structure of matter as described in the framework of QCD.

Particle physicists can hardly evade the complexity of hadrons and also that of the vacuum. The vacuum is indeed opaque to colour. This results from its behaving in much the same way as a superconductor. As explained by 't Hooft [13]. The condensation of colour magnetic monopoles could build a field similar to that associated with the condensate of Cooper pairs in the BCS theory. This would confine colour flux tubes inside bubbles (the hadrons) in analogy to the behaviour observed for the magnetic flux in "class-2" superconductors.

The challenge of this complexity, which is also that of nucleons met inside nuclear matter, appeals to the nuclear physicists. The hadronic interior and the vacuum are complicated media, as nuclear matter has long been known to be.

When it comes to understanding the colour field in the vacuum, the study of the colour field inside nuclear matter appears to be another very interesting approach to be followed also. When it comes to understanding hadron formation from quarks, the filter properties of nuclear matter should offer promising clues.

It is therefore not surprising to find a very strong interest in the nuclear physics community in the study of these very difficult questions which have been left unanswered by particle physics as it moved to new ground. It is clear that the study of very high energy processes (in the TeV range) is likely to provide new insight on hadronization and colour confinement. One is more generally after the origin of symmetry breaking in gauge theory. However a direct approach, trying to collect clues from the detailed experimental study of processes where hadrons turn into quarks and vice versa, has certainly also a very legitimate interest.

The question is whether this research can rally a large enough constituency to justify a major facility, and probably the major investment in nuclear physics in Europe for the coming decade. The answer is with the nuclear physics community.

The quark structure of matter is already rather well explored and a few figures present some dramatic pieces of evidence, standing as witnesses for the success of QCD. Figure 1 shows a three-jet event as now routinely observed at LEP. A Z fragments into a quark- antiquark pair while an energetic gluon is radiated. The three coloured partons eventually appear as three jets of hadrons. Yet the basic mechanism is clear from the hadron distribution observed [14].

Figure 2 shows the probability of observing three-jets in electron-positron annihilation. This probability is proportional to α_s . It has been measured at PEP, PETRA, TRISTAN and now LEP. It is here presented as a function of $(\ln E)^{-1}$, where E is the electron-positron annihilation energy. This more than suggests asymptotic freedom with $\alpha_s(E) \sim (\ln E)^{-1}$ at high energy [14].

With figure 3 we have the modern version of the Rutherford experiment. One sees the high-energy jets routinely seen in collider experiments [15]. They bear witness to the hard scattering of point-like constituents (quarks, antiquarks and gluons) inside the colliding hadrons. In addition to the basic scattering process (two-jets), one (three-jets) or two (four-jets) high-energy gluon(s) can sometimes be radiated. All this could be predicted from QCD used here, in its perturbative form, at short distances. With figure 4 we have the modern version of the "hydrogen atom" problem [15]. One sees the spectral lines of charmoniums with radiation observed between the levels of a system formed by a charm quark and its antiquark. The colour force potential has a coulombic part at short distance ($\sim r^{-1}$) and a confining part ($\sim r$) at large distance. The heavy

mass of the charm quark allows a non-relativistic potential approach [16]. Finally, with figure 5 we see the inclusive pion distribution in jet fragmentation in e^+e^- annihilation [14]. The fraction of the quark momentum taken by a pion is denoted by x_p . The shape of the spectrum, with its depletion a low x_p , its central rise and the shift of the maximum with increasing annihilation energy, could be predicted from the QCD evolution of a parton shower with radiation of gluons and their fragmentation into gluons and quark-antiquark pairs [17].

This is shown to illustrate the fact that we already have a solid framework for the understanding of the quark structure of the matter. Yet this also underlines all the questions which are still much open. We have still to parametrize in a phenomenological way the quark-hadron transition which involves QCD at small transfers where perturbation theory cannot be used.

At present one may say that QCD has come of age ! Indeed :

- (i) It is a theory with which one can in principle calculate everything and there is no alternative;
- (ii) When calculation can be done and data exist good agreement is found (fig. 1-5);
- (iii) When calculation cannot (yet) be done and data exist there is no clear conflict.

This is our solid present theoretical framework, however :

- (i) We are still in a situation comparable to the "pre-Lamb shift time" in QED. Namely we have a wide array of positive results with a precision which now reaches 10 % some of the times. However, we do not have yet any precise test of a specific effect.
- (ii) We have still to parametrize hadronization distributions and structure fractions and we still do not understand quantitatively how quarks bind themselves into a proton.
- (iii) While lattice gauge calculation bears some promise which is slow to be borne out, we have little theoretical clues how to improve on the present situation. Everything seems very complicated when one looks beyond the first glittering successes.

There is no reason not to try to proceed with clever and clean experiments. This is the very essence of physics. There is little need for more of the experiments already done studying processes where quarks turn into hadrons or vice versa. There is on the contrary a strong need for new, more ambitious experiments which would provide a novel detailed view of these processes. There is no reason to lose hope in advance.

We have seen in the report of K. Rith [7] the complicated pattern of the EMC effect.

Looking at the ratio of the structure functions in nuclei and with free nucleons, one sees shadowing at low x with depletion, an enhancement at medium x ($x \sim 0,1$) associated with valence quarks and gluons, followed by a depletion at larger x . There is finally a tantalizing region beyond $x=1$. All this stands as a challenge to physics. The inclusive study should be followed by a detailed analysis of the reaction process.

5. HOW TO PROCEED

One of the key question is how is the proton built, when alone and when inside a nucleus ? High-energy electrons offer an a priori very valuable probe. One has to look with scrutiny, i.e., with large recoils. There is a need for energy. This is the price for resolution. One has to study as much as possible the whole reaction, observing also the recoiling hadrons. There is a need for a high-duty-cycle. This is the price for coincidence studies.

This workshop has been the occasion to corner some important issues, sorting out some energy thresholds.

- (i) One should "see" quarks recoiling as such. The electron energy has therefore to be larger than 10 GeV.
- (ii) There is much interest in using charm (and in particular the J/ψ) as a probe. One can thus study how a tiny $c\bar{c}$ system evolves inside nuclear matter. In that case, one gains using an electron energy greater than 15 GeV, significantly above threshold.
- (iii) The detailed analysis of the EMC effect, from collective effects at $x > 1$ to shadowing effects at small x , pushes us to reach 20 GeV.
- (iv) The study of colour transparency or, more generally, of hadron production inside nuclear matter, also pushes us to reach 20 GeV. One wishes to cover the initial SLAC energy range, with a strong depletion seen, and go beyond it, to reach an energy where the EMC experiment indicates only small screening [7].

If one tries to reach a Dourdan consensus, one could say that a machine which would start at 15 GeV to eventually reach 25 GeV, would meet most of the present demand.

Such an energy coverage appears as offering a very promising step after CEBAF.

The questions under study are very complex and difficult. Yet the challenge raised by their apparent complexity seems to appeal to the nuclear physics community. One is after experimental clues on a fundamental question about which we have at present very little theoretical insight. Some people may consider it as a "plus" after the lack of complete surprises met at the $p\bar{p}$ colliders and, so far, at LEP. Theorists were lucky predicting everything right. However, one should not forget that when preparing for the $p\bar{p}$ collider and for LEP, the W, the Z and the hadronic jets were still hypotheses and there were many doubts about their observability, let alone their existence ! [18] Nothing was obvious.

In the present case everything depends therefore on a clever experimental approach. There is not even a "jackpot" to mention, such as the finding of glueballs in the LEAR programme. We are only after clues and further insight from experiment.

The whole question is therefore in the hands of the nuclear physics community. Is it the experimental programme on which they wish to base a good fraction of their future? This is also a question of constituency. One needs 300 to 400 physicists to exploit properly such a facility. They have to manifest their number and their enthusiasm. This workshop has certainly been a very good start. It has brought together a large number of physicists from Europe. More encouraging is the fact that the attendance included a good fraction of young physicists ($\sim 30\%$, say). They have taken the opportunity of the workshop to organize themselves as a network HPN (hadron physics (with electrons) network). This is a very positive sign. One has now to see whether a large number of experimentalists will rally around and proclaim their priority.

Continuing, one definitely needs a "blessing" which would make such a project recognized as the priority of the nuclear physics community in Europe for the coming decade. Nuclear physics in Europe is in need of a forum similar to ECFA [19]. As repeatedly said, any new big nuclear physics project has now to have a European base right from the beginning. Even if a country (some countries) is (are) to eventually take the lead, it (they) has (have) to be assured of having the full support of the European nuclear physics community. The HERA model is likely to be followed, although adapted to this particular case [20].

A European collaboration is needed not only for the cost involved but even more for the constituency required by such a facility.

NuPECC should clearly help the budding of the best project. Its present structure, its connection with the ESF and the EPS, makes it the natural existing body to assess whether the project, which we have been discussing still in general terms at this

workshop, can be deemed the priority of the European nuclear physics community [21].

The ball has started rolling and it should be kept rolling ! [22] Physicists have to define better their goals, but there is already a good convergence of view within a sizeable community. Machine physicists seem to find it a very interesting challenge [7]. This is indeed a challenging machine to build, but it appears possible with available technology. It is also bound to trigger interesting technological developments.

There is a tendency to try to combine such a machine with a $b-\bar{b}$ factory. The idea behind that is to use an important common part for both machines and to rally a larger constituency around a global project. I do not think that this should be attempted at the beginning, even if it may eventually appear as a good combination.

Indeed the two user communities have very different goals and adding the two user groups into a single constituency would be misleading. One indeed needs 300 to 400 dedicated users to exploit either option and, since both communities are after integrated luminosity, they will be competing strongly for beam-time. Both machines are also rather difficult to build since very high intensities (luminosities) have to be achieved in both cases. It is perhaps better not to try to compromise between the two.

Focusing on a high-energy, high-intensity and high-duty-cycle electron machine, the next step should see an interplay between machine physicists and users with some definite ideas about detectors. The discussion could be monitored by NuPECC.

The situation should become much clearer in about one year. Indeed the completion of such a new large machine should be considered for before the end of the nineties.

It should be considered as the new big step forward after the present machine and those at the construction stage have been fully or already partially exploited. There is also much to be done in the meantime with the high-energy muon beams at CERN and with the experimental conditions offered at HERA and PEP and also at LEP. One should make full use of these many facilities in preparation for the unique and high energy and duty cycle possibilities offered on the new machine. It will allow one to come back with a much higher intensity to the first exploration made with PEGASYS at PEP.

I mentioned some of the different interests now met within the particle physics community. The intense secondary neutral kaon beam which could be built at such a machine is probably the most interesting possibility as presently seen from a strictly particle physicist point of view. Such a beam was long recognized as an interesting element of high-energy electron accelerators [23] and SLAC made good use of it. However, as this workshop bears witness, there are particle physicists who are individually

interested in the main research programme. Some particle physicists resent the huge size of collaborations and some of them have even gone "underground" to work within smaller teams on proton decay, cosmic neutrinos or dark matter searches.

Some will eventually "come back to the surface" and could be very interested to join. The same may apply in a fraction of the present LEAR community.

The wide discussion which has started, and which will continue, is therefore likely to add to the constituency a good number of particle physicists. It is a fact in any case that the clear separation between nuclear and particle physics, which has lasted over 25 years, is now gradually fading away. The partial merging of the two communities is a great asset for the further study and understanding of the quark structure of matter.

I would like to thank the organizing Committee for inviting me to the workshop and to give the concluding talk. My interest in nuclear physics has been sharpened by the audit of 1989.

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- [3] H. Grunder, Contribution to this Workshop.
- [4] A paraphrase of the beginning of A. Jackson's contribution to this workshop.
- [5] B. Frois, Contribution to the High Energy facility meeting of the EPS, Zagreb (1988).
- [6] At this stage a cartoon was shown. It featured a concert with a listener reading from the programme "In the final movement, the mood abruptly changes from despair to joy as the composer is awarded a grant from the National Endowment for the Arts". We are however still at the end of the first movement, if one follows this allegorical parenthesis.

- [7] K. Rith; P. Mulders; F. Scheck; F. Close; J. L. Faure, summary talks at this workshop.
- [8] A thorough review of all these issues can be found in "The quark structure of matter", proceedings of the Franco-German Conference organized by the SFP and the DPG in Strasbourg and Karlsruhe, (1985). WSPC (1985).
- [9] "La Physique Nucléaire Fondamentale" Rapport de l'Académie des Sciences 24 (1990). Study done by G. Charpak, P. Darriulat, M. Goldman and M. Jacob.
- [10] "Künftige Entwicklung der Grundlagenforschung in der Mittelenergie und Kernphysik." BMFF report. Study done by A. Faessler, P. Keinele, K. Kleinkecht, A. Richter, H. Specht and J. Wess.
- [11] J. Sick, "Nuclear Physics in Europe, planning the future", *Europhysics news*, June 1990.
- [12] M. Jacob "Physics with accelerators", Opening talk, European Conference on Accelerators, Nice (1990).
- [13] G. 't Hooft, Opening talk at this Workshop.
- [14] M. Jacob, "Jet physics and QCD". Rapporteur talk, 25th International Conference on High-Energy Physics, Singapore, 1990.
- [15] C. Rubbia, "Particle physics today", report to CERN Council, December 1989.
- [16] A. Martin and H. Grosse, *Phys. Reports*, **60** (1980) 6 ;
C. Quigg and J. Rosner, *Phys. Reports*, **56** (1979) 4.
- [17] For a review see V.A. Khoze, contribution to the Stanford lepton-photon Conference (1989).
- [18] R. Horgan and M. Jacob, Physics at Collider Energy, CERN, Yellow report 81-04 for $p\bar{p}$ collider physics, and;
LEP Les Houches summer study, CERN, Yellow report 79-01 for LEP physics.
- [19] During this summer I had several occasions to present my views about the convergence of particle and nuclear physics and the need for a European organization of research in basic nuclear physics. I shall not repeat the arguments here. They can be found in :
Concluding talk, "Quark matter'90", Menton, *Nuclear Physics*, to be published;
Invited talk, Dalitz Symposium, Oxford, *WSPC*, to be published;
Invited talk, "QCD '90", Montpellier, *Nuclear Physics*, to be published.

[20] HERA, whilst at the beginning a German project, was discussed within ECFA and collected a wide grass-root support in the European particle physics community. This resulted in important participations to the funding originating on a rather wide basis. This defines the "HERA model". The LEP experiments were simultaneously developed in the same way and can be used at defining the same model.

[21] Psalm 85-11 : "Truth shall spring out of the earth; and righteousness shall look down from heaven."

[22] W. Shakespeare, Julius Caesar, Act 4, 215 : "There is a tide in the affairs of men ...". These two references are to convey the flavour of numerous quotes during the talk which are not repeated here.

[23] S. Drell and M. Jacob, *Phys. Rev.*, 1388 (1965) 1312.

FIGURE CAPTIONS

Fig. 1. Three-jet decay of a Z (Aleph).

Fig. 2. The variation of the three-jet rate with $(\ln E)^{-1}$. Almost a proof of asymptotic freedom.

Fig. 3. Jets in hadronic collisions (CERN $p\bar{p}$ collider).

Fig. 4. The spectral lines of Charmonium (Crystal ball detector).

Fig. 5. Inclusive hadron distribution in jet fragmentation at LEP (Opal).

- Fig. 1 -

- Fig. 2 -

The Spectrum of Charmonium

Photon Energy in MeV

Results from the Crystal Ball Detector
which was used at SLAC and DESY

- Fig. 5 -