SPIN AND FLAVOUR:
CONCLUDING REMARKS

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Abstract

We review some of the salient results presented at this Workshop, together with some comments on the underlying physics, and the proposed facilities for future experiments.

1Invited talk at the Workshop on Spin and Flavour in Hadronic and Electromagnetic Interactions, Turin, September 1992, to appear in the Proceedings.
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1 Introduction

The Workshop on *Spin and Flavour in Hadronic and Electromagnetic Interactions* was organized at Torino by R. Bertini, F. Balestra and R. Garfagnini, with the efficient help of their colleagues and secretaries. It gave the opportunity of making interesting comparisons between high-energy and low-energy problems, hadronic and photon beams, old and new physics.

We have learned, or have been reminded, that there are intriguing spin effects in high-energy hadronic collisions, and this seems to challenge Quantum Chromodynamics (QCD) or at least its perturbative version (pQCD). Striking spin effects also show up at very low energy, for instance in the reaction $pp \rightarrow \Lambda\bar{\Lambda}$, and here, one is tempted by a more conventional type of picture, involving hadron-exchange between hadrons.

Many important results in the field of this Workshop come from LEAR and the $pp$ experiment E760, while electron or photon beams are involved in projects like DAΦNE or GRAL which have been presented.

In the course of the discussions, especially during the theory talks, I was amazed by the mixing of modern concepts, such as pQCD, Skyrmions, etc., and more conventional approaches based on meson exchanges, potential models or Regge trajectories. One of the first speakers quoted a great physicist, who did much pionnering work on strong interactions, but might have underestimated the role of spin forces at high energy. Let me, in turn, recall a remark made once by the same physicist on the $\Delta$ resonance, which is described either as a $q^3$ cluster or as a $\pi N$ state. Both pictures are probably valid. The former is usually more appropriate in the general framework of hadron spectroscopy, while the later is more efficient for describing the $\Delta$ inside a nucleus.
The equivalence between quark and hadron pictures is the basis of the “QCD sum rules”, an approach to strong interactions which has proved rather successful. It includes an interesting mixture of old-fashioned dispersion relations and modern field theory. The Skyrmion model is also based on the possible equivalence between QCD, initially written in terms of interacting fermions, and a reformulation in terms of bosons. The equivalence remains however to be demonstrated with the actual number of colours and dimensions.

There is also a duality in the presentation of the experimental projects. Shooting photons, antiprotons or kaons on a nucleon or a nucleus can clearly not be considered as a new experiment. The promoters stress together the need for improved statistics, to answer old questions, and the possibility of looking at new observables, to test the most recent speculations.

I shall shortly comment on what we have heard on strangeness, charm, and spin physics, and then on the approved or proposed experimental facilities. This will hardly cover all the subjects which have been discussed. In particular, I will not comment much on the interesting discussions on neutrino scattering \cite{1}, hadron dynamics in the nuclear medium \cite{2}, and light meson physics \cite{3}.

\section{Strangeness}

We had a variety of talks dealing with particles containing strange quarks: mesons with hidden strangeness, hyperons and hypernuclei with increasing strangeness. States with both charm and strangeness will be discussed in the next section.

\subsection{Hidden strangeness}

The quark picture of mesons is usually considered as being under control, especially in the sector of vectors \((J^P = 1^-)\), where one registers only a small departure from the ideal mixing of

\[ (s\bar{s}) \quad \text{and} \quad \left( \frac{u\bar{u} + d\bar{d}}{\sqrt{2}} \right)_{I=0}. \]

However, recent LEAR data \cite{4, 5} show that ratios of the type

\[
\begin{align*}
\frac{p\bar{p} \rightarrow \Phi + X}{p\bar{p} \rightarrow \omega + X}
\end{align*}
\]

are together larger than expected and state-dependent. This raises questions about mechanisms for violation of the OZI rule and in particular, the influence of multiquark resonances on the dynamics of annihilation.

I note that the \(\Phi\Phi\) channel is presently studied at LEAR, in a narrow \(\sqrt{s}\) range, which could be enlarged if SuperLEAR is built. Studies on electro- or photo-production of the \(\Phi\) were also presented by Laget \cite{6}, who reviewed several aspects of strangeness production.
Radiative decays of the $\Phi$, such as $\Phi \rightarrow \gamma + S$, where $S$ is a scalar ($J^P = 0^+$) meson, can reveal some aspects of the $\Phi$ wave function, but this is so far more oriented toward studying the scalar mesons themselves, whose $q\bar{q}$ vs. $(q\bar{q})^2$ vs. $K\bar{K}$ nature is highly controversial [7].

The situation is presumably more delicate in the pseudoscalar sector than in the vector one. Here, besides the $(ss)$ and $(u\bar{u} + d\bar{d})$ configurations, one expects a rather large gluonic component, especially for the $\eta'$ meson. This is why looking at the relative importance of $\eta\eta$, $\eta\eta'$, and $\pi^0\pi^0$ decays is acknowledged as crucial for separating glueballs from multiquarks.

There are many new data on the decays of neutrals into $\eta$, $\eta'$ and $\pi^0$, thanks to the Cristal Barrel experiment at LEAR [4]. We have also been reminded that $\eta$ and $\eta'$ production is studied at Saturne [8]. To the extent that $\eta$ are produced through specific $N^*$ resonances, on can study how these $N^*$ behave in the nuclei.

Not surprisingly, one thinks of building $\Phi$ or $\eta$ factories, to study CP violation and rare, very rare or forbidden decays [9]. These are very delicate experiments, which compete with those based on high-energy kaon beams.

### 2.2 $S = -1$ baryons and hypernuclei

We have heard that progress have been made recently or can be expected on the magnetic moments of hyperons [10]. This helps measuring small departures of the naive quark model, which works astonishingly well.

The data clearly show that the masses and magnetic moments of ground-state baryons exhibit a very smooth behaviour in flavour space. For instance, we have for the mass differences $\Lambda - N < \Delta - N$, meaning that flavour excitation costs less than a single spin excitation. This is rather naturally explained in the very naive constituent models with flavour-independent confinement and moderate quark-mass difference $m_s - m_q$.

On the other hand, one needs a more laborious tuning in some more ambitious models, where at zeroth order, spin is averaged and flavour excitation is pushed very high.

The excitations of hyperons are either not too well known, or poorly understood by simple extrapolation of the non-strange sector. We are all aware of the long-standing problem of the $\Lambda(1520) - \Lambda(1415)$ splitting. There are difficulties with other multiplets. Moreover, several states in the $\Lambda$ or $\Sigma$ spectrum await confirmation or discovery, and this is a severe handicap for studying how the strange quark feels confinement forces.

Hypernuclei with $S = -1$ have been known for years, thanks to $(K^-, \pi^-)$ and other experiments. This was reviewed by Gal [11]. An interesting progress was made at CERN, with heavy hypernuclei seen as delayed fission products following $\vec{p}$ annihilation. Refined measurements at KEK, in the $^{12}$C sector, includes polarization and a comparison of mesonic vs. non-mesonic decay modes [12].
2.3 $S = -2$ dibaryons and hypernuclei

As recalled by Gal (see the references in his paper [11]), the $H$ (uuddss) was first predicted by Jaffe in 1977, with a simple wave function

$$|H\rangle = \sqrt{\frac{1}{5}} \left( \sqrt{\frac{1}{8}} |\Lambda\Lambda\rangle + \sqrt{\frac{4}{8}} |\Xi N\rangle + \sqrt{\frac{3}{8}} |\Sigma \Sigma\rangle \right) + \cdots$$

where the dots can be read either as an hidden-colour component or as the result of permuting the quarks. This wave function optimizes the chromomagnetic interaction and leads to a sizeable binding of $\sim 150 \text{ MeV}$. The stability suffers however from many types of effects: chromoelectric forces, kinetic energy, breaking of the $SU(3)$ symmetry, etc. As a result, the predictions considerably vary from one author to another, and even the existence of the $H$ is controversial.

The $H$ has been sought for in several experiments, without success so far. The problem is that the behaviour of the hypothetical $H$ depends dramatically on its mass. One does not design the same detector for a $\Lambda\Lambda$ resonance, a loosely bound state which decays weakly, and a very stable state to be seen from its missing mass and momentum.

An indirect indication against the $H$ is provided by the $S = -2, B > 2$ hypernuclei. Comparing the binding energy with those of $S = -1$ hypernuclei leads to an estimate

$$\delta B_{\Lambda\Lambda} \equiv B_{\Lambda\Lambda} - 2B_{\Lambda} \simeq 4 - 5 \text{ MeV},$$

which can be interpreted in terms of average baryon–baryon potentials (attractive) as

$$| V_{AN} | < | V_{AA} | < | V_{NN} |.$$

The later inequality makes it unlikely for a $\Lambda\Lambda$ bound state to exist, unless there is some very short range attraction separated by a repulsive barrier from the moderate attraction seen in $S = -2$ hypernuclei. New experiments are planned, with stopped $\Xi$, $(K^-, K^+)$ reactions, or with the strange quarks produced in $p$ annihilation.

2.4 Larger ($-S$) states

We have seen that the speculations on strange matter first written in terms of quarks by Fahri, Jaffe, etc. have been reanalyzed using a more conventional baryon basis [11]. The results are qualitatively similar, and very dramatic. When one tries to increase the average strangeness $(-S)/A$, one better spreads strangeness into different types of hyperons. Then $\Sigma$'s, $\Xi$'s and heavier hyperons supplement the $\Lambda$'s as constituents of the nucleus, and the resulting hypernucleus becomes more and more stable. This new spectroscopy

is unfortunately out of reach of our experimental devices.
3 Charm

3.1 Hidden charm

Our knowledge of Charmonium is now much more accurate, thanks to the measurements of the E760 experiment at Fermilab, which confirm and improve the results obtained earlier by the R704 collaboration at CERN. The $p\bar{p}$ reaction gives access to all quantum numbers and allow for very precise mass determinations.

It was underlined by Palestini [13] that the mass of the $^1P_1$ state almost coincides with the centre-of-gravity of the triplet states, namely

$$^1P_1 = \frac{1}{9}(^3P_0) + \frac{3}{9}(^3P_1) + \frac{5}{9}(^3P_2) + 1 \text{ MeV}.$$ 

This confirms the most accepted ideas about spin forces: the spin-spin term is very short ranged, and thus does not affect the $\ell > 0$ partial waves, whose wave function vanishes at the origin.

One would be tempted to jump on the small “1 MeV” departure and interpret it in terms of $\alpha_s^2$ corrections in QCD (running coupling constant and vertex corrections), smearing of the Breit–Fermi contact term, relativistic effects, deviations from a purely scalar confinement, etc. However, at this level of precision, one should first account for more trivial effects. Let me quote some of these:

1) The centre-of-gravity formula (see above) eliminates spin-orbit and tensor forces only at first order. In the Hamiltonian, the spin-orbit and tensor couplings enter linearly and vary from one $^3P_J$ state to another. The lowest eigenvalue is thus a concave function of these couplings [14]. This means that the fictitious triplet state free of spin-orbit and tensor forces should lie slightly above the naive centre of gravity. My numerical estimates give something like $3 - 5 \text{ MeV}$, indicating that the spin–spin force is attractive in the $\ell = 1$ sector.

2) From general symmetry considerations (and the literature on NN, N\(\bar{N}\), etc.) we know that a spin 1/2 – spin 1/2 system as $c\bar{c}$ involves five independent spin operators. A type of “quadratic spin-orbit” operator should supplement the usual central, spin-spin, spin-orbit and tensor terms.

3) The tensor force induces a small mixing between $^3P_2$ and $^3F_2$, which slightly lowers the former.

In short, the phenomenological analysis becomes rather delicate at the MeV level, and probably requires a relativistic framework.

New data are expected on the $\eta_c'$ whose present status is rather weak. It was noted by many authors (see, e.g., Ref. [15]), that the ratio

$$\frac{\Psi' - \eta_c'}{J/\Psi - \eta_c} = \frac{93 \text{ MeV}}{112 \text{ MeV}}'$$

as given by $e^+e^-$ data, is a little too large to be easily reproduced in potential models. With the recent increase of the hyperfine splitting ($J/\Psi - \eta_c$) of the ground state in $p\bar{p}$ data, this becomes even more problematic.
It was noted in [15] that some sophisticated models with explicit account for the
coupling to continuum states,

$$|\Psi\rangle = |c\bar{c}\rangle + \epsilon |c\bar{q}, \bar{c}q\rangle + \cdots$$
do not improve the fit of fine and hyperfine splittings. This is an amazing paradox that
the simplest models work at best.

There are also open questions concerning the decay of Charmonium. Most of them
are understood in terms of a simple mechanism folded with the probability $|\Phi(0)|^2$
of finding the quark and the antiquark together. However, the ratio

$$\frac{\Psi' \to \pi\rho}{J/\Psi \to \pi\rho}$$

seems abnormally small, as if a mysterious long-range component would make it sen-
sitive to the node structure, or as if it was influenced by a resonance sitting near the
$J/\Psi$.

Anselmino [16] also pointed out that the branching ratio for

$$\eta_c \to \pi\bar{p}$$
is much larger than the most optimistic theoretical expectations. This is fortunate
for experimentalists, and this might help the projects of doing refined $c\bar{c}$ or even $b\bar{b}$
spectroscopy with antiprotons (SuperLEAR project [4]). This is however a challenge
for theorists. I note that in a similar energy range, one starts measuring branching
ratios for flavoured mesons (with $b$ or $c$) into baryon–antibaryon pairs: they are due
to weak forces, but the hadronization might be comparable.

As noted by Amsler [4], SuperLEAR is not just a machine to do quarkonium spec-
troscopy. This is a good place to look at hybrid states, of content $c\bar{c}g$. Those states can
be seen as excitations of the gluon field surrounding the heavy quarks. Hybrids might
exist in several sectors of hadron spectroscopy, but they are better seen in Charmo-
nium: the spectrum of ordinary $c\bar{c}$ excitations is well measured and well understood,
so any exotic state that does fit as a radial or orbital excitation is easily singled out.

### 3.2 Open charm

The spectroscopy of $D$ mesons is regularly improved, and some orbital excitations are
now identified [17]. During recent months, more activity was devoted to charmed
baryons. The subject was reviewed by Paul [18]. Again, simple potential models,
extrapolated from ordinary and strange baryons, account quite reasonably for the
masses of charmed baryons with or without strangeness. I notice in a recent paper
by Riska [19], that his estimates of $Q\bar{Q}q$ masses in the Skyrmion model are significantly
lower than these predicted by potential models.

Besides spectroscopy, charmed baryons are interesting for studying the weak decays
and subsequent hadronization. From the comparison between $D^+$ and $D^0$ lifetimes
and branching ratios, we understand that the charmed quark, while decaying, does not ignore its environment. The same is true for baryons, and one expects significant differences between the decay patterns of cud, csu, csd, and css.

There are many developments one might dream of in the field of charmed baryons: magnetic moments, detailed decay properties, orbital excitations, etc. One can anticipate a stimulating competition between various experiments with electron or hadron beams.

The sector of baryons with two heavy quarks, previously considered as a pure speculation [20], is now taken more seriously: there is some hope to produce them at Fermilab [21], and there are presently new studies on their spectroscopy [22] and decay properties [24, 22]. If QQq baryons are accessible, one should also look at QQQ̅ mesons, whose existence has been predicted [23], as a consequence of flavour independence. Baryons with charm $C = 1$ and strangeness $S = -1$ have been seen [17], and are under active study at CERN and Fermilab [13]. There are speculations about baryons with $C = -1$ and $S = -1$ or $-2$, i.e. of quark structure $[c\bar{s}uud]$ or $[c\bar{s}sud]$ [24, 13]. There are active searches, again at both CERN and Fermilab [13, 23].

### 3.3 Charm in nuclei

The subject was discussed by Seth [26] and also touched by other speakers.

One might first think of charmed hypernuclei. Since $\Lambda_c$ is heavy, it would experience the inner part of the nucleus. But these states are not easily produced. The kinematics is much less favourable than for ordinary hypernuclei.

More fashionable is the $c\bar{c}$–nucleon or $c\bar{c}$–nucleus interaction. In principle, this is a clean example of interhadronic force without quark interchange, so a nice laboratory for studying the Van-der-Waals regime of QCD. It may be that the interaction is attractive enough to produce $c\bar{c}$–nucleus bound states.

The so-called $J/\Psi$ suppression is considered as a signature for the quark–gluon plasma. The interpretation of the data coming from relativistic heavy ions requires the knowledge of “ordinary” rescattering effects, i.e. the $J/\Psi$ and $\Psi'$ cross section on nucleons and nuclei.

One usually accepts the idea that these cross-sections are small, because Charmonia are small objects, and that $\sigma(\Psi') > \sigma(J/\Psi)$. In fact $J/\Psi$ and $\Psi'$ have two radii: one is the mean $c\bar{c}$ separation, which is indeed small for $\Psi'$, and even smaller for $J/\Psi$; the second is the radius of the gluon field surrounding the quarks, typically 1 fm in bag models, for both $\Psi'$ and $J/\Psi$. So, if one believes that the gluons contribute to the cross-section, one expects $\sigma(\Psi')$ and $\sigma(J/\Psi)$ to be nearly equal and not too small.

Studying how charmed quarks are produced in nuclei is one of the goals of future high-intensity machines.
4 Spin

Spin observables were mentioned in almost every talk, including these on future facilities. I shall come back only on three topics: \( \bar{N}N \) scattering, \( \Lambda \) production and high-energy reactions.

4.1 \( \bar{N}N \) scattering

The experimental results and their interpretation were reviewed by Bradamante \[27\]. The \( \bar{N}N \) interaction is very strong and includes many contributions: meson exchanges, s-channel resonances, annihilation. To learn something, one has to apply filters, which enhance one component after the other. This is precisely the job of spin parameters, and already constraints have been set on the phenomenological models from the data on analysing power and depolarization.

If I had to comment on the theoretical activity, I would say that one does not gain much by searching the minimal \( \chi^2 \) in models with many parameters. Sometimes, after many hours of expensive computing, one is not able to say which ingredients of the model are crucial, and which new observables are worth measuring.

One gets better insight by crude fits with simple models whose physical content is better understood. For instance, one expects that the combined contributions of pseudoscalar and vector meson exchanges lead to dramatic tensor forces. This induces large values of specific rank-2 observables, with longitudinal polarization, whose measurement has never been done. It is a pity that the LEAR programme of \( \bar{N}N \) scattering has been stopped. I hope it will be resumed very soon.

As reviewed by Amsler \[4\] and Bressani \[5\], we have now many data on the branching ratios for annihilation at rest. One cannot understand annihilation without a good control of the initial state interaction, which is strongly spin and isospin dependent. This is why the annihilation and the scattering experiments with antiprotons are complementary.

This complementarity is nicely illustrated by the data of the PS172 collaboration on the \( p\bar{p} \rightarrow \pi\pi \) and \( p\bar{p} \rightarrow K\bar{K} \) reactions. They found very large asymmetry parameters, nearly saturating the unitarity limit in a wide angle and energy range. This implies a maximal interference between the two independent helicity amplitudes \( F_{++} \) and \( F_{+-} \), which is due to the strong tensor force in the initial state, and the non-local character of the annihilation operator \[28\].

4.2 \( \Lambda \) production

The hyperons produced in high-energy experiments are polarized, even at very large momentum transfer, while antihyperons produced on nuclear targets are not polarized \[10, 16, 29\].

At first sight, this seems a leading particle effect associated with an intrinsic polarization of the strange quark. If, indeed, one identifies the spin of the \( \Lambda \) with that of
the strange quark, the spin of the \( \Sigma \) with its opposite, and the spin of the \( \Xi \) with half the spin of the ss pair, then a 20\% polarization of the strange quark explains the data on hyperons.

The problem is that one does not believe anymore that the spin of a baryon is so simply related to the spins of its valence quarks: recent experiments on lepton scattering have taught us to be cautious, though the situation might depend on the region of the structure functions one is looking at.

The study of \( \Lambda \) polarization is now performed at lower energy. An experiment has been approved at Saturne [30], based on the reaction \( pp \rightarrow N K \Lambda \). The comparison with

\[
pp \rightarrow p K \Lambda + \text{cc. (feasible at CERN)}
\]

would be instructive.

The PS185 collaboration at CERN has beautiful data on the hypercharge-exchange reaction \( pp \rightarrow p \Lambda \bar{\Lambda} \): cross-section, polarization and spin correlation in the final state. An intriguing result is that the reaction takes place always in the triplet state, instead of 75\% of the time only if spin-dependent forces would be absent. One has difficulties understanding why the transition is so much suppressed in the spin singlet case.

### 4.3 QCD and spin effects

This is a well-known and well-ignored problem. Some physicists persistingly stress the failure of QCD, or at least of the naive approach to QCD, for the spin effects which are observed at large energy and momentum transfer. The rest of the community, unfortunately, does not care too much about the spin measurements, and behaves as if everything was fine with QCD. At this point, this becomes more a problem of sociology than of physics.

Some the hotest questions have been reviewed by Anselmino [16] and also discussed by Maggiora [31]. Among the possible remedies, Anselmino suggested the use of di-quark clusters for constructing the baryon wave functions. Diquarks will be discussed at length at another Workshop, which will also take place at Villa Gualino.

From what we heard on the surprizing results of spin measurements, we should seriously study the possibility of polarizing the beams, when designing the future accelerators. Otherwise, one risks missing important pieces of physics.

The same is true for electro-weak physics. To test the standard model in detail, and look at possible departures, for instance a restoration of left-right symmetry, one has to use spin measurements.

### 5 Future facilities

Everyone in the audience has in mind his favourite project, for continuing the physics we have discussed along this Workshop: kaon factory (EHF, KAON), \( \tau \)-charm factory, B–factory, SuperLEAR, high-flux electron machine, etc.
This abundance of projects, all studied in great detail, shows how our field is alive. What is less encouraging, is that most proposals are here for years, and we do not see any sign of serious approval. For sure, only an ambitious project can stimulate the community toward a long-term programme of hadronic physics in the confinement regime. However, preliminary investigations can be done by improving existing machines or by using other facilities not primarily devoted to this field.

5.1 Improving existing facilities

As stressed by Vigdor [32], there are many developments possible at Brookhaven or Fermilab, besides the main stream, which are top quark physics and quark-gluon plasma, respectively. The same is true for CERN. There are many workshops, study groups, proposals, to examine the physics which can be done apart from LEP2 and LHC, but nothing is on the track of being approved.

SuperLEAR [4] is a typical example: the cost is small, the physics programme is very interesting, the community is active and eager to continue, but the project is not supported by the CERN authorities.

We have also been informed of projects concerning Saturne [33]. This is not the first proposal for upgrading Saturne; I hope this one will be further discussed. After all, we know from the PS and AGS, that many developments are possible, once one has in hand a good machine.

5.2 Parasitic experiments

The approved DAΦNE facility at Frascati will be mainly devoted to studies of kaon decay, and in particular CP violation. One can also use the clean kaon beams to do strong interaction physics [3], for instance the study of hyperons resonances, in free air or in the nuclear medium.

A. d’Angelo [34] gave a status report on the GRAL project, with is a polarized photon beam built out of the ESRF (synchrotron radiation) at Grenoble. Again, strangeness production can be studied, but there are many other interesting applications.

5.3 New facilities

We have learned that the italian community [35] is very eager to benefit from the new facility CEBAF, which will be operative rather soon. Meanwhile, other electron beams (with lower energy) will be running in Europe. The very ambitious european project of 15 GeV electron machine was not presented at this Workshop, but very present in our mind. The name is now EEF, to recall the late EHF, and the Workshops take place at Mainz, in the very same rooms where the EHF proposal was elaborated. The cost of EEF is also comparable to that of a kaon factory. Of course, one cannot compare the physics programme of EEF with the huge shopping list of EHF or KAON, which have a variety of secondary beams, but EEF would allow for very precise and
clean investigations of the behaviour of the quarks in the nuclear medium. Tons of documents have been produced, and the best QCD experts have stressed the relevance of the planned experiments. I think there is no reason for postponing the decision. One should balance the physics and the cost, and either give the green light or propose new means for investigating confinement.

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