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SYMPOSIUM SUMMARY

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Abstract

Highlights of the Sixth International Symposium on Meson-Nucleon Physics and the Structure of the Nucleon are reviewed and put in perspective.

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1. Introduction

The Sixth International Symposium on Meson-Nucleon Physics and the Structure of the Nucleon covered a rich variety of subjects:

1. The properties of the N^* and Δ^* resonances including their electromagnetic couplings; clusters of resonances, parity doublets and other patterns found in the ensemble of resonances.
2. The values of the pion-nucleon and eta-nucleon coupling constants.
3. The values of the πN and ηN scattering lengths.
4. The strangeness content of the nucleon via the σ-term.
5. The SU(3) and quark-model classification of the nucleon resonances.
6. The applicability of effective field theories which are consistent with QCD such as chiral perturbation theory.
7. The possible existence of non-traditional nuclear matter.
8. The structure functions of the nucleon.
9. The nucleon form factors.
10. Charge independence and charge symmetry,

and a lot more.

The symposium featured 78 talks, plus contributions. We have seen, or at least had a chance to see, over 1500 transparencies. I have asked many speakers for their favorite picture for possible presentation in the summary talk. I was happy with the universally generous response to this request as I received at least 3 transparencies from most speakers! I want to apologize for not being able to show and comment on all of the work presented.

2. Nucleon Resonances and πN Partial Wave Analyses

The complete listing of the baryon resonances given in the latest edition of the Review of Particle Properties [1] is summarized in Table 1. It is customary to classify the resonances in four categories:

- **a** four-star states; they are well established and their properties have been explored in some detail;
- **b** three-star cases; their existence ranges from very likely to certain; further confirmation is desirable and/or the properties are not well determined;
- **c** two-star candidates; the evidence of their existence is only fair;
- **d** one-star cases; the evidence of their existence is poor.

Table 1:Inventory of the light-quark baryon states.

* * * * = well established
* * * = reasonably established
* * = questionable
* = hint

				Star Assignment			
I	S	Family Symbol	Total # of Resonances	****	***	**	*
$\frac{1}{2}$	0	N^*	22	11	3	5	3
$\frac{3}{2}$	0	Δ^*	22	7	4	4	7
0	-1	Λ^*	18	9	5	1	3
1	-1	Σ^*	26	6	4	8	8
$\frac{1}{2}$	-2	Ξ^*	11	2	4	2	3
0	-3	Ω^*	4	1	1	2	-

Until recently the star assignment of resonances and the determination of the quantum numbers, the mass, width and elasticities, was the provenance of πN partial wave analyses (PWA). This situation is changing as excellent new data on photo- and electroproduction of mesons is becoming available; for example the precision $\gamma p \rightarrow \eta p$ data from MAMI provide new insight into the $N^*(1535)$ resonance. Inelastic channels such as $(\pi, 2\pi)$, (π, ω) and (γ, ω) reactions are expected to contribute substantially in the future to baryon spectroscopy, especially to the search for new states.

The phenomenology of basic πN elastic scattering requires a data base that consists of $d\sigma/d\Omega$, $A_y = P$ (transverse polarization) and A (spin transfer) experimental results for all three isospin channels, $\pi^{\pm}p \rightarrow \pi^{\pm}p$ and $\pi^{-}p \rightarrow \pi^{o}n$. The full ensemble of all published data is used for an energy-dependent partial wave analysis (PWA). Unfortunately, the data base is incomplete at most energies. The notable exception is at p_π = 427 to 657 MeV/c where the full set of 8 experiments [2] was run at the same beam settings; the work was performed at LAMPF in its heyday. There are some overlapping data sets which are mutually incompatible and there are even a few data sets that are plainly wrong. Finally, one must deal with the ambiguities that plague any PWA. The available πN PWA's can be divided into two categories. The first one depends heavily on constraints from theory for obtaining a unique set of partial waves. This includes the use of Lorentz invariance, unitarity and Mandelstam analyticity in the form of dispersion relations. This approach is favored by the groups of Karlsruhe-Helsinki (K-H), which is spearheaded by Gerhard Höhler, Carnegie-Mellon-Lawrence-Berkely-Laboratory (C-L) which was headed by the late Dick Cutkosky, and by the Petersburg Nuclear Physics Institute (PNPI) whose chief analyst is Vladimir Abaev. The other category uses some theory, but the main constraints are based on χ^2-tests. This approach is used by the group of the Virginia Polytechnic Institute (VPI) headed by Dick Arndt, it is known everywhere for its popular SAID program. The most recent entrant in the πN PWA business is R. Timmermans with a brand new low-energy version. The resonance parameters listed in the Review of Particle Properties are a consensus of the results obtained by the K-H, C-L and VPI groups.

Even a cursory inspection of the pole positions of the various baryon resonances reveals some clustering, see Table 2. This is unexpected and is not anticipated by any model or theory. It was first reported by G. Höhler and I would like to suggest naming these the **Höhler clusters.** To determine the extent to which the cluster phenomenon holds requires making more detailed measurements of the elastic, charge exchange and particularly the inelastic channels.

Further inspection of the list of baryon resonances shows that quite a few states can be grouped into parity doublets, e.g. the $N^*(1670)$, $J^P = \frac{5}{2}^-$, pairs with the $N^*(1680)$, $J^P = \frac{5}{2}^+$. These parity doublets could be the result of the cluster pattern. Or they could be indicative of an underlying geometric structure of the resonances as is emphasized by Iachello [3]. Or, they may be a manifestation of chiral dynamics as championed by D. Riska [4]. To establish uniquely the extent and origin of the parity doublets a large series of accurate baryon spectroscopy measurements is needed to obtain the full picture of all resonances including the ones that are mainly inelastic.

Many high points and subtle details laced the invited talks on the different PWA's that are currently in use.

a G. Höhler concentrated on theoretical constraints which because of the continuum ambiguities are important for a PWA. He stressed the importance of verifying the compatibility of the PWA with Mandelstam analyticity. He pointed out an urgent

Table 2. Clusters of baryon resonances having the same pole position (Höhler clusters).

Symbol	Name (mass)	Pole (MeV)	Comment
N^*	$S_{11}(1650), P_{11}(1710), P_{13}(1720), D_{13}(1700), D_{15}(1675), F_{15}(1680)$	$(1665\pm25) -(55 \pm15)i$	well establ.
N^*	$S_{11}(2090), P_{11}(2100), D_{13}(2080), D_{15}(2200), G_{17}(2190), G_{19}(2250), H_{19}(2230)$	$(2110\pm 50) -(180\pm50)i$	less establ.
Δ^*	$S_{31}(1890), P_{31}(1910), P_{33}(1920), D_{33}(1940), D_{35}(1930), F_{17}(1950)$	$(1820\pm30) -(120\pm30)i$	well establ.
Δ^*	$D_{35}(2350), F_{37}(2390), G_{39}(2400), H_{39}(2300), H_{3,11}(2400)$		less establ.
Λ^*	$S_{01}(1800), P_{01}(1810), P_{03}(1890), D_{05}(1830), F_{05}(1820)$		well establ.
Σ^*	$S_{11}(1620), P_{11}(1660), D_{13}(1670), ?(1690)$		less establ.

need for more accurate π-charge-exchange cross section measurements. He also advised that sufficient attention be given to the electromagnetic corrections.

b R. Arndt discussed the new resonance parameters obtained from the latest VPI PWA which is now constrained by fixed-t dispersion relations. He presented two new resonance candidates, the $S_{11}(1712)$ and the F_{15} (1814); each one is assigned 2 stars. This VPI PWA does not show any indication of the existence of the $D_{13}(1700)$ which is prominent in K-H and C-L and is even listed in the Review of Particle Properties as deserving 3 stars. This matter needs clarification.

c The PNPI group has made a new measurement of the spin rotation parameters for π^+p elastic scattering at 1.43 GeV/c. V. Abaev discussed how the preliminary results favor the VPI PWA but are in substantial disagreement with K-H and C-L.

d R. Timmermans presented the outline and the results of his brand-new low-energy PWA. It has good analyticity properties but otherwise the theoretical input is kept to a minimum, this is of course in stark contrast to K-H. Charge dependence is allowed. The problem of the inconsistent data sets is handled by renormalization, using standard χ^2 criteria. The approach is certainly very interesting and should be pursued, with proper attention paid to an adequate justification of the data renormalizations. Fine tuning of the method should include a way to account for the error in the beam momentum which often can explain inconsistent data sets. It would be an interesting challenge to extend this PWA to higher energies where the inelastic channels play a large role. This holds particularly at the opening of the η channel with its associated cusp in the elastic channels.

3. πN Scattering and Pion Photoproduction

An important objective of the πN symposia is to provide an open, international forum for discussing the quality of the data bases used in the major πN PWA's. A frank and full discussion of the experimental and theoretical problems is needed in order to achieve reliable PWA's. This was an important motivation in launching the first πN symposium 12 years ago [5]. At that occasion the star evaluation schema for experimental data [6] was introduced in an effort to improve the πN PWA's.

It happens occasionally that overlapping data sets from different experiments are not compatible with one another. Sometimes this can be remedied by an overall renormalization of one or both data sets. This happens when systematic factors such as beam contamination are not evaluated adequately. A stickier problem is an error in the absolute beam momentum. This is the case in some older experiments particularly at low energy. If such beam momentum error is corrected in the data amalgamation for the PWA by a renormalization of the absolute scale of the cross section one is likely to introduce an error in the shape of the angular distribution.

A single data set may be in error even though there is no other, analogous experiment for bringing this to light by a χ^2 compatibility test. Such a case may become apparent when the data set does not agree with reasonable theoretical constraints. A classic case is the large set of charge exchange data which are not consistent with the expected behavior of their zero trajectories. G. Höhler is the acknowledged expert in the subtle business of using theoretical constraints in the PWA.

Much needed attention was given in this symposium to the discussion of recent low-energy experiments where older data show some serious discrepancies. Low-energy πN results are necessary ingredients when evaluating the πN scattering lengths, the πNN coupling constant and the σ-term. Invited talks on these subjects included the following:

a R. Ristinen reviewed the results of the measurements of "partial total cross sections", an oxymoron that stands for partially integrated differential cross sections, typically 20° to 180°. The Colorado data is still preliminary but the analysis is far enough along to conclude that there is 5-10% disagreement with the venerable Pedroni et al. data as well as with Brack et al. and consequently with the K-H PWA.

b L. D. Isenhower et al. now have the world record for lowest energy charge-exchange measurements.

c A parallel session on πN scattering featured detailed accounts of the latest experiments; this included M. Pavan on $\pi^{\pm}p$ elastic scattering at TRIUMF at energies that span the delta resonance and R. Wieser on the PSI $\pi^{\pm}p$ results at 33 to 68 MeV. G. Hofman showed the newest $\pi^{\pm}$ analysing power data at $p_{\pi} = 67 - 139$ MeV obtained with the versatile CHAOS detector at TRIUMF. The status of the data was summarized by G. Smith, the workshop chairman, as follows: "there are still discrepancies at lower T_π, qualitatively the overall picture clearly shows that the K-H PWA overpredicts low energy cross sections, the K-H S waves are about 20% too high."

d There are beautiful PSI data on pionic hydrogen and deuterium obtained with a bent-crystal spectrometer, presented by A. Badertscher. This provides the best information on the hadronic S-wave πN scattering length, $a_{\pi\to\pi^- p} = (0.0885 \pm 0.0009) m_\pi^{-1}$, and $a_{\pi^- p\to\pi^o n} = (0.136 \pm 0.010) m_\pi^{-1}$.

e There is a wealth of new data coming from the new electron accelerators. This was the main subject of workshop *Ib* and it has been summarized succinctly by its chairman, L. Tiator. F. Härter presented precise $\sigma_t(\gamma, \pi^o)$ in the energy region 200-780 MeV from MAMI. Pedroni showed complete measurements of the 2π channels on p and d, also from MAMI. CEBAF's CLAS collaboration has great plans to go after many N^* resonances, at least from P_{11} to F_{15}, this was outlined by D. Cords. M. Distler discussed $(e, e'\pi^o)$ at threshold to test chiral perturbation theory.

f A. Bernstein discussed a method to find the unitary cusp in $p(\gamma, \pi^0)p$ near threshold at the opening of the $p(\gamma, \pi^+)n$ channel.

4. Eta Physics

There were 12 contributions on eta production which is an indication of the growing popularity of this field. The interest in η physics is driven by several factors. Firstly, η production is a practical isospin filter. E.g. the reaction $\pi^- p \to \eta n$ probes just the $I = \frac{1}{2}$ states. By contrast, the more common $\pi^- p \to \pi^- p$ reaction involves a mixture of $I = \frac{1}{2}$ and $\frac{3}{2}$ states. Secondly, the ηN S-wave scattering length $(a_{\eta N})$ is large and attractive, unlike $a_{\pi N}$, which is small and repulsive. The large $a_{\eta N}$ has given rise to speculations about the existence of a new type of nuclear matter, the eta-mesic nucleus. Thirdly, eta production by π or γ near threshold is dominated by an unusual S-wave resonance, the $N^*(1535)$. Thus, inelastic η production will allow to trace sequential baryon decays. E.g. consider the reaction $\pi^- p \to \pi\eta N$. This may occur via two different N^* intermediate states, one decaying to the other, like $\pi^- p \to N^*(X) \to \pi^o N^*(1535) \to \pi^o N\eta$. Fourthly, the η, which is a pseudo-scalar meson with G-parity + 1, mixes with the π^o, which has G$= -1$. $\pi^o - \eta$ mixing potentially can cause a large breaking of charge symmetry. It provides therefore a way to measure the mass difference of the up and down quarks.

In the area of photoproduction, B. Krusche presented an impressive collection of high precision total and differential cross section data for η production on p, d and other nuclear targets from threshold to 780 MeV measured with the TAPS multiphoton spectometer at MAMI. G. Anton outlined the η photoproduction program underway at ELSA, covering higher energies, up to 1150 MeV, by the PHOENICS collaboration. Already seen is coherent η photoproduction on d. The preliminary results indicate that the $\gamma d \to \eta d$ cross section is considerably smaller than reported years ago by Anderson et al. This solves a long standing puzzle for the theorists.

The very precise TAPS data has inspired much theoretical activity. Ch. Sauermann reported obtaining excellent agreement with the η production data on p and d using an effective field theory. N. Mukhopadyay found excellent agreement with the data on protons using his effective Lagrangian model; he also showed new predictions for η' production.

M. Clajus presented new η production data by pions on p and d near threshold from two just completed experiments at the AGS. The ratio $R_\eta = d\sigma(\pi^+ d \rightarrow \eta pp)/d\sigma(\pi^- p \rightarrow \eta nn)$ is expected to be 1.0 if charge symmetry is conserved. Near $p_\pi = 750$ Mev/c the preliminary experimental value is $R_\eta = 0.9$ which indicates a large violation of charge symmetry due to $\pi^o - \eta$ mixing. This experiment will allow a measurement of the dependence of charge symmetry breaking on the four-momentum transfer. This is of interest in connection with conflicting theoretical prognoses for the four-momentum-transfer dependence of the related $\rho^o - \omega$ mixing. The preliminary results on $\pi^- p \rightarrow \eta n$ showed conclusively that the original data by Brown et al. are in error. Forthcoming are new threshold data on $K^- p \rightarrow \eta\Lambda$ obtained by the same collaboration.

E. Vercellin reported on $pp \rightarrow pp\eta$ and $pd \rightarrow pnp\eta$ data from Saturne. The cross section rises rapidly near threshold, then levels off for $T_p \gtrsim 1.7$ GeV. $\sigma(np \rightarrow np\eta)$ is significantly larger than $\sigma(pp \rightarrow pp\eta)$, up to a factor of 10; this supports the idea that $\pi - \rho$ interference is involved in η production. This experiment also sees strong indications for a substantial inelastic η production at higher incident energies which can occur either via a well defined sequential decay, $pp \rightarrow NN^*(X) \rightarrow N\pi^o N^*(1535) \rightarrow N\pi^o N\eta$ or it can occur via double resonance production, $pp \rightarrow N^*(Y)N^*(1535) \rightarrow N\pi^o N^*(1535) \rightarrow N\pi^o N\eta$. This is of particular interest for the spectroscopy of higher mass N^*'s, as well as for theories of heavy ion collisions to understand the large η production.

The new cooler/storage ring CELSIUS is getting up to speed. T. Johansson reported on new measurements of the Dalitz plot for $pp \rightarrow pp\eta$ near threshold. By a comparison with the related reaction $pp \rightarrow pp\pi^o$ at suitable kinematics a tantalizing hint was seen for a strong ηp final state interaction at low energy.

There is a lot of interest in the value of the ηN scattering length ($a_{\eta N}$). The prospect for the existence of a bound, light, eta-mesic nucleus is much enhanced when $a_{\eta N}$ is large.

Abaev reported that $a_{\eta N} = [0.621 \pm 0.040 + i(0.306 \pm 0.034)]$ fm based on an S-wave resonance coupled-channel analysis. This value is in reasonable accord with the results of C. Wilkin and Ch. Sauermann. The original low value of 0.3 fm by Bhalerao-Liu was based on an erroneous data set. Arima et al. still hold the record for the highest value, $a_{\eta N} \simeq 1.0$ fm. An extensive comparison of the world's data was made by A. Švarc. Based on a 3-coupled channel multiresonance model he proposed $a_{\eta N} = (0.88 + i0.27)$ fm.

Bennhold et al. have analyzed with an effective Lagrangian model the precision η photoproduction data obtained by the TAPS collaboration, supplemented by preliminary ELSA data at higher energies, in an effort to obtain the ηNN coupling constant. They discussed both pseudo-vector and pseudo-scalar coupling, favoring the latter based on a slight backward/forward asymmetry seen in the TAPS differential cross section data. The ηNN coupling constant appears to be substantially less than πNN, though the case is not airtight.

A. Moalem presented a way to calculate the final-state corrections for η production near threshold in NN interactions. T. Ueda discussed the coupled ηNN-πNN systems near threshold and argued the case for a quasibound state with $I = 0, J^P = 1^-$.

5. The Pion-Nucleon Coupling Constant

The πNN coupling constant ($f_{\pi NN}$) is a basic parameter in nuclear and particle physics. Its precise value is of crucial importance for the quantitative treatment of nuclear stability. The low-energy theorems for pion photo- and leptoproduction and the Goldberger-Treiman relation depend on $f_{\pi NN}$ and so does the extraction of the σ-commutator from the πN cross section measurements. During the symposium excursion to Tübingen a Festvortrag at the University was presented by Torleif Ericson on "Problems in Pion-Nucleon Physics". Special emphasis was given to $f_{\pi NN}$. Torleif outlined eloquently the importance of this basic parameter and reminded his audience about the drastic consequences that even a small change in $f_{\pi NN}$ would have for the universe. A one percent increase is sufficient to have a bound diproton, while a one percent decrease causes the deuteron not to be bound; in either case we would not exist!

There are two symbols in use when referring to the πNN coupling constant. $f_{\pi NN}$ is used to indicate a pseudo-vector coupling while $g_{\pi NN}$ indicates the pseudo-scalar form. The relation between them is simply $f_{\pi NN} = (m_\pi/2m_N)g_{\pi NN}$. The historical value which originates from the Karlsruhe-Helsinki 1980 PWA is $f^2_{\pi NN} = 0.079 \pm 0.002$ or $g^2_{\pi NN} = 14.3 \pm 0.4$.

The symposium enjoyed learning about 3 new values for $f^2_{\pi NN}$. They are listed in Table 3 together with two older values which are based on the Nijmegen NN and $N\bar{N}$ analyses. $f^2_{\pi NN}$ is related to the isospin $\frac{1}{2}$ and $\frac{3}{2}$ scattering lengths (a_1 and a_3) by the Golberger-Miyazawa-Oehme relation $f^2_{\pi NN} = 0.1904(a_1 - a_3) + 0.0264$ as discussed for instance by Höhler in his talk. Using the best available value for $a_1 - a_3 = (0.288 \pm 0.021)m_\pi^{-1}$ he obtains the value quoted in the table.

Table 3. Determinations of the πNN coupling constant.

System	Origin	$f^2_{\pi NN}$
πN	VPI (Arndt)	0.076 ± 0.001
πN	Timmermans	0.0741 ± 0.0008
np	Uppsala (Loiseau)	$0.0808 \pm 0.0003 \pm 0.0017$
NN	Nijmegen	0.0748 ± 0.0003
$N\bar{N}$	Nijmegen	0.0732 ± 0.0011
πN	$a_1 - a_3$ (Höhler)	0.081 ± 0.004

The $f^2_{\pi NN}$ value from the VPI PWA presented by A. Arndt is based on a χ^2 minimization procedure which was carried out separately for the full data sets of π^+p, π^-p elastic scattering and $\pi^-p \rightarrow \pi^o n$ with consistent results. The coupling constant obtained by R. Timmermans is based on his brand new πN PWA which covers only the low energy πN data. The surprise result came from the Uppsala group reported by Loiseau. He discussed a new determination based on new np scattering differential cross section measurements at $T_n = 162$ MeV in the backward hemisphere and an improved extrapolation technique to the pole. The main input is the new np data from Uppsala. The vital absolute normalization of these data was done only indirectly; we eagerly await the results of an absolute measurement. In the meantime we must live with the discrepancies displayed in Table 3. Our personal choice is to use the result of the VPI group but to double the error, thus $f^2_{\pi NN} = 0.076 \pm 0.002$.

6. Pion Production

The production of pi-mesons in $(p, p\pi)$, $(\pi, 2\pi)$, etc. three-body reactions is important to baryon spectroscopy because the processes are dominated by N^* and Δ^* resonances in the intermediate state. Threshold π-production is of special interest for chiral perturbation theory; furthermore, the $(\pi,\ 2\pi)$ reaction allows a determination of the important S-wave $\pi\pi$-scattering lengths. They cannot be measured directly and must be obtained from $(\pi,\ 2\pi)$, or from the spectrum of the rare K_{e4}-decay.

Two parallel workshops were devoted to meson production, their chairmen, R. R. Johnson and R. Silbar have provided generous assistance with this part of the summary.

Low energy $pp \rightarrow pp\pi^o$ data taken in the early stages of the IUCF-Cooler operation have demonstrated that the $(p, p\pi^o)$ reaction is an effective filter for short-range contributions. Fresh data from the new CELSIUS cooler/storage ring confirmed this, the new measurements extend down to threshold + 600 keV. Dalitz-plot measurements of $(pp\pi^o)$ were made as well. The shape of the cross section is described by phase space plus pp final state interactions. The value of the absolute cross section is dominated by the short range part of the axial exchange charge-operator calculated by Lee and Riska. J. Haidenbauer has made a critical analysis of the theoretical approximations commonly used in calculating $pp \rightarrow pp\pi^o$ and concluded that the energy dependence is not yet fully understood.

Recently the new COSY cooler storage ring began operation. H. Machner presented the first data on $pp \rightarrow d\pi^+$ obtained very close to threshold. The angular distribution is isotropic and does not support the backward-forward asymmetry found at TRIUMF in the isospin related reaction $np \rightarrow d\pi^o$.

The Canadian High Acceptance Orbit Spectrometer (CHAOS) is a very good device for measuring 4 of the 5 different $\pi p \rightarrow \pi\pi N$ reactions; this was discussed in two contributions by M. Kermani and M. Sevior. Furthermore, J. Matthews presented new data on $\pi^-p \rightarrow \pi^+\pi^-n$ cross sections obtained at LAMPF with a special magnetic spectrometer. One of the objectives of the $(\pi, 2\pi)$ program is to determine the S-wave $\pi\pi$ scattering lengths. Chiral perturbation theory has made some spectacular predictions for these.

Improved theoretical analyses of the world $\pi\pi N$ data were obtained by V. Vereshagin and A. Miranda. It was concluded that more and better data are needed before a unique analysis is feasible. In the theoretical analyses one should include the effect of various N^* resonances, especially the Roper. Also, the validity of the Chew-Low extrapolation to threshold must be established.

7. Non-traditional Baryon Resonances

It is remarkable that every baryon and baryon resonance appears to be a simple 3-quark (qqq) state. Each such state is an SU(3) color singlet, meaning it is a completely antisymmetric state in the three quark colors [1]. Therefore, the space-spin-flavor part of the state function of every baryon must be symmetric. No glue is needed to describe a baryon and at low energy there is no evidence so far for a gluon degree of freedom. Yet, every theory of hadronic interactions implies the existence of many non-traditional states. One obvious type is the hybrid baryon consisting of 3 quarks and a gluon ($qqqG$); it is distinguished by a non-traditional spin-color combination. A hybrid baryon may be identified by its electromagnetic decay rate which is different for charged and neutral isospin partners [7]. This behavior is a consequence of the Moorhouse-Close-Barnes electromagnetic selection rules. The radiative decay of the charged baryons is best measured using the photoproduction reactions on a proton target $\gamma p \rightarrow N^+ \rightarrow \pi N$, while the decay rate for a neutral baryon must be measured via the inverse process, $\pi^- p \rightarrow N^o \rightarrow \gamma n$.

Ordinary nuclei are made of the traditional three-quark nucleons. Many QCD inspired models of strong interactions imply the existence of multi-quark bound states with hidden color degrees freedom and/or multi-quark states with exotic quark-cluster arrangements; the latter have non-traditional spin-color combinations. A much searched-for example is the so-called dibaryon. This could be a six-quark state, a six-quark-hybrid and/or a diquark-tetra-quark cluster. The Tübingen group and their collaborators have studied the possible existence of a unique, narrow dibaryon called d'; it has the quantum numbers $J^P = 0^-$, $I = 0$ and mass $\simeq$ 2065 MeV. A hint for this is the occurrence of a narrow peak of width $\simeq$ 5 MeV observed in the (π^+, π^-) double charge exchange (DCX) cross section at $T_\pi = 50$ MeV near $\Theta = 5°$ on a number of different nuclei from ^{12}C to ^{56}Fe. This peak is not explained by conventional DCX but rather well by the d' hypothesis. Details were discussed in a special session devoted to dibaryons with excellent presentations of the experimental aspects by R. Bilger, A. Lehmann and A. Khrykin, and the theoretical perspectives by M. Schepkin and A. Buchmann. Future endeavors concern finding new evidence for the d' in different type reactions. This is in accord with the first rule for a true dibaryon discovery outlined by M. Huber at the πN symposium held in Bad Honnef 4 years ago, namely: "detection must be at least in two independent reactions with consistent values of the mass and other properties."

8. The Polarized Structure Functions of the Nucleon

The discovery of scaling in deep inelastic electron scattering some 25 years ago and the successful launch of QCD shortly thereafter brought major changes in the approach to strong interactions. Quickly ignored were Regge poles and dispersion relations in favor of models based on gauge invariance. At low energy, QCD is not of much use, it is rendered impotent by lack of proper calculational tools, so one must turn to high energy reactions where perturbative calculations of QCD are possible. This requires among other things the experimental determination of the different polarized nucleonic structure functions which describe the quark distributions. Excellent survey talks and a spirited workshop were given on these matters including presentations by A. Bruell, U. Landgraf, M. Karliner and W. Meyer. The present situation may be summarized as follows.

1. Data obtained with different experimental probes involving polarized lepton beams and nuclear targets are substantially in agreement, typically at the 10% level. This has been possible because of the impressive improvements in polarization techniques, this aspect was strongly emphasized by W. Meyer. Currently available are $\vec{e}$ and $\vec{p}$ polarizations in the range 80-95%, $\vec{d}$ from 30-50% and $^3\vec{He}$ up to 40%.
2. It is currently not possible to calculate the quark distributions ab initio in QCD. However, some relations for integrals over the structure function, called sum rules, have been derived. The best known is the one by Bjorken, it governs the difference of the spin integrals for the proton and neutron; it can be derived rigorously in QCD. This Bjorken sum rule has now been confirmed at $1\sigma(\sim 10\%)$
3. A precise determination of the strong coupling strength α_s from the Bjorken sum rule yields $\alpha_s(m_Z^2) = 0.122^{+0.005}_{-0.009}$, this agrees with many other determinations of α_s which use very different processes. The remarkable q^2-dependence of α_s as predicted by QCD, $\alpha_s \propto 1/\ell n(q^2/\Lambda^2)$, is now well established.
4. The Ellis-Jaffe sum rule concerns just the proton structure functions. It has two additional assumptions over the Bjorken sum rule, namely it assumes SU(3) symmetry of the baryon wave function, and the strange-quark sea must be unpolarized (i.e. $\Delta S = 0$). All experiments now agree that the Ellis-Jaffe sum rule is violated at the level $\gtrsim 3\sigma$. The spin contribution of strange quarks is $\Delta S = -0.1$.
5. The nucleonic spin fraction carried by the $u-$, $d-$ and s-quarks combined is $\Delta\Sigma = 0.3 \pm 0.1$.
6. The gluon distribution in the nucleon increases for $x \longrightarrow 0$ where x is the momentum fraction of the quark that has been struck by the lepton.
7. There is a significant positive q^2-dependence of the ratio of the structure functions ${F_2}^0/F_2^c$ for $0.01 < x < 0.05$.
8. Important experimental programs for 1995 and 1996 are in progress at CERN (SMC), SLAC and DESY.

9. Miscellaneous

This symposium featured a wide spectrum of important topics involving pions and nucleons. The full coverage would exceed all reasonable boundaries of space and time. Below is a modest selection of some favorite subjects.

a The pion-nucleon sigma-term has been discussed in detail at all previous symposia. The theoretical value, labelled σ, is the nucleon matrix element of the quark mass term, $\sigma = [(m_u + m_d)/4M] < p|u\bar{u} + d\bar{d}|p >$. The experimental value, labelled Σ, is obtained from the continuation of the on-shell πN elastic scattering amplitude to the Cheng-Dashen point which lies in the unphysical region. M. Sainio gave an excellent update. The effect of lowering the pion-nucleon coupling constant $f^2_{\pi NN}$ from 0.079 to 0.076 would reduce Σ by 3 MeV to $\Sigma \simeq 60$ MeV. The uncertainty in Σ is about 10 MeV. The value for σ is $\simeq$ 45MeV with about 20% uncertainty, based on the u and d quark contribution in the nucleon. The difference between Σ and σ is thus a measure of the strangeness content of the proton which is defined as $y = 2 < p|s\bar{s}|p > / < p|u\bar{u} + d\bar{d}|p >$. This is of particular interest in view of the violation of the Ellis-Jaffe sum rule for the proton structure functions discussed in the previous section. The above values for Σ and σ yield $y = 0.2 \pm 0.2$. The expected value is $y \simeq 0.1$. This is based on a simple estimate of the $s\bar{s}$ content of the proton due to such classical sources as $\pi^o - \eta$ mixing combined with the $s\bar{s}$ content of the η. Thus we may conclude that within the present generous errors, the value of the σ-term is no reason for concern. However, there is room for ample improvement in theory and experiment.

2. Chiral perturbation theory, χPTh, is rapidly becoming a favorite model for many low energy QCD-based calculations involving a pion. H. Leutwyler eloquently discussed the foundations of χPTh which lie in chiral symmetry. The confrontation of χPTh with experiments in the πN sector was handled expertly by Ulf Meisner, including:

a Threshold πN scattering and the values of the S-wave pion-nucleon scattering lengths. This is certainly a great success story. E.g. the experimental results, based on pionic H and D are $a^- = (0.096 \pm 0.007)m_\pi^{-1}$, and $a^+ = (-0.0077 \pm 0.0071)m_\pi^{-1}$, the χPTh calculations give $a^- = (0.0092 \pm 0.004)m_\pi^{-1}$ and $a^+ = 0.00$.

b $\pi N \longrightarrow \pi\pi N$ at threshold and the determination of the S-wave $\pi\pi$ scattering lengths. This is another shining example of the success of χPTh.

c Low energy Compton scattering, $\gamma p \longrightarrow \gamma p$ provides a way to investigate the electromagnetic polarizabilities of the nucleon.

d Low-energy theorems for π^o photoproduction for the S-wave multipole E_{0+} and the P-wave multipoles. Such theories are quite successful in describing the order of magnitude; there is still plenty of room for improvement in experiment and the calculations. Recent work on charged pion electroproduction looks very promising.

e D. Riska discussed how the absence of nearby parity partners in the lowest states of the nucleon and hyperon resonances shows that approximate chiral symmetry is realized in the hidden mode at low excitation energy. With the assumption of an harmonic effective confining interaction between the constituent quarks he is able to predict the baryonic resonance levels within 5%.

3. The nucleonic form factors are helpful functions for testing models of the nucleon in the non-perturbative regime. Several new results were presented:

a J. Jourdan discussed the neutron magnetic form factor, new results are coming from inelastic electron scattering on deuterium which drastically reduces the error, down to the 2% level.

b S. Kopecky reported on new work on the charge radius of the neutron, the preliminary result is $\langle r_n^2 \rangle = (-0.124 \pm 0.03 \pm 0.07)$ fm^2.

c T. Hehl reported on work done at MAMI to measure the electric form factor of the neutron $G_E(n)$ with much improved accuracy using the $d(\vec{e}, e'\vec{n})$ reaction and involving an $\vec{n}$-spin rotating magnet.

d S. Gerasimov discussed the use of sum rules in connection with the electromagnetic moments of the baryons and the hidden strangeness of the nucleon.

e G. Holzwarth discussed the electromagnetic form factors of the proton using a chiral soliton model; G_m looks pretty good, but G_E leaves something to be desired.

4. Effective meson Lagrangians are the appropriate tool for the non-perturbative regime of QCD. J. Speth first discussed the scalar mesons $f_o(980)$ and $a_o(980)$ in the Jülich approach in which the $f_o(980)$ turns out to be a $K\bar{K}$ bound state and the a_o is generated as a dynamical threshold effect. Secondly, the P_{11} partial wave of πN scattering can be described without including a genuine Roper resonance.

5. Charge symmetry breaking is the only available phenomenon that enables us to determine the mass difference of the up and down quarks. The mass is not measurable since very likely no one will ever see a free quark. G. Miller reviewed different aspects of the breaking of charge symmetry and isospin with special emphasis on $\rho - \omega$ mixing and the hotly debated dependence on off-mass shell extrapolation. N. Kochelev discussed an interesting mechanism for charge symmetry breaking in $f_{\pi NN}$ that is based on the axial anomaly contribution to the nucleon spin. W. Gibbs outlined isospin breaking in πN interactions at low energy. The available data on $\pi^\pm p \to \pi^\pm p$ and $\pi^- p \to \pi^o n$ cross sections show a clear violation of order 7% of the triangle inequality beyond the Coulomb interactions and hadron mass differences.

10. Conclusion

Vigorous experimental programs in pion-nucleon physics in the regime of non-perturbative QCD are being conducted at the AGS, IUCF, PSI, PNPI, TRIUMF, ELSA and MAMI. We extend a big welcome to CELSIUS, COSY and CEBAF. Unfortunately, activities at LAMPF and Saturne are tapering off and they might come to a halt. There is a window of opportunity for expanded work in this area at the AGS, which for all practical purposes is a mini-KAON facility that is already in operation. The AGS can provide fluxes of $10^9 \pi^\pm$/sec and $10^{4-6} K^\pm$/sec in several beam lines simultaneously. The proposed move of the Crystal Ball from SLAC to BNL would increase enormously the opportunity for investigating baryon spectroscopy with neutrals in the final state.

On the theoretical side there is plenty of exciting activity centered around low-energy QCD. The high-fashion topic this year is chiral symmetry but the bulk of activity concerns the "ready-to-wear" effective Lagrangians, quark and flux-tube models, isospin and quark masses, structure functions, form factors, scattering lengths, coupling constants and so forth.

The success of this conference is due, not surprisingly, to a complicated non-linear combination of good speakers with excellent topics, spirited discussions and an efficient, fluid organization. It is a pleasure to express the gratitude of all participants for the excellent organization provided by Gerhard Wagner and his splendidly efficient local committee. A special thanks goes to Mareike Khalil, the symposium secretary, for carrying out effectively and cheerfully the daily activities that insured the smooth running of the Sixth International Symposium on Meson-Nucleon Physics and the Structure of the Nucleon, which I am happy to classify as a true four-star symposium.

References

1. Review of Particle Properties. Particle Data Group, Phys. Rev. **D50**, 1174 (1994).
2. ACU-GWU-LAMPF-UCLA collaboration. I. Supek et al., Phys. Rev. **D47**, 1762 (1993) and references quoted therein.
3. F. Iachello, Phys. Rev. Lett **62**, 2440 (1989).
4. Dan O. Riska, contribution to this conference and submitted to the πN Newsletter.
5. πN Newsletter # 1, January 1984, G. Höhler and B. M. K Nefkens, editors.
6. B. M. K. Nefkens in Few Body X, vol. I, ed. B. Zeitnitz, North Holland 1984, p. 193c.
7. T. Barnes and F. Close, Phys. Lett **128B**, 277 (1983).