GOLDSTONE BOSON–NUCLEON DYNAMICS: WORKING GROUP SUMMARY AND OUTLOOK

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We highlight some of the recent results in chiral dynamics for systems with one nucleon/baryon presented at Chiral Dynamics 2000. We outline the most urgent experimental and theoretical challenges to be tackled in the coming years.

1 Introduction

This working group was concerned with processes involving exactly one nucleon (baryon), addressing topics like pion–nucleon scattering, the πN sigma–term, all kinds of nucleon form factors, real and virtual Compton scattering, electromagnetic pion production, strangeness and so on. There has been considerable progress on the experimental as well as on the theoretical side in this domain of chiral dynamics. This was reported in a number of plenary talks as well as the working group contributions compiled in these proceedings. It is the main task of this summary talk to point out the directions of research which should be pursued in the coming years. This certainly is a highly subjective undertaking, nevertheless, the presentations given at this conference have highlighted a variety of clear–cut questions and problems to be addressed. These will be touched upon here.

2 Theory: Status and perspectives

Formal aspects: The tool to perform the calculations in chiral perturbation theory (CHPT) or extensions thereof is an effective Lagrangian of the Goldstone bosons coupled to matter fields. General decoupling theorems [1] tell us that to leading order only the ground–state baryons should be included, the effect of baryon as well as meson resonances appears indirectly through the low-energy constants of the effective Lagrangian. This effective Lagrangian has been worked out to complete one–loop accuracy (fourth order) for the two–flavor case [2] including renormalization. The precise treatment of the baryon fields is still under debate. The baryon mass scale complicates the power counting. This can be dealt with in two ways. The first solution, the so–called heavy baryon approach (HBCHPT), is by now standard and many processes have been studied in that framework and many interesting results have been obtained. It has the disadvantage that due to the strict expansion in the inverse of the baryon mass, in some cases the analytical structure of a given amplitude can be deformed. That happens e.g. in case of the nucleon scalar form factor or the isovector electromagnetic ones (as detailed below). In the first case, this has numerical consequences, in the second it does not.[3] An alternative approach has been discussed in the plenary talks by Becher and Leutwyler. It is based on a different regularization of the relativistic loop integrals (see also ref.[4]) and automatically fulfills all analyticity requirements in the low–energy region (the cut structure of the so regulated integrals can become incorrect for momenta outside the range where CHPT is valid). The method is called infrared regularization (IR). Another advantage is the automatic resummation of all recoil corrections through the full Dirac propagator. There is, however, some ambiguity in treating the polynomial pieces stemming from the numerators in loop integrals. This very elegant and promising method certainly has to be scrutinized by a thorough investigation of many processes. Such a program is underway at various institutions. Much work has been done to extend effective Lagrangians to higher energies. Only in the case of including the spin-3/2 decuplet (the delta and its cousins) a truly systematic effective field theory has been formulated [5] after the pioneering work in ref.[6] (based on the observation that the octet-decuplet splitting can be treated as another small parameter compared to the scale of chiral symmetry breaking). The inclusion of vector mesons still needs to be addressed in more detail (see refs.[7] for the present status), the problem to overcome is the non–conservation of boson number, which makes it difficult to formulate a consistent power counting. Furthermore, resummation methods have been used to not only improve convergence but also to generate (pseudo) bound states. This inevitably leads to some model-dependence, which can however be minimized by employing appropriate dispersion relation techniques.[8] This is particularly important for the studies of chiral dynamics with strange quarks, as discussed below, or to extend πN scattering into the region of the first and second resonances.

Nucleon form factors: The electromagnetic form factors are a good testing ground for certain aspects of the theory. First, the isovector radii are dominated by the anomalous threshold in the triangle diagram, which is exactly reproduced in the relativistic (IR) framework. Using HBCHT, one encounters a formal divergence. Its influence is, however, suppressed by phase space and one still obtains a decent description of the isovector spectral functions in HBCHT,[3] as shown in fig.1. Second, from studies of the neutron charge form

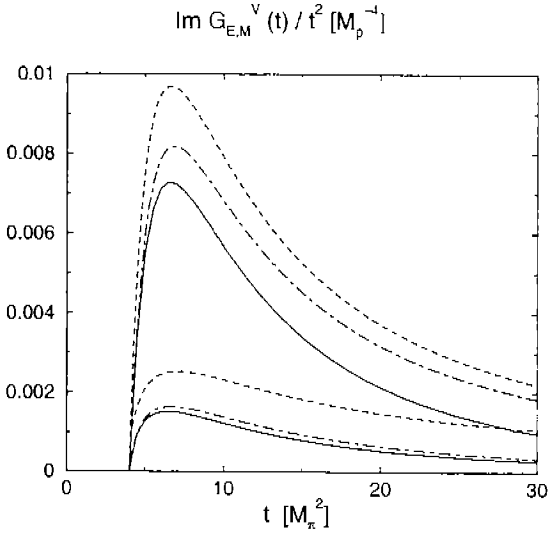

Figure 1. Spectral distribution of the isovector electric and magnetic nucleon form factors weighted with $1/t^2$ calculated in heavy baryon CHPT. Shown are $\text{Im}\, G_M^V(t)/t^2$ (upper lines) and $\text{Im}\, G_E^V(t)/t^2$ (lower lines). The dot–dashed and dashed lines refer to the order q^4 and q^3 calculations, respectively. These results are very close to the ones based on a dispersion theoretical analysis with the ρ-meson contribution subtracted, as shown by the solid lines.

factor in HBCHT, one expects a bad convergence due to recoil effects. This expectation is borne out by the calculation using IR, it leads to a substantially improved description of this much discussed observable.[9] There is also some progress concerning the strange and bizarre (a.k.a. anapole) form factors, which are at the heart of some dedicated experimental programs at JLab, Bates and MAMI. A third order HBCHPT analysis of the strange proton form factors is available,[10] but it again might prove fruitful to combine these with the dispersive results presented here.[11] In addition, the anapole moment [12] and corresponding form factor pose a veritable challenge to theory, not so much from the chiral dynamics point (for calculations of the momentum dependence of the anapole form factor, see e.g.[13]), but rather from the point of radiative corrections and parity–violating meson–nucleon interactions. A dedicated theoretical effort is needed to sharpen the tools to uniquely extract the physics hidden in the data of the existing and upcoming parity violation experiments.

Pion–nucleon scattering: Pion–nucleon scattering has long been recognized as a particular playground for chiral dynamics, triggered by the observation that the isoscalar S-wave scattering length vanishes in the chiral limit. In the last years, very detailed and precise studies have been performed or are being performed in the heavy baryon as well as in the IR formalism. Much interest has focused on the so–called sigma term, which is nothing but the matrix element of the QCD quark mass term within proton states at zero momentum transfer. This quantity can only be obtained indirectly by various means - dispersion relations,[14,15,16] sum rules[17] (which let one express the sigma term via threshold parameters and calculable integrals) as well as by CHPT [18] (or extensions therefore, see e.g.[19]). In all cases, one needs experimental input as given in terms of various partial wave analyses (PWA). Unfortunately, only the by now outdated KA85 PWA passes all these tests. In addition, only recently a new calculation of electromagnetic corrections has become available [20] and a full CHPT analysis including virtual photons is not yet completed. Since the precise determination of $\sigma(0)$ is only possible if one knows a variety of small corrections precisely, a more detailed look at isospin violation is certainly needed. First studies seem to indicate non–negligible effects, see refs.[21] It is important to stress that the large range of values for the sigma term found in the literature appears to have narrowed down sizeably, as discussed in more detail in section 3. Isospin violation is also of importance in the physical region close to threshold. Some phenomenological studies seem to indicate an astonishingly large effect in the S–wave (when comparing elastic scattering and CEX data via a triangle relation), but a complete CHPT calculation including virtual photons to settle this issue is not yet available but has to be done. So far, it has not been possible to obtain an accurate description simultaneously in the physical (threshold) region and inside the Mandelstam triangle. Clearly, a systematic marriage of the dispersive machinery with the chiral constraints has to be done. Such efforts are under way but are also very tedious, so it will take some time before a completely consistent and accurate picture of pion–nucleon scattering from the inside of the Mandelstam triangle to the low energy region of the available data has emerged. Furthermore, as discussed by Rusetsky, the effective field theory study of hadronic atoms offers the possibility of reliably extracting πN scattering lengths from pionic hydrogen and deuterium. Again, it is absolutely necessary to account for isospin violation. Finally, the analysis of the Goldberger-Treiman discrepancies in the octet favors a smaller πN coupling constant, $f^2 = 0.075$,[22] (which is consistent with most recent phase shift analysis of πN and NN scattering) if one assumes the standard scenario of chiral symmetry breaking (for an alternative view, see ref.[23]).

Electromagnetic meson production: Threshold pion photo– and electroproduction has been one of the cornerstones of testing chiral dynamics in the single nucleon sector. In particular, the production of neutral pions off protons and neutrons is very sensitive to explicit chiral symmetry breaking since the corresponding S–wave multipoles vanish in the chiral limit. This multipole also exhibits very clearly the unitary cusp due the opening of the secondary $\pi^+ n$ threshold. In addition, it was found many years ago that two particular combinations of the P–waves can also be predicted to high accuracy in a third order calculation. This needs to be sharpened by a complete fourth order calculation,[24] in particular in view of the MAMI data reported here.[25] Also progress has been made for charged pion production and the inverse capture process.[26] The case of neutral pion electroproduction is even more intricate, there appears to be a serious discrepancy between the HBCHPT calculation and the data as discussed by Merkel. Clearly, a more thorough look at the P–waves is also necessary here, in particular at their variation with the photon virtuality. The announced problem in the longitudinal S–wave multipole might well be a reflection of the insufficient treatment of the P–waves. Only after a complete understanding of these processes on the proton has been obtained, a truely qualitative analysis of extracting the corresponding neutron amplitudes from pion production off light nuclei will be feasible. Also, so far all studies have been performed within HBCHPT. While the analysis of photoproduction does not reveal any large recoil effects but rather is sensitive to some special and unique loop contributions, the IR formalism might allow to consider a larger range of photon virtualities in the electroproduction case. More work on these topics is urgently called for.

Compton scattering: Over the last few years, real (RCS) and virtual Compton scattering (VCS) of protons and neutrons has developed into another precision tool for not only testing chiral dynamics but also employing dispersive techniques.[27] Concerning the electromagnetic polarizabilities, it is now well established that major cancellations appear at NLO between the large delta and almost equally large πN loop corrections. This leads to a good agreement of theory with experiment at LO (which is a pure loop effect) and NLO for the proton. Unfortunately, the unsettled experimental situation concerning the neutron does so far not allow to draw any firm conclusion.[28] Much attention has also been paid to the spin sector, which is characterized by four spin–polarizabilities, but so far no direct experimental determinations of these fundamental quantities exist. This area will certainly gain importance in the coming years. Much attention has shifted to VCS, in particular since first data from MAMI have become available.[29] They agree amazingly well with the third order HBCHPT calculation at a fairly large photon virtuality.[30] Clearly, a complete one–loop (fourth order) calculation is called for. A related topic is the momentum dependence of the DHG sum rule. The HBCHPT calculation is only applicable for small virtualities, but in case of the proton-neutron difference, where the resonance contributions drop out to a large extent, this range is somewhat larger.[31] Based on the experience obtained in the form factor calculation, using the IR formalism, this momentum dependence might be accurate up to a photon virtuality where pQCD is still valid. After many years of mumbling and talking, a direct matching of the hadronic to the quark based description is in sight. Such a calculation is underway[32] and its result is eagerly awaited.

Muon capture: Ordinary (OMC) and radiative muon capture (RMC) on the proton is sensitive to the elusive pseudoscalar form factor of the nucleon and its associated coupling constant g_P. While the presently available data for OMC are consistent with the accurate CHPT prediction, the pioneering experiment on RMC performed at TRIUMF [33] lead to a value of g_P exceeding the expection by 50%. It was one of the highlights of this working group that two different groups [34,35] performed detailed analysis, which not only show that the method used by the TRIUMF group of simply rescaling the Born graphs $\sim g_P$ is inconsistent with what is known from OMC, but also that the combination of certain small effects related to the strong interactions as well as atomic physics can explain the measured photon spectrum using a coupling constant consistent with theoretical expectations. This is reminiscent of the sigma–term story that unfolded in πN scattering over the last decade. More precisely, the occupation numbers of the atomic structure in muonic atoms/molecules need to be carefully re-examined and a N^2LO calculation should be redone including all isospin breaking effects because of the sensitivity to the exact pion mass in the pion-pole contributions.

Strange quarks: Because of the fact that $m_s \sim \Lambda_{\rm QCD}$, it is not so obvious that the strange quark can be treated on the same footing as the light up and down quarks, for example one can entertain the possibility that the three-flavor quark condensate is much smaller than its two flavor cousin.[36] Often, one finds rather sizeable kaon loop corrections which cast some doubt on the convergence of the chiral expansion. Some progress has been made e.g. in the discussion of the baryon masses or magnetic moments because the so–called reordering [2] of the chiral series based on relating observables to a given order (i.e. performing a chiral expansion of the low energy constants) can improve the convergence dramatically. This needs to be explored in more detail. In addition, the existence of (subthreshold) boundstates in certain channels of the SU(3) meson–baryon system necessitates the implementation of some resummation techniques. While quite a bit of progress has been made in the past years,[37,38] one should further minimize the model-dependence (which comes in e.g. via the regulator functions in the Lippmann–Schwinger equation). This can be done by using subtracted dispersion relations which has the further advantage that explicit resonance fields can be included by building up the crossed channel (left-hand) cuts in a perturbative manner.[39] In that way, one can address the question whether a particular resonance is "pre-existing" (corresponding to a quark model state) or is dynamically generated through the strong meson–baryon interactions. As an illustrative example how that can work, let us mention meson–meson scattering and the octet of scalar mesons, discussed e.g. in ref.[40] Other areas were three–flavor CHPT is very useful are the CP–violating sector of QCD,[41] or hypernuclear physics.[42]

3 Experiment: Status and perspectives

The πN Σ Term – Experiments: With respect to the πN Σ term, presentations were given describing new experiments particularly sensitive to the phases which determine $\Sigma_{\pi N}$, as well as new analyses of existing data which lead to improved determinations of $\Sigma_{\pi N}$. The new experiments which were described both capitalize on interference regions to heighten their sensitivity to the smaller partial waves.

Meier described [43] experiments at both TRIUMF and PSI to measure pion-proton analyzing powers at low energies. At TRIUMF the effort focussed on π^-p analyzing powers in the S-P interference region, which occurs at backward angles near 50 MeV. At PSI the focus has been on low energy π^+p analyzing powers near the Coulomb-nuclear interference region, although some π^-p data near the S-P interference region are also planned. Both experiments explored the region from roughly 50–100 MeV. By the time of the next chiral dynamics meeting, the data from both these experiments should be published. They should dramatically improve our understanding of the smaller low energy partial waves which have been difficult to accurately determine until now due to the normalization uncertainties which have plagued differential cross section measurements in the past at low energies. On top of that the analyzing power itself is an interference term, which gives it better sensitivity to small partial waves than the differential cross section. These small partial waves dominate at threshold and their accurate determination is crucial to our evaluation of $\Sigma_{\pi N}$.

The other new experiment relevant to $\Sigma_{\pi N}$ was presented by Tacik.[44] He described measurements ongoing at TRIUMF which map out the angular dependence of the $\pi^{\pm}$p differential cross section at low energies right through the Coulomb-nuclear interference region. The experiment covers the kinematic regime from $\sim 6^\circ < \theta < 180^\circ$ and $15 < T_\pi < 67$ MeV. Normalization uncertainties are mitigated by measuring $\mu^{\pm}$p scattering simultaneously. These data, which also should be available by the time of CD2003, provide a measure of Re(D^+) at t=0, where the πN amplitude D is the same amplitude which is directly proportional to $\Sigma_{\pi N}$ at the Cheng-Dashen point. In addition these measurements provide a direct measure of the πN scattering length a^+_{0+}, which along with it's P-wave counterpart a^+_{1+} characterizes the usual determination of $\Sigma_{\pi N}$. Future plans of the TRIUMF CHAOS group are to explore the $\vec{H}(\pi^{\pm}, \pi^{\pm}\pi^{+})n$ reaction near threshold.

Taken together, and in light of the previously existing body of πN experimental data, these new low energy πN cross sections and analyzing powers will to a large extent complete the experimental information we require in order to determine $\Sigma_{\pi N}$. There are some relatively minor holes to be filled in and improvements to be made to be sure, but on the whole we will have about as complete an experimental picture of low energy πN scattering as we can expect to ever have by the time of CD2003. It seems unlikely that any new experiments will come forward after that which could provide new information relevant to the sigma-term puzzle. On the other hand, it is equally clear that the two experiments discussed above will provide two crucial and at present missing pieces of this puzzle. It is at once unfortunate and exciting that these are probably the last pieces of the sigma-term puzzle that can be provided by πN scattering experiments.

Having said that, it's important to point out that low energy πN cross section and analyzing power measurements in the single charge exchange channel are still missing and are still important observables to measure. Like the extraordinarily precise pionic hydrogen atom experiments,[45] they are primarily sensitive to isospin odd amplitudes, and are thus to first order not especially relevant to $\Sigma_{\pi N}$, which is determined from isospin even amplitudes. Their importance lies primarily in the context of isospin violation, an extremely interesting topic in its own right. However, it is not yet clear how isospin violation may affect the value of $\Sigma_{\pi N}$ although first steps have been done in this direction. An effort to provide SCX observables at PSI seems to have stalled due to problems getting the appropriate π^0 detector to that laboratory. It is hoped that this bottleneck can be overcome by the time of the next meeting, and furthermore, that the impact of isospin violation on $\Sigma_{\pi N}$ will have been established theoretically by then as well. SCX at higher energies will be provided by PNPI, as discussed by Kruglov,[46] as well as spin rotation parameters which will be important in pinning down with better precision the higher partial waves which, we are beginning to suspect, play a greater role than previously thought in the determination of $\Sigma_{\pi N}$.

The πN Σ Term – Analyses: In addition to the new experiments reported at the meeting, there were several new analyses of πN scattering data presented which were used to deduce new values for $\Sigma_{\pi N}$. At the time of the last chiral dynamics meeting, only two analyses were available: KH80 and VPI/GWU. In a nutshell, each uses a different selection of the available body of experimental data to determine the πN partial wave amplitudes in the physical region. Each uses different techniques to extrapolate below threshold to the Cheng-Dashen point ($\nu = 0, t = 4M_\pi^2$) where the connection to $\Sigma_{\pi N}$ is made. It is widely agreed that the sub-threshold extrapolation machinery of the KH80 analysis is superior to that employed in the VPI/GWU analysis, although the sophistication of the VPI/GWU analysis is approaching that of the original KH80 analysis through the introduction of dispersion constraints. On the other hand, the data available to the KH80 analysis in 1980 was miniscule compared to what is presently available for use by the VPI/GWU analysis. In fact it appears that some of the most crucial experimental input used in the KH80 analysis was wrong, since it is at variance with all modern measurements performed at all three meson factories. In any case, the situation at CD97 was that the KH80 value for $\Sigma_{\pi N}$ was on the order of 64 ± 8 MeV, whereas the VPI/GWU value was a whopping 92 ± 3 MeV, which corresponds to an $s\bar{s}$ content in the proton of over 25%!

So it was an important development in the field that at CD2000, several new determinations of $\Sigma_{\pi N}$ were presented, and in fact some degree of convergence was even observed. Stahov [15] reported the results of an analysis which combined fixed-t dispersion relations and interior dispersion relations. As input he chose the VPI/GWU partial waves (SP00) in the s-channel (the VPI/GWU analysis is far more succesful at reproducing experiment than KH80 is). Surprisingly, he found his results were relatively insensitive to the choice of VPI/GWU or KH80 partial wave input, a result at variance with the work of Sainio, discussed below. For the t-channel KH80 input was used. His result was $\Sigma_{\pi N} = 72 \pm 2$ MeV, where the error reflects only the uncertainty estimated for the extrapolation procedure. The error associated with the input partial waves is difficult to estimate and is one of the reasons we look forward to the next meeting when the results of the experiments discussed above will be available, presumably improving the partial wave input to analyses like these. Pavan [16] presented the latest VPI/GWU result, which changes in response to the increasing πN database as well as with improvements in their analysis, particularly with respect to their dispersion constraints. Their new result is $\Sigma_{\pi N} = 84 \pm 5$ MeV, around 6 MeV lower than their previous result, but still significantly higher than KH80 or Stahov's result. Sainio [14] has reported at the previous meetings the result of an analysis based on six forward dispersion relations and partial wave input above a cutoff momentum of 185 MeV/c. In the past he has chosen KH80 phases as input, and got a result of $\Sigma_{\pi N} = 60$ MeV, consistent with the KH80 value of $\Sigma_{\pi N} = 64 \pm 8$ MeV. At CD2000 he reported a new result based on the same technique but using VPI/GWU phases as input (SP00). This moved his result to $\Sigma_{\pi N} = 93$ MeV, consistent with the previous VPI/GWU result of $\Sigma_{\pi N} = 90$ MeV, and underscoring the sensitivity of these analyses to the partial wave input. It would seem obvious, given the vastly superior predictive power of the VPI/GWU phases relative to those of KH80, that a higher value of $\Sigma_{\pi N}$ is inescapable. Finally, a novel analysis was presented by Olsson [17] which used fixed-t dispersion relations to derive a new sum rule for $\Sigma_{\pi N}$ in terms of threshold paramters like the scattering lengths. His result of $\Sigma_{\pi N} = 71 \pm 5$ MeV supports the trend to a higher value of $\Sigma_{\pi N}$ relative to the old KH80 canonical value of 64 MeV.

To summarize, the analyses of $\Sigma_{\pi N}$ seem to be converging on values between 71 and 84 MeV, implying that the $s\bar{s}$ content of the proton is 18–24%. New experiments, especially those aimed at threshold parameters, should improve still further the convergence of the different $\Sigma_{\pi N}$ analyses by the time of the next chiral dynamics meeting.

Strange Form Factors: Rather than probe the isoscalar amplitude connected to $\Sigma_{\pi N}$, a number of ongoing and planned experiments at electron facilities are probing the electric and magnetic form factors of the strange quark sea in the proton by measuring parity violation in ep scattering. Pitt [48] presented the status of the four experiments pursuing this line of research. So far only SAMPLE at Bates and HAPPEX at JLab have presented results for publication. By the time of the next chiral dynamics meeting, new results from both those collaborations as well as G0 at JLab and A4 at Mainz will be available. This will permit the separate extraction of G_E^s and G_M^s over a wide range of Q^2 (0.1 - 1.0 GeV/c^2) with overlapping results from different experiments at selected Q^2 values. The resulting insight ought to be one of the highlights of CD2003. Of related interest is the determination of the anapole moment of the nucleon, a topic discussed by Ramsey-Musolf.[12] Experimental information on this fundamental parameter has been extracted from the SAMPLE

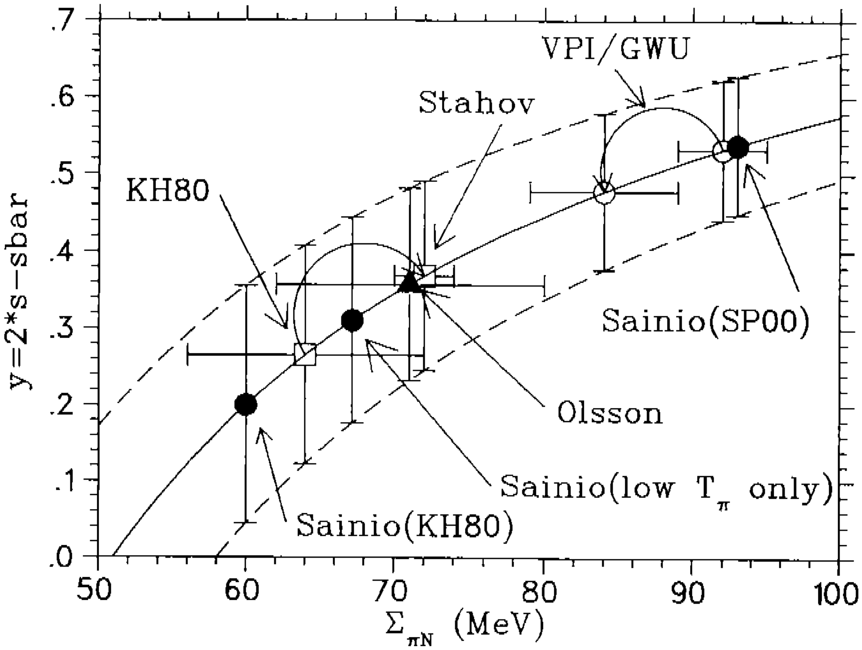

Figure 2. Values of the πN Σ term reported at the workshop. The solid curve and it's dashed counterparts indicate the relationship between $\Sigma_{\pi N}$ and the $s\bar{s}$ content of the proton given by Borasoy and Meißner.[47] The points indicate the results of various analyses which lead to $\Sigma_{\pi N}$, discussed in the text.

experiment at Bates by combining the results of parity violating electron scattering asymmetries on hydrogen and deuterium targets. This, as well as new results in atomic parity violation, has stimulated theorists to revisit the anopole moment prediction using chiral perturbation theory. Unfortunately, the experimental measure of the anapole moment is at least an order of magnitude more challenging than the measure of the strange electromagnetic form factors. As a result, progress on this topic will be relatively slow in coming, and will no doubt be a topic of considerable interest at the next several chiral dynamics workshops.

Tests using electromagnetic probes: Recent progress in our understanding of the axial form factor of the nucleon was summarized by Širca.[49] For some time now there has been a puzzling discrepancy between results for the axial form factor determined on the one hand by quasi-elastic antineutrino nucleus scattering, and on the other by charged pion electroproduction on the proton. However, ancient CHPT work has actually predicted a difference (~5%) in the axial mass determined each way. To test this prediction, the A1 group at Mainz has measured $p(e,e'\pi^+)n$ to high precision and has confirmed the predicted axial mass discrepancy. However, their results were acquired far enough from threshold that an effective Lagrangian model had to be employed rather than CHPT directly in the extraction of their result. As a consequence, measurements at lower Q^2 are planned, as well as measurements closer to threshold with a new device that should improve the reliability of their result in time for presentation at the next chiral dynamics conference. Measurements of the photon asymmetry in neutral pion photoproduction on the proton using TAPS at Mainz were described by Beck.[25] These data allow the separate determination of all (S- and) P-wave multipoles for the first time. Prior to this only the S-wave E_{0+} and the P-wave multipoles P_1 and P_{23} (a combination of the P_2 and P_3 multipoles) could be extracted from the available unpolarized cross sections. Only preliminary results were available at CD2000, but they confirmed the CHPT prediction for P_3. It will clearly be interesting to see the outcome of the stringent test of CHPT these data will constitute when the final results for all the multipoles are available at CD2003. By then we should also have the results of further experiments, now in the planning stage, such as that presented by Lindgren to measure $H(\vec{e},e'p)\pi^0$ at Jefferson Lab. This 3 GeV coincidence experiment will cover the Q^2 region from 0.05 to 0.8 GeV/c^2 and should permit the extraction of the S&P wave multipoles very near threshold. The TAPS group is also planning further work, with higher intensity and with both beam and target polarized.

Another fundamental property of the nucleon which can be predicted by CH-PT is its electric and magnetic polarizability. Although these quantities are well measured for the proton, the neutron remains a formidable challenge. Hornidge [26] described measurements of tagged photon elastic scattering from the deuteron, as well as quasi-free Compton scattering $d(\gamma,\gamma'n)p$ at SAL which were performed to shed some light on the polarizibilities of the neutron. The elastic data have small statistical errors, but the extraction of polarizibilities is model dependent. Further theoretical guidance here is clearly required. In contrast, the quasi-free data minimized the model dependence but suffered from a lack of statistics. Given that further measurements at SAL are no longer possible, it would be nice to see similar measurements performed somewhere else with more statistical significance by the time of CD2003. Happily, plans exist to measure the quasi-free channel at MAMI and the elastic channel at LUND. It is worth mentioning that a recent MAMI measurement on the bound proton at backward angles gives further credit to the idea of using quasi-free Compton to determine the elusive neutron polarizabilities.[50]

The spin structure functions $g_1(x,Q^2)$ and $g_2(x,Q^2)$ for the neutron as well as the Gerasimov-Drell-Hearn sum rule were investigated in an experiment described by Choi [51] at Jefferson Lab. The $^3\vec{He}(\vec{e},e')$ reaction was studied from Q^2 of 0.03 to 1.1 GeV/c^2. The preliminary results reported at the workshop were in good agreement with older, much less precise data from SLAC and agreed well with a calculation by Drechsel, Kamalov, and Tiator. A follow-up experiment is in the works to pursue these measurements at much lower Q^2, where a reliable comparison to CHPT can be made, and where no information presently exists on the GDH integral.

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