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EDITORS

G. Höhler
Universität Karlsruhe
Germany

W. Kluge
Universität Karlsruhe
Germany

B.M.K. Nefkens
University of California Los Angeles
USA

EDITORIAL

The purpose of the *πN Newsletters* is to improve the exchange of information between physicists working in πN scattering and related fields such as $\pi N \to N\pi\pi$, $\pi^- p \to n\eta$, $\gamma N \to N\pi$, $\pi\pi \to \pi\pi$, and electromagnetic form factors of pions and nucleons. The *Newsletters* will give results of new experiments, plans for experiments in the near future, analyses of experimental data, and related theoretical development.

Since our first *Newsletter* appeared, subjects that have come under the limelight are for instance: the "experimental value" of the πN sigma term and its consequences for the strange quark content of the nucleon, applications of the Skyrme model and K-spin symmetry, and the pole structure of πN and ππ resonances in different sheets. There continues to be an interest in various quark and bag models of nucleon resonances, the existence of clusters of nucleon resonances, and so forth.

Copies can be obtained from the editors at the addresses below. Short contributions for No.3 of the *Newsletter*, scheduled for the end of this year, are welcome.

We are grateful to Mrs. M. Frasure for her help.

G. Höhler
Universität Karlsruhe
Inst. Theoretische Kernphysik
Postfach 6980
D-7500 Karlsruhe 1
West Germany

BF01@DKAUNI2
Fax: +49-721-6084290

W. Kluge
Kernforschungszentrum Karlsruhe
Inst. Experimentelle Kernphysik
Postfach 3640
D-7500 Karlsruhe 1
West Germany

IKP097@DKAKFK3
Fax: +49-721- 07247-825070

B.M.K. Nefkens
UCLA
Dept. of Physics
Los Angeles, CA 90024
U.S.A.

NEFKENS@UCLAPH
Fax: (213)206-4397

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The Status of Low-Energy πN-Scattering Parameters: Sigma Term, Scattering Lengths and Coupling Constants

G. Höhler

Institut für Theoretische Kernphysik der Universität Karlsruhe

1. Introduction: The phase-shift solutions KH80, KA84 and KA85

When I wrote my book in the early eighties [1], the low-energy πN-scattering amplitudes and the parameters derived from them were apparently well determined. R. Koch and E. Pietarinen [2] had improved the Karlsruhe–Helsinki solution described in [3] by reanalyzing the data below p_{Lab}=500 MeV/c (solution **KH80**). Again, they employed constraints from fixed-t dispersion relations and treated the electromagnetic effects according to the NORDITA method [4].

The study of the solution KH80 was continued in a series of papers by R. Koch. After a new calculation of the "experimental value" Σ of the πN sigma term (see below) [5], he modified the solution KH80 slightly in order to make it compatible with the partial-wave dispersion relations [6], which had been investigated earlier in great detail by Hamilton et al. (see the references in [1]). Koch extended and improved the method and took into account our evaluation of the Mandelstam double spectral function [8] in order to obtain better results for the (small) high partial waves, which in the solutions KH80 and CMU-LBL80 showed large fluctuations as functions of energy.

Contrary to the expectation of earlier authors, the partial-wave dispersion relations turned out not to be useful for the S-waves, because there are large contributions from distant cuts whose energy dependence is not known. Aside from the S-waves, the new solution **KA84** is smooth. This is an advantage over KH80, which is the result of an iteration procedure in which the last step was a fit to the data and therefore it shows fluctuations in its energy dependence. Distant cuts cause problems also for the P13-, P31-, D33-, and F17-waves.

In [7] R. Koch used the solution KH80 in an evaluation of partial-wave projections of the fixed-t dispersion relations ("partial-wave relations"), following the ideas of Chew, Low, Goldberger and Nambu [9]. He obtained real parts of the partial-wave amplitudes with a smooth energy dependence, from which the imaginary parts follow in the elastic region. His solution **KA85** has the advantage to give unique results also for the S-waves, but it can be applied at most up to about 500 MeV/c. Both dispersion methods [6,7] allow one to continue the P_1 and higher partial-wave amplitudes towards their singularities below threshold. For the 1^- waves, this can be done in a reliable way only with the partial-wave relations. The relatively small discrepancies shown in [7] between the three solutions KH 80, KA84 and KA85 give a lower bound of the uncertainties and demonstrate the approximate compatibility with the Mandelstam hypothesis.

2. Comparison of the predictions with new data: discrepancies

At low energies, the analysis of Koch and Pietarinen is mainly based on the data of Bussey et al. [10] and Bertin et al. [11], only the data at 153 MeV/c of [11] could not be included because they violated the analyticity constraint. The TRIUMF data of Auld et al. [12] deviated by a 10% renormalization factor from the fit which prefers the data of Bertin et al.

After the completion of the KH80 analysis, a large number of new low energy πN scattering experiments has been carried out at the meson factories. Some of them agree with the prediction from KA85 but others show serious disagreements. As an example we mention the LAMPF data of Frank et al. (1983) [13] which have a small systematic error only at 29.4 MeV. The magnitude of the discrepancy from the KA85 prediction can be described by the fact that a good fit to the new π^+p data is obtained if a renormalisation factor 1.37 is applied, which is **10 times the error estimate** of the authors. Koch [14] has discussed the comparison with the new data available in 1985, including the large discrepancy between the π^-p scattering length of the KH80 solution and the value derived from pionic hydrogen X-ray transitions [15]. This difficult experiment was repeated and led to the value $2a_1+a_3=0.262\pm0.012\mu^{-1}$ in agreement with Koch's result in [7]: $0.249\pm0.012\mu^{-1}$ (see the contribution of Beer et al. to this Newsletter). A detailed comparison of the KH80 phase shift predictions with the new data available in spring 1989 can be found in W. Kluge's invited talk at the Leningrad Symposium [16]. The comparison of KA85 predictions with more recent low energy data is treated in the contribution by J. Stahov and myself to this Newsletter.

3. New partial-wave analyses at low energies

In 1983 Alder et al. [17] performed single-energy phase shift analyses at 98 MeV and higher energies, which include their data for the analyzing power for π^-p elastic and charge-exchange scattering.

R.A. Arndt et al. described their method for an energy dependent partial-wave analysis in [18] (see also Arndt's contribution to this Newsletter and [19]). They present four solutions per year in updated versions of their SAID facility. The problems of their method are discussed in my talk at the Few Body Conference in Vancouver [20].

The main point is that their parametrization omits the well-known singularity structure of the πN partial waves which starts relatively near to threshold, in particular the nucleon Born term contributions. Furthermore, they do not use the NORDITA method but an older one for the treatment of the electromagnetic corrections. R. Arndt and I will perform a comparison in order to find out to what extent results of our single-energy analyses differ due to the treatment of electromagnetic effects.

Siegel and Gibbs [21] analyzed the low energy πN scattering data using a coupled channel model with nonlocal potentials. It is difficult to see what one can learn from this treatment since the authors ignored well-established results of dispersion theory for the πN amplitudes and the final version of the NORDITA method for the treatment of the electromagnetic effects [4].

In order to investigate the influence of new data in the low energy region on the scattering lenghths and the sigma term, Gasser et al. [22,23] developed an interesting new method which employs constraints from forward dispersion relations, using the KH80 amplitudes above about 180 MeV/c pion lab. momentum ($T_\pi \simeq 90$MeV). It can be expected that the results are practically the same as of a new analysis based on the Koch-Pietarinen programs which, however, would require a considerably greater effort. Two parameters are determined from the fit: the isospin even scattering lengths a^+_{0+} and a^+_{1+} which are related to the two subtraction constants of the dispersion relations. From the result, all other S- and P-wave scattering lengths can be calculated as well as the S-wave effective ranges and the coefficients of the subthreshold expansion at $\nu := (s-u)/4m = 0$, $t=0$ and the "experimental" sigma term Σ. The method can be applied only to data below 80 MeV. Since the $\Delta(1232)$ resonance peak plays an important role in the dispersion analyses, a test of the KH80 solution by a continuation of the "integral cross section" experiment ($\theta_{Lab}=30°...180°$) of Friedman et al. [25] to higher energies will be of great interest.

In collaboration with M. Rittberger [24] and J. Stahov we have performed single-energy analyses of all new data above 180 MeV/c up to 687 MeV/c. The preliminary results indicate that some corrections of the KH80 solution are necessary. Furthermore, J. Stahov and I have performed single-energy analyses of the new PSI data in the Coulomb interference region [26] combined with the new TRIUMF data [27] at 30-67 MeV (see our contribution to this Newsletter).

4. Scattering lengths, effective ranges and coefficients of the subthreshold expansion

The best method for the determination of the coefficients of expansions at threshold and of the subthreshold expansion at ν=t=0 is to use dispersion relations as constraints in a partial-wave analysis. The results are usually called "experimental values" of these parameters. In the literature several authors expressed the expectation that in experiments at meson factories one can take accurate data at very low energies and in this way measure effective ranges and scattering lengths directly. Unfortunately, this is impossible because the errors blow up as the energy decreases. One reason is that in elastic scattering the Coulomb effects become dominant and another one is that too many of the slow pions decay within the apparatus. The above mentioned large discrepancies between the new low energy data demonstrate the experimental difficulties. Furthermore, one does not know the energy range in which the effective range approximation is valid (unless one uses Koch's dispersion calculation [7]).

The final results for the low energy parameters derived from the KH80 solution are given in my book (Tables 2.4.7.1 and 2.4.7.2 in [1]); based on further calculations, in Koch's paper [7]; and for a^{+}_{0+} in [5]. A comparison of these tables with our earlier results derived from fixed-t dispersion relations and "CERN Experimental" phase shifts kindly given to us by C. Lovelace in 1969 [28] and 1971 [29] shows remarkably small changes. The main effect of the high precision experiments in the seventies and the

Koch–Pietarinen analysis was that the errors became smaller. But if certain experiments carried out at the meson factories are correct, the true scattering lengths will have values far outside these errors.

It is worthwhile to mention that in [29] we have calculated the isospin even S-wave effective range b^+_{0+} from a formula derived by Geffen in 1958 [30] as a simple consequence of the forward dispersion relation for the amplitude D^+ (m,μ = nucleon and pion mass, respectively; a factor $(1-\mu^2/4m^2)^{-1}$ was omitted in the Born term):

$$b^+_{0+} + 2a^+_{1+} + a^+_{1-} + a^+_{0+}/2m\mu \simeq (1 + \frac{\mu}{m}) \left\{ \frac{f^2}{m\mu^2} + \frac{1}{2\pi^2} \int_0^\infty \frac{dk}{k^2} [\sigma^+(k) - \sigma^+(0)] \right\} \qquad (1)$$

As mentioned above, the method of Gasser et al. [22,23] is well suited for the determination of scattering lengths, effective ranges and subthreshold parameters from new low energy data. But due to the discrepancies between the new experiments it is at present not possible to derive a unique and reliable result.

5. The sigma term

The "experimental" sigma term Σ is given by the analytic continuation of the on-shell amplitude $\bar{D}^+$ (see Sect.2.5.1 in [1] for the notation) to the Cheng–Dashen point which lies in the unphysical region at $\nu=0$, $t=2\mu^2$. Obviously it is important to use a πN partial-wave solution which is constrained by dispersion relations. The continuation can be performed in several ways:

i) A first method employs the subthreshold expansion and starts with a linear extrapolation in t [31]. In order to take into account the curvature due to the cusp at

$t=4\mu^2$, Nielsen and Oades [32] employed a fixed-ν dispersion relation for the determination of the quadratic term in t. An improved version of this method was used later by Koch and Pietarinen [3] who calculated the cusp structure in detail (see Figs.5.1.1, 4.6.2a, and A.3.5 in [1]).

ii) In [22], equation (10), Gasser et al. used only the linear extrapolation in t and estimated the curvature caused by the cusp from the result of the one-loop evaluation of chiral perturbation theory [34].

iii) The most elaborate calculation of the sigma term from the KH80 solution is due to R. Koch [5]. He calculated the extrapolation to the Cheng-Dashen point along about 50 hyperbolas in the Mandelstam plane, taking into account the contributions of the nearby left hand cuts. He found $\Sigma=64\pm8$ MeV, pointing out that the error is the fluctuation obtained from the choice of different paths. The smallness of the error shows the approximate compatibility of the solution with Mandelstam analyticity. This uncertainty was frequently misquoted as the total error which cannot be estimated. One source of a further uncertainty is the choice for the $\pi\pi$ S-wave scattering length. If the theoretical value of Gasser and Leutwyler [35] is chosen (a_0^0 = 0.20 ± 0.01 μ^{-1}), Σ is reduced to 59 MeV [39].

iv) Several authors wanted to express the value of Σ by the scattering lengths. This relation was first calculated in an approximation by Altarelli et al. [36] who thought that it was an advantage to start from "experimental" values, since they did not realize that the "experimental" scattering lengths were determined from the same dispersion relations as the coefficients of the subthreshold expansion. Part of their approximation was later on replaced by exact dispersion calculations by Olsson and Osypowsky [37] and Olsson [38], but the effect of the t-channel cusp was still estimated from a crude model calculation although the evaluation of the fixed-ν dispersion relation at ν=0 was already available. Olsson's paper [38] contains an equation equivalent to the above equation (1).

In [39] Gasser expressed Σ by a combination of S- and P-wave scattering lengths, an integral J^+ taken from Koch's evaluation [14] (which has to be changed if certain new experiments are correct) and an additional term following from the one-loop evaluation of chiral perturbation theory [34]. This an an improvement over similar formulas derived by earlier authors [36-38]. The good compatibility with the results obtained from our application of the Mandelstam hypothesis is remarkable.

In [33] Gasser derived a more general expression for Σ which also includes the S-wave effective range and pointed out the existence of a sum rule valid in the one-loop approximation for the combination on the l.h.s. of our (1). His discussion does not yet include Geffen's sum rule (1) which shows that the internal consistency of the scattering lengths and the effective range is already a consequence of the forward dispersion relation. It will be interesting to discuss the relation between the two sum rules with respect to the chiral representation.

v) Ericson's paper [40] on the sigma term starts from the fact that in a partial-wave decomposition at the Cheng-Dashen point the S-wave contribution is strongly dominant. The P-wave is suppressed since $\cos\theta$=-0.006≃0 and the contributions of the higher waves are small. Therefore, he attempted to calculate Σ by an analytic continuation of the S-partial-wave, using the first two terms of the effective range expansion (the PV Born term subtracted). He noticed that this power series expansion at a branch point is not valid for $q^2<0$, but this is a minor problem (see eq.A.3.65 in [1]). In his quotation of my remark in his new paper [41] he omitted the main point: I argued that it is not acceptable **to use two terms of a series for an**

extrapolation to the close neighborhood of the nearest singularity. The Cheng–Dashen point is located at $s=m^2$ and this is very close to the t-channel cut which starts at $s=m^2(1-\mu^2/m^2)\simeq 0.98m^2$ (the circle cut in the s plane, see Fig.A.7.2 in [1]). Hamilton et al. and, more recently, Koch [6] have shown that this cut gives a substantial contribution. A further complication arises from the fact that instead of the simpler $\bar{f}_{0+}(s)$ the function $\bar{f}_{0+}(q^2)$ is considered in the expansion and $s(q^2)$ has a branch point at $q^2=-\mu^2$ very near the Cheng–Dashen point ($q^2=-0.994\mu^2$). The necessity of a continuation to the close neighborhood of the t channel cut is a disadvantage of the attempt to work with partial waves, since the distance to the singularity is much larger ($2\mu^2$) in the continuation of the invariant amplitude described above in i).

The only reliable analytic continuation of the S-partial-wave amplitudes towards the left hand cut singularities is the method used by Koch in [7]. He has not included a table for the partial waves in the unphysical region in his paper, but a copy is available on request. A continuation based on the partial-wave dispersion relation is also possible, but it has the problem of a large contribution from distant cuts. A special method has been developed by Hamilton and Lyng Petersen [48].

A simple calculation which leads to an approximation for the shape of $\bar{f}^{+}_{0+}$ in the unphysical region has been performed by Rittberger [24], who evaluated the projection integrals directly from the coefficients of the subthreshold expansion (Tab.2.4.7.1 in [1]). He found that the S-, P-, and D-wave contributions to Σ give $\Sigma=62.0+0.9-2.8\simeq 60$MeV. The result agrees of course with the simple addition of three terms of the subthreshold expansion given in [1] ($f_\pi=132$MeV):

$$\Sigma = f_\pi^2/2\ (-1.46 + 2\times 1.14 + 4\times 0.036)\ \mathrm{MeV}^2\mu^{-1} \simeq 60\ \mathrm{MeV} \qquad (2)$$

whereas an accurate extrapolation along ν=0 leads to Σ=63 MeV [1]. In this case we have also used a few terms of a series for an extrapolation near to a singular point and it is good luck that the error is small, because the cusp of the invariant amplitude is weaker than the cusp of the S-partial-wave. The important point is, however, that we have studied the cusp in detail as mentioned above in i).

In an attempt to obtain a more accurate result for Σ, Ericson gave up the idea to use the expansion of the S-wave at the s-channel threshold. Instead, he employed the subthreshold expansion at ν=t=0, taking the coefficients given in my table [1]. Although a simple determination of Σ follows from (2), he preferred a rearrangement of the expansion in terms of Breit frame quantities and arrived at an expression similar to the results of Altarelli et al. [36], Olsson et al. [37,38] and Gasser et al. [33,39], since the application of Geffen's sum rule (1) is not a significant change. The deviation of his numerical result from that given in (2) is due to his approximations. The weak point of his procedure is that it is based on an intuitive "dynamical statement" [41] instead of fundamental theories like Mandelstam analyticity or chiral perturbation theory. As a consequence "there is no physical explanation at present for the accuracy of the parametrization in terms of linear Breit variables with small higher order terms" [40].

It is difficult to follow the arguments given in Ericson's conclusion. Some pioneers in the fifties believed that the effect of b^+_{0+} can be observed in the behavior of the S-wave phase shifts at low energies and also the authors of some more recent papers [21,37,38]. But my argument given at the beginning of section 4 above will be confirmed by those who have studied in detail the large discrepancies between "high precision" experiments made at the meson factories in the past decade. In my opinion, the simplest way to determine b^+_{0+} is to use Geffen's sum rule (1) and to take the scattering lengths from calculations based on dispersion relations, for instance from [22].

It is true that one can write expressions for Σ in which the dominant contribution comes from b^{+}_{0+}(see [42]), but b^{+}_{0+}can as well be eliminated using the sum rule (1). A unique partial-wave analysis can be carried out only if one imposes strong constraints derived from the Mandelstam hypothesis [20]. Then **there are many equivalent descriptions** and the result for the sigma term will be the same, independent of the path of the analytic continuation ($\cos\theta=0$ offers no advantage, see [5]) or of the choice of the low energy parameters, i.e. **it is not crucial to think about experiments which have a special sensitivity to the S-waves**. I do not understand how an experiment of this kind can be carried out with reasonable accuracy, except for the work with pionic hydrogen.

My conclusion on Ericson's approach is that it cannot compete with the systematic methods based on Mandelstam analyticity or chiral perturbation theory since he uses parameters derived from evaluations of dispersion relations and replaces the exact calculations by an uncontrollable approximation. It is a shortcoming that the effect of the t-channel singularity close to the Cheng–Dashen point is not studied in detail. Because of consequences of analyticity, there is no reason to stress the importance of the S-wave effective range.

6. The πNN coupling constants

Starting from a new energy–dependent phase shift analysis of all pp scattering data up to 300 MeV and all np scattering data up to 30 MeV in which improved methods were used, the Nijmegen group has recently redetermined the π^0pp coupling constant [43-45]. The result reads in our notation [1]

$$\frac{g_0^2}{4\pi} = 13.53 \pm 0.14 \; ; \; f_0^2 = [\frac{\mu}{2m}]^2 \frac{g_0^2}{4\pi} = (74.8 \pm 0.8)10^{-3} \tag{3}$$

where m is the nucleon mass, μ the charged pion mass and the index 0 refers to π^0pp. The authors compare this value with the charged coupling constant

$$\frac{g_c^2}{4\pi} = 14.3 \pm 0.2 \; ; \; f_c^2 = (79 \pm 1)10^{-3} \tag{4}$$

determined by Koch and Pietarinen [2] mainly from elastic $\pi^{\pm}$p scattering data and conclude that the difference indicates a larger breaking of charge independence than expected. Rijken et al. [45] point out that their coupling constant is determined at the pion pole, i.e. the low value is not an effect of the πNN form factor.

Thomas and Holinde [46] proposed another interpretation based on a discussion of πNN form factors. See also Meißner's contribution to this Newsletter.

I think that an important point has not yet been taken into account. The value of f^2 given by Koch and Pietarinen is based on the data available in 1979. Some of the new low energy πp scattering experiments show fairly large discrepancies with the KH80 solution, but it is too early to redetermine f^2 because there are also large discrepancies between the various new experiments. Furthermore, our preliminary single-energy analyses of the new data up to 687 MeV/c also suggest some changes of the KH80 solution. So the present uncertainty of the value for f^2 derived from πN scattering is certainly larger than 0.001, but there are no good arguments for a new estimate.

The determinations of f^2 from πN scattering use the nucleon pole terms of fixed-t dispersion relations. The amplitude B^+ has the greatest sensitivity to f^2, but the method used in [28] and [2] gives additional information. The other amplitude of interest is C^-, in particular at t=0, where ImC^- follows from total cross section data and ReC^- can be obtained either from the analysis of elastic scattering data in the Coulomb interference region or from $\pi^- p$ charge-exchange forward cross sections [28].

7. Conclusion

Because of the large discrepancies between the results of high precision πp scattering experiments at low energies carried out in the last decade at the meson factories, the uncertainties of the πN low energy parameters given for instance in the publications of our group ([1], [7] etc.) or in the Compilation [47] are considerably too small. So at present a reliable experimental information for a discussion of the strange quark content of the nucleon or the breaking of isospin invariance does not exist.

Further progress is expected on the one hand from the work of experimentalists who measure a more complete set of differential cross sections and analyzing powers in a large angular range, and search for the origin of the big systematic errors which are undoubtedly present is some of the experiments. Phase shift analysts can try to find data sets which are compatible with each other and lead to new phase shifts. Then one can check if the energy dependence of the phase shifts and the shape of the zero trajectories (Sect.2.4.3 in [1]; [49]) are reasonable. Since some of the new data agree well with the prediction from the KH80 solution, it is an open question how large the corrections will be. The important problem of the stability of phase shifts with respect to small changes of the experimental differential cross sections and polarization parameters has recently been investigated by Sabba-Stefanescu [50]. The final step should be an energy-dependent analysis based on dispersion constraints [22,2].

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COMMENT ON THE EXPERIMENT BY FRANK et al.

Phys. Rev. D 28(1983)1569*

D.V. Bugg
Physics Department
Queen Mary College
Mile End Road
GB–London E1 4NS

There is a significant discrepancy of normalization between results shown in Fig.9 of this paper and phase shift analyses fitting previous data. Inevitably, these data will be compared at 89.6 MeV with nearby data of Bussey et al., Nucl. Phys. B 58(1973)363. It is necessary to form some opinion of which experiment is more likely to be right. In the remarks below, I summarize the points where one has to regard the data critically. In so doing, I believe it is useful to compare with the techniques of Bussey et al. Many of the points I raise are adequately described by Frank et al. in their paper, that is the points are not new criticisms which have escaped the attention of the authors at the analysis stage. Rather, these points address the question of what possible explanations there might be for the $\geq$20% normalization discrepancy between the two experiments, in the face of the estimated normalization errors: as low as 4.7% for 89.6 MeV π^+p data of Frank et al. and $<$1% for 94.5 MeV data of Bussey et al.

In a measurement of $d\sigma/d\Omega$ the requirements are:

1. to know beam intensity accurately,
2. to know beam composition accurately,
3. to know beam momentum accurately,
4. to know target length and density accurately,
5. to know solid angles accurately,
6. to avoid backgrounds.

*This comment was written in 1983.

1. Bussey et al. defined the beam intensity by a threefold scintillator coincidence plus a Cerenkov counter. Frank et al. defined the beam intensity from a single counter. This is not good practice electronically. A single counter is subject to (i) noise, and (ii) double pulsing caused by extra large pulses (or pileup of pulses). At LAMPF, the interval between beam pulses is 5 ns. To handle the LAMPF beam structure, it seems likely the counter was clipped. But this can give rise to problems of one pulse riding on the back edge of a previous one. The paper does not discuss this problem. The paper quotes beam intensities of 10^5 to 10^6/s and a duty cycle of 6%, that is an instantaneous rate of 1.6×10^6 to 1.6×10^7/s, although I understand from a letter of Frank that the situation was in practice less severe. Nonetheless, counting this sort of rate with a single counter is exceedingly hazardous. With a 5 ns beam repetition rate, one infers a probability of 0.8 to 8% for two particles arriving simultaneously; the paper does not mention any correction for this. However, it would lower cross sections, hence increasing the discrepancy with Bussey et al., and phase shift predictions. Conversely, double pulsing of the photomultiplier or discriminator could account for low cross sections. My own experience is that double pulsing can be a problem, easily giving rise to 10 or 20% too many beam counts; they are of course eliminated if one has a manifold beam coincidence. My opinion is that this is the weakest point in the experiment of Frank et al. Although their counter tracked well with the ionization chamber and with the muon counters at any given momentum, they were able to check only reproducibility, and there is no check that their beam counter had an accurate absolute normalization. This is a great pity. In retrospect, it would have been possible to check absolute normalization by several methods, for instance (i) viewing the single beam counter with two or more photomultipliers in coincidence; (ii) doing checks with the beam counter in coincidence with other scintillators large enough to cover the whole beam; (iii) photographs of oscilloscope traces from the beam counter at intensities

low enough that randoms from the 5 ns repetition rate of LAMPF were negligible (although this does not check against possible variations in pulse height at high intensity).

2. In the experiment of Bussey et al., pions in the beam were positively identified in the trigger by a Cerenkov counter having a rejection against μ and e of better than 1000:1. In the experiment of Frank et al., the beam was heavily contaminated by μ and e, and the beam normalization was corrected for what they believe the beam composition to have been. However, for the first five entries of Tab.IV (90 and 70 MeV, and 50 MeVπ^+), Frank et al. did not record the running conditions (chopper polarity) so as to be able to sort out the beam composition accurately at the analysis stage. Consequently, there is some guesswork in their values of f_π^B. The authors say the errors cover the extreme possibilities of doubling or halving the e/π ratio; however, they do not quote e/π and μ/π ratios, making it impossible to check their arithmetic. Taking 70 MeV as an example, I would expect the difference in f_π^B between negative and positive polarities to be due purely to electrons (i.e. $\mu^+/\pi^+=\mu^-/\pi^-$). Since there must be some e^+ in the positive beam, I would expect e^- in the negative beam to affect $f_\pi^{B(-)}$ by an amount in excess of (0.761–0.553) = 0.208; this arithmetic does not tally with the error ±0.145 they quote. On Fig.8, the electron contamination is much greater than that due to muons. Presuming this to be true at other momenta, I find the ±0.030 error in f_π^B for 90 MeV π^+ to be questionable. Note that the "muon counters" could not monitor f_π since the lab acceptance for muons varies rapidly with lab angle, making these counters very sensitive to beam phase space and geometry. They were useful only as monitors of beam stability.

3. There is little reason to doubt the accuracy of beam momentum for either Bussey et al. or Frank et al. The former monitored beam momentum with a simple bending magnet and

four chambers. Frank et al. took the central pion energy from measurements of the fields of the bending magnets; this requires that quadrupoles in the beamline did not steer the beam. They do not comment on this possibility, but would presumably have noticed it during beam tuning. They also have, potentially, an independent check from their range telescope. Although they do not say so, I presume their beam energies refer to the center of the target.

4. The uncertainty in target length and density quoted by Bussey et al. was 0.2%. The target of Frank et al. bulged. The bulge varied between 5 and 12% with liquid level in the reservoir. The error of ±3% they quote on target length corresponds only to the error of measurement described in Section III.C.3. They add nothing for the possibility that the liquid level changed with time during data taking (except one explicit occasion) nor between data taking and the calibrations.

5. Bussey et al defined solid angles by a scintillator; edge effects in a simple scintillator extend only over microns and the efficiency of the scintillator can easily be 99.9%. From a letter of Frank I understand that solid angles were defined by software cuts on chamber data. This is less satisfactory, but probably adequate. Using chambers, one has to worry at the few % level about (i) the performance of the chambers on angled tracks near the edge of the acceptance; (ii) those events where one chamber failed to fire; (iii) $\pi \rightarrow \mu$ decays within the region covered by the chambers, giving a kink in the track; (iv) the 10% of unreconstructible events (some overlap with iii). Undoubtedly, Frank et al. have thought carefully about the bookkeeping of these effects, but I would prefer to eliminate them in the design of the experiment. In the experiment of Bussey et al. there was a cancelation between decays of scattered pions out of the acceptance of the defining scintillator and

decays of other pions into this acceptance; this well-known in/out cancelation was so close that the maximum correction for pion decays was 0.65%. It would be interesting to have a corresponding number from Frank et al. If the solid angle was defined purely by the last chamber, the cancelation should be equally good (at 90 MeV). Was there any significant cut on front chambers?

6. Frank et al had a background up to 18% of electrons from Dalitz pairs in $d\sigma_{-}/d\Omega$. The experiment of Bussey et al. eliminated these with a magnetic spectrometer. Frank et al. used pulse height to separate electrons and scattered pions; pulse height is a difficult technique, being subject to the Landau spread of pulse heights and variation of light collection efficiency over the scintillator.

In summary, I can see no point where Frank et al. improved on the techniques of Bussey et al., and many where their techniques were less good. This is reflected in the normalization errors quoted by the two experiments. I believe that dispersion relation checks may provide an objective test of the normalization of both experiments. The data of Bussey et al. by themselves (or with recent SIN polarization data) satisfy such dispersion relation checks well. Will the data of Frank et al. by themselves give phase shifts satisfying dispersion relations?

Bussey et al. also checked their normalization by demonstrating that the integrated cross section agreed with σ_{total} for π^+ and ($\sigma_{\text{total}}-\sigma_{\text{neutral}}$) for π^-. A second check of normalization was that for π^-p, $\sigma_{\text{elastic}}/\sigma_{\text{neutral}}$ was close to the value 0.5 dictated by P_{33} dominance. The small deviation from 0.5 gave values of P_{13} which are sensible in magnitude and energy dependence; this would not happen if the normalization of σ_{elastic}

were seriously wrong. Hence it seems to me inconceivable that the 20% normalization discrepancy lies in the Bussey et al. data.

I have made a point of the 20% normalization discrepancy between Frank et al. and Bussey et al. around 90 MeV because failure to account for it lowers the confidence in the normalization of Frank et al. at other, lower, energies. Any normalization error could be energy dependent. Dispersion relations predict S and P waves at the lower energies, and it will be of interest to compare these predictions with Frank et al.

The weakness of the Bussey et al. data is that there are only three points on the angular distributions at the lowest momenta; the Frank et al. data are welcome in determining the shape of the differential cross section. At these energies, D and F waves are very small, and $d\sigma/d\Omega$ should be accurately quadratic in $\cos\theta$, except in the Coulomb interference region. It seems to me unlikely that phase shift analysis and dispersion relations will accommodate the shape of $d\sigma/d\Omega$ at 90 MeV backward of 120°.

REPLY TO THE PRECEDING COMMENT BY D.V. BUGG*

J.S. Frank
Los Alamos National Laboratory
Los Alamos, NM 87545, U.S.A.

We welcome the opportunity to reply to the preceding comments by D. Bugg on low energy elastic $\pi^{\pm}p$ differential cross sections. He questions predominantly the accuracy of the normalization of the Frank et al. data. The factors that could contribute significantly to a ≃20% normalization error are a mistake in (i) the pion beam flux, (ii) the number of protons in the target, or (3) the data acquisition system. Each of these factors was examined in detail. We have been unable to find any reason to change or distrust the measured cross sections and the uncertainties placed on them.

We now reply to Dr. Bugg's comments. We refer to sections, tables, and figures of our paper, Phys. Rev. D 28(1983)1569.

1a. **Beam intensity**. The single-counter measurement of the beam intensity was possible due to the speed of the scintillator, tube, amplifier, and scaler stages. By scaling the counter output during the beam-off time, we found little tube noise (≃16Hz). The pion beam tune was of small size and low divergence (Table I) and the beam counter was quiet and well understood; adding more counters to define the beam intensity would have only added material upstream of the target.

1b. **Beam counter pileup.** This was studied during the data taking time; we concluded then that pileup was not a significant problem. However, the numbers from which pileup

*This reply was written in 1983.

may be calculated were incorrectly stated in the paper. The highest intensity runs were for the normal tune 30 MeV π^+ at 1.7×10^5 and 50 MeV π^- at 2.5×10^5 (average). The lowest was for the 90 MeV π^+ data with 3×10^4 average counts per second. The duty factor was 7.5% rather than 6% as stated in the paper. This implies a 1.7% probability of two particles arriving within 5 ns at the highest intensity.

1c. **Beam counter double pulsing.** The question of double pulsing was studied when the beam counter was initially installed. Its performance was thoroughly checked with a source and oscilloscope; no evidence for double pulsing was found. The accuracy of the beam counter scaler, which also checks the possibility of double pulsing as well as the reliability of the data acquisition system, was checked by noting that the number of events on tape was quite close to the beam counter scaler when this was the only trigger requirement (Sec.IV.C.1). In addition, for a calibration run at 30 MeV with full intensity, a coincidence was formed between the beam counter and a large counter located upstream of the ion chamber (Fig.1). The agreement between the coincidence scaler and the single beam counter scaler, after correction for pion decay, was excellent.

2. **Beam composition.** The technique that we used to measure the pion fraction of the beam was to use an electric field to remove all protons from the LAMPF beam except those in selected beam micropulses. This allowed good time of flight separation of the different particle types between the production target and the beam counter. During the final week of data acquisition we discovered that the proton beam position was perturbed by this field. The perturbation was too small to be seen directly by the LAMPF beam position monitors, but caused significant changes to the electron contamination of the beam. At that time we began recording the field direction and including both polarity

measurements in the f_π determination. Fortunately we realized the importance of deliberately reversing the polarity of the chopping field in time to do it for the lower energy data. However, we did not have time to repeat the higher energy points with both chopper polarities. It should be remembered that the higher energy beams contained less contamination and therefore the results were less sensitive to uncertainties in f_π than was the case for the lower energy beams.

As discussed in Sec.II.C.2, when the beam composition was measured with both polarities of the beam chopping electric field, we found that the e/π ratio varied by almost a factor of two. This set the level of uncertainty to place on the true pion fraction for those cases in which measurements were made with only one polarity. For example, some numbers for beam composition with only one polarity measurement were: at 90 MeV, e^+/π^+=0.056 and μ^+/π^+=0.116; at 70 MeV, e^-/π^-=0.68 and μ^-/π^-=0.092. To a very good approximation, only the electron contamination changed as a function of the small motion of the beam on the pion production target; the numbers in Table IV that give the uncertainties of the pion fractions follow directly.

The agreement between f_π as found from the pulse height analysis of the beam counter and as determined from the chopped beam was excellent (Table IV). The self-consistency of two different pion beam tunes that yielded consistent cross sections at 30 MeV for both polarities is added confirmation of the determination and the uncertainties of the pion flux.

3. As stated in Table I, the beam energy is given at the center of the target.

4. **Target thickness determination.** As discussed thoroughly in Sec.II.C.3, the thickness determination was based upon two very different and independent techniques: an optical

measurement and a differential range technique. The differential range measurements were conducted between 30 MeV data runs. The optical measurements were done at the end of the experiment. Each had a different set of $\simeq\pm3\%$ systematic uncertainties. The difference between their central values was $<4\%$. When constrained by the observed variation of the target thickness, the quoted uncertainty brackets the extremes of the possible target bulging. Because the heights of the liquid detecting sensors were fixed in the target reservoir and the bulge was measured twice, with a complete warmup between the measurements, we believe the optical measurement was measuring the same amount of LH_2 in the target as the range measurements were during the data acquisition.

5. **Solid angle.** The trajectory of each scattered particle was measured with MWPCs and this trajectory was extrapolated into the scintillation counters (Sec.III.B.1 and III.C.1). Cuts were defined that avoided the edge regions of the counters. This is the method of choice for solid angle determination when MWPCs with inherently high resolution and efficiency are used. The solid angle was determined by making identical cuts in the data and in the Monte Carlo calculation. As part of the analysis procedure, the cuts were varied; the change of signal matched the expected change as calculated from the Monte Carlo simulation. This demonstrated the insensitivity of the results to variation of fiducial boundaries.

The method of dealing with pion decays is quite different in a MWPC experiment than in a counter experiment. Pions that decayed between the target and the first MWPC generally did not project back to the target. Those that decayed between the first and last MWPC would have generally had a bad fit to a straight line. In addition, muons from in-flight pion decay did not give the same energy loss pattern in the scintillation counters as a pion. These effects were studied by examining the net signal as a function of applied cuts in both the data and simulation. Again, the simulation and the data tracked well.

An additional advantage of MWPCs is that a fiducial region may be defined that includes only the target region. At these low energies, the presence of liquid H_2 in the target can introduce sufficient changes to the beam that the backgrounds downstream of the liquid can be dependent upon the presence of the liquid. These would not be correctly subtracted by target empty runs. Only a requirement that demands the tracks project back to the target eliminates these events from being included. In this experiment, projection to within a fiducial volume containing the LH_2 reduced the uncertainties associated with the systematic differences between target full and target empty in the gas region surrounding the liquid cell.

6. Backgrounds. At large backward scattered angles for 90 MeV π^-p scattering, the electron background was as high as 18% of the pion signal. The uncertainty of this number was taken as 25% of the background. This was the largest angle-dependent uncertainty for the experiment. We chose to include electron backgrounds rather than trying to eliminate them in the electronics, so that the self-consistency of the detector response could be verified. We believed it was better to include a relatively small background fully rather than discard the background at the design stage and perhaps in so doing discard an undetermined amount of signal.

These backgrounds were handled correctly because the response of the detectors to π, μ, and e were directly measured in calibration runs (Sec.III.A). The accuracy of this technique is summarized in Table II.

In conclusion, the experimental techniques we used optimized the data reliability at these low energies. A claim that one experiment is "better" than another only because the quoted error bars are smaller is at best superficial. The normalization uncertainty in these experiments is dominated by estimates of possible systematic errors. These are difficult to estimate and are best confirmed by attempting to measure the same quantity in more than one way. We did this with the thickness of the LH_2 target, with the electronics and analysis (Sec.IV.A–C), and with the number of pions on target at lower energies (which in turn determined the uncertainty of the pion flux at higher energy).

We know that the results of this experiment at ≃90 MeV are at variance with the normalization of the lowest energy points of Bussey et al. Also, the shape of the differential cross sections for both π^+p and π^-p scattering is different from the phase shift predictions by more than allowed by the angular dependent systematic and statistical uncertainties of the data. It is true that dispersion techniques can help to untangle some of this. However, due to the precision of these low energy measurements, sophisticated treatment of the "inner" Coulomb effects may be necessary first.

In order to resolve the discrepancy between the normalization as well as the shape of these data and other data, future excellent differential cross section measurements presumably will be required.

R.A. Ristinen

University of Colorado at Boulder

THE COLORADO/TRIUMF PION-NUCLEON STUDIES

RECENT HISTORY

There are four completed pion-nucleon experiments:

TRIUMF E322 Two-arm πp coincidence measurements of differential cross sections for both π^+p and π^-p at seven energies from 67 to 139 MeV. Normalization uncertainties are from ±1% to ±3%. Phys. Rev. C **34**, 1771 (1986), J. T. Brack *et al.*

TRIUMF A single-arm measurement of differential cross sections for π^+p at large angles at 67 MeV. The normalization uncertainties are ±2%. Phys. Rev. C **38**, 2427 (1988), J. T. Brack *et al.*

TRIUMF E441 A measurement of analyzing powers for π^+p and π^-p elastic scattering at 98, 139, 166, 215, and 263 MeV. Phys. Rev. C **40**, 2780 (1989), M. E. Sevior *et al.*

TRIUMF E394 A πp coincidence measurement of differential cross sections. An active target was used to detect the recoil protons. Measurements for both π^+p and π^-p at 30, 45, and 67 MeV. The normalization uncertainties are ±2%. Accepted for publication Phys. Rev. C, J. T. Brack *et al.*

NEAR-TERM PLANS

Three πN projects are either underway or pending approval.

TRIUMF E471 Spokesmen J. T. Brack and G. R. Smith. Participants from Vancouver and Boulder.

This experiment is scheduled to run at TRIUMF in the summer of 1990. Differential cross sections will be measured for $\pi^\pm$p elastic scattering. It will use the active target techniques of our earlier work [TRIUMF E394] and extend the measurements to higher energy and smaller scattering angle.

TRIUMF E560 Spokesman G. R. Smith. Participants from Vancouver and Boulder.

A proposal to measure the large-angle polarization in π^- p scattering at 50 MeV has been approved. This proposal is in response to the suggestion of Locher and Sainio that the experimental value of the πN sigma term is very sensitive to the spin observable P in this kinematic region (PSI preprint PR-88-17). Beam time for preliminary tests has been scheduled for the summer of 1990.

LAMPF E1190 Spokesmen R. Ristinen and C. Morris. Participants from Boulder, Vancouver, and Los Alamos.

This is a proposal to do at Los Alamos an experiment which would be similar to the Friedman experiment at TRIUMF which measured integral cross sections for πp scattering. The major differences between the two experiments would be the use of liquid hydrogen targets, the use of ADC and TDC signals from the counters, and extension to higher beam energy in LAMPF 1190.

This proposal was reviewed by the Los Alamos Program Advisory Committee in January of 1990 and rejected. We intend to submit this again to the next LAMPF PAC in the summer of 1990, for consideration for running in 1991.

The motivation for this proposal rises from the very large discrepancies now apparent in the total cross sections at low energy. Some of these discrepancies are illustrated in Figure 1 which compares directly the total cross sections reported by Carter *et al.*(1971) to those of Pedroni *et al.*(1978). In the region of 150 MeV, the discrepancies between the two experiments are as large as ten times the reported experimental uncertainties. In addition, total cross sections estimated from the Friedman integral cross sections and from integration of the Colorado/TRIUMF differential cross sections are shown for comparison. No errors are indicated for the latter two data sets because they are estimated values rather than direct measurements. It is clear, however, that the discrepancies between the various experiments exceed the reported uncertainties by a large factor.

SUMMARY AND CONCLUSIONS

The π^+p data base at low energies is sadly confused. There is a set of differential cross section measurements for π^+p [Auld 1979, Frank 1983, Brack 1986, Brack 1988, Brack 1990, Wiedner 1987 (at the five largest angles measured)] which lie well below the accepted phase shift solutions at larger scattering angles, and other measurements [Bussey 1973, Bertin 1976, Ritchie 1983] which are in reasonable agreement with the phase-shift analyses. For π^-p, there is at least fair agreement between the phase-shift analyses and experiment.

The Colorado/TRIUMF group has measured π^+p and π^-p differential cross sections by three different methods, using solid targets, at several energies from 30 to 139 MeV. The normalization errors are about $\pm 2\%$. The first and third of these measurements detected scattered pions and recoil protons in coincidence. All previous measurements of $\pi^{\pm}p$ differential cross sections below 140 MeV used only a single-arm detection apparatus.

There is some suspicion in the πN community that our measured differential cross sections may be OK for π^-p, but not for π^+p. We have tested this possibility by replacing the active CH scintillator-target used in TRIUMF E394 with a CD (deuterated scintillator) target, and looking at the elastic πd scattering for both π^+ and π^-, where the cross sections are the same within a few percent. This is exactly what we have found, in accord with our belief that the πp experiment was responding properly for both pion polarities. This work (TRIUMF E399) on the elastic πd cross sections at 50 and 65 MeV is now being prepared for publication.

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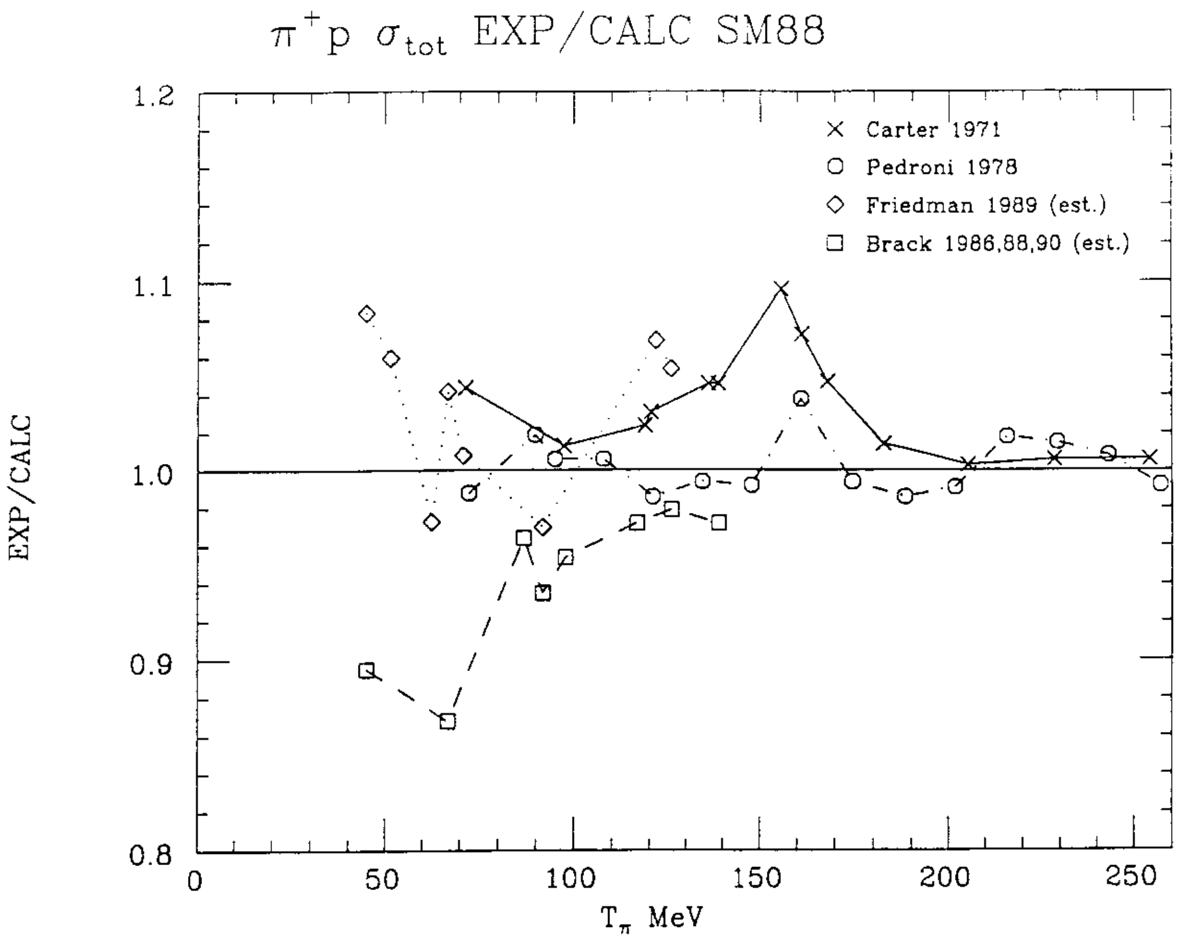

FIGURE 1.

A phase-shift calculation (SM88) is used as a basis for comparison of four different experiments. The Carter and Pedroni results are total cross sections as reported in those references. The Friedman results shown are total cross sections estimated from the integral cross sections reported in Friedman 1989. The Brack results shown are estimated total cross sections derived from the differential cross sections reported in Brack 1986, 1988, 1990. The overall experimental uncertainty, including both random and systematic errors, is as small as ±0.3% for some of the Carter points. The overall errors on the Pedroni points are about ±2% near the resonance.

Integral measurements of π^+p cross sections

E. Friedman

Racah Institute of Physics
The Hebrew University, Jerusalem, Israel

Results of recent measurements of differential cross sections for positive pion-proton scattering at low energies [1-3] disagree with predictions made with currently accepted sets of phase shift values [4-6]. An alternative experimental approach of measuring integrals over limited angular ranges of the differential cross sections has been applied recently [7,8] and yielded results that are basically in agreement with the predictions.

The same sets of phase shifts predict differential cross sections that are generally up to 15-20% above the recent experimental differential cross sections [1-3], whose quoted accuracies are at the 2-4% level.
At several energies (e.g. 66.8 MeV) the differential data extends low to sufficiently small angles to enable the calculation of the integral cross sections directly. At 66.8 MeV the integral cross section was measured at 30deg as 20.8+-0.5 mb whereas integration of the differential data yields 18.1+-0.4 mb. Similarly, for 20deg the results are 21.8+-0.5 and 18.5+-0.4 mb respectively.

The situation described above can be summarized as follows:
1. Integral data between 45 and 126 MeV agree perfectly with the KA85 [6] phase shifts. Below 90 MeV the agreement is good also with the SP89 [4] and KH80 [5] phase shifts.
2. Below 70 MeV the discrepancy between integral and differential data is the same as the discrepancy between phase shift predictions and the differential data (of Brack et al [1-3]).
3. At 66.8 MeV a discrepancy of about 5 standard errors is obsereved between the integral and differential data that is independent of any theoretical input.

In addition, at 54.3 MeV the results of Coulomb-nuclear interference measurements [9,10] are in agreement with the KH80 [5] phase shifts.

Such discrepancies between experimental results are unfortunate but not uncommon. However, as the integral measurements are in agreement with dispersion relation constrained phase shifts, these discrepancies may be very significant and could lead to far reaching consequences for low energy pion nucleon physics, because discrepancies between differential data and phase shifts at low energies could be associated with problems with our knowledge of the interaction in the resonance region. Additional precision measurements over that region may help solve some of the above problems. Such measurements between 100 and 300 MeV are the topic of a recent research proposal to TRIUMF.

We plan to extend our previous integral measurements to higher energies and to cover the resonance region with a similar technique to that used by us at lower energies [7,8]. In these measurements solid targets of graphite and polyethylene are used and the hydrogen cross section is obtained by subtraction. In this way high precision is possible with regards to target composition and thickness together with stability and reproducibility. The subtraction poses no problem as the cross section due to the two atoms of hydrogen is typically 25-40% of that due to carbon and therefore very high statistical accuracy is possible. Some of the systematic errors cancel out in the subtraction.

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Elastic pion- proton scattering below 100 MeV

M. Metzler*, B.M. Barnett+, R. Bilger+, H. Clement+, J. Jaki*, Ch. Joram*, K. Kärcher*, T. Kirchner*, W. Kluge*, S. Krell+, H. Matthäy*, G.J. Wagner+, R. Wieser*

*Institut für experimentelle Kernphysik, Universität Karlsruhe

+Physikalisches Institut, Universität Tübingen

The renewed interest in low energy πN scattering has arisen from the calculation of the $\sigma_{\pi N}$-term within the framework of chiral perturbation theory [1], which revealed a significant discrepancy with the value obtained from πN scattering.

Gasser and Leutwyler calculated $\sigma_{\pi N} = (35\pm5)$ MeV. They also showed that the analytic continuation of the isospin even πN amplitude D^+ to the unphysical Cheng- Dashen point $t=2m_\pi^2$, $\nu=0$

$$\Sigma = \frac{f_\pi^2}{2}\left(D^+(t=2m_\pi^2, \nu=0) - \frac{g^2}{2m_N} \right) \tag{1}$$

is related to the σ- term by $\Sigma = \sigma + 5$ MeV. Using a phase shift analysis constrained by analyticity [2] and dispersion relations along hyperbolas in the Mandelstam plane (ν^2, t) Koch [3] calculated $\Sigma_{\pi N} = (64\pm8)$ MeV, where the error gives only a part of the uncertainty. In a more recent dispersion analysis including new data for low energy πp scattering and using the results from [2] above k=170 MeV/c, Gasser et al. [4] obtained a value of $\Sigma=(56\pm8)$ MeV. This was achieved partly by using a value of the $\pi\pi$ s-wave scattering length $a_0^0=(0.20\pm0.01)m_\pi^{-1}$ which has been obtained by chiral perturbation theory [5]. The discrepancy between the σ-term from the dispersion analysis and from chiral perturbation theory might be due to systematic errors of the experiments used in [2], [3]. If the discrepancy will persist it suggests an unexpected large contribution of sea quark pairs to the nucleon mass.

In the low energy range the KH80 phase shifts are mainly based on the data of Bertin et al. [5] and of Bussey et al. [7]. Some of the recent πN differential cross sections obtained at LAMPF [8] and TRIUMF [9] differ from the earlier data and therefore also from the values calculated from the KH80 phase shift analysis by up to 30% [10]. However, the new TRIUMF data from Friedman et al. [11] agree with the prediction from KH80. The large uncertainties of πN scattering data at low energies have to be regarded as a serious problem.

In a recent experiment we explored the Coulomb nuclear interference region at $T_\pi = 55$ MeV for the first time [12]. In that angular region it is possible to extract the real part of the isospin- even forward scattering amplitude $D^+(s,t=0)$ directly:

$$\mathrm{Re}\,D^{+}(\nu,t{=}0) \propto \lim_{t\to 0}\left[\left(\frac{d\sigma}{d\Omega}(\pi^{+}p)-\frac{d\sigma}{d\Omega}(\pi^{-}p)\right)\cdot t\right] := \lim_{t\to 0}\Delta(t) \qquad (2)$$

The experiment was performed by using a setup of wire chambers and a range telescope without the new spectrometer LEPS. It gave a slightly larger value of Re D^{+} than the KH80 prediction (s. fig 4).

In 1989 we completed our measurements of the angular distributions of the elastic $\pi^{\pm}$-p scattering at T_{π} = 33.3, 44.6, 67.1 MeV for scattering angles between 10^{o} and 120^{o} with the LEPS spectrometer at the πE3 channel (fig. 1).

The LEPS spectrometer [13] consists of 2 dipoles in a splitpole configuration preceded by a quadrupole triplet which images the target spot onto an intermediate focus detector. The focal plane detector arrangement consists of a vertical drift chamber [14] which has a spatial resolution of 100 μm, two scintillators and a range telescope. The two scintillators serve as trigger in coincidence with the proportional chamber consisting of 6 planes with 128 wires 1mm apart at the intermediate focus.

The advantages for using the magnetic spectrometer LEPS are the following:

- Measurements at forward angles down to 10^{o}
- Identical identification for both pion charges [15]
- Good momentum resolution $\Delta p/p$ = 0.3% (including the beam momentum resolution) which is needed for an efficient background suppression
- Large solid angle (20 msr)

Additional advantages of this set-up are:

- Absolute counting rates of the incident beam particles are obtained by a 2 × 16 strip hodoscope [16] which is positioned 40 cm downstream the scattering target.
- Unique particle identification of $\pi^{\pm}$, $\mu^{\pm}$, $e^{\pm}$ is achieved by time of flight measurements relative to the RF of the isochronous cyclotron
  a) with the scintillator hodoscope
  b) with one of the trigger scintillators in the focal plane
- Absolute normalisation of the cross- sections is realised by relating the π-p cross sections to the experimentally and theoretically well known μ-p and e-p cross sections.
- Additional μ-e discrimination is possible with a range telescope.
- A counter arrangement upstream the scattering target detecting muons from pion decay is used to provide an additional relative incident pion flux measurement.

We used both CH_2 and liquid hydrogen as targets. Most of the background from scattering on carbon could be identified due to the measurement of the pion momenta which are different from those in the case of π-p scattering. The remaining background was determined by carbon and empty target measurements.

In the following we present our results for the scattering in the Coulomb nuclear interference region from 10^o to 45^o (lab. angle) for 33.3 MeV and 44.6 MeV obtained with a LH_2 target. Preliminary results for T_π = 67.1 MeV are presented in the article of Joram et al. in this newsletter.

Figure 1 shows the measured $\pi^{\pm}p$ cross sections in comparison with the prediction from the KH80 phase shift analysis. The π^-p data agree quite well with the phase shift analysis, whereas the π^+p data differ from the phase shift analysis dependent on the angle by up to 30%. At very forward angles, where the electromagnetic interaction dominates the cross section, the data are in very good agreement with the calculation. This is taken as an indication that our systematic error of the absolute normalisation is less than ±5%.

A preliminary single energy partial wave analysis [17] shows that our data can be reconciled with the data from Brack et al. [9]. If one extrapolates the expression given in equation (2) to t=0 the following values of Re $D^+(s,t=0)$ are obtained (fig. 3):

$$\text{Re } D^+(T_\pi=33\text{MeV},t=0) = (8.5\pm0.6)\text{GeV}^{-1}, \text{Re } D^+(T_\pi=45\text{MeV},t=0) = (10.8\pm0.8)\text{GeV}^{-1}.$$

These numbers including the result of our former experiment at T_π = 55 MeV are shown as a function of energy in figure 4 in comparison with the KH80 solution. The preliminary data suggest that the isospin- even scattering length has a larger value than predicted by KH80. According to Gasser's relation for the σ- term [18] one of the contributions to Σ (eq. 1) becomes larger (see for a more detailed discussion G. Höhler's contribution to this Newsletter).

We thank very much Prof. G. Höhler for continuous and helpful discussions.

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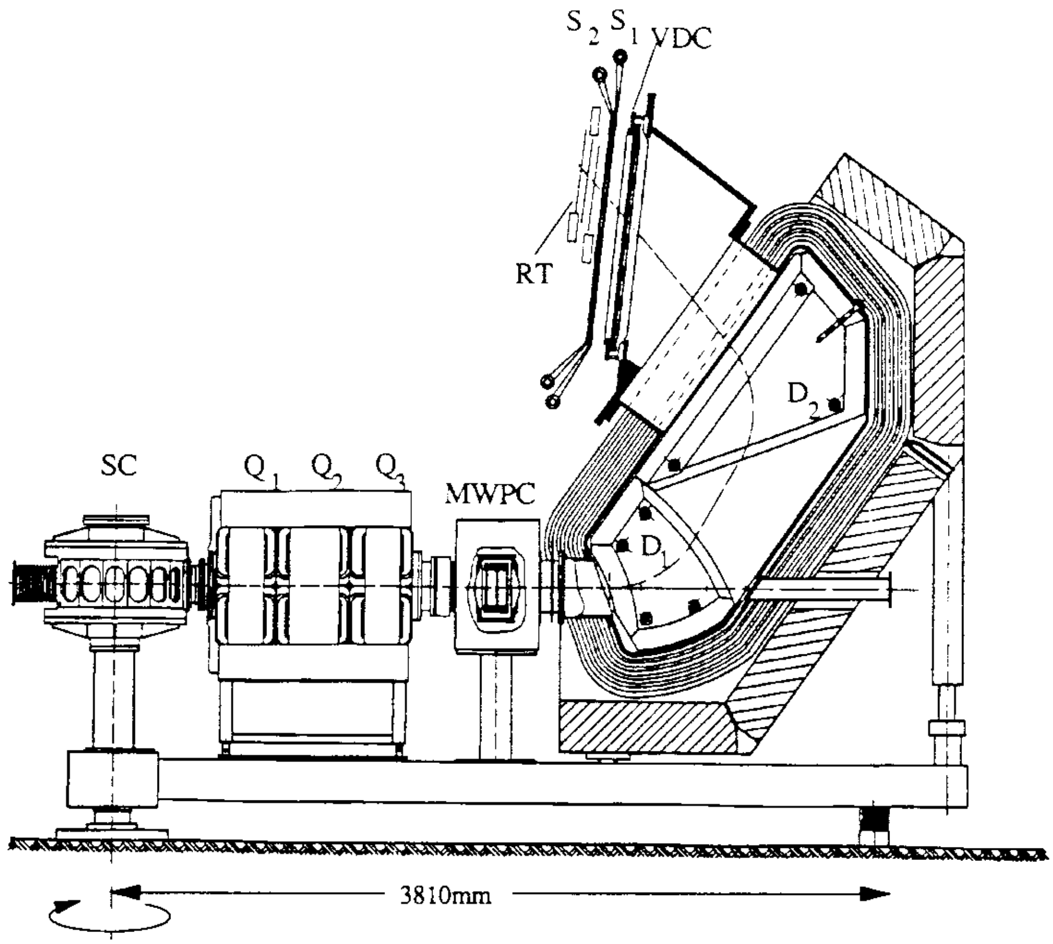

Fig.1: Magnetic spectrometer **LEPS** at the πE3 channel at PSI.

- SC - Scattering chamber
- Q_1-Q_3 - Quadrupoletriplett
- MWPC - Intermediate focus detector (multi wire proportional chamber)
- D_1, D_2 - Splitpole
- VDC - Focal plane detector (vertical drift chamber)
- S_1,S_2 - Trigger scintillator
- RT - Range telescope

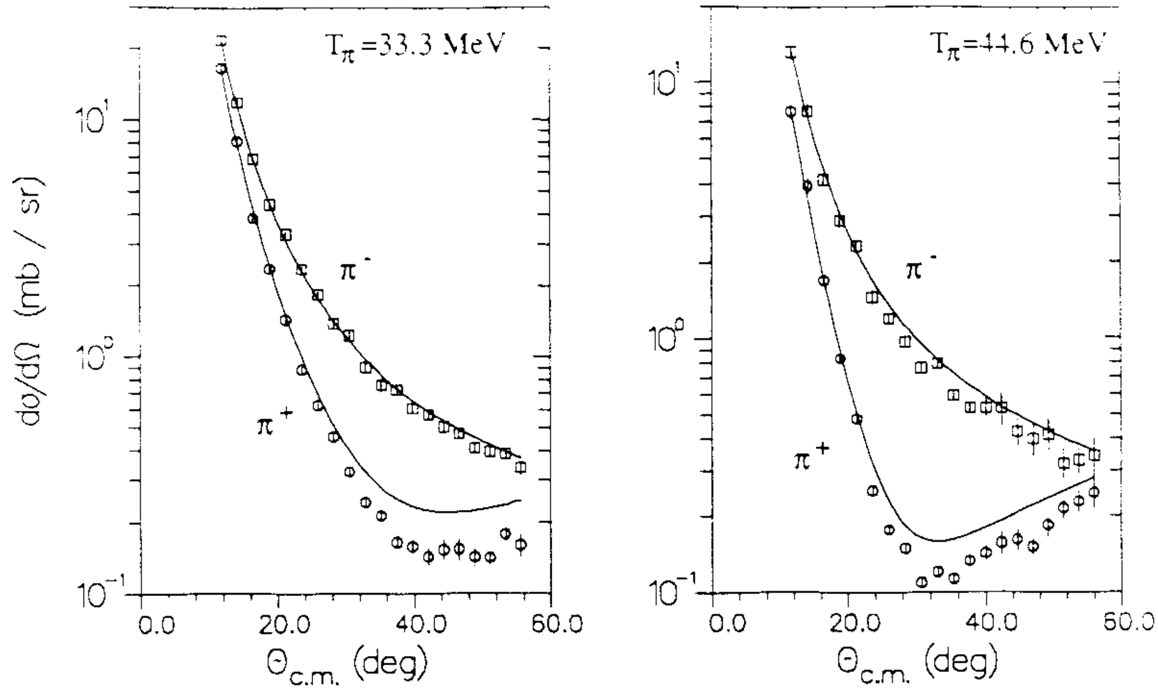

Fig.2: Differential cross-sections for T_π=33.3, 44.6 MeV. The KH80 solutions are plotted as solid lines.

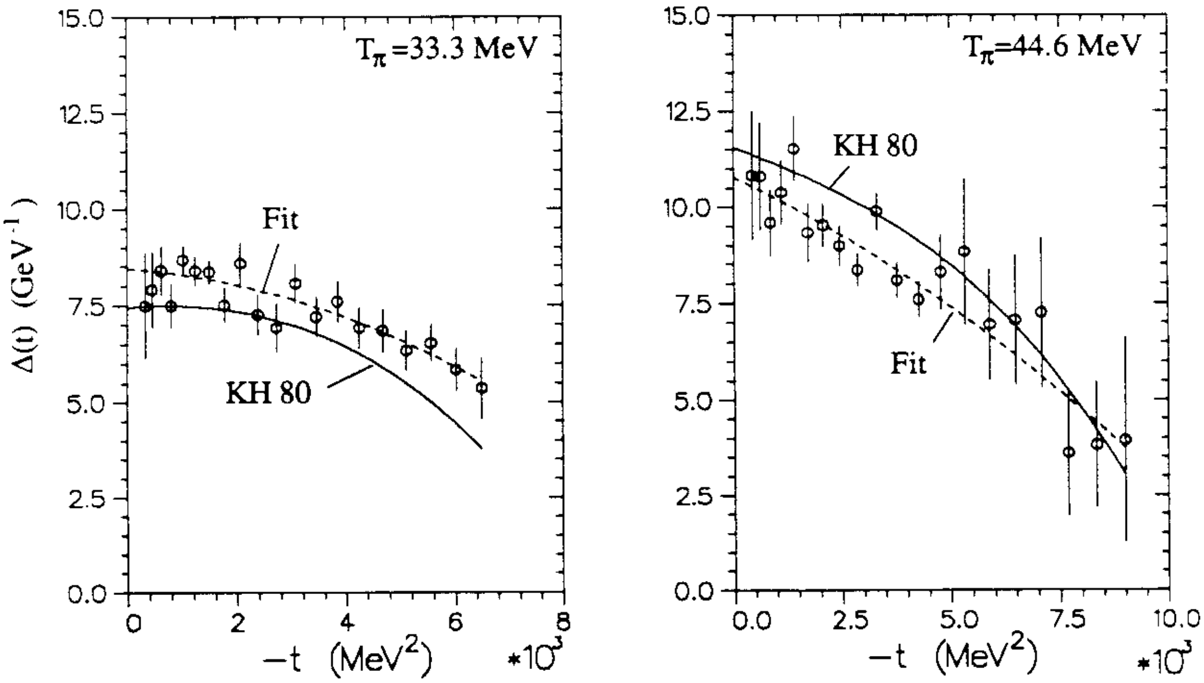

Fig.3: $\Delta(t)$ as defined in equation (2) for T_π=33.3MeV and for T_π=44.6MeV. The solid lines are the KH80 solution. The dashed curves represent a fit to the data.

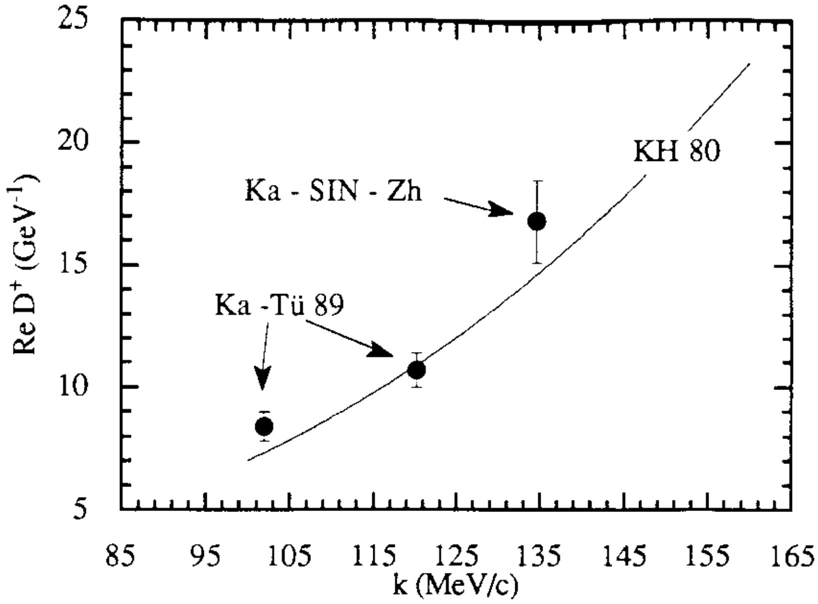

Fig.4: Re D^+ as a function of the pion momenta. The value for k=138MeV/c is taken from Ref. [8].

Preliminary results from pion nucleon scattering at 67.1 MeV

Ch. Joram*, B.M. Barnett+, R. Bilger+, H. Clement+, J. Jaki*, K. Kärcher*, T. Kirchner*, W. Kluge*, S. Krell+, H. Matthäy*, M. Metzler*, G.J. Wagner+, R. Wieser*

*Institut für experimentelle Kernphysik, Universität Karlsruhe

+Physikalisches Institut, Universität Tübingen

Recently analysed and hence still preliminary elastic pion proton scattering data at 67.1 MeV are presented. The measurements were performed with a CH_2 - target and a ^{12}C - target to subtract the physical background. The preliminary character of the results refers mainly to the absolute normalisation which was achieved by relating the πp cross sections to the well known cross sections of elastically scattered muons on ^{12}C, whereas the relative angular distribution is believed to be known within a few percent. It may be stated that especially for π^+ the relative angular distribution differs significantly from the published TRIUMF results [1] at this energy.

The data at the very forward angles (10° to 25°) as well as measurements at T_π = 32 and 45 MeV which cover the angular range from 25° to 125° are currently analysed.

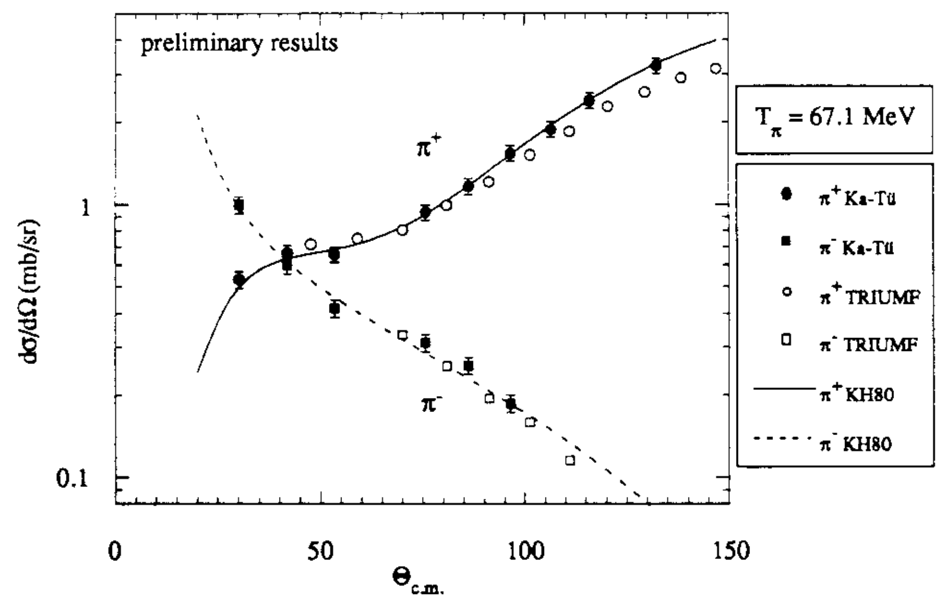

Fig. 1: Differential cross sections for T_π = 67.1 MeV Also included are the energy scaled TRIUMF results. The KH80 solutions are plotted as solid and dashed lines respectively.

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J.T. Brack et al. Phys. Rev. C 38 (1988) 2427

DETERMINATION OF THE STRONG INTERACTION PARAMETERS IN PIONIC HYDROGEN WITH A CRYSTAL SPECTROMETER

R-86-05, ETHZ - NEUCHATEL - PSI

W. Beer[*,§], M. Bogdan[*], D. Bovet[†], E. Bovet[†°], D. Chatellard[†], J.-P. Egger[†], G. Fiorucci[†°], K. Gabathuler[‡], P.F.A. Goudsmit[*], H.J. Leisi[*], A.J. Rusi El Hassani[*], D. Sigg[*], L. Simons[‡], St. Thomann[*], W. Volken[*]

- [*] Institut für Mittelenergiephysik der ETHZ, CH-5232 Villigen PSI
- [†] Institut de Physique de l'Université, Breguet 1, CH-2000 Neuchâtel
- [°] also at Ecole d'Ingénieurs, CH-2610 St. Imier
- [‡] Paul Scherrer Institut, CH-5232 Villigen PSI

We report on the progress of an experiment to measure both the strong interaction shift (ϵ) and broadening (Γ) of the 1S level in pionic hydrogen. These two quantities completely determine the two independent, isospin decomposed $\pi - N$ S-wave scattering lengths a_1 and a_3.

The experimental setup consists of a high resolution double focusing silicon crystal spectrometer of the reflection type (Johann geometry). In order to maximize the π^- stopping rate, a cyclotron trap is used. The X-rays are detected with two-dimensional position sensitive CCD (charge coupled device) detectors.

The principle of the cyclotron trap is to wind up the range curve of the 85 MeV/c pion beam in a weak focusing magnetic field. This field of 25 kG is produced by a superconducting split coil magnet. After injection the pions spiral towards the center while loosing energy in the target gas and in a few thin degraders. The beam is then stopped within a volume with dimensions of a few cm.

The crystal arrangement of the spectrometer consists of 13 thin spherically bent Si (111) crystals with a diameter of 5 cm each. These crystals were obtained from Philips Research Laboratories, Eindhoven. The crystal curvature is achieved by mounting them under vacuum onto glass supports with the given curvatures. Special care was taken to align each individual crystal.

The CCD X-ray detectors used are 8.5 mmx12.7 mm in size (385x576 pixels, 20μ x 20μ each). The advantages of using CCDs lie in their excellent intrinsic position resolution (in our case 22μ), together with good energy resolution ($\approx$180 eV FWHM) and crucial background rejection capabilities.

The whole set-up is precisely aligned and temperature stabilized. The position difference of the CCDs between hydrogen data taking and Argon calibration runs is measured with an accuracy of 10μ.

A preliminary measurement was carried out at the end of 1988 at the πE3 beam line with the cyclotron trap with plastic and Si (Li) detectors in order to determine the best experimental conditions. X-ray yield measurements as a function of gas pressure convinced us that an optimal experiment should measure the K_β (3P-1S) line at ~2.9 keV with a hydrogen target pressure of 15 ρ_{STP}. A nearby line (Argon K_α, 2.96 keV) whose energy is accurately known is used for energy calibration.

In March-April 1989 a first measurement was done with the full setup operational and the first data were obtained. In November-December 1989 the run was repeated with an improved crystal alignement, trap efficiency etc. Figure 1 presents an Ar Calibration spectrum

Data analysis is in progress. It is already clear that:

- the signal to background ratio is 1.5
- the results of both runs are consistent
- the strong interaction shift ϵ will be determined with high statistical accuracy (<0.2 eV).

We plan to measure after the PSI shut-down the width Γ (1S), and to extend the experiment to pionic deuterium.

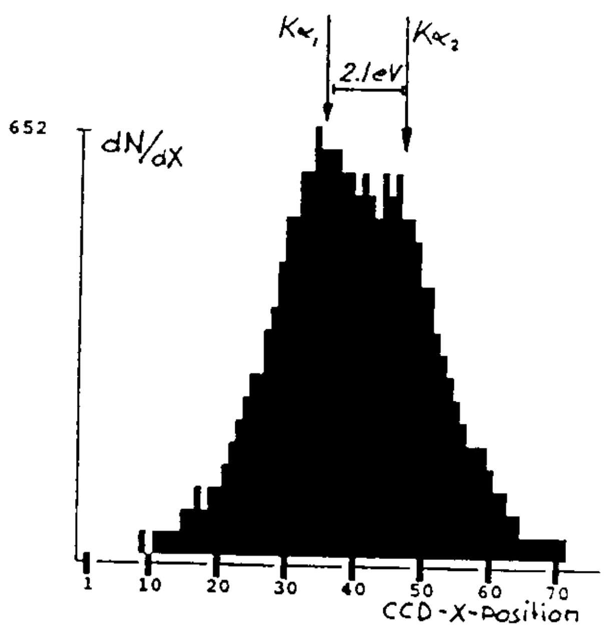

Figure 1: Position spectrum of Argon X-rays (K_{α_1} and K_{α_2}) (fluoresced by 5.9 and 6.5 keV ^{55}Mn X-rays) diffracted by our curved Si crystal assembly and taken with the CCDs.

Addendum:

At the Zuoz Spring School 1990 the ETHZ-NEUCHATEL-PSI group presented the value $3a_{-} = 0.262 \pm 0.012\ \mu^{-1}$ for the $\pi^{-}p$ S-wave scattering length, which agrees with Koch's value of $0.249 \pm 0.012\ \mu^{-1}$ within the errors. It is remarkable that a combination of the new result with $a_1 - a_3 = 0.263 \pm 0.005$ from the Panofsky ratio (Spuller et al., 1977) gives the value **zero for the isospin even S-wave scattering length** well within the errors.

Phase shift analysis of the new $\pi^{\pm}p$ cross sections at low energies

G. Höhler and J. Stahov †)
Institut für Theoretische Kernphysik, Universität Karlsruhe, West Germany
and
Faculty of Technology, University of Tuzla, Jugoslavia

1. Introduction

As discussed in [1] some of the new high precision πN scattering data at low energies deviate not only considerably from the predictions derived from the KH80 phase shift solution, but they also show discrepancies between each other far outside the estimates of the systematic errors. One possibility is to perform an energy dependent analysis constrained by forward dispersion relations (see Refs. 22 and 23 in [1]). This method is applicable to data up to about 80 MeV and it assumes that the KH80 amplitudes above about 90 MeV are correct. A problem is the selection of a consistent data base. A considerable part of the (contradictory) data sets had to be omitted in Ref.23 in [1].

As an alternative at low energies, and in order to find corrections to the KH80 solution at higher energies, we have performed single-energy analyses of all new πN scattering data data measured at the meson factories. Preliminary results have been reported in Refs. 20 and 24 in [1]. In this article, we shall describe our analyses of new data of the PSI and TRIUMF groups near 33, 45, 54 and 67 MeV [2-5] and of the LAMPF data near 29 MeV [6]. The aim is to find a subset of solutions whose partial wave amplitudes have approximately a smooth energy dependence and can therefore be used in an energy-dependent analysis.

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2. The method of our single-energy analyses

Of special interest are elastic scattering data in the Coulomb interference range [2-4], since to a certain extent (see below) one has an additional check of the normalization and energy and the real part of the forward amplitude can approximately be determined without a phase shift analysis. We think that in the special cases under consideration, the following method for the analysis is preferable to the method of Koch and Pietarinen (Ref.2 in [1]). The electromagnetic effects are treated according to the prescription of the NORDITA group (Ref.4 in [1]).

In the decomposition of the differential cross section

$$\sigma_{exp} = |G_{exp}|^2 + |H_{exp}|^2 = \sigma_C + \sigma_N + \sigma_{Int} \tag{2.1}$$

the pure Coulomb cross cross section σ_C is accurately known. Therefore we consider the expression ($1/\gamma = 137\ v_{Lab}/c$)

$$S_{dat} := g(z)(\sigma_{dat} - \sigma_C)\ ;\ g(z) = \frac{q}{2\ \mathrm{Re}G_C} \simeq \frac{t}{4\gamma} = \frac{z-1}{2\gamma} q^2 \tag{2.2}$$

which goes to a **finite value** as $z=\cos\theta \rightarrow 1$. A problem with the Coulomb phase is unimportant.

The same quantity expressed in terms of the nuclear cross section σ_N and the nuclear spin noflip and flip amplitudes, which follow from a partial wave solution, reads (H_C is real)

$$S_{pw}(z) = \mathrm{Re}\ qG_N(z) + g(z)\ (\sigma_N + 2\mathrm{Im}\ G_C \mathrm{Im}\ G_N + 2H_C \mathrm{Re}\ H_N) \tag{2.3}$$

At small angles, the first term is strongly dominant, so an extrapolation to z=1 determines the real part of the invariant forward ampiitude D and a combination of the nuclear S- and P-phase shifts (written for π^+p scattering)

$$\mathrm{Re}\ D_N(z=1) = 4\pi\frac{k}{q}\ \mathrm{Re}\ G_N(z=1)\ ;\ \mathrm{Re}\ qG_N(1) \simeq \delta^N_{0+} + (2\delta^N_{1+} + \delta^N_{1-}) \tag{2.4}$$

k and q are the pion momenta in the lab. and cm frame, respectively. $S_{pw}(z)$ has a simple and slowly varying dependence on z, since D- and higher waves are very small in our energy range (Refs. 6 and 7 in [1]). In a first step we compare $S_{dat}(z)$ as following from [2,4] with $S_{pw}(z)$ as calculated from the partial wave solution KA85 [1]. Next, we perform a fit to S_{dat}, varying the nuclear S, P1 and P3 phase shifts. Due to the small angular range of the data [2,4] one cannot determine the three phase shifts accurately. Only the combinations which belongs to Re $D_N(z=1)$, eq.(2.4), and to the slope

$$dS/dz|_{z=1} \simeq (2\delta^N_{1+}+\delta^N_{1-}) + \sigma_N(1)q^2/(2\gamma) \tag{2.5}$$

are determined fairly well.

In a second step, we fit a combination of the data sets of [2] and [5], applying a correction calculated from KA85 for the small energy difference.

In the fits to the π^-p data we vary only the I=1/2 phase shifts and use the result of the fits to the π^+p data for the I=3/2 phase shifts, taking into account the corrections given by the NORDITA method. The small D- and F-waves are taken from KA85.

Since we are interested in the real part of the forward amplitude (2.4), our plots will show

$$\tilde{S}(z) = \frac{4\pi k}{q^2} S(z) \text{ GeV}^{-1} \tag{2.6}$$

so the extrapolation to z=1 gives Re $D_N(1)$ in GeV^{-1} in a good approximation.

3. The data near 30 MeV

3.1 The π^+p data at 33.3 and 29.4 MeV

The new preliminary PSI data [2] at 33.3 MeV show a large discrepancy with the KA85 prediction (Figure 3.1). In particular, Re $D_+(z=1)$ is somewhat higher (Table 3.1), but it should be noted that the value of Re D_+ is small and that it passes zero at an energy not far below 30 MeV. Its rapid energy dependence can be seen in the last two lines of Table 3.1.

The best fit to the PSI data has a χ^2 per degree of freedom $\chi^2_{df}=1.4$ which indicates that part of the errors is not of statistical origin. If we choose fixed S31 phases which are nearer to the KA85 value, we find solutions with almost the same χ^2 but the P31 phase moves to positive values which disagree qualitatively with the dispersion calculations. χ^2 becomes much higher if $\sigma(180^\circ)$ or the phase P33 are fixed at the KA85 values. Phases calculated from the TRIUMF data [5] also have a fairly large uncertainty due to the small angular range.

Table 3.1: Nuclear π^+p phase shifts at 33.3 and 29.4 MeV in degrees, Re $D_N(z=1)$ in GeV^{-1}, σ_N^{tot} in mb and $\sigma(180^\circ)$ in mb/sr from KA85 and from our fits. Delta(P31)=0° was kept fixed in the solution denoted by an asterisk. The lower part of the table gives the result of an analysis of the LAMPF data at 29.4 MeV [6] and an estimate of the shift to 33.3 MeV using the energy dependence of the solution KA85. From the difference between the two lowest lines one can estimate the effect of the experimental determination of the energy.

S31	P31	P3	Re D_N	σ_N^{tot}	$\sigma_N(180^\circ)$	χ^2_{df}	Reference
-4.10°	-0.49°	2.91°	3.58	6.76	1.42		KA85
-1.40°	-1.27°	2.03°	4.01	2.35	0.28	1.4	[2]
-3.50°	*0°	2.52°	4.46	4.96	1.16	1.4	[2]
-3.52°	-0.65°	2.72°	3.64	5.48	1.10	1.5	[5]
-3.79°	-0.02°	2.74°	4.85	5.85	1.36	2.8	[2]+[5]
-2.85°	-0.45°	2.41°	4.39	3.97	0.83	1.3	[2]+[5, N=0.72]
-2.99°	-0.40°	2.14°	2.75	4.16	0.86	0.7	[6] 29.4 MeV
-3.31°	-0.48°	2.69°	4.70	5.13	1.09		[6]→33.3 MeV

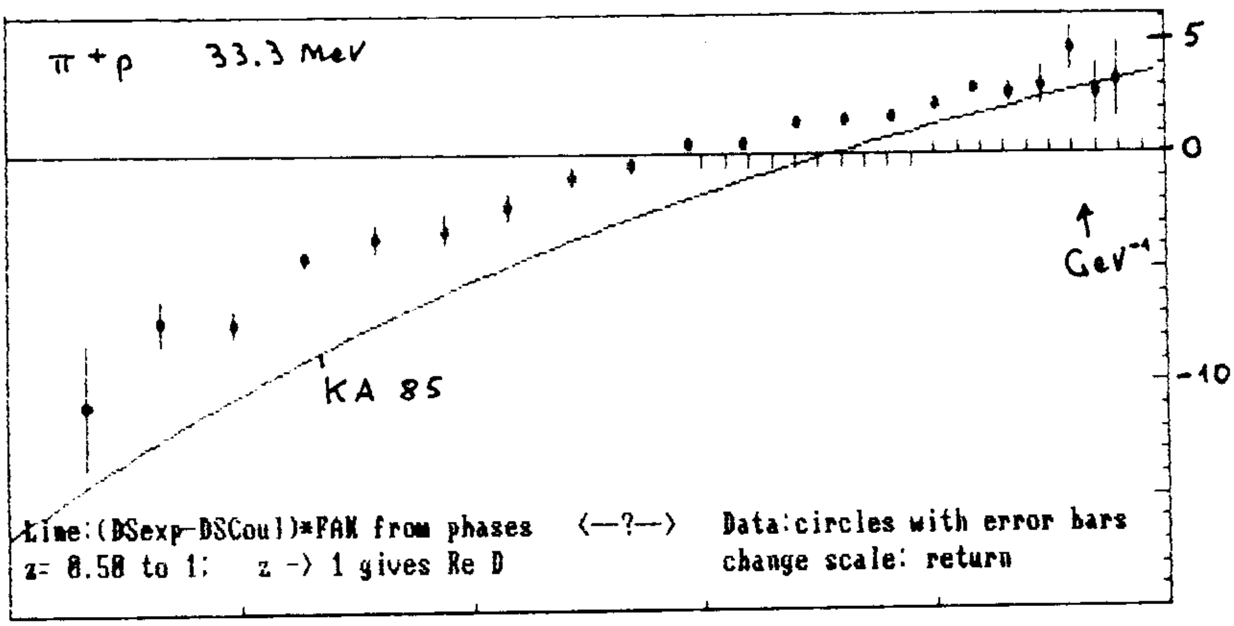


Figure 3.1: $\tilde{S}_{pw}(z)$ from KA85 for π^+p scattering at 33.3 MeV and $\tilde{S}_{dat}(z)$ from [2]. The last point on the left is the first point of the TRIUMF data [5]. The extrapolation to z=1 gives Re $D_N(1)$ in GeV^{-1}.

Next, we consider the combined PSI and TRIUMF data sets [2,5], estimating from KA85 the correction to [5] due to the energy shift. The correction amounts to about 10% at the largest angles and is smaller at smaller angles. Near θ_{cm}=55° the two data sets show a reasonable connection, but the best fit to the combined set has $\chi^2_{df}\simeq 2.8$, i.e the **shape** is not compatible with the constraint to vary only S- and P-waves. We have made a second fit, taking the normalization of the TRIUMF data (6 points) as an adjustable parameter. It is surprising to see that the renormalization factor N=0.72 leads to a good fit to both data sets, in which the PSI data contribute about as much to χ^2 as in a fit to these data alone. However, the small systematic error of the TRIUMF data (3.6%) excludes such a large renormalization. Since a renormalization of the PSI data leads to a structure in $S_{dat}(z)$ near $z=1$, it cannot be used for a substantial reduction of the χ^2. An appreciable error of the energy of the PSI data also would lead in Figure 3.1 to a distortion in the Coulomb region. The error of the energy estimated by the TRIUMF group (±0.5 MeV) is too small to explain the discrepancy.

We have also made a fit to the LAMPF data at 29.4 MeV, using fixed KA85 phase shifts and an adjustable normalization factor. It is surprising that one obtains a good fit (χ^2_{df}=1.1), but unfortunately the renormalization factor is 1.37, i.e. ten times the systematic error estimated by the authors, so we do not want to draw a conclusion.

Table 3.1 shows that there is at present a large uncertainty of the experimental total cross section and of the backward cross section near 33 MeV, since the KA85 solution is compatible with the data of Bertin et al. (Ref.11 in [1]).

3.2 The π^-p data at 33.3 and 29.4 MeV

Figure 3.2 shows that the discrepancy between the new elastic π^-p scattering data and the prediction from KA85 is smaller than in the π^+p case.

In Table 3.2 we have listed the results of various phase shift analyses keeping the I=3/2 phases fixed as determined in the analyses of the π^+p data (Table 3.1) but corrected according to the NORDITA prescription.

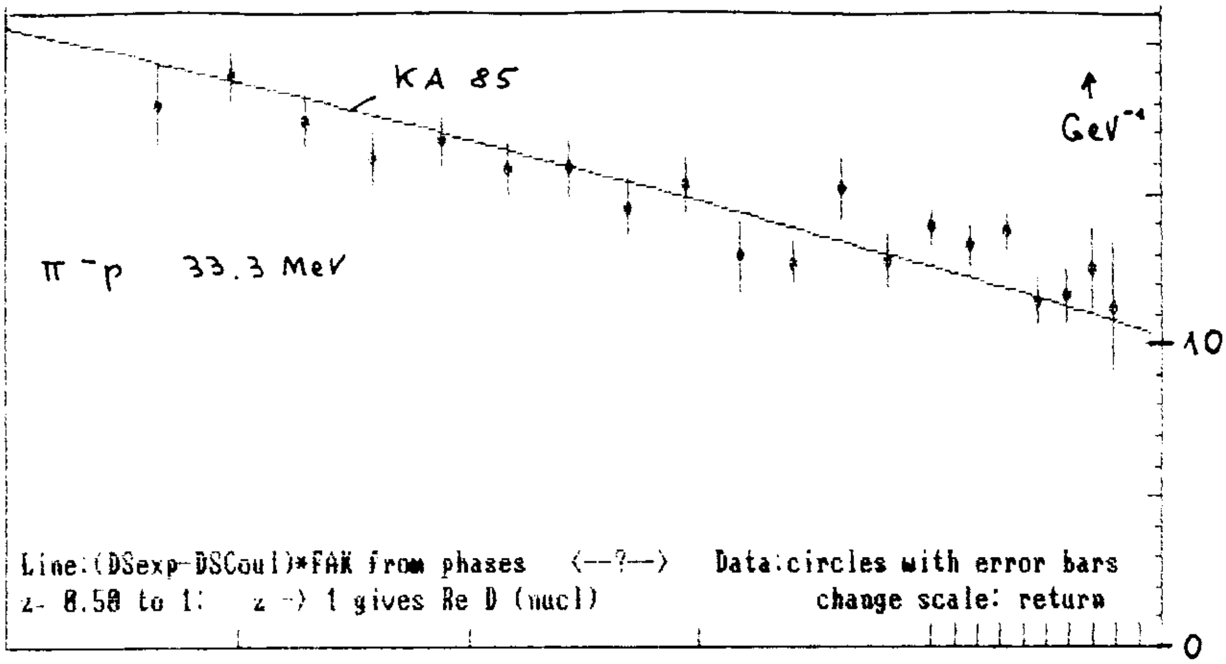


Figure 3.2: $\tilde{S}_{pw}(s)$ from KA85 for π^-p scattering at 33.3 MeV and $\tilde{S}_{dat}(s)$ from [2].

Table 3.2: Nuclear I=1/2 phase shifts at 33.3 and 29.4 MeV in degrees, and other quantities (seeTab.3.1). The I=3/2 phase shifts were taken from KA85 or from the results of the analysis of the combined π^+p data of [2,5]. The first and second line of the lower part of the table follow from an analysis of the LAMPF data at 29.4 MeV. Last line: a correction for the energy shift estimated from KA85 has been added to the solution [6]*. The contribution to χ^2 of the PSI data to the combined fits is about 1.5 times larger than the χ^2 of the fit to the PSI data alone, i.e. the two data sets are not compatible with each other. The large values of $\chi^2{}_{df}$ indicate the presence of nonstatistical errors. The I=1/2 phase shifts of the solution denoted by § are close to the KA85 values.

			π^-p:					
S11	P11	P13	Re D_N	σ_N^{tot}	$\sigma(180^\circ)$	I=3/2	χ^2_{df}	Reference
5.93°	-0.72°	-0.35°	10.5	8.33	0.04	KA85		KA85
5.70°	-0.28°	-0.38°	10.8	7.91	0.02	KA85	1.5	[2]
5.35°	0.01°	-0.41°	11.0	7.05	0.01	[2,5]	1.3	[2]
5.93°	-0.68°	-0.35°	10.5	8.30	0.04	KA85	1.6	[2,5] §
5.87°	-0.80°	-0.37°	10.5	7.89	0.04	[2,5]	1.6	[2,5] §
5.45°	-0.70°	-0.24°	9.8	7.92	0.04	KA85	1.4	[6]
5.13°	-0.61°	-0.19°	9.9	6.78	0.04	[6]	1.5	[6]*
5.45°	-0.70°	-0.24°	10.3	7.03	0.03			[6]*→33.3 MeV

4. The new data near 45 MeV

4.1 The π^+p data at 44.6 and 45 MeV

Figure 4.1 shows that at 44.6 MeV $\tilde{S}_{dat}(z)$ deviates from the KA85 prediction in a similar way as at 33.3 MeV. Table 4.1 shows the best fits obtained by a variation of the S- and P-phases.

In general, the values of χ^2_{df} are too high, so there are contributions from nonstatistical errors. The best fit to the PSI data alone has unrealistic small values of the S31 phase and the total cross section, but similar to the situation at 33.3 MeV, there are other solutions with almost the same χ^2. However, it is seen that χ^2_{df} is increasing considerably if we approach the KA85 phases. The large value χ^2=2.5 of the fit to the combined PSI + TRIUMF data sets shows that the data are not compatible although the connection at $\theta \simeq 55°$ is reasonable. A renormalization of the TRIUMF data leads to a much smaller χ^2_{df}, but this is excluded by the small systematic error (2.2%) of the latter data set.

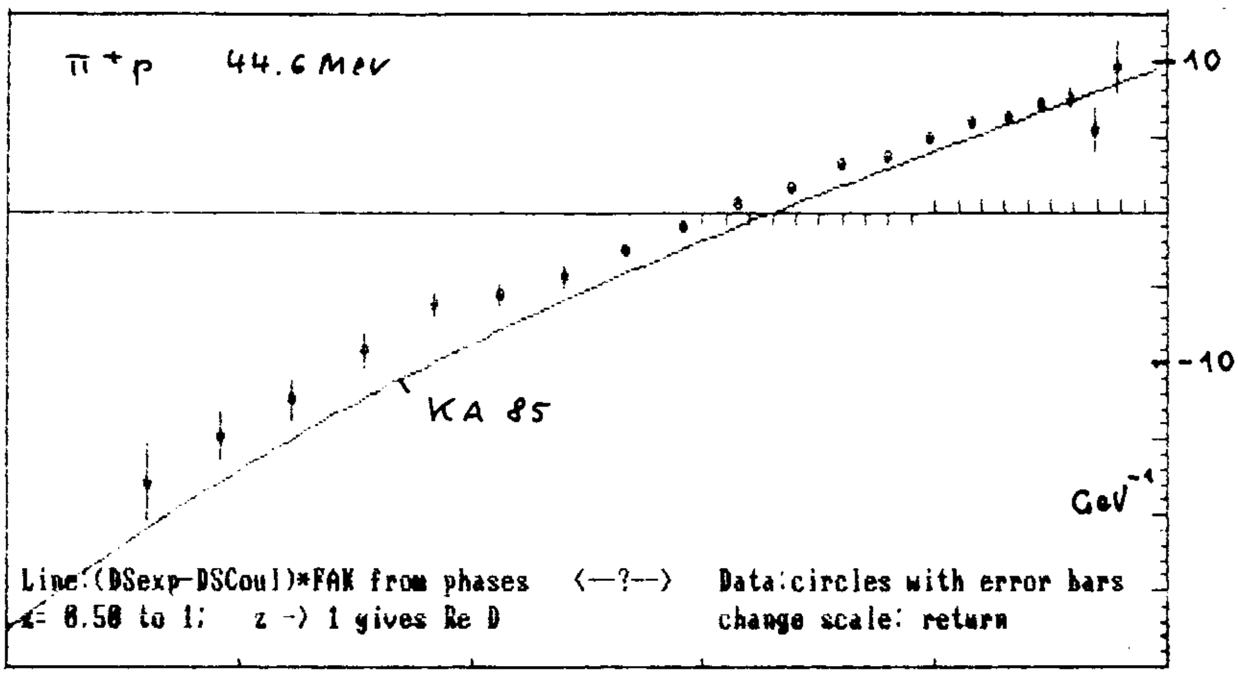


Figure 4.1: $\tilde{S}_{pw}(z)$ from KA85 for π^+p scattering at 44.6 MeV and $\tilde{S}_{dat}(z)$ from [2].

Table 4.1: Nuclear π^+p phase shifts at 44.6 MeV and other quantites (see Tab3.1). Phase shifts denoted by an asterisk have been kept fixed.

S31	P31	P33	Re D_N	σ_N^{tot}	$\sigma(180°)$	χ^2_{df}	Reference
-5.01°	-0.74°	4.77°	9.5	10.3	2.22		KA85
-0.76°	-1.97°	3.22°	9.4	3.68	0.33	1.34	[2]
-3.00°*	-1.05°	4.01°	10.0	6.16	1.16	1.42	[2]
-4.50°*	-0.35°	4.49°	10.4	8.86	2.01	1.67	[2]
-5.33°	0.07°	4.77°*	10.8	10.77	2.59	1.90	[2]
-4.35°	-0.74°	4.44°	9.5	8.56	1.82	1.52	[5]
-4.29°	-0.54°	4.51°	10.5	8.64	1.90	2.5	[2]+[5]
-3.77°	-0.70°	4.27°	10.2	7.45	1.57	1.32	[2]+[5, N=0.86]

It is of great interest to compare the predictions from these phase shifts with the results of the experiment of Friedman et al. [7], who measured the integrated π^+p cross section from 30° (lab) to 180° at 45 MeV. We use the phase shifts of Table 4.1 for a calculation of the integrated cross section in the same range:

Table 4.2: Integrated π^+p cross sections in mb from 30° Lab to 180° near 45 MeV.

mb	Source
11.7 ±0.5	Friedman et al. [7] 45 MeV
11.1	KA85 at 45 MeV
9.0	[5] at 44.6 MeV
9.0	[2,5] at 44.6 MeV (χ^2_{df}=2.5)
7.8	[2]+[5, N=0.86] at 44.6 MeV

Since the cross section increases towards the backward direction, the result of the fit to the combined data is dominated by the TRIUMF data which have a normalization error of 2.2%, so there is a clear discrepancy, because the effect of the small energy difference is of the order of 0.1 mb.

The last line shows that the fit with the renormalized TRIUMF data (Table 4.1) leads to an **increase** of the discrepancy. Since the renormalization follows from the combination with the PSI data, the latter data are not compatible with the Friedman et al. data combined with the condition that only S- and P-waves are varied in the fit. The same conclusion follows from Table 4.1: fits to the PSI data become very bad, if one demands a value of the total cross section near to that belonging the KA85 solution, which is compatible with the Friedman et al. data [7].

4.2 The π^-p data at 44.6 MeV

Figure 4.2 shows that the discrepancy between the KA 85 solution and the PSI data is larger than at 33.3 MeV. Unfortunately, the errors beyond about θ_{cm}=40° are considerably larger than at 33.3 MeV. The connection with the TRIUMF data is good.

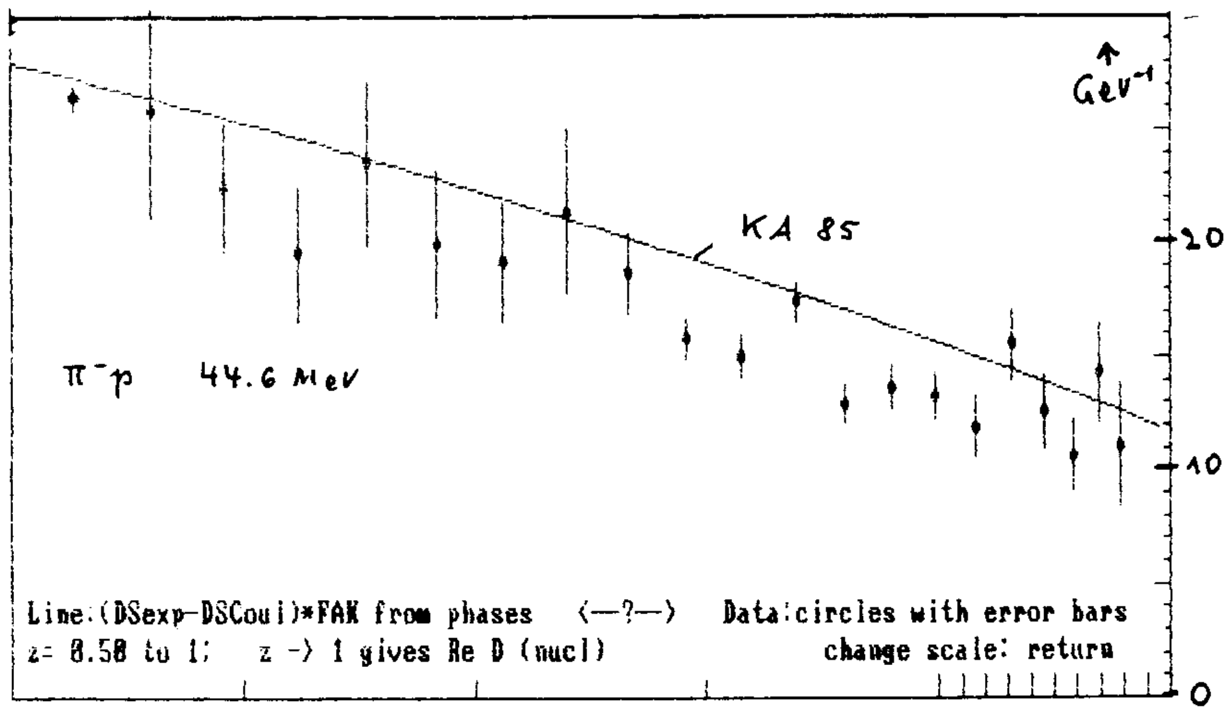


Figure 4.2: $\tilde{S}_{pw}(z)$ from KA85 for π^-p scattering at 44.6 MeV and $\tilde{S}_{dat}(z)$ from [2]. The first point on the left belongs to the TRIUMF data.

Table 4.3 gives the results of various fits. The large χ^2_{df} of the fit to the combined data sets indicates that the data sets are not compatible with each other.

Table 4.3: Nuclear I=1/2 phase shifts at 44.6 MeV and other quantities (see Tab.3.1).

			π^-p:					
S11	P11	P13	Re D_N	σ_N^{tot}	$\sigma(180^\circ)$	I=3/2	χ^2_{df}	Reference
6.75°	-0.97°	-0.51°	12.0	9.42	0.01	KA85		KA85
6.01°	-1.02°	-0.50°	10.6	8.48	0.004	KA85	1.3	[2]
6.05°	-1.10°	-0.61°	10.6	7.98	0.01	[2]+[5]	1.3	[2]
6.62°	-1.[illegible]6°	-0.61°	11.2	9.26	0.01	KA85	1.9	[2]+[5]
6.15°	-1.28°	-0.38°	11.2	8.05	0.01	[2]+[5]	1.7	[2]+[5]

5. Data at 54.3 MeV

At this energy there exist only the data of the PSI group. In their Letter [3], the authors normalized the data by adjusting them to the prediction for pure Coulomb scattering at very small angles. The experimental normalization was used in the detailed paper [4], because the authors thought that the Coulomb normalization may be questioned due a paper by Sawada [8], who claimed to have found evidence for a new long range (van der Waals type) strong force, which was proposed in some speculations. However, immediately afterwards, Hutt and Koch [9] showed by a comparison with their more careful treatment of the dispersion relation that there is no evidence for Sawada's effect. Since Sawada has made no attempt to defend his result, I think that one can ignore his paper. Of course, one cannot exclude the possibility that QCD leads to new singularities not yet included in Mandelstam's hypothesis, so it is of interest to look for unexpected phenomena at very small angles. However, the PSI data are compatible with the electromagnetic effects treated by the NORDITA method and fits varying only S- and P-wave phase shifts.

Since the angular range of the first PSI experiment [3,4] is considerably smaller than that of the subsequent measurements and the experimental method was simpler, one can determine only two combinations of the three phase shifts: the intersection of $\tilde{S}(z)$ with the ordinate at z=1, eq.(2.4) and the slope $d\tilde{S}/dz$ at z=1 eq.(2.5).

5.1 The π^+p data at 54.3 MeV

Figure 5.1 for π^+p shows an approximate agreement with the prediction from KA85.

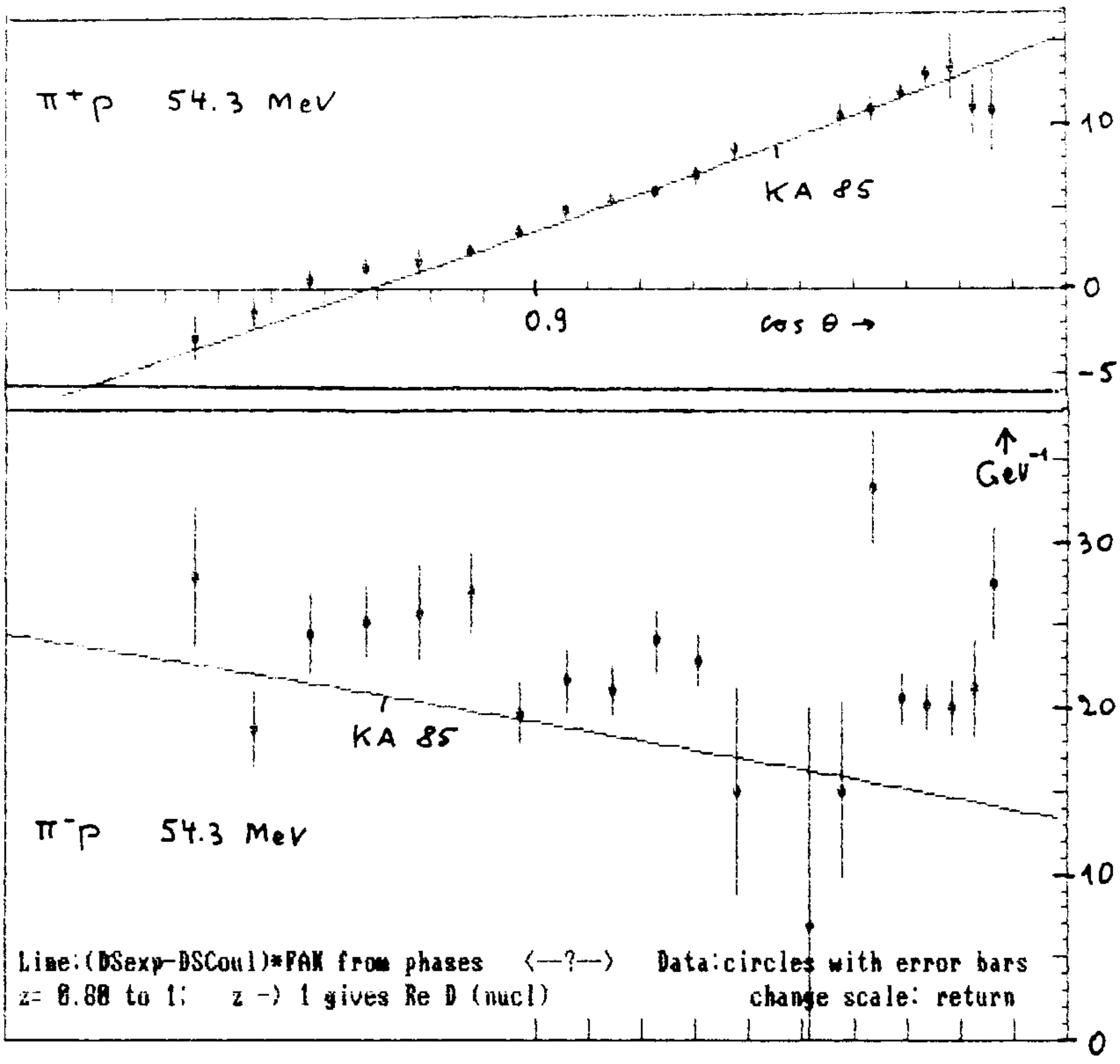


Figure 5.1: $\tilde{S}_{pw}(z)$ from KA 85 for $\pi^{\pm}p$ scattering at 54.3 MeV and $\tilde{S}_{dat}(z)$ from [4].

However, a variation of the phase shifts leads to a significant reduction of χ^2 from 29.7 to 12.1. The first two points at the smallest angles are somewhat too low, but the fit cannot be improved by a change of the energy since this would lead to a distortion in a larger angular range.

Table 5.1: Nuclear π^+p phase shifts at 54.3 MeV. An interpolation of the data of Friedman et al. [7] at 51.5 and 62.6 MeV favors the solutions marked by §. The solution marked by † shows that $\chi^2{}_{df}$ decreases considerably if the two points at the smallest angles are omitted in the fit. N≲1 leads to a positive P31 phase which is far from all dispersion calculations. See Table 5.2 for ‡.

S31	P31	P33	Re D_N	σ_N^{tot}	$\sigma(180°)$	χ^2_{df}	Reference
-5.76°	-0.98°	6.71°	15.1	14.6	3.11		KA85
-6.66	+0.07	6.66	15.3	15.6	3.75	0.73	[4]
-6.28	-0.47	6.53	14.3	14.7	3.32	0.95	[4] N=1.065 §
-6.44	+0.26	6.64	16.1	15.3	3.73	0.78	[4] N=0.935
-6.20	-0.22	6.56	15.2	14.6	3.41	0.76	[4] § ‡
-6.57	-0.26	6.64	14.6	15.5	3.58	0.42	[4] N=1.065 †

It is seen that Re D_N is fairly well determined, but accurate phase shifts can be obtained only if an additional information on the cross sections at larger angles is provided.

5.2 The π^-p data at 54.3 MeV

Again, we start with a comparison of $\tilde{S}_{dat}(z)$ with the prediction from the solution KA 85 (Figure 5.1). It is seen that the experimental value of Re $D_N(z{=}1)$ is higher. Table 5.2 gives the result of our variation of the I=1/2 phase shifts.

Table 5.2: Nuclear I=1/2 phase shifts at 54.3 MeV. For the I=3/2 phases we have taken some of the solutions listed in Table 5.1. ‡ refers to a solution in Table 5.1.

S11	P11	P13	π^-p: Re D_N	σ_N^{tot}	$\sigma(180°)$	I=3/2	χ^2_{df}	Reference
7.36°	-1.15°	-0.65°	13.6	10.8	0.001	KA85		KA85
7.85°	+0.01°	-0.70°	15.9	11.3	0.002	KA85	3.9	[4]
8.26°	+0.48°	-1.03°	16.0	12.0	0.003	[4] N=1.065	3.9	[4]
7.93°	-0.72°	-0.68	14.9	11.5	0.002	[4] ‡	2.7	[4] N=0.95
7.02°	-0.42°	-0.70°	14.0	10.4	0.007	[4] ‡	1.9	[4] N=0.90
6.65°	-0.56°	-0.85°	12.7	10.0	0.006	[4] ‡	1.6	[4] N=0.84

The χ^2_{df} values indicate large nonstatistical errors which are fluctuating as a function of the scattering angle (Figure 5.1, lower part). As a consequence, the information on the I=1/2 phase shifts and Re $D_{N-}(1)$ is poor. $\chi^2{}_{df}$=3.9 is reduced to 2.7 if the normalization used in [4] is replaced by the Coulomb normalization, taking N=0.95 as given in [4] and to 1.9 if N=0.90 is taken from [3]. The reduction of χ^2 is, of course, a consequence of our method. An adjustable renormalization factor leads to N=0.84 which is outside the errors.

6. The data near 67 MeV

6.1 The π^+p data at 66.8 MeV

We present results only for the combined three sets of π^+p data of Brack et al. [5,10]. We find the P33 phase near to the KA85 value, but the S31 phase much smaller in absolute value.

Table 6.1:
Nuclear π^+p phase shifts at 66.8 MeV obtained from a fit to the combined π^+p data of Brack et al.

S31	P31	P33	Re D_N	σ_N^{tot}	$\sigma(180°)$	χ^2_{df}	Reference
-6.69°	-1.29°	9.62°	22.7	21.6	4.51		KA85
-5.27°	-1.72°	9.41°	23.9	19.4	3.74	1.2	[5,10]

Again, we show a comparison with the results of Friedman et al. [7].

Table 6.2:
Integrated π^+p cross section from 30° Lab to 180° at 66.8 MeV.

mb	Source
20.8 ±0.6	Friedman et al. [7]
20.9	KA85
18.5 ±0.4	phase shifts derived from [5,10]

The discrepancy between the two TRIUMF experiments is much larger than the error estimates.

6.2 The π^-p data at 66.8 MeV

Table 6.3 gives the phases derived from the combined sets of π^-p data of Brack et al. [5,10], using the I=3/2 phases determined from the π^+p data (Table 6.1).

Table 6.3: Nuclear I=1/2 phase shifts at 66.8 MeV and other quantities (see Tab.3.2).

			π^-p:				
S11	P11	P13	Re D_N	σ_N^{tot}	$\sigma(180°)$	χ^2_{df}	Reference
8.06°	-1.35°	-0.84°	15.8	13.3	0.01		KA85
7.48°	-0.36°	-0.52°	17.6	11.8	0.03	1.9	[5,10]

7. Real parts of the forward amplitudes

When Koch and Pietarinen carried out their partial wave analysis in 1979, data in the Coulomb interference region where available only at very high energies, except for a few measurements by Baillon et al. starting at 600 MeV/c, which did not join smoothly to other data sets (see Figure 6.2.10 on p.321 in my book). The imaginary parts of the forward amplitudes were known from total cross section data and the optical theorem, but the real parts derived from single-energy analyses fluctuated strongly as a function of energy.

In this situation the authors used as part of their input our "Table of Forward Amplitudes" [11] calculated from a smooth fit to the total cross sections and the smooth real parts derived from an evaluation of the forward dispersion relations. The treatment of the high energy tail and the determination of the subtraction constant are described in [11,12] and in my book (Ref.1 in [1], sections 2.2.1 and 2.4.7). Since the table is based on isospin invariance, it has to be considered as an approximation for the hadronic quantities. The forward amplitudes calculated from the phase shift solution KH80 differ only slightly from the input (see the yellow pages in [12]). Earlier versions of our table were used in the CERN phase shift analysis by Lovelace et al. and the table was also used in the recent analyses of Arndt et al. ("SAID").

As a consequence, the determination of the real part of the forward amplitude from an extrapolation of the $\pi^{\pm}p$ scattering data in the Coulomb interference region to 0° [2–4] is not a check of details of the KH80 solution, but essentially only of the input from our table

[11] which almost agrees with [12]. Assuming the total cross sections in our table to be correct, one can use the result of [2–4] for a correction of our subtraction constant. Our (hadronic) value of this constant [11,12] and the corresponding S-wave scattering length are in the usual units.

$$D^{+}(\mu,t=0) = 4\pi(1+\mu/m)a^{+}_{0+} = -0.99\ \text{GeV}^{-1}\ ;\ \ a^{+}_{0+} = -0.0096\ \mu^{-1} \tag{7.1}$$

The result of Koch and Pietarinen is practically the same, but their analysis gives in addition an error of a^{+}_{0+}: $\pm 0.002\ \mu^{-1}$.

We start with Re $D_N(z=1)$ at 54.3 MeV because this quantity has been discussed in the literature [3,4,13]. Results for the **nuclear value** (Re D_{N-}+Re D_{N+})/2 (which should not be denoted by the symbol Re D^{+} for the isospin even combination because isospin invariance is valid only for the hadronic amplitudes) are listed in Table 7.1.

Table 7.1: **Results for (Re D_{N-}+Re D_{N+})/2 from the extrapolation of experimental data to z=1, from an interpolation of the table [12] (shifted to the nuclear value) and from calculations from nuclear phase shifts at 54.3 MeV. The statistical error and the normalization error are listed separately in [4].**

(Re D_{N-}+Re D_{N+})/2 in GeV^{-1}	
[3]: 14.3 ±0.8	[12]: 14.2
[4]: 16.8 ±0.5 ±1.2	KH80: 14.6
	KA85: 14.3

We conclude that the agreement of the experimental result with the values in the second column is good, since we see no reason against the Coulomb normalization [3].

The error given in [3] is almost as large as $D^{+}(\mu,t=0)$, eq.(7.1), and in an attempt to determine the S-wave scattering length, one has to add the error due to the uncertainty of the total cross sections (Tables 3.1 to 6.2). Of course, the small error given by Koch and Pietarinen for a^{+}_{0+} is not valid any more due to the discrepancy of their solution with the new data. If one takes into account the correction following from [4], one obtains $D^{+}(\mu,t=0)=(+1.2\pm0.5\pm1.2)\ \text{GeV}^{-1}$, i.e. a **positive** value of a^{+}_{0+} with a large error.

The extrapolation of the data in the lower part of Figure 5.1 demonstrates that the uncertainty is much larger than in the case of Re $D_{N+}(1)$. The errors given in Table 7.1 for the combination are probably too optimistic. In the following table we summarize the results for the real parts of forward amplitudes.

Table 7.2:
Comparison of the results for the nuclear forward amplitudes with those of solution KA85.

T_π MeV	Re D_{N+} GeV^{-1}		Re D_{N-} GeV^{-1}	
	KA	Fit	KA	Fit
29.4	1.6	2.75	10.1	9.9
33.3	3.6	4.5 ±0.5	10.5	10.6 ±0.2
44.6	9.5	10.3 ±0.3	12.0	10.9 ±0.3
54.3	15.1	14.7 ±0.5	13.6	14.0 ±? (N=0.9)
66.8	22.7	23.9	15.8	17.6

8. Discussion of the results for the partial wave amplitudes

Unfortunately, the results of the single-energy solutions are not satisfactory. The angular range of the PSI data is not large enough for the determination of the S- and P-waves and if one considers in addition the TRIUMF data [5,10], the χ^2_{df} of the fits is too large. A useful comparison of the new phase shifts with the old ones is to plot the **hadronic** quantities Re T_{0+}/q and Re $T_{1\pm}/q^3$ vs. q^2, since they approach the scattering lenghts and volumes as $q \to 0$. Of special interest are Re T^+_{0+}/q and Re $T^+_{1\pm}/q^3$ for applications of Gasser's formula for the sigma term (Ref.39 in [1]) and Re T^-_{0+}/q for a comparison with the scattering length derived from the Panofsky ratio [16]. We show only the figure for the latter case.

This calculation is certainly too simple, because our knowledge of the total cross sections is not "superb" [13] but rather poor due to the discrepancies discussed above. It deviates from the recent discussion in Ericson's lecture at Lisbon [13] for several reasons:

i) The deep dip of the π^-p charge-exchange forward cross section near 46 MeV [14] is not important for Wiedner et al. [3] (they do not even quote [14]), since they consider the limit $t \to 0$, where the Coulomb interference term can be separated from the strong interaction due to its $1/t$ dependence. The method was used at high energies already in Krubasik's thesis [15].

ii) Wiedner et al. [3] have **not** evaluated the forward dispersion relation but simply **quoted the result** given by Koch and Pietarinen for a^+_{0+}. The above discussion and our tables of phase shifts and total cross sections from the new data show that it is **misleading to say that "the scattering length is no longer a source of uncertainty in the analysis"**.

We add a remark concerning the relation of the experiment of Wiedner et al. [3,4] to the sigma term. If the Coulomb normalization is used [3], the authors confirm the first term in the expansion eq.(2) in [1], but an even larger contribution comes from the second term, which is the subtraction constant of the dispersion relation for $\partial D/\partial t$ at $t=0$. The slope $d\tilde{S}/dz$ at $t=0$ in our figures depends on $\partial D/\partial t$, but there is an additional term $\sim\sigma_N$ at $t=0$ (see (2.5)), of which only the contribution $(\mathrm{Re}\ G_N)^2$ is known. Our figures show that, unfortunately, the PSI data deviate from the KA85 prediction, and therefore they do not support Koch's extrapolation to the Cheng-Dashen point.

In our analysis of the π^+p data at 54.3 MeV we ignore the solutions with positive values of P31, since they disagree qualitatively from the dispersion calculations. This leads to the estimate $\mathrm{Re}\ D_+(1)=14.7\pm0.5\ \mathrm{GeV}^{-1}$ (see Figure 5.1).

For the analysis of the π^-p data at 54.3 MeV it is important to notice that the dip in the π^-p charge-exchange forward cross section occurs at about 46 MeV [14]. There is a zero of the hadronic $\mathrm{Re}\ D^-=(\mathrm{Re}\ D_+-\mathrm{Re}\ D_-)/2$ at $t=0$ nearby at 48.5 MeV (KA85). For the **nuclear** amplitudes, the equality of $\mathrm{Re}\ D_{N\pm}$ is shifted to 51 MeV. Since $\mathrm{Re}\ D_{N-}>\mathrm{Re}\ D_{N+}$ at 33.3 and 44.5 MeV, we expect that **$\mathrm{Re}\ D_{N-}$ is slightly smaller than $\mathrm{Re}\ D_{N+}$** at 54.3 MeV. Table 5.2 shows that this condition is fulfilled only if a renormalization factor $N\simeq0.9$ is applied to the data [4], i.e. if the Coulomb normalization is used.

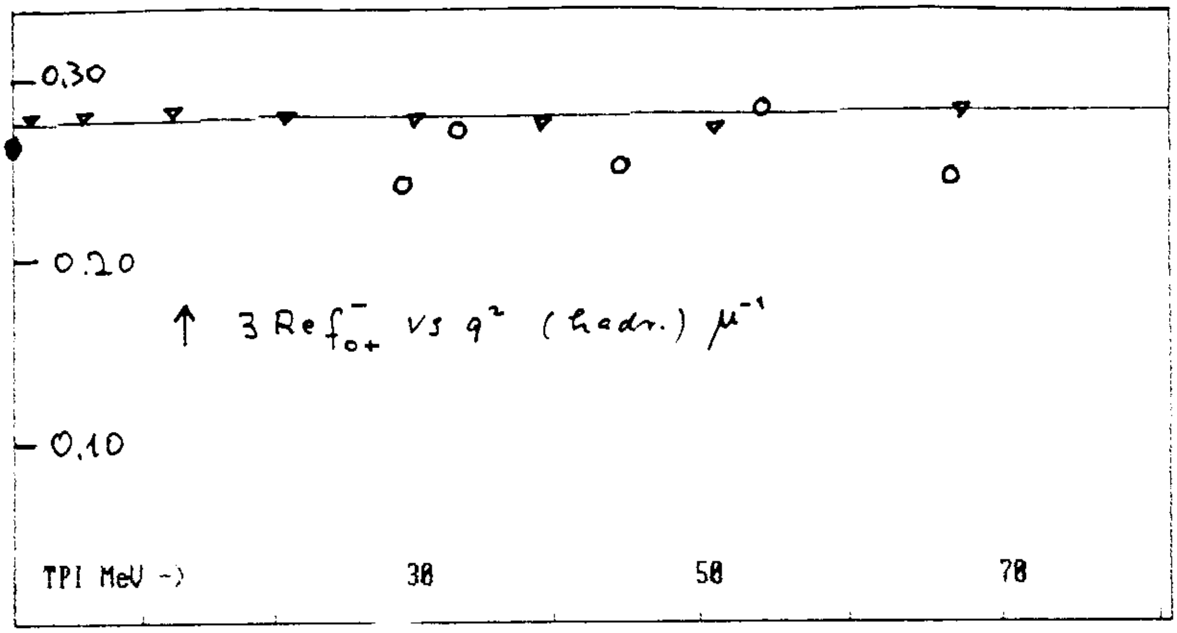


Figure 8.1: Re T^{-}_{0+}/q vs. q^2 (hadronic). This quantity is well determined from the projected fixed-t dispersion relation, if the input at higher energies is correct (Ref.7 in [1]). The circle at q=0 shows the scattering length following from the Panofsky ratio: $(0.265\pm0.005)\mu^{-1}$. Solid line: KA85, triangles: KH80. The other circles belong to the following nuclear S-wave phase shifts in degrees. I=1/2: 5.1, 5.9, 6.2, 7.0, 7.5; I=3/2: -3.0, -3.8, -4.3, -6.2, -5.3 for our five energies (see the tables). The fluctuations are larger for other partial waves.

9. How can one resolve the discrepancies?

One way is, of course, to repeat the $\pi^{\pm}p$ differential and integral cross section measurements, but we think that it would be even more useful to measure other quantities: to improve the accuracy of the charge-exchange cross sections and to measure analyzing powers A_N=P for all three reactions. In our opinion, it is much better to concentrate the available manpower and facilities on these experiments instead of performing the very difficult and time consuming spin-rotation experiments.

At a given energy, there are six S- and P-wave phase shifts. As can be seen from Legendre expansions of the **nuclear** quantities, nine parameters can be obtained from differential cross section experiments, six additional parameters from measurements of the analyzing power. Further information can be obtained from elastic scattering data in the Coulomb interference region and from integral cross section measurements similar to [7]. So the phase shifts are strongly overdetermined and this is necessary for a good test of the treatment of the electromagnetic effects and the search for evidence for isospin breaking. Furthermore, these data would be very useful for the selection of a subset of data which are compatible with each other under the constraint that S- and P-waves are strongly dominant in the low energy region.

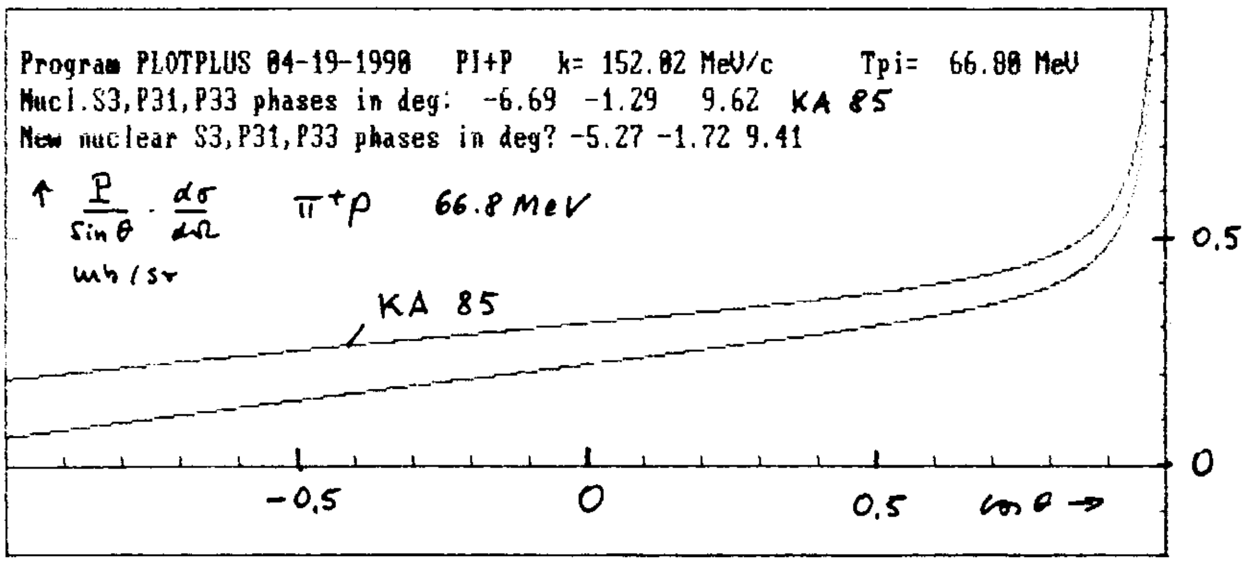
9.1 Determination of the polarization parameter $P=A_N$

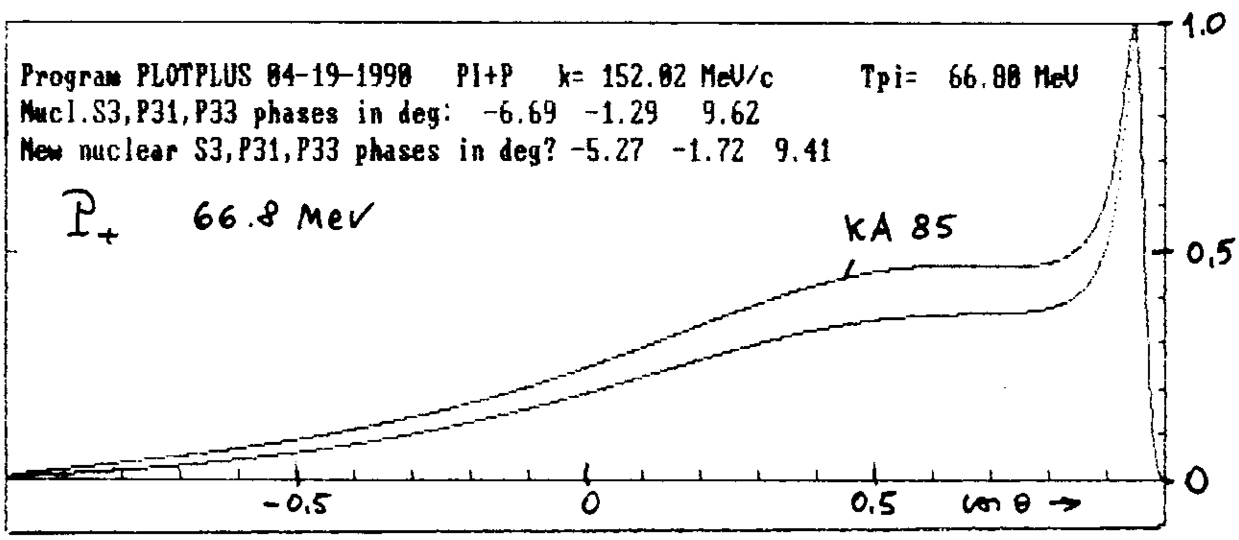
Measurements of A_N have been proposed and started [17,18]. In terms of **nuclear** amplitudes, the simplest quantity is the combination

$$\frac{P}{\sin\theta}\,\frac{d\sigma}{d\Omega} = \frac{1}{q^2}\left[\mathrm{Im}(T_{0+}T^*_{1+} - T_{0+}T^*_{1-}) + 3z\,\mathrm{Im}(T_{1-}T^*_{1+})\right] + \ldots \tag{9.1}$$

which is **linear in** $z=\cos\theta$ as long as S- and P-waves are strongly dominant. In the case of charge-exchange scattering, this is valid also for the experimental data and can be used as a for the internal consistency. The linear shape is modified by Coulomb interference for the experimental data in elastic scattering.

Figure 9.1 shows the difference between the predictions from KA85 at 66.8 MeV and from the second solution in Table 6.1. The shape of $P_+(\cos\theta)$ at the same energy is shown in Fig.9.2.





The narrow peak in the Coulomb interference region occurs near $\theta_{Lab}\simeq 15°$. If P=1 is found in an experiment, one has two simple relations between the three phase shifts from the zero of the transversity amplitude $F_+(-)$ (see Section A2.1.2 in Ref.1 in [1]). A similar peak was shown in Figure 3.2.3 of Ref.1 in [1] and in Figure 1b of [17]. It will probably be difficult to measure the structure shown in Figure 1a of [17] because $d\sigma_-/d\Omega$ is very small near $\theta=180°$.

The data for the analyzing power will be helpful for a new determination of the πNN coupling constant, which is of interest because of the comparison with the results of the Nijmegen group (Ref.43–45 in [1]) obtained from pp-scattering. In πN scattering the most accurate method uses the invariant amplitude B near the forward direction, which is relat to the quantity (9.1).

9.2 Charge-exchange differential cross sections

Several measurements of the π^-p charge–exchange differential cross sections have been performed after the completion of the KH partial wave analysis [14,19–21]. The experiment of Salomon [19] et al. and the low energy part of the experiment of Bagheri et al. [20] are consistent with the KH analysis. Fitzgerald et al. [14] had not realized that their result at $\theta=0°$ is not a test of the phase shifts, but essentially of the input from the table of forward amplitudes [11,12]. It is surprising how well the prediction from our old table for the narrow dip agrees with the data. A check of the phase shifts follows by a comparison of the prediction for the **slopes** of $d\sigma/d\Omega$ vs cos θ with the data. A preliminary calculation shows discrepancies only for the points with the lowest and the highest energy.

Towell [21] presented preliminary results for charge–exchange cross sections at near-forward and near-backward directions between about 10 and 40 MeV. Contrary to his figure, we find a serious discrepancy with KH80 only at 39 MeV in the backward direction, where the KH solution is consistent with the data of Salomon et al. [19].

The next task will be to calculate predictions for charge–exchange scattering from the tables of phase shifts given in this paper and to compare the results with the new experiments.

10. Conclusion

There are fairly large discrepancies between some of the new πN scattering data measured during the last decade in the low energy region and the predictions from the KH phase shifts. However, there are also discrepancies of comparable magnitude between the different experiments and there is no sufficiently large subset of data which are consistent with each other. Therefore, one cannot derive improved new values for the scattering lengths, the coupling constant and the sigma term.

The data in the Coulomb interference region give results for the real parts of the forward amplitudes which deviate only slightly from earlier evaluations of the forward dispersion relation. Furthermore, sufficiently large errors of the energy or of the normalization can be detected from distortions of the curves in our plots.

New experiments should include the charge–exchange cross sections and the analyzing powers in all three reactions. It is very important that **the energies are the same** as for the existing data. Otherwise, one has to perform interpolations and these introduce fairly large uncertainties because of the rapid variation of the data with energy.

Our numerical results are preliminary. The calculation will be repeated in order to check the rather complicated Coulomb corrections and to apply a more sophisticated minimization program.

***

Acknowledgments

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"VPI&SU Elastic Scattering Analyses: About SAID"

Richard A. Arndt, VPI&SU, Blacksburg, Va

VPI&SU Pion-Nucleon Analyses:

The default solution run by SAID is the VPI&SU energy-dependent fit as described most recent publication[1]. This paper presents the formalism by which VPI solutions are obtained as we as a fit (solution FA84) to Tlab=1100 MeV which is still accessible through SAID. In the last 5 years, however, there have been some important new contributions to the Pi-N scattering data base which has been assimilated, more or less continuously, into new solutions which then become the default solutions for SAID: these new solutions have been given "seasonal" names and we are presently working with FA89 which is a fit to Tlab=1300 MeV. Not all the differences between successive solutions can be attributed to changes in the data base: there is an ongoing effort to refine the functional forms by which energy dependence is described and there have been some changes in the formalism used: primarily in the adoption of scattering length constraints and in a minor change to the way in which coulomb effects are treated.

Scattering length constraints were implemented following the Pi-N workshop held in Los Alamos in the summer of 1987. After some consultation with Professor Höhler, we were convinced to adopt the scattering lengths for S, P, D, and F waves as determined by René Koch from partial wave dispersion calculations. These constraints control the very low energy behaviour as is done in the Karlsruhe solutions with the consequence that very low energy extrapolations taken from our more recent solutions are strongly affected by these constraints. Beginning in late 1987, the constraints were implemented by fixing the lowest energy dependent term in our expansion of the underlying coupled channel K-Matrix. More recently Professor Höhler has indicated that, perhaps, the constraints need to be relieved somewhat for the S waves so that we have begun (starting with FA89) to include these constraints with errors in our analyses rendering them as "softer" constraints. This is a question which is still being studied and is part of the larger question (for VPI) of how (with what weight) dispersion theory constraints should be included with the real constraints of measured scattering data.

Coulomb corrections are basically three in type: a direct contribution to the scattering amplitudes, a rotation phase for the partial wave summation, and corrections to the "Nuclear" partial waves used in the summation. These are spelled out clearly in Professor Höhler's Pion Nucleon Handbook[2]. VPI&SU has, since well before the solution published in 1985, used the same direct contribution as is used in the Karlsruhe representations; Rutherford scattering with Nucleon and Pion form factors. The same phase is also attached to this direct coulomb piece. The coulomb rotations used by VPI&SU prior to the most recent solution, FA89, were those obtained from point-particle interactions; this has now been changed to be identical to those used by the Karlsruhe group; these changes produced entirely inconsequential effects to the solutions. Chisquared changes by very small amounts as one goes from one rotation phase to the other.

The third type of charge correction which manifests itself, eg, in the difference between particular partial waves used to describe Pi+P and Pi-P scattering, remains different from that used by the Karlsruhe group. It should be emphasized that there is no model independent determination of this charge splitting; all methods involve a recipe of some sort. An "experimental" determination of charge splitting can be accomplished by varying S31 and P33 in fits to Pi+P and Pi-P data separately. This was done by VPI as part of it's 1985 published solution; the results were quite convincing that the VPI recipe worked remarkably well for those states to 500 MeV. Although we are still studying the question, we continue to use the method we described in 1985.

The differences which persist between the VPI solutions and those of Karlsruhe or Carnegie-Mellon-Berkeley (both of which are available for use with SAID) result, we believe, primarily from the different treatments accorded the data base. The choice of data used in analysis is, of course, of great importance; in 1983 VPI went to a flagged data base as suggested and implemented by Professor Ben Nefkens of UCLA. Data are classified on a 1 star (suspicious data) to a 3 star (top quality) scale; Since then all VPI analyses have been performed on 2 star (and higher) experiments only. All data is maintained in the SAID data base and can be examined against various solutions. This rating system is incomplete at this time and requires the active participation of knowledgeable experimentalists to finish it off in proper fashion. Other factors which would cause differences are binning of the data to obtain solutions at single energies, how unsearched partial waves are treated, and how systematic uncertainties (which plague the Pi-N data base) are handled. We feel that the differences which exist between various solutions (VPI, Karlsruhe, CMU-Berkeley) are not so extreme given the noisy nature of the elastic scattering data base from which they were derived.

The Scattering Analysis Dialin System (SAID):

SAID (Scattering Analysis Interactive Dialin) is a collection of data bases and interactive computer programs designed to present as much information as possible on low energy (below 2 GeV) scattering processes. At present SAID is a source for Nucleon-Nucleon elastic, Pion-Nucleon elastic, K(+)-Nucleon elastic, Pion-Nucleon to Pi-Pi-N reactions, and Pion-Photoproduction. In each case the raw scattering data is obtainable as are a variety of solutions (through partial wave analyses) to each reaction. SAID can be used to compare predictions from a variety of solutions to the raw data and to measure sensitivity of the data to variations of the partial wave amplitudes. The programs are intended to be "interactive" with the computer issuing prompts which should be easily understandable to a user who is familiar with the interaction being studied. The many features available are described following the entry of a "?" mark whenever numerical input is requested by the computer.

The system is strongly oriented toward graphical representations and much effort has been spent on building in support for a variety of Graphics terminals (or Terminal emulators). The first terminal prompt issued is for "Terminal Type"; a "?" on input will create a listing of supported terminal systems. SAID can be accessed either by Dialin to VPI&SU, or as a package available on VAX backup tapes. Information for either case can be obtained from R. Arndt (BITNET PHYS0@VTCC1) or L. D. Roper (BITNET ROPERLD@VTVM1).

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Measurement of the Spin Rotation Parameters A and R in $\pi^+p \to \pi^+p$ and $\pi^-p \to \pi^-p$ from 427 to 657 MeV/c

UCLA-ACU-GWU-LAMPF collaboration *

B.M.K. Nefkens

Physics Dept. UCLA, Los Angeles, CA 90024–1547

The determination of the complete set of ambiguity free πN scattering amplitudes requires the input of at least eight independent measurements. The UCLA-ACU-GWU-LAMPF collaboration thus far has obtained six data sets consisting of $d\sigma/d\Omega$ and A_N for $\pi^+p \to \pi^+p, \pi^-p \to \pi^-p$, and $\pi^-p \to \pi^\circ n$ scattering at six pion momenta between 427 and 687 MeV/c, Ref. [1-6]. This set is special in that it is obtained at precisely the same π^+ and π^- incident momenta, it eliminates extrapolation errors. Data on A as well as R for $\pi^\pm p \to \pi^\pm p$ make the set overdetermined [7] and one can use the extra information to investigate isospin invariance. The necessary algebraic relations have been spelled out by Doncel, Michel, and Minnaert [8] and a lucid exposé is given by G. Hohler in [9].

The measurement of the spin rotation parameters requires a longitudinally polarized hydrogen target and a proton polarimeter. The rarity and expense of this equipment presumably accounts for the lack of A and R data, their intrinsic importance notwithstanding. The sole previous experiment has been performed at CERN at 6 and 16 GeV/c by a Saclay group using the Saclay frozen spin target [10]. The superconducting solenoid of this target has found its way to LAMPF and after suitable improvements was a vital part of our A and R measurements [7]. Measurements of A and R are also under way at Gatchina; preliminary results are available for π^-p scattering [11, 12].

In terms of the spin-non-flip amplitude f and the spin-flip g, the spin rotation parameters are

$$A = \frac{(|f|^2 - |g|^2)\sin\theta + 2\ Re\ (fg*)\cos\theta}{|f|^2 + |g|^2},$$

$$R = \frac{(|f|^2 - |g|^2)\cos\theta - 2\ Re\ (fg*)\sin\theta}{|f|^2 + |g|^2}.$$

Recall that

$$P = A_N = \frac{2\ I_m(fg*)}{|f^2 + |g|^2},$$

thus we have the unique relation

$$A^2 + P^2 + R^2 = 1,$$

which is valid separately for π^+p and π^-p elastic scattering. The layout of the experimental set up is shown in [7]. It included a longitudinally (in plane) polarized hydrogen target that consisted of the HERA superconducting Helmholtz coils and a LAMPF dilution refrigerator mounted vertically. The target was operated in the frozen spin mode to limit the bending of the incoming and outgoing charged particles and to minimize undesired recoil proton spin precision. The polarization phase took place at 25 KG, the holding field was only 5 KG with a relaxation time around 200 hours. Scattered pions were detected in a scintillator hodoscope. The recoil protons were measured using the LAS spectrometer and their spin direction was analyzed with the JANUS polarimeter. To economize on running time we measured A and R simultaneously using LAS to bend the proton vertically out of the scattering plane. This precesses the proton spin such that the P component initially oriented along $\hat{n}$, the normal to the scattering plane, is nearly aligned with the momentum vector after going through the spectrometer bending magnet. The R component originally oriented along $\hat{l}_f$, the recoil proton direction, is rotated to be normal to the momentum. A, the polarization component along $\hat{n} \times \hat{l}_f$, is barely affected by the bending. The spin precession is

$$\theta_R = \frac{1}{2}\ \gamma\theta_b(g-2),$$

θ_R = angle between the proton spin and momentum,

θ_b = bending angle of the proton momentum vector in the magnetic field,

g = Lande factor, $g = 5.586$,

γ = Lorentz factor.

A spin rotation of 90° requires a bending angle of $50.2°/\gamma$ which is close to the LAS value.

A is obtained from the up-down asymmetry after nuclear scattering in the carbon of the JANUS polarimeter and R is the left-right asymmetry. A three by three spin transformation matrix is used to relate the measured polarizations S_f and L_f to the initial spin components S_i and L_i and the desired A and R values at the target,

$$S_f = -A|\vec{L}_i| - R|\vec{S}_i|,$$

$$L_f = -R|\vec{L}_i| + A|\vec{S}_i|.$$

The transformation matrix was calculated by Monte Carlo technique that incorporates various magnetic and geometric aspects of the target and LAS.

Measurements were made at $p_\pi = 427$, 471, 547, 625, and 657 MeV/c both for π^+ and π^- elastic scattering mainly in the backward direction as the proton energy must be sufficiently high to be polarization analyzable by JANUS. The preliminary results [7] support the main features of the Karlsruhe-Helsinki [13], CMU-LBL [14], and VPI [15] πN Parital Wave Analysis, PWA. The final results are anticipated in the near future. They will be presented in terms of the traditional spin rotation parameter A and R as well as the spin rotation angle β where

$$\beta = arg[(f - ig)/(f + ig)]$$

which corresponds to the relative phase between the transversity down and up scattering amplitudes. In terms of A and R we have

$$\beta = -\tan^{-1}(-A/R) + \theta_N + \bar{\theta}_\pi$$

where θ_N is the laboratory angle of the recoil proton and $\bar{\theta}_\pi$ is the pion scattering angle in the c.m. frame. The redundant information on A and R will be used to test isospin invariance along the lines suggested in [8] and [9].

* Currently the participants include
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Recently Completed and Proposed LAMPF Charge Exchange Measurements

submitted by Michael Sadler, Abilene Christian University

Two differential cross section measurements of πN charge exchange using the PI0 spectrometer at LAMPF have been completed and are being analyzed. The first is measurement of differential cross sections for $\pi^- p \rightarrow \pi^0 n$ near 0° and 180° at T_π = 10, 20, and 40 MeV. Electron and muon contamination of the π^- beam at these low energies was suppressed by incorporating a crossed-field DC separator into the beam line of the low energy pion channel. CH_2 targets were used for most of the measurements after three thin liquid hydrogen (LH_2) failed during the course of the experiment. Even so, good rejection of the carbon background was obtained due to the energy determination of the scattered π^0 derived from the opening angle and calorimeter information provided by the PI0 spectrometer.

Yields have been extracted and preliminary results have been made available to interested parties. The data have been analyzed allowing different ranges of energy sharing between the two photon arms and with different fiducial areas for the acceptance of the wire chambers following the converter planes with good agreement. Effort is continuing to determine the overall normalizations as accurately as possible. The most important of these are the effective solid angle and efficiency of the PI0 spectrometer. Particular attention has been paid to the photon conversion probability and the wire chamber efficiencies. Measurements of the photon conversion and the subsequent detection of charged particles from the shower were made by removing all but one converter plane in one arm of the spectrometer and using the other arm as a tag.

The second charge-exchange measurements are differential cross sections near 0° and 180° at nine momenta from P_π^{lab} = 427 to 687 MeV/c, extending to the P_{11} resonance. Again, due to target difficulties, a 2.5-cm CH_2 target was used for the forward angles. The 10-cm LH_2 target was repaired in time for use at the backward angles where the cross sections go through a very deep minimum near 547 MeV/c. Three different physical settings were required to cover the angular intervals $0° < \theta_{cm} < 30°$ and $140° < \theta_{cm} < 180°$, due to the small minimum opening angles between the γ rays for the higher energy π^0's. These angular coverages were accomplished with single settings at the lower energies.

A third experiment, Polarization Asymmetry Measurements for $\pi^- p \rightarrow \pi^0 n$ Between 45 and 190 MeV, has been approved by the LAMPF Program Advisory Committee. The experiment may utilize either the existing PI0 Spectrometer or the new Neutral Meson Spectrometer (NMS) which is presently being designed and prototyped. The experiment will run during the summer, 1991, or later. No measurements of these asymmetries exist in this energy region. Data at lower energies are very sensitive to small changes in the P_{11} phase.

STRANGE QUARKS IN THE NUCLEON

J. Gasser [1,2]
Institute for Theoretical Physics
University of Berne, Sidlerstrasse 5
CH - 3012 Berne, Switzerland

and

M.E. Sainio [3]
Research Institute for Theoretical Physics
University of Helsinki, Siltavuorenpenger 20 C
SF-00170 Helsinki, Finland

Chiral symmetry relates the value of the isospin even amplitude $\bar{D}^+$ in elastic πN - scattering at the Cheng-Dashen point

$$\Sigma = F_\pi^2 \bar{D}^+_{|_{\nu=0,t=2\mu^2}} \tag{1}$$

to the nucleon matrix element of the quark mass term [1]

$$\begin{aligned} \frac{m_u + m_d}{2} < p' \mid \bar{u}u + \bar{d}d \mid p > &= \bar{u}' u \sigma(t); \qquad t = (p'-p)^2 \\ \sigma &= \sigma(0). \end{aligned} \tag{2}$$

Since the Cheng-Dashen point is outside the physical region, one needs to extrapolate the available experimental information to this point. The remarkable work of the Karlsruhe group [2] shows that analyticity and unitarity allow one to perform this extrapolation in a meaningful manner. The result for the Σ-term is 64 ± 8 MeV [3]. A sigma-term of this size calls for rather drastic changes in the standard picture [4], as it implies that the matrix element $< p \mid \bar{s}s \mid p >$ is large and that half of the nucleon mass is generated by the mass of the strange quark. We, therefore, consider it necessary that the low-energy structure of the πN - amplitude be reexamined, both experimentally and theoretically.

The main problem is that the sigma-term - which measures the chiral asymmetry generated by the u and d quark masses - is an inherently small effect. Since the data analysis underlying the value of Σ quoted above is very complex, it is difficult to analyze error propagation and to reliably relate the uncertainties in the value of Σ to the uncertainties in the experimental information. [In this connection, we mention that the prediction of chiral symmetry concerning the isospin odd amplitude (one-loop improved version of the Adler-Weisberger relation) is in excellent

[1] Work supported in part by Schweizerischer Nationalfonds.
[2] Bitnet: U171@CBEBDA3T
[3] Bitnet: SAINIO@FINUHCB

agreement with the Karlsruhe analysis[5]. In contrast to the case of the Σ-term, this test of the theory does however not concern an inherently small effect.] In the following, we propose an extrapolation method which allows one to analyze error propagation in a more direct manner.

We write the sigma-term as

$$\sigma \;=\; \Sigma_d - (\Delta_\sigma - \Delta_D + \Delta_R), \tag{3}$$

where Σ_d contains the contribution from the linear terms in the expansion of $\bar{D}^+(\nu = 0, t)$ around t=0, and Δ_D denotes the curvature in $\bar{D}^+(\nu = 0, t)$, $\Delta_D = \bar{D}^+(\nu = 0, t = 2\mu^2) - \Sigma_d$. The quantity Δ_σ stands for the difference $\sigma(2\mu^2) - \sigma(0)$ of the scalar form factor of the nucleon, and Δ_R denotes the difference between the amplitude Σ and the scalar form factor at $t = 2\mu^2$, $\Delta_R = \Sigma - \sigma(2\mu^2)$. The present status of the calculation of the four quantities $\Sigma_d, \Delta_\sigma, \Delta_D$ and Δ_R is as follows.

1. Exploiting unitarity and analyticity, a set of integral equations has been derived in ref.[6]. They determine the behaviour of the S- and P- wave phase shifts near threshold in terms of two subtraction constants, which also fix the value of Σ_d. The integral equations allow one to straightforwardly investigate the influence of new low-energy data, not yet included in the work of the Karlsruhe group. The analysis is nearly completed, and the result for Σ_d will be published soon [7,8].

2. To evaluate Δ_σ, we write a once subtracted dispersion relation for the scalar form factor,

$$\sigma(t) \;=\; \sigma + \frac{t}{\pi}\int_{4\mu^2}^{\infty} \frac{dt'}{t'} \frac{\mathrm{Im}\sigma(t')}{t' - t}. \tag{4}$$

Neglecting inelastic contributions, the absorptive part $\mathrm{Im}\sigma$ may be expressed in terms of the scalar form factor $\sigma_\pi(t)$ of the pion and of the isospin even pion-nucleon S-wave $f_+^0(t)$,

$$\begin{aligned} \mathrm{Im}\sigma(t) &= \frac{3}{2}\sqrt{\frac{t-4\mu^2}{t}}\,\frac{f_+^0(t)^*}{4m^2 - t}\sigma_\pi(t), \\ \frac{m_u + m_d}{2} < \pi^a(q')|\bar{u}u + \bar{d}d|\pi^b(q) > &= \delta^{ab}\sigma_\pi(t), \end{aligned} \tag{5}$$

where m is the nucleon mass. We determine σ_π by solving numerically a set of coupled integral equations of the Muskhelishvili-Omnès type [9], and evaluate f_+^0 in the timelike region below $t = 1$ GeV^2 by repeating the analysis of the Karlsruhe group [2], using, however, new information on the I=0, S-wave $\pi\pi$ phase shift as provided by chiral perturbation theory [10].

3. The curvature Δ_D is evaluated as follows. For spacelike momentum transfers, we adopt the values of $\bar{D}^+$ published in ref.[2]. We then continue to the point

$t = 2\mu^2$ by dispersion techniques, again using the I=0, S-wave $\pi\pi$ phase shift from chiral perturbation theory.

4. Finally, $\triangle_R$ is a quantity of order μ^4. It has been calculated from the one-loop representation of the elastic amplitude in the framework of chiral perturbation theory [11].

All numerical difficulties which are hidden in this programme are now under control, and we hope to present the result for σ in the near future [12].

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A Comment on the Status of Skyrme Model Results for πN-Scattering

G. Holzwarth
Siegen University, FB 7, 59 Siegen, W.-Germany

Since the appearance of the first πN Newsletter the Skyrme model has emerged as an alternative way for describing baryon structure and meson-baryon interaction. Complementary to the standard quark model mesonic field variables $\phi(x,t)$ are the only dynamical entities in Skyrme-type lagrangians which supposedly approximate the low-energy effective action of QCD (although a firm connection has not yet been established). The amount of material which has been covered is vast and cannot be repeated in this short comment; we shall simply refer to the extensive compilations given in refs. 1-5.

Before discussing specific features we have to consider a technical aspect because it is crucial for almost all results obtained so far: Classical static solutions $\phi_s(x)$ with finite energy (solitons) fall into separate classes characterized by an integer topological index which is identified with baryon number B. Dynamical degrees of freedom for these baryons are collective coordinates $\alpha(t)$ which parametrize the degeneracies of the static solutions due to the symmetries of the effective lagrangian, i.e. mainly translations and orientations in coordinate and flavor space, i.e.

$$\phi(x,t) = D(\alpha(t))\phi_s(x) + \xi(x,t) \qquad (1)$$

with $D(\alpha)$ a symmetry transformation of the lagrangian. Time-dependent field fluctuations $\xi(x,t)$ in the presence of the soliton background describe changes in shape or structure of the soliton and thus incorporate information about excited configurations of the baryons. At the same time, asymptotically, they correspond to vacuum fluctuations and thus represent in- or outgoing mesons, depending on boundary conditions. This then leads to an S-matrix for meson-baryon scattering, complete for the set of meson fields allowed for in the effective lagrangian. In the representation (1) collective coordinates α supply spin σ, isospin τ, hypercharge, recoil momentum to the target baryon ϕ_s, and the tower of collective eigenstates obtained from quantizing the variables α reflects kinetic energies of target motion. They may contain many states (exotics) which have no counterpart in a simple 3-quark model (e.g. states with $\tau = \sigma \geq 5/2$) and it may be advisable to have means for excluding some of them (without violating unitarity). Coupling target and fluctuational quantum numbers to conserved quantities of the total system finally supplies the S-matrix for physical reaction channels. Unfortunately, all collective states are contained as zero energy modes in the mesonic fluctuations ξ, too, and have to be removed from there by constraints in order to avoid redundancies. This renders treating the interaction between collective and fluctuational modes difficult. Evidently, in this simultaneous treatment of collective and fluctuation modes the set of equations to be solved for the scattering waves ξ will necessarily involve the coordinates α (even if dealing with unbroken symmetries of the lagrangian).

Starting, alternatively, from

$$\phi(x,t) = D(\alpha(t))(\phi_s(x) + \eta(x,t)) \tag{2}$$

the collective coordinates α (for unbroken symmetries) disappear from the eqs. of motion for the fluctuations η, the momenta conjugate to α being conserved quantities of the total meson + baryon system. In (2), evidently, fluctuations η comprise also recoil motion of the target baryon in a frame of fixed total momentum, (angular momentum, isospin). It is only in the limit of infinitely large baryon inertia parameters (number of colors $N_c \rightarrow \infty$) that fluctuations η represent mesons scattering off the static soliton ϕ_s, thereby defining an "intrinsic" S-matrix[6] which, in this case, is simply related to the physical S-matrix by recoupling coefficients [7]. Results obtained so far for πN-scattering from Skyrme (and related) models have almost exclusively been obtained in this "adiabatic" approximation in which all collective velocities $\dot{\alpha}$ are put equal to zero. This approximation implies that all flavor multiplets are degenerate at zero energy (and correspondingly, Δ (or hyperon) channels occur with zero thresholds), that there is no dynamical interaction between collective modes and mesonic fluctuations and that there is no recoil. This should always be kept in mind when comparing present Skyrme model results with experimental data or phase shift analyses. There is no reason to assume that these defects may be of only minor importance, although we expect S,P and D-channels to be most seriously affected because they would mix strongly with collective translations or rotations.

The peculiar feature of the adiabatic approximation is that (for a hedgehog soliton) the intrinsic S-matrix conserves grand spin $K = j + t$, the sum of the pionic angular momentum and isospin [6,8,5], and does not depend on global labels like total spin or isospin of the combined meson-baryon system. After recoupling, this implies that physical S-matrix elements are expressed in terms of few elements of the intrinsic S-matrix diagonal in K. Thus linear relations are established [7,1,8,4] between scattering amplitudes for different spin-isospin channels, and groups of resonances in different spin-isospin amplitudes find a common dynamical origin in the few vibrational modes of the soliton ϕ_s labeled by multipolarity K and parity (Electric or Magnetic type modes[6,3]). This scheme then creates a very transparent picture of nucleon resonances: In its restframe in space and isospace the soliton vibrates and the projection of these intrinsic modes onto the laboratory frame provides the resonances in the different spin-isospin channels of πN-scattering.

Quite independent of dynamical details it is a truly remarkable achievement of the Skyrme model that

a) with the static soliton adjusted to static nucleon properties the vibrational frequencies reproduce average nucleon resonance positions (first noticed in refs. 9 and 6, demonstrated in detail in fig. 1b in ref. 4);

b) the recoupling scheme based on grand spin K reproduces the observed spin-isospin structure of the nucleon and delta excitation spectrum;

c) the recoupling coefficients are such that observed size patterns for the amplitudes in Argand diagrams for fixed pion orbital angular momentum ℓ are reproduced [1,2,4];

d) the linear relations between different spin-isospin amplitudes for fixed ℓ are surprisingly well observed [1,4] (at least for $\ell > 2$).

The fact that so many facets of baryon dynamics flow so easily from a purely mesonic model is ample support for the idea that the soliton picture comprises essentials of baryon structure at low energies, even if in a detailed comparison the agreement must be taken cum grano salis (as can be seen from the surveys presented in refs. 1,2,3). Perhaps one should not ask more of such a simple model and leave it at that, especially because changing dynamical details (adding meson mass and higher order interaction terms to the lagrangian) only adds to ambiguities of the model without really decisive improvement of results.

However, there have been from the beginning several very serious failures in the simple SU(2) version (pion fields only) which point to essential defects in the degrees of freedom allowed for in the model:

Both experimentally well established S-resonances are conspicuously missing and only the introduction of a symmetric fourth-order term in the pion lagrangian (as remnant of eliminated scalar degrees of freedom) can bring back signatures[10] of S-resonances. But this still cannot be the full story because experimentally the lower S11(1535) resonance is found to strongly decay to the ηN-channel (not contained in the SU(2) version). While this points to the need of adding more mesons, the linear relation for S-waves ($S13 \equiv S11$) violates the Tomozawa-Weinberg rule (which follows from chiral symmetry) an. conflicts drastically with phase shift analyses. This signals a complete breakdown of the adiabatic approximation [11,13].

A similar conclusion is reached for P-waves: The (1440) Roper resonance does appear as a well-defined structure in the P11 channel; there is, as expected, no P33 resonance, in fact, it is explicitly excluded by the linear relations between P33, P11 and P13 amplitudes. On the other hand the linear relations enforce a resonance in the D35 channel which experimentally is not seen. Even in those cases where the linear relations are reasonably well observed, the calculated amplitudes stay too close to the unitarity circle and reflect an unphysical continuous rise in the phaseshifts which distorts the shapes of resonances and the background. This is especially disappointing because the Skyrme model in contrast to quark models does not simply provide resonance parameters but the complete scattering amplitudes instead.

In order to overcome these serious shortcomings of the otherwise promising soliton model two main extensions heave been considered: 1.) Inclusion of the complete SU(3) pseudoscalar meson octet while staying with the Skyrme lagrangian [13,4]; 2.) Replacing the higher order terms in the lagrangian by explicit vector mesons while staying within the SU(2) frame [10,14,5].

Until very recently the SU(3) extension has only been considered in the unbroken limit with all meson and hyperon masses degenerate. Although rather unrealistic this approximation again allows for constructing the intrinsic S-matrix, leading to additional linear relations between many different amplitudes, some of which prove helpful as may be seen from the extensive survey in ref. 4. But on the whole, this SU(3) extension is not overly successful, the $\pi N \rightarrow \pi N$ amplitudes are hardly affected, the $\pi N \rightarrow \pi\Delta$ amplitudes getting significantly smaller, which helps the $L = L'$ amplitudes but enlarges the discrepancies for $L = L' \pm 2$ channels, $\pi N \rightarrow \eta N$ amplitudes coming out much too small. Agreement in channels which involve strange particles, in instances where it does occur, may be fortuitous considering that K-hyperon channels occur with zero threshold in this approximation. Interestingly, the results for $\bar{K}N$ elastic scattering are of a quality comparable to the πN case. As pointed out in ref. 4 KN vs. $\bar{K}N$ scattering may turn out a crucial testing ground for soliton models because we would expect (and actually observe) large differences between $\bar{K}N$ and KN scattering, while results obtained so far in the unbroken SU(3) adiabatic approximation for these processes do essentially coincide.

The vector meson extension is slightly more successful in remedying problems of the simple SU(2) Skyrme model: The vector mesons completely remove the unnatural rise of the scattering phaseshifts above resonance region and thus bring out shapes of resonances and background very clearly. In fact, this is no surprise, because these unphysical features can be traced[3] directly to higher order terms in the Skyrme lagrangian which the vector mesons replace. Naturally also, due to the increase in the number of final channels, the inelasticities at higher energies become more realistic[5]. Still, the problems with S,P and D waves persist.

It seems that the only way to get resonances in the S-channels is by explicitly allowing for scalar mesons σ in the effective lagrangian. Unfortunately, there is a wide variety of ways for doing that. To use the trace anomaly as a guideline[15,5] is just one possibility, but it works and creates a broad S11 resonance through the coupling of the pions to the σ-bag[5]. Additionally, as has been just recently shown[16], the SU(3) extension with symmetry-breaking mass terms leads to a bound state of the η-meson in the potential well created by the σ, just below ηN-threshold. Through its coupling to the πN incoming channel it provides another (sharp) S11 resonance with strong ηN characteristics. The P11 amplitude proves sensitive to different versions of the model; but finally, with σ meson included and $K\Lambda$ and $K\Sigma$ channels excluded (which may be a more realistic approximation than allowing for them with zero threshold) produces a very pronounced P11 resonance[16] which, however, is still about 120MeV below the observed P11(1440) Roper.

In any case, to obtain better results for S, P and D waves requires to go beyond the adiabatic approximation, i.e. to include those parts of the lagrangian which couple the collective velocities to time derivatives of the mesonic fluctuations. A crucial step towards this goal has been the recent observation by Verschelde[17], that the contribution of the P-wave zero mode and the linear time-derivative interaction add up to the well establised Δ isobar model which very successfully describes the low energy P-wave scattering amplitudes. In fact, combining the soliton-background scattering amplitude (which is largely determined by the zero mode) with linear and quadratic time derivate interactions[18] leads to a very satisfactory description of all essential features of low-energy P-wave scattering. The only remaining deficiency is the softness of the Skyrme stabilized soliton against compression, which prevents quantitative agreement with the results of the P-wave phaseshift analysis.

This again demonstrates the great potential of the idea to describe baryons as solitons in effective meson theories and it clearly points out the direction for future research within this framework. Although inclusion of more mesons adds to the flexibility of the model and will allow for a better description of specific features observed in πN scattering we think that major progress will have to come from a better understanding of the collective dynamics. It appears that including the time-derivative interactions in Born approximation is sufficiently accurate, but the most important still missing part is the inclusion of the baryonic threshold energies in the calculation of the meson-soliton background scattering. Only after completion of this task in a satisfactory way will we be able to fully appreciate the strength of the soliton concept in general and to determine the most appropriate form of the effective mesonic lagrangian.

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THE PION-NUCLEON VERTEX: ALL THAT CONFUSION

Ulf-G. Meißner
Institut für Theoretische Physik, Universität Bern
CH-3012 Bern, Switzerland

The size of the pion-nucleon interaction region is of utmost importance for low energy strong interaction physics. The recent and not so recent literature is full of statements concerning this important quantity – unfortunately, many of these statements are orthogonal to each other. I will try to outline here some facts, review some model predictions and put certain model-dependent statements into proper perspective.

FACTS

Unfortunately, not many rigorous statements can be made about the πN vertex. Assuming that QCD is the theory of strong interactions, we know that for very large momentum transfer $\vec{q}^{\,2}$ the πN vertex function behaves as $\mathcal{N}\,[\vec{q}^{\,2} ln(\vec{q}^{\,2}/\Lambda^2_{QCD})]^{-3}$ with $\Lambda_{QCD} \approx 100...200$ MeV the QCD scale parameter and $\mathcal{N}$ some unknown normalization[1]. This asymptotic form of $G_{\pi NN}(\vec{q}^{\,2})$ holds in the leading log, lowest twist approximation which is likely to be pertinent in the asymptotic regime. The normalization $\mathcal{N}$ cannot be calculated at present. For the low-energy side, the most reliable information comes from dispersion theory[2]. From the pseudo-physical $N\bar{N} - \pi\pi$ helicity amplitudes one can reconstruct the most important contributions to the πN vertex function and finds that for moderate momentum transfer $|\vec{q}| \leq 1$ GeV/c, the πN vertex can be well described by a monopole form, $G_{\pi NN}(\vec{q}^{\,2}) = g_{\pi NN}(\Lambda^2_\pi - m^2_\pi)/(\Lambda^2_\pi + \vec{q}^{\,2})$, with the cut-off mass $\Lambda_\pi \approx \sqrt{50}...\sqrt{70}\; m_\pi \approx 1.0...1.2$ GeV. This analysis is not completely model independent, but nevertheless will serve as a corner-stone for the following discussions. Relatively clean empirical information comes from the study of the charge exchange reactions $np \to pn$ and $\bar{p}p \to \bar{n}n$, as first suggested by Chew in 1958[17]. Fitting the pertinent cross sections by a monopole form factor and neglecting all contributions which are not due to one-pion-exchange[3], one finds $\Lambda_\pi \approx 0.9$ GeV, quite in agreement with the dispersion theoretical approach. It would be nice to have a reanalysis of this and more recent data to confirm these by now ten years old result.

MODELS OF THE NUCLEON AND THE πN VERTEX

At present, there exist a plethora of nucleon models, some of which are more and some of them are less successful in direct comparison to empirical facts. I will discard here any model which does not obey to basic chiral symmetry principles and/or leads to unphysical oscillations in the πN form factor (such as cloudy or chiral bag models with a sharp bag boundary). Also, my choice will be highly subjective and should not be considered overly representative. In Ref. [4], we considered a generalized bag model where the quarks are confined via a volume and a surface tension term. This allows for a fair description of the even-parity excited states of the nucleon, the Δ and all other members of the octet. The bag is vibrating, which means that the surface is treated as a dynamical variable. Pions are coupled to the quarks by conservation of the axial current, and the overlap of the radially oscillating nucleon wave function with the pion source determines the πN form factor – which turns out to be of monopole type for $|\vec{q}| \leq 1$ GeV with cut-off mass $\Lambda_\pi = 1.1$ GeV. It is important to notice that for higher momentum transfer, the predicted πN form factor falls off faster than a monopole. Similar trends can be observed in the much discussed topological chiral soliton model of the nucleon[5]. There, nucleons emerge as solitons of an underlying non-linear chiral theory of π-,ρ- and ω- mesons. All parameters are fixed in the meson sector. The model is rather successful in describing many static and dynamical nucleon properties, with the exceptions of the nucleon mass (too large) and the axial-vector coupling constant g_A (too low). The πN coupling constant is, however, by virtue of the Goldberger-Treiman relation, well reproduced and the pion form factor turns out to be of monopole type with $\Lambda_\pi = 0.9$ GeV[6]. The somewhat refined analysis in Ref. [22] gives an even smaller value, for the most reliable mesonic input data one finds $\Lambda_\pi = 0.83$ GeV. For larger momentum transfer, one observes again a faster decrease than the monopole behaviour. The model can, however, not be extended to such high $\vec{q}^2$ that one could make contact to the QCD-asymptotia. A first attempt to match the low energy meson-nucleon theory and perturbative QCD was done in Ref. [7]. In this model the a priori unknown normalization constant $\mathcal{N}$ of the perturbative sector is determined by demanding continuity in the $\vec{q}^2$ - dependence of the form factor. Although the meson-baryon sector is treated in a somewhat simplified manner, it is encouraging to notice that for momentum transfer $\vec{q}^2 \leq 1$ GeV^2 the form factor turns out to be a monopole with $\Lambda_\pi = 1.0$ GeV. So it appears that present day nucleon models converge to give a monopole-type formfactor with cut-off mass 1 GeV at modest momentum transfer.

NUCLEAR PHYSICS FOLKLORE

The NN-interaction can be successfully described by boson-exchange models like e.g. the Paris[8] or Bonn[9] potential. There, the inter-nucleon force is parametrized by meson-exchange ($\pi, \rho, \omega, \sigma, \ldots$) with the meson-nucleon vertex functions given by $G_{MNN} = g_{MNN}[(\Lambda_M^2 - m_M^2)/(\Lambda_M^2 - \vec{q}^2)]^{n_M}$, with n_M an integer (1 for monopole, 2 for dipole,...). The coupling constants are commonly taken from available data like $N\bar{N} \to \pi\pi$ helicity amplitudes, where as the form factors are used to minimize the χ^2 per datum in the fit to the NN scattering data. The Bonn group in particular has always claimed that they find $n_\pi = 1$ (monopole) and have to use $\Lambda_\pi \geq 1.3$GeV so as not to destroy the least square fit to the NN-data. Further information pointing towards this direction comes from the deuteron, like e.g. the pionic disintegration[10] or the D/S-ratio[11]. Again, for a given ρ-coupling, it is stated that $\Lambda_\pi \geq 1.2$ GeV is mandatory. Let us, however, take a closer look at the pionic disintegration of the deuteron. What counts here is the isovector tensor force at intermediate distances. It is an easy exercise to construct the isovector tensor potential in momentum space using e.g. the Bonn parameters (OBEPR) and then reduce Λ_π from 1.3 to 1 GeV and, at the same time, decrease κ_ρ from 6.1 to 4.5 with all other parameters fixed – this leads to exactly the same potential. Of course, present day determinations of κ_ρ seem to give a value around 6[12], but here I just wanted to demonstrate a trend – in a more elaborate calculation there are obviously more tunable parameters. The lesson to be learned from this undergraduate exercise is that the model builders of the NN force should allow more freedom in their parameters before they can really state that cut-off masses like e.g. $\Lambda_\pi = 1$ GeV are absolutely excluded. This very necessary also tedious exercise should be done – after all, the machinery exists. A first attempt in this direction has recently been performed by the Bochum group[18]. Using meson-nucleon form factors of the type discussed in Ref. [7], these authors can fit NN-scattering data with $\Lambda_\pi = 0.8$ GeV, clearly below the values favored by the Bonn group. It remains to be seen whether the contact interactions introduced to mimic the exchanges of heavy mesons can be put on firmer theoretical grounds. There are, of course, dissenters[13], but their results are all very model dependent and it is not clear whether they can be considered genuine.

HIGH ENERGY PHYSICS FOLKLORE

There are some indications from the high-energy side that Λ_π is considerably smaller than 1 GeV. In a recent analysis by the Leningrad group[14], the old idea of Thomas[15] that the quark-antiquark sea in the nucleon constrains the pion form factor, was refined. These authors come to the rather stunning conclusion that Λ_π has to be smaller than 0.5 GeV. What's wrong with that? In principle, nothing, only the pertinent data on the quark distributions are typically measured at $\vec{q}^2 \approx 25$ GeV^2 – we just know that it does not make sense to use a monopole form factor in this domain. Of course, if one insists on doing so, one has to get a rather small Λ_π to mimik the much faster asymptotic QCD fall-off behaviour. What should be done here is a reanalysis of the same data by using e.g. a form of the form factor as advocated in Ref. [7]. Another indication which points towards a small Λ_π is the so-called Goldberger-Treiman discrepancy, i.e. the deviation of the Goldberger-Treiman relation from unity, $\Delta_{\pi N} = 1 - (M_N g_A / f_\pi g_{\pi NN})$. Here, M_N is the nucleon mass and $f_\pi = 93.3$ MeV the charged pion decay constant. For the most recent value of $g_A = 1.26$, one finds $\Delta_{\pi N} \approx 6\%$. If, and only if, one claims this discrepancy to come from a monopole form factor alone, one has to take $\Lambda_\pi = 0.57$ GeV. In the framework of rigorous work based on chiral perturbation theory[16], the GT-discrepancy can be resolved easily by a particular choice of a low-energy constant which is (at present) not further constrained. It therefore remains unclear without further theoretical efforts how stringent this limit given by the GT-discrepancy really is. Finally, there have always been speculations that the πN form factor is related to the axial form factor $G_A(\vec{q}^2)$. The latter follows nicely a dipole fit with $M_A = 1.032$ GeV, which for a monopole would mean $\Lambda_A = 0.73$ GeV. However, although this identification is suggestive, chiral perturbation theory demonstrates that there are extra contributions to the axial form factor which do not influence the pion-nucleon vertex[16]. The magnitude of these terms has, however, not been worked out at present. Furthermore, a monopole form factor with $\Lambda_A = 0.73$ GeV does not fit the high energy data of the axial form factor of the nucleon, which are known up to $\vec{q}^2 = 3$ GeV^2 [19].

TASKS

Finally, I will briefly summarize what should be done to clarify our understanding of the πN vertex function (I only list the points which appear most important to me):

- Do a thorough reanalysis of the NN scattering data and deuteron properties in the framework of boson-exchange models, taking into account *e.g.* the asymptotic behavior of the πN form factor as predicted by perturbative QCD (for a first step see Ref. [18]).
- Clarify the relation between the pion-nucleon and the axial vector form factor *e.g.* in the framework of chiral perturbation theory.
- Try to understand how stringent the limit on Λ_π from the Goldberger-Treiman discrepancy really is (see *e.g.* Ref. [20]).
- Redo the analysis of the sea quark structure functions to constrain the πN form factor by allowing for a more general form than used at present.

Once the dust has settled, I believe that everybody will be able to live together peacefully with a πN form factor of monopole type and cut-off mass $\Lambda_\pi \approx 0.8 \cdots 1$ GeV[21] and the $|\vec{q}|^{-6}$ QCD fall-off at high momentum transfer.

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A STATUS REPORT ON NUCLEON-NUCLEON AND NUCLEON-ANTINUCLEON FORWARD DISPERSION RELATIONS

P. Kroll

Physics Department, University of Wuppertal, 5600 Wuppertal 1, Fed. Rep. Germany

Abstract:The present status of forward dispersion relations (DR) in nucleon-nucleon and nucleon-antinucleon scattering is reviewed. The NN and $N\bar{N}$ amplitudes are critically examined in the light of new data and current phase shifts. The determination of meson-nucleon coupling constants from DR analyses is also touched upon.

1. INTRODUCTION

Elastic nucleon-nucleon forward scattering has been extensively studied within the dispersion theoretical approach by us [1]. Data on total cross-sections in pure spin states permitted a dispersion relation (DR) analysis of the full set of 6 NN forward amplitudes from which valuable information about the unphysical part of the $p\bar{p}$ cut (UPC) had been extracted [2]. Thus, for instance, the need of contributions from the 3π continuum was convincingly demonstrated, a dynamic piece not explicitly taken into account in current NN potentials.
Lack of total cross-section data in pure spin states for $N\bar{N}$ scattering restricts, right from the beginning, the application of DR to the spin-averaged amplitude of that process. Furthermore, because for $n\bar{p}$ scattering the data basis is utterly scarce, the $p\bar{p}$ forward amplitude is the only case which can be seriously analysed at present. This has been attempted in ref. [3] recently.
Any DR analysis requires input from both the reactions NN and $N\bar{N}$ yet of different quality. If the emphasis is placed on NN scattering the $N\bar{N}$ cut represents a far-away contribution. Therefore, local structures of the $N\bar{N}$ amplitude are unimportant, only its global strength is felt on the NN side (which in some cases may even be negligible). Thus, if treating NN scattering only rough $N\bar{N}$ information is required. For a DR study of $N\bar{N}$ the situation is reversed. The local structures of the $N\bar{N}$ amplitudes are explored whereas NN scattering enters only globally. Due to this feature a precision analysis of the 6 NN amplitudes is possible without having at disposal data on total cross-sections in pure spin states for $N\bar{N}$ scattering. Nevertheless, both the reactions are connected by analyticity and a combined analysis is certainly the ultimate goal.
Forward dispersion relations have the particular advantage of allowing very precise analyses since the input to them, namely the imaginary parts of the forward amplitudes, are proportional to measured quantities, the cross-sections (total as well as those in pure spin states), whereas for other scattering angles the observables are bilinear in the amplitudes which leads, among other problems, to ambiguities a problem phase shift analyses also have to struggle with. By virtue of that accuracy the forward amplitudes as obtained from DR constitute on one hand a severe test of any phase shift analysis and on the other hand may be used as valuable input to such analyses, stabilizing the phase shifts and reducing ambiguities. Indeed, Arndt et al [4], for instance, have made use of our forward amplitudes in their phase shift analysis.
DR analyses are of importance not only as a method to calculate real parts of a given amplitude from its imaginary parts or vice versa. They also constitute a powerful tool for exploring unphysical regions unravelling the dynamics there (e.g. meson-nucleon coupling constants, continuum contributions). Furthermore, they allow to detect inconsistencies in the data and to extract infor-

mation on the asymptotic behaviour of the amplitudes. Last not least a DR analysis implicitly forms a test of the analytic properties of strong interaction amplitudes. With regard to QCD as the underlying dynamics in which quarks are confined, such a test is by no means useless.

2. WHAT HAS BEEN DONE IN NUCLEON-NUCLEON SCATTERING?

The last complete DR analysis has been carried out by us in 1982 [1]. Solely the spin-averaged proton-proton amplitude F_1, its imaginary part being proportional to the total cross-section

$$\sigma_{tot} = \frac{4\pi}{p_L} Im F_1 \tag{2.1}$$

has been updated in the context of the $p\bar{p}$ analysis [3]. Except of minor modifications at very high energies (I am going to discuss that at the end of the next section) this new amplitude agrees with those from the previous analysis and is, at low energies, in good agreement with present phase shift results [5,6].
The other two pp forward amplitudes F_2 and F_3 of the 82 analysis need some refinements. The data on the cross-sections in transversal ($\Delta\sigma_T$) and longitudinal ($\Delta\sigma_L$) spin states related to ImF_2 and ImF_3 by

$$\Delta\sigma_T = -\frac{4\pi}{p_L} Im F_2 \tag{2.2}$$

and

$$\Delta\sigma_L = \frac{4\pi}{p_L} Im F_3 \tag{2.3}$$

respectively, have changed somewhat above 500 MeV kinetic energy (T). Moreover, there have been measured a few data points on the real parts of F_2 and F_3 from Coulomb interference experiments performed at LAMPF [7]. Comparison of our old results with these real parts and with those reconstructed from phase shifts reveals some deviations between DR theory, experiment and phase shift results in the T region 500-800 MeV which, however, will most likely disappear when the imaginary parts are adjusted to the new cross-section data. This is merely a minor local problem without any global consequences on the amplitudes or on the discontinuity of the UPC.
Stronger modifications, in particular for F_2 and F_3, are to be expected from a revised DR analysis of pn scattering. The only direct experimental information on $ImF_3(pn)$ available in 1982 came from the Argonne measurement of

$\Delta\sigma_L(pd)$ [8]. Proper Glauber corrections carried out by us with the method described in ref. [9], lead us then to $\Delta\sigma_L(pn)$ data and ImF_3 respectively. Recently such data have been measured using polarized neutrons at SIN [10] and Saclay [11]. Although these data are not in contradiction with the Argonne data, they will have some impact on the DR analysis since they extend over a larger range of energy. A definite improvement is to be expected for F_2 since now $\Delta\sigma_T$ data are available for proton-neutron scattering [10,11] whereas in our 1982 analysis we had to extract the input for the corresponding DR from the forward pn charge exchange differential cross-section data which procedure requires additional assumptions and approxi- mations accompanied by loss of precision. Moreover, since at very low energies ($< 200MeV$) we have then and now to rely on phase shifts as input to the DR a revised DR analysis will also profit from the improvements in the phase shifts in that energy region.

3. THE RECENT PROTON-ANTIPROTON ANALYSIS

As compared to previous attempts to analyse the amplitude F_1 substantial progress has been made in [3] on the basis of the new LEAR data. Extensive measurements of σ_{tot} [12] and of the ρ_1 parameter ($= ReF_1/ImF_1$) [13] as well as the determination of the $p\bar{p}$ (complex) scattering length from the line shift and width of the 1s $p\bar{p}$ atomic state [14] have provided us with data filling the gap between the $p\bar{p}$ threshold and the energy region above 50 MeV where data were already available in the pre-LEAR era.

We believe that a consistent picture of $p\bar{p}$ forward scattering emerges from our analysis. All the prominent features seem to be on a sound basis although, of course, some details and the numerical values may change with more precise data to be measured in the future. The intriguing features of the ρ_1 parameter at low energies (dips and bumps) are well reproduced by the calculated real parts of the $p\bar{p}$ forward amplitude. An important point in our analysis is the behaviour of F_1 around the $p\bar{p}$ threshold. The scattering length plays here the central role; its actual value leads to a strong cusp effect at threshold. This cusp correlates the sharp rise of ρ_1 from the value at threshold ($\simeq -1$) up to about zero at 20 MeV with a sharply localized bump in ImF_1 below threshold (see fig.1) which dynamic origin is not clear at present. It might be related to a $p\bar{p}$ bound state.

Our analysis provides rather small values of ρ_1 around 1GeV/c (see fig.2) which are at variance with pre-LEAR data [15] but are in excellent agreement with recent data measured by the PS 172 group at LEAR [13] but published after we had completed our analysis. I emphasize that large values of ρ_1 in the vicinity of 1GeV/c can only be obtained if either ImF_1 (i.e. σ_{tot}) is changed below 1GeV/c or one is willing to accept rather large negative value of ρ_1 around 20 MeV. This successful prediction nicely demonstrates the power of DR.

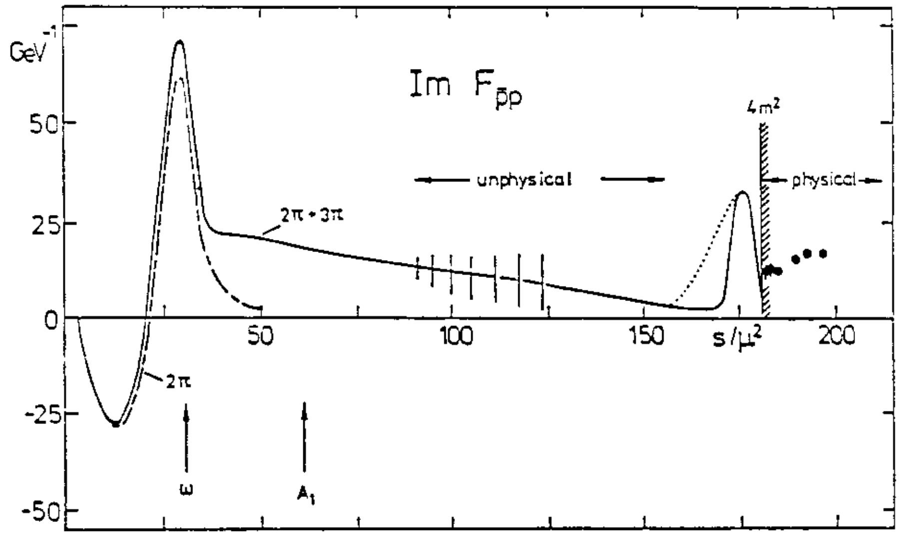


Figure 1: ImF_1 in the unphysical region vs. s/μ^2. The solid line represents the results of ref. [2] up to $100\mu^2$, the $p\bar{p}$ effective range expansion and the link between these two contributions used in [3].

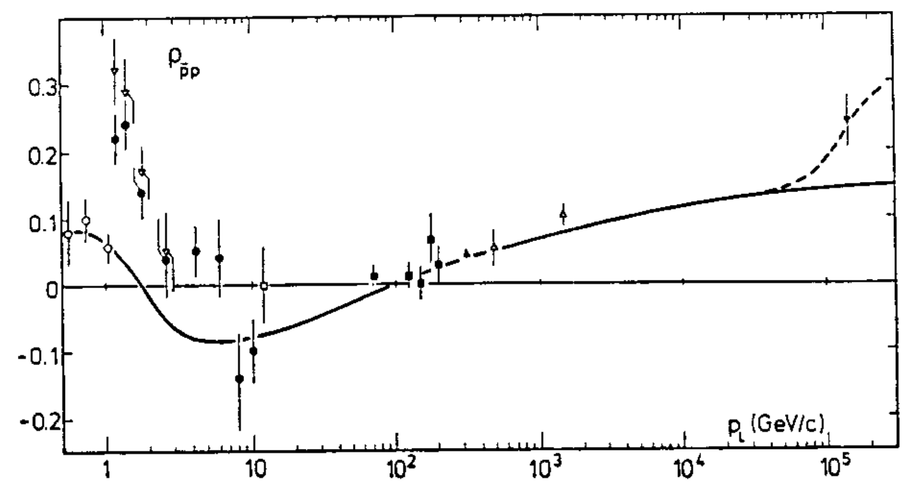
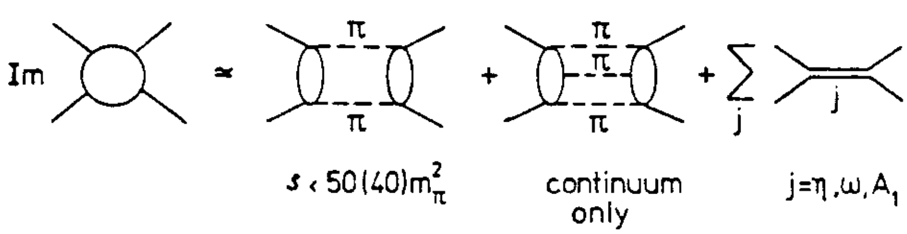


Figure 2: The $p\bar{p}$ parameter vs. p_L at high energies. Data taken from ref. [15] (• without, ∇ with spin contribution η) and from PS 172 (o) [13]. For other symbols refer to ref. [3].

At energies larger than, say, a few GeV with the contributions to the DR from around the threshold dying gradually away, our results are again in good agreement with the data although, admittedly, the poor data do not provide a crucial test. Also here some more precise data are definitely needed. What remains to be solved is a little problem with the data point at the highest measured energy. The UA4 datum [16] is by about 1.5 standard deviations larger than our result which is obtained and this is crucial, with a standard extrapolation of σ_{tot} to infinity ($\sim ln^2 s$). In ref. [17] we have demonstrated that the crossing-odd part of the spin-averaged amplitude is not responsible for that discrepancy. Pure Regge behaviour for s tending to infinity is favoured by the data; there is no need for a more complicated asymptotic behaviour. Therefore, we believe that the reason for the large value of ρ_1 found by the UA4 group is rather an unexpectedly strong rise of the crossing symmetric part of σ_{tot} above the energy of the CERN collider as has been suggested by Martin [18].

4. THE UNPHYSICAL PART OF THE PROTON-ANTI-PROTON CUT

Underlying all these DR analysis is a specific model of the UPC which is taken from ref. [2]. In that paper we have studied the dynamics of the UPC by means of discrepancy functions defined as the difference between experimental real parts (from Coulomb-nuclear interference data or reconstructed from phase shifts) and the dispersive real parts as evaluated from all known parts of the DR, i.e. the contributions from both the physical parts of the NN and $N\bar{N}$ cuts and the pion pole terms. Systematic exploration of the 6 discrepancy functions revealed that the following dynamic pieces are needed for a sufficiently accurate approximation of the UPC:



For $s \leq 100\mu^2$ (μ being the mass of the π) the 2π continuum is calculated via unitarity from the $N\bar{N} \to \pi\pi$ partial waves derived by Gustafson et al [19].

The 3π continuum has been estimated under the assumption that it is dominated by $\pi\epsilon$ and $\pi\rho$ states and the dynamics of the reactions $N\bar{N} \to \pi\epsilon, \pi\rho$ is controlled by nucleon exchange. In addition there are ω and a_1 pole terms their coupling constants being obtained from a best fit to the discrepancy functions ($g_V^2/4\pi = 8.1, g_T/g_V = 0.14$ for the ω and $g^2/4\pi = 7.3$ for the a_1). The region $s > 100\mu^2$ was irrelevant in the analysis [2] since the discrepancy functions were only known at small energies ($< 500MeV$). Contrarily the $p\bar{p}$ amplitudes near threshold are very sensitive to the part of the UPC for $160\mu^2 < s < 181\mu^2$. For the spin-averaged amplitude we have learnt that in that region the discontinuity shows a pronounced bump and may then be linked up smoothly with the discontinuity in the region explored by the studies of NN scattering [3]. It turned out that the results of the DR analysis are insensitive to the actual values of ImF_1 for s between 100 and $160\mu^2$, say, as long as the discontinuity there is kept small. In fig.1 the discontinuity of F_1 in the unphysical region as determined by us and used in our later DR studies is shown.
Since the study of the UPC in NN forward scattering is a reliable method for the determ... tion of meson-nucleon coupling constants which have found much interest r... in the context of the surprising results on the polarized proton structure ... ion as mea... ed in deep inelastic lepton-nucleon scattering [20] and the renewed interest in the strange quark content of the proton, I want to repeat here some details of our analysis of the UPC.
It is appropriate for our aim to form combinations of the nucleon-nucleon discrepancy functions with definite $N\bar{N}$ quantum numbers (each combination is understood to have definite isospin in the $N\bar{N}$ channel):

$$\Delta_s = (\Delta_1 - \Delta_2 - \Delta_3/2)/2 \tag{4.1}$$

Only spin singlet part... waves (f_0^J contribute to the corresponding NN amplitude F_S, that is only states with unnatural parity ($J^P = A$).

$$\Delta_t = (\Delta_1 + \Delta_2 - \Delta_3/2)/2 \tag{4.2}$$

Here,only coupled triplet partial waves (f_{11}^J) with $J^P = N$ contribute.

$$\Delta_m = \Delta_1 + \Delta_3/2 \tag{4.3}$$

to which coupled triplet waves (f_{22}^J) with $J^P = N$ and uncoupled triplet waves (f_1^J) with $J^P = A$ contribute.
In the table the most important contributions to the discrepancy functions (4.1-3) are compiled whereby, for convenience, the lowest angular momentum states of the 3π continuum are classified in terms of $\pi\epsilon$ and $\pi\rho$ states. ϵ stands for a $\pi\pi$ S wave (I=0) and ρ for a $\pi\pi$ P wave (I=1).
In fig.3 the two discrepancy functions Δ_s are shown. Comparison with the table reveals that the negative sign of the I=1 function and the positive sign of

the I=0 one require contributions from the 3π continuum. Contributions from heavy mesons cannot be responsible for the behaviour of these discrepancy functions since their energy dependences (the curvature) call for effective masses considerably below 1000 MeV.

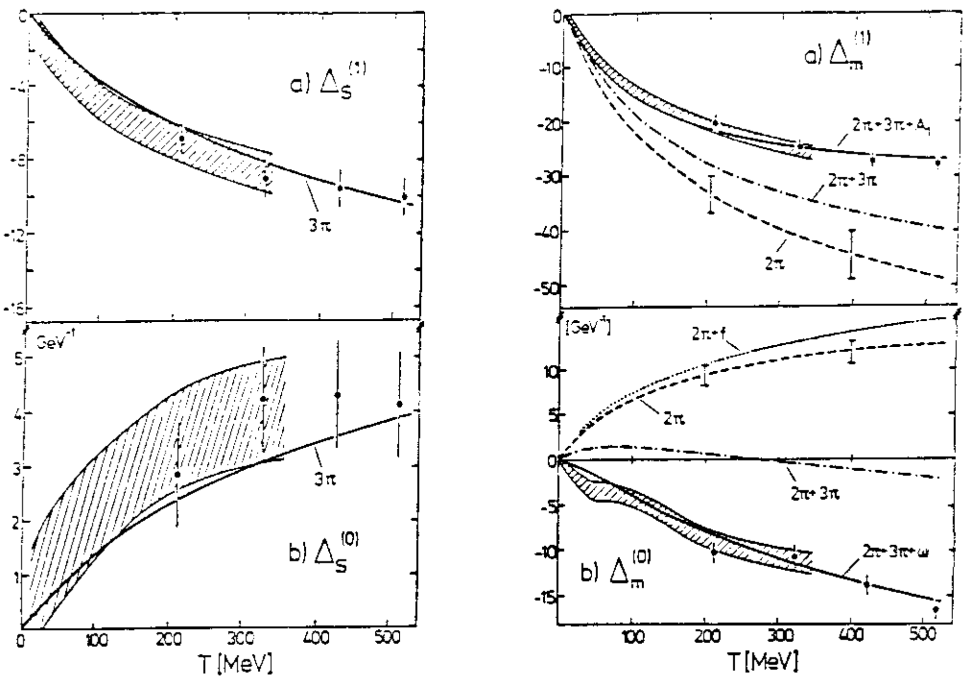


Figure 3: (left) The discrepancy function Δ_s as taken from ref. [2]. The hatched band and the dots indicate the experimental data. The solid line is the 3π contribution as described in the text.(right) The discrepancy functions Δ_m.

In the I=0 function there is no room left for an $\eta(\eta\prime)$. Therefore, their coupling constants are compatible with zero (in fact, $g^2/4\pi < 1.0$). So, one may conclude that a large η coupling constant as found in some models is an artifact of having ignored the 3π continuum. As an example of what could happen let me assume that we had analysed only pp data. Then, because we cannot separate isospins in this case, we would have only $\Delta_s(pp)$ which is negative (see fig.3). We would take this fact as evidence for an η contribution. Fitting a pole term to $\Delta_s(pp)$, we would obtain $g^2/4\pi = 4.7$!

Similar evidences for contributions from the 3π continuum are also found in the other discrepancy functions (see for example fig.3). There is of course also a clear signal for the ω pole term, allowing us to determine its coupling constant (see above). Since the ω and the ϕ terms contribute always with the same sign to the various discrepancy functions (see table) the two contributions can only be separated through their energy dependences, i.e through their masses. With the accuracy of the discrepancy functions in ref. [2] this separation is not possible. Thus, the quoted ω coupling constants might be contaminated by a small ϕ contribution. Such small ϕ coupling constants are well compatible with vector dominance and the fact that the net number of strange quarks in the nucleon is zero [21].

I wish to stress here that the DR method gives much more reliable values of meson-nucleon coupling constants than potential models based on meson exchanges. In the DR approach contrarily to potential models the meson pole terms are really picked up at the position of the poles. One has not to worry about form factors. Moreover, the accurate forward DR analysis allows to disentangle various groups of $N\bar{N}$ quantum numbers and to explore them separately. In potential models where a large set of meson exchange terms is fitted to the full set of low energy NN data (or phase shifts) of quite a different quality, there is the danger of making a given coupling constant large at the cost of another one. None of the current potentials have included the 3π continuum, its contribution must therefore be absorbed in an uncontrolled way into the meson exchange terms or into other parameters. The contributions of the 3π continuum are small as compared with those of the 2π contributions or the ω pole but are comparable with other exchanges and by no means negligible. It is also not unimportant to realize that these contributions are centred around rather small effective masses (500 to 800 MeV) corresponding to fairly long-range forces. Of course, these remarks do not concern the role of potential models as useful parametrizations of low energy nucleon-nucleon scattering.

5. CONCLUDING REMARKS

From the above remarks it is obvious that although the 82 DR analysis produced reliable results at least for some of the 6 forward NN amplitudes, a revised analysis is in order (and indeed is intended by us) due the vast amount of new experimental information which became available to us over the last decade. Updated DR analyses exist for the spin-averaged proton-proton and proton-antiproton amplitudes and provide a consistent picture. Although a revised DR analysis of NN scattering is required I am convinced that the prominent features of the dynamics of the UPC will remain unchanged. Rather I expect improvements in the values of coupling constants and due the extended range of energy in which reliable NN phase shifts nowadays exist (rather 1000 MeV instead of 500 MeV) and their improved quality, one may learn about the couplings of heavy mesons (ϕ, b_1, a_2 and so on). This certainly is a goal worth to carry out again such an old- fashioned analysis as a DR one is.

discrepancy function	*intermediate state*	*sign of contribution*	*remarks*
$\Delta_s(I=1)$	$\pi\epsilon(Swave)$	$-$	π *subtracted out*
	$\pi\rho(Pwave)$	$-$	*no* 2π
			next important meson : $b1(1235)$
$\Delta_s(I=0)$	$\eta(549), \eta\prime(958)$	$-$	*no* 2π
	$\pi\rho(Swave)$	$+$	
$\Delta_t(I=1)$	$f_+^{1,3,..}(N\bar{N}\rightarrow\pi\pi)$	$-$	f_+^1 *contains the* ρ
	$\pi\rho(Dwave)$	$+$	
	$a_0(980)$	$+$	
$\Delta_t(I=0)$	$f_+^{0,2,..}(N\bar{N}\rightarrow\pi\pi)$	$+$	f_+^0 *contains the* ϵ
	$\pi\rho(Pwave)$	$-$	*next important*
	$\omega(783)$	$-$	*meson* : $f_2(1270)$
	$\phi(1020)$	$-$	
	$f_0(975)$	$+$	
$\Delta_m(I=1)$	$f_-^{1,3,..}(N\bar{N}\rightarrow\pi\pi)$	$-$	f_-^1 *contains the* ρ
	$\pi\epsilon(Pwave)$	$+$	
	$\pi\rho(Swave)$	$+$	*next important*
	$a_1(1270)$	$+$	*meson* : $a_2(1320)$
$\Delta_m(I=0)$	$f_-^{2,4,..}(N\bar{N}\rightarrow\pi\pi)$	$+$	
	$\pi\rho(Pwave)$	$-$	
	$\omega(783)$	$-$	*next important*
	$\phi(1020)$	$-$	*meson* : $f_2(1270)$

Table 1: Contributions from the UPC to the NN discrepancy functions (only masses $< 1200 MeV$ are considered)

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Photoproduction of Neutral Pions and Low Energy Theorems

L. Tiator and D. Drechsel
Institut für Kernphysik, Universität Mainz
D-6500 Mainz, FRG

Low energy theorems (LET) have been a very powerful tool to determine the threshold amplitudes for reactions involving photons and pions. Gauge invariance and the (partial) conservation of the axial current (PCAC) allow to express these amplitudes in the low energy limit in terms of the global properties of the hadrons, such as their masses, magnetic moments, and coupling constants. While these theorems are exact in the case of photons, their application to pions involves an expansion about the unphysical soft-pion limit of massless pions[1,2]. Though it had been noted earlier that a power series expansion in the pion-nucleon mass ratio, $\mu = m_\pi/m_N$, might not be justified[3], it came as a great surprise when recent experimental results on the reaction $\gamma + p \rightarrow \pi^0 + p$ indicated that LET was in serious trouble[4,5].

The s-wave amplitude for threshold production of pions has the isospin structure

$$E_{0^+} = \frac{ef}{4\pi m_\pi} \frac{m}{W} \chi_f^+ \left(\frac{1}{2} [\tau_\alpha, \tau_0]\, A^{(-)} + \tau_\alpha\, A^{(0)} + \delta_{\alpha 0}\, A^{(+)}\right) \chi_i,$$

with the pion-nucleus coupling constant f ($f^2/4\pi \simeq 0.08$), $W = m + m_\pi$ the total c.m. threshold energy, and χ_f and χ_i the isospinors of the final and initial nucleon, respectively.

As for any radiative process, low energy theorems (LET) assert that the threshold behaviour is determined by the Born terms. The leading order term, the "Kroll-Ruderman" amplitude, is fixed by the gauge invariance of the electromagnetic current. The higher order terms in the mass ratio μ are determined by chiral invariance, i.e. by the partial conservation of the axial current (PCAC)[1,2]. Typical model-dependent corrections are of relative order μ^2.

The predictions of LET were assumed to be particularly powerful for neutral pion production with amplitudes of order μ and μ^2 for protons and neutrons, respectively. It came as a great surprise that the new Saclay data fell below the predicted values by a factor 5. However, this puzzling result has been corroborated by a recent Mainz experiment. In a series of precise angular distribution measurements the forward backward asymmetry has been accurately determined giving rise to an E_{0+} amplitude which is even smaller than the Saclay data (see table 1).

Therefore, additional contributions which are not contained in LET have been studied. The axial anomalies arising from t-channel γ, ω and ρ^0 exchange give corrections only of the order of 10 % of the LET value and also the Δ-resonance contribution at threshold is of the same order. Microscopic models for the nucleon as the constituent quark model[6], the chiral bag model[7] and the Skyrme model[8] have been shown to reproduce the LET value. However, these models must be treated very carefully, and spurious effects arising from violation of translation invariance could lead to accidental agreement with the new experimental data.

The role of the pion rescattering in the process of pion photoproduction also has been treated incompletely with confusing results, like the K-matrix approach. In a recent paper, however, by Nozawa et al.[9] pion photoproduction and pion nucleon scattering have been calculated consistently in a dynamical model. The result reduces the E_{0+} amplitude to $-1.92 \cdot 10^{-3}/m_\pi$ at the physical threshold.

The most reasonable correction to LET, however, arises from chiral symmetry breaking in QCD[10,11]. Similarly as in the case of pion nucleon scattering, in the current algebra approach of Furlan, Paver and Verzegnassi[12] a sigma term can be derived which is proportional to the finite quark masses[13] $m_0 = (m_u + m_d)/2 = 7 \pm 2$ MeV leading to chiral symmetry breaking (CSB) and $\delta m = m_u - m_d = -3.8 \pm 0.4$ MeV leading to additional isospin symmetry breaking (ISB). These sigma terms can be expressed in terms of equal time commutators between the axial charge Q_5, the time derivative $\dot{Q}_5$ and the transverse electromagnetic current $\vec{J}_{em} \cdot \vec{\varepsilon}$,

$$\sigma_{\pi N} \sim \langle N | [\dot{Q}_5^\alpha, Q_5^\beta] | N \rangle$$
$$\Sigma_{\gamma N} \sim \langle N | [\dot{Q}_5^\alpha, \vec{J}_{em} \cdot \vec{\varepsilon}] | N \rangle .$$

The evaluation of the commutators leads to the following matrix elements (e.g. $\pi^0 p$ channel)

$$\sigma_{\pi^0 p} = \frac{m_0}{2M_p} \langle p|\bar{u}u + \bar{d}d|p\rangle + \frac{\delta m}{4M_p} \langle p|\bar{u}u - \bar{d}d|p\rangle$$

$$\Sigma_{\gamma\pi^0 p} = \frac{m_0}{2M_p} \langle p|\bar{u}\hat{O}u + \frac{1}{2}\bar{d}\hat{O}d|p\rangle + \frac{\delta m}{4M_p} \langle p|\bar{u}\hat{O}u - \frac{1}{2}\bar{d}\hat{O}d|p\rangle$$

with the tensor operator $\hat{O} = \gamma_0\gamma_5\vec{\gamma}\cdot\vec{\varepsilon}$. For a numerical calculation of the nucleon matrix element different nucleon models as constituent quark model[10] or a relativistic potential model[11] have been applied. Using the cloudy bag model which preserves chiral symmetry in the soft pion limit we obtain the following corrections to the E_{0+} amplitudes

$$A^{(-)} = 0\ , \qquad A^{(0)} = \frac{10}{9}\,\eta\,\frac{m_0}{m_\pi}$$

$$A^{(+)}_{p\pi^0} = 2\eta\,\frac{m_0}{m_\pi}\left(1 + \frac{\delta m}{m_0}\right), \qquad A^{(+)}_{n\pi^0} = 2\eta\,\frac{m_0}{m_\pi}\left(1 - \frac{2}{3}\,\frac{\delta m}{m_0}\right)$$

with

$$\eta = \frac{1}{g_A}\,N^2\int_0^R j_0(m_\pi r)\left(j_0^2\left(\frac{\omega_0 r}{R}\right) + \frac{1}{3}\,j_1^2\left(\frac{\omega_0 r}{R}\right)\right) r^2\,dr \sim 0.7.$$

In table 1 we show our numerical values in comparison to LET, the dynamical model of Nozawa (FSI) and the experimental numbers. In addition to the 4 physical channels we have evaluated the amplitude of $\gamma n \to \pi^0 n$ from isospin symmetry according to

$$E_{0+}^{\text{Iso-Symm}}(\gamma n \to \pi^0 n) = E_{0+}(\gamma p \to \pi^0 p) - \frac{1}{\sqrt{2}}\,\{E_{0+}(\gamma,\pi^+) + E_{0+}(\gamma,\pi^-)\}.$$

The difference in the two values for $\gamma n \to \pi^0 n$, whenever available, gives a direct measure of isospin symmetry breaking. Note that the small effect obtained with LET arises from using different pion masses, $m_{\pi^\pm} - m_{\pi^0} = 4.60$ MeV.

Table 1

	LET	FSI [9]	CSB/ISB	Experiment	
$\gamma p \to \pi^+ n$	27.7	26.9	28.8	28.6±.2	[14]
$\gamma n \to \pi^- p$	-31.8	-29.7	-30.7	-31.5±1.0	[14]
$\gamma p \to \pi^0 p$	- 2.4	- 1.9	- 0.9	-.35±.1	[5]
$\gamma n \to \pi^0 n$	0.4	-	+ 1.6	-	
Iso-Symm. $\gamma n \to \pi^0 n$	0.5	0.1	+ 0.4	1.7±.7	

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LIST OF PION-NUCLEON SCATTERING EXPERIMENTS (1982-MAY 1990)

INSTITUT FUER THEORETISCHE KERNPHYSIK
UNIVERSITAET KARLSRUHE,WEST GERMANY

LEGEND:

1ST COLUMN: NAME OF THE DATA SET. THE NAME CONSISTS OF THE LAST TWO DIGITS OF THE YEAR AND THE FIRST SIX LETTERS OF THE NAME OF THE FIRST AUTHOR. THE LAST LETTER HAS BEEN MODIFIED,IF NECESSARY FOR UNIQUENESS.

2ND COLUMN: LABEL FOR THE DATA SET:

- +,-,0: INDEX FOR PI+P,PI-P ELASTIC AND FOR CHARGE-EXCHANGE SCATTERING
- T+,T-: TOTAL CROSS SECTIONS
- D+,D-,D0: DIFFERENTIAL CROSS SECTIONS
- D0L: THE AUTHORS GIVE ONLY LEGENDRE COEFFICIENTS (CHARGE-EXCHANGE)
- TI+,TI-,TI0 INTEGRATED DIFFERENTIAL CROSS SECTIONS
- P+,P-,P0: POLARIZATION PARAMETERS
- R+,R-,A+,A-: SPIN ROTATION PARAMETERS

3RD COLUMN: APPROXIMATE PION LABORATORY MOMENTUM RANGE

4TH COLUMN: ANGULAR RANGE OF THE DATA(C.M.SCATTERING ANGLE)

- C: COULOMB INTERFERENCE REGION
- F: NEAR FORWARD SCATTERING
- B: NEAR BACKWARD SCATTERING
- M: INTERMEDIATE ANGLES
- FB:ALL ANGLES

5TH COLUMN: FULL NAME OF THE FIRST AUTHOR AND REFERENCE.
ABBREVIATIONS FOR THE NAMES OF JOURNALS:

- NP: NUCLEAR PHYSICS
- PL: PHYSICS LETTERS
- PR: PHYSICAL REVIEW
- PRL: PHYSICAL REVIEW LETTERS
- SJNP: SOVIET JOURNAL OF NUCLEAR PHYSICS.TRANSLATION OF YADERN.FIZ.

6TH COLUMN: STATUS

- P: DETAILED PUBLICATION OF THE FINAL ANALYSIS OF THE EXPERIMENT
- R: REPLACED BY A MORE RECENT PUBLICATION
- T: THE KARLSRUHE DATA BASE INCLUDES A TABLE OF THE DATA
- PRE: PRELIMINARY DATA AVAILABLE

L I S T O F E X P E R I M E N T S

YEAR,NAME		PLAB GEV/C	ANG. RANGE	REFERENCE	STATUS
90 BRACK	D+,D-	.10-.15	MB	BRACK J.T. PR C (IN PRESS)	PT
90 FRIEDM	TI+	.12-.27	MB	FRIEDMAN E. NP A (IN PRESS)	PT
90 FRIEDM				20-180 AND 30-180 DEG LAB	
90 JORAM	D+,D-	.15	M	JORAM Ch. PIN NEWSLETTER NO.2, PRELIM.	PRE
90 KIM	P0	.30-.63	M	KIM G.J. PR D 41,733	TP
90 METZLE	D+,D-	.09,.12	C	METZLER M. PIN NEWSLETTER NO.2, PRELIM.	PRE
89 ABAEV	A-,R-	.57-.68	MB	ABAEV V.V SJNP 48,852	PT
89 ABRAMO	D-	.90-2.1	MB	ABRAMOV B.M. PROC. SYMPOSIUM LENINGRAD	
89 ALEKSE	D-	1.40-2.1	MB	ALEKSEEV I.S. PROC. SYMPOSIUM LENINGRAD	PRE
89 ALEKSE				NO ABSOLUTE NORMALISATION	
89 BARLOW	A+,A-	.43-.66	MB	BARLOW D.B. PRL 62,1009	T
89 BARLOW	R+,R-				
89 KANAVE	P-	1.40-2.10	MB	KANAVETZ V.P.PROC. SYMPOSIUM LENINGRAD	PRE
89 KIM	P0	.30-.62	MB	KIM G.J. PL B219,62 SEE 90 KIM	R

89 SEFTOR	P+,P-	.54-.63	M	SEFTOR C. PR D39,2457	
89 SEVIOR	P+,P-	.19-.38	MB	SEVIOR M.E. PR C40,2780	PT
89 SMITH	D+,D-	.10-.15	MB	SMITH G.R. PROC.SYMP.LENINGRAD,SEE 90 BRACK	R
89 TOWELL	DO	.05-.11	FB	TOWELL R.S. PROC.SYMPOSIUM LENINGRAD	PRE
89 TOWELL	DO	.43-.69	FB		
89 WIEDNE	D+,D-	0.135	FB	WIEDNER U. PR D40,3568	PT
88 ABAEV	A-,R-	.57-.68	MB	ABAEV V.V. YAD FIZ 48 1338 SEE 89 ABAEV	PT
88 BAGHER	DOL	.12-.22	FB	BAGHERI	PT
88 BRACK	D+	.15	MB	BRACK J.	PT
89 FRIEDM	TI+	.13-.23	FM	FRIEDMAN ... EG LAB	T
88 WIGHTM	PO	.55-.69	FB	WIGHTMAN	PT
87 BEKREN	A-,R-	.57	MB	BEKRENEV ... SEE 89 ABAEV	R
87 MINOWA	DO	2.-4.2	FB	MINOWA M	PT
87 MOKHTA	P+,P-	.47-.69	MB	MOKHTARI	PT
87 SADLER	D+,D-	.38-.69	FB	SADLER M.E. PR D35,2718	PT
87 SUZUKI	DO	2.-3.	FB	SUZUKI Y. NP B294,961	PT
87 WIEDNE	D+,D-	.14	F	WIEDNER U. PRL 58,648 SEE 89 WIEDNER	R
87 WIGHTM	PO	.55-.69	FB	WIGHTMAN J.A. PR D36,3529 SEE 88 WIGHTM	R
86 BRACK	D+,D-	.15-.24	MB	BRACK J.T. PR C34,1771	PT
86 FITZGE	DO	.10-.15	F	FITZGERALD D.H. PR C34,619	PT
86 MOKHTA	P-	.47-.69	MB	MOKHTARI A. PR D33,296 SEE 87 MOKHTA	R
85 ASAD	D+,D-	20.-50.	F	ASA'D Z. NP B255,273	PT
85 APOKIN	PO	40.	F	APOKIN V.D. NP B255,253	PT
85 MOKHTA	P+	.47-.69	MB	MOKHTARI A. PRL 55,359 SEE 87 MOKHTA	R
84 CANDLI	D+	1.3-2.5	MB	CANDLIN D.J. NP B244,23	PT
84 GAILLE	DO	.52	F	GAILLE F.C. PR D30,2408	T
84 RUBINS	D+,D-	100.,200.	F	RUBINSTEIN R. PR D30,1413	PT
84 SALOMO	DO	.09,.11	FB	SALOMON M. NP A414,493	PT
83 ABAEV	P+	.45-.71	M	ABAEV V.V. Z.PHYS.A311,217	PT
83 ALDER	P-PO	.35-.43	M	ALDER J.C. PR D27,1040	PT
83 BAGLIN	D+D-	20.,30.	M	BAGLIN C. NP B216,1	PT
83 BAKER	D+D-	30.-90.	B	BAKER W.F. PR D27,1999	PT
83 BURQ	D-	100.-345.	C	BURQ J.P. NP B217,285	PT
83 FRANK	D+D-	.09-.18	FB	FRANK J.S. PR D28,1569	PT
83 KALBAC	D+D-	100.,200.	F	KALBACH R.M.PR D27,2752 SEE 84 RUBINS	R
83 MOYSSI	D-	1.3-1.5	M	MOYSSIDES P.G. NC 75A,163	PT
83 RITCHI	D+	.15-.24	M	RITCHIE B.G. PL 125B,128	T
82 APOKIN	PO	40.	F	APOKIN V.D. Z.PHYS.C15,293	PT
82 ASAD	D+D-	20.,50.	F	ASAD Z. PL 118B,442	T
82 BRICK	D+T+	147.	F	BRICK D. PR D25,2794	PL
82 BURQ	D-	100.-345.	C	BURQ J.P. PL 109B SEE 83 BURQ	R
82 GHIDIN	D-	10.	B	GHIDINI B. NP B195,12	PT
82 KITAGA	D-	8.	FB	KITAGAKI T. PR D26,1572	PL
82 SADLER	D+D-	.38-.69	M	SADLER M.E. PL 119B,69 SEE 87 SADLER	R

A CONTINUATION OF THIS LIST TO EARLIER EXPERIMENTS CAN BE FOUND IN
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EDITOR H.SCHOPPER, SPRINGER VERLAG