

What have we learned from antiproton proton scattering?

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From recent charge exchange measurements in the extreme forward direction, an independent and precise determination of the pion nucleon coupling constant is possible. This determination has reopened the debate on the value of this fundamental coupling constant of nuclear physics. Precise measurements of charge exchange observables *at forward angles* below 900 MeV/c would also give a better understanding of the long range part of the two-pion exchange potential. For example, the confirmation of the coherence of the tensor forces from the pion exchange and the isovector two-pion exchange would be very valuable. With the present data first attempts at an $\bar{N}N$ partial wave analysis have been made where, as in nucleon nucleon scattering, the antinucleon nucleon high J partial waves are mainly given by one-pion exchange. Finally a recent $\bar{p}p$ atomic cascade calculation and the fraction of P-state annihilation in gas targets is commented on.

1. INTRODUCTION

In this presentation which is dedicated to the memory of Carl Dover, I shall discuss what low energy antiproton proton scattering data have contributed or can contribute to our knowledge of hadronic physics.

The low energy strong interactions are governed by chiral symmetry, an approximate but very good symmetry of the QCD lagrangian. This symmetry is perfect if the u- and d- quarks are massless. In reality the quark masses are not zero but since $m_u \approx m_d \ll \Lambda_{QCD}$ or since the pion mass $m_\pi \ll \Lambda_\chi$, where the chiral symmetry scale $\Lambda_\chi \sim 1$ GeV, we expect this symmetry to be very good.

The successes of chiral symmetry (current algebra) predictions when confronted with the experimental measurements have been very successful. The next order corrections to these lowest order predictions as calculated in chiral perturbation theory (ChPT), indicate that we have achieved a much deeper understanding of how chiral symmetry is broken in hadronic phenomena. Simultaneously the evolution of the chiral quark models, which implements chiral symmetry on the quark level in hadronic models, leaves us with the fol-

lowing model understanding of the structure of the nucleon: The nucleon consists of quarks confined to a core of radius of the order 0.8 fm, a core which by necessity (due to chiral symmetry) is surrounded by a pionic (Goldstone boson) cloud. This pionic cloud is distributed around the quark core according to the requirements of the (approximate) chiral symmetry.

This “chiral” nucleon model predicts that for large impact parameter scattering of two nucleons (NN) or antinucleon-nucleon ($\bar{N}N$), only the pionic clouds will overlap. Consequently, we expect that for these large impact parameter scatterings the effective meson exchange potential models should give a reasonable description of the scattering data and we can relate the NN and $\bar{N}N$ meson exchanges using G-parity invariance arguments. From these arguments we find that the one-pion-exchange (OPE) potential, V_π , has opposite signs for NN and $\bar{N}N$, whereas the two-pion-exchange (TPE) potential, $V_{2\pi}$, has the same sign for both NN and $\bar{N}N$. In the following we shall discuss the consequences and some experimental confirmations of these ideas.

2. THE STRENGTH OF THE PION NUCLEON COUPLING

The pion nucleon coupling constant is a fundamental constant in nuclear physics. It determines

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the strength of the very important long distance nuclear tensor potential.

The recent very precise charge exchange measurements ($\bar{p}p \rightarrow \bar{n}n$) of Birsa et al. [1–3] in the extreme forward direction has established beyond any doubt the dominance of the one pion exchange between the antinucleon and the nucleon. These data were presented at this conference by A. Martin [2]. As expected, the extreme forward scattering cross section is dominated by the OPE pole which, at four momentum transfer $t = +m_\pi^2$, is located just below the physical region. By extrapolating these data at forward scattering angles ($0 < -t < 1.5m_\pi^2$) to the pion pole, the residue of the pole is evaluated, i.e., the pion-nucleon coupling constant, $g_{\pi NN}$, is determined. The assumption here is that

$$(m_\pi^2 - t)^2 \cdot \frac{d\sigma}{d\Omega} = \frac{1}{E_{cm}^2} \sum_{n=0}^{\infty} a_n (m_\pi^2 - t)^n, \quad (1)$$

is a smooth polynomial in $(m_\pi^2 - t)$ and can be extrapolated to $t = m_\pi^2$ [2]. In the above expression E_{cm} is the center of mass energy. In fact, these new data give a very precise value for $g_{\pi NN}^2/4\pi$ [1,4,5], a value which is smaller than the accepted value by about 5%. Recently the Nijmegen group, who analyzed both the NN data [6] and the $\bar{N}N$ data [7] within a OBEP model, also advocated a smaller value for $g_{\pi NN}^2/4\pi$. Due to this development, the nuclear physics community is re-examining the previous determinations of $g_{\pi NN}$, by repeating some of the experiments relevant for its determination as discussed below.

The pion nucleon coupling constant has been [8], and will be [9] determined from the extreme forward angles of the reaction $np \rightarrow pn$ which like $\bar{p}p \rightarrow \bar{n}n$ is dominated by the OPE pole just beyond the physical region. The Uppsala group redid the $np \rightarrow pn$ experiment. They compared various $np \rightarrow pn$ experiments and showed that several experiments are not as accurate as was originally claimed [8,9], the normalization (systematic) errors of some experiments are more uncertain than what was quoted in the publications. New experiments paying particular attention to the normalization errors are presently being considered/performed/analyzed at several laborato-

ries. We look forward to the results of these experiments and analysis.

The coupling constant $g_{\pi NN}$ is also determined from the $\pi^\pm p$ total cross section data using dispersion theory (and analyticity). For πN scattering Locher and Sainio in a contribution to the PANIC'93 conference [10] discussed the possible uncertainties coming from the integral part of the dispersion relation expression. They conclude that the dispersion integral itself contributes a value with very small uncertainty to $g_{\pi NN}$. The isovector πN scattering length, which enters this expression for $g_{\pi NN}$, is also very well determined. We should keep in mind that the value of $g_{\pi NN}$ determines the strength of the long range nuclear potential (V_π) which gives, for example, the dominant contribution to the measured deuteron asymptotic D/S ratio [11].

These three independent reactions should of course give the same value for this coupling constant. Presently the $\bar{p}p \rightarrow \bar{n}n$ appears to give a smaller coupling constant ($g_{\pi NN}^2/4\pi \approx 13.7$) about 5% smaller than the other two methods ($g_{\pi NN}^2/4\pi \approx 14.4$). This will be discussed more in detail in a contribution by T. Ericson [12] to this conference. It should be remarked that at this level of precision (accuracy) the Coulomb corrections of the $\bar{p}p \rightarrow \bar{n}n$ reaction should be carefully considered. In addition, for the accuracy of $g_{\pi NN}$ being discussed, we possibly should discuss the difference of $g_{\pi+pn}$ and g_{π^0pp} as well.

An experimentally precisely determined value of $g_{\pi NN}$ is necessary in order to judge the accuracy of the theoretical calculated $g_{\pi NN}$ value using ChPT. Theoretically we know that $g_{\pi NN}$ is given to lowest order (when $m_u = m_d = m_\pi = 0$) by the Goldberger Treiman relation

$$g_{\pi NN} = \frac{g_A}{f_\pi} \cdot M \approx 12.7, \quad (2)$$

a value which is smaller than the measured value. Here the nucleon axial coupling constant, g_A , the pion decay constant, f_π , and the nucleon mass, M , are the physical constants in the ChPT effective lagrangian. However, chiral symmetry is not a perfect symmetry and the loop corrections to the r.h.s. of this relation will increase the value of $g_{\pi NN}$. The corrections due to the broken chi-

ral symmetry may be evaluated in ChPT, but do depend on low energy constants, see e.g. Bernard et al. and others [13].

3. THE MESON-EXCHANGE MODELS

What more can be learned from $\bar{N}N$ scattering relevant to nuclear physics ?

3.1. The two-pion exchange potential

The charge exchange reaction is a unique testing ground for the meson exchange potential (MEP) models since this reaction is given by the differences of two large isospin amplitudes. The long range part of $V_{2\pi}$ is not well known, but we know that $V_{2\pi}$ has a range of $(2m_\pi)^{-1}$ or shorter as is evident from the following expression:

$$V_{2\pi}^J \sim \int_{2m_\pi}^{\infty} \frac{e^{-\mu r}}{r} \rho^J(\mu) d\mu, \quad (3)$$

where the mass spectral function, $\rho^J(\mu)$, includes the $J = 0$ or 1 $\bar{N}N \rightarrow \pi\pi$ helicity amplitudes. Theoretically the two-pion exchange potential has been calculated from πN and $\pi\pi$ scattering data using dispersion theory and analyticity to determine $\rho^J(\mu)$ in Eq.(3) [14,15] or has been constructed from effective meson-baryon models [16]. (As remarked at the conference: using dispersion theory and the NN total cross section data in pure NN spin states [17], the 2π NN exchange contribution can be extracted and thereby used to evaluate $V_{2\pi}$, or more precisely to test $\rho^J(\mu)$ in Eq.(3).) These theoretically determined long range parts ($< (2m_\pi)^{-1}$) of the correlated isoscalar two-pion S-wave and isovector two-pion P-wave, predict the $\bar{N}N$ observables at forward angles, and these "predictions" can now be confronted with $\bar{N}N$ forward angle scattering experiments.

The differential cross section for the charge exchange reaction has a characteristic dip-bump (minimum - second maximum) structure at forward angles as now firmly established by the LEAR experiment, PS206, of Birsa et al. [1]. As discussed by Phillips [18] this behavior of the cross section with a second maximum "is a typical OPE effect, coming from the double spin-flip amplitude". However, as will be clear from the arguments below, we can extract information about

$V_{2\pi}$ from this particular angular behavior of the differential cross section for $\bar{p}p \rightarrow \bar{n}n$.

In terms of the five helicity amplitudes the differential cross section for the charge exchange reaction is

$$\frac{d\sigma}{d\Omega} = |\phi_1^{cex}|^2 + |\phi_2^{cex}|^2 + |\phi_3^{cex}|^2 + |\phi_4^{cex}|^2 + |\phi_5^{cex}|^2 \quad (4)$$

In the Born approximation for most one-boson-exchange models the double helicity flip amplitudes ϕ_2^{cex} and ϕ_4^{cex} are dominated by OPE. In Eq.(4) the amplitude ϕ_2^{cex} has a strong forward peak whereas ϕ_4^{cex} is zero at zero degrees and increases to a maximum at larger angles (30° - 60°). The sum of these two OPE dominating helicity amplitudes generates the dip-bump structure of the forward differential cross section. The point is that $V_{2\pi}$ (which is a sum of an isoscalar, $V_{2\pi}^0$, and an isovector, $V_{2\pi}^1$, potential) also contribute to ϕ_2^{cex} and ϕ_4^{cex} . However, as stated, in the Born approximation both amplitudes are dominated by OPE but with a smaller and important contribution from the shorter range " ρ -meson" exchange or more precisely the TPE isovector part, $V_{2\pi}^1$, of Eq.(3) [19]. This potential includes in addition to the "bare" ($\bar{q}q$) ρ -meson exchange, the long range correlated isovector TPE which is described by $\rho^J(\mu)$ of Eq.(3). In other words, $V_{2\pi}^1$ describes a "bare" $\bar{q}q$ ρ -meson embedded in the correlated isovector two-pion continuum [14]. At the forward angles ($< 40^\circ$ at $p_{lab} = 600$ MeV/c) under discussion the three other helicity amplitudes in Eq.(4) are given by " ρ -exchange" in the Born approximation. These three amplitudes are smaller by a factor 2-10 depending on the MEP model used in the calculation of these amplitudes [19]. Given the accuracy of the PS206 data [1], it is the exploration of this minimum, typical of OPE but modified by the long range part of TPE where we can extract more information about $V_{2\pi}$ itself.

As we shall discuss next, the effects of $V_{2\pi}$ also manifest themselves in other $\bar{N}N$ observables which will contain further information about the long distance part of $V_{2\pi}$. Two other observables, A_{on} and D_{onon} , can give valuable information about $V_{2\pi}$ and complement the information from $d\sigma/d\Omega$ just presented. Both NN and

$\bar{N}N$ have an intermediate range attraction due to the two-pion isoscalar exchange potential, $V_{2\pi}^0$. The strength of the isoscalar two-pion exchange at intermediate distances has an important $\vec{L} \cdot \vec{S}$ component which, together with the strong, coherent $\bar{N}N$ $I = 0$ tensor part of the V_π and $V_{2\pi}^1$, accounts for the very rapid rise from zero of the measured analyzing powers, A_{on} , in $\bar{p}p$ elastic, see e.g. Ref.[20], and charge exchange reactions at small forward angles. (For NN the two tensor potentials, from V_π and from $V_{2\pi}^1$, have opposite signs and cancel at medium NN distances.) In addition, as can be clearly seen in Ref.[21], e.g., by comparing Figs. 10.1 through 10.6 of Ahmichouch's Ph.D. Thesis [21], all MEP models predict a maximum peak at non-zero but forward angles in the D_{onon} $\bar{p}p \rightarrow \bar{n}n$ observable. This forward D_{onon} peak is again mainly due to V_π and $V_{2\pi}$. In other words for both A_{on} and D_{onon} $\bar{N}N$ observables, meson exchanges are clearly seen at forward angles. (In OBEP models the continuous mass distribution of $V_{2\pi}$ is simulated by σ and ρ exchange potentials, e.g. [7].) These two features of the two $\bar{p}p \rightarrow \bar{n}n$ spin observables, the rapid increase of A_{on} for increasing scattering angles and the peak at forward angles of D_{onon} , would be reasonable experimental testing grounds for the expectation that the isovector TPE tensor potential adds coherently to the tensor part of OPE, as stressed by Carl Dover and Jean-Marc Richard [22]. We do, however, need to measure D_{onon} at forward angles ($< 30^\circ$ for $p_{lab} < 900$ MeV/c) to determine the maximum value of the "predicted" peak.

In short the $\bar{p}p \rightarrow \bar{n}n$ reaction is very promising to accurately determine both V_π and $V_{2\pi}$ and to test the tensor part of V_π plus " ρ -exchange". To experimentally test the theoretically long range predictions of $V_{2\pi}$, and to separate better the V_π effects, we need to measure, a la PS206, the energy dependence of the forward $d\sigma/d\Omega(\bar{p}p \rightarrow \bar{n}n)$ minimum, we need measurements for at least two more momenta in the range $p_{lab} \sim 200 - 800$ MeV/c. Here the lower LEAR energies are emphasized since the concept of the OPE- and TPE potentials and their connections to nuclear matter are only reasonable for not too large energies and momentum transfers.

The implication of a better known $V_{2\pi}$ is as follows. In NN models the $V_{2\pi}$ attraction must always be "balanced" by models for the unknown short range NN repulsion, a repulsion which contributes to the stiffness of the equation of state of nuclear matter. (The point of "balancing" the intermediate $V_{2\pi}$ attraction and the short range repulsion in NN , is most easily seen in OBEP models: There is a close relation between the strong short range repulsion of ω exchange and intermediate attraction of the scalar isoscalar (σ) exchange, which simulates the scalar two-pion exchange. For very low three-momentum transfer $|\vec{q}| \ll m_\omega$ or m_σ , the OBEP coupling constants of ω and σ exchange have to be related by $g_\omega^2/m_\omega^2 = g_\sigma^2/m_\sigma^2$ so that only V_π effects remain at large distances.) Therefore, a better known $V_{2\pi}$ would indirectly give information about how stiff is the nuclear equation of state. This would allow us to better predict what happens with nuclear matter at high densities which is believed to occur during, for example, supernova explosions.

3.2. The short range $\bar{N}N$ phenomena.

Do the short range annihilation reactions modify the previous discussions?

Based on our model understanding of the nucleon discussed in the introduction, we expect annihilation to occur only for low impact parameter scattering when the quark cores of N and \bar{N} overlap [23]. In other words, we expect $\bar{N}N$ annihilation to have a much shorter range than OPE. However, the ρ meson has not only a large width, the " ρ -exchange" has a range as large as $(2m_\pi)^{-1}$, as is evident from Eq.(3), thereby creating a long range $\bar{N}N$ $V_{2\pi}$ tail which extends beyond the annihilation region. By contrast, the ω meson has a very small width. Therefore, a short range meson exchange, like ω exchange, becomes masked by the short range but violent annihilation reactions. However, in $\bar{p}p \rightarrow \bar{n}n$ observables like A_{on} we may see traces of ω exchange provided the effective model coupling constant $g_\omega^2/4\pi$ is forced to be very large $> 10 - 20$ [24]. Below we shall present the ideas behind the various annihilation models.

Phenomenologically we know that these model ideas just presented, of a nucleon consisting of a

quark core surrounded by a pion cloud, are reasonable. This is based on, for example, the quark model calculations of Oka and Yazaki and others, who successfully reproduce the energy behavior of the NN S-wave phase-shifts, for reviews see, e.g. Refs.[25]. For NN S-wave (zero impact parameter) scattering the two nucleons feel the meson exchange forces at large separations. But at shorter NN distances, when the two quark cores overlap, the antisymmetry requirement of the overlapping six quark wave functions (with a little help from one gluon exchange to get the correct N - Δ mass difference) generates the observed hard-core-like S-wave phase shifts for increasing NN energy. Our chiral quark model, which naturally includes meson exchanges, has a short distance NN repulsion which arises from quark antisymmetry requirements, and which easily accommodates ω exchange with the standard SU(3) value for $g_\omega^2/4\pi = 4.5$. In most MEP models, which are used in $\bar{N}N$ calculations, a value $g_\omega^2/4\pi = 10 - 12$ is required when the NN short range repulsion is ascribed to ω -exchange alone. These models [15,16,26] necessarily include form factors and/or short distance parametrizations, but as discussed above modify to some extent the effects of V_π and $V_{2\pi}$.

In $\bar{N}N$ scattering only the bulk properties of the apparently dominating annihilation reactions are of importance. In a Skyrme model inspired calculation of $\bar{N}N$ annihilation, the bulk properties of the many pions produced have been reasonably reproduced, but annihilation appears to take place as soon as the N (soliton, size of about 1 fm) and \bar{N} (antisoliton) touch, see Ref.[27] and references therein. Within our chiral quark model we can understand this seemingly large range annihilation by the following example: In the simple absorptive “black sphere” model of radius 0.5 fm, the annihilation still appears to have a range of 1.5 fm [28]. This is generated by the long range attractions of V_π and $V_{2\pi}$ which enhance the $\bar{N}N$ wave function in the short distance annihilation region.

A more practical annihilation description of $\bar{N}N$ scattering, which includes explicitly V_π and $V_{2\pi}$, invokes the effective doorway mesons. As shown by Vandermeulen [29], the many specific

annihilation cross sections have been successfully described by postulating that $\bar{N}N$ first form two doorway mesons which then decay with known branching ratios into pion and kaon final states. He argued that it is necessary to average the spin and isospin of the intermediate mesons, and showed that the pairs of two intermediate mesons with sum of masses closest to the available $\bar{N}N$ c.m. energy dominate the annihilation process. This doorway mesons mechanism can easily account for the apparent observed OZI violations in specific $\bar{p}p$ annihilation channels, see e.g. [30].

Several groups, e.g., [31–33] are using the doorway mesons in coupled channel models where it is imperative that “very many mesons” channels will contribute to the process such that the annihilation processes will contribute only extremely weak spin and isospin dependences to the $\bar{N}N$ scattering itself. Since most of these doorway mesons have widths, most meson thresholds will not be reflected in sharp cusps like what two stable mesons will generate. Also the Nijmegen [7] and Moscow [35] groups use effective coupled channels to include some energy dependence expected from the annihilation reactions. For a short overview of these coupled channel calculations, see Ref.[34]. This energy dependence is neglected in the standard optical potential description of the annihilation processes. The common features in these models are (i) the short range of the annihilation process itself and (ii) the very weak explicit isospin dependence of the combined $\bar{N}N$ short range parametrizations and annihilation descriptions, a dependence which is necessary in order to reproduce the data.

4. Meson exchange “model analysis” and $\bar{N}N$ partial waves.

Fortunately, we do have some very useful theoretical restrictions to start an analysis. As for NN , the very high $\bar{N}N$ partial wave amplitudes are dominated by OPE with some TPE corrections. The dominance of OPE has now been verified experimentally as discussed. Both the Nijmegen [7] and the Paris [36] groups have made a first attempt at a “partial wave” analysis of the $\bar{N}N$ scattering data. These analysis are useful

in the sense that we learn which aspects of $\bar{N}N$ scattering data are sensitive to which parameters of the models used in the analysis.

There is some controversy regarding the present $\bar{N}N$ energy-dependent analysis [38]. At a given energy there are not sufficient observables measured yet to perform a model independent partial wave analysis. In the above energy dependent analysis [7,36], the models are used (with their unknown parameters) to provide the link between measurements at different energies. To test the present analysis, measurements of $d\sigma/d\Omega$ and A_{on} for $p_{lab} < 400$ MeV/c would be very desirable.

However, we know that different data have different types of systematic errors. To ignore data points or whole data sets just because they give too large χ^2 in a specific model analysis is too subjective a criteria and should be avoided. We need data with good statistics and with reasonable published systematic errors to make a serious analysis. As an example of a useful discussion on comparing different measurements with different systematic errors, the discussion of $np \rightarrow pn$ by the Uppsala group [9] should serve as a model. In addition the systematic errors should be used to evaluate and re-examine data and be included in a χ^2 fit. D'Agostini [37] gives one indication of how to include systematic errors in a χ^2 analysis of data. This is certainly a less subjective criteria to be used in an analysis of published data.

5. ANTIPROTONIUM CASCADE CALCULATIONS

I would like to make a short comment on a recent $\bar{p}p$ atomic cascade calculation and the fraction of P-state annihilation in gas targets. In a recent paper Batty [39] compares two different atomic cascade model calculations and shows how they compare to, e.g. measured P-wave annihilation fractions, f_P , as a function of the target density, and how both atomic cascade models predict an f_P versus target density somewhat different from the “measured” f_P especially at low target densities.

He also discusses the fine structure populations of the atomic states and how the popula-

tions could depend on target density. The lowest atomic states are not statistically populated due to strong $\bar{p}p$ interactions. However, the lowest 3P_0 atomic state is more populated at higher target densities [39]. These findings warrant further investigations since they are important in order to determine the atomic annihilation channel branching ratios into specific final meson states. In the $\bar{p}p$ atom the $\bar{n}n$ component of the atomic wave function changes rapidly with distance for $r < 5$ fm. Since the annihilation effectively occurs at shorter atomic $\bar{N}N$ distances (≈ 1 fm) we need a better understanding of the atomic wave function for $r < 5$ fm in order to calculate specific relative annihilation branching ratios from specific atomic states ($^1S_0, ^3P_0, ^1P_1$, etc.). The precise measurements of X-rays from $\bar{p}p$ and $\bar{p}d$ [40] should contribute towards this understanding.

6. CONCLUSIONS

The new $\bar{N}N$ scattering data have revived the discussion of the $g_{\pi NN}$ value, a fundamental coupling constant in nuclear physics. The value of this coupling constant can be evaluated in ChPT. However, the question is if the present ChPT correction to Goldberger-Treiman relation, Eq.(2), is sufficient, or do we have to consider the next order in ChPT? We will not know until we know the precise value of $g_{\pi NN}$, an accuracy which approaches the level where Coulomb and isospin breaking interactions might be of importance.

For the charge exchange reaction the dip-bump in the differential cross section and the forward angle behavior of A_{on} and D_{onon} at low energies will teach us more about the long range part of $V_{2\pi}$. Further precise measurements of both elastic and charge exchange observables like A_{on} and D_{onon} at forward angles would contribute to the understanding of the long range part of the two-pion exchange. As advocated by Carl Dover and Jean-Marc Richard, the confirmation of the possible coherence effects in the $\bar{p}p$ $I = 0$ amplitude from the pion exchange and the isovector two-pion exchange would be very striking. The charge-exchange reaction is the most sensitive probe because it is given by the difference

between two large isospin amplitudes. The other $\bar{N}N$ scattering processes are determined by either a single isospin amplitude or the sum of two large isospin amplitudes. As discussed, since annihilation dominates the shorter range processes, the heavier meson exchanges will not be apparent in the scattering data at forward angles.

The meson exchange description presented here cannot be valid for large momentum transfer, \vec{q} (or small impact parameter scattering), where not only MEP vertex form factors (quark structure of the hadrons) but annihilation processes become very important. As discussed, in $\bar{N}N$ scattering processes only the global properties of annihilation are of importance but our models for annihilation are still too primitive to generate a reliable physics description of $d\sigma/d\Omega$, A_{0n} and D_{onon} for large \vec{q} or backward angles when $p_{lab} > 0.4$ GeV/c.

As stated the charge exchange reaction is a unique testing ground for the MEP models since this reaction is given by the differences of two large isospin amplitudes. Experimentally it is now established that for the very forward $d\sigma/d\Omega(\bar{p}p \rightarrow \bar{n}n)$ we have a minimum in the angular distribution, a minimum which is due to the interference of two dominant helicity amplitudes ϕ_2^{cx} and ϕ_4^{cx} , confirming the inference of Phillips [18] that this angular behavior of the forward cross section is tied to the long range one-pion-exchange. This information can now be used to extract more precise information on the long range two-pion-exchange potential, $V_{2\pi}$, which is the same in the NN potential. However, this part of the NN potential has to be balanced with the largely unknown strong short range NN repulsion. The strength of this short range repulsion is found by fitting the NN potential to the measured NN phase shifts. This NN potential is then used in nuclear matter calculations and the repulsion will give the stiffness of the nuclear equation of state. A better determined $V_{2\pi}$ would therefore indirectly give more reliable knowledge of what happens for example in the compressed nuclear matter stage of a supernova explosion where the stiffness of the nuclear equation of state is important. In other words the more detailed knowledge of the long range $V_{2\pi}$

is very important in several branches of nuclear physics and the $\bar{p}p \rightarrow \bar{n}n$ reaction is a unique tool to learn more about this part of the nuclear forces.

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