

# A meson exchange model for the $YN$ interaction

J. Haidenbauer\*, W. Melnitchouk<sup>†</sup> and J. Speth\*

\*Forschungszentrum Jülich, IKP, D-52425 Jülich, Germany

<sup>†</sup>Jefferson Lab, 12000 Jefferson Avenue, Newport News, VA 23606, USA

**Abstract.** We present a new model for the hyperon-nucleon ( $\Lambda N$ ,  $\Sigma N$ ) interaction, derived within the meson exchange framework. The model incorporates the standard one boson exchange contributions of the lowest pseudoscalar and vector meson multiplets with coupling constants fixed by SU(6) symmetry relations. In addition—as the main feature of the new model—the exchange of two correlated pions or kaons, both in the scalar-isoscalar ( $\sigma$ ) and vector-isovector ( $\rho$ ) channels, is included.

## INTRODUCTION

The hyperon-nucleon ( $YN$ ) interaction is an ideal testing ground for studying the importance of SU(3) flavor symmetry breaking in hadronic systems. Existing meson exchange models of the  $YN$  force usually assume SU(3) flavor symmetry for the hadronic coupling constants, and in some cases [1, 2] even the SU(6) symmetry of the quark model. The symmetry requirements provide relations between couplings of mesons of a given multiplet to the baryon current, which greatly reduce the number of free model parameters. Specifically, coupling constants at the strange vertices are connected to nucleon-nucleon-meson coupling constants, which in turn are constrained by the wealth of empirical information on  $NN$  scattering. Essentially all  $YN$  interaction models can reproduce the existing  $YN$  scattering data, so that at present the assumption of SU(3) symmetry for the coupling constants cannot be ruled out by experiment.

One should note, however, that the various models differ dramatically in their treatment of the scalar-isoscalar meson sector, which describes the baryon-baryon interaction at intermediate ranges. For example, in the Nijmegen models [3, 4] this interaction is generated by the exchange of a genuine scalar meson SU(3) nonet. The Tübingen model [5], on the other hand, which is essentially a constituent quark model supplemented by  $\pi$  and  $\sigma$  exchange at intermediate and short ranges, treats the  $\sigma$  meson as an SU(3) singlet.

In the  $YN$  models of the Jülich group [1, 2] the  $\sigma$  (with a mass of  $\approx 550$  MeV) is viewed as arising from correlated  $\pi\pi$  exchange. A rough estimate for the ratios of the  $\sigma$ -coupling strengths in the various channels can then be obtained from the relevant pion couplings. In practice, however, in the Jülich  $YN$  models, which start from the Bonn  $NN$  potential, the coupling constants of the fictitious  $\sigma$  meson at the strange vertices ( $\Lambda\Lambda\sigma$ ,  $\Sigma\Sigma\sigma$ ) are free parameters—a rather unsatisfactory feature of the models.

These problems can be overcome by an explicit evaluation of correlated  $\pi\pi$  exchange in the various baryon-baryon channels. A corresponding calculation was already performed for the  $NN$  case in Ref. [6]. The starting point there was a field theoretic model

for both the  $N\bar{N} \rightarrow \pi\pi$  Born amplitudes and the  $\pi\pi$  and  $K\bar{K}$  elastic scattering [7]. With the help of unitarity and dispersion relations, the amplitude for the correlated  $\pi\pi$  exchange in the  $NN$  interaction was computed, showing characteristic differences compared with the  $\sigma$  and  $\rho$  exchange in the (full) Bonn potential.

In a recent study [8] the Jülich group presented a microscopic derivation of correlated  $\pi\pi$  exchange in various baryon-baryon ( $BB'$ ) channels with strangeness  $S = 0, -1$  and  $-2$ . The  $K\bar{K}$  channel was treated on an equal footing with the  $\pi\pi$  channel in order to reliably determine the influence of  $K\bar{K}$  correlations in the relevant  $t$ -channels. In this approach one can replace the phenomenological  $\sigma$  and  $\rho$  exchanges in the Bonn  $NN$  [9] and Jülich  $YN$  [1] models by correlated processes, and eliminate undetermined parameters such as the  $BB'\sigma$  coupling constants. As a first application of the full model [10] for correlated  $\pi\pi$  and  $K\bar{K}$  exchange, we present here new results for  $YN$  cross sections for various  $YN$  channels, and compare them with the available data.

Alternative approaches to describing baryon-baryon interactions using effective field theory, based on chiral power counting schemes, have recently been applied to the  $NN$  interaction. However, at present a quantitative description of  $NN$  scattering within a consistent power counting scheme is still problematic [11]. Furthermore, it is not clear that such a description can be applied in the strangeness sector, where the expansion parameter,  $m_K/m_N$ , may no longer be small enough to allow an accurate low order truncation. In addition, contact terms, which parameterize the intermediate and short range interaction, do not fulfill any SU(3) relations, and cannot be fixed by currently available  $YN$  data. At present, therefore, to obtain a quantitative description of  $YN$  scattering data over a large energy range one is forced towards a more traditional approach, such as that adopted here.

## POTENTIAL FROM CORRELATED $\pi\pi + K\bar{K}$ EXCHANGE

Let us briefly describe the dynamical model [6, 8] for correlated two-pion and two-kaon exchange in the baryon-baryon interaction, both in the scalar-isoscalar ( $\sigma$ ) and vector-isovector ( $\rho$ ) channels. The contribution of correlated  $\pi\pi$  and  $K\bar{K}$  exchange is derived from the amplitudes for the transition of a baryon-antibaryon state ( $BB'$ ) to a  $\pi\pi$  or  $K\bar{K}$  state in the pseudophysical region by applying dispersion theory and unitarity. For the  $BB' \rightarrow \pi\pi, K\bar{K}$  amplitudes a microscopic model is constructed, which is based on the hadron exchange picture.

The Born terms include contributions from baryon exchange as well as  $\rho$ -pole diagrams (cf. Ref. [12]). The correlations between the two pseudoscalar mesons are taken into account by means of a coupled channel ( $\pi\pi, K\bar{K}$ ) model [7, 12] generated from  $s$ - and  $t$ -channel meson exchange Born terms. This model describes the empirical  $\pi\pi$  phase shifts over a large energy range from threshold up to 1.3 GeV. The parameters of the  $BB' \rightarrow \pi\pi, K\bar{K}$  model, which are interrelated through SU(3) symmetry, are determined by fitting to the quasiempirical  $N\bar{N}' \rightarrow \pi\pi$  amplitudes in the pseudophysical region,  $t \leq 4m_\pi^2$  [8], obtained by analytic continuation of the empirical  $\pi N$  and  $\pi\pi$  data.

From the  $BB' \rightarrow \pi\pi$  helicity amplitudes one can calculate the corresponding spectral functions (see Ref. [8] for details), which are then inserted into dispersion integrals to

obtain the (on-shell) baryon-baryon interaction in the  $\sigma$  ( $0^+$ ) and  $\rho$  ( $1^-$ ) channels:

$$V_{B'_1, B'_2; B_1, B_2}^{(0^+, 1^-)}(t) \propto \int_{4m_\pi^2}^{\infty} dt' \frac{\rho_{B'_1, B'_2; B_1, B_2}^{(0^+, 1^-)}(t')}{t' - t}, \quad t < 0. \quad (1)$$

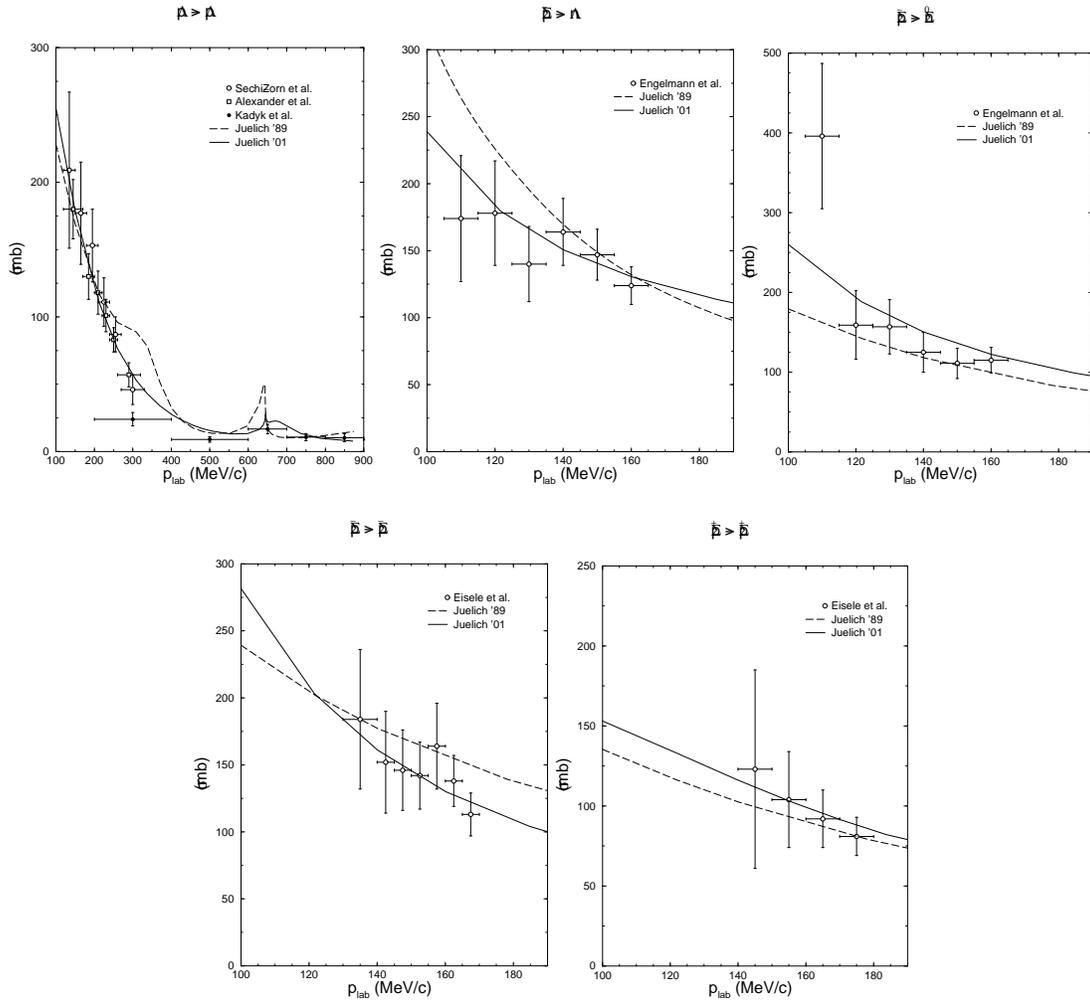
Note that the spectral functions characterize both the strength and range of the interaction. For the exchange of an infinitely narrow meson the spectral function becomes a  $\delta$ -function at the appropriate mass.

## RESULTS AND DISCUSSION

As shown by Reuber et al. [8], the strength of the correlated  $\pi\pi$  and  $K\bar{K}$  in the  $\sigma$  channel exchange decreases as the strangeness of the baryon-baryon channels becomes more negative. For example, in the hyperon-nucleon systems ( $\Lambda N$ ,  $\Sigma N$ ) the scalar-isoscalar part of the correlated exchanges is about a factor of 2 weaker than in the  $NN$  channel, and, in particular, is also weaker than the phenomenological  $\sigma$  meson exchange used in the original Jülich  $YN$  model [1]. Accordingly, we expect that the microscopic model with correlated  $\pi\pi$  exchange will lead to a  $YN$  interaction which is less attractive.

Besides replacing the conventional  $\sigma$  and  $\rho$  exchanges by correlated  $\pi\pi$  and  $K\bar{K}$  exchange, there are in addition several new ingredients in the present  $YN$  model. First of all, we now take into account contributions from  $a_0(980)$  exchange. The  $a_0$  meson is present in the original Bonn  $NN$  potential [9], and for consistency should also be included in the  $YN$  model. Secondly, we consider the exchange of a strange scalar meson, the  $\kappa$ , with mass  $\sim 1000$  MeV. Let us emphasize, however, that these particles are not viewed as being members of a scalar meson SU(3) multiplet, but rather as representations of strong meson-meson correlations in the scalarisovector ( $\pi\eta K \bar{K}$ ) [12] and scalarisospin-1/2 ( $\pi K$ ) channels, respectively. In principle, their contributions can also be evaluated along the lines of Ref. [8], however, for simplicity in the present model they are effectively parameterized by one boson exchange diagrams with the appropriate quantum numbers. In any case, these phenomenological pieces are of rather short range, and do not modify the long range part of the  $YN$  interaction, which is determined solely by SU(6) constraints (for the pseudoscalar and vector mesons) and by correlated  $\pi\pi$  and  $K\bar{K}$  exchange.

In Fig. 1 we compare the integrated cross sections for the new  $YN$  potential (solid curves) with the  $YN \rightarrow Y'N$  scattering data as a function of the laboratory momentum,  $p_{lab}$ . The agreement between the predictions and the data [13] is clearly excellent in all channels. Also shown are the predictions from the original Jülich  $YN$  model A [1] (dashed curves). The main qualitative differences between the two models appear in the  $\Lambda p \rightarrow \Lambda p$  channel, for which the Jülich model [1] (with standard  $\sigma$  and  $\rho$  exchange) predicts a broad shoulder at  $p_{lab} \approx 350$  MeV/c. This structure, which is not supported by the available experimental evidence, is due to a bound state in the  $^1S_0$  partial wave of the  $\Sigma N$  channel. It is not present in the new model. The agreement in the other channels is equally good, if not better, for the new model. Further results and more details about the model can be found in Ref. [14].



**FIGURE 1.** Total  $YN$  scattering cross sections as a function of laboratory momentum,  $p_{lab}$ . The solid lines are results of the new  $YN$  model, based on correlated  $\pi\pi$  and  $K\bar{K}$  exchange, while the dashed are results of the Jülich  $YN$  model A [1]. The data are from Ref.[13].

## ACKNOWLEDGMENTS

This work is supported in part by the U.S. Department of Energy contract DE-AC05-84ER40150, under which the Southeastern Universities Research Association (SURA) operates the Thomas Jefferson National Accelerator Facility (Jefferson Lab).

## REFERENCES

1. B. Holzenkamp, K. Holinde and J. Speth, Nucl. Phys. A500 (1989) 485.
2. A. Reuber, K. Holinde and J. Speth, Nucl. Phys. A570 (1994) 543.
3. P.M.M. Maessen, T.A. Rijken and J.J. de Swart, Phys. Rev. C40 (1989) 2226.

4. Th.A. Rijken V.G.J. Stoks and Y. Yamamoto, Phys. Rev. C59 (1999) 21.
5. U. Straub, et al., Nucl. Phys. A483 (1988) 686; Nucl. Phys. A508 (1990) 385c.
6. H.-C. Kim, J.W. Durso and K. Holinde, Phys. Rev. C49 (1994) 2355.
7. D. Lohse, J.W. Durso, K. Holinde and J. Speth, Nucl. Phys. A516 (1990) 513.
8. A. Reuber, K. Holinde, H.-C. Kim and J. Speth, Nucl. Phys. A608 (1996) 243.
9. R. Machleidt, K. Holinde and Ch. Elster, Phys. Rep. 149 (1987) 1.
10. J. Haidenbauer, W. Melnitchouk and J. Speth, Nucl. Phys. A663 (2000) 549.
11. D.R. Entem and R. Machleidt, nucl-th/0107057.
12. G. Janssen, B.C. Pearce, K. Holinde, and J. Speth, Phys. Rev. D52 (1995) 2690.
13. G. Alexander et al., Phys. Rev. 173 (1968) 1452; B. Sechi-Zorn et al., Phys. Rev. 175 (1968) 1735; F. Eisele et al., Phys. Lett. 37B (1971) 204; R. Engelmann et al., Phys. Lett. 21 (1966), 587.
14. J. Haidenbauer, W. Melnitchouk and J. Speth, in preparation.