Nucleon-Nucleon Scattering in a Chiral Constituent Quark Model*

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Abstract. We study the nucleon-nucleon interaction in the chiral constituent quark model of Refs. [1,2] by using the resonating group method, convenient for treating the interaction between composite particles. The calculated phase shifts for the $^3S_1$ and $^1S_0$ channels show the presence of a strong repulsive core due to the combined effect of the quark interchange and the spin-flavour structure of the effective quark-quark interaction. Such a structure stems from the pseudoscalar meson exchange between quarks and is a consequence of the spontaneus breaking of the chiral symmetry. We perform single and coupled channel calculations and show the role of coupling of the $\Delta\Delta$ and hidden colour CC channels on the behaviour of the phase shifts. The addition of a σ-meson exchange quark-quark interaction brings the $^1S_0$ phase shift closer to the experimental data. We intend to include a tensor quark-quark interaction to improve the description of the $^3S_1$ phase shift.

In this talk I shall mainly present results obtained in collaboration with Daniel Bartz [3,4] for the nucleon-nucleon (NN) scattering phase shifts calculated in the resonating group method.

The study of the NN interaction in the framework of quark models has already some history. Twenty years ago Oka and Yazaki [5] published the first $L = 0$ phase shifts with the resonating group method. Those results were obtained from models based on one-gluon exchange (OGE) interaction between quarks. Based on such models one could explain the short-range repulsion of the NN interaction potential as due to the chromomagnetic spin-spin interaction, combined with quark interchanges between $3q$ clusters. In order to describe the data, long- and medium-range interactions were added at the nucleon level. During the same period, using a cluster model basis as well, Harvey [6] gave a classification of the six-quark states including the orbital symmetries $[6]_O$ and $[42]_O$. Mitja Rosina, Bojan Golli and collaborators [7] discussed the relation between the resonating group method and the generator coordinate method and introduced effective local NN potentials.

Here we employ a constituent quark model where the short-range quark-quark interaction is entirely due to pesudoscalar meson exchange, instead of one-gluon exchange. This is the chiral constituent quark model of Ref. [1], parametrized in a nonrelativistic version in Ref. [2]. The origin of this model is thought to lie in the spontaneus breaking of chiral symmetry in QCD which implies the existence of Goldstone bosons (pseudoscalar mesons) and constituent quarks with dynamical mass. If a quark-pseudoscalar meson coupling is assumed this generates a pseudoscalar meson exchange between quarks which is spin and flavour dependent. The spin-flavour structure is crucial in reproducing the correct order of the baryon spectra [1,2]. The present status of this model is presented by L. Glozman and W. Plessas at this workshop. Hereafter this model will be called the Goldstone boson exchange (GBE) model.

It is important to correctly describe both the baryon spectra and the baryon-baryon interaction with the same model. The model [1,2] gives a good description of the baryon spectra and in particular the correct order of positive and negative parity states, both in nonstrange and strange baryons, in contrast to the OGE model. In fact the pseudoscalar exchange interaction has two parts : a repulsive Yukawa potential tail and an attractive contact δ-interaction. When regularized, the latter generates the short-range part of the quark-quark interaction. This dominates over the Yukawa part in the description of baryon spectra. The whole interaction contains the main ingredients required in the calculation of the NN potential, and it is thus natural to study the NN problem within the GBE model. In addition, the two-meson exchange interaction

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between constituent quarks reinforces the effect of the flavour-spin part of the one-meson exchange and also provides a contribution of a σ-meson exchange type [8] required to describe the middle-range attraction.

Preliminary studies of the NN interaction with the GBE model have been made in Refs. [9–11]. They showed that the GBE interaction induces a short-range repulsion in the NN potential. In Refs. [9,10] this is concluded from studies at zero separation between clusters and in [11] an adiabatic potential is calculated explicitly. Here we report on dynamical calculations of the NN interaction obtained in the framework of the GBE model and based on the resonation group method [3,4]. In Ref. [3] the $^3S_1$ and $^1S_0$ phase shifts have been derived in single and three coupled channels calculations. It was found that the coupling to the $\Delta\Delta$ and CC (hidden colour) channels contribute very little to the NN phase shift. These studies show that the GBE model can explain the short-range repulsion, as due to the flavour-spin quark-quark interaction and to the quark interchange between clusters.

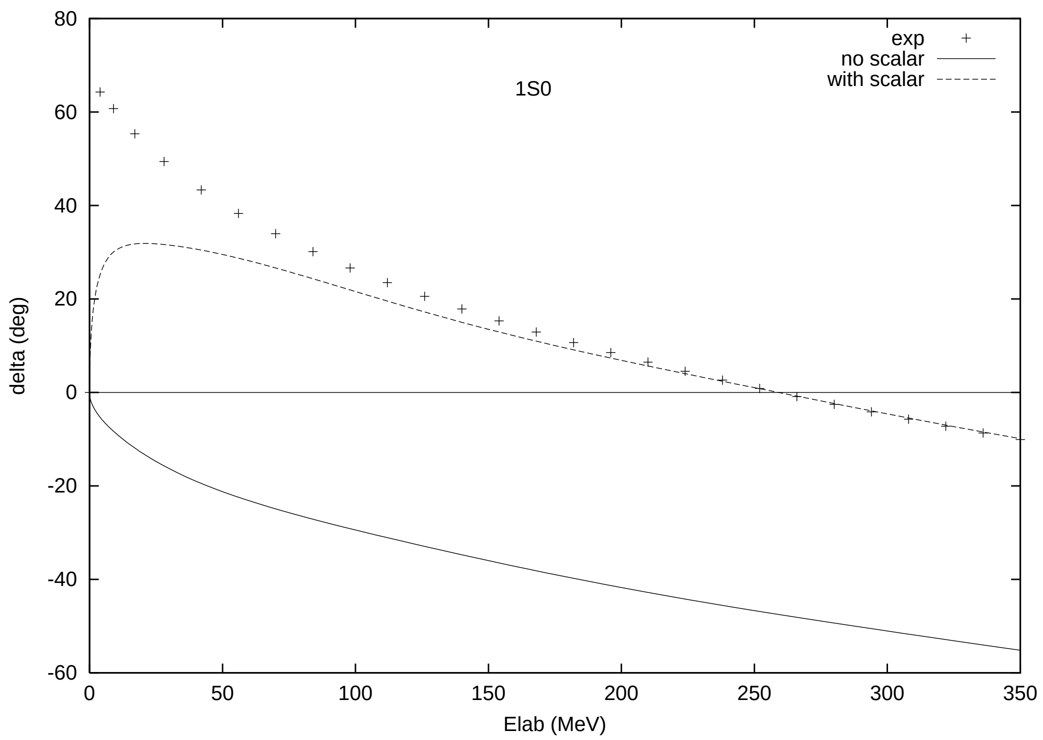

Fig. 1. The $^1S_0$ NN scattering phase shift obtained in the GBE model as a function of E_{lab}. The solid line is without and the dashed line with the σ-meson exchange potential between quarks with μ_σ = 0.60 GeV and Λ_σ = 0.83 GeV. Experimental data are from Ref. [12].

However, to describe the scattering data and the deuteron properties, intermediate- and long-range attraction potentials are necesary. In Ref. [4] a σ-meson exchange interaction has been added at the quark level to the six-quark Hamiltonian. This interaction has the form

$$V_\sigma = -\frac{g_{\sigma q}^2}{4\pi} \left(\frac{e^{-\mu_\sigma r}}{r} - \frac{e^{-\Lambda_\sigma r}}{r}\right) , \tag{1}$$

An optimal set of values of the parametres entering this potential has been found to be

$$\frac{g_{\sigma q}^2}{4\pi} = \frac{g_{\pi q}^2}{4\pi} = 1.24, \qquad \mu_\sigma = 0.60 \text{ GeV} , \qquad \Lambda_\sigma = 0.83 \text{ GeV} . \tag{2}$$

As one can see from Fig. 1, with these values the theoretical phase shift for $^1S_0$ gets quite close to the experimental points without altering the good short-range behaviour, and in particular the change of sign of the phase shift at $E_{lab} \approx 260$ MeV. Thus the addition of a σ-meson exchange interaction alone leads to a good description of the phase shift in a large energy interval. One can argue that the still existing discrepancy at low energies could possibly be removed by the coupling of the $^5D_0$ N-Δ channel. To achieve this coupling, as well as to describe the $^3S_1$ phase shift, the introduction of a tensor interaction is necessary.

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