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Spin observables of the NN interaction in a relativistic harmonic model with confined gluons and mesons

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Abstract. Polarization observables for the nucleon–nucleon (NN) scattering are investigated in the frame work of relativistic harmonic model below $E_{\rm lab} = 250\,{\rm MeV}$, with the inclusion of the σ and π meson exchange. The results can be interpreted as the 'Cheshire cat principle' of NN interaction.

Keywords. Quark model; harmonic model; confined gluon; polarization observables; Cheshire cat.

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1. Introduction

We investigate here the effect of exchange of confined gluons among relativistically confined quarks in nucleon–nucleon (NN) scattering calculations.

In our previous work [1–3], we investigated the $^1S_0$ and $^3S_1$ (without S-D coupling) phase shifts by using different size parameters with and without the exchange of σ and π mesons in the hamiltonian. The agreement of the results of both the models was interpreted as the 'Cheshire cat principle' [1] valid also for NN interaction. The term in the confined one gluon exchange potential (COGEP) arising from the confinement of gluons plays the role of σ by giving the required attraction in the NN interaction. In our subsequent work [3] we studied the phase shifts of higher order partial waves without invoking σ and π mesons in our model with only α_s (strong coupling constant) as a new parameter. Even though the calculated phase shifts for higher partial waves did not compare well with the phenomenological phase shifts of Arndt *et al* [4] the proton–proton (pp) and neutron–proton (np) differential cross sections ($\sigma(\theta)$) obtained were in good agreement with the experimental $\sigma(\theta)$. The purpose of the present calculation is to establish our earlier claim of 'Cheshire cat principle' [1] of NN interaction. The Cheshire cat models are the version of the MIT bag model [5–7], where physics become completely insensitive to the change in the bag radius. In these models the shifting of the bag wall has no physical effect. Therefore, the radius of the bag can be pushed to infinity resulting in a purely fermionic description (i.e. QCD) or to zero, so that the description is entirely bosonic (i.e. some effective meson theory). To test the validity of the 'Cheshire cat' syndrome we have performed the calculations with the exchange of σ and π mesons in the spirit of non-relativistic quark models (NRQM) [8–11] and with the quark core size 0.5–0.6 fm. It is to be noted that this is smaller than the physical size of a nucleon and has to be supplemented by a pion cloud as in NRQM.

For the confinement of quarks we are making use of the relativistic harmonic model (RHM) [12] which has been successful in explaining the properties of light hadrons. For the confinement of gluons we have made use of the current confinement model (CCM) [13–15] which was developed in the spirit of the RHM. The CCM has been quite successful in describing the glue-ball spectra [14]. The full hamiltonian used in our investigation has the usual kinetic energy, two body confinement potential and the COGEP along with σ and π meson potentials. In consistency with our earlier work [1] we have used a smaller oscillation size parameter so as to include σ and π mesons in our calculation. The parameters used in our calculation are listed in reference [1]. We have employed the exact analogous formulation of NRQM, using the resonating group method (RGM) [16, 17] and have calculated the scattering phase shifts as a function of energy using the Kohn–Hulthen–Kato variational principle formulated by Kamimura [18].

Here, we report the results of NN polarization observables (PO) by including phase shifts of all significant partial waves up to angular momentum $(L) = 2$ with the inclusion of σ and π mesons exchange potentials but taking into account the effect of confinement of gluons. Further, we compare the np PO calculated from the theoretical computed phase shifts with the existing experimental data so as to test directly the predictions of our calculation with the observable quantities.

2. Spin polarization in NN scattering

In this section we present the results of calculated PO in comparison with the PO obtained from the phase shifts of Arndt *et al* [19]. In our work we have employed the formulation and the notation of Bystricky *et al* [20]. In the formulation the polarization matrix X_{pqik} with four indices, which correspond to the polarization directions of the scatterer, recoil, beam and target. If the polarization of the particle is not analysed (or unpolarized) the corresponding index is set to zero. If the analysis of the polarization of particle is carried out, then these index are set to n, m or l corresponding to the spin projection on the basis vectors. The polarization matrix X_{pqik} is defined through the NN scattering matrix M. The scattering matrix M for each iso-spin state is expressed in terms of the invariant scattering amplitude a, b, c, d and e which are complex functions of energy and scattering angle θ. The five amplitudes a, b, c, d, e with the T-matrix (T-matrix $= S$-matrix-1) elements can be determined from the phase shifts and the mixing parameters using the partial wave decomposition [20–22]. The details can be found in standard reference of Bystricky *et al* [20]. We have calculated PO in the energy range $E_{\rm lab}$ 0 MeV to 250 MeV for np interaction. The standard convention is to call P a polarization, and D a depolarization. The expressions for the following variables are given in references [20–22].

In figure 1 we display spin observables P_{n000} at 50 and 150 MeV for np interaction. The agreement between experimental data [19] and theoretically computed phase shifts is good at 150 MeV. But there is a typical deviation to the theoretical curve at 50 MeV. This

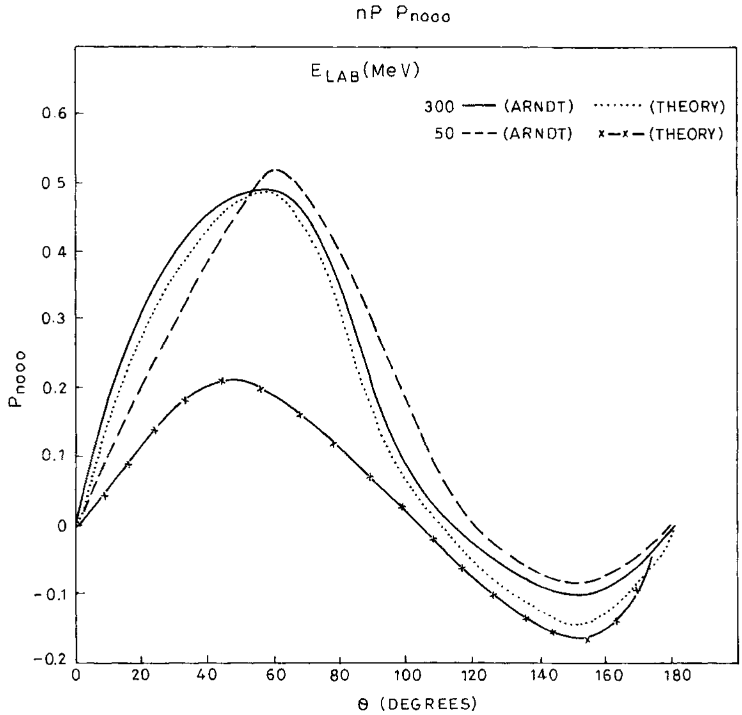

Figure 1. The calculated np polarization observable P_{n000} as a function of scattering angle (θ) in degrees, in comparison with Arndt *et al* [19].

means at low energy the phase shifts are not well determined. This implies that polarization is sensitive to NN interaction at small distances. Similar conclusions have been arrived by Macharvariani *et al* [21]. Figure 2 is a plot of depolarization D against the scattering angle (θ). The D determines the amount of polarization perpendicular to the scattering plane converted into the same after the second scattering. Here, the agreement between theory and experiment is better at all energies [19]. In the next section the important results are stated and summarized.

3. Conclusion

In this paper an attempt has been made to understand the NN PO in the frame work of the RHM and the CCM by employing the RGM formulation. The aim was to understand the role played by the confined gluons on NN interaction. We have computed the phase shifts of all partial waves up to $L = 2$ taking into account the confinement of gluons but by invoking σ and π mesons in the spirit of NRQM. With a smaller oscillator size parameter in consistent with RHM, the model is able to reproduce the phase shifts of most of the partial waves. The np PO are also in agreement with the corresponding experimental observables. However, for the majority of the PO no direct data exists. The confined gluons along with conventional σ and π mesons satisfactorily explain NN observables.

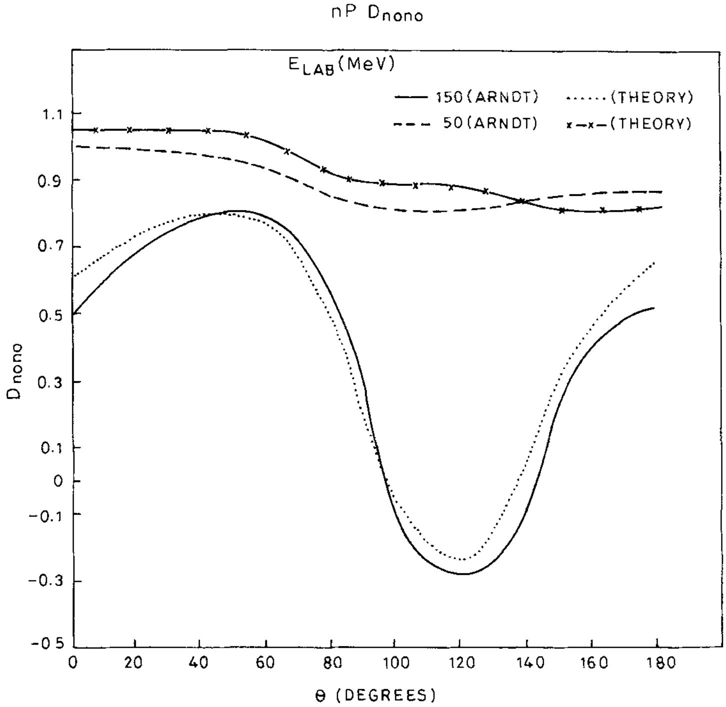

Figure 2. The calculated np polarization observable D_{n0n0} as a function of scattering angle (θ) in degrees, in comparison with Arndt *et al* [19].

The results obtained clearly establishes the validity of 'Cheshire cat principle' in NN interaction.

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