PARITY VIOLATION IN PP SCATTERING AND VECTOR-MESON WEAK-COUPLING CONSTANTS

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We calculate the parity-nonconserving longitudinal asymmetry in the elastic \( \vec{p} p \) scattering at the energies where experimental data are available. In addition to the standard one-meson exchange weak potential, the variation of the strong-coupling constants and the non-standard effects such as form factors and \( 2\pi \)-exchange description of the \( \rho \)-exchange potential are taken into account. With the extra effects, we investigate the compatibility of the experimental data and the presently-known range of the vector-meson weak-coupling constants.

1. Introduction

The measurements of the parity-nonconserving (PNC) asymmetry in \( \vec{p} p \) scattering at both low energies (13.6 and 45 MeV) and at high energy (221 MeV) have been expected to determine the \( \rho NN \) and \( \omega NN \) coupling constants of a one-meson exchange model of the PNC \( NN \) force. The analysis has been recently performed by Carlson et al.\(^{1}\) and they obtain a positive \( \omega NN \) PNC coupling. Though their results do not disagree with the largest range provided by Desplanques, Donoghue and Holstein (DDH)\(^{2}\), updated calculations of the weak-coupling constants do not give much room for positive values of the \( \omega NN \) weak coupling\(^{3,4}\).

With the DDH “best-guess” values of PNC meson-nucleon couplings, the contribution of PNC effects in \( pp \) scattering is dominated by the \( \rho \)-meson exchange. When the low-energy data are well reproduced, it gives a result suppressed roughly by a factor of 2 at high energy. In this work, we concentrate on the \( \rho \)-meson exchange with various effects such as strong-coupling constants of the \( \rho \) and \( \omega \) mesons, form factor in the strong or weak vertices\(^{5,6}\) and the two-pion resonance nature of the \( \rho \)
2. Extra effects

Coupling constants
The concerned PNC potential reads
\[ V_\rho(r) = \frac{g_{\rho NN}}{m_N} \left[ h_\rho \tau_1 \cdot \tau_2 + \frac{1}{2} h_1^1 (\tau_1^z + \tau_2^z) + \frac{h_2^2}{2\sqrt{6}} (3\tau_1^z \tau_2^z - \tau_1^0 \tau_2^0) \right] \times \]
\[ \left( (\sigma_1 - \sigma_2) \cdot \{ p, f_\rho^+ (r) \} - (\sigma_1 \times \sigma_2) \cdot \hat{r} f_\rho^- (r) \right). \] (1)

In the one-meson-exchange description, \( f_\rho^+ \) is the usual Yukawa function, \( e^{-m_\rho r/4\pi r} \), and \( f_\rho^- (r) \) is its derivative with respect to \( r \) (with the factor \((1 + \kappa_V)\)).

The relevant PNC coupling constants are \( h_{\rho\rho} \equiv h_0^0 + h_1^1 + h_2^2/\sqrt{6} \) and \( h_{\omega\omega} \equiv h_0^0 + h_1^1 \) and their “best-guess” values are \(-15.5\) and \(-3.04\), respectively. We consider the variations on the strong-coupling constants \( g_{\rho NN} \) and \( \kappa_V \) as well as \( g_{\omega NN} \) and \( \kappa_S \).

Our choices of the strong-coupling constants are summarized in Tab. 1.

<table>
<thead>
<tr>
<th>( g_{\rho NN} )</th>
<th>( g_{\omega NN} )</th>
<th>( \kappa_V )</th>
<th>( \kappa_S )</th>
<th>( \Lambda_\rho )</th>
<th>( \Lambda_\omega )</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1 2.79</td>
<td>8.37</td>
<td>3.70</td>
<td>-0.12</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>S2 2.79</td>
<td>8.37</td>
<td>6.10</td>
<td>0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>S3 2.79</td>
<td>8.37</td>
<td>3.70</td>
<td>-0.12</td>
<td>1.31</td>
<td>1.50</td>
</tr>
<tr>
<td>Cal 3.25</td>
<td>15.58</td>
<td>6.10</td>
<td>0</td>
<td>1.31</td>
<td>1.50</td>
</tr>
</tbody>
</table>

Form factor at the strong vertex
In Tab. 1, the set S3 introduces the cutoffs in the strong meson-nucleon vertices in the PNC potential. With a monopole-type form factor, the normal Yukawa function is modified as
\[ e^{-m_\rho r/\Lambda_\rho} \to \frac{e^{-m_\rho r}}{r} - \frac{e^{-\Delta r}}{r} \left[ 1 + \frac{1}{2} \Delta r \left( 1 - \frac{m_\rho^2}{\Lambda_\rho^2} \right) \right]. \] (2)

Contributions with \( 2\pi \) and \( N^* \) intermediate states
In order to account for the two-pion resonance nature of the \( \rho \)-meson, we rely on the work presented in Ref. 7 based on dispersion relations. In this formalism, only stable particles are involved and the \( \rho \)-meson appears indirectly in the transition amplitude \( N\bar{N} \to \pi\pi \) through its propagator. To satisfy unitarity, the width of the \( \rho \)-meson has to be accounted for. A background contribution involving the exchange of the nucleon and the \( \Delta \) or \( N^* \) resonances in the t-channel includes the three lowest-lying resonances, \( \Delta(1232) \), \( N(1440) \) and \( N(1520) \).
Table 2. Sensitivity of the PNC asymmetry, $A_L(\times10^7)$, to different choices of strong-coupling constants or to monopole form factors, and comparison with experiment.

<table>
<thead>
<tr>
<th>Strong</th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>Cal</th>
<th>Exp.</th>
</tr>
</thead>
<tbody>
<tr>
<td>13.6</td>
<td>−0.96</td>
<td>−1.33</td>
<td>−0.66</td>
<td>−1.13</td>
<td>−0.95 ± 0.15</td>
</tr>
<tr>
<td>45</td>
<td>−1.73</td>
<td>−2.39</td>
<td>−1.16</td>
<td>−2.00</td>
<td>−1.50 ± 0.23</td>
</tr>
<tr>
<td>221</td>
<td>0.43</td>
<td>0.75</td>
<td>0.25</td>
<td>0.52</td>
<td>0.84 ± 0.29</td>
</tr>
</tbody>
</table>

Correction at the weak vertex

As a result of a specific dynamics, the weak meson-nucleon interaction may acquire a momentum dependence that cannot be reduced to a monopole form factor. This could affect in particular the isoscalar $\rho NN$ coupling. In momentum space, the corresponding $NN$ interaction here represented by the meson propagator, $(q^2 + m^2)^{-1}$, in absence of form factor, can be approximately parametrized as

$$f_\rho(q) = \left(1 - 2\frac{q^2}{q^2 + \Lambda^2}\right) \frac{1}{q^2 + m_\rho^2}.$$  

The Fourier transformation to configuration space gives

$$\tilde{f}_\rho(r) = \frac{\Lambda^2 + m^2_\rho}{\Lambda^2 - m^2_\rho} f_\rho(r) - \frac{2\Lambda^2}{\Lambda^2 - m^2_\rho} f_N(r).$$  

3. Results and discussions

Coupling constants and form factor at the strong vertex

In Tab. 2 we show our results with various strong-coupling constants and form factors. DDH “best-guess” values are employed for the weak couplings. The resulting asymmetry is sensitive to the strong couplings as well as the form factor, but results do not fall within experimental error bars simultaneously.

Corrections with $2\pi$ and $N^*$

The effect of the $2\pi + N^*$ contribution is investigated with the strong parameter sets S1 and S2, and DDH “best-guess” values for the weak-coupling constants. The results are summarized in Tab. 3. In the column for $2\pi + N^*$, the numbers in the parentheses represent the ratios $(2\pi + N^*)/(\text{bare } \rho)$. The $2\pi + N^*$ contribution gives a relatively larger enhancement at 13.6 MeV than at the remaining two energies, but as a whole, the ratios are similar. Since the magnitudes of the asymmetry at 13.6 and 45 MeV are larger than that at 221 MeV, similar ratios give more increase of the asymmetry at low energies. As a result, $2\pi + N^*$ with S1 gives asymmetries out of the error bars at all the three energies. For S2, the $2\pi + N^*$ contribution worsens the situation at low energies, while keeping it at 221 MeV.

Correction at the weak vertex

The results with the form factor given by the chiral-soliton model at the isoscalar weak $\rho NN$ vertex are given in Tab. 4. The set S1 is used for the strong parameters and DDH “best-guess” values for the weak couplings. The asymmetry is also
Table 3. Sensitivity of the PNC asymmetry, $A_L (\times 10^7)$, to the effect of the finite $\rho$-width correction of the weak potential.

<table>
<thead>
<tr>
<th></th>
<th>S1</th>
<th>S2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>bare $\rho$ 2$\pi + N^*$</td>
<td>bare $\rho$ 2$\pi + N^*$</td>
</tr>
<tr>
<td>13.6</td>
<td>$-0.96$</td>
<td>$-1.22 (1.27)$</td>
</tr>
<tr>
<td>45</td>
<td>$-1.73$</td>
<td>$-2.14 (1.24)$</td>
</tr>
<tr>
<td>221</td>
<td>$0.43$</td>
<td>$0.53 (1.23)$</td>
</tr>
</tbody>
</table>

Table 4. Sensitivity of the PNC asymmetry, $A_L (\times 10^7)$, to the effect of a specific correction of the isoscalar PNC $\rho NN$-vertex.

<table>
<thead>
<tr>
<th>$\Lambda'$ (GeV)</th>
<th>bare $\rho$</th>
<th>3</th>
<th>1.31</th>
<th>0.771</th>
</tr>
</thead>
<tbody>
<tr>
<td>13.6</td>
<td>$-0.96$</td>
<td>$-1.04$</td>
<td>$-1.33$</td>
<td>$-1.69$</td>
</tr>
<tr>
<td>45</td>
<td>$-1.73$</td>
<td>$-1.88$</td>
<td>$-2.38$</td>
<td>$-2.92$</td>
</tr>
<tr>
<td>221</td>
<td>$0.43$</td>
<td>$0.47$</td>
<td>$0.61$</td>
<td>$0.67$</td>
</tr>
</tbody>
</table>

sensitive to the values of the cutoff $\Lambda'$, but in this case again, the correction at the PNC vertex does not change the trends we have been observing in other cases.

4. Conclusion

We calculated the PNC asymmetry in $\bar{p}p$ scattering at the energies 13.6, 45 and 221 MeV. We investigated the role of the effects such as different strong-coupling constants, cutoffs in the regularization of the potential, long–range contributions to the $\rho$-exchange PNC potential and PNC form factors of the isoscalar $\rho NN$ vertex. The effects we considered in this work are not helpful to solving the problem raised in the introduction. With this observation, we’d like to suggest the following issues: The first one is that the value of the $\omega NN$ coupling, its sign in particular, is correct. This implies that present estimates are missing important contributions. The second issue is the existence of large corrections to the PNC single-meson exchange potential. The last issue concerns the experiment, especially at the highest energy of 221 MeV. Whatever the issue, they are quite interesting problems to be studied in the future.

References