πNN, YN AND YY INTERACTIONS

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I A narrow-width πNN resonance near threshold[1]

Whether dibaryon exists is one of longstanding problems in intermediate-energy nuclear physics. The energy-dependent structure in the $\Delta\sigma_L$ data on pp scattering, found first by Argonne group, has been explained in terms of the πNN dynamics. Two poles have been found in the theoretical πNN amplitudes: At mass $2116 - i61$ MeV in $I = 1, J^P = 2^+$ channel and at mass $2155 - i60$ MeV in $I = 1, J^P = 3^-$ channel [2].

In this paper we investigate whether the πNN dynamics generates a resonance in $I = 0$, $J^P = 0^-$ channel near the pion production threshold. The following two points are new and remarkable. (1) This system is dominated by the S wave configurations of its subsystems in contrast with the P wave configurations in the $J^P = 2^+$ and 3^- cases. (2) This system decouples with the NN channel. Therefore the possibility of a narrow width is inferred, if a πNN resonance is generated.

We make the πNN calculation based on πNN three-body equation by taking into account the two configurations as follows. One involves a NN $^1S_0$ interacting pair with the remaining pion in the S state: This configuration is denoted as $\pi(S)NN(^1S_0)$. The other involves a πN S_{11} interacting pair with the remaining nucleon in the S state: The configuration $N(S)\pi N(S_{11})$. All other configurations are allowed to be ignored, since the present problem concerns only the energy region for one pion production threshold.

In 1996 we made the first report of the result for the πNN calculation for this channel, where the initial state is put off energy shell while the final state is on energy shell[3]. The resulting cross section shows a peak at $M = 2.06 - 2.09$GeV with width $\Gamma = 30 - 50$ MeV. The reason why we put the initial state off energy shell was as follows. The experiment related with the present problem detects a $pp\pi^-$ resonance in the reaction of $pp \to pp\pi^-\pi^+$— the search experiment of d'[4]. Therefore the initial state of the $pp\pi^-$ system is off energy shell. However, to compare the theoretical amplitude with the experiment, we have the ambiguity what value to assume for the relative momentum between an spectator and an interacting pair particles in the initial state. If one follows the experimental situation exactly, the relative momentum is independent of the total three-body energy and should be integrated over with the weight of the production probability of this subsystem which is in turn governed by the four-body dynamics of the $pp\pi^-\pi^+$ system. Since the effective value for the relative momentum was not known, the value was put as $q = 0.92 - i0.18$ fm^{-1} incidentally in the previous calculation[3]. In the present calculation we avoid the ambiguity for the choice of the effective value for the relative momentum by putting the initial state on energy shell as well as the final state.

The πNN equation[5] is employed for anti-symmetrized amplitudes. For the πN S_{11} interaction we use a separable potential derived in reference[6]. For the NN $^1S_0$ interaction we use the $^1S_0$ interaction due to OBEP which is converted to rank two form by keeping the same off-shell structure as the original OBEP[7, 8].

We find that the major amplitude is the one between $\pi(S)NN(^1S_0)$ configurations. We make the Argand plot of this amplitude, $\bar{X}(^1S_0, ^1S_0; E)$, at $E = 0.5 - 23$ MeV. It is remarkable that the amplitude makes an anti-clock wise looping structure as is seen in Fig. 1(Left) and that the partial cross sections have a structure of width 4-5 MeV at $E \sim 5$ MeV as are shown in Fig. 1(Right).

Bilger et al have reported a signal of a πNN resonance with width $\Gamma \sim 0.5$ MeV and mass $M \sim 2.06$ GeV in $pp \rightarrow pp\pi^-\pi^+$ reaction[4]. However, Kulikov has reported a result against this evidence[9]. The relationship between the signal and our theoretical result is not known. It is a question whether a production mechanism of the πNN subsystem in this reaction is possible to make a change of the width and the mass for the structure found in this paper.

The off shell effect of the input two-body interactions is that, if the input two-body interactions are assumed such as a resonance position comes lower than the present, then the resulting width changes narrower.

In conclusion the πNN dynamics generates a strong and narrow structure in the $I = 0,\ J^P = 0^-$ πNN amplitude with width $\Gamma = 4 - 5$ MeV and total three-body kinetic energy $E \sim 5$ MeV. The structure is due to the interactions of the NN $^1S_0$ and πN S_{11} subsystems. In view of the present result we would like to propose that the d' search is to be extended to the energy region of $E = 0 - 50$ MeV. Furthermore we remind ones that the three-body amplitude at pion threshold in the $I = 1, J^P = 0^-$ channel shows an enhancement[6].

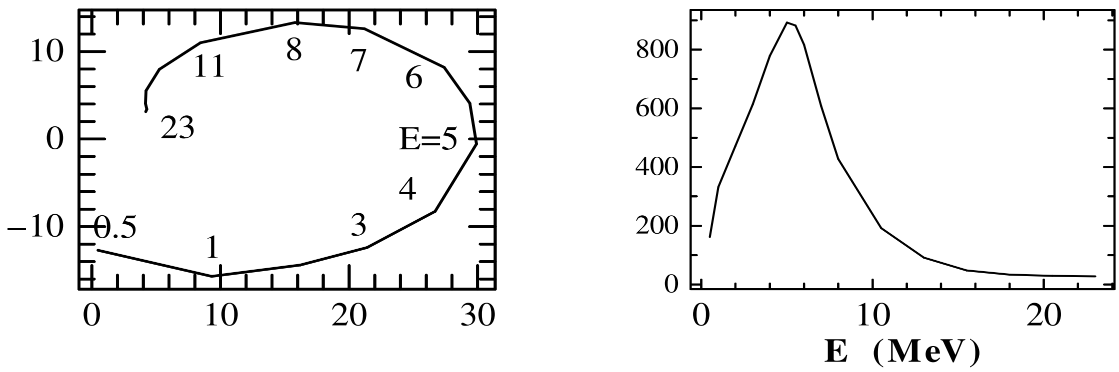

Fig. 1 Left: The Argand plots of the amplitude between the $\pi(S)NN(^1S_0)$ configurations at total three-body kinetic energy in CMS $E = 0.5 - 23$MeV are shown. The attached values indicate E in units of MeV. The real and imaginary axes are given in an arbitrary units. Right: The partial cross sections for the transitions between the $\pi(S)NN(^1S_0)$ configurations are shown. The abscissa indicates the total three-body kinetic energy in CMS, E, in units of MeV. The ordinate is given in an arbitrary unit.

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II ΛN and $\Lambda\Lambda$ interactions and hypernuclei[1]

A realistic NN OBEP by Ueda and Green (1968,1978) involves the ingredients of the π, η, ρ, ω, δ, S^* and σ exchanges with the vertex form-factors. This model employs neither hard nor soft phenomenological core. In this paper we present the extension of the potential to ΛN and $\Lambda\Lambda$ systems. An SU(3) nonet meson scheme is considered for pseudoscalar, vector and scalar mesons: $(\pi, \eta, K, \eta'), (\rho, \omega,\ K^*,\ \phi)$ and $(\delta, S^*, K_0^*(1430)\ f_0(1581))$, respectively. Additionally the isosinglet scalar meson σ is involved and represents the $I = 0, J^P = 0^+$ part of the 2π exchange contributions as well as the ones from the $\Lambda - \Sigma$ channel couplings.

We allow the mixing parameters of the scalar and vector mesons as adjustable by taking into account that they involve effectively the correlated and uncorrelated two octet-meson exchange contributions. The uncertainties arising from this treatment are removed in combined analyses with hypertriton.

Result: The presently available data for Λp cross sections and hypertriton are reproduced. Then the $\Lambda N\ {}^1S_0$ phase shift is found to be more attractive than the ${}^3S_1$ without ambiguity. At low energy limit we find a considerable difference from the Nijmegen soft-core model result in $\sigma({}^3S_1)$ cross section, while a similar result in $\Lambda N {}^1S_0$ one. Furthermore the data for the separation energies of ${}^{6}_{\Lambda\Lambda}He$, ${}^{10}_{\Lambda\Lambda}Be$ and ${}^{13}_{\Lambda\Lambda}B$ are reasonably reproduced. No bound state exists in the $\Lambda\Lambda$ system. The $\Lambda\Lambda\ {}^1S_0$ phase shift is approximately similar with the $\Lambda N\ {}^1S_0$. The $\Lambda\Lambda$ total cross section below $E_L = 47$ MeV is predicted.

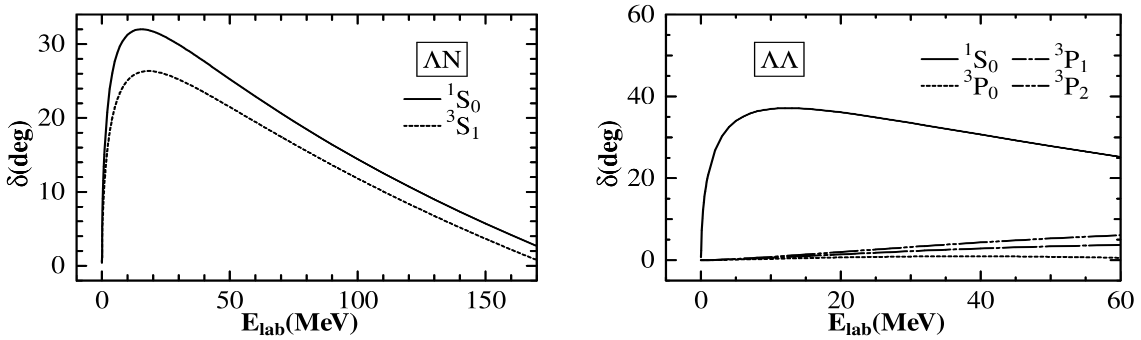

Fig. 1 Left: The ΛN $\delta({}^1S_0)$ and $\delta({}^3S_1)$ and Right: the $\Lambda\Lambda$ $\delta({}^1S_0)$ and $\delta({}^3P)$

Table 1: Binding energy of hypertriton, scattering lengths and cross sections at $E_L = 0$

$B({}^3_\Lambda H)$ MeV	$B({}^3_\Lambda H)$(Experiment)	$a({}^1S_0)$ fm	$a({}^3S_1)$ fm	$\sigma({}^1S_0)$ mb	$\sigma({}^3S_1)$ mb
2.35	2.355±0.05	-2.71	-1.95	231	358

Table 2: The separation energies of double Λ hypernuclei

Double Λ hypernuclei	Theory (MeV)	Experiment (MeV)
${}^{6}_{\Lambda\Lambda}He$	3.6	4.7
${}^{10}_{\Lambda\Lambda}Be$	4.1	4.3
${}^{13}_{\Lambda\Lambda}B$	4.9	4.9

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