Chapter 1

General Introduction

1.1 General Review

The phase-shift analysis was proposed by E. Fermi for the analysis of the π-N scattering and contributed to detecting the $\Delta(1232)$ resonance. Ever since this method has constantly given a motivation for particle scattering experiments and played an important role in determining hadron scattering amplitudes. Especially this method has brought a detection of many kinds of meson-baryon resonances.

The outline of this method is as follows; the scattering amplitude is expanded by Legendre polynomials into the partial wave amplitudes f_ℓ, where ℓ is the angular momentum, and the partial S-matrix is represented by $S_\ell = 1 - if_\ell = \exp(2i\delta_\ell)$. The phase shifts δ_ℓ are determined in such a way that the scattering amplitudes reproduce experimental data. This method is regarded, as it were, as a translator of experimental data into the scattering amplitudes without any model. The high reliability is a reason that the phase-shift analysis has played an important role in a study of hadron physics.

In the history of the phase-shift analysis two flows are found, one of which is a research of meson-baryon resonances in late 1960's. This flow resulted in the Sakata model, and then the quark model for hadron mass formula. The other flow is a study of the mechanism of the strong interaction, and, in addition to a detection of many kinds of hadrons, detailed knowledge of the hadron interaction was obtained, which resulted in the Regge model.

1.2 Nucleon-Nucleon Scattering

At the beginning, Yukawa's π-meson theory faced such a problem that it contradicts the perturbation theory. The central component phase-shift of triplet p-wave ($\delta_1^{(c)}$) of the p-p scattering was determined by Wisconsin group's experiment at the incident proton energy $T_L = 2 - 4$ MeV in 1954. It was shown that the values ($\delta_1^{(c)}$), being positive at the higher energies, tend to be negative below about 5 MeV with decreasing the energy. Otsuki and

Tamagaki[1] showed that this energy dependence corresponds to a weekly repulsive character of the one-pion-exchange (OPE) potential at a large inter-nucleon distance r$\gtrsim$2.5 fm. This was the first dynamical verification of the Yukawa theory in the midst of numerous successes of the shape-independent theory.

Following to this success of the pion theory, Iwadare et al.[2, 3] proposed a three-step method for the study of the nuclear force. They divided the inter-nucleon distance into three regions and showed the validity of OPE-potential in Region I (r$\gtrsim$2.5 fm), which has since been a common view of the strong interaction. They supposed that the two-pion exchange potential is enhanced and the recoil effect is also appreciable in Region II (2.5$\gtrsim$r$\gtrsim$1.5 fm), and various complicated effects appear in Region III (r $\lesssim$1.5 fm).

The three-step method was firstly realized by Livermore group. They proposed a modified phase-shift analysis of the N-N scattering, in which the peripheral part of the scattering amplitude is given by the one-pion exchange amplitude, and succeeded in obtaining the phase-shift solution at $T_L \lesssim$300 MeV[4, 5].

Hiroshima group[6] succeeded in giving a theoretical explanation of the Livermore phase-shift solution in terms of one-boson-exchange contributions of the well-known bosons π, σ, ρ and ω.

In the energy region higher than 300 MeV, which is beyond the threshold energy of one-pion production in the N-N scattering, inelastic effects should be evaluated in the phase-shift analysis. Hoshizaki and Machida[7] represented the partial-wave S-matrix as $S_\ell = \eta_\ell \exp(2i\delta_\ell)$, where η_ℓ is the reflection parameter for the absorption effect of ℓ-wave due to the inelastic channel, and succeeded in analyzing of the p-p scattering at T_L=660 MeV. This method was extended by Hoshizaki and some other groups and contributed to the research of dibaryons by using the data obtained by polarized-spin experiments at Argonne and Saclay in 1980's[8, 9, 10, 11, 12, 13].

On the other hand, the spin-correlation data of the p-p scattering at the incident momenta P_L= 3, 6 and 12 GeV/c, which were supplied by the polarized-spin experiment at Argonne National Laboratory (ANL), were rich enough to attract a theoretical interest. We expected an appearance of quark-gluon dynamics, besides quark-counting effects, in hadron-interaction phenomena at such high energies.

In the phase-shift analysis, one can satisfy the unitarity condition for scattering amplitudes automatically and account for the t-dependence of spin effects more easily than in the total amplitude analysis. The phase-shift analysis, however, has some faults at high energies. The main one is the difficulty that arises from the ever-increasing number of participating partial waves with increasing the energy of the incident particle. This causes a doubt about the utility of this analysis at high energies, although the utility of the phase-shift analysis of the N-N scattering was shown by several groups in the dibaryon region of a few GeV as mentioned above.

Some methods of overcoming this difficulty have been proposed. They are, for example, the phase-band method suggested by Moravcsik[14], for the analysis of the N-N scattering, and the accelerated convergence-expansion method by Cutkosky[15] for that of the π-N scattering. Cutkosky's method succeeded in analyzing the π-N scattering at a few tens of GeV. A similar success by some new method was also expected in the analysis of the N-N scattering at high energies.

We proposed a new modified phase-shift analysis of the N-N scattering at high energies and succeeded in obtaining the phase-shift solutions at 3, 6 and 12 GeV/c[16, 17, 18, 19, 20, 21]. The obtained solutions suggested a surprising phenomenon, of a " dynamical shrinkage