$\Sigma^{\pm}$p scattering experiment at J-PARC Hadron Experimental Facility

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Nucleons (N), namely, protons (p) and neutrons (n) are the most basic baryons comprising only u and d quarks. Octet baryons (p, n, Λ, Σ^+, Σ^0, Σ^-, Ξ^0, Ξ^-) are extension of nucleons consisting of u, d, and s quarks. The latter six baryons include at least one s quark and are called Hyperons (Y). By investigating interactions between octet baryons (BB interaction), the role of dynamics of quarks and gluons in the short-range nuclear force can be multi-directionally examined. In particular, it is expected that the ΣN interaction is strongly affected by the Pauli principle at the quark level (quark Pauli effect) [1] and that a larger repulsive core can be observed in the Σ^+p channel than in the NN interaction. A scattering experiment is the most direct method to investigate BB interactions. However, YN scattering experiments have been difficult for a long time due to the short lifetime of hyperons. Recently, we successfully performed a novel high-statistics $\Sigma^{\pm}$p scattering experiment at J-PARC (J-PARC E40 [2]). This experiment aimed at a systematic study of the ΣN interaction and the verification of the large predicted repulsive core in the Σ^+p channel.

The experiment was performed at the K1.8 beam line in the J-PARC Hadron Experimental Facility. A conceptual drawing of the experiment is shown in Fig. 1. A liquid hydrogen target (LH_2 target) was used both for the incident $\Sigma^{\pm}$ production and for the $\Sigma^{\pm}$p scattering. $\Sigma^{\pm}$p scattering events can be identified by measuring the $\Sigma^{\pm}$ momentum, the recoil proton's kinetic energy and the proton's recoil angle.

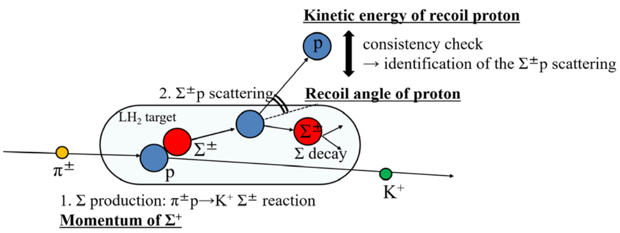

Fig. 1 Conceptual drawing of the $\Sigma^{\pm}$p scattering experiment. The $\Sigma^{\pm}$p elastic scattering case is drawn.

$\Sigma^{\pm}$ particles were produced via the $\pi^{\pm}p \to K^+\Sigma^{\pm}$ reaction induced by a $\pi^{\pm}$ meson beam. By measuring the momenta of the beam $\pi^{\pm}$ and of the outgoing K^+ meson using two magnetic spectrometers, events which resulted in the production of $\Sigma^{\pm}$ particles were identified, and the momentum of each $\Sigma^{\pm}$ was determined. In total, 1.62×10^7 Σ^- and 4.9×10^7 Σ^+ events were accumulated. The produced $\Sigma^{\pm}$ particles can induce additional reactions, such as the desired $\Sigma^{\pm}$p scattering. $\Sigma^{\pm}$ particles also decay, such as the $\Sigma^- \to n\pi^-$ decay. Using the CATCH detector system [3] surrounding the LH_2 target, charged particles involved in these reactions and decays were detected. For each detected proton, the direction and kinetic energy could be measured.

The $\Sigma^{\pm}$p scattering events were identified by a kinematical consistency check. An illustrative example can be taken to be the case of a $\Sigma^{\pm}$p elastic scattering event, in which a proton was detected by CATCH. The kinetic energy of the recoil proton can be calculated from the kinematics of elastic scattering using the $\Sigma^{\pm}$ momentum vector and the proton direction. This energy is then compared to the one measured by CATCH. If the detected proton is really the recoil proton from $\Sigma^{\pm}$p scattering, the calculated and measured energies should be consistent with each other. Approximately 4500 Σ^-p elastic [4], 2400 Σ^+p elastic, and 2300 $\Sigma^-p \to \Lambda n$ inelastic [5] scattering events were identified. These numbers are approximately 100 times larger than those achieved in past experiments. From this high-statistic data, differential cross sections were obtained. Figure 2 shows the angular distribution of the differential cross sections for Σ^-p elastic scattering. The quality of the data has improved significantly. The present data show a forward-peaking angular distribution in agreement with theoretical predictions, although some small discrepancies can also be seen. The present data in turn constitute a new excellent input which can be used to improve theoretical models. These systematic studies of the ΣN interactions will play an important role to establish more realistic BB interaction models and to constrain the size of the repulsive force owing to the quark Pauli effect.

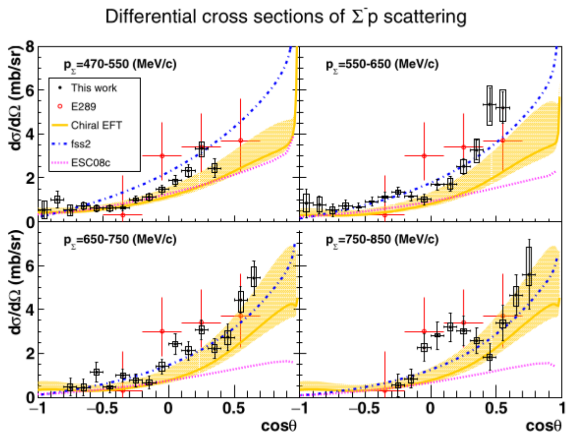

Fig. 2 Differential cross sections for the Σ^-p elastic channel obtained in J-PARC E40 experiment [4] (black points), grouped into four graphs corresponding to different ranges of the Σ^- incident momenta. The error bars and boxes show statistical and systematic uncertainties. The red points show the previous experimental data [6]. The pink dotted, blue dot-dashed, and orange solid lines show theoretical predictions; ESC08c [7], fss2 [8], and Chiral EFT with shadows representing error bands [9].

References

[1] M. Oka and K. Shimizu, and K. Yazaki, Nucl. Phys. A, 464, 700 (1987).
[2] K. Miwa et al., J-PARC Proposal P40 (2010).
[3] Y. Akazawa et al., Nucl. Instr. Meth. A1029, 166430 (2022).
[4] K. Miwa et al., Phys. Rev. C, 104, 045204 (2021).
[5] K. Miwa et al., Phys. Rev. Lett., 128, 072501 (2022).
[6] Y. Kondo et al., Nucl. Phys. A 676, 371 (2000).
[7] T. A. Rijken, M. M. Negels, and Y. Yamamoto, Prog. Theor. Phys. Suppl. 185, 14 (2010).
[8] Y. Fujiwara, Y. Suzuki, and C. Nakamoto, Prog. Part. Nucl. Phys. 58, 489 (2007).
[9] J. Haidenbauer et al., Nucl. Phys. A915, 24 (2013).