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Short Note

Asymmetry measurement of the polarized Σ^+p elastic scattering and the hyperon-nucleon spin-orbit interaction

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Abstract. In order to study the hyperon-nucleon spin-orbit interaction, asymmetries of the polarized Σ^+ elastic scattering on protons have been measured. The polarized hyperons were produced through the p$(\pi^+, \mathrm{K}^+)\Sigma^+$ reaction in a liquid-scintillator active target, and tracks of Σ^+p scattering events were recorded with a newly developed track detector named SCITIC (scintillating track image camera). Although analyses of 10 times more data with more sophisticated data-taking systems and more elaborated analyzing tools are under way, data from an early stage of this experiment indicate a large Σ^+p spin-orbit interaction in contrast to the case of the small ΛN spin-orbit interaction.

PACS. 13.75.Ev Hyperon-nucleon interactions – 25.80.Pw Hyperon-induced reactions

One of the most interesting results from hypernuclear experiments was the indication of the small spin-orbit (LS) interaction in the old Λ-hypernuclear experiment by the Heidelberg-Saclay collaboration at CERN in 1978 [1]. The smallness of the LS splitting was also suggested in other hypernuclei at BNL [2]. This result has recently been confirmed by experiments at KEK and BNL with better precision. Two KEK-PS experiments [3,4] reported small but finite values of the LS splitting, and two BNL-AGS experiments [5,6] measuring hypernuclear gamma-rays determined the small splittings quantitatively with high precision.

Just after the CERN experiment in 1978, H. Pirner [7] pointed out that, in contrast to the ΛN system, the LS interaction must be large in the ΣN system ($V_{\mathrm{LS}}^{\Lambda\mathrm{N}} \simeq 0$, $V_{\mathrm{LS}}^{\Sigma\mathrm{N}} = \frac{4}{3}V_{\mathrm{LS}}^{\mathrm{NN}}$) based on a naive quark model. K. Yazaki [8] has also indicated a possible large LS interaction for the ΣN system, while the ΛN LS interaction is small due to cancellation between anti-symmetric and symmetric LS terms. Following these suggestions, efforts were made to observe the LS effect in Σ-hypernuclear experiments at CERN and KEK. However, it was shown that the Σ-hypernuclei were observable only in very limited cases [9,10].

Since that time, the possibility has been explored at KEK-PS to study the ΣN interaction through the hyperon-scattering experiments using active targets of scintillating track detectors. A scintillation-fiber detector, named SCIFI [11] was successfully used for the scattering experiments, E251 [12] and E289 [13]. For the present experiment, however, we developed another type of track detector named SCITIC (scintillating track image camera) [14,15]. The track image in the liquid scintillator was focussed on a photocathode of an image intensifier tube (IIT) through an optical-lens system, and after multiplications of the photoelectrons in 4-stages of IIT, the picture was recorded with a CCD camera. These track detectors were used for observation of hyperon events selected with electronic trigger signals from beam and kaon spectrometers.

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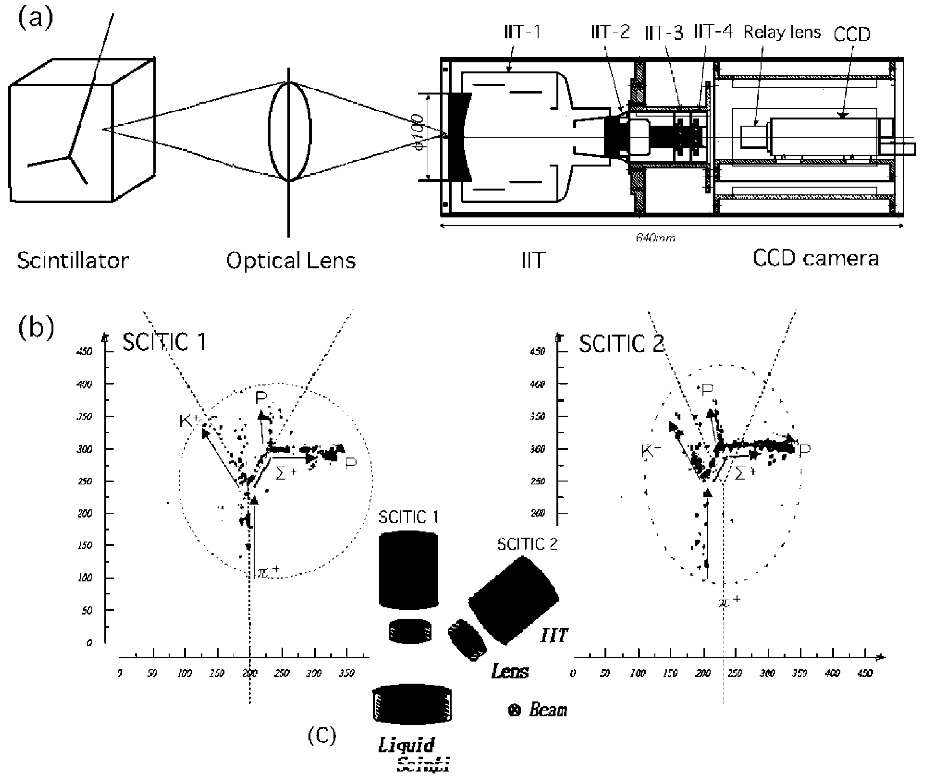

Fig. 1. (a) Schematic illustration of SCITIC. (b) Typical pictures of hyperon scattering seen by two sets of SCITIC arranged as shown in (c).

We started an experiment (KEK-PS E452) to measure asymmetries of the polarized hyperon-nucleon elastic scattering for the determination of $V_{\rm LS}^{\rm YN}$. The experiment consisted of three stages, E452A, B and C. This paper is reporting a result from the early-stage experiment E452A which has already indicated a large $V_{\rm LS}^{\Sigma\rm N}$.

The experiments were carried out at KEK-PS. The polarized hyperons were produced through the $\rm p(\pi^+, K^+)\Sigma^+$ reaction. Pion beams of 1.6 GeV/c from the K2 beam line were used on the active target of SCITIC with a liquid scintillator (Bicron BC-517S with $H/C = 1.7$). The experimental setup was essentially the same as that for the previous experiment E289 [12] except for the active target (SCITIC) and the angular coverage of the kaon spectrometer. The $(\pi, \rm K)$ events were selected with trigger signals indicating kaon production from the kaon spectrometer whose coverage of kaon angle was $\theta_{\rm K}^{\rm Lab} = 20$–$30$ degree. Large polarizations of the Σ^+ in this angular range have been reported in previous experiments [16,17] (see fig. 2(a) below).

Scintillating track images of the selected events were recorded with two sets of SCITIC at different azimuthal angles, from which we deduced three-dimensional pictures from off-line analyses. Shown in fig. 1(a) is a schematic illustration of the SCITIC. A conventional camera lens (Canon $F = (f/D) = 1.2$, $f = 85$ mm) was used for the SCITIC in the early phase, E452A. In order to obtain a large acceptance for photons, an electrostatic-type IIT (Hamamatsu V4440PX) with 10 cm diameter was used for the first stage of the IIT cascade while the diameter of the second to fourth stage IIT were 2.5 cm. The first- and second-level trigger signals from the beam and kaon spectrometers were applied to the third and fourth IIT which were of microchannel-plate type. The images on the fluorescent output screen of the last stage IIT were recorded by a CCD camera (Kodak ES310).

The pictorial data from the CCD camera were stored after compression so as to speed up the data recording. Using data-compression up to 25 events per beam spill of 2 s duration could be recorded. A typical picture of a $\Sigma^+\rm p$ scattering event is shown in fig. 1(b).

About 60000 pictures of $(\pi, \rm K)$ events were taken in E452A. These contain pictures of Σ^+ or Λ productions, and their scatterings on a proton or a carbon nucleus in the active target, as well as background nuclear reactions. Scanning of the pictorial data was assisted with a computer, which indicated vertex points from pion and kaon tracks and possible directions of the produced hyperons with use of the beam and particle spectrometer data. All events were scanned by two or three scanners, and only those events selected by at least two scanners were taken as the candidates.

Out of the 60000 pictures about 500 candidates for the $\Sigma^+\rm p$ scattering were selected through the eye scanning. These candidates, however, include also the quasifree scattering with a proton in carbon nuclei. Therefore, in order to distinguish pure hyperon-proton elastic scattering from the quasifree-scattering or background due to mul-

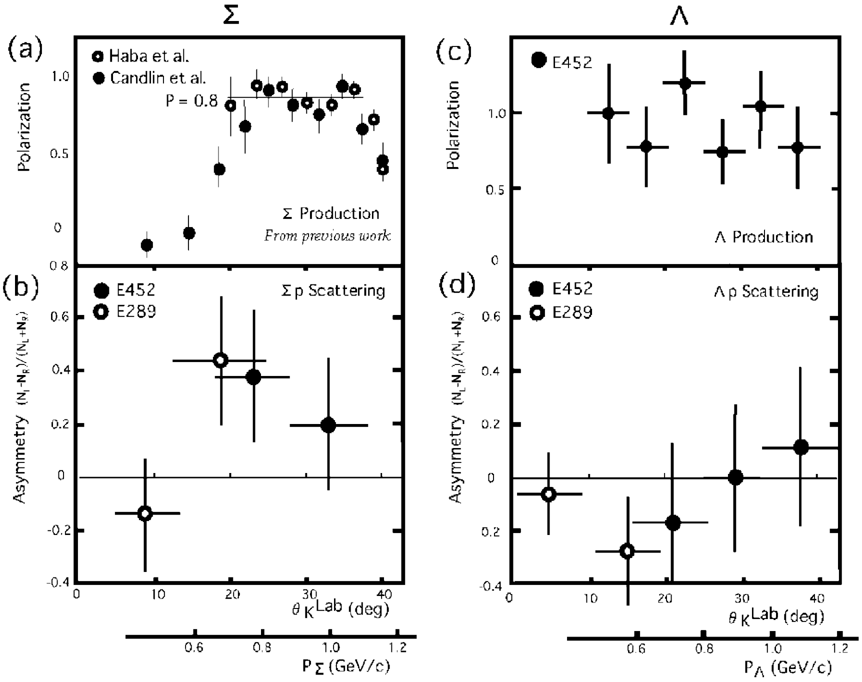

Fig. 2. Polarizations of hyperons produced through the (π^+, K^+) reaction, and left/right asymmetries of the polarized hyperon elastic scattering on protons: (a), (b) for Σ^+ and (c), (d) for Λ. Data on the Σ^+ polarization in (a) are from refs. [16,17].

tiple tracks possibly from nuclear reactions, kinematical cuts were applied. Those were 1) missing-mass cut to select the Σ^+ hyperon, 2) co-planarity cut on the Σ^+ production angle relative to the (π, K)-plane in the hyperon-production stage, and 3) co-planarity cut on the Σ^+ scattering angle relative to the plane of the incident Σ^+ and a recoil proton in the scattering stage. The cuts 1) and 2) were for the Σ^+ production process. They were necessary to assure that our analysis was consistent with the existing data on the Σ^+ polarization from refs. [16] and [17], which were taken with hydrogen targets. The cut 3) was for rejection of the hyperon scattering on a proton in carbon nucleus. After these cuts, 31 candidates for the Σ^+p scattering survived.

Since Σ^+ hyperons are polarized perpendicular to the reaction plane, the effect of the LS interaction on the scattering can be observed as a left/right asymmetry, which can be determined simply by identifying the left or right direction of the scattered hyperons. In the Σ^+p scattering, the scattered Σ^+ was identified against the recoil proton by its decay kink.

The left/right asymmetry A was determined from the numbers of events of left-scattering (N_{L}) and of right-scattering (N_{R}) as

$$A = \frac{N_{\mathrm{L}} - N_{\mathrm{R}}}{N_{\mathrm{L}} + N_{\mathrm{R}}}\,.$$

Shown in fig. 2 is a summary of the data. The data on polarization of the Σ^+ produced through the (π^+, K^+) reaction (fig. 2(a)) are from previous experiments [16,17]. The polarization was determined also from the analysis of the present data, which was consistent with the previous result. The data in fig. 2(a) were used to determine the polarization to be $P = 0.8$, averaging over the kaon-angle range $\theta_{\mathrm{K}}^{\mathrm{Lab}} = 20$–38 degree.

Results from the present experiment E452A on the asymmetry of the Σ^+p scattering are shown in fig. 2(b) together with data from an analysis of the E289 data [15]. Significantly large left/right asymmetries are observed for the range of $\theta_{\mathrm{K}}^{\mathrm{Lab}} = 20$–30 degree where the polarization of Σ^+ was large ($P = 0.8$) as seen in fig. 2(a).

Although the motivation for the present experiment was to study the Σ^+ interactions, the data include comparable number of Λ-associated events. The asymmetry of Λ is also interesting to compare the LS effect in the ΛN two-body interaction with the weak LS effect in hypernuclei. Since the Λ hyperons are produced only through interaction of a pion with a neutron in a carbon nucleus, the polarization axis is not unique because of the Fermi motion. The normal vector of a plane determined by tracks of the incident pion and the produced Λ was selected as the polarization axis. The E452A data on Λ hyperon polarization formed through the (π, K) reaction are plotted in fig. 2(c). The asymmetries of the Λp scattering shown in fig. 2(d) are results from the present experiment E452A and from a new analysis of the E289 data. While the polarizations of Λ were large, the Λp scattering asymmetry was consistent with zero, indicating the weak LS interaction in the ΛN system.

Although these data suffer from poor statistics, we may already conclude experimentally that the asymmetry of the Σ^+p scattering is about as large as predicted by the quark model [7,8].

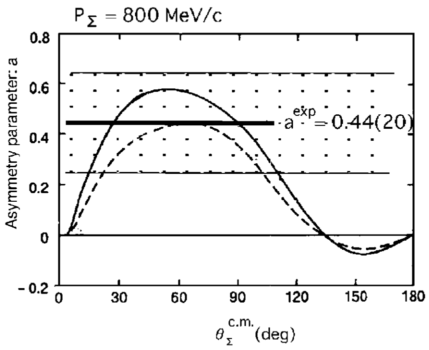

Fig. 3. Comparison of the experimental result on Σ^+p scattering with the theoretical calculation [18]. The solid and dashed curves are by the RGM and FSS calculations, respectively. The asymmetry parameters were calculated *versus* scattering angle θ^{cm} of Σ^+. The experimental asymmetry a^{exp} is an average value over the scattering angles.

The experimental result is compared with a theoretical calculation in fig. 3. Taking the average of 3 points in fig. 2(b) for the range of $p_\Sigma = 800 \pm 200$ MeV/c ($\theta_{\mathrm{K}}^{\mathrm{Lab}} = 18$–$32$ degree), we obtain the left/right asymmetry $A = 0.35 \pm 0.15$. Theoretical curves drawn in the figure are for quark models developed by the Kyoto-Niigata group (RGM and FSS) [19]. Calculated asymmetry parameters $a(\theta)$ are drawn *versus* the scattering angle θ of Σ^+ hyperon, $\theta_\Sigma^{\mathrm{c.m.}}$ [18]. Experimentally, the asymmetry parameter a^{exp} was determined dividing the left/right asymmetry A by the incident hyperon polarization P_Σ. The experimental asymmetry $a^{\mathrm{exp}} = A/P_\Sigma = (0.35 \pm 0.15)/0.8 = 0.44 \pm 0.2$ is shown in the figure. Direct comparison with theories is not possible, since the experimental number is an average value integrated over the angle θ_Σ with weights determined by angular dependences of cross-sections, scanning efficiency, etc. Nevertheless, the theoretical calculation by the Kyoto-Niigata group [18] for $p_\Sigma = 800$ MeV seems to be in accord with the data. So far, this quark model predicted the largest asymmetry.

Detailed arguements are, however, meaningless under the present statistics. The experiments E452B and C have been carried out, and further analyses are under way with data containing 10 times more pictures taken with more sophisticated detector and trigger system.

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