Hadron spin polarization: Dynamical spin-orbit interaction and puzzle

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This presentation contains two subjects on the hadron spin polarization. The first is on the interaction to provide the spin asymmetry. The origin producing spin polarization of hadrons in high energy hadron collisions had been interpreted as a spin-orbit type interaction. However after one theoretical work which pointed out failure of the spin-orbit interaction not providing correct P_T dependence of the spin polarizations, its genuine origin becomes obscure. Here we clearly indicate what sort of spin-orbit interaction we should argue and we solve the existing confusion. The second subject is on the spin transfer mechanism in $\mathbf{\Lambda}$ production reactions. We attempt to resolve an anomaly found in the spin observables; presumably zero analyzing power A_N and spin depolarization D_{NN} of Λ hyperon production reactions from the quark parton recombination model, whereas apparently non zero in the observation.

1. Introduction

In this presentation, we will discuss two subjects; the first is on interaction producing the spin polarization, and the second is on mechanism producing the spin asymmetry.

The spin observables in high energy hadron reactions, such as spin polarization, analyzing power and spin depolarization, are increasing interest to extract precise information of structure function of quark partons in hadrons [1] and even in leptons and photon.[2] Almost two decades ago, DeGrand and Miettinen (DM) proposed a kinematical model[3] based on the quark recombination picture to predict sign and to estimate order of magnitude of the spin observables produced in the inclusive high energy hadron collisions. In their model, they assumed one empirical rule; shortly expressed as "fast spin up and slow spin down". The rule refers to a preferential direction of spin polarization of the produced hadrons in connection with velocity of participating partons. From the momentum distribution functions of quark parton in hadrons, it is known that valence parton has large velocity while sea parton has small velocity. DeGrand and Miettinen found a systematics existing in the empirical data of spin observables that the parton(s) with large (small) velocity carries up (down) spin mostly. The rule then states that the valence parton(s) plays preferentially to produce hadrons with spin-up and sea parton(s) does hadrons with spin-down . They also showed that the spin-orbit type interaction derived from the empirical rule and Thomas precession of spin carring parton(s) is the sourse producing the observed spin asymmetries.

Meanwhile, after work of Fujita and Matsuyama,[4] the DM's conclusion became obscure. Fujita and Matsuyama (FT) pointed out that calculation using the ordinal form of spin-orbit interaction gives an incorrect P_T dependence of the spin polarization of Λ compared with the result observed in the high energy pp inclusive reactions. DeGrand's comment [5] to the FM indication was not able to make clear cut argument, since in the first place the DM model does not predict spin polarization as function of P_T, but predict its sign and estimate only its order of magnitude.

Recently, we have proporsed a general formulation[6] for description of the spin observables of hadrons inclusively produced in the high energy hadron collisions and we showed that our microscopic quark recombination (QRC) model is successful to reproduce the experimentally obtained spin observables. In the formulation, we do not premise the DM empirical rule at all, but start from a relativistic expression of transition amplitude with participating quark parton's distribution functions in hadrons. The QRC formulation can provide the spin observables as function of the transverse momentum P_T and Feynman's variable x_F. This is an advantage of the model and extremely useful for extracting precise and valuable information from the observed data.

Therefore, it is quite interesting and critical for our QRC model to clarify origin producing the observed spin asymmetries since our microscopic model can present spin observables as function of P_T and x_F. We have already but briefly indicated [6] that the DM's empirical rule naturally results from our QRC formulation and our spin dependent transition amplitude contains certain type of spin-orbit interaction. Here we will discuss it in detail.

So, for the first subject, our motivation is to clarify origin producing the spin asymmetries and solve the existing confusion. We will conclude that not ordinal or static but *dynamical* spin-orbit interaction is the essential one. Significant difference between the two types of spin-orbit interaction will be discussed.

The second subject is on an anomaly found in the measurements[7] of analyzing power A_N and spin depolarization D_{NN} in the $\vec{p}p \to \Lambda X$ reactions, where $\vec{p}$ represents the incident protons with spin perpendicularly polarized in the scattering plane. The observed A_N and spin depolarization D_{NN} exhibit apparently non-zero values in the kinematical region over $x_F = 0.5$, contrary to the prediction of the quark recombination model with SU(6) baryon wave functions. Namely, in the model, the ud diparton with spin $S = 0$ from the pro-

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jectile and the s parton from sea interact and compose Λ, while the initial spin carrier, the rest u parton in the polarized proton, does not participate in the Λ formation. Therefore the Λ has no way to know whether or not the incident proton is spin polarized, and consequently $A_{\rm N}$ and $D_{\rm NN}$ should be zero.

This inconsistence is called as puzzle. To solve this puzzle, here we propose a possible spin transfer mechanism and show that it is quite promising to provide finite values of $A_{\rm N}$ and $D_{\rm NN}$ in the hyperon production.

On the one hand, the other asymmetry observation has been recently reported[8)] in the exclusive Λ production $\vec{p}p \to \Lambda K^+ p$ at just above the threshold energy and sign of the $D_{\rm NN}$ is different from that of the inclusive Λ production case mentioned above. This gives another difficulty to understand a whole story of the spin depolarization in the Λ productions.

In section 2 a brief description of the QRC formulation will be presented, and in section 3 derivation of the dynamical spin-orbit interaction and its role in Λ productions induced by pp and $\rm K^-p$ collisions will be discussed. An interesting feature of the present dynamical spin-orbit interaction will be discussed in section 4. Afterwards in section 5, we will discuss the puzzle regarding $A_{\rm N}$ and $D_{\rm NN}$ found in Λ production. Then we will summarize the present works.

2. The QRC formulation and the spin dependent transition term

We will present here an essence of our QRC formulation and the expressions to be needed for the later use. The general formulations of cross section and spin observables have been reported in Ref. 6. Our cross section is obtained by folding the transition probability $|M|^2$ with the initial and the final momentum distribution functions $G_i (i = 1{\sim}4)$ of participating quark partons as shown in Fig. 1. The transition amplitude M is sum of the lowest-order $M^{(2)}$ and the higher-order $M^{(\rm h)}$ terms

$$-iM = -i(M^{(2)} + M^{(\rm h)}) . \tag{1}$$

For the case of $pp \to \Lambda$X collision, the lowest-order $M^{(2)}$ is

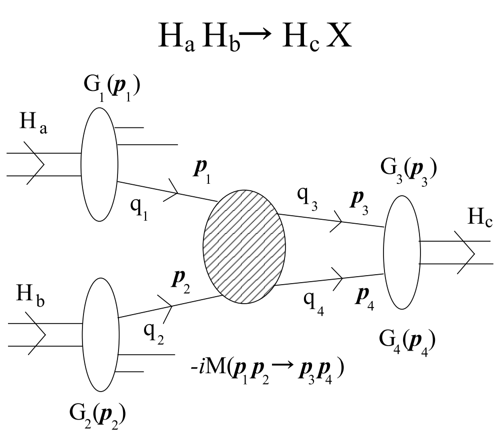

Fig. 1. The graphical description of the microscopic quark recombination (QRC) model.

expressed as

$$-iM^{(2)}(p_4\mu_4 p_3\mu_3; p_2\mu_2 p_1\mu_1) = -g^2 V(q) \bar{u}^{(\mu_4)}(p_4) u^{(\mu_2)}(p_2) , \tag{2}$$

where

$$u^{(\mu_j)}(p_j) = N \begin{pmatrix} \chi^{(\mu_j)} \\ \dfrac{\boldsymbol{s}_j \cdot \boldsymbol{p}_j}{E_j + m_j} \chi^{(\mu_j)} \end{pmatrix} \quad \text{for} \quad j = 2, 4 . \tag{3}$$

u are the Dirac four-component spinors of the spin carrier s partons in the initial sea ($j = 2$) and the final lambda particle ($j = 4$). We assume that the transition interaction $V(q)$ is scalar type constant and the higher-order term is also constant. Therefore, in the QRC model, spin dependence arises only from property of the Dirac spinor.

Inserting Eqs. (3) into (2), we calculate the transition probability and we get for the spin non-flip component[6)]

$$\begin{aligned} \left| M(\mu_4 = \mu_2 = \pm 1/2; \mu_3 = \mu_1 = 0) \right|^2 &= (E_4 + m_2)(E_2 + m_2) \\ \times \Bigg[g^4 V(q)^2 \Bigg\{ &\left(1 - \frac{\boldsymbol{p}_4 \cdot \boldsymbol{p}_2}{(E_4 + m_2)(E_2 + m_2)} \right)^2 \\ + &\left(\frac{(\boldsymbol{p}_4 \times \boldsymbol{p}_2)_z}{(E_4 + m_2)(E_2 + m_2)} \right)^2 \Bigg\} \\ \mp 2(-g^2) V(q)\, \mathrm{Im}\,[I^{(\rm h)}] &\left(\frac{(\boldsymbol{p}_4 \times \boldsymbol{p}_2)_z}{(E_4 + m_2)(E_2 + m_2)} \right) \Bigg] . \end{aligned} \tag{4}$$

We have found that only this component contains such term effective providing spin asymmetry. Namely, the last term in the rectangular parentheses in Eq. (4) changes its sign with change of spin projection $\mu_2 = \mu_4 = \pm 1/2$, where μ_2 and μ_4 are the spin projections of the spin carrier s parton in initial (s_2) and in final (s_4) stage, respectively. This term includes z-axis projection of an outer product form of $\boldsymbol{p}_2$ and $\boldsymbol{p}_4$, where, for instance for the $\rm pp \to \Lambda X$ production, $\boldsymbol{p}_2 (= \boldsymbol{P}_{\rm s}(\rm S))$ is the initial momentum of s-parton in sea (S) and $\boldsymbol{p}_4$ $(= \boldsymbol{P}_{\rm s}(\Lambda))$ the final momentum of s-parton in Λ particle. For the case of $\rm K^- p \to \Lambda X$ production, $\boldsymbol{p}_2 (= \boldsymbol{P}_{\rm s}(\rm K^-))$ is the initial momentum of s-parton in projectile $\rm K^-$ and $\boldsymbol{p}_4 (= \boldsymbol{P}_{\rm s}(\Lambda))$ the final momentum of s-parton in Λ particle.

3. What sort of spin-orbit interaction ?

3.1 pp → ΛX

First we consider the $\rm pp \to \Lambda X$ collision. From Eq. (4), the spin dependent transition probability producing Λ is proportional to the transition probability $M_\pm$-square defined for $\mu = \pm 1/2$ ($\mu = \mu_2 = \mu_4$) in the momentum and time spaces,

$$|M_\pm(t, \boldsymbol{p})|^2 = \mp \left[\boldsymbol{P}_{\rm s}(\Lambda) \times \boldsymbol{P}_{\rm s}(\rm S) \right]_z . \tag{5}$$

The spin dependent partial cross section is given by averaging the $M_\pm$-square over time space,

$$\begin{aligned} \left\langle f \left| |M_\pm|^2 \right| i \right\rangle &= \frac{1}{\Delta t} \int_0^{\Delta t} \left\langle f \left| |M_\pm(t, \boldsymbol{p})|^2 \right| i \right\rangle_{\boldsymbol{p}} dt \\ &= \mp \frac{1}{\Delta t} \left\langle f \left| [\boldsymbol{P}_{\rm s}(\Lambda) \times \boldsymbol{P}_{\rm s}(\rm S)]_z \right| i \right\rangle_{t\boldsymbol{p}} . \end{aligned} \tag{6}$$

The incident proton with constituent uud quark partons comes in along the x-axis as shown in Fig. 2. The ud dipar-

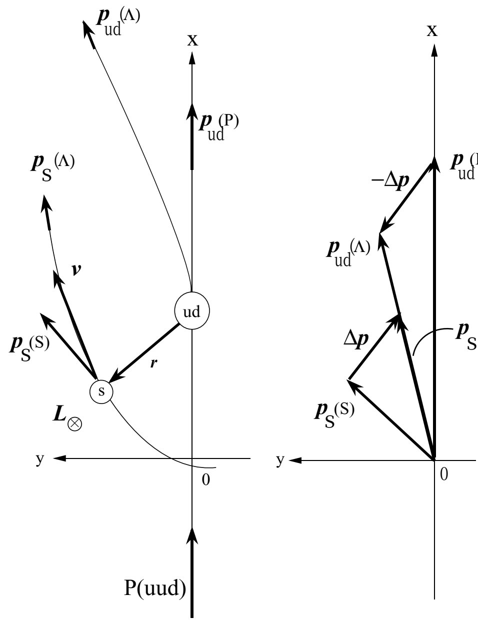

Fig. 2. The left-hand side; the pictorial presentation of recombination process of the pp → **Λ**X collision and the right-hand side; relations of the linear momenta appearing in the collision.

ton picks s parton up from sea and constructs Λ. Through the collision, the incident ud parton is decelerated whereas the s parton is accelerated through recombination. Various momenta of the participating partons in collision are summrized in the right hand side of Fig. 2 where $\boldsymbol{P}_{\mathrm{s}}(\mathrm{S})$ changes to $\boldsymbol{P}_{\mathrm{s}}(\Lambda)$ with momentum transfer $\Delta\boldsymbol{P}$.

It will be worthwhile for the later use to mention two dynamical vectors appearing in the pp → ΛX collision: in Fig. 2, (1) the direction of $\Delta\boldsymbol{P}$ is antiparallel to the radial vector $\boldsymbol{r}$ between the interacting ud and s partons and (2) the direction of orbital angular momentum $\boldsymbol{L}$ of the s parton around the ud parton faces to back side of the xy-plane. The first relation indicates that a force $\boldsymbol{F}$ acting on the s parton from the ud parton is an attractive one,

$$\boldsymbol{F} = \frac{d\boldsymbol{p}}{dt} = \frac{d\boldsymbol{p}}{dp}\,\frac{dp}{dt} = -\boldsymbol{r}\left(\frac{1}{r}\,\frac{dp}{dt}\right) < 0\,, \tag{7}$$

then

$$\left(\frac{1}{r}\,\frac{dp}{dt}\right) > 0\,. \tag{8}$$

Using the relation $\boldsymbol{P}_{\mathrm{s}}(\mathrm{S}) = \boldsymbol{P}_{\mathrm{s}}(\Lambda) - \Delta\boldsymbol{P}$, Eq. (6) becomes,

$$\begin{aligned}\left\langle f\left||M_\pm|^2\right|i\right\rangle &= \pm\hbar\left\langle f\left|\left(\frac{1}{r}\,\frac{dp}{dt}\right)(\boldsymbol{L})_z\right|i\right\rangle \\ &= 2\hbar\left\langle f\left|\left(\frac{1}{r}\,\frac{dp}{dt}\right)(\boldsymbol{L}\cdot\boldsymbol{S})_z\right|i\right\rangle .\end{aligned} \tag{9}$$

Namely we find that the spin dependent transition probability is expressed as transition matrix of a spin-orbit type interaction potential. The acting force may be strongly nonlocal, therefore we leave $\left(\frac{1}{r}\,\frac{dp}{dt}\right)$ without changing into the conventional form $\left(\frac{1}{r}\,\frac{dV}{dr}\right)$, where V is normally a local potential. Once we accept certain V as a static central potential, we usually use it for all the way through collision. In this sense we may refer such potential as a static spin-orbit interaction potential and distinguish it from the present spin-orbit potential which is non static due to its dynamical origin.

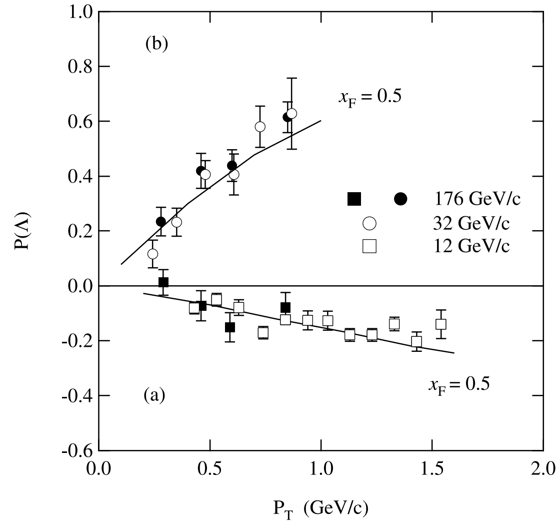

Fig. 3. The **Λ** spin polarization induced by the inclusive (a) pp and (b) K⁻p collisions at the three different incident momenta. The data are from Refs. 9 and 10, respectively. The solid curves are the results of QRC calculation.

The spin polarization of Λ is obtained as

$$P_{\mathrm{pp}\to\Lambda\mathrm{X}}(p_{\mathrm{T}}, x_{\mathrm{F}}) \propto \left\langle f\left||M_+|^2\right|i\right\rangle - \left\langle f\left||M_-|^2\right|i\right\rangle \tag{10}$$

In Fig. 3(a), the microscopic QRC calculation[6)] is compared with the experimental data.[9)] From this result and Eq.(10), we are aware of predominance of the transition $\left\langle f\left||M_-|^2\right|i\right\rangle$ (with spin down) if the matrices have positive sign and this case equals to that predicted by the DM empirical rule.

3.2 K⁻p → **Λ**X

For the case of K⁻p → ΛX collision, we can proceed the

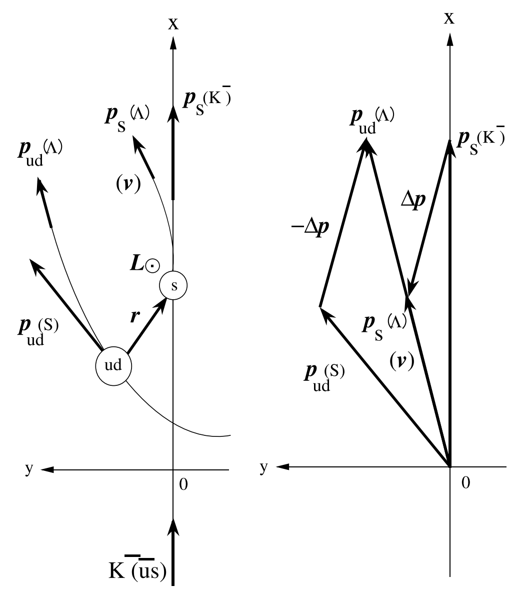

Fig. 4. The left-hand side; the pictorial presentation of recombination process of the pp → **Λ**X collision and the right-hand side; relations of the linear momenta appearing in the collision.

same calculation as we made above and get the same expressions as Eqs.(9) and (10), but difference is now direction of the orbital angular momentum $\boldsymbol{L}$; as we can see from Fig. 4, it faces to the front side from the xy-plane. This change from the pp $\rightarrow$ ΛX case is consequence of the fact that the spin carrier s parton appears now as a valence parton in the incident K^- and the ud parton is picked up from sea. The s parton is then decelerated, therefore the $\boldsymbol{L}$ becomes parallel to the z-axis. From Fig. 3(b), we can see predominance of the transition $\left\langle f \left| |M_+|^2 \right| i \right\rangle$ with spin up provided positive sign for the transition matrices and this case is also consistent with prediction by the DM rule.

As we have seen above, the present spin-orbit interaction arises from the dynamical origin and its sign directly depends on the participating momentum variables. We have also seen where it appears and how it plays an essential role to predict the spin polarization induced by the high energy hadron collisions.

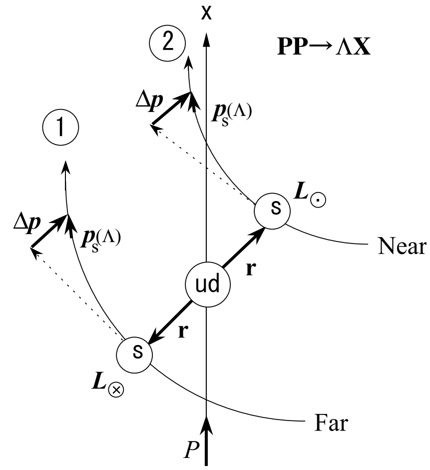

Fig. 5. The momentum transfer Δp and the orbital angular momentum L in the near-side and far-side collisions for the pp→ ΛX collisions.

4. A significant feature of the dynamical LS-interaction

The present spin-orbit interaction obtained above shows a distinct feature from the conventional (static) spin-orbit potential. We show this for the pp $\rightarrow$ ΛX production case as an example. In the formation of Λ particles, every sea s parton is accelerated by the ud valence parton in protons, of which momentum is extremely large compared with that of the s parton.

Therefore, as we can see in Fig. 5, the two momentum transfers $\Delta\boldsymbol{P}$ in the different trajectories face to the same direction. Hence the forces acting on the spin carrier s partons from the ud parton in near-side/far-side collision is respectively expressed by

$$\left\{ \begin{array}{c} \boldsymbol{F}_{\rm Near} \\ \\ \boldsymbol{F}_{\rm Far} \end{array} \right\} = \left\{ \begin{array}{c} +\dfrac{\boldsymbol{r}}{r}\dfrac{dp}{dt} \geq 0 \\ \\ -\dfrac{\boldsymbol{r}}{r}\dfrac{dp}{dt} \leq 0 \end{array} \right\}. \tag{11}$$

The corresponding Thomas precession angular velocity is calculated as

$$\begin{aligned} \left\{ \begin{array}{c} \boldsymbol{\omega}_{\rm T}^{\rm Near} \\ \\ \boldsymbol{\omega}_{\rm T}^{\rm Far} \end{array} \right\} &= \frac{1}{2mc^2} \left\{ \begin{array}{c} \boldsymbol{F}_{\rm Near} \times \boldsymbol{v} \\ \\ \boldsymbol{F}_{\rm Far} \times \boldsymbol{v} \end{array} \right\} \\ &= \left\{ \begin{array}{c} +\dfrac{\hbar}{2m^2c^2}\left(\dfrac{1}{r}\dfrac{dp}{dt}\right)\boldsymbol{L} \\ \\ -\dfrac{\hbar}{2m^2c^2}\left(\dfrac{1}{r}\dfrac{dp}{dt}\right)\boldsymbol{L} \end{array} \right\}. \end{aligned} \tag{12}$$

Then a spin-orbit type interaction potential is obtained

$$\begin{aligned} \left\{ \begin{array}{c} U_{LS}^{\rm Near} \\ \\ U_{LS}^{\rm Far} \end{array} \right\} &= \left\{ \begin{array}{c} \hbar\,(\boldsymbol{\omega}_{\rm T}^{\rm Near} \cdot \boldsymbol{S}) \\ \\ \hbar\,(\boldsymbol{\omega}_{\rm T}^{\rm Far} \cdot \boldsymbol{S}) \end{array} \right\} \\ &= \left\{ \begin{array}{c} +\dfrac{1}{2}\left(\dfrac{\hbar}{mc}\right)^2\left(-\dfrac{1}{r}\dfrac{dp}{dt}\right)(\boldsymbol{L}\cdot\boldsymbol{S}) \\ \\ -\dfrac{1}{2}\left(\dfrac{\hbar}{mc}\right)^2\left(-\dfrac{1}{r}\dfrac{dp}{dt}\right)(\boldsymbol{L}\cdot\boldsymbol{S}) \end{array} \right\}. \end{aligned} \tag{13}$$

Note that the orbital angular momentum $\boldsymbol{L}$ has opposite direction between near-side and far-side collisions. Therefore the spin-orbit potential, thus obtained from the dynamical origin, becomes to have the same sign in both near-side and far-side collisions. This feature is quite different from the conventional spin-orbit interaction arising from the static origin, which used to appear in the nuclear shell model and the low energy nuclear reactions.

It is notable that the spin-orbit interaction we concern here is not like one between a scattering particle and its center usually appearing in the nuclear scattering, but the interaction between s and ud partons in the rearrangement to compose Λ particle. If the two spin-orbit interactions corresponding to the two different trajectories, depicted in Fig. 5, had different sign, such case usually happens in the conventional spin-orbit interaction, only small or no spin polarization could occur due to a large cancellation between the two polarizations produced in the near-side and far-side collisions. In this reason, consideration of the present nonlocal spin-orbit interaction induced by the dynamics is essential to describe and understand the sizable spin asymmetry distributions in the high energy hadron productions.

In this way, we can recognize that the spin asymmetry of hadrons produced is raised by the spin-orbit interaction induced through quark partons rearrangement process, not by static LS interaction. This point is essential to distinguish the result of Fujita-Matsuyama's work[4)] from the present work; they considered only the static LS interaction appearing in the final Λ particle and derived $P_{\rm T}$-dependence of the spin polarization from the energy eigenvalues in the final Λ particle. Instead, we have to consider the spin-orbit interaction induced by the momentum dependent rearrangement process. In fact in the QRC model,[6)] by the microscopic calculation of the transition process, the quark parton rearrangement can be fully taken into account in the spin polarization and we can predict its correct $P_{\rm T}$ dependence.

5. $A_{\rm N}$ and $D_{\rm NN}$ in the inclusive Λ production

As for the unexpected finite values of $A_{\rm N}$ and $D_{\rm NN}$ in the

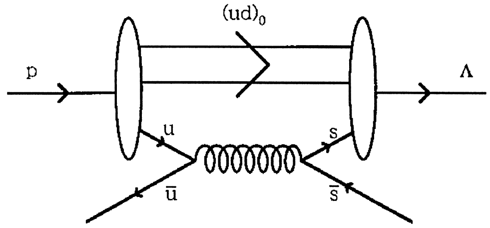

Fig. 6. The diagram for the production of $\mathbf{\Lambda}$ from pp collision through $u\bar{u}$ annihilation and $s\bar{s}$ creation.

$\vec{p}p \to \Lambda X$ reaction measurement,[7] mentioned in the Introduction, the question is how to transfer the initial spin direction of proton to the Λ produced. For this we propose an extension of the QRC model by introducing new mechanism as shown in Fig. 6 called as annihilation and creation mechanism.[6] The initial valence u quark, which carries the proton's spin information, annihilates with $\bar{u}$ in the target proton, then $s\bar{s}$ pair is created through gluon propergation and s quark in the pair recombines with ud scalar diquark to form Λ. Suppose the case that the u quark with spin up annihilates with $\bar{u}$ quark with spin up. Then the intermediate gluon carries up spin, and hence the created s and $\bar{s}$ quarks carry up spin therefore the s transfers up spin into the produced Λ. On the other hand, the second case is that, if the u quark with spin up annihilates with $\bar{u}$ quark with spin down, the intermediate gluon carries zero spin, then the created s quarks do not have any prefered spin directions and the initial spin direction can not be transferred into Λ. Hence through the first case mentioned above, we can transfer spin information of the projectile into the Λ particle produced.

We can estimate s quark in the created pair has up spin with probability 75% and down spin 25%. However, this annihillation and creation process is not the entire story. The standard QRC process also participates in Λ production. Then, since we do not know the amount of the two contributions in the kinematical region of interest, we write the probability creating s quark with spin parallel to the incident proton's spin as $(1+\gamma)/2$ and that for s quark with spin anti-parallel as $(1-\gamma)/2$. Using the DM empirical rule and parameter ε they used,[3] the $\vec{p} \to \Lambda$ production cross-sections may be expressed as

$$\sigma_{\uparrow\uparrow(\uparrow\downarrow)} = (1 \pm \gamma)/2 \cdot (1 \mp \varepsilon)\,,\ \sigma_{\downarrow\uparrow(\downarrow\downarrow)} = (1 \mp \gamma)/2 \cdot (1 \mp \varepsilon)\,, \qquad (14)$$

where, *e.g.*, $\uparrow\downarrow$ denotes proton (u) spin up and Λ (s) spin down. From these cross sections, the following relations are obtained

$$P = -\varepsilon\,, \quad D_{\rm NN} = \gamma\,, \quad A_{\rm N} = -\gamma\varepsilon = D_{\rm NN}P\,. \qquad (15)$$

We can calculate $P(x_{\rm F}, P_{\rm T})$ from the QRC model,[6] but at present we are not able to predict the spin depolarizing parameter γ, which requires information of the dynamics of quark-antiquark annihilation and creation through gluon propergation. Therefore at this moment, we only test consistency of the last relation in Eq. (15). Inserting the calculated polarization into $P(x_{\rm F}, P_{\rm T})$ and the observed values into $D_{\rm NN}(x_{\rm F}, P_{\rm T})$, we obtain $A_{\rm N}$ from Eq. (15) and compare it with the measurements.[7] In Fig. 7, the results are given by the solid curves. The kinematical parameters $P_{\rm T} = 1$ GeV/c in (a) and $x_{\rm F} = 0.2-1.0$ in (b) are used in the $P(x_{\rm F}, P_{\rm T})$ calculation. Therefore the obtained results should be compared with the solid circles in both Figs. 7(a) and (b); the sign and slope thus obtained are well consistent with the measurements. This fact indicates that the present u annihilation and s creation mechanism is quite promising to solve the puzzle.

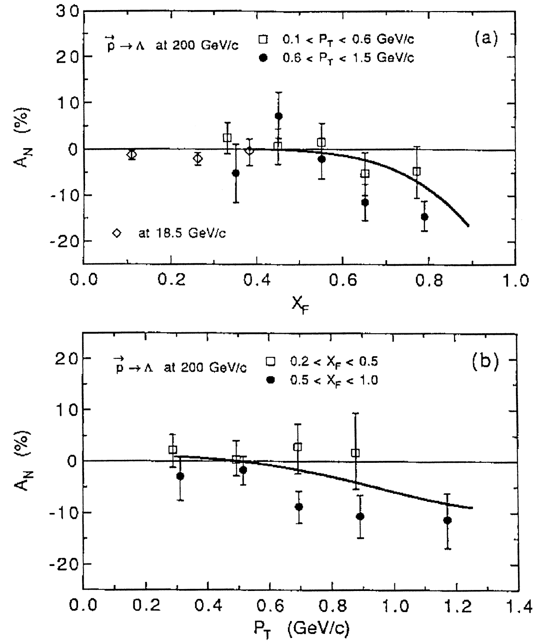

Fig. 7. The $A_{\rm N}$ of the $\vec{p}p \to \mathbf{\Lambda}$X reaction. The solid curves were obtained using the calculated P and the obserbed $D_{\rm NN}$, according to the relation $A_{\rm N} = D_{\rm NN}P$ for the kinematical parameters $P_{\rm T} = 1$ GeV/c in (a) and $x_{\rm F} = 0.2$–1.0 in (b). The experimental data are taken from Ref. 7.

6. $D_{\rm NN}$ in the $\vec{p}p \to \mathbf{\Lambda}K^+p$ production

Recently $D_{\rm NN}$ in the exclusive Λ production measurement $\vec{p}p \to \Lambda K^+p$ was reported at 3.76 GeV/c (Ref. 8). It is quite interesting to note its sign in $P_{\rm T}$ and $x_{\rm F}$ distributions, which is negative for all the way. This result is in contrast to that observed in the inclusive Λ production at higher momentam region.[7] The QRC model with the new mechanism introduced above predicts positive sign for the $D_{\rm NN}$ in the exclusive Λ production.

The π meson exchange model[11] predicts sign consistent with the observation. To solve this problem in the quark recombination framework, it may be essential to consider that the present exclusive Λ production process is a parity nonconserving process at the low momentum collision.

7. Summary

We have studied dynamics behind success of the microscopic quark recombination model(QRC) and pointed out appearance and its characteristic feature of the dynamical spin-orbit interaction. The present work is summarized in the following three folds:

(1) We have clarified dynamics behind the general success of

the microscopic QRC model formulated for calculation of the spin observables in the high energy hadron productions; it is the spin-orbit interaction arising from the dynamical origin.
(2) The spin-orbit interaction discussed here has the same sign for the both near-side and far-side collisions, which is contrast to the ordinary static spin-orbit interaction potential popular in the nuclear physics study. This feature is essential for producing the spin asymmetry of the produced hadrons, otherwise small or no spin polarization may occur due to a large cancellation between the near-side and far-side collisions.
(3) An obscure argument, existed in the discussion of origin of the high energy hadron spin polarization after Fujita-Matsuyama's indication, has been now clearly resolved by showing that it is the spin-orbit interaction arising from the quark partons rearrangement process and gives a correct P_T dependence of the Λ spin polarization.

For the second subject on an puzzle of the unexpected analyzing power and spin depolarization in the $\vec{p}p \to \Lambda X$ reaction, we have indicated a possible spin transfer process, the u annihilation and s creation mechanism. A simple relationship among the three spin observables $(P, A_\mathrm{N}, D_\mathrm{NN})$ has been found and we have confirmed the relation is well held and thus the mechanism is quite promising to solve the puzzle. Study of the spin depolarizing parameter γ, and therefore the sea quark polarizing dynamics through the u annihilation and s creation is presently underway. It is a useful finding that the spin depolarization provides direct information for the q-q interaction study.

The new data of the exclusive Λ production at the low momentum show different sign in comparision with that of the inclusive collision at higher momentum. We are now working for this problem in the framework of the quark recombination model.

This work has been proceeded under collaboration and discussion with Yuichi Yamamoto, H. Toki and Y. Kitsukawa.

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