The Unified Model for High Energy Spin Observables

-Further Extension to $\gamma + p, \nu_\mu + A \to \Lambda + X$ Reactions-

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Abstract

The spin polarizations of hadrons produced by pp, γp and νA collisions are studied by the quark rearrangement model. The present model is a phenomenological one based on the relativistic quantum equation of motion and using the quark distribution functions in hadron and photon. A general success of the model is demonstrated. We find usefulness of the present formulation for studying the dynamics producing spin asymmetry distributions and the statics determining sign and magnitude of spin polarization by reflecting the characteristic quark structure in hadrons.

1. Introduction

This study is one of our long range works and in several times of the Varenna Conference, we have reported the results we achieved up to each time. The first report was made in the VIII-th (1997) conference, and the second in the IX-th (2000), then this time in the X-th (2003).

Almost two decades ago, T. M. DeGrand and H. I. Miettinen proposed the kinematical model [1] to predict sign and relative magnitude of spin observables produced by the inclusive high energy hadron collisions. Their model, the so-called parton recombination model, has been recognized as a useful one to study and interpret the origin of sign and size of the spin polarization induced by proton projectiles on hadrons. In their model, an essential source producing spin asymmetry is acceleration or deceleration mechanism of the parton(s) which carries spin through recombination process. They found a useful rule by looking at result of the observed sign systematics of the spin polarizations of hadrons produced. Namely, if spin is carried by sea parton, of which velocity is lower than that of valence parton, the parton (being accelerated) preferentially carries down-spin into the produced hadrons. On the other hand, if the valence parton carries spin, of which velocity is higher than that of sea parton, the parton (being decelerated due to the momentum conservation)

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preferentially carries up-spin into the produced hadrons. This empirical rule is shortly referred to as *'Slow spin down while Fast spin up* (the SSD/FSU rule)'.

Independently, we proposed a formulation to calculate spin dependent cross sections of inclusive hadron productions [2]. It is very

simple; based on the Dirac equation, the essential form of amplitude is calculated within the Born approximation with Dirac spinor for spin 1/2 parton and the polarization vector for spin 1 diquark parton. We use a constant scalar type parton confinement interaction. We do not assume the DeGrand and Miettinen's empirical rule in the formulation, but we have shown that our model can naturally derive *a priori* their empirical rule [2]. We have shown that the essential source producing spin asymmetry is a dynamically induced spin-orbit interaction, which is found to be automatically included in the formulation. Possible existence of such a spin-orbit interaction was pointed out by DeGrand and Miettinen in their interpretation of the rule.

How is taken into account the acceleration-deceleration dynamics in our formulation? The formulation includes the two sources: one in the form factor part and the other in the kinematical part. For instance for the lambda production from the p-injection, the form factor part in the spin-dependent cross section contains the four different momentum distribution functions; two of them are of s parton in sea and in lambda, which is accelerated through collision, while the other two are of ud-diquark in projectile and lambda, which is decelerated due to picking up the s-parton. This acceleration-deceleration mechanism prescribes the kinematical part of amplitude, which can be rewritten into the spin-orbit potential form. Our description of the spin dependent amplitude through the quarks rearrangement is referred to as the *quark rearrangement model* (QRM). An advantage of our microscopic description is that it provides the spin observables in terms of transverse momentum P_T and Feynman's variable x_F.

In this paper, first a brief survey of our past reports; what understood and what left will be presented. This is useful for understanding of the present somewhat extended works. Second a discussion of the spin depolarization D_{NN} of the exclusive lambda particle production $\vec{p} + p \rightarrow \Lambda + K^+ + p$. Finally the exotic lambda production processes induced by $\gamma + p$ and $\nu_\mu + A$ collisions will be discussed.

2. The quark(s) rearrangement collisions; the simple FFU/SSD cases

In the VIII-th (1997) Conference, Our basic idea to describe the spin observables of the hadrons inclusively produced in the high energy hadron collisions was presented. That is expressed in short as "Quark-rearrangement (QR) process with acceleration-deceleration mechanism". Its essence and historical back ground was explained in Introduction. As a typical example, the spin polarizations of lambda particle productions from pp and K^-p collisions are shown in Fig.1. The sign is minus in pp case, whereas plus in K^-p case and they follow the SSD/FSU rule; the spin carrier s parton appears as sea (valence) parton in the pp (K^-p) collision, respectively. Our calculation (the solid curves) well reproduces the observed results. We have found that the model and formulation is fairly successful in general in reproducing the most of the observed data.

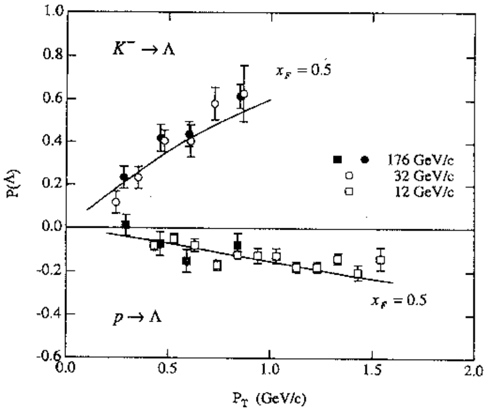


Figure 1: The P_T distributions of the spin polarization of Λ induced by the pp and K^-p collisions. The experimental data are from refs. [3,4] and the solid curves are the present QR calculations.

3. The first difficulty; how to polarize spin in the non-valence parton processes

Then we met the first difficulty. Our acceleration-deceleration model requires at least one valence-parton and one sea-parton. For instance, in the $\bar{\Xi}^- = \bar{\Xi}^+(\bar{d}\bar{s}\bar{s})$ production from pp collision, we have no valence parton, therefore, the model cannot say anything about spin polarization or simply null polarization. However, the observation shows apparently finite spin polarization with minus sign; the magnitude is as big as that of the normal Ξ^- production, that is produced by d-valence quark and sea ss-diquark in the pp collision.

To overcome the difficulty, we have proposed a new hadron production mechanism [5]. We assume that, prior to the final hadron production, quark(s) and anti-quark(s) are created and they are moving with velocity as large as that of the incident hadrons. They participate as leading partons by recombining with sea quark(s) in constructing final hadrons. We do not directly calculate the primary step, but assume that it is an essentially spin-independent process factorized in the amplitude and cancels out between numerator and denominator in the expression of spin observables.

Accepting this so-called "*primary quark(s) production mechanism*", we can apply our parton rearrangement formulation and calculate the above anti-hyperon polarization. The observed $\bar{\Xi}^-$ spin polarization can be reasonably well reproduced by the calculation as shown in Fig. 2. For the other similar cases, such as $\bar{\Lambda}$ and $\bar{\Sigma}^-$ spin-polarizations, can be also well interpreted by the same mechanism as shown in Fig. 2. This mechanism will be frequently used in the following discussions in the present works.

4. The second difficulty; how to transfer the initial spin to the final stage

In the IX-th (2000) Conference, the second difficulty was reported, that was about analyzing

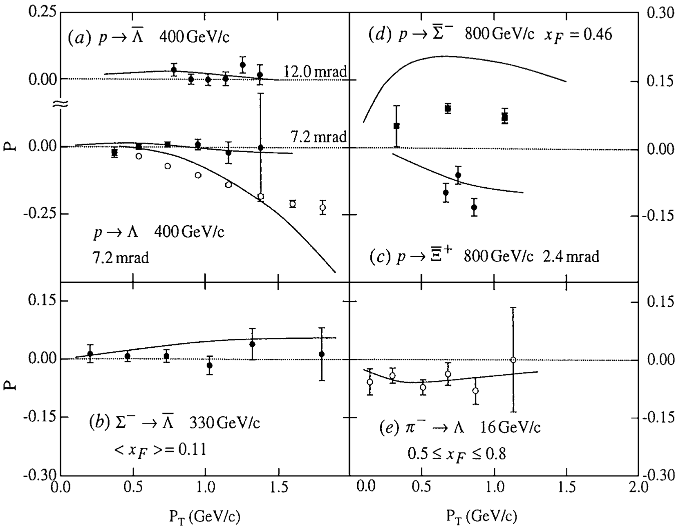


Figure 2: The hyperon spin polarizations as function of P_T in the kinematical regions indicated. The observed data are taken from the works quoted in [5] and shown by the open symbols for the hyperons and by the solid symbols for the anti-hyperons. The solid curves for the anti-hyperons show the results obtained by the QR process with the present primary *ud*-quark mechanism, and for the Λ polarizations in (a) and (e) are obtained by the standard QRC process.

power A_N and spin depolarization D_{NN} of Λ production processes in pp collision. In the quark rearrangement model, Λ is produced by the valence *ud*-parton from projectile nucleon and the *s*-parton from sea. We know that the SU(6) wave function, which has been widely and successfully accepted in the description of hadrons, contains the only *ud*-diquark component with spin 0 [6]. This means that the produced Λ is not able to know whether the projectile is spin polarized or not, because the spin carrier *u*-quark in the projectile does not participate in Λ formation. Consequently, our quark rearrangement model predicts null analyzing power and null spin depolarization, which are induced by the spin-polarized projectiles.

Contrary to this anticipation, the observed A_N and D_{NN} in $\vec{p}p \to \Lambda + X$ are non-zero but show apparently finite values (see Figs. 3 and 4). This was our second difficulty, and the observed results are very interesting and challenging. Solving this difficulty, we proposed a new mechanism, so-called "*one-gluon propagation*" mechanism [5]. The initial valence u quark, which carries the proton's spin information, annihilates with u quark produced by the primary parton production mechanism and decays into one gluon with spin z-components 0 and 1. The gluon decays into $s\bar{s}$, and the *s*-parton participates in Λ formation. Through this process, only the +1 component can transfer the initial spin information to the lambda particle.

In the actual calculation, we consider all the spin z-components of gluon and we obtain a relation among spin polarization P, spin depolarization D_{NN} and analyzing power A_N; $A_N = D_{NN} \times P$. We calculate Λ spin polarization $P(x_F, P_T)$. Using the observed spin depolarization $D_{NN}(x_F, P_T)$

(Fig. 3, the dotted line), we semi-empirically predict the analyzing power $A_N(x_F, P_T)$, which is shown in Fig. 4. The obtained result reasonably reproduces the measurement, suggesting a promising interpretation of the present spin transfer mechanism with one gluon propagation.

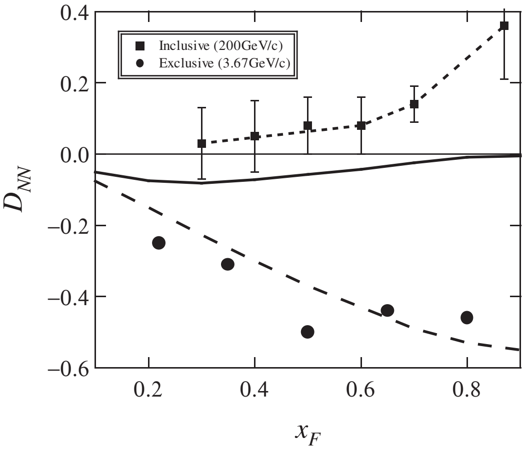


Figure 3: The D_{NN} of the inclusive $\vec{p}p \to \Lambda + X$, and exclusive $\vec{p}p \to \Lambda K^+ p$ productions as function of x_F. The dotted line is the average values obtained by smoothly connecting the data points for the sake of obtaining A_N of Fig. 4. The dashed line is obtained for the exclusive case by considering only $s_z = -1$ component of the triplet S state of $s\bar{s}$ pair in Fig. 5. The solid line is obtained for the exclusive case by mixing the both of $s_z = -1$ and $s_z = 0$ components.

5. The third difficulty; D_{NN} of the exclusive $\vec{p}p \to \Lambda K^+ p$ production

Just before the 2000 Varenna Conference, the measurement of spin depolarization D_{NN} in the exclusive $\vec{p}p \to \Lambda K^+ p$ production at 3.67 GeV/c has been reported [7] (see Fig.3). The D_{NN} shows now negative sign, different from the previous inclusive Λ production case. This measurement brought us a new difficulty. The reason was that; our previous spin transfer (one gluon propagation) diagram proposed in [5] can be naturally extended to the exclusive case by merging $\bar{s}$ (counter parton of the s parton participating in Λ production) and u parton (from the spin polarized projectile p) into K^+. This, however, provides Λ with spin-up, therefore the D_{NN} should have positive sign contrary to negative sign in the measurement. That was the difficulty and our situation at that time.

Now we become aware of that this collision is rather simple one to be described by a lower-order diagram compared to the previous one-gluon propagation diagram. This is due to the fact that the produced K^+ plays a role to select spin direction through K^+ formation since it has spin 0, as shown in Fig. 5. For the exclusive case, we consider creation of the s and $\bar{s}$ sea partons in the triplet S state ($^3S_1$) with 0, ±1 spin z-components. Since the projectile proton's spin is polarized, the u-parton's spin is polarized. Therefore the $\bar{s}$ quark with -1 component can participate to compose K^+. The counter s parton with down-spin is picked up to compose Λ with down-spin, providing D_{NN} with favorable minus sign. Note that this production process satisfies the predominance

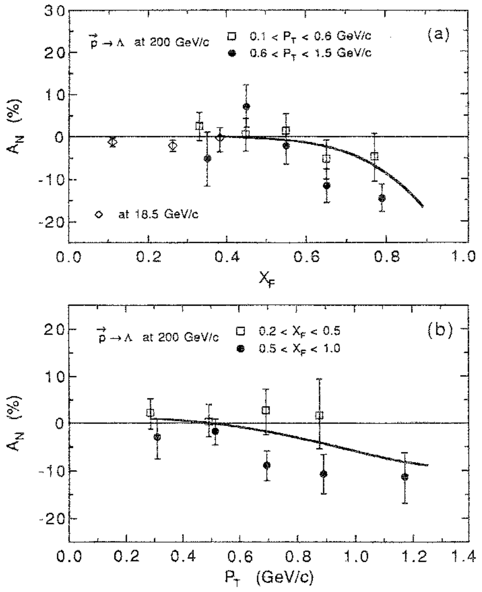


Figure 4: A_N of inclueive Λ production in $pp \to \Lambda + X$

rule of FSU/SSD. The calculation of D_{NN}, within the framework of quark rearrangement model with only this component, provides the dashed curve in Fig. 3, of which sign and magnitude are consistent with the observation.

But this should not be the goal because we have to have one more spin-component $s_z = 0$ with the down-spin $\bar{s}$ and up-spin s partons, which is also allowed to produce K^+. We found that mixing of this term reduces D_{NN} significant amount of magnitude and comes down to very small value, as shown in Fig. 3 with the solid curve.

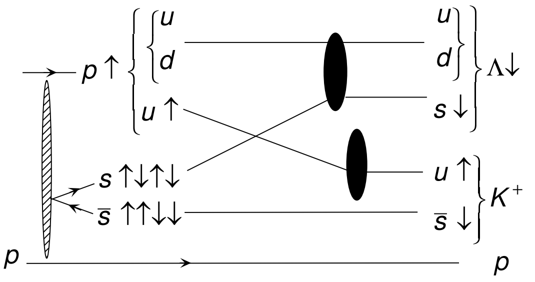


Figure 5: A possible lowest order for the exclusive $\vec{p}p \to \Lambda K^+ p$ production with the triplet S state ($^3S_1$) $s\bar{s}$ contribution.

At this moment, we do not know reason of the discrepancy between the observation and our calculation. We like to continue this study and will hopefully bring certain answer to this problem in the next Varenna conference.

6. The spin polarization of hyperon in photo-production ; $\gamma + p \to \Lambda + X$

It is extremely interesting that the spin polarization of Λ has been measured in the photon-proton collision. The experimental data are shown in Fig. 6. We have less chance to consider such an exotic hadron production mechanisms and less information on the distribution of quarks in the photon field. Therefore it is challenging to study the hyperon spin asymmetry in the photo-production.

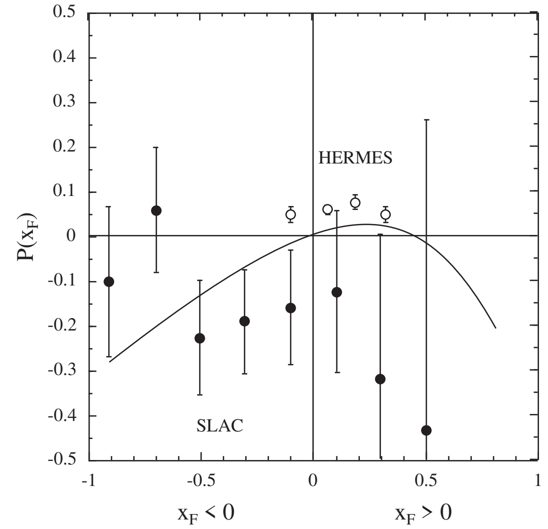
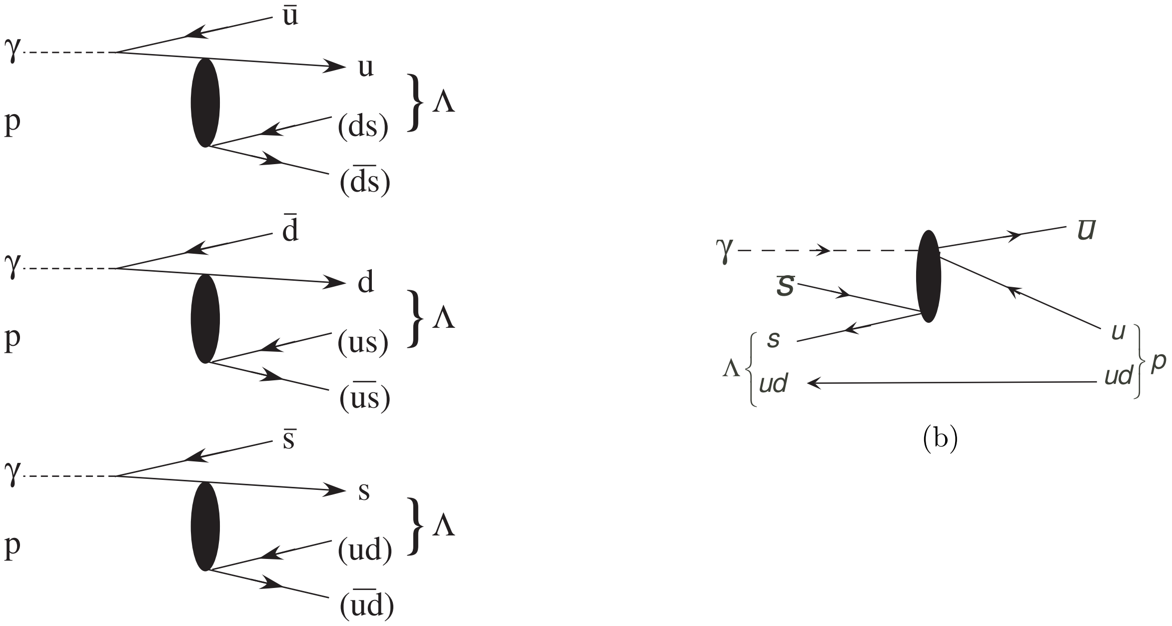


Figure 6: The inclusive Λ photo-production. The experimental data are from SLAC [8] and HERMES [9].

Our attempt is to consider the production process based on the quark rearrangement mechanism and extend the primary quark production mechanism to the $\gamma + p$ collision process. In the beam fragmentation region $x_F > 0$, we can consider valence $u\bar{u}$, $d\bar{d}$ or $s\bar{s}$ pairs from the photon, since the real photon contains such hadronic components substantially. Then u, d, or s parton picks up diquark ds, us, or ud respectively and composes Λ particle. The corresponding diagram is shown in Fig. 7(a). We sum all the three processes. We use the quark distribution functions of the photon from [10] to calculate the spin polarizations.

In the target fragmentation region ($x_F < 0$), ud valence diquark from the target picks up s parton which is produced by annihilation of u parton in the target through interaction with the incident photon as depicted in Fig. 7b. So the spin polarization could become similar to nothing but the $pp \to \Lambda X$ collision.

The results are shown in Fig. 6, which are essentially consistent with the observed data in SLAC. In the small x_F region, our calculation changes sign and seems to be consistent to the HERMES data. However we should not take so seriously the present calculations since the results are rather sensitive to the ingredients accepted in the calculation and we sum up three diagrams.



(a)

(b)

Figure 7: The diagrams of the inclusive lambda photoproduction mechanisms considered in the beam (a) and target (b) fragmentation regions..

7. The Hyperon Spin Polarization in Neutrino Collision; $\nu_\mu A \to \mu^- \Lambda X$

The final exotic production is $\nu_\mu A \to \mu^- \Lambda X$; the lambda production from the μ^--neutrino and nucleus collision. The observed data are reported in [11] and shown in Fig. 8. In the beam fragmentation region, a possible diagram is d-annihilation and u-creation through W^+ boson exchange and ds-diuqark from sea is picked up to compose Λ. The corresponding diagram is shown in Fig. 9a. Therefore the essential mechanism of this collision is just the same one for $\pi p \to \Lambda + X$ production process.

In the target fragmentation region, we consider the same W^+ boson exchange process, where also many pair creations occur. The ud valence diquark from the target nucleon picks up s parton from one pair $s\bar{s}$ created through W^+ boson exchange as show in Fig. 9b. Therefore the diagram becomes similar to the $pp \to \Lambda X$ collision.

We show the results in each fragmentation region in Fig. 8. The calculated sign and magnitude are consistent to the experimental result. The NOMADO collaboration paper indicated the two comments. First, they noted, in the measurement, much small spin polarization in the beam fragmentation region in comparison to the target fragmentation region. The present calculations are consistent to the measurement. Second, the P_T distribution of the spin polarization of lambda show very similar structure to that of the process as they are compared in Fig. 9. These two points are easily understood by our present extended quark rearrangement interpretation, although we must be careful that in the small x_F region the two mechanisms are mixed up which we did not calculate here.

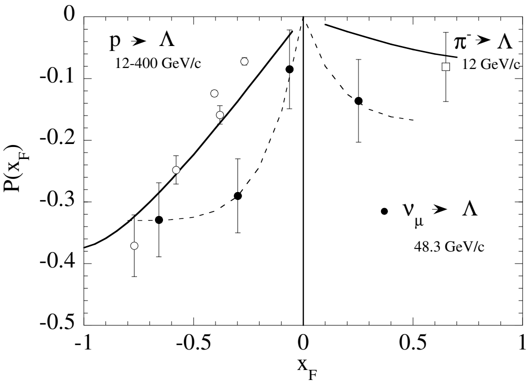
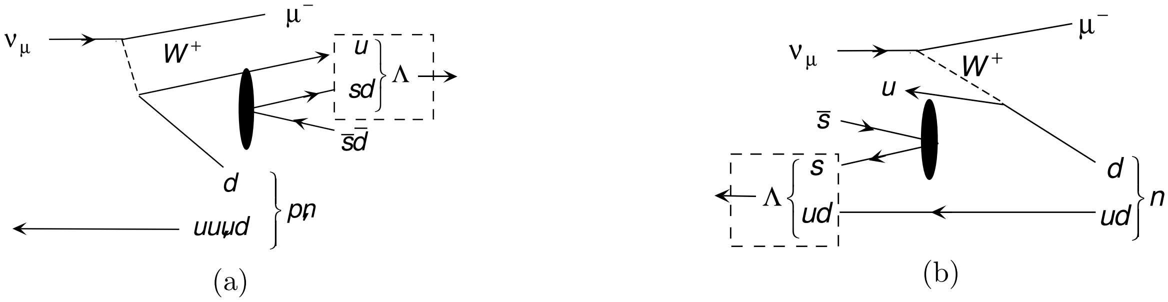


Figure 8: The inclusive lambda productions by the neutrino-nucleus collisions (solid circles) from the NOMAD collaboration at CERN. The dotted curves are tendancy of the x_F distributions quated in [11]. The experimental data of the inclusive lambda production from pp (open circles) and πp (open squar) collisions are shown with the QR model calculations (solid curves).



(a) (b)

Figure 9: The diagrams corresponding to the semi-inclusive lambda productions in the $\nu_\mu p \to \mu^- \Lambda X$.

8. Conclusion

We have reported here a general success of the microscopic quark rearrangement collision model in the standard spin polarizations where both valence and sea quark partons contribute in the high energy hadron collisions. The model is useful to understand the mechanisms and dynamics producing spin asymmetry distribution in the inclusive hadron production collisions.

Beyond the standard collision process, we have extended the model to the exotic spin asymmetry processes such as the collision with no valence parton in the initial collision. We have proposed a new mechanism so-called "*the primary quark(s) production mechanism*", which can fairly well reproduce the spin polarization observed in the exotic collisions.

Another exotic collision is such case that is no way to transfer the initial spin direction to the final stage within our simple QR process. For overcome this difficulty, we have proposed "*the one-gluon propagation*" mechanism and we found a promising result of the mechanism.

The spin depolarization observed in the exclusive $\vec{p}p \to \Lambda K^+ p$ production is still in question.

The hyperon productions induced by the photon-proton collision and by the neutrino-nucleus collision are challenging observations and they have been well understood in the extended quark rearrangement model.

Our present model is a phenomenological one based on the relativistic quantum equation of motion with the scalar constant interaction. It has been, however, found that it is quite useful to study mechanisms of the hadron production processes, dynamics of creating spin asymmetry and the quark distributions in hadron and photon.

References;

[1] T. M. DeGrand and H. I. Miettinen, Phys. Rev. D24, 2419(1981); 31, 661E(1985).
[2] Yuichi Yamamoto, K.-I. Kubo and H. Toki, Prog. Theor. Phys. 98, 95(1997).
[3] S. A. Gourly et al., Phys. Rev. Lett. 56, 2244(1986).
[4] K. Heller et al., Phys. Lett. B68, 480(1977), L. G. Pondrom et al., Phys. Rep. 122, 57(1985), B. Lundberg et al., Phys. Rev. D40(1989), S. Erhan et al., Phys. Lett. B82, 4557(1979)301, F. Abe et al., Phys. Rev. Lett. 50, 1102(1983), A. M. Smith et al., Phys.Lett. B185, 209(1987).
[5] K.-I. Kubo, Y. Yamamoto and H. Toki, Prog. Theor. Phys. 101, 615(1999).
[6] See for the SU(6) wave function, e.g., D. B. Lichtenberg, Unitary Symmetry and Elementary Particles, Academic Press (1978).
[7] F. Balestra et al., Phys. Rev. Lett. 83, 1534(1999).
[8] K. Abe et al., Phys. Rev. D29, 1877(1984) (SLAC data).
[9] S. L. Belostoski, in Proc. Intern. Workshop on Deep Inelastic Scattering (DIS99), Zeuthen, Germany, April 1999 (HERMES data).
[10] M. Glueck, E. Reya and A. Vogt, Phys. Rev. D46, 3986(1992).
[11] P. Astier et al., Nucl. Phys. B588, 3(2000).