What about the contribution from reggeons in hard process of strong interactions？

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Abstract

We discuss in this paper the possible contributions from $R_\rho$ ($\rho$-reggeon associated with $\rho$ meson) in DIS process on protons. Using results from phenomenological analysis of high energy $\pi$-N charge-exchanged scattering process, we get the expression of effective propagator of $R_\rho$ and the coupling constant $\beta_\rho$ between $R_\rho$ and light quarks. As a simple and concrete example, we use them to evaluate the contributions of $R_\rho$ to $F_2(x,Q^2)$ from charge-exchanged photoproduction quark-pair process, $\gamma^* + p \rightarrow n + q_u + \bar{q}_d(\rightarrow n + X)$, in HERA kinematical regions. For a comparison, we also evaluate contributions both from pomeron and partons in the same process. The ratio of contributions in $F_2(x,Q^2)$ from $R_\rho$ versus $P$ is larger than 1%, therefore, the former may be tested experimentaly.

$^1$The project is supported in part by National Science Foundation of China, Doctoral Program Foundation of Institution of Higher Education of China.
I Introduction

It is well known in high energy strong interactions that the regge pole theory is the sole one
which has both correctly explained and successfully predicted a lot of soft physics phenomena
\cite{1}. The entities playing most important roles in this phenomenological theory are pomeron,
$IP$, (a regge trajectory with vacuum quantum number) and reggeons, $IR$, (regge trajectory
with quantum numbers of various hadrons). In recent years since the observations of hard
diffractive scattering events in high energy P-P collisions were reported \cite{2}, physicists got
excited and tried with great interesting to explain these phenomena from QCD and to study
the partonic structure of pomeron. Much progress both from experimental and theoretical
research has been achieved and several models of pomeron have been proposed \cite{3}. But so
far as we know nothing has been done on this way for the reggeons. Perhaps the following
things could account for the occurrence:

1. From the Chew-Frautschi plot of regge trajectories as shown in Fig. 1, it can be easily
   understood that in genuine elastic scattering process, contributions of reggeons are
   always overwhelmed by that of pomeron.

2. Several reggeons with different quantum numbers could often be exchanged simultane-
   ously in the $t$ (or $u$) channel of a single scattering amplitude, thus the phenomenological
   analysis for reggeons is rather difficult.

3. It seems mysterious about duality in strong interactions which is intimately related with
   reggeons but irrelevant to pomeron, so perhaps the dynamical structure of reggeons is
   more complicated than that of pomeron.

So the study of partonic structure of reggeons and its QCD explanation is indeed a
serious and difficult subject. As a primary and simple test of this problem, we first start
from phenomenology of $\pi$-N scattering and try to derive from them the effective propagator
of one single reggeon. For this purpose, the ideal testing place is the high energy charge-exchanged $\pi$-N scattering process,

$$\pi^- + P \rightarrow \pi^0 + n,$$

(1)

in which only the charged reggeon $R_\rho$ with quantum number $J^{PC} = 1^{--}$ (the same as that of $\rho^+$ meson) could be exchanged in its t-channel. Then, we want to discuss and evaluate the contributions of reggeon $R_\rho$ in some high energy hard process. The ideal candidate for this purpose is the charge-exchanged photoproduction quark-pair process

$$\gamma^* + P \rightarrow n + q_u + \bar{q}_d (\rightarrow n + X),$$

(2)

which may be implemented on HERA of DESY. It is special relevant to our aim that the ZEUS Collab. of DESY has installed recently the forward proton spectrometer (FPS) and the forward neutron calorimeter (FNCAL) [4], which perhaps can be used to detect the neutron in final state like Eq.(2) process. Thus with the propagator and coupling constant obtained, we evaluate the contributions of $R_\rho$ in $F_2(x, Q^2)$ for Eq.(2). In order for comparison we also evaluate the contribution from $P$,

$$\gamma^* + P \rightarrow P + q + \bar{q} (\rightarrow n + X),$$

(3)

and from $\gamma^* + P \rightarrow X$ mediated by hard subprocess

$$\gamma^* + q \rightarrow q, ~ q + g, ~ \gamma^* + g \rightarrow q + \bar{q},$$

(4)

respectively.

Their results are shown in final section with some comments, the ratio of contributions in $F_2(x, Q^2)$ from $R_\rho$ versus $P$ is larger than 1%, therefore the former may be tested experimentaly.
II Charge-exchanged $\pi$-N scattering and $\rho$-reggeon phenomenology

It is well known that the transition amplitude of $\pi$-N scattering is (Fig. 2):
\[ A = \bar{u}(p_1)M u(p_2), \]  
the matrix $M$ is usually written as
\[ M = A(s, t) + \frac{1}{2}(p_2 + p_4)B(s, t) \]  
A, B are scalar functions of Mandelstam variales $s$ and $t$, $s + t + u = 2(m_\pi^2 + m_N^2)$. When $s \gg m_N^2$, scalar functions A, B would be expressed as the sum of Regge-pole terms which could be exchanged in $t$-channel. In order to remove the kinematical singularities in reggeized expressions, we introduce $A'$ instead of $A$, 
\[ A' = A + \frac{E_L - \frac{t}{4m_N}}{1 - \frac{t}{4m_N}}B \equiv A - m_N\frac{s}{z}\sqrt{\frac{4m_\pi^2 - t}{4m_N^2 - t}}B \]  
where $E_L = \frac{1}{4m_N}(s + t - u) \approx \frac{s}{2m_\pi}$ is the energy of $\pi$-N in Lab. system,
\[ Z_t \equiv \cos\theta_t = \frac{s - u}{\sqrt{(4m_\pi^2 - t)(4m_N^2 - t)}} = \frac{4m_N(E_L - \frac{t}{4m_N})}{\sqrt{(4m_\pi^2 - t)(4m_N^2 - t)}}. \]

For charge-exchanged process Eq.(1), only charged $\rho$-regge trajectory with quantum numbers $J^{PC} = 1^{--}$ (the same as that of $\rho$-meson) could be exchanged in the $t$-channel. The scalar functions $A'$, $B$ expressed in terms of parametric regge formalism have been given by Rarita et al. 
\[ A'(s, t) = \sqrt{2}C_0[e^{C_1 t}(1 + C_2) - C_2](\alpha_\rho(t) + 1)(\frac{s}{2m_N^2})^{\alpha_\rho(t)}(\frac{1 - e^{-i\pi\alpha_\rho(t)}}{\sin\pi\alpha_\rho(t)}), \]  
\[ B(s, t) = \sqrt{2}D_0e^{D_1 t}\alpha_\rho(t)(\alpha_\rho(t) + 1)(\frac{s}{2m_N^2})^{\alpha_\rho(t)-1}(\frac{1 - e^{-i\pi\alpha_\rho(t)}}{\sin\pi\alpha_\rho(t)}), \]
where $\alpha_\rho(t)$ is the trajectory function of $I_{\rho}$ and $\xi_\rho \equiv \left( \frac{1-e^{-i\pi\alpha_\rho(t)}}{\sin\pi\alpha_\rho(t)} \right)$ is the signature of $\rho$-reggeon from phenomenological analysis, the set of parameters $C_i, D_i$ were given in ref.[5], here we list them in Table 1.

Table 1. The magnitudes of parameters $C_i$ and $D_i$

|   | $C_0$ (mbGeV) | $C_1$ ($GeV^{-2}$) | $C_2$ | $D_0$ (mb)   | $D_1$ ($GeV^{-2}$) |
|---|--------------|-------------------|-------|-------------|-------------------|
| 1 | 1.47         | 0.20              | 15.2  | 26.3        | 0.34              |
| 2 | 1.51         | 2.39              | 1.48  | 29.4        | 0.14              |
| 3 | 1.57         | 2.02              | 1.52  | 29.1        | 0.11              |

The differential and total cross section for Eq.(1) may be obtained from above formulas.

$$
\frac{d\sigma}{dt}(s, t) = \frac{1}{ps} \left( \frac{m_N}{4k} \right)^2 [(1 - \frac{t}{4m_N^2})|A'|^2 - \frac{t}{4m_N^2} (\frac{4m_N^2 p^2 + st}{4m_N^2 - t})|B|^2],
$$

(10)

$$
\sigma^{\pi^-p \rightarrow \pi^0 n}(s) = \frac{1}{p} Im A'(s, 0),
$$

(11)

where

$$
p \equiv p_{Lab} \approx \frac{s}{2m_N}, \quad k \equiv p_{c.m.} \approx \frac{s + m_\pi^2 - m_N^2}{2\sqrt{s}} \approx \frac{\sqrt{s}}{2}.
$$

(12)

With those parameters shown in Table 1, ref. [3] has shown that the results from Eqs.(8), (9) and (10) fitted with relevant data very well over a large energy range. In order to extract the coupling constants between $I_{\rho}$ and hadrons, we should rewrite the transition amplitude in terms of $s$-channel helicity amplitudes. Since from above formulas and coefficients $C_i, D_i$, everything is known and ready, thus this is just a matter of converting manipulations. The $s$-channel helicity amplitudes $A_{Hs}$ and the differential cross sections for large $s$ are

$$
A_{Hs}(s, t) \sim \left( \frac{-t}{2m_N^2} \right)^m \left( \frac{1 - e^{-i\pi\alpha_\rho(t)}}{\sin\pi\alpha_\rho(t)} \right) \left( \frac{s}{2m_N^2} \right)^{\alpha_\rho(t)} \gamma_{\mu_2\mu_4}(t),
$$

(13)

where

$$
m \equiv |\mu_2 - \mu_4|
$$
\[
\frac{d\sigma}{dt}(s,t) = \frac{1}{64\pi s k^2} \frac{1}{2} \sum |A_{Hs}(s,t)|^2.
\] (14)

\(\mu_2, \mu_4 = \pm \frac{1}{2}\) are helicities of the initial proton and final neutron, and \(\gamma_\pi(t), \gamma_{\mu_2\mu_4}(t)\) are vertex functions of \(I_R \rho \pi\pi\) and \(I_R \rho NN\), respectively. We are interested in \(|t| \approx 0\), so only the \(m=0\) case in Eq.(13) is considered.

From Eqs.(7)-(11), we get the expression for the residue function \(\gamma_\pi(t) \gamma_N(t)\) of \(I_R \rho\) in the Eq.(1) process,

\[
\gamma_\pi(t)\gamma_N(t) = \frac{\sqrt{2}}{m_N} C_0[(1 + C_2)e^{C_1 t} - C_2](\alpha_\rho(t) + 1),
\] (15)

where \(\gamma_N(t) \equiv \gamma_{\frac{1}{2}+\frac{1}{2}}(t) = \gamma_{\frac{-1}{2}+\frac{1}{2}}(t)\).

Now let us give a brief discussion about the interaction between reggeon and partons. Since all reggeons are colour singlet and have definite \(I, S, C, B\), etc quantum numbers, they could not couple with gluon. As for the coupling between reggeon and quarks, neither model build-up nor experimental observation yet has been done about partonic structure of reggeon, so we can only get access to this problem from strong interaction phenomenologies.

In related to this case, we shall make following ansatzs:

1. The couplings between reggeon and hadrons, like that in pomeron case, could be described as a reggeon incoherently coupling with each quark in the hadron. These coupling constants have \(SU_2\) (isotopic spin) symmetry.

2. Regge pole residues could be factorized into a contribution to each vertex. For \(\pi^- p \to \pi^0 n\) process, residue function \(\gamma(t)\) could be written as

\[
\gamma^{I_R \rho}(t) = \gamma^{I_R \rho}_{\pi\pi} \gamma^{I_R \rho}_{PN}(t),
\]

where \(\gamma^{I_R \rho}_{\pi\pi}, \gamma^{I_R \rho}_{PN}\) are coupling vertex functions of \(I_R \rho\) with \(\pi, N\) respectively.

3. The duality effect manifested in hadron-hadron interactions should be embodied by Zweig allowed diagrams, this would prescribe the possible linkage ways between \(I_R\) and quark lines.
On the basis of these assumptions, we can deduce following relations:

\[ \gamma_{\pi\pi}^{R}(t) = \beta_{\rho}(t)F_{\pi}(t), \quad \gamma_{NN}^{R}(t) = 2\beta_{\rho}(t)F_{N}(t), \]

(16)

where \( \beta_{\rho}(t) \) is the coupling function between \( IR_{\rho} \) and light \((u, d)\) quarks, \( F_{\pi}(t) \) and \( F_{N}(t) \) are normalized form factors for a quark in \( \pi\)-meson and nucleon respectively. Factor 2 in the second part of Eq.(16) comes from the proton \((uud)\) which has two up-quarks. Put Eq.(16) into Eq.(12), we get

\[ \beta_{\rho}^{2}(t) = \frac{\sqrt{2}C_{0}[(1 + c_{2})e^{c_{1}t} - c_{2}](\alpha_{\rho}(t) + 1)}{2m_{N}F_{\pi}(t)F_{N}(t)}, \quad (t \leq 0) \]

(17)

and from Eq.(11)

\[ \sigma_{\pi^{-p}\rightarrow\pi^{0}n}(s) = 2\beta_{\rho}^{2}(\frac{s}{2m_{N}^{2}})^{\alpha_{\rho}(0)-1}. \]

(18)

From Eq.(17) and Table 1, we get \( \beta_{\rho} = 2.038, 2.066 \) and \( 2.107 \) GeV\(^{-1} \) which correspond to the three sets of parameters in Table 1. We shall take their average value, i.e. \( \beta_{\rho} \equiv \beta_{\rho}(t)|_{t=0} = 2.070 \) GeV\(^{-1} \) in our following calculations. The \( \rho \)-trajectory, \( \alpha_{\rho}(t) \), could be estimated from Chew- Fraditschi plot,

\[ \alpha_{\rho}(t) = \alpha_{\rho}(0) + \alpha'_{\rho}t, \quad \alpha_{\rho}(0) \approx 0.5, \quad \alpha'_{\rho} \approx 0.9 \text{GeV}^{-2}. \]

Thus the effective \( \rho \)-reggeon propagator radiated from nucleon is

\[ D_{\gamma_{\rho}}(t) = 2\beta_{\rho}^{2}F_{N}(t)(\frac{s}{2m_{N}^{2}})^{\frac{1}{2}(\alpha_{\rho}(t)-1)}(\frac{1 - e^{-i\pi\alpha_{\rho}(t)}}{sin\pi\alpha_{\rho}(t)}). \]

(19)

For comparing and later calculating, we write out the effective pomeron propagator which is also radiated from nucleon [3]:

\[ D_{P}(t) = -3\beta_{P}^{2}F_{N}(t)(\frac{s}{2m_{N}^{2}})^{\frac{1}{2}(\alpha_{P}(t)-1)}(\frac{1 + e^{-i\pi\alpha_{P}(t)}}{sin\pi\alpha_{P}(t)}), \]

(20)

where \( \beta_{P} \equiv \beta_{P}(t)|_{t=0} \approx 1.8 \) GeV\(^{-1} \) is the coupling constant between \( IP \) and quarks, \( \alpha_{P}(t) \approx 1.086 + 0.25t \) is \( IP \)-trajectory expansion in small \(|t|\), factor 3 in Eq.(20) corresponds to the three quarks in the nucleon.
III $\gamma^* + IR_\rho$ hard process

Both ZEUS and HI Collabs. at the end of 93’ in e-p DIS process, observed in e-p DIS the large rapidity gap (LRG) phenomena on HERA. Such phenomena were caused by those events in which the protons were diffractively scattered (or dissociated) and a pomeron was radiated. Since $IP$ is a colourless entity, which is quite different from quark or gluons, colour string would not attach between X (hard subprocess products) and $X_\rho$ (the remment of proton), thus LRG is manifested in the rapidity distribution of final hadrons\[.\] This is a further evidence which supports the inference that pomeron participates in hard subprocesss and itself has partonic structure.

It seems naturally to ask oneself whether the reggeons, like that case of pomeron, could appear in hard subprocess and themself would have partonic structure. As a primary test on such problems, we choose the charge-exchanged photoproduction quark-pair process $\gamma^* + p \rightarrow n + q_u + \bar{q}_d (\rightarrow n + X)$, as sketched in Fig. 3, which is the simplest hard process induced by $IR_\rho$ and we have got the $\rho$-reggeon effective propagator $D_{IR_\rho}(t)$ and the $IR_\rho \ q\bar{q}$ coupling constant $\beta_\rho$ in the last section. It should be emphasized here that we do not in any case want to discuss or evaluate the whole story about contributions from $IR_\rho$ in DIS process, but only want to estimate the relative percents for contributions from $IR_\rho$ to that from $IP$, and want to know whether it can be observed experimentally. As for a comparison, we also evaluated the similar contributions both from $IP$ and partons, as shown in Fig. 4 and Fig. 5.

In the following we shall write down the relevant formalism sketchily. Under the equivalent photo approximation, the cross section for absorption of a virtual transverse photon, $\sigma_{\gamma^*N}^T(s, Q^2)$ is related with the nucleon structure function $F_2(x, Q^2)$ as

$$F_2(x, Q^2) = \frac{Q^2}{4\pi^2\alpha} \sigma_{\gamma^*N}^T(s, Q^2). \quad (21)$$

\[2\] Of course, since $IR$ are also colourless entities, LRG would also be manifested in the rapidity distribution of final hadrons as that in $IP$ case.
the cross section \( \sigma_{\gamma^*p}(s, Q^2) \) for Fig. 4 is

\[
\sigma_{\gamma^*p}(s, Q^2) = \frac{1}{4q_{s12} \sqrt{s}} \sum |\mathcal{M}|^2 (2\pi)^4 \delta^4(p + q - p' - k - k') \frac{d^3p'}{(2\pi)^3 2E_{p'}} \frac{d^3k}{(2\pi)^3 2E_k} \frac{d^3k'}{(2\pi)^3 2E_{k'}}
\]

where \( s \equiv (p + q)^2 \), \( q_{s12} \simeq \frac{1}{2\sqrt{s}} (s + Q^2) \). After some operations the invariant phase space elements can be transformed to

\[
\frac{d^3p'}{2E'} \simeq \frac{2\pi \sqrt{s}}{s + Q^2} dt d\omega,
\]

where \( t = (p - p')^2 \), \( \omega = q_0 \). Thus we can rewrite Eq.(18) as

\[
\sigma_{\gamma^*p}(s, Q^2) = \frac{\sqrt{s}}{8(2\pi)^4 (s + Q^2)^2} \int_{-1}^{0} dt \int_{\frac{2m_s + Q_2}{2\sqrt{s}}}^{\frac{s + Q^2}{10\sqrt{s}}} d\omega \int \frac{d^3k}{E_k} \int \frac{d^3k'}{E_{k'}} \sum |\mathcal{M}|^2 \delta^4(q + q' - k - k'),
\]

In order for comparing conveniently, we have taken the same integral bounds of \( t \) and \( \omega \) as in the \( IP \) case, i.e. \(-1 \leq t \leq 0\), \( \frac{2m_s + Q^2}{2\sqrt{s}} \leq \omega \leq \frac{s + Q^2}{10\sqrt{s}} \). According to Eq.(19) and Fig. 4, matrix element \( \mathcal{M} \) is expressed as

\[
\mathcal{M} = 2\beta_\rho^2 F_N(t) \left( \frac{s}{2m_N^2} \right)^{\frac{1}{2}(\alpha(t)-1)} \left( \frac{1 - e^{-i\pi\alpha(t)}}{\sin\pi\alpha(t)} \right) \right]

\[
[Q_u \overline{u}(k)\gamma_\mu (q' - k') \gamma_\rho \nu_d(k') + Q_d \overline{u}(k)\gamma_\mu (q' - k') \gamma_\rho \nu_d(k')][\overline{u}(p')\gamma_\mu u(p),
\]

where \( Q_u = \frac{2}{3} e \), \( Q_d = -\frac{1}{3} e \) for u, d quark charge respectively. Here we have assumed that in field formalism, the coupling type between \( \rho \)-reggeon and quarks is a vector (i.e. \( \gamma_\rho \) matrix in Eq.(25)), as the same as that in the Pomeron case.\(^3\)

The operations about \( \sum |\mathcal{M}|^2 \) are standard, and it is completed in computer by using the Reduce Programm.

We have also considered the pomeron contributions which come from Fig. 4 to \( \sigma_{\gamma^*p}(s, Q^2) \) (or \( F_2(x, Q^2) \)), here the formalism is almost the same as that of \( \rho \)-reggeon, except the effective

\(^3\)According to Chew-Frautschi plot, one could alternatively choose the scalar type (I unit matrix instead of \( \gamma_\rho \) in Eq.(25)), but would lead to a result which is 2-3 order of magnitudes smaller than the vector one.
propagator $D_{IR}(t)$ in Eq.(19) is replaced by $D_{P}(t)$ in Eq.(20) and change some trivial factors such as coupling constant $\beta$, quark charge etc. As we have mentioned, we need also evaluate contributions in $O(\alpha_s)$ from ordinary photo-partons interaction, its diagrams are described in Fig. 5. This could be easily done since everything is known and ready. Ref. [7] has given out the next leading order related formula

$$\frac{1}{x} F_2(x, Q^2) = \sum c_q^2 \{ q(x, Q^2) + \bar{q}(x, Q^2) + \frac{\alpha_s(Q^2)}{2\pi} [C_{q,2} \otimes (q + \bar{q}) + C_{g,2} \otimes g] \} ,$$  (26)

where $C_{q,2}(z)$ and $C_{g,2}(z)$ are structure functions of quark and gluon at $O(\alpha_s)$ respectively,

$$C_{q,2}(z) = \frac{4}{3} \left\{ \frac{1 + z^2}{1 - z^2} \left[ \ln \left( \frac{1 - z}{z} \right) - \frac{3}{4} \right] + \frac{1}{4} (9 + 5z) \right\}_+, \quad (27)$$

$$C_{g,2}(z) = \frac{1}{2} \left\{ [z^2 + (1 - z)^2] \ln \left( \frac{1 - z}{z} \right) - 1 + 8z(1 - z) \right\}. \quad (28)$$

$C_{q,2} \otimes (q + \bar{q})$ and $C_{g,2} \otimes g$ are short hand notations of following convolutions respectively,

$$C_{q,2} \otimes (q + \bar{q}) \equiv \int_1^1 \frac{dy}{y} C_{q,2}(\frac{x}{y}) [q(y, Q^2) + \bar{q}(y, Q^2)],$$

$$C_{g,2} \otimes g \equiv \int_1^1 \frac{dy}{y} C_{g,2}(\frac{x}{y}) g(y, Q^2), \quad (29)$$

where the $\overline{MS}$ renormalization scheme has been used. As for the parton distribution functions, $q(x, Q^2)$, $\bar{q}(x, Q^2)$ and $g(x, Q^2)$ needed in Eq.(26), we take them from [8].

**IV Results and Conclusions**

Since in this paper we want to study the possible contributions of Reggeon in hard process of strong interaction and such work had never been done by others. We must start out to get the effective propagator of a reggeon, $D_{IR}(t)$ and the coupling constant $\beta$ between reggeon and partons. Thus we choose an ideal process, $\pi^- + p \rightarrow \pi^0 + n$, in which only the $\rho$-reggeon could be exchanged. From the related phenomenological analysis and under some ansatzs,
we have got the $\rho$-reggeon effective propagator $D_{I\rho}(t)$ and coupling constant between $\rho$-reggeon with light quark, $\beta_\rho(t)$. Put $D_{I\rho}(t)$ and $\beta_\rho$ in comparing with the corresponding $D_{IP}(t)$ and $\beta_{IP}$ of pomeron, we see they are reasonable.

For the $\rho$-reggeon contribution in hard process aspects, as a simple example we have discussed the charge-exchanged photon production quark-pair process, $\gamma^* + p \to n + q_u + \bar{q}_d (\to n + X)$, which may be tested at HERA. The kinematical regions covered by our calculation for above process and its contributions to structure function $F_2(x, Q^2)$ in e-p DIS process are shown in Fig. 6. As for comparison, contributions from the process as described by Eq.(3) and (4) for pomeron and ordinary partons are also shown in it. From Fig. 6 one can see that:

1. The ratio of $F_2(x, Q^2)$ from $I_{\rho}$ to that from $IP$ is larger than one percent from small $x$ to large $x$ range when $Q^2 = 10 \text{ GeV}^2$. This is what we expected. Since from Chew-Frautschi plot in Fig. 1 and Eqs.(19), (20) and (24), we see factors $(\frac{s}{2m_N^2})^{\alpha_{I_{\rho}}(t)-1}$ and $(\frac{s}{2m_N^2})^{\alpha_{IP}(t)-1}$ which are critical ingredients for cross sections of $I_{\rho}$ and $IP$, the ratio between them is $e^{-0.586 \ln(\frac{s}{2})}$, which is $O(10^{-2})$, in our main kinematical regions.

2. The standard parton contributions (Fig. 5) to $F_2(x, Q^2)$ are $1 \sim 2$ orders of magnitude larger than that of $IP$, but we can see its major contributions come from leading order (i.e. from the modified naive parton model with $q(x, Q^2)$ instead of $q(x)$). Results show that all next leading order corrections to $F_2(x, Q^2)$ are about, on the average, the same order as that from $IP$.

Since the $F_2(x, Q^2)$ of $I_{\rho}$ is $1 \sim 2$ orders smaller than that of $IP$, we expect that the $I_{\rho}$ signals may be tested at HERA in hard process such as Fig. 3. But as prerequisite, there must be a sensitive neutron detector to detect the final forward neutrons. Since the critical step to distinguish events coming from $I_{\rho}$-exchanged or from $IP$-exchanged is to observe whether the detected final forward hardron is a neutron or a proton. Recently, ZEUS Collab. in DESY have installed on HERA a forward proton spectrometer(FPS) and
a forward neutron calorimeter (FNCAL) [9] which perhaps would be feasible for above test.

Acknowledgement

We are grateful to Feng Yuan and Jiasheng Xu for their kindly help.

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Fig. 2 The scattering processes in the s-channel of $\pi + N \rightarrow \pi + N$. 
Fig. 3 Feynman diagrams for charge-exchanged photoproduction quark-pair process.
Fig. 4 Feynman diagrams for diffractive photoproduction quark-pair process.

\[ \frac{u, d(k) \leftrightarrow \bar{u}, \bar{d}(k')}{\text{permutation}} \]
Fig. 5 Feynman diagrams for deep inelastic $\gamma^* + p \rightarrow X$ process at leading and next leading order.