SPIN-DISCRIMINATE EXCHANGE IN HIGH ENERGY DIFFRACTION*

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We speculate that in high energy diffractive scattering many features of data can be explained under assumption that the scattering amplitude contains sizable part sensitive to the spin of colliding particles. This spin-dependent part of the amplitude does not vanish at high energies and becomes leading at momentum transfer $-t > 1$–$2\,\mathrm{GeV}^2$ and energy $\sqrt{s} > 10$–$20\,\mathrm{GeV}$. In terms of Regge approach, the amplitude corresponds to exchange of a reggeon with vacuum quantum numbers, negative signature, intercept $\alpha(0) \approx 1$ and zero slope.

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It is well-known that in high energy diffraction most of data are well described by the model of the pomeron exchange. In particular, the pomeron exchange describes behavior of the total hadronic cross sections and elastic cross sections at small momentum transferred. The same "soft" pomeron explains behavior of spin-independent structure function at small x and small Q^2. Phenomenologically, the "soft" pomeron amplitude is usually written in terms of Regge language as a reggeon with intercept 1.08 and slope $0.25\,\mathrm{GeV}^2$. The large value of the intercept marks the "anomalous" pomeron out from the "normal" reggeons which have intercepts less that 0.5. The signature of the pomeron is positive, it is flavor singlet and carries vacuum quantum numbers $P = C = +1$. Thus, the pomeron is not sensitive to quantum numbers of the colliding particles. Its coupling strength to a hadron is just proportional to the number of constituent quarks in it. At large Q^2 intercept of the pomeron differs from the small Q^2 case and is approximately 1.2 (the "hard" pomeron).

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Theoretical understanding of the pomeron is one of the main issues in QCD. It involves both perturbative (BFKL resummation, [1]) and non-perturbative (Landshoff–Nachtmann model [2]) approaches, which can qualitatively explain many of the pomeron's features. The common wisdom is that the pomeron is a gluonic object (most simple picture — two gluons in color singlet state), that differ it from the "normal" mesonic exchanges which do not survive as the energy grows.

The idea that gluonic exchanges play important role at high energy, lead to both attempts to investigate multiple gluon exchanges theoretically in the framework of QCD and phenomenological searches of the anomalous exchanges. The well known theoretical prediction called the odderon is an exchange of three gluons in color singlet state. The odderon's quantum numbers are $P = C = -1$, it has negative signature and intercept close to one. The odderon was believed to give dominant contribution to the proton–proton differential cross section at energy $\sqrt{s} > 20\,\mathrm{GeV}$ and momentum transferred $-t > 2\,\mathrm{GeV}^2$ [3]. It was measured, that the differential cross section is almost independent from energy in this region and that is why the odderon with intercept close to 1 was a natural explanation of the data. However, recent results of H1 collaboration [6] do not indicate any signal of the odderon in π^0, $f_2(1270)$ and $a_2(1320)$ mesons production, where only an exchange with the odderon quantum numbers can contribute. That is why interpretation of the proton–proton data in terms of the odderon exchange is challenged.

At the same time, there exists a clear evidence of another exchange with intercept close to 1. Measurement of neutron spin-dependent structure function [4] showed that spin-dependent part of photon–nucleon scattering amplitude vanishes very slowly as the energy grows. This is reflected in the asymptotic (Fig. 1)

$$g_1^n(x) \sim \frac{1}{x^{0.96}}, \quad (x \to 0)\,. \tag{1}$$

In terms of Regge theory, this can be described as an exchange of a reggeon with vacuum quantum numbers, negative signature and intercept which is close to 1. Due to the quantum numbers, the exchange observed in g_1^n can not be the pomeron or the odderon.

It is also should be noted, that the exchange is not necessarily a single Regge pole and other interpretations, like Regge cuts, *etc.* are possible. The only necessary condition is that its helicity amplitudes should satisfy the following relations

$$A_{++\to++} = -A_{+-\to+-}, \quad A_{++\to--} = A_{+-\to-+} = A_{++\to+-} = 0. \tag{2}$$

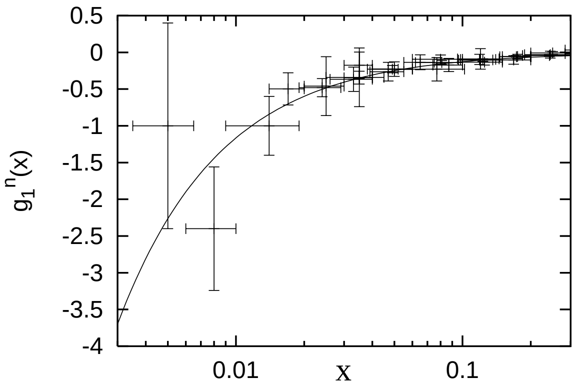

Fig. 1. Neutron spin structure function at small x and its Regge fit (1).

If we assume that the exchange gives dominant contribution to the proton–proton elastic cross section at large $|t|$, we can extract its coupling to the nucleon. Its contribution to the cross section is given by formula

$$\frac{d\sigma}{d|t|} = \frac{g^4 F_p^4(t)}{4\pi(t-m^2)^2}\,, \tag{3}$$

where m is effective mass of the resonance corresponding to the exchange, g is its coupling to the nucleon and $F_p(t)$ is axial vector proton form factor, which we take as $1/(1-t/m^2)^2$. It is quite interesting that to explain the data one need to take values $m = 1.29$ and $g = 2.5$, that is in good agreement with mass of axial vector $f_1(1285)$ meson ($P = C = +1$) and its coupling, which was found [11] from analysis of axial vector mesons mixing. The form factor also appears to be similar to experimentally found $1/(1-t/1.08^2)^2$ [5]. It is important that to understand appearance of three isoscalar axial vector mesons ($f_1(1285)$, $f_1(1420)$ and $f_1(1510)$) instead of only two states in pseudo-scalar channel (η, η'), one needs to add some gluonic component to the doublet. Thus, the exchange may be related to the gluonic state.

Now we can try to find reactions where the exchange can manifest itself. The most clear case, similar to the odderon's, is meson photoproduction. For the "f_1" exchange one should look to the vector meson photoproduction. The situation here is similar to what was observed in proton–proton elastic scattering. At low momentum transferred, $|t| < 1\,\mathrm{GeV}^2$, the value of the differential cross section is described by the model of the pomeron exchange. At larger $|t|$ the cross section is larger than its prediction.

It was suggested [7] that the main contribution to the cross section comes here from the hard pomeron. If it is so, *i.e.* if the hard pomeron manifests itself in reaction with small quark virtuality, it should also give contribution to the proton–proton elastic cross section at large $|t|$. Thus, if we assume that the large $|t|$ tail of vector meson photoproduction cross section is dominated by the hard pomeron exchange, the same should be true for the proton–proton elastic cross section. And since coupling of the pomeron to a hadron is just proportional to number of constituent quarks in it, the hard pomeron should also determine the behavior of πp differential cross section at large $|t|$. The ratio of the cross sections should be then proportional to $\left(\frac{3}{2}\frac{F_p(t)}{F_\pi(t)}\right)^2$, where $F_p(t)$ and $F_\pi(t)$ are elastic form factors of the proton and π meson correspondingly. The latest data gives for the proton [8] $F_p(t) = (3.52 - 2.34t)/((3.52 - t)(1 - t/0.71)^2)$ and for the π-meson [9] $F_\pi(t) = (1/(1 - t/0.56)$. Then for $-t{=}4\,\mathrm{GeV}^2$ the ratio is around 0.2, while experimentally it is of order 50 (Fig. 2). That is why we assume that the hard pomeron is not responsible for the behavior of differential cross section of elastic pp scattering and it looks questionable that it gives leading contribution to vector mesons photoproduction cross section at large $|t|$.

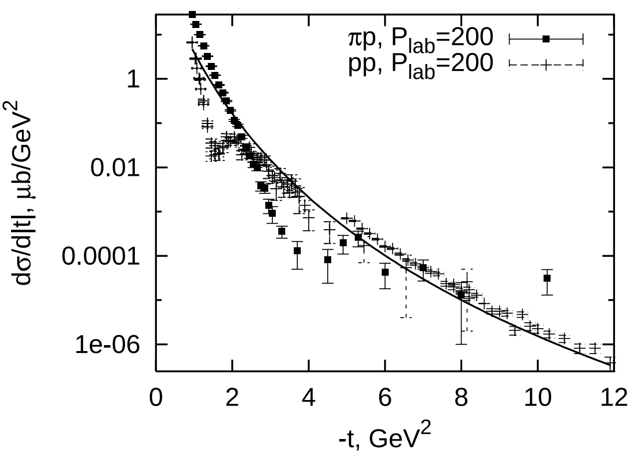

Fig. 2. Differential cross section of elastic πp and pp scattering. The line corresponds to Eq. (3).

On a contrary, the spin discriminate exchange can explain numerically both $pp \to pp$ and $\gamma p \to Vp$ differential cross sections and the small value of πp cross section at large momentum transferred. The later is provided by the properties of the helicity amplitudes (2). The π meson is composed of quarks with opposite spins and thus the exchange gives no contribution to πp cross section.

To calculate the contribution of the exchange to vector meson production cross section, one can do in the same way as in the pomeron's case [10]. It is assumed that initial soft photon dissolves into pair of constituent quark and antiquark which interact diffractively with the proton and form the final vector meson. The wave function of the vector meson is supposed to be simple, $\Phi_V(p_q, p_{\bar{q}}) = C\delta(p_q - p_{\bar{q}})$. Constant C is chosen to reproduce the value of $\Gamma_{V\to e^+e^-}$. With the soft pomeron exchange, this simple model explains differential cross section at $-t < 1\,\mathrm{GeV}^2$. We did the same procedure for the spin discriminate exchange. Its coupling to the constituent quark is taken to be the same as to the nucleon, since it is proportional to the spin of the hadron and does not depend on flavor. Then the formula for the cross section reads

$$\frac{d\sigma_{\gamma p\to Vp}}{d|t|} = \frac{3m_V^3 g^4 \Gamma_{V\to e^+e^-}}{\pi\alpha_{em}} \frac{F_p^2(t)}{(m_V^2 - t)^2(m^2 - t)^2}\,. \tag{4}$$

The result is shown in Fig. 3. As it can be seen, taking into account the exchange with the same parameters as in elastic pp scattering enables one to

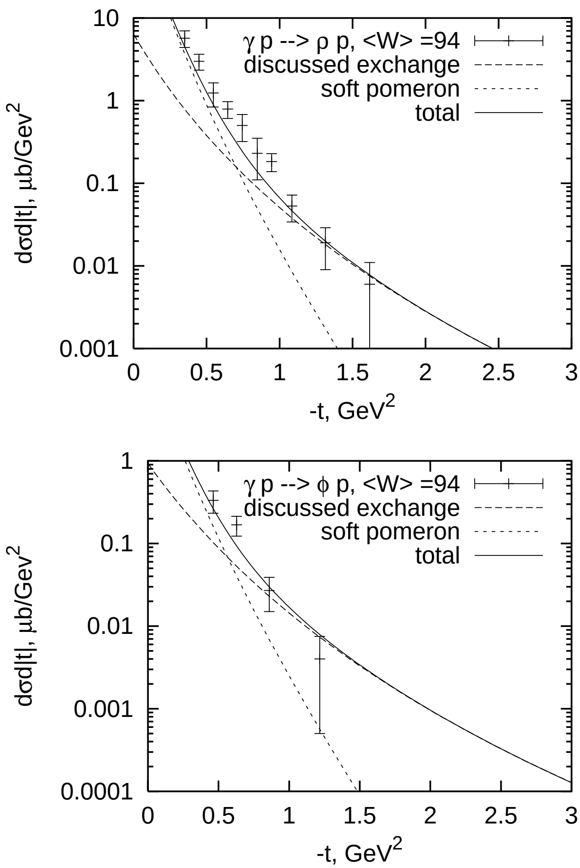

Fig. 3. HERA data on $\gamma p \to Vp$ cross section and results of calculation using (4).

reproduce numerically the value of differential cross section of light vector mesons elastic photoproduction at $-t > 1\,\mathrm{GeV}^2$. Moreover, almost the same result one can get using the value of $\Gamma_{f_1 \to V\gamma}$ to estimate the value of coupling of the exchange to the photon and vector meson. This supports the idea that the origin of the exchange could be glueball associated with the f_1 meson.

The existence of the exchange can be further tested in experiments at HERA and RHIC. In the new HERA run with polarized electron beam the exchange can be detected by measurement of parity asymmetry $P_\sigma = 2r^1_{1-1} - r^1_{00}$ in vector meson photoproduction. If the cross section is dominated by soft or hard pomeron, $P_\sigma = +1$. For the spin discriminate exchange it is -1. That is why we expect that it will flip from $+1$ at small $|t|$ to -1 at $|t| >$1–2 GeV^2 [13]. At RHIC, the exchange can be detected by measurement of double spin asymmetry in proton collisions in *pp*2*pp* experiment. If the cross section is dominated by the soft and hard pomerons or the odderon, there should not be any asymmetry. If there exist the spin discriminate exchange, the asymmetry should be $\approx 20\%$ for $|t| =$ 1–1.5 GeV^2 [12].

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