Abstract

One of the well known effects of the asymptotic freedom is splitting of the leading-log BFKL pomeron into a series of isolated poles in complex angular momentum plane. Following our earlier works we explore the phenomenological consequences of the emerging BFKL-Regge factorized expansion for the small-$x$ charm ($F^c_2$) and beauty ($F^b_2$) structure functions of the proton. As we found earlier, the color dipole approach to the BFKL dynamics predicts uniquely decoupling of subleading hard BFKL exchanges from $F^c_2$ at moderately large $Q^2$. We predicted precocious BFKL asymptotics of $F^c_2(x, Q^2)$ with intercept of the rightmost BFKL pole $\alpha^-_P(0) - 1 = \Delta_P \approx 0.4$. High-energy open beauty photo- and electro-production probes the vacuum exchange at much smaller distances and detects significant corrections to the BFKL asymptotics coming from the subleading vacuum poles. In view of the accumulation of the experimental data on small-$x$ $F^c_2$ and $F^b_2$ we extended our early predictions to the kinematical domain covered by new HERA measurements. Our structure functions obtained in 1999 agree well with the determination of both $F^c_2$ and $F^b_2$ by the H1 published in 2006 but contradict to very recent (2008, preliminary) H1 results on $F^b_2$. We present also comparison of our early predictions for the longitudinal structure function $F_L$ with recent H1 data (2008) taken at very low Bjorken $x$. We comment on the electromagnetic corrections to the Okun-Pomeranchuk theorem.

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1 Introduction

The Okun-Pomeranchuk theorem on the isospin independence of asymptotic cross sections [1] is a precursor to the QCD pomeron which is a flavour-neutral bound state of gluons in the $t$-channel. Within the color-dipole (CD) framework, this flavor independence is a feature of the dipole cross section, while the QCD pomeron contribution would depend on the interacting particles through the QCD impact factors, calculable in terms of the flavour-dependent color dipole structure of the target and projectile.

As noticed by Fadin, Kuraev and Lipatov in 1975 ([2], see also more detailed discussion by Lipatov [3]), incorporation of asymptotic freedom into BFKL equation turns the spectrum of the QCD vacuum exchange into series of isolated BFKL-Regge poles. Such a spectrum has a far-reaching theoretical and experimental consequences because the contribution of each isolated hard BFKL pole to scattering amplitudes and/or structure functions (SF) would satisfy very powerful Regge factorization [4]. The resulting CD BFKL-Regge factorized expansion allows one to relate in a parameter-free fashion SFs of different targets, $p, \pi, \gamma, \gamma^*$ [5, 6, 7] and/or contributions of different flavors to the proton SF [8, 9]. The first analysis of small-$x$ behavior of open charm SF of the proton, $F_2^c$, in the color dipole formulation of the BFKL equation [10] has been carried out in 1994 [11, 12, 13] with an intriguing result that for moderately large $Q^2$ it is dominated by the leading hard BFKL pole exchange. Later this fundamental feature of CD BFKL approach has been related [14] to nodal properties of eigen-functions of subleading hard BFKL-Regge poles [15].

In [15] we applied the latter property of the CD BFKL-Regge factorization and quantified the strength of the subleading hard BFKL and soft-pomeron background to dominant right-most hard BFKL exchange. One of our findings [15] is that the BFKL-Regge expansion (10) truncated at $m = 2$ appears to be very successful in describing of the proton SFs in a wide range of $Q^2$. Very recently this phenomenon has been rediscovered in [16].

In view of the accumulation of the experimental data on small-$x$ $F_2^c, F_2^b$ we extended our early predictions to the kinematical domain covered by new HERA measurements. Based on CD BFKL-Regge factorization we report parameter-free description of both $F_2^c$ and $F_2^b$. We comment on the phenomenon of decoupling of soft and subleading BFKL singularities at the
scale of the open charm production which results in precocious color dipole BFKL asymptotics of the the structure function \(F_2\). In view of this fundamental conclusion open charm excitation by real photons and in DIS gives a particularly clean access to the intercept of the rightmost hard BFKL pole for which our 1994 prediction has been \(\Delta_{IP} = \alpha_{IP}(0) - 1 = 0.4\) [11].

We show that the interplay of leading and subleading vacuum exchanges gives rise to the beauty structure function \(F_2^b\) growing much faster than it is prescribed by the exchange of the leading pomeron trajectory with intercept \(\Delta_{IP} = 0.4\) (see also [9]).

Because the CD BFKL-Regge expansion for color dipole-proton cross section has already been fixed from the related and highly successful phenomenology of light flavor contribution to the proton SF the CD BFKL-Regge factorization predictions for the charm SF of the proton are parameter free. The found nice agreement with the experimental data from H1 Collaboration [17] on the charm and beauty SF of the proton strongly corroborates our 1994 prediction \(\Delta_{IP} \approx 0.4\) for the intercept of the rightmost hard BFKL pole. It is worth mentioning that very recent (preliminary) H1 date on \(F_2^b\) [18] does not agree with our early predictions.

Besides charm and beauty structure functions there are several more observables which are selective to the dipole size. One of them is the longitudinal structure function of the proton \(F_L\). We present the BFKL-Regge factorization results for \(F_L\). The recent H1 measurements of \(F_L\) [19] do not contradict to our predictions made in [8] but they are too uncertain for any firm conclusions.

2 Open charm production: scanning the dipole cross section

In color dipole (CD) approach to small-\(x\) DIS excitation of heavy flavor is described in terms of interaction of \(q\bar{q}\) color dipoles in the photon of a predominantly small size,

\[
\frac{4}{Q^2 + 4m_q^2} \lesssim r^2 \lesssim \frac{1}{m_q^2}.
\] (1)
Therefore, the heavy flavor excitation at large values of the Regge parameter,

\[
\frac{1}{x} = \frac{W^2 + Q^2}{4m_c^2 + Q^2} \gg 1, \tag{2}
\]

is an arguably sensitive probe of short distance properties of vacuum exchange in QCD.

Interaction of color dipole \( \mathbf{r} \) in the photon with the target proton is described by the beam, target and flavor independent color dipole cross section \( \sigma(x, \mathbf{r}) \). The contribution of excitation of open charm/beauty to photo-absorption cross section is given by color dipole factorization formula

\[
\sigma^c(x, Q^2) = \int dz d^2r |\Psi_{\gamma^* c \bar{c}}(z, \mathbf{r})|^2 \sigma(x, \mathbf{r}). \tag{3}
\]

Here \( |\Psi_{\gamma^* c \bar{c}}(z, \mathbf{r})|^2 \) is a probability to find in the photon the \( c \bar{c} \) color dipole with the charmed quark carrying fraction \( z \) of the photon’s light-cone momentum [20]. Hereafter we focus on the charm structure function

\[
F_2^c(x_B j, Q^2) = \frac{Q^2}{4\pi^2\alpha_{em}} \sigma^c(x, Q^2)
= \int \frac{dr^2}{r^2} \frac{\sigma(x, r)}{r^2} W_2(Q^2, m_c^2, r^2). \tag{4}
\]

A detailed analysis of the weight function \( W_2(Q^2, m_c^2, r^2) \) found upon the \( z \) integration has been carried out in [12, 13], we only cite the principal results: (i) at moderate \( Q^2 \lesssim 4m_c^2 \) the weight function has a peak at \( r \sim 1/m_c \), (ii) at very high \( Q^2 \) the peak develops a plateau for dipole sizes in the interval (1). One can say that for moderately large \( Q^2 \) excitation of open charm probes (scans) the dipole cross section at a special dipole size \( r_S \) (the scanning radius)

\[
r_S \sim 1/m_c. \tag{5}
\]

The difference from light flavors is that in contrast to the peak for heavy charm the \( W_2 \) for light flavors always has a broad plateau which extends up to large dipoles \( r \sim 1/m_q \).
3 Scanning radius and nodes of subleading CD BFKL eigen-cross sections

In the Regge region of $\frac{1}{x} \gg 1$ CD cross section $\sigma(x, r)$ satisfies the CD BFKL equation

$$\frac{\partial \sigma(x, r)}{\partial \log (1/x)} = \mathcal{K} \otimes \sigma(x, r),$$

(6)

for the kernel $\mathcal{K}$ of CD approach see [21]. The solutions with Regge behavior

$$\sigma_m(x, r) = \sigma_m(r) \left(\frac{1}{x}\right)^{\Delta_m}$$

(7)

satisfy the eigen-value problem

$$\mathcal{K} \otimes \sigma_m = \Delta_m \sigma_m(r)$$

(8)

and the CD BFKL-Regge expansion for the color dipole cross section reads [11, 6]

$$\sigma(x, r) = \sum_{m=0}^{\infty} \sigma_m(r) \left(\frac{x_0}{x}\right)^{\Delta_m}.$$  

(9)

The practical calculation of $\sigma(x, r)$ requires the boundary condition $\sigma(x_0, r)$ at certain $x_0 \ll 1$. We take for boundary condition at $x = x_0$ the Born approximation,

$$\sigma(x_0, r) = \sigma_{\text{Born}}(r),$$

5
i.e. evaluate dipole-proton scattering via the two-gluon exchange. This leaves the starting point $x_0$ the sole parameter. We follow the choice $x_0 = 0.03$ which met with remarkable phenomenological success [15, 5, 6].

The properties of our CD BFKL equation and the choice of physics motivated boundary condition were discussed in detail elsewhere [12, 13, 14, 15, 5], here we only recapitulate features relevant to the considered problem. Incorporation of asymptotic freedom exacerbates well known infrared sensitivity of the BFKL equation and infrared regularization by infrared freezing of the running coupling $\alpha_S(r)$ and modeling of confinement of gluons by the finite propagation radius of perturbative gluons $R_c$ need to be invoked.

The leading eigen-function

$$\sigma_0(r) \equiv \sigma_{\text{IP}}(r)$$

for ground state i.e., for the rightmost hard BFKL pole is node free. The subleading eigen-function for excited state $\sigma_m(r)$ has $m$ nodes. We find $\sigma_m(r)$ numerically [15, 5], for the semi-classical analysis see Lipatov [3]. The intercepts (binding energies) follow to a good approximation the law

$$\Delta_m = \Delta_0/(m + 1).$$

For the preferred $R_c = 0.27$ fm as chosen in 1994 in [13, 12] and supported by the analysis [22] of lattice QCD data we find

$$\Delta_0 \equiv \Delta_{\text{IP}} = 0.4.$$  

The node of $\sigma_1(r)$ is located at $r = r_1 \simeq 0.056$ fm, for larger $m$ the rightmost node moves to a somewhat larger $r = r_1 \sim 0.1$ fm. The second node of eigen-functions with $m = 2, 3$ is located at $r_2 \sim 3 \cdot 10^{-3}$ fm which corresponds to the momentum transfer scale $Q^2 = 1/r_2^2 = 5 \cdot 10^3$ GeV$^2$. The third node of $\sigma_3(r)$ is located at $r$ beyond the reach of any feasible DIS experiments. It has been found [15] that the BFKL-Regge expansion (10) truncated at $m = 2$ appears to be very successful in describing of the proton SFs at $Q^2 \lesssim 200$ GeV$^2$. However, at higher $Q^2$ and moderately small $x \sim x_0 = 0.03$ the background of the CD BFKL solutions with smaller intercepts ($\Delta_m < 0.1$) should be taken into account (see below).

The exchange by perturbative gluons is a dominant mechanism for small dipoles $r \lesssim R_c$. In Ref.[13] interaction of large dipoles has been modeled by the non-perturbative, soft mechanism
which we approximate here by a factorizable soft pomeron with intercept $\alpha_{\text{soft}}(0) - 1 = \Delta_{\text{soft}} = 0$ i.e. flat vs. $x$ at small $x$. The exchange by two non-perturbative gluons has been behind the parameterization of $\sigma_{\text{soft}}(r)$ suggested in [23] and used later on in [14, 15, 5, 6, 7].

Via equation (4) each hard CD BFKL eigen-cross section plus soft-pomeron CD cross section defines the corresponding eigen-SF $f_m^c(Q^2)$ and we arrive at the CD BFKL-Regge expansion for the charm SF of the proton ($m = \text{soft}, 0, 1, ..$) [8]

$$F_2^c(x_B, Q^2) = \sum_m f_m^c(Q^2) \left( \frac{x_0}{x} \right)^{\Delta_m},$$

(10)

Now comes the crucial observation that numerically $r_1 \sim r_S/2$ and the node of hard CD BFKL eigen-cross sections is located within the peak of the weight function $W_2$. Consequently, in the calculation of open charm eigen-SFs $f_m^c(Q^2)$ one scans the eigen-cross section in the vicinity of the node, which leads to a strong suppression of subleading $f_m^c(Q^2)$.

4. Open charm structure functions from CD BFKL-Regge factorization

Because a probability to find large color dipoles in the photon decreases rapidly with the quark mass, the contribution from soft-pomeron exchange to open charm excitation is very small down to $Q^2 = 0$. As we discussed elsewhere [6, 8], for still higher solutions, $m \geq 3$, all intercepts are very small anyway, $\Delta_m \ll \Delta_0$. For this reason, for the purposes of practical phenomenology, we truncate expansion (10) at $m = 3$ lumping in the term $m = 3$ contributions of still higher singularities with $m \geq 3$. The term $m = 3$ is endowed with the effective intercept $\Delta_3 = 0.06$ and is presented in [8] in its analytical form.

We comment first on the results on $F_2^c$. The solid curve in Fig. 2 is a result of the complete CD BFKL-Regge expansion. The dashed curve is the pure rightmost hard BFKL pomeron contribution (LHA), There is a strong cancellation between soft and subleading contributions with $m = 1$ and $m = 3$. Consequently, for this dynamical reason in this region of $Q^2 \lesssim 10$ GeV$^2$ we have an effective one-pole picture and LHA gives reasonable description of $F_2^c$.

In agreement with the nodal structure of subleading eigen-SFs discussed in [6, 8], LHA over-predicts slightly $F_2^c$ at $Q^2 \gtrsim 30$ GeV$^2$, where the negative valued subleading hard BFKL
Figure 2: Prediction from CD BFKL-Regge factorization for the charm structure function of the proton $F_2^c(x, Q^2)$ as a function of the Bjorken variable $x_{Bj}$ in comparison with the experimental data from H1 Collaboration [17]. The solid curve is a result of the complete CD BFKL-Regge expansion, the contribution of the rightmost hard BFKL pole with $\Delta_{IP} = 0.4$ is shown by dashed line.

Exchanges overtake the soft-pomeron exchange and the background from subleading hard BFKL exchanges becomes substantial at $Q^2 \gtrsim 30 \text{ GeV}^2$ and even the dominant component of $F_2^c$ at $Q^2 \gtrsim 200 \text{ GeV}^2$ and $x \gtrsim 10^{-2}$. In this region of $Q^2$ the soft-pomeron exchange is numerically very small. We predicted in [8] that open charm SF is dominated entirely by the contribution from the rightmost hard BFKL pole at $Q^2 \lesssim 20 \text{ GeV}^2$, which is due to strong cancellations between the soft-pomeron and subleading hard BFKL exchanges. The soft-subleading cancellations become less accurate at smaller $x$, but at smaller $x$ the both soft and subleading hard BFKL exchange become rapidly Regge suppressed $\propto x^{\Delta_{IP}}, x^{\Delta_{IP}/2}$, respectively. In Fig. 2 we compare our CD BFKL-Regge predictions to the recent experi-
Figure 3: Comparison of predictions from CD BFKL-Regge factorization for the beauty structure function \( F_2^b(x, Q^2) \) with data [17] (full circles) and [18] (open circles). The solid curve is a result of the complete CD BFKL-Regge expansion, the contribution of the rightmost hard BFKL pole with \( \Delta_{\text{IP}} = 0.4 \) is shown by dotted curves.

Experimental data from the H1 Collaboration [17] and find very good agreement between theory and experiment which lends support to our 1994 evaluation \( \Delta_{\text{IP}} = 0.4 \) of the intercept of the rightmost hard BFKL pole in the color dipole approach with running strong coupling. The negative valued contribution from subleading hard BFKL exchange is important for bringing the theory to agreement with the experiment at large \( Q^2 \). For an alternative interpretation of heavy flavor production see [24, 25, 26] and references therein.
5 $F_2^b$ and hierarchy of pre-asymptotic pomeron intercepts

The characteristic feature of the QCD pomeron dynamics at distances $\sim m_b^{-1}$ is large negative valued contribution to $F_2^b$, coming from subleading BFKL singularities, see Fig. 1 and Ref.[9]. Consequences of this observation for the exponent of the energy dependence of the structure function

$$F_2^b \propto \left( \frac{x_0}{x} \right)^{\Delta_{\text{eff}}}$$

are quite interesting. In terms of the ratio $r_m = \sigma_m/\sigma_0$ (see Fig. 1) the exponent $\Delta_{\text{eff}}$ reads

$$\Delta_{\text{eff}} = \Delta_0 \left[ 1 - \sum_{m=1}^{\infty} r_m (1 - \Delta_m/\Delta_0) (x_0/x)^{\Delta_m - \Delta_0} \right]$$

Coefficients $r_m$ in eq.(12) depend on $r$. They are negative on the left from the rightmost node (Fig. 1) and positive on the right. Because for $r \sim m_b^{-1}$ all $r_m$ are negative, except $r_{\text{soft}}(0) > 0$ [9], at HERA energies the effective intercept $\Delta_{\text{eff}} \equiv \Delta_{\text{beauty}}$ overshoots the asymptotic value

$$\Delta_{\text{IP}} \equiv \Delta_0 = 0.4.$$  

At still higher collision energies both the soft and subleading hard BFKL exchanges become rapidly Regge suppressed. This results in decreasing $\Delta_{\text{eff}}$ down to $\Delta_{\text{IP}}$ [9].

For comparison, in photoproduction of open charm which scans, as we discussed above, the color dipole cross section at distances $\sim 1/m_c$, in the vicinity of the rightmost node, there is a strong cancellation between soft and subleading contributions to $F_2^c$ [14, 8]. Consequently, for this dynamical reason in open charm photoproduction we have an effective one-pole picture and the effective pomeron intercept

$$\Delta_{\text{eff}} \equiv \Delta_{\text{charm}} \simeq \Delta_{\text{IP}}.$$ 

In photoproduction of light flavors the CD cross section $\sigma_m(r)$ is close to the saturation regime $\sigma_m(r) \propto \text{const}$ and all subleading and soft terms of the CD BFKL-Regge expansion are positive valued and numerically important (see [6] for more details). This is the dynamical
reason for smallness of a pre-asymptotic pomeron intercept in photoproduction of light flavors. Hence, the hierarchy of pre-asymptotic intercepts

\[ \Delta_{\text{beauty}} > \Delta_{\text{charm}} > \Delta_{\text{light}} \] (13)

which brings to light the internal dynamics of leading-subleading cancellations at different hardness scales.

In Fig. 3 we presented our predictions for the beauty structure function. The solid curve corresponds to the complete expansion (10) while the dotted curve is the leading hard pole approximation, \( F_{2}^{b}(x, Q^{2}) \simeq f_{0}^{b}(Q^{2})(x_{0}/x)^{\Delta_{0}} \). In agreement with the nodal structure of subleading eigen-SFs the latter over-predicts \( F_{2}^{b} \) significantly because the negative valued contribution from subleading hard BFKL exchanges overtakes the soft-pomeron exchange and the background from subleading hard BFKL exchanges is substantial for all \( Q^{2} \) [9]. Our structure functions obtained in 1999 agree well with the determination of \( F_{2}^{b} \) by the H1 published in 2006 [17] (full circles) but contradict to very recent (2008, preliminary) H1 results on \( F_{2}^{b} \) [18] (open circles).

6 Elastic \( \Upsilon(1S) \) meson photoproduction.

The cross section of elastic \( \Upsilon(1S) \) meson photoproduction has been measured at HERA [27]. Quarks in \( \Upsilon \) meson are nonrelativistic and |\( \gamma \rangle \propto m_{b}K_{0}(m_{b}r) \). The forward \( \gamma \rightarrow \Upsilon \) transition matrix element \( \langle \Upsilon |\sigma_{n}(r)| \gamma \rangle \) is controlled by the product \( \sigma_{0}(r)K_{0}(m_{b}r) \) [28] and the amplitude of elastic of \( \Upsilon(1S) \) photoproduction is dominated by the contribution from the dipole sizes \( r \sim r_{\Upsilon} = A/m_{\Upsilon} \) with \( A = 5 \). The crucial observation is that at distances \( r \sim r_{\Upsilon} \) cancellation between soft and subleading contributions to the elastic photoproduction cross section results in the exponent \( \Delta \) in

\[ \frac{d\sigma(\gamma p \rightarrow \Upsilon p)}{dt}|_{t=0} \propto W^{4\Delta} \] (14)

which is very close to \( \Delta_{\text{IP}}, \Delta = 0.38 \) [9, 23]. This observation appears to be in agreement with the cross section rise observed by ZEUS&H1 [27].
Figure 4: Prediction from CD BFKL-Regge factorization for the longitudinal structure function of the proton $F_L(x, Q^2)$ as a function of the Bjorken variable $x_{Bj}$. The solid curve is a result of the complete CD BFKL-Regge expansion, the contribution of the rightmost hard BFKL pole with $\Delta_{\Pi} = 0.4$ is shown by dashed line. Data points are from [19]

7 $\Delta_{\Pi}$ from measurements of $F_L(x, Q^2)$

It has been demonstrated in [12] that the longitudinal structure function $F_L(x, Q^2)$ emerges as local probe of the dipole cross section at $r^2 \simeq 11./Q^2$. The subleading CD BFKL cross sections have their rightmost node at $r_1 \sim 0.05 - 0.1$ fm. Therefore, one can zoom at the leading CD BFKL pole contribution and measure the pomeron intercept $\Delta_{\Pi}$ from the $x$-dependence of $F_L(x, Q^2)$ at $Q^2 \sim 10 - 30$ GeV$^2$. The discussed above cancellation of the soft-subleading contributions is nearly exact at $Q^2 \sim 10 - 30$ GeV$^2$. This results in the leading hard pole dominance in this region, see Fig. 4) where comparison with the very recent H1 data [19] is presented.
8 Electromagnetic corrections to the Okun-Pomeranchuk theorem

Compare the total cross section of charged and neutral components of isotriplets of mesons like the $\rho$-mesons or pions on an electrically neutral target like a neutron. Arguably, for such a target the electromagnetic breaking of the Okun-Pomeranchuk theorem [1] will be dominated by the electromagnetic lifting of the degeneracy of sizes of charged and neutral $\rho$’s. The strength of the Coulomb interaction in the charge and neutral mesons is proportional to $e_u e_d$ and $-(e_u^2 + e_d^2)/2$, respectively, the net difference is $\propto (e_u + e_d)^2$. Consequently, the difference of the radii mean squared can be estimated as $\sim \alpha_{em} (e_u + e_d)^2 \langle r^2 \rangle$, what would entail

$$\frac{\sigma_\pm - \sigma_o}{\sigma_\pm + \sigma_o} \sim \alpha_{em} (e_u + e_d)^2$$

(15)

9 Conclusions

Color dipole approach to the BFKL dynamics predicts uniquely decoupling of subleading hard BFKL exchanges from open charm SF of the proton at $Q^2 \lesssim 20 \text{ GeV}^2$, from $F_L$ at $Q^2 \simeq 20 \text{ GeV}^2$ and from $\partial F_2/\partial \log Q^2$ at $Q^2 \simeq 4 \text{ GeV}^2$. This decoupling is due to dynamical cancellations between contributions of different subleading hard BFKL poles and leaves us with an effective soft+rightmost hard BFKL two-pole approximation with intercept of the soft pomeron $\Delta_{soft} = 0$. We predict strong cancellation between the soft-pomeron and subleading hard BFKL contribution to $F_2^c$ in the experimentally interesting region of $Q^2 \lesssim 20 \text{ GeV}^2$, in which $F_2^c$ is dominated entirely by the contribution from the rightmost hard BFKL pole. This makes open charm in DIS at $Q^2 \lesssim 20 \text{ GeV}^2$ a unique handle on the intercept of the rightmost hard BFKL exchange.

High-energy open beauty photoproduction probes the vacuum exchange at distances $\sim 1/m_b$ and detects significant corrections to the BFKL asymptotics coming from the subleading vacuum poles. We show that the interplay of leading and subleading vacuum exchanges gives rise to the cross section $\sigma^{bb}(W)$ growing much faster than it is prescribed by the exchange of the leading pomeron trajectory with intercept $\alpha_{IP}(0) - 1 = \Delta_{IP} = 0.4$. Our calculations within
the color dipole BFKL model are in agreement with the recent determination of $\sigma_{b\bar{b}}^{h}(W)$ by the H1 collaboration. The comparative analysis of diffractive photoproduction of beauty, charm and light quarks exhibits the hierarchy of pre-asymptotic pomeron intercepts which follows the hierarchy of corresponding hardness scales. We comment on the phenomenon of decoupling of soft and subleading BFKL singularities at the scale of elastic $\Upsilon(1S)$ -photoproduction which results in precocious color dipole BFKL asymptotics of the process $\gamma p \rightarrow \Upsilon p$.

Similar hard BFKL pole dominance holds for $F_L(x, Q^2)$. At still higher values of $Q^2$ the soft-pomeron exchange is predicted to die out and negative valued background contribution from subleading hard BFKL exchange with effective intercept $\Delta_3 \approx 0.06$ becomes substantial at not too small $x \sim x_0$. The agreement with the presently available experimental data on open charm/beauty in DIS confirm the CD BFKL prediction of the intercept $\Delta_{IP} = 0.4$ for the rightmost hard BFKL-Regge pole. The experimental confirmation of our predictions for hierarchy of soft-hard exchanges as function of $Q^2$ is a strong argument in favor of the CD BFKL approach.

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