conserve the s-channel helicity. The mechanism of SCHNC is well understood. SCHNC offers an unique window at the spin-orbit coupling in vector mesons. SCHNC in diffractive DIS drives, via unitarity relation, a dramatic small-x rise of the transverse spin structure function g_2 which breaks the Wandzura-Wilczek relation and invalidates the Burkhardt-Cottingam sum rule. The related unitarity effect is the tensor polarization of sea quarks in the deuteron which persists at small x.

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REGGE INTERCEPTS AND COUPLINGS FROM HIGH ENERGY FORWARD SCATTERING DATA

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This is the first part of the two presentations on the results of the analytic models for high energy forward scattering. We present primarily the results of the intercepts and couplings of the soft Pomeron as a Regge pole as well as those of the ρ/ω and f/a effective Reggeons from all accumulated data set available for total cross section and real part of the hadronic amplitudes. Factorization and quark counting rules are satisfied by the Pomeron couplings to within 10%, which allows us to make predictions on γp and $\gamma\gamma$ total cross sections with the help of the generalized vector dominance idea. In addition we check the range of validity in energy for the Regge pole model from the criteria for acceptable fits and establish the bounds on the Odderon and hard Pomeron contributions.

1 Introduction

Universal description of forward scattering by hadrons and of rising total cross section have been with us over two decades [1]. The interest in this topic has been revived by the recent activities at HERA on deep-inelastic and diffractive scattering. While the deep inelastic scattering data from HERA shows a qualitative rise in the off-shell cross sections extrapolated to low Q^2, the hadronic total cross sections measured from forward scattering reveal a very slow rise in energy.

The simplest idea for the slow rise with energy of the hadronic total cross sections is to assume a Regge trajectory with an intercept slightly larger than 1, having quantum members of vacuum, *i.e.* the Pomeron as a simple Reggeon with $\alpha_P(0) = 1+\varepsilon$, ε being a small positive number. This approach can predict the universal rise with energy of the total cross sections, the factorization of the Pomeron coupling and the quark counting based on the additive coupling of the Pomeron to the constituent quarks of hadrons. In fact our experience of several decades has proven that the Pomeron is a simple Regge pole to a good approximation. Regge theory has been a successful framework for describing soft hadronic interactions and offers a useful guideline in searching a fundamental description for the soft processes based on QCD. The soft Pomeron intercept is a crucial element in HERA analyses and provides the starting point at low x and low Q^2, from which QCD evolution can be performed. It also determines the Pomeron flux factor, which enters gap cross section, and has a bearing on the extrapolation of total cross section to higher energies.

The idea to start from perturbative QCD assumes that a higher order effects would unitarize the amplitude and tame the fierce rise observed at large Q^2 to something compatible with the Froissart bound. But no one has reliably unitarized QCD amplitudes. Moreover such unitarisation will involve necessarily multi-gluon exchanges between the quarks and therefore will require detailed quark structure, i.e., the hadronic wave functions. In such scheme, one is likely to lose the factorization property of the Pomeron as well as the quark counting rules and the universality property [2]. In addition, such unitarisation will lead to cut singularity rather then a pole type so that a power behavior in log s instead of s will be likely for the total cross sections.

Thus the simple pole model for the Pomeron remains to be the simplest and perhaps the most attractive option for near forward hadron scattering at high energies, even though this model does not offer a simple and automatic extension to the off-shell particle scattering and in particular to the deep inelastic scattering. A possible suggestion is to assume an extra "hard Pomeron" [3] that decouples at $Q^2 = 0$. Such extra trajectory is to some extent confirmed by the DGLAP evolution but the BFKL re-summation of energy logarithms is generally believed to be relevant to the high energy hadron processes. It has recently been shown[4] that the next-to-leading order corrections can drastically lower the intercept of the BFKL Pomeron, leading to a very weak dependence on Q^2 result that can be consistent with the soft Pomeron behavior exhibited by the hadronic cross section. However this is achieved by a fine-tuned compensations between the leading order and next-to-leading order corrections in BFKL re-summation, which offers no simple clue for the off-shell extension.

Mainly because of the simplicity, the simple Regge pole idea has been pushed by Donnachie and Landshoff (DL) [5,6] to fit all soft data for scattering of on-shell particles even at non-zero t. The DL Regge model contains an exchange-degenerate meson Reggeon term in addition to the Pomeron term. However it was shown by Cudell, Kang and Kim (CKK) [7] that the assumption of an exchange-degenerate meson trajectory is not even supported by the fits to the total cross sections alone and fails to give stable parameters when fitted to the total cross sections and the real parts of the forward scattering amplitudes. The simplest modification of the DL model suggested by CKK [7] that contains exchanges of two non-degenerate ρ/ω and f/a trajectories is called the model

RRP in our work [8] and in the second presentation [9] by V.V. Ezhela.

Then the question is to what extent can one say that the RRP model is a unique analytic possibility to describe all hadronic soft data. Since it is clear that the Froissart bound, which is a consequence of the unitarity and positivity of the imaginary part of the amplitude in the Lehmann ellipse, will be violated eventually by the bare Pomeron term with an intercept $\alpha_P(0) = 1 + \epsilon$ in the RRP model, the amplitude parameterization of RRP will not be valid at high energies where the unitarisation by multi-Pomeron exchanges is needed. Thus the validity region in energy of RRP model will necessarily have both a minimum cut-off energy below which the lower secondary trajectory and multi-Regge exchange effects are important and a maximum energy above which the unitarisation is needed. It was suggested in [7] that the stability of the values and errors of the parameters would be a good working criteria to decide the minimum cut-off energy of the validity region. This criteria is also adopted in the present work[8]. The bare Pomeron term can lead to either $\ln^2 s$ or $\ln s$ behavior for the cross section upon making an eikonal unitarisation [10]. Combined with the correct analyticity and crossing symmetry of the near forward amplitude, the results of the parameterization are given by either the model RRL2, which saturates the Froissart bound, or the model RRL1, which has a $\ln s$ behavior for the total cross section in our works [8,9]. We note in addition that the analytic parameterizations of RRL2 and RRL1 can easily be derived as solutions of the derivative dispersion relations [11], which approximate the region of analyticity at high energies but with a full unitarity of the scattering amplitude, or from the prescription of Block and Cahn [12]. In particular, RRL2 is often called as the Amaldi model[1] but has been around since 1974 [11] while RRL1 was proposed by Block, Kang and White [13] in 1990.

The results of comparative study of these three analytic models are presented in the second part [9], which shows that the simple pole model RRP is only one possibility of analytic amplitude models along with RRL2 and RRL1. Consideration of the χ^2 of the fits alone, though the largest data set [14] available is used, does not discriminate between the three analytic possibilities, implying that the effect of unitarisation is negligible and the maximum cut-off energy of the validity region is not evident up to the Tevatron energies.

In this presentation we concentrate on the results of the RRP model fits to the total cross sections and the ratio parameter ρ, *i.e.*, the ratio of the real part to the imaginary part of the forward scattering amplitudes. In particular we present the determination of the intercepts and couplings of the Pomeron and meson Reggeons. As we shall see, the only discrimination that the soft data can bring is lies in the confirmation of the properties that follow from that the Pomeron is a simple Regge pole coupled to constituent quarks, *i.e.*, factorizaion, quark counting and universality, though such property is also exhibited o some extent by RRL2 and RRL1. In the interest of saving the repetition, ve refer to Ezhela presentation [9] for the notations of the RRP parameters. There are three Regge terms coming from the Pomeron and $C = \pm 1$ meson rajectories in RRP model for a given $h\ p$ scattering process where $h = p^{\pm}$, $\pi^{\pm}$ and $K^{\pm}$. In addition, $\gamma\ p$ and $\gamma\ \gamma$ cross section are described by two terms epresenting contributions from the bare Pomeron and $C = +1$ (a/f) Reggeon. Since the intercepts of the Pomeron and meson trajectories are universal, there are altogether 16 parameters for fitting the RRP model to the data set of total ross sections and ρ parameter of $h\ p$ scattering, ($h = p^{\pm}, \pi^{\pm}$, and $K^{\pm}$) and he total cross sections of $\gamma\ p$ and $\gamma\ \gamma$ collisions. The results presented in this and the second talks [9] complement the earlier preliminary results [15,16].

: Dataset and Statistical Procedure

Ve have used the largest data set [14] prepared and maintained by the COMPAS roup for the cross sections and ρ parameters. They contain 2747 (303) data oints for total cross sections (ρ parameters) for $\sqrt{s} \geq 3$ GeV, and 271 (112) ata points for total cross sections (ρ parameters) for $\sqrt{s} \geq 9$ GeV. The umber of data points used in our fits is shown as a function of the minimum ut-off energy in Fig.1. As the dataset is large enough and contains no substantial inconsistencies, we have used the conventional definition of χ^2. Note owever that the most interesting parameter ε is sensitive to the highest energy region where the data are scarce. One may thus consider a scheme giving nore weight to the high energy data. Also one may remember that the total ross sections are better measured than the ρ parameters because of lingering oubt on the Coulomb - nuclear interference calculations. One further point s that the RRP model can not describe the resonance region which is also the ase for other asymptotic analytic models and they can be trusted only above certain minimum energy $\sqrt{s}_{min}$, which should be well above the threshold f resonance production. Thus the minimum cut-of energy $\sqrt{s}_{min}$ could be in rinciple process dependent. In spite of these worries we see no reason to use on-conventional definition of χ^2 and to invent different weighting schemes [6] or different energy data points but using the inverse squares of their total rrors as weights. We demand that $\chi^2/d.o.f. \leq 1$ and that the values of the arameters and their errors remain stable with respect to the minimum cut-off nergy $\sqrt{s}_{min}$, in order for the fits to be acceptable. This criterion implies that he Pomeron parameters are stable with respect to $\sqrt{s}_{min}$ and the low energy ata becomes of no primary importance. The resulting $\chi^2/d.o.f.$ as well as he stability pattern of the parameters of RRP model is also shown in Fig.1.

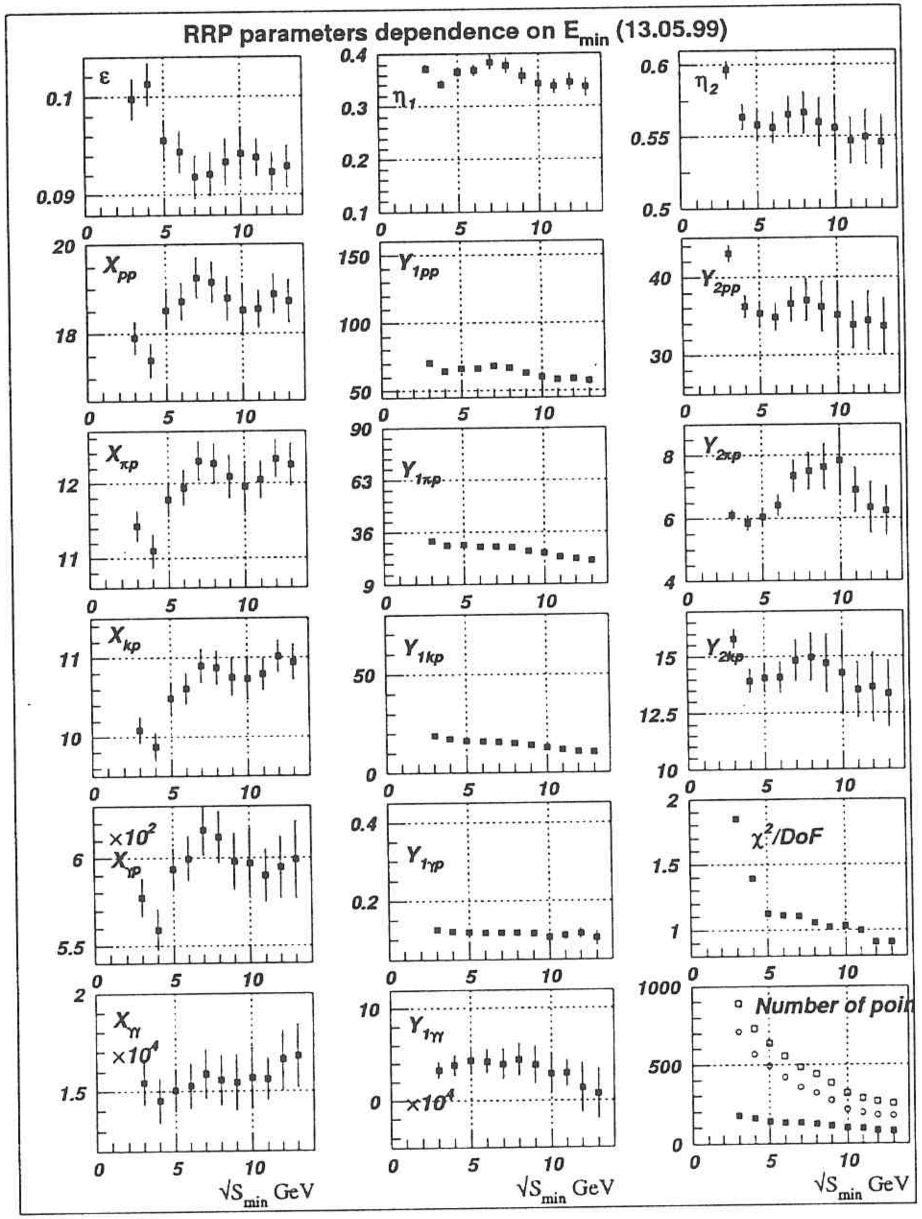

Figure 1: Parameters of the RRP model, as functions of the minimum energy considered in the fit

ε	η_1	η_2	$\chi^2/d.o.f.$	Number of data points	
0.0933(24)	0.357(15)	0.560(17)	1.02	383	
	pp	πp	Kp	$\gamma p \times 10^{-2}$	$\gamma\gamma \times 10^{-4}$
X_1 (mb)	18.79(51)	12.08(29)	10.76(23)	5.98(17)	1.55(14)
Y_1 (mb)	63.0(2.3)	26.20(74)	14.08(57)	11.64(88)	3.9(2.0)
Y_2 (mb)	36.2(3.2)	7.63(72)	14.7(1.3)		

Table 1: Summary of the fit results for E^{cm}_{min} = 9 GeV

Clearly, the fit is bad for small energies and in particular the criterion for the acceptable fits can be satisfied for $\sqrt{s}_{min} \geq 9$ GeV. As in the previous work of CKK [7], the proposed criteria fails to meet for the exchange-degenerate meson trajectories because $\chi^2/d.o.f.$ is large and of order 1.3 and the parameter values and their errors are unstable when fitted to the total cross sections and ρ parameters. In fact the results confirm the conclusion reached by CKK [7] that the assumption of exchange-degeneracy for $C = \pm 1$ meson tr ajectories is not supported even by the fits to the total cross sections alone. We need $C = \pm 1$ meson trajectories that are non-degenerate, particularly when we want to fit ρ parameters in addition to the total cross sections. Since the minimum cut-off energy $\sqrt{s}_{min}$ turns out to be as high as 9 GeV, the Pomeron parameters are reasonably well determined while those of the lower trajectories are determined less accurate. As it can be seen from Fig.1, the Pomeron intercept and couplings are stable with respect to $\sqrt{s}_{min}$ beyond 8 GeV. But as for the lower trajectories though $C = \pm 1$ intercepts and the $C = -1$ coupling are stable, $C = -1$ couplings do have $\sqrt{s}_{min}$ dependence within large errors. Note also that the $C = +1$ parameters are highly correlated to the Pomeron parameters so that we can not determinate the a/f couplings reliably. With these in mind, we give in Table 1 the values of the parameters determined for $\sqrt{s}_{min}$ = 9 GeV.

We see that the global $\chi^2/d.o.f.$ is good, even though the data is not filtered as in CKK [7], where it was shown that χ^2 per data points for total cross section (ρ parameter) was high for $p\bar{p}$ (pp) scattering due to possible inconsistencies within the data but could drastically be lowered by fitting the data without changing the determination of the parameters. In the present work, we see also high χ^2 per data points for these two processes but a few of these high χ^2 do not affect much for the global $\chi^2/d.o.f$ and our conclusions. The RRP fits for the total cross sections and ρ parameters for $\sqrt{s}_{min}$ = 9 GeV, extrapolated down to $\sqrt{s} \leq 5$ GeV, are shown and compared with the other two competing models in Figs.1 and 2 in the second part [9] of our presentations. Although the value of $\chi^2/d.o.f$ goes above 2 as it can be seen from Fig.1, so that statistically unacceptable, the fits look deceptively good. This is why we need a careful statistical analysis of the fits with physically sound criteria imposed on.

3 Discussion on the Results

3.1 Universality

As we see it from the comparative study [8, 9] of the three popular competing models, the χ^2 value alone can not differentiate the RRP model because other fits fare also as well. Thus the support for RRP model which treats the Pomeron as a simple Regge pole must come from some other evidence. In Regge theory, the l-plane singularities are universal, be they poles or cuts. Hence the energy dependence of the data has to be a combination of points which rise or fall with energy in a process-independent manner. Within the context of perturbative QCD, one could *a priori* expect a small deviation from ality [2], because the hadronic wave functions must come into calculation of the various terms. The universality of the Pomeron and meson trajectory intercepts is closely linked to the structure function F_2 at HERA [17]. There the effective Pomeron intercept, extracted from the power behavior in $1/x$ from $F_2(x)/x$, seems to depend on Q^2, the negative mass squared of the virtual photons. In order to check if a target mass M-dependent behavior of the Pomeron intercept is seen on the other side of $M^2 = 0$, we made a partial fit, fixing $C = \pm 1$ meson intercepts, at $\sqrt{s}_{min}$ = 9 GeV with the errors in the intercept corresponding to a change of 1 unit in the $\chi^2/d.o.f.$ The result is shown in Fig. 2 which seems to imply that the soft Pomeron intercept may be universal and independent of the target mass within the errors, though not terribly overwhelming.

3.2 Factorization and Quark Counting Rule

The couplings of the Reggeon exchanges are expected to factorize into a product of two couplings, one for each interacting hadron. Also the Pomeron couples to single quarks like a $C = +1$ photon in Regge theory. The Pomeron being an extended object, this will be a viable scenario only for constituent quarks if the Pomeron as a simple pole. The result of Table 1 gives

$$\frac{(X_{pp}/X_{\pi p})}{3/2} = 1.04 \pm 0.11$$

$$X_{Kp}/X_{\pi p} = 0.89 \pm 0.05$$

$$X_{\gamma p}/\left\{g_{em}^2\left[\frac{1}{f_p^2}+\frac{1}{f_\omega^2}+\frac{1}{f_\rho^2}\right](1+\delta)X_{\pi p}\right\} \approx \frac{213.9 X_{\gamma p}}{X_{pip}} = 1.06 \pm 0.04$$

$$X_{pp}X_{\gamma\gamma}/X_{\gamma p}^2 = 0.78 \pm 0.15$$

The first and second relations reflect the quark counting rule, the third is the factorization combined with generalized vector dominance [18] where the contribution from off-diagonal terms δ is expected to be about 15%, and the forth is an example of factorization. From these, we see that the properties of factorization and quark counting, expected from the Pomeron as a simple Regge pole, seem to hold within 10 %. Note however that quark counting fails to be for meson Reggeons, as they have to probe multi-quark configuration unlike the Pomeron which seems to couple to single quarks.

3.3 *Other Possible Trajectories*

The sharp rise observed at the HERA might be due to the presence of another singularity, hither to undetected, called the hard Pomeron. Assuming that this is a simple pole [3], one can fit the deep inelastic scattering data. To see the possible manifestation of the hard Pomeron in soft interactions, we tested its contribution assuming the hard Pomeron intercept to be 0.4 and obtained the following 2σ bounds on the hard Pomeron

$$X_{hard}^{pp}/X_{soft}^{pp} < 2 \times 10^{-6}$$

$$X_{hard}^{\pi p}/X_{soft}^{\pi p} \approx X_{hard}^{Kp}/X_{soft}^{Kp} < 3 \times 10^{-2}$$

$$X_{hard}^{\gamma p}/X_{soft}^{\gamma p} < 10^{-4}$$

Hence if the hard Pomeron exists as a simple pole, it much decouple at $Q^2 \leq 0$.

The exchange of a $C = -1$ trajectory [19] with intercept close to 1 is needed within the Donnachie- Landshoff model to reproduce the large $-t$ dip in elastic scattering. Assuming its intercept to be as low as 1, we obtain the 2σ bounds

$$\left|X_{odd}^{pp}/X_{soft}^{pp}\right| < 2 \times 10^{-3}$$

$$\left|X_{odd}^{\pi p}/X_{soft}^{\pi p}\right| < 10^{-3}$$

$$\left|X_{odd}^{Kp}/X_{soft}^{Kp}\right| < 2 \times 10^{-3}$$

Thus such object does not seem to be present at $t = 0$.

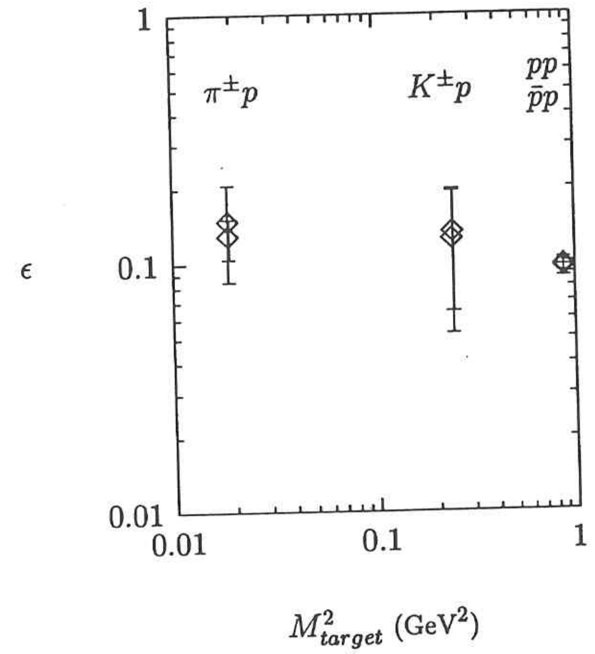

Figure 2: The value of the Pomeron intercept for three different processes.

4 Concluding Remarks

We have shown that RRP model produces very good fits to all data for $\sqrt{s}_{min} \geq 9$ GeV, with $\chi^2/d.o.f \leq 1$ and stable intercepts and Pomeron couplings. The Pomeron intercept is determined to be $\alpha_P(0) = 1.093(3)$ in agreement with the conclusion of CKK [7]. We have shown the $C = \pm 1$ meson trajectories are non-degenerate and have intercepts as given in Table 1. The interplay between the Pomeron and $C = +1$ meson Reggeon contribution makes the determination of the couplings of the latter Reggeon problematic, as there seems to be characteristic $\sqrt{s}_{min}$ dependence. Further stabilization of these couplings is needed. Furthermore we have indicated that the $t = 0$ data, based on the χ^2 consideration alone, can not rule out other analytic models of forward scattering amplitudes, which means that the unitarity effect is in no sight up to the available Tevatron energy. But the factorization and quark counting properties, which a re well respected within 10 %, are difficult to understand outside the context of the Pomeron as a simple Regge pole, which makes the RRP model rather attractive. It will be interesting to be able to enlarge the region of stability in energy, in particular, into the low energy region, while improving the stability of $C = +1$ couplings, either through the use of crossing-symmetric variable $\tilde{s} = (s-u)/2$ or $E_{lab} = (s-u)/4M_{target}$ or by modifying the variable with effective thresholds.

Finally a few comments on an observation form the comparative study of competing analytic models [8,9] are in order: we see from Fig. 3 in the second talk [9] that the stability of the parameters and $\chi^2/d.o.f \leq 1$ set in for RRL1 sooner at $\sqrt{s}_{min} = 5$ GeV than in RRP and RRL2 models. What is more intriguing is that a special case, denoted as RRL2s0, of RRL2 in which the constant term $A = 0$ with varying scale s_0 gives similar $\chi^2/d.o.f$ values as in RRL1 but with a low $\sqrt{s_0}$ about 20 MeV. Thus we seem to have two options, based on this limited study of comparative data fittings, for the Pomeron as a singularity in the l-plane. In view of the phenomenological success of the Pomeron as a simple bare Regge pole with an intercept slightly larger than 1, one may choose to favor the RRL1 model as a unitarized version of such bare Pomeron. On the other hand, the special RRL2s0 model corresponds to the l-plane singularity of a triple pole with the intercept exactly at 1. For such Pomeron, one needs no unitarisation as it respects the Froissart bound already. It will be important to be able to differentiate the two options for the Pomeron by further studies.

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