

# Saturation in DIS at HERA energies

---

Errol Gotsman\* †

*School of Physics and Astronomy, Raymond and Beverly Sackler Faculty of Exact Science, Tel Aviv University, Ramat Aviv 6998, Israel*

*E-mail: gotsman@post.tau.ac.il*

ABSTRACT: We examine HERA data with a view of determining whether unique signs of saturation can be identified. Concentrating on two channels the logarithmic slope of  $F_2$ , and the production of  $J/\Psi$ , which are sensitive to the behaviour of  $xG(x, Q^2)$  the gluon density distribution in the proton, we show that alternative models comprising a sum of a "soft" and "hard" component also fit the data.

---

## 1. Introduction

The problem we address, is whether the experimental results emanating from HERA [1] contain clear evidence for the presence of saturation effects, or whether they are consistent with orthodox pQCD evolution.

To quantify saturation it is instructive to introduce the concept of a packing factor (PF) which is related to the density of the partons in a parton cascade.

$$PF \equiv \kappa = \frac{3\pi^2\alpha_S}{2Q_s^2(x)} \times \frac{xG(x, Q_s^2(x))}{\pi R^2} \quad (1.1)$$

The saturation scale  $Q_s^2$  is defined by  $\kappa = 1$ , for which  $Q^2 = Q_s^2$ . (see fig.1)

In the dilute region ( $\kappa < 1$ ) the partons are distant from one another (and have no interaction in the parton cascade), so pQCD (i.e. DGLAP and BFKL) evolution holds, and the dominant process is the emission of gluons. In the high density phase ( $\kappa > 1$ ) the partons in the parton cascade interact, these interactions give rise to screening corrections (SC), which slow down the growth of the parton density distributions. The correct description of parton evolution in the high density phase is given by a non-linear evolution equation of the type first suggested by Gribov, Levin and Ryskin [3], which incorporates parton recombination as well as emission.

There have been numerous attempts to find both approximate analytical and numerical solutions to the non-linear equation (for a recent review see [4]). These solutions suggest that the saturation scale  $Q_S(x) \approx 1 - 2 GeV^2$ , in the HERA kinematic region. The very

\*Speaker.

†in collaboration with E. Levin, U. Maor and E. Naftali

successful phenomenological model of Golec-Biernat and Wuesthoff [5], which provides an excellent description of HERA data based on the premise that the saturation region has been reached at HERA, is additional evidence supporting the saturation hypothesis.

## 2. The GLMN model

In a series of papers, the latest of which are listed in [6], we have applied screening (unitarity) corrections to a number of inclusive and exclusive channels. We follow the Glauber-Mueller (eikonal) approach [7] in calculating screening (unitarity) corrections to pQCD evolution. The technique used for evaluating the SC in the quark and gluon sectors are given in reference [8].

As the SC are much larger for the gluon sector than for the quark sector, we quote results here for two channels that in LLA of pQCD are directly proportional to  $xG(x, Q^2)$ , the gluon distribution in the proton.

- 1) The logarithmic slope of  $F_2$ :

$$\frac{\partial F_2(x, Q^2)}{\partial \ln Q^2} = \frac{2\alpha_S}{9\pi} xG^{DGLAP}(x, Q^2), \quad (2.1)$$

- 2) The cross section for the exclusive production of the vector meson  $J/\Psi$ . For which the contribution of pQCD to the imaginary part of the  $t = 0$  differential cross section is given by

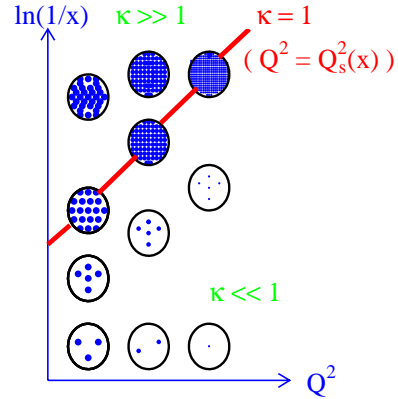
$$\left( \frac{d\sigma(\gamma^* p \rightarrow V p)}{dt} \right)_{t=0}^{pQCD} = \frac{\pi^3 \Gamma_{ee} M_V^3}{48\alpha} \frac{\alpha_S^2(\bar{Q}^2)}{\bar{Q}^8} (xG^{DGLAP}(x, \bar{Q}^2))^2 \left( 1 + \frac{Q^2}{M_V^2} \right),$$

here  $xG^{DGLAP}$  denotes the gluon distribution function as obtained from the DGLAP analysis.

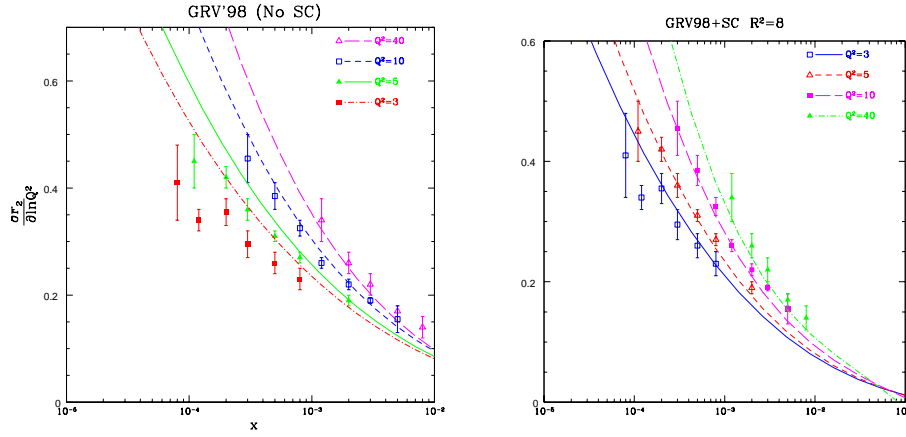
Our results. see Fig.2 and Fig.3, suggest that already at HERA energies the SC are considerable for these two channels.

## 3. Alternative Models

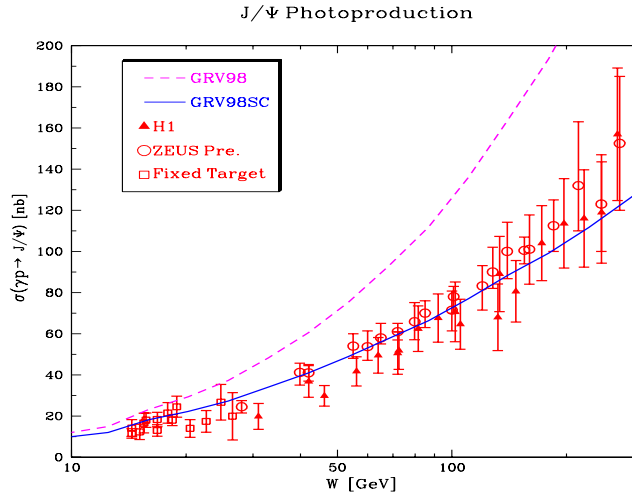
Although, the results presented above are consistent with the hypothesis that signs of saturation have been seen at HERA, they are not conclusive. Since models based on the sum of the contributions of a "hard" and a soft "Pomeron" e.g. [9] and [10], provide a fair description of the HERA data. These models do not incorporate pQCD evolution, but have a common feature in that they both require the "soft" Pomeron component to be appreciable at fairly small scales  $\approx 0.3 - 0.5$  fm.



**Figure 1:** Parton distribution in the transverse plane.



**Figure 2:** Logarithmic derivative of  $F_2$  with and without SC.

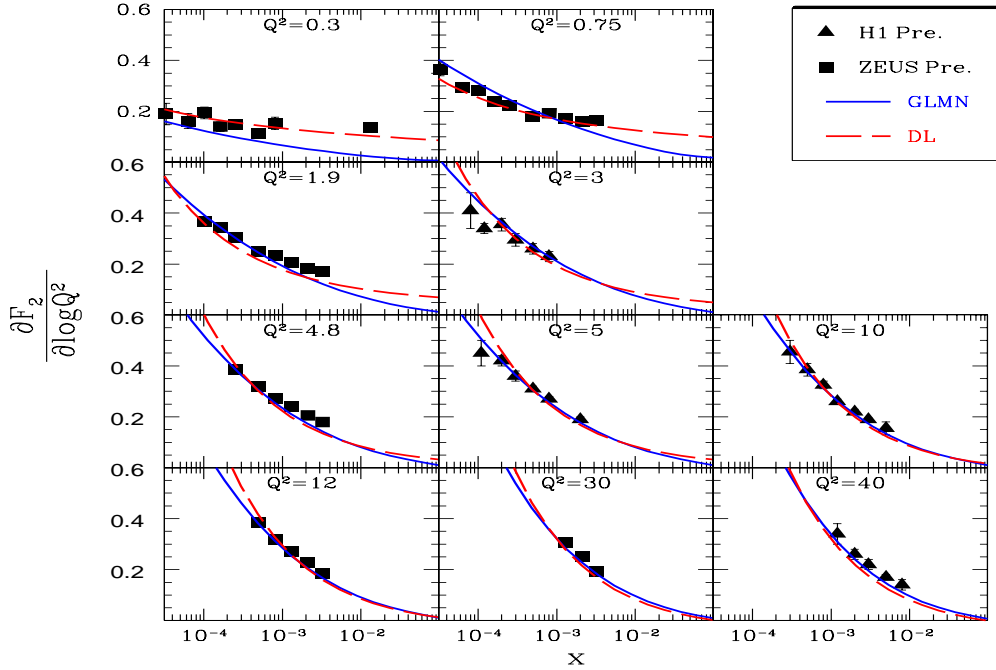


**Figure 3:**  $\sigma(\gamma p \rightarrow J/\Psi)$  with and without SC.

In Fig.4 we compare the DL predictions for  $\frac{\partial F_2(x, Q^2)}{\partial \ln Q^2}$  with those of our model (GLMN) i.e. screened GRV'98, and show that there is little to choose between them for  $Q^2 \geq 1.9 \text{ GeV}^2$ . For values of  $Q^2 \leq 1 \text{ GeV}^2$  there is no justification for using pQCD (our model).

#### 4. Conclusions

Although, HERA data is consistent with the hypothesis that we are dealing with parton densities that are sufficiently dense ( $\kappa \approx 1$ ), that SC are necessary. The findings are not conclusive as an alternative explanation is also valid i.e. that of a matching between a "soft" and a "hard" process (e.g. the DL model) where the "soft" component dominates at relatively short distances of 0.3 - 0.5 fm.



**Figure 4:**  $W$  dependence of HERA data for logarithmic slope at fixed  $Q^2$  (in  $\text{GeV}^2$ ) compared with our calculations screened GRV98 and the DL model.

## References

- [1] see experimental papers presented by H1 and ZEUS collaboration at HEP2001 (this volume).
- [2] A.H. Mueller, *Nucl. Phys.* **B 355** (1990) 115.
- [3] L.V. Gribov, E.M. Levin and M.G. Ryskin, *Phys. Rept.* **100** (1983) 1; *Nucl. Phys.* **B 188** (1981) 555.
- [4] M. Lublinsky, "Scaling Phenomena from Non-Linear Evolution in high energy DIS" hep-ph/0106112.
- [5] K. Golec-Biernat and M. Wuesthoff, *Phys. Rev.* **D 59** (1999) 014017; *Phys. Rev.* **D 60** (1999) 114023.
- [6] E. Gotsman, E. Ferreira, E. Levin, U. Maor and E. Naftali, *Phys. Lett.* **B 500** (2001) 87; *ibid Phys. Lett.* **B 503** (2001) 277.
- [7] A. Zamolodchikov, B. Kopeliovich and L. Lapidus, *Sov. Phys. JETP Lett.* **33** (1981) 595; E.M. Levin and M.G. Ryskin, *Sov. J. Nucl. Phys.* **45** (1987) 150; A.H. Mueller, *Nucl. Phys.* **B 415** (1994) 373.
- [8] E.Gotsman, E.M. Levin, U. Maor and E. Naftali, *Nucl. Phys.* **B 539** (1999) 535.
- [9] A. Donnachie and P.V. Landshoff, *Phys. Lett.* **B 437** (1998) 408; *Phys. Lett.* **B 470** (1999) 243.
- [10] J.R. Forshaw, G. Kerley and G. Shaw *Phys. Rev.* **D 60** (1999) 074012.