

QCD and total cross-sections : photons and hadrons

R.M. Godbole*, A. Grau[†], G. Pancheri** and Y.N. Srivastava[‡]

*Centre for High Energy Physics, Indian Institute of Science, Bangalore, 560012, India

[†]Departamento de Física Teórica y del Cosmos Universidad de Granada, 18071 Granada, Spain

**INFN Frascati National Laboratories, Via Enrico Fermi 40, I-00044 Frascati, Italy

[‡]INFN and Physics Department, University of Perugia, Via A. Pascoli, I-06123 Perugia, Italy

Abstract. In this contribution, we discuss a total cross-section model which can be applied to both photon and purely hadronic processes. We find that the model can reproduce photo-production cross-sections, as well as extrapolation of γ^*p processes to γp using Vector Meson Dominance models, with minimal modifications from the proton case.

Keywords: total and inclusive cross-sections, optical models, resummation, eikonal approximation

PACS: 13.60.Hb, 13.85.Lg, 12.40.Nn, 12.38.Cy, 11.80.Fv

INTRODUCTION

All total cross-sections are seen to rise asymptotically [1]. For all processes, the rise starts in the region $\sqrt{s} \approx 10 \div 50 \text{ GeV}$. It has long been advocated that the rise is due to the onset of perturbative parton-parton collisions [2] and a large amount of modelling has been developed to describe the energy dependence of the total cross-section. A compilation of total cross-section data [3] from purely hadronic processes [1, 4] together with the available ones from photon processes [5, 6, 7] shows that while photoproduction data could accommodate a rise similar to the pure hadronic processes, this may not be so for purely photon processes. Indeed we have shown this not to be true for the case of $\gamma\gamma$ scattering [8].

If one ignores the limits imposed by the Froissart-Martin bound, namely $\sigma_{total} \leq C \log^2 s$, a phenomenologically successful model for the energy behaviour of total cross-sections for different processes is given by the expression proposed in [9], namely

$$\sigma_{tot}^{AB} = X_{AB} s^{-\eta} + Y_{AB} s^{\varepsilon} \quad (1)$$

with $\varepsilon \approx 0.08 \div 0.09$. The above equation however implies that all the cross-sections should have the same power law behaviour.

In order to develop a model which might go beyond the low energy description, we notice that the range of energy of total cross-section measurements can be divided into four different regions:

- the resonance region which depends on the quantum numbers of the s-channel process
- the Regge region, where analyticity, crossing and unitarity predict an energy behaviour with a decreasing power law, i.e. $\sigma_{total} \simeq s^{-\eta}$, and $\eta \approx 0.5$ and whose

details depend on the quantum numbers of the t-channel process

- a region with the onset of the rise and where σ_{total} starts rapidly to grow, possibly with a power law type behaviour
- the truly asymptotic region where the cross-section should obey the Martin-Froissart bound.

The first two regions are related in their energy behaviour through Finite Energy Sum Rules (FESR) [10], while the last two are dominated by the dynamics of perturbative QCD processes. In the model we have developed [11] and which shall be described in this contribution, we focus on the high energy (rising) part, and describe the rise by perturbative gluon-gluon scattering, with saturation effects, which lead to a satisfaction of the Froissart bound due to soft gluon emission. According to our model, infact, resummation of gluons in the infrared region is the major origin of the transformation of the rise from a power law to a $\log s$ or $\log^2 s$ type behaviour.

THE BLOCH-NORDSIECK MODEL FOR THE TOTAL CROSS-SECTION

We work in the eikonal representation, for which

$$\sigma_{tot}^{\gamma p} = 2P_{had}^{AB} \int d^2\vec{b} [1 - e^{-n(b,s)/2}] \quad (2)$$

with $P_{had}^{AB} = 1$ for purely proton processes, otherwise related to the probability that a photon behaves like a hadron, for which a matter distribution is expected. We use $P_{had}^{\gamma\gamma} = [P_{had}^{\gamma}]^2$ and put $P_{had}^{\gamma} \equiv P_{had} = 1/240$ from Vector Meson Dominance.

In Eq. 2 the real part of the eikonal function has been approximated to zero, and the imaginary part is given by the average number of inelastic collisions $n(b, s)$. To calculate this quantity, we distinguish between collisions with an outgoing parton with $p_t \geq p_{tmin}$, with p_{tmin} in a region where perturbative QCD calculations can be used, and all other collisions, i.e. we write

$$n(b, s) = n_{soft}(b, s) + n_{hard}(b, s) \quad (3)$$

and calculate $n_{hard}(b, s)$ from QCD, using QCD mini-jets to drive the rise. For photo-production processes we have

$$n^{\gamma p}(b, s) = n_{soft}^{\gamma p}(b, s) + n_{hard}^{\gamma p}(b, s) = n_{soft}^{\gamma p}(b, s) + A(b, s) \sigma_{jet}^{\gamma p}(s) / P_{had} \quad (4)$$

with n_{hard} including all outgoing parton processes with $p_t > p_{tmin}$. The parameter p_{tmin} is a cut-off imposed on the jet cross-section, namely

$$\sigma_{jet}^{AB}(s, p_{tmin}) = \int_{p_{tmin}}^{\sqrt{s}/2} dp_t \int_{4p_t^2/s}^1 dx_1 \int_{4p_t^2/(x_1 s)}^1 dx_2 \sum_{i,j,k,l} f_{i|A}(x_1, p_t^2) f_{j|B}(x_2, p_t^2) \frac{d\hat{\sigma}_{ij}^{kl}(\hat{s})}{dp_t} \quad (5)$$

where A and B are the colliding hadrons or photons, in this case $A = \text{proton}, B = \gamma$. By construction, this cross-section depends on the particular parametrization of the DGLAP evolved parton distribution functions (PDFs). Phenomenology of the early rise in proton-proton suggests $p_{tmin} \approx 1 \text{ GeV}$, and these low energy jets are called *mini-jets*. Because the jet cross-sections are calculated using actual photon densities, which themselves give the probability of finding a given quark or gluon in a photon, P_{had} needs to be canceled out in n_{hard} .

In Eq.4 the impact parameter dependence has been factored out: this is an approximation which could be relaxed in the future. There exist many models in the literature to describe the impact parameter distribution of matter in the colliding particles, the earliest of such models based on convolution of the particles form factors. The problem with these models is the difficulty to extend them to the photon, although Vector Meson Dominance (VMD) might suggest to use a meson-like description, namely a monopole functional dependence, with an *ad hoc* scale. There exist also more fundamental recent studies from perturbative Reggeon calculus [12].

The impact parameter distribution

In our model the matter distribution in two colliding hadrons or hadron-like particles (for the case of the photon in its interactions with matter) are determined by the k_t distribution of soft gluons emitted in the interaction [13]. As the partons move through the field of the other colliding quarks and gluons, they are deviated from their collinear path through soft gluon emission. The Fourier transform of the resultant resummed k_t -distribution gives the energy-dependent impact parameter function to enter the eikonal. We use

$$A_{BN}^{AB}(b, s) = \mathcal{N} \int d^2\mathbf{K}_\perp \frac{d^2P(\mathbf{K}_\perp)}{d^2\mathbf{K}_\perp} e^{-i\mathbf{K}_\perp \cdot \mathbf{b}} = \frac{e^{-h(b, q_{max})}}{\int d^2\mathbf{b} e^{-h(b, q_{max})}} \equiv A_{BN}^{AB}(b, q_{max}(s)). \quad (6)$$

The function A_{BN}^{AB} is normalized to 1 and is obtained from the Fourier transform of the soft gluon resummed transverse momentum distribution. This impact parameter distribution is energy dependent through the function

$$h(b, q_{max}(s)) = \frac{16}{3} \int_0^{q_{max}(s)} \frac{dk_t}{k_t} \frac{\alpha_s(k_t^2)}{\pi} \left(\log \frac{2q_{max}(s)}{k_t} \right) [1 - J_0(k_t b)] \quad (7)$$

which is defined by $q_{max}(s)$, the maximum transverse momentum allowed to single gluon emission, averaged over the parton-parton cross-sections, as described in [3]. To fully include in the model the very low momentum gluons, emitted in indefinite number during the interaction, we have made an ansatz as to the behaviour of the strong coupling constant $\alpha_s(k_t^2)$ with

$$\alpha_s(k_t) = \frac{12\pi}{33 - 2N_f} \frac{p}{\ln[1 + p(\frac{k_t}{\Lambda})^{2p}]} \approx \text{constant} \times \left(\frac{\Lambda}{k_t} \right)^{2p} \quad k_t \rightarrow 0 \quad (8)$$

with $p < 1$ for the soft gluon integral to converge.

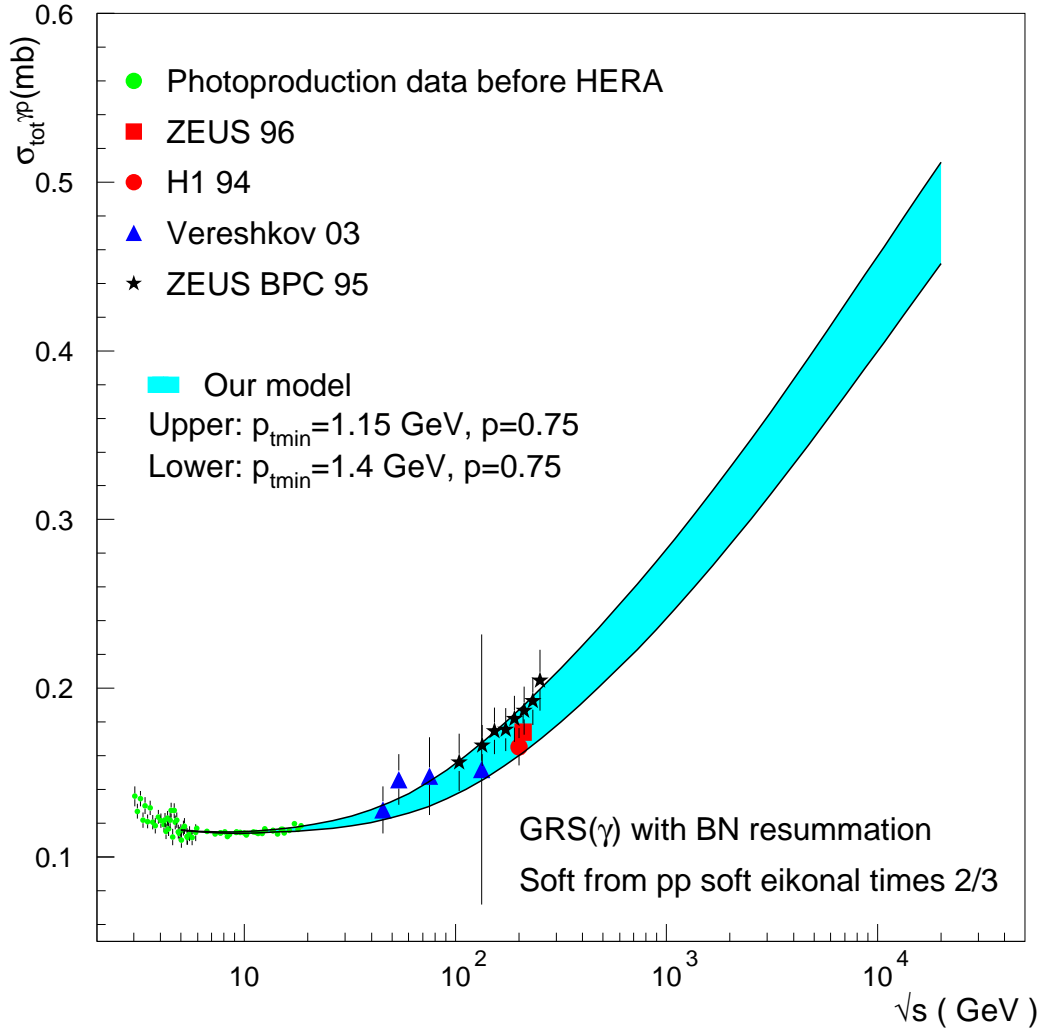


FIGURE 1. Description of γp data from the Bloch Nordsieck model described in the text

PHOTOPRODUCTION TOTAL CROSS-SECTION

We show in Fig. 1 the results of this model when applied to photoproduction data, and to a set of $\gamma^* p$ data from ZEUS BPC, extrapolated to $Q^2 = 0$ using Generalized Vector Meson Dominance [14, 15, 16]. In the figure, the upper end of the band corresponds to the model with the same parameters found to give a good fit to proton-proton and proton-antiproton scattering, namely GRV densities for the proton, $p_{\text{tmin}} = 1.15 \text{ GeV}$, $p = 0.75$. The lower edge corresponds to a higher value of p_{tmin} , as indicated. Curves for other values of the parameters and different densities for quarks and gluons are described in ref. [3].

In conclusion, we have applied to photoproduction our QCD model, originally developed to describe total cross-sections for purely hadronic processes, obtaining a good description of existing data, with minimal changes in the model parameters.

ACKNOWLEDGMENTS

R.G. acknowledges support from the Department of Science and Technology, India, under the J.C. Bose fellowship. G. P. thanks the Laboratory for Nuclear Science of the Massachusetts Institute of Technology Laboratory for hospitality while this work was being written. This work has been partially supported by MEC (FPA2006-05294) and Junta de Andalucía (FQM 101 and FQM 437).

REFERENCES

1. W.-M. Yao *et al.* **Particle Data Group**, J. Phys. G **33** (2006) 1.
2. D. Cline, F. Halzen and J. Luthe, Phys. Rev. Lett. **31** (1973) 491.
3. R. Godbole, A. Grau, G. Pancheri and Y.N. Srivastava, *Total photoproduction cross-section at very high energy*, submitted to EPJC, hep-ph/0812.1065.
4. G. Arnison *et al.*, **UA1** Collaboration, Phys. Lett. **128B** (1983) 336 ; R. Battiston *et al.* **UA4** Collaboration, Phys. Lett. **B117** (1982) 126; C. Augier *et al.* **UA4/2** Collaboration, Phys. Lett. **B344** (1995) 451 ; M. Bozzo *et al.* **UA4** Collaboration, Phys. Lett. **147B** (1984) 392 ; G.J. Alner *et al.* **UA5** Collaboration, Z. Phys. **C32** (1986) 153 ; N. Amos *et. al.*, **E710** Collaboration, Phys. Rev. Lett. **68** (1992) 2433 ; C. Avila *et. al.*, **E811** Collaboration, Phys. Lett. **B445** (1999) 419; F. Abe *et. al.*, **CDF** Collaboration, Phys. Rev. **D50** (1994) 5550.
5. H1 Collaboration, S. Aid *et al.*, Zeit. Phys. **C69** (1995) 27, hep-ex/9509001.
6. ZEUS collaboration, S. Chekanov *et al.*, Nucl. Phys. **B627** (2002) 3, hep-ex/0202034.
7. L3 Collaboration, M. Acciarri, *et al*, **CERN-EP/2001-012**, Phys. Lett. **B519** (2001) 33 , hep-ex/0102025; OPAL Collaboration. G. Abbiendi *et al.*, Eur. Phys. J. **C14** (2000) 199 .
8. R. M. Godbole, A. De Roeck, A. Grau and G. Pancheri, JHEP **0306** (2003) 061 [arXiv:hep-ph/0305071].
9. A. Donnachie and P. V. Landshoff, Phys. Lett. B **296** (1992) 227 [arXiv:hep-ph/9209205]; A. Donnachie and P. V. Landshoff, Phys. Lett. B **595**(2004) 393 [arXiv:hep-ph/0402081].
10. K. Igi and M. Ishida, Phys. Lett. **B622** (2005) 286 and references therein.
11. A. Achilli, R. M. Godbole, A. Grau, R. Hegde, G. Pancheri and Y. Srivastava, Phys. Lett. B **659** (2008) 137 [arXiv:0708.3626 (hep-ph)]; R. M. Godbole, A. Grau, G. Pancheri and Y. N. Srivastava, Phys. Rev. D **72** (2005) 076001, [arXiv:hep-ph/0408355].
12. J. Bartels, D. Colferai, S. Gieseke, A. Kyrieleis, Phys.Rev. **D66** (2002) 094017. e-Print: hep-ph/0208130; J. Bartels, S. Gieseke and C.F. Qiao, Phys. Rev. **D63** (2001) 056014, Erratum-ibid. **D65** (2002)079902, e-Print: hep-ph/0009102.
13. A. Grau, G. Pancheri and Y. N. Srivastava, Phys. Rev. D **60** (1999) 114020 [arXiv:hep-ph/9905228]; A. Corsetti, A. Grau, G. Pancheri and Y. N. Srivastava, Phys. Lett. B **382** (1996) 282 [arXiv:hep-ph/9605314].
14. D. Haidt , *The transition from $\sigma(\gamma^* p)$ to $\sigma(\gamma p)$* , Prepared for 9th International Workshop on Deep Inelastic Scattering (DIS 2001), Bologna, Italy, 27 Apr - 1 May 2001. Published in *Bologna 2001, Deep inelastic scattering* 287-290, and refs. therein.
15. B. Surrow, DESY-THESIS-1998-004; A. Bornheim, in the *Proceedings of the LISHEP International School on High Energy Physics, Brazil, 1998*, hep-ph/9806021.
16. ZEUS Collaboration, J. Breitweg *et al.*, EPJC **7** (1999) 609, DESY-98-121, hep-ex/9809005v1.