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Total Photonic and Hadronic Cross-sections [1]

Rohini M. Godbole
Centre for Theoretical Studies, Indian Institute of Science, Bangalore 560 012, India.
E-mail: rohini@cts.iisc.ernet.in

A. Grau
Departamento de Física Teórica y del Cosmos,
Universidad de Granada, Spain
E-mail: igrau@ugr.es

G. Pancheri
INFN - Laboratori Nazionali di Frascati,
Via E. Fermi 40, I00044 Frascati, Italy
E-mail: Giulia.Pancheri@lnf.infn.it

Abstract

We discuss total cross-sections within the context of the QCD calculable mini-jet model, highlighting its successes and failures. In particular we show its description of $\gamma\gamma \to hadrons$ and compare it with OPAL and L3 data. We extrapolate this result to $\gamma\, p$ total cross-sections and propose a phenomenological ansätz for virtual photon cross-sections. We point out that the good agreement with data obtained with the Eikonal Minijet Model should not hide the many uncertainties buried in the impact parameter distribution. A model obtained from Soft Gluon Summation is briefly discussed and its application to hadronic cross-sections is shown.

[1] Talk presented by G.P. at Photon-2000, Ambelside, U.K., Aug 26-31, 2000

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R.M. Godbole*, A. Grau†, G. Pancheri**

*Centre for Theoretical Studies, Indian Institute of Science, Bangalore 560 012, India
† Departamento de Física Teórica y del Cosmos, Universidad de Granada, Spain
** INFN - Laboratori Nazionali di Frascati, Via E. Fermi 40, I00044 Frascati, Italy

Abstract. We discuss total cross-sections within the context of the QCD calculable mini-jet model, highlighting its successes and failures. In particular we show its description of $\gamma\gamma \to hadrons$ and compare it with OPAL and L3 data. We extrapolate this result to $\gamma\, p$ total cross-sections and propose a phenomenological ansätz for virtual photon cross-sections. We point out that the good agreement with data obtained with the Eikonal Minijet Model should not hide the many uncertainties buried in the impact parameter distribution. A model obtained from Soft Gluon Summation is briefly discussed and its application to hadronic cross-sections is shown.

I INTRODUCTION

This talk will be a short review of the status of the calculation of total cross-sections using a QCD driven mini-jet model [1], with particular emphasis on recent measurements and results of theoretical calculations of $\gamma\gamma$ cross-sections.

One of the aim of QCD is to calculate cross-sections for hadronic processes. We find that the level of available experimental information on total hadronic cross-sections has now reached a stage so as to allow, for the first time, definite progress in the calculation of the one quantity which has so far escaped a complete quantitative understanding in a QCD framework, namely the total hadronic cross-section. We have a complete set of processes, pp, $p\bar{p}$, γp and $\gamma\gamma$ measured in a common energy range, $\sqrt{s} = 1 \div 100\ GeV$, with the purely hadronic processes measured up to $\sqrt{s} \approx 3 \times 10^5\ GeV$ [2]. The latter allows for very good parametrizations in a large energy range, the other two cross-sections to test the QCD content of hadrons versus the one in the photons. In Figure 1 we show a compilation of all presently available photon and proton total cross-sections, scaling them so as to be able to compare one to each other. For $\gamma\ p$ processes, the scale factor is the product of a Quark Parton Model factor 3/2 multiplied by a Vector Meson Dominance type factor 1/240 [1], for $\gamma\gamma$ we just square this factor.

The plan of this paper is as follows :

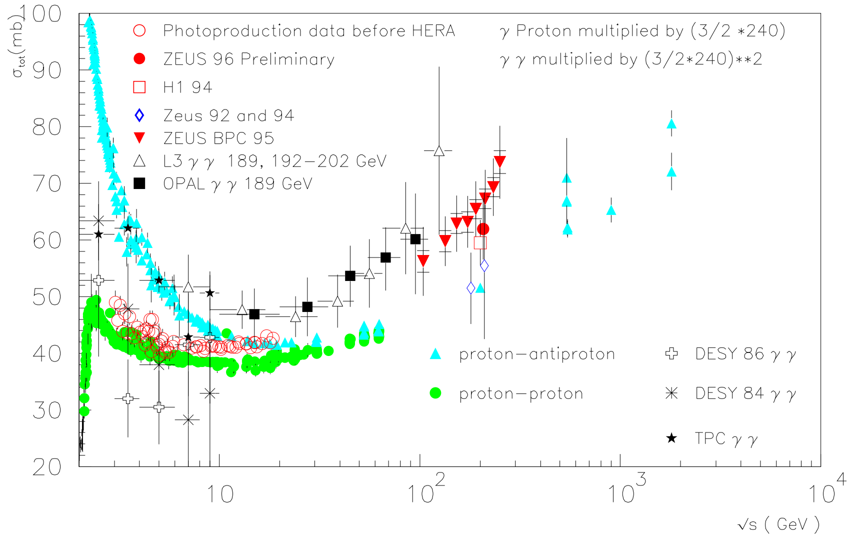

FIGURE 1. Energy dependence of $\sigma_{ab}^{\rm tot}$ for various choices of a, b as indicated in the figure. The cross-sections for the photon-induced processes have been scaled as indicated on the figure.

1. In Sect. II we describe our recent results for $\gamma\gamma$ and extrapolate them to $\gamma\ p$
2. In sect. III we discuss a possible ansätz on an extension of the minijet model to $\gamma^*\gamma^*$
3. In Sect. IV we present recent results for pp and $p\bar{p}$, using an impact parameter distribution for partons in the hadrons obtained from the Bloch-Nordsieck summation technique, and discuss its possible extensions to real and virtual photons.

II $\gamma\gamma$ AND γ *proton*

While for quite some time the photon-photon data at LEP exhibited a discrepancy between different collaborations (although within the experimental errors), we now have two sets of data points which are in excellent agreement with each other. A theorist can then start his/her work. We show in Figure 2 the description of L3 [3] and OPAL data [4] using the Eikonal Minijet Model (EMM). The theoretical context in which this curve was obtained is discussed in [1,5] : the EMM uses the eikonal approximation [6] to calculate the total cross-section, i.e.

$$\sigma_{tot} = 2P^{ab}_{had}\int d^2\vec{b}[1-e^{i\chi(b,s)}] \qquad (1)$$

and approximates the eikonal function neglecting $\Re e\chi(b,s)$ and putting

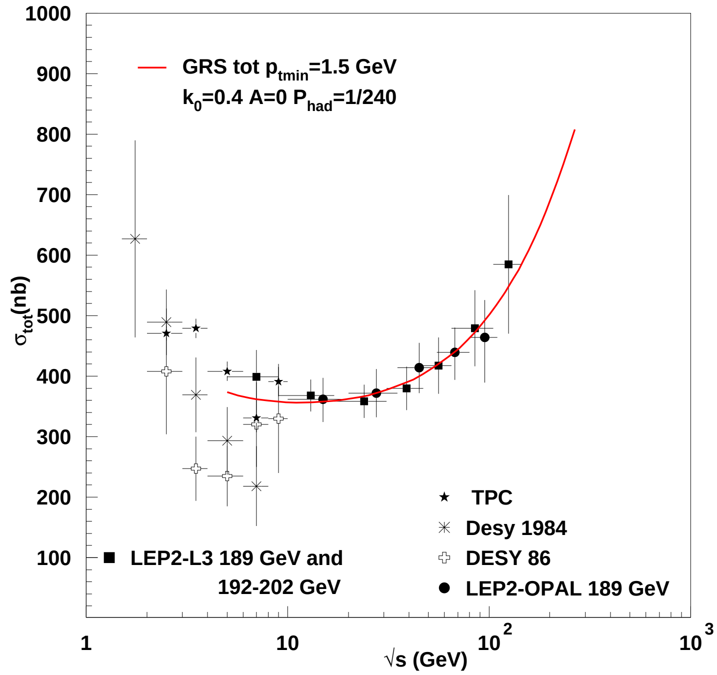

FIGURE 2. The total photon-photon cross-section as described by the EMM (see text)

$$2\Im m\chi(b,s) = n(b,s) = A(b)[\sigma_{soft}(s) + \frac{\sigma_{jet}(s,p_{tmin})}{P^{ab}_{had}}] \tag{2}$$

where the QCD calculable jet cross-section is the quantity which drives the rise [7] in all total cross-sections. This function is defined as

$$\sigma_{jet} = \int d^2\vec{p}_t \frac{d\sigma^{QCD}}{d^2\vec{p}_t} = \sum \int dx_1 dx_2 f^{i/a}(x_1) f^{j/b}(x_2) \int d^2\vec{p}_t \frac{d\hat{\sigma}^{ij,kl}}{d^2\vec{p}_t} \tag{3}$$

where $\hat{\sigma}$ is the parton-parton cross-section for the subprocess $ij \to kl$, the sum runs over i,j,k,l,=parton type and the integration covers a region from a minimum p_t to the entire phase space. The quantity σ_{jet} is higly dependent upon the regulator p_{tmin} and one of the aims of a complete QCD calculation is to eliminate this dependence. Presently this is not yet possible, but one can nonetheless expect p_{tmin} to be the smallest momentum exchanged between partons such that perturbative QCD can be applied, namely not less than 1 GeV and probably not more than 2 GeV. The parameter $P^{ab}_{had} \equiv P^a_{had} P^b_{had}$ is in principle energy dependent and P^a_{had} can be interpreted as the probability for particle a to behave like a hadron, i.e. $P^{hadron}_{had} \equiv 1$ and, typically, $P^{\gamma}_{had} \approx \mathcal{O}(\alpha)$ [8,9]. Phenomenologically, in order to obtain a description of the measured total cross-sections, there are other input quantities which need to be fixed, namely σ_{soft} and the b-distribution function $A(b)$. One way to proceed has been, previously, to determine all the parameters from the process γp. However, the EMM model is not working very well for the proton case, as discussed in [10], probably because of uncertainties in the hadronic transverse momentum distributions, and we have opted, in this note, for a different approach, namely we obtain the parameters from γp, extrapolate them to $\gamma\gamma$ varying them within at most 10% to fit the $\gamma\gamma$ cross-section, and then revert back and see what the best description of $\gamma\gamma$ will produce, when applied to photoproduction. The result of this *modus operandi* is presented here. For Figure 2, we have chosen to describe the partonic matter distribution inside the hadrons through a function inspired by the pion electromagnetic form factor, namely

$$A(b) = \frac{1}{(2\pi)^2} \int d^2\vec{q} e^{i\vec{q}\cdot\vec{b}} (\frac{k_0^2}{q^2 + k_0^2})^2 \tag{4}$$

The scale k_0 has been let to vary, according to an intrinsic transverse momentum ansätz [1]. Thus, Figure 2 corresponds to $k_0 = 0.4\ GeV$, $P_{had}^{\gamma} = 1/240$, $\sigma_{soft} = (21 + \frac{42}{s})\ mb$, $p_{tmin} = 1.5\ GeV$ and GRS [11] type densities for the photon. Next we extrapolate this curve to γp processes, putting $\sigma_{soft}^{\gamma p} = 3/2\sigma_{soft}$, the proton form factor with dipole type expression instead of one of the photon type monopole expressions, GRV type densities for the proton [12] and GRS for the photon. The result is the upper curve shown in Figure 3 and compared with old and recent data [13–16]. For completeness and as a reference to our previous work, we also show a band, with the lowest curve corresponding to GRV densities for both proton and photon, $p_{tmin} = 2\ GeV$, $k_0 = 0.66\ GeV$ for the photon, same P_{had}^{γ} as the upper curve, and $\sigma_{soft}^{\gamma p} = (31 + \frac{10}{\sqrt{s}} + \frac{38}{s})\ mb$.

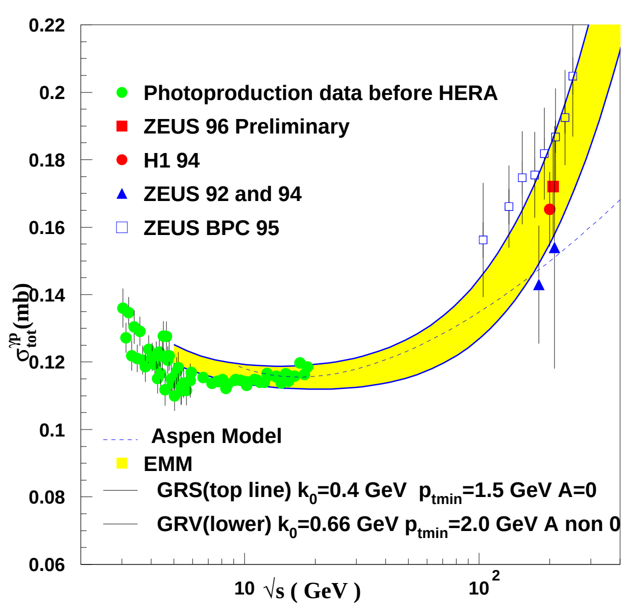

FIGURE 3. Comparison between the eikonal minijet model predictions and data for total $\gamma\ p$ cross-section as well as BPC data extrapolated from DIS [15]. Predictions from [17] are also shown.

III THE CASE OF THE VIRTUAL PHOTON

Hadronic interactions of the virtual photon in e^+e^- and $\gamma\gamma$ processes have been a subject of interest for some time now [18]. The appearance of experimental data on jet production with virtual photons at HERA [19] and total $\gamma^*\gamma^*$ cross-sections at LEP [20], has given added impetus to develop a model which will describe the total cross-sections for virtual photons, especially the 'resolved' part [21].

We want to develop a model to understand these cross-sections in the context of EMM. We propose that the virtual photon description is the same as for the case of real photons except that the intrinsic transverse momentum ansätz is complemented with a factor inspired by Extended Vector Meson Dominance [22]. At high Q^2_γ, a factor like

$$A((b, Q_1^2, Q_2^2) = \frac{m_\rho^2}{m_\rho^2 + Q_1^2}\frac{m_\rho^2}{m_\rho^2 + Q_2^2} A(b) \tag{5}$$

will suppress the part of the cross-section which has a hadronic content. In Eq.(5), $P^\gamma_{had}(Q^2_\gamma = 0)$ is the usual factor, $\approx 1/240$, obtained from Vector meson Dominance and discussed in many papers [5,8,9]. In Figure 4 we show our predictions for the hadronic content of the $\gamma^*\gamma^*$ cross-section, excluding for the time being the direct and single resolved contribution. Similar results can also be obtained using factorization [23] in the context of the Aspen [17] model.

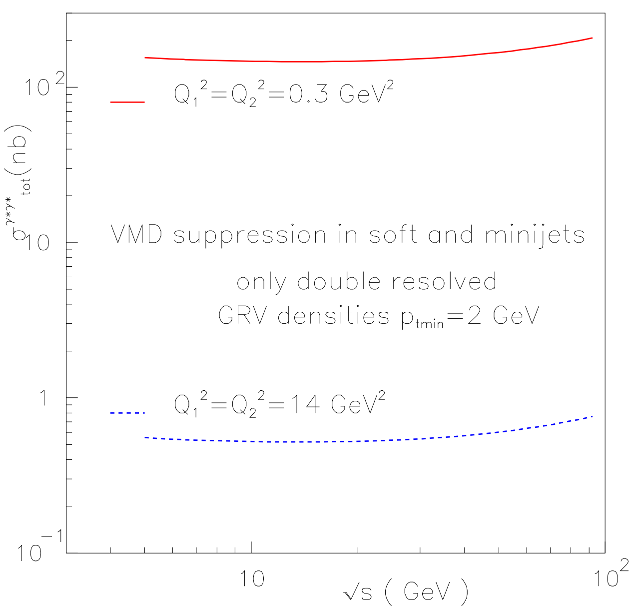

FIGURE 4. The EMM predictions for virtual photons cross-section. Q_i^2 corresponds to the virtual photon mass

IV THE BLOCH NORDSIECK MODEL FOR THE IMPACT PARAMETER DISTRIBUTION

It is evident from the previous discussion, and we have pointed this out in many papers, that it is not possible to have a QCD description of the total cross-section without understanding the transverse momentum distribution of partons in the colliding hadrons, or, in the eikonal language, without understanding the impact parameter distribution. We have attempted such description, and will show in the following the main highlights. Some very recent results in the case of proton proton and proton antiproton are shown in Figure 5, where the two curves have

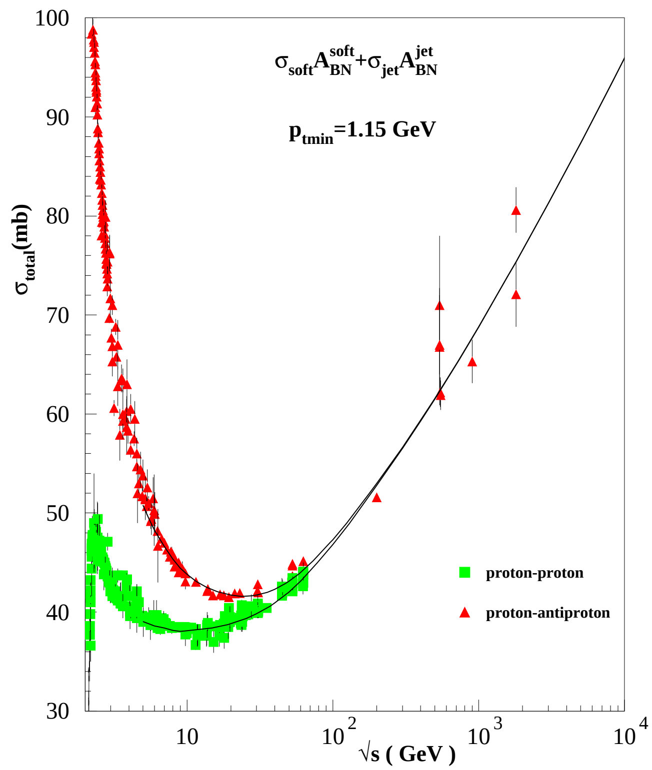

FIGURE 5. Total proton-proton and proton-antiproton cross-sections, compared with an eikonal minijet model which incorporates soft gluon summation

been obtained using the eikonal formula of Eq.(1), the jet cross-sections with GRV densities and $p_{tmin} = 1.15\ GeV$, $\sigma^{pp}_{soft} = 48\ mb$, $\sigma^{p\bar{p}}_{soft} = 48(1 + \frac{2}{\sqrt{s}})mb$. Unlike the curves obtainable in a straightforward application of the EMM with b-distribution determined by the proton form factor, this figure uses an s-dependent b-distribution given by

$$A(b,s) = \frac{\int d^2\vec{q}e^{i\vec{b}\cdot\vec{q}}\Pi(q,s)}{(2\pi)^2\Pi(0,s)} = \frac{e^{-h(b,s)}}{\int d^2\vec{b}e^{-h(b,s)}} \tag{6}$$

where $\Pi(q,s)$ is the transverse momentum distribution of colliding partons generated by soft gluon radiation from the initial state and, to leading order,

$$h(b,s) = \frac{8}{3\pi}\int_0^{q_{max}} \alpha_s(k_t)\frac{dk_t}{k_t}[1-J_0(bk_t)]\log\frac{q_{max}+\sqrt{q^2_{max}-k_t^2}}{q_{max}-\sqrt{q^2_{max}-k_t^2}} \tag{7}$$

The functions $h(b,s)$ and $A(b,s)$ are energy dependent inasmuch as the kinematics of a given subprocess determine how much energy is available to single soft gluon emission. The energy dependence appears through the quantity q_{max} which is a function of the c.m. energy $\sqrt{s}$ and p_{tmin}. In addition $h(b,s)$ depends upon the single soft gluon distribution function $\alpha_s(k_t)dk_t/k_t$. Since $\Pi(q,s)$ is summed over all possible gluon distributions, the infrared divergence is of course cancelled, there remains, however, the problem of evaluating α_s in the infrared limit. We have used a phenomenological ansätz, namely a singular but integrable α_s and the result shown in Figure 5 is discussed in [10] for the rising part of the total proton cross-sections. The main characteristics of this treatment is that, as the minijet cross-section rises with energy, soft gluon emission produces an acollinearity of the partons and reduces the probability of collisions. This affects the cross-sections in two ways : at low energy it produces a very soft decrease in σ^{pp} and contributes to the faster decrease in $\sigma^{p\bar{p}}$, at high energy it tames the rise due to σ^{jet}. It is then possible to have a very small p_{tmin} to see the very beginning of the rise around $10 \div 20\ GeV$, without having too large a cross-section when the energy climbs into the TeV range and beyond.

The above discussion illustrates also the way to study virtual and real photon interactions : the aim is to obtain an energy and momentum dependence in the impact parameter distribution through the kinematics characterizing real or virtual photon process, as it has been done for the proton. At high Q^2_γ, one can expect q_{max} in Eq.(7) to increase with Q^2_γ, thus producing the same suppression effect that high c.m. energy values have in the softening of the rise due to the jets. The overall effect may be similar to the EVMD factor discussed in Sect. III. Work is in progress to apply the Bloch-Nordsieck formalism to these collisions.

V CONCLUSION

We have discussed total cross-sections for protons and photons, real and virtual, using QCD calculable mini-jets cross-sections as the physical process which drives the rise of all total cross-sections. We have used the eikonal formalism to unitarize the cross-section and discussed possible ways to reduce the arbitrariness introduced in this formalism by the impact parameter distribution. A QCD model using soft gluon summation has been presented and compared with data for purely proton processes.

VI ACKNOWLEDGEMENT

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