

IISc-CHEP/09/07

# Total cross-section and rapidity gap survival probability at the LHC through an eikonal with soft gluon resummation

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## Abstract

New results are presented for total pp/ $\bar{p}$ p cross-sections, in the framework of our QCD based model (GGPS). This is an improved eikonal mini-jet model, where soft gluon radiation tames the fast energy rise normally present in mini-jet models. We discuss the variability in our predictions and provide a handy parametrization of our results for the LHC. We find that our model predictions span the range  $\sigma_{tot}^{LHC} = 100_{-13}^{+10} \text{ mb}$ . While this matches nicely with the range of most other models, it does not agree with recent ones which include a "hard" Pomeron, even though our model does include hard scattering. We compute the survival probability for Large Rapidity Gap (LRG) events at the LHC and at the Tevatron. These events are relevant, for example, for Higgs signal in the  $WW$  fusion process. We also explore whether measurements of the total cross-sections at the LHC can help us sharpen the model parameters and hence estimates for these survival probabilities, further.

# 1 Introduction

In this letter we discuss the upcoming measurements of the total proton-proton cross-section at LHC, in the context of a QCD based model, which may be used to shed light on the role played by soft gluon resummation in the infrared limit [1]. We work in an Eikonalised mini-jet model and achieve unitarisation through an Eikonal, where the energy dependent impact parameter distribution is calculated in a QCD based model using realistic parton densities. This model, for specific values of the parameters, chosen by confronting it with available data, gave a value  $\sigma_{tot}^{LHC} = 100.2 \text{ mb}$  [2]. It is our purpose here to present cross-section estimates at LHC for a full range of parameter choices and provide a useful parametrisation of these for comparison with the LHC data. It can then be further used to describe other soft quantities such as the underlying event distributions and rapidity gap survival probabilities. Note that a reliable prediction of total non-diffractive cross-section is essential for a correct projection of the expected underlying activity at the LHC, which in turn is required at times to ensure the correct extraction of new physics from the LHC data. Surely we will have to depend -at the initial stages of LHC- upon predictions based on our current understanding of these matters. There exists a close relationship between the energy dependence of the total cross-section and the size as well as the energy dependence of the survival probability of the large rapidity gaps (LRG). These are regions in angular phase space devoid of any particles which might exist in events in  $pp$  /  $\bar{p}p$  reactions, where a colour singlet state is produced and there exist no color connections between the two colliding hadrons [3, 4, 5, 6]. Such events are predicted, for example, when a Higgs boson is produced through  $WW$  fusion. This unique signature can be used very effectively, also in searches of other color singlet states which are sometimes predicted in various Beyond the SM (BSM) scenarios and which can also give rise to events with large rapidity gaps. Both the events with LRG and the survival probabilities of the rapidity gaps continue to be a subject of intense study for this reason [3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14].

The plan of the letter is as follows : in Section 2 we present the salient features of the above model, and explore the dependence of results for total cross-section on the QCD inputs such as the parton density functions (PDFs). In section 3 we explore the various perturbative, nonperturbative inputs and parameters of the model and compare the predictions of our model with the data. We use the results of this exploration of model parameters to obtain an estimate of the “theoretical” uncertainty. We also provide a simple parametrisation of our model and a table with numerical estimates for the LHC. In Section 4 we present our expression for the survival probability for LRG and evaluate it within our model, using a representative set of parameters, and comparing it with predictions from other approaches.

## 2 Eikonal Mini-jet Model model with soft gluon resummation in impact parameter space.

In this section, we recall briefly some of the relevant details of our model [1, 2]. We shall then apply it to estimate the total cross-section at LHC and, in the last section, to predict Survival Probabilities for Large Rapidity Gaps (SPLRG) at LHC.

Generically, the total cross-section can be written as

$$\sigma_{tot}^{AB}(s) = \sigma_{soft}(s) + \vartheta(s - \bar{s})\sigma_{hard}(s) \quad (1)$$

with  $\sigma_{soft}$  containing a constant (the “old” Pomeron with  $\alpha_P(0) = 1$ ) term plus a (Regge) term decreasing as  $1/\sqrt{s}$ , with an estimate for the constant  $\sim 40$  mb [2]. In the mini-jet model the rising part [15] of the cross-section  $\sigma_{hard}$  is provided by jets which are calculable by perturbative QCD [16, 17, 18], obviating (at least in principle) the need of an arbitrary parameter  $\epsilon$  which controls the rise as in [19, 20]. The increase in  $\sigma_{tot}^{pp/p\bar{p}}$  with energy is driven by the rise with energy of  $\sigma_{jet}^{AB}$  which is given by

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

Here subscripts  $A$  and  $B$  denote the colliding particles ( $p$  and/or  $\bar{p}$ ),  $i, j, k, l$  the partons and  $x_1, x_2$  the fractions of the parent particle momentum carried by the parton.  $\sqrt{\hat{s}} = \sqrt{x_1 x_2 s}$  and  $\hat{\sigma}$  are the centre of mass energy of the two parton system and the hard parton scattering cross-section respectively. Let us note that parton density functions (PDF's) in the proton, extracted from QCD analysis of a variety of data and the basic elements of perturbative QCD such as the elementary subprocess cross-sections, are the only inputs needed for the calculation of  $\sigma_{jet}^{AB}$ . Needless to say one uses the DGLAP evolved,  $Q^2$  dependent PDF's. The rate of rise with energy of this cross-section is determined by  $p_{tmin}$  and the low- $x$  behaviour of the parton densities. As often discussed, this rise is much steeper than can be tolerated by the Froissart bound. Hence the mini-jet cross-section is imbedded in an eikonal formulation [21], namely

$$\sigma_{tot}^{AB} = 2 \int d^2\vec{b} [1 - e^{-2\Im m \chi^{AB}(b, s)} \cos(\Re \chi^{AB}(b, s))] \quad (3)$$

where  $2\Im m \chi^{AB}(b, s) = n^{AB}(b, s)$  is the average number of multiple collisions assumed to be Poisson distributed [22]. The quantity  $n(b, s)$  has contributions coming from both soft and hard physics and we write it as

$$n^{AB}(b, s) = n_{soft}^{AB}(b, s) + n_{hard}^{AB}(b, s) \quad (4)$$

By construction,  $n_{hard}$  includes only parton-parton collisions where the scattered partons have  $p_t \geq p_{tmin}$ , the cut off in the mini-jet cross-section. It follows that all other collisions are included in  $n_{soft}$ .

In the standard formulation of the eikonal for the total cross-section,  $n(b, s)$  is assumed to factorize into a  $b$ -dependent overlap function  $A(b)$ , which is a measure of the overlap

in the transverse plane of the partons in the colliding beams, and an  $s$ -dependent (soft + jet) cross-section. Most eikonal models, including QCD driven ones of *Refs.* [12, 14, 23], propose a functional  $b$ -dependence derived from the Fourier transform of the electromagnetic Form Factor (FF). However, as already noted some time ago in [21], these eikonal models would lead to too steep a rise of the total cross-section with energy, if one would use actual QCD mini-jet cross-sections with a fixed  $p_{tmin}$ . This was shown in detail for GRV densities [24] in [2].

An altogether different approach is to relax the  $b - s$  factorization and assume that the  $b$ -distribution,  $A(b)$ , is energy dependent. This is physically what one expects, since when two hadrons collide the matter distribution cannot stay constant, rather the partons influence each other's path. We make this idea of the shift in the path of the parton more quantitative by modeling the  $b$ -distribution as the Fourier transform of the change in collinearity of the partons due to soft gluon emission before the collision. Let  $A(b) = A_0$  at time  $t = -\infty$ , before the collision. At this time the partons do not yet influence each other and stay in some ideal "hadronic" configuration. This configuration gets modified as they approach each other and soft gluon emission takes place as partons feel each other's color field and scatter. Let  $\Pi(\mathbf{K}_t)d^2\mathbf{K}_t$  be the probability distribution that a pair of partons acquires a transverse acollinearity  $\mathbf{K}_t$  because of soft gluon emission before the collision. Then the change in the static ideal  $b$ -distribution  $A_0$  in our model is calculated as the Fourier transform of this probability and the quantity  $A_0$  is fixed by the normalization requirement, namely that the probability of finding two partons at a distance  $\mathbf{b}$  from each other must be 1 when we sum over all possible values. This gives

$$A(b, s) = A_0 \int d^2\mathbf{K}_t e^{-i\mathbf{K}_t \cdot \mathbf{b}} \Pi(\mathbf{K}_t) = \frac{e^{-h(b, q_{max})}}{\int d^2\mathbf{b} e^{-h(b, q_{max})}} \equiv A_{BN}(b, q_{max}) \quad (5)$$

where the function  $h(b, q_{max})$  is obtained from soft gluon resummation techniques [1]. Because, in general, soft gluon emission is energy dependent, the assumption of the factorization into a  $b$ -dependent piece and an  $s$ -dependent piece is automatically relaxed. We denote the corresponding overlap functions by  $A_{BN}(b, q_{max})$ , where BN stands for Bloch-Nordsieck, to remind us of the origin of the soft gluon resummation factor and notice that it depends (i) on the energy, (ii) the kinematics of the subprocess and (iii) the parton densities. Depending on how one models  $q_{max}$ , the rapid rise in the hard, perturbative jet part of the eikonal can then be tamed, into the experimentally observed mild increase, by soft gluon radiation whose maximum energy ( $q_{max}$ ) rises slowly with energy.

Before evaluating  $n_{hard}$ , we point out that the evaluation of  $A_{BN}$  through the function  $h(b, s)$  in Equation 5, involves  $\alpha_s$  in the infrared region [1, 2]. In our model, an important role is played by the integral of  $\alpha_s$  down to zero momentum gluons. This is a non-perturbative region and we model the behaviour as a power law, namely  $\alpha_s(k_t) \approx k_t^{-p}$  as  $k_t \rightarrow 0$ . As noticed before [25], what is observable are only moments of  $\alpha_s$  and not the single vertex. In order to have a continuous analytic expression valid also in the perturbative region, we then use a phenomenological form inspired by the Richardson potential [1], namely

$$\alpha_s(k_t^2) = \frac{12\pi}{33 - 2N_f} \frac{p}{\ln[1 + p(\frac{k_t}{\Lambda})^{2p}]} \quad (6)$$

This parametrization of the infrared behaviour of  $\alpha_s$  involves the parameter  $p$  which for the Richardson potential is 1, but which we take always as *less than* 1 for the integral to be convergent.

One can now use  $q_{max}$  values (obtained from kinematical considerations [26, 27]) to calculate the impact parameter distribution for the hard part of the eikonal, namely  $A_{BN}(b, q_{max}^{jet})$ , and then  $n_{hard}(b, s)$ , using the mini-jet cross-sections. Notice that for a given set of QCD parton densities, one obtains corresponding values for  $\sigma_{jet}$  and  $q_{max}^{jet}$ . The interplay of these quantities and their dependence upon the densities and  $p_{tmin}$  has been explicitly discussed in [27]. The "hard" part is thus fully determined. The subsequent step of obtaining the full  $n(b, s)$  and its eikonalization requires finding appropriate values for the soft part of the eikonal. The 'soft' part, determined by non-perturbative dynamics, is modeled as follows:  $n_{soft}$  is factorized into a non-rising soft cross-section  $\sigma_{soft}$  and  $A_{soft} = A_{BN}(b, q_{max}^{soft})$ . The non-perturbative, soft part of the eikonal includes only limited low energy gluon emission and leads to the initial decrease in the proton-proton cross-section.  $q_{max}$  is assumed to be the same for the hard and soft processes at low energy ( $\sim 5$  GeV), parting company around 10 GeV where hard processes become important.

Thus, neglecting the real part of the eikonal, one can now calculate the total  $pp$  and  $p\bar{p}$  cross-section with Equation 3 and  $n(b, s)$  as given below:

$$n(b, s) = A_{BN}(b, q_{max}^{soft})\sigma_{soft}^{pp,\bar{p}} + A_{BN}(b, q_{max}^{jet})\sigma_{jet}(s; p_{tmin}), \quad (7)$$

where

$$\sigma_{soft}^{pp} = \sigma_0, \quad \sigma_{soft}^{p\bar{p}} = \sigma_0(1 + \frac{2}{\sqrt{s}}) \quad (8)$$

The three parameters of the model so far are  $p_{tmin}$ ,  $\sigma_0$  and  $p$ . Values of  $p_{tmin}$ ,  $\sigma_0$  and  $p$  which give a good fit to the data with the GRV parametrisation of the proton densities [24] are 1.15 GeV, 48 mb and 3/4 respectively, as presented in Ref. [2]. These values are consistent with the expectations from a general argument [2]. Figure 1 compares the predictions of GGPS with data [28, 29, 30, 31, 32, 33, 34] as well as the one obtained in [35] by phenomenological considerations along with unitarity and factorisation. It should be noted here that, in contrast to other models which employ the eikonal picture, in our model the eikonal is determined in terms of just these three parameters along with the parton densities in the proton and the QCD subprocess cross-sections. We expect these *favourite* values to change somewhat with the choice of parton density functions. Since we are ultimately interested in the predictions of the model at TeV energies, we need PDF parametrisation which cover both the small and large  $Q^2$  range and are reliable up to rather small values of  $x$  ( $\sim 10^{-5}$ ). Further, since our calculation here is only LO, for consistency we have to use LO densities.

We notice [27] that not all sets of PDF's return the correct energy dependence for the total cross-section. This is clearly due to the fact that our model probes down to very low- $x$  values for the mini-jet cross-sections. As the energy increases, the fixed value of  $p_{tmin}$  amounts to receiving contributions from  $x_{gluon} \approx 10^{-5}$  and not all densities have the same behaviour at such low  $x$ -values. Recall that only limited amount of data are available in the small- $x$  region and for  $x_{gluon} \lesssim 10^{-5}$ , almost all the PDF's use extrapolation of the parton densities at higher values of  $x$  where they are obtained by fits to the data. In

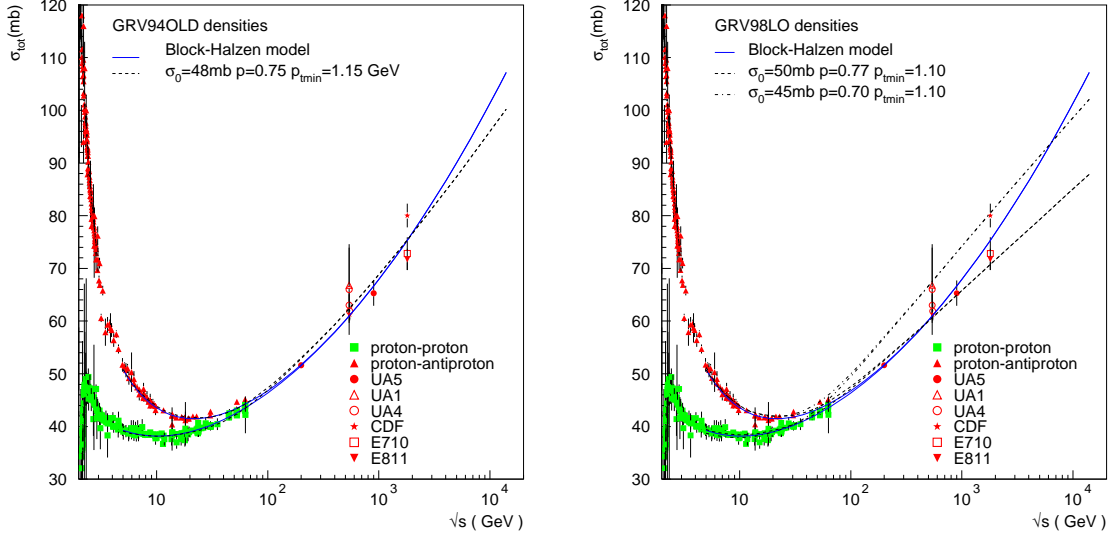


Figure 1: Comparison of the GGPS predictions for GRV and GRV98lo densities with data and with the BH [35] prediction. The parameter set used for the GGPS model are also shown.

particular, we note that the CTEQ [36] densities lead to total cross-sections which start decreasing beyond the Tevatron energy range, thus differing from all the other densities. Within our model,  $q_{max}^{CTEQ}$  is seen to rise to higher values, the consequent decrease in the cross-section more than compensates for the rise due to the minijets, thus leading to cross-sections decreasing with energy. This shows the interplay between the densities and soft gluon emission. On the other hand, it is comforting to see that other commonly used densities, such as GRV and MRST [37, 38, 39], give results in the same range and with acceptable energy behaviour up to cosmic ray energies. This characterizes our model as being stable versus most available density types. From now on we shall only employ the GRV and MRST densities in further analysis.

### 3 Predictions for $\sigma_{tot}^{pp/pp}$ at LHC

Having described the role played by PDF's in a computation of total cross-sections at LHC, we explore for a range of PDF's [37, 38, 39] different inputs for  $p$ ,  $p_{tmin}$  and  $\sigma_0$ . For each PDF, the onset of the rise fixes  $p_{tmin}$ ,  $\sigma_0$  controls the normalization and  $p$  determines the slope of the rising part of the cross-section (as well as the normalization through  $A_{BN}$ ). We find that it is possible to get a satisfactory description of all current data, for all choices of PDF's considered, namely MRST and GRV. The corresponding range of values of  $p_{tmin}$ ,  $\sigma_0$  and  $p$  are given in Table 1, together with expected values of  $\sigma_{tot}$  for the LHC as well as the expectations for  $\langle |S^2| \rangle$ , the probability of survival for large rapidity gaps. The latter will be discussed in the next section.

PDF	$p_{tmin}$ (GeV)	$\sigma_0$ (mb)	p	$\sigma_{tot}^{LHC}$ (mb)	$< S^2 >$
GRV [24]	1.15	48	0.75	100.2	0.101
GRV94lo[37]	1.10	46	0.72	103.82	0.127
	1.10	51	0.78	89.65	0.089
GRV98lo[38]	1.10	45	0.70	102.05	0.154
	1.10	50	0.77	87.83	0.106
MRST[39]	1.25	47.5	0.74	95.92	0.123
	1.25	44	0.66	110.51	0.172

Table 1: Values of  $\sigma_{tot}$  for  $p_{tmin}$ ,  $\sigma_0$  and  $p$  corresponding to different parton densities in the proton, for which GGPS gives a satisfactory description of  $\sigma_{tot}^{pp/pp}$ .

We now compare the expectations from different models. The DL parameterisation [19]

$$\sigma_{tot}(s) = X s^\epsilon + Y s^{-\eta}, \quad (9)$$

is a fit to the existing data with  $\epsilon = 0.0808$ ,  $\eta = 0.4525$ . This fit has been extended to include a 'hard' pomeron [40] due to the discrepancy between different data sets. The BH model [35] gives a fit to the data using duality constraints. The BH fit for  $\sigma^\pm = \sigma^{\bar{p}p}/\sigma^{pp}$  as a function of beam energy  $\nu$ , is given as

$$\sigma^\pm = c_0 + c_1 \ln(\nu/m) + c_2 \ln^2(\nu/m) + \beta_{P'}(\nu/m)^{\mu-1} \pm \delta(\nu/m)^{\alpha-1},$$

where  $\mu = 0.5$ ,  $\alpha = 0.453 \pm 0.0097$  and all the other parameters (in mb) are  $c_0 = 36.95$ ,  $c_1 = -1.350 \pm 0.152$ ,  $c_2 = 0.2782 \pm 0.105$ ,  $\beta_{P'} = 37.17$ ,  $\delta = -24.42 \pm 0.96$  from [41]. The fit obtained by Igi et al. [42], using FESR [43], gives LHC predictions very similar to those given by the BH fit. Predictions have been advanced by Luna and Menon [44] using fits to low energy proton-proton and cosmic ray data from Akeno [45] and Flye's Eyes [46]. Avila, Luna and Menon give also fits [47] using analyticity arguments and different sets of cosmic ray data. Depending on the analytic expression used and set or model used to extract the cross-sections from the cosmic ray data, their cross-section predictions at LHC vary. Finally, using an eikonal model inspired by BGHP [23], Luna and collaborators [48] predict  $\sigma_{tot}^{LHC} = 102.9 \pm 7.1$  mb. In the framework of the COMPETE program, Cudell et al [49] give predictions for the LHC energies by extrapolating fits obtained to the current data based on an extensive study of possible analytic parametrisations, using again constraints from unitarity, analyticity, factorization, coupled with a requirement that the cross-section asymptotically goes to (i) a constant, (ii) as  $\ln s$  or as (iii)  $\ln^2 s$ . Their central value of the fit has no  $\ln s$  term, and it predicts  $\sigma^{pp}(LHC) = 111.5 \pm 1.2_{-2.1}^{+4.1}$  (mb), where the systematic errors come from the choice in the fit between CDF and E710/E811 data at the Tevatron. Recently, Cudell and Selyugin [50] have considered predictions from a model with both a hard and a soft Pomeron term, leading to a cross-section of the order of 140 mb at LHC energies.

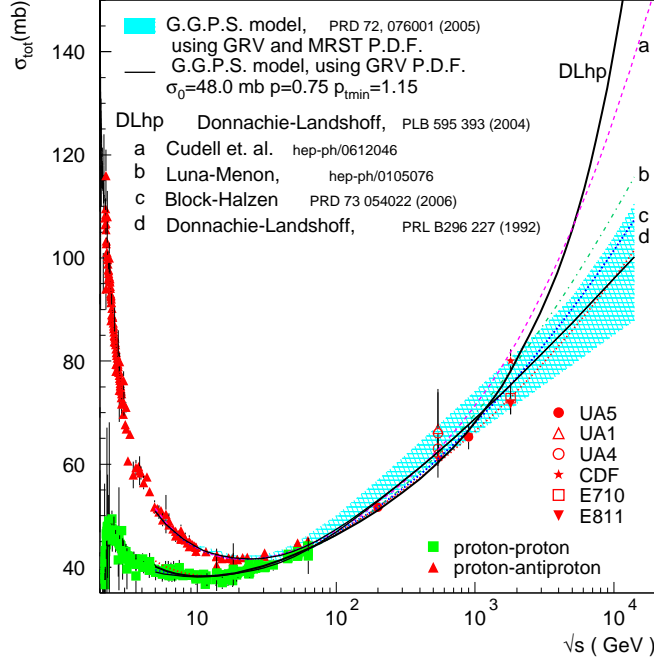


Figure 2: Predictions for  $\sigma_{\text{tot}}^{\text{pp/p}\bar{\text{p}}}$  in various models. The shaded area gives the range of results from GGPS [2] the solid line giving the prediction obtained using the GRV parton densities [24] in the model.

Figure 2 summarizes the predictions of some of the models described in the previous paragraphs. Curve (d), indicates the predictions of the standard Regge-Pomeron fit [19], while the new fit with a hard Pomeron term is labeled (DLhp). The two curves labeled (c) and (b) are the results of fits with the analytical models from [41] and [44] respectively. The short dash dotted curve (a) is from [50] with a hard Pomeron term. The shaded area gives the range of predictions in the GGPS model with soft gluon resummation [2], the different PDF's used giving the range as described earlier, and the solid line at the center of the band being the one obtained with the GRV parton densities [24] and other parameters as in [2]. We see that the range of results from GGPS for LHC spans other predictions based on models using unitarity, factorization, analyticity and fits to the current data. The predictions shown fall in two groups, those with an explicit "hard" Pomeron and those based on analyticity and unitarity constraints which seem consistent with each other. We are in disagreement with models which incorporate a "hard" Pomeron. Indeed our model has a hard QCD component, the mini-jet cross-section discussed in the previous section, but soft QCD emission tempers it and brings the fast rise back to a smooth behaviour. In the end it predicts a growth with energy not faster than  $\ln^2 s$ , as we shall see in the following.

The top edge of the GGPS prediction is obtained for the MRST parametrization whereas the lower edge for the GRV98lo, with other parameters as in Table 1. In GGPS,



proton-antiproton				$a_0$ (mb)	$a_1$ (mb)	b	$a_2$ (mb)	$a_3$ (mb)
$\sigma_0$ (mb)	$p_{tmin}$ (GeV)	p						
50	1.10	0.77	Lower edge	$17 \pm 1$	$122 \pm 6$	-0.5	$2.7 \pm 0.1$	$0.054 \pm 0.036$
44	1.25	0.66	Top edge	$19 \pm 2$	$127 \pm 4$	-0.5	$1.9 \pm 0.3$	$0.149 \pm 0.013$
48	1.15	0.75	Center	$20 \pm 1$	$125 \pm 6$	-0.5	$1.6 \pm 0.1$	$0.135 \pm 0.012$
proton-proton				$a_0$ (mb)	$a_1$ (mb)	b	$a_2$ (mb)	$a_3$ (mb)
$\sigma_0$ (mb)	$p_{tmin}$ (GeV)	p						
50	1.10	0.77	Lower edge	$17 \pm 2$	$65 \pm 7$	-0.5	$2.7 \pm 0.4$	$0.054 \pm 0.017$
44	1.25	0.66	Top edge	$19 \pm 2$	$63 \pm 5$	-0.5	$1.8 \pm 0.3$	$0.148 \pm 0.015$
48	1.15	0.75	Center	$20 \pm 1$	$66 \pm 5$	-0.5	$1.6 \pm 0.2$	$0.135 \pm 0.013$

Table 2: Values of  $a_0, a_1, a_2, a_3$  and  $b$  parton densities in the proton, for which GGPS Ref. [2] gives a satisfactory description of  $\sigma_{tot}^{pp/pp\bar{p}}$ .

we have parametrised the maximum growth with a  $\ln^2 s$  term. We find it to give a better representation of our results than a term of the Regge-Pomeron type. We give fits to our results for  $\sigma_{\text{tot}}^{\text{pp/p}\bar{\text{p}}}$  of the form,

$$\sigma_{\text{tot}}^{\text{pp/p}\bar{\text{p}}} = a_0 + a_1 s^b + a_2 \ln(s) + a_3 \ln^2(s). \quad (10)$$

In these parametrizations we have constrained the  $\log^2 s$  term to have a positive coefficient, whereas in [51] this coefficient had been let free to assume either sign. We show the corresponding GGPS model parameters  $\sigma_0, p_{tmin}$  and  $p$  in Table 2. The corresponding PDF's used in the calculation of  $\sigma_{jet}$  can be read from Table 1 for the given set of parameter values.

Once the LHC measurements for the total cross-section will have indicated the best parameter set to use, the model can be used to calculate the  $b$ -distributions, namely average number of collisions, shape of the overlap function, etc. at the LHC [52].

## 4 Large Rapidity Gap Survival Probability

We now employ our model to estimate the survival probability for LRG. As mentioned already, events with LRG may arise as a signal of (say) Higgs bosons produced through WW fusion. The importance of the WW fusion channel for the production of the Higgs boson at LHC to enhance the potential of LHC towards discovering a 'light' Higgs and its properties in detail cannot be overemphasized [53]. The studies in this channel crucially use the LRG to increase signal/background ratio. But as Bjorken [6] pointed out, it is important to estimate the probability that ordinary QCD processes, including bremsstrahlung radiation, and the soft spectator jet activity will not fill this gap in the angular space with hadrons. The first part can be computed using perturbation theory [9, 54, 55], it is the second part corresponding to the soft rescattering contribution that requires non-perturbative techniques.

Let the cross-section for the hard process  $AB \rightarrow H$  be calculated through a convolution of the parton densities in the transverse impact parameter plane as

$$\sigma_H(s) = \int d^2\mathbf{b} A^{AB}(b, s) \sigma_H(b, s) \quad (11)$$

where  $A^{AB}(b, s)$  is the transverse overlap function for the two projectiles A and B.

Then the gap survival probability [5, 6] is given by

$$\langle |S|^2 \rangle = \frac{\int d^2\mathbf{b} A^{AB}(b, s) |S(b)|^2 \sigma_H(b, s)}{\int d^2\mathbf{b} A^{AB}(b, s) \sigma_H(b, s)}. \quad (12)$$

Here  $|S(b)|^2$  is the probability that the two hadrons A,B go through each other without an inelastic interaction if they arrive at an impact parameter  $\mathbf{b}$  and  $A^{AB}(b, s)$  is the distribution in impact parameter space for non-jet like interactions.

In the eikonal formulation used in [12] and more recently in [14], this probability is given by  $|S(b)|^2 = e^{-2\Im m\chi(b, s)}$ . Since it is precisely this eikonal function that is also

involved in the calculation of the total cross-section  $\sigma_{\text{tot}}^{\text{pp/p}\bar{\text{p}}}$ , one can then use it to calculate the above mentioned survival probability. In the hypothesis that the hard process can be factorized out of the  $b$ -integration, the net survival probability then is given by

$$\langle |S|^2 \rangle = \int d^2\mathbf{b} A^{AB}(b, s) e^{-2\Im\chi(b, s)}. \quad (13)$$

Here, the transverse overlap functions are always assumed to be normalized to unity. The impact parameter distribution which was used in the QCD inspired model of [12] and [14], corresponded to the term for quark scattering, one of three terms used to parametrize the  $b$ -distribution of the eikonal. For us it is different and we shall compare our results with these models, as well as with other predictions in the literature.

We are looking at the probability of survival of large rapidity gaps which are present in production of colour singlet state (like the Higgs boson production via WW fusion) without an accompanying hard QCD process. Our model has both soft and hard components, with hard parton scattering cross-section for which  $p_t \geq p_{tmin}$ . To exclude hard interactions, for LRG, we only need to consider the  $b$ -distribution of “soft” events, where the hadronic activity is due to collisions with  $p_t \leq p_{tmin}$ . Thus, our model automatically selects processes, with very low  $p_t$  through the soft  $A_{BN}(b, q_{max}^{soft})$  distribution. Recall that this distribution, as we obtain it, is through calculation and a choice of  $q_{max}^{soft}$  and  $\sigma_0$ , to ensure a good description of the low energy total cross-section. Hence, our prediction for SPLRG is to be calculated from the expression

$$\langle |S|^2 \rangle = \int d^2\mathbf{b} A_{BN}(b, q_{max}^{soft}) e^{-n_{soft}(b, s) - n_{hard}(b, s)} \quad (14)$$

The quantity  $q_{max}^{soft}$  has only a very slight energy dependence, but in principle it can be different for different  $p_{tmin}$  and different densities. We calculate the survival probability for a set of parameters and parton densities as used for the total cross-section. This is given in Figure 3, where we use MRST and GRV densities and the set  $p_{tmin} = 1.15 \text{ GeV}$ ,  $\sigma_0 = 48 \text{ mb}$ ,  $p = 0.75$ .

Our predictions for  $\langle |S|^2 \rangle$  are compared here with other similar models, namely with Luna [14], with Block and Halzen (BH) [12], with Khoze, Martin and Ryskin (KMR) [11] and with Bjorken prediction for SSC energies [6].

Our results for LHC energies differ from both BH and Luna models, however, the difference with BH is not as pronounced as with the Luna model, and we would favour a lower value for the survival probability, closer to the KMR value and within the range predicted by Bjorken. Not shown in the figure, there is also the Pythia prediction [56], which, in a multiple scattering formulation using CTEQ5 densities within Rich Field’s “Tune A” of Pythia [57], gives a value 0.026, which lies lower than all the others.

The comparison with other models shown in Figure 3 indicates a good agreement between different approaches to the rather loose idea of survival probability. It is important to notice how all the predictions from QCD inspired models like BH, BN resummation like ours, perturbative QCD like KMR and Bjorken’s estimate all fall within a band of  $5 \div 10\%$ . In our opinion, this convergence of different models lends a strong credibility to this type of predictions and puts the concept of Rapidity Gaps and studies of their Survival Probability on a rather firm ground. This increases our confidence in using these to

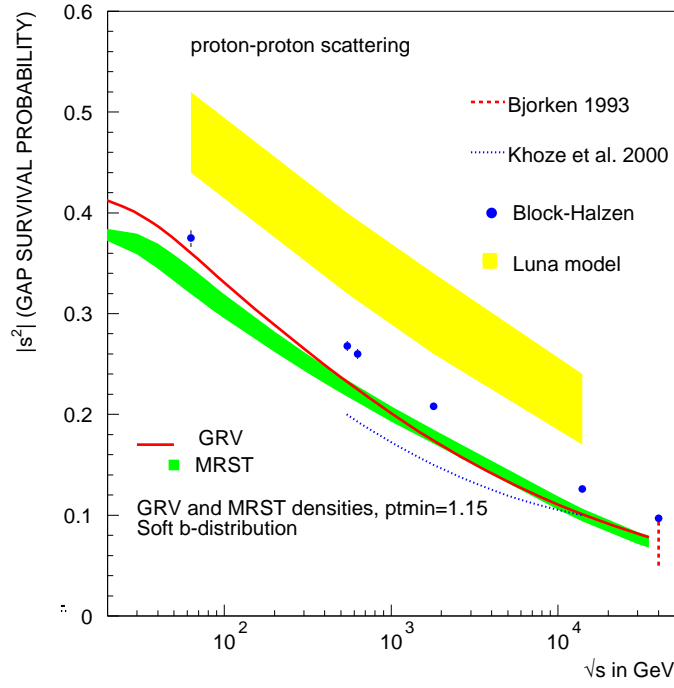


Figure 3: Predictions for survival probability using different parton densities in the GGPS model described in the text and comparison with other models.

estimate efficacy of existence of events with Rapidity Gaps as a means to detect interesting BSM signals isolating them from the background.

## 5 Conclusions

We have shown above that the range of the results for  $\sigma_{\text{tot}}^{\text{pp/p}\bar{\text{p}}}$  from our GGPS model [2] spans the range of other computations made using current data and general arguments based on unitarity and/or factorization. Further, we give our own estimate of the survival probability for large rapidity gaps at the LHC and show that our estimates are in reasonable agreement with other models.

## Acknowledgments

One of us, A.G., acknowledges partial support for this work by MEC (FPA2006-0594) and by Junta de Andalucía (FQM 101 and FQM 437). R.G. would like to thank the theory group at LNF, Frascati for hospitality where part this work was done during a visit. G.P. gratefully acknowledges the hospitality of the Theoretical Physics group of Boston University where part of this work was finished. G.P. is grateful to J.-R. Cudell, V. Khoze and Leif Lönnblad for providing numerical estimates for survival probabilities in their models. Work was also partly supported by EU contract 2002-00311.

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