Survival probability of large rapidity gaps in a QCD model with a dynamical infrared mass scale

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Abstract

We compute the survival probability $\langle |S|^2 \rangle$ of large rapidity gaps (LRG) in a QCD based eikonal model with a dynamical gluon mass, where this dynamical infrared mass scale represents the onset of nonperturbative contributions to the diffractive hadron-hadron scattering. Since rapidity gaps can occur in the case of Higgs boson production via fusion of electroweak bosons, we focus on $WW \to H$ fusion processes and show that the resulting $\langle |S|^2 \rangle$ decreases with the increase of the energy of the incoming hadrons, in line with the available experimental data for LRG. We obtain $\langle |S|^2 \rangle = 27.6 \pm 7.8 \% (18.2 \pm 7.0 \%)$ at Tevatron (CERN-LHC) energy for a dynamical gluon mass $m_g = 400$ MeV.
I. INTRODUCTION

The study of the survival probability $\langle |S|^2 \rangle$ of large rapidity gaps (LRG) is currently a subject of intense theoretical and experimental interest. Its importance lies in the fact that systematic analyses of LRG open the possibility of extracting New Physics from hard diffractive processes. On the theoretical side, its significance is due to the reliance of the $\langle |S|^2 \rangle$ calculation on subtle QCD methods.

Rapidity gaps are defined as regions of angular phase space devoid of particles [1, 2, 3, 4], and at high-energy hadron-hadron collisions it has been suggested that their observation may serve as a signature for production of Higgs bosons and other colour-singlet systems via fusion of electroweak bosons [1, 2, 4, 5, 6, 7, 8]. However, as pointed out by Bjorken [4, 5], we are not able to distinguish between the theoretically calculated rate of a large rapidity gap, $F_{\text{gap}}$, and the actual measured rate, $f_{\text{gap}}$. These rates are related by the proportionality relation $f_{\text{gap}} = \langle |S|^2 \rangle F_{\text{gap}}$, where $\langle |S|^2 \rangle$ is the so-called “survival probability” of a large rapidity gap: it gives the probability of survival of LRG and not the probability for the production and survival of LRG, which is the quantity actually measured. More specifically, the survival factor $\langle |S|^2 \rangle$ gives the probability of a large rapidity gap not to be filled by debris originated from the rescattering of spectator partons ($\langle |S_{\text{spec}}|^2 \rangle$), or from the emission of bremsstrahlung gluons from partons ($\langle |S_{\text{brem}}|^2 \rangle$). Hence we can write

$$\langle |S|^2 \rangle = \langle |S_{\text{brem}}(\Delta y = |y_1 - y_2|)|^2 \rangle \langle |S_{\text{spec}}(s)|^2 \rangle,$$

(1)

where $y_1$ and $y_2$ are the rapidities of the jets (produced with large transverse momenta), $\Delta y = |y_1 - y_2| \gg 1$, and $s$ is the square of the total center-of-mass (CM) energy. The factor $\langle |S_{\text{brem}}(\Delta y)|^2 \rangle$, which depends on the value of the LRG as well as on the kinematics of each specific process, can be calculated using perturbative QCD [33]. On the other hand, the survival factor $\langle |S_{\text{spec}}|^2 \rangle$ cannot be calculated perturbatively: it takes account of soft rescatterings in both the initial and final state interactions. To calculate $\langle |S_{\text{spec}}|^2 \rangle$ we need to obtain the probability of the two incoming hadrons do not interact inelastically, i.e. the probability of large rapidity gaps do not be populated by additional hadrons produced from the rescattering of spectator degrees of freedom. As discussed by Gotsman, Levin and Maor some time ago, this task is a difficult one since partons at long distances contribute to such a calculation [10]. However, the survival probability can be properly defined in the impact
parameter space \([4, 5]\):

\[
\langle |S_{\text{spec}}|^{2} \rangle = \frac{\int d^{2}\vec{b} \ F(b, s) \ P(b, s)}{\int d^{2}\vec{b} \ F(b, s)}, \tag{2}
\]

where \(b\) is the impact parameter, \(F(b, s)\) is a factor related to the overlap of the parton densities in the colliding hadrons in the transverse impact plane, and \(P(b, s)\) is the probability that the two incoming hadrons have not undergone a inelastic scattering at the parton level. The above definition sets up the stage for carrying out a systematic computation of \(\langle |S_{\text{spec}}|^{2} \rangle\), since the probability \(P(b, s)\) can be easily obtained, for example, from the QCD-inspired eikonal approach \([11, 12, 13, 14]\). In this picture the probability that neither hadron is broken up in a collision at impact parameter \(b\) is given by \(P(b, s) = e^{-2\chi_{I}(b, s)}\), where \(\chi_{I}(b, s)\) is the imaginary part of the eikonal function. In QCD-inspired eikonal models the increase of the total cross sections is associated with semihard scatterings of partons in the hadrons, and the high energy dependence of the cross sections is driven mainly by gluon-gluon scattering processes. Nevertheless, the gluon-gluon subprocess cross section is potentially divergent at small transferred momenta, and the usual procedure to regulate this behaviour is the introduction of a purely \(ad \ hoc\) parameter separating the perturbative from the non-perturbative QCD region, like an infrared mass scale \([11, 12]\), or a cut-off at low transverse momentum \(p_{T}\) \([13, 14]\).

Recently we introduced a QCD-based eikonal model where the \(ad \ hoc\) infrared mass scale was substituted by a dynamical gluon mass one \([15]\). One of the central advantages of the model is that it gives a precise physical meaning for the quoted infrared scale. Furthermore, since the behaviour of the running coupling constant is constrained by the value of dynamical gluon mass \([16, 17]\), the model also has a smaller number of parameters than similar QCD models.

In this letter we perform a detailed computation of the survival probability in \(pp\) and \(\bar{p}p\) channels in the framework of the QCD eikonal model with a gluon dynamical mass. We are concerned with the calculation of \(\langle |S_{\text{spec}}|^{2} \rangle\), the probability that LRG survive the soft rescattering of spectator partons, which we shall denote henceforth simply as \(\langle |S|^{2} \rangle\). In the next section we introduce the QCD eikonal model and address the question of calculating the survival factor \(\langle |S|^{2} \rangle\) from processes of Higgs boson production through \(W\) fusion. The results are presented in the Sec. III, where we provide a systematic study of \(\langle |S|^{2} \rangle\) and its sensitivity to the infrared mass scale. The conclusions are drawn in Sec. IV.
II. LARGE RAPIDITY GAPS AND THE DYNAMICAL GLUON MASS

It has been suggested that in hadron-hadron collisions the production of Higgs bosons can occur by means of the fusion of gluons or electroweak bosons [1, 2, 3, 4]. The two main Higgs production mechanisms are the gluon fusion $gg \rightarrow H$ and the $W$ fusion $WW \rightarrow H$. In the gluon fusion process each hadron emits a gluon (a colour octet), and the Higgs boson is coupled to each one through a fermion loop. Since the Higgs boson couples to fermions according to their masses, its production cross section via gluon fusion is dominated by top quark loops. In gluon fusion the hadrons remnants must exchange colour with each other in order to become singlet states again.

On the other hand, the $W$ fusion process has a different colour flow structure: since the incoming hadrons (as well as the $W$ bosons) are colour singlets, when they emit a $W$ boson they remain as singlet states. Thus no colour is exchanged between the scattered partons, and the two outgoing hadron remnant states are expected to be separated by a central rapidity gap. As indicated in the previous section, the survival probability of these rapidity gaps can be naturally defined in the impact parameter representation. In this formalism the inclusive differential Higgs boson production cross section via $W$ fusion is given by

$$\frac{d\sigma_{\text{prod}}}{d^2b} = \sigma_{WW \rightarrow H} W(b; \mu_W), \quad (3)$$

where $W(b; \mu_W)$ is the overlap function at impact parameter space of the $W$ bosons. This function represents the effective density of the overlapping $W$ boson distributions in the colliding hadrons. The cross section for producing the Higgs boson and having a large rapidity gap is given by

$$\frac{d\sigma_{\text{LRG}}}{d^2b} = \sigma_{WW \rightarrow H} W(b; \mu_W) P(b, s), \quad (4)$$

where $P(b, s)$ is the probability that the two initial hadrons have not undergone a inelastic scattering at the parton level. In QCD-inspired eikonal models this probability is given by $P(b, s) = e^{-2\chi_I(b, s)}$, where the imaginary part $\chi_I(b, s)$ of the eikonal function receives contributions of parton-parton interactions. Therefore, the factor $P(b, s)$ suppresses the contribution to the Higgs boson cross section where the two initial hadrons overlap and there is soft rescatterings of the spectator partons. From the expressions (2), (3) and (4) we
can write down the survival factor $\langle |S|^2 \rangle$ for Higgs production via $W$ fusion:

$$\langle |S|^2 \rangle = \frac{\int d^2 b \sigma_{W W \to H} W(b; \mu_W) e^{-2\chi_I(b,s)}}{\int d^2 b \sigma_{W W \to H} W(b; \mu_W)} = \int d^2 b W(b; \mu_W) e^{-2\chi_I(b,s)}, \quad (5)$$

where we have used the normalization condition $\int d^2 b W(b; \mu_W) = 1$. In this letter we shall compute the probability factor $P(b, s) = e^{-2\chi_I(b,s)}$ using a recently developed QCD eikonal model, where the onset of the dominance of gluons in the interaction of high-energy hadrons is managed by the dynamical gluon mass scale [15]. The model, henceforth referred to as DGM model, satisfies analyticity and unitarity constraints. The latter is automatically satisfied in the eikonal representation, where the total cross section, the ratio $\rho$ of the real to the imaginary part of the forward scattering amplitude, and the differential elastic scattering cross section are given by

$$\sigma_{\text{tot}}(s) = 4\pi \int_0^\infty b \, db \, [1 - e^{-\chi_I(b,s)} \cos \chi_R(b, s)], \quad (6)$$

$$\rho(s) = \frac{\text{Re} \{ i \int b \, db \, [1 - e^{i\chi(b,s)}] \}}{\text{Im} \{ i \int b \, db \, [1 - e^{i\chi(b,s)}] \}}, \quad (7)$$

and

$$\frac{d\sigma_{\text{el}}}{dt}(s, t) = \frac{1}{2\pi} \left| \int b \, db \, [1 - e^{i\chi(b,s)}] \, J_0(qb) \right|^2, \quad (8)$$

respectively, where $s$ is the square of the total CM energy, $J_0(x)$ is the Bessel function of the first kind, and $\chi(b, s) = \chi_R(b, s) + i\chi_I(b, s)$ is the (complex) eikonal function. In the DGM model the eikonal function is written as a combination of an even and odd eikonal terms related by crossing symmetry. In terms of the proton-proton ($pp$) and antiproton-proton ($\bar{p}p$) scatterings, this combination reads $\chi_{\bar{p}p}(b, s) = \chi^+(b, s) \pm \chi^-(b, s)$. The even eikonal is written as the sum of gluon-gluon, quark-gluon, and quark-quark contributions:

$$\chi^+(b, s) = \chi_{qq}(b, s) + \chi_{qg}(b, s) + \chi_{gg}(b, s)$$

$$= i[\sigma_{qq}(s)W(b; \mu_{qq}) + \sigma_{qg}(s)W(b; \mu_{qg}) + \sigma_{gg}(s)W(b; \mu_{gg})], \quad (9)$$

where $W(b; \mu)$ is the overlap function at impact parameter space and $\sigma_{ij}(s)$ are the elementary subprocess cross sections of colliding quarks and gluons ($i, j = q, g$). The overlap
function, normalized so that \( \int d^2 \vec{b} W(b; \mu) = 1 \), is associated with the Fourier transform of a dipole form factor,

\[
W(b; \mu) = \frac{\mu^2}{96\pi} (\mu b)^3 K_3(\mu b),
\]

(10)

where \( K_3(x) \) is the modified Bessel function of second kind. The odd eikonal \( \chi^-(b, s) \), that accounts for the difference between \( pp \) and \( \bar{p}p \) channels, is parametrized as

\[
\chi^-(b, s) = C^- \Sigma \frac{m_g}{\sqrt{s}} e^{\pi/4} W(b; \mu^-),
\]

(11)

where \( m_g \) is the dynamical gluon mass and the parameters \( C^- \) and \( \mu^- \) are constants to be fitted. The factor \( \Sigma \) is defined as

\[
\Sigma = \frac{9\pi \alpha_s^2(0)}{m_g^2},
\]

(12)

with the dynamical coupling constant \( \alpha_s \) set at its frozen infrared value. The origin of the dynamical gluon mass and the frozen coupling constant can be traced back to the early work of Cornwall [16], and the formal expressions of these quantities can be seen in Ref. [15].

The eikonal functions \( \chi_{qq}(b, s) \) and \( \chi_{qg}(b, s) \), needed to describe the lower-energy forward data, are simply parametrized with terms dictated by the Regge phenomenology:

\[
\chi_{qq}(b, s) = i \Sigma A \frac{m_g}{\sqrt{s}} W(b; \mu_{qq}),
\]

(13)

\[
\chi_{qg}(b, s) = i \Sigma \left[ A' + B' \ln \left( \frac{s}{m_g^2} \right) \right] W(b; \sqrt{\mu_{qq} \mu_{gg}}),
\]

(14)

where \( A, A', B', \mu_{qq} \) and \( \mu_{gg} \) are fitting parameters. The gluon-gluon eikonal contribution, that dominates at high energy and determines the asymptotic behaviour of the total cross sections, is written as \( \chi_{gg}(b, s) \equiv \sigma_{gg}^{DPT}(s) W(b; \mu_{gg}) \), where

\[
\sigma_{gg}^{DPT}(s) = C' \int_{4m_g^2/s}^1 d\tau F_{gg}(\tau) \hat{\sigma}_{gg}^{DPT}(\hat{s}).
\]

(15)

Here \( F_{gg}(\tau) \) is the convoluted structure function for pair \( gg \), \( \hat{\sigma}_{gg}^{DPT}(\hat{s}) \) is the subprocess cross section and \( C' \) is a fitting parameter. In the above expression it is introduced the energy threshold \( \hat{s} \geq 4m_g^2 \) for the final state gluons, assuming that these are screened gluons [18]. The structure function \( F_{gg}(\tau) \) is given by

\[
F_{gg}(\tau) = [g \otimes g](\tau) = \int_{\tau}^1 \frac{dx}{x} g(x) g \left( \frac{\tau}{x} \right),
\]

(16)
where \( g(x) \) is the gluon distribution function, adopted as

\[
g(x) = N_g \frac{(1-x)^5}{x^J},
\]

where \( J = 1 + \epsilon \) and \( N_g = \frac{1}{240} (6 - \epsilon)(5 - \epsilon)(1 - \epsilon) \). The correct analyticity properties of the model amplitudes is ensured by substituting \( s \to se^{-i\pi/2} \) throughout Eqs. (13), (14) and (15).

In the expression (13) the gluon-gluon subprocess cross section \( \hat{\sigma}_{gg}^{DPT}(\hat{s}) \) is calculated using a procedure dictated by the dynamical perturbation theory (DPT) [19]: amplitudes that do not vanish to all orders of perturbation theory are given by their free-field values, whereas amplitudes that vanish in all orders in perturbation theory as \( \propto \exp(-1/g^2) \) (\( g \) is the coupling constant) are retained at lowest order. In our case this means that the effects of the dynamical gluon mass in the propagators and vertices are retained, and the sum of polarizations is performed for massless (free-field) gluons. As a result, since the dynamical masses go to zero at large momenta, the elementary cross sections of perturbative QCD in the high-energy limit are recovered. Other details of the calculation can be seen in Ref. [15].

According to the expression (5), the final step in order to calculate \( \langle |S|^2 \rangle \) is to determine the overlap function \( W(b; \mu_{qq}) \) of the electroweak bosons. It is worth mentioning that the survival factor \( \langle |S|^2 \rangle \) depends on the nature of the colour-singlet exchange which generates the gap as well as on the distributions of partons inside the proton in impact parameter space [10, 20, 21, 22, 23]. We simply assume that the distribution of \( W \) bosons in impact parameter space in the hadron is the same as for the quarks. In this way, we can finally write down a phenomenologically useful expression to the survival factor \( \langle |S|^2 \rangle \):

\[
\langle |S|^2 \rangle = 2\pi \int_0^\infty b \, db \, W(b; \mu_{qq}) \, e^{-2\chi_I(b, s)}. \tag{18}
\]

In the above expression the inverse size (in impact parameter) \( \mu_{qq} \) is the same as in the expression (13). Its value, as well as the value of the remaining fitting parameters, is determined from global fits to \( pp \) and \( \bar{p}p \) forward scattering data, as discussed in the next section.

**III. RESULTS**

In order to determine the exponential damping factor \( e^{-2\chi_I(b, s)} \) of Eq. (18) and produce a consistent estimate of \( \langle |S|^2 \rangle \), we carry out global fits to the elastic differential scattering
cross section for $\bar{p}p$ at $\sqrt{s} = 1.8$ TeV and to all high-energy forward $pp$ and $\bar{p}p$ scattering data above $\sqrt{s} = 15$ GeV. This energy threshold is the same one used in the estimate of $\langle |S|^2 \rangle$ through the analysis of $pp$ and $\bar{p}p$ scattering carried out by Block and Halzen using a previous QCD-inspired model [8]. The forward data sets include the total cross section ($\sigma_{tot}$) and the ratio of the real to imaginary part of the forward scattering amplitude ($\rho$). We use the data sets compiled and analyzed by the Particle Data Group [24], with the statistic and systematic errors added in quadrature. The input values of the $m_g$ have been chosen to lie in the interval $[350, 650]$ MeV, as suggested by the value $m_g = 400^{+350}_{-100}$ MeV obtained in a previous analysis of the $pp$ and $\bar{p}p$ channels via the DGM model [15]. This input dynamical gluon mass range is also supported by recent studies on the $\gamma p$ photoproduction and the hadronic $\gamma\gamma$ total cross sections [25], and on the behaviour of the gluon distribution function at small $x$ [26]. In all the fits performed in this letter we use a $\chi^2$ fitting procedure, assuming an interval $\chi^2 - \chi^2_{\min}$ corresponding, in the case of normal errors, to the projection of the $\chi^2$ hypersurface containing 90% of probability. In the case of the DGM model (8 fitting parameters) this corresponds to the interval $\chi^2 - \chi^2_{\min} = 13.36$.

The $\chi^2/DOF$ values obtained in the global fits are relatively low, as shown in Table I. These results (for 168 degrees of freedom) indicate the excellence of the fits and show that the DGM model naturally accommodates all the data sets used in the fitting procedure. In Table I we have included the values of the $\mu_W(\equiv \mu_{qq})$ parameter, which determines the spatial distribution of the $W$ bosons at the impact parameter $b$. We can observe a small dependence of their values on the dynamical gluon mass: the greater the input scale $m_g$, the smaller the inverse size $\mu_W$.

The sensitivity of the survival probability $\langle |S|^2 \rangle$ (for $pp$ collisions) to the gluon dynamical mass is shown in Figure 1 for some CM energies. We note a slow increase of their values with the dynamical gluon mass and a fast decrease with the CM energies. As shown in Figure 2, where we have also plotted the exponential damping factor, this behaviour is related to the energy dependence of the imaginary part of the eikonal: $\chi_I(b, s)$ grows with the energy and hence suppresses the integral (18). In Table II we list our results for the survival factor $\langle |S|^2 \rangle$ for some values of the proton-proton energy, and compare with other calculations in the literature, where $\langle |S|^2 \rangle_{DGM1}$ and $\langle |S|^2 \rangle_{DGM2}$ denote the results obtained by setting the mass infrared scale at $m_g = 400$ and 600 MeV, respectively. The last value is the same one adopted by Block and Halzen with respect to the ad hoc mass scale $m_0$ [8]. We see
that the DGM results are systematically larger than the Block-Halzen ones (denoted by $\langle |S|^2 \rangle_{BH}$), but the large statistical errors resulting from our choice for the confidence region of the parameters (CL=90 %) indicate a reasonable compatibility between the $\langle |S|^2 \rangle_{DGM}$ and $\langle |S|^2 \rangle_{BH}$ results at higher energies.

The $\langle |S|^2 \rangle_{DGM2}$ results at $\sqrt{s} = 1.8$ and 16 TeV are in line with the $\langle |S|^2 \rangle_{GLM1}$ ones, obtained by Gotsman and collaborators using a Regge pole model [27]. In their approach they use an eikonalized version of the Donnachie-Landshoff model in order to satisfy unitarity [28]. The authors argue that their relatively large values for $\langle |S|^2 \rangle$ can be reduced by an appropriate change in some parameters included in their Gaussian approximation for $F(b,s)$ and $P(b,s)$ factors. We hasten to emphasise that the $\langle |S|^2 \rangle_{DGM1}$ results have been obtained using the preferred statistical value of the dynamical gluon mass for $pp$ and $\bar{p}p$ scattering, namely $m_g = 400$ GeV [15]. In this case we believe that an eventual change in the parameters of the GLM1 model may reduce their results in such a way to be compatible with the DGM1 ones.

The $\langle |S|^2 \rangle_{KMR}$ results have been obtained by Khoze and collaborators using a two-channel eikonal model which embodies pion-loop insertions in the Pomeron trajectory, diffractive dissociation, and rescattering effects [20]. The authors have calculated the survival probability $\langle |S|^2 \rangle$ in single, central and double diffractive processes at several energies, assuming that the spatial distribution in the parameter space is controlled by the slope $b$ of the Pomeron-proton vertex. We show the $\langle |S|^2 \rangle_{KMR}$ results for double diffractive processes with $2b = 5.5$ GeV$^2$, which corresponds to the slope of the electromagnetic proton form factor. These results are compatible with the DGM ones, in particular with the results taking into account $m_g = 400$ MeV, the optimum value for the dynamical gluon mass in $pp$ and $\bar{p}p$ diffractive scattering [15].

IV. CONCLUSIONS

In this letter we have calculated the survival probability $\langle |S|^2 \rangle$ of large rapidity gaps by means of an eikonal QCD model with a dynamical gluon mass. Since rapidity gaps can occur from production of Higgs boson via fusion of electroweak bosons, we have focused on $WW \rightarrow H$ fusion processes. The eikonal function have been determined by fitting $pp$ and $\bar{p}p$ accelerator scattering data. Owing to the quality of the global fits, the DGM model
allows us to describe successfully the \( \bar{p}p \) differential cross section at \( \sqrt{s} = 1.8 \) TeV, as well as the forward scattering quantities \( \sigma_{\text{tot}}^{\bar{p}p} \) and \( \rho^{\bar{p}p} \), in excellent agreement with the available experimental data. These results show that the DGM model is well suited for the prediction of the survival probability of LRG at higher energies, in particular for \( \langle |S|^2 \rangle \) one at the CERN-LHC energy.

In Table II we list our results for \( \langle |S|^2 \rangle \) and notice that their values decrease with the increase of the energy of the incoming protons. This behaviour, in line with results for LRG dijet production at the Tevatron \([29, 30]\), is a direct consequence of the energy dependence of the imaginary part of the eikonal, that grows with the energy. A strong dependence of \( \langle |S|^2 \rangle \) on the dynamical gluon mass \( m_g \) emerges from our calculations, as shown in Figure 1. This scale dependence arises as follows: the dynamical gluon mass affects strongly the behaviour of the gluon-gluon subprocess cross section \( \hat{\sigma}_{gg}^{\text{DPT}}(\hat{s}) \), which dominates at high energy and determines the asymptotic behaviour of the \( pp \) and \( \bar{p}p \) total cross section. Hence the procedure consisting of global fits to diffractive \( pp \) and \( \bar{p}p \) data in order to determine \( m_g \) is well justified, and the value \( m_g = 400^{+350}_{-100} \) MeV obtained in Ref. \([15]\) via the DGM model is a suitable one.

Our estimates for the survival probability of large rapidity gaps using a QCD based eikonal model with a dynamical gluon mass are, within the errors, compatible with estimates obtained using other eikonal models. In particular, our estimates are close to the ones obtained by Khoze \textit{et al.} using a two-channel model, and to the ones obtained by Block and Halzen using a similar QCD-inspired approach. Owing to the interval \([300, 750]\) MeV inferred from the optimal value of \( m_g \) discussed above, there is room for smaller values of the survival factor in DGM model. For example, a mass scale \( m_g \sim 300 \) MeV gives a survival factor \( \langle |S|^2 \rangle \sim 15.3 \% \) at LHC, very close to the central value obtained via the KMR model.

However, we call attention to the fact that all these estimates are model dependent, despite their apparent agreement. For example, the \( \langle |S|^2 \rangle_{KMR} \) results for other values of \( 2b \) and for central and single diffractive processes do not agree with ours \([20]\). The same is expected in the \( \langle |S|^2 \rangle_{BH} \) results for other choices of the mass scale \( m_0 \).

In summary, there is a strong dependence in the size of the survival probabilities and in their energy dependence on specific models for the rise of total hadronic cross section. More specifically, the survival factor \( \langle |S|^2 \rangle \) depends on the dynamics of the whole diffractive part of the scattering matrix as well as the nature of the colour-singlet exchange which
generates the gap. From the experimental viewpoint, it is known that the survival factor $\langle |S|^2 \rangle$ in the case of Higgs production via $WW \rightarrow H$ fusion processes can be monitored by observing the closely related central production of a $Z$ boson with the same jet and rapidity gap configuration \[32\]. More recently, this idea has been developed further by considering the decays of both Higgs and $Z$ bosons into $\bar{b}b$ pairs \[33\]. This allows to gauge Higgs weak boson fusion production at the LHC and permits to observe a light Higgs boson via its dominant $H \rightarrow \bar{b}b$ decay mode in addiction to the usually discussed $\tau\tau$ and $WW^*$ channels. This option would permit to reduce the theoretical uncertainty in the rate of Higgs central production events with rapidity gaps.

The success of the QCD-based eikonal model with a dynamical gluon mass in reproducing diffractive scattering data, over a large energy range, shows that such a model provides a reliable estimate of the survival probability $\langle |S|^2 \rangle$ as a function of energy in the case of $pp$ and $\bar{p}p$ channels. The study of the survival factor $\langle |S|^2 \rangle$ is interesting in its own right since they enables us to increase our understanding of some features of hadronic interactions, and may provide an useful tool to probe physics beyond the Standard Model.

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TABLE I: The $\mu_W$ parameter as a function of the dynamical gluon mass $m_g$. The $\chi^2$/DOF values resulting from the global fits are obtained for 168 degrees of freedom.

| $m_g$ [GeV] | $\mu_W$ [GeV] | $\chi^2$/DOF |
|-------------|----------------|--------------|
| 350         | 0.8308±0.1394  | 1.043        |
| 400         | 0.8091±0.1410  | 1.022        |
| 450         | 0.7848±0.1411  | 1.010        |
| 500         | 0.7823±0.1392  | 1.009        |
| 550         | 0.7227±0.1356  | 1.000        |
| 600         | 0.7254±0.1333  | 1.001        |
| 650         | 0.7025±0.1305  | 0.999        |

TABLE II: The survival probability $\langle |S|^2 \rangle$ (in %) for pp collisions in different models.

| $\sqrt{s}$ [GeV] | $\langle |S|^2 \rangle_{DGM1}$ | $\langle |S|^2 \rangle_{DGM2}$ | $\langle |S|^2 \rangle_{BH}$ | $\langle |S|^2 \rangle_{GLM1}$ | $\langle |S|^2 \rangle_{KMR}$ |
|------------------|-------------------------------|-------------------------------|--------------------------|-----------------------------|--------------------------|
| 63               | 45.4±8.4                      | 50.9±9.3                     | 37.5±0.9                 | -                           | -                        |
| 546              | 34.2±8.1                      | 39.4±8.9                    | 26.8±0.5                 | -                           | 26.0                     |
| 630              | 33.4±8.1                      | 38.6±8.9                    | 26.0±0.5                 | -                           | -                        |
| 1800             | 27.6±7.8                      | 32.6±8.8                    | 20.8±0.3                 | 32.6                        | 21.0                     |
| 14000            | 18.2±7.0                      | 22.8±8.3                    | 12.6±0.06                | -                           | 15.0                     |
| 16000            | 17.7±6.9                      | 22.6±8.2                    | -                        | 22.1                        | -                        |
FIG. 1: The survival probability $\langle |S|^2 \rangle$ (central values) as a function of the dynamical gluon mass $m_g$. 

$\langle |S|^2 \rangle$ (%) 

- $\sqrt{s}=63$ GeV 
- $\sqrt{s}=546$ GeV 
- $\sqrt{s}=1.8$ TeV 
- $\sqrt{s}=14$ TeV 

$m_g$ (MeV) 

350 400 450 500 550 600 650
FIG. 2: The imaginary part $\chi_I(b,s)$ of the eikonal and the exponential factor $e^{-2\chi_I(b,s)}$ for $pp$ collisions as a function of the impact parameter $b$, where $\sqrt{s_I} = 1.8$ TeV and $\sqrt{s_{II}} = 14$ TeV. The dynamical gluon mass scale was set to $m_g = 400$ MeV.