ASPECTS OF HIGGS PRODUCTION AT THE LHC

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Outline

- GLMM model for high energy soft interactions incorporating multi eikonal scattering plus multi-Pomeron vertices.
- Hard matrix element
- Estimates of Survival Probability for Central Higgs production at LHC.
- Comparison with competing models
- Summary

Good-Walker Formalism-2

Unitarity constraints:

$$Im\, A_{i,k}\,(s,b) = |A_{i,k}\,(s,b)\,|^2 + G^{in}_{i,k}(s,b),$$

$G^{in}_{i,k}$ is the contribution of all non diffractive inelastic processes i.e. it is the summed probability for these final states to be produced in the scattering of particle i off particle k.

A simple solution to the above equation is:

$$A_{i,k}(s,b) = i\left(1 - \exp\left(-\frac{\Omega_{i,k}(s,b)}{2}\right)\right),$$

$$G^{in}_{i,k}(s,b) = 1 - \exp\left(-\Omega_{i,k}(s,b)\right).$$

Good-Walker Formalism-3

Note

$$P^S_{i,k} = \exp\left(-\Omega_{i,k}(s,b)\right)$$

is the probability that the initial projectiles (i,k) reach the final state interaction unchanged, regardless of the initial state rescatterings, (i.e. no inelastic interactions).

Amplitudes in two channel formalism are:

$$a_{el}(s,b) = i\{\alpha^4 A_{1,1} + 2\alpha^2\beta^2 A_{1,2} + \beta^4 A_{2,2}\},$$

$$a_{sd}(s,b) = i\alpha\beta\{-\alpha^2 A_{1,1} + (\alpha^2 - \beta^2)A_{1,2} + \beta^2 A_{2,2}\},$$

$$a_{dd} = i\alpha^2\beta^2\{A_{1,1} - 2A_{1,2} + A_{2,2}\}.$$

With the G-M mechanism σ_{el} , σ_{sd} and σ_{dd} occur due to elastic scattering of ψ_1 and ψ_2, the correct degrees of freedom.

Opacities $\Omega_{i,k}$:

$$\Omega_{i,k}\,(s,b) \;=\; g_i\,g_k \left(\frac{s}{s_0}\right)^{\Delta_{I\!P}} S\,(b; m_i, m_k; \alpha'_{I\!P} \ln(s/s_0))$$

The profile function

$S\,(b, \alpha'_{I\!P}; m_i, m_k; \ln(s/s_0))$ at $s = s_0$,

corresponds to the power-like behaviour of the Pomeron-hadron vertices

$$S\,(b; m_i, m_k; \alpha'_{I\!P} \ln(s/s_0) = 0) = \int \frac{d^2 q}{(2\pi)^2}\, g_i(q)\, g_k(q)\, e^{i\vec{q}_\perp \cdot \vec{b}}$$

We choose

$$g_i(q) \;=\; \frac{1}{(1 \;+\; q^2/m_i^2)^2}$$

Opacities $\Omega_{i,k}$ contd. :

We obtain for $S\,(b; m_i, m_k; , \alpha'_{I\!P} \ln(s/s_0) = 0)$

$$\frac{1}{(1 \;+\; q^2/m_i^2)^2} \times \frac{1}{(1 \;+\; q^2/m_k^2)^2}\,, \;\Longrightarrow\; S\left(b; m_i, m_k; , \alpha'_{I\!P} \ln(s/s_0) = 0\right) \;=$$

$$= \;\frac{m_i^3\, m_k^3}{4\pi\,(m_i^2 - m_k^2)^3}.$$

$$\left\{4m_i\, m_k\,(K_0\,(m_i b) \;-\; K_0\,(m_k b)) \;\;+\;\; (m_i^2 - m_k^2) b\;(m_k K_1\,(m_i b) \;+\; m_i K_1\,(m_k b))\right\}.$$

TAU Parameters for the two channel model fit to elastic processes

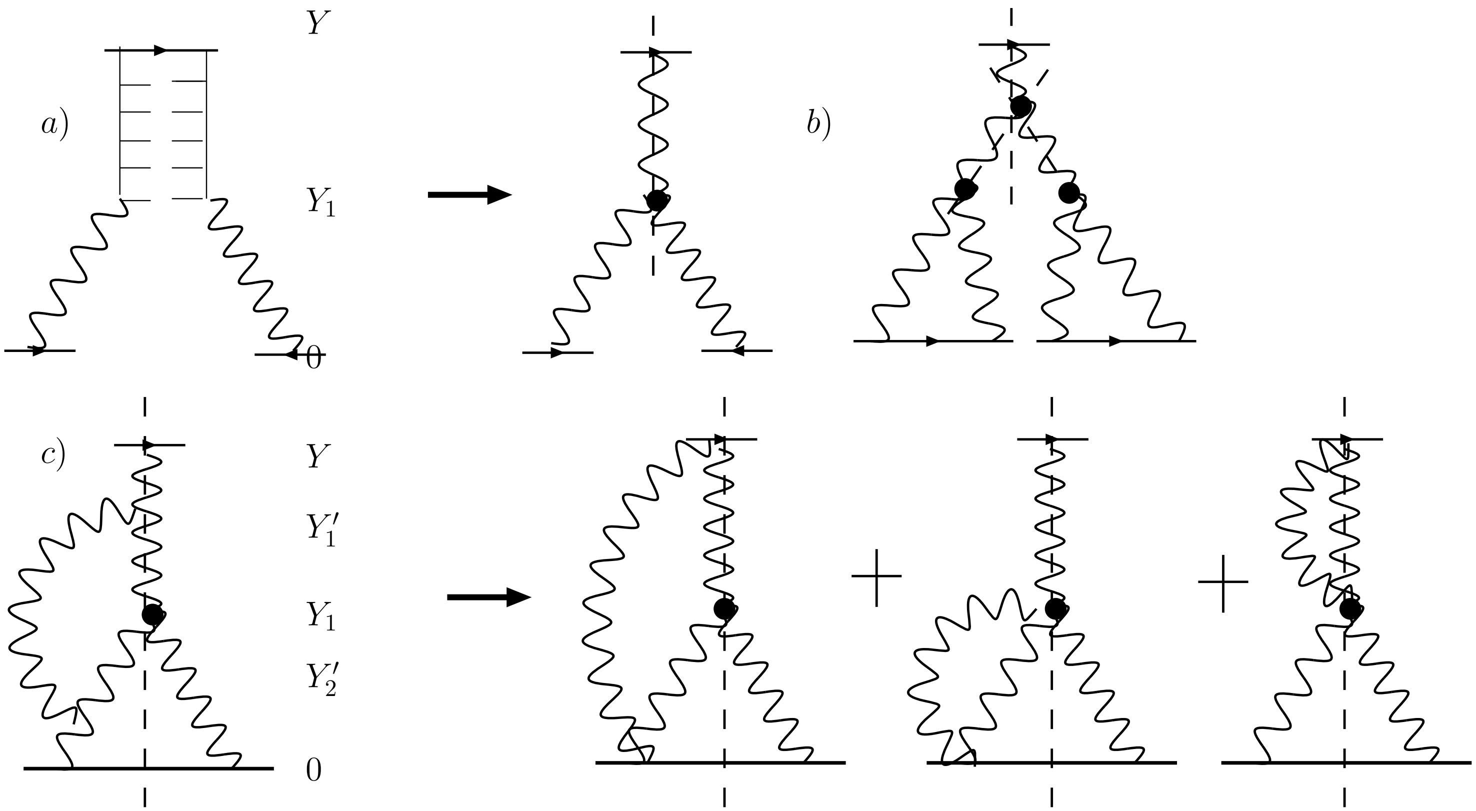
$\sigma_{tot}(s)$, $\sigma_{el}(s)$ and $B_{el}(s)$

$\Delta_{I\!P}$	β	$\alpha'_{I\!P}$	g_1	g_2	m_1	m_2
0.120	0.46	0.012 GeV^{-2}	1.27 GeV^{-1}	3.33 GeV^{-1}	0.913 GeV	0.98 GeV
$\Delta_{I\!R}$	β	$\alpha'_{I\!R}$	$g_1^{I\!R}$	$g_2^{I\!R}$	$R^2_{0,1}$	$\chi^2/d.o.f.$
-0.438	0.46	0.60 GeV^{-2}	4.0 GeV^{-1}	118.4 GeV^{-1}	4.0 GeV^{-2}	0.87

- With the above parameters the predicted values for $\sigma_{sd}(s)$ and $\sigma_{dd}(s)$ are much smaller than measured values.
- In G-W formalism something is missing in the diffractive channels.
- LARGE MASS DIFFRACTION

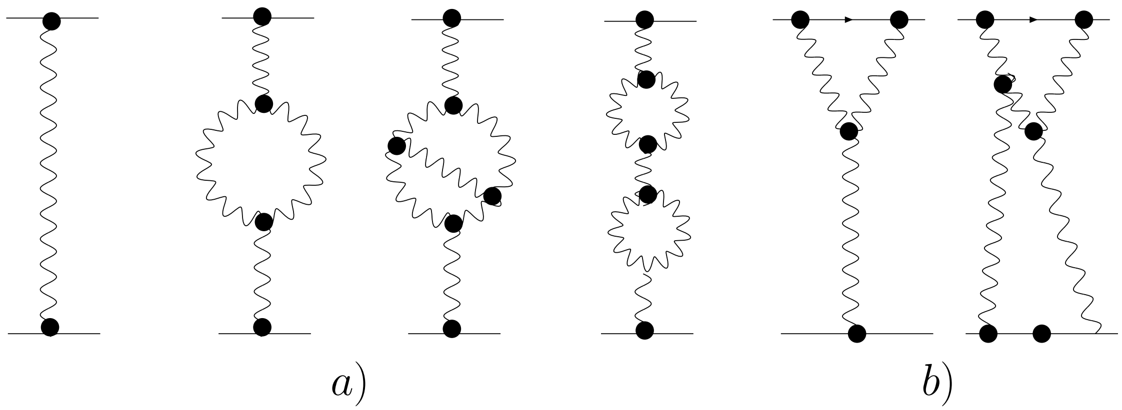
Examples of Pomeron diagrams

leading to diffraction NOT included in G-W mechanism



Examples of the Pomeron diagrams that lead to a different source of the diffractive dissociation that cannot be described in the framework of the G-W mechanism. (a) is the simplest diagram that describes the process of diffraction in the region of large mass $Y - Y_1 = \ln(M^2/s_0)$. (b) and (c) are examples of more complicated diagrams in the region of large mass. The dashed line shows the cut Pomeron, which describes the production of hadrons.

Example of enhanced and semi-enhanced diagram



Different contributions to the Pomeron Green's function
a) examples of enhanced diagrams (which are included); b) examples of semi-enhanced diagrams (which have not yet been included in most of our calculations)
Multi-Pomeron interactions are crucial for the production of LARGE MASS DIFFRACTION

Tel Aviv approach for summing interacting Pomeron diagrams

We can write the LO pQCD in terms of a generating function

$$Z(y,\, u) \;=\; \sum_n \; P_n(y)\; u^n,$$

$P_n(y)$ is the probability to find n-Pomerons (dipoles) at rapidity y.
The solution, with boundry conditions, gives us the sum of enhanced diagrams.

For the function $Z\,(u)$ the following evolution equation can be written

$$-\frac{\partial\, Z(y,\, u)}{\partial\, y} \;=\; -\,\Gamma(1 \rightarrow 2)\, u\,(1-u)\; \frac{\partial\, Z(y,\, u)}{\partial\, u} \;+\; \Gamma(2 \rightarrow 1)\, u\,(1-u)\; \frac{\partial^2\, Z(y,\, u)}{\partial^2\, u},$$

$\Gamma(1 \longrightarrow 2)$ describes the decay of one Pomeron (dipole) into two Pomerons (dipoles), while $\Gamma(2 \longrightarrow 1)$ relates to the merging of two Pomerons (dipoles) into one Pomeron (dipole).

Tel Aviv approach for summing interacting Pomeron diagrams contd.

Using the functional Z, we find the scattering amplitude, using the following formula:

$$N\,(Y) \;\equiv\; \text{Im}A_{el}\,(Y) \;=\; \sum_{n=1}^{\infty} \frac{(-1)^n}{n!}\;\frac{\partial^n\, Z(y,\,u)}{\partial^n\, u}|_{u=1}\,\gamma_n(Y=Y_0,b),$$

$\gamma_n(Y=Y_0,b)$ is the scattering amplitude of n-partons (dipoles) at low energy.

Using the MPSI approximation (where only large $I\!\!P$ loops of rapidity size O(Y) contribute) we obtain the exact Pomeron Green's function

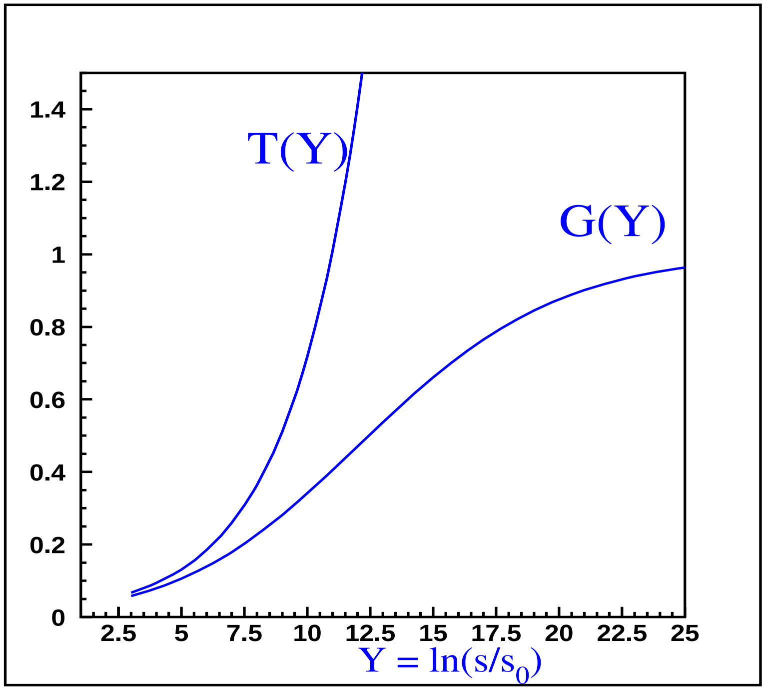
$$G_{I\!\!P}\,(Y) \;=\; 1 \;-\; \exp\left(\frac{1}{T(Y)}\right)\,\frac{1}{T(Y)}\,\Gamma\left(0,\frac{1}{T(Y)}\right),$$

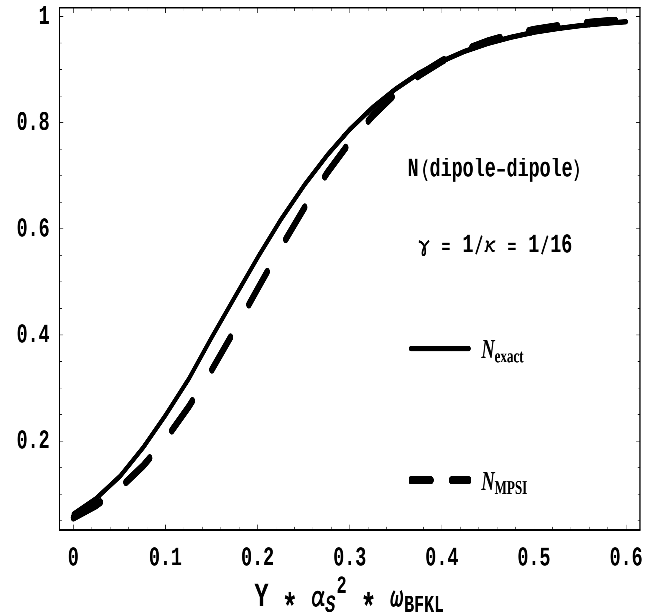
$\Gamma\,(0,x)$ is the incomplete gamma function and

$$T\,(Y) \;=\; \gamma\, e^{\Delta_{I\!\!P}\,Y}.$$

γ is the amplitude of the two dipoles interaction at low energy.
MPSI approximation is only valid for $Y \leq \frac{1}{\gamma}$.

MPSI Approximation





L.H. figure: The exact Green's function of the Pomeron versus $Y = \ln(s/s_0)$ and $T\,(Y) = \gamma e^{\Delta Y}$ for $\Delta = 0.339$ and $\gamma = 0.0242$. The values of the parameters were taken from our fit.

R.H. figure:(from Kozlov and Levin) Comparison of the exact solution for the Pomeron Green's function $G\,(Y)$ with $G\,(Y)$ in the MPSI approximation.

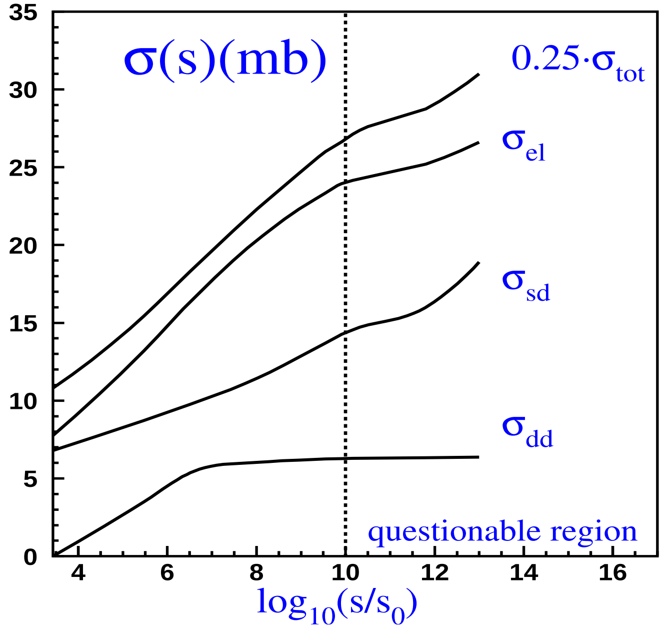
Parameters for our model fit includes G-W PLUS enhanced Pomeron diagrams

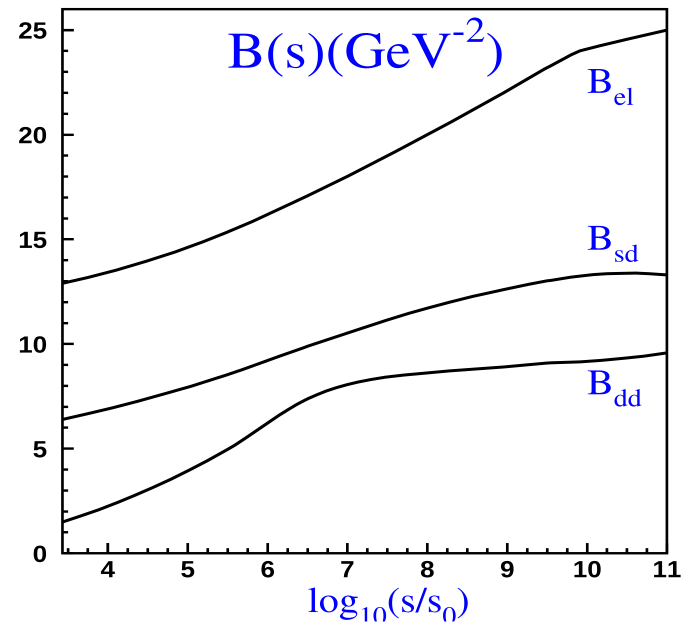
$\Delta_{I\!P}$	β	$\alpha'_{I\!P}$	g_1	g_2	m_2	m_1
0.335	0.339	0.012 GeV^{-2}	5.82 GeV^{-1}	239.6 GeV^{-1}	1.54 GeV	3.06 GeV
$\Delta_{I\!R}$	γ	$\alpha'_{I\!R}$	$g_1^{I\!R}$	$g_2^{I\!R}$	$R^2_{0,1}$	$\chi^2/d.o.f.$
- 0.60	0.0242	0.6 GeV^{-2}	13.22 GeV^{-1}	367.8 GeV^{-1}	4.0	1.0

For comparison parameters for the two channel model fit
(only G-W processes)

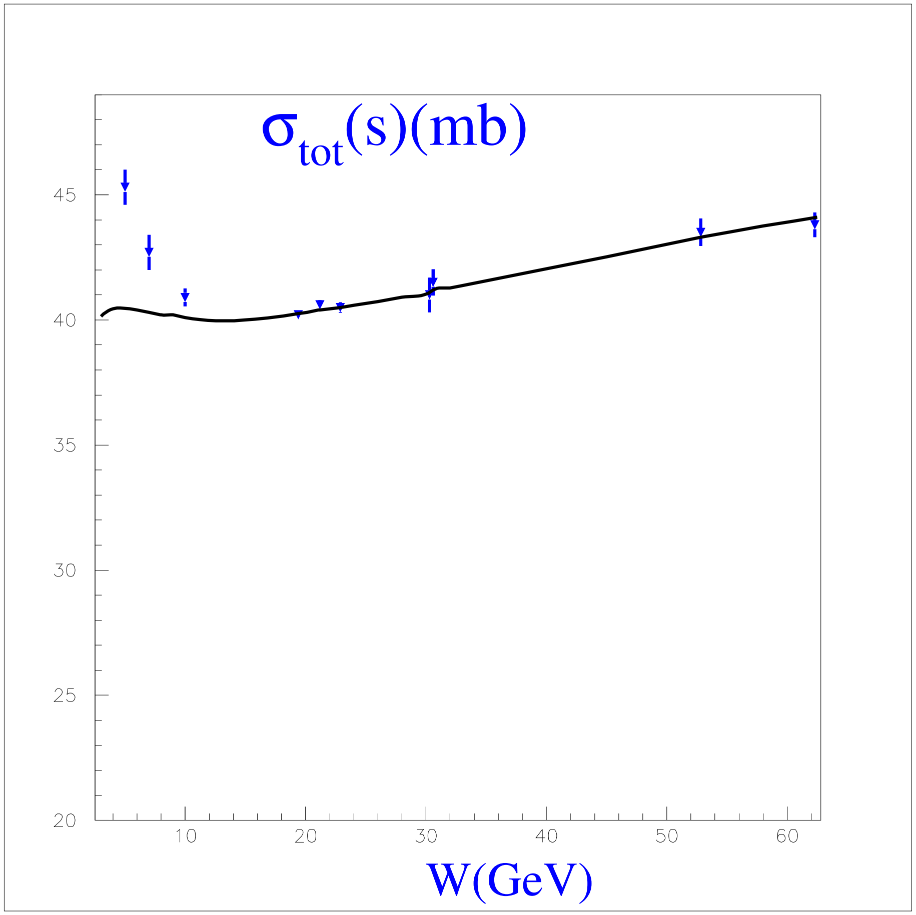
$\Delta_{I\!P}$	β	$\alpha'_{I\!P}$	g_1	g_2	m_1	m_2
0.120	0.46	0.012 GeV^{-2}	1.27 GeV^{-1}	3.33 GeV^{-1}	0.913 GeV	0.98 GeV
$\Delta_{I\!R}$	β	$\alpha'_{I\!R}$	$g_1^{I\!R}$	$g_2^{I\!R}$	$R^2_{0,1}$	$\chi^2/d.o.f.$
-0.438	0.46	0.60 GeV^{-2}	4.0 GeV^{-1}	118.4 GeV^{-1}	4.0 GeV^{-2}	0.87

Energy dependence of cross sections





Total Cross Section at Low Energies



The total cross section ($\sigma_{tot} = 1/2[\sigma_{tot}(pp) + \sigma_{tot}(p\bar{p})]$). The curve illustrates our parametrization. No need for rapidity cut at low enegies, we identify low mass diffraction with G-W. KMR differentiate between low and high mass diffraction with a Δy cut.

Survival Probability for exclusive central diffractive production of the Higgs boson

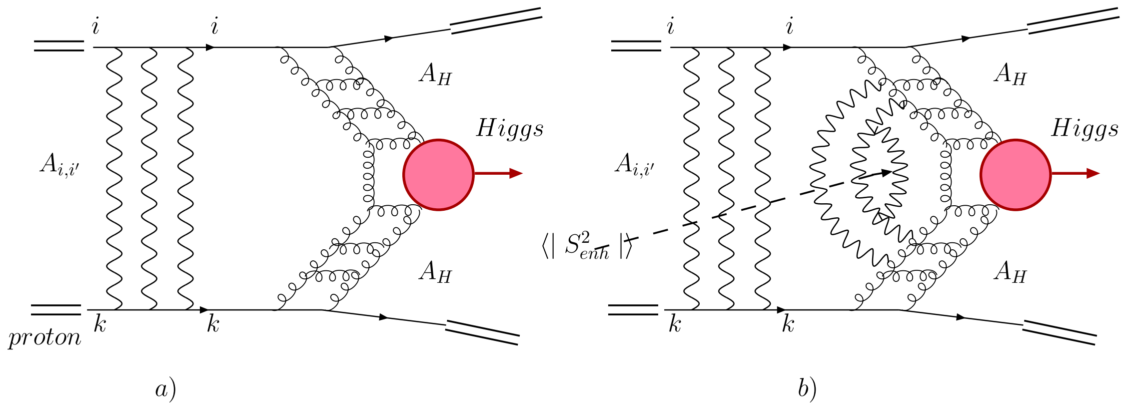
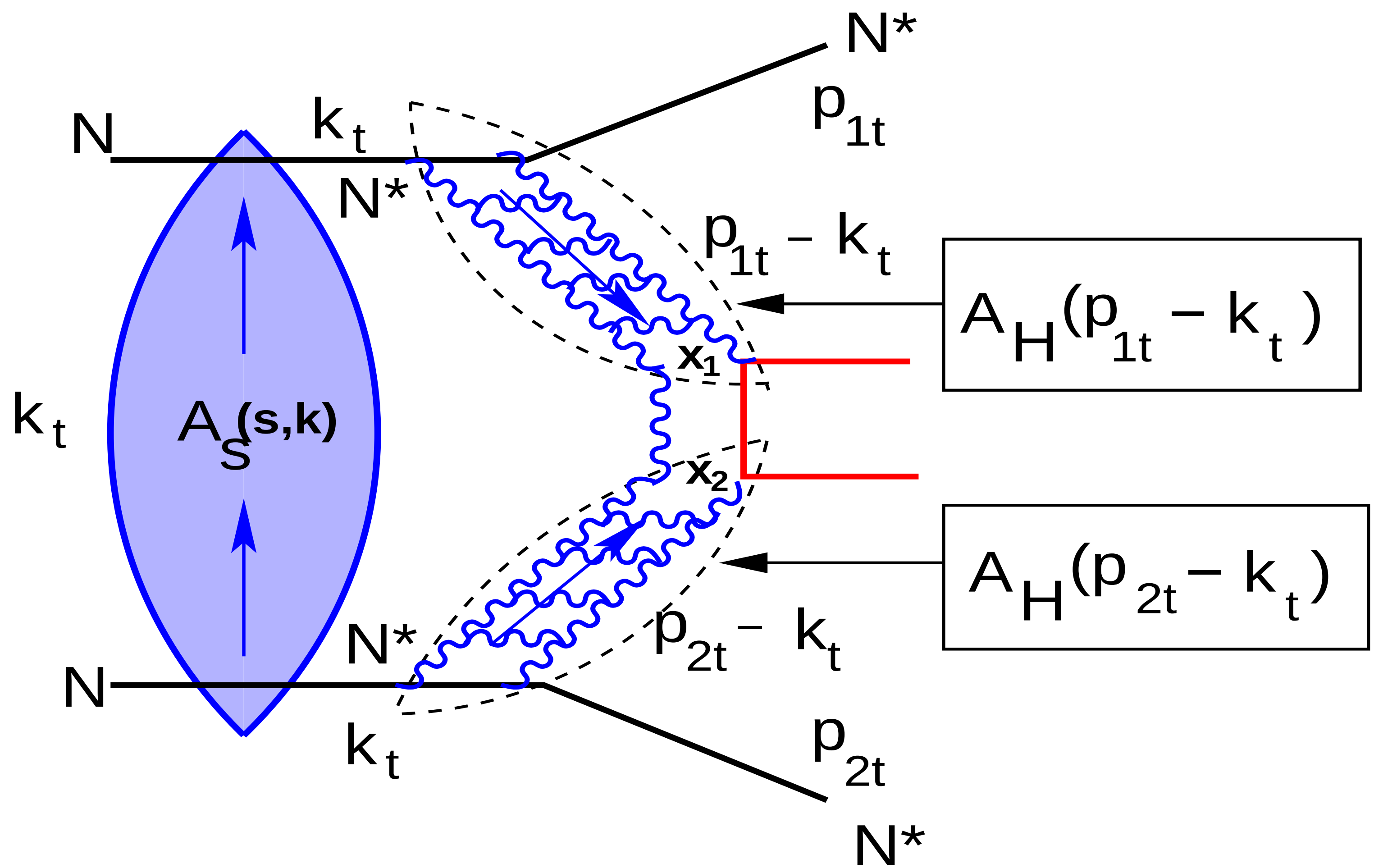


Fig-a shows the contribution to the survival probability in the G-W mechanism
Fig-b illustrates the origin of the additional factor $\langle| S^2_{enh} |\rangle$

Eikonal s-channel corrections give rise to the LRG survival probability of hard diffraction.
Experimental evidence $\rightarrow$ hard dijets with LRG at Tevatron are scaled down by a factor $\langle| S^2 |\rangle \approx 0.1$, compared to dijets at Desy (due to screening).

Central Production of Two Hard Jets



Survival Probability of diffractive Higgs production

$$\langle \mid S^2_{2ch} \mid \rangle = \frac{N(s)}{D(s)},$$

where,

$$N(s) = \int d^2\, b_1\, d^2\, b_2 \left[\sum_{i,k} < p|i >^2 < p|k >^2 \;\; A^i_H(s, b_1)\, A^k_H(s, b_2)(1 - A^{i,k}_S\,((s, (\mathbf{b}_1 + \mathbf{b}_2))) \right]^2,$$

$$D(s) = \int \; d^2\, b_1\, d^2\, b_2 \left[\sum_{i,k} < p|i >^2 < p|k >^2 \;\; A^i_H(s, b_1)\, A^k_H(s, b_2) \right]^2.$$

A_s denotes the "soft" strong interaction amplitude.

For the "hard" amplitude $A_H(b, s)$ we assume an input Gaussian b-dependence:

$$A^H_{i,k} = A_H(s)\,\Gamma^H_{i,k}(b)$$

and

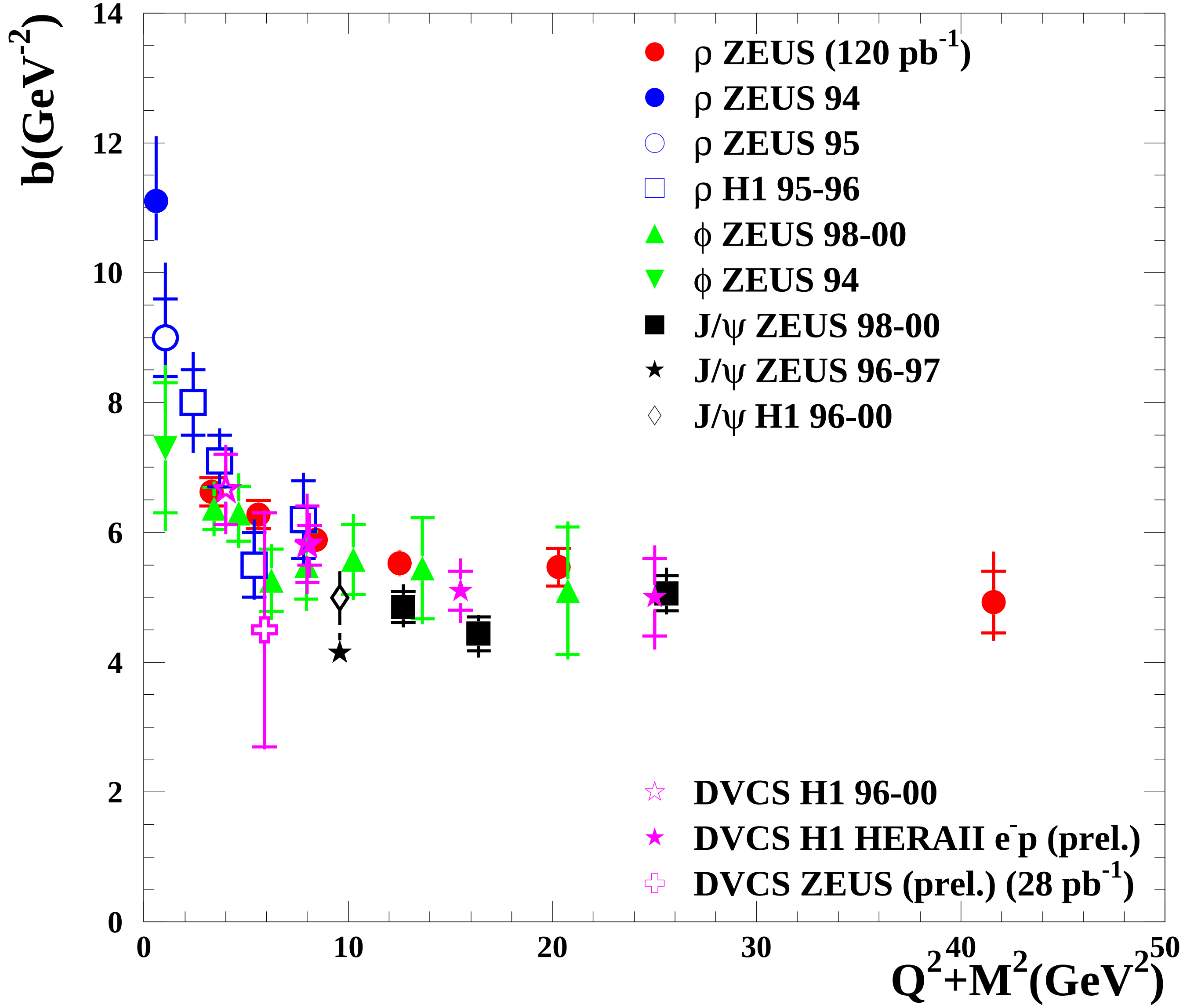
$$\Gamma^H_{i,k}(b) = \frac{1}{\pi (R^H_{i,k})^2}\, e^{-\frac{2\,b^2}{(R^H_{i,k})^2}}.$$

The "hard" radii are constants determined from HERA data on elastic and inelastic J/Ψ production. We introduce TWO hard b-profiles

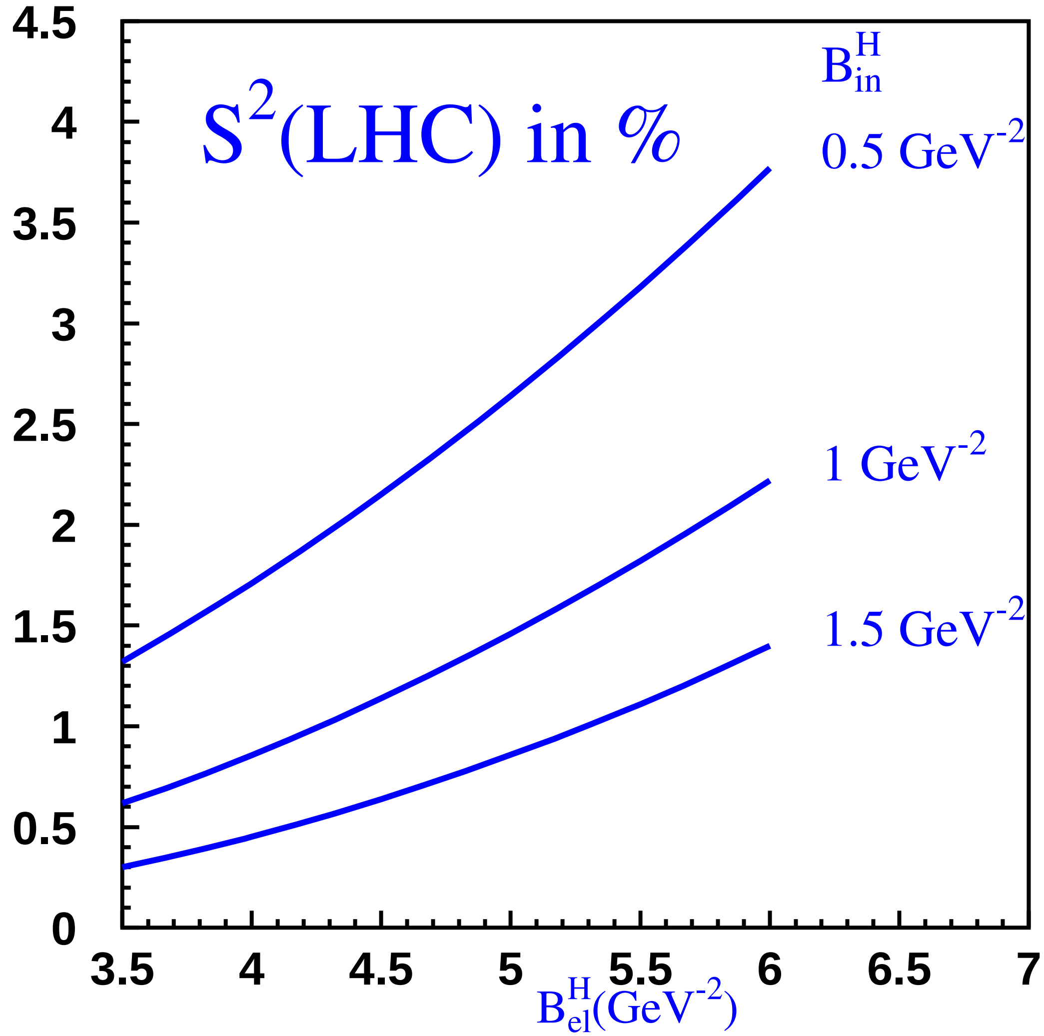
$$A^{pp}_H(b) \;=\; \frac{V_{p\to p}}{2\pi B^H_{el}} \exp\left(-\frac{b^2}{2\,B^H_{el}}\right), \qquad and \quad A^{pdif}_H(b) \;=\; \frac{V_{p\to dif}}{2\pi B^H_{in}} \exp\left(-\frac{b^2}{2B^H_{in}}\right).$$

The values B^H_{el}=5.0 (3.6) GeV^{-2} and B^H_{in}=1 GeV^{-2} have been taken from ZEUS data.

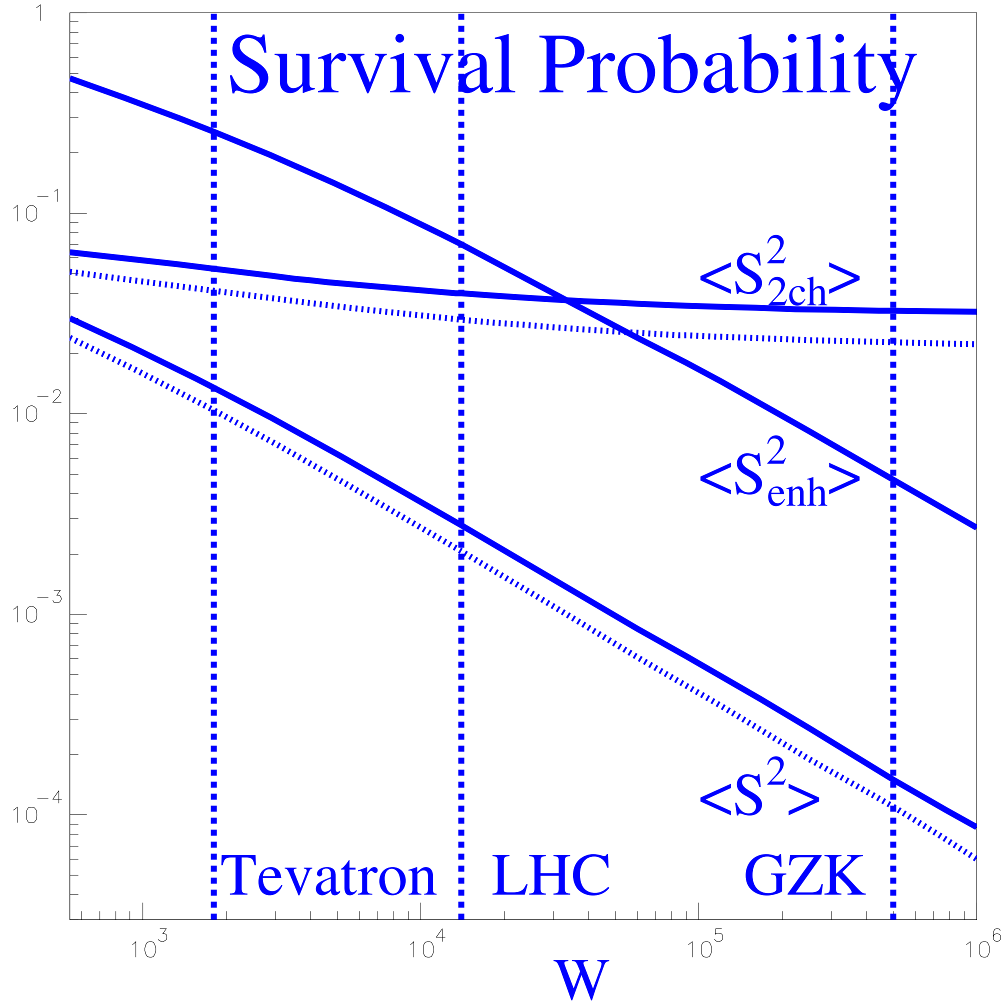
- Contrast to KMR treatment they assume: $A^{pp}_H(b) \;=\; A^{pdif}_H(b) \;\propto\; \exp\left(-\frac{b^2}{2B^H}\right)$
- with $B^H_{el} \;=\; B^H_{inel} = 4$ or 5.5 GeV^{-2}


b(GeV^{-2})
14
12
10
8
6
4
2
0
0
10
20
30
40
50
Q^2+M^2(GeV^2)
ρ ZEUS (120 pb^{-1})
ρ ZEUS 94
ρ ZEUS 95
ρ H1 95-96
φ ZEUS 98-00
φ ZEUS 94
J/ψ ZEUS 98-00
J/ψ ZEUS 96-97
J/ψ H1 96-00
DVCS H1 96-00
DVCS H1 HERAII e$^-$p (prel.)
DVCS ZEUS (prel.) (28 pb^{-1})

The dependence of S^2 at the LHC on B_{el}^H and B_{in}^H



Energy dependence of centrally produced Higgs survival probability



Comparison of results obtained in GLMM and KMR models

	Tevatron		, LHC		$W = 10^5 GeV$	
	GLM	KMR	GLM	KMR	GLM	KMR
σ_{tot}(mb)	73.29	74 .0	92.1	88.0	108.0	98.0
σ_{el}(mb)	16.3	16.3	20.9	20.1	24.	22.9
σ_{sd}(mb)	9.76	10 .9	11.8	13.3	14.4	15.7
$\sigma_{sd}^{\text{low M}}$	8.56	4.4	10.52	5.1	12.2	5.7
$\sigma_{sd}^{\text{high M}}$	1.2	6.5	1.28	8.2	2.2	10.0
σ_{dd}(mb)	5.36	7.2	6.08	13.4	6.29	17.3
$(\sigma_{el} + \sigma_{sd} + \sigma_{dd}) / \sigma_{tot}$	0.428	0.464	0.421	0.531	0.412	0.57
$S^2_{2ch}(\%)$	5.3	2.7 - 4.8	3.89	1.2-3.2	3.23	0.9 - 2.5
$S^2_{enh}(\%)$	28.5	100	6 .3	100	3.3	100
$S^2(\%)$	1.51	2.7 - 4.8	0.24	1.2-3.2	0.11	0.9 - 2.5

Other results for S^2_{2ch},

Calculations based on L.O. QCD by Bartels, Bondarenko, Kuta and Motyka [P.R.,D73,093004 (2006)] find

$$S^2_{2ch} \; = \; 0.024$$

They have also calculated corrections for hard rescattering which depend on the value taken for α_s.

Frankfurt, Strikman and Weiss have used a mean field approximation (independent hard and soft scattering).

They find that at LHC energies absorptive interactions of hard spectator partons associated with the process $g + g \to H$, reach the black disc region and cause substantial additional suppression, pushing

$$S^2_{2ch} \; < \; 0.01$$

Other results for S^2, contd.

New version of the Durham model (EPJC60,265(2009)) includes 3 components of the POMERON, with different transverse momenta of the partons in each component, to mimic BFKL diffusion in k_t.

The Survival Probability is now multiplied by a "renormalizing" factor $(\langle p_t^2 \rangle B)^2$ and referred to as $\langle S^2_{eff} \rangle$

Their result for LHC energy is $\langle S^2_{eff} \rangle = 0.015^{+0.01}_{-0.005}$

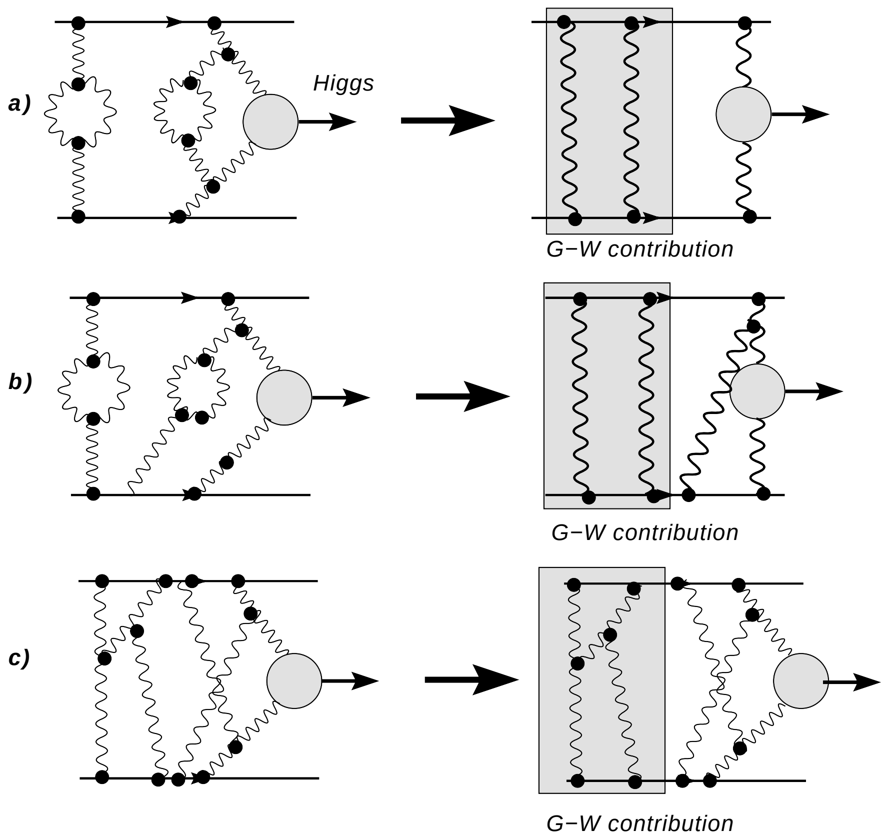
For enhanced screening limited to outside the rapidity threshold:-

For Δ y =	0	1.5	2.3
$S^2_{eff}(\%) =$	0.4	0.9	1.5

The new Durham result $\langle S^2_{eff}(\%) \rangle =$ 1.0 -2.5 is compatable with their "old" Soft Model result of $S^2(\%) =$ 1.2 - 3.2 Is $\langle S^2_{enh} \rangle = 1$ or $\approx 1/3$?

This is to be compared with the amended Tel Aviv value of $S^2(\%) =$ 0.24

G-W, Enhanced and Semi-Enhanced Diagrams contributing to $\langle | S^2 | \rangle$



The set of diagrams that is selected and summed for the calculation of the survival probability for diffractive Higgs production.fig(a) shows the diagrams in G-W + enhanced diagrams approach, in fig(b) the same approach is shown but we add the first semi-enhanced diagram to calculate the value of the survival probability. The approach for $\tilde{g}_i T(Y) \approx 1$ but $\Delta T(Y) \ll 1$ (net diagrams) is shown in fig(c).

Survival Probalitity including G-W, Enhanced, and Semi-Enhanced diagrams

(Preliminary)

Survival probability ($S^2\%$)	Tevatron	LHC
G-W + enhanced diagrams	1.51	0.24
G-W + enhanced diagrams + semi-enhanced (perturbative)	1.48	0.23

Summary

- We present a model for soft interactions having two components:
  (i) G-W mechanism for elastic and low mass diffractive scattering
  (ii) Pomeron enhanced contributions for high mass diffractive production.
- Key Hypothesis:
  Soft processes are not "soft", but orginate from short distances:
- Due to enhanced $I\!P$ diagrams, find σ_{tot} and σ_{el} at LHC energy will be SMALLER than D.L. predictions.
- Result with practical application is value obtained for S^2_H,
  for central diffractive Higgs production at the LHC, of about 0.24 %
  as S^2_{2ch}, is multiplied by a small S^2_{enh}, while $S^2_{semi-enh} \approx 1$.