Total Cross-sections at the LHC.

- Introduction.
- BN Model: Eikonamlised minijet model with soft gluon resummation.
- Application to gap survival probabliity.
- Further validation of the model by its application to γp case.

Some references:

1)A. Corsetti, A. Grau, G. Pancheri,Y.Srivastava, PLB382 (1996)

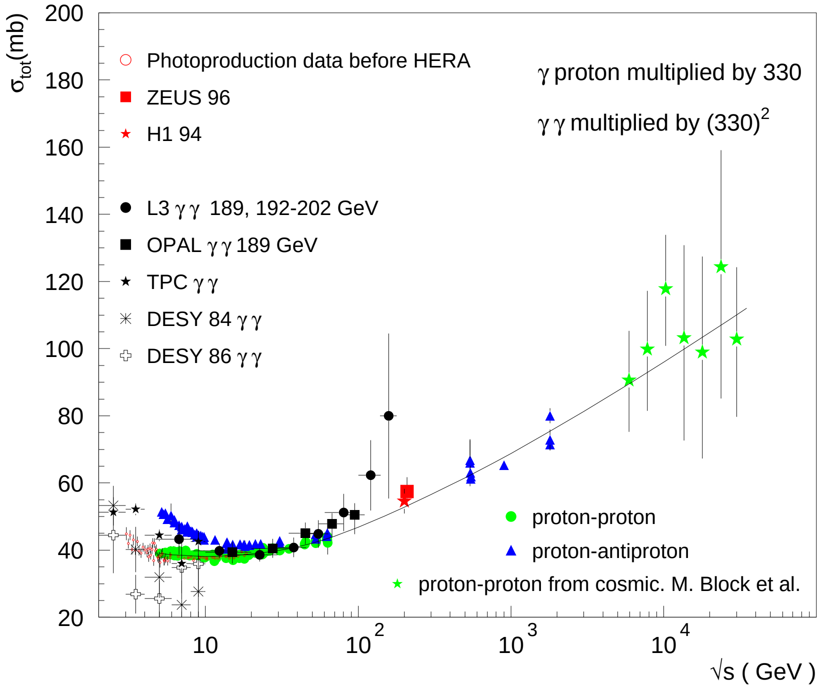
2) A. Grau, G.Pancheri, Y. Srivasatava, PRD60 1999, hep-ph/9905228

3)Rohit Hegde, R.G., A. Grau, G. Pancheri and Y. Srivastava, Pramana **66**, 657

4)A. Achilli, R. Hegde, R. M. Godbole, A. Grau, G. Pancheri and Y. Srivastava, arXiv:0708.3626, Phys. Lett. 659 (2007) 137.

5)R.G., A. Grau, G. Pancheri, Y. Srivastava : Total photoproduction cross-sections at high energy (in preparation)

All total cross-sections rise with energy.



Solid line: Eikonal model improved with soft gluon resummation (Pancheri, Grau Srivastava, RG)

Charge to models:

Explain 1) The normalisation, 2) The rise **and** 3) the initial fall with energy.

- Which mechanism drives the rise?
- Do they all rise with same slope?
- Do they satisfy the Froissart bound

  $\sigma_{tot} \leq \log^2(s)$ as $s \to \infty$.

The tools:

- Bounds from Analyticity and Unitarity.
- Regge Pomeron exchange.
- The Eikonal Minijet Model: EMM.
- Bloch-Nordsieck Resummation for the EMM.
- Minijet model and gluon saturation

1]

Regge-Pomeron Exchange:

$$\sigma_{tot} = \beta_R \left(\frac{s}{s_0}\right)^{\alpha_R(0)-1} + \beta_P \left(\frac{s}{s_0}\right)^{\alpha_P(0)-1} \equiv X s^{-\eta} + Y s^{\epsilon}$$

with $\eta \simeq 0.45, \epsilon \simeq 0.08$.

DL Parameterisation: A. Donnachie, P. Landschoff, PLB 296 (1992) 227

The fit had to be extended to include a 'hard' pomeron. DL (PLB 595 (2004) 393)

2] Fits using Unitarity

Block and Halzen: Phys. Rev. D72 (2005) 036006, PRD D73 (2006) 054022

The BH fit for $\sigma^{\pm} = \sigma^{\bar{p}p}/\sigma^{pp}$ as a function of beam energy ν, is given as

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

The Froissart bound is saturated. They make predictions for the LHC cross-sections.

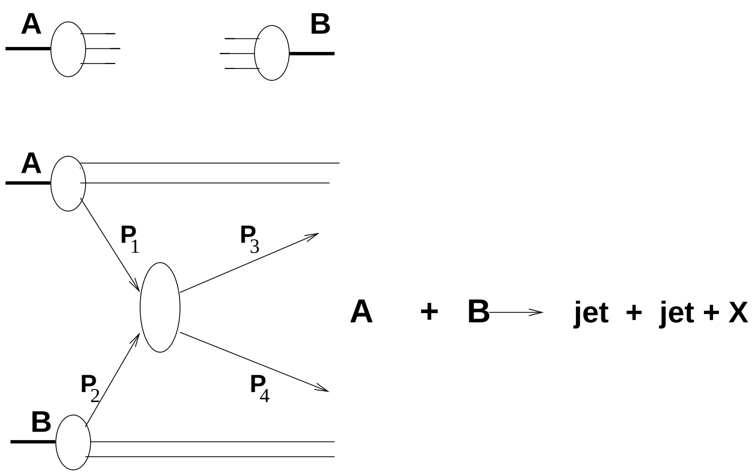
Igi and Ishida: obtain fits using Finite Energy sum rules Igi and M. Ishida, Phys. Lett. B622 (2005) 286 Similar predictions.

COMPETE Program: J. R. Cudell et. al. Phys. Rev. Lett. 89 (2002) 201801 J.-R. Cudell and O.V. Selyugin, hep-ph/061246; J.R. Cudell, E. Martynov, O.V. Selyugin and A. Lengyel, Phys. Lett. B 587 (2004) 78.

Constraints from analyticity, unitarity, factorisation and the fact that cross-sections grows at most as $\log^2(s)$, but they also obtain fits assuming the cross-section goes as a constant.

3] Eikonalised Minijet models : there is a whole class of them.

Basic philosophy:



Try to explain the rise and the initial fall in terms of partons in the colliding hadrons using experimentally determined parton densities and basic QCD interactions among partons.

Increasing beam energy ⇒ increase in # and energy of collding partons.

$\sigma_{jet} = \sigma(A + B \to jet + jet + X)$

calculated in pQCD rises with increasing $\sqrt{s}$.

Energy rise in σ_{tot} driven by the rise of σ_{jet}.

Minijet Model Halzen and Cline (1985)

$$\sigma_{jet} = \int_{p_t min} \frac{d^2\sigma_{jet}}{d^2\vec{p}_t} d^2\vec{p}_t = \sum_{partons} \int_{p_t min} d^2\vec{p}_t \int f(x_1)dx_1 \int f(x_2)dx_2 \frac{d^2\sigma^{partons}}{d^2\vec{p}_t}$$

Dominated by gluons

Depends strongly on the transverse momentum cutoff p_{tmin}.

• σ_{jet} rises with s as a power in violation Frossiart Bound too fast towards σ_{tot}.

• Unitarization essential. Done using eikonal formalism

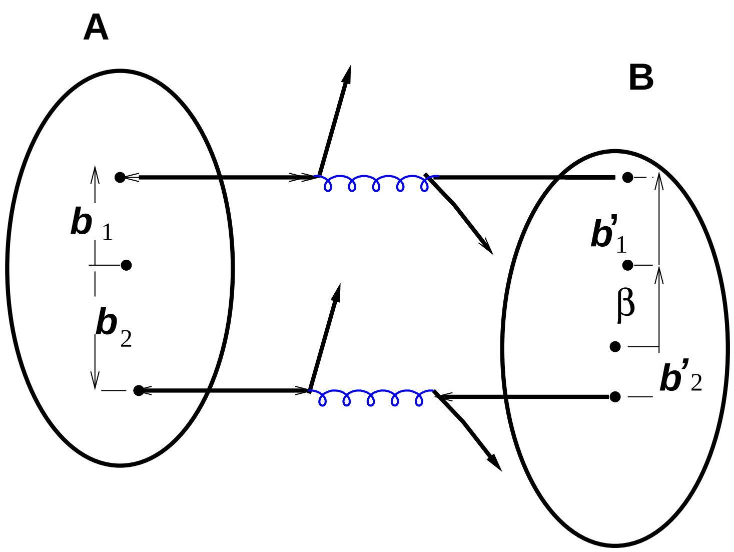
• The steep rise of σ_{jet} with s is NOT reflected in the energy rise of $\sigma_{tot}, \sigma_{inel}$.

With increasing energy the probability of multiple parton scattering (MPS) in a given hard scatter increases

$$\sigma_{AB}^{jet}(s) = < n_{pair}^{jet} > (s) \sigma_{AB}^{inel}(s)$$

Rising MPS $\Rightarrow$ rising jet pair multiplicity

Need to calculate the s dependence of $< n_{pair}^{jet} >$.



Transverse Overlap of the hadrons

s dependence related to that of the MPS probability. This in turn decided by the overlap of the partons in the transverse plane.

$$A_{AB}(\beta) = \int d^2 b_1 \rho_A(\vec{b_1}) \rho_B(\vec{\beta} - \vec{b_1})$$

The different models differ in how one models this overlap.

Number of collisions:

$n(b,s) = A_{AB}(b,s)\sigma(s) = 2\chi_I(b,s)$

$\chi(b,s)$ (EIKONAL function.)

- $\sigma^{\text{inel}}_{pp(\bar{p})} = 2\int d^2\vec{b}[1 - e^{-n(b,s)}]$

- Build n(b,s) for σ^{inel} and use it for

- $\sigma^{\text{tot}}_{pp(\bar{p})} = 2\int d^2\vec{b}[1 - e^{-n(b,s)/2}cos(\chi_R)],\ \chi_R = 0$ in EMM

Approximations normally used:

$n(b,s) = n_{NP}(b,s) + n_P(b,s)$

Further factorisation:

$n(b,s) = A(b)[\sigma_{soft} + \sigma_{jet}]$

- Model for A(b).
- σ_{soft} parametrized
- σ_{jet} LO QCD jet x-sections
- Eikonal model not restricted to calculate ONLY c.sections also used to calculate properties of hadronic events. pioneering: T. Sjostrand , More recent : M. Seymore + Borozan JHEP (2002), J. Butterworth, Mike Seymour, 0806.2949.

At low energies and small σ^{jet}

$$\sigma_{AB}^{\text{inel}} = 2\int d^2\vec{b}[1 - e^{-n(b,s)}] \simeq \sigma_{AB}^{soft} + \sigma_{AB}^{jet}$$

At high energies, the eikonalisation softens the energy rise of σ^{inel} compared to that of σ^{jet}.

• Eikonal $\chi(b,s)$ contains information on the energy and the transverse space distribution of the partons in the hadrons.

• simplest formulation with minijets to drive the rise and eikonalization to ensure unitarity :

$$2\chi_I(b,s) \equiv n(b,s) = A(b)[\sigma_{soft} + \sigma_{jet}]$$

• The normalization depends both on σ_{soft} and on the b-distribution.

How to calculate the transverse overlap function in terms of 'measured' quantities?

- σ^{jet} depends on the parton densities $f_{q/A}(x_1), f_{q/B}(x_2)$ x_i the longitudinal mmtm fraction

- Overlap function on the transverse space (momentum) distribution.

Calculate the overlap functions using Fourier Transforms of form factors.

One can also calculate it using Fourier Transform of the transverse momentum distribution of the partons inside the proton.

Even the eikonalised minijet model predicts too strong a growth DIf-ficult to get the initial fall and the rise both at the right energies.

BN model is a QCD based model to calculate the overlap function $A(b, s)$.

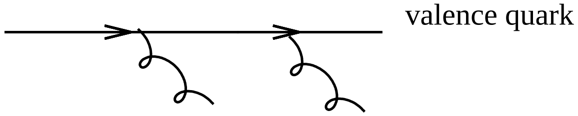
EMM model does O.K. qualitatively but is certainly not the whole story. Improve the model by removing the approximations used.

Recall **assumed** $n(b,s) = A(b)[\sigma_{soft} + \sigma_{jet}]$.

- The separation between s and b dependence only an approximation.

- Writing the overlap function as a $\mathcal{F}.\mathcal{T}$. of measured distributions does not allow for a s dependence of A

Pancheri, Grau, Srivatava had developed a model based on semi-classical method to calculate the impact parameter space distribution of partons in a hadron using resummation of soft gluon emissions.



BN model uses this computation.

• It is like EMM model with σ_{jet}^{QCD} driving the rise

and in addition

Soft Gluon Emission from Initial State Valence Quarks in k_t-space to give impact parameter space distribution of colliding partons

• introduces energy dependence in the **b-distribution** of partons in the hadrons $\Longrightarrow$ which depends on

1. p_{tmin}

2. parton densities

Net effect is the energy rise is toned down.

The softening effect happens

- as $\sqrt{s} \Uparrow$ the phase space available for soft gluon emission also $\Uparrow$
- the transverse momentum of the initial colliding pair due to soft gluon emission $\Uparrow$
- more straggling of initial partons $\Rightarrow$ less probability for the collision
- The soft gluons in the eikonal in fact restore the Froissart bound.

Important issue how to handle α_s for this very soft gluon emissions how to compute $A(b, s)$ for hard and soft contribution and how Frossiart bound is restored (Achille's talk)

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

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

p is a parameter controlling $\alpha_s(k_t^2)$ at small k_t^2.

q_{max} is a the maximum momentum allowed for gluon emission. For hard part it is calculated in terms of the parton densities. For soft part it is parmaterised and fitted.

$$\sigma_{tot} \simeq \int_o^\infty d^2b \left[1 - e^{-n_{hard}(b,s)/2}\right]$$

$$n_{hard}(b,s) = \sigma_{hard}(s) A_{hard}(b,s)$$

$\sigma_{hard} \simeq \left(\frac{s}{s_0}\right)^\epsilon \sigma_1$

$A(b,s) \sim e^{-(bq)^{2p}}$

Thus the quenching is controlled by p a parameter which is motivated by Rinchardson potential. p has to be less than 1 for the singularity in α_s to be integrable.

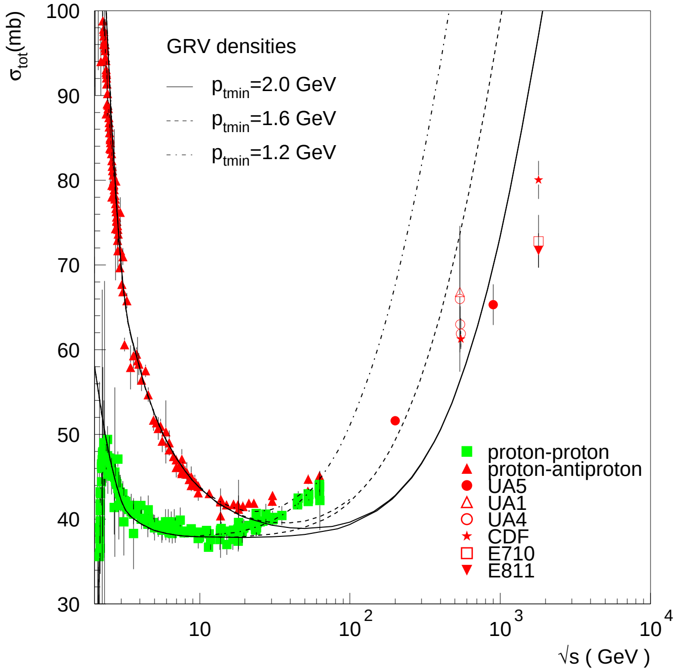
$\sigma_{tot} \simeq (\epsilon \ln s)^{1/p}$

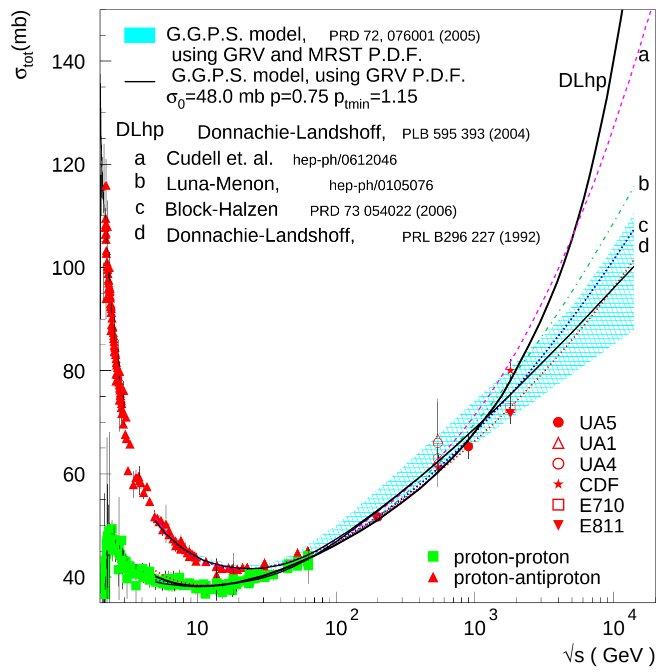
$1/2 < p < 1$.

Aspen Model (BGHP model): QCD inspired model. Use analyticity, unitarity, factorisation etc. Fit the eikonal functions. Overlap function calculated using form factors. M. M. Block, E. M. Gregores, F. Halzen and G. Pancheri, Phys. Rev. D D60 (1999) 054024,

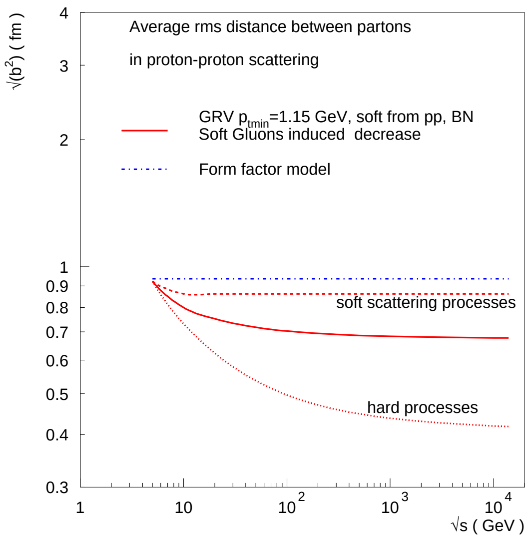
Luna-Menon Model: Dynamical gluon mass used. A further variant of the BGHP model E. G. S. Luna, A. F. Martini, M. J. Menon, A. Mihara and A. A. Natale, Phys. Rev. D72 (2005) 034019.

Based on Colour Glass condensate Model F. Carvallo et al, 0705.1842 also try to use the gluon saturation phenomena to tone down fast rise!





$$\sigma_{tot}^{LHC} = 102 + 12 - 13 mb$$



• Indeed the rms distance between the centres of two hadrons decreases with energy causing more shadowing and taming the rise

• Similar observation by M. Seymore and collab. from a study of properties of the events in $p\bar{p}$ data from CDF in an eikonal picture.

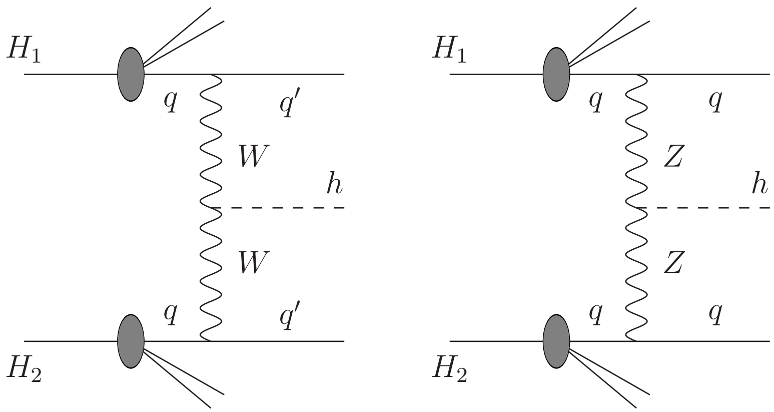
Consider Higgs production via WW fusion processes.

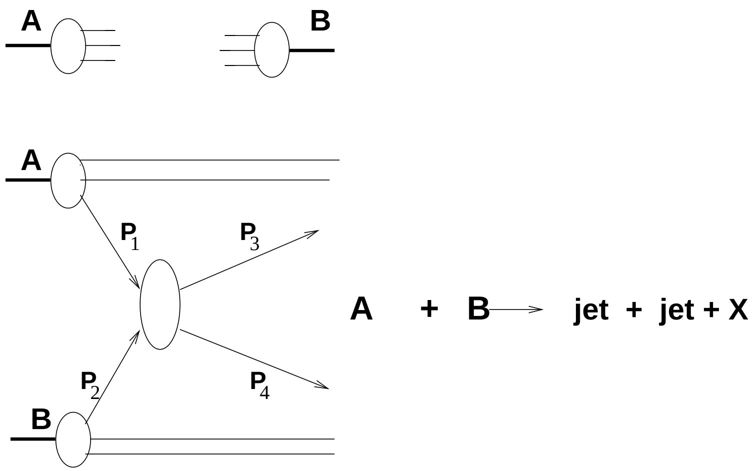
Usually one demands that the the two jets 'forward' jets have very little hadronic activity among them.

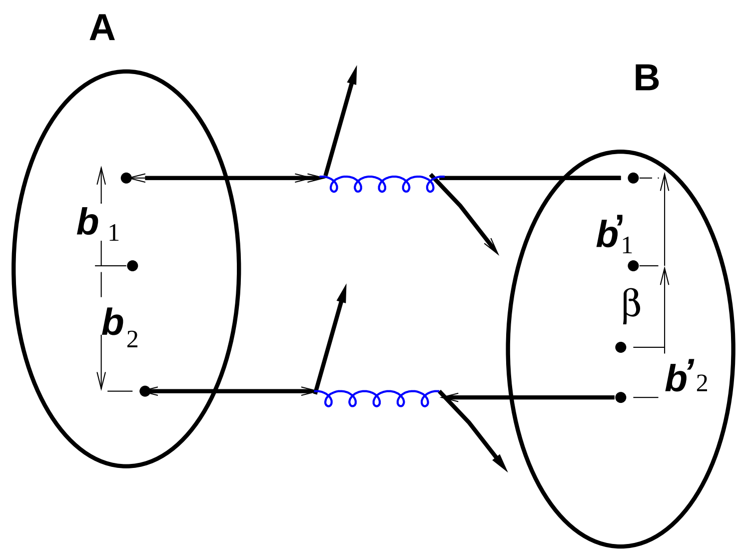
These are called 'large rapidity gap' events.

Question: How do we decide that the the underlying event does not fill the fap?

This depends on the models for multi-parton interactions in a given collision.







Transverse Overlap of the hadrons

Bjorken pointed out that the gap survival probablity could be computed if one knew this overlap.

The same overlap function is also needed to calculate the total cross section as a function of energy in QCD based models using eikonal picture.

Eikonal picture per se was pioneered by Tjostrand is tested at Tevatron/HERA.

The description and the overlap integral depends on parametrisation of nonperturbative physics and the models used.

Gap Survivial probability:

$$< |S|^2 >= \frac{\int d^2\vec{b} A^{AB}(\vec{b},s)|S(\vec{b})|^2\sigma(b,s)}{\int d^2\vec{b} A^{AB}(\vec{b},s)\sigma(b,s)}.$$

Here $|S(\vec{b})|^2$ is the probability that the two hadrons A,B go through each other without an inelastic interactioni, which will also be different in different models of calculation of total cross-section.

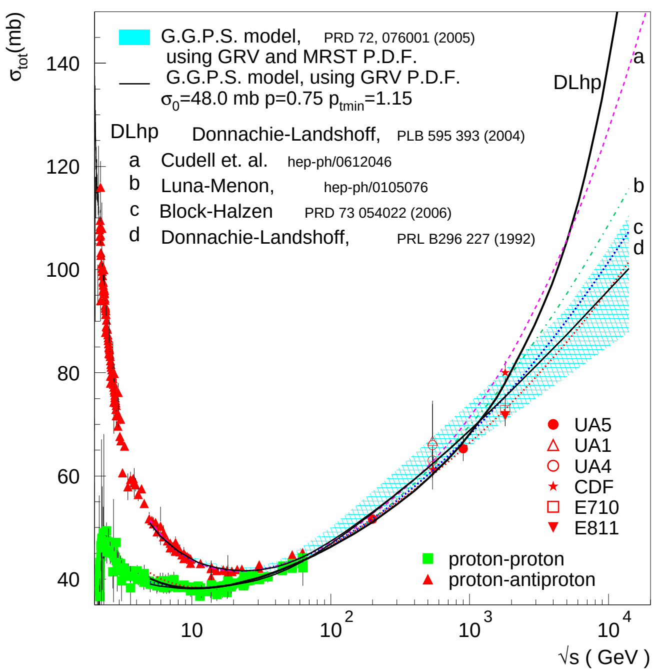
$$\sigma_{tot}^{AB} = 2\int d^2\vec{b}[1 - e^{-n(b,s)}]$$

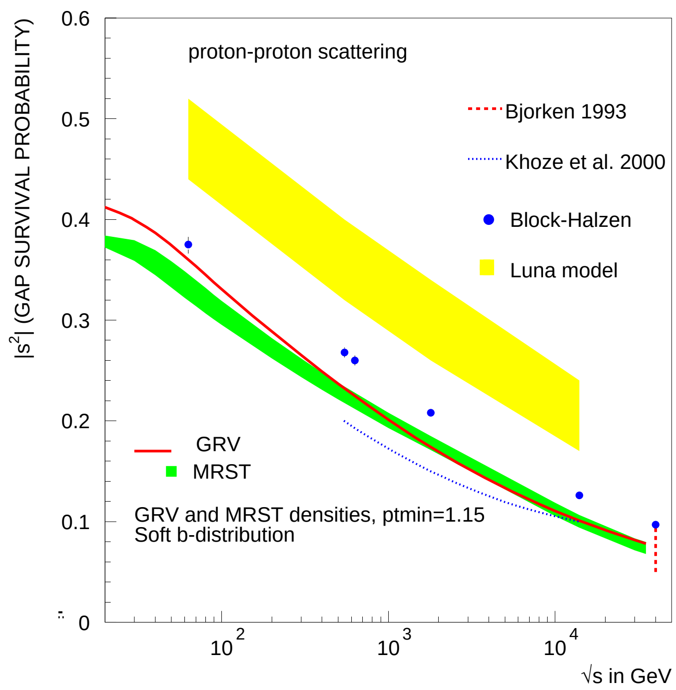
$n(b,s)$ is the average number of multiple collisions at an impact parameter b and energy $\sqrt{s}$.

In our model:

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

Parameters fixed by fits to total c.section, make prediction for GSP.


G.G.P.S. model, PRD 72, 076001 (2005)
using GRV and MRST P.D.F.
G.G.P.S. model, using GRV P.D.F.
σ0=48.0 mb p=0.75 ptmin=1.15
DLhp Donnachie-Landshoff, PLB 595 393 (2004)
a Cudell et. al. hep-ph/0612046
b Luna-Menon, hep-ph/0105076
c Block-Halzen PRD 73 054022 (2006)
d Donnachie-Landshoff, PRL B296 227 (1992)
DLhp
a
b
c
d
UA5
UA1
UA4
CDF
E710
E811
proton-proton
proton-antiproton
σtot(mb)
√s (GeV)


proton-proton scattering
Bjorken 1993
Khoze et al. 2000
Block-Halzen
Luna model
GRV
MRST
GRV and MRST densities, ptmin=1.15
Soft b-distribution
|s2| (GAP SURVIVAL PROBABILITY)
√s in GeV

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

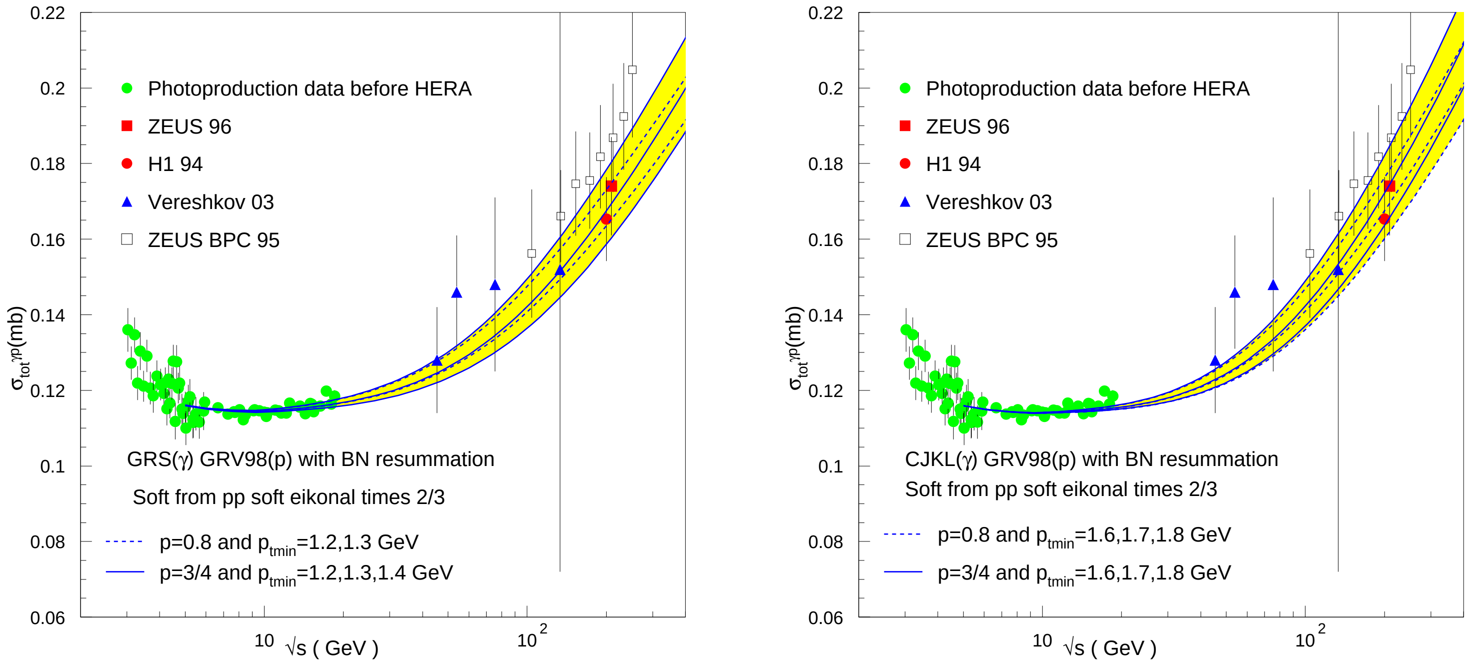
WHile now calculating $n^{\gamma p}$ one has to be careful. Involves now an additional parameter P_{had}

$$n^{\gamma p}(b,s) = n^{\gamma p}_{soft}(b,s) + n^{\gamma p}_{hard}(b,s) = n^{\gamma p}_{soft}(b,s) + A(b,s)\sigma^{\gamma p}_{jet}(s)/P_{had}$$

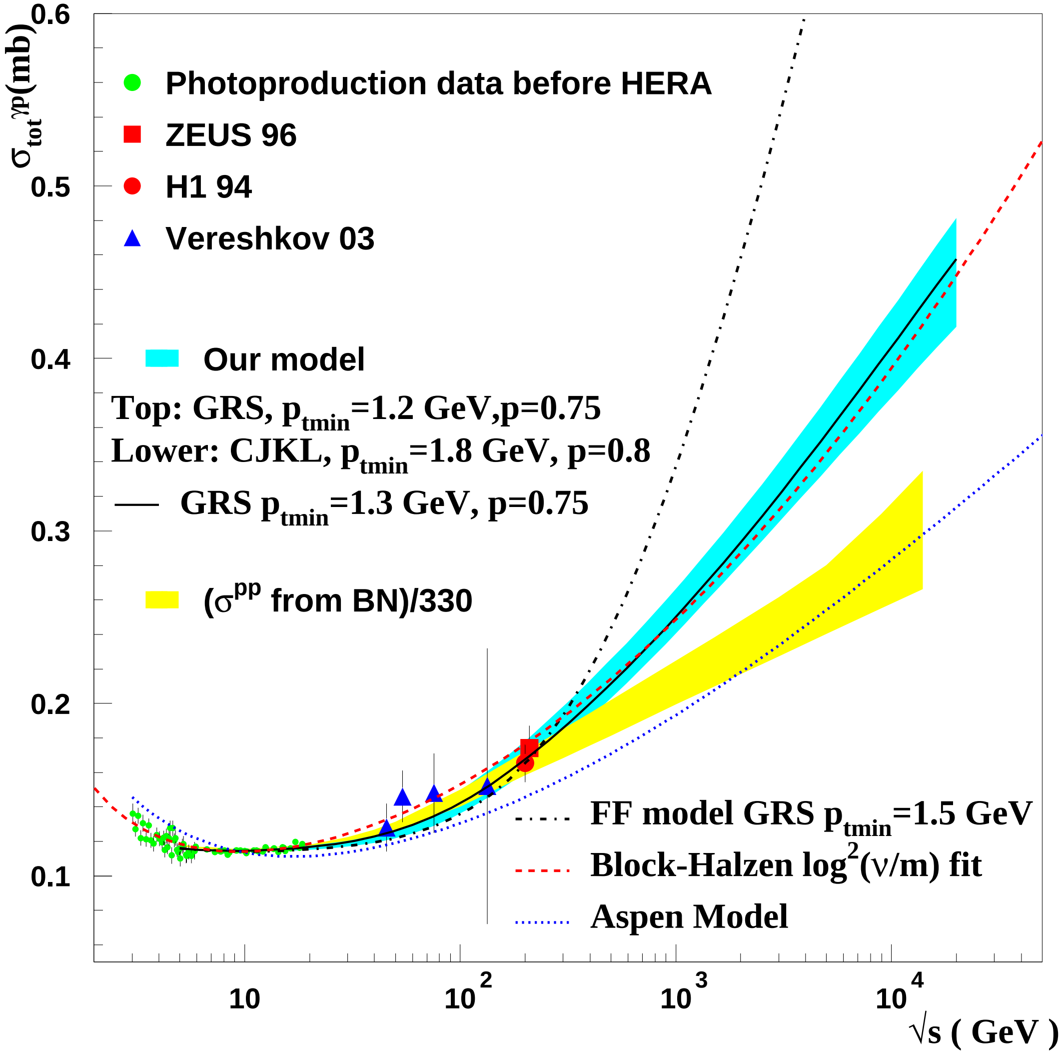
We now use

$$n_{hard}(b,s) = \frac{A^{AB}_{BN}(b,s)\sigma_{jet}}{P_{had}}$$

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



Predictions obtained using the photonic parton densities and parametes p, p_{tmin} and σ_{soft} similar to the proton case.


$\sigma_{tot}^{\gamma p}$(mb)
0.6
0.5
0.4
0.3
0.2
0.1
Photoproduction data before HERA
ZEUS 96
H1 94
Vereshkov 03
Our model
Top: GRS, p_{tmin}=1.2 GeV,p=0.75
Lower: CJKL, p_{tmin}=1.8 GeV, p=0.8
GRS p_{tmin}=1.3 GeV, p=0.75
(σ^{pp} from BN)/330
FF model GRS p_{tmin}=1.5 GeV
Block-Halzen $\log^2(\nu/m)$ fit
Aspen Model
10
10^2
10^3
10^4
$\sqrt{s}$ (GeV)

- Soft gluon resummation effects tame the high energy rise of unitarised minijet cross-sections and restore the Froissart bound.

- The BN Eikonalised model predicts LHC cross-sections consistent with other fits which were done requiring analticity and unitarity properties.

- In particular the predicitons of our model for *both* the pp and γp case agree with those of Block Halzen fits where they argue saturation of Froissart bound.

- This in fact means a violation of simple factorisation in going from p to γp and further $\gamma\gamma$.