Photoproduction total cross-sessions at very high energies and the Froissart bound

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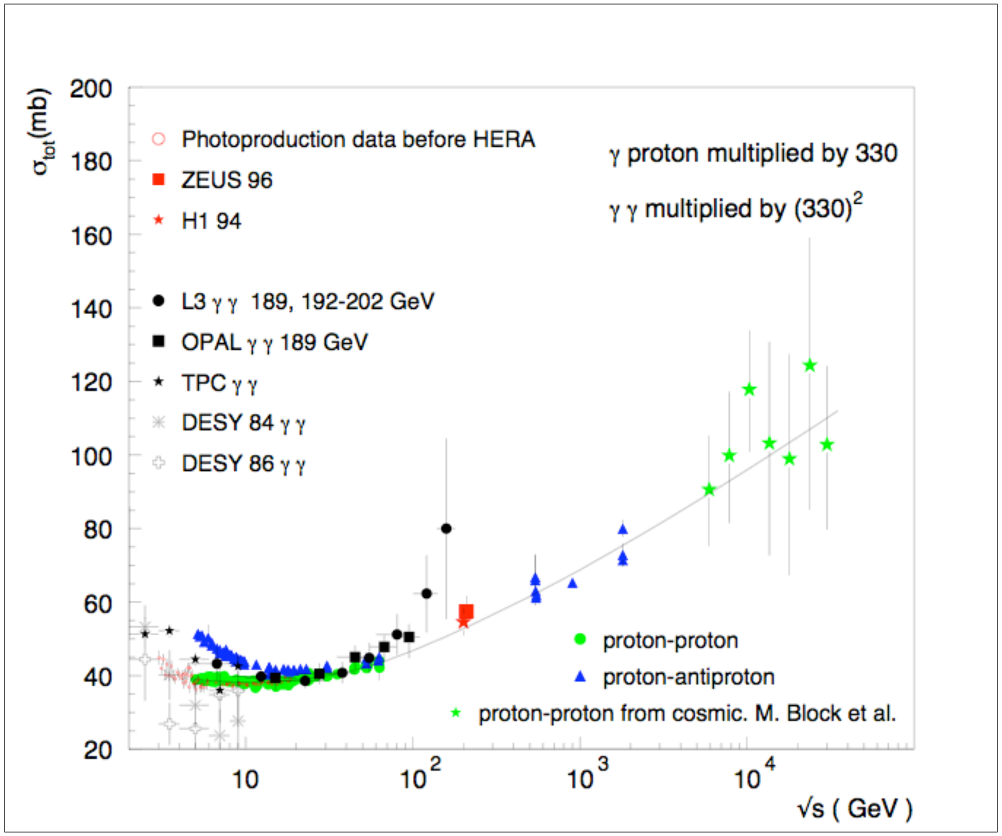
Outline

- The Bloch-Nordsieck (BN) model :
  very soft k_t gluons and QCD minijets
- Total cross-section and the Froissart bound
- From protons to photons:
  Photoproduction and Factorization

Hadronic cross-section and power-law features:our BN model is based on the occurrence of *fractal-type* behavior for a number of quantities

- ★ $\alpha_s(Q^2) \rightarrow \left(\frac{1}{Q^2}\right)^p, \; as \; Q^2 \rightarrow 0 \qquad 1/2 < p < 1$
- ★ $\sigma_{jet}(s; p_{tmin}) \rightarrow \sigma_1[\frac{s}{s_o}]^\epsilon, \; as \; s \rightarrow \infty; \; (p_{tmin} \; fixed)$
  $\epsilon \sim \frac{1}{3}$
- ★ $\sigma_{tot}(s) \rightarrow [ln(\frac{s}{s_o})]^f, \; as \; s \rightarrow \infty$
  $1 < f \leq 2$

All total cross-sections rise asymptotically with energy



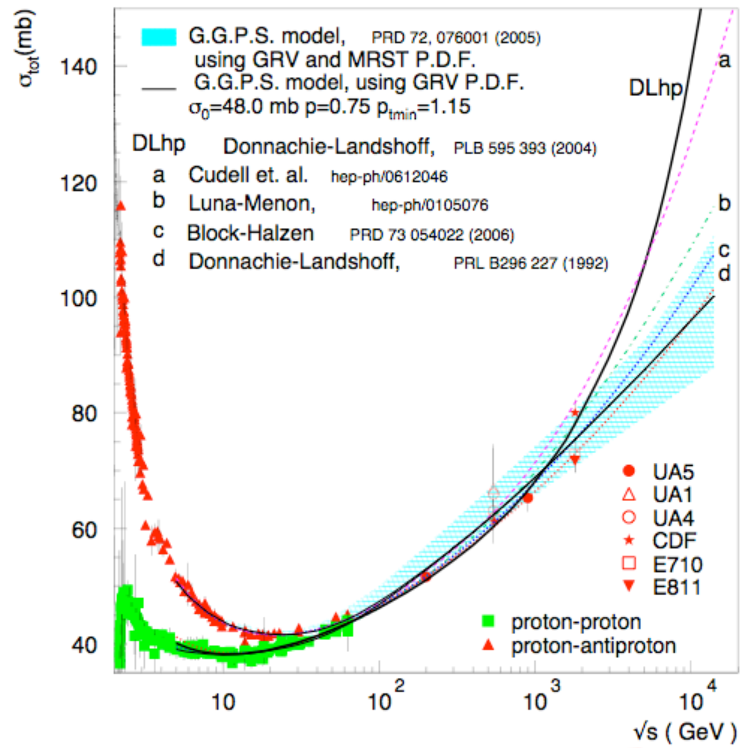
- Which mechanism drives the rise?
- Do they all rise with same slope?
- Do they satisfy the Froissart bound?

$$\sigma_{tot} \leq \log^2 s \quad as \quad s \to \infty$$

The Bloch-Nordsieck (BN) model

Eikonal mini-jet model with soft gluon resummation

- A. Corsetti, A. Grau, G. Pancheri,Y.N.S., PLB382 (1996)
- A. Grau, G.Pancheri, Y.N.S., PRD60 1999, hep-ph/9905228
- A. Achilli, R.M. Godbole, A. Grau, R. Hedge, G.Pancheri, Y.N. S., PLB659 (2008), arXiv:0708.36262008



$$\sigma_{tot}(\sqrt{s} = 14\ TeV) = 100 + 10 - 13\ mb$$

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The Bloch-Nordsieck model for saturation of total cross-sections

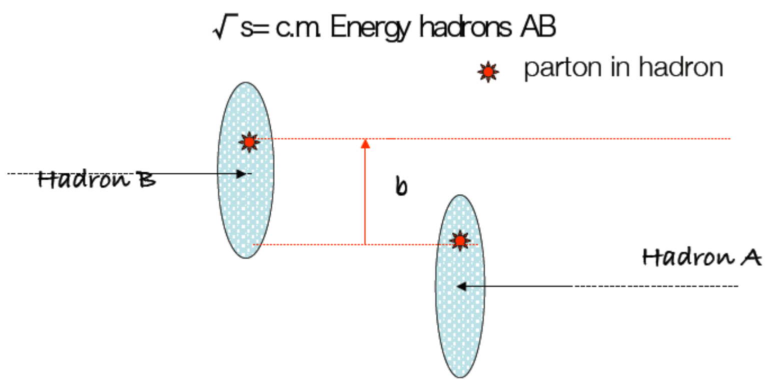
- QCD mini-jets to drive the rise of the total cross-section in the QCD asymptotic freedom regime;

- eikonal representation for the total cross-section (with Real part = 0) to incorporate the mini-jet cross-section

- an impact parameter distribution, as input to the eikonal representation, obtained as the Fourier transform of the resummed soft gluon transverse momentum distribution.

→ resummation of soft gluon emission down to zero momentum to soften the rise due to the increasing number of gluon-gluon collisions between hard perturbative, but low-x, gluons;

The impact parameter distribution in the BN model



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

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

The large b cut-off

$$A_{hard}(b,s) \approx e^{-h(b,s)} \rightarrow e^{-(bq)^{2p}}$$

$$h(b,s) = \int d^3 n_g(k)[1 - e^{-i\vec{k}_t \cdot \vec{b}}] \rightarrow (bq)^{2p}$$

$$d^3 n_g(k) \propto \alpha_s(k_t^2)$$

$$\alpha_s(k_t^2) \approx \frac{1}{(k_t)^{2p}} \quad as \quad k_t \rightarrow 0$$

Our toy model for
zero momentum gluons
a' la richardson (potential)

How soft gluons in the eikonal lead to saturation and restore the Froissart bound

At very large energies

$$\bar{\sigma}_{tot} \approx 2\pi \int_0^\infty (db^2)[1 - e^{-n_{hard}(b,s)/2}]$$

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

$$\sigma_{jet}(s) \approx (\frac{s}{s_0})^\epsilon \sigma_1$$

$$n_{hard} = 2C(s/s_0)^\varepsilon e^{-(bq)^{2p}}$$

Infrared gluons tame low-x gluon-gluon scattering (mini-jets) and restore the Froissart bound

$$\sigma_{tot}(s) \approx 2\pi \int_0^\infty db^2 [1 - e^{-C(s)e^{-(b\bar{\Lambda})^{2p}}}]$$

$$\sigma_{tot}(s) \to [\varepsilon \ln(s)]^{(1/p)}$$

$$\frac{1}{2} < p < 1$$

How the model works phenomenologically for protons

1. The mini-jet QCD cross-section to input $n_{hard}(b,s)$ is calculated choosing PDF's and a pt cutoff

$$p_{tmin}$$

1. The b-distribution for same PDF's and p_{tmin} is calculated choosing the infrared power *p*

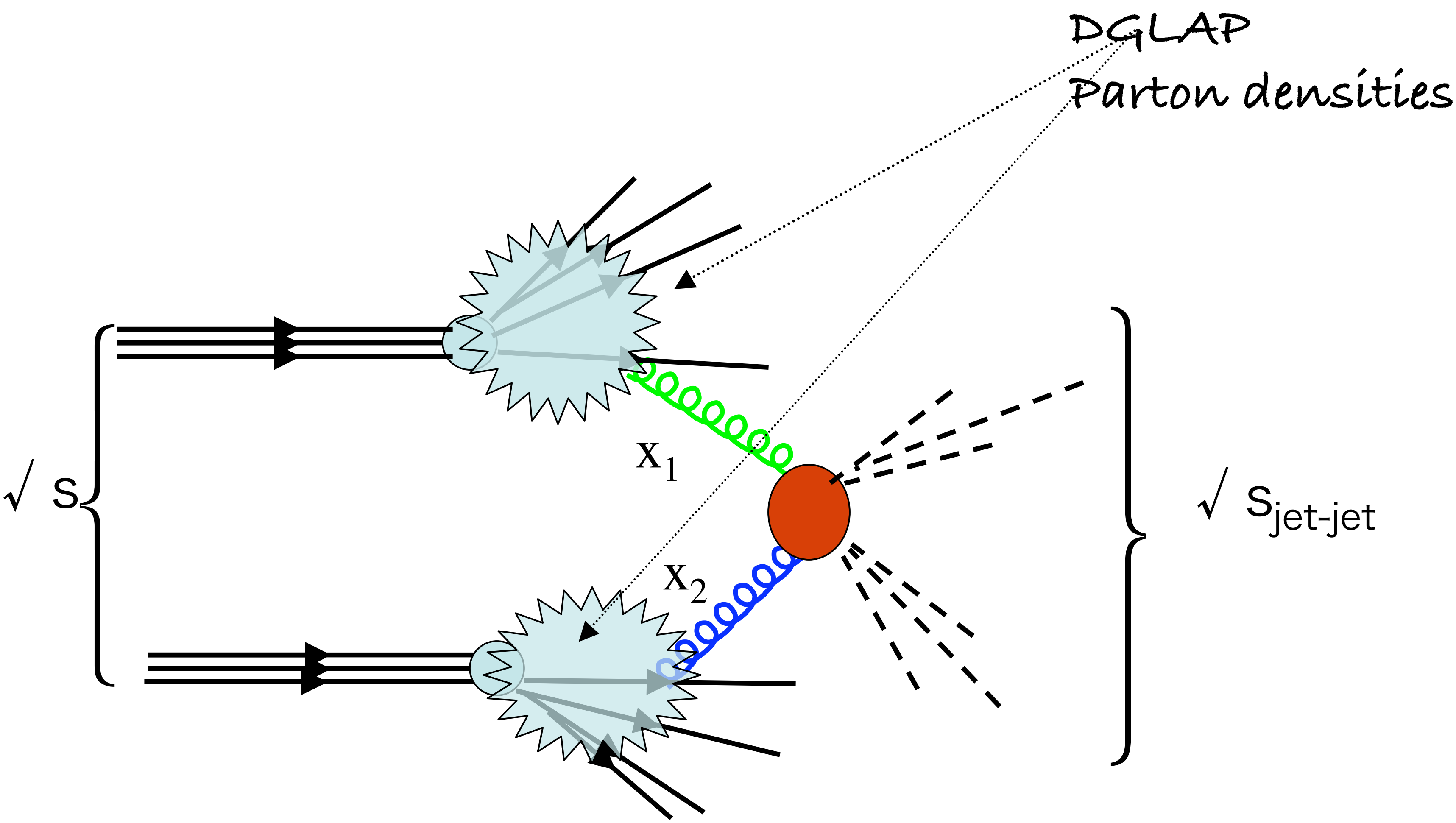
2. Fit low energy data $\sqrt{s} \approx 5 \div 10\ GeV$ to get

$$n_{soft}(b,s)$$

3. Input minijets and b-distribution in the eikonal representation

$$\sigma_{tot} = 2\int d^2\vec{b}[1 - e^{-n_{soft}(b,s)+n_{hard}(b,s)}]$$

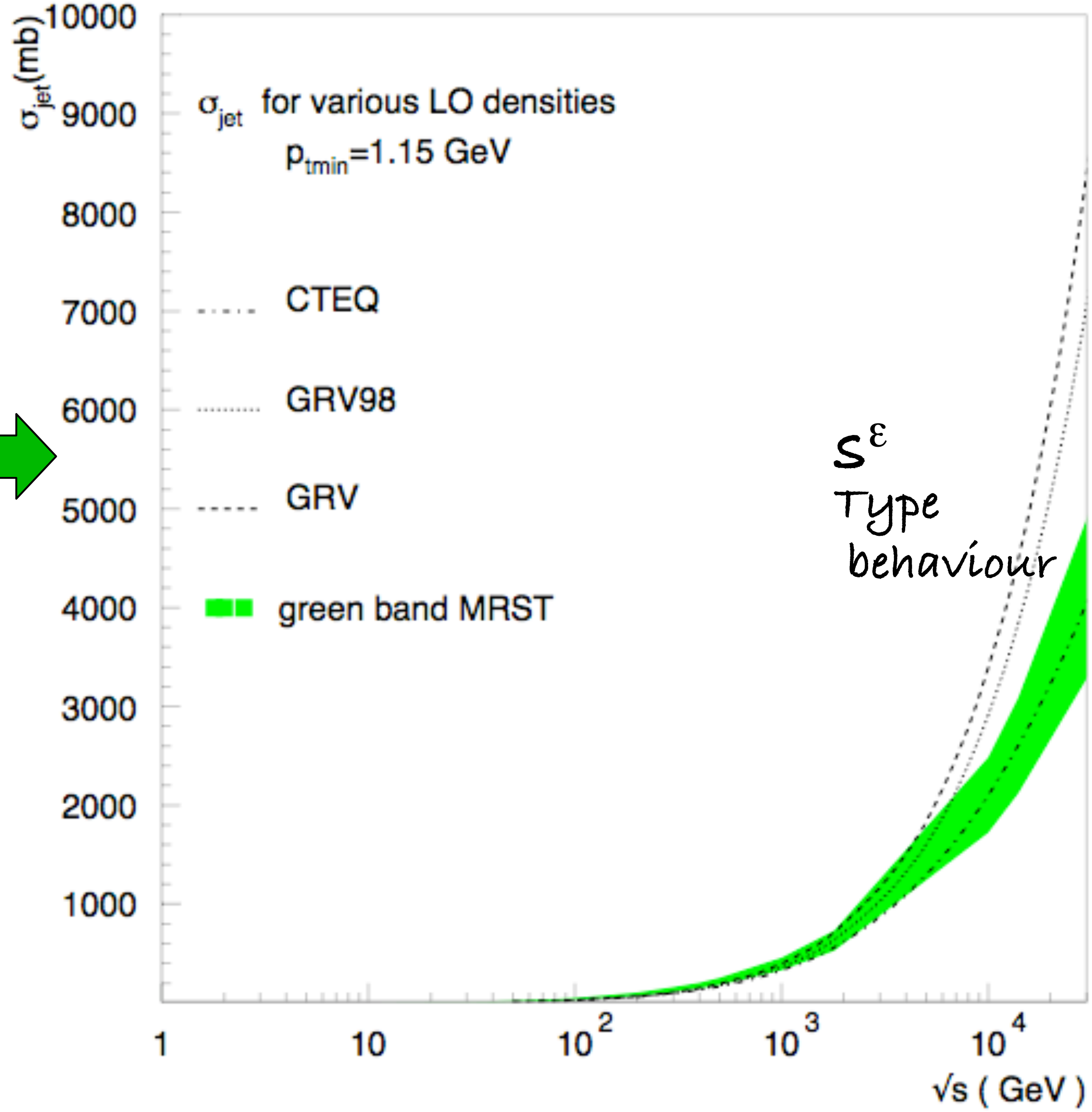
1. Hard component of scattering responsible for the rise of the total cross-section



$$\sigma_{hard} \equiv \sigma_{\rm jet}^{AB}(s, p_{tmin})$$

1.

Hard component of scattering responsible for the rise of the total cross-section



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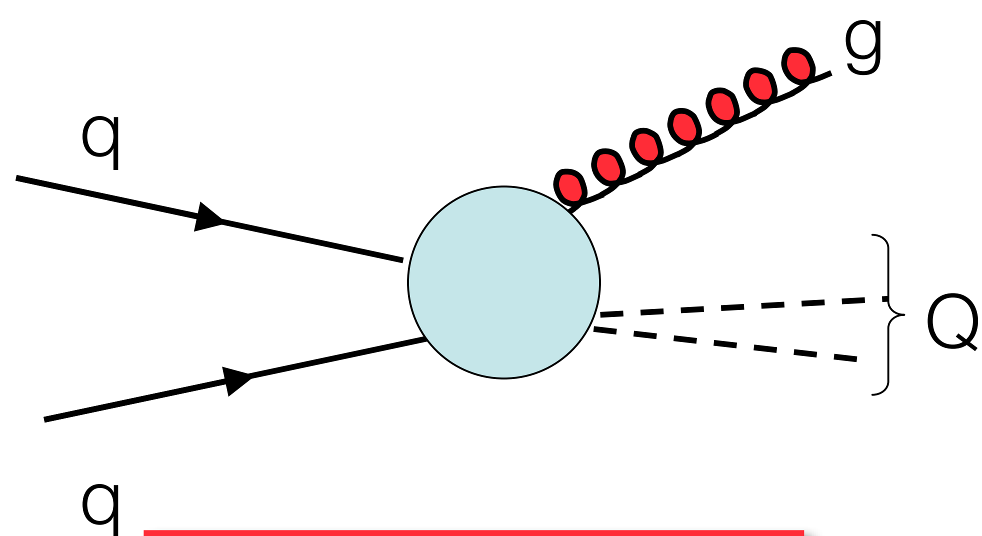
2. Doing the soft gluon integral and b-distribution

Kinematical constraints on single gluon emission

$q(p_1) + q(p_2) \longrightarrow g + Q$

$Q^2 = s_{jet\text{-}jet}$

$\hat{s} = (p_1 + p_2)^2$

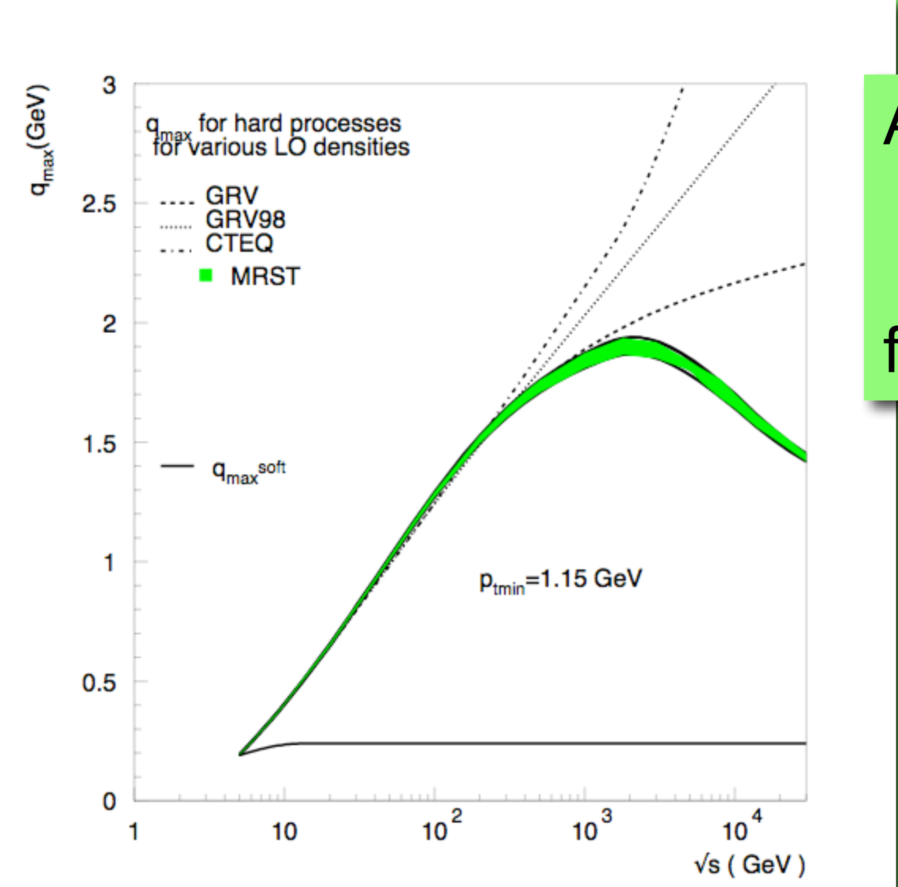


$$q_{max} = \frac{\sqrt{s}}{2}\left(1 - \frac{Q^2}{\hat{s}}\right)$$

Averaging over the densities

$$q_{max}(s) = \frac{\sqrt{s}}{2} \frac{\sum_{i,j} \int \frac{dx_1}{x_1} f_{i|A}(x_1) \int \frac{dx_2}{x_2} f_{j|B}(x_2) \sqrt{x_1 x_2} \int_{z_{min}}^{1} dz (1-z)}{\sum_{i,j} \int \frac{dx_1}{x_1} f_{i|A}(x_1) \int \frac{dx_2}{x_2} f_{j|B}(x_2) \int_{z_{min}}^{1} (dz)}$$

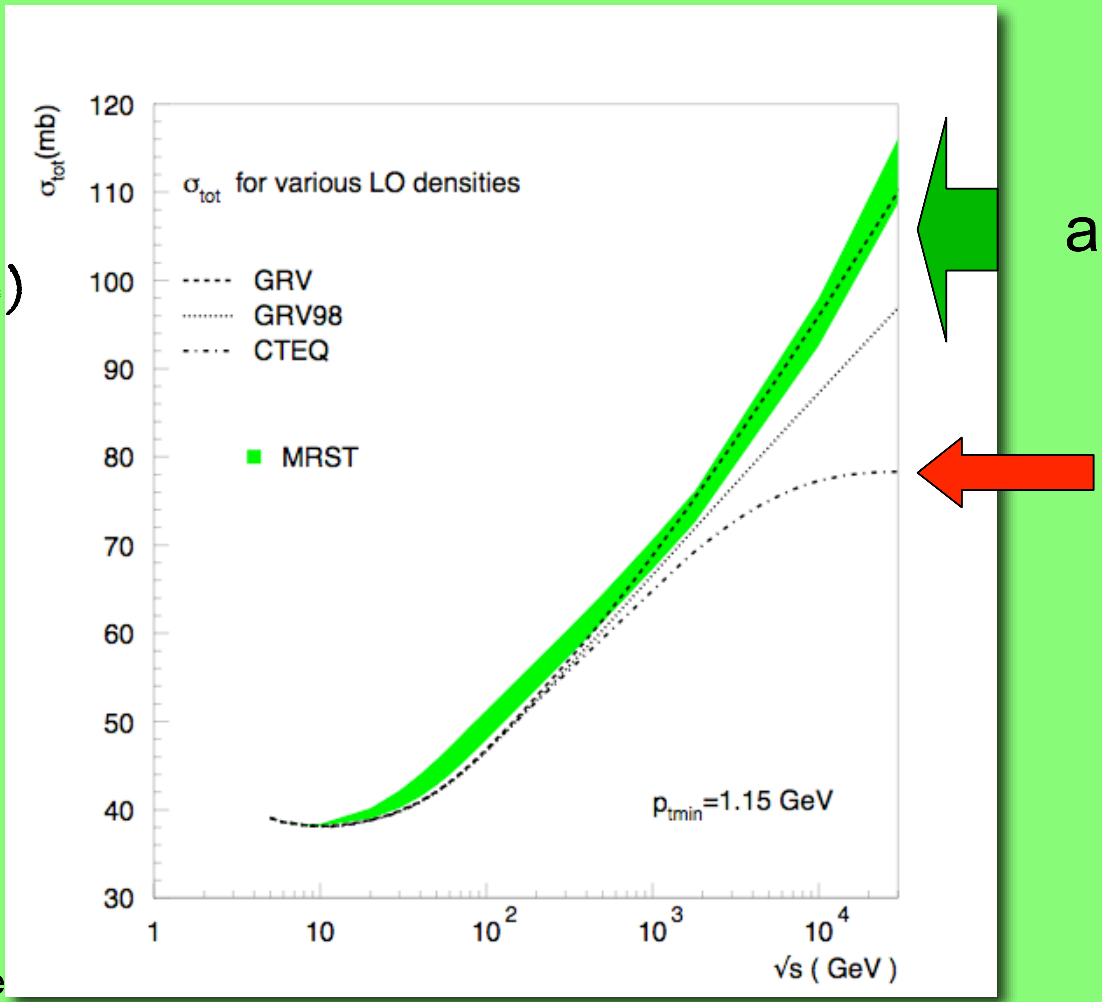
Soft gluon scale



Average over same PDF as for σ_{jet}

For p_{tmin}=1.15 GeV and a chosen set of low energy parameters

σ_{tot} (mb)



acceptable

Not good

V. Khoze, J. Bjorken,…

Survival probability

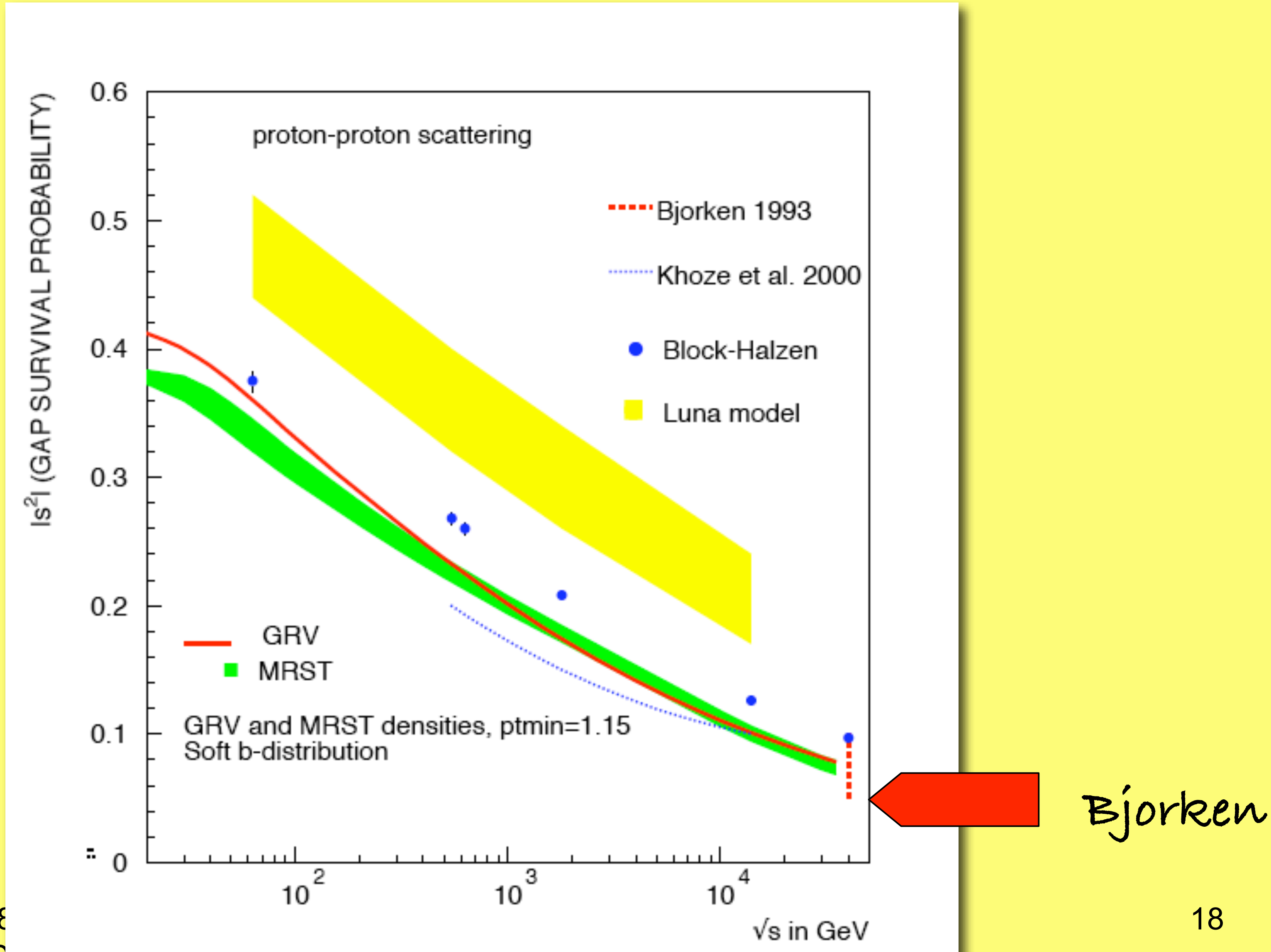
$$< |S|^2 >= \int d^2\vec{b} A(\vec{b}, q_{max}^{soft}) |S(\vec{b})|^2$$

we use the soft b-distribution $A(\vec{b}, q_{max}^{soft})$

$$\int d^2\vec{b} A(\vec{b}, q_{max}^{soft}) = 1$$

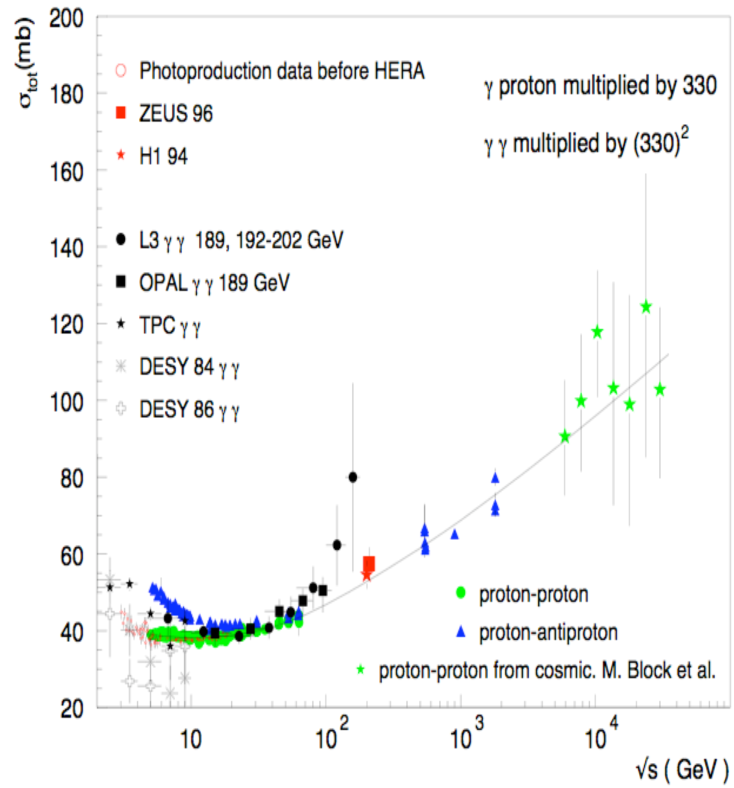
$$|S(\vec{b})|^2 = P_{no-inel}$$

Comparing with other models



Extension to photon processes

1. Photon like a hadron at all energies: multiply given model for protons times ad hoc factor $\approx \frac{1}{330}$



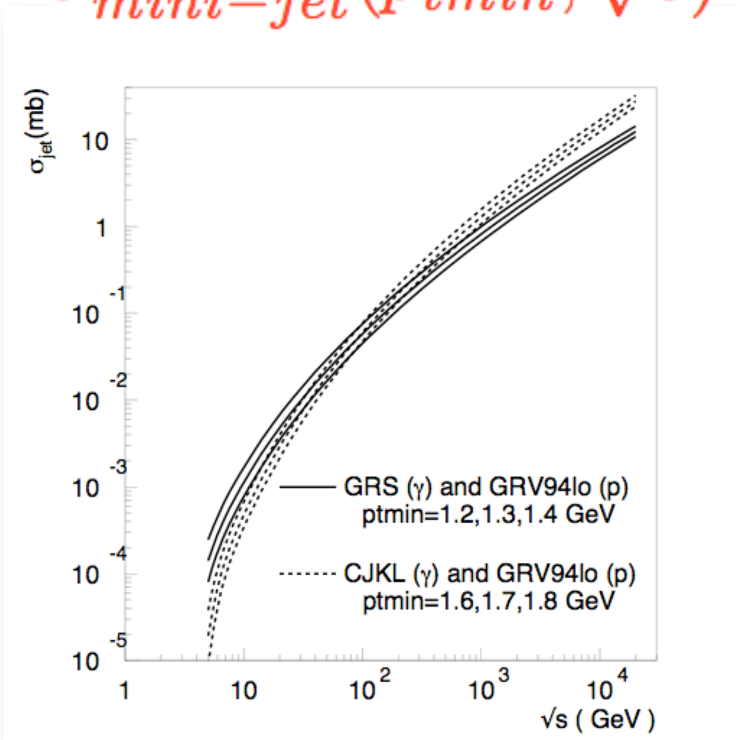
2. Use eikonal with

$$P_{had} = \Sigma_{\rho,\omega,\phi} \frac{4\pi\alpha}{f_V^2}$$

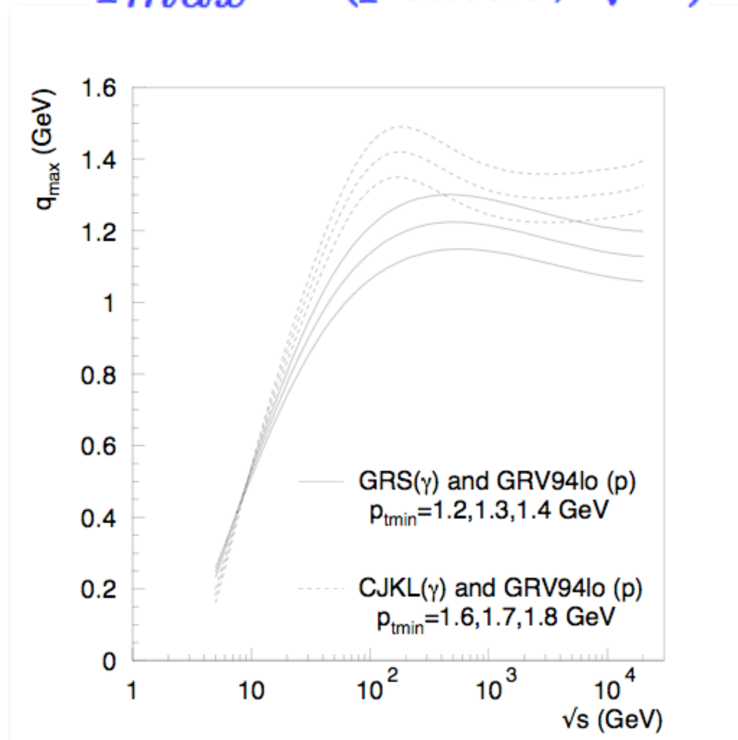
$$\sigma_{tot}^{\gamma p} = P_{had} \int d^2\vec{b}[1 - e^{-n^{\gamma p}(b,s)}]$$

The BN model for Photons

$$\sigma^{PDF's}_{mini-jet}(p_{tmin}, \sqrt{s})$$

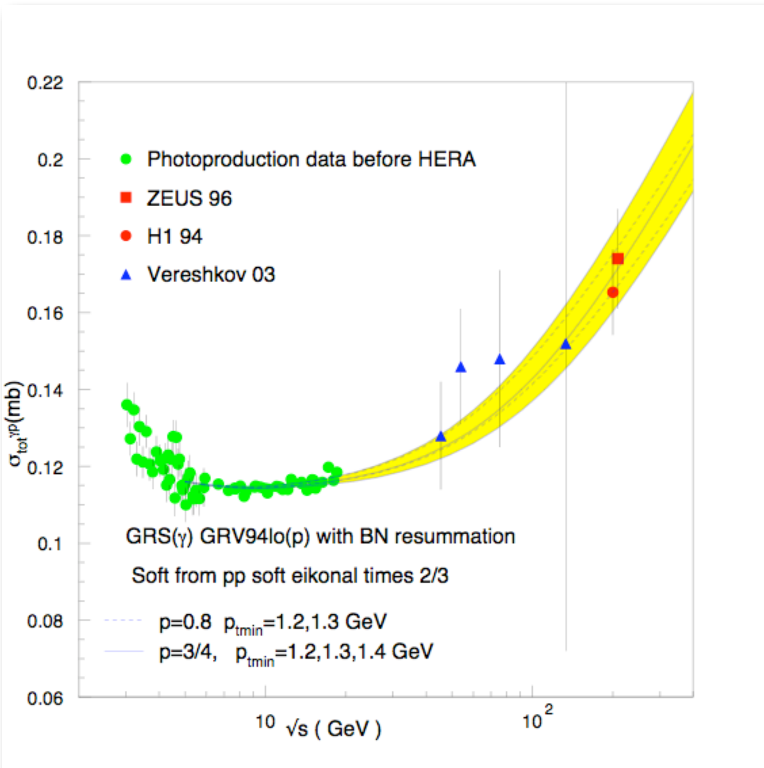


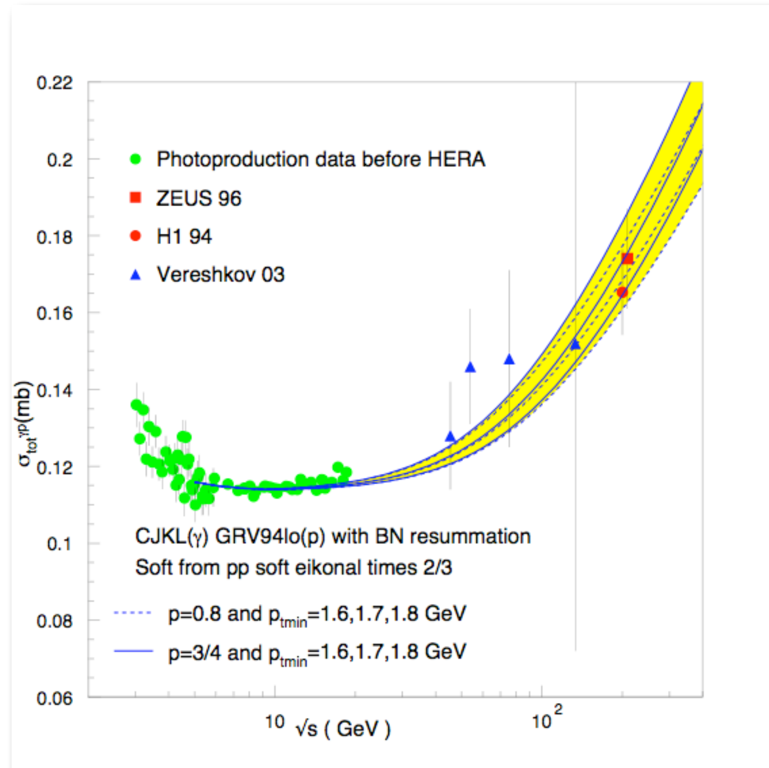
$$q^{PDF's}_{max}(p_{tmin}, \sqrt{s})$$



- Using GRV (p) and GRS or CJKL photon densities for mini-jet cross-sections
- Impact parameter distribution with
  - momentum saturation from photon and proton densities

Total photo-production cross-section and BN model

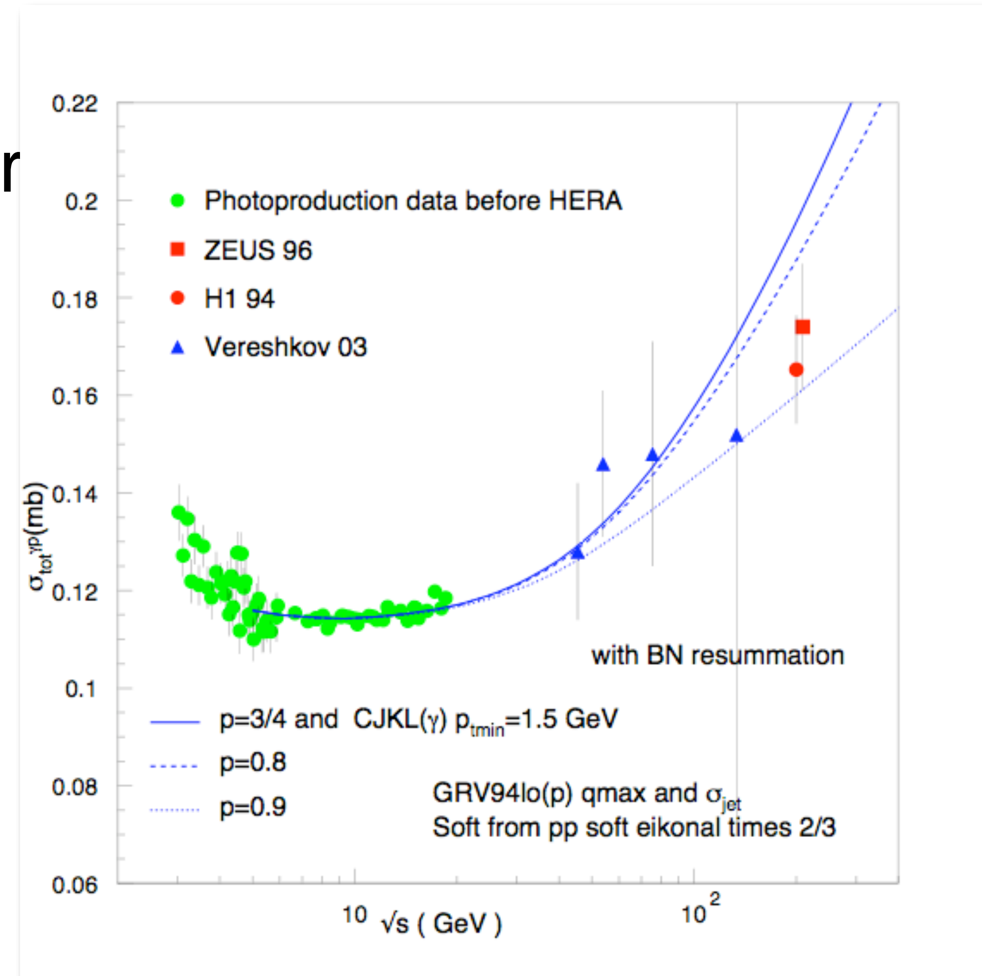




- Both lower energy and HERA data can be reproduced using current photon densities GRS or CJKL
- For GRS parameter set similar to those used for protons
- Using CJKL densities, one needs a higher pt cut-off

Dependence from the singularity parameter p

- The parameter p allows to increase or decrease the saturation effects
- Most values found between 0.75 (as in pp) and 0.9



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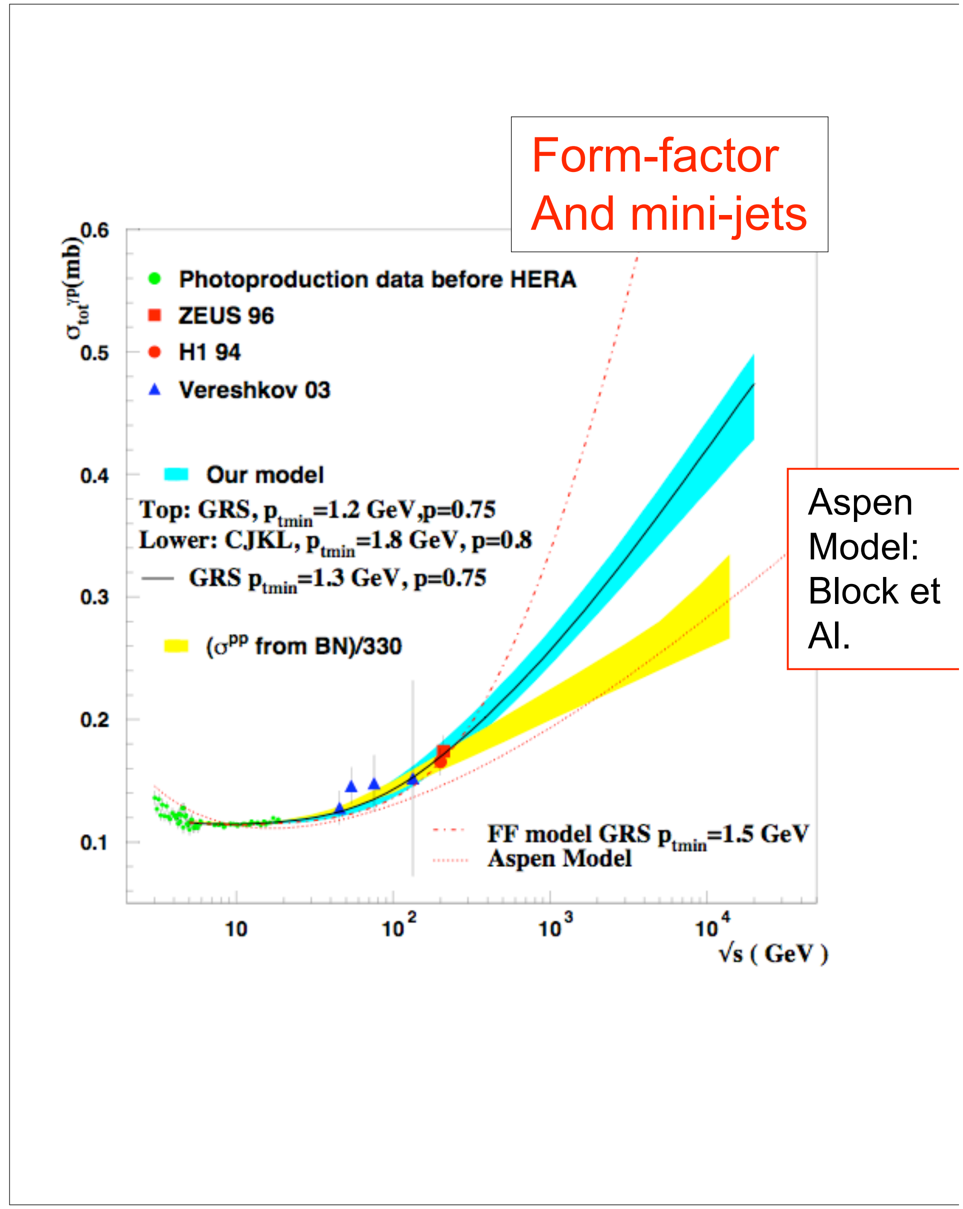
Models for γp total cross-section

- Eikonal with Form Factor and minijets
- BN model with photon densities for soft gluons and minijets
- Proton BN model with multiplicative factor
- “Aspen Model”: QCD inspired

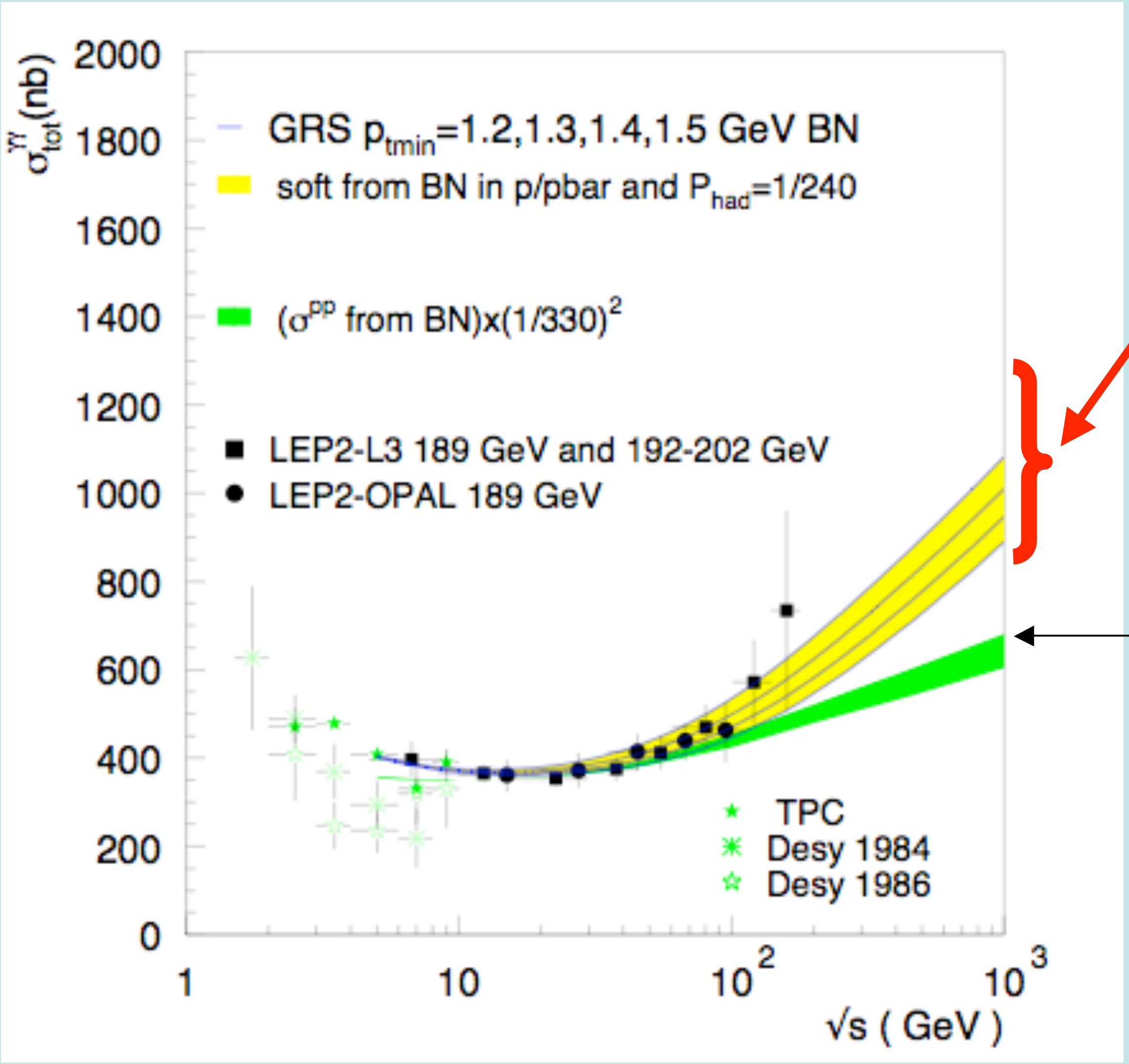


Conclusion

- At present energies for γp
  Various models can fit the data
  - Aspen (Block et al.)
  - Eikonal mini-jet (EMM)
  - EMM with soft gluons (BN)
  - BN for proton X normalization factor
- Extrapolation to higher energies shows sizable differences
- $\gamma\gamma$ model indicates that photons are NOT like hadrons at high energies

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

$\gamma\gamma$

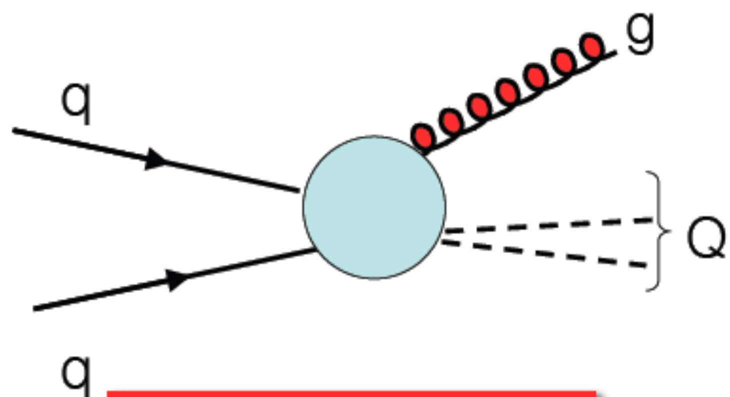


Eikonal minijets + soft gluons

From proton-proton

The soft gluon distribution parameters

- The momentum saturation parameter



$$q_{max} = \frac{\sqrt{s}}{2}\left(1 - \frac{Q^2}{\hat{s}}\right)$$

- The zero energy index *p*