QCD issues in photon-photon total cross-section

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Or why we would need a photon collider

Why total cross-sections

- One needs to know their values for background calculations

But they are also of

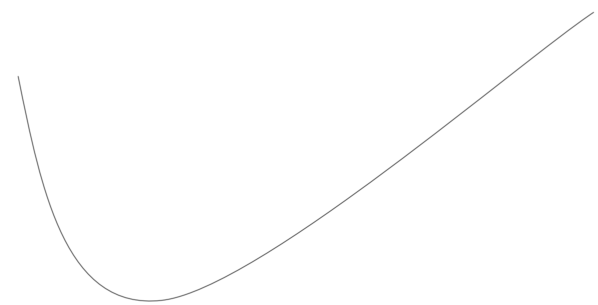
- Fundamental interest to understand particle structure

Total cross-sections are a testing ground of our understanding of QCD beyond perturbative regime

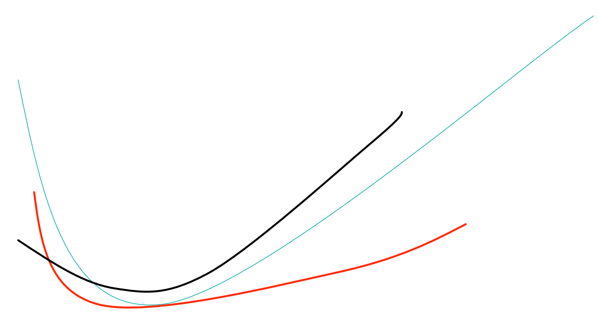
work in collaboration with R.M. Godbole, A. Grau, Y.N. Srivastava

Do all total cross-section look alike?

- Yes
  - They all start falling and then rise with energy



and



- No
  - They fall with different slopes at low energy
  - They may be rising with different slopes at high energy

Difference at low energy?

- Quantum numbers in the s-channel give rise to different resonances in the very low region
- Quantum numbers in the t-channel bring in different Regge pole exchanges and through FESR different power law decrease with energy

$$\sigma_{total} \approx s^{-\eta} \qquad with \quad \eta \approx 0.5$$

Difference at high energy?

- Not well understood yet

- Pomeron exchange was supposed to give universal behaviour

  – Soft Pomeron $\sigma_{total} \approx s^{\epsilon} \quad with \quad \epsilon \approx 0.09$ $\sqrt{s} \uparrow$

- It violates the Froissart bound

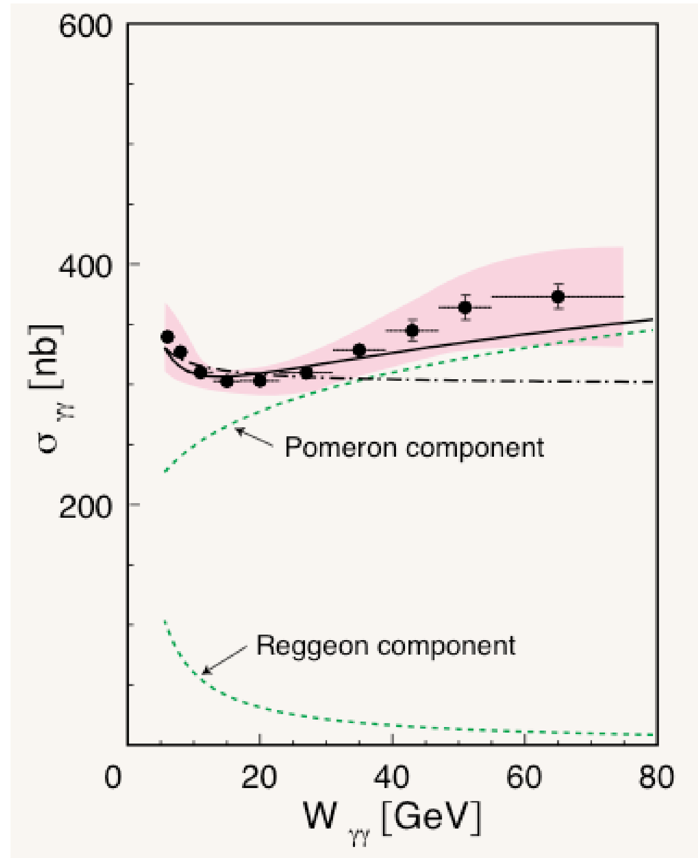
  $\sigma_{tot} \leq \log^2 s$

What to do for photons?

The simplest version of the Regge-Pomeron model

shows that ε is not the same for proton and photon cross-sections

- from L3 fits



600
400
200
$\sigma_{\gamma\gamma}$ [nb]
Pomeron component
Reggeon component
0
20
40
60
80
$W_{\gamma\gamma}$ [GeV]

$\sigma = Bs^{-\eta} + As^{\varepsilon} + Cs^{\varepsilon 1}$

- Fit3

C≠ 0 ε=0.093

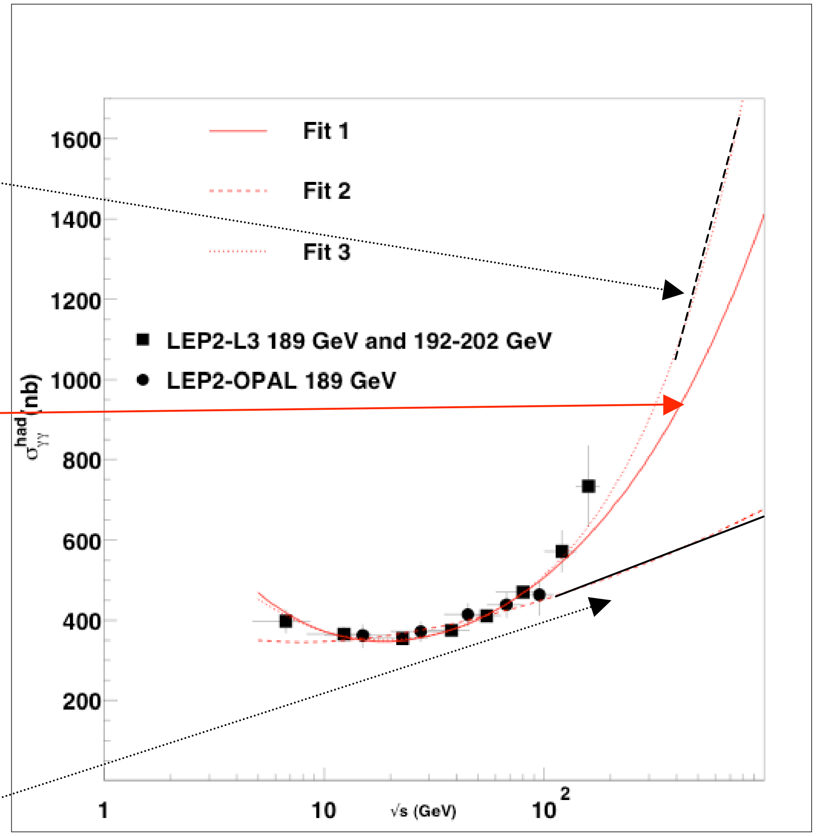
ε1=0.418

- Fit 1

C=0 ε=0.250

- Fit2

C=0 ε=0.093 as in pp

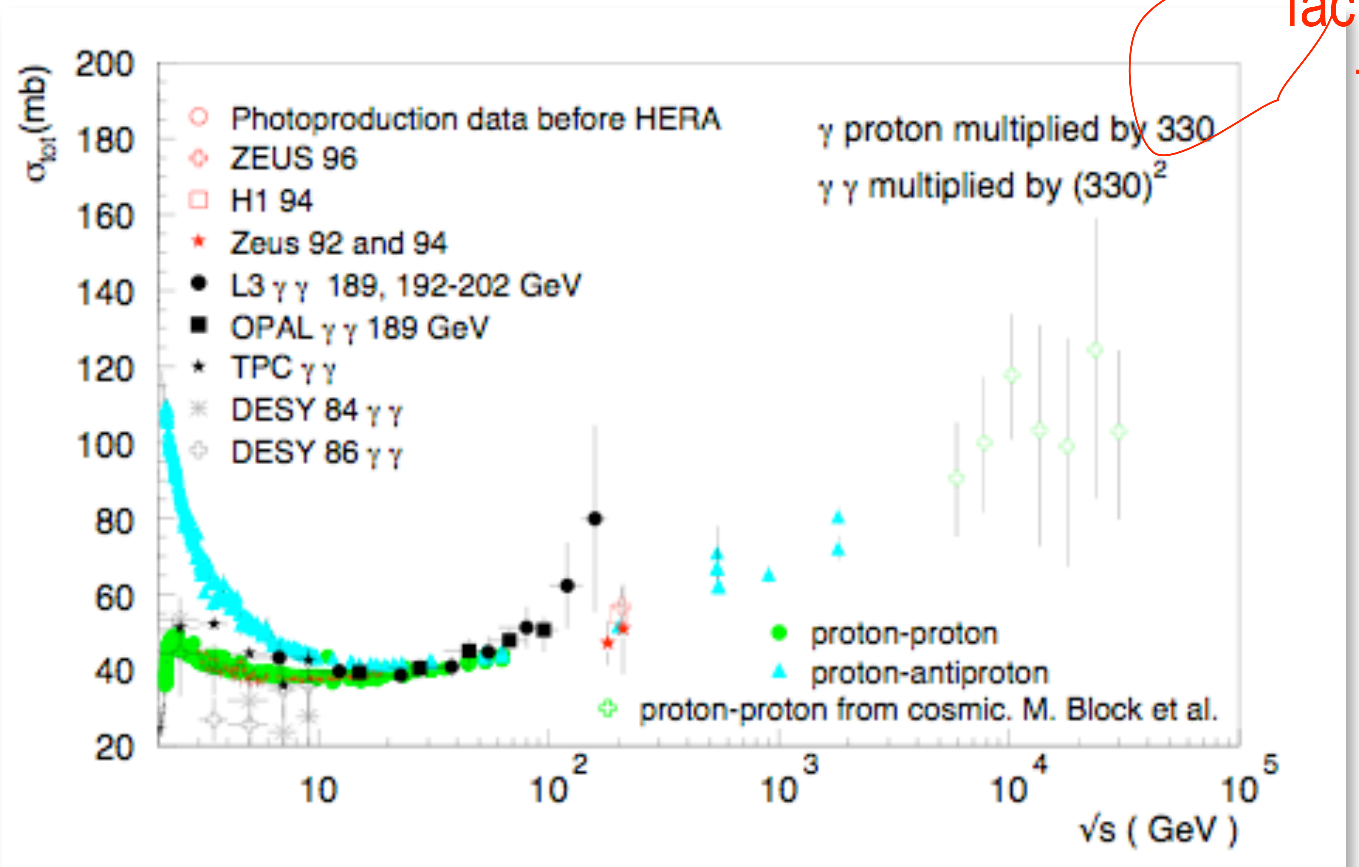


A.de Roeck, R. Godbole, A. Grau, G.Pancheri, JHEP 2003

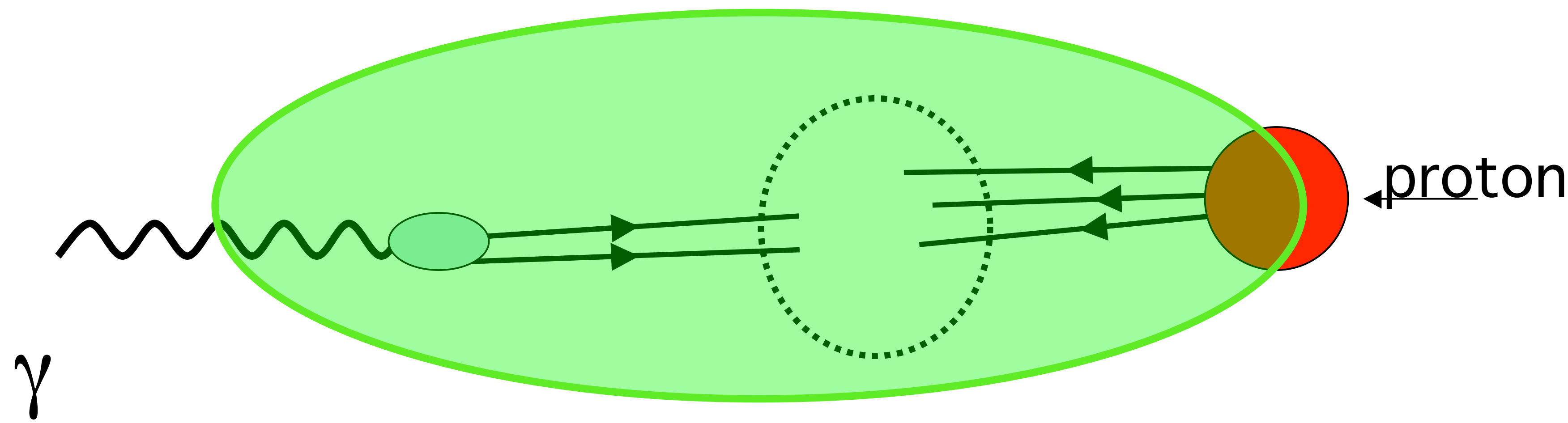
Clearly to understand total cross sections we need models which work for protons and photons as well

Do all total cross-section look alike?

Where does this factor come from?



The proportionality factor: from protons to photons -from pp to pγ to $\gamma\gamma$–



The normalization factor

$$R_\gamma \approx \alpha_{QED} \left(\frac{N^{photon}_{fermion\ lines}}{N^{hadron}_{fermion\ lines}} \right)^2 \approx \frac{1}{300} \quad (1)$$

$$P_{had} = P_{VMD} = \sum_{V=\rho,\omega,\phi} \frac{4\pi\alpha}{f_V^2} = \frac{1}{250} \quad (2)$$

where the sum extends to all vector mesons, not just the ρ. If only ρ, then

$$R_\gamma \approx P_{had} \quad (3)$$

Factors used in factorization models

R_γ is just a multiplicative factor

P_{had} is a phenomenological input describing the hadronic content of the photon in eikonal models

R.Fletcher, T.Gaisser. F.Halzen, 1993

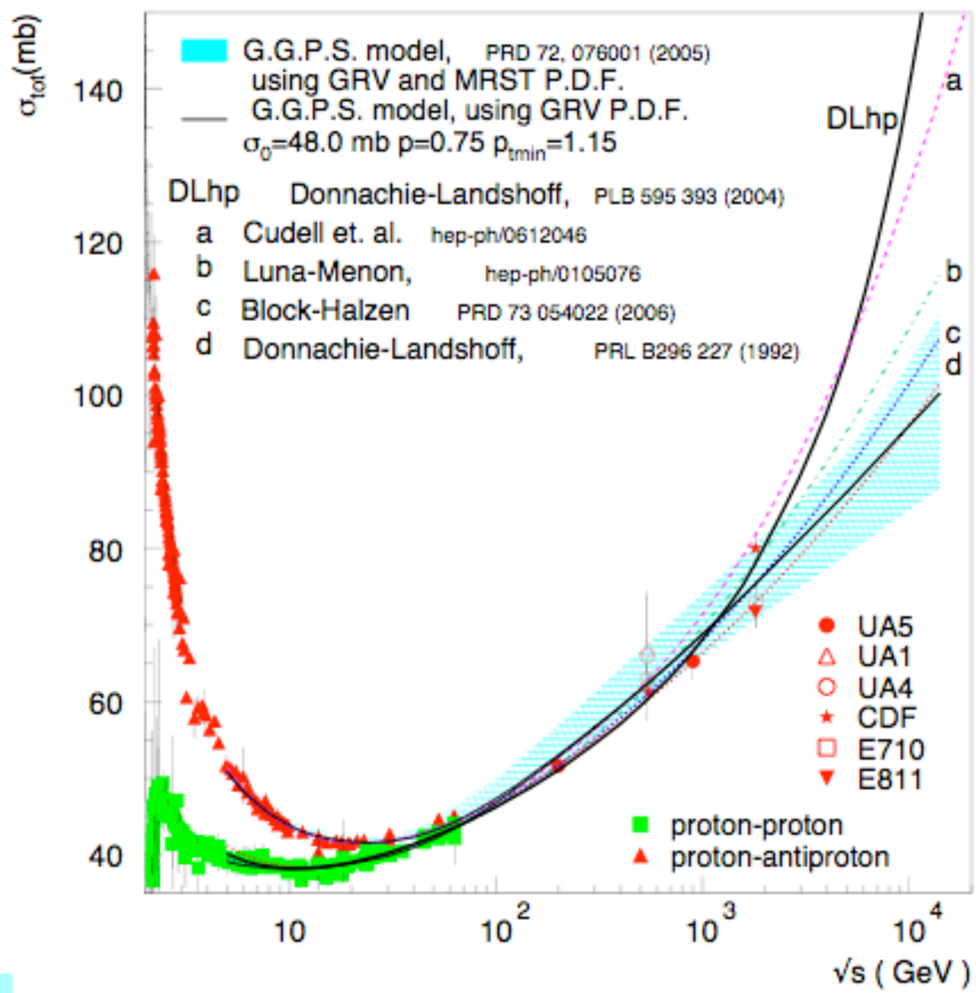
Models for protons

- Regge - Pomeron exchange, power law type terms,
  Donnachie-Landshoff

•Logarithmic fits and power law
  Cudell et al.

•Eikonalization and b-distribution
  •Block and Halzen
  •Luna-Menon
  •Bloch-Nordsieck Model GGPS

A. Achilli, R.M.Godbole, A. Grau, G.P., Y.N. Srivastava
Phys. Lett. 2008



The Bloch-Nordsieck model for σ_{total}

1. QCD mini-jets to drive the **rise**

2. resummation of soft gluon emission down to zero momentum to **soften** the rise

3. eikonal representation for the **total cross-section** to incorporate the mini-jet cross-section, using an impact parameter distribution obtained as the Fourier transform of resummed soft gluon transverse momentum distribution.

The hard scattering part

- qq,qg and mostly

$gg \rightarrow gg$

Minijet cross-section depends upon

- parton densities
  - GRV, MRST, CTEQ for protons
  - GRS, CJK for photons
- p_t cutoff p_{tmin}=1~ 2 GeV

In all mini-jet models densities make all the difference between photon and proton processes

Proton-proton and proton-antiproton

Most commonly used densities

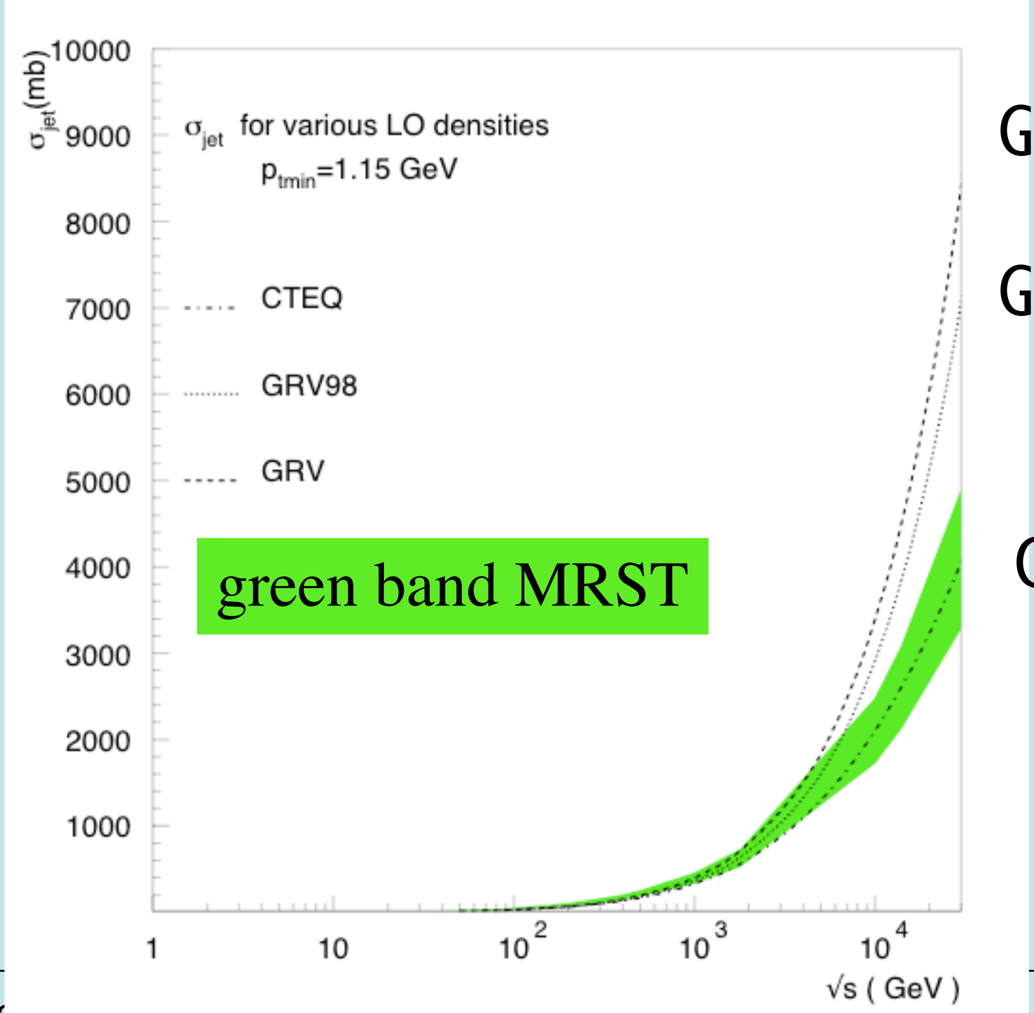
- GRV
- CTEQ
- MRST

γ–proton and $\gamma\gamma$

Most commonly used densities

- GRV
- GRS
- Cornet Jankowsky Krawczyk Lorca

σ_{jet} for p_{tmin}=1.15 GeV



GRV

GRV98

CTEQ

About the Froissart bound and QCD minijets

For all densities we find

$$\sigma_{jet}^{PDF}(s, p_{tmin}) \approx s^{\epsilon}$$

with

$\epsilon \approx 0.4$ for GRV and GRV98 $\rightarrow$ more singular

$\epsilon \approx 0.3$ for CTEQ and MRST $\rightarrow$ less singular

QCD Mini-jets violate the Froissart bound

- Consequence of infinite range of QCD
- One needs to introduce a finite distance of the interaction
- The eikonal does it through the hadron finite size

Finite size of hadrons

- The finite size can be introduced through the Form Factor

$A(b) \sim e^{-b \text{ constant}}$ as $b \sim$ very large :

not enough to tame the rise because the growth of

σ_{jet}^{PDF} is too strong!! G.P. et al. PRD 2005

or

We shall use an energy and PDF dependent soft gluon emission down into the infrared

Soft gluon emission from scattering particles softens the rise and gives b-distribution

$$A_{BN}(b,s) = N \int d^2K_\perp \; e^{-iK_\perp \cdot b} \frac{d^2P(K_\perp)}{d^2K_\perp}$$

$$\frac{d^2P(K_\perp)}{d^2K_\perp} = \frac{1}{(2\pi)^2} \int d^2\vec{b} \; e^{iK_\perp \cdot b - h(b, q_{max})}$$

$$h(\vec{b}, q_{max}) = \int_0^{q_{max}} d^3\bar{n}(k)[1 - e^{-ik_t \cdot b}]$$

$$\approx \int_0^{q_{max}} \frac{\alpha_s(k_t^2)}{8\pi} \frac{dk_t}{k_t} \log \frac{2q_{max}}{k_t} [1 - e^{-ik_t \cdot b}]$$

⇑

Soft gluon emission factor

Soft gluon emission factor

$$\int_0^{q_{max}} \frac{\alpha_s(k_t^2)}{8\pi}\frac{dk_t}{k_t}\log\frac{2q_{max}}{k_t}[1-e^{-ik_t\cdot b}] \quad \sim$$

q_{max} is the maximum transverse momentum allowed by kinematics to single soft gluon emission in a given hard collision, averaged over the parton densities.

M. Greco and P. Chiappetta

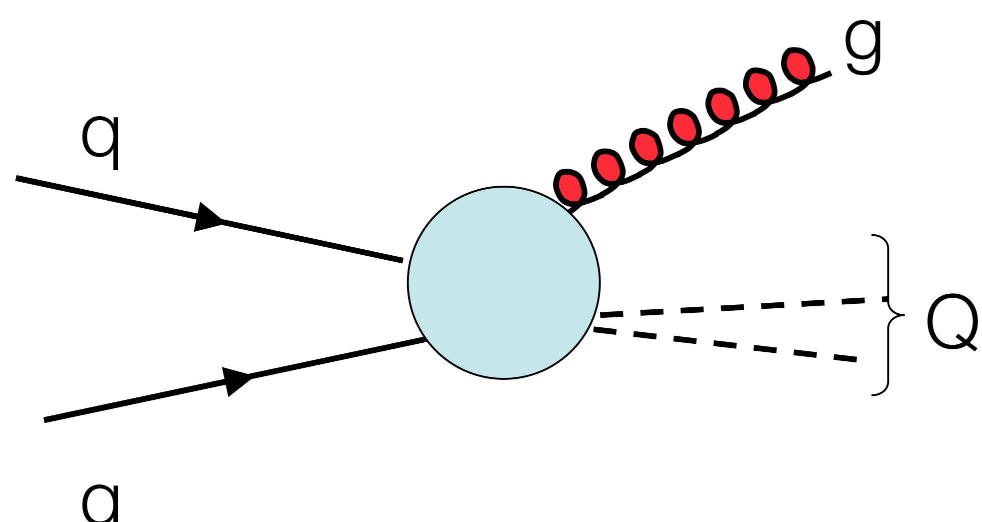
Kinematical constraints on single gluon emission

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

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

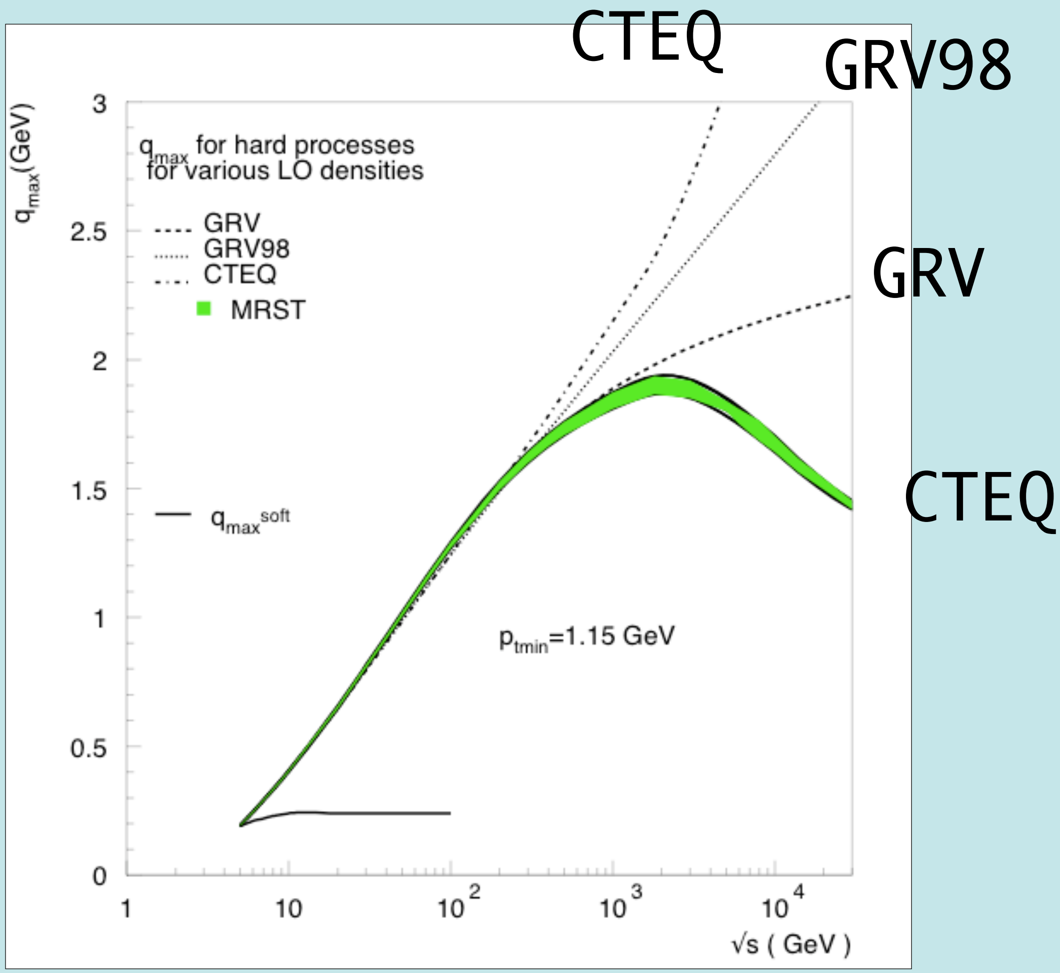
$\hat{s} = (p_1 + p_2)^2$

Chiappetta & Greco
1982



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

q_{max} for ptmin=1.15 geV



$$\int_0^{q_{max}} \frac{\alpha_s(k_t^2)}{8\pi} \frac{dk_t}{k_t} \log \frac{2q_{max}}{k_t} [1 - e^{-ik_t \cdot b}]$$

What about the $k_t \rightarrow 0$ limit for α_s ?

Modeling the infrared behaviour

- frozen
- Our choice : singular but integrable, phenomenological choice

Our model in the infrared

- Singular but integrable

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

- Singularity regulated by $p < 1$

Soft gluon resummation effects

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

Virtual gluons

Energy-momentum conservation factor for real soft gluons

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

Model

$$A_{hard}(b) \propto e^{-(b\Lambda)^{2p}}$$

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

At very large energies :

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

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

$$\sigma_{jet}(s) = (s/s_o)^\epsilon \sigma_1.$$

$$A_{hard}(b,s) \propto e^{-h(b,s)}$$

where

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

From power law to log behaviour

$$A_{hard}(b) \propto e^{-(bq)^{2p}} \qquad C(s) = A_o(s/s_o)^{\epsilon}\sigma_1$$

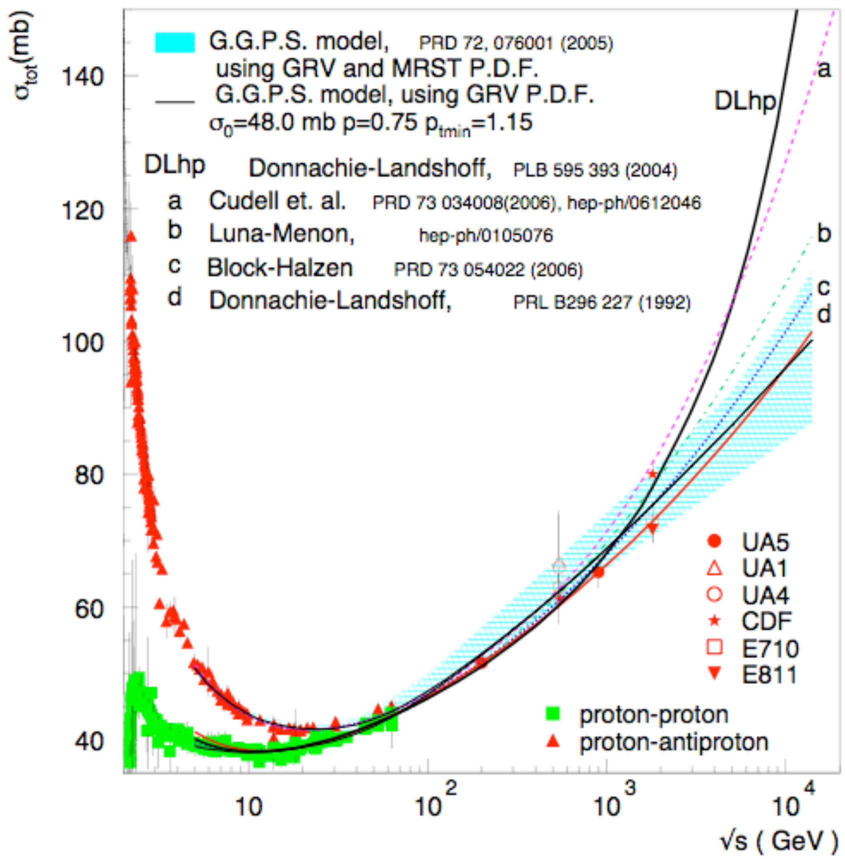
$$\bar{\sigma}_T(s) = 2\pi \int_o^{\infty} db^2[1 - e^{-C(s)e^{-(bq)^{2p}}}]$$

$$q^2\bar{\sigma}_T(s)] \rightarrow \ (2\pi)[lnC(s)]^{1/p}$$

$$\sigma_T(s) \approx\rightarrow [\ln s^{\epsilon}]^{1/p} \approx [\epsilon \ln s]^{(1/p)}$$

Main result

Comparison with proton data



R.Godbole,
A. Grau
R. Hedge
G. Pancheri
Y. Srivastava
Les Houches 2005
Pramana **67** (2006)

GGPS PRD **2005**

For all pdf's

- For different PDF , with soft gluon emission to give an energy dependent size and QCD hard gluon minijets to drive the rise

- All the Bloch-Nordsieck type curves

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

even though $\sigma_{jet} \Uparrow s^\epsilon$

Protons and photons

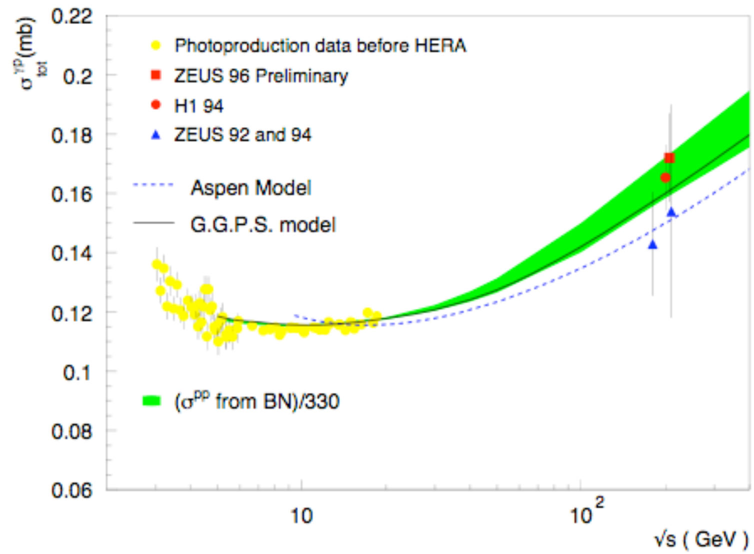
Once you have a model for protons

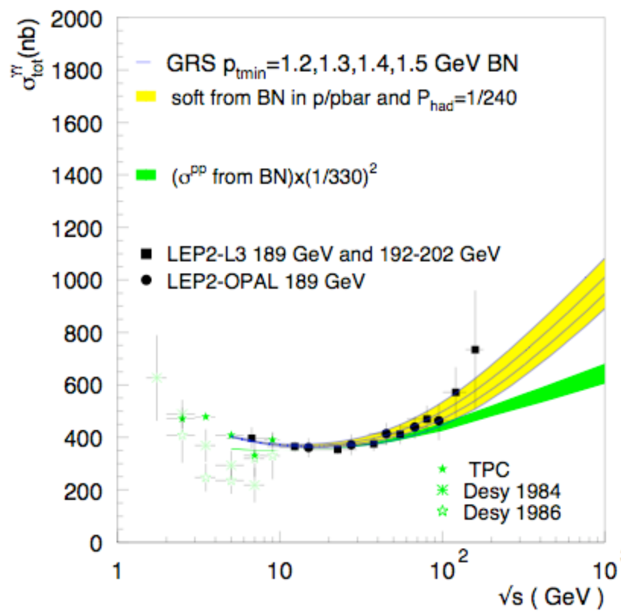
How to you extend it to photons?

- factorization
  - just a multiplicative factor
  - Regge and Pomeron vertices

– Fully apply the model to photon structure

Brute force factorization





- Multiplication factor (1/330) or $(1/330)^2$

- O.k. for γ p
- Not so good for $\gamma\gamma$: could be off by a factor 2

We can apply the

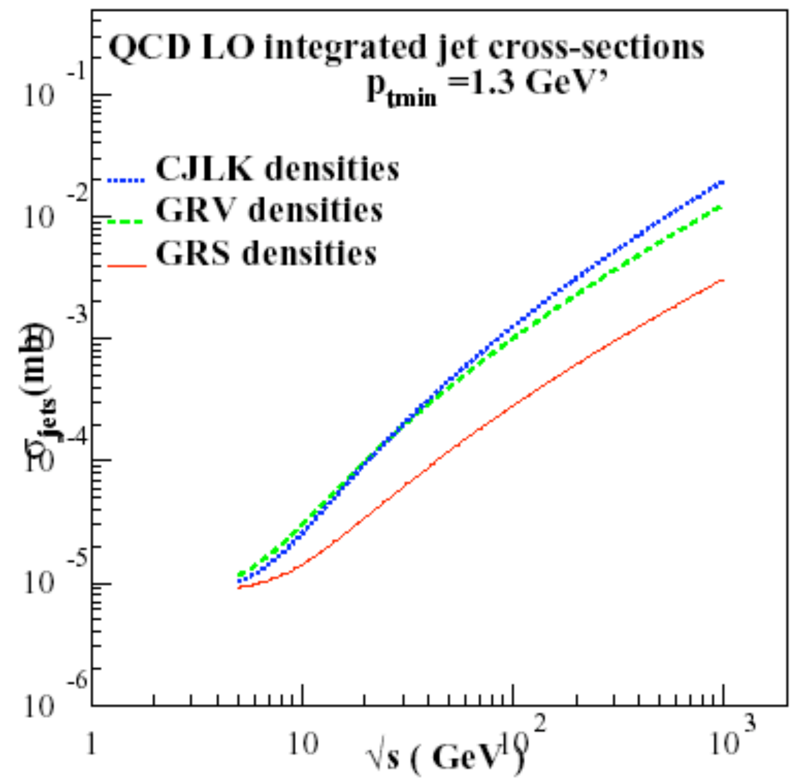
Eikonal mini-jet Model cum Soft Gluon resummation to $\gamma\gamma$

Choose p_{tmin} = 1÷2 GeV for mini-jets and parton densities

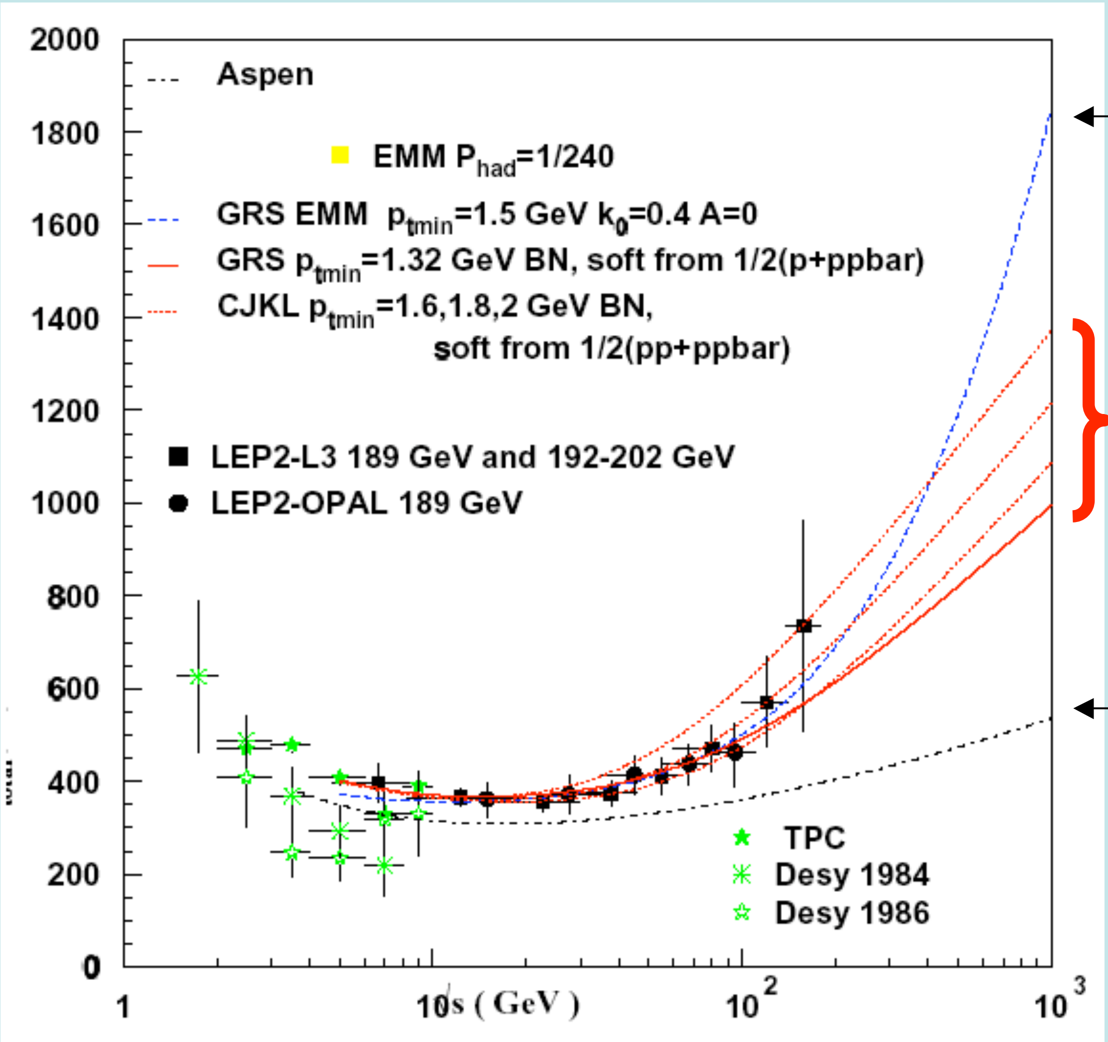
For photons, LEP data suggest

p_{tmin} ~ 1.3 ÷ 1.8 GeV

- Gluck Reya Vogt
- Gluck Reya Shielbein
- Cornet Jankowski Lorca Krawczyk



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

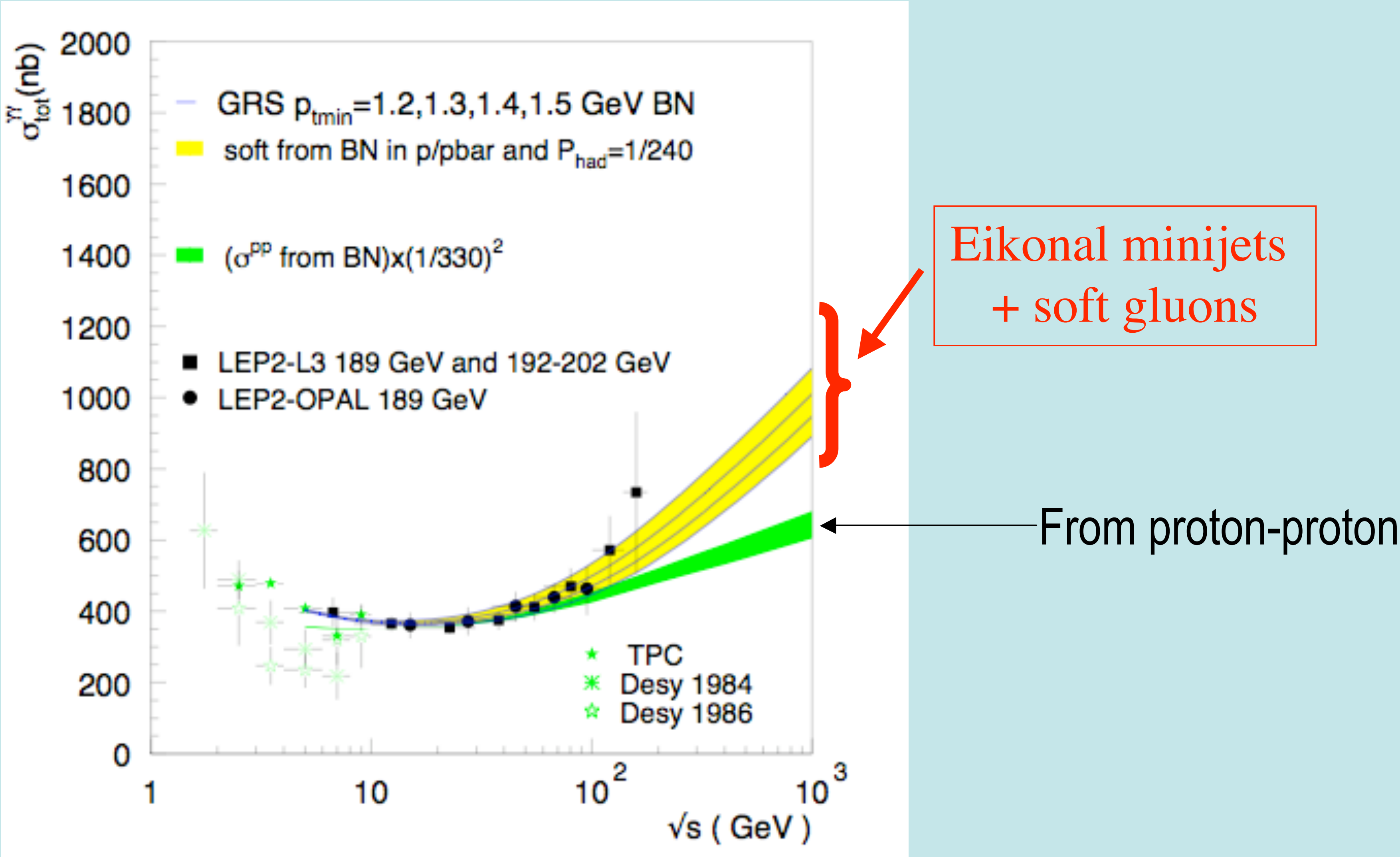


Only eikonal + minijets

Eikonal minijets + soft gluons

M. Block & F. Halzen

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



Conclusions

- Predictions at ILC vary according to which densities better describe the behaviour at low x
- Total cross-sections measurements in Collider mode would allow clean information on $\gamma\gamma$ cross-sections, reducing the errors due to modelling of diffractive components
- Even in regular mode, difference in the model predictions are measurable and can give insights into the soft or non perturbative region of QCD.