QCD issues in photon-photon total cross-section

Giulia Pancheri - INFN-Frascati

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

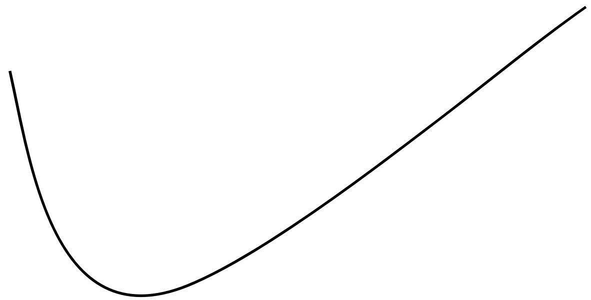
- Fundamental interest to understand particle structure

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

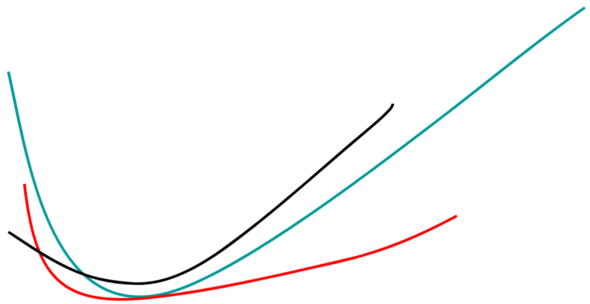
Do all total cross-section look alike?

- 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 $\sigma_{total} \approx s^{\epsilon}$ $with \quad \epsilon \approx 0.09$ $\sqrt{s}$ ↑

- 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

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

- from L3 fits

$\sigma = Bs^{-\eta} + As^{\varepsilon} + Cs^{\varepsilon_1}$

- Fit3

C≠ 0 ε=0.093

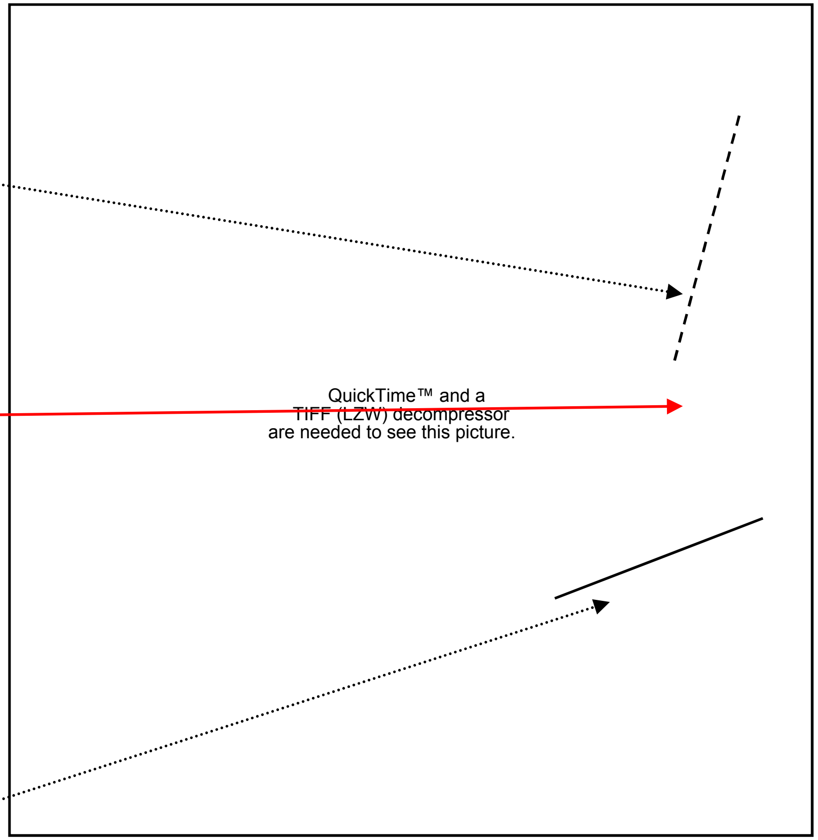
ε_1=0.418

- Fit 1

C=0 ε=0.250

- Fit2

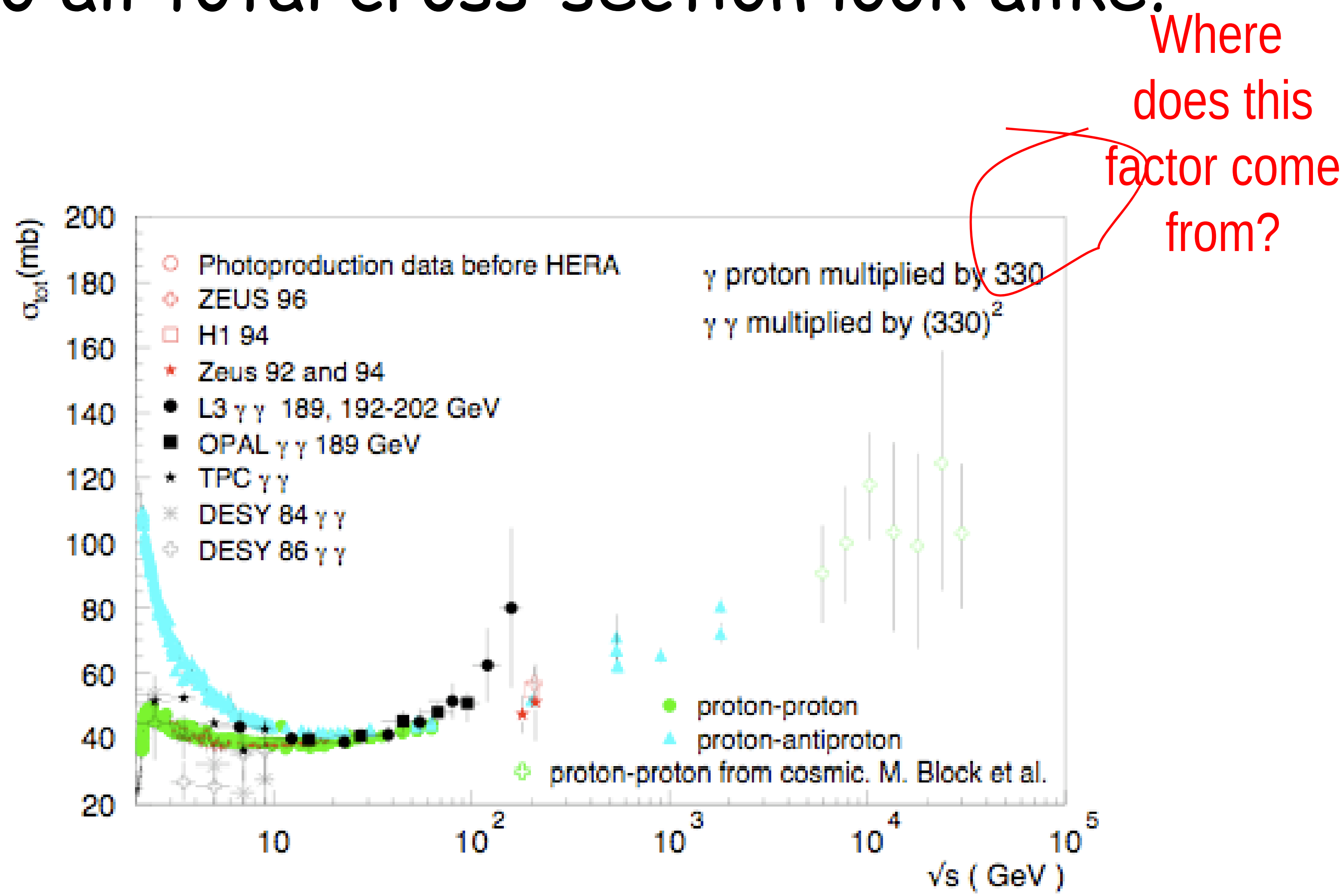
C=0 ε=0.093 as in pp



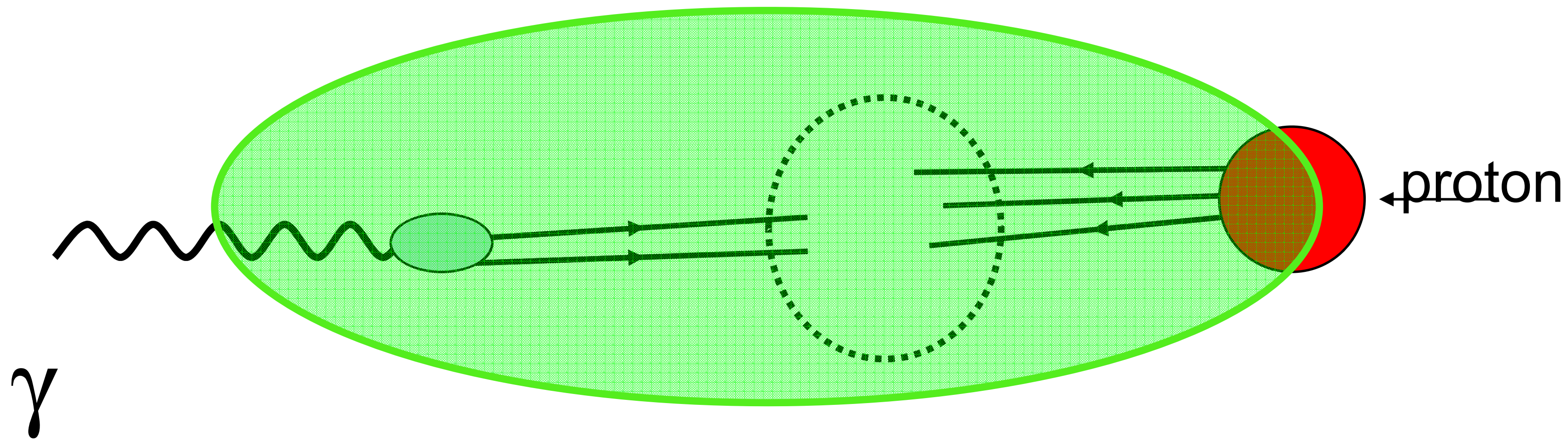
A.de Roeck, R. Godbole, A. Grau, G.Pancheri, JHEP 2003

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

Do all total cross-section look alike?



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

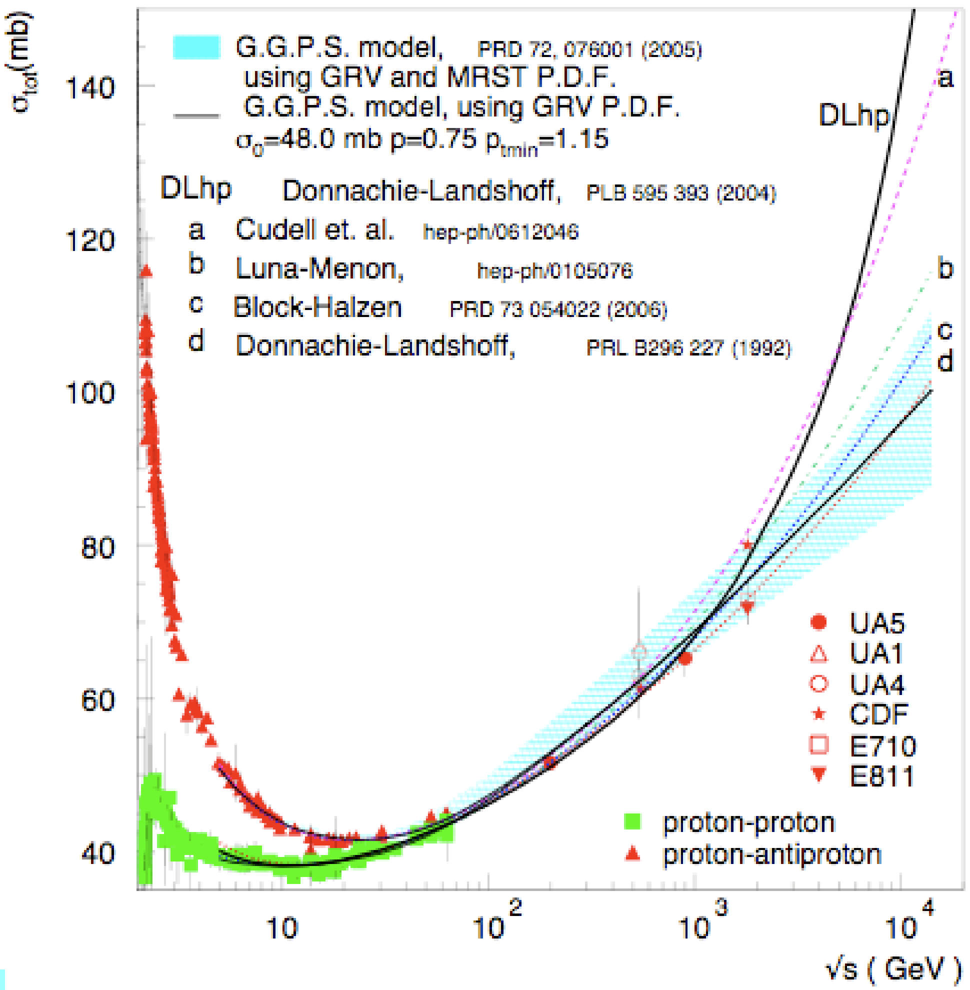
Models for protons

- 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

g g → g g

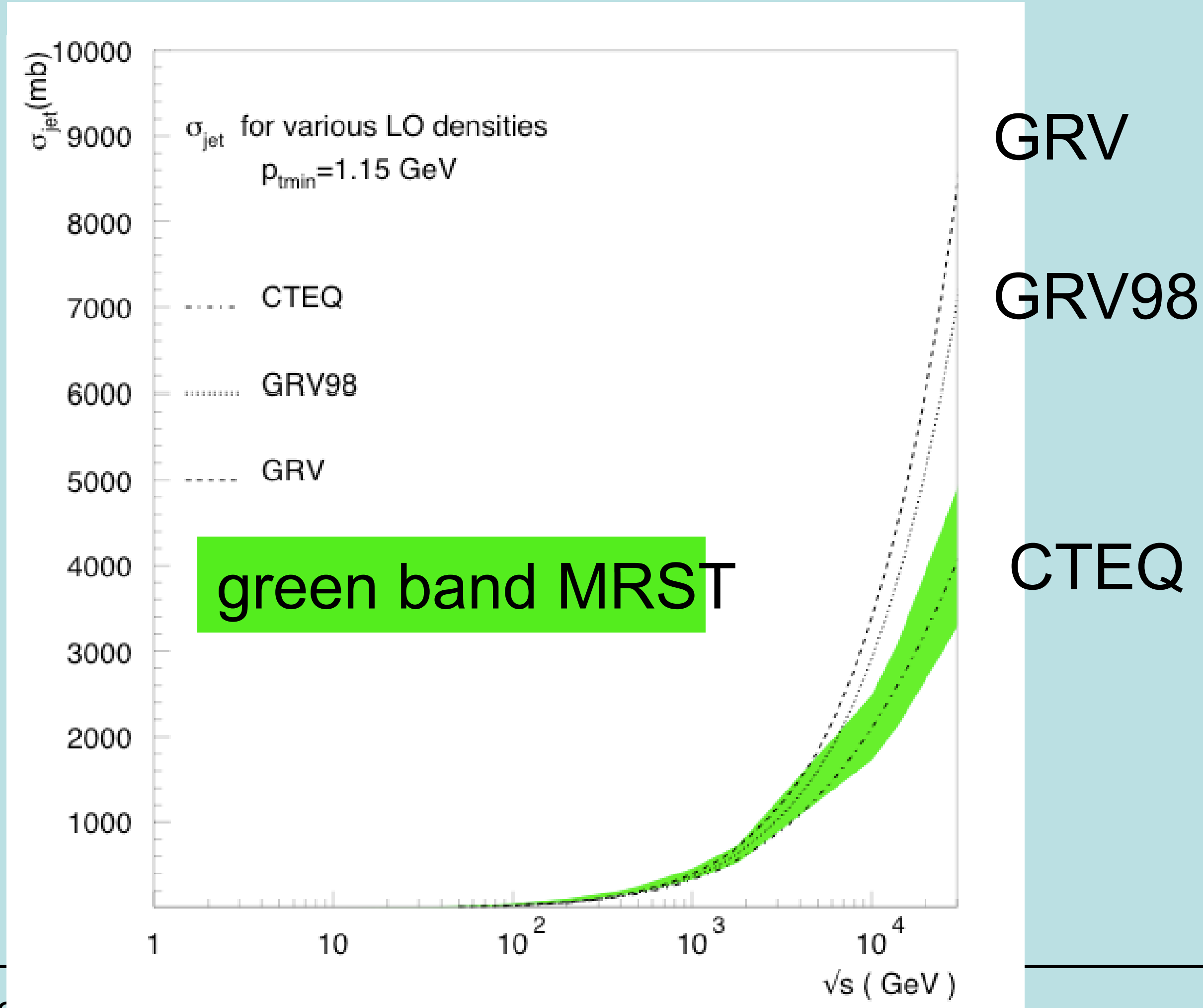
Minijet cross-section depends upon

- 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	γ–proton and $\gamma\gamma$
Most commonly used densities	Most commonly used densities
• GRV • CTEQ • MRST	• GRV • GRS • Cornet Jankowsky Krawczyk Lorca

σ_{jet} for p_{tmin}=1.15 GeV



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

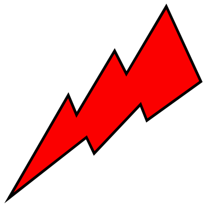
$\epsilon \approx 0.3$ for CTEQ and MRST $\rightarrow$ less singular

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

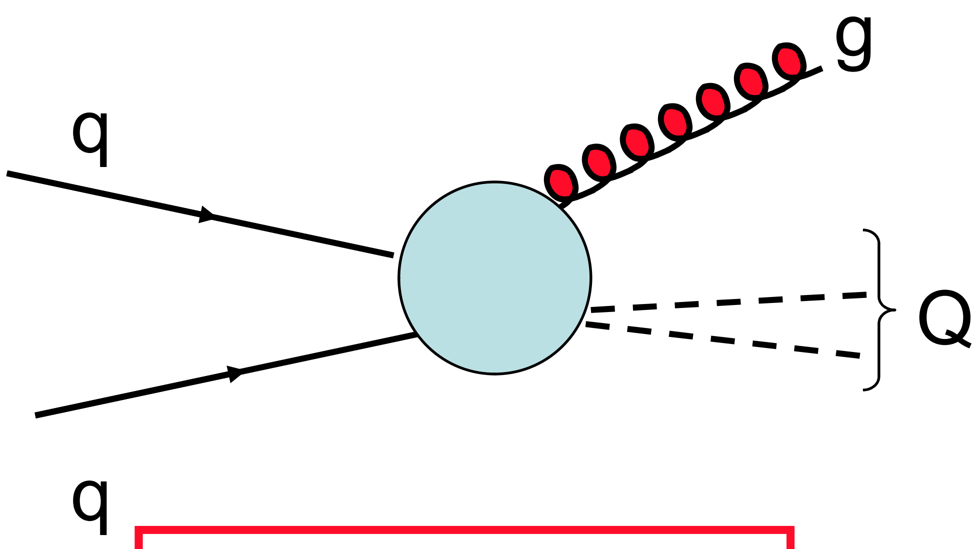
Kinematical constraints on single gluon emission

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

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

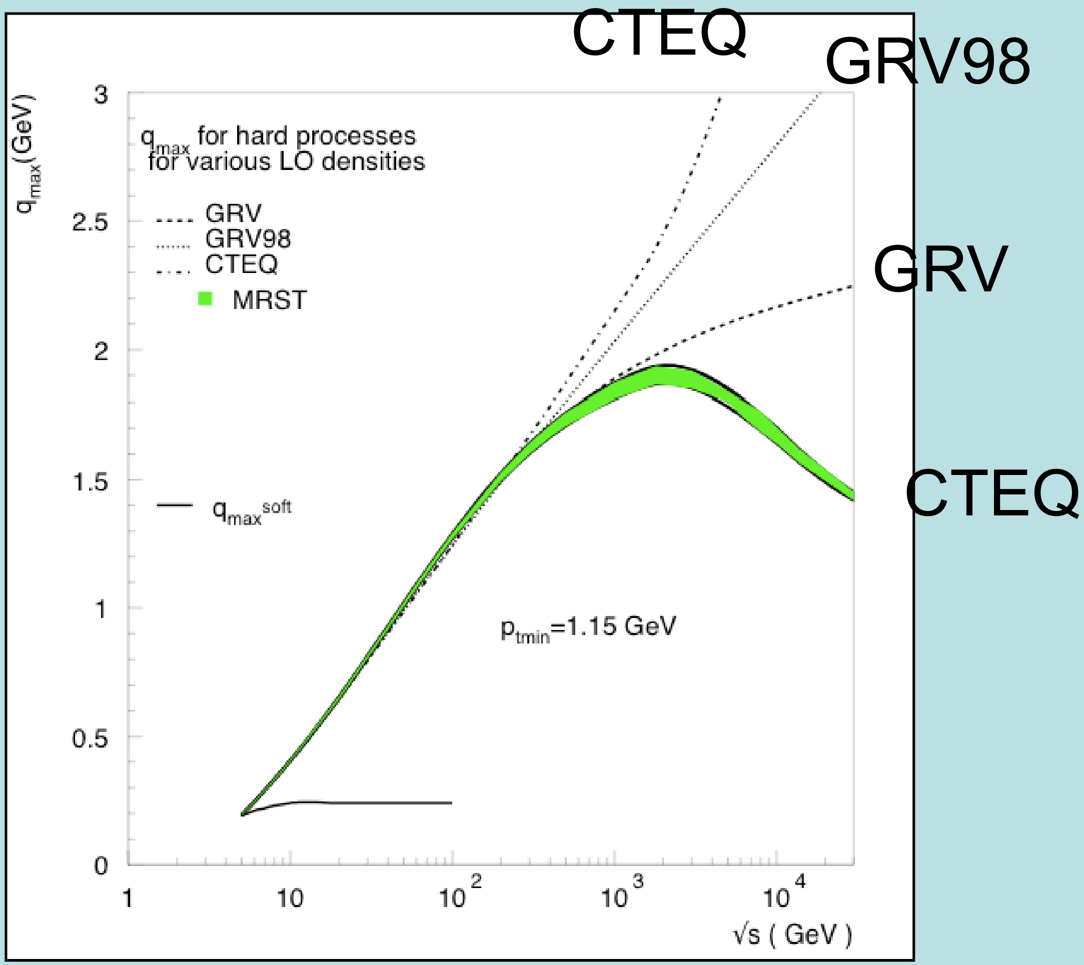
$\hat{s} = (p_1 + p_2)^2$

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 $k_t \to 0$ 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

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

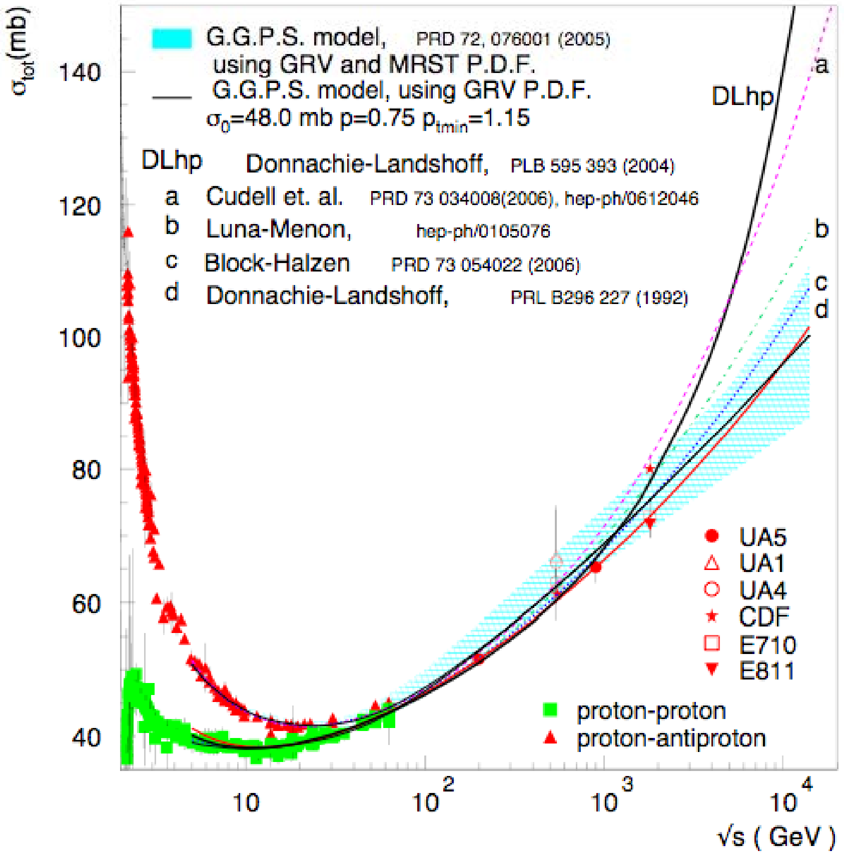
$$\bar{\sigma}_T(s) = 2\pi \int_o^{\infty} db^2 [1 - e^{-C(s)e^{-(bq)^{2p}}}]$$

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

Main result

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

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

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

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

Protons and photons

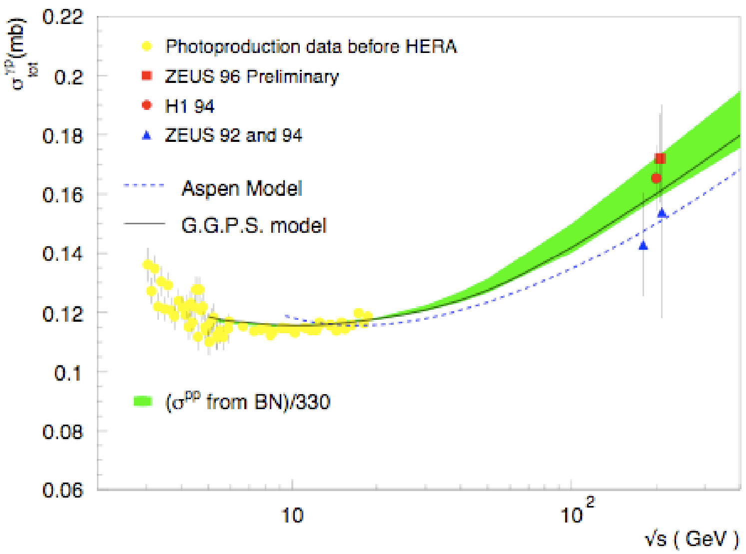
Once you have a model for protons

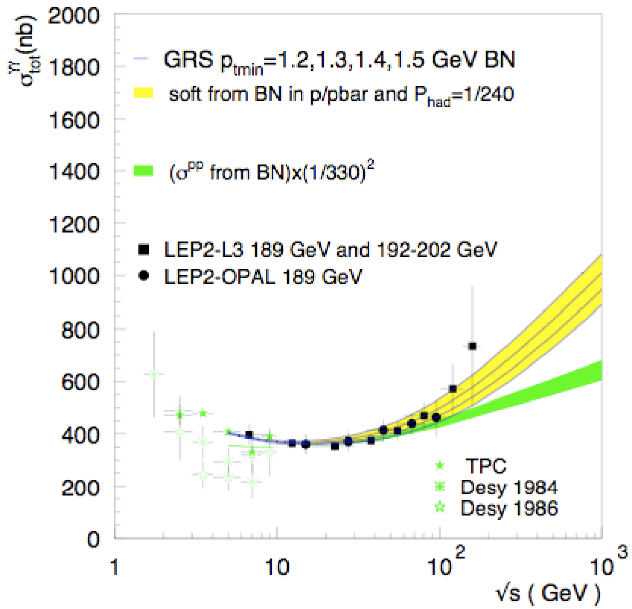
How to you extend it to photons?

- 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

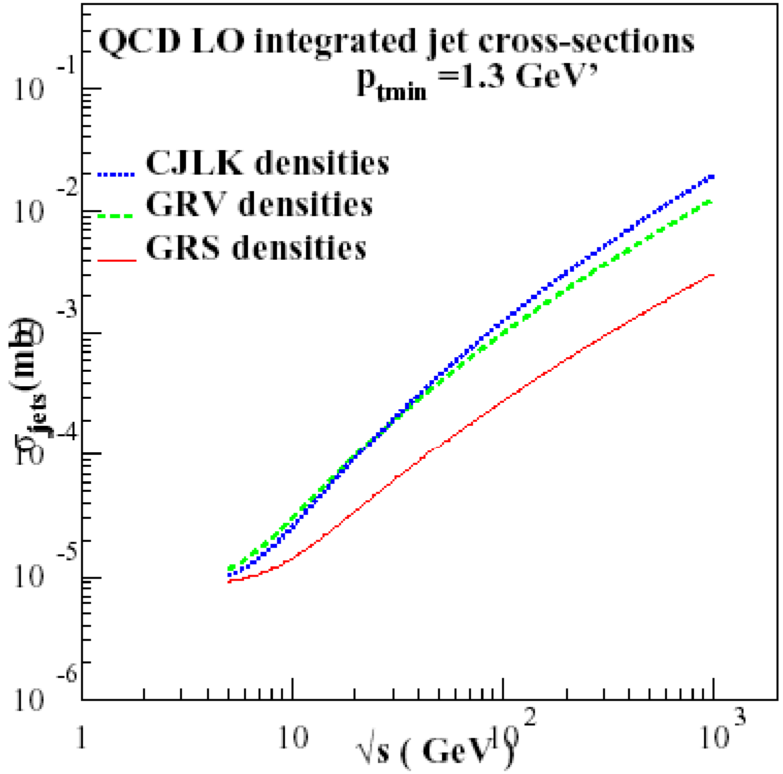
Eikonal mini-jet Model cum Soft Gluon resummation to $\gamma\gamma$

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

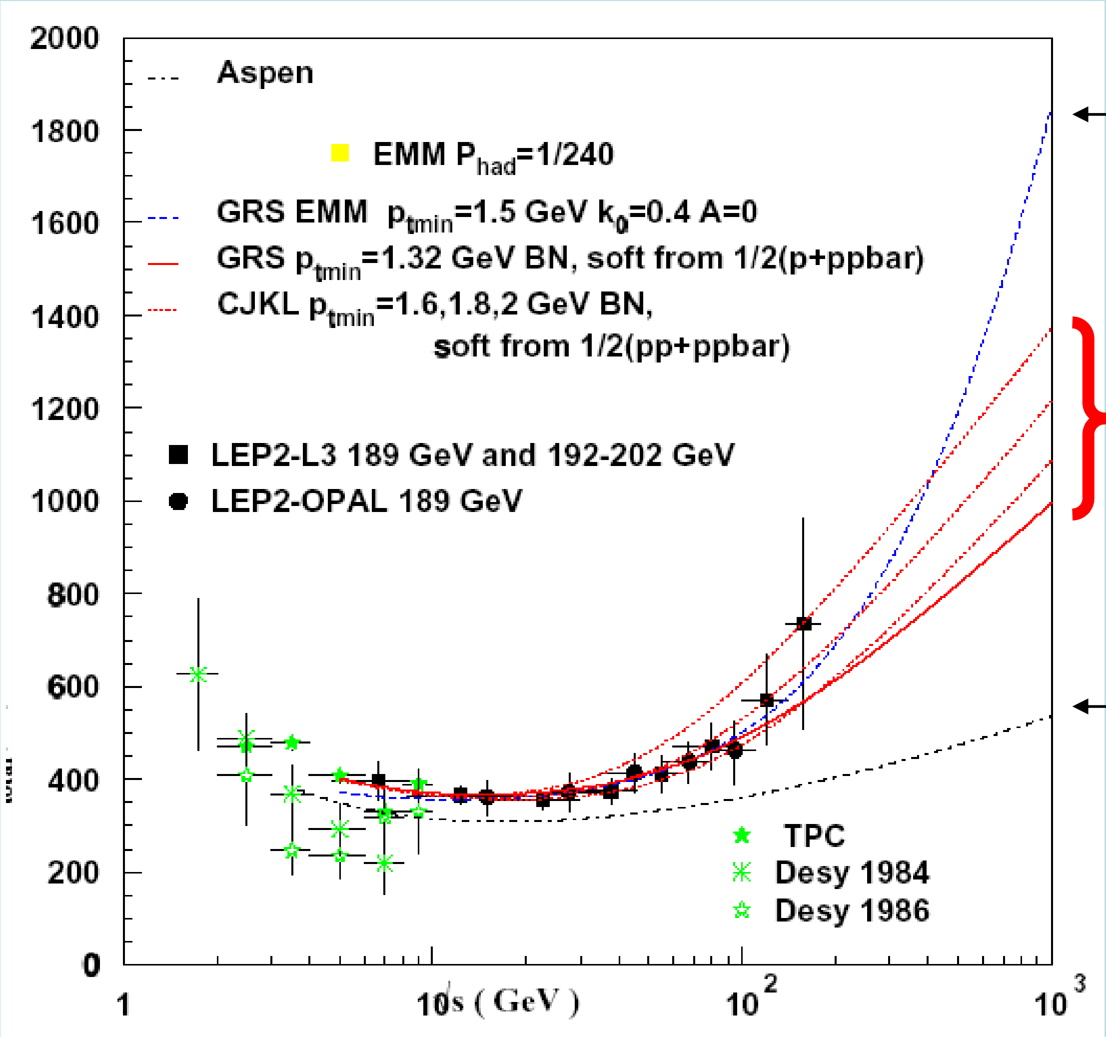
For photons, LEP data suggest

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

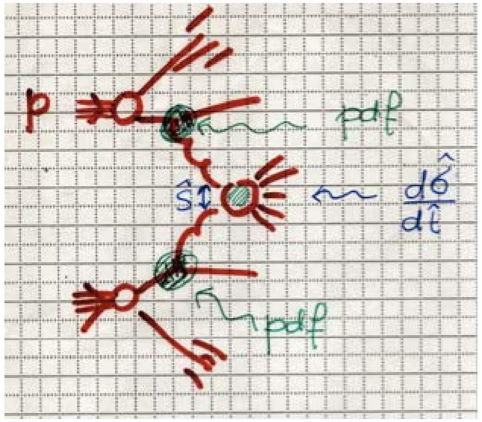
Eikonal minijets + soft gluons

M. Block & F. Halzen

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.

The BN Eikonal Minijet model includes k_t resummation



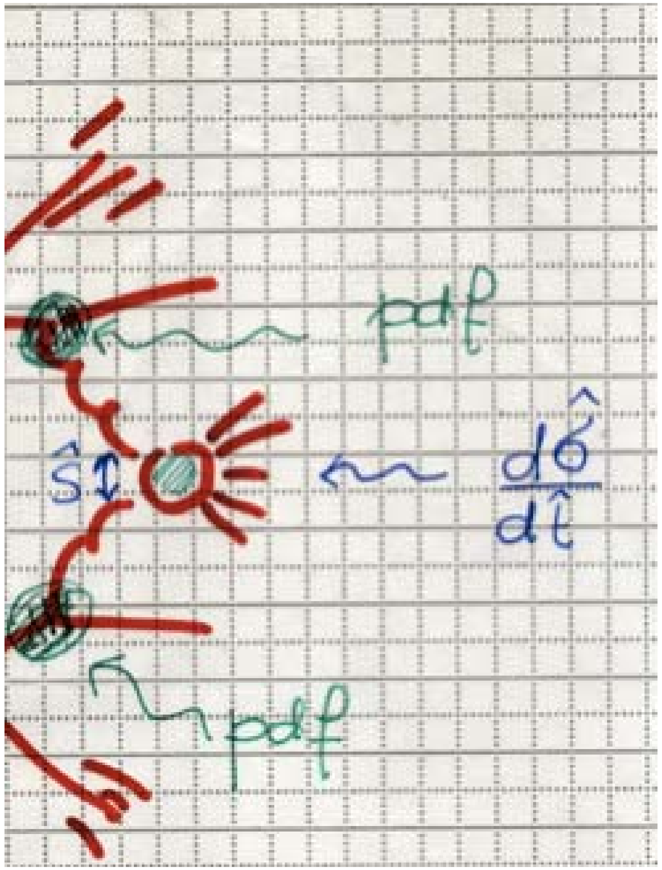
R.Godbole, A. Grau, G.Pancheri, Y.Srivastava PRD 2005
A. Corsetti, A. Grau, G.Pancheri, Y. Srivastava PLB 1996

1. Multiple parton interactions : optical theorem and eikonal representation for $T_{el}(s,t)$
2. Hard scattering to drive the rise due to 1/x
3. Soft gluons down to zero momentum to tame the rise

The hard cross-section

- Mini-jet cross-section

$\Sigma\int$ densities $\int dp_t \, d\hat{\sigma}/dp_t$

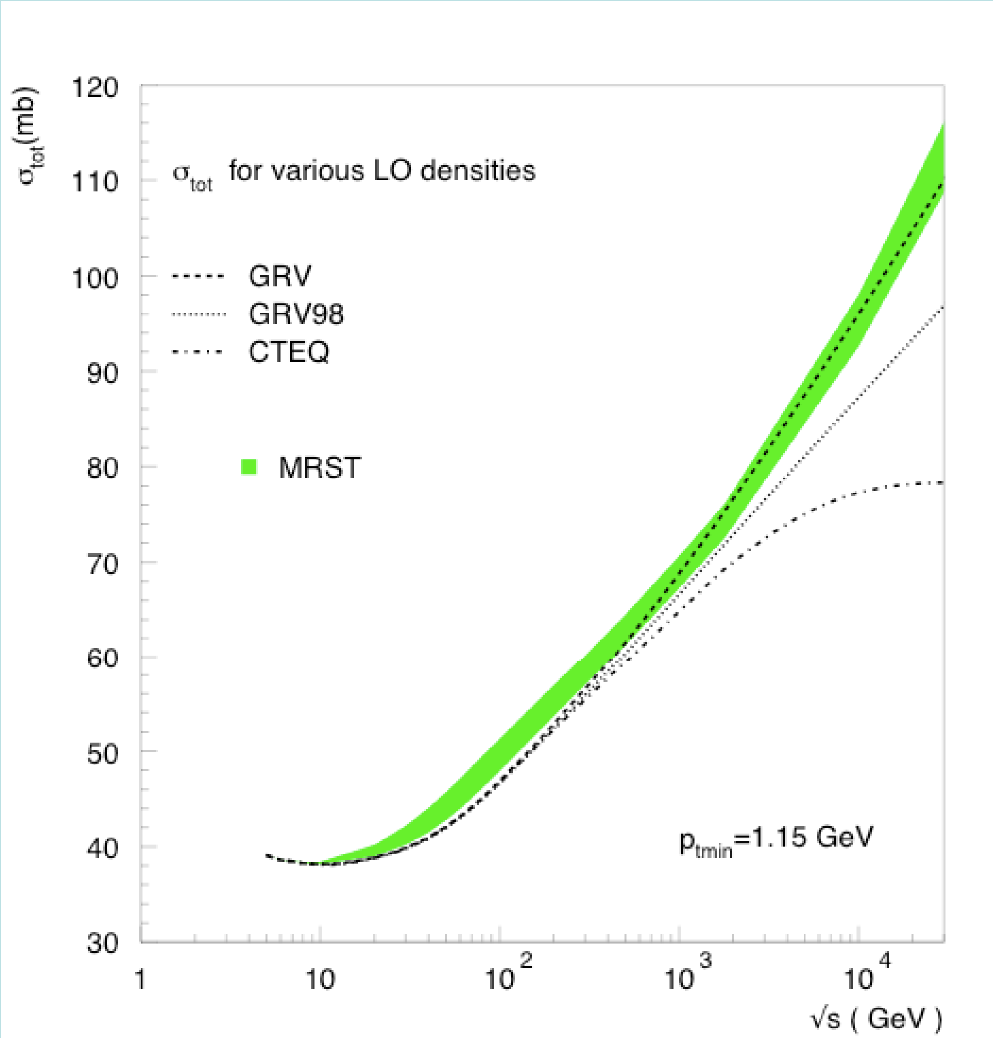


Which parameters in soft emission?

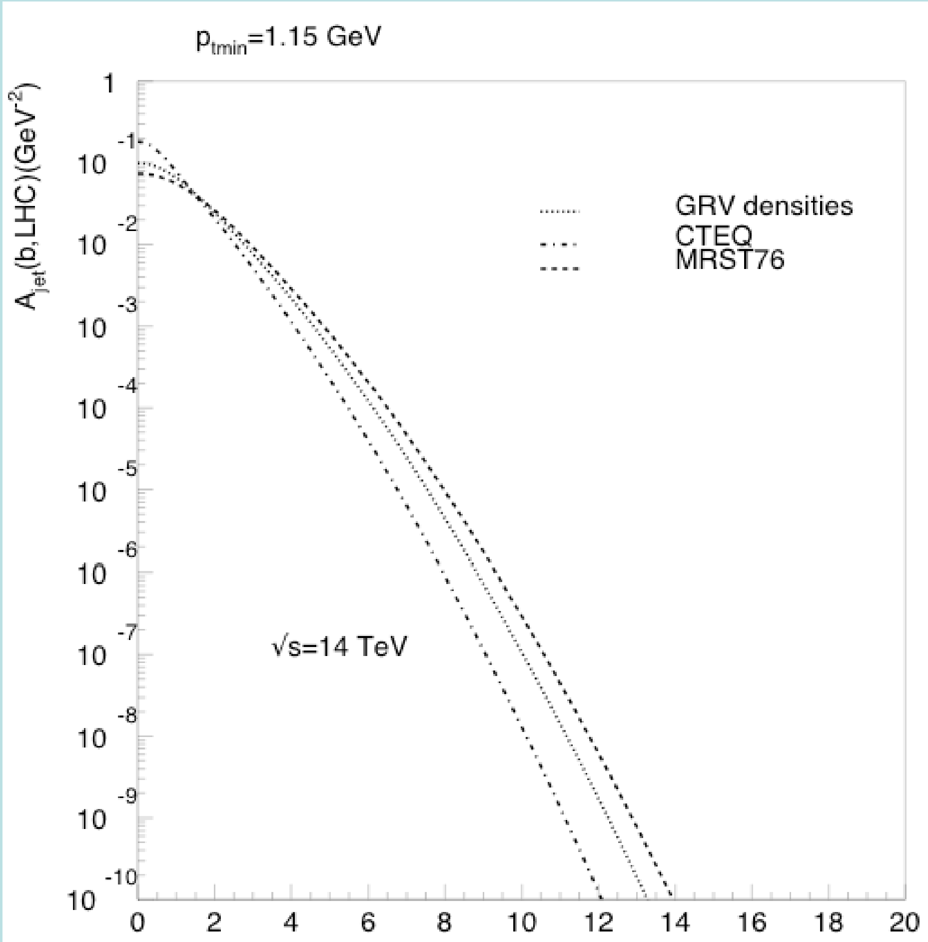
p_{tmin} and p regulate how large is the maximum energy , but PDF's also play a role

- P_{tmin} ⟺ hard scattering lowest scale
- p ⟺ infrared (integrable) behaviour

Example of Eikonalized proton-antiproton total cross-section for ptmin=1.15



b-distribution for hard collisions from soft gluon resummation for ptmin=1.15 GeV for singular α_s



How the model works

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

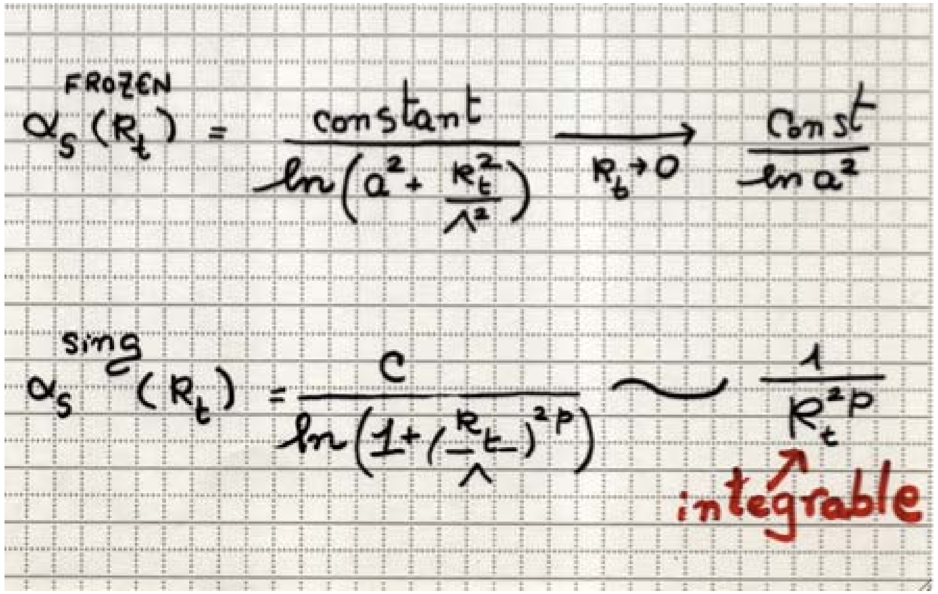
- Choose parton densities
- Calculate minijet x-section
- Calculate q_{max} for soft gluons
- Calculate A(b,s) for given q_{max}
- Calculate $n_{hard}(b,s)=A(b,s)\ \sigma_{jet}(p_{tmin},s)$
- Parametrize n_{soft}
- Evaluate $n(b,s)= n_{soft} + n_{hard}$

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

Zero momentum quanta

- Soft gluons need to be resummed if they are indeed soft ≈1/k
- Resummation implies integration over dk_t

Models for infrared behaviour



- What matters will be

$\int \alpha_s(k_t)dk_t\, f(k_t)$

and not $\alpha_s(0)$

An aside on the Froisart bound and minijet cross-sections

s^{ε} : Should ε be the same for all hadronic cross-sections?

- Yes if the model
  - is based on Regge poles and a universal Pomeron pole exchange

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

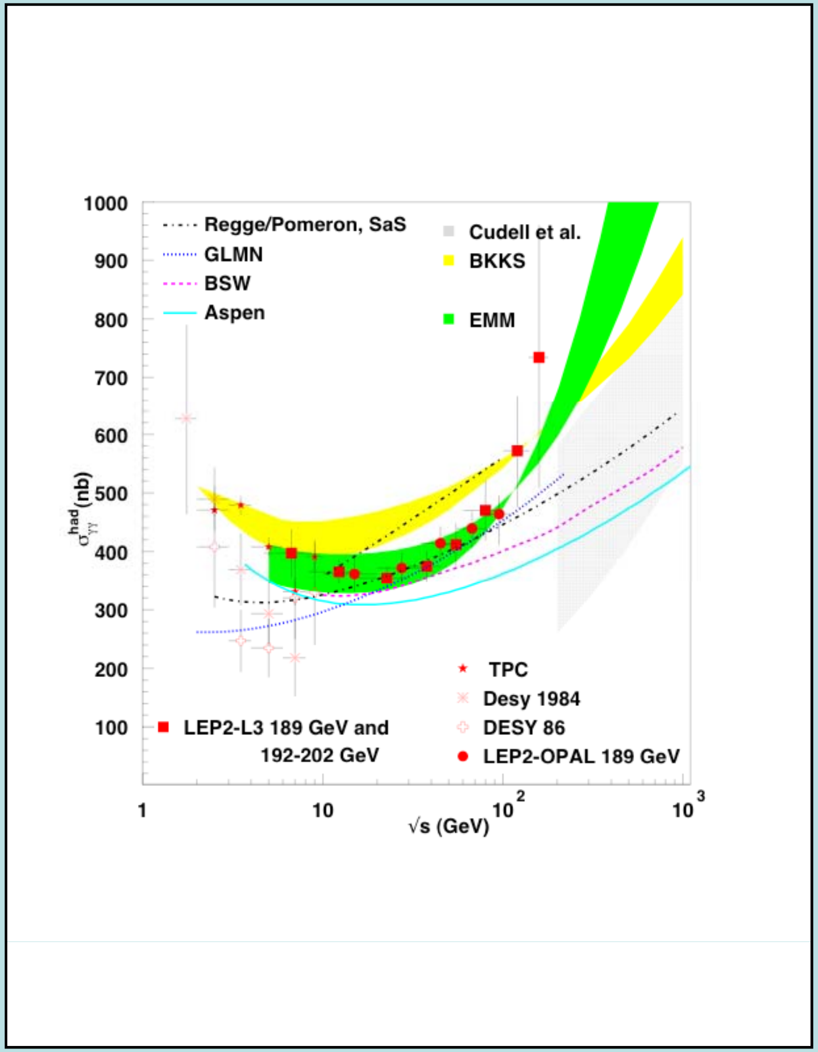
- Not necessarily if
  - The model has some connection with QCD and parton densities play a role

A fit to LEP data shows that ε is not the same for proton and photon cross-sections

A realistic QCD model should relate the fit to QCD phenomenological inputs quantities like densities etc.

Models for total cross-section

- The interest lies in QCD role
- What is the Pomeron? The Reggeon?
- Are these concepts universal?
- Or do they just phenomenologically describe our ignorance?
- How can ILC/LPC help ?



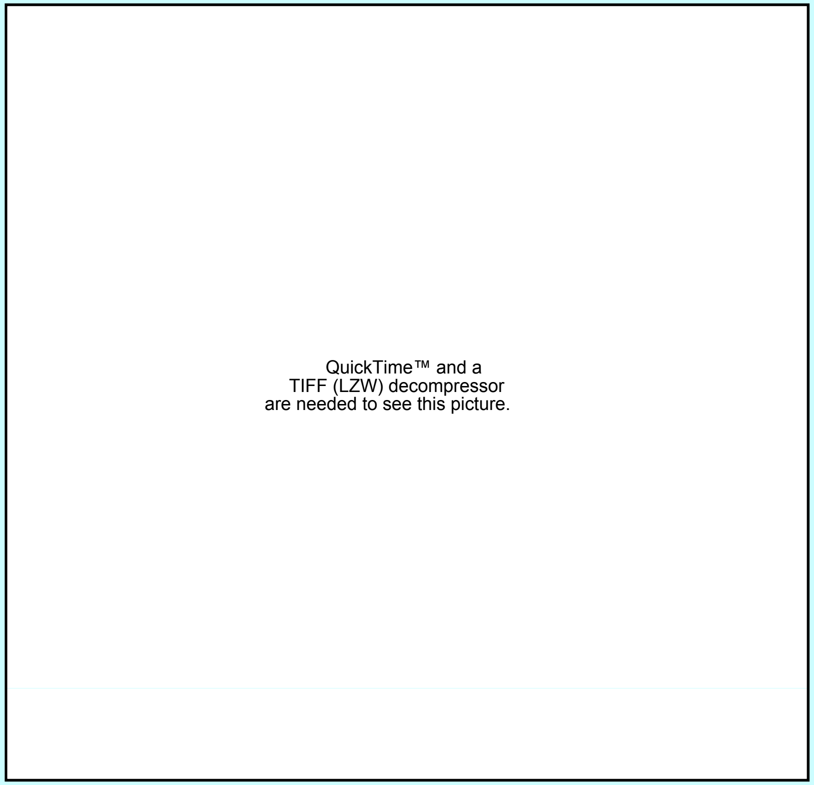
A.de Roeck, R. Godbole, A. Grau, G.Pancheri, JHEP 2003

s^{ε} : Should ε be the same for all hadronic cross-sections?

- Yes if the model
  - is based on Regge poles and a universal Pomeron pole exchange

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

- Not necessarily if
  - The model has some connection with QCD and parton densities play a role



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 $A(\vec{b}, q_{max}^{soft})$

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

$$|S(\vec{b})|^2 = P_{inel}$$

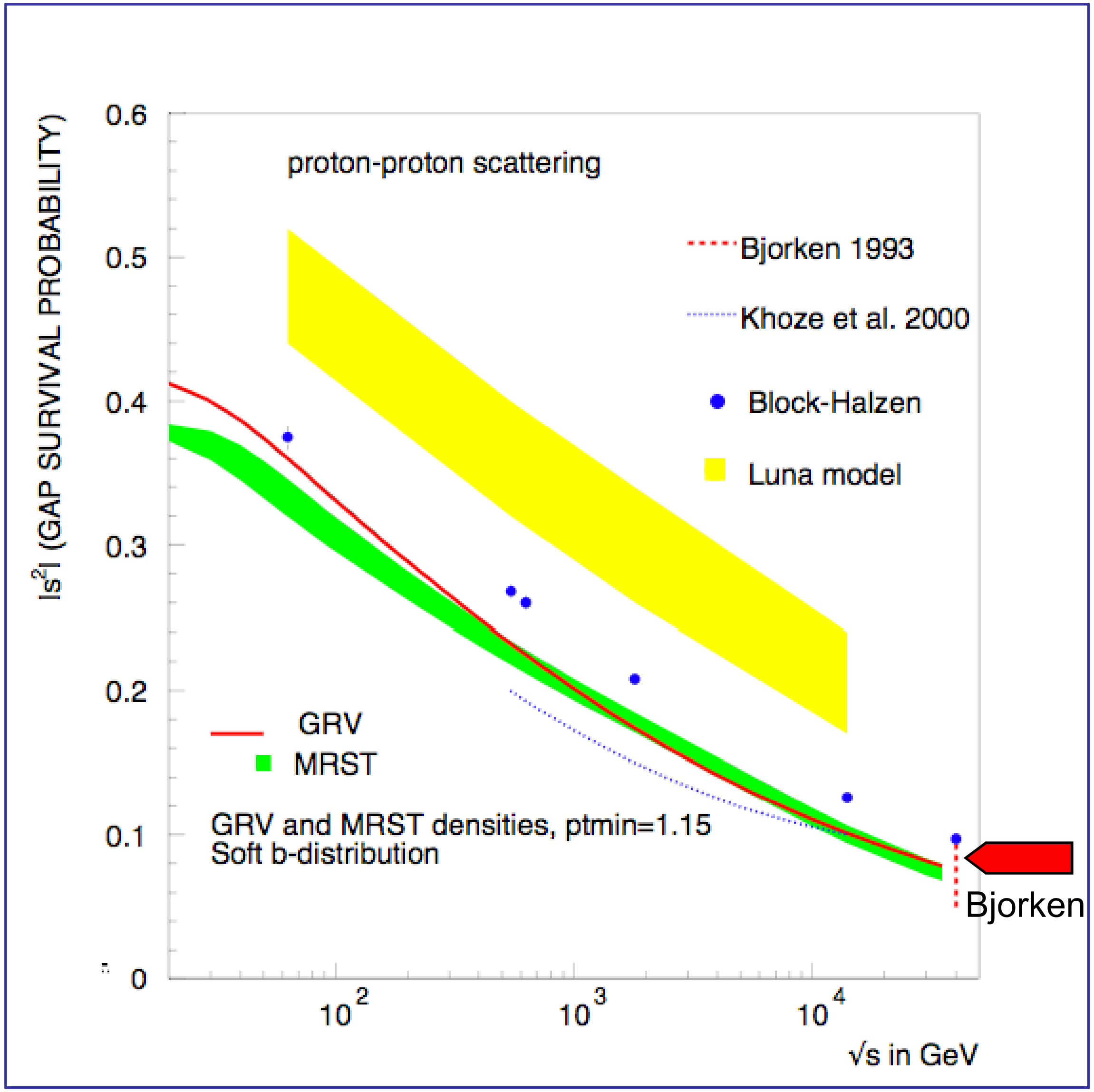
Survival probability

Probability of not having an inelastic collision

$$P_{inel} = e^{-n(b,s)}$$

Can be used to calculate the survival probability of Large Rapidity Gaps for collisions at given b-value

Comparison with other models



The Bloch-Nordsiek Eikonal Minijet model includes k_t resummation

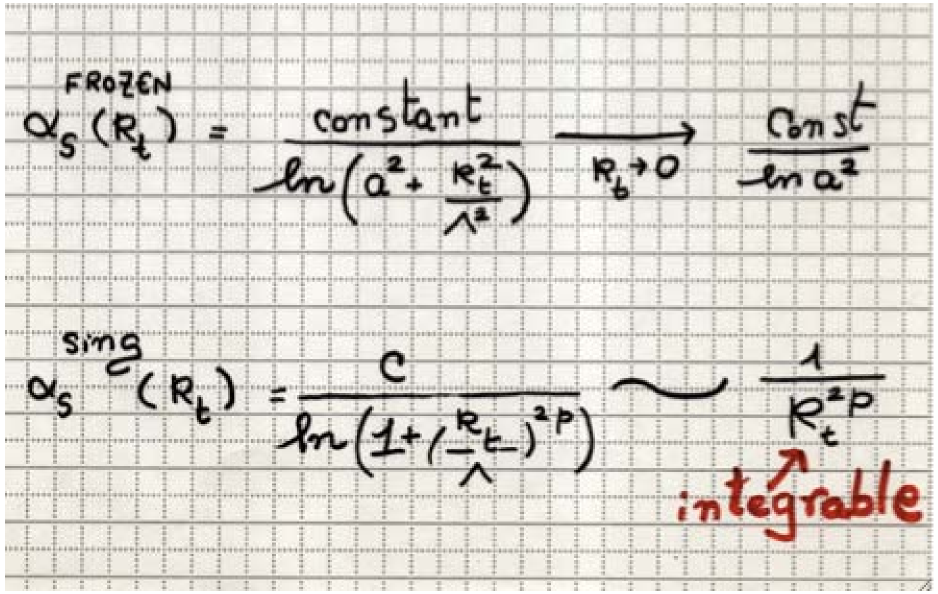
R.Godbole, A. Grau, G.Pancheri, Y.Srivastava PRD 2005
A. Corsetti, A. Grau, G.Pancheri, Y. Srivastava PLB 1996

1. Multiple parton interactions : optical theorem and eikonal representation for $T_{el}(s,t)$
2. Hard scattering to drive the rise due to 1/x
3. Soft gluons down to zero momentum to tame the rise

Zero momentum quanta

- Soft gluons need to be resummed if they are indeed soft ≈1/k
- Resummation implies integration over dk_t
- What matters will be $\int \alpha_s(k_t)dk_t\, f(k_t)$

and not $\alpha_s(0)$



Soft gluons give b-distributions

In eikonal representation

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

- n(b,s)=average # of collisions at distance b, at energy $\sqrt{s}$
- b-distribution is needed

Our ansatz:

b-distribution =
Fourier transform of soft gluon K_t distribution

Soft gluons give b-distributions

In eikonal representation

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

- n(b,s)=average # of collisions at distance b, at energy $\sqrt{s}$
- b-distribution is needed

Our ansatz:

b-distribution =
Fourier transform of soft gluon K_t distribution

Resummation of soft gluons down to k_t=0

- Gluon emission in k_t changes the collinearity of initial partons
- And for same energy and p_{tmin}, acollinearity of initial partons will bring loss of luminosity of the parton beams and parton-parton cross-sections will decrease
- As the energy available for soft gluon emission increases, so does the acollinearity of the parton-parton collision
- The rate of rise of total cross-sections due to rising minijet cross-section is reduced (softened by) by soft gluon emissions.
- Softening effect more important the more singular α_s

We shall illustrate how the model works for the proton-proton case and then show its application to $\gamma\gamma$

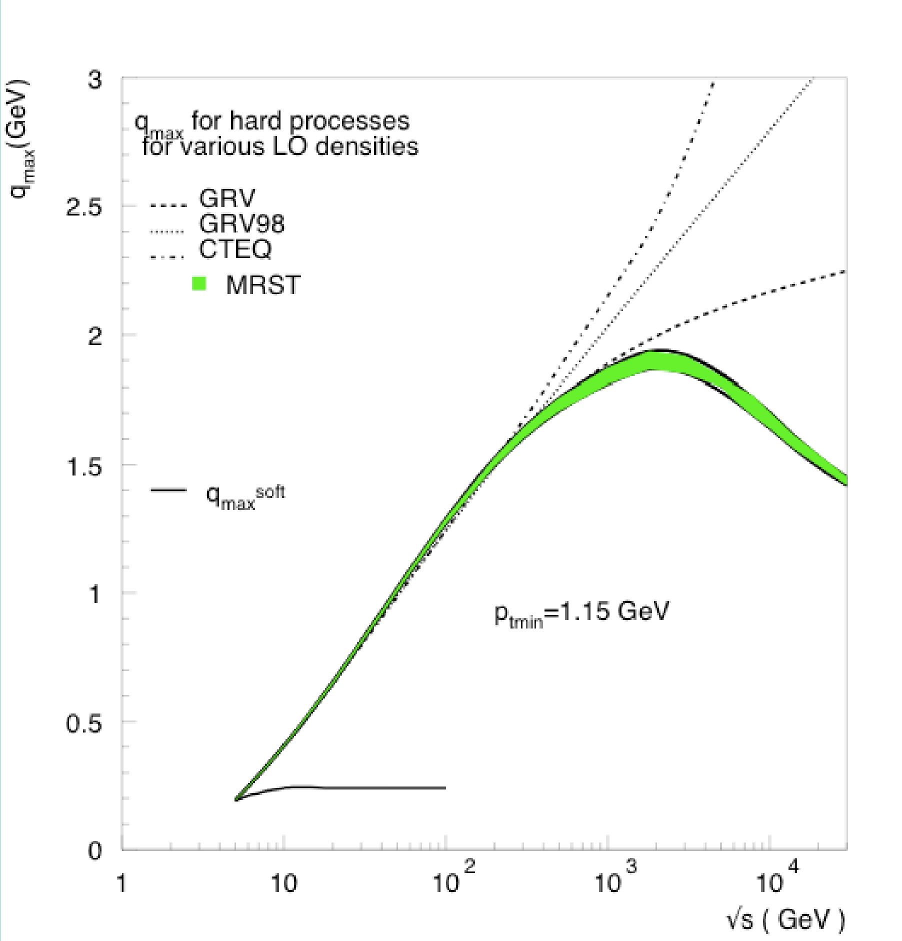
How the model works

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

- Choose parton densities
- Calculate minijet x-section
- Calculate q_{max} for soft gluons
- Calculate A(b,s) for given q_{max}
- Calculate $n_{hard}(b,s)=A(b,s)\,\sigma_{jet}(p_{tmin},s)$
- Parametrize n_{soft}
- Evaluate $n(b,s)= n_{soft} + n_{hard}$

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

q_{max} for ptmin=1.15 geV



Now apply the model to $\gamma\gamma$

photon-photon

Normal mode of operation

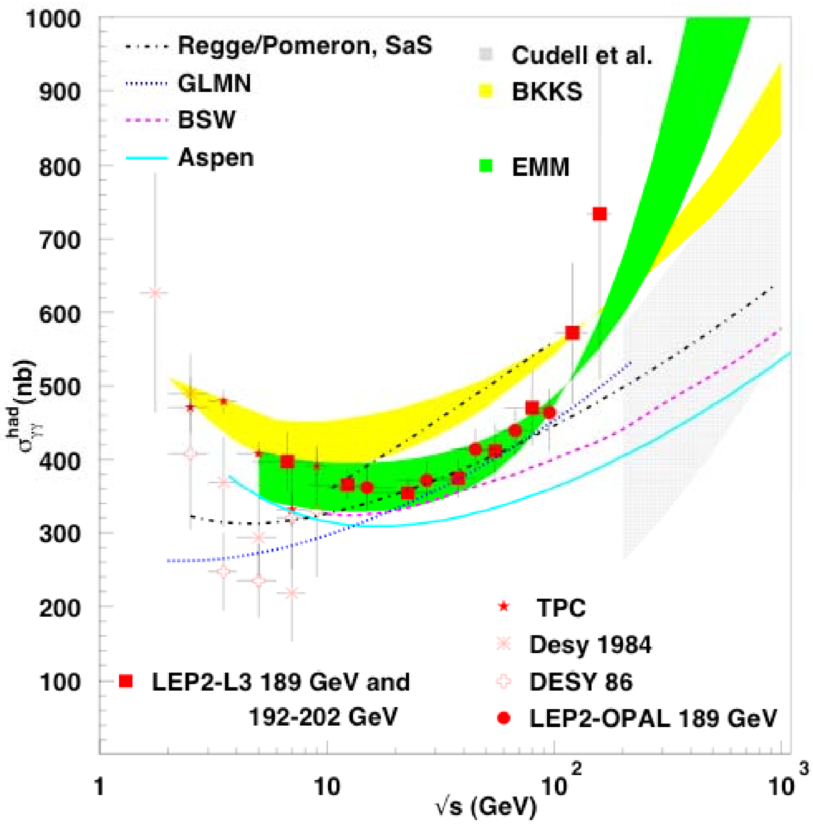
- E_{CM} approx up to 1/2 ee
- Non-monochromatic
- Can access $JP=0^{\pm}$
- QCD and some top
- Total cross-sections

Photon Collider

- $E_{CM} \sim 0.8\ E^{ee}_{CM}$
- Lum ~ 0.2 ee
- Higgs and top physics
- EWSB, SUSY are accessible and interesting

Models for total x-sections

- Interest lies in QCD role
- What is the Pomeron? The Reggeon?
- Are these concepts universal?
- Or do they just phenomenologically describe our ignorance?
- How can ILC help ?



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

s^{ε} : ε controls the rise

- Should ε be the same for all hadronic cross-sections?
- Yes if the model
  - is based on Regge poles and a universal Pomeron pole exchange or
  - On Gribov factorization alone
- Not necessarily if
  - The model has some connection with QCD and photon densities play a role

Soft resummation

Probablity of total K_T from infinite # of soft gluons

$$\int d^2b\, e^{iK_T b} \exp\{-\int d^3n(k)[1-e^{-ik_t b}]\}$$

depends upon single gluon energy

- maximum : use Kinematics
- minimum : 0 if Bloch-Nordsieck states

Role of resummation

An infinite number of soft quanta

- down to zero momentum but how?

  next slides

- Up to an energy dependent limit q_{max}
  - Higher hadron energy ⇨ possibility of more small x partons with "high energy" (≈1-2 GeV) ⇨ higher q_{max}

How the model works

- Choose p_{tmin} = 1÷2 GeV for mini-jets
- Choose parton densities
- Calculate minijet x-section
- Calculate q_{max} for soft gluons
- Calculate A(b,s) for given q_{max}
- Calculate $n_{hard}(b,s)=A(b,s)\,\sigma_{jet}(p_{tmin},s)$
- Parametrize n_{soft}
- Evaluate $n(b,s)= n_{soft} + n_{hard}$
- Eikonalize $\sigma_{tot} \approx 2\int d^2b\,[1-e^{-n(b,s)/2}]$

Conclusions (I)

- We have built a model for the total cross-section which
  - Incorporates **hard** and **gluon** effects
  - Satisfies the limits from the **Froissart** bound
  - Can be used to study other minimum bias effects
  - Easily extended to γp and $\gamma\gamma$

Conclusions (II)

- 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.

Photons and QCD

- Photons probe the QCD vacuum
- How a photon becomes a hadron
- Two photons have a unique signature in producing scalar or pseudoscalar resonances
- If new strong WW interactions would be detected at LHC possible new scalar states could be probed to extract threshold dynamics information not unlike what happens in $\gamma\gamma \longrightarrow \pi^0\pi^0$ around the σ-meson
- One can study $\gamma\gamma \longrightarrow \gamma\gamma$ if enough luminosity
  - Light-by-light and hadronic contributions
  - Insight into the trace anomaly