Soft gluon kt-resummation for total and inelastic cross-sections at LHC at CM energy of 7 TeV

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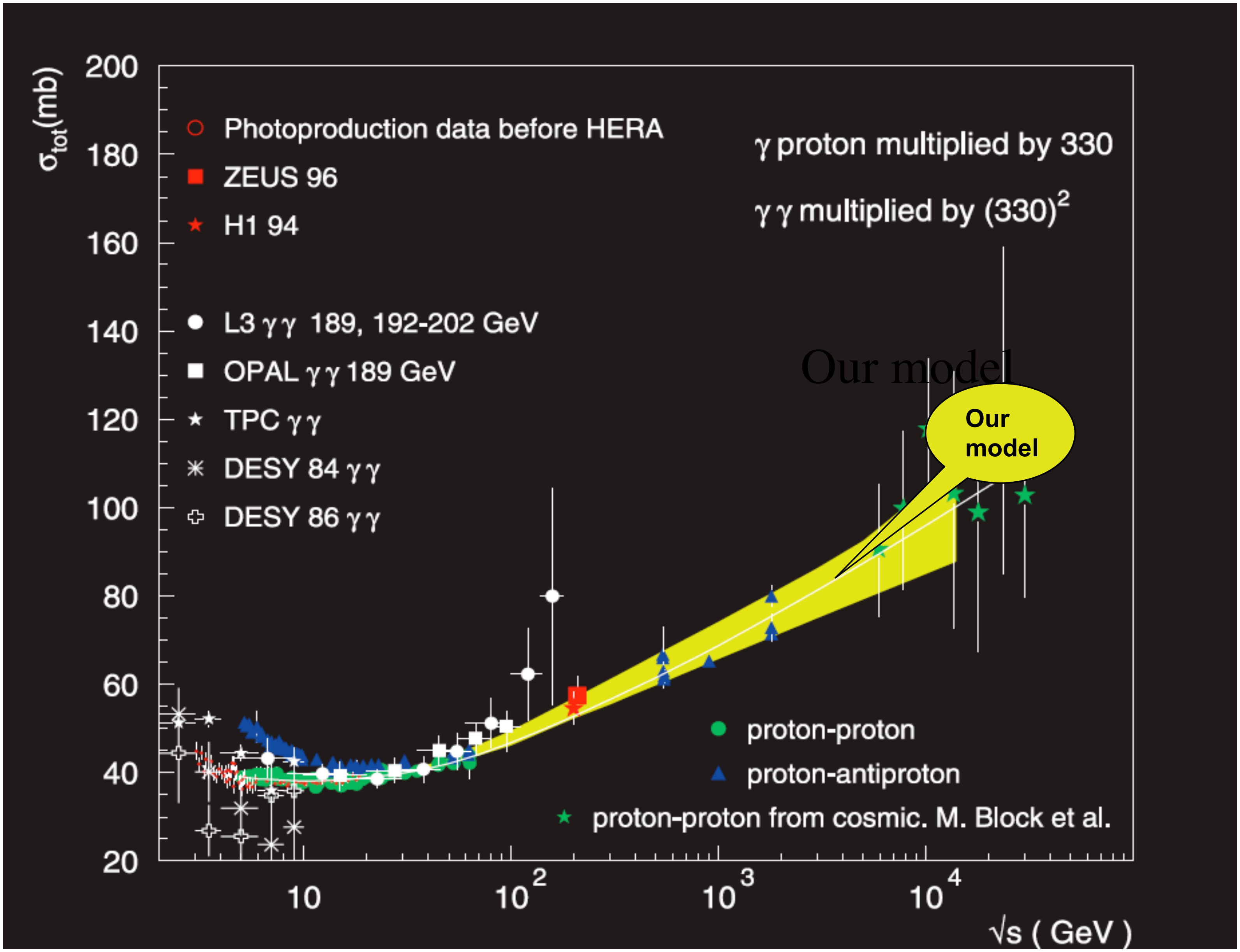
arXiv:1102.1949

Outline

- What we know about σ_{total} and what is new
- Models
- Rivisiting kt-resummation
- Our model
- Results
- What the recent ATLAS data can teach us

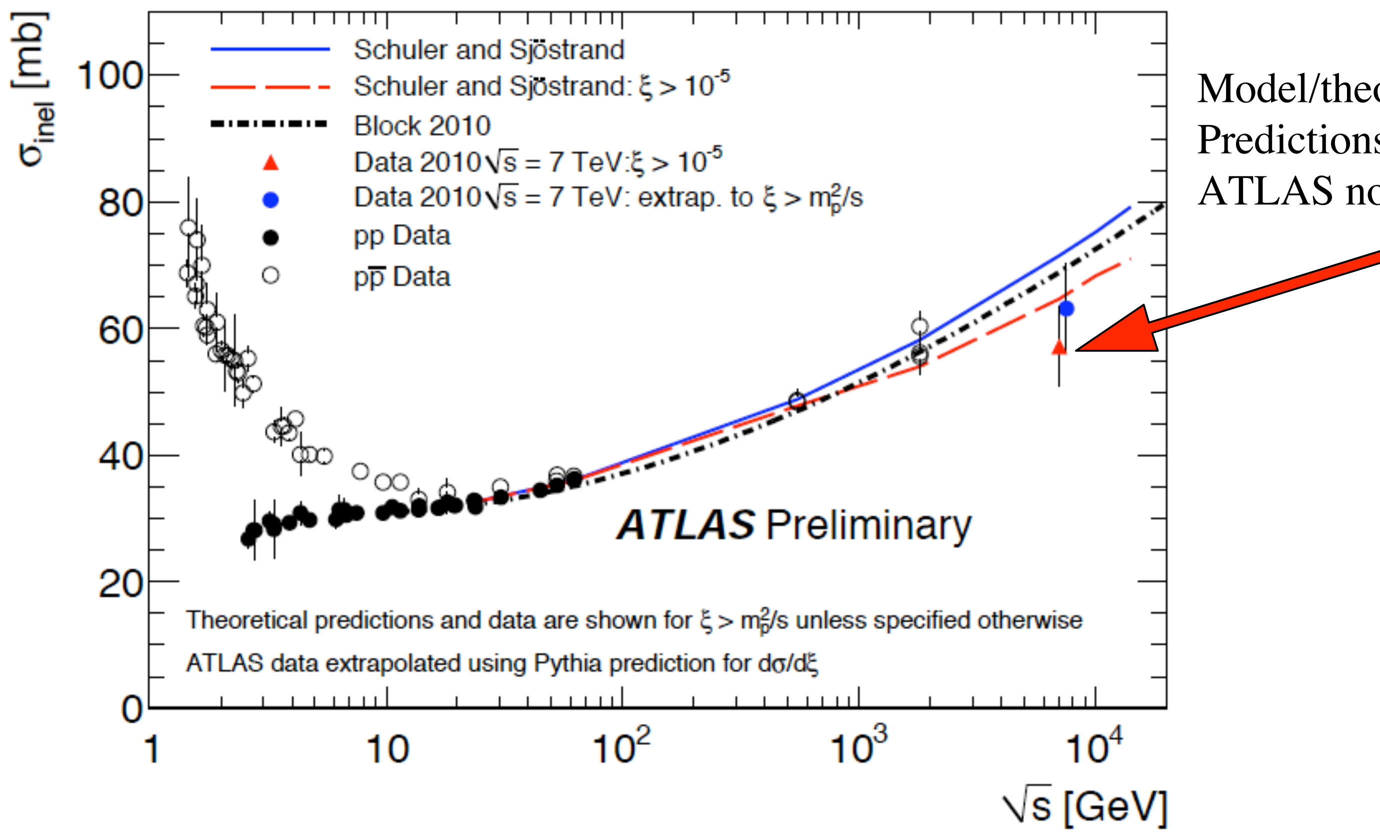
What we know



σ_{tot}(mb)
200
180
160
140
120
100
80
60
40
20
Photoproduction data before HERA
ZEUS 96
H1 94
L3 γγ 189, 192-202 GeV
OPAL γγ 189 GeV
TPC γγ
DESY 84 γγ
DESY 86 γγ
γ proton multiplied by 330
γγ multiplied by $(330)^2$
Our model
Our model
proton-proton
proton-antiproton
proton-proton from cosmic. M. Block et al.
10
10^2
10^3
10^4
√s (GeV)

WHAT is NEW

http://cdsweb.cern.ch/record/1326894/files/ATLAS-CONF-2011-002.pdf



Model/theoretical Predictions are ~ higher than ATLAS non-diffractive data

The total cross-section: confinement and deconfinement at work

$$\sigma_{total} = \sigma_{elastic} + \sigma_{inelastic}$$

A confined system:quarks and gluons remain inside the original hadrons even at high energy

deconfined

Central production: quarks and gluons scatter away and then hadronize

Fully deconfined

Single and double diffractive Production: quarks and gluons remain “close” to original hadrons and then hadronize

Major phenomenological facts on σ_{total}

- All total cross-sections rise with energy after $\sqrt{s} \approx 10-15\ GeV$

Present fits $\approx s^{\sim 0.1}$

Success of Donnachie-Landshoff (DL) Regge-Pomeron Model 1992

$Xs^{-\eta} + Ys^{\epsilon}$

- the rise is fast at the beginning

- The rise slows down to $\ln s$ or $\ln^2 s$

Status of phenomenological/theoretical predictions for σ_{total}

$$\sigma_{total} \approx \frac{\pi}{m_\pi^2} \ln^2 \frac{\sqrt{s}}{< E_0 >}$$

- Heisenberg model 1952
- Froissart limit $\leq \ln^2 s$
- Models are based on optical theorem, eikonals, Glauber theory, Reggeon field theory
- Most popular
  - Regge-Pomeron exchange DL 1992
  - Eikonal models ~ 1970 -> now
  - Dual Parton Model, many Pomerons, Levin et al, Khoze et al, Martynov…
  - Mini-jets + eikonal, QCD inspired, Block et al, PYTHIA, Lipari Lusignoli (LL),
  - AdS/CFT C-I Tang
- Fits and Froissart bound
  - Constant +Powers + logarithms (up to log square)

W. Heisenberg, Zeit. Phys., **Bd. 133, 3** 65 **1952**

Production of Mesons as a Shock Wave Problem

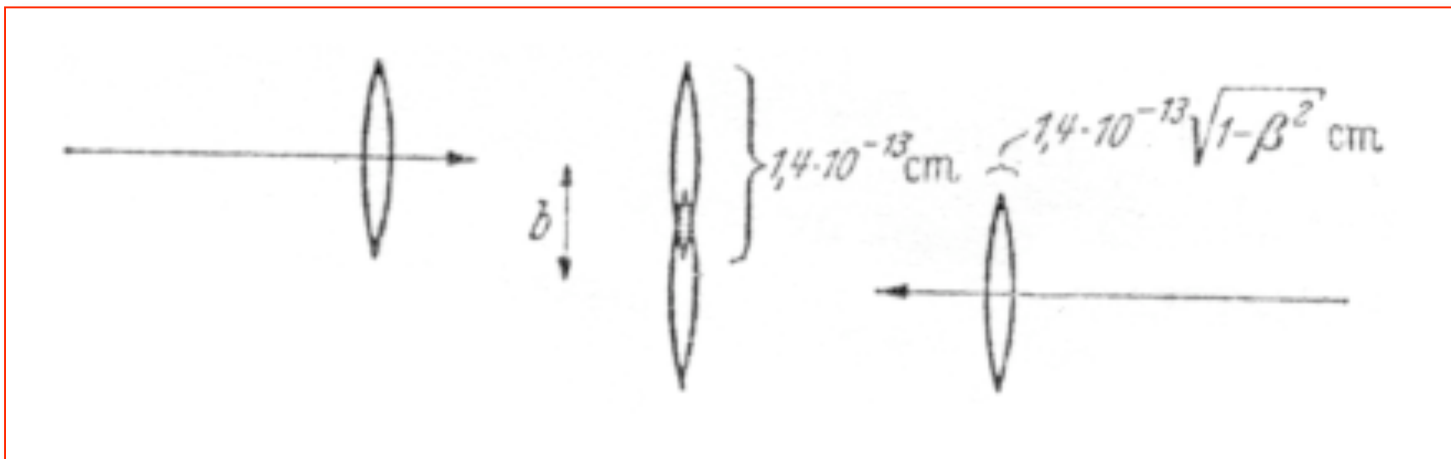
W. Heisenberg

With 6 figures in text
Received on 5 May 1952

Translated by Herman Boos

Abstract

Multi-meson production in two-nucleon collision is described as a shock wave process which is governed by a non-linear wave equation. Since one deals with big quantum numbers, these quantum processes may be approximately described by means of the correspondece principle. Analysing solutions to the non-linear wave equation one can get the energy and angular distribution for different meson sorts.



Heisenberg and total cross-sections

$$\sigma_{total} = \pi b_{max}^2$$

If pion wave function ~ $e^{-b_{max} m_\pi}$

$$\sigma_{total} \approx \frac{\pi}{m_\pi^2} \ln^2 \frac{\sqrt{s}}{< E_0 >}$$

$< E_0 >$: average energy of single pion in emitted pion cloud

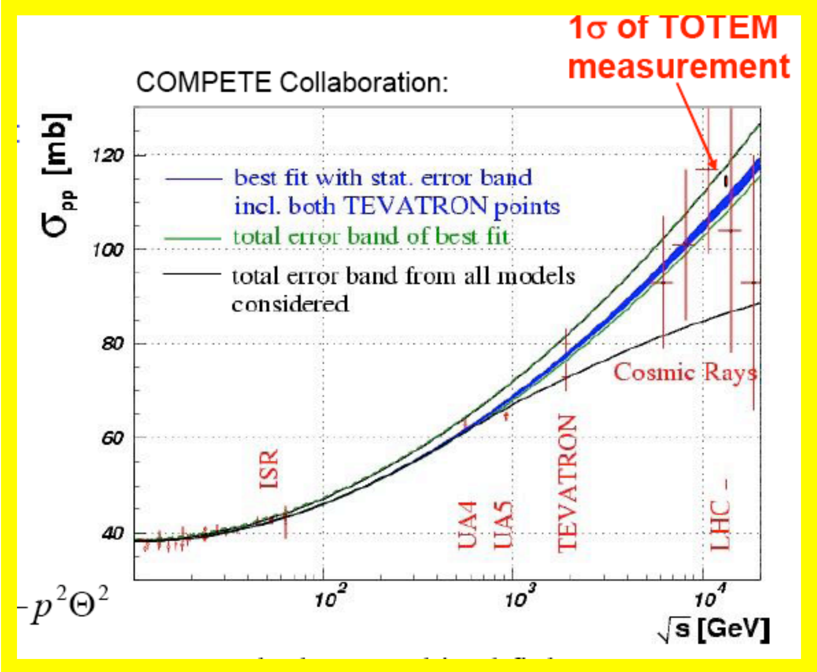
$< E_0 >$ Constant

σ_{total} Rising like $\ln^2 s$

$< E_0 >$ ~ $\sqrt{s}$

σ_{total} ~ constant

Phenomenological status of σ^{pp}_{total} from TOTEM proposal



Reflects a geometrical picture[Froissart bound]

Regge terms

$$\sigma_{ab,\bar{a}b} = Z^{ab} + \ln^2\left(\frac{s}{s_0}\right) + Y_1^{ab}\left(\frac{s_1}{s}\right)^{\eta_1} \pm Y_2^{ab}\left(\frac{s_1}{s}\right)^{\eta_2}$$

Cudell, J. R. and others,Phys. Rev.D65, 2002,074024,hep-ph/0107219

From the elastic to the total with the Optical theorem

$$F(s,t) = \int d^2\mathbf{b} f(b,s) = i\int d^2\mathbf{b} e^{i\mathbf{q}\cdot\mathbf{b}}[1 - e^{i\chi(b,s)}]$$

$$\frac{d^2\sigma_{elastic}}{d^2\mathbf{b}} = |1 - e^{i\chi(b,s)}|^2$$

Optical Theorem

$$\sigma_{total} = 2\int d^2\mathbf{b} \Re e[1 - e^{i\chi(b,s)}]$$

$$= 2\int d^2\mathbf{b}[1 - \cos \Re e\chi(b,s) e^{-\Im m\chi(b,s)}]$$

Eikonal model

$$\sigma_{elastic} = \int d^2\vec{b}|1 - e^{i\chi(b,s)}|^2$$

$$\sigma_{total} = 2\int d^2\mathbf{b}[1 - e^{-\Im m\chi(b,s)} cos\Re e\chi(b,s)]$$

$$\sigma_{total\ inelastic} = \int d^2\mathbf{b}[1 - e^{-2\Im m\chi(b,s)}]$$

Models for inelastic collisions can give $\boxed{\Im m\chi}$

$$\sigma_{inelastic} = \int d^2\vec{b}\ P(b)_{all\ inelastic\ collisions}$$

Inelastic scattering : sum over all possible distributions of n independent collisions between particles in impact parameter space

$$P(\{n,\bar{n}\}) = \frac{(\bar{n})^n e^{-\bar{n}}}{n!}$$

$$\sigma_{inel}(s) = \sum_{n=1} \int d^2\mathbf{b}\ P(\{n,\bar{n}\})$$
$$= \int d^2\mathbf{b}[1 - e^{-\bar{n}(b,s)}]$$

$$\sigma_{total} = \sigma_{elastic} + \sigma_{inelastic}$$

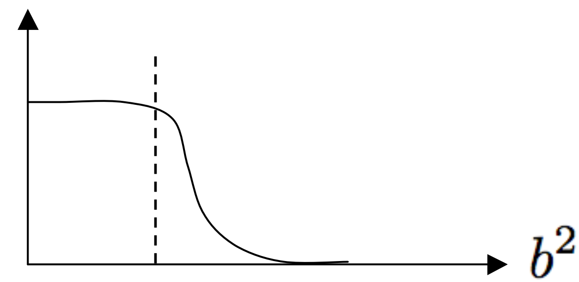
$$\sigma_{inel} = \int d^2\mathbf{b}[1 - e^{-2\Im m\chi(b,s)}]$$

$$\Rightarrow \quad 2\Im m\chi(b,s) = \bar{n}(b,s)$$

Semiclassical derivation

Geometrical picture

$$[1 - e^{-\bar{n}(b,s)}]$$



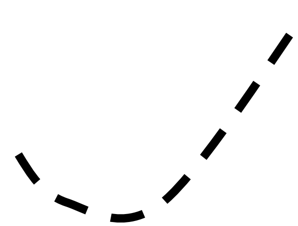
Describes the probability distribution of matter during the scattering process

$$\bar{n}(b, s) \simeq constant$$

Geometrical scaling   Chou and Yang

The unique energy dependence of all total x-sections

- What makes the cross-section rise?



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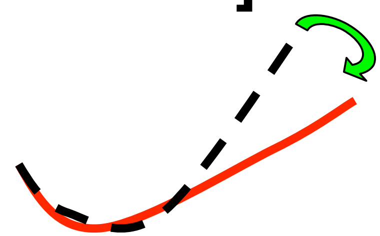
Pomerons? Low-x parton collisions [**Halzen 1971…]**
embedded into eikonal



- What makes the cross-section rise within the limits imposed by the Froissart bound?

Saturation?

Acollinearity induced by IR k_t-emission [G.P. et al. **Phys.Lett.B68, 2009**]

Building sigma$_{total}$

$$\sigma_{total} = 2\int d^2\mathbf{b}[1 - e^{-\Im m\chi(b,s)} cos\Re e\chi(b,s)]$$

$$\bar{n}(b,s) = 2\Im m\chi(b,s) \simeq A(b)\sigma(s)$$

$$\Re e\chi(b,s) \simeq 0$$

Two component simplest model

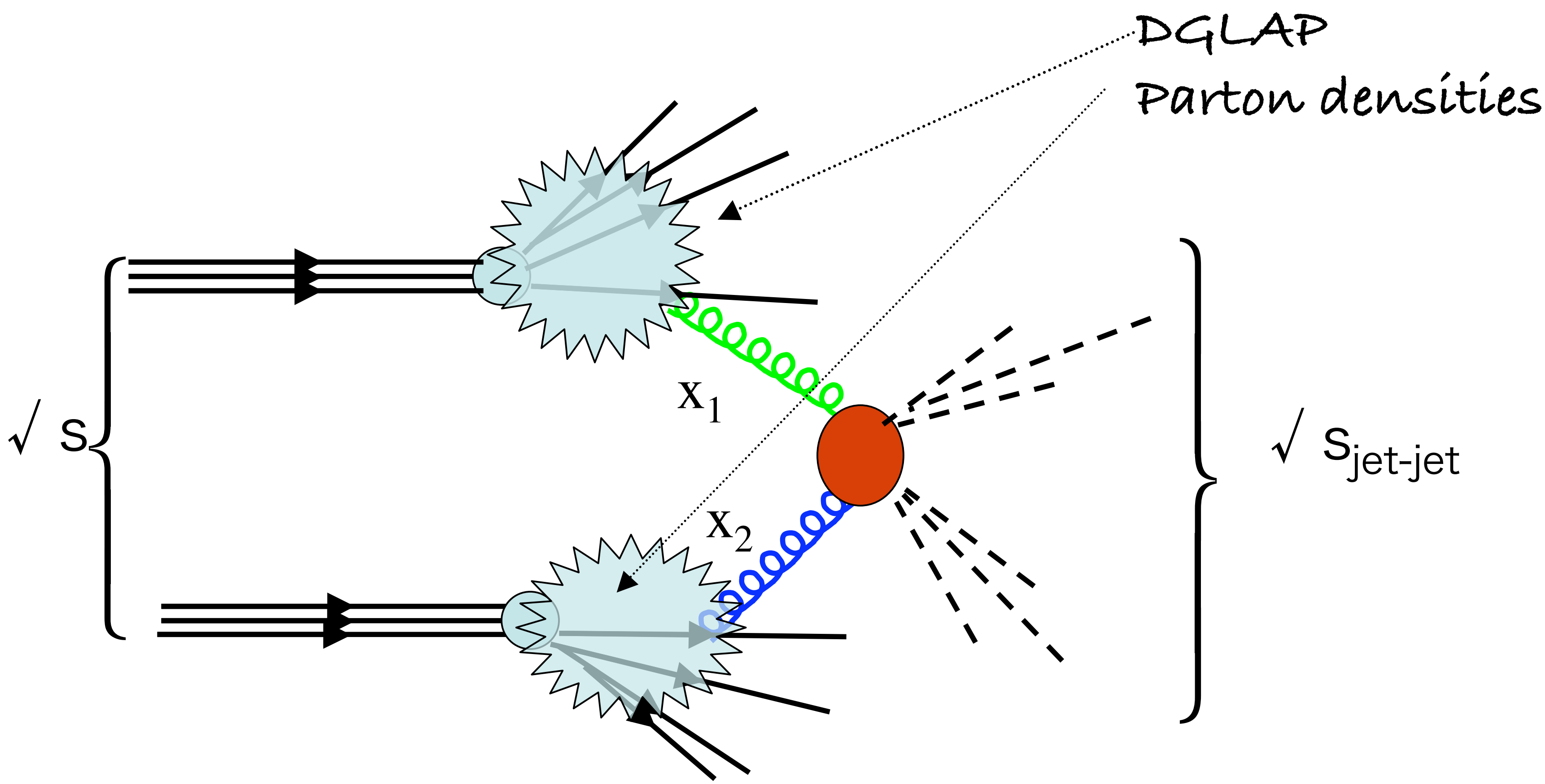
$$\bar{n}(b,s) = \bar{n}_{soft}(b,s) + \bar{n}_{hard}(b,s)$$

$$\bar{n}_{soft/hard}(b,s) = A_{soft/hard}(b,s)\sigma_{soft/hard}(s)$$

Overlap function

What makes the cross-section rise?

Mini-jets are responsible for the rise of the total cross-section
Cline,Halzen,Luthe 1972- Gaisser, Halzen 1985- G.P., Srivastava 1985



Mini-jets drive the rise of σ_{total}

$$\sigma_{\text{jet}}^{AB}(s, p_{tmin}) = \int_{p_{tmin}}^{\sqrt{s}/2} dp_t \int_{4p_t^2/s}^{1} dx_1 \int_{4p_t^2/(x_1 s)}^{1} dx_2 \times \sum_{i,j,k,l} f_{i|A}(x_1, p_t^2) f_{j|B}(x_2, p_t^2) \frac{d\hat{\sigma}_{ij}^{kl}(\hat{s})}{dp_t}$$

$$p_{tmin} \sim 1 \div 2\ GeV$$

DGLAP evoluted PDF

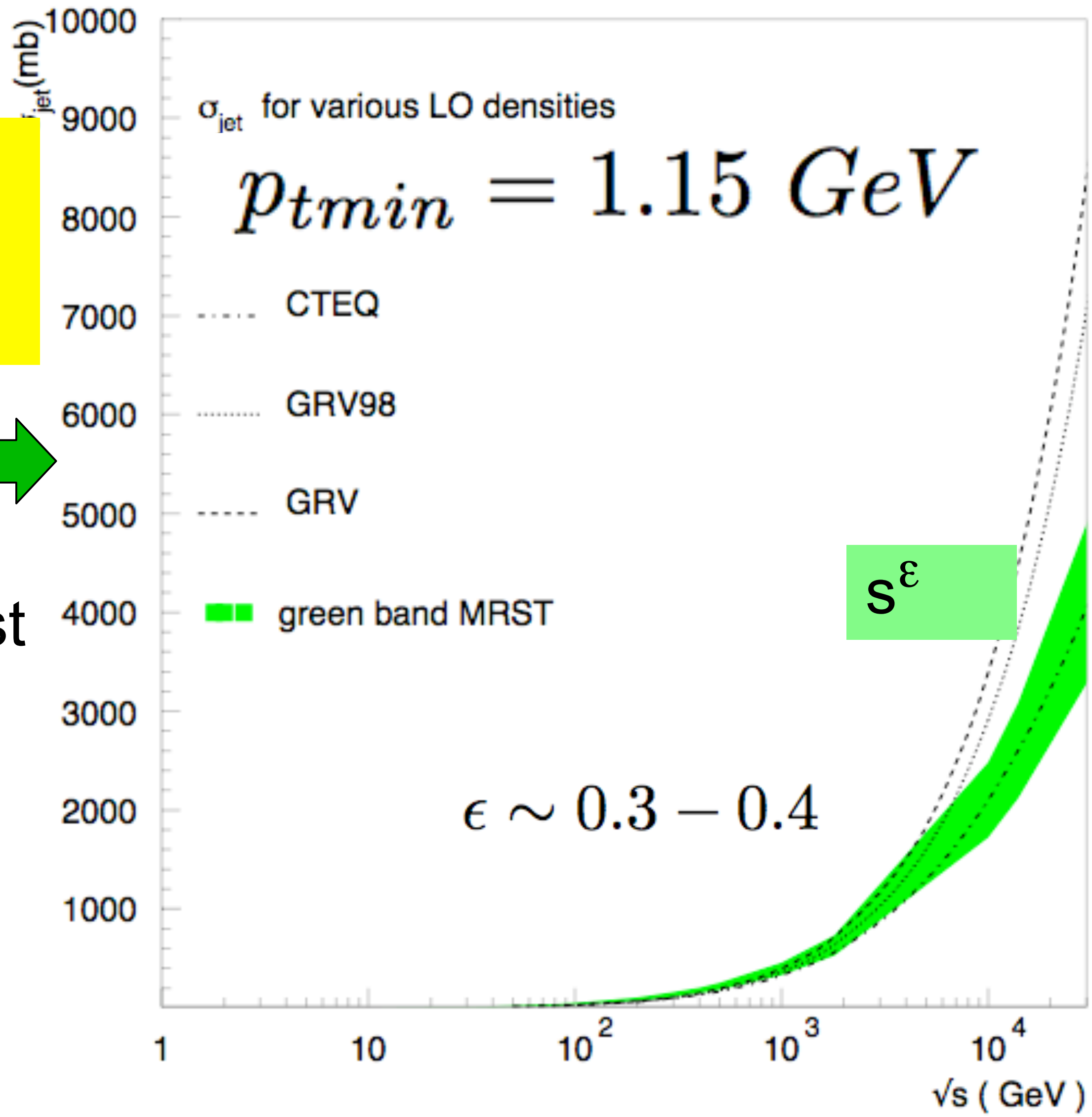
Parton-parton x-sections: $parton_i + parton_j \to parton_k(p_t) + parton_l(-p_t)$

1.

QCD calculation of $\sigma^{AB}_{jet-jet}$

- parton densities
- cut-off in parton momentum

The rise is way too fast



Eikonal models: b-distribution can quench the rise

$$n_{hard-minijets}(b) \approx A(b,s)\sigma_{jet}(s,p_{tmin})$$

How to choose it:
Form factors?

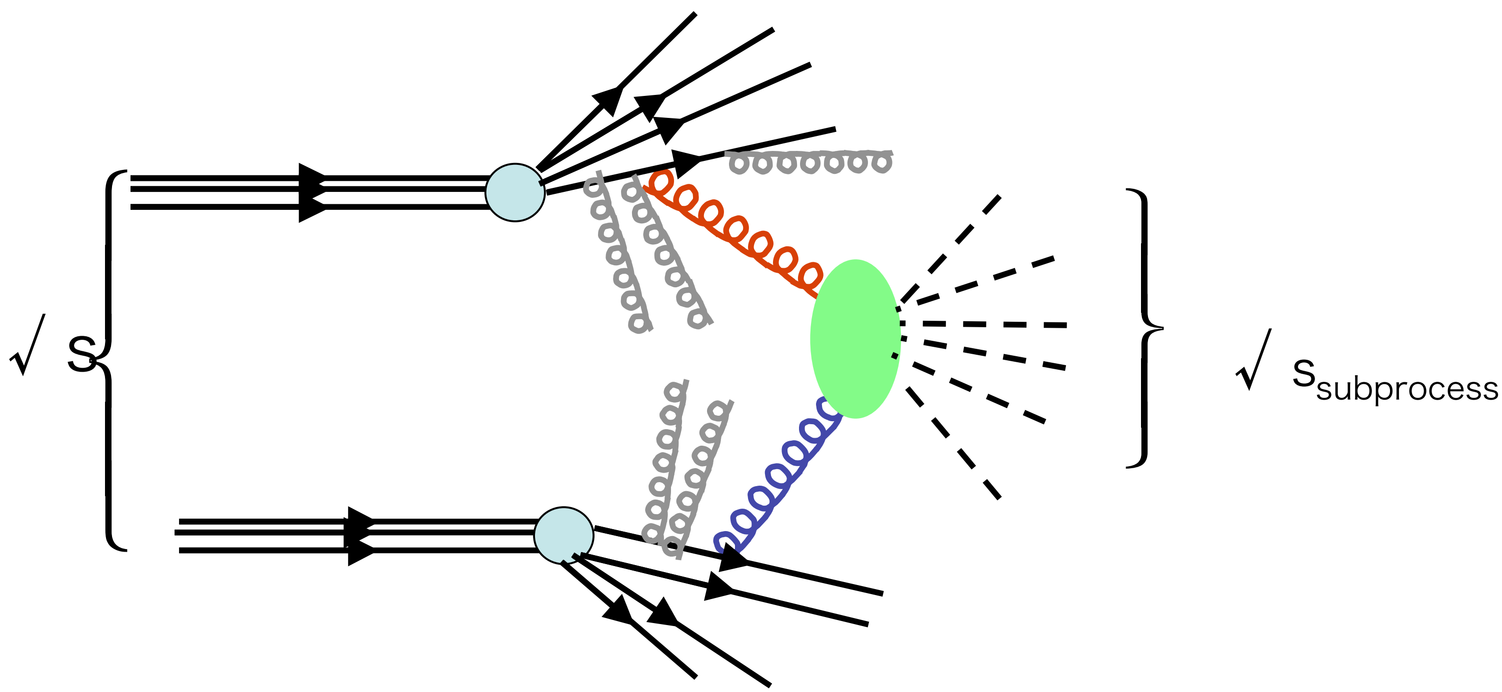
In our model, it is the emission of infrared gluons which tame low-x gluon-gluon scattering (mini-jets) and restore the Froissart bound

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

$$\sigma_{tot}(s) \to [\varepsilon \ln(s)]^{(1/p)} \qquad \frac{1}{2} < p < 1$$

Godbole, Grau, GP, Srivastava
Phys.Lett.B682:55-60,2009.
e-Print: arXiv:0908.1426 [hep-ph]

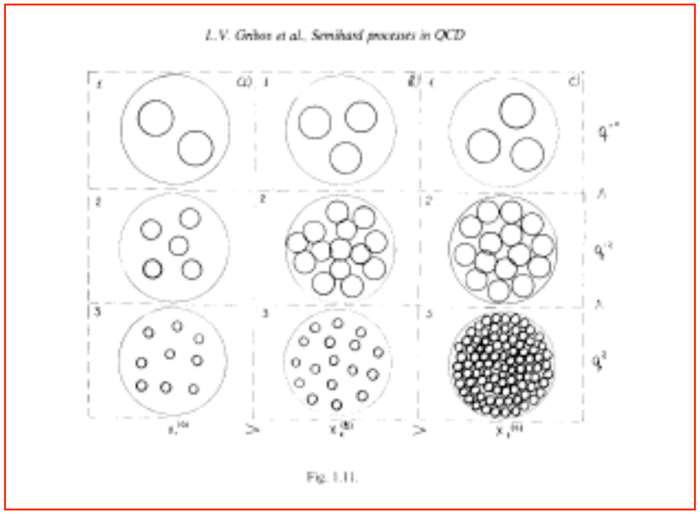
One component missing in the mini-jet picture is soft gluon emission from the initial state to break the collinearity and reduce the parton-parton cross-section

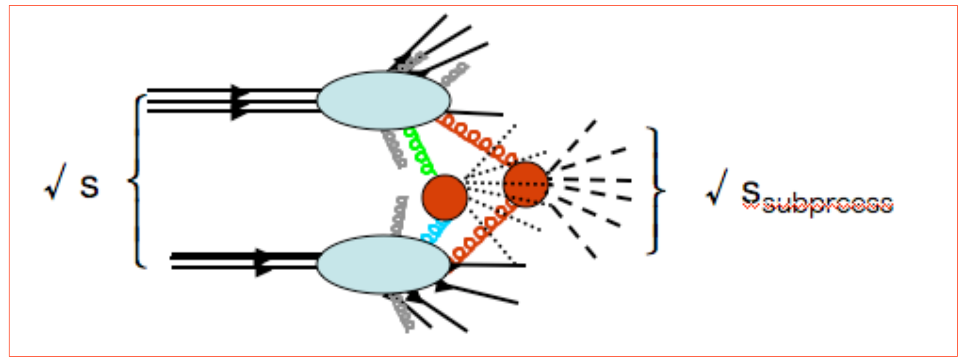


A picture of fast rise and then saturation

- As soon as gluons and partons are free to interact with each other, a very fast rise takes place, as reflected by a power law behaviour
- As the hadrons “see ” each other and the energy increases, soft gluons are emitted by the colliding partons and modify the process collinearity
- The result is an equilibrium situation between the rise from 2 $\rightarrow$ 2 parton-parton processes, most of them at very low x - increasing the x-section- and soft gluon emission -decreasing the x-section
- Soft gluon emission is also energy dependent, as always with the scale for soft resummation

In our model the Levin saturation cartoon is substituted by a microscopic scattering picture





- Hard scattering- 2 → 2

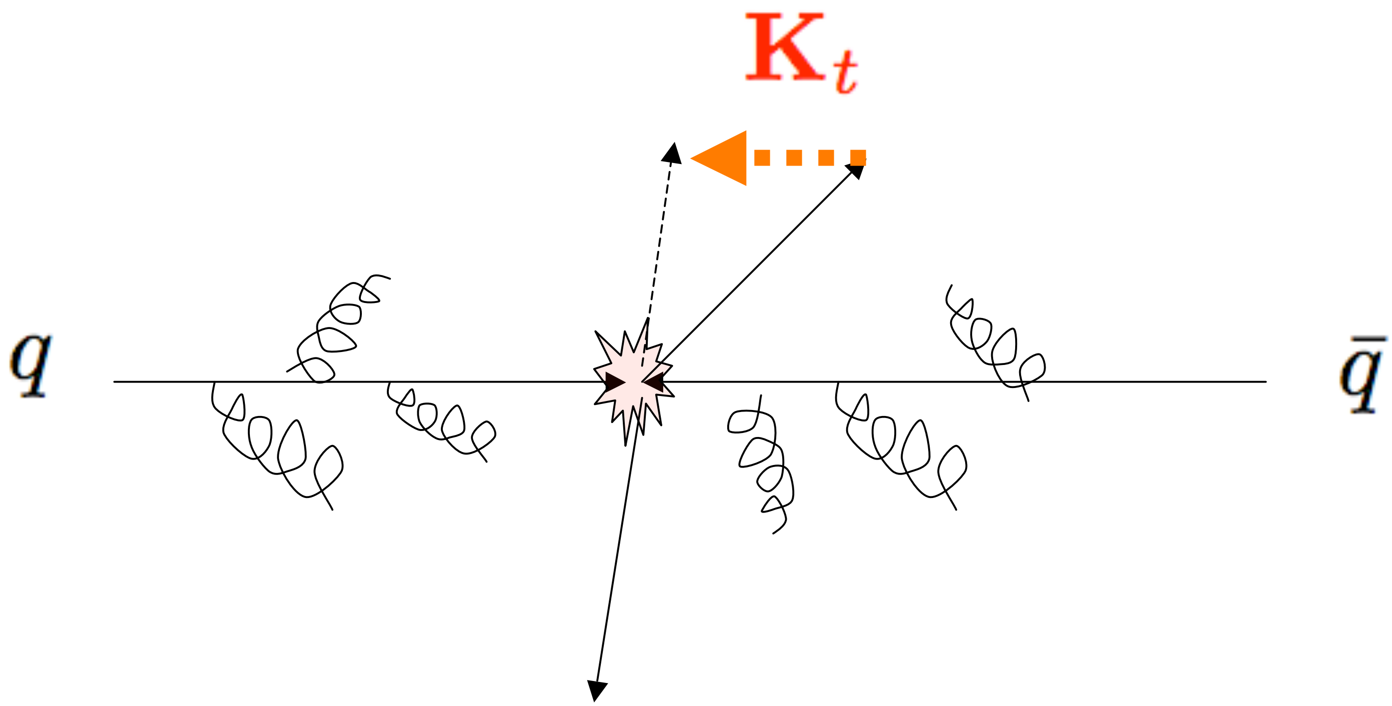
$$p_t > 1 - 2 \ GeV$$

- Soft gluon emission (resummed)

$$k_t \ll p_t$$

Embedded into the eikonal representation with multiple collisions

Soft gluon emission introduces acollinearity



Acollinearity reduces the collision cross-section as partons do not scatter head-on any more: aka saturation?

Resummation from the beginning: QED case

$$d^4P(K) = \sum_{n_k} P\{n_k, \bar{n}_k\}\delta^4(K - \sum_k n_k k)d^4K$$

Poisson distributions
Bloch-Nordsieck 1937

Energy-momentum Conservation induces IR real and virtual cancellation

Going to the continuum and integrating over the 3-momentum variable

$$d^4P(K) = \frac{d^4K}{(2\pi)^4}\int d^4x\ e^{-iK\cdot x - h(x)}$$

$$h(x) = \int d^3\bar{n}(k)[1 - e^{ik\cdot x}]$$

$$dP(\omega) = \frac{d\omega}{\omega}\mathcal{N}(\frac{\omega}{E})^{\beta(E)}$$

$$\int_\Omega d^3\bar{n}(k) = \beta(E)\frac{dk}{k}$$

$$\beta(E) \sim \alpha_{QED}\ln\frac{2E}{m_e}$$

Revisit soft k_t Resummation

$\mathbf{K}_\perp$ Overall transverse momentum carried by all soft gluons emitted in a given process

$$d^2P(\mathbf{K}_\perp) = d^2\mathbf{K}_\perp \frac{1}{(2\pi)^2} \int d^2\mathbf{b}\; e^{-i\mathbf{K}_\perp\cdot\mathbf{b}-h(b,E)}$$

Enforces momentum Conservation
Between overall and all the soft
gluons emitted through various
independent processes

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

Process dependent single soft gluon distribution,

The single soft gluon integral h(b,E)

[Dokshitzer, Dyakonov, Troyan, Parisi,Petronzio 1978-79,
Collins, Soper $h(b,E) = c_0(\mu, b, E) + \Delta h(b,E),$

$$\Delta h(b,E) = \frac{16}{3}\int_{\mu}^{E} \frac{\alpha_s(k_t^2)}{\pi}[1 - J_o(bk_t)]\frac{dk_t}{k_t}\ln\frac{2E}{k_t}.$$

$J_0(bk_t)$~0 for large bk_t

$$\approx \frac{16}{3}\int_{1/b}^{E} \frac{\alpha_s(k_t^2)}{\pi}\frac{dk_t}{k_t}\ln\frac{2E}{k_t}$$

$N_f = 4$

Upon exponentiation

$$e^{-h_{eff}(b,E)} = [\frac{ln(1/b^2\Lambda^2)}{ln(E^2/\Lambda^2)}]^{(16/25)ln(E^2/\Lambda^2)}$$

By dropping the J_0 one deliberately ignores the IR region

- This is **acceptable** as long as
  - No singularity is present in the IR region **Parisi Petronzio 1979**
  - Moderate b and relatively large k_t- values are involved - as in W-p_t or Drell-Yan

[S. Ellis and J. Stirling 1980, …Altarelli, Ellis,Greco, Martinelli 1984

- May **not** be a **good** approximation if
  - A singularity is present
  - Very large b-values and small k_t are involved as in

total x-section

Our proposal

- Use the full integration range

$$h(b,E) = \frac{16}{3\pi}\int_0^E \frac{dk_t}{k_t}\alpha_{eff}(k_t)\ln(\frac{2E}{k_t})[1-J_0(bk_t)]$$

- With a singular but integrable expression for

$$\alpha_{eff}$$

inspired by the Richardson potential for a dressed gluon that exhibits confinement

We use a functional form for the coupling of ultra-soft gluons to the quark current inspired by the confining part of the Richardson potential

- $$\alpha_{eff} \sim \frac{B}{(k_t^2/\Lambda^2)^p} \qquad k_t^2 \ll \Lambda^2 \qquad p \lesssim 1$$

p < 1 for soft gluon integral to converge

- $k_t^2 \gg \Lambda^2$ Usual one loop AF expression

$$\boxed{\alpha_{eff}(k_t^2) = \frac{12\pi}{33 - 2N_f} \frac{p}{\ln[1 + (k_t^2/\Lambda^2)^p]}}$$

Singular α_{eff} and one gluon exchange type potential

- $V(r) = K\left(\frac{\Lambda}{\pi 2^{2p+1}}\right)(r\Lambda)^{2p-1}\frac{\Gamma(3/2-p)}{(2p-1)\Gamma(1-p)}$

- p = 1 linearly rising
- p = 1/2 rising like ln r
- p = 0 Coulomb potential

Our singular α_{eff} allows to perform the soft k_t integral down to $k_t \approx 0$

At very large distances $$b > \frac{1}{\Lambda} > \frac{1}{E}$$

$$h(b,E) = \frac{16}{3\pi}\int_0^E \frac{dk_t}{k_t}\alpha_{eff}(k_t)\ln(\frac{2E}{k_t})[1 - J_0(bk_t)]$$

$$1 - J_0(bk_t) \approx (1/4)\ b^2 k_t^2$$

$$h(b,E,\Lambda) = constant\ (b^2\Lambda^2)^p \left[2\ln(2Eb) + \tfrac{1}{1-p}\right] + \ \ double\ logs$$

Comparing DDT vs. a soft k_t integral with singular coupling in the IR

$$e^{-h(b,E)}|_{DDT} = e^{-c_0(\mu,b,E)}\left[\frac{\ln(1/b^2\Lambda^2)}{\ln(E^2/\Lambda^2)}\right]^{(16/25)\ln(E^2/\Lambda^2)}$$

Our proposal

$$e^{-h(b,E)}|_{ours} = e^{-(b\bar{\Lambda})^{2p}}$$

This extension to the IR produces a cut-off in impact parameter space

Infrared singular but integrable gluon coupling has various applications

- One can estimate Dokshitzer's integral relevant to event shapes

$$\alpha_0 = \frac{\int_0^\mu d^2 k_t \alpha_s(k_t^2)}{\int_0^\mu d^2 k_t}$$

$$\mu \sim \Lambda_{QCD}$$

- For

$$\alpha_0 = \int_0^\mu \alpha_{IR}(k_t^2) \frac{d^2 k_t}{\mu^2}$$
$$\propto \frac{1}{1-p} \left(\frac{\mu^2}{\Lambda_{QCD}^2}\right)^{1-p}$$

$$\lim_{p \to 1} \alpha_0 = \infty$$

A simple model to include QCD mini-jets and implement resummation in total cross-sections

$$P_{all\ inelastic\ collisions}(\{n(b,s)\}) =$$

$$= \sum_{number\ of\ collisions} Poisson\ distributions$$

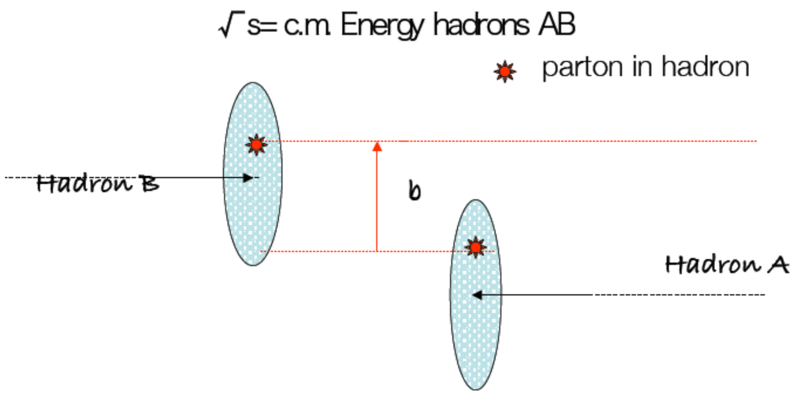
$$= \sum_{n=1} \frac{\bar{n}(b,s)^n}{n!} exp[-\bar{n}(b,s)] = 1 - exp[-\bar{n}(b,s)]$$

$$\bar{n}(b,s) = 2\Im m\chi(b,s) \approx n_{soft} + n_{hard-minijets}$$

We model the impact parameter distribution as the Fourier-transform of ISR soft k_t distribution and thus obtain a cut-off at large distances : Froissart bound?

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

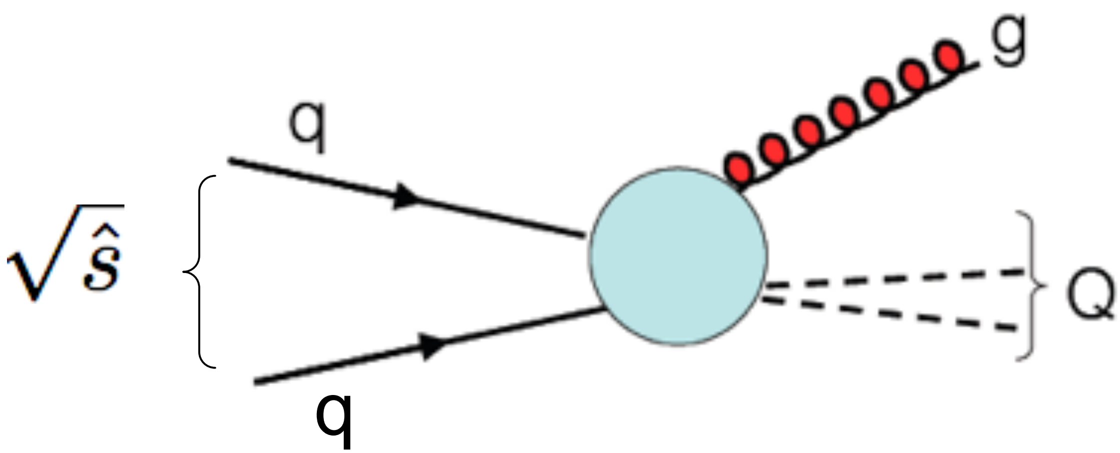
$$h(b,E) = \frac{16}{3\pi}\int_0^{qmax} \frac{dk_t}{k_t}\alpha_{eff}(k_t)\ln(\frac{2q_{max}}{k_t})[1-J_0(bk_t)]$$



$$\boxed{A_{BN}(b,s) \sim e^{-(b\bar{\Lambda})^{2p}}}$$

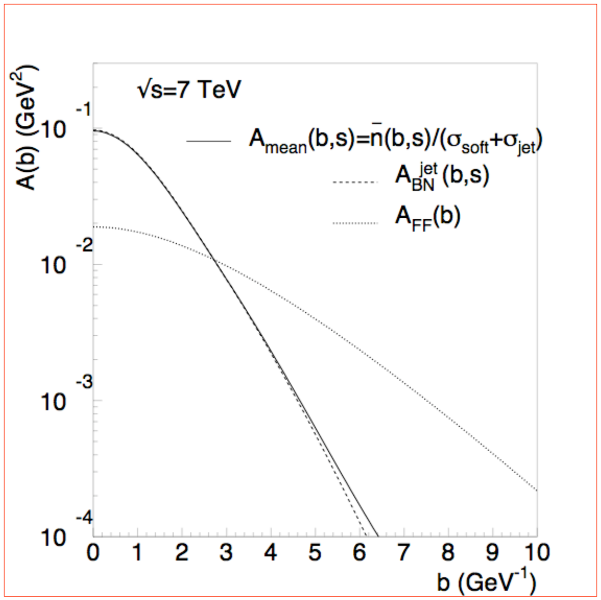
$\boxed{q_{tmax}}$?

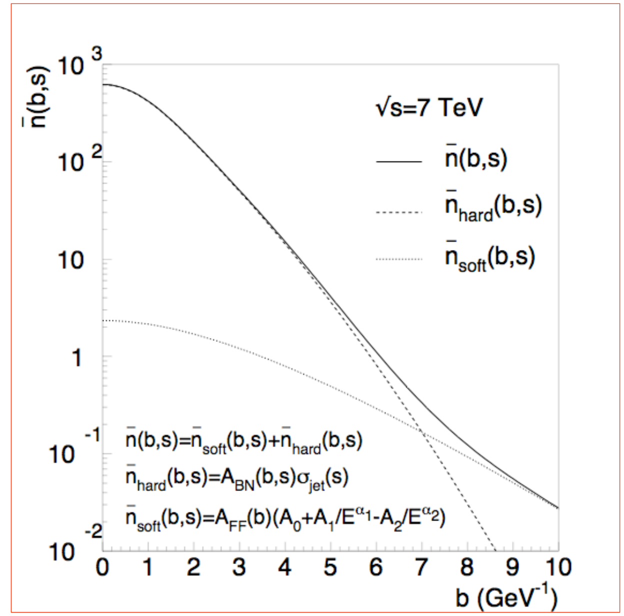
The single soft gluon Integration limit can be obtained from kinematics



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

Overlap function and number of collisions





$$A_{mean}(b,s) = \frac{A_{soft}(b,s)\sigma_{soft}(s) + A_{BN}(b,s)\sigma_{jet}(s)}{\sigma_{soft}(s) + \sigma_{jet}(s)}$$

- At low CM energy A(b,s) ~ convolution of Form factors, but falling faster at high energy

σ_{total} and the large-s limit

$$2\Im m\chi = n_{soft} + n_{hard-minijets} \qquad Re\chi \approx 0$$

$$\sigma_{total} = 2\int d^2\vec{b}[1 - e^{-n_{soft}-n_{hard-minijets}}]$$

$$n_{hard-minijets}(b) \approx A(b,s)\sigma_{jet}(s,p_{tmin}) \qquad >> n_{soft}$$

$$\sigma_{total} \to 2\pi \int db^2[1 - e^{-C(s)e^{-(bq)^{2p}}}]$$

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

$$C(s) = (s/s_0)^{\varepsilon}\sigma_1$$

Mini-jets

Ultra-soft gluons effects

At very large energy:
from power law to log behaviour

$$\sigma_T(s) \approx \frac{2\pi}{p}\frac{1}{\bar{\Lambda}^2}\int_0^\infty du u^{1/p-1}[1-e^{-C(s)e^{-u}}]$$

$u = (\bar{\Lambda}b)^{2p}$ $\qquad$ $I(u,s) = 1 - e^{-C(s)e^{-u}}$ has the limits

$$I(u,s) \to 1 \text{ at } u = 0$$

$$I(u,s) \to 0 \text{ as } u = \infty$$

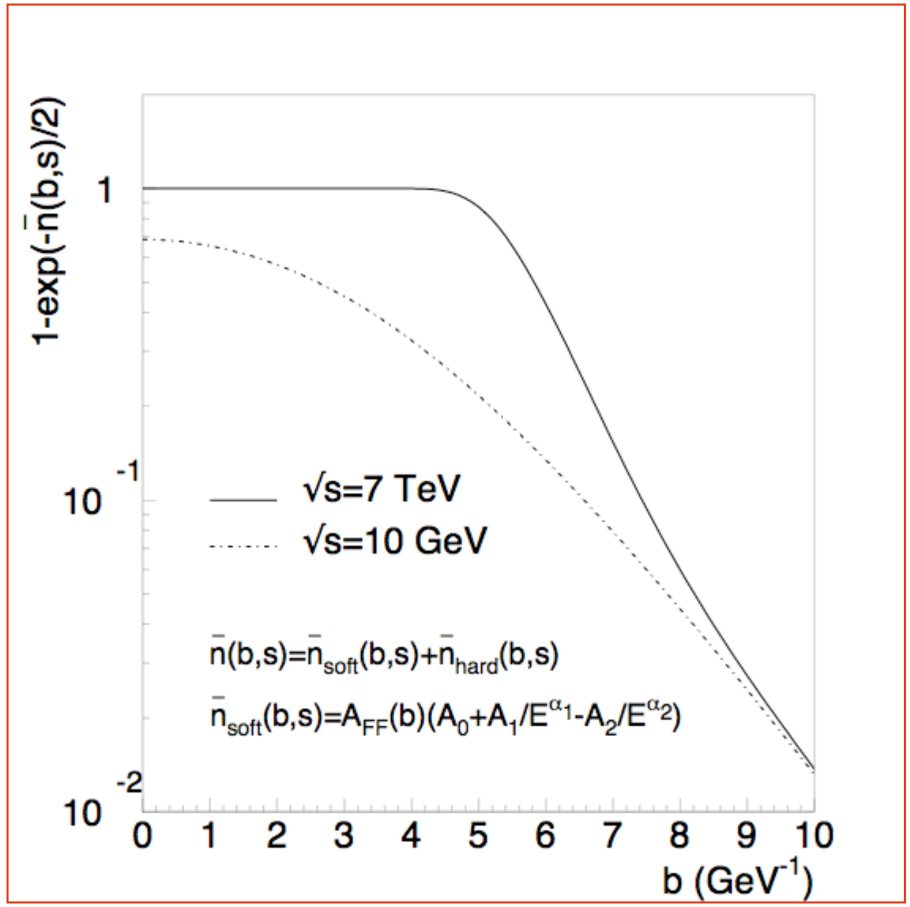
$$\sigma_T \approx \frac{2\pi}{\bar{\Lambda}^2}[\varepsilon \ln \frac{s}{s_0}]^{1/p}$$

$\sim \ln^2 s \qquad p = 1/2$

$\sim \ln s \qquad p = 1$

The fall-off of the probability distribution of matter in the interaction region

- At low energy, gentle fall off
- As the energy increases, a plauteau is formed which extends ~ 1 fm in the TeV region and extends farther and farther as energy increases

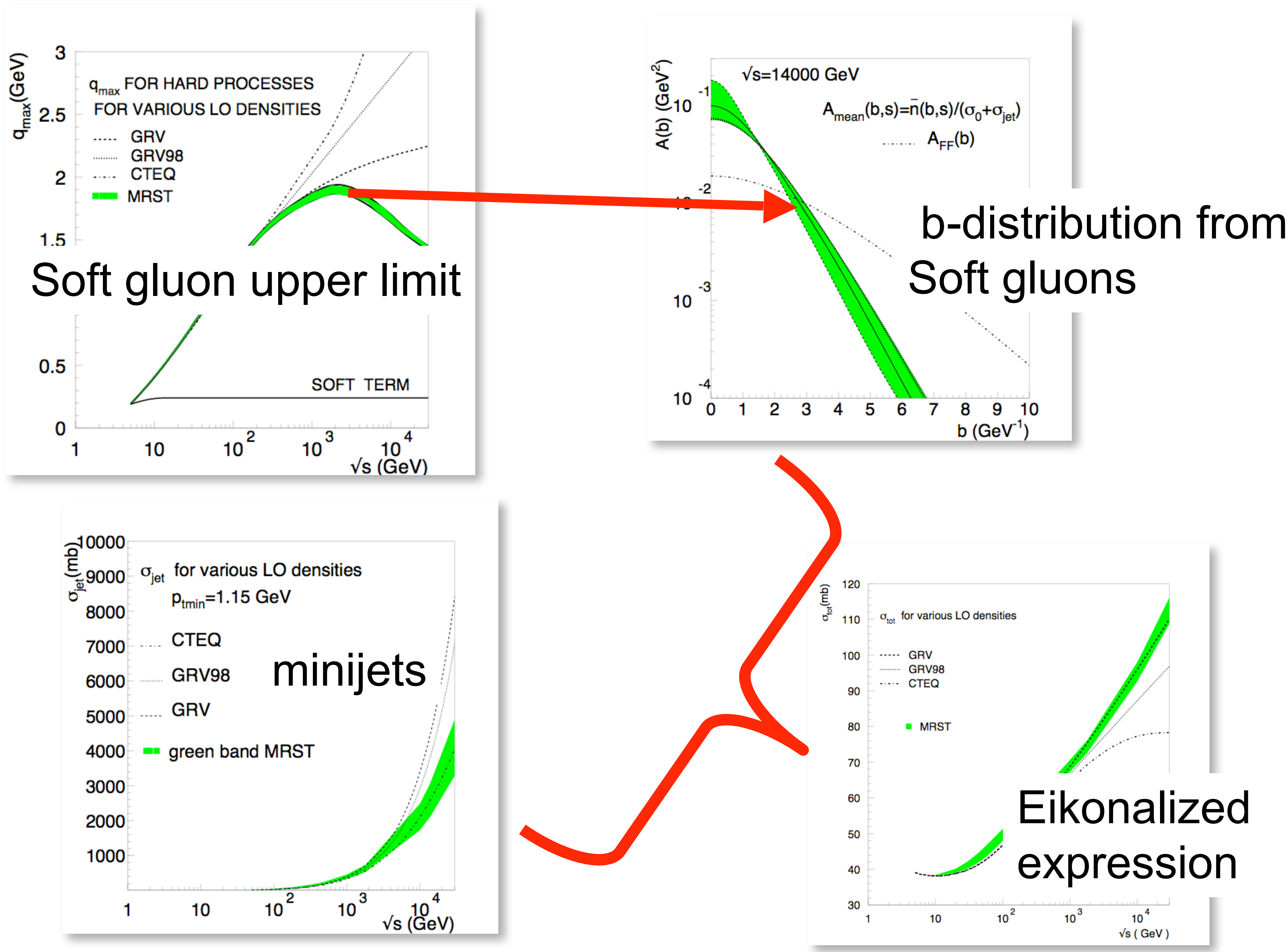


How the model works

- Choose a low energy parametrization for $\boxed{n_{soft}}$
- Choose high energy parameters: $\boxed{p_{tmin}}$ and densities

1. Calculate minijet cross-section
2. Calculate $\boxed{q_{tmax}}$
3. Enter $\boxed{q_{tmax}}$ in calculation of b-distribution and calculate A(b,qmax)
4. Calculate average number of collisions
5. Exponentiate and eikonalize

The model at work



A general scheme for various processes

- Start with PDF for the chosen process
  - Proton-proton, pion-proton, pion-pion, photons (nuclear matter, heavy ions)
  - Calculate mini-jet basic cross-section, quark-antiquark, gluon-gluon (dominant), quark-gluon
  - Calculate qmax (s) for soft emission

- Fix p (singularity) for one process, say proton-proton
- Calculate A(b,qmax(s))
- Parametrize $\bar{n}_{soft}(b, s)$
- Eikonalize and integrate

pp and $\bar{p}p$

R.M.Godbole, A. Grau, G.P.
Y.N. Srivastava, +A. Achilli,
+A.Corsetti

- Eur.Phys.J.C63:69-85,2009. e-Print: arXiv:0812.1065 [hep-ph]
- Phys.Lett.B659:137-143,2008. e-Print: arXiv:0708.3626 [hep-ph]
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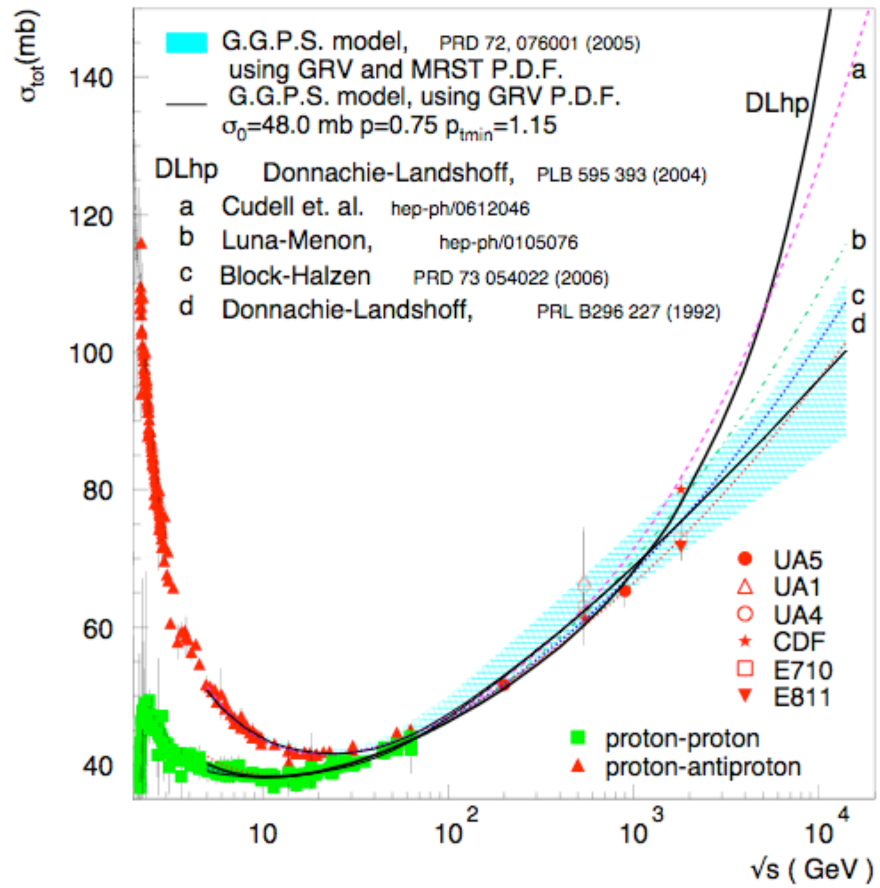
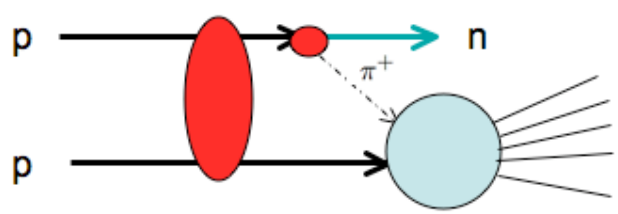
- Phys.Rev.D60:114020,1999. e-Print: hep-ph/9905228
- Phys.Lett.B382:282-288,1996. e-Print: hep-ph/9605314

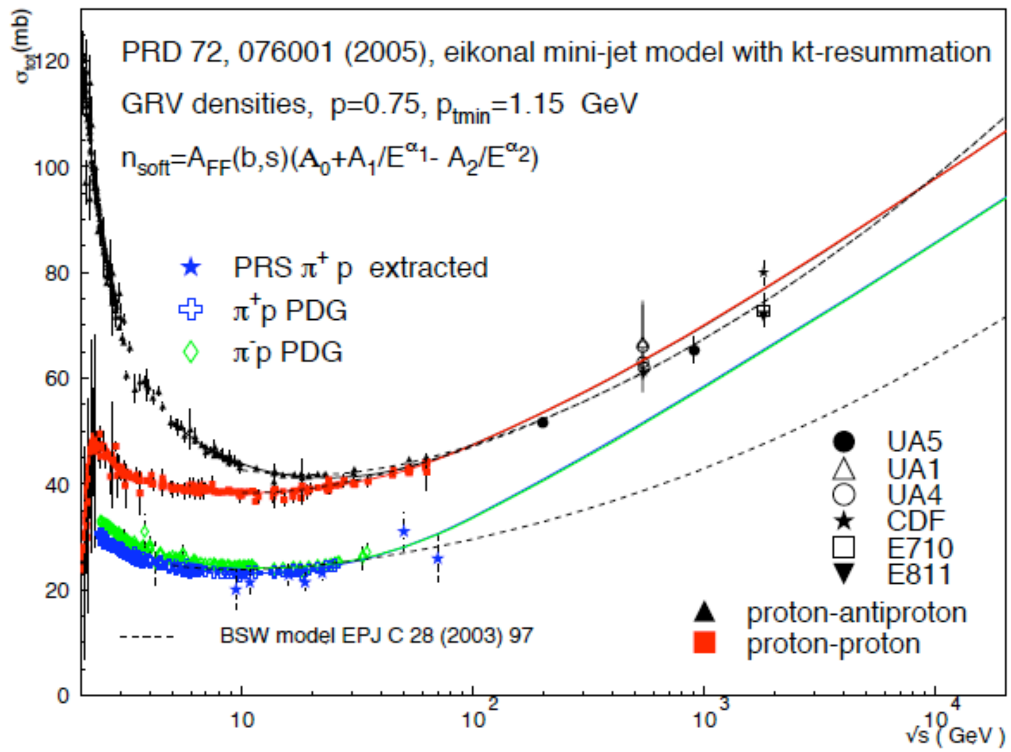


Protons and pions

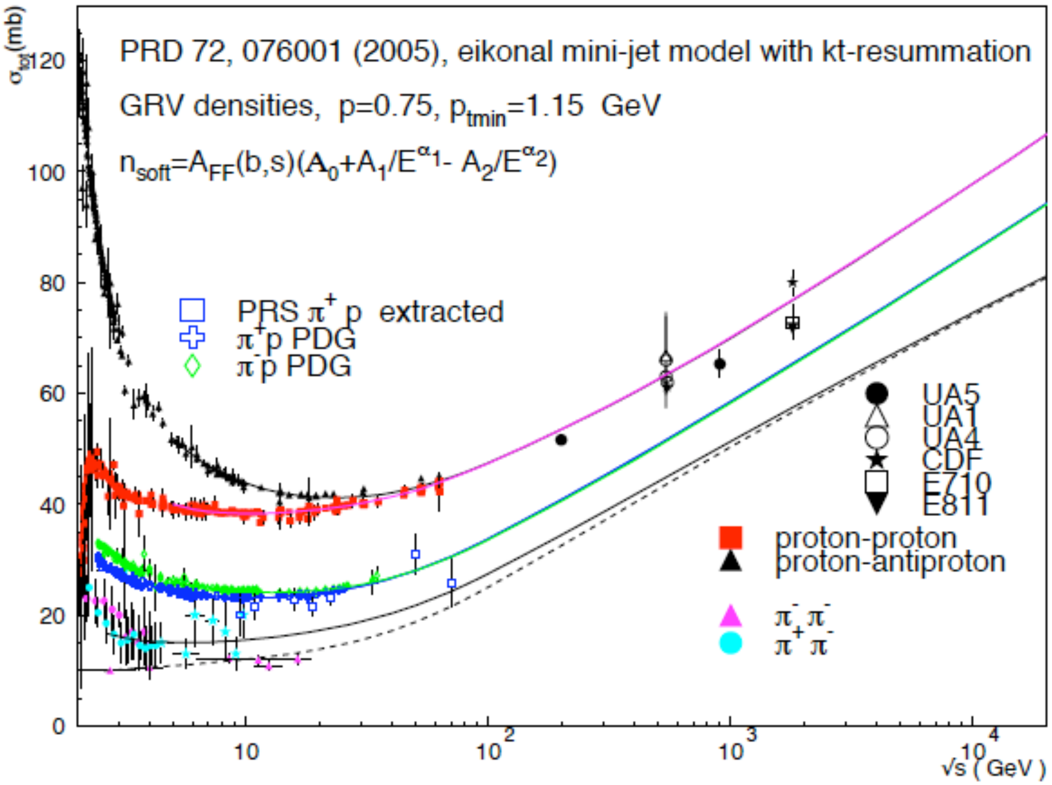
Results from our model

We should try to measure pion proton cross-section in the TeV range to test various models: can it be done by ZDCs in CMS or ATLAS?





With Grau and Srivastava + O. Shekhovtsova



PLBB693:456-461,2010

$$pp - p\bar{p}$$

$$\pi p$$

$$\pi\pi$$

•Is AQPM (2/3 rule) satisfied in this model?

Yes, in the constant part of the Eikonal

•Is factorization valid?

Yes, in the full range of energies

$$\sigma_{tot}^{\pi\pi} = \frac{(\sigma_{tot}^{\pi N})^2}{\sigma_{tot}^{NN}}$$

The measured inelastic cross-section at LHC

Inelastic cross-section relevant for

- extracting pp from p-air
- Tune MC
- Establish normalizations at LHC
- Understand the microscopic structure, i.e. differnce between elastic (confined) and inelastic (jets and minijets
- role layed played by parameters in different models (Donnachie and Landshoff?)

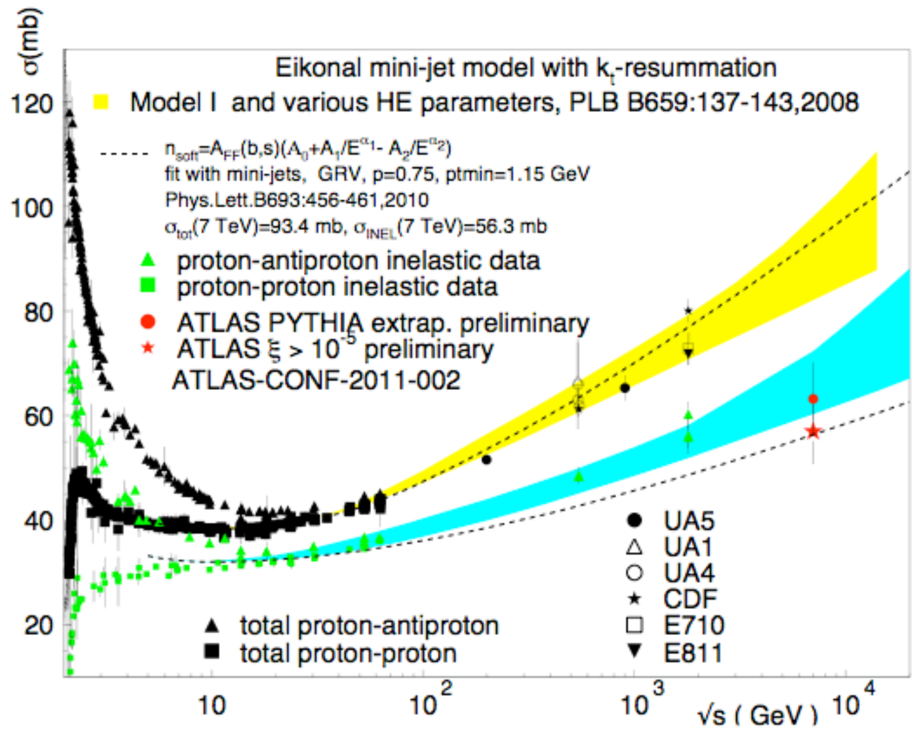
- Can models like the eikonal mini-jets with only one function for inelastic and total (hence elastic), describe the inelastic cross-section as well as the total?

Not really, inelastic is too low (elastic is too large)

Lipari and Lusignoli 2009 : only elastic and inelastic is too simple

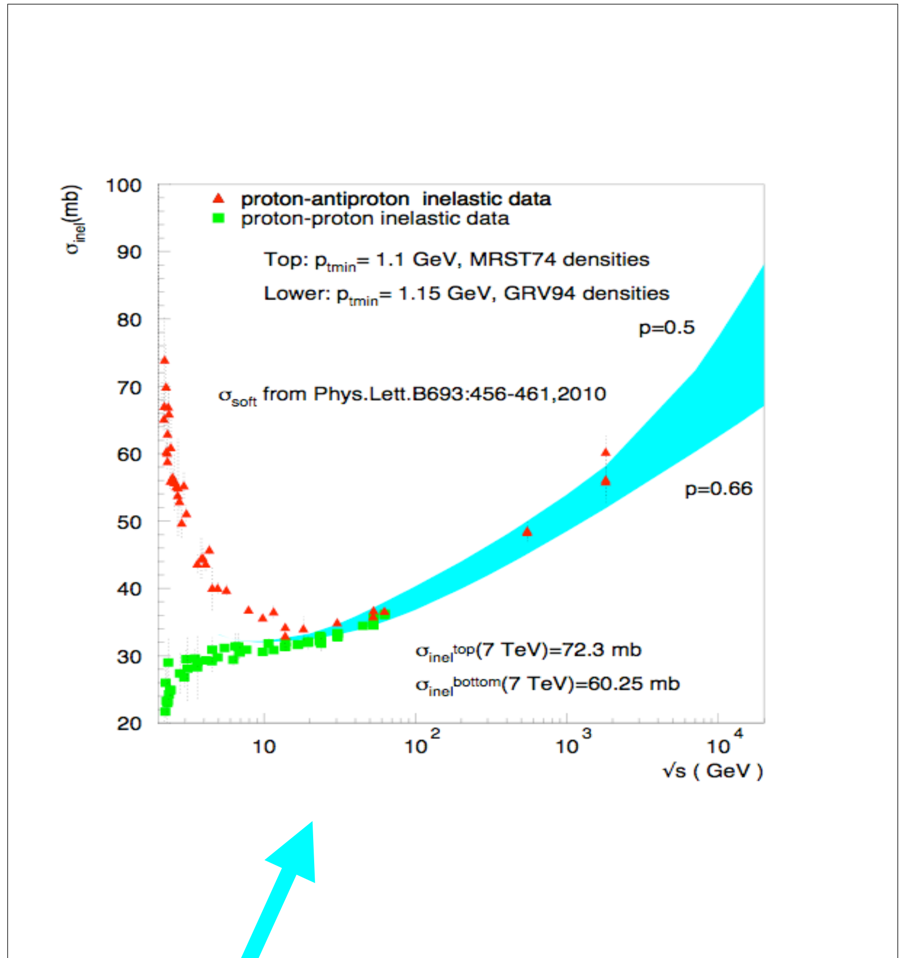
- Usually one needs to add some semi-hard component (and thus other parameters) or change parameters

Total and Inelastic



Our model results for the inelastic

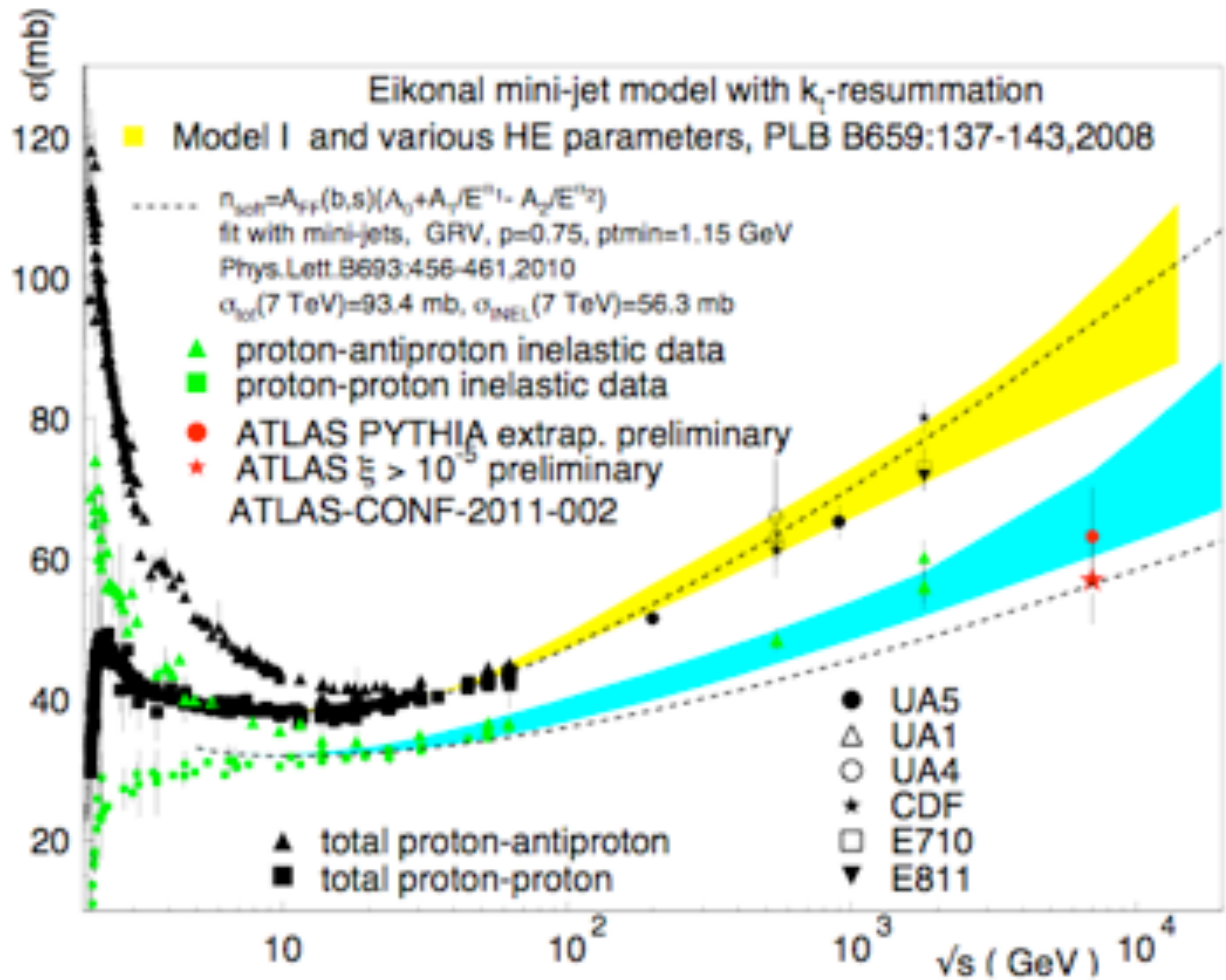
- With the range of High Energy Parameters used for the total cross-section, the high energy data up to Tevatron cannot be well described well
- Changing only the singularity parameter gives good description



$$from\ p = 0.75\ (total\ cross - section)\ to\ p = 0.5$$

Comparing with pp, pbar p and ATLAS data

- Yellow: total x-section
- Dash : total cross-section or inelastic (same eikonal)
- Blue : inelastic changing p



BN model references

Work with Rohini Godbole, Agnes Grau, Yogendra Srivastava + A. Achilli+A.Corsetti

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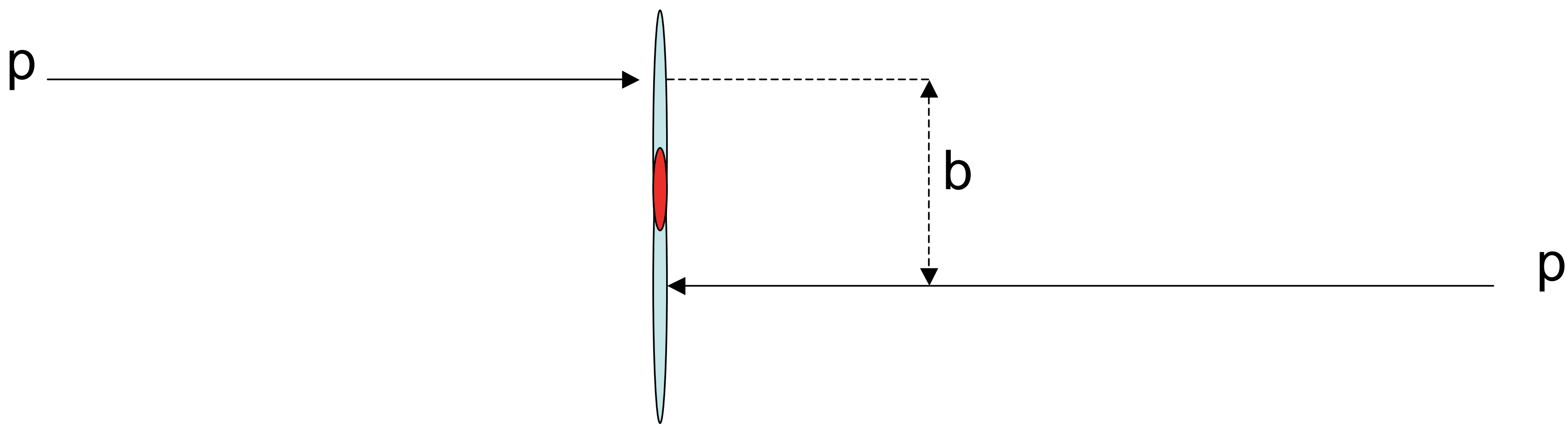
- Phys.Rev.D60:114020,1999. e-Print: hep-ph/9905228
- Phys.Lett.B382:282-288,1996. e-Print: hep-ph/9605314

Conclusions

- Our kt-resummation model
  - has a clear physical content:
    - Parton-parton Scattering with evolved PDFs
    - Soft gluon emission producing fall off in b-space
  - It gives a good description of the high energy behaviour of many processes, protons, photons, pions once you know PDFs
  - It confirms the importance of the Infrared Region in high energy scattering
  - It provides a phenomenological extension of Resummation to describe initial state collinearity
  - It could be extended to nuclear collisions at very high energy with appropriate PDFs
- The Measurement of the inelastic cross-section by ATLAS gives insight into dynamics of inelastic vs. diffractive processes
- Eikonal mini-jet models seem to work with same eikonal for both total and inelastic when diffraction is not included in the inelastic

Spares

Heisenberg (1952) picture
with Lorentz-contracted
Colliding particles



b_{max} = maximum b beyond which no-scattering takes place

Our model : microscopic description

- σ_{inel} from a sum over independent multiple collisions in impact parameter space
- σ_{total} using the Optical theorem
- rising mechanism in number of collisions : PQCD
- decrease : from initial state acollinearity due to soft gluon emission $d^2P(\mathbf{K}_t)$

Resummation of soft quanta

$$\boxed{d^4P(K)}$$

4-momentum loss due to independent (Poisson distributed) emissions

$$\sum_{n_{\mathbf{k}}} \Pi_{\mathbf{k}} P(\{n_{\mathbf{k}}, \bar{n}_{\mathbf{k}}\})\delta^4(K - \sum_k k n_{\mathbf{k}}) d^4K$$

$$d^4P(K) = \frac{d^4K}{(2\pi)^4} \int d^4x \; exp[-h(x) + iK \cdot x]$$

$$h(x) = \int d^3\bar{n}_{\mathbf{k}} (1 - exp[-ik \cdot x])$$

Etim, GP
Touschek 1968

$\mathbf{K_t}$ -resummation

$$d^2\ P(K_\perp) = \frac{d^2\mathbf{K}_\perp}{(2\pi)^2}\int d^2\mathbf{b}\ exp[-h(\mathbf{b}) - i\mathbf{K}_\perp\cdot\mathbf{b}]$$

Strong coupling
GP, Srivastava 1977

$$h(b, q_{max}) = \int d^3\bar{n}_g(k)[1 - e^{i\mathbf{k}_t\cdot\mathbf{b}}]$$

Vertex
corrections

Real emission

$$\boxed{h(b) \sim \int_\mu d^3\bar{n}(k)}$$

QED Sudakov 1956

$$\boxed{h(b, q_{max}) \sim \int_\mu^{q_{max}} d^2\mathbf{k}_t \frac{\alpha_s(k_t)}{k_t^2} \ln\frac{2q_{max}}{k_t}}$$

QCD
Dokshitzer, Dyakonov,
Troyan, 1978
Parisi, Petrozio 1979

Models needed to describe the large distance behaviour

- Shock wave Heisenberg description:exponential fall off of the pion cloud (1950)
  - Constant
  - Rising like $\ln^2 s$
- Froissart limit: exponential cut-off in the potential (1960)

  rising at most like $\ln^2 s$
- Geometrical Models
- <1973- Decreasing cross-sections: Duality and Regge behaviour
- 1973- Rising cross-cross-sections
  - Parton scattering for the rise
  - Regge behaviour + Pomeron exchange (Donnachie and Landshoff 1992)

down with energy: $s^{-0.5}$

Up with energy: $s^{0.08}$

Large distance dominance in σ_{total}

The Optical theorem relates the total cross-section to the scattering amplitude in the forward direction

$$\sigma_{total} \qquad = \text{Im } f_{elastic}(s,t=0)$$

Some deconfinement

Large distance behaviour of a confined system

Revisiting k_t-resummation

Very large b-values require going into the Infrared region (IR)

$q\bar{q}$

•We extend soft gluon integration down to IR

•We exploit the IR limit with an ansatz inspired by the
Richardson potential