Inelastic cross-section and Survival Probabilites at LHC in mini-jet models

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With

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Motivation and outline

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Motivation

- There is a wide range of estimates for Survival Probabilities (SP) at LHC:
  - Bjorken 1993
  - ....
  - Achilli, Godbole GP et al PLB 2008
  - Block et al. (BDHH) PRD92 2015
  - Gotsman et al (GLM) EPJC76 2016
  - Khoze, et al (KMR) EPJC73 2013
  - ....

  which one to apply ?

- Needs to understand the inelastic cross-section and parton distributions in

  b-space

Outline

- PDF driven eikonal minijet model
- **BN model** : All Order Resummation (AOR) scheme
- The total and inelastic cross-section in a single channel eikonal vs an empirical model
- Survival probabilities: LO vs AOR
- Survival probabilities: comparison with other models

PDF driven eikonal minijet model:

1. Minijets vs total cross-section

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

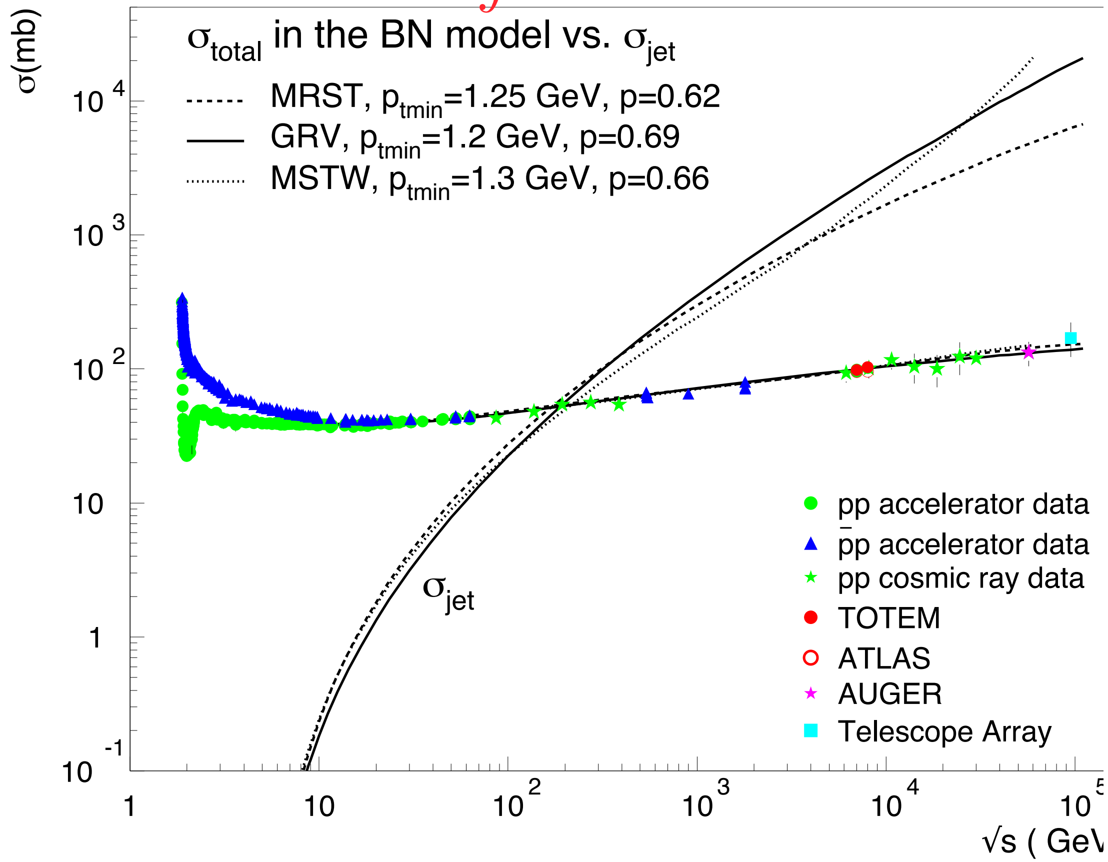
$$\sigma^{AB}_{\text{jet}}(s;p_{t_{min}}) = \int_{p_{tmin}}^{\sqrt{s}/2} dp_t \int_{4p_t^2/s}^{1} dx_1 \int_{4p_t^2/(x_1 s)}^{1} dx_2 \sum_{i,j,k,l} f_{i|A}(x_1,p_t^2) f_{j|B}(x_2,p_t^2) \frac{d\hat{\sigma}^{kl}_{ij}(\hat{s})}{dp_t}.$$

Negligible at low energies

But

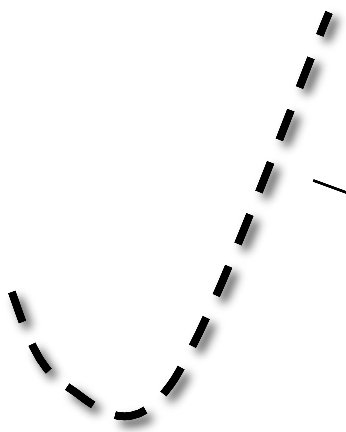
$$\sqrt{s} \simeq 20 \div 30\ GeV$$

$$\sigma^{AB}_{\text{jet}}(s;p_{t_{min}} \simeq 1\ GeV) \sim 10\%\ \sigma^{AB}_{total}$$



All total cross-sections rise… but not too much (Froissart and Martin dixit)

What generates the rise? Low-x parton collisions

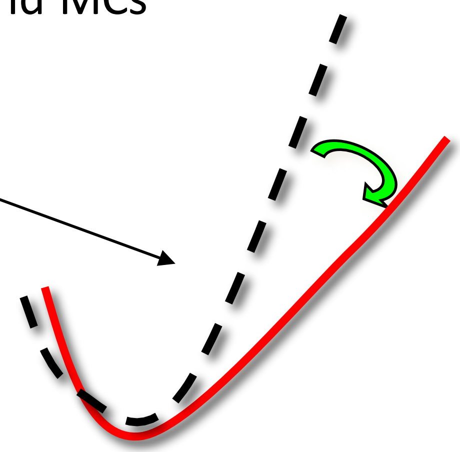


$s^{\epsilon} \quad \epsilon \sim 0.3$

How to go from hard to soft ?

Cline, Halzen & Luthe 1973
Gaisser, Halzen, Stanev 1985
G.P., Y.N. Srivastava 1986
Durand, Pi 1987
Sjostrand, van Zijl 1987
…
PYTHIA and MCs

What tames the rise into to a Froissart-like behavior?

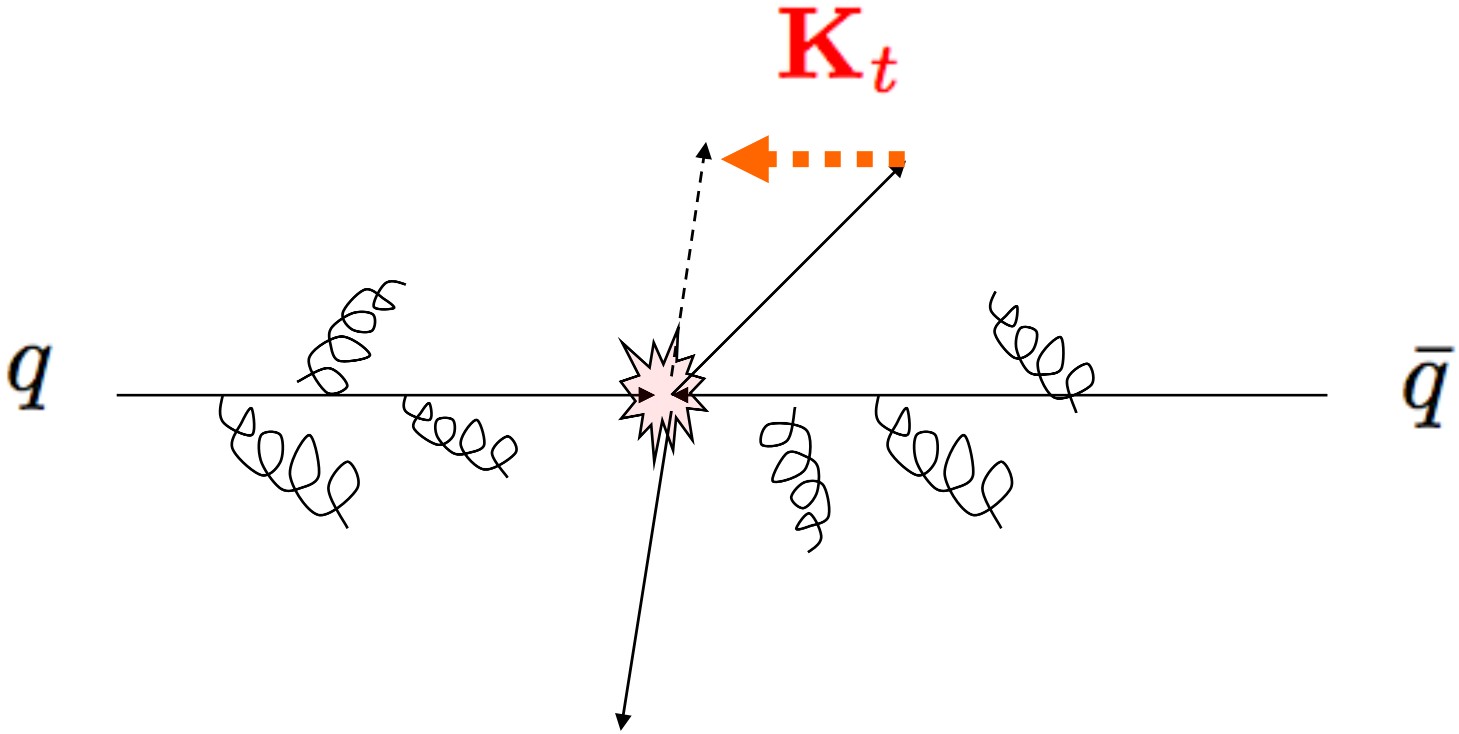


A large distance cut off

A cut off can be obtained by [embedding into the eikonal] the acollinearity induced by IR kt-emission

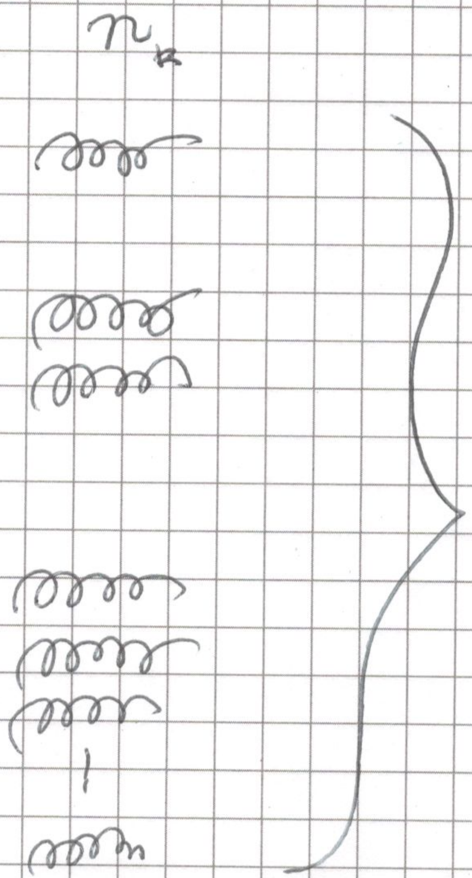
[our model, G.P. et al. **Phys.Lett.B382 (1996), PRD60 (1999), PRD72 (2005)**]

BN model : All Order Resummation (AOR) scheme
Soft gluon emission introduces acollinearity



Acollinearity reduces the collision cross-section as
partons do not scatter head-on any more, also explained as the gluon cloud
Becoming too thick for partons to see each other : gluon saturation

“Democratic” emission of infrared gluons



$$\prod_k \frac{(\bar{n}_k)^{n_k}\, e^{-\bar{n}_k}}{n_k!} \equiv P(\{n_k\})$$

$\Rightarrow$ n_{k_1} with mom k_1

n_{k_2} with mom k_2

etc ...

From Bloch Norsdieck (1937) (B-N) theory of emission from a classical source to our proposal for maximally allowed infrared singularity in QCD (1984)

- F. Bloch and A. Nordsieck
  - Neglecting recoil → Poisson distribution of soft photons (gluons) emitted

$$P(\{n_{\mathbf{k}}\}) = \Pi_{n_{\mathbf{k}}} \frac{[\bar{n}_{\mathbf{k}}]^{n_{\mathbf{k}}}}{n_{\mathbf{k}}!} e^{-\bar{n}_{\mathbf{k}}}$$

  - Only emission of infinite number of soft photons (gluons) is finite

- B. Touschek
  - 1952 with W. Thirring : covariant formulation
  - 1968 (with E.Etim+GP) : summation to all orders

$$d^4P(K) = \sum_{\mathbf{k}} P(\{n_{\mathbf{k}}\})\delta^4(\sum_{k'} k' n_{\mathbf{k}'} - K) d^4K$$

$$\delta^4(\sum_{n_k} n_k k - K) = \int \frac{d^4x}{(2\pi)^4} e^{-iK\cdot x} e^{\sum n_k k\cdot x}$$

  - And exchange Sum (in k) with Product (on n)

Semi-classical and democratic (no branching or ordering) summation

$$d^4P(K) = \frac{1}{(2\pi)^4}\int d^4x \; e^{-h(x)-iK\cdot x}$$

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

→ Integrate over $K_0 \quad and \quad K_3$

$$\Pi(K_t, s) = d^2\mathbf{K}_t \int d^2\mathbf{b} e^{-i\mathbf{K}_t\cdot\mathbf{b}-h(b,s)}$$

→ $h(b,s)$ Soft gluons spectrum regularizd and exponentiated

Applied to K-t resummation in QCD

$$h^{(PP)}(b,s) = \frac{4}{3\pi^2}\int_{M^2}^{Q^2} d^2k_\perp [1 - e^{i\mathbf{k}_\perp\cdot\mathbf{b}}]\alpha_s(k_\perp^2)\frac{\ln(Q^2/k_\perp^2)}{k_\perp^2}$$

G.Parisi R.Petronzio 1979
With Asymptotic Freedom

Our Proposal (ZPC 1984)

$$M^2 \to 0 \qquad \alpha_{IR}(k_t) \propto [\frac{\Lambda}{k_t}]^{2p}$$

For integrability $p < 1$

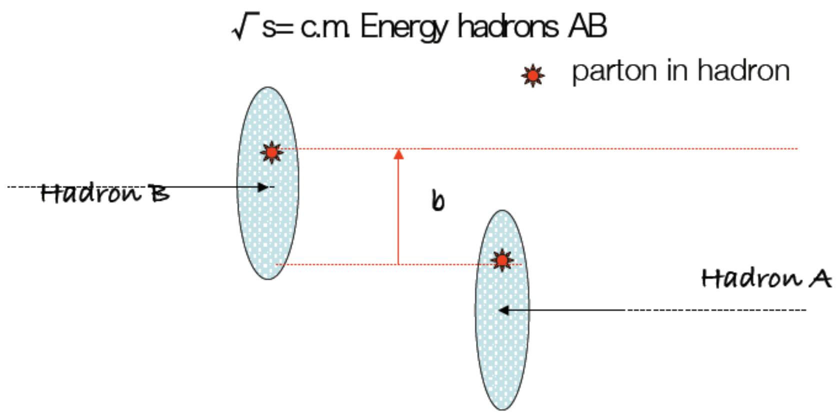
We model the impact parameter distribution for minijets as the Fourier-transform of ISR soft k_t distribution and thus obtain a cut-off at large distances : Froissart bound?

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

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

$$\alpha_{eff}(k_t \to 0) \sim k_t^{-2p}$$

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



q_{tmax} ? **Calculated** from single gluon emission kinematics

b-distributions of partons

$$2\chi_I(b,s) = \bar{n}_{soft}(b,s) + \bar{n}_{hard}(b,s) = A_{FF}(b)\sigma_{soft}(s) + A_{BN}(b,s)\sigma_{mini-jet}(s,p_{tmin})$$

$$\sigma_{soft} \simeq constant \;\; + \;\; decreasing$$

- For partons with contribute to processes not rising with energy

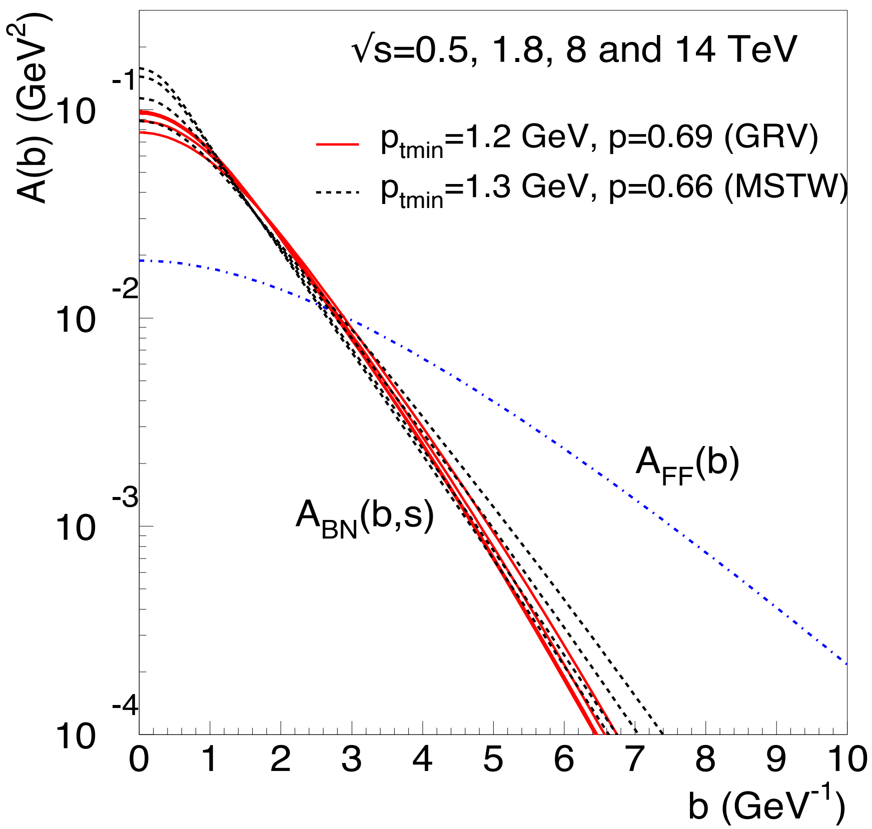
$$A_{FF}(b) = \frac{\mu^2}{96\pi}(\mu b)^3 K_3(\mu b)$$

- For partons -> minijets

Calculate

$$q_{max}(s; PDF, p_{tmin})$$

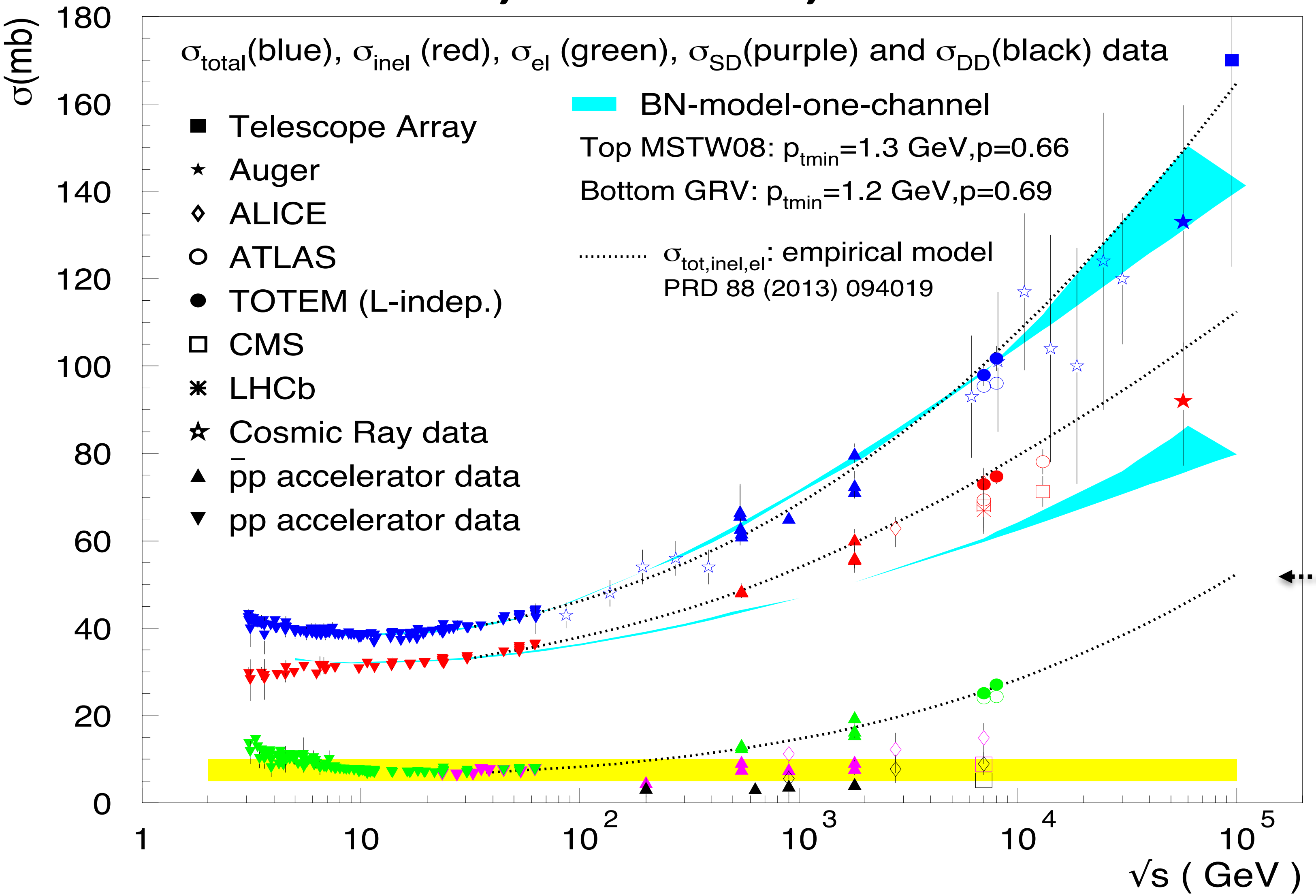
-> $$A_{BN}(b,s)$$



Caveat: Missing Single Diffraction which rises with energy but is not described by minijets

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

Total, elastic, inelastic

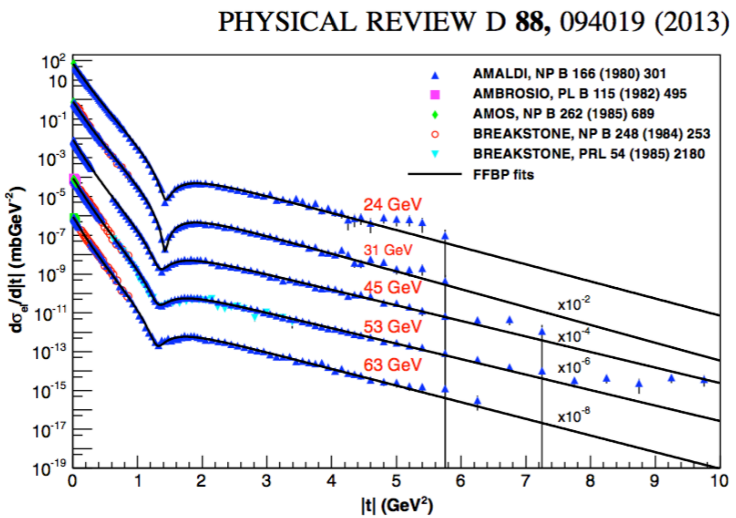


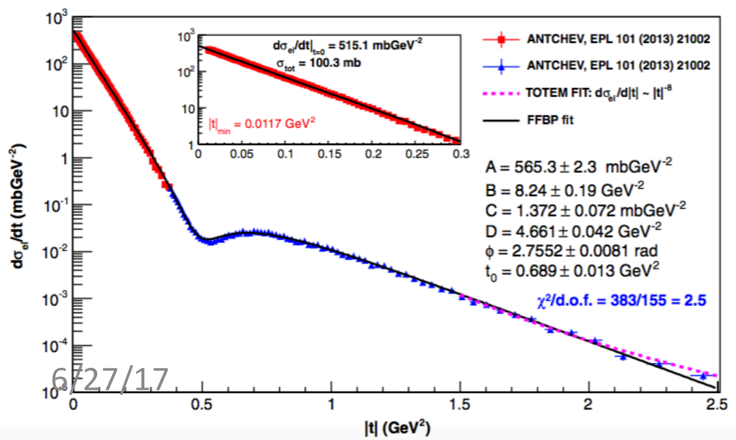
Empirical Model for Elastic Differential Cross-section

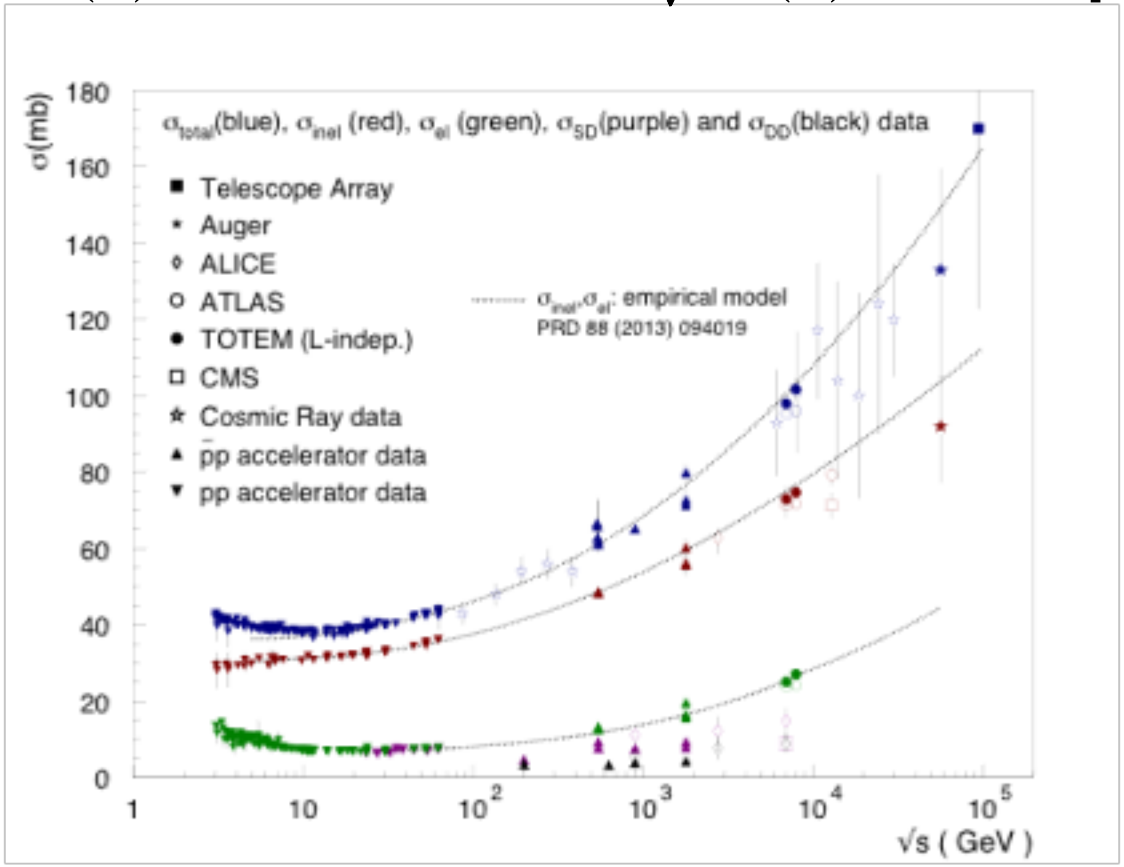
Empirical model Fagundes,Grau,Pacetti,GP,Srivastava, PR88 (2013)

from Phillips and Barger 1974

1. $\mathcal{A}(s,t) = i[F_P^2(t/t_0)\sqrt{A(s)}e^{B(s)t/2} + e^{i\phi(s)}\sqrt{C(s)}e^{D(s)t/2}]$







2. Using asymptotic theorems and sum rules, one can extrapolate to 8, 13 TeV and beyond

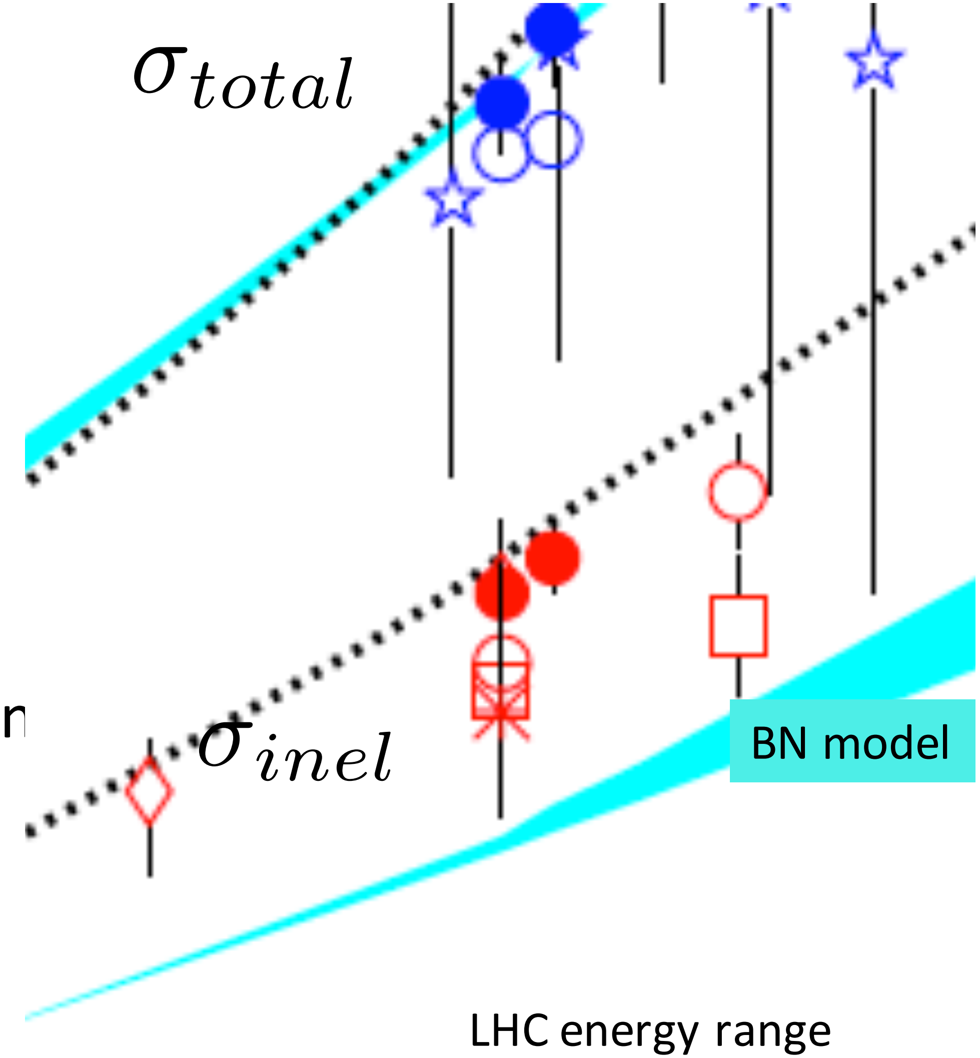
Single diffraction is not included in the eikonal BN cum minijets

- Single channel two component does not have single diffraction (SD) -> needs further work

  GP et al., Phys.Rev. D91 (2015)

BUT

- It gives an inelastic x-section adequate to calculate Survival Probabilities in Central region



Survival probabilities

$$\mathcal{S}^2(s) \equiv < |S(b,s)|^2 > = \int d^2\mathbf{b} A(b,s) e^{-\bar{n}(b,s)}$$

- Inelastic cross-section
  (SD not excluded)

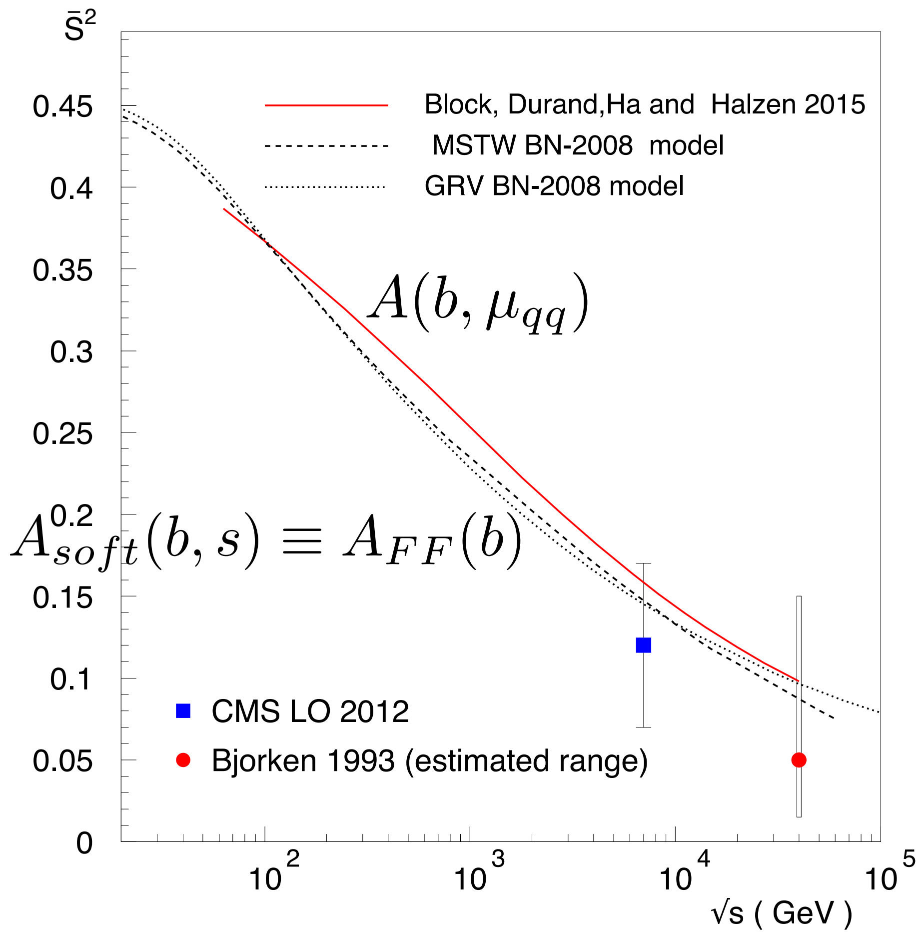
  x

- Impact parameter distribution

  – LO

  – NLO?

  – AOR = all order as in BN model



Our proposal

$$< |S(b)|^2 >_{hard} = \int d^2\mathbf{b}\ A_{BN}(b,s) e^{-\bar{n}_{hard}(b,s)}$$

$$< |S(b)|^2 >_{soft} = \int d^2\mathbf{b}\ A_{FF}(b,s) e^{-\bar{n}_{soft}(b,s)}$$

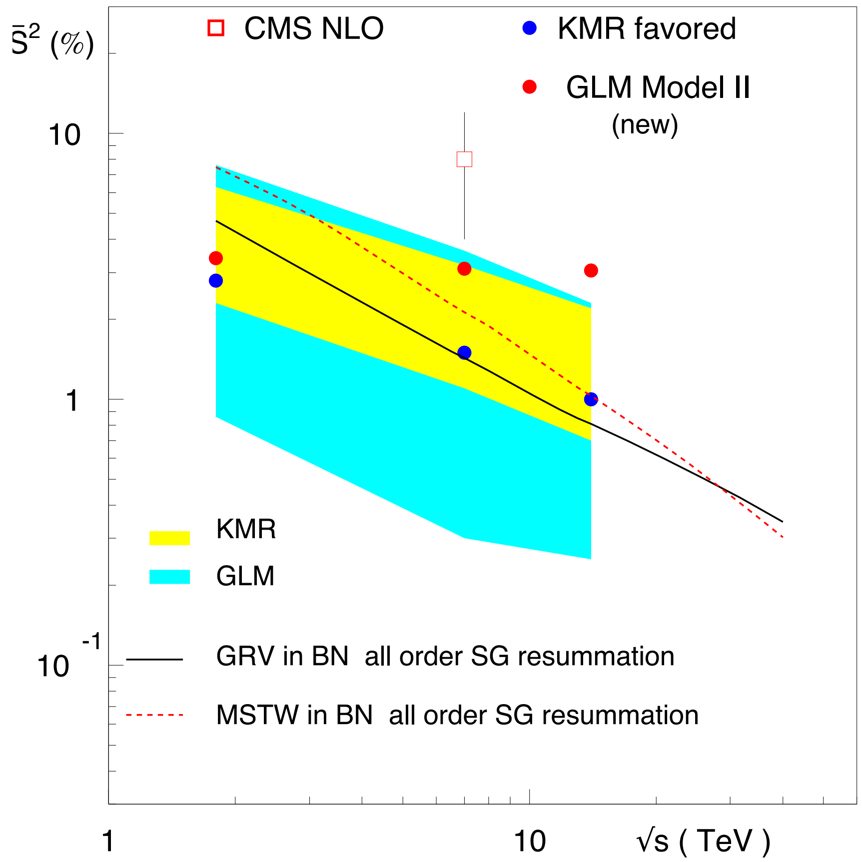
$$\bar{\mathcal{S}}^2_{total}(s) = \bar{\mathcal{S}}^2_{soft}(s) + \bar{\mathcal{S}}^2_{hard}(s)$$

$$\equiv w_{soft}(s) < |S(b)|^2 >_{soft} + w_{hard}(s) < |S(b)|^2 >_{hard}$$

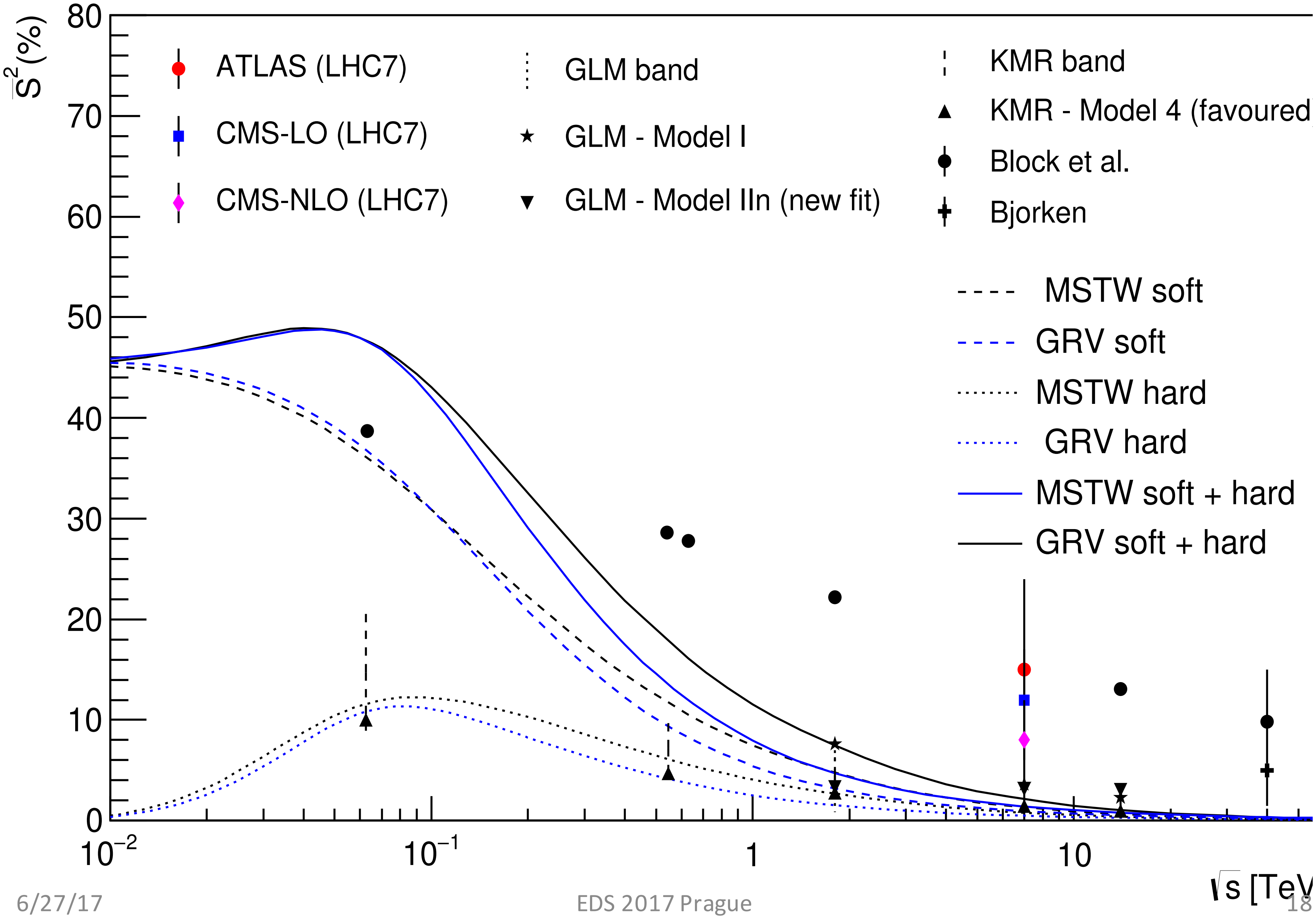
$$w_{soft/hard}(s) \equiv \frac{\sigma_{soft/jet}(s)}{\sigma_{soft}(s) + \sigma_{jet}(s)} \equiv \frac{\sigma_{soft/jet}(s)}{\sigma_B(s)}$$

Comparison with Regge-Pomeron

- NLO CMS still higher than shown models
- Wide band of predictions from Khoze Martin Ryskin (KMR) and Gotsman Levin Maor (GLM)
- KMR in ~ good ~ agreement
  with our proposal



Overall view



Conclusions

- Our single channel two component eikonal does not include Single Diffraction in the calculated inelastic cross-section -> Can be useful for SP factor calculations
- We propose to split SP beween soft and hard SP factors, with hard SP including an all order “democratic” resummation procedure with singular but integrable coupling (phenomenologically determined)
- AOR reduces the LO calculation such as Block et al, or our BN-2008, by a factor 10 at least, in agreement with Regge-Pomeron explicit calculations by Khoze et al, Gotsman et al, and others.

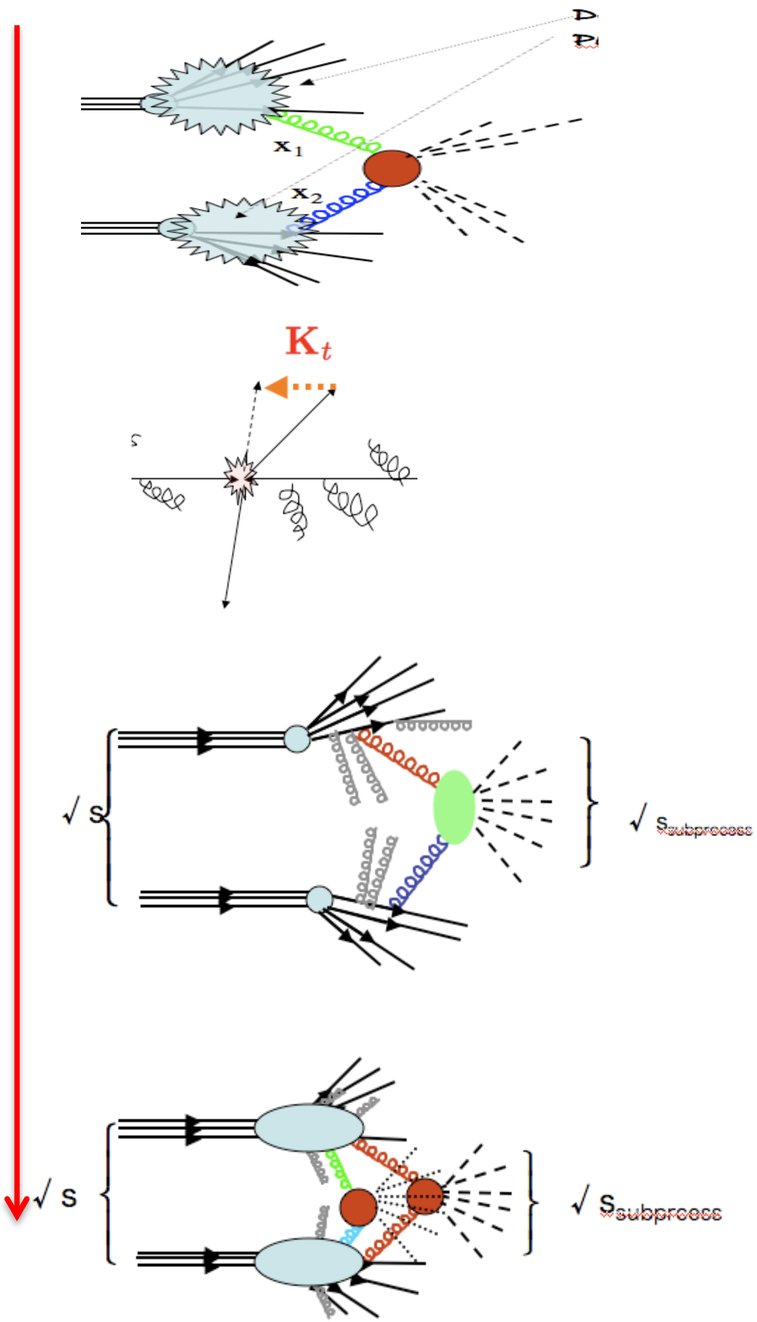
EXTRAS

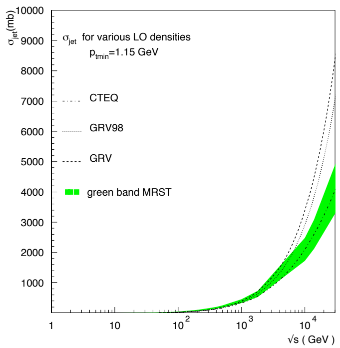
BN model : All order resummation (AOR) and the infrared region in hadronic collisions

- To access the infra-red region and tame the rise of total x-sections from minijets contributions, we use a resummation procedure different from the usual LLA or Sudakov

- The Bloch and Nordsieck theorem on infinite "photon" emission + Energy Momentum Conservation

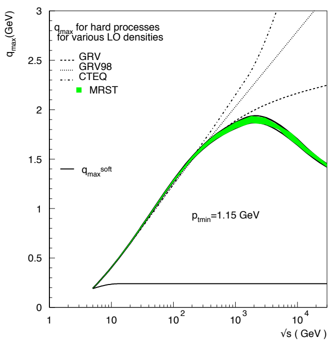
- Maximally allowed divergence of the coupling of soft gluons to quarks





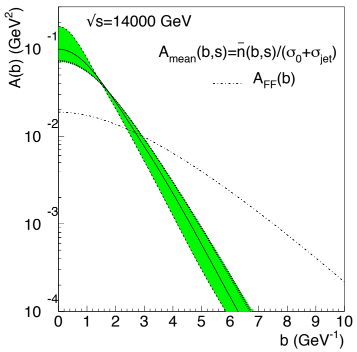
1. Calculate mini-jet cross-section Choosing densities and ptmin

$$\sigma_{mini-jet} \simeq s^{\epsilon}$$
$$\epsilon \simeq 0.3 - 0.4$$



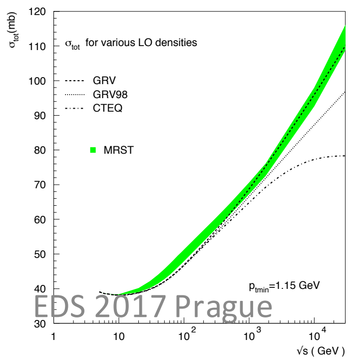
2. Calculate qmax: single soft gluon upper scale, for given PDF, ptmin

$$q_{max} \simeq p_{tmin}$$
$$\lesssim 2 - 3\ GeV$$



3. Calculate qmax and then Impact distribution for fitting infrared parameter p

$$2\ \chi(b,s) = 2\chi_{low\ energy} + $$
$$+ A(b, qmax)\sigma_{jet}$$



4. Eikonalize

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