Hunting for asymptotia at LHC

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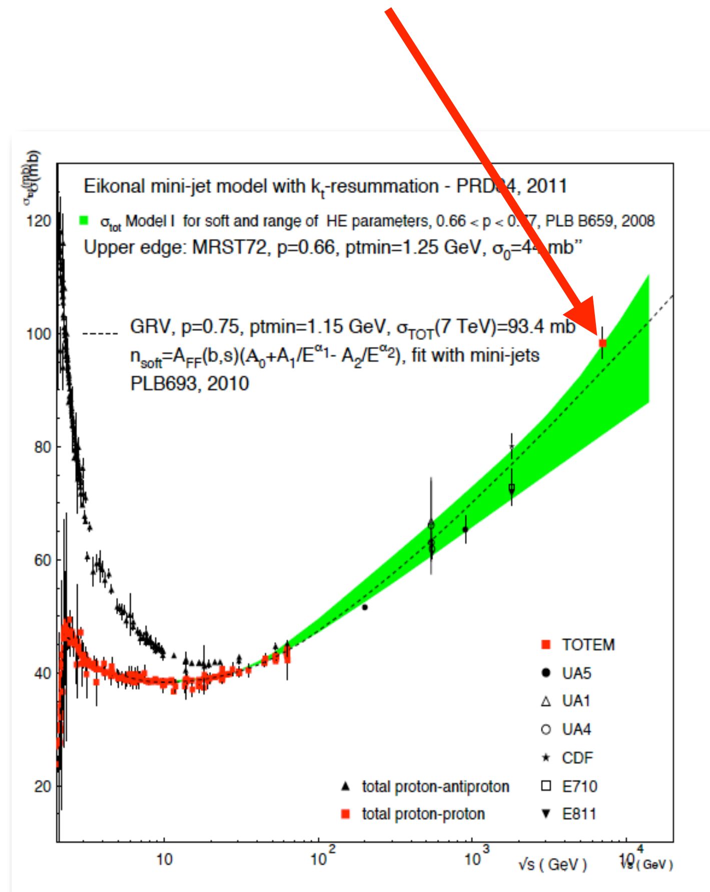
with

With A. Grau, S. Pacetti and Y.N. Srivastava (+R. Godbole)

Is LHC in asymptotia?

$$\sigma_{total}^{TOTEM-2011} = 98.3 \pm 3\ mb$$

- The game was opened by LHC7 TOTEM measurement for σ_{total}
- It was then followed by Block and Halzen [BH 2011 PRL](latest) claim that we have reached asymptotic saturation of the Froissart bound (FBS)
- And then still followed by claims that
  - This might exclude hidden extra-dimensions, [YSrivastava et al. arXiv:1104.2553 BH1201.0960]
  - There could be new baryonic interactions [Piran, 1204.1488]



GP et al, PRD84(2011), PLB659(2008)

Some tests of Asymptotia (GP et al. PLB2012,)

1. The Froissart-Martin bound
   [our mini-jet model]

$$\sigma_{total} \lesssim \log^2 s$$

2. The black disk limit,
   [one-channel eikonal models]

$$\mathcal{R}_{el} = \frac{\sigma_{elastic}}{\sigma_{total}} \lesssim \frac{1}{2}$$

3. Total absorption for the elastic amplitude in impact parameter space:
   Asymptitoc Sum Rules (ASR)

$$\Re e A_{el}(s, b=0) \rightarrow 0$$
$$\Im m A_{el}(s, b=0) \rightarrow 1$$

Not here

4. An almost model independent parametrization for from 53 GeV to 7 TeV to check ASR [with faint reappearance of the dip at the TeVatron for proton-antiprotons]

$$d\sigma_{el}/dt$$

5. The asymptotic vanishing of the rho parameter
   [Our mini-jet model]

$$\rho(s,0) = \frac{\Re e F(s,0)}{\Im m F(s,0)} \rightarrow \frac{\pi}{\log s}$$

Not here

6. The slope parameter:

$$B(s, t=0) \geq \frac{\sigma_{total}}{18\pi} \frac{\sigma_{total}}{\sigma_{elastic}} \sim \sigma_{total}$$

Inclusive tests

1. Total cross-section (using our mini-jet model as a tool)
2. Total vs elastic cross-section (some considerations about the black disk limit)

1. Is the Froissart bound saturated?

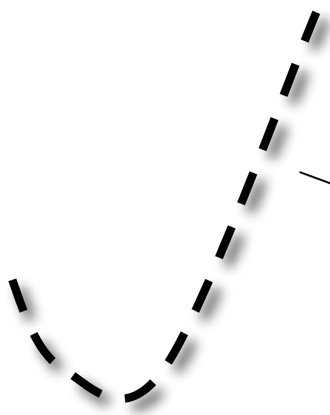
[In the sense of a $\log^2 s$ behaviour]

$$\sigma_{total} \lesssim \log^2 s$$

Issues from a QCD mini-jet description

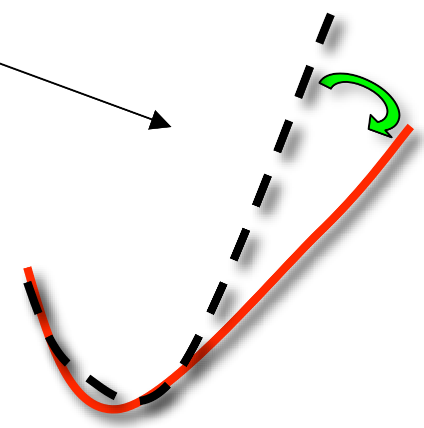
What generates the rise? Low-x parton collisions

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



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

How to go from hard to soft ?



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

A cut off obtained by [embedding into the eikonal] the acollinearity induced by IR kt-emission
[our model, G.P. et al. **Phys.Lett.B382, 1996**]

In our model, the emission of singular infrared gluons tames low-x gluon-gluon scattering (mini-jets) and restores the Froissart bound

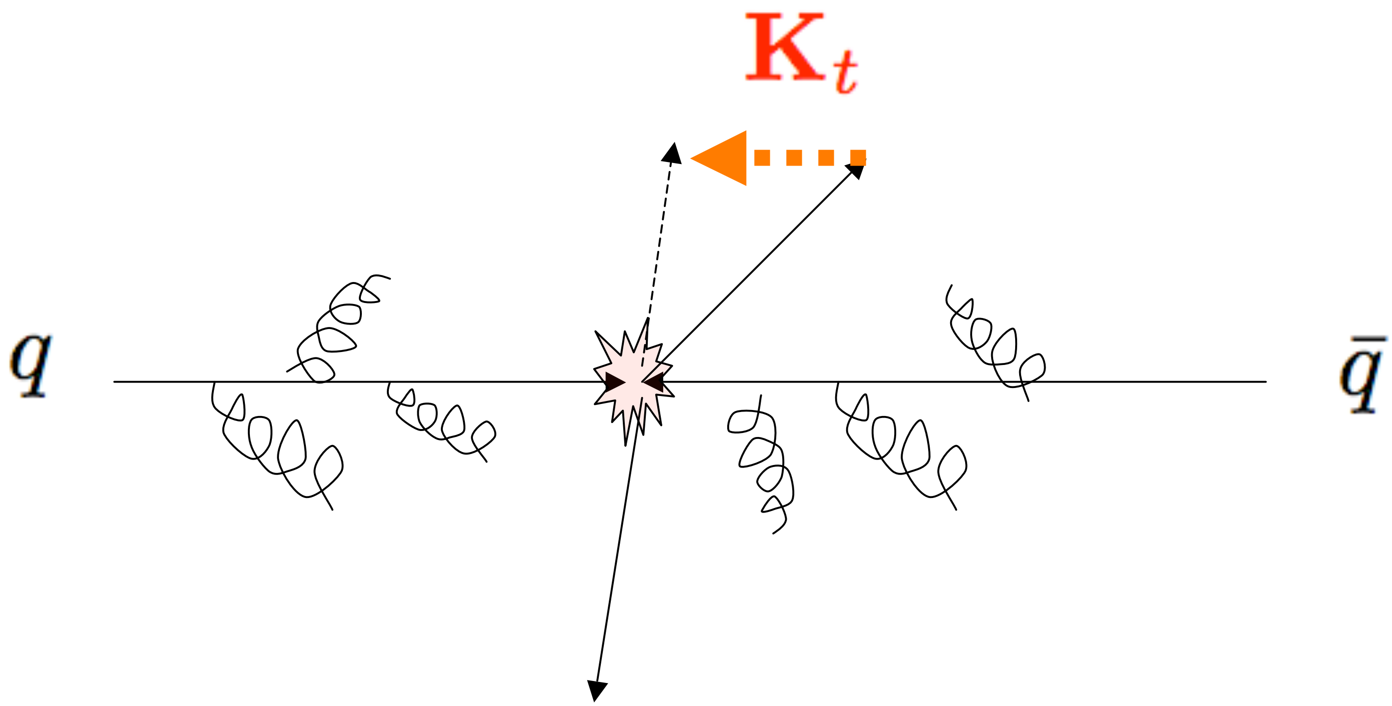
s^{ε}

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

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

Grau, Godbole,GP,Srivastava,PLB682 2009

Soft gluon emission introduces acollinearity

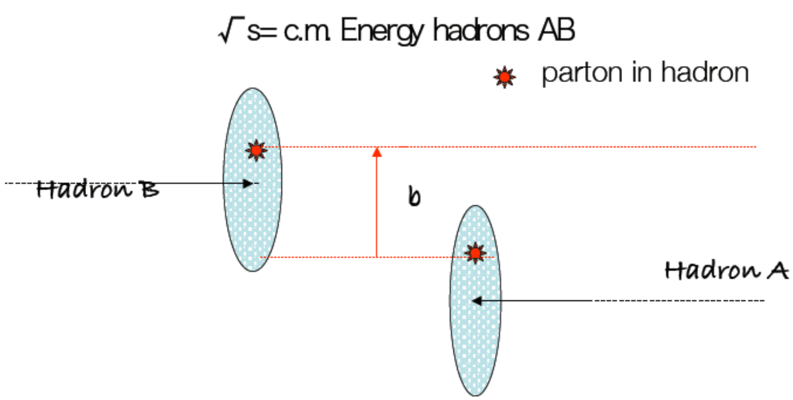


Acollinearity reduces the collision cross-section as partons do not scatter head-on any more, i.e. the gluon cloud is too thick for partons to see each other : gluon saturation

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?

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

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



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

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

q_{tmax} ? Fixed by single gluon emission kinematics

Our interpolation for running alpha_s from IR to AF

$$\alpha_{eff}(k_t) = \frac{12\pi}{11N_c - 2N_f}\frac{p}{\log[1+p(k_t/\Lambda_{QCD})^{2p}]}$$

$$\propto k_t^{-2p} \qquad k_t << \Lambda$$

$$\propto \frac{1}{\log k_t^2/\Lambda^2} \qquad k_t >> \Lambda$$

Are we seeing saturation of FB ? (with the dire consequences for extra-dimensions predicted by Srivastava et al. 2011 and Block-Halzen 2012)

In our minijet model

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

$$\Omega(b,s) \sim e^{-(b\Lambda)^{2p}} \sigma^{PDF}_{minijet}$$

$$\sigma^{PDF}_{minijet} \sim s^{0.3-0.4}$$

$$\sigma_{total} \sim [\log s]^{1/p}$$

Our phenomenology
PLB682 2009,PRD2011
leads to
p~0.66-0.75

TOTEM point is obtained with p=0.66

$$\sigma_{total} \sim [\log s]^{3/2} < [\log s]^2$$

2. The Black Disk Limit

$$\mathcal{R}_{el} = \frac{\sigma_{elastic}}{\sigma_{total}} \rightarrow \frac{1}{2}$$

Why R_{el} may not reach 1/2 at all GP et al, PRD2011

When data from ATLAS and CMS appeared, a problem with the one-channel eikonal formulation became evident:

Use independent collisions in b-space to obtain total inelastic collisions

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

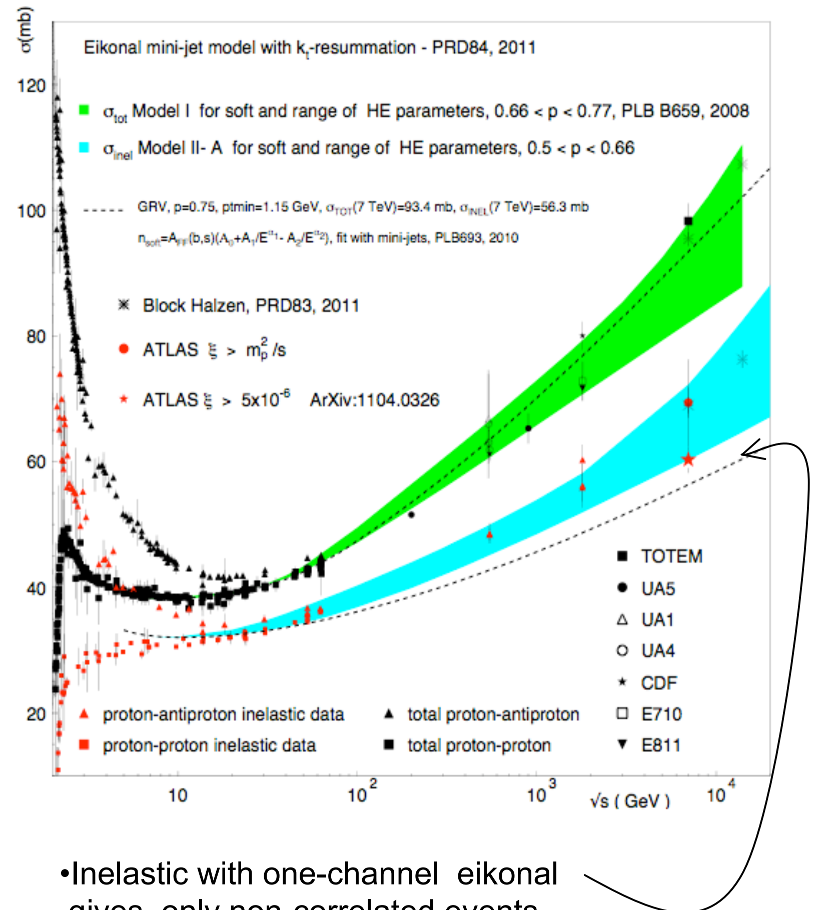
$$\sigma_{inel}(s) = \sum_{n=1} \int d^2\mathbf{b}\, P(\{n,\bar{n}\})$$

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

$$\equiv \sigma_{tot}(s) - \sigma_{el}(s)$$

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

For approaches to Diffraction: KMR, GLM,BSW,MBR…



•Inelastic with one-channel eikonal gives only non-correlated events
• Diffraction must have been put in the elastic!

In one-channel eikonal

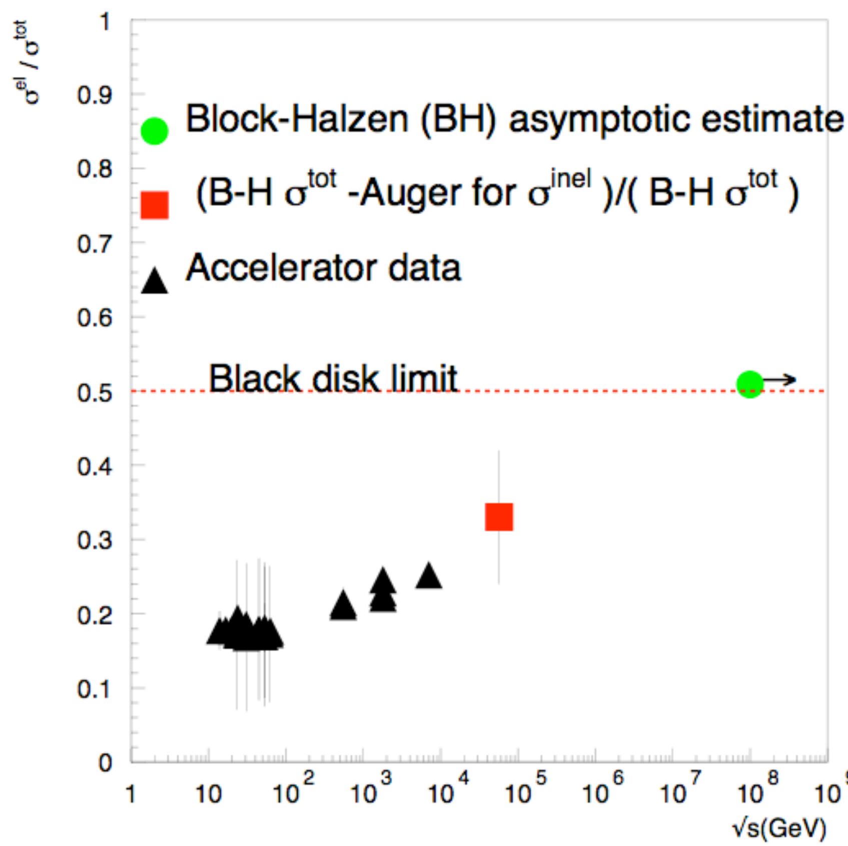
$$\sigma_{inel}^{one-chann} \equiv uncorrelated\ collisions$$

$$\mathcal{R} = \frac{\sigma_{el} + \sigma_{correlated}}{\sigma_{total}} \to \frac{1}{2}$$

Pumplin limit

The black disk limit R_{el} -> 1/2 ?

- R_{el} is not yet 1/2
- R_{el} is more like 1/4
- Auger data suggest 1/3
- Is 1/3 the asymptotic limit for R_{el}?



The eikonal one channel formulation has problems

- Ok for the sigma total but

Sigma elastic and sigma inelastic get mixed up: diffraction, single and double, goes into the elastic [GP et al PRD84]

- Need for a different formalism [e.g KMR,GLM, for MC mini-jet approaches also Lipari&Lusignoli]

- Work in progress in our model

- Turn to the elastic differential to see what happens

The elastic cross-section

3. Total absorption in b-space [PLB2012 not discussed here]

4. The small t-distribution and a simple model to discuss dips and bumps

5. The rho parameter [not discussed here]

6. The slope parameter

4. The elastic amplitude at small t and a simple model to look at dips and bumps

A simple (old)model from
(Barger and Phillips 1973)

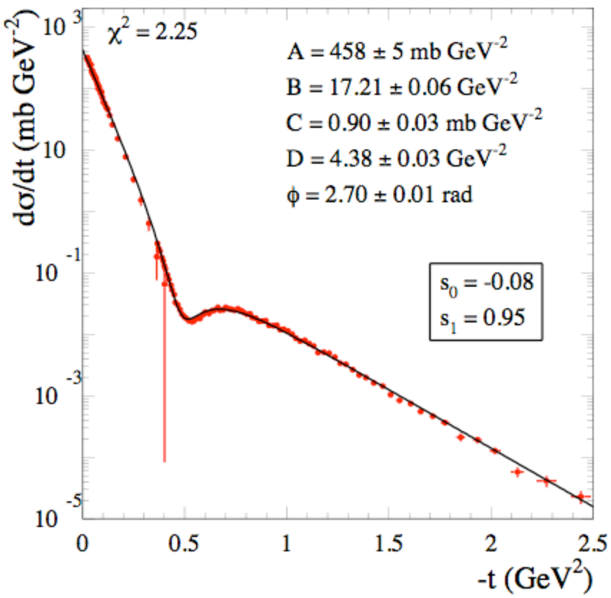
$$\mathcal{A}(s,t) = i[\sqrt{A(s)}e^{\frac{1}{2}B(s)t} + \sqrt{C(s)}e^{i\phi(s)}e^{\frac{1}{2}D(s)t}]$$

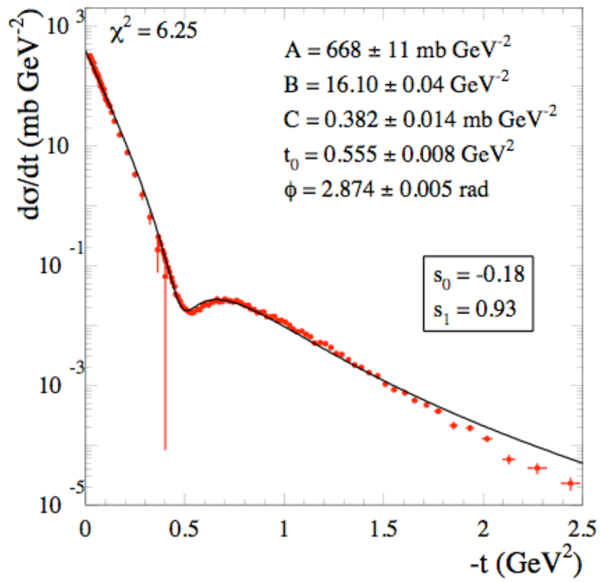
$$\frac{d\sigma}{dt} = A(s)e^{B(s)t} + C(s)e^{D(s)t} + 2\sqrt{A(s)}\sqrt{C(s)}e^{\frac{(B(s)+D(s))t}{2}}\cos\phi$$

five s-dependent real parameters, A B C D ϕ

How does it work with LHC TOTEM data?

How to describe both the diffraction peak and the tail of TOTEM data : models for the tail





- Model 1 : two exponentials
- TOTEM $|t|^{-n}$ with $n = 7.8 \pm 0.3^{stat} \pm 0.1^{syst}$
- Donnachie and Landshoff (1996) $|t|^{-8}$
- Model 2 : $\mathcal{A}(s,t) = i[\sqrt{A(s)}e^{Bt/2} + \frac{\sqrt{C(s)}}{(-t+t_0)^4}e^{i\phi}]$

The two exponential is still the best

Troshin,Tyurin for tail

6. The forward slope

$$B(s) \geq \frac{\sigma_{total}}{18\pi} \frac{\sigma_{total}}{\sigma_{elastic}} \gtrsim \sigma_{total}$$

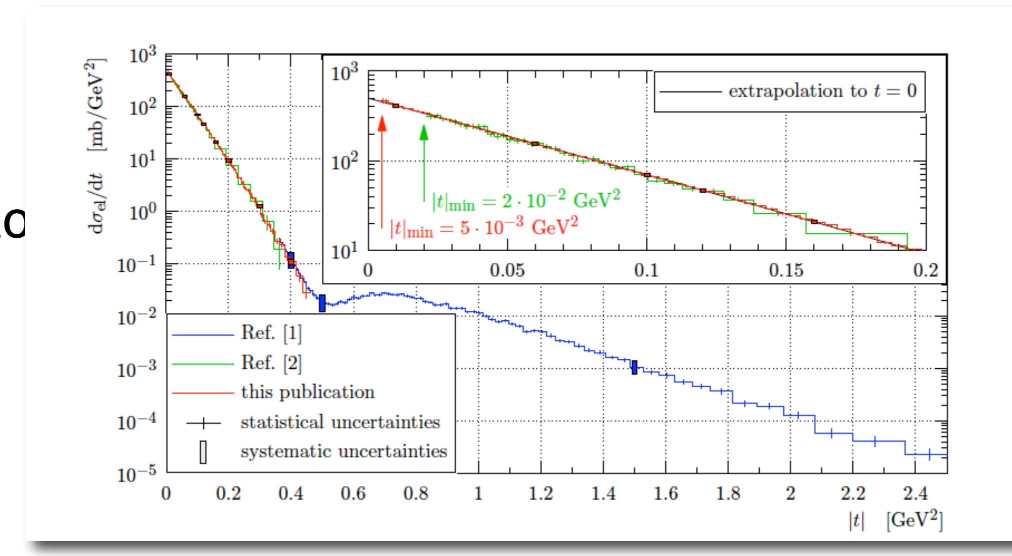
TOTEM : the slope of forward peak

$$\frac{d\sigma}{dt} = \frac{d\sigma}{dt}|_{t=0}\ e^{B_{exp}t}$$

- The slope changes as one measures away from t=0 to the dip region

- ~ 19.9 pm 0.3 GeV^{-2} for
  $0.005 < -t < 0.2\ GeV^2$

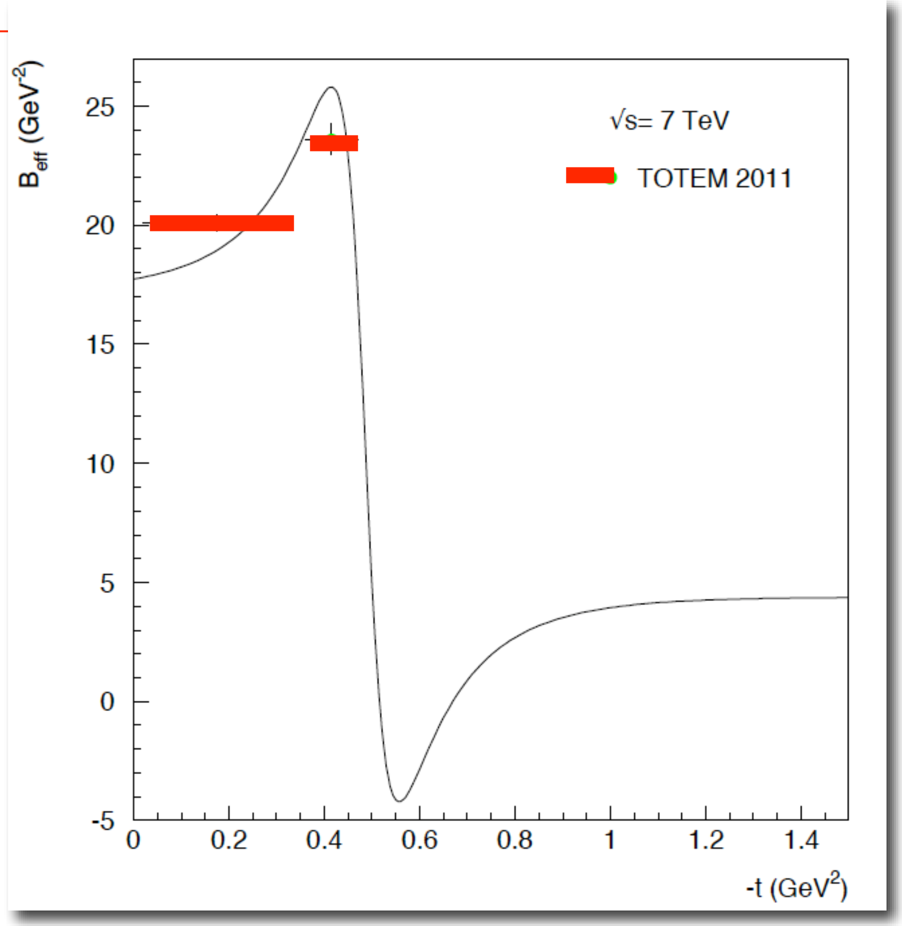
- ~23 GeV^{-2} at -t before the dip



TOTEM August 2012

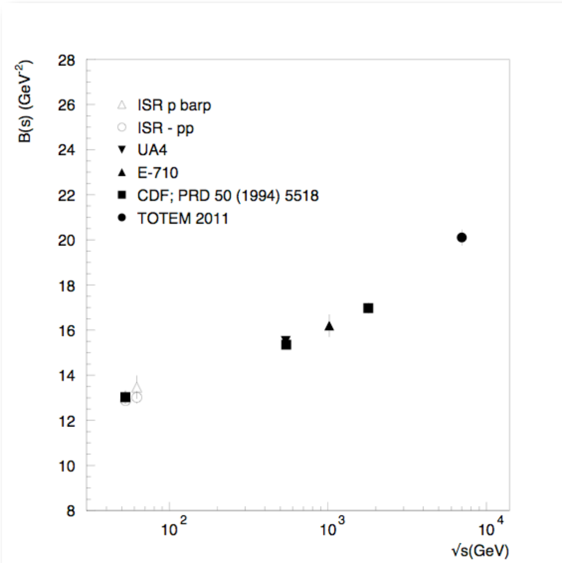
? How about the slope in the two exponential model ?

$$B_{eff}(s,t) \equiv \frac{d \ln \frac{d\sigma}{dt}}{dt}$$

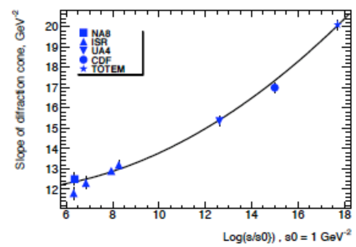


$$B_{eff}(s,t=0) = \frac{AB + CD + \sqrt{A}\sqrt{C}(B+D)\cos\phi}{A + C + \sqrt{A}\sqrt{C}\cos\phi}$$

Slope from (a selected set of)data:



$$B_{exp}(s) \sim \sigma_{total}$$
$$\sim log^2 s \quad ?$$



1. Ryskin-Schegelsky 2012 : $log^2 s$ behaviour?
2. Not yet clear :
    1. Our analysis shows that data past the dip influence the effective slope at small t, hence possibly B may depend from more than 1 slope parameter and by the phase as well
    2. Data plotted mix protons and antiprotons, quite possible that there are other contributions and BP model would rather give B~log s

Conclusion

- Our model with minijets and soft gluon resummation is able to describe the total cross-section from 5 GeV to cosmic rays energies
- A model with two exponentials and a phase is well suited to describe the dip structure at LHC as well as the forward diffraction peak and should be used to parametrize future data at 8 TeV or beyond
- The connections between these two models is still under study
- Asymptotia? Need to understand what the asymptotic theorems imply

Our interpolation for alpha_s from IR to AF

$$\alpha_{eff}(k_t) = \frac{12\pi}{11N_c - 2N_f} \frac{p}{\log[1 + p(k_t/\Lambda_{QCD})^{2p}]}$$

$$B_{eff}(s,t) = \frac{ABe^{Bt} + CDe^{Dt} + \sqrt{A}\sqrt{C}(B+D)e^{(B+D)t/2}\cos\phi}{Ae^{Bt} + Ce^{Dt} + \sqrt{A}\sqrt{C}e^{(B+D)t/2}\cos\phi}$$

the large-s limit

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

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

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

Mini-jets

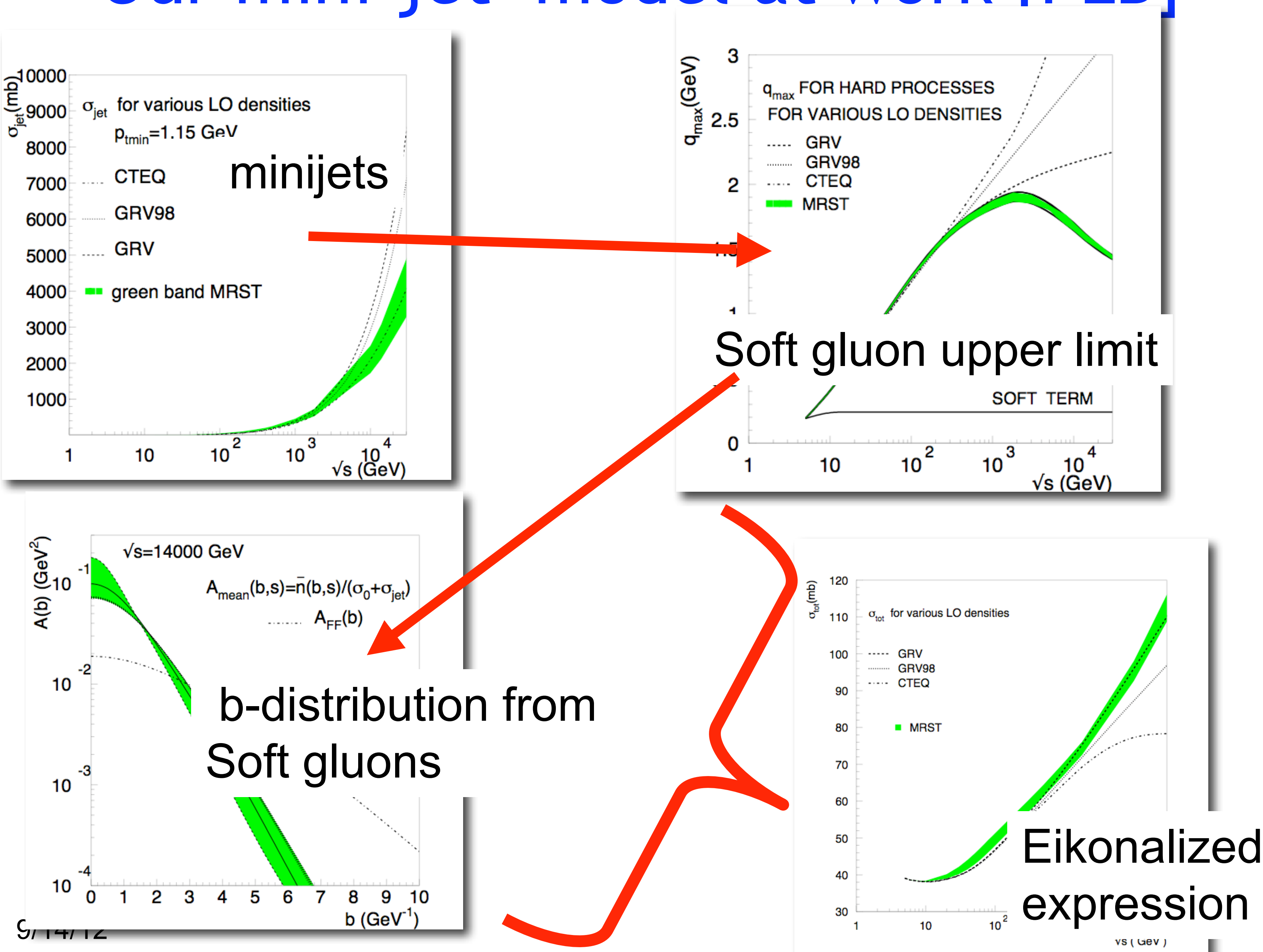
Ultra-soft gluons effects

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

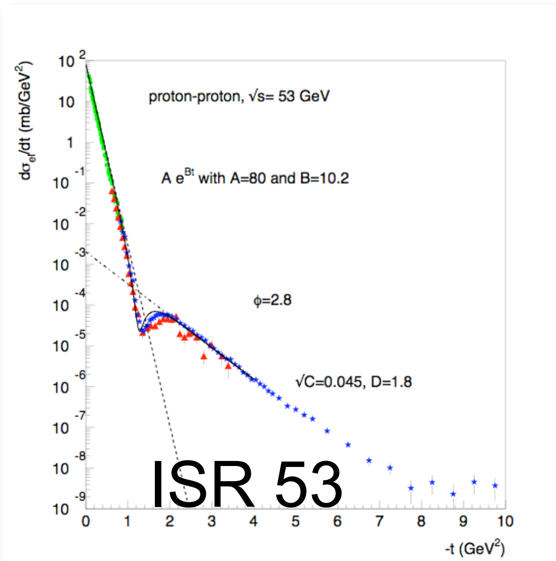
$\sim \ln^2 s \quad p = 1/2$

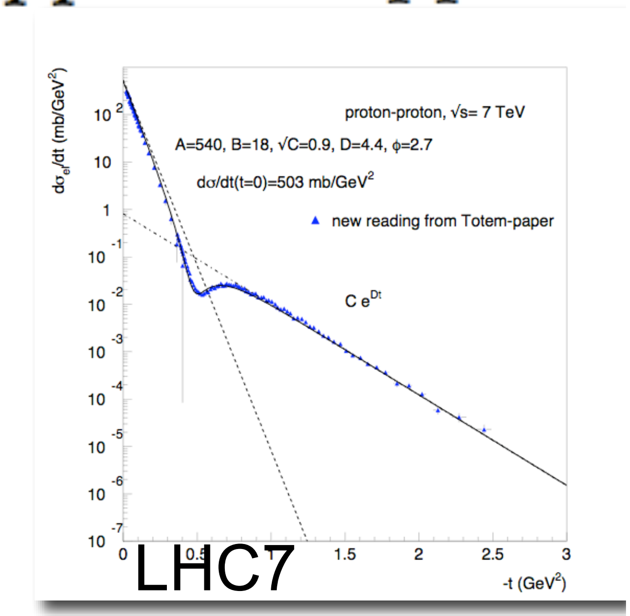
$\sim \ln s \quad p = 1$

Our mini-jet model at work [PLB]

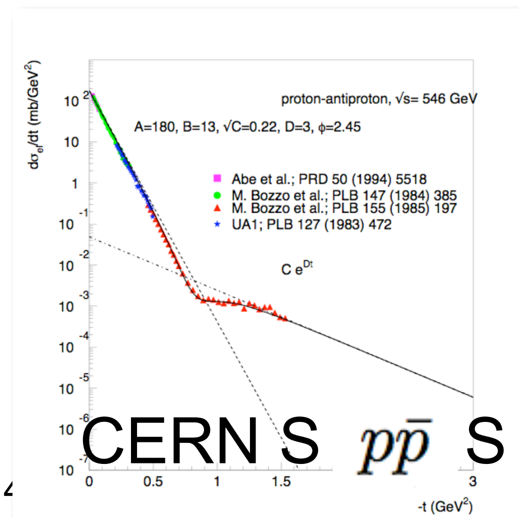


The return of the dip: pp v $p\bar{p}$



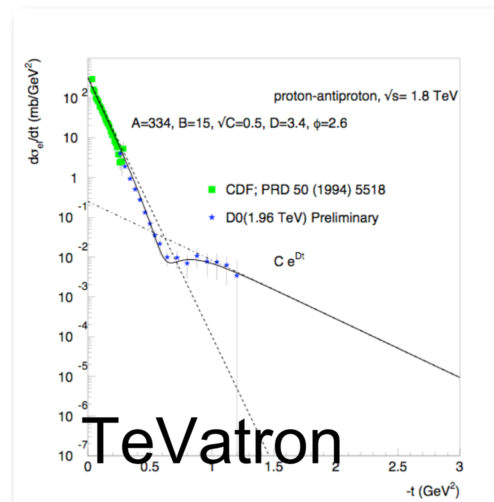


A simpler system



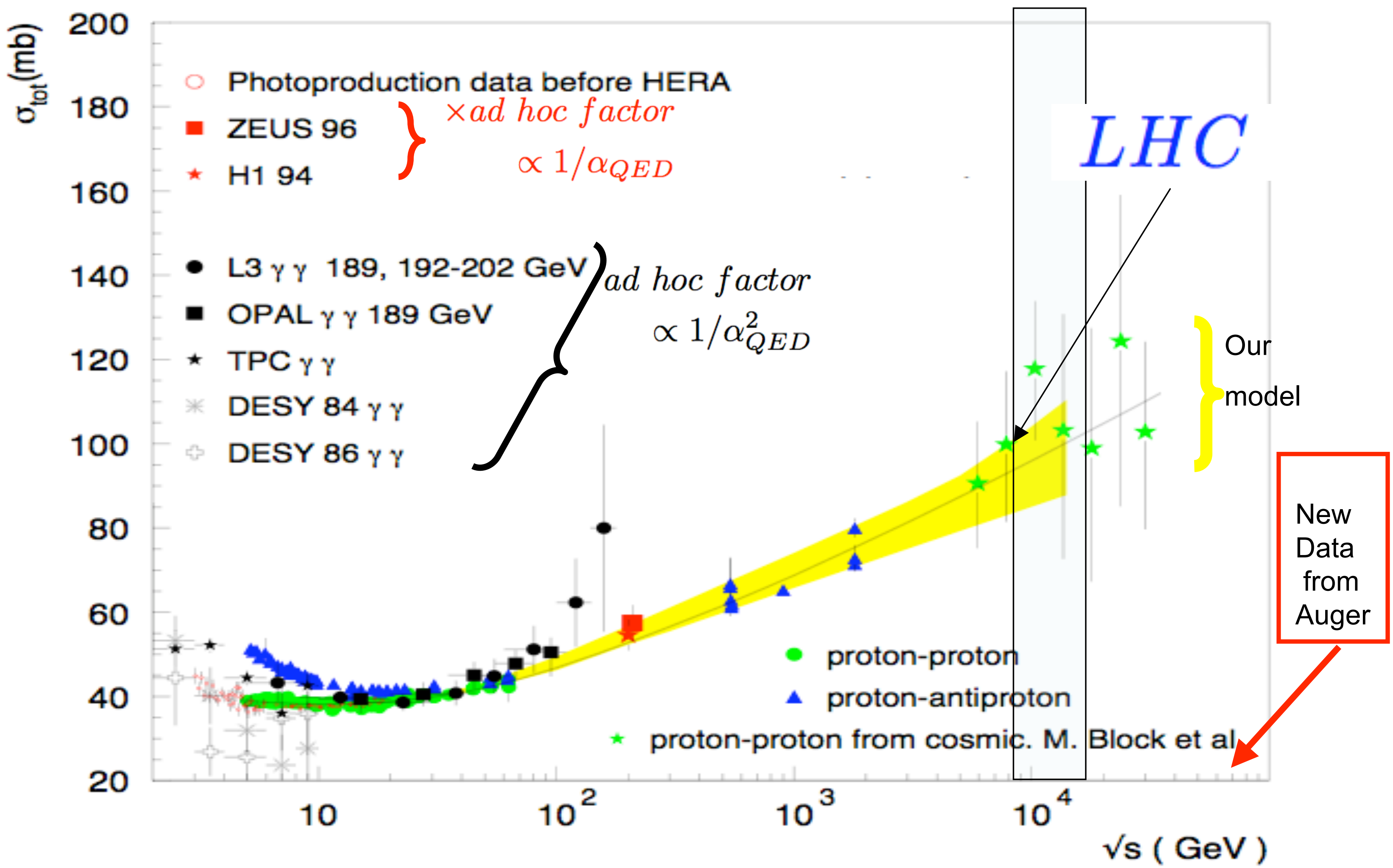
$p\bar{p}$

Complicated
By non-leading
Regge exchanges



Total cross section data before 2011

[GP et al. EPJC2008]



In the BP model

- B(s,t) depends on both slope parameters

B(s) and D(s)

Where B/D ~ 4

- But pp and pbarp are not described by same amplitude from 53 to 7 TeV so we cannot yet extract a precise behaviour for the slope

3. Total absorption in b-space

Dip or no dip?

- Before and after the dip the two processes pp and $p\bar{p}$ should be described by the same physics

- At the dip the basic amplitude is almost zero (5 orders of magnitude lower in the cross-section) so the *leftovers* from Regge exchange, present only in $p\bar{p}$, fill the dip

How to check asymptotia in the elastic amplitude?

$$\mathcal{F}(s,t) = i\int_o^\infty (bdb) J_o(b\sqrt{-t})[1 - e^{2i\delta_R(b,s)} e^{-2\delta_I(b,s)}]$$

$$\sigma_{total}(s) = 4\pi \Im m \mathcal{F}(s,0)$$

- Two asymptotic sum rules in impact parameter space [EPJC 2005]

$$(\frac{1}{2}) \int_{-\infty}^{0} (dt) \Im m \mathcal{F}(s,t) \ \rightarrow \ 1; \ \ as \ s \rightarrow \ \infty. \qquad S_1$$

$$\int_{-\infty}^{0} (dt) \Re e \mathcal{F}(s,t) \ \rightarrow \ 0; \ \ as \ s \rightarrow \ \infty \qquad S_0$$

BP model allows easy check of the sum rules

- With parameters from fit

$$s_1 = \sqrt{\frac{A}{1+\hat{\rho}^2}\frac{1}{\sqrt{\pi}B} + \frac{\sqrt{C}}{\sqrt{\pi}D}\cos\phi} = 0.94$$

at LHC7

- At ISR 53 GeV $s_1 = 0.75$

5. The rho parameter

To satisfy both sum rules, add a real part to the first term

$s \leftrightarrow u$ Use our minijet model with soft gluon resummation with 0.66<p<0.77 PLB08

$$\mathcal{A}(s,0) \rightarrow i\left[ln(s/s_o e^{-i\pi/2})\right]^{1/p}$$

$$= i\big(\big(ln(s/s_o) - i\pi/2\big)\big)^{1/p}$$

$$\frac{\Re e\mathcal{A}(s,0)}{\Im m\mathcal{A}(s,0)} \rightarrow \frac{\pi}{2pln(s/s_o)} = 0.134 \div 0.115$$

$$s_0 \sim 0.05\ LHC7$$

The model

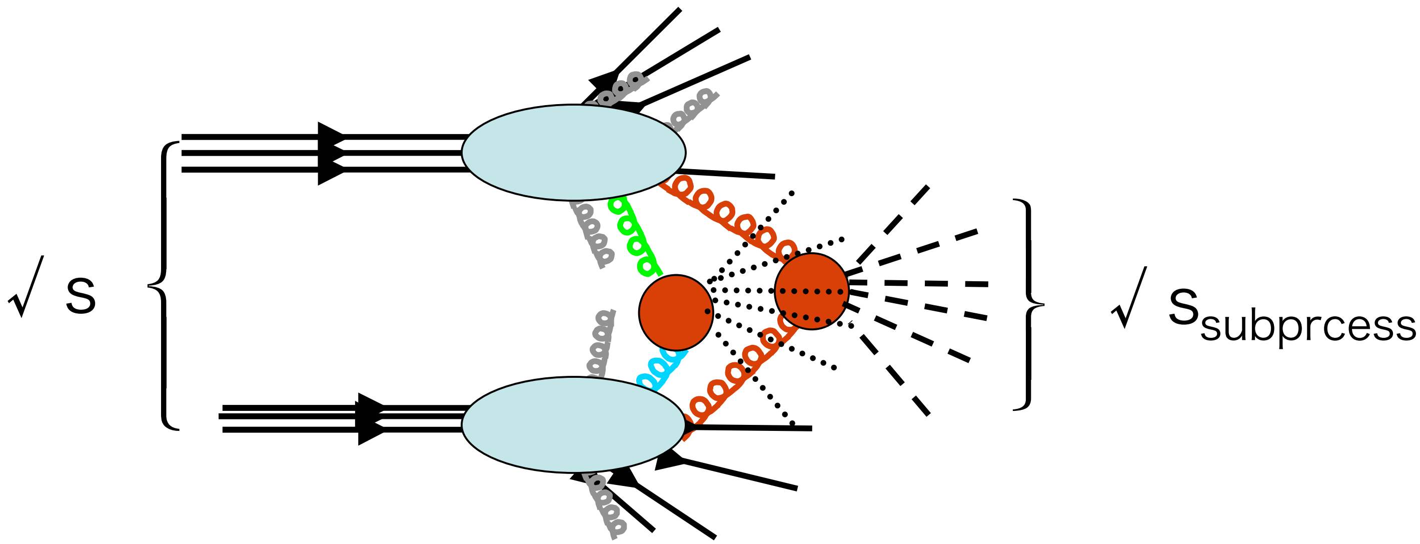
- Start with eikonal representation $\sigma_{tot}(s) = 2\int (d^2b)[1 - e^{-\bar{n}(b,s)/2}]$ $\Re e\chi \approx 0$
- Low and high energy component $\bar{n}(b,s) = \bar{n}_{low}(b,s) + \bar{n}_{high}(b,s)$
- **Low** energy component is parametrized with **No rising** term
- **High** energy (rising) component is from **PQCD** $\bar{n}_{high} = A(b,s)\sigma_{jet}(s)$

  Minijets to get the rise $p_t^{parton-out} \geq p_{tmin} \simeq 1\ GeV$

- To **tame the rise** $A(b,s)$ is obtained from $K_t - resummation$ with integration down into the infrared with an ansatz for infrared behaviour

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

Cartoon view of the model for σ_{total}



- QCD minijets with PDFs from CERNLIB to drive the rise
- Soft Gluon k_t-resummation (ISR) in the infrared main original ingredient of our model
- Multiple scattering (in Eikonal representation to implement unitarity)

pp and $\bar{p}p$

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

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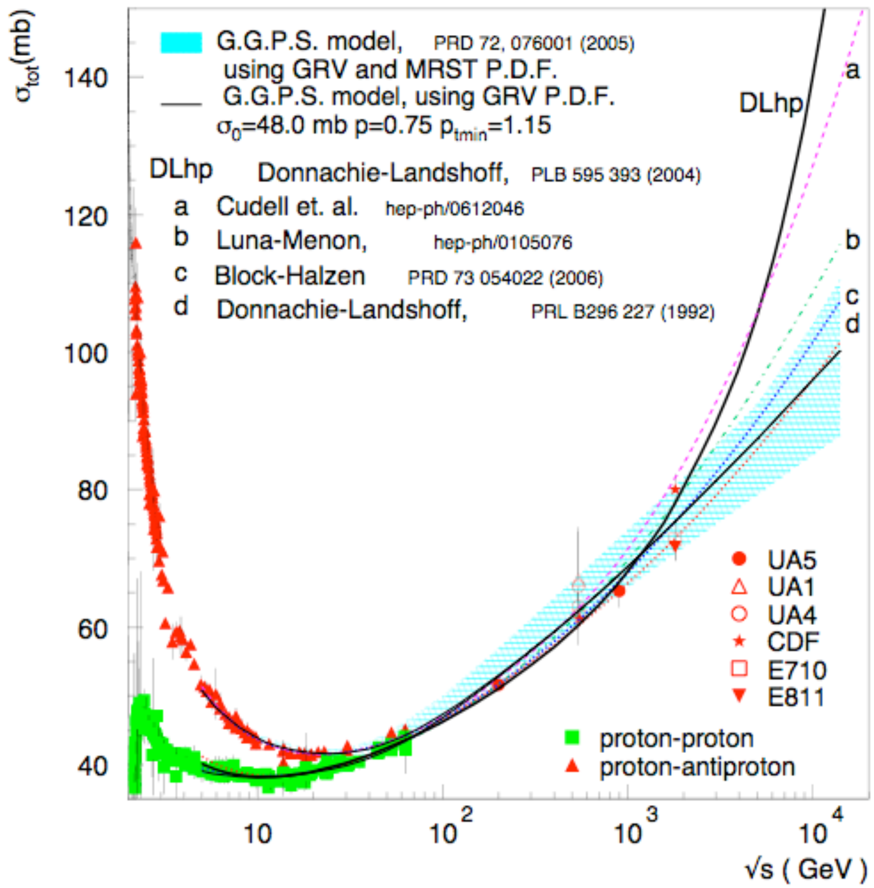


Some details

Mini-jets

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

DGLAP evolved

Which value of p_{tmin}?
Which densities?

Parametrize data choosing PDF and p_{tmin} to catch the early rise of σ_{total}

Mini-jets drive the rise of σ_{total}

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

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

DGLAP evoluted PDF

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

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

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

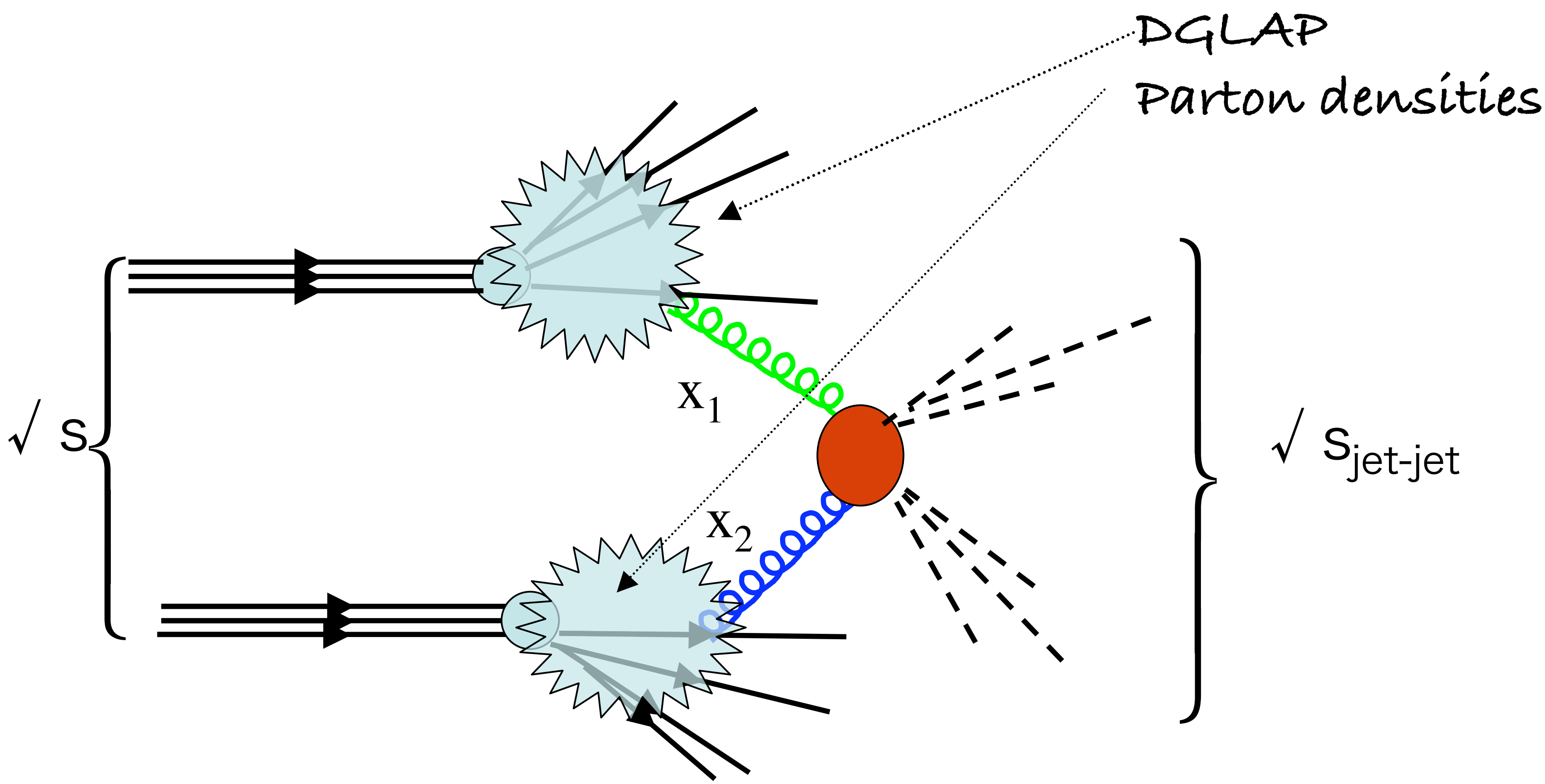
$$\bar{n}_{soft/hard}(b,s) = A_{soft/hard}(b,s)\sigma_{soft/hard}(s)$$

Overlap function

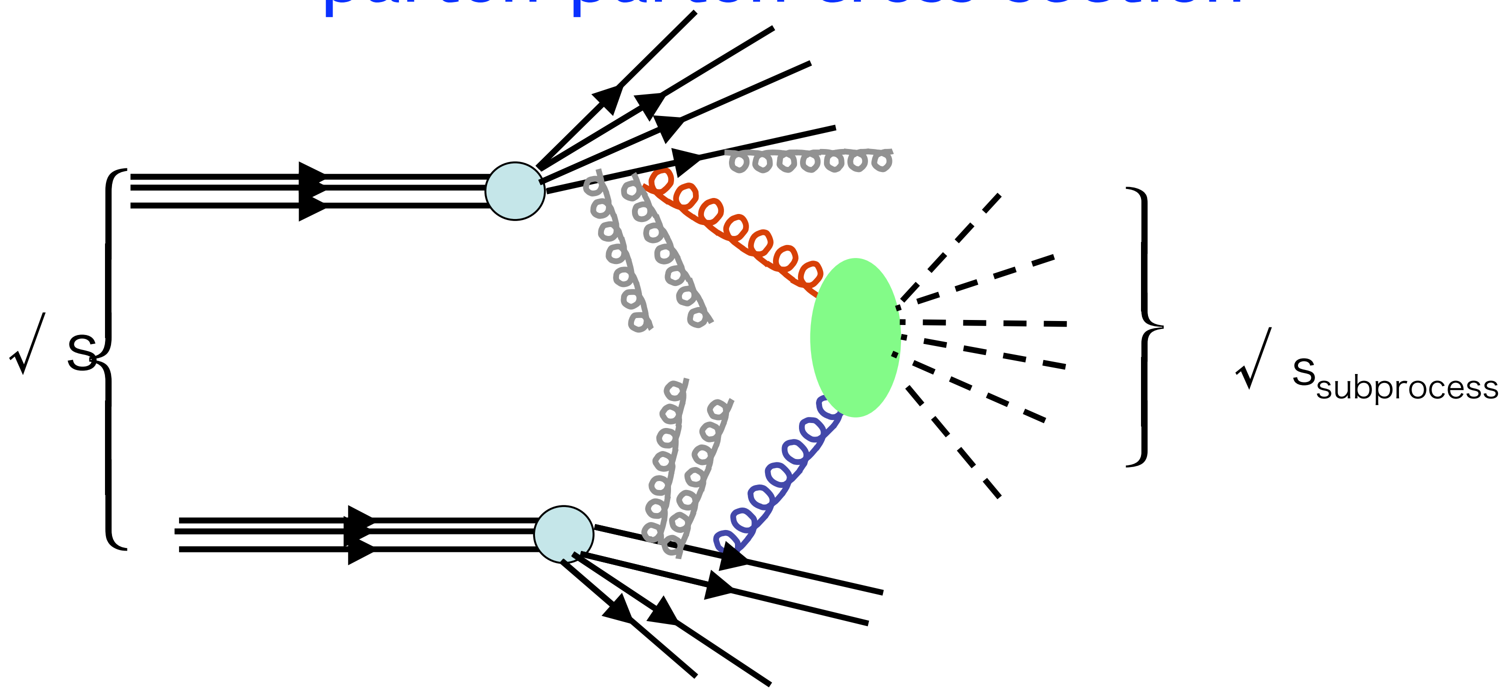
What makes the cross-section rise?

Mini-jets are responsible for the rise of the total cross-section

Cline,Halzen,Luthe 1972- Gaisser, Halzen 1985- G.P., Srivastava 1985



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



Eikonal models: b-distribution can quench the rise

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

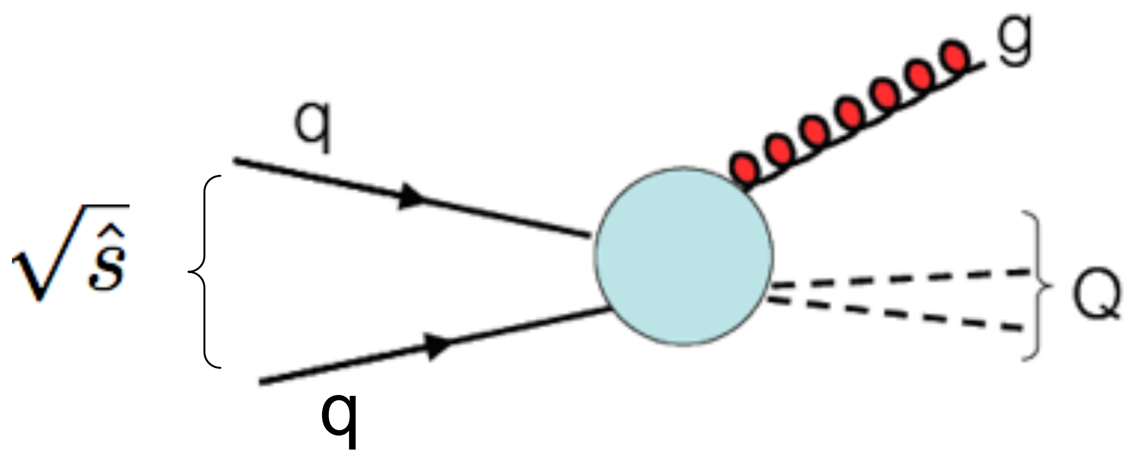
How to choose it:
Form factors?

Choice of densities for mini-jet x-section

Because we use resummation to access large distance behaviour

- LO PDFs are used, to avoid double counting the most important contribution (small kt) to observables like σ_{tot}
- LO: GRV, MRST, CTEQ
- For illustration purposes: GRV
- Bands are also presented with GRV and MRST
- We are working to include other densities

The single soft gluon Integration limit can be obtained from kinematics



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

σ_{total} and the large-s limit

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

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

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

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

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

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

Mini-jets

Ultra-soft gluons effects

At very large energy: from power law to log behaviour

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

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

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

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

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

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

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

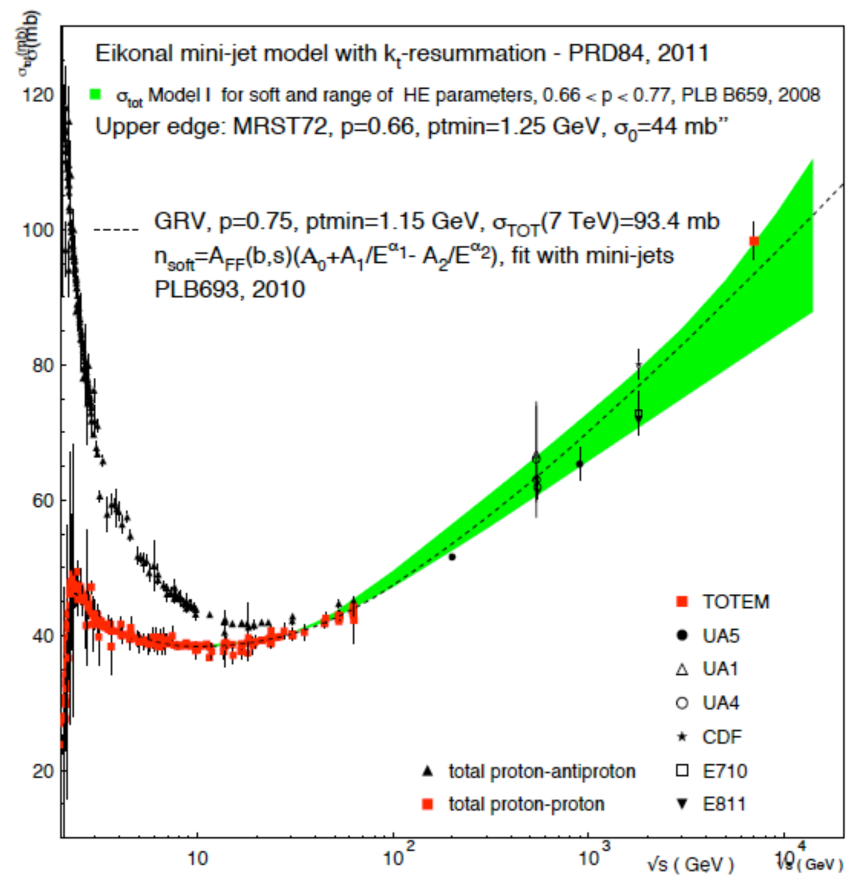
A general scheme for various processes

- 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

Are we seeing saturation of FB ? (with the dire consequences for extra-dimensions predicted by Srivastava et al. 2011 and Block-Halzen 2012)

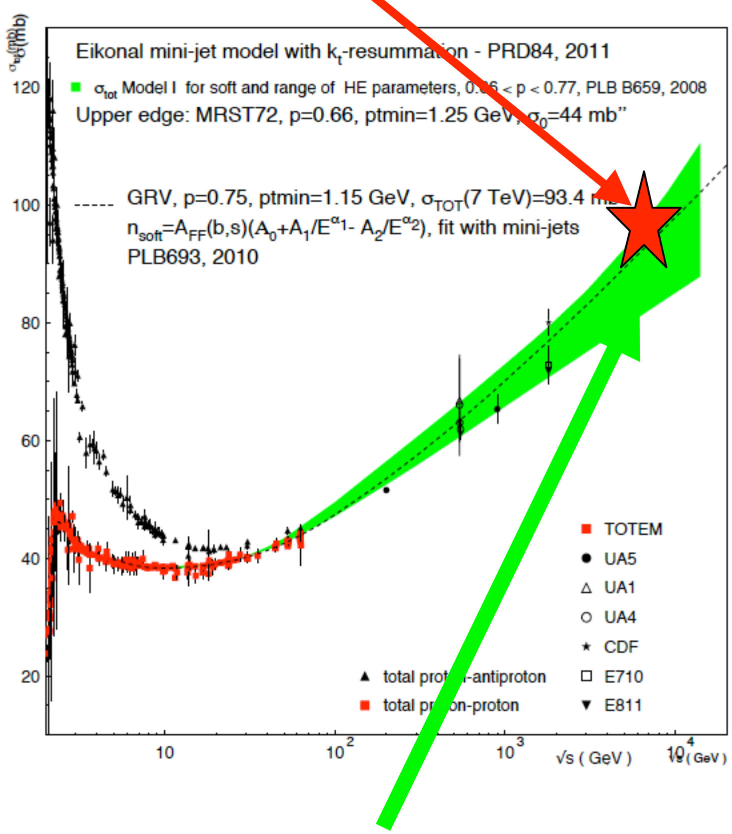
From our minijet model:



TOTEM measurements in 2011

$\sigma_{total} = 98.3 \pm 3mb$

$\frac{d\sigma_{el}}{dt}$



Achilli, GP, et al, PRD84(2011)

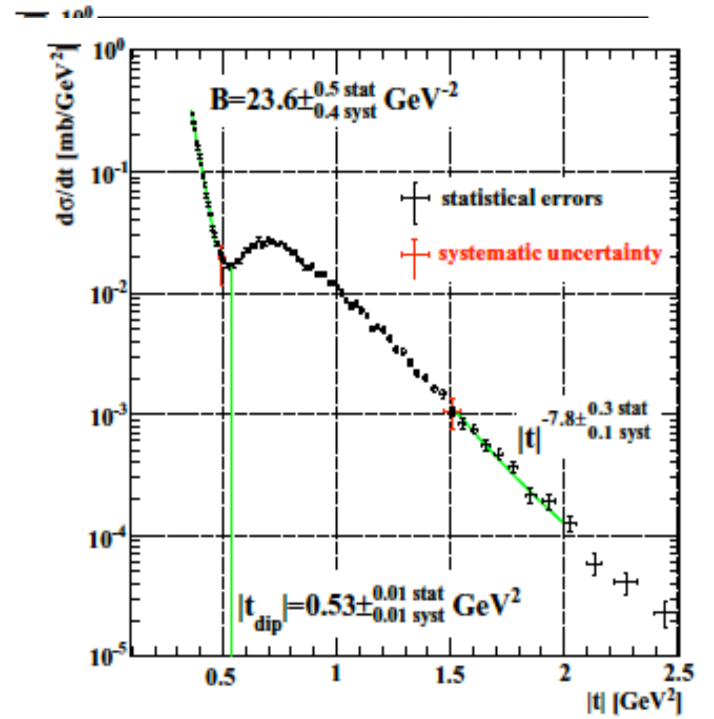


Fig. 3: The measured differential cross-section $d\sigma/dt$. The superimposed fits and their parameter values are discussed in the text.

G. Antchev et al.Eur.Phys.Lett. 2011

Interesting?

✷ Is **asymptotia** reached? i.e. is the Froissart bound (FB) for sigma total saturated? Why would this be interesting?

1. Because **saturation** of FB could exclude power-like behaviour as from hidden extra dimensions [Block Halzen 2012 , Srivastava et al, 2011]
2. Or data could hint to **new baryonic** interactions at 10-100 TeV and thus solve problems with cosmic rays composition based on current ex σ_{total} ns [Piran, april 2012]
3. Because there is a connection between **Froissart** bound and **confinement** which the total cross-section can investigate

✷ Why the **dip in pp elastic differential cross-section**?

The total cross-section: confinement and deconfinement at work

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

$\sigma_{elastic}$ → A **confined** system: quarks and gluons remain inside the original hadrons even at high energy

$\sigma_{inelastic}$ → **deconfined**

- Central production: quarks and gluons scatter away and then hadronize

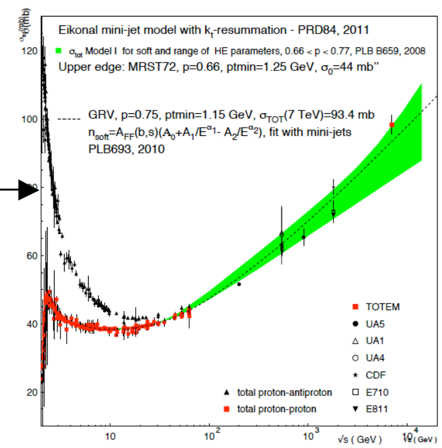
  Fully deconfined

- Single and double diffractive Production: quarks and gluons remain "close" to original hadrons and then hadronize

Our QCD model: a formalism to study confinement in total cross-section

We have developed a model

green band in



which connects σ_{total}

to the study of ultra soft gluon coupling

Where one can expect confinement effects to arise

The eikonal 2-component formulation has problems

- Ok for the sigma total but

Sigma elastic and sigma inelastic get mixed up: diffraction, single and double, goes into the elastic [GP et al PRD84]

- Need for a different formalism [Lipari&Lusignoli 2009]

- Or further understanding

- Turn to the elastic differential to see what happens