Elastic pp scattering from the optical point to past the dip

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New data from LHC7 and LHC8 for pp total, inelastic and elastic cross-sections

pp : not seen since ISR, 40 years ago the cleanest way to study the proton

Given $Sp\bar{p}S$ and TeVatron for $p\bar{p}$, pp at these energies was not so important for the total (Pomeranchuk theorem), but very important for the differential elastic x-section

Outline

- The total cross-section

eikonalized minijets with IR gluon resummation model

- The inelastic cross-section
- The elastic differential cross-section

empirical model a' la Barger&Phillips+ proton FF

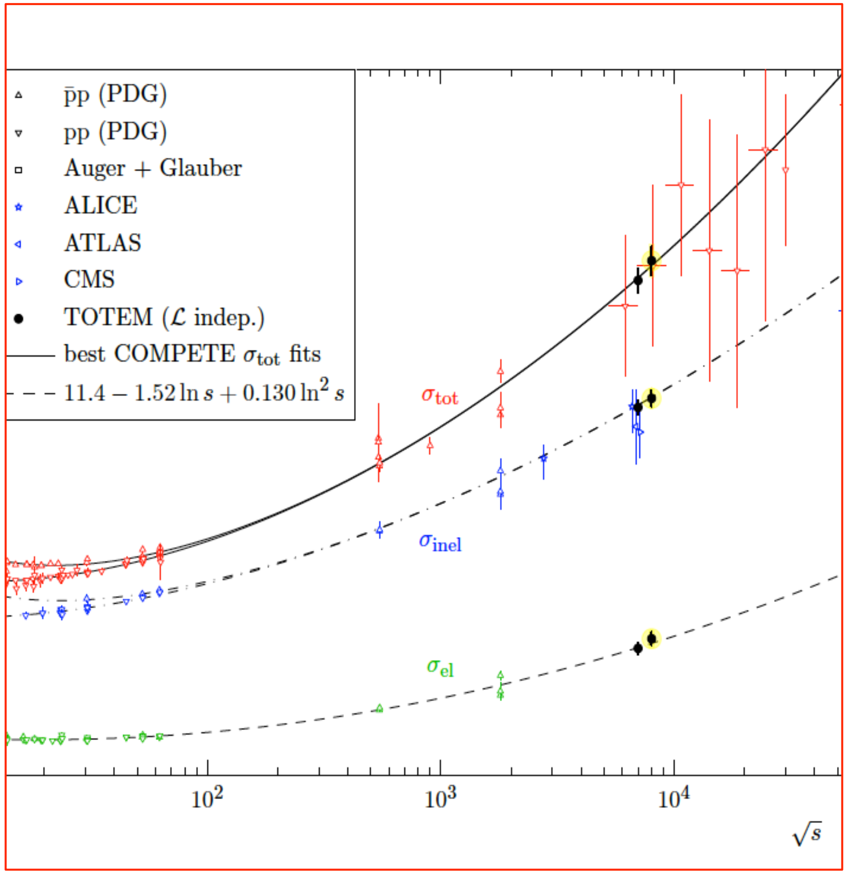
- The black disk limit with empirical model

The total pp cross-section:

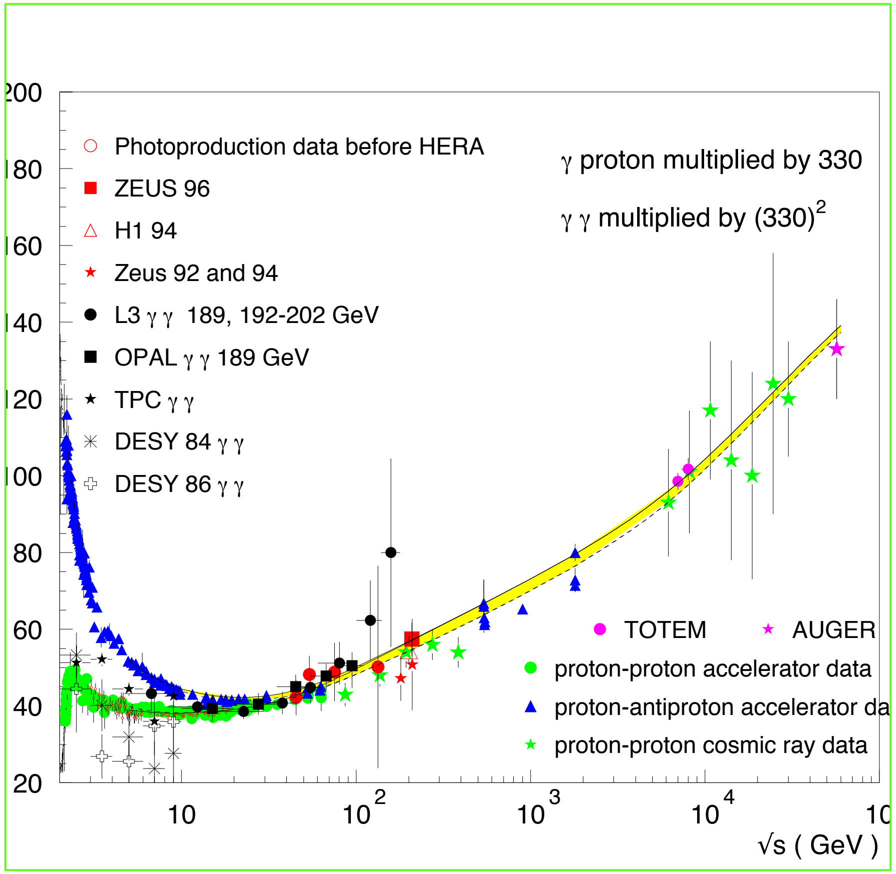
$$\sqrt{s} \sim (0.002 - 57)\ TeV$$

Total cross-sections: do we understand them?

TOTEM plot : total, elastic, inelastic



Sigmatotal: 5 decades in energy
2 GeV -> 57 TeV



QCD model for the total cross-section R. Godbole, A. Grau, GP, YN Srivastava

PLB1996-PRD2005

$$\sigma_{total} \simeq 2 \int d^2\vec{b}[1 - e^{-\chi_I(b,s)}]$$

- Minijets to drive the rise
- Soft kt-resummation to tame the rise
- Phenomenological singular but integrable soft gluon coupling to relate confinement with the rise
- Interpolation between soft and asymptotic freedom region

$$2\chi_I(b,s) = \sigma_{soft} + A(b,s)\sigma_{jet}$$

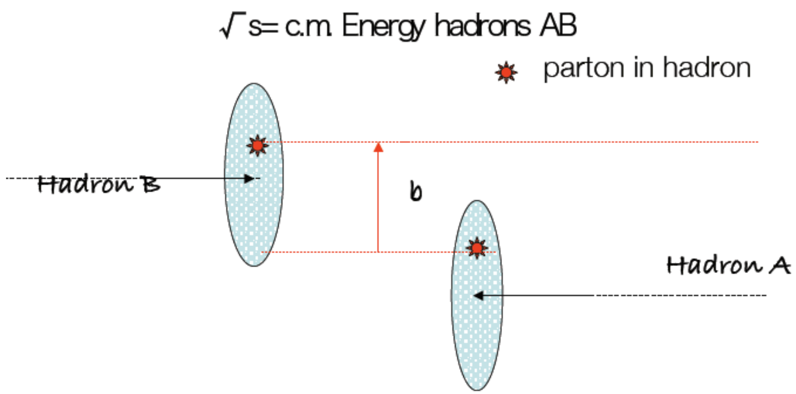
We model the impact parameter distribution as the Fourier-transform of ISR soft k_t distribution and thus obtain a cut-off at large distances : Froissart bound?

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

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

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

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



q_{tmax} ?

Fixed by single gluon emission kinematics

Our proposal for running $\alpha_s(k_t)$ in the infrared region

$$V_{one\ gluon\ exchange} \sim r^{2p-1}$$

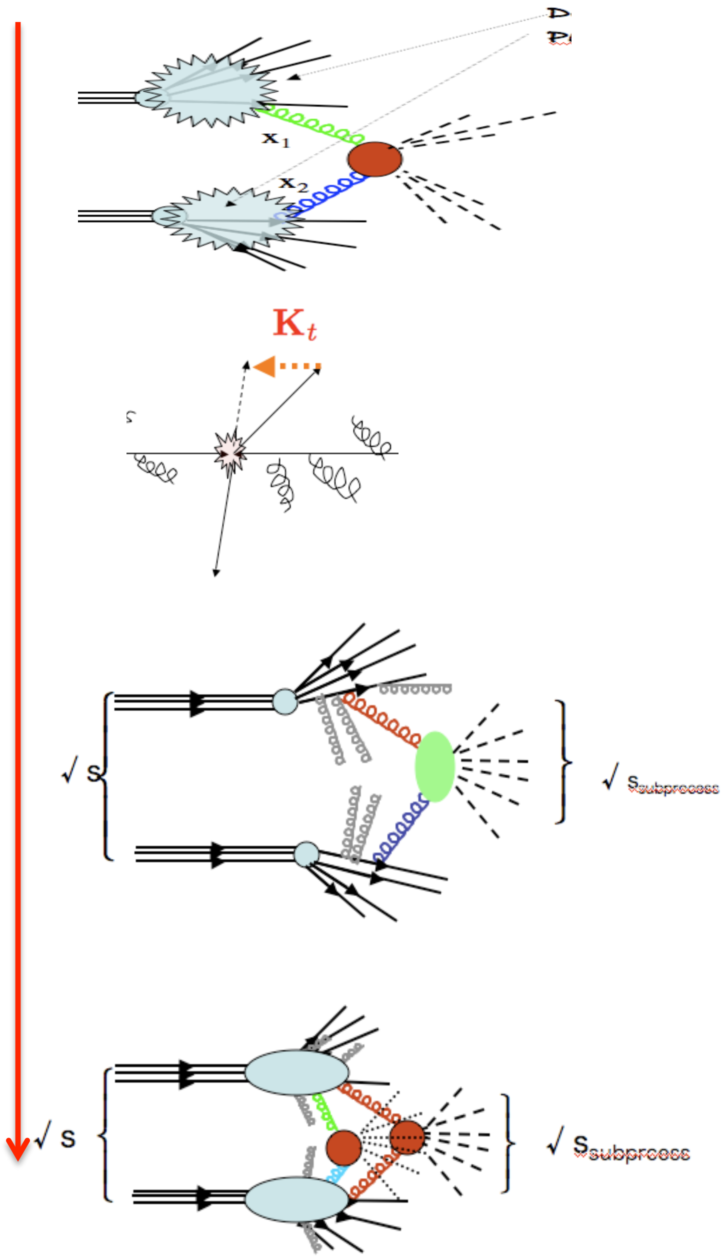
$$\propto k_t^{-2p} \qquad k_t << \Lambda$$

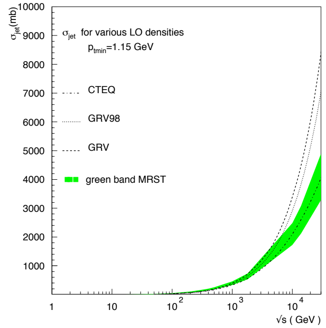
To reconcile with asymptotic Freedom

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

A phenomenological interpolation

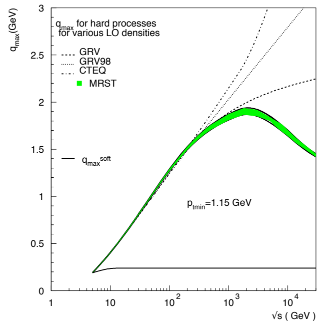
$$\alpha_{eff}(k_t) = \frac{12\pi}{11N_c - 2N_f} \frac{p}{\log[1 + p(k_t/\Lambda_{QCD})^{2p}]}$$





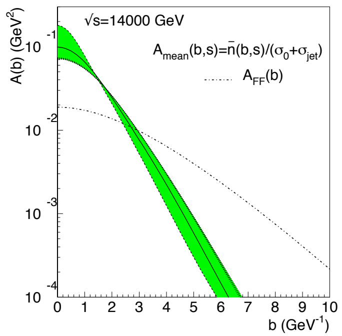
1. Calculate mini-jet cross-section
Choosing densities and ptmin

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



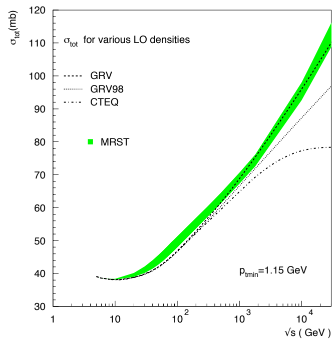
2. Calculate qmax: single soft gluon upper scale, for given PDF, ptmin

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



3. Calculate impact parameter distribution for given qmax and given infrared parameter p

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



4. Eikonalize

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

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

s^{ε}

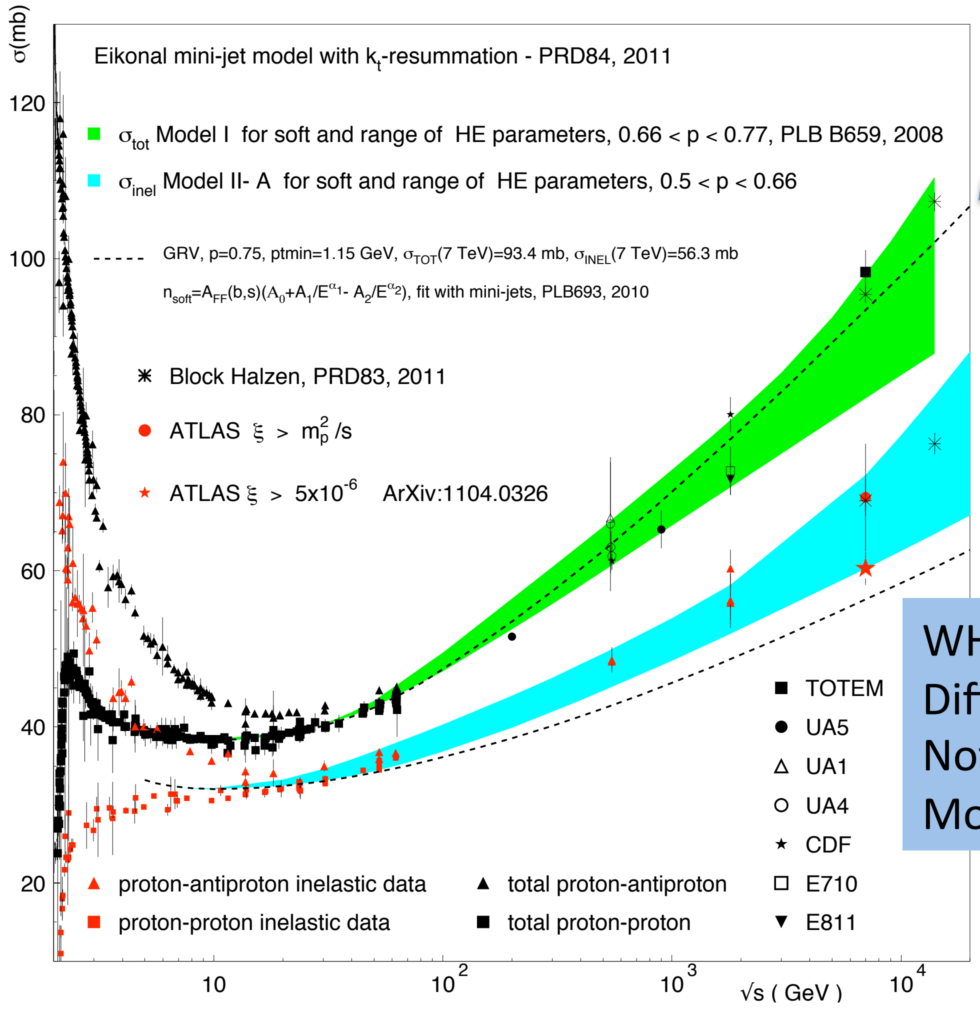
$$\sigma_{tot}(s) \approx 2\pi \int_0^\infty db^2 [1 - e^{-C(s)e^{-(b\bar{\Lambda})^{2p}}}]$$

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

Grau, Godbole,GP,Srivastava,PLB682 2009

The inelastic cross-section

PLB 2008
Band
for the total

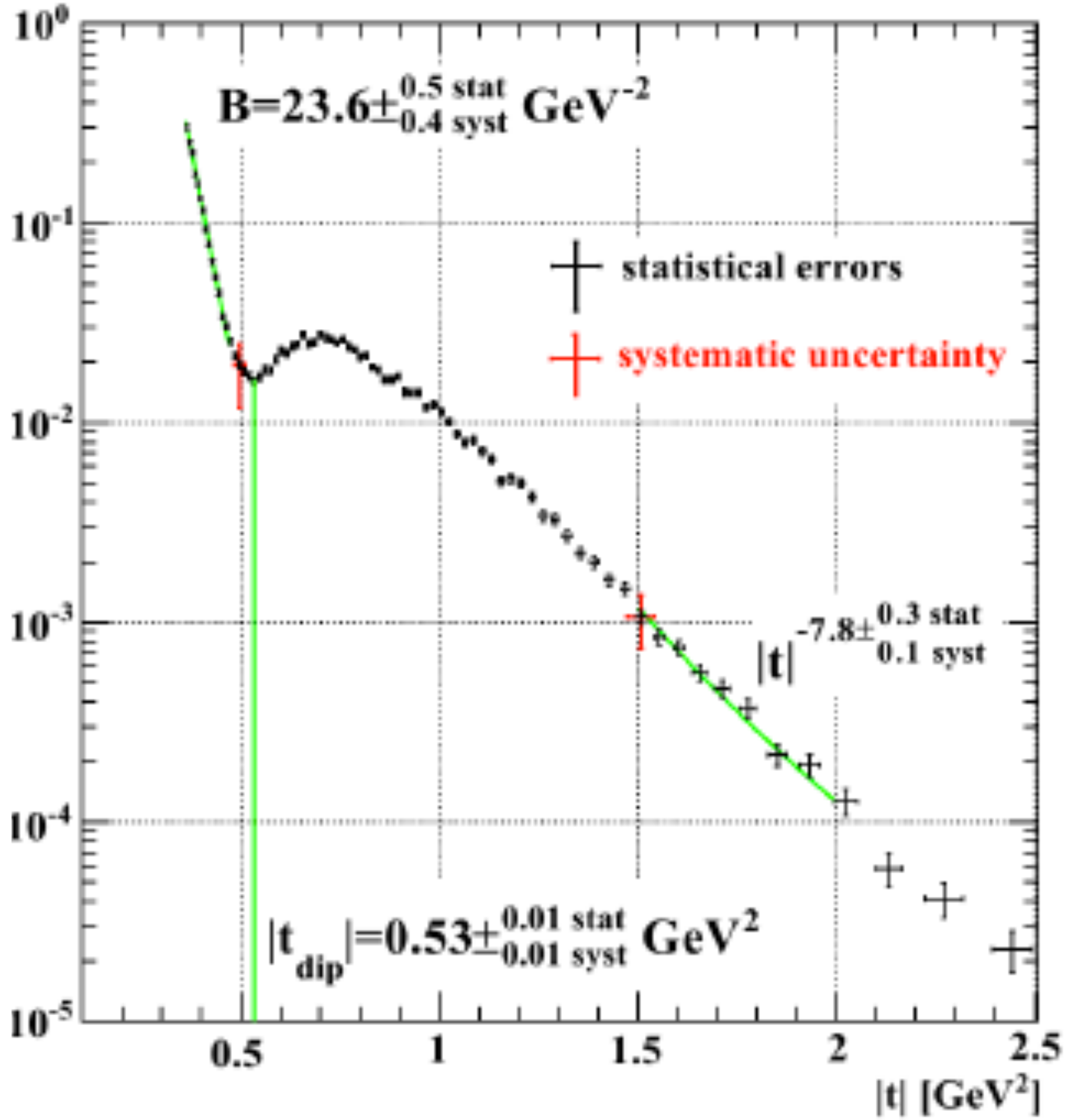


Inelastic
Is not so clear

WHY?
Diffraction is
Not yet well
Modeled/understood

The elastic differential cross-section

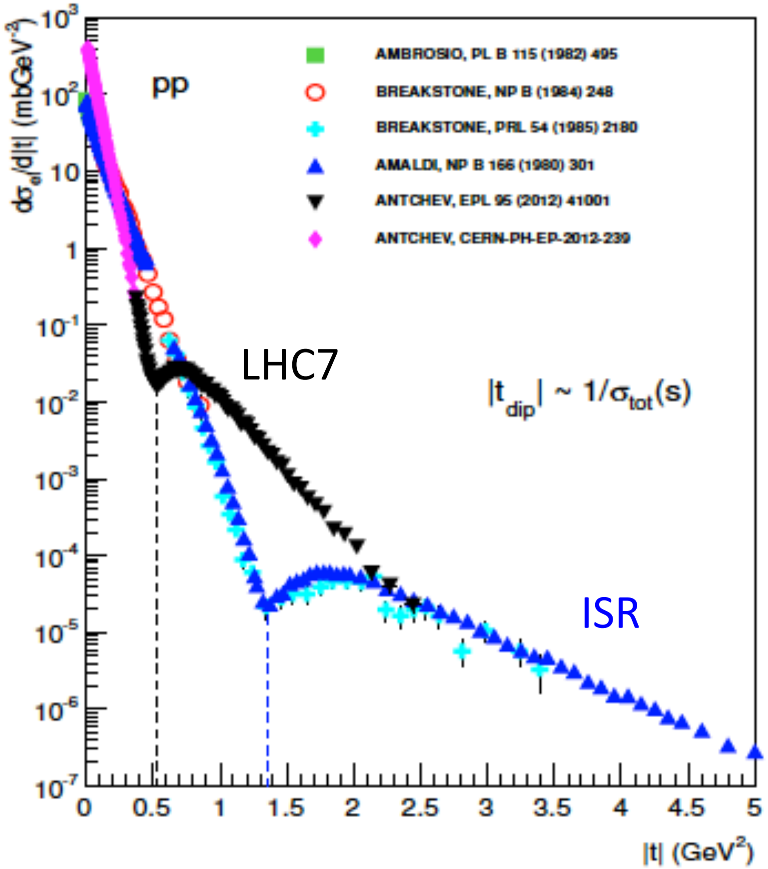
TOTEM data 2011: the elastic differential cross-section

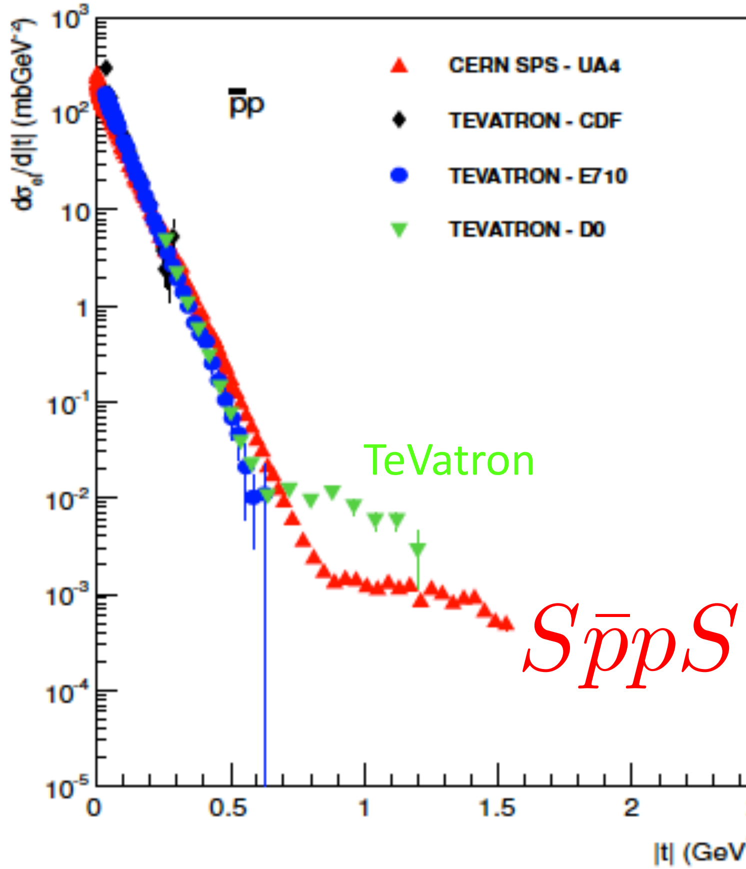


The return of the **dip!** It had not been seen since ISR

[because it not really present in pbarp]

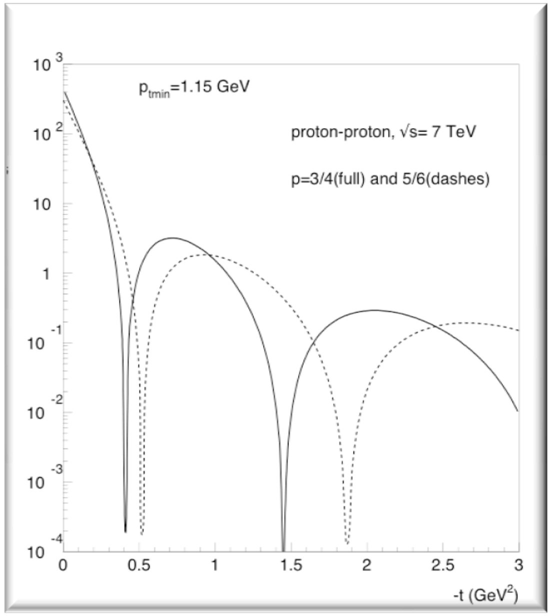
Elastic ISR,LHC pp S $p\bar{p}$ S,Tevatron $p\bar{p}$





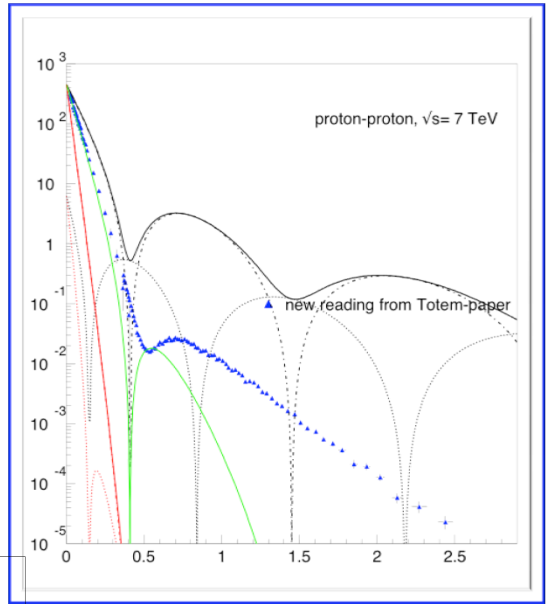
From D. Fagundes, DIS 2013 Marseille

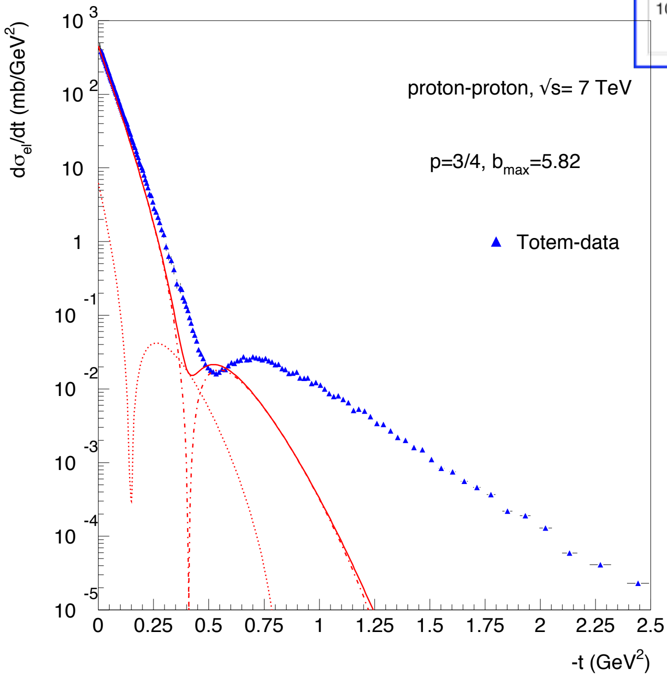
Our QCD one-channel eikonal model with mini-jets and resummation



Purely imaginary eikonal

With real part a' la Martin





Complex eikonal
With a gaussian cutoff
In b-space: but the dip and tail are still wrong
Parameters could be added
But choose to change strategy

Change in strategy: break up the amplitude in its components

- The optical point $$\frac{d\sigma}{dt}|_{t=0} \propto \sigma_{tot}^2$$
- The forward precipitous descent $$\frac{d\sigma}{dt}|_{t\sim 0} \propto e^{-Bt}$$
- The dip in pp (and not in pbarp) $a\ phase\ ?$
- The tail $$\frac{d\sigma}{dt} \sim t^{-(7\div 8)}$$

Empirical model for pp scattering from ISR to LHC, from the optical point to past the dip

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

$$G(s,t) \equiv 1$$

Barger-Phillis 1973
ISR data

Grau, GP,Pacetti,Srivastava 2012
ISR & LHC7

This work, 2013, with D. Fagundes $G(s,0) = 1$

$$G(s,t) = e^{-\sqrt{4\mu_\pi^2 - t} - 2\mu_\pi}$$

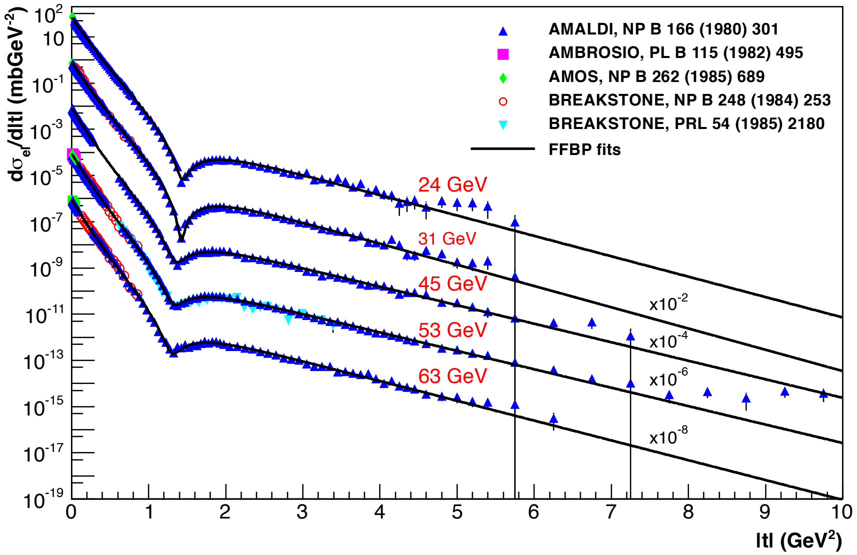
Pion-loop singularity
Anselm&gribov, KMR, Jenkovszki

$$G(s,t) = [\frac{1}{(1-t/t_0)^2}]^2$$

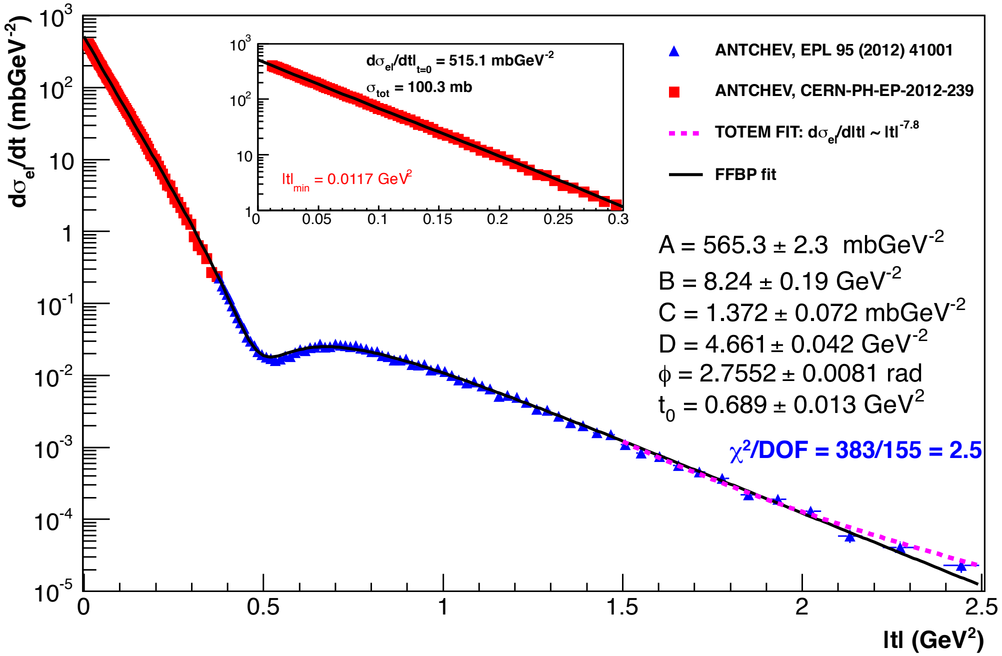
Proton form factor

BP model with Proton Form Factor

ISR for pp



TOTEM LHC7 for pp



How about physical meaning and predictions for higher energies?

Leading term

Non leading at t=0

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

Form factor

$\sim \sigma_{total}$

Mixture of $C = \pm 1$

Forward slope

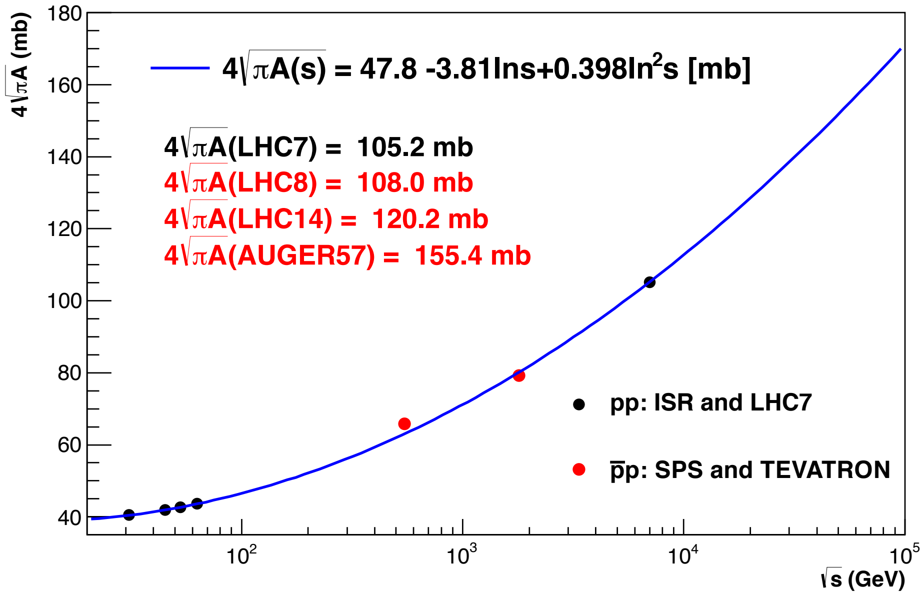
Can one make predictions?

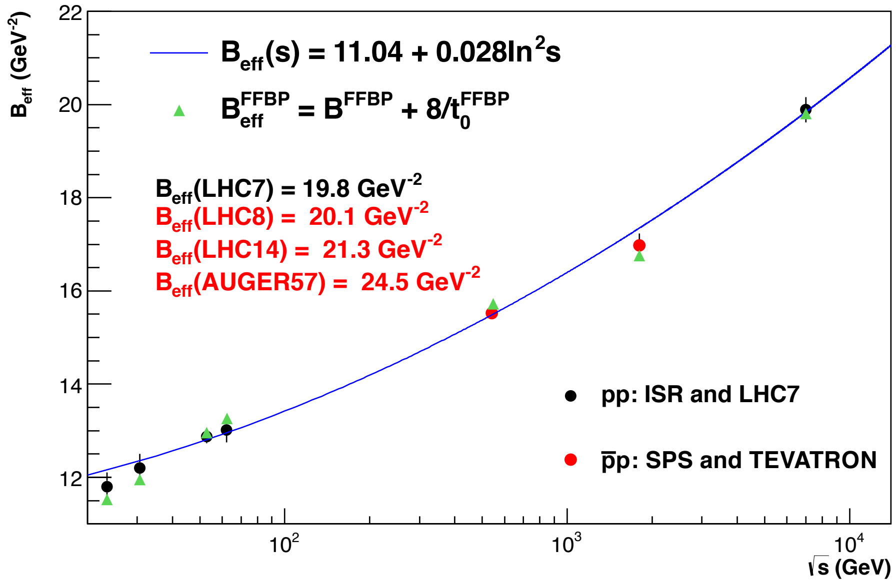
An asymptotic model of maximal saturation

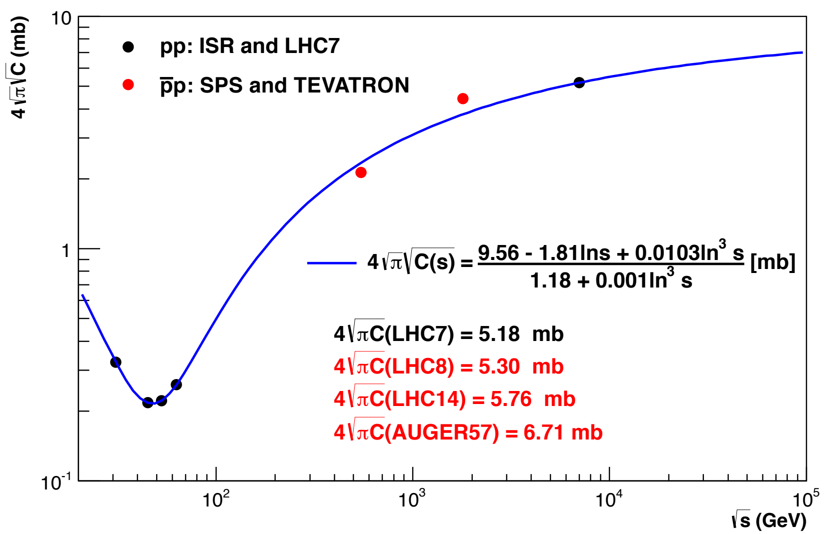
- Froissart-Martin bound $\sigma_{total} \sim (\log s/s_0)^2$
- Khuri-Kinoshita $\rho(s) = \frac{\Re e \mathcal{A}(s,0)}{\Im m \mathcal{A}(s,0)} \sim \frac{\pi}{\log s}$
- Total absorption at b=0 $\Re e \mathcal{F}(s, b=0) = 0$

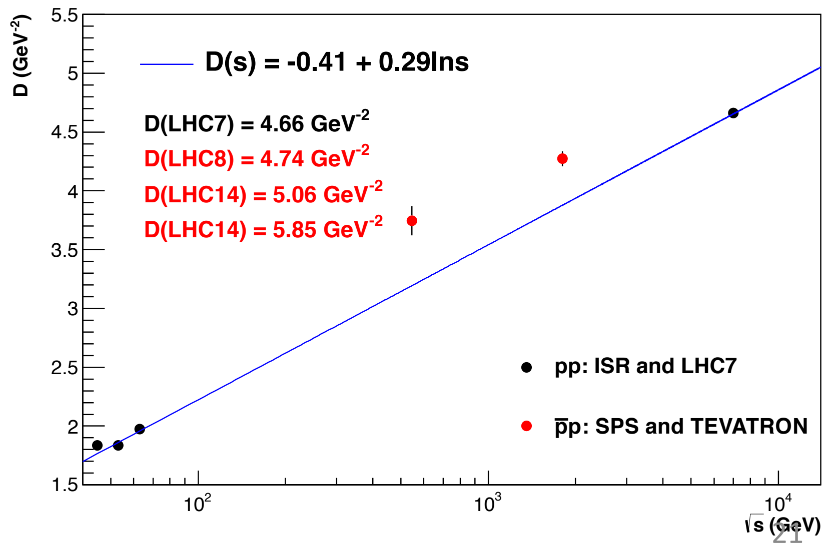
$$\Im m \mathcal{F}(s, b=0) = 1$$

Asymptotic model for pp $\bar{p}p$





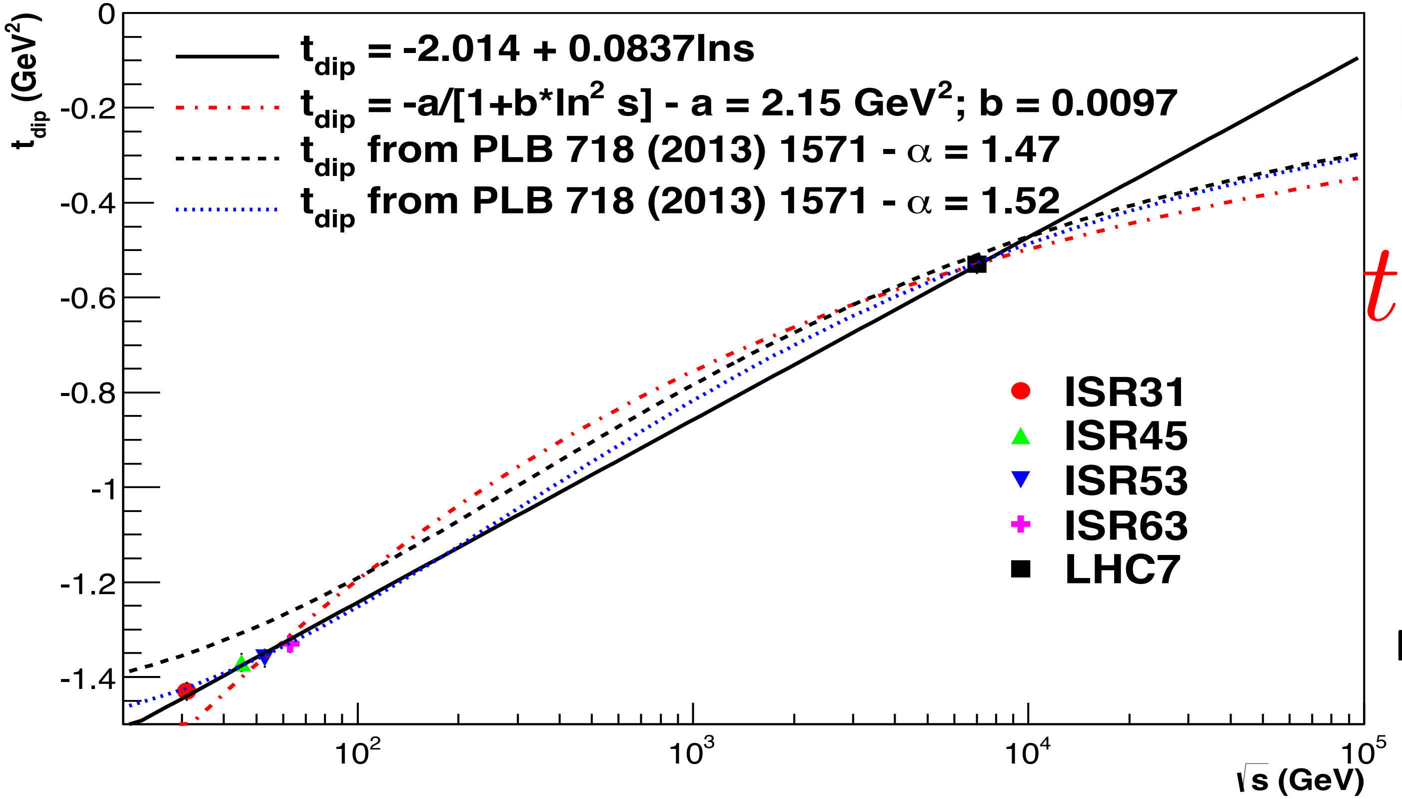




ϕ

How about ϕ ?

- t-independent in the model – probably average over t
- approximately constant from ISR to LHC7
- determines the dip position (together with the other parameters)

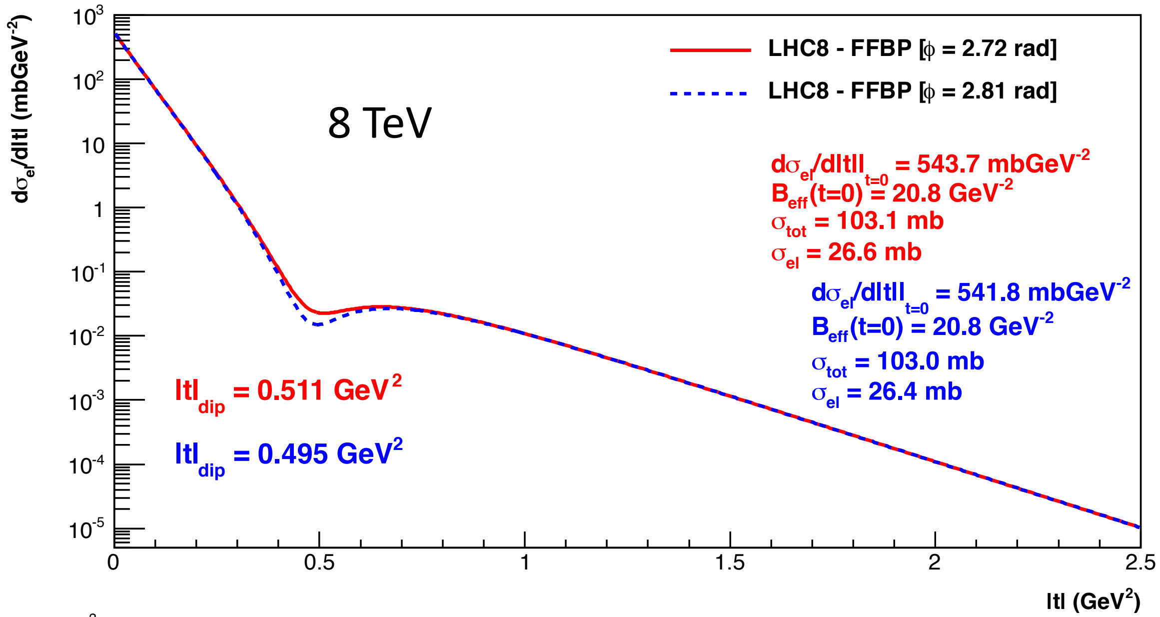


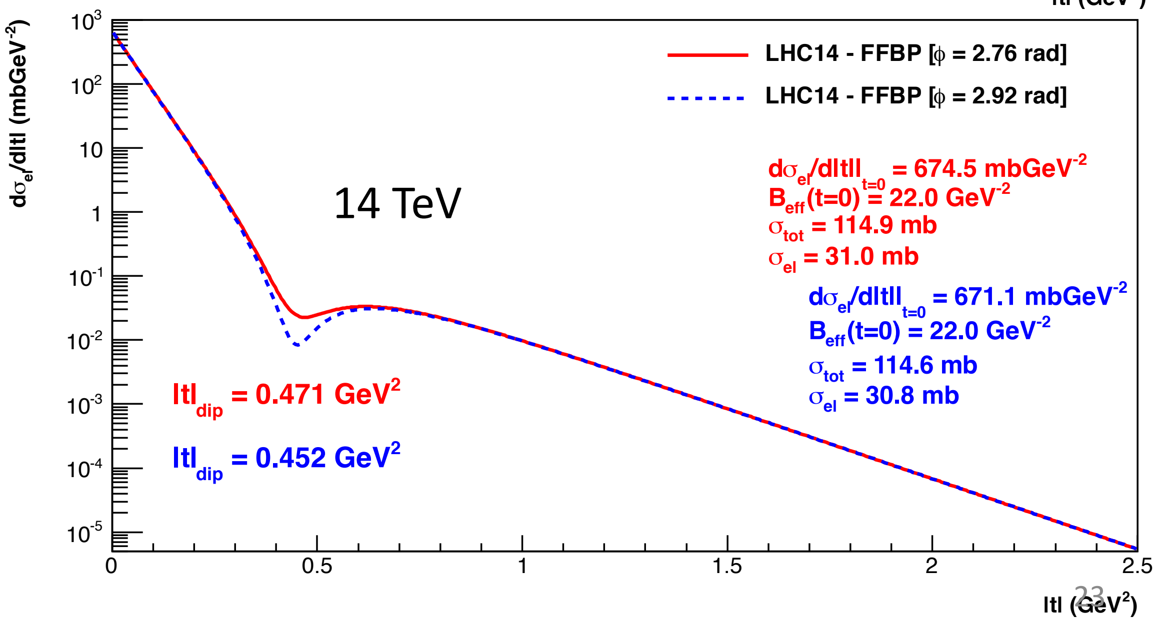
$t_{dip}\ vs. \sqrt{s}$

Fix ϕ for higher energies

Predictions from asymptotic model

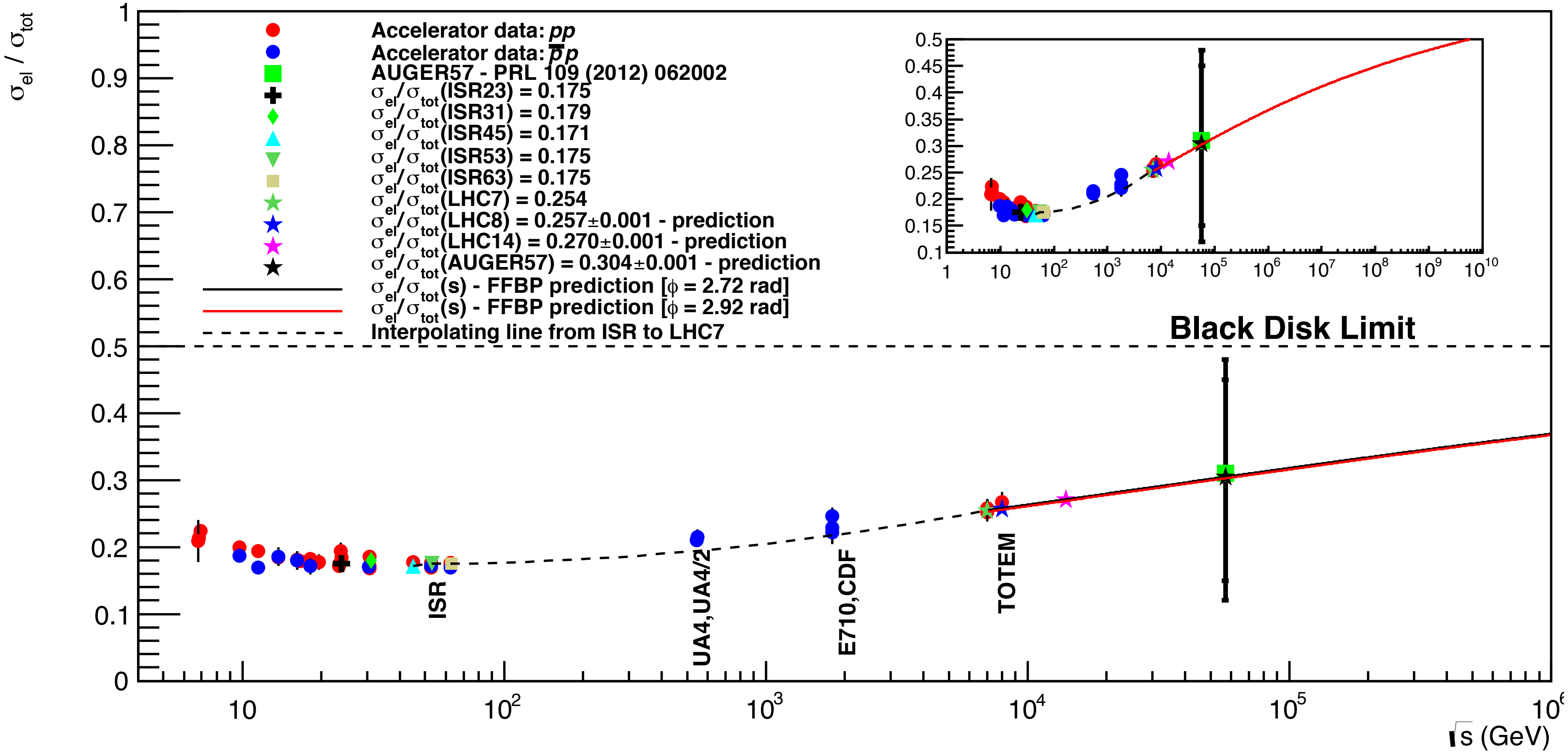
At any given energy
the difference
Is in the phase,
Which is so far
unconstraind





The black disk limit in the asymptotic model

$$R_{el} = \frac{\sigma_{elastic}}{\sigma_{total}}$$



The black disk limit in this asymptotic extrapolation is not reached until

$$\sqrt{s} \sim 10^5 \ TeV$$

Outlook

- Include Diffraction in our QCD model
- Compare with empirical BP model to understand role of non-leading term
- Wait for LHC8 and LHC14 (mostly) new data

SPARES

Outline

LHC7 and LHC8: new data for elastic and total pp scattering
Ultimate chance to study large and small distances QCD
Total cross-section: confinement dominates
Still far from understanding
A soft kt-resummation model for total cross-section (BN model)
Application to elastic differential cross-section and difficulties
Change of perspective: find a good parametrization to analyze data
The Barger and Phillips model
Fits and facts
Asymptotic predictions
The dip
The black Disk limit
Outlook

The eikonal mini-jet model with infrared soft gluon resummation links confinement to the total cross-section

1. One channel eikonal format (to be improved next) with real profile function $\chi_I(b,s)$

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

1. Profile $\chi_I(b,s)$ function built with
   - QCD Minijets to get the rise: use actual PDF (LO)

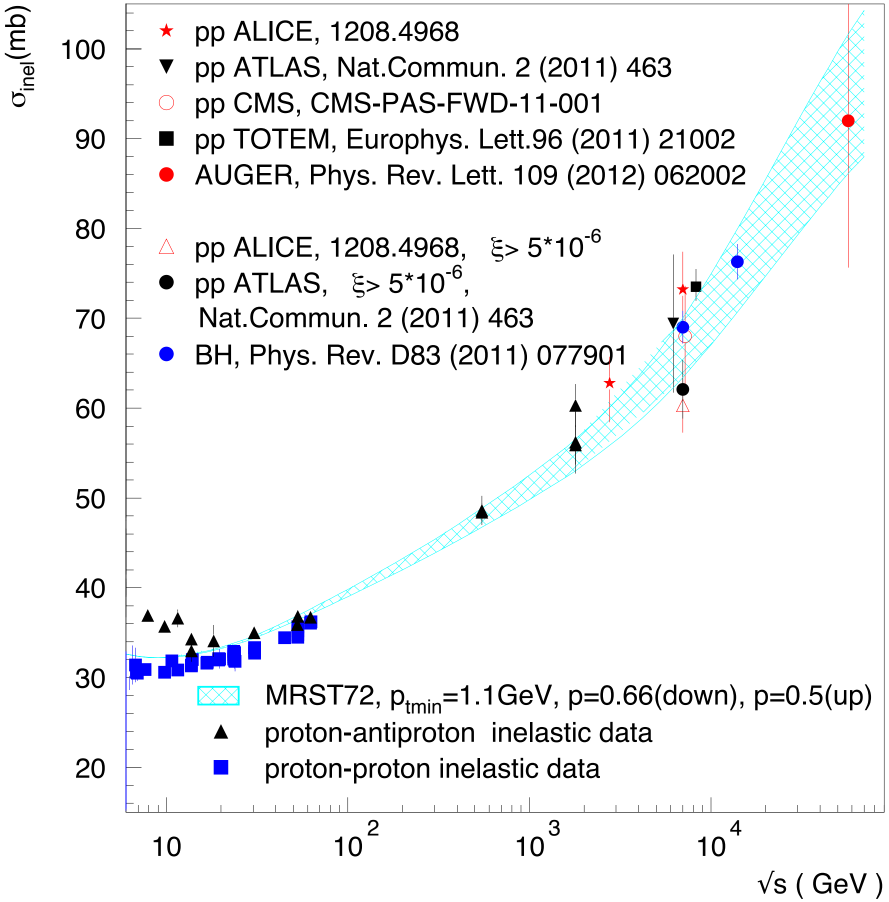
$$\sigma_{mini-jet} \sim s^{0.3-0.4}$$

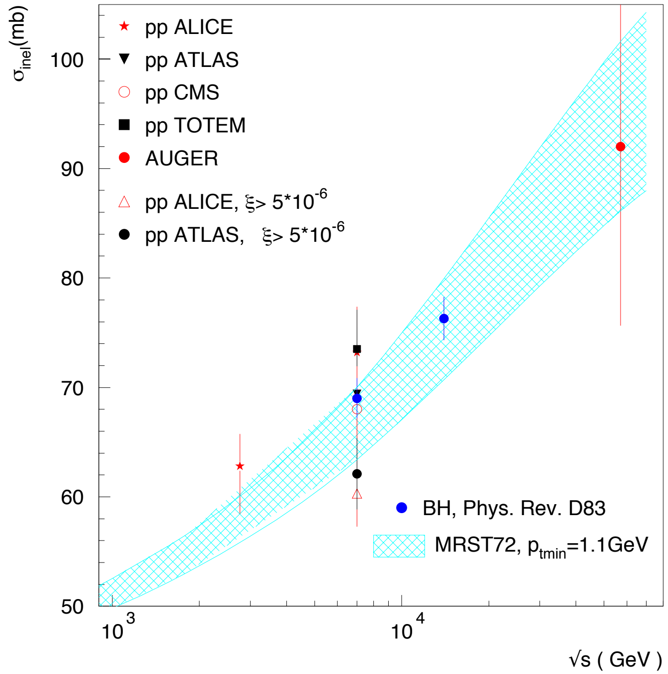
   - b-distribution from soft gluon emission in parton-parton scattering leading to saturation

$$A(b,s) = \mathcal{F}[soft\ gluons]$$

Update of PRD2012 analysis

With Olga Shekhovtsova





Why the uncertainty in the inelastic?

The problem with the inelastic: the extrapolation to diffractive region where particles are correlated

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

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

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

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

but

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

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

Zero Degrees: elastic scattering, total inelastic, total cross-section

- What do we have from a theoretical point of view? A large variety of theorems based on analyticity, crossing, and unitarity, basically

- For TOTAL CROSS-SECTION

  Optical theorem, only assumption is unitarity,

  Froissart bound with assumptions

- For ELASTIC amplitude $\mathcal{A}(s,t)$
  - t=0 ok

  Asymptotic theorems with assumptions : such as Froissart bound for Imaginary part at t=0, Kinoshita-Khuri for $\rho(s,t=0)$

- Martin suggestion for

$$\Re e F_+(s,t) \simeq \rho(s)\frac{d}{dt}[t\Im m F_+(s,t)]$$

- for the inelastic?

$$\sigma_{inelastic} \equiv \sigma_{total} - \sigma_{elastic}$$

In Eikonal models

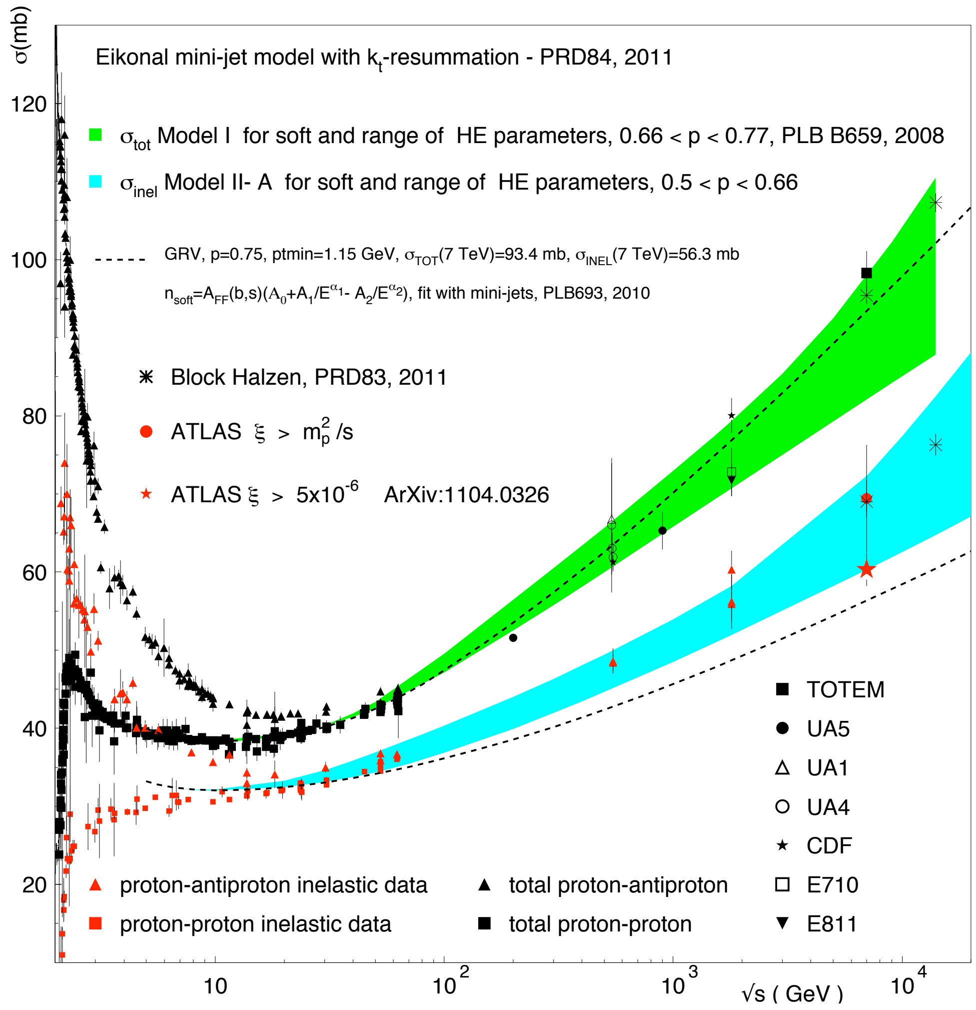
$$\sigma_{inel} = \sigma_{total} - \sigma_{elastic} = \int d^2\mathbf{b}[1 - e^{-2\Im\chi(b,s)}]$$

one channel eikonal approach: formula interpretation
advantage: once you have the imaginary part , you do not need further modeling, but you miss the two channel eikonal : needs further modeling

Our approach for the time being: the singularity parameter of our QCD model can span the region and then use
sigmatotal=sigmainel+sigmaelastic work is in progress, FIGURE

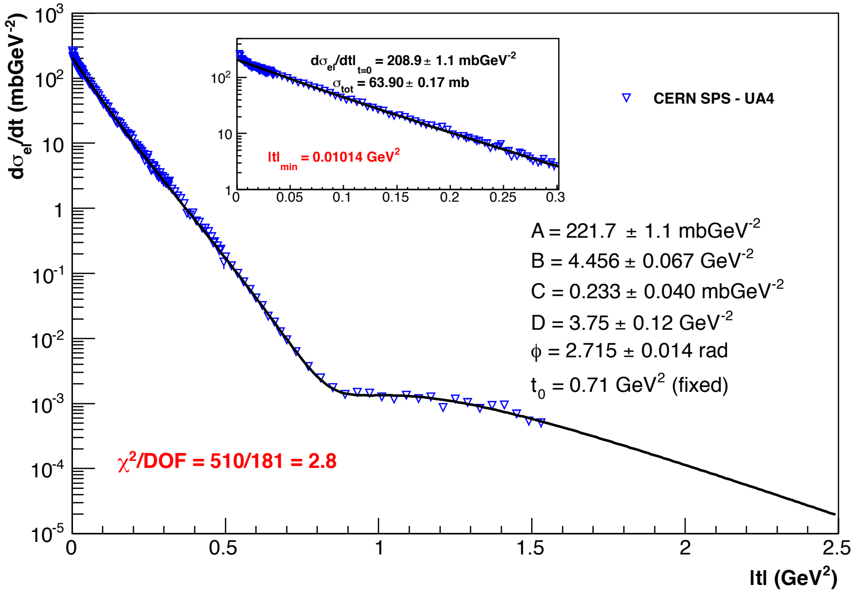
let me describe our model, whose aim is to give a QCD partonic interpretation to all the components of
forward scattering, elastic, total
and inelastic non-diffractive. At present clear ideas about total, some ifdeads about inelastic, lots of work in progress for the elastic.

The inelastic cross-section

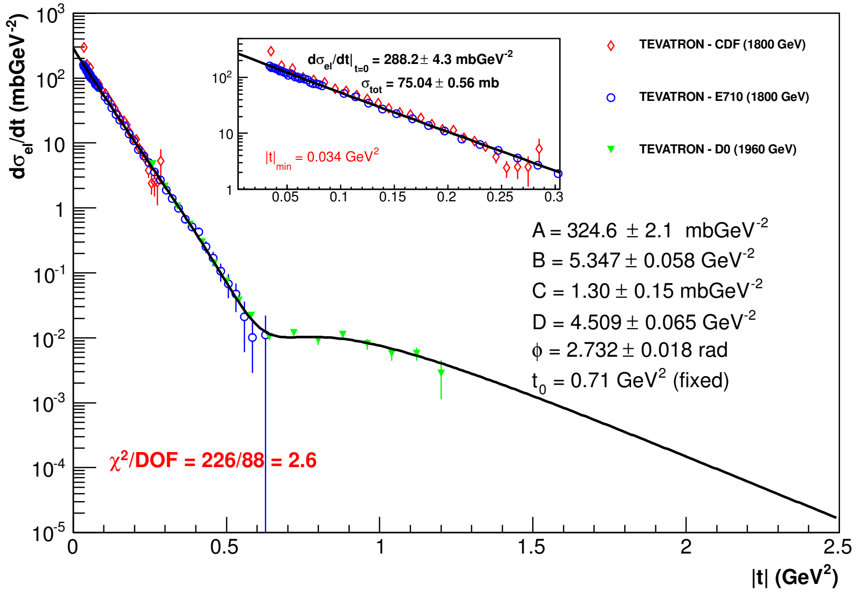


Empirical model applied to pbarp

UA4 data



CD-E710-D0 data



Asymptotic model

From asymptotic theorems

$$4\sqrt{\pi A(s)}(mb) = 47.8 - 3.8\log s + 0.398(\log s)^2$$

$$B(s)(GeV^{-2}) = 11.04 + 0.028(\log s)^2 - \frac{8}{0.71} = -0.23 + 0.028(\log s)^2$$

$$D(s)(GeV^{-2}) = -0.41 + 0.29\log s$$

Empirical

$$4\sqrt{\pi C(s)}(mb) = \frac{9.6 - 1.8\log s + 0.01(\log s)^3}{1.2 + 0.001(\log s)^3}$$