p-air production cross-section and uncorrelated mini-jets processes in pp-scattering

Giulia Pancheri- INFN – Frascati
with
D.A. Fagundes, A. Grau, Y.N. Srivastava, O. Shekhovtsova

Thanks to the Organizers!

Outline of a study of

Uncorrelated processes in pp scattering from a minijet model with soft gluon k-t resummation applied to p-air production cross-section

- Our model for pp : called Bloch Nordsieck (BN) model because of resummation down to zero momenta [PLB 1996, PRD 1999, PRD 2005]

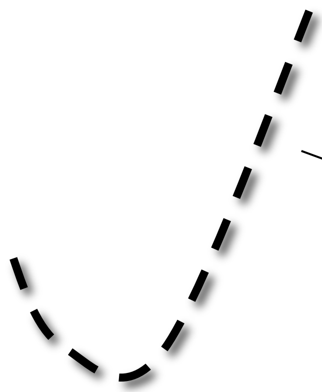
- Photoproduction and showers [under completion]

- pp and p-air cross-section model [arXiv:1408.2921]

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

What generates the rise? Low-x parton collisions

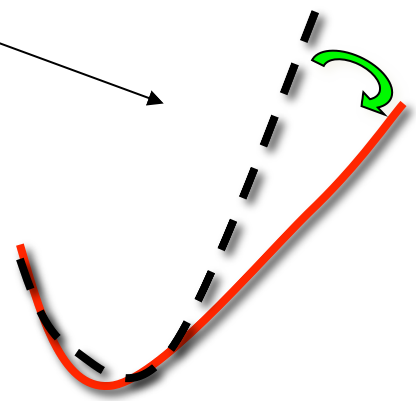
Cline,Halzen &Luthe 1973
Gaisser, Halzen,Stanev 1985
G.P., Y.N. Srivastava 1986
Durand,Pi 1987
Sjostrand, van Zijl 1987
…



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

How to go from
hard to soft ?

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**]

State-of-the-art of total cross-section : before LHC and AUGER

1973
Barger

VOLUME 33, NUMBER 17 PHYSICAL REV

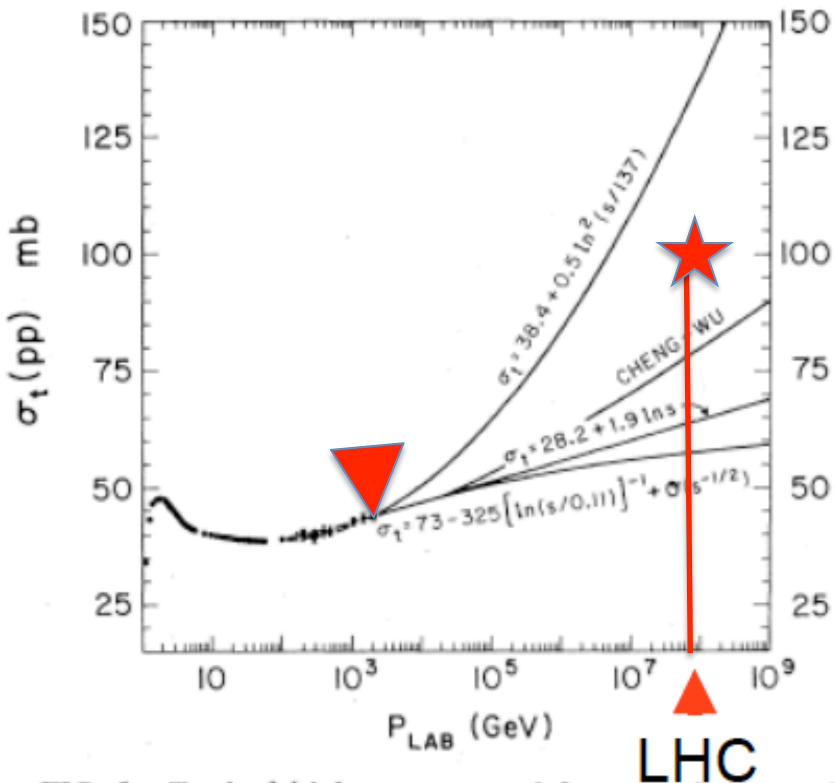
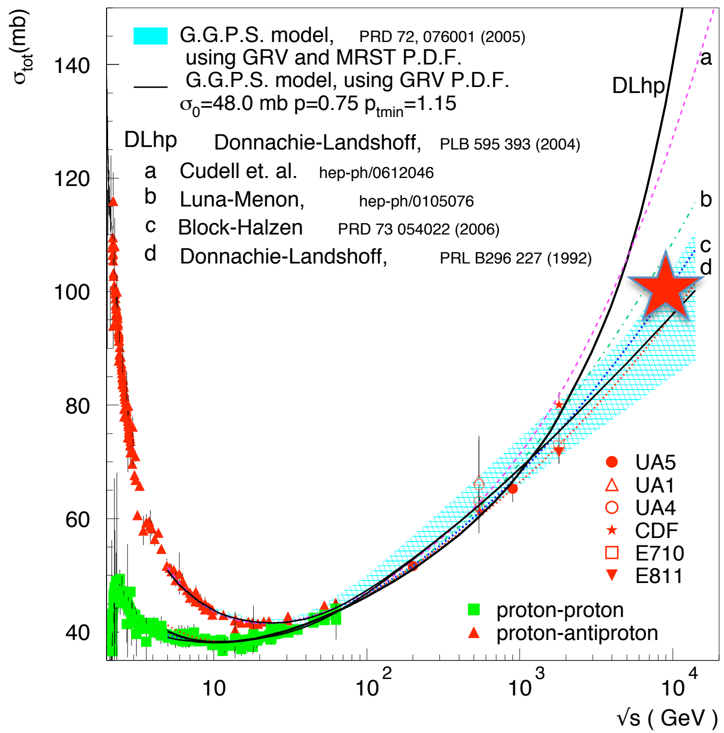


FIG. 1. Typical high-energy model extrapolations of the proton-proton total cross section to the energy range accessible to extensive-air-shower experiments.

2008, PLB, GP etc.



Our QCD model for the total cross-section

R. Godbole, A. Grau, GP, YN Srivastava

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

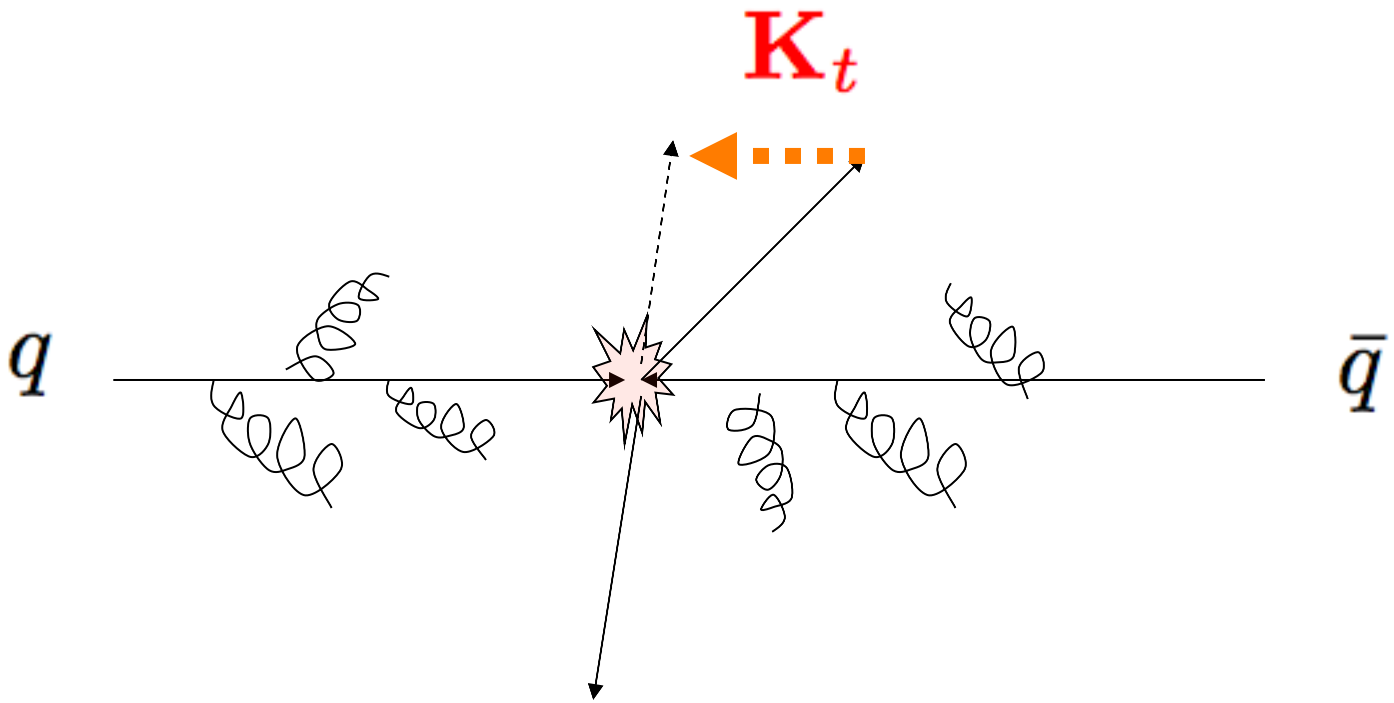
$$2\chi_I(b,s) = \sigma_{soft} + A(b,s)\sigma_{jet}$$

- Minijets to drive the rise
- Soft kt-resummation to tame the rise and introduce the cut-off needed to satisfy theFroissart bound

- Phenomenological singular but integrable soft gluon coupling to relate confinement with the rise
- Interpolation between soft and asymptotic freedom region

PLB1996-PRD2005

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

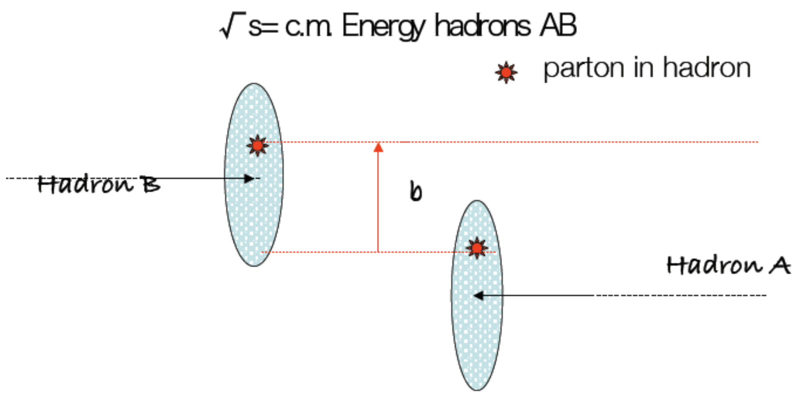
We model the impact parameter distribution as the Fourier-transform of ISR soft k_t distribution and thus obtain a cut-off at large distances : Froissart bound?

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

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

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

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



q_{tmax} ? Fixed by single gluon emission kinematics

Major traits of our model

- Energy rise from mini-jets (to be obtained from DGLAP evoluted PDF and parton-parton x-sections)

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

- Saturation comes as a large distance effect: at large distances, soft gluon emission leads to a cut-off

$$A(b,s) \sim e^{-[b\bar{\Lambda}(s)]^{2p}}$$

- Embedded into eikonal formulation

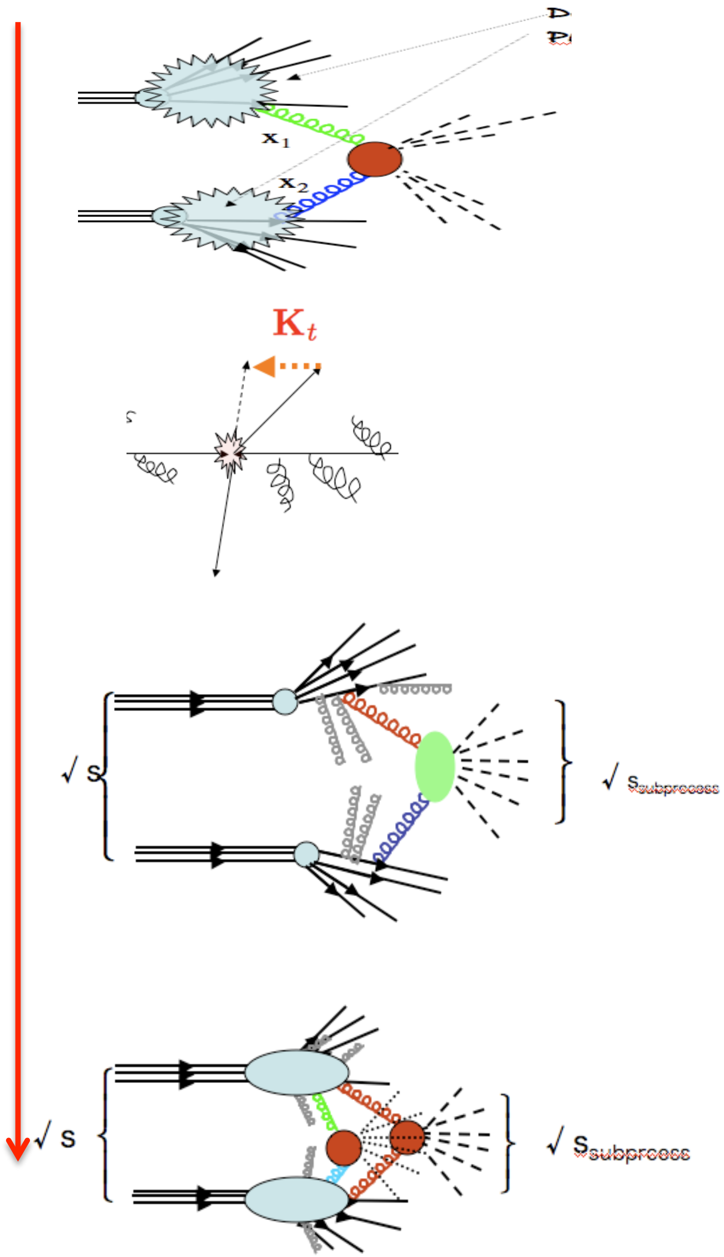
In our model, the emission of singular infrared gluons tames low-x gluon-gluon scattering (mini-jets) and restores the Froissart bound

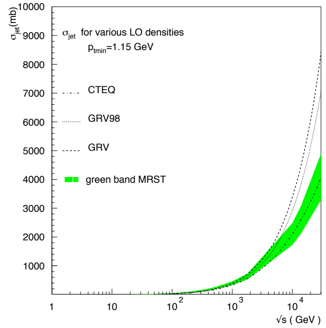
s^{ε}

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

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

Grau, Godbole,GP,Srivastava,PLB682 2009

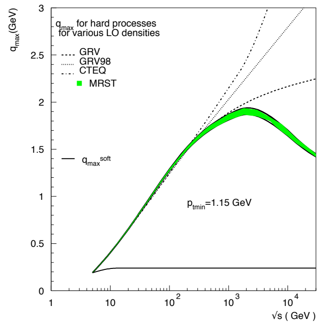




1. Calculate mini-jet cross-section
Choosing densities and ptmin

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

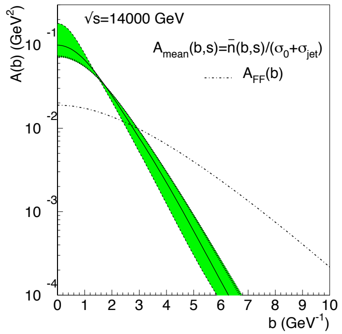
$$\epsilon \simeq 0.3 - 0.4$$



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

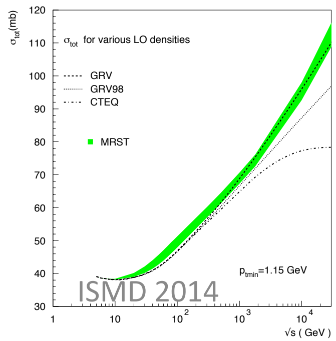
$$q_{max} \simeq p_{tmin}$$

$$\lesssim 2 - 3\ GeV$$



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

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

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

- Elastic cross-section: *pp* amplitude $-t \neq 0$

  well defined both theoretically and experimentally

$$\int_0^\infty dt\{[\Im m\mathcal{A}(s,t)]^2 + [\Re e\mathcal{A}(s,t)]^2\}$$

- Inelastic : what is not elastic!!! Yes, but not so simple, diffractive, central, large mass,small mass

Diffraction?

- Our model is so far a one-channel model
- This does neither allow a full description of elastic cross-section through the dip
- Nor does it include diffraction yet

- Basically because the model only includes ISR only for communicating partons in different protons, whereas diffraction is correlated emissions
- However, one-channel formalism allows to calculae a quantity very important in cosmic ray collisions.

Application to LHC7 data: ATLAS, CMS, TOTEM GP et al, PRD2011

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

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

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

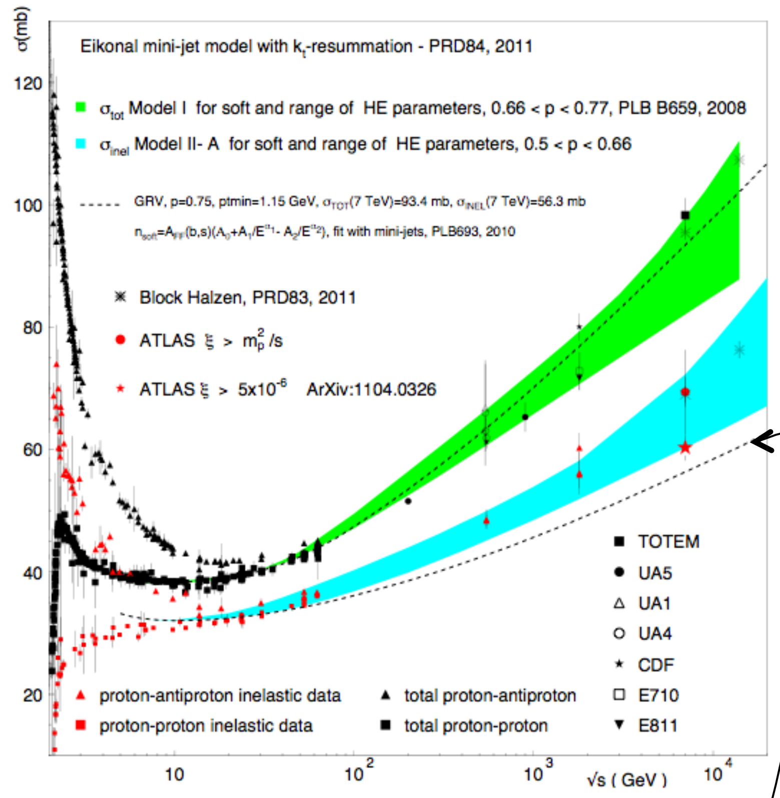
$$\sigma_{inel}(s) = \sum_{n=1} \int d^2\mathbf{b}\, P(\{n,\bar{n}\})$$

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

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

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

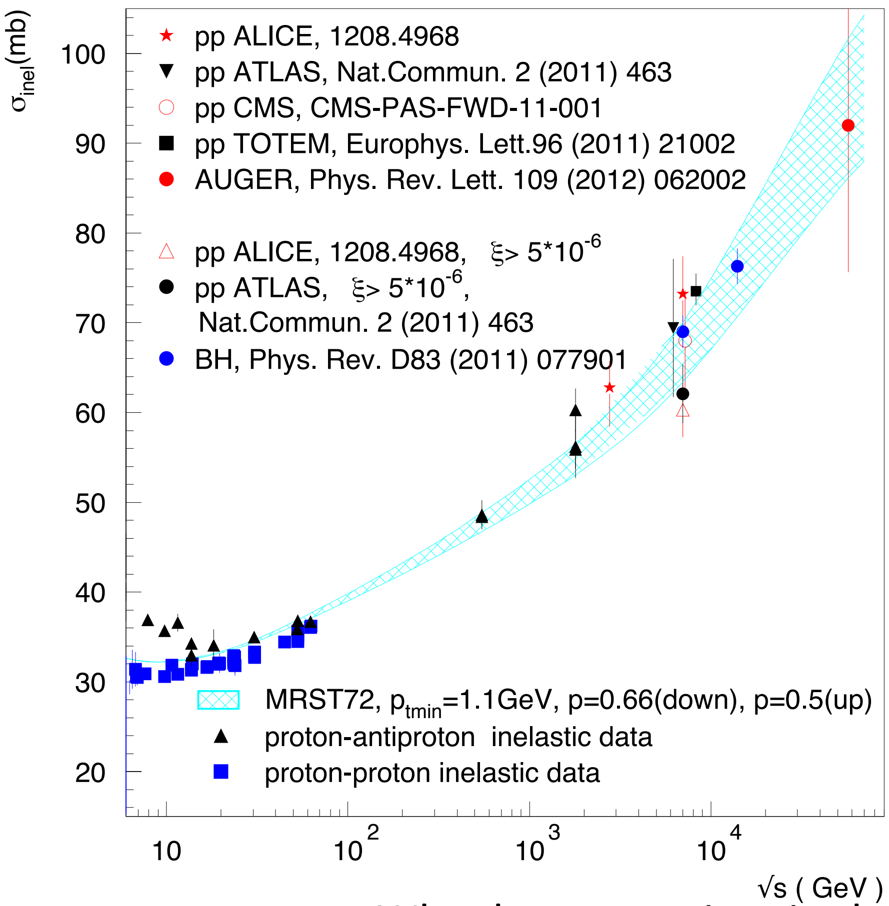
For a different approach : Lipari Lusignoli PRD2009]

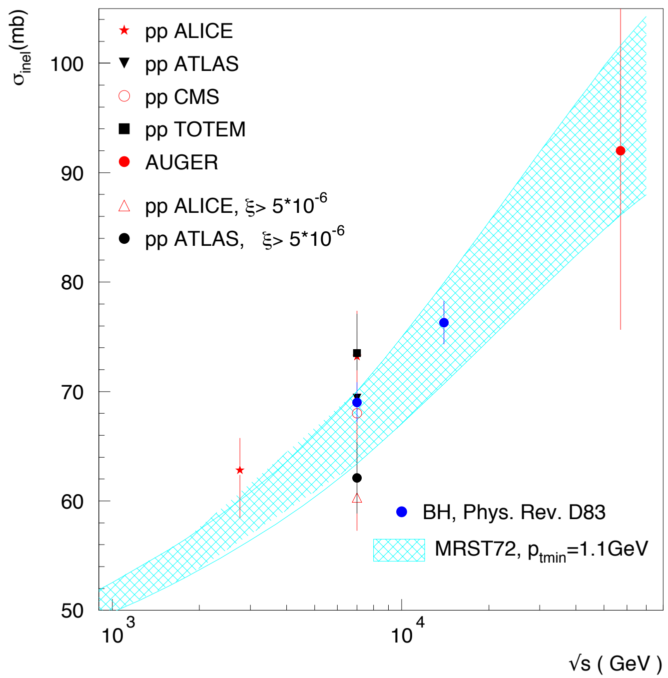


•Inelastic with 2-component eikonal is only non-correlated events
• Diffraction must have been put in the elastic!

Inelastic pp cross-section

Update of Phys.Rev. D84 (2011) 094009 with O. Shekhovtsova





Why the uncertainty in the inelastic? Models for diffraction

AUGER Collaboration Measurement 2012

- Different MCs

  Sybill

  QSGJET

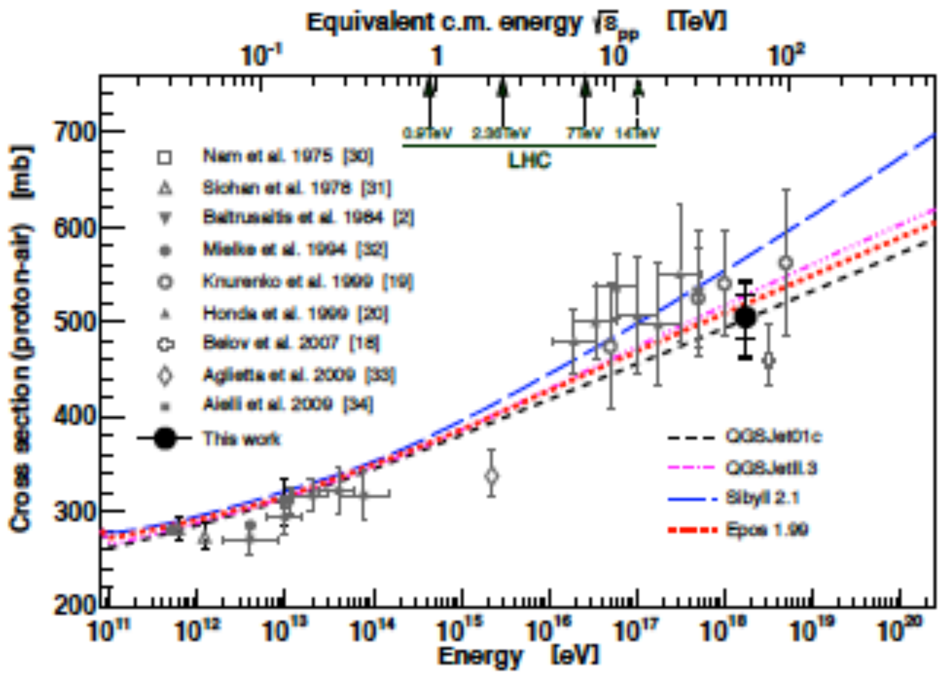
  EPOS

Give different results

- Errors are large

- Extraction of pp data at this energy is affected by large errors ~ 15%

p-air



$$\sigma_{pp}^{inel} = [92 \pm 7(stat)^{+9}_{-11} sys) \pm 7(Glauber)]mb$$

$$\sigma_{pp}^{tot} = [133 \pm (stat)^{+17}_{-20}(sys) \pm 16(Glauber)]mb$$

p-air production with or without diffraction?

- Usually $\sigma^{prod}_{p-air} = \sigma^{tot}_{p-air} - (\sigma^{el}_{p-air} + \sigma^{q-el}_{p-air})$
  - we need to model three terms in p-air + model diffraction in pp as well

BUT

There is no unique definition of diffraction (Khoze-ISVHECRI 2014)

- And then we need to take it away!

How can you take away something you do not see? (Katkov-ISVHECRI 2014)

Our proposal*:*

- In one-eikonal formalism

$$\sigma^{prod}_{p-air} = \int d^2\mathbf{b}[1 - e^{-2\chi_I^{p-air}}]$$

$$2\chi_I^{p-air} = n^{p-air}(b, E_{Lab})$$

Where only uncorrelated (Poisson distributed) p-air collisions are summed up in the integral

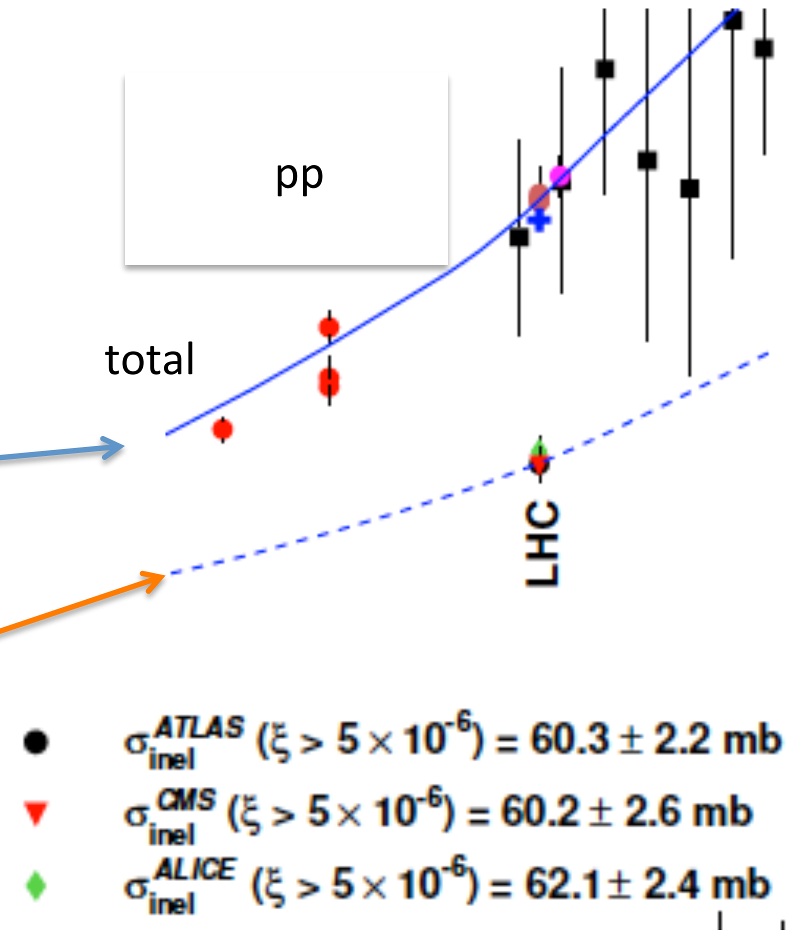
$$n^{p-air} \equiv n^{p-air}_{ind-coll} \quad \longleftrightarrow \quad \sigma^{pp}_{inel}$$

The non-diffractive part of σ_{inel}^{pp} can be obtained

1. from multichannel formalism, subtracting elastic and diffraction from the total, thus further modeling (KMR, GLM, Ostapchenko, … see Khoze's talk)

   Or

2. from one-channel eikonal formulations where a fit to the total gives the uncorrelated non-diffractive inelastic cross-section *for free*

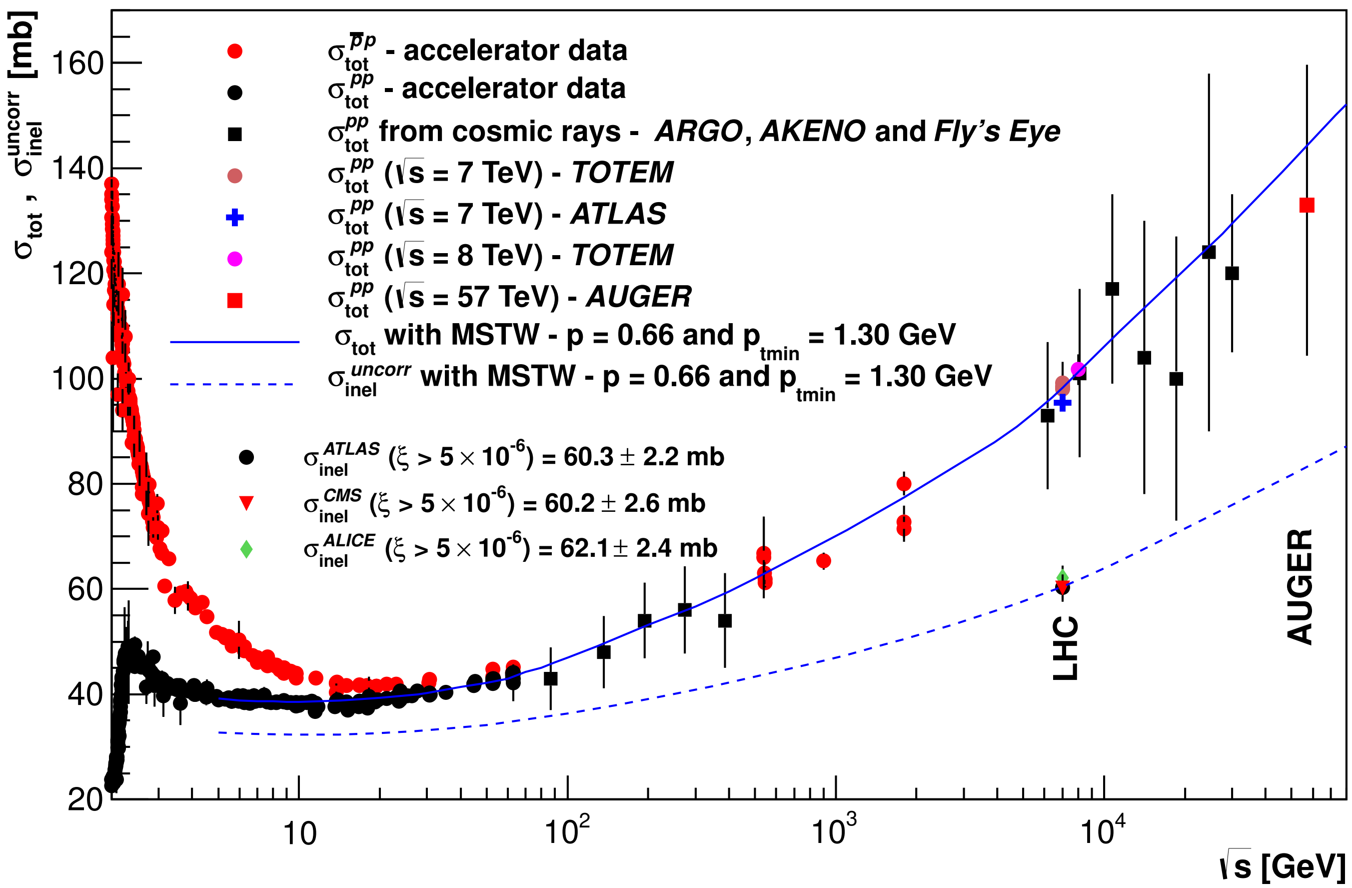


$$\sigma_{inel}^{pp} = \int d^2\mathbf{b}[1 - e^{-2\chi_I(b,s)}]$$

Achilli,Godbole, Grau,GP, Shekhovtsova, Srivastava
Phys.Rev. D84 (2011) 094009,

pp : Updated (after LHC) modeling of total and central inelastic collisions with one-channel eikonal, mini-jet with soft gluon resummation model arXiv:1408.2921

MSTW LO densities for mini-jet cross-sections



Now … to p-air

$$n_{p-air}(b,s) = T_N(\mathbf{b})\sigma_{\mathbf{inel}}^{\mathbf{pp}}(\mathbf{s})$$

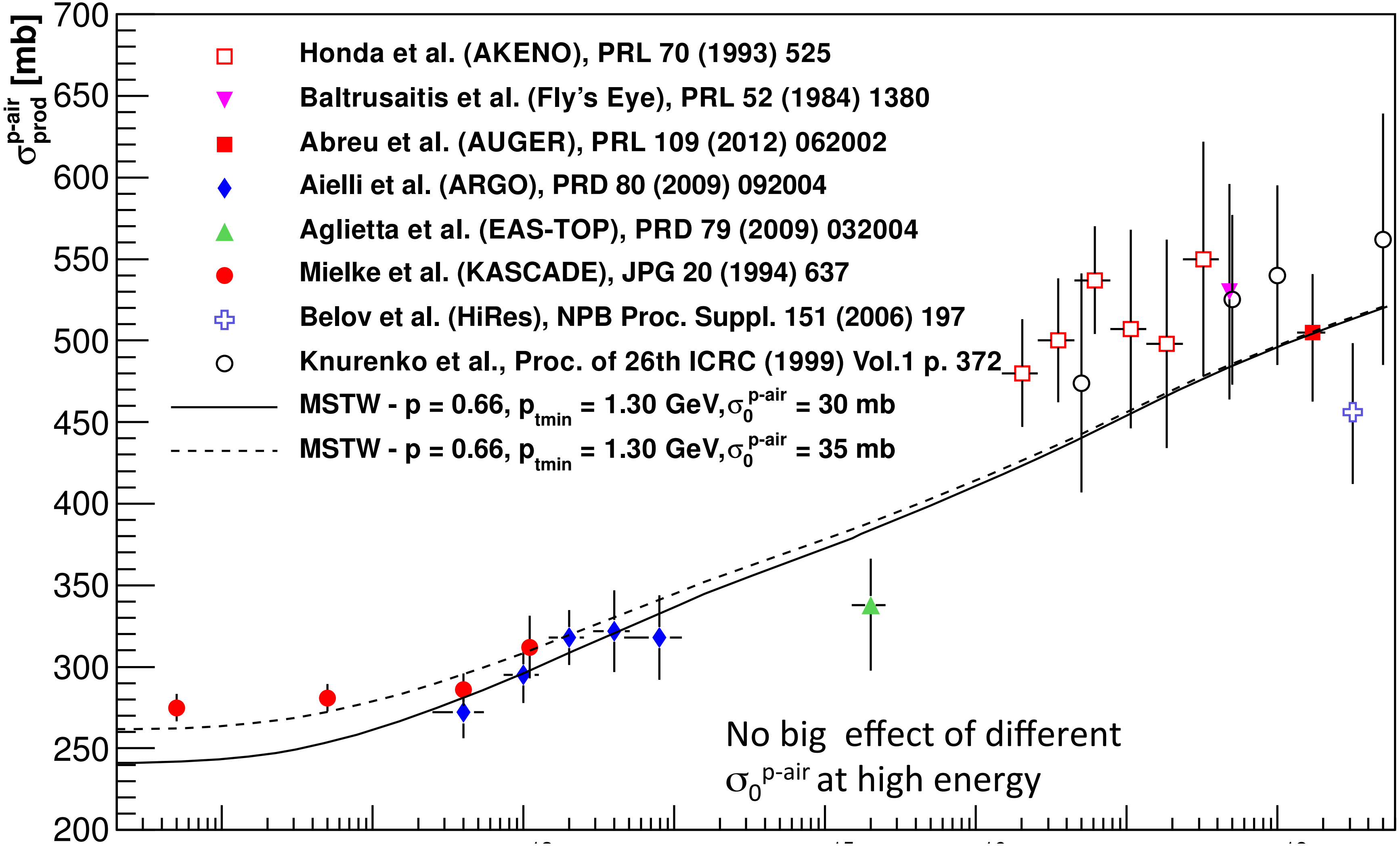
$$T_N(b) = \frac{A}{\pi R_N^2}\mathrm{e}^{-b^2/R_N^2}$$

$$\int d^2\mathbf{b}T_N(b) = A$$

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

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

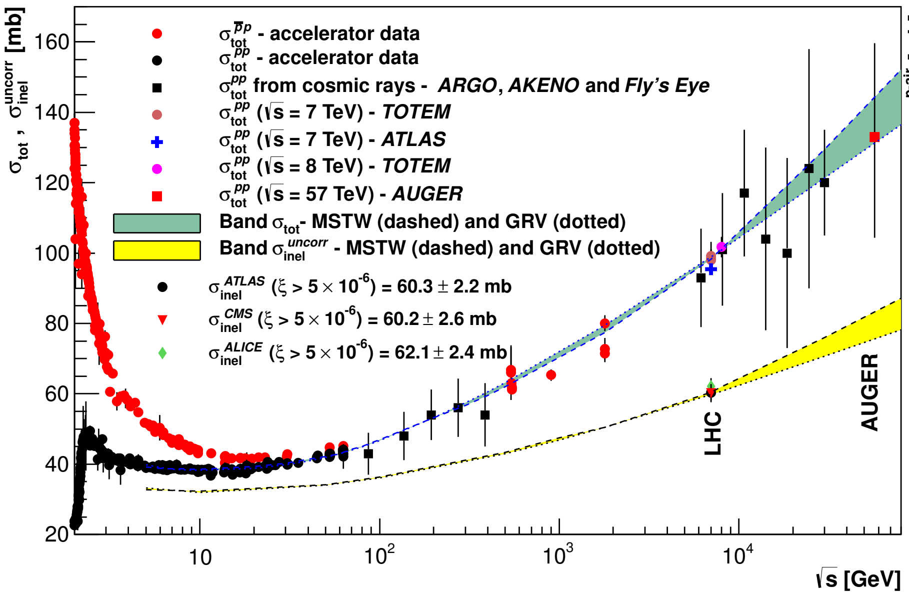
p-air = Glauber+inelastic pp



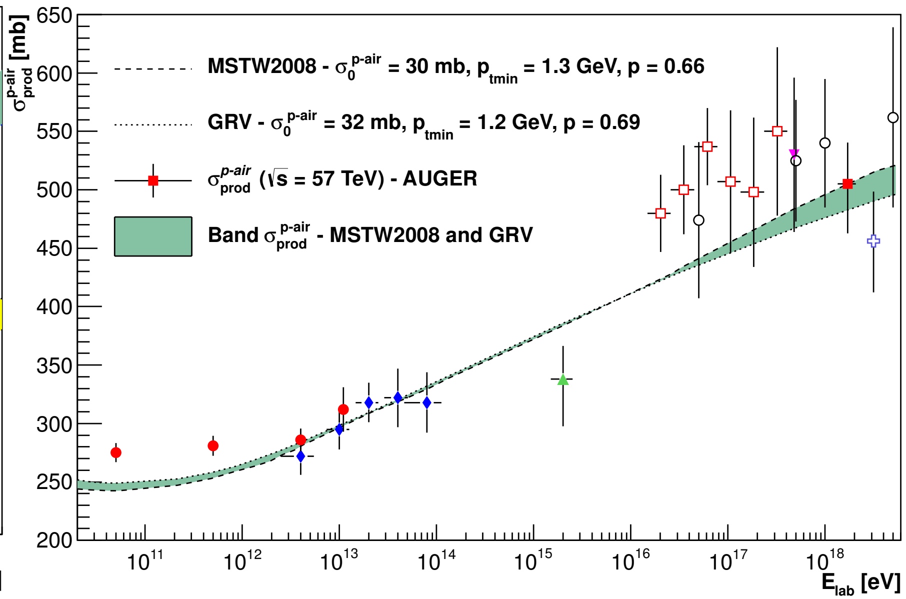
arXiv:1408.2921 with Fagundes, Grau, Srivastava, Shekhovtsova

From pp total to p-air production: estimating the uncertainty due to PDFs

pp



p-air



Calculation with LO PDFS:

1. GRV
2. MRST72
3. MSTW

Band = uncertainty in PDFs low-x parametrization in GRV or MSTW

Final comment (before conclusion)

Major differences with most other mini-jet models=>pQCD +explicit NPQCD

Mini-jet cross-sections

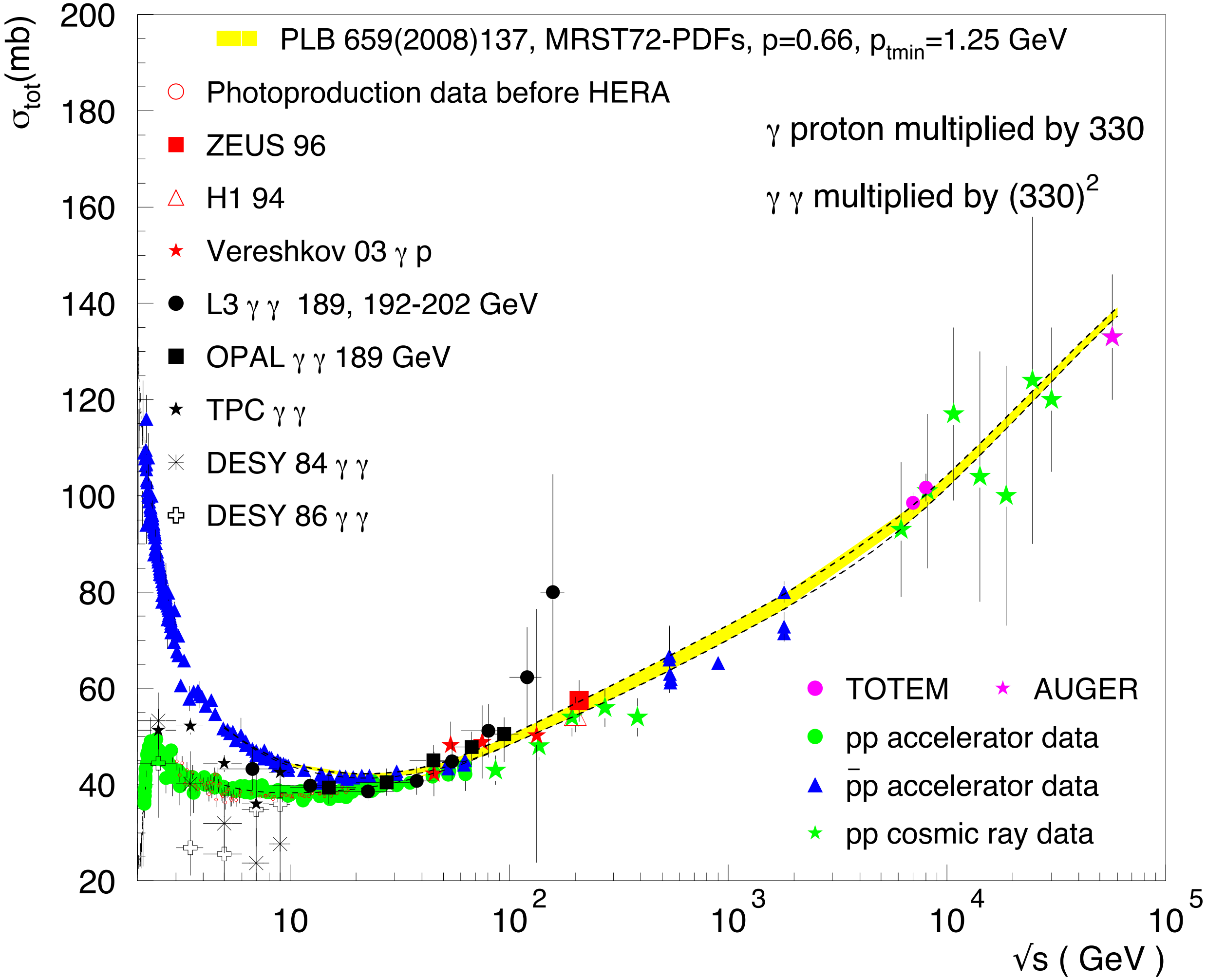
- We use LO parton-parton cross-sections and current DGLAP evoluted LO parton densities
  - GRV (various versions)
  - MRST72
  - MSTW (new)
- LO because model already includes all order gluon resummation (may be modified in the future)

Zero k_t gluons resummed

- Large distance cut-off (Froissart limit-FL) is obtained from resumming very small momentum gluons
- Direct connection to confinement : FL is a manifestation of confinement
  - Need to extend resummation below pQCD cut-off
  - Ansatz for $\alpha_s (k_t)$ with link to confining potential

All total cross-sections rise

Update of EPJC 2009, GP + R.M.Godbole, A. Grau, Y. Srivastava



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

OUR Model

Rise

Rise driven by low-x gluon-gluon collisions
minijets → p_t >1 GeV

Saturation

Acollinearity from ISR soft gluons, k_t resummed, reduces the mini-jet x-section and can lead to saturation

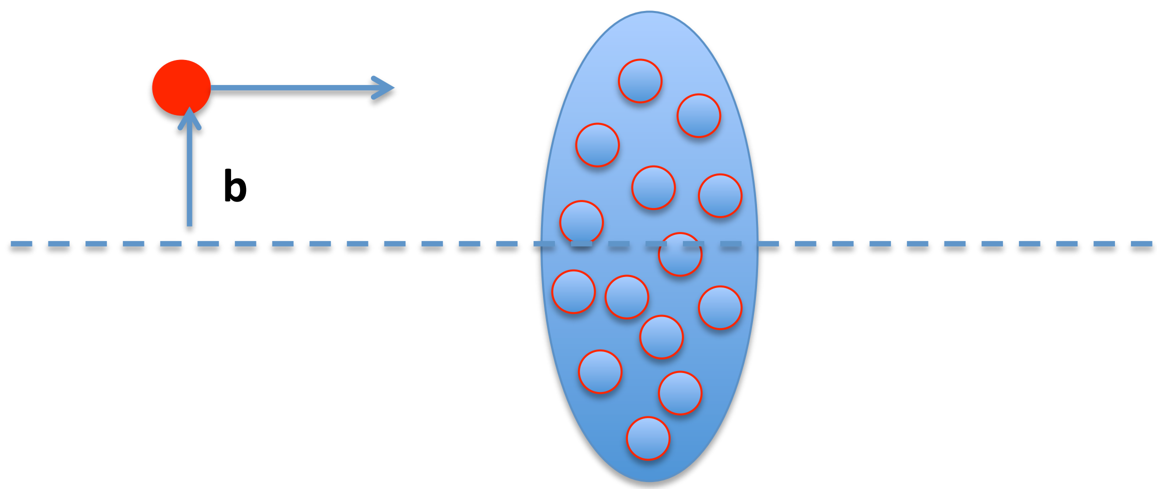
Conclusions

- The BN model can be extrapolated up to $\sqrt{s}$ = 50-100 TeV with uncertainty past LHC due to to low-x behaviour of PDFs

→ pp and γp can be explored at CR energies

- The one-channel eikonal gives an inelastic cross-section without the remnants of the proton

→ If you have a single eikonal that fits the total pp cross-section, that eikonal would give the uncorrelated, non diffractive inelastic cross-section which is what is needed for cosmic rays (Bloch, Kopeliovich, etc) without having to break up the total into pieces and then reassemble.


b

Lesson from p-air: a defense of one channel eikonal formalism

- In p-air one need the non-diffractive inelastic pp cross-section
- One channel eikonals (OCE) for pp give

  sigtot <->siginel-nondiff

Namely they directly give the non-diffractive inelastic input to a Glauber formalism

- Sigtot pp <-> siginel non diffractive without added parameters
- Extrapolation to full phase space is model dependent, but we dpo not need to do it for p-air calculations

Ansatz:

- The multichannel, GW or LL, eikonal formalism is needed for diffraction but at t=0 the amplitude must reduce to just one term, i.e. one-channel formalism

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

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

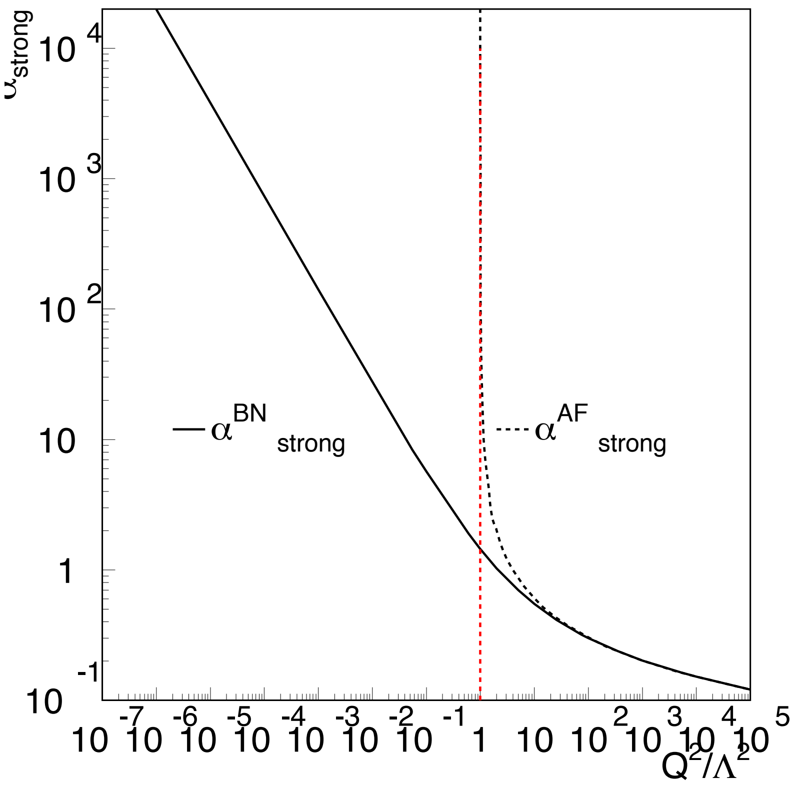
About our ansatz for α_s in the infrared

- The expression we use

$$\alpha_s(k_t^2) = \frac{p}{b_0 \ln[1 + p(\frac{k_t^2}{\Lambda^2})^p]}$$

$$\alpha_s(k_t^2) \to \frac{1}{b_0}(\frac{k_t}{\Lambda})^{-2p} \qquad k_t^2 << \Lambda^2$$

$$\alpha_s(k_t^2) \to \alpha_s^{AF}(k_t^2) = \frac{1}{b_0 \ln[\frac{k_t^2}{\Lambda^2}]} \qquad k_t^2 >> \Lambda^2$$



The actual calculation

1. Extension of the mini-jet model to photoproduction Eur.Phys.J. C63 (2009) 69-85

$$\sigma_{tot}^{\gamma p} = 2P_{had} \int d^2b \left[1 - e^{-n^{\gamma p}(b,s)/2}\right]$$

$$P_{had} = \sum_{V=\rho,\omega,\phi} \frac{4\pi\alpha}{f_V^2}$$

Mimics details of photon fluctuation into a hadron

$$n^{\gamma p}(b,s) = n_{soft}^{\gamma p}(b,s) + n_{hard}^{\gamma p}(b,s)$$

Fletcher, Gaisser, Halzen,Phys.Rev. D45 (1992) 377

$$n_{hard}^{\gamma p}(b,s) = A_{BN}(b,s)\sigma_{jet}^{\gamma p}(s)/P_{had}$$

resummation

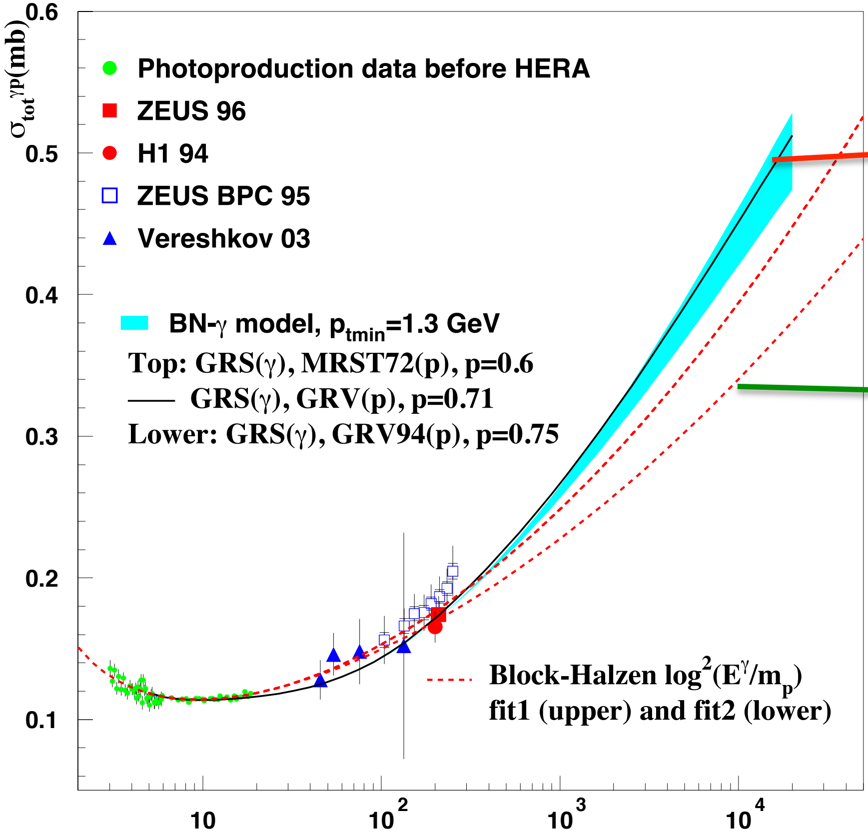
LO current PDFs

Input from our BN model

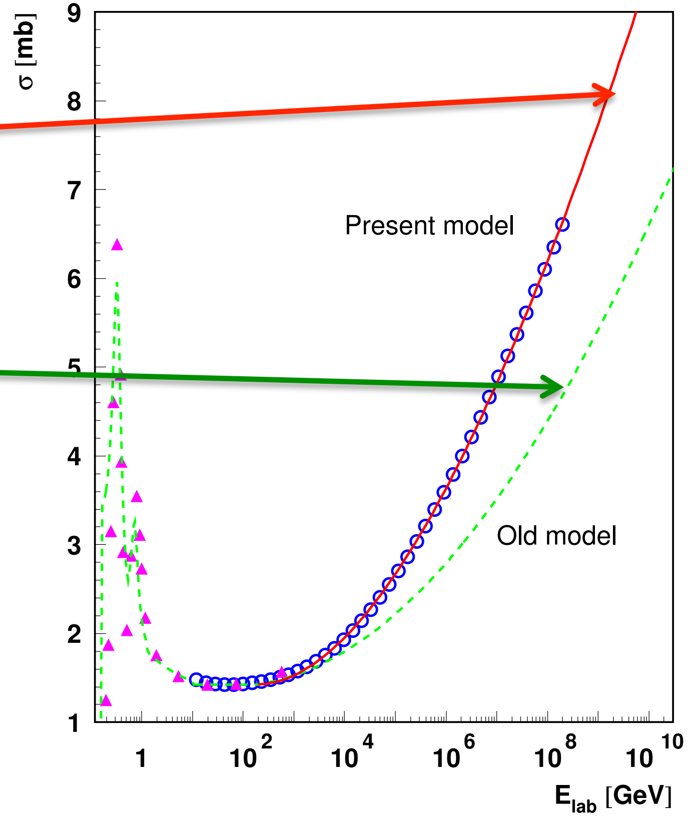
Shapes of shower observables

With F. Cornet, C.A. Garcia Canal , A. Grau and S. Sciutto

Photon-proton



Photon-air

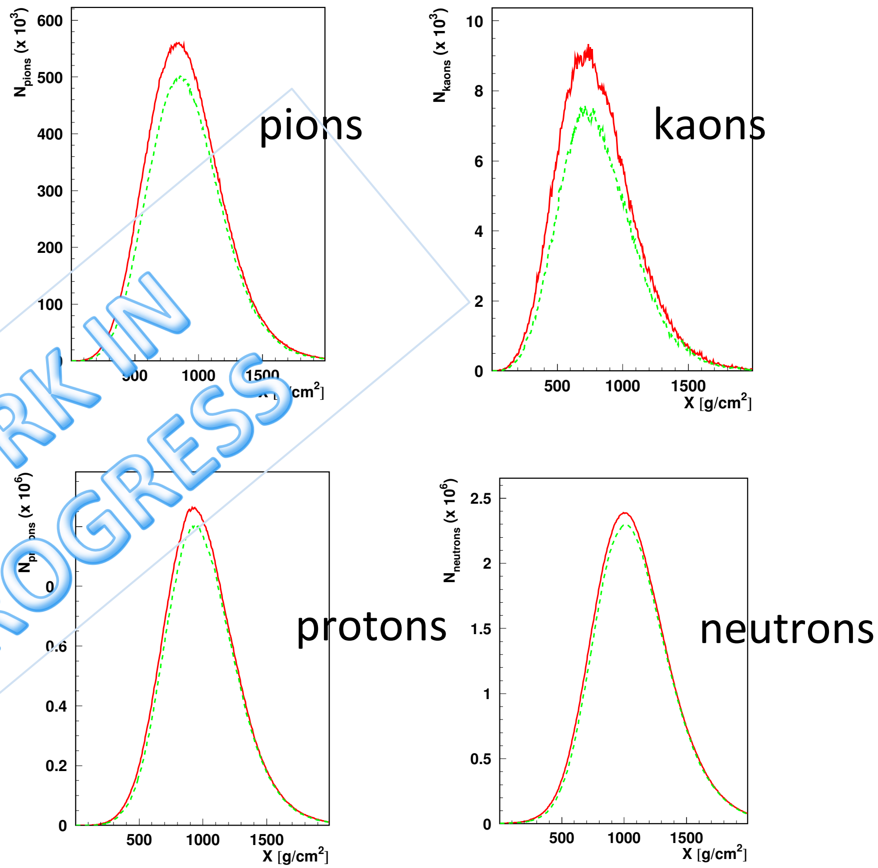


“old”= standard cross sections implemented in AIRES and other SP

Longitudinal shower development of hadrons from BN-γ model input

Using central curve from BN model for proton - γ cross-section into AIRES simulation

[On behalf of C. Garcia Canal, F. Cornet, S. Sciutto]

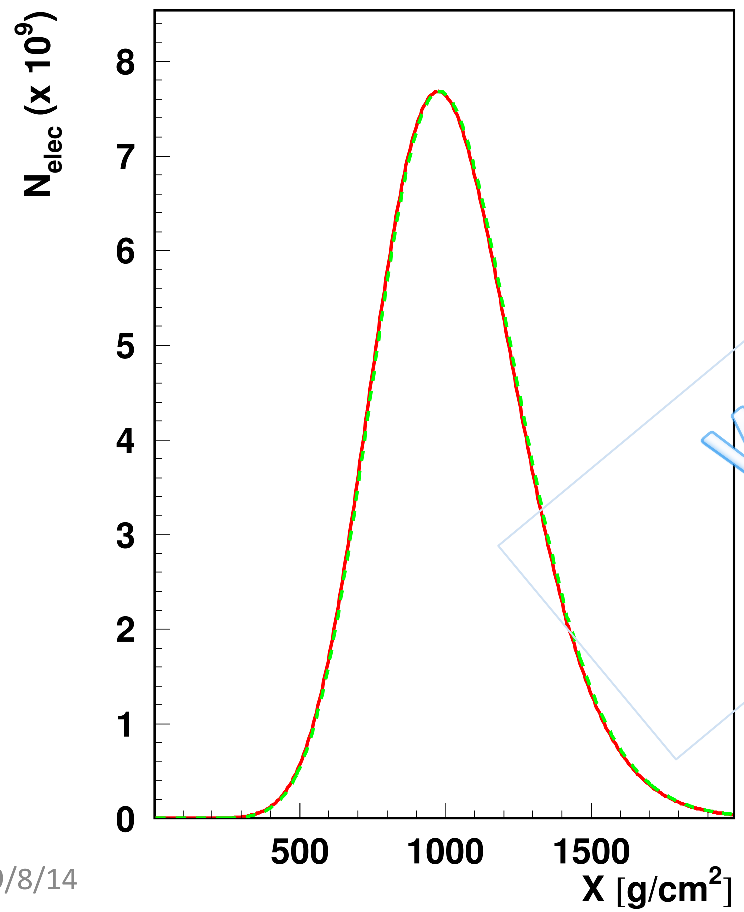


---- standard cross sections implemented in AIRES

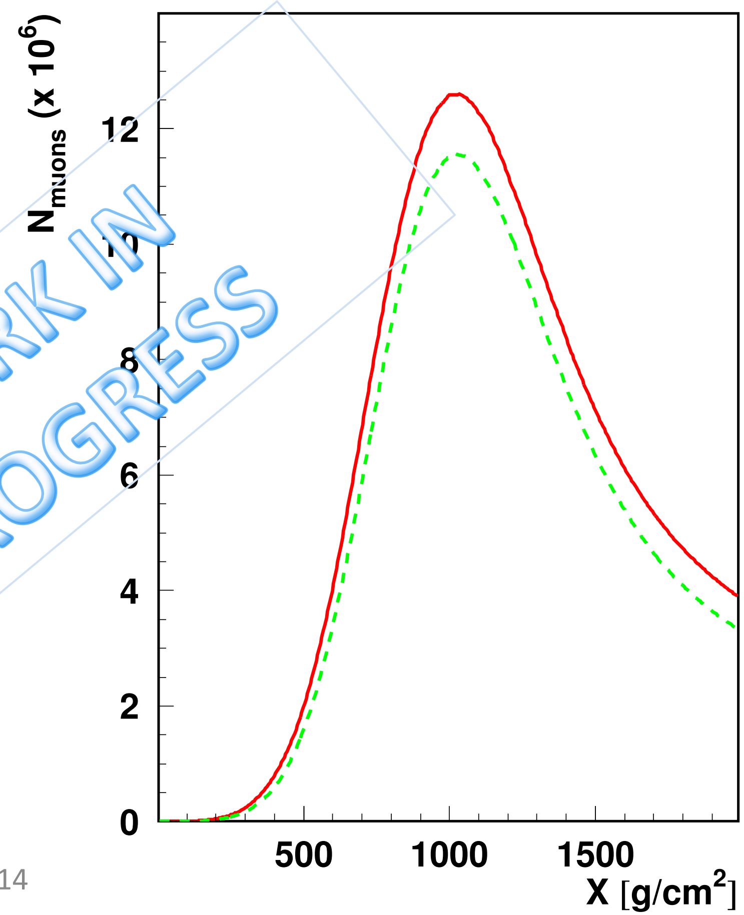
Longitudinal development from 10^{19} eV photon showers

---- standard cross sections implemented in AIRES

Electrons and positrons

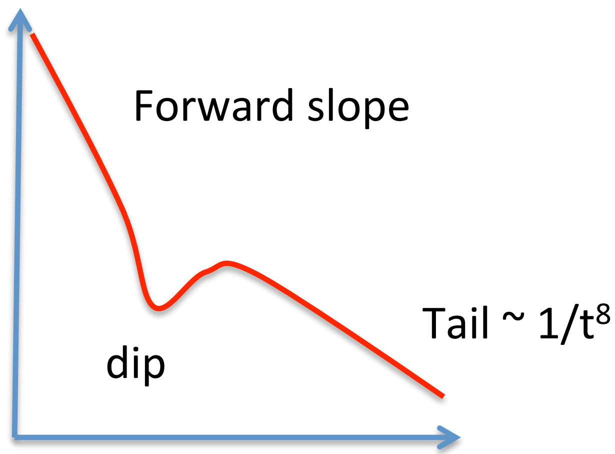


muons



The one eikonal does not work

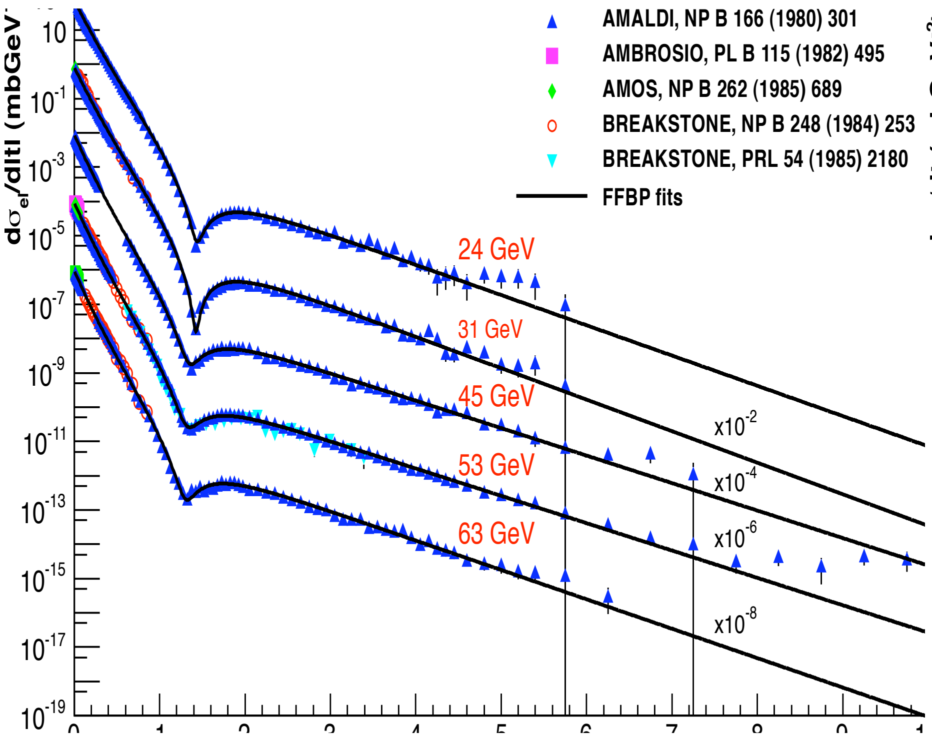
- Optical point : total cross-section
- Forward slope? Regge?
- The dip? ??
- The tail? 3 gluons perhaps



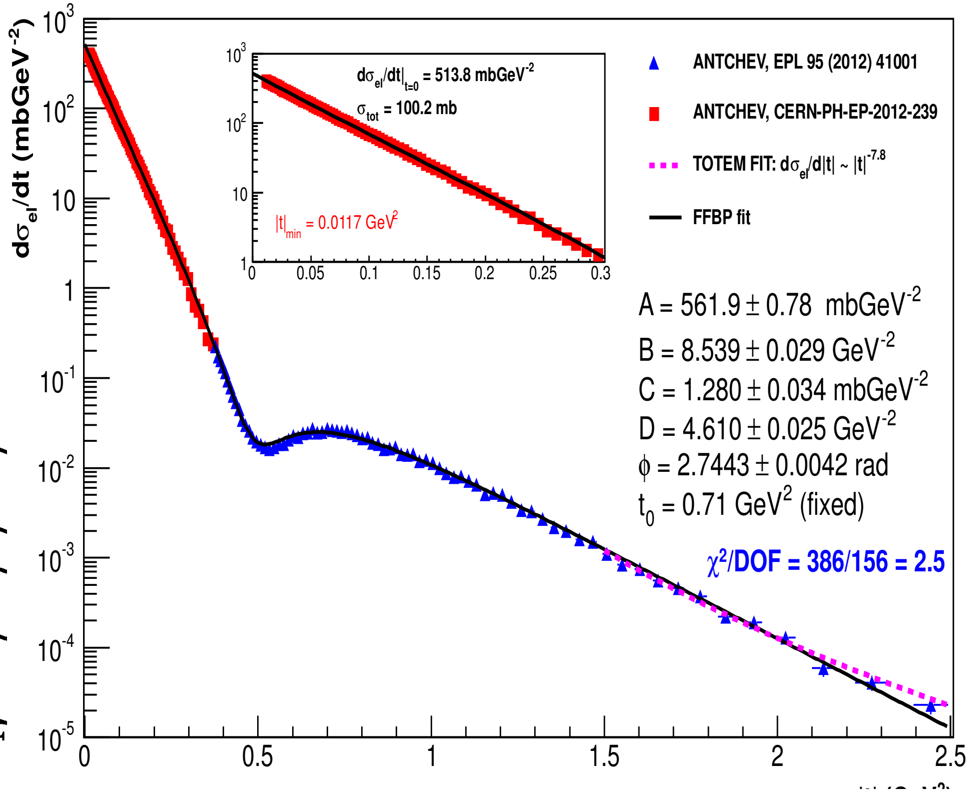
Resort to an EMPIRICAL MODEL to try to understand the building blocks

BP model with Proton Form Factor

ISR for pp



TOTEM LHC7 for pp



Fagundes, Grau, GP, Srivastava PRD 2013

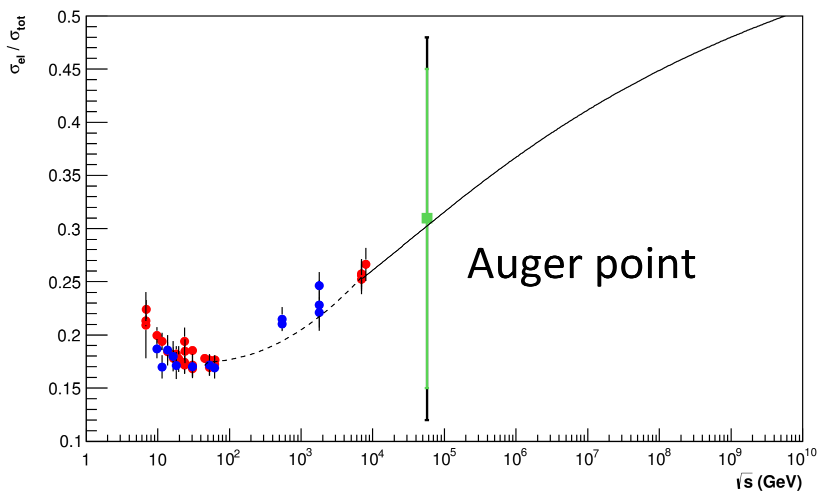
A lesson from the empirical model

- The black disk limit is very far away

$$\sigma_{total}^{blackdisk} = 2\pi R^2(s)$$

$$\sigma_{elastic}^{blackdisk} = \pi R^2(s)$$

$$\mathcal{R}(s) = \frac{\sigma_{elastic}}{\sigma_{total}} \neq \frac{1}{2}$$



About the inelastic

- Inelastic=central+diffraction
- One-channel eikonals which describe sigmatotal fail to give the full contribution including diffraction
- GW mechanism-> multichannel eikonals, continuous distributions, etc. -> diffraction can be included through more parametrs and various modeling
- For sigma p-air we do not need diffraction

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