Small x, saturation and diffraction in multiparticle production

with dipole formalism

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Introduction - motivation

The PYTHIA MC-model is the most successful description of inelactic reaction in DIS and pp collisions.

But: there are simplified assumptions about correlations and diffraction. It needs input structure function from data.

Our goal: to undestand underlying dynamics in more detail.

- evolution of parton densities
- correlations and fluctuations
- diffraction
- nuclear collisions

Introduction - correlations

Earlier ***Sjöstrand and van Zilj*** assumed that the dependence of double-parton density on kinematic variables (x, Q^2) and on the separation in impact parameter space (b) factorizes.

↓

Implemented in PYTHYA and HERWIG event generators

Problem: how to extrapolate to higher energies (LHC)

↓

Our solution: detailed dynamical model for parton evolution (Lund Dipole Cascade Model)

Introduction - the model

Lund Dipole Cascade Model:

Based on BFKL and Müller's dipole cascade model

E. A. Kuraev, L. N. Lipatov, and V. S. Fadin, *Sov. Phys. JETP* **45** (1977) 199–204.

I. I. Balitsky and L. N. Lipatov, *Sov. J. Nucl. Phys.* **28** (1978) 822–829.

A. H. Mueller, *Nucl. Phys.* **B415** (1994) 373–385.

A. H. Mueller and B. Patel, *Nucl. Phys.* **B425** (1994) 471–488, `arXiv:hep-ph/9403256`.

A. H. Mueller, *Nucl. Phys.* **B437** (1995) 107–126, `arXiv:hep-ph/9408245`.

The Lund Dipole Cascade Model

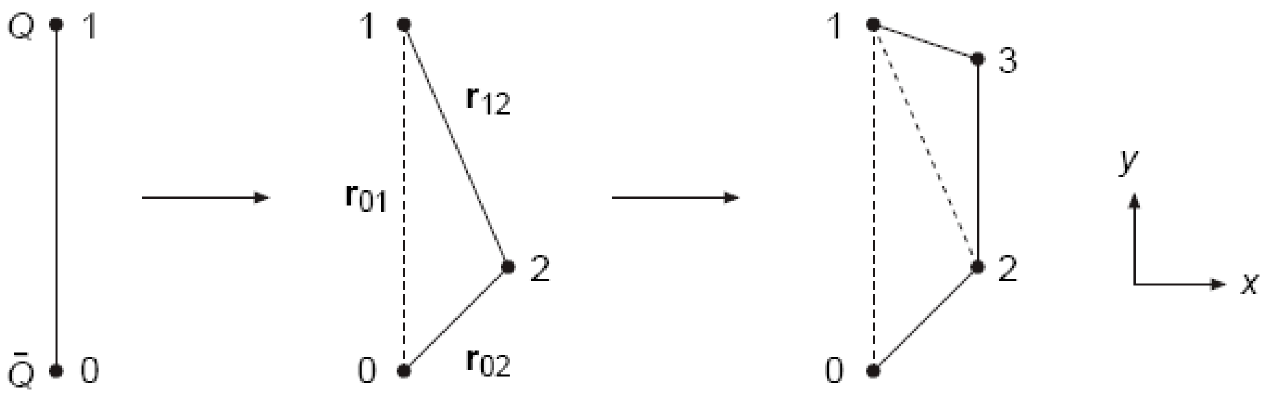
It improves BFKL evolutions :

- LL BFKL is not good enough. NLL corrections are very large.
- Non-linear effects in the evolution are not included.
- Massless gluon exchange implies a violation of Froissart's bound.
- It is difficult to include fluctuations and correlations; the BK equation represents a mean field approximation.
- They can only describe inclusive features, and not the production of exclusive final states.
- Analytic calculations are mainly applicable at extreme energies, well beyond what can be reached experimentally.

The Lund Dipole Cascade Model

Dipole cascades:

LL BFKL evolution in transverse coordinate space

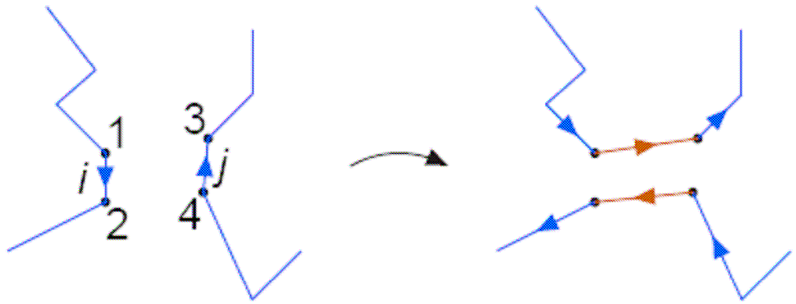


Gluon emission probality: $$\frac{d\mathcal{P}}{dy} = \frac{\bar{\alpha}}{2\pi} d^2\mathbf{r}_2 \frac{r_{01}^2}{r_{02}^2 r_{12}^2}$$

The Lund Dipole Cascade Model

Dipole-dipole scattering:

Single gluon exhange ⇒ Colour reconnection between projectile and target



Born amplitude:

$$f_{ij} = \frac{\alpha_s^2}{2} \ln^2 \left(\frac{r_{13} r_{24}}{r_{14} r_{23}} \right)$$

Multiple interactions:

Stochastic process ⇒ Born ampl. $F = \sum_{ij} f_{ij}$

Unitarity: Eikonal approx. in imp. parameter space

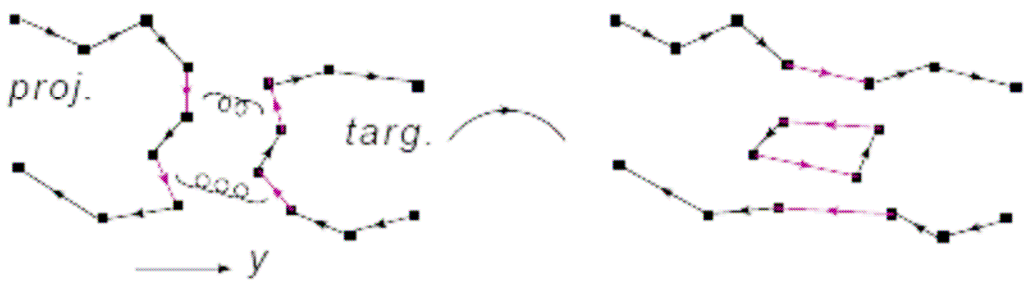
Uniterized ampl.: $T = 1 - e^{-\sum f_{ij}}$ (neglecting fluctuations)

$d\sigma_{el}/d^2b = T^2, \qquad d\sigma_{tot}/d^2b = 2T$

The Lund Dipole Cascade Model

Saturation:

Multiple interactions ⇒ colour loops ∼ pomeron loops



Multiple interaction in one frame ⇒
colour loop within evolution in another frame

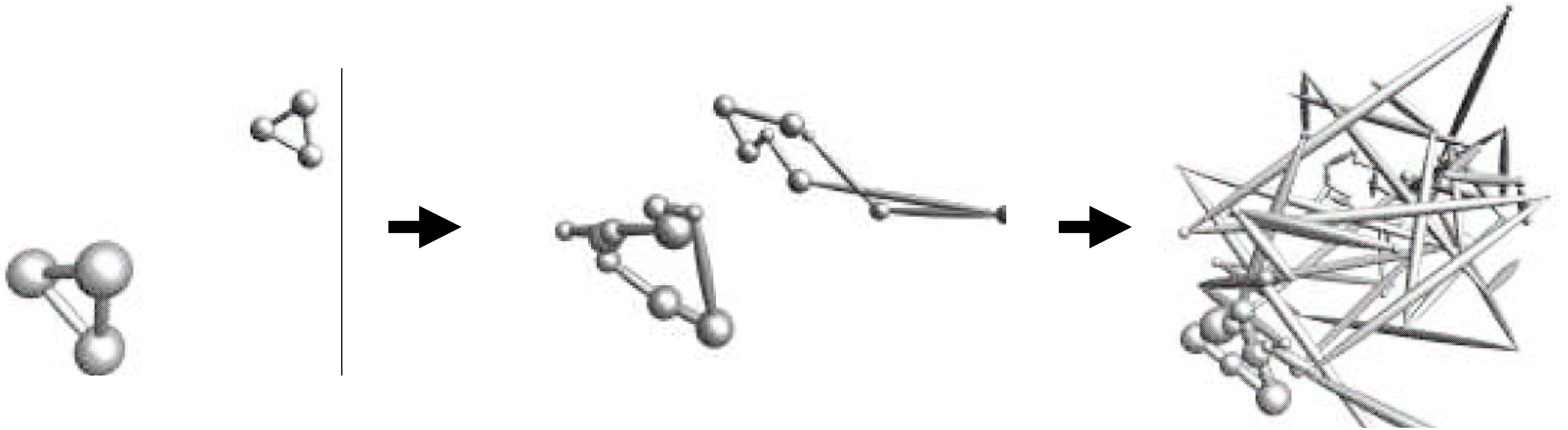
Application in MC code DIPSY

It includes:

- important not-leading effects in BFKL (E cons., runnnig α_s)
- saturation in pomeron loops in the evolution
- confinement
- correlations and fluctuation
- collision between e,p,A

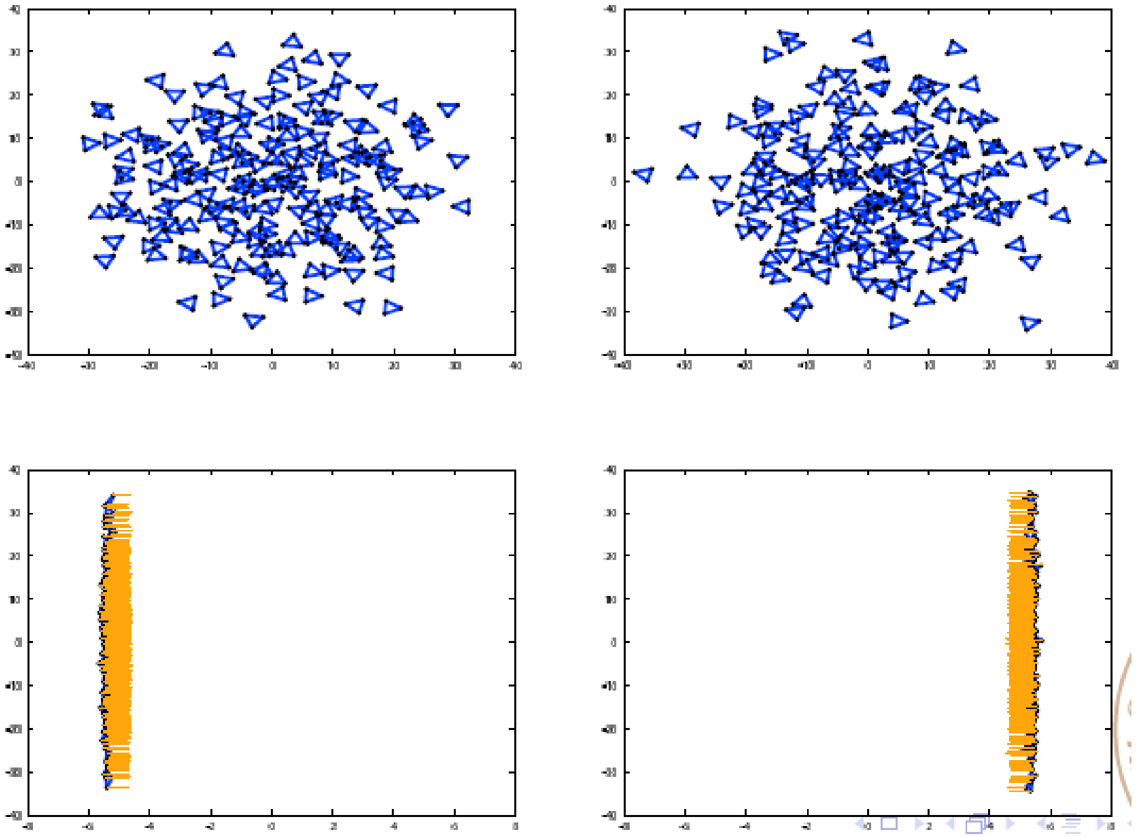
Application in MC code DIPSY

Dipole interactions:



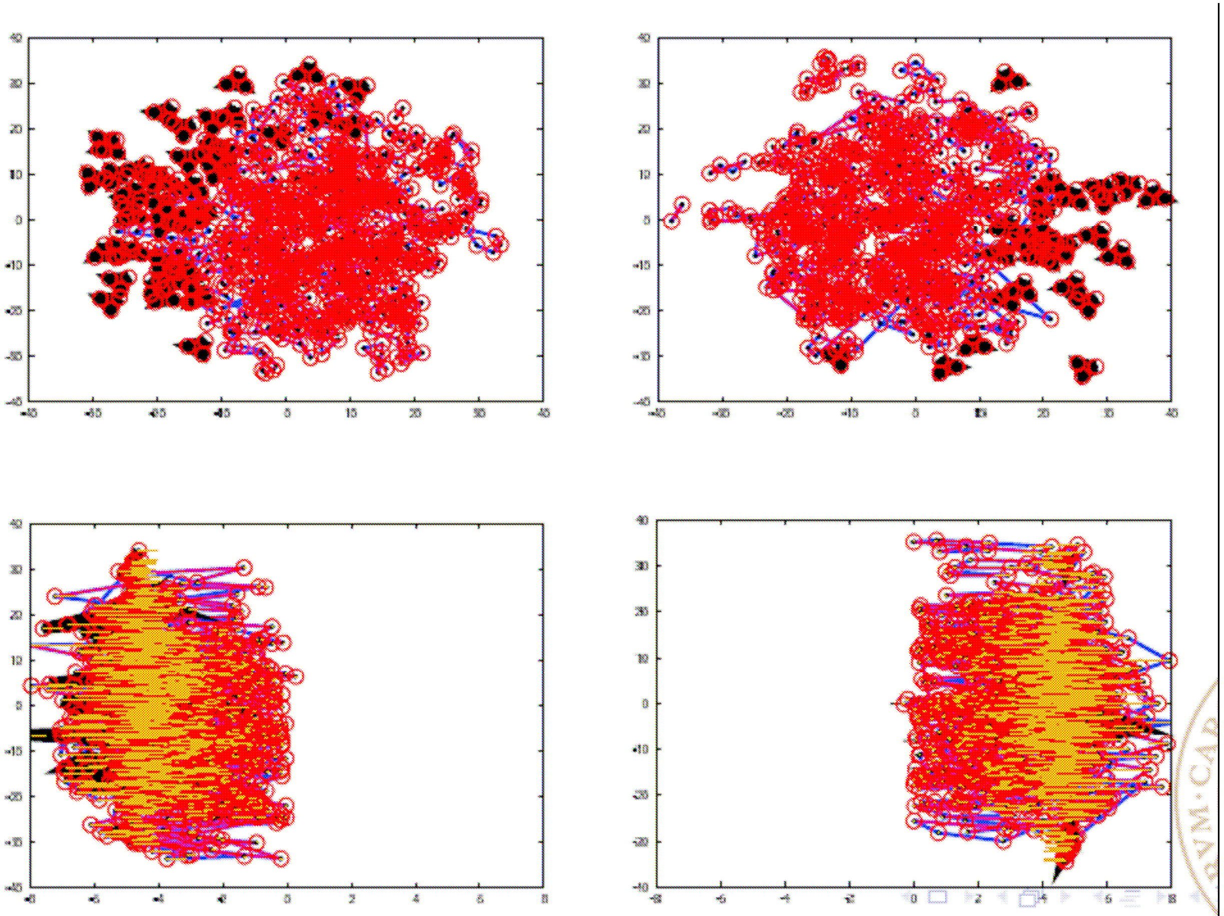
Application in MC code DIPSY

Sample Au-Au event: (nucleons are dipole triangles here)



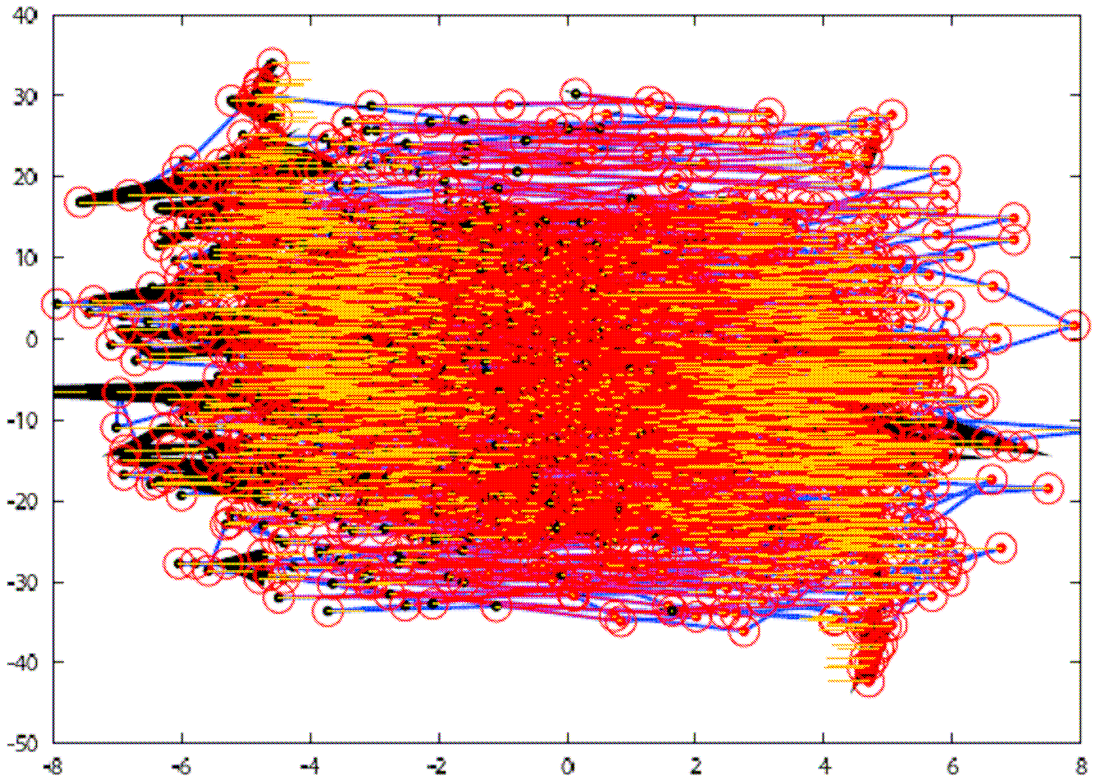
Application in MC code DIPSY

Sample Au-Au event:



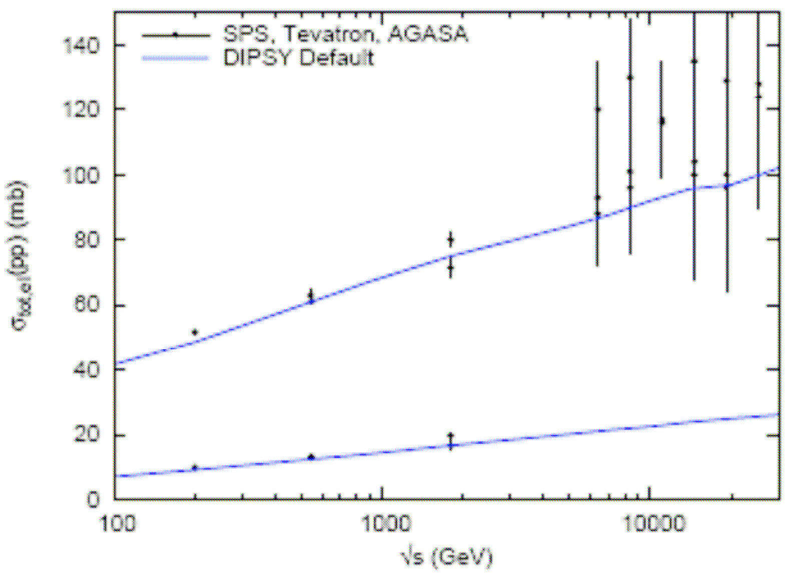
Application in MC code DIPSY

Sample Au-Au event:

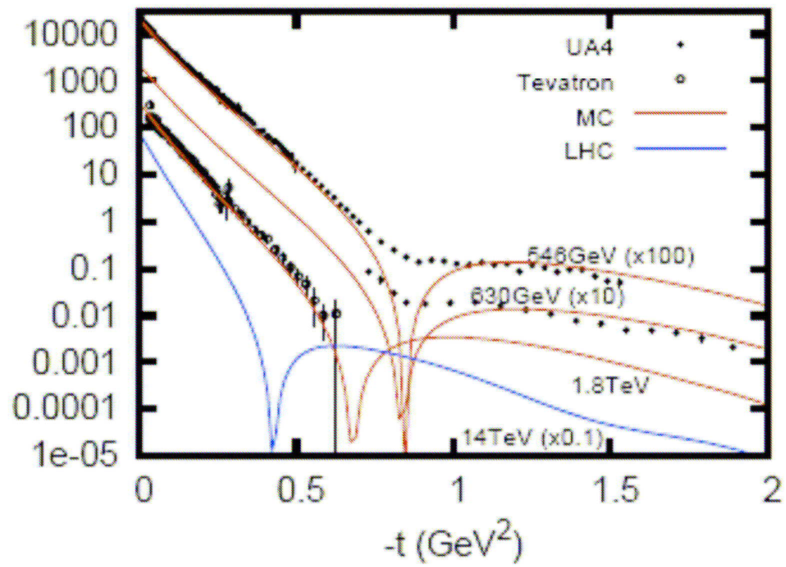


Some older results

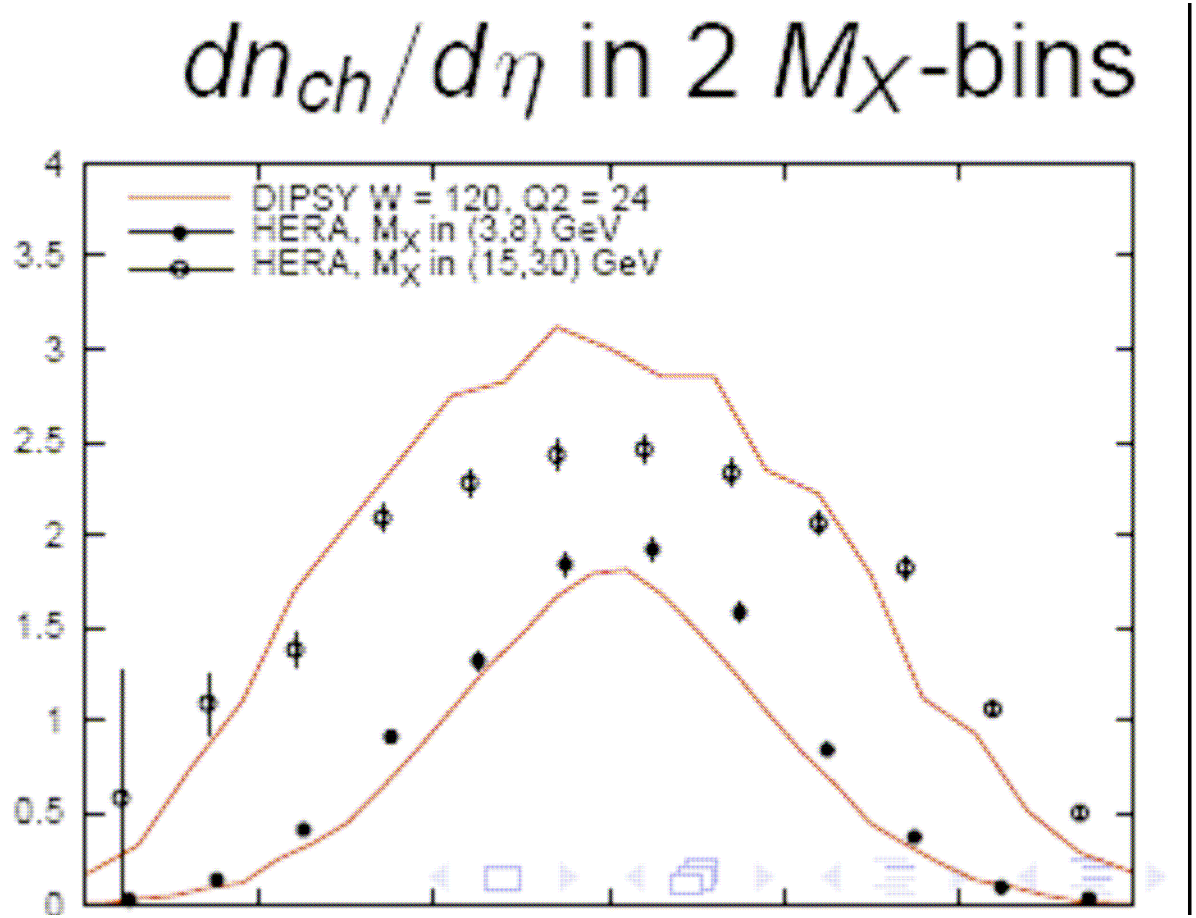
σ_{tot} and σ_{el}



$d\sigma/dt$

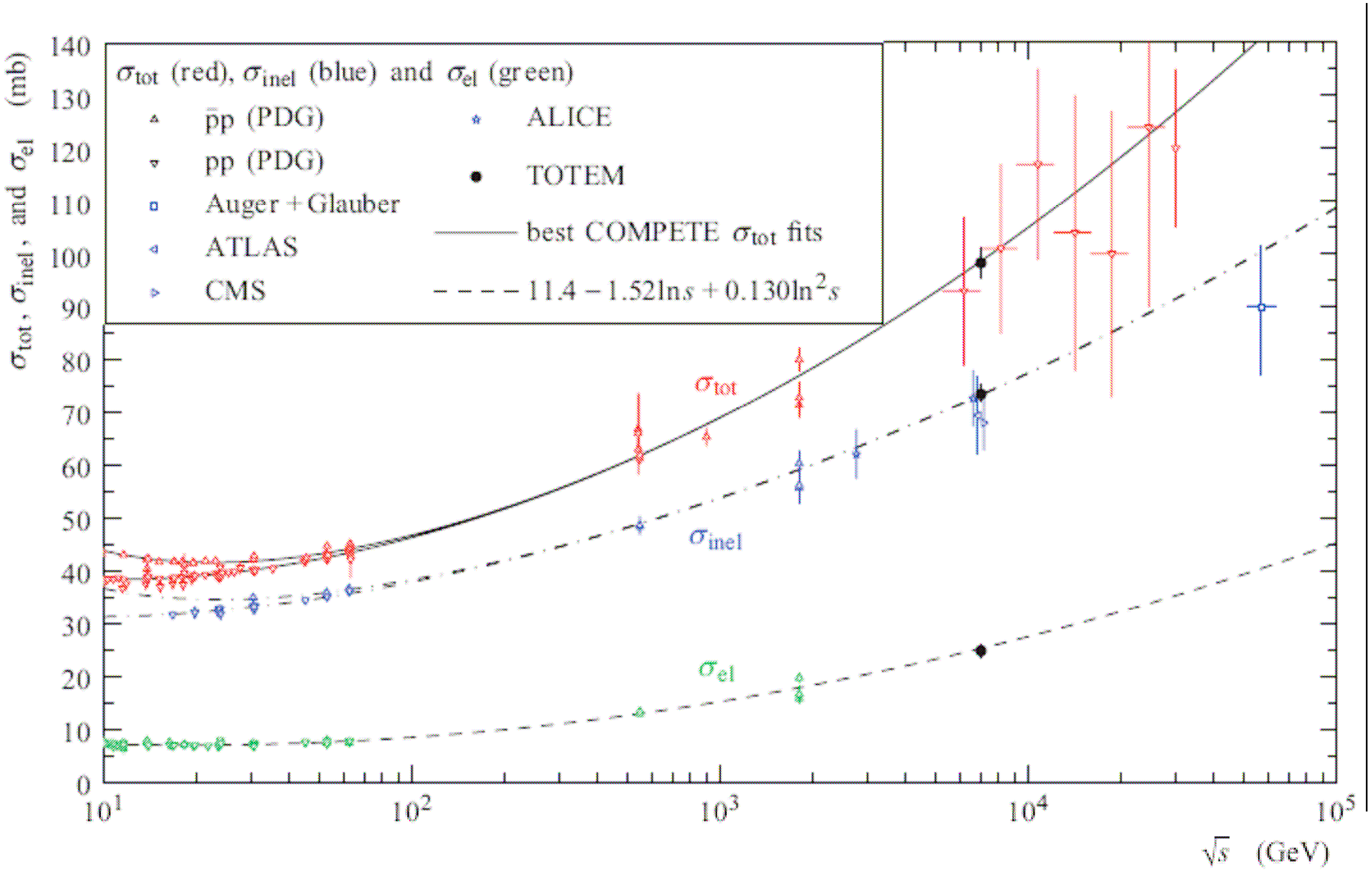


Some older results

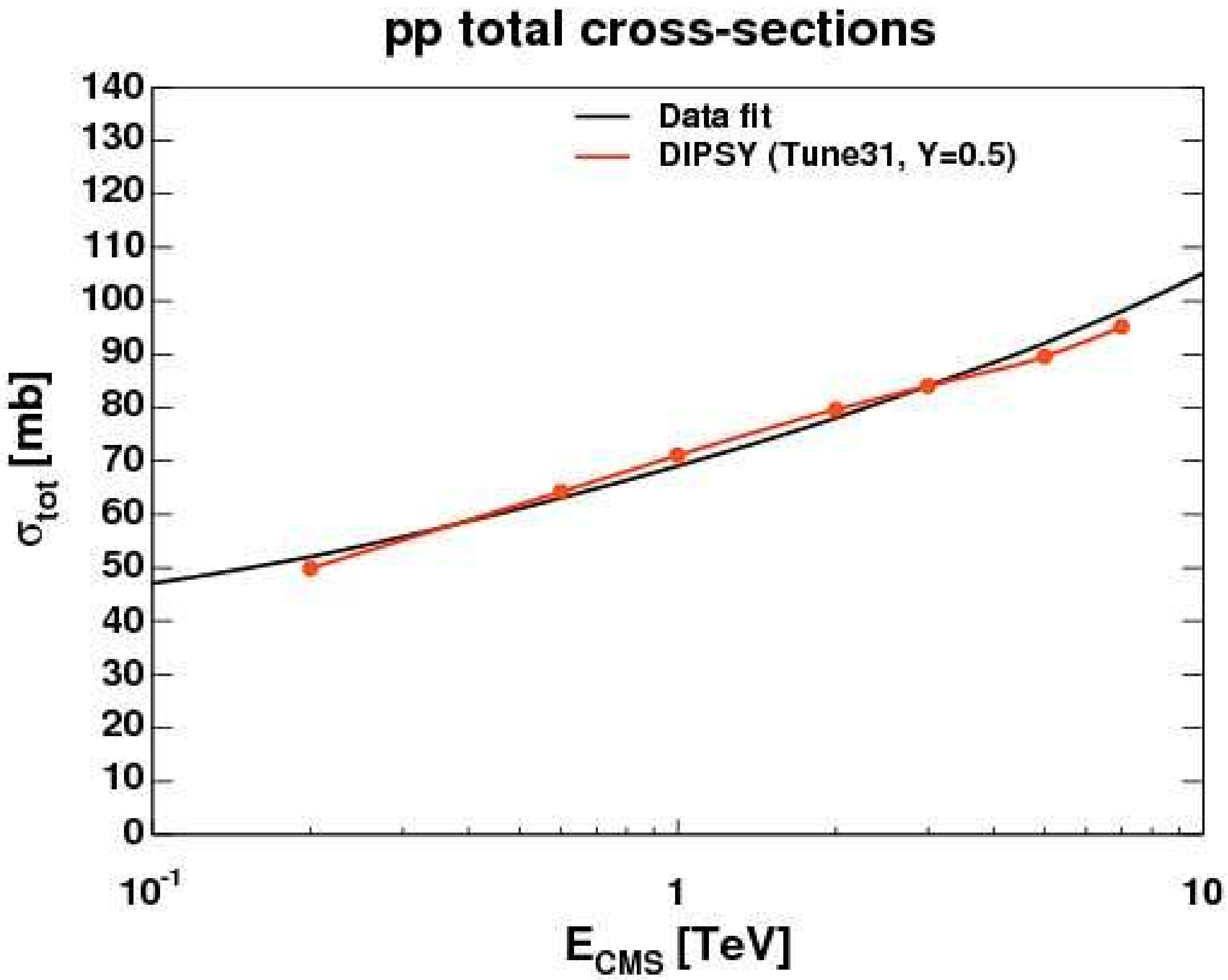


Preliminary results

Simulations are based on tunes to pp total cross section fit curve shown in TOTEM paper 2011 EPL 96 21002:



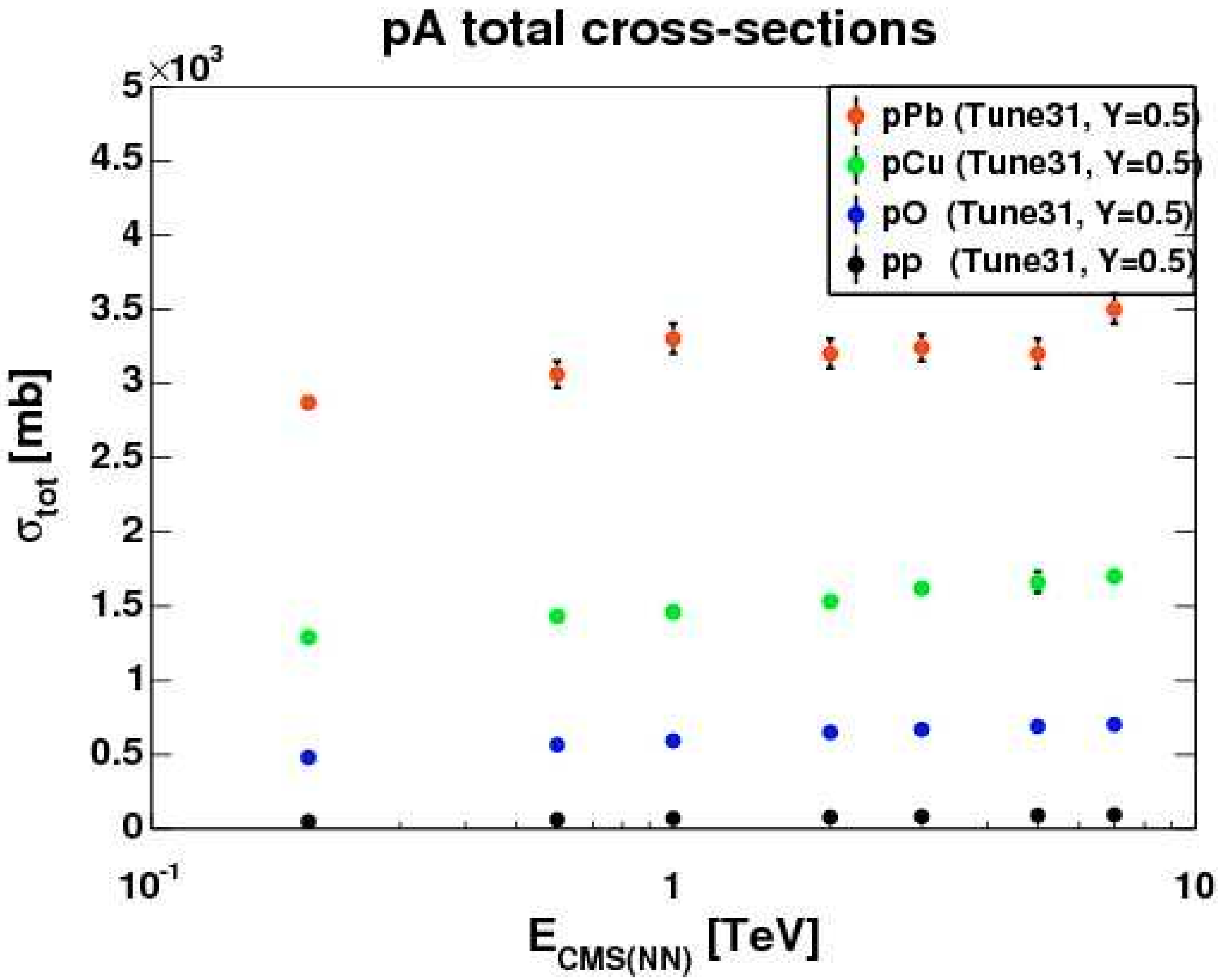
Preliminary results



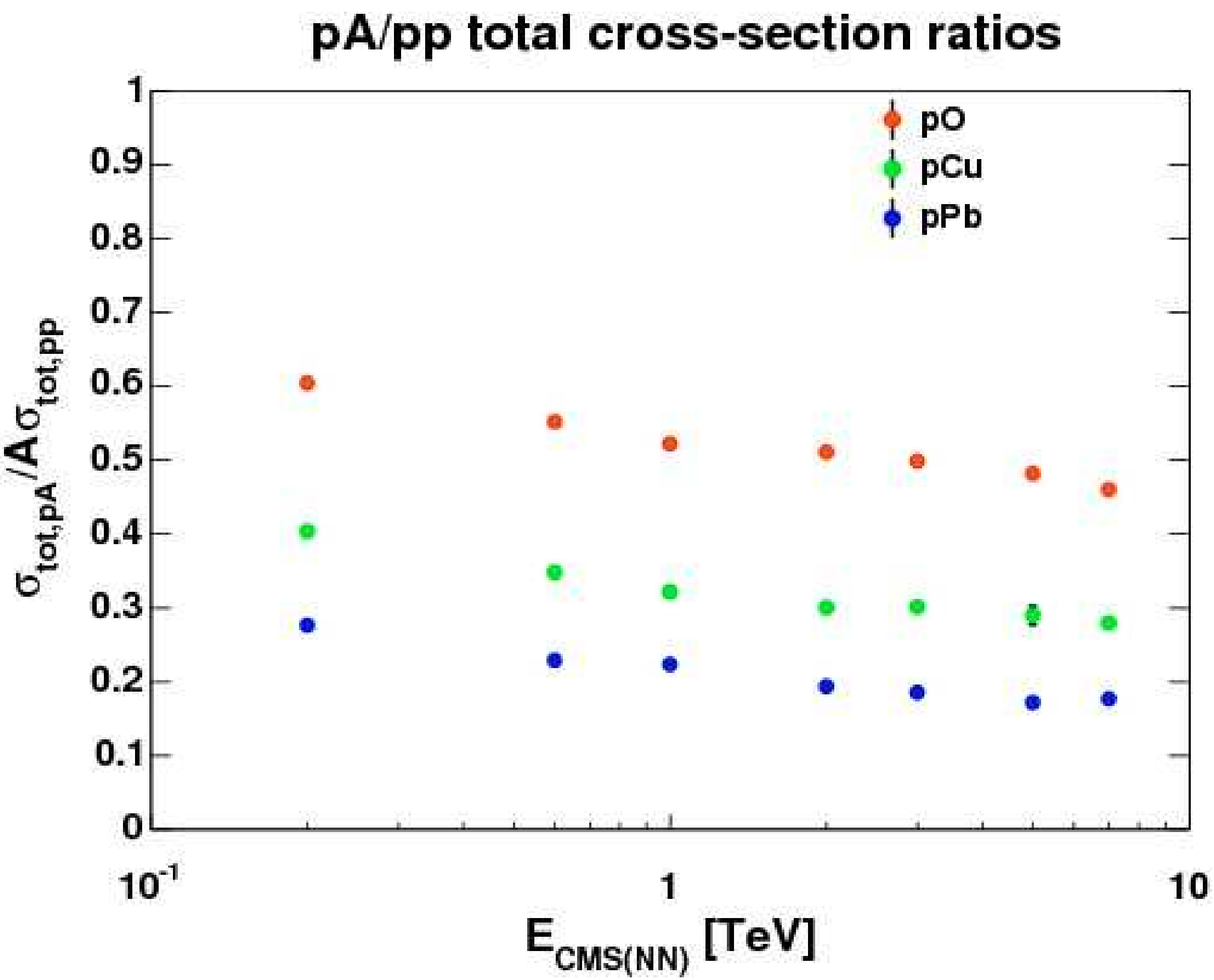
With tune parameter

$\Lambda_{QCD} = 0.23$

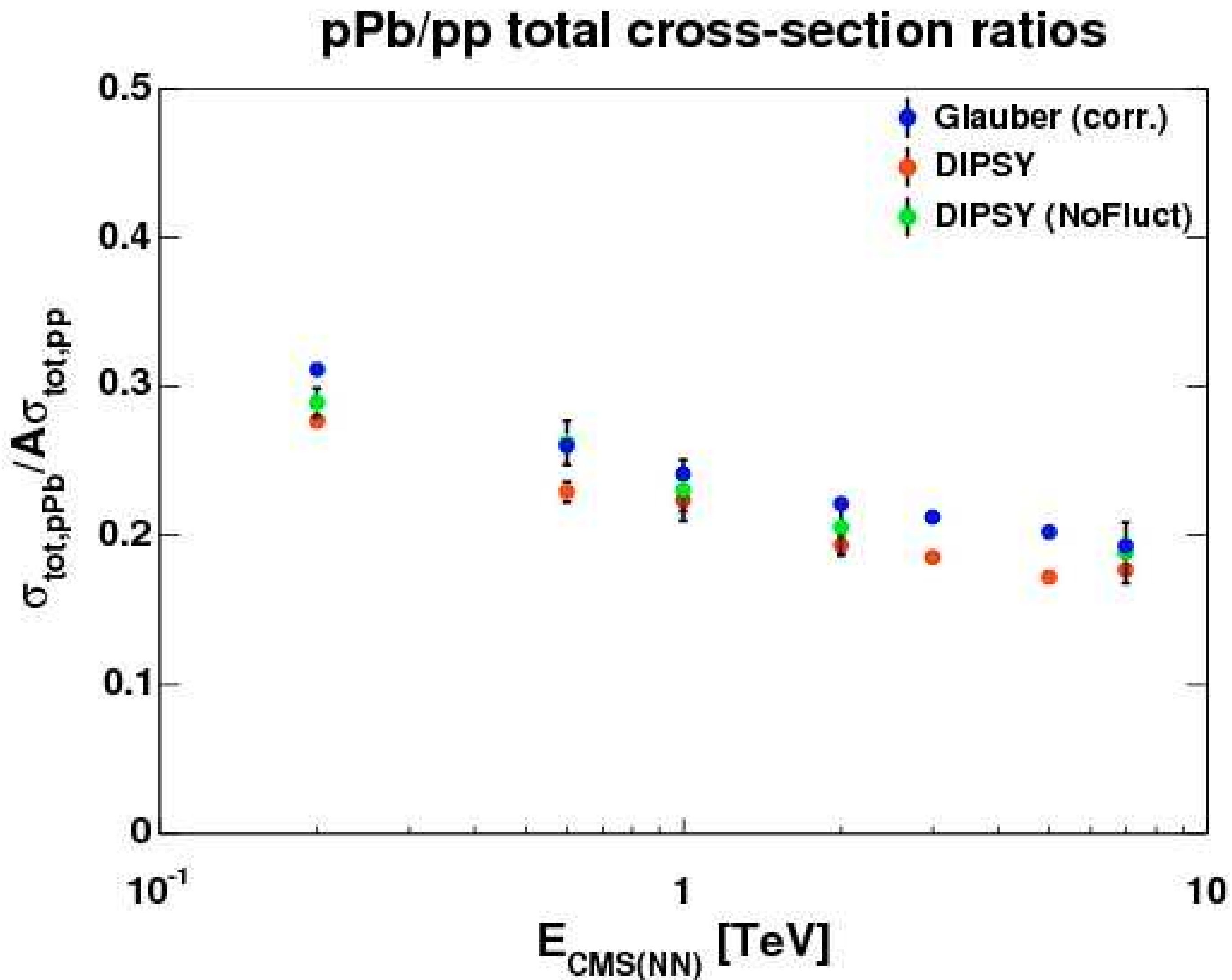
Preliminary results



Preliminary results

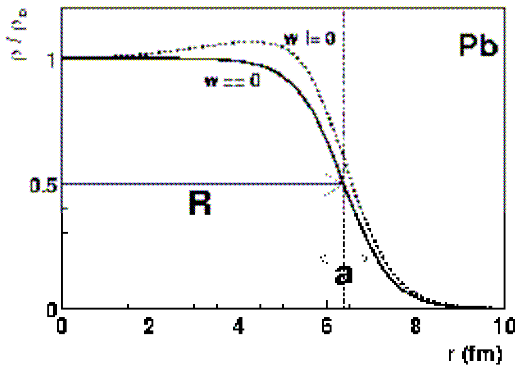


Preliminary results



Based on using the same Wood-Saxon nucleus density:

$$\rho(r) = \frac{\rho_0\left(1 + wr^2 / R^2\right)}{1 + \exp((r - R)/a)}$$



Preliminary results

pPb data vs DIPSY at high energies

Inelestic cross section found:

LHCb: $\sigma_{inel} = 2.09 \pm 0.12_{sys}$ barn

DIPSY: $\sigma_{inel} = 1.85 \pm 0.04_{stat}$ barn

(agreement within 2σ)

Preliminary results

Further ongoing simulations are for:

- AA collisions (take lots of execution time)
- dn/dy distributions

Outlook

Things to do:

- speed-up large ion calculations
- final state effects
- diffractive final states
- NLL effects
- ...

Summary

Lund Dipole Cascade Model offers unique possibility to study gluon evolution inside hadrons at small x

Reconstruction of pp total cross sections from RHIC energies to LHC energies was successful.

Predictions for total cross sections in various pA, γ^*A high energy reactions were made.