Total, inelastic and elastic cross sections of high energy pp, pA and γ^*A reactions with dipole formalism

András Ster

Wigner Research Centre for Physics, Budapest, Hungary

Work in collaboration with Gösta Gustafson and Leif Lönnblad in
Dept. of Astronomy and Theoretical Physics, Lund University, Sweden

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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

Motivations - 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)

Motivation - a new model

The Lund Dipole Cascade Model is based on

BFKL evolution equations 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

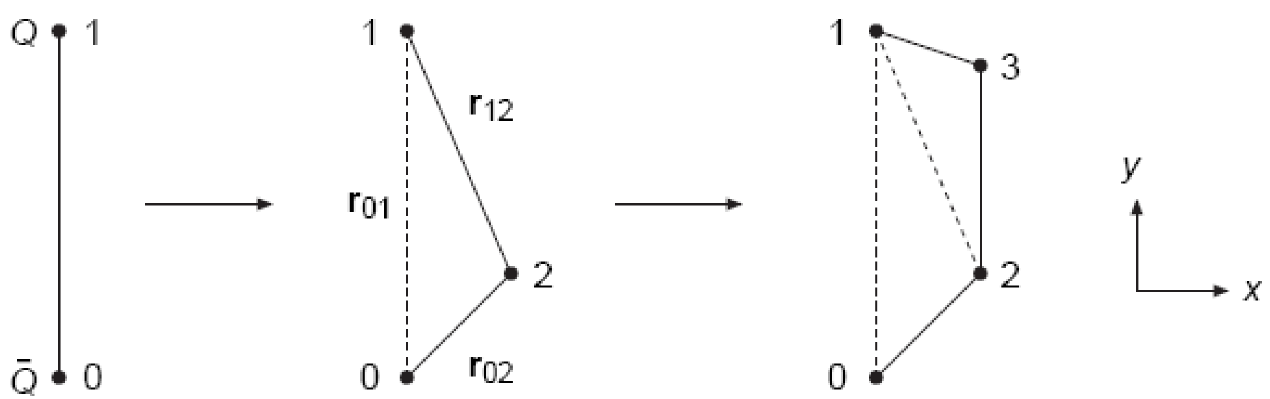
It improves BFKL evolutions :

- 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

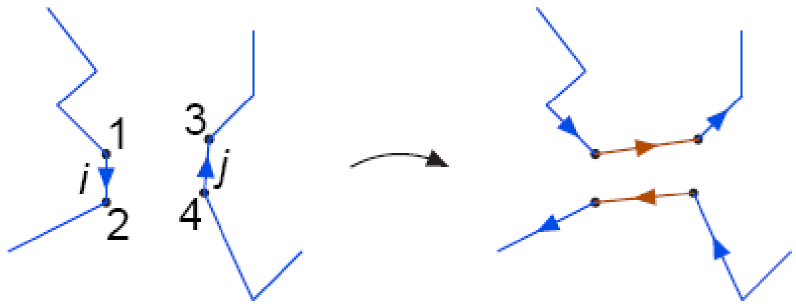


Gluon emission probality: $$\frac{d\mathcal{P}}{dy} = \frac{\bar{\alpha}}{2\pi} d^2\mathbf{r}_2 \frac{r_{01}^2}{r_{02}^2\, r_{12}^2}$$

The Lund Dipole Cascade Model

Dipole-dipole scattering:

Single gluon exchange ⇒ 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

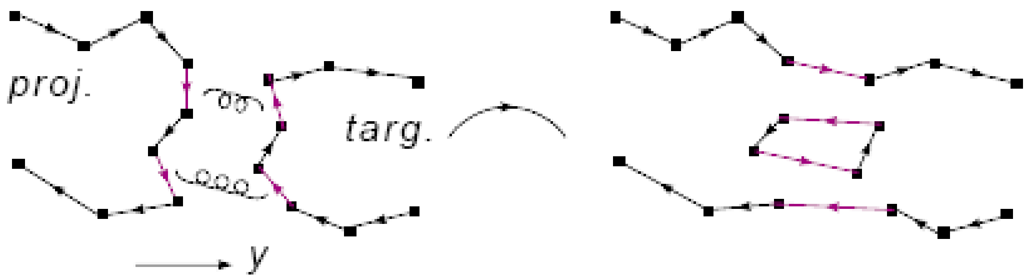
Uniterized ampl.: $T = 1 - e^{-\sum f_{ij}}$ (neglecting fluctuations)

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

The Lund Dipole Cascade Model

Saturation:

Multiple interactions $\Rightarrow$ colour loops $\sim$ pomeron loops



Multiple interaction in one frame $\Rightarrow$ colour loop within evolution in another frame

E. Avsar, G. Gustafson, and L. Lönnblad, *JHEP* 07 (2005) 062, hep-ph/0503181.

E. Avsar, G. Gustafson, and L. Lonnblad, *JHEP* 01 (2007) 012, hep-ph/0610157.

E. Avsar, G. Gustafson, and L. Lönnblad, *JHEP* 12 (2007) 012, arXiv:0709.1368 [hep-ph].

C. Flensburg, G. Gustafson, and L. Lonnblad, *Eur. Phys. J.* C60 (2009) 233–247, arXiv:0807.0325 [hep-ph].

C. Flensburg and G. Gustafson, arXiv:1004.5502 [hep-ph].

The Lund Dipole Cascade Model

Inclusive observables:

$$\sigma_{tot} = 2\int d^2b \langle 1 - e^{-F(b)} \rangle$$

$$\sigma_{el} = \int d^2b \langle 1 - e^{-F(b)} \rangle^2$$

$$\sigma_{D} = \int d^2b \left(\langle (1 - e^{-F(b)})^2 \rangle - \langle 1 - e^{-F(b)} \rangle^2 \right)$$

$$\sigma_{inND} = \int d^2b \langle 1 - e^{-2F(b)} \rangle$$

With the ikonal form of the transition probability:

$$T(b) = 1 - e^{-F(b)}$$

The Lund Dipole Cascade Model

In the (Glauber like) black disk limit : $T(b) = \Theta(R - b)$

$$\begin{aligned}
\sigma_{tot} &= 2\int d^2b\Theta(R-b) = 2\pi R^2 \\
\sigma_{el} &= \int d^2b\Theta(R-b)^2 = \pi R^2 \\
\sigma_D &= 0 \\
\sigma_{inND} &= \int d^2b\left(1-(1-T(b))^2\right) = \pi R^2
\end{aligned}$$

Hence:

$$\sigma_{inND} = \sigma_{el} = \sigma_{tot}/2$$

Application in MC code DIPSY

It includes:

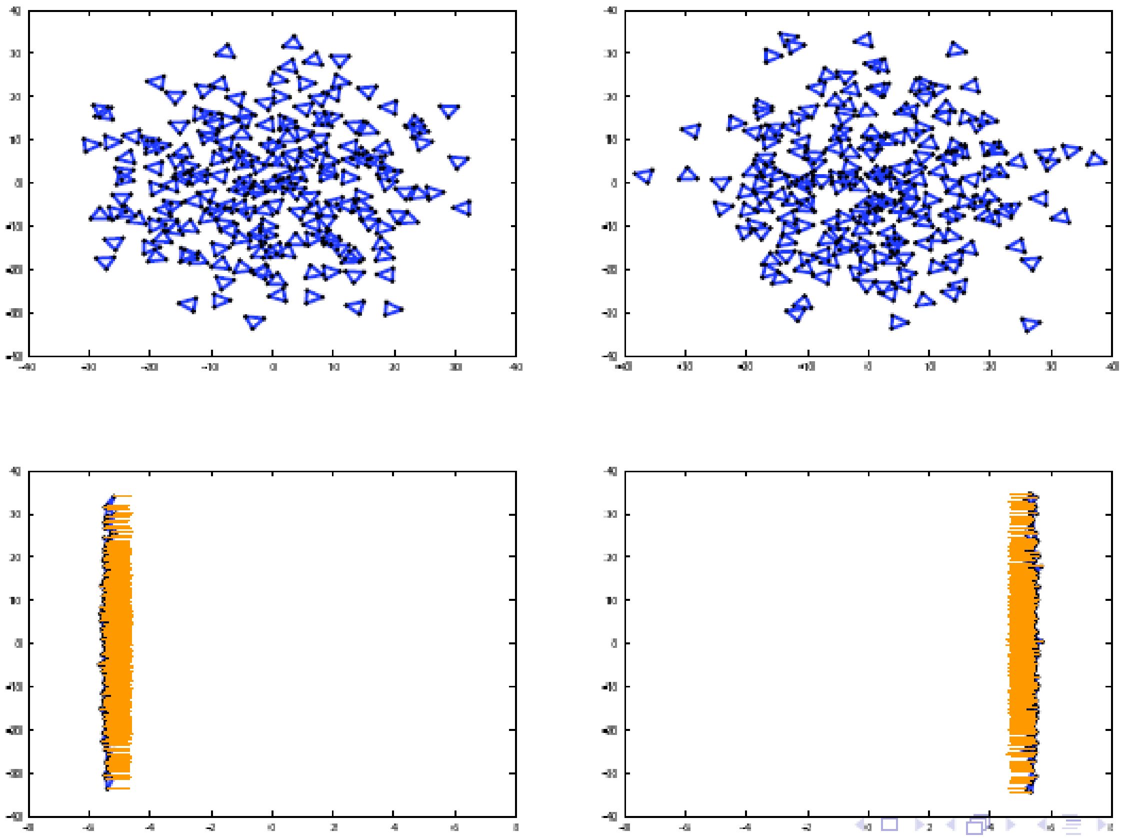
- important not-leading effects in BFKL (E cons., runnnig α_s)
- saturation in pomeron loops in the evolution
- confinement
- correlations and fluctuation
- collision between e,p,A

Application in MC code DIPSY

Dipole interactions:

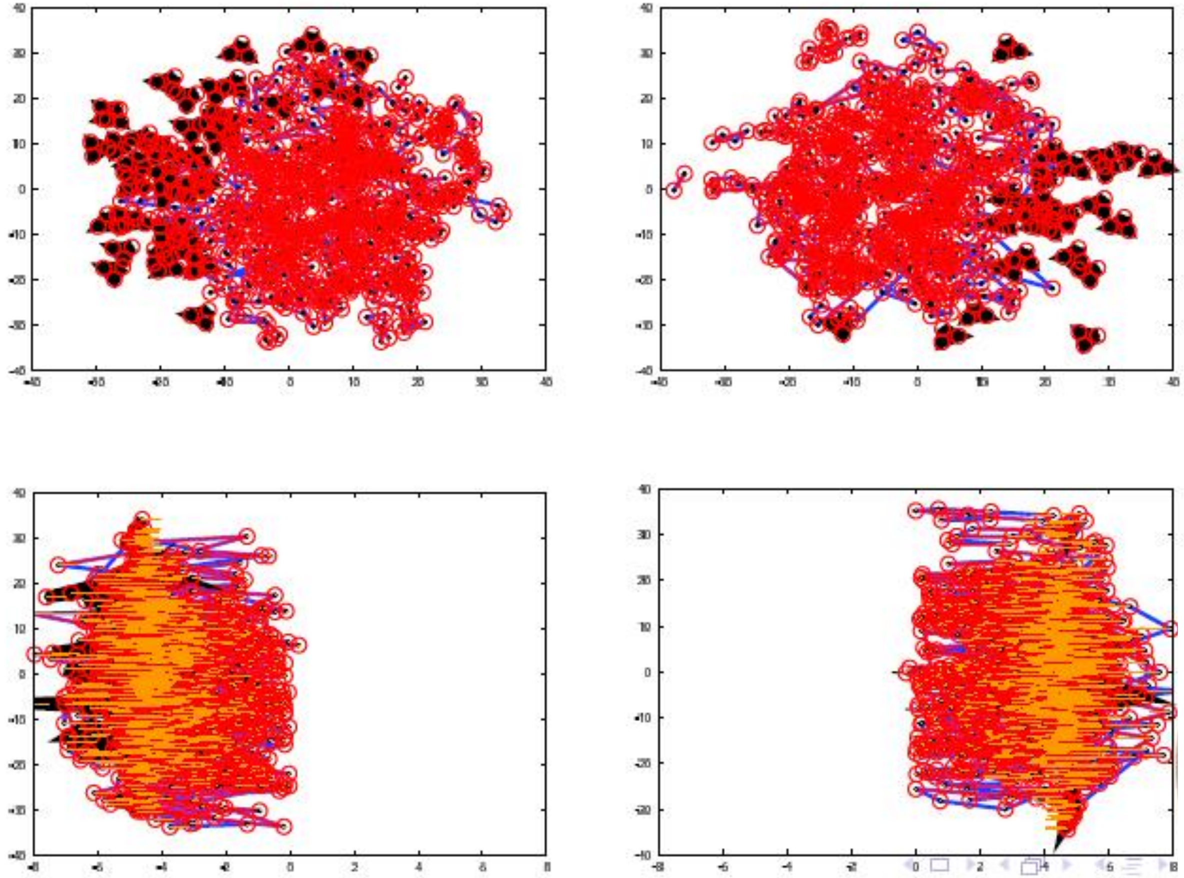
Application in MC code DIPSY

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



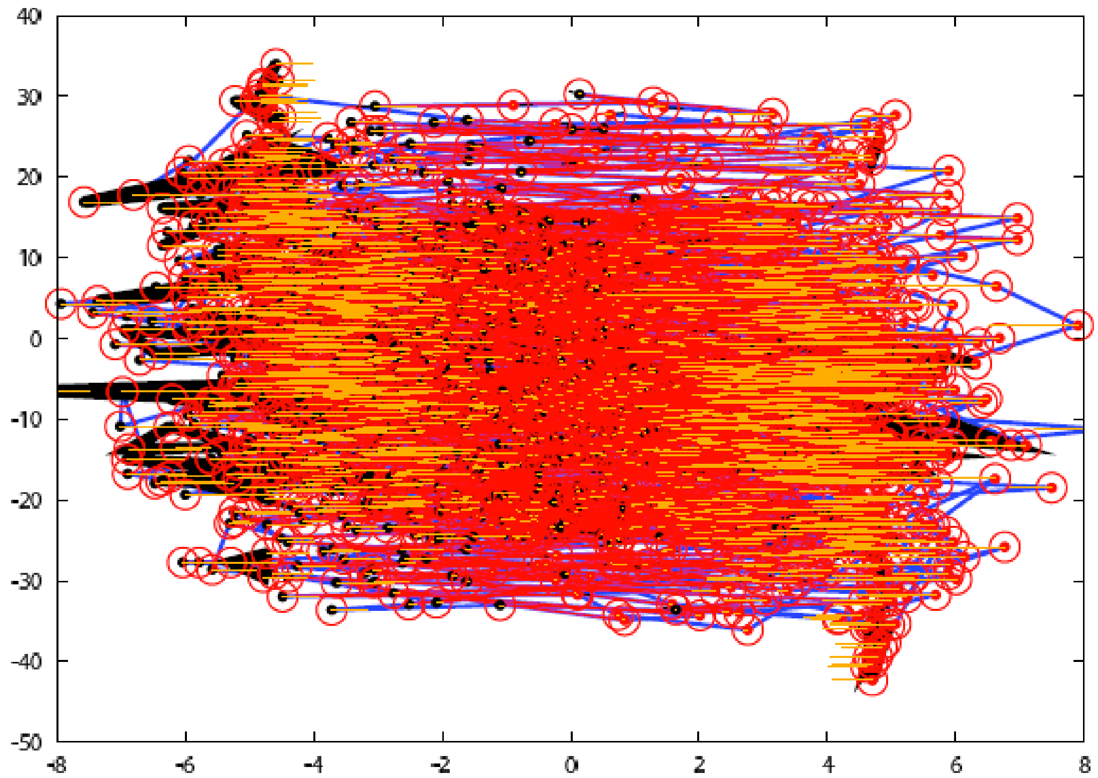
Application in MC code DIPSY

Sample Au-Au event:



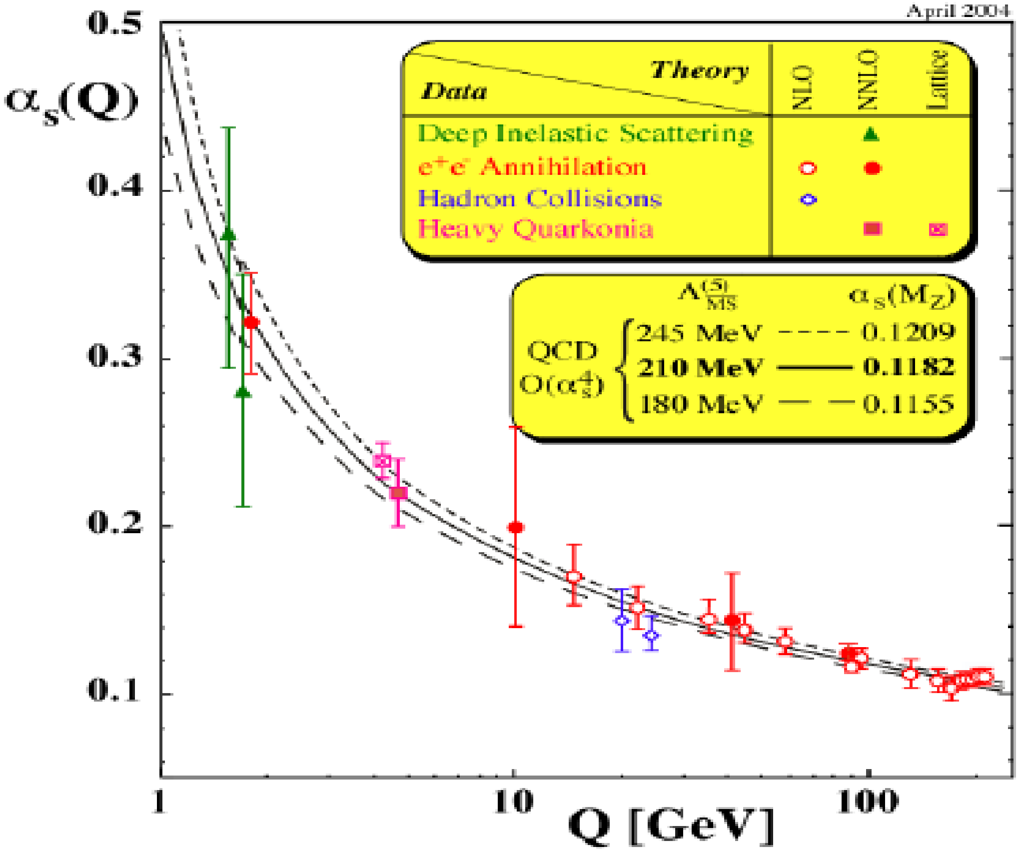
Application in MC code DIPSY

Sample Au-Au event:



Preliminary results

Simulations are based on tunes to pp total cross sections because some tune parameters are inevitable in MC. For example, Λ_{QCD} :



$$\alpha_S(Q) = \frac{1}{b\ln(Q^2/\Lambda^2)} \quad \text{(LO)}$$

hep-ex/0407021

Preliminary results

DIPSY parameters:

R_{max}: Non-perturbative regularization

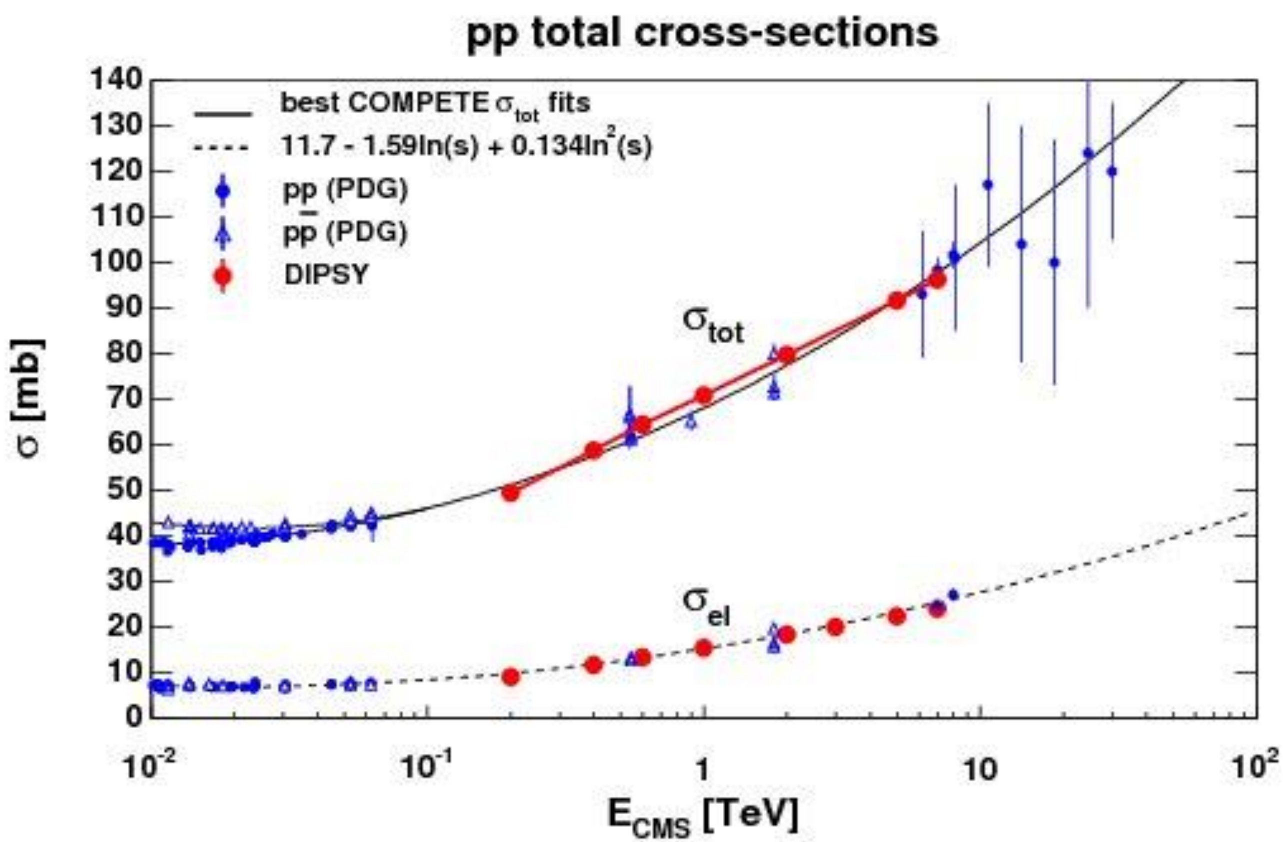
R_p: Proton size ($\approx R_{\text{max}}$)

w_p: Fluctuations in the initial proton size (small)

Λ_{QCD}: in the running α_s

λ_r: Swing parameter (saturated)

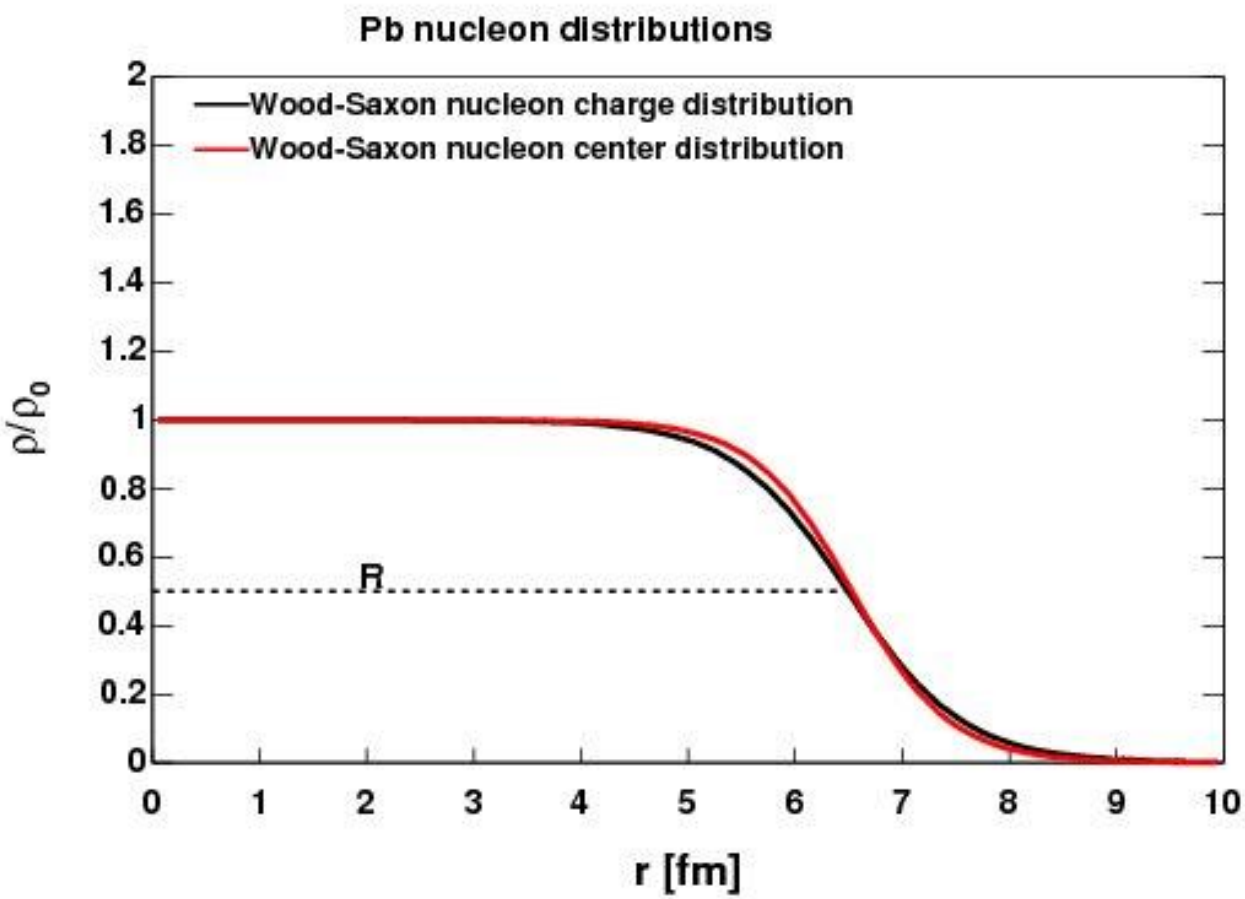
Preliminary results



With, for example:

Λ_{QCD}= 0.23 GeV

Preliminary results



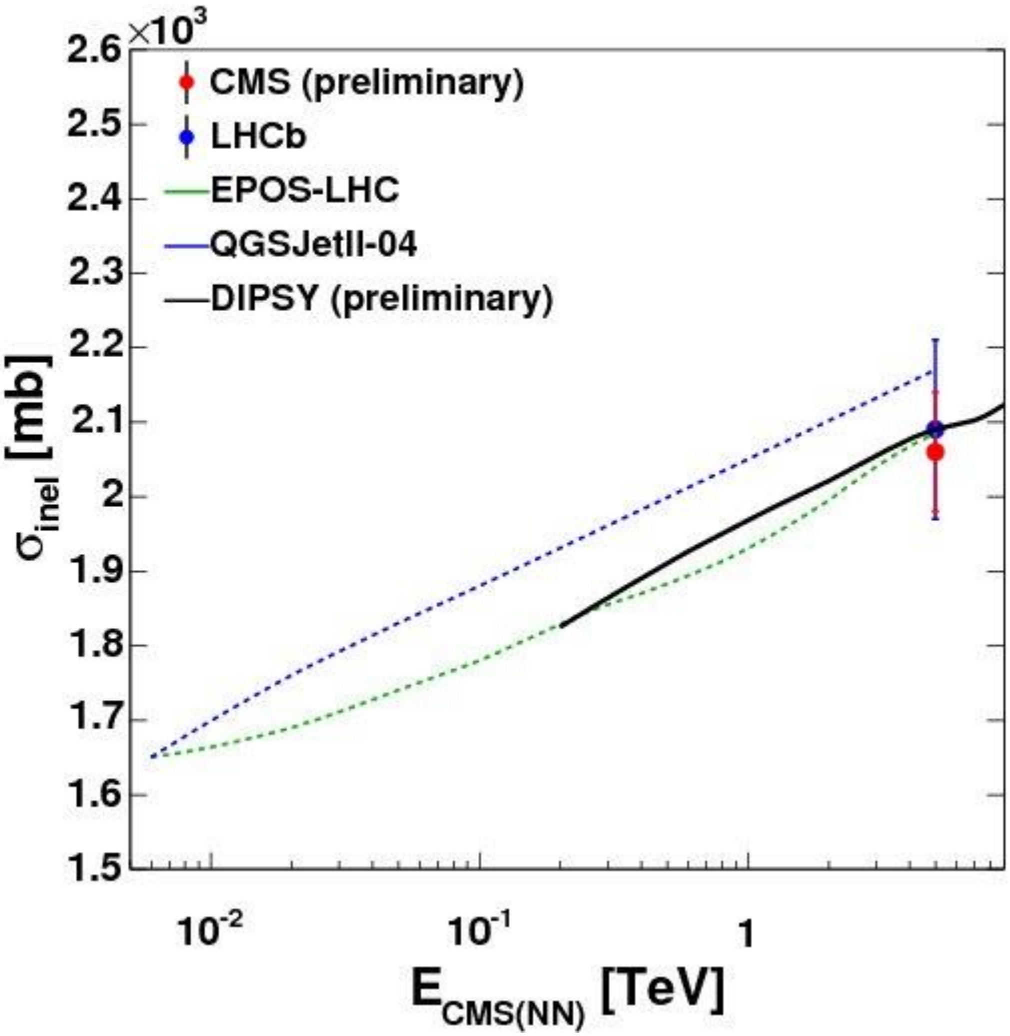
Based on theWood-Saxon nucleus charge density*:

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

Modified by GLISSANDRO for the nucleon center density for MC**

* : H. DeVries et al., Atom. Data Nucl. Tabl. 36 (1987)
**: W.Broniowski et al., GLISSANDRO, nucl-th/0710.531v3

Preliminary results

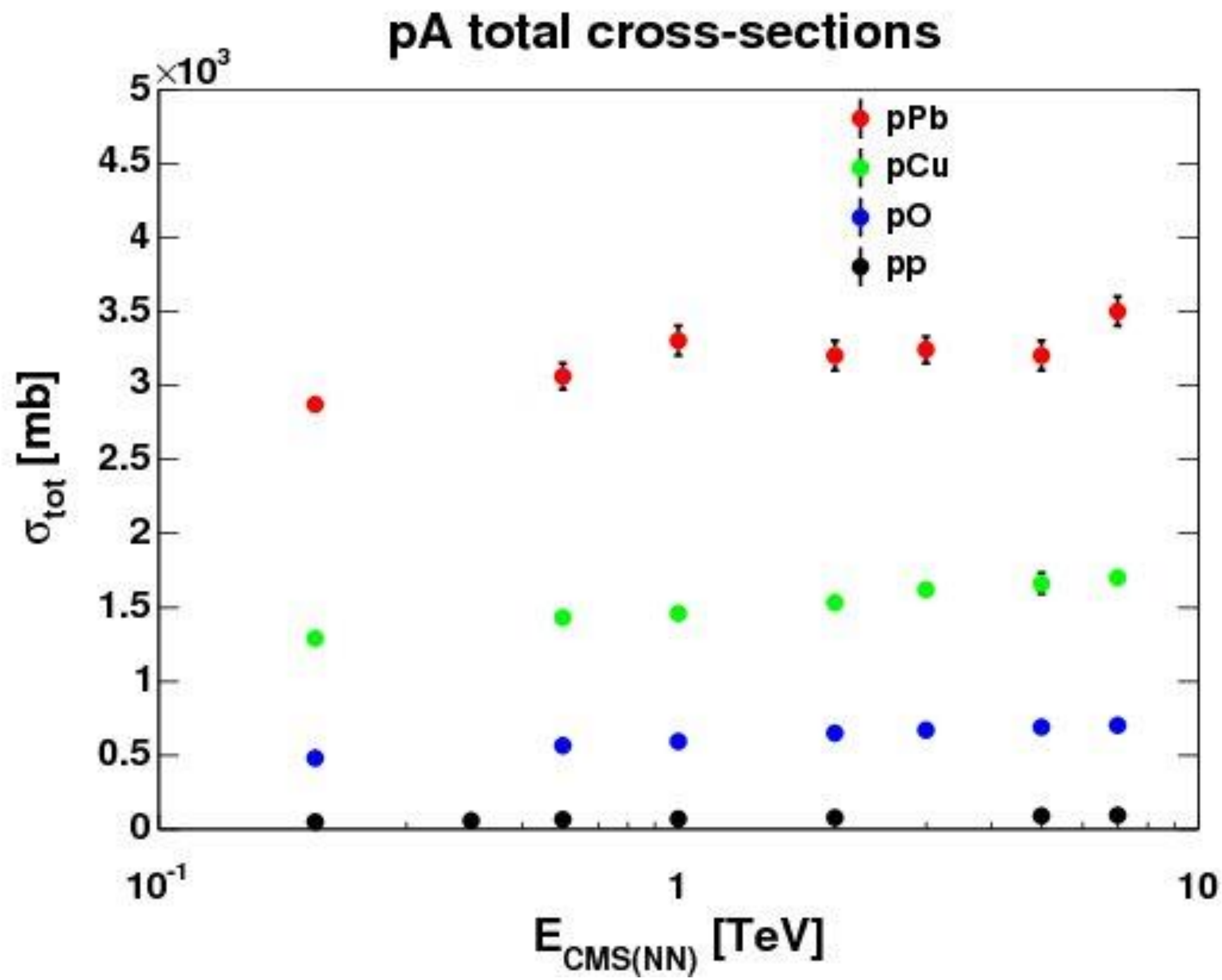


pPb data of total inelastic cross sections:

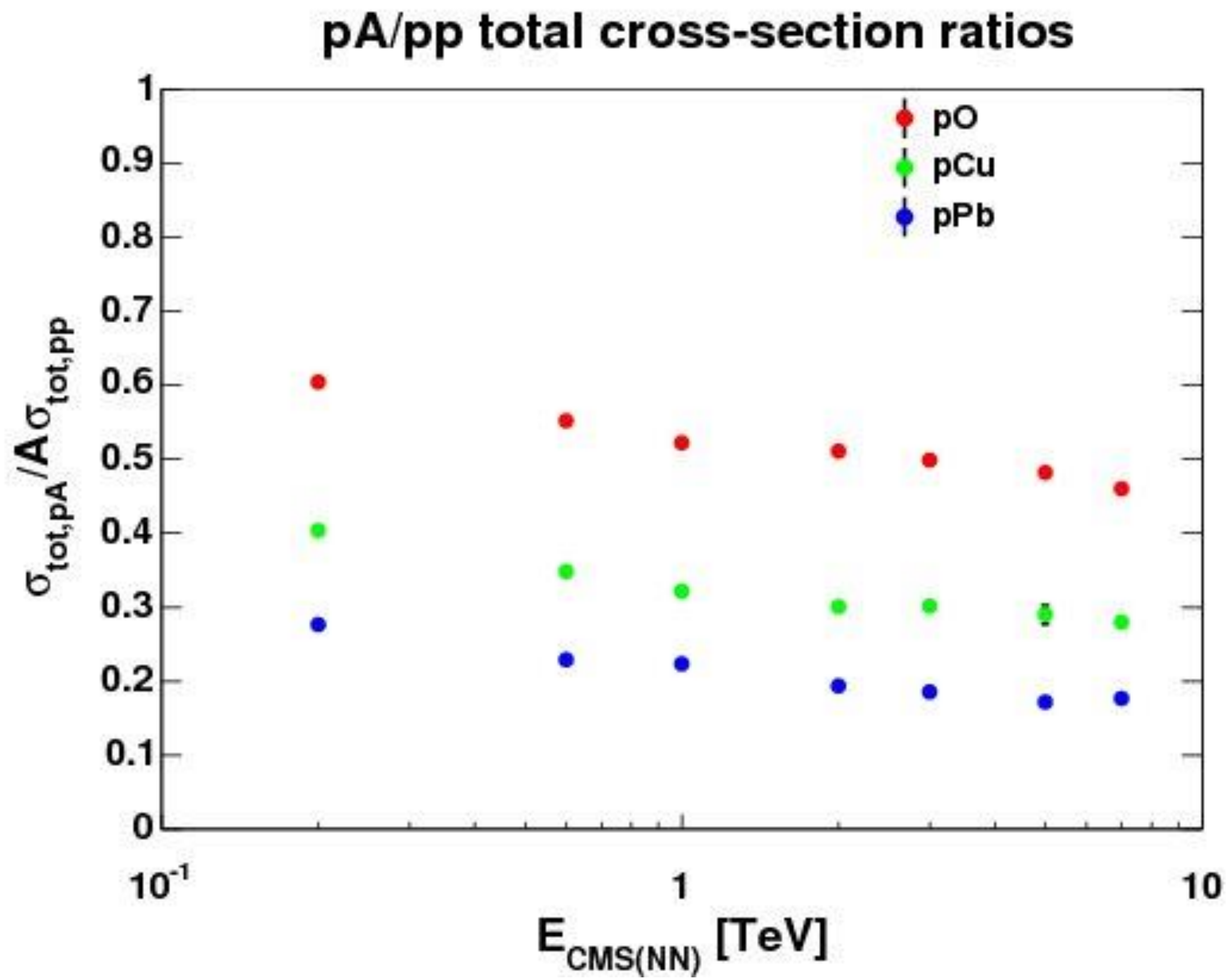
- CMS: preliminary

- LHCb: first measurement

Preliminary results



Preliminary results



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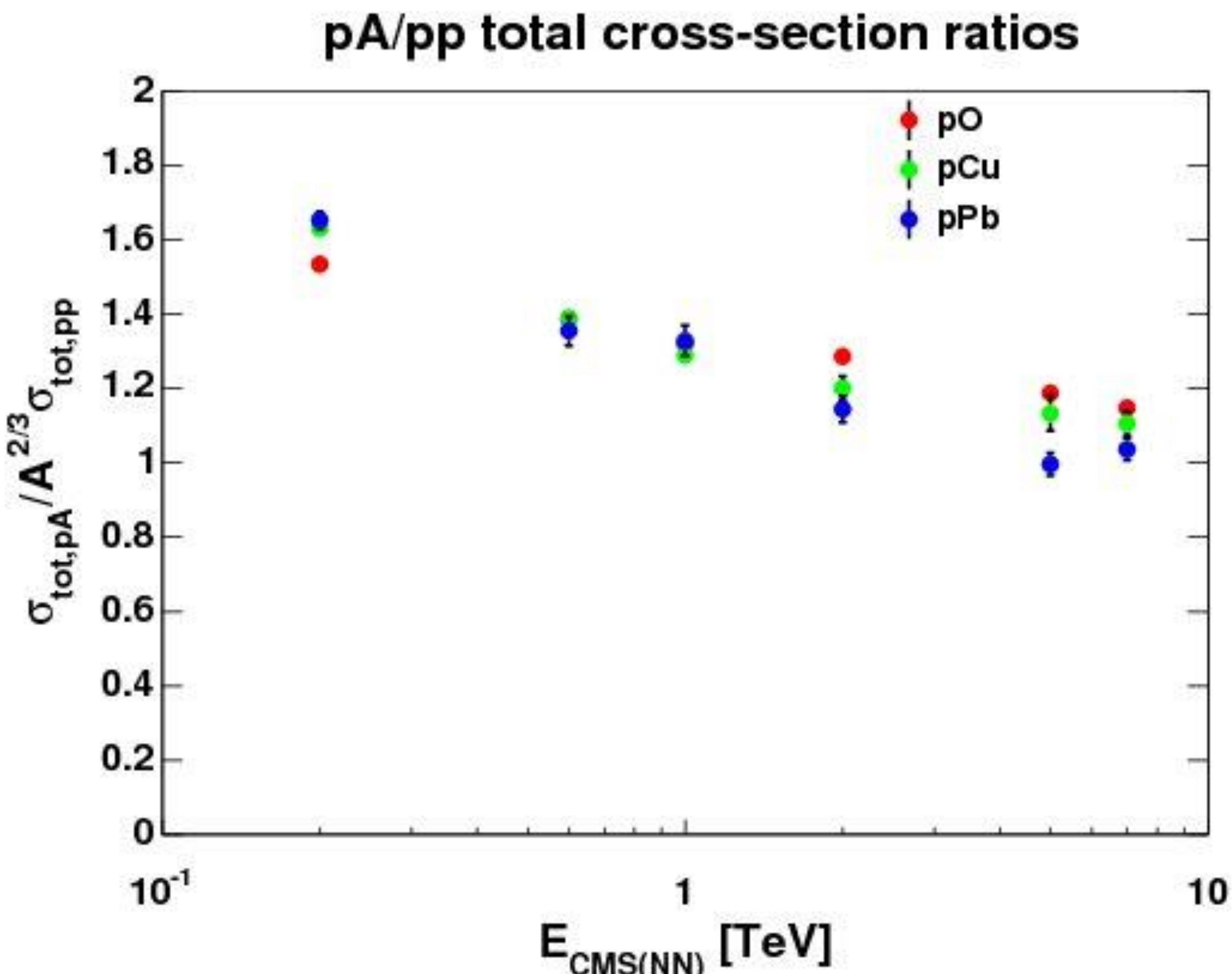
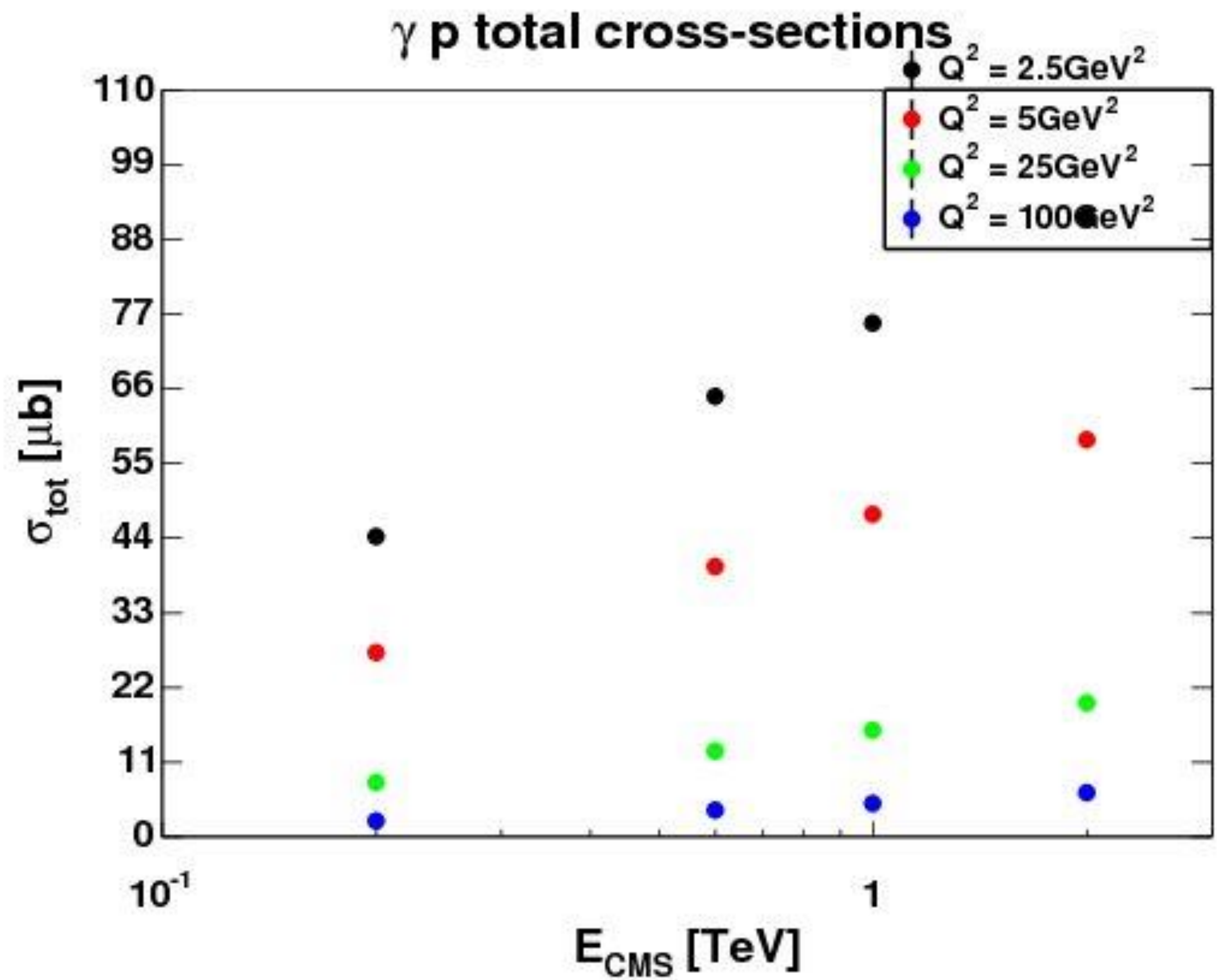
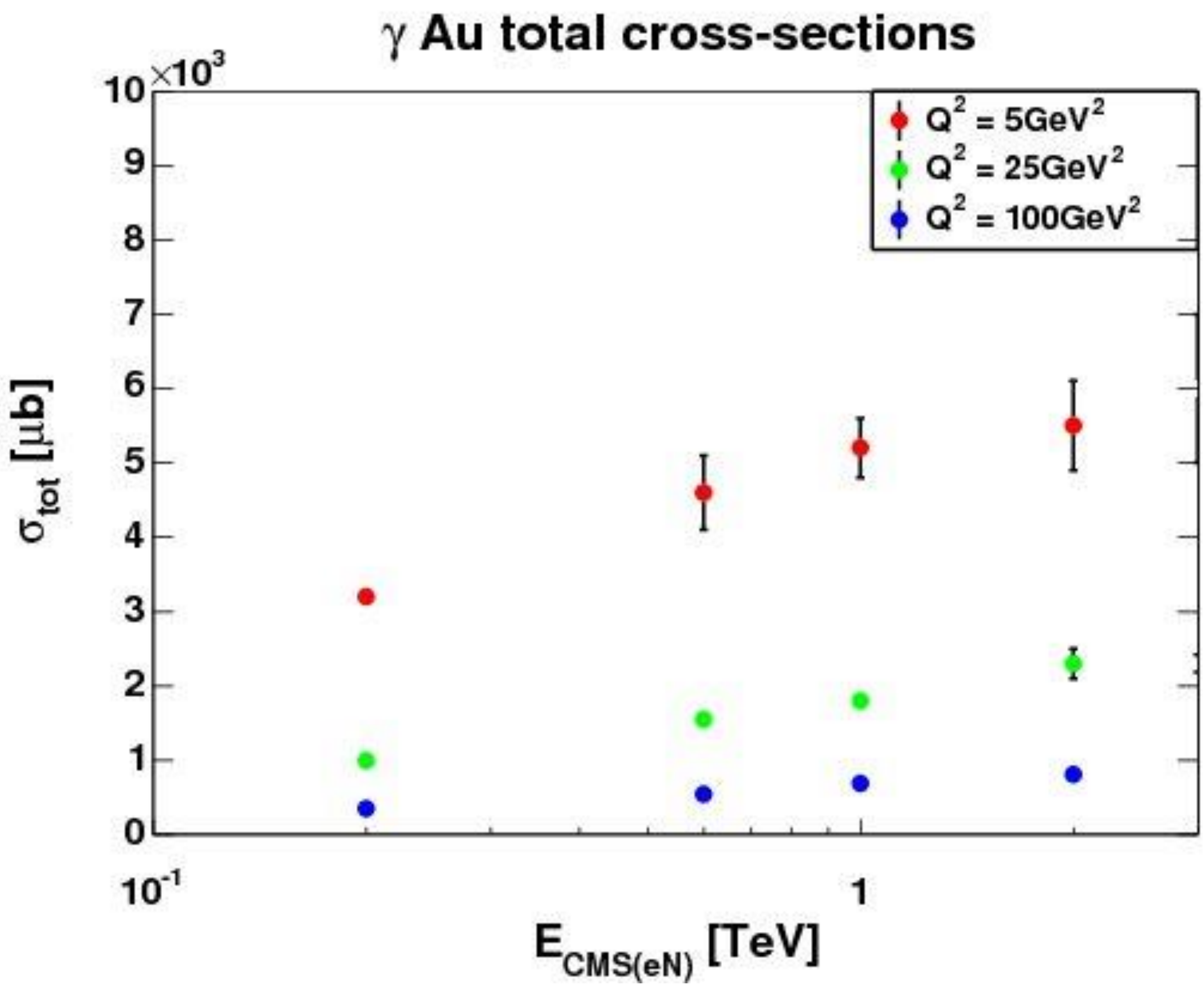


Preliminary results



Preliminary results



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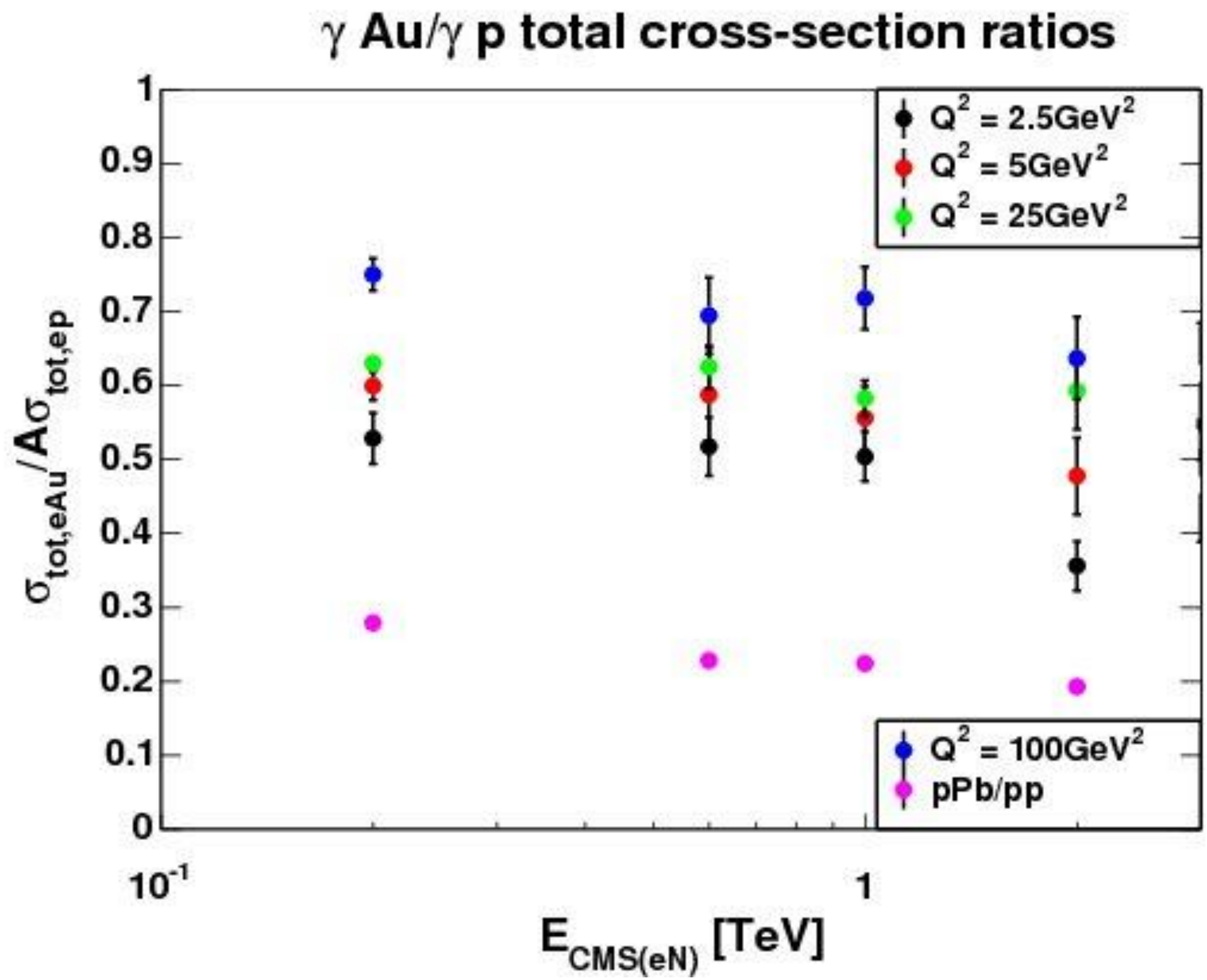

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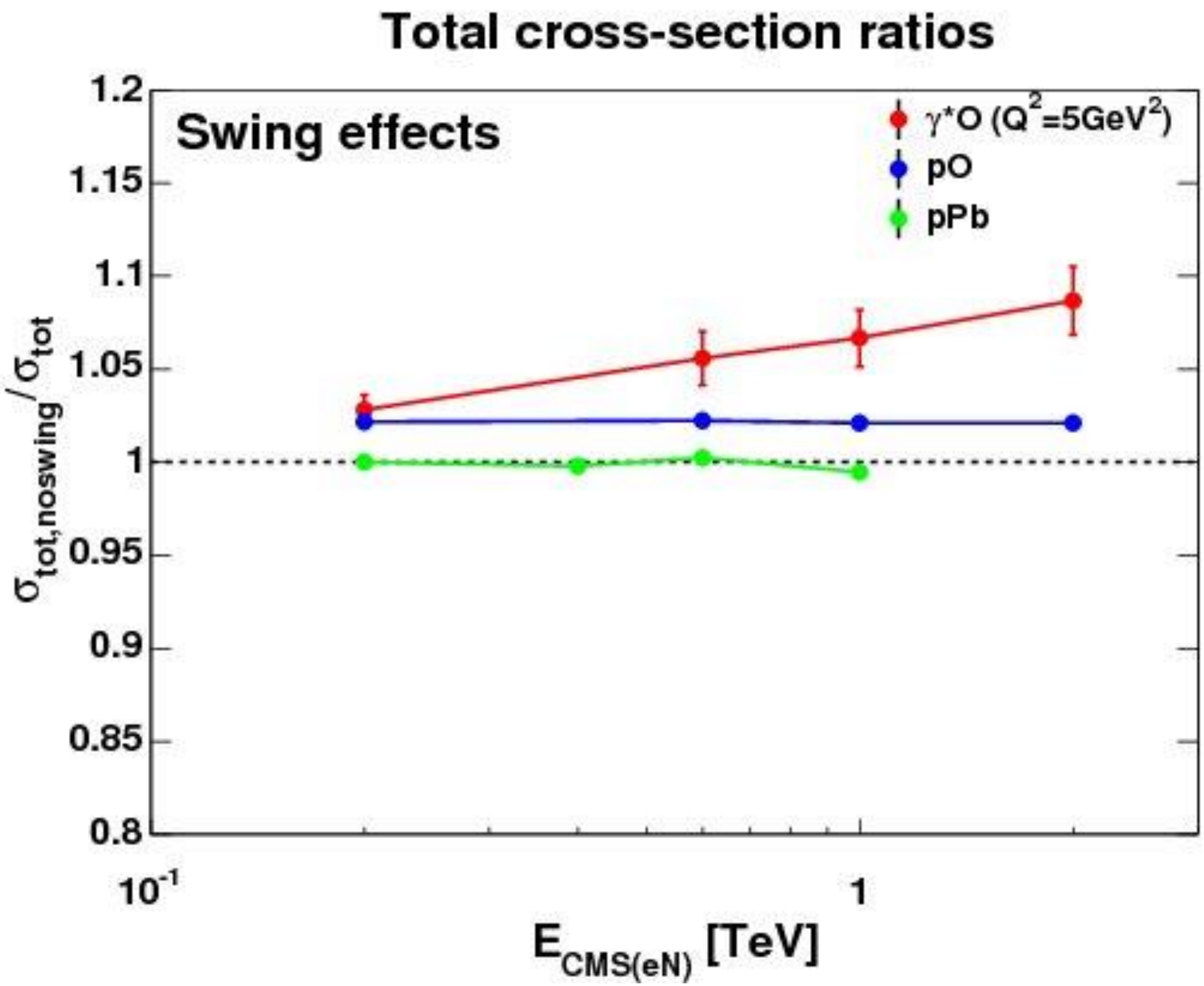
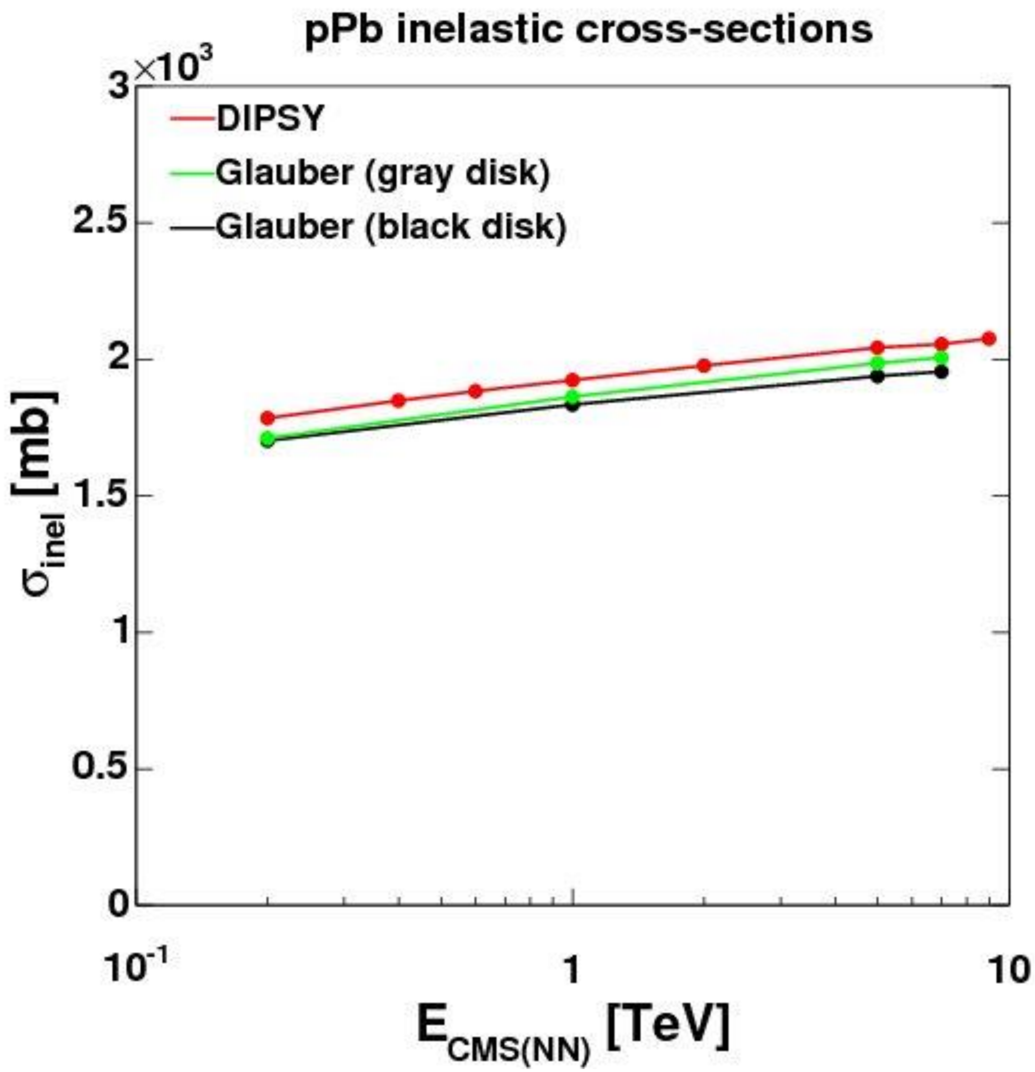


Preliminary results



<u>Conditions set to the same:</u>

- same WS distribution

- same R-hard-core = 0.45fm

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.