Diffractive and total cross sections in high energy pp, pA and γ^*A reactions with the dipole formalism

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- The Lund Dipole Cascade Model
- Application in MC code DIPSY
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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

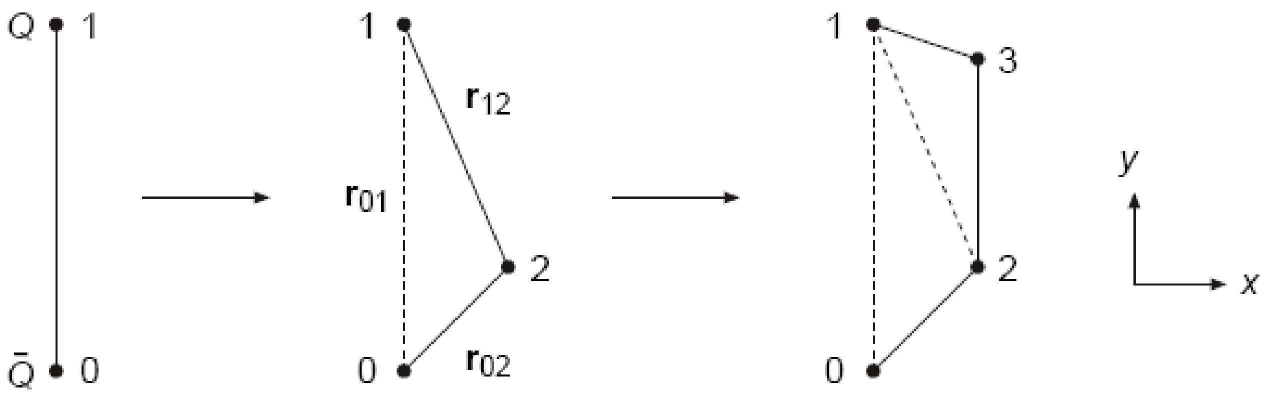
It improves BFKL evolutions :

- 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



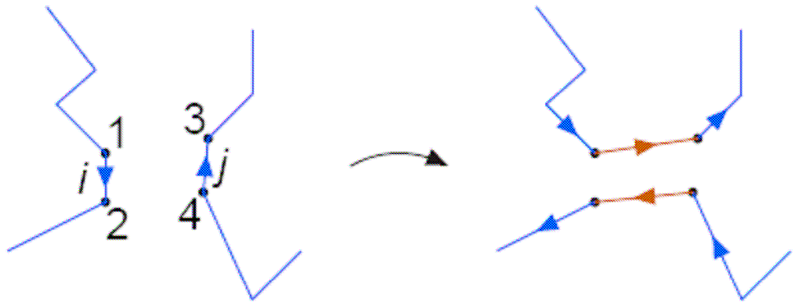
Gluon emission probality:

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

The Lund Dipole Cascade Model

Dipole-dipole scattering:

Single gluon exhange $\Rightarrow$ 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 $\Rightarrow$ Born ampl. $F = \sum_{ij} f_{ij}$

Unitarity: Eikonal approx. in imp. parameter space

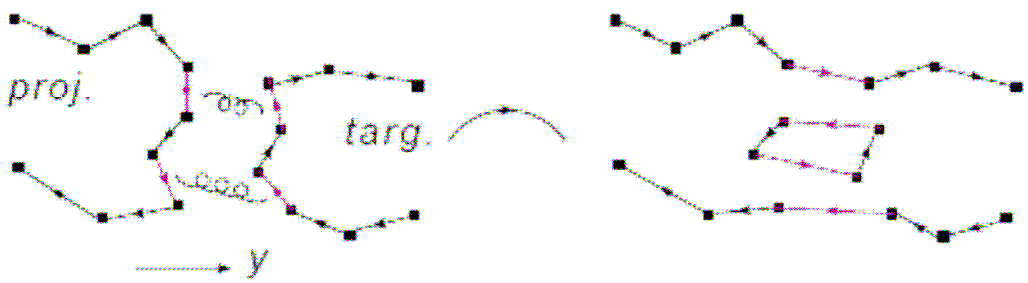
Uniterized ampl.: $T = 1 - e^{-\sum f_{ij}}$ (neglecting fluctuations)

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

The Lund Dipole Cascade Model

Saturation:

Multiple interactions ⇒ colour loops ~ pomeron loops



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

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:

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

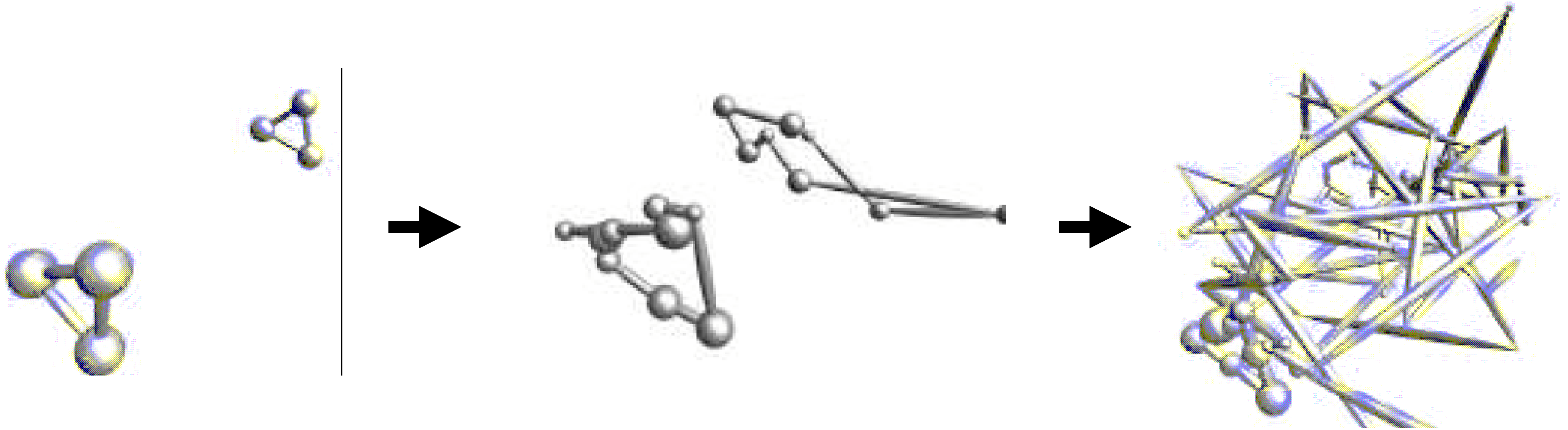
Application in MC code DIPSY

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

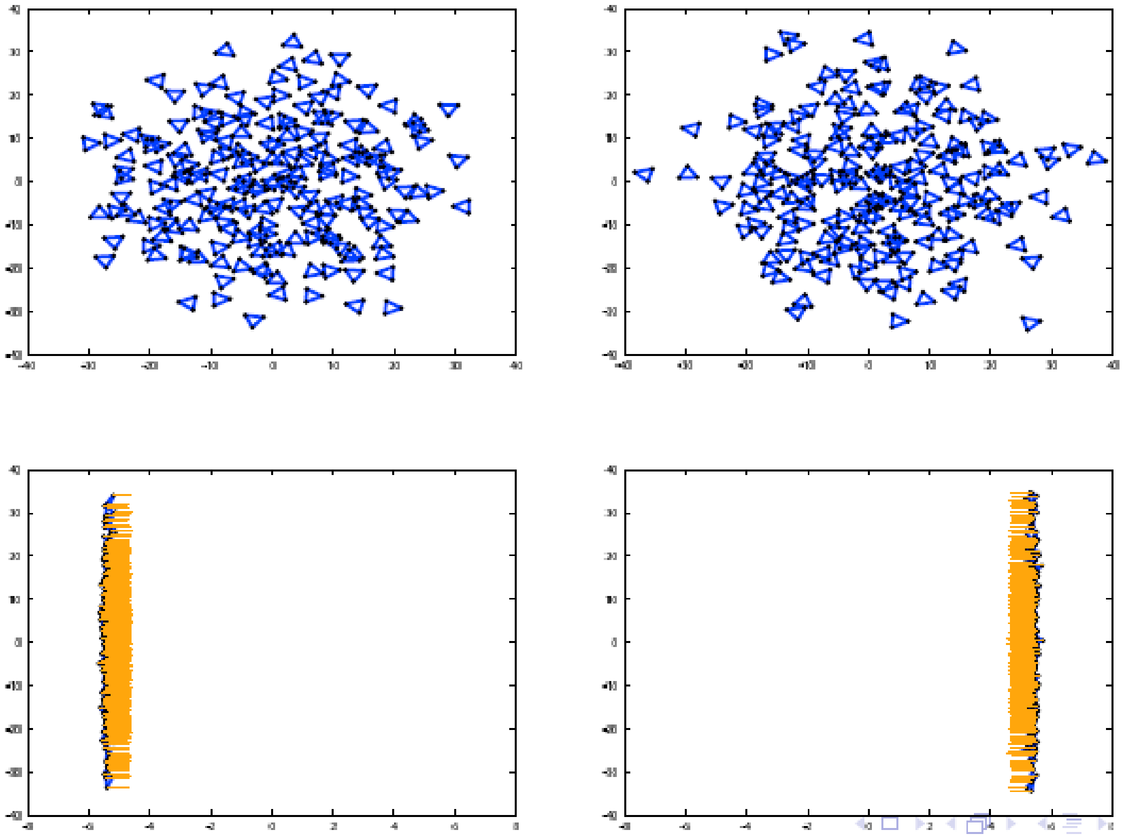
Application in MC code DIPSY

Dipole interactions:



Application in MC code DIPSY

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



Application in MC code DIPSY

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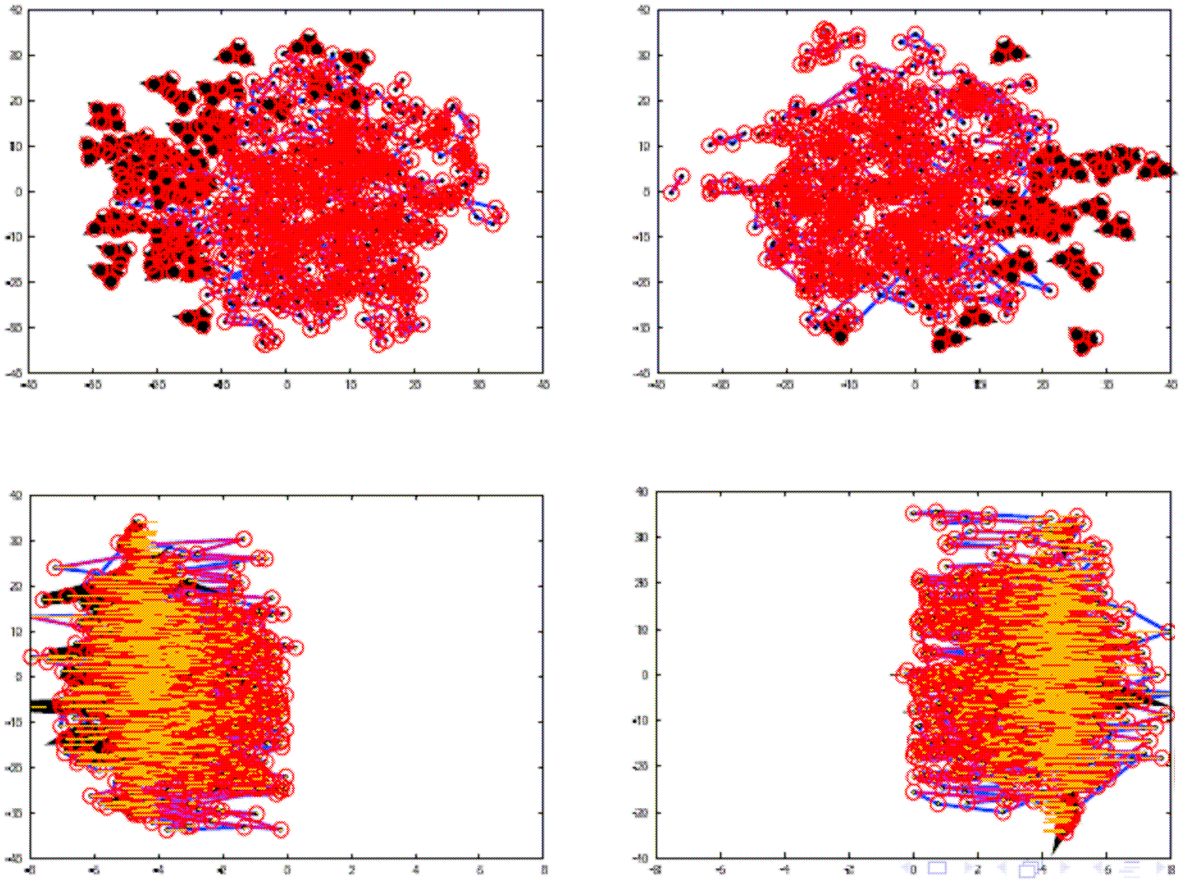

Application in MC code DIPSY

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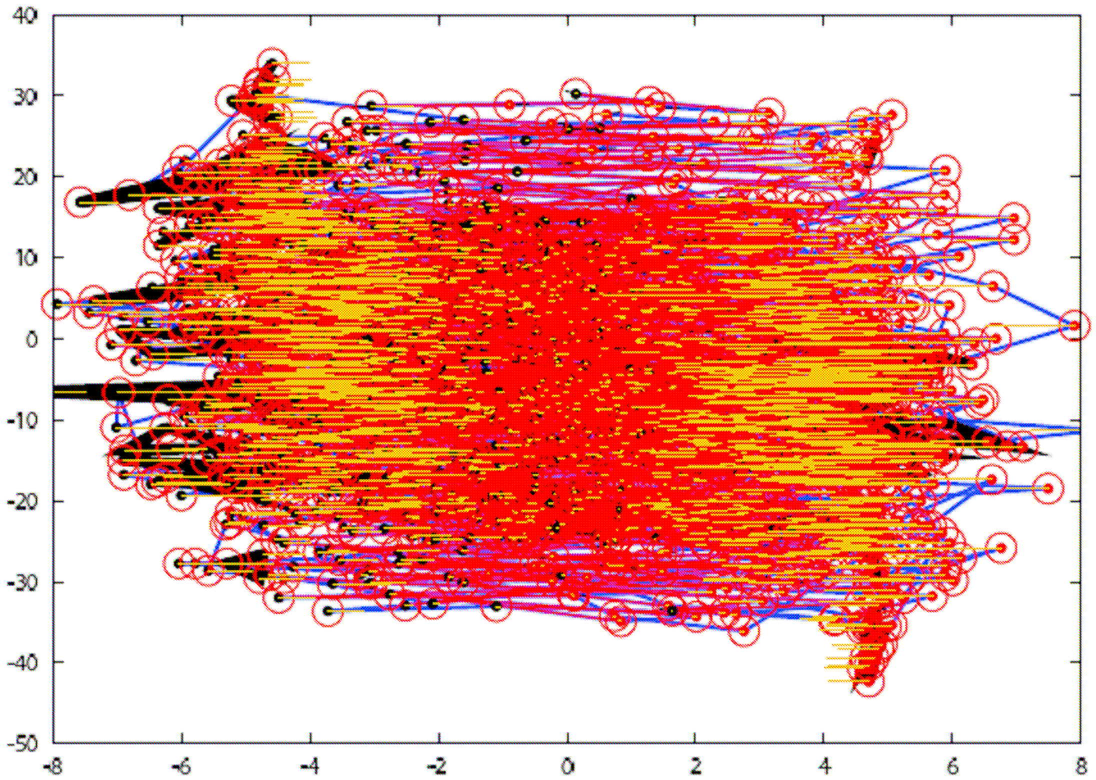
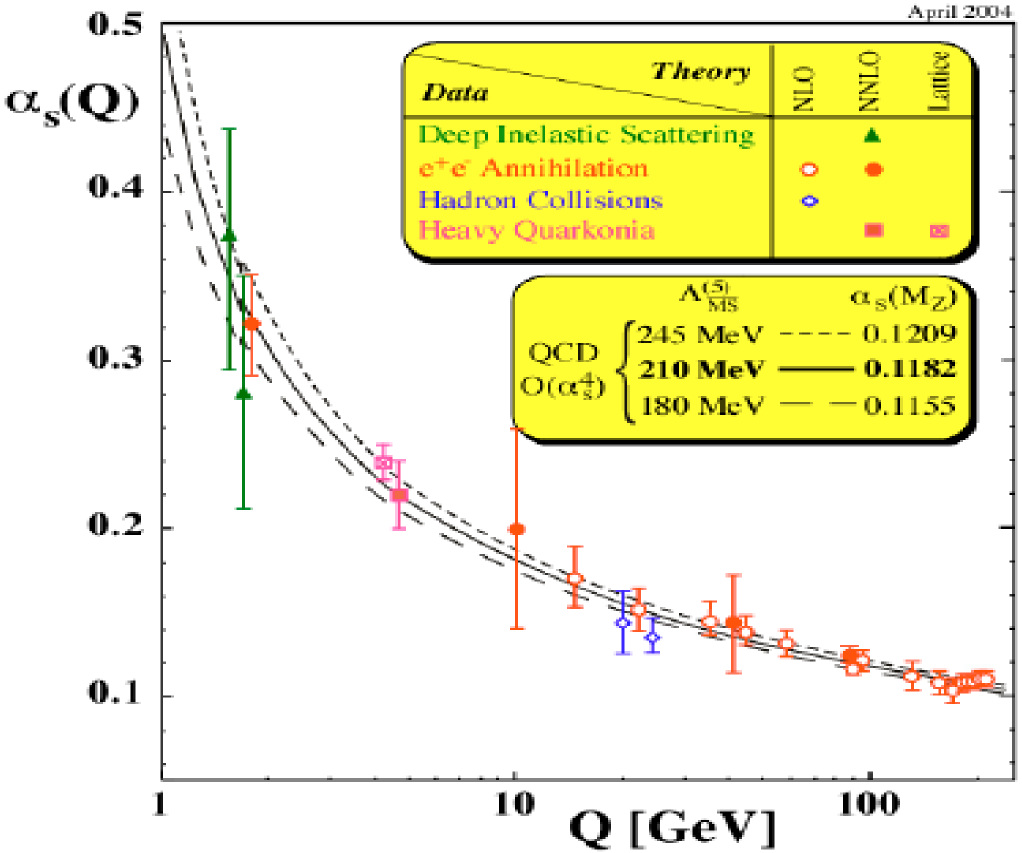


Preliminary results

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

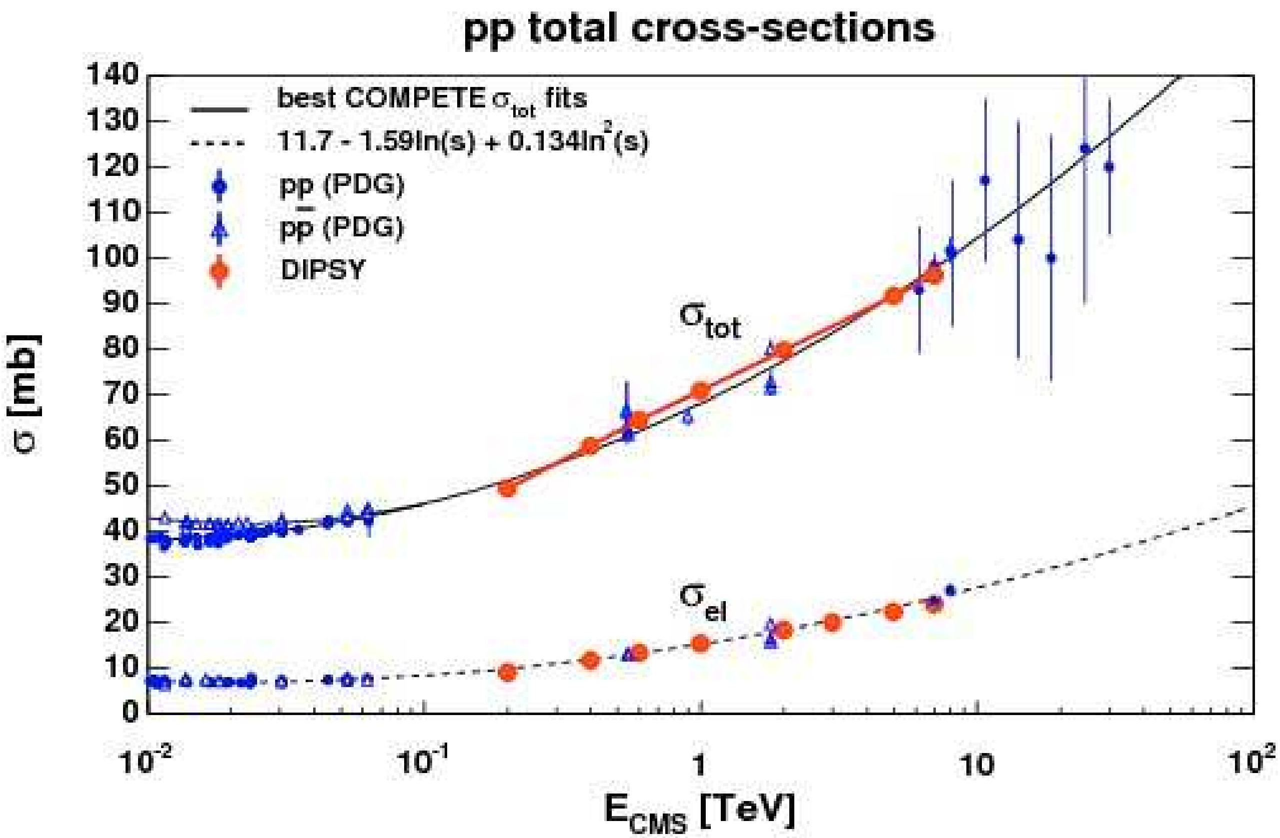
R_p: Proton size ($\approx R_{\max}$)

w_p: Fluctuations in the initial proton size (small)

Λ_{QCD}: in the running α_s

λ_r: Swing parameter (saturated)

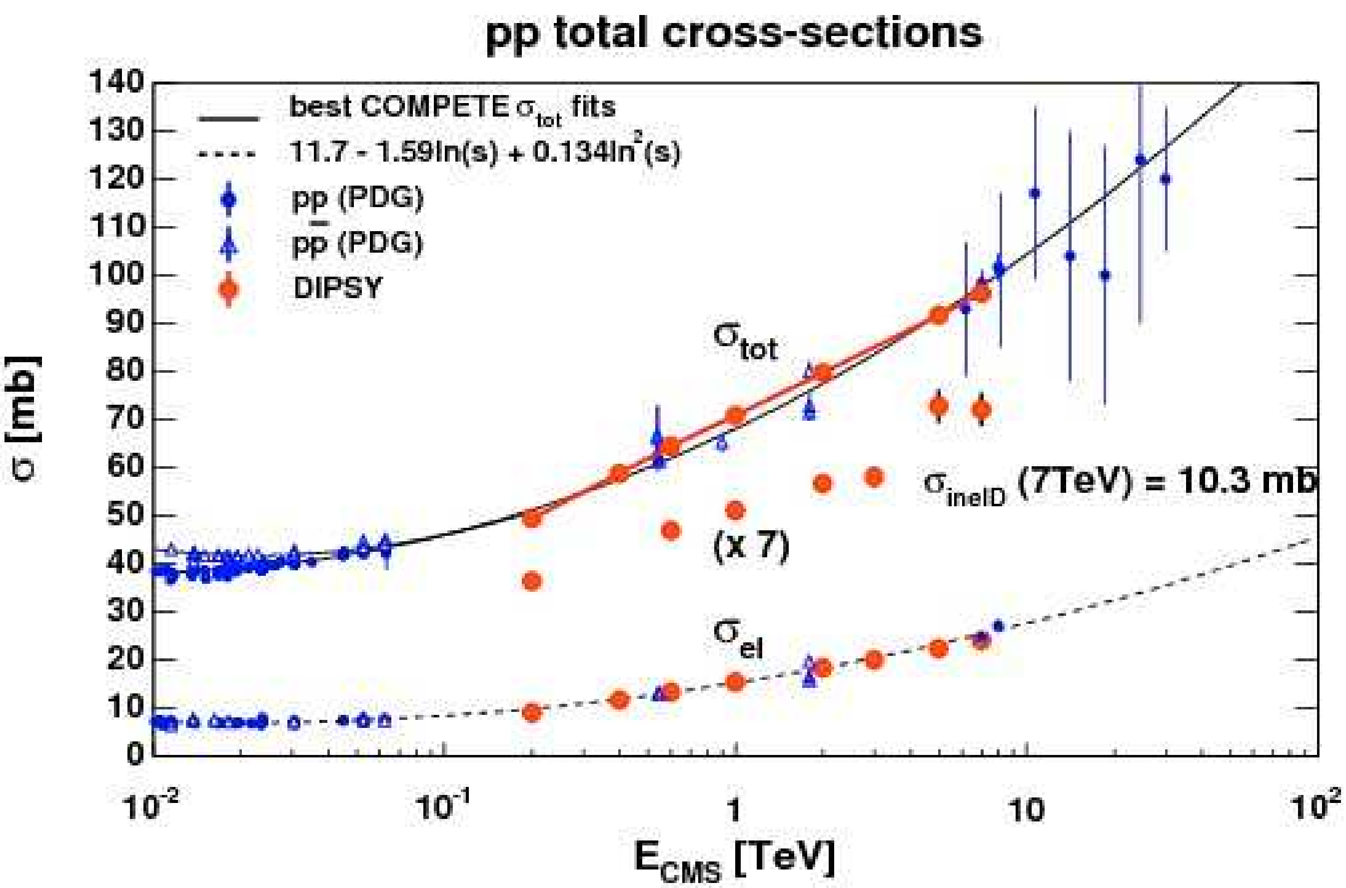
Preliminary results



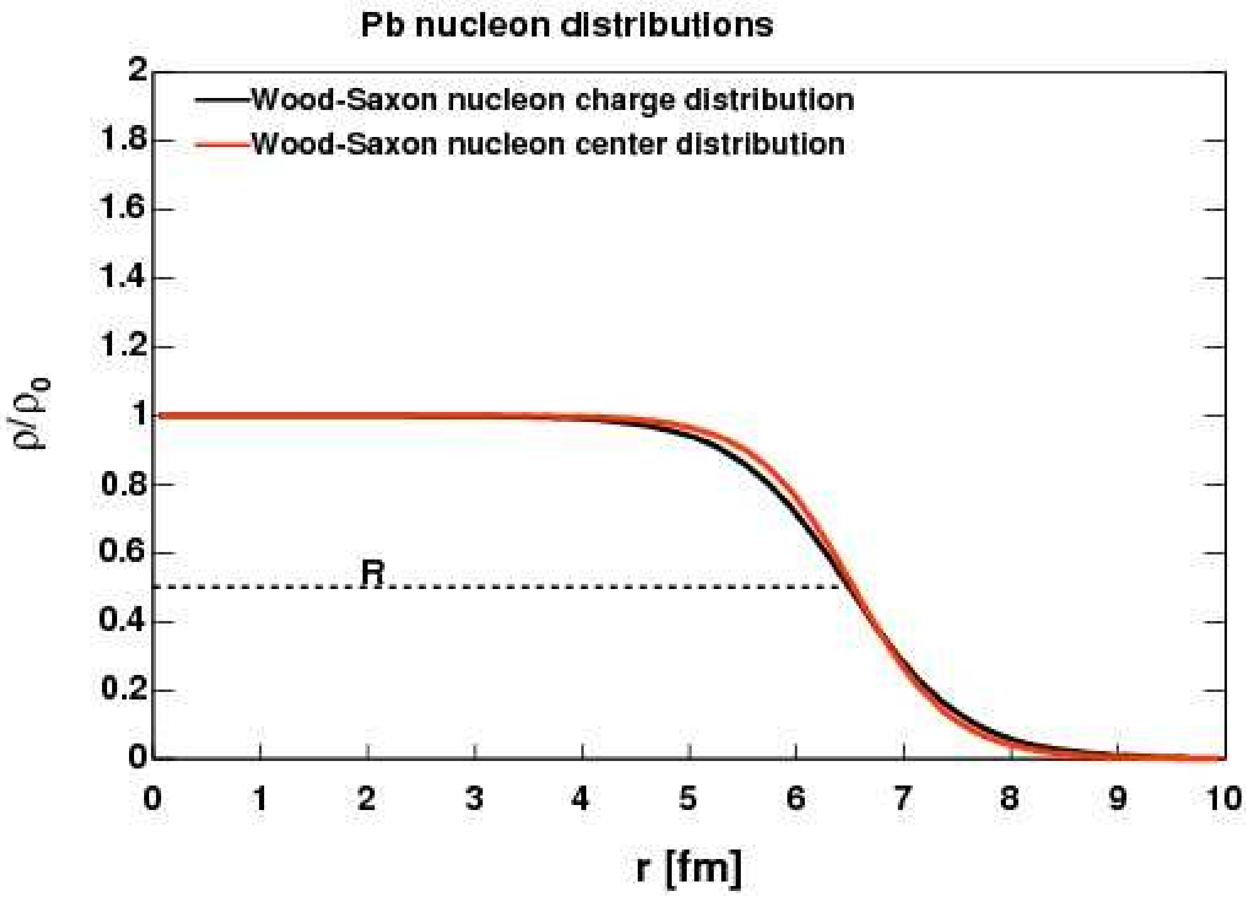
With, for example:

$\Lambda_{QCD} = 0.23$ GeV

Preliminary results



Preliminary results



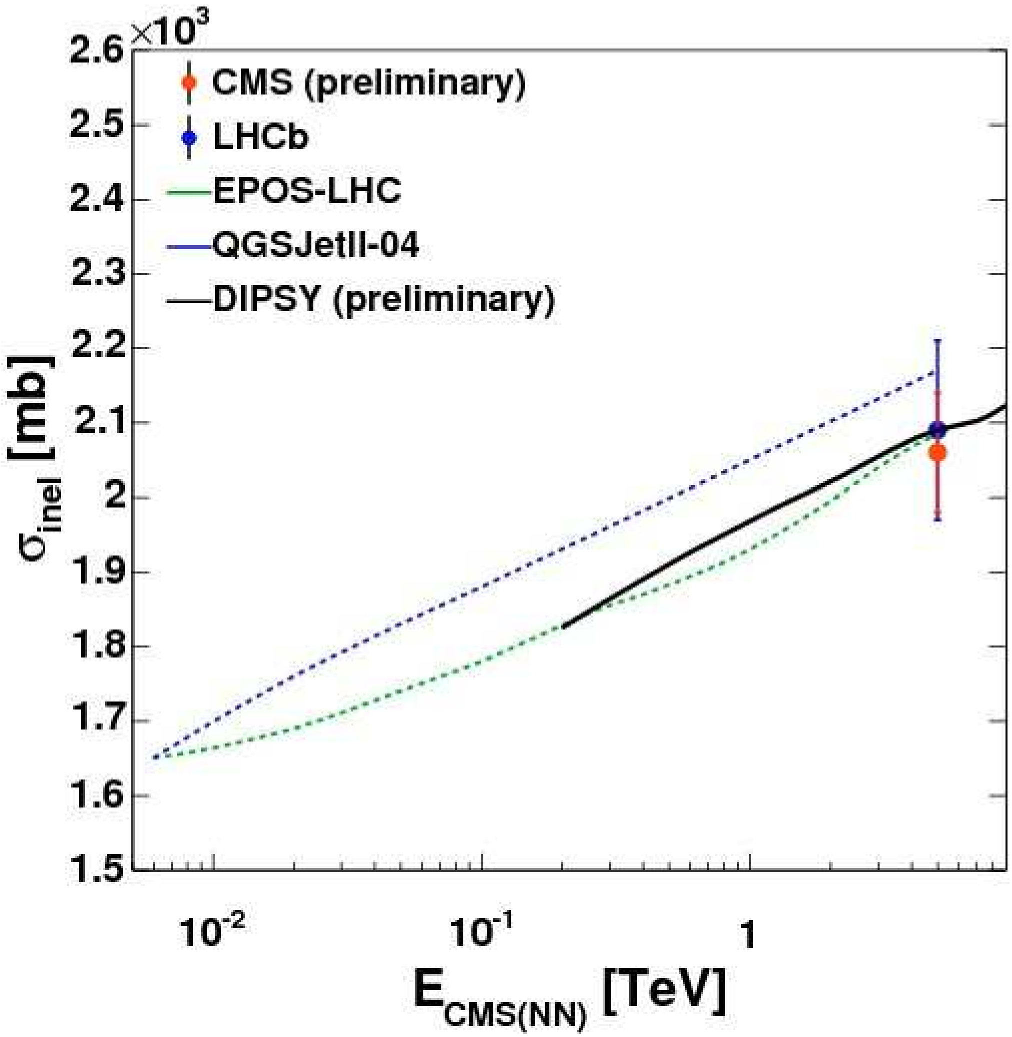
Based on the Wood-Saxon nucleus charge density*:

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

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

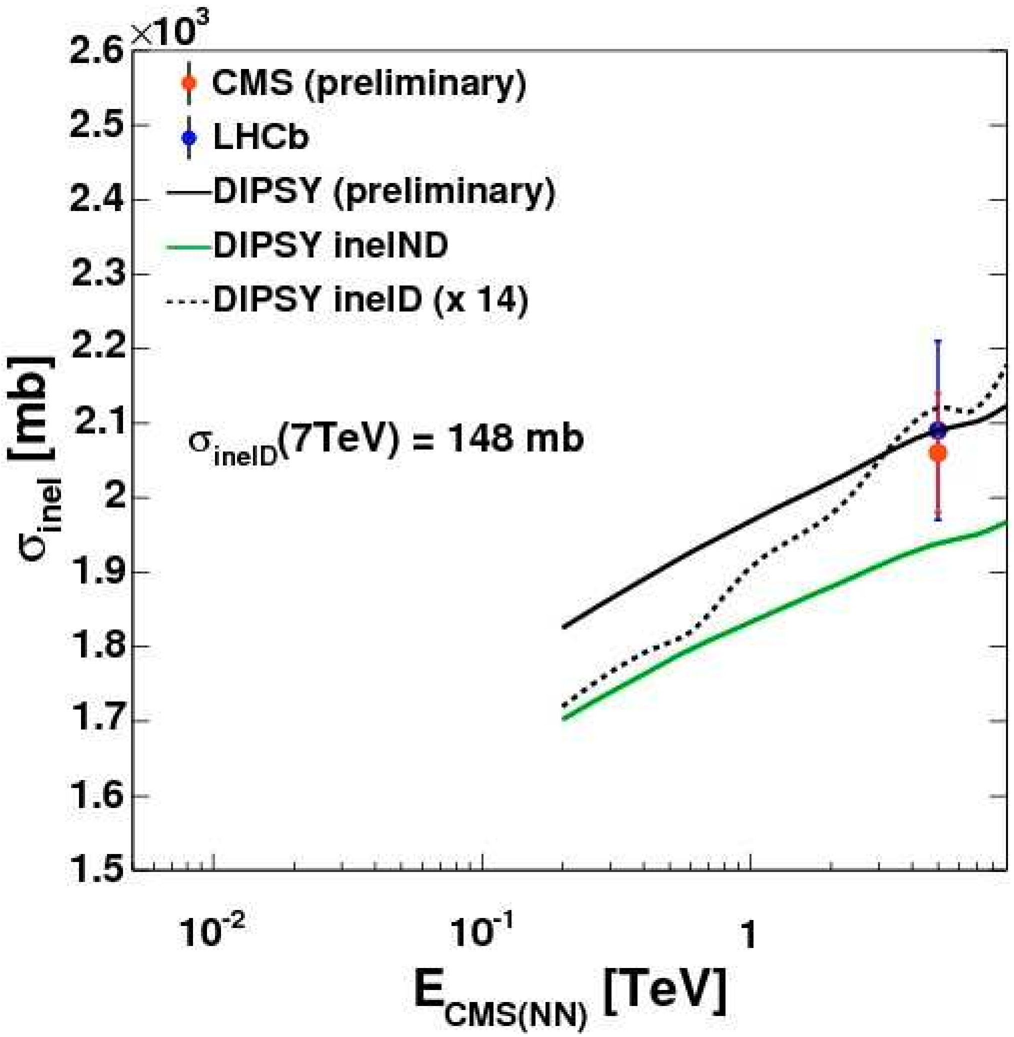


pPb data of total inelastic cross sections:

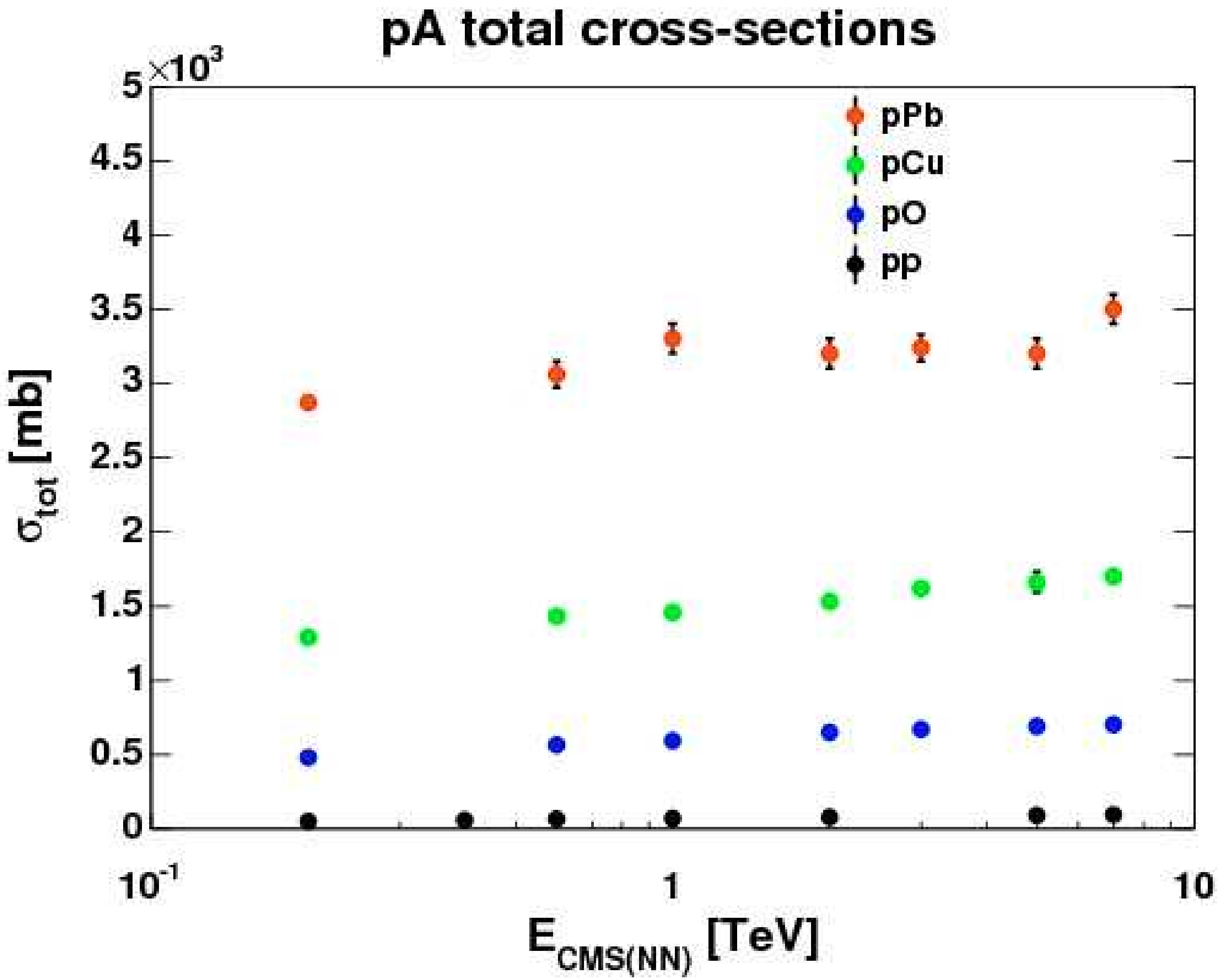
- CMS: preliminary

- LHCb: first measurement

Preliminary results



Preliminary results



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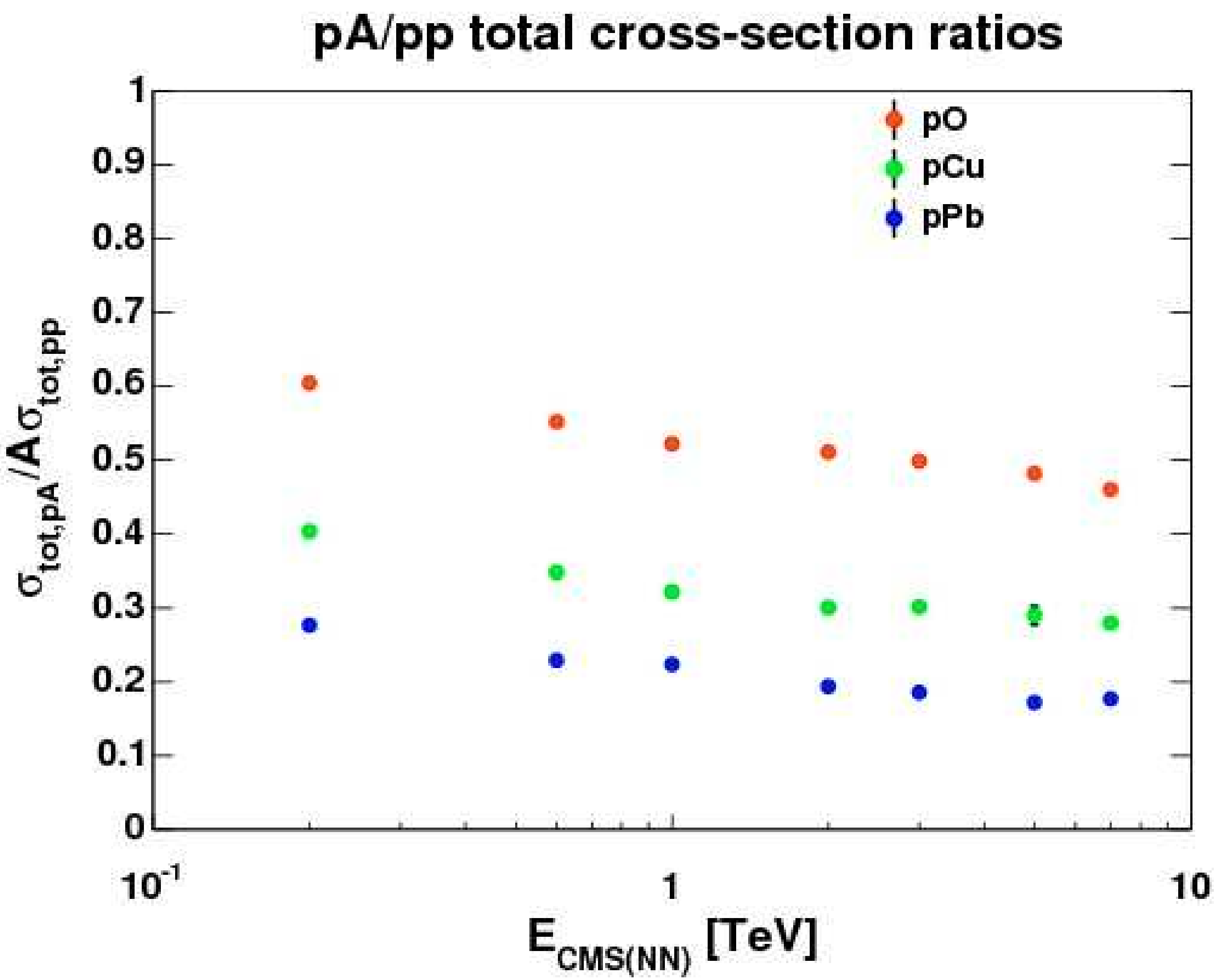

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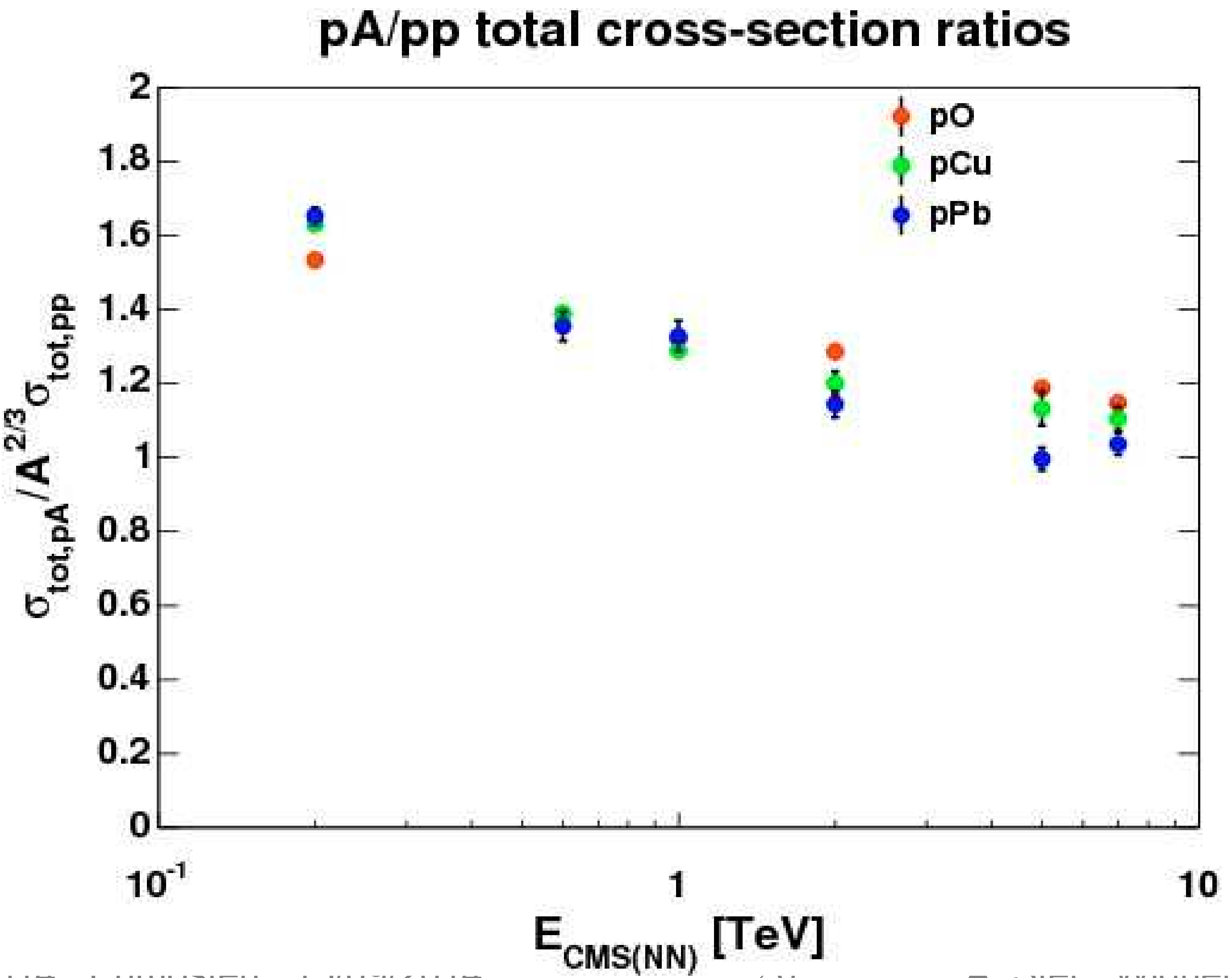

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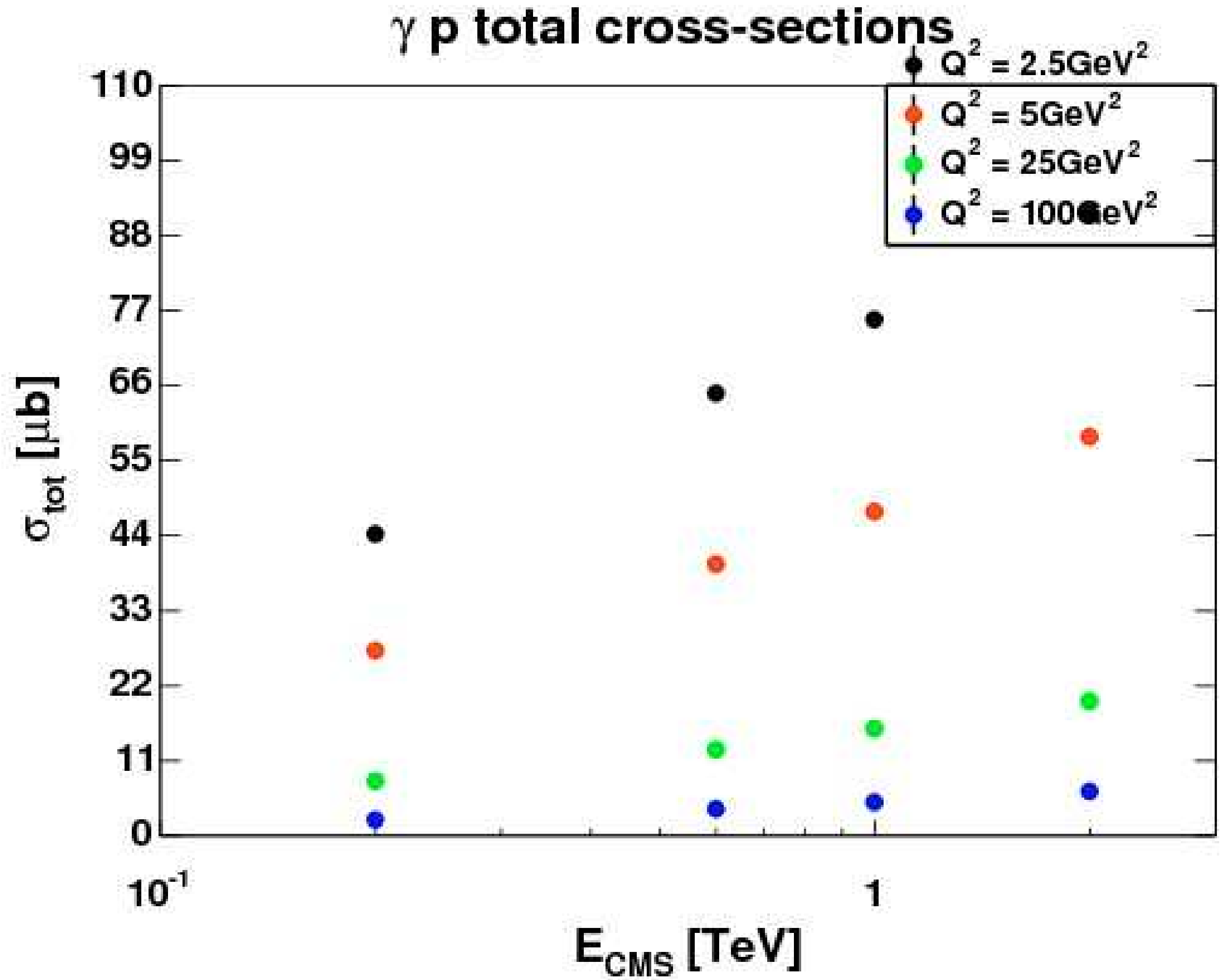

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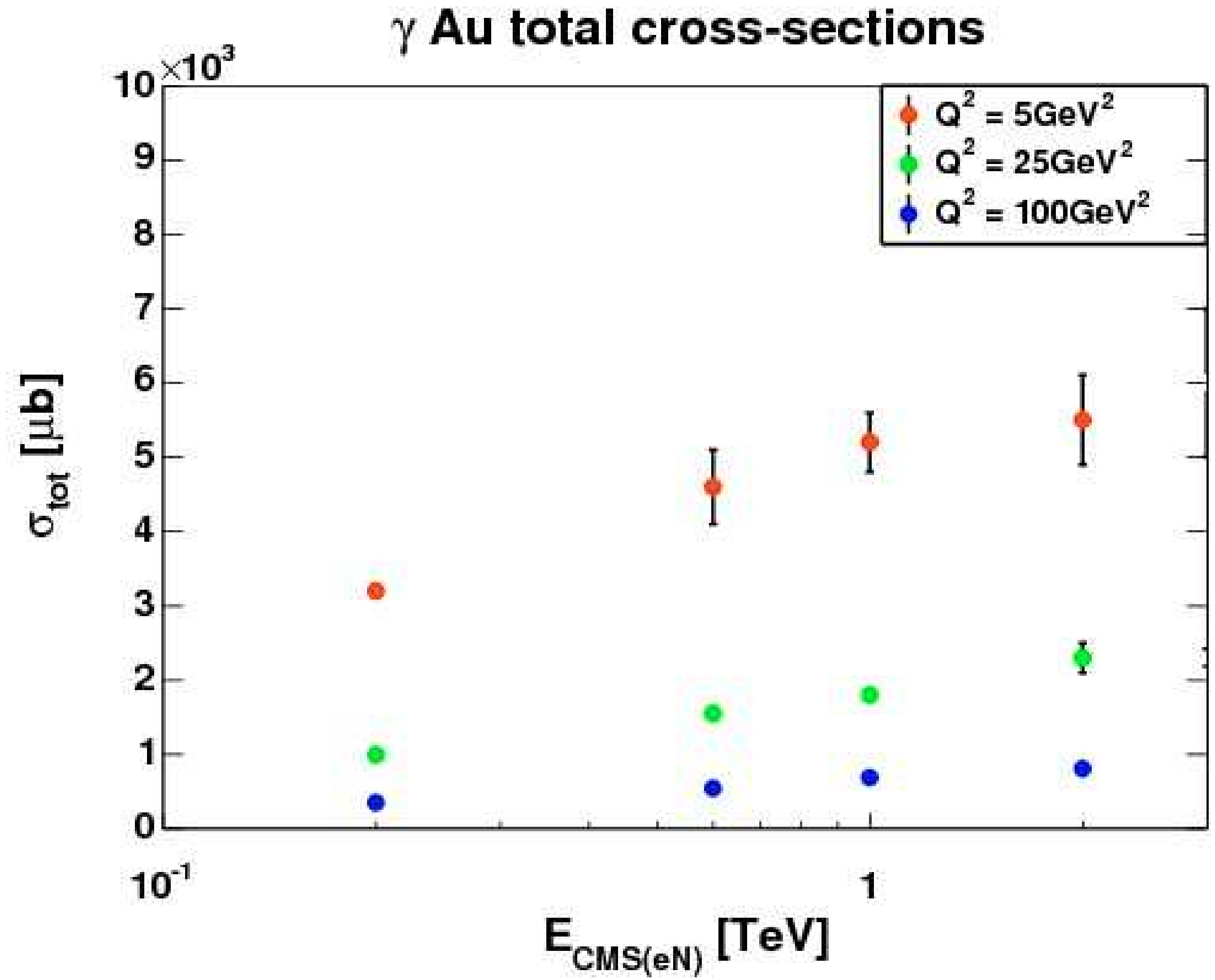

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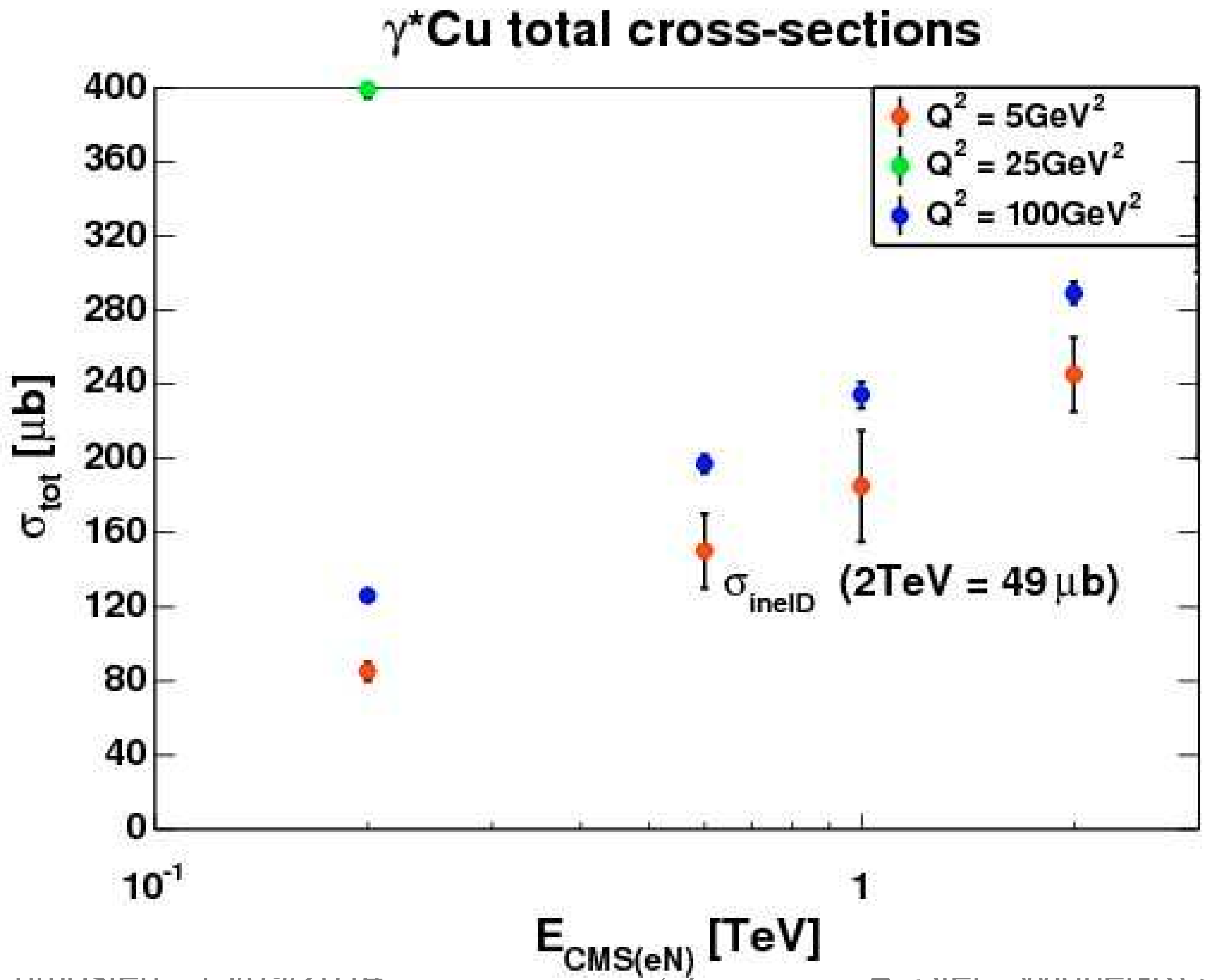

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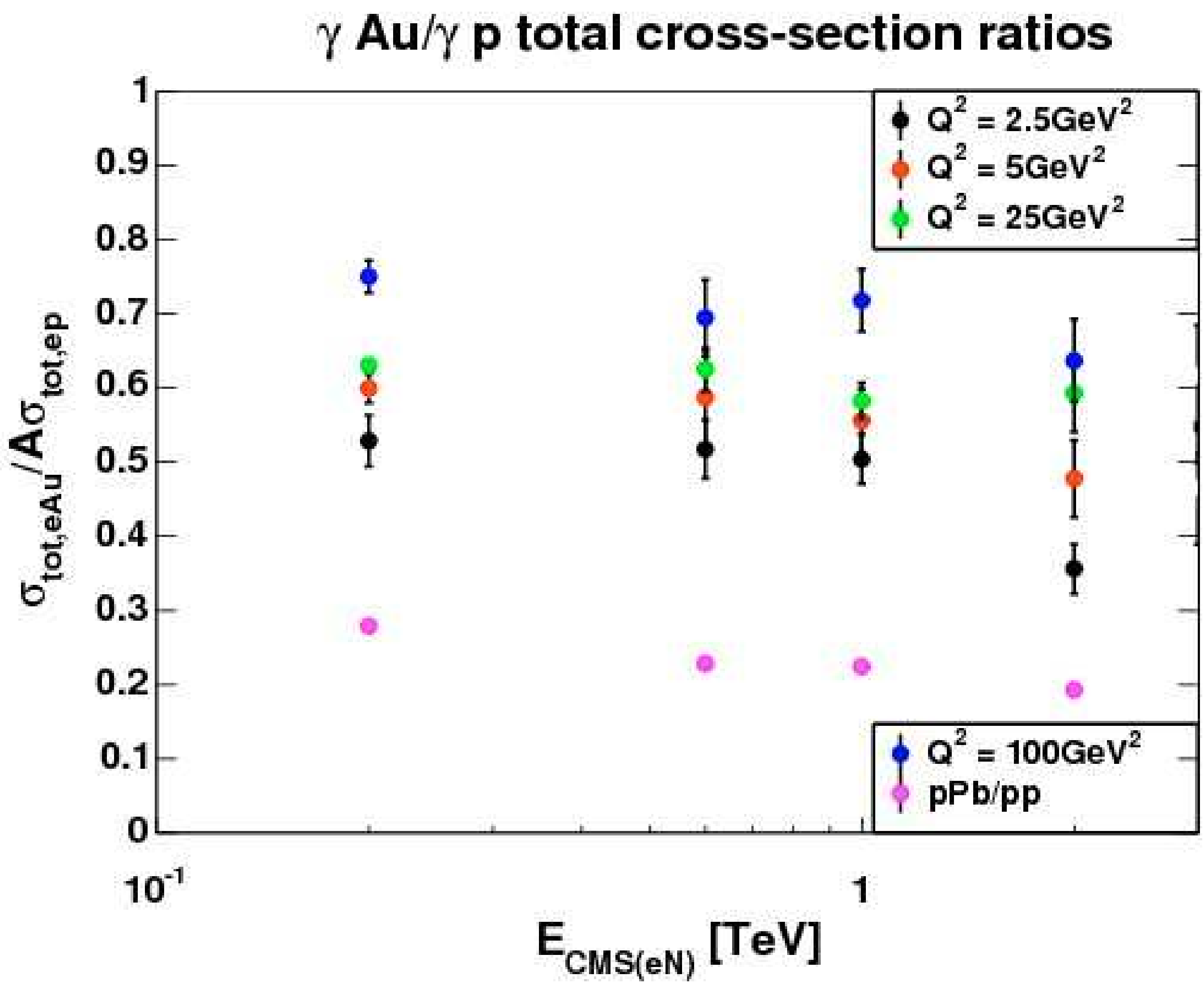

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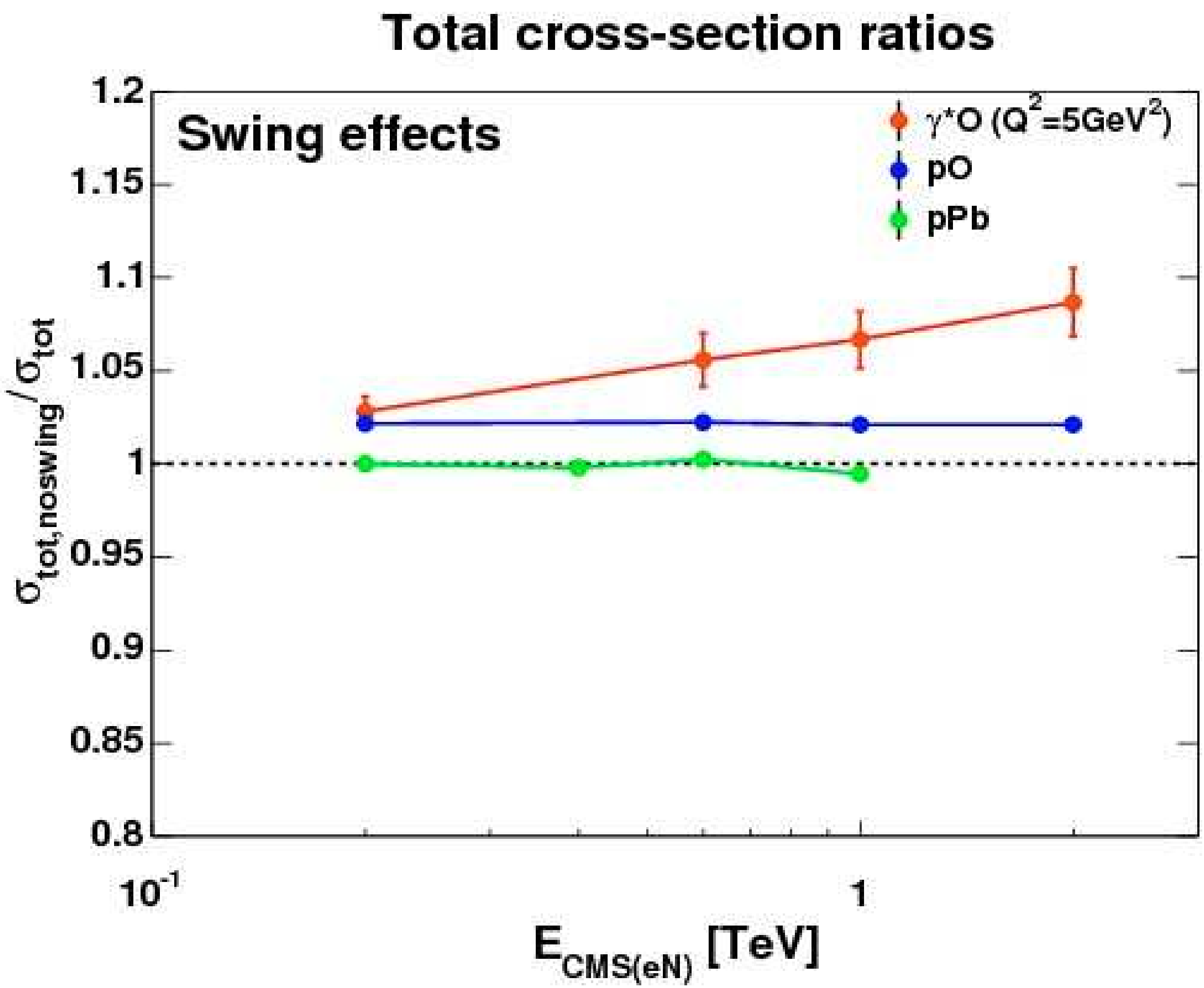

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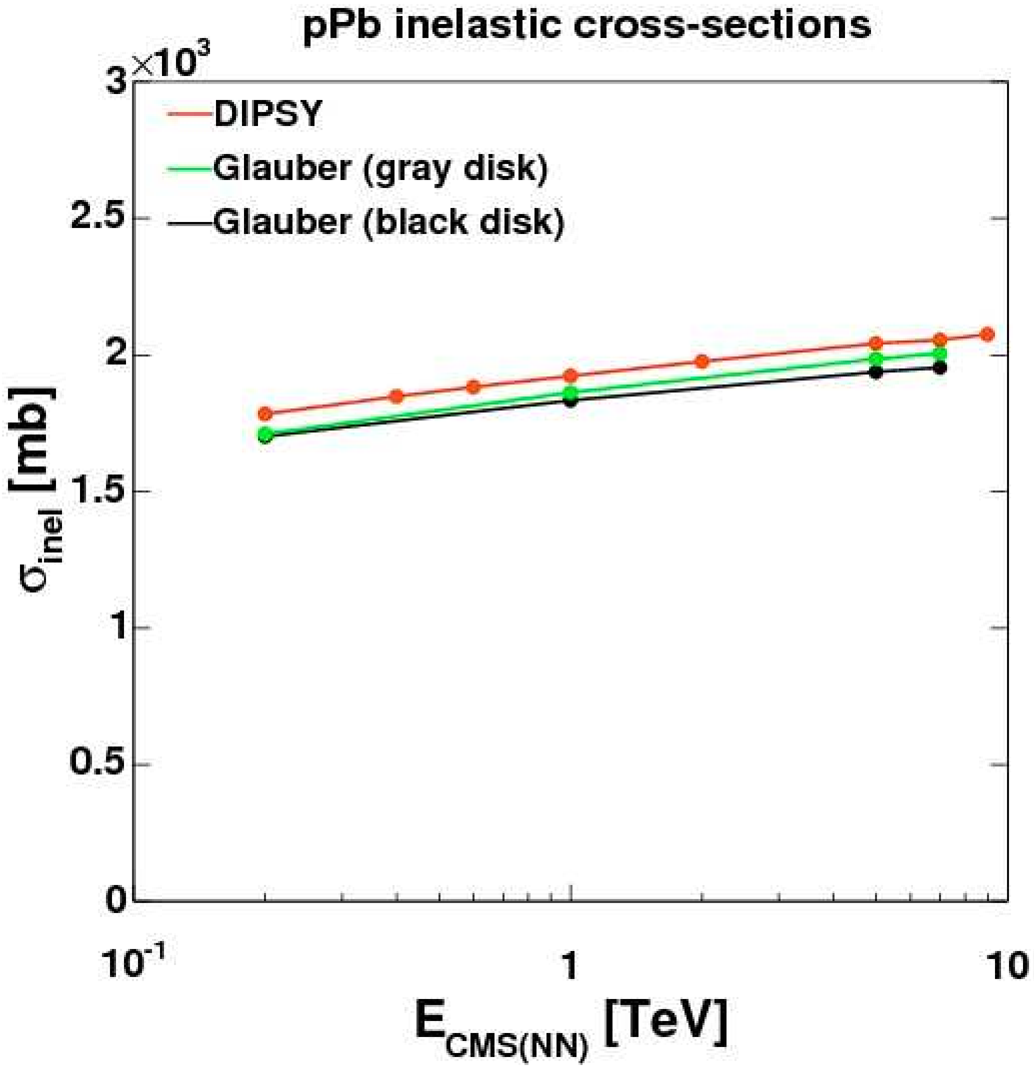

Conditions set to the same:

- same WS distribution
- same R-hard-core = 0.45fm
- same sigma_tot(pp)
- same sigma_inelND

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 cross sections and pPb inelasctic cross sections from RHIC to LHC energies was successful.

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