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

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- The Lund Dipole Cascade Model
- Application in MC event generator DIPSY
- Preliminary DIPSY-MC cross section results
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Motivations

An example: 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.

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)

Motivations: a new improved 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

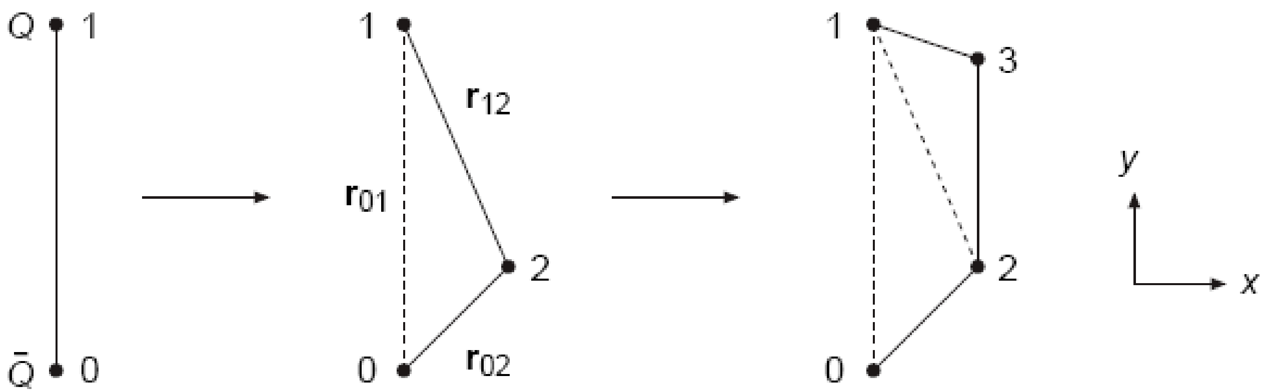
It improves BFKL evolutions :

- 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

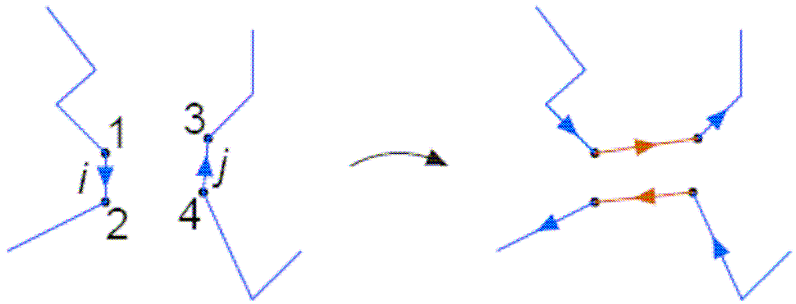


Gluon emission probality: $\frac{d\mathcal{P}}{dy} = \frac{\bar{\alpha}}{2\pi} d^2\mathbf{r}_2 \frac{r_{01}^2}{r_{02}^2 r_{12}^2}$

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

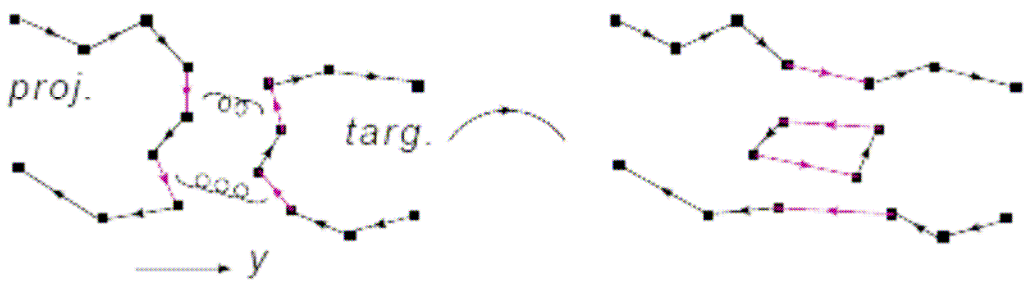
Uniterized ampl.: $T = 1 - e^{-\sum f_{ij}}$ (neglecting fluctuations)

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

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:

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

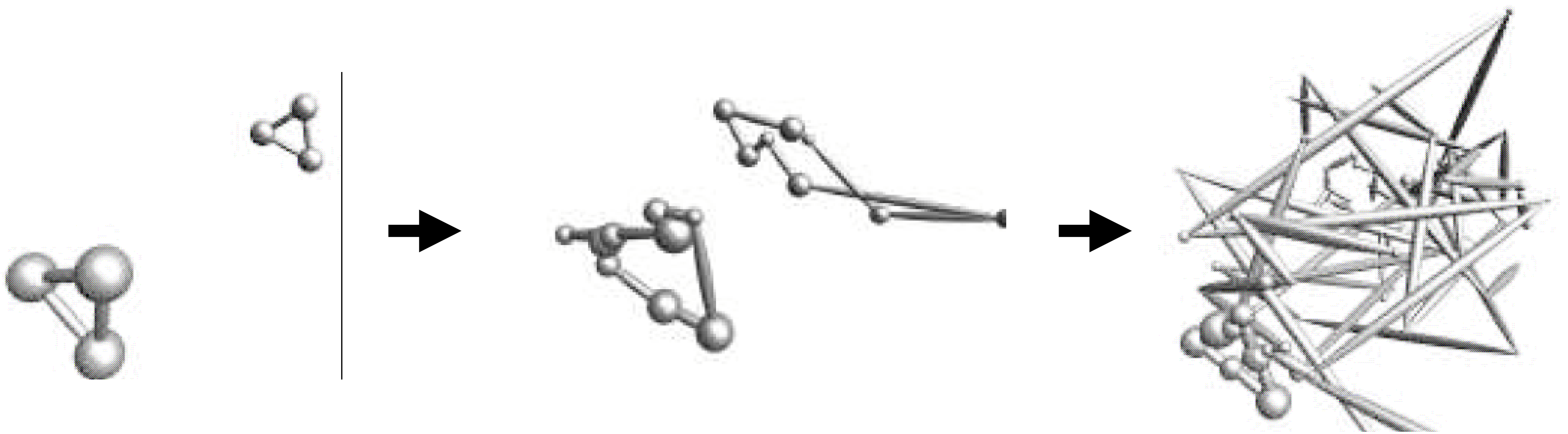
Application in DIPSY-MC

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

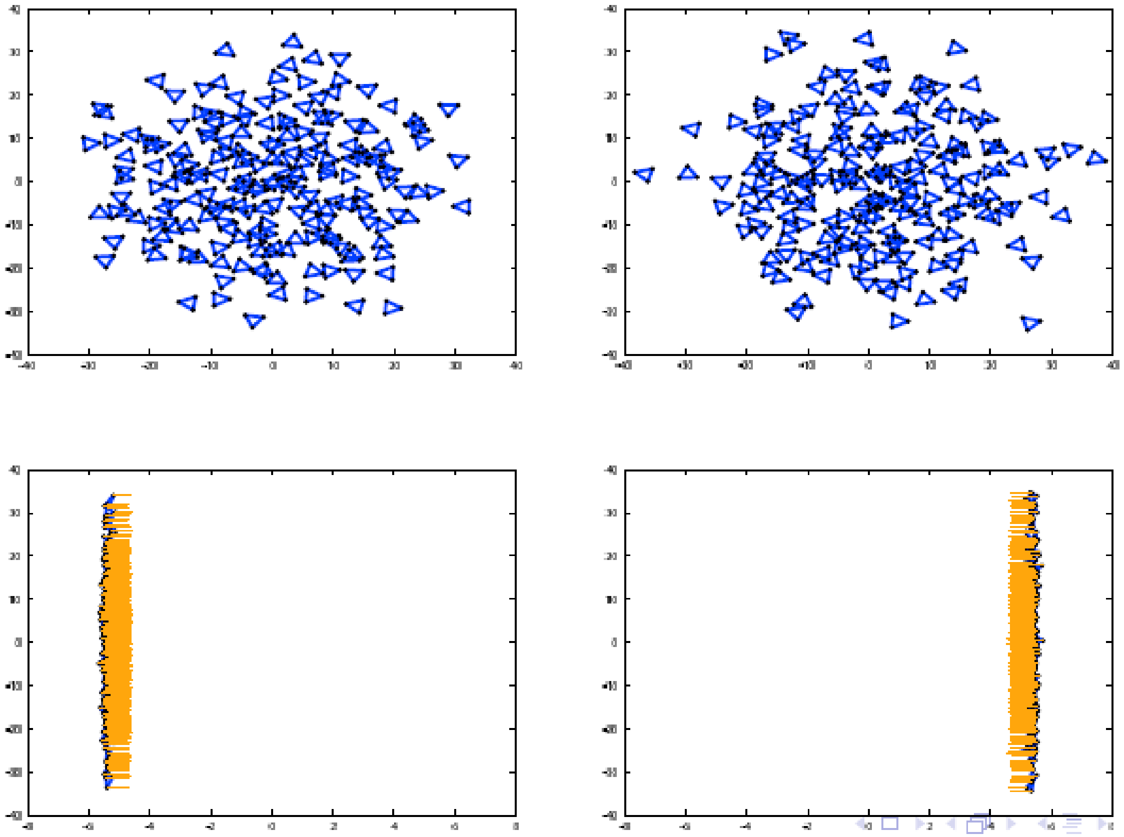
Application in DIPSY-MC

Dipole interactions:



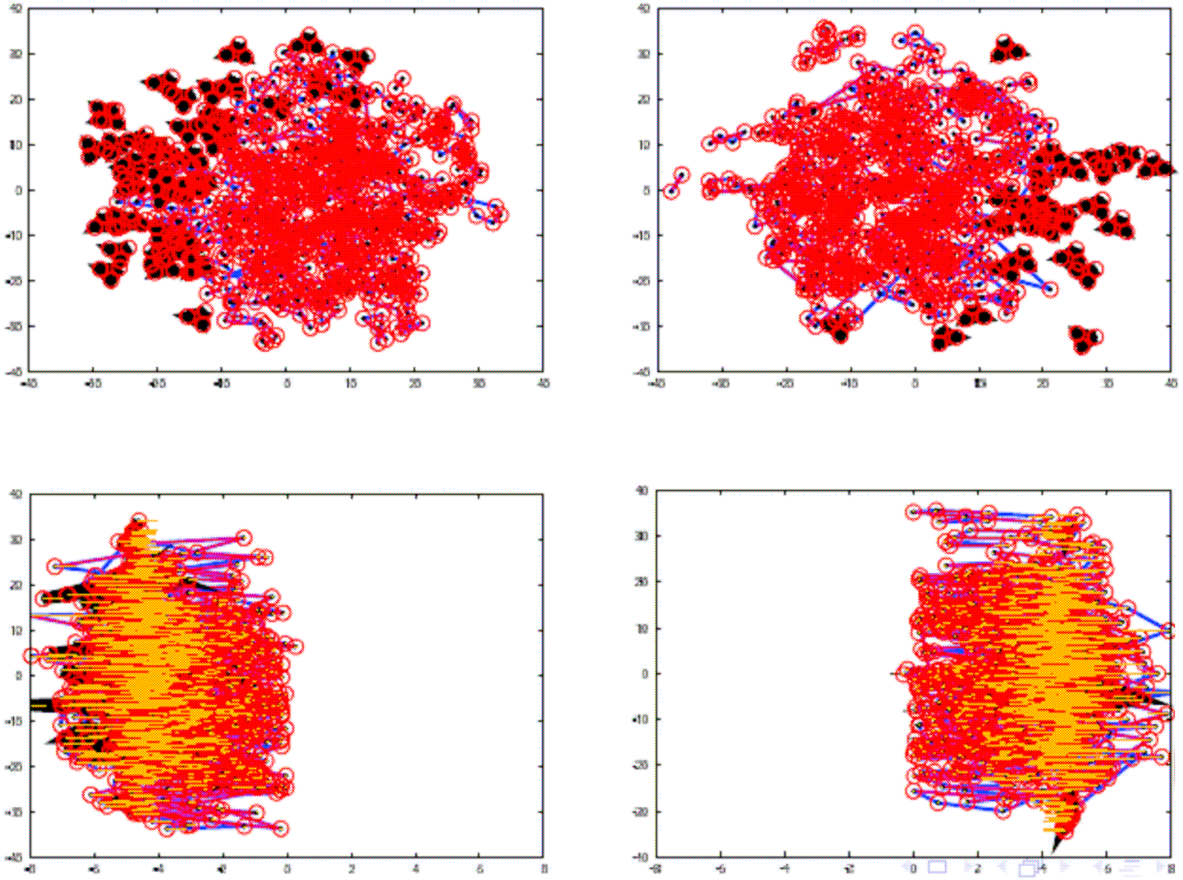
Application in DIPSY-MC

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



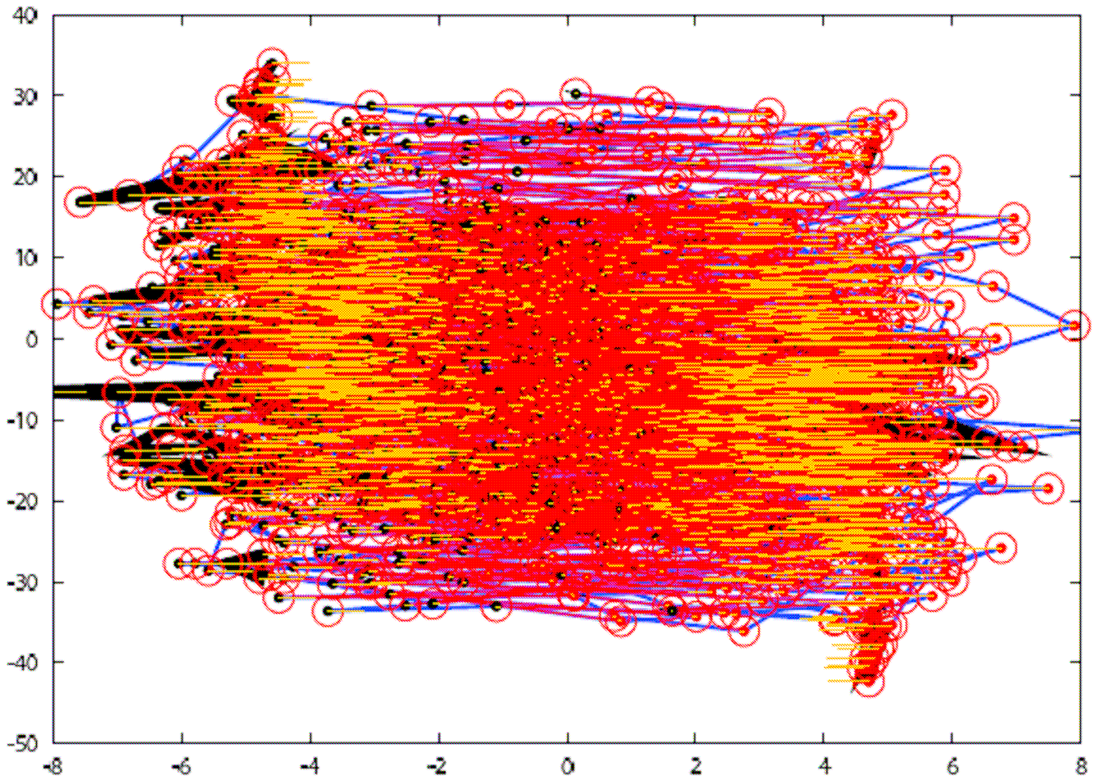
Application in DIPSY-MC

Sample Au-Au event:



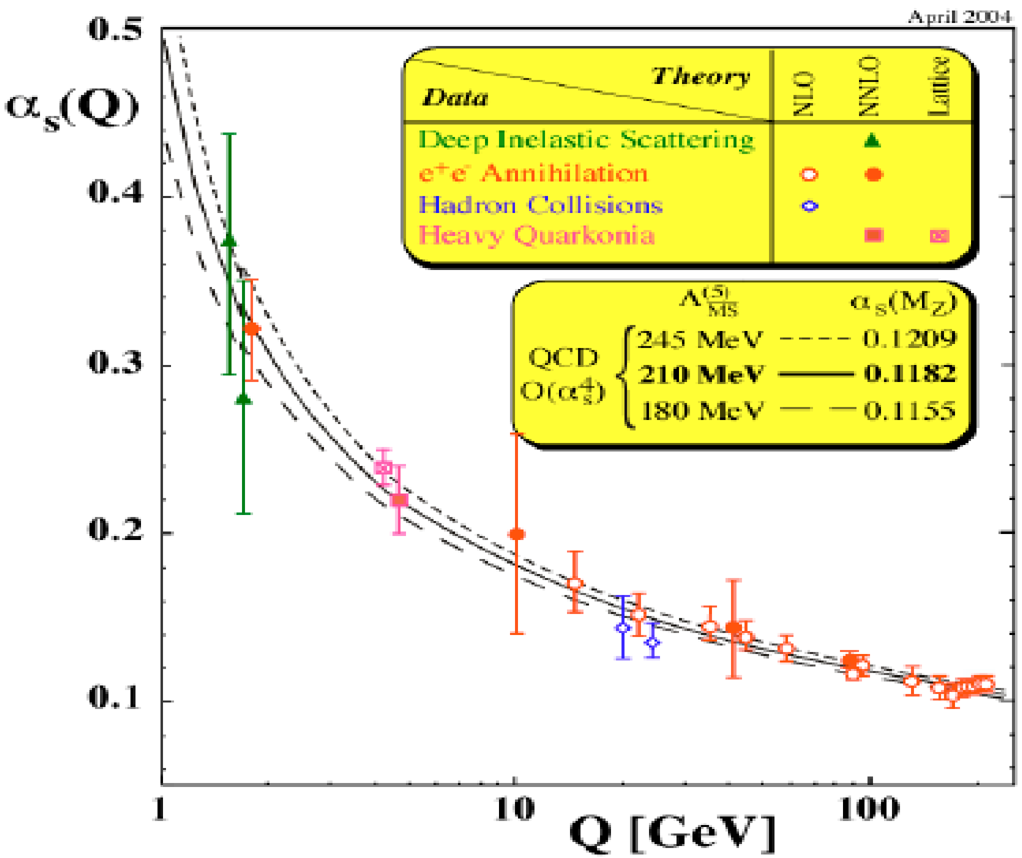
Application in DIPSY-MC

Sample Au-Au event:



Cross section results

Simulations are based on tunes of a few model parameters to pp total cross sections. An example: Λ_{QCD}.



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

hep-ex/0407021

Cross section results

Main model parameters in DIPSY:

R_{max}: Non-perturbative regularization

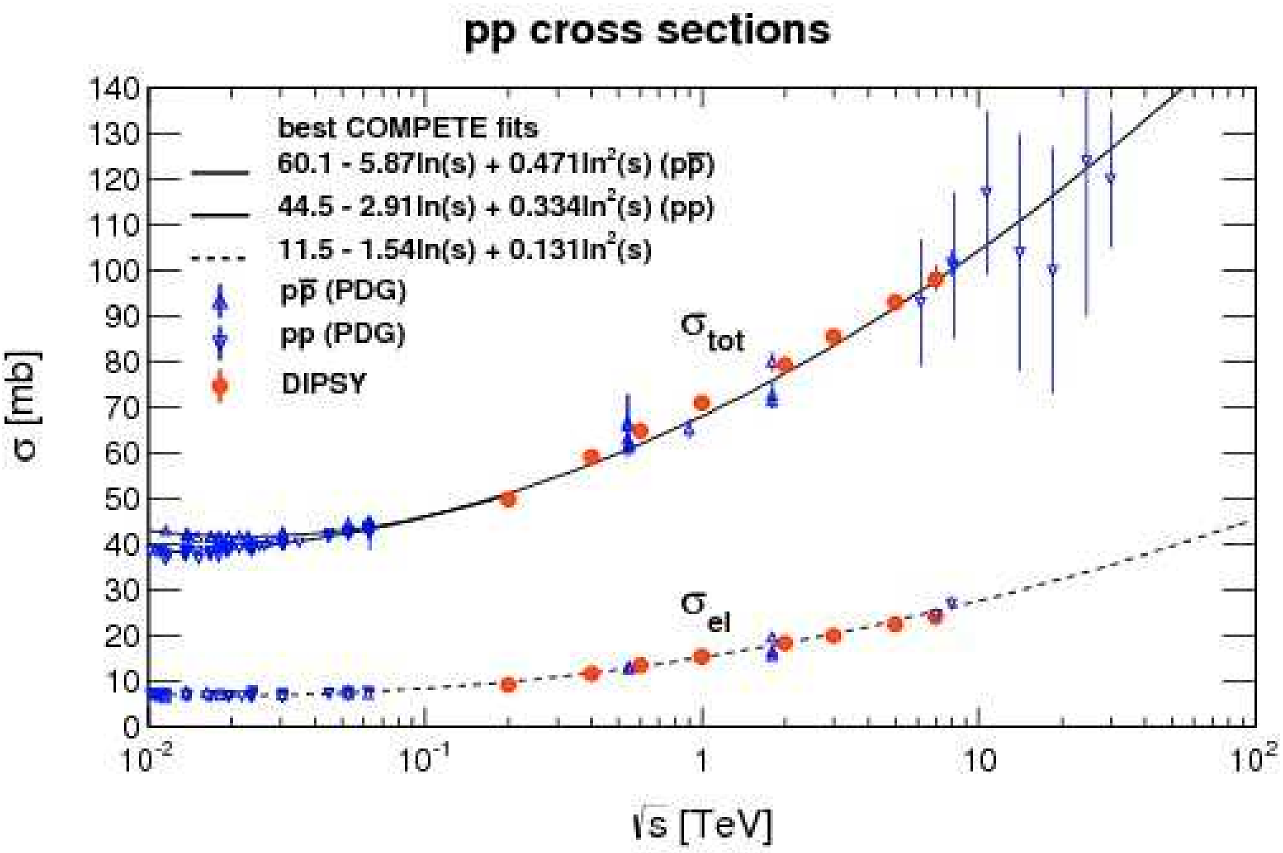
R_p: Proton size ($\approx R_{\mathrm{max}}$)

w_p: Fluctuations in the initial proton size (small)

Λ_{QCD}: in the running α_{s}

λ_r: Swing parameter (saturated)

Cross section results

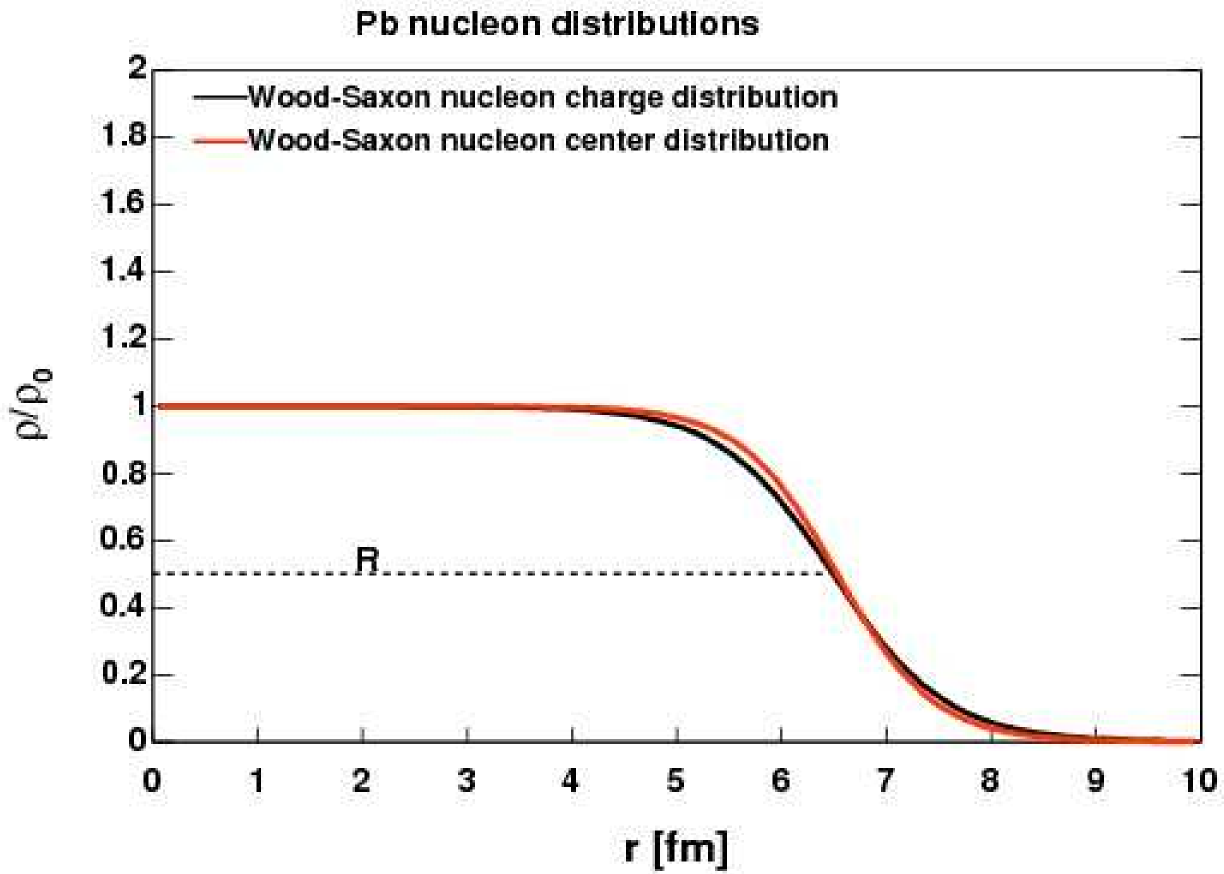


parameters tuned to:

Λ_{QCD}= 0.23 GeV

R_p = 0.57 fm

Cross section results



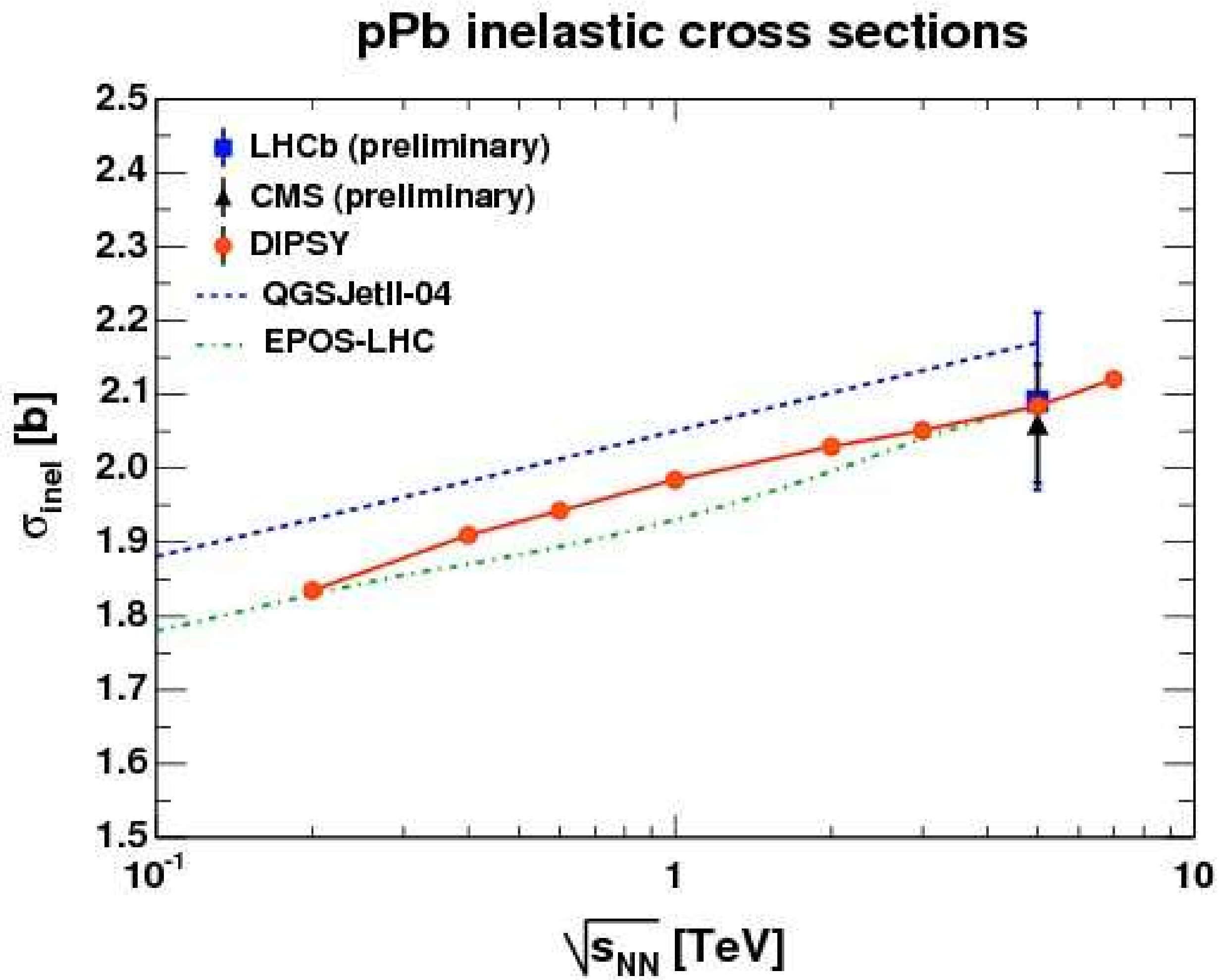
Ion MC's are based on theWood-Saxon nucleus charge density*:

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

GLISSANDRO **: provides nucleon center density

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

Cross section results

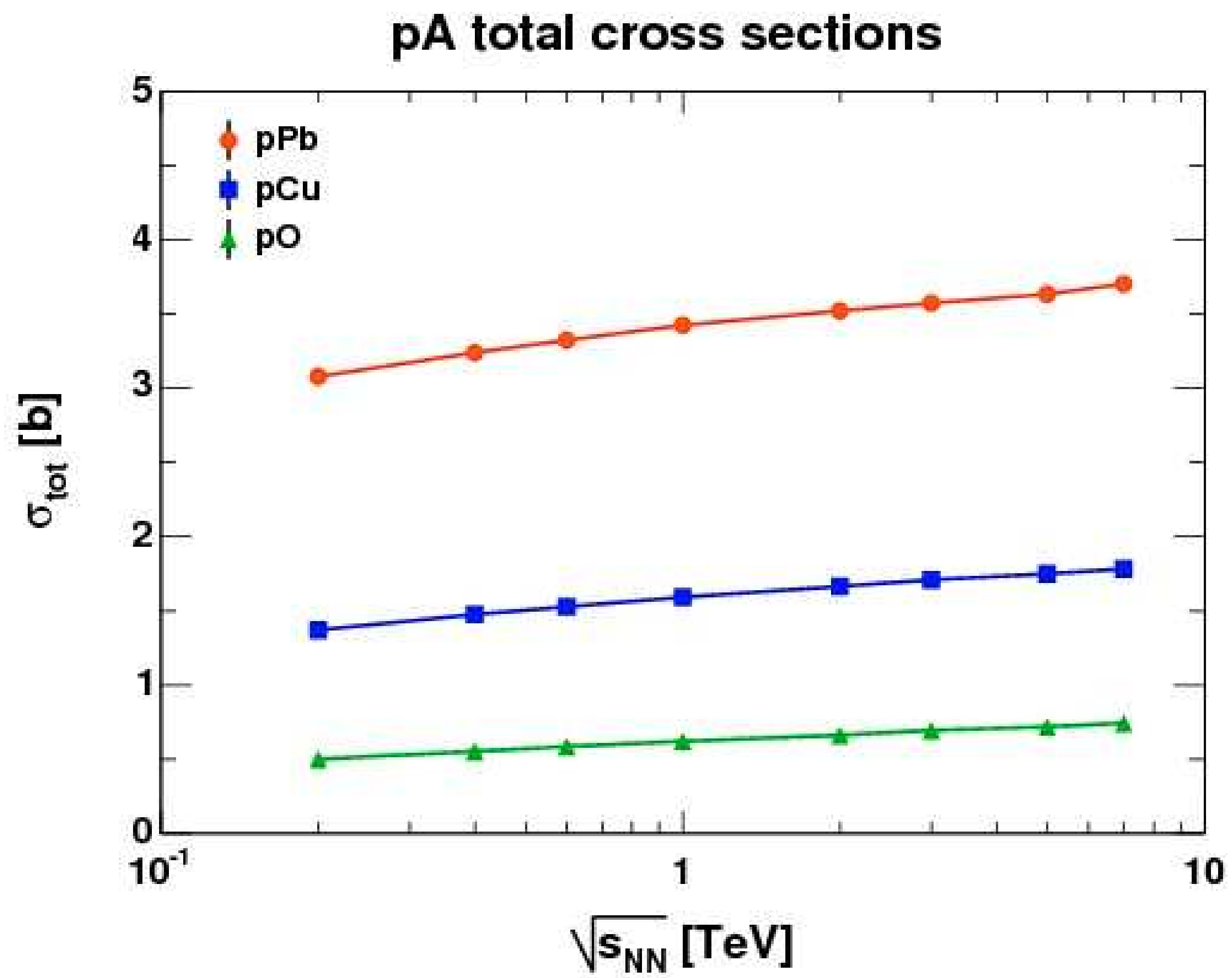


<u>Total inelastic pPb data:</u>

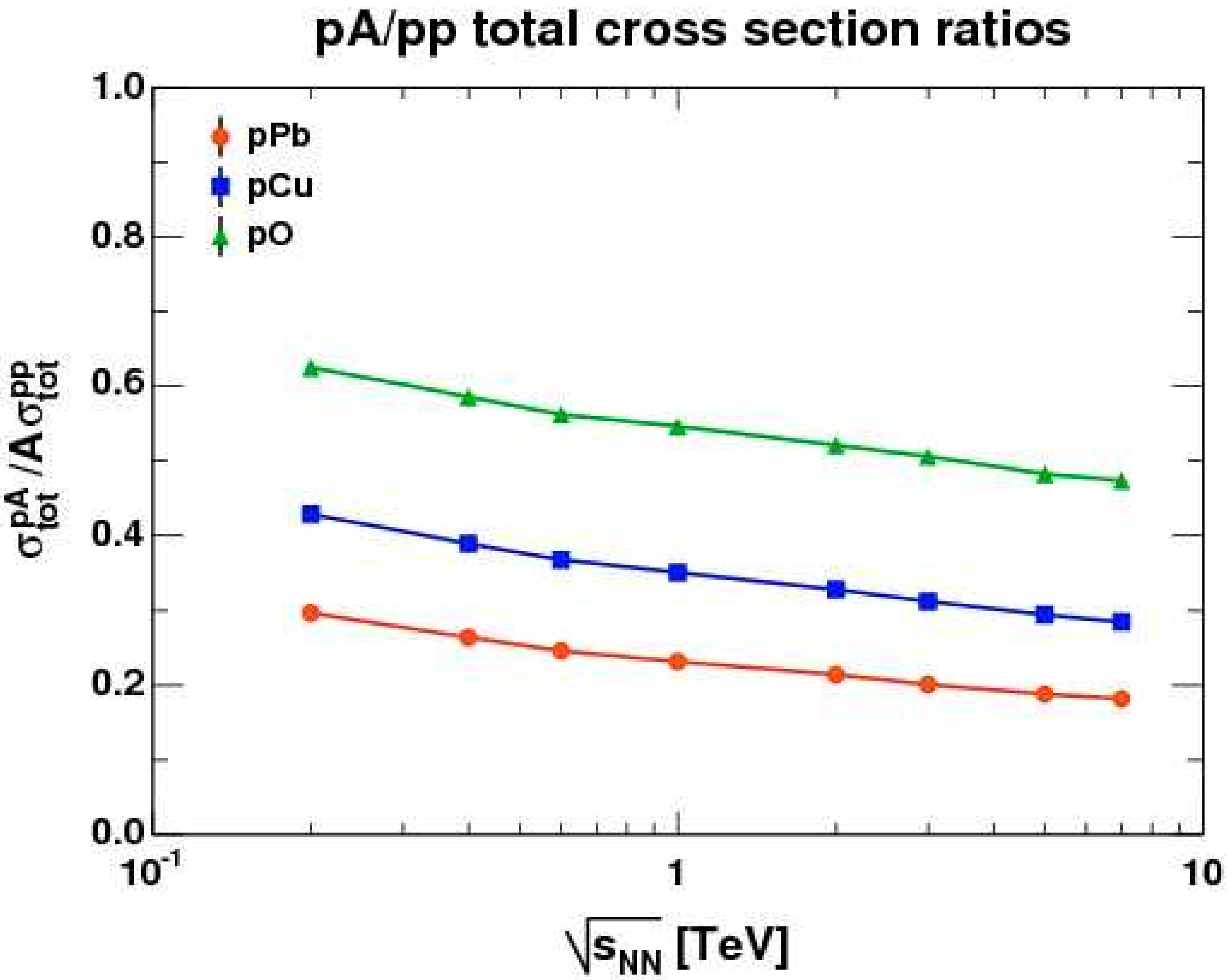
CMS: preliminary

LHCb: first measurement

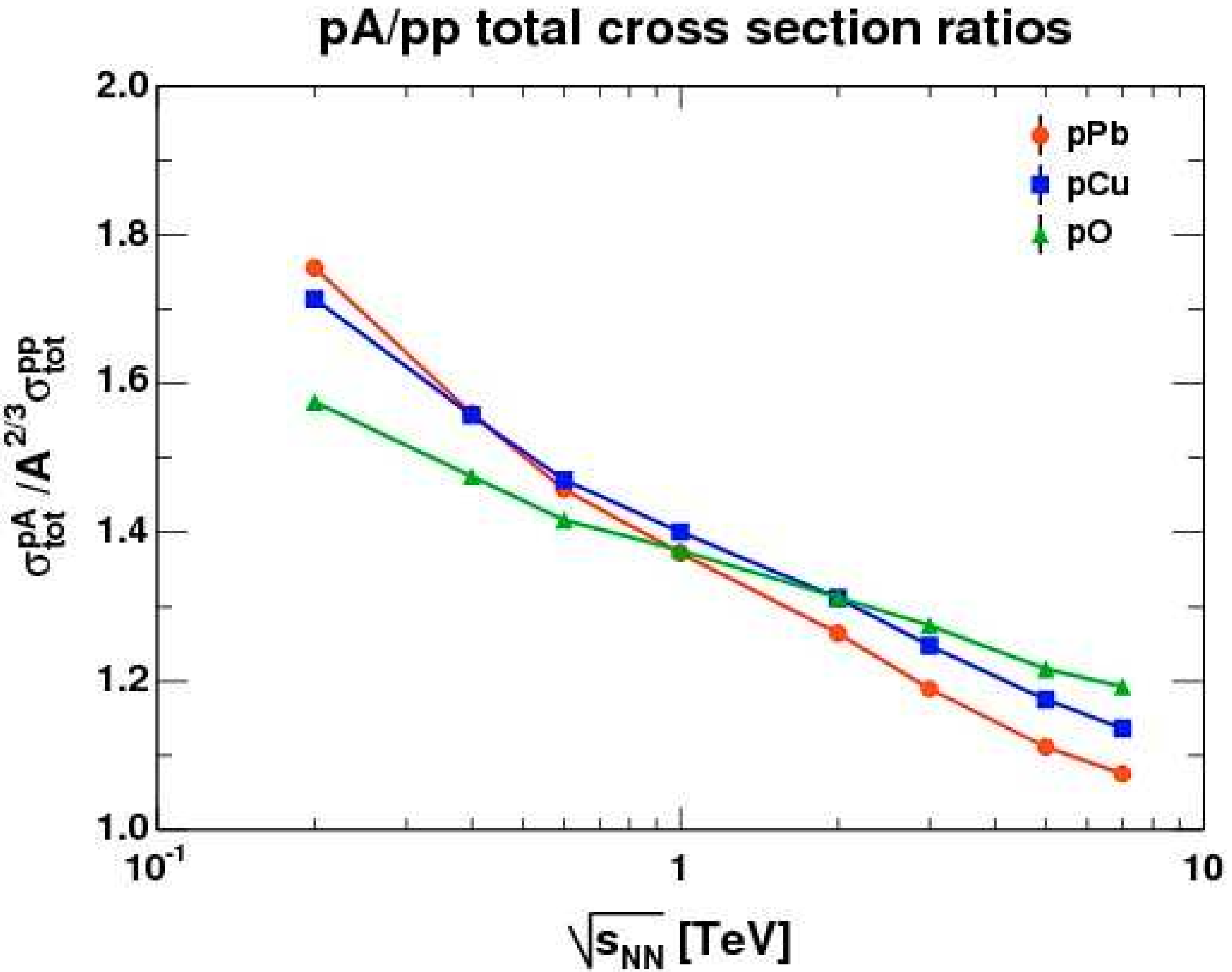
Cross section results



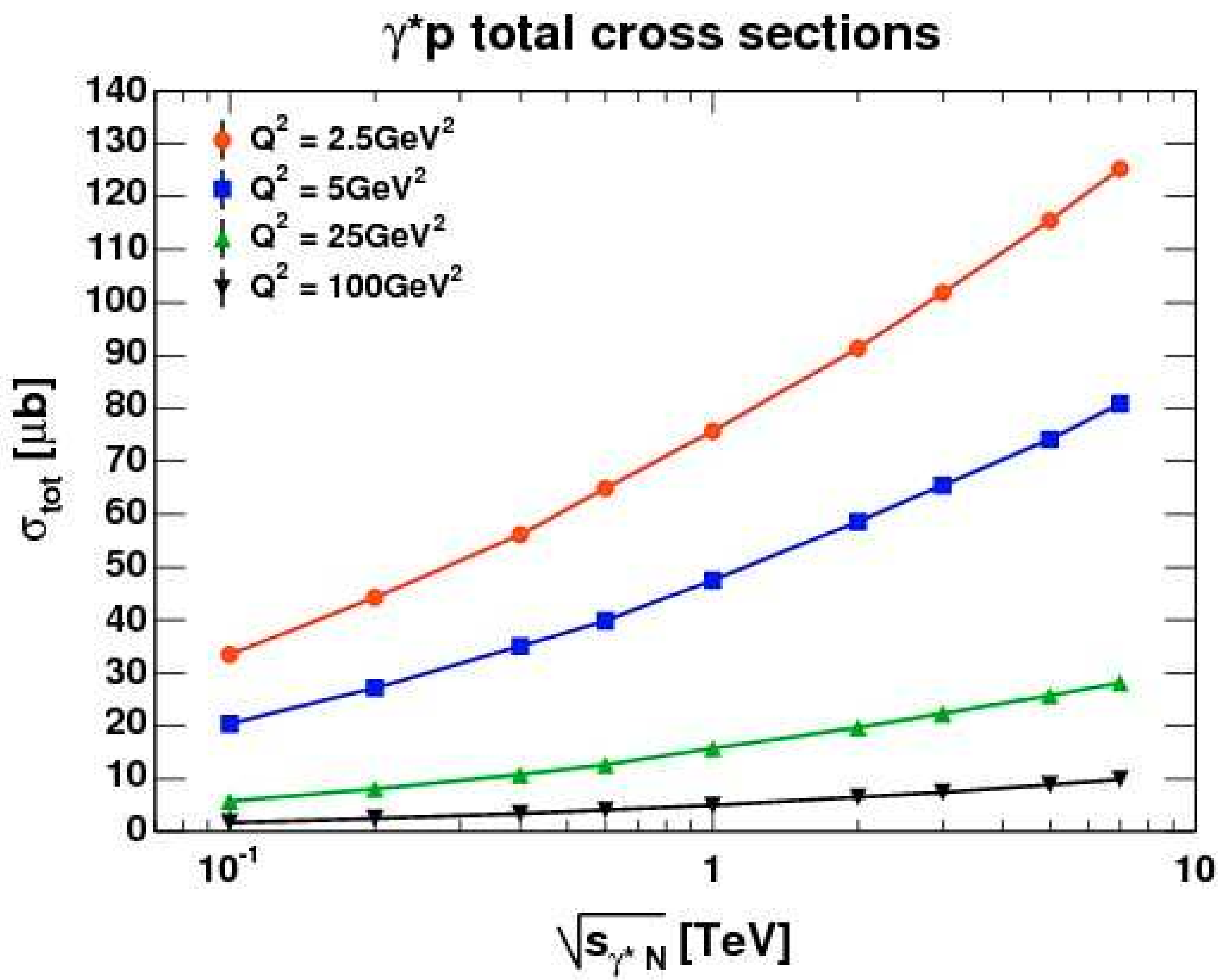
Cross section results



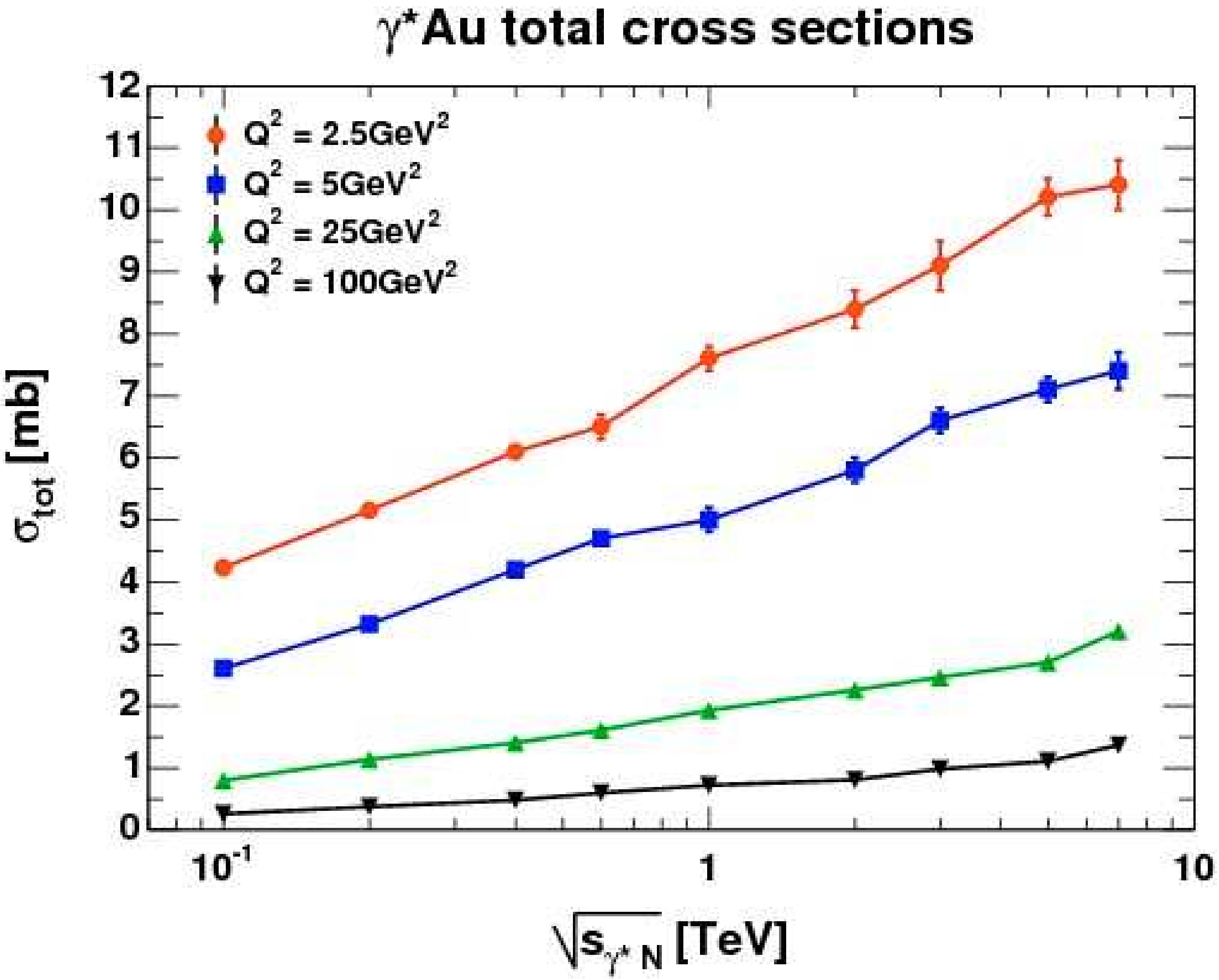
Cross section results



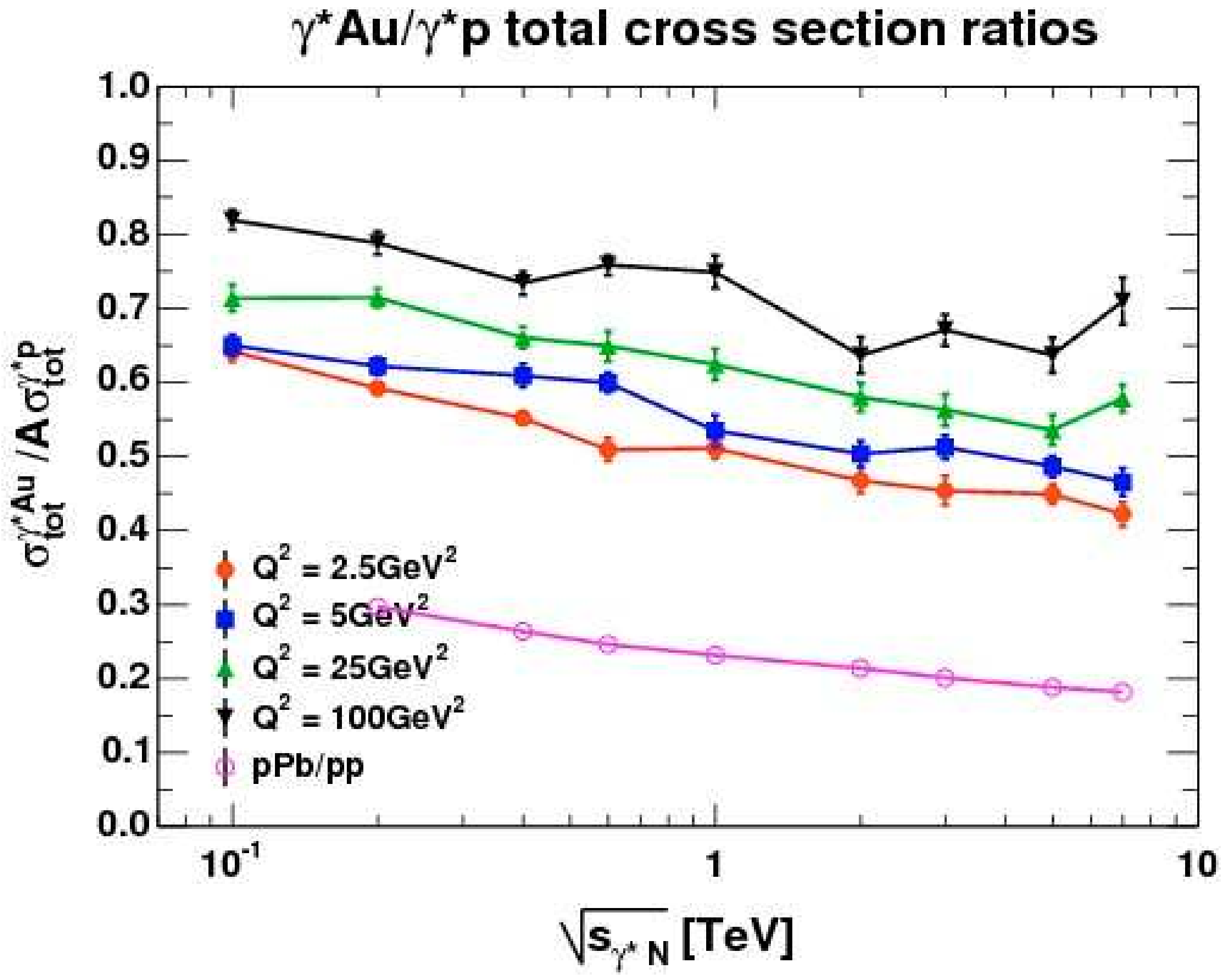
Cross section results



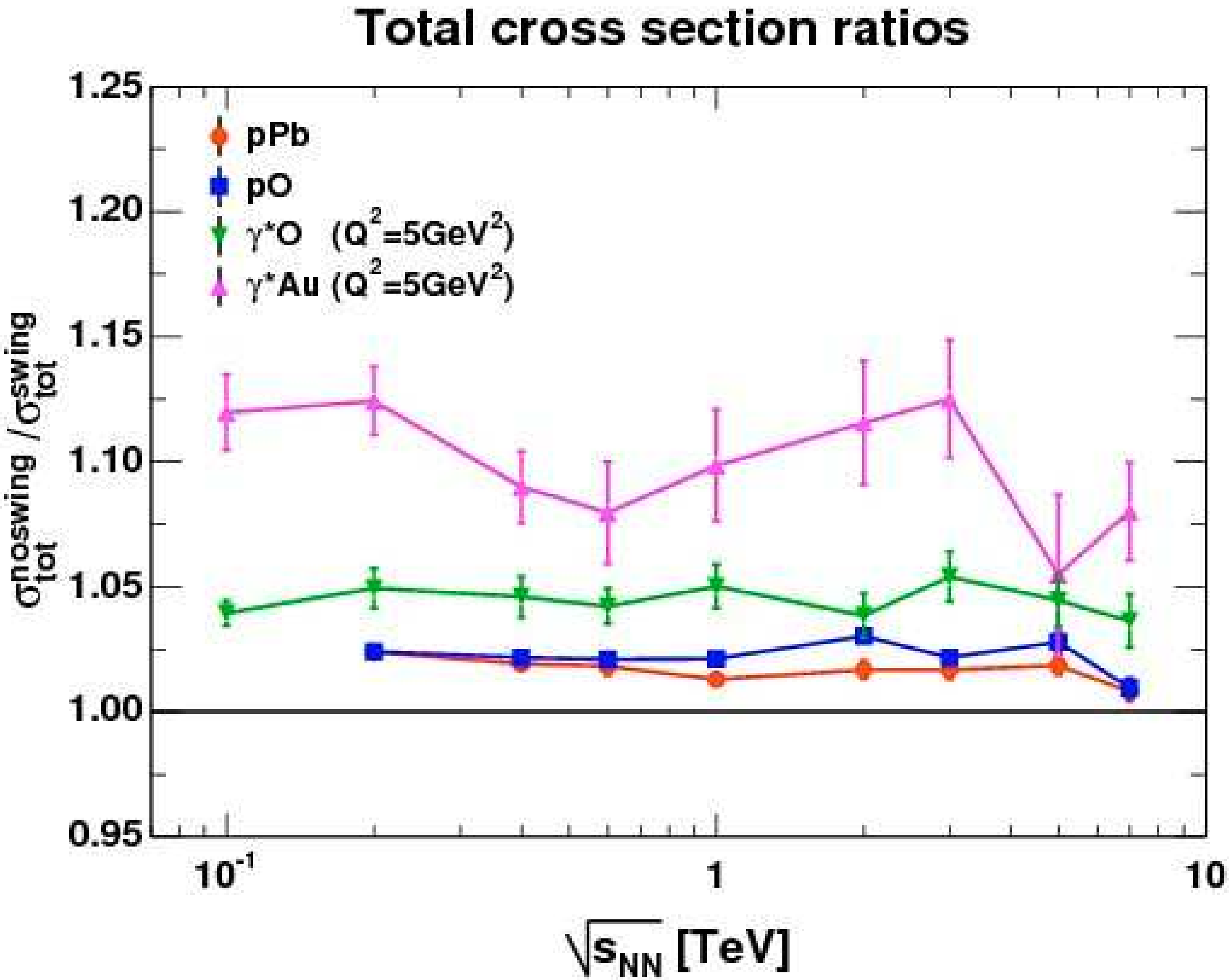
Cross section results



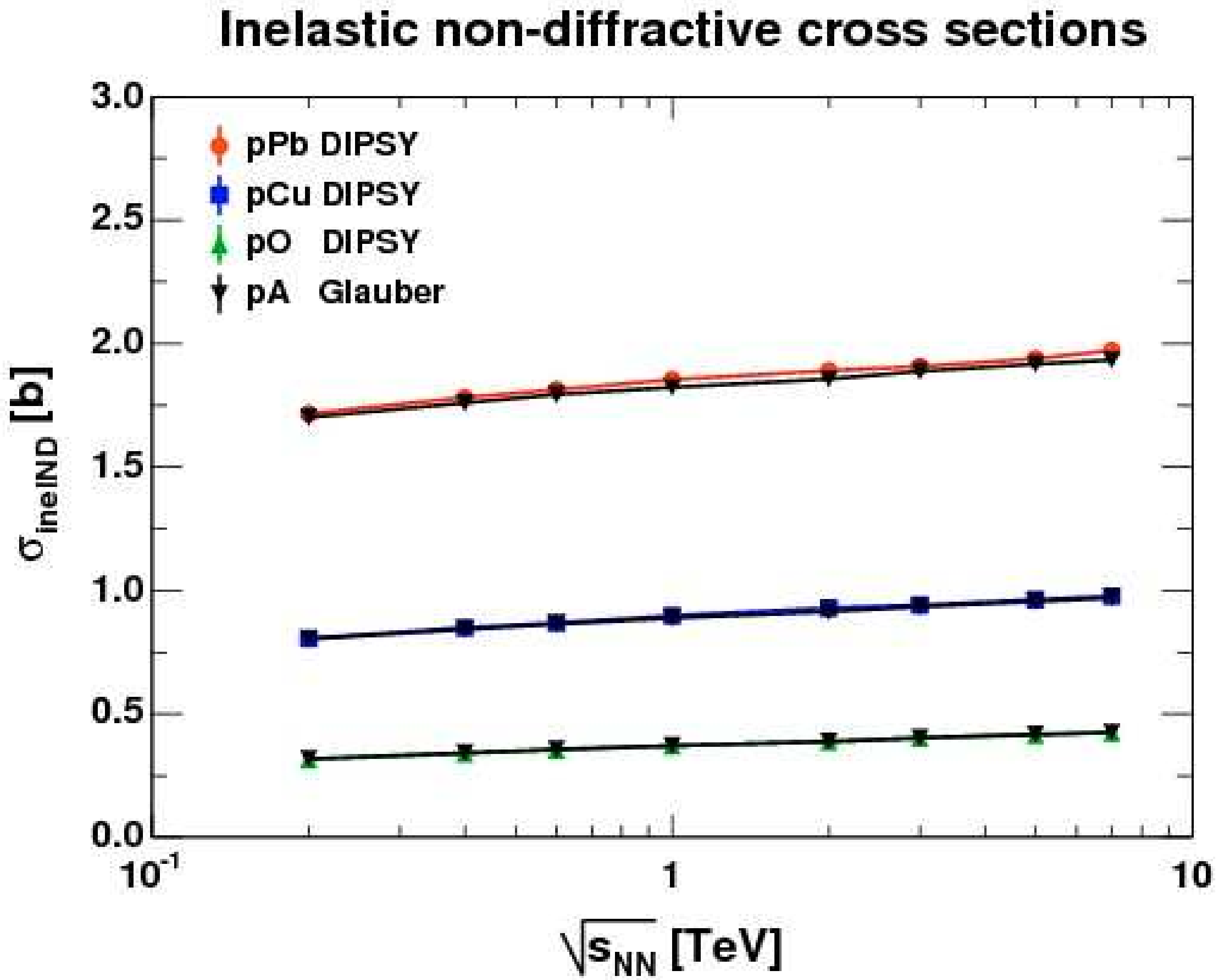
Cross section results



Cross section results



DIPSY vs Glauber cross section results



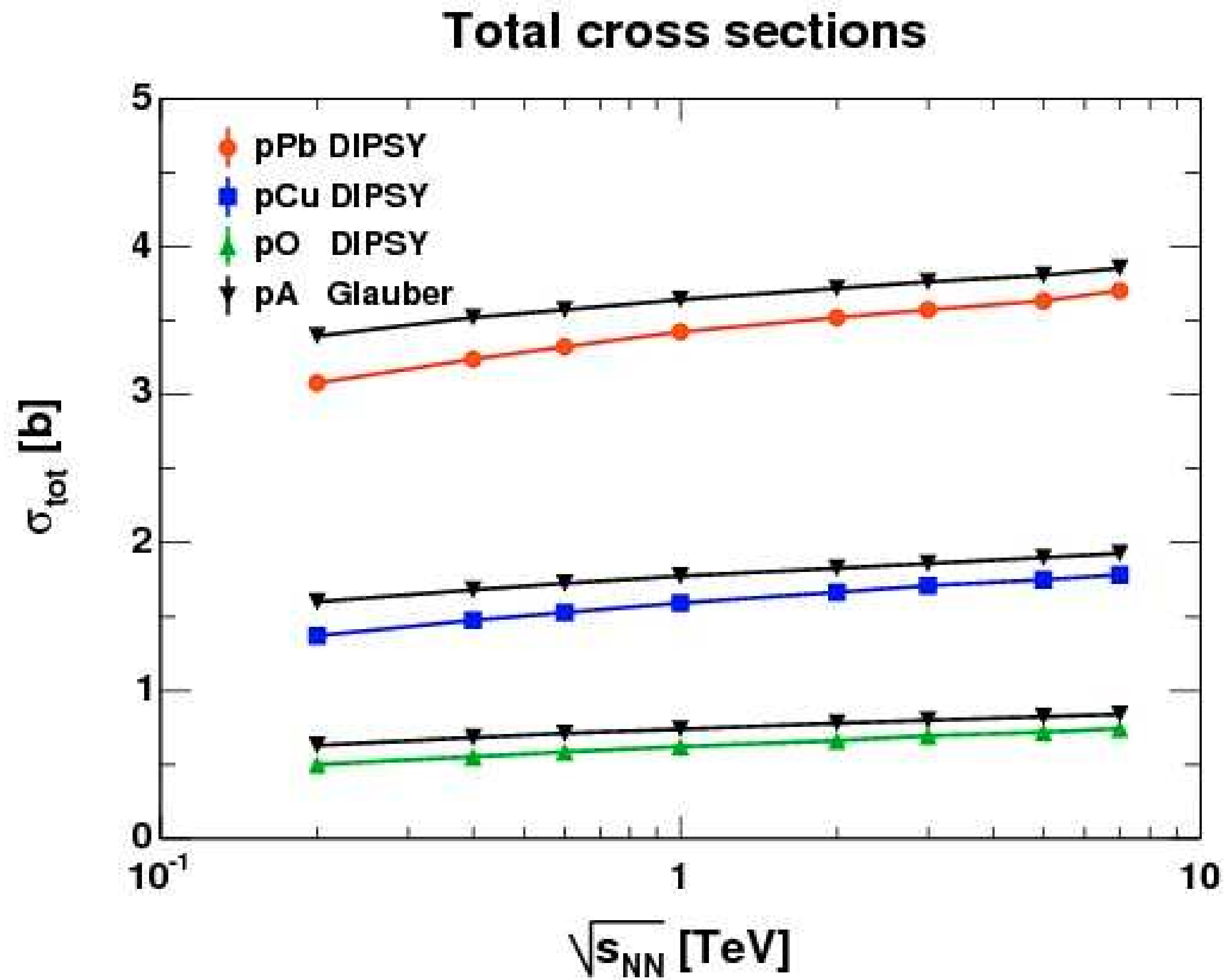
Same initial conditions:

- WS distribution

- hard-core = 0.45fm

- input: pp σ_{inelND}

DIPSY vs Glauber cross section results



Cross section 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 and pPb inelastic ones at 5 TeV was successful.

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