pPb cross-sections at LHC
and high energy pp, pA and eA collisions in DIPSY

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Motivation:
pPb@LHC and dAu@RHIC
The Lund Dipole Cascade Model DIPSY
New: nuclei in DIPSY
Monte Carlo cross section results
Comparison with Glauber results
(quasi-)elastic pPb cross-section at 8 TeV

arXiv:1103.4320
arXiv:1103.4321
arXiv:1206.1733
+ arXiv:1506.09095 +

Introduction: Glauber theory++

$$p \propto \exp\left(-\sigma_{in}^{hN}\rho L\right)$$

Glauber, 1955, 1967, 1970
Glauber and Matthiae, 1970
Bialas, Bleszynski, Czyz, 1976, …

Optical model, high energy physics

$$T_A(b) = \int \rho(z,b)\,dz$$

$$\int d^2b\,T_A(b) = A$$

Nuclear thickness function

$$T_{AB}(b) = \int d^2s\,T_A(s)\,T_B(|s-b|)$$

Overlap function

$$\sigma_{AB} = \int d^2b \int d^2s_1^A \dots d^2s_A^A d^2s_1^B \dots d^2s_B^B \quad \times$$
$$T_A(s_1^A)\dots T_A(s_A^A)T_B(s_1^B)\dots T_B(s_B^B) \quad \times$$
$$\left\{1 - \prod_{j=1}^{B}\prod_{i=1}^{A}\left[1-\sigma(b-s_i^A+s_j^B)\right]\right\}$$

Configuration space

Nuclear geometry (uncorrelated)

Elementary n-n interactions

Analytically ~ impossible. Nuclear short range correlations?
-> Monte-Carlo simulations

SR Correlations, Gribov corrections

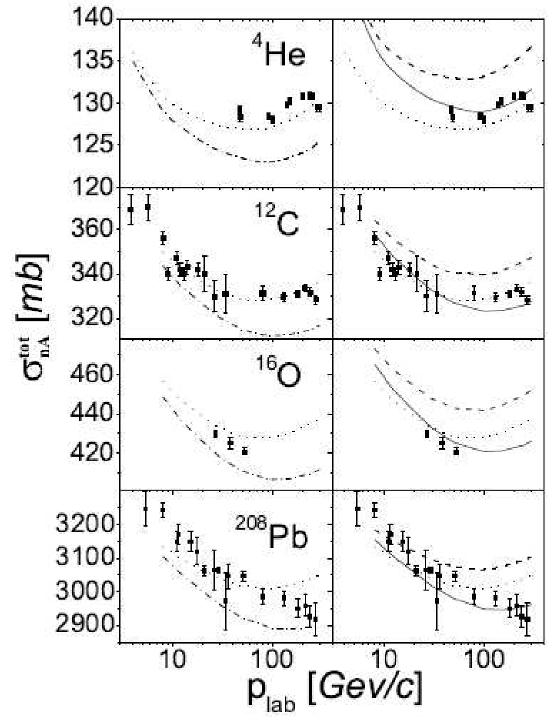
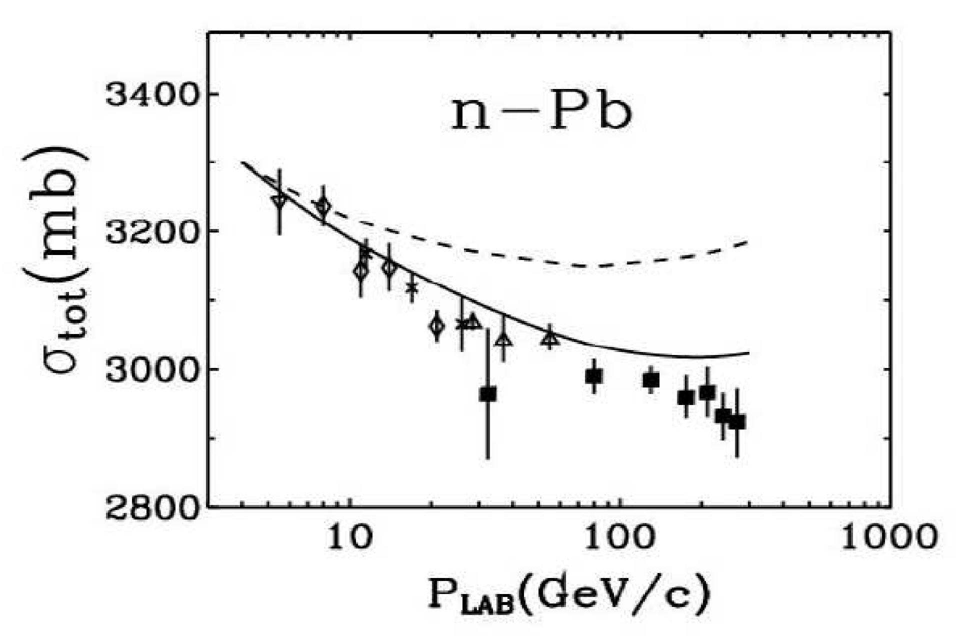


FIG. 2: σ_{tot}^{nA} *vs* p_{lab}. *Left panel*: Glauber single density approximation (σ_G; *dots*) and Glauber plus Gribov inelastic shadowing ($\sigma_G + \Delta\sigma_{IS}$; *dot-dash*). *Right panel*: Glauber (σ_G; *dots*); Glauber plus SRC ($\sigma_G + \sigma_{SRC}$; *dashes*); Glauber plus SRC plus Gribov inelastic shadowing ($\sigma_G + \sigma_{SRC} + \Delta\sigma_{IS}$; *full*). Experimental data from [6, 17].

<- Avioli et al, arXiv:0708.0873



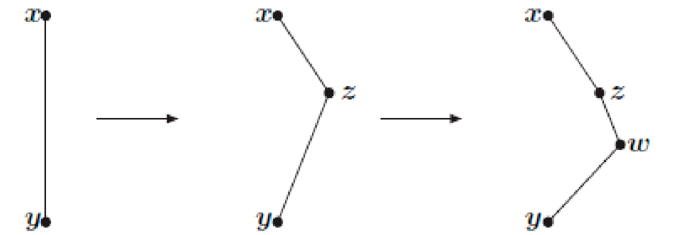
Gribov: fluctuations in the size of n decrease total nA cross-sections

Short range nucleon-nucleon correlations (SRC) + Gribov diffractive corrections are important for nA and pA collisions
→ DIPSY detailed MC study for future accelerators

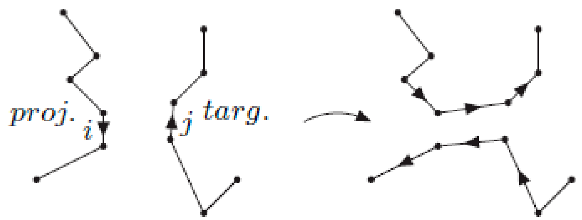
DIPSY: Lund Dipole Cascade Model

$$\frac{d\mathcal{P}}{dY} = \frac{\bar{\alpha}}{2\pi} d^2 z \frac{(x-y)^2}{(x-z)^2(z-y)^2}, \quad \text{with } \bar{\alpha} = \frac{3\alpha_s}{\pi}.$$

Based on: Mueller’s dipole cascade
Formulation of BFKL evolution
in rapidity and trasverse coordinates



The evolution of the dipole cascade in transverse coordinate space.



A dipole–dipole interaction implies exchange of colour and reconnection

2 dipoles interact (in Born approx.)
Multiple collisions:
in eikonal approx., unitarity OK

$$2f_{ij} = 2f(x_i, y_i | x_j, y_j) = \frac{\alpha_s^2}{4}\left[\log\left(\frac{(x_i - y_j)^2 (y_i - x_j)^2}{(x_i - x_j)^2 (y_i - y_j)^2}\right)\right]^2.$$

Forward amplitude and cross sections:

$$T = 1 - e^{-F},$$

$$\text{Int. prob.} = 1 - e^{-2F}, \quad \text{with } F = \sum f_{ij}.$$

$$\sigma_{\text{inel}} = \int d^2\boldsymbol{b} \langle 1 - e^{-2F(\boldsymbol{b})} \rangle = \int d^2\boldsymbol{b} \langle 1 - (1 - T(\boldsymbol{b}))^2 \rangle.$$

$$\sigma_{\text{el}} = \int d^2\boldsymbol{b} \langle T(\boldsymbol{b}) \rangle^2.$$

$$\sigma_{\text{diff}} = \int d^2\boldsymbol{b} \langle T(\boldsymbol{b})^2 \rangle.$$

$$\sigma_{\text{diff ex}} = \sigma_{\text{diff}} - \sigma_{\text{el}} = \int d^2\boldsymbol{b} \left(\langle T(\boldsymbol{b})^2 \rangle - \langle T(\boldsymbol{b}) \rangle^2 \right)$$

DIPSY: a graphical summary

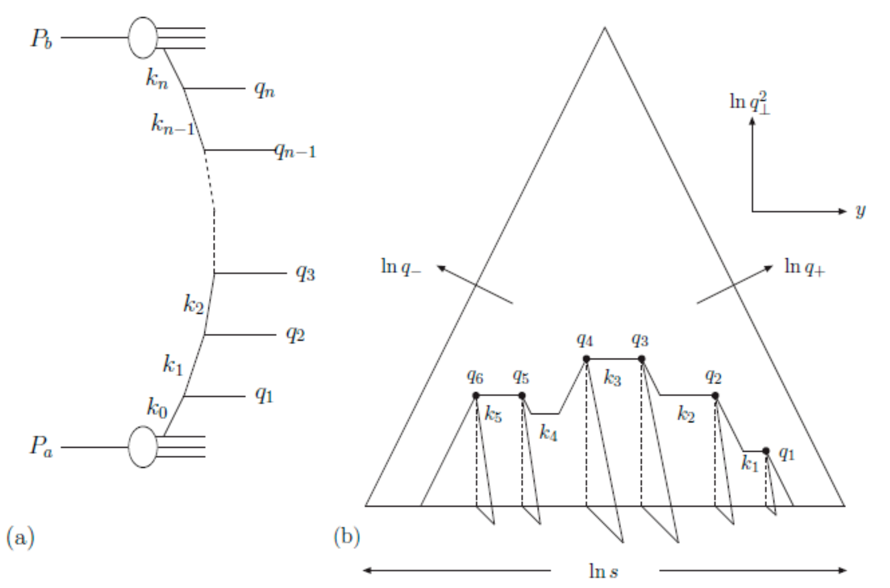


Figure 5: (a) A parton chain stretched between projectile and target. (b) A backbone of $k_\perp$-changing gluons in a $(y, \ln q_\perp^2)$ plane. The transverse momentum of the virtual links k_i are represented by horizontal lines.

Dipole chain
(top)

Chain split
(bottom)

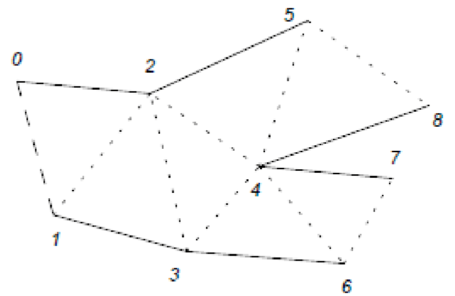


Figure 27: Two interactions makes a chain split in two. Dotted lines show parent structure, full lines show colour flow.

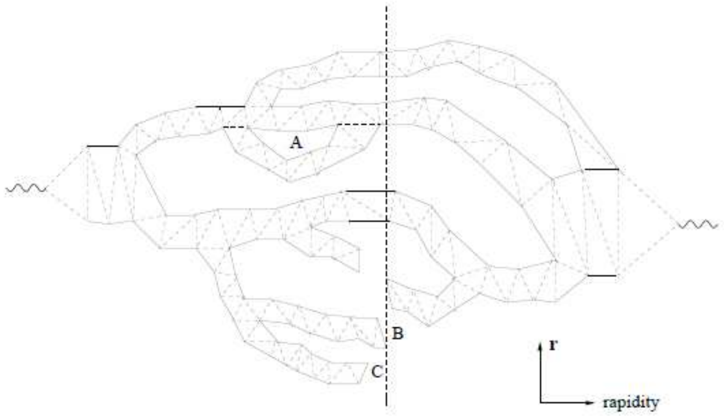


Figure 6: Collision of two dipole cascades in $\boldsymbol{r}$-rapidity space. The dashed vertical line symbolizes the Lorentz frame in which the collision is viewed. The dipole splitting vertex can result in the formation of different dipole branches, and loops are formed due to multiple sub-collisions. The loop denoted by A is an effect of saturation within the cascade evolution, which can be formed via a dipole swing. Branches which do not interact, like those denoted B and C are to be treated as virtual, and to be absorbed.

Saturation
(top)

Swing:
rearranged
color flow
(bottom)

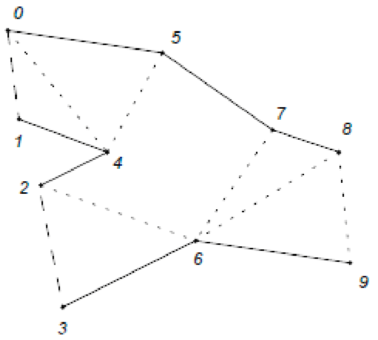
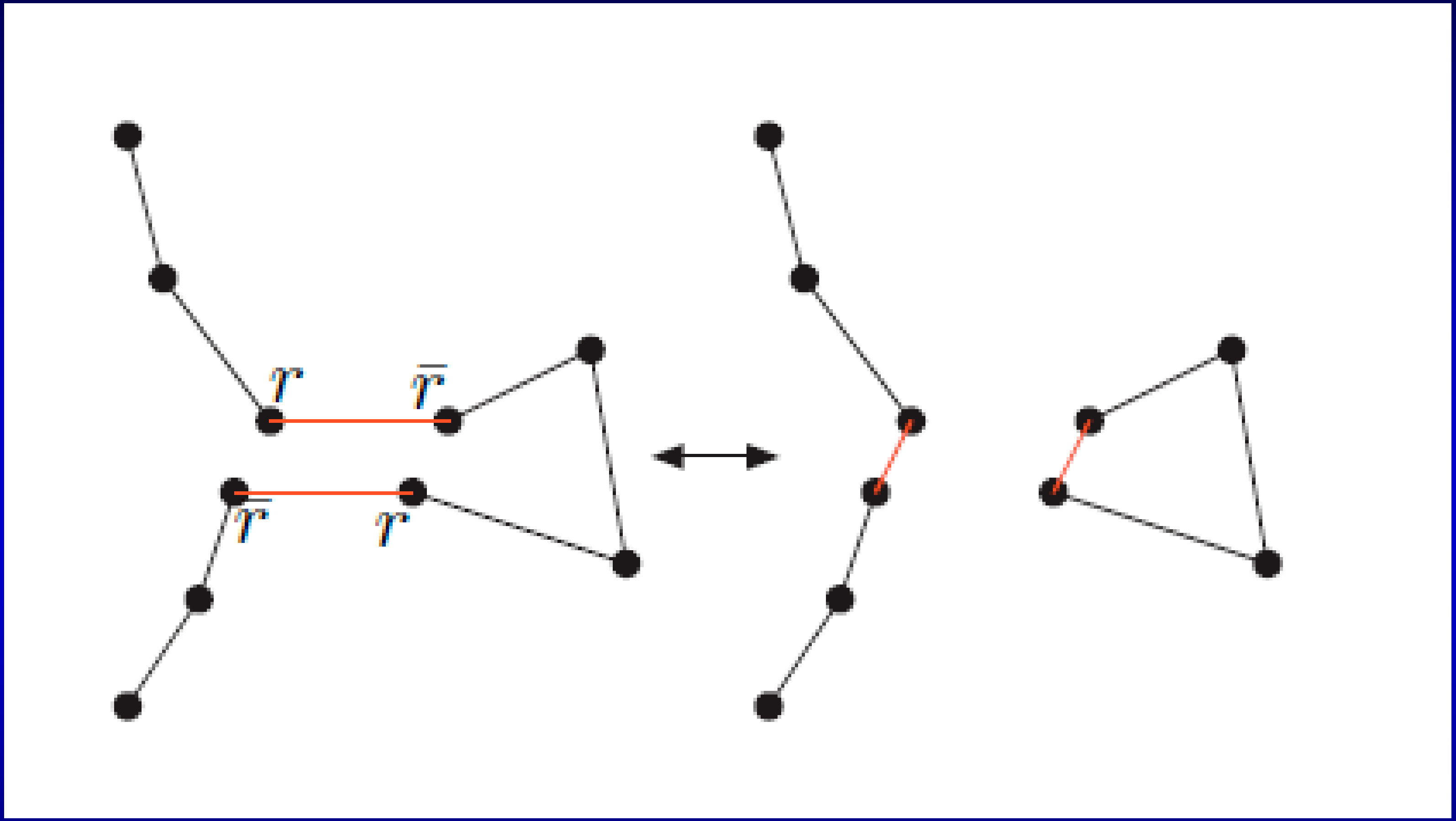


Figure 28: A swing between (45) and (26) causing two chains of backbone gluons to merge. Dotted lines show parent structure, full lines show colour flow. The picture is in impact-parameter space.

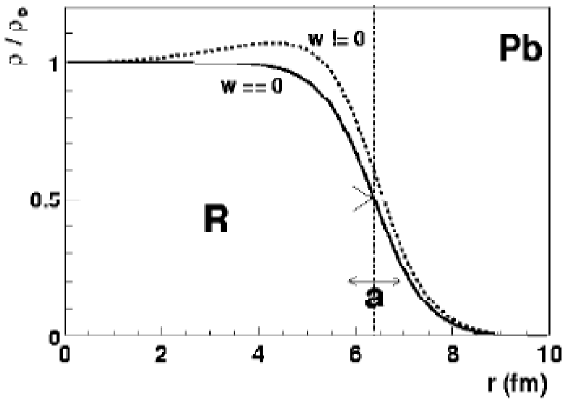
Swings for glueball production?



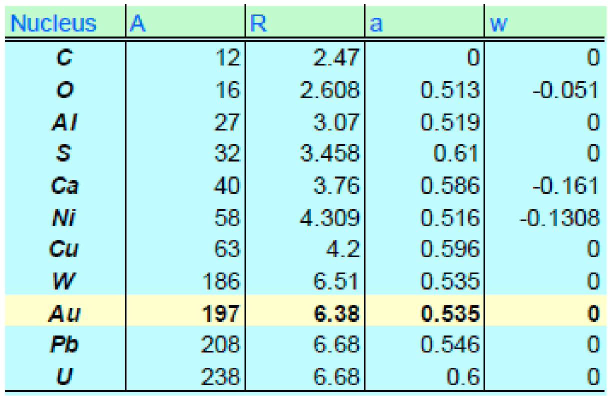
Dipole-dipole interactions may lead
to increased probability of glueball
(closed color dipole loop) production
See the talk of H. Stöcker yesterday.

Treatement of nuclei in DIPSY

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



Electron Scattering Measurements



Nucleus	A	R	a	w
C	12	2.47	0	0
O	16	2.608	0.513	-0.051
Al	27	3.07	0.519	0
S	32	3.458	0.61	0
Ca	40	3.76	0.586	-0.161
Ni	58	4.309	0.516	-0.1308
Cu	63	4.2	0.596	0
W	186	6.51	0.535	0
Au	**197**	**6.38**	**0.535**	**0**
Pb	208	6.68	0.546	0
U	238	6.68	0.6	0

H. DeVries, C.W. De Jager, C. DeVries, 1987

$$T_A(s) = \int_{-\infty}^{+\infty} \rho_A(\vec{s}, z)$$

Extended Woods-Saxon charge density

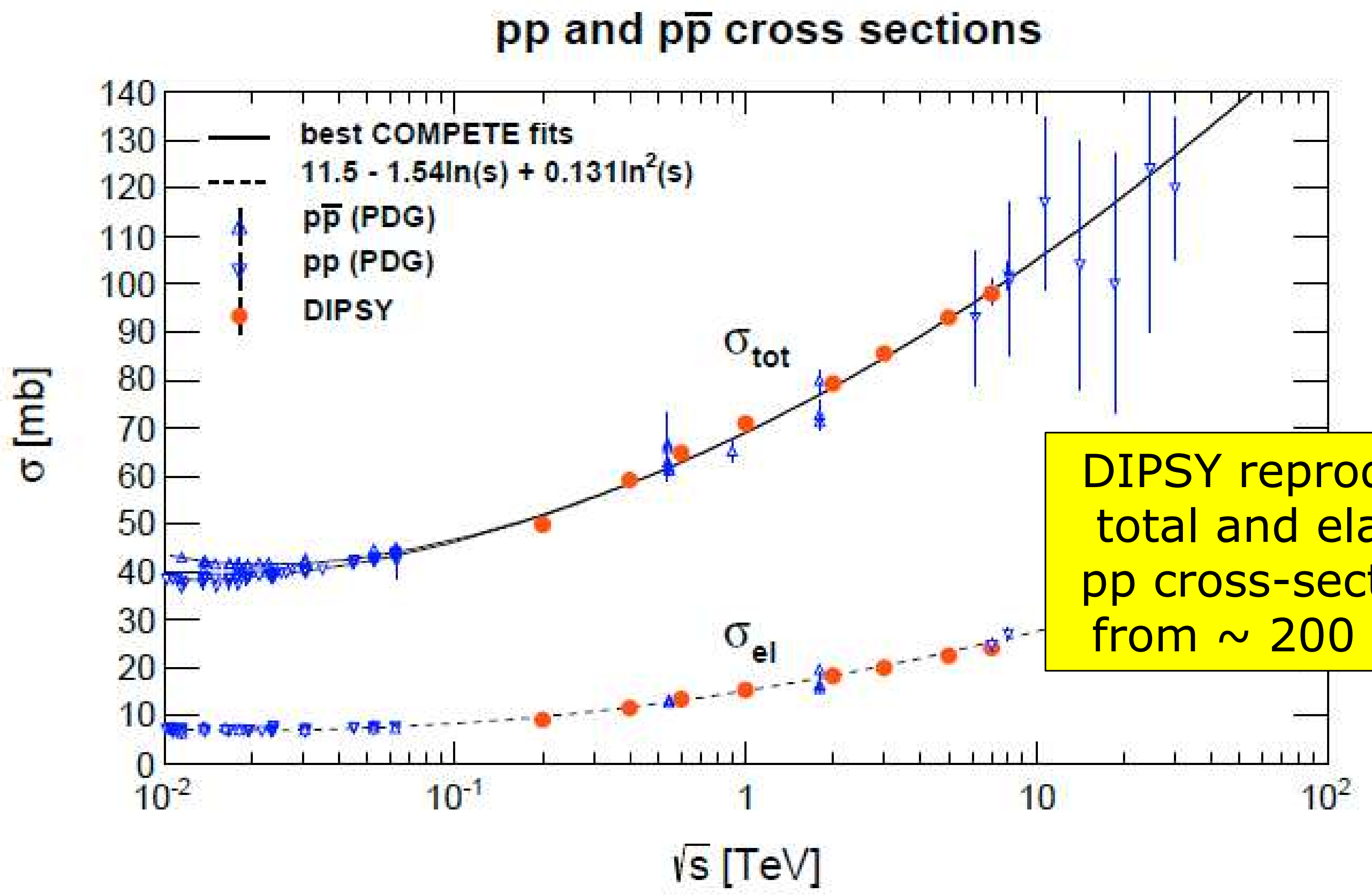
Currently
in DIPSY
for
He, O, Cu,
Au and Pb

GLISSANDRO:
(Broniowski et al)
corrections for
nuclear center

R(Pb,NC) = 6.40 fm
R(Au, NC) = 6.28 fm
R(Cu,NC) = 4.23 fm
R(O,NC) = 2.51 fm

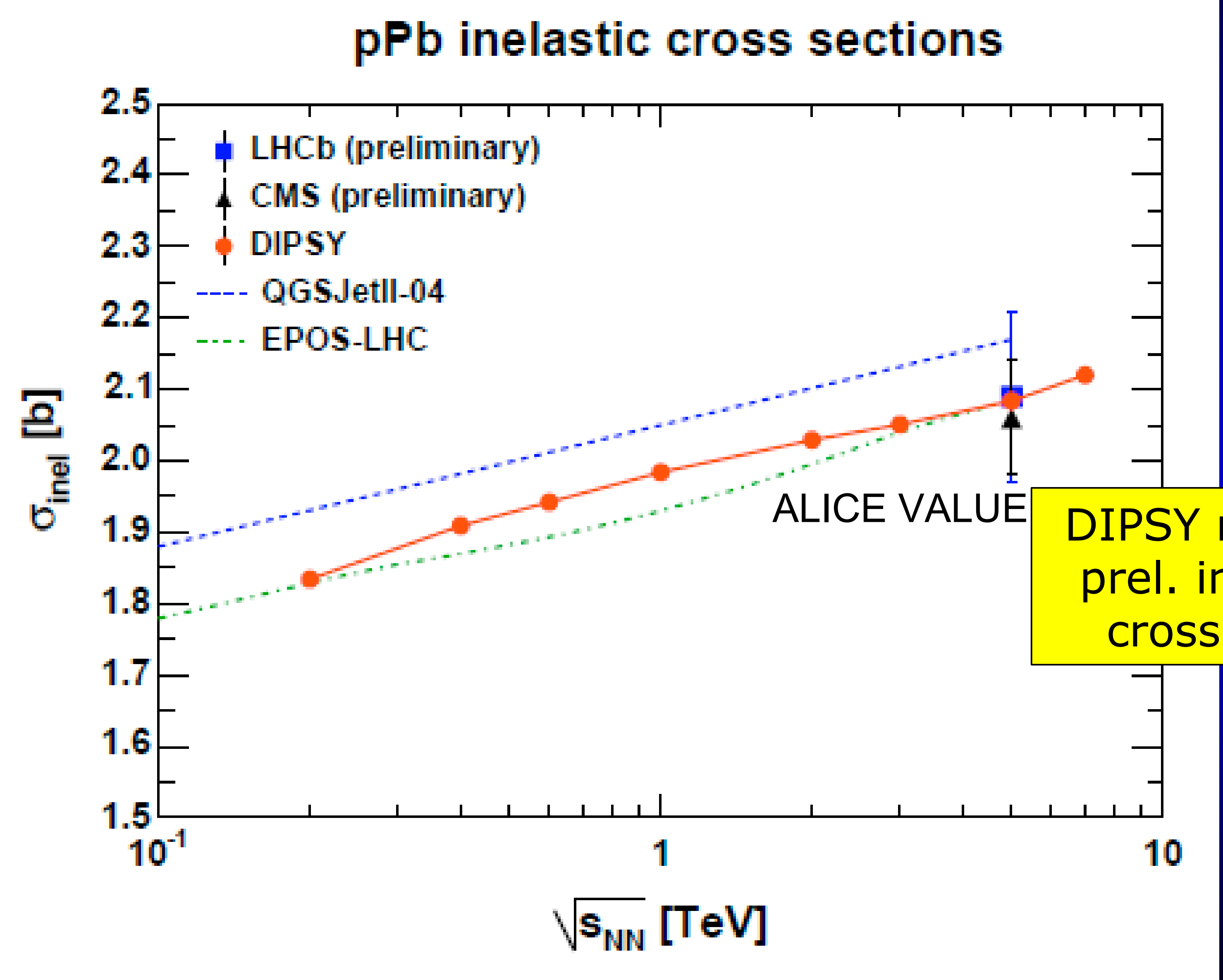
$$(1.1A^{1/3} - 0.656A^{-1/3})\ \mathrm{fm}$$

DIPSY test 1: pp cross sections



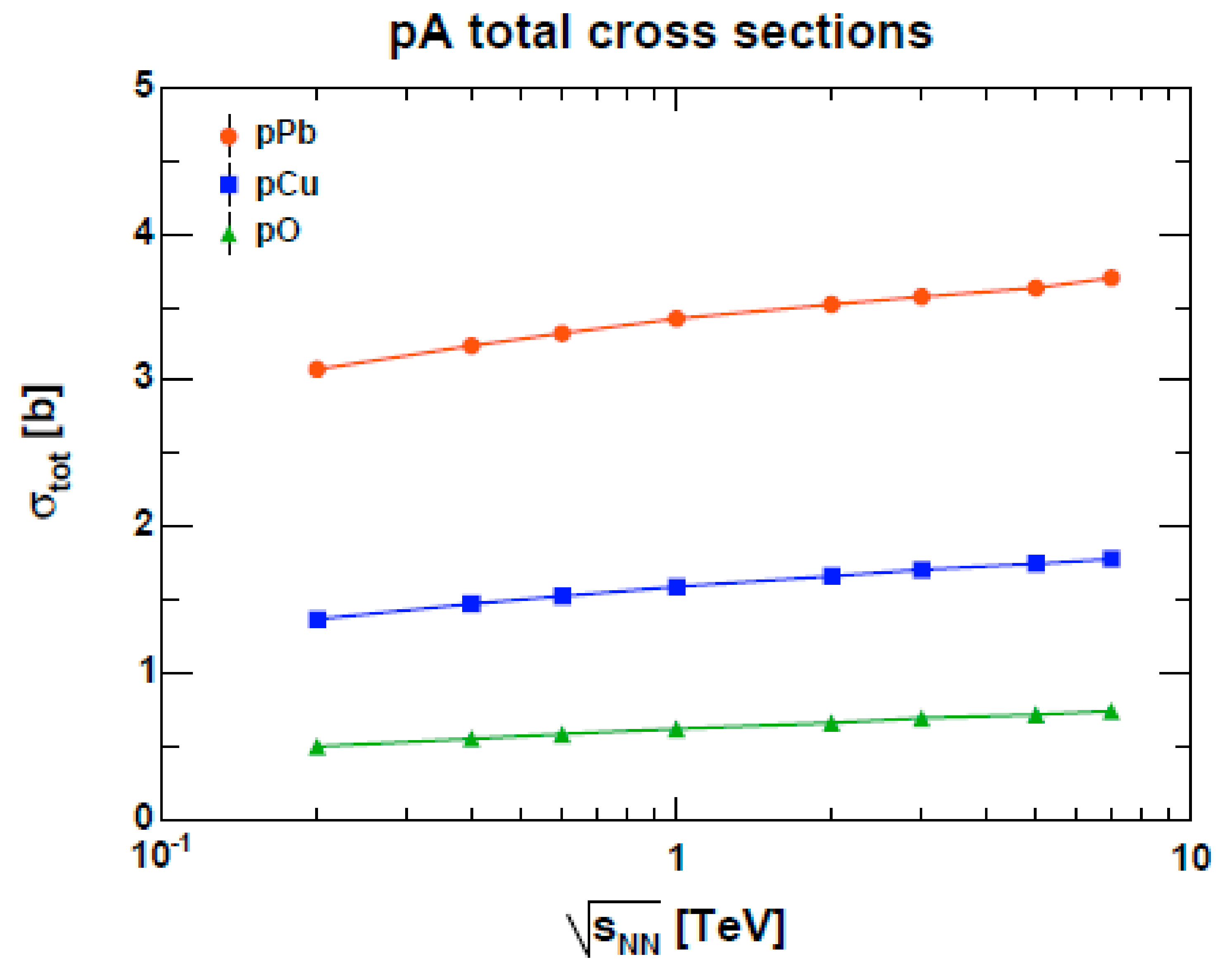
DIPSY reproduces total and elastic pp cross-sections from ~ 200 GeV

DIPSY test 2: pPb cross sections

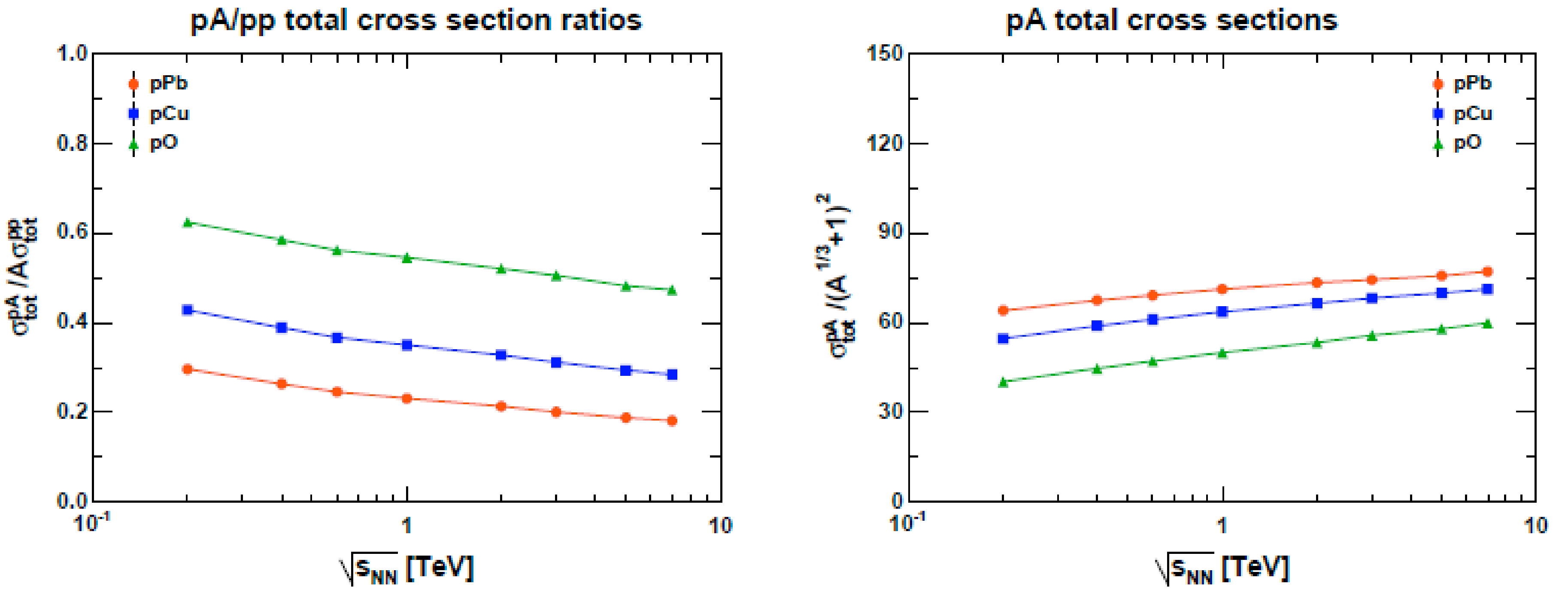


DIPSY reproduces prel. inelastic pPb cross-sections

DIPSY predictions: pA



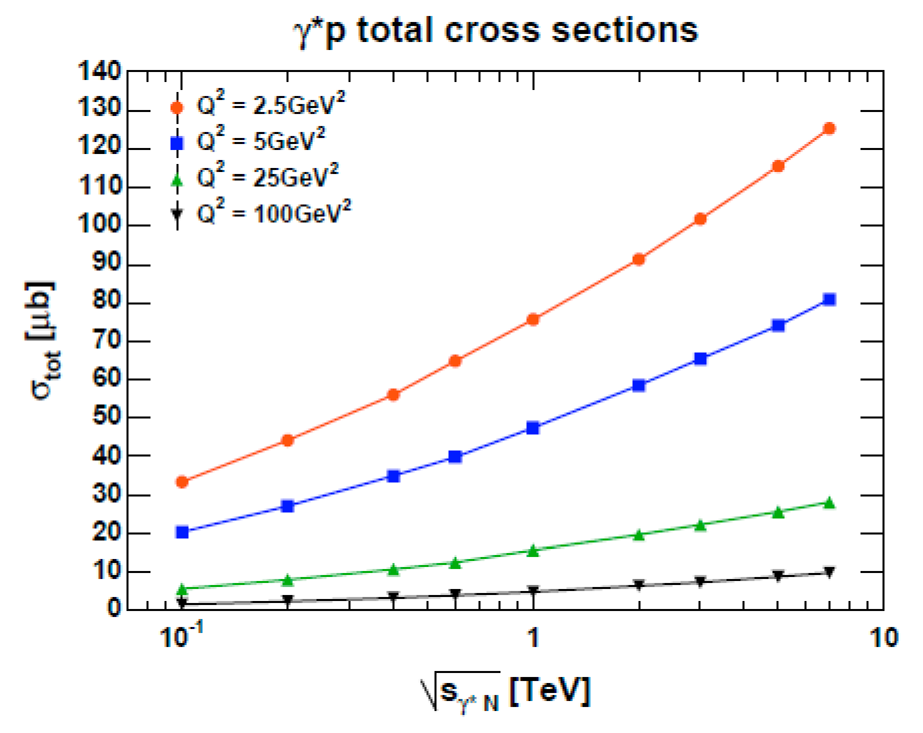
DIPSY pA/pp ratios

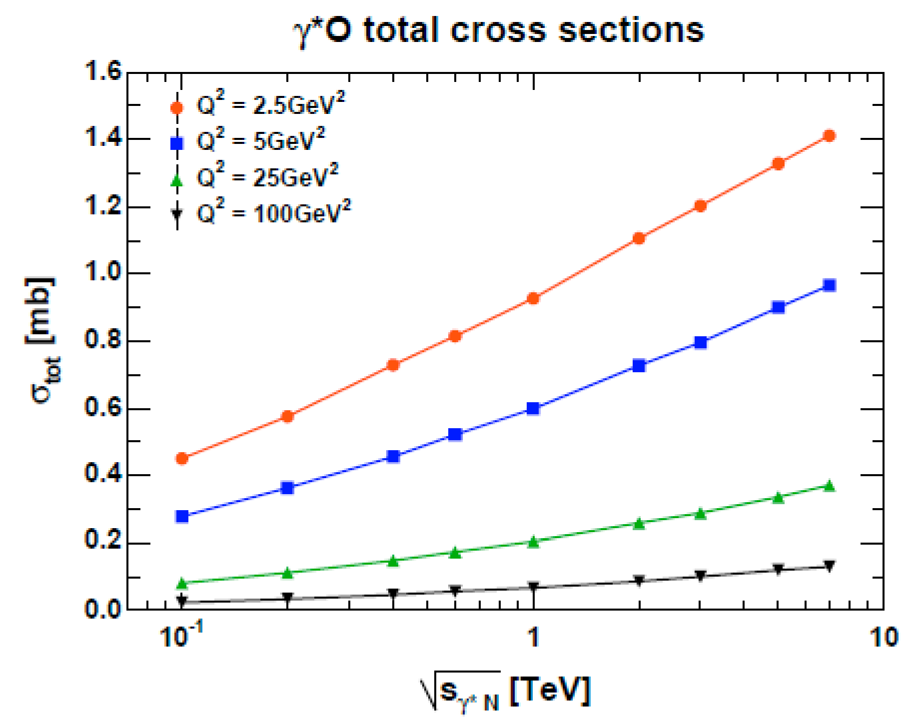


pA total cross section does not scale with A (fluctuations, swing)

DIPSY: $\sigma_{tot}(pA)$ asymptotically scales with $(A^{1/3}+1)^2$

DIPSY for a future ep and eA collider

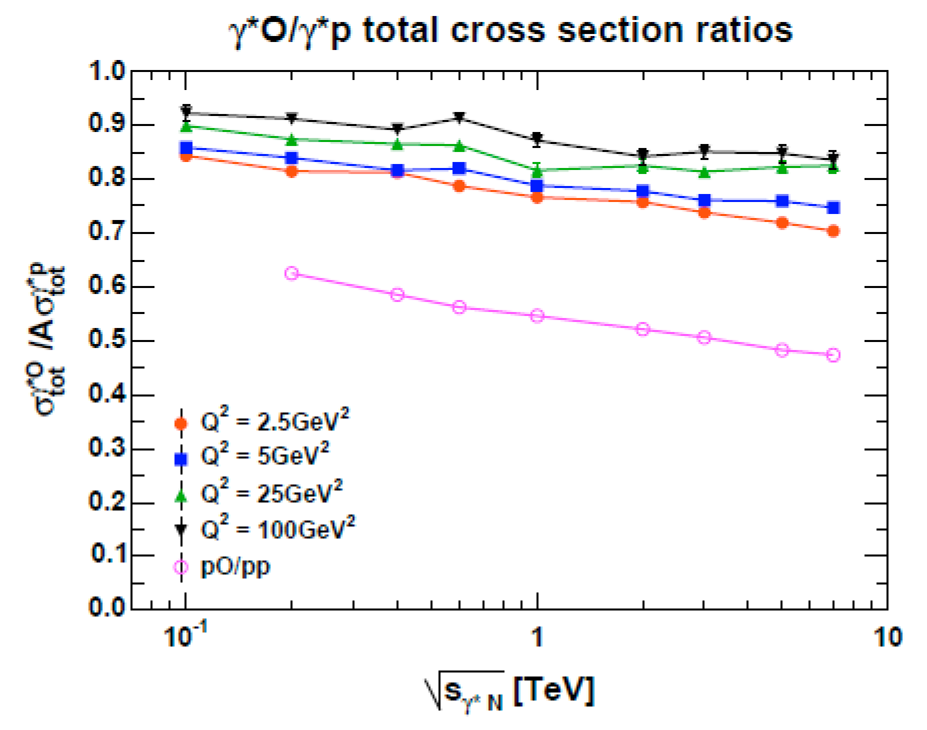


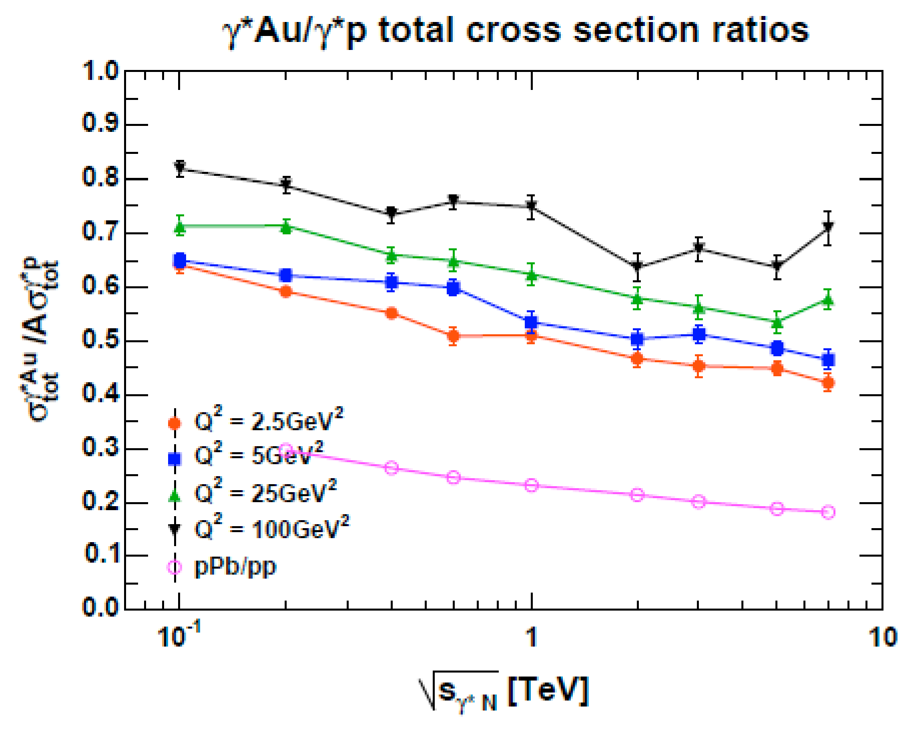


γ^*p
DIPSY predictions

γ^*A
DIPSY predictions

DIPSY predictions for eA collisions



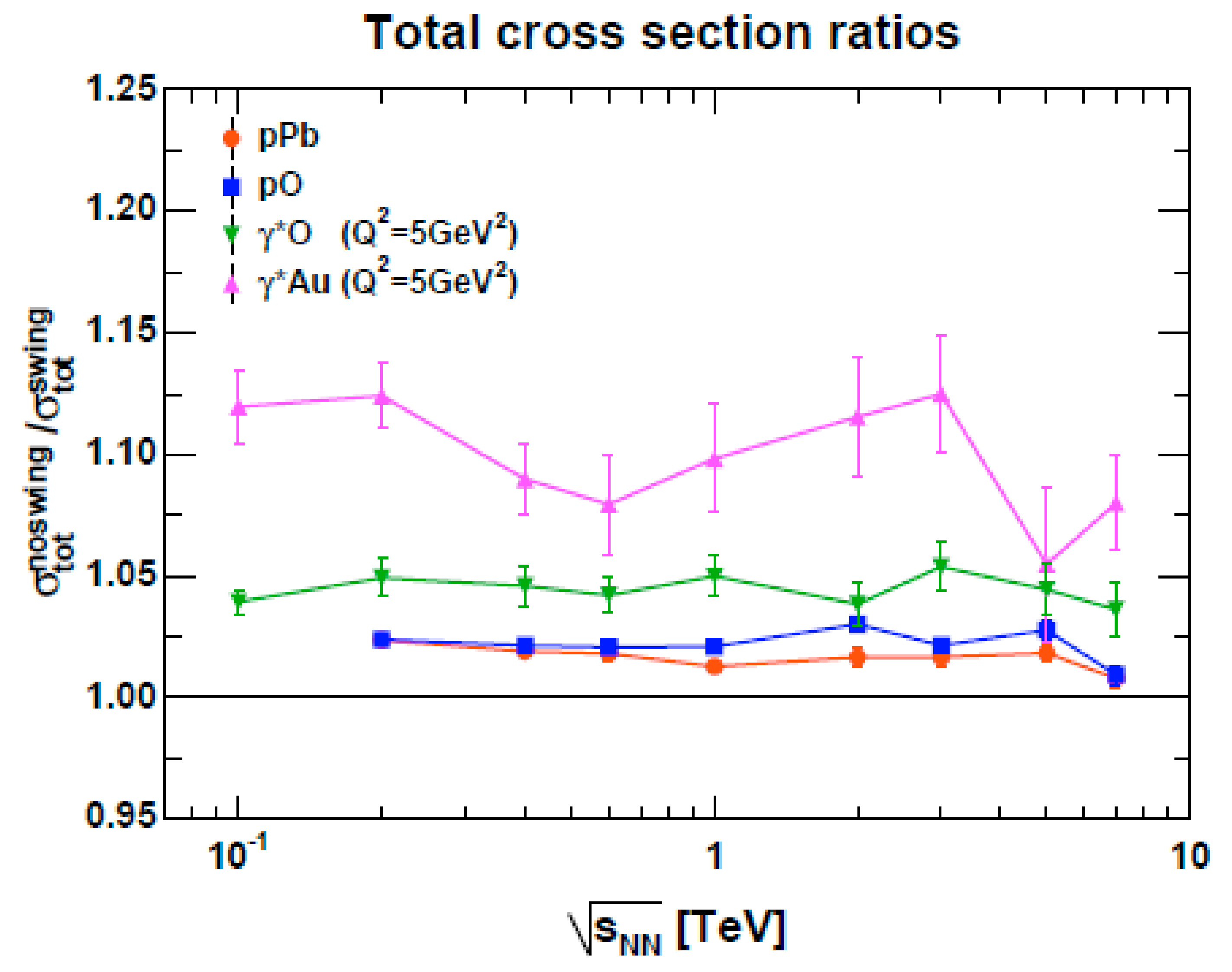


eO σ_{tot}
~ scales with A :

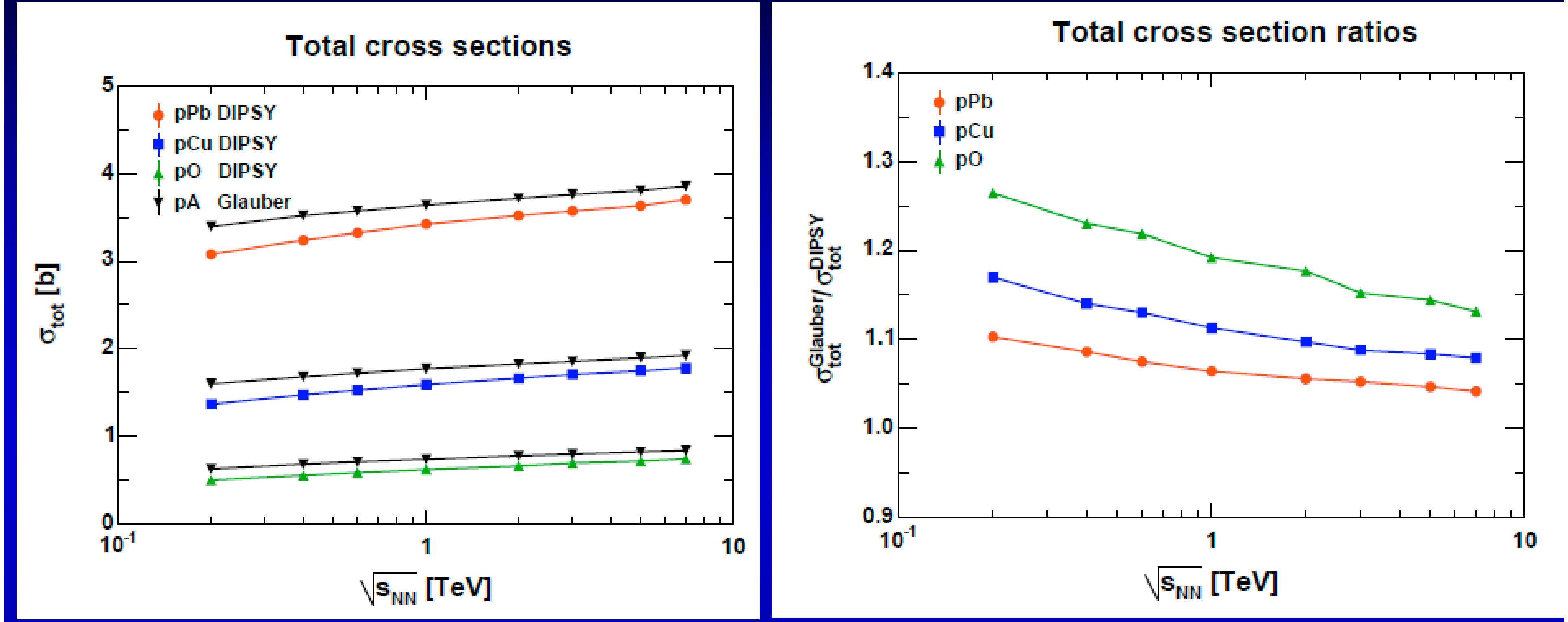
fluctuations, swing
important

eAu σ_{tot}
reduced wrt eO
but large wrt pp :
fluctuations, swing
still important

Swing effects in DIPSY



DIPSY predictions vs Glauber MC



DIPSY with dipole fluctuations and swing effects reduce pA cross sections by cca 5 – 15 %. Effect bigger for smaller A.

Formalism for Black/Grey Discs

$$\begin{aligned}\sigma_{\rm tot} &= 2\int d^2b\langle T(b)\rangle = 2\pi R^2\\ \sigma_{\rm el} &= \int d^2b\langle T(b)\rangle^2 = \pi R^2\\ \sigma_{\rm D} &= \int d^2b(\langle T(b)^2\rangle - \langle T(b)\rangle^2) = 0\\ \sigma_{\rm in,ND} &= \int d^2b\langle 1-(1-T(b))^2\rangle = \pi R^2.\end{aligned}$$

In Black Disc approximation,
3 ways to define
the radius of the nucleons
σ_{tot}, σ_{el}, $\sigma_{in,ND}$

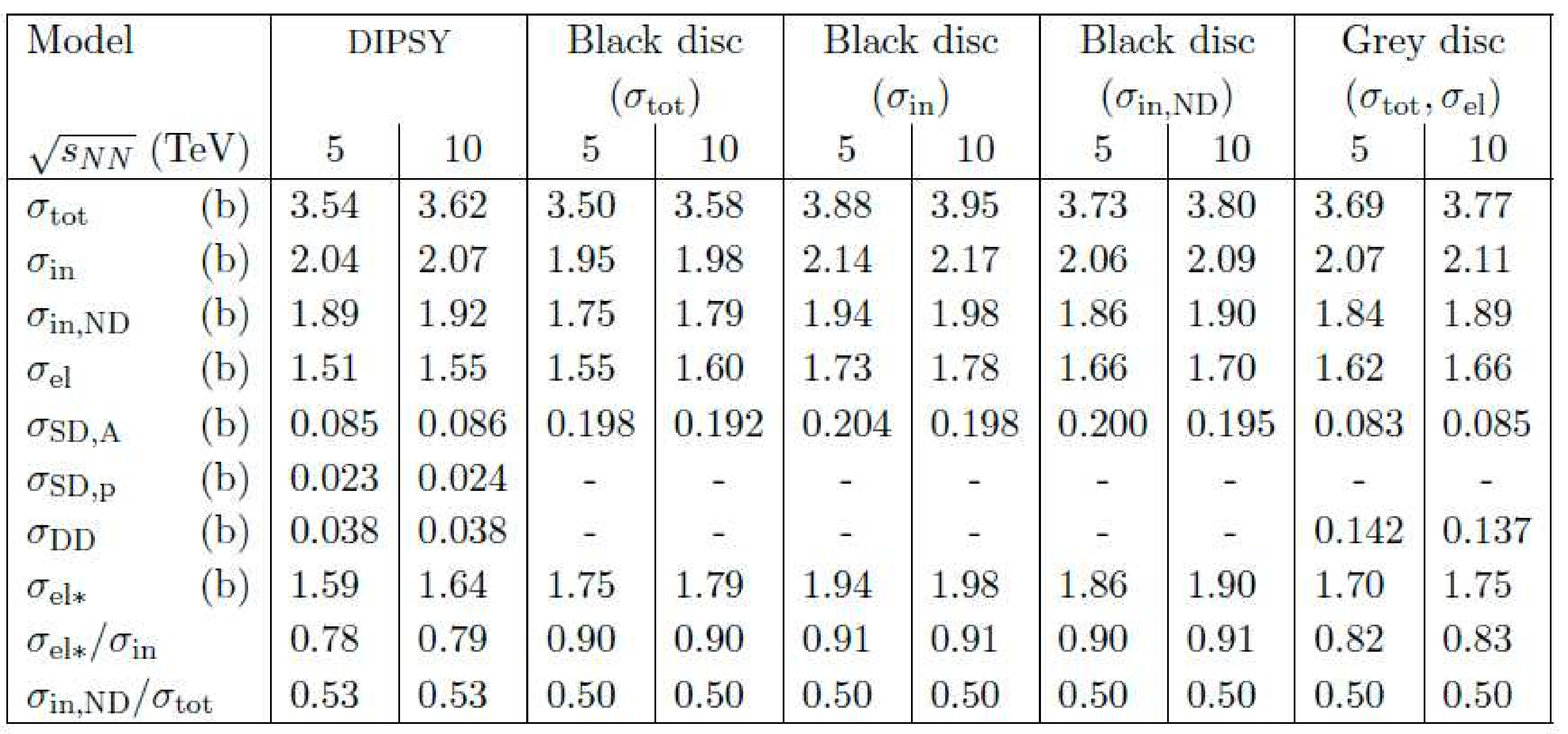
$$\begin{aligned}\sigma_{\rm tot} &= 2\int d^2b\langle T(b)\rangle = 2\pi R^2 a\\ \sigma_{\rm el} &= \int d^2b\langle T(b)\rangle^2 = \pi R^2 a^2\\ \sigma_{\rm D} &= \int d^2b(\langle T(b)^2\rangle - \langle T(b)\rangle^2) = \pi R^2 a(1-a)\\ \sigma_{\rm in,ND} &= \int d^2b\langle 1-(1-T(b))^2\rangle = \pi R^2 a.\end{aligned}$$

In Grey Disc approx,
R and „a”
are usually given by
σ_{tot} and σ_{el}

$$\sigma_{\rm el}+\sigma_{\rm D} = \sigma_{\rm in,ND} = \sigma_{\rm tot}/2$$

DIPSY for quasi-elastic σ_{tot}(pPb)

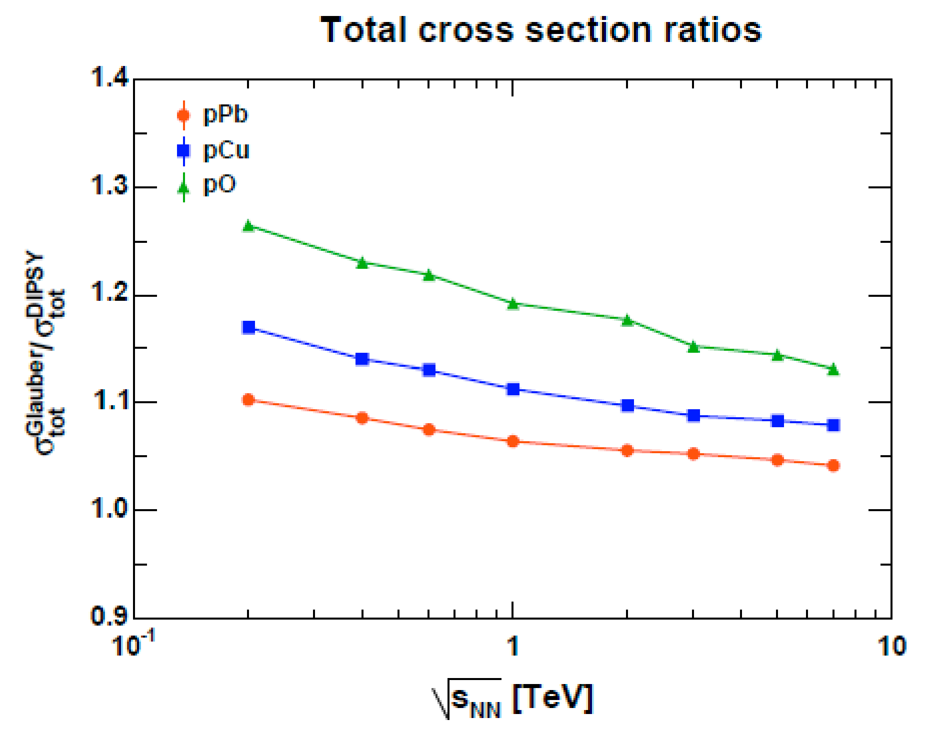
All cross-sections in barns, for pPb at 5 and 10 TeV

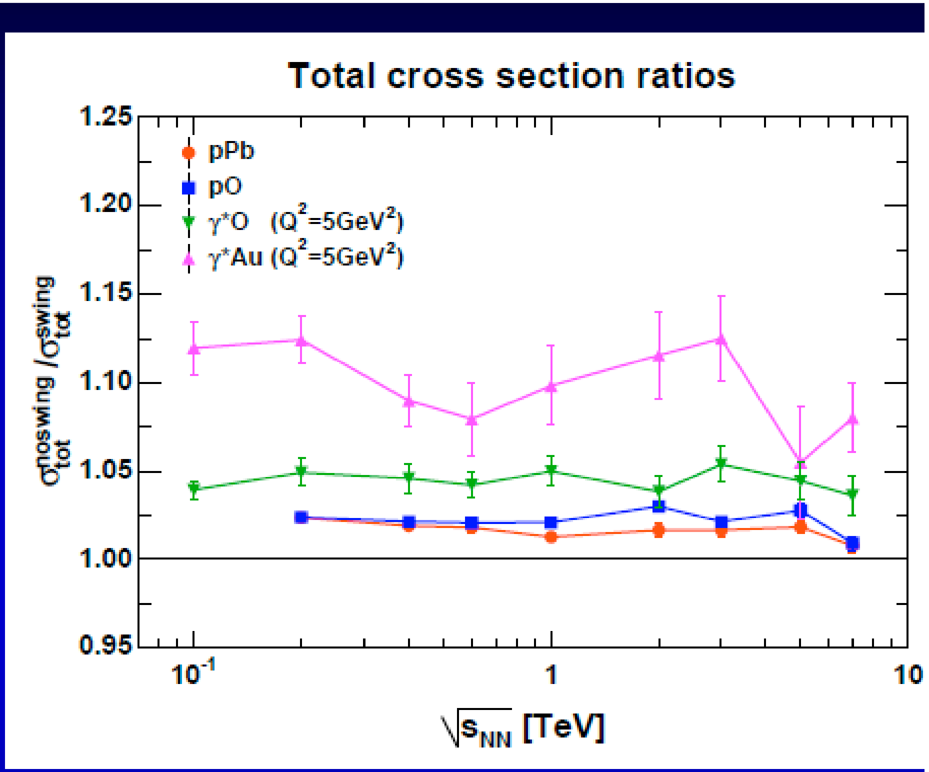


Model	DIPSY		Black disc ($\sigma_{\rm tot}$)		Black disc ($\sigma_{\rm in}$)		Black disc ($\sigma_{\rm in,ND}$)		Grey disc ($\sigma_{\rm tot}, \sigma_{\rm el}$)	
$\sqrt{s_{NN}}$ (TeV)	5	10	5	10	5	10	5	10	5	10
$\sigma_{\rm tot}$ (b)	3.54	3.62	3.50	3.58	3.88	3.95	3.73	3.80	3.69	3.77
$\sigma_{\rm in}$ (b)	2.04	2.07	1.95	1.98	2.14	2.17	2.06	2.09	2.07	2.11
$\sigma_{\rm in,ND}$ (b)	1.89	1.92	1.75	1.79	1.94	1.98	1.86	1.90	1.84	1.89
$\sigma_{\rm el}$ (b)	1.51	1.55	1.55	1.60	1.73	1.78	1.66	1.70	1.62	1.66
$\sigma_{\rm SD,A}$ (b)	0.085	0.086	0.198	0.192	0.204	0.198	0.200	0.195	0.083	0.085
$\sigma_{\rm SD,p}$ (b)	0.023	0.024	-	-	-	-	-	-	-	-
$\sigma_{\rm DD}$ (b)	0.038	0.038	-	-	-	-	-	-	0.142	0.137
$\sigma_{\rm el*}$ (b)	1.59	1.64	1.75	1.79	1.94	1.98	1.86	1.90	1.70	1.75
$\sigma_{\rm el*}/\sigma_{\rm in}$	0.78	0.79	0.90	0.90	0.91	0.91	0.90	0.91	0.82	0.83
$\sigma_{\rm in,ND}/\sigma_{\rm tot}$	0.53	0.53	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50

DIPSY predicts 3.5 - 3.9 barn for total and
1.6 - 1.9 barn for quasi-elastic cross section,
80 – 90 % of inelastic, ~ 50% of total
regardless of fluctuations, swings and other effects.

What have we learned ?





pA cross sections reduce by 10% due to dipole fluctuations + swing

Effect is larger in eA than in pA, decreases with increasing dipole size

What have we learned ?

Initial conditions
for hydro evolution
from cross-section ratios

DIPSY Monte Carlo’s
stable prediction:

$\sigma^*/\sigma_{tot} \sim 1/2$
$\sigma^*/\sigma_{in} \sim 4/5$
in pPb at LHC

Swings:
glueballs in pPb?

eA collider:
favourable
as compared to pPb or dAu

Backup slides – Questions?

Hydro behaviour in h+p (NA22/EHS)

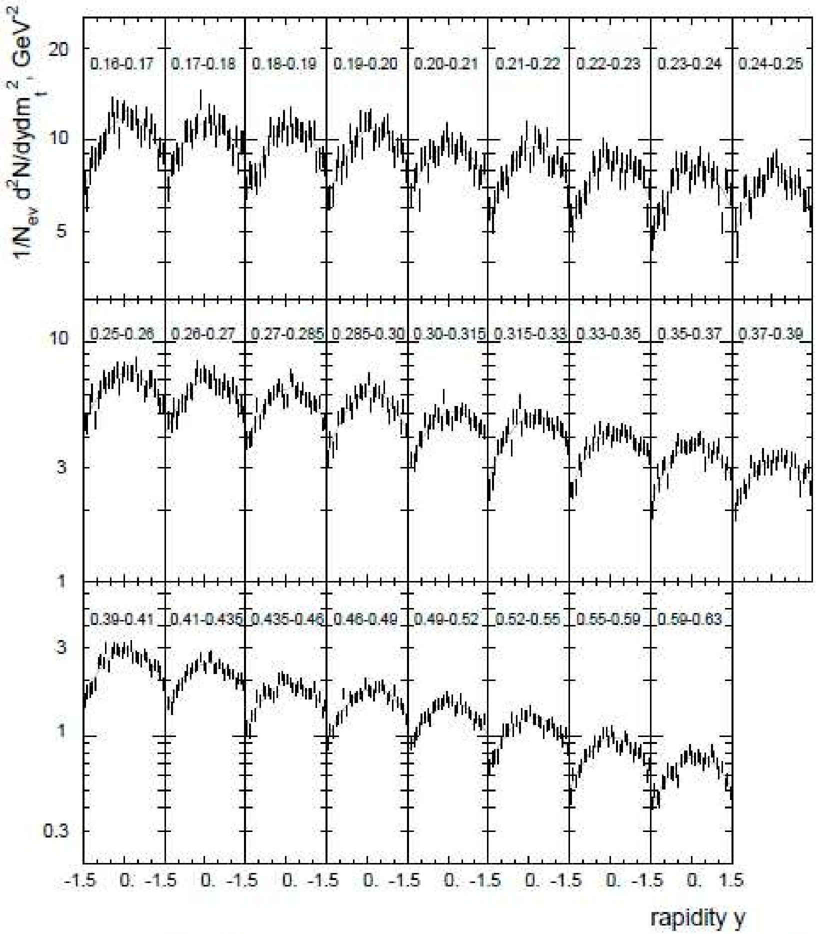


Fig. 11. The rapidity distributions of centrally produced pions ($|y| < 1.5$) for different m_t-slices given. The curves are the fit results obtained analytically using the BL-H parameterization.

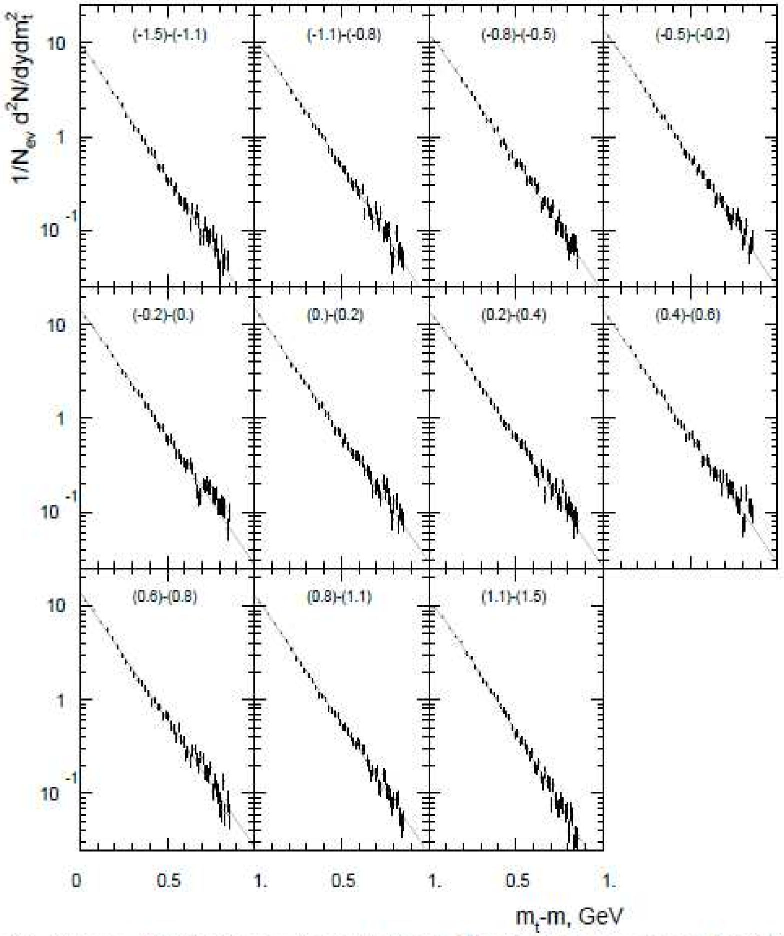
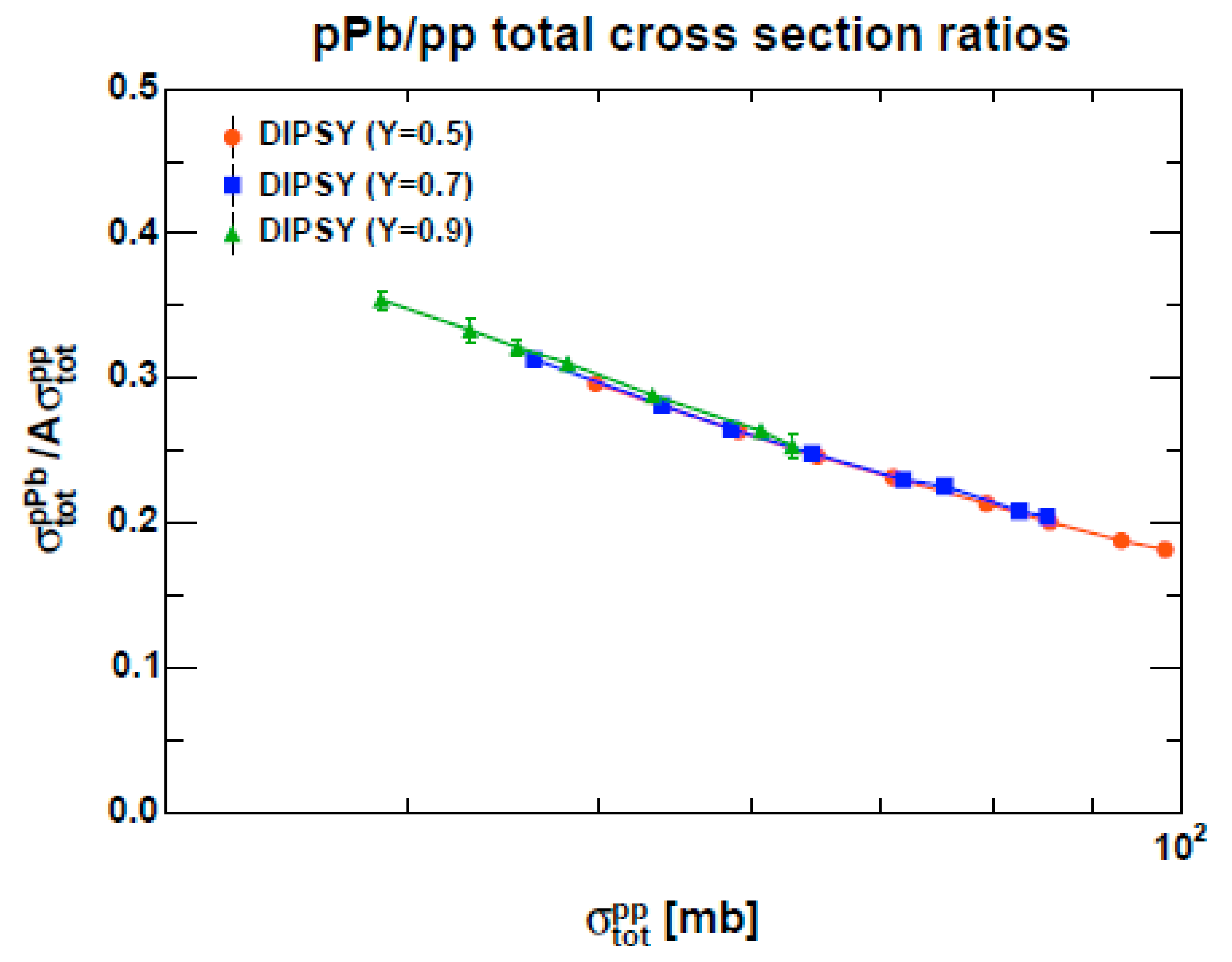


Fig. 12. The m_t distributions of centrally produced pions ($|y| < 1.5$) for different y-slices given. The curves are the fit results obtained analytically using the BL-H parameterization.

Hydro behaviour in h+p reactions at sqrt(s)=22 GeV
Reviewed in T. Cs, hep-ph/0001233

Frame dependence?



DIPSY pp cross sections need to be tuned in each frame, after this step the cross section ratios are frame independent.