

Multiplicities at the LHC in a geometric scaling model

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Last call for LHC predictions - CERN May 2007

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Idea

***Start from lepton-proton and
lepton-nucleus and extrapolate
by geometric scaling***

Dipole model and geometric scaling

⇒ The total $\gamma^* h$ cross section in the dipole model

$$\sigma_{T,L}^{\gamma^* h}(x, Q^2) = \int d\mathbf{r} \int_0^1 dz |\Psi_{T,L}^{\gamma^*}(Q^2, \mathbf{r}, z)|^2 \sigma_{\text{dip}}^h(\mathbf{r}, x),$$

⇒ Geometric scaling → all x-dependence in the saturation scale

$$\sigma_{\text{dip}}^h(\mathbf{r}, x) = \sigma_{\text{dip}}^h(\mathbf{r}Q_{\text{sat}}(x))$$

⇒ For massless quarks and without impact parameter

$$|\Psi_{T,L}^{\gamma^*}(Q^2, \mathbf{r}, z)|^2 = Q^2 f(r^2 Q^2) \implies \sigma_{T,L}^{\gamma^* h}(x, Q^2) = \sigma_{T,L}^{\gamma^* h}(Q^2 / Q_{\text{sat}}^2(x))$$

N_h(\mathbf{r}Q_{\text{sat}})

⇒ Geometric scaling present in the lepton-hadron data

Geometric scaling in lp data

⇒ All lepton-proton data with $x \leq 0.01$ only function of

$$\tau_p = \frac{Q^2}{Q_{\text{sat}}^2}$$

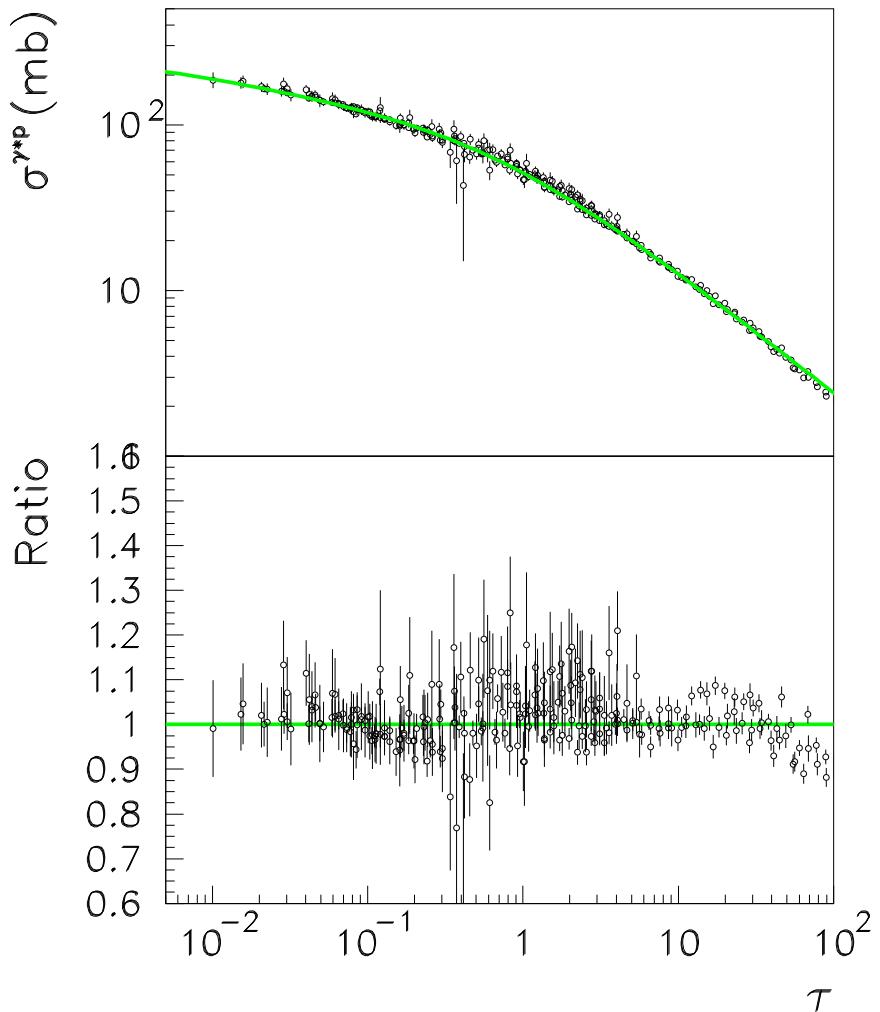
$$Q_{\text{sat}}^2 = \left(\frac{x_0}{x} \right)^\lambda ; \quad \lambda = 0.288$$

Stasto, Golec-Biernat, Kwiecinski
PRL86, 596 (2001); Golec-Biernat,
Wusthoff PRD59, 014017 (1999)

⇒ We fit this scaling function to

$$\Phi(\tau) = \bar{\sigma}_0 [\gamma_E + \Gamma(0, \xi) + \ln \xi] ,$$

$$\xi = \frac{a}{\tau^b} ; \quad a = 1.868 , \quad b = 0.746$$



The nuclear case - impact parameter

⇒ With impact parameter: suppose all the b dependence can be scaled-out by the radius R_h : $\bar{b} = b / \sqrt{\pi R_h^2}$

$$\int d^2b N_h(r Q_{\text{sat},h}(x, b)) \longrightarrow \pi R_h^2 \int d^2\bar{b}, N_h(r Q_{\text{sat},h}(x, \bar{b}))$$

⇒ If these two rescalings are exact

$$\frac{\sigma_{T,L}^{\gamma^* h}(Q^2/Q_{\text{sat},h}^2(x))}{\pi R_h^2}$$

is a universal function for any h = proton or nuclei

⇒ So the scaling condition for the nuclear case is

$$\frac{\sigma^{\gamma^* A}(\tau)}{\pi R_A^2} = \frac{\sigma^{\gamma^* p}(\tau)}{\pi R_p^2}$$

Geometric scaling in 1A data

⇒ We define

$$Q_{\text{sat},A}^2 = Q_{\text{sat},p}^2 \left(\frac{AR_p^2}{R_A^2} \right)^{1/\delta}$$

$$R_A = 1.12 A^{1/3} - 0.86 A^{-1/3}$$

⇒ With free parameters
fitted to data [$\chi^2/\text{dof} = 0.95$]

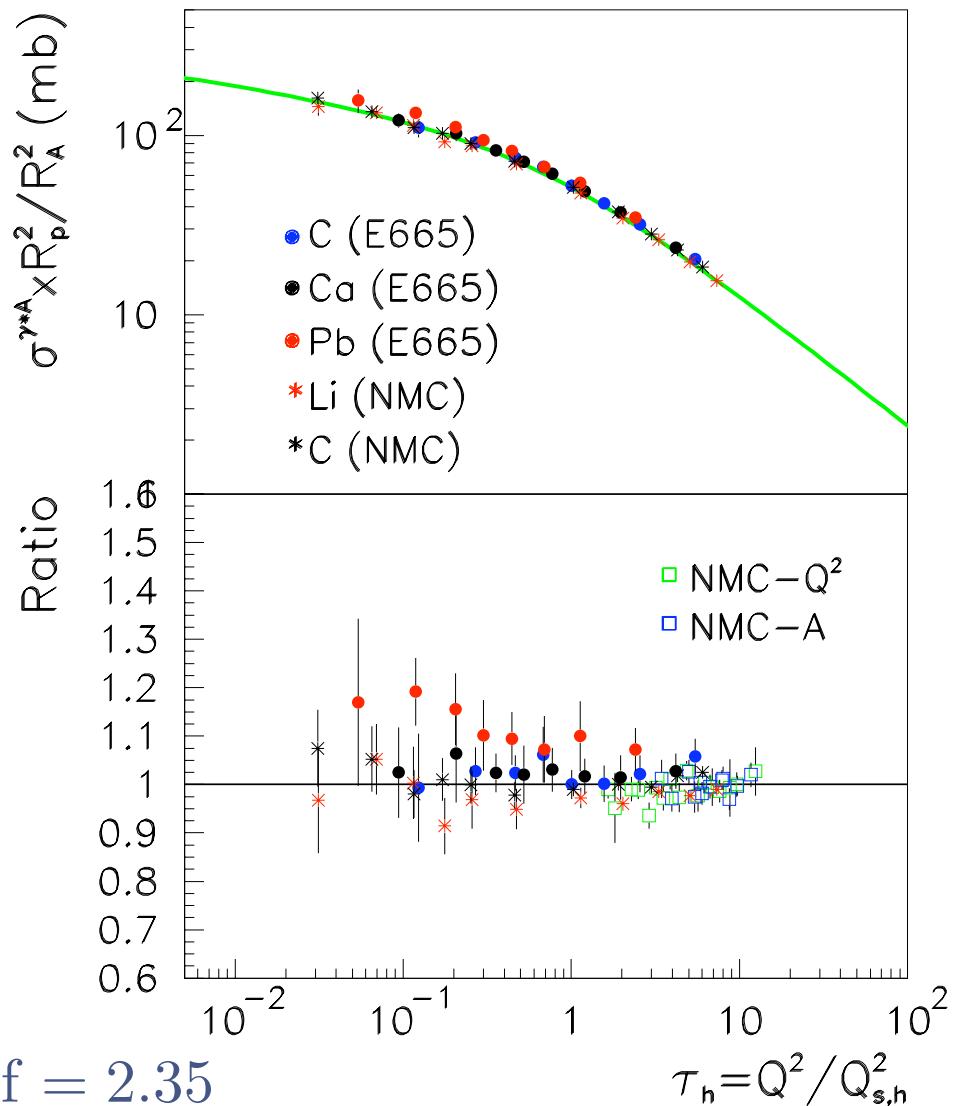
$$R_p = 0.70 \pm 0.08 \text{ fm}$$

$$\delta = 0.79 \pm 0.02$$

$$Q_{\text{sat}}^2 \sim A^{4/9}$$

$$\delta = 1 [Q_{\text{sat}}^2 \sim A^{1/3}] \implies \chi^2/\text{dof} = 2.35$$

[See also Freund et al. 2003]



Multiplicities in AA collisions

⇒ Factorization formula Gribov, Levin, Ryskin Phys Rep 100, 1 (1983) ...

$$\frac{dN_g^{AB}}{dy d^2 p_t db} \propto \frac{\alpha_S}{p_t^2} \int d^2 k \phi_A(y, k^2, b) \phi_B(y, (k - p_t)^2, b),$$

where

$$\phi_h(y, k^2, b) = \int \frac{d^2 r}{2\pi r^2} \exp\{i\mathbf{r} \cdot \mathbf{k}\} N_h(r^2, x; b)$$

⇒ Geometric scaling: $\phi_h(y, k^2, b) = \phi(k^2/Q_{\text{sat},h}^2)$

$$\frac{dN_g^{AA}}{dy} \Big|_{y \sim 0} \propto Q_{\text{sat},A}^2 \pi R_A^2 \left[\int \frac{d\mathbf{s}}{\mathbf{s}^2} d\tau d\bar{\mathbf{b}} \phi(\tau^2) \phi((\tau - \mathbf{s})^2) \right]$$
$$\frac{1}{N_{\text{part}}} \frac{dN^{AA}}{d\eta} \Big|_{\eta \sim 0} = N_0 \sqrt{s}^\lambda N_{\text{part}}^{\frac{1-\delta}{3\delta}}$$

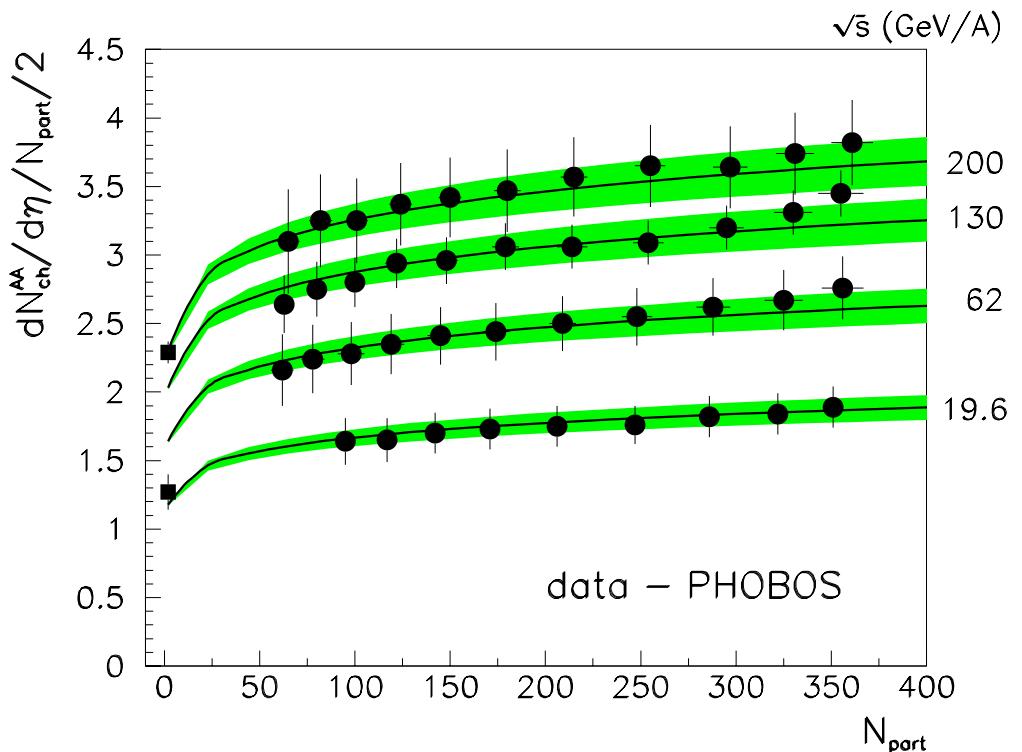
⇒ But factorization not really needed, only geometric scaling.

Multiplicities and RHIC data

$$\frac{1}{N_{\text{part}}} \frac{dN^{AA}}{d\eta} \Big|_{\eta \sim 0} = N_0 \sqrt{s}^{\lambda} N_{\text{part}}^{\frac{1-\delta}{3\delta}}$$

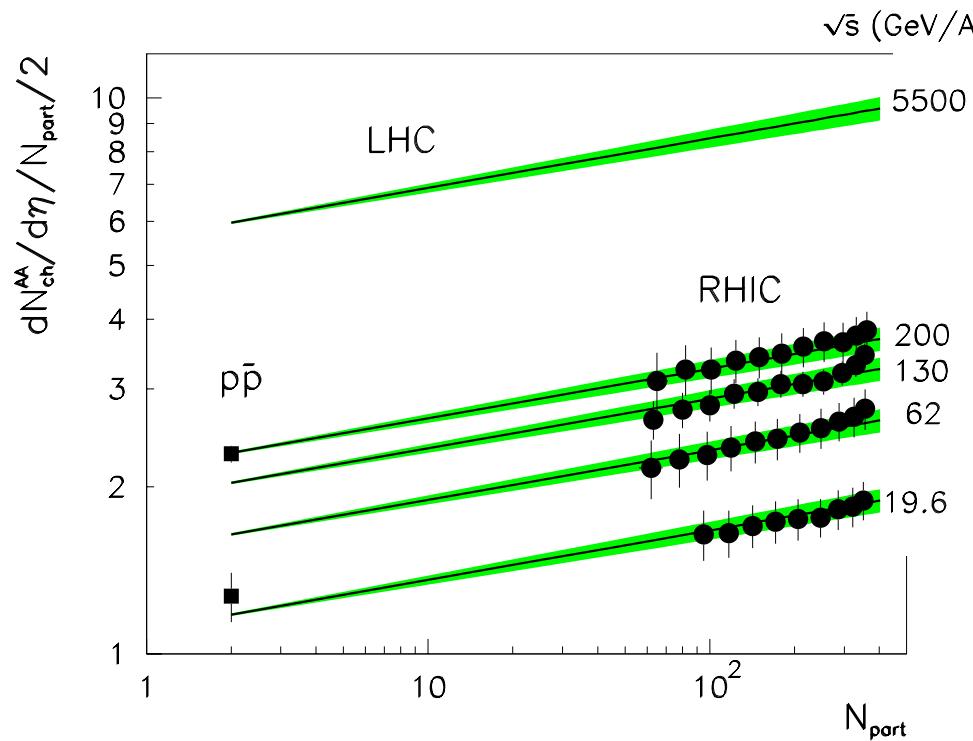
$N_0 = 0.23$ ← normalization
 $\lambda = 0.288$ ← lp data
 $\delta = 0.79 \pm 0.02$ ← IA data

[ASW 2005]



- ⇒ Energy dependence fixed by lepton-proton data
- ⇒ Centrality dependence fixed by lepton-nucleus data
- ⇒ Energy and centrality dependence factorize

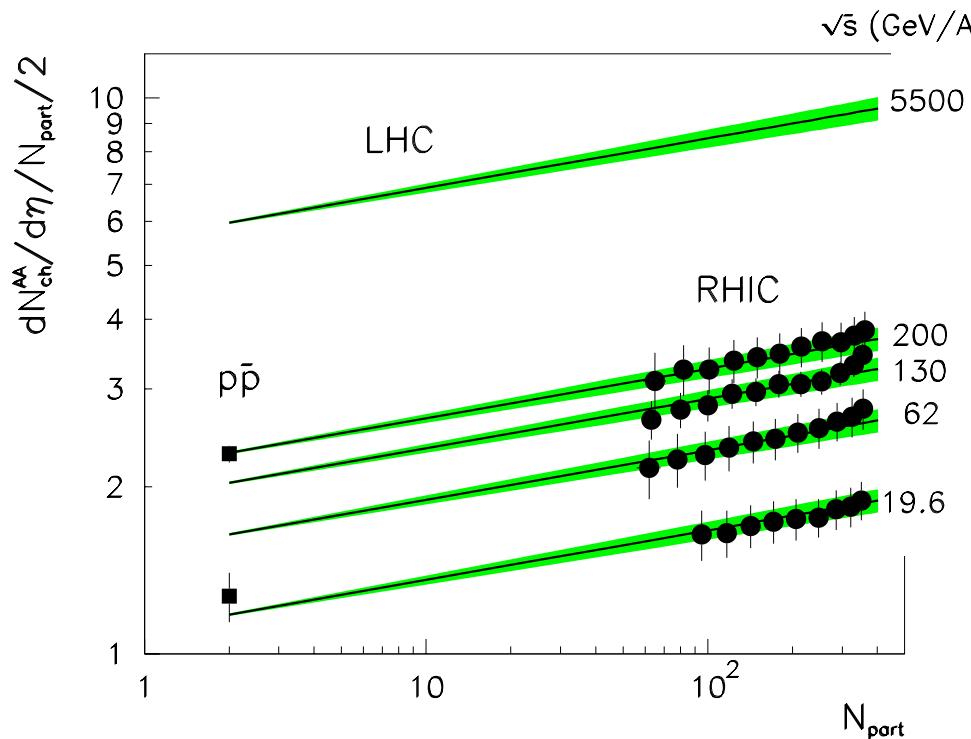
Predictions for the LHC



$$\frac{1}{N_{\text{part}}} \frac{dN^{AA}}{d\eta} \Big|_{\eta \sim 0} = N_0 \sqrt{s}^\lambda N_{\text{part}}^{\frac{1-\delta}{3\delta}}$$

$$\frac{dN^{AA}}{d\eta} \Big|_{\eta \sim 0} = \begin{cases} 1550 \div 1760 & \text{for } N_{\text{part}} = 350 \\ 1670 \div 1900 & \text{for } N_{\text{part}} = 375 \end{cases}$$

Predictions for the LHC



$$\frac{1}{N_{part}} \frac{dN^{AA}}{d\eta} \Big|_{\eta \sim 0} = N_0 \sqrt{s}^\lambda N_{part}^{\frac{1-\delta}{3\delta}}$$

$$\frac{dN^{AA}}{d\eta} \Big|_{\eta \sim 0} = \begin{cases} 1550 \div 1760 & \text{for } N_{part} = 350 \\ 1670 \div 1900 & \text{for } N_{part} = 375 \end{cases}$$

$$\delta = 0.79 \pm 0.02$$

High- p_t at forward rapidities

⇒ Forward rapidities → testing ground for saturation.

⇒ To check geometric scaling

→ Use the factorization formula

$$\frac{dN_g^{AB}}{dy d^2 p_t db} \propto \frac{\alpha_S}{p_t^2} \int d^2 k \phi_A(y, k^2, b) \phi_B(y, (k - \mathbf{p}_t)^2, b),$$

→ Suppose

$$\phi_A(k = Q/2) \simeq \Phi(\tau_A); \tau_A = k^2 / 4\bar{Q}_{\text{sat},A}^2; \bar{Q}_{\text{sat},A}^2 = \frac{N_c}{C_F} \bar{Q}_{\text{sat},A}^2$$

→ Taking $\phi_d \sim 1/k_t^n$, $n \gg 1$

$$\frac{\frac{dN_{c_1}^{\text{dAu}}}{N_{\text{coll}_1} d\eta d^2 p_t}}{\frac{dN_{c_2}^{\text{dAu}}}{N_{\text{coll}_2} d\eta d^2 p_t}} \approx \frac{N_{\text{coll}_2} \phi_A(p_t/Q_{\text{s},c_1})}{N_{\text{coll}_1} \phi_A(p_t/Q_{\text{s},c_2})} \approx \frac{N_{\text{coll}_2} \Phi(\tau_{c_1})}{N_{\text{coll}_1} \Phi(\tau_{c_2})}$$

where c_1, c_2 are two centrality classes.

⇒ I.e. we make ratios of the DIS scaling function at the appropriate τ .

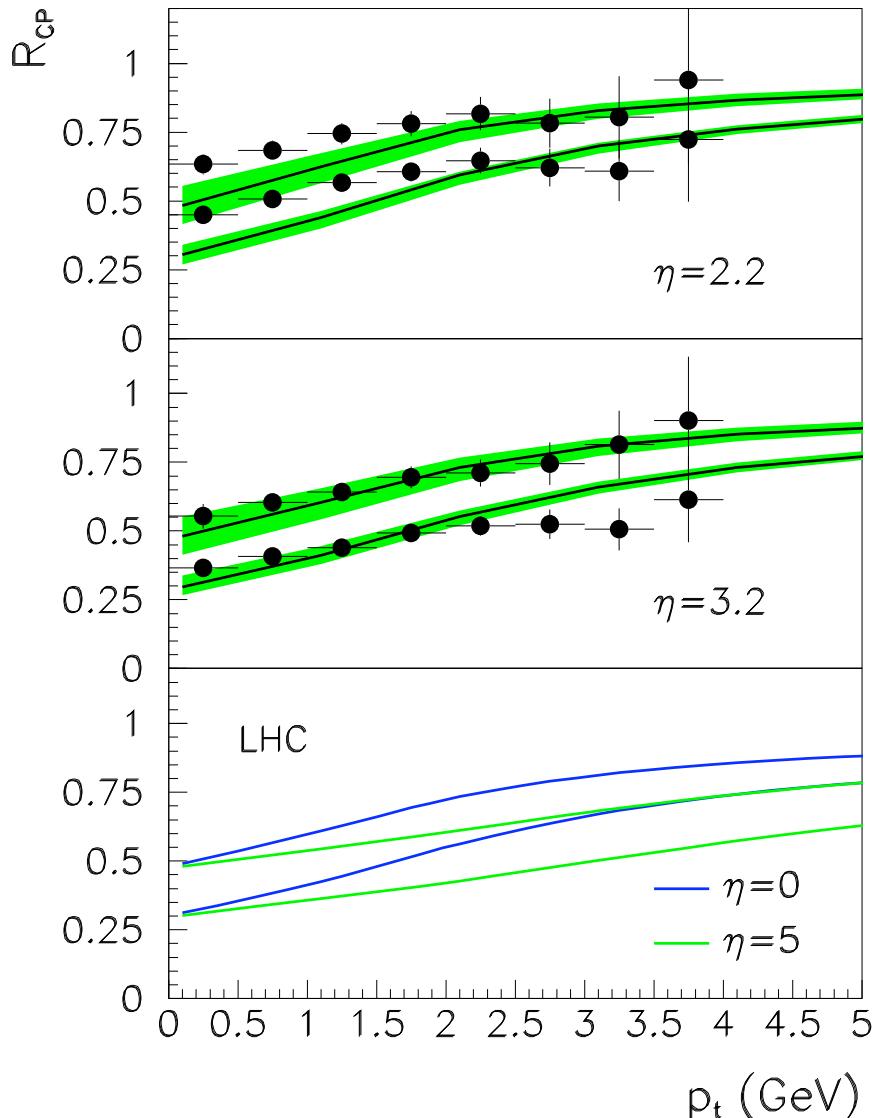
Geometric scaling and dAu data

⇒ Saturation scale for dAu

$$Q_{\text{sat}}^2 \propto N_{\text{coll}}^{1/\delta}$$

$$N_{\text{coll}} = \\ 13.6 \pm 0.3, \ 7.9 \pm 0.4, \ 3.3 \pm 0.4$$

⇒ LHC at central rapidities →
suppression similar to RHIC at
forward rapidities



Summary

- ⇒ Geometric scaling able to describe a variety of data
 - ↳ lepton-proton
 - ↳ lepton-nucleus
 - ↳ AA multiplicities
 - ↳ pA suppression at large rapidities
- ⇒ From analysis of lepton-hadron data
 - ↳ Energy dependence
 - ↳ Saturation scale grows faster than $A^{1/3}$
- ⇒ Predictions for the LHC multiplicities

$$Q_{\text{sat}}^2 = \frac{1}{R_0^2} x^{-\lambda} A^{1/3\delta}$$

$$\left. \frac{dN^{AA}}{d\eta} \right|_{\eta \sim 0} = \begin{cases} 1550 \div 1760 & \text{for } N_{\text{part}} = 350 \\ 1670 \div 1900 & \text{for } N_{\text{part}} = 375 \end{cases}$$