

# Investigating the Extended Geometric Scaling Region at the LHC With Polarized and Unpolarized Final States

Erik Wessels

VU University Amsterdam

Heavy ion collisions at the LHC, last call for predictions

in collaboration with Daniël Boer, Adrian Dumitru and Andre Utermann



# Outline

- 1 Introduction: (Extended) Geometric Scaling
  - EGS: DHJ model
- 2 (Extended) Geometric Scaling Region at LHC
  - DHJ model predictions  $\pi$  production
  - DHJ model prediction  $\Lambda$  polarization
- 3 Conclusions



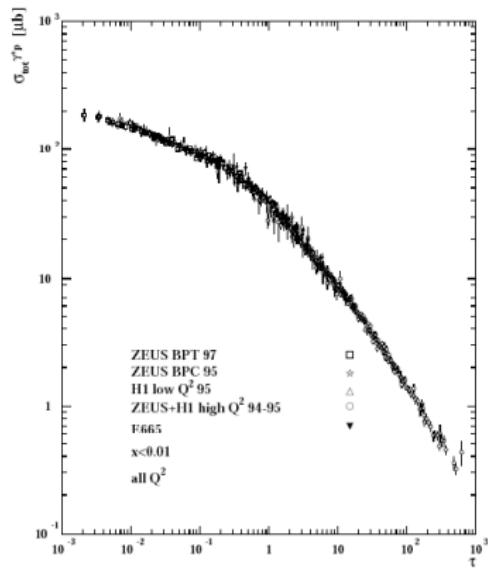
# Saturation and Geometric Scaling

- At small  $x$ , gluon density is expected to saturate
- Associated saturation scale  $Q_s(x)$  grows exponentially with  $1/x$
- For  $Q^2 \leq Q_s^2(x)$ , Geometric Scaling is expected
- GS: cross section depends on combination  $Q^2/Q_s^2(x)$



# Geometric Scaling at HERA

- DIS data show Geometric Scaling
- Described by Golec-Biernat Wüsthoff (GBW) model for dipole scattering amplitude (for  $Q^2$  not too large)



$$N(r, x) = 1 - \exp \left[ -\frac{1}{4} r^2 Q_s^2(x) \right],$$

$$Q_s^2(x) = A^{1/3} Q_0^2 \left( \frac{x_0}{x} \right)^{\lambda/2},$$

$$Q_0 = 1 \text{ GeV}$$

$$\lambda = 0.3,$$

$$x_0 = 3 \cdot 10^{-4}$$

Plot by Stasto, Golec-Biernat, Kwiecinski  
PRL 86 (2001)



# Extended Geometric Scaling

- For  $Q^2$  in a range above  $Q_s^2(x)$ , GS holds approximately

Levin, Tuchin N.Ph. A (2001) 779

- Deviations from scaling behaviour become sizable at  $Q^2 = Q_{gs}^2$
- $Q_s^2(x) < Q^2 < Q_{gs}^2(x)$ : Extended Geometric Scaling Region
- Upper bound estimated:  $Q_{gs}(x) \sim Q_s^2(x)/\Lambda$

Iancu, Itakura, McLerran NPA (2002) 327

- $Q^2 > Q_{gs}^2(x)$ : DGLAP evolution



# Extended Geometric Scaling at RHIC

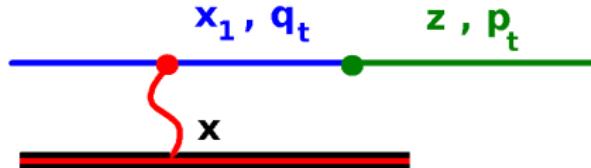
- EGS region probed at RHIC
- RHIC data described by Dumitru, Hayashigaki, Jalilian-Marian (DHJ) model

$$N(r, x) = 1 - \exp \left[ -\frac{1}{4} (r^2 Q_s^2(x))^{\gamma(r,x)} \right]$$

- $\gamma(r, x)$  taken from data: still undetermined in Saturation Region
- $\gamma(r, x)$  encodes scaling violations of EGS data:  
not function of  $rQ_s(x)$  only



# Extended Geometric Scaling at RHIC



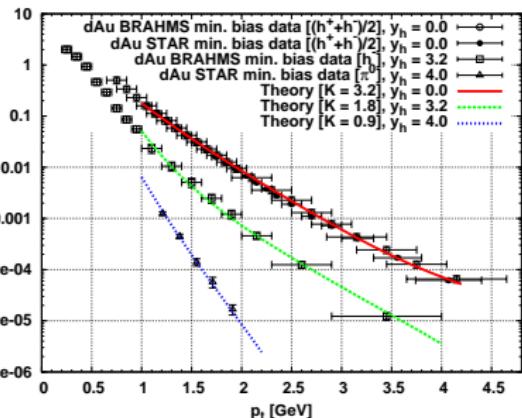
- DHJ formalism for hadron production

$$\frac{d\hat{\sigma}}{dy d^2 p_t} \sim pdf(x_1) \otimes N\left(q_t = \frac{x_1}{x_F} p_t, x\right) \otimes FF(z)$$

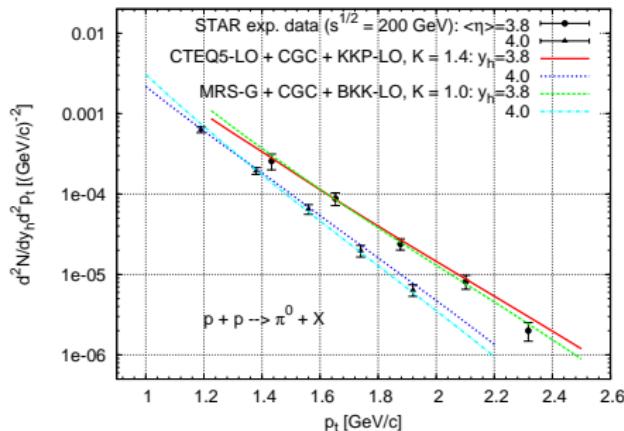
- Factorized description requires  $p_t \gtrsim 1\text{GeV}$
- 1 extra free parameter w.r.t. GBW



# DHJ results for RHIC



DHJ, NPA (2006)



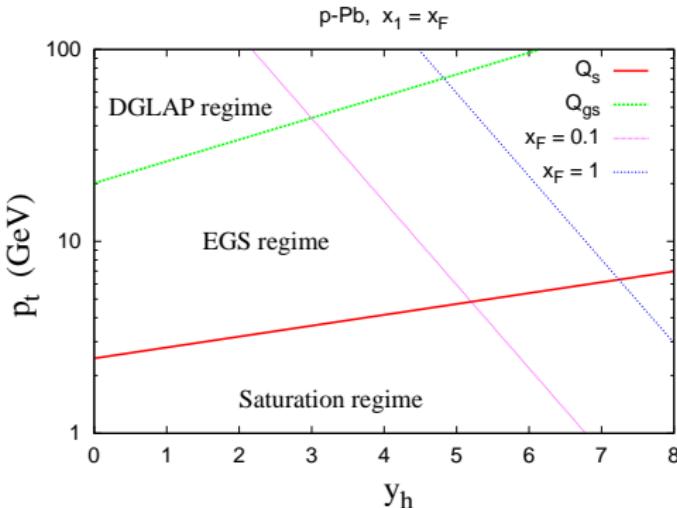
Boer, Dumitru, Hayashigaki PRD 74 (2006)

## LO DHJ formalism describes

- $d-Au \rightarrow \pi + X$  at  $y_h$  of  $0 - 4$
- $p - p \rightarrow \pi + X$  at  $y_h \sim 4$
- Normalization fixed by  $p_t$ -independent  $K$ -factors



# (Extended) Geometric Scaling Region at LHC



- Hadron production in  $p$ -Pb at  $\sqrt{s} = 8.8$  TeV
- Typically  $x_1 \sim x_F$

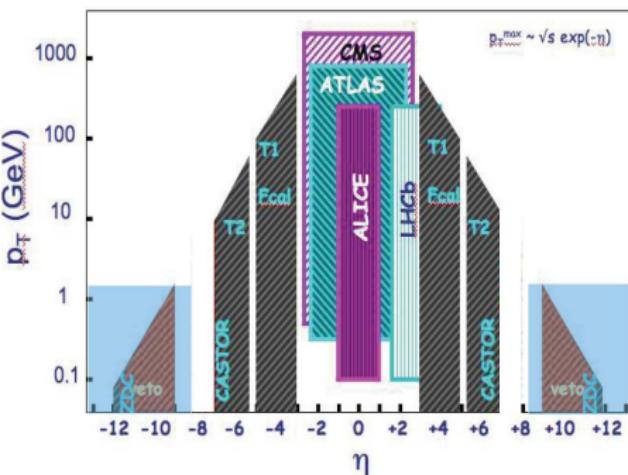
$$Q_s(y_h) = A^{1/6} Q_0 \left( \frac{x_0}{x} \right)^{\lambda/2}$$

$$x = x_1 e^{-2y_h}$$

- Need forward detector to probe Saturation Region
- Note:  $y_h = 4$  at RHIC  $\hat{=} y_h \approx 8$  at LHC



# Kinematics CMS



Plot by David d'Enterria

## CMS detector:

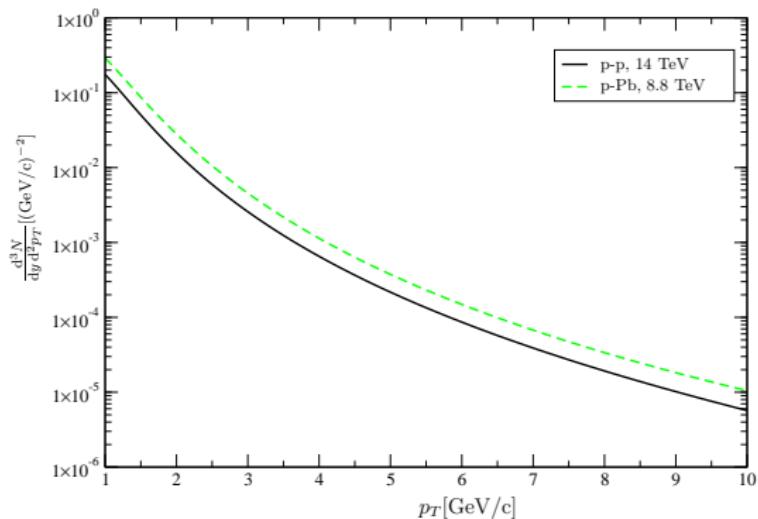
- Charged hadrons for  $p_t < 1000\text{GeV}$
- Tracking for  $|\eta| \leq 2.5$   
⇒ focus on  $\eta \approx y_h = 2$
- Hadrons are assumed to be  $\pi^\pm$

In DHJ model for  $\pi$  production at  $y_h = 2$  and LHC energies:

- $p\text{-}Pb$  probes EGS region for  $1\text{GeV} \lesssim p_t \lesssim 10\text{GeV}$
- $p\text{-}p$  probes EGS region for  $1\text{GeV} \lesssim p_t \lesssim 5\text{GeV}$



# DHJ model prediction invariant yield $\pi^\pm$ production $y_h = 2$



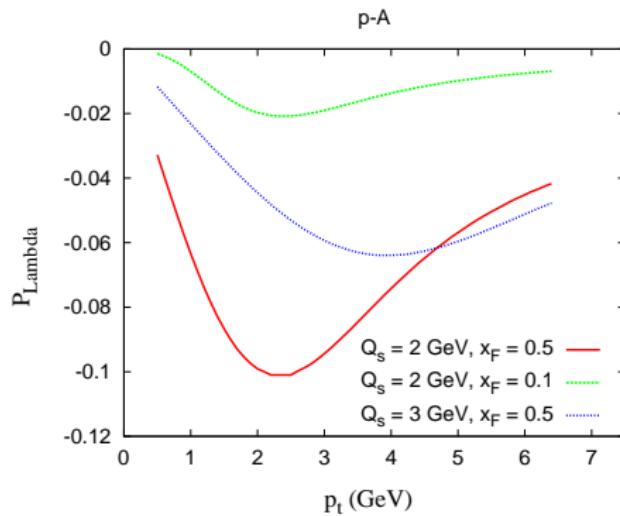
- Probably  $K$ -factors needed to fix normalization
- LHC provides further test of DHJ model in EGS region
- Saturation Region not probed at  $y_h = 2$



# $\Lambda$ polarization in MV model

- $\Lambda$  polarization from scattering of unpolarized hadrons

Boer, Dumitru PLB 556 (2003) 33



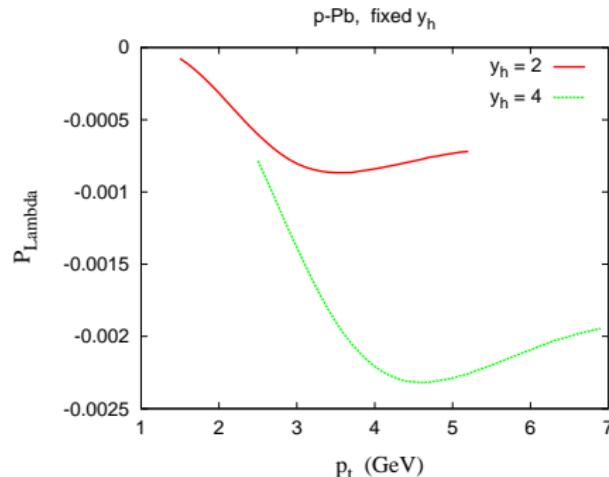
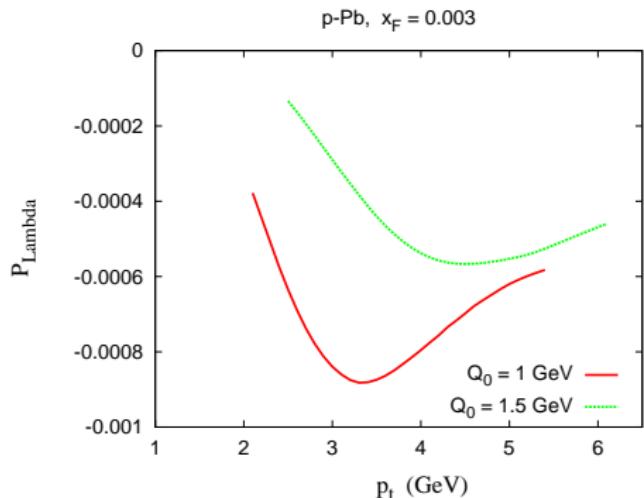
$$P_{\Lambda} = \frac{d\sigma^{\Lambda\uparrow} - d\sigma^{\Lambda\downarrow}}{d\sigma^{\Lambda\uparrow} + d\sigma^{\Lambda\downarrow}}$$

- $P_{\Lambda}$  probes  $dN/dq_t$
- Peaks near  $Q_s$
- $|P_{\Lambda}|$  scales with  $x_F$

Expect  $P_{\Lambda}$  very small for  $p$ - $Pb$  at CMS ( $y_h = 2$ )



# DHJ model prediction for $\Lambda$ polarization

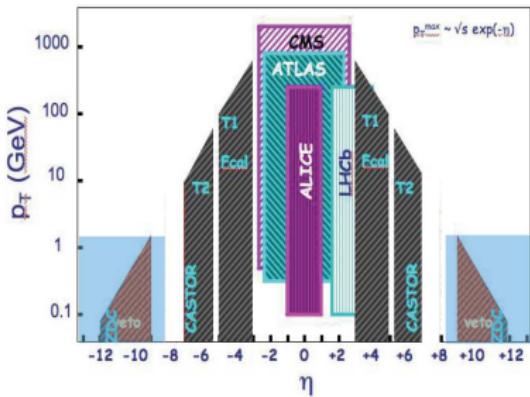


- $P_\Lambda$  probes derivative of  $N$ : peaks at average  $Q_s(x)$
- Same systematics as in MV model: scales with  $Q_0$  and  $y_h$  ( $x_F$ )
- Very small at CMS due to small  $x_F \Rightarrow$  requires forward detector



# Measuring $\Lambda$ polarization at LHC

- $\Lambda \rightarrow p\pi^-$  detection requires PID (protons)
- Detectors with PID not forward enough ( $P_\Lambda \sim 0.1\%$ )



- Alternatively:  $\Lambda \rightarrow n\pi$  ( $\pm 30\%$  branching ratio).
- Measure  $n$ 's and  $\gamma$ 's from  $\pi \rightarrow \gamma \gamma$
- Possibly detectable with forward detector ZDC ( $|\eta| > 8$ )



# Conclusions

## Predictions for $\pi$ production in $p$ - $Pb$ and $p$ - $p$

- Provides useful further data EGS region w.r.t. RHIC
- Opportunity to further test DHJ and similar models

Boer, Utermann, EW hep-ph/0701219, KKT, IIM

## Predictions for $\Lambda$ -polarization in $p$ - $Pb$

- $P_\Lambda \sim 0.1\%$  for CMS due to small  $x_F$  (large  $\sqrt{s}$ )
- Peaks at  $\langle Q_s(x) \rangle$ , peak scales with  $x_F$ : DHJ similar to MV
- Measurement requires a future forward detector

