Saturation effects at forward rapidities at LHC

Amir H. Rezaeian

Universität Regensburg/Universidad Tecnica Federico Santa Maria

The 2009 Europhysics Conference on High Energy Physics
Krakow July 2009
Saturation scale from HERA to LHC/LHeC

Hadrons and direct photon productions from RHIC to LHC in $pp$ and $pA$ collisions: Short-coherence versus Long-coherence

Our main predictions for LHC for $pp$ and $pA$ collisions

References:
B. Z. Kopeliovich, E. Levin, AHR, Ivan Schmidt, PLB 675, 190 (2009)
AHR and Z. Lu, NPA 826, 198 (2009)
AHR and A. Schäfer, To be submitted (Most of LHC predictions in this talk)
Saturation scale $Q_s(x)$ separates linear from non-linear regimes of QCD: For $Q \ll Q_s(x)$ non-linear QCD dynamics (JMWLK/BK Eqs.), for $Q \gg Q_s(x)$ weak coupling regime (DGLAP/BFKL Eqs.)
Saturation scale predicted from HERA

Perturbative QCD:

\[ Q_s^{\text{GBW}}(x) \equiv Q_s(x) = \left( \frac{x_0}{x} \right)^{\lambda/2} \text{GeV. } \lambda = 0.25 - 0.3 \]


\[ Q_s^{\text{AdS}}(x) = \frac{2 \mathcal{A}_0 x}{\mathcal{M}_0^2 (1 - x) \pi} \left( \frac{1}{\rho_m^3} + \frac{2}{\rho_m} - 2 \mathcal{M}_0 \sqrt{\frac{1 - x}{x}} \right). \]
The saturation scale varies in the range of 1-3 GeV becoming independent of energy/Bjorken-\(x\) at very small \(x\). This leads to the prediction of \(x\)-independence of the \(F_2\) structure function at very small \(x\): Does it show up at LHC or LHeC (we need \(x_B < 10^{-8}\)?)
From Available measurements in \((x, Q^2)\) to LHC

**Graphs and Data:**
- **Top Graph:** Illustrates measurements from LHC, RHIC, and SPS, showing the range of \(Q^2\) from 10^{-6} to 10^{0} GeV^2.
- **Middle Graph:** Compares DIS and DY data from various experiments:
  - NMC, SLAC-E139, FNAL-E665, EMC, FNAL-E772.
  - Perturbative vs. non-perturbative regions.
- **Bottom Graph:** Shows data from p-p collisions at 14 TeV, highlighting ATLAS, CMS, ALICE, and other detectors.

**Experiment Data:**
- **H1:** Nuclear DIS & DY data:
  - NMC (DIS)
  - SLAC-E139 (DIS)
  - FNAL-E665 (DIS)
  - EMC (DIS)
  - FNAL-E772 (DY)

**Nuclear DIS & DY data:**
- **ALICE, LHCb, CASTOR, T2:**
  - TOTEM RPs, ALFA RPs, FP420.

**Other Data:**
- **y = 1 (HERA, \(\sqrt{s} = 320\) GeV):**
  - Extracted from HQ LHC, pA.
- **saturation, Pb:**
  - Pb-p @ 200 GeV.
- **saturation, p:**
  - p-p @ 14 TeV.

**References:**
- D. d’Enterria, 0708.0551, hep-ex/0610061
Light-cone color dipole factorization (Long-coherence scheme)

\[
\frac{d\sigma(pp(A) \to hX)}{d^2p_T} = F_{g/p} \otimes \frac{d\hat{\sigma}}{d^2k_T}(gp(A) \to ggX) \otimes D^h_g \\
+ F_{q/p} \otimes \frac{d\hat{\sigma}}{d^2k_T}(qp(A) \to qgX) \otimes D^h_q \\
+ F_{q/p} \otimes \frac{d\hat{\sigma}}{dk_T}(qp(A) \to qgX) \otimes D^h_g
\]

\[
\frac{d\sigma(pp(A) \to \gamma X)}{d^2p_T} = F_2^P \otimes \frac{d\hat{\sigma}}{d^2k_T}(qp(A) \to \gamma X)
\]
Light-cone color dipole factorization (Long-coherence scheme)

\[
\frac{d\sigma(pp(A) \rightarrow hX)}{d^2p_T} = F_{g/p} \otimes \frac{d\hat{\sigma}}{d^2k_T}(gp(A) \rightarrow ggX) \otimes D_g^h \\
+ F_{q/p} \otimes \frac{d\hat{\sigma}}{d^2k_T}(qp(A) \rightarrow qgX) \otimes D_q^h \\
+ F_{q/p} \otimes \frac{d\hat{\sigma}}{dk_T}(qp(A) \rightarrow qX) \otimes D_g^h
\]

\[
\frac{d\sigma(pp(A) \rightarrow \gamma X)}{d^2p_T} = F_2^P \otimes \frac{d\hat{\sigma}}{d^2k_T}(qp(A) \rightarrow \gamma X)
\]

- Direct photons: photons not from hadron decays
  A powerful probe for the initial state of matter created in Heavy-Ion collisions, direct photon $R_{pA}$, $R_{AA}$, $\nu_2$ yet to be understood even at RHIC.

- In our approach, we do not need $k$-factor. All parameters are already fitted to other reactions. We have no free-parameter to adjust at RHIC and LHC.

- Valid at small $x$, high energy.
Photon and hadrons in $pp$ at RHIC

Direct Photon at RHIC in $pp$ collision (Right), hadrons productions at RHIC (Left) in the color dipole approach.

- At RHIC at midrapidity for $p_T \approx 2$ GeV we have $x_2 \sim 0.01$ and color dipole approach is not valid more!
Photon and hadrons productions at LHC for different rapidities in $pp$

- Various saturated models are different by a factor about $2 \div 3$.
- It seems that when the saturation scale is smaller (the CGC model) at higher transverse momentum $p_T = 2$ GeV, the peak will be replaced by a plateau.
The presence of the peak at forward rapidities for hadrons/photon results from an interplay between nonabelian/abelian nature of gluons/photon radiation and saturation effects.
The ratio of direct photon to pion $\gamma/\pi^0$ can be about $10 \div 20$ at very forward rapidities $\eta = 7 \div 8$ at the LHC energy $\sqrt{s} = 14$ TeV in $pp$ collision. Therefore, direct photon production at forward rapidities at LHC should be substantially cleared up from background.
It is well known that the saturation effects start being essential when the anomalous dimension reaches the value $\gamma_{cr} = 1 - \gamma_{eff} = 0.37$.

At LHC at forward rapidities diffusion term is not important and the preferred value of anomalous dimension turn out to be larger than $\gamma_{cr} = 0.37$.

Hadrons and photon productions at LHC are both sensitive to the gluon saturation effects, and strongly depends on the value of the anomalous dimension.
Pion Cronin enhancement at RHIC will be replaced by a moderate suppression at the LHC energy.
Cronin effect in $pA$ collisions at LHC, saturation and shadowing effects

- Pion Cronin enhancement at RHIC will be replaced by a moderate suppression at the LHC energy due to gluon shadowing and saturation effects.
Cronin effect in \( pA \) collisions at LHC, other predictions:

- **Left:** \( R_{pA}(y = 0) \) versus \( p_T \) for pions in dAu collisions at RHIC (upper panel) and in pPb collisions at the LHC, by Kopeliovich et al. Solid and dashed lines correspond to the calculation with and without gluon shadowing respectively.

- **Center:** \( R_{pA} \) for pions versus \( p_T \) in dAu collisions at RHIC and in pPb collisions at the LHC, for different \( \eta \), from Tuchin et al..

- **Right,** AHR et al., similar approach to the left with a list of improvement.
Summary and main predictions for LHC/LHeC:

- AdS/CFT color dipole: Prediction of $x$-independence of the $F_2$ structure function at very small $x$ and small $Q^2$. 
Summary and main predictions for LHC/LHeC:

- AdS/CFT color dipole: Prediction of \( x \)-independence of the \( F_2 \) structure function at very small \( x \) and small \( Q^2 \).

- Direct photon production persists to a higher rapidity compared to hadrons production: the ratio of direct photon to pion \( \gamma/\pi^0 \) can be about \( 10 \div 20 \) at very forward rapidities \( \eta = 7 \div 8 \) at the LHC energy \( \sqrt{s} = 14 \text{ TeV} \) in \( pp \) collision. Therefore, direct photon production at forward rapidities at LHC should be substantially cleared up from background.
Summary and main predictions for LHC/LHeC:

- AdS/CFT color dipole: Prediction of $x$-independence of the $F_2$ structure function at very small $x$ and small $Q^2$.

- Direct photon production persists to a higher rapidity compared to hadrons production: the ratio of direct photon to pion $\gamma/\pi^0$ can be about $10 \div 20$ at very forward rapidities $\eta = 7 \div 8$ at the LHC energy $\sqrt{s} = 14$ TeV in $pp$ collision. Therefore, direct photon production at forward rapidities at LHC should be substantially cleared up from background.

- Hadrons and photon productions are both sensitive to the gluon saturation effects, and strongly depends on the value of the anomalous dimension.
Summary and main predictions for LHC/LHeC:

- AdS/CFT color dipole: Prediction of x-independence of the $F_2$ structure function at very small $x$ and small $Q^2$.

- Direct photon production persists to a higher rapidity compared to hadrons production: the ratio of direct photon to pion $\gamma/\pi^0$ can be about $10 \div 20$ at very forward rapidities $\eta = 7 \div 8$ at the LHC energy $\sqrt{s} = 14$ TeV in $pp$ collision. Therefore, direct photon production at forward rapidities at LHC should be substantially cleared up from background.

- Hadrons and photon productions are both sensitive to the gluon saturation effects, and strongly depends on the value of the anomalous dimension.

- We calculated the rapidity dependence of the invariant cross-section and found some peculiar enhancement at forward rapidity which is more pronounced in the case of photon production. The presence of this peak at forward rapidities for hadrons/photon results from an interplay between nonabelian/abelien nature of gluons/photon radiation and saturation effects.
Summary and main predictions for LHC/LHeC:

- AdS/CFT color dipole: Prediction of x-independence of the $F_2$ structure function at very small $x$ and small $Q^2$.

- Direct photon production persists to a higher rapidity compared to hadrons production: the ratio of direct photon to pion $\gamma/\pi^0$ can be about $10 \div 20$ at very forward rapidities $\eta = 7 \div 8$ at the LHC energy $\sqrt{s} = 14$ TeV in $pp$ collision. Therefore, direct photon production at forward rapidities at LHC should be substantially cleared up from background.

- Hadrons and photon productions are both sensitive to the gluon saturation effects, and strongly depends on the value of the anomalous dimension.

- We calculated the rapidity dependence of the invariant cross-section and found some peculiar enhancement at forward rapidity which is more pronounced in the case of photon production. The presence of this peak at forward rapidities for hadrons/photon results from an interplay between nonabelian/abelian nature of gluons/photon radiation and saturation effects.

- Pion Cronin enhancement at RHIC will be replaced by a moderate suppression at the LHC energy due to gluon shadowing and saturation effects.