Saturation effects at forward rapidities at LHC

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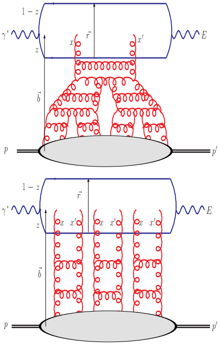
Outline

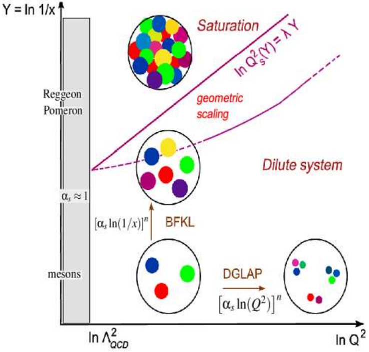
- Saturation scale from HERA to LHC/LHeC
- Hadrons and direct photon productions from RHIC to LHC in *pp* and *pA* collisions: Short-coherence versus Long-coherence
- Our main predictions for LHC for *pp* and *pA* collisions

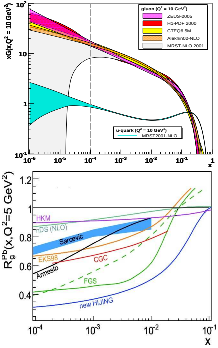
References:

Y. V. Kovchegov, Z. Lu, AHR, arXiv:0906.4197
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)

QCD x-Q^2 phase diagram







- Saturation scale $Q_s(x)$ separates linear from non-linear regimes of QCD: For $Q << Q_s(x)$ non-linear QCD dynamics (JMWLK/BK Eqs.), for $Q >> Q_s(x)$ weak coupling regime (DGLAP/BFKL Eqs.)

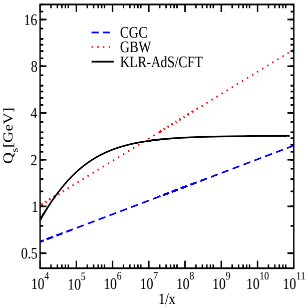
Saturation scale predicted from HERA

Perturbative QCD :

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

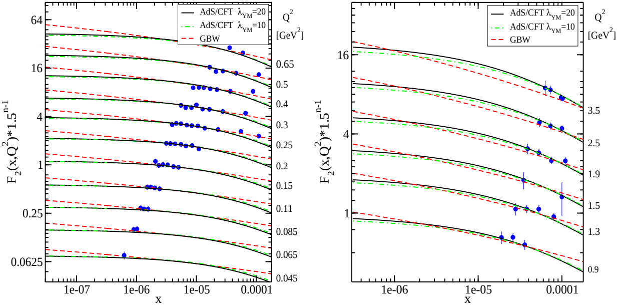
Non-perturbative QCD (AdS/CFT approach: Y. V. Kovchegov, Z. Lu, AHR, arXiv:0906.4197):

$$Q_s^{\rm AdS}(x) = \frac{2\,\mathcal{A}_0\,x}{\mathcal{M}_0^2\,(1-x)\,\pi}\left(\frac{1}{\rho_m^3} + \frac{2}{\rho_m} - 2\mathcal{M}_0\sqrt{\frac{1-x}{x}}\right).$$



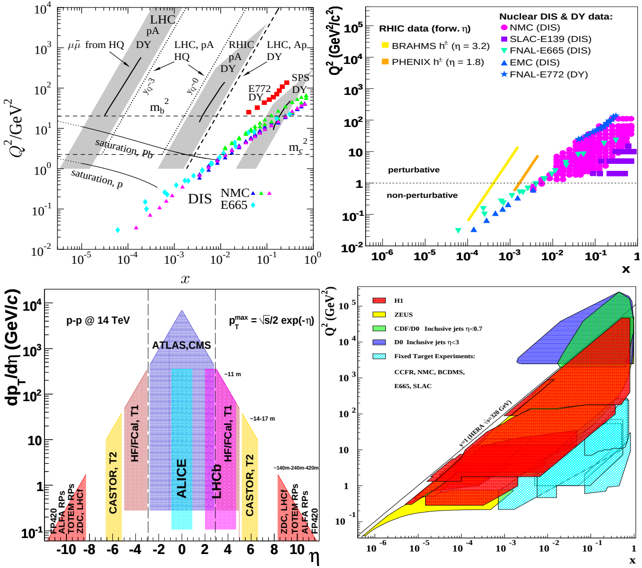
AdS/CFT color dipole at HERA and saturation of saturation:

Y. V. Kovchegov, Z. Lu, AHR, arXiv:0906.4197



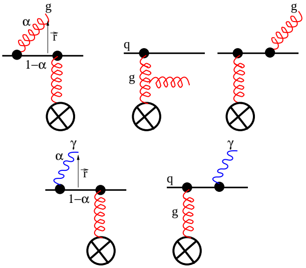
- The saturation scale varies in the range of 1-3 GeV becoming independent of energy/Bjorken-x at very small x. This leads to the prediction of x-independence of the F_2 structure function at very small x.: Does it show up at LHC or LHeC (we need $x_B < 10^{-8}$)?

From Available measurements in (x, Q^2) to LHC



D. d'Enterria, 0708.0551, hep−ex/0610061

Light-cone color dipole factorization (Long-coherence scheme)



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

$$\frac{d\sigma(pp(A)\to \gamma X)}{d^2p_T} = F_2^p\otimes\frac{d\hat{\sigma}}{d^2k_T}(qp(A)\to \gamma X)$$

Direct photon and hadrons productions at RHIC and LHC, Color dipole approach

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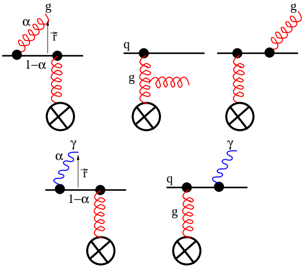

$$\frac{d\sigma(pp(A)\rightarrow hX)}{d^2p_T} = F_{g/p}\otimes\frac{d\hat{\sigma}}{d^2k_T}(gp(A)\rightarrow ggX)\otimes D_g^h + F_{q/p}\otimes\frac{d\hat{\sigma}}{d^2k_T}(qp(A)\rightarrow qgX)\otimes D_q^h + F_{q/p}\otimes\frac{d\hat{\sigma}}{dk_T}(qp(A)\rightarrow qgX)\otimes D_g^h$$

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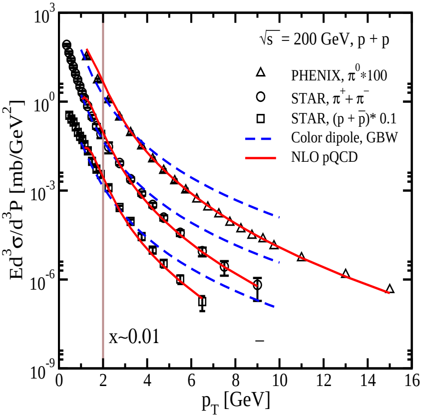
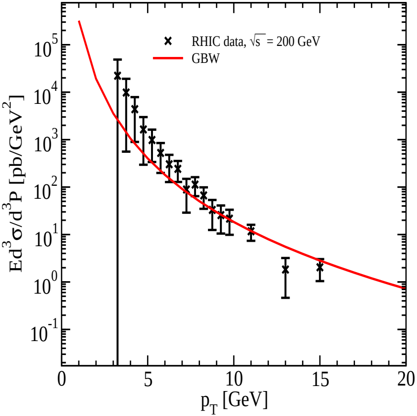
- Direct photons: photons not from hadron decays
  A powerful probe for the initial state of matter created in Heavy-Ion collisions, direct photon R_{pA}, R_{AA}, v_2 yet to be understood even at RHIC.
- In our approach, we do not need k-factor. All parameters are already fitted to other reactions. We have no free-parameter to adjust at RHIC and LHC.
- Valid at small x, high energy.

Photon and hadrons in *pp* at RHIC

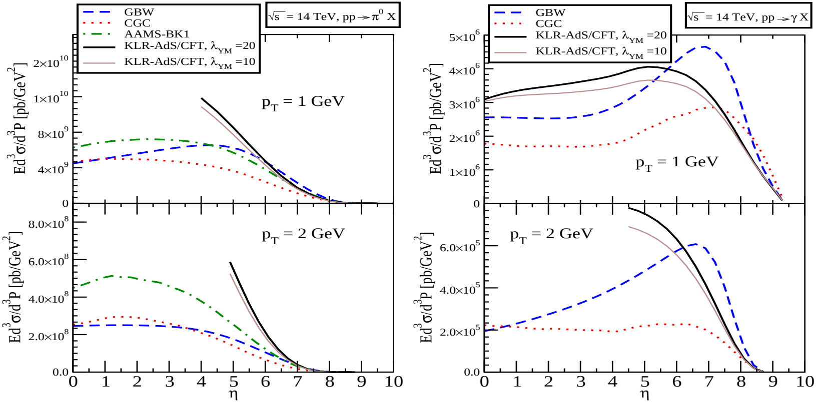




Direct Photon at RHIC in *pp* collision (Right), hadrons productions at RHIC (Left) in the color dipole approach.

- At RHIC at midrapidity for $p_T \approx 2$ GeV we have $x_2 \sim 0.01$ and color dipole approach is not vaild more!.

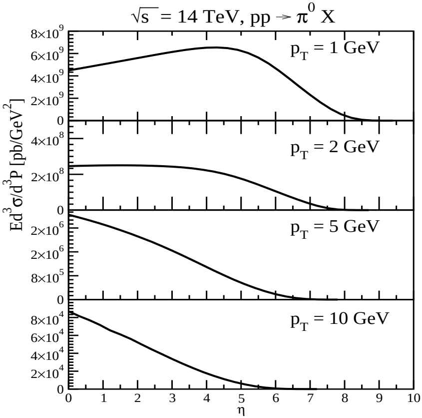
Photon and hadrons productions at LHC for different rapidities in *pp*

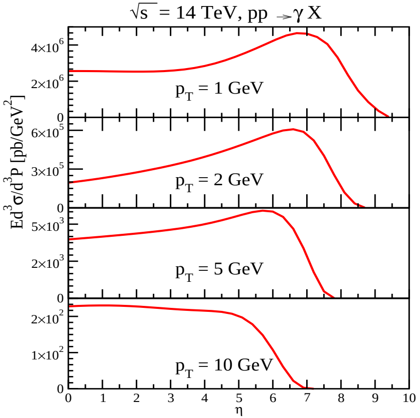


Invariant cross-section for pion (left) and direct photon (right) productions in *pp* collisions at LHC as a function of rapidity η calculated with various color dipole models for various fixed p_T.

- 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.

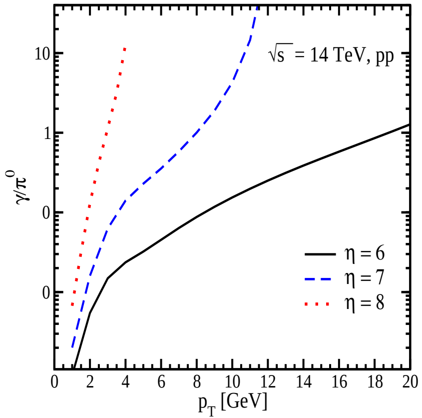
Hadrons and photon at LHC for different rapidities in *pp*

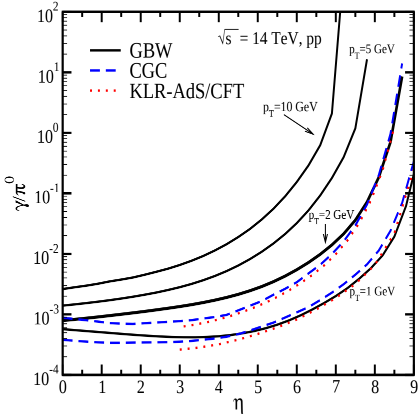




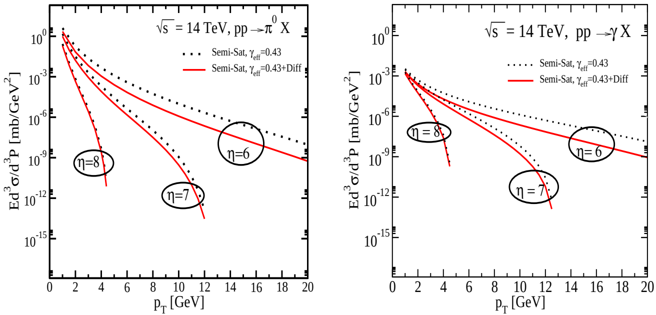
- The presence of the peak at forward rapidities for hadrons/photon results from an interplay between nonabelian/abelien nature of gluons/photon radiation and saturation effects.

Photon/pion ratio at LHC for different rapidities in *pp*



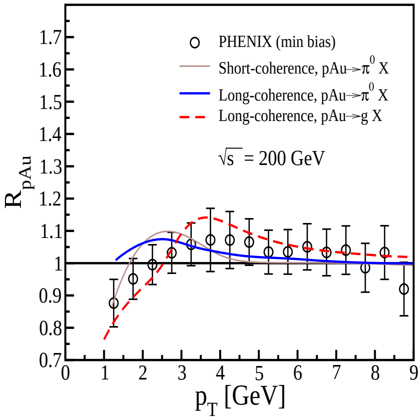


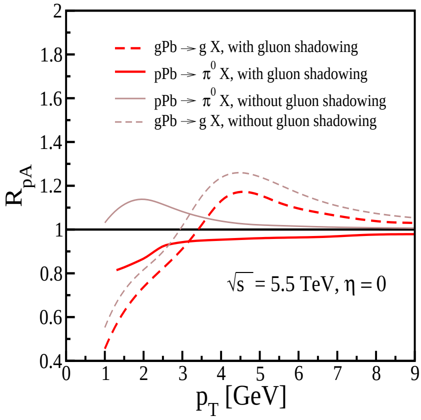
- The ratio of direct photon to pion γ/π^0 can be about $10 \div 20$ at very forward rapidities $\eta = 7 \div 8$ at the LHC energy $\sqrt{s} = 14$ TeV in *pp* collision. Therefore, direct photon production at forward rapidities at LHC should be substantially cleared up from background.



- 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.

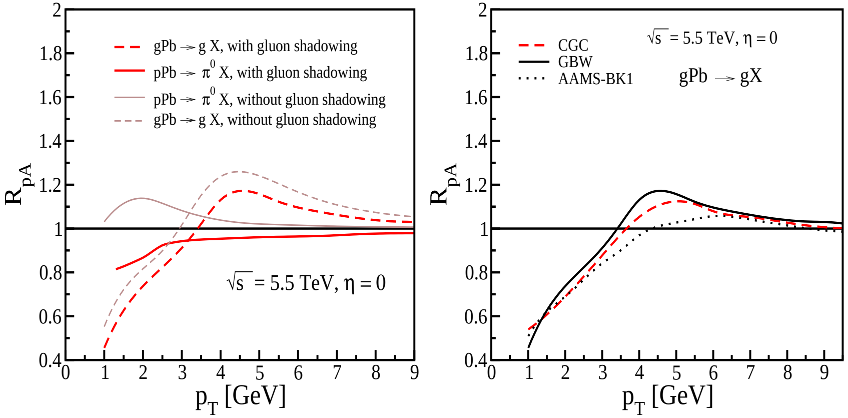
Cronin effect in pA collisions from RHIC to LHC





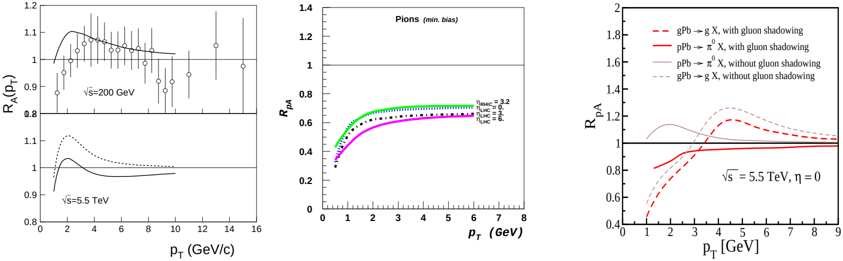
- Pion Cronin enhancement at RHIC will be replaced by a moderate suppression at the LHC energy.

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 η, 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:

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- 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.

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