Some CGC predictions for p+A run at the LHC and their implications for EIC

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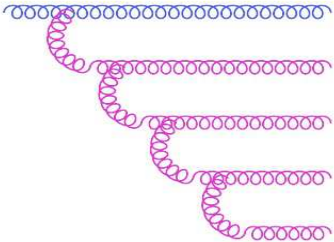
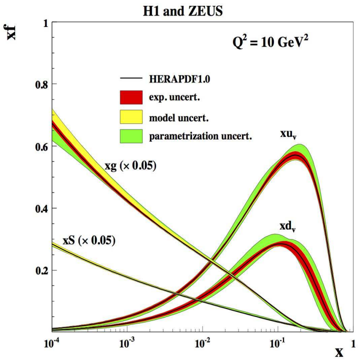
Physics Opportunities at an Electron-Ion Collider (POETIC 2013)





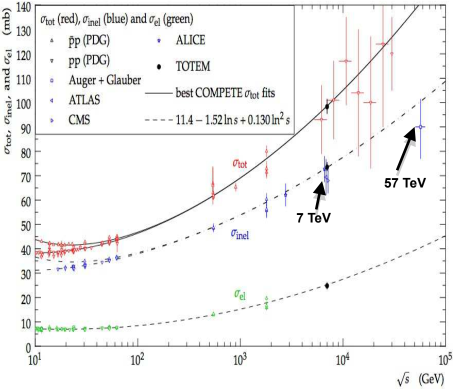
$$\frac{\partial \phi(\mathbf{x}, \mathbf{k}_\perp)}{\partial \ln(\mathbf{x_0}/\mathbf{x})} \approx \mathcal{K} \otimes \phi(\mathbf{x}, \mathbf{k}_\perp) \longrightarrow \phi_{\mathbf{BFKL}} \sim \mathbf{x}^{-\alpha_s \omega}$$

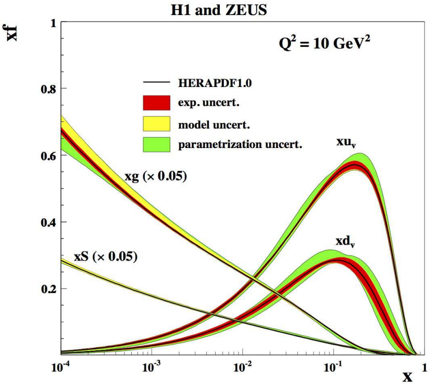
"BFKL eqn"

Balitsky- Fadin-Kuraev-Lipatov

- Both DGLAP and BFKL are linear evolution equations: exponential growth of the gluon distributions at small-x
- **Linear $\Longrightarrow$ unstable growth of the gluon distribution!**

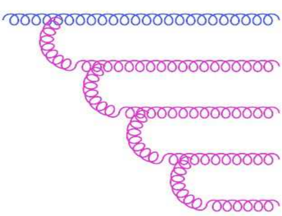
Growth of the gluon distribution at small-x, **where do gluons go?**





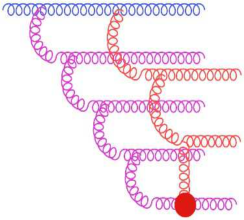
- Unitarity or Froissart bound: $\sigma_{tot} < c \ln^2(s)$: Gluon saturation at small-x

BFKL versus BK-JIMWLK evolution equation



$$\frac{\partial \phi(\mathbf{x}, \mathbf{k}_\perp)}{\partial \ln(\mathbf{x_0}/\mathbf{x})} \approx \mathcal{K} \otimes \phi(\mathbf{x}, \mathbf{k}_\perp)$$

"BFKL eqn"



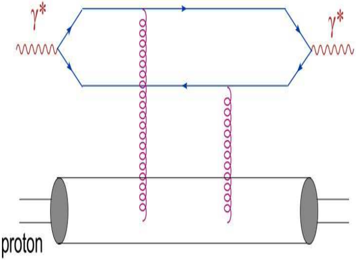
$$\frac{\partial \phi(\mathbf{x}, \mathbf{k}_\perp)}{\partial \ln(\mathbf{x_0}/\mathbf{x})} \approx \mathcal{K} \otimes \phi(\mathbf{x}, \mathbf{k}_\perp) - \phi(\mathbf{x}, \mathbf{k}_\perp)^2$$

radiation recombination

"BK-JIMWLK eqns"

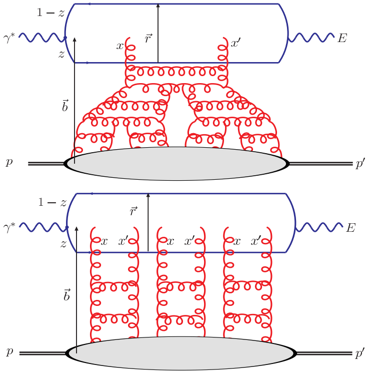
Balitsky, Kovchegov, Jalilian-Marian, Iancu, McLerran, Weigert, Leonidov, and Kovner (1997-2000)

- High energy/density: recombination processes $\Longrightarrow$ saturation:
  The number of partons created at a given step depends non-linearly on the number of partons present previously.
- **Nonlinear $\Longrightarrow$ stable fixed point at high energy!**



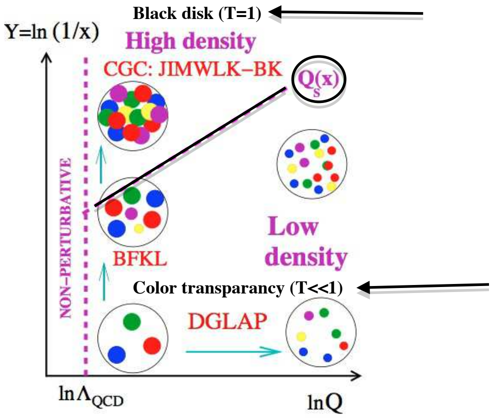
$$T(x,r,b) \simeq \alpha_s r^2 \frac{xG(x,1/r^2)}{\pi R^2} \equiv \alpha_s n(x, Q^2 \sim 1/r^2)$$

Unitarization



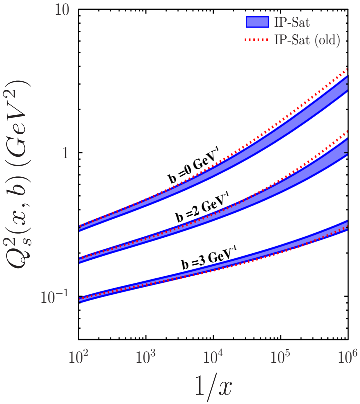
Strong scattering $T \sim 1 \Longleftrightarrow$ High gluon density $n \sim 1/\alpha_s \Longrightarrow$ gluon saturation

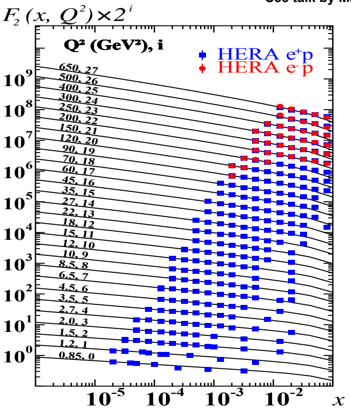
To preserve unitarity $\Longleftrightarrow$ Multiple scattering is important: $(\alpha_s n)^n \sim 1$



- Dilute regime: Bjorken limit in QCD $s \to \infty; Q^2 \to \infty; x \approx \frac{Q^2}{s} = \text{fixed}$
  Asymptotic freedom, Machinery of precision pQCD...
- Dense regime: Regge limit in QCD $s \to \infty; x \to 0; Q^2 = \text{fixed}$
  Physics of strong fields in QCD, Saturation/CGC...

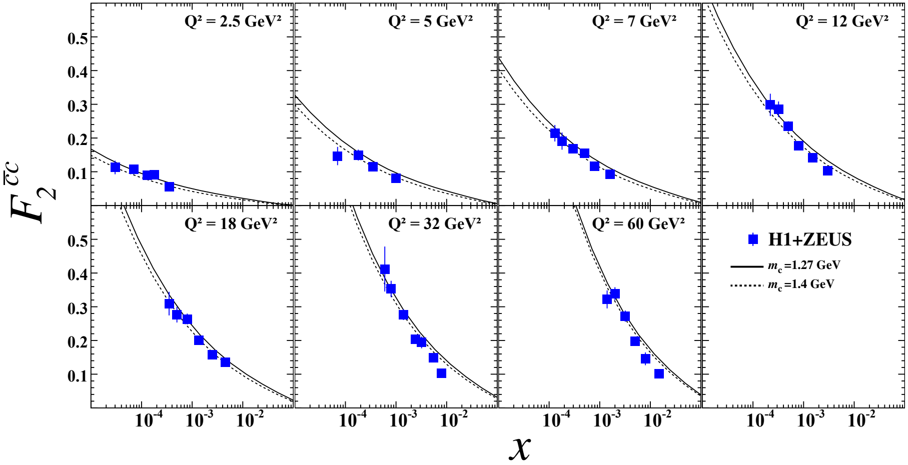
See talk by Marat Siddikov





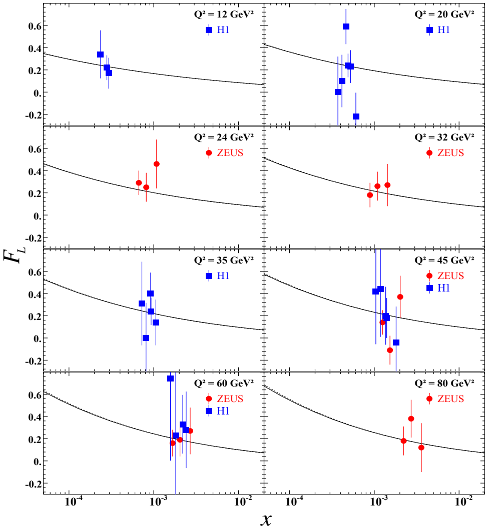
Rezaeian, Siddikov, Van de Klundert, Venugopalan, arXiv:1212.2974

- Saturation scale extracted from old and new combined data have similar trend although parameters of the model change significantly: Old IP-Sat & combined data: $\chi^2/d.o.f \approx 3$, Revised IP-Sat: $\chi^2/d.o.f \approx 1$.

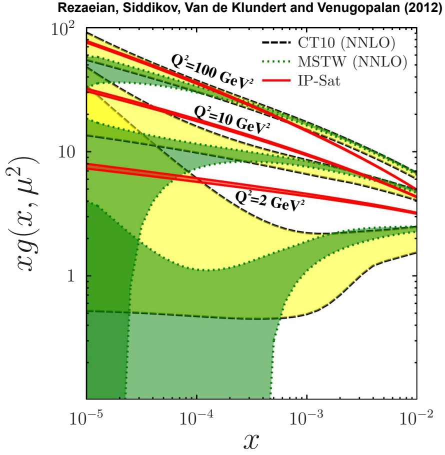


- $F_2^{c\bar{c}}$ data (combined from HERA) not included in the fit!.

CGC description of recent combined HERA data: F_L structure function

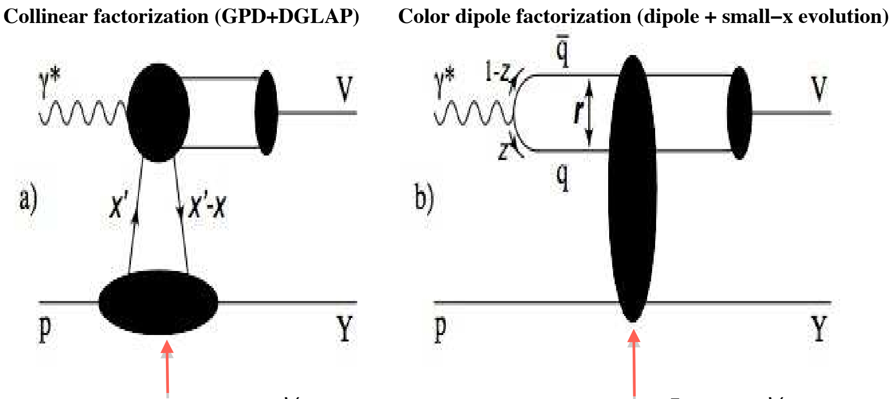


- F_L data not included in the fit (Combined data are not yet available).



- Color dipole (or CGC) approach (small-x resummation): ground state constructed from classical color field background→ stable results at small-x.
- Collinear factorization: ground state constructed from free-field-vacuum.

Diffractive vector meson production and DVCS : $\gamma^* + p \to V + p$ with $V = J/\Psi, \rho, \phi, \gamma$

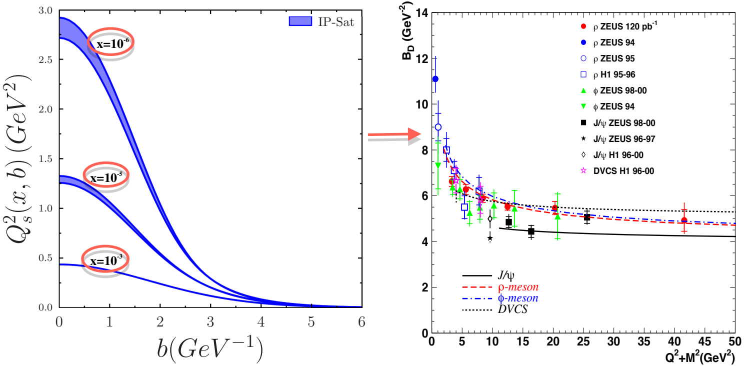


$GPD_{i/p} \otimes H_{ij} \otimes \Psi_j^V$

$\psi_{q\bar{q}}^{\gamma} \otimes \mathcal{N}^{q\bar{q}-p} \otimes \phi_{q\bar{q}}^{V}$

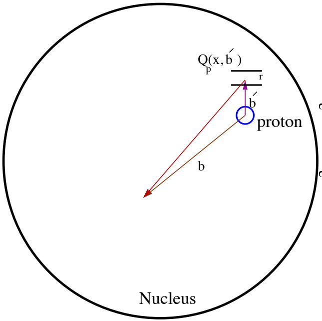
Slope of t-distribution of exclusive processes, a unified picture

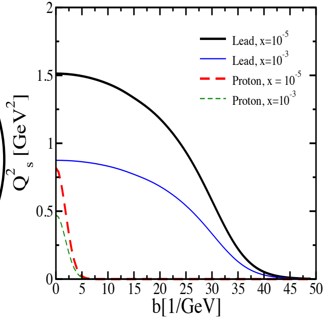
Rezaeian, Siddikov, Van de Klundert, Venugopalan, arXiv:1212.2974



$$\frac{d\sigma^{\gamma^* p\to Ep}_{T,L}}{dt} \approx e^{-B_G|t|} \text{ (large } Q^2 \text{ or small } r) \Longrightarrow Q_s^2(x,b) \approx Q_s^2(x)e^{-b^2/2B_G}$$

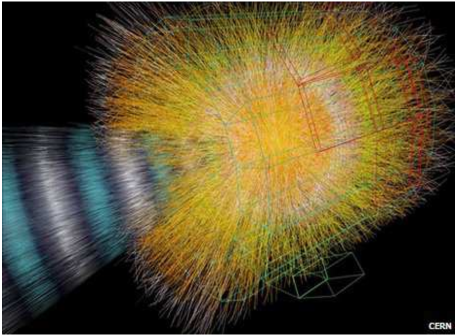
- At a fixed Q^2, the typical dipole size is bigger for lighter vector meson $\Longrightarrow$ validity of the above asymptotic expression is postponed to a higher Q^2.
- Universality of extracted impact-parameter distribution of the proton.



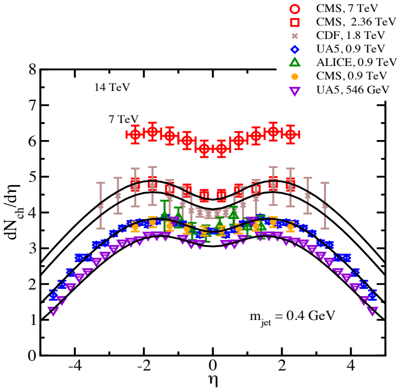


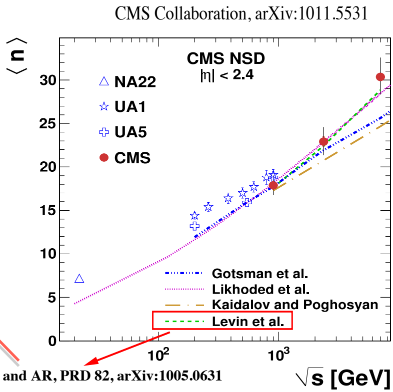
- $Q^2_{sA}(x;b) \;=\; K\int d^2\vec{b}'\;T_A\left(\vec{b}-\vec{b}'\right)\;Q^2_{sp}(x;b')$.
- $Q^2_{sA} \approx Q^2_{sp}A^{1/3}$ since typical $b' << b \sim R_A$.
- $Q^2_{sA} \to KQ^2_{sA}$, $K \approx 2$ will change hadron multiplicity at LHC less than 5%.

To extract $Q_{sA}(x;b)$ from data: t-distributions of diffractive processes with nuclear target are needed (**EIC**).



- 99% of the produced particles have $p_T < 2$ GeV
- x: fraction of target momentum carried by parton
- $x \approx p_T/\sqrt{s} \approx 10^{-2}$ at RHIC ($\sqrt{s} = 200$ GeV)
- $x \approx p_T/\sqrt{s} \approx 10^{-4}$ at the LHC ($\sqrt{s} = 2.76 \div 7$ TeV)

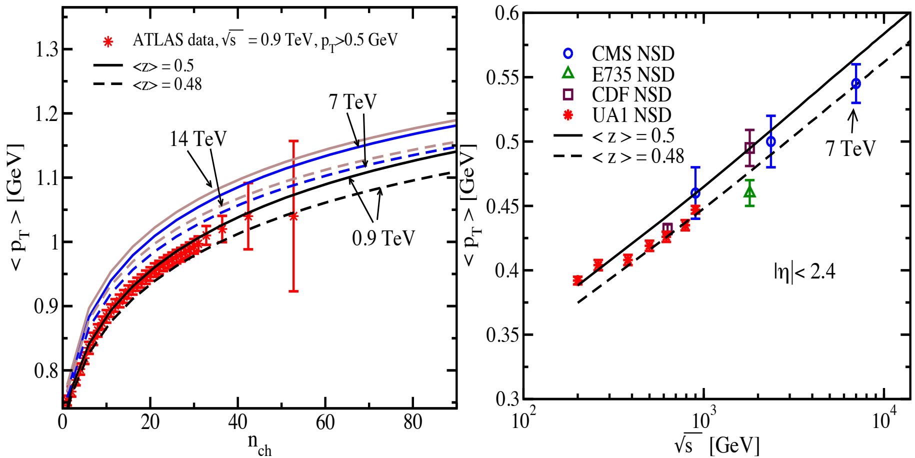




Levin and AR, PRD 82, arXiv:1005.0631

- Correct energy/rapidity and centrality dependence of charged-hadron multiplicity (Levin and Rezaeian, 2010).

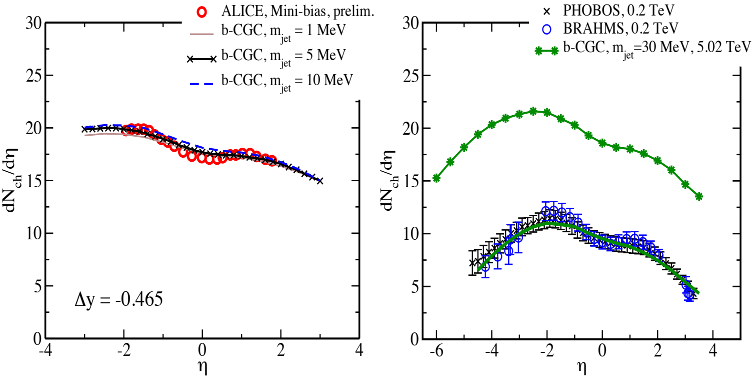
- Are there any other signature of saturation in pp@LHC(7 TeV)? The Ridge: See Raju Venugopalan's talk



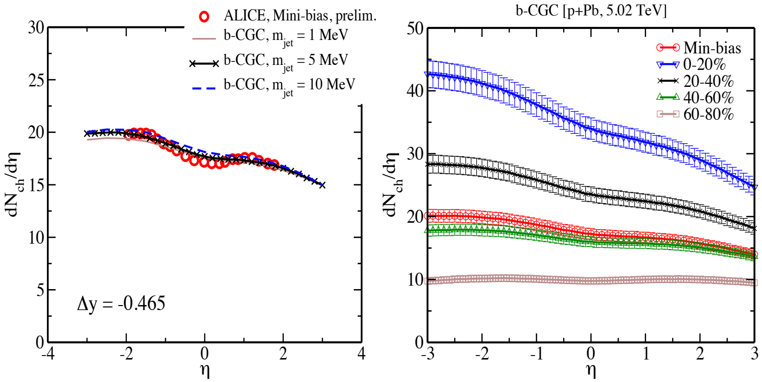
- $\langle p_T \rangle \sim \langle z Q_s \rangle$ ✓
- $\langle p_T \rangle \sim \langle z Q_s\,(n_{ch}; x) \rangle$ ✓

In the CGC framework, dynamical saturation scale plays role of infrared cutoff!.

Rezaeian, PLB718 (2013) 1058; PRD85 (2012) 014028

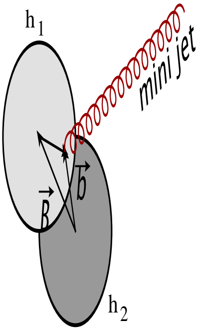


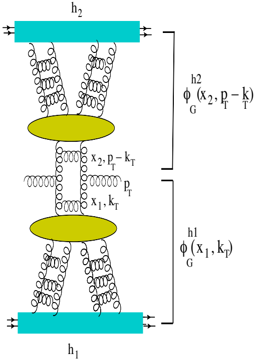
- Two free parameters mini-jet mass m_{jet} and overall normalization (are related to hadronization) cannot be uniquely fixed by only RHIC data $\Longrightarrow 5 \div 15\%$ uncertaintes.
- $m_{jet} = m_{\text{current quark}}$ gives a good description of both RHIC and ALICE data.

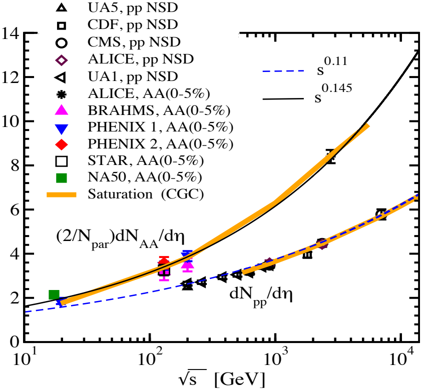


- Centrality dependence of multiplicity in p+A@LHC: a very non-trivial test of saturation physics.

Levin and Rezaeian, **D82** (2010) 014022, **D83** (2011) 114001





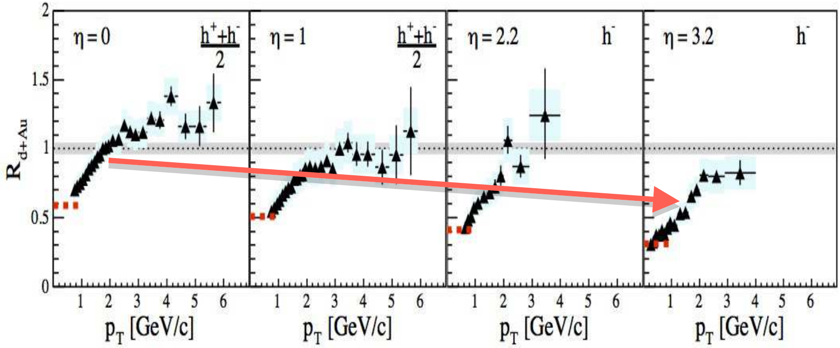


$$\frac{dN_h}{d\eta} \propto Q_s^2 \propto s^{\lambda/2} = s^{0.11 \div 0.145}$$

Signatures of the CGC in d+A@RHIC: Initial-state effect

$$R_{pA}(\eta, p_\perp) \equiv \frac{1}{N_{coll}} \frac{\left.\frac{dN_h}{d^2p_\perp d\eta}\right|_{pA}}{\left.\frac{dN_h}{d^2p_\perp d\eta}\right|_{pp}} \simeq \frac{1}{A^{1/3}} \frac{\Phi_A(Y, p_\perp)}{\Phi_p(Y, p_\perp)}.$$

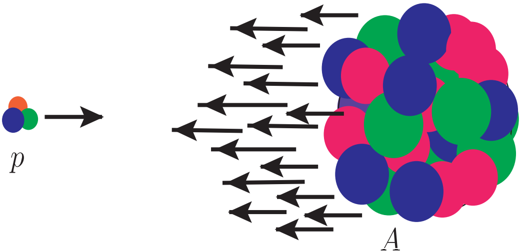
- Suppression of single inclusive hadron production at forward rapidities



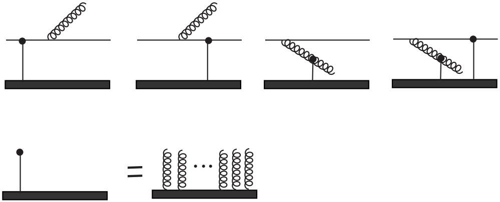
p+A@LHC Sep 2012 & Feb 2013

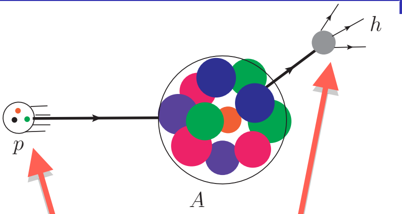
$$y^{RHIC}_{forward} \Leftrightarrow y^{LHC}_{mid-rapidity}$$

Suppression or not?



- Test of saturation/CGC dynamics, based-line for future experiments:EIC, LHeC
- Based-line for A+A collisions at the LHC.





Altinoluk and Kovner, PRD83, arXiv:1102.5327
Chirilli, Xiao and Yuan, PRL108,arXiv:1112.1061

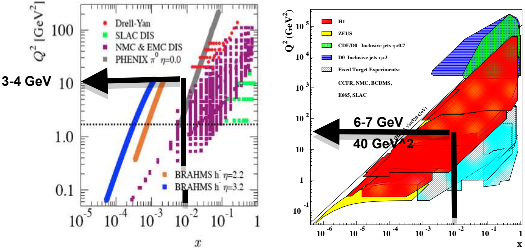
$$\frac{dN^{pA\to hX}}{d^2p_T\,d\eta} = \frac{K}{(2\pi)^2}\left[\int_{x_F}^{1}\frac{dz}{z^2}\left[x_1 f_g(x_1,Q^2)\,N_A(x_2,\frac{p_T}{z})\,D_{h/g}(z,Q) + \Sigma_q x_1 f_q(x_1,Q^2)\,N_F(x_2,\frac{p_T}{z})\,D_{h/q}(z,Q)\right]\right.$$

$$\left. + \int_{x_F}^{1}\frac{dz}{z^2}\frac{\alpha_s}{2\pi^2}\frac{z^4}{p_T^4}\int_{k_T^2<Q^2} d^2k_T\,k_T^2\,N_F(k_T,x_2)\int_{x_1}^{1}\frac{d\xi}{\xi}\Sigma_{i,j=q,\bar{q},g}\,w_{i/j}(\xi)P_{i/j}(\xi)x_1 f_j(\frac{x_1}{\xi},Q)D_{h/i}(z,Q)\right]$$

$$\frac{\partial\mathcal{N}_{A(F)}(r,x)}{\partial\ln(x_0/x)} = \int d^2\vec{r}_1\; K^{\mathrm{run}}(\vec{r},\vec{r}_1,\vec{r}_2)\left[\mathcal{N}_{A(F)}(r_1,x)+\mathcal{N}_{A(F)}(r_2,x)-\mathcal{N}_{A(F)}(r,x)-\mathcal{N}_{A(F)}(r_1,x)\,\mathcal{N}_{A(F)}(r_2,x)\right]$$

Initial condition: $\longrightarrow$ $\mathcal{N}(r,Y\!=\!0) = 1-\exp\left[-\frac{\left(r^2\,Q_{0s}^2\right)^{\gamma}}{4}\,\ln\left(\frac{1}{\Lambda\,r}+e\right)\right]$

Albacete et al (2011-2012)

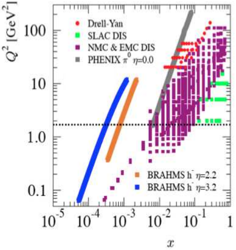


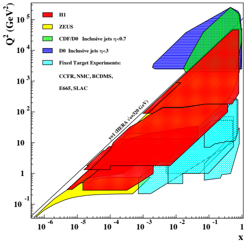
- Available data (HERA+RHIC+LHC) cannot **uniquely** determine the initial condition (initial saturation scale) of the BK equation.

  For proton: $p_t \leq 6$ GeV, $x \leq 0.01$: $Q_{0p}^2 \approx 0.168\,\text{GeV}^2$ with $\gamma \approx 1.119$

- For heavy nuclei: $Q_{0A}^2 = \mathbf{c} A^{1/3}\ Q_{0p}^2$,

  $p_t \leq 4$ GeV, $x \leq 0.01$: $\mathbf{c} \approx 0.5 \Longrightarrow Q_{0A}^2 \approx (3 \div 4) Q_{0p}^2$





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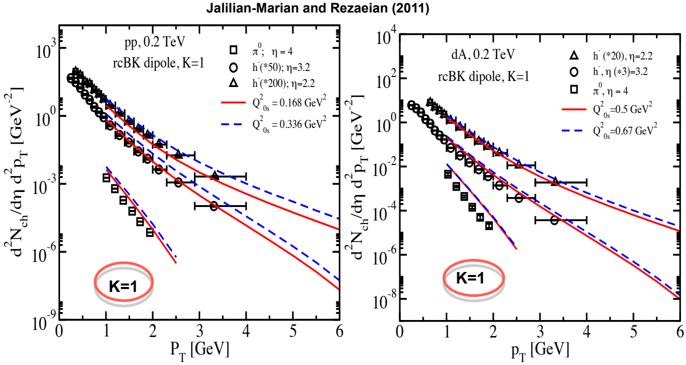
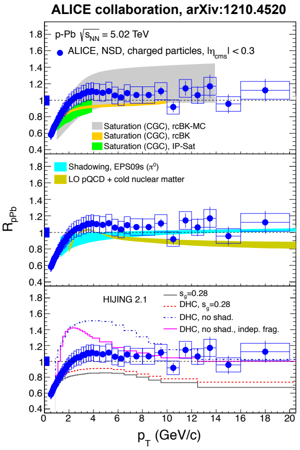
$$R_{pA}^{ch}(p_T >> 1) = \frac{Q_{0A}^2 S_A}{Q_{0p}^2 A S_p} \approx \frac{Q_{0A}^2}{Q_{0p}^2 A^{1/3}} \to 1 \Longrightarrow Q_{0A}^2 = \mathbf{c}A^{1/3}\ Q_{0p}^2 \text{ with } \mathbf{c} \approx 1$$

$3 \div 4\ Q_{0p}^2 \leq Q_{0A}^2(x_0 = 0.01) \leq 6 \div 7\ Q_{0p}^2$ $\quad Q_{0A}^2 = NQ_{0p}^2$ with $N = 3 \div 7$.



- What is the role of cold matter energy loss which is not included in the above? Kopeliovich, Frankfurt, Strikman; Neufeld, Vitev, Zhang.

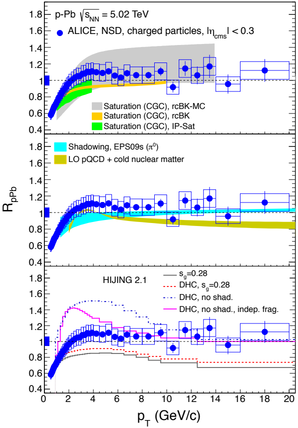
CGC predictions for R^h_{pA} in p+Pb@LHC and ALICE data



CGC predictions are from:

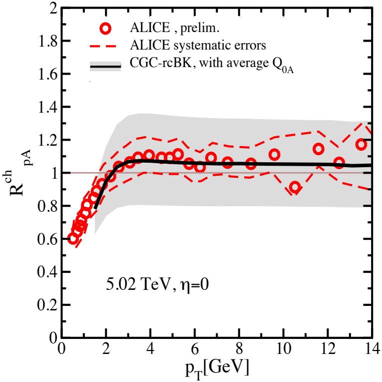
Tribedy and Venugopalan, PLB710, arXiv:1112.2445.
Albacete, Dumitru, Fujii and Nara, NPA897, arXiv:1209.2001.
Rezaeian, PLB718, arXiv:1210.2385.

CGC predictions for R^h_{pA} in p+Pb@LHC and ALICE data



- Data seem to rule out any (or strong) Cronin-type peak!.
- Npdf may be questionable if R^h_{pA} remains above one at high-p_T!.

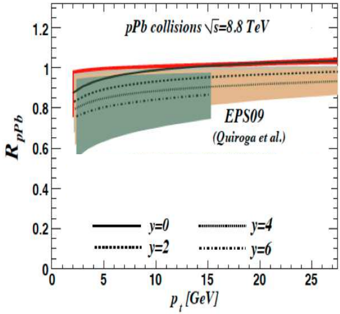
Rezaeian, PLB718, arXiv:1210.2385



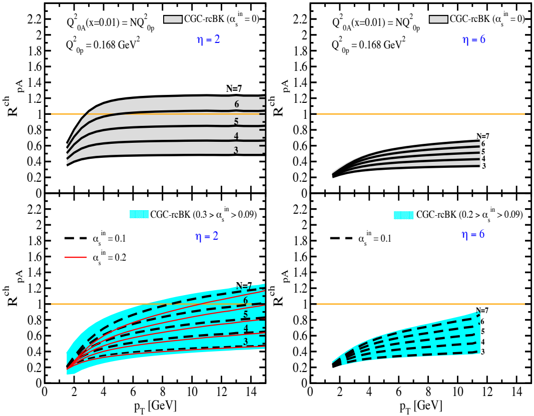
- The black curve corresponds to $Q^2_{0A} = NQ^2_{0p}$ with the average $N = 5$.

Collinear (parton model) v. k_t-factorization (CGC) at the LHC

Quiroga-Arias, Milhano, Wiedemann (2010)

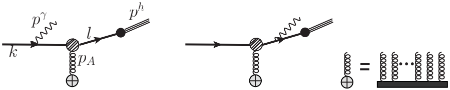


Rezaeian (2012)



- **The CGC predicts more suppression for R^h_{pA} at forward rapidities and low-p_T compared to the standard parton model approach.**

Photon-hadron production in high-energy pA collisions: $p + A \to \gamma + h + X$



Kopeliovich, Tarasov, Schafer (1999)
Gelis and Jalilian-Marian (2002)
Baier, Mueller and Schiff (2004)
Jalilian-Marian and Rezaeian (2012)

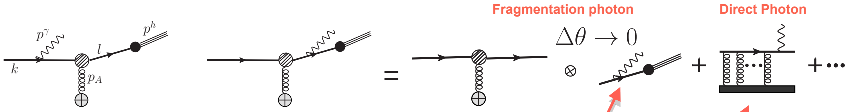
$$\frac{d\sigma^{q\,A\to q(l)\,\gamma(p^\gamma)\,X}}{d^2\vec{b_T}\;d^2\vec{p_T}^{\gamma}\;d^2\vec{l_T}\;d\eta_\gamma\;d\eta_h} = \frac{Ke_q^2\,\alpha_{em}}{\sqrt{2}(4\pi^4)}\;\frac{p^-}{(p_T^\gamma)^2\sqrt{S}}\;\frac{1+(\frac{l^-}{k^-})^2}{[p^-\;\vec{l_T} - l^-\;\vec{p_T}^{\gamma}]^2}$$

$$\delta[x_q - \frac{l_T}{\sqrt{S}}e^{\eta_h} - \frac{p_T^\gamma}{\sqrt{S}}e^{\eta_\gamma}]\left[2l^-\,p^-\;\vec{l_T}\cdot\vec{p_T}^{\gamma} + p^-\,(k^- - p^-)\,l_T^2 + l^-\,(k^- - l^-)\,(p_T^\gamma)^2\right]N_F(|\vec{l_T}+\vec{p_T}^{\gamma}|, x_g)$$

$$x_q = x_{\bar q} = \frac{1}{\sqrt{S}}\left(p_T^\gamma\,e^{\eta_\gamma} + \frac{p_T^h}{z_f}\,e^{\eta_h}\right),\quad x_g = \frac{1}{\sqrt{S}}\left(p_T^\gamma\,e^{-\eta_\gamma} + \frac{p_T^h}{z_f}\,e^{-\eta_h}\right),$$

$$z_f = p_T^h/l_T, \qquad \text{with} \qquad z_f^{min} = \frac{p_T^h}{\sqrt{S}}\left(\frac{e^{\eta_h}}{1-\frac{p_T^\gamma}{\sqrt{S}}\,e^{\eta_\gamma}}\right).$$

$$\frac{d\sigma^{p\,A\to h(p^h)\,\gamma(p^\gamma)\,X}}{d^2\vec{b_T}\;d^2\vec{p_T}^{\gamma}\;d^2\vec{p_T}^{h}\;d\eta_\gamma\;d\eta_h} = \int_{z_f^{min}}^1 \frac{dz_f}{z_f^2}\int dx_q\;f_q(x_q, Q^2)\,\frac{d\sigma^{q\,A\to q(l)\,\gamma(p^\gamma)\,X}}{d^2\vec{b_T}\;d^2\vec{p_T}^{\gamma}\;d^2\vec{l_T}\;d\eta_\gamma\;d\eta_h}D_{h/q}(z_f, Q^2)$$



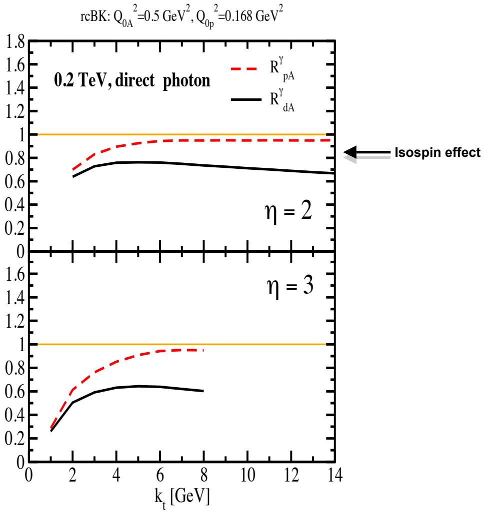
$$\frac{d\sigma^{pA\to\gamma(p^{\gamma})X}}{d^2\vec{b_T}\, d^2\vec{p_T}^{\gamma}\, d\eta_{\gamma}} = \frac{K}{(2\pi)^2}\Big[\int_{x_q^{min}}^{1} dx_q\, f_q(x_q, Q^2)\frac{1}{z}\, N_F(x_g, p_T^{\gamma}/z) D_{\gamma/q}(z, Q^2)$$

$$+ \frac{e_q^2 \alpha_{em}}{2\pi^2 (p_T^{\gamma})^4}\int_{x_q^{min}}^{1} dx_q\, f_q(x_q, Q^2) z^2 [1+(1-z)^2] \int_{l_T^2<Q^2} d^2\vec{l_T}\, l_T^2\, N_F(\bar{x}_g, l_T)\Big],$$

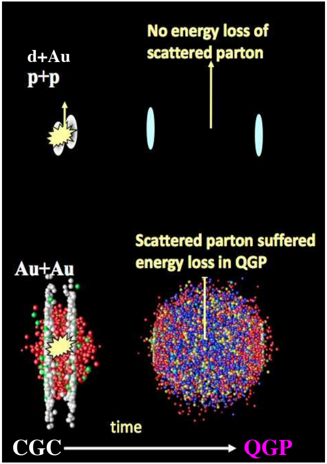
$$x_g = x_q\, e^{-2\,\eta_{\gamma}}, \quad \bar{x}_g = \frac{1}{x_q\, S}\left[\frac{(p_T^{\gamma})^2}{z} + \frac{(l_T - p_T^{\gamma})^2}{1-z}\right] \quad z = \frac{p_T^{\gamma}}{x_q\sqrt{S}} e^{\eta_{\gamma}}, \quad \text{with} \quad x_q^{min} = \frac{p_T^{\gamma}}{\sqrt{S}} e^{\eta_{\gamma}}.$$

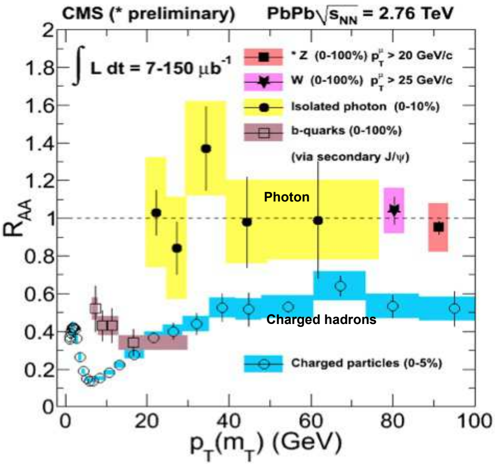
- Both fragmentation and direct photon are sensitive to saturation via N_F. However, direct photon is more sensitive to the saturation effects.
- pA is different from dA (unlike hadron production) due to charge squared of quarks $\to$ non-trivial isospin effect.

pA vs. dA at RHIC



- Sizable isospin effect → suppression at high transverse momentum (NOT due to saturation effect).

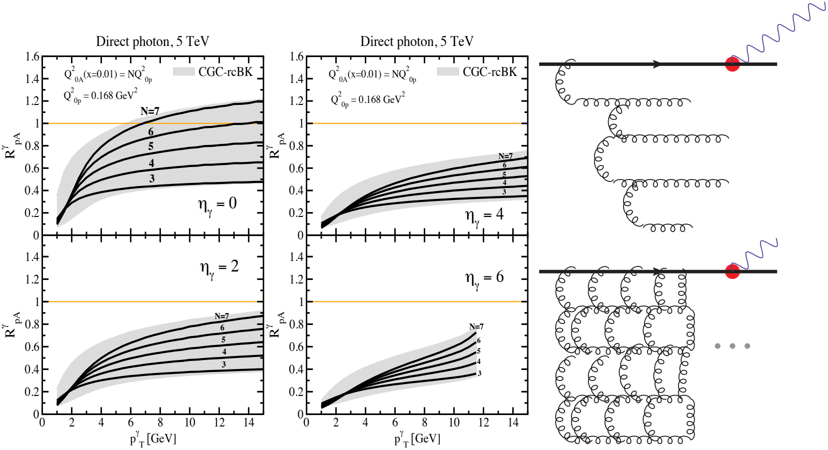




- **Fundamental properties of QGP: All hadrons are strongly quenched except prompt photon.**

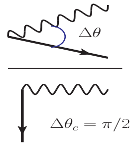
Direct photon production at the LHC in p+A collisions

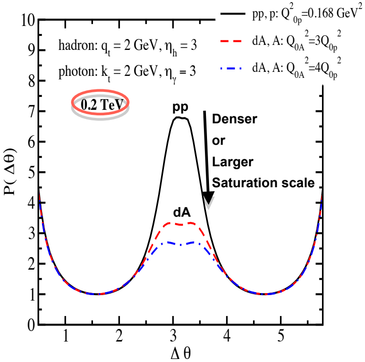
Rezaeian, PLB718 (2013) 1058 [arXiv:1210.2385]

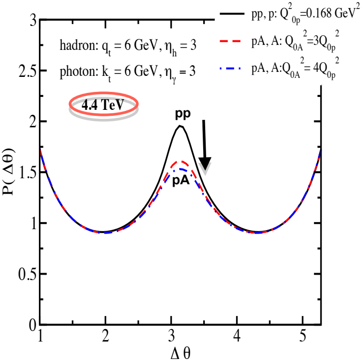


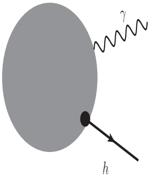
Prompt photons are not suppressed in QGP, but are subject to suppression in CGC medium due to gluon saturation.

$$P(\Delta\theta) = \frac{d\sigma^{p(d)\,T\rightarrow h(q)\,\gamma(k)\,X}}{d^2\vec{b}_t\, dk_t^2\, dq_t^2\, dy_\gamma\, dy_l\, d\theta}[\Delta\theta] \Big/ \frac{d\sigma^{p(d)\,T\rightarrow h(q)\,\gamma(k)\,X}}{d^2\vec{b}_t\, dk_t^2\, dq_t^2\, dy_\gamma\, dy_l\, d\theta}[\Delta\theta = \Delta\theta_c] =$$

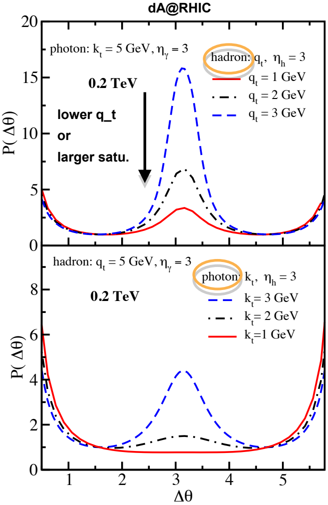








- Denser nuclei (or bigger saturation scale) $\rightarrow$ more suppression of away-side correlations. Jalilian-Marian, Rezaeian, PRD86 [arXiv:1204.1319]

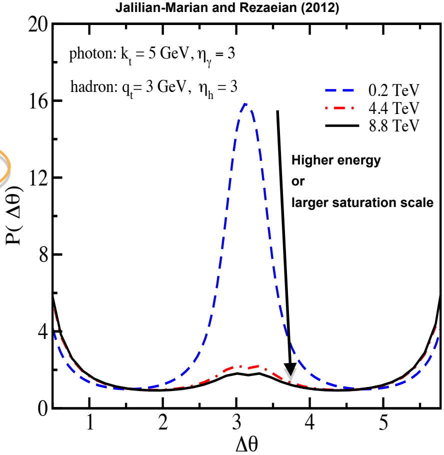


- Lower transverse momentum → more suppression of away-side correlations.

Decorrelation is universal: Dihadron, photon-hadron, DY

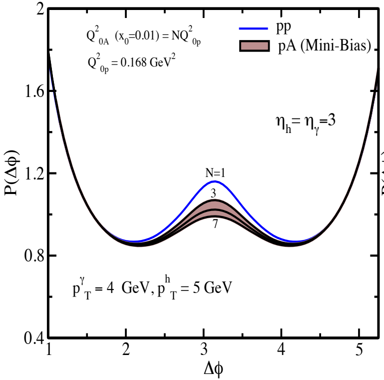
The advantage of photon-hadron: ONly dipole appears, no 4-points

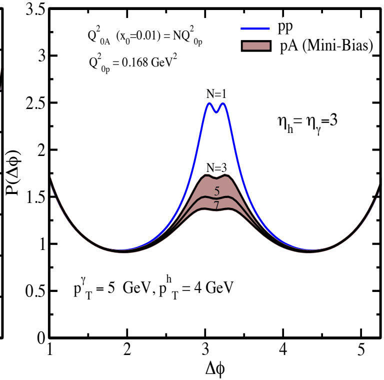
For DY see: Stasto, Xiao, Zaslavsky (2012)



- Higher energy $\rightarrow$ more suppression of away-side correlations.

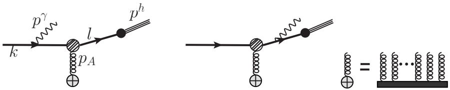
Rezaeian, PRD86 [arXiv:1209.0478]





$p_T^h > p_T^\gamma$ $\quad$ $p_T^h < p_T^\gamma$

- Photon-hadron correlations can have a double or single peak structure depending on ratio of $z_T = p_T^h / p_T^\gamma$.



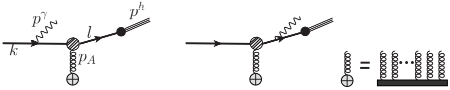
$$\frac{d\sigma^{q\,A\to q(l)\,\gamma(p^\gamma)\,X}}{d^2\vec{b_T}\;d^2\vec{p_T}^\gamma\;d^2\vec{l_T}\;d\eta_\gamma\;d\eta_h} = \frac{Ke_q^2\,\alpha_{em}}{\sqrt{2}(4\pi^4)}\;\frac{p^-}{(p_T^\gamma)^2\sqrt{S}}\;\frac{1+(\frac{l^-}{k^-})^2}{[p^-\;\vec{l_T} - l^-\vec{p_T}^\gamma]^2}$$

$$\delta[x_q - \frac{l_T}{\sqrt{S}}e^{\eta_h} - \frac{p_T^\gamma}{\sqrt{S}}e^{\eta_\gamma}]\left[2l^-\,p^-\;\vec{l_T}\cdot\vec{p_T}^\gamma + p^-(k^- - p^-)\,l_T^2 + l^-(k^- - l^-)\,(p_T^\gamma)^2\right]N_F(|\vec{l_T}+\vec{p_T}^\gamma|, x_g)$$

$$\frac{d\sigma^{p\,A\to h(p^h)\,\gamma(p^\gamma)\,X}}{d^2\vec{b_T}\;d^2\vec{p_T}^\gamma\;d^2\vec{p_T}^h\;d\eta_\gamma\;d\eta_h} = \int_{z_f^{min}}^1 \frac{dz_f}{z_f^2}\;\int dx_q\;f_q(x_q, Q^2)\,\frac{d\sigma^{q\,A\to q(l)\,\gamma(p^\gamma)\,X}}{d^2\vec{b_T}\;d^2\vec{p_T}^\gamma\;d^2\vec{l_T}\;d\eta_\gamma\;d\eta_h}D_{h/q}(z_f, Q^2)$$

Photon-hadron correlations have a double peak structure if:

- $|\vec{l_T} + \vec{p_T}^\gamma| = 0 \to \sigma\,(q + A \to \gamma(p^\gamma) + q(l) + X){=}0$
- Existence of saturation scale: $p_T^2 N_F(p_T, x_g)$ has a maximum at $p_T \sim Q_s$.



$$\frac{d\sigma^{q\,A\to q(l)\,\gamma(p^\gamma)\,X}}{d^2\vec{b_T}\,d^2\vec{p_T}^{\gamma}\,d^2\vec{l_T}\,d\eta_\gamma\,d\eta_h} = \frac{K e_q^2\,\alpha_{em}}{\sqrt{2}(4\pi^4)}\,\frac{p^-}{(p_T^\gamma)^2\sqrt{S}}\,\frac{1+(\frac{l^-}{k^-})^2}{[p^-\,\vec{l_T} - l^-\,\vec{p_T}^{\gamma}]^2}$$

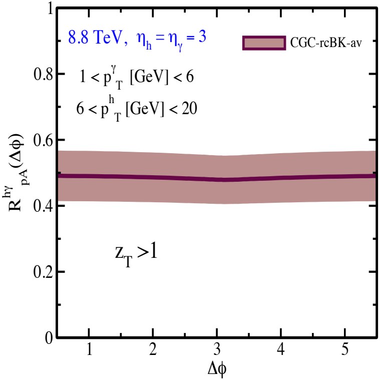
$$\delta[x_q - \frac{l_T}{\sqrt{S}}e^{\eta_h} - \frac{p_T^\gamma}{\sqrt{S}}e^{\eta_\gamma}]\left[2l^-\,p^-\,\vec{l_T}\cdot\vec{p_T}^{\gamma} + p^-(k^- - p^-)\,l_T^2 + l^-(k^- - l^-)\,(p_T^\gamma)^2\right]N_F(|\vec{l_T}+\vec{p_T}^{\gamma}|, x_g)$$

$$\frac{d\sigma^{p\,A\to h(p^h)\,\gamma(p^\gamma)\,X}}{d^2\vec{b_T}\,d^2\vec{p_T}^{\gamma}\,d^2\vec{p_T}^{h}\,d\eta_\gamma\,d\eta_h} = \int_{z_f^{min}}^1 \frac{dz_f}{z_f^2}\int dx_q\, f_q(x_q, Q^2)\,\frac{d\sigma^{q\,A\to q(l)\,\gamma(p^\gamma)\,X}}{d^2\vec{b_T}\,d^2\vec{p_T}^{\gamma}\,d^2\vec{l_T}\,d\eta_\gamma\,d\eta_h}D_{h/q}(z_f, Q^2)$$

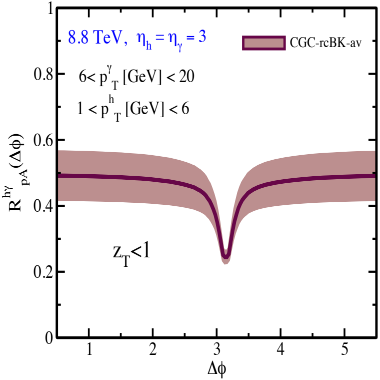
Photon-hadron correlations have a double peak structure if:

$$z_T = \frac{p_T^h}{p_T^\gamma} \leq 1 \quad \text{and} \quad p_T^\gamma\frac{(e^{\eta_h}+e^{\eta_\gamma})}{\sqrt{S}} \leq 1.$$

Nuclear modification of semi-inclusive $\gamma - \pi^0$ production at the LHC



$p_T^h > p_T^\gamma$



$p_T^h < p_T^\gamma$

The $\gamma - \pi^0$ azimuthal correlation; coincidence probability

- In the contrast to dihadron production, here we have freedom to select the trigger particle to be a produced prompt photon or a hadron.
  Rezaeian, PRD 86, arXiv:1209.0478.

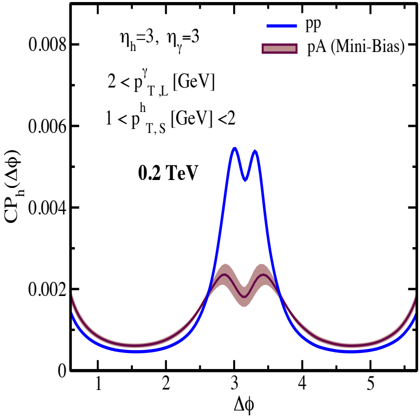
Trigger(leading) particle is a prompt photon:

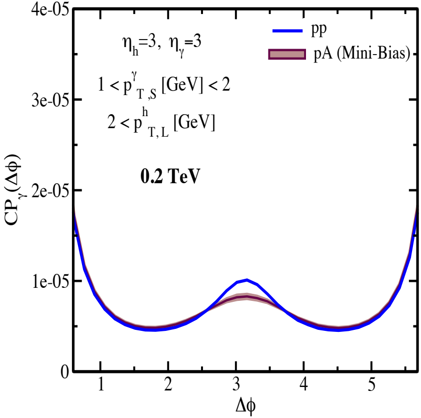
$$CP_h(\Delta\phi; p^h_{T,S}, p^\gamma_{T,L}; \eta_\gamma, \eta_h) = N^{\text{pair}}_h(\Delta\phi)/N_{\text{photon}} = \frac{2\pi \int_{p^\gamma_{T,L}} dp^\gamma_T p^\gamma_T \int_{p^h_{T,S}} dp^h_T p^h_T \frac{dN^{p\,A\to h(p^h_T)\,\gamma(p^\gamma_T)\,X}}{d^2\vec{p_T}^\gamma\, d^2\vec{p_T}^h\, d\eta^\gamma\, d\eta^h}}{\int_{p^\gamma_{T,L}} d^2\vec{p_T}^\gamma \frac{dN^{p\,A\to\gamma(p^\gamma_T)\,X}}{d^2\vec{p_T}^\gamma\, d\eta_\gamma}}$$

Trigger particle is a hadron:

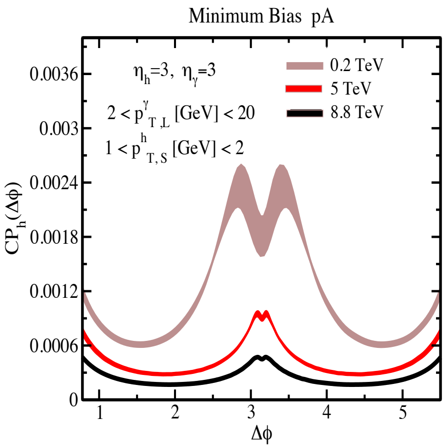
$$CP_\gamma(\Delta\phi; p^\gamma_{T,S}, p^h_{T,L}; \eta_\gamma, \eta_h) = N^{\text{pair}}_\gamma(\Delta\phi)/N_{\text{hadron}} = \frac{2\pi \int_{p^h_{T,L}} dp^h_T p^h_T \int_{p^\gamma_{T,S}} dp^\gamma_T p^\gamma_T \frac{dN^{p\,A\to h(p^h_T)\,\gamma(p^\gamma_T)\,X}}{d^2\vec{p_T}^\gamma\, d^2\vec{p_T}^h\, d\eta^\gamma\, d\eta^h}}{\int_{p^h_{T,L}} d^2\vec{p_T}^h \frac{dN^{p\,A\to h(p^h_T)\,X}}{d^2\vec{p_T}^h\, d\eta_h}}$$

The $\gamma - \pi^0$ coincidence probability at RHIC





The $\gamma - \pi^0$ azimuthal correlation; RHIC v LHC



- Higher energy $\rightarrow$ more suppression of away-side correlations and diminishing the double peak (Rezaeian, PLB718, arXiv:1210.2385).

Conclusion:

The CGC picture at RHIC and HERA at small-x is consistent with the LHC data (p+p, p+A, A+A) so far: the upcoming p+A data at the LHC is crucial test of gluon saturation/CGC.

- Await to be verified:
  - ➤ Centrality dependence of the multiplicity distribution.
  - ➤ Suppression of inclusive charged hadron, and direct photon production at *very* forward rapidities.
  - ➤ Suppression of away-side photon-hadron (and dihadron) correlations at forward rapidities.

    Standard (DGLAP-like) QCD calculations cannot reproduce none of $\gamma - \pi^0$ away-side decorrelation features

$Q^2_{sA} \propto A^\alpha Q^2_{sp}$ at small-x and low Q^2

- Empirical geometric scaling and DIS data:
  Armesto, Salgado and Wiedemann (2004):
  $Q^2_{sA} = c_1 A^{4/9} Q^2_{sp} \Longrightarrow Q^2_{sA} \approx 3.1 Q^2_{sp}$

- BK-JIMWLK equation and DIS data
  McLerran and Venugopalan (1994), Albacete et al. (2010), Dusling, Gelis, Lappi and Venugopalan (2010), Rezaeian and Levin (2010)
  $Q^2_{sA} = c_2 A^{1/3} Q^2_{sp} \Longrightarrow Q^2_{sA} \approx 2.96 Q^2_{sp}$

- Running-coupling BFKL evolution near the saturation boundary
  Mueller (2003): $Q^2_{sA} = c_3 A^0 Q^2_{sp}$, is **independent** of A.

➤ Available data cannot **uniquely** determine the A-dependence of the saturation scale $\Longrightarrow$ needs for EIC and p+A@LHC with different A.