Nuclear modification factor for gluon jets

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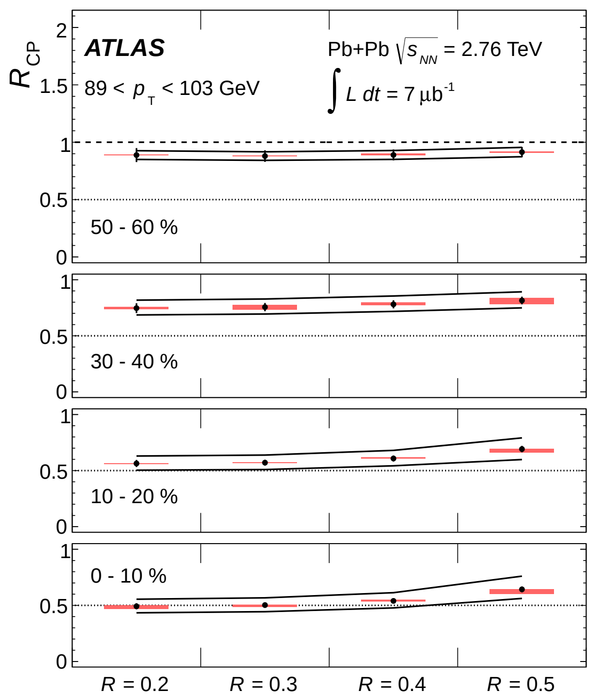
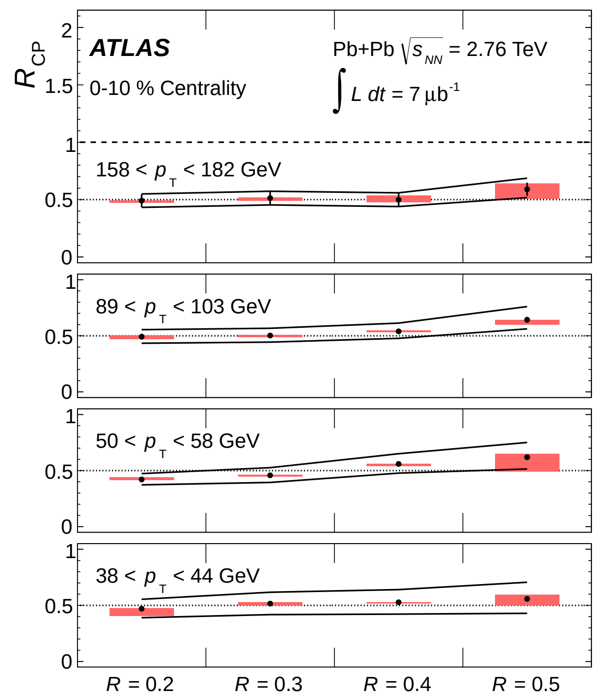
Diffraction'2012, Lanzarote,Canary Islands, September 10-15 , 2012

E. L.: *"Nuclear modification factor for gluon jets," arXiv:1203.4467 [hep-ph])*

ATLAS data: arXiv:1208.1967 [hep-ex].





CMS (Pelin Kurt talk at QM'2012):

"More than 95% of the jet energy deposited in $R < 0.2$ for 10% centrality. "

Two theoretical questions:

1. **Could be NMF < 1 at low x and large $p_T \gg Qs$ without violation of the factorization theorem ?**

2. **Can be the value of NMF of the order of the value measured by ATLAS?**

QCD factorization.

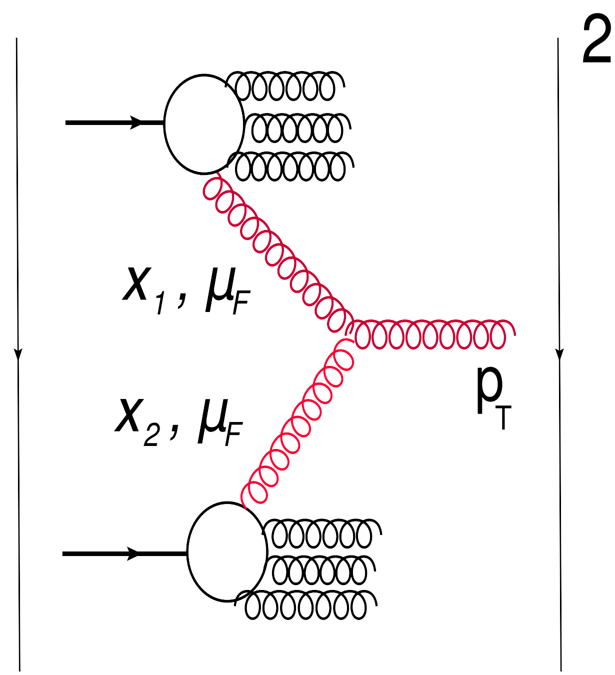
- $\frac{d^2\sigma(Y',p_T)}{dY'd^2p_T} =$

$\sigma_{hard} \bigotimes x_1 G_{Pr}\left(x_1, \mu_F^2\right) x_2 G_{Tr}\left(x_2, \mu_F^2\right)$

- $xG_A(x,\mu_F^2) = AxG_P(x,\mu_F^2)$

- **NMF** $= \frac{d^2\sigma(AA)\left(Y',p_T\right)}{dY'd^2p_T} / A^2 \frac{d^2\sigma(pp)\left(Y',p_T\right)}{dY'd^2p_T}$

$= (xG_A(x,\mu_F^2))^2/(A\,xG_p(x,\mu_F^2))^2 = 1$



Violation of QCD factorization ?!

No violation of QCD factorization, but

- $xG_A\left(x,\mu_F^2/Q_s^2\left(A;x_0\right)\right) = AxG_P\left(x,\mu_F^2/Q_s^2\left(A;x_0\right)\right)$

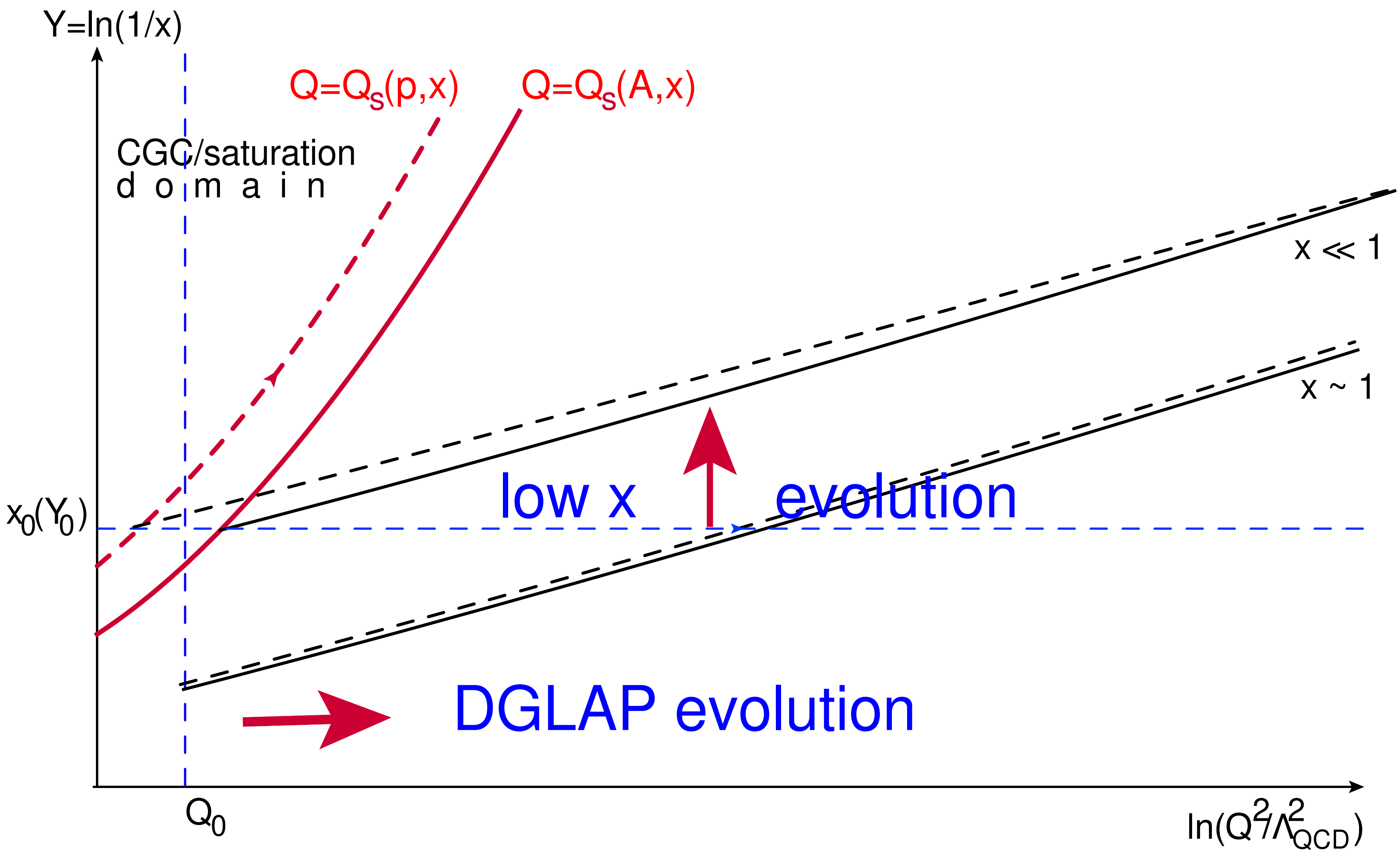
$$= AxG_P\left(x,\mu_F^2/\left(A^{1/3}Q_s^2\left(P;x_0\right)\right)\right)$$

for $\mu_F \approx p_T \gg Q_s\left(A;x\right)$

- $$R_{AA} = \frac{x_1 G_P\left(x_1,\mu_F^2/Q_s^2\left(A;x_{10}\right)\right)\,x_2 G_P\left(x_2,\mu_F^2/Q_s^2\left(A;x_{20}\right)\right)}{x_1 G_P\left(x_1,\mu_F^2/Q_s^2\left(P;x_{10}\right)\right)\,x_1 G_P\left(x_2,\mu_F^2/Q_s^2\left(P;x_{20}\right)\right)} < 1$$

Linear equations at large p_T and $x \to 0$

Evolution in $\ln Q^2$ (DGLAP evolution):



Evolution in $\ln(1/x)$ (BFKL-type evolution):

For low x both BFKL and DGLAP evolution equations have the form:

- $$\frac{\partial xG\left(Y;p_T^2\right)}{\partial Y} = \int d^2k_T\,K\left(p_T,k_T\right)\,xG\left(Y,k_T^2\right)$$

Solutions have the form

$$xG\Big(Y,\xi \equiv \ln\left(p_T^2/\Lambda^2_{QCD}\right)\Big) = \int d\xi'\,G\left(Y-Y_0,\xi-\xi'\right)\,xG_{in}\left(Y=Y_0,\xi'\right)$$

- $G\left(Y-Y_0,\xi-\xi'\right) \Longrightarrow$ Green's function,
- $G\left(Y=Y_0,\xi-\xi'\right) = \delta\left(\xi-\xi'\right)$.
- $xG_{in}\left(Y=Y_0,\xi'\right)$ is the initial condition for xG

General property of the solutions:

- $xG\left(Y,\xi \equiv \ln\left(p_T^2/\Lambda_{QCD}^2\right)\right) = \int d\xi'\; G\left(Y - Y', \xi - \xi'\right)\, xG\left(Y', \xi'\right)$

Indeed, the general solution has the form

- $xG\left(Y,\xi\right) \;=\; \int_{\epsilon - i\infty}^{\epsilon + i\infty} \frac{d\gamma}{2\pi i}\, e^{\omega(\gamma) Y + \gamma \xi}\, g\left(\gamma\right) \;=\; \int_{\epsilon - i\infty}^{\epsilon + i\infty} \frac{d\omega}{2\pi i}\, e^{\omega Y + \gamma(\omega) \xi}\, g\left(\omega\right)$
- $\omega = \omega(\gamma) \longrightarrow$ Mellin image of K; $\gamma = \gamma(\omega) \longrightarrow$ solution of $\omega = \omega(\gamma)$
- $G\left(Y - Y', \xi\right) \;=\; \int_{\epsilon - i\infty}^{\epsilon + i\infty} \frac{d\gamma}{2\pi i}\, e^{\omega(\gamma)\left(Y - Y'\right) + \gamma\left(\xi - \xi'\right)}$

Assume: $x_0 G\left(Y_0, k_T\right) \;=\; S\, Q_s^2(Y_0) g\left(\tau = k_T^2/Q_s^2\left(Y_0\right)\right)$

- $xG\Big(Y, \xi \equiv \ln\left(p_T^2/\Lambda^2_{QCD}\right)\Big)$

$$= \int \frac{d k_T^2}{k_T^2}\, G\left(Y - Y_0, \xi - \xi'\right)\, xG\left(Y_0, k_T^2\right)$$

$$= S\, Q_s^2\left(Y_0\right) \int \frac{d k^2}{k_T^2} G\left(Y - Y_0, p_T^2/k_T^2\right)\, g\left(k_T^2/Q_s^2\left(Y_0\right)\right)$$

$$= S\, Q_s^2(Y_0) \int_{\epsilon - i\infty}^{\epsilon + i\infty} \frac{d\gamma}{2\pi i}\, e^{\omega(\gamma)(Y - Y_0)} \left(\frac{p_T^2}{k_T^2}\right)^{\gamma} g\left(\frac{k_T^2}{Q_s^2\left(Y_0\right)}\right)$$

$$= S\, Q_s^2(Y_0) \int_{\epsilon - i\infty}^{\epsilon + i\infty} \frac{d\gamma}{2\pi i}\, e^{\omega(\gamma)(Y - Y_0)} \left(\frac{p_t^2}{Q_s^2\left(Y_0\right)}\right)^{\gamma} \int \frac{d\tau}{\tau} \tau^{-\gamma}\, g\left(\tau\right)$$

$$= S\, Q_s^2(Y_0) \int_{\epsilon - i\infty}^{\epsilon + i\infty} \frac{d\gamma}{2\pi i}\, e^{\omega(\gamma)(Y - Y_0)} \left(\frac{p_t^2}{Q_s^2\left(Y_0\right)}\right)^{\gamma} f\left(\gamma\right)$$

Proof: $x_0 G\left(Y_0, k_T\right) = S\, Q_s^2(Y_0) g\left(\tau = k_T^2/Q_s^2\left(Y_0\right)\right)$

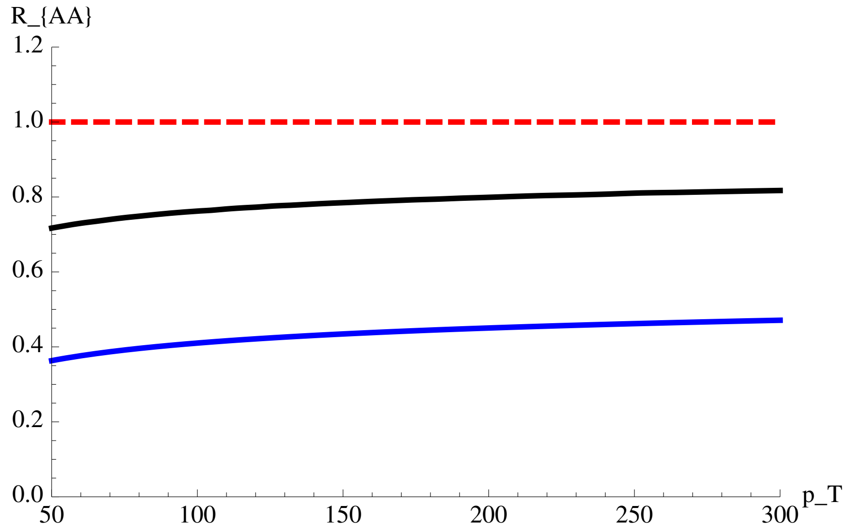
- $xG\left(x, p_T^2\right) = \int^{p_T^2} dk^2 \phi(Y, k^2)$
- $\phi_G^A\left(x_0; \vec{k}_T\right) = \frac{1}{\bar{\alpha}_S\, 4\pi} \int d^2b\, d^2r e^{i\vec{k}_T \cdot \vec{r}}\, \nabla_\perp^2\, N_G^A\left(Y_0; r; b\right)$
- $N_G^A\left(Y_0; r, b\right) = 2\, N\left(Y_0; r, b\right) - N^2\left(Y_0; r, b\right)$

$\rightarrow \quad 1 - \exp\left(-r^2 Q_s^2\left(Y_0; b\right)/2\right)$

for $N\left(Y_0; r, b\right) = 1 - \exp\left(-r^2 Q_s^2\left(Y_0; b\right)/4\right)$ **(McLerran-Venugopalan)**

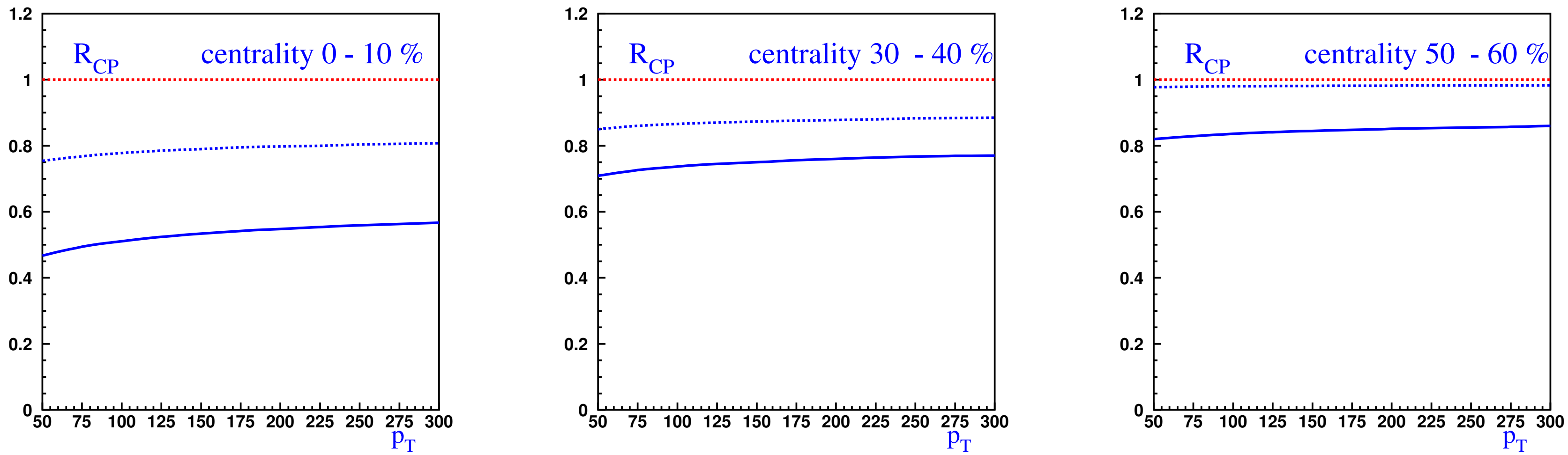
- $$x_0 G\left(x_0, p_T^2\right) = \frac{\pi}{2} S\, Q^2\left(Y_0\right))\left(1 - \left(1 + 2\,\tau\right)\,\exp\left(-2\tau\right)\right) = S\, Q_s^2\left(Y_0\right)\, g\left(\tau\right)$$

Estimates for NMF

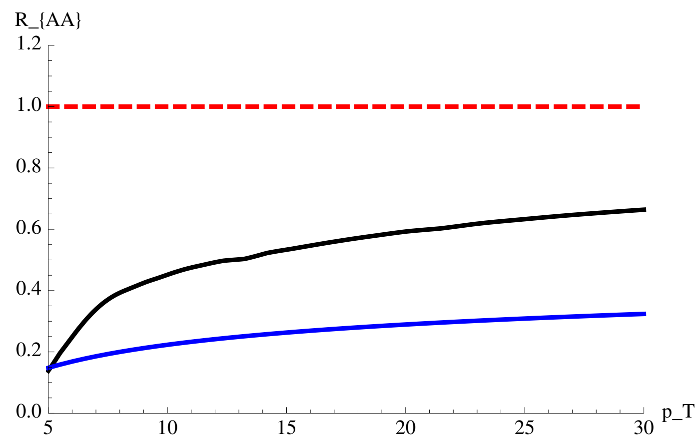


- $\gamma = \bar{\alpha}_S \left(\frac{1}{\omega} - 1 \right)$ **or** $\omega(\gamma) = \frac{\alpha_S}{\gamma + \bar{\alpha}_S}$
- $G(Y, \tau) = f(\gamma_{SP}) \exp\left(2 \sqrt{\bar{\alpha}_S Y \ln(\tau)} - \bar{\alpha}_S \ln(\tau) \right)$

with $\gamma_{SP} = \sqrt{\frac{\bar{\alpha}_S Y}{\ln(\tau)}}$



- $x = 10^{-3}$ **!!!** **ATLAS(** $p_T \approx 50 GeV$**):** $R_{CP}(0 - 10\%) = 0.5 \pm 0.05$; $R_{CP}(30 - 40\%) = 0.7 \pm 0.05$; $R_{CP}(50 - 60\%) = 0.9 \pm 0.05$.



Conclusions

1. Could be NMF < 1 at low x and large $p_T \gg Qs$ without violation of the factorization theorem ?

2. Can be the value of NMF of the order of the value measured by ATLAS?

YES

Prediction: For proton-nucleus collision

$$R(pA) \approx \sqrt{R(AA)} < 1$$