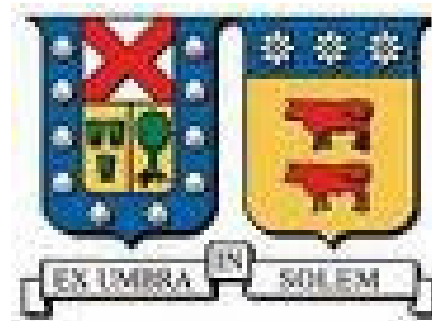# Nuclear modification factor for gluon jets
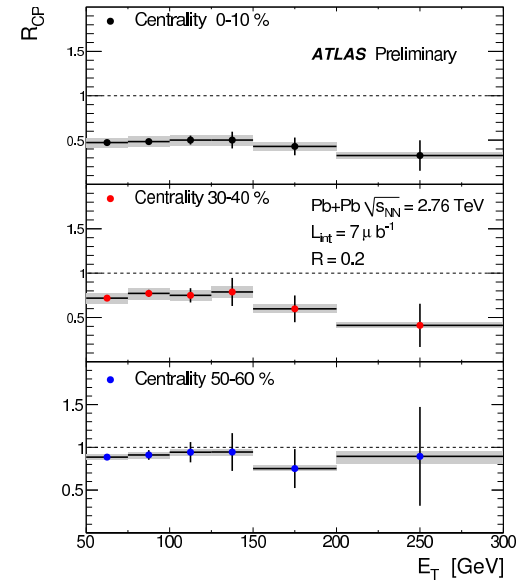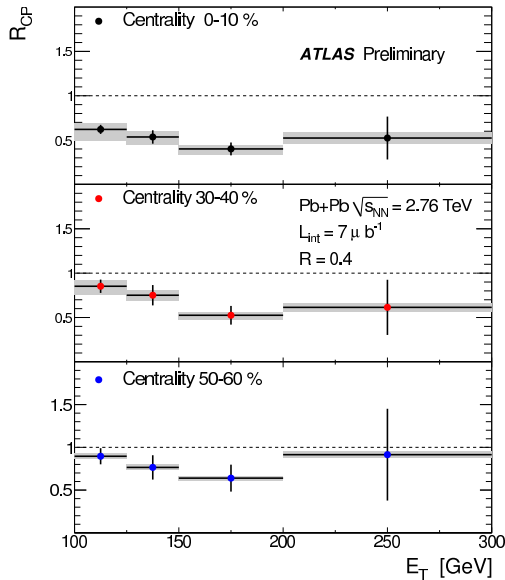
Eugene Levin, UTFSM / TAU

June 27- July 1, 2012 ,Paphos, Cyprus

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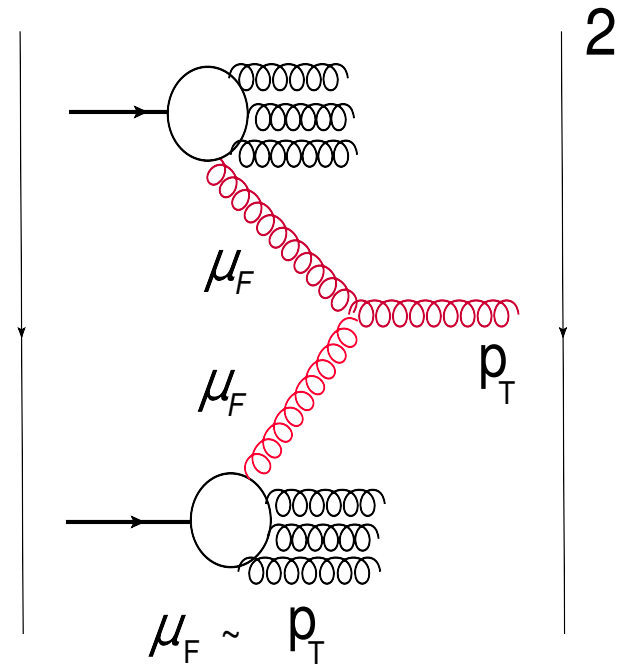
ATLAS data.

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.

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

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

- $x G_A(x,\mu_F^2) = A x G_P(x,\mu_F^2)$

- NMF $= \dfrac{d^2\sigma(AA)(Y',p_T)}{dY'd^2p_T} \Big/ A^2 \dfrac{d^2\sigma(pp)(Y',p_T)}{dY'd^2p_T}$

$= (x G_A(x,\mu_F^2))^2 / (A\, x G_p(x,\mu_F^2))^2 = 1$

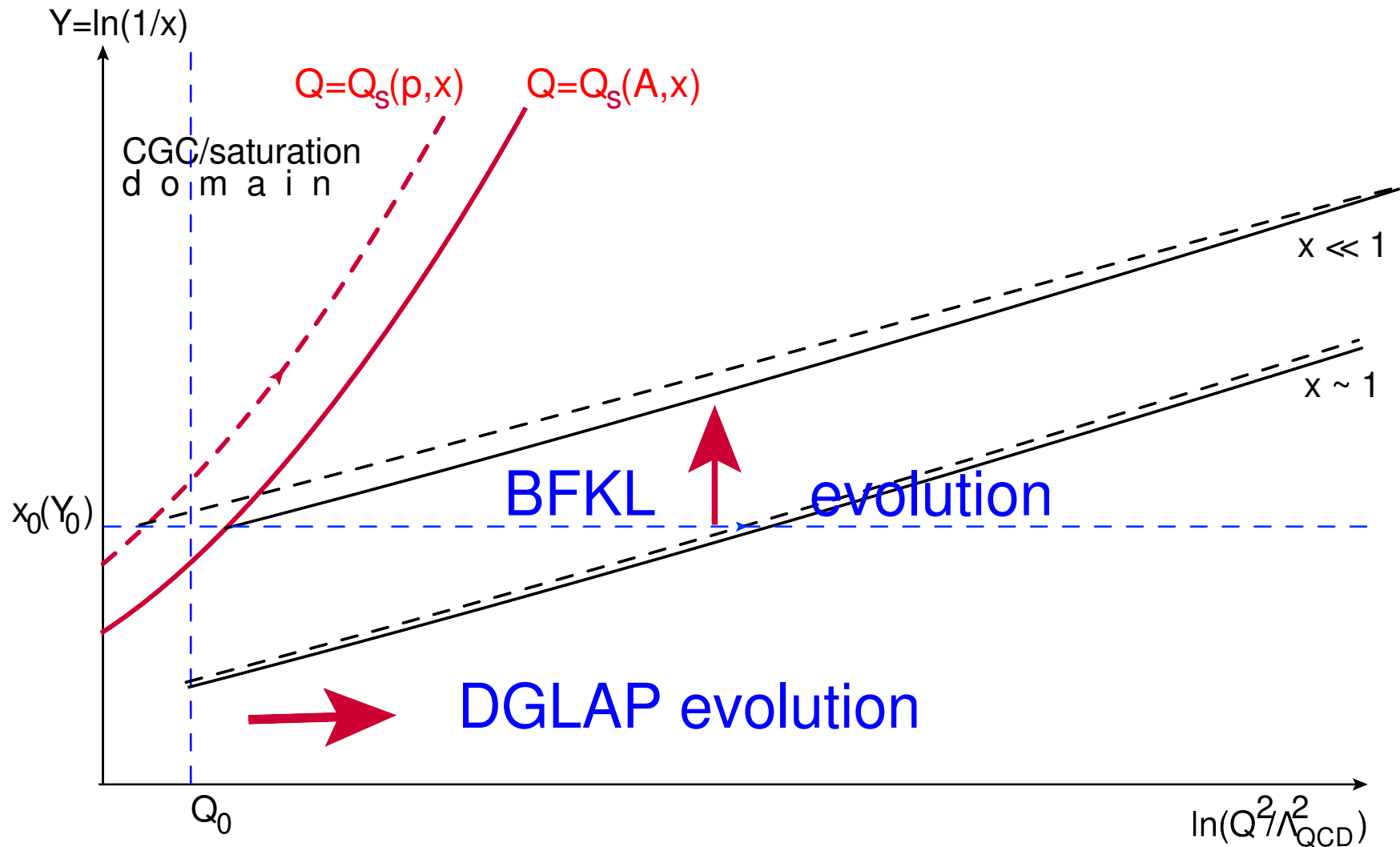
Violation of QCD factorization ?!

No violation of QCD factorization, but

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

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

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

Linear equations at large p_T

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

Y=ln(1/x)

$Q=Q_S(p,x)$ $Q=Q_S(A,x)$

CGC/saturation
d o m a i n

$x \ll 1$

$x \sim 1$

$x_0(Y_0)$

BFKL ⬆ evolution

DGLAP evolution

Q_0

$\ln(Q^2/\Lambda^2_{QCD})$

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

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

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

Solutions have the form

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

$\bullet$ $G\left(Y - Y_0, \xi - \xi'\right) \Longrightarrow$ **Green's function,**

$\bullet$ $G\left(Y = Y_0, \xi - \xi'\right) = \delta\left(\xi - \xi'\right).$

$\bullet$ $xG_{in}\left(Y = Y_0, \xi'\right)$ **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** $\omega = \omega(\gamma)$

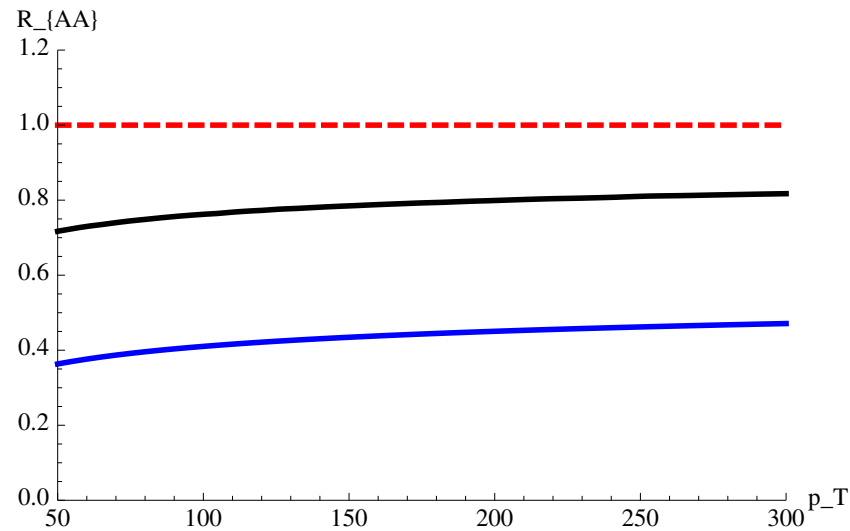- $G\left(Y - Y', \xi\right) = \int_{\epsilon-i\infty}^{\epsilon+i\infty} \frac{d\gamma}{2\pi i}\ e^{\omega(\gamma)\left(Y-Y'\right)+\gamma\left(\xi-\xi'\right)}$

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

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

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

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

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

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

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

Proof: $\quad x_0 G\left(Y_0, k_T\right) \;=\; S\, Q_s^2(Y_0) g\left(\tau = k_T^2/Q_s^2\left(Y_0\right)\right)$
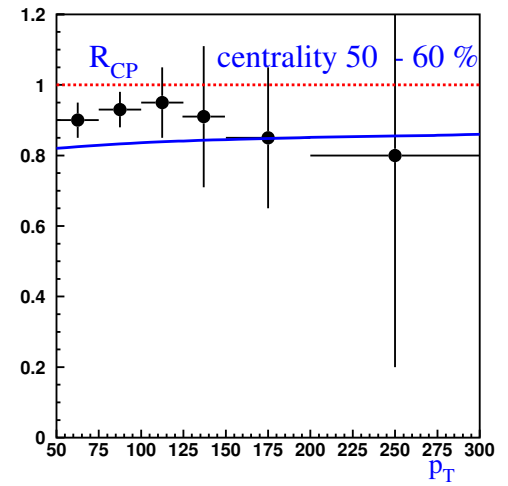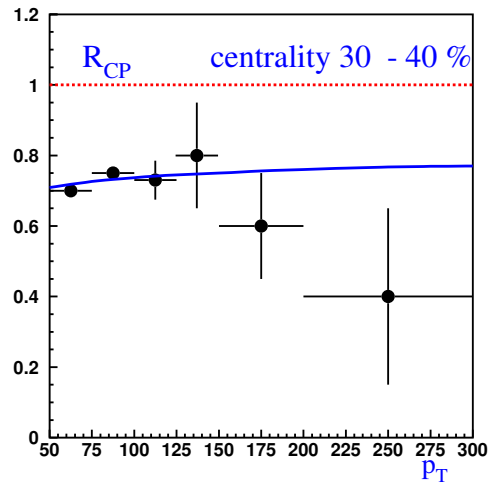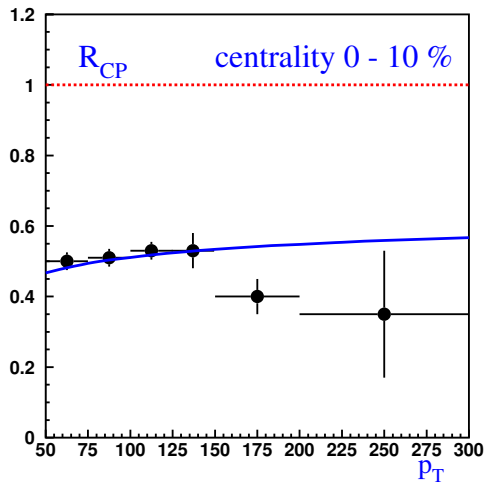
- $xG\left(x, p_T^2\right) \;=\; \int^{p_T^2} dk^2 \phi(Y, k^2)$

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

- $N_G^A\left(Y_0; r, b\right) \;=\; 2\, N\left(Y_0; r, b\right) \;-\; N^2\left(Y_0; r, b\right)$

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

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

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

$\qquad\qquad\qquad = \;\; S\, Q_s^2\left(Y_0\right)\, g\left(\tau\right)$
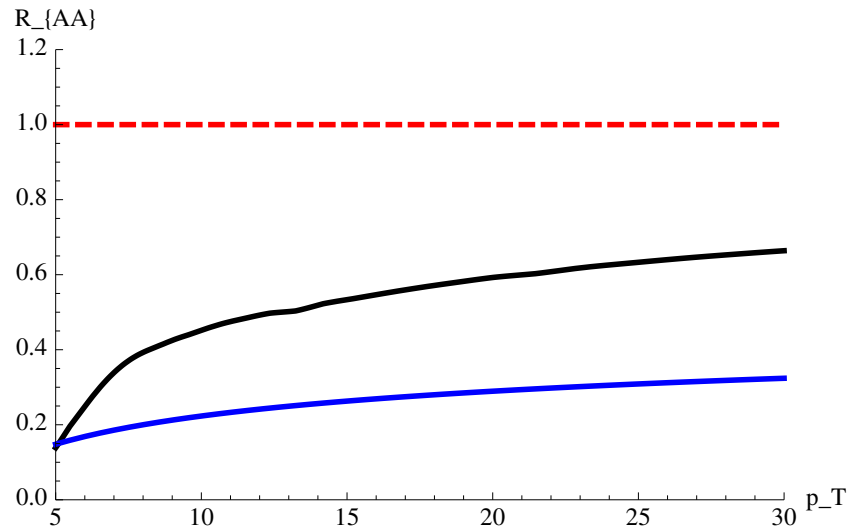
Estimates for NMF

R_{AA}

- $\gamma = \bar{\alpha}_S\left(\dfrac{1}{\omega} - 1\right)$ **or** $\omega\left(\gamma\right) = \dfrac{\alpha_S}{\gamma + \bar{\alpha}_S}$

- $G\left(Y, \tau\right) = f\left(\gamma_{SP}\right)\exp\left(2\sqrt{\bar{\alpha}_S\,Y\,\ln\left(\tau\right)} - \bar{\alpha}_S\,\ln\left(\tau\right)\right)$

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

$x = 10^{-3}$!!!

Nuclear modification factor for gluon jets

Conclusions

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

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

   YES