Probing nuclear parton densities and parton energy loss processes through photon + heavy-quark jet production in p-A and A-A collisions

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Introduction

The detailed phenomenological study of the associated production of a prompt photon and a heavy quark jet (charm ; bottom) in $p-A$ and $A-A$ collisions is presented below. Depending on the collision type this process can be useful in various ways.

1. In $p-\bar{p}$ collisions (Tevatron) it is sensitive to the charm (bottom) PDF - arXiv:0901.3791 - useful for testing for intrinsic charm/bottom (IC/IB) (theory - data comparison : arXiv:0901.0739).

2. In $p-p$, $p-A$ collisions (LHC,RHIC) can test for IC/IB again (work in progress) and can be used to constrain the gluon nuclear PDF (nPDF) - (arXiv:1012.1178) (dominant subprocess is $g-Q$ initiated).

Knowing the precise nPDFs is necessary for obtaining reliable predictions in $A-A$ collisions!

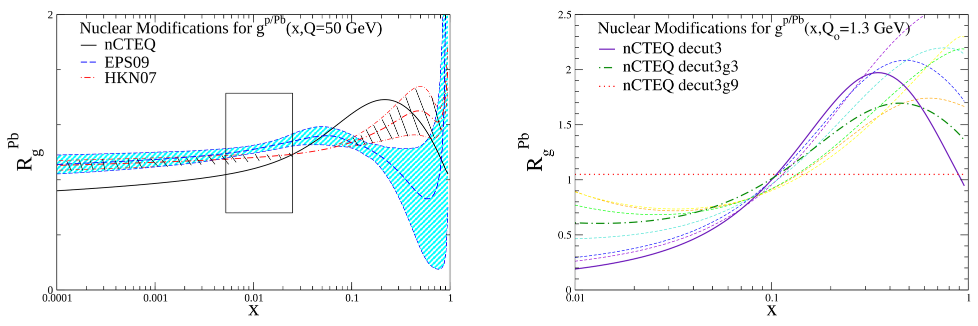
3. In $A-A$ collisions it can help us obtain a better understanding of the parton energy loss processes in the massive quark sector (work in progress). Here the photon transverse momentum can be used to gauge the initial energy of the massive parton which is expected to lose energy while propagating through the dense QCD medium produced in ion-ion collisions. While at the same time the two-particle final state provides a range of observables (jet asymmetry, photon-jet pair momentum, among others) allowing for a detailed investigation of the energy lost by the HQ, as shown below.

Constraining the gluon nPDF with the help of $\gamma + Q$ production (arXiv:1012.1178)

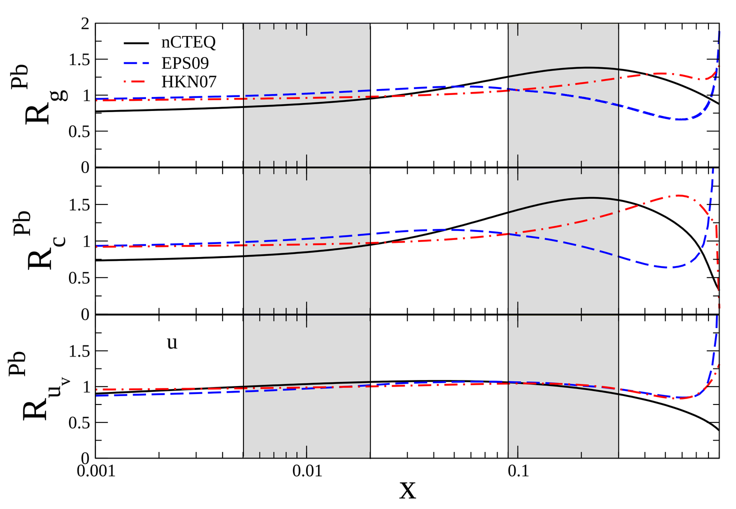
The gluon nPDF

- The nuclear PDFs are far less constrained than the proton PDFs. The gluon nuclear PDF is largely unconstrained, illustrated by the nuclear modification factor:

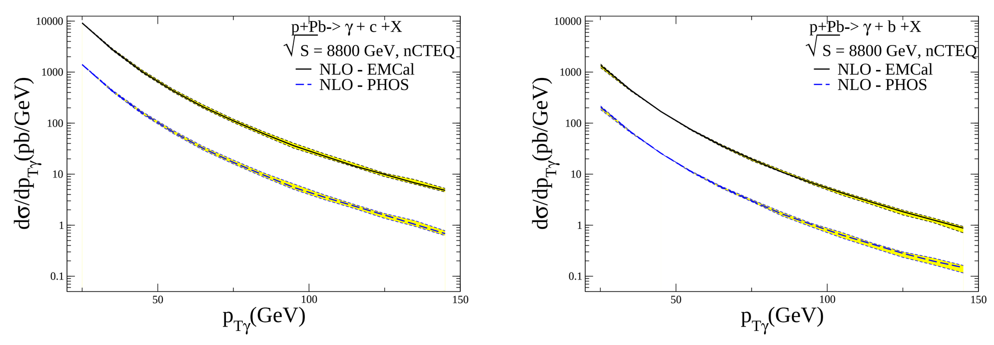
$$R_g^{Pb}(x,Q) = g^{p/Pb}(x,Q)/g^p(x,Q)$$



- Different nPDF sets (nCTEQ, EPS and HKN) including the errors → differing predictions - need a more precise determination of $g^{p/Pb}(x,Q) \Rightarrow$ LHC data is needed!
- Standard approach: HQ PDFs are generated radiatively $\Rightarrow R_g^{Pb} \simeq R_c^{Pb}$:



$\gamma + Q$ production in $p-Pb$ collisions @ the LHC

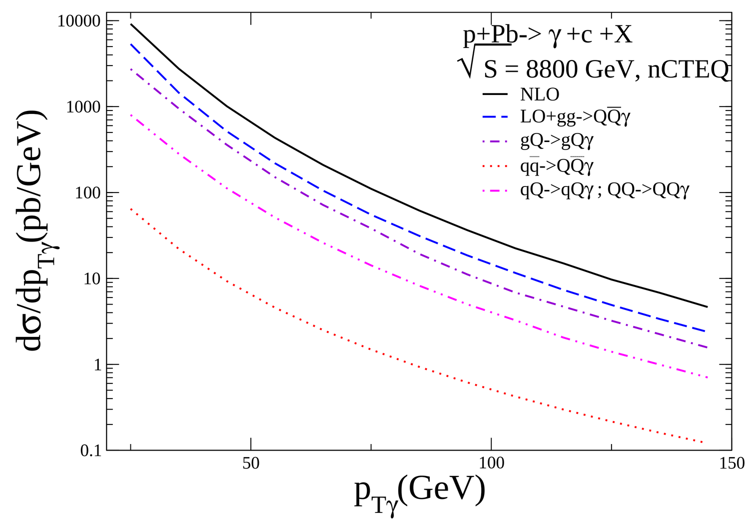


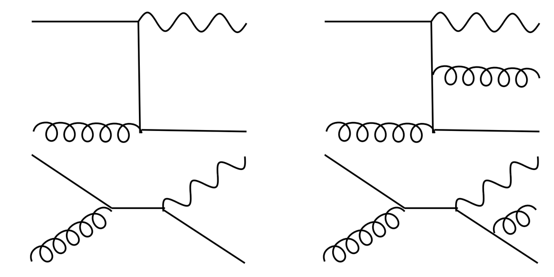
- The above predictions are obtained using the experimental cuts appropriate for ALICE:

	p_T	Rapidity	ϕ	Isolation Cuts
Photon (PHOS)	$p_{T,\gamma}^{min} = 20$ GeV	$\lvert y_\gamma \rvert < 0.12$	$220° < \phi < 320°$	$R=0.2$, $p_T^{th} = 2$ GeV
Photon (EMCal)	$p_{T,\gamma}^{min} = 20$ GeV	$\lvert y_\gamma \rvert < 0.7$	$60° < \phi < 180°$	$R=0.2$, $p_T^{th} = 2$ GeV
Heavy Jet	$p_{T,Q}^{min} = 15$ GeV	$\lvert y_Q \rvert < 0.7$	——	——

- Using an integrated yearly luminosity of $\mathcal{L} = 10^{-1} pb^{-1}$ a precursory estimate for the number of events per year at EMCal for $\gamma + c$ is $\mathcal{N}_{\gamma+c}^{pPb} = 11900$ ($\sigma_{\gamma+c}^{pPb} = 119 nb$) and for $\gamma + b$ is $\mathcal{N}_{\gamma+b}^{pPb} = 2270$ ($\sigma_{\gamma+b}^{pPb} = 22.7 nb$)

Subprocess Contributions & nPDF dependence

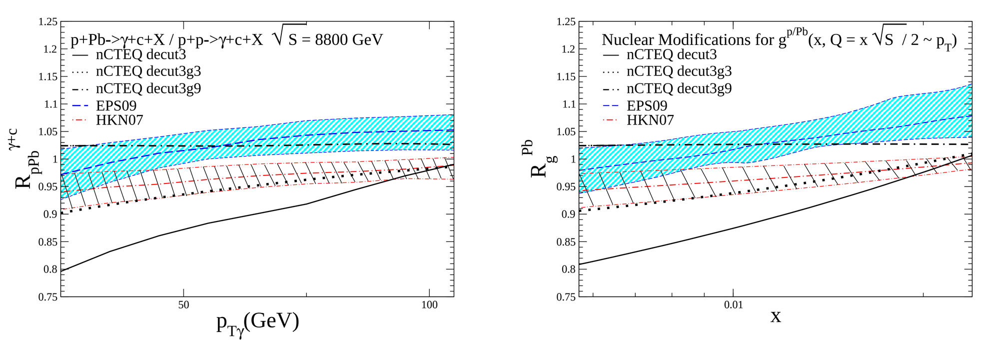




- Compton subprocess dominates ($> 80\%$) $\Rightarrow$ sensitivity to gluon and HQ PDFs.

Nuclear Modifi cations - $\gamma + Q$ cross-section

$$R_{pA}^{\gamma Q} = \frac{\sigma\,(pA \to \gamma\; Q\; X)}{A\; \sigma\,(pp \to \gamma\; Q\; X)} \qquad (1)$$



- $R_{pA}^{\gamma Q} \simeq R_g^{Pb}$ - in the x region probed at ALICE
- Almost no overlap between the predictions using EPS09 and HKN07 even within the error bands. The nCTEQ predictions cover a wide range of space
- Measurements of $\gamma + Q$ with appropriate error bars will allow to distinguish between the different nPDF sets and place useful constraints on the gluon nPDF

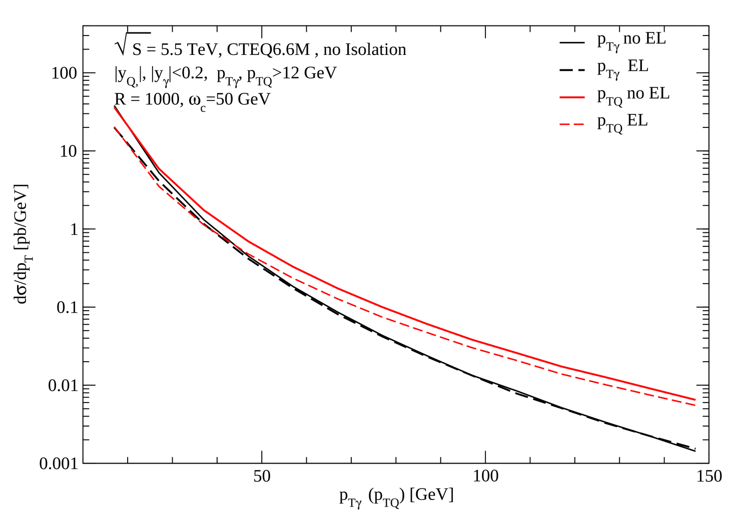
Heavy Quark Energy Loss in $\gamma + Q$ Production

$\gamma + Q$ in AA Collisions

- $\gamma + Q$ is ideal for probing hot QCD medium
  - Q - Jet Quenching
  - γ is medium insensitive $\Rightarrow$ can gauge HQ's initial energy
- The energy loss of the heavy quark - ϵ_Q is computed on an event by event basis, with the use of the quenching weight obtained perturbatively [Armesto Dainese Salgado Wiedemann 2005 (arXiv:hep-ph/0501225)]

The effects of energy loss on the $\gamma + Q$ cross-section

γ+c at LO



- Difference in spectrum vs p_{TQ} in vacuum and in medium $\Rightarrow$ due to energy loss
- $\frac{d\sigma}{p_{T\gamma}}$ spectrum almost unchanged (small difference between $\frac{d\sigma^{med}}{p_{T\gamma}}$ and $\frac{d\sigma^{vac}}{p_{T\gamma}}$ at low p_T due to experimental cuts)

Observables

- The two-particle final state further offers a range of observables $\Rightarrow$ can get a better handle on the energy lost in the hot medium
  - Photon-jet energy asymmetry :

$$A_J = \frac{E_{T1} - E_{T2}}{E_{T1} + E_{T2}}, \Delta\phi > \pi/2 \qquad (2)$$

  - Momentum imbalance:

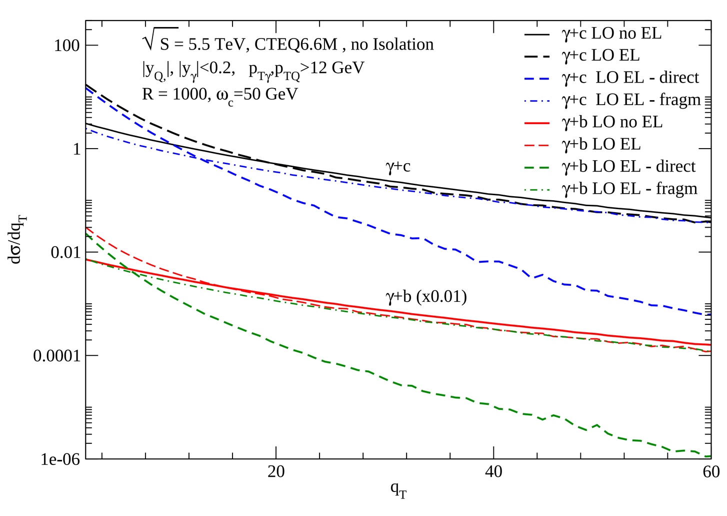
$$z_{34} = -\frac{\vec{p}_{T\gamma} \cdot \vec{p}_{TQ}}{p_{T\gamma}^2} \qquad (3)$$

  - Photon-jet pair momentum:

$$q_\perp = |\vec{p}_{T\gamma} + \vec{p}_{TQ}| \qquad (4)$$

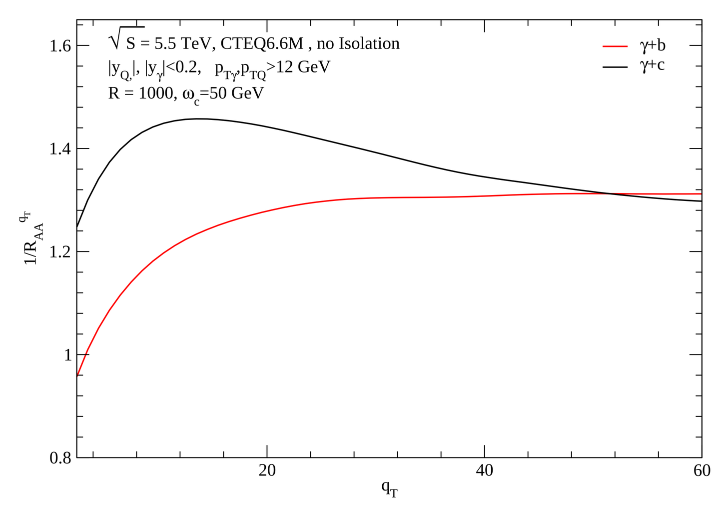
    - At LO direct component - $q_\perp \simeq \epsilon_Q$
    - At LO fragmentation component - ϵ_Q represents the shift of the q_T spectrum in vacuum vs the one in medium

$q_\perp$ in more detail



- Direct and fragmentation component behave very distinctly
  - In medium the direct contribution decreases sharply with increasing q_T $\Rightarrow$ small probability of events with large ϵ_Q
  - In vacuum the direct contribution is non-zero only at $q_T = 0$
- Therefore compare only the vacuum and medium fragmentation contributions

LO Fragmentation Contribution



- $\Delta E_c > \Delta E_b$; as q_T grows the difference disappears, as the quenching weight depends on m/E, which becomes similar for $\gamma + c$ and $\gamma + b$ at large q_T
- Need to compare σ in medium and vacuum at the NLO level, where the particles have a larger kinematic phase-space!

Conclusions

$\gamma + Q$ **production** is an extremely useful and versatile process. It can can be employed to constrain the HQ PDFs in hadron-hadron collisions, while measurements in $p-A$ collisions can help constrain the gluon nPDF. In $A-A$ collisions it can be used for an estimate of the HQ energy loss, where it also provides access to the mass hierarchy of parton energy loss.