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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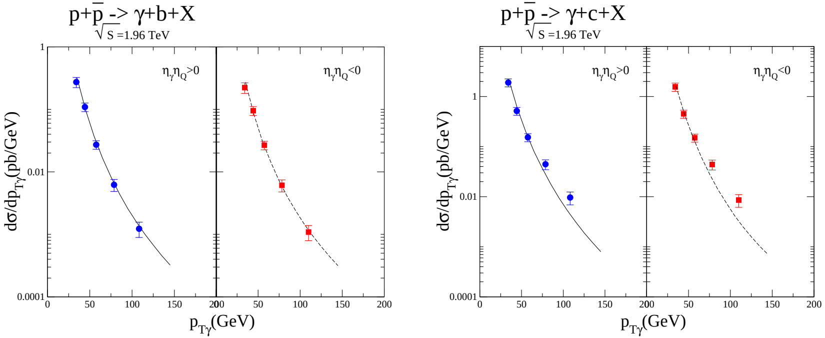
Prompt Photons and Heavy Quark Jets

- Prompt photons - produced in hard scattering or via fragmentation
- Heavy quark jet - charm or bottom jet
- Depending on the collision type this process can be useful in various ways
- In $p - \bar{p}$ collisions (Tevatron) it is sensitive to the charm (bottom) PDF - arXiv:0901.3791 - useful for testing for intrinsic charm or bottom (IC or IB) (theory - data comparison : arXiv:0901.0739).
- 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!
- 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)

Comparison between theory and data @ $p - \bar{p}$

Measurements by DØ Collaboration

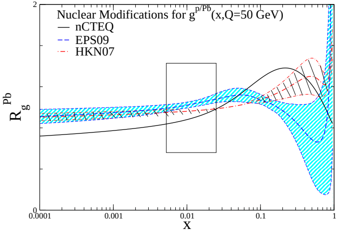


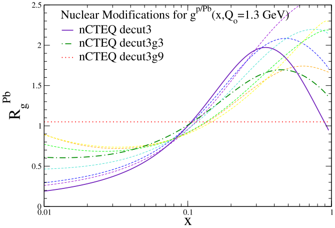
- Really good agreement between data and theory for $\gamma + b$
- For $\gamma + c$ data at large $p_{T\gamma}$ is above the theory curve $\rightarrow$ possible explanation - existence of intrinsic charm

Constraining the gluon nPDF

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

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

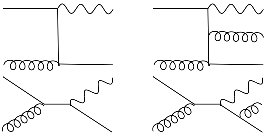


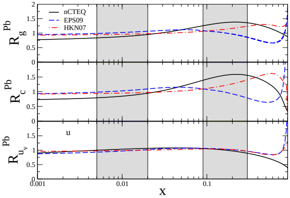


- Different nPDF sets (nCTEQ, EPS and HKN) including the errors $\rightarrow$ differing predictions - need a more precise determination of $g^{p/Pb}(x, Q) \Rightarrow$ LHC data is needed!

How can $\gamma + Q$ help ?

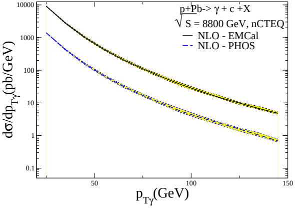
- At LO - only one hard scattering subprocess Compton subprocess - $g - Q$ initiated
- Standard approach: HQ PDFs are generated radiatively $\Rightarrow$ $R_g^{Pb} \simeq R_c^{Pb}$

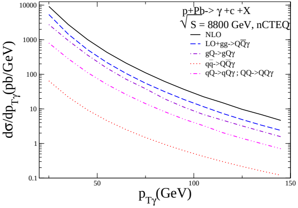




- Direct access to gluon nPDF

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

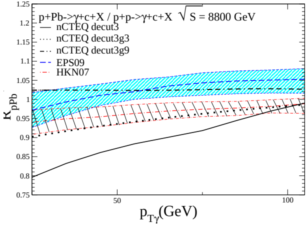


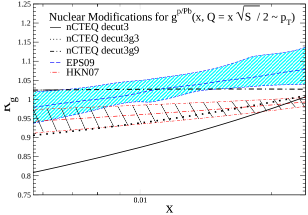


- g & Q initiated subprocesses dominate $(> 80\%) \Rightarrow$ sensitivity to gluon and HQ PDFs.
- Using an integrated yearly luminosity of $\mathcal{L} = 10^{-1} pb^{-1}$ a precursory number of events per year at EMCal for $\gamma + c$ is $\mathcal{N}^{pPb}_{\gamma+c} = 11900$ ($\sigma^{pPb}_{\gamma+c} = 119nb$) and for $\gamma + b$ is $\mathcal{N}^{pPb}_{\gamma+b} = 2270$ ($\sigma^{pPb}_{\gamma+b} = 22.7nb$)

Nuclear Modifications

$$R_{pA}^{\gamma Q} = \frac{\sigma(pA \to \gamma\ Q\ \mathrm{X})}{A\ \sigma(pp \to \gamma\ Q\ \mathrm{X})}$$



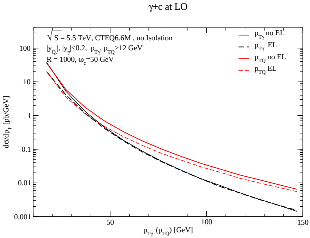


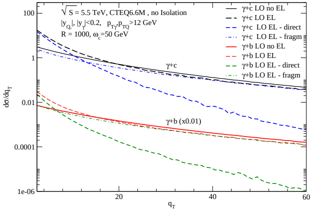
- $R_{pA}^{\gamma Q} \simeq R_g^{Pb}$ - in the x region probed at ALICE
- Measurements of $\gamma + Q$ with appropriate error bars will allow to distinguish between the different nPDF sets and place useful constraints on the gluon nPDF (arXiv:1012.1178)

$\gamma + Q$ in $A - A$ Collisions

- Single hadron production R_{AA} not enough to constrain/quantify the amount of energy loss of partons in QGP $\Rightarrow$ need more differential observables, like double inclusive particle production and in particular $\gamma + jet$ correlations (X.-N. Wang, Z. Huang, I. Sarcevic hep-ph/9605213, F. Arleo, P. Aurenche, Z. Belghobsi, J.-P. Guillet hep-ph/041008)
- $\gamma + Q$ is ideal for probing hot QCD medium
- Q - Jet Quenching
- γ is medium insensitive $\Rightarrow$ can gauge HQ's initial energy
- $\gamma + Q$ can help to clarify the energy loss in the heavy quark sector ($\epsilon_q > \epsilon_c > \epsilon_b$) (Heavy quark colorimetry of QCD matter -Y. L. Dokshitzer, D.E. Kharzeev)
- The two-particle final state further offers a range of observables $\Rightarrow$ can get a better handle on the energy lost - Photon-jet energy asymmetry, Momentum imbalance, Photon-jet pair momentum
- 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)]
- work in progress T.S., F.Arleo, I. Schienbein

Effects of energy loss on the $\gamma + Q$ cross-section - LO





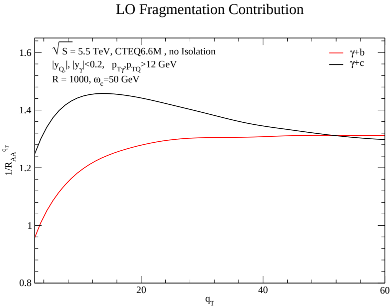
- Difference in spectrum vs p_{TQ} in vacuum and in medium $\Rightarrow$ due to energy loss
- $\frac{d\sigma}{p_{T\gamma}}$ spectrum almost unchanged (small difference between $\frac{d\sigma^{med}}{p_{T\gamma}}$ and $\frac{d\sigma^{vac}}{p_{T\gamma}}$ at low p_T due to experimental cuts)

- $q_\perp$ in more detail
- 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 - I

- Direct and fragmentation components 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

$q_\perp$ in more detail - II



- $\Delta E_c > \Delta E_b$; 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 a very useful 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.