Direct Photon Production In Association With A Heavy Quark Jet at Hadron and Ion Colliders

Rencontre de Physique des Particules

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LPSC

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Direct Photons and Heavy Quarks

Direct Photons

- Any photon that is produced during the hard scattering process or via fragmentation
- Escape confinement
- Photon acts as a probe of the hard scattering
- Great for testing PDFs

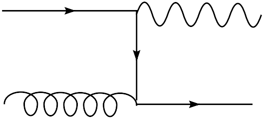
$\gamma + Q$ production

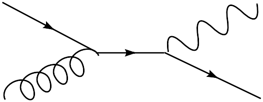
- Direct photons are produced in association with many different particles
- Look at one part of the cross section $\rightarrow$ piece with heavy quarks
- Better understand the role of heavy quarks in high p_T collisions
- Possibility to better constrain Parton Distribution Functions of heavy quarks

Leading Order Contributions

Compton Subprocess $g + Q \to Q + \gamma$

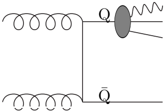
- Leading Order - $\mathcal{O}(\alpha\alpha_s)$ - Only **one** hard-scattering subprocess

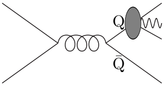




Fragmentation Effects

- LO: include all $2 \to 2$ subprocesses $\sim \mathcal{O}(\alpha_s^2)$, $\mathcal{O}(\alpha_s^2) \otimes D_{\gamma/q,g} \sim \alpha_s^2\alpha/\alpha_s = \alpha\alpha_s$





Isolation

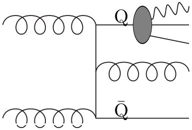
- Fragmentation contributions are greatly reduced due to isolation requirements
- Helps minimize background from photons coming from the decay of hadrons, e.g. $\pi^0 \to \gamma\gamma$

NLO Contributions

- $2 \rightarrow 3$ hard-scattering subprocesses - $\mathcal{O}(\alpha\alpha_s^2)$

$$g + g \rightarrow Q + \bar{Q} + \gamma \qquad Q + Q \rightarrow Q + Q + \gamma$$
$$g + Q \rightarrow g + Q + \gamma \qquad Q + \bar{Q} \rightarrow Q + \bar{Q} + \gamma$$
$$Q + q \rightarrow q + Q + \gamma \qquad q + \bar{q} \rightarrow Q + \bar{Q} + \gamma$$
$$Q + \bar{q} \rightarrow Q + \bar{q} + \gamma$$

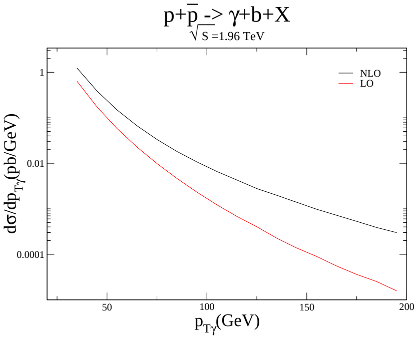
- Also need to include NLO fragmentation contributions - convolute all $2 \rightarrow 3 \sim \mathcal{O}(\alpha_s^3)$ with γ FF



Subprocesses and PDFs

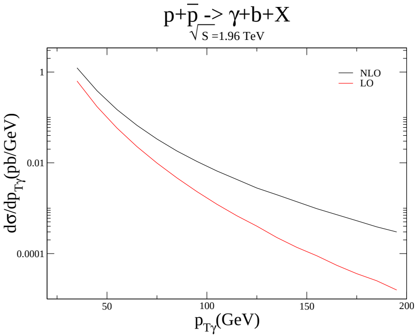
- Which subprocess dominates is highly dependent on collider type (pp, $p\bar{p}$) and center of mass energy
- Depending on this is what PDF and what x range can be probed

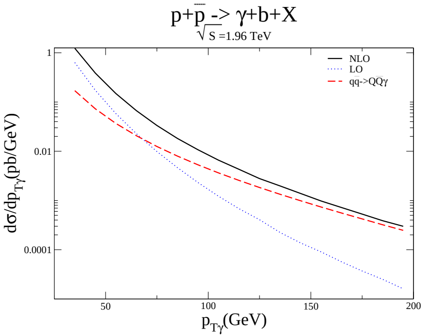
Tevatron Predictions



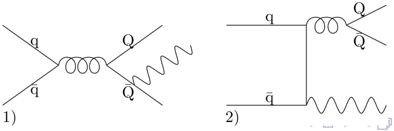
- As $p_{T\gamma}$ increases the difference between LO and NLO grows
- What drives this difference?

Tevatron Predictions



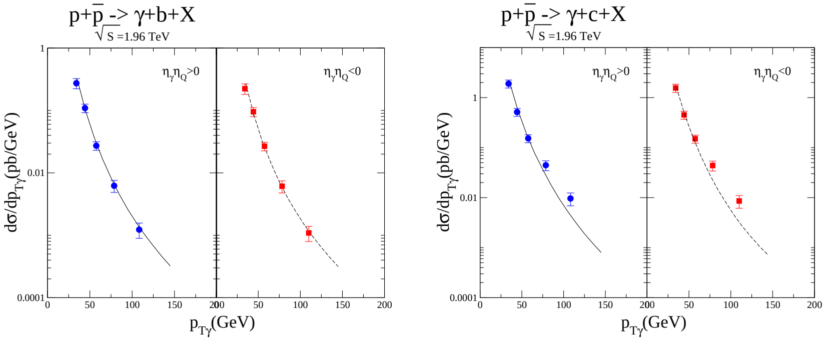


- As $p_{T\gamma}$ increases the difference between LO and NLO grows
- What drives this difference?
- Abundance of q and $\bar{q}$ $\rightarrow$ annihilation subprocess dominates $q\bar{q} \rightarrow \gamma Q\bar{Q}$



Comparison between theory and data

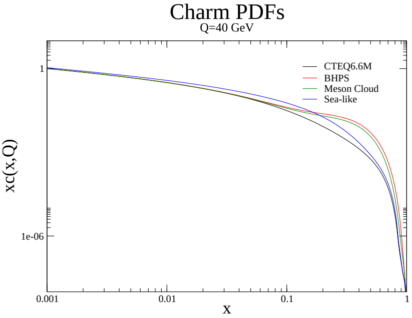
Measurements by DØ Collaboration



- There is really good agreement between data and theory for the bottom cross section
- For charm the data points at large $p_{T\gamma}$ lie above the theory curve $\rightarrow$ possible explanation - existence of intrinsic charm

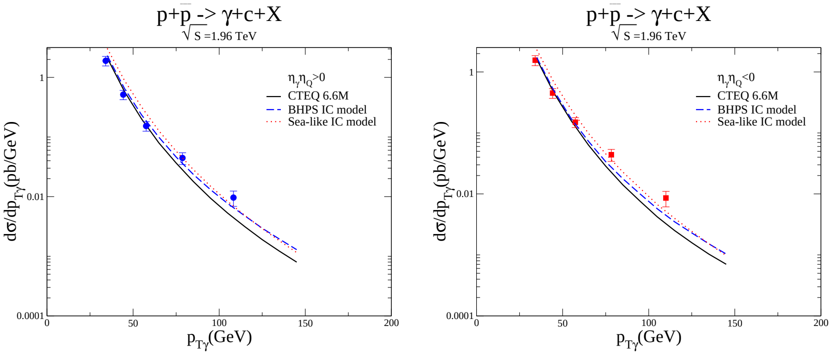
Intrinsic Charm

- Even if annihilation process dominates due to the center of mass energies can probe for IC at Tevatron
- Presently assumed that $c(x, \mu = m_c) = 0$, *i.e.* need only knowledge of gluon PDF, $c(x, Q) \sim g(x, Q)$
- Three intrinsic charm models - Non-perturbative charm component of the nucleon



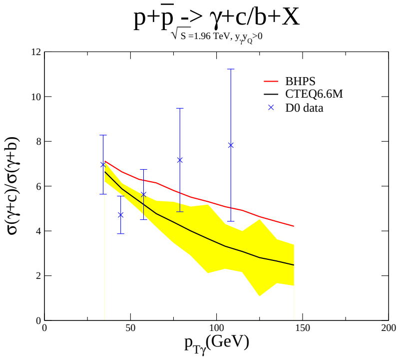
- For central rapidity $x \sim \frac{2p_T}{\sqrt{S}} \rightarrow$ at higher p_T can test for BHPS model

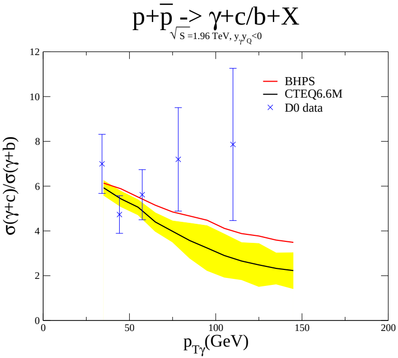
Comparison between theory and data - IC $c + \gamma$



- With the use of the BHPS PDFs the cross section grows at large $p_{T\gamma}$, but is still below the data
- However if we are to look at the ratio of the c to b cross section ...

Ratio of c and b

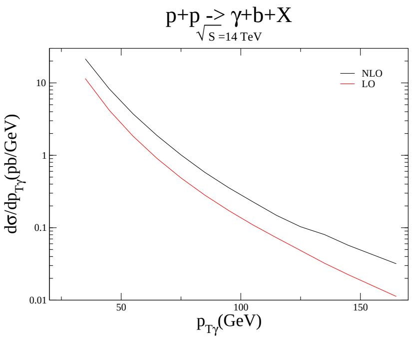


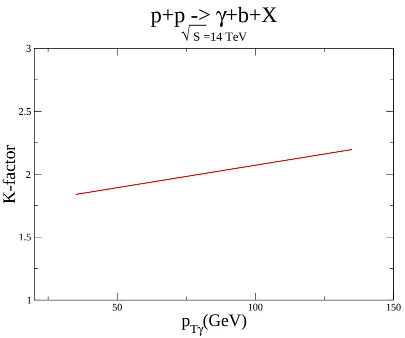


Things look better

LHC at 14 TeV

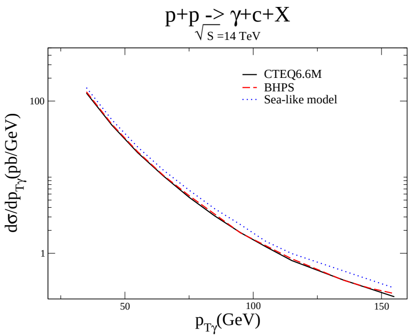
- At LHC *p* beams and higher center of mass
- No longer such a difference between LO and NLO





- Due to this there is great sensitivity to gluon and Q PDFs

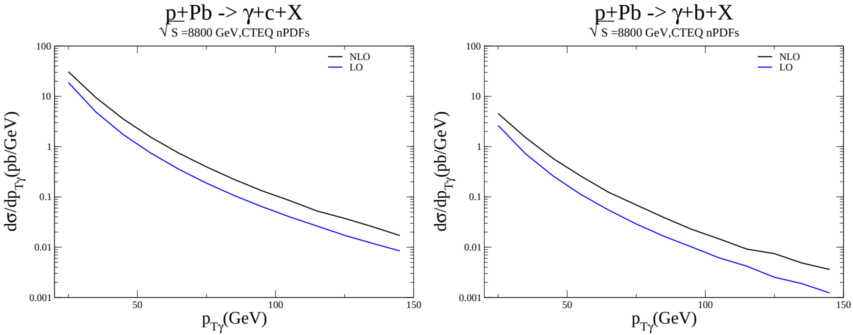
Intrinsic Charm at the LHC



- Due to smaller x probed at the LHC can still test IC, but mainly the Sea-like model

pPb collisions at the LHC

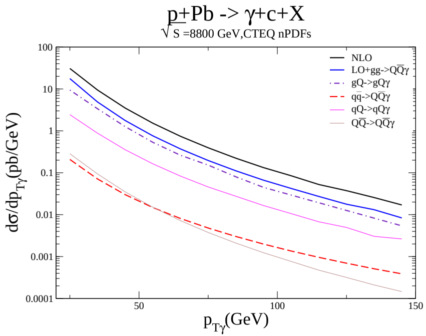
- $p_{T\gamma} > 20$ GeV, $p_{TQ} > 15 GeV$, $|y_\gamma| < 0.12$, $|y_Q| < 0.7$



- Not a big difference between NLO and LO → check other contributing subprocesses

pPb collisions - subprocess contributions

- $p_{T\gamma} > 20$ GeV, $p_{TQ} > 15\,GeV$, $|y_\gamma| < 0.12$, $|y_Q| < 0.7$



- The Compton subprocess dominates
- $\gamma + Q$ great probe of gluon + HQ nuclear PDFs

$\gamma + Q$ and nuclear PDFs

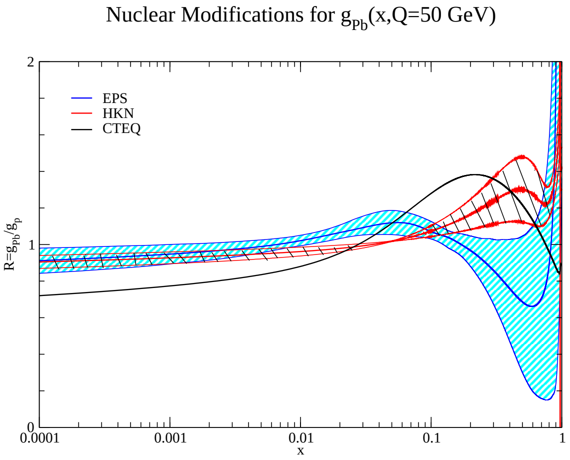
nuclear PDFs

- Give probability of finding a parton with a momentum fraction x in a nucleus
- Needed for heavy ion collisions, at ALICE , RHIC
- Gluon nPDF largely unconstrained

$\gamma + Q$

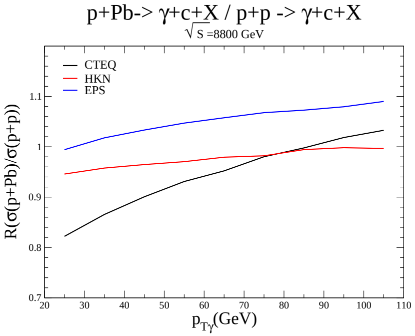
- Over 80% of the cross section is from $g + Q$ initiated subprocesses
- Can test both g + charm PDF in $\gamma + c$ processes
- If no IC charm all this sensitivity is due to the gluon PDF
- Same in $\gamma + b \rightarrow$ test g PDF

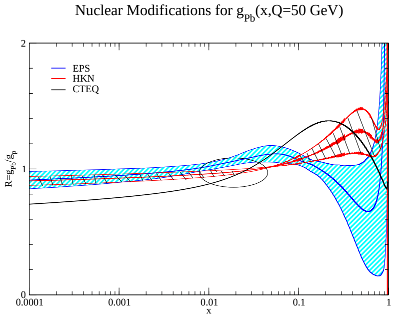
Nuclear Modifications



- Comparison between different nPDF sets for the gluon nuclear modifications $R = \frac{g_{Pb}(x,Q)}{g_p(x,Q)}$

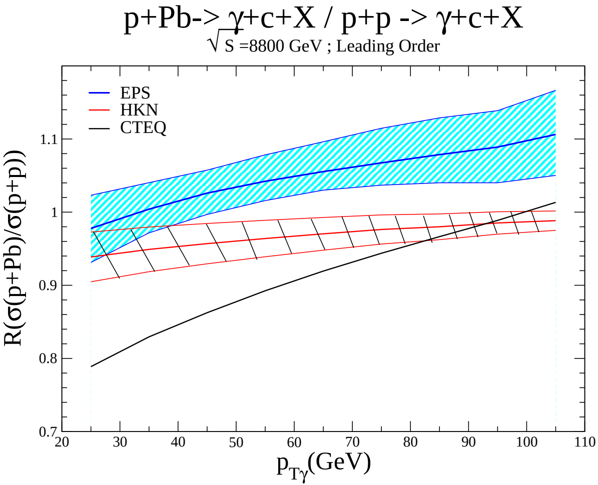
Nuclear Modifications to $\gamma + c$





- Probes relatively small x

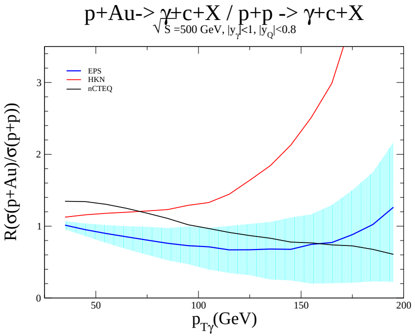
Nuclear Modifications to $\gamma + c$ LO

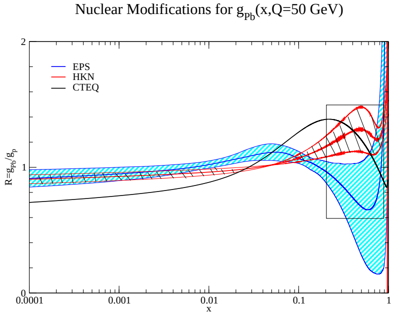


- Measurements with appropriate error bars can distinguish between the different nPDFs

gamma+Q at RHIC

- Preliminary ratios

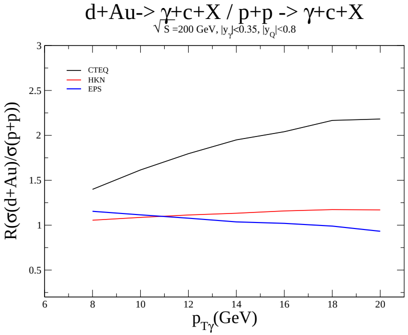


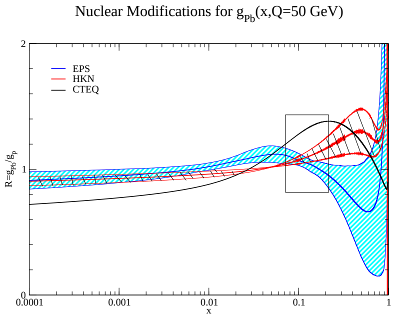


- At RHIC higher x region is probed

gamma+Q at RHIC

- Preliminary ratios





- At RHIC higher x region is probed

Conclusions

- At Tevatron energies $q\bar{q}$ dominates the cross section at large $p_{T\gamma}$
- Good distinction between different IC models, can test for BHPS, Sea-like
- At the LHC (pp 14 TeV or pPb) subprocesses with initial gluons and heavy quarks dominate
- Great process for constraining g and Q PDFs
- Can distinguish between different nPDF sets, CTEQ, HKN, EPS
- ALICE and RHIC probe different x regions → supplemental information
- Future work - predictions for **AA collisions**