Probing intrinsic heavy quark distributions through $\gamma + Q$ production

GDR PH-QCD

Tzvetalina Stavreva

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Direct Photons and Heavy Quarks

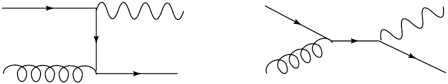
- Any photon that is produced during the hard scattering process or via fragmentation
- Escape confinement - photon acts as a probe of the hard scattering
- Useful for acquiring information on PDFs
- Focus on one part of the cross section $\rightarrow$ piece with heavy quarks - $\gamma + Q$ production
- PDFs of heavy quarks - possibility to constrain them
- Calculation of inclusive cross section for $p\bar{p}/pp \rightarrow \gamma QX$ (Q=c or b) up to Next to Leading Order
- Massless approximation
- NLO fragmentation effects included

Direct Photon and Heavy Quarks

how are they produced?

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

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



- Next-to-Leading Order - $\mathcal{O}(\alpha\alpha_s^2)$
  - Real Corrections - $2 \rightarrow 3$ body scattering subprocesses

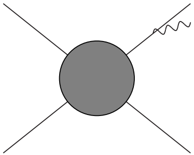
$$g + g \rightarrow Q + \bar{Q} + \gamma \qquad Q + Q \rightarrow Q + Q + \gamma$$
$$g + Q \rightarrow g + Q + \gamma \qquad Q + \bar{Q} \rightarrow Q + \bar{Q} + \gamma$$
$$Q + q \rightarrow q + Q + \gamma \qquad q + \bar{q} \rightarrow Q + \bar{Q} + \gamma$$
$$Q + \bar{q} \rightarrow Q + \bar{q} +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

  - Virtual Corrections -interference between LO Born diagram and virtual diagrams

Final state collinear singularities

- Absorb in Fragmentation Function (FF)
- Cancel when integrating over PS (KLN Theorem)

Photon Fragmentation

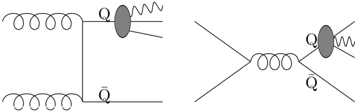


- When γ emitted collinearly to quark $\rightarrow$ absorb collinear singularity in Fragmentation Function into photons - $D_{\gamma/q,g}(z, \mu_F)$
- Large logs appear, while integrating over angle between photon and quark ; resum in γ FF via DGLAP
- Photon couples to quark, responsible for $\alpha \log(Q^2/\Lambda^2)$ behavior of γ FF; $\log(Q^2/\Lambda^2) \sim \frac{1}{\alpha_s}$
- $D_{\gamma/q,g}(z, \mu_F)$ is of order $\mathcal{O}(\alpha/\alpha_s)$

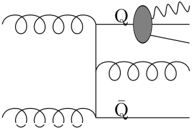
Direct Photon and Heavy Quarks

how are they produced?

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

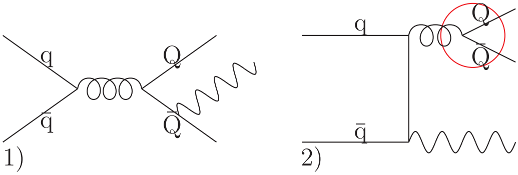


- Also need to include NLO fragmentation contributions - convolute all $2 \to 3 \sim \mathcal{O}(\alpha_s^3)$ with γ FF

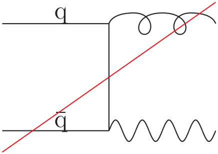


- Fragmentation contributions are greatly reduced due to isolation requirements
- Isolation useful for minimizing background from photons coming from the decay of hadrons, e.g. $\pi^0 \to \gamma\gamma$

Final State Collinear Singularity: $q\bar{q} \to Q\bar{Q}\gamma$

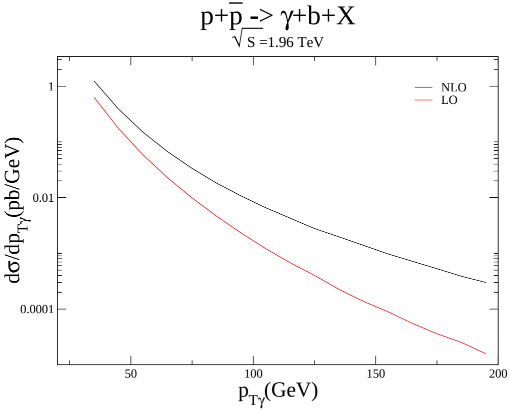


- Unlike for inclusive direct photon the annihilation subprocess does not appear at LO



- Jet observed in final state (not meson $\to$ no HQ FF)
- Regulate singularity by retaining HQ mass: $(p_Q + p_{\bar{Q}})^2 > 4m_Q^2$

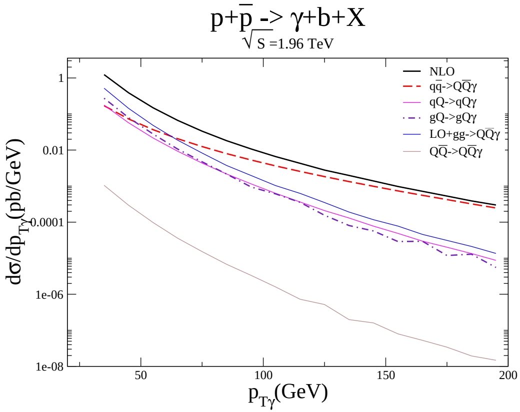
Tevatron Predictions



DØ cuts: $p_{T\gamma} > 30\ \mathrm{GeV}, p_{Tb} > 15 GeV, |y_\gamma| < 1, |y_b| < 0.8$

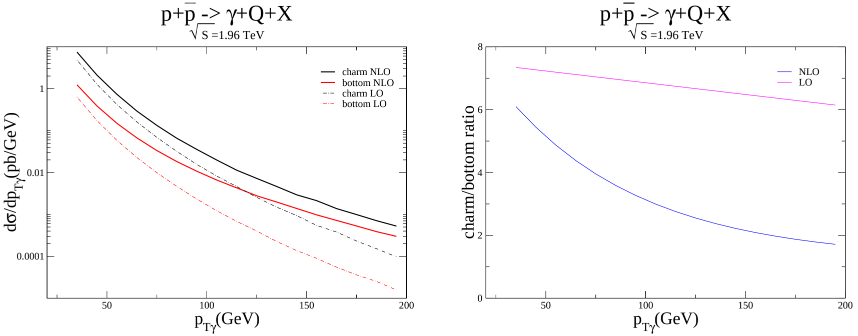
- As $p_{T\gamma}$ increases the difference between LO and NLO grows

Subprocess Contributions



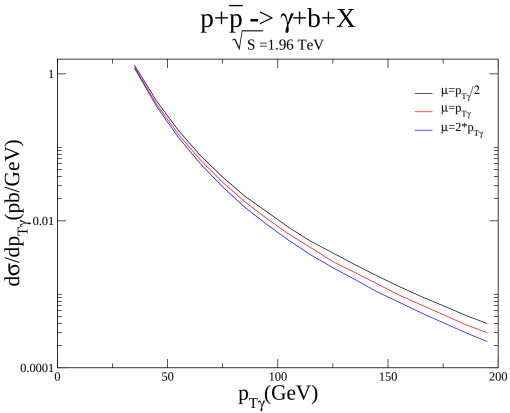
- At $p_{T\gamma} \sim 70$ GeV $q\bar{q} \to Q\bar{Q}\gamma$ starts to dominate
- Abundance of q & $\bar{q}$ at $p\bar{p}$ colliders

Comparison between charm and bottom



- Difference between b and c: quark charge $e_c^2 = 4/9, e_b^2 = 1/9$ and c PDF larger than b PDF - LO
- At higher $p_{T\gamma}$, $q\bar{q}$ dominates and difference is reduced - NLO

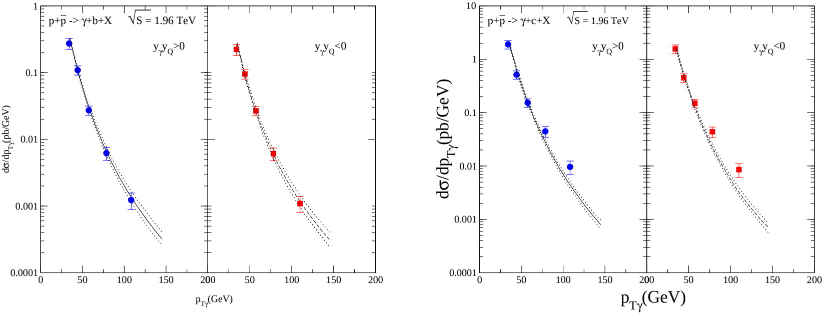
Scale Dependence



- Scale dependence increases with $p_{T\gamma}$
- $q\bar{q} \to Q\bar{Q}\gamma$ dominates at large $p_{T\gamma}$, it should really be considered as a LO subprocess

Comparison between theory & data

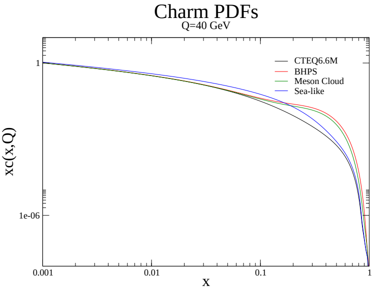
Measurements by DØ Collaboration [arXiv:0901.0739]



- Really good agreement for $\gamma + b$
- Not so for $\gamma + c$
- Given this: Possible explanation - existence of intrinsic charm rather than higher order corrections

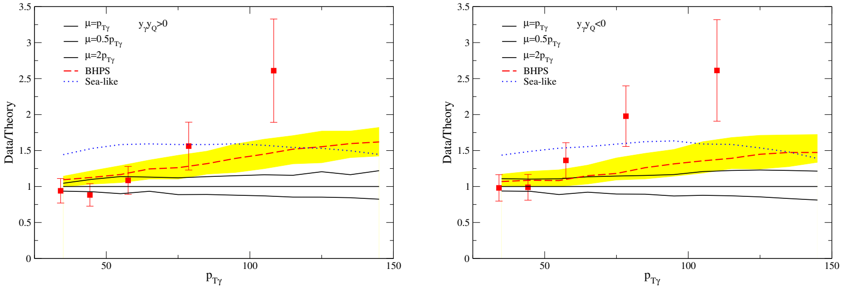
charm PDF

- Presently assumed charm PDF radiatively generated , i.e. need only knowledge of gluon PDF
- Some data (EMC charm structure function at large x suggest) IC component in nucleus - checked by global analysis by CTEQ6.5, CTEQ6.6
- Non perturbative models for IC component to nucleus:



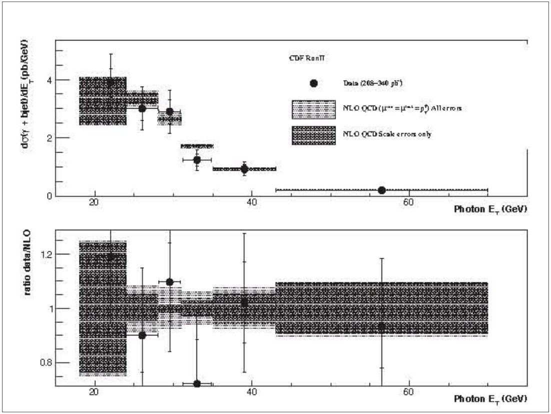
- BHPS (Brodsky et.al.) (CTEQ6.6C0, CTEQ6.6C1) & Meson Cloud (CTEQ6.5C2, CTEQ6.5C3) - light-cone models - IC at high x
- Sea-like model (CTEQ6.6C2, CTEQ6.6C3) - $c(x, Q) \sim \bar{u}(x, Q) + \bar{d}(x, Q)$

Intrinsic Charm effect on $\gamma + c$



- Sealike - overshoots data at low pT and undershoots at high pT
- BHPS - the cross section grows at large pT, but still below data
- Result inconclusive -
  - Pending New Measurements - Tevatron - CDF & DØ
  - Test at pp Colliders - RHIC & LHC

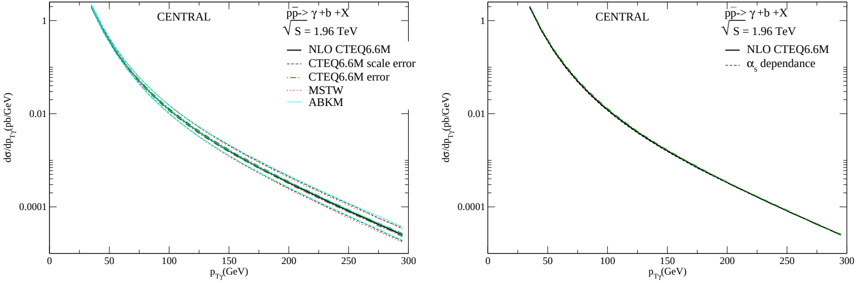
CDF



Tuesday, October 18, 2011

- arXiv:0912.3453
- Good agreement for $\gamma + b$

PDF Sets

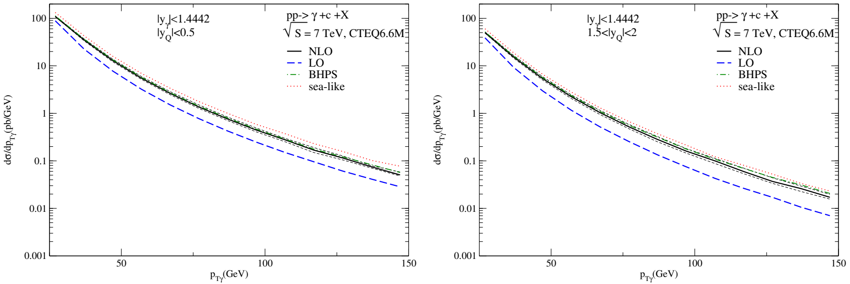


- Different PDF sets: CTEQ6.6M,MSTW,ABKM - result unchanged
- $\alpha_s(M_Z) = 0.116, 0.117, 0.119, 0.120$ CTEQ6.6AS

LHC - CMS
Experimental Cuts

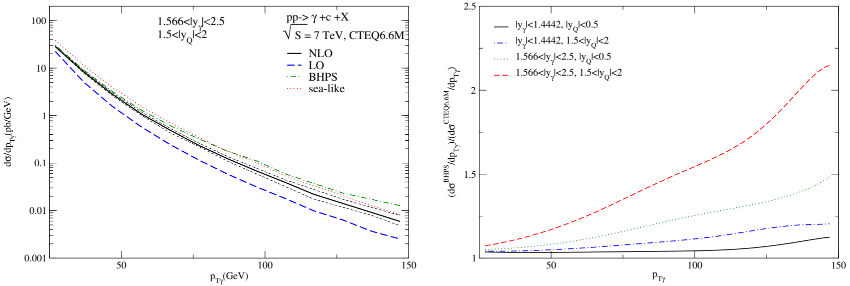
	p_T	Rapidity	Isolation Cuts
Photon	$p_{T,\gamma}^{min} = 20$ GeV	$\lvert y_\gamma \rvert < 1.4442$	$R = 0.4$, $p_T^{\rm th} = 4.2$ GeV
		$1.566 < \lvert y_\gamma \rvert < 2.5$	
Heavy Jet	$p_{T,Q}^{min} = 18$ GeV	$\lvert y_Q \rvert < 2.0$	——

Intrinsic Charm at the LHC - CMS



- At LHC p beams and higher center of mass
- 3 combinations demonstrate dependence on rapidity cut on BHPS
    - $|y_\gamma| < 1.4442$, $|y_Q| < 0.5$
    - $|y_\gamma| < 1.4442$, $1.5 < |y_Q| < 2$
    - $1.566 < |y_\gamma| < 2.5$, $1.5 < |y_Q| < 2$

Intrinsic Charm at the LHC - CMS



- $x \sim \frac{p_T}{\sqrt{S}}(e^{y_1} + e^{y_2})$
- Need to consider forward rapidities - smaller x - to test for BHPS-IC at the LHC

LHC - ATLAS - Experimental Cuts

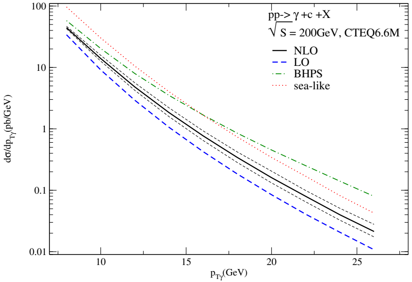
	p_T	Rapidity	Isolation Cuts/Jet
Photon - C	$p_{T,\gamma}^{min} = 45$ GeV	$\|y_\gamma\| < 1.37$	$R = 0.4,\ p_T^{had} < 4 GeV$
Photon - F	$p_{T,\gamma}^{min} = 45$ GeV	$1.52 < \|y_\gamma\| < 2.37$	$R = 0.4,\ p_T^{had} < 4 GeV$
Heavy Jet - C	$p_{T,Q}^{min} = 20$ GeV	$\|y_Q\| < 1$	$R_{jet} < 0.5$
Heavy Jet - F	$p_{T,Q}^{min} = 20$ GeV	$1 < \|y_Q\| < 2$	$R_{jet} < 0.5$
			$\Delta R(\gamma, jet) > 0.6$

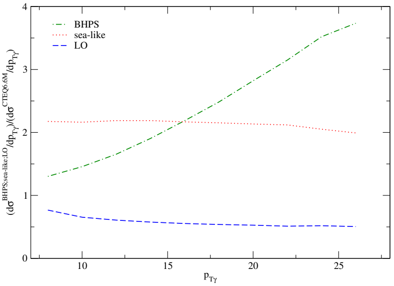
- Experimental Cuts similar to CMS
- Should measure up to $p_{T\gamma} \sim 500 GeV$

RHIC - PHENIX
Experimental Cuts

	p_T	Rapidity	Isolation Cuts
Photon*	$p_{T,\gamma}^{min} = 7$ GeV	$\|y_\gamma\| < 0.35$	$R = 0.5$, $\epsilon < 0.1 E_\gamma$
Heavy Jet	$p_{T,Q}^{min} = 5$ GeV	$\|y_Q\| < 0.8$	——

Intrinsic Charm at the RHIC - PHENIX



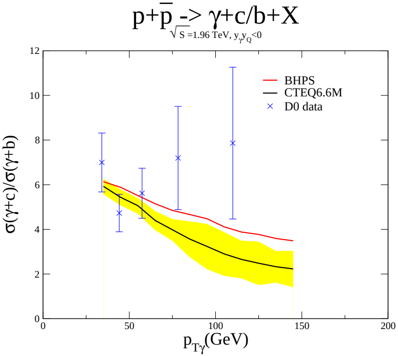


- Small center of mass energy probes high $x \sim p_T/\sqrt{S}$
- Cross section is very sensitive to IC - especially BHPS

Conclusions

- At Tevatron $q\bar{q}$ 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 collisions - subprocesses with initial gluons and heavy quarks dominate
- Higher rapidity needed to test for IC
- RHIC probes high x regions $\rightarrow$ good for probing IC
- $\gamma + Q$ good process for constraining charm (bottom) PDFs

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



- things look better