Probing the intrinsic heavy quark content of the nucleon through direct photon & heavy quark production

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LPSC Grenoble

Direct Photons

- Direct Photons
  - Produced during hard scattering or via fragmentation
  - Not from the decay of hadrons, such as $\pi^0 \rightarrow \gamma\gamma$, etc.

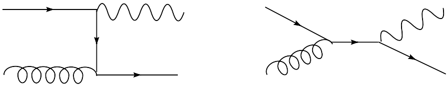
  - Carriers of electromagnetic force
  - Escape confinement
  - Photon acts as a probe of the hard scattering
  - Charge coupling allows for a distinction between charm and bottom
- Direct Photons + Heavy Quarks
  - Naturally sensitive to heavy quark PDFs

Direct Photon and Heavy Quarks - hardscattering

how are they produced?

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

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



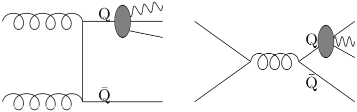
- Next-to-Leading Order - $\mathcal{O}(\alpha\alpha_s^2)$
  - Real Corrections - $2 \to 3$ body scattering subprocesses

$g + g \to Q + \bar{Q} + \gamma$	$Q + Q \to Q + Q + \gamma$
$g + Q \to g + Q + \gamma$	$Q + \bar{Q} \to Q + \bar{Q} + \gamma$
$Q + q \to q + Q + \gamma$	$q + \bar{q} \to Q + \bar{Q} + \gamma$
$Q + \bar{q} \to Q + \bar{q} + \gamma$	

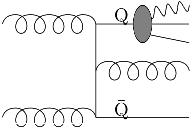
  - Virtual Corrections - interference between LO Born diagram and virtual diagrams

Direct Photon and Heavy Quarks - fragmentation

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

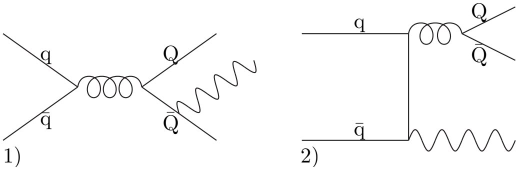


- Also need to include NLO fragmentation contributions - convolute all $2 \to 3 \sim \mathcal{O}(\alpha_s^3)$ with γ FF

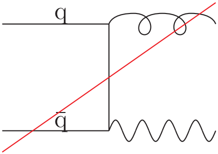


- Reduced due to isolation requirements
- minimizes background from photons : $\pi^0 \to \gamma\gamma$

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



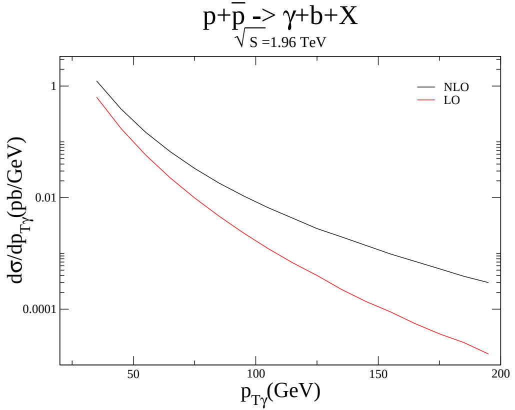
- Unlike for inclusive direct photon the annihilation subprocess does not appear at LO



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

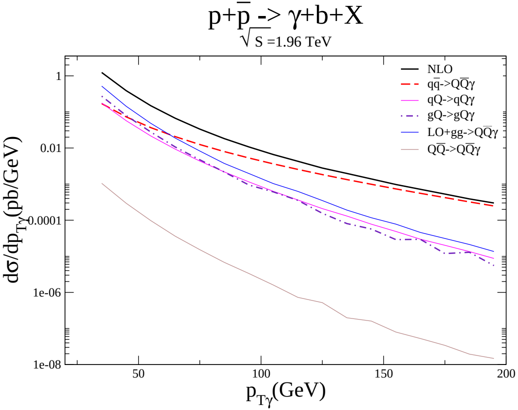
Tevatron Predictions

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



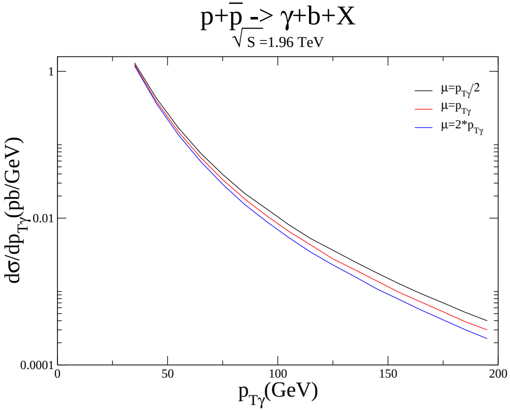
- As $p_{T\gamma}$ increases the difference between LO and NLO grows

Subprocess Contributions



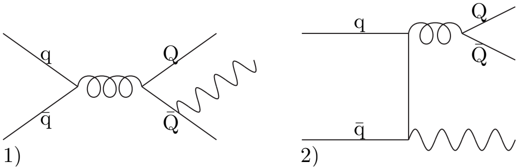
- At $p_{T\gamma} \sim 70\ \mathrm{GeV}$ $q\bar{q} \to Q\bar{Q}\gamma$ starts to dominate
- Abundance of q & $\bar{q}$ at $p\bar{p}$ colliders

Scale Dependence



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

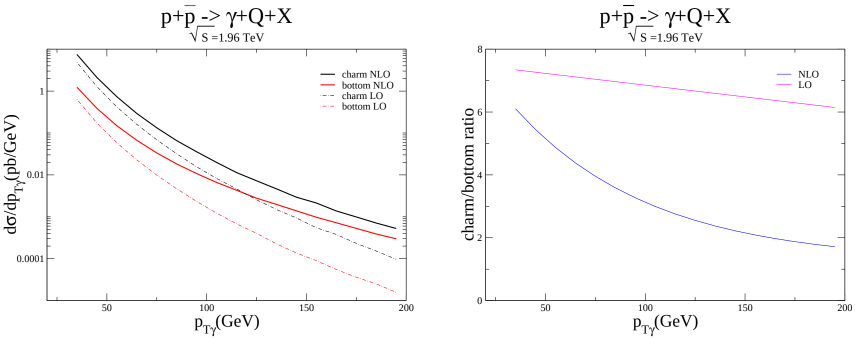
Comparison between charm and bottom



- Diagram 1)$\sim e_Q^2$ - photon couples to heavy quark
- Diagram 2)$\sim e_q^2$ - photon couples to initial quarks

Diagram 2) is the dominant one $\rightarrow$ the difference between the c and b distribution should decrease at large p_T

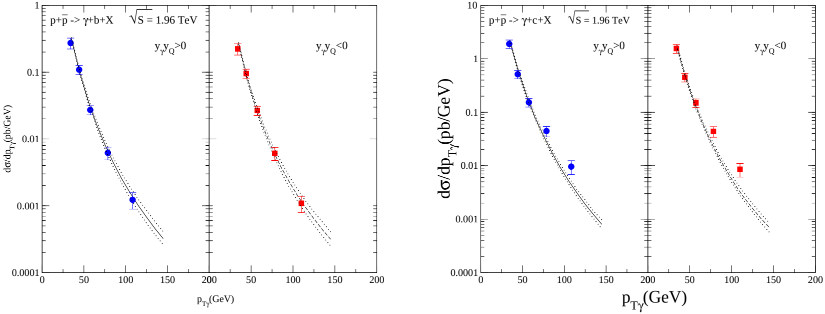
Comparison between charm and bottom



- 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

Comparison between theory & data

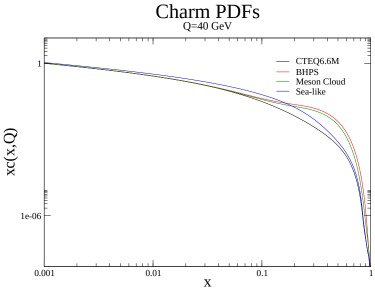
Measurements by DØ Collaboration [arXiv:0901.0739]



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

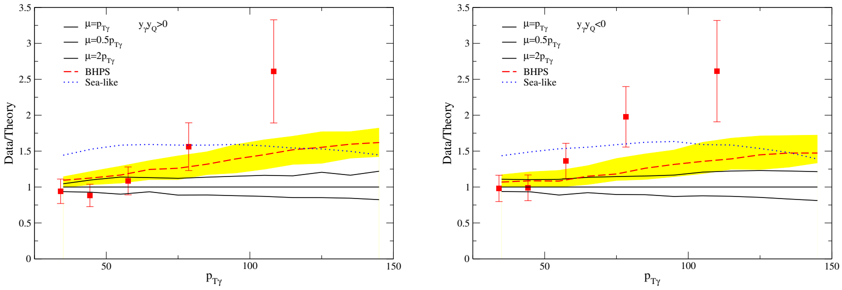
charm PDF

- Presently assumed charm PDF radiatively generated $c(x, \mu = m_c) = 0$, i.e. need only knowledge of gluon PDF $c(x, Q) \sim g(x, Q)$
- 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:



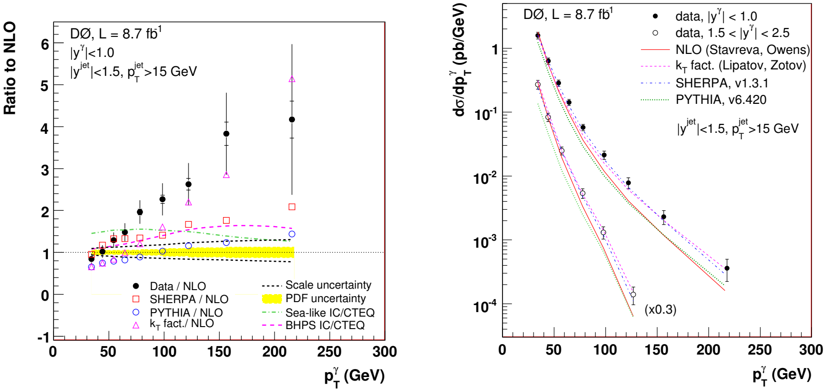
- BHPS (Brodsky et.al.) (CTEQ6.6C0, CTEQ6.6C1) & Meson Cloud (CTEQ6.5C2, CTEQ6.5C3) - light-cone models - IC at high x
- Sea-like model (CTEQ6.6C2, CTEQ6.6C3) - $c(x, Q) \sim \bar{u}(x, Q) + \bar{d}(x, Q)$

Intrinsic Charm effect on $\gamma + c$



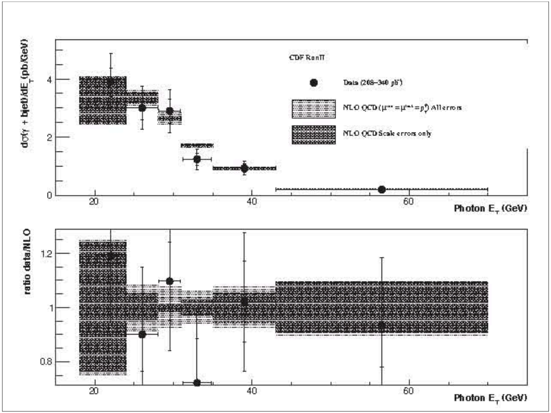
- Sealike - overshoots data at low pT and undershoots at high pT
- BHPS - the cross section grows at large pT, but still below data
- Result inconclusive -
  - New Measurements - Tevatron - CDF & DØ
  - Test at pp Colliders - RHIC & LHC

new results DØ



- $\gamma + c$ - left - arXiv:1210.5033
- $\gamma + b$ - right - arXiv:1203.5865
- Even higher discrepancy - now consider all leading jets

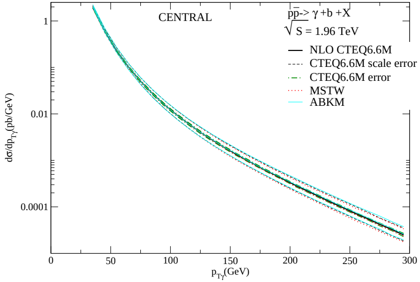
CDF



Tuesday, October 18, 2011

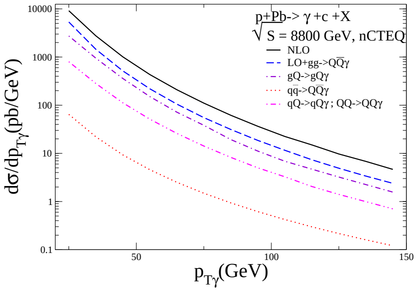
- arXiv:0912.3453
- Good agreement for $\gamma + b$

PDF Sets



- Different PDF sets: CTEQ6.6M,MSTW,ABKM - result unchanged

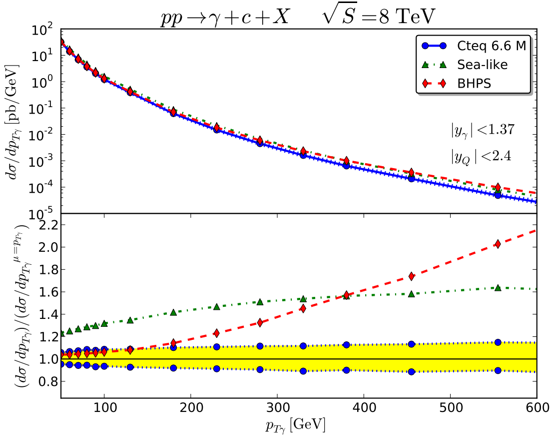
Subprocess Contributions in pp Collisions



- *g & Q* initiated subprocesses dominate ($> 80\%$) $\Rightarrow$ sensitivity to gluon and HQ PDFs.

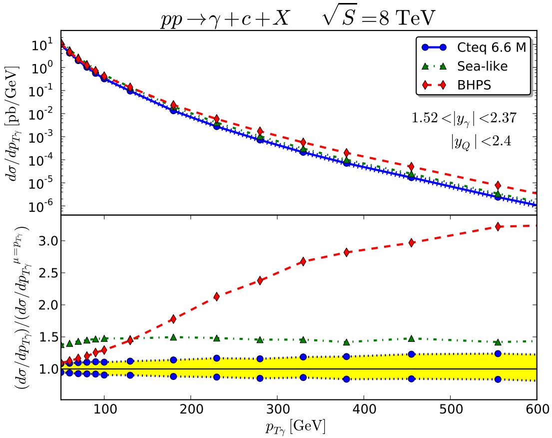
	p_T	Rapidity	Isolation Cuts
Photon	$p_{T,\gamma}^{min} = 45$ GeV	$\|y_\gamma\| < 1.37$	$R = 0.4,\ E_T = 7$ GeV
	$p_{T,\gamma}^{max} = 1000$ GeV	$1.52 < \|y_\gamma\| < 2.37$	
Heavy Jet	$p_{T,Q}^{min} = 20$ GeV	$\|y_Q\| < 2.4$	$R_{jet} > 0.4, R_{Q\gamma} > 1$

$\gamma + c$ Central Rapidity

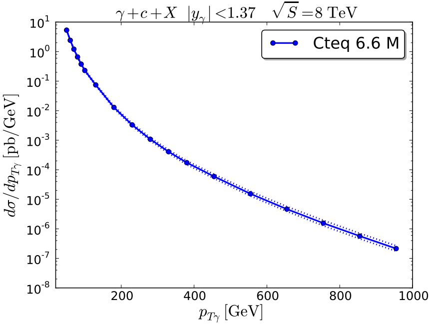


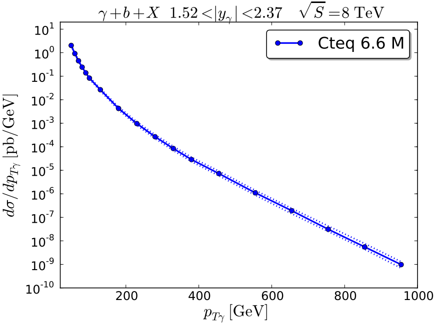
- IC shows up at much higher p_T
- dependence on rapidity

$\gamma + c$ Forward Rapidity



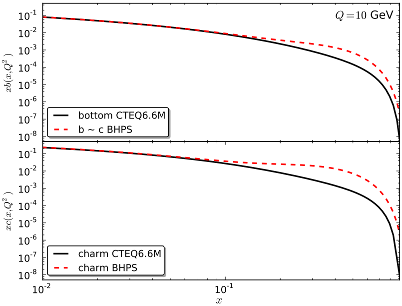
- $x \sim \frac{p_T}{\sqrt{S}}(e^{y_1} + e^{y_2})$
- Consider forward rapidities at LHC

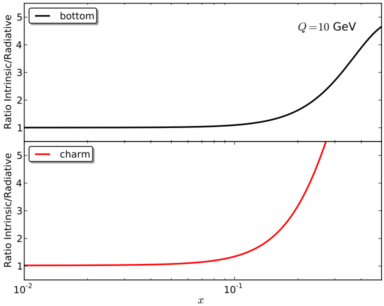




- IB$\sim m_c^2/m_b^2$IC

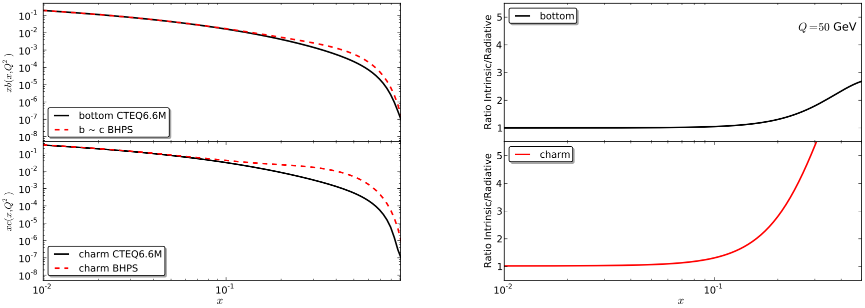
Intrinsic c/b





- $Q = 10$ GeV

Intrinsic c/b

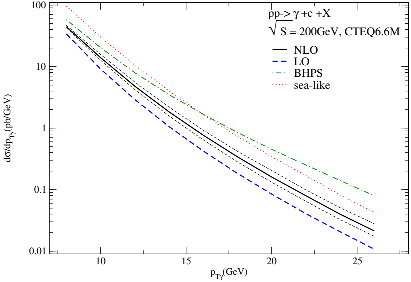


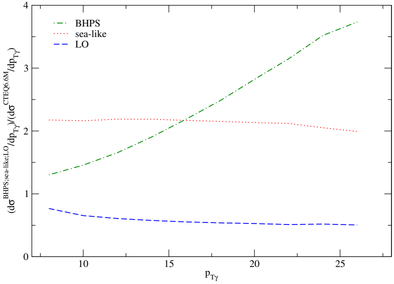
- $Q = 50$ GeV

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 RHIC





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

Summary

- $\gamma + Q$ production very sensitive to the heavy quark PDFs
- Discrepancy between data and experiment @ Tevatron
- LHC measurements needed to search for IC & IB