# Impact of Light-cone models for intrinsic charm on production of $\gamma + c$-jet differential cross section at LHC and Tevatron

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# Outline

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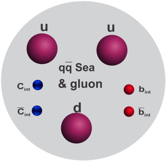
- Introduction
- Intrinsic charm and BHPS
- Light-cone models for intrinsic charm
- Evolution of intrinsic charm
- Role of intrinsic charm in the $\gamma + c$-jet Cross section

# The Intrinsic Charm (IC)

In 1980, Brodsky, Hoyer, Peterson, Sakai (BHPS) suggested the existence of "intrinsic" charm[1] to explain unexpected experimental results:

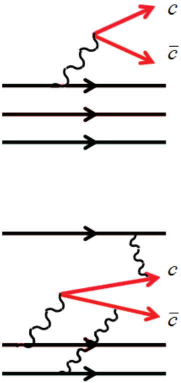
1. The copious diffractive production of charmed hadrons at large longitudinal momentum in high energy proton-nucleon and pion-nucleon collisions.
2. The anomalously large number of same-sign di-muon events observed in deep inelastic neutrino reactions.

$$|p\rangle = \mathscr{P}_{3q}|uud\rangle + \mathscr{P}_{5c\bar{c}}|uudc\bar{c}\rangle + \dots .$$



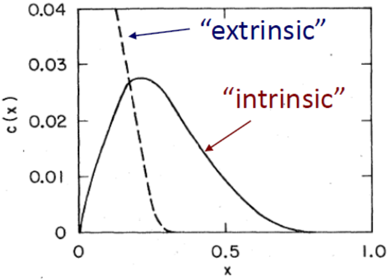

[1] S.J. Brodsky, P. Hoyer, C. Peterson, and N. Sakai, Phys. Lett. B 93, 451 (1980).

# Intrinsic vs extrinsic




"extrinsic"

"intrinsic"



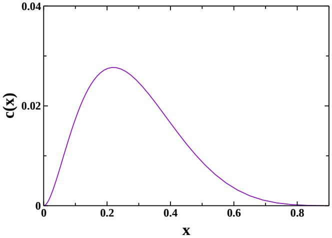

The intrinsic charm originating from the five-quark Fock state is to be separated from the extrinsic charm produced in the splitting of gluons into $c\bar{c}$.

# $x$-distribution for intrinsic charm

$$|p\rangle = \mathscr{P}_5^{uud}|uud\rangle + \mathscr{P}_5^{Q\bar{Q}}|uudQ\bar{Q}\rangle + \dots .$$

In the limit of large mass for quark Q (charm) $(m_Q, m_{\bar{Q}} \gg m_p, m_q)$

$$\bar{c}(x) = c(x) = \mathscr{N} x^2 \left[ \frac{(1-x)}{3} \left(1 + 10x + x^2\right) + 2x(1+x)\ln(x) \right].$$



# Scalar five-quark model

Scalar five-quark model[2]

$$dP = \mathcal{N} \prod_{i=1}^{N} \frac{dx_i}{x_i} \delta(1 - \sum_{i=1}^{N} x_i) \prod_{i=1}^{N} d^2 k_{i\perp} \delta^{(2)}(\sum_{i=1}^{N} k_{i\perp}) \frac{F^2(s)}{(s - M^2)^2},$$

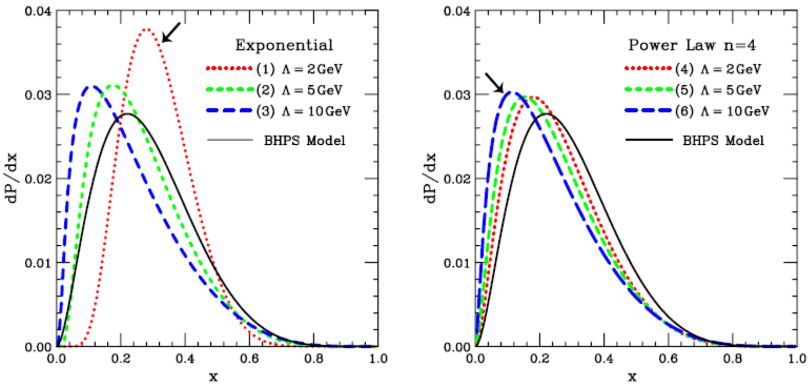
$$s = \sum_{i=1}^{N} (m_i^2 + k_{i\perp}^2)/x_i,$$

$$F^2(s) = \exp[-(s - M^2)/\Lambda^2],$$

Wave function factor

$$F^2(s) = (s + \Lambda^2)^{-n},$$

[2] J. Pumplin, Phys. Rev. D **73**, 114015 (2006) [hep-ph/0508184].


Exponential
(1) Λ = 2GeV
(2) Λ = 5GeV
(3) Λ = 10GeV
BHPS Model
dP/dx
x
Power Law n=4
(4) Λ = 2GeV
(5) Λ = 5GeV
(6) Λ = 10GeV
BHPS Model
dP/dx
x

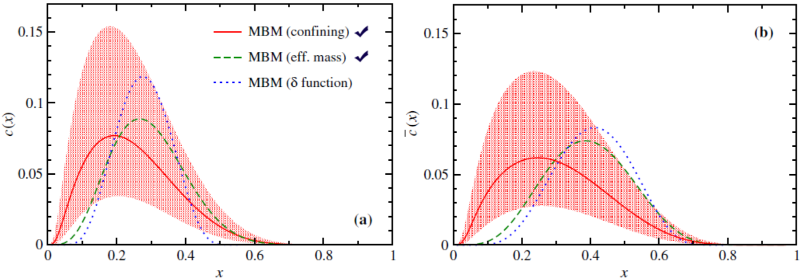
# Meson Baryon model (MBM)

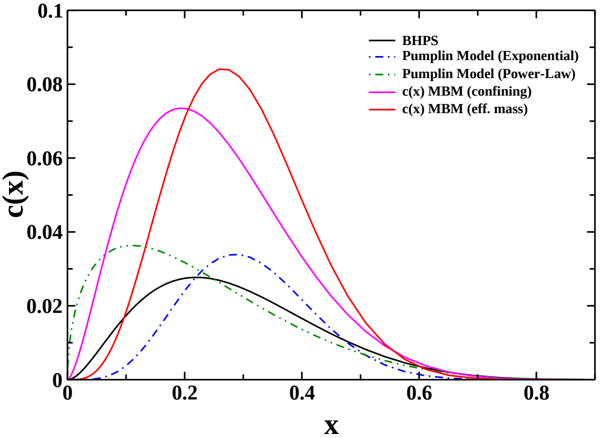
The proton fluctuates to a virtual baryon plus a meson state[3] [4]

$$p(uud) \rightarrow \Lambda_c^+(udc) + \bar{D}^0(u\bar{c})$$

$$|p\rangle = \sqrt{Z}|p\rangle_{bare} + \sum_{M,B} \int dy d^2\mathbf{k}_\perp \phi_{MB}(y, k_\perp^2)|M(y, \mathbf{k}_\perp); B(1-y, -\mathbf{k}_\perp)\rangle,$$

[3] A. W. Thomas, Phys. Lett. B **126**, 97 (1983).
[4] S. Kumano, Phys. Rep. **303**, 183 (1998).


0.15
0.1
0.05
0
$c(x)$
0
0.2
0.4
0.6
0.8
1
$x$
MBM (confining)
MBM (eff. mass)
MBM (δ function)
(a)
0.15
0.1
0.05
0
$\bar{c}(x)$
0
0.2
0.4
0.6
0.8
1
$x$
(b)


0.1
0.08
0.06
0.04
0.02
0
c(x)
0
0.2
0.4
0.6
0.8
x
BHPS
Pumplin Model (Exponential)
Pumplin Model (Power-Law)
c(x) MBM (confining)
c(x) MBM (eff. mass)

# Evolution of charm distribution

The DGLAP evolution equation that used for the standard approach of global analysis has compact form as

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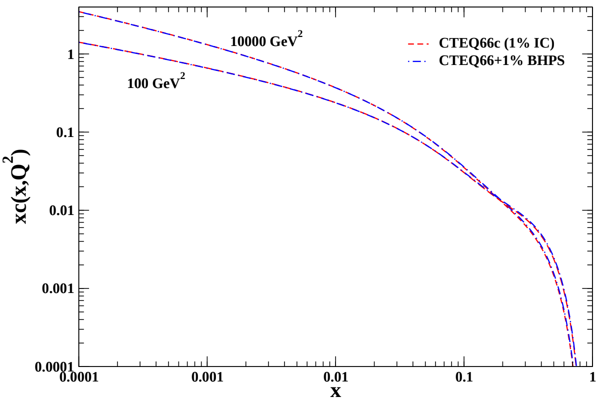
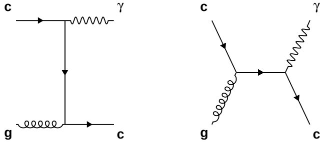
$$\dot{Q}_{ext} = P_{Qg} \otimes g + P_{Qg} \otimes q + P_{QQ} \otimes Q_{ext}$$
$$\dot{Q}_{int} = P_{QQ} \otimes Q_{int}$$


10000 GeV$^2$
100 GeV$^2$
CTEQ66c (1% IC)
CTEQ66+1% BHPS
1
0.1
0.01
0.001
0.0001
0.0001
0.001
0.01
0.1
1
x
xc(x,Q$^2$)

# The prompt photon production in association with a c-jet

Leading order (LO) Compton hard-scattering subprocess $\mathcal{O}(\alpha_S \alpha)$

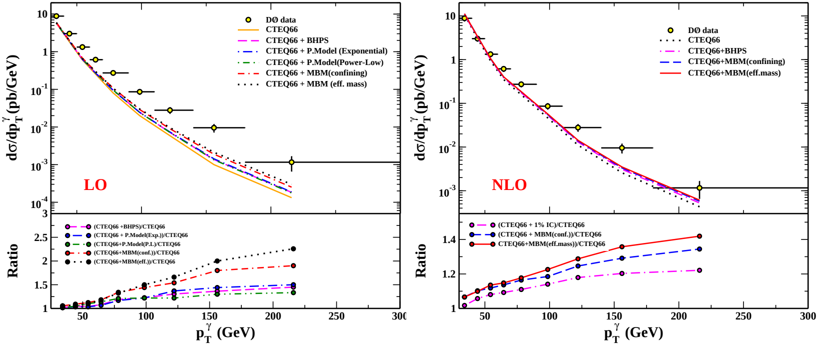
$$g\ c \rightarrow \gamma\ c$$




Next-to-leading order (NLO) contributions $\mathcal{O}(\alpha_S^2 \alpha)$

$$gg \rightarrow \gamma c\bar{c} \qquad gc \rightarrow \gamma gc$$
$$c\bar{q} \rightarrow \gamma \bar{q}c \qquad c\bar{c} \rightarrow \gamma c\bar{c} \qquad q\bar{q} \rightarrow \gamma c\bar{c}$$
$$cq \rightarrow \gamma qc \qquad cc \rightarrow \gamma cc$$

# Comparison to Tevatron data

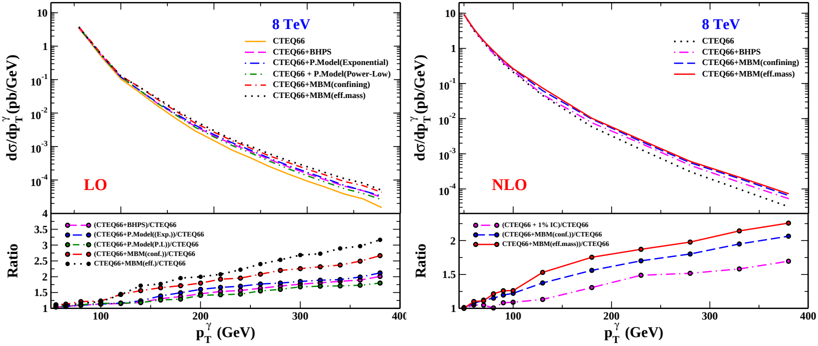



$|y^\gamma| < 1.0, \quad 30 < p_T^\gamma < 300$ GeV,
$|\eta^c| < 1.5$ and $p_T^c > 15$ GeV,

$\sqrt{s} = 1.96$ TeV

$$x_c \geq x_F = 2p_T^\gamma/\sqrt{s}\sinh(\eta_\gamma)$$

# Predictions for the LHC




$1.52 < |y^\gamma| < 2.37, \quad 50 < p_T^\gamma < 400$ GeV,
$|\eta^c| < 2.4, \quad p_T^c > 20$ GeV

$\sqrt{s} = 8$ TeV [5].

[5] V. A. Bednyakov, M. A. Demichev, G. I. Lykasov, T. Stavreva and M. Stockton, Phys. Lett. B **728**, 602 (2014).

# Conclusion

1. Non singlet evolution of IC allows us adding IC distribution to any PDF set without performing a new global analysis of PDFs.

2. Regardless of the chosen intrinsic model, the IC contribution increases the magnitude of the cross section and have a more significant effect at large transverse momentum of the photon.