Intrinsic charm and photon production cross section

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Introduction

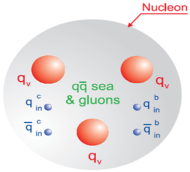
- In 1980, Brodsky, Hoyer, Peterson, Sakai (BHPS) suggested the existence of "intrinsic" charm in the nucleon.

J. Brodsky, P. Hoyer, C. Peterson, and N. Sakai, Phys. Lett. B **93**, 451 (1980).

S. J. Brodsky, C. Peterson, and N. Sakai, Phys. Rev. D **23**, 2745 (1981).

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

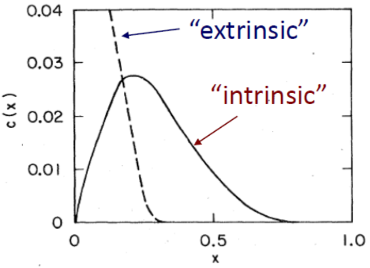
The $\mathscr{P}_{5c\bar{c}}$ is probability for the $|uudc\bar{c}\rangle$ five-quark Fock state in the proton.



Schematic presentation of a nucleon consisting of valence, sea quarks, gluons, and pairs of the intrinsic charm and bottom quarks.

Introduction

- The intrinsic charm originating from the five-quark Fock state is to be distinguished from the extrinsic charm produced in the splitting of gluons into $c\bar{c}$, which is well described by QCD.



Intrinsic heavy quark content of the nucleon

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- In the standard approach employed by almost all global analyses of PDFs, the heavy quark distributions are generated *radiatively*, according to DGLAP evolution equations, starting with a perturbatively calculable boundary condition at a scale of the order of the heavy quark mass.

- There are no free fit parameters associated to the heavy quark distribution and it is entirely related to the gluon distribution function at the scale of the boundary condition.

S. J. Brodsky, et. al arXiv:1504.06287 [hep-ph].

Intrinsic heavy quark content of the nucleon

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- "Intrinsic heavy quarks": charm, and bottom quarks are thus a fundamental property of the wave functions of hadronic bound states.
  Intrinsic heavy quarks are dominant at high x and depend on $1/M_Q^2$.

Intrinsic heavy quark content of the nucleon

The probability distribution as a function of x in a general n–particle intrinsic $c\bar{c}$ Fock state is

$$\frac{dP_{\mathrm{IC}}}{dx_i \cdots dx_n} = N_n \, \frac{\delta(1 - \sum_{i=1}^{n} x_i)}{(m_h^2 - \sum_{i=1}^{n} (\widehat{m}_i^2 / x_i))^2} \, ,$$

where N_n normalizes the n-particle Fock state probability.
In the heavy quark limit, $\widehat{m}_c$, $\widehat{m}_{\bar{c}} \gg m_h$, $\widehat{m}_q$,

$$\frac{dP_{\mathrm{IC}}}{dx_i \cdots dx_n} = N_n \frac{x_c^2 x_{\bar{c}}^2}{(x_c + x_{\bar{c}})^2} \, \delta\left(1 - \sum_{i=1}^{n} x_i\right) ,$$

So the intrisic charm distribution is as followings:

$$xc_{int}(x) = x \int dx_1 \cdots dx_{\bar{c}} \frac{dP_{\mathrm{IC}}}{dx_i \cdots dx_{\bar{c}} dx_c} \, .$$

Five-quark $|uudQ\bar{Q}\rangle$ Fock state

According to the BHPS model the probability distribution for the five-quark $|uudQ\bar{Q}\rangle$ Fock state , can be written as

$$P(x_1,...,x_5) = \mathcal{N}\,\delta(1-\sum_{i=1}^{5} x_i)[M^2 - \sum_{i=1}^{5} \frac{m_i^2}{x_i}]^{-2}$$

For the case that Q is a heavy quark:

$$P(x_1,...,x_5) = \mathcal{N}_5\,\delta(1-\sum_{i=1}^{5} x_i)\frac{x_4^2 x_5^2}{(x_4+x_5)^2},$$

where $\mathcal{N}_5 = \mathcal{N}/m^4_{Q\bar{Q}}$ and $\mathcal{N}_5 = 3600\mathcal{P}_5^{Q\bar{Q}}$. Finally, the probability distribution for the intrinsic heavy quark in the proton by integrating over $dx_1...dx_4$ is given by

$$P(x_5) = \mathcal{P}_5^{Q\bar{Q}} 1800 x_5^2 \left[\frac{(1-x_5)}{3}\left(1+10x_5+x_5^2\right) + 2x_5(1+x_5)\ln(x_5)\right].$$

Intrinsic heavy quark content of the nucleon

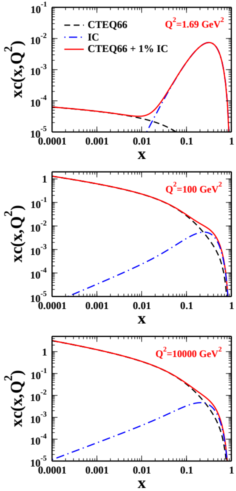
Definiteness: Two Components (separate evolution)

- c_{ext} : extrinsic charm
- c_{int} : intrinsic charm
- $c(x,Q^2) = c_{ext}(x,Q^2) + c_{int}(x,Q^2)$: full charm parton distribution

By using DGLAP evolution equations, we can obtain the extrinsic charm at any scale since the intrinsic component $c_{int}(x,Q)$ is governed (to a very good approximation) by a non-singlet evolution equation.

F. Lyonnet, et. al arXiv:1504.05156 [hep-ph].

Q^2 dependent of intrinsic heavy quarks



P. M. Nadolsky, et. al, Phys. Rev. D **78**, 013004 (2008) [arXiv:0802.0007 [hep-ph]]

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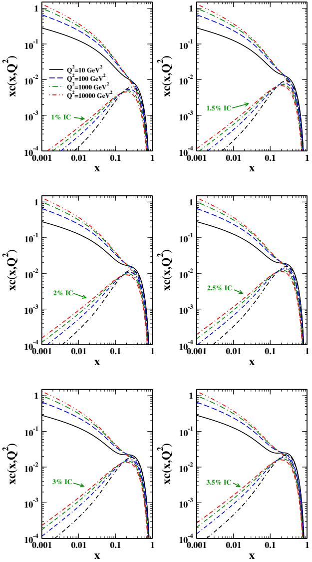

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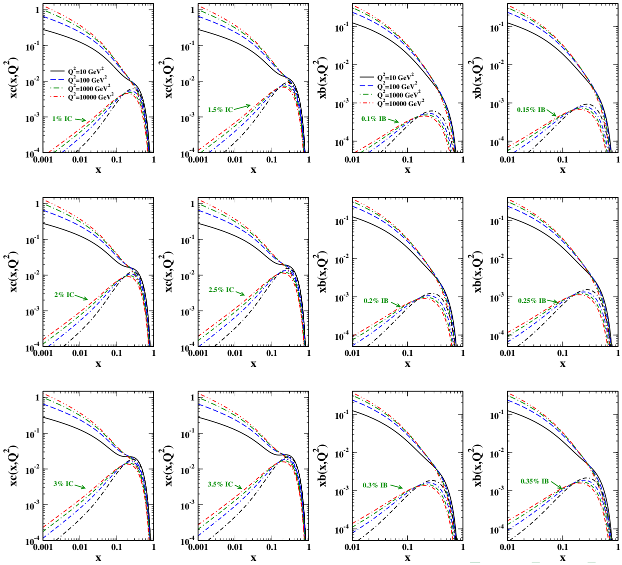
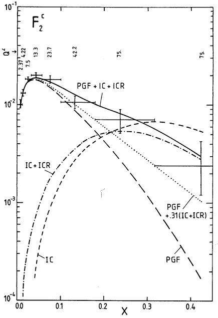


Measurement of Charm Structure Function

First Evidence for Intrinsic Charm

- J.J. Aubert, et al. [EMC], Nucl. Phys. B **213**, 31 (1983)



- The first experimental evidence of intrinsic heavy quarks came from the EMC measurement of the large x charm structure function.

Production of a photon in association with a charm quark

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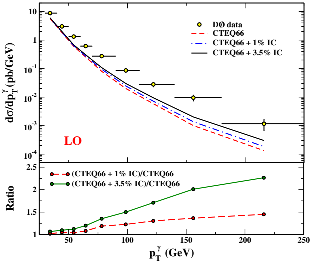
We will see, for the BHPS model the cross section can be enhanced by a factor of 2-3 for $p_T^\gamma > 200$ GeV.

D0 data and the prompt photon production in association with charm quark jet

Recent years, the prompt photon and heavy quark jet production in $p\bar{p}$ collisions at the Tevatron have been investigated that this process can be very useful for testing the possible existence of intrinsic quarks in the nucleon.



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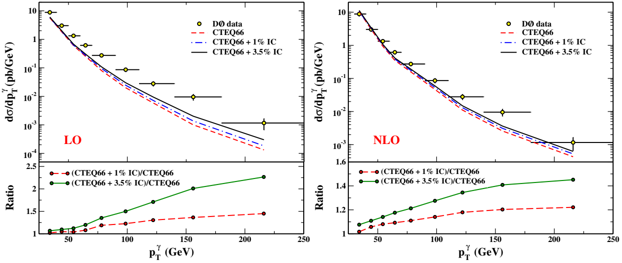
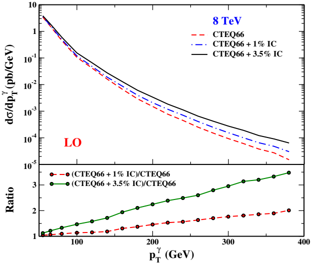


D0 Collaboration, Physics Letters B 719 (2013) 354361

NLO predictions for the photon production in association with charm quark jet in pp with and without IC



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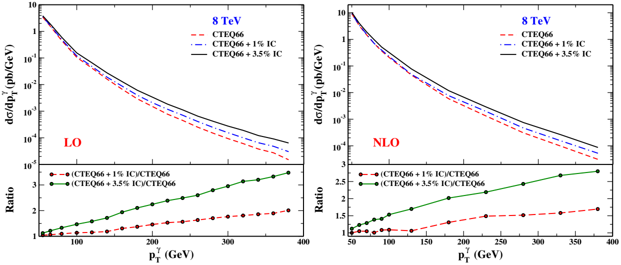

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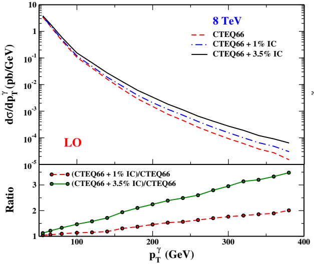

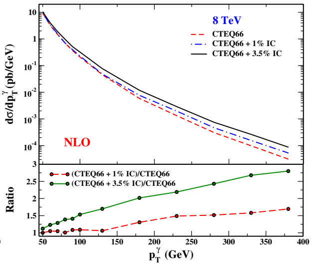

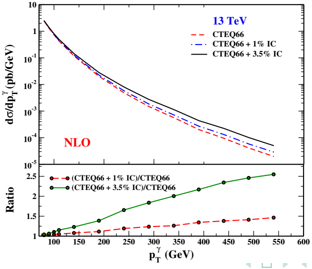

Summarize

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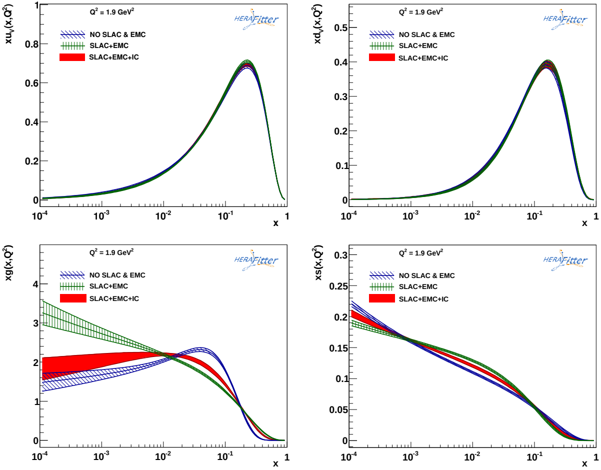
Thank you.

Backup

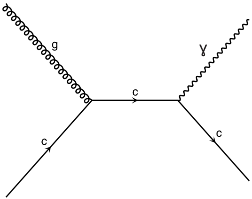
The total charm structure function in any x and Q^2 can be obtained by adding the intrinsic contribution $F_{2,IC}^{c\bar{c}}$ to the extrinsic component $F_2^{c\bar{c}}$ as follows

$$\mathrm{F}_2^c(x,Q^2,m_c^2) = F_2^{c\bar{c}}(x,Q^2,m_c^2) + F_{2,IC}^{c\bar{c}}(x,Q^2,m_c^2).$$

where m_c is the mass of the charm.


Q² = 1.9 GeV²
HERAFitter
NO SLAC & EMC
SLAC+EMC
SLAC+EMC+IC
xu_V(x,Q²)
xd_V(x,Q²)
xg(x,Q²)
xs(x,Q²)
x

At leading order (LO), the main sub-process for the production of the photon and the charm quark is the Compton process $gc \to \gamma c$ which dominated at low p_T^γ.



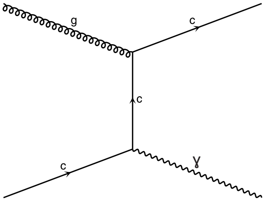


Figure : The Feynman diagrams for the QCD leading order contribution of the Compton process $gc \to \gamma c$ in the s-channel (left) and in the t-channel (right).