Intrinsic charm of the proton

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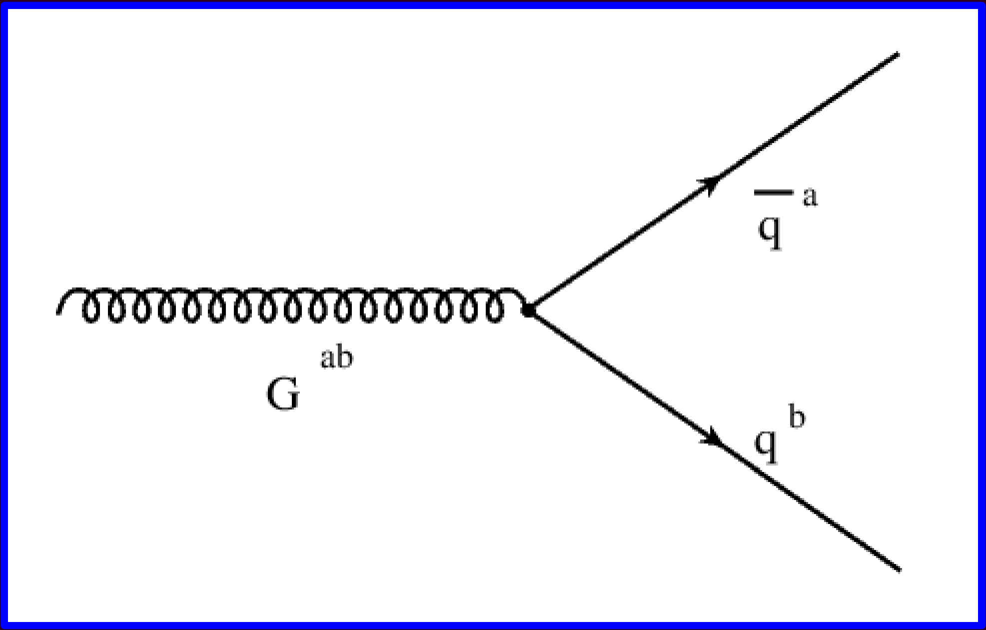
charm production and scaling

properties of *extrinsic* evolution

quark-antiquark produced symmetrically via gluon splitting

dominated by *low-x* structure



standard PDF global fits:

$$f_c^{ext}(x, Q) = 0 \Leftrightarrow Q < m_c$$

evolve via scheme of choice (e.g., ZMVFNS, FFNS)

induces cross section abundance at *large-x*

charm-anticharm asymmetry → non-perturbative, *intrinsic* component

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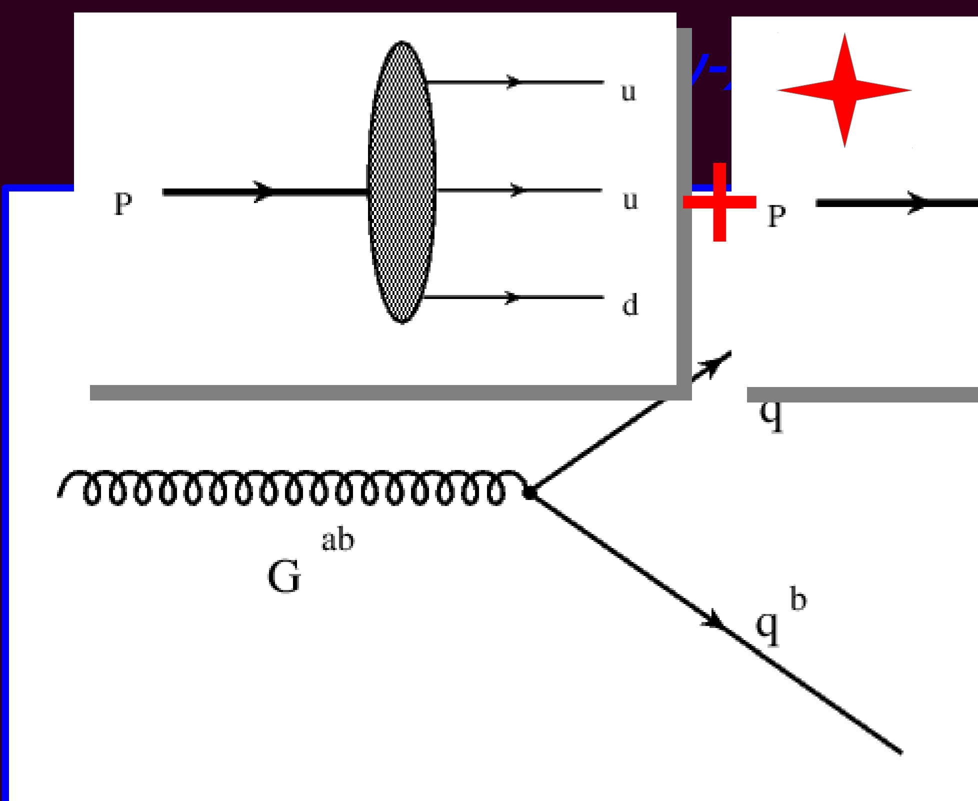
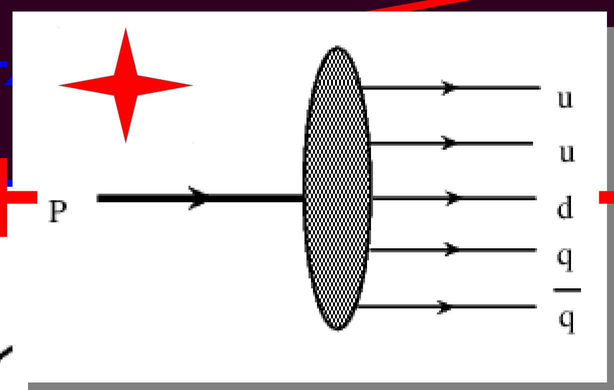
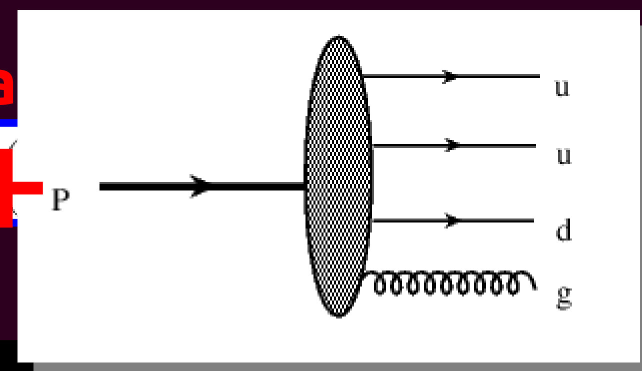






evolve via scheme of choice (e.g., ZMVFNS, FFNS)

induces cross section abundance at *large-x*

charm-anticharm asymmetry → non-perturbative, *intrinsic* component

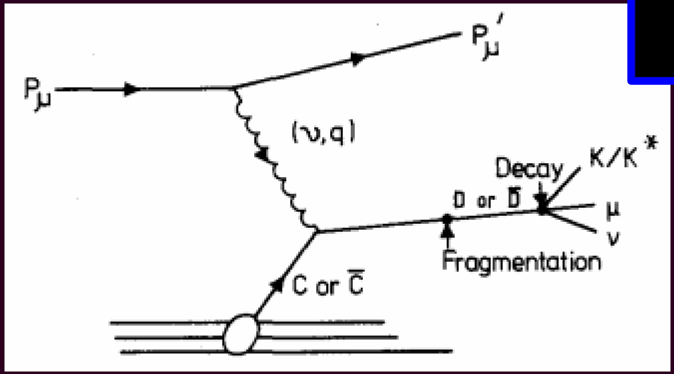
historical measurements

originally, H1 and EMC determinations

observables?

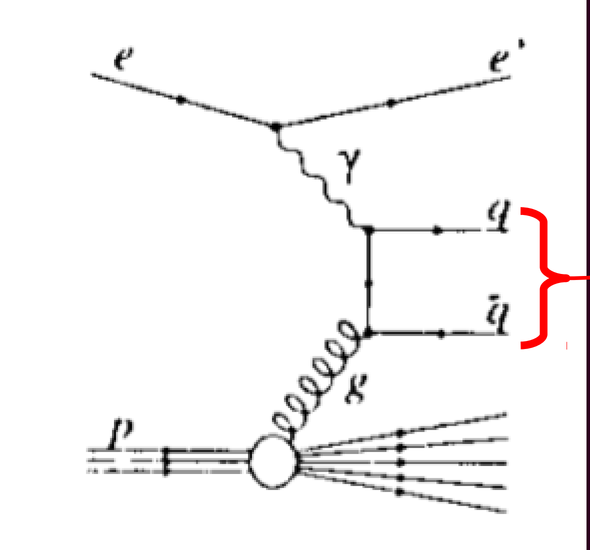
$$F_2^{c\bar{c}}(x,Q^2) \sim x[f_c(x,Q^2) + f_{\bar{c}}(x,Q^2)]$$

charmed hadron production cross sections



suggestive high-x F_2 excesses from EMC:

EMC collab., NPB 213, 31 (1983).



photon-gluon fusion → D production

$$D^0 \to K^- \pi^+$$

$$D^{*+} \to D^0 \pi^+ \to K^- \pi^+ \pi^+$$

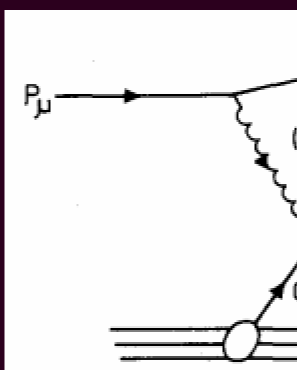
H1 collaboration, Z. Phys. C 72, 593 – 605 (1996).

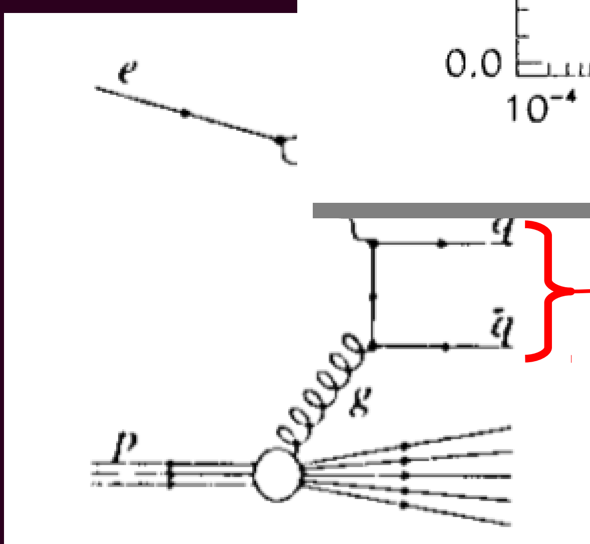
historical measurements

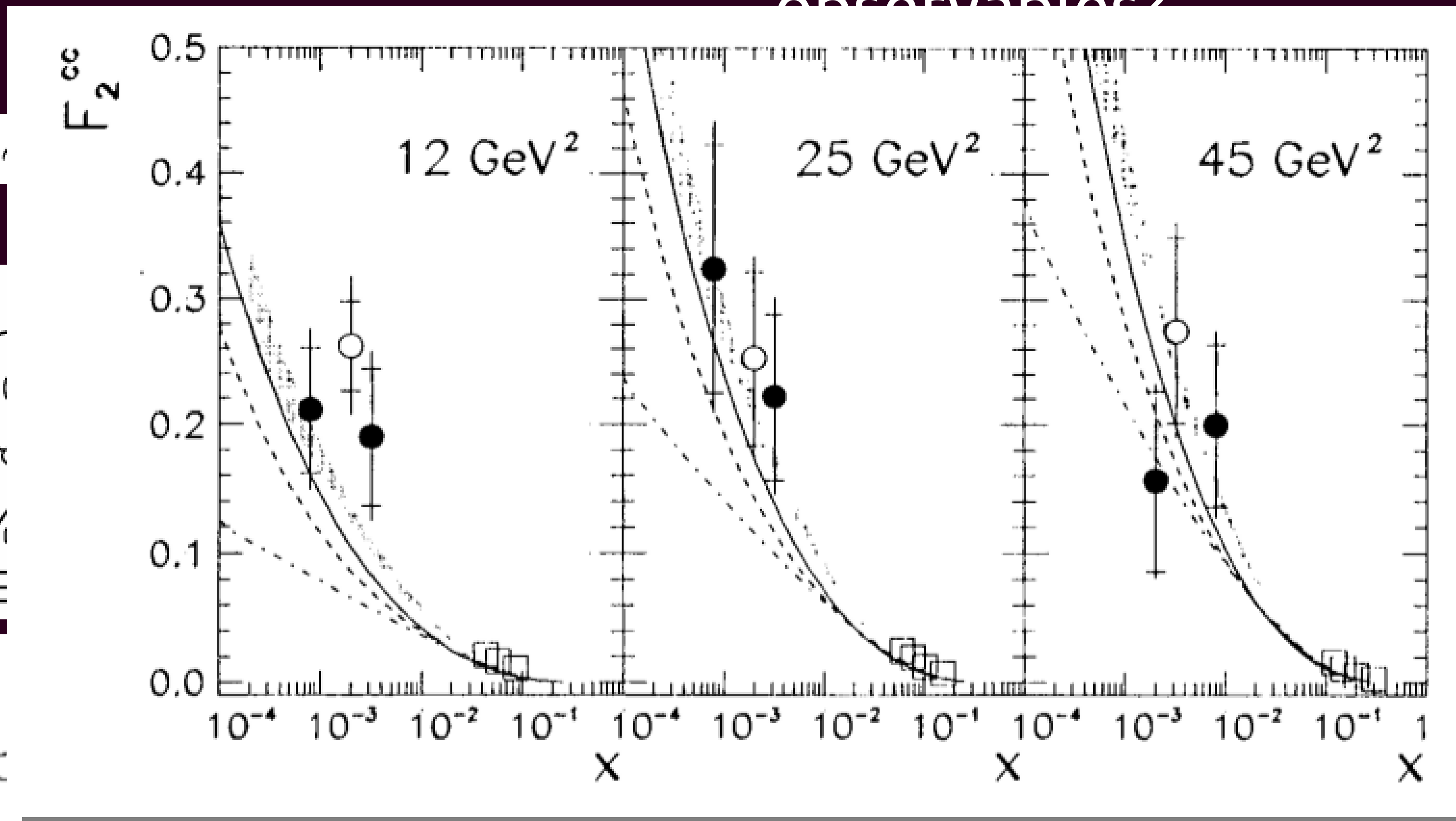
originally, H1 and EMC determinations

observables?

$F_2^{c\bar{c}}(x,Q^2)$







s

m EMC:

(1983).

$D \rightarrow K\pi$

$$\langle F_2^{c\bar{c}}/F_2\rangle = 0.237 \pm 0.021 \pm 0.041$$

H1 collaboration, Z. Phys. C 72, 593 – 605 (1996).

the **BHPS** idea

Brodsky et al., Phys. Lett. 93B, 4 (1980).

THE INTRINSIC CHARM OF THE PROTON

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Recent data give unexpectedly large cross-sections for charmed particle production at high x_F in hadron collisions. This may imply that the proton has a non-negligible $uudc\bar{c}$ Fock component. The interesting consequences of such a hypothesis are explored.

…a simple, ***flavor-independent*** model from 'old-fashioned' PT:

$$P(A \to B_1 ... B_n) = \left(\frac{< B_1 ... B_n | M | A >}{E_A - (E_{B_1} + ... + E_{B_n})} \right)^2$$

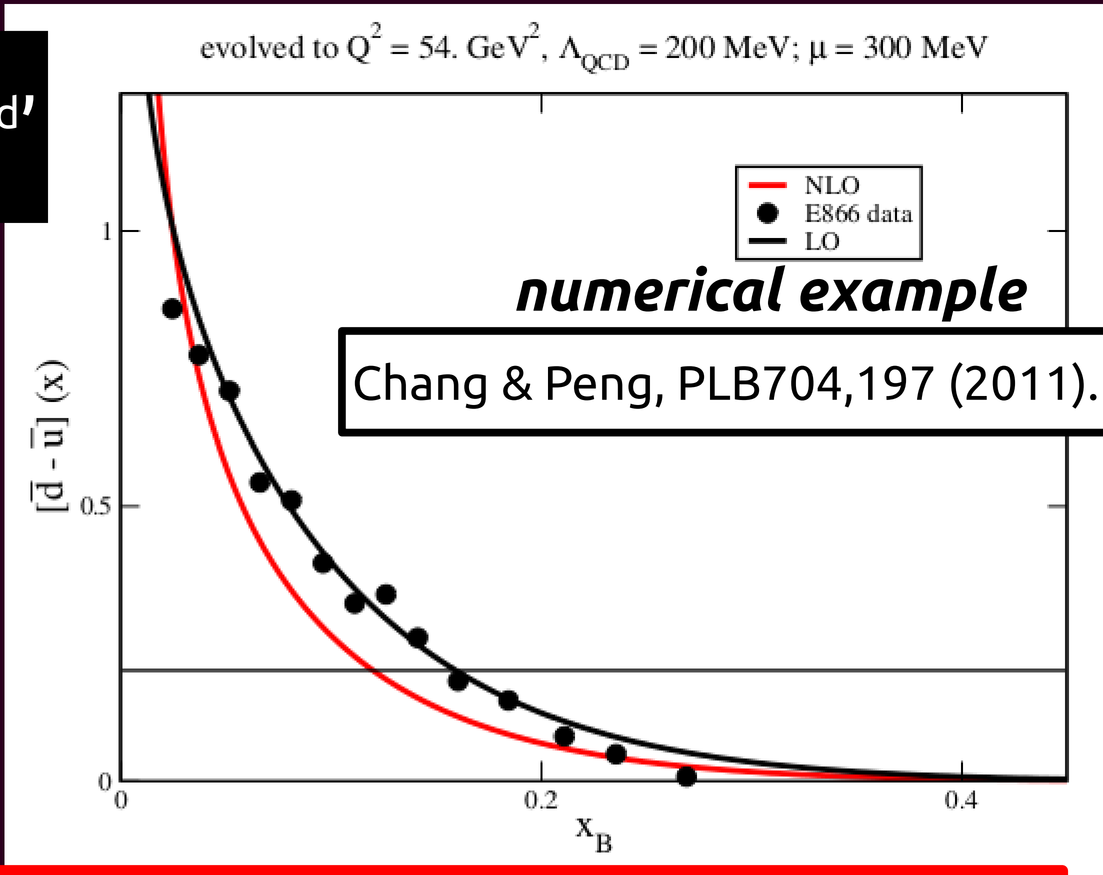
arbitrary, overall normalization, ~1%

$$P_{uudq\bar{q}}(x_u, ..., x_{\bar{q}}) = N \left[m_p^2 - \left(\frac{m_{\perp u}^2}{x_u} + ... + \frac{m_{\perp \bar{q}}^2}{x_{\bar{q}}} \right) \right]^{-2}$$

BHPS in the large m_c limit

away from $m_q >> m_{u/d}$, use Monte Carlo

mass limits render *analytic*

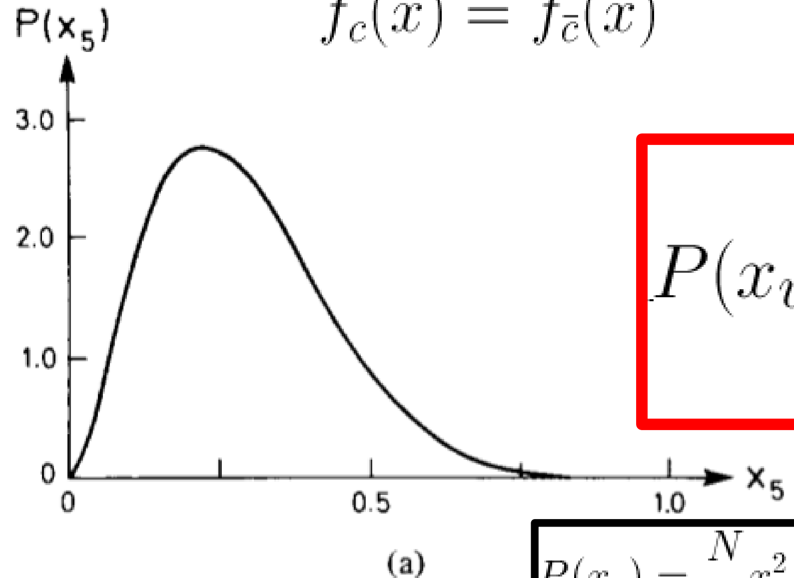


numerical example

Chang & Peng, PLB704,197 (2011).

integrate away extraneous d.o.f.:

$$f_c(x) = f_{\bar{c}}(x)$$



(a)

$$P(x_u, ..., x_{\bar{q}}) = N \frac{x_q^2 x_{\bar{q}}^2}{(x_q + x_{\bar{q}})^2} \delta \left(1 - \sum_{i=1}^{5} x_i\right)$$

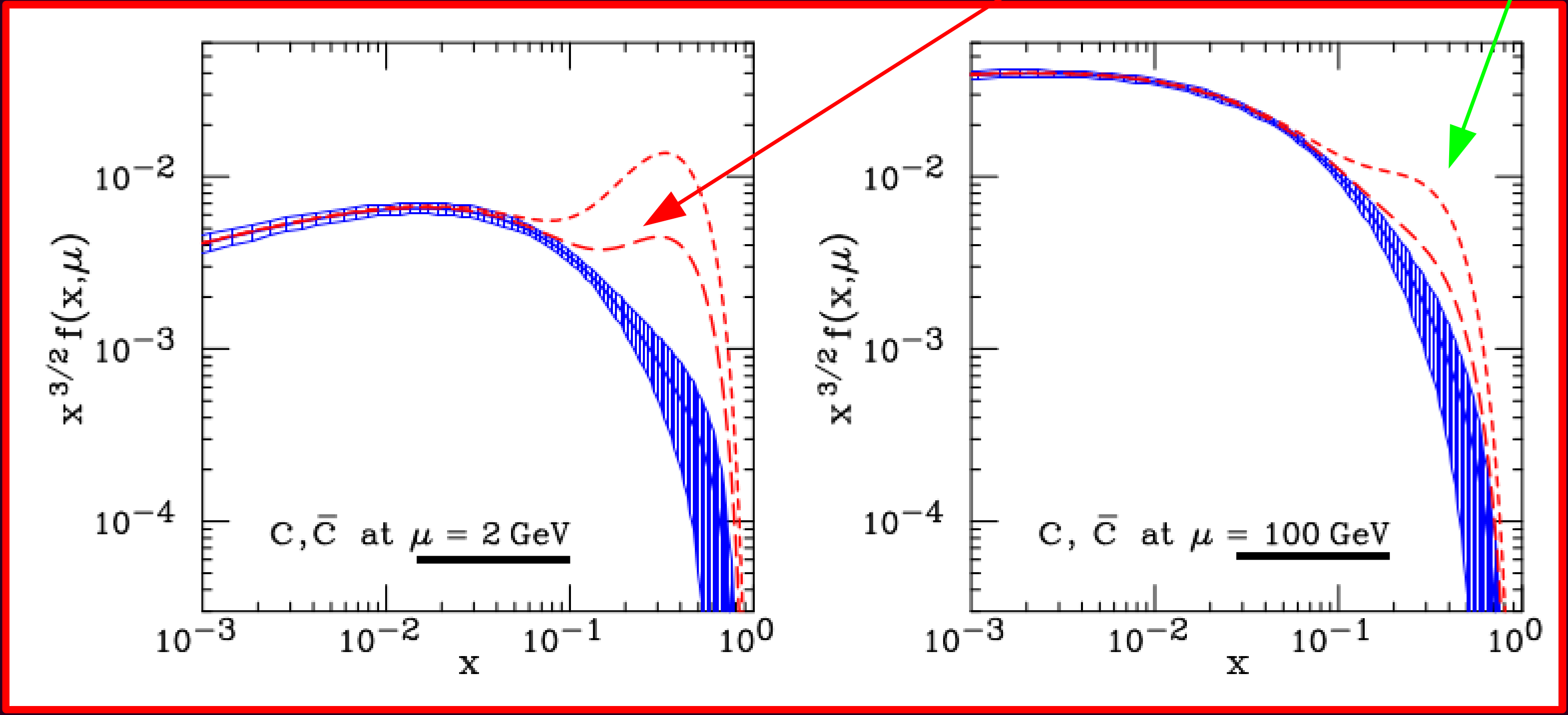
$$P(x_q) = \frac{N}{2} x_q^2 \left[\frac{1}{3}(1 - x_q)(1 + 10x_q + x_q^2) - 2x_q(1 + x_q) ln \frac{1}{x_q}\right]$$

efforts to constrain IC

M. Guzzi et al., INT-produced EIC whitepaper 2010

IDEA: permit IC in global PDF fits – see how these limit overall normalization

ascribe charm momentum fractions: **0.57%**, and **2.0%**



"Roughly, an intrinsic momentum fraction of 2% or 3% is at the outer limit of what is allowed in the context of a global fit."

convolution approach

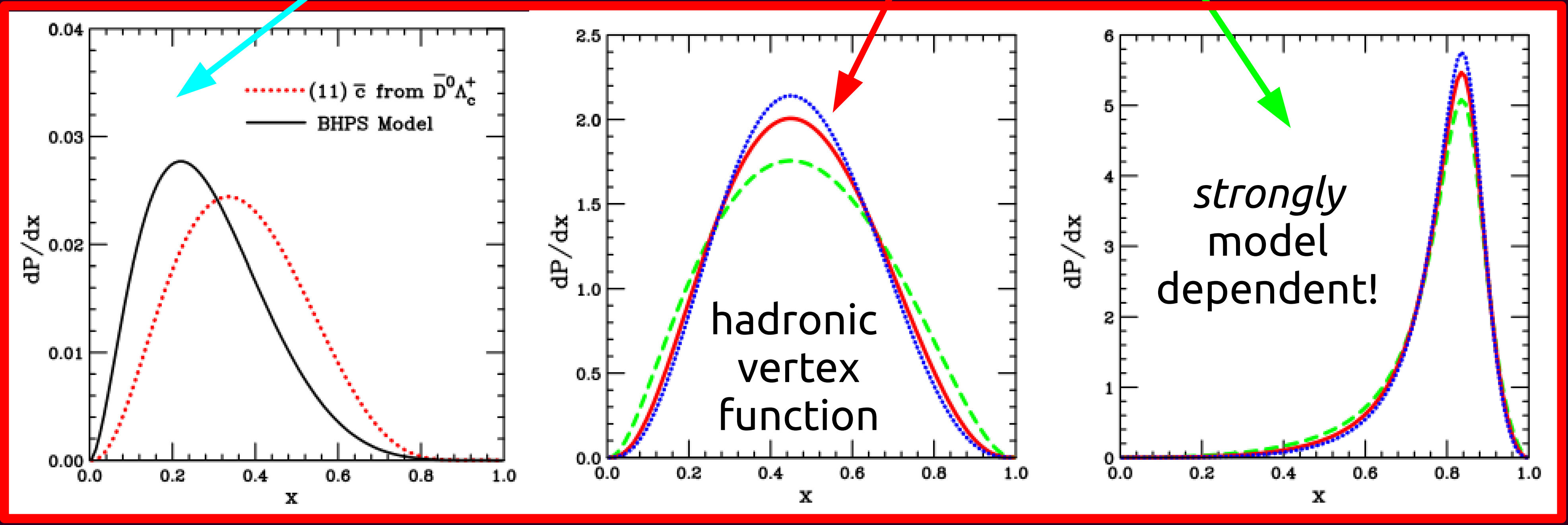
BHPS simple, flavor-blind formulation

meson cloud/convolution picture a "natural" approach from TOPT

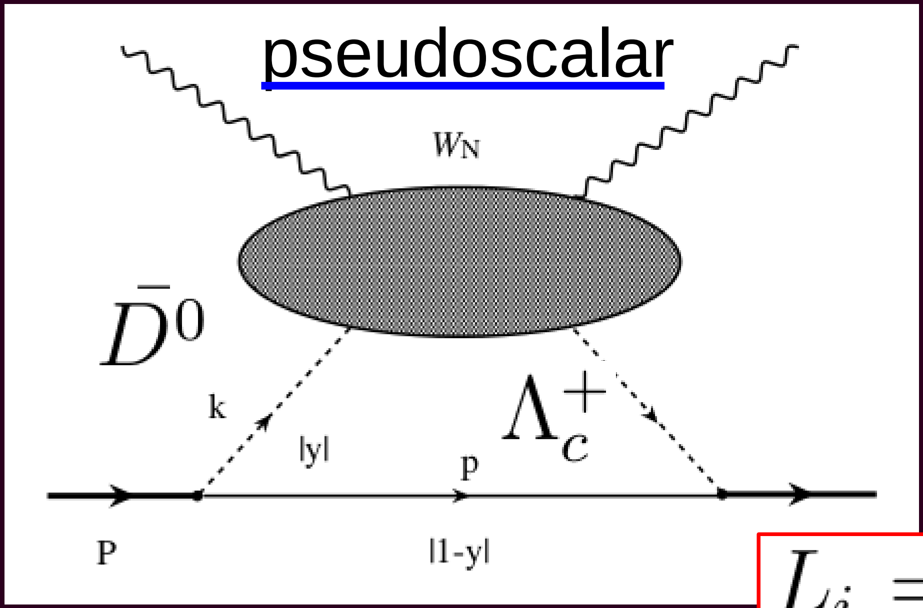
Pumplin, PRD73,114015 (2006).

amenable to quark models

$$\bar{c}(x) = N \int_x^1 \frac{dy}{y} \phi_{MB}\left(\frac{x}{y}\right) \bar{c}_M(y)$$



computing the vertex



IMF TOPT

write effective lagrangian in terms of hadronic d.o.f.

$$L_i = i \cdot g\bar{\psi}\gamma_5\pi\psi$$

$$p \to (D^*)^0\Lambda_c^+$$

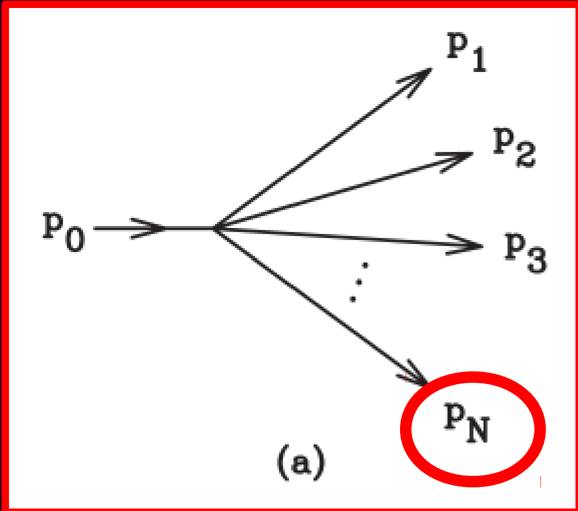
vector, Rarita-Schwinger dissociations also

$$L_v = g \cdot \bar{\psi}\gamma_\mu\theta^\mu\psi + if \cdot \bar{\psi}\sigma_{\mu\nu}\psi F^{\mu\nu}$$

from the pseudoscalar diagram:

$$\phi_{D\Lambda}(y) = \frac{g^2}{16\pi^2}\int_0^\infty dk_T^2 \left\{\frac{k_T^2 + (m_\Lambda - y m_N)^2}{1-y}\right\} \frac{F^2(s)}{y(1-y)(s_{D\Lambda} - m_N^2)^2}$$

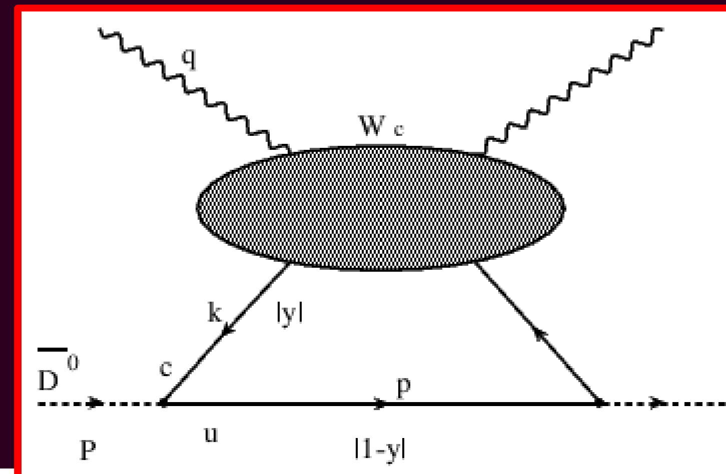
quark models



$$dP = \frac{g^2}{(16\pi^2)^{N-1}(N-2)!} \prod_{j=1}^{N} dx_j \, \delta\left(1 - \sum_{j=1}^{N} x_j\right) \times \int_{s_0}^{\infty} \frac{(s-s_0)^{N-2}[F(s)]^2 ds}{(s-m_0^2)^2}$$

***N* particle dissociation**

scalar, point-like ansätz derived by Pumplin



incorporating quark spin d.o.f.:

$$\bar{c}(x) = \frac{g^2}{16\pi^2} \int_0^{\infty} dk_T^2 \frac{1}{x(1-x)} \frac{[F(s)]^2}{(m_{\bar{D}}^2 - s)} \cdot \left(\frac{x^2(k_T^2 + m_u^2) + (1-x)^2(k_T^2 + m_{\bar{c}}^2) + 2x(1-x)(k_T^2 - m_{\bar{c}} m_u)}{x(1-x)} \right)$$

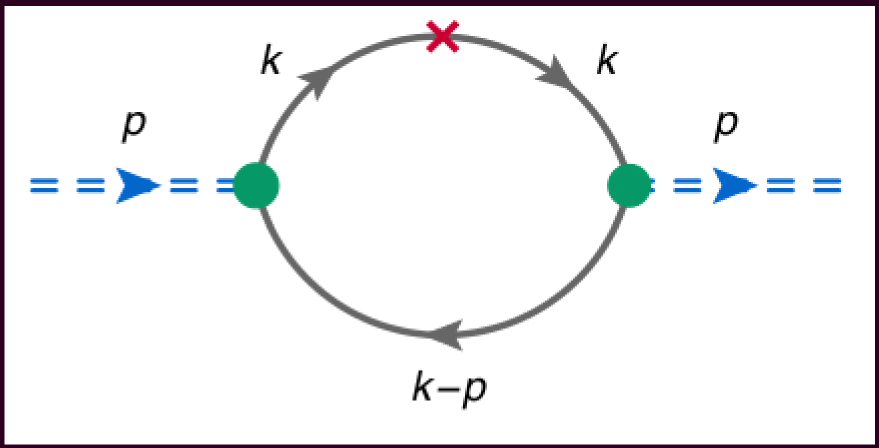
NJL

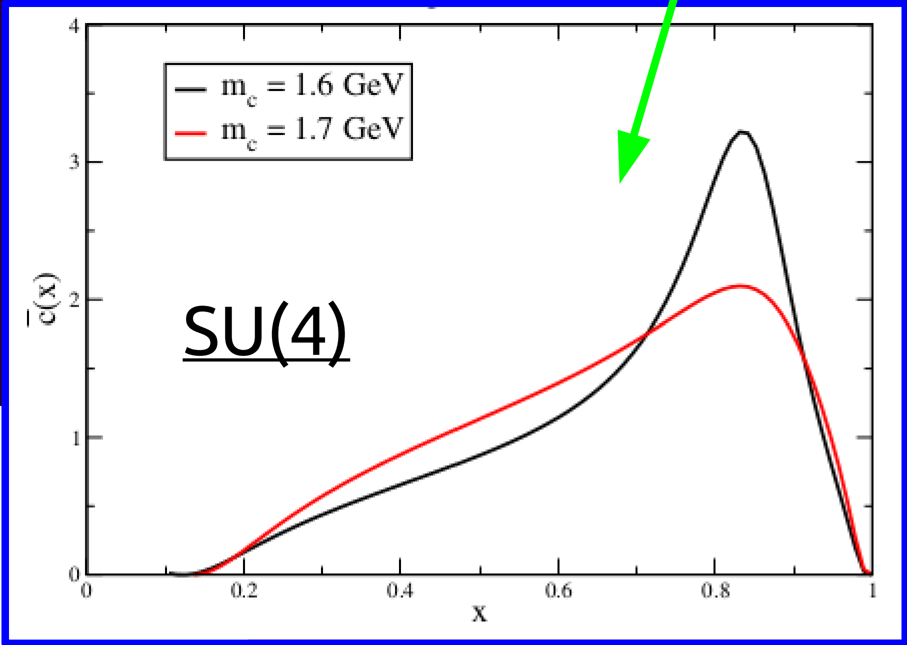
$$L = \bar{\psi}(i\,\partial\!\!\!/ - [m + 2\frac{G_0}{N}(\sigma + i\pi\cdot\tau\gamma_5)])\psi - \frac{G_0}{N}(\sigma^2 + \pi^2)$$

***QCD* propagator structure**

applicable to distribution *and* fragmentation

γ^+





Matevosyan et al., PRD83, 074003 (2011).

$$f_q^m(x) = iN_c \frac{C_q^m}{2} g_{mqQ}^2 \int \frac{dk_+ d^2k_\perp}{(2\pi)^4}$$
$$\times \mathrm{Tr}[\gamma_5 S_1(k)\gamma^+ S_1(k)\gamma_5 S_2(k-p)]$$

quark models from HQET

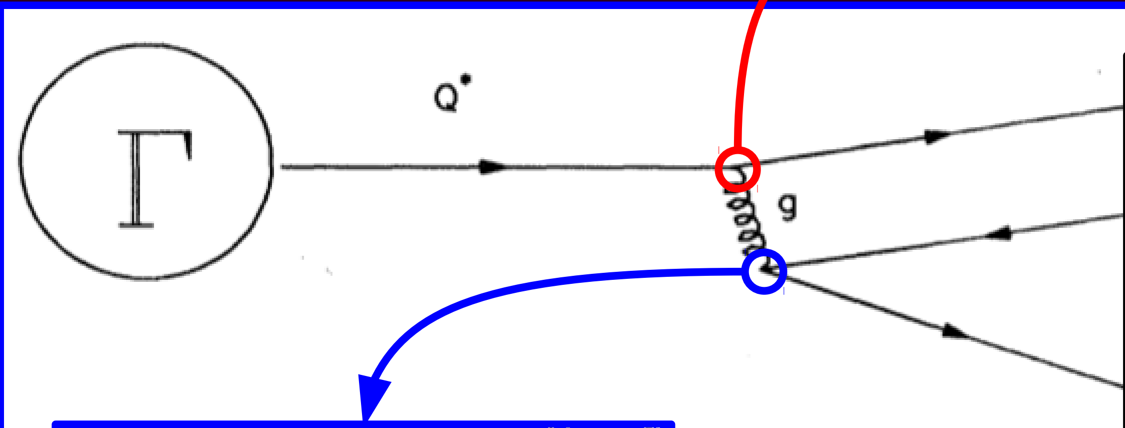
Braaten et al., PRD51, 9 (1995).

non-relativistic formalism...

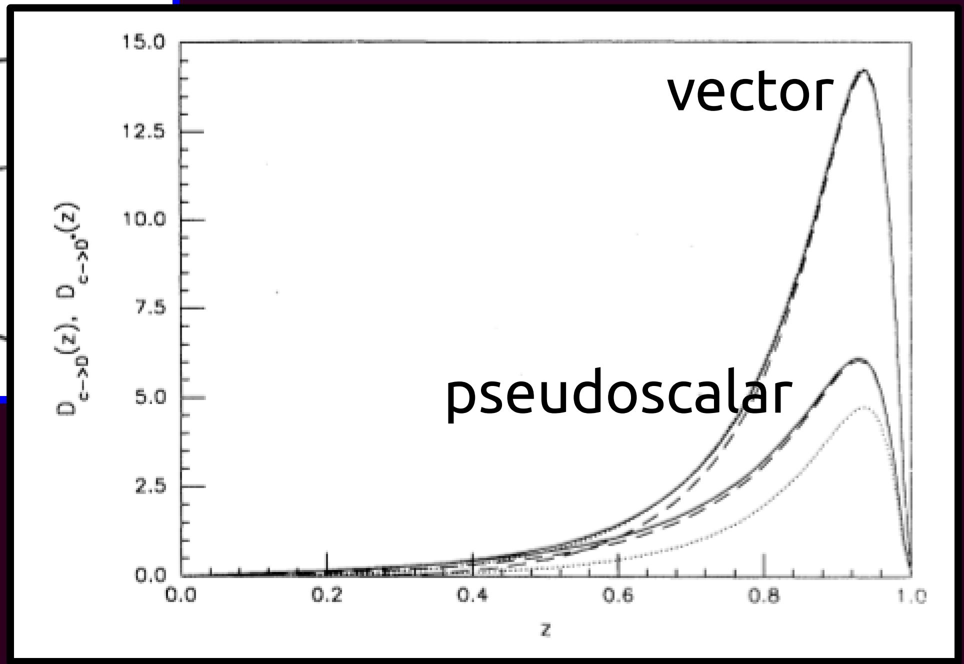
$$\mathcal{L} = \bar{h}_v \left\{ iv \cdot D + \frac{1}{2m_Q} \left(C_1 (iD)^2 - C_2 (v \cdot iD)^2 - \frac{C_3}{2} g_s \sigma^{\mu\nu} G_{\mu\nu} \right) \right\} h_v$$

expanded to $O(1/m_Q)$

$$D = \partial\!\!\!/ - igT_a v^\mu A_\mu^a$$



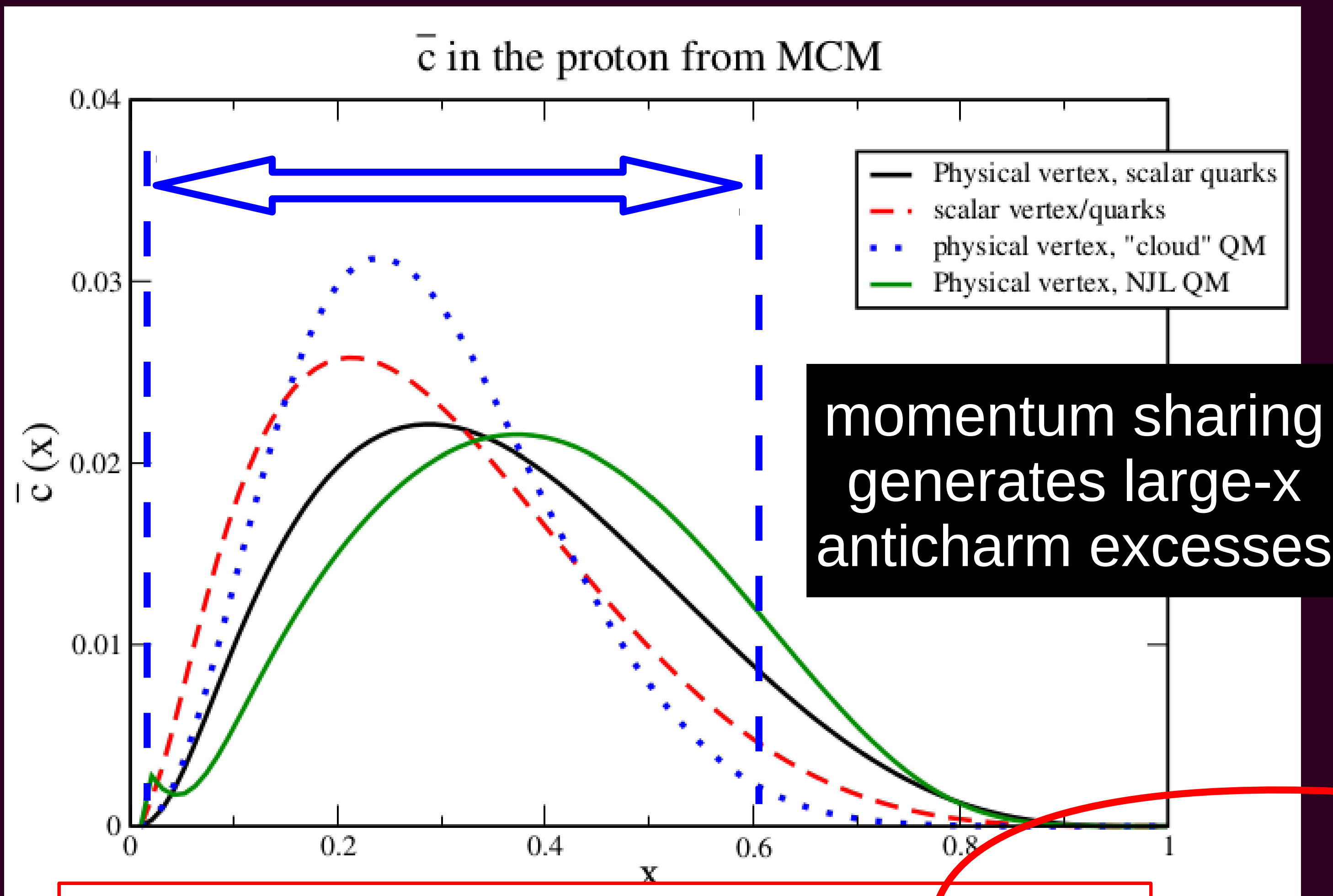
$$D = \partial\!\!\!/ - igT_a \gamma^\mu A_\mu^a$$

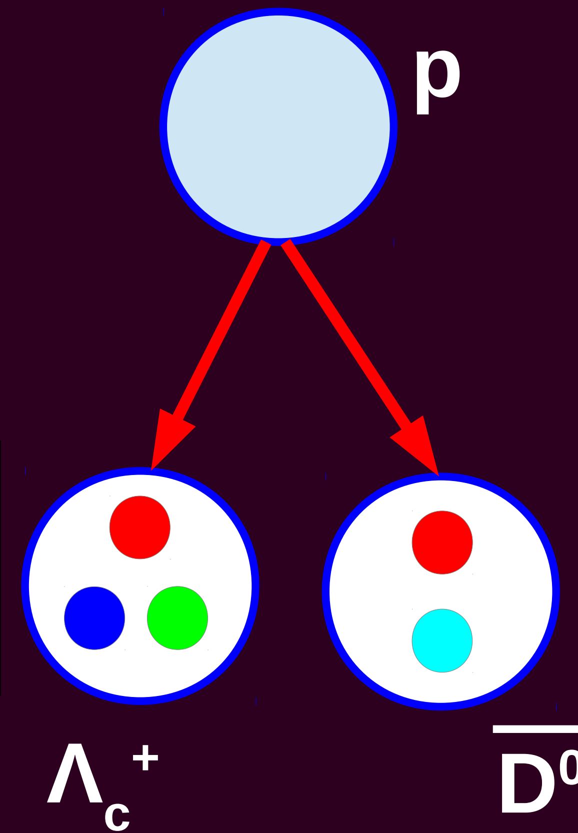


may extend to distribution functions!

quark-level prediction for anticharm

following convolution...





$$\bar{c}(x) = N \int_x^1 \frac{dy}{y} \phi_{MB}\left(\frac{x}{y}\right) \bar{c}_M(y)$$

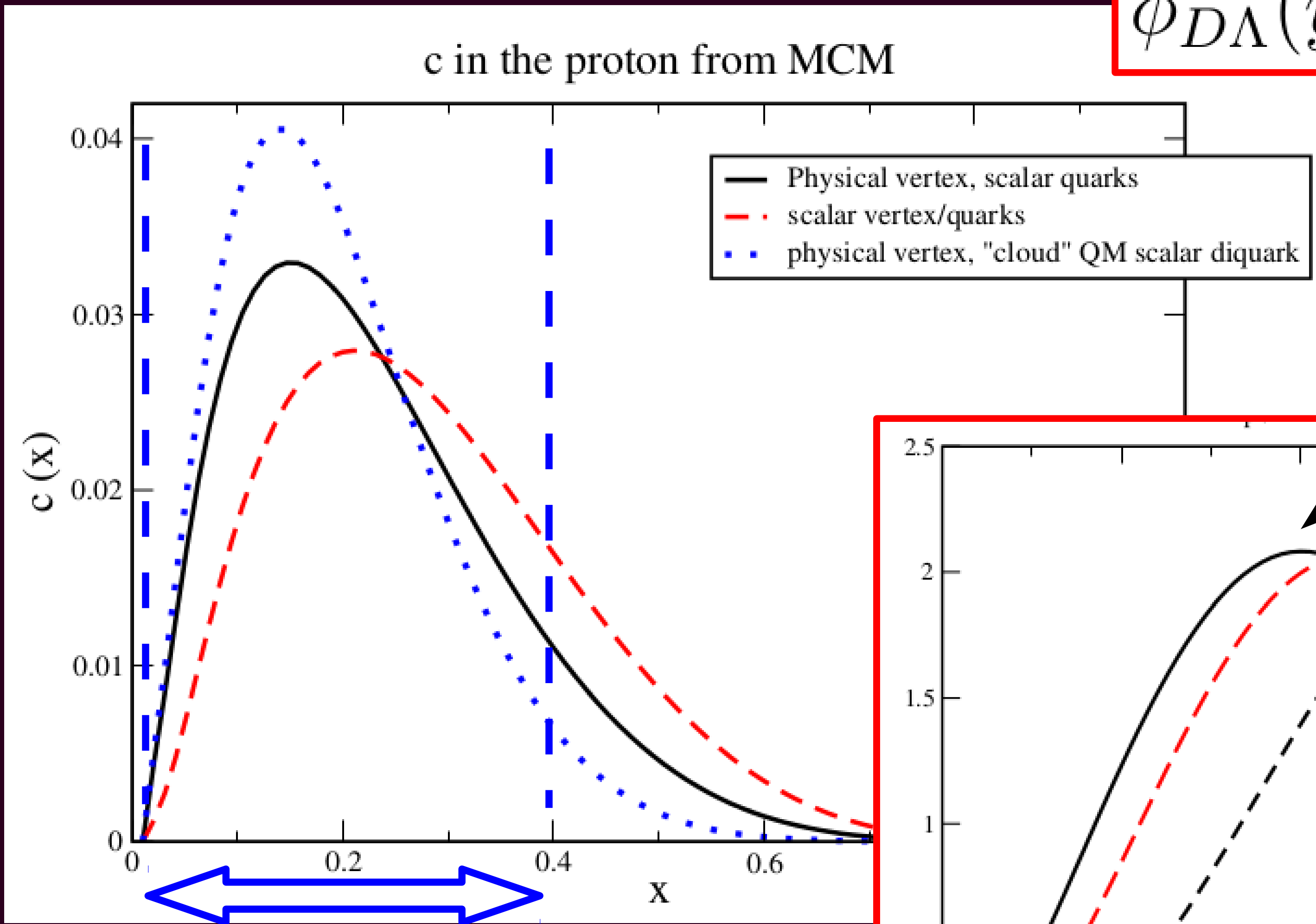
kinematics **and** vertices enhance high-x structure

...and for charm

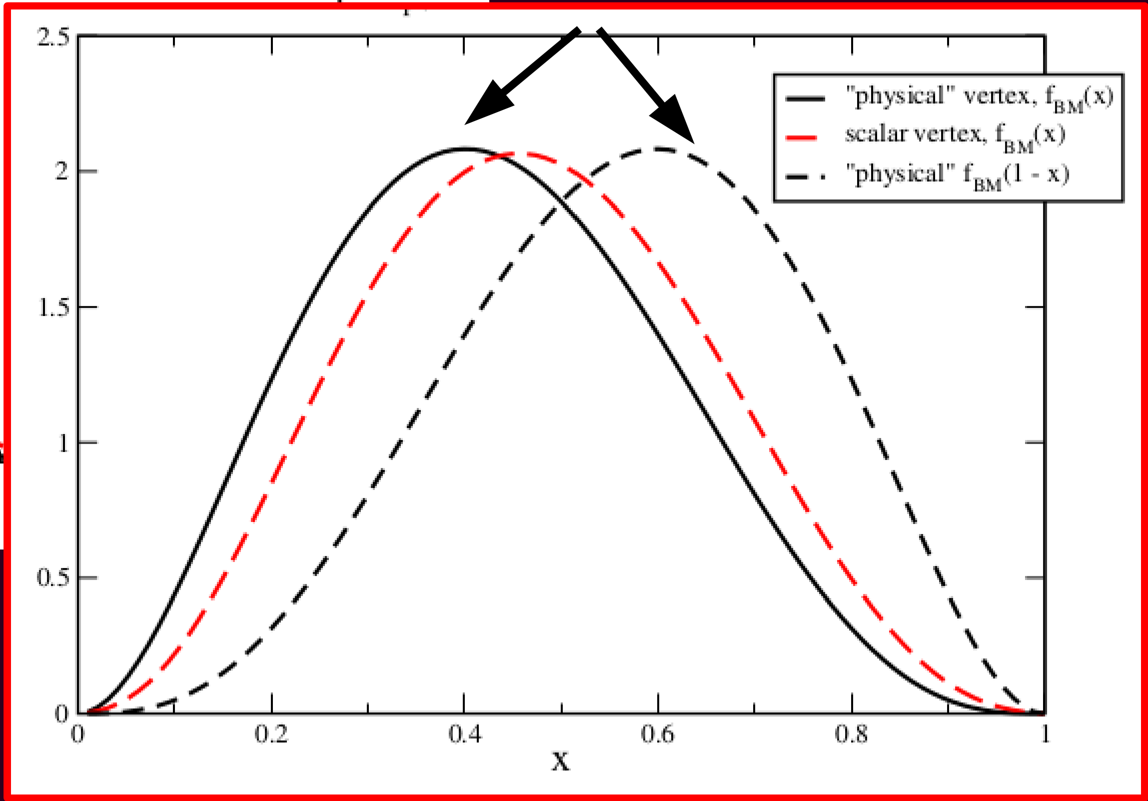
...treating Λ_c as quark + scalar diquark

$$\phi_{D\Lambda}(y) = \phi_{\Lambda D}(1-y)$$

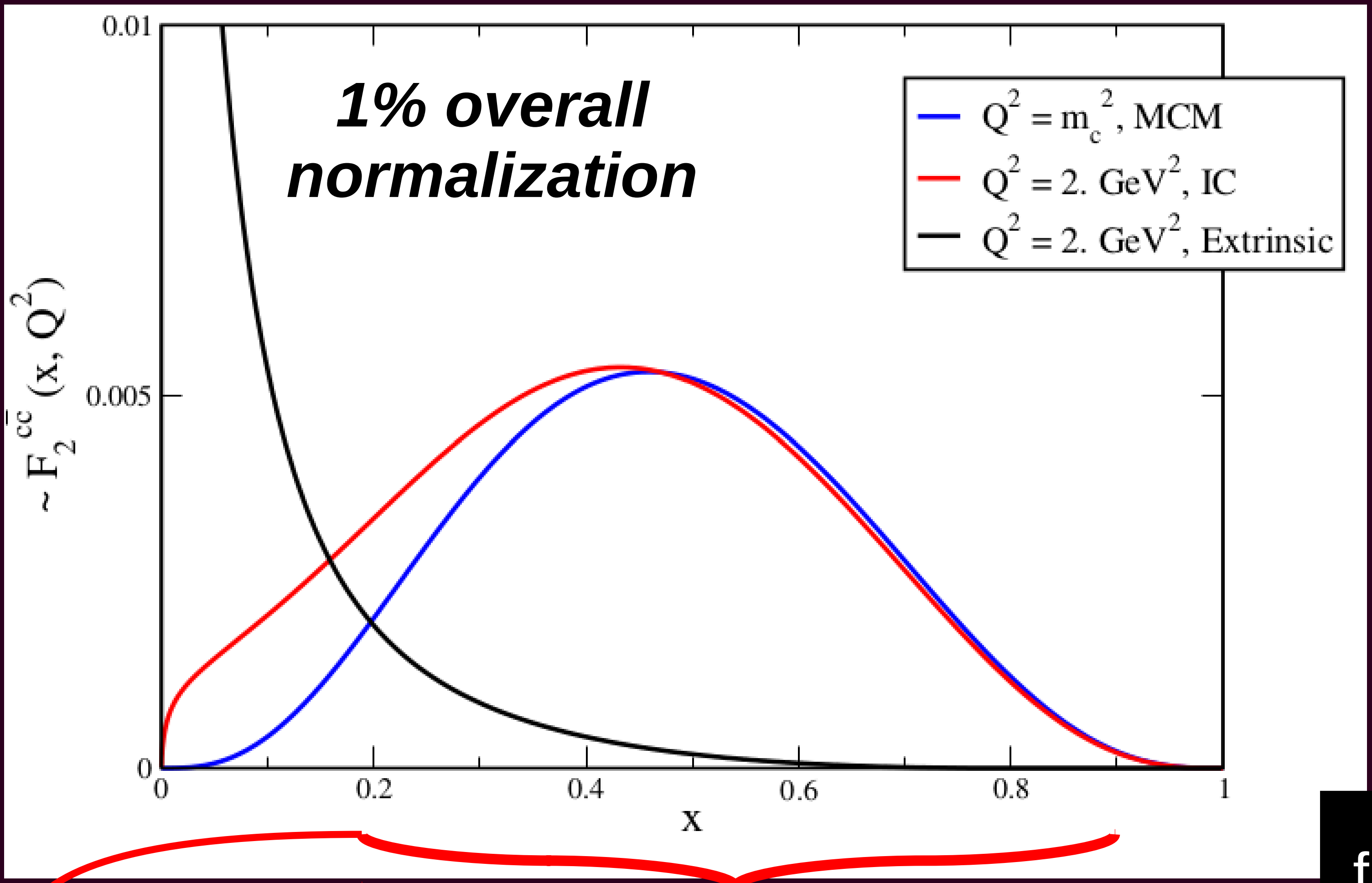
hadronic spin d.o.f. enhance vertex asymmetry



dominated by ***low-x*** physics



F_2^{charm} and Q^2 dependence



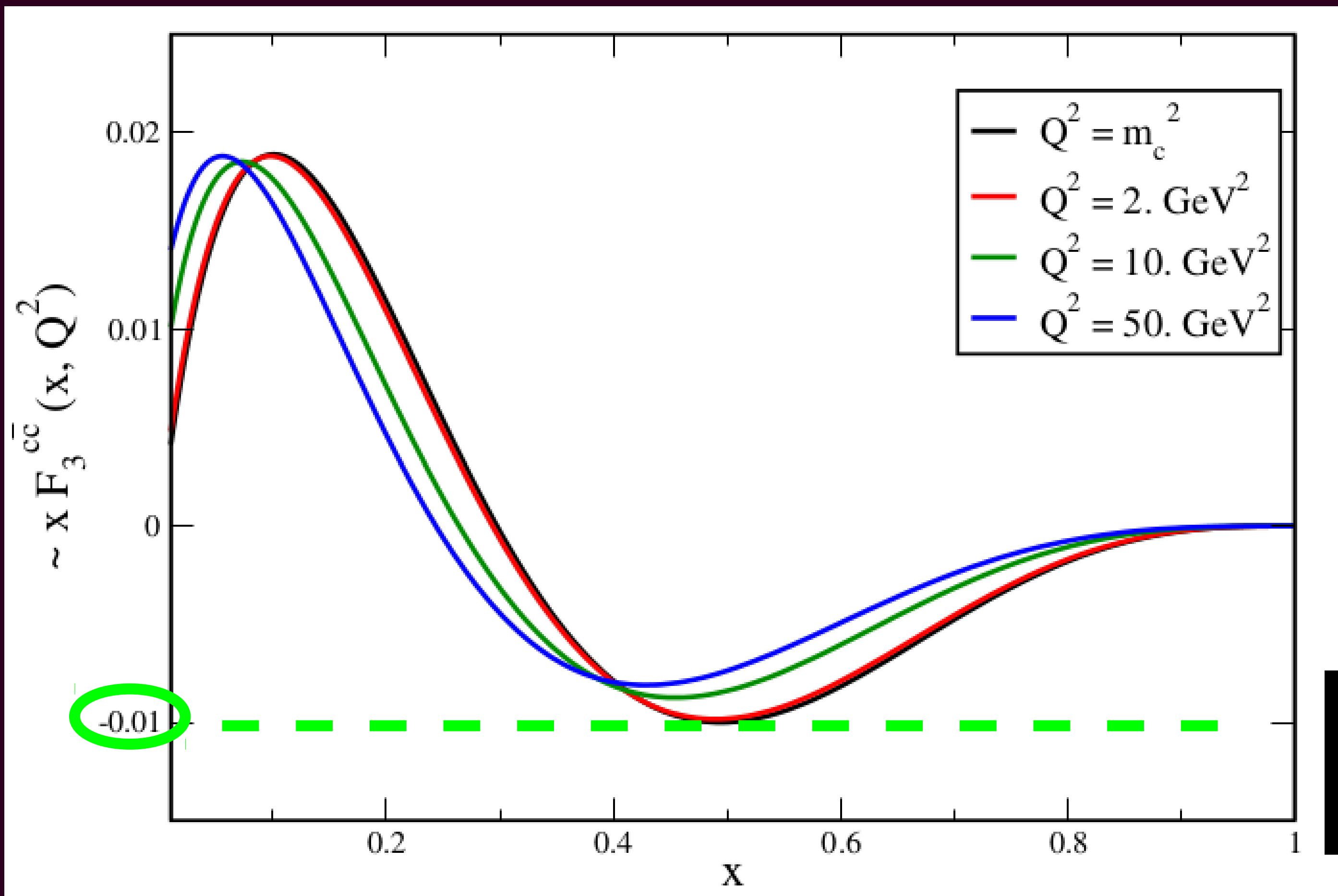
evolved via generic flavor singlet DGLAP

Q^2 dependence awaits systematic study

from *conservative*, scalar QM

intrinsic component dominates for **x ≥ 0.1 – 0.2**

non-singlet: xF_3^{charm}



non-singlet
evolution
tempers
leftward shift

$\sim [\sigma^{\bar{\nu}p} - \sigma^{\nu p}]$?

$F_3^{\gamma Z}$?

moderate x, Q^2:
~1% magnitude

$$P \otimes q = \int_x^1 \frac{dy}{y} P(y) q\left(\frac{x}{y}, \mu^2\right)$$

$$\widetilde{P}_{qq}(y) = \frac{P_{qq}(y)}{C_F}$$

***NO** gluon splitting contribution!*

experimental directions?

cloud models suggest that valence excesses may be somewhat larger than previously suspected...

more sensitive F_2^{charm} measurements

…particularly in the large-x region over a range of Q^2

…also, **c-$\bar{c}$** asymmetry signal may be accessible

dimuon production/**neutrino** cross-sections? **PVDIS**??

guidance from experimentalists is needed!

conclusions

…this is **fascinating!** many theoretical/phenomenological issues at work

pseudoscalar proton dissociations done here; **spin-1**, **-3/2** analysis promise more

…in progress…

quark models principal source of model dependence; calculations now being done

non-perturbative c-$\bar{c}$ *asymmetry* may be accessible (as well as valence region IC!)

suggestive of potential experimental tacks (esp. **EIC**-related)!

Thank-you!

Appendix I: evolution

schemes

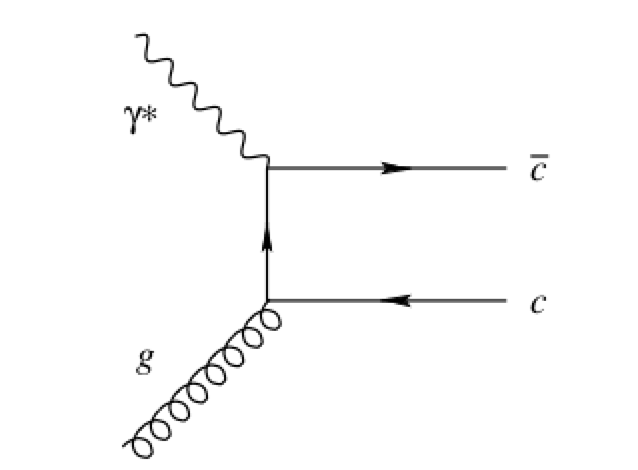
variable **OR** *fixed* flavor number

heavy flavors treated as massless

at mass threshold

$n_f \to n_f + 1$

valid for neighborhood of heavy quark mass $Q \sim m_c$



$F_2^{charm}(x, Q^2)$

generated via photon-gluon fusion

Appendix II: hadronization

fragmentation models (e.g., Lund, HQET)

what about coalescence??

family of plots showing model dependence here