

# Heavy Quark Mass Effects in PQCD and Heavy Flavor Parton Distributions

DIS07

HFL-2

Tung

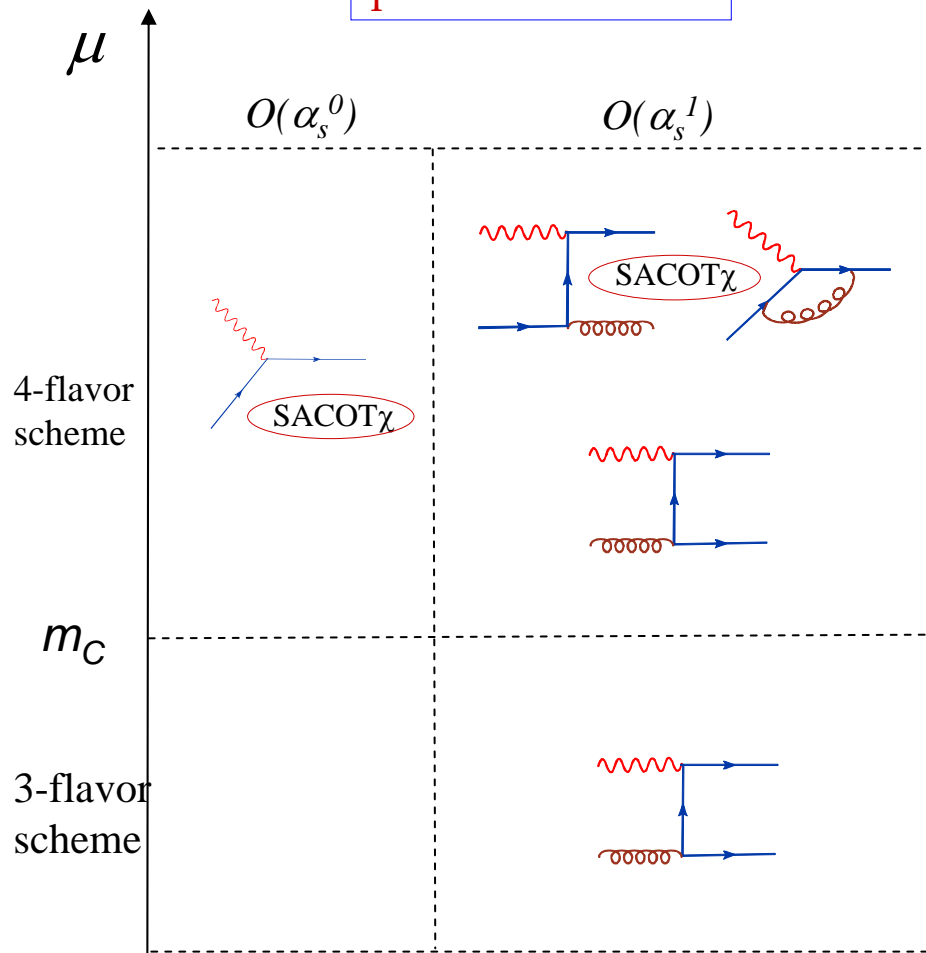
## Outline

- A simple formulation of the General-mass (GM) QCD formalism;
    - - Factorization scheme (Collins)
        - Mass-dependence of hard cross section (SACOT)
      - Correct on-shell kinematics ...
        - Rescaling ( $ACOT_\chi$ ), Phase space, ...
  - precision global analysis:
    - CTEQ6.5M + uncertainties (hep-ph/0611254)
  - 1<sup>st</sup> focused study of *strange* distributions:
    - CTEQ6.5Sx (hep-ph/0702268)
- (wkt: SF-2)
- • Fit to heavy flavor production data;
  - • 1<sup>st</sup> study of *charm degrees of freedom* (intrinsic charm?): CTEQ6.5Cx (hep-ph/0701220)
  - • Can the charm mass be determined in a global analysis?

# New Implementation of the GM Formalism: $F^{tot}$

$$\sum_a \int \frac{d\xi}{\xi} f_N^a(\xi, \mu) \hat{w}_{Ba}^\lambda \left( \frac{x}{\xi}, \frac{\hat{s}}{\mu}, \frac{m_Q}{\mu}, \alpha_s(\mu) \right)$$

$\Sigma$  final State  
parton flavors

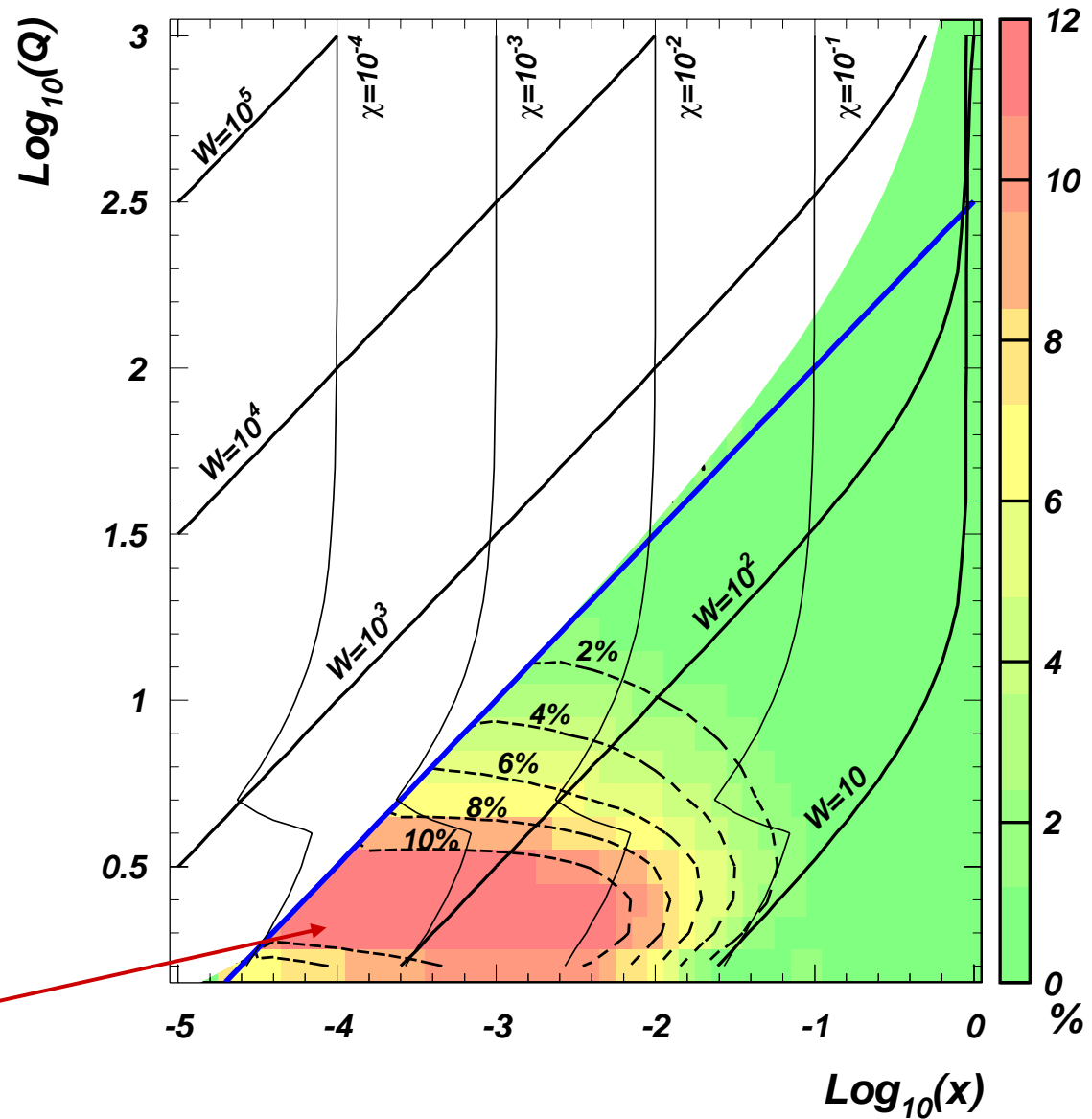


- Summing Initial S. partons
  - Variable-flavor # schemes (3,4,5: depends on Q)
- Summing Final S. partons
  - All flavors allowed by P.S.
  - Final state HQ on-shell.
- Kinematic Constraints:
  - Mass effects in phase space integration limits;
  - Rescaling—smooth and physical threshold behavior
    - $A_{cot}\chi$
- Wilson Coefficients:
  - Simplified ACOT (initial state parton mass  $\rightarrow 0$ )—more natural parton kinematics and greatly simplified W.C.

Comparison of  
GM and ZM  
Calculations:  
where in the  
(x,Q) plane do  
the differences  
matter?

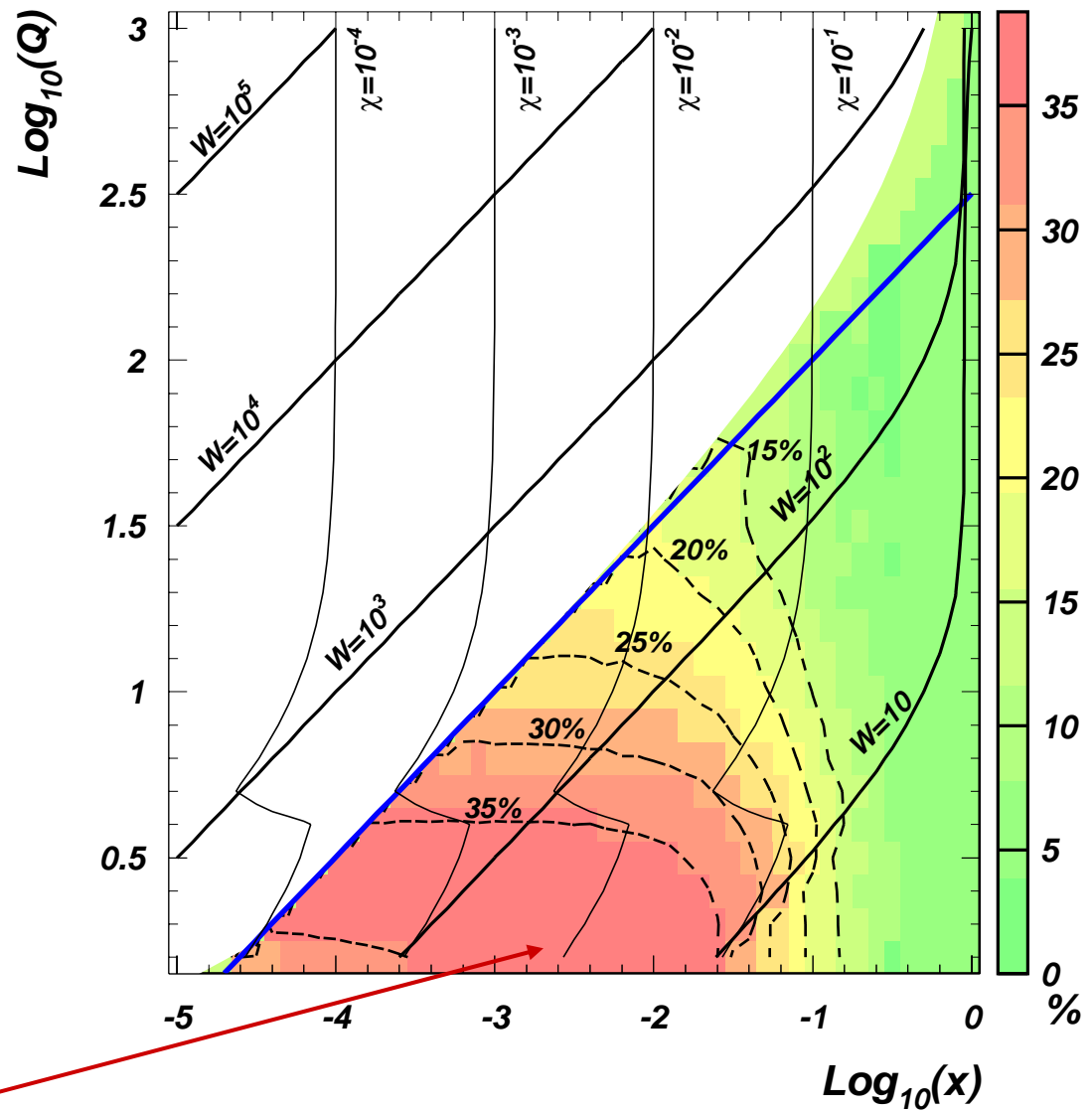
$$F_2(x, Q)$$

low  $Q^2$   
mostly



Comparison of  
GM and ZM  
Calculations:  
where in the  
(x,Q) plane do  
the differences  
matter?

$$F_L(x, Q)$$



Much larger ranges  
of both  $x$  and  $Q^2$

- Physical quantities, such as  $F_2$ ,  $F_L$ , are *positive definite* and *smooth* across heavy flavor thresholds; predictions on SFs and Xsecs are stable and robust.
- The physics of HQ in PQCD is fundamentally simple when organized in a natural way (order-by-order with proper attention to correct kinematics).
- This implementation of HQ mass effects serves as the basis of new comprehensive Global Analyses:
  - conventional parametrizations: CTEQ6.5Mxx;
  - independent strange sector: CTEQ6.5Sx;
  - independent charm sector: CTEQ6.5Cx;
  - Study of charm mass  $M_c$  in global analysis.

## New *Conventional* Analysis: CTEQ6.5M

- In conjunction with the comprehensive HERA I (+ Fixed Target and Hadron Collider) data, the new *GM* calculation →

Precision global QCD analysis of PDFs under conventional assumptions at  $Q_0$ :

- $s(x) = \bar{s}(x) = r(\bar{u}(x) + \bar{d}(x))/2$ ;
- radiatively generated charm/bottom  
i.e. no non-perturbative (intrinsic) charm, ... etc.

Quality of global fit improves in general compared to previous analysis (CTEQ6.1).

→ CTEQ6.5M + eigenvector uncertainty sets;

The shifts in PDFs have significant impact on LHC physics.

(hep-ph/0611254; wkt: SF-2)

## Strangeness Structure of the Nucleon

- Charm production in CC neutrino scattering is sensitive to the strange PDFs through the partonic processes;

$$\nu : W_+ s \rightarrow c$$

$$\bar{\nu} : W_- \bar{s} \rightarrow \bar{c}$$

- With improved data in general, and precise theoretical treatment of charm mass effects, it is time to determine  $s(x)$  and  $\bar{s}(x)$  inside the nucleon that are independent of the (convenient but ad hoc) ansatz

$$s(x) = \bar{s}(x) = r(\bar{u}(x) + \bar{d}(x))/2$$

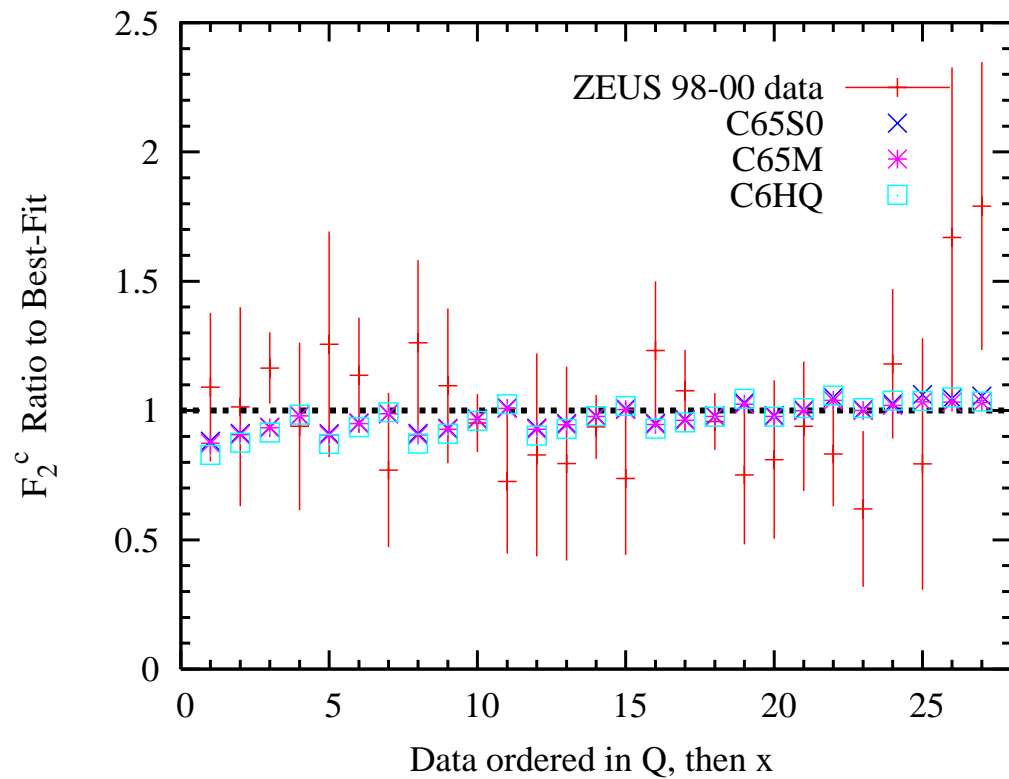
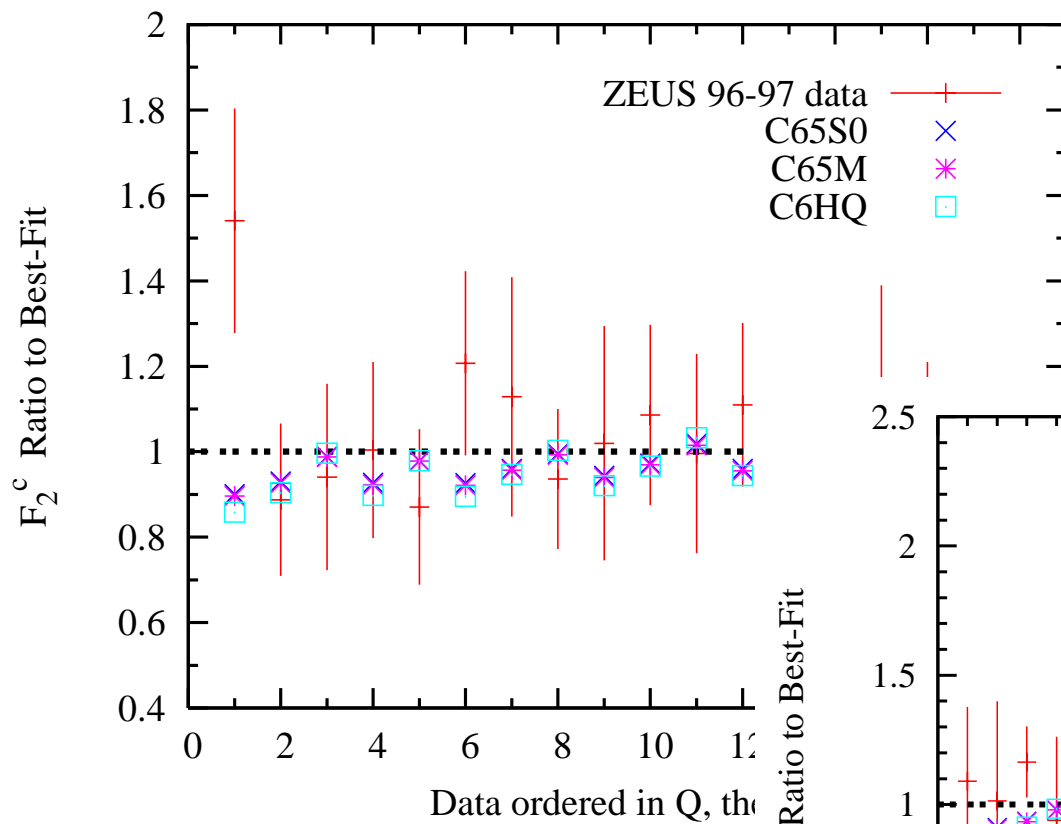
(hep-ph/0702268)

(wkt: SF-2)

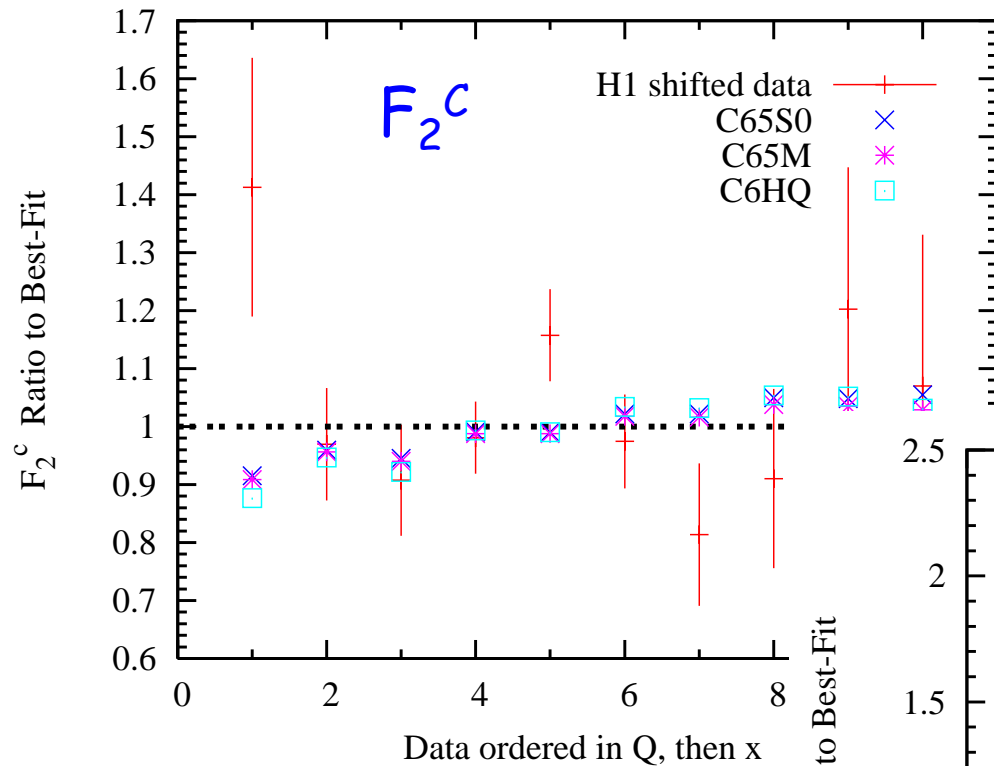


CTEQ6.5M and CTEQ6.5S fits to the  
heavy quark production data from HERA

# Fits to the ZEUS charm production data: $F_2^C$

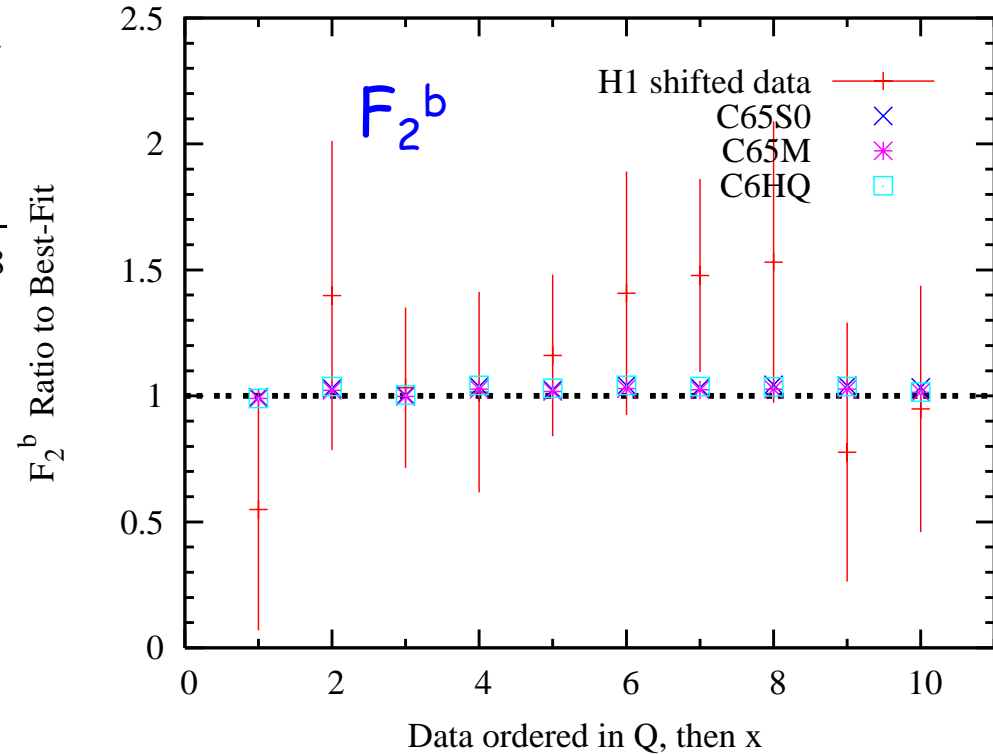


# Fits to the H1 charm and bottom production data



Correlated systematic errors incorporated in the global fit.

Data points are shifted according to the fitted systematic errors.



## The Charm Content of the Nucleon

## Why should we care about $c(x,Q)$ ?

- Intrinsic interest: the structure of the nucleon;
- Practical interests: collider phenomenology, especially beyond the SM, e.g.
  - Charged Higgs production,  $c + s\text{-bar} \rightarrow H^+$  ;
  - Single top production in DIS (flavor-changing NC) ...
- Conventional global analysis assume that heavy flavor partons are purely “radiatively generated”, i.e. by gluon splitting. (This ansatz is not well-defined. See later.)
- But, many non-perturbative models suggest the possibility of intrinsic charm content inside the nucleon;
- What can current global analysis reveal about the charm structure of the nucleon?

## Scenarios for the Charm parton sector

- Radiatively generated  $c(x, Q_0)$ ;
- Intrinsic (non-perturbative) charm (IC) scenarios:
  - Sea-like  $c(x, Q_0)$  — similar to light quark seas
  - light-cone model scenarios:
    - Model of Brodsky et al (BHPS);
    - Meson-cloud model (MC)(similar, except  $c$  .ne.  $\bar{c}$  for the latter).

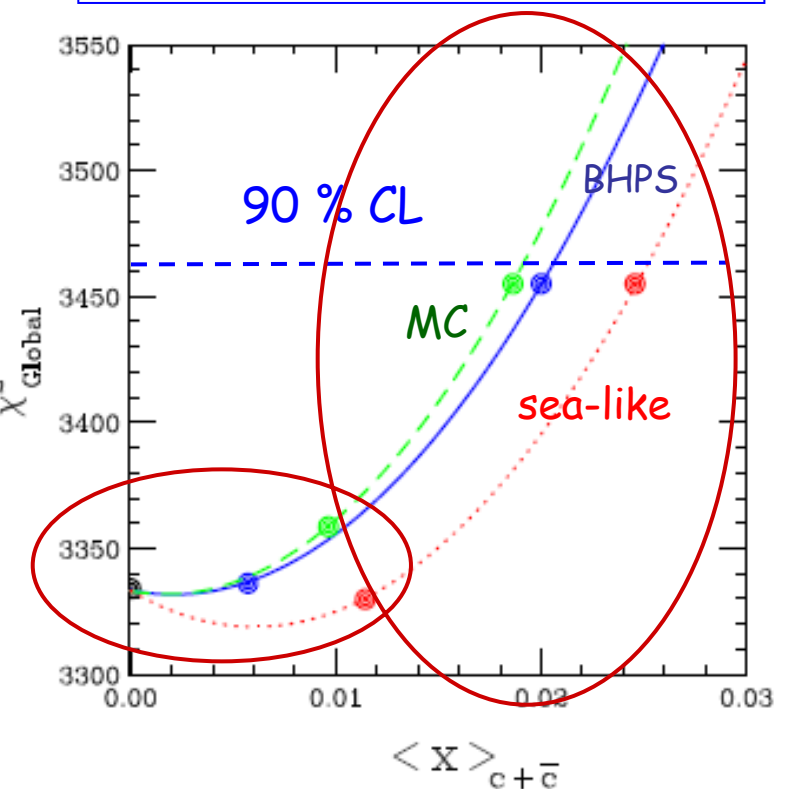
(Pumplin, Lai, wkt: hep-ph/0701220)

## Results:

- In the range  $0 < \langle x \rangle_{c+\bar{c}} < 0.01$ :  
Current global analysis does not require IC;
- For  $0.01 < \langle x \rangle_{c+\bar{c}}$  (assuming IC exists, as is natural in the models), our analysis sets a useful upper bound  $\langle x \rangle_{c+\bar{c}} < 0.02$ ;  
Light-cone model guesstimates,  $\langle x \rangle_{c+\bar{c}} \sim 0.01$ , are within this bound.
- A IC component of the nucleon of  $0.01 < \langle x \rangle_{c+\bar{c}} < 0.02$  has important implications for BSM phenomenology at the LHC

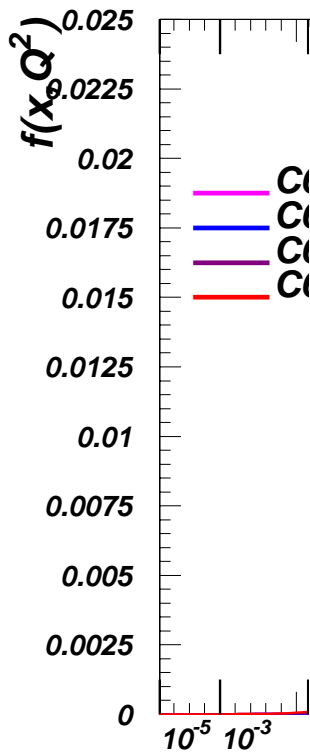
(Yuan: in EW-5 session)

Goodness-of-fit vs. amount of IC (momentum fraction) for the three models

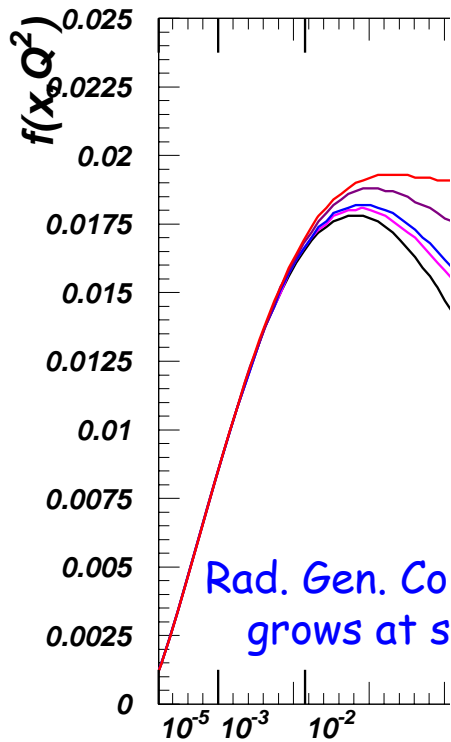


# Pictures (BHPS model)

Charm PDF,  $Q = 1.3 \text{ GeV}$

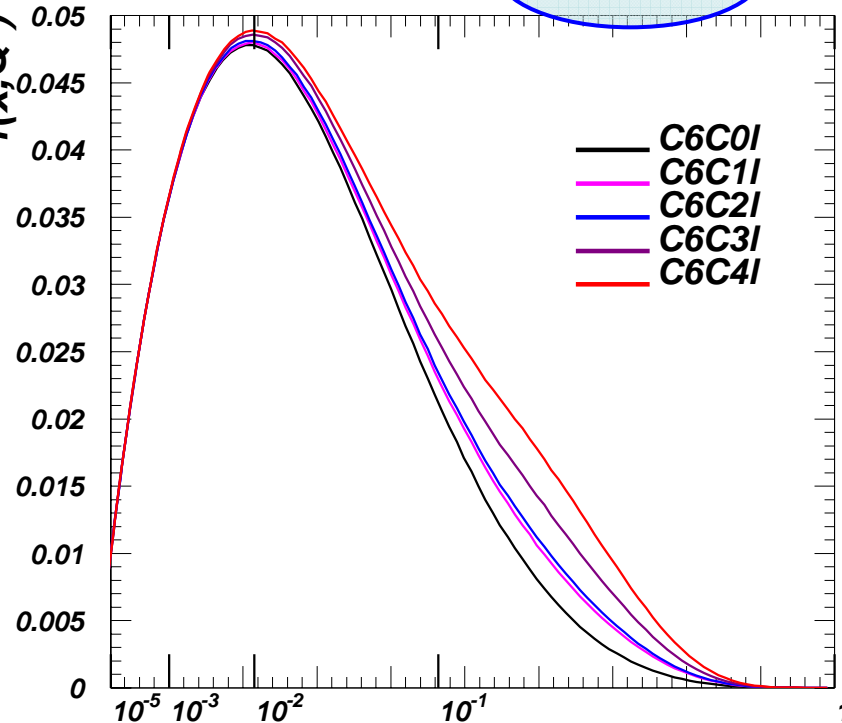


Charm PDF,  $Q^2 = 10 \text{ GeV}^2$



Radiatively-dominated at small  $x$ , but IC very important at  $x > 0.1$

Charm PDF,  $Q = 85 \text{ GeV}$



$x$



## "Heavy Quark Mass" in Global QCD Analyses:

- \* Can we "measure"  $M_{b,c}$  by fitting in global analysis?
- \* Are these "Pole masses", " $\overline{MS}$  masses", or neither?

## Heavy Quark masses in Global QCD Analysis

- $M_c$  is a basic QCD parameter, it can in principle be determined by global analysis, just like  $\alpha_s(M_Z)$ .
- When we try to fit " $M_c$ " in a conventional global analysis, we found:
  - A smaller value of " $M_c$ " (1.3 GeV) is much preferred over a larger value (1.5 GeV);
  - $\Delta\chi^2_{\text{global}} \sim 35$  ( / 2714 pts) (not significant by itself)
  - But,  $\Delta\chi^2_{F2c} \sim 30$  ( / 55 pts) — quite significant.

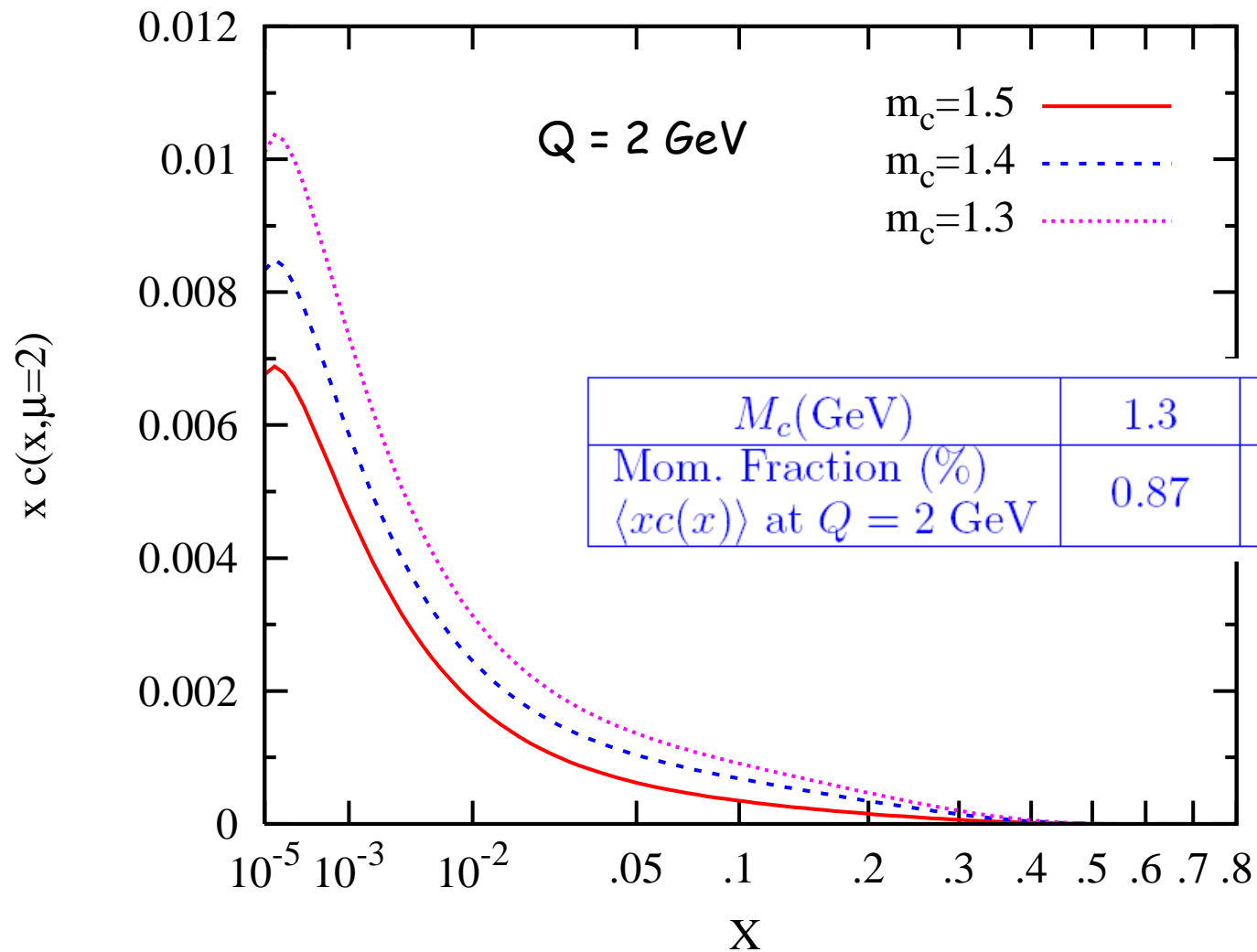
What is the physical meaning of this " $M_c$ ", or  $M_c^{\text{global}}$ ?

How does  $M_C$  affect a conventional global analysis?

1. The coefficient functions (Wilson coefficients) depends on  $M_C$  (pole mass);
2. Less obvious: through the implicit "radiatively generated HQ" ansatz):  $c(x, M_C) = 0$  ,  
the initial condition on the charm PDF is changed along with  $M_C$ .

(2) is much more influential on the global analysis than (1) !

Varying  $M_c$  in conventional global analysis amounts to varying the input charm distribution at a fixed scale  $Q$



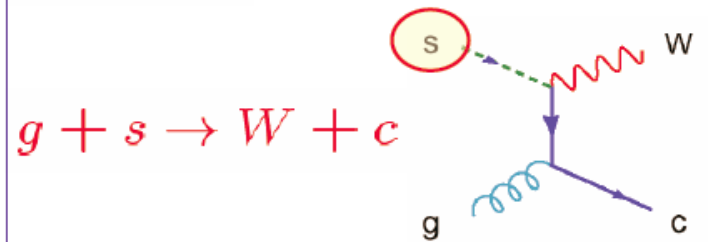
$M_C^{global}$  is neither  $M_C^{pole}$  nor  $M_C^{msbar}$  !

- Can  $M_C^{global}$  be converted to  $M_C^{pole}$ ?
- This will be left as a homework problem.

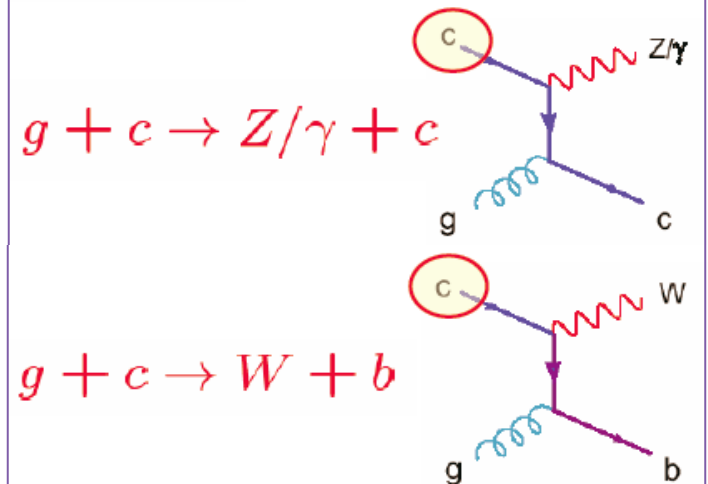
## Outlook

- This is just the beginning. Looking forward to more comprehensive and accurate data from HERA II
- With  $W/Z/\gamma$  + tagged heavy flavor events at the hadron colliders, we can get direct information on  $s/c/b$  quark distributions;  
Challenges at the Tevatron and the LHC  $\Rightarrow \Rightarrow \Rightarrow \Rightarrow$
- $c$ -quark and  $b$ -quark are important phenomenologically in the physics program at LHC for exploring beyond the SM scenarios.

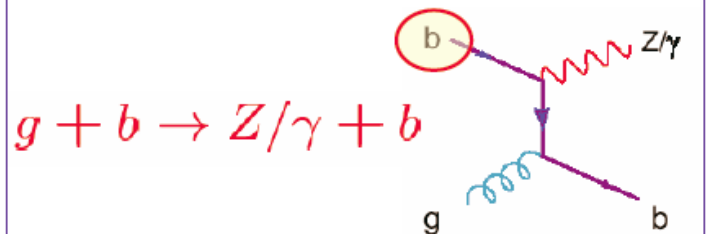
$s(x, Q) :$



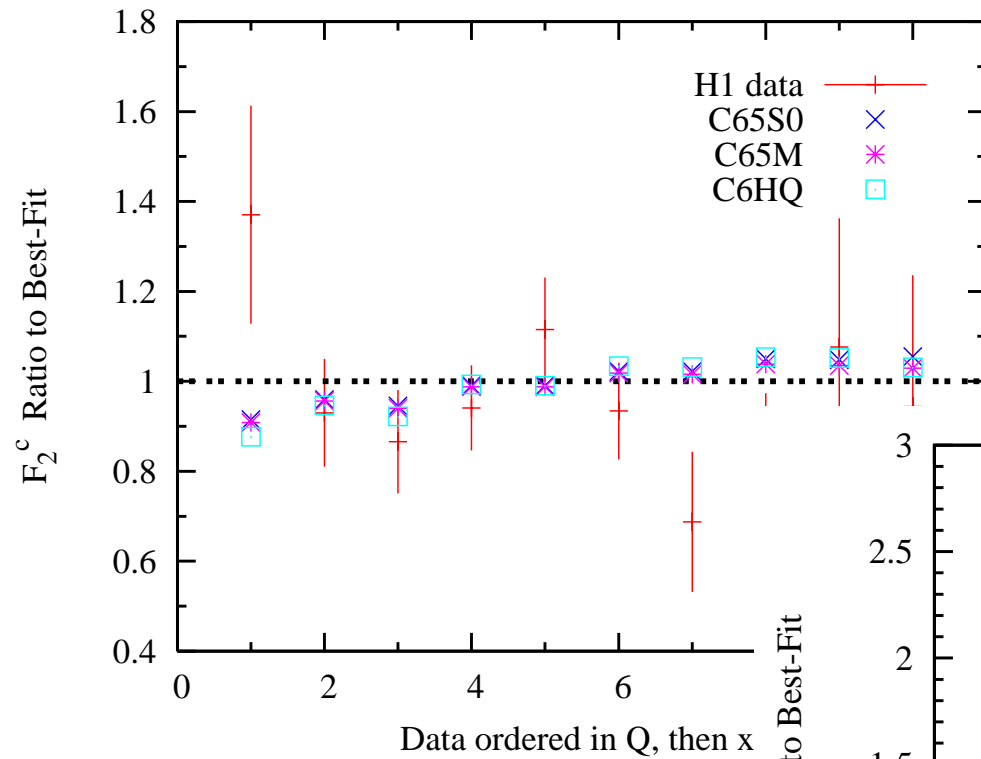
$c(x, Q) :$



$b(x, Q) :$



# Fits to the H1 charm and bottom production data (without correlated systematic shift)



Data not shifted by  
systematic errors.

