# 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)
- 1st focused study of *strange* distributions:
  CTEQ6.5Sx (hep-ph/0702268)

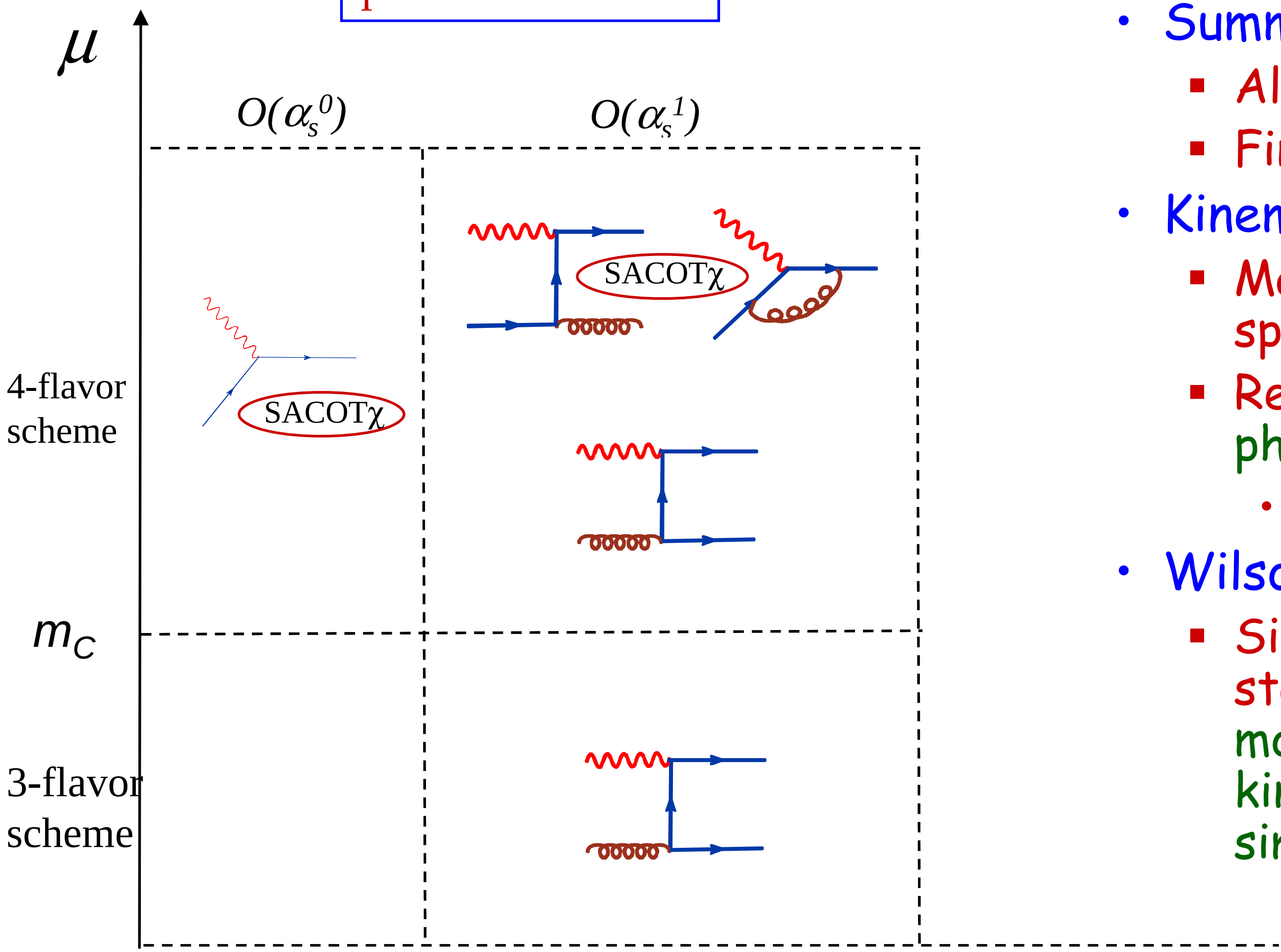
(wkt: SF-2)

- Fit to heavy flavor production data;
- 1st 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: $F^{tot}$

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

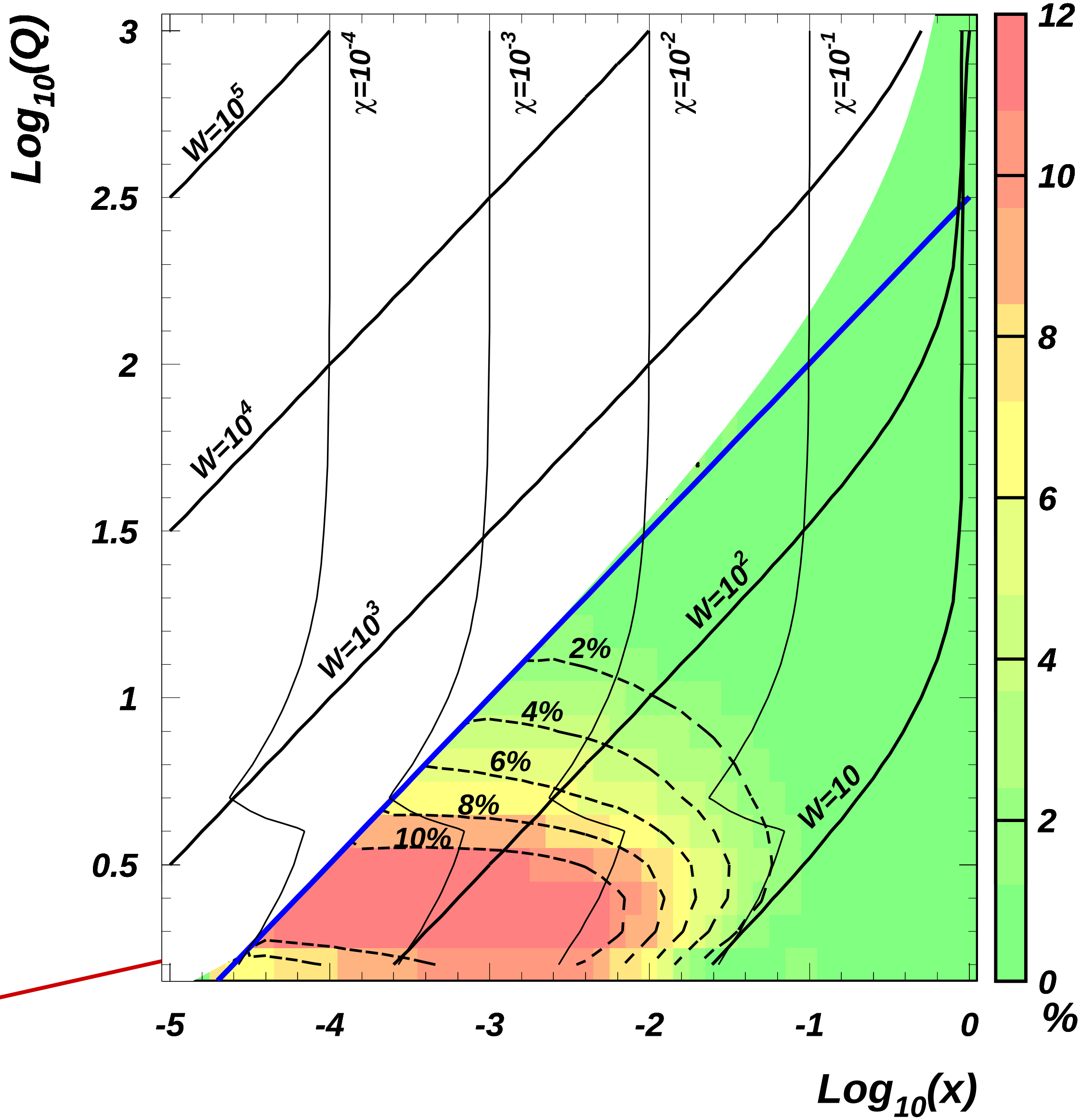
Σ final State parton flavors




- 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
    - Acotχ
- Wilson Coefficients:
  - Simplified ACOT (initial state parton mass→ 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?

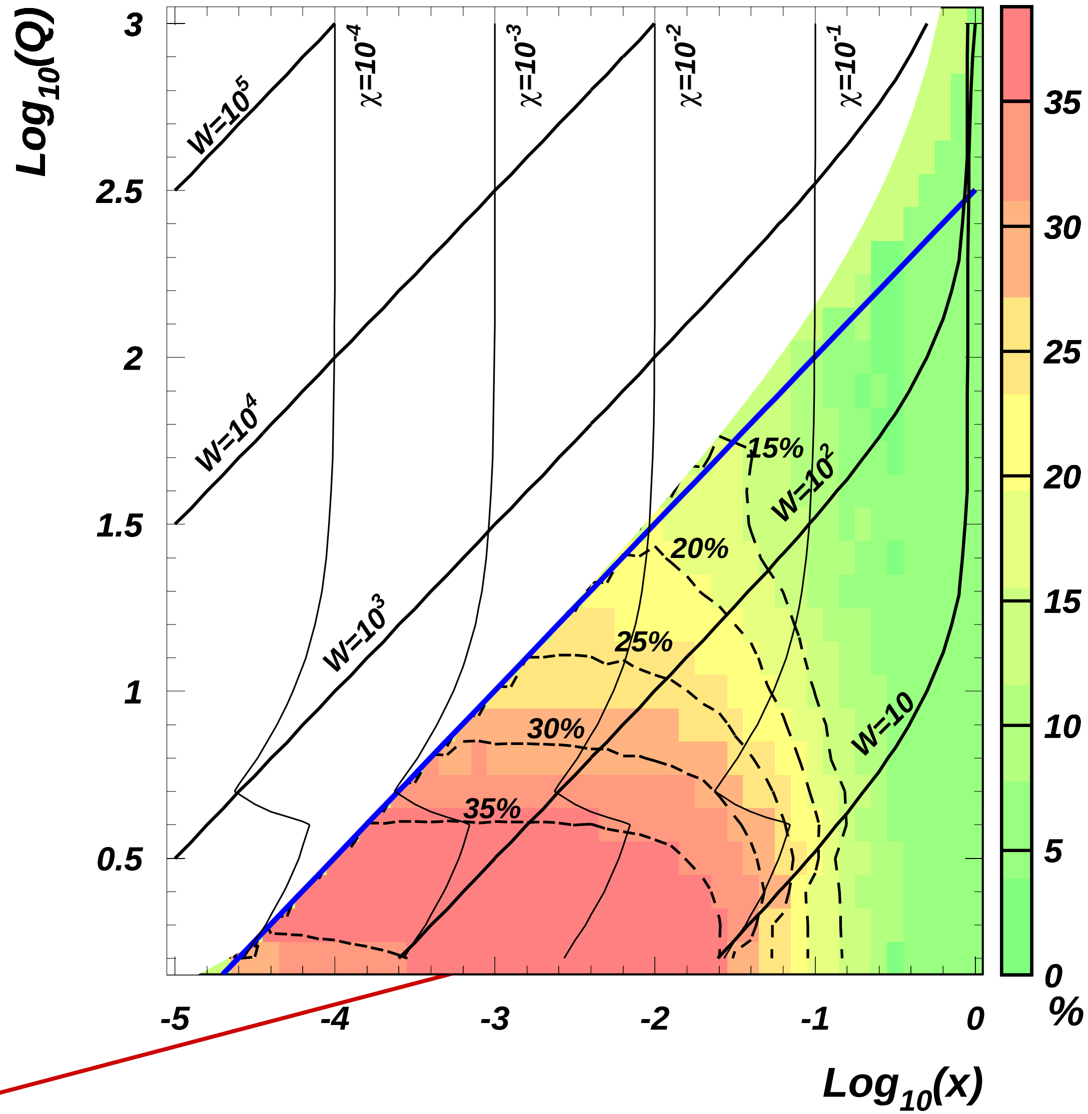
$F_2(x,Q)$




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;

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

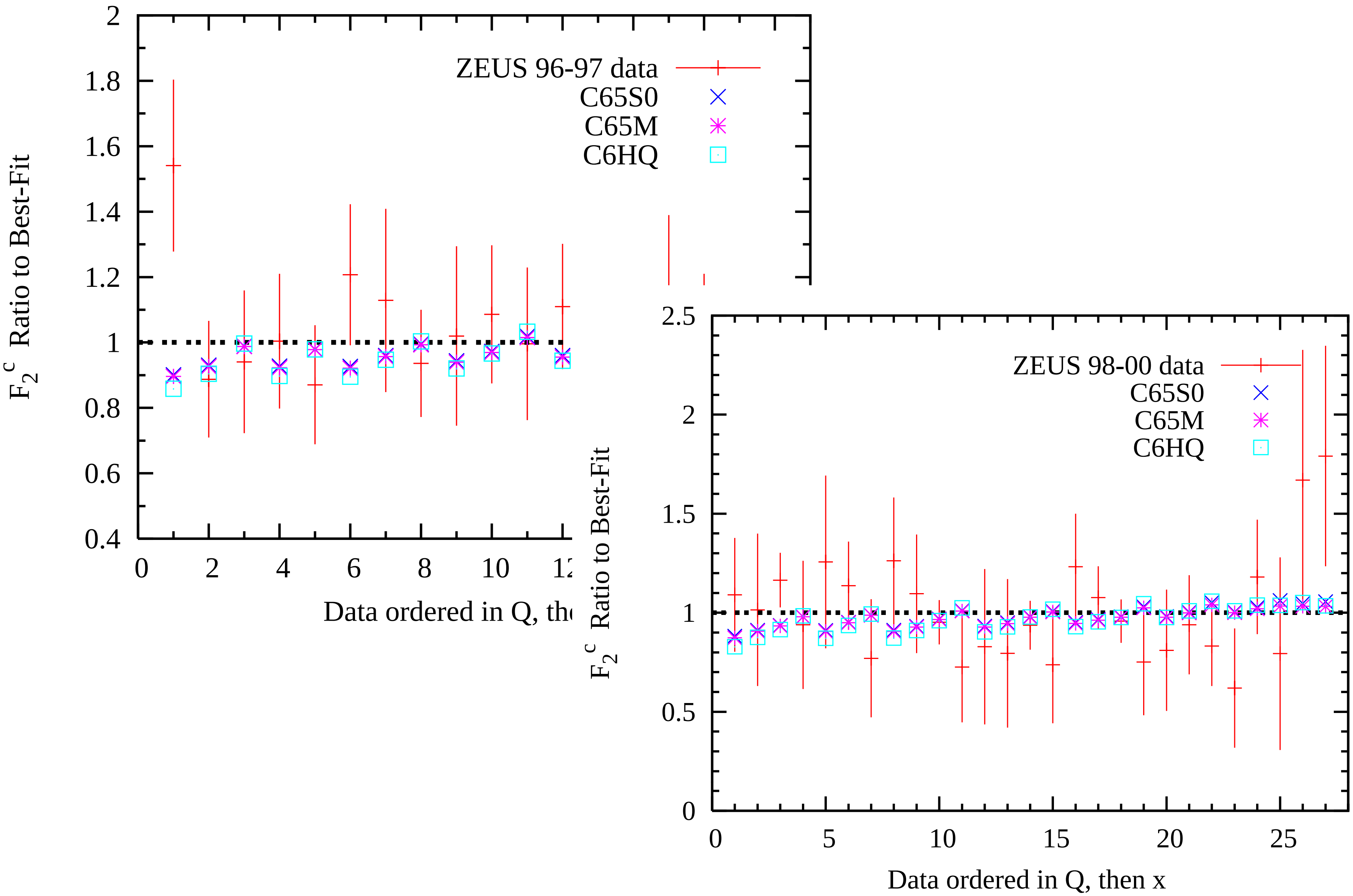
- With improved data in general, and precise theoretical treatment of charm mass effects, it is time to determine s(x) and sbar(x) inside the nucleon that are independent of the (convenient but ad hoc) ansatz

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

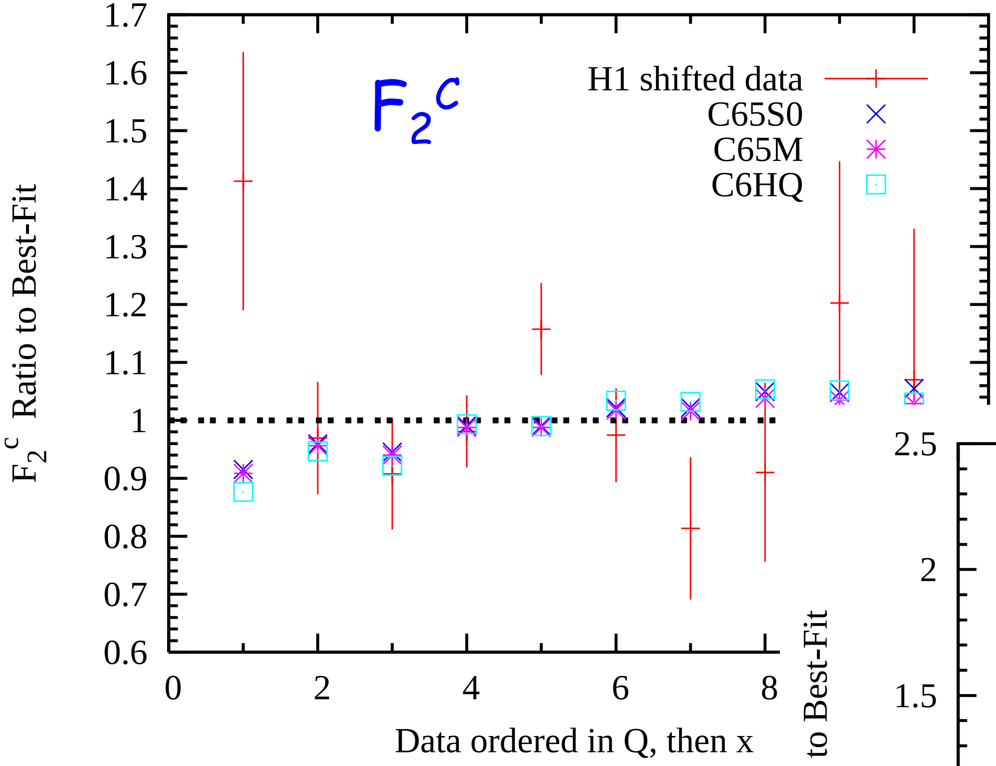
(hep-ph/0702268) (wkt: SF-2)

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

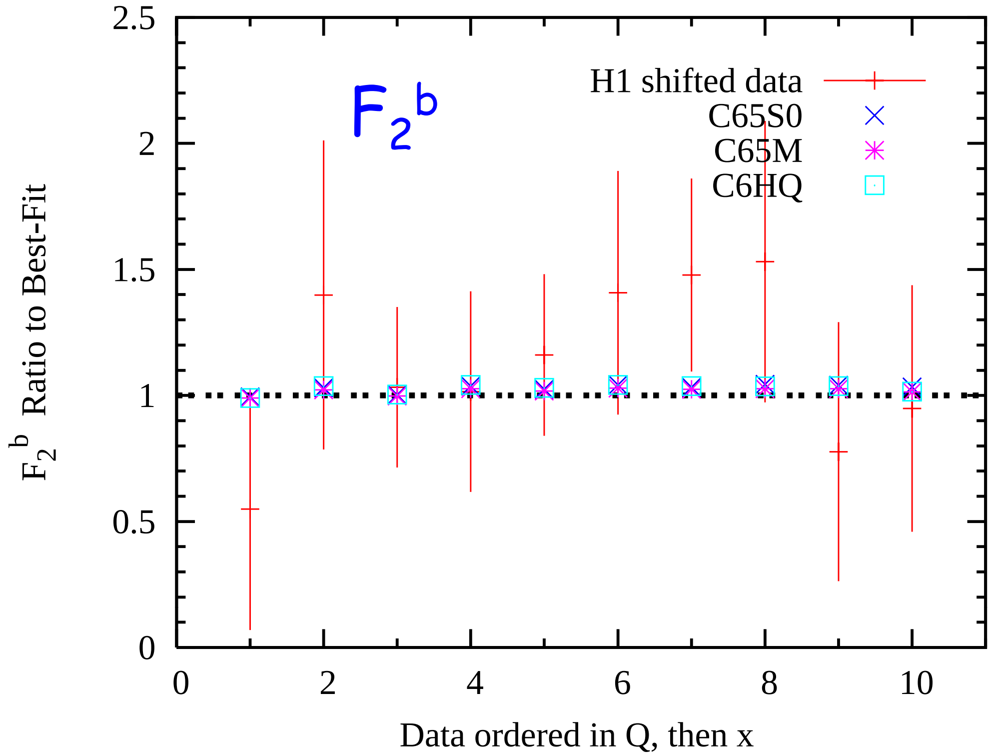
# Fits to the ZEUS charm production data: $F_2^C$



# 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-bar --> $H^+$ ;
  - 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 etal (BHPS);
    - Meson-cloud model (MC)

  (similar, except c .ne. cbar for the latter).

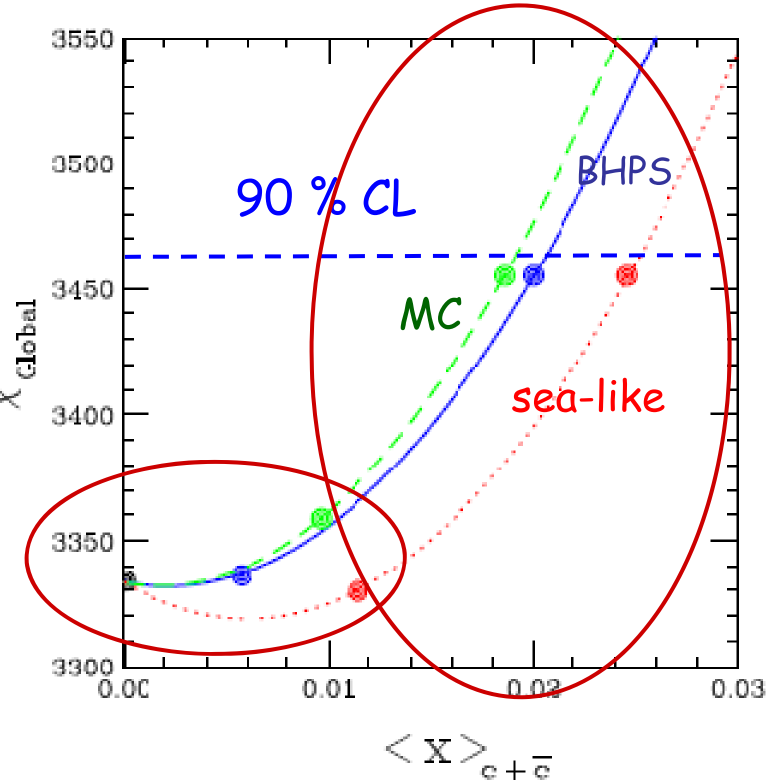
(Pumplin, Lai, wkt: hep-ph/0701220)

# Results:

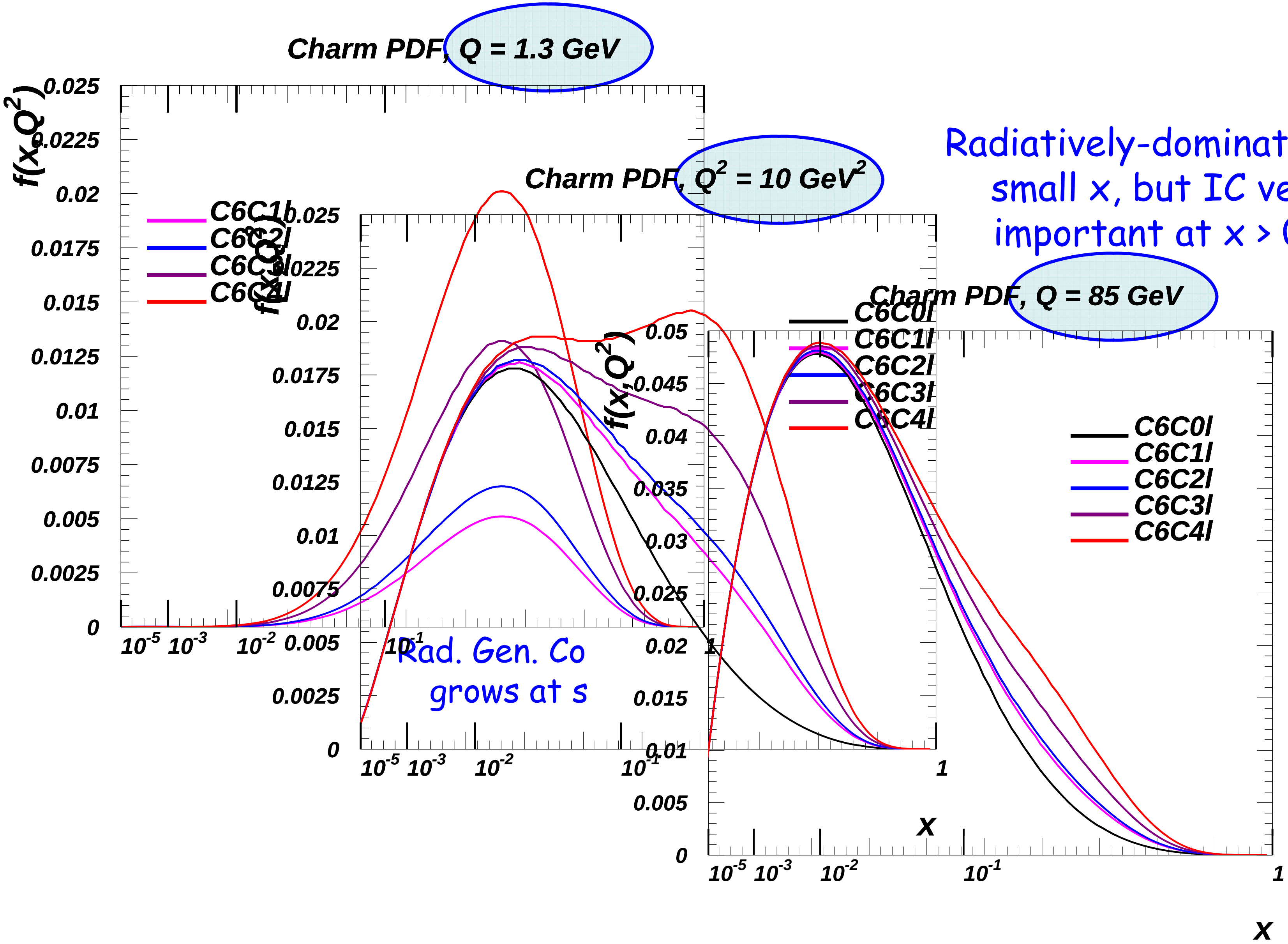
- In the range $0 < \langle x \rangle_{c+\bar{c}} < 0.01$: Current global analysis does not require IC;
- For $0.01 < \langle x \rangle_{c+\bar{c}}$ (assuming IC exists, as is natural in the models), our analysis sets a useful upper bound $\langle x \rangle_{c+\bar{c}} < 0.02$; Light-cone model guesstimates, $\langle x \rangle_{c+\bar{c}} \sim 0.01$, 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)




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

"Heavy Quark Mass" in Global QCD Analyses:

* Can we "measure" $M_{b,c}$ by fitting in global analysis?

* Are these "Pole masses", "Msbar 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);
  - $\Delta\chi^2_{global} \sim 35$ ( / 2714 pts) (not significant by itself)
  - But, $\Delta\chi^2_{F2c} \sim 30$ ( / 55 pts) — quite significant.

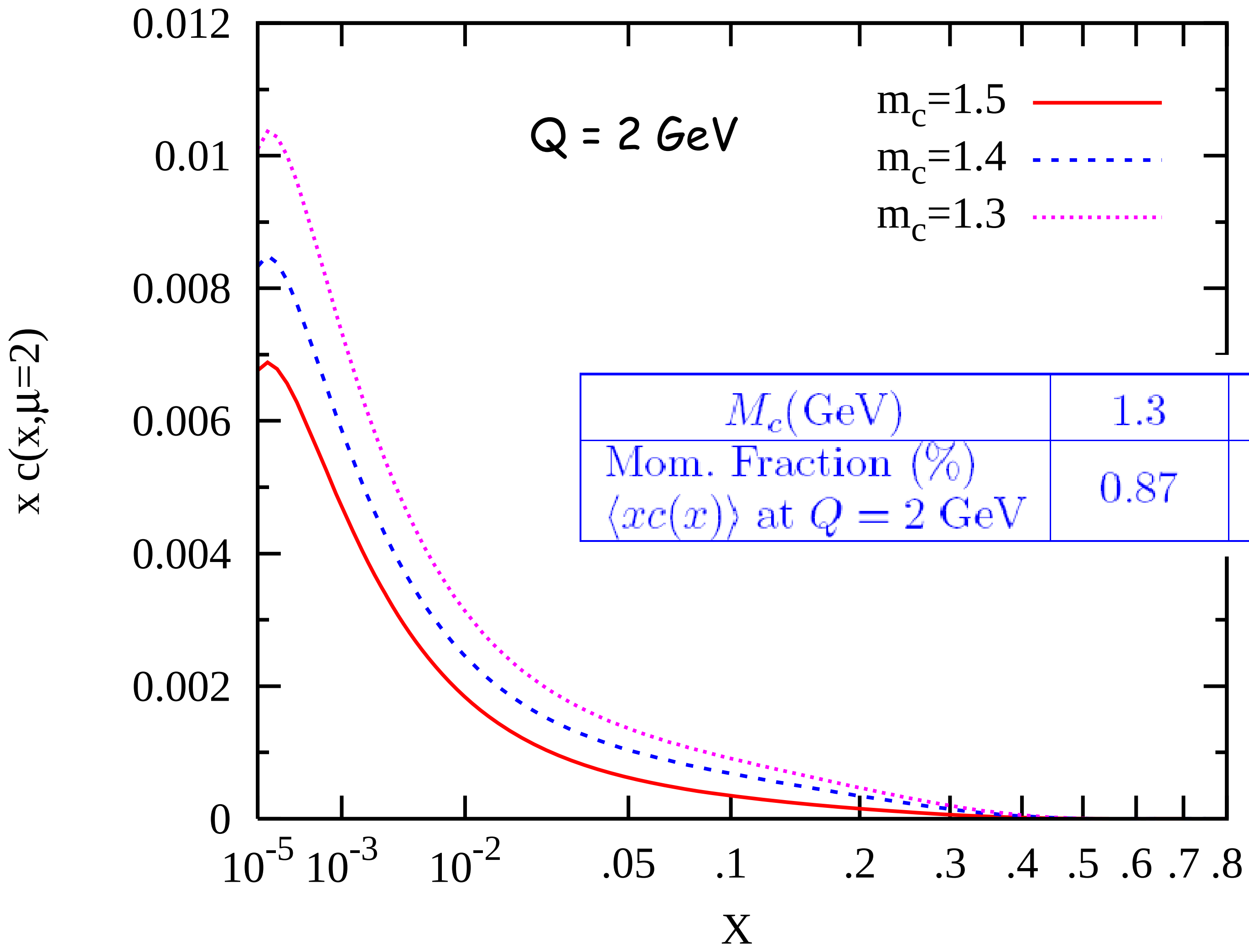
What is the physical meaning of this "$M_C$", or $M_C^{global}$?

## 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



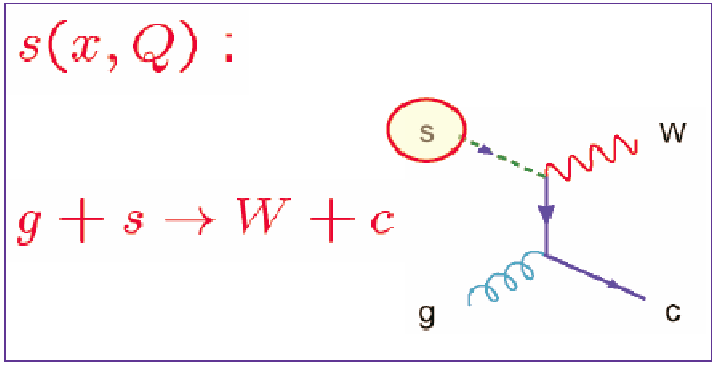

| $M_c$(GeV) | 1.3 | 1.4 | 1.5 |
|---|---|---|---|
| Mom. Fraction (%) $\langle xc(x) \rangle$ at $Q = 2$ GeV | 0.87 | 0.71 | 0.57 |

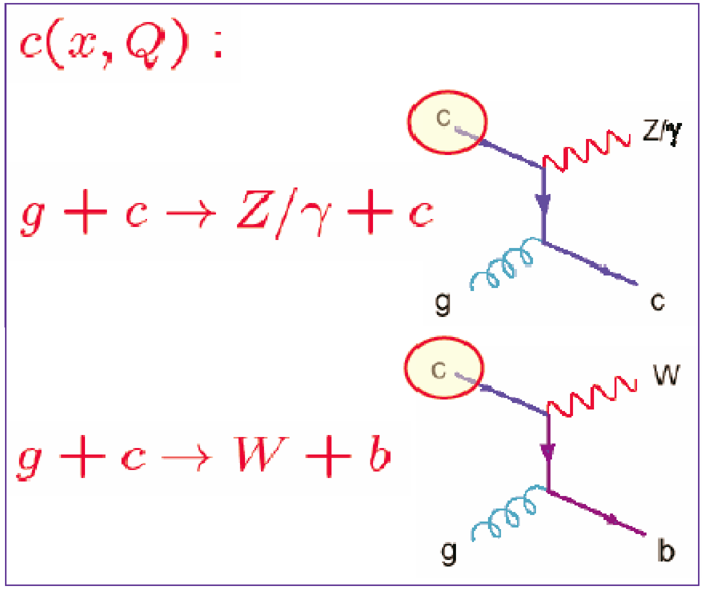
$M_c^{global}$ is neither $M_c^{pole}$ nor $M_c^{msbar}$ !

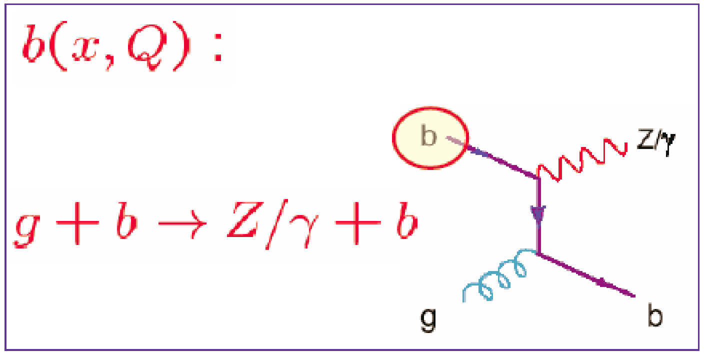
- Can $M_c^{global}$ be converted to $M_c^{pole}$?
- This will be left as a homework problem.

# Outlook

- This is just the beginning. Looking forward to more comprehensive and accurate data from HERA II
- With W/Z/γ + 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 =>=>=>
- c-quark and b-quark are important phenomenologically in the physics program at LHC for exploring beyond the SM scenarios.

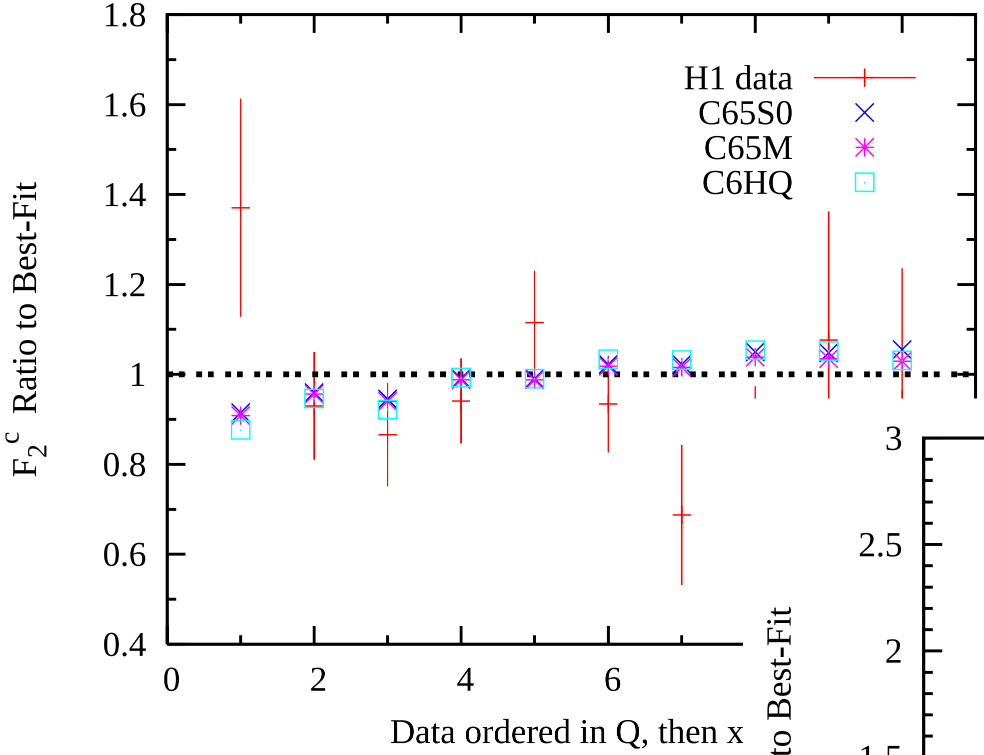


# Fits to the H1 charm and bottom production data

(without correlated systematic shift)




Data not shifted by systematic errors.