Heavy flavour schemes, masses, scales

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- Measurement/fit of b, c masses
- Variants of FFNS scheme
- QCD scale choice

Can we measure the charm and bottom quark masses as physical parameters from F_2^c/F_2^b data?

heavy quark mass in different schemes

- ZM-VFNS: mass is just kinematic threshold parameter (onset of massless "heavy" quark PDF)
  -> can not be used for meaningful mass measurement in QCD

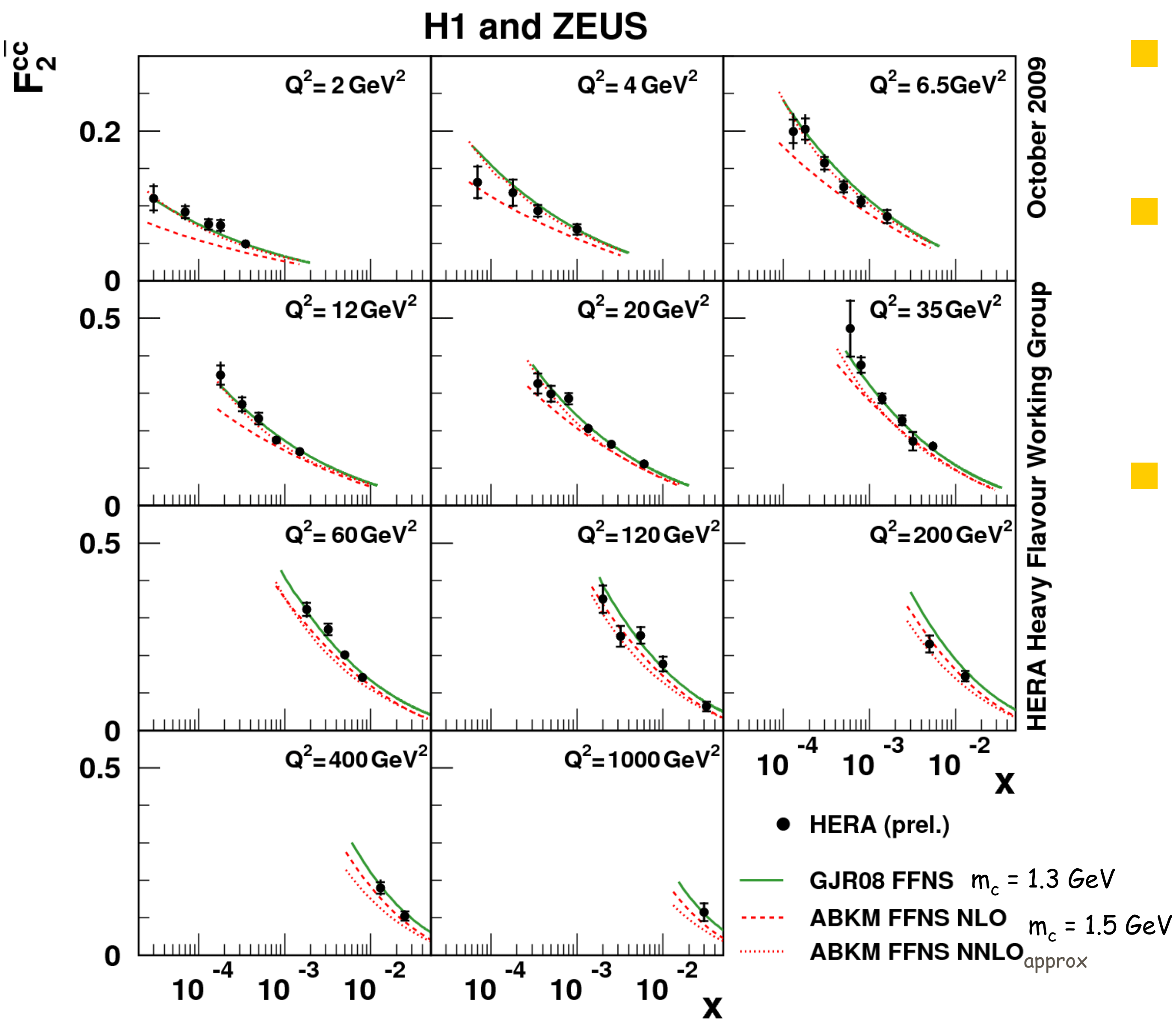
- FFNS: until recently, all existing calculations for ep have used pole mass (on-shell mass renormalization scheme)
  PDG09: $m_b \sim$ 4.79+0.19-0.08 GeV, $m_c \sim$ 1.65 ± 0.18 GeV

  but: pole mass definition has intrinsic uncertainty of order Λ_{QCD}
  -> change scheme to $\overline{MS}$ running mass to predict and fit F_2^c ?
  see talk S. Alekhin (ABKM FFNS)
  -> $m_c(m_c) \sim 1.30 \pm 0.12$ GeV (PDG: 1.27+0.07-0.11 GeV)

  might be relatively clean way to measure charm mass

  but: beware of systematics from higher order QCD corrections !

FFNS predictions: NNLO vs. NLO



- both ABKM and GJR use pole mass
- ABKM: approximate NNLO correction (threshold resummation) very large at low Q^2
- GJR seems to compensate absence of threshold correction terms in matrix elements by choice of very low charm mass

-> systematic uncertainty on m_c from higher order corrections ~ 0.2 GeV ?

heavy quark mass in different schemes

- GM-VFNS: all existing calculations use pole mass for massive part of calculation,

  e.g. Martin, Stirling, Thorne, Watt, arXiv:1007.2624 [hep-ph].

  Their pole mass evaluation from conversion of running masses:

  m_b ~ 4.9 ± 0.2 GeV, m_c ~ 1.5 ± 0.2 GeV

  However, massive calculation is matched to massless part through various different matching schemes

  -> sensitivity of cross sections to mass is modified through model assumptions in the matching

  -> mass, although still based on pole mass concept, becomes effective model parameter

  my conclusion: GM-VFNS schemes can probably not be used for well-defined measurement of heavy quark masses (unless unphysical zero mass effects can somehow be eliminated)

Example: variants of TR-VFNS

NLO mass effects — NLL resummation of logs — interpolation

$$F_{2,c}^{\text{VFNS}} = F_{2,c}^{\text{FFNS}}(N_f = 3) + F_{2,c}^{\text{ZMVFNS}}(N_f = 4) - F_{2,c}^{\text{ASYMP}}(N_f = 3)$$

pole mass — "massless" !

spoils mass definition

Thorne: each term in the combination $(F_2^{\text{ZMVFNS}} - F_2^{\text{asymp}})$ can be modified by corrections which fall like m_H^2/Q^2.

-> 4 "free" parameters a,b,c,d (of range 0-1)

Variants of TR-VFNS (m_c=1.4 GeV fixed)

Thorne

+my comments

6 extreme variations tried.

GMVFNS1 – $b = -1, c = 1$.

GMVFNS2 – $b = -1, c = 0.5$.

GMVFNS3 – $a = 1$.

GMVFNS4 – $b = +0.3, c = 1$ – fit.

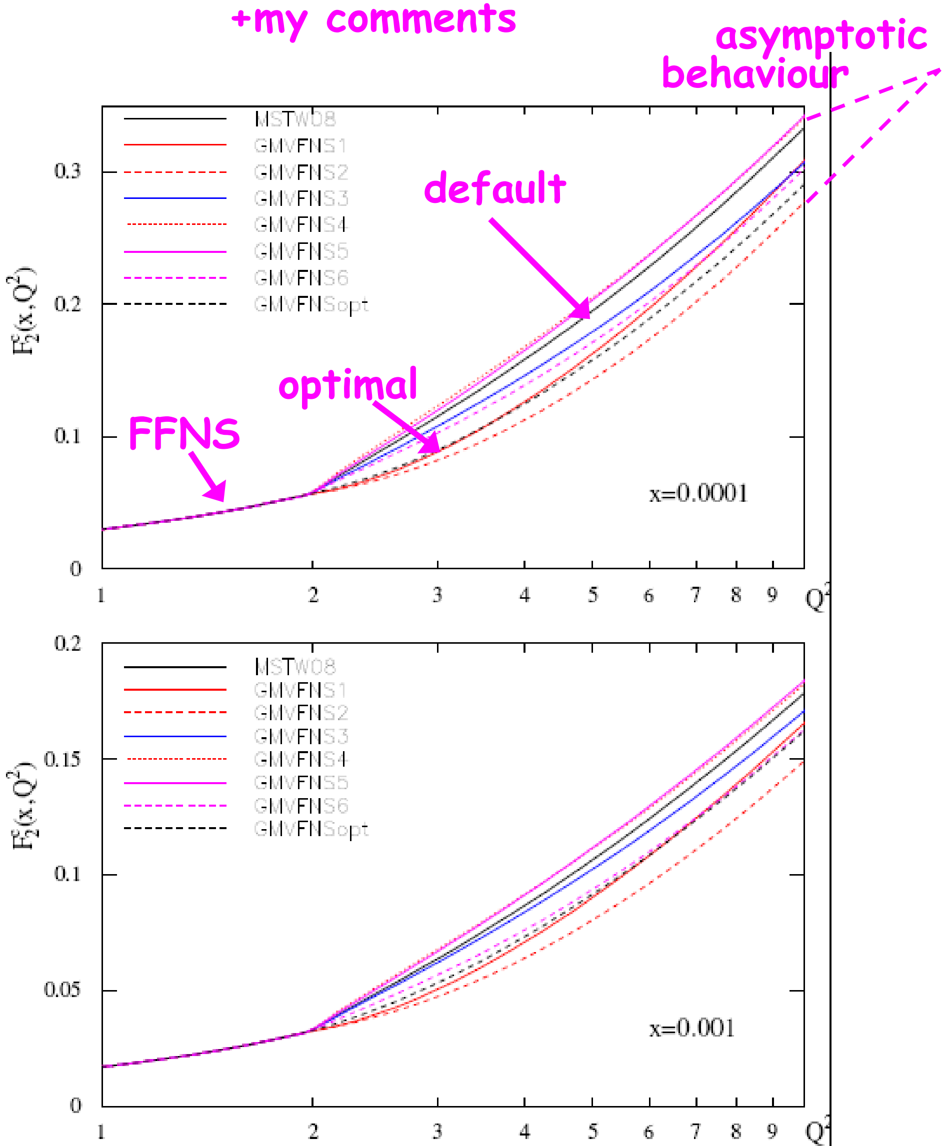
GMVFNS5 – $d = 0.1$ – fit.

GMVFNS6 – $d = -0.2$ – fit.

Variations in $F_2^c(x,Q^2)$ near the transition point at NLO due to different choices of GM-VFNS.

Optimal, $b = -2/3, c = -1, d = -1$, smooth behaviour.

can have noticeable effect even at LHC (3% on σ_Z)



fit to data with Q^2 > 2 GeV^2 will lead to different optimal m_c values

-> model dependence, not QCD ! -> effective mass parameter

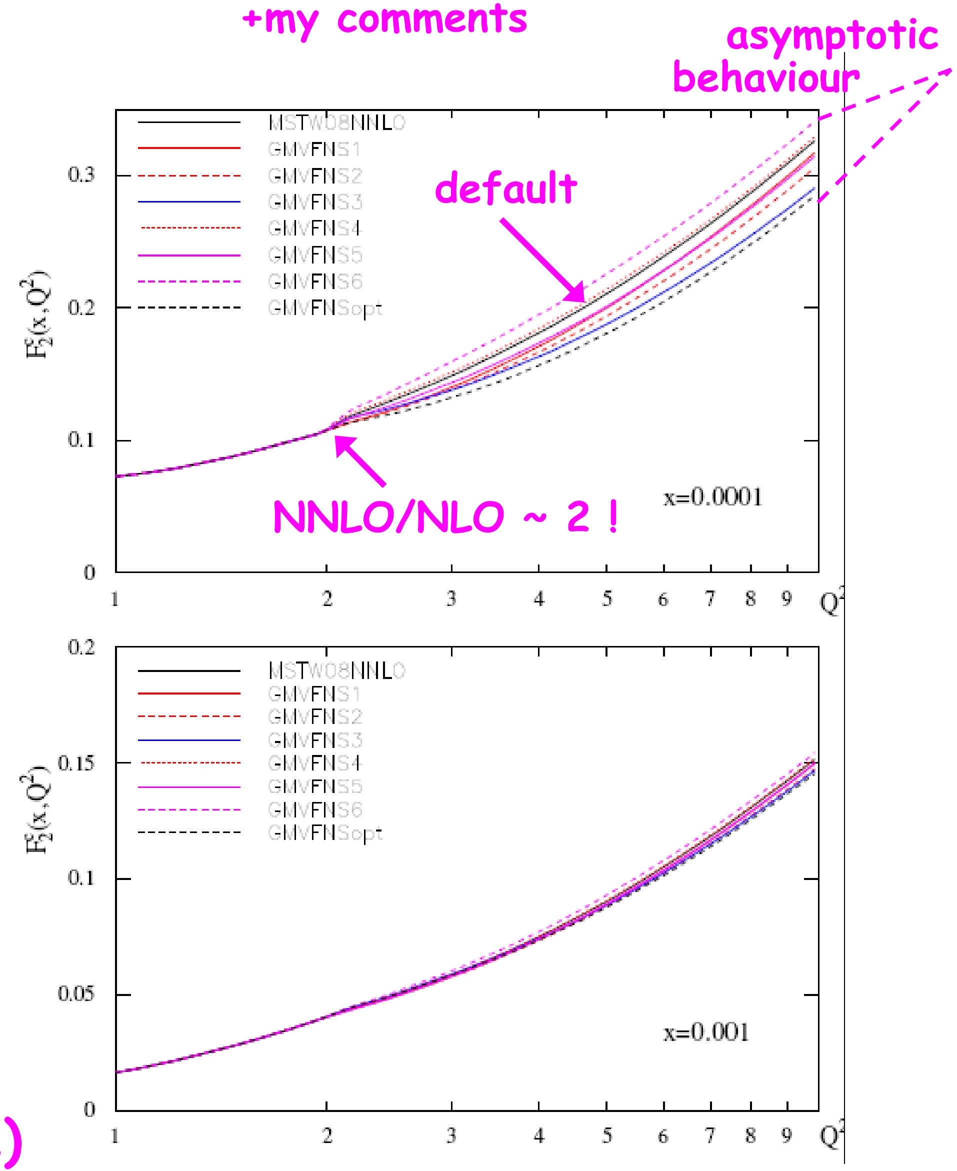
Variants of TR-VFNS, NNLO (approx)

Thorne
+my comments

Variations in $F_2^c(x,Q^2)$ near the transition point due to different choices of GM-VFNS at NNLO.

Very much reduced, almost zero variation until very small x.

Shows that NNLO evolution effects most important in this regime.



still noticeable effect at low x

GMVNS1 smooth both at NLO and NNLO (see curves), better χ^2 for global MRST fit (Thorne)

- Can we reduce the heavy quark mass uncertainty on LHC standard candle processes by fitting m_c ?

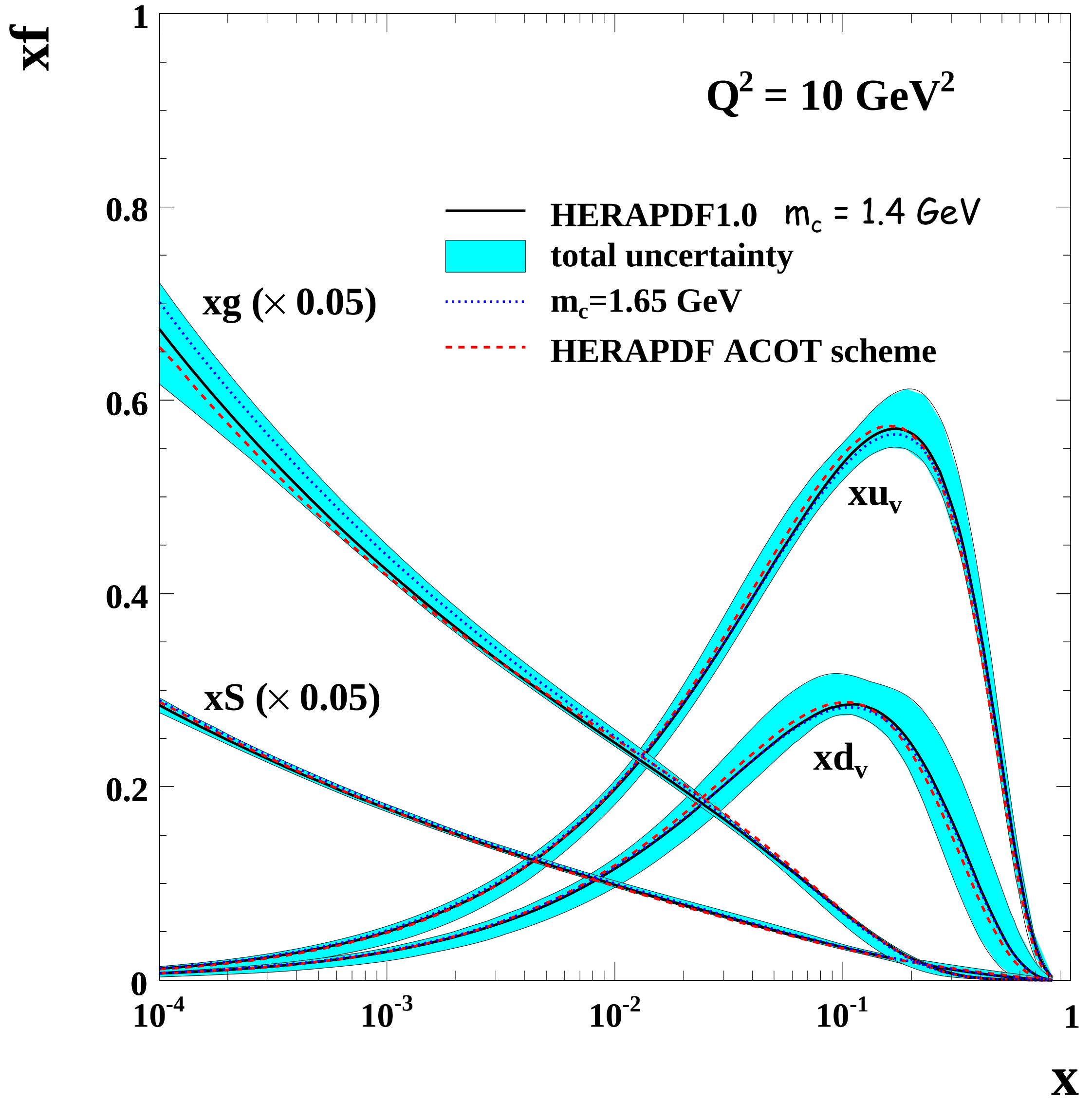
-> for W/Z probably yes, see previous talk (R. Placakyte)
m_c does NOT need to be physical parameter for this purpose
-> can use “any” scheme

Why does it work?

inspect e.g. HERAPDF

Cooper-Sarkar

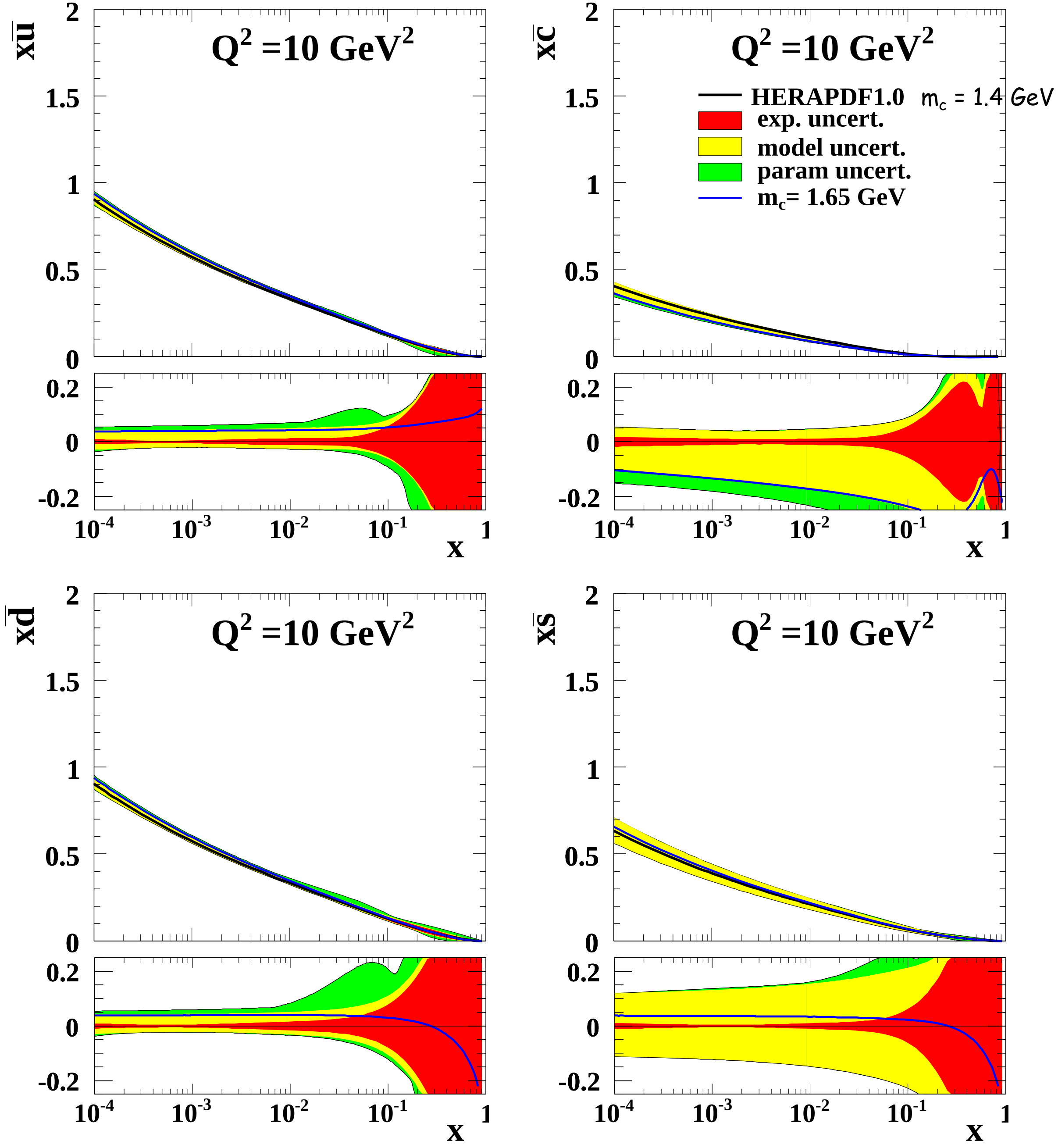
+my comments



larger m_c

-> more gluon at low x

H1 and ZEUS



Cooper-Sarkar

+my comments

larger m_c

-> more gluon, less c

-> more light quarks

fitting m_c to describe F_2^c seems to yield almost the same sea quark flavour mixture in relevant x range for "any" scheme

-> reduced uncertainty on W/Z predictions at LHC

- Will this also work for gluon-initiated processes (Higgs, top, …) ?
- will it work for other kinematic regions?

not clear (under investigation)

until clarified: propose to keep enveloping mass variation as PDF uncertainty, e.g. m_c = 1.50 ± 0.15 GeV

Variants of FFNS scheme

- Variants of GM-VFNS discussed repeatedly
- Less well known: variants of FFNS scheme exist, too !

All FFNS schemes have fixed number of real flavours in PDFs
+ heavy flavours generated dynamically, but

  - fixed flavour α_s evolution, e.g. MRST04FF, CTEQ5F3, CTEQ5F4, Riemersma et al., HVQDIS (Harris & Smith)

    -> heavy flavour loops consistently removed from theory (?)

    or

  - variable flavour α_s evolution, e.g. ABKM, GJR

    -> heavy flavour loops treated explicitly (and partially resummed?)

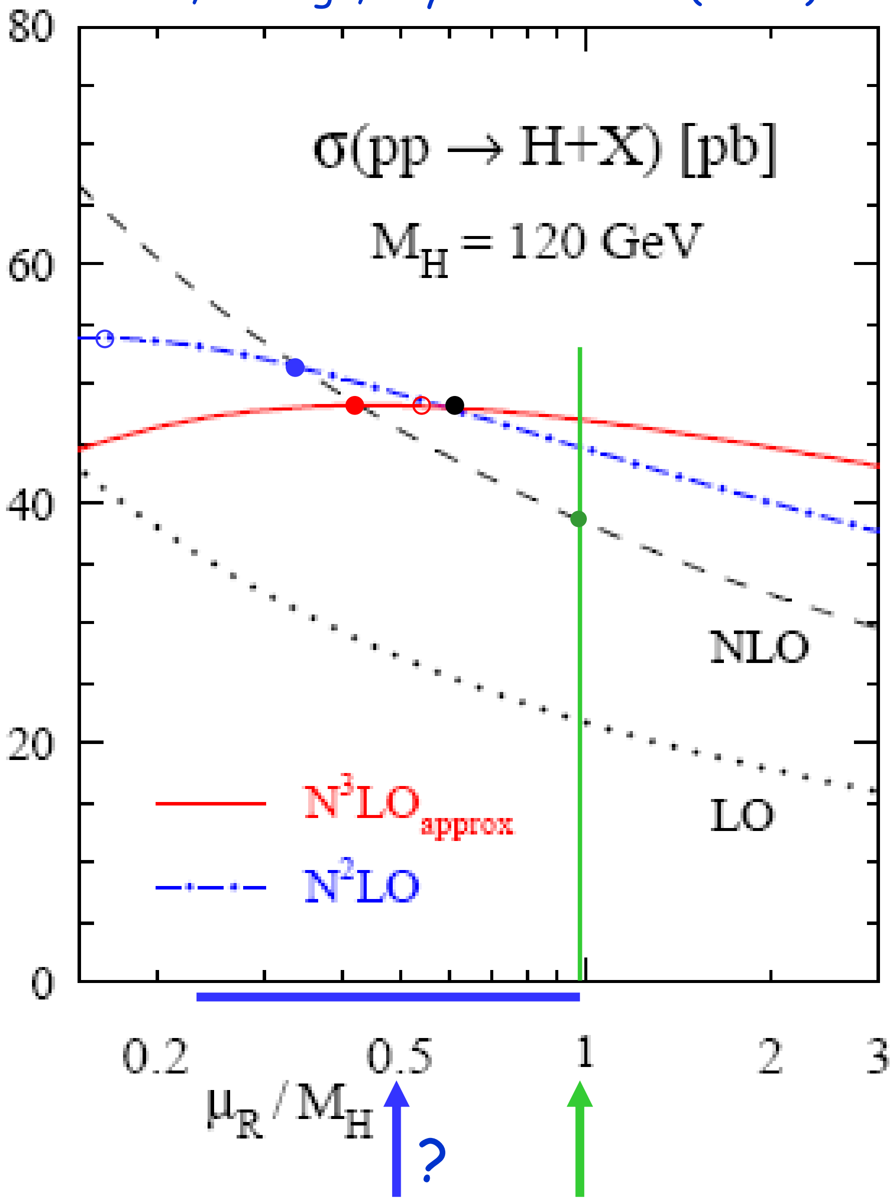
- Schemes differ by $\alpha_s \log(\mu^2/m^2)$ terms in α_s and by corresponding heavy flavour loop terms in (both light and heavy) matrix elements/coefficient functions to avoid double counting of loops
- consider highest HERA energies: $\log(10000/1.5^2) \sim 8$,

for PDFs and matrix elements evaluated at LHC energies even larger

-> variable flavour α_s evolution scheme seems preferable for global fits and/or precise LHC predictions

NLO scale choice? example: Higgs at LHC

S. Moch, A. Vogt, Phys.Lett. B631 (2005) 48



in principle arbitrary, but

NNLO stability:

- • NNLO = NLO
- ○ $d\sigma_{NNLO}/d\mu = 0$

N³LO stability:

- • N³LO = NLO
- • N³LO = NNLO
- ○ $d\sigma_{NLO+NLL}/d\mu = 0$

— "natural" scale

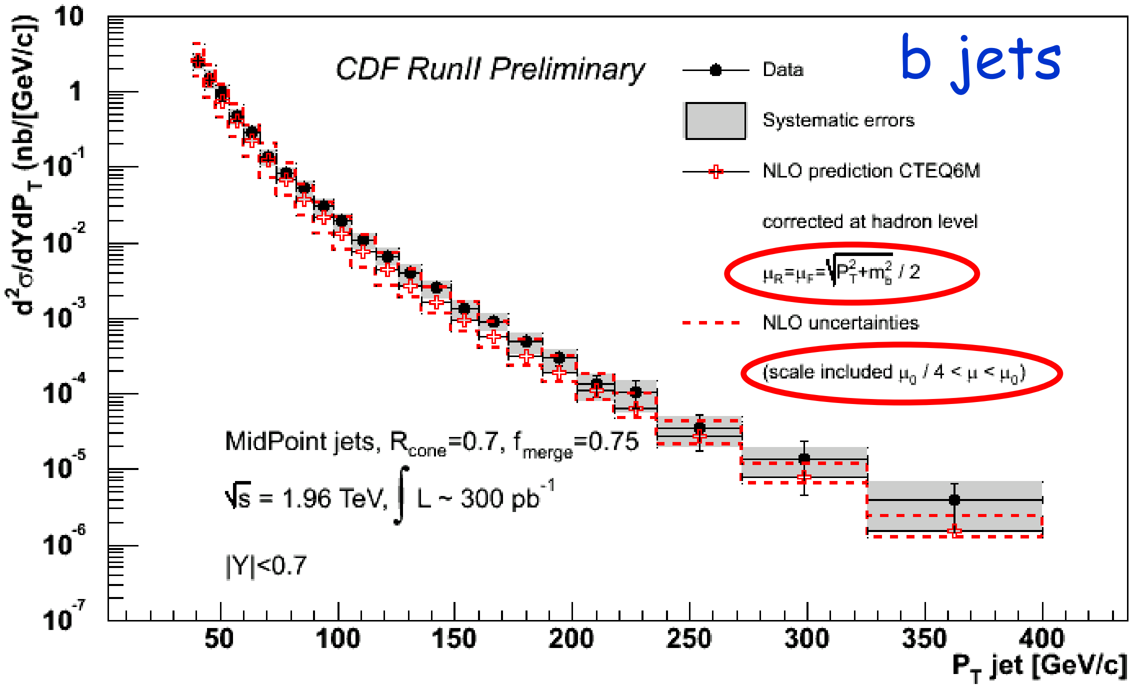
NNLO/N3LO calculations, where available, often suggest ren./fact. scale ~ half "natural" scale for NLO

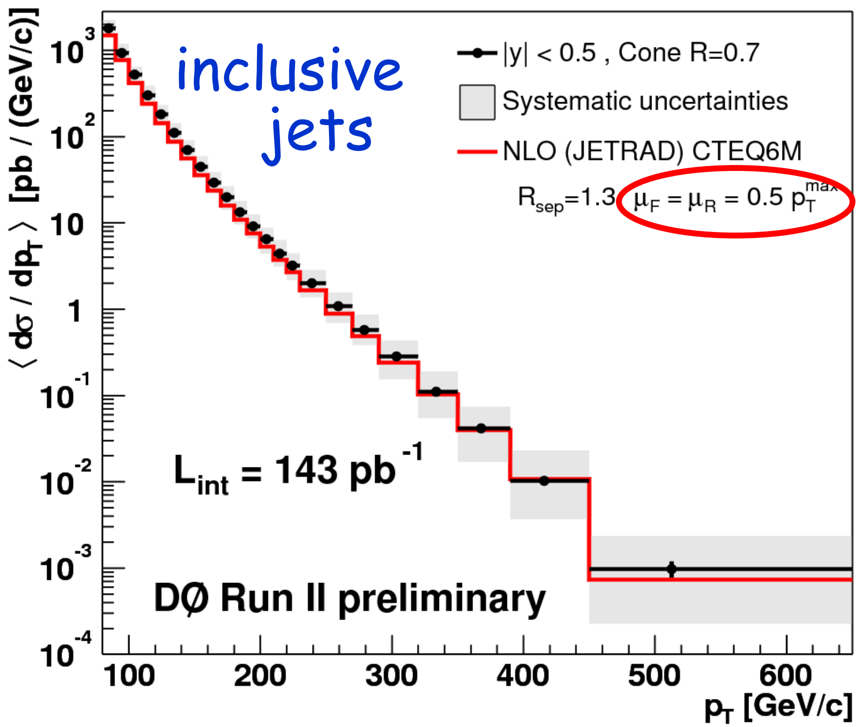
more details: **arXiv:0711.1983** [hep-ex] personal remark: either dedicated scale study, or

- consider to use default QCD scale $\mu_0/2$ for your favourite NLO cross section predictions, <u>including LHC,</u> in particular before claiming discrepancies

more details: **arXiv:0711.1983** [hep-ex]

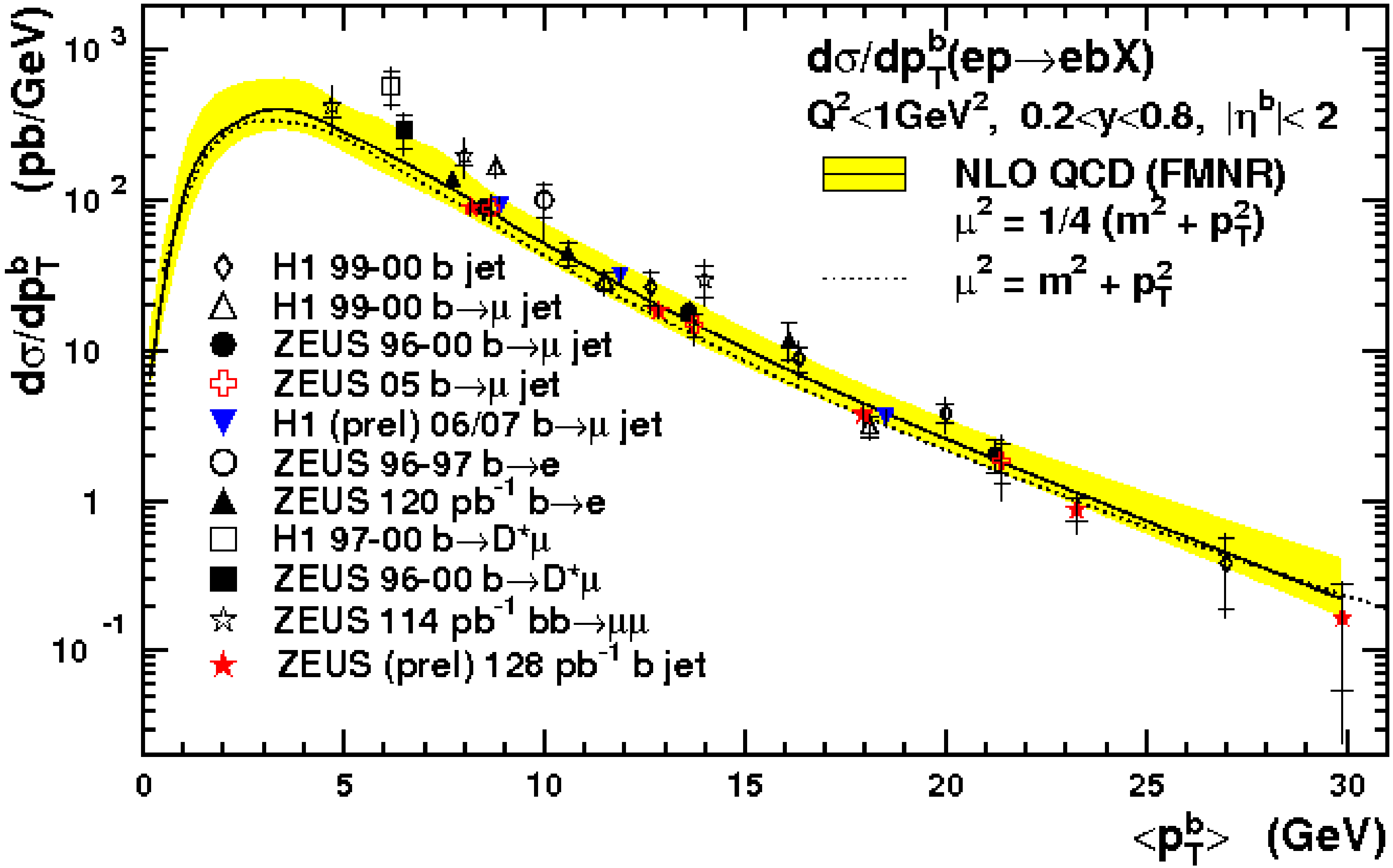
some people are doing this already:
(also see talks J. Huston and M. Grazzini)





beauty in photoproduction

HERA

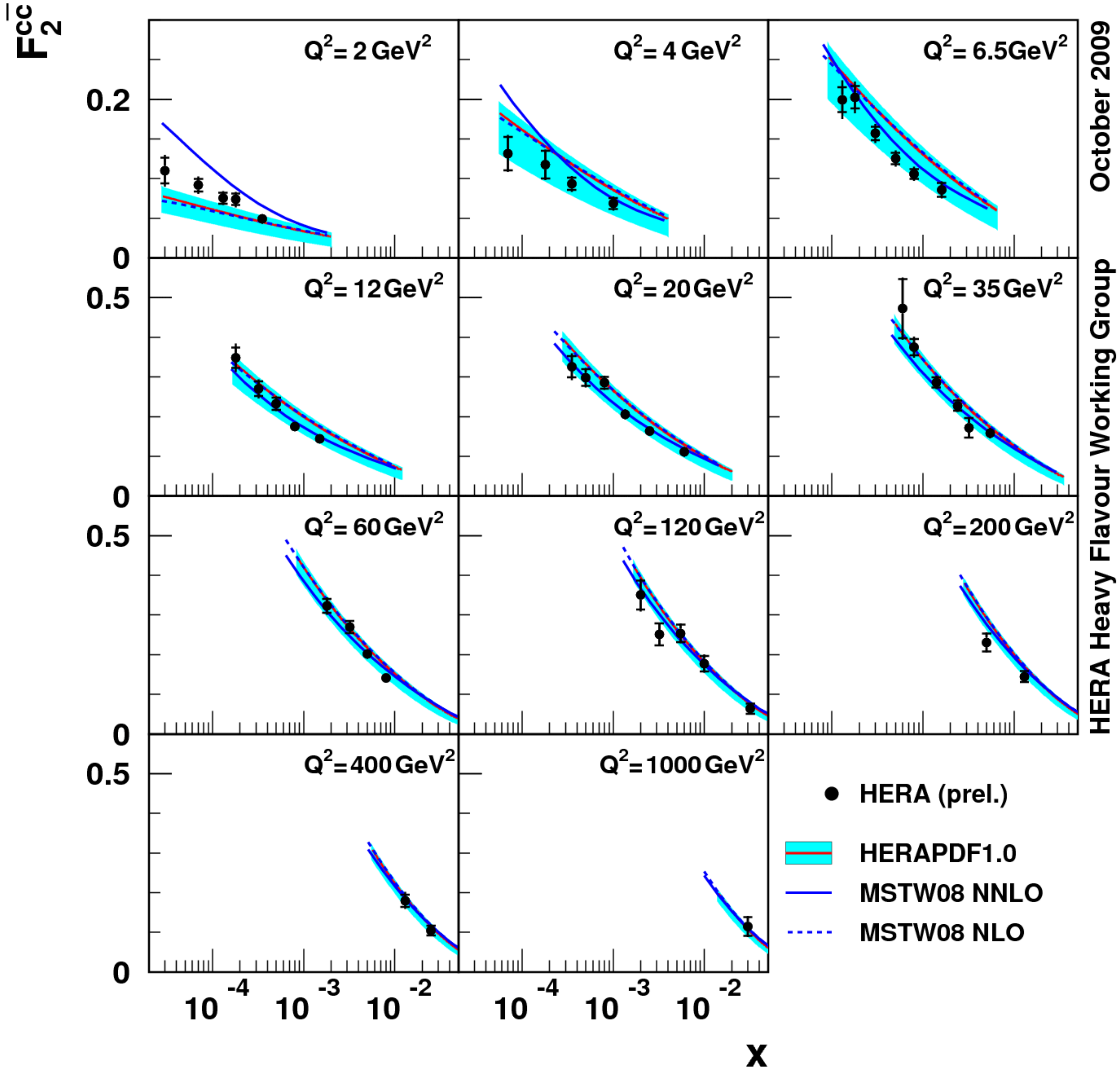


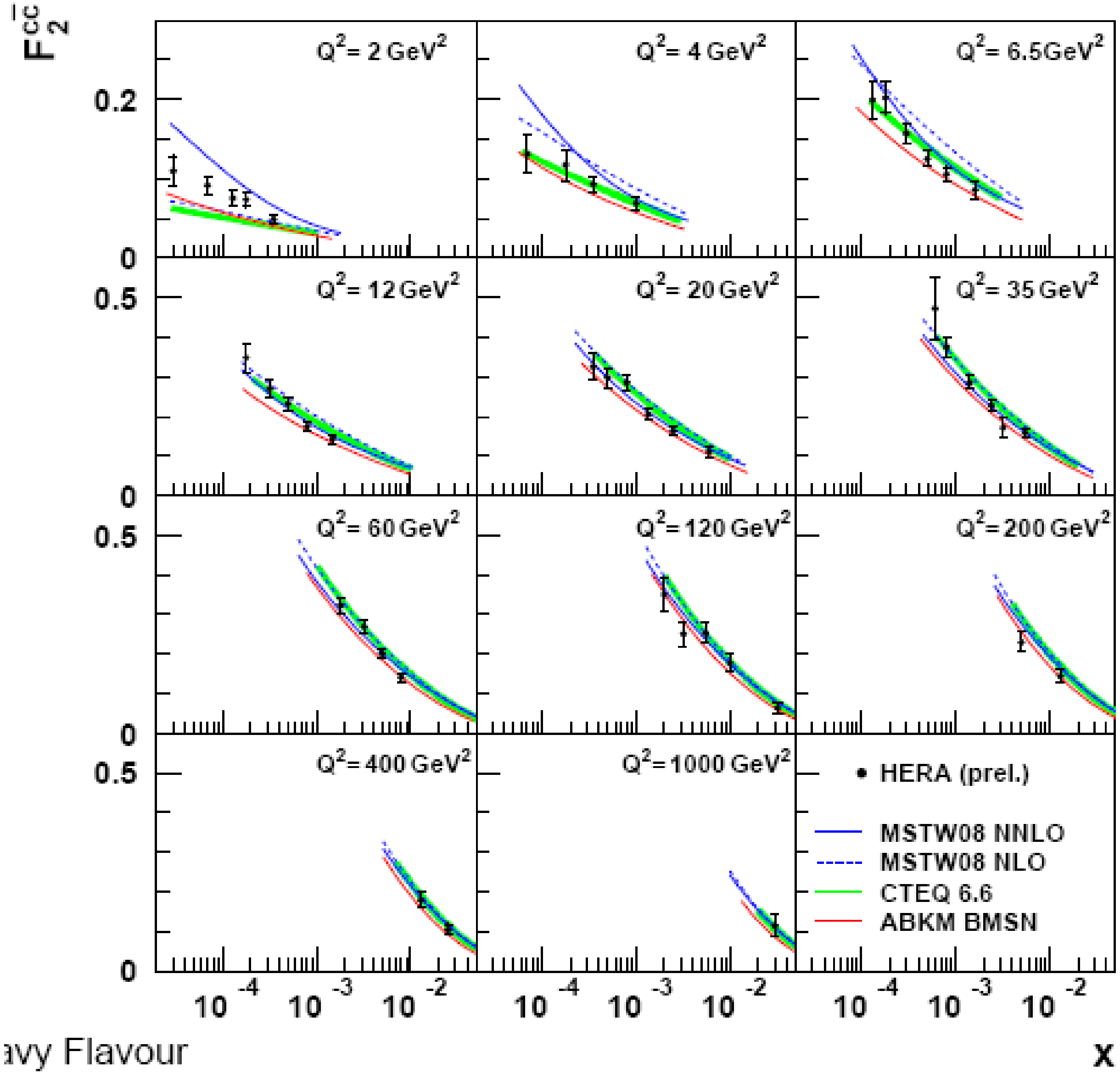
reasonably described by NLO QCD

Summary and conclusions

- Use FFNS with $\overline{MS}$ mass renormalization scheme to measure physical b and c masses ?   need NNLO?
- Uncertainty on W/Z standard candle cross sections can probably be reduced through empirical m_c fit to F_2^c in each scheme. Need further studies to check whether this is also true for other cross sections (might not).
- Different FFNS schemes exist. Variable flavour α_s evolution scheme preferable for global fits/LHC predictions?
- Consider to use ~ half natural scale for NLO cross section predictions (photo- and hadroproduction)

Backup slides


$F_2^{c\bar{c}}$
Q^2= 2 GeV^2
Q^2= 4 GeV^2
Q^2= 6.5GeV^2
Q^2= 12 GeV^2
Q^2= 20 GeV^2
Q^2= 35 GeV^2
Q^2= 60 GeV^2
Q^2=120 GeV^2
Q^2=200 GeV^2
Q^2=400 GeV^2
Q^2=1000 GeV^2
HERA (prel.)
HERAPDF1.0
MSTW08 NNLO
MSTW08 NLO
HERA Heavy Flavour Working Group October 2009
x



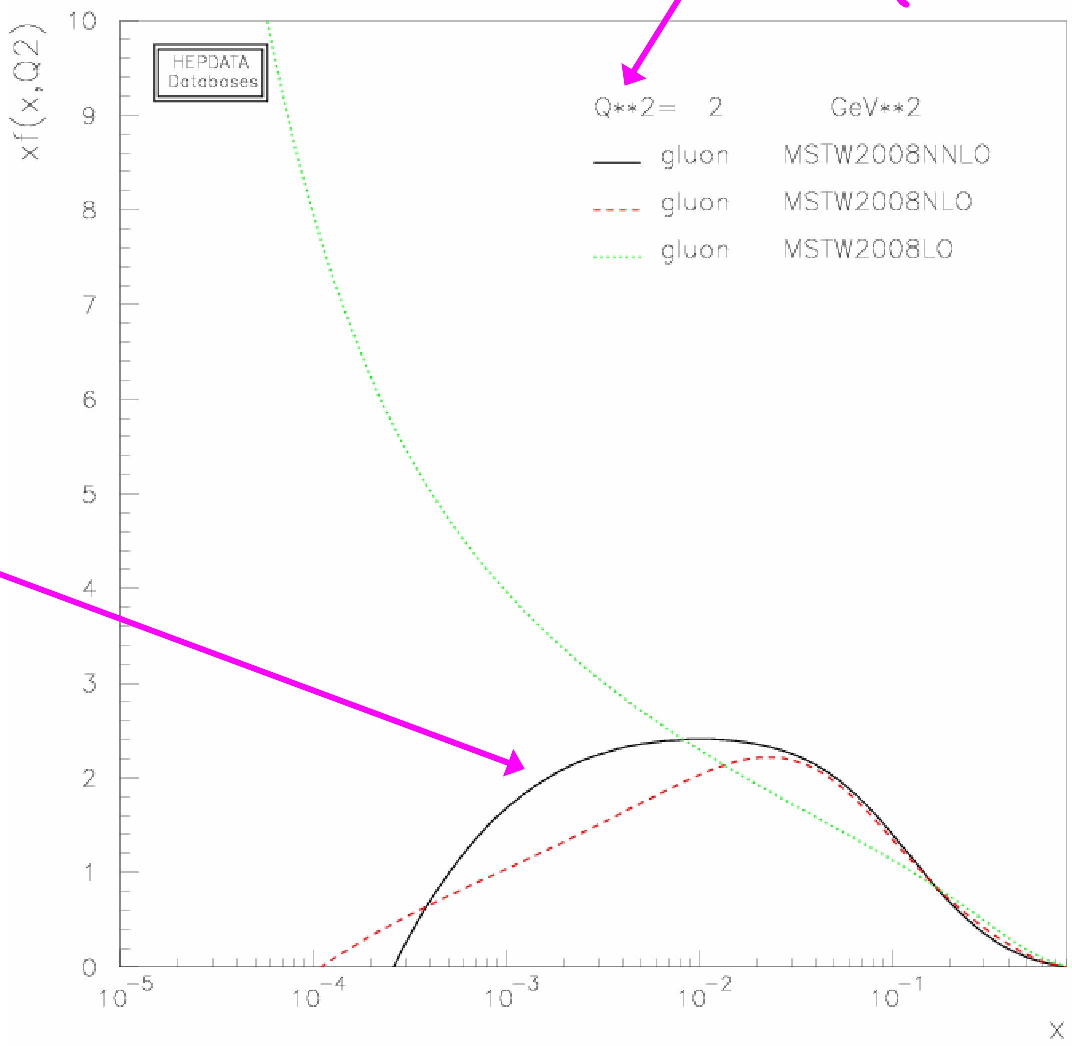
$F_2^{c\bar{c}}$
Q²= 2 GeV²
Q²= 4 GeV²
Q²= 6.5GeV²
Q²= 12 GeV²
Q²= 20 GeV²
Q²= 35 GeV²
Q²= 60 GeV²
Q²= 120 GeV²
Q²= 200 GeV²
Q²= 400 GeV²
Q²= 1000 GeV²
HERA (prel.)
MSTW08 NNLO
MSTW08 NLO
CTEQ 6.6
ABKM BMSN
x

avy Flavour

Why so large ratio NNLO/NLO for MRST F2c ?

- NNLO only approximate, is it reliable?
- large contribution from change of gluon (courtesy O. Behnke / PDFplotter)

not the right scale? (M. Corradi)



why does gluon change so much?