Running-mass definition in the heavy-quark electroproduction

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(in collaboration with J.Blümlein, and S.Moch)

- Quark mass definitions
- Improved heavy-quark threshold corrections
- Running masses in the FFN and VFN schemes
- Updated ABM PDF fit
- Summary

St.Andrews, 23 Aug 2011

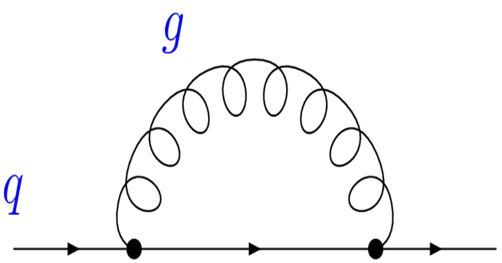
Pole mass definition

The pole mass is defined as a the QCD Lagrangian parameter and is commonly used in the QCD calculations

$$\mathcal{L} = -\frac{1}{4} F_{\mu\nu} F^{\mu\nu} + \sum_{\text{flavors}} \bar{q} \left(i \not{D} - m_q \right) q$$

Pole mass is defined for the free (unobserved) quarks

$$\not{p} - m_q - \Sigma(p, m_q) \Big|_{p^2 = m_q^2}$$

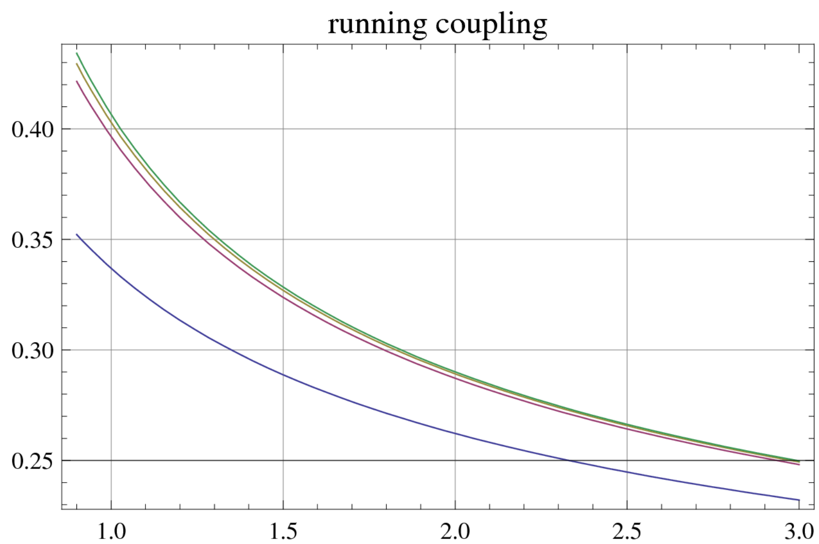


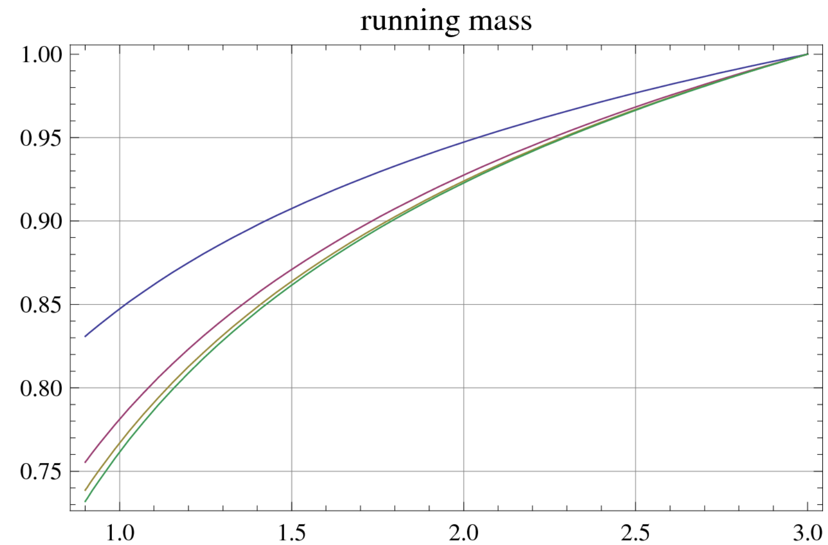
The quantum corrections due to the self-energy loop integrals receive contribution down to scale of $O(\Lambda_{QCD})$ → sensitivity to the high order corrections, particularly at the production threshold

Running quark mass

The renormgroup equation for mass is similar to one for the coupling constant

$$\mu^2 \frac{d}{d\mu^2}\alpha_s(\mu) = \beta(\alpha_s) \qquad \mu^2 \frac{d}{d\mu^2}m(\mu) = \gamma(\alpha_s)m(\mu)$$





The corrections up to 4-loops are known

van Ritbergen, Vermaseren, Larin PLB 400, 379 (1997)

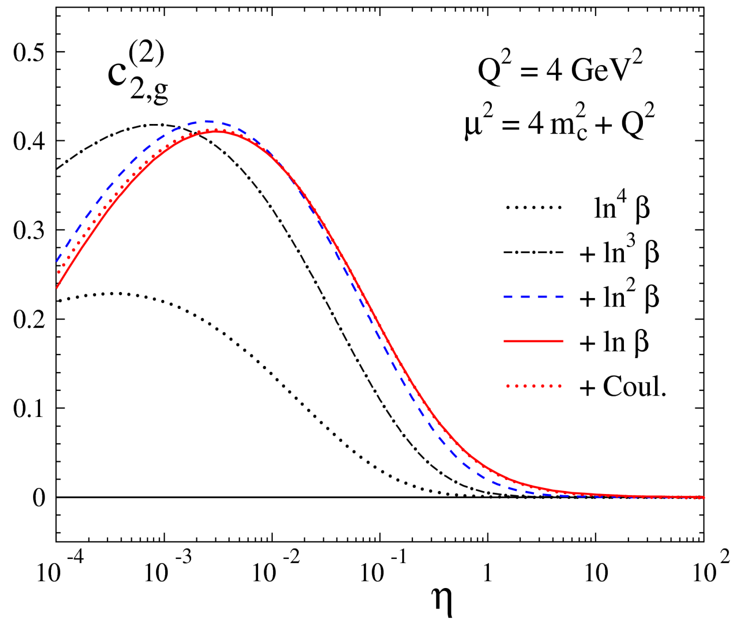
Chetyrkin PLB 404, 161 (1997)

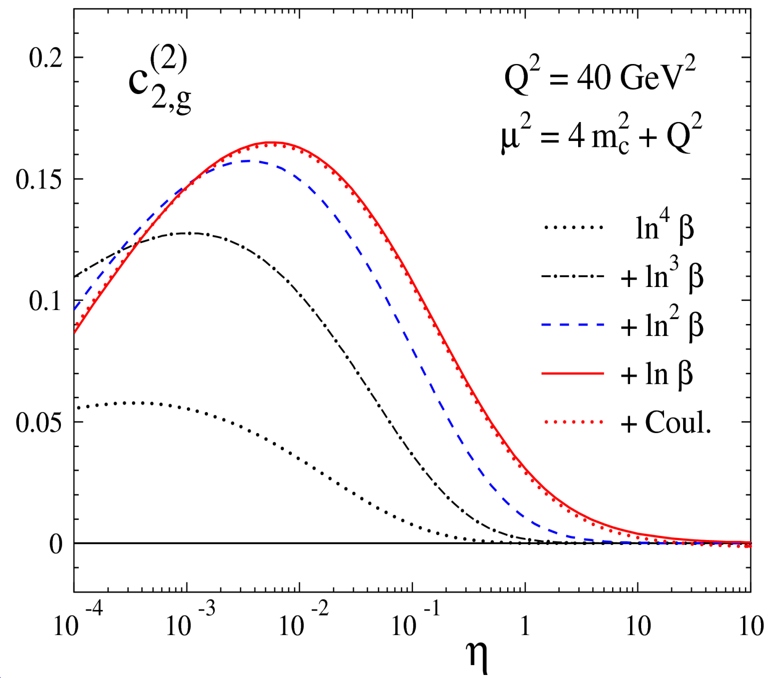
Vermaseren, Larin, van Ritbergen PLB 405, 327 (1997)

The choice of $\mu_R = m_c$ is close to the hard scattering data kinematic → better perturbative convergence and reduced scale dependence

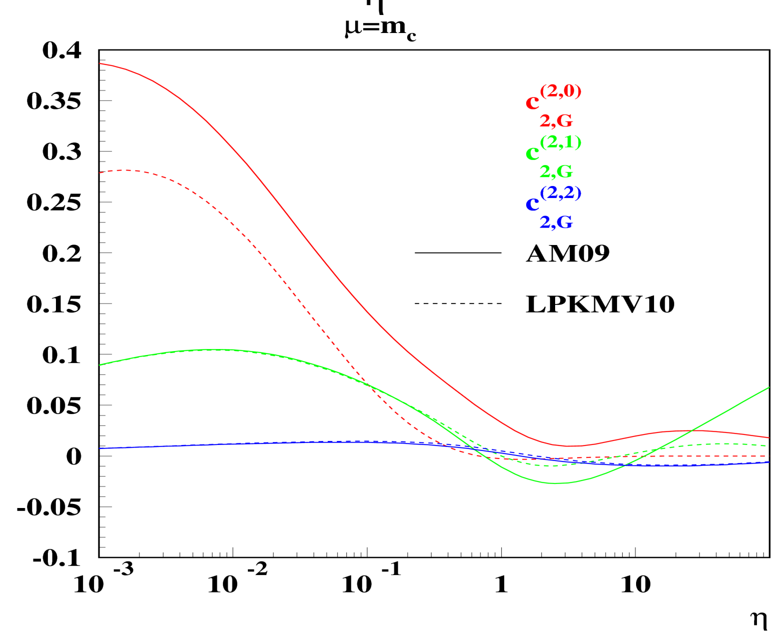
- The ttbar production in hadronic collisions **Laengenfeld, Moch, Uwer PRD 80, 054009 (2009)**
- The heavy-quark electroproductoin in the approximate NNLO (full NLO + NNLO threshold resummation) **sa, Moch [hep-ph 1011.5790]**

Approximate NNLO heavy-quark coefficients





- At small *x* and small *Q* the main contribution comes from η<1 due to the gluon distribution shape (threshold production)
- The large logs ~ $\ln^{2n}(\beta)$ can be resummed in all orders, this gives a good approximation to the exact NNLO expression at small β with the tower of large logs

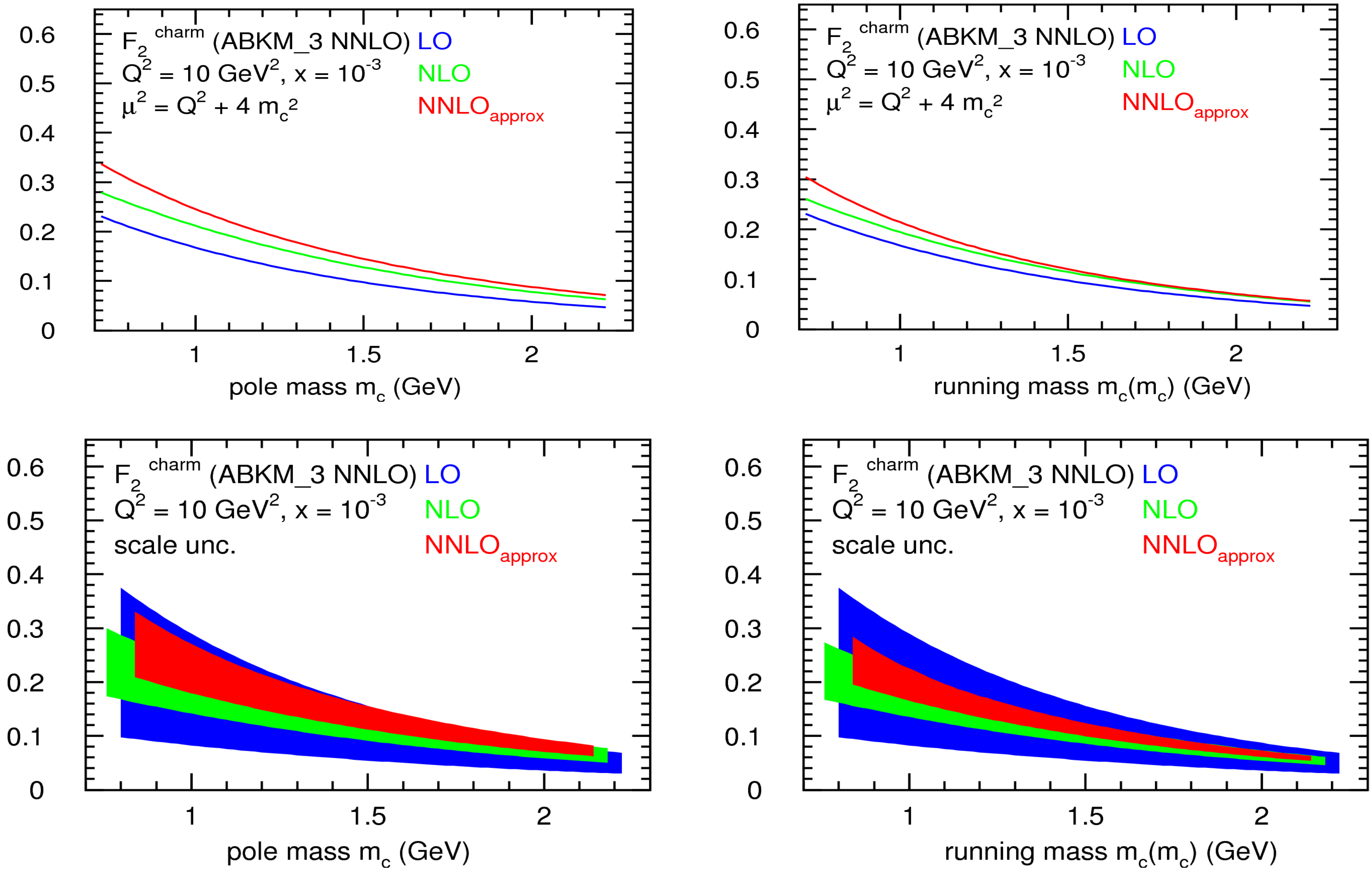


- The first log and Coulumb terms have been recently added → F_2^c gets somewhat smaller at small Q and somewhat bigger at large Q

Lo Presti, Kawamura, Moch, Vogt [hep-ph 1008.0951]

Running mass definition for the DIS SFs

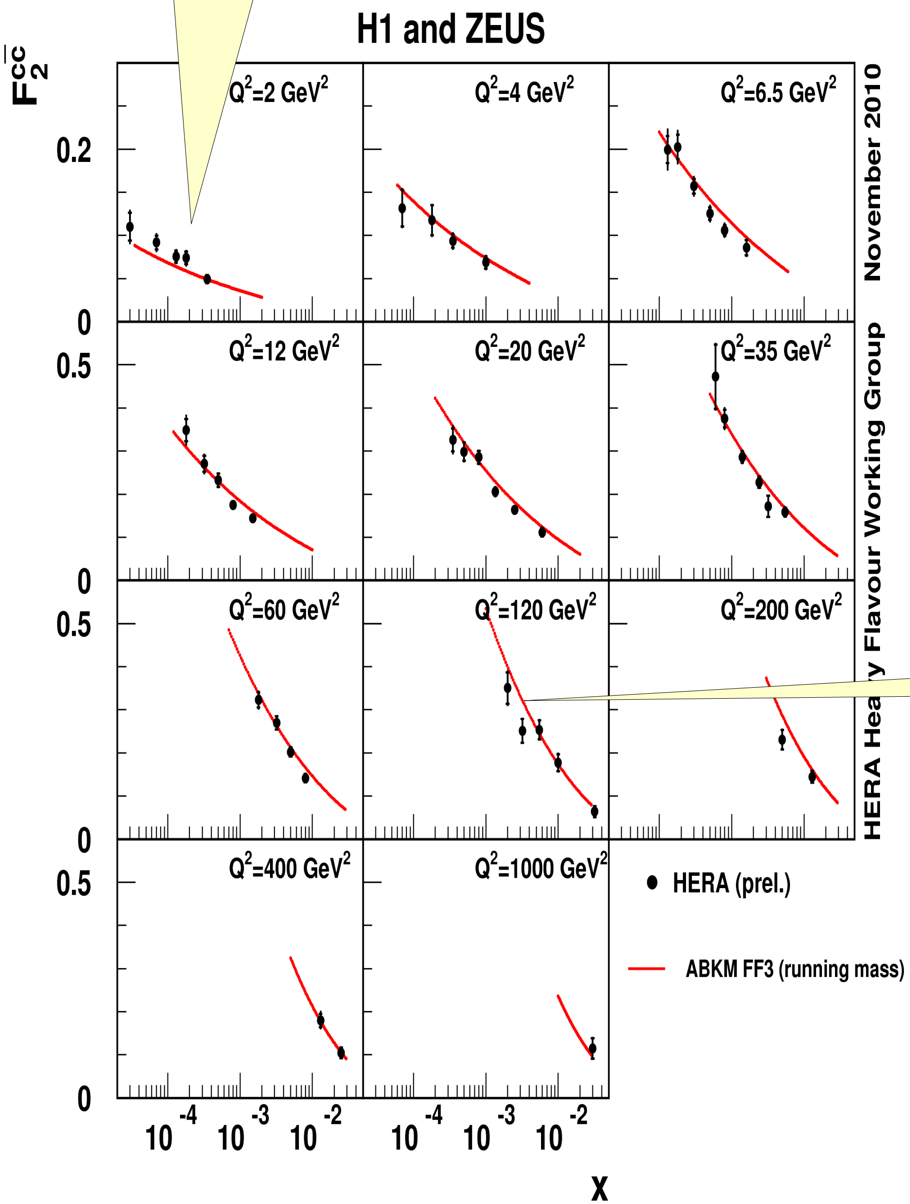
Pole mass | Running mass



c-quark DIS production

The NNLO(approx.) FFNS ABM ***predictions*** based on the running mass definition are In nice agreement with the new HERA data

N³LO corrections?



$m_c(m_c)$=1.27±0.08 GeV (PDG '10)

ABKM09 fit with the running-mass definiton

$m_c(m_c)$=1.18±0.06 GeV (incl.F_2 +PDG)

HERA data prefer value of mc close to the PDG one

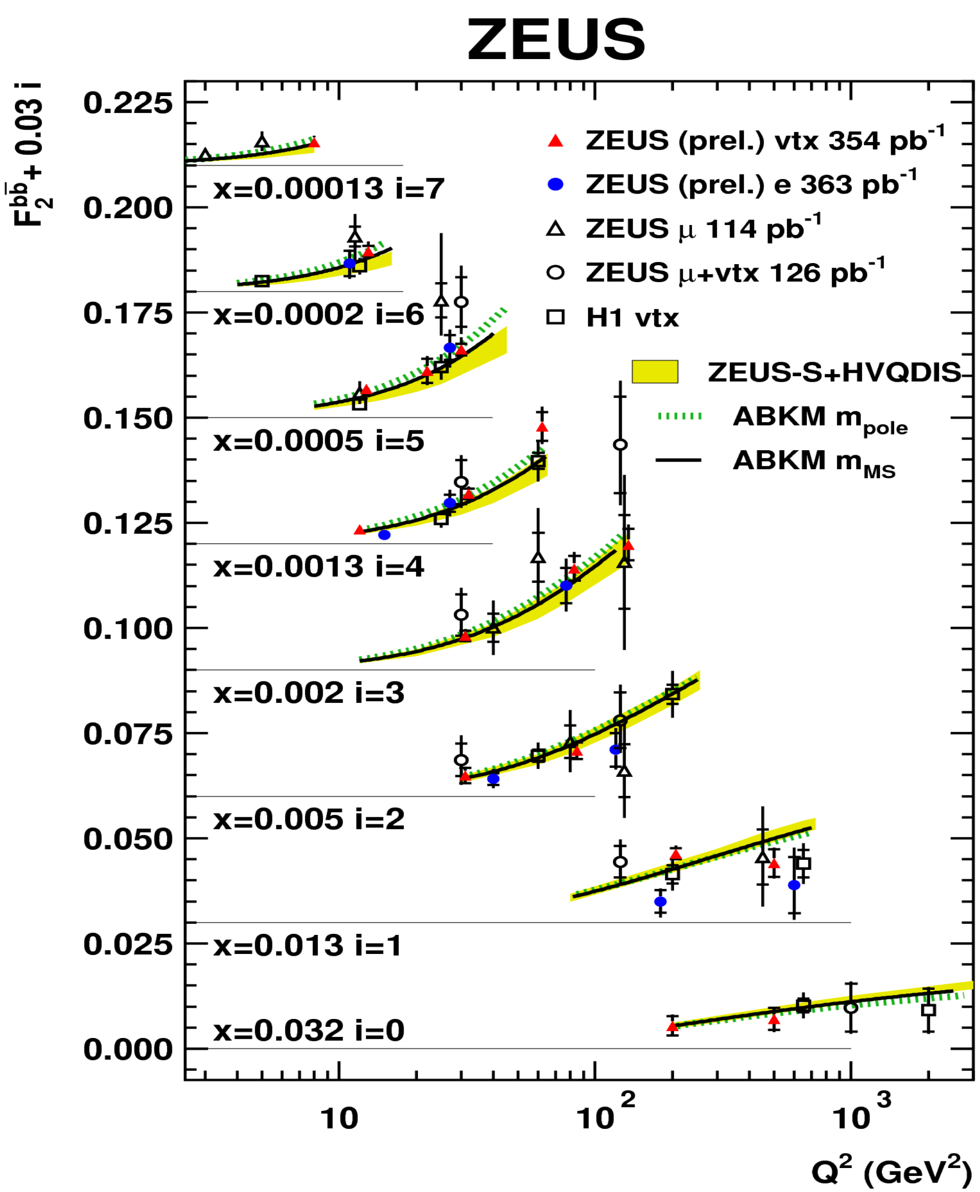
No need of the resummation

At $Q >> m_c$ first Mellin NNLO moments are known

Ablinger at al. NPB 844, 26 (2011)

Bierenbaum, Blümlein, Klein NPB 829, 417 (2009)

b-quark production



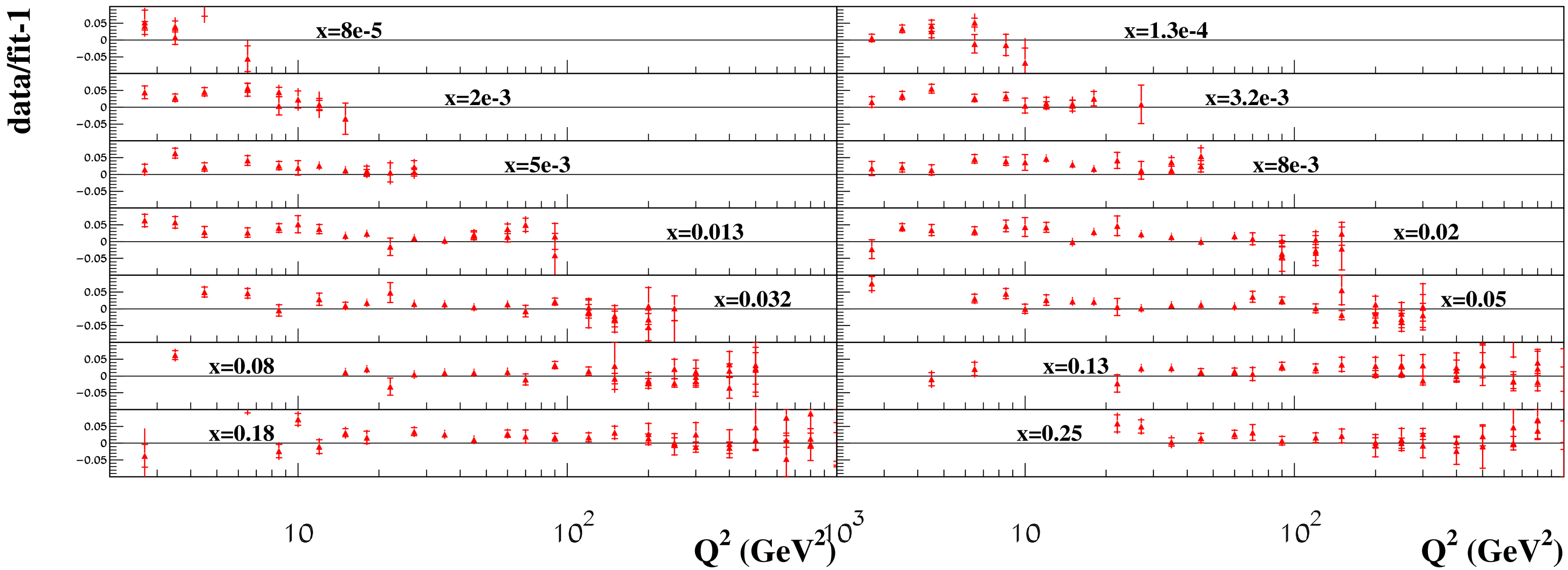
(courtesy of A.Geiser and P.Roloff)

For the b-quark production NNLO$_{approx}$ predictions work well → the threshold approximation is better justified

No sensitivity to m_b → fixed at the PDG value $m_b(m_b)$=4.19±0.12 GeV

High-Q inclusive DIS data

H1 and ZEUS Collaborations JHEP 1001, 109 (2010)



- The PDF shape was modified to accommodate new data

$$xS(x) = exp\left[a \ln x(1 + \beta \ln x)(1 + \gamma_1 x)\right](1-x)^b$$

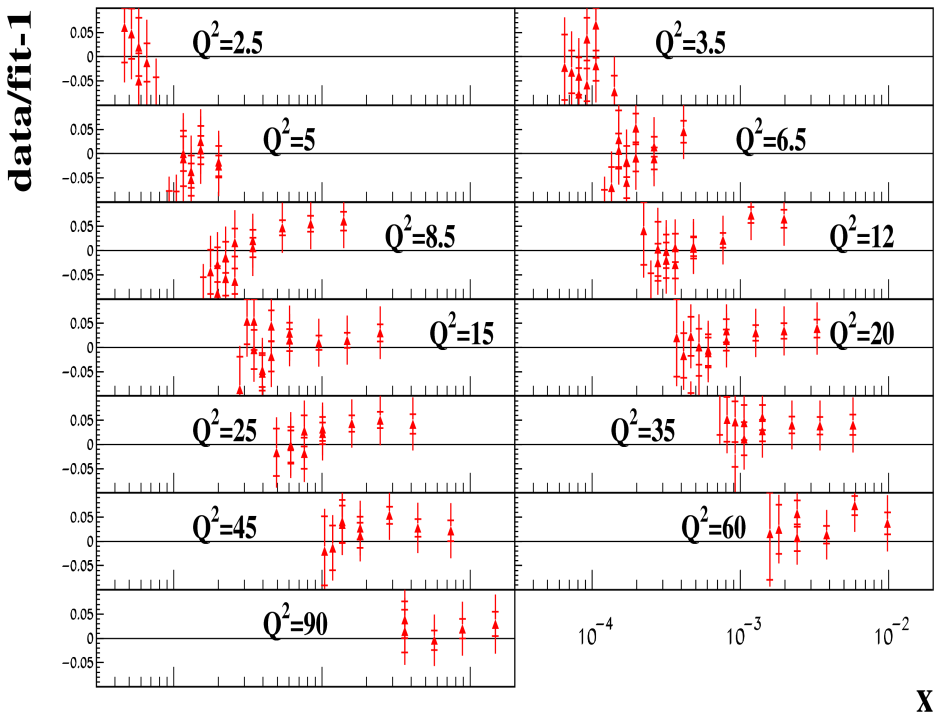
$$xu_V(x) = exp\left[a \ln x(1 + \gamma_1 x + \gamma_2 x^2 + \gamma_3 x^3)\right](1-x)^b$$

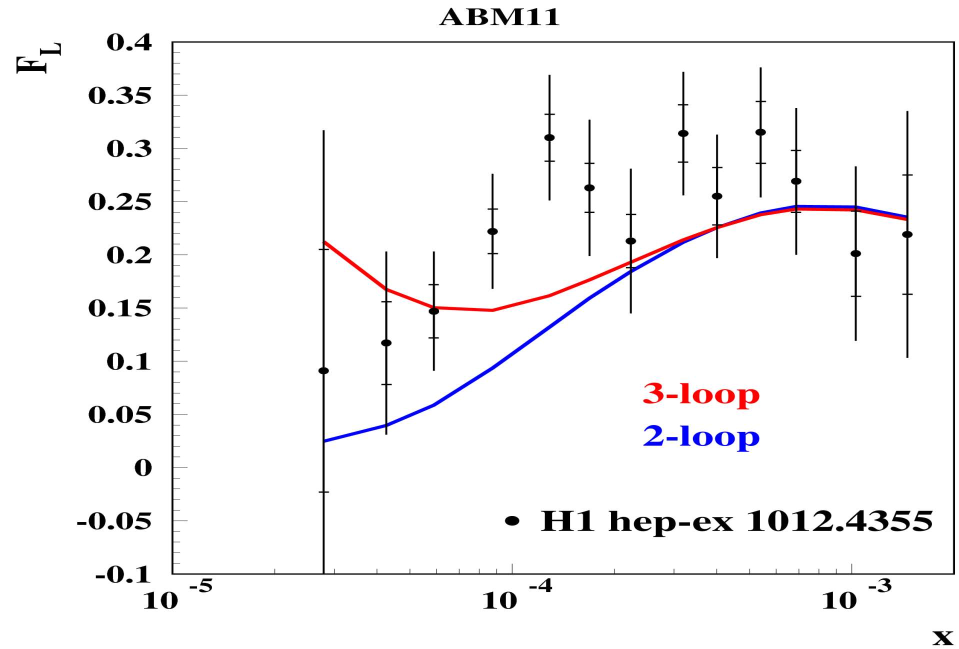
- χ^2/NDP=1.1, with account of the systematic error correlations (114 sources). Slightly worse for the small-Q part, the same observed in the model-independent fit

sa, Blümlein, Moch [hep-ph 1007.3657]

$m_c(m_c)$=1.27±0.08 GeV $m_b(m_b)$=4.19±0.13 GeV   (PDG '10)

Low-Q inclusive DIS data





The data prefer quite big 3-loop corrections to F_L at small x

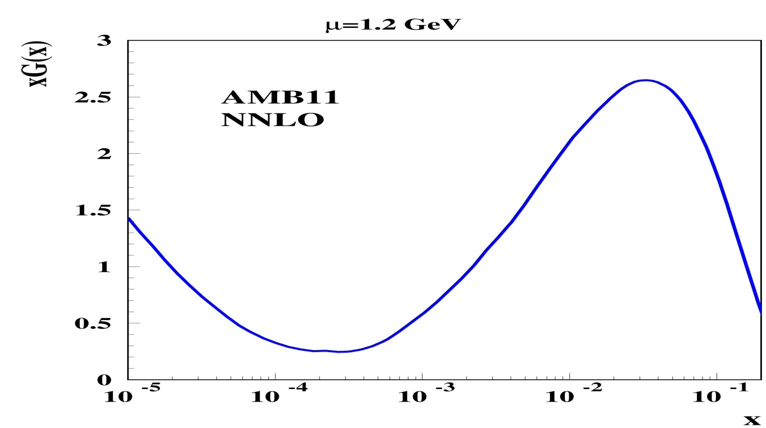
Moch, Vermaseren, Vogt PLB 606, 123 (2005)

- The low-energy H1 data are quite sensitive to F_L at small *x* and *Q*

  H1 Collaboration [hep-ex 1012.4355]

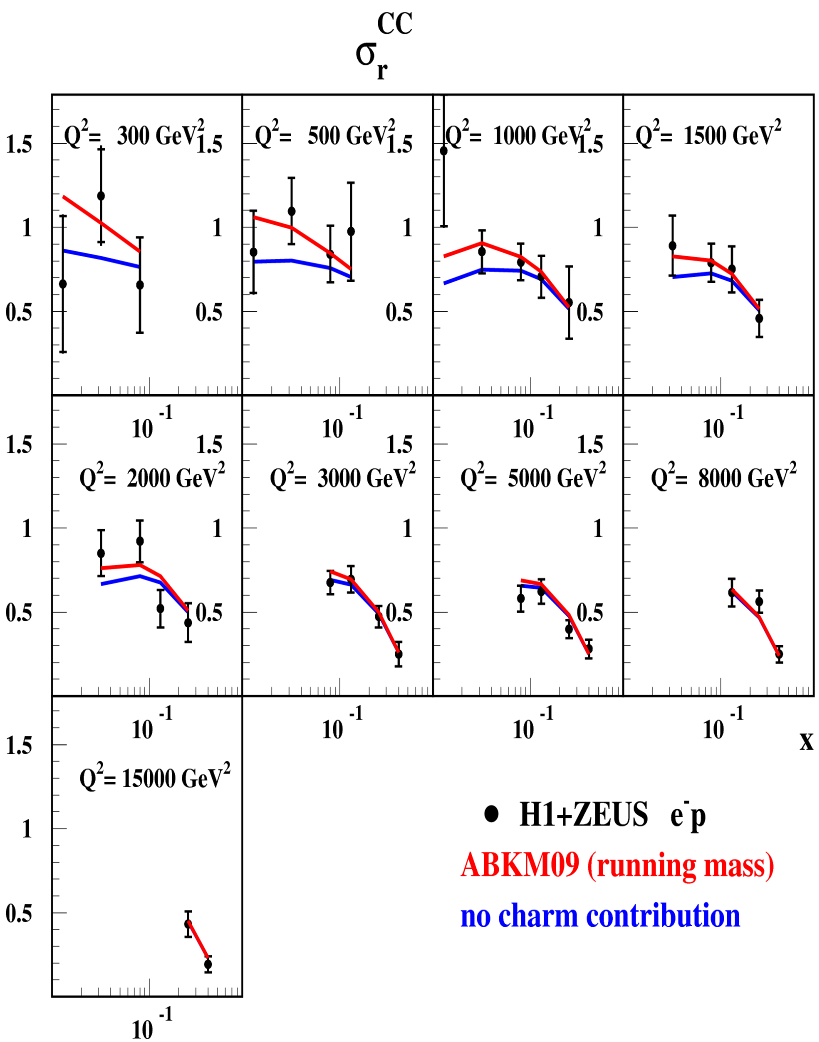
- The data can be easily accommodated in the fit: the value of χ^2/NDP=1.05; no clear sign of the collinear evolution violation

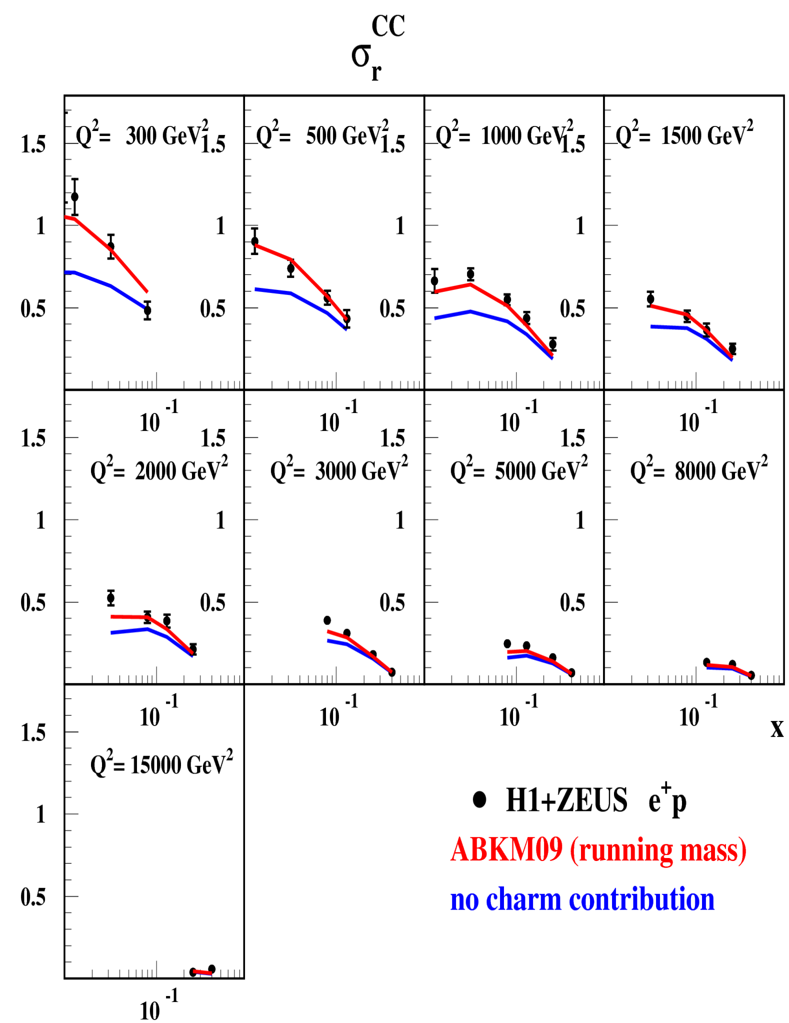
- Positive small-x gluons are preferred by the data at low scale



CC inclusive data

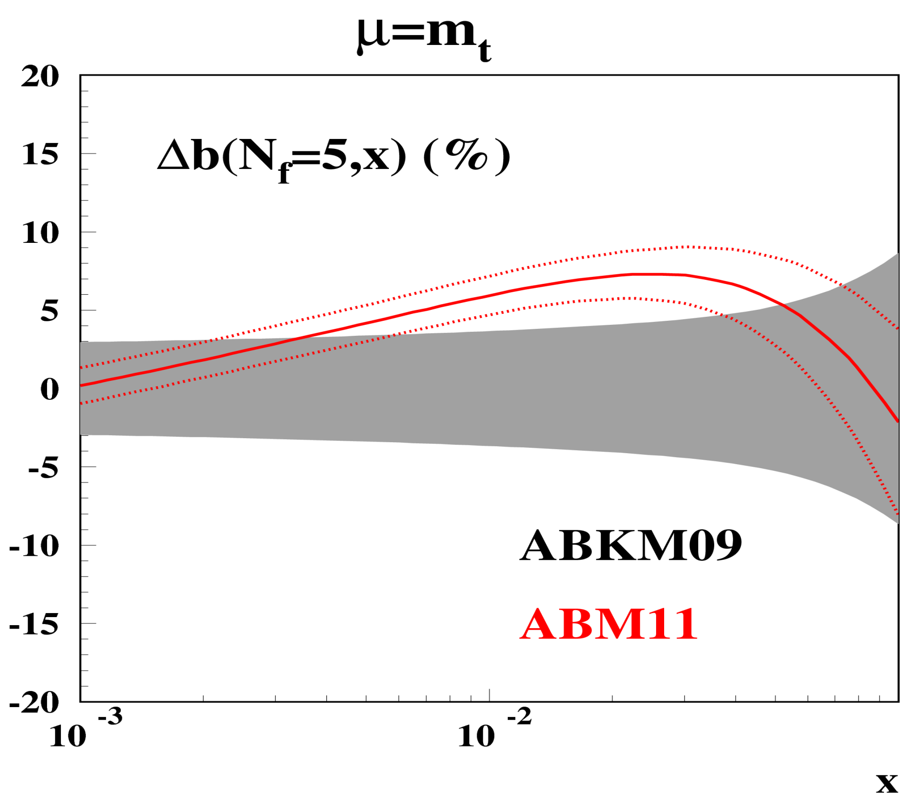
H1 and ZEUS Collaborations JHEP 1001, 109 (2010)





- Nice agreement with ABKM09 **predictions**
- Impact of the data on ABKM09 fit is marginal
- With the improved accuracy at future facilities, (at EIC?), the strange
- distribution can be better constrained.

Running mass and the VFN scheme



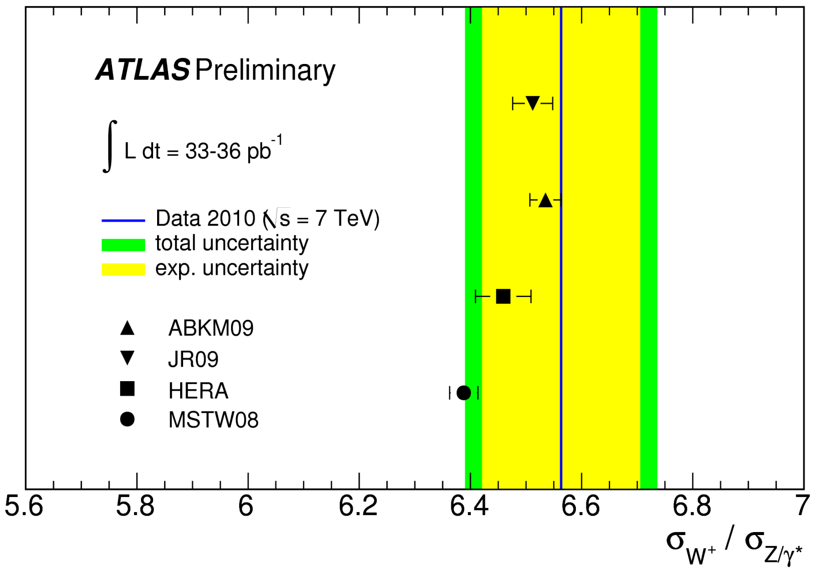
The 4- and 5-flavour PDFs are generated from the ABM11 fit preformed with the running-mass definition; the massive OMEs with the running-mass definition are used

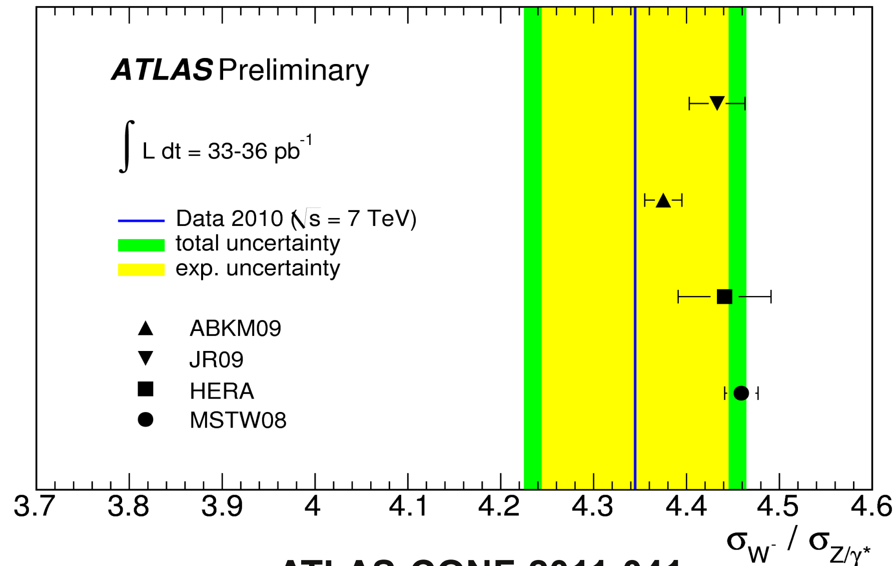
The change in the heavy-quark distribution id due to:

- change in the 3-flavor distributions from ABKM09 to ABM11
- change in the masses: m_b = 4.5 → 4.19±0.12 GeV (PDG '10)
- modification of the massive OMEs

The b-quark distribution uncertainty is reduced → impact on the single-top production

NNLO benchmarks





ATLAS-CONF-2011-041

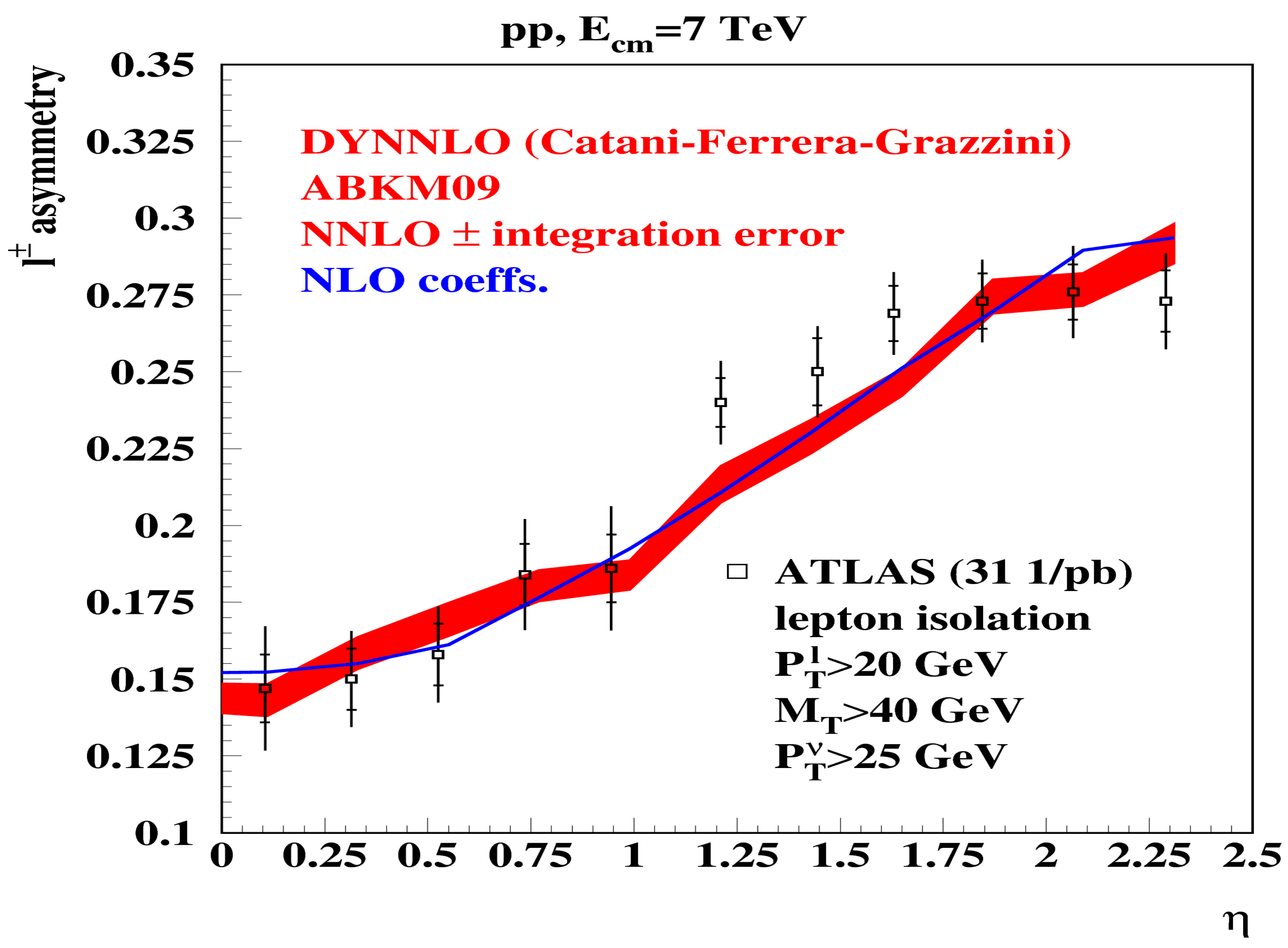
The luminosity uncertainty cancels in the ratio

ABKM09 $\alpha_s(M_Z)$=0.1135(14)

	σ(W+) (nb)	σ(W-) (nb)	σ(Z) (nb)	$\sigma(M_H$=165 GeV) (pb)
Tevatron	26.1(3)		7.69(8)	0.25(2)
LHC7	58.9(9)	39.4(6)	28.4(5)	7.05(23)

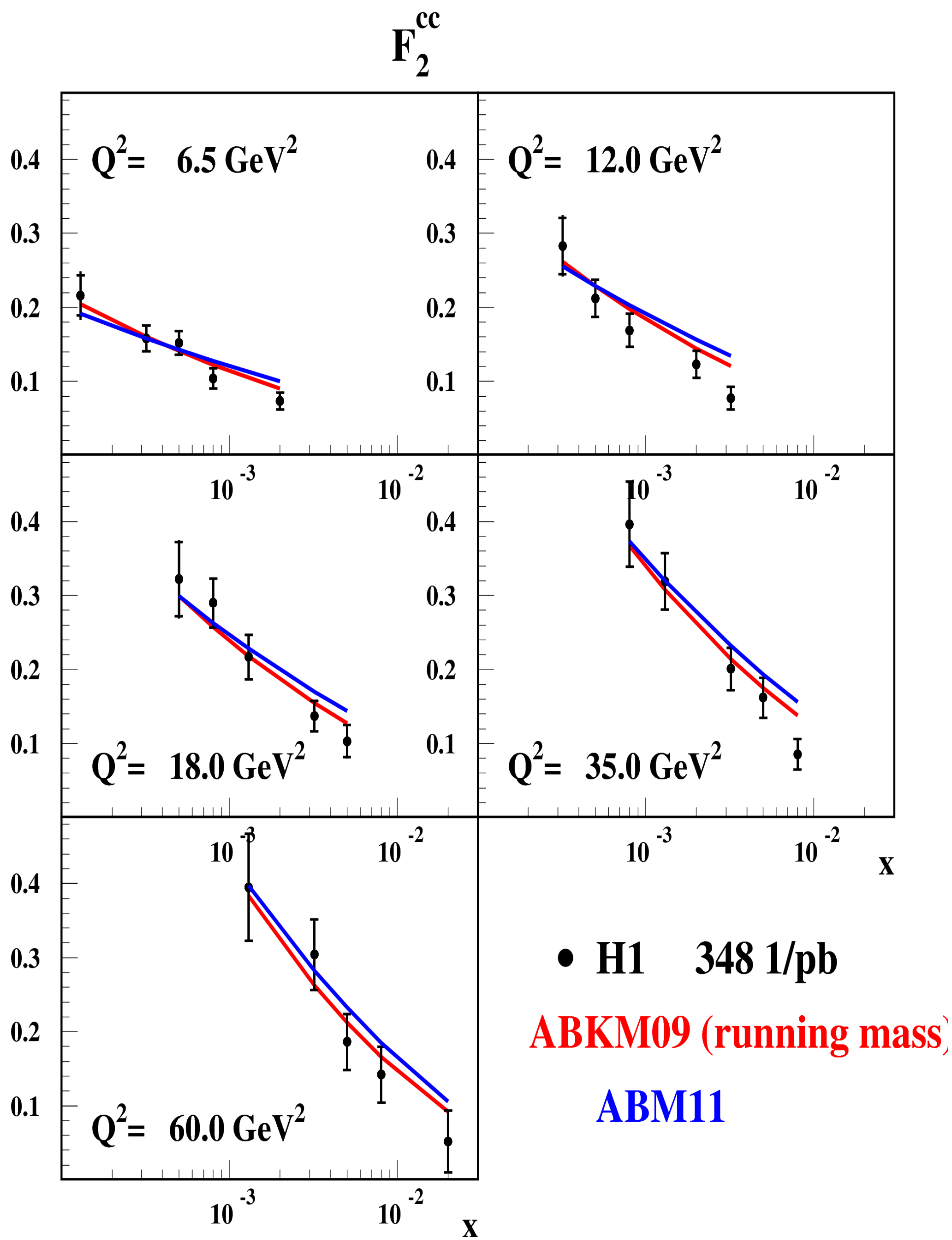
ABM11 = ABKM09 + running mass definition + new HERA data $\alpha_s(M_Z)$=0.1134(11)

Tevatron	26.41(23)		7.76(7)	0.241(16)
LHC7	58.9(7)	39.6(5)	28.5(3)	7.21(18)



- The ABKM09 predictions are in nice agreement with the ATLAS data
- The updated ABM11 fit gives similar results

Toward determination of $m_c(m_c)$ from DIS



Improved accuracy can be obtained with the semi-inclusive data included due to correlation between quark and gluon PDFs is reduced

ABKM09 (running mass):

$m_c(m_c)$=1.18±0.06 GeV (incl.F_2 +PDG)

With semi-inclusive data added

$m_c(m_c)$=1.10±0.04 GeV (incl.F_2 + F_2^{cc})
(prel.)

Work in progress

H1 Collaboration [hep-ex 1106.1028]

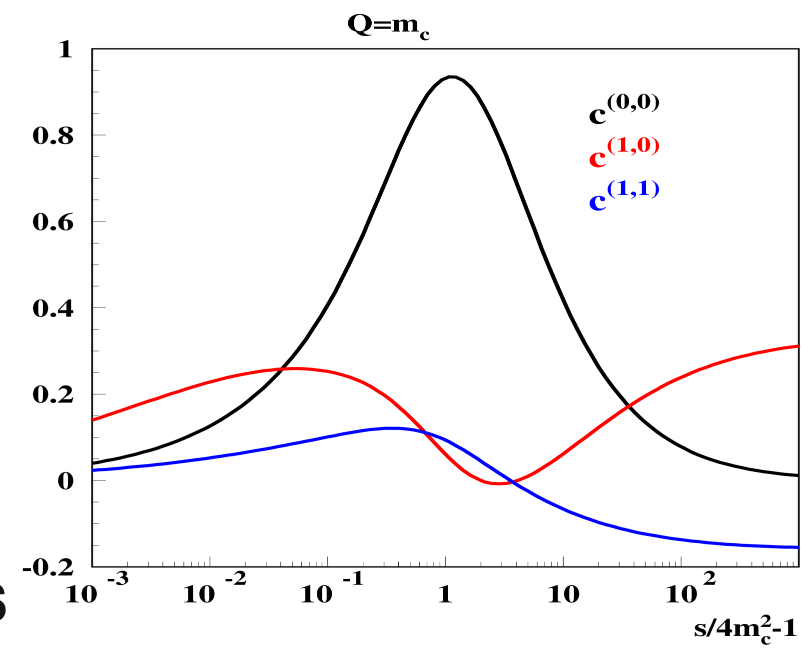
$m_c(m_c)$=1.27±0.08 GeV (PDG '10)

Summary and outlook

- The running mass definition is implemented for the DIS semi-inclusive structure functions
  - Improved perturbative stability and the scale variation uncertainty
  - Consistent treatment of the mass in DIS and other processes, like e+e- initiated
  - First determination of running mass from the DIS data
- Better determination on the heavy-quark PDFs
- Improved uncertainty foreseen with inclusion of the HERA combined charm data
  - Resolving correlation between gluon and sea distribution

The heavy-quark electro-production

The dominant mechanism is photon-gluon fusion, contributes up to 30% to the inclusive structure functions. The massive coefficient functions are known up to the NLO.



$$C_{2,g}^{LO} = c^{(0,0)}$$ **Witten NPB 104, 445 (1976)**

$$C_{2,g}^{NLO} = c^{(1,0)} + c^{(1,1)} \ln(\mu_F^2/m_c^2)$$

Laenen, Riemersma, Smith, van Neerven NPB 392, 162 (1993)

FFNS

- Only 3 light flavors in the initial state are considered.
- Accurate at $Q \sim m_c$
- At large Q the fixed-order results may be insufficient due to big logs $\sim ln^n(Q/m_c)$ must be resummed
- Involved high-order calculations: The full NNLO corrections are missed, however numerically important threshold resummation results are available

Laenen, Moch PRD 59, 034027 (1999)

ZMVFNS

Collins, Tung NPB 278, 934 (1986)

- At $Q >> m_c$ the heavy quarks are considered as massless → the NNLO evolution and the coefficient functions up to N^{3}LO are ready
- The big logs $\sim ln^n(Q/m_c)$ are in a natural way resummed in the QCD evolution
- Matching conditions for the 3(4)-flavor and the 4(5)-flavor massless theories
- *A smooth matching with the FFNS in the limit of $Q \rightarrow m_c$ must be provided*

Lo Presti, Kawamura, Moch, Vogt [hep-ph 1008.0951]