Update of the NNLO ABM PDFs

S.Alekhin (*IHEP Protvino & DESY-Zeuthen)*

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

- Improved treatment of the heavy quark electro-production

  – threshold corrections
  – running masses in the FFN and VFN schemes

- New HERA data

- Standard candles
-

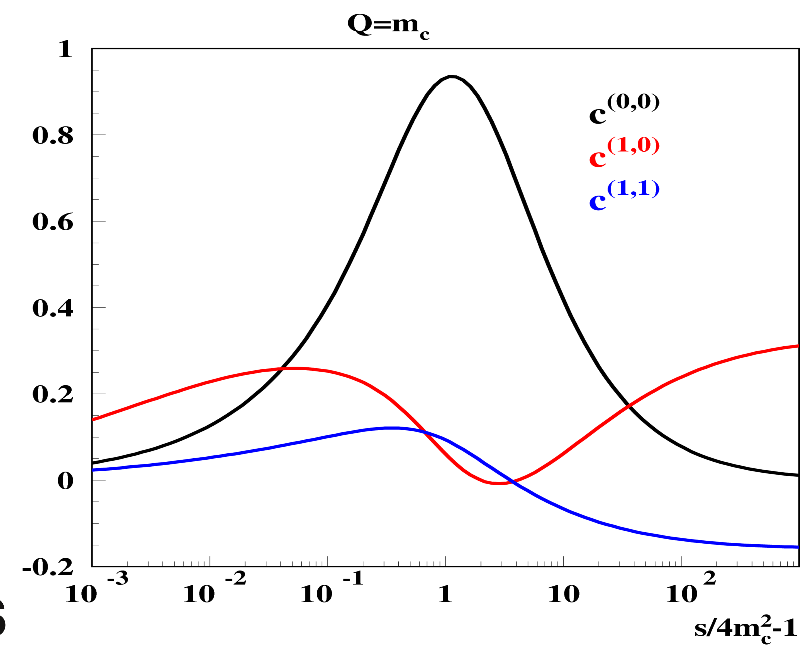
  – charged-lepton asymmetry
  – impact of the jet Tevatron data on the Higgs c.s.

- Summary/outlook

Ringberg, 26 Sep 2011

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 $Q \to m_c$ must be provided*

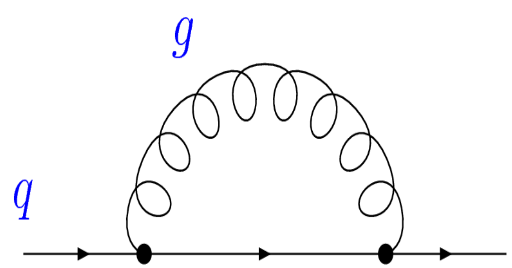
Pole mass definition

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

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



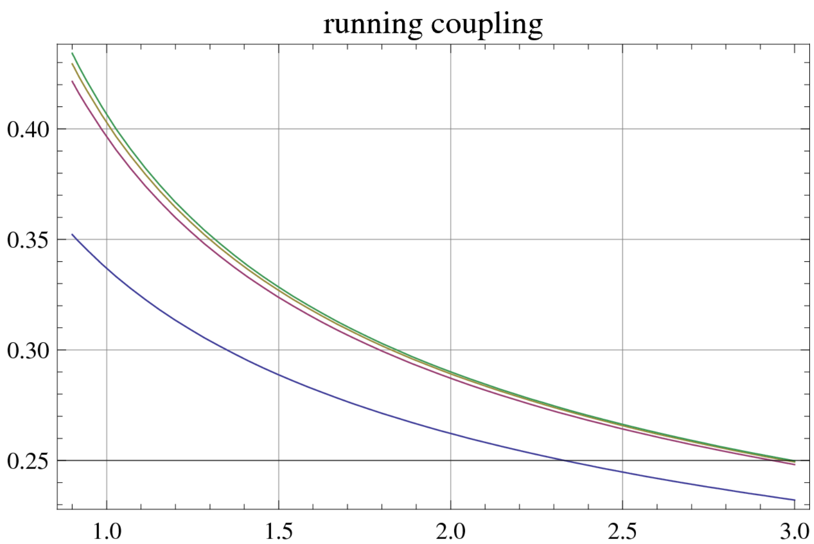
The quantum corrections due to the self-energy loop integrals receive contribution down to scale of O(Λ_{QCD}) → sensitivity to the high order corrections, particularly at the production threshold

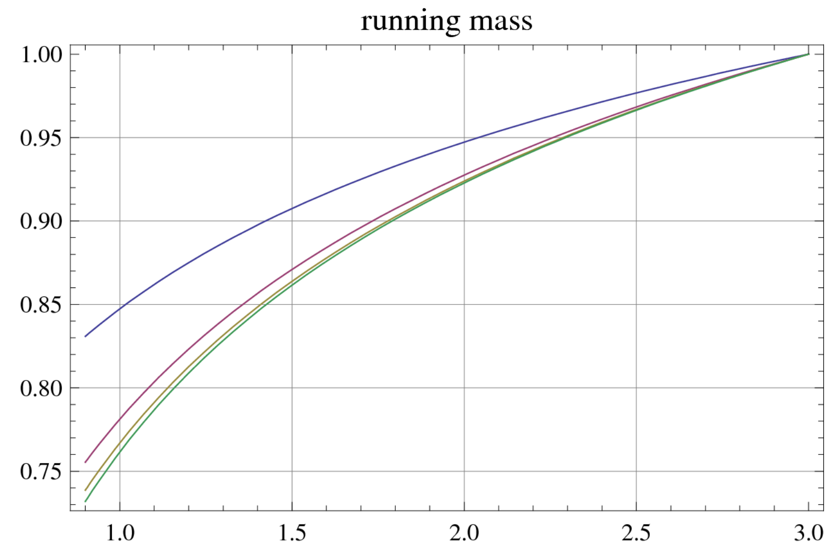
Running quark mass

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

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

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





The corrections up to 4-loops are known

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

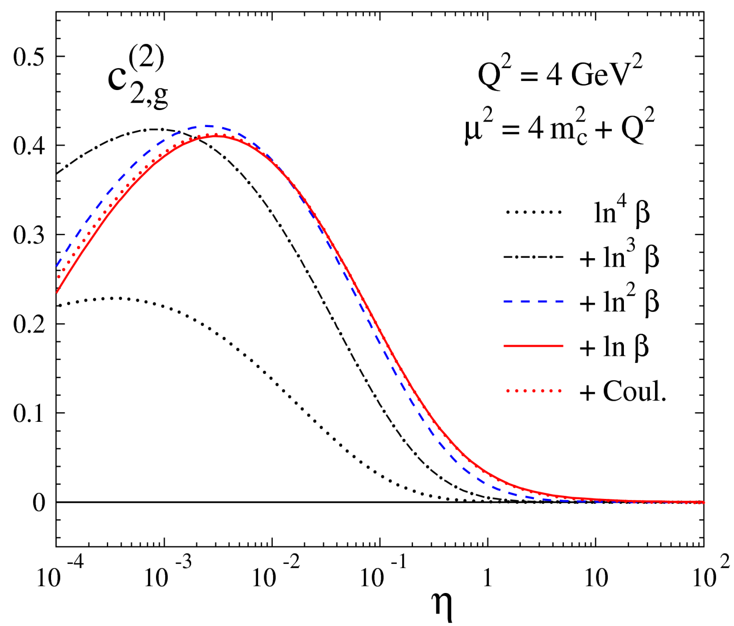
Chetyrkin PLB 404, 161 (1997)

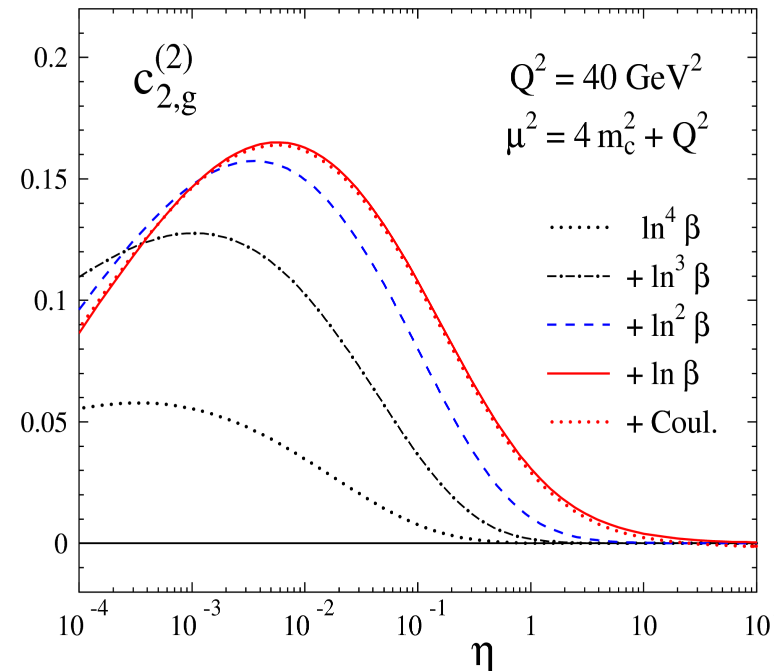
Vermaseren, Larin, van Ritbergen PLB 405, 327 (1997)

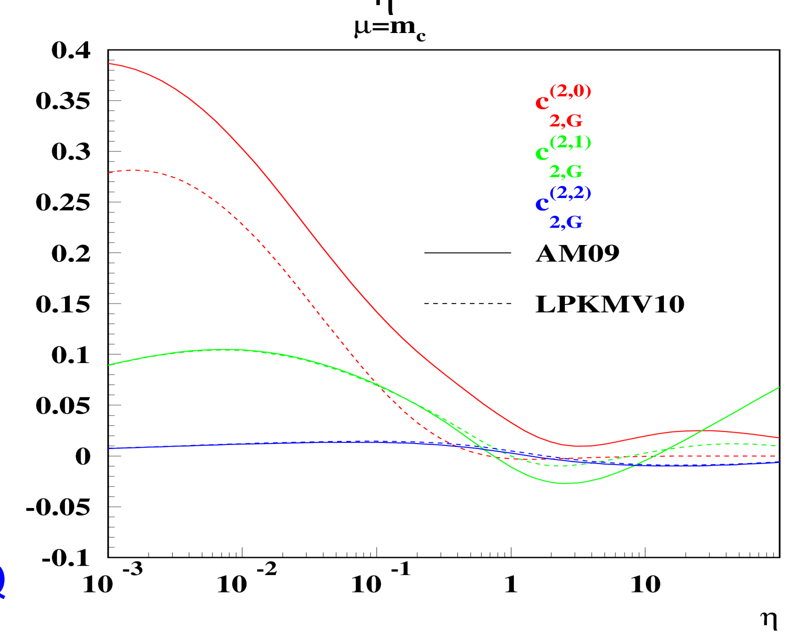
The choice of $\mu_R = m_c$ is close to the hard scattering data kinematic → better perturbative convergence and reduced scale dependence

- 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 ~ $\ln^n(\beta)$ 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

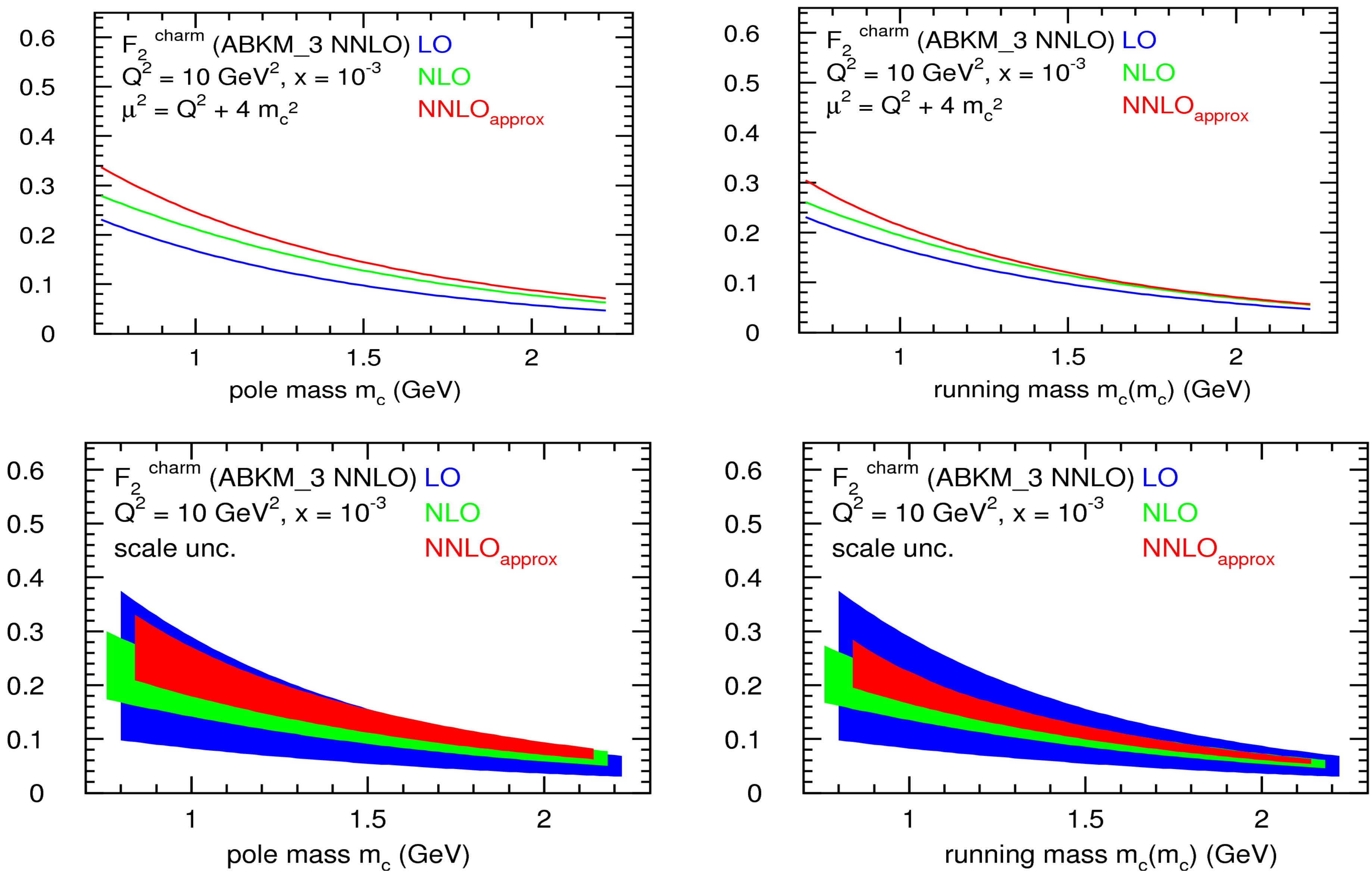
- The first log and Coulomb terms have been recently added → F_2^c gets somewhat smaller at small Q and somewhat bigger at large Q

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

Running mass definition for the DIS SFs

Pole mass

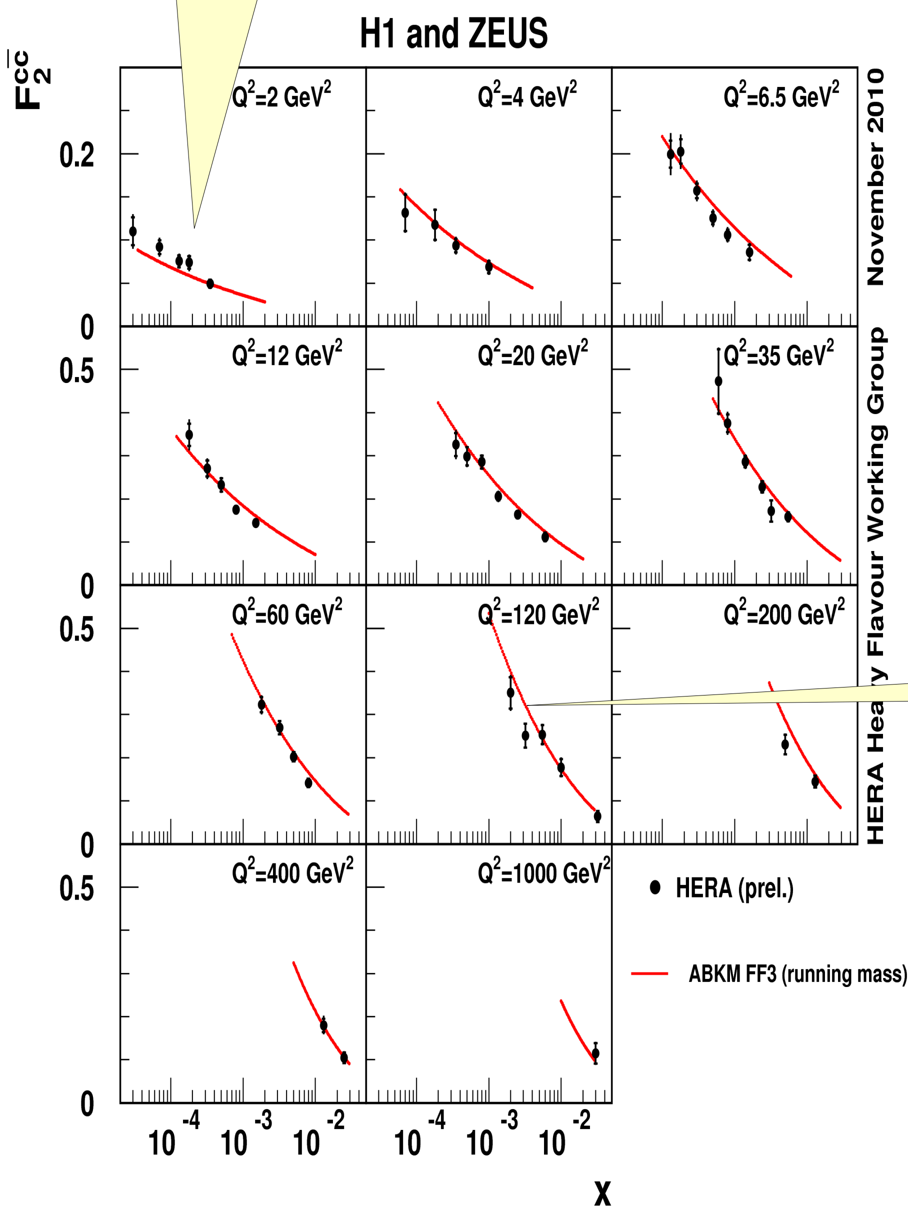
Running mass



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

N^3LO corrections?



No need of the resummation

$m_c(m_c)$=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)

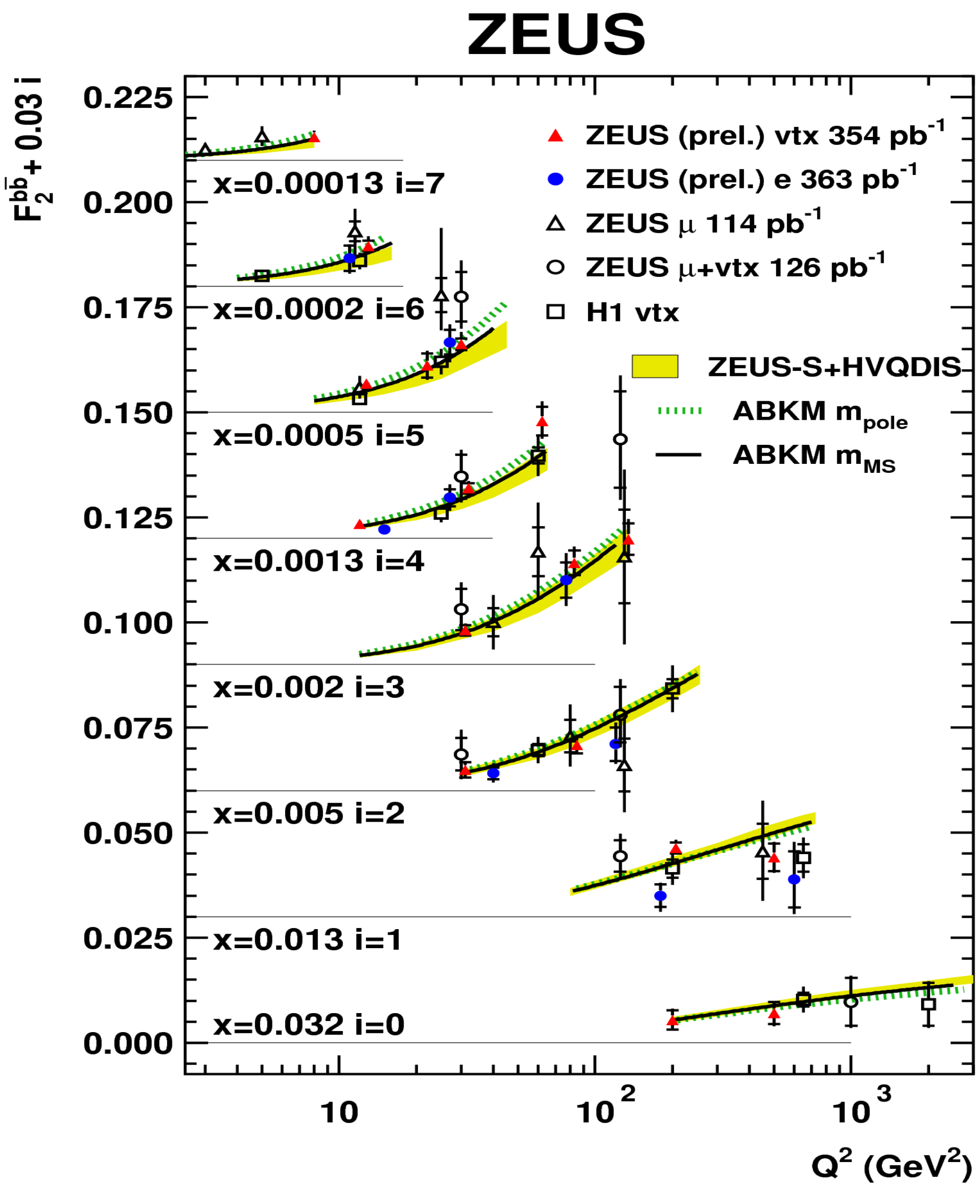
HERA data prefer value of mc close to the PDG one

At $Q \gg m_c$ first Mellin NNLO moments are known

Ablinger at al. NPB 844, 26 (2011)

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

b-quark production



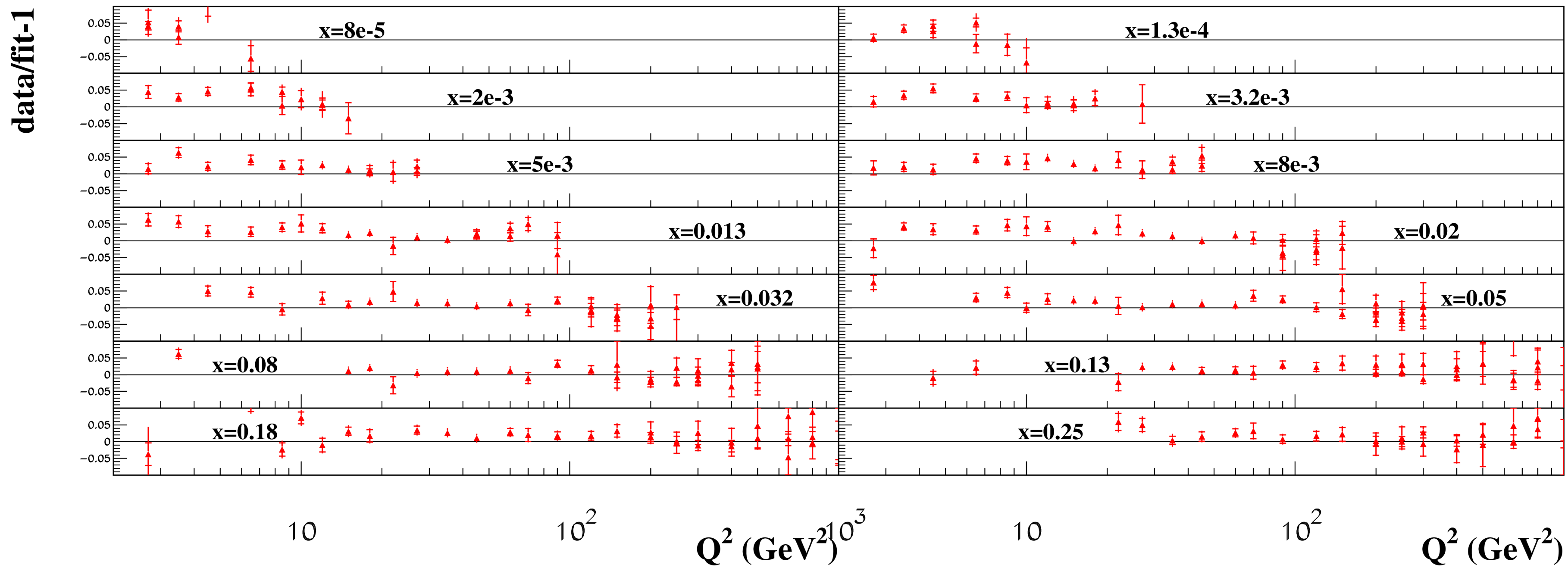
(courtesy of A.Geiser and P.Roloff)

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

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

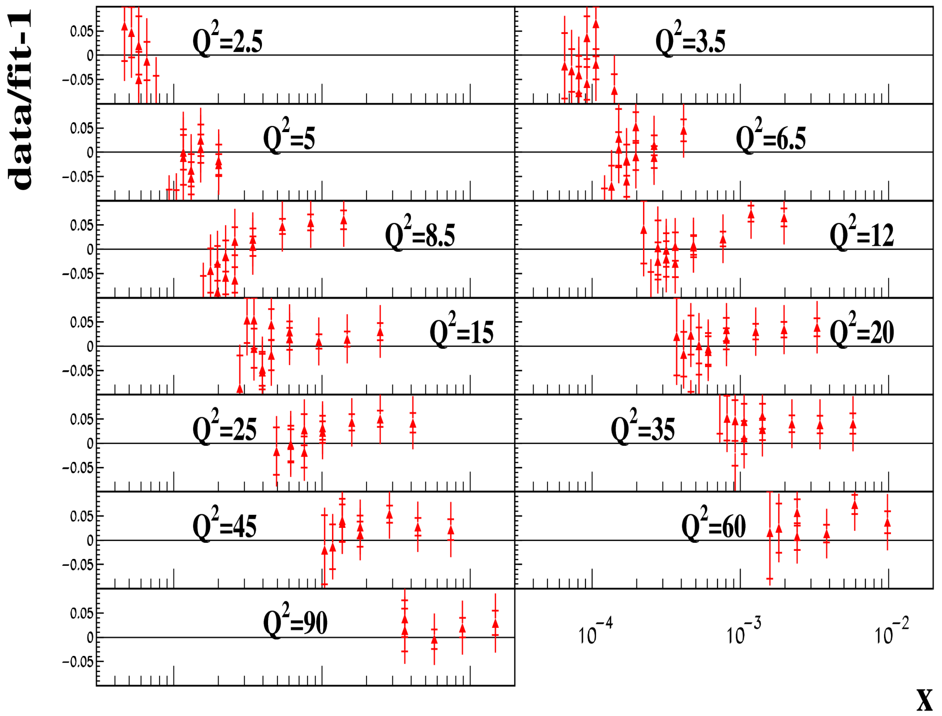
$$xu_V(x) = exp\left[a \ln x (1 + \gamma_1 x + \gamma_2 x^2 + \gamma_3 x^3)\right](1-x)^b$$

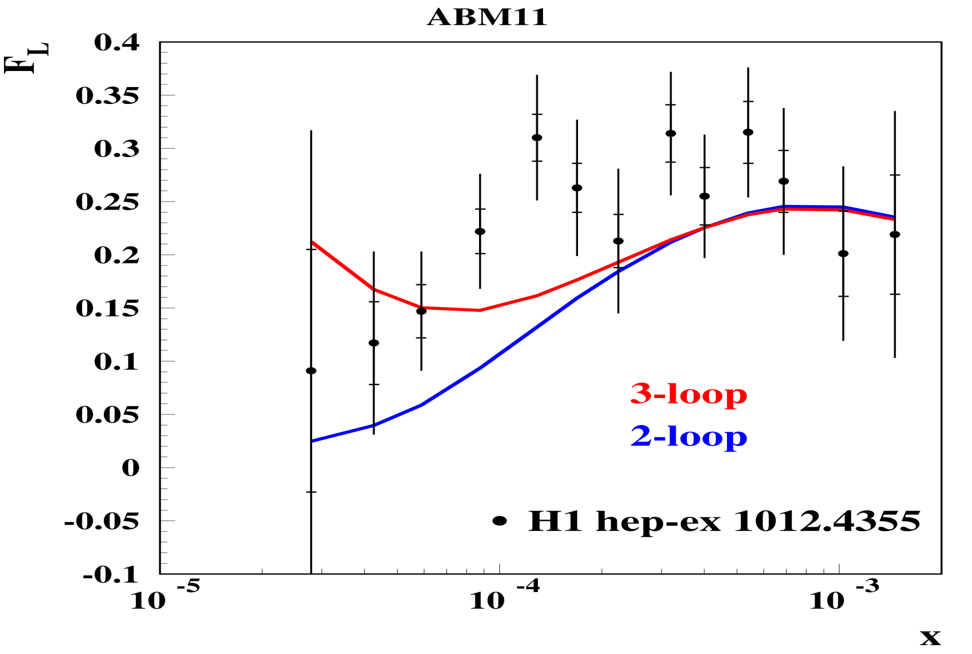
- χ^2/NDP=1.1, with account of the systematic error correlations (114 sources). Slightly worse for the small-Q part, the same observed in the model-independent fit

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

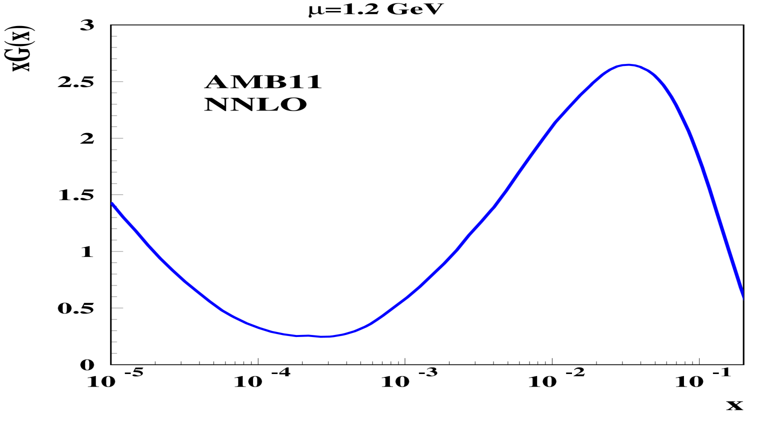
Moch, Vermaseren, Vogt PLB 606, 123 (2005)

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

H1 Collaboration [hep-ex 1012.4355]

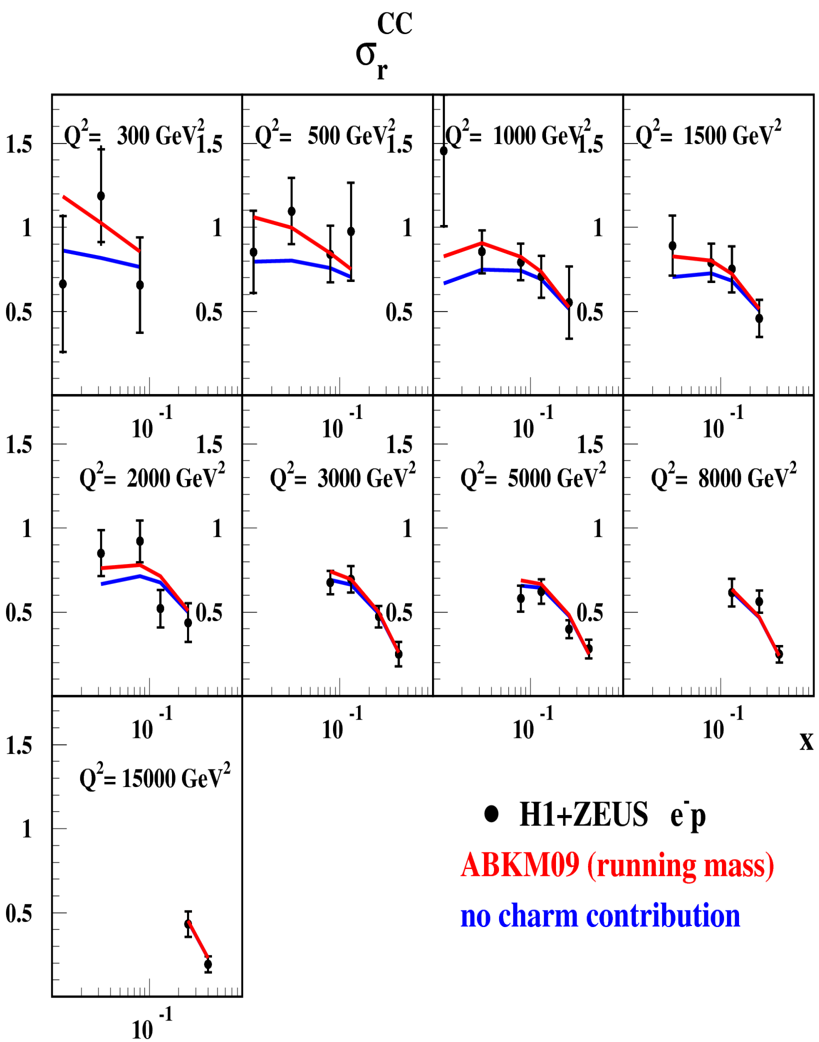
- The data can be easily accommodated in the fit: the value of χ^2/NDP=1.05; no clear sign of the collinear evolution violation

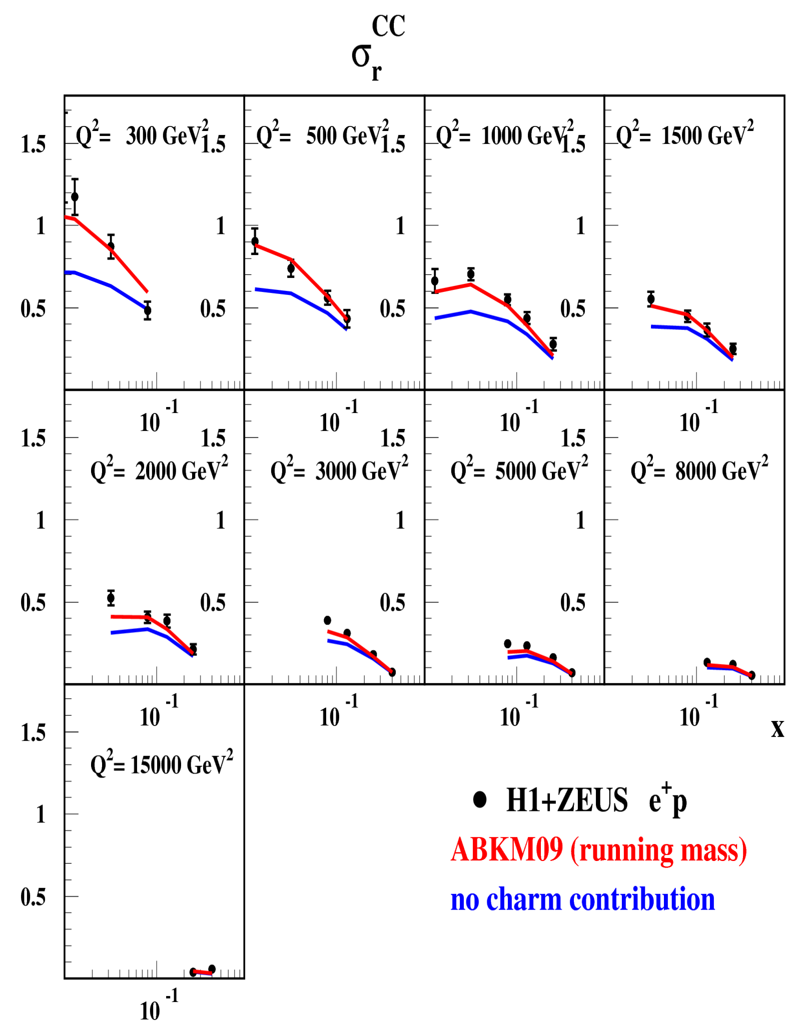
- Positive small-x gluons are preferred by the data at low scale



CC inclusive data

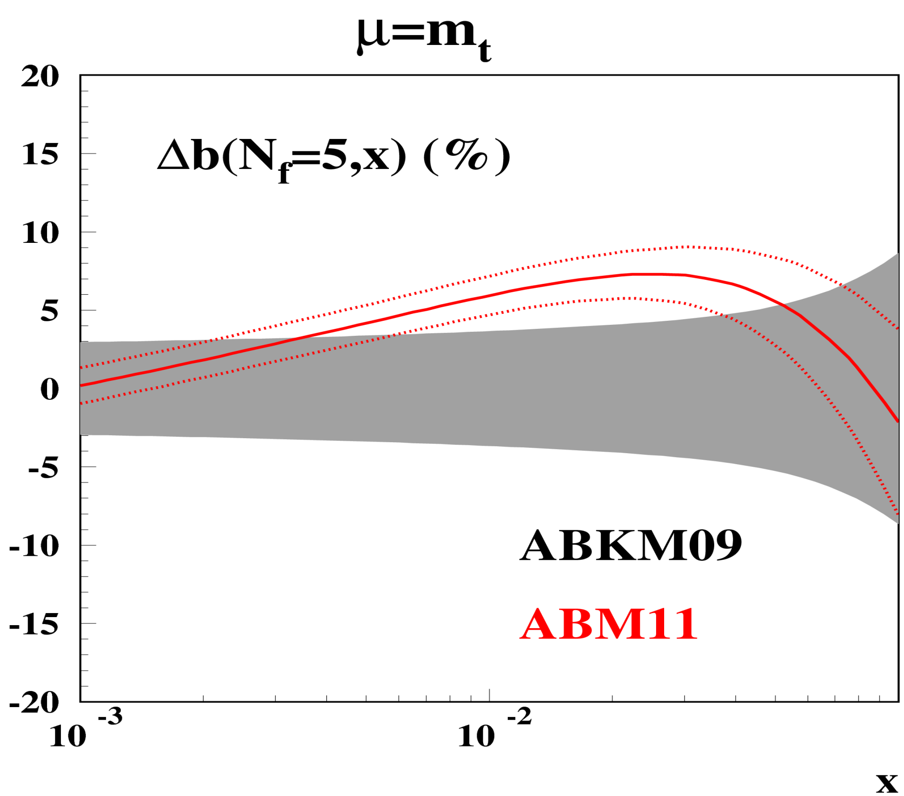
H1 and ZEUS Collaborations JHEP 1001, 109 (2010)





- 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

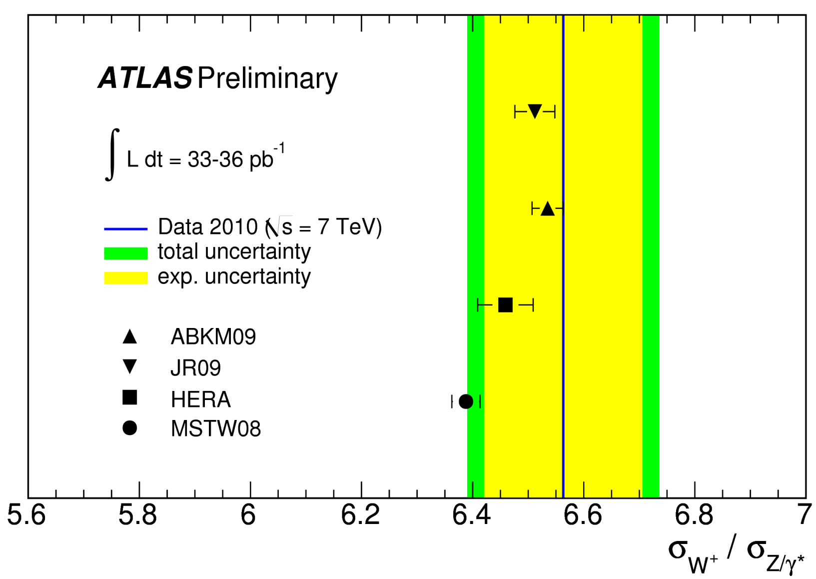
NNLO benchmarks

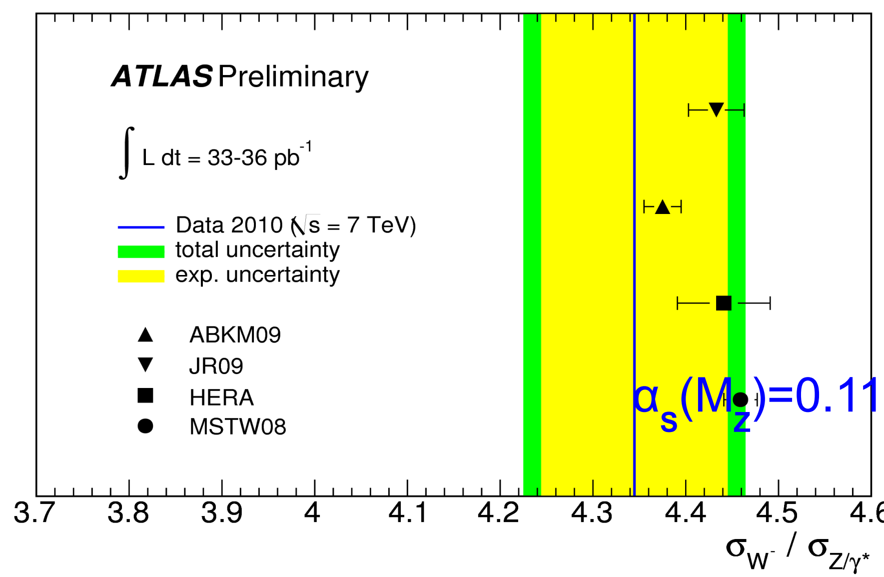
ABKM09 $\alpha_s(M_Z)=0.1135(14)$

	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

	σ(W+) (nb)	σ(W-) (nb)	σ(Z) (nb)	$\sigma(M_H=165$ GeV) (pb)
Tevatron	26.41(23)		7.76(7)	0.241(16)
LHC7	58.9(7)	39.6(5)	28.5(3)	7.21(18)

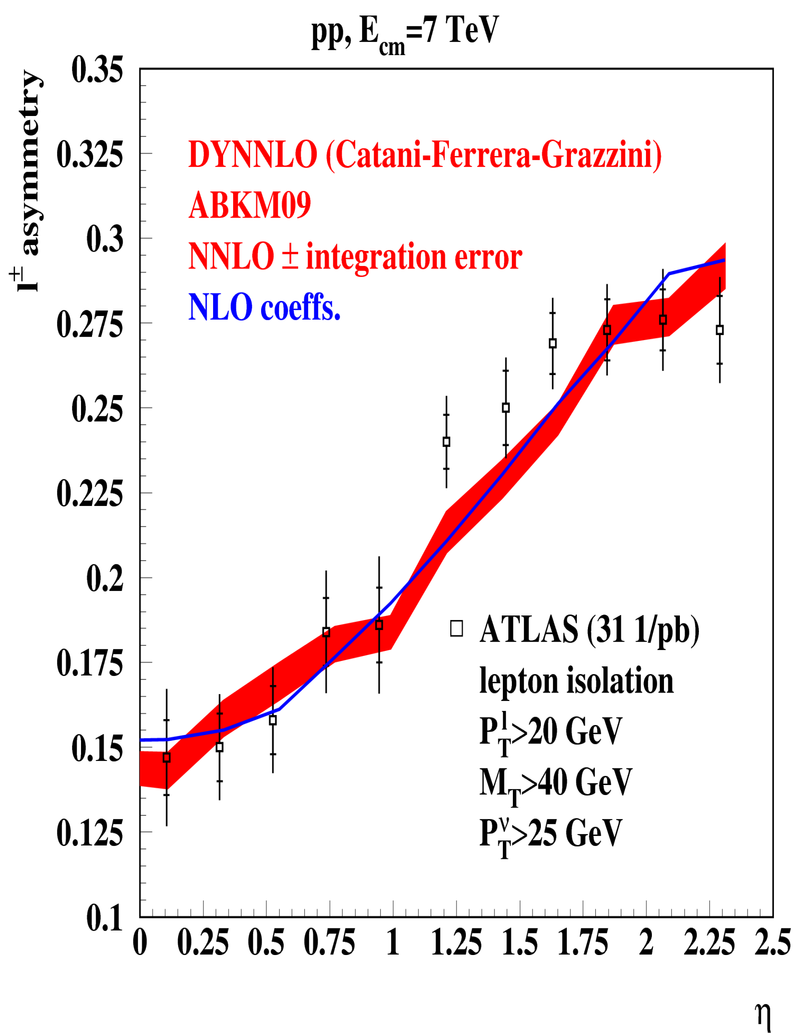


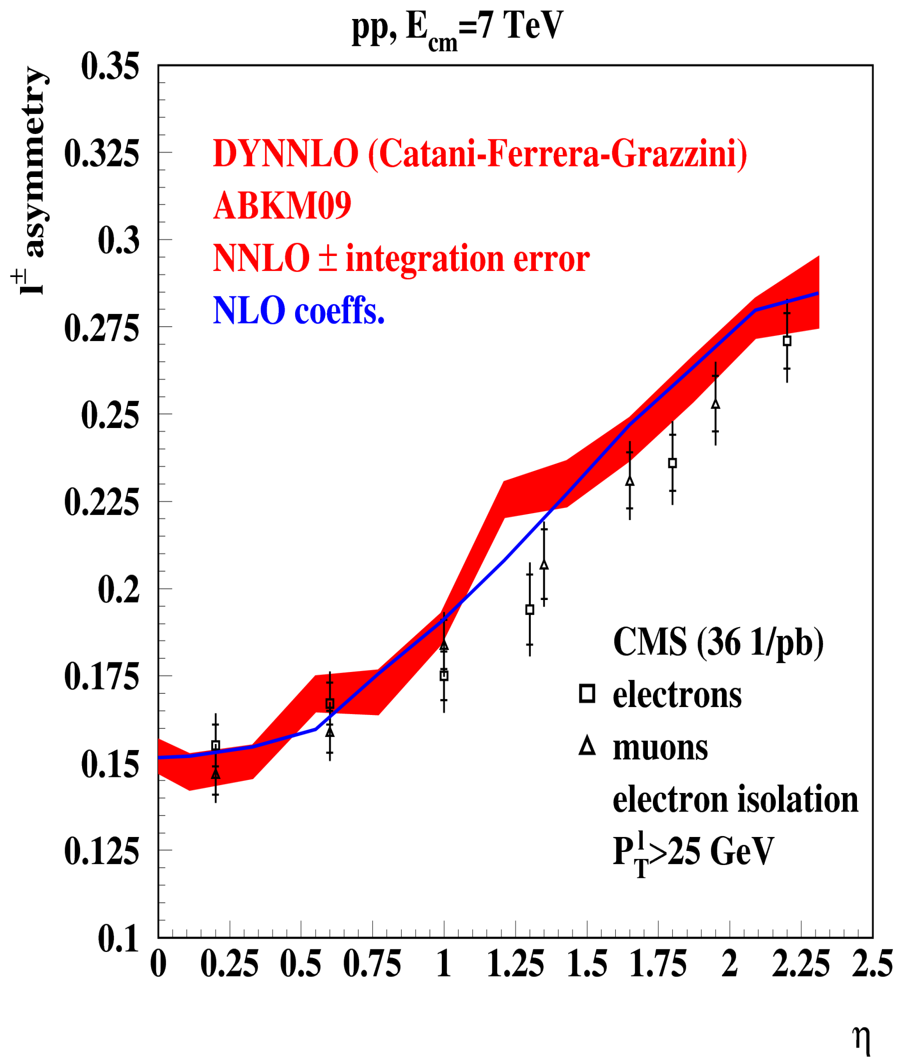


$\alpha_s(M_Z)=0.1134(11)$

The luminosity uncertainty cancels in the ratio

ATLAS-CONF-2011-041





- The ABKM09 predictions are in reasonable agreement with the ATLAS data
- Impact of the data on fit is marginal

Impact of the jet data on gluons

- The NNLO corrections to jet production are cumbersome (non-trivial subtraction of the IR singularities), only the e+e- case has been solved recently.

Gehrmann-De Ridder, Gehrmann, Glower, Heinrich, Weinzierl

NLO evolution + NLO coefs
- consistent fit
- QCD evolution is inaccurate

NNLO evolution + NLO coefs
- the PDF evolution more accurate
- the PDFs ready for the HO calculations

RunII Tevatron data checked wrt ABKM09:

D0 midpoint inclusive (R=0.7)
PRL101, 062001 (2008)

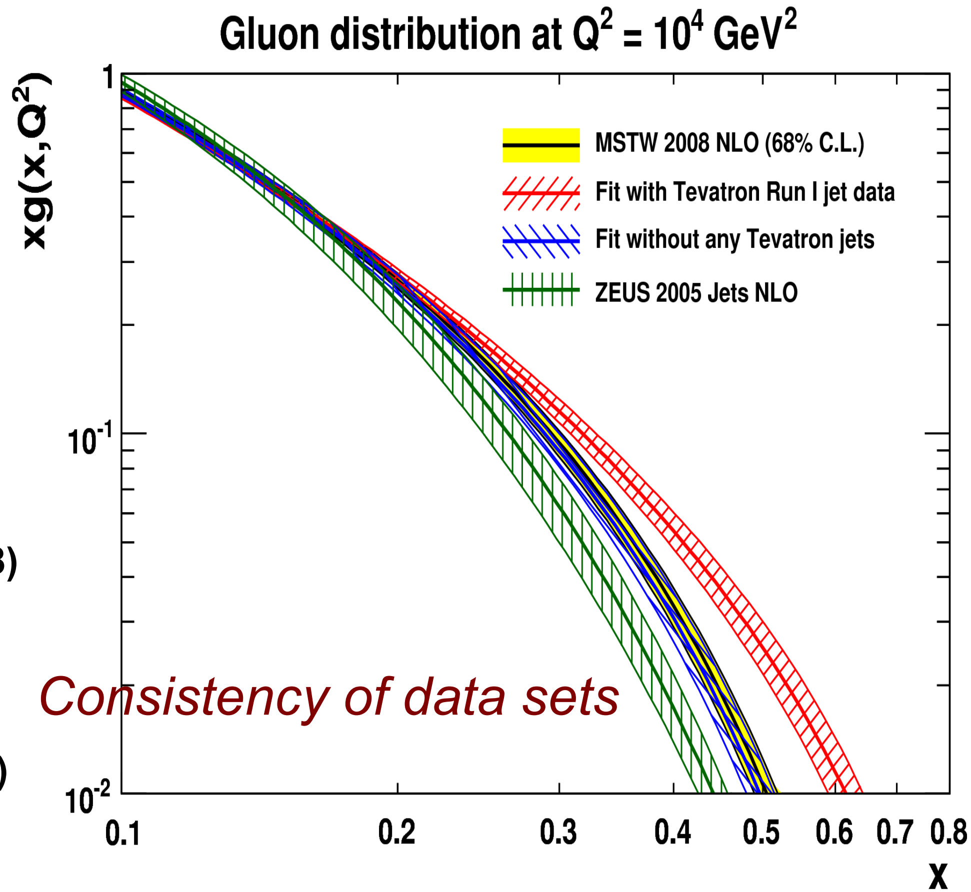
D0 midpoint di-jet (R=0.7)
PLB 693, 531 (2010)

CDF K_T inclusive (D=0.7)
PRD 75, 092006 (2007)

CDF midpoint inclusive (R=0.7)
PRD 78, 052006 (2008)

FastNLO is used to employ NLO corrections.

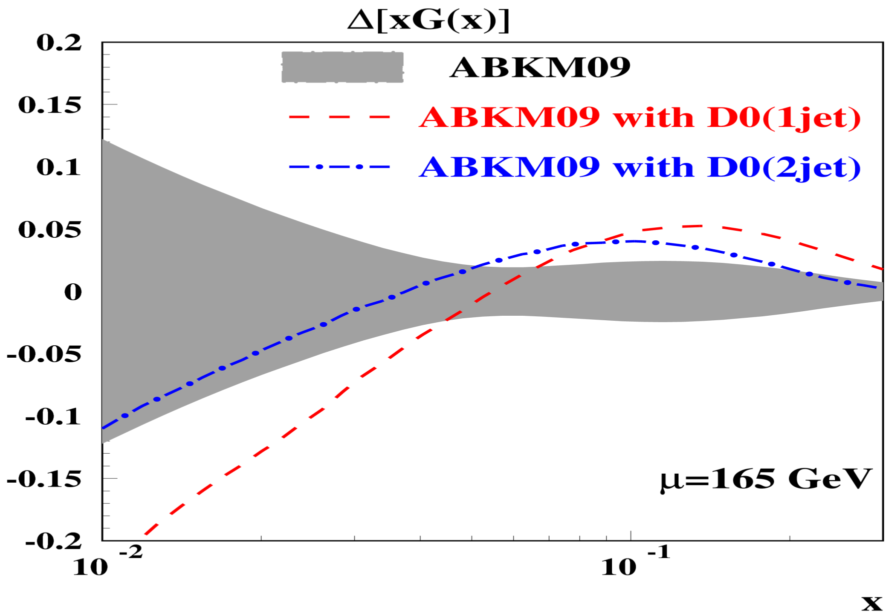
Kluge, Rabberitz, Wobbisch [hep-ph 0609285]

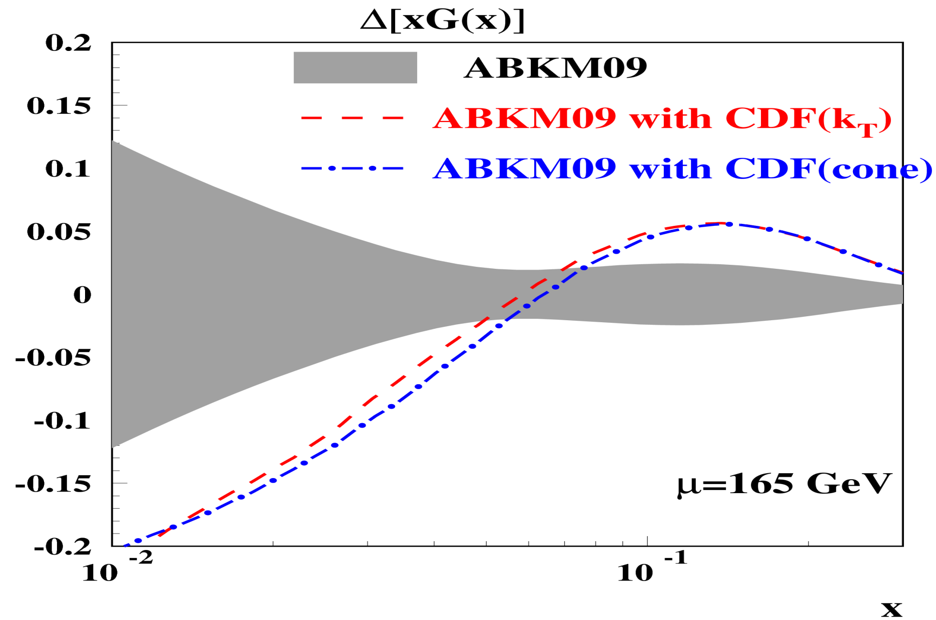


Consistency of data sets

MSTW Collaboration EPJC 63, 189 (2009)

Gluons at small x and Higgs c.s.

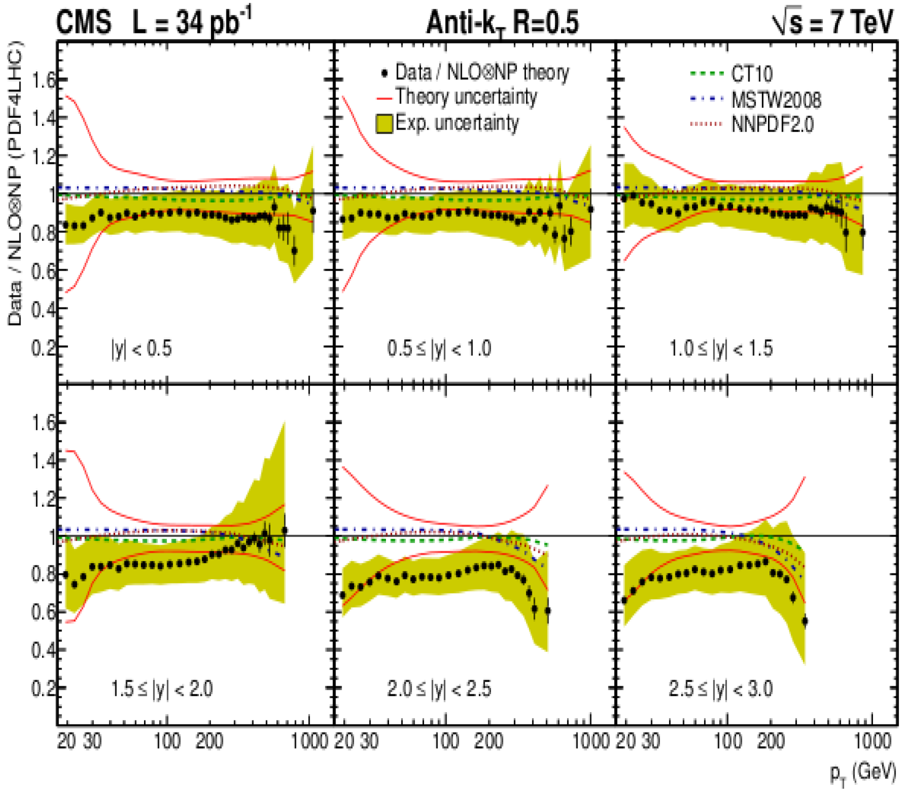




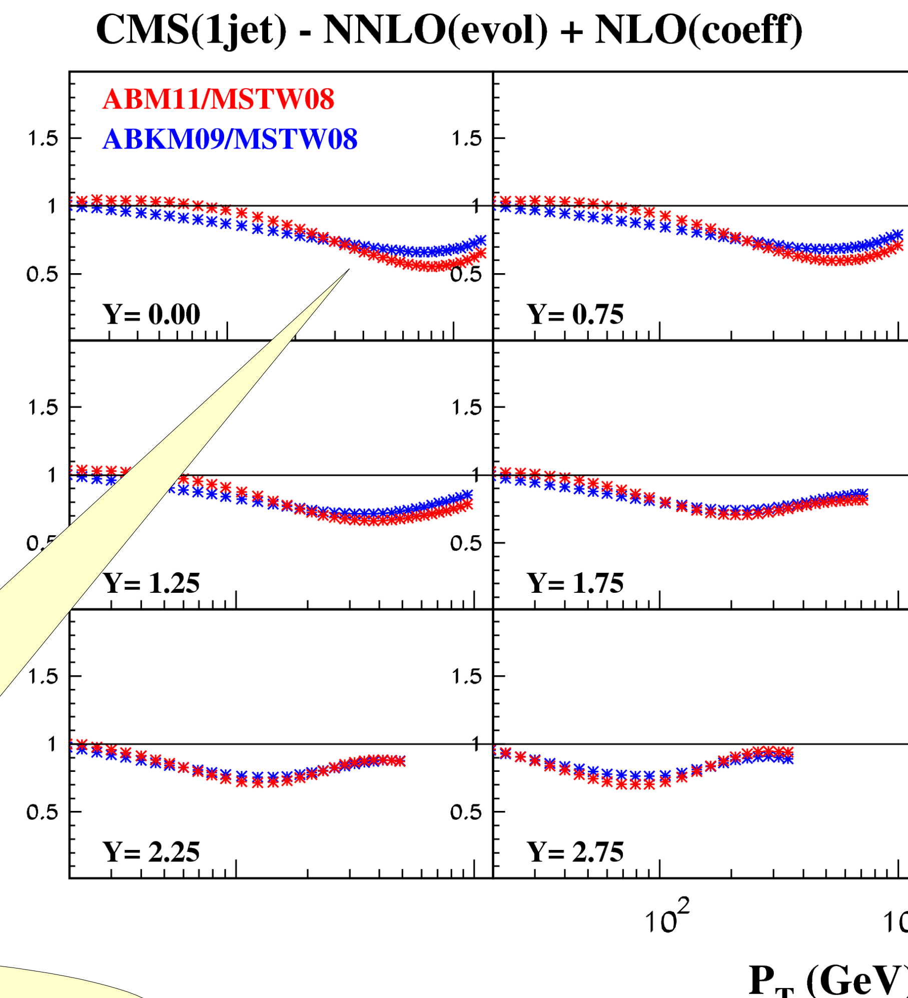
	$\alpha_s(M_Z)$(NNLO)	$\sigma(M_H$=165 GeV) (pb) Tevatron	LHC7
ABKM09	0.1135(14)	0.253(22)	7.05(23)
+ D0(1jet):	0.1149(12)	0.297(12)	7.30(15)
+ D0(2jet):	0.1145(9)	0.281(12)	7.28(14)
+ CDF/k_T	0.1143(9)	0.292(10)	7.18(14)
+ CDF/cone	0.1134(9)	0.283(10)	7.02(14)

- The Tevatron jet data pull the Higgs up by 1-2σ, depending on the data set; the effect must reduce with the NNLO correction to the jet production taken into account
- For the LHC7 relative effect is smaller, than for the Tevatron
- *The value of α_s is still "small"*

CMS inclusive jets (7 TeV, 34 1/pb)



CMS Collaboration [hep-ex/1106.0208]

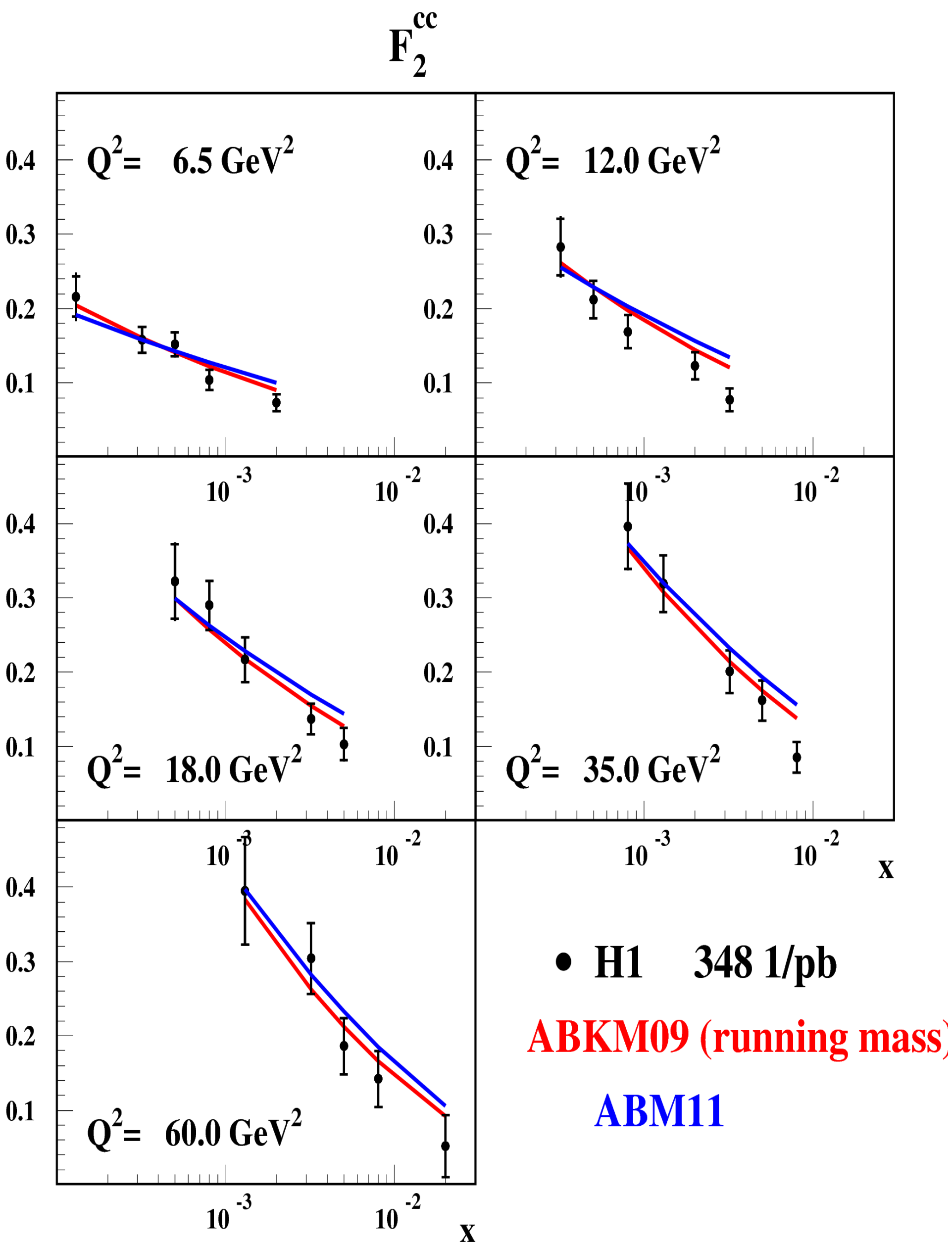


Kinematics for M_H=165 GeV at Tevatron

(FastNLO courtesy of K.Rabberitz)

The CMS data go systematically lower that the predictions based on the PDF fitted to the Tevatron jet data. For the PDF, which do not use the Tevatron jet data, agreement at large P_T is better. At small P_T the PDFs are constrained by the HERA data.

Toward determination of $m_c(m_c)$ from DIS



H1 Collaboration [hep-ex 1106.1028]

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.)

Consistent correction for the unmeasured phase space: work in progress

(in collaboration with K.Daum and K.Lipka)

$m_c(m_c)$=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
- Good agreement with the LHC data on the charge-lepton asymmetry
  - Impact data on the fit foreseen with improved statistics

The “small” value of α_s is confirmed in the approximate NNLO fit with the Tevatron jet data included:

$\alpha_s(M_z)$=0.1135(14) → 0.1134 – 0.1149 (NNLO)

depending on the data set used

The Higgs cross section can go up by ~1-2σ, effect must be smaller for the LHC jet data