Update of the NNLO ABM PDFs

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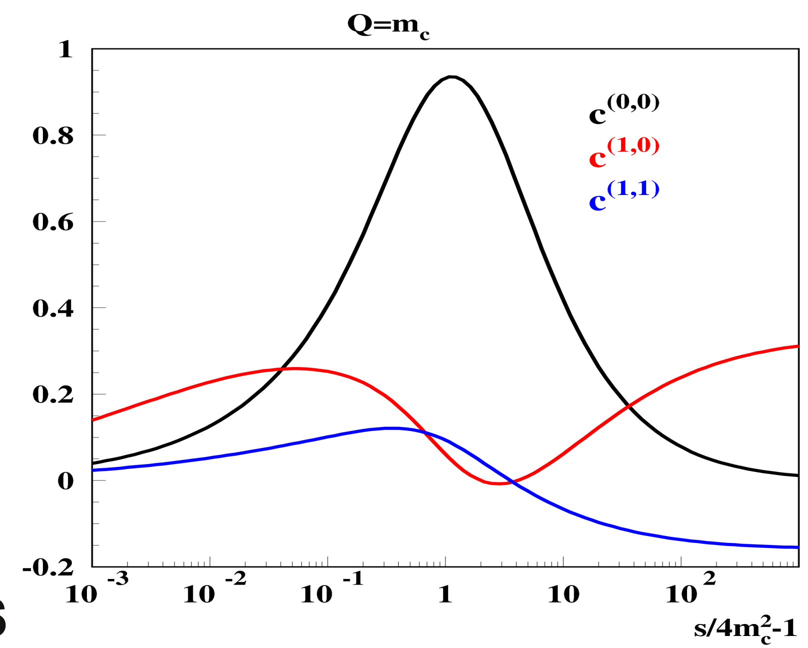
(in collaboration with J.Blümlein, and S.Moch)

- Improved treatment of the heavy quark electro-production
- New HERA data
- Standard candles
- PDF benchmarking
- Summary/outlook

Physics at the Terascale, Bonn, 8 Dec 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*

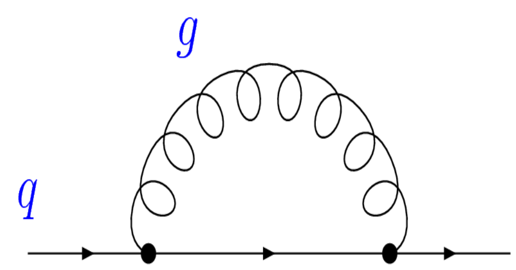
Pole mass definition

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

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

Pole mass is defined for the free (unobserved) quarks

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

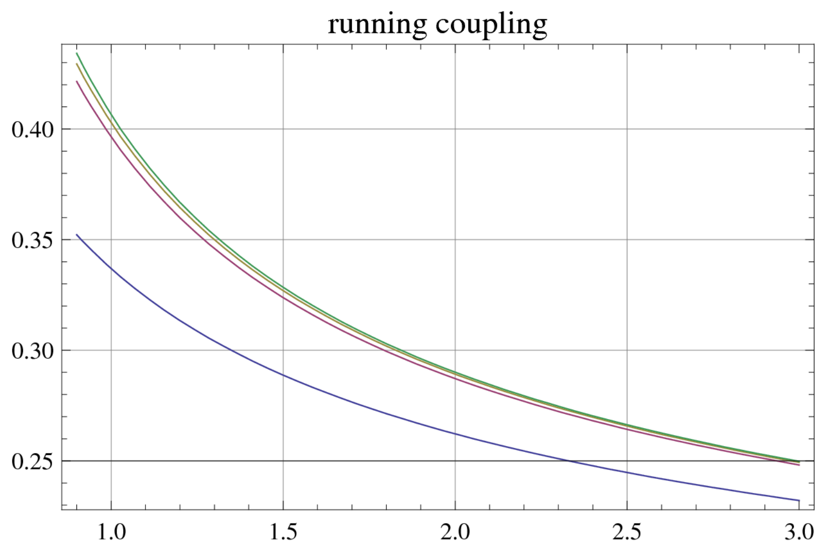


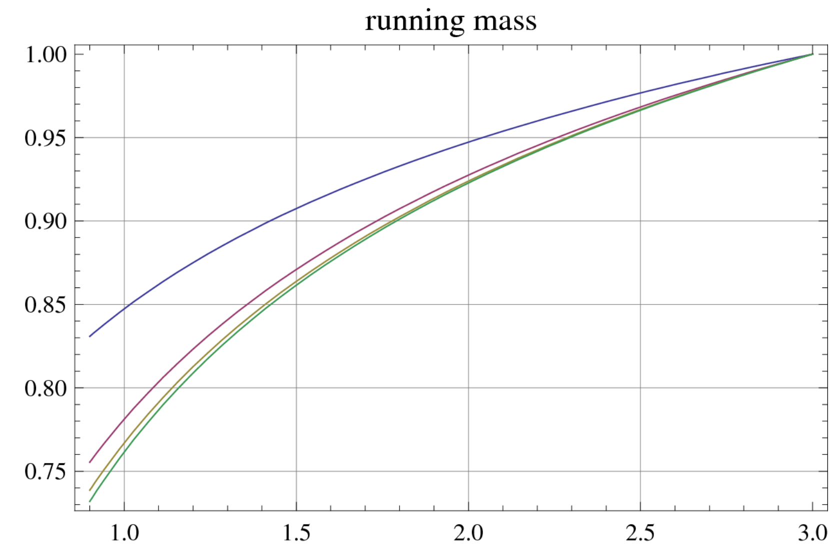
The quantum corrections due to the self-energy loop integrals receive contribution down to scale of O(Λ_{QCD}) → sensitivity to the high order corrections, particularly at the production threshold

Running quark mass

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

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





The corrections up to 4-loops are known

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

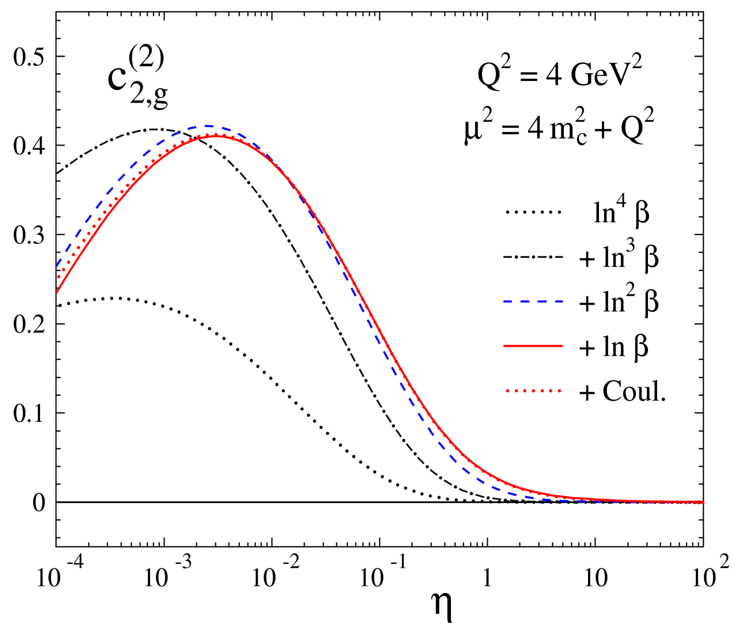
Chetyrkin PLB 404, 161 (1997)

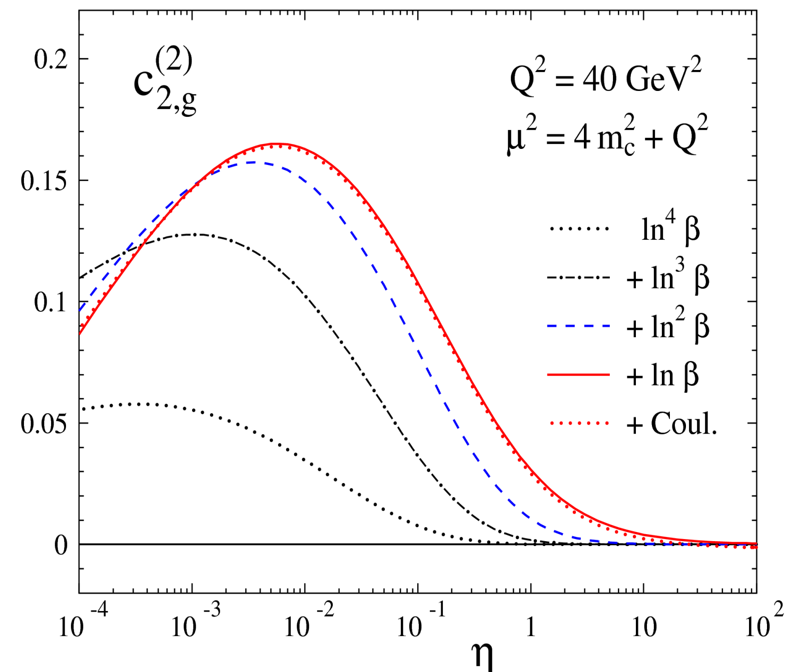
Vermaseren, Larin, van Ritbergen PLB 405, 327 (1997)

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

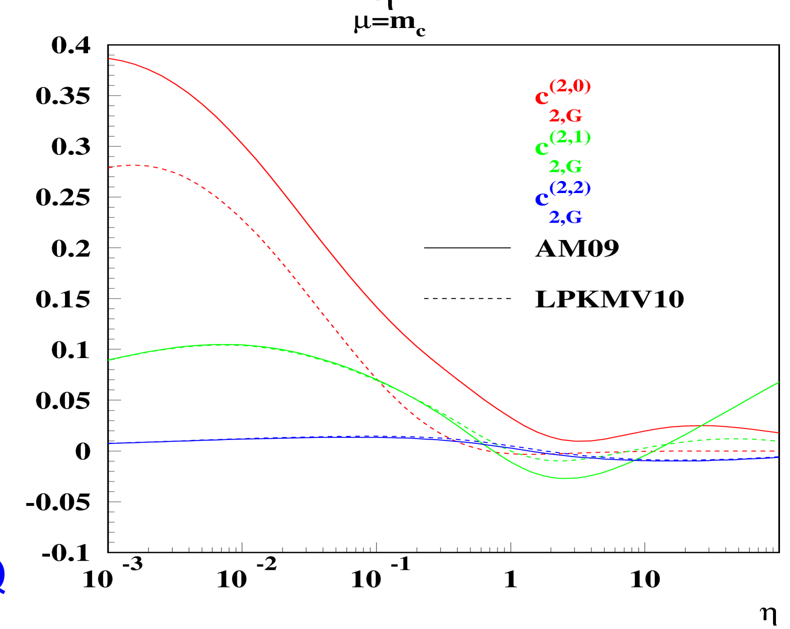
- The ttbar production in hadronic collisions **Laengenfeld, Moch, Uwer PRD 80, 054009 (2009)**
- The heavy-quark electroproductoin in the approximate NNLO (full NLO + NNLO threshold resummation) **sa, Moch [hep-ph 1011.5790]**

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 ~ $\ln^n(\beta)$ 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

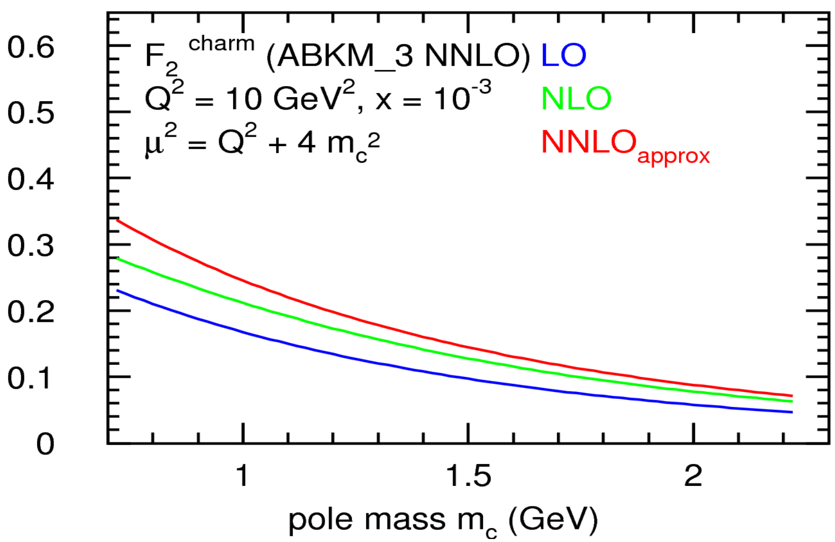


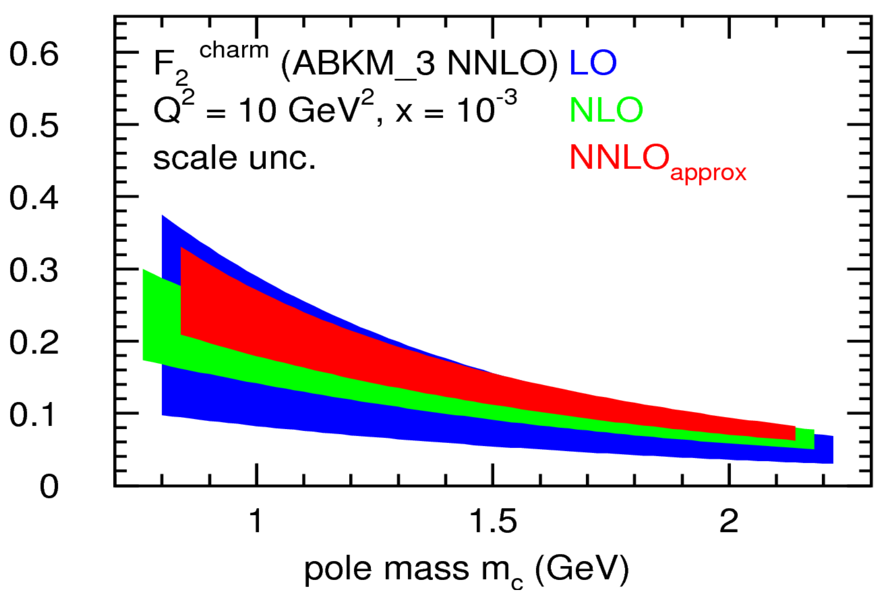
- The first log and Coulomb terms have been recently added → F_2^c gets somewhat smaller at small Q and somewhat bigger at large Q

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

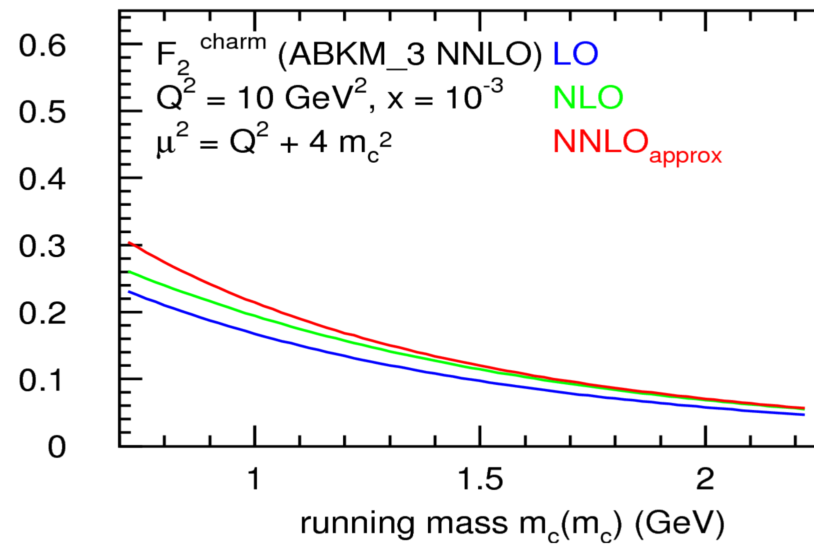
Running mass definition for the DIS SFs

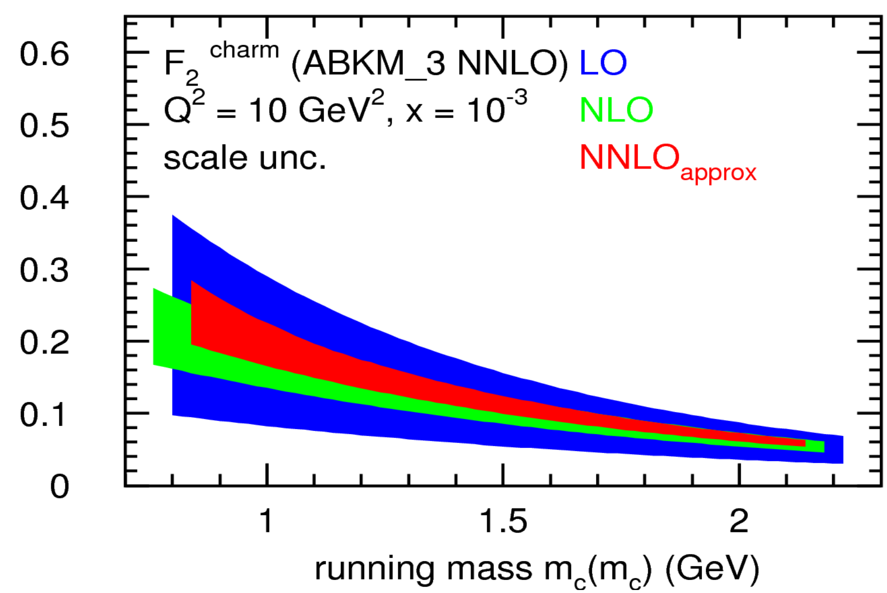
Pole mass





Running mass

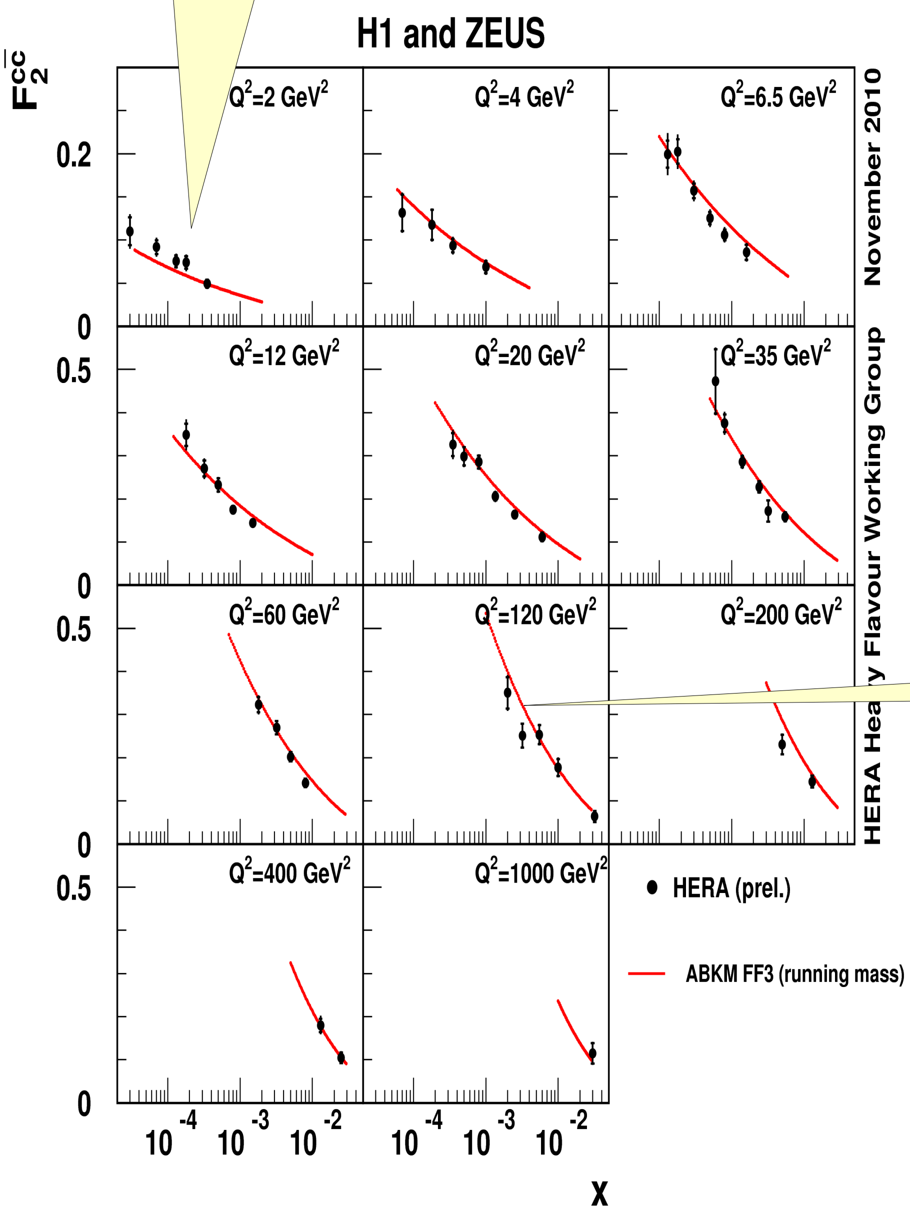




c-quark DIS production

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

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

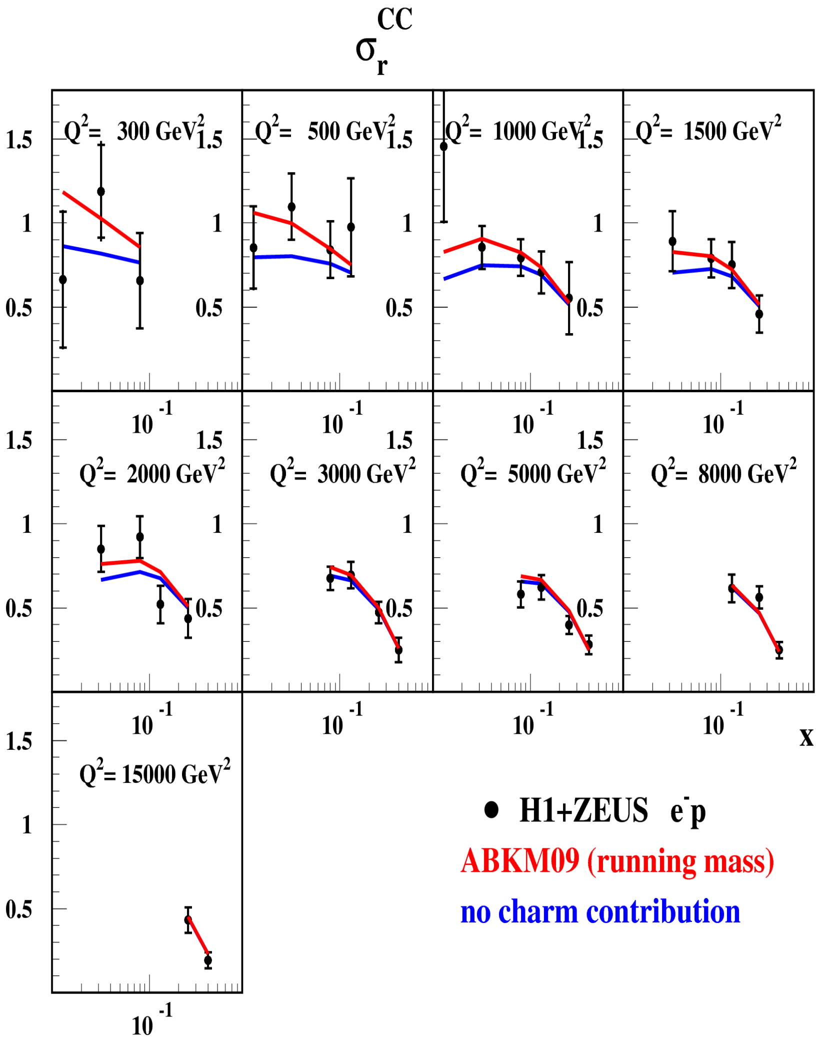
At $Q >> m_c$ first Mellin NNLO moments are known

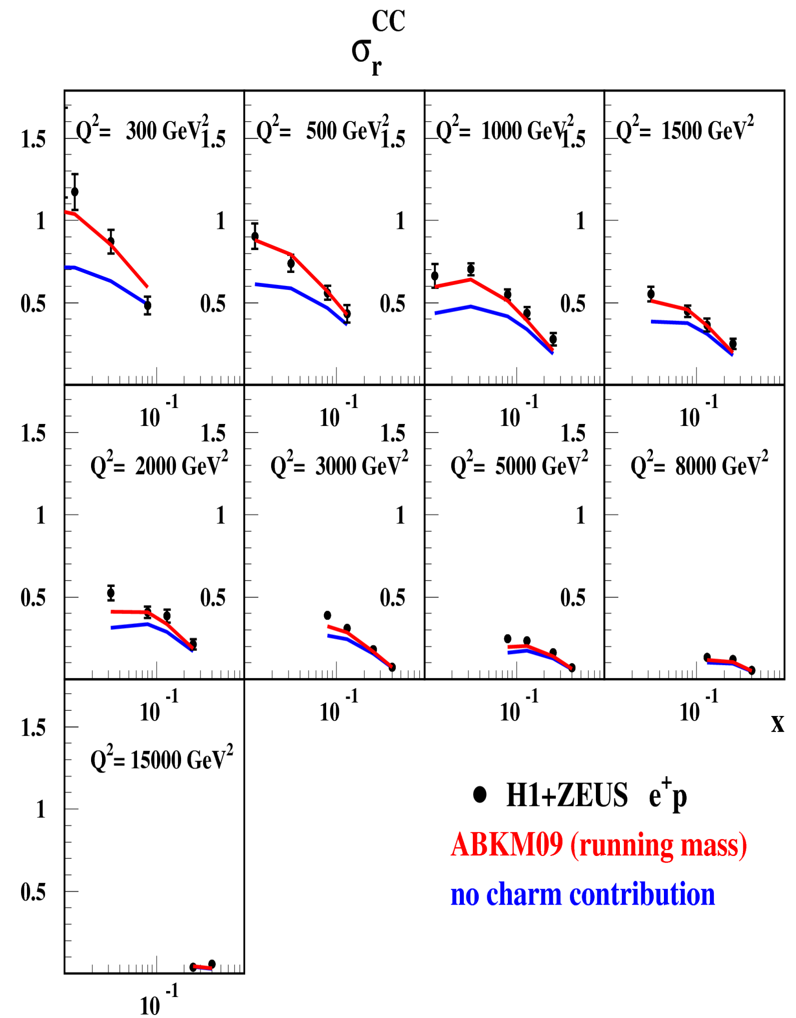
Ablinger at al. NPB 844, 26 (2011)

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

CC inclusive data

H1 and ZEUS Collaborations JHEP 1001, 109 (2010)

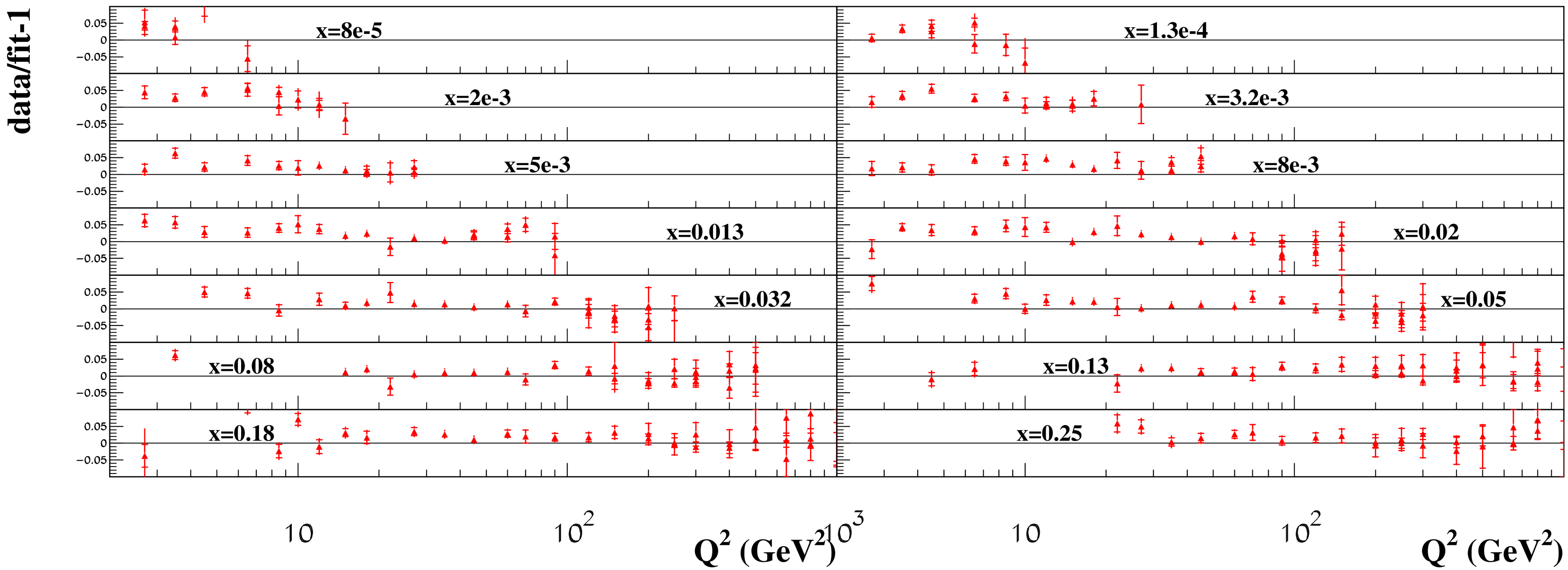




- Nice agreement with ABKM09 **predictions**
- Impact of the data on ABKM09 fit is marginal
- With the improved accuracy at future facilities, (at EIC?), the strange distribution can be better constrained.

High-Q inclusive DIS data

H1 and ZEUS Collaborations JHEP 1001, 109 (2010)



- The PDF shape was modified to accommodate new data

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

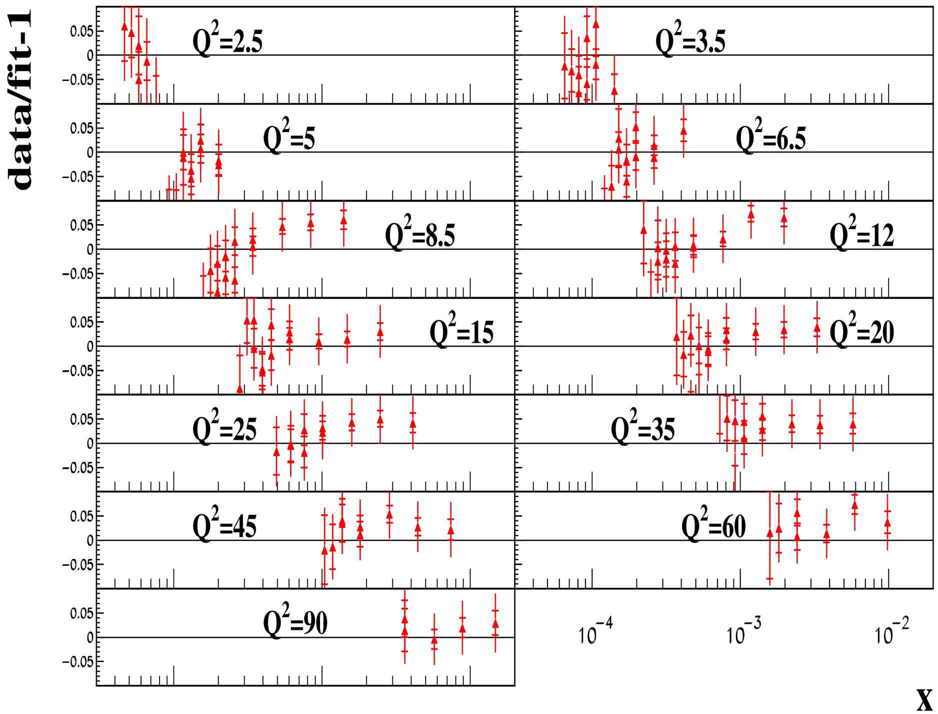
$$xu_V(x) = exp\left[a \ln x(1 + \gamma_1 x + \gamma_2 x^2 + \gamma_3 x^3)\right](1 - x)^b$$

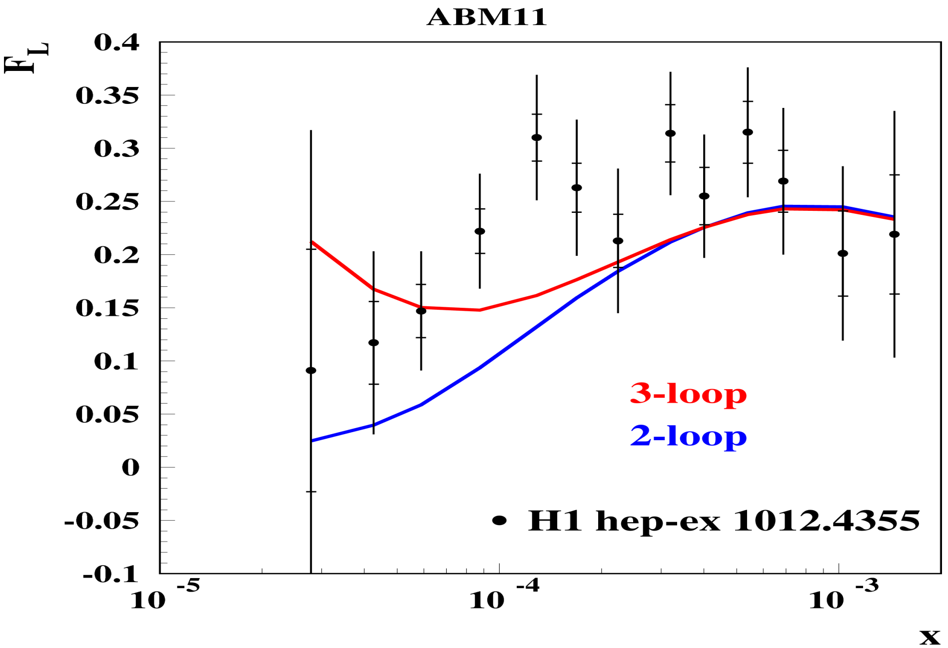
- χ^2/NDP=1.1, with account of the systematic error correlations (114 sources). Slightly worse for the small-Q part, the same observed in the model-independent fit

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

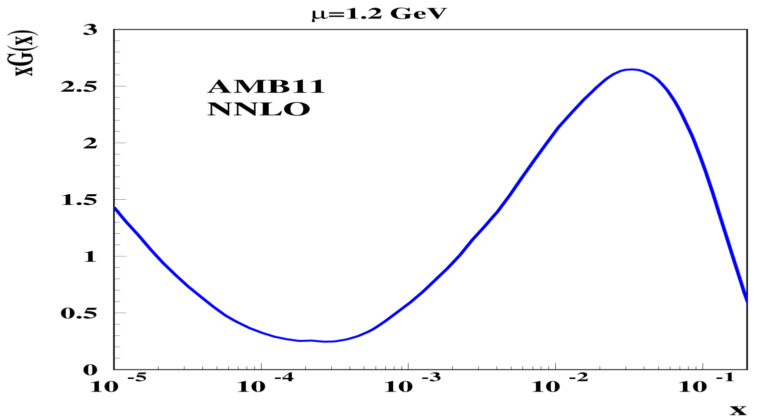
Moch, Vermaseren, Vogt PLB 606, 123 (2005)

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

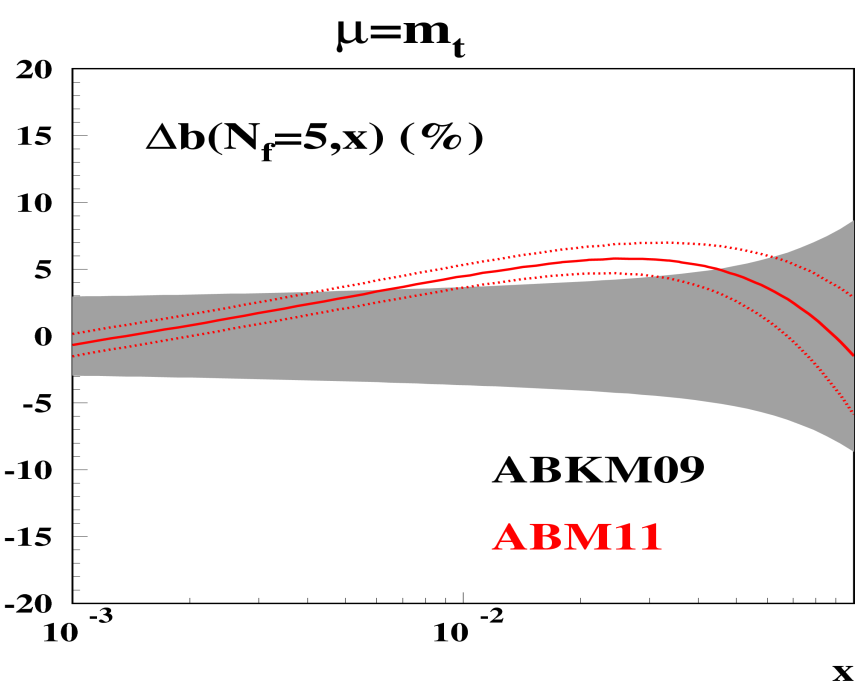
H1 Collaboration [hep-ex 1012.4355]

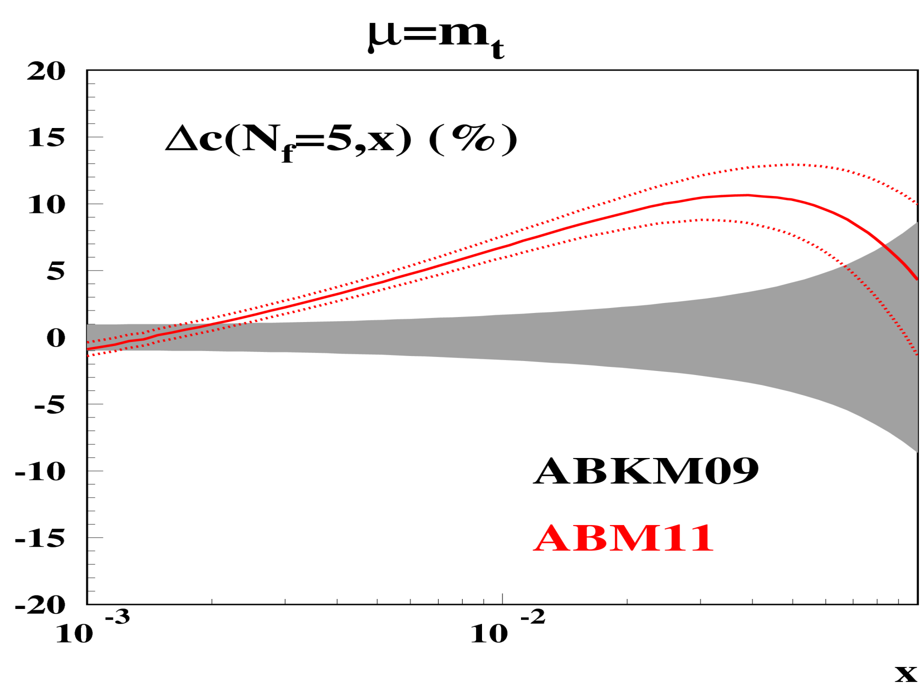
- The data can be easily accommodated in the fit: the value of χ^2/NDP=1.05; no clear sign of the collinear evolution violation

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



Heavy-quark PDFs





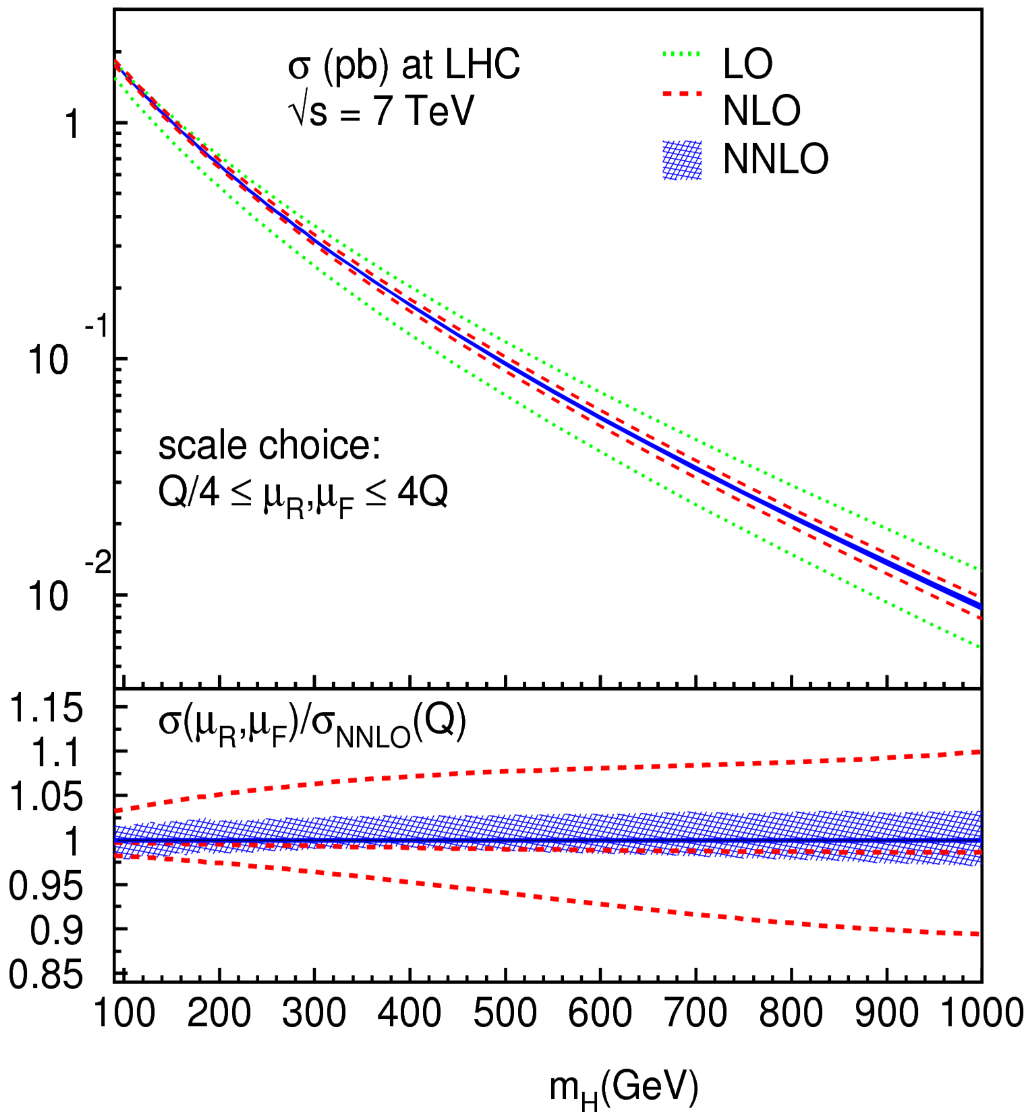
The 4- and 5-flavour PDFs are generated from the ABM11 fit preformed with the running-mass definition; the massive OMEs with the running-mass definition are used

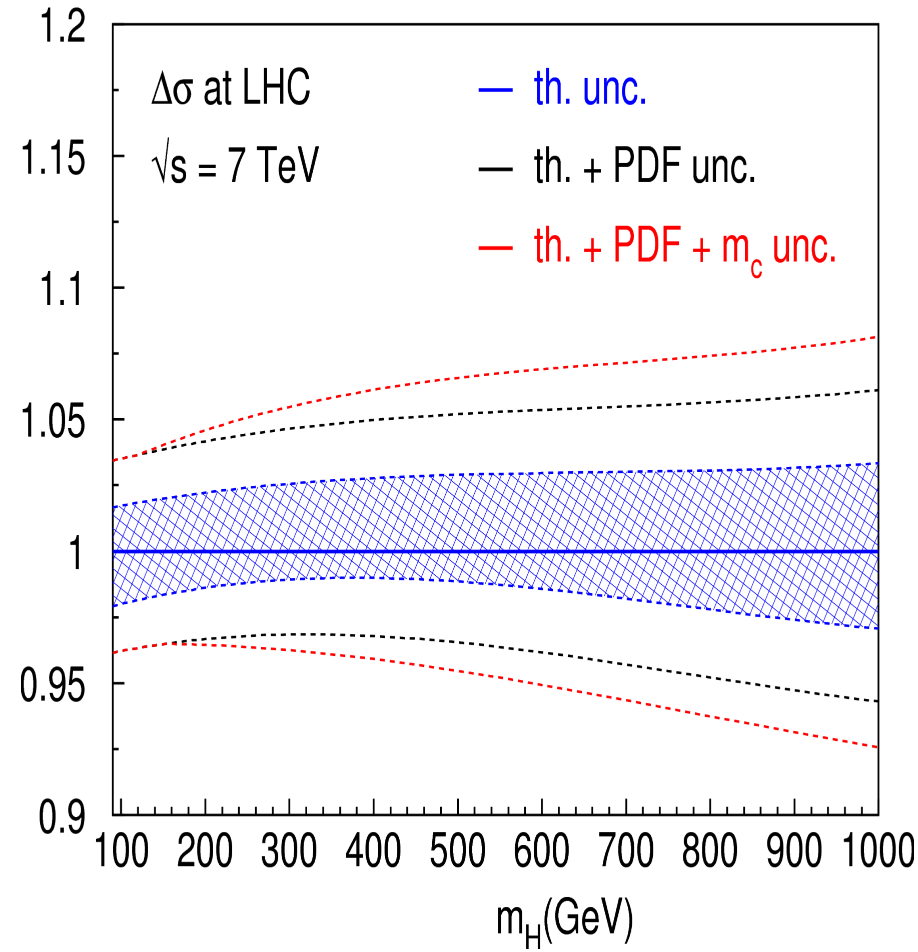
The change in the heavy-quark distribution is due to:

- change in the 3-flavor distributions from ABKM09 to ABM11
- change in the masses:
  - $m_b = 4.5 \rightarrow 4.19 \pm 0.13$ GeV
  - $m_c = 1.5 \rightarrow 1.27 \pm 0.08$ GeV (PDG '10)
- modification of the massive OMEs

The b-quark distribution uncertainty is reduced → impact on the single-top production, higgsstrahlung, etc.

Higgs production in VBF





Bolzoni, Maltoni, Moch, Zaro
PRL 105, 011801 (2010)

Sizable uncertainties for large Higgs masses due to m_c

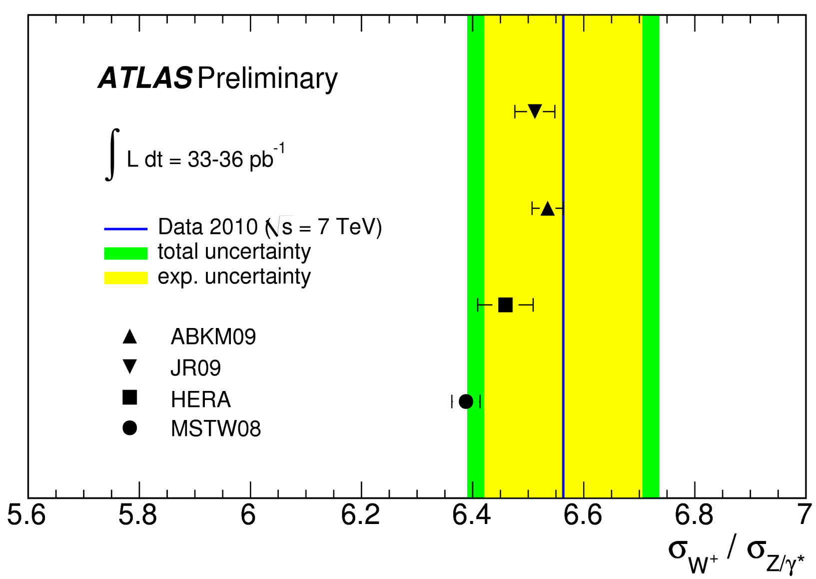
NNLO benchmarks

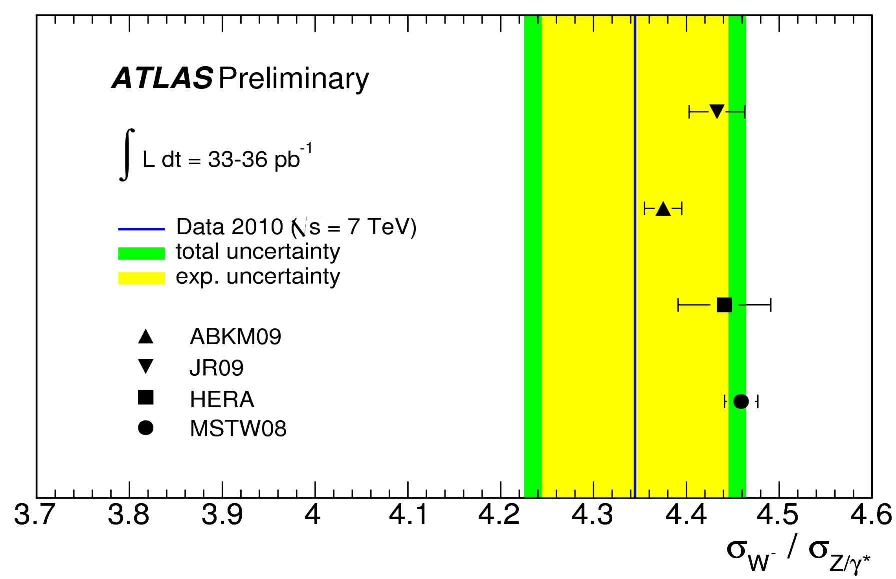
ABKM09 $\alpha_s(M_Z)$=0.1135(14)

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

	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)

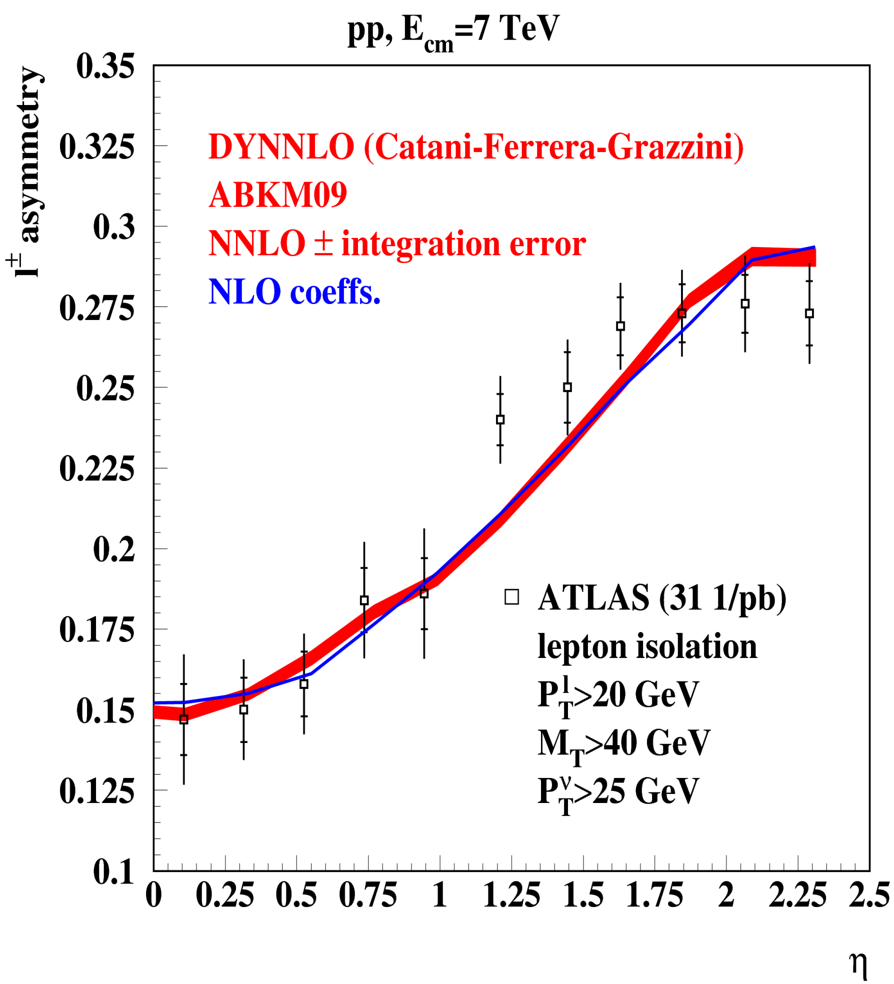


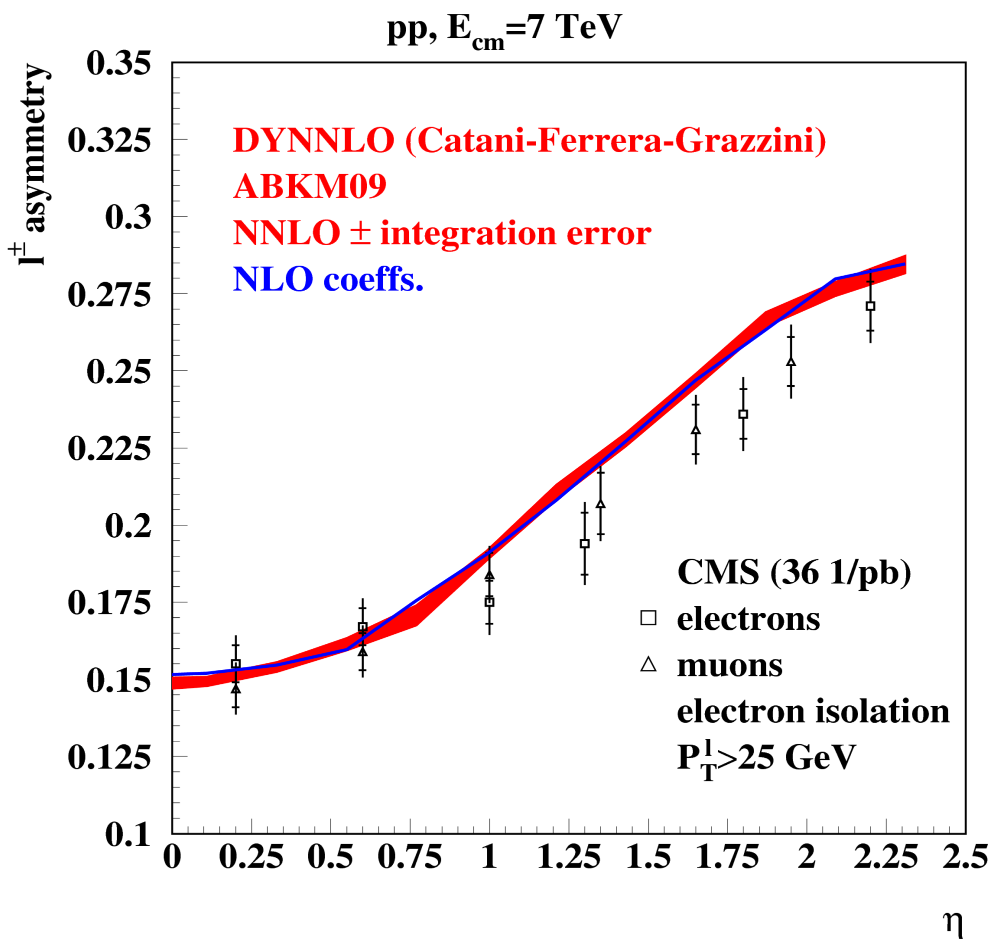


The luminosity uncertainty cancels in the ratio

ATLAS-CONF-2011-041

Charge-lepton asymmetry data from LHC





- The ABKM09 predictions are in reasonable agreement with the LHC data, some tension between ATLAS and CMS
- The ATLAS data were included into the trial fit → marginal impact on the PDFs, an improvement foreseen with bigger statistics

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)

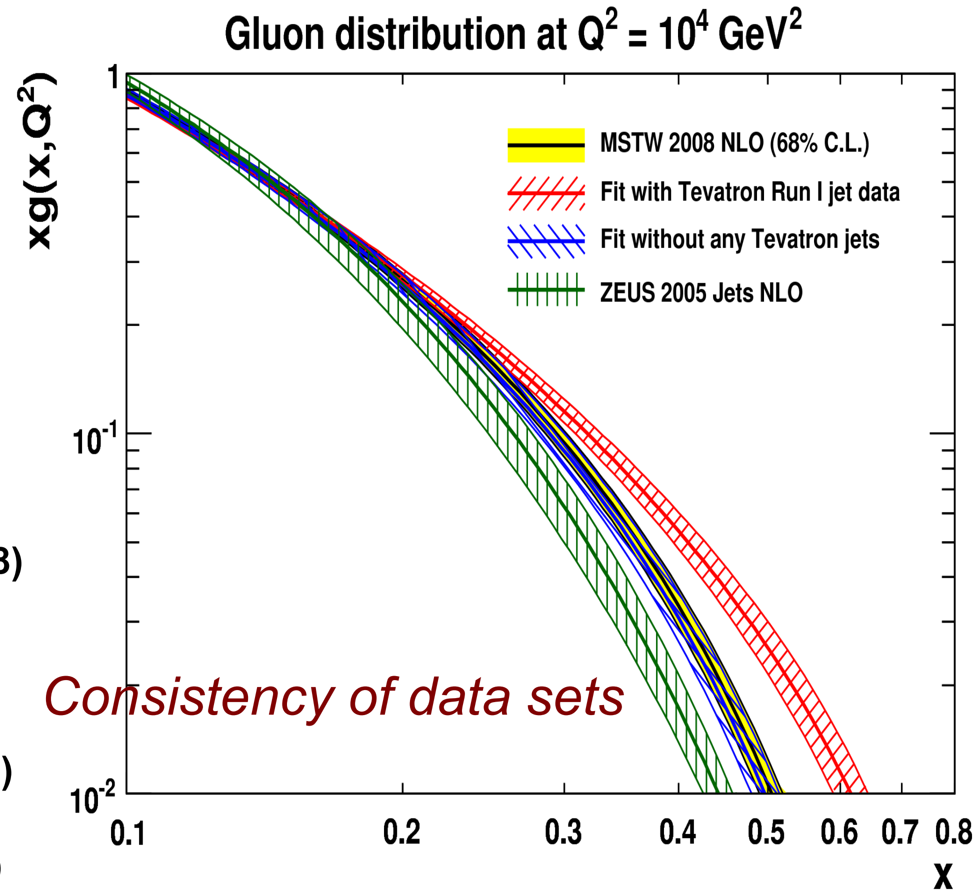
D0 midpoint di-jet (R=0.7)
PLB 693, 531 (2010)

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

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

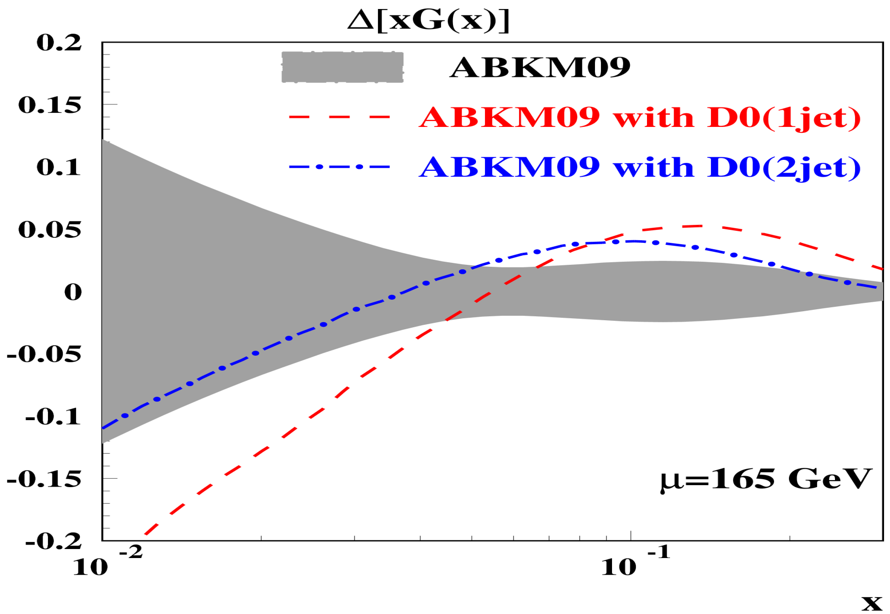
FastNLO is used to employ NLO corrections.

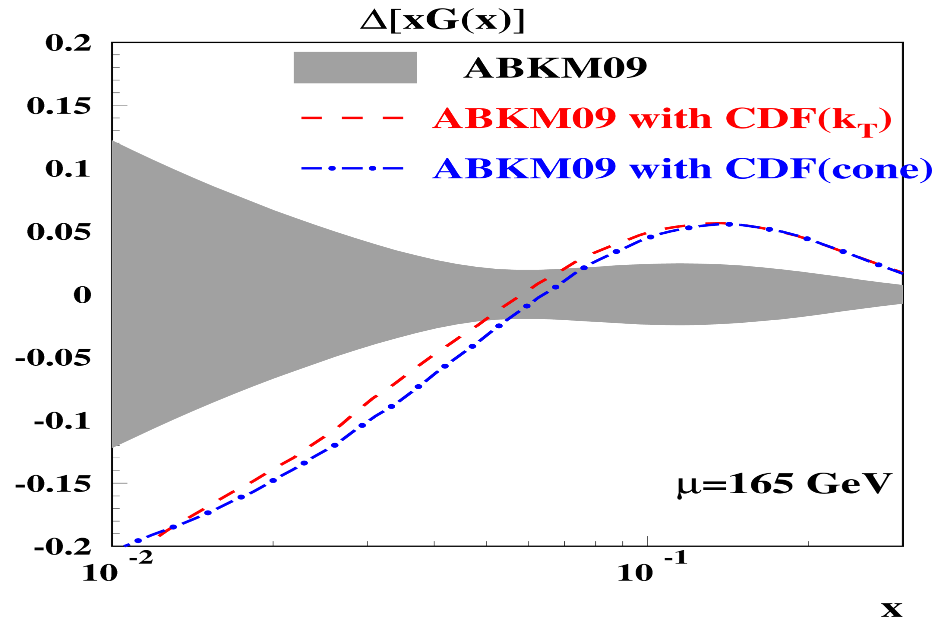
Kluge, Rabberitz, Wobbisch [hep-ph 0609285]



MSTW Collaboration EPJC 63, 189 (2009)

Gluons at small x and Higgs c.s.



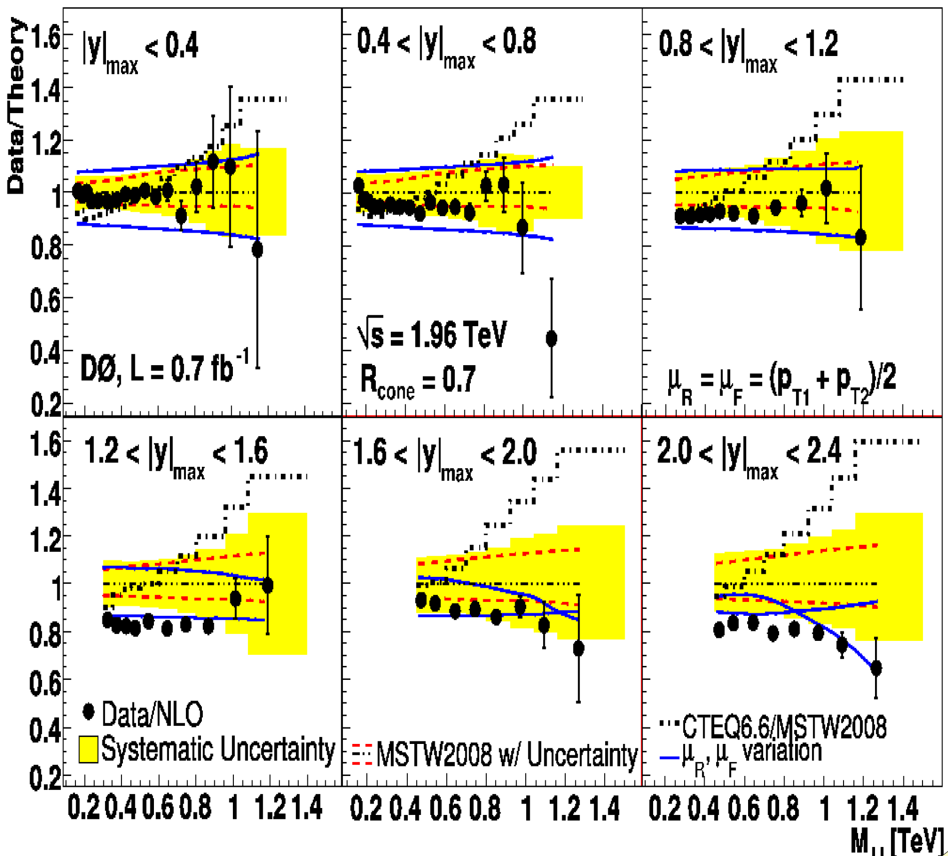


	$\alpha_s(M_Z)$(NNLO)	$\sigma(M_H$=165 GeV) (pb) Tevatron	LHC7
ABKM09	0.1135(14)	0.253(22)	7.05(23)
+ D0(1jet):	0.1149(12)	0.297(12)	7.30(15)
+ D0(2jet):	0.1145(9)	0.281(12)	7.28(14)
+ CDF/k_T	0.1143(9)	0.292(10)	7.18(14)
+ CDF/cone	0.1134(9)	0.283(10)	7.02(14)

- 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"*

Dijet and three-jet c.s.

"Truly global" PDFs tuned to jet data



D0 Collaboration PLB 693, 531 (2010)

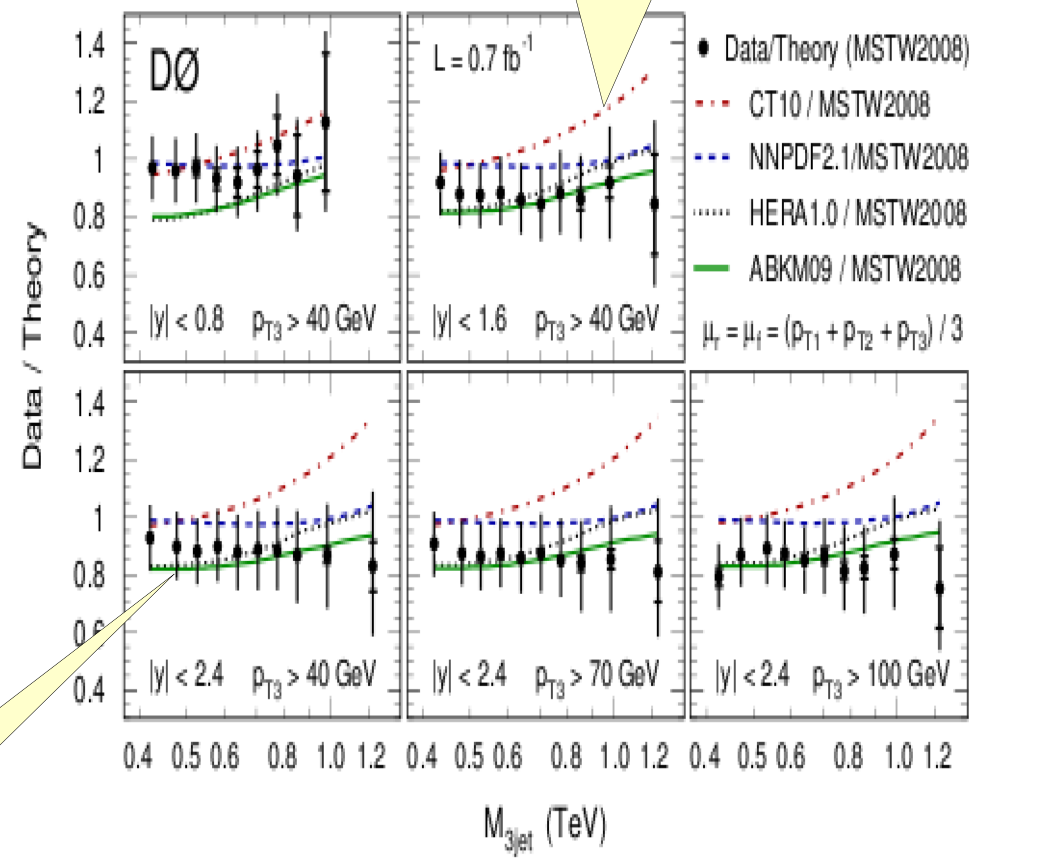


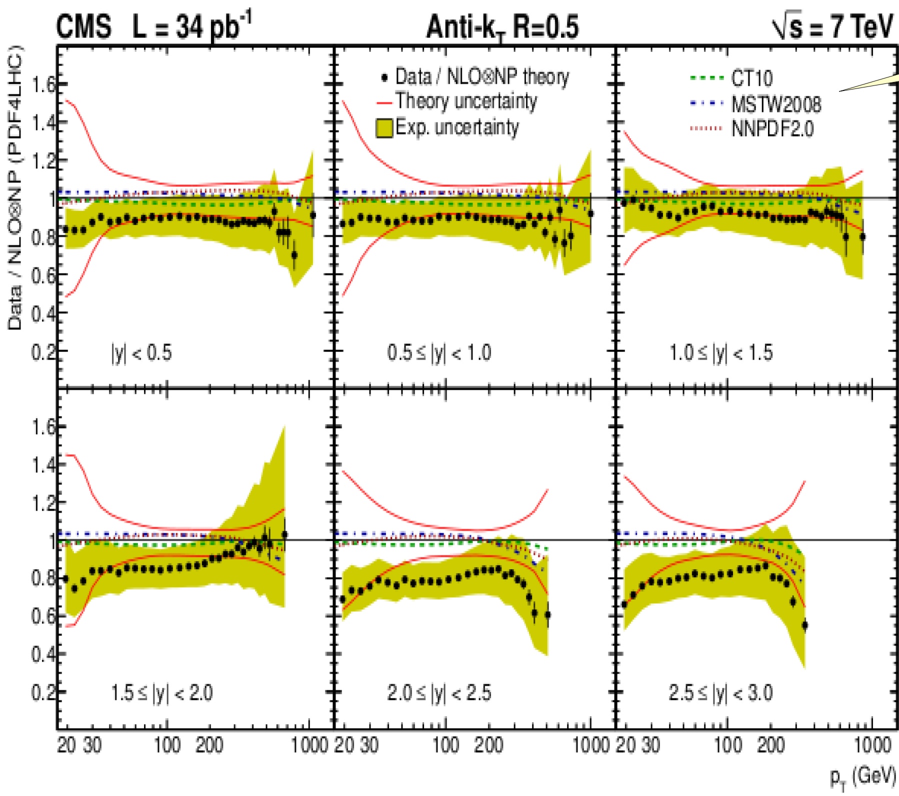
Figure 2: The 3-jet mass differential cross section in the three jet rapidity intervals are compared to NLO pQCD with different PDF sets.

No jet data in the fit

The "truly global" PDFs provide worse agreement with the data?

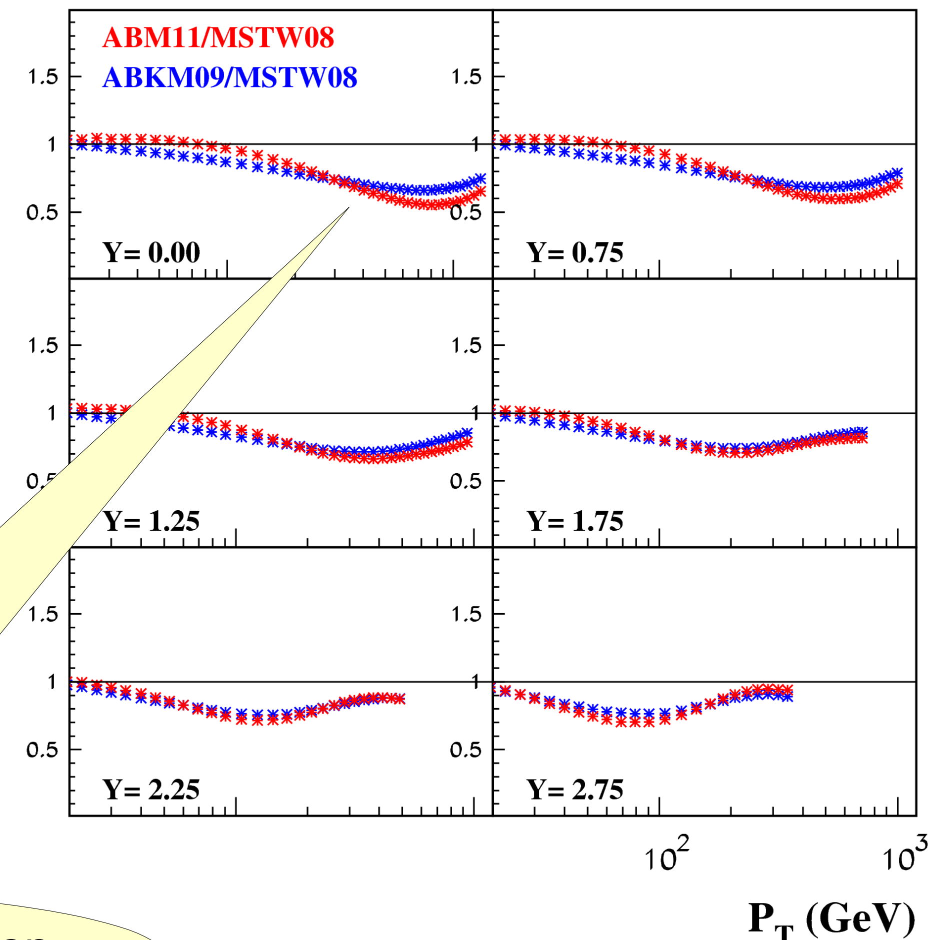
CMS inclusive jets (7 TeV, 34 1/pb)

PDF4LHC recommendation



CMS Collaboration [hep-ex/1106.0208]

CMS(1jet) - NNLO(evol) + NLO(coeff)

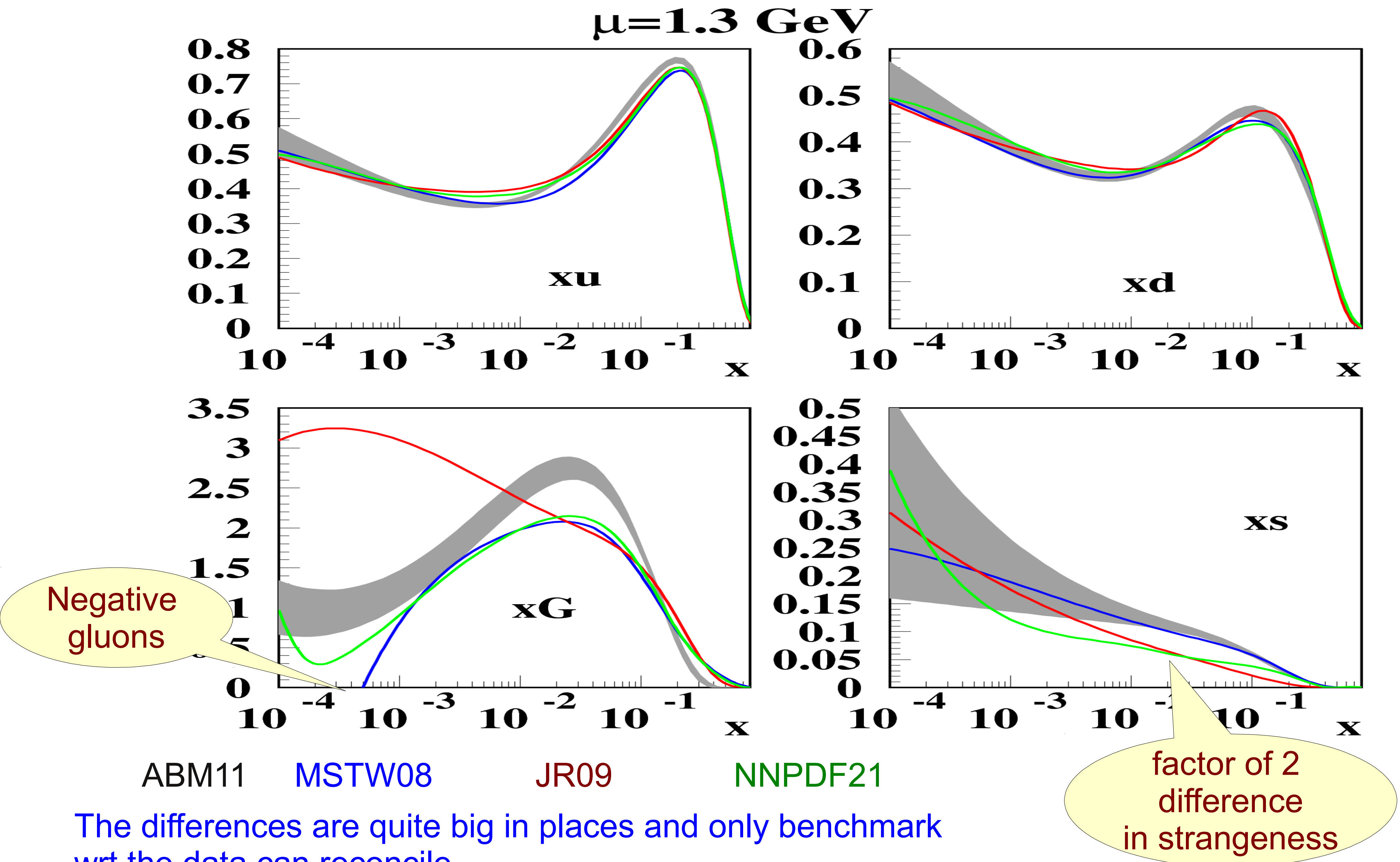


(FastNLO courtesy of K.Rabberitz)

Kinematics for M_H=165 GeV at Tevatron

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.

NNLO PDFs comparison



ABM11 MSTW08 JR09 NNPDF21

The differences are quite big in places and only benchmark wrt the data can reconcile

For the DIS data the FFNS and variants of of GMVNS employed → PDF different by definition

Benchmark of the DIS with the 3-flavour FFNS

Matching of the 3-, 4-, and 5-flavour PDFs is unique up to the matching point

Buza, Matounine, Smith, van Neerven EPJC 1, 301 (1998)

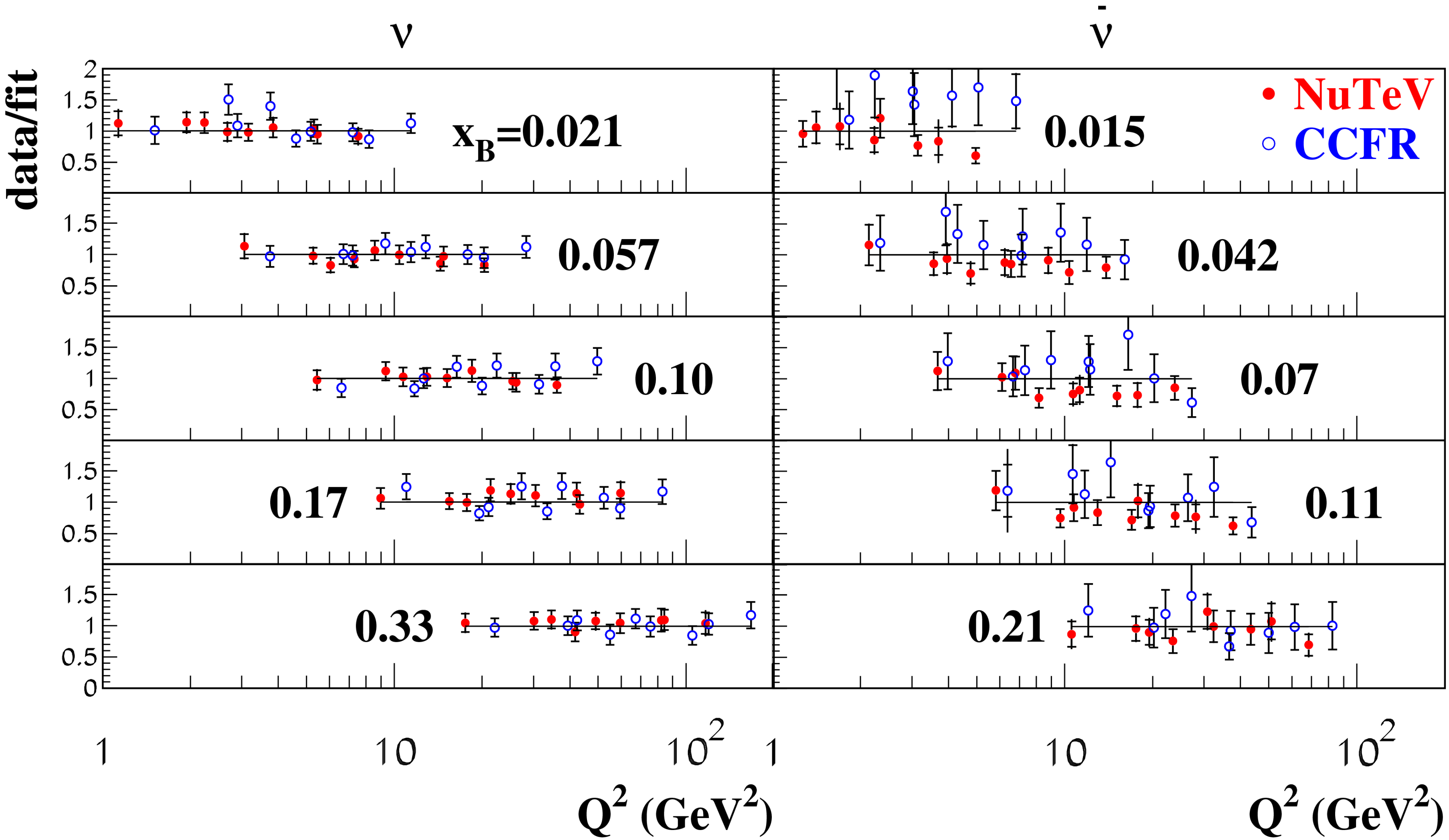
The 3-flavor PDFs are often provided even the fit is based on the GMVFNS
and can be easily generated otherwise

- Convolution with the FFNS coefficient must reproduce the FFNS results at small scales once a GMVFNS should tend to FFNS
- At large Q the data may overshoot the predictions due to impact of big logs taken into account the the GMVFNS and not in FFNS
- Additional tuning may need due to:
  - heavy-quark masses
  - power corrections
  - nuclear corrections
  - data selection
  - ,,,,,

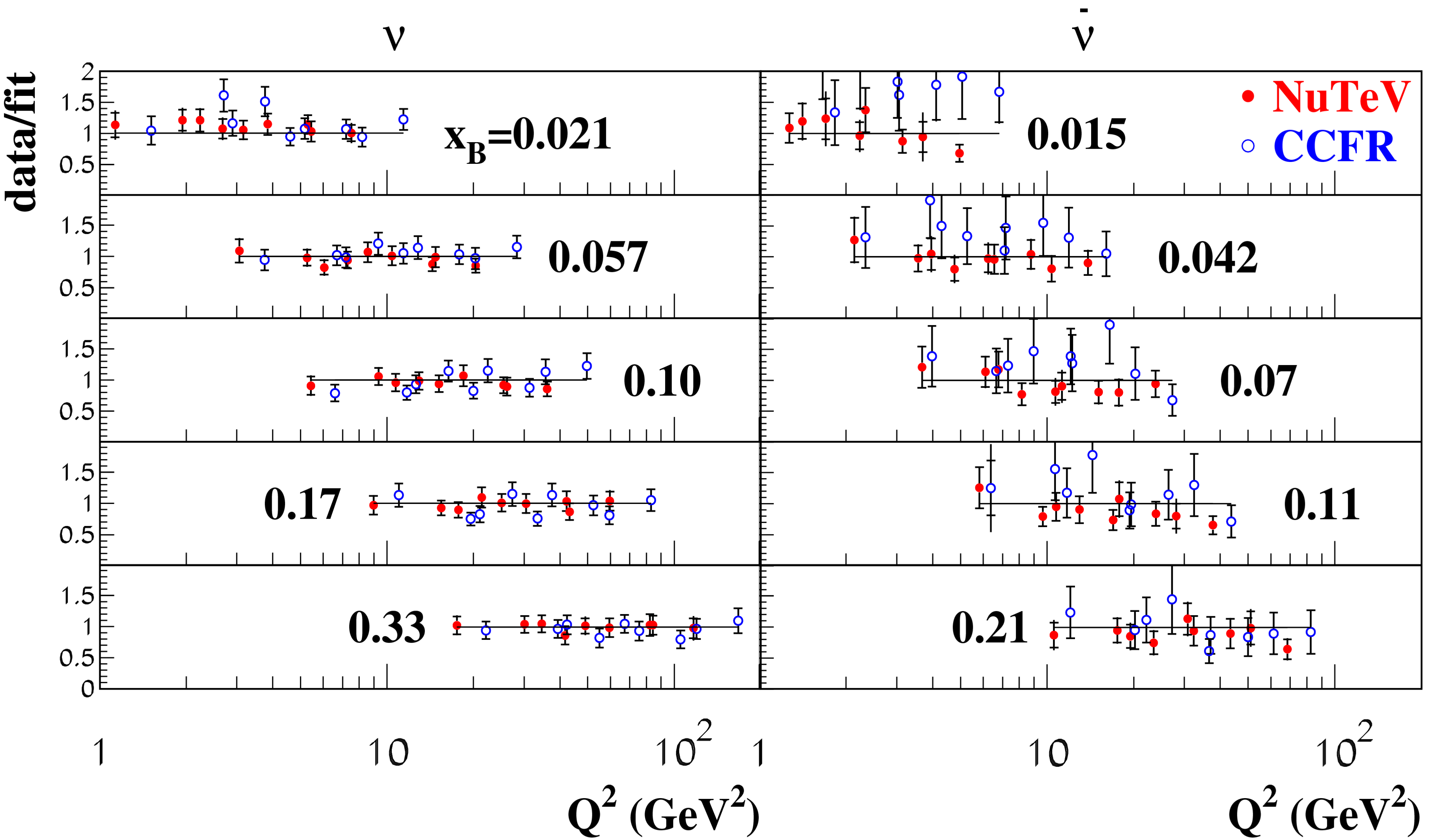
www-zeuthen.desy.de/~alekhin/OPENQCDRAD

Massless NC coefficients up to NNLO
Massive NC coefficients up to NLO + NNLO threshold corrections
Massive CC coefficients up NLO
Pole and running mass schemes for the massive coefficients
Interface to LHAPDF library

Comparison with the dimuon neutrino data

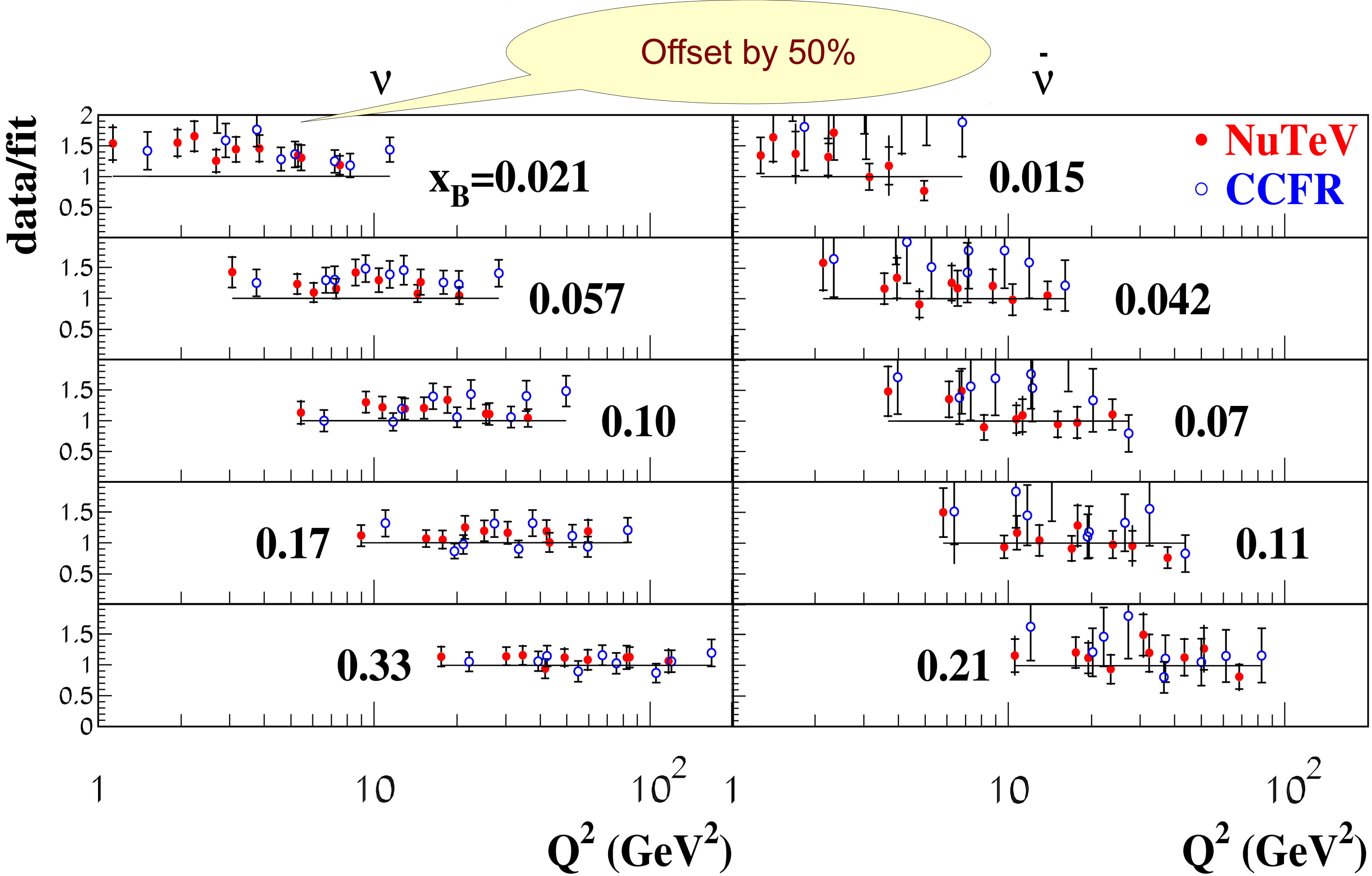


abm11_3_nlo
NLO coefficients
mc(mc)=1.27 (PDG 10), running mass definition



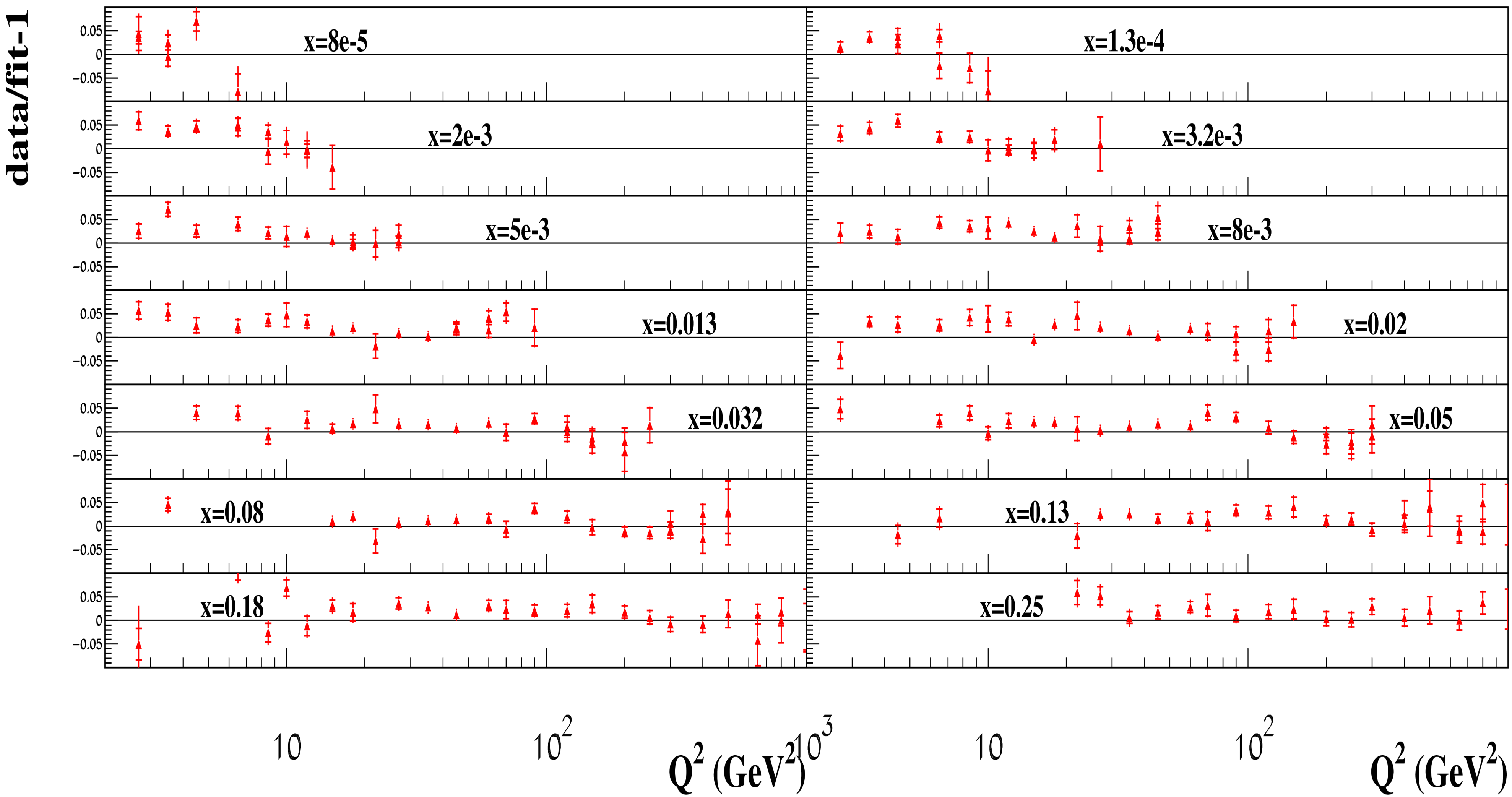
MSTW08nlo68cl_nf3 with our code: reasonable agreement

The same for CT10f3

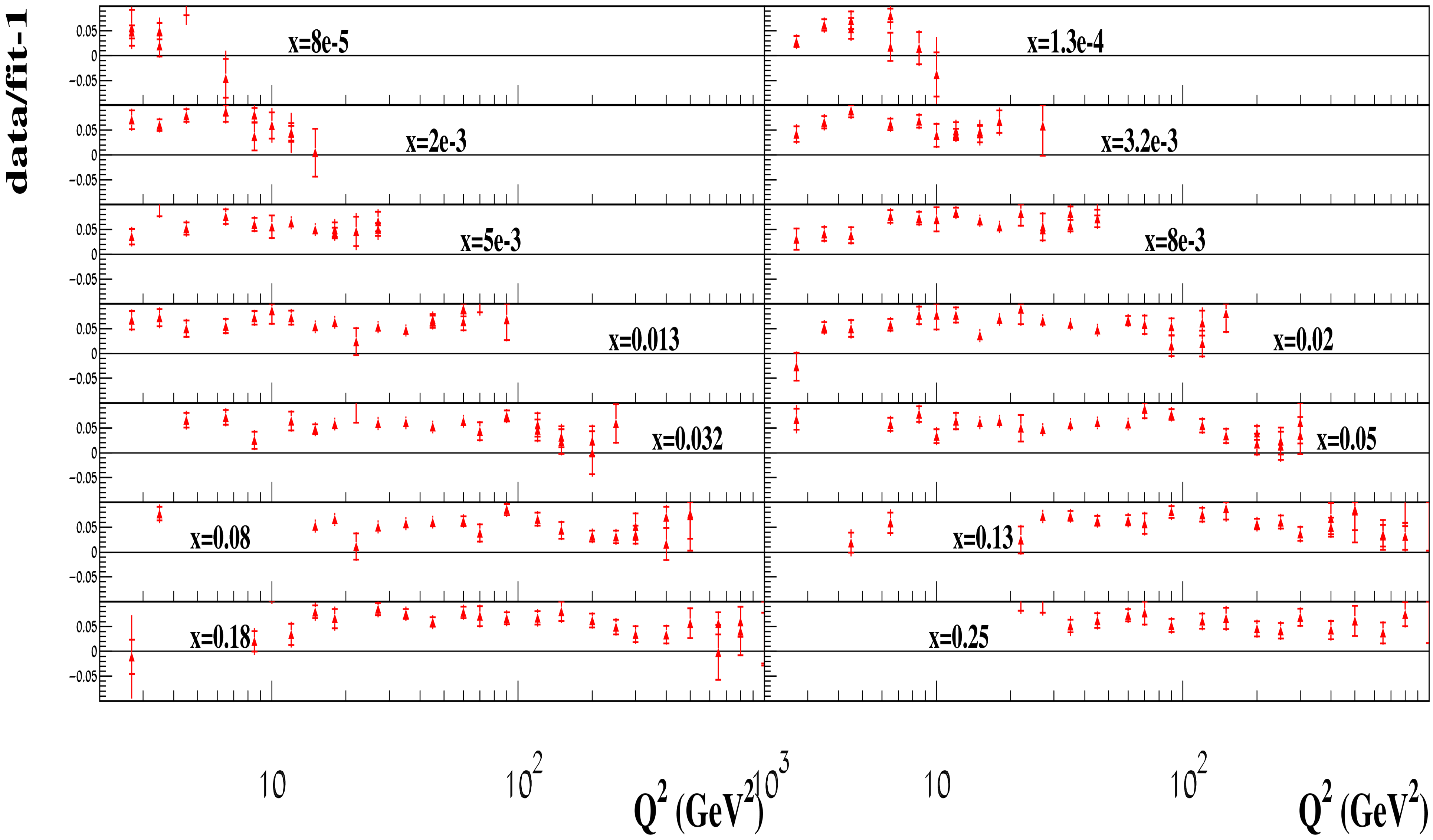


NNPDF21_FFN_NF3_100 with our code:
Discrepancy of 50% at x=0.02 → *in line with the difference in the strange sea*
Can be apparently localized in the codes

Comparison with HERA NC data in NLO



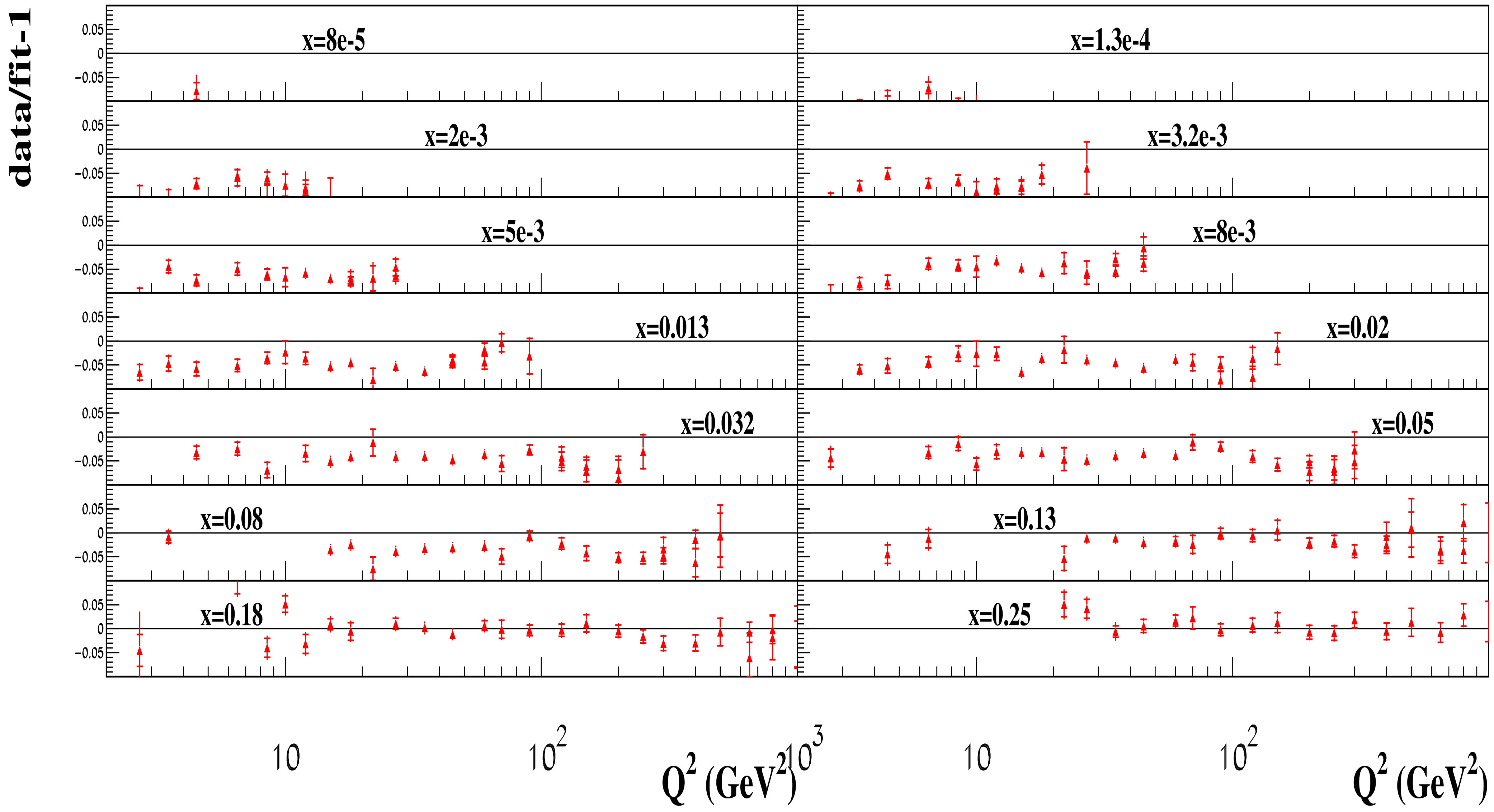
abm11_3_nlo
NLO coefficients
mc(mc)=1.27 (PDG 10), running mass definition



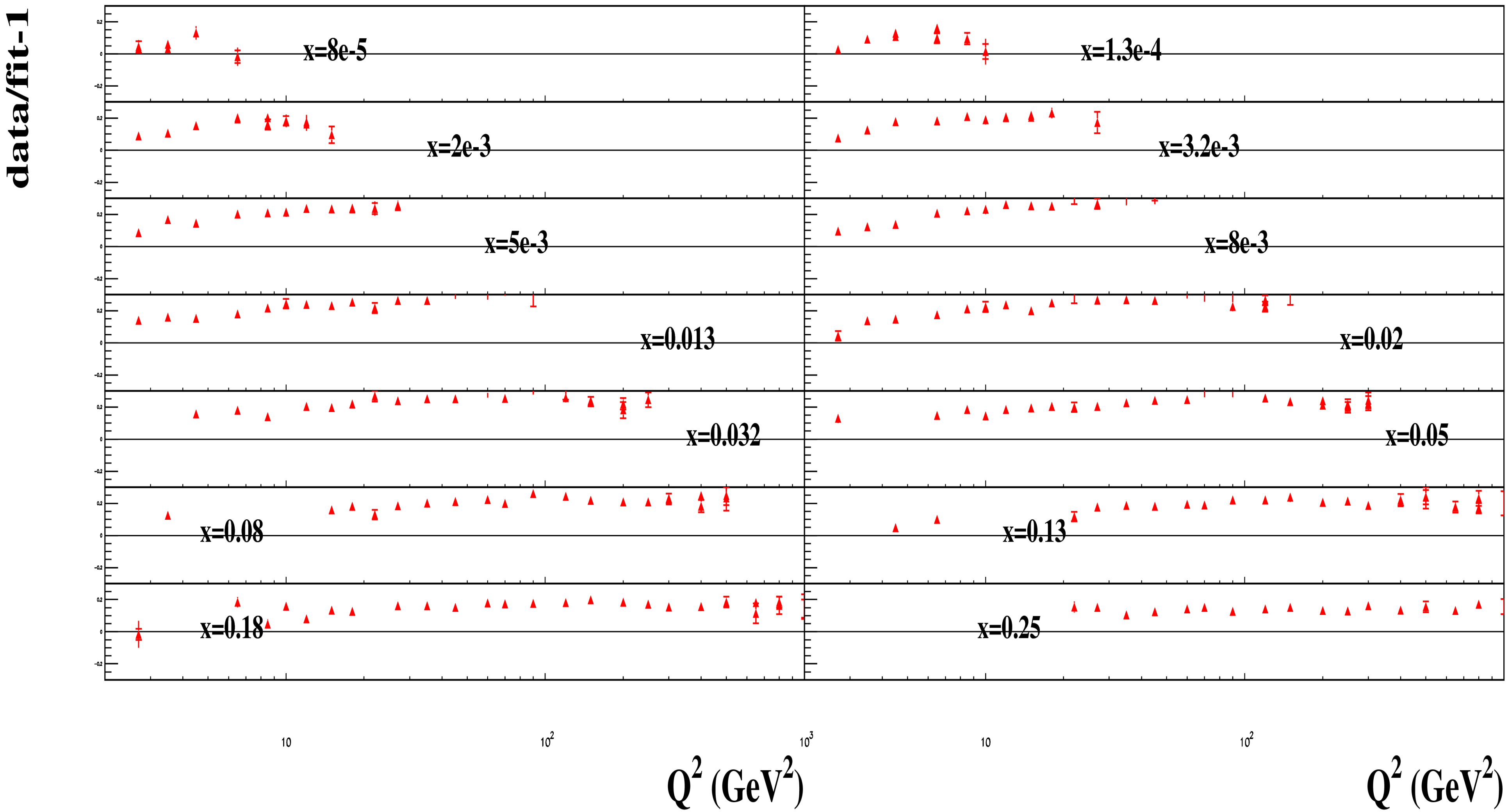
MSTW08nlo68cl_nf3 with our code: reasonable agreement

Data somewhat overshoot the predictions → may be improved when included into the fit

No trend of pulls with Q → *big logs do not manifest*



CT10f3 with our code: poor agreement
No match with FFNS → *wrong 3-flavor grid? massive OMEs implementation? .....?*
At large Q the discrepancy is smaller



NNPDF21_FFN_NF3_100 with our code: worst agreement
Data go above predictions at small Q → *no match with FFNS*
At large Q the discrepancy is as big as 50%

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
- Precise HERA data added → better determination of the low-x PDFs
- 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:

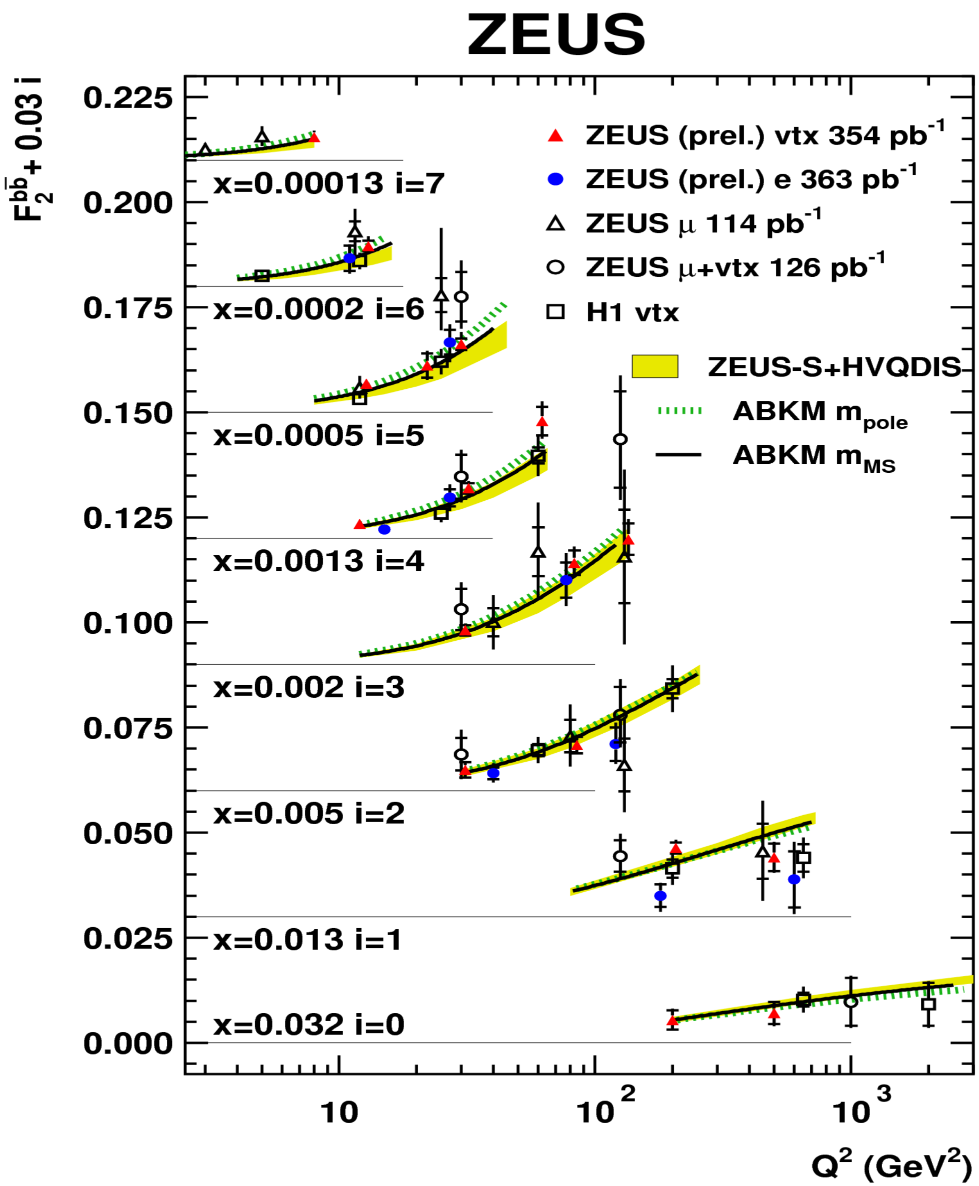
$$\alpha_s(M_z)=0.1135(14) \quad \rightarrow \quad 0.1134 - 0.1149 \qquad \text{(NNLO)}$$

  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
- The benchmark studies underway → *the first surprises observed*

Extras

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