ABM parton distributions

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

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

- Theory: Improved treatment of the heavy quark electro-production
- Experiment: New HERA data
- Tevatron and LHC jet data in the PDF fit
- PDF and α_s benchmarking
- Summary/outlook

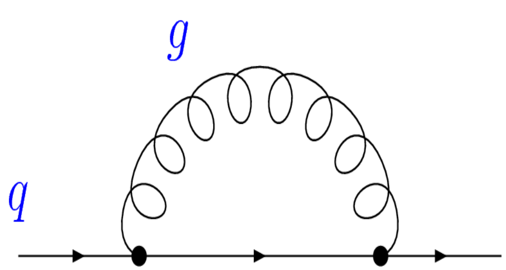
sa, Blümlein, Moch hep-ph/1202.2281

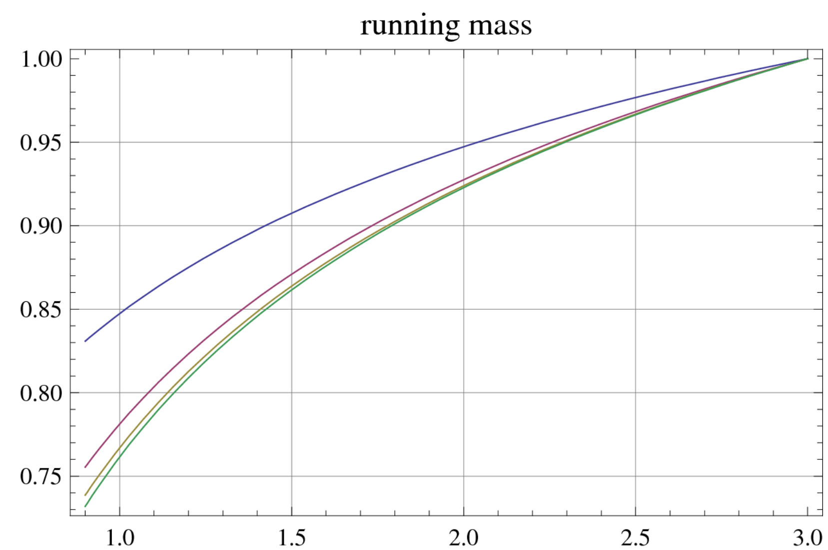
SFB workshop Karlsruhe, 19 Mar 2012

Mass definition

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 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

The corrections up to 4-loops are known

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

Chetyrkin PLB 404, 161 (1997)

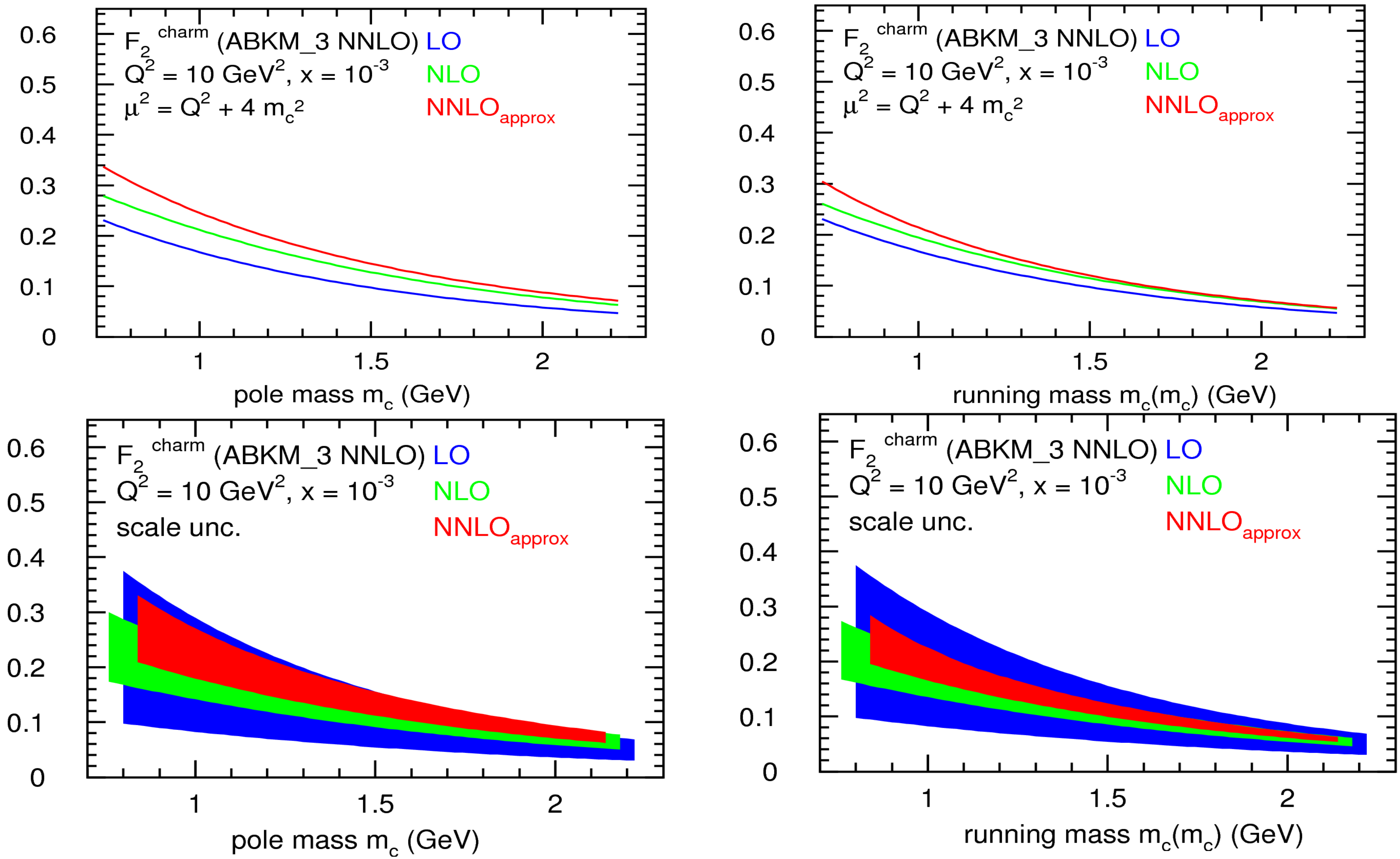
Vermaseren, Larin, van Ritbergen PLB 405, 327 (1997)

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)**

Running mass definition for the DIS SFs

Pole mass | Running mass



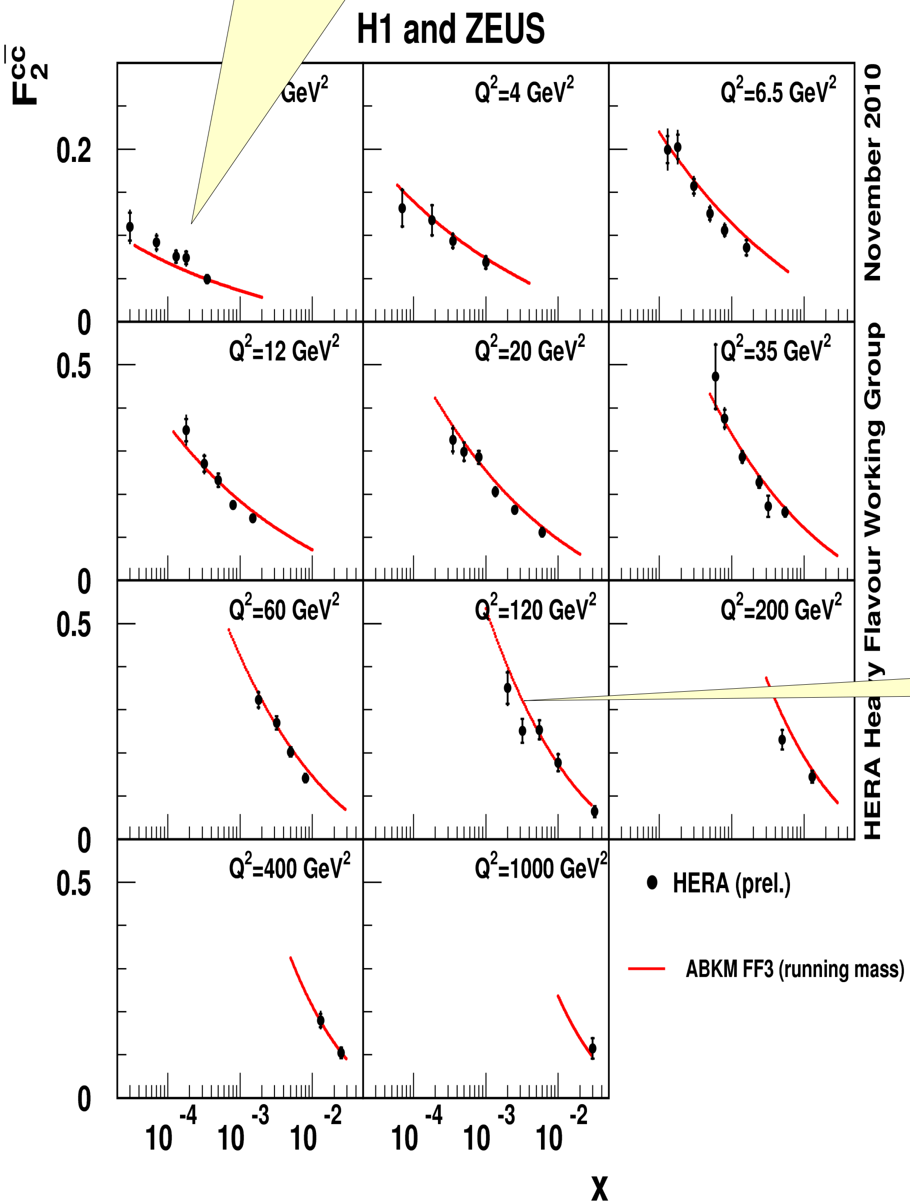
- The heavy-quark electroproductoin in the approximate NNLO (full NLO + NNLO threshold resummation)

Lo Presti, Kawamura, Moch, Vogt [hep-ph 1008.0951] **sa, Moch PLB 699, 345 (2011)**

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

Better agreement for c.s.



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

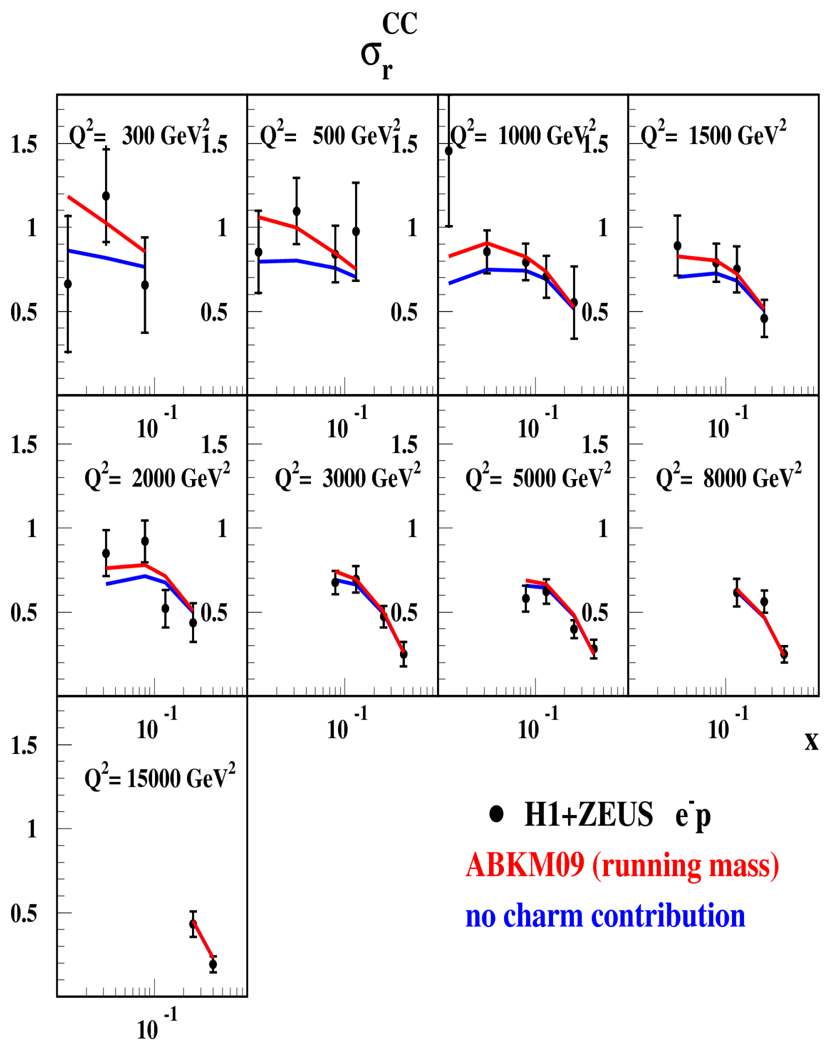
At Q >> m_c first Mellin NNLO moments are known

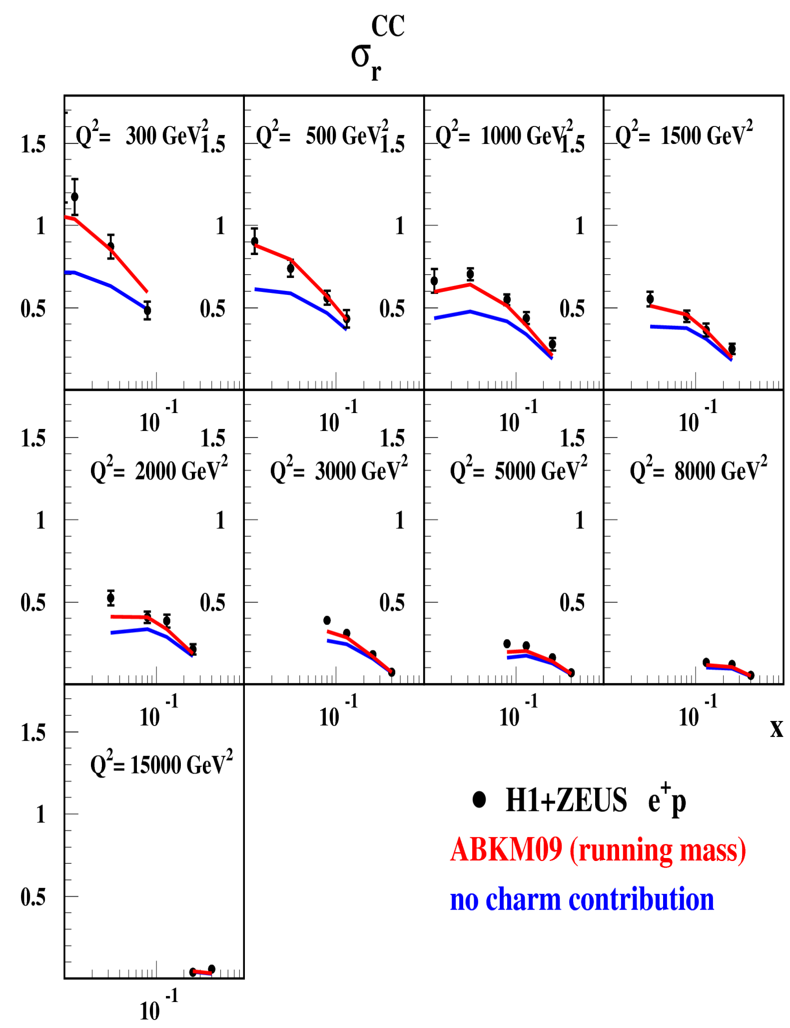
Ablinger at al. NPB 844, 26 (2011)

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

CC inclusive data

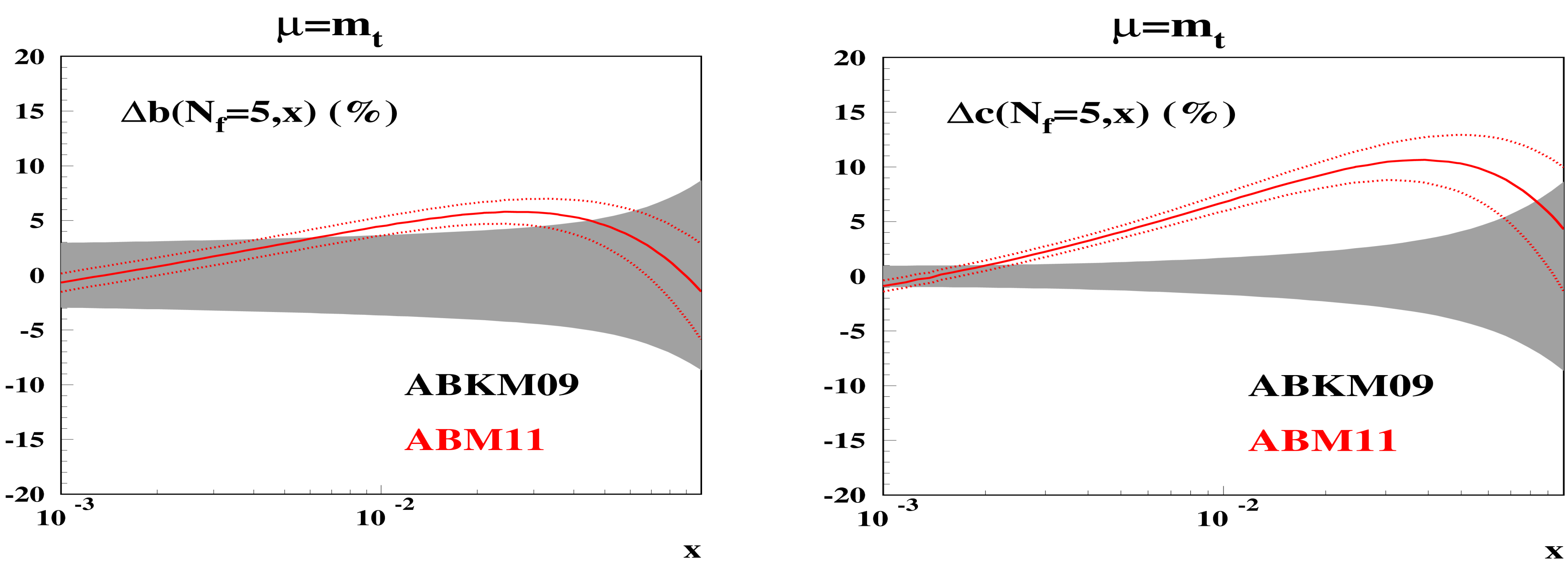
H1 and ZEUS Collaborations JHEP 1001, 109 (2010)





- 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.

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 → 4.19±0.13 GeV
  - m_c = 1.5 → 1.27±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.

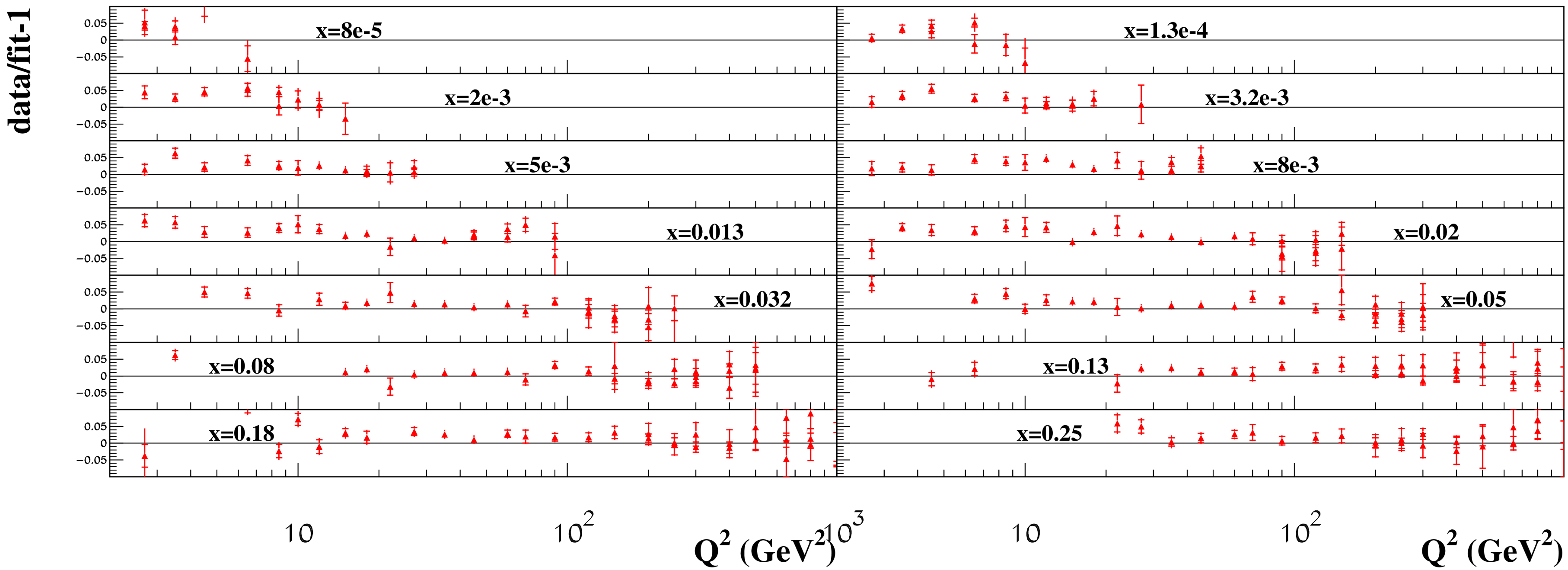
Data used in ABM11 fit

Experiment	NDP	NSE (corr.+ norm.)	χ^2
H1+ZEUS(NC+CC)	486	114	530
H1 (low-E)	130	9	132
BCDMS	605	10	695
SLAC-E-49a	118	3	63
SLAC-E-49b	299	3	356
SLAC-E-87	218	3	219
SLAC-E-89a	148	5	214
SLAC-E-89b	162	3	132
SLAC-E-139	17	3	11
SLAC-E-140	26	4	29
NMC	490	12	660
FNAL-E-605	119	2	166
FNAL-E-866	39	5	55
NuTeV	89	8	49
CCFR	89	1	61
Total	3036	190	3377

For the experiments without normalization calibration the normalization factors are fitted (details in Extras)

High-Q inclusive DIS data

H1 and ZEUS Collaborations JHEP 1001, 109 (2010)



- The PDF shape was modified to accommodate new data

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

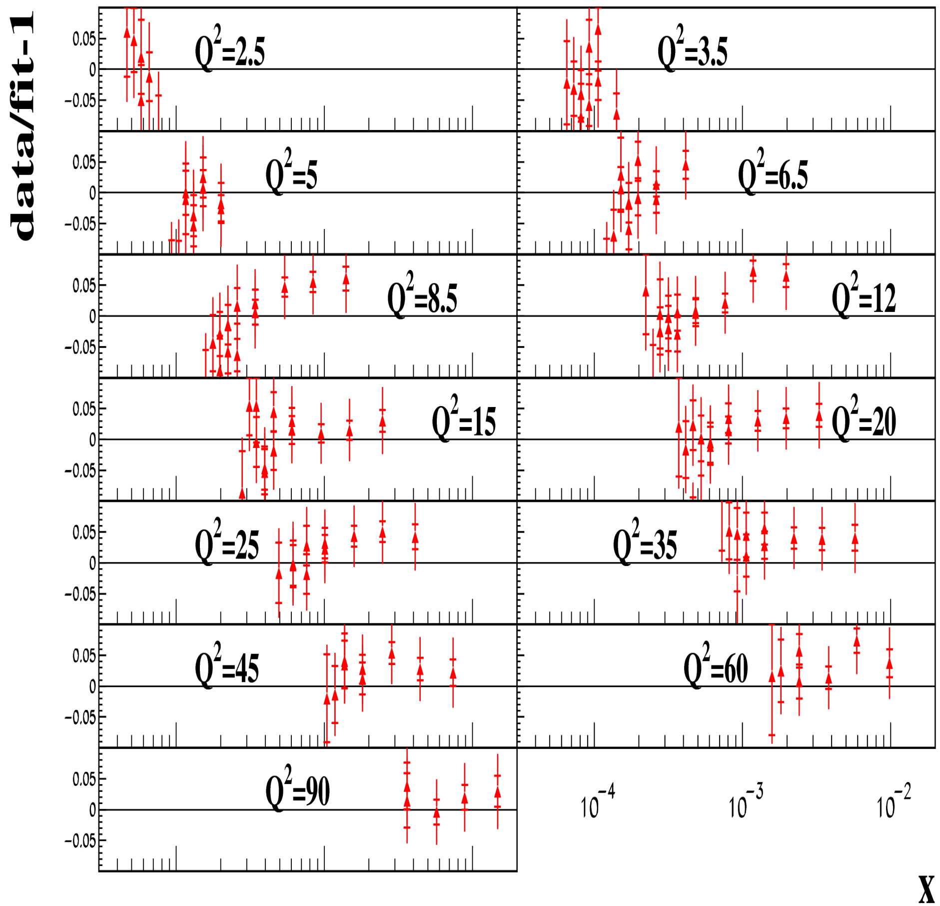
$$xu_V(x) = exp\left[a \ln x(1+\gamma_1 x+\gamma_2 x^2+\gamma_3 x^3)\right](1-x)^b$$

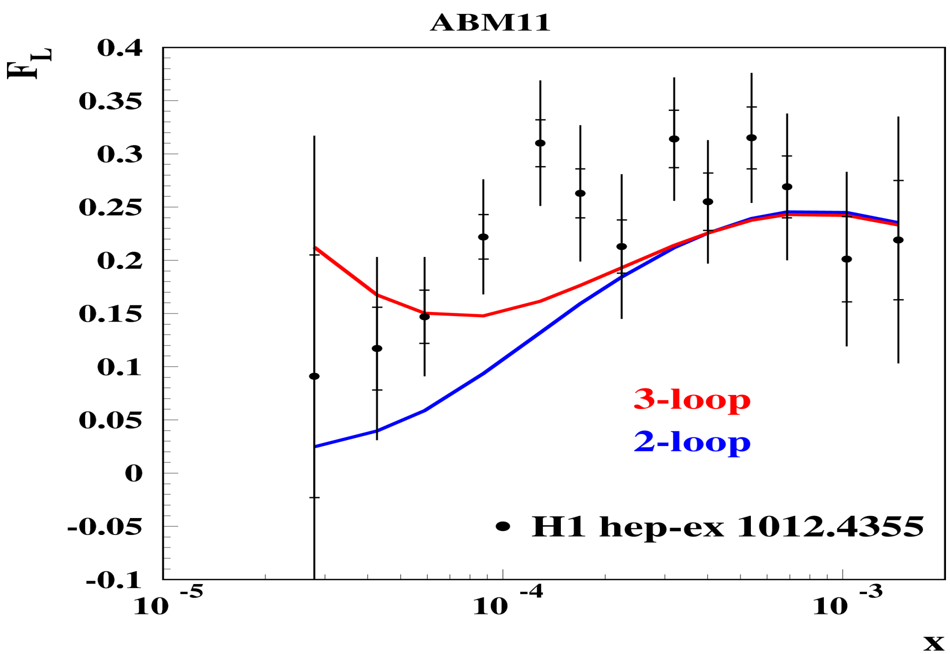
- χ^2/NDP=1.1, with account of the systematic error correlations (114 sources). Slightly worse for the small-Q part, the same observed in the model-independent fit

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

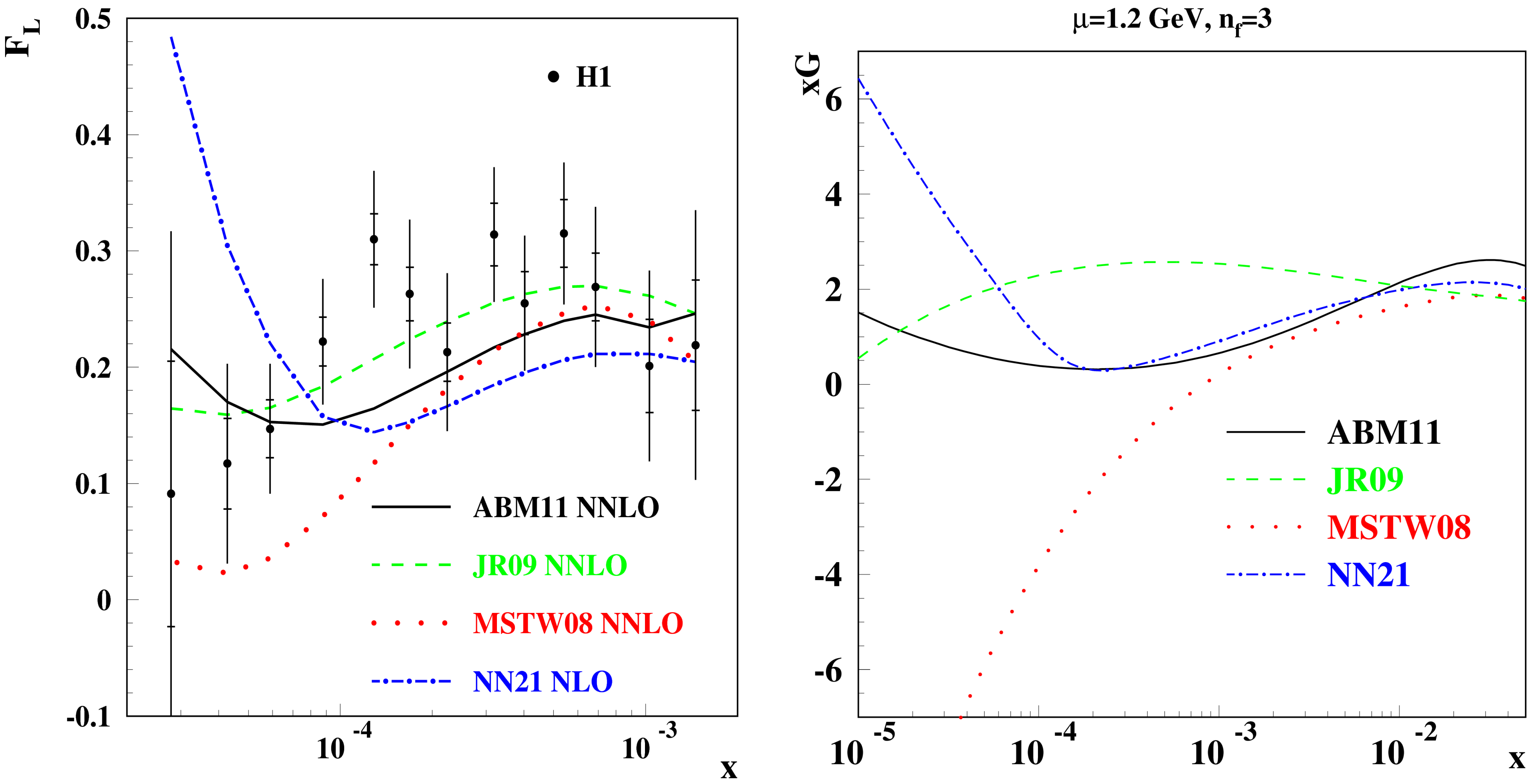
Moch, Vermaseren, Vogt PLB 606, 123 (2005)

- 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

Discrimination of the small-x gluons



Large-x gluons: jet data

- 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)

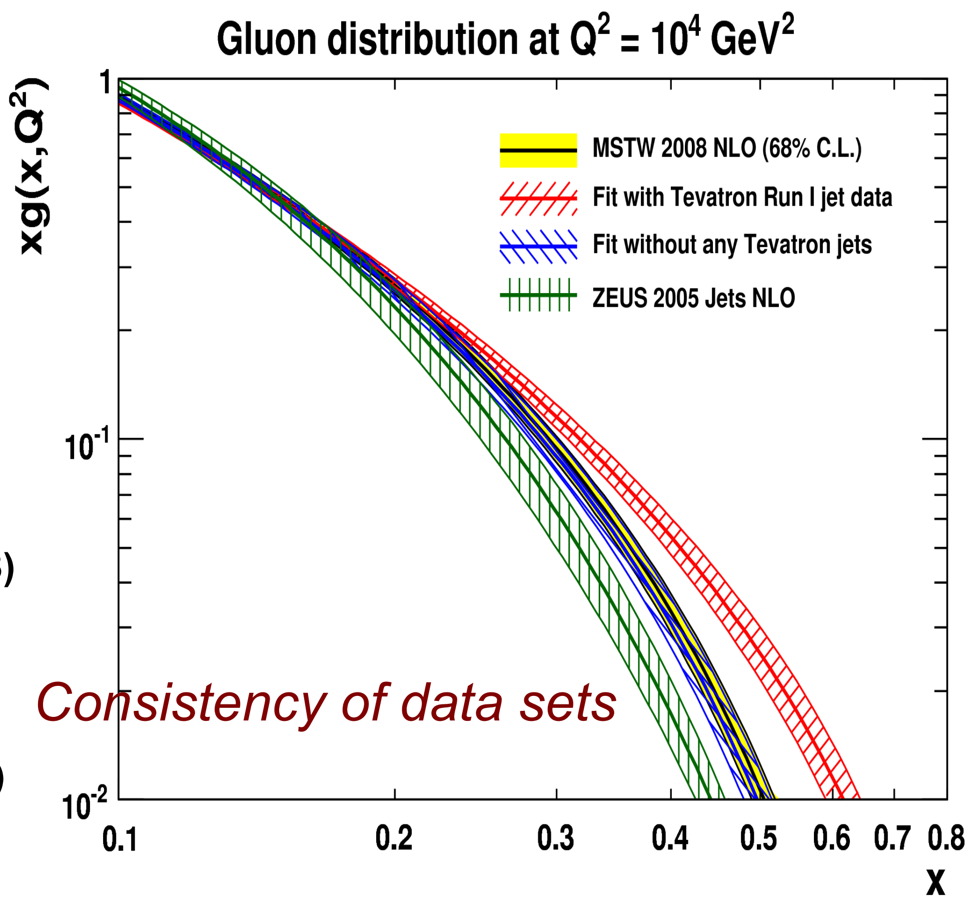
D0 midpoint di-jet (R=0.7)
PLB 693, 531 (2010)

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

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

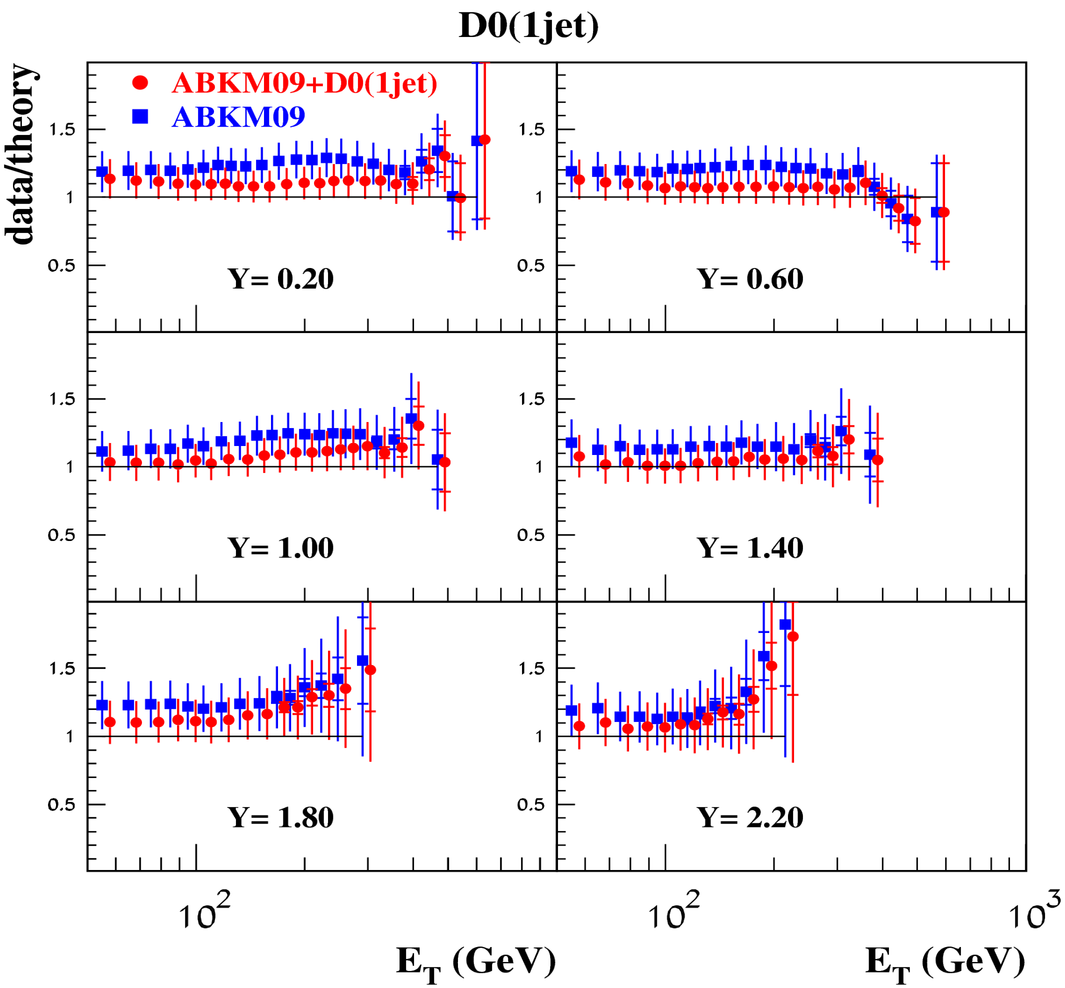
FastNLO is used to employ NLO corrections.

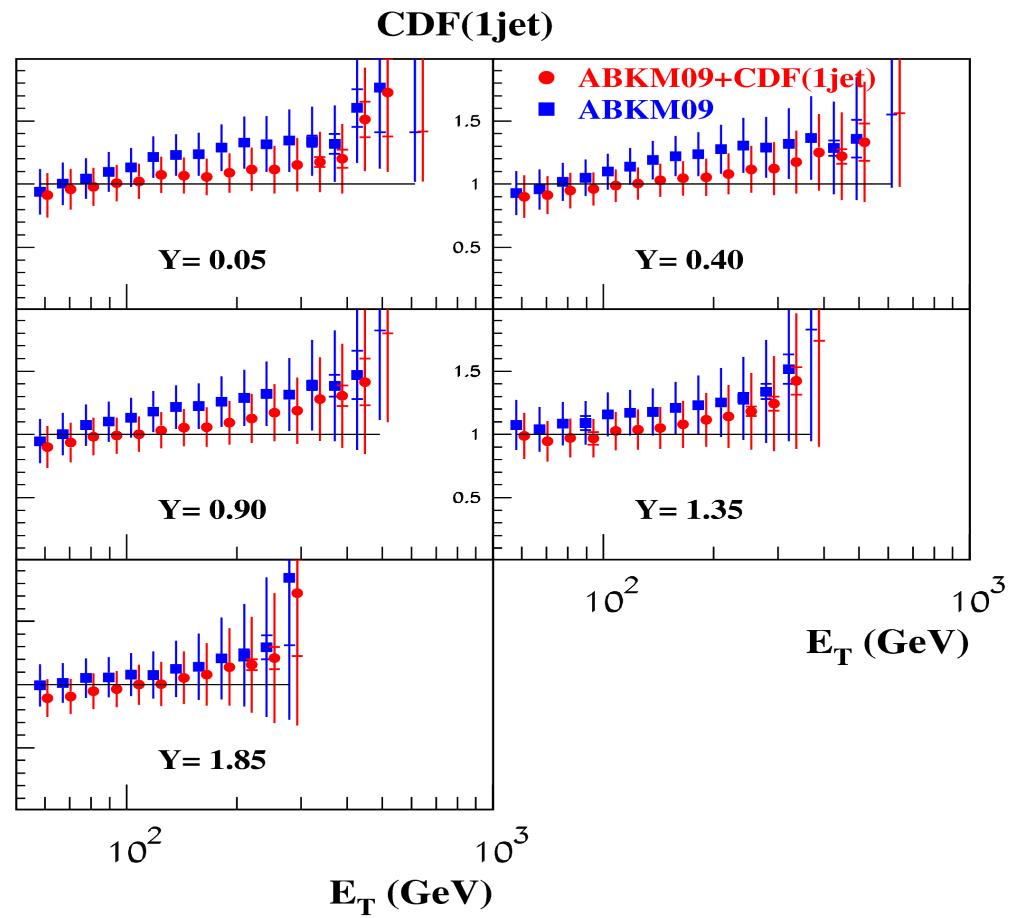
Kluge, Rabbertz, Wobisch [hep-ph 0609285]



MSTW Collaboration EPJC 63, 189 (2009)

Inclusive Tevatron jets

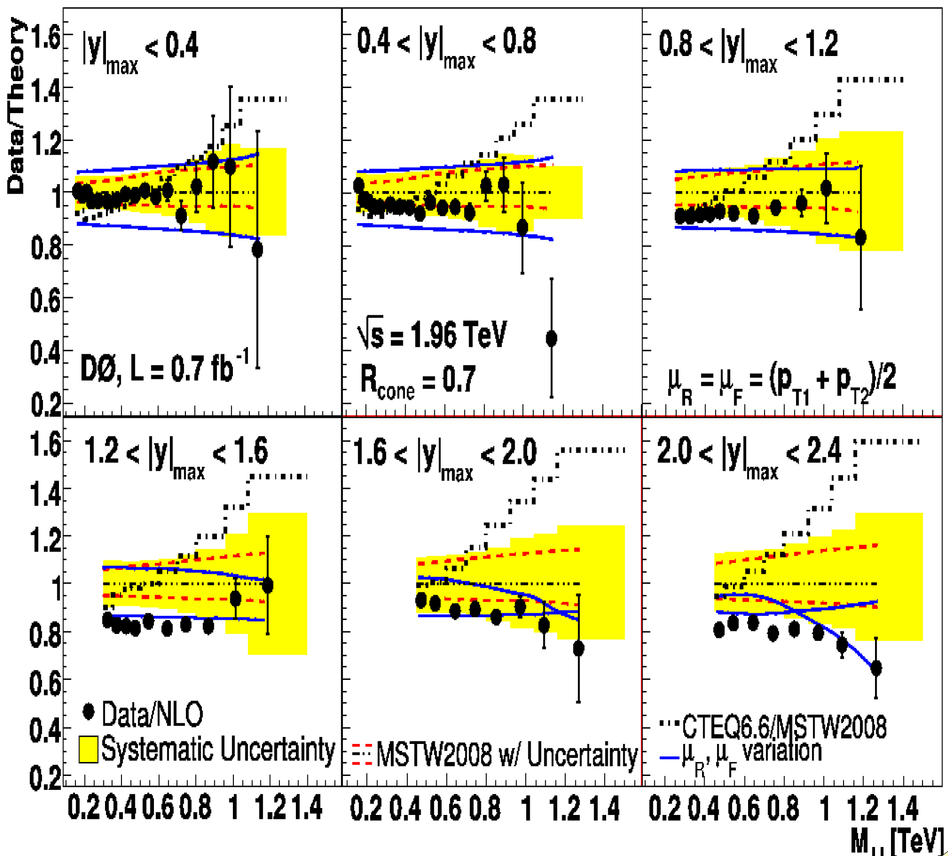




	$\alpha_s(M_Z)$(NNLO)	$\sigma(M_H$=165 GeV) (pb) Tevatron	LHC7
ABKM09	0.1135(14)	0.253(22)	7.05(23)
+ D0(1jet):	0.1149(12)	0.297(12)	7.30(15)
+ D0(2jet):	0.1145(9)	0.281(12)	7.28(14)
+ CDF/k_T	0.1143(9)	0.292(10)	7.18(14)
+ CDF/cone	0.1134(9)	0.283(10)	7.02(14)

Dijet and three-jet c.s.

“Truly global” PDFs tuned to jet data



D0 Collaboration PLB 693, 531 (2010)

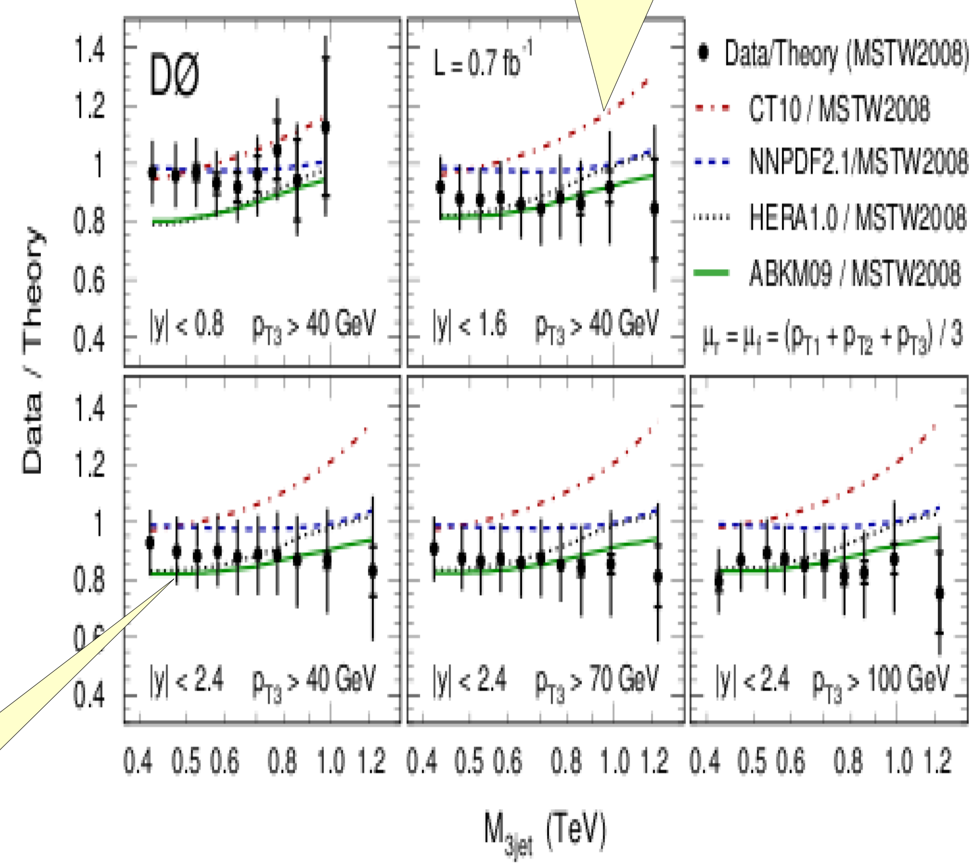
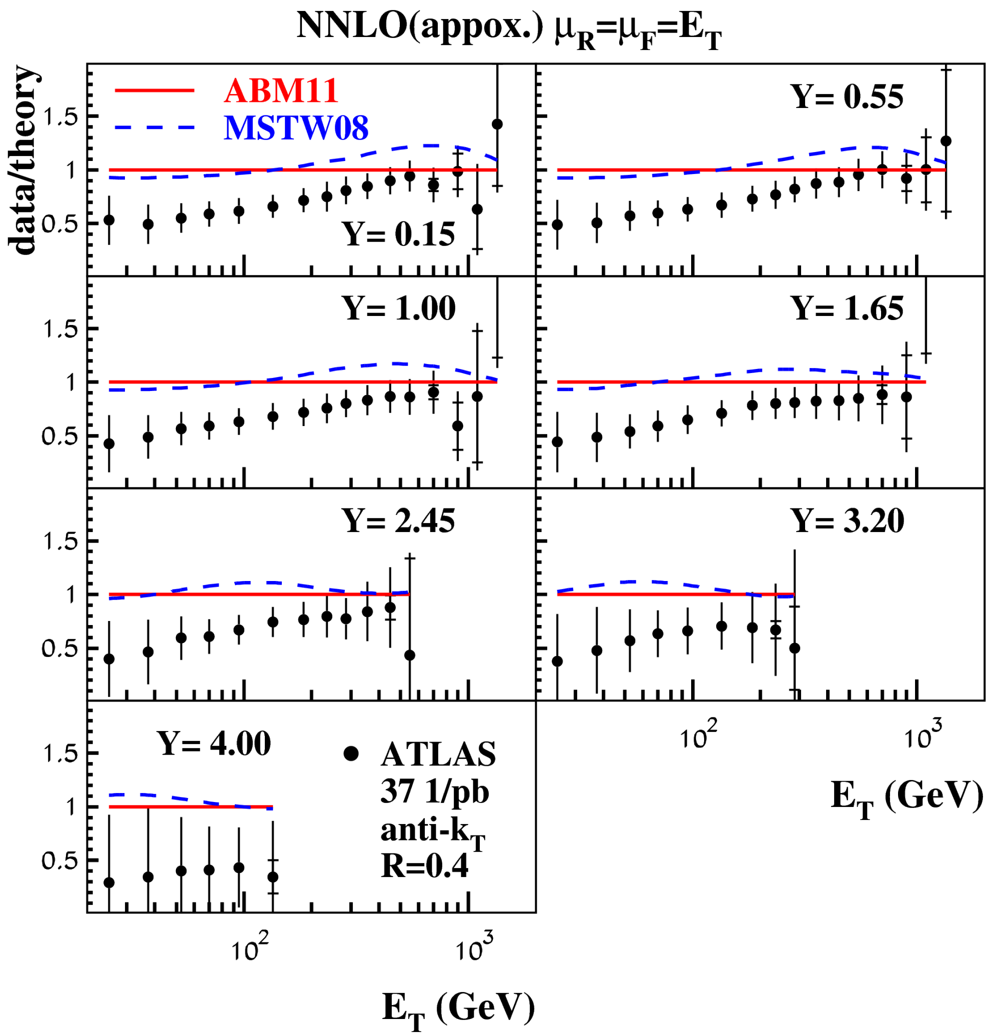


Figure 2: The 3-jet mass differential cross section in the three jet rapidity intervals are compared to NLO pQCD with different PDF sets.

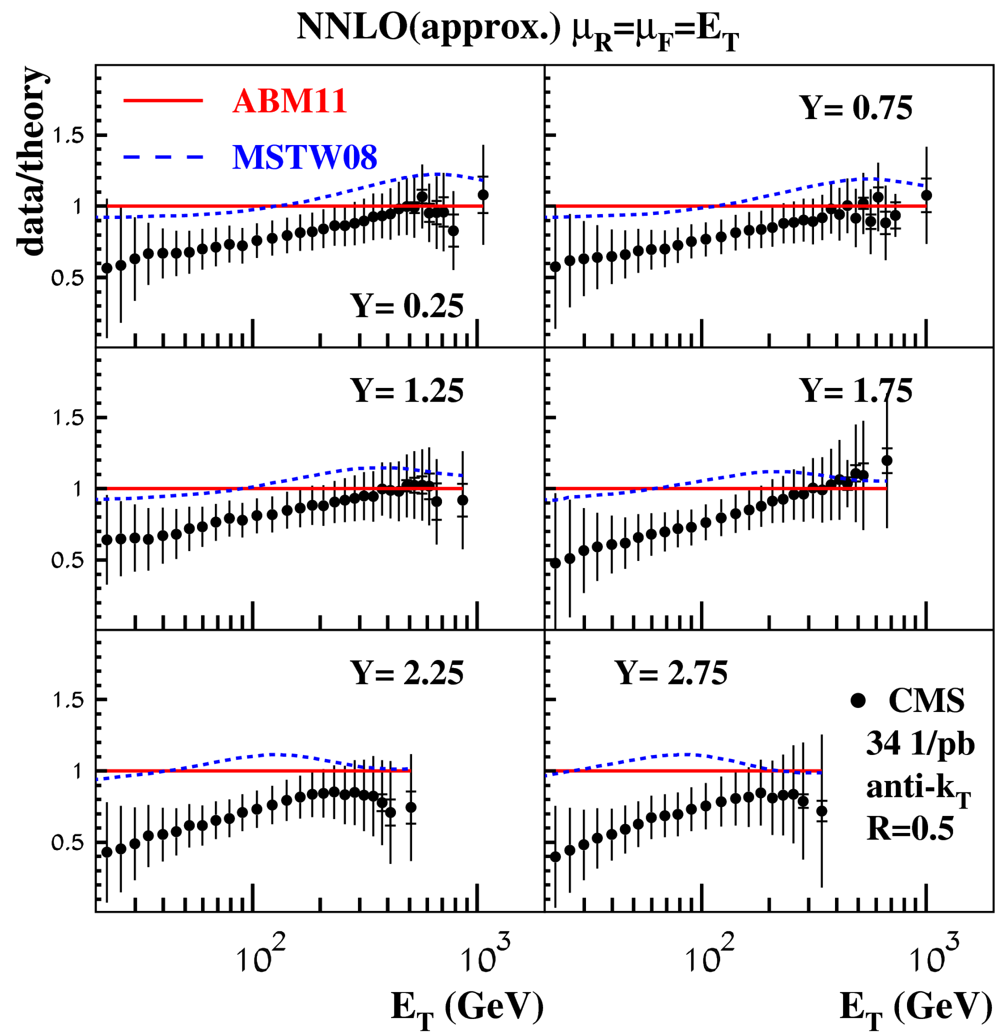
No jet data in the fit

The “truly global” PDFs provide worse agreement with the data?

Inclusive LHC jets



ATLAS collaboration [hep-ex/1112.6297]

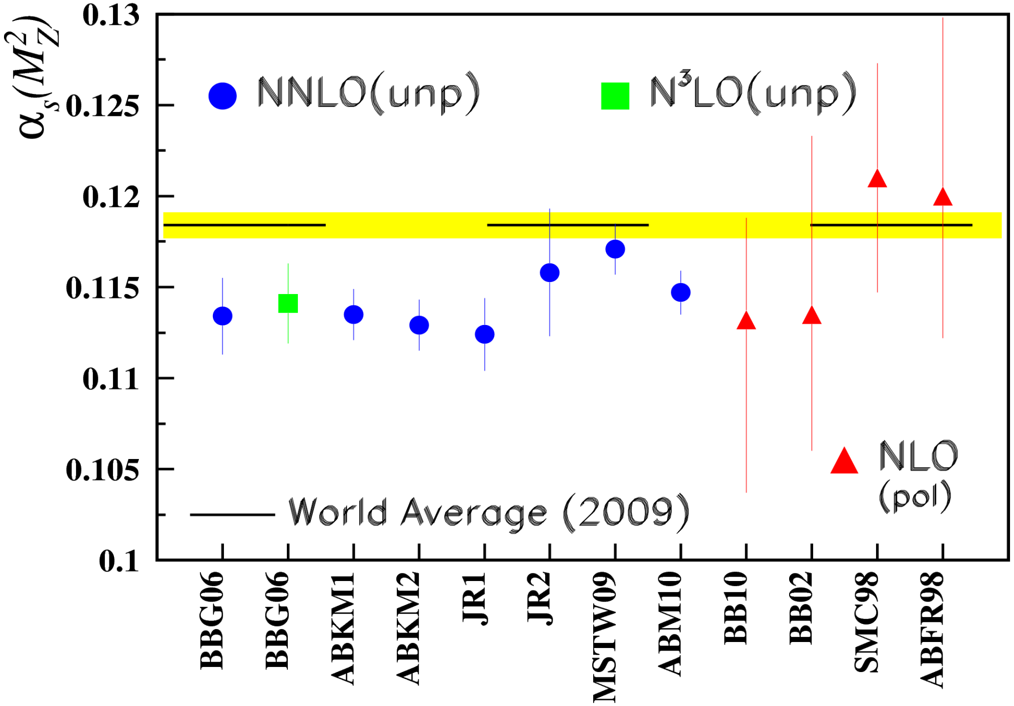


CMS collaboration PRL 107, 132001 (2011)

Britzger, Kluge, Rabbertz, Stober, Wobisch [hep-ph/1109.1310]]

The ATLAS and CMS data are in good agreement, both prefer smaller large-x gluons than the Tevatron experiments

PDFs and α_s



Blümlein, Böttcher NPB 841, 205 (2010)

- Many important hadronic processes i.e. Higgs and top-quark production are ~α_s^2.
- The gluon distribution is correlated with α_s → effect is accumulated.
- The value of α_s from DIS *(mostly defined by the non-singlet part)* is about 3σ lower than the world average of 2009.

Bethke EPJC 64, 689 (2009)

From the Tevatron jet data

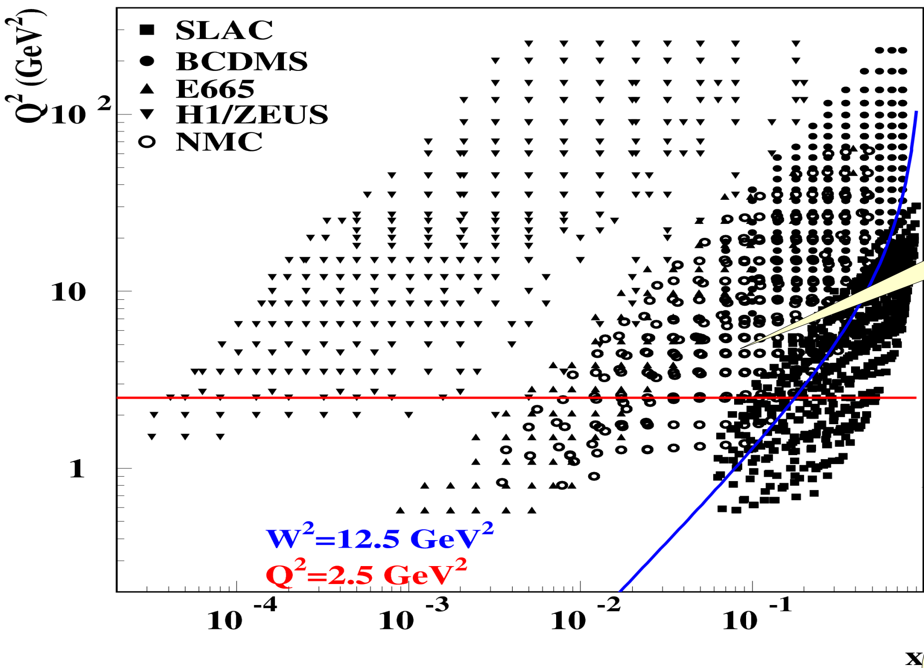
$\alpha_s(M_z)$=0.1161±0.0045 (NLO)

D0 Collaboration [hep-ex 1006.2855]

	$\alpha_s(M_z)$ at NNLO	Target mass corr.	High-twists	Error correl.
ABM	0.1134±0.0011	+	+	+
NNNPDF(DIS)	0.1166±0.0008	+	-	+
MSTW08	0.1171±0.0014	-	-	-

The differences are mainly due to treatment of the DIS data, the jet data pull MSTW value down

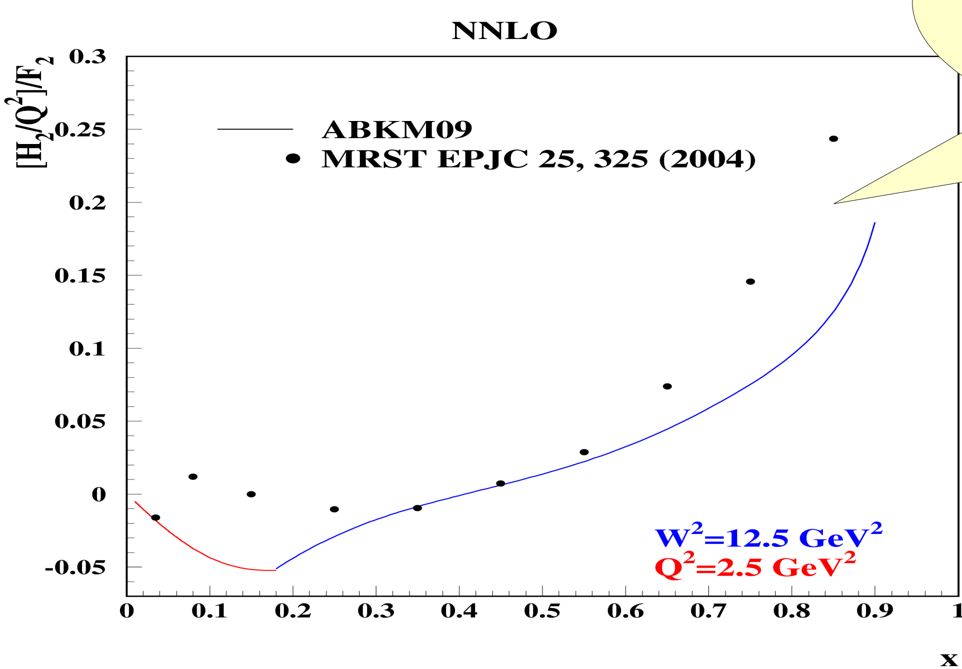
High-twist terms in DIS



Is not removed with the "safe" cut on W

At small Q and /or W the high-twist (HT) terms give substantial contribution. One can try to get rid of them with a "safe" cut on W:

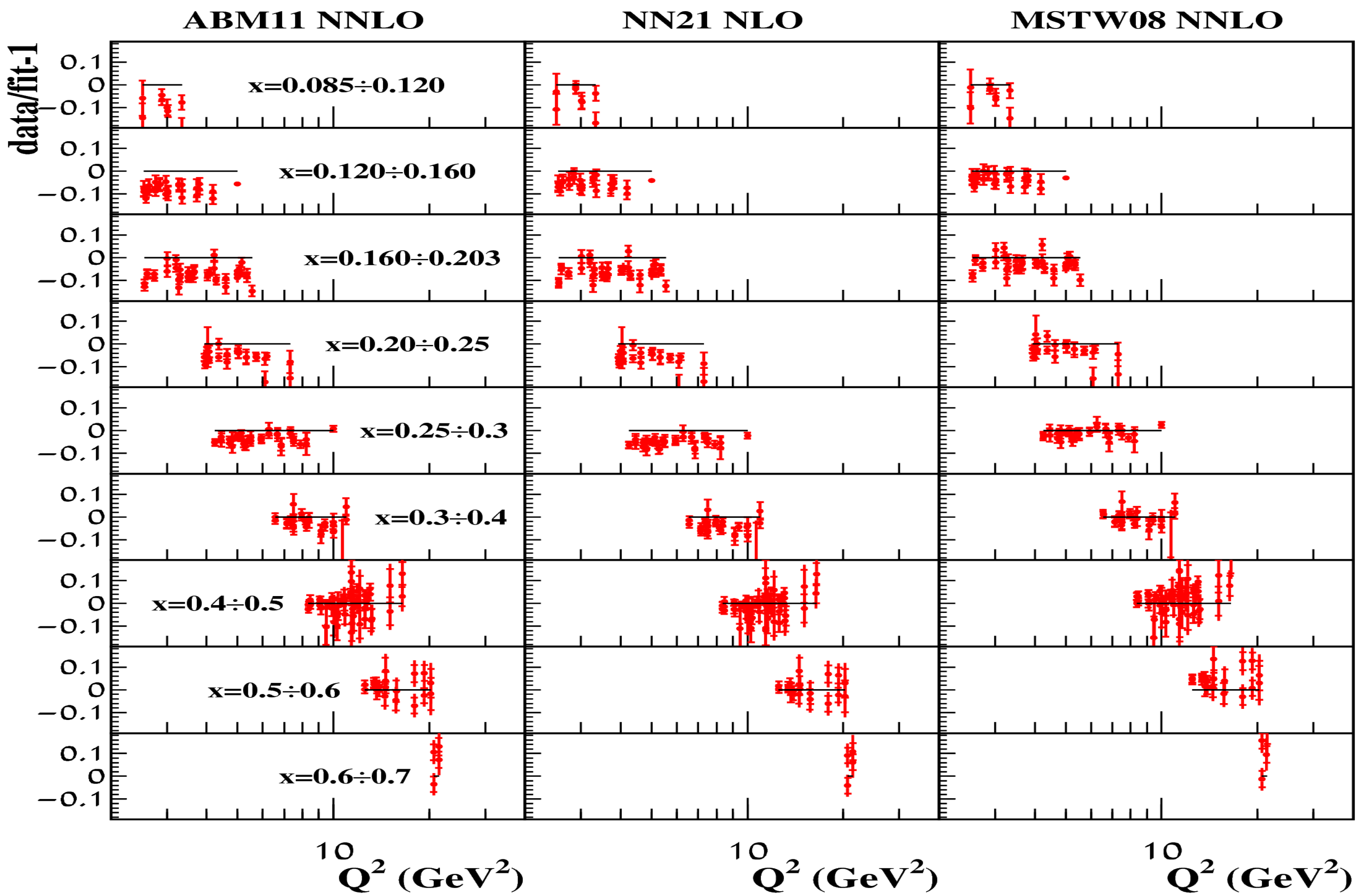
The selection of W_{cut} is unclear due to fluctuations
In the data → the HT terms are essential at the border of kinematics left after the cut



In the ABKM fit the twist-4 terms are fitted simultaneosly with the leading-twist PDFs → consistent separation:

$$F_{2T} = F_{2T}\,(LT) + H_{2T}\,(x)/Q^2$$

Comparison to SLAC data w.o. HT terms and $W^2>12.5$ GeV^2



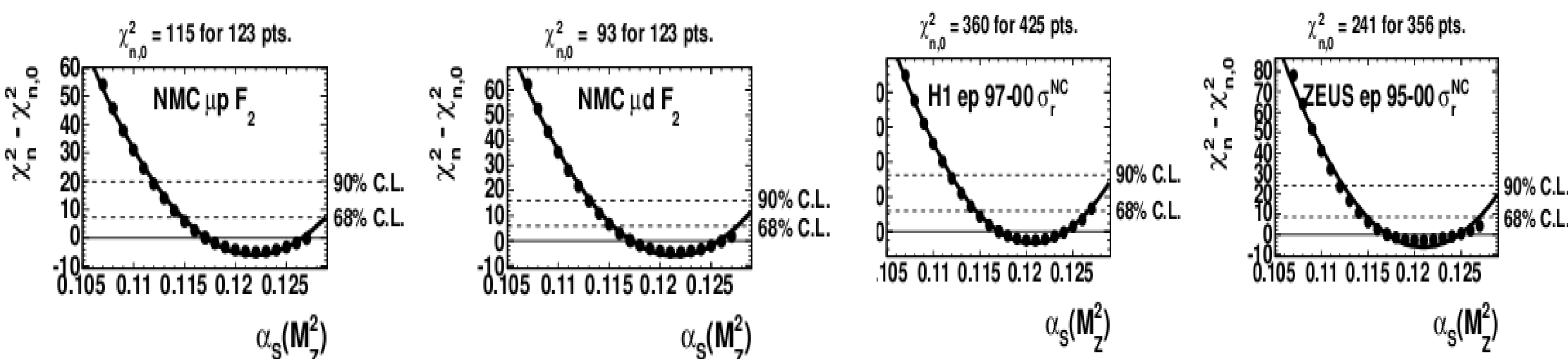
Consistent comparison: 3-flavor PDFs and 3-flavor coefficients

- The high-twist terms are essential for the SLAC data even with the “safe” cut on W
- The same for the NMC data

sa, Blümlein, Moch EPJC71, 1723 (2011)

Benchmark of α_s in NNLO

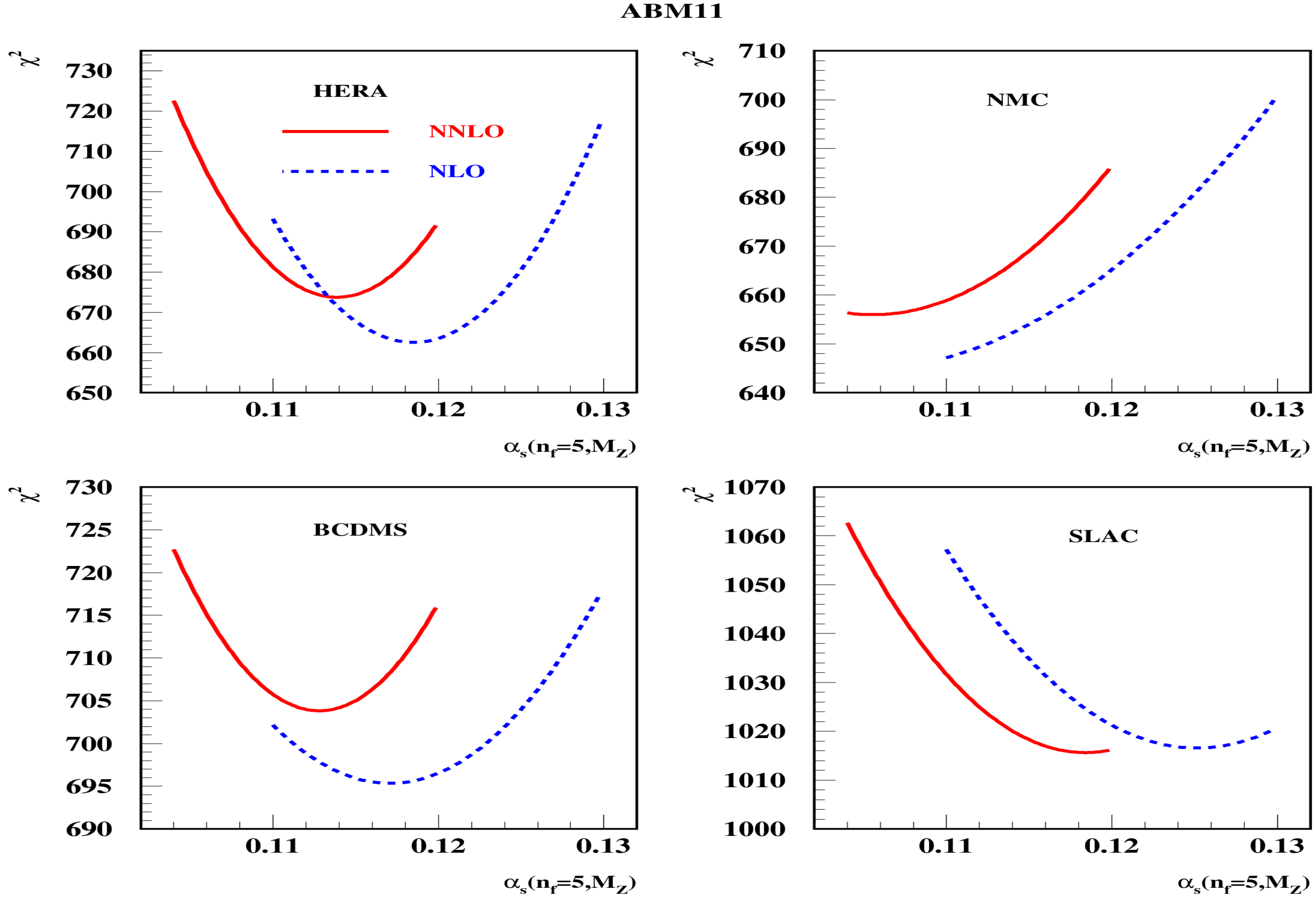
	Combined HERA data		H1/ZEUS separate data	
Variant of our ansatz	ABM11	NNPDF(DIS)	ABKM09	MSTW08
Nominal	0.1134(11)		0.1135(14)	
No HT, $W^2>12.5$ GeV^2	0.1191(6)	0.1166(8)		
No correlation in NMC and HERA data errors			0.1164(14)	
+No HT, $W^2>20$ GeV^2 $Q^2>10$ GeV^2				0.1171



MSTW Collaboration EPJC 64, 653 (2009)

We approach NNPDF and MSTW with the modified ansatz, more cross-checks are desirable from other side

Another way to get rid of HT terms



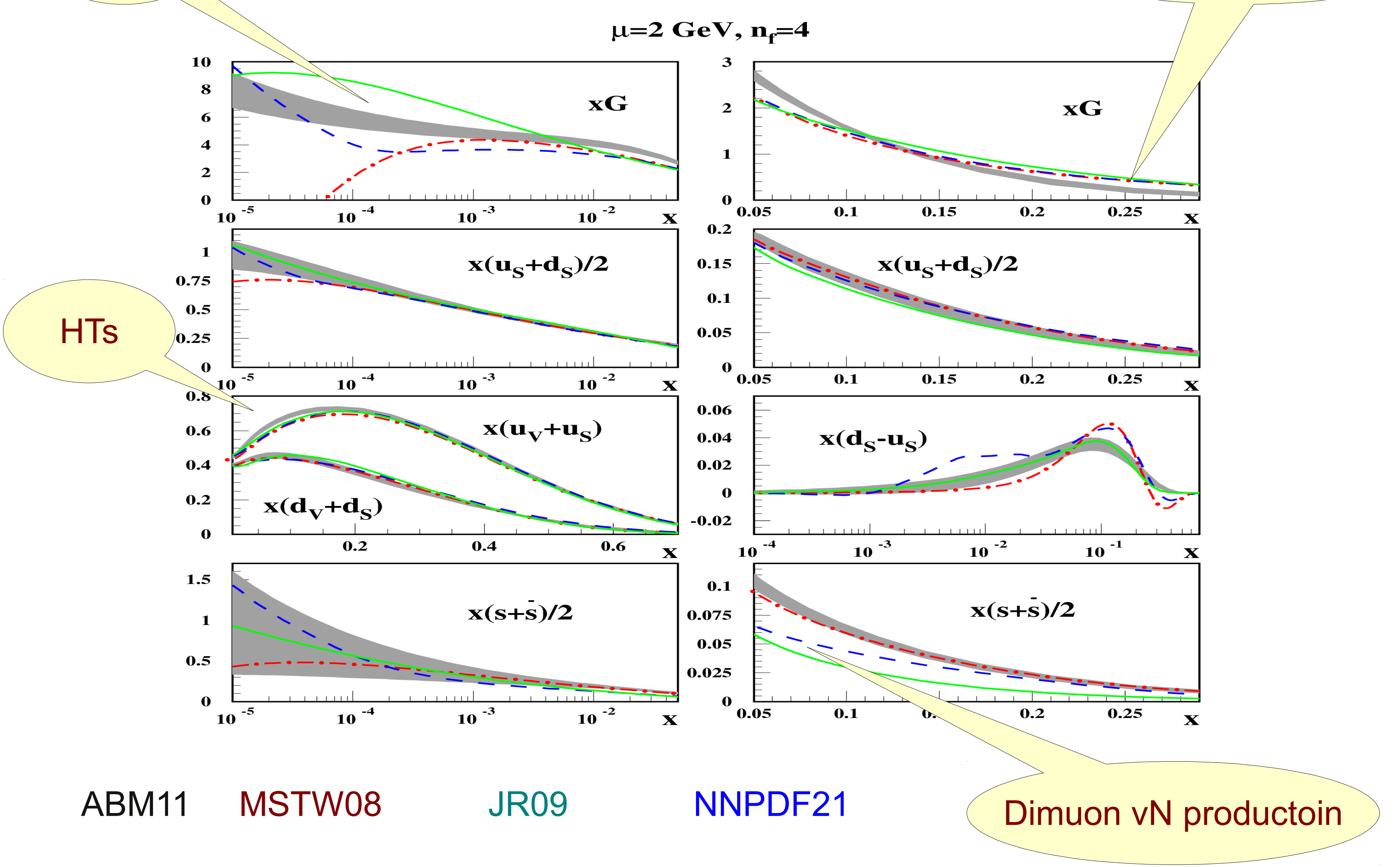
The HERA and BCDMS data are insensitive to the HT contribution and are quite Complementary in the α_s fit

H1 Collaboration EPJC21, 33 (2001)]

With the NMC and SLAC dropped $\alpha_s(M_z)$=0.1133±0.0011 (NNLO)

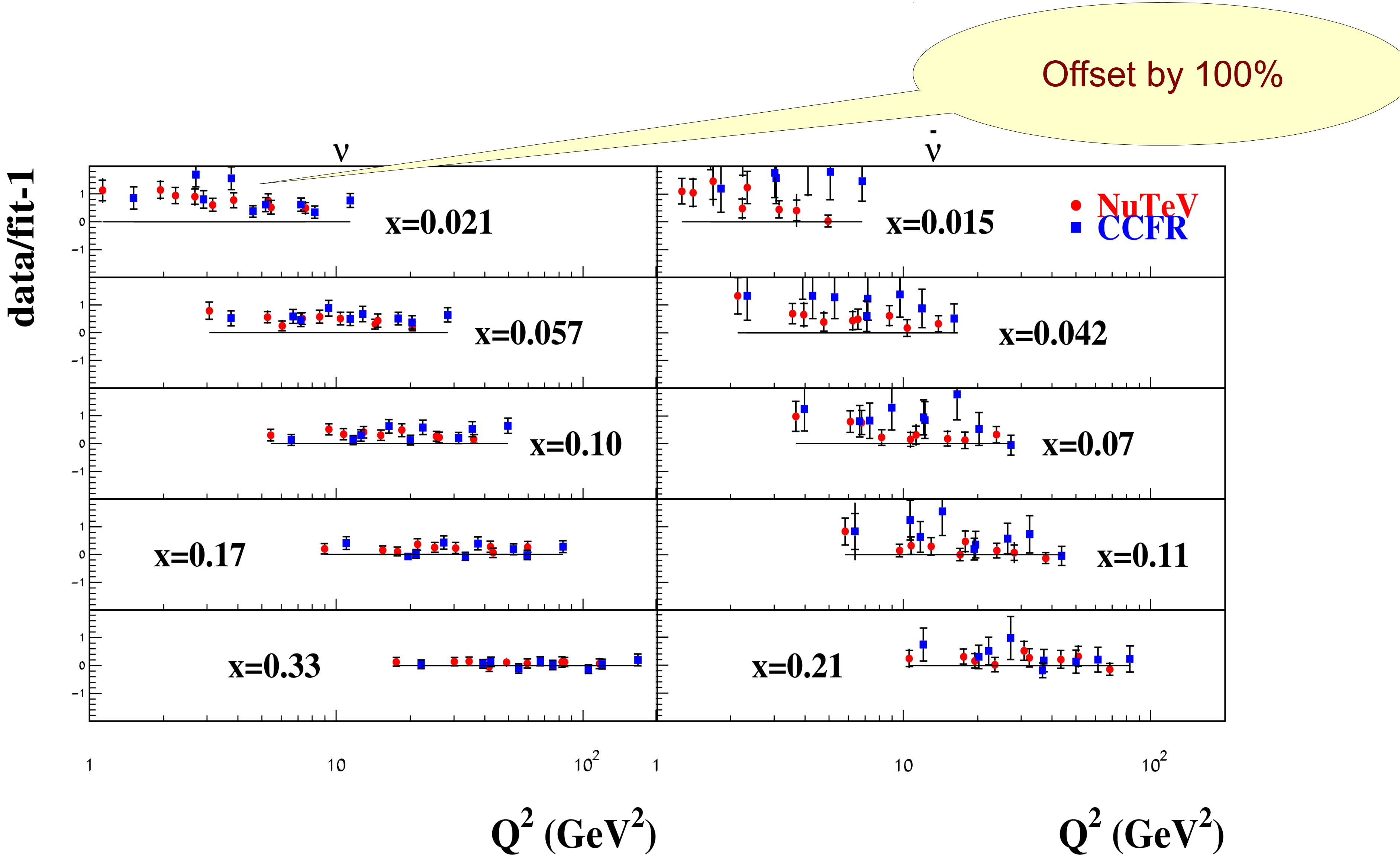
0.1184±0.0011 (NLO)

NNLO PDFs comparison



The differences are quite big in places and only benchmark w.r.t. the data can reconcile

Dimuon data in the NNPDF fit

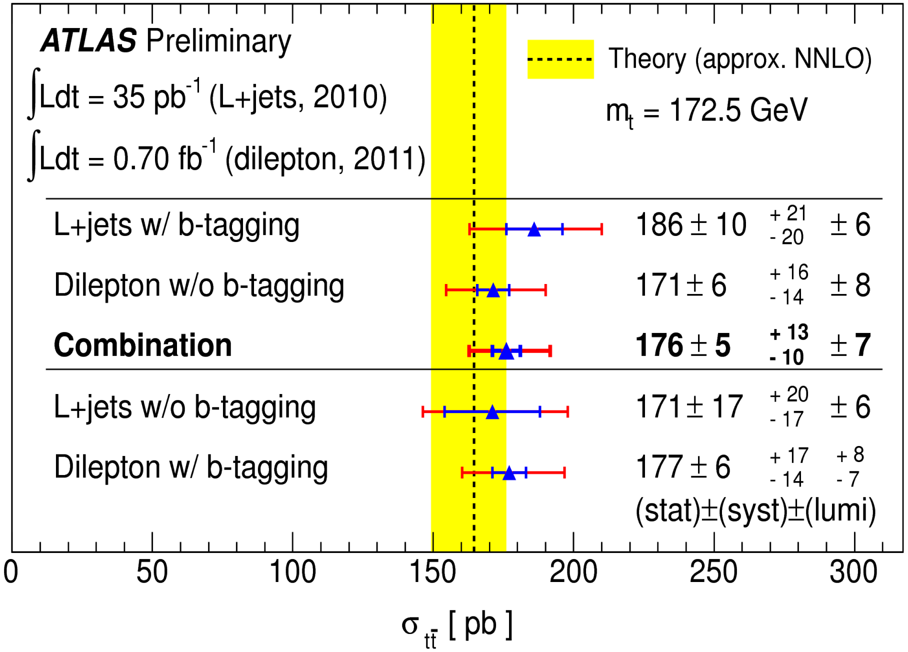


NNPDF21_FFN_NF3_100 with our code: www-zeuthen.desy.de/~alekhin/OPENQCDRAD

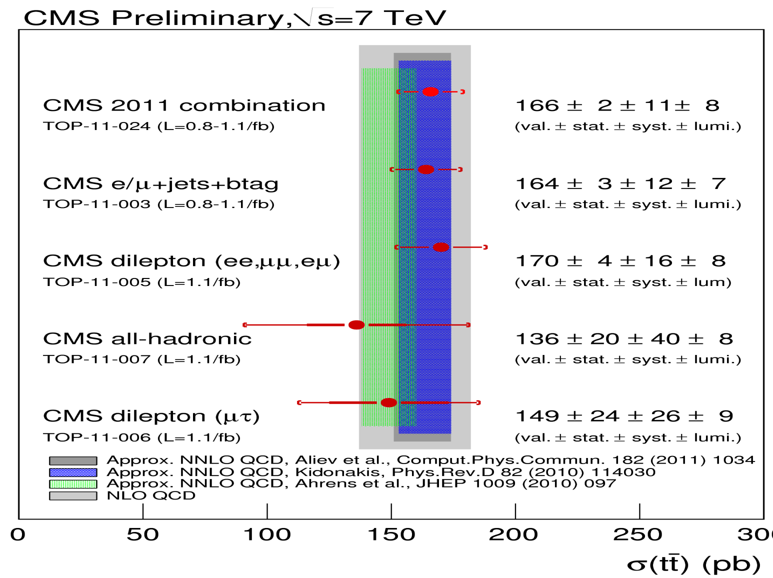
Discrepancy of 100% at x=0.02 → *in line with the difference in the strange sea*

Appears due to wrong factor of $(1+m_c^2/Q^2)$ in the NNPDF cross section formula

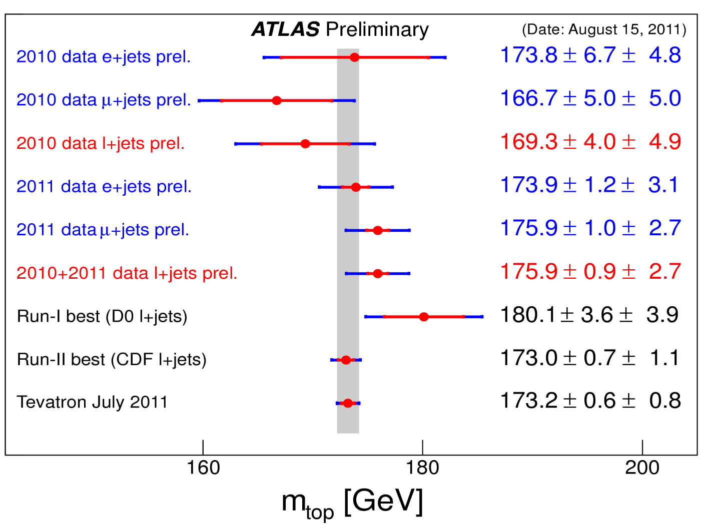
Top-quark production



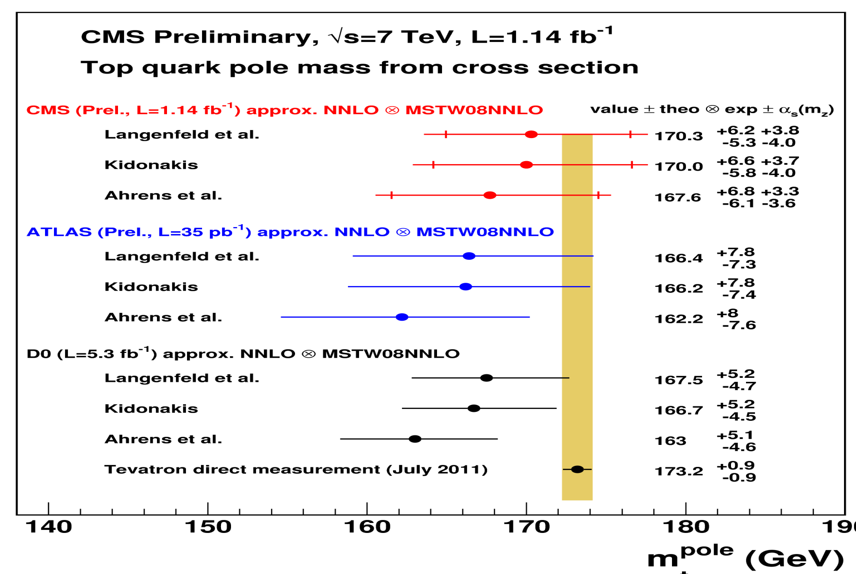
ATLAS collaboration ATLAS-CONF-2011-108



CMS collaboration TOP-11-024



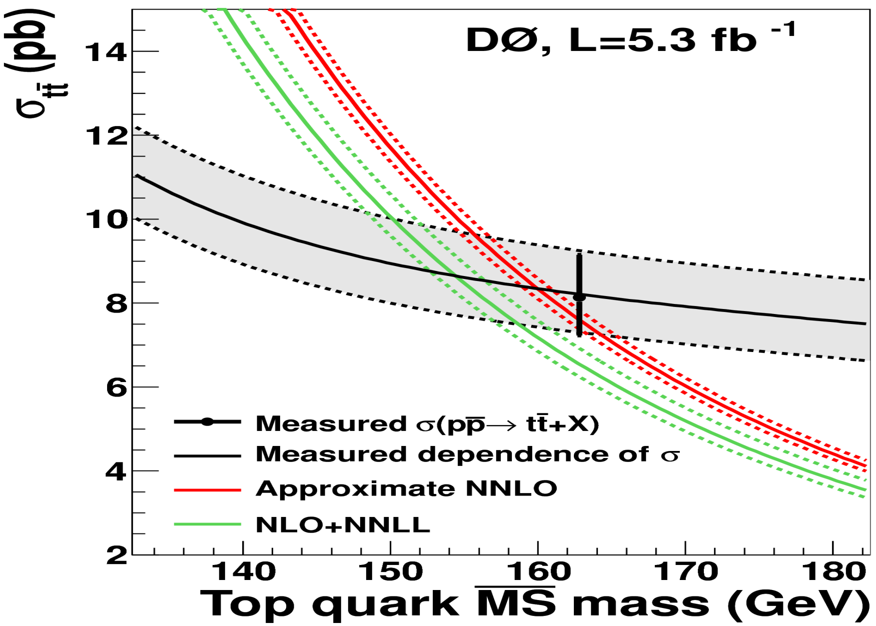
ATLAS collaboration ATLAS-CONF-2011-120

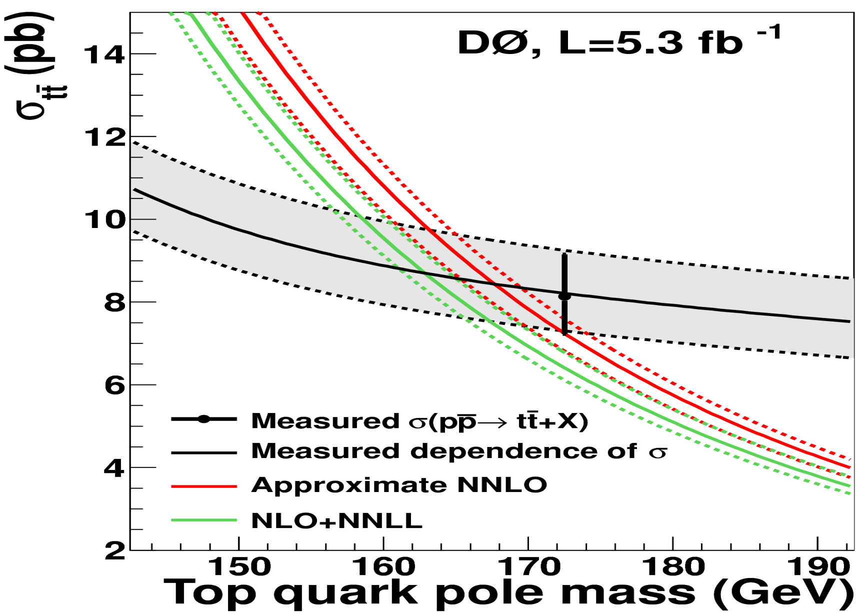


CMS collaboration TOP-11-008

The theory predictions are quite sensitive to the top mass

Tuning top-quark mass with the Tevatron c.s. data





D0 Collaboration PLB 703, 422 (2011)

σ_{tt} = 7.56 + 0.63 -0.56 (pb) D0 **PLB 704, 403 (2011)**

7.46 +0.66, -0.80 (pb) CDF **hep-ex/1010.1202**

	mt(MSbar) (GeV)	mt(pole) (GeV)	σ_{tt}(LHC@7) (pb)	σ_{tt}(LHC@7)/mt(MSbar)=160 GeV (pb)
ABM11	161.8	169.9	145.5	154.4
MSTW08	162.8	171.1	175.6	192.0
NN21	164.1	172.6	172.7	196.9
JR09	163.2	171.3	170.4	188.4

The HATTOR code is used **Laengenfeld, Moch, Uwer PRD 80, 054009 (2009)**

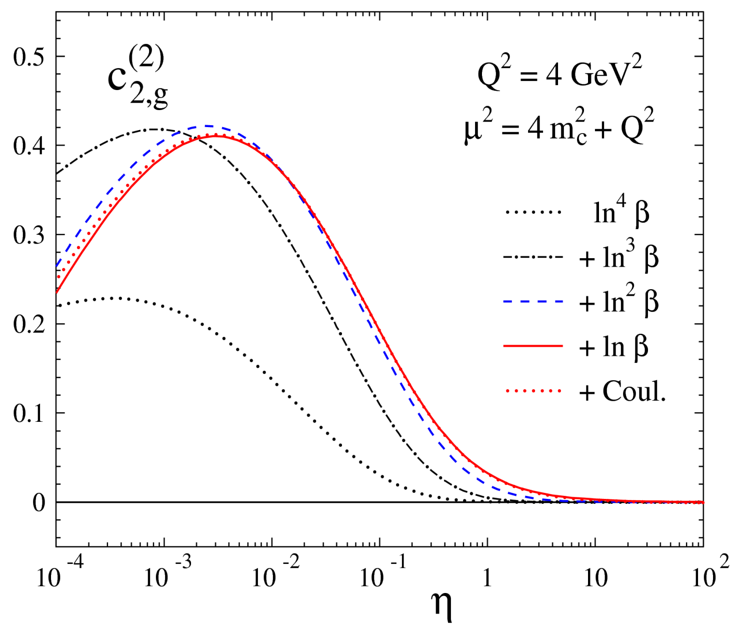
Summary and outlook

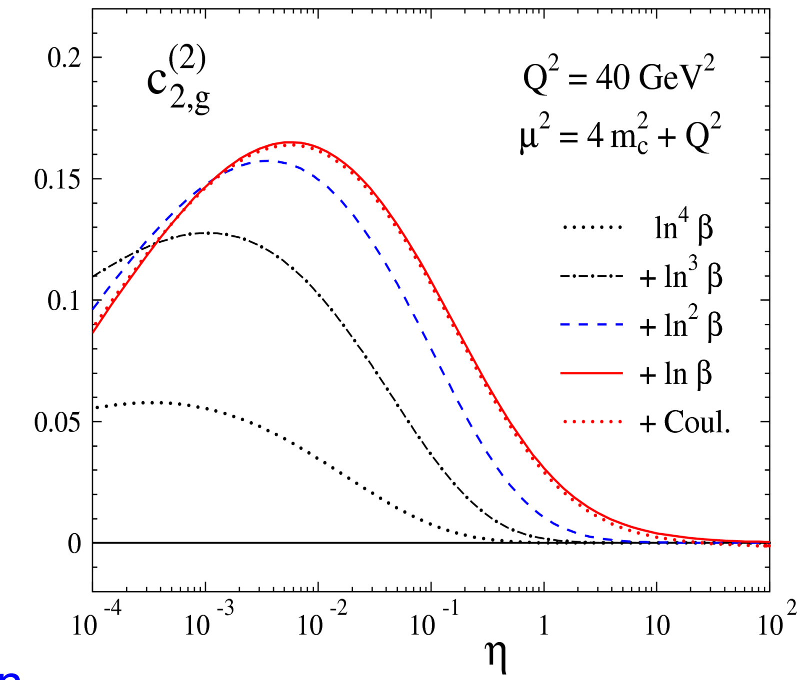
- The running mass definition is implemented for the DIS semi-inclusive structure functions
  - Improved perturbative stability and the scale variation uncertainty
  - Consistent treatment of the mass in DIS and other processes, like e+e- initiated
  - First determination of running mass from the DIS 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 "small" value of α_s is confirmed in the approximate NNLO fit with the Tevatron jet data included:

  $\alpha_s(M_z)=0.1135(14) \rightarrow 0.1134 - 0.1149$ (NNLO)

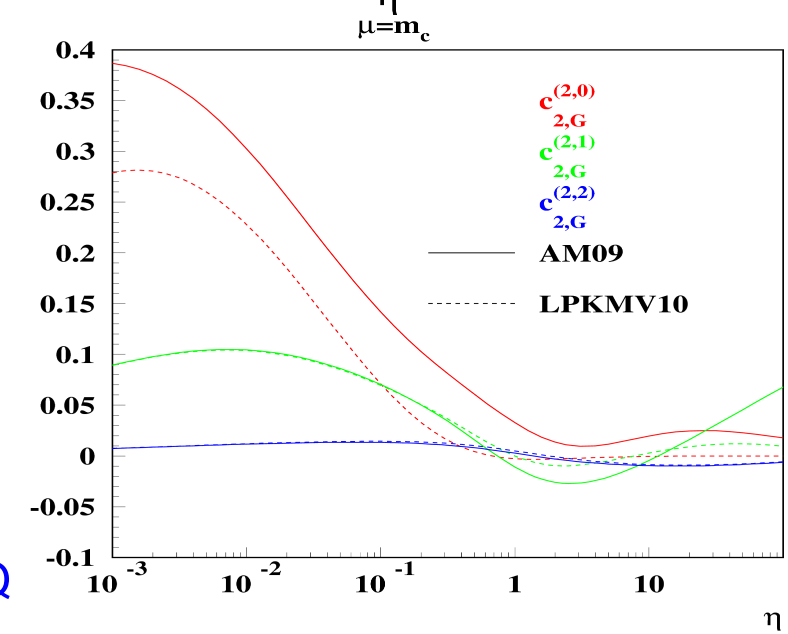
  depending on the data set used. For the LHC jet data the value of α_s should be comparable with the DIS.
- Benchmarking ongoing (the VFN/FFN schemes comparison, nuclear corrections, ...)

Approximate NNLO heavy-quark coefficients





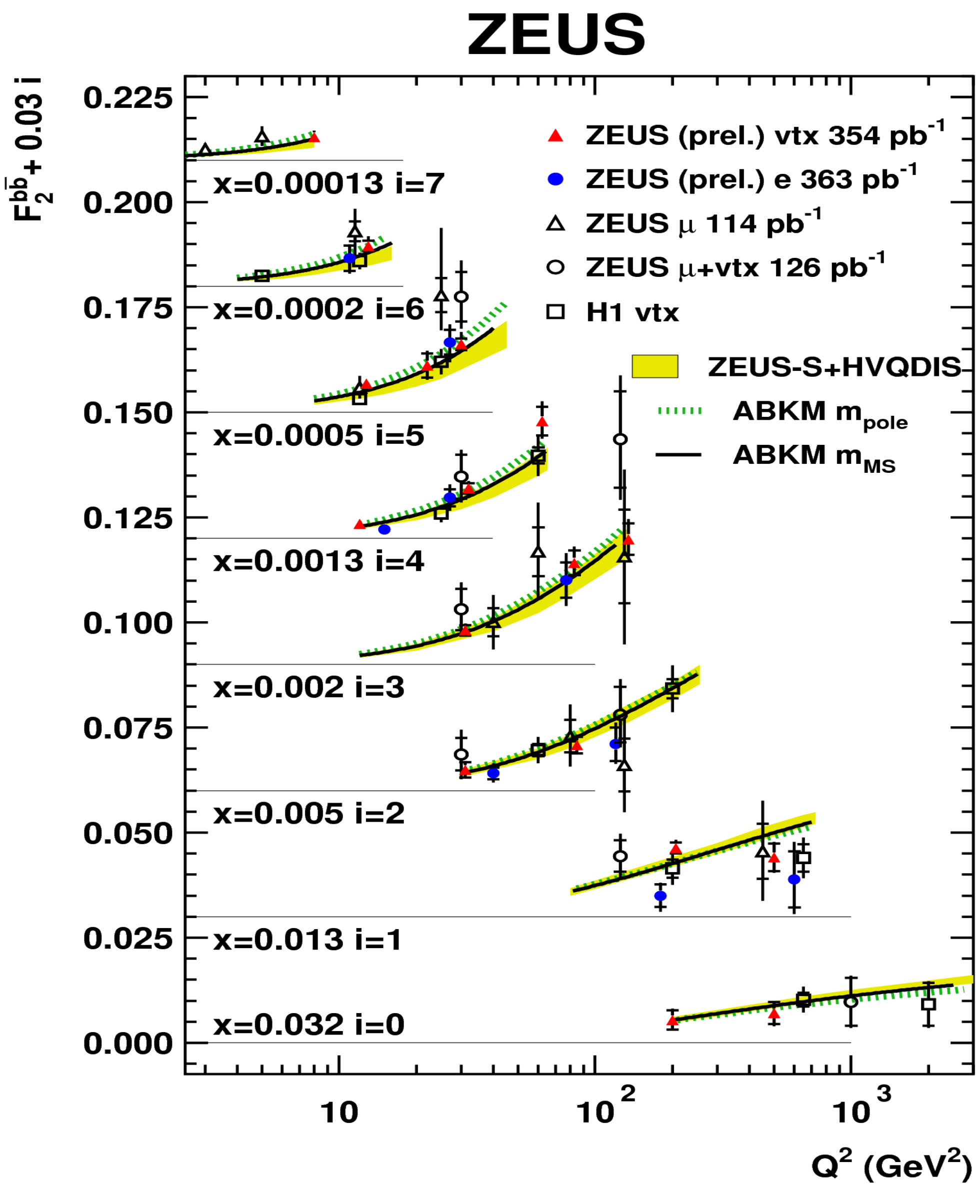
- At small *x* and small *Q* the main contribution comes from η<1 due to the gluon distribution shape (threshold production)
- The large logs ~ $\ln^n(\beta)$ can be resummed in all orders, this gives a good approximation to the exact NNLO expression at small β with the tower of large logs



- 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]

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

Fixed-normalization data sets

H1+ZEUS	The absolute normalization of 0.5%, 113 sources of the correlated systematics	**JHEP 1001, 109 (2010)**
H1	The absolute normalization is 3%, 8 sources of the correlated systematics	**EPJC 71, 1579 (2011)**
BCDMS	The general normalization uncertainty of 3%, an additional normalization uncertainty of 1-1.5% for each beam energy; 5 sources of correlated systematics.	**PLB 223, 485 (1989)** **PLB 237, 592 (1990)**
FNAL-E-605	The absolute normalization uncertainty is 15%, one source of the correlated systematics	**PRD 43, 2815 (1991)**
FNAL-E-866	No normalization uncertainty (cancels in the pD/pp ratio); 5 sources of correlated systematics	**PRD 64, 052002 (2001)**
NuTeV	8 independent sources of systematics; the normalization error is included into the flux uncertainty (marginal due to calibration with the inclusive data sample)	**PRD 64, 112006 (2001)**
CCFR	Only combined systematic errors are available; considered as a one source of the correlated systematics. The normalization uncertainty Is the same with the NuTeV data	**PRD 64, 112006 (2001)**

Fitted-normalization data sets (SLAC)

Whitlow et al. PLB 250, 193 (1990)

Experiment	Target	NDP	NSE	Norm.
E-49A	p	59	3	1.019
	D	59	3	1.000
E-49b	p	154	3	1.025
	D	145	3	1.005
E-87	p	109	3	1.029
	D	109	3	1.013
E-89a	p	77	4	1.
	D	71	5	1.
E-89b	p	90	3	1.012
	D	72	3	0.992
E-139	D	17	3	1.010
E-140	D	26	4	1.

- The E-140 data normalization was calibrated in the experiment, the normalization uncertainty of 1.7%
- The E-89a data normalization was tuned to the elastic data; the general normalization of 2.8% and additional normalization uncertainty of 0.5 % for the deuterium sample
- The rest of samples were fitted in [PLB 250, 193 (1990)] to the E-140 data with the E-49b used as a bridge between the proton and deuterium samples, In our fit the deuteron samples are driven by E-140 and the proton samples by BCDMS and (indirectly) by HERA
- 3 additional sources of correlated systematics for each data set

Fitted-normalization data sets (NMC)

NPB 483, 3 (1997)

Beam energy (GeV)	Target	Norm.
90	p	1.008
	D	0.986
120	p	1.021
	D	1.000
200	p	1.029
	D	1.010
280	p	1.022
	D	1.003

- The data were normalized to combination of SLAC and BCDMS data in [NPB 483, 3 (1997)]
- In our fit the proton NMC sample normalization is driven by HERA and the deuterium one by SLAC
- 12 sources of correlated uncertainties (some of them correlated between different targets and some between different energies)

Benchmark of the DIS with the 3-flavour PDFs

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)

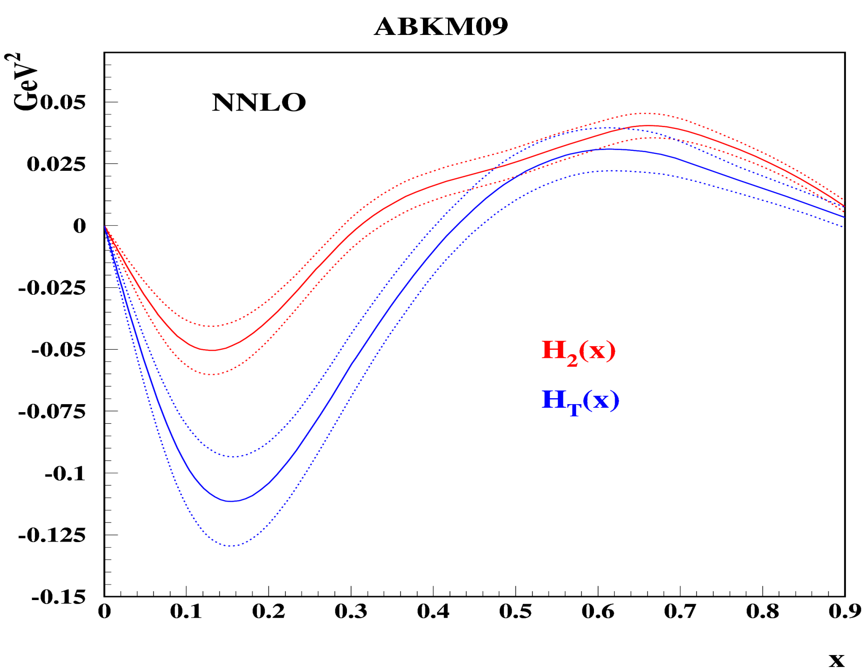
The 3-flavor PDFs are often provided even the fit is based on the GMVFNS and can be easily generated otherwise

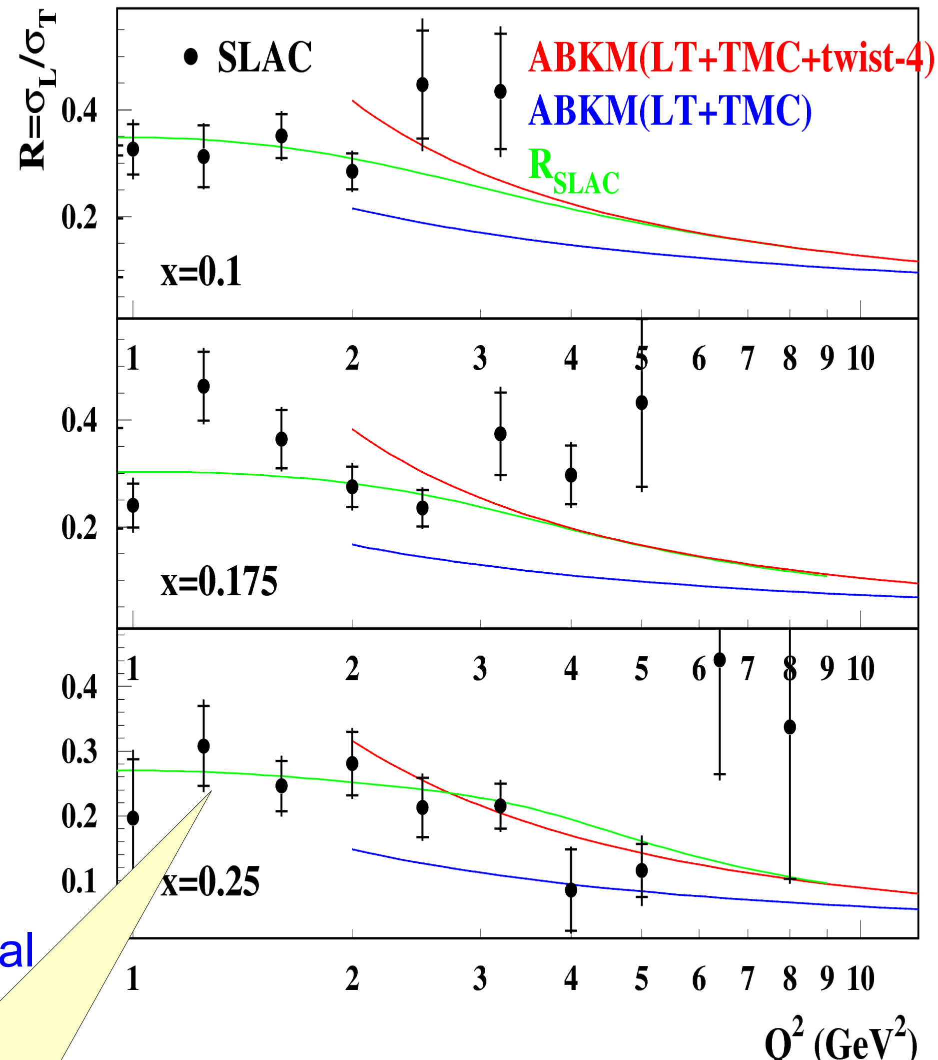
- Convolution with the FFNS coefficient must reproduce the FFNS results at small scales once a GMVFNS should tend to FFNS
- At large Q the data may overshoot the predictions due to impact of big logs
- Additional tuning may need due to:
  - heavy-quark masses
  - power corrections
  - nuclear corrections
  - data normalization

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

High-twist terms in ABKM fit





At x~0.1 the twist-4 terms in F_T are important:

- In the ABKM fit they give about half of the total value of R at the SLAC kinematics

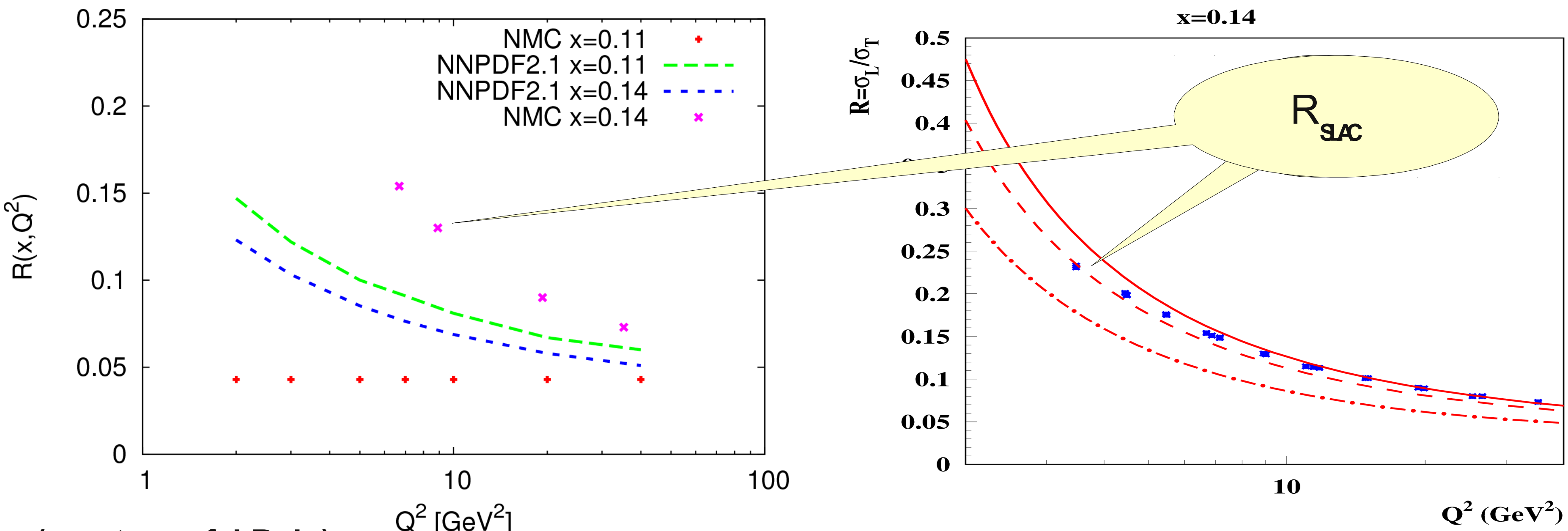
Twist-6 terms are necessary?

sa, Kulagin, Petti [hep-ph 0710.0124]

A verification of the SLAC data is highly desirable

NNPDF reanalysis

NNPDF Collaboration hep-ph 1102.3182



(courtesy of J.Rojo)

sa, Blümlein, Moch [hep-ph 1101.5261]

- The NNPDF model of R doesn't match with the SLAC parameterization – *the high-twist terms are essential*

$$R^{\rm fit} = \frac{b_1}{\ln(Q^2/\Lambda^2)}\Theta(x,Q^2) + \frac{b_2}{Q^2} + \frac{b_3}{Q^4+0.3^2},$$

Whitlow et al. PLB 250, 193 (1990)

- The correlation between α_s and gluons is not considered by NNPDF

More consistent comparison is necessary

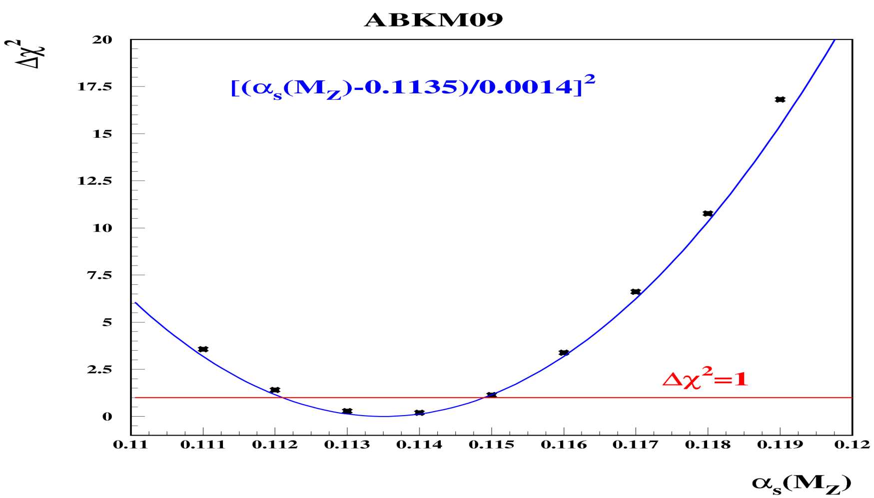
MSTW reanalysis

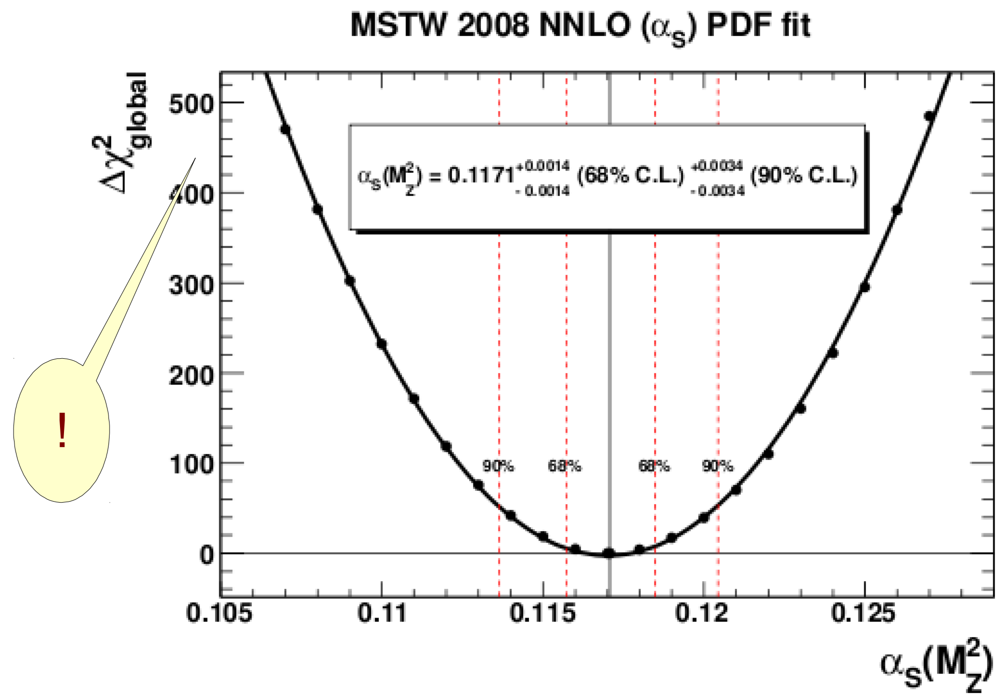
MSTW Collaboration, Munchen Jan 2011

The shift in $\alpha_s(M_z)$ is small: 0.1171 → 0.1168

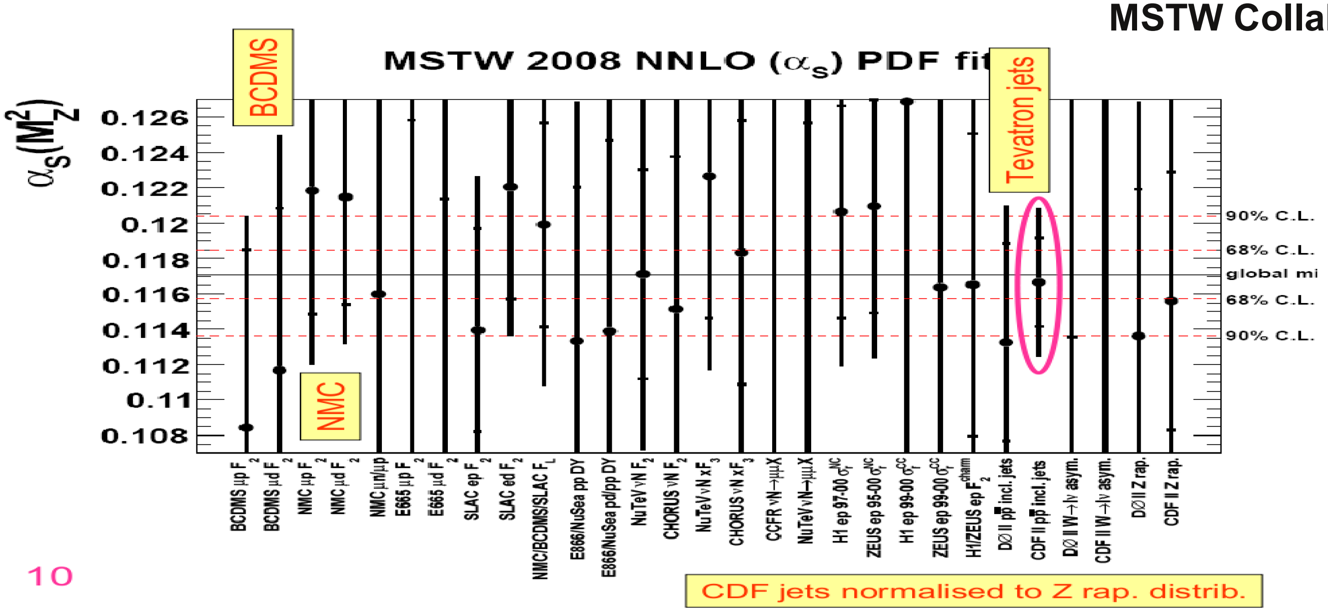
In the MSTW fit α_s is more constrained:

- the high-twist terms set to 0
- impact of the jet data





MSTW Collaboration EPJC 64, 653 (2009)



10