ABM update

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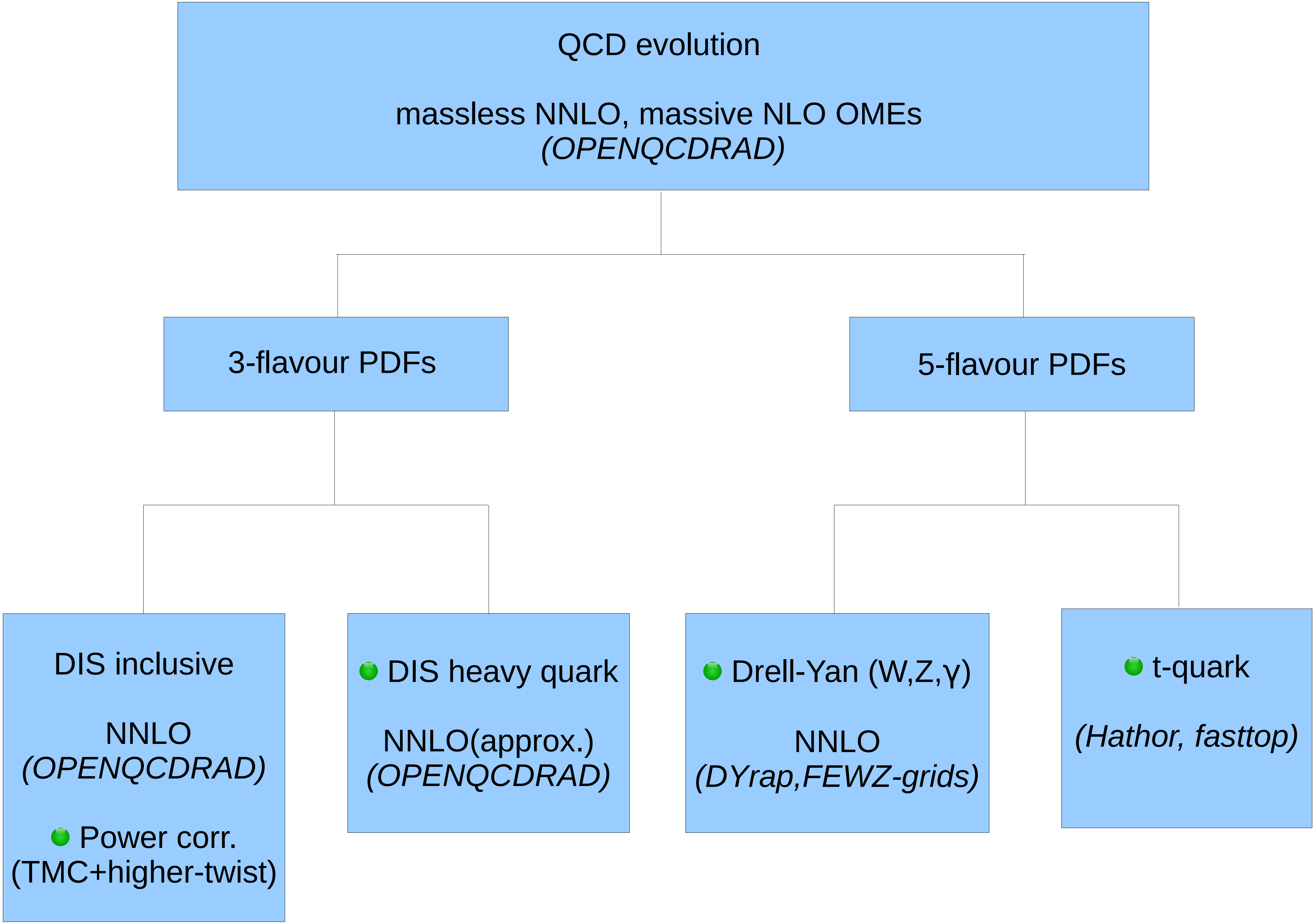
(in collaboration with J.Blümlein and S.Moch)

DIS2019, Turin, 9 Apr 2019

PDF fit framework



Higher twists: generalities

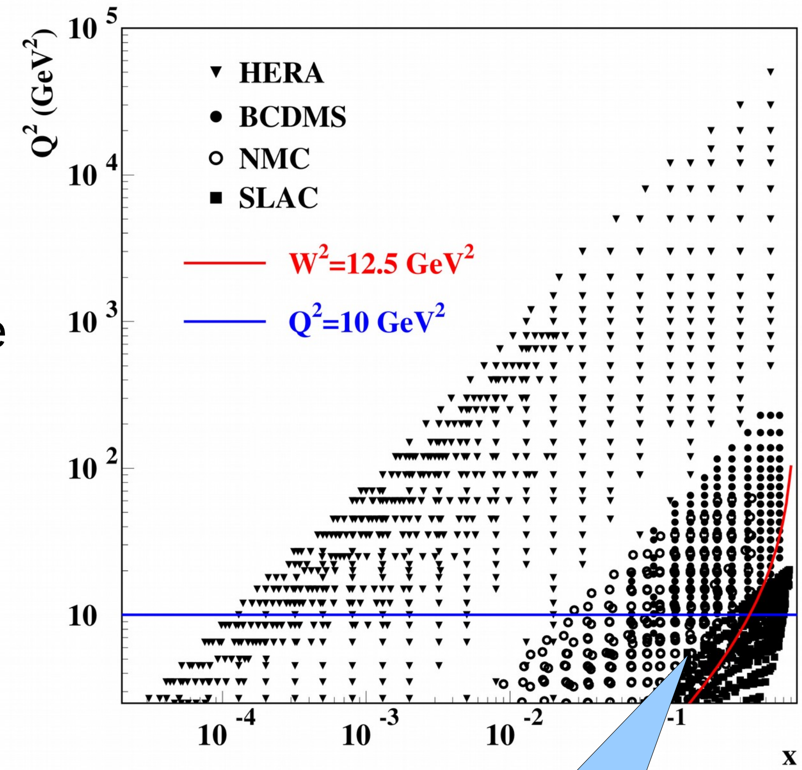
Operator product expansion:

$F_{2,T}=F_{2,T}(\text{leading twist}) + H_{2,T}(x)/Q^2 + \ldots$ – additive

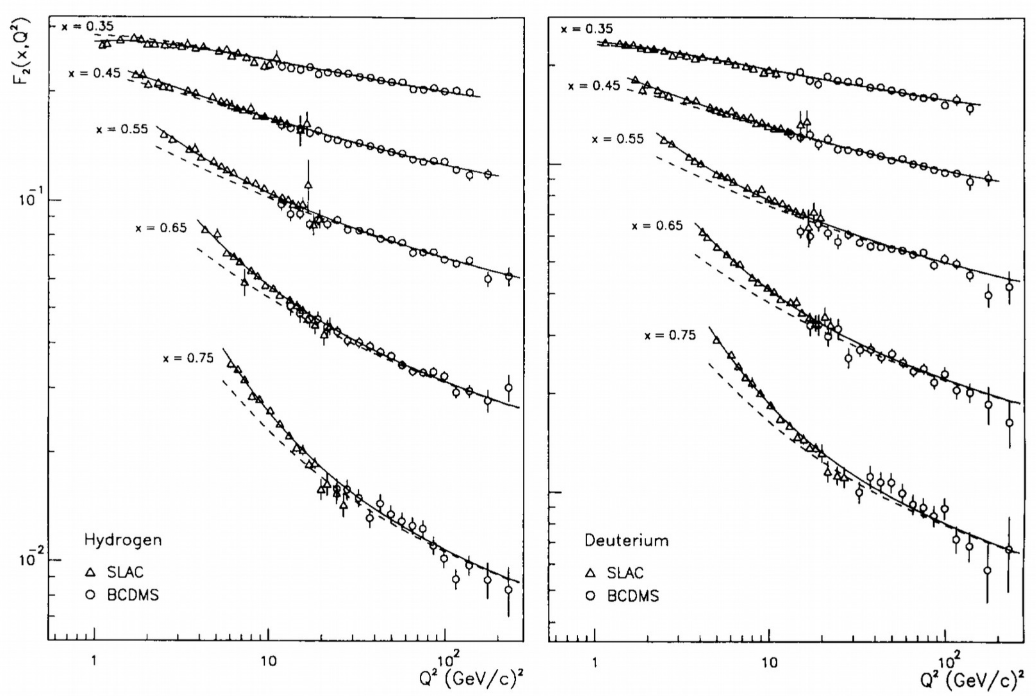
$F_{2,T}=F_{2,T}(\text{leading twist})\,(1 + h_{2,T}(x)/Q^2 +\ldots)$ – multiplicative

- The only one in accordance with QCD

- For multiplicative form the LT anomalous dimensions strongly affect the HT terms at small x



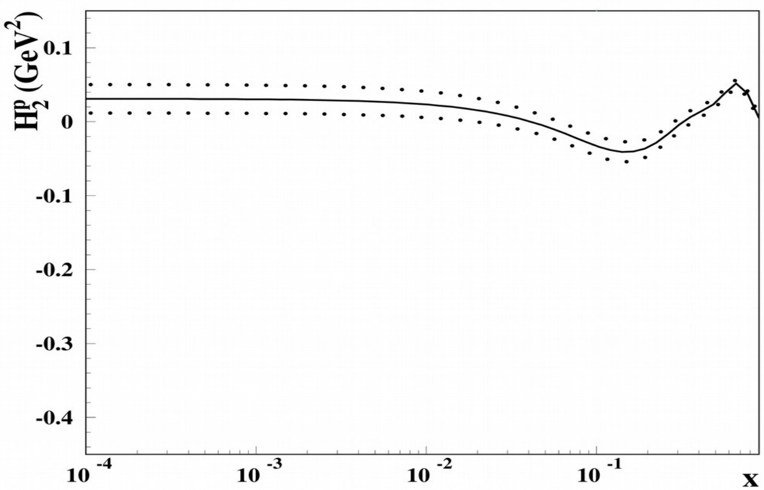
High twists appear in the DIS data at large x(equiv. W) and/or small Q2

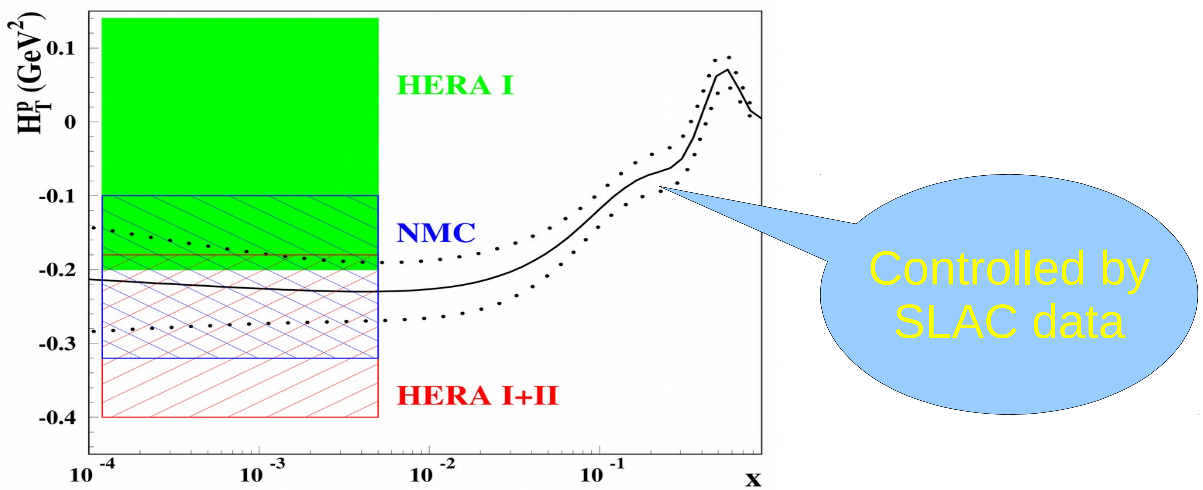


Virchaux, Milsztajn PLB 274, 221 (1992)

Higher twists: small and moderate x

$F_{2,T} = F_{2,T}(\text{leading twist}) + H_{2,T}(x)/Q^2$ $H(x) = x^h P(x)$



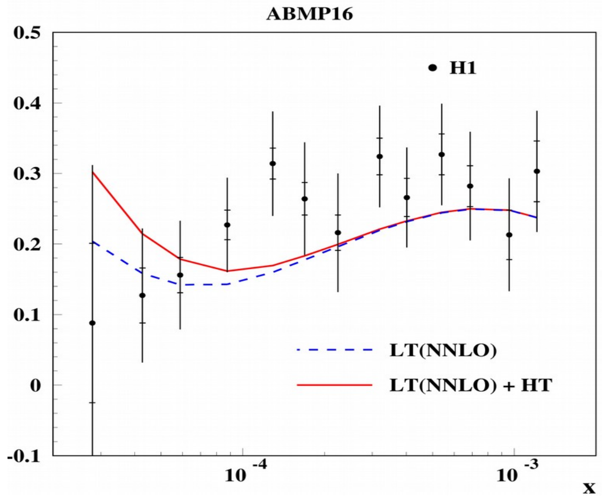


sa, Blümlein, Moch, Plačakytė PRD 96, 014011 (2017)

- $H_T(x)$ continues a trend observed at larger x; $H_2(x)$ is comparable to 0 at small x
- h_T=0.05±0.07 → slow vanishing at x → 0

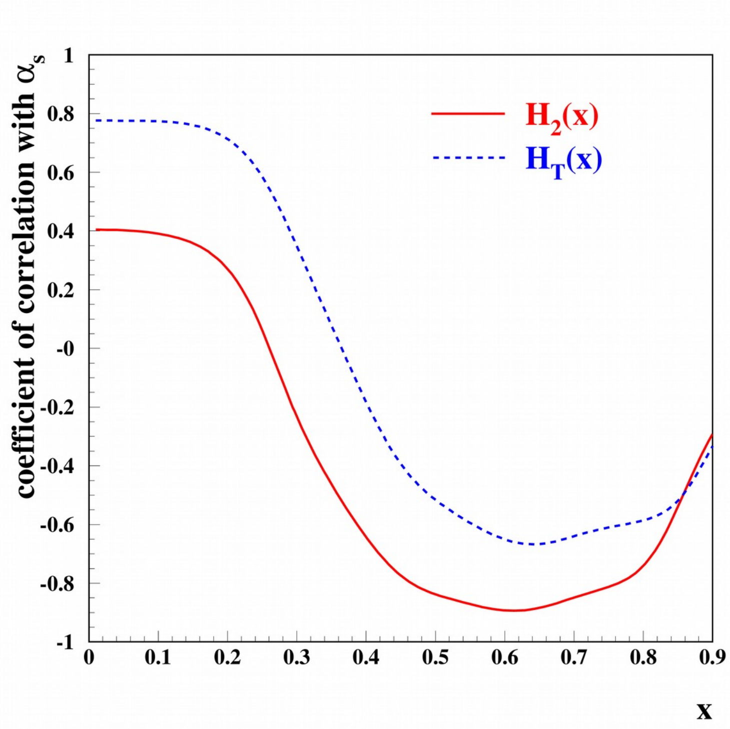
- No dramatic increase of F_L at small x: different from the study with multiplicative form of HTs

Abt et. al. hep-ph/1604.02229



- Alternative explanations are available in literature: resummation, saturation, etc.

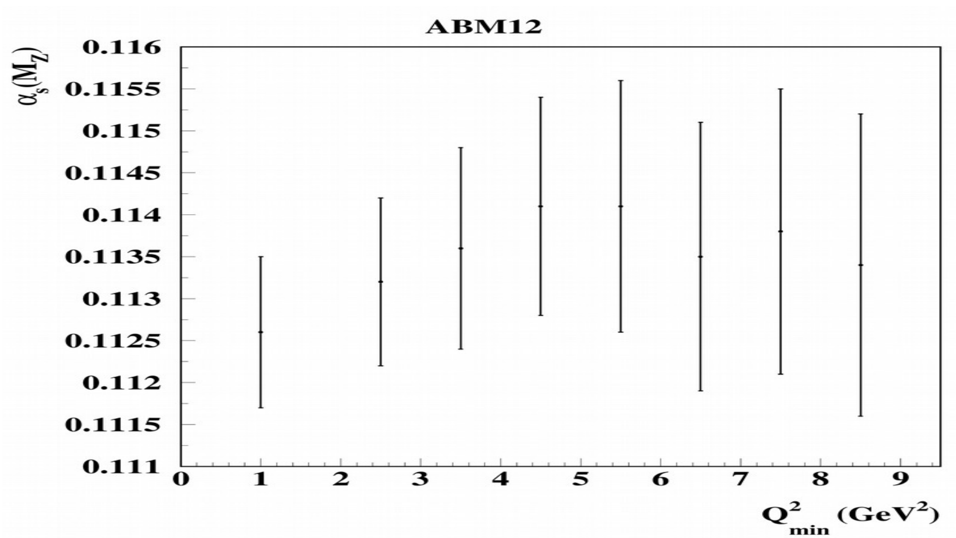
Higher twists: correlation with α_s



- The value of α_s and twist-4 terms are strongly correlated
- With HT=0 the errors are reduced → no uncertainty due to HTs
- With account of the HT terms the value of α_s is stable with respect to the cuts

fit ansatz		$\alpha_s(M_Z)$	
higher twist modeling	cuts on DIS data	NLO	NNLO
higher twist fitted	$Q^2 > 2.5$ GeV^2, $W > 1.8$ GeV	0.1191(11)	0.1147(8)
higher twist fixed at 0	$Q^2 > 10$ GeV^2, $W^2 > 12.5$ GeV^2	0.1212(9)	0.1153(8)
	$Q^2 > 15$ GeV^2, $W^2 > 12.5$ GeV^2	0.1201(11)	0.1141(10)
	$Q^2 > 25$ GeV^2, $W^2 > 12.5$ GeV^2	0.1208(13)	0.1138(11)

sa, Blümlein, Moch EPJC 78, 477 (2018)



MRST: $\alpha_s(M_z)$=0.1153(20) (NNLO)
(W^2>15 GeV^2, Q^2> 10 GeV^2)

A stringent cut on Q is necessary for the fit with HT=0

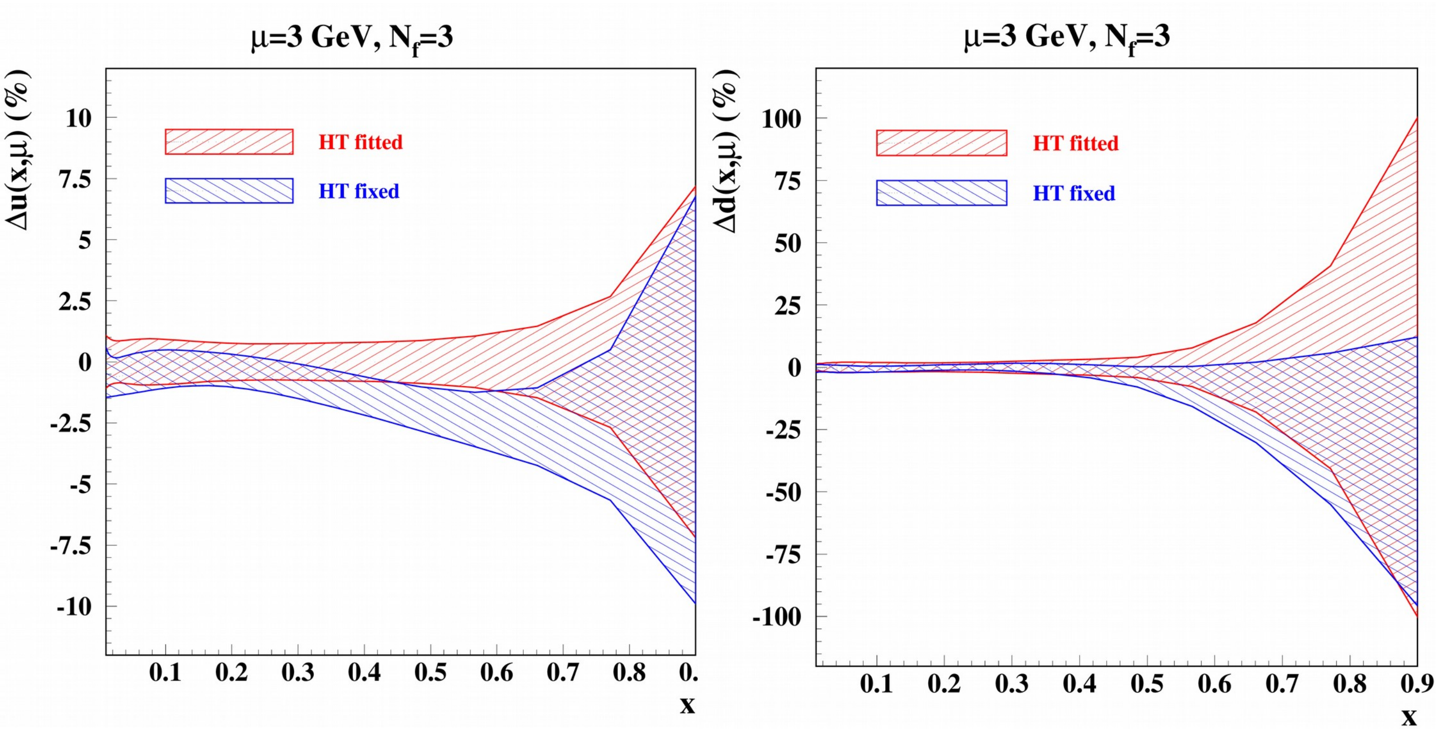
Moch et al. hep-ph/1405.4781

Higher twists: fit with stringent cut on Q,W

χ^2/NDP

	HT fitted Q^2>2.5 GeV^2, W>1.8 GeV	HT=0, Q^2>10 GeV^2, W^2>12.5 GeV^2
HERA	1510/1168	1220/1007
Fixed target: SLAC, NMC,BCDMS	1145/1008	498/444

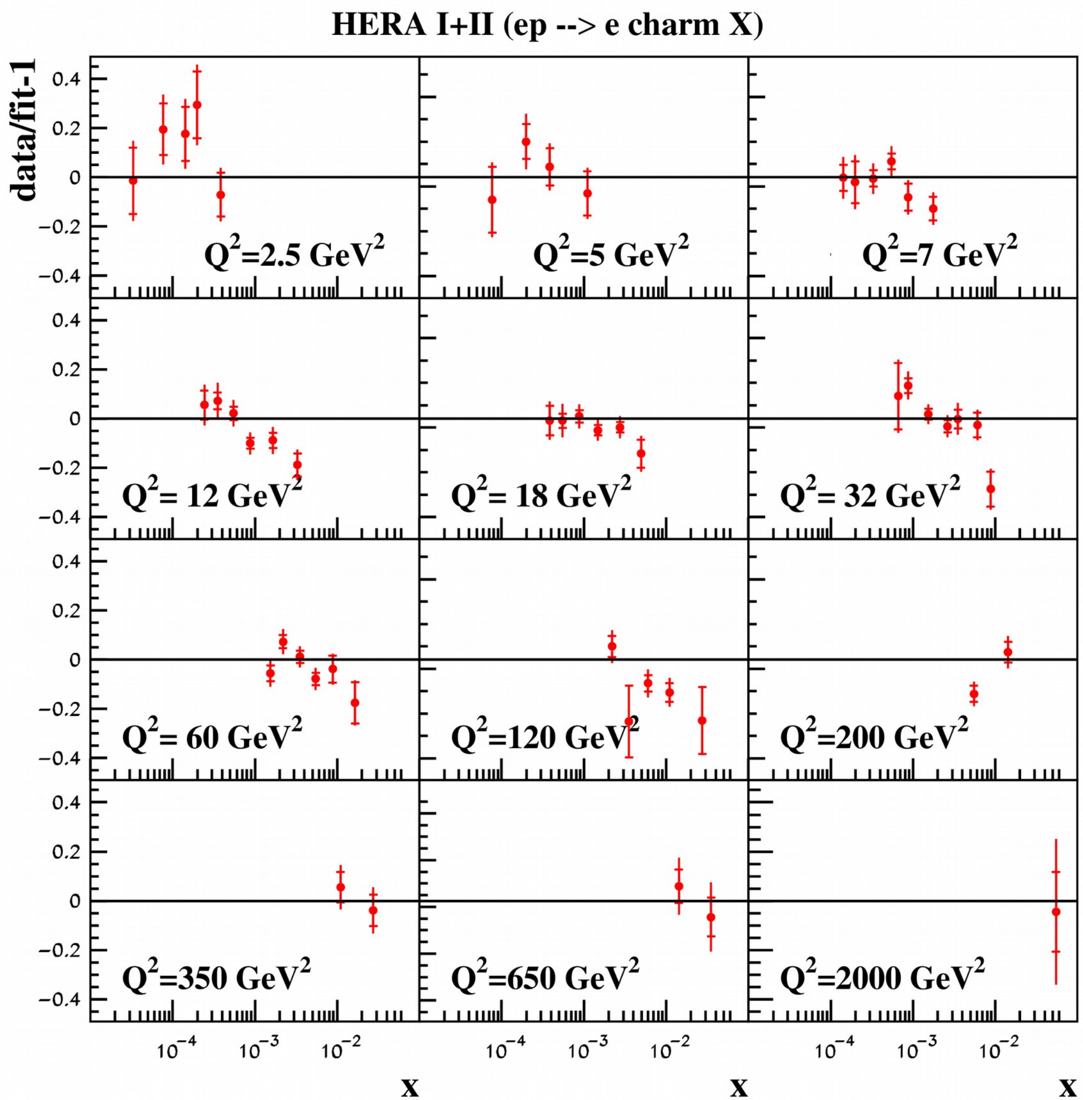
Value of χ^2 is stable w.r.t. to cuts



Stringent cut affects high-x data, however, the large-x PDF uncertainties remain stable

HERA charm data and m_c

H1, ZEUS EPJC 78, 473 (2018)



X^2/NDP=86/52

Theory: FFN scheme, running mass definition (cf. talk afternoon)

$m_c(m_c)$=1.245±0.019(exp.) GeV

present analysis

$m_c(m_c)$=1.252±0.018(exp.) GeV

ABMP16

m_c(pole)~1.9 GeV (NNLO)

Marquard et al. PRL 114, 142002 (2015)

$m_c(m_c)$=1.246±0.023 (h.o.) GeV NNLO

Kiyo, Mishima, Sumino PLB 752, 122 (2016)

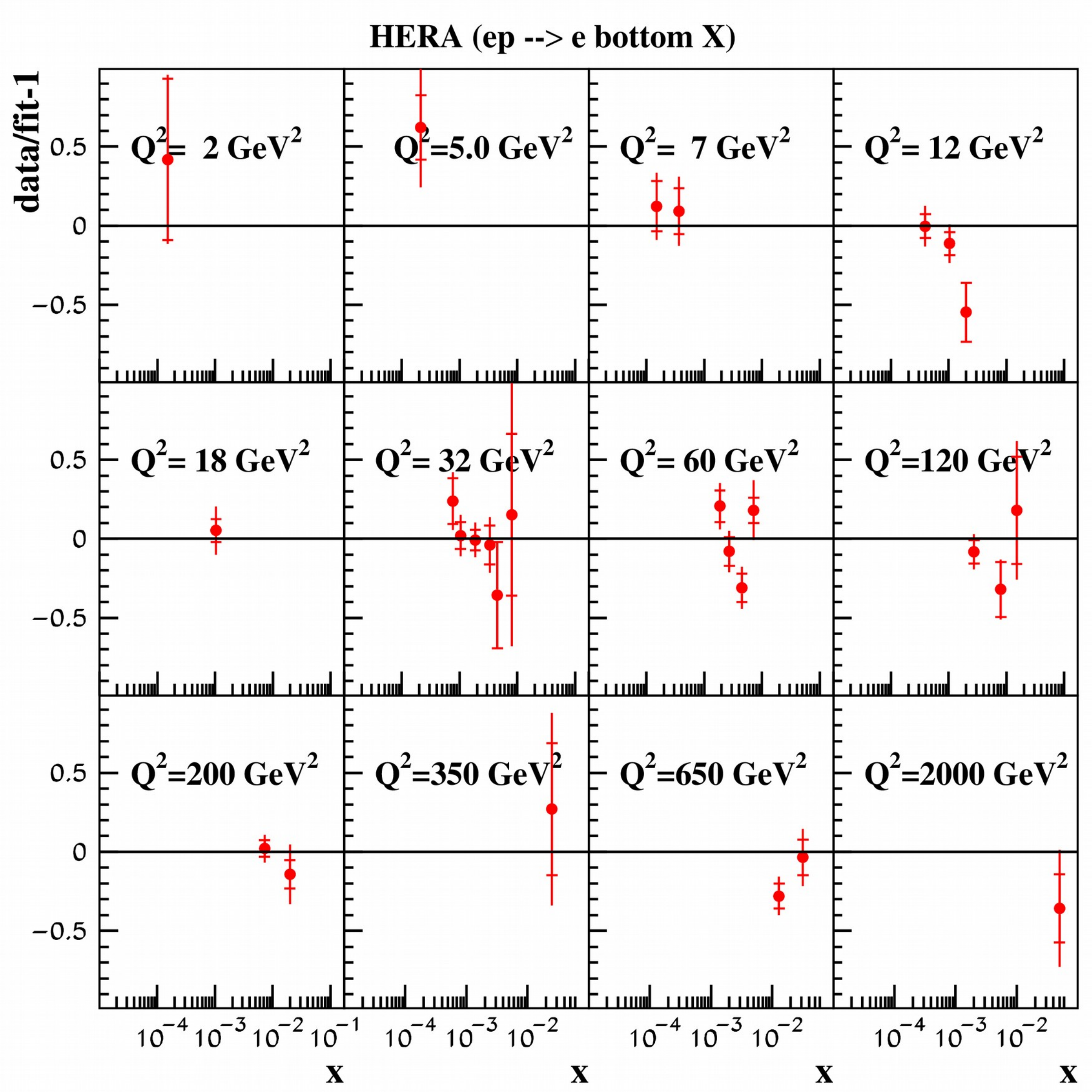
$m_c(m_c)$=1.279±0.008 GeV

Kühn, LoopsLegs2018

Good consistency with the earlier results and other determinations → further confirmation of the FFN scheme relevance for the HERA kinematics

HERA beauty data and m_b

H1, ZEUS EPJC 78, 473 (2018)



$m_b(m_b)$=3.96±0.10(exp.) GeV

present analysis

$m_b(m_b)$=3.84±0.13(exp.) GeV

ABMP16

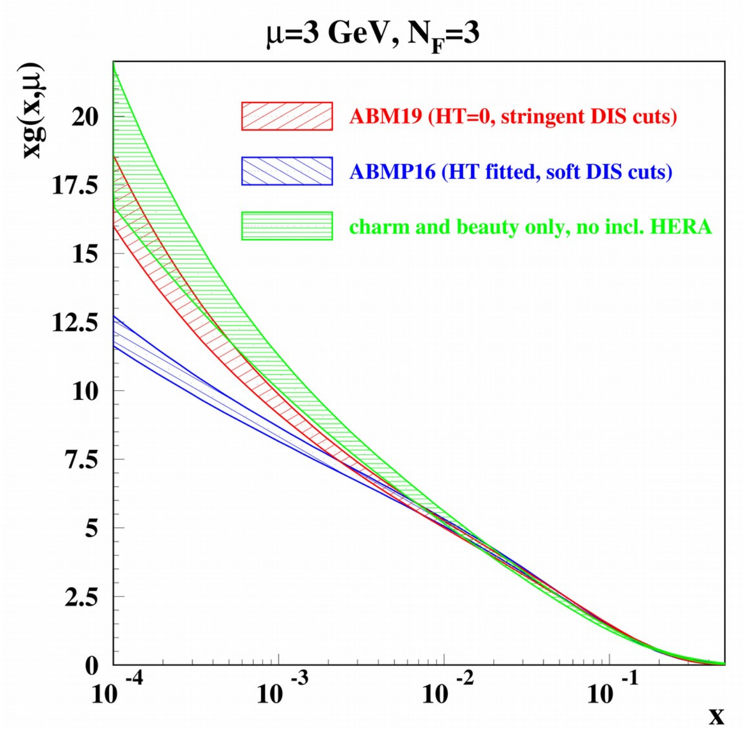
$m_b(m_b)$=4.18+0.04-0.03 GeV

PDG 2018

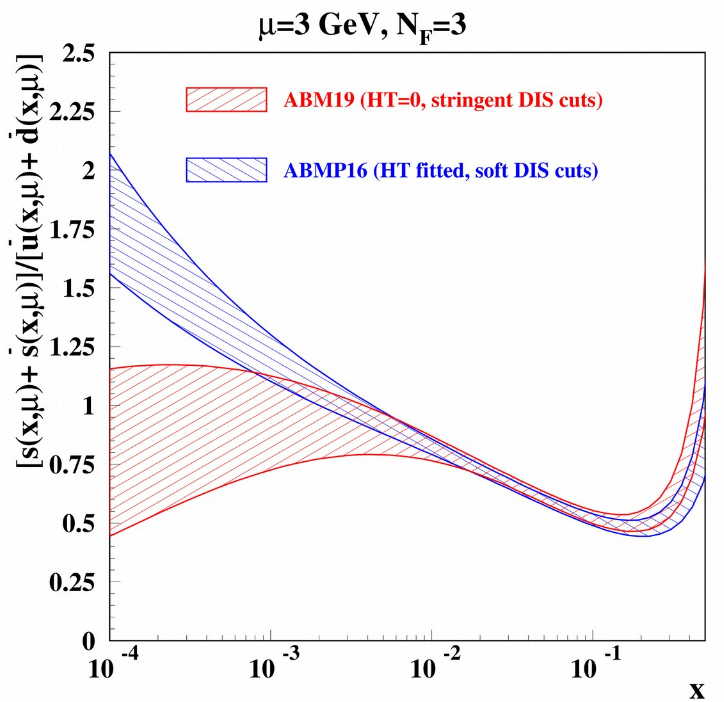
X^2/NDP=36/27

Improved agreement with other determinations, evidently due to data purification

Impact of stringent cut on PDFs at small x

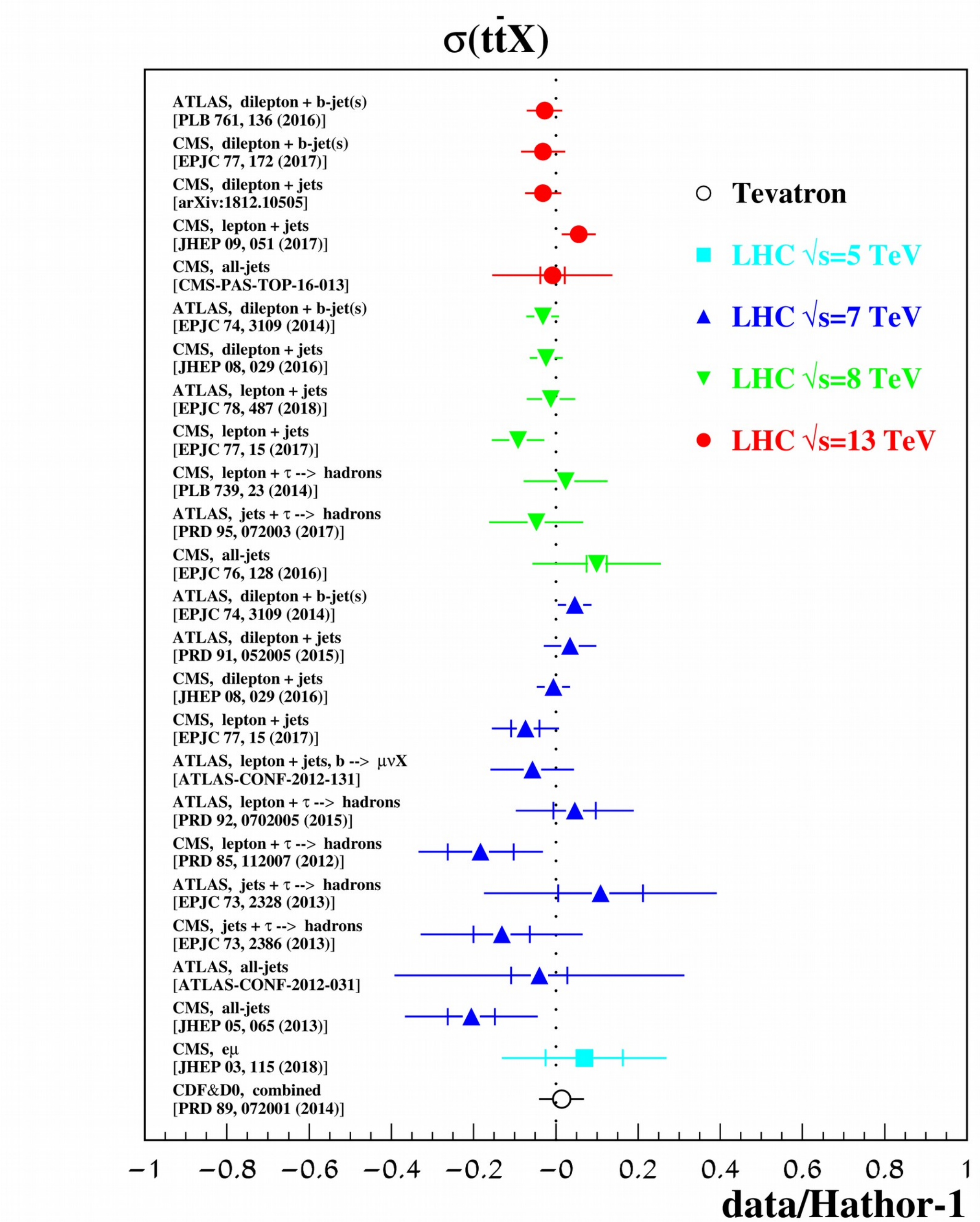


Gluon goes higher, consistent with the constraint from charm/beauty



Strange sea goes lower at small x, consistent with 1 within errors → SU(3) symmetry

t-quark: pair production



- Running t-quark mass can be determined simultaneously**

$m_t(m_t)$= 160.8±1.1 GeV

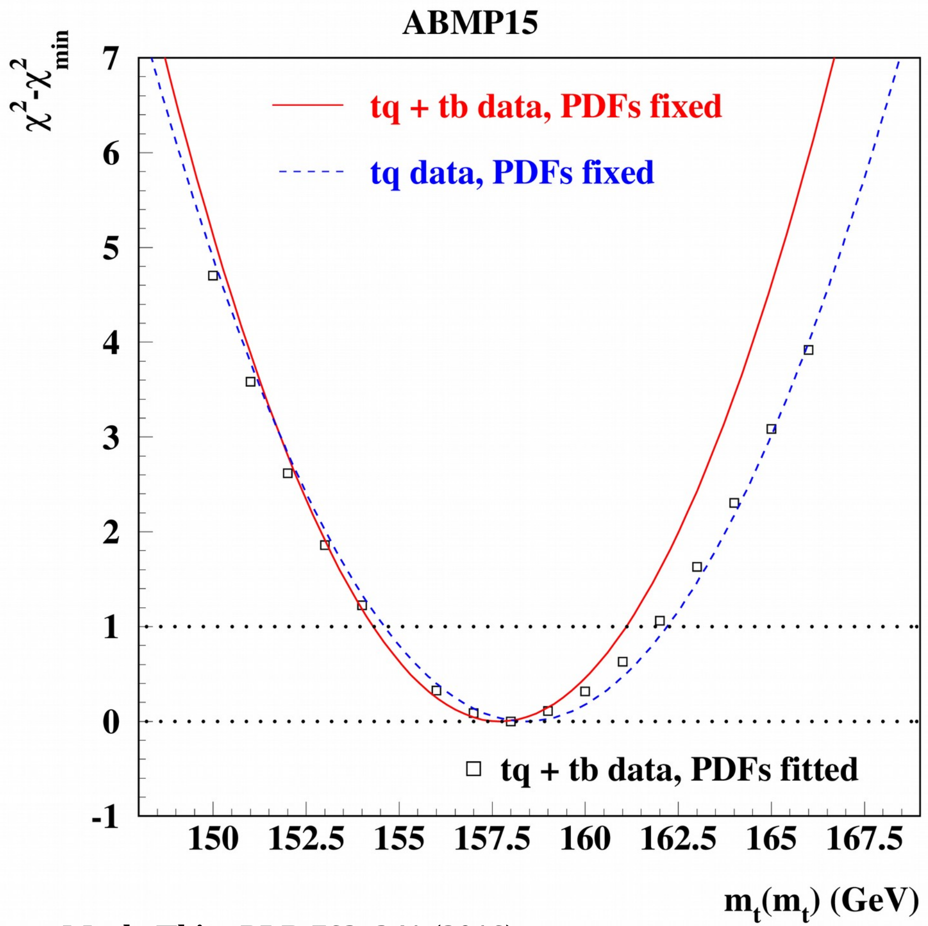
m_t(pole)=170.4±1.2 GeV

m_t(MC)~172.5 GeV from LHC

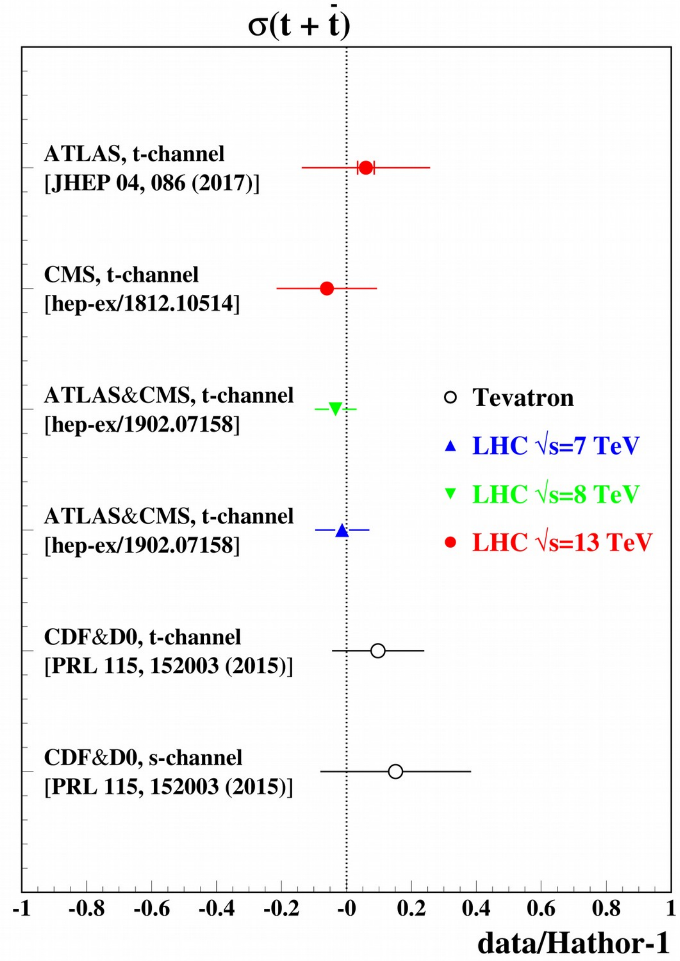
(Hoang et al. try to quantify the difference)

** Running-mass definition provides better perturbative stability (Extras)

t-quark: single production (mass determination)



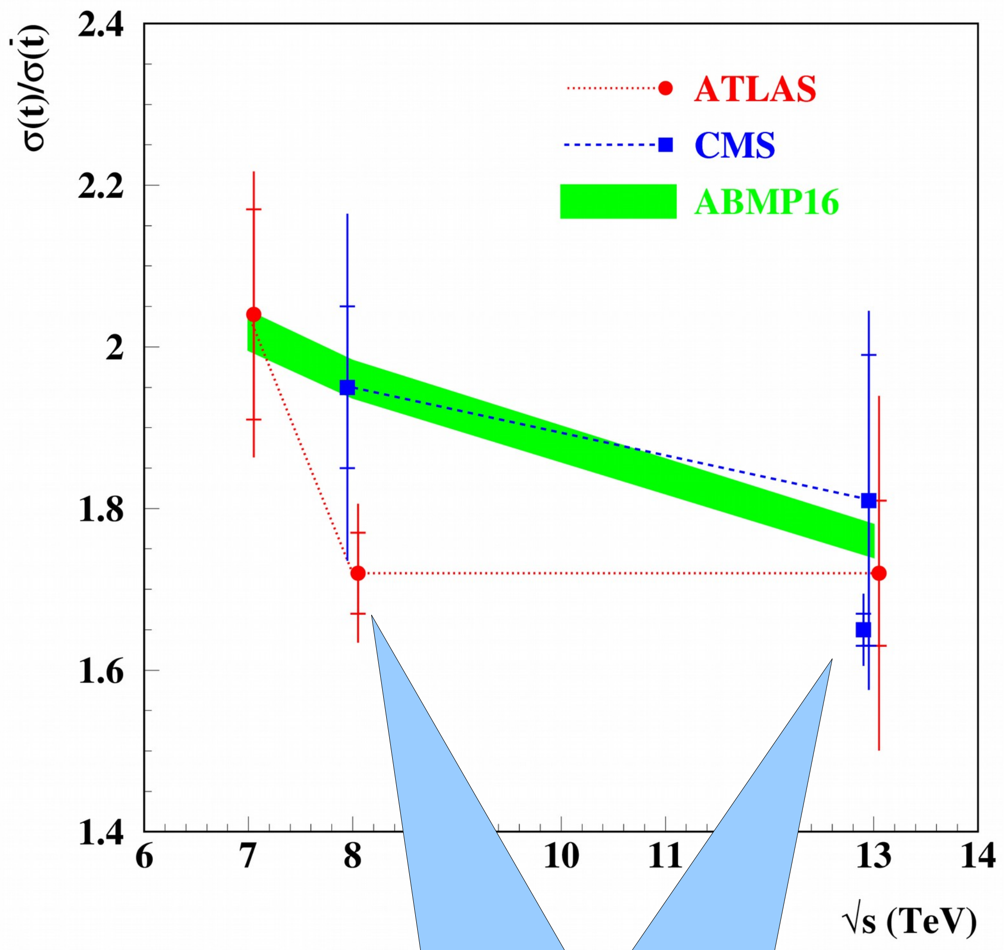
sa, Moch, Thier PLB 763, 341 (2016)



$m_t(m_t)$= 161.1± 3.8GeV (single-top only)

Channel	ABM12 [21]	ABMP15 [52]	CT14 [55]	MMHT14 [56]	NNPDF3.0 [57]
$t\bar{t}$	158.6 ± 0.6	158.4 ± 0.6	164.7 ± 0.6	164.6 ± 0.6	164.3 ± 0.6
t-channel	158.7 ± 3.7	158.0 ± 3.7	160.1 ± 3.8	160.5 ± 3.8	164.0 ± 3.8
s- & t-channel	158.4 ± 3.3	157.7 ± 3.3	159.1 ± 3.4	159.6 ± 3.4	162.4 ± 3.5

t-quark: single production (flavour separation)



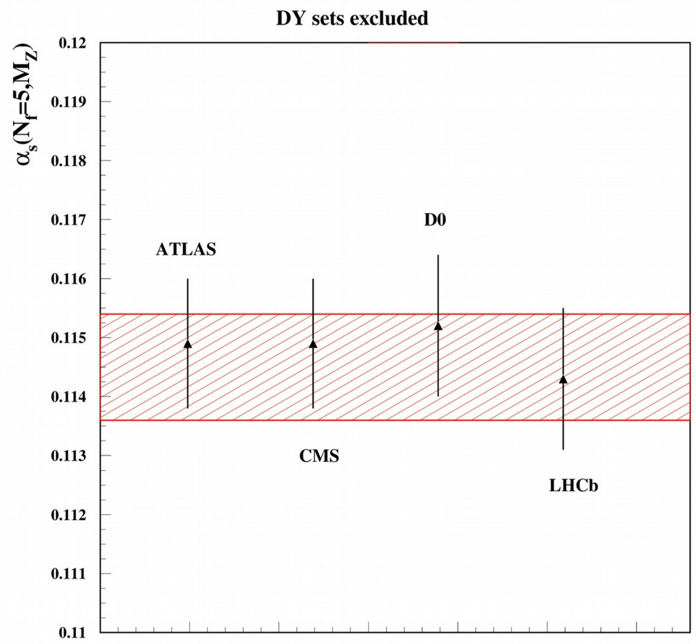
Small errors due to cancellation of theor. unc. in case the MC version is fixed; they are much larger if different MCs are considered

- The single-top data are sensitive to the u/d ratio, however in general they are not competitive with the DY constraints
- The only window opens when the hadronization MC is fixed and the modeling errors cancel in the ratio → model dependent result
- The comparison can be also inverted in order to discriminate hadronization models

Data set used for study of impact PDF shape on α_s

sa, Blümlein, Moch PLB 777, 134 (2018)
sa, Blümlein, Kulagin, Moch, Petti hep-ph/1808.06871

Experiment	Process	NDP
DIS		
HERA I+II	$e^{\pm}p \to e^{\pm}X$ $e^{\pm}p \to \overset{(-)}{\nu} X$	1168
Fixed-target (BCDMS, NMC, SLAC)	$l^{\pm}p \to l^{\pm}X$	1935
DIS heavy-quark production		
HERA I+II	$e^{\pm}p \to e^{\pm}cX$	52
H1, ZEUS	$e^{\pm}p \to e^{\pm}bX$	29
Fixed-target (CCFR, CHORUS, NOMAD, NuTeV)	$\overset{(-)}{\nu} N \to \mu^{\pm}cX$	232
DY		
Fixed-target (FNAL-605, FNAL-866)	$pN \to \mu^{+}\mu^{-}X$	158



DY data have no essential impact on α_s

The ABMP16 framework with:

– DY data replaced by the deuteron ones ⇒ comparable quark disentangling at moderate and large x

– t-quark data excluded (no relevance for the first round of estimates)

Checking styles of PDF shape

	ABMP16	CJ15	CT10	CT14	epWZ16	MMHT14
N_{PDF}	28	21	26	26	14	31
μ_0^2 (GeV^2)	9	1.69	1.69	1.69	1.9	1
χ^2	4065	4108	4148	4153	4336	4048
PDF shape	$x^\alpha(1-x)^\beta$ $\exp[P(x,\ln(x))]$	$x^\alpha(1-x)^\beta P(x,\sqrt{x})$	$x^\alpha(1-x)^\beta$ $\exp[P(x,\sqrt{x})]$	$x^\alpha(1-x)^\beta$ $\exp[P(x,\sqrt{x})]$	$x^\alpha(1-x)^\beta P(x,\sqrt{x})$	$x^\alpha(1-x)^\beta P(x,\sqrt{x})$
Constraints		$\bar{u}=\bar{d}$ $(x\to 0)$	$\alpha_{uv}=\alpha_{dv}$ $\alpha_{\bar{u}}=\alpha_{\bar{d}}=\alpha_s$ $\bar{u}=\bar{d}$ $(x\to 0)$	$\alpha_{uv}=\alpha_{dv}$ $\beta_{uv}=\beta_{dv}$ $\alpha_{\bar{u}}=\alpha_{\bar{d}}=\alpha_s$	$\alpha_{\bar{u}}=\alpha_{\bar{d}}=\alpha_s$ $\bar{u}=\bar{d}$ $(x\to 0)$	
$\alpha_s(M_Z)$	0.1153	0.1147	0.1150	0.1160	0.1162	0.1158

- Various PDF-shape modifications provide comparable description with N_{PDF}~30
- Some deterioration, which happens in cases is apparently due to constraints on large(small)-x exponents

Conservative estimate of uncertainty in $\alpha_s(M_Z)$: 0.0007, more optimistic: 0.0003

DY: data used in the ABMP16 fit

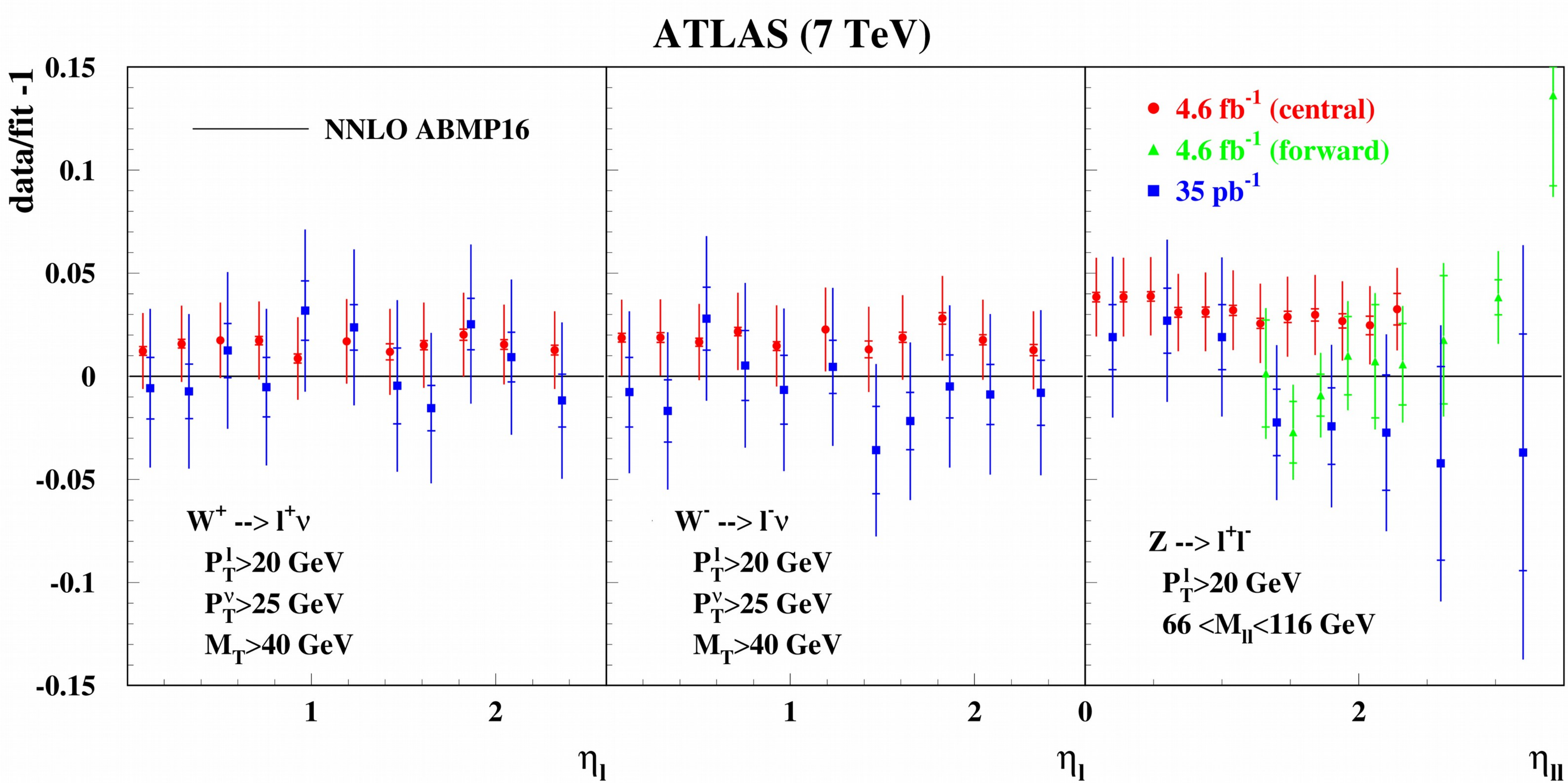
Experiment	ATLAS		CMS		DØ		LHCb		
$\sqrt{s}$ (TeV)	7	13	7	8	1.96		7	8	
Final states	$W^+ \to l^+\nu$ $W^- \to l^-\nu$ $Z \to l^+l^-$	$W^+ \to l^+\nu$ $W^- \to l^-\nu$ $Z \to l^+l^-$	$W^+ \to \mu^+\nu$ $W^- \to \mu^-\nu$ (asym)	$W^+ \to \mu^+\nu$ $W^- \to \mu^-\nu$	$W^+ \to \mu^+\nu$ $W^- \to \mu^-\nu$ (asym)	$W^+ \to e^+\nu$ $W^- \to e^-\nu$ (asym)	$W^+ \to \mu^+\nu$ $W^- \to \mu^-\nu$ $Z \to \mu^+\mu^-$	$Z \to e^+e^-$	$W^+ \to \mu^+\nu$ $W^- \to \mu^-\nu$ $Z \to \mu^+\mu^-$
Cut on the lepton P_T	$P_T^l > 20$ GeV	$P_T^e > 25$ GeV	$P_T^\mu > 25$ GeV	$P_T^\mu > 25$ GeV	$P_T^\mu > 25$ GeV	$P_T^e > 25$ GeV	$P_T^\mu > 20$ GeV	$P_T^e > 20$ GeV	$P_T^\mu > 20$ GeV
Luminosity (1/fb)	0.035	0.081	4.7	18.8	7.3	9.7	1	2	2.9
NDP	30	6	11	22	10	13	31(33) [a]	17	32(34)
ABMP16	31.0	9.2	22.4	16.5	17.6	19.0	45.1(54.4)	21.7	40.0(59.2)
CJ15	–	–	–	–	20	29	–	–	–
CT14	42	–	– [b]	–	–	34.7	–	–	–
HERAFitter	–	–	–	–	13	19	–	–	–
MMHT16	39 [c]	–	–	21	21 [c]	26	(43)	29	(59)
NNPDF3.1	29	–	19	–	16	35	(59)	19	(47)

[a] The values of NDP and χ^2 correspond to the unfiltered samples.
[b] For the statistically less significant data with the cut of $P_T^\mu > 35$ GeV the value of $\chi^2 = 12.1$ was obtained.
[c] The value obtained in MMHT14 fit.

Experiment	NDP	χ^2 after the data sets excuded				
		–	ATLAS	CMS	DØ	LHCb
ATLAS	36	37.7	–	37.0	38.3	39.6
CMS	33	26.6	25.6	–	26.0	23.5
DØ	23	48.5	48.1	47.7	–	**44.2**
LHCb	80	98.2	100.2	97.4	**78.8**	–

- Good overall agreement in NNLO with some tension between D0 and LHCb data

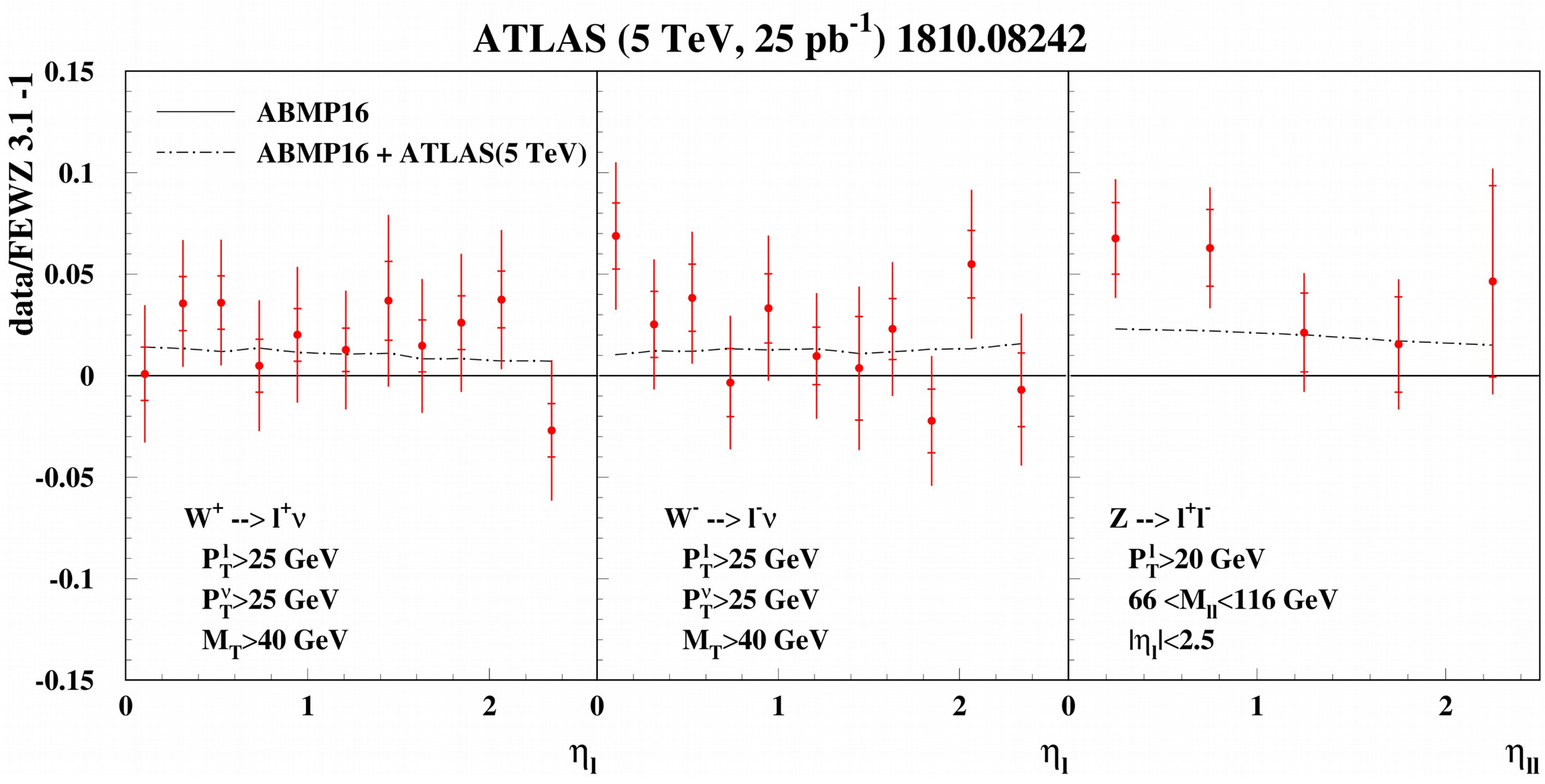
New input: ATLAS at 7 TeV



- *Good agreement with W data*
- *Undershooting Z-boson data*
- *Different trends for the central and forward Z-boson data*

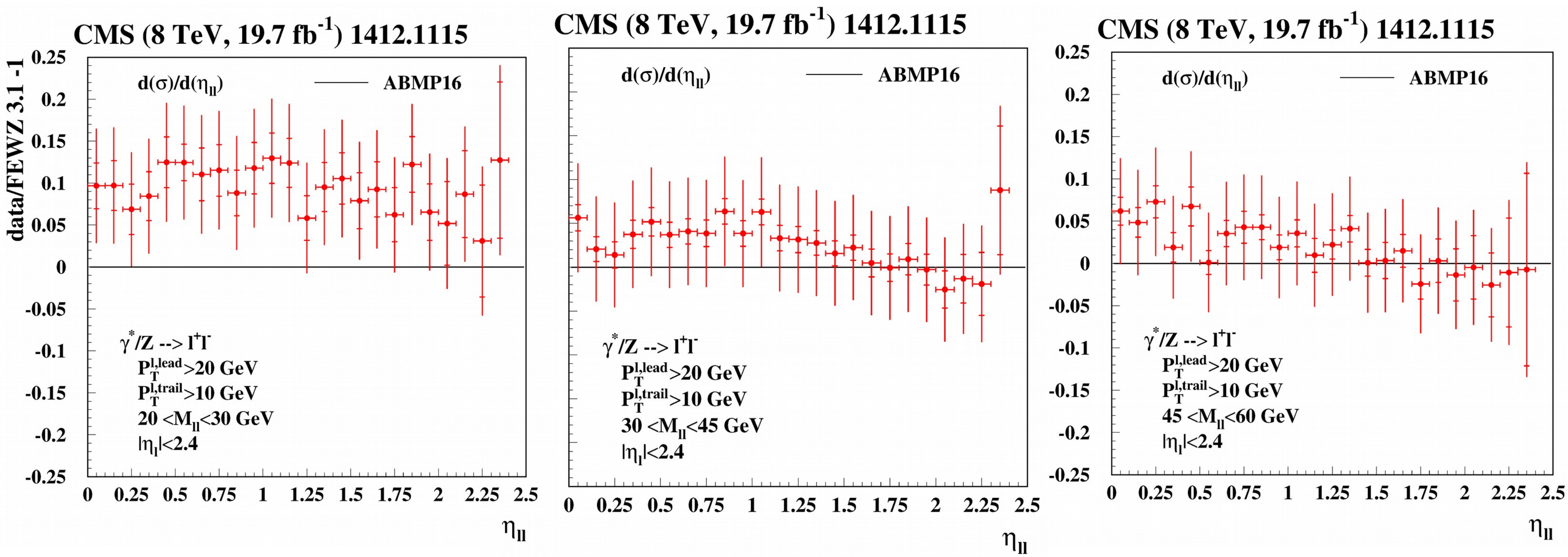
ATLAS data set	χ^2/NDP
W±, Z(central)	43/34
W±, Z(central), Z(forward)	84/43

DY: impact of the recent data (ATLAS, 5 TEV)



PRELIMINARY: Uncertainty correlations are not taken into account (still unpublished); smaller impact on fit is expected when they are included

DY: towards double differential distributions



- Reasonable agreement with the ABMP16 predictions
- Complimentary constraint on PDFs → improved quark disentangling
- Other CMS and ATLAS data in progress; the bottleneck is NNLO computations with the fiducial-volume cuts

Summary

- The fit with stringent cuts, W^2>12.5 GeV^2, Q^2> 10 GeV^2, on the DIS data is considered
  - impact of the higher-twist terms is minimized
  - small-x gluon goes higher, consistent with the constraint from charm/beauty; small-x strange sea goes lower at small x, consistent with 1 within errors; valence quarks stable
  - reasonable description of the recent charm/beauty HERA data with

$$m_c(m_c)=1.245\pm0.019(\text{exp.})\ \text{GeV}$$

$$m_b(m_b)=3.96\pm0.10(\text{exp.})\ \text{GeV}$$

- Update of the pair- and single-top production with

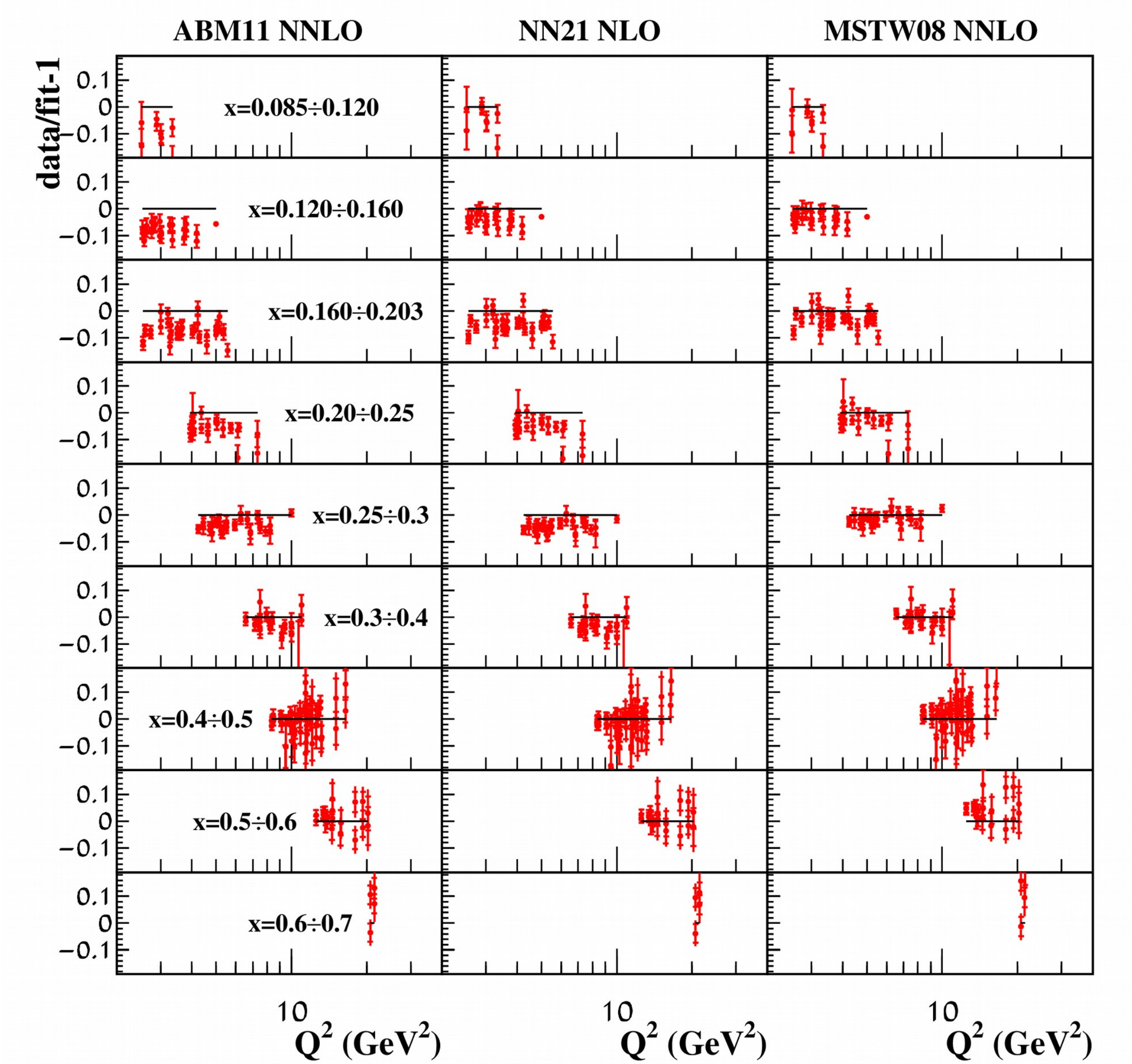
$$m_t(m_t)== 160.8\pm1.1\ \text{GeV}$$

$$m_t(m_t)= 161.1\pm 3.8\text{GeV} \qquad \text{(single-top only)}$$

  - potential impact on the d/u ratio form t/tbar, however validation of MC tools is still needed
- Steady progress with accommodating more DY data into the fit
  - recent ATLAS data at 5 and 7 Tev
  - double differential data on Z-boson production from CMS and ATLAS

EXTRAS

Impact of high twists on SLAC data

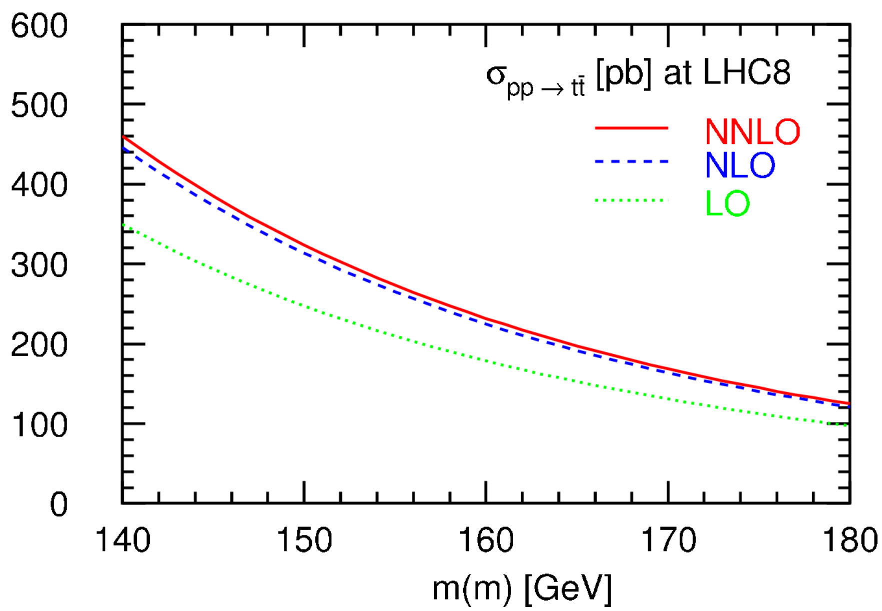


sa, Blümlein, Moch PRD 86, 054009 (2012)

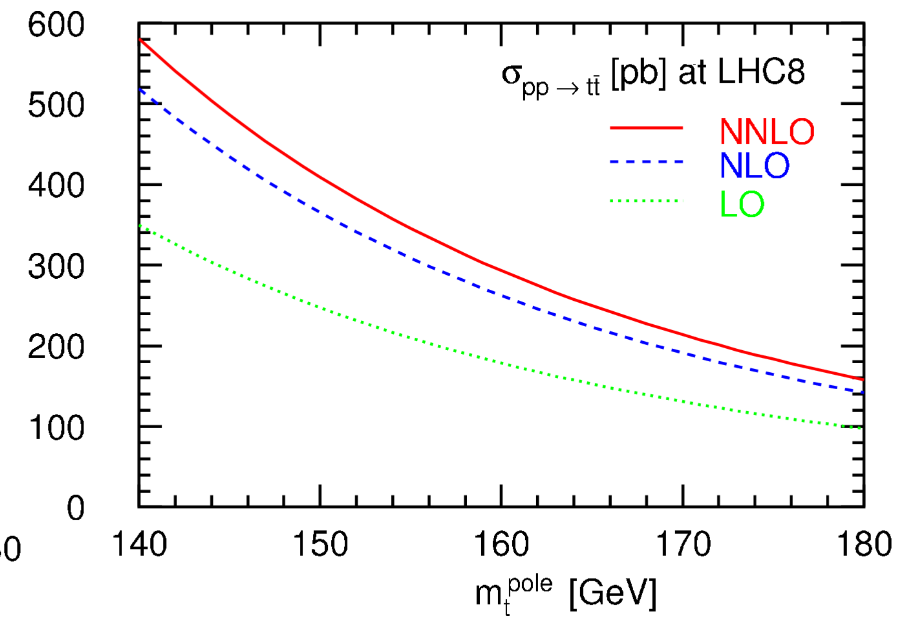
Power-like terms affect comparison even with a cut $W^2 \geq 12.5$ GeV^2

Impact of the t-quark data on the ABMP16 fit

MSbar



Pole

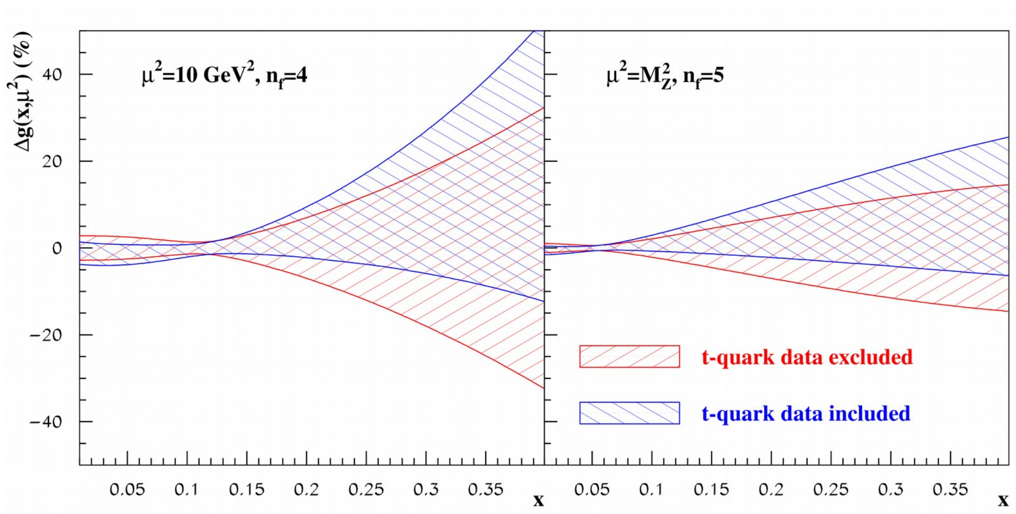


HATHOR (NNLO terms are checked with TOP++)

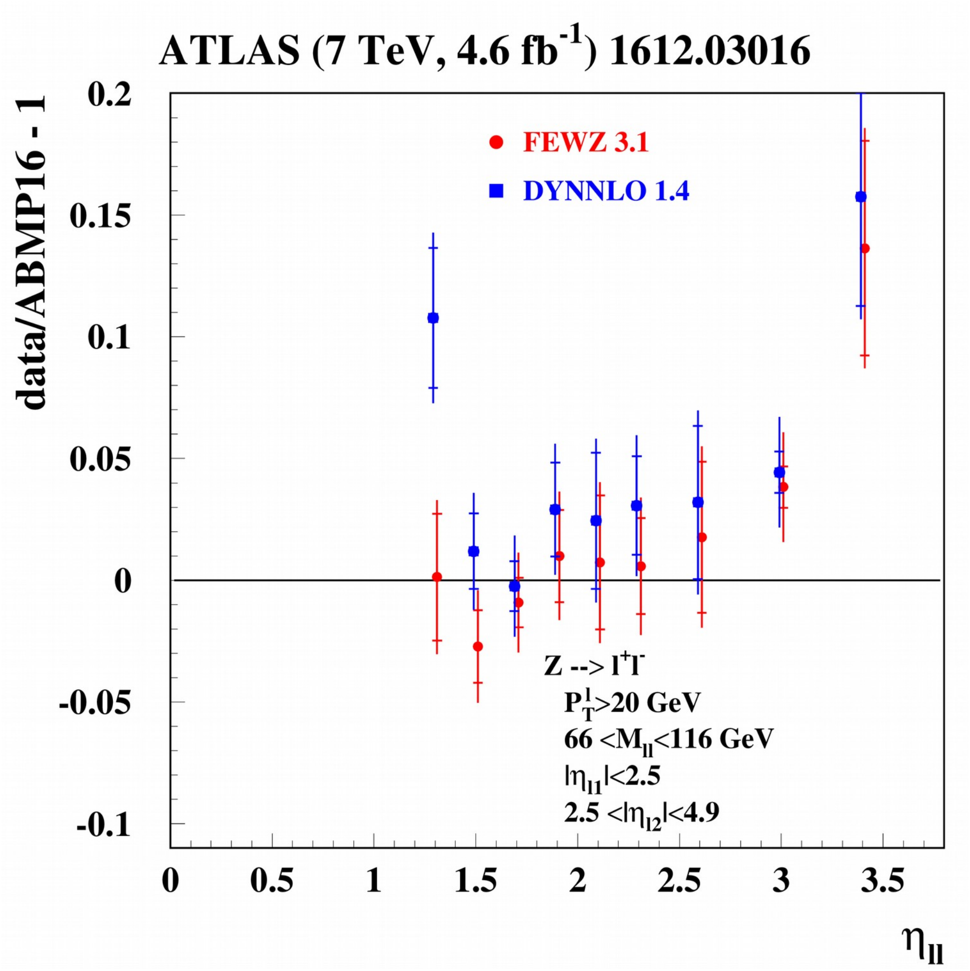
Langenfeld, Moch, Uwer PRD 80, 054009 (2009)

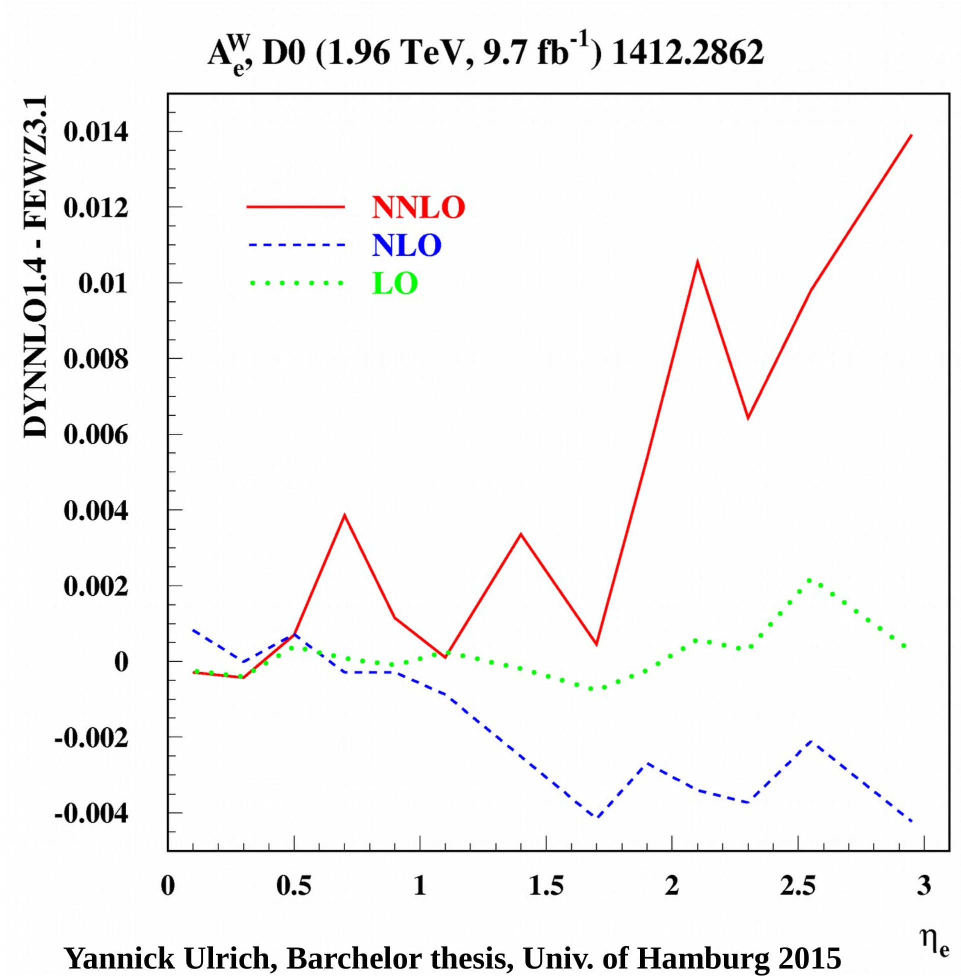
Running mass definition provides nice perturbative stability

Czakon, Fiedler, Mitov PRL 110, 252004 (2013)

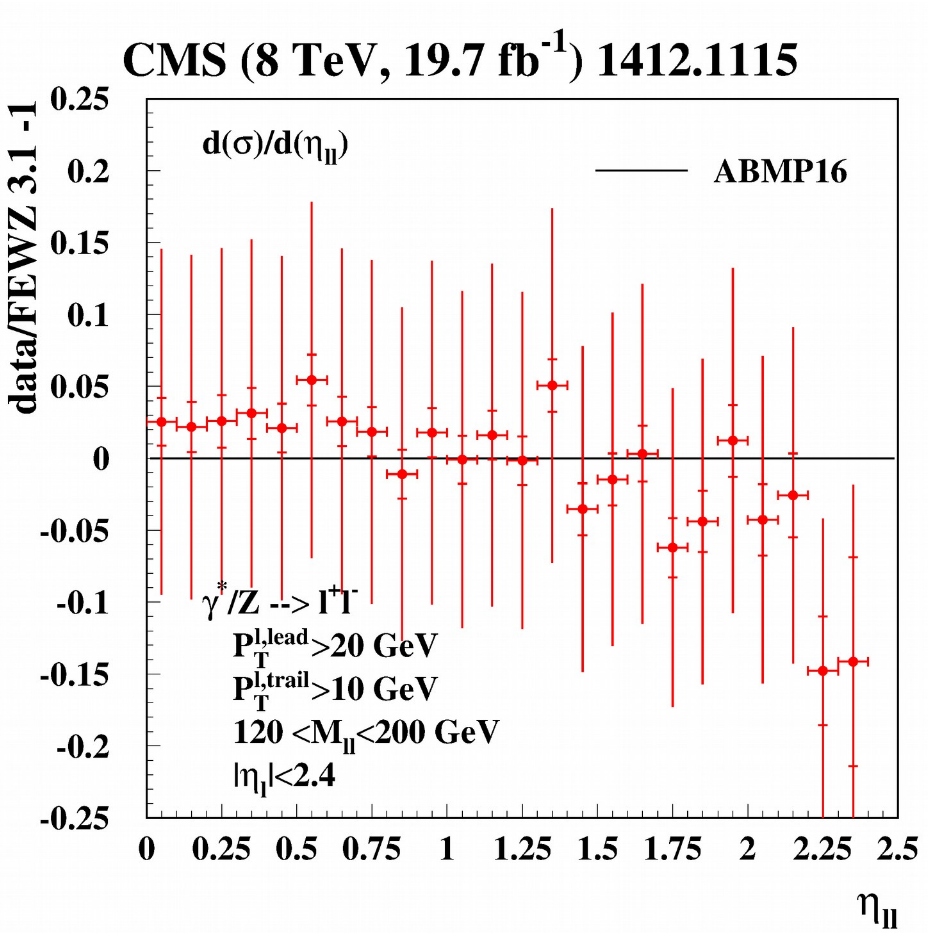


NNLO tools benchmarking

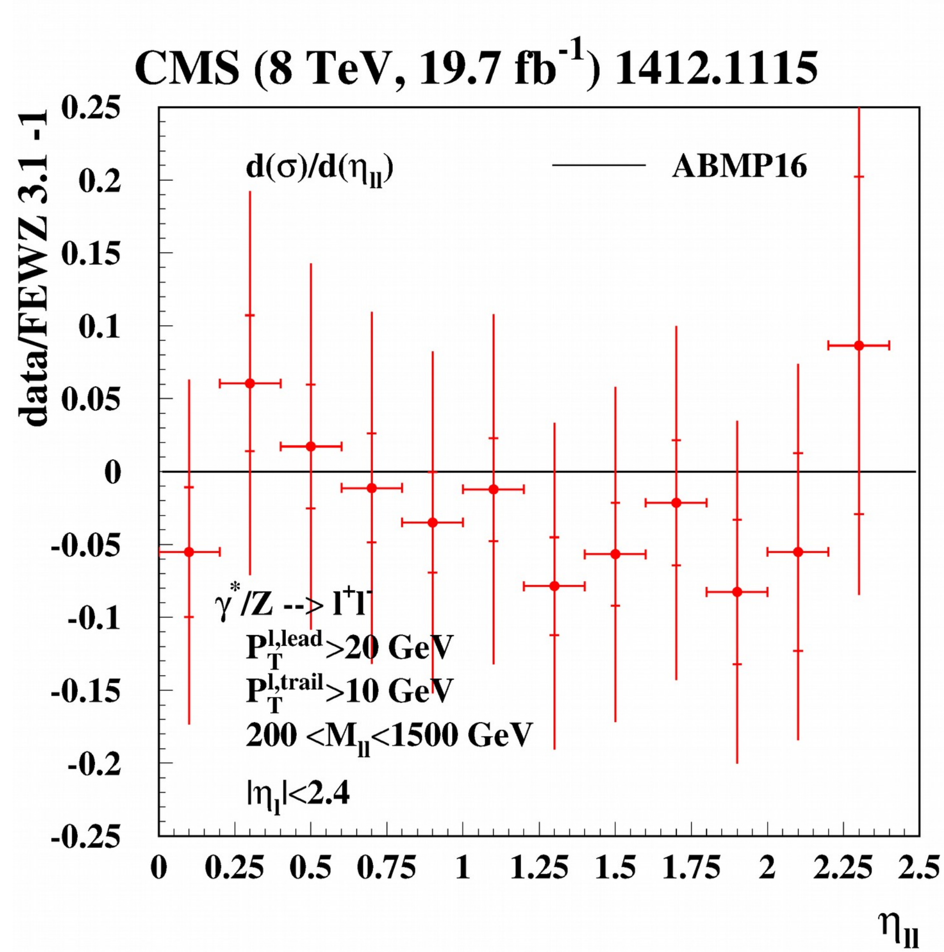




DYNNLO-FEWZ difference not fully understood; further benchmarking is needed

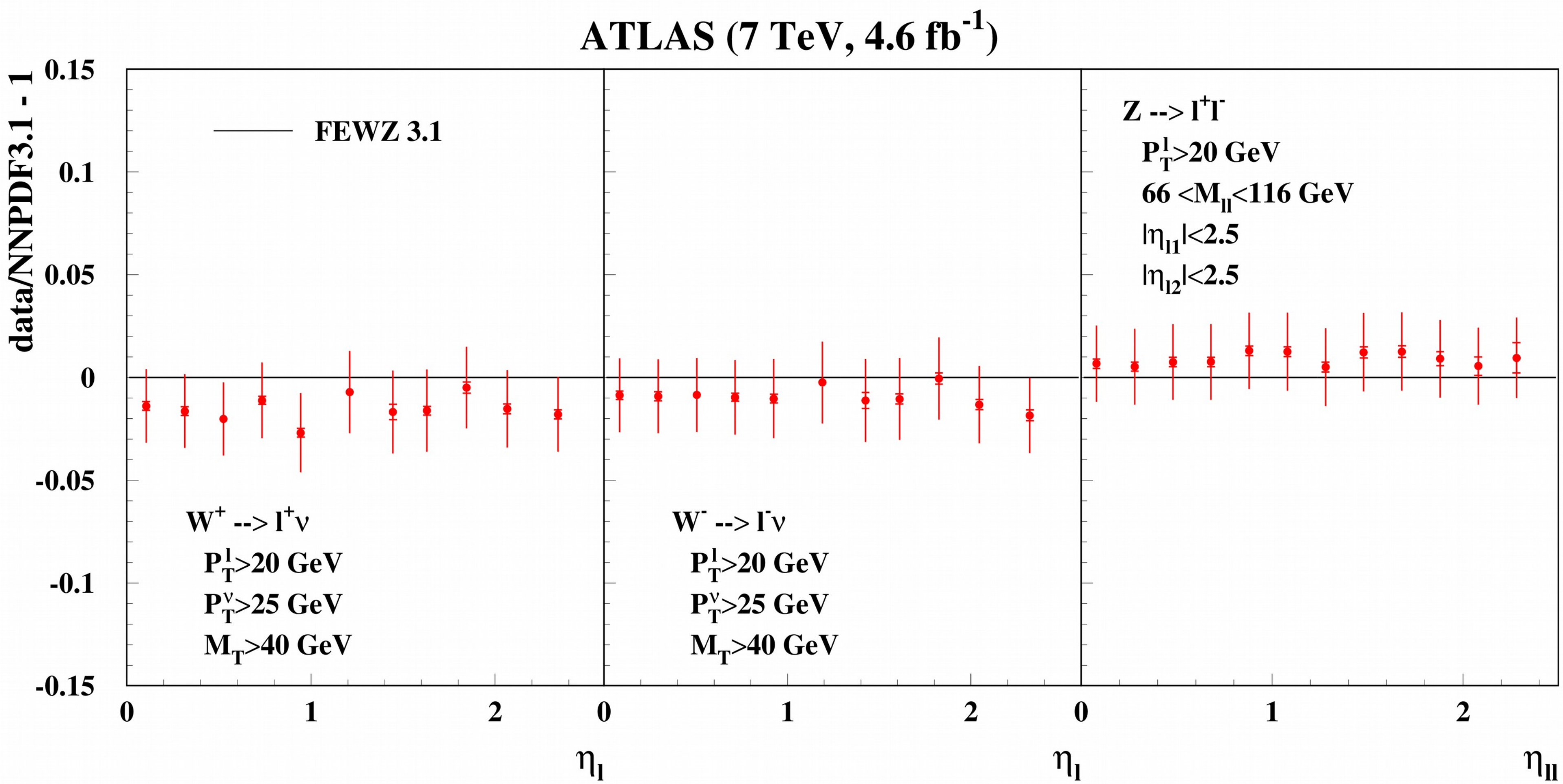


CMS (8 TeV, 19.7 fb-1) 1412.1115
d(σ)/d(ηll)
ABMP16
data/FEWZ 3.1 -1
γ*/Z --> l+l-
PTl,lead>20 GeV
PTl,trail>10 GeV
120 <Mll<200 GeV
|ηl|<2.4
ηll



CMS (8 TeV, 19.7 fb-1) 1412.1115
d(σ)/d(ηll)
ABMP16
data/FEWZ 3.1 -1
γ*/Z --> l+l-
PTl,lead>20 GeV
PTl,trail>10 GeV
200 <Mll<1500 GeV
|ηl|<2.4
ηll

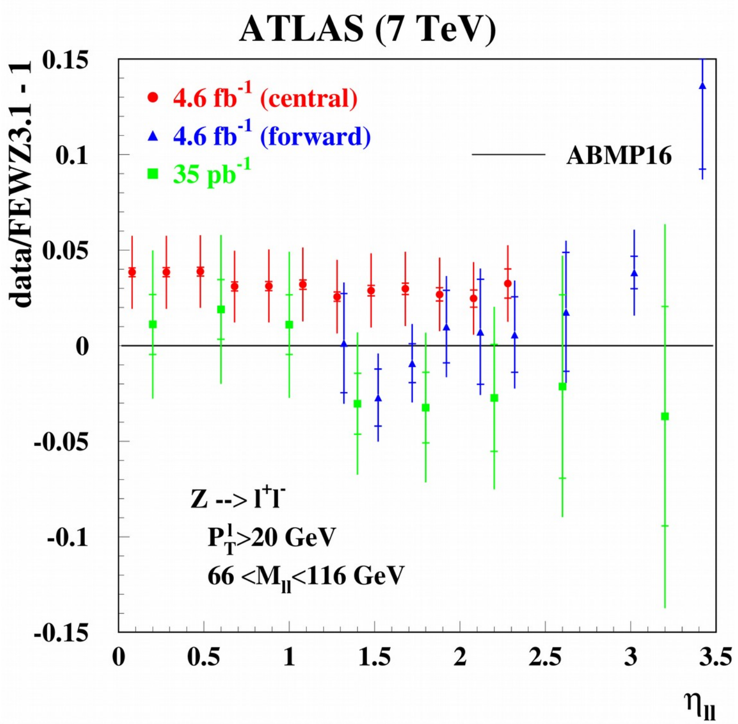
Closure test of the NNPDF3.1 fit

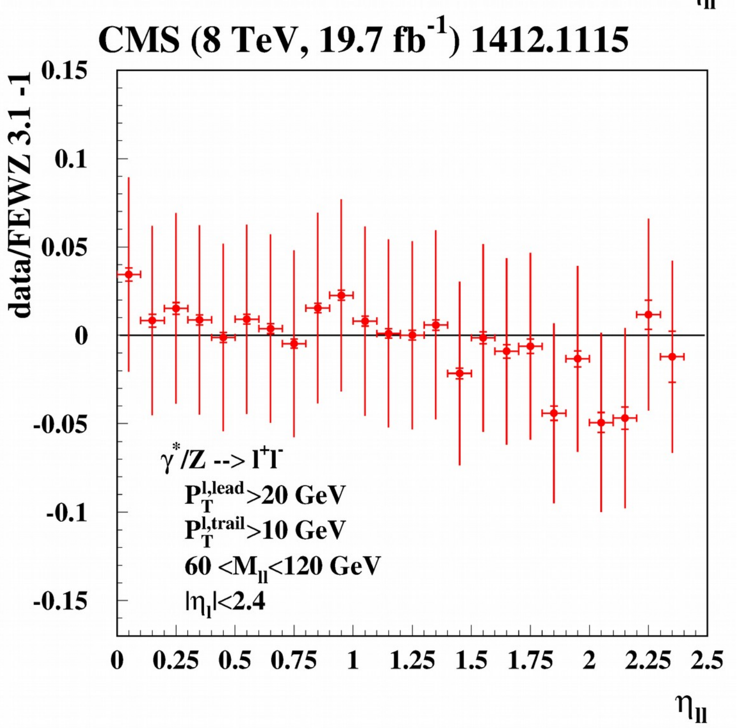


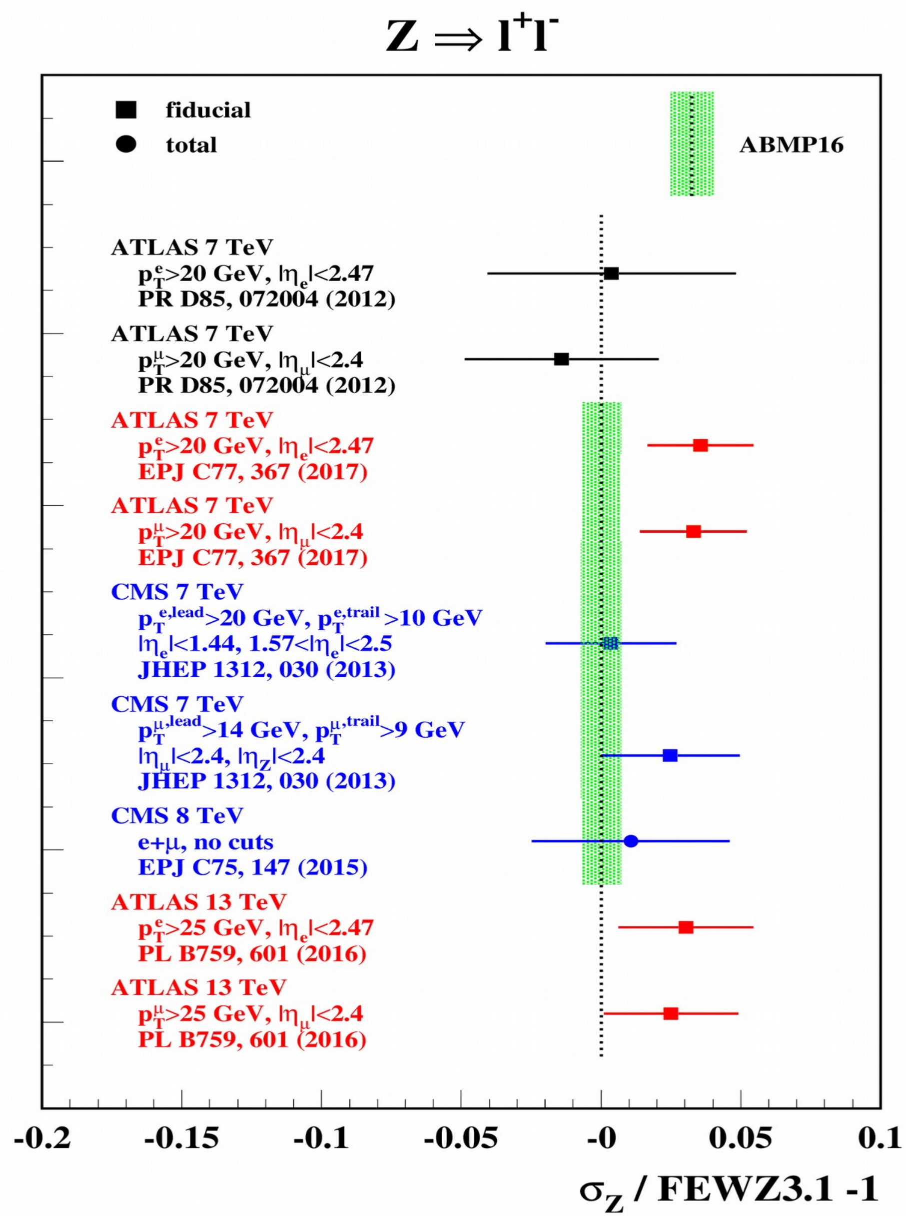
- Different trend for W and Z data ⇒ χ^2/NDP= 400/34; problems with the flavor disentangling

- Suppressed (fitted) charm distribution requires corresponding enhancement of strangeness sur to constraint from W data

DY: ATLAS versus CMS







Different trends for ATAS and CMS Z-production data: ATLAS seems to go higher than CMS with a different trend w.r.t. rapidity; however the errors are still large

NNLO DY corrections in the fit

The existing NNLO codes (DYNNLO, FEWZ) are quite time-consuming → fast tools are employed (FASTNLO, Applgrid,.....)

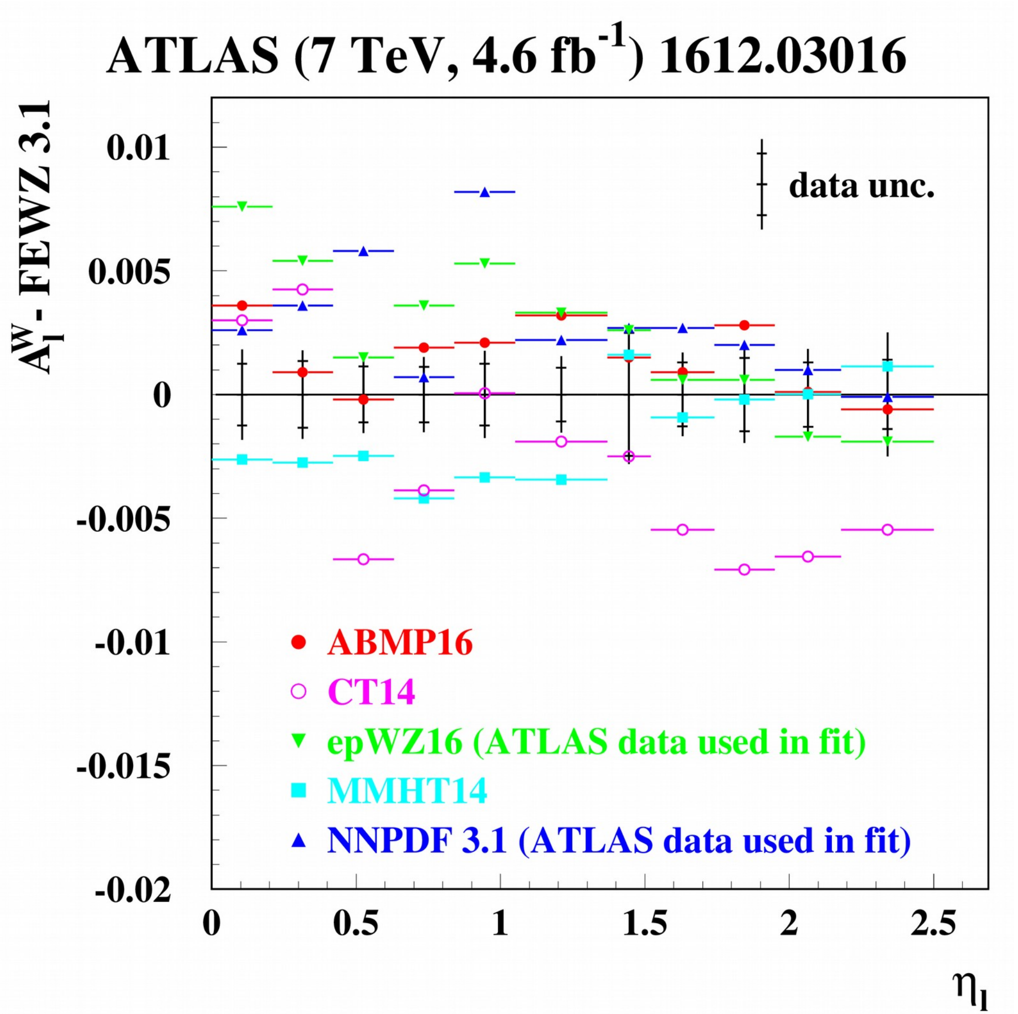
- the corrections for certain basis of PDFs are stored in the grid
- the fitted PDFs are expanded over the basis
- the NNLO c.s. in the PDF fit is calculated as a combination of expansion coefficients with the pre-prepared grids

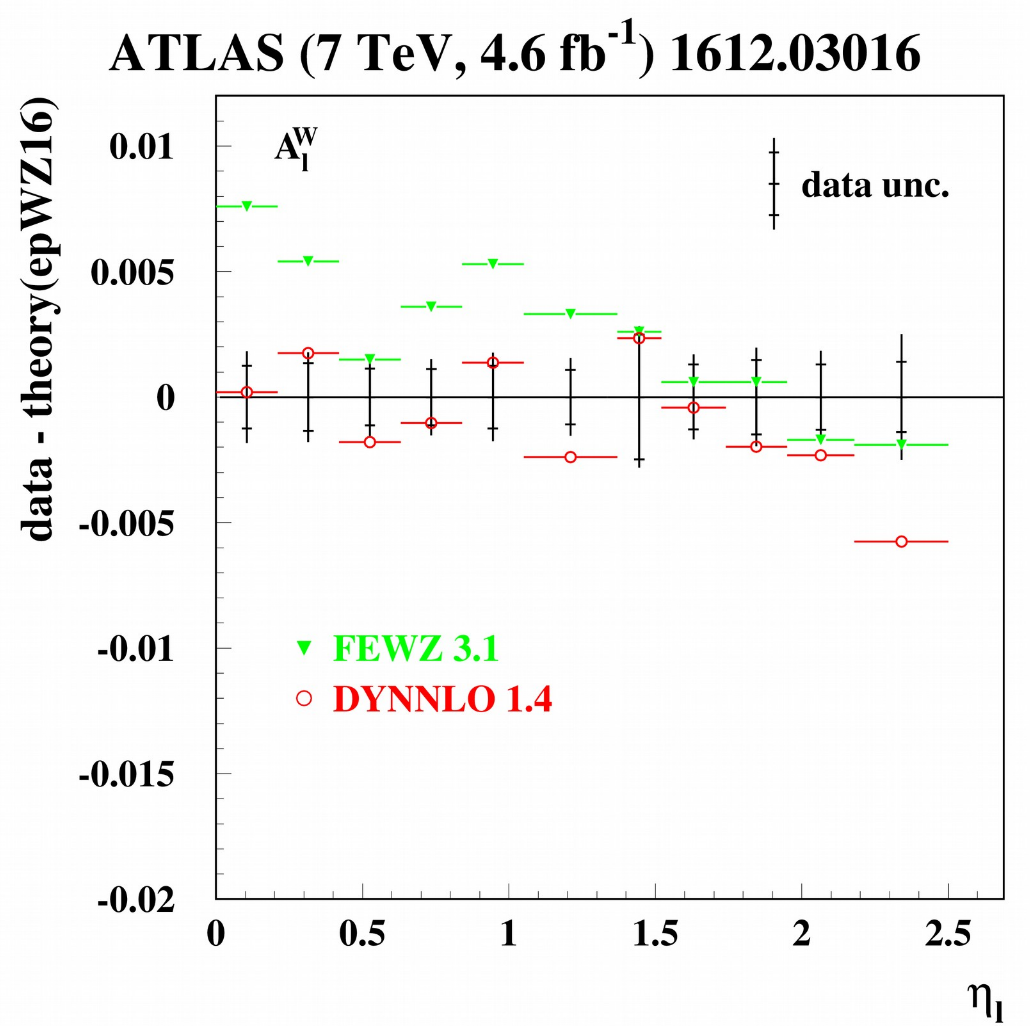
The general PDF basis is not necessary since the PDFs are already constrained by the data, which do not require involved computations → *use as a PDF basis the eigenvalue PDF sets obtained in the earlier version of the fit*

$\mathbf{P_0} \pm \Delta\mathbf{P}_0$ – vector of PDF parameters with errors obtained in the earlier fit
E – error matrix
P – current value of the PDF parameters in the fit

- store the DY NNLO c.s. for all PDF sets defined by the eigenvectors of **E**
- the variation of the fitted PDF parameters ($\mathbf{P} - \mathbf{P}_0$) is transformed into this eigenvector basis
- the NNLO c.s. in the PDF fit is calculated as a combination of transformed ($\mathbf{P} - \mathbf{P}_0$) with the stored eigenvector values

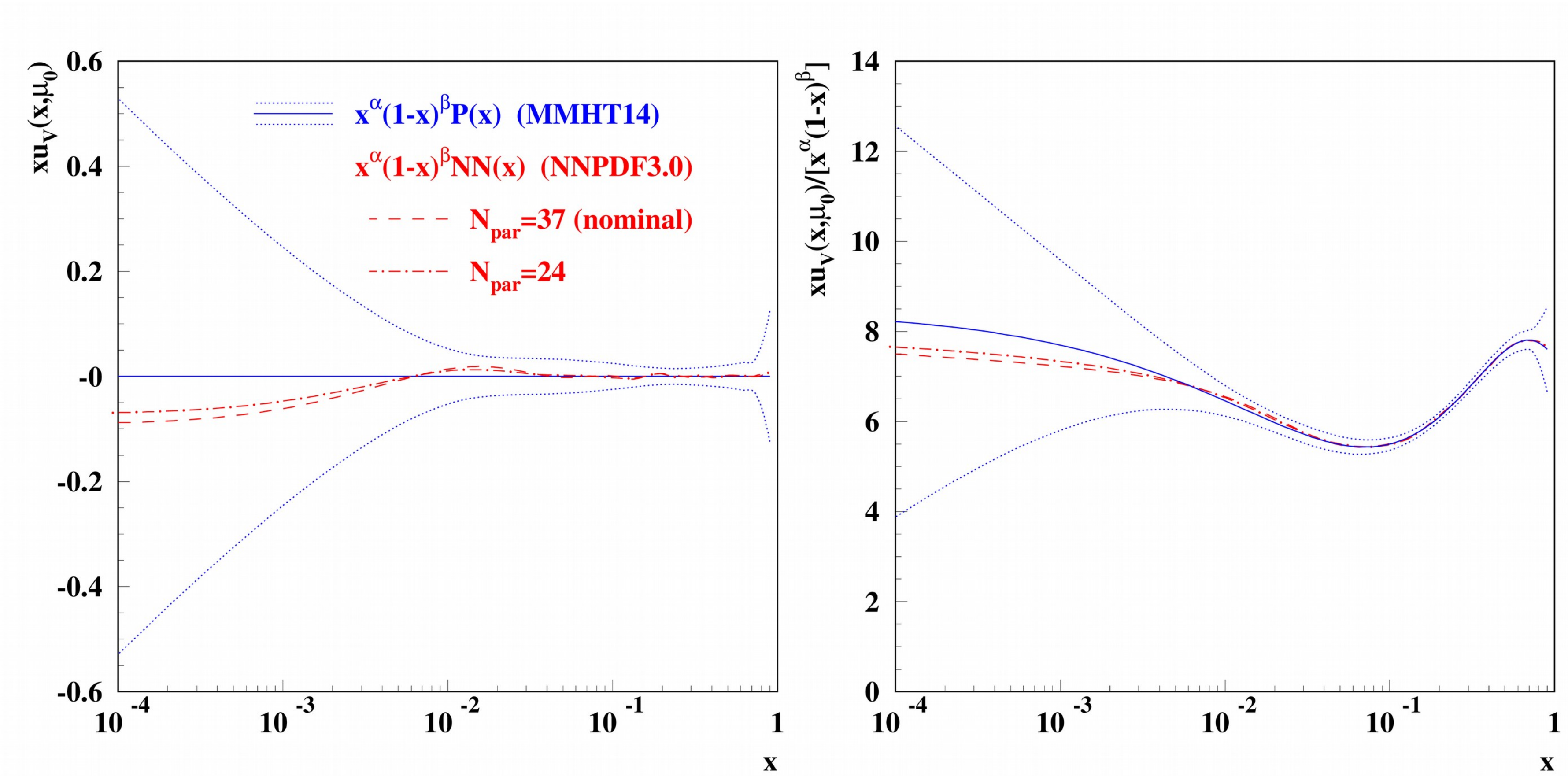
DY: tool benchamrking





A variety of tools/methods employed in the PDF fits: DYNNO/FEWZ/ResBos, NLO combined with NNLO K-factors, etc. → a consolidation is required for using potential of the existing data.

Test fit with the neural network shape



- Valence u-quark is modeled by $x^\alpha(1-x)^\beta NN(x)$, where NN is neural network with 37 parameters (NNPDF3.0 ansatz), other PDFs use MMHT14 shape

- Result is in quite agreement with the MMHT14 shape $x^\alpha(1-x)^\beta P(x)$ with 4 paramters in P(x) ⇒ no particular flexibility is provided by neural network

- Study of sea and gluon distribution in progress, the same behaviour expected