ABM PDFs tuned to the LHC data

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

- Heavy quark electro-production
- LHC Drell-Yan data in the ABM fit
- Impact of the ttbar production data on the PDFs and α_s
- Standard candle benchmarks

sa, Blümlein, Moch hep-ph/1310.3059
sa, Blümlein, Moch hep-ph/1308.5166
sa, Blümlein, Moch hep-ph/1308.4750
sa, Blümlein, Moch hep-ph/1303.1073
sa, Blümlein, Moch hep-ph/1302.1516
sa, Blümlein, Daum, Lipka, Moch PLB 720, 172 (2013)

7-th Annual workshop "Physics at Terascale", Karlsruhe, 3 Dec 2013

The ABM fit ingredients

DATA:

- DIS NC inclusive (Q^2>1000 GeV^2)
- DIS charm production (determination of $m_c(m_c)$) **cf. Lipka's talk on PROSA**
- DIS μμ CC production
- fixed-target DY
- LHC DY distributions
- t-quark production c.s.

QCD:

- NNLO evolution
- NNLO massless DIS and DY coefficient functions (Z- and Z-γ terms)
- NLO+ massive DIS coefficient functions (**FFN scheme**)
  (NLO + NNLO threshold corrections, running mass)
- NNLO exclusive DY (DYNNLO 1.3 / FEWZ 3.1)
- NNLO inclusive ttbar production (pole / running mass)

Deuteron corrections in DIS:

- Fermi motion
- off-shell effects

Power corrections in DIS:

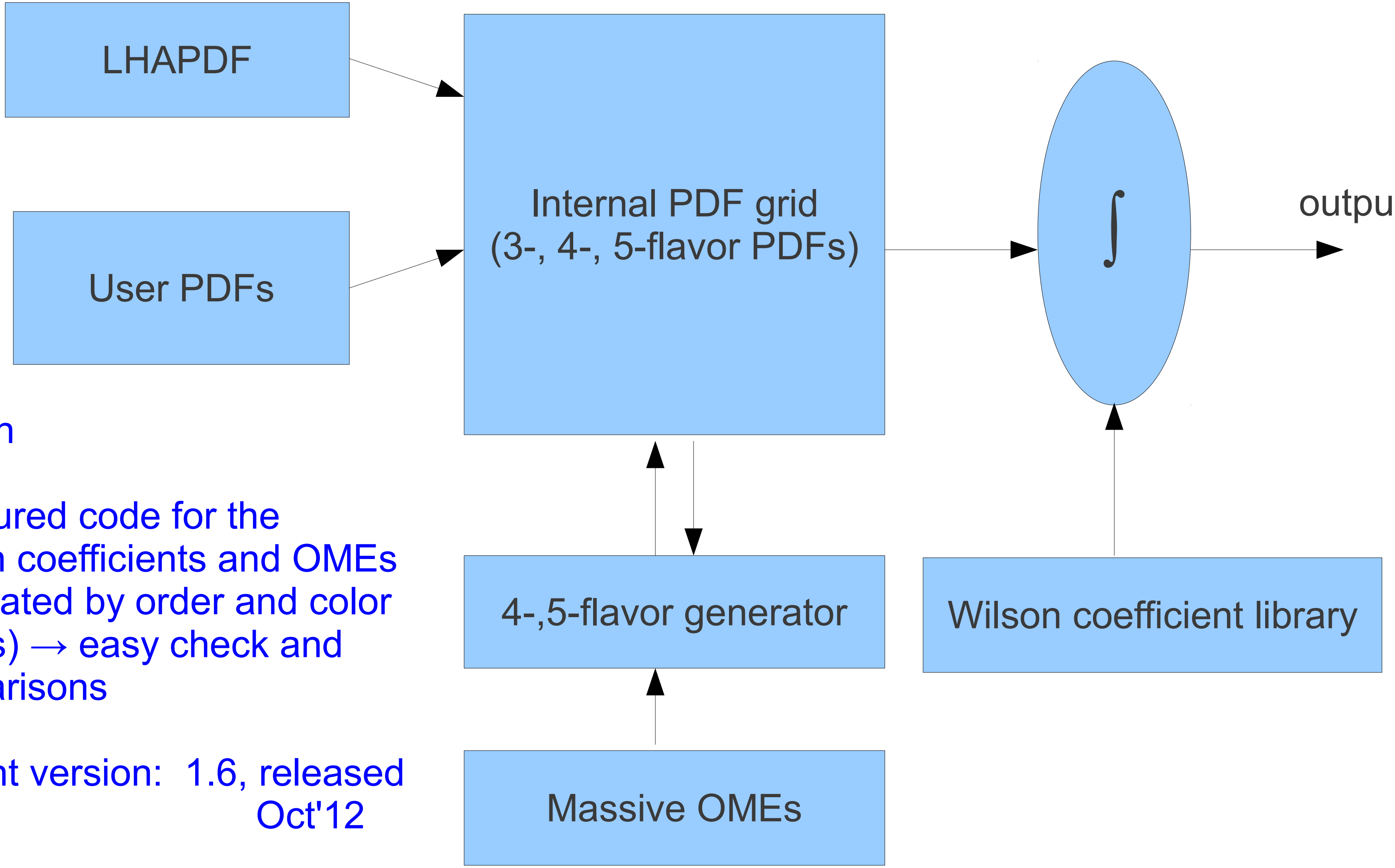
- target mass effects
- dynamical twist-4 terms

The jet data are still not included: The NNLO corrections may be as big as 15-20%

Gehrmann-De Ridder, Gehrmann, Glover, Pires JHEP 1302, 026 (2013)

OPENQCDRAD

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



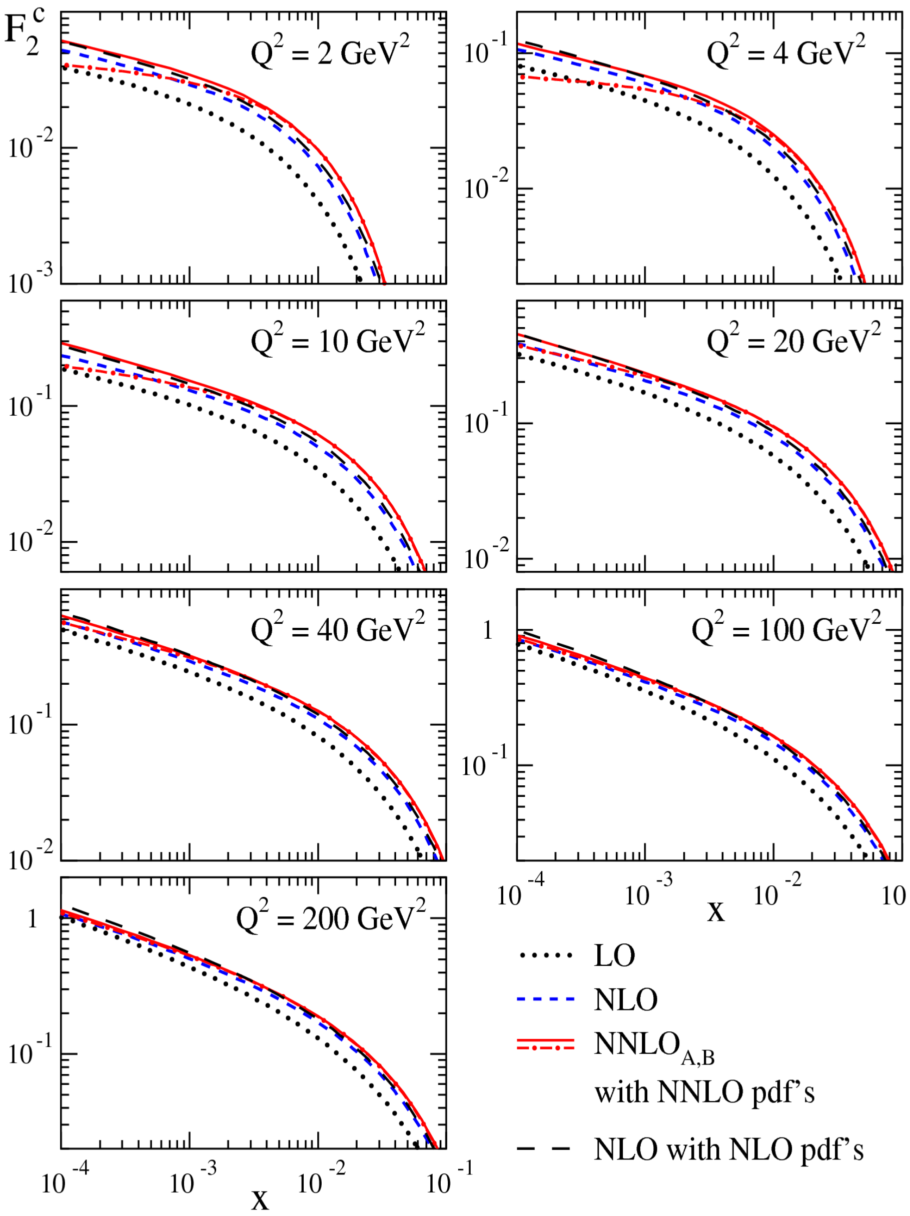
Fortran

Structured code for the Wilson coefficients and OMEs (separated by order and color factors) → easy check and comparisons

Current version: 1.6, released Oct'12

- Updated massive NNLO Wilson coefficients **Kawamura, Lo Presti, Moch, Vogt NPB 864, 399 (2012)**
- Z-exchange term up to NNLO **Klein, Rieman ZPC 24, 151 (1984)** **Zijlstra van Neerven NPB 383, 525 (1992)**

Massive NNLO coefficients updated



Kawamura, Lo Presti, Moch, Vogt NPB 864, 399 (2012)

- The NNLO log terms are known due to the recursive relations
- The constant NNLO term stem from:
  - the threshold resummation terms including the Coulomb one
  - high-energy asymptotics obtained with the small-x resummation technique

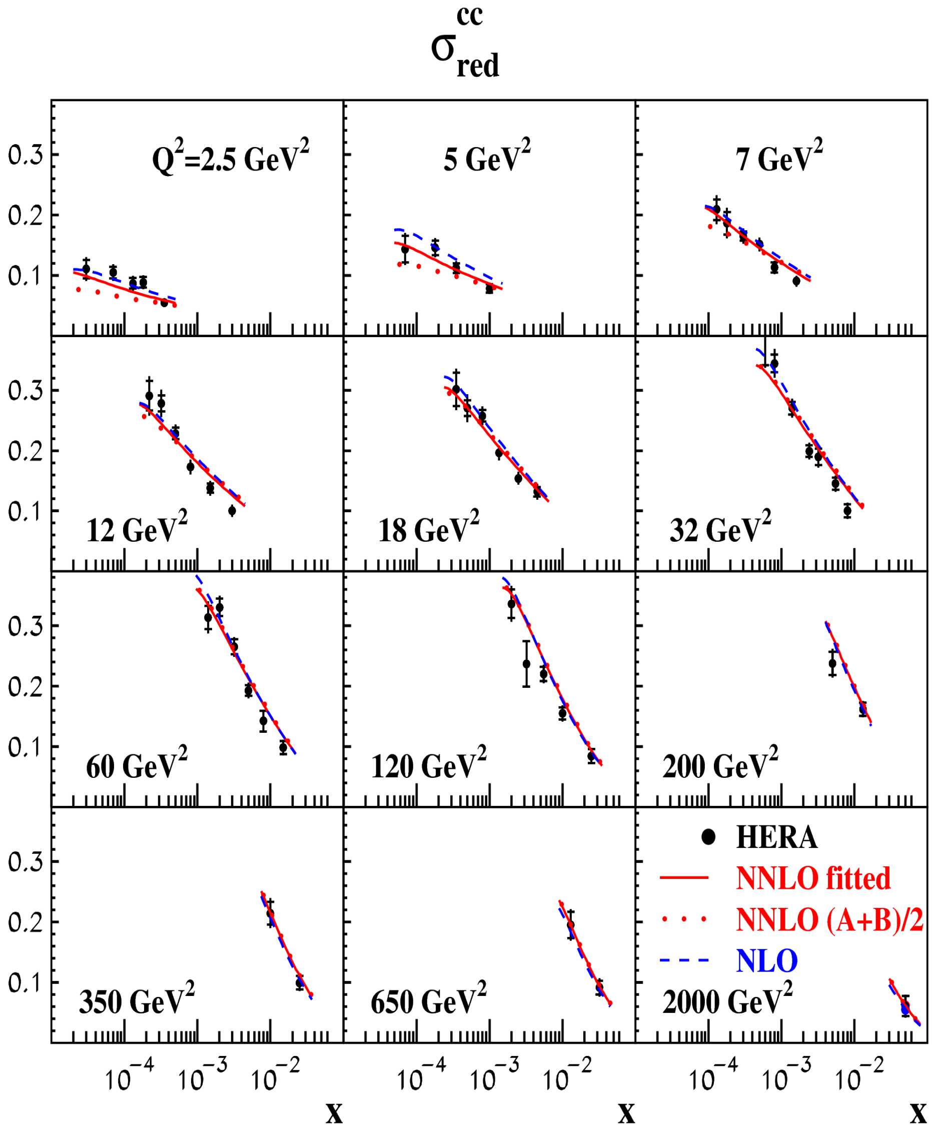
    Catani, Ciafaloni, Hautmann NPB 366, 135 (1991)
  - available NNLO Mellin moments for the massive OMEs

    Ablinger at al. NPB 844, 26 (2011)

    Bierenbaum, Blümlein, Klein NPB 829, 417 (2009)
- The uncertainty in the NNLO coefficients is due to matching of the threshold corrections with the high-energy limit → two options for the coefficients are provided
- Further improvement should come from additional Mellin moments

Blümlein at al. in progress

HERA charm data in the ABM fit



sa, Blümlein, Daum, Lipka, Moch PLB 720, 172 (2013)

- Combined H1-ZEUS data on the c-quark DIS

  H1/ZEUS PLB 718, 550 (2012)

- Approximate NNLO massive Wilson coefficients (combination of the threshold corrections, high-energy limit, and the NNLO massive OMEs)

  Kawamura, Lo Presti, Moch, Vogt NPB 864, 399 (2012)

- Running-mass definition of m_c

  sa, Moch PLB 699, 345 (2011)

- χ^2/NDP=61/52 (data prefer option A for the massive Wilson coefficients)

$m_c(m_c)$=1.15±0.04(exp.) GeV NLO

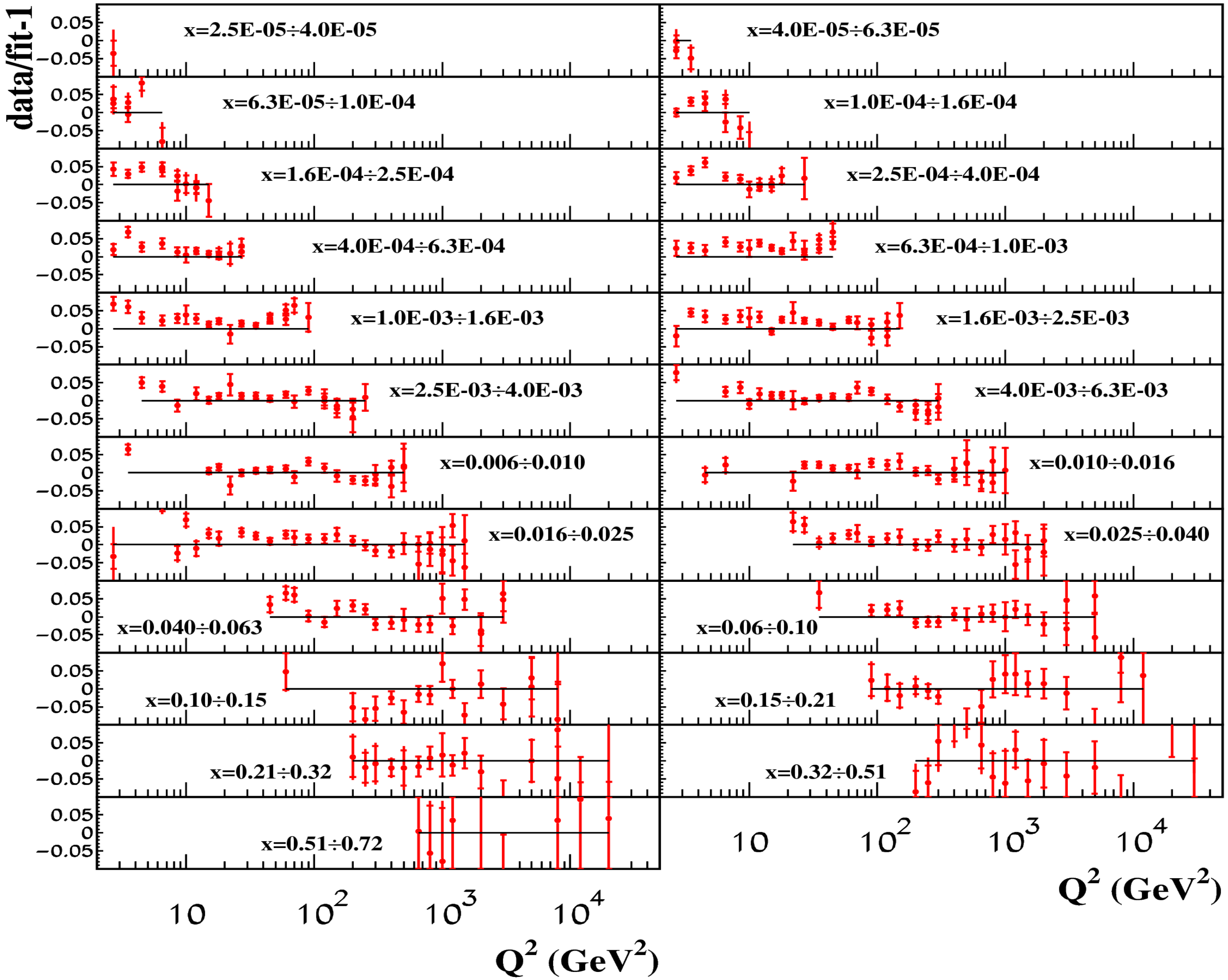
$m_c(m_c)$=1.24±0.03(exp.),+0.-0.07(th) GeV NNLO

(theoretical uncertainty due to choice of massive NNLO coefficients)

Good agreement with the e+e- determinations → the FFN scheme nicely works for the existing data

HERA inclusive data in the ABM fit

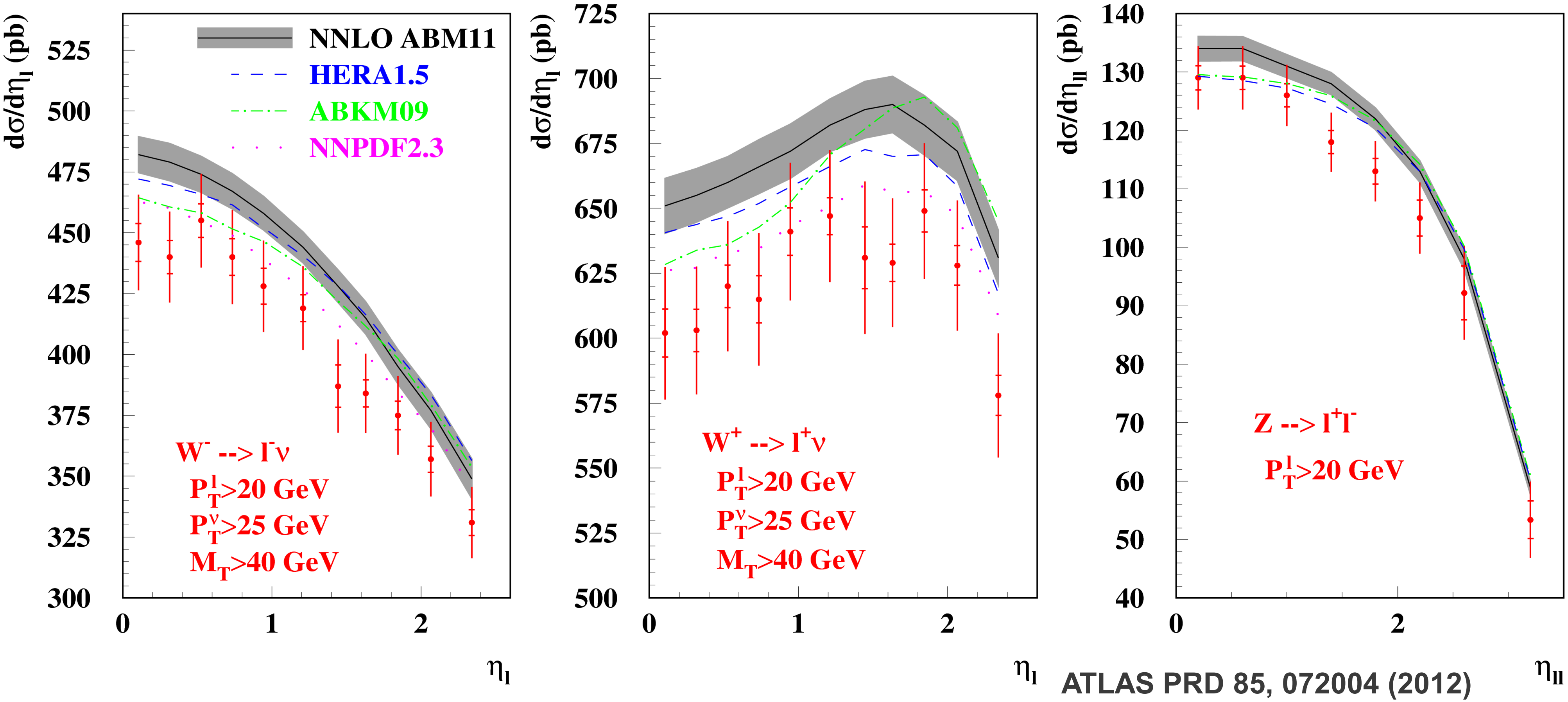
H1/ZEUS JHEP 1001, 109 (2010)



FFN scheme is relevant up to the biggest values of Q^2 at HERA

NNLO Drell-Yan codes

ATLAS (7 TeV, 35 1/pb)



ATLAS PRD 85, 072004 (2012)

- DYNNLO 1.3 provides better numerical stability for the W-production in central region ~ 200h

Catani, Cieri, Ferrera, de Florian, Grazzini PRL 103, 082001 (2009)

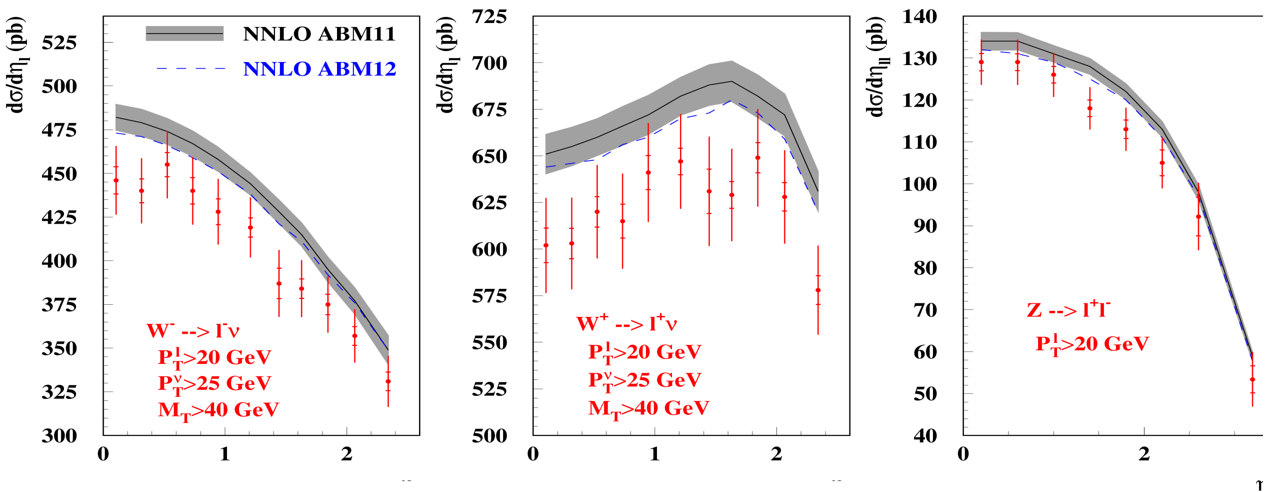
- FEWZ 3.1 more convenient/stable for estimation of the PDF uncertainties ~ 50h x 24proc.

Li, Petriello PRD 86, 094034 (2012)

→ central values are calculated with DYNNLO and the PDF errors are obtained with FEWZ the results for different PDF eigenvectors can be used in the fit to compute the NNLO DY c.s. for the varied PDF parameters (cf.Extras for details)

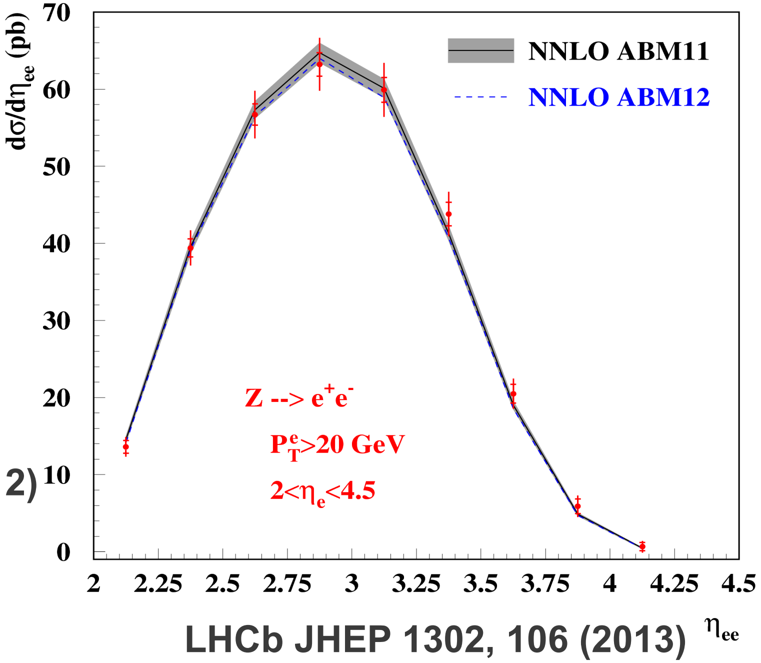
LHC Drell-Yan data in the ABM fit

ATLAS (7 TeV, 35 1/pb)



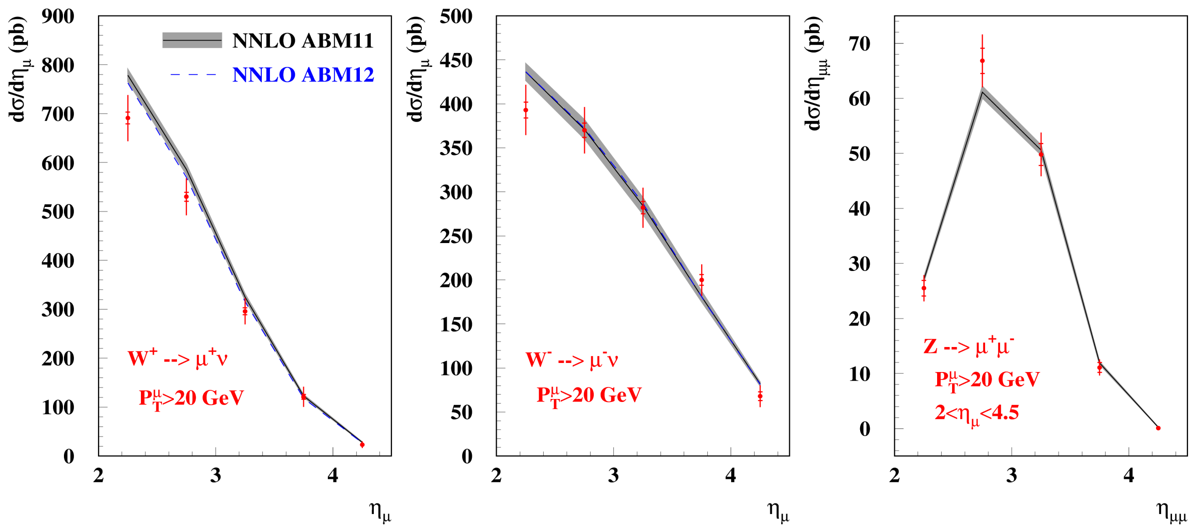
ATLAS PRD 85, 072004 (2012)

LHCb (7 TeV, 940 1/pb)



LHCb JHEP 1302, 106 (2013)

LHCb (7 TeV, 37 1/pb)



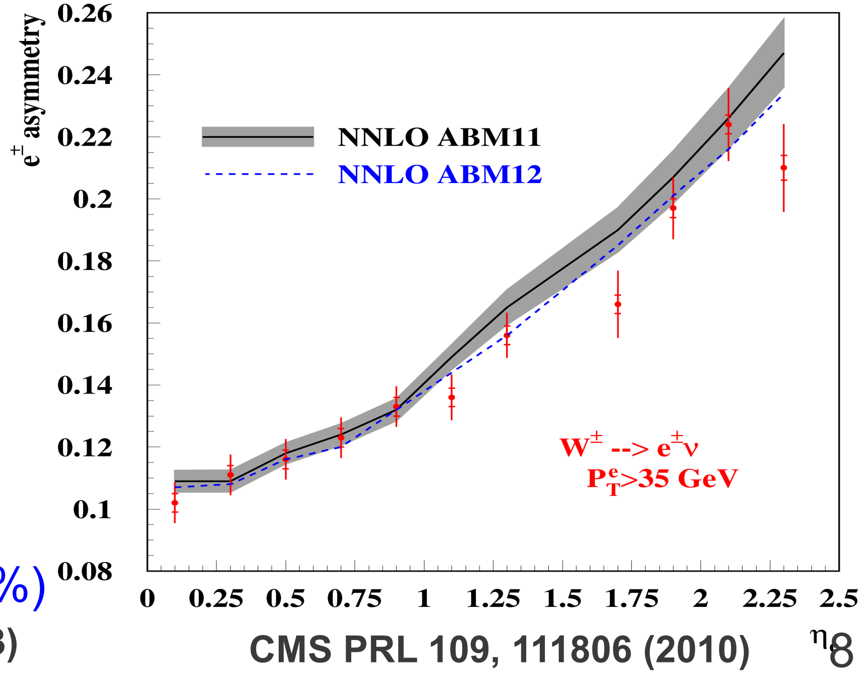
LHCb JHEP 1206, 058 (2012)

- Good overall agreement: χ^2/NDP=68/60

- Some tension between data in places:
  – ATLAS data go above recent LHCb e+e- data
(note. however change in the ATLAS luminosity by 1.9%)

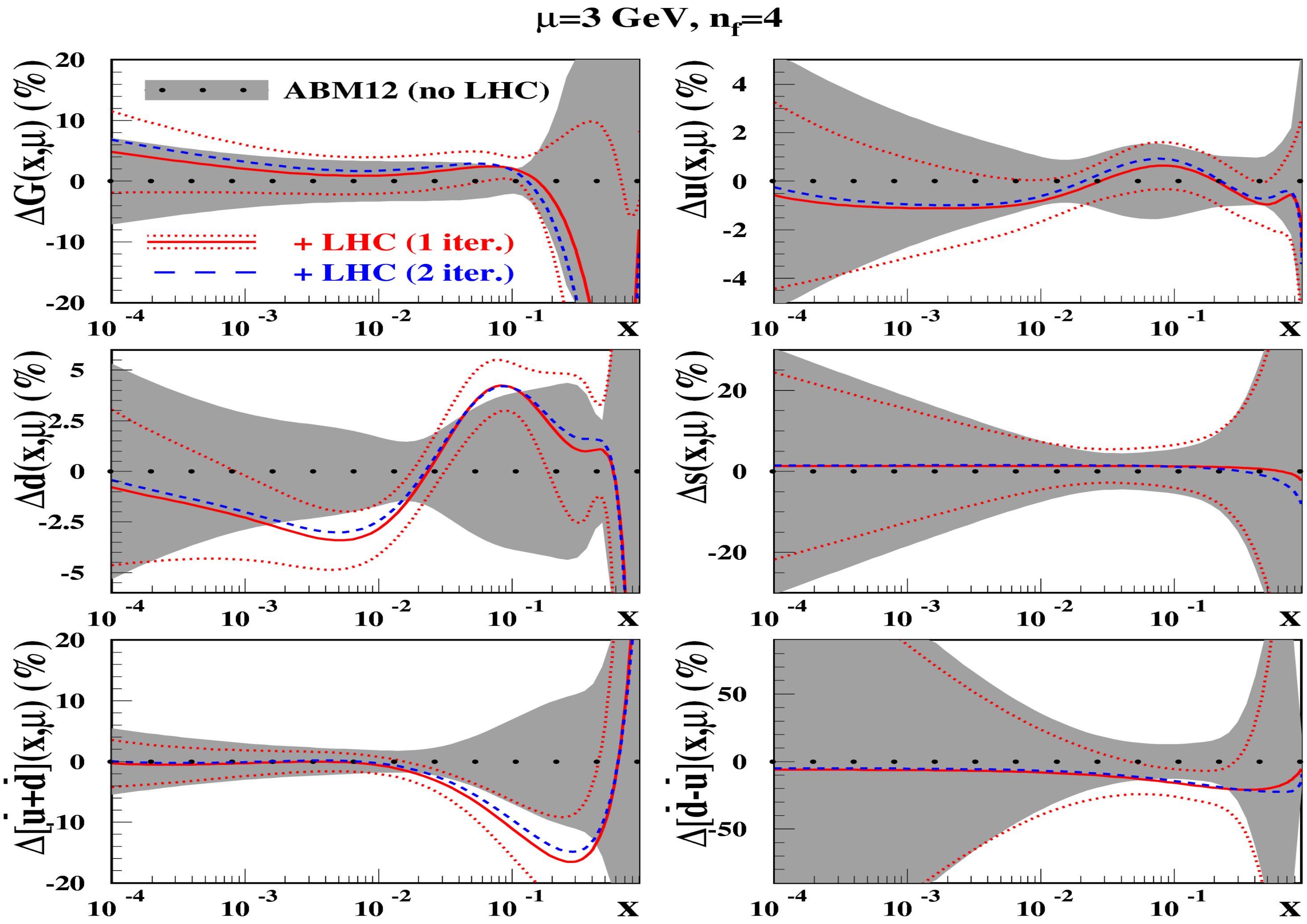
ATLAS EPJC 73, 2518 (2013)

CMS (7 TeV, 840 1/pb)



CMS PRL 109, 111806 (2010)

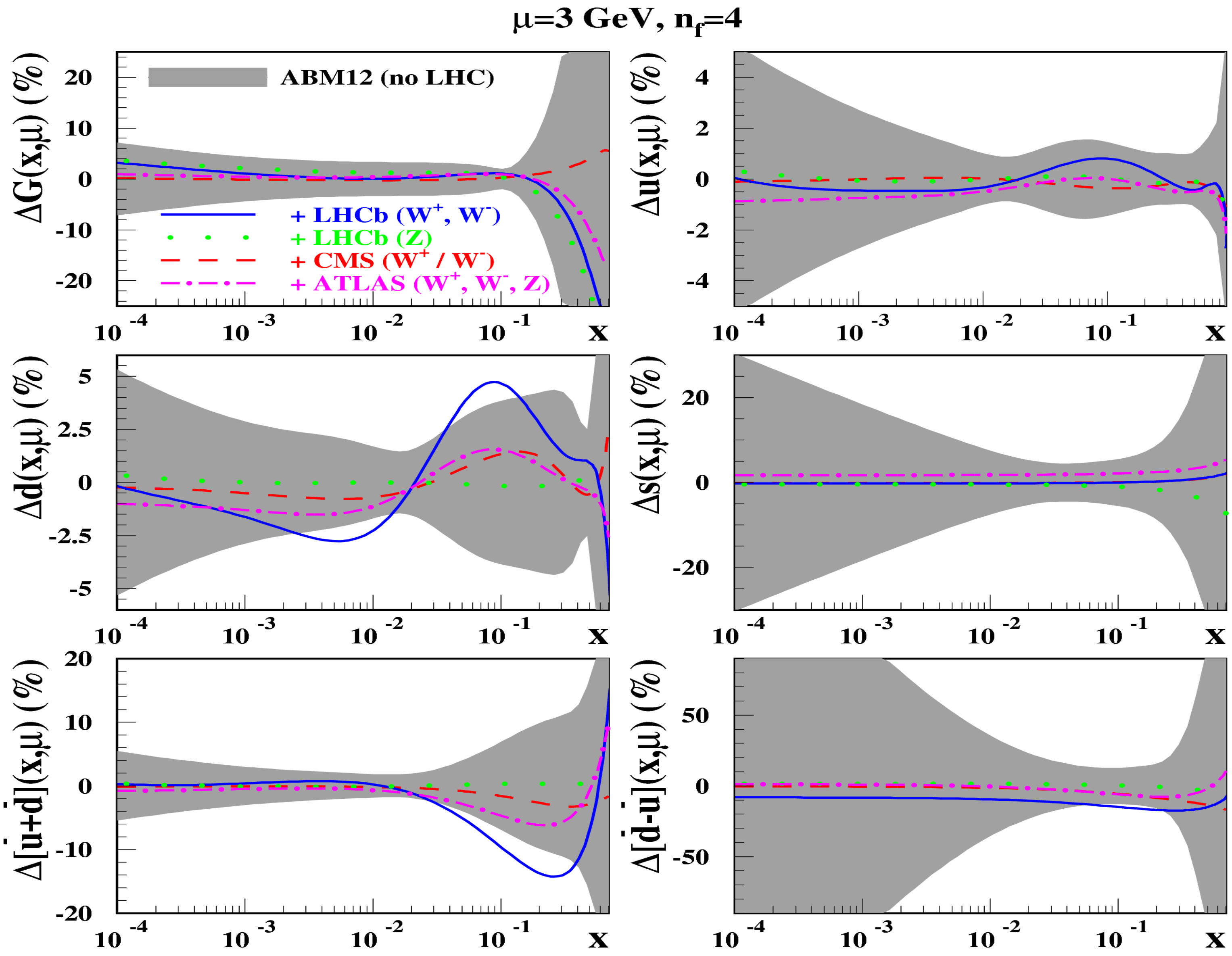
Impact of the LHC DY data on the PDFs



- d-quarks increase at x~0.1; *the errors get smaller*
- non-strange sea decrease at x~0.1
- strange sea stable → the enhancement observed by ATLAS is not confirmed

The algorithm used to include the LHC data is quite stable

Impact of the separate LHC data sets

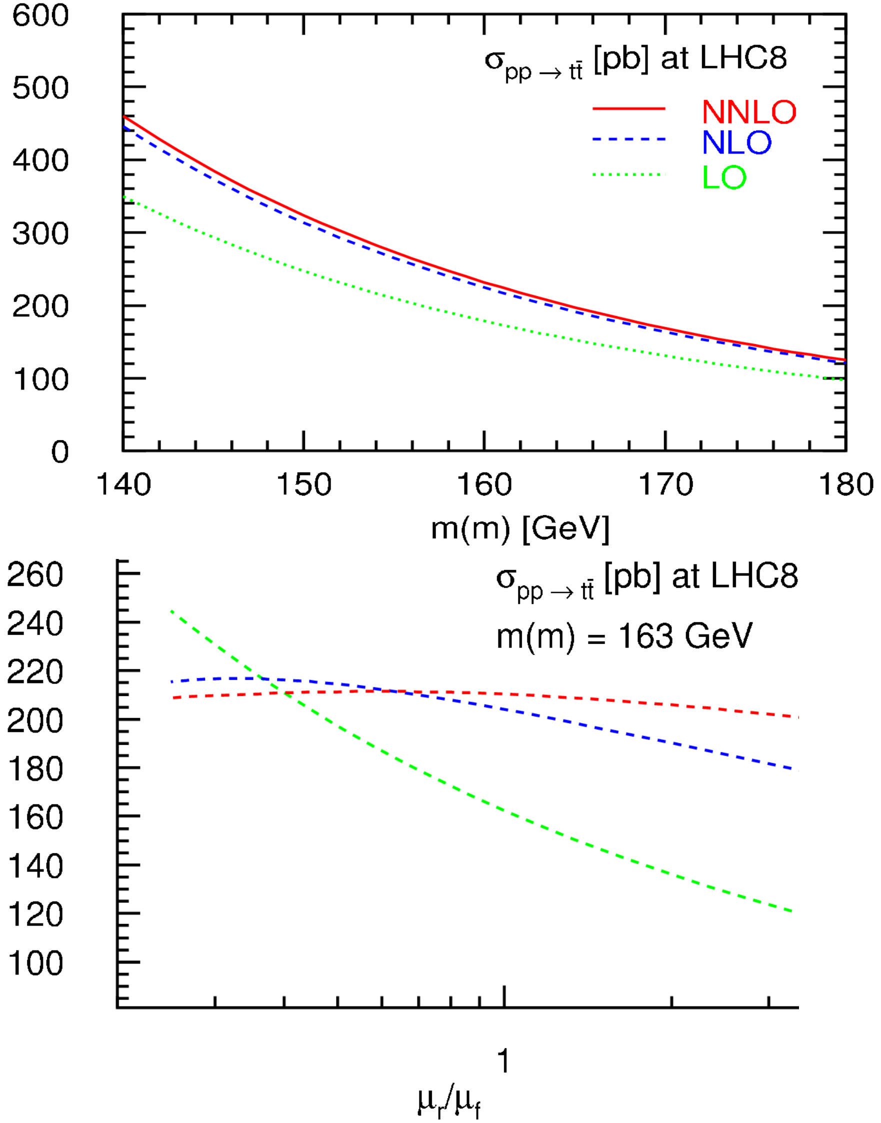


The biggest effect come from the LHCb data, i.e. from the large rapidity region

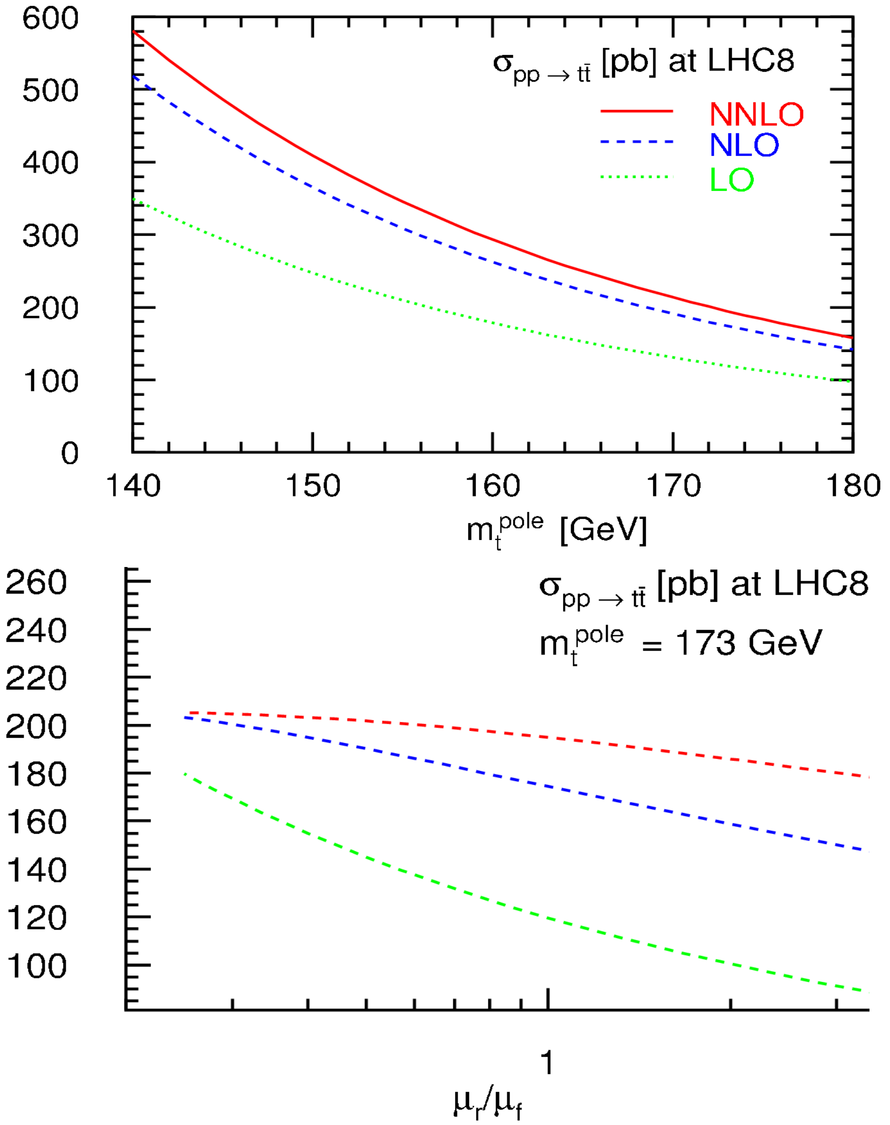
Pole- and running-mass definitions

Dowling, Moch hep-ph/1305.6433

Running mass



Pole mass



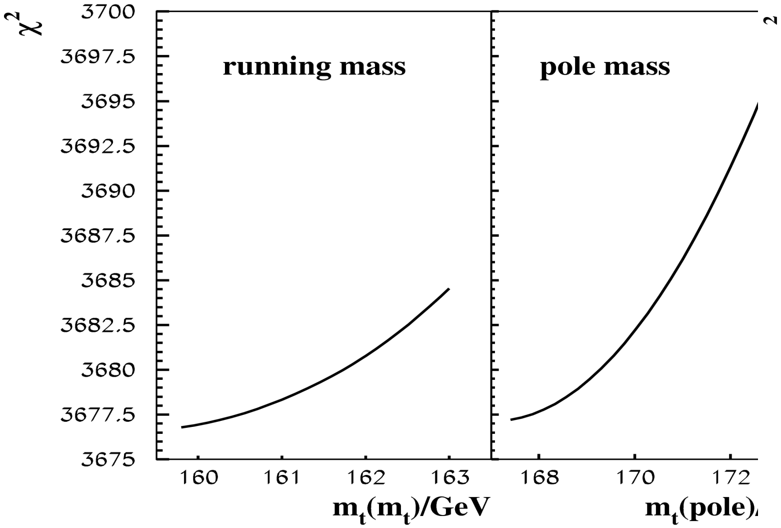
Hathor (NNLO terms are checked with TOP++)

Langenfeld, Moch, Uwer PRD 80, 054009 (2009)
Czakon, Fiedler, Mitov hep-ph/1303.6254

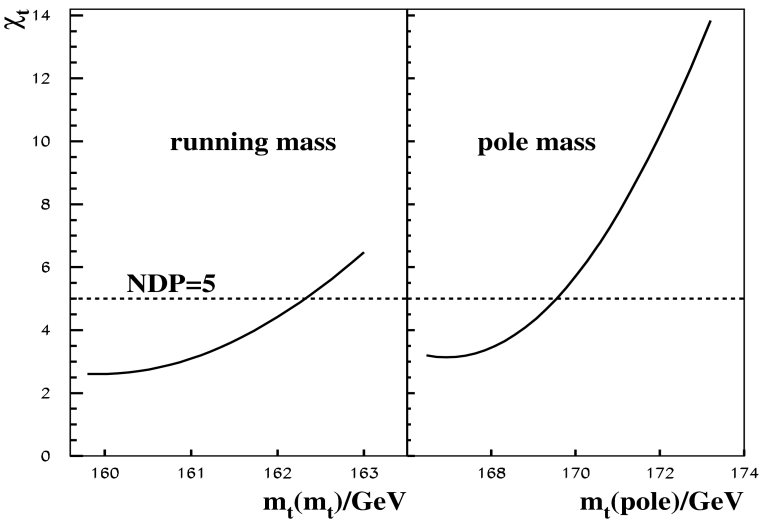
Running mass definition provides nice perturbative stability

Impact of the t-quark data on PDFs and α_s

total χ^2

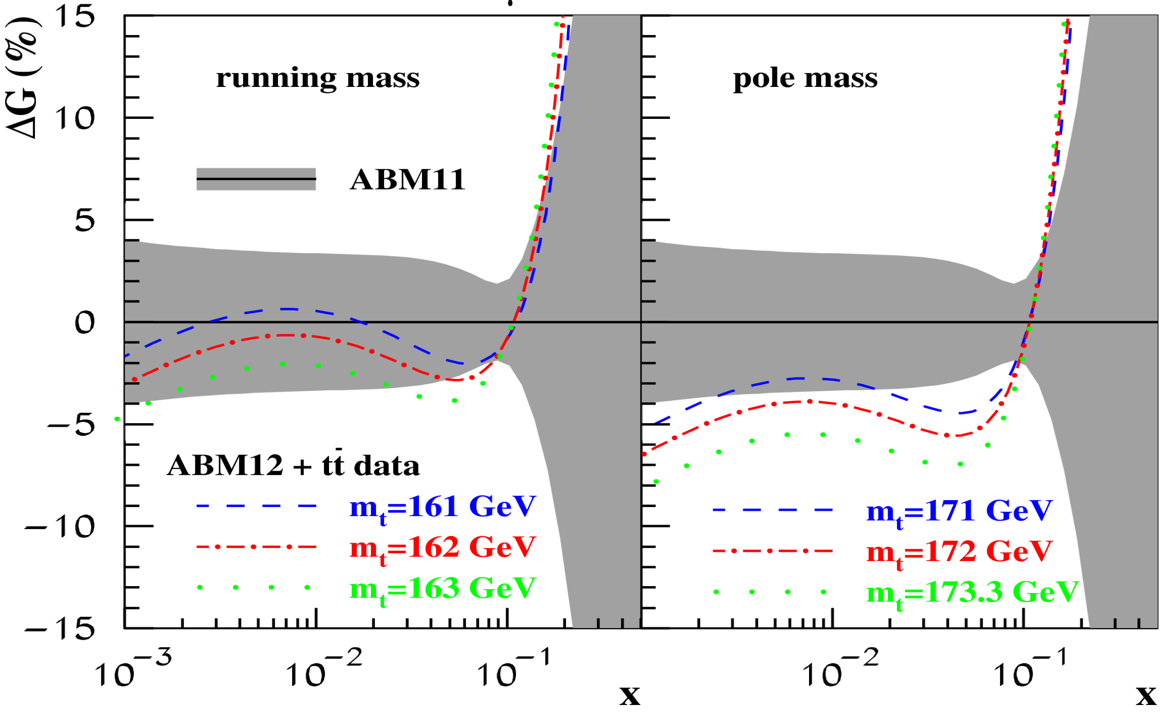


χ^2 for t-quark data



CMS-PAS-TOP-12-003
CMS-PAS-TOP-12-006
ATLAS-CONF-2012-149
CMS JHEP 122, 067 (2012)
ATLAS-CONF-2012-024
D0 Note 6363

μ=3 GeV



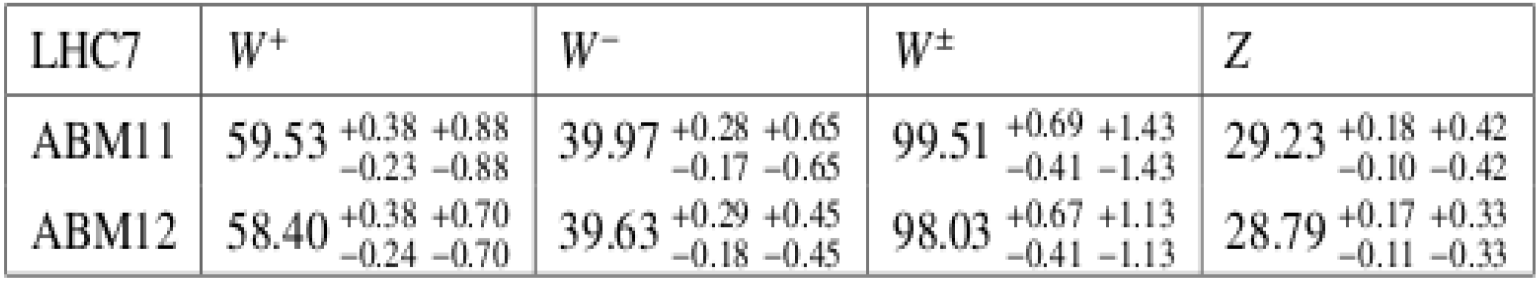
$\alpha_s(M_z)$ 0.1133 – 0.1142 0.1144 – 0.1154

- Steeper χ^2 profile for the pole-mass definition → bigger impact of the t-quark data
- For the running-mass definition the change in PDFs is within uncertainties

$\alpha_s(M_z)$=0.1133(8) with the CMS and Tevatron data only and $m_t(m_t)$=162 GeV (c.f. $\alpha_s(M_z)$=0.1187(27) obtained by CMS with the ABM11 PDFs and m_t(pole)=173.2 GeV)

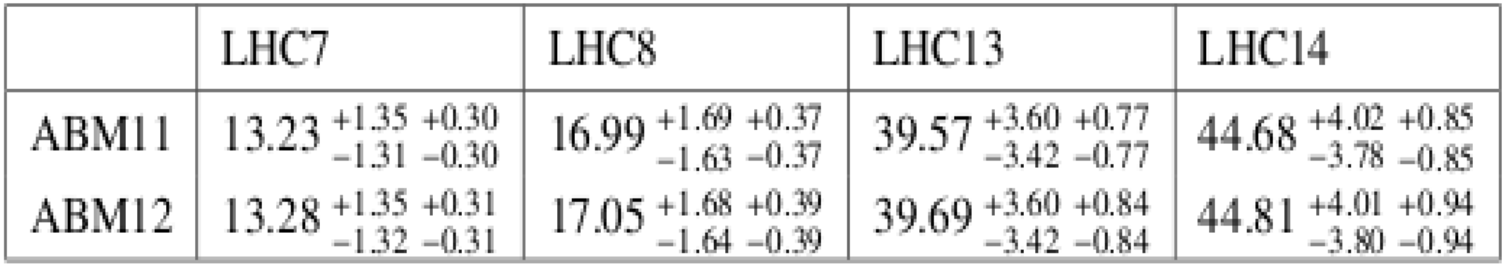
CMS hep-ex/1307.1907

NNLO benchmarks for the LHC



LHC7	W^+	W^-	$W^\pm$	Z
ABM11	$59.53^{+0.38}_{-0.23}{}^{+0.88}_{-0.88}$	$39.97^{+0.28}_{-0.17}{}^{+0.65}_{-0.65}$	$99.51^{+0.69}_{-0.41}{}^{+1.43}_{-1.43}$	$29.23^{+0.18}_{-0.10}{}^{+0.42}_{-0.42}$
ABM12	$58.40^{+0.38}_{-0.24}{}^{+0.70}_{-0.70}$	$39.63^{+0.29}_{-0.18}{}^{+0.45}_{-0.45}$	$98.03^{+0.67}_{-0.41}{}^{+1.13}_{-1.13}$	$28.79^{+0.17}_{-0.11}{}^{+0.33}_{-0.33}$

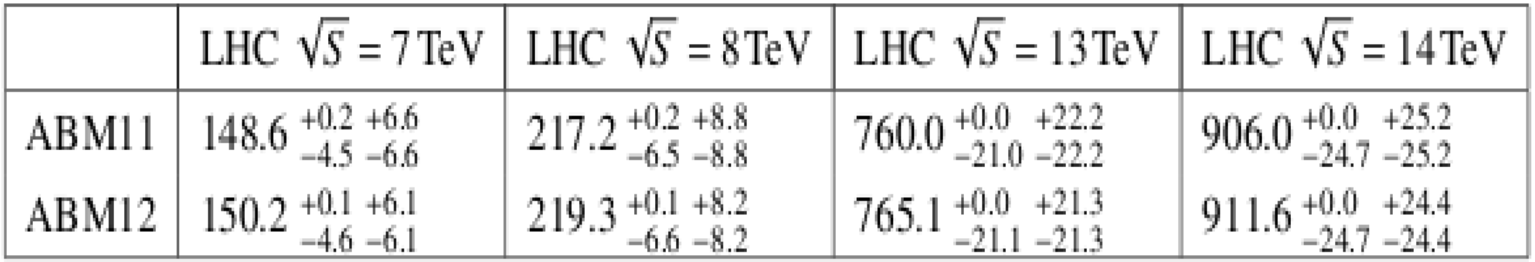
The W,Z cross sections go down by ~1σ



	LHC7	LHC8	LHC13	LHC14
ABM11	$13.23^{+1.35}_{-1.31}{}^{+0.30}_{-0.30}$	$16.99^{+1.69}_{-1.63}{}^{+0.37}_{-0.37}$	$39.57^{+3.60}_{-3.42}{}^{+0.77}_{-0.77}$	$44.68^{+4.02}_{-3.78}{}^{+0.85}_{-0.85}$
ABM12	$13.28^{+1.35}_{-1.32}{}^{+0.31}_{-0.31}$	$17.05^{+1.68}_{-1.64}{}^{+0.39}_{-0.39}$	$39.69^{+3.60}_{-3.42}{}^{+0.84}_{-0.84}$	$44.81^{+4.01}_{-3.80}{}^{+0.94}_{-0.94}$

The Higgs cross sections are stable

m_H=125 GeV



	LHC $\sqrt{S}=7$ TeV	LHC $\sqrt{S}=8$ TeV	LHC $\sqrt{S}=13$ TeV	LHC $\sqrt{S}=14$ TeV
ABM11	$148.6^{+0.2}_{-4.5}{}^{+6.6}_{-6.6}$	$217.2^{+0.2}_{-6.5}{}^{+8.8}_{-8.8}$	$760.0^{+0.0}_{-21.0}{}^{+22.2}_{-22.2}$	$906.0^{+0.0}_{-24.7}{}^{+25.2}_{-25.2}$
ABM12	$150.2^{+0.1}_{-4.6}{}^{+6.1}_{-6.1}$	$219.3^{+0.1}_{-6.6}{}^{+8.2}_{-8.2}$	$765.1^{+0.0}_{-21.1}{}^{+21.3}_{-21.3}$	$911.6^{+0.0}_{-24.7}{}^{+24.4}_{-24.4}$

The t-quark cross sections go somewhat up

$m_t(m_t)$=162 GeV

Summary

- The LHC DY data are smoothly accommodated into the ABM fit
  - exact NNLO corrections, no K-factors
  - the value of χ^2/NDP=68/60
  - some increase(decrease) of the d(nonstr. sea)-quarks at x~0.1 / μ=3 GeV; marginal change in the strange quarks
- The value of $\alpha_s(M_z)$ = 0.1132(11), in agreement with ABM11 and recent JR and CT results
- The t-quark data are checked in the ABM fit
  - the running-mass definition provides better description of data as compared to the pole mass case
  - the value of χ^2/NDP~5/5 is obtained for the Tevatron&LHC data with $m_t(m_t)$=162-163 GeV (equivalent to m_t(pole)=171-172); the change in gluons is ~1σ
  - the value of $\alpha_s(M_z)$ = 0.1133(8) with the CMS data and $m_t(m_t)$=162 GeV
- Standard candle cross sections are stable, within the PDF uncertainties

Extras

NNLO DY corrections in the fit

The (N)NLO calculations are quite time-consuming → fast tools are employed (FASTNLO, Applegrid,.....)

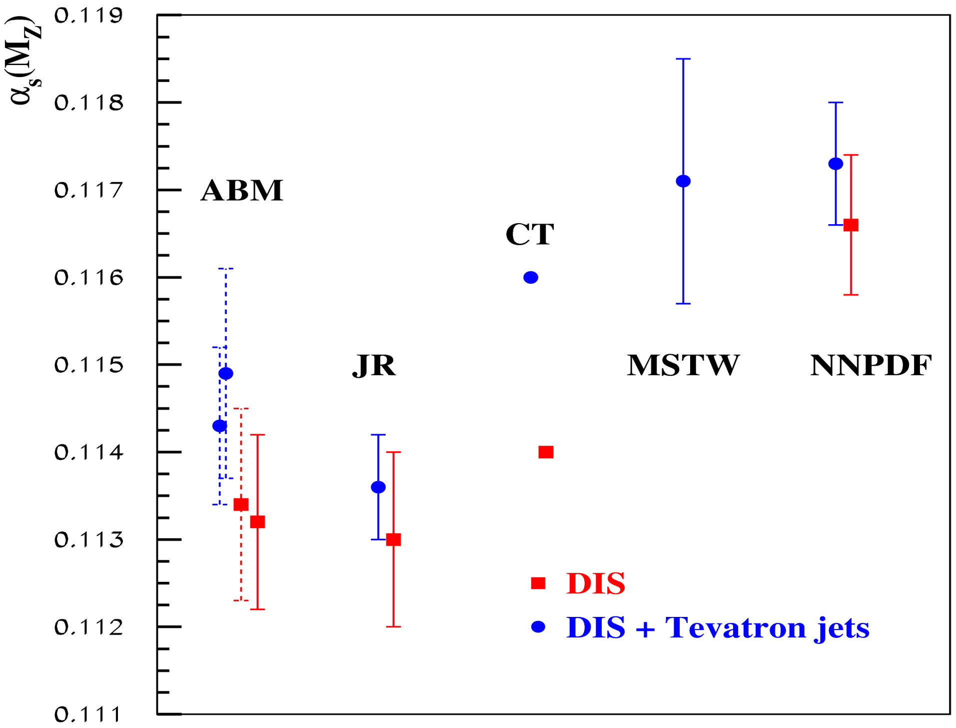
- the corrections for certain basis of PDFs are stored in the grid
- the fitted PDFs are expanded over the basis
- the NNLO c.s. in the PDF fit is calculated as a combination of expansion coefficients with the pre-prepared grids

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

Value of α_s in/from the PDF fits



- The Tevatron jet data push α_s up by ~0.001
- The MSTW and NNPDF values are bigger than the ABM one in particular due to impact of hight-twist terms and/or error correlations

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

- Recent CT 10 value is more close to ABM (no SLAC data used, stronger cut on Q^2, the error correlations are taken into account)

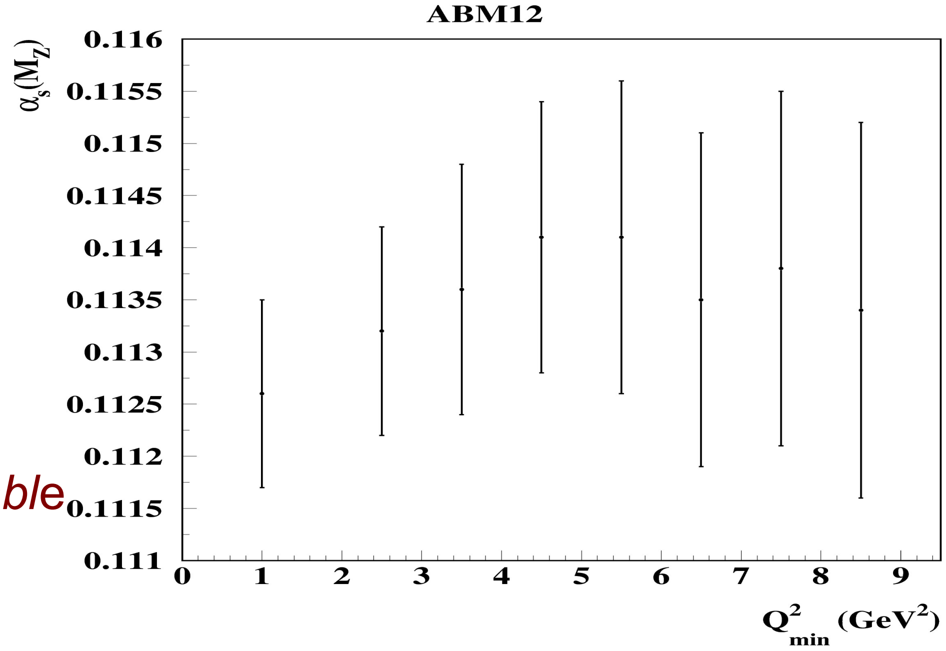
N.B. The MSTW update gives 0.1155 – 0.1171 depending on the jet data treatment

Thorne QCD@LHC2013

Consistent treatment of HT terms in the ABM fit:

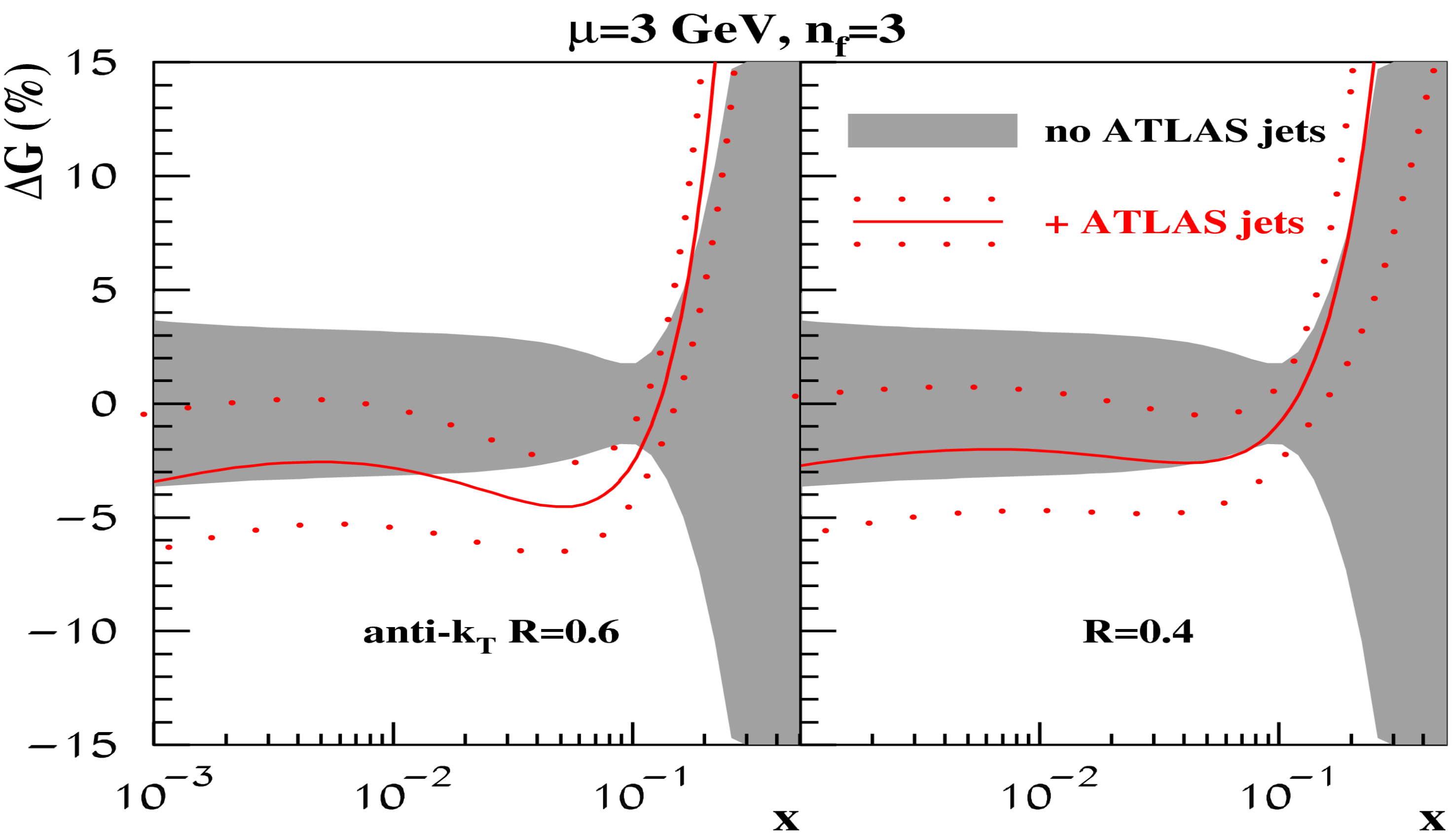
– no sensitivity to the low-Q cut

– $\alpha_s(M_z)$ = 0.1132(11) w/o SLAC and NMC data sensitive to the HT terms → *the cross-check with MSTW, CTEQ and NNPDF is highly desirable*



ATLAS jet data in the ABM fit

ATLAS PRD 85, 0142022 (2012)



$\delta\alpha_s(M_z)$ = +0.0010 $\delta\alpha_s(M_z)$ = +0.0006

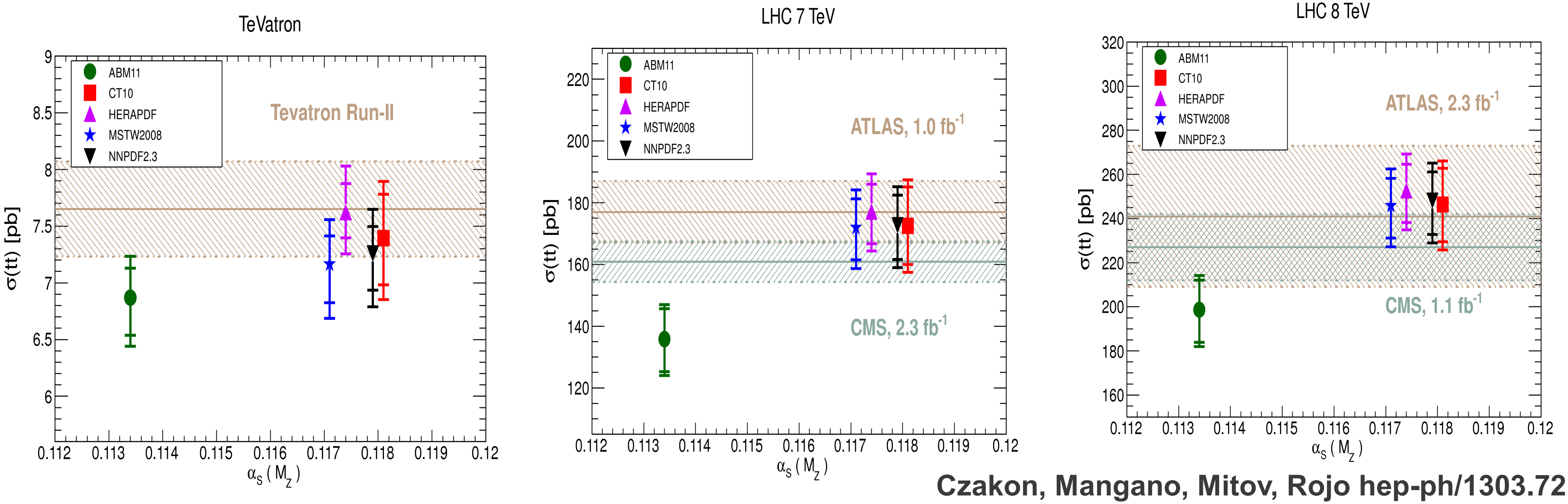
- Pure NLO fit, no NNLO threshold corrections are applied since they are out of control at LHC

  Kumar, Moch hep-ph/1309.5311

- Impact depends on the cone size → underlying events or the NNLO corrections?
- The NNLO corrections may be as big as 15-20% → jet data are irrelevant for the NNLO fit

  Gehrmann-De Ridder, Gehrmann, Glover, Pires JHEP 1302, 026 (2013)

Benchmarking of ABM11 PDFs with t-quark data



Czakon, Mangano, Mitov, Rojo hep-ph/1303.7215

The value of χ^2 is 40 for the ABM11 PDFs?? – computed without account of the PDF uncertainties and with m_t(pole)=m_t(MC)=173.3 GeV

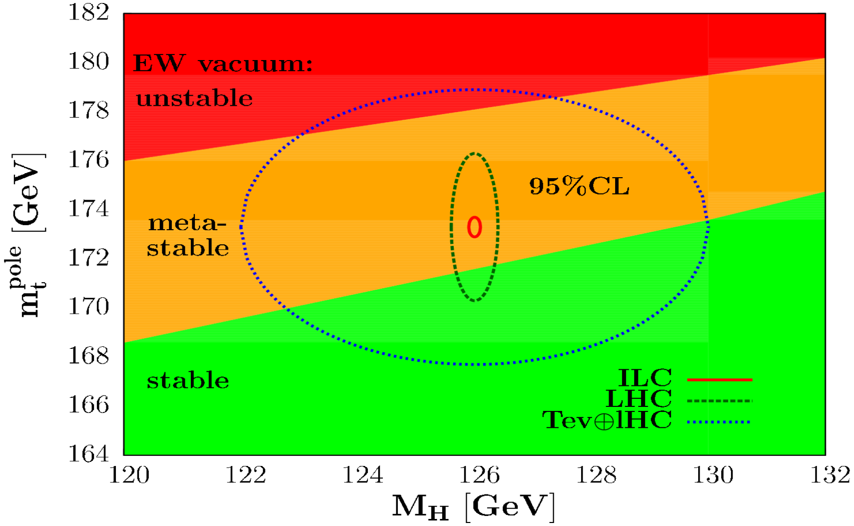
ABM11 χ^2 with account of the PDF uncertainties (NDP=5)

+ m_t(pole)=172 / 171 GeV	17.4 / 12.5	
or $m_t(m_t)$=163 / 162 GeV	10.6 / 7.0	dominate contribution from one point: Atlas@7 TeV

- *The error correlations are missing*

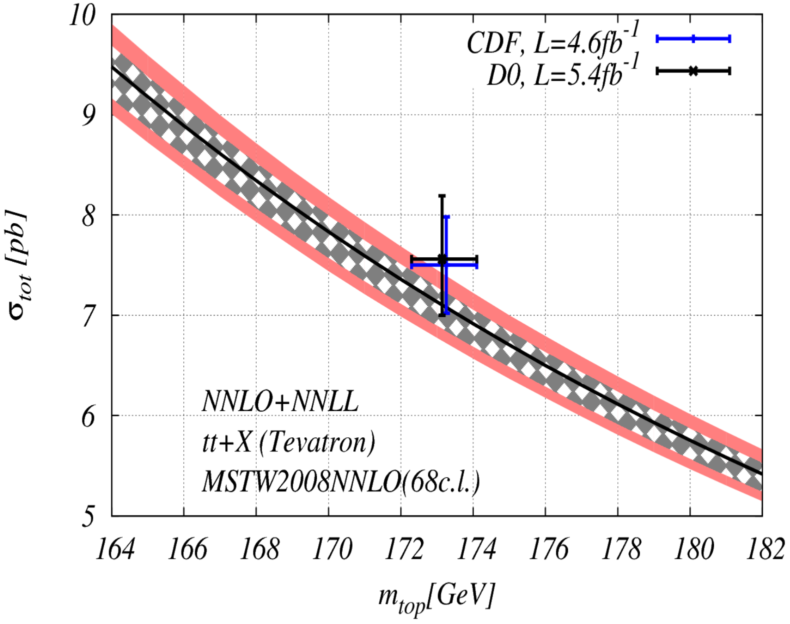
t-quark mass

- m_t(MC)=173.3±1 GeV (Tevatron/LHC)
- m_t(pole)≈ m_t(MC) - 1 GeV
- $m_t(m_t)$≈ m_t(pole) - 9 GeV



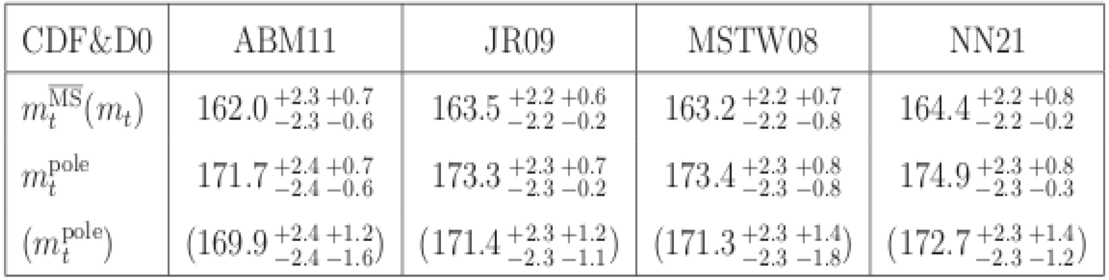
Vacuum stability condition requires m_t(pole)~171 GeV

sa, Djouadi, Moch PLB 716, 214 (2012)

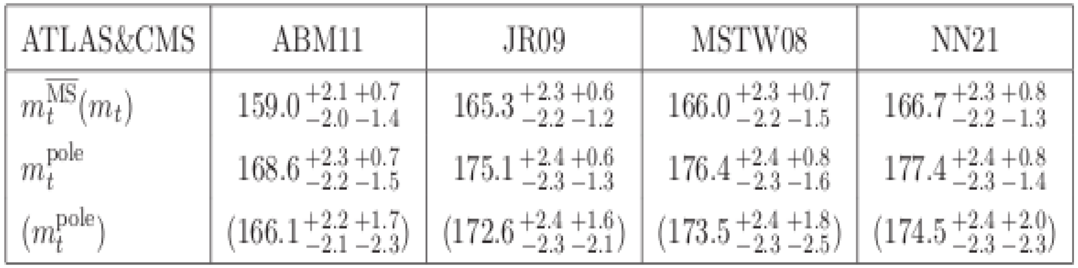


Bärnreuther, Czakon, Mitov hep-ph/1204.5201

From the Tevatron c.s. m_t(pole)~171 GeV



CDF&D0	ABM11	JR09	MSTW08	NN21
$m_t^{\overline{\rm MS}}(m_t)$	$162.0\,^{+2.3\,+0.7}_{-2.3\,-0.6}$	$163.5\,^{+2.2\,+0.6}_{-2.2\,-0.2}$	$163.2\,^{+2.2\,+0.7}_{-2.2\,-0.8}$	$164.4\,^{+2.2\,+0.8}_{-2.2\,-0.2}$
$m_t^{\rm pole}$	$171.7\,^{+2.4\,+0.7}_{-2.4\,-0.6}$	$173.3\,^{+2.3\,+0.7}_{-2.3\,-0.2}$	$173.4\,^{+2.3\,+0.8}_{-2.3\,-0.8}$	$174.9\,^{+2.3\,+0.8}_{-2.3\,-0.3}$
$(m_t^{\rm pole})$	$(169.9\,^{+2.4\,+1.2}_{-2.4\,-1.6})$	$(171.4\,^{+2.3\,+1.2}_{-2.3\,-1.1})$	$(171.3\,^{+2.3\,+1.4}_{-2.3\,-1.8})$	$(172.7\,^{+2.3\,+1.4}_{-2.3\,-1.2})$



ATLAS&CMS	ABM11	JR09	MSTW08	NN21
$m_t^{\overline{\rm MS}}(m_t)$	$159.0\,^{+2.1\,+0.7}_{-2.0\,-1.4}$	$165.3\,^{+2.3\,+0.6}_{-2.2\,-1.2}$	$166.0\,^{+2.3\,+0.7}_{-2.2\,-1.5}$	$166.7\,^{+2.3\,+0.8}_{-2.2\,-1.3}$
$m_t^{\rm pole}$	$168.6\,^{+2.3\,+0.7}_{-2.2\,-1.5}$	$175.1\,^{+2.4\,+0.6}_{-2.3\,-1.3}$	$176.4\,^{+2.4\,+0.8}_{-2.3\,-1.6}$	$177.4\,^{+2.4\,+0.8}_{-2.3\,-1.4}$
$(m_t^{\rm pole})$	$(166.1\,^{+2.2\,+1.7}_{-2.1\,-2.3})$	$(172.6\,^{+2.4\,+1.6}_{-2.3\,-2.1})$	$(173.5\,^{+2.4\,+1.8}_{-2.3\,-2.5})$	$(174.5\,^{+2.4\,+2.0}_{-2.3\,-2.3})$

Stronger correlation between m_t, PDFs and α_s at LHC