ABM PDFs with improved constraints on the quark distributions

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

- Basic features
  - – heavy quarks in NNLO, m_c, m_b, m_t and α_s
- Strange sea
  - – new DIS charm data
  - – CMS and ATLAS W+charm data

sa, Blümlein, Caminadac, Lipka, Lohwasser, Moch, Petti, Placakyte hep-ph/1404.6469

- Non-strange quarks
  - – CMS charged-lepton asymmetry
  - – inclusive W/Z by LHCb

sa, Blümlein, Caminadac, Lipka, Lohwasser, Moch, Petti, Placakyte hep-ph/1410.7007

- – Tevatron charged-lepton and W asymmetry

PHENONET meeting, Berlin, 26 Nov 2014

The ABM fit ingredients

DATA:

- DIS NC inclusive
- DIS charm production
- DIS μμ CC production
- DIS charmed-hadron CC production
- fixed-target DY
- LHC DY distributions (CMS 4.7 1/fb, LHCb 1/fb)
- W+charm production (CMS and ATLAS data)

QCD:

- NNLO evolution
- NNLO massless DIS and DY coefficient functions
- NLO+ massive DIS coefficient functions (**FFN scheme**)
  - – NLO + NNLO threshold corrections for NC
  - – NNLO CC at Q>> m_c
  - – running mass
- NNLO exclusive DY (DYNNLO 1.3 / FEWZ 3.1)
- NNLO inclusive ttbar production (pole / running mass)

Deuteron corrections in DIS:

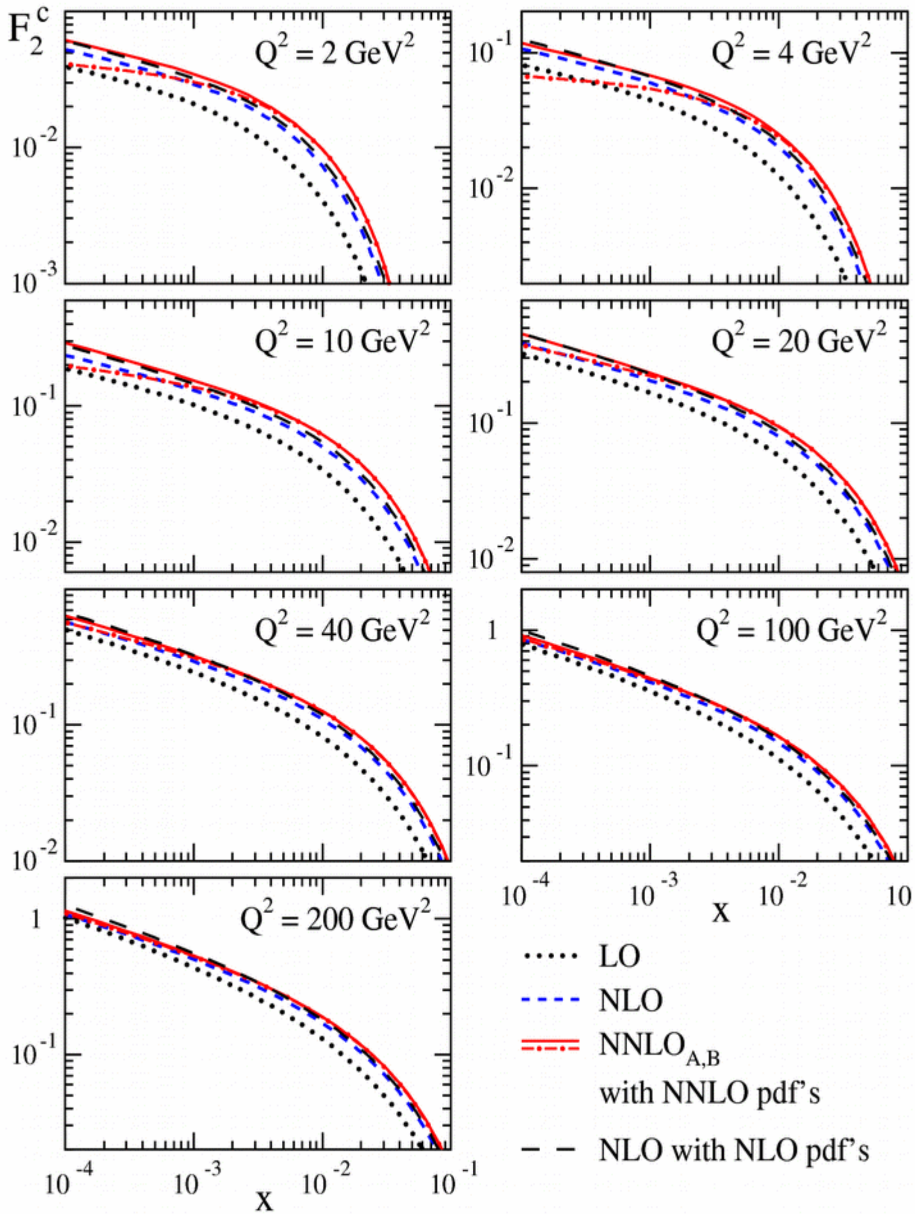
- Fermi motion
- off-shell effects

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%

Massive NNLO coefficients: state of art



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

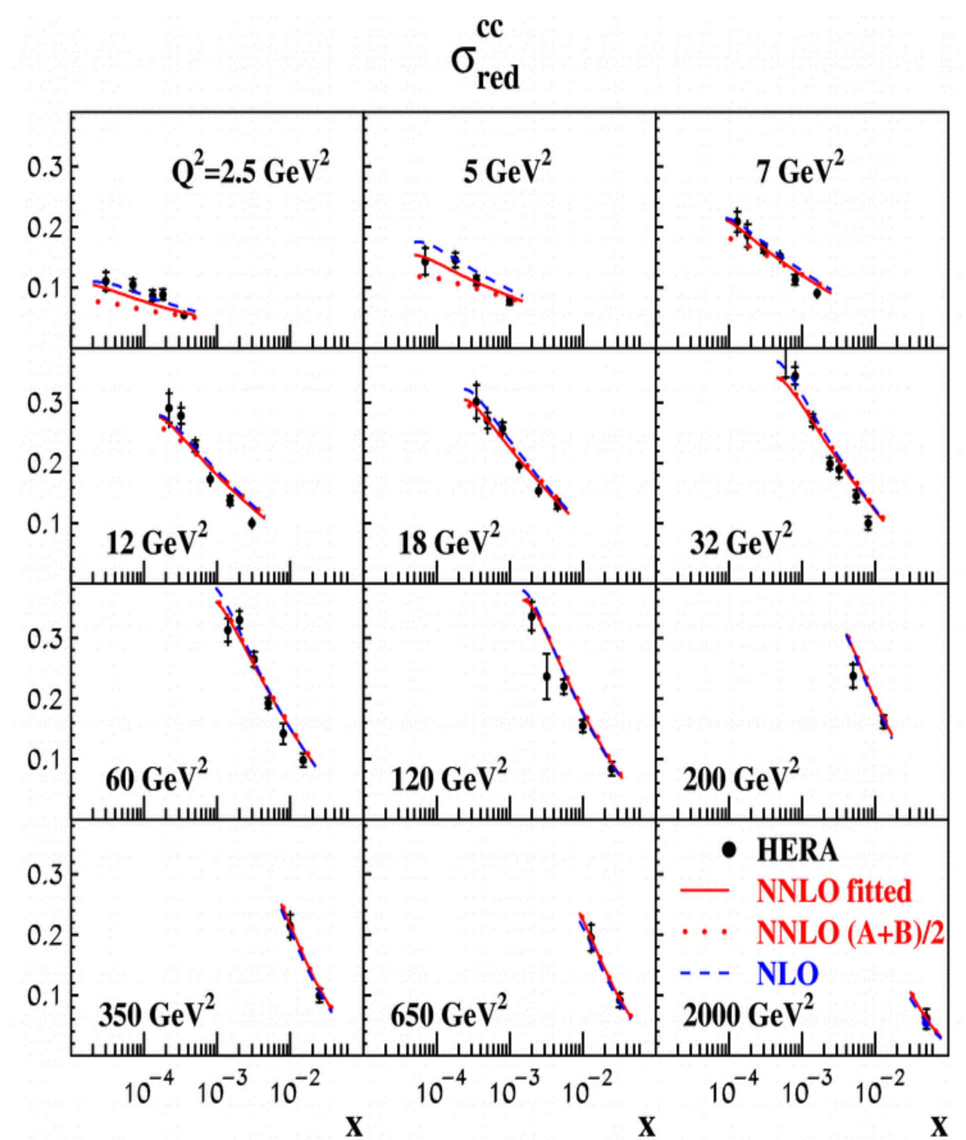
    Ablinger at al. NPB 844, 26 (2011)

    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

- X^2/NDP=61/52

$m_c(m_c)$=1.15±0.04(exp.) GeV NLO

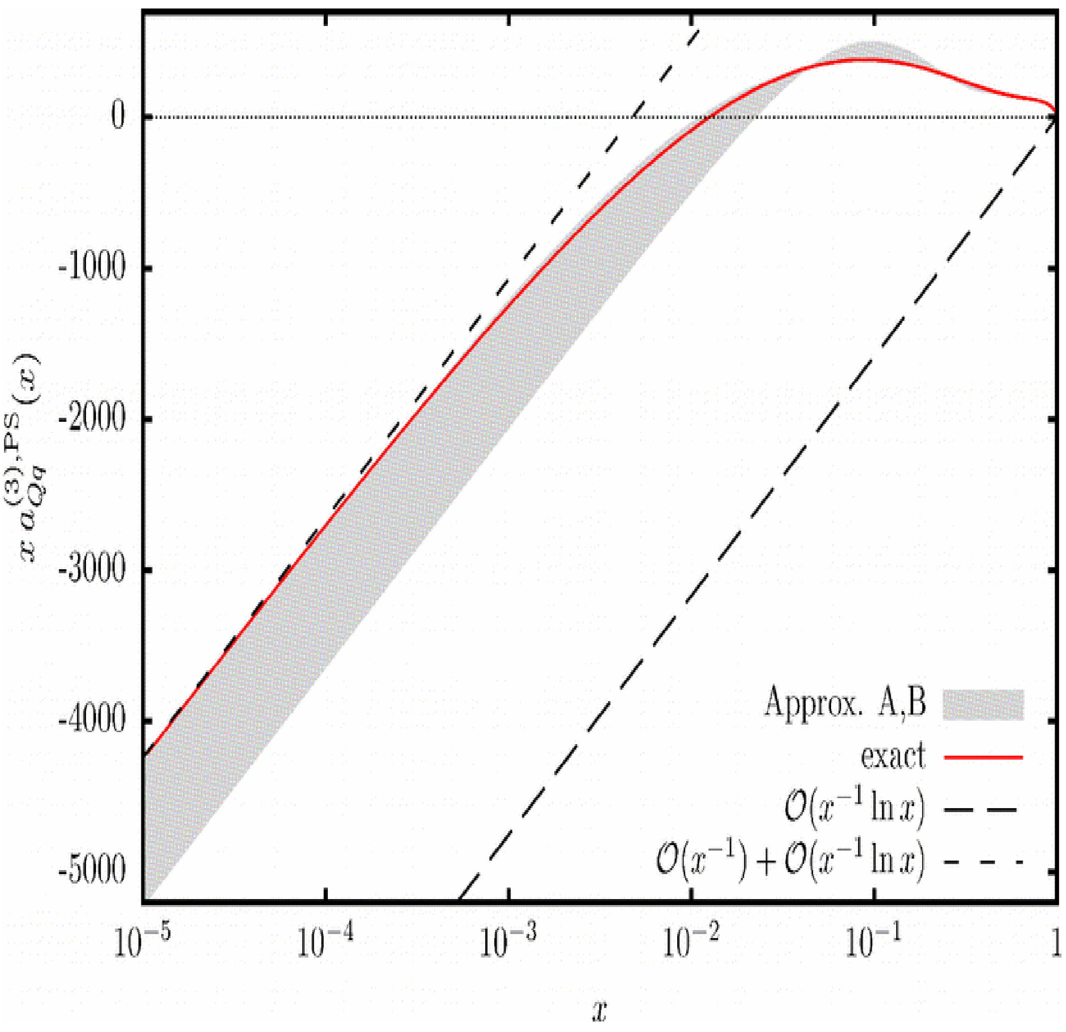
$m_c(m_c)$=1.24±0.03(exp.),+0.-0.07(th) GeV NNLO

(theoretical uncertainty due to choice of massive NNLO coefficients, data prefer option A)

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

News in theory

talk by Johannes



- Exact pure-singlet NNLO term in the massive OME is in agreement with the option A of the KLPMV approximation

Ablinger et al. hep-ph/1409.1135

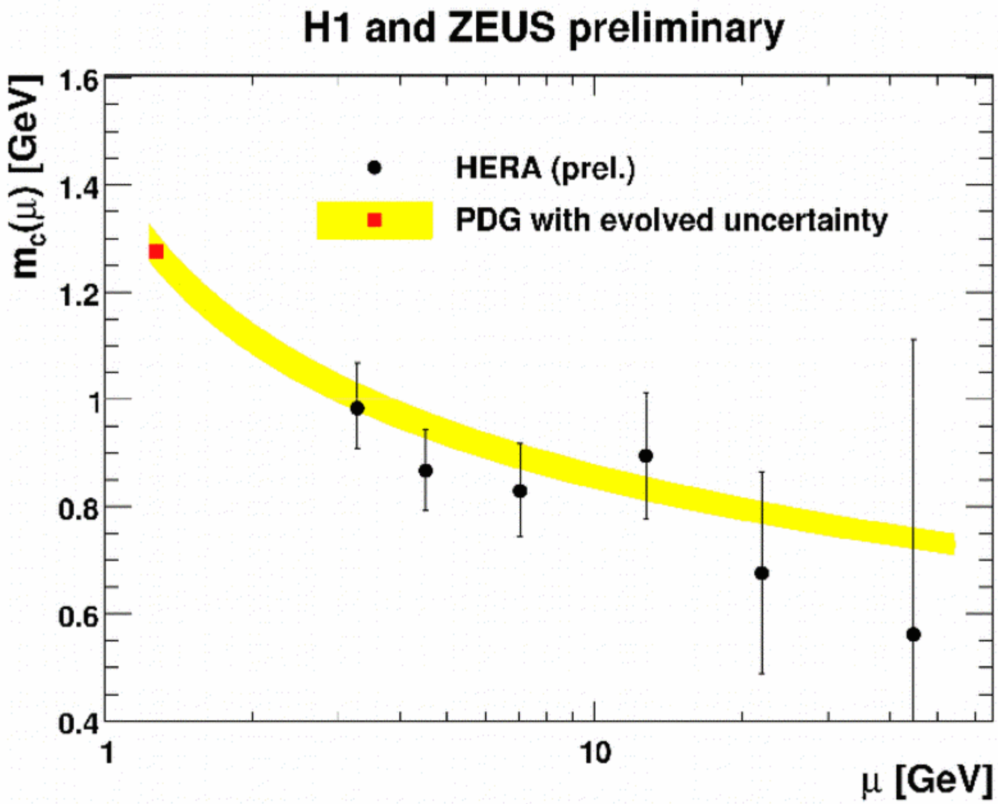
- The exact non-singlet NNLO term is also available

Ablinger et al. NPB 886, 733 (2014)

the running charm quark mass

H1-prelim-14-071, ZEUS-prel-14-006, + S. Moch

translate back to $m_c(\mu)$ using LO formula consistent with NLO $\overline{MS}$ QCD fit (OpenQCDrad, Alekhin et al.)



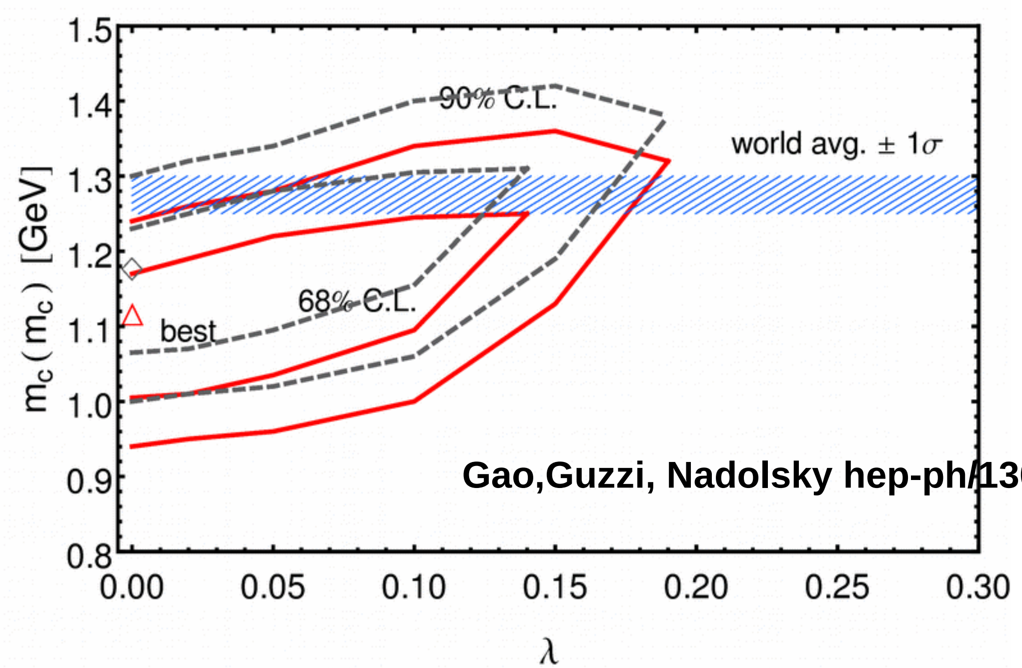
running mass concept in QCD is self-consistent !

26. 8. 14 A. Geiser, charm and beauty mass, QCDLHC 14 15

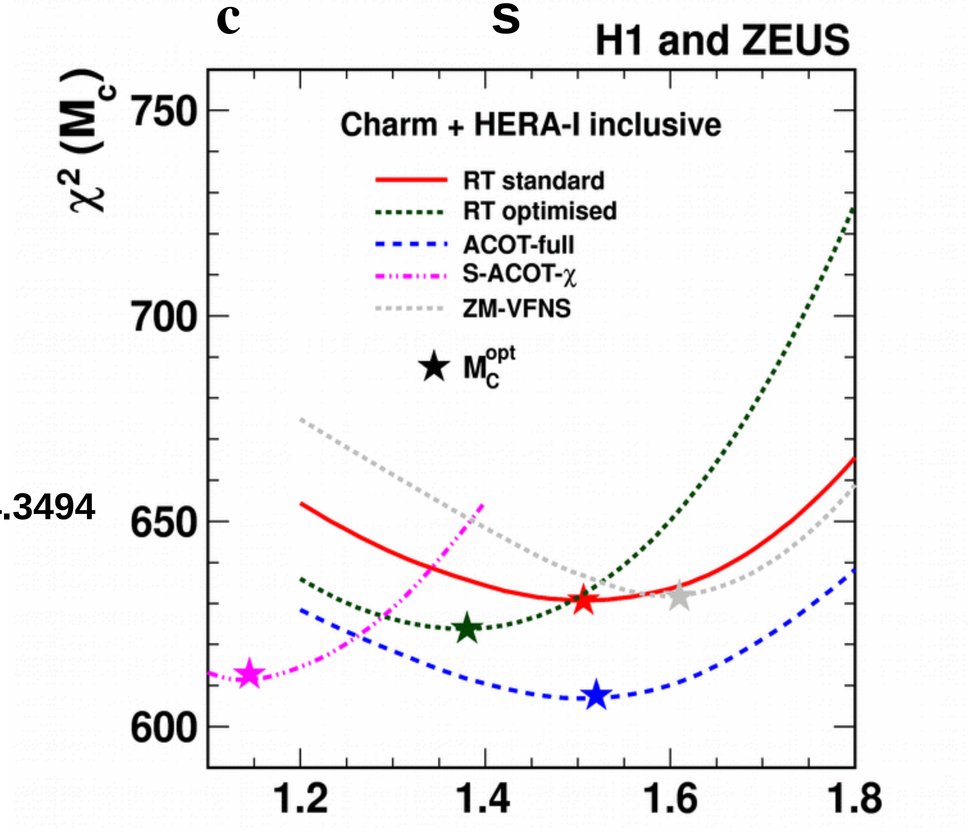
$m_b(m_b)$=4.07±0.14(exp.),+0.08-0.075(th) GeV NLO **ZEUS hep-ex/1405.6915**

$m_b(m_b)$=3.96±0.14(exp.),+0.-0.09(th) GeV NNLO **ABM prel.**

VFNS uncertainties in m_c and α_s

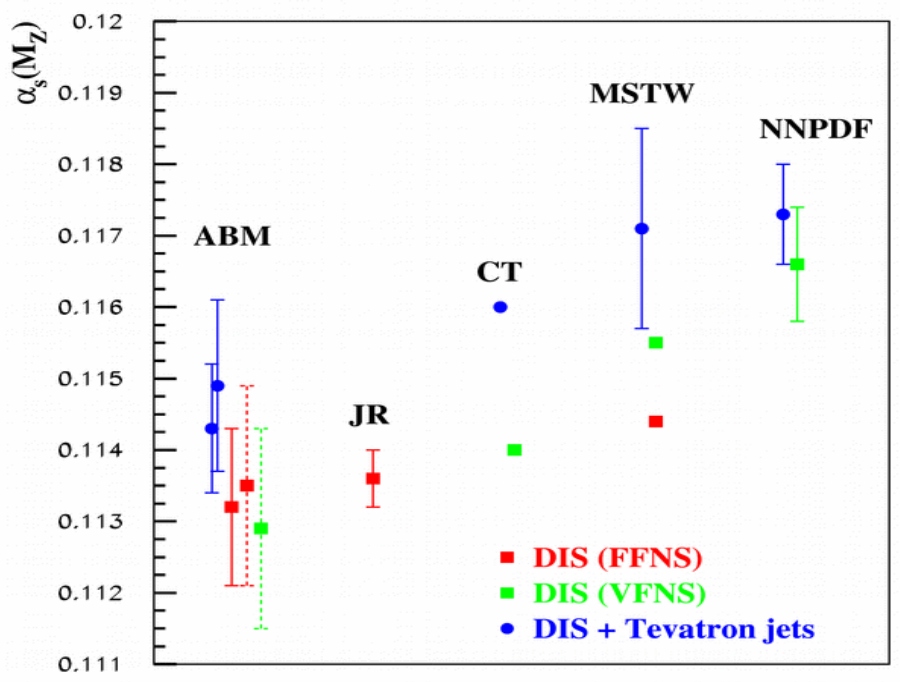


Gao,Guzzi, Nadolsky hep-ph/1304.3494



H1/ZEUS PLB 718, 550 (2012)

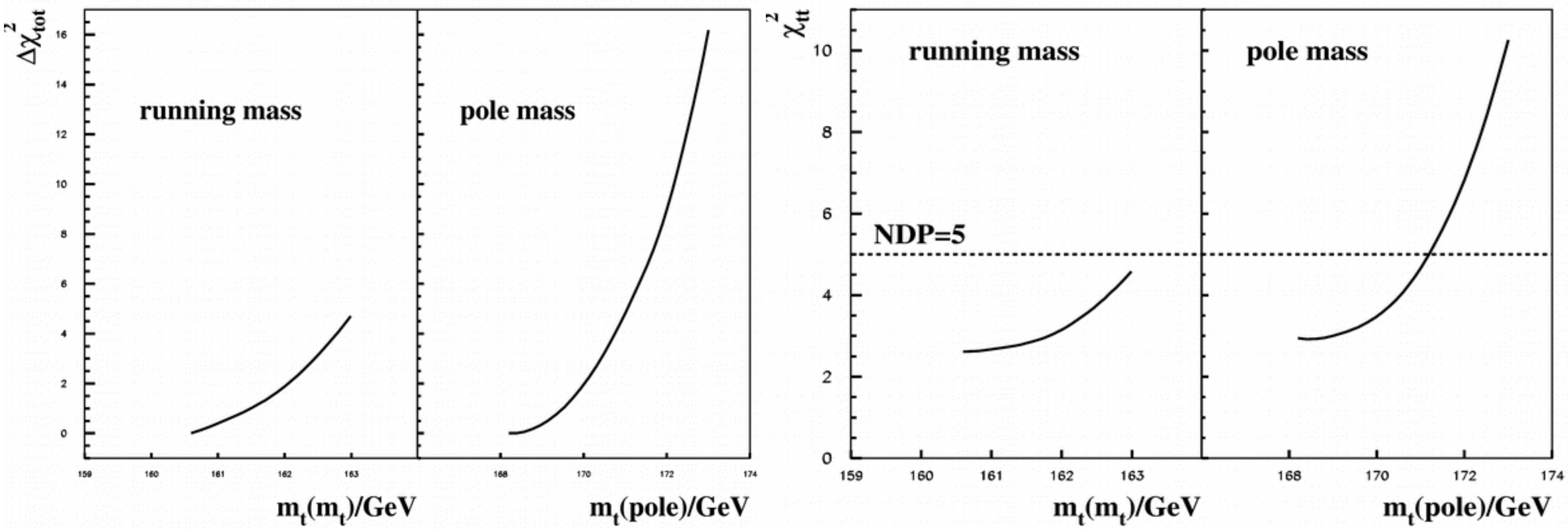
M_c [GeV]



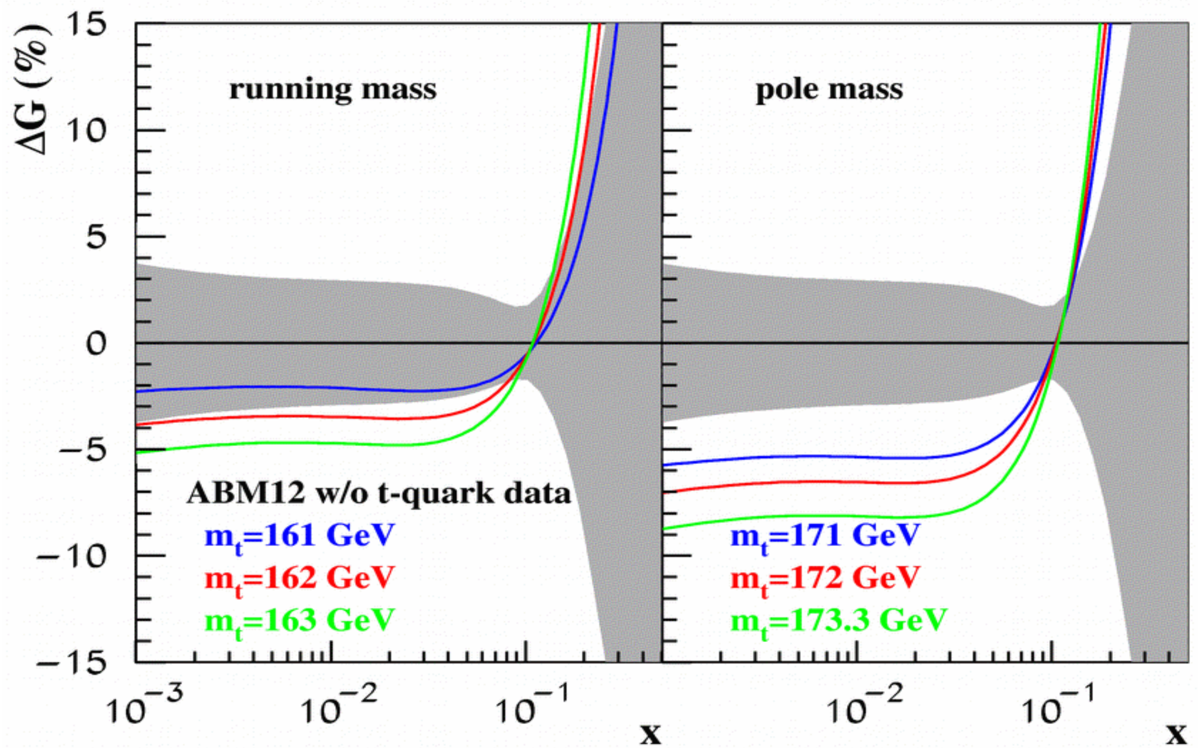
Wide spread obtained in different version of the GMVFN schemes → quantitative illustration of the GMVFNS uncertainties

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



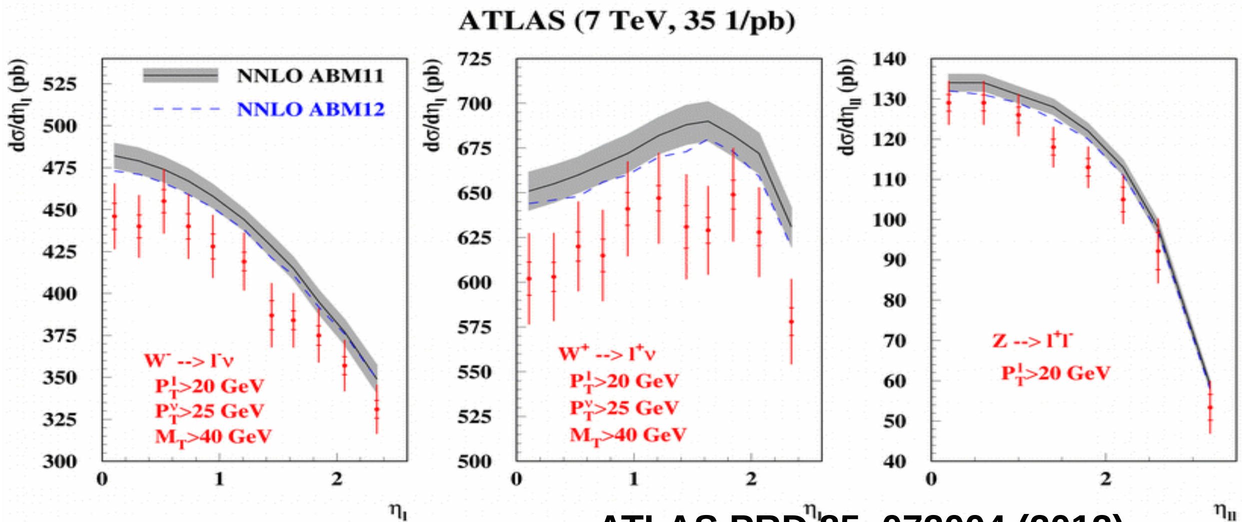
- Steeper χ^2 profile for the pole-mass definition → bigger impact of the t-quark data
- For the running-mass definition the change in PDFs is within uncertainties

Extrapolation to the unmeasured phase space?

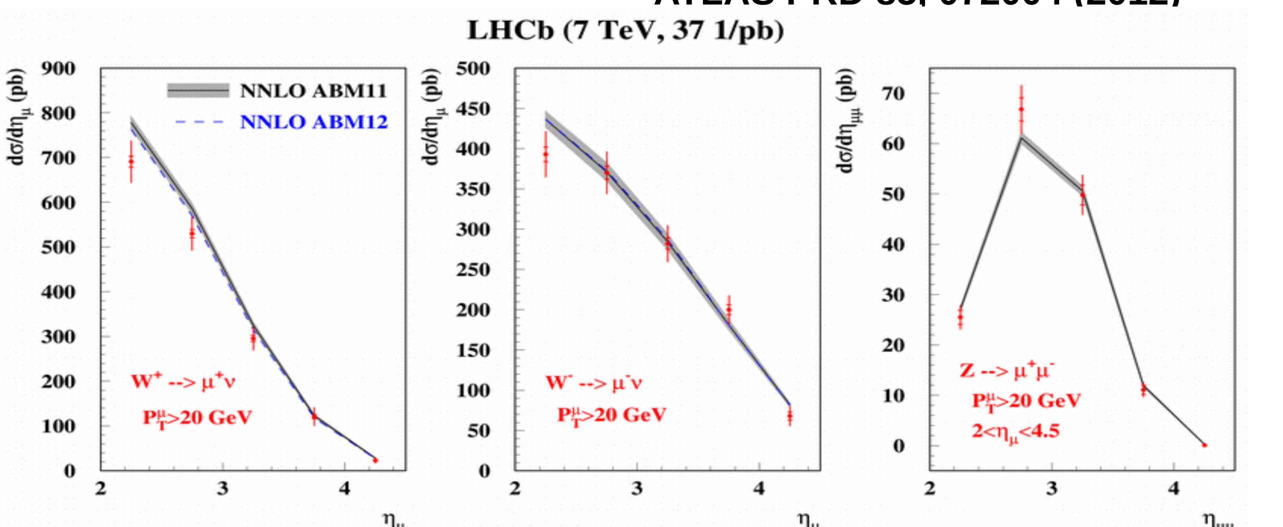
$\alpha_s(M_z)$ 0.1138 – 0.1149 0.1150 – 0.1159

LHC Drell-Yan data included

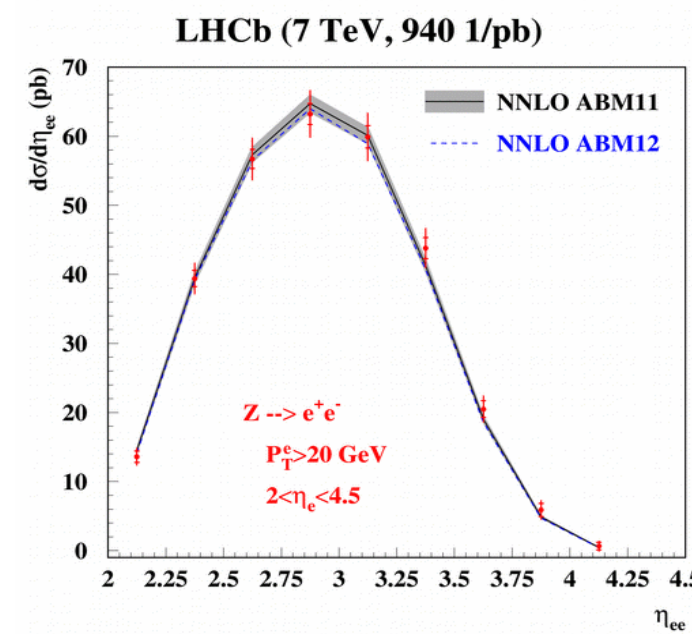
sa, Blümlein, Moch PRD 89, 054028 (2014)



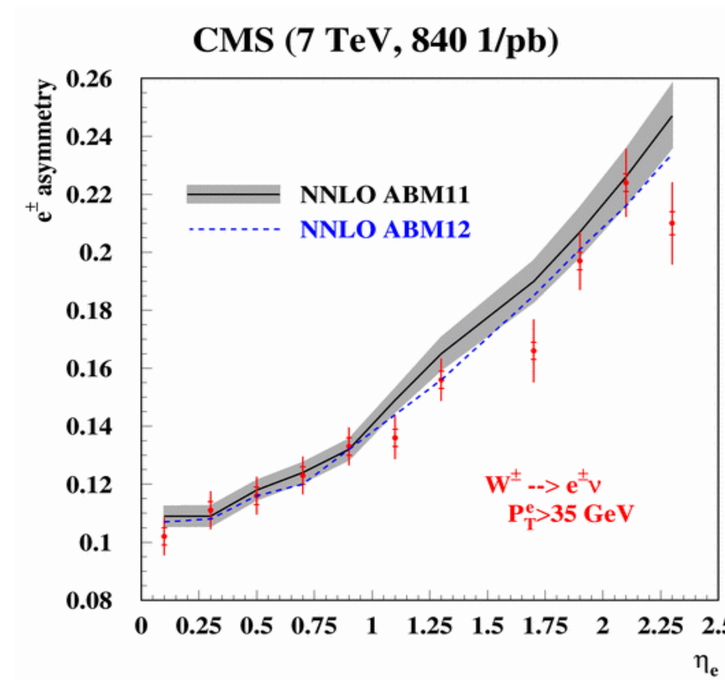
ATLAS PRD 85, 072004 (2012)



LHCb JHEP 1206, 058 (2012)



LHCb JHEP 1302, 106 (2013)

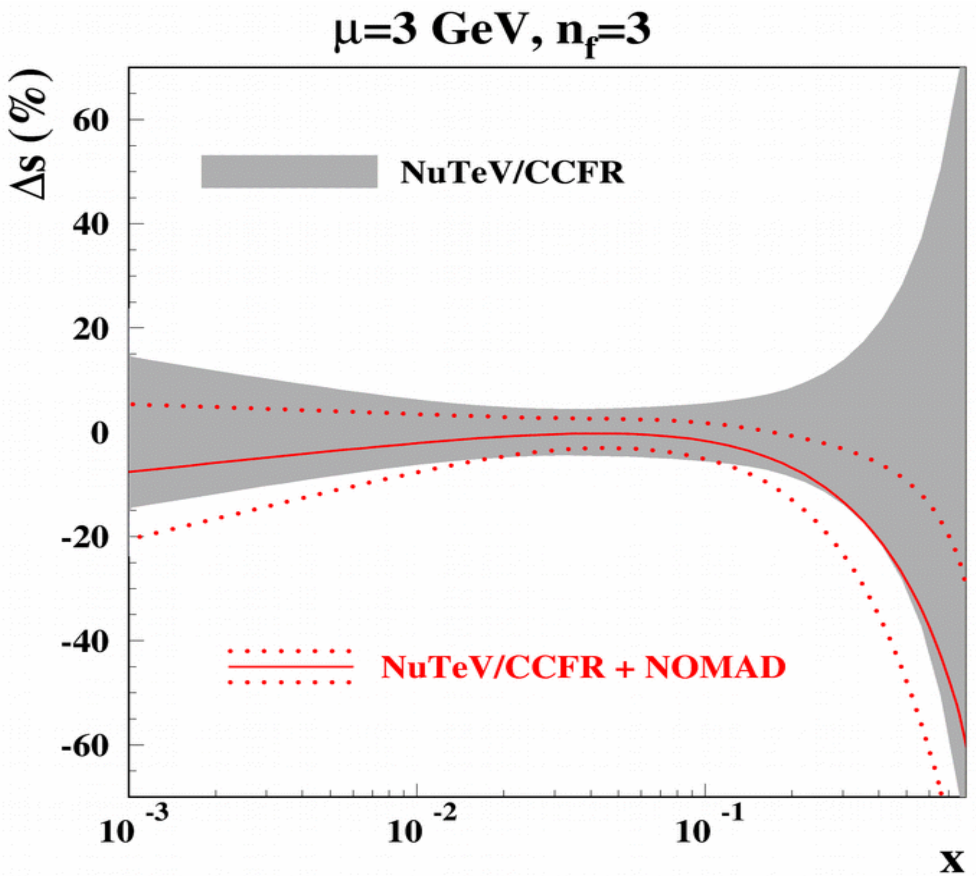


CMS PRL 109, 111806 (2010)

- Exact NNLO calcuations (DYNNLO&FEWZ)
- Good overall agreement

ATLAS	CMS	LHCb	
36/30	9/11	14/10	13/11

NOMAD charm data in the ABM fit



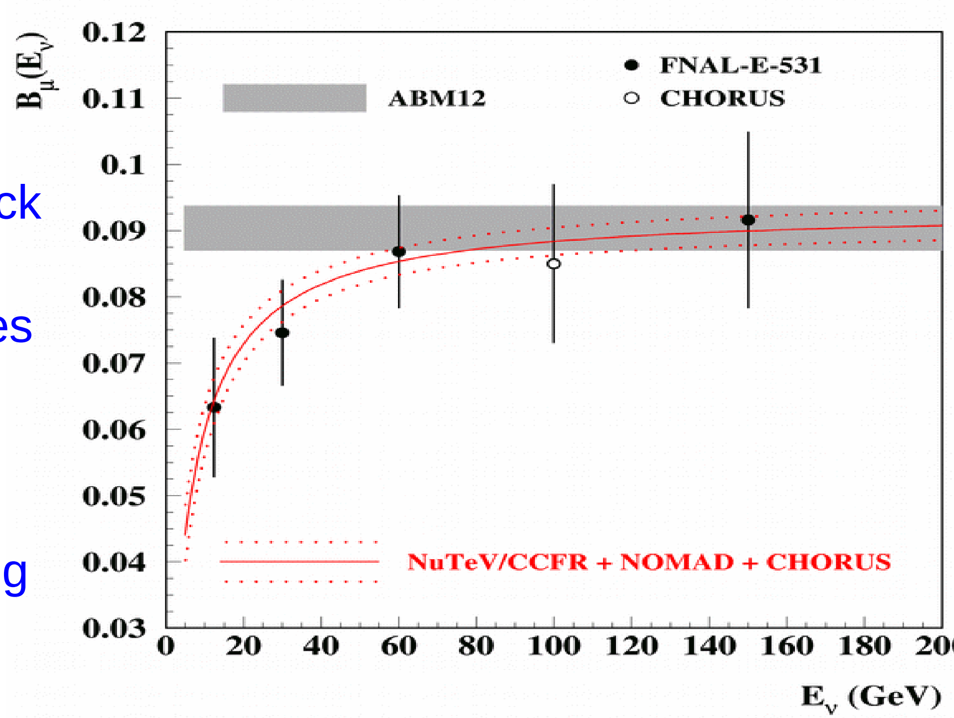
The data on ratio 2μ/incl. CC ratio with the 2μ statistics of 15000 events (much bigger than in earlier CCFR and NuTeV samples).

NOMAD NPB 876, 339 (2013)

Systematics, nuclear corrections, etc. cancel in the ratio

– pull down strange quarks at x>0.1 with a sizable uncertainty reduction

– $m_c(m_c)$=1.23±0.03(exp.) GeV is comparable to the ABM12 value



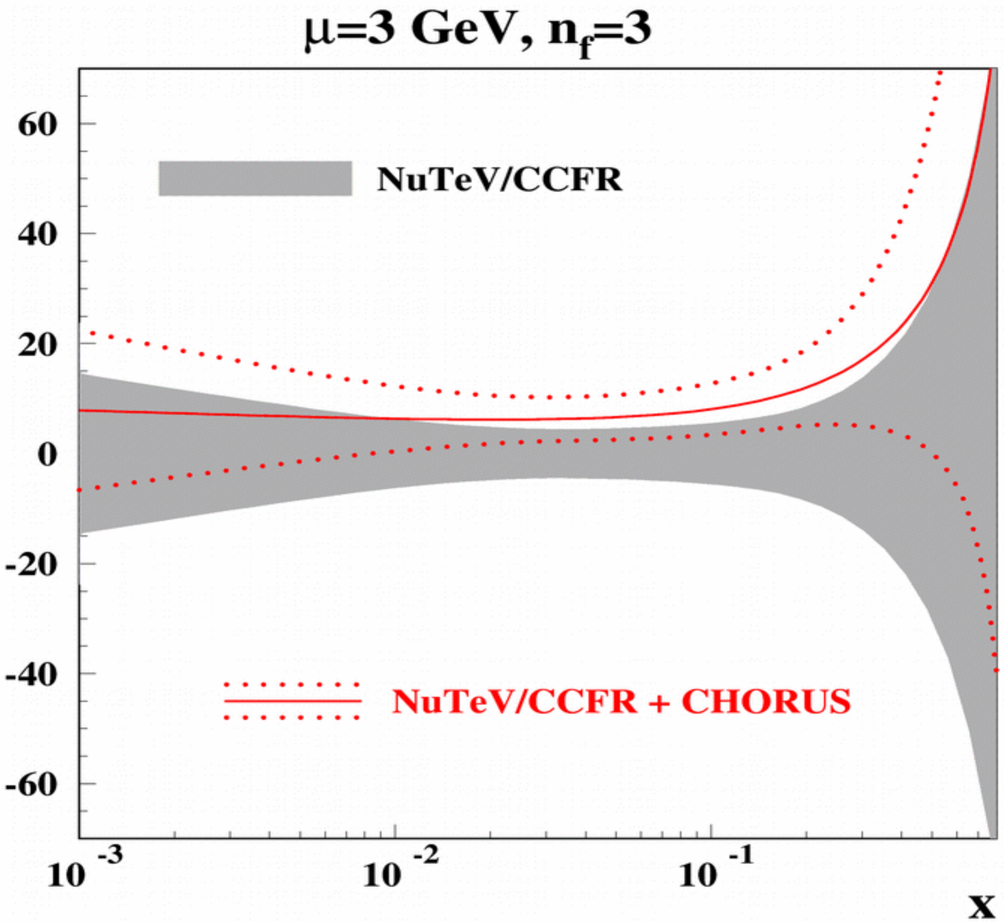
The semi-leptonic branching ratio B_μ is a bottleneck

– weighted average of the charmed-hadron rates

$$B_\mu(E_\nu)=\sum_h r^h(E_\nu)B^h_\mu = a/(1+b/E_\nu)$$

– fitted simultaneously with the PDFs, etc. using the constraint from the emulsion data

CHORUS charm data in the ABM fit



Emulsion data on charm/CC ratio with the charmed hadron vertex measured

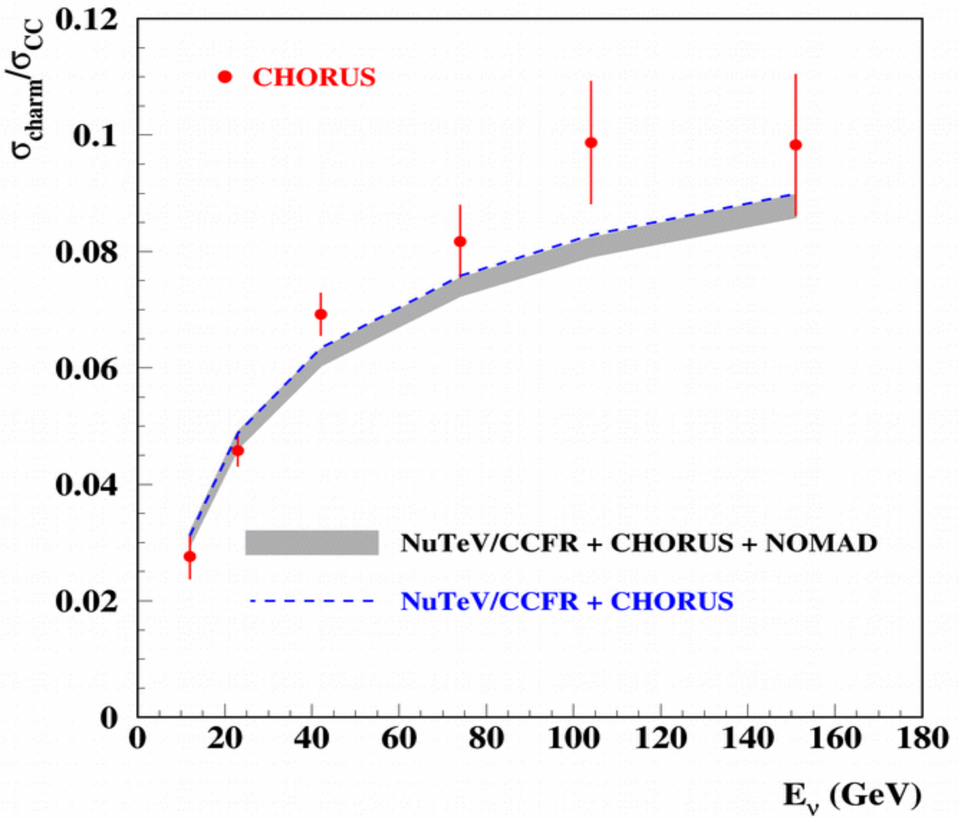
CHORUS NJP 13, 093002 (2011)

– full phase space measurements

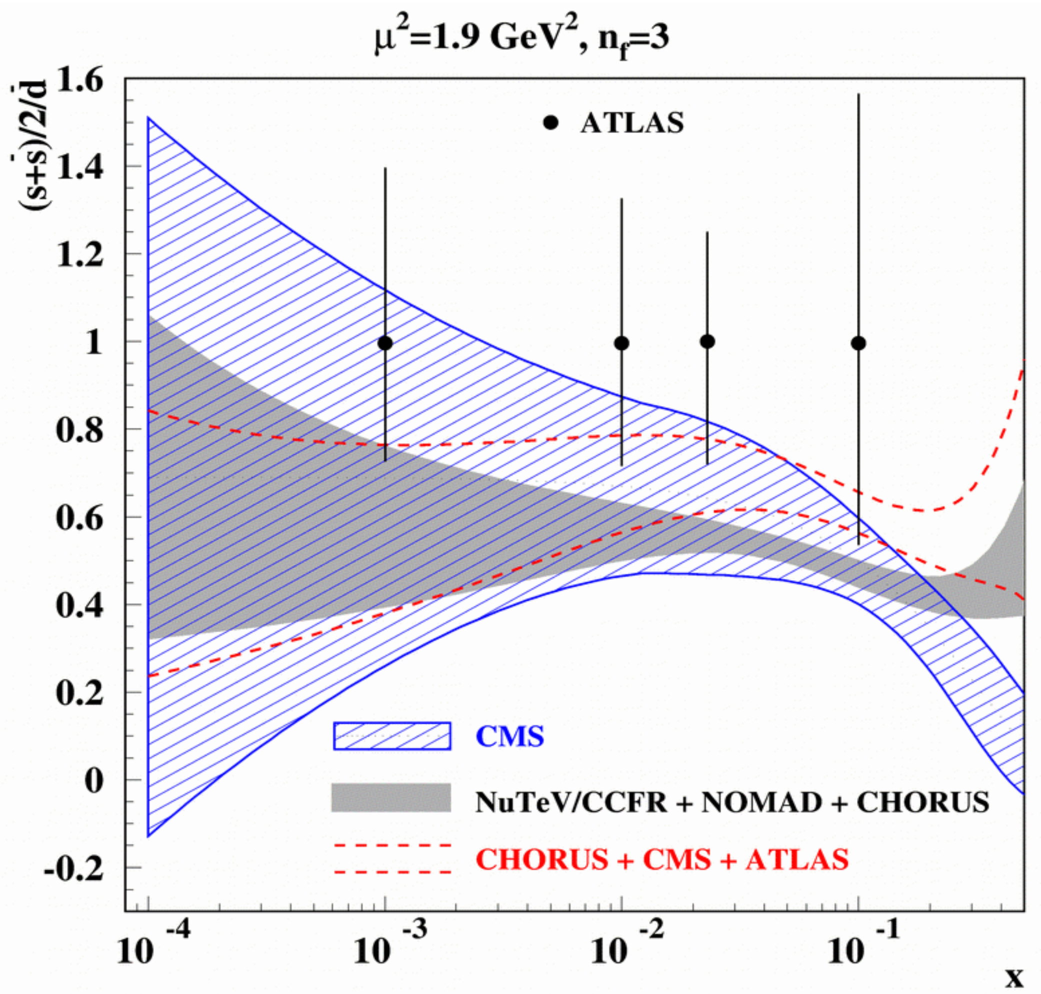
– no sensitivity to B_μ

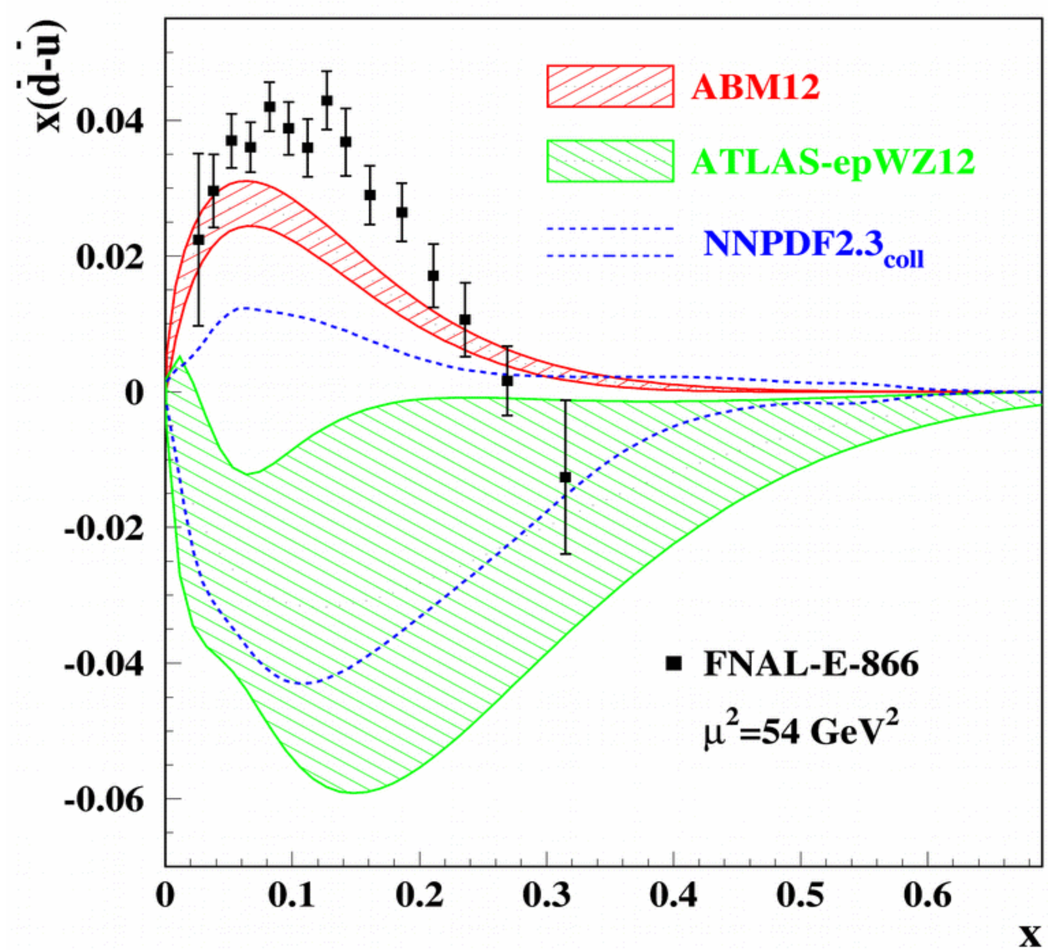
– low statistics (2013 events)

CHORUS data pull strangeness up, however the statistical significance of the effect is poor



Strange sea improvement





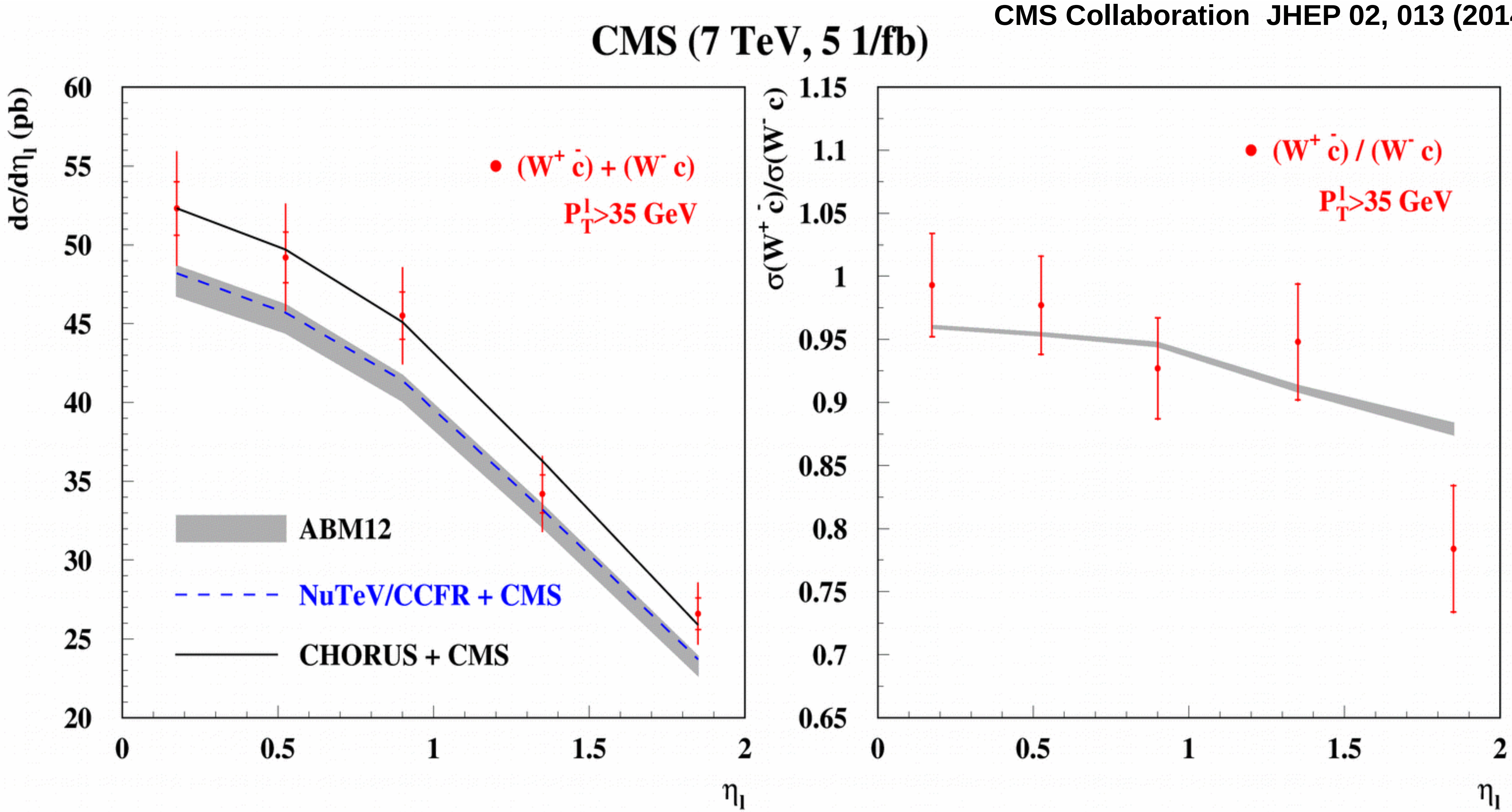
- Nominal ABM update (NuTeV/CCFR+NOMAD+CHORUS) demonstrate good agreement with the CMS results
- The ATLAS strange-sea in enhanced, however it is correlated with the d-quark sea suppression → *disagreement with the FNAL-E-866 data*
- Upper margin of the ABM analysis (CHORUS+CMS+ATLAS) is still lower than ATLAS

	X^2/NDP
ATLAS W/Z(incl.)	35/30
NOMAD (2μ)	52/48
CHORUS (charm)	10/6

Integral strangeness suppression factor $\kappa_s(20\ \mathrm{GeV}^2)=0.654(30)$

CMS W+charm data in the ABM fit

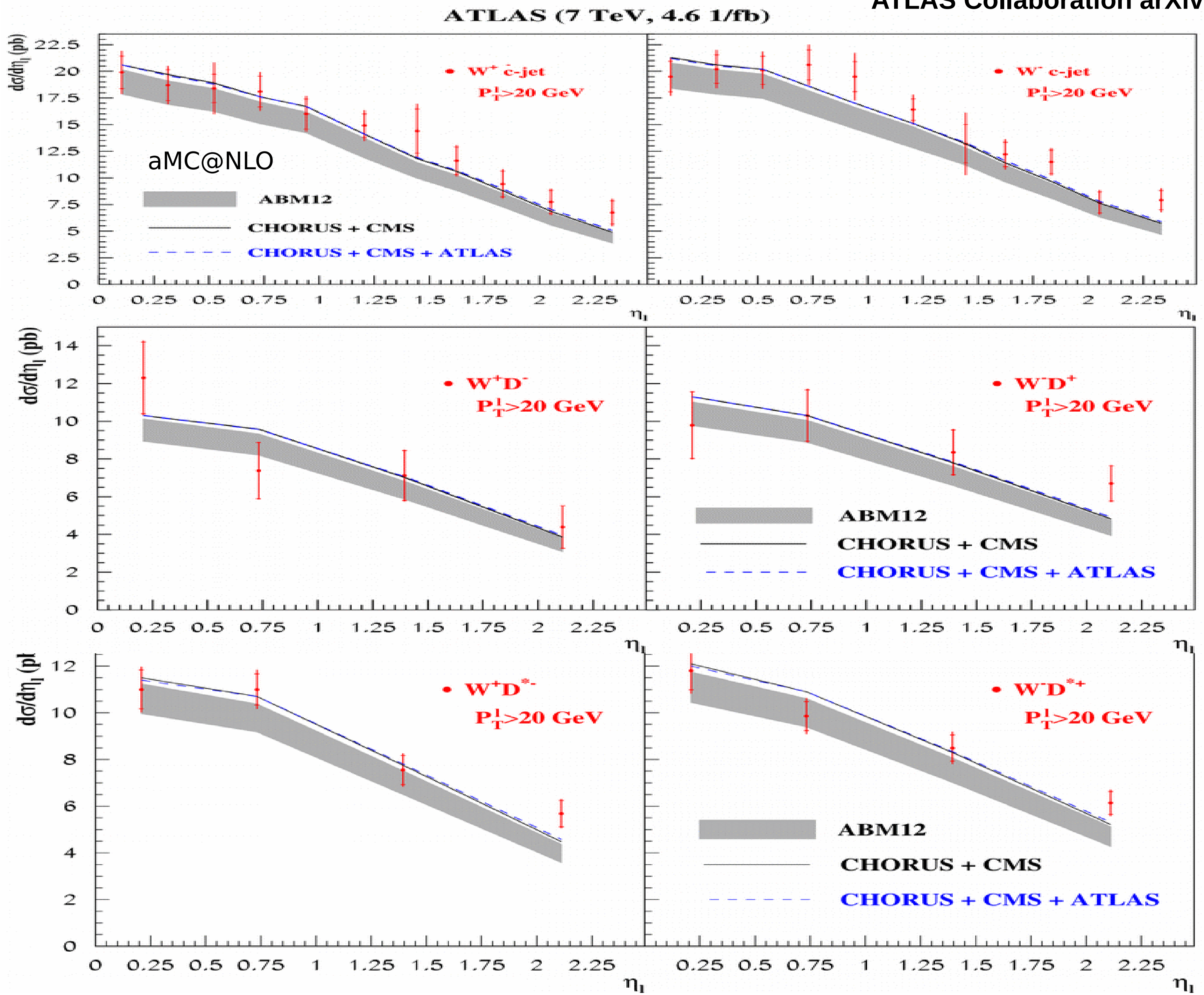
CMS Collaboration JHEP 02, 013 (2014)



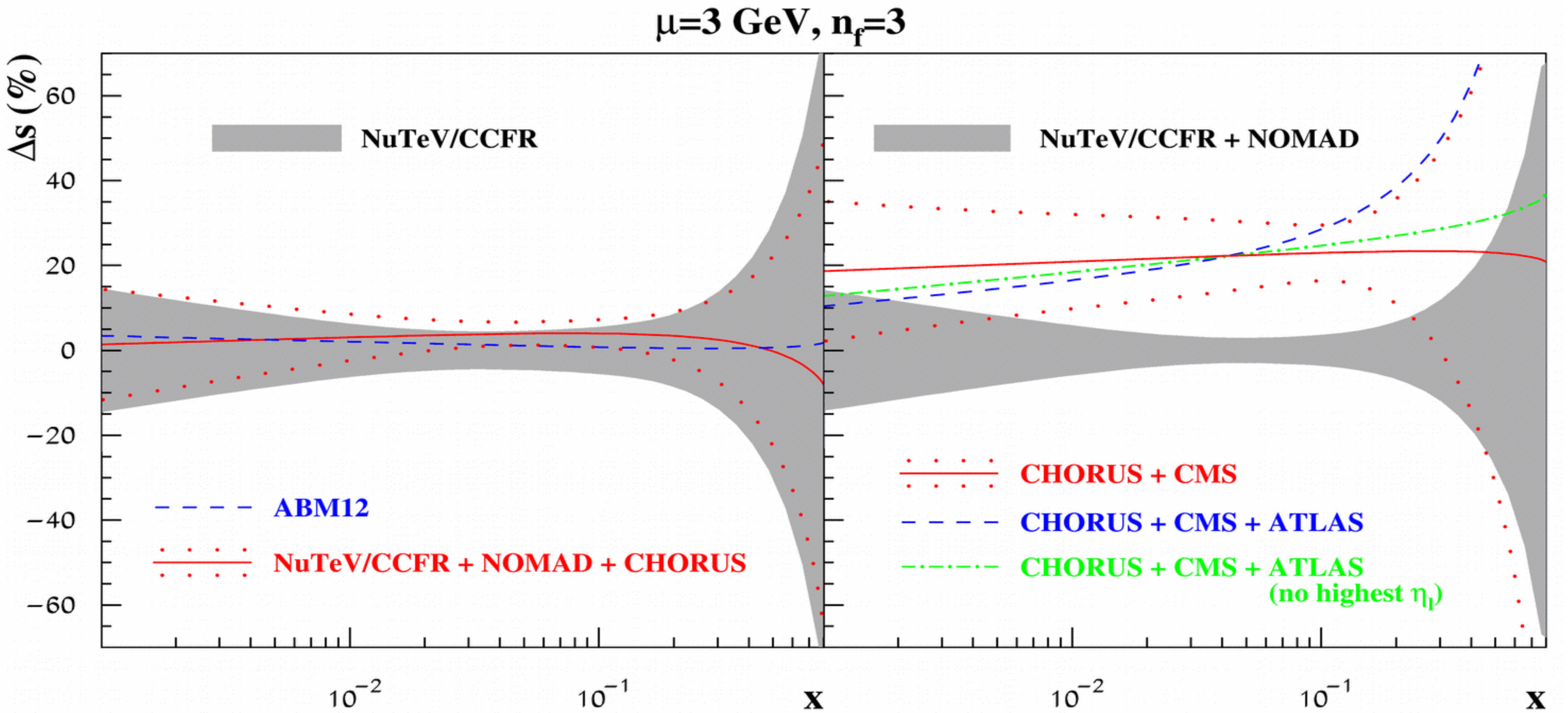
- CMS data go above the NuTeV/CCFR by 1σ; little impact on the strange sea
- The charge asymmetry is in a good agreement with the charge-symmetric strange sea
- Good agreement with the CHORUS data; enhancement ~ 20% in the strange sea

ATLAS W+charm data in the ABM fit

ATLAS Collaboration arXiv:1402.6263

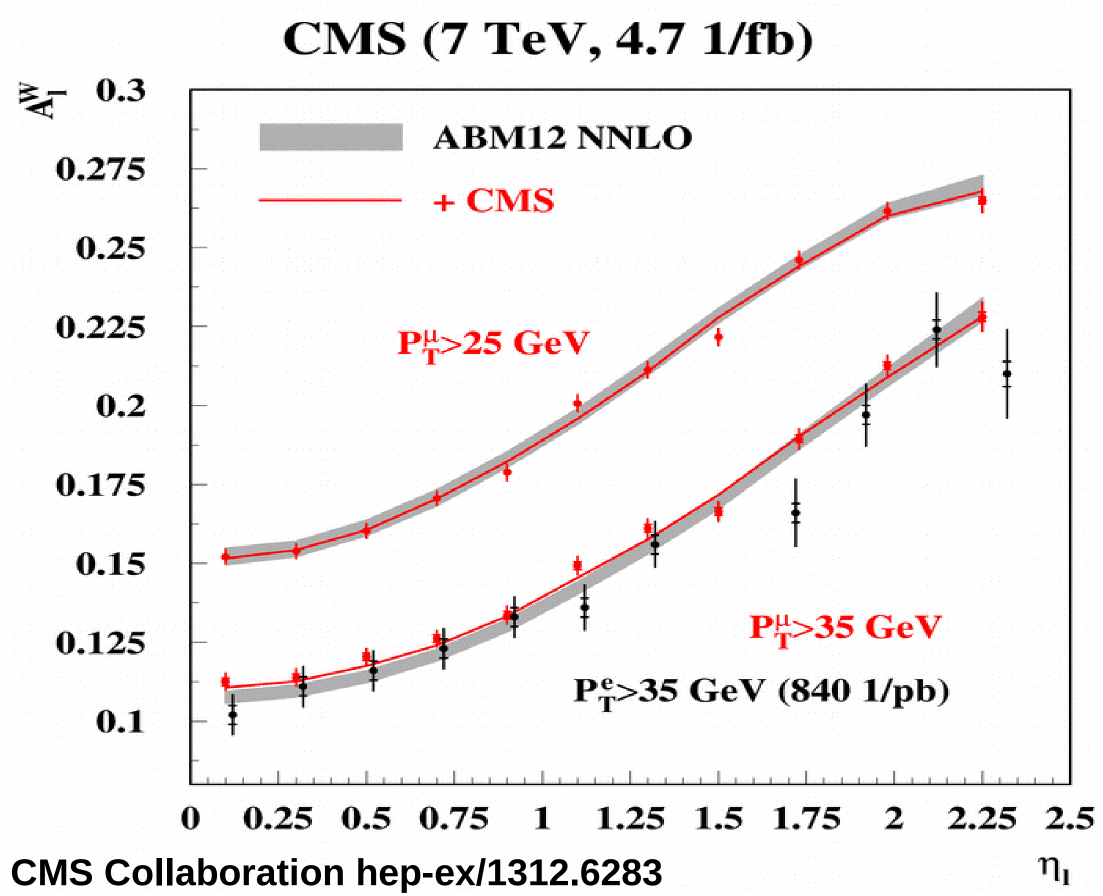


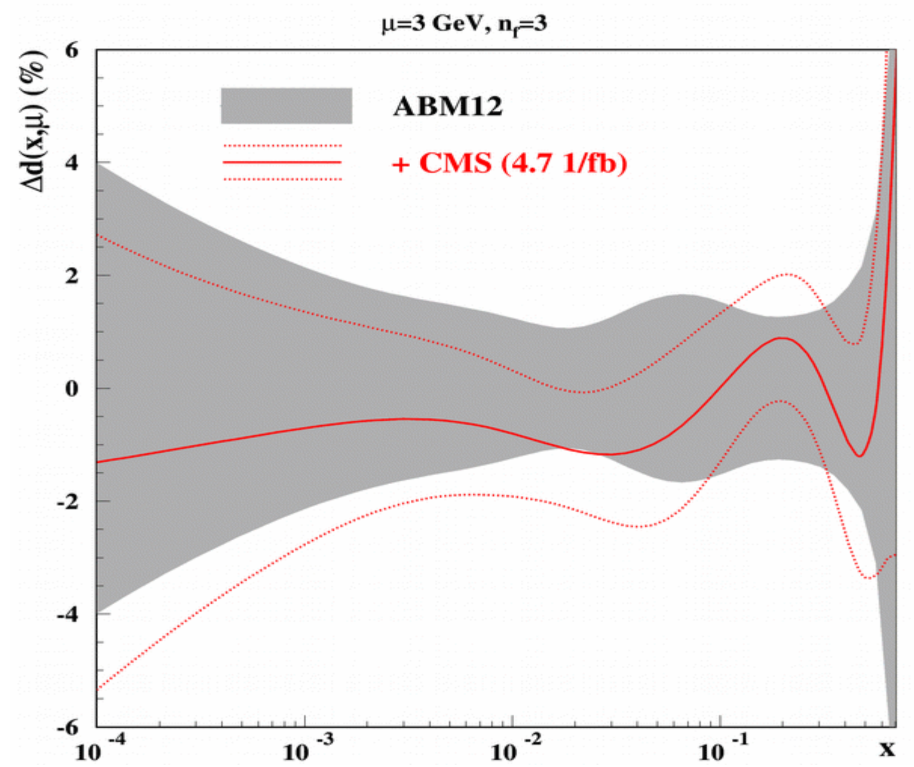
Strange sea preferred by LHC (W + c) data



- NOMAD+CHORUS do not go far from NuTeV/CCFR; improved strangeness accuracy
- CHORUS+CMS+ATLAS differ from NuTeV/CCFR+NOMAD by 2-3σ at x~0.1 (upper margin of the data tension)
- Largest-η ATLAS bin pulls strangeness up by 1σ – edge effect?

CMS DY data iteration





CMS Collaboration hep-ex/1312.6283

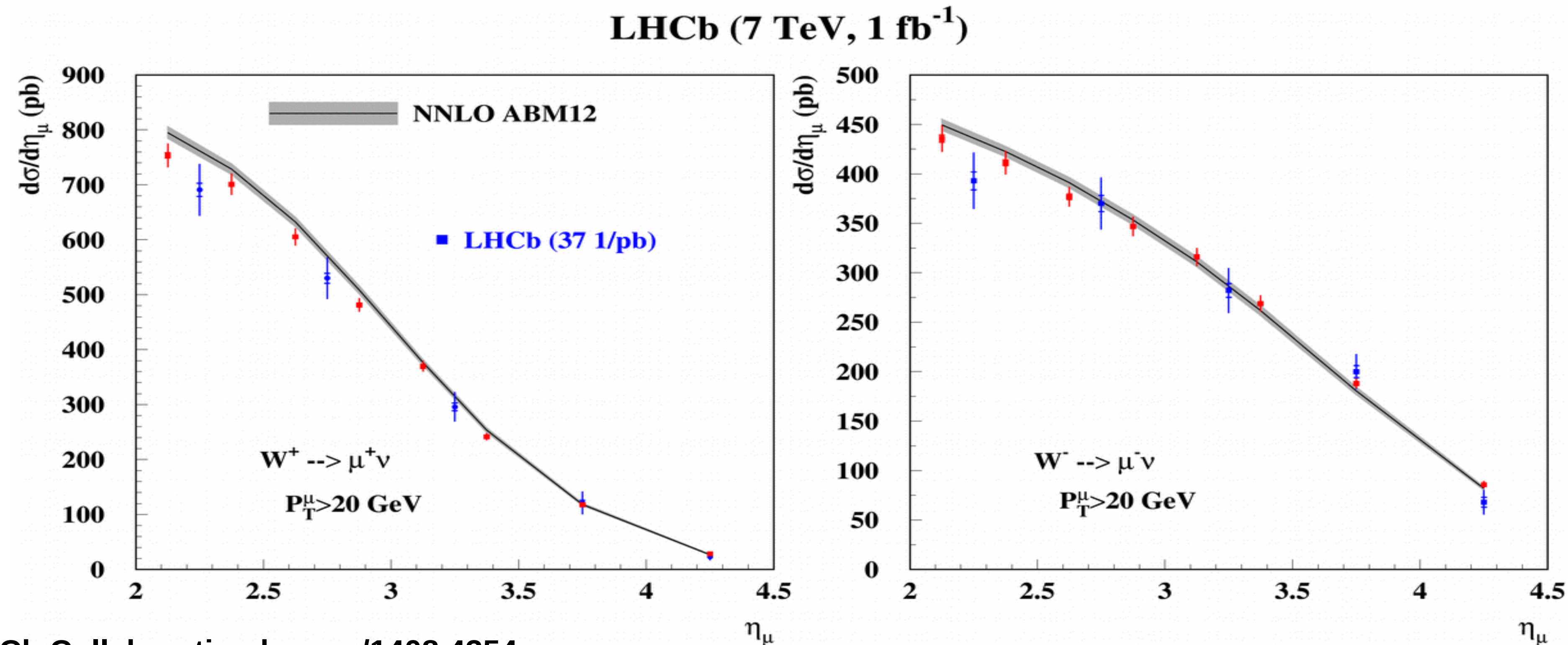
- Data converge to the ABM12 predictions in general, however at P_T>35 GeV and small η overshoot predictions and earlier data

- Improved accuracy of predictions is required(*7000h of DYNNLO 1.3 to get a smooth curve*!)

  – good agreement with the updated CMS data

P_T	>25 GeV	>35 GeV	
X^2	16	11	for NDP=11

LHCb DY data iteration



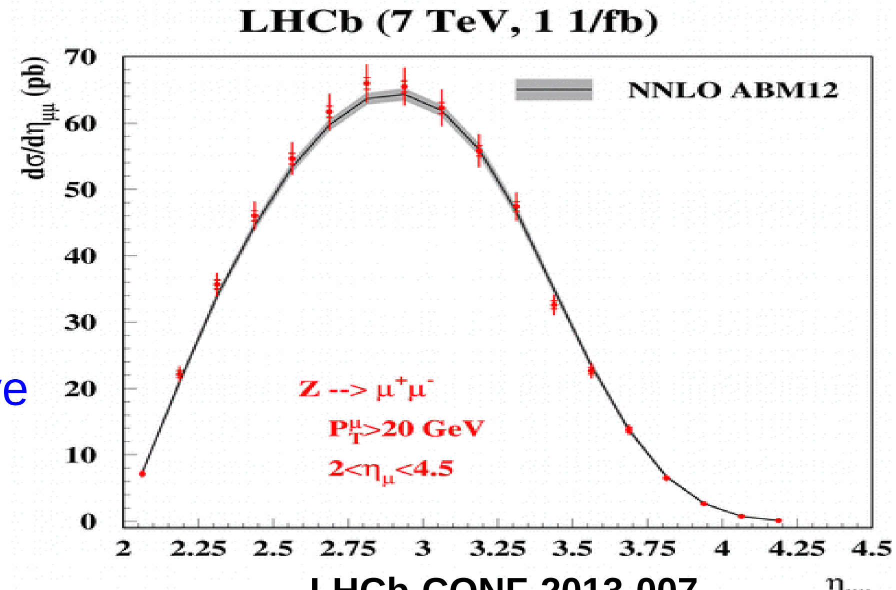
LHCb Collaboration hep-ex/1408.4354

- Inclusive W data converge to the predictions

  -- χ^2=27/16 before the fit, with account of the PDF unc.

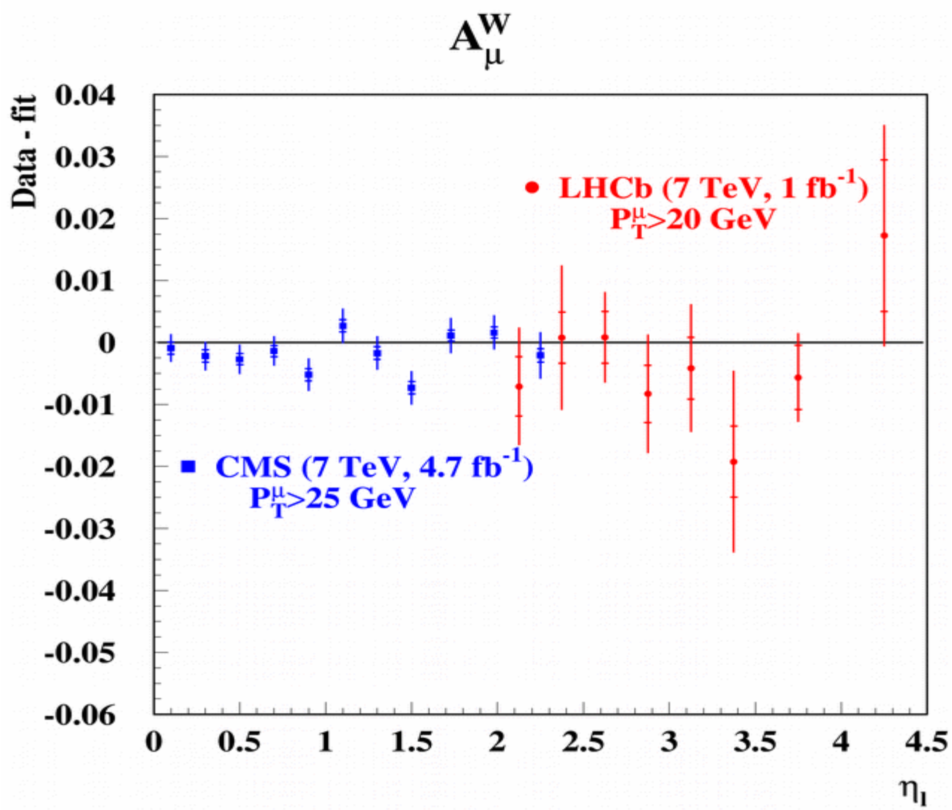
- Good agreement with the preliminary inclusive Z data

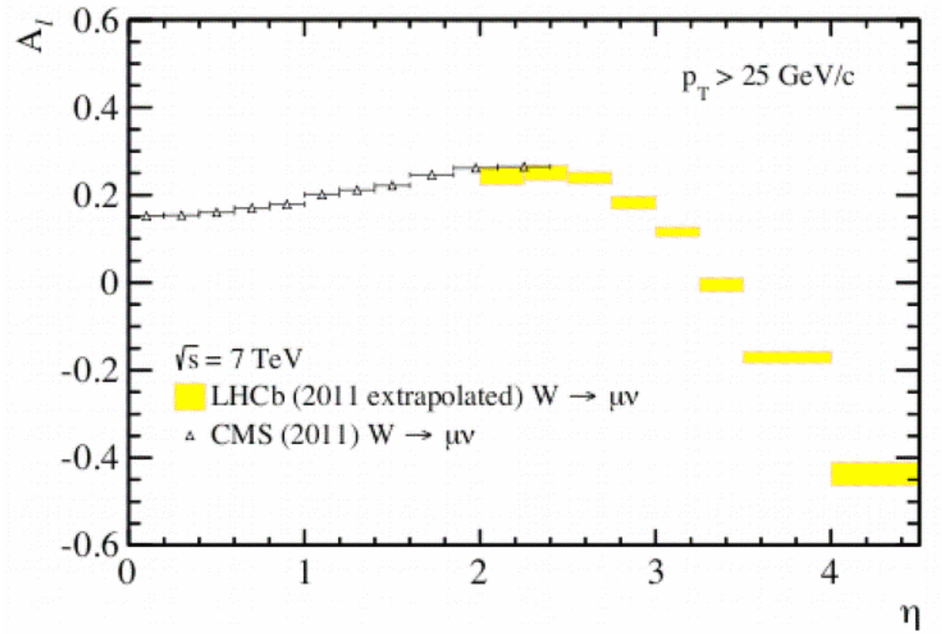
Improvement in the quark unc. up to x~0.5



LHCb-CONF-2013-007

Updated LHC data in the fit

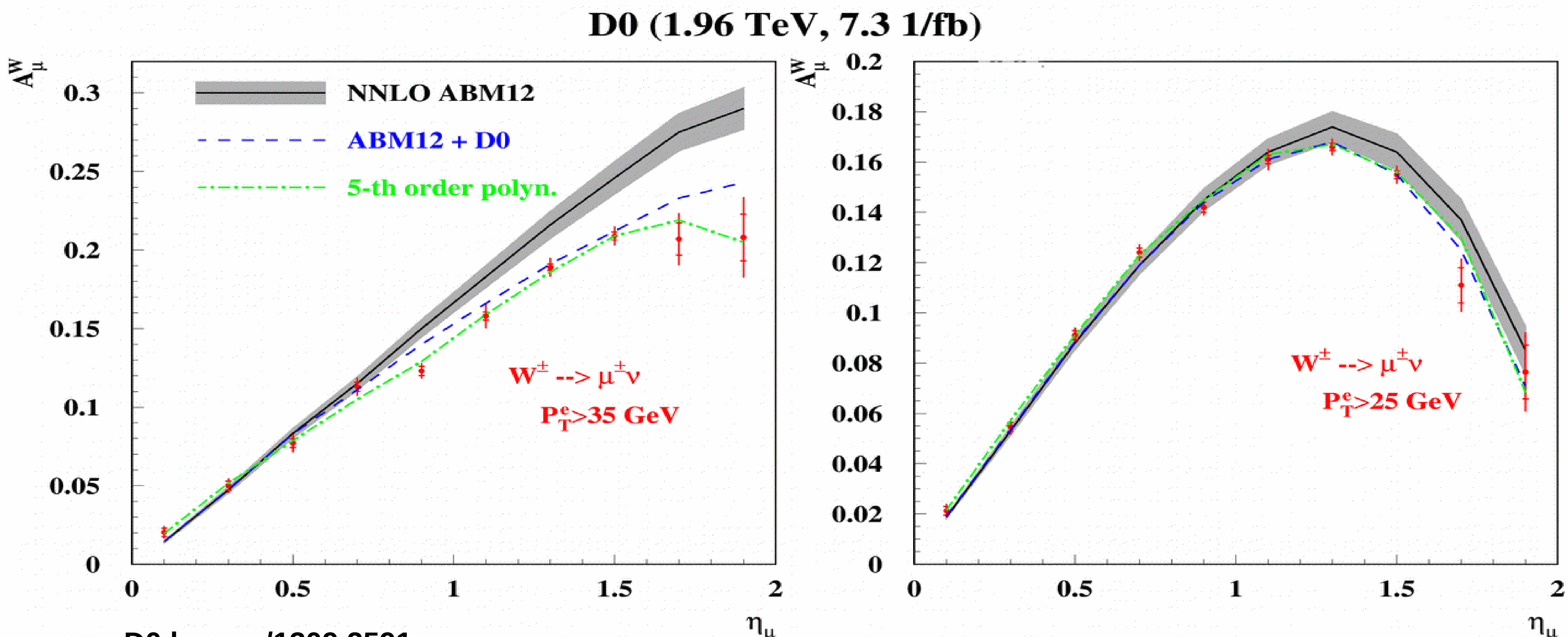




LHCb Collaboration hep-ex/1408.4354

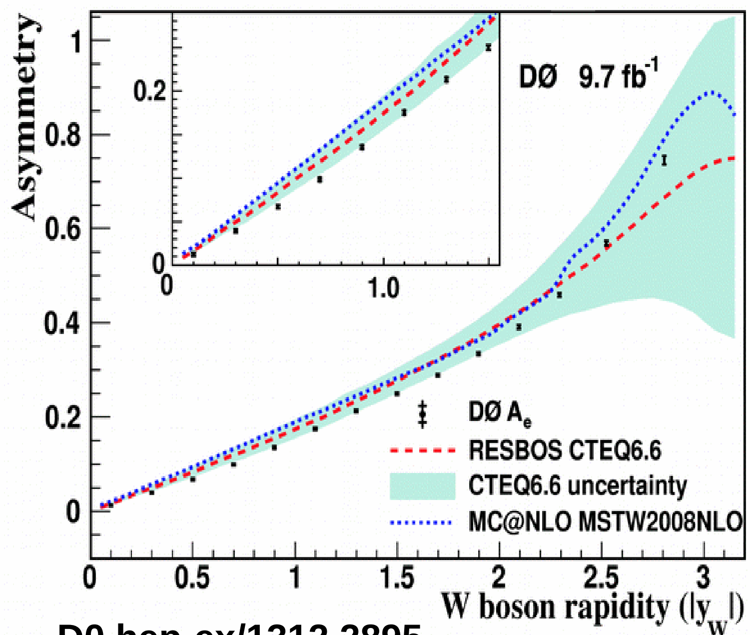
- LHCb goes somewhat lower than CMS
- Fluctuations in the data are bigger than the errors → the value of χ^2 is not ideal

Comparison with recent DY Tevatron data



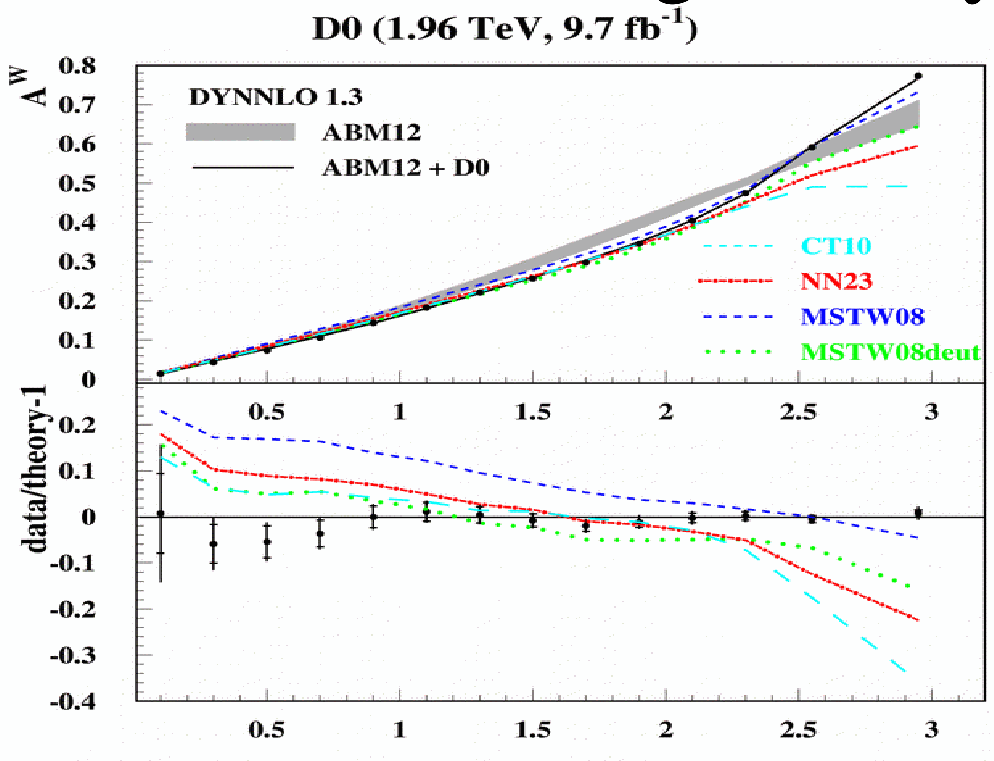
D0 hep-ex/1309.2591

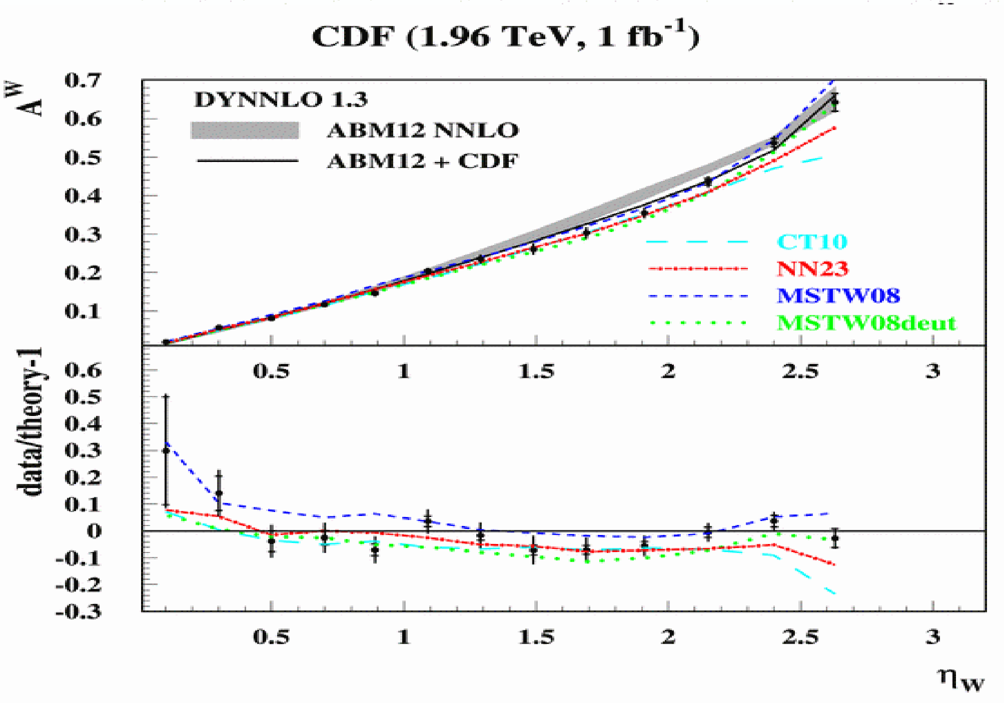
- Poor agreement with the ABM12 predictions at $P_T > 35$ GeV
- Poor description in the fit: $\chi^2 = 40/10$ and $19/10$ for $P_T > 35$ and 25, respectively
- Polynomial fit gives $\chi^2 = 11/10$, however displays a step structure at Y~1
- Smooth shape is observed in case of electron

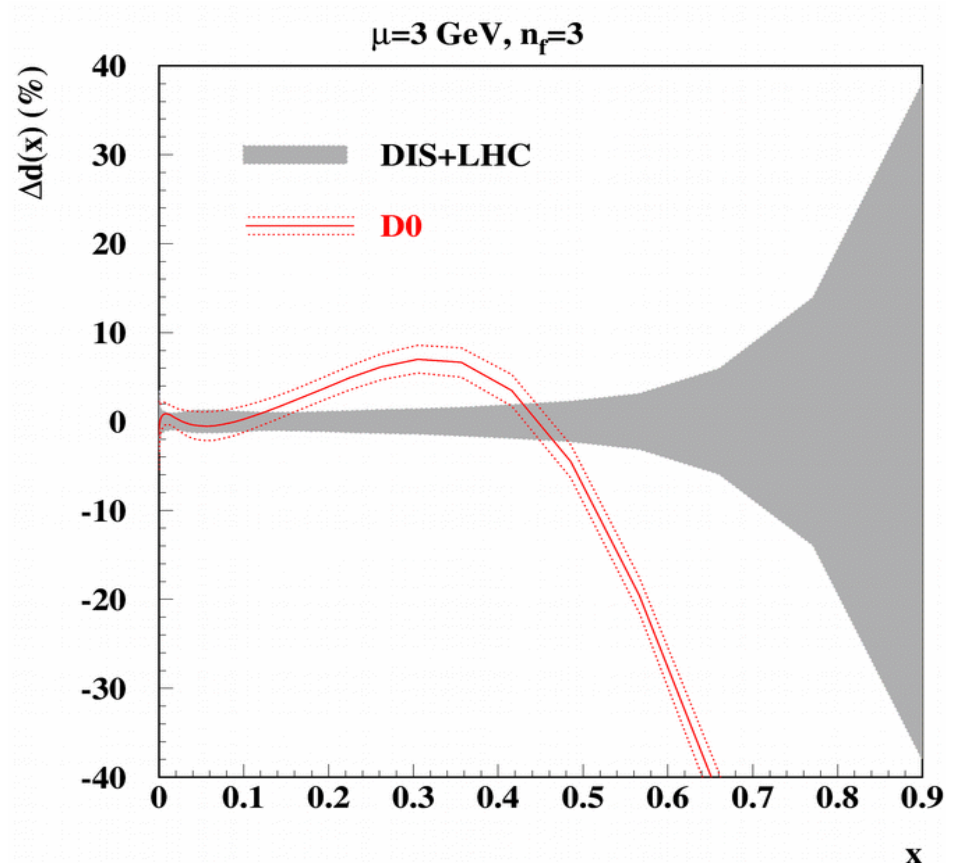


D0 hep-ex/1312.2895

Charge W asymmetry from D0







Potentially can constraint quark distributions at large x, however

- *Differ from CDF data in places*
- *Disagreement with the predictions → strong suppression of d-quark at large x*
- *Unfolding at large rapidity?*

Summary

- Consistent treatment of the heavy-quark production with the running-mass definition
  - theoretically solid small-x PDFs from the DIS data
  - good description of the available t-quark data with

    $m_t(m_t)$=162.3±2.3 GeV
    m_t(pole)=171.2±2.4 GeV

- Good overall description of the LHC DY data in the NNLO accuracy; new input from CMS and LHCb improves the quark PDF determination

- Improved accuracy of strange sea using NOMAD and CHORUS data, factor of 2 at x~0.1

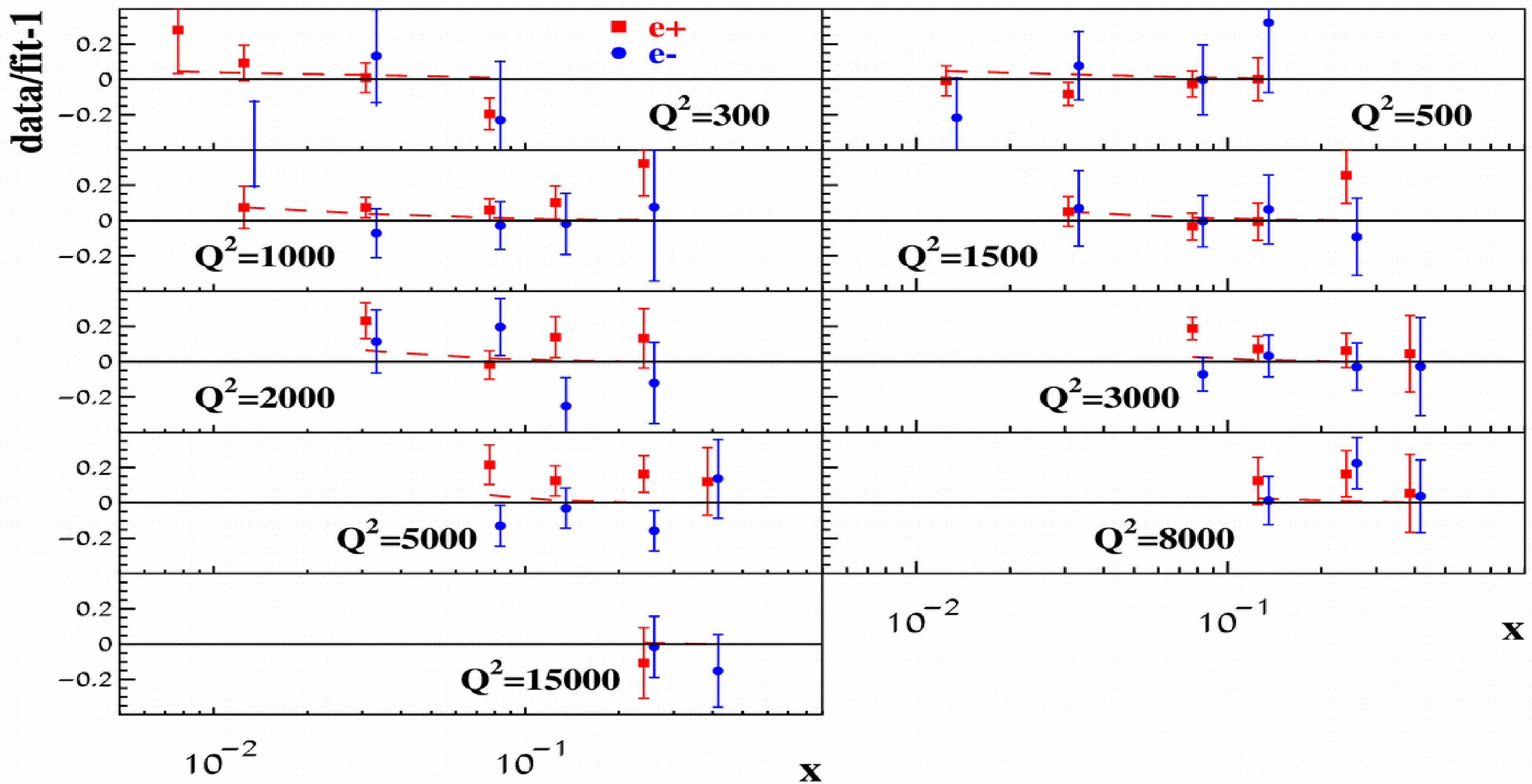
- Enhancement of ~20% due to CMS, and ATLAS data: statistical fluctuation? impact of the NNLO corrections on W+charm production?

- Poor agreement with the recent D0 data → clarification is necessary

Extras

The NNLO CC corrections

HERA-RunI



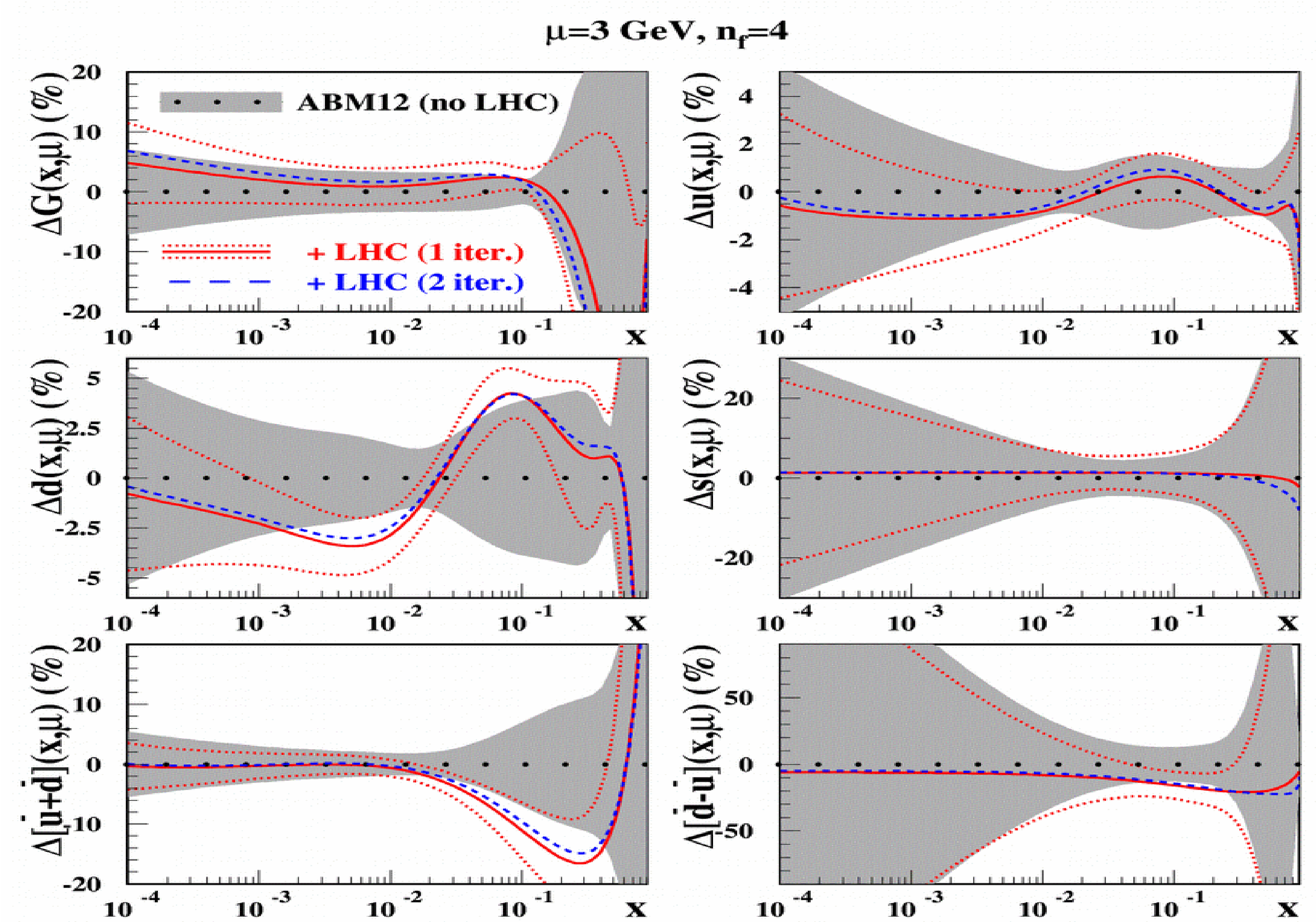
- Asymptotic NNLO CC corrections at Q>> m_c relevant for the HERA kinematics

Buza van Neerven, NPB 500, 301 (1997)
Blümlein, Hasselhuhn, Pfoh NPB881, 1 (2014)
Moch (2013) (unpublished)

- Effect is ~5% at small x

- ΔX^2 = -6/114 for the HERA RunI CC data; bigger impact for RunII expected

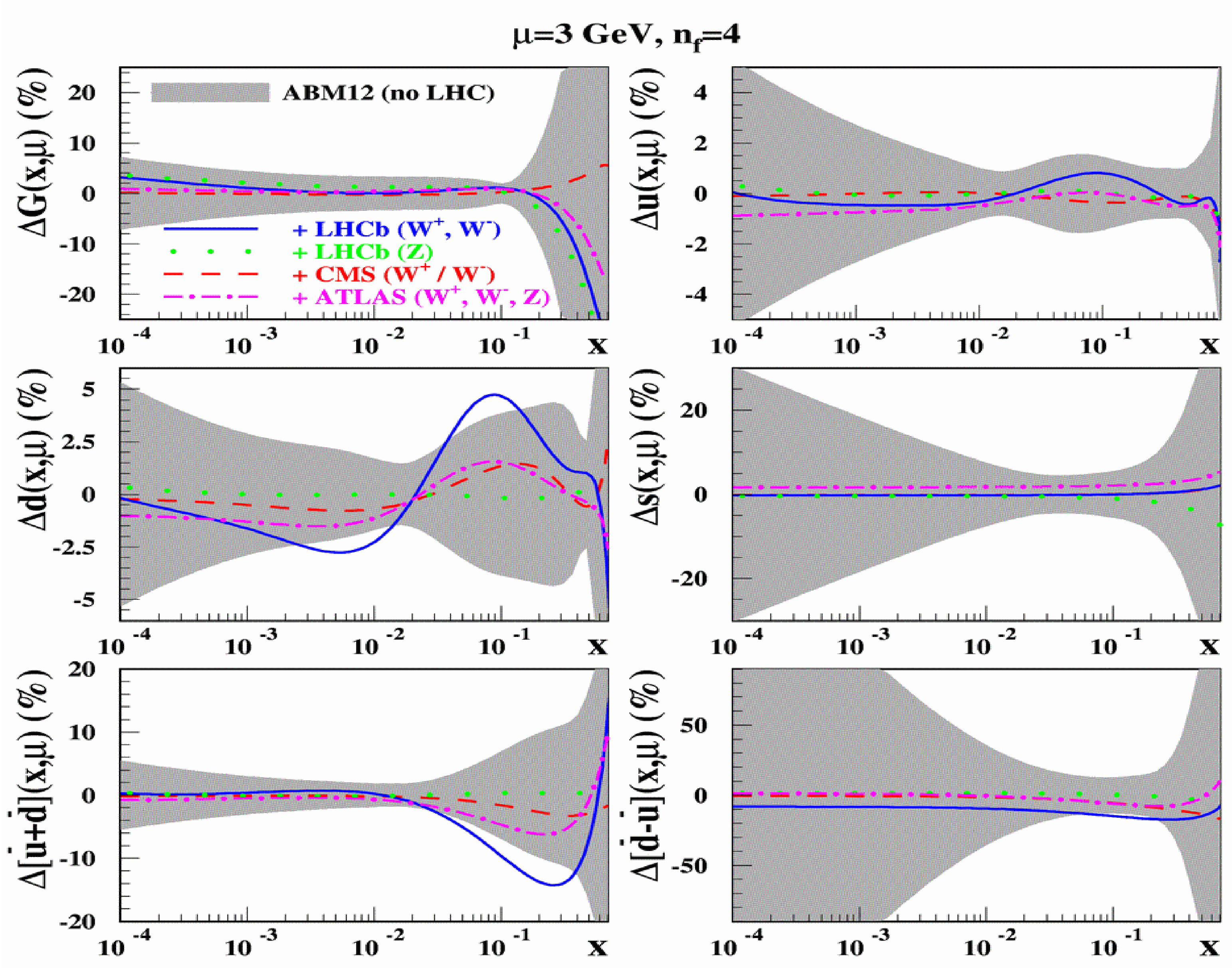
Impact of the LHC DY data on the PDFs



- 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 reproduced

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

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

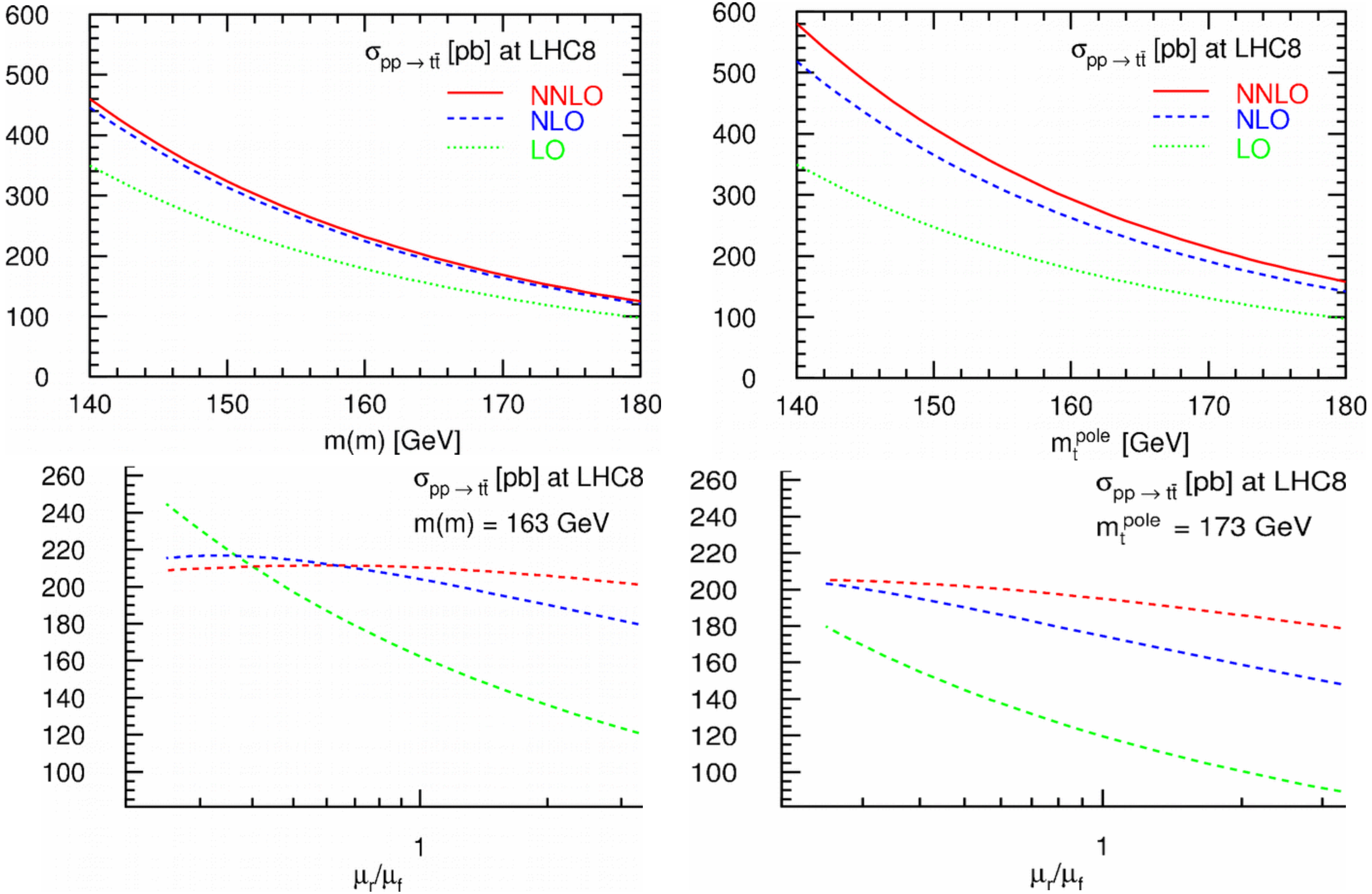
The general PDF basis is not necessary since the PDFs are already constrained by the data, which do not require involved computations → *use as a PDF basis the eigenvalue PDF sets obtained in the earlier version of the fit*

$\mathbf{P_0} \pm \Delta\mathbf{P}_0$ – 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

Pole- and running-mass definitions

Running mass | Pole mass



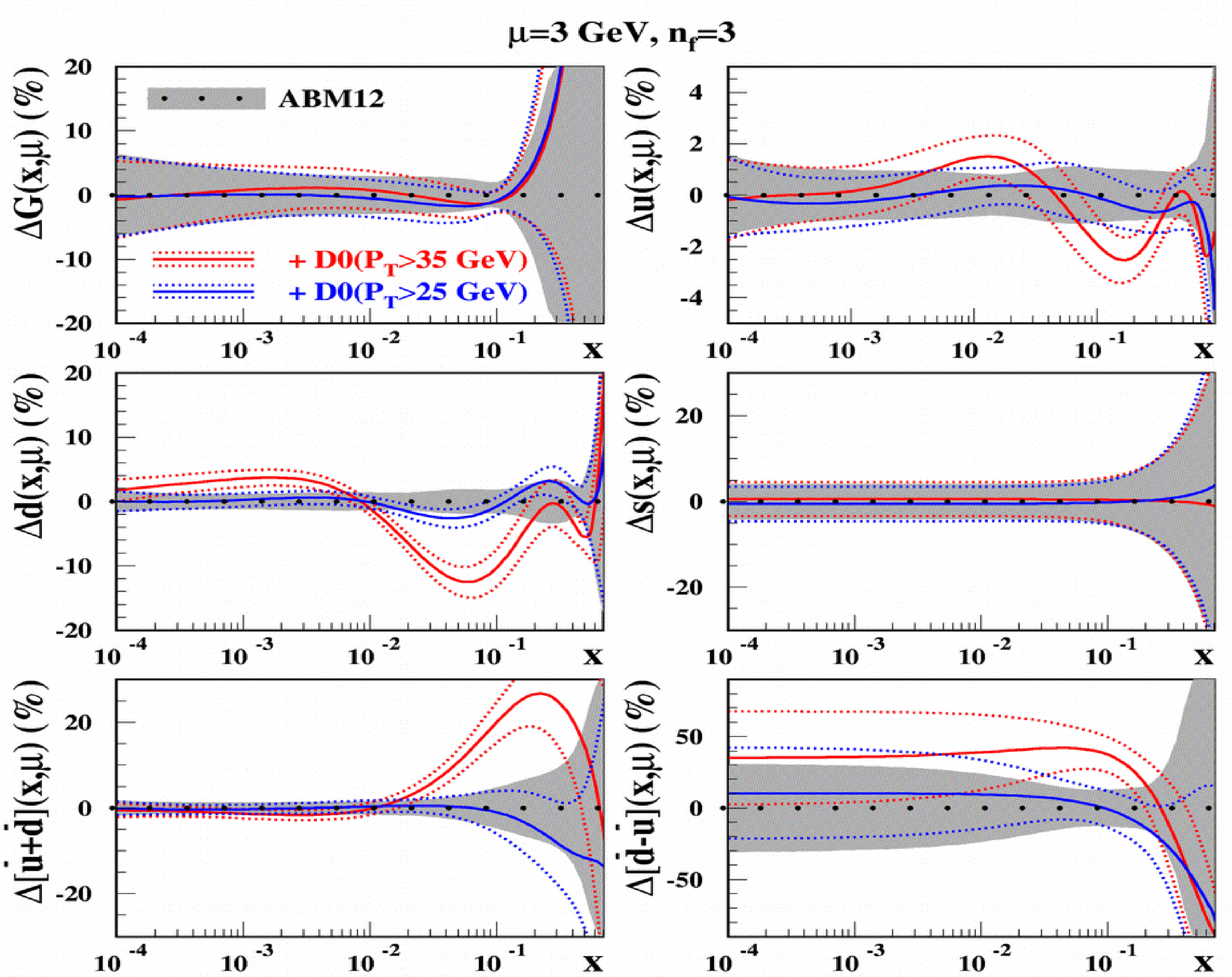
HATTOR (NNLO terms are checked with TOP++)

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

Czakon, Fiedler, Mitov hep-ph/1303.6254

Running mass definition provides nice perturbative stability

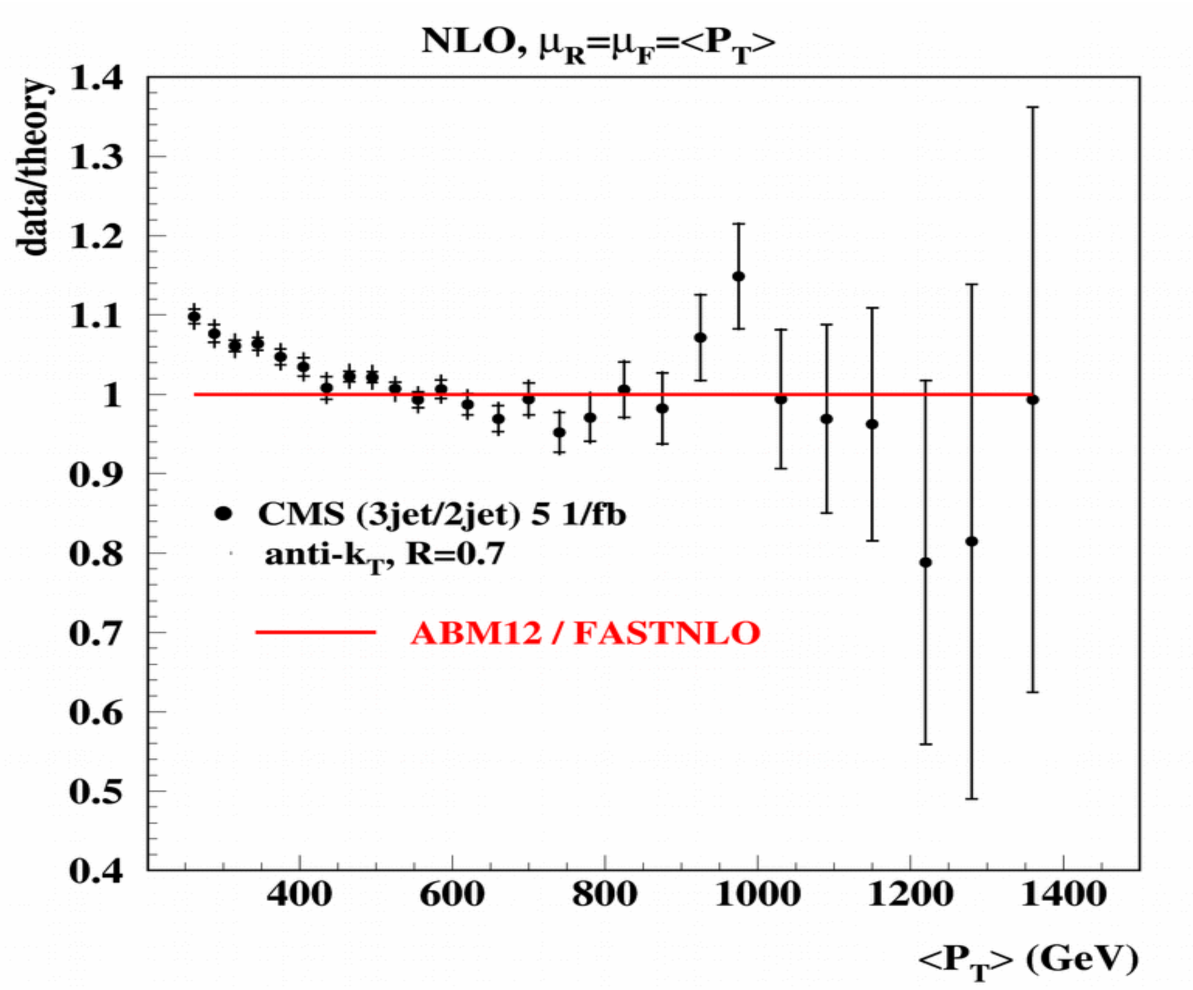
Impact of DY D0 data



Impact of the data on PDFs is quite sensitive to the the cut on P_T

→ clarification is necessary

CMS jets in ABM fit



CMS hep-ex/1304.7498

P_T(GeV) >	500	400	300	NLO ABM12
$\alpha_s(M_Z)$	0.1181(10)	0.1200(9)	0.1220(9)	0.1179(11)

The discrepancies are localized at small PT: NNLO corrections? scale choice?