# ABMP16 PDFs

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

- HERA I+II data: $\alpha_s(M_Z)$, $m_c$, and $m_b$
- Drell-Yan data from the LHC and Tevatron: Isospin asymmetry and d/u at large x
- t-quark data: $m_t$ and gluon distribution
- Charm production data from NOMAD and CHORUS: strange sea

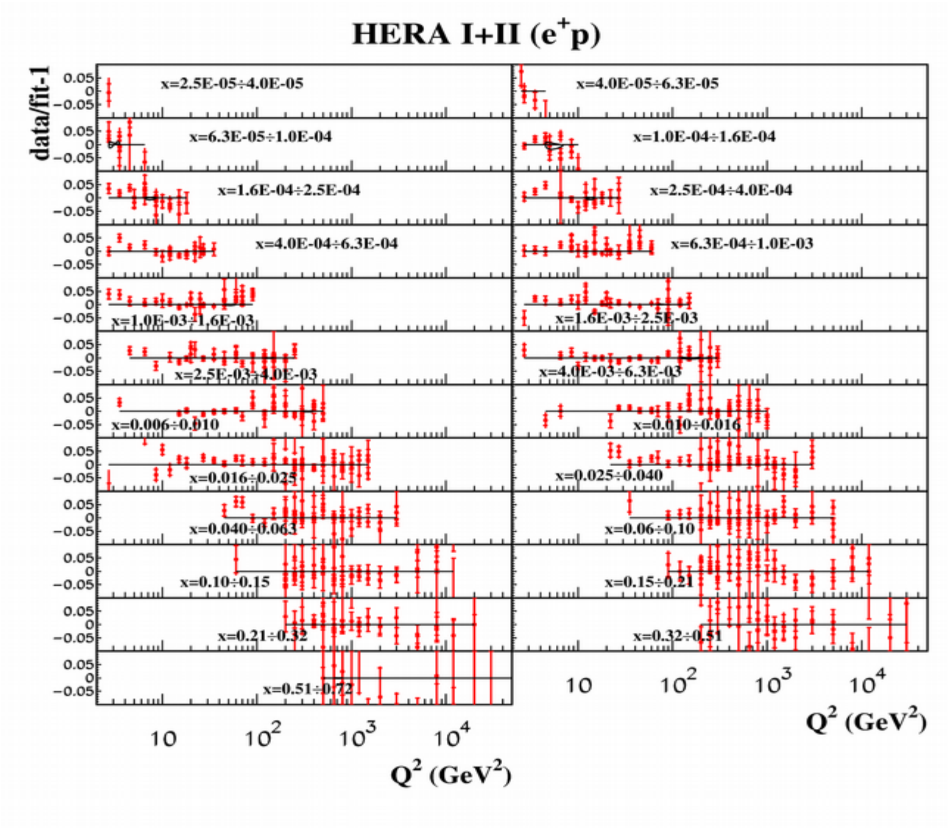
**sa, Blümlein, Caminada, Lipka, Lohwasser,**
**Moch, Petti, Plačakytė hep-ph/1404.6469**

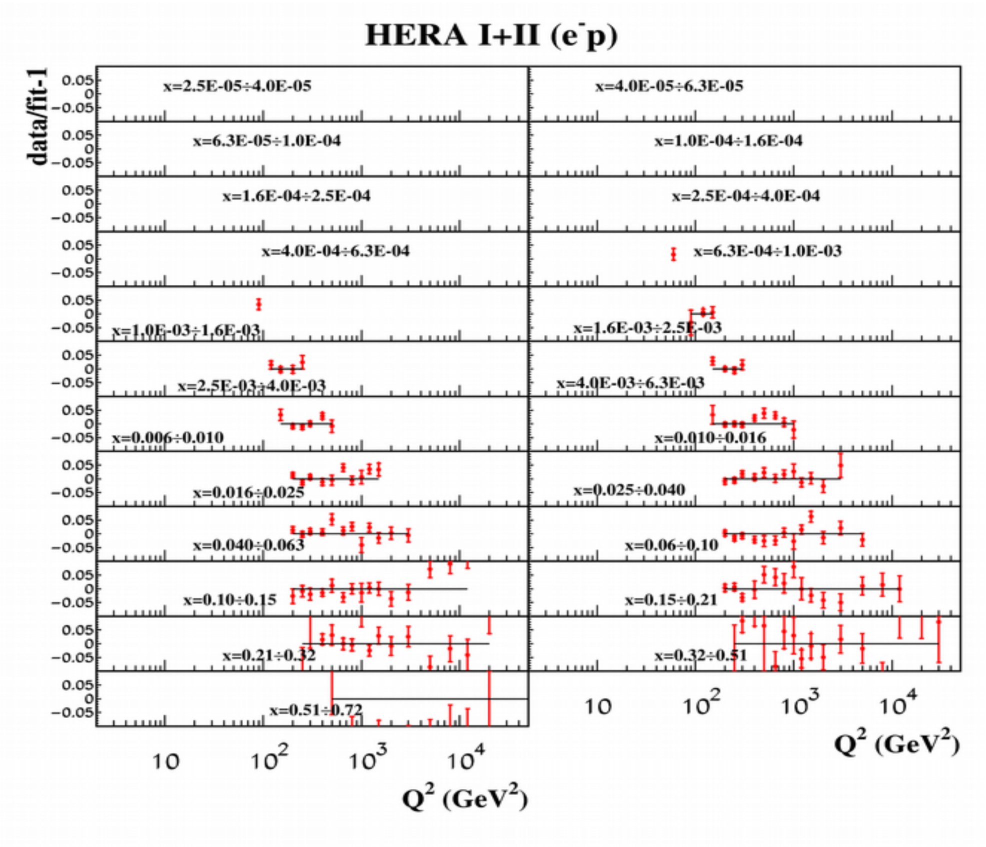
**sa, Blümlein, Moch, Plačakytė, hep-ph/1508.07923**

*QCD@LHC2016, Univ. Zurich*, 25 *Aug 2016*

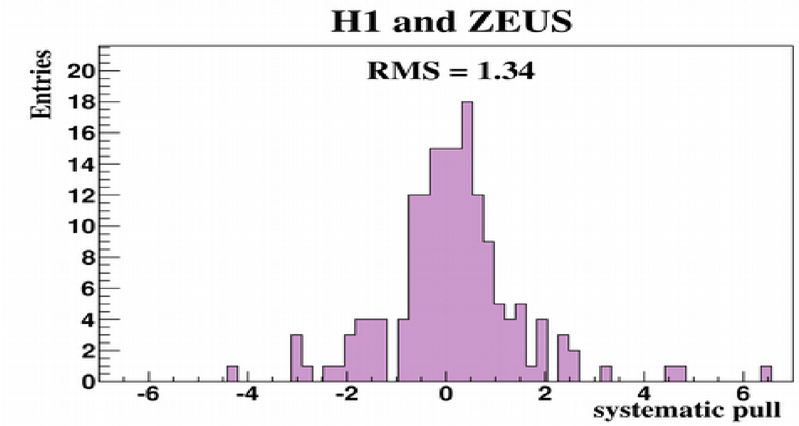
# Inclusive HERA I+II data

H1 and ZEUS hep-ex/1506.06042





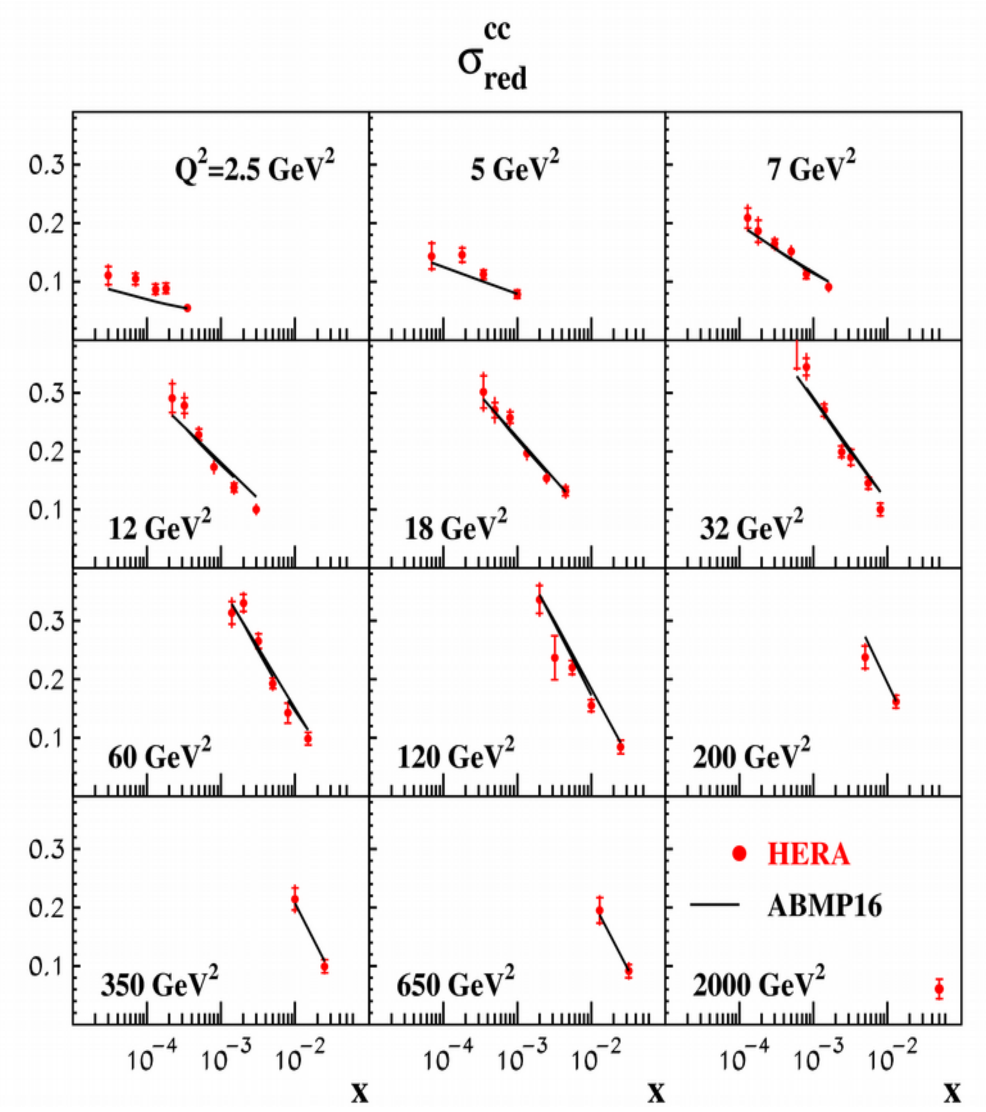
| $Q^2$(HERA) | $\chi^2$/NDP(HERA) |
|---|---|
| >2.5 $GeV^2$ | 1509/1168=1.29 |
| >5 $GeV^2$ | 1354/1092=1.24 |
| >10 $GeV^2$ | 1228/1007=1.22 |



The value of $\chi^2$/NDP is bigger than 1, however still comparable to the pull distribution width

# HERA charm data and $m_c(m_c)$

**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)**

  Update with the pure singlet massive OMEs

  **Ablinger et al. NPB 890. 48 (2014)**

  → improved theoretical uncertainties

- Running-mass definition of $m_c$

  $\chi^2$/NDP=66/52

  $m_c(m_c)$=1.252±0.018(exp.) GeV ABMP16

  $m_c(m_c)$=1.24±0.03(exp.) GeV ABM12

- RT optimal

  $\chi^2$/NDP=82/52 NNLO

  $m_c$(pole)=1.25 GeV **MMHT14 EPJC 75, 204 (2015)**

- F0NLL

  $\chi^2$/NDP=60/47 NNLO

  $m_c$(pole)=1.275 GeV **NNPDF3.0 JHEP 1504, 040 (2015)**

- S-ACOT-χ

  $\chi^2$/NDP=59/47 NNLO

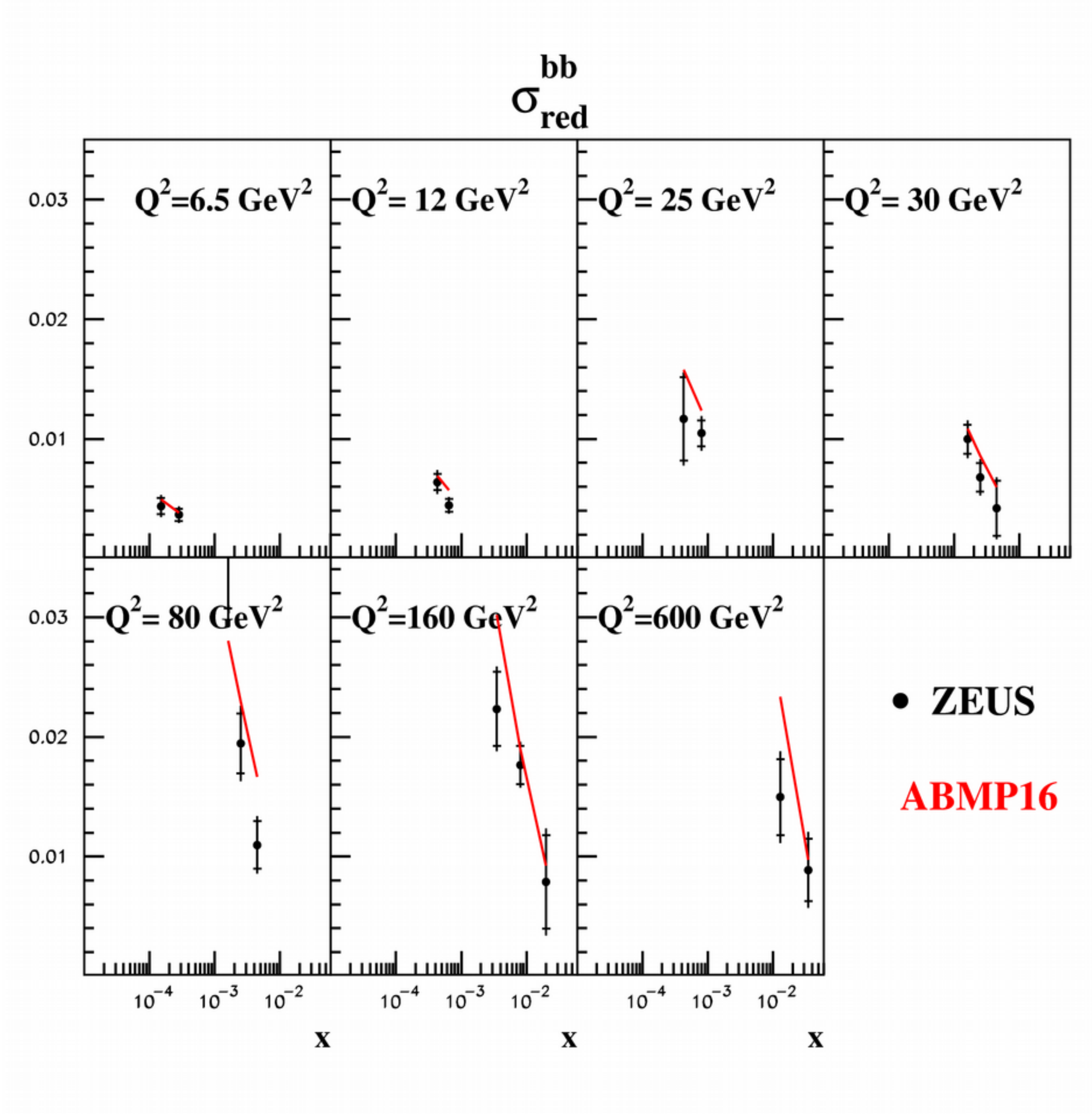
  $m_c$(pole)=1.3 GeV **CT14 hep-ph 1506.07443**

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

**Kiyo, Mishima, Sumino hep-ph/1510.07072**

**Accardi, et al. hep-ph/1603.08906**

# HERA bottom data and $m_b(m_b)$



**ZEUS JHEP 1409, 127 (2014)**

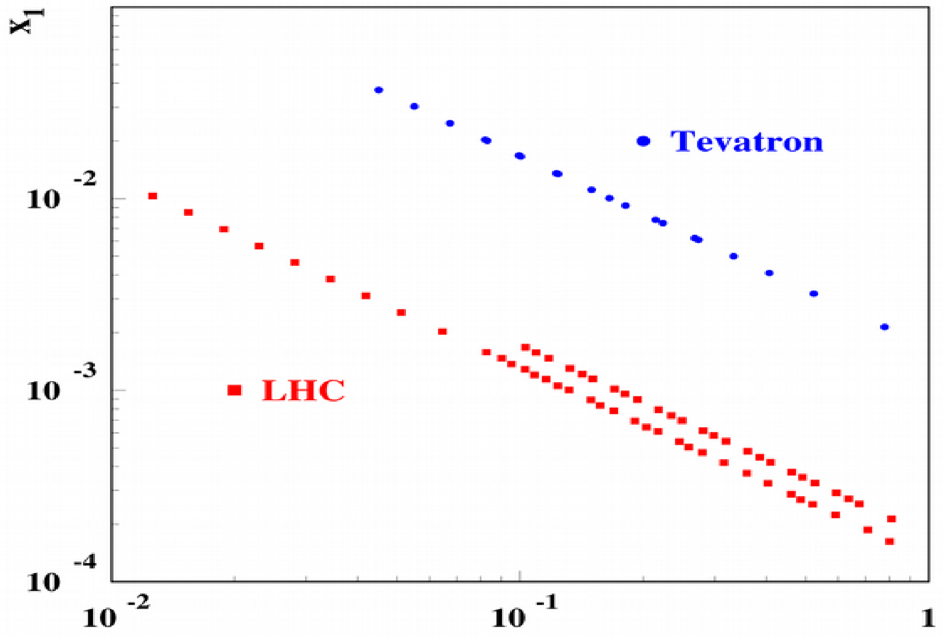
$\chi^2$/NDP=16/17

**H1 EPJC 65, 89 (2010)**

$\chi^2$/NDP=5/12

$m_b(m_b)$=3.83±0.12(exp.) GeV

# Collider W&Z data used in the fit



In the forward region $x_2 >> x_1$

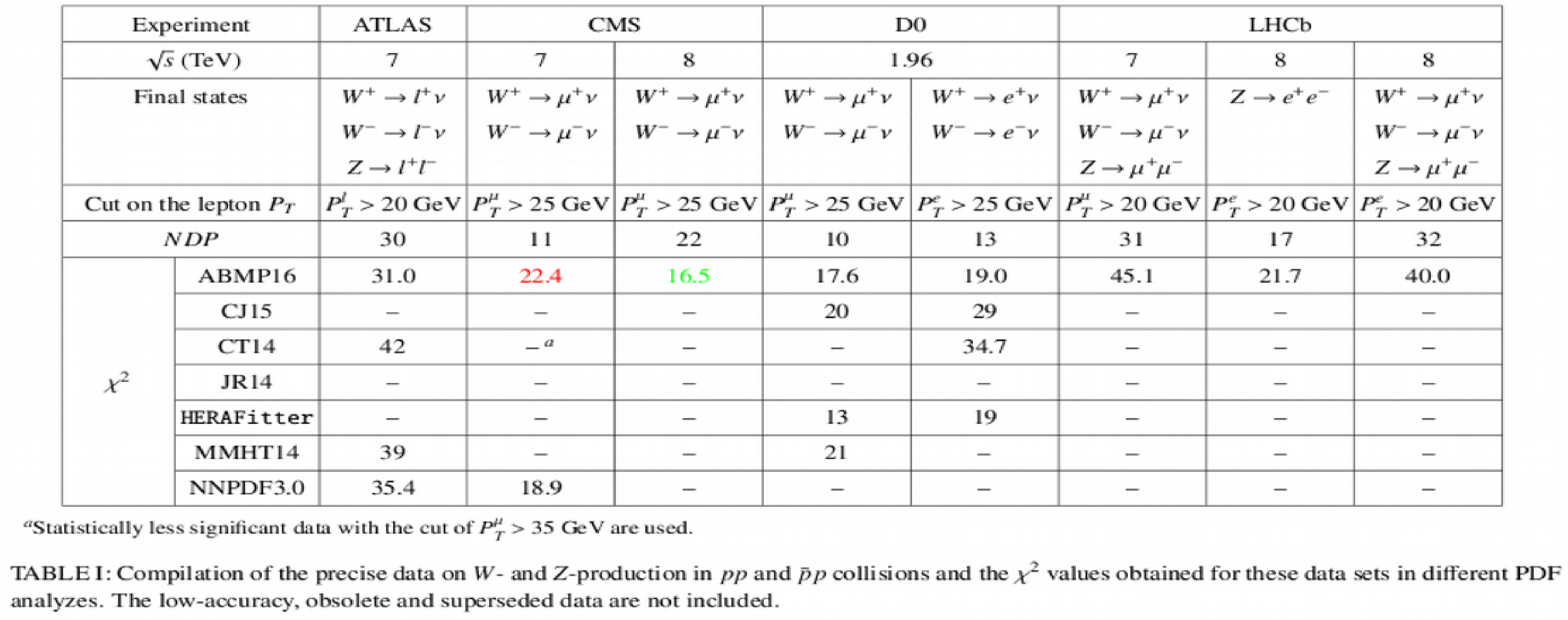
$\sigma(W^+) \sim u(x_2)$ dbar $(x_1)$

$\sigma(W^-) \sim d(x_2)$ ubar$(x_1)$

$\sigma(Z) \sim Q_U{}^2 u(x_2)$ ubar $(x_1) + Q_D{}^2 d(x_2)$ dbar$(x_1)$

$\sigma(\mathrm{DIS}) \sim q_u{}^2 u(x_2) + q_d{}^2 d(x_2)$

*Forward W&Z production probes small/large x and is complementary to the DIS → constraint on the quark iso-spin asymmetry*



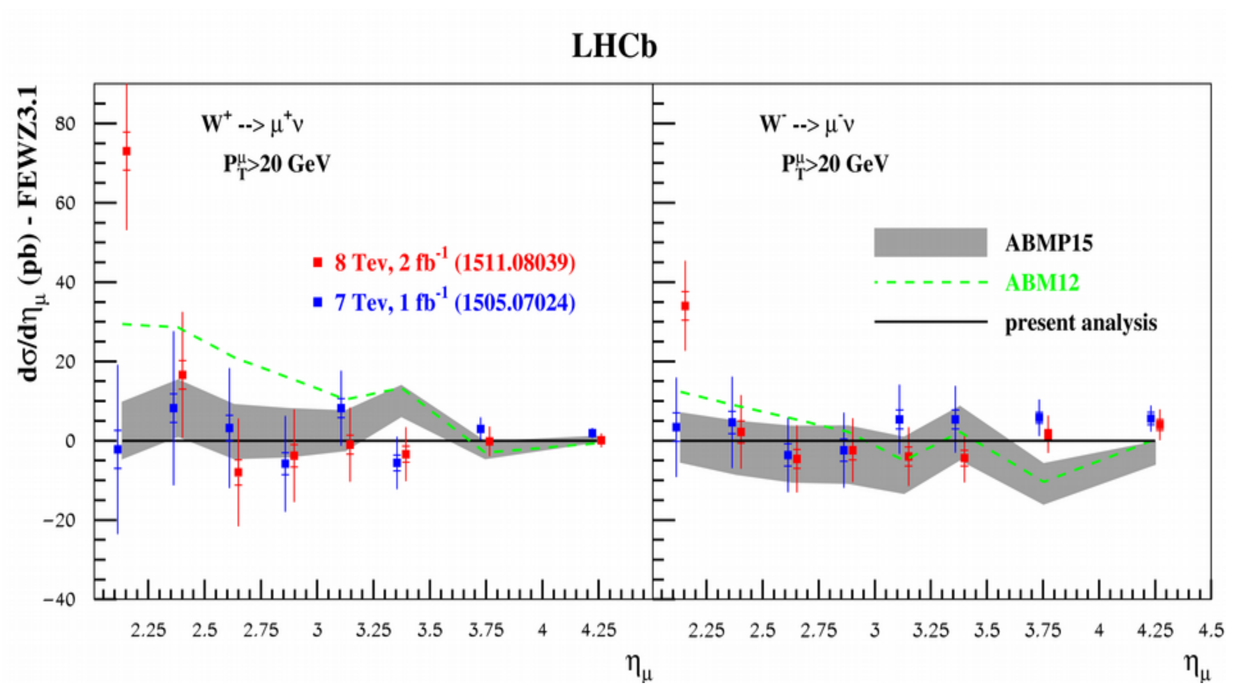
| Experiment | | ATLAS | CMS | | D0 | | LHCb | | |
|---|---|---|---|---|---|---|---|---|---|
| $\sqrt{s}$ (TeV) | | 7 | 7 | 8 | 1.96 | | 7 | 8 | 8 |
| Final states | | $W^+ \to l^+\nu$<br>$W^- \to l^-\nu$<br>$Z \to l^+l^-$ | $W^+ \to \mu^+\nu$<br>$W^- \to \mu^-\nu$ | $W^+ \to \mu^+\nu$<br>$W^- \to \mu^-\nu$ | $W^+ \to \mu^+\nu$<br>$W^- \to \mu^-\nu$ | $W^+ \to e^+\nu$<br>$W^- \to e^-\nu$ | $W^+ \to \mu^+\nu$<br>$W^- \to \mu^-\nu$<br>$Z \to \mu^+\mu^-$ | $Z \to e^+e^-$ | $W^+ \to \mu^+\nu$<br>$W^- \to \mu^-\nu$<br>$Z \to \mu^+\mu^-$ |
| Cut on the lepton $P_T$ | | $P_T^l > 20$ 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 | $P_T^e > 20$ GeV |
| $NDP$ | | 30 | 11 | 22 | 10 | 13 | 31 | 17 | 32 |
| $\chi^2$ | ABMP16 | 31.0 | 22.4 | 16.5 | 17.6 | 19.0 | 45.1 | 21.7 | 40.0 |
| | CJ15 | – | – | – | 20 | 29 | – | – | – |
| | CT14 | 42 | –[a] | – | – | 34.7 | – | – | – |
| | JR14 | – | – | – | – | – | – | – | – |
| | `HERAFitter` | – | – | – | 13 | 19 | – | – | – |
| | MMHT14 | 39 | – | – | 21 | – | – | – | – |
| | NNPDF3.0 | 35.4 | 18.9 | – | – | – | – | – | – |

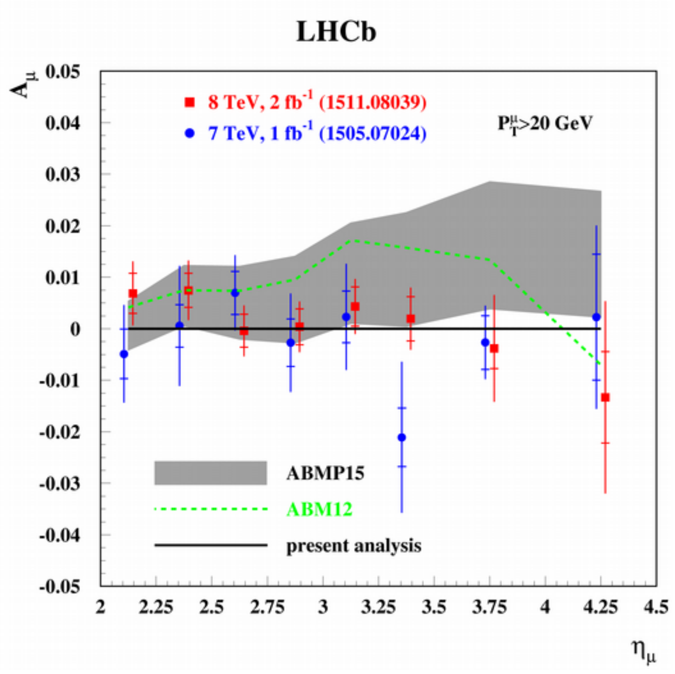
[a] Statistically less significant data with the cut of $P_T^\mu > 35$ GeV are used.

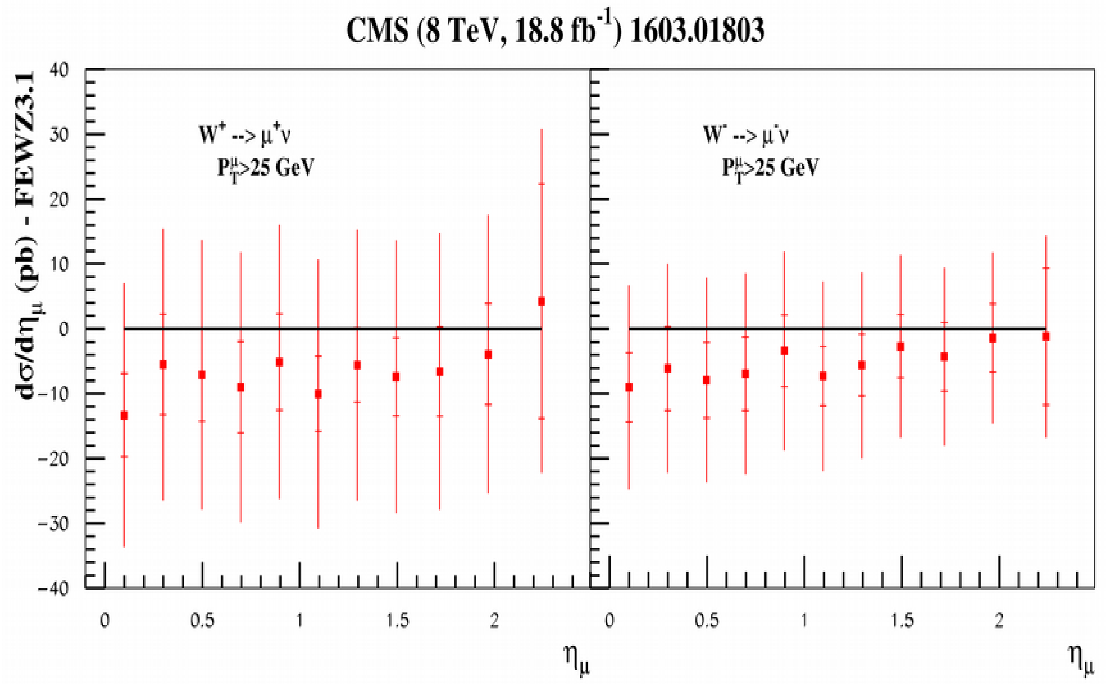
TABLE I: Compilation of the precise data on $W$- and $Z$-production in $pp$ and $\bar{p}p$ collisions and the $\chi^2$ values obtained for these data sets in different PDF analyzes. The low-accuracy, obsolete and superseded data are not included.

*Obsolete/superseded/low-accuracy Tevatron and LHC data are not used*

# Most recent DY inputs







cf. earlier data in sa, Blümlein, Moch, Plačakytė, hep-ph/1508.07923

Filtering of the LHCb data has been performed:

– a bump at 7 Tev and Y=3.275 (not confirmed by the LHCb data at 8 TeV)

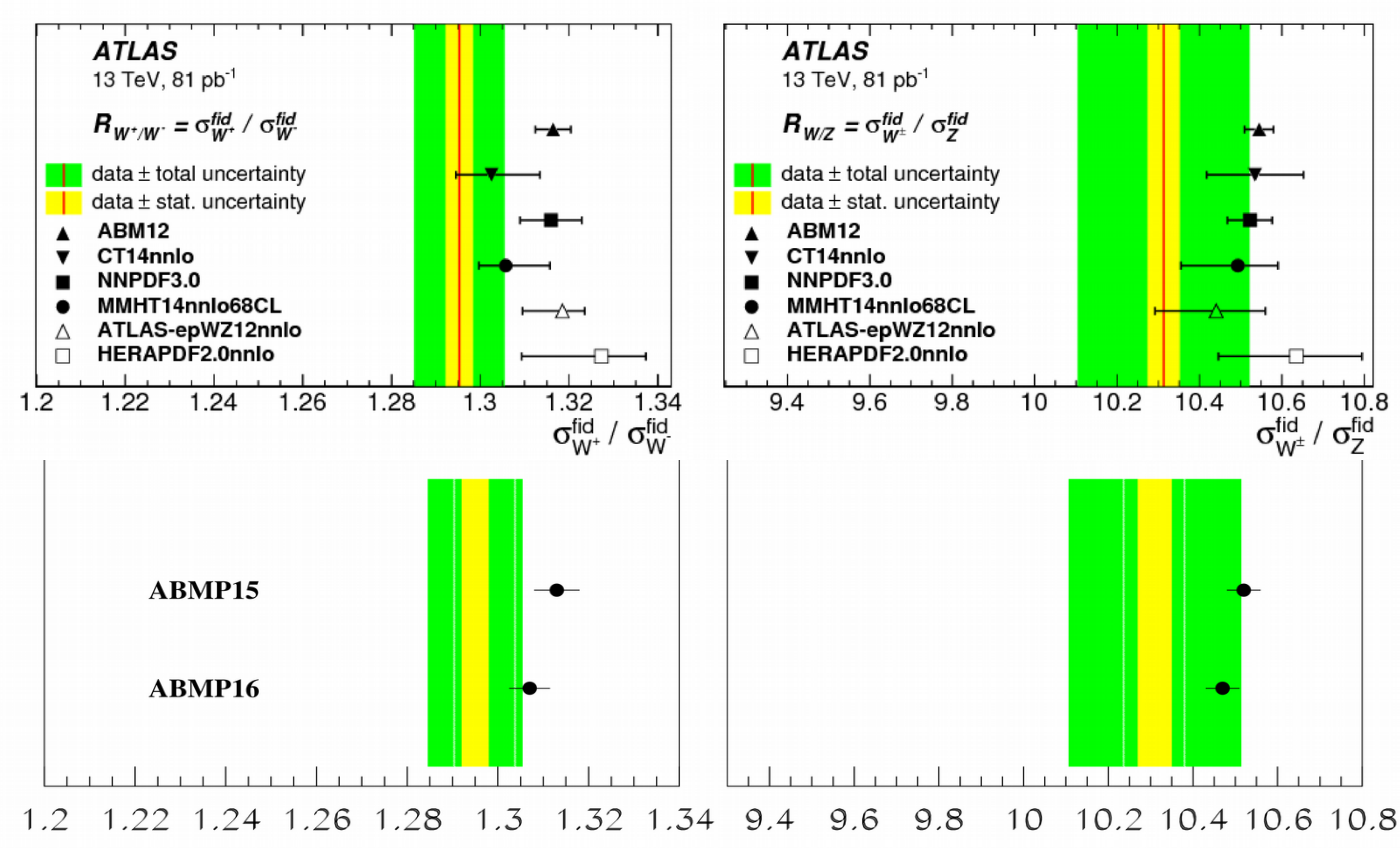
– and excess at 8 TeV and Y=2.125 (not confirmed by the CMS data at 8 TeV)

The CMS data at 8 TeV are much smoother than the ones at 7 TeV:

$\chi^2$=17/22 versus 22/11

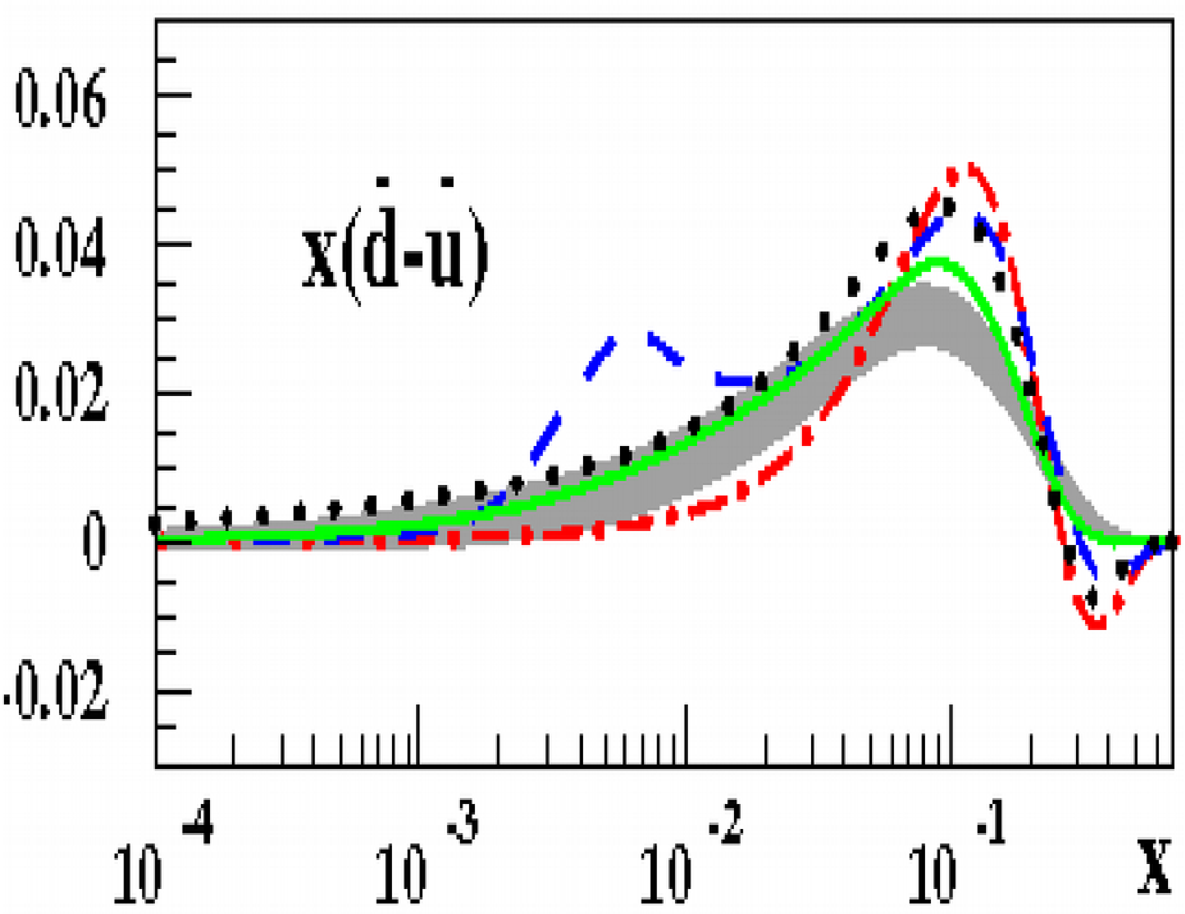
# ATLAS W&Z at 13 TeV

ATLAS, hep-ex/1603.09222



Data are well accommodated into the fit $\chi^2$/NDP=9/6

# Sea quark iso-spin asymmetry



ABM12

CT10

JR09

MSTW08

NNPDF2.3

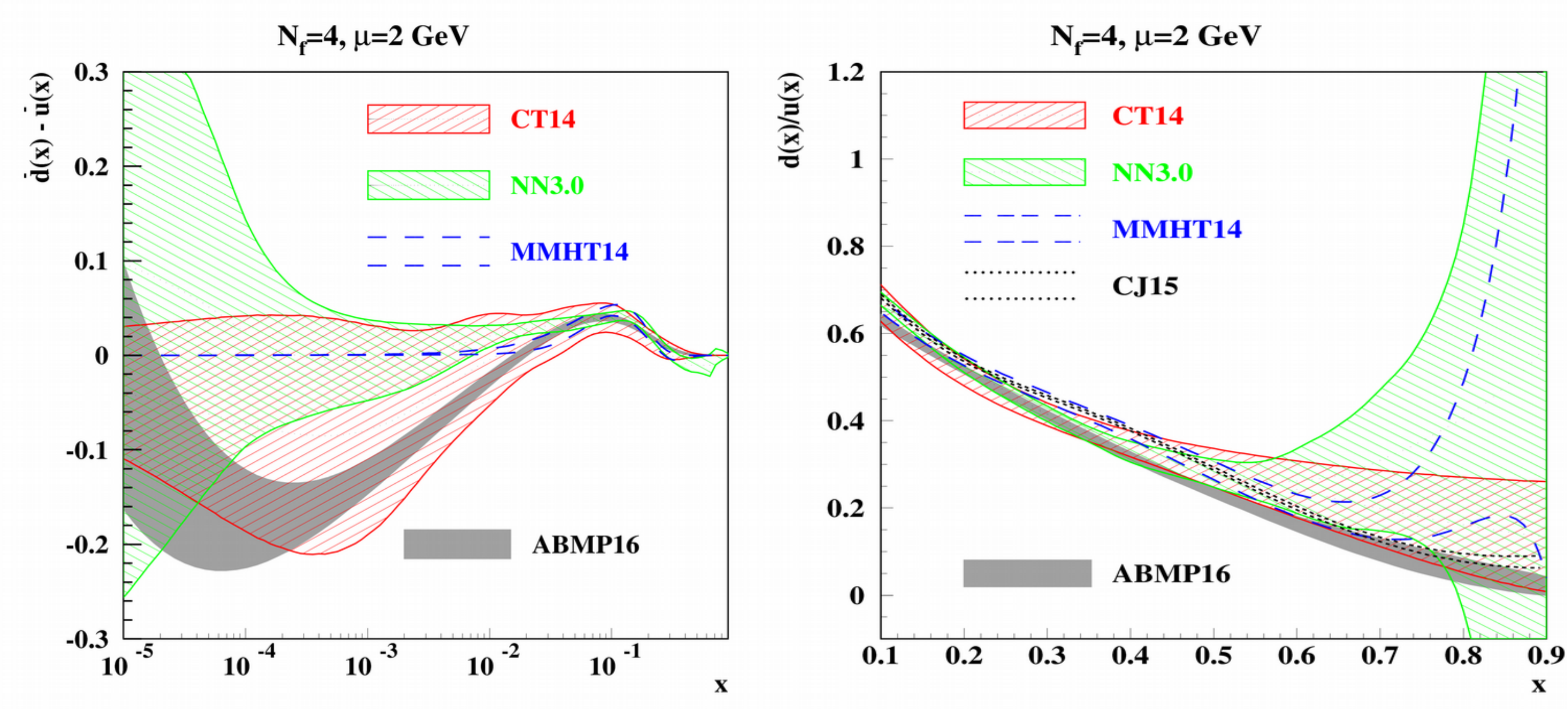
**sa, Blümlein, Moch PRD 89, 054028 (2014)**

- At x~0.1 the sea quark iso-spin asymmetry is controlled by the fixed-target DY data (E-866), weak constraint from the DIS (NMC)

- At x<0.01 Regge-like constraint like $x^{(a-1)}$, with a close to the meson trajectory intercept; the “unbiased” NNPDF fit follows the same trend

*Onset of the Regge asymptotics is out of control*

# Impact of the forward Drell-Yan data

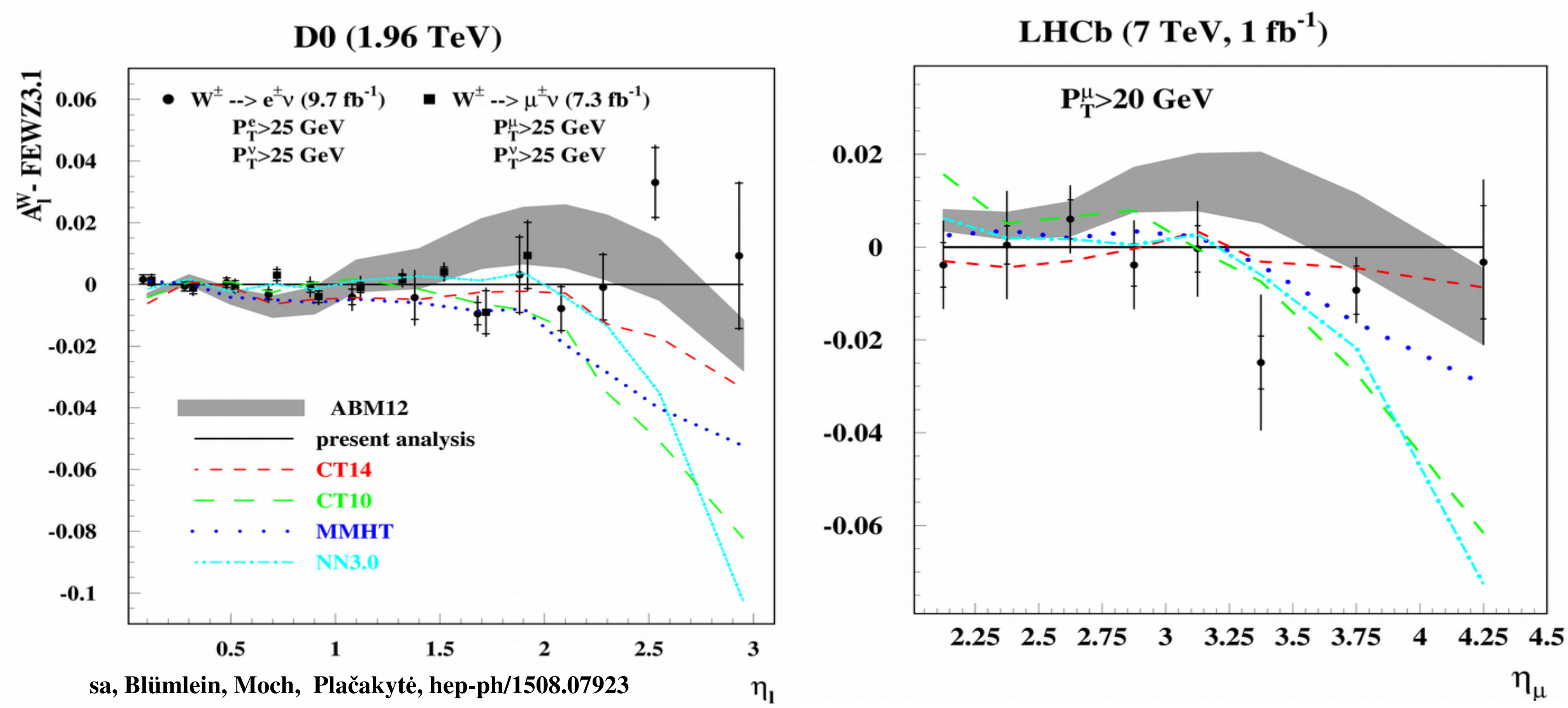


- Relaxed form of the sea iso-spin asymmetry I(x) at small x; Regge-like behaviour is recovered only at x~$10^{-6}$; at large x it is still defined by the phase-space constraint

- Good constraint on the d/u ratio w/o deuteron data → independent extraction of the deuteron corrections **Accardi, Brady, Melnitchouk, Owens, Sato hep-ph/1602.03154;**

- Big spread between different PDF sets, up to factor of 30 at large x → PDF4LHC averaging is misleading

# DY at large rapidity

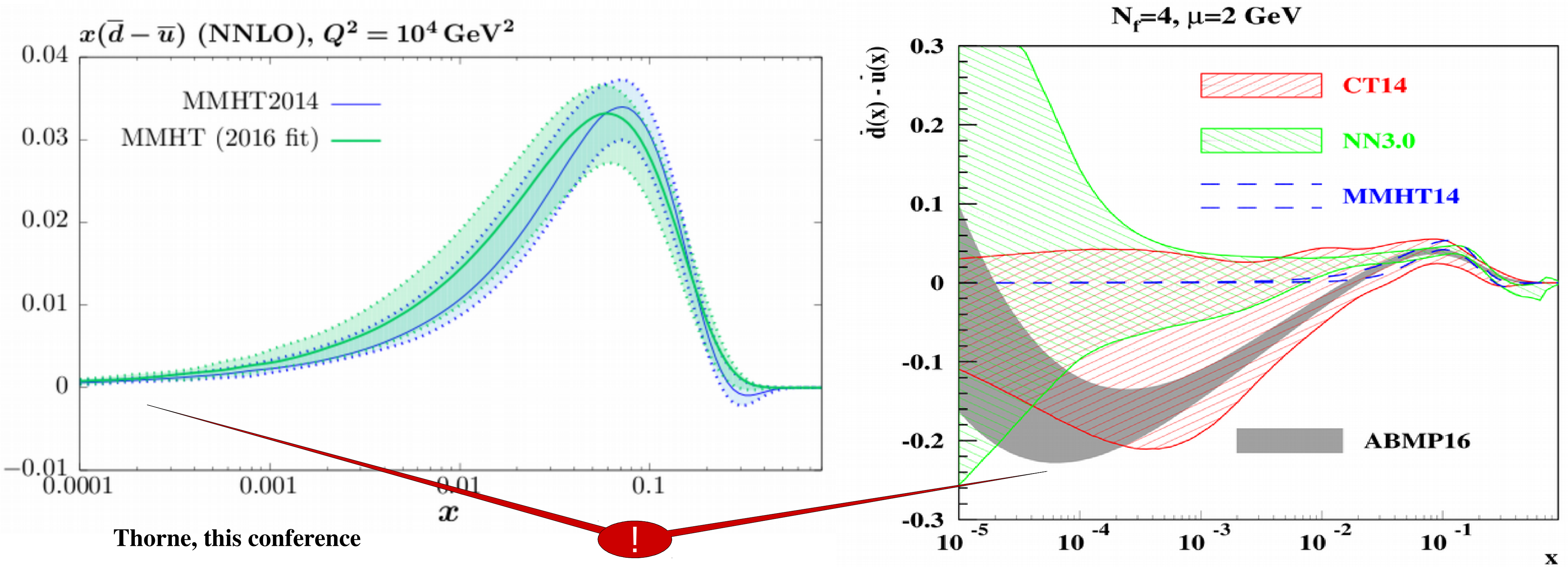


sa, Blümlein, Moch, Plačakytė, hep-ph/1508.07923

- The data can be evidently used for consolidation of the PDFs, however, unification of the theoretical accuracy is also needed

| ABM | CT | MMHT | NNPDF |
|---|---|---|---|
| Interpolation of accurate NNLO grid (a la FASTNLO) | NNLL (ResBos) | NLO +<br>NNLO K-factor | NLO +<br>NNLO C-factors (y-dependent K-factors) |

$$(\bar{d}-\bar{u})(x,Q_0^2) = A(1-x)^{\eta_{sea}+2}x^{\delta}(1+\textstyle\sum_{i=1}^{4} a_i T_i(1-2x^{\frac{1}{2}})),$$



**Thorne, this conference**

| | no. points | NLO $\chi^2_{pred}$ | NLO $\chi^2_{new}$ | NNLO $\chi^2_{pred}$ | NNLO $\chi^2_{new}$ |
|---|---|---|---|---|---|
| $\sigma_{t\bar{t}}$ Tevatron +CMS+ATLAS | 18 | 19.6 | 20.5 | 14.7 | 15.5 |
| LHCb 7 TeV $W+Z$ | 33 | 50.1 | 45.4 | 37.1 | 36.7 |
| LHCb 8 TeV $W+Z$ | 34 | 77.0 | 58.9 | 76.1 | 67.2 |
| LHCb 8TeV $e$ | 17 | 37.4 | 33.4 | 30.0 | 27.8 |
| CMS 8 TeV $W$ | 22 | 32.6 | 18.6 | 57.6 | 29.4 |
| CMS 7 TeV $W+c$ | 10 | 8.5 | 10.0 | 8.7 | 8.0 |
| D0 $e$ asymmetry | 13 | 22.2 | 21.5 | 27.3 | 22.9 |
| total | 3738/3405 | 4375.9 | 4336.1 | 3768.0 | 3739.3 |

$$xu_s(x,\mu_0^2) = \bar{u}_s(x,\mu_0^2) = A_{us}(1-x)^{b_{us}} x^{a_{us}P_{us}(x)},$$

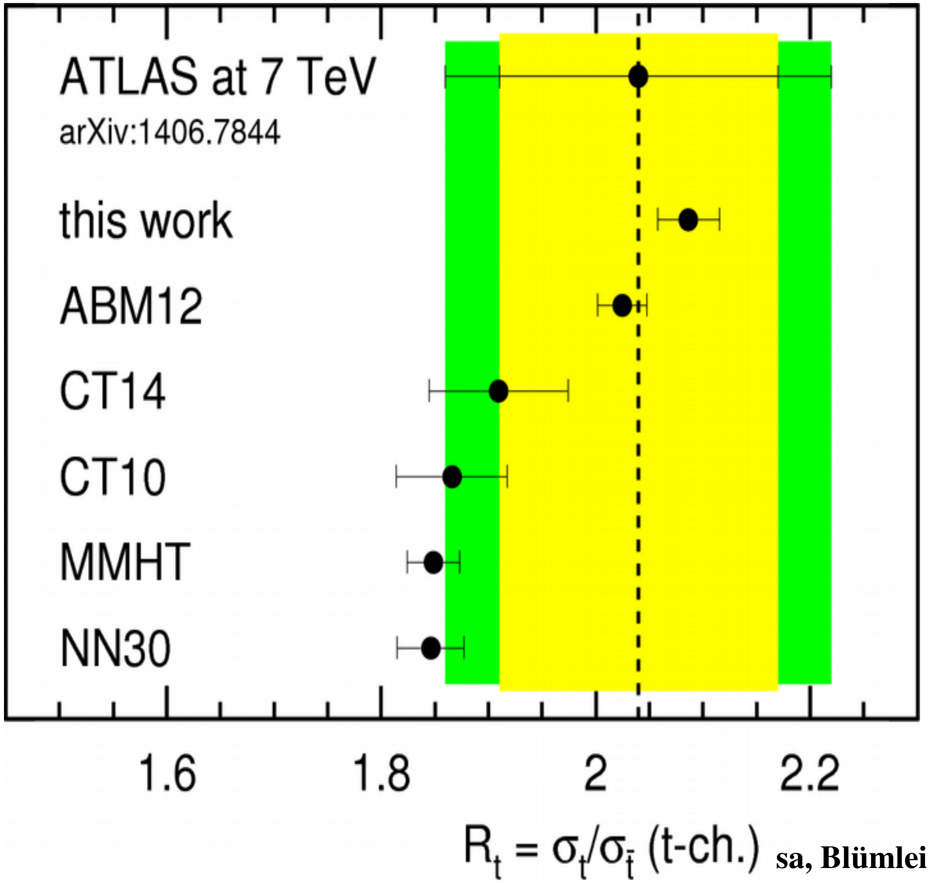
$$xd_s(x,\mu_0^2) = \bar{d}_s(x,\mu_0^2) = A_{ds}(1-x)^{b_{ds}} x^{a_{ds}P_{ds}(x)},$$

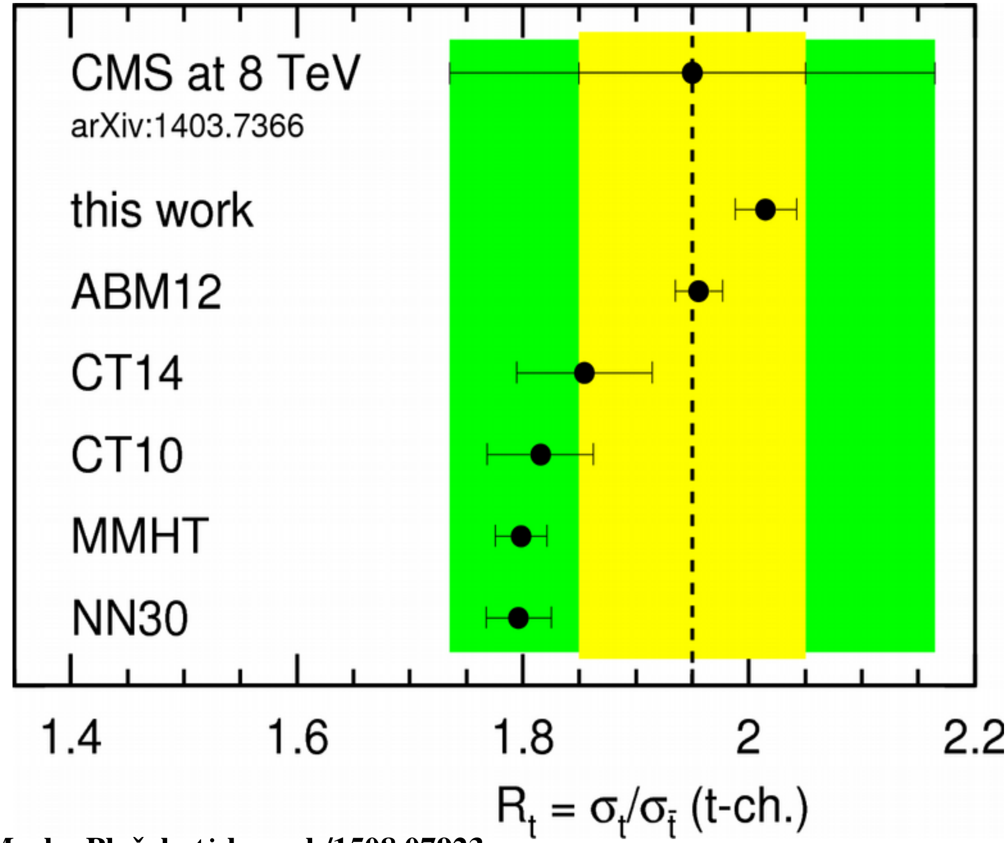
dbar≠ubar at small x
(the same applies for CT14)

The sum of $\chi^2$/NDP for the DY data by LHCB, CMS, and D0 from the table:

184/119 (MMHT16) 142/115 (ABMP16)

# Implication for(of) the single-top production



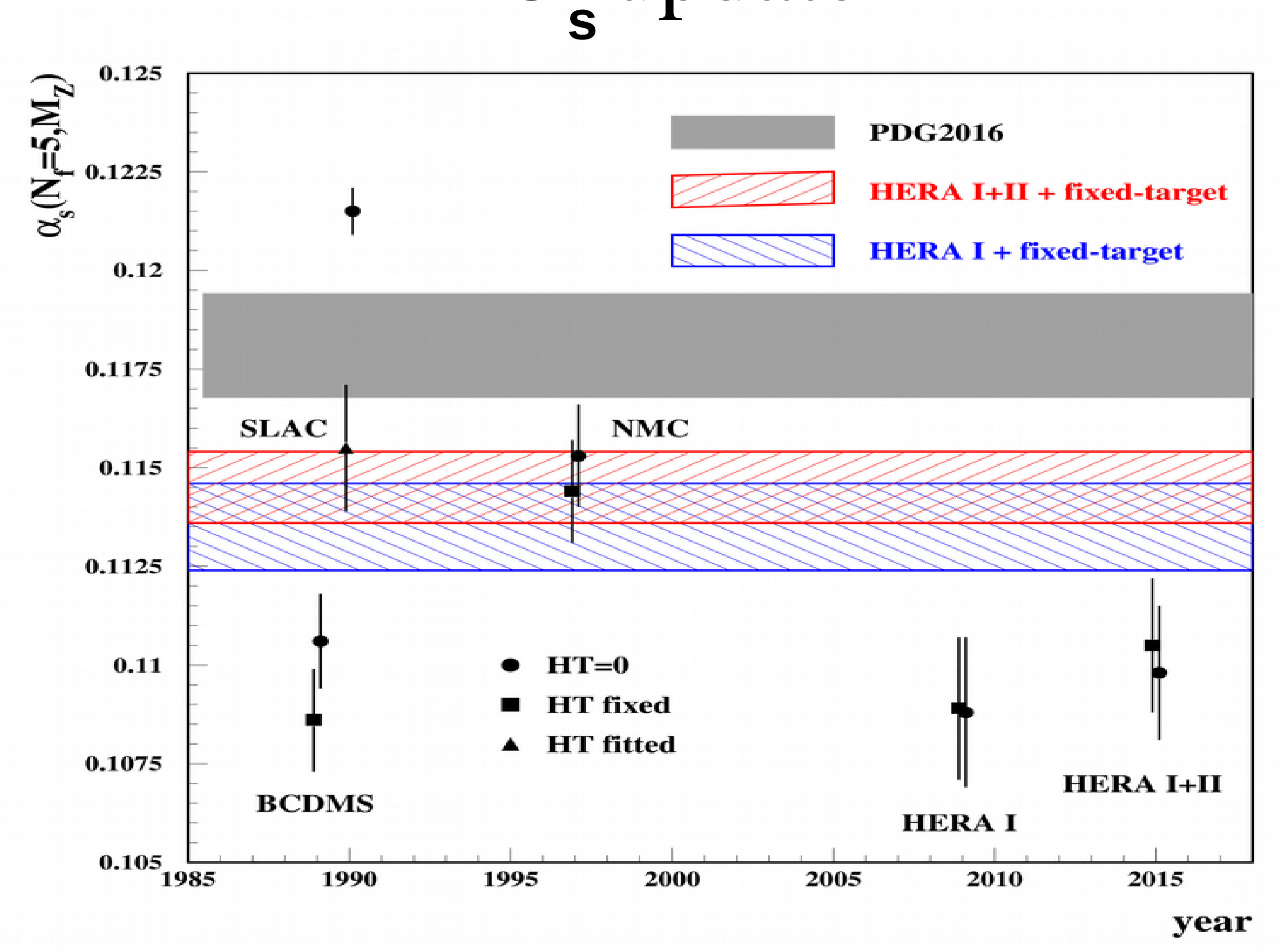


**sa, Blümlein, Moch, Plačakytė hep-ph/1508.07923**

- ATLAS and CMS data on the ratio t/tbar are in a good agreement
- The predictions driven by the froward DY data are in a good agreement with the single-top data (N.B.: ABM12 is based on the deuteron data → consistent deuteron correction was used) **talks by Petti at DIS2016**

*Single-top production discriminate available PDF sets and can serve as a standard candle process*

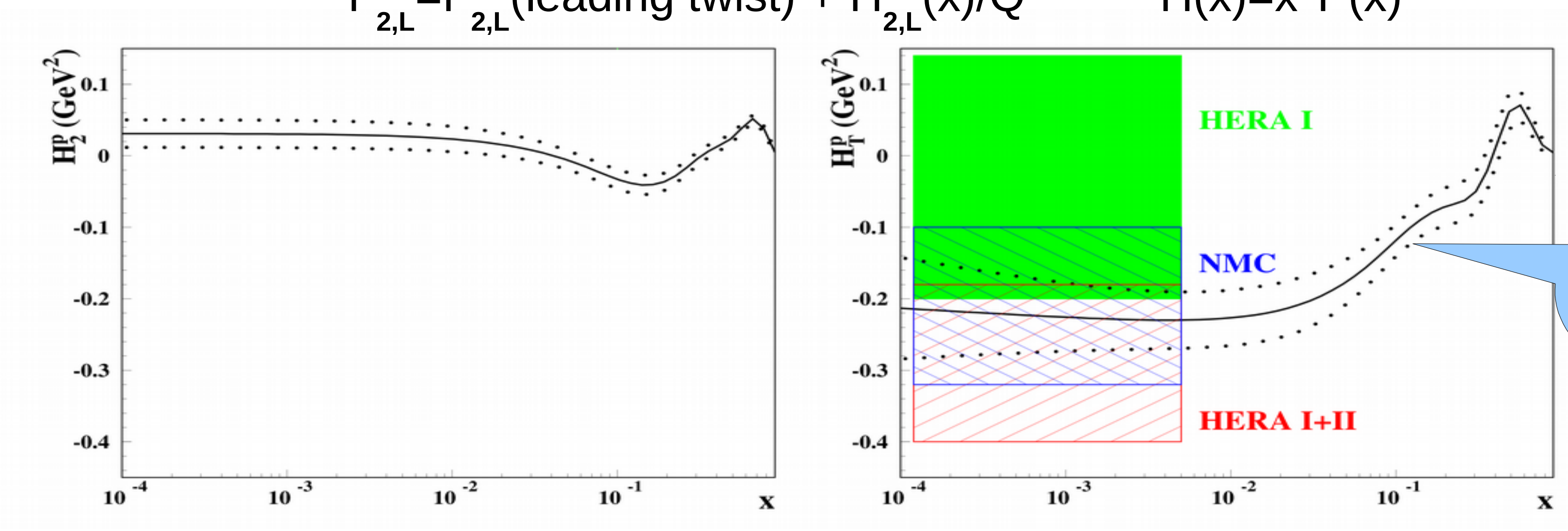
# $\alpha_s$ update



- Combination of the DY data (disentangle PDFs) and the DIS ones (constrain $\alpha_s$ )
- Run-II data pull $\alpha_s$ up by 0.001
- the value of $\alpha_s$ is still lower than the PDG one: pulled up by the SLAC and NMC data; pulled down by the BCDMS and HERA ones
- only SLAC determination overlap with the PDG band provided the high-twist terms are taken into account

# High twists at small x

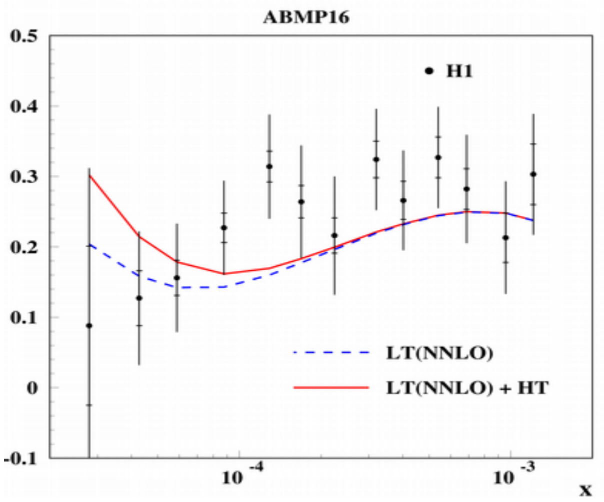
$F_{2,L}=F_{2,L}$(leading twist) + $H_{2,L}(x)/Q^2$    $H(x)=x^hP(x)$



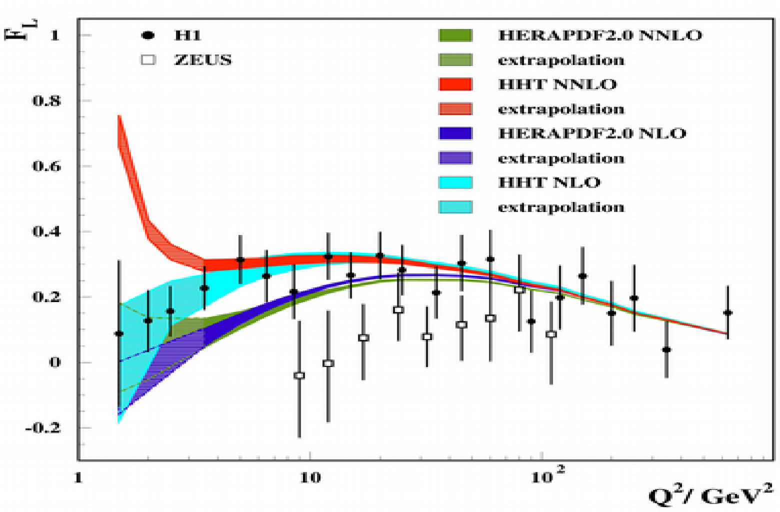
Controlled by SLAC and NMC data

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

- $H_T(x)$ 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
- $\Delta\chi^2 \sim -40$    **Harland-Lang, Martin, Motylinski, Thorne hep-ph/1601.03413**

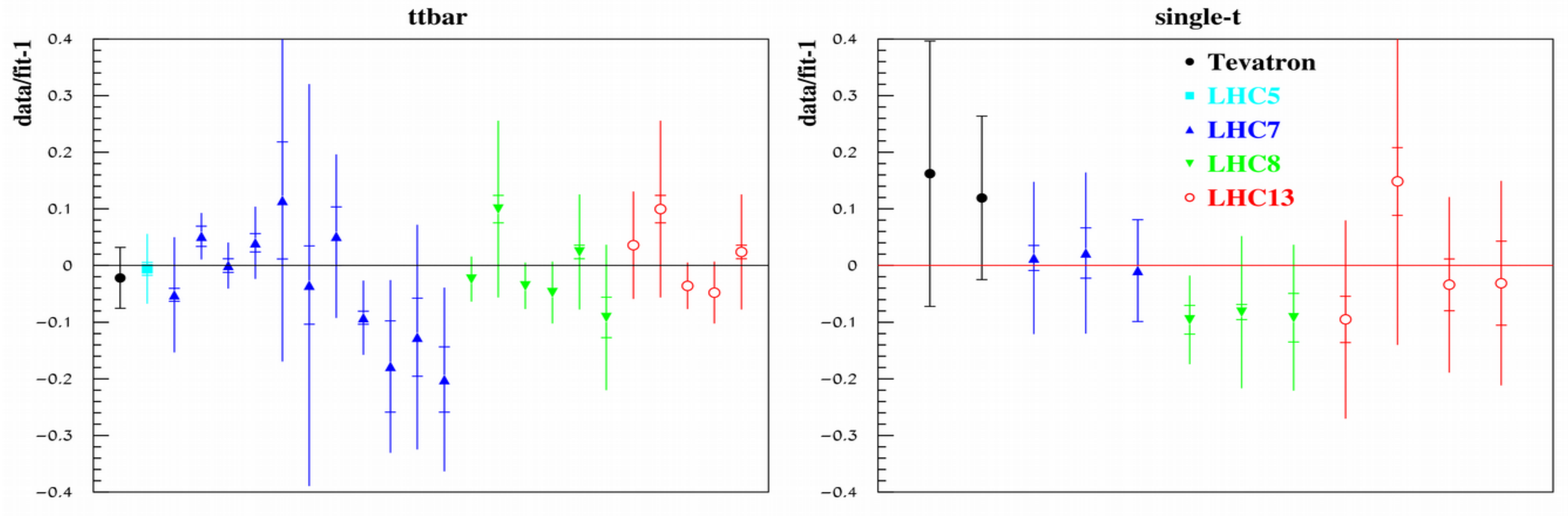


No dramatic increase of $F_L$ at small x



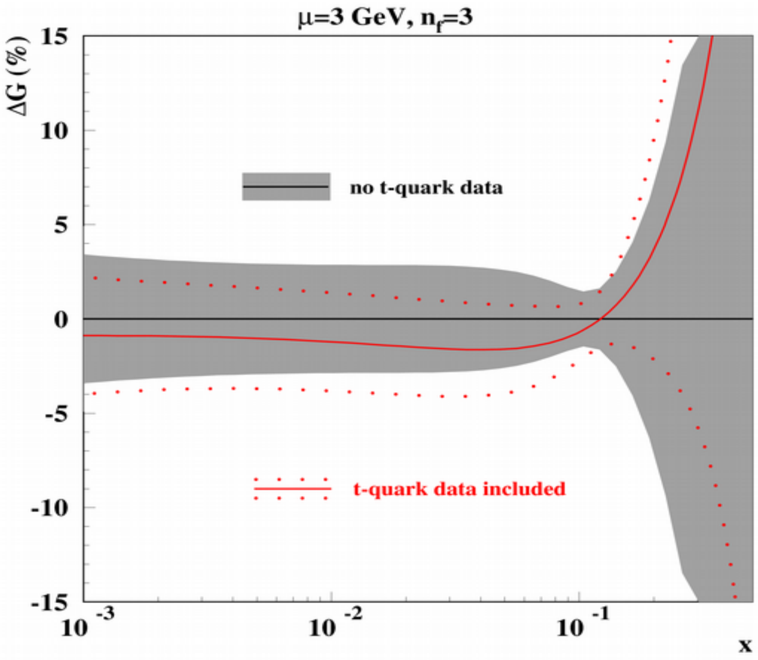
**Abt, et al. hep-ex/1604.02299**

# t-quark data from the LHC and Tevatron



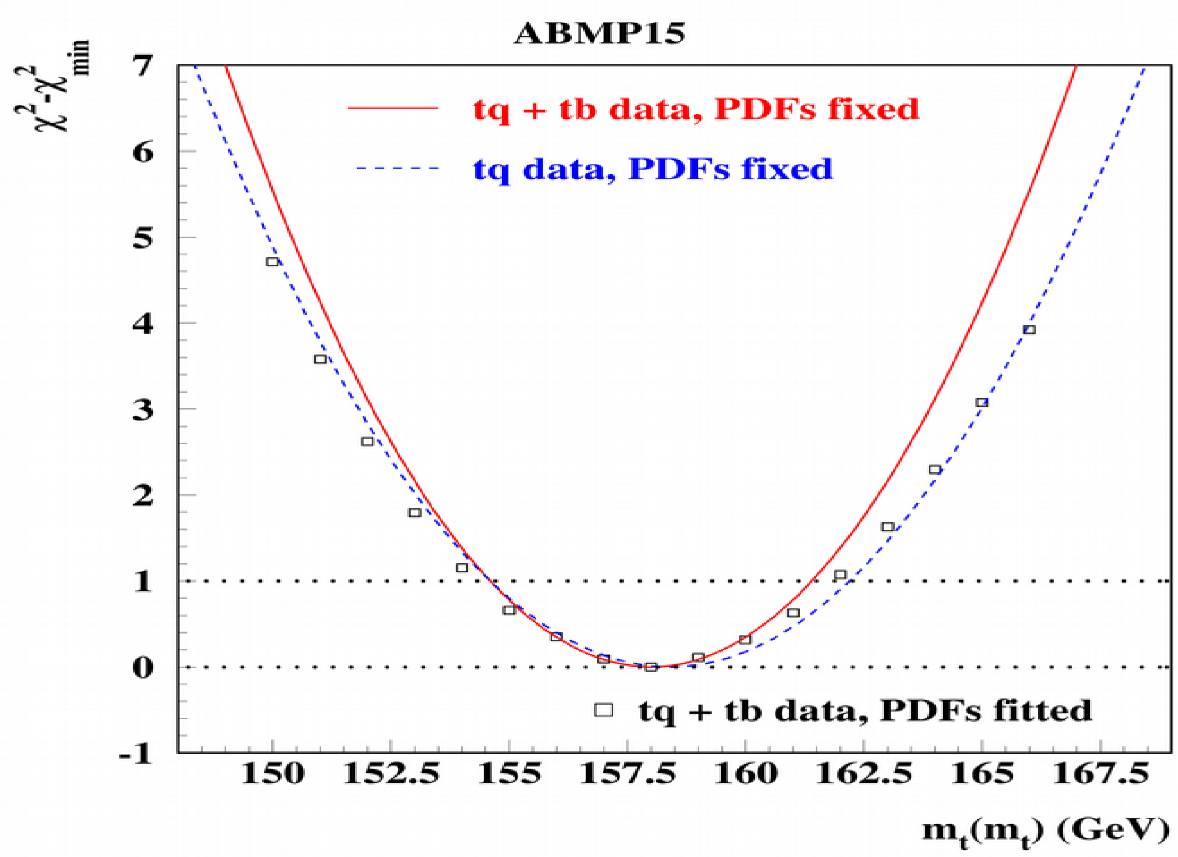
Running mass definition → better perturbative stability

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



- $m_t(m_t)$=160.9±1.1(exp.) GeV NNLO
- $\alpha_s(M_Z)$=0.1145(9) → 0.1147(8) NNLO
- moderate change in the large-x gluon distribution

# t-quark mass from the single-top production



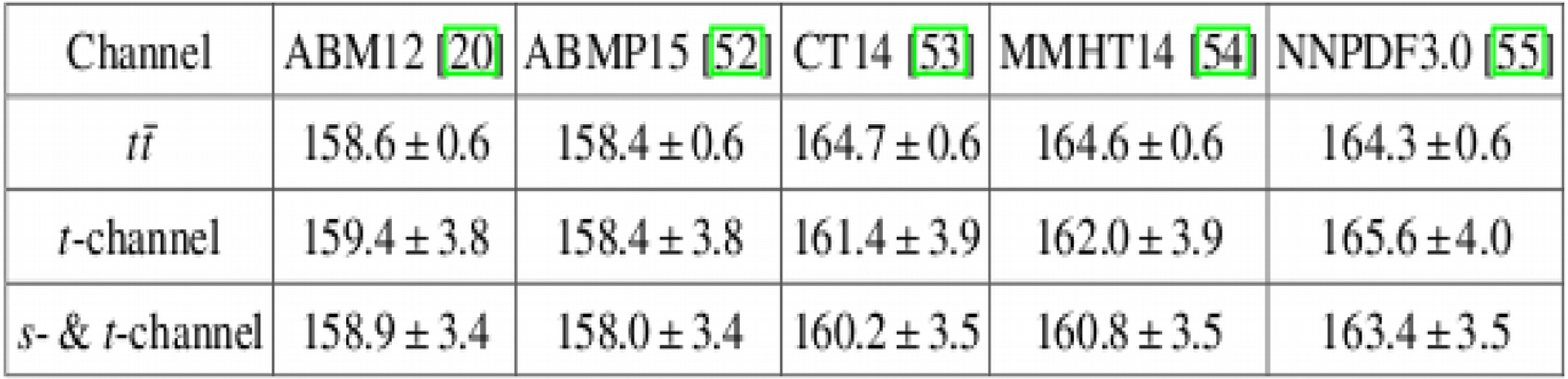
- Electroweak production → reduced impact of $\alpha_s$ and the PDF umcertainties
- HATHOR framework
  - t-channel: NNLO
    **Brucherseifer, Caola, Melnikov PLB 736, 58 (2014)**
  - s-channel: NNLO threshold. resum.
- Different PDFs prefer value of

  $m_t(m_t)$ ~160± 3.5 GeV

NNPDF goes higher by 3 GeV.

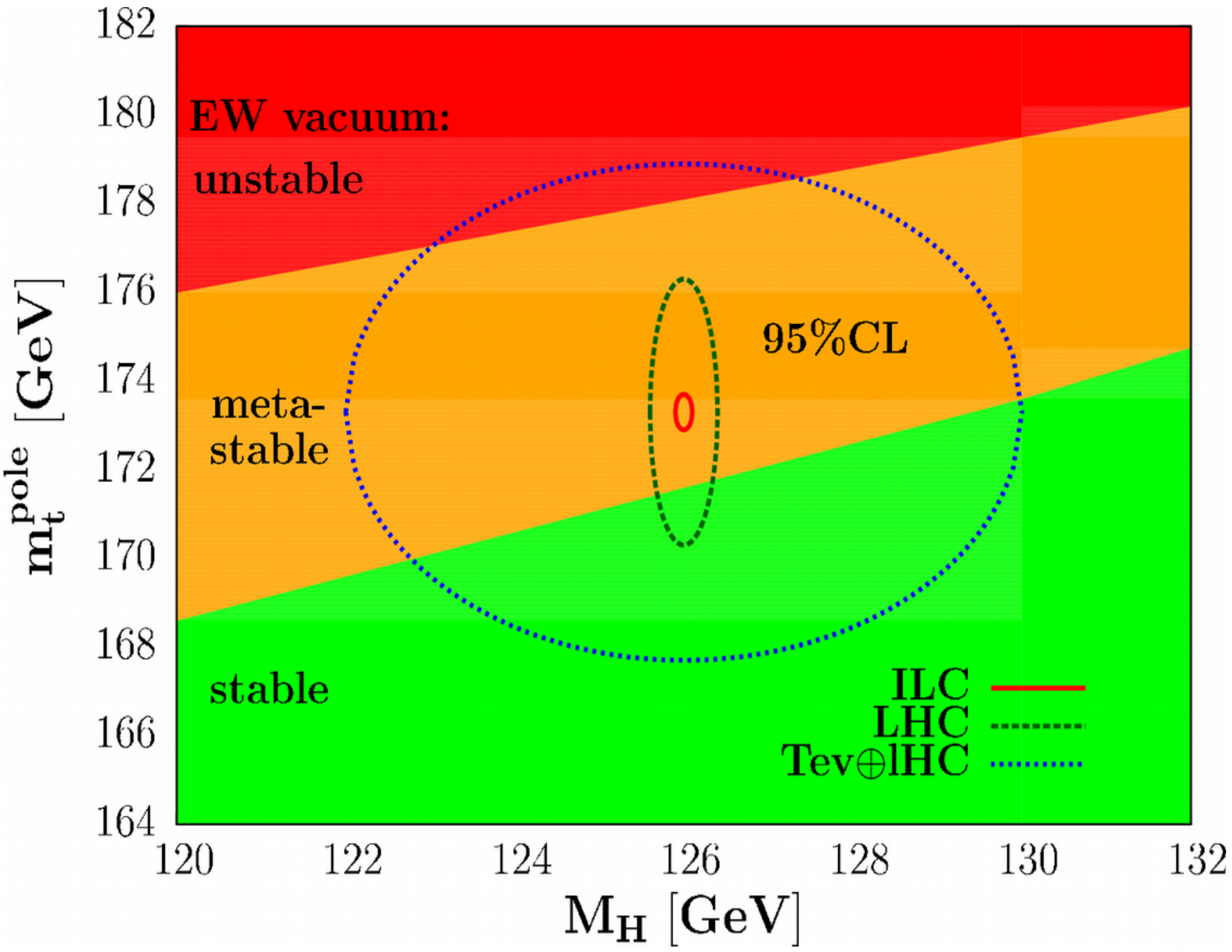
- The CT14 and MMHT14 go higher by 3 GeV with the ttbar channel

*PDFs fixed*



| Channel | ABM12 [20] | ABMP15 [52] | CT14 [53] | MMHT14 [54] | NNPDF3.0 [55] |
|---|---|---|---|---|---|
| $t\bar{t}$ | 158.6±0.6 | 158.4±0.6 | 164.7±0.6 | 164.6±0.6 | 164.3±0.6 |
| $t$-channel | 159.4±3.8 | 158.4±3.8 | 161.4±3.9 | 162.0±3.9 | 165.6±4.0 |
| $s$- & $t$-channel | 158.9±3.4 | 158.0±3.4 | 160.2±3.5 | 160.8±3.5 | 163.4±3.5 |

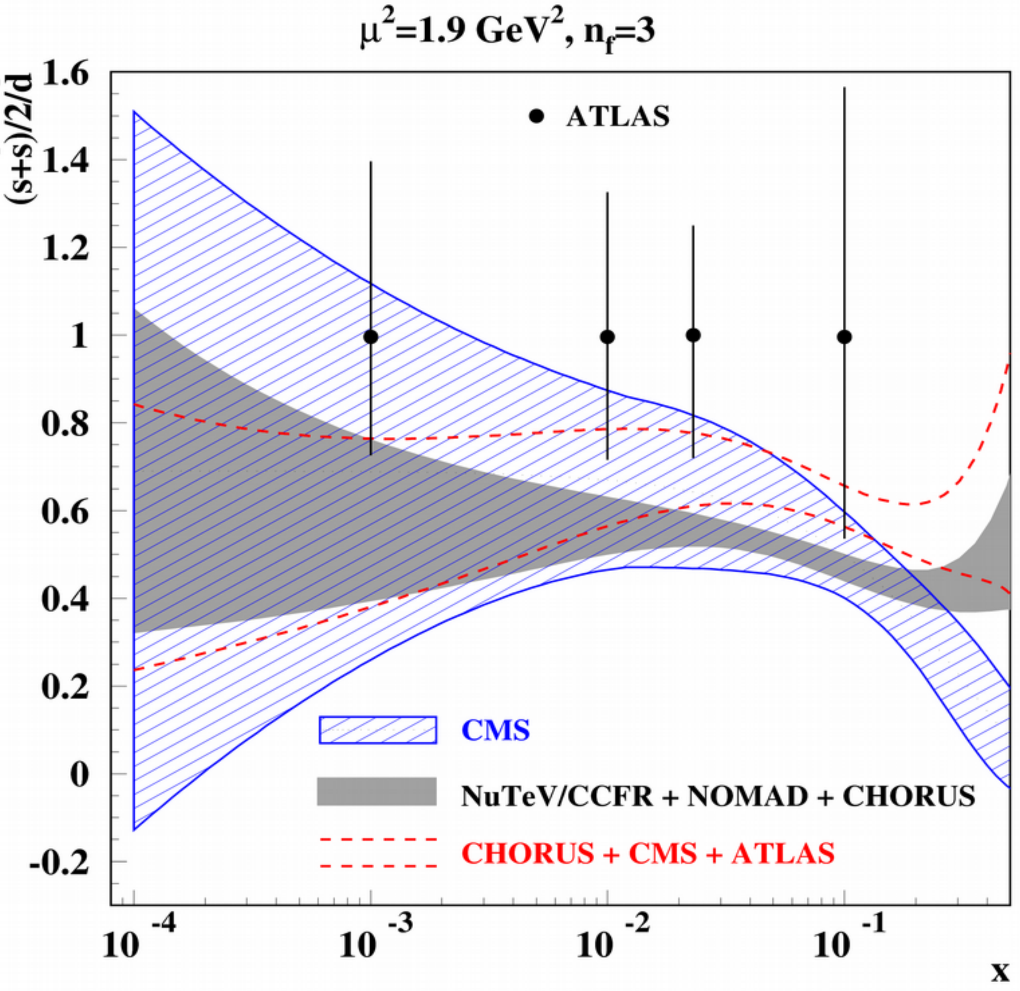
**sa, Moch, Thier hep-ph/1608.05212**

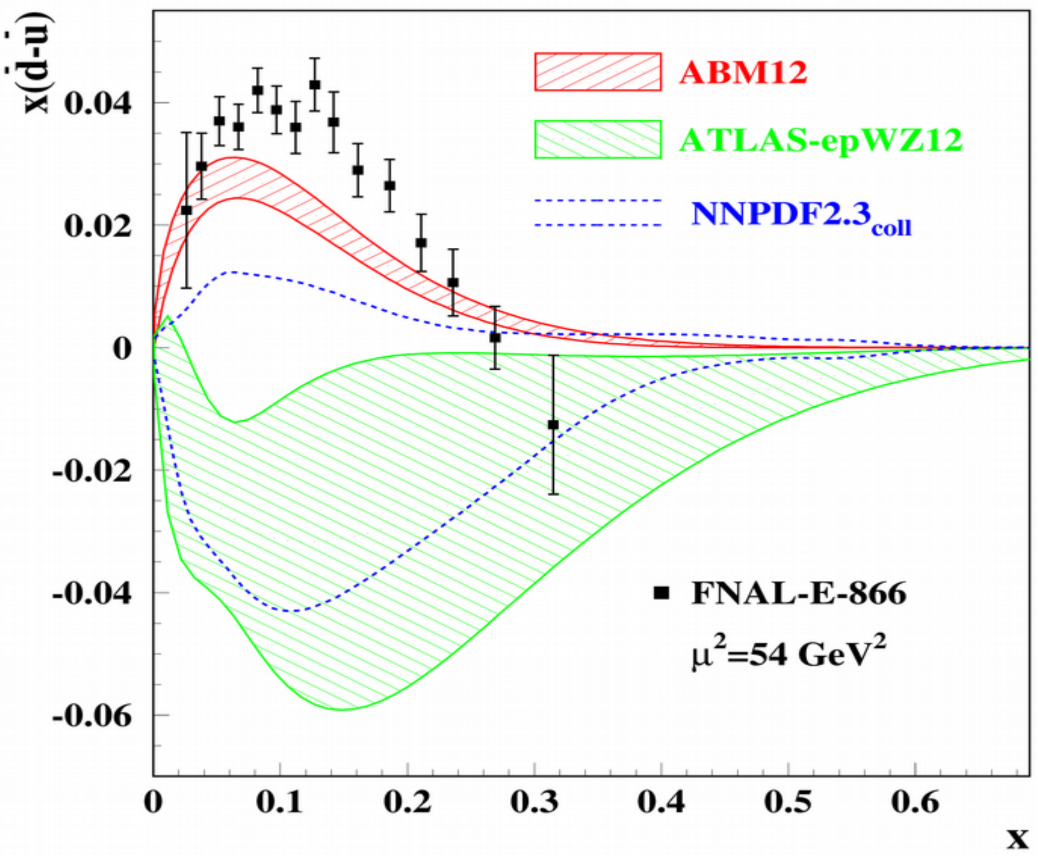


**sa, Djouadi, Moch PLB 716, 214 (2012)**

Vacuum stability is quite sensitive to the t-quark mass

# Strange sea determinations





sa, Blümlein, Caminada, Lipka, Lohwasser,
Moch, Petti, Plačakytė hep-ph/1404.6469

- 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 GeV²)=0.654(30)

# Summary

The improvements summarized in the new PDF set:

- deuteron data are replaced by the Drell-Yan ones from the LHC and Tevatron → reduced theoretical uncertainties in PDFs, in particular in d/u at large x
- the small-x iso-spin sea asymmetry is relaxed and turns negative at $x{\sim}10^{-3}$; an onset of the Regge asymptotics still may occur at $x<10^{-5}$
- improved strange sea determination, particularly at large x
- moderate increase in the large-x gluon distribution due to impact of the ttbar data
- HERA I+II data included → improved determination of $m_c(m_c)$;

$m_c(m_c)$=1.252±0.018 GeV
$m_b(m_b)$=3.83±0.12 GeV
$m_t(m_t)$=160.9±1.1 GeV

| | |
|---|---|
| $\alpha_s(M_Z)$=0.1145(9) | DIS |
| $\alpha_s(M_Z)$=0.1147(8) | DIS+ttbar |

# EXTRAS

# The fit ingredients

DATA:

- DIS NC/CC inclusive (HERA I+II added, no deuteron data included)
- DIS NC charm production (HERA)
- DIS CC charm production (HERA, NOMAD, CHORUS, NuTeV/CCFR)
- fixed-target DY
- LHC DY distributions (ATLAS, CMS, LHCb)
- t-quark data from the LHC and Tevatron

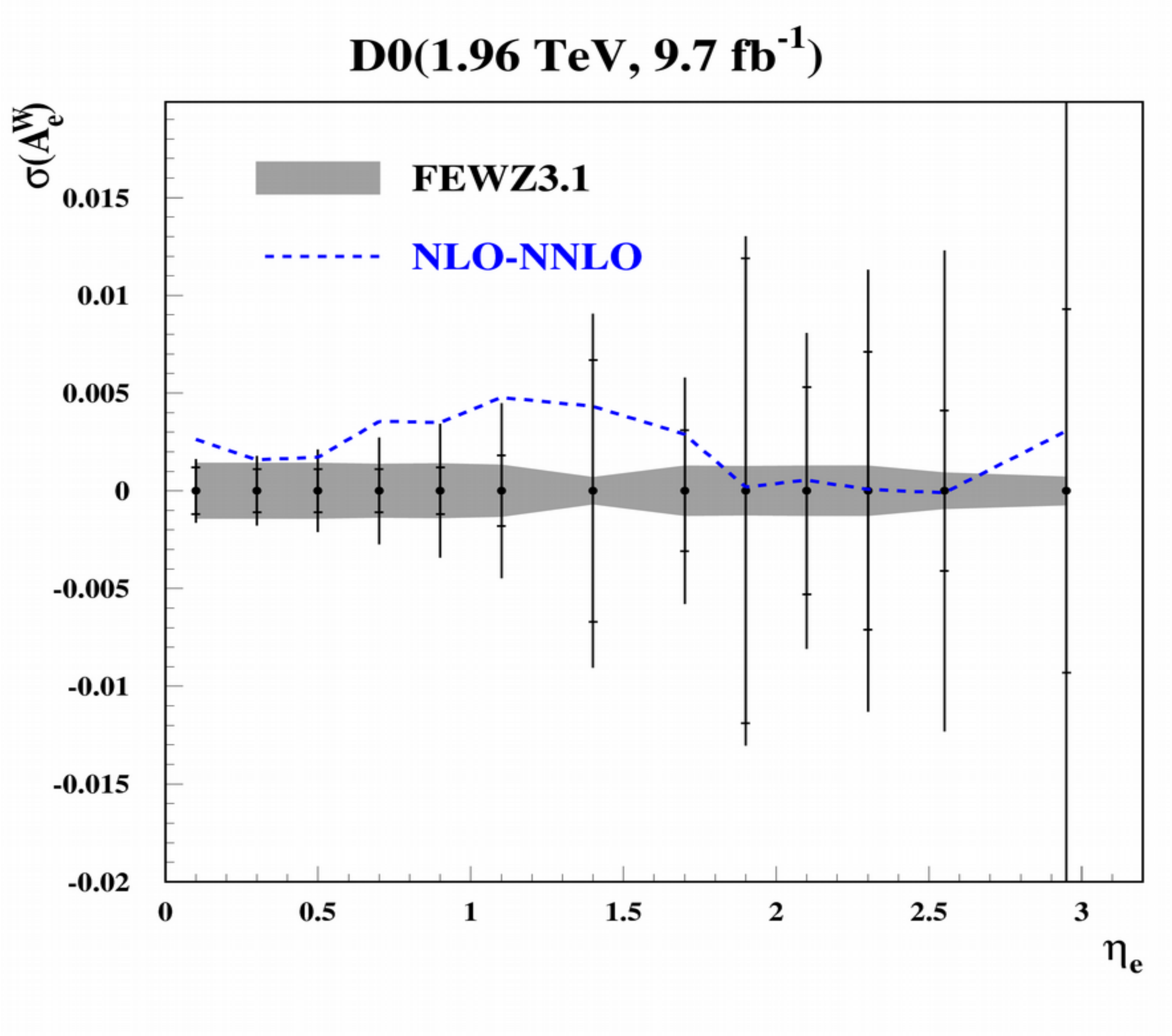
QCD:

- 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 (FEWZ 3.1)
- NNLO inclusive ttbar production ( pole / running mass )
- Relaxed form of (dbar-ubar) at small x

Power corrections in DIS:

- target mass effects
- dynamical twist-4 terms

# Computation accuracy



- Accuracy of O(1 ppm) is required to meet uncertainties in the experimental data → O($10^4$ h) of running FEWZ 3.1 in NNLO

- An interpolation grid a la FASTNLO is used

# NNLO DY corrections in the fit

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

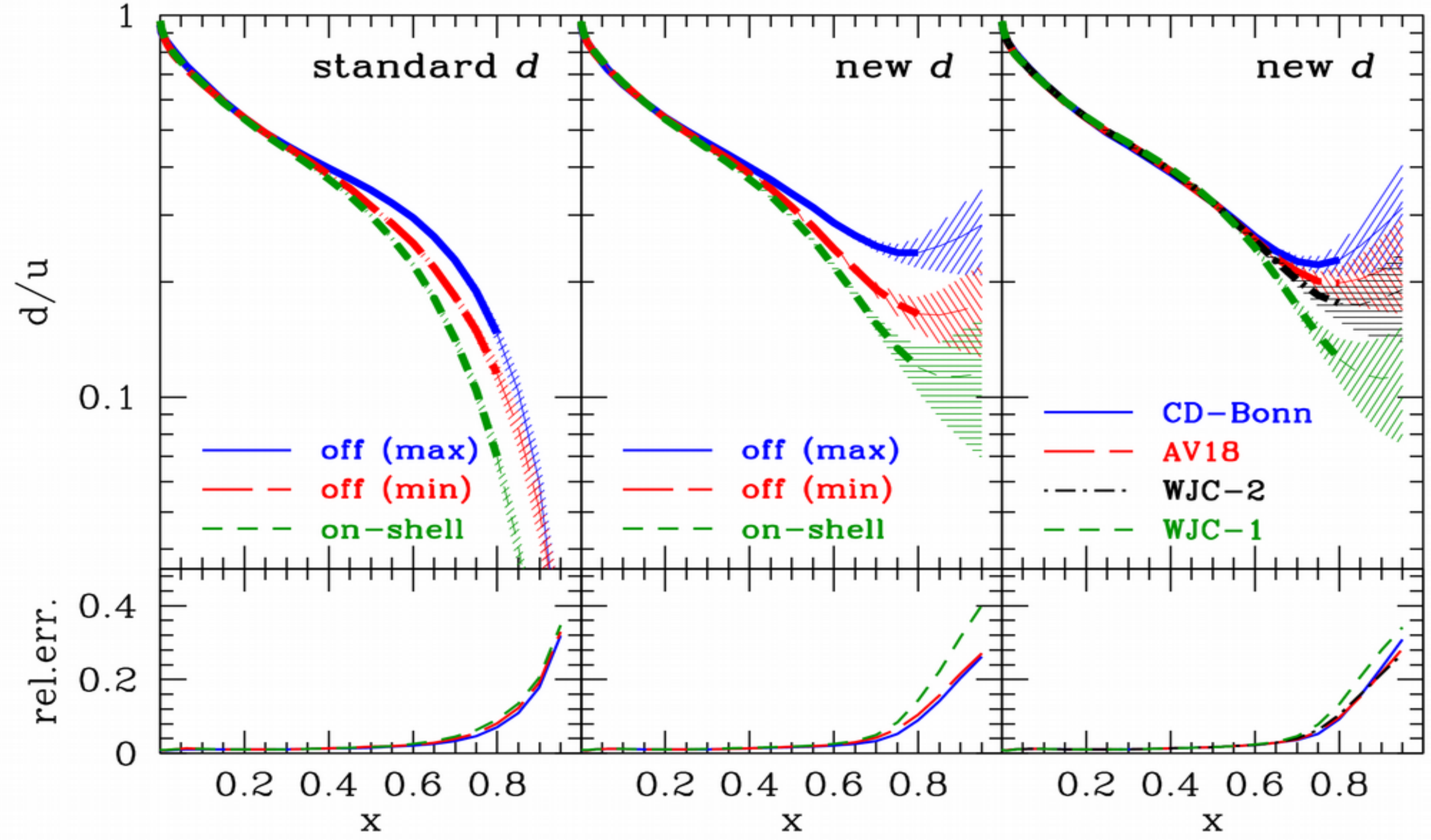
- the corrections for certain basis of PDFs are stored in the grid
- the fitted PDFs are expanded over the basis
- the NNLO c.s. in the PDF fit is calculated as a combination of expansion coefficients with the pre-prepared grids

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

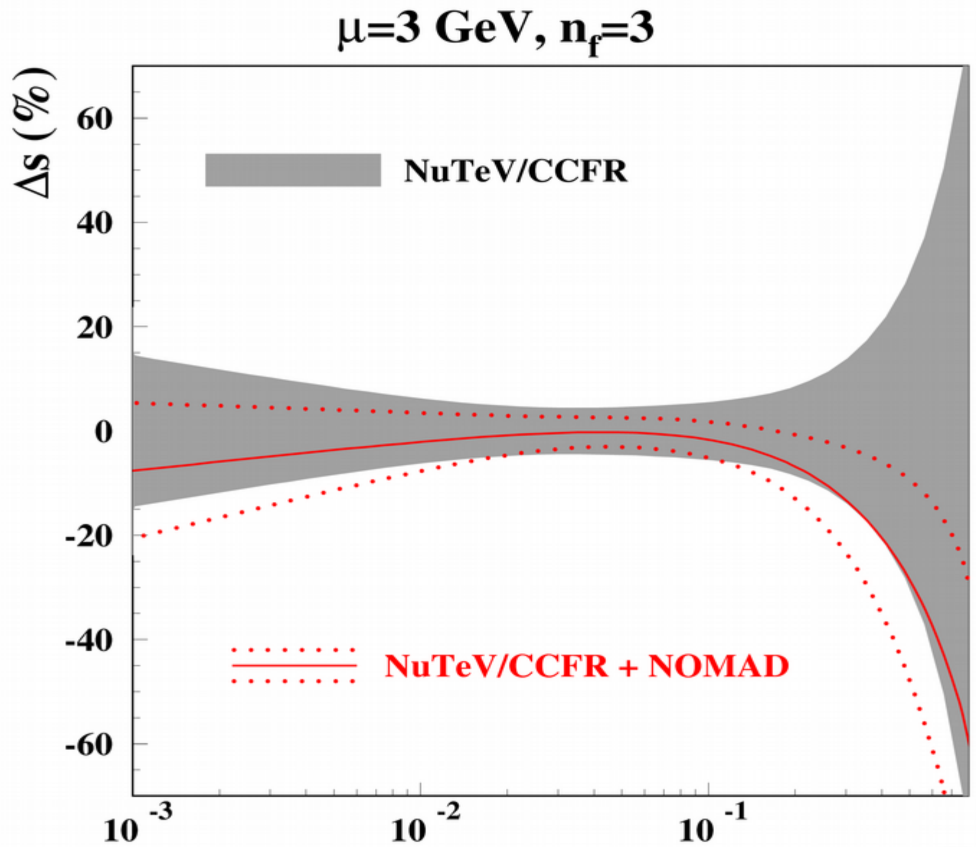
# d/u ratio at large x



**Accarti et al. PRD 84, 014008 (2011)**

*d/u ratio extracted from the DIS data is quite sensitive to the details of modeling nuclear effects in deuterium*

# 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

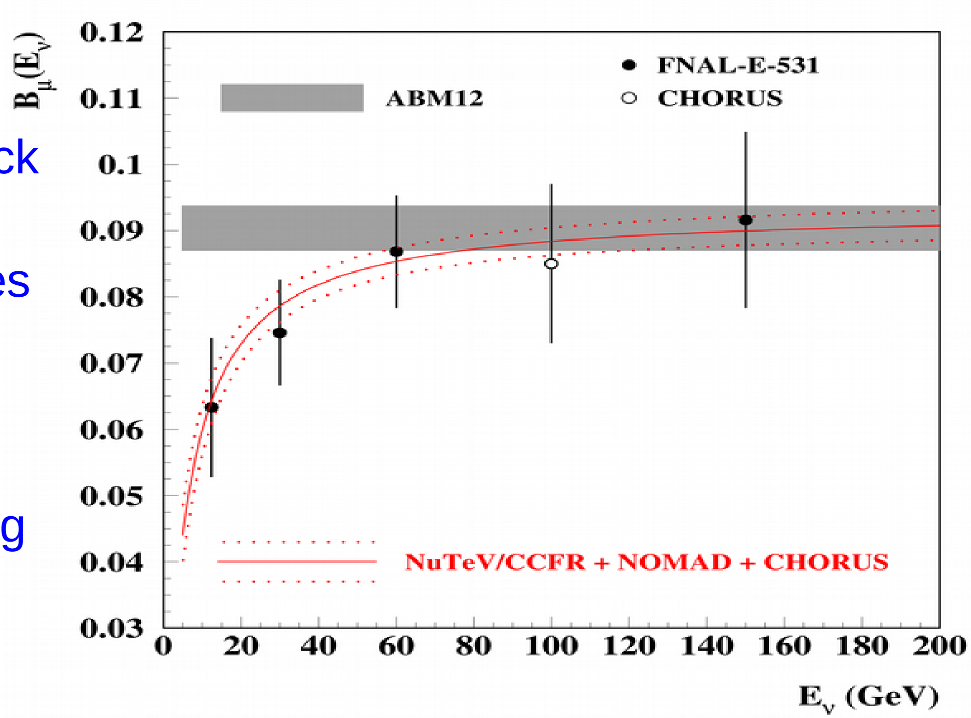
The semi-leptonic branching ratio $B_\mu$ is a bottleneck

- weighted average of the charmed-hadron rates

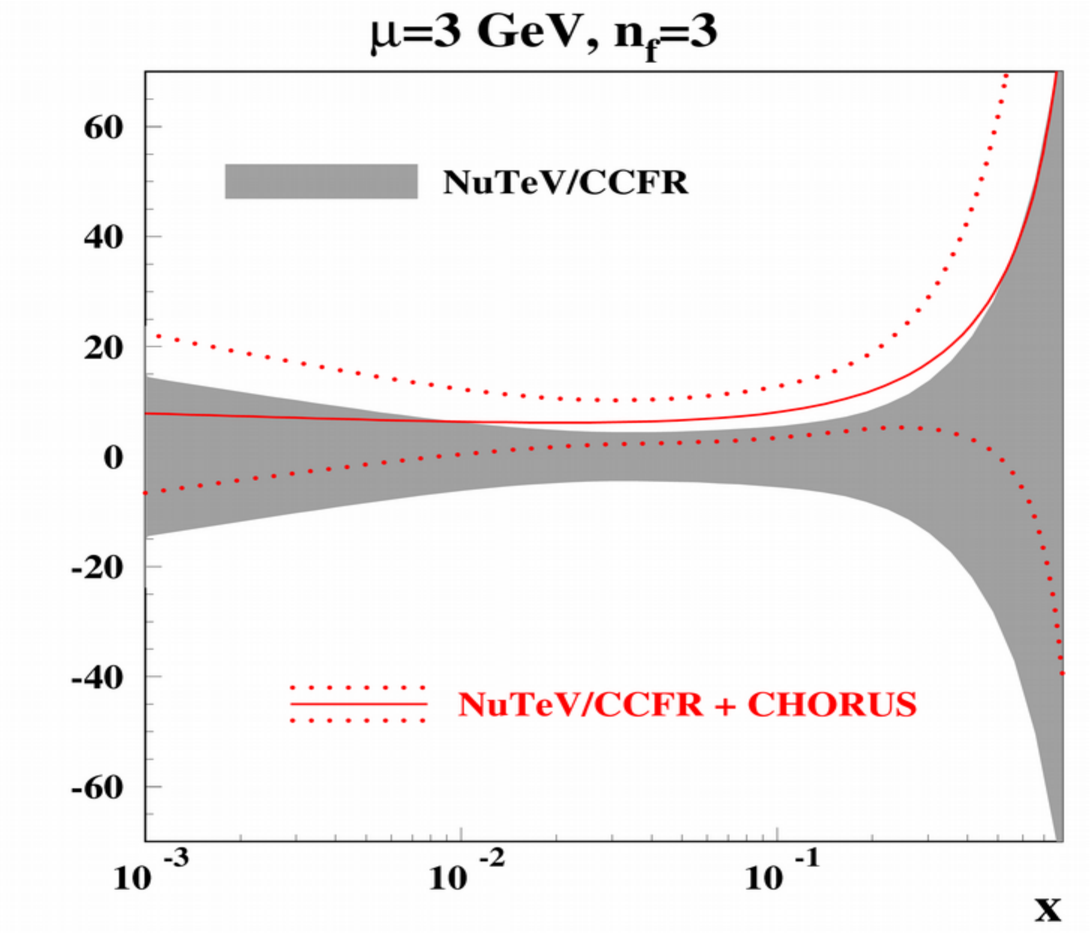
$$B_\mu(E_\nu)=\sum_h r^h(E_\nu)B^h_\mu = a/(1+b/E_\nu)$$

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

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



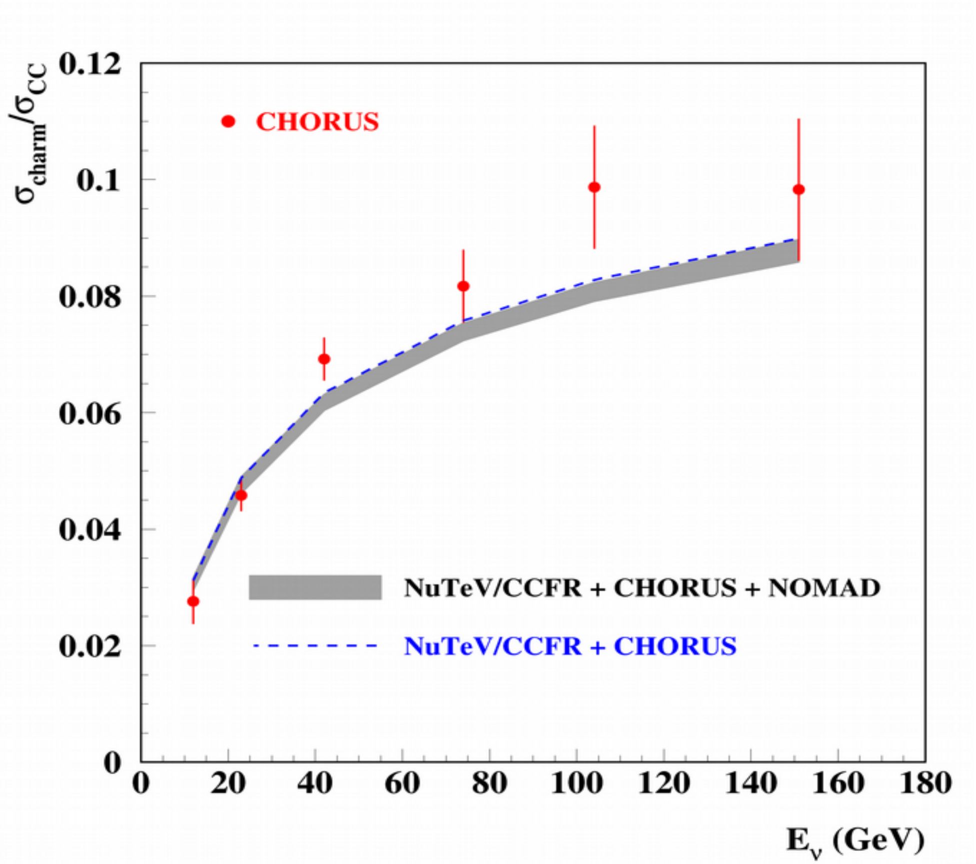
# CHORUS charm data in the ABM fit



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

**CHORUS NJP 13, 093002 (2011)**

- full phase space measurements
- no sensitivity to $B_\mu$
- low statistics (2013 events)

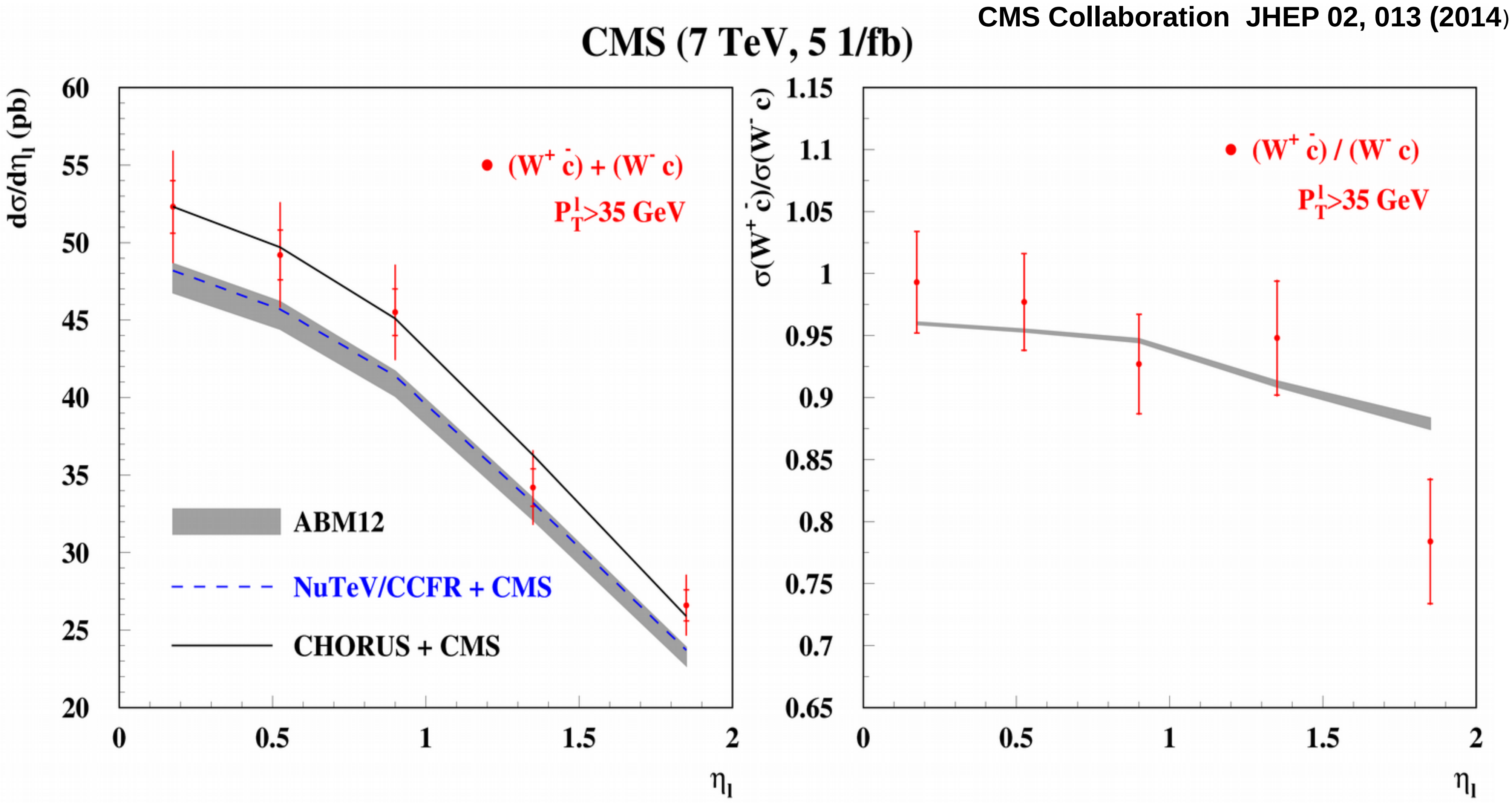


CHORUS data pull strangeness up, however the statistical significance of the effect is poor

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

# CMS W+charm data in the ABM fit

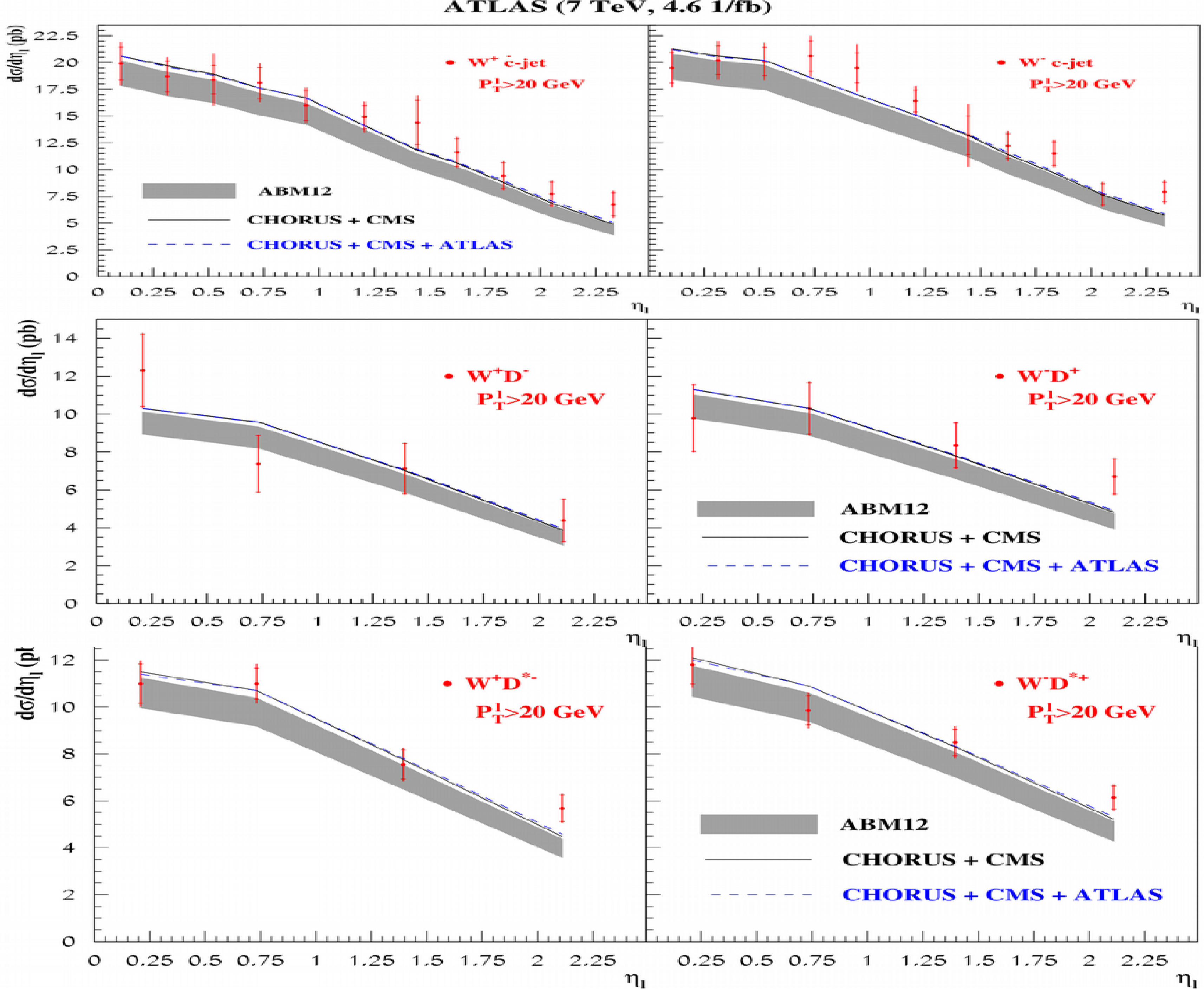
CMS Collaboration JHEP 02, 013 (2014)

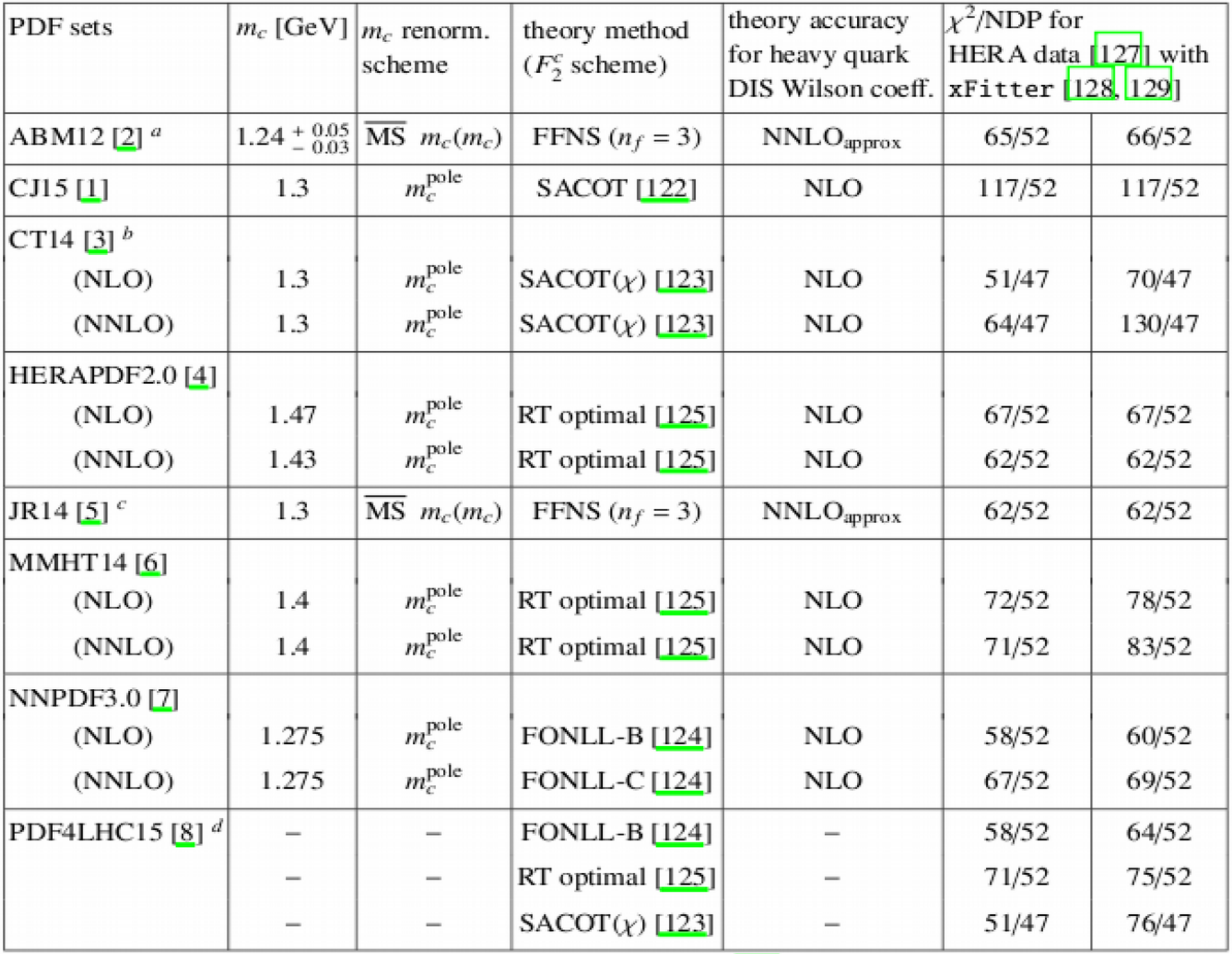


- CMS data go above the NuTeV/CCFR by 1σ; little impact on the strange sea
- The charge asymmetry is in a good agreement with the charge-symmetric strange sea
- Good agreement with the CHORUS data

# ATLAS W+charm data in the ABM fit

ATLAS Collaboration arXiv:1402.6263



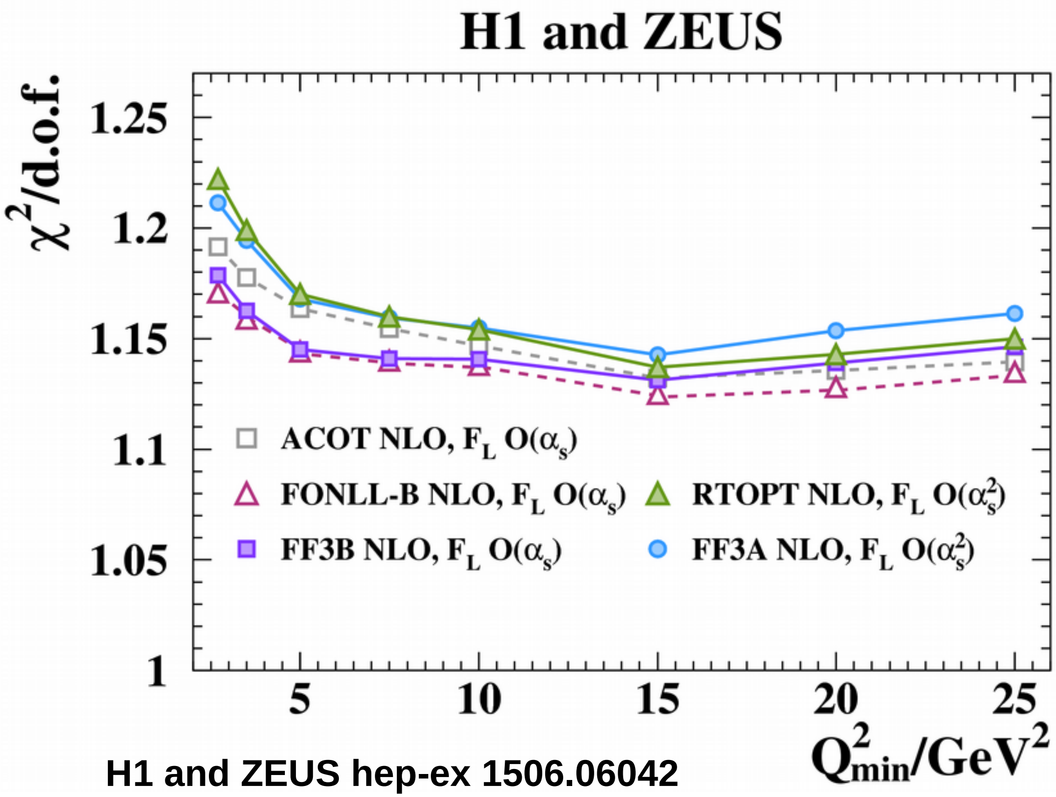


| PDF sets | $m_c$ [GeV] | $m_c$ renorm. scheme | theory method ($F_2^c$ scheme) | theory accuracy for heavy quark DIS Wilson coeff. | $\chi^2$/NDP for HERA data [127] with `xFitter` [128, 129] | |
|---|---|---|---|---|---|---|
| ABM12 [2] [a] | $1.24\,^{+\,0.05}_{-\,0.03}$ | $\overline{\text{MS}}$ $m_c(m_c)$ | FFNS ($n_f = 3$) | NNLO$_{\text{approx}}$ | 65/52 | 66/52 |
| CJ15 [1] | 1.3 | $m_c^{\text{pole}}$ | SACOT [122] | NLO | 117/52 | 117/52 |
| CT14 [3] [b] | | | | | | |
| (NLO) | 1.3 | $m_c^{\text{pole}}$ | SACOT($\chi$) [123] | NLO | 51/47 | 70/47 |
| (NNLO) | 1.3 | $m_c^{\text{pole}}$ | SACOT($\chi$) [123] | NLO | 64/47 | 130/47 |
| HERAPDF2.0 [4] | | | | | | |
| (NLO) | 1.47 | $m_c^{\text{pole}}$ | RT optimal [125] | NLO | 67/52 | 67/52 |
| (NNLO) | 1.43 | $m_c^{\text{pole}}$ | RT optimal [125] | NLO | 62/52 | 62/52 |
| JR14 [5] [c] | 1.3 | $\overline{\text{MS}}$ $m_c(m_c)$ | FFNS ($n_f = 3$) | NNLO$_{\text{approx}}$ | 62/52 | 62/52 |
| MMHT14 [6] | | | | | | |
| (NLO) | 1.4 | $m_c^{\text{pole}}$ | RT optimal [125] | NLO | 72/52 | 78/52 |
| (NNLO) | 1.4 | $m_c^{\text{pole}}$ | RT optimal [125] | NLO | 71/52 | 83/52 |
| NNPDF3.0 [7] | | | | | | |
| (NLO) | 1.275 | $m_c^{\text{pole}}$ | FONLL-B [124] | NLO | 58/52 | 60/52 |
| (NNLO) | 1.275 | $m_c^{\text{pole}}$ | FONLL-C [124] | NLO | 67/52 | 69/52 |
| PDF4LHC15 [8] [d] | – | – | FONLL-B [124] | – | 58/52 | 64/52 |
| | – | – | RT optimal [125] | – | 71/52 | 75/52 |
| | – | – | SACOT($\chi$) [123] | – | 51/47 | 76/47 |

**Accardi, et al. hep-ph/1603.08906**

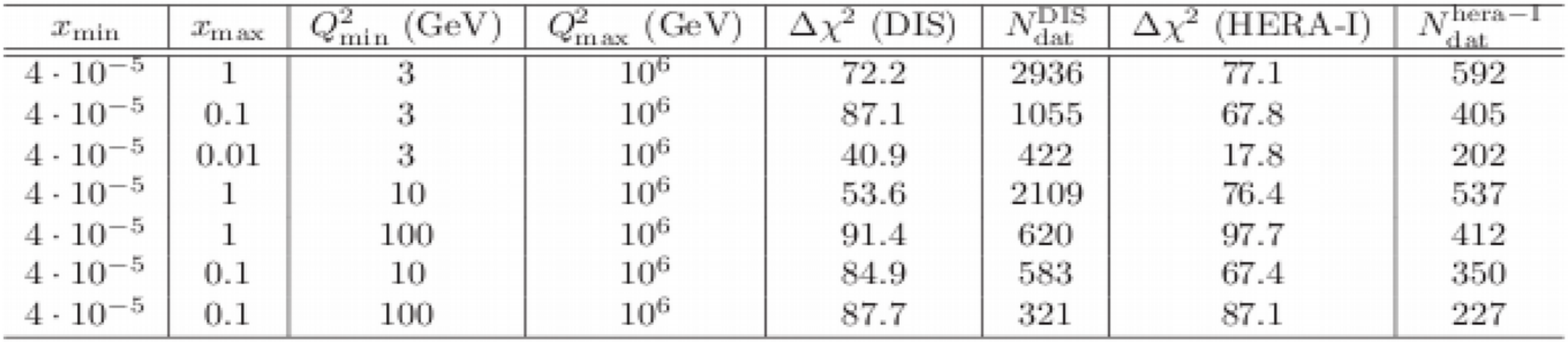
*No advantage of the GMVFN schemes: the VFN $\chi^2$ values are systematically bigger than the FFN ones*

# Factorization scheme benchmarking



**H1 and ZEUS hep-ex 1506.06042**

- Data allow to discriminate factorization schemes
- FFN scheme works very well in case of correct setting (running mass definition and correct value of $m_c$) → no traces of big logs due to resummation

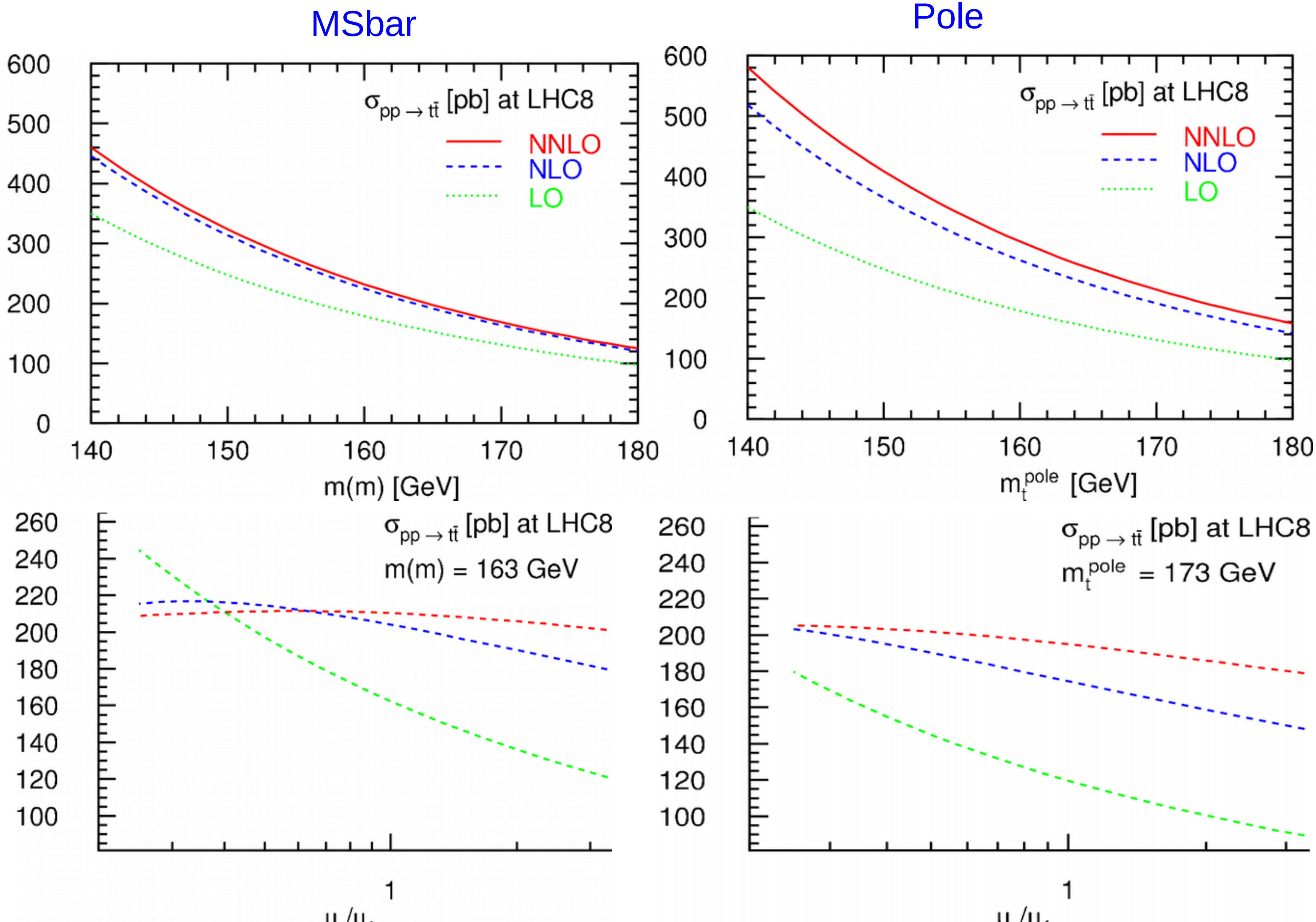


| $x_{\rm min}$ | $x_{\rm max}$ | $Q^2_{\rm min}$ (GeV) | $Q^2_{\rm max}$ (GeV) | $\Delta\chi^2$ (DIS) | $N_{\rm dat}^{\rm DIS}$ | $\Delta\chi^2$ (HERA-I) | $N_{\rm dat}^{\rm hera-I}$ |
|---|---|---|---|---|---|---|---|
| $4 \cdot 10^{-5}$ | 1 | 3 | $10^6$ | 72.2 | 2936 | 77.1 | 592 |
| $4 \cdot 10^{-5}$ | 0.1 | 3 | $10^6$ | 87.1 | 1055 | 67.8 | 405 |
| $4 \cdot 10^{-5}$ | 0.01 | 3 | $10^6$ | 40.9 | 422 | 17.8 | 202 |
| $4 \cdot 10^{-5}$ | 1 | 10 | $10^6$ | 53.6 | 2109 | 76.4 | 537 |
| $4 \cdot 10^{-5}$ | 1 | 100 | $10^6$ | 91.4 | 620 | 97.7 | 412 |
| $4 \cdot 10^{-5}$ | 0.1 | 10 | $10^6$ | 84.9 | 583 | 67.4 | 350 |
| $4 \cdot 10^{-5}$ | 0.1 | 100 | $10^6$ | 87.7 | 321 | 87.1 | 227 |

*We conclude that the FFN fit is actually based on a less precise theory, in that it does not include full resummation of the contribution of heavy quarks to perturbative PDF evolution, and thus provides a less accurate description of the data*

**NNPDF PLB 723, 330 (2013)**

# ttbar production with pole and Msbar 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*