Update of PDFs with the LHC, Tevatron, and HERA data

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

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

DIS2016, DESY, *12 Apr 2016*

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

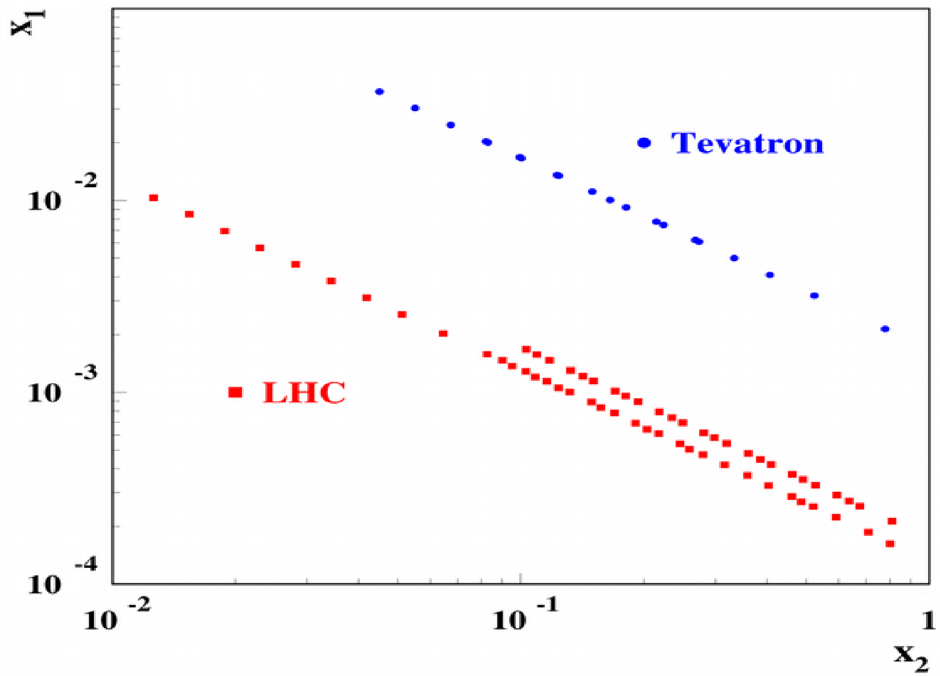
QCD:

- 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

Collider W&Z data used in the fit



In the forward region $x_2 >> x_1$

$\sigma(W^+) \sim u(x_2)\ \bar{d}(x_1)$

$\sigma(W^-) \sim d(x_2)\ \bar{u}(x_1)$

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

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

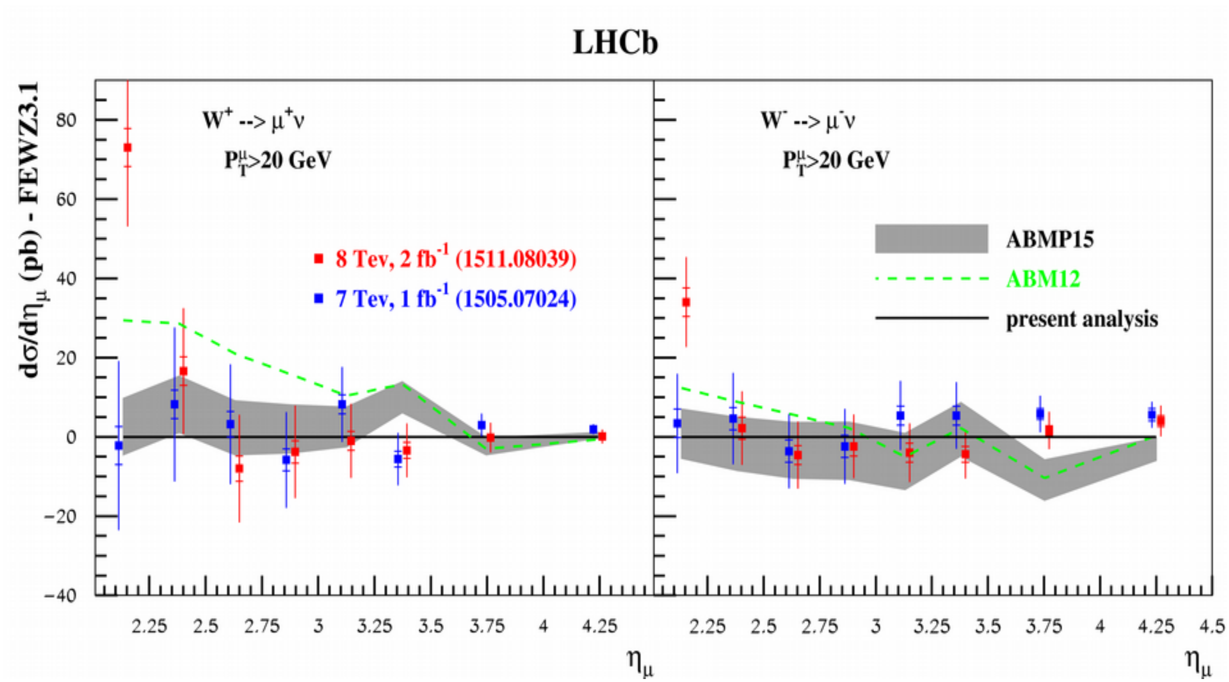
Forward W&Z production probes small/large x and is complementary to the DIS → constraint on the quark iso-spin asymmetry

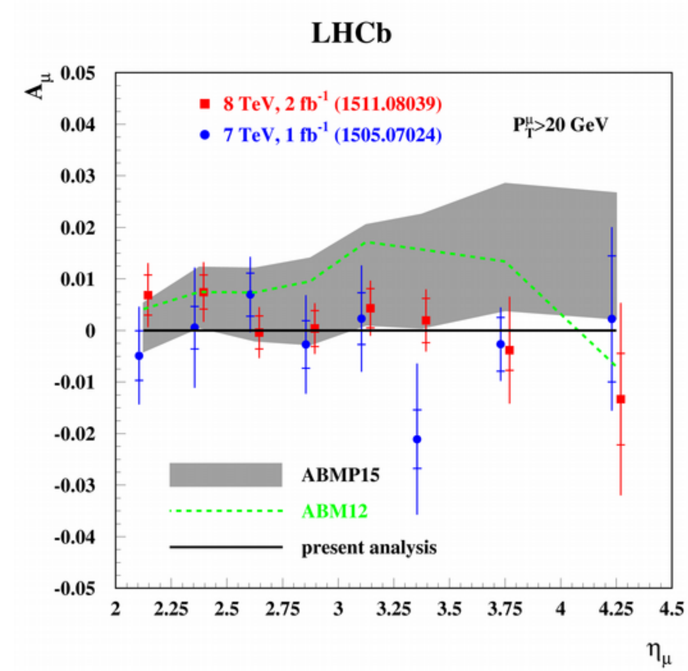
Experiment		ATLAS	CMS		D0		LHCb		
$\sqrt{s}$ (TeV)		7	7	8	1.96		7	8	8
Final states		$W^+ \to l^+\nu$ $W^- \to l^-\nu$ $Z \to l^+l^-$	$W^+ \to \mu^+\nu$ $W^- \to \mu^-\nu$	$W^+ \to \mu^+\nu$ $W^- \to \mu^-\nu$	$W^+ \to \mu^+\nu$ $W^- \to \mu^-\nu$	$W^+ \to e^+\nu$ $W^- \to e^-\nu$	$W^+ \to \mu^+\nu$ $W^- \to \mu^-\nu$ $Z \to \mu^+\mu^-$	$Z \to e^+e^-$	$W^+ \to \mu^+\nu$ $W^- \to \mu^-\nu$ $Z \to \mu^+\mu^-$
Cut on the lepton P_T		$P_T^l > 20$ GeV	$P_T^\mu > 25$ 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
χ^2	ABMP16	30.0	22.0	16.8	18.2	19.6	45.4	21.5	45.4
	CJ15	–	–	–	20	29	–	–	–
	CT14	42	–[a]	–	–	34.7	–	–	–
	JR14	–	–	–	–	–	–	–	–
	HERAFitter	–	–	–	13	19	–	–	–
	MMHT14	39	–	–	21	–	–	–	–
	NNPDF3.0	35.4	18.9	–	–	–	–	–	–

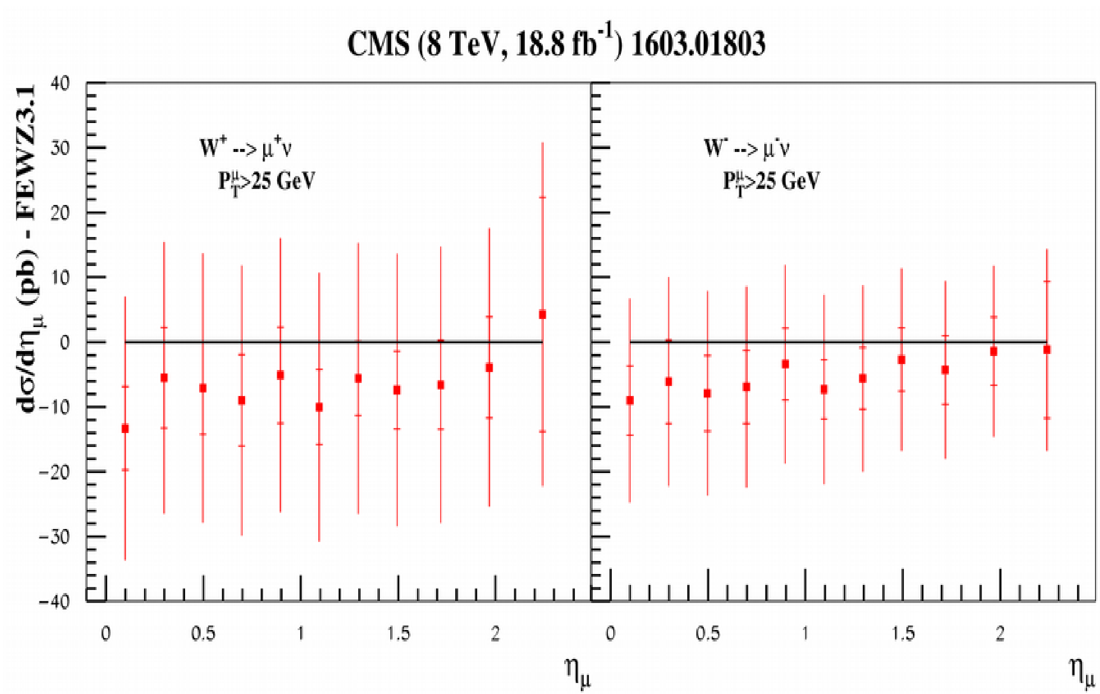
[a]Statistically less significant data with the cut of $P_T^\mu > 35$ GeV are used.

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

Most recent DY inputs







A 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)

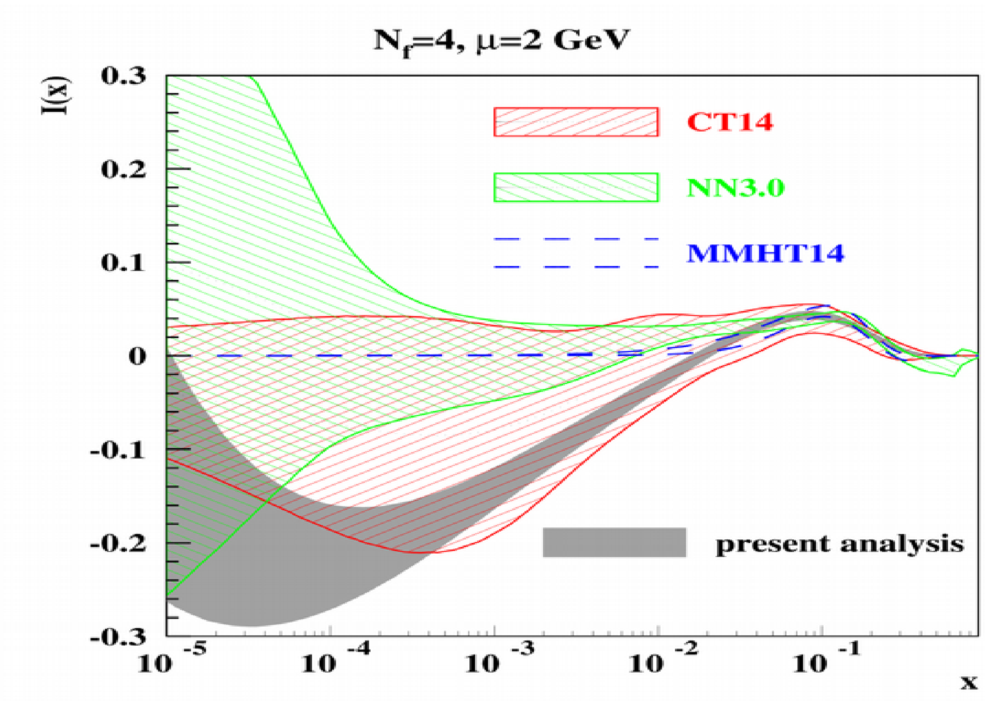
– and excess at 8 TeV and Y=2.125
(not confirmed by the CMS data at 8 TeV)

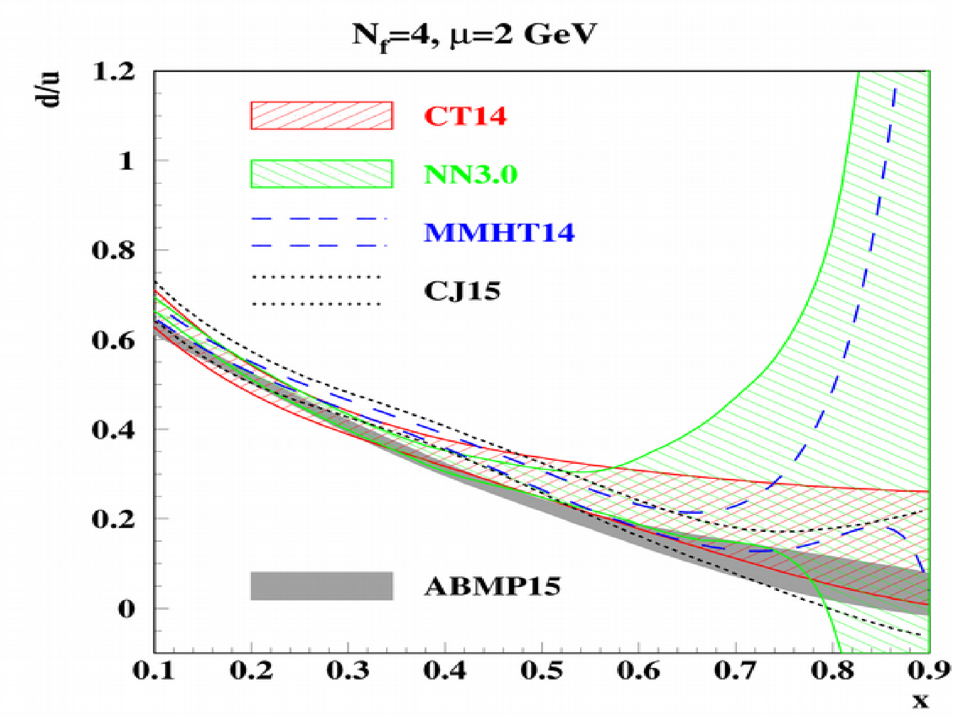
The CMS data at 8 TeV are much smoother than the ones at 7 TeV:

χ^2=17/22 versus 22/11

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

Impact of the forward Drell-Yan data



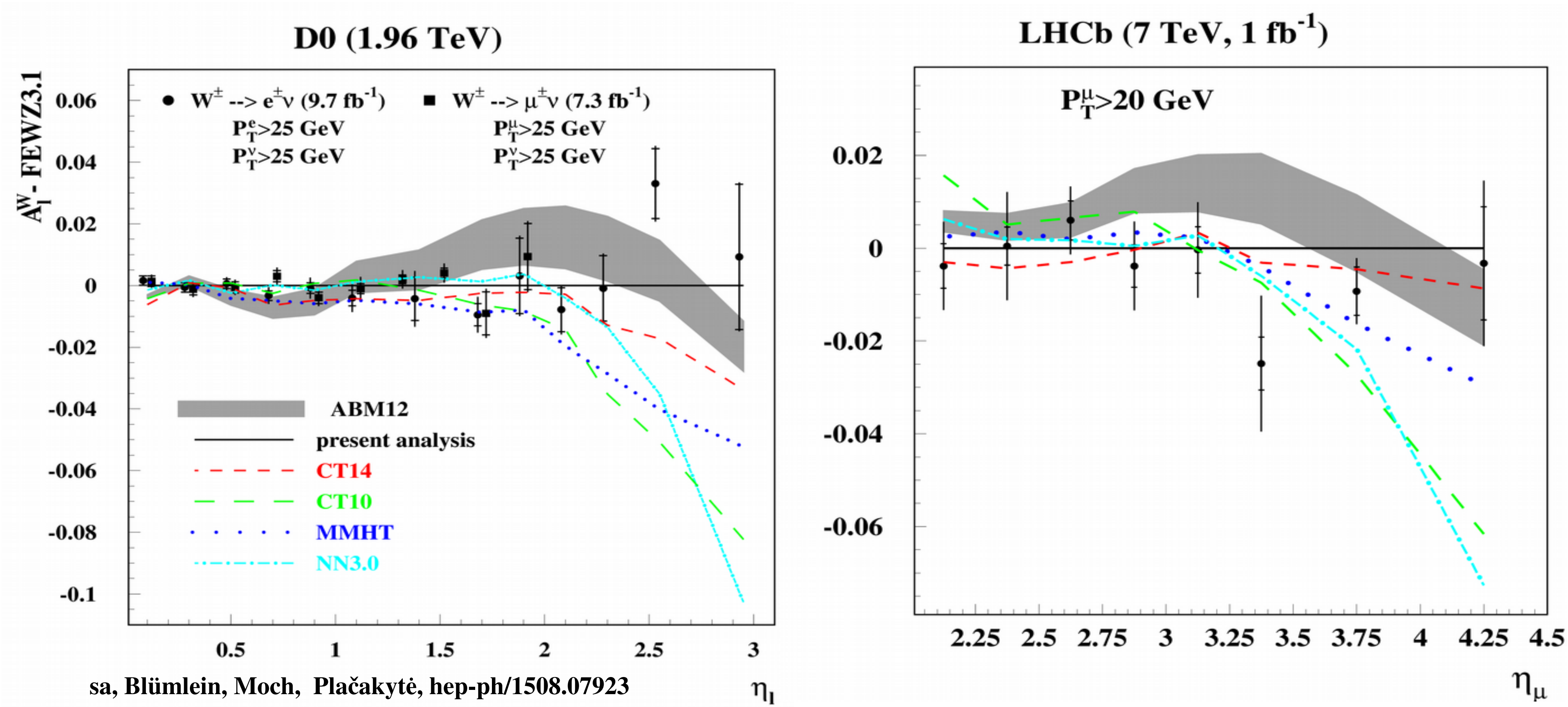


sa, Blümlein, Moch, Plačakytė, hep-ph/1508.07923

Accardi, et al. hep-ph/1603.08906

- Relaxed form of the sea iso-spin asymmetry I(x) at small x; Regge-like behaviour is recovered only at $x{\sim}10^{-6}$; 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; talks by Accardi and Petti at this conference**
- Big spread between different PDF sets, up to factor of 30 at large x → PDF4LHC recommendations are misleading in this part **talk by Plačakytė at this conference**

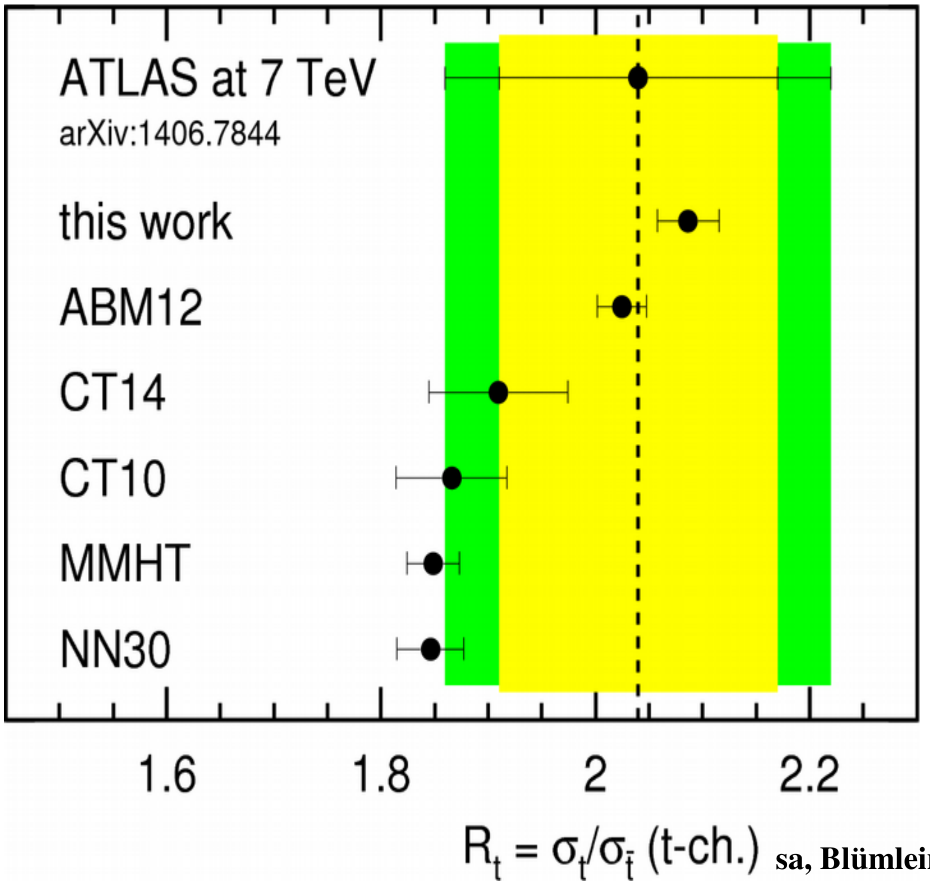
DY at large rapidity

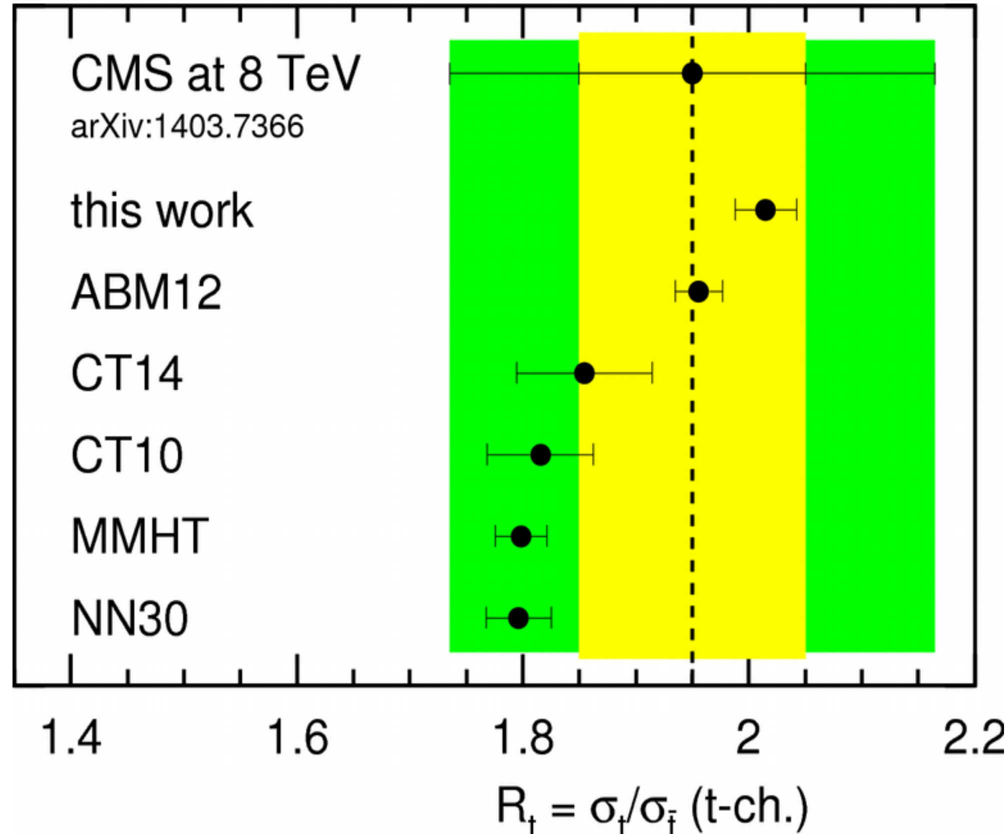


- The data can be evidently used for consolidation of the PDFs, however, unification of the theoretical accuracy is also needed

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

Implication for(of) the single-top production





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

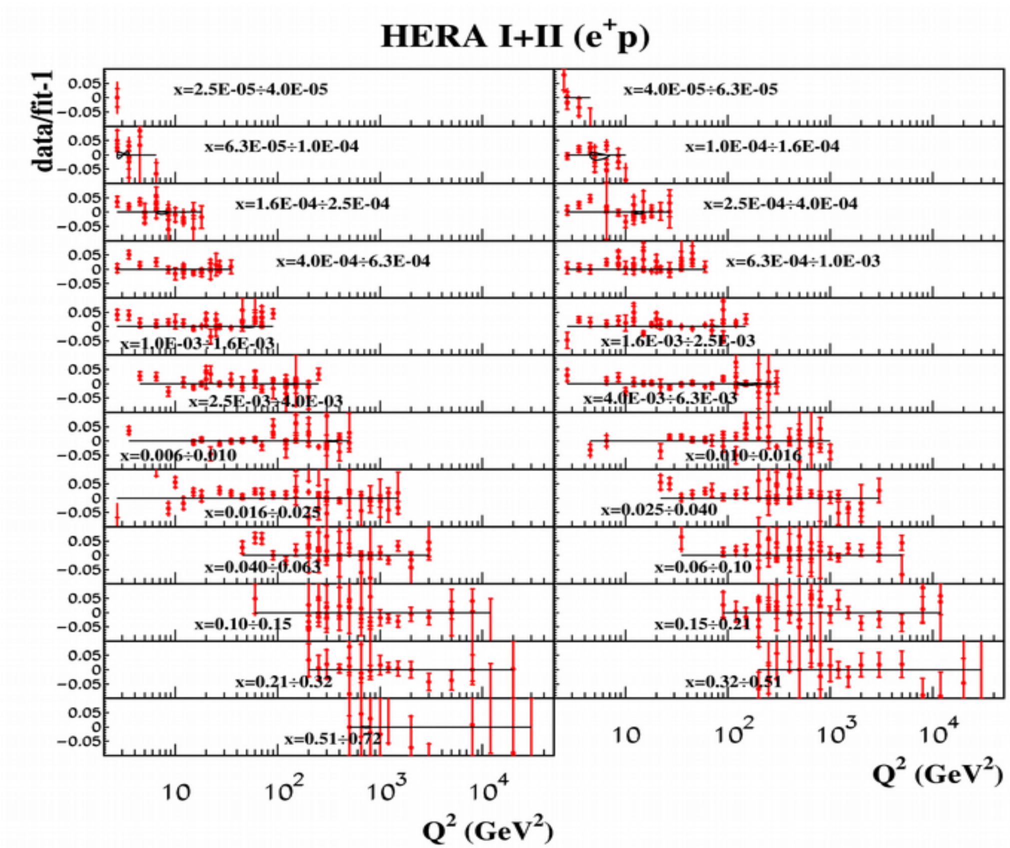
- ATLAS and CMS data on the ratio t/tbar are in a good agreement

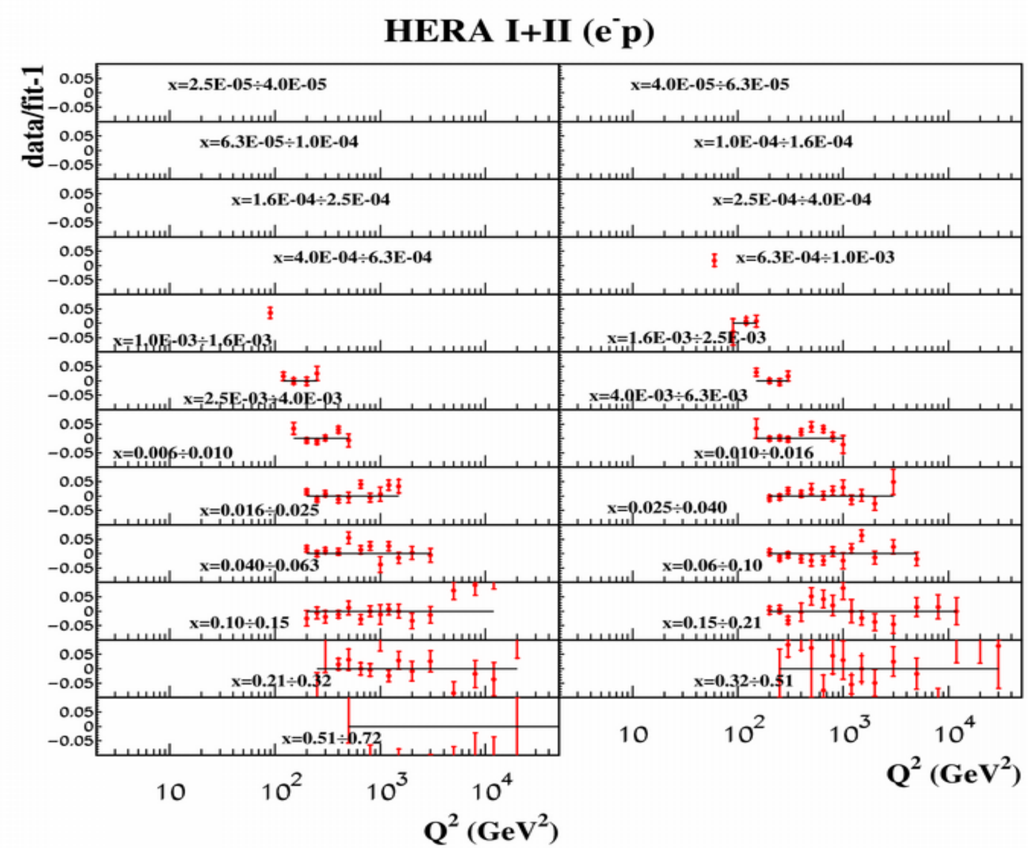
- The predictions driven by the froward DY data are in a good agreement with the single-top data (N.B.: ABM12 is based on the deuteron data → consistent deuteron correction was used **talk by Petti at this conference**)

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

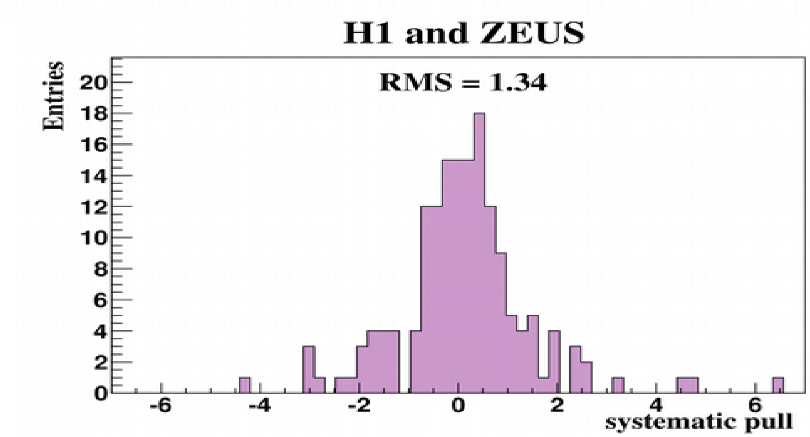
Inclusive HERA I+II data

H1 and ZEUS hep-ex/1506.06042



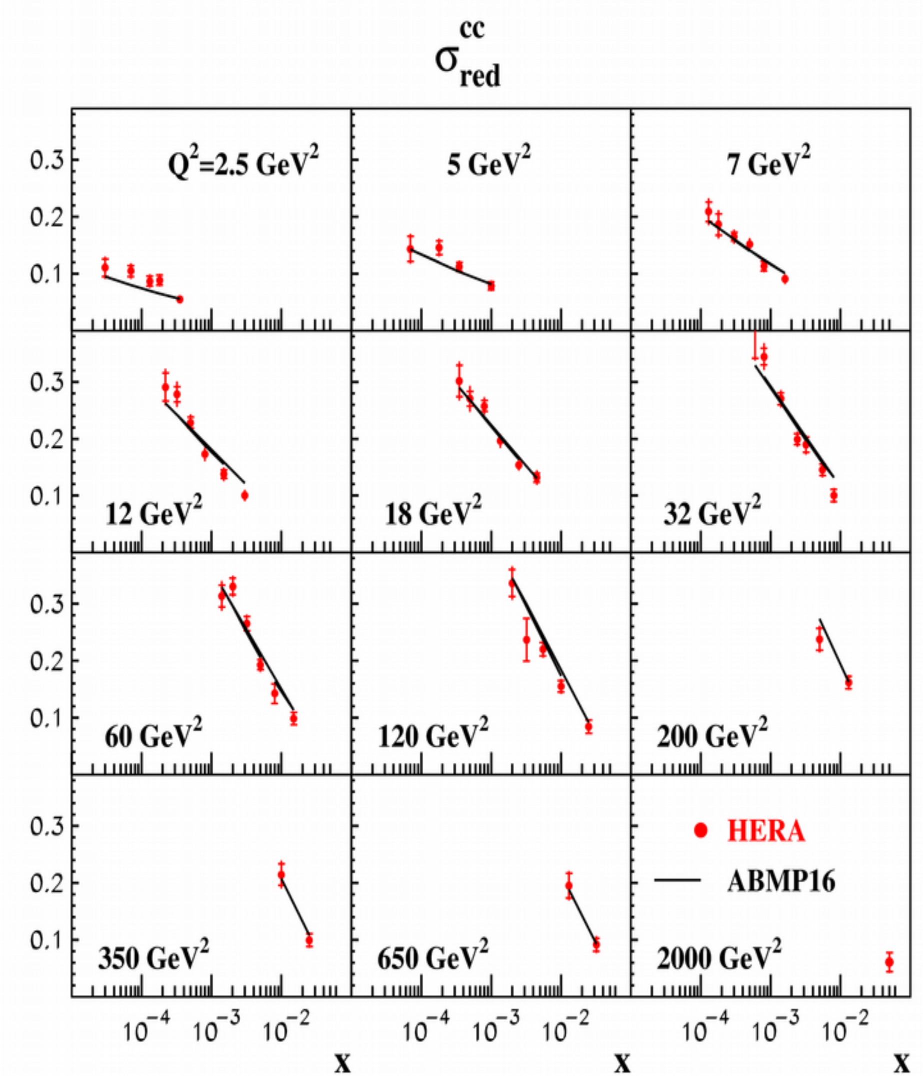


Q^2(HERA)	χ^2/NDP(HERA)
>2.5 GeV^2	1505/1168=1.29
>5 GeV^2	1350/1092=1.24
>10 GeV^2	1225/1007=1.22



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

HERA charm data and $m_c(m_c)$



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

Kiyo, Mishima, Sumino hep-ph/1510.07072

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

  $m_c(m_c)$=1.250±0.020(exp.) GeV ABMP16

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

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

- RT optimal

  X^2/NDP=82/52 NNLO

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

- F0NLL

  X^2/NDP=60/47 NNLO

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

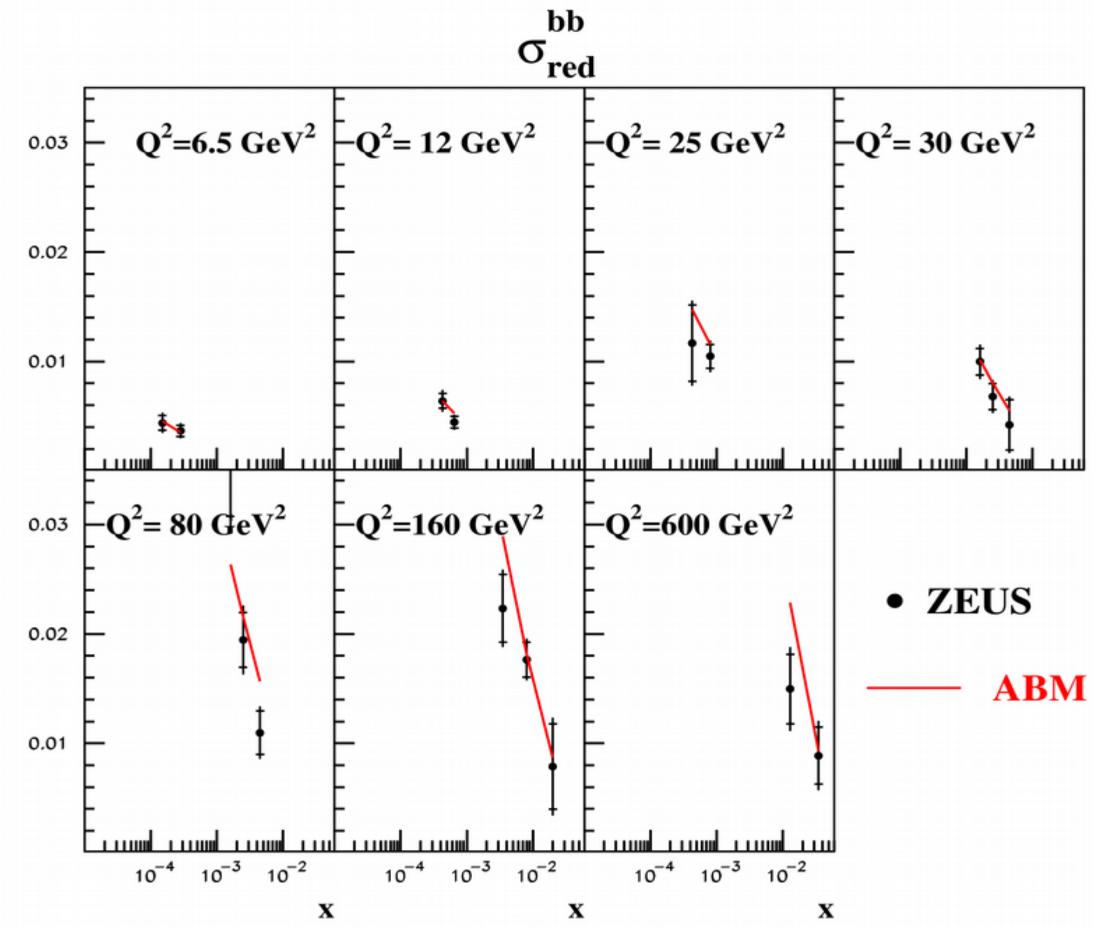
- S-ACOT-χ

  X^2/NDP=59/47 NNLO

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

ZEUS bottom data and $m_b(m_b)$

ZEUS hep-ex/1405.6915



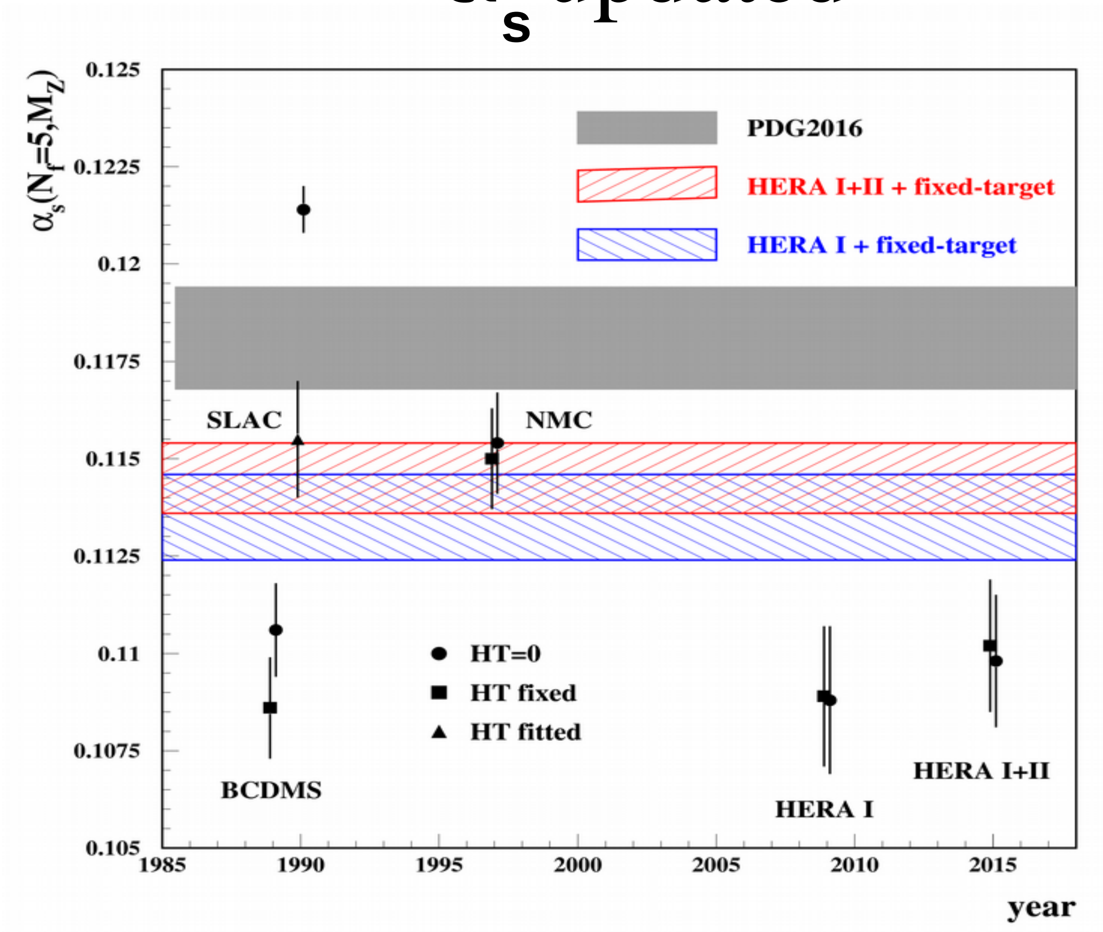
χ^2/NDP=16 / 17

$m_b(m_b)$=3.91±0.14(exp.) GeV ABMP16

$m_b(m_b)$=4.19±0.13(exp.) GeV PROSA

PROSA EPJC 75, 396 (2015)

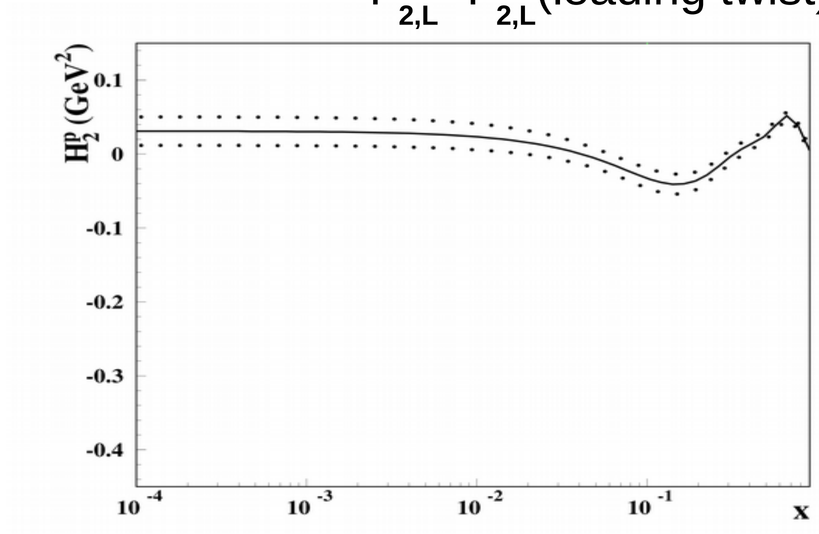
α_s updated

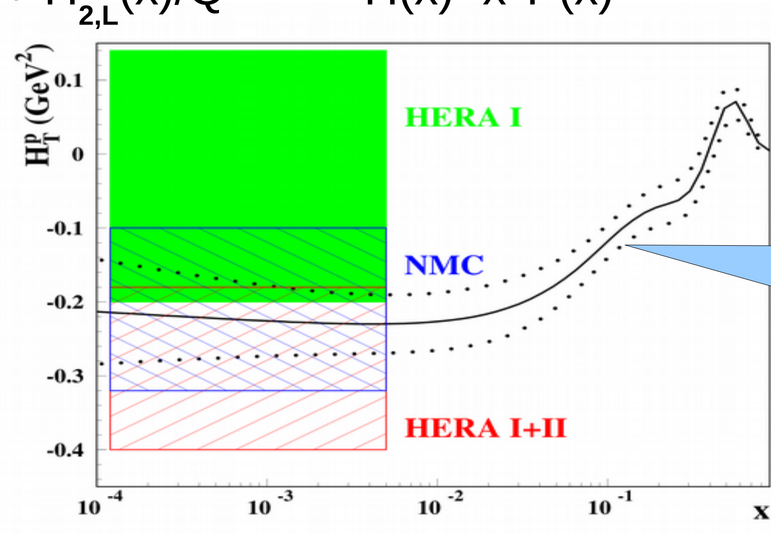


- α_s goes up by 1σ with HERA I+II data
- the value of α_s is still lower than the PDG one: pulled up by the SLAC and NMC data; pulled down by the BCDMS and HERA ones
- only SLAC determination overlap with the PDG band provided the high-twist terms are taken into account

High twists at small x

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

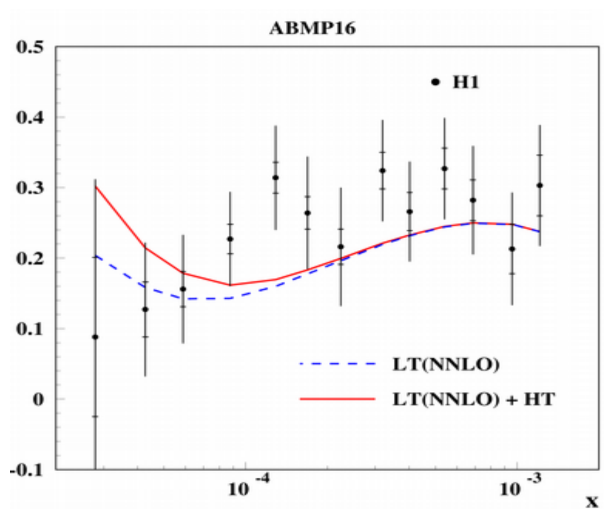


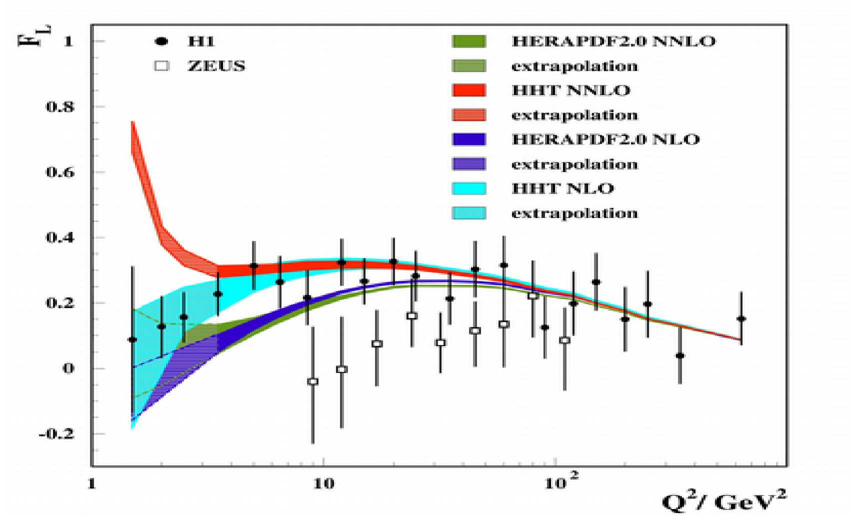


Controlled by SLAC and NMC data

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
- $h_T = 0.05 \pm 0.07$ → slow vanishing at x → 0
- $\Delta\chi^2 \sim -40$ **Harland-Lang, Martin, Motylinski, Thorne hep-ph/1601.03413**

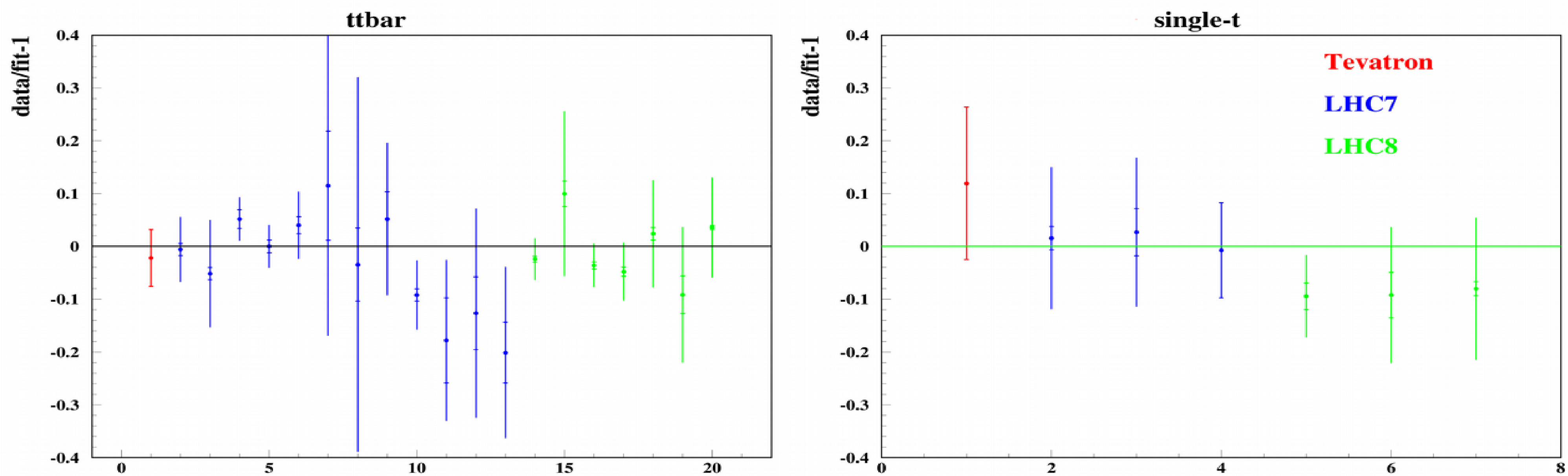




No dramatic increase of F_L at small x

Abt, et al. hep-ex/1604.02299

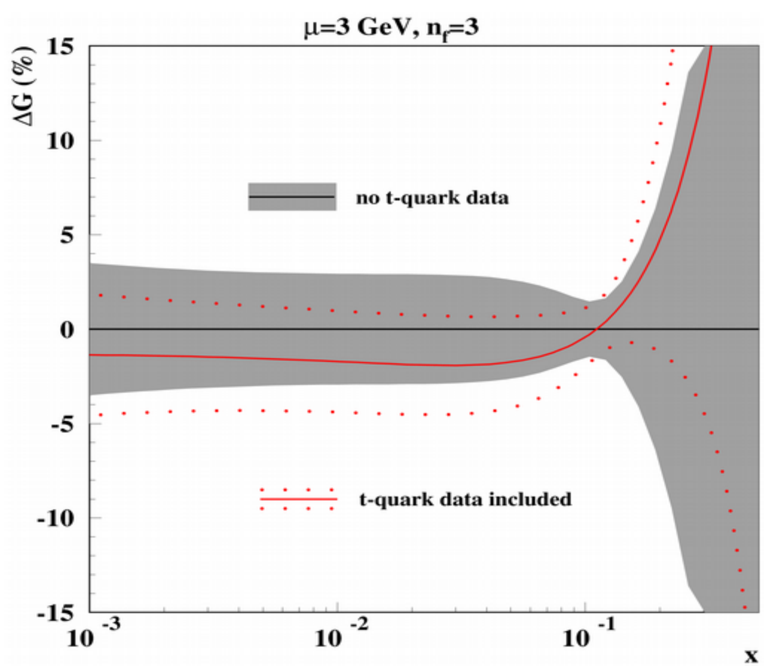
t-quark data from the LHC and Tevatron



talk by Thier at this conference

Running mass definition → better perturbative stability

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



- $m_t(m_t)$=160.9±1.2(exp.) GeV NNLO
- $\alpha_s(M_Z)$=0.1145(9) → 0.1149(9) NNLO
- moderate change in the large-x gluon distribution

Summary

The improvements are 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 $x < 10^{-5}$

- moderate increase in the large-x gluon distribution due to impact of the ttbar data

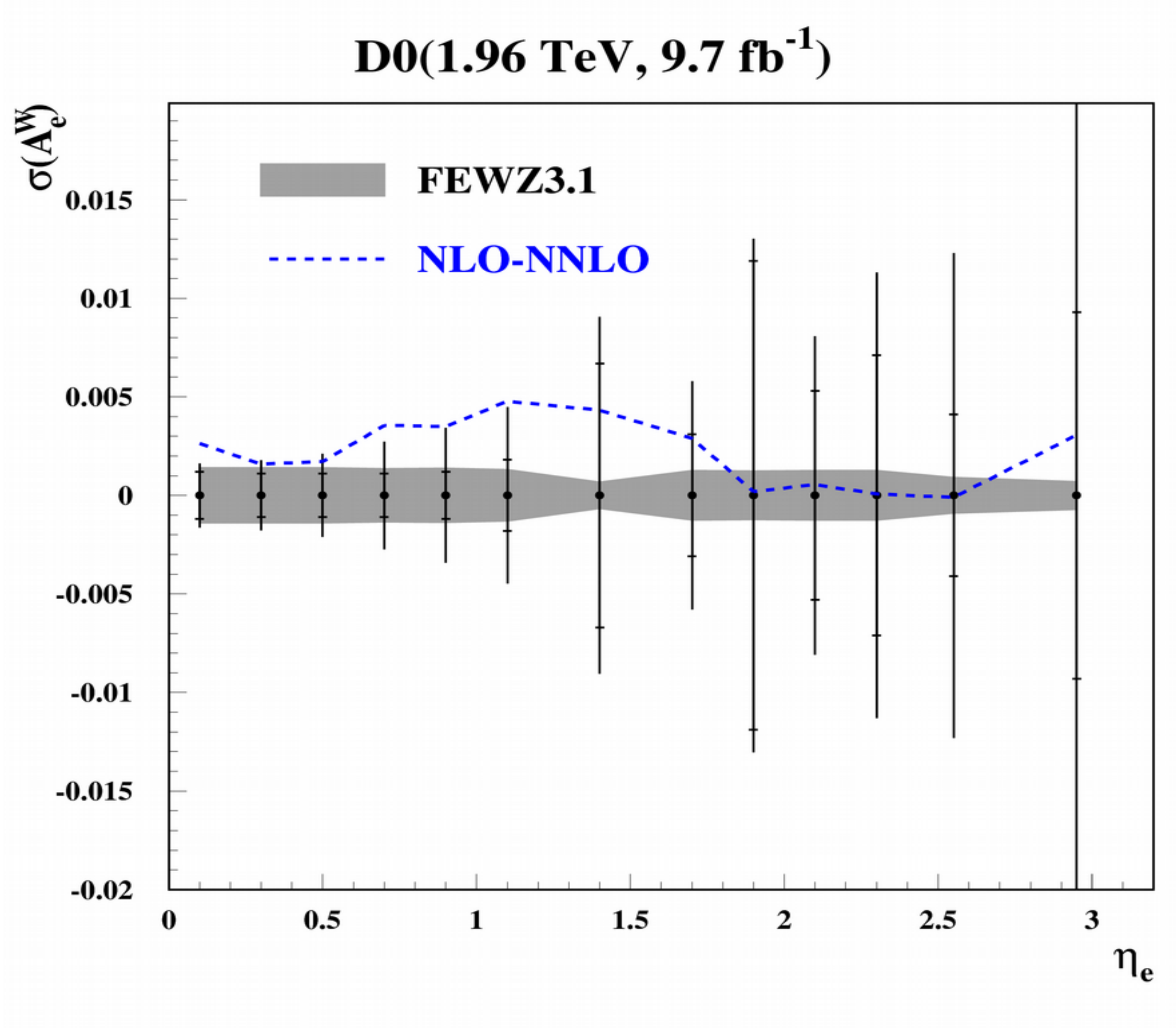
- HERA I+II data included → improved determination of $m_c(m_c)$; α_s increased by 1σ

$m_c(m_c)$=1.250±0.020 GeV
$m_b(m_b)$=3.91±0.14 GeV
$m_t(m_t)$=160.9±1.2 GeV

$\alpha_s(M_Z)$=0.1145(9)	DIS
$\alpha_s(M_Z)$=0.1149(9)	DIS+ttbar

EXTRAS

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,.....)

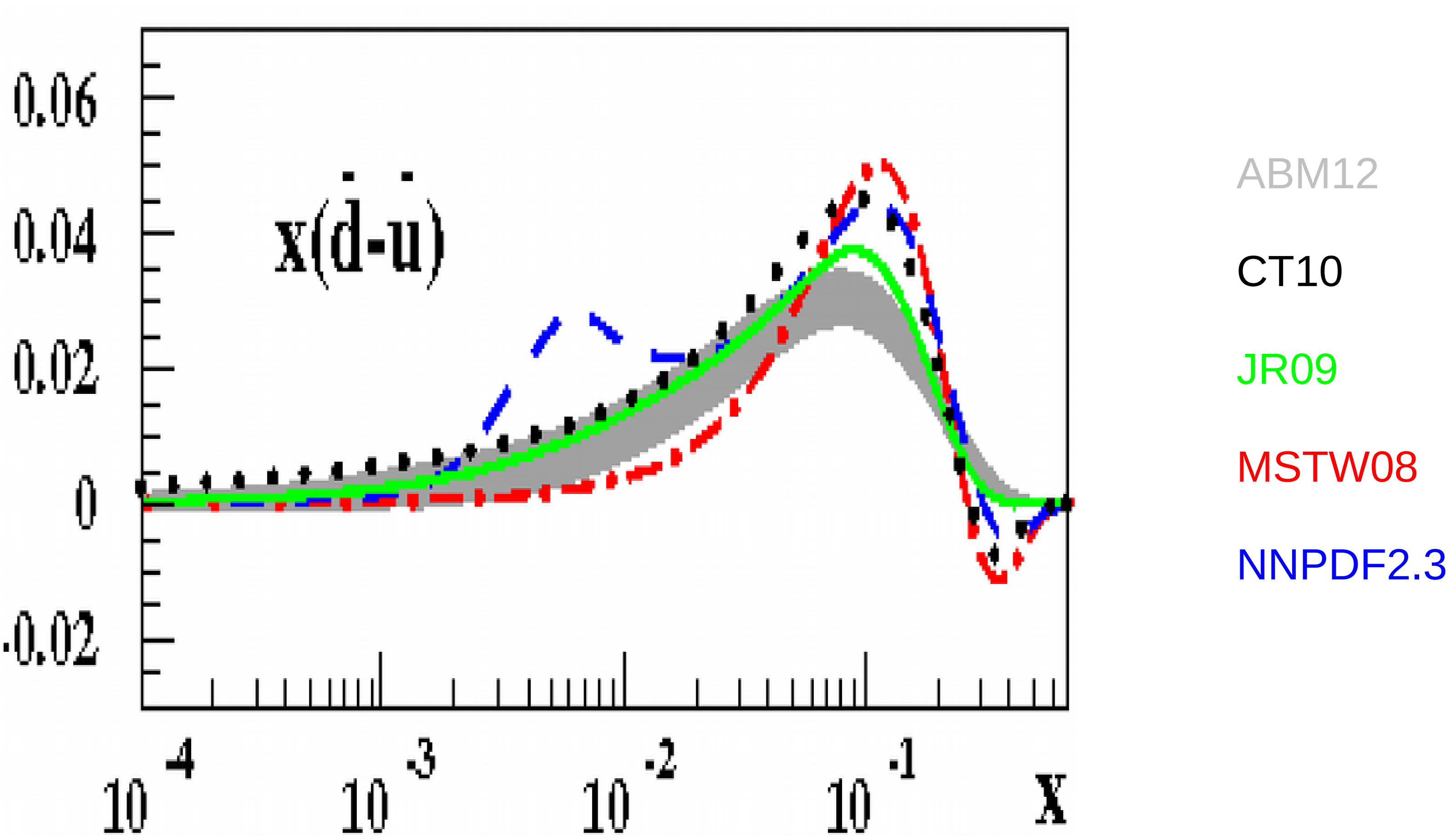
- the corrections for certain basis of PDFs are stored in the grid
- the fitted PDFs are expanded over the basis
- the NNLO c.s. in the PDF fit is calculated as a combination of expansion coefficients with the pre-prepared grids

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

Sea quark iso-spin asymmetry



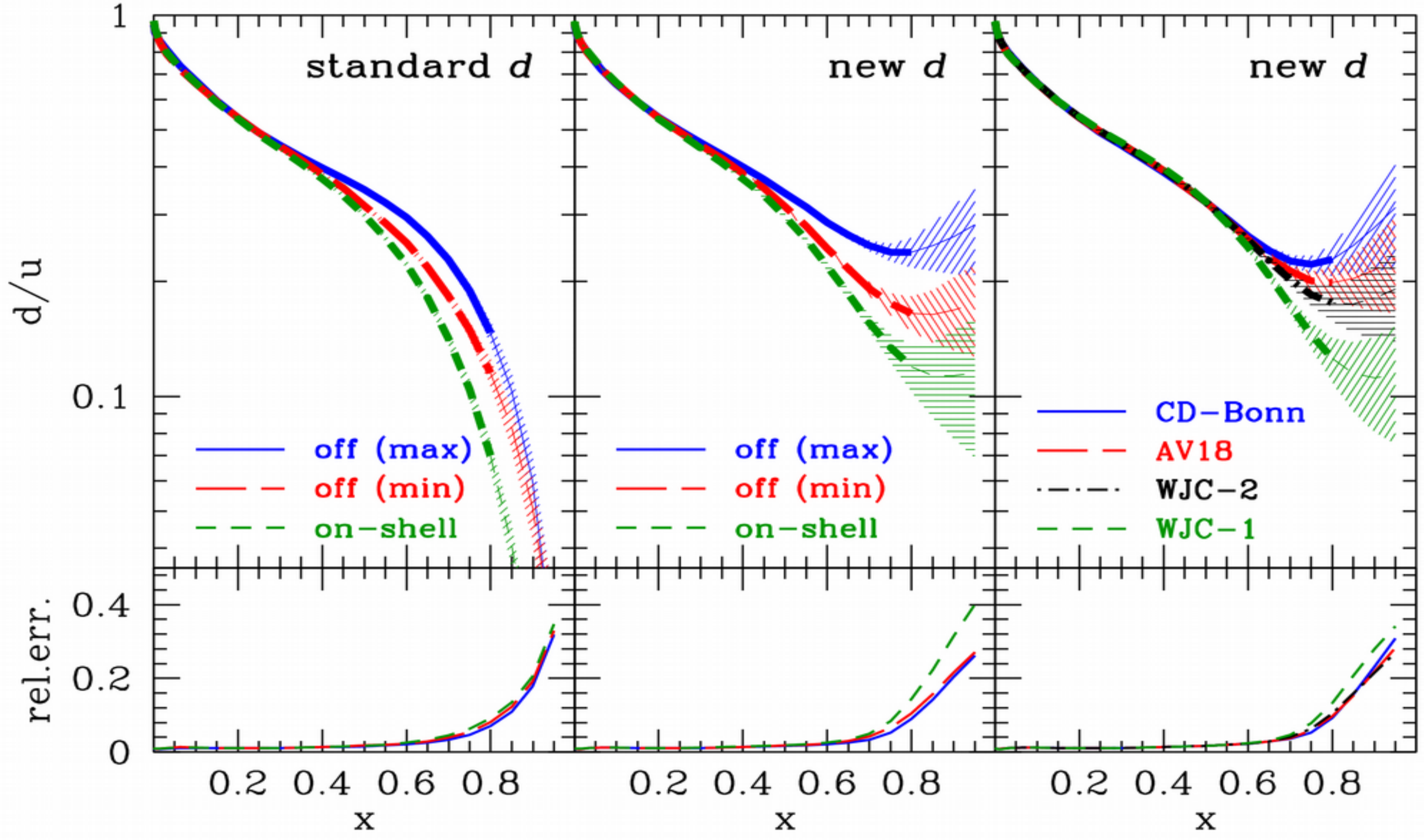
sa, Blümlein, Moch PRD 89, 054028 (2014)

- 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

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