ABMP16 and **xFitter**

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in collaboration with

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Introduction (and some history)

ABM and **xFitter** collaboration is active since the beginning of the xFitter (h1fitter, HERAFitter) project

- interface to OPENQCDRAD *https://www-zeuthen.desy.de/~alekhin/OPENQCDRAD/*
- Interface to HATHOR *https://www-zeuthen.desy.de/~moch/hathor/* *(see Artur's talk)*

- support of the xFitter activities:
  - S. Alekhin is one of the authors of the general xFitter paper **EPJC (2015), 75: 304**
  - support members of xFitter (ABM → ABMP)

Introduction (and some history)

ABM and **xFitter** collaboration

- interface to OPENQCDRAD, *https://www-zeuthen.desy.de/~alekhin/OPENQCDRAD/*

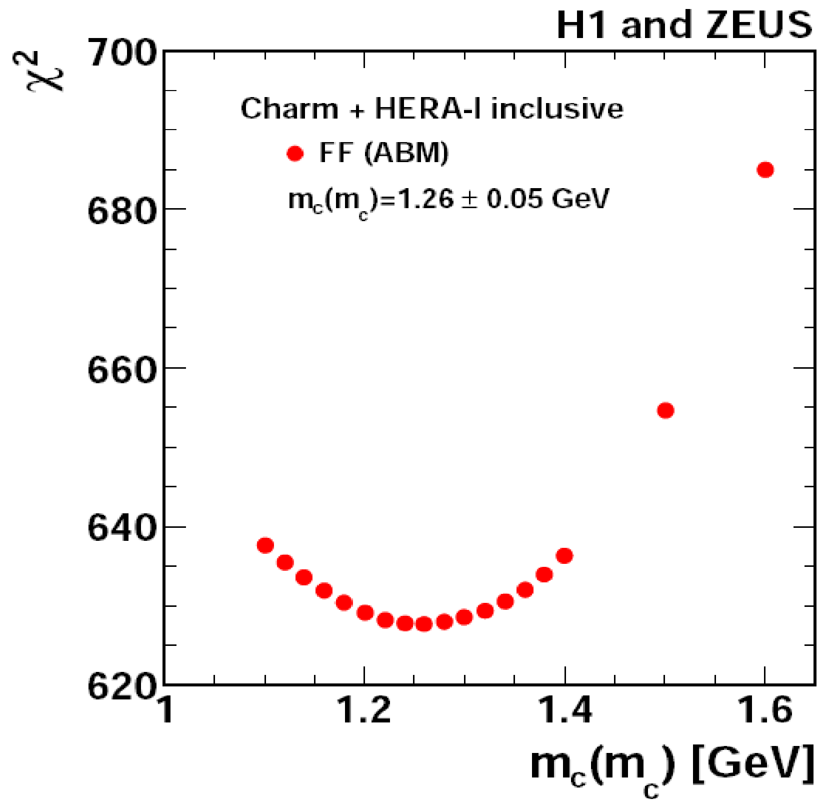
  (ABM) fixed flavour scheme (FFNS) in xFitter *(*)*

  → including *pole* and *running* heavy quark masses **S.Alekhin, S.Moch, PLB 699, (2011) 345, arXiv:1011.5790**

Implementation for the first time used in the H1 and ZEUS publication

Eur.Phys.J. C73 (2013) no.2, 2311

→ results used in PDG2014



(*) QCDNUM provides FFNS with pole masses

Introduction (and some history)

ABM and **xFitter** collaboration

- interface to OPENQCDRAD, *https://www-zeuthen.desy.de/~alekhin/OPENQCDRAD/*

  (ABM) fixed flavour scheme (FFNS) in xFitter

→ <u>followed by other publications</u>:

Determination of Charm Mass Running from an Analysis of Combined HERA Charm Data [H1 and ZEUS Collaborations and S.Moch] **H1-prelim-14-071, ZEUS-prel-14-006**

Combination of Measurements of Inclusive Deep Inelastic e±p Scattering Cross Sections and QCD Analysis of HERA Data, [H1 and ZEUS Collaborations], **arXiv:1506.06042**

→ *some results (FF3B) are not reproducible by xFitter as code was not propagated to the package*

Impact of heavy-flavour production cross sections measured by the LHCb experiment on parton distribution functions at low x, [PROSA Collaboration] **EPJC {75}, no. 8, 396 (2015)**

A determination of mc(mc) from HERA data using a matched heavy flavor scheme [xFitter and APFEL teams and A. Geiser] **JHEP 1608 (2016) 050**

+ other ongoing studies

OPENQCDRAD in xFitter

OPENQCDRAD is a code designed for various cross-checks of the hard-scattering cross sections related to the determination of PDFs and the standard candle processes at the hadron colliders

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

in the xFitter code:

→ nf=3 Fixed Flavour scheme available, could be extended to more flavours

→ additional functions like α_s can be used in existing implementation (currently not steerable)

→ QPENQCDRAD contains separate evolution which with a new QCDNUM version could be employed

→ possible to add BMSN implementation **PRED 81, 014032 (2010)**

Several updates of OPENQCDRAD package performed in the last years,

for the next release the new theory interface planned to be use *(see Sasha's talk)*

ABMP16 PDFs arXiv.17.01.05838

Summary of what's new in **ABMP16**:

→ **Data**:

HERA I+II inclusive data: $\alpha_s(M_Z)$, m_c, and m_b

charm di-muon data (NOMAD, CHORUS): s-quark sea

LHC W,Z: iso-spin asymmetry and d/u at large x (including Tevatron data)

t-quark: m_t and gluon

→ **Theory**:

heavy quarks in DIS

single-top (HATHOR, **CPC 182, 1034 (2011), CPC 191, 74 (2015)**)

ABMP16 PDFs profited from many cross checks performed with xFitter

→ datasets (HERA, LHC)

→ χ^2 code (e.g. scaling parameters, nuisance vs covariance, etc)

→ PDF grids (LHAPDFv5 vs LHAPDFv6)

ABMP16 PDFs: Main 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 $Q \gg m_c$
– running mass definition
NNLO exclusive DY (FEWZ 3.1) via fast grid technique
NNLO inclusive ttbar production

Power corrections in DIS:
target mass effects
dynamical twist-4 terms

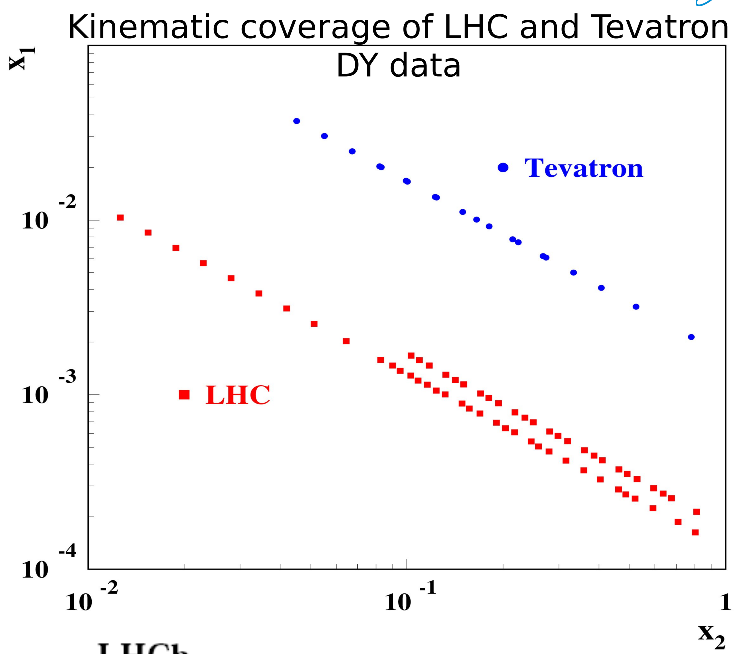
PARAMETRISATION:

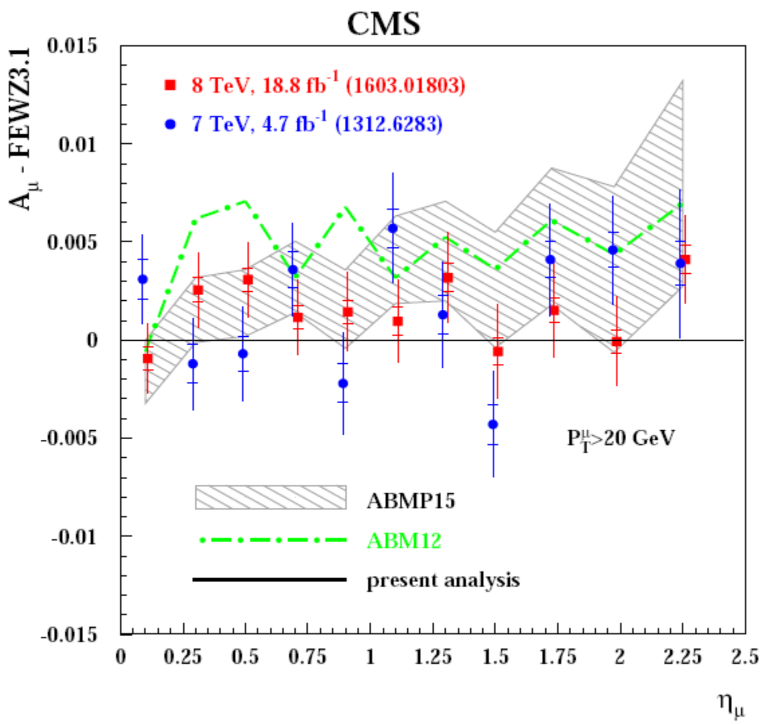
follows earlier prescription but with relaxed form of (dbar-ubar) at small x

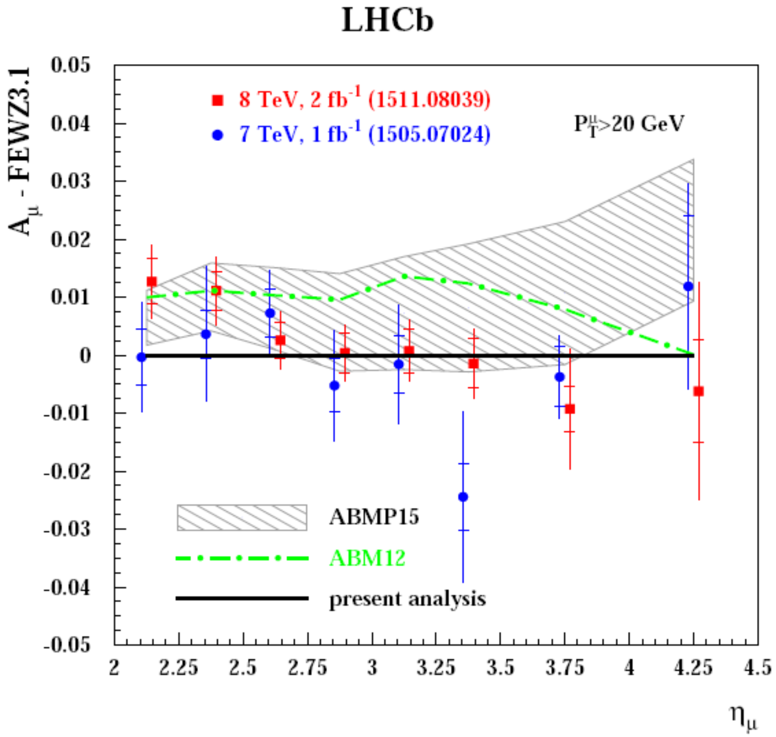
ABMP16 Highlights: Drell-Yan data

Z and W production at LHC and Tevatron

- → probe different flavour combinations
- → potential to improve quark PDFs
- → forward W,Z production probes small/large x
  - → complementary to the DIS, constraint on the quark iso-spin asymmetry







ABMP16 Highlights: Drell-Yan data

Latest Z and W production data from LHC and Tevatron used in the **ABMP16** fit

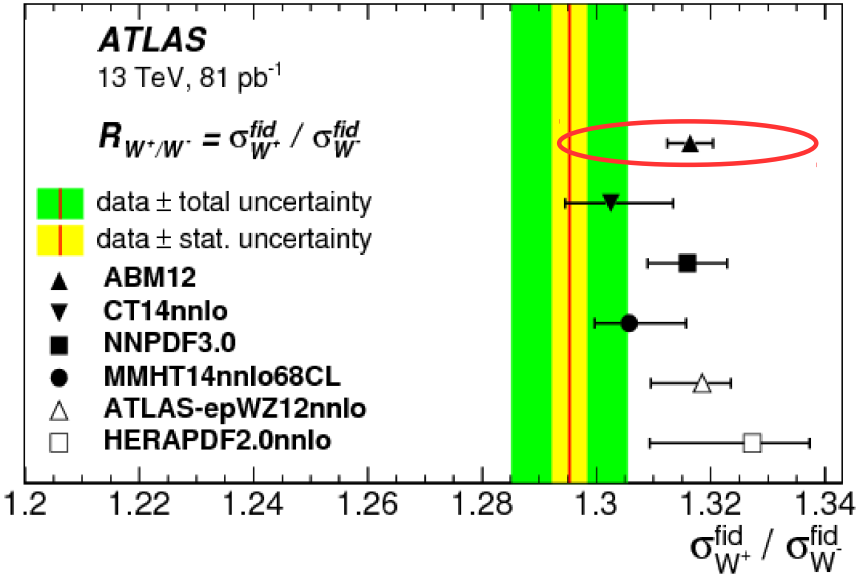
Experiment		ATLAS		CMS		DØ		LHCb		
$\sqrt{s}$ (TeV)		7	13	7	8	1.96		7	8	
Final states		$W^+ \to l^+\nu$ $W^- \to l^-\nu$ $Z \to l^+l^-$	$W^+ \to l^+\nu$ $W^- \to l^-\nu$ $Z \to l^+l^-$	$W^+ \to \mu^+\nu$ $W^- \to \mu^-\nu$ (asym)	$W^+ \to \mu^+\nu$ $W^- \to \mu^-\nu$	$W^+ \to \mu^+\nu$ $W^- \to \mu^-\nu$ (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
Reference		[66]	[26]	[24]	[25]	[23]	[22]	[19]	[21]	[20]
NDP		30	6	11	22	10	13	31	17	32
χ^2	present analysis [a]	31.0	9.2	22.4	16.5	17.6	19.0	45.1	21.7	40.0
	CJ15 [6]	–	–	–	–	20	29	–	–	–
	CT14 [7]	42	–	– [b]	–	–	34.7	–	–	–
	JR14 [8]	–	–	–	–	–	–	–	–	–
	HERAFitter [197]	–	–	–	–	13	19	–	–	–
	MMHT14 [9]	39	–	–	–	21	–	–	–	–
	NNPDF3.0 [10]	35.4	–	18.9	–	–	–	–	–	–

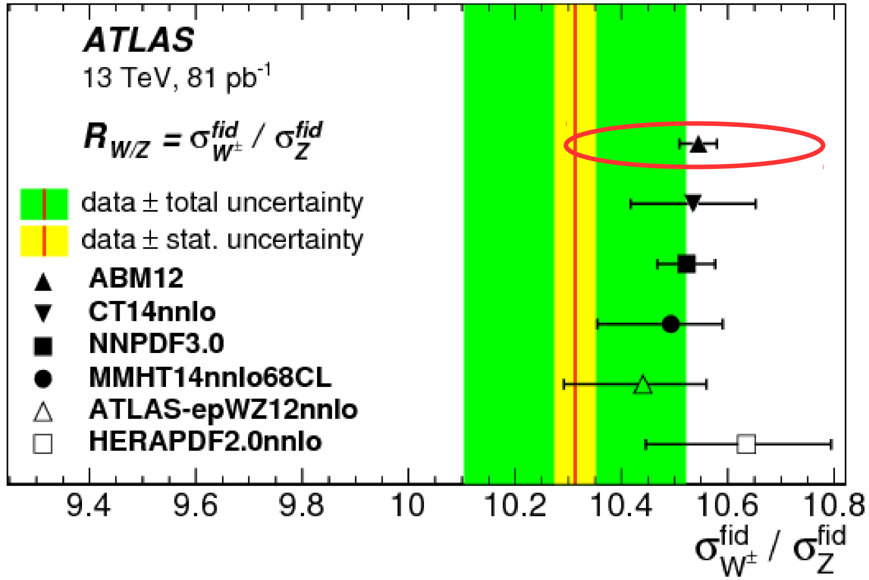
[a] The ABM12 [1] analysis has used older data sets from CMS and LHCb.
[b] For the statistically less significant data with the cut of $P_T^\mu > 35$ GeV the value of $\chi^2 = 12.1$ was obtained.

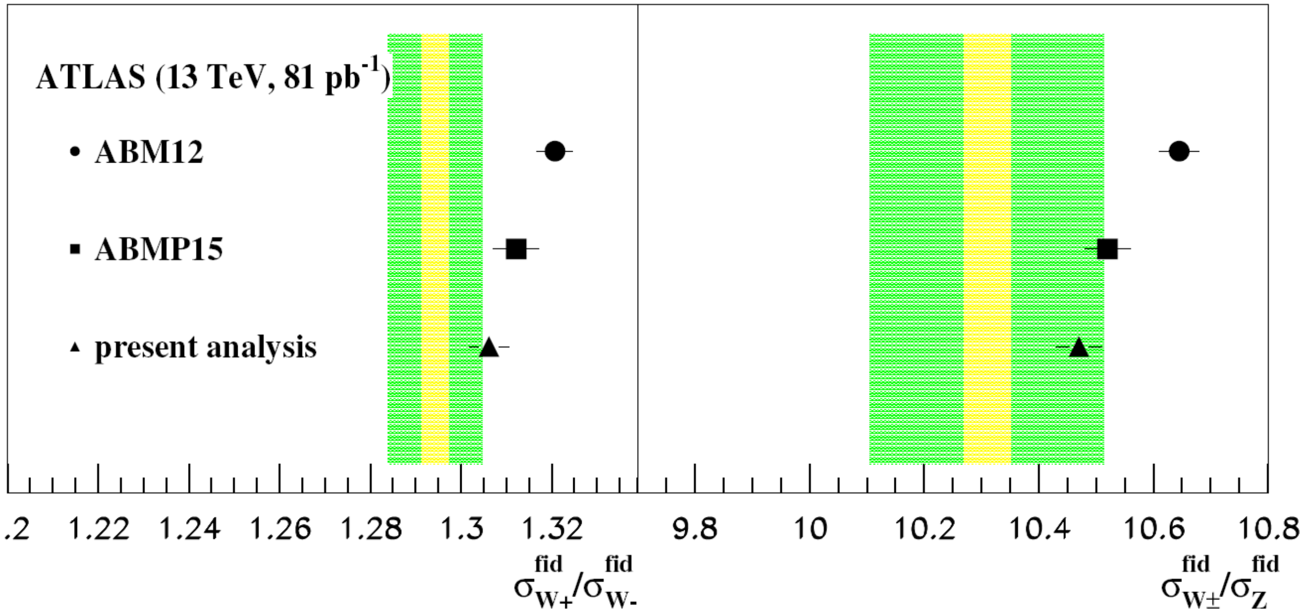
→ overall good description of all DY data

ABMP16 Highlights: ATLAS DY Data at 13 TeV

PLB 759 (2016) 601





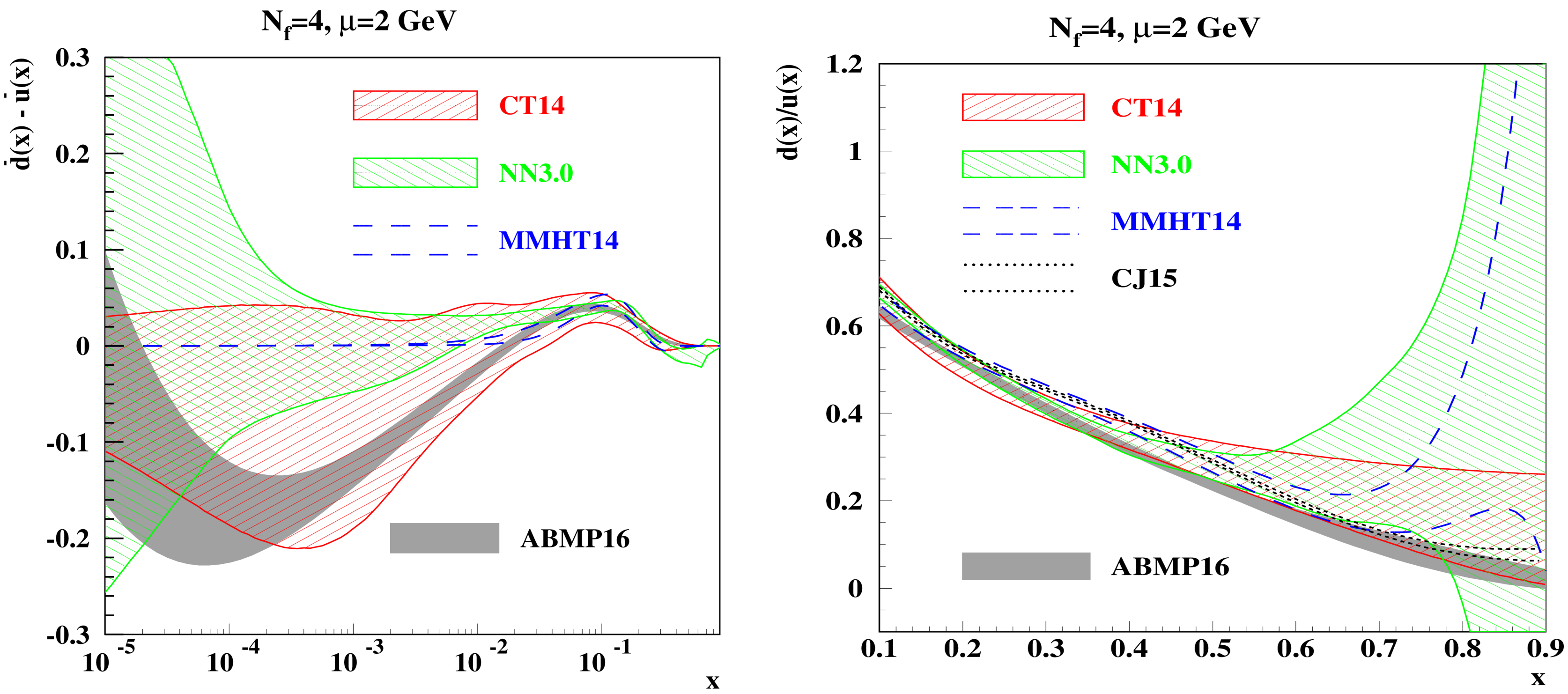


→ part of the discrepancy in DY cross sections is coming form the difference in **FEWZ** (ABMP) and **DYNNLO** (ATLAS) calculations

→ ATLAS W,Z inclusive data well accommodated into the fit, χ^2 = 9.2/6 NDP

ABMP16 Highlights: Impact of Forward DY Data

Precise forward DY data allow to relax parametrisation of the sea iso-spin asymmetry 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

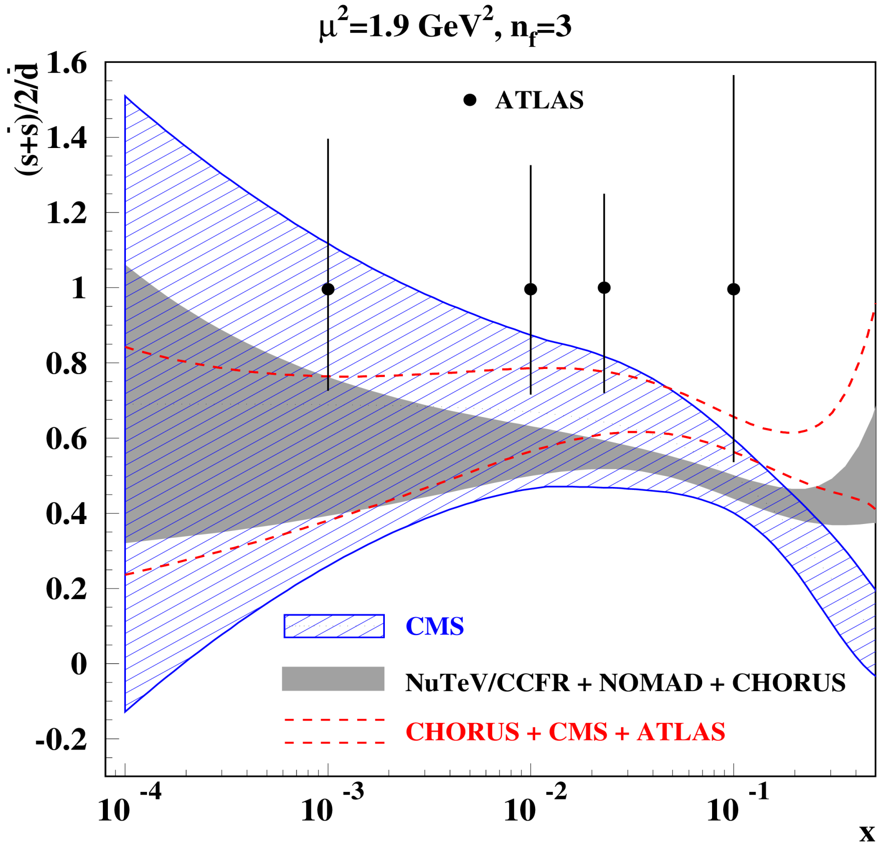
→ constraint on the d/u ratio without deuteron data
→ independent extraction of the deuteron corrections (**PRD 93, 114017 (2016)** and **arXiv:1609.08463**)

→ large spread between different PDF sets (large x)

ABMP16 Highlights: Strange Sea

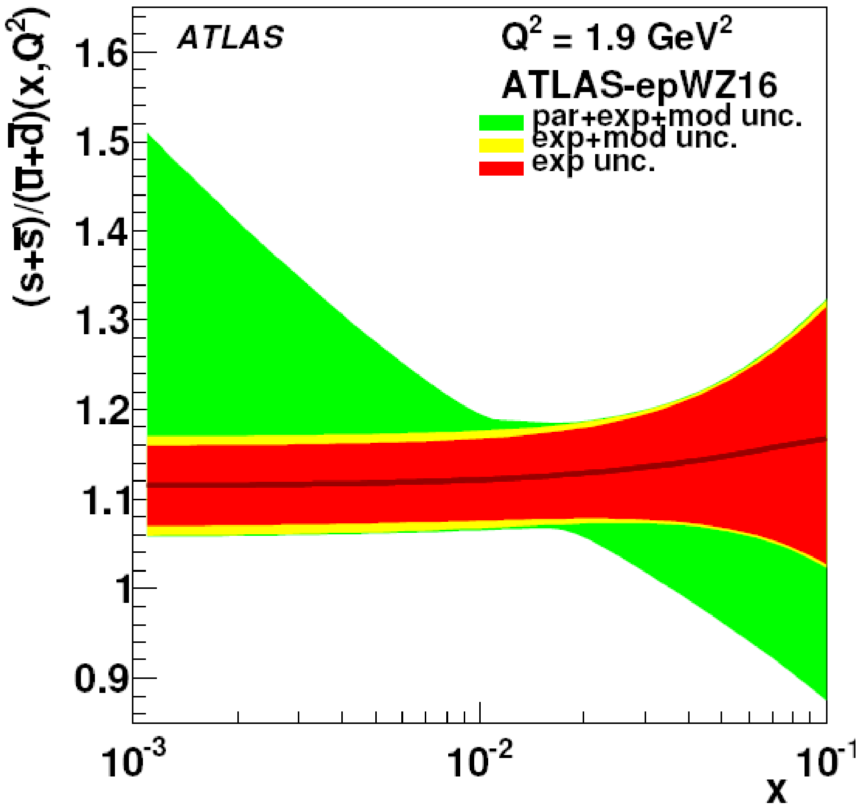
Strange quark is the least known from the light quarks

Update of **ABMP** PDFs with latest fixed target data (NOMAD+CHORUS) with smaller uncertainties on s-quark PDF



PRD 91, no 9 (2015) 094002, arXiv:1404.6469

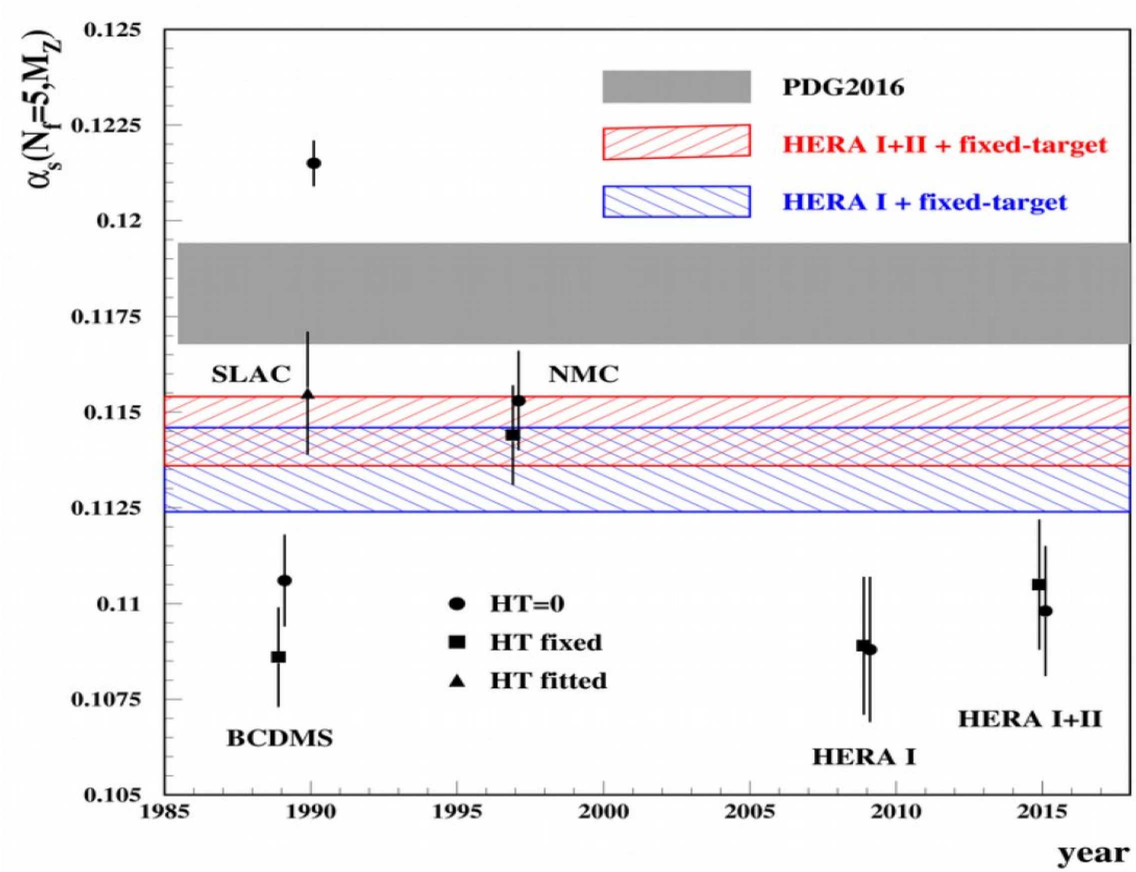
arXiv:1612.03016



→ new results from ATLAS with improved accuracy
→ disagreement with the neutrino-beam results?

ABMP16 Highlights: Strong Coupling Constant

Combination of the DY data (disentangle PDFs) and the DIS ones (constrain α_s)



→ HERA run-II data slightly pull pull α_s up, however it is still lower than PDG value

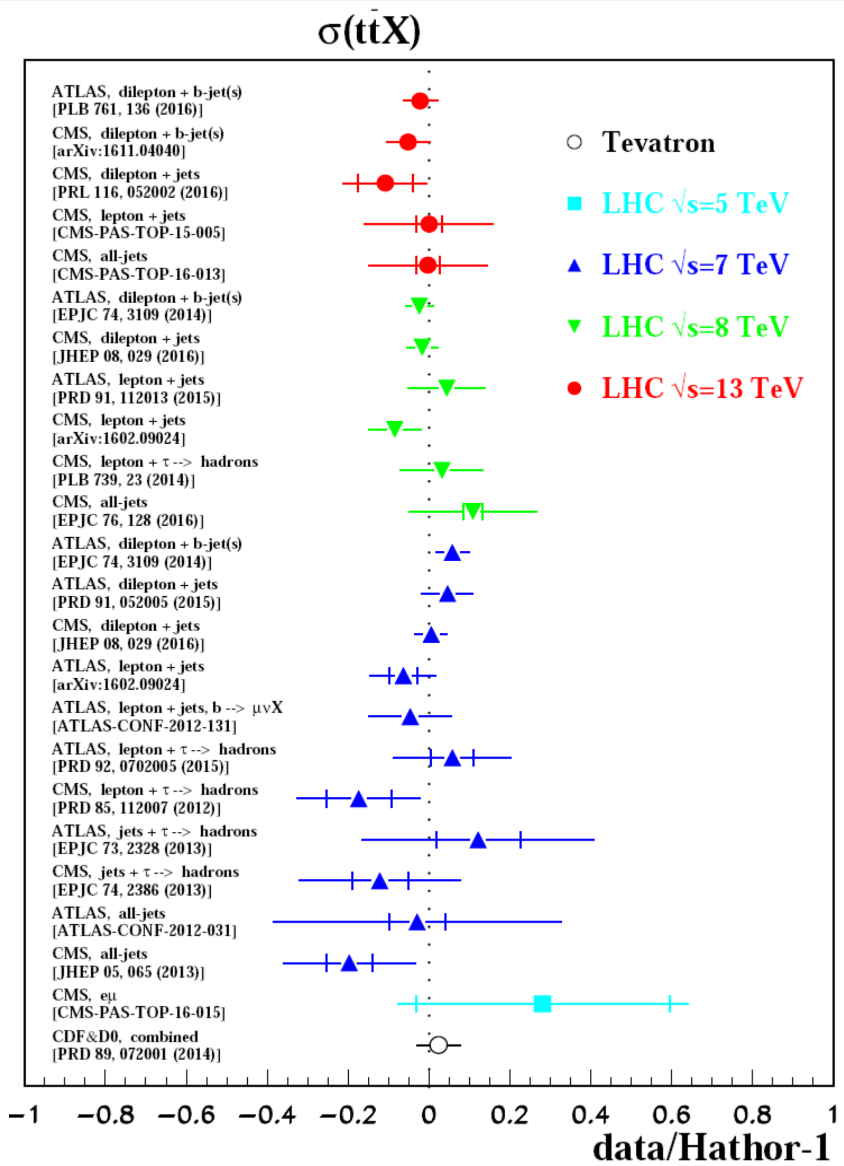
→ only SLAC determination overlap with the PDG band provided the high-twist terms are taken into account

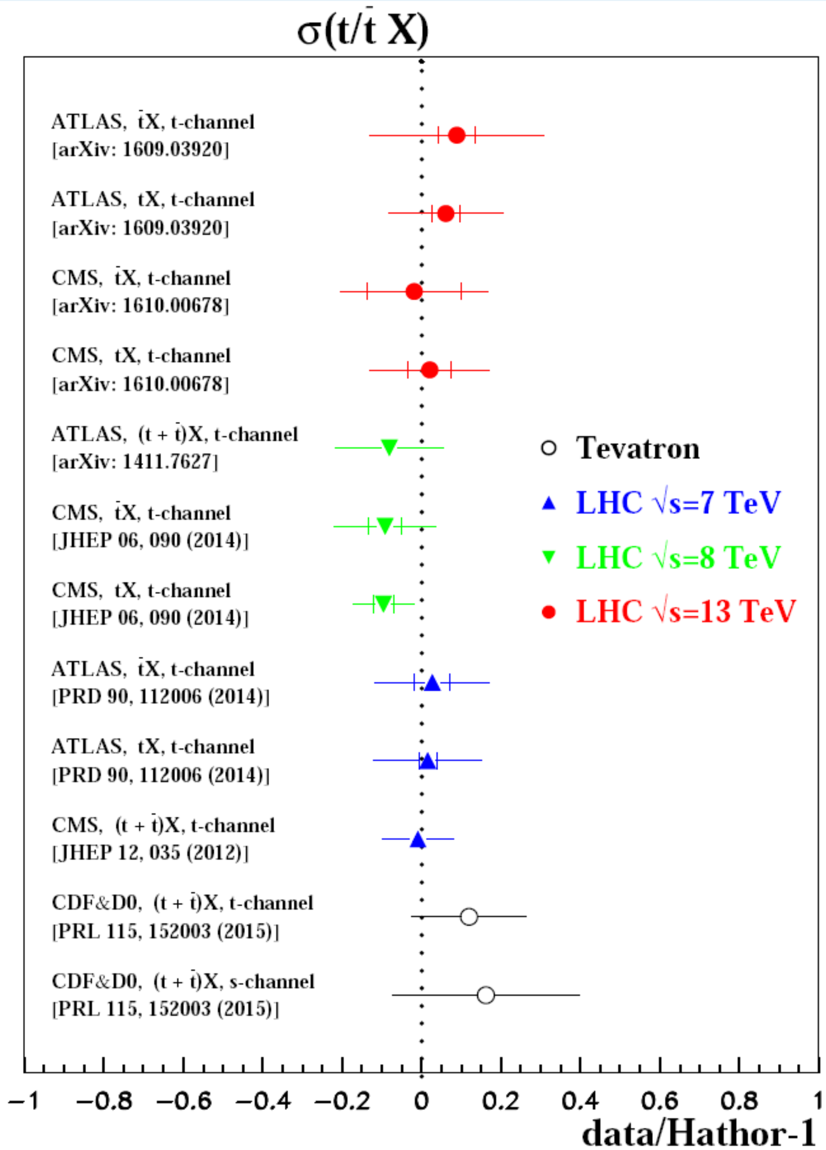
ABMP16 Highlights: Top Quark

Recent top-quark data from the LHC and Tevatron provide constraints on the gluon

→ consistent determination of the top-quark mass with full account of correlations with α_s

→ determined running top-quark mass $m_t(m_t)$=160.9±1.1 GeV





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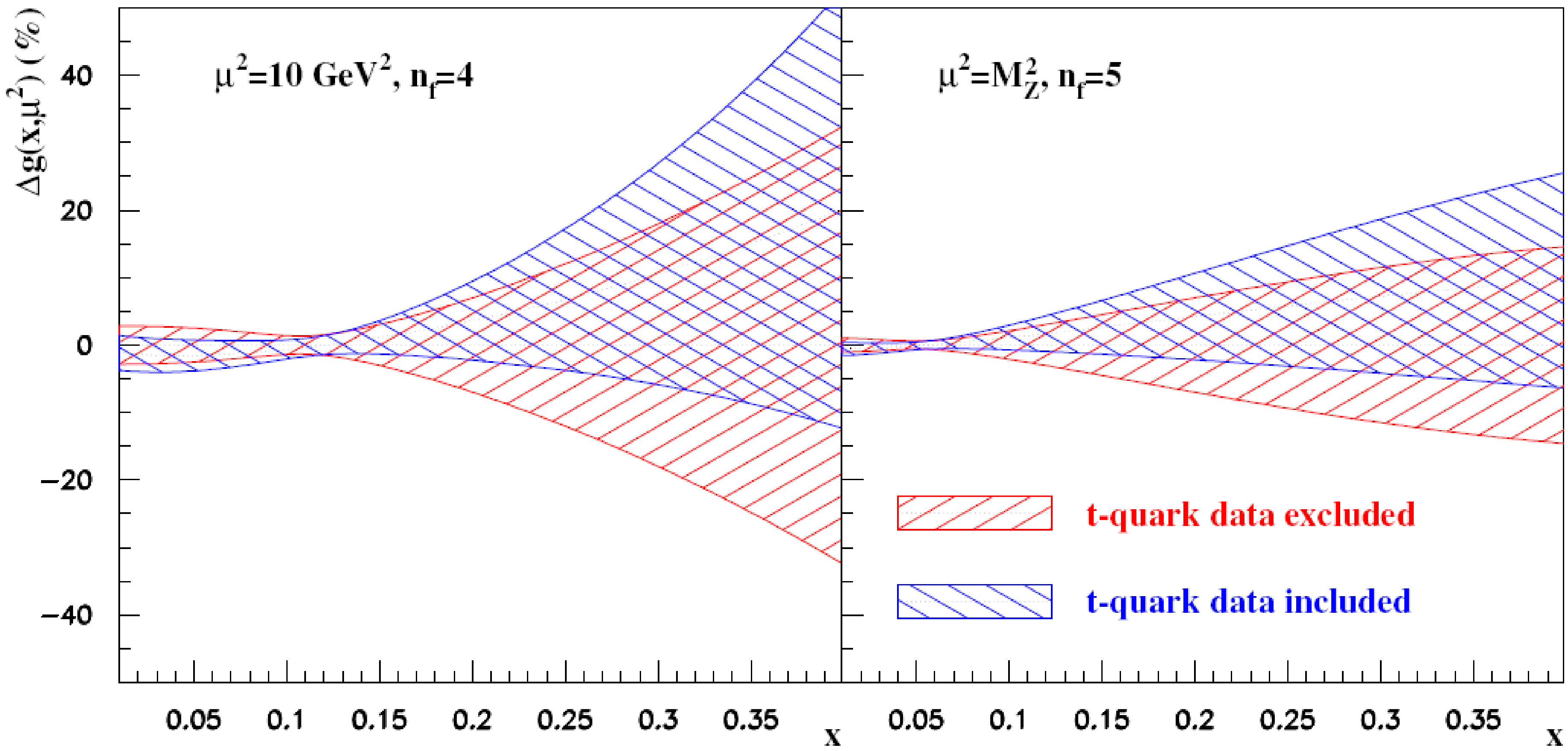
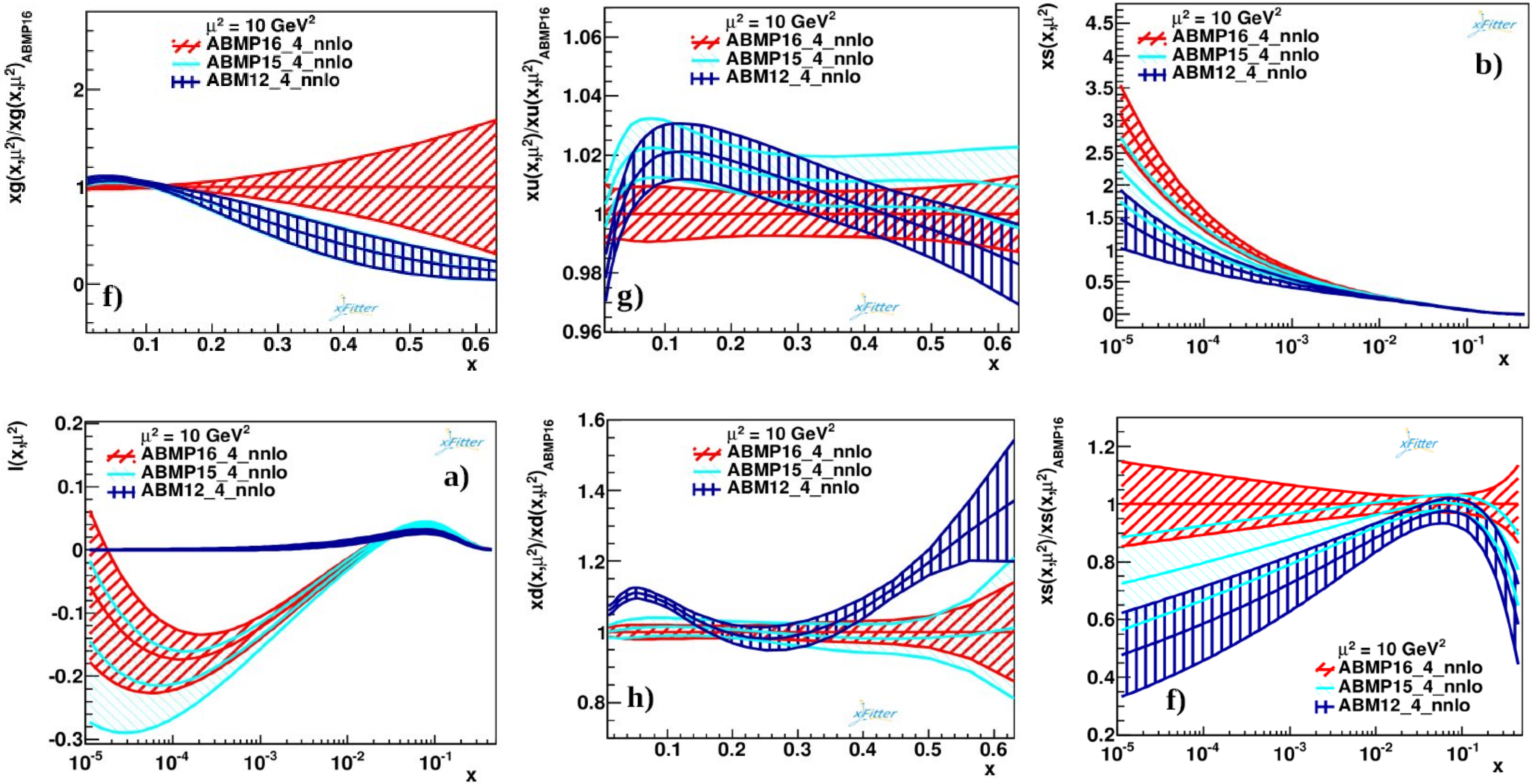
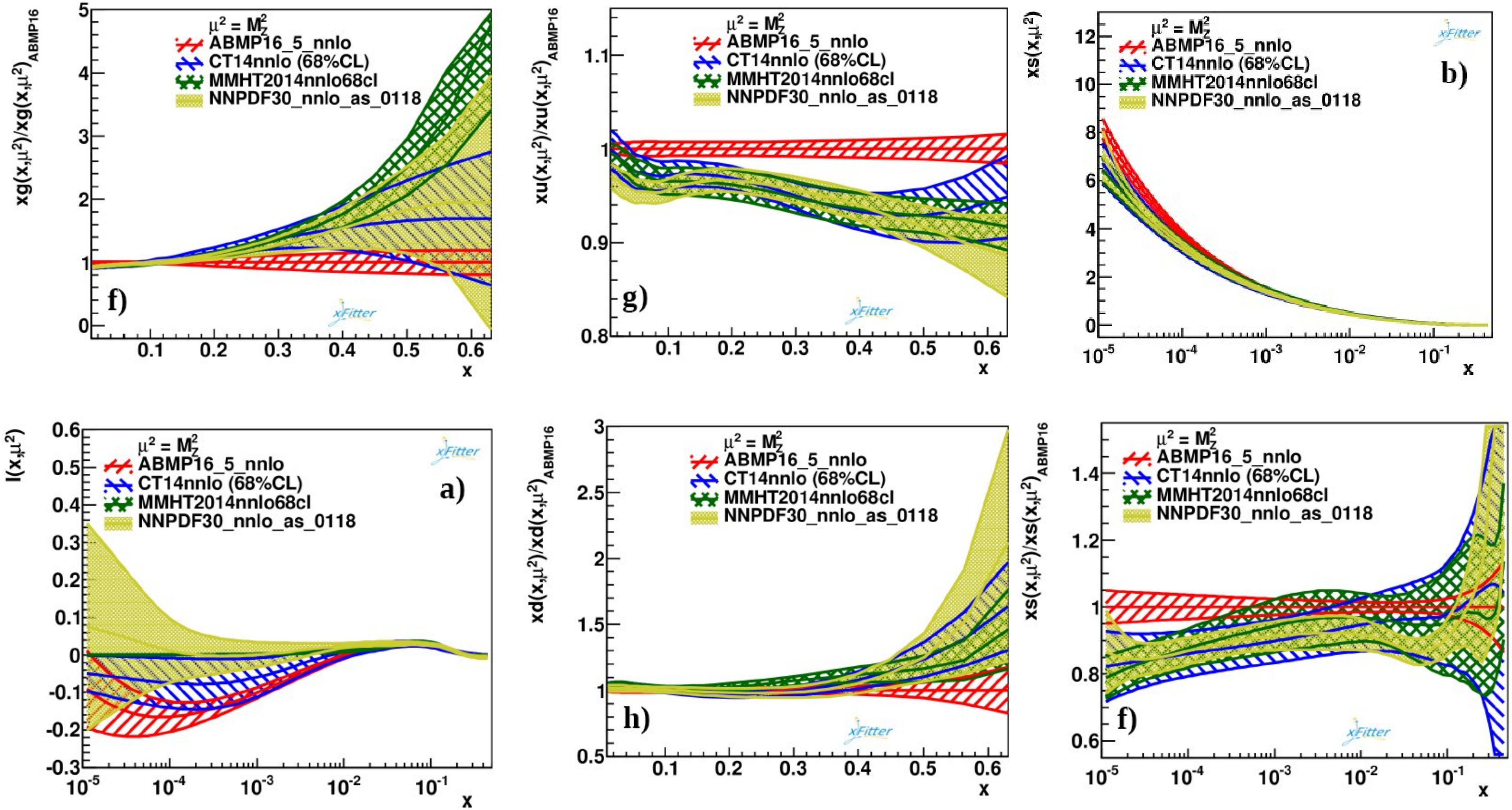


Comparison of ABMP16 with older PDFs



Iso-spin asymmetry I constrained by DY data, increased strange sea (fixed target and DY)

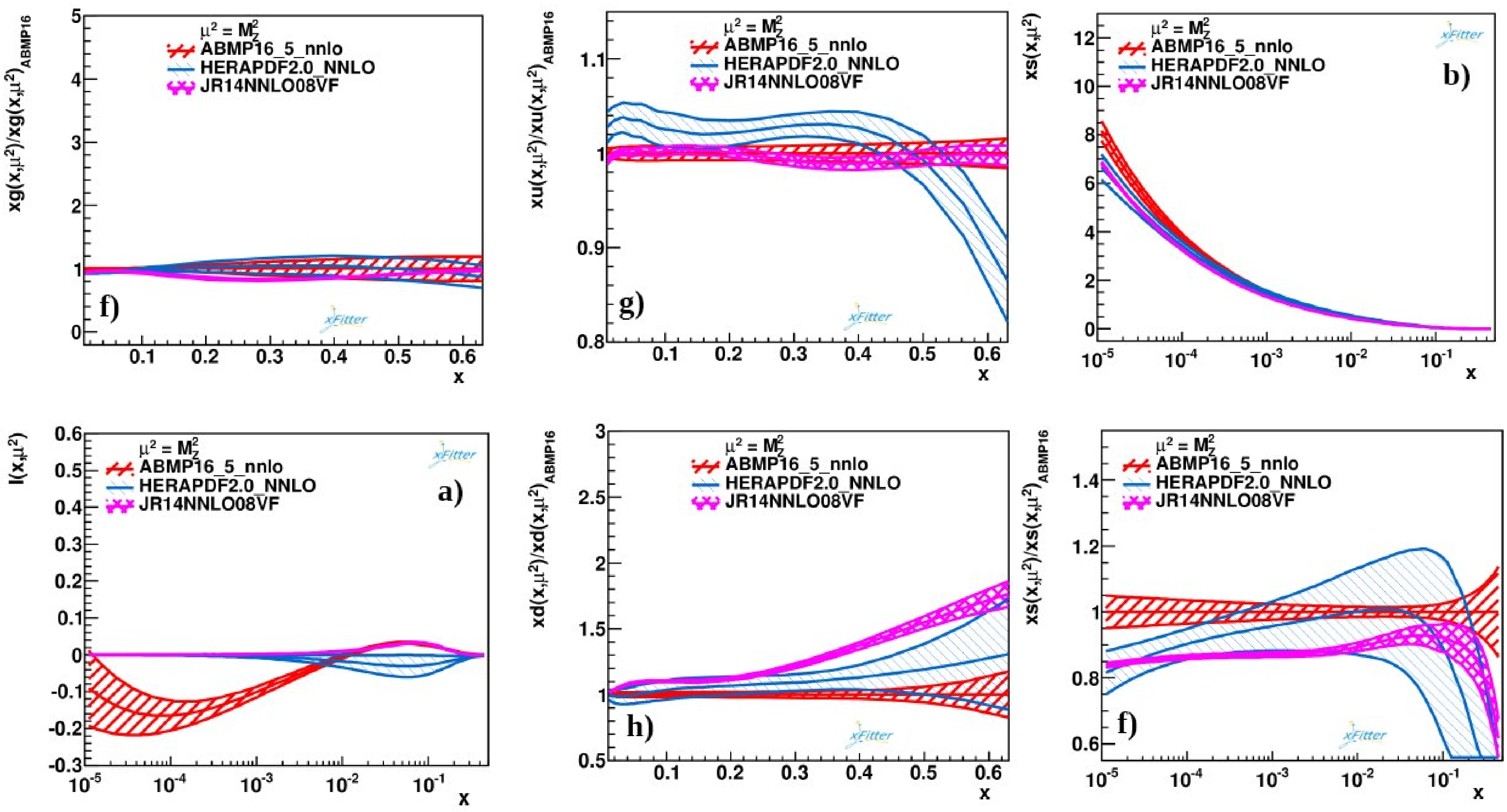
Comparison of ABMP16 with other PDFs



Overall good agreement, smaller uncertainties due to latest data added in ABMP16 fit

→ smaller gluon at low x (compared to other global PDFs)

Comparison of ABMP16 with other PDFs



Overall good agreement, smaller uncertainties due to latest data added in ABMP16 fit

Summary

Thanks to close collaboration and support of **ABM** group, several of the latest theory developments (especially for heavy quarks) are included in **xFitter** package

- new **ABMP16** parton distribution functions (certain cross-checks performed with xFitter)

  arXiv:1701.05838

- interfaces to OPENQCDRAD and HATHOR packages in xFitter

  → both planned to be updated with the new theory interface in the next xFitter release

  → additional options could be added (BMSN, additional evolution in OPENQCDRAD, addition of single-top quark production in HATHOR2.X versions)

Future collaboration and developments strongly depend on the person-power situation

Back-up Slides

Inclusive HERA I+II data

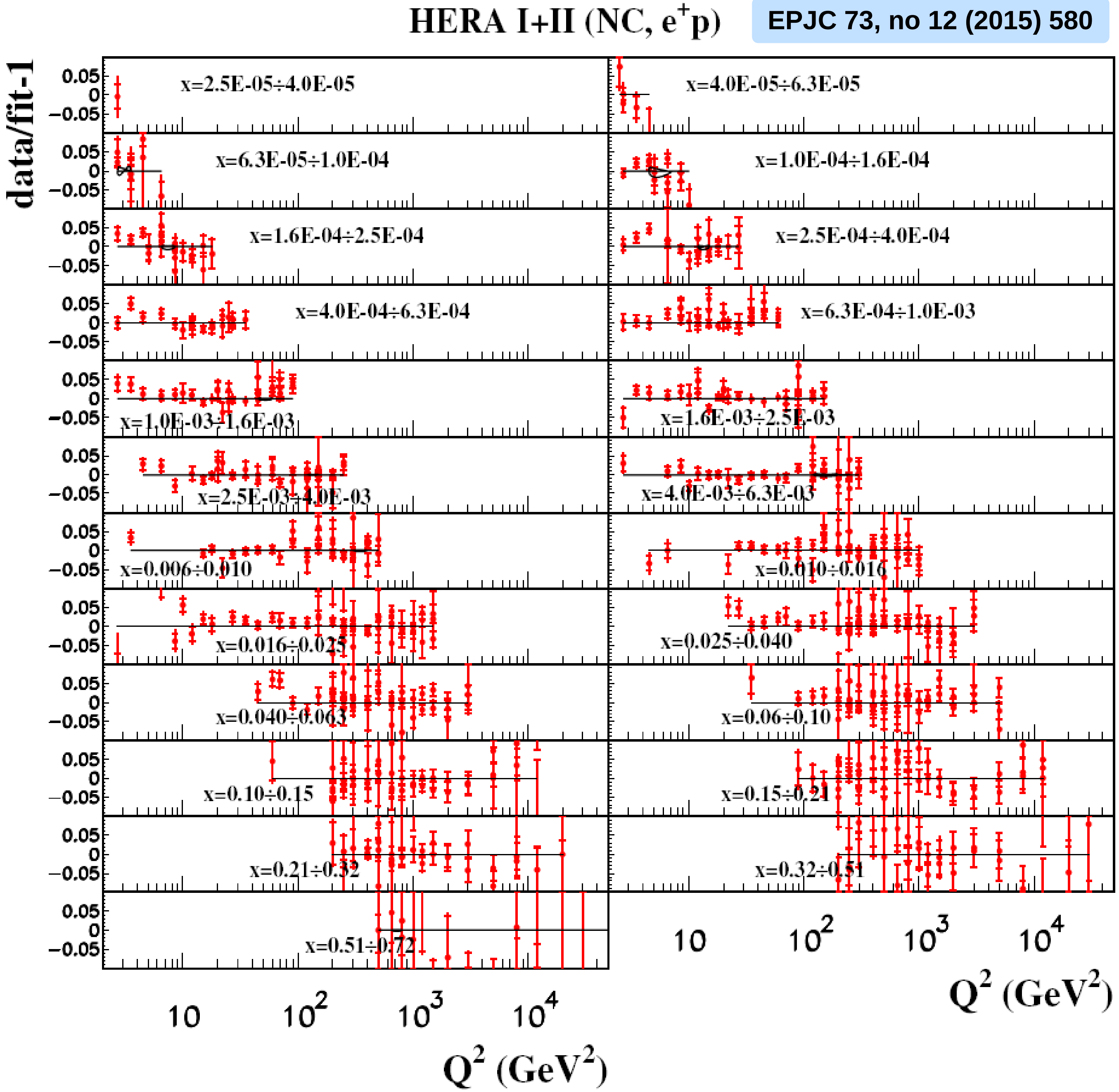
The final HERA I+II combination of inclusive data

→ increased data accuracy, especially in high Q^2 region

→ similar dependence on Q^2_{min} observed:

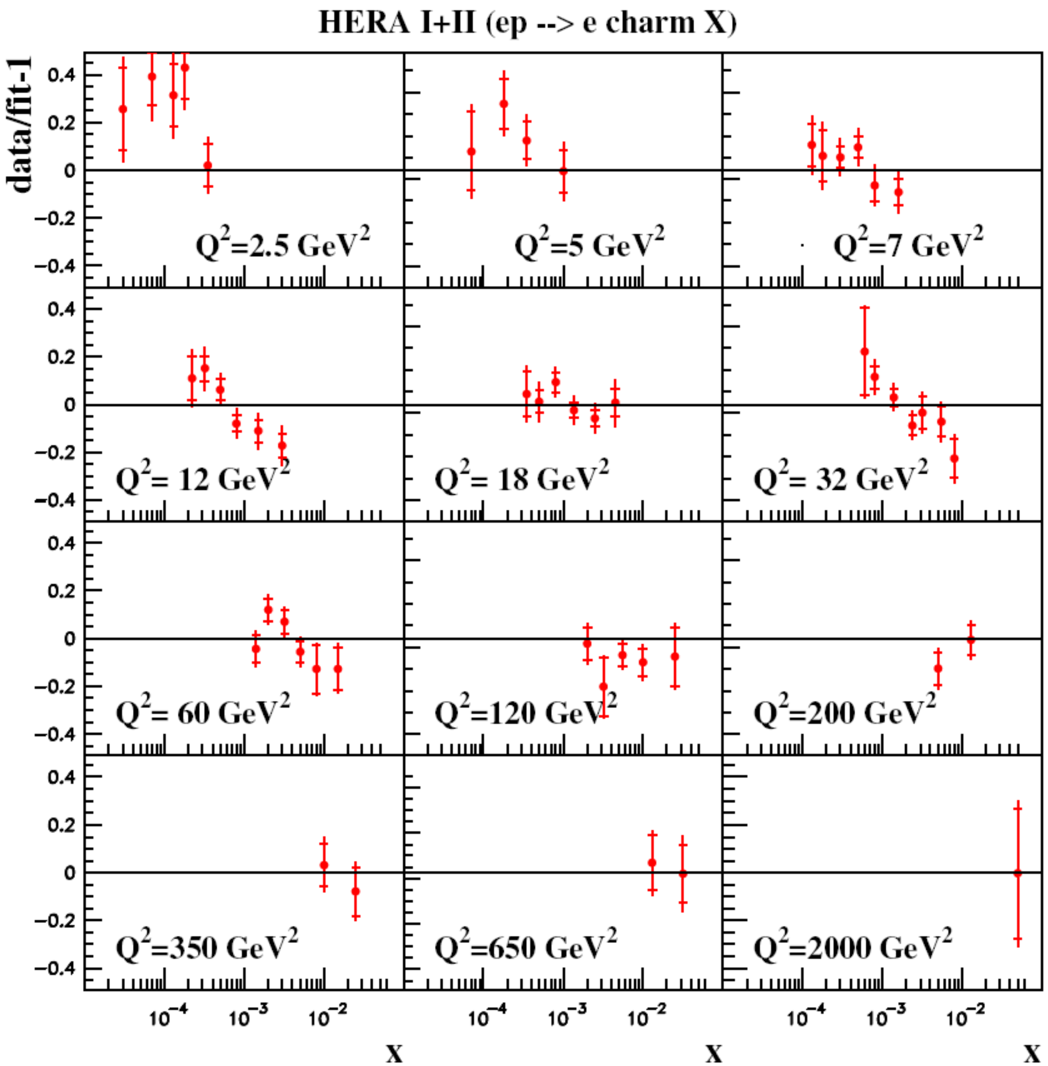
Q^2(HERA)	χ^2/NDP(HERA)
>2.5 GeV²	1509/1168=1.29
>5 GeV²	1354/1092=1.24
>10 GeV²	1228/1007=1.22

EPJC 73, no 12 (2015) 580



HERA Combined Charm Data

EPJC 73, 2311 (2013)



- **ABMP16** includes 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

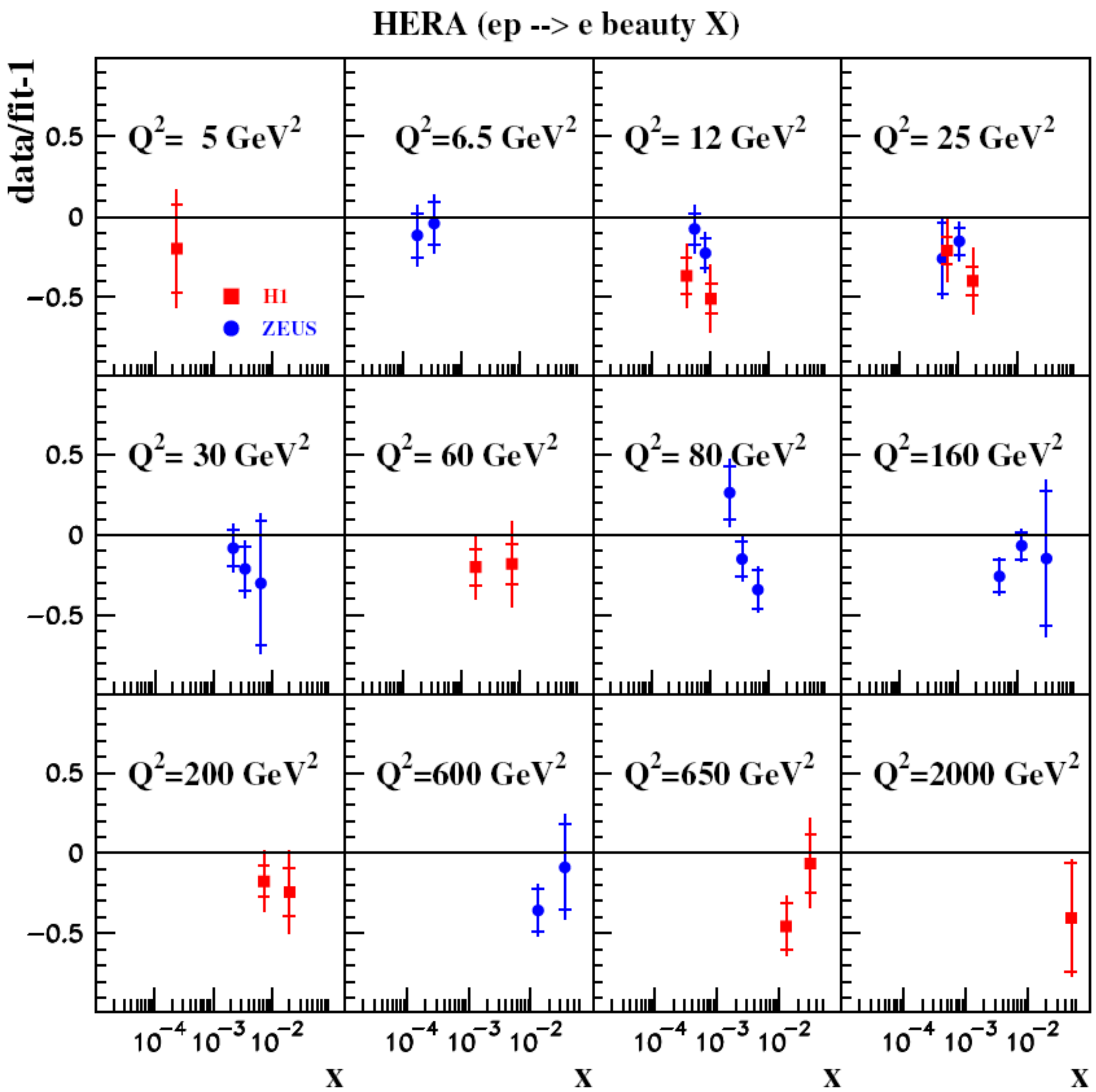
χ^2/NDP=66/52

$m_c(m_c)$=1.252±0.018(exp.)±0.012(th.) GeV ABMP16

$m_c(m_c)$=1.24±0.03(exp.) GeV ABM12

PDG: $m_c(m_c)$=1.275±0.025 GeV

HERA Beauty Data



Similarly to charm, the running-mass definition of m_b used:

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

χ^2/NDP=5/12

ZEUS **JHEP 09, 127 (2014)**

χ^2/NDP=16/17

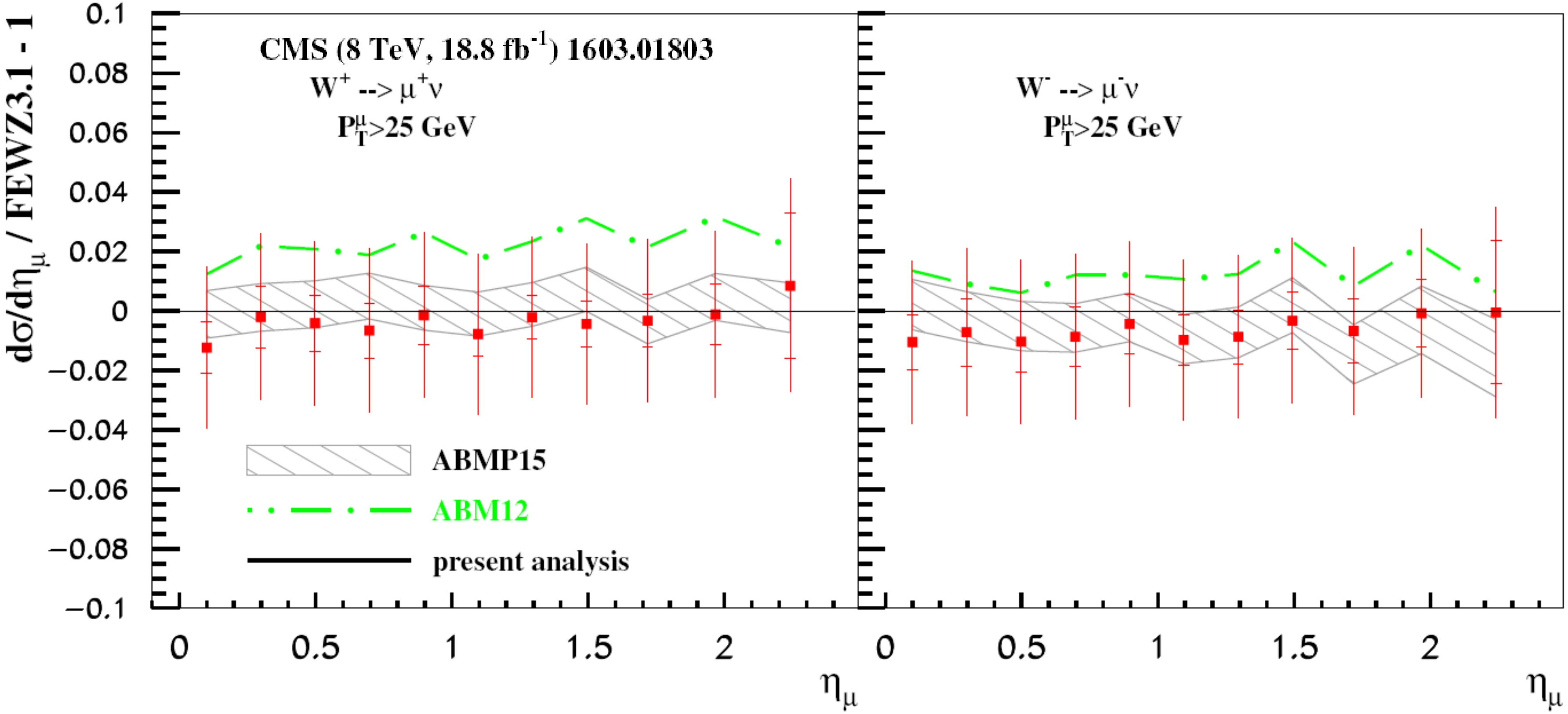
$m_b(m_b)$=3.83±0.12(exp.)±0.12(th.) GeV

ABMP16 Highlights: Drell-Yan data

CMS measurement of the differential W cross section and charge asymmetry at 8 TeV

→ very good description of data, χ^2 = 16.5/22 NDP

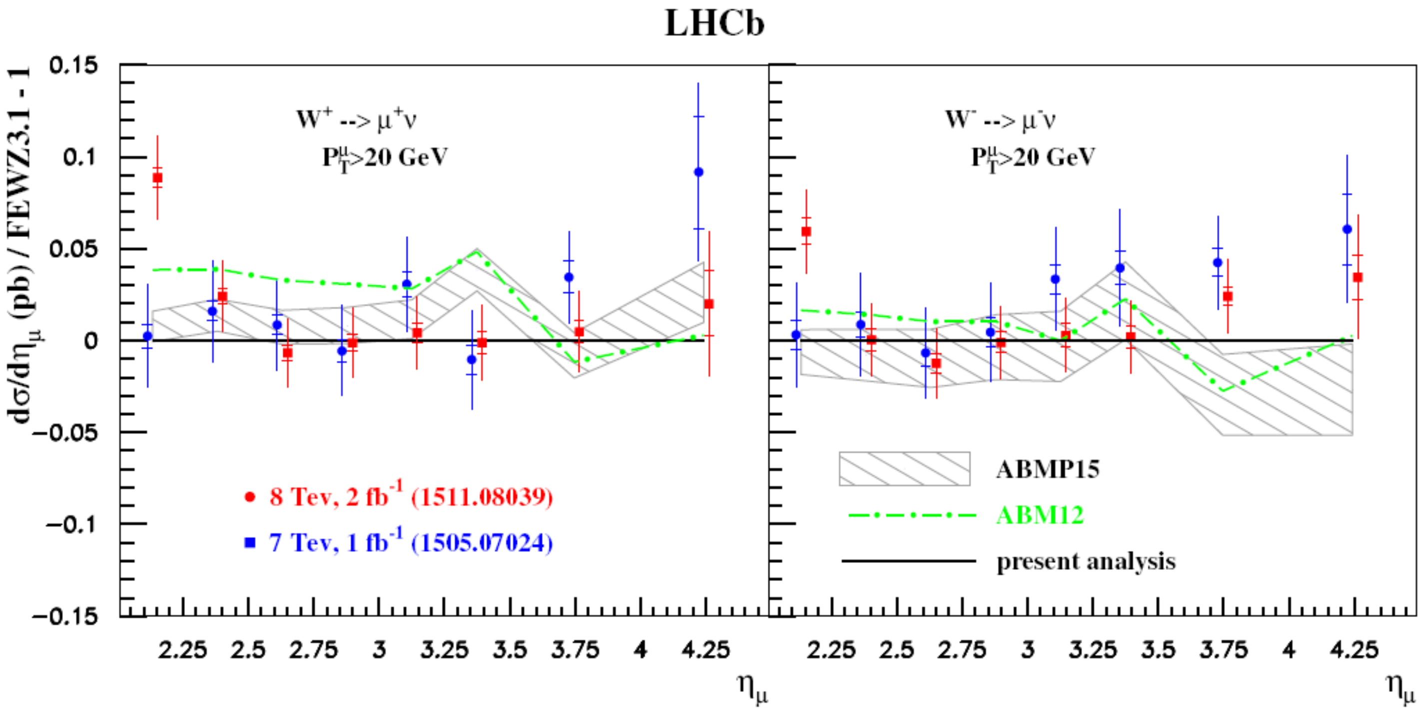
arXiv:1603.01803

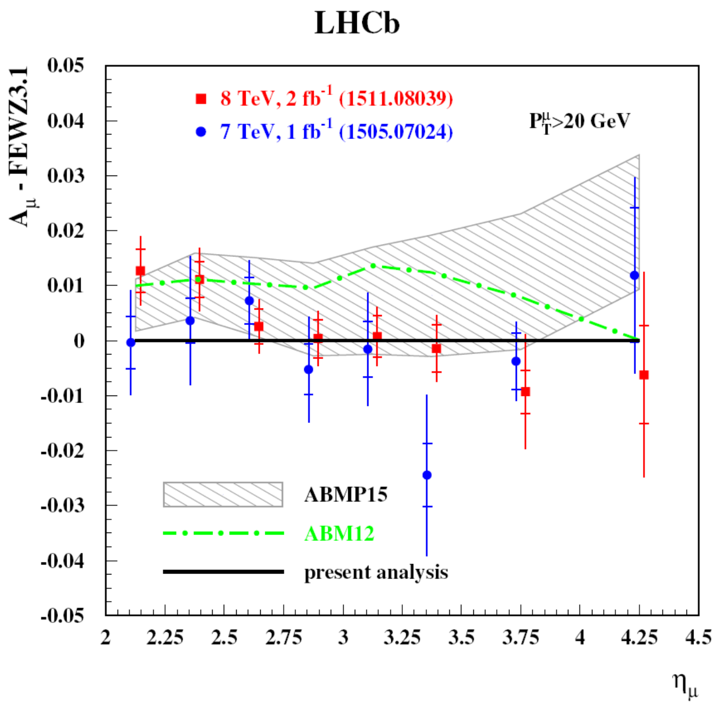


Earlier study and description of CMS W asymmetry data at 7 TeV available in arXiv:1508.07923

LHCb W^+, W^- and Asymmetry Data

LHCb W-boson production and asymmetry data: constraints of PDFs in the low-x region





Some fluctuations observed in the data:

→ LHCb W asymmetry data at 7 TeV: η_μ = 3.275 bin excluded from the fit

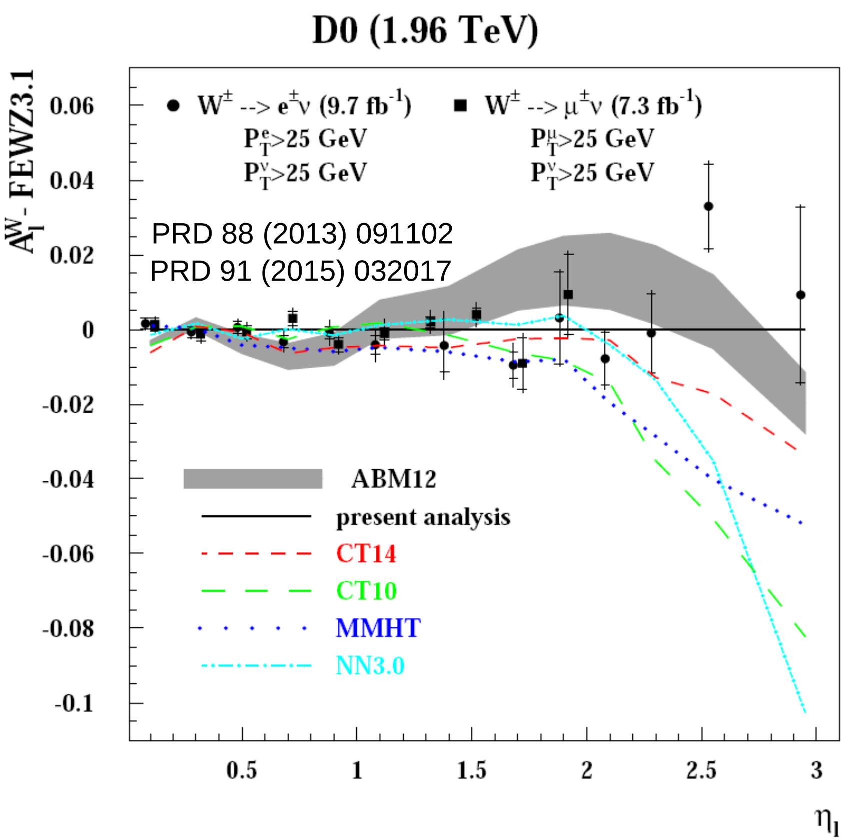
→ for W production data in muon channel point at small η_μ (8 TeV) excluded

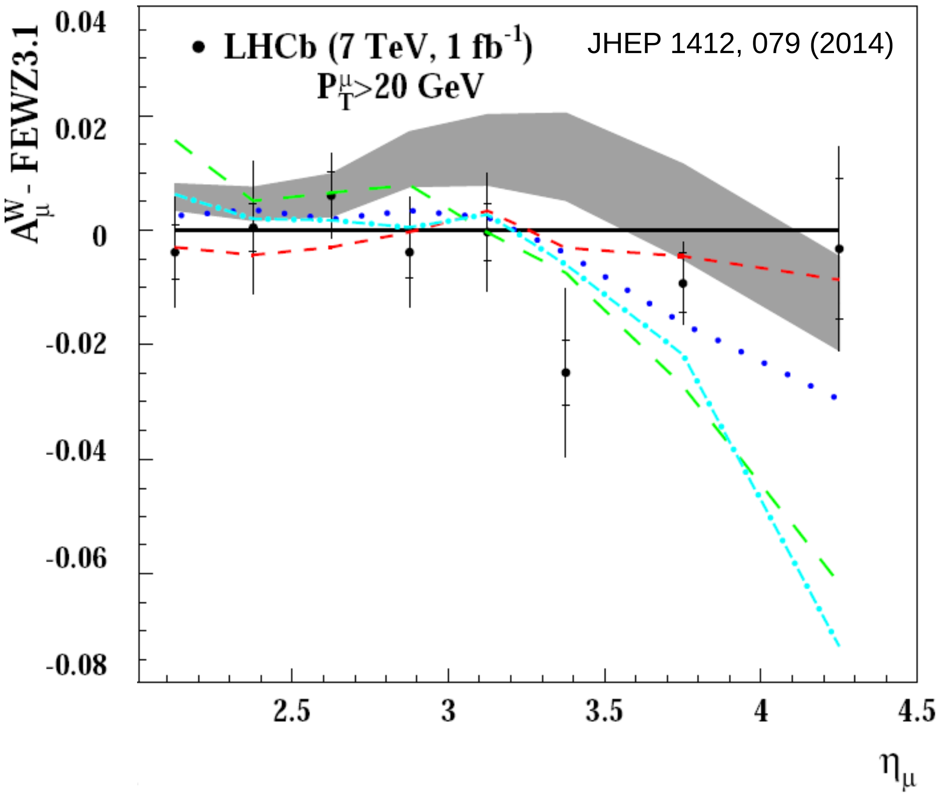
→ LHCb Z electron data at 7 TeV show different trend as compared to the muon ones

→ excluded from the fit until these issues are resolved

→ 13 TeV data are also not yet included (currently larger uncertainties than in earlier sets)

DY Data and Theory Predictions





DY data compared with theory predictions calculated with FEWZ (PRD 094034 (2012), CPC 184, 208 (2013))

→ using interpolation of accurate NNLO grids (similar to FastNLO and Applgrid)

→ other PDF groups often use NLO+NNLO k-factor technique, may cause additional differences

Full study available in **arXiv:1508.07923**

Charm Di-muon Production: NOMAD

In addition to NuTeV and CCFR, a new **NOMAD** (NPB 876, 339 (2013)) data added

→ $\mathcal{R}_{\mu\mu} \equiv \sigma_{\mu\mu}/\sigma_{CC}$ measurement (cancellation of systematics, nuclear corrections)

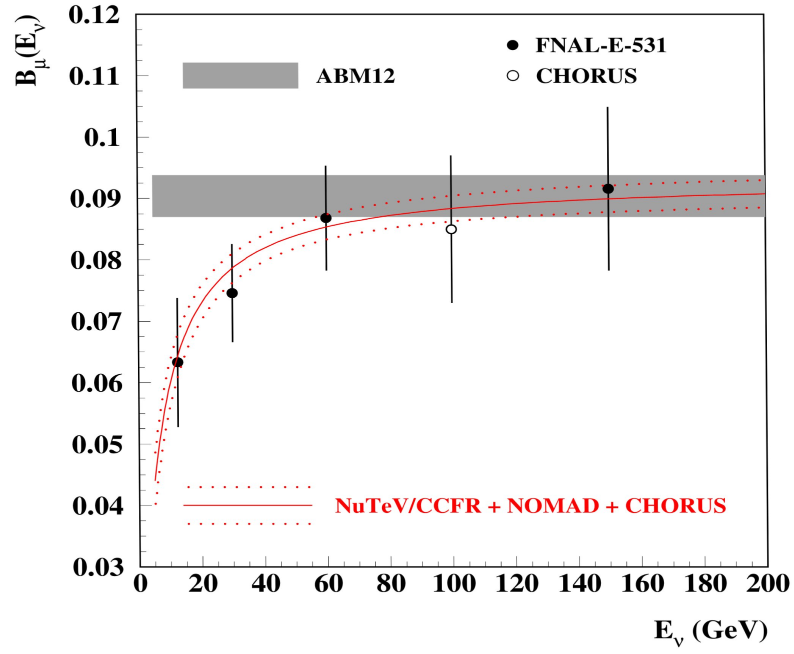
→ extended phase in E_ν = 6 GeV, better sensitivity to charm mass

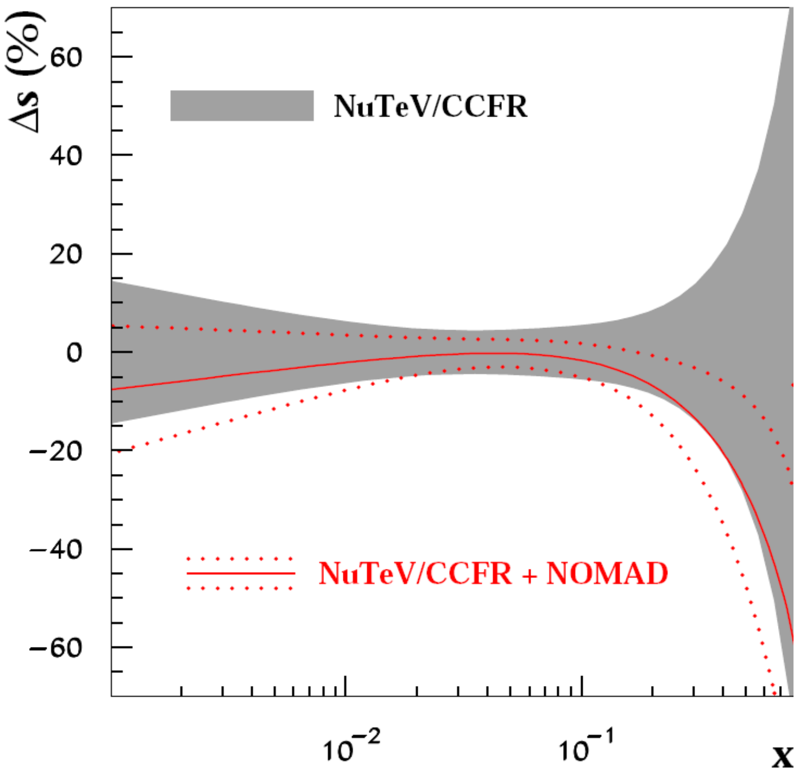
→ dependence on the semi-leptonic branching ratio B_ν:

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

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

PRD 91, no 9 (2015) 094002, arXiv:1404.6469





→ prefers smaller s quark at x>0.1, sizable uncertainty reduction

→ $m_c(m_c)$=1.23±0.03(exp.) GeV is comparable to the previous determination in ABM12

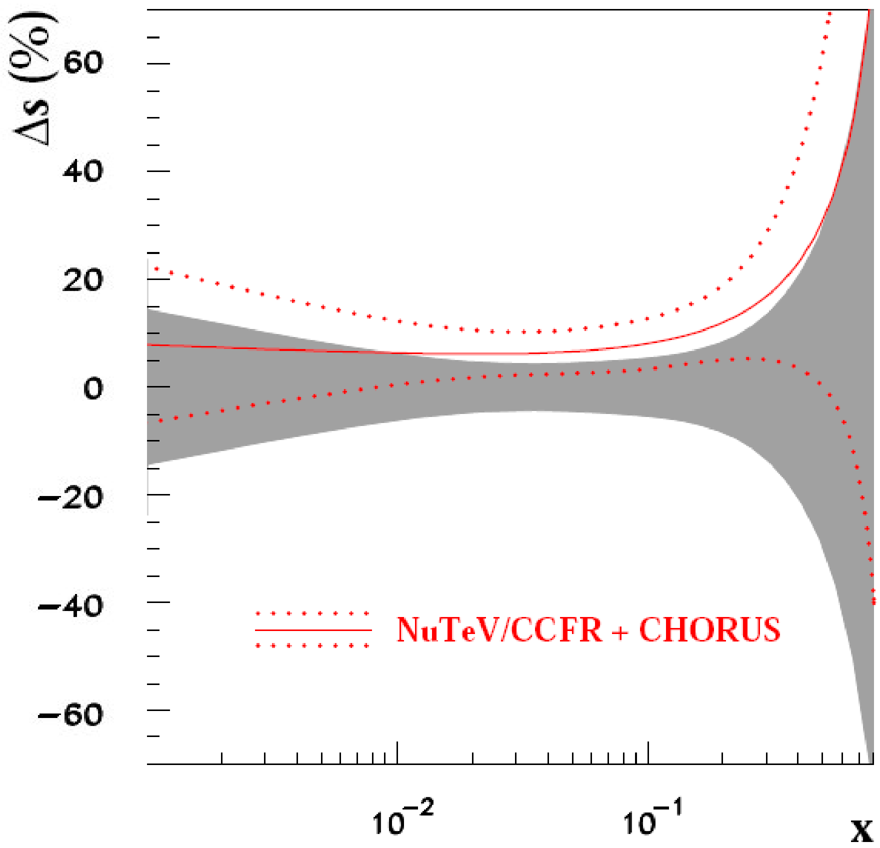
Charm Di-muon Production: CHORUS

Recent **CHORUS** (NJP 13, 093002 (2011)) measurement of $\mathcal{R}_{\mu\mu} \equiv \sigma_{\mu\mu}/\sigma_{CC}$

→ uses nuclear emulsion targets: independence on B_ν

→ lower energy resolution, less statistics

PRD 91, no 9 (2015) 094002, arXiv:1404.6469



→ in contrast to NOMAD, CHORUS prefers enhanced s quark (both measurements are consistent within uncertainties)

→ statistical significance of the effect is small

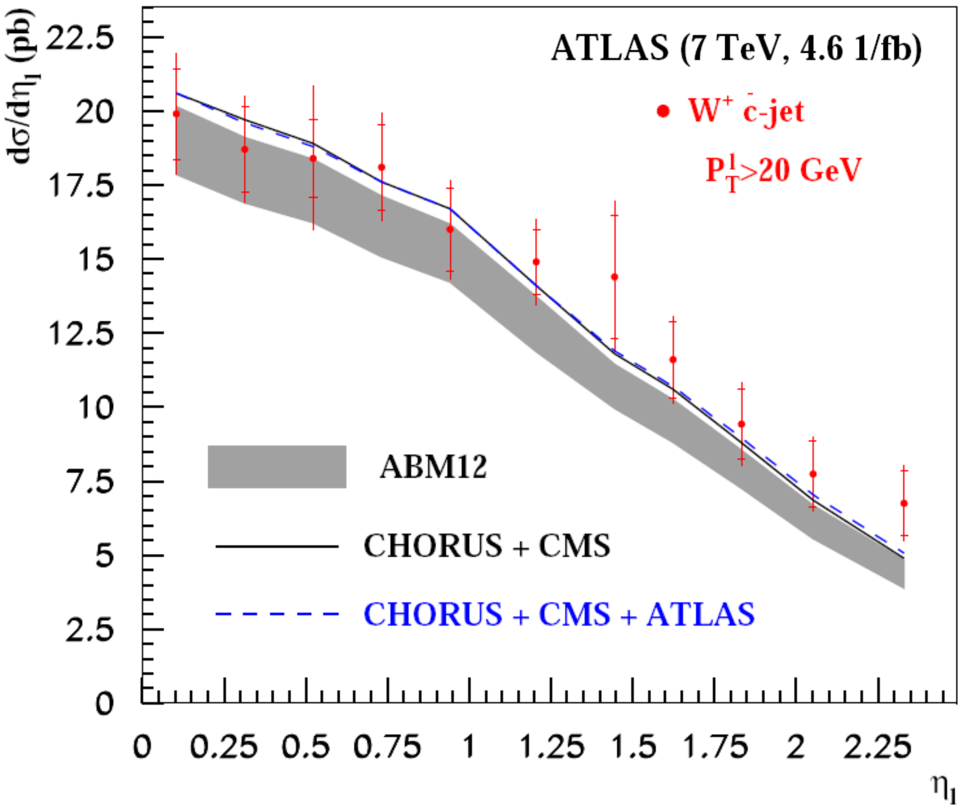
W+charm Data from LHC

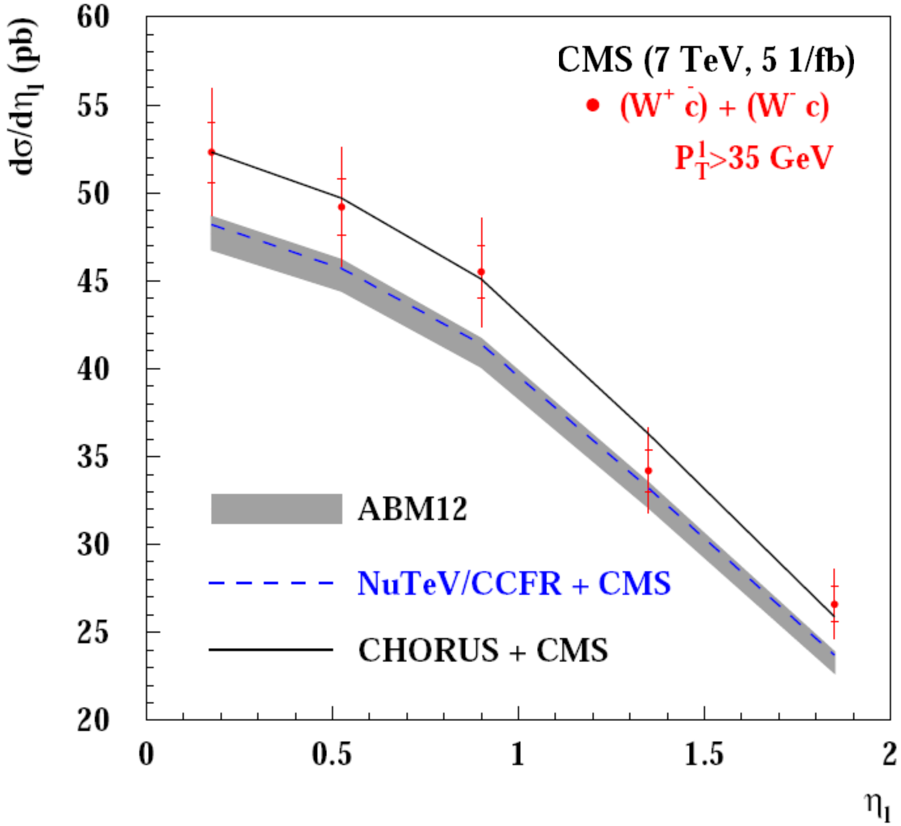
PRD 91, no 9 (2015) 094002, arXiv:1

W+charm production at LHC → direct sensitivity to strange quark

→ corresponding measurements at 7 TeV published by ATLAS and CMS collaborations

JHEP 05 (2014) 068 JHEP 02, 013 (2014)





→ enhances strange sea from ATLAS determination: correlated with d-quark sea suppression

→ CMS data in good agreement with CHORUS data, overall little impact on strange sea

→ due to little impact, both measurements are **not** included in ABMP16 fit

Summary of ABMP16

New **ABMP16** Parton Distribution Functions:

- deuteron data are replaced by the LHC and Tevatron Drell-Yan data
  → 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
- impact of the ttbar data and $\alpha_s(M_Z)$ extraction
- final HERA inclusive I+II data and t-quark data from LHC and Tevatron included
  → improved determination of heavy quark masses:

$$m_c(m_c) = 1.252 \pm 0.018 \text{ GeV}$$
$$m_b(m_b) = 3.83 \pm 0.12 \text{ GeV}$$
$$m_t(m_t) = 160.9 \pm 1.1 \text{ GeV}$$

- New ABMP16 grids (in LHAPDFv6 format) available upon request (soon in LHAPDF hepforge page)

ABMP16_3_NNLO
ABMP16_4_NNLO
ABMP16_5_NNLO

ABMP16 PDFs: Parametrisation

FIT PARAMETRISATION:

$$xq_v(x, Q_0^2) = \frac{2\delta_{qu} + \delta_{qd}}{N_q^v} x^{a_q}(1-x)^{b_q} x^{P_{qv}(x)}$$

$$P_{qv}(x) = \gamma_{1,q} x + \gamma_{2,q} x^2 + \gamma_{3,q} x^3$$

$$xg(x, Q_0^2) = A_g x^{a_g}(1-x)^{b_g} x^{a_g P_g(x)}$$

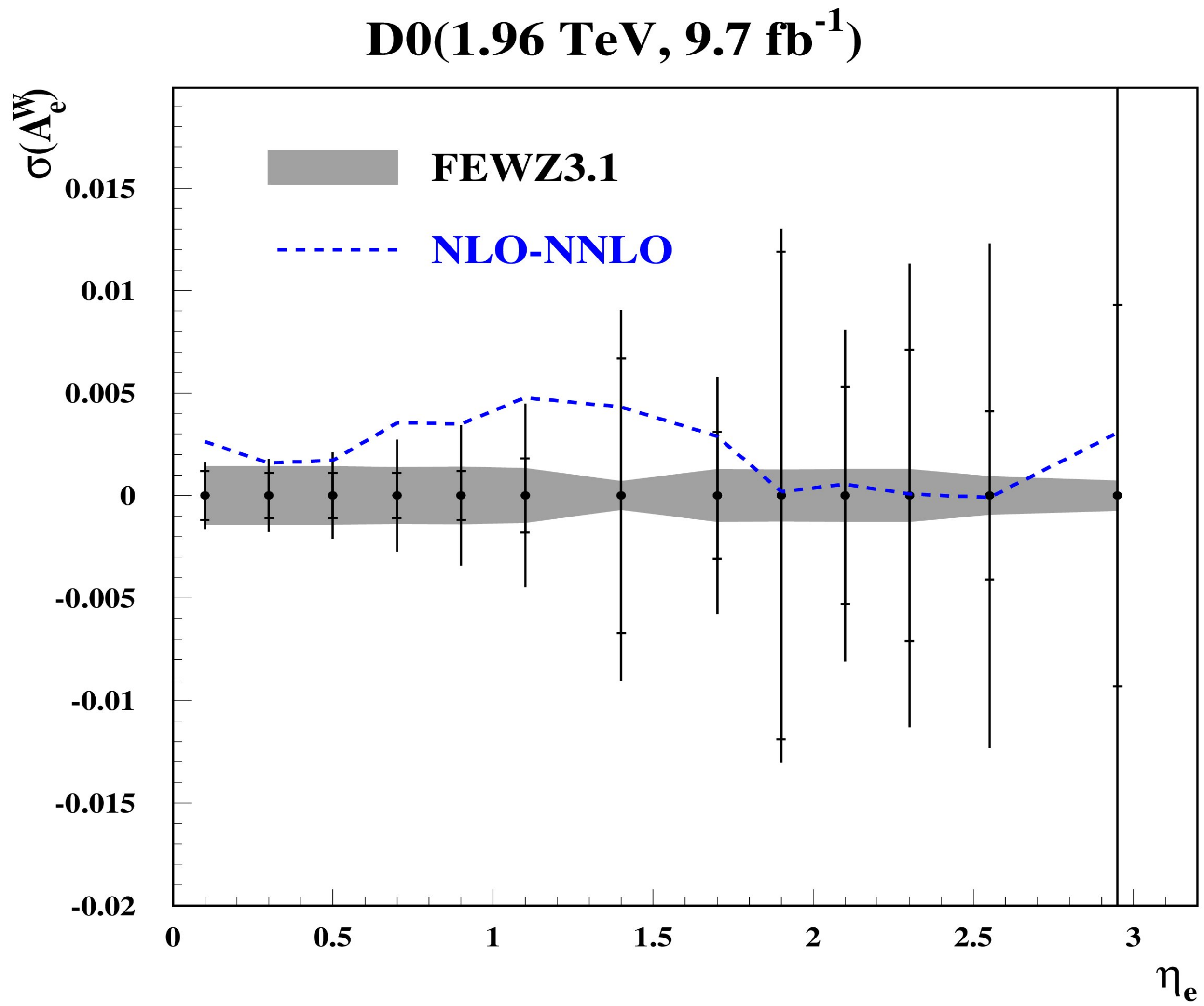
$$P_g(x) = \gamma_{1,g} x$$

$$xq_s(x, \mu_0^2) = \bar{q}_s(x, \mu_0^2) = A_{qs}(1-x)^{b_{qs}} x^{a_{qs} P_{qs}(x)}$$

$$q = u, d, s, \qquad P_{qs}(x) = (1 + \gamma_{-1,qs} \ln x)(1 + \gamma_{1,qs} x)$$

allows non-zero values of the sea isospin asymmetry: $I(x) = x[\bar{d}(x) - \bar{u}(x)]$

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

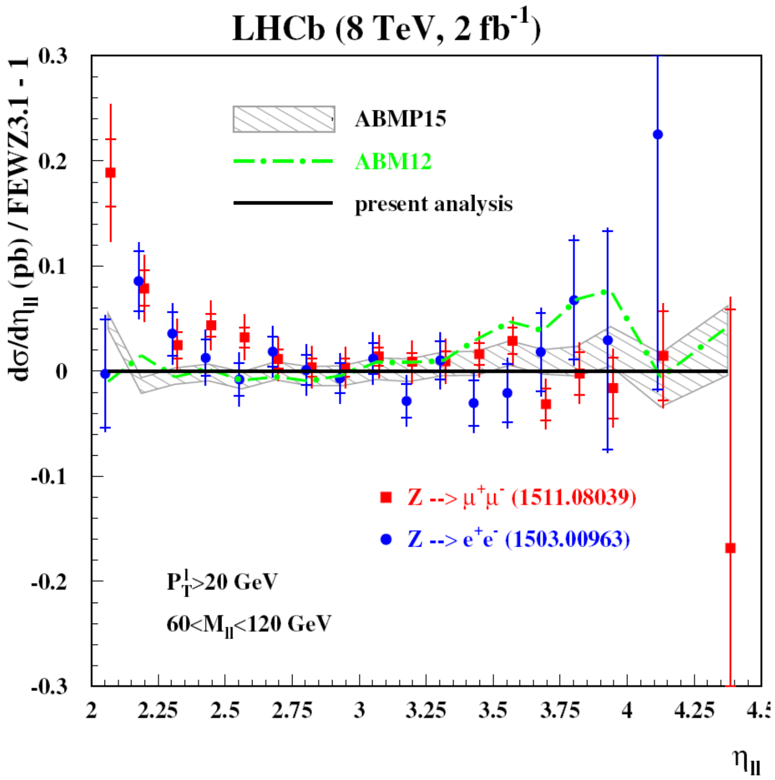
The general PDF basis is not necessary since the PDFs are already constrained by the data, which do not require involved computations → *use as a PDF basis the eigenvalue PDF sets obtained in the earlier version of the fit*

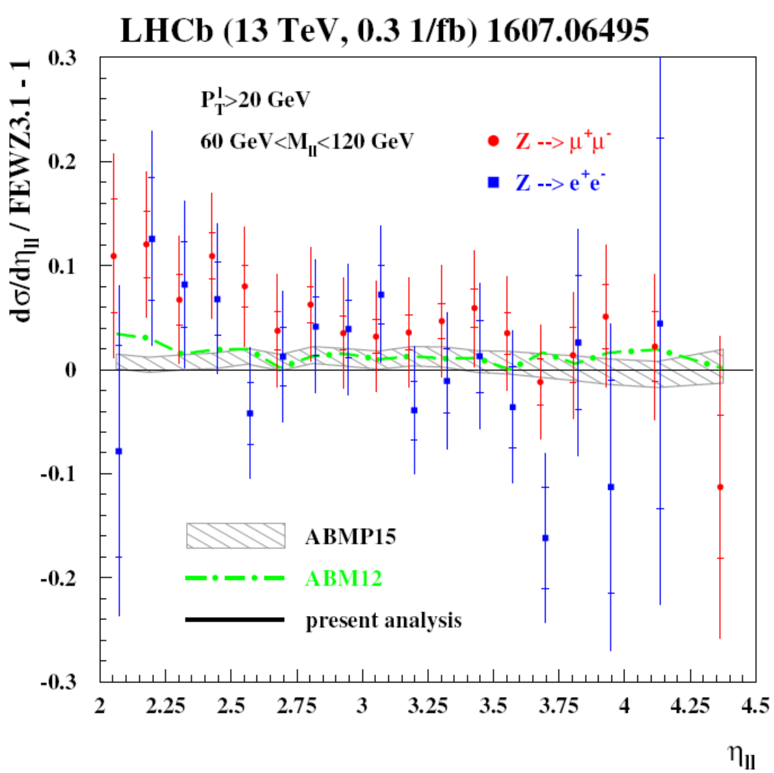
$\mathbf{P_0} \pm \Delta\mathbf{P}_0$ – vector of PDF parameters with errors obtained in the earlier fit
E – error matrix
P – current value of the PDF parameters in the fit

- 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

LHCb W^+, W^- Production Data

LHCb Z-boson production data: constraints of PDFs in the low-x region



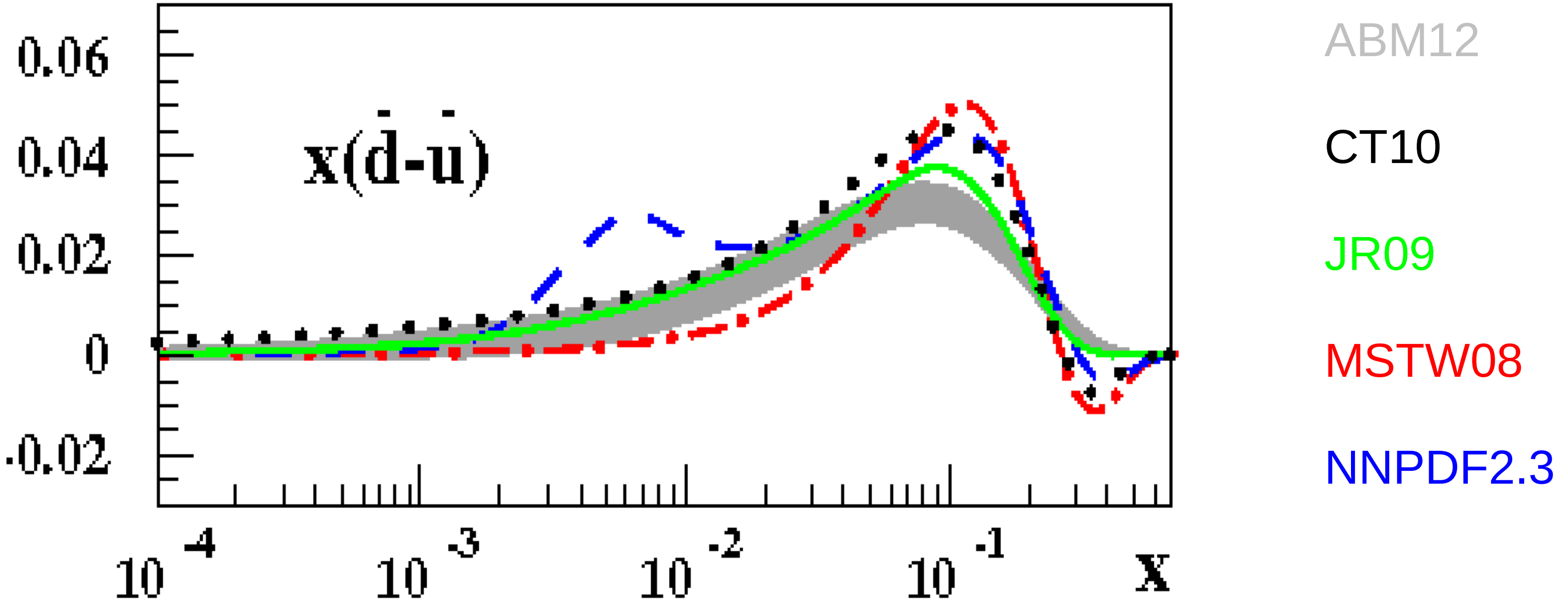


→ LHCb Z electron data at 7 TeV show different trend as compared to the muon ones

→ excluded from the fit until these issues are resolved

→ 13 TeV data are also not yet included (currently larger uncertainties than in earlier sets)

Sea 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

Comparison with other PDFs: d-u