Parton Distribution Functions, α_s and Heavy-Quark Masses for LHC Run II

Sven-Olaf Moch

Universität Hamburg

LHC Physics Discussion, DESY, Hamburg, June 12, 2017

Based on work done in collaboration with:

- *Parton Distribution Functions, α_s and Heavy-Quark Masses for LHC Run II*
  S. Alekhin, J. Blümlein, S. M. and R. Plačakytė arXiv:1701.05838

- *A Critical Appraisal and Evaluation of Modern PDFs*
  A. Accardi, S. Alekhin, J. Blümlein, M.V. Garzelli, K. Lipka, W. Melnitchouk, S. M., J.F. Owens, R. Plačakytė, E. Reya, N. Sato, A. Vogt and O. Zenaiev arXiv:1603.08906

- *Iso-spin asymmetry of quark distributions and implications for single top-quark production at the LHC*
  S. Alekhin, J. Blümlein, S. M. and R. Plačakytė arXiv:1508.07923

- *Determination of Strange Sea Quark Distributions from Fixed-target and Collider Data*
  S. Alekhin, J. Blümlein, L. Caminada, K. Lipka, K. Lohwasser, S. M., R. Petti, and R. Plačakytė arXiv:1404.6469

- Many more papers of ABM and friends . . .
  2008 - ...

PDF landscape

- Significant number of active groups ABMP16, CJ15, CT14, HERAPDF2.0, JR14, MMHT14, NNPDF3.1
  - PDFs accurate to NNLO in QCD, except for CJ15 (NLO)
  - different choices of data sets
  - different fitting procedures ($\Delta\chi^2$ criterium)

PDF sets	$\Delta\chi^2$ criterion	data sets used in analysis
ABMP16 arXiv:1701.05838	1	incl. DIS, DIS charm, DY, $t\bar{t}$, single t
CJ15 arXiv:1602.03154	1	incl. DIS, DY (incl. $p\bar{p} \to W^{\pm}X$), $p\bar{p}$ jets, γ+jet
CT14 arXiv:1506.07443	100	incl. DIS, DIS charm, DY, $p\bar{p}$ jets, pp jets
HERAPDF2.0 arXiv:1506.06042	1	incl. DIS, DIS charm, DIS jets
JR14 arXiv:1403.1852	1	incl. DIS, DIS charm, DY, $p\bar{p}$ jets, DIS jets
MMHT14 arXiv:1510.02332	$2.3 \ldots 42.3$ (dynamical)	incl. DIS, DIS charm, DY, $p\bar{p}$ jets, pp jets, $t\bar{t}$
NNPDF3.1 arXiv:1706.00428	n.a.	incl. DIS, DIS charm, DY, $p\bar{p}$ jets, pp jets, $t\bar{t}$, $W +$ charm, $Z p_T$

Recommendations (I)

PDF4LHC recommendations for LHC Run II

- Recommendations by CT14, MMHT14, NNPDF3.0
- PDFs averaged in set PDF4LHC15
  - to be used for Higgs cross sections, in seaches,
    for PDF uncertainties and for Monte Carlo simulations

PDF4LHC recommendations for LHC Run II

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Abstract:

Recommendations (II)

Recommendations for PDF usage in LHC predictions

- Shortcomings in PDF4LHC recommendations addressed
- Recommendations by ABMP16, CJ15, HERAPDF2.0, JR14

Recommendations for PDF usage in LHC predictions

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Recommendations (II)

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- Recommendations by ABMP16, CJ15, HERAPDF2.0, JR14

(i) Precision theory predictions

Recommendation: Use the individual PDF sets ABMP16, CJ15, CT14, HERAPDF2.0, JR14, MMHT14, NNPDF3.0 (or as many as possible), together with the respective uncertainties for the chosen PDF set, the strong coupling $\alpha_s(M_Z)$ and the heavy quark masses m_c, m_b and m_t.

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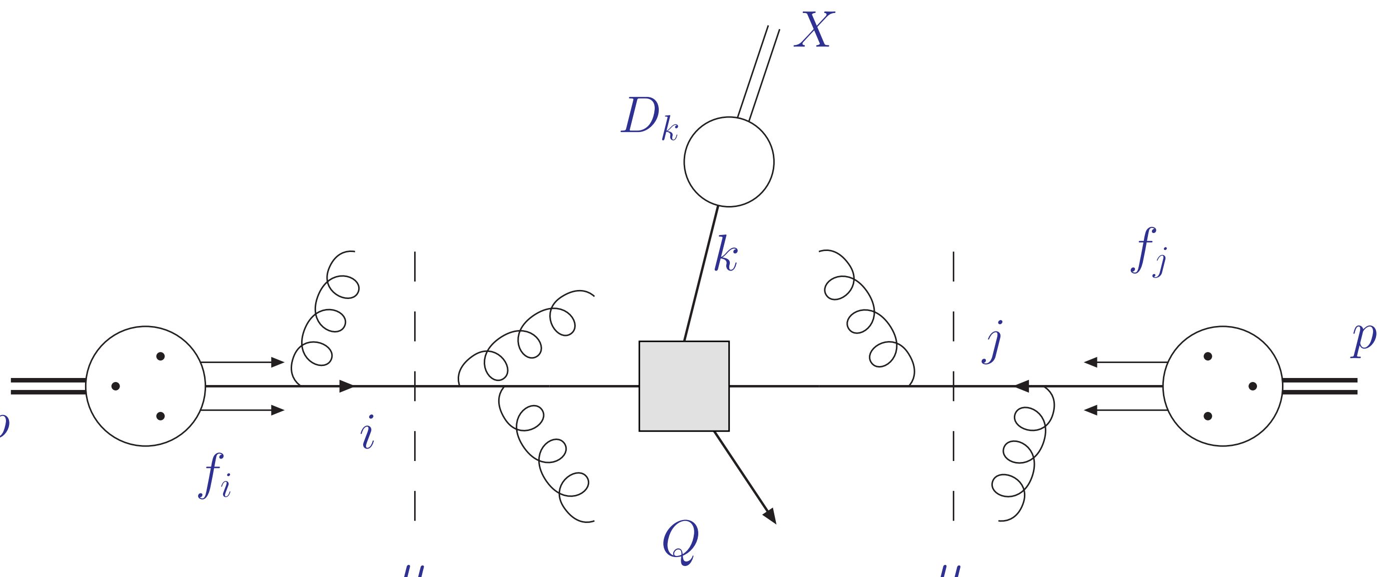
(ii) Other theory predictions

Recommendation: Use any one of the PDF sets listed in LHAPDF(v6).

QCD factorization



$$\sigma_{pp\to X} = \sum_{ij} f_i(\mu^2) \otimes f_j(\mu^2) \otimes \hat{\sigma}_{ij\to X}\left(\alpha_s(\mu^2), Q^2, \mu^2, m_X^2\right)$$

- Factorization at scale μ
  - separation of sensitivity to dynamics from long and short distances
- Hard parton cross section $\hat{\sigma}_{ij\to X}$ calculable in perturbation theory
  - cross section $\hat{\sigma}_{ij\to k}$ for parton types i, j and hadronic final state X
- Parton distribution functions f_i, strong coupling α_s, particle masses m_X
  - known from global fits to exp. data, lattice computations, . . .

The ABMP16 PDF fit

Data sets considered in ABMP16 analysis

- Analysis of world data for deep-inelastic scattering and fixed-target data for Drell-Yan process
  - inclusive DIS data HERA, BCDMS, NMC, SLAC ($NDP = 2155$)
  - DIS heavy-quark production data HERA, CCFR, Chorus, NOMAD, NuTeV ($NDP = 313$)
  - Drell-Yan data (fixed target) E-605, E-866 ($NDP = 158$)
  - Tevatron & LHC data for $W^{\pm}$- and Z-boson production D0, ATLAS, CMS, LHCb ($NDP = 172$)
  - Top-quark production D0, ATLAS, CMS, LHCb ($NDP = 36$)

Iterative cycle of PDF fits

i) check of compatibility of new data set with available world data

ii) study of potential constraints due to addition of new data set to fit

iii) perform high precision measurement of parton distributions, strong coupling $\alpha_s(M_Z)$ and heavy quark masses

Theory considerations in PDF fits

Theory considerations in ABMP16

- Strictly NNLO QCD for determination of PDFs and α_s
- Consistent scheme for treatment of heavy quarks
  - $\overline{\mathrm{MS}}$-scheme for quark masses and α_s
  - fixed-flavor number scheme for $n_f = 3, 4, 5$
- Consistent theory description for consistent data sets
  - low scale DIS data with account of higher twist
- Full account of error correlations

Interplay with perturbation theory

- Accuracy of determination driven by precision of theory predictions
- PDF parameters, α_s, m_c, m_b and m_t sensitive to
  - radiative corrections at higher orders
  - chosen scheme (e.g. ($\overline{MS}$ scheme)
  - renormalization and factorization scales μ_R, μ_F
  - ...

ABMP16 PDF ansatz

- PDFs parameterization at scale $\mu_0 = 3\mathrm{GeV}$ in scheme with $n_f = 3$
  Alekhin, Blümlein, S.M., Placakyte ‘17
  - ansatz for valence-/sea-quarks, gluon

$$
\begin{aligned}
xq_v(x,\mu_0^2) &= \frac{2\delta_{qu}+\delta_{qd}}{N_q^v}(1-x)^{b_q} x^{a_q P_{qv}(x)} \\
xq_s(x,\mu_0^2) &= x\bar{q}_s(x,\mu_0^2) \;=\; A_{qs}(1-x)^{b_{qs}} x^{a_{qs} P_{qs}(x)} \\
xg(x,\mu_0^2) &= A_g(1-x)^{b_g} x^{a_g\, P_g(x)}
\end{aligned}
$$

  - strange quark is taken in charge-symmetric form
  - function $P_p(x)$

$$
P_p(x) \;=\; (1+\gamma_{-1,p}\ln x)\left(1+\gamma_{1,p}x+\gamma_{2,p}x^2+\gamma_{3,p}x^3\right)\;,
$$

  - 29 parameters in fit including $\alpha_s^{(n_f=3)}(\mu_0 = 3$ GeV), m_c, m_b and m_t
  - simultaneous fit of higher twist parameters (twist-4)
- Ansatz provides sufficient flexibility; no additional terms required to improve the quality of fit

Quality of fit

Statistical tests

- Goodness-of-fit estimator
  - χ^2 values compared to number of data points (typically a few thousand in global fit)

Covariance matrix

- Positive-definite covariance matrix
  - correlations for fit parameters of ABMP16 PDFs

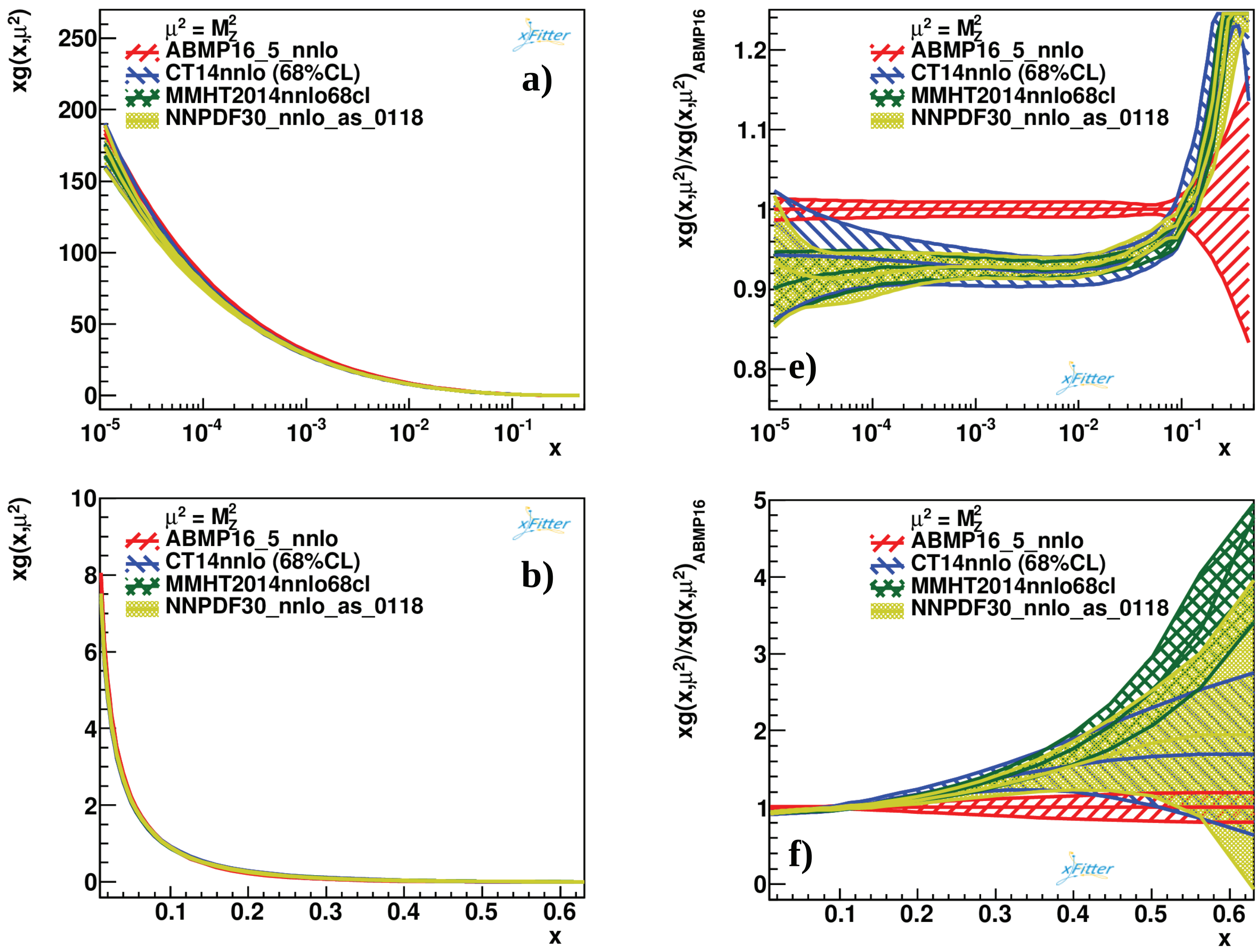
	a_u	b_u	$\gamma_{1,u}$	$\gamma_{2,u}$	$\gamma_{3,u}$	a_d	b_d	$\gamma_{1,d}$	$\gamma_{2,d}$	$\gamma_{3,d}$
a_u	1.0	0.7617	0.9372	-0.5078	0.4839	0.4069	0.3591	0.4344	-0.3475	0.0001
b_u	0.7617	1.0	0.6124	-0.1533	-0.0346	0.3596	0.2958	0.3748	-0.2748	0.0001
$\gamma_{1,u}$	0.9372	0.6124	1.0	-0.7526	0.7154	0.2231	0.2441	0.2812	-0.2606	0.0001
$\gamma_{2,u}$	-0.5078	-0.1533	-0.7526	1.0	-0.9409	0.2779	0.2276	0.2266	-0.1860	0.0
$\gamma_{3,u}$	0.4839	-0.0346	0.7154	-0.9409	1.0	-0.1738	-0.1829	-0.1327	0.1488	0.0
a_d	0.4069	0.3596	0.2231	0.2779	-0.1738	1.0	0.7209	0.9697	-0.6529	0.0001
b_d	0.3591	0.2958	0.2441	0.2276	-0.1829	0.7209	1.0	0.7681	-0.9786	-0.0001
$\gamma_{1,d}$	0.4344	0.3748	0.2812	0.2266	-0.1327	0.9697	0.7681	1.0	-0.7454	0.0002
$\gamma_{2,d}$	-0.3475	-0.2748	-0.2606	-0.1860	0.1488	-0.6529	-0.9786	-0.7454	1.0	-0.0002
$\gamma_{3,d}$	0.0001	0.0001	0.0001	0.0	0.0	0.0001	-0.0001	0.0002	-0.0002	1.0
a_{us}	-0.0683	-0.0081	-0.2094	0.3881	-0.3206	0.2266	0.1502	0.2000	-0.1293	0.0
b_{us}	-0.3508	-0.3089	-0.3462	0.0906	-0.0537	-0.1045	-0.2000	-0.2241	0.2798	0.0
$\gamma_{-1,us}$	0.2296	0.1387	0.3367	-0.4043	0.3474	-0.1171	-0.1127	-0.0810	0.0767	0.0
$\gamma_{1,us}$	-0.4853	-0.4119	-0.3844	-0.0365	0.0064	-0.4380	-0.3592	-0.4957	0.3771	-0.0001
A_{us}	0.0506	0.0807	-0.0949	0.3198	-0.2560	0.2527	0.1648	0.2350	-0.1509	0.0
a_{ds}	-0.0759	-0.0443	-0.0951	0.0263	-0.0382	-0.2565	-0.2541	-0.2666	0.2380	0.0
b_{bs}	0.0452	-0.0197	0.0345	-0.0589	0.0683	-0.2084	0.0190	-0.1841	-0.0522	0.0
$\gamma_{1,ds}$	-0.0492	-0.0809	0.0101	-0.1791	0.1309	-0.5576	-0.2029	-0.4584	0.0946	0.0
A_{ds}	-0.1980	-0.1262	-0.2349	0.1526	-0.1428	-0.1113	-0.2167	-0.1739	0.2407	0.0
a_{ss}	-0.2034	-0.1285	-0.2362	0.2328	-0.2080	0.0960	0.1596	0.0661	-0.1054	0.0
b_{ss}	-0.1186	-0.0480	-0.1532	0.1549	-0.1536	0.0486	0.1508	0.0267	-0.1161	0.0
A_{ss}	-0.1013	-0.0411	-0.1458	0.1802	-0.1625	0.1216	0.1678	0.0924	-0.1196	0.0
a_g	0.0046	-0.0374	0.1109	-0.1934	0.1653	-0.0288	-0.0122	0.0053	0.0059	0.0
b_g	0.2662	0.3141	0.1579	-0.0050	-0.0207	0.0973	0.0870	0.0646	-0.0666	0.0
$\gamma_{1,g}$	0.2008	0.2274	0.0706	0.0876	-0.0835	0.0919	0.0574	0.0493	-0.0364	0.0
$\alpha_s^{(n_f=3)}(\mu_0)$	0.1083	-0.0607	0.0848	-0.0250	0.0765	0.0763	-0.0306	0.0725	0.0243	0.0
$m_c(m_c)$	-0.0006	0.0170	-0.0104	0.0206	-0.0201	-0.0123	-0.0161	-0.0114	0.0108	0.0
$m_b(m_b)$	0.0661	0.0554	0.0605	-0.0367	0.0287	-0.0116	0.0029	-0.0074	-0.0051	0.0
$m_t(m_t)$	-0.1339	-0.2170	-0.0816	0.0081	0.0250	-0.0616	-0.0813	-0.0491	0.0736	0.0

	a_{us}	b_{us}	$\gamma_{-1,us}$	$\gamma_{1,us}$	A_{us}	a_{ds}	b_{bs}	$\gamma_{1,ds}$	A_{ds}	a_{ss}
a_u	-0.0683	-0.3508	0.2296	-0.4853	0.0506	-0.0759	0.0452	-0.0492	-0.1980	-0.2034
b_u	-0.0081	-0.3089	0.1387	-0.4119	0.0807	-0.0443	-0.0197	-0.0809	-0.1262	-0.1285
$\gamma_{1,u}$	-0.2094	-0.3462	0.3367	-0.3844	-0.0949	-0.0951	0.0345	0.0101	-0.2349	-0.2362
$\gamma_{2,u}$	0.3881	0.0906	-0.4043	-0.0365	0.3198	0.0263	-0.0589	-0.1791	0.1526	0.2328
$\gamma_{3,u}$	-0.3206	-0.0537	0.3474	0.0064	-0.2560	-0.0382	0.0683	0.1309	-0.1428	-0.2080
a_d	0.2266	-0.1045	-0.1171	-0.4380	0.2527	-0.2565	-0.2084	-0.5576	-0.1113	0.0960
b_d	0.1502	-0.2000	-0.1127	-0.3592	0.1648	-0.2541	0.0190	-0.2029	-0.2167	0.1596
$\gamma_{1,d}$	0.2000	-0.2241	-0.0810	-0.4957	0.2350	-0.2666	-0.1841	-0.4584	-0.1739	0.0661
$\gamma_{2,d}$	-0.1293	0.2798	0.0767	0.3771	-0.1509	0.2380	-0.0522	0.0946	0.2407	-0.1054
$\gamma_{3,d}$	0.0	0.0	0.0	-0.0001	0.0	0.0	0.0	0.0	0.0	0.0
a_{us}	1.0	-0.3156	-0.8947	-0.5310	0.9719	0.2849	0.0241	-0.0470	0.2983	0.4131
b_{us}	-0.3156	1.0	0.1372	0.8258	-0.3995	0.0467	-0.0221	-0.1190	0.1856	0.0291
$\gamma_{-1,us}$	-0.8947	0.1372	1.0	0.2611	-0.7829	-0.1695	0.0156	0.0501	-0.2117	-0.7191
$\gamma_{1,us}$	-0.5310	0.8258	0.2611	1.0	-0.6479	0.0086	0.0076	0.1460	0.0781	-0.0010
A_{us}	0.9719	-0.3995	-0.7829	-0.6479	1.0	0.2983	0.0515	-0.0404	0.3055	0.2811
a_{ds}	0.2849	0.0467	-0.1695	0.0086	0.2983	1.0	-0.1608	0.0719	0.9152	-0.2941
b_{bs}	0.0241	-0.0221	0.0156	0.0076	0.0515	-0.1608	1.0	0.7834	-0.3022	-0.0390
$\gamma_{1,ds}$	-0.0470	-0.1190	0.0501	0.1460	-0.0404	0.0719	0.7834	1.0	-0.1838	-0.1373
A_{ds}	0.2983	0.1856	-0.2117	0.0781	0.3055	0.9152	-0.3022	-0.1838	1.0	-0.1833
a_{ss}	0.4131	0.0291	-0.7191	-0.0010	0.2811	-0.2941	-0.0390	-0.1373	-0.1833	1.0
b_{ss}	0.2197	0.0643	-0.4479	0.1286	0.1193	-0.1579	-0.0260	0.0169	-0.0896	0.6522
A_{ss}	0.3627	0.0261	-0.6319	0.0102	0.2412	-0.2688	-0.0180	-0.0960	-0.1797	0.9280
a_g	-0.2570	0.0001	0.2196	0.0039	-0.2493	-0.2190	-0.0454	-0.1031	-0.2571	0.0626
b_g	-0.1419	0.1266	0.0694	0.2648	-0.1715	-0.0515	0.0917	0.2130	-0.0469	-0.0092
$\gamma_{1,g}$	-0.0241	0.0332	-0.0226	0.1296	-0.0489	-0.0137	0.0503	0.1409	0.0022	-0.0279
$\alpha_s^{(n_f=3)}(\mu_0)$	0.0954	-0.2866	-0.0341	-0.3493	0.1110	-0.0604	-0.1265	-0.1811	-0.1330	-0.0841
$m_c(m_c)$	0.0704	-0.0093	-0.0033	-0.0462	0.1182	0.0849	0.0547	0.0413	0.1193	-0.0728
$m_b(m_b)$	-0.0183	-0.0132	0.0044	0.0209	-0.0298	-0.0006	0.0332	0.0695	-0.0432	-0.0159
$m_t(m_t)$	0.0641	-0.1841	-0.0408	-0.2635	0.0755	-0.0573	-0.1067	-0.2003	-0.0869	0.0169

	b_{ss}	A_{ss}	a_g	b_g	$\gamma_{1,g}$	$\alpha_s^{(n_f=3)}(\mu_0)$	$m_c(m_c)$	$m_b(m_b)$	$m_t(m_t)$
a_u	-0.1186	-0.1013	0.0046	0.2662	0.2008	0.1083	-0.0006	0.0661	-0.1339
b_u	-0.0480	-0.0411	-0.0374	0.3141	0.2274	-0.0607	0.0170	0.0554	-0.2170
$\gamma_{1,u}$	-0.1532	-0.1458	0.1109	0.1579	0.0706	0.0848	-0.0104	0.0605	-0.0816
$\gamma_{2,u}$	0.1549	0.1802	-0.1934	-0.0050	0.0876	-0.0250	0.0206	-0.0367	0.0081
$\gamma_{3,u}$	-0.1536	-0.1625	0.1653	-0.0207	-0.0835	0.0765	-0.0201	0.0287	0.0250
a_d	0.0486	0.1216	-0.0288	0.0973	0.0919	0.0763	-0.0123	-0.0116	-0.0616
b_d	0.1508	0.1678	-0.0122	0.0870	0.0574	-0.0306	-0.0161	0.0029	-0.0813
$\gamma_{1,d}$	0.0267	0.0924	0.0053	0.0646	0.0493	0.0725	-0.0114	-0.0074	-0.0491
$\gamma_{2,d}$	-0.1161	-0.1196	0.0059	-0.0666	-0.0364	0.0243	0.0108	-0.0051	0.0736
$\gamma_{3,d}$	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
a_{us}	0.2197	0.3627	-0.2570	-0.1419	-0.0241	0.0954	0.0704	-0.0183	0.0641
b_{us}	0.0643	0.0261	0.0001	0.1266	0.0332	-0.2866	-0.0093	-0.0132	-0.1841
$\gamma_{-1,us}$	-0.4479	-0.6319	0.2197	0.0694	-0.0226	-0.0341	-0.0034	0.0044	-0.0408
$\gamma_{1,us}$	0.1286	0.0102	0.0039	0.2648	0.1296	-0.3493	-0.0462	0.0209	-0.2635
A_{us}	0.1193	0.2412	-0.2493	-0.1715	-0.0489	0.1110	0.1182	-0.0298	0.0755
a_{ds}	-0.1579	-0.2688	-0.2190	-0.0515	-0.0137	-0.0604	0.0849	-0.0006	-0.0573
b_{bs}	-0.0260	-0.0180	-0.0454	0.0917	0.0503	-0.1265	0.0547	0.0332	-0.1067
$\gamma_{1,ds}$	0.0169	-0.0960	-0.1031	0.2130	0.1409	-0.1811	0.0413	0.0695	-0.2003
A_{ds}	-0.0896	-0.1797	-0.2571	-0.0469	0.0022	-0.1330	0.1193	-0.0432	-0.0869
a_{ss}	0.6522	0.9280	0.0626	-0.0092	-0.0279	-0.0841	-0.0728	-0.0159	0.0169
b_{ss}	1.0	0.6427	-0.0179	0.1967	0.1164	-0.2390	-0.0965	0.0169	-0.1675
A_{ss}	0.6427	1.0	-0.0211	0.1403	0.0997	-0.1385	0.0216	0.0072	-0.1109
a_g	-0.0179	-0.0211	1.0	-0.5279	-0.8046	0.1838	-0.2829	0.0076	0.3310
b_g	0.1967	0.1403	-0.5279	1.0	0.8837	-0.5124	0.1438	0.1255	-0.7275
$\gamma_{1,g}$	0.1164	0.0997	-0.8046	0.8837	1.0	-0.2511	0.1829	0.0814	-0.5180
$\alpha_s^{(n_f=3)}(\mu_0)$	-0.2390	-0.1385	0.1838	-0.5124	-0.2511	1.0	-0.1048	0.0423	0.6924
$m_c(m_c)$	-0.0965	0.0216	-0.2829	0.1438	0.1829	-0.1048	1.0	0.0328	-0.1577
$m_b(m_b)$	0.0169	0.0072	0.0076	0.1255	0.0814	0.0423	0.0328	1.0	-0.0900
$m_t(m_t)$	-0.1675	-0.1109	0.3310	-0.7275	-0.5180	0.6924	-0.1577	-0.0900	1.0

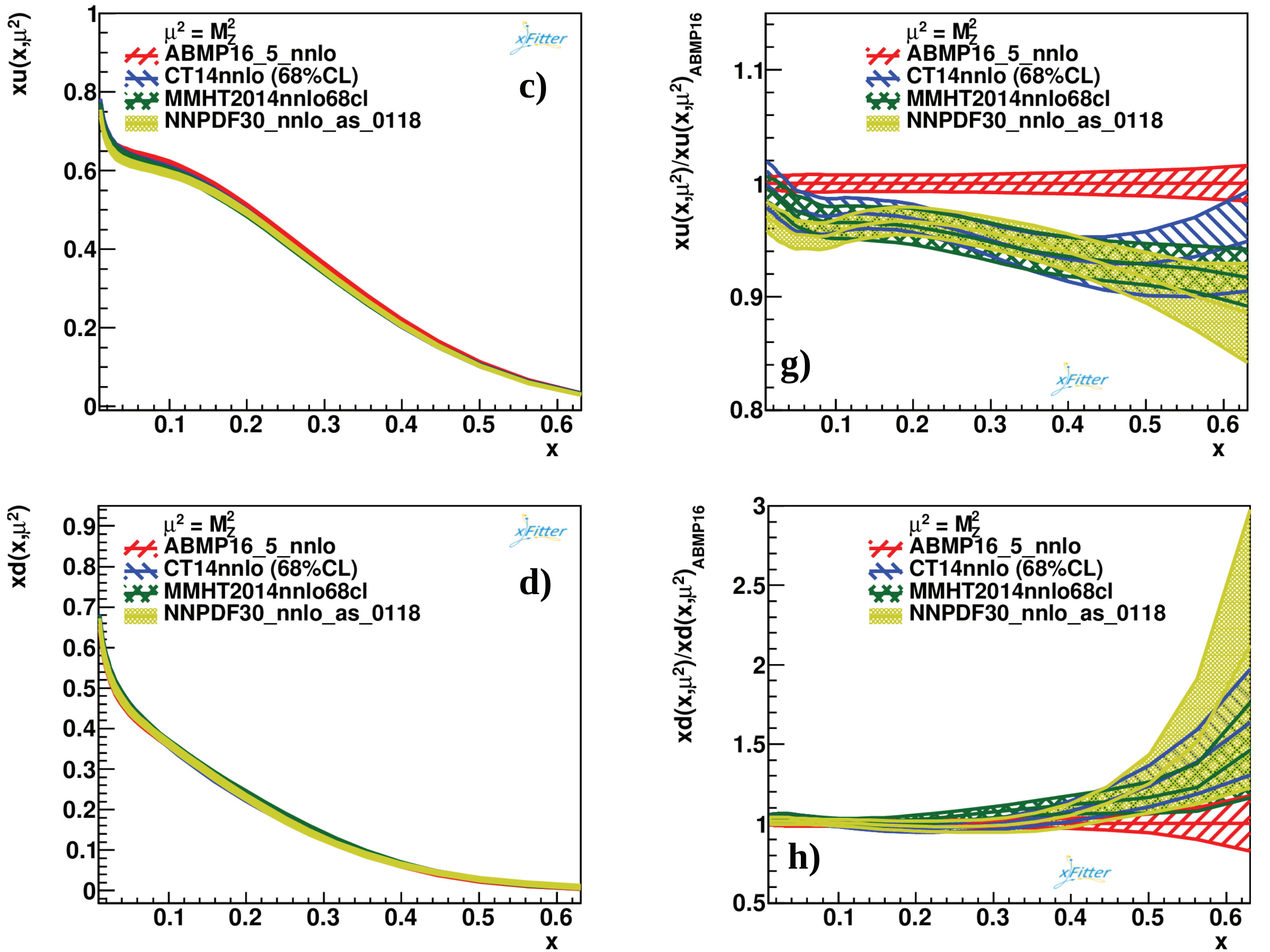
Results for parton distributions (I)

- PDFs with 1σ uncertainty bands; compare ABMP16, CT14, MMHT14 NNPDF3.0
- Gluon $g(x)$



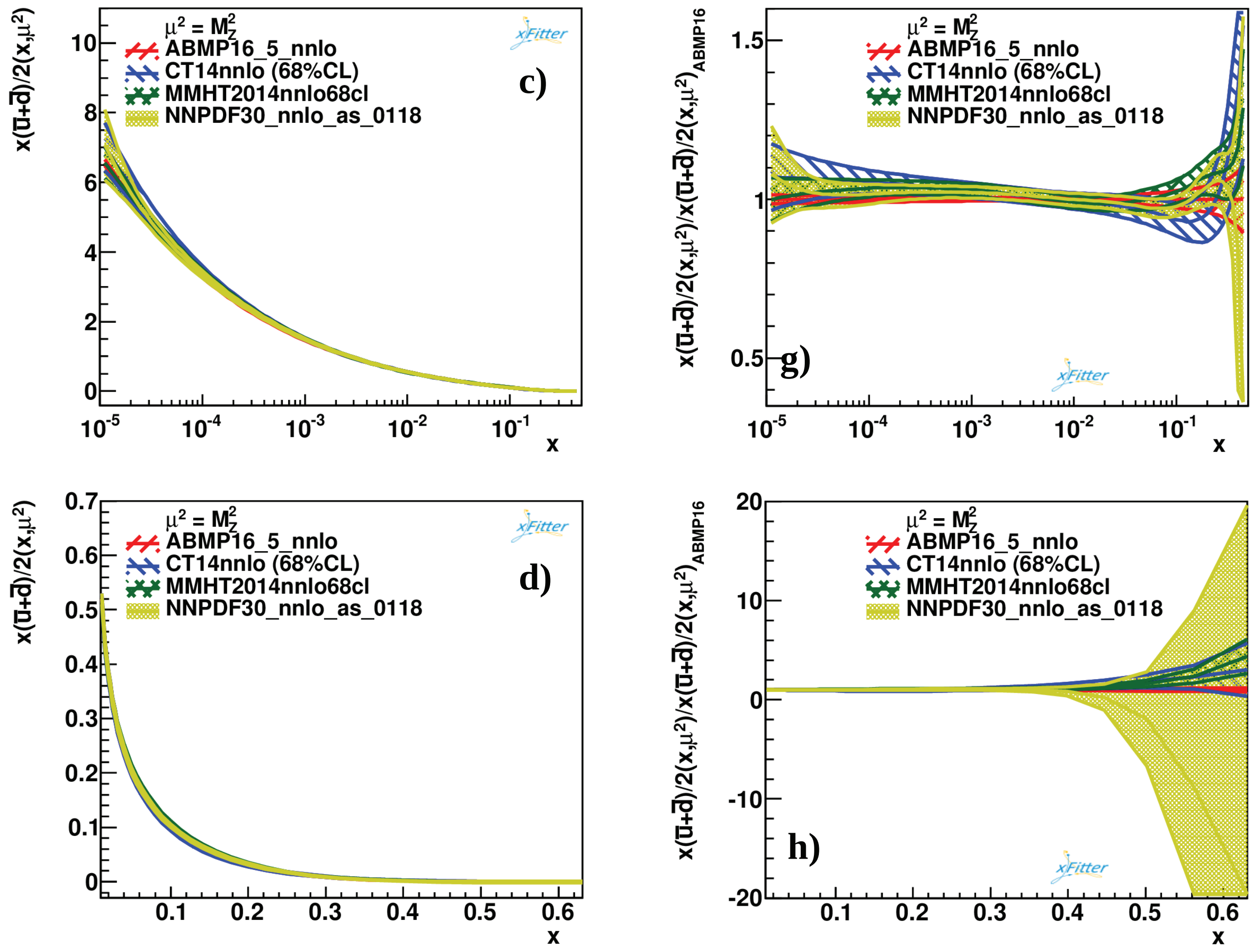
Results for parton distributions (II)

- PDFs with 1σ uncertainty bands; compare ABMP16, CT14, MMHT14 NNPDF3.0
- Light valence quarks $u(x)$, $d(x)$



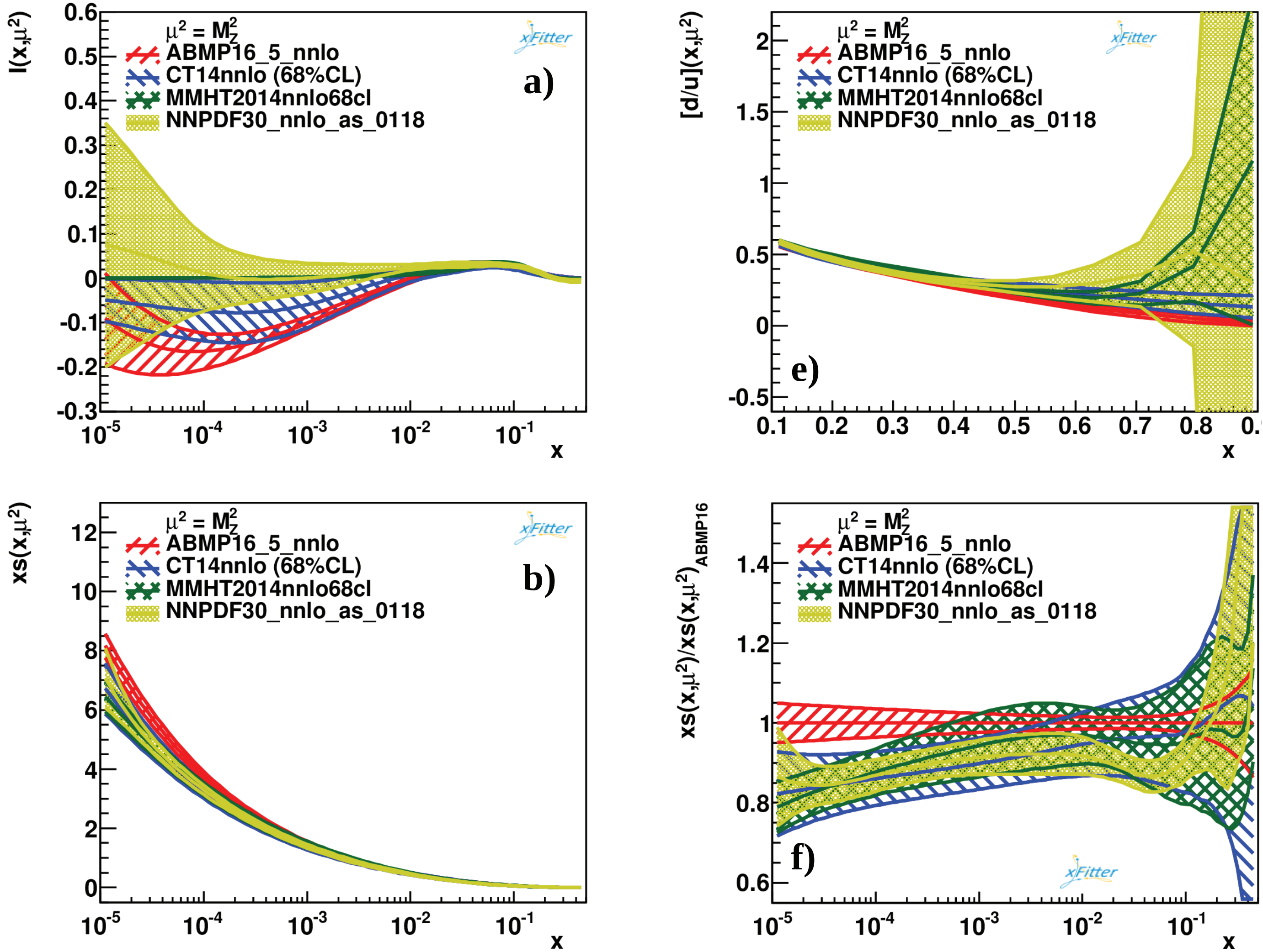
Results for parton distributions (III)

- PDFs with 1σ uncertainty bands; compare ABMP16, CT14, MMHT14 NNPDF3.0
- Sea quarks $\bar{u}(x) + \bar{d}(x)$



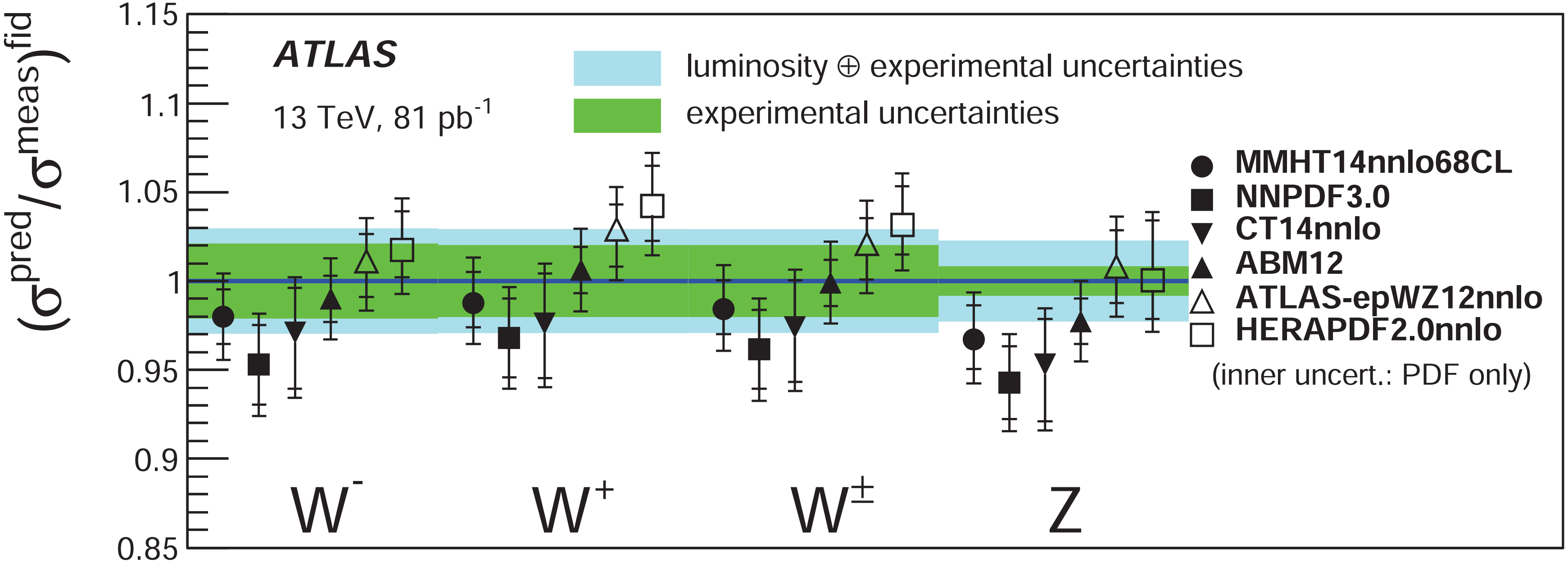
Results for parton distributions (IV)

- PDFs with 1σ uncertainty bands; compare ABMP16, CT14, MMHT14 NNPDF3.0
- Iso-spin asymmetry $x(\bar{d}(x) - \bar{u}(x))$; ratio $d(x)/u(x)$; strange $s(x)$



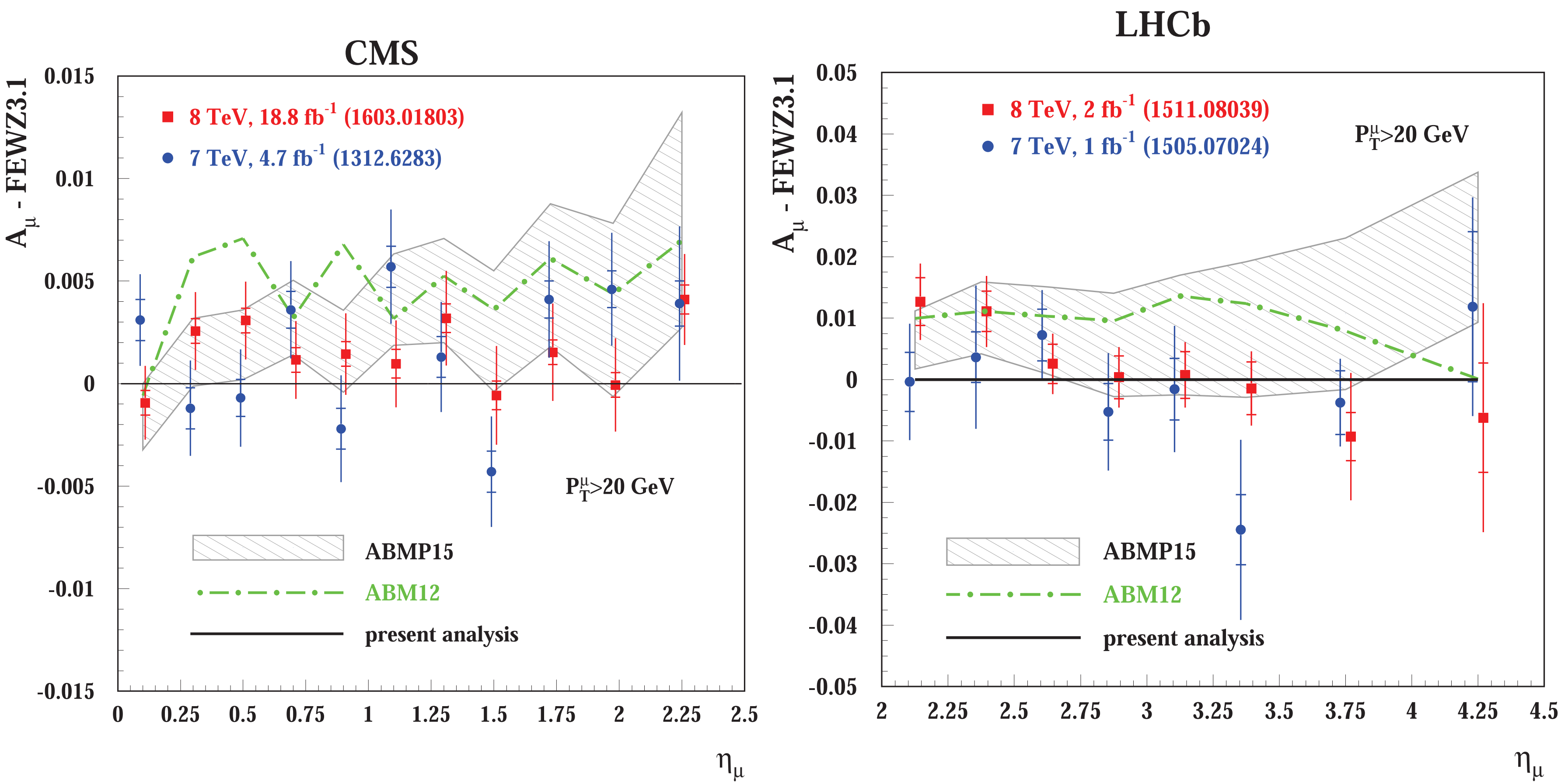
W - and *Z* -boson cross sections

- High precision data from LHC ATLAS, CMS, LHCb and Tevatron D0
  - differential distributions extend to forward region
  - sensitivity to light quark flavors at $x \simeq 10^{-4}$
  - statistically significant: $NDP = 172$ in ABMP16
- ATLAS measurement at $\sqrt{s} = 13$ TeV from arXiv:1603.09222



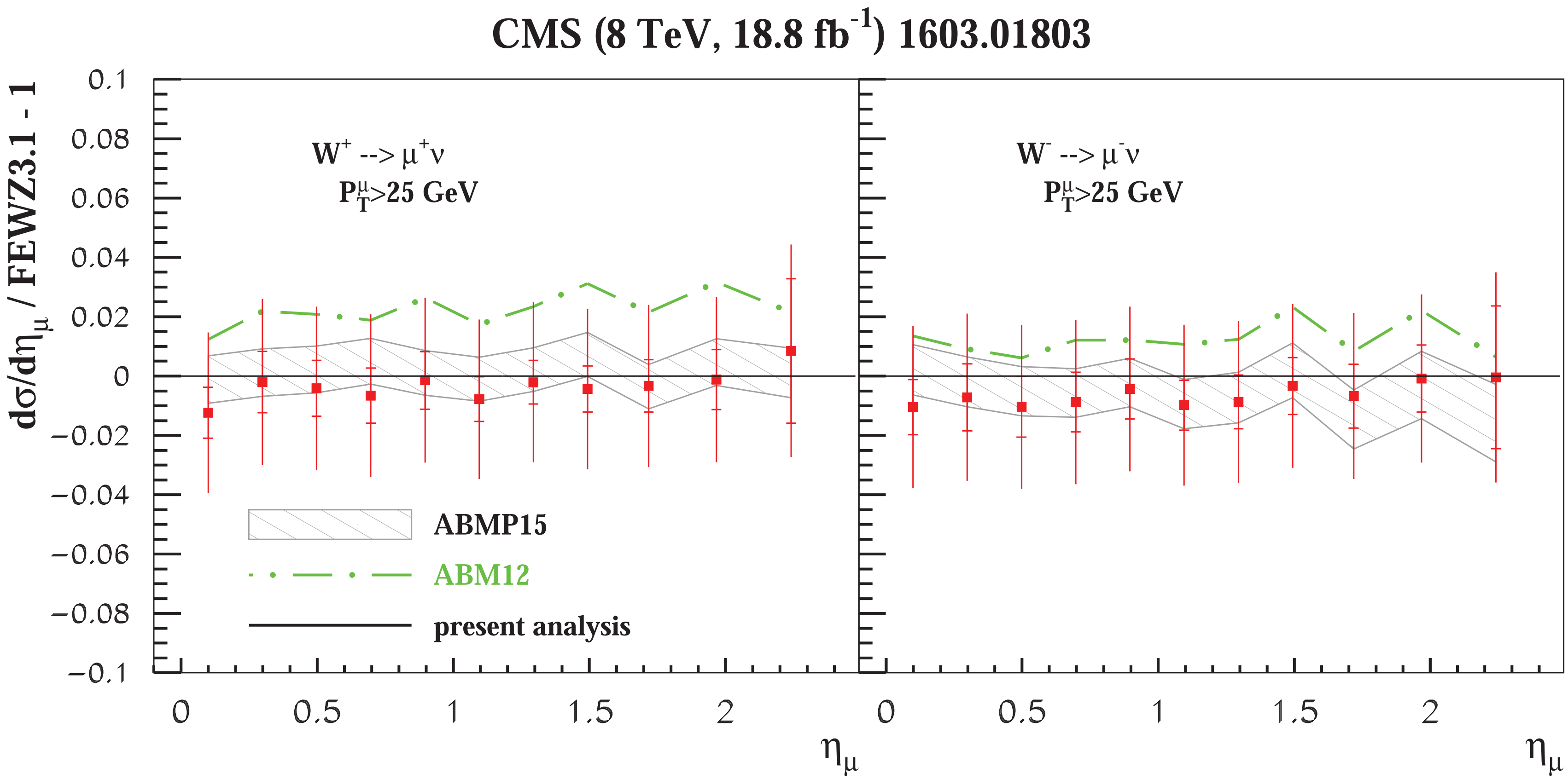
- Spread in predictions from different PDFs significantly larger than experimental precision

Muon charge asymmetry from LHC



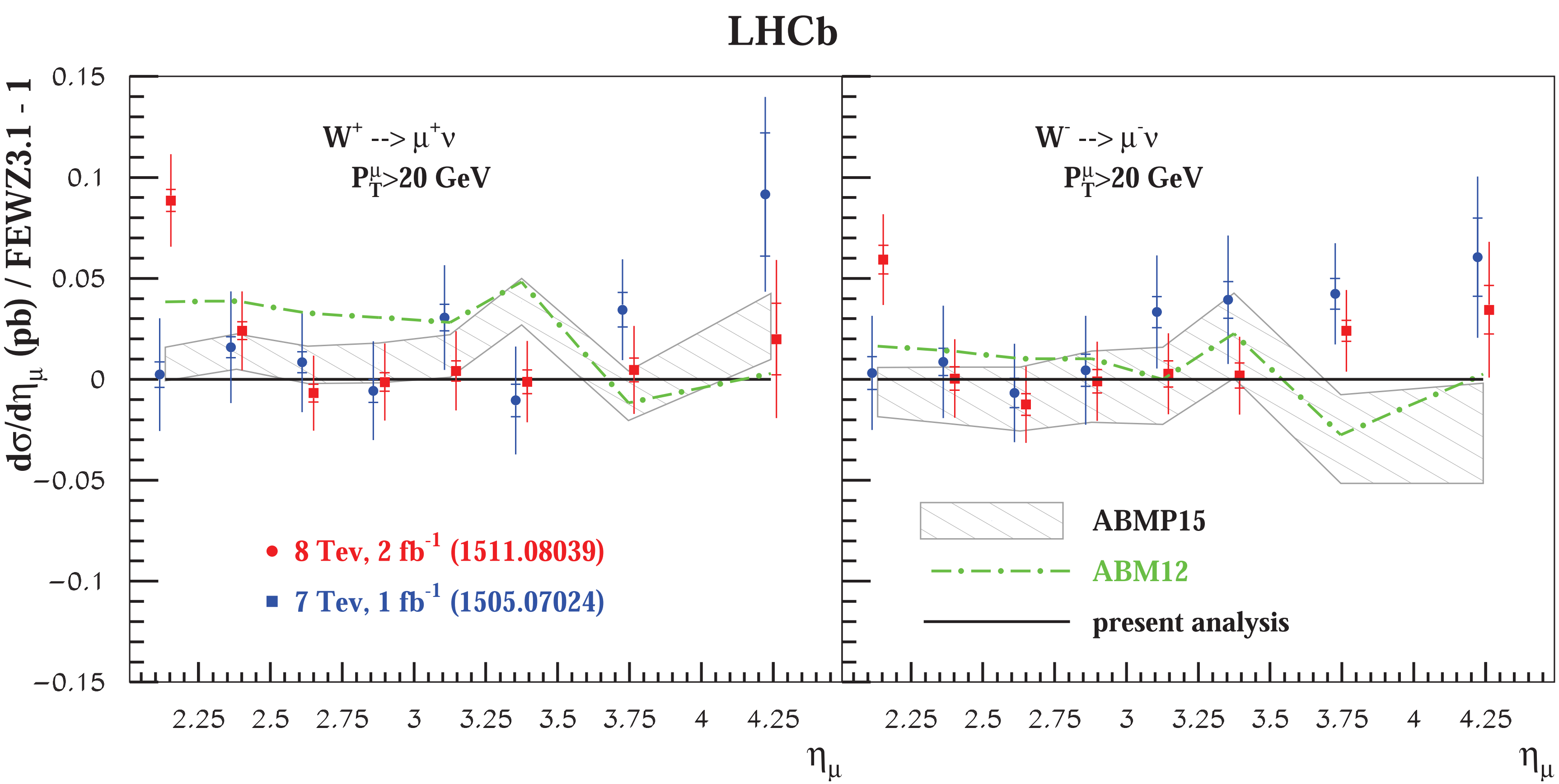
- CMS and LHCb data for $pp \to W^{\pm} + X \to \mu^{\pm}\nu + X$ at $\sqrt{s} = 7$ TeV and $\sqrt{s} = 8$ TeV
  - comparison of ABM12, ABMP15 and ABMP16 fits
- Problematic data point at $\eta_{\mu} = 3.375$ for $\sqrt{s} = 7$ TeV in LHCb data are omitted in fit

$W^{\pm}$-boson production from LHC (I)



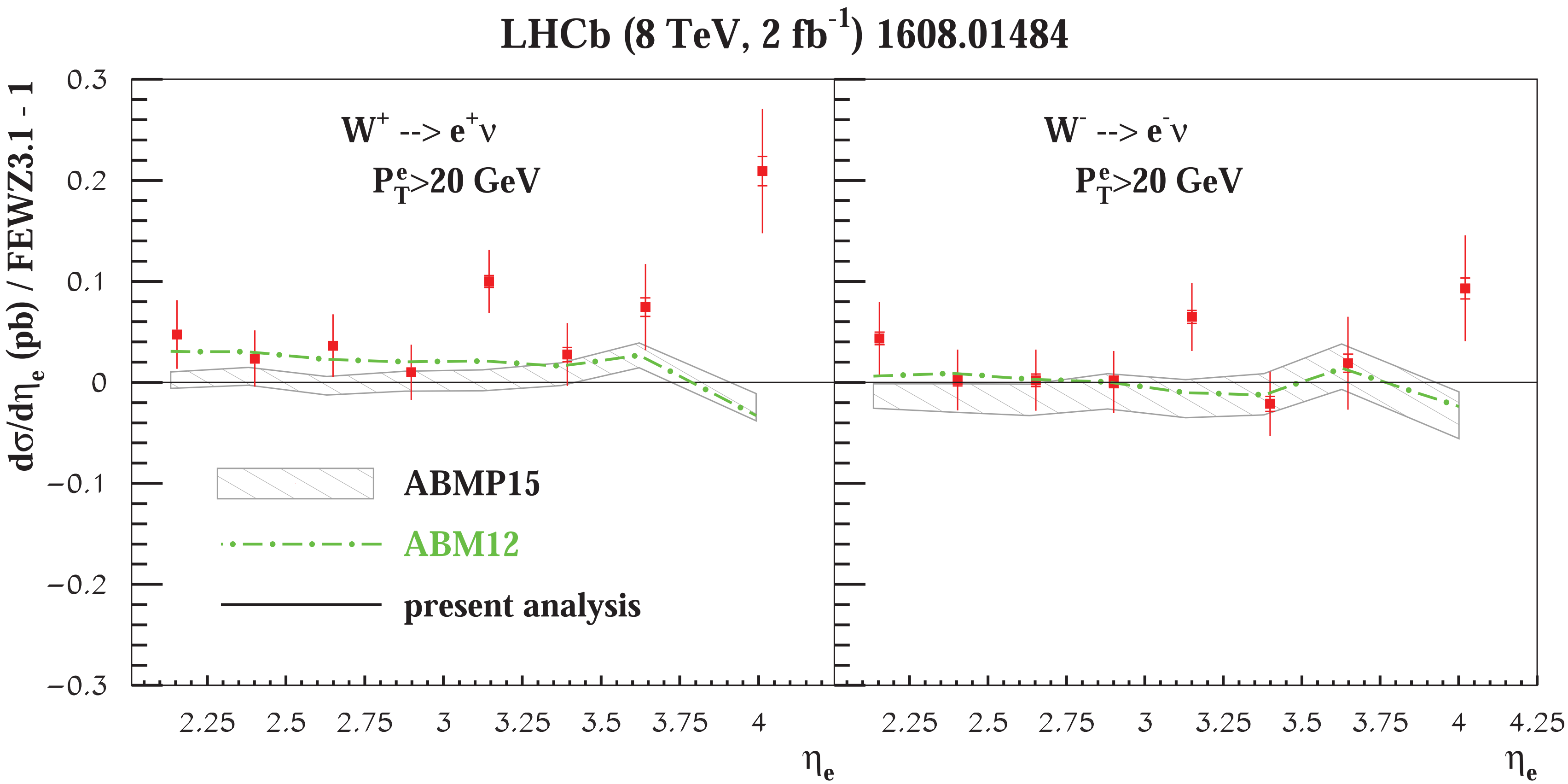
- CMS data on cross section of inclusive $W^{\pm}$-boson production at $\sqrt{s} = 8$ TeV
  - channel $W^{\pm} \to \mu^{\pm}\nu$

$W^{\pm}$-boson production from LHC (II)



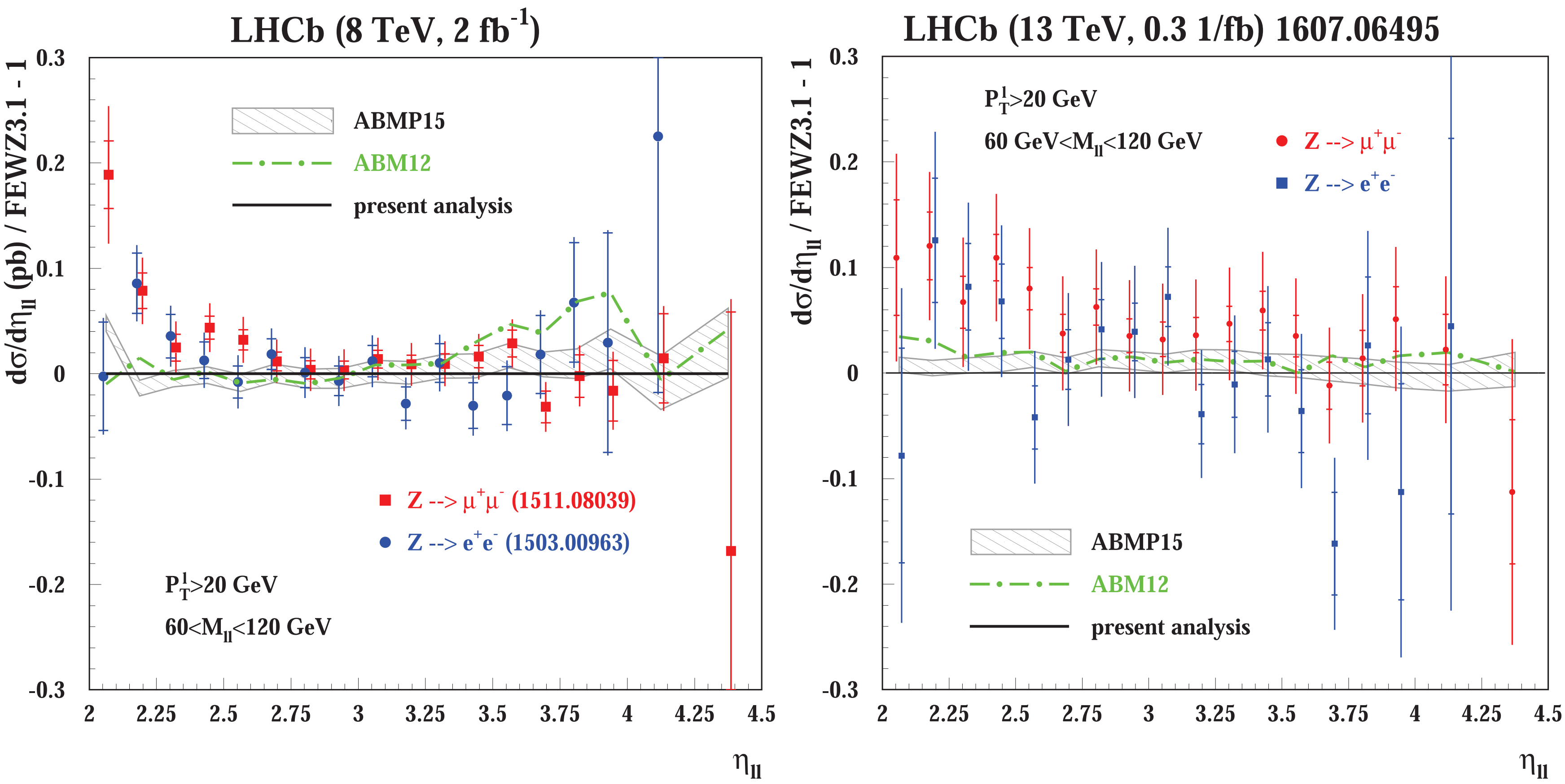
- LHCb data on cross section of inclusive $W^{\pm}$-boson production at $\sqrt{s} = 7$ TeV and $\sqrt{s} = 8$ TeV
  - channel $W^{\pm} \to \mu^{\pm}\nu$
- Points at $\eta_{\mu} = 2.125$ for $\sqrt{s} = 8$ TeV are not used in fit

$W^{\pm}$-boson production from LHC (III)



- LHCb data on cross section of inclusive $W^{\pm}$-boson production at $\sqrt{s} = 8$ TeV
  - channel $W^{\pm} \to e^{\pm}\nu$

Z-boson production from LHC



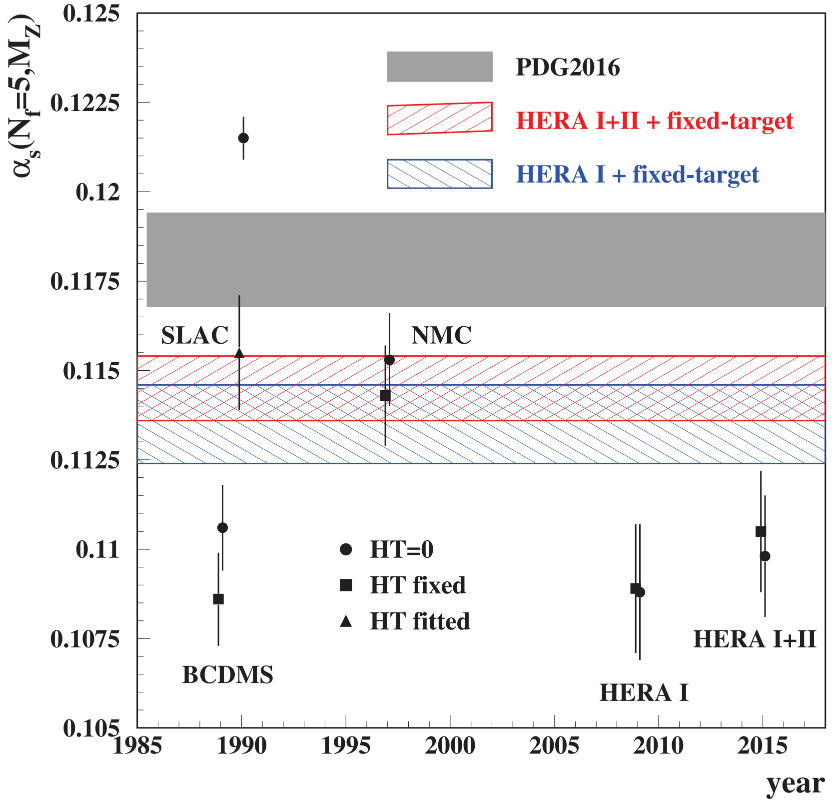
- LHCb data for $pp \to Z + X \to l\bar{l}$ at $\sqrt{s} = 8$ TeV and $\sqrt{s} = 13$ TeV
  - channels $Z \to e^+e^-$ and $Z \to \mu^+\mu^-$

$\alpha_s(M_Z)$ in PDFs

PDF sets	$\alpha_s(M_Z)$	method of determination
ABMP16 Alekhin, Blümlein, S.M., Placakyte '17	0.1147 ± 0.0008	fit at NNLO
CJ15 Accardi, Brady, Melnitchouk et al. '16	0.118 ± 0.002	fit at NLO
CT14 Dulat et al. '15	0.118	assumed at NNLO
HERAPDF2.0 H1+Zeus Coll.	$0.1183\ ^{+0.0040}_{-0.0034}$	fit at NLO
JR14 Jimenez-Delgado, Reya '14	0.1136 ± 0.0004	dynamical fit at NNLO
	0.1162 ± 0.0006	standard fit at NNLO
MMHT14 Martin, Motylinski, Harland-Lang, Thorne '14	0.118	assumed at NNLO
	0.1172 ± 0.0013	best fit at NNLO
NNPDF3.1 Ball et al. '17	0.118	assumed at NNLO
PDF4LHC15 Butterworth et al. '15	0.118	assumed at NLO
	0.118	assumed at NNLO

- Values of $\alpha_s(M_Z)$ often assumed and not fitted (no correlations)
- Large spread of fitted values at NNLO: $\alpha_s(M_Z) = 0.1136 \ldots 0.1172$
- PDF4LHC: order independent recommendation
  - use $\alpha_s(M_Z) = 0.118$ at NLO and NNLO

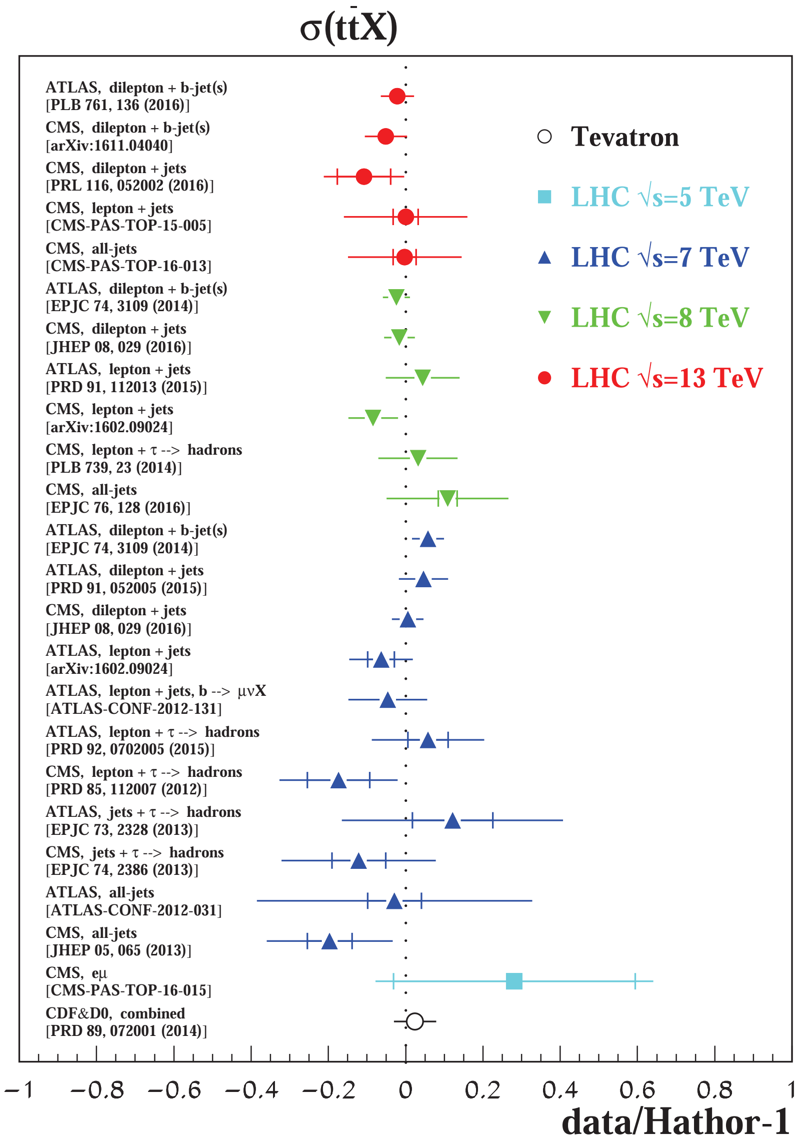
World DIS data and value of α_s

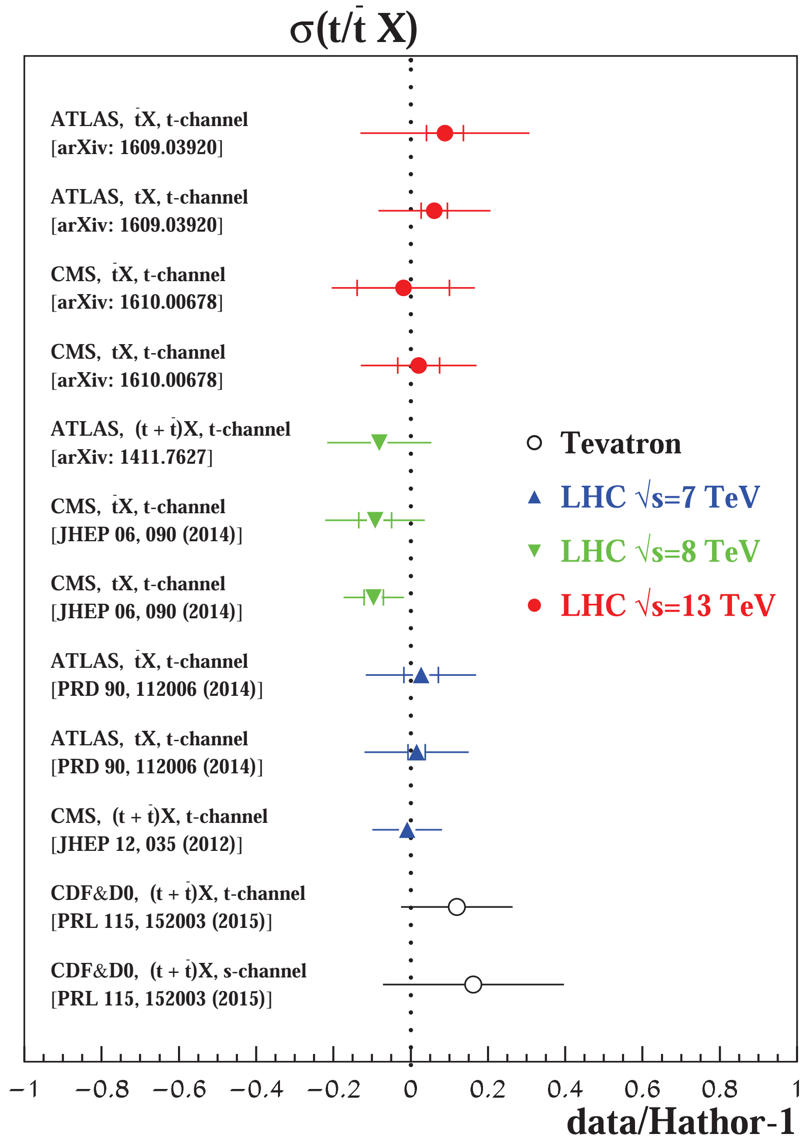


- Value of $\alpha_s(M_Z) = 0.1147 \pm 0.0008$ is lower than PDG average
  - value of $\alpha_s(M_Z)$ is pulled up by SLAC and NMC and pulled down by BCDMS and HERA data
- Only $\alpha_s(M_Z)$ preferred by SLAC data is compatible with PDG average (provided higher twist terms are accounted for)
- Update of the α_s determination with combined data HERA I+II
  - value of $\alpha_s(M_Z)$ increases by 1σ

Data on top-quark cross sections

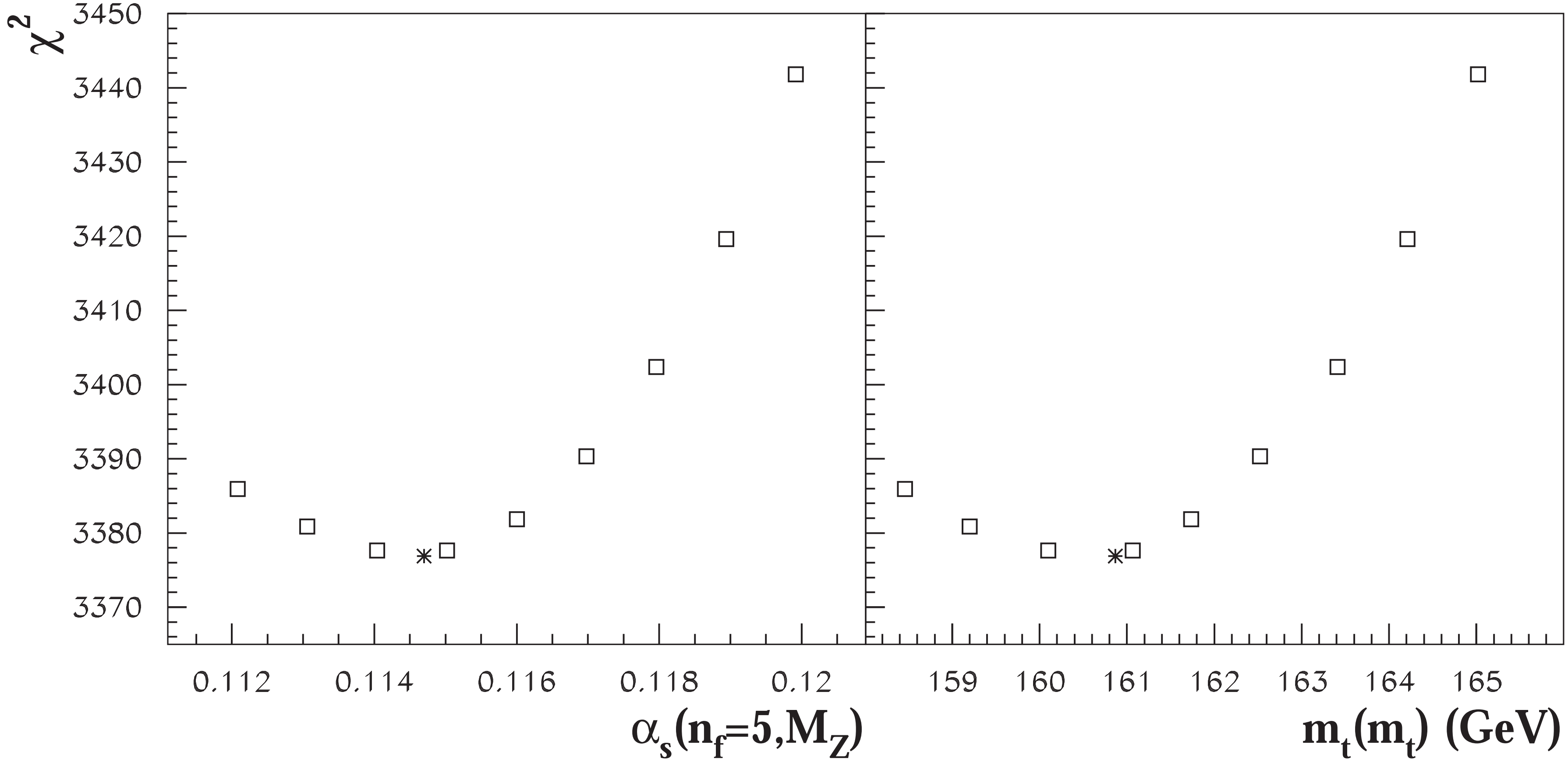
- Pulls for $t\bar{t}$- and single-t inclusive cross sections





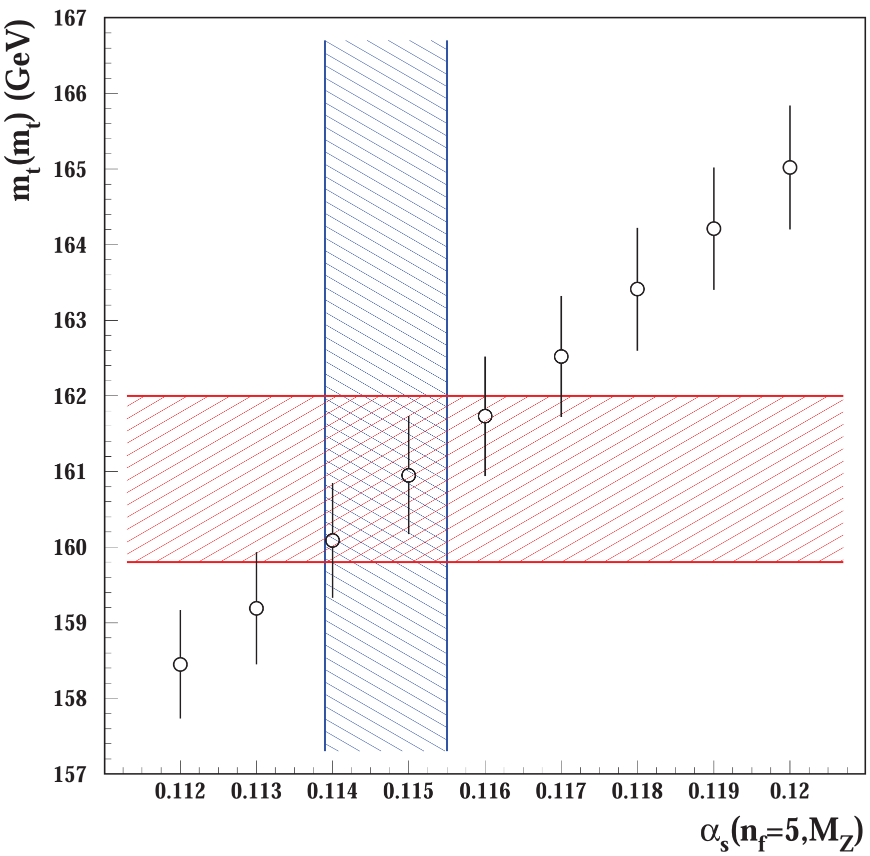
Fit quality

- Goodness-of-fit estimator χ^2 for extracted $\alpha_s(M_Z)$ and $m_t(m_t)$ values
  - fit result $m_t(m_t) = 160.86$ GeV corresponds to $m_t(m_t) = 170.37$ GeV
  - χ^2 of global fit with $NDP = 2834$
  - data on top-quark production with $NDP = 36$ D0, ATLAS, CMS, LHCb



Correlations

- Cross section for $t\bar{t}$-production with parametric dependence
  $\sigma_{t\bar{t}} \sim \alpha_s^2 \, m_t^2 \, g(x) \otimes g(x)$
- Correlations between gluon PDF $g(x)$, $\alpha_s(M_Z)$ and $m_t(m_t)$
  - PDFs and $\alpha_s(M_Z)$ already well constrained by global fit



Summary

- Precision determination of non-perturbative parameters is essential
  - parton content of proton (PDFs), strong coupling constant $\alpha_s(M_Z)$, quark masses m_c, m_b, m_t
  - correlations are important and need to be taken into account
- LHC data for $W^{\pm}$- and Z-boson production provides valuable information on light flavor PDFs u, d and s over wide range of x
- Values of $\alpha_s(M_Z)$ at NNLO from measurements at colliders lower than world average
  - $\alpha_s(M_Z) = 0.118$ at NNLO not preferred by data
  - data analysis with fixed value of $\alpha_s(M_Z)$ lacks correlation with parameters of PDF fits
- PDF4LHC recommendations introduce bias and inflated uncertainties
  - very difficult to quantify potential discrepancies between individual PDF sets