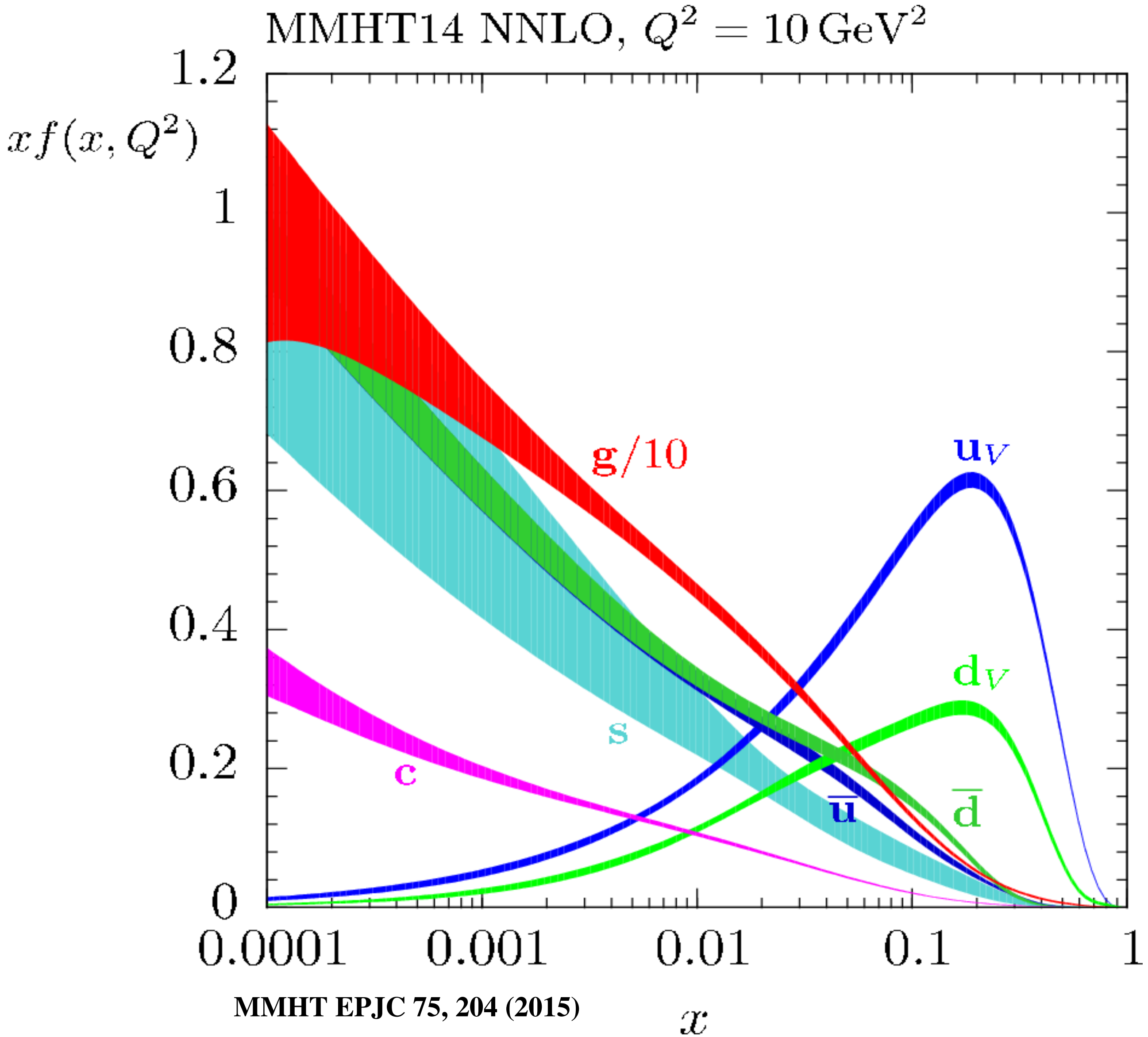
Strange and non-strange quark distributions

S.Alekhin (*Univ. of Hamburg & IHEP Protvino)*

- Strange and non-strange sea disentangling **sa, Blümlein, Moch PLB 777, 134 (2018)**
- d/u ratio at large x **sa, Kulagin, Petti work in progress**
- NLO ABMP16 **sa, Blümlein, Moch hep-ph/1803.07537**

DIS2018, Kobe, 17 Apr 2018

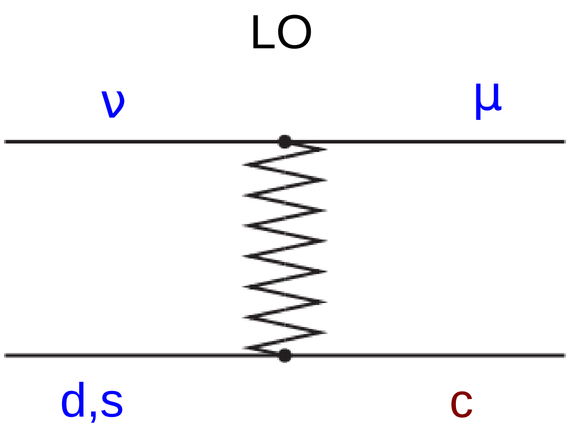


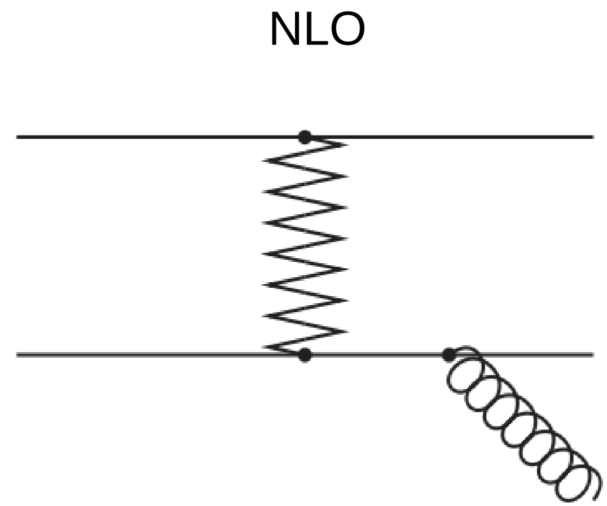
MMHT EPJC 75, 204 (2015)

Strange sea is the most uncertain PDF

S.Schmitt, this conference
J.Kretzschmar, this conference

Strange sea from the νN DIS





Two decay modes of c-quark are used: hadronic (emulsion experiments) and semi-leptonic (electronic experiments)

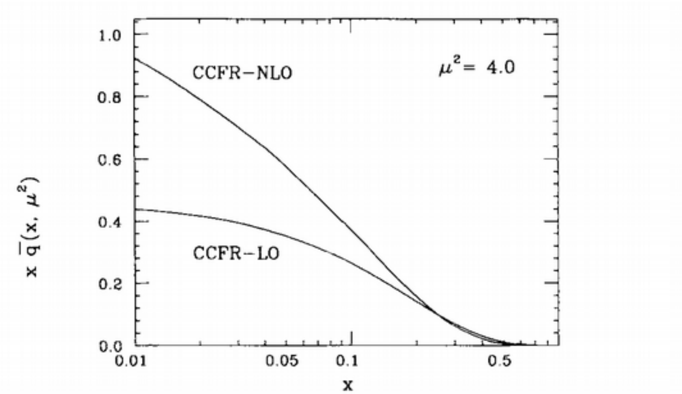


Fig. 3. The quark sea distribution $x\bar{q}(x, \mu^2 = 4.0\,\mathrm{GeV}^2/\mathrm{c}^2)$ determined at next-to-leading order and leading order

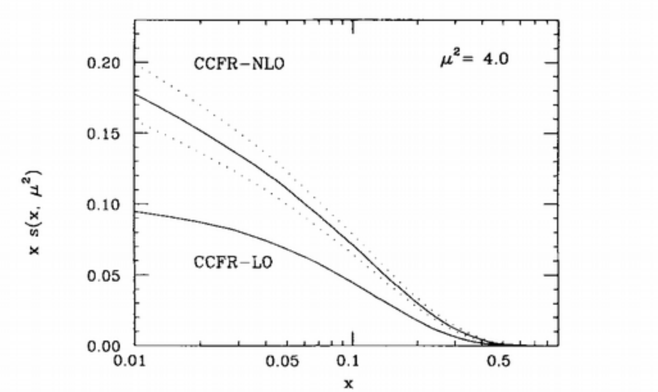
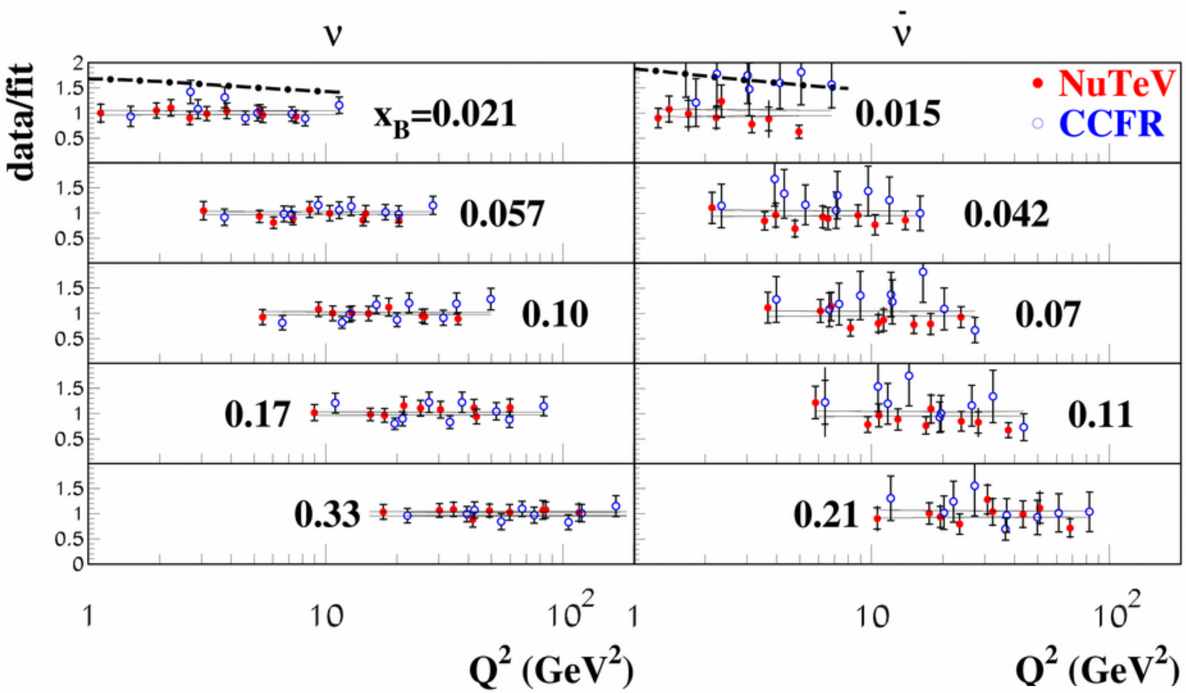


Fig. 4. The strange quark distribution $xs(x, \mu^2 = 4.0\,\mathrm{GeV}^2/\mathrm{c}^2)$ determined at next-to-leading order (described in section 4.1) and leading order. The band around the NLO curve indicates the $\pm 1\sigma$ uncertainty in the distribution

CCFR ZPC 65, 189 (1995)

Primary source for the strange sea was for a long time neutrino-induced charm production measured by CCFR/NuTeV at Fermilab preferring a suppression of ~0.5 w.r.t. non-strange sea

NuTeV/CCFR data in the PDF fit framework

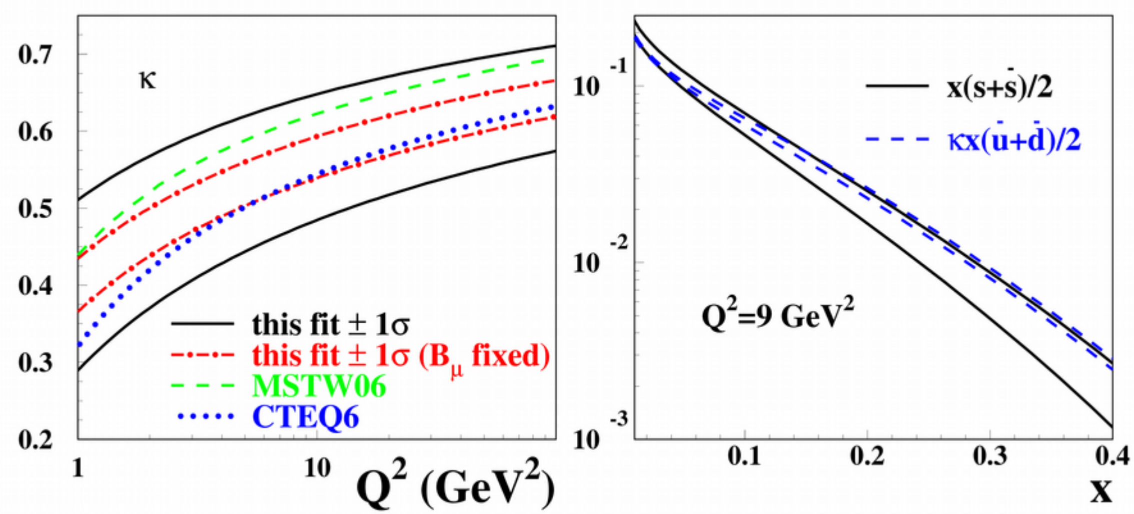


- CCFR and NuTeV are in a good agreement
- Charge asymmetry in the strange sea is consistent with 0 within uncertainties

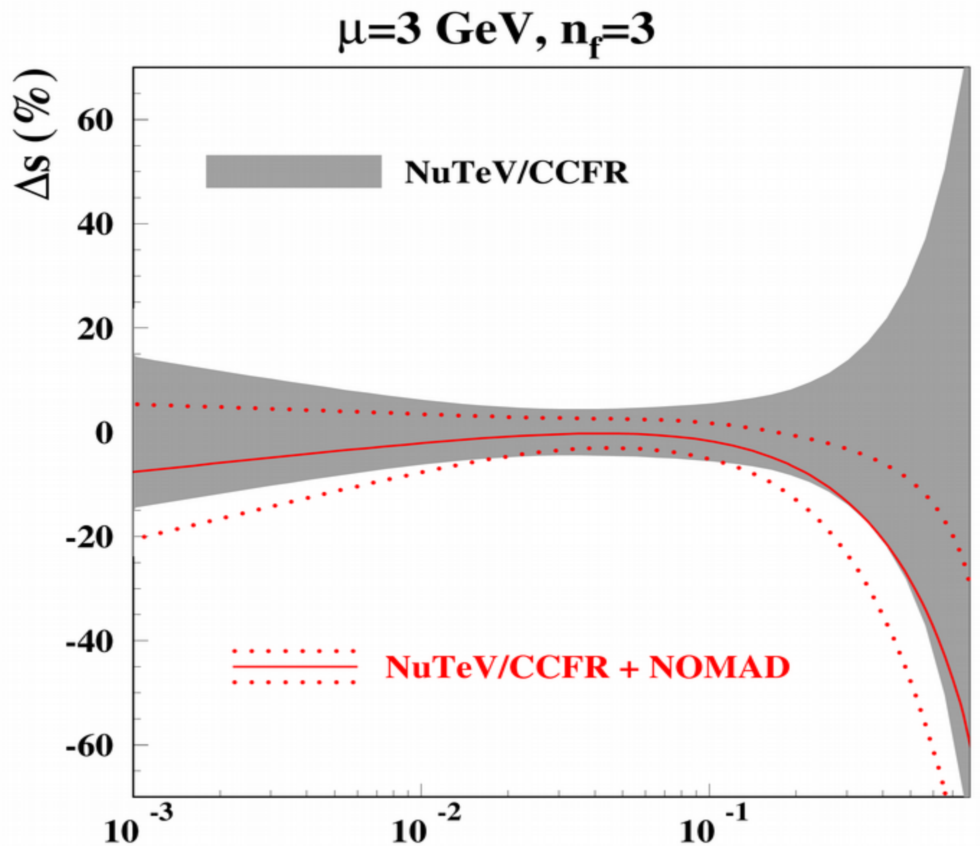
sa, Kulagin, Petti PLB 675, 433 (2009)

$$\kappa_s(\mu^2) = \frac{\int_0^1 x[s(x,\mu^2)+\bar{s}(x,\mu^2)]dx}{\int_0^1 x[\bar{u}(x,\mu^2)+\bar{d}(x,\mu^2)]dx},$$

Integral suppression factor
K_s(20 GeV^2)=0.62±0.04 is obtained



NOMAD charm data



NOMAD NPB 876, 339 (2013)

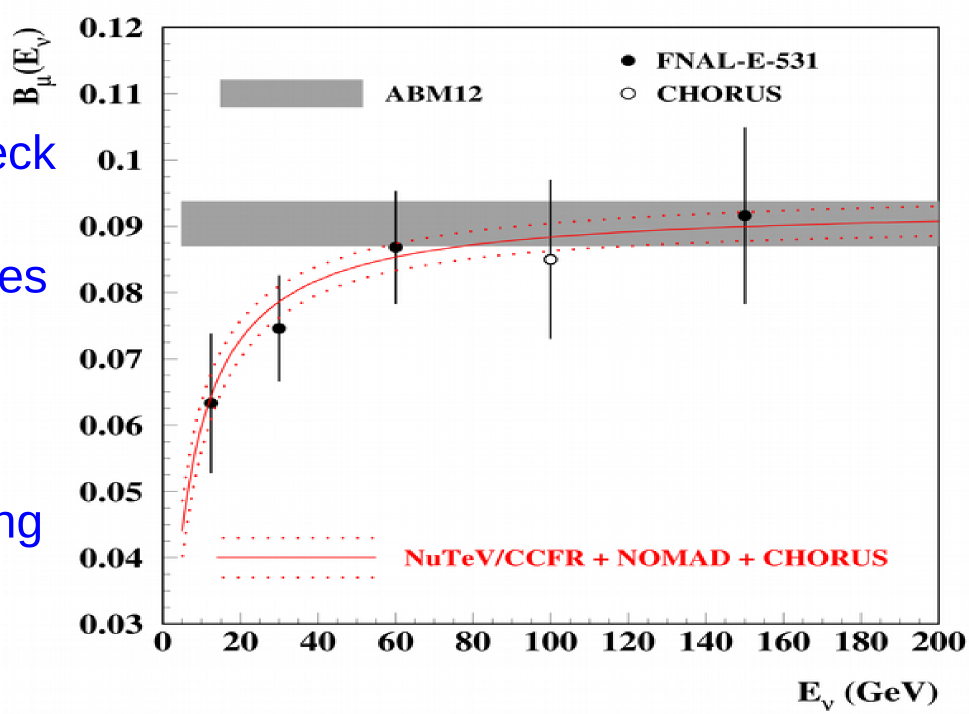
- The data on ratio 2μ/incl. CC ratio with the 2μ statistics of 15000 events (much bigger than in earlier CCFR and NuTeV samples).
- Systematics, nuclear corrections, etc. cancel in the ratio
- Pull down strange quarks at x>0.1 with a sizable uncertainty reduction

The semi-leptonic branching ratio B_μ is a bottleneck

– weighted average of the charmed-hadron rates

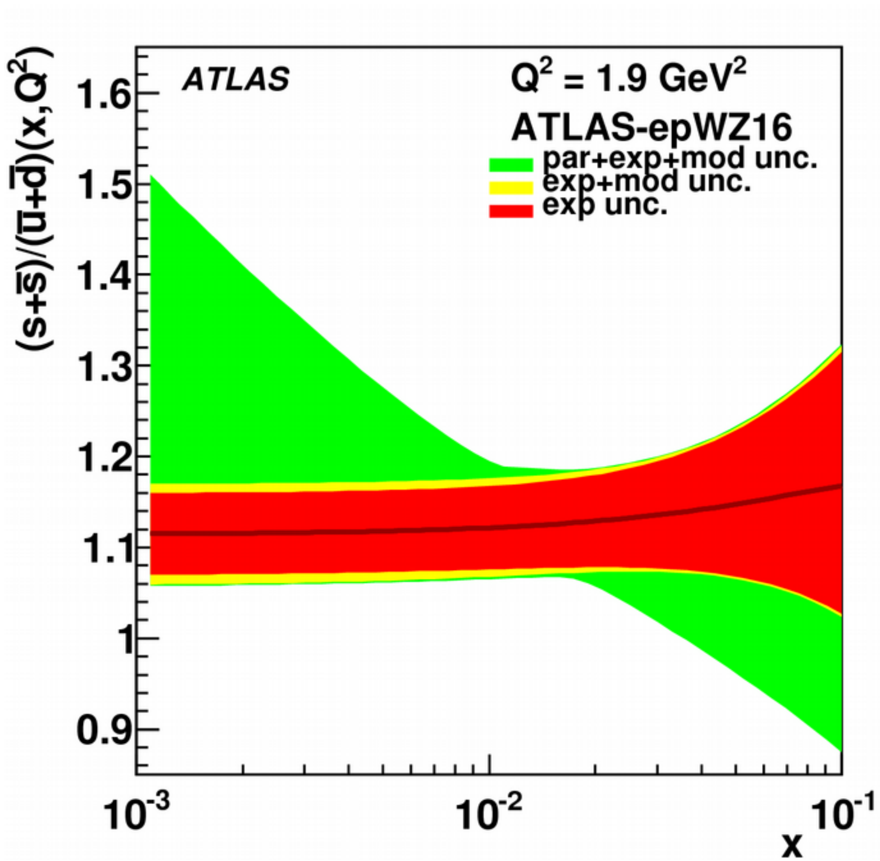
$$B_\mu(E_\nu)=\sum_h r^h(E_\nu)B^h_\mu = a/(1+b/E_\nu)$$

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

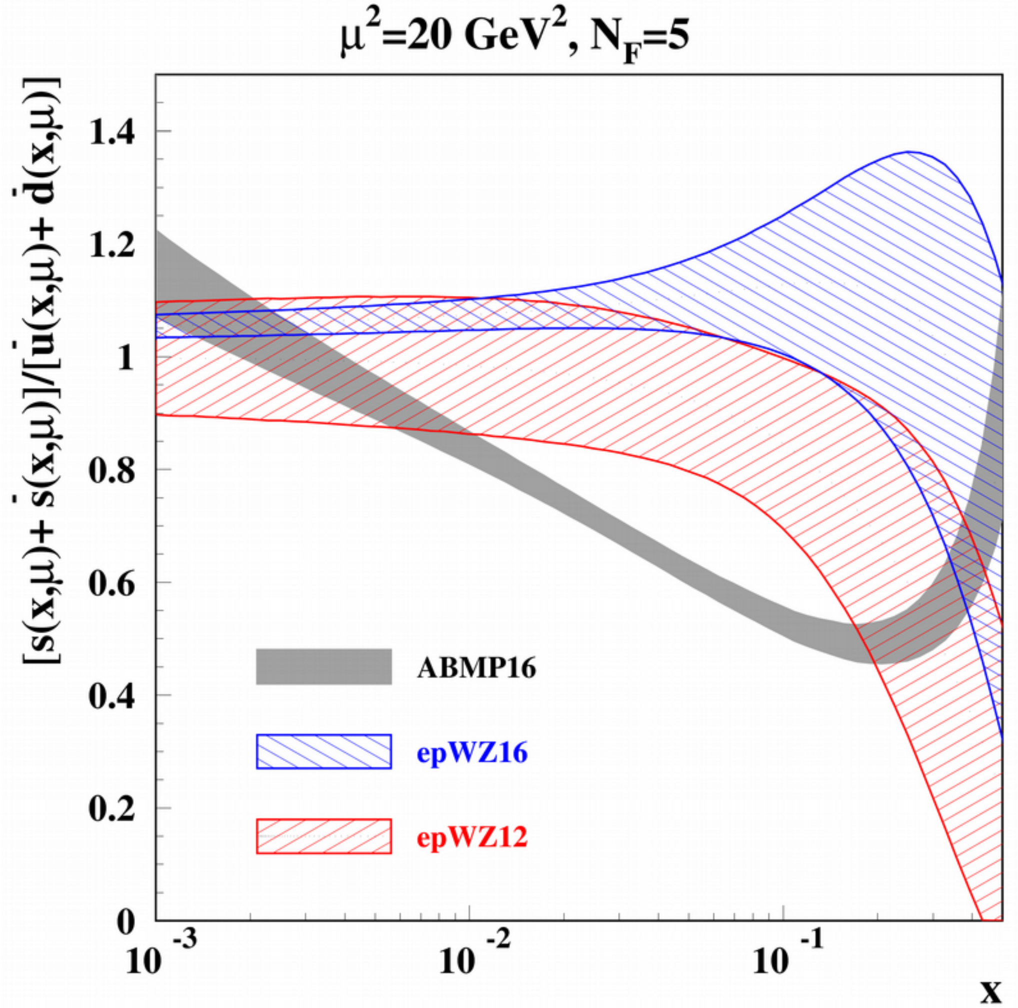


sa, Blümlein, Caminada, Lipka, Lohwasser, Moch, Petti, Plačakytė PRD 91, 094002 (2015)

ATLAS strange enhancement



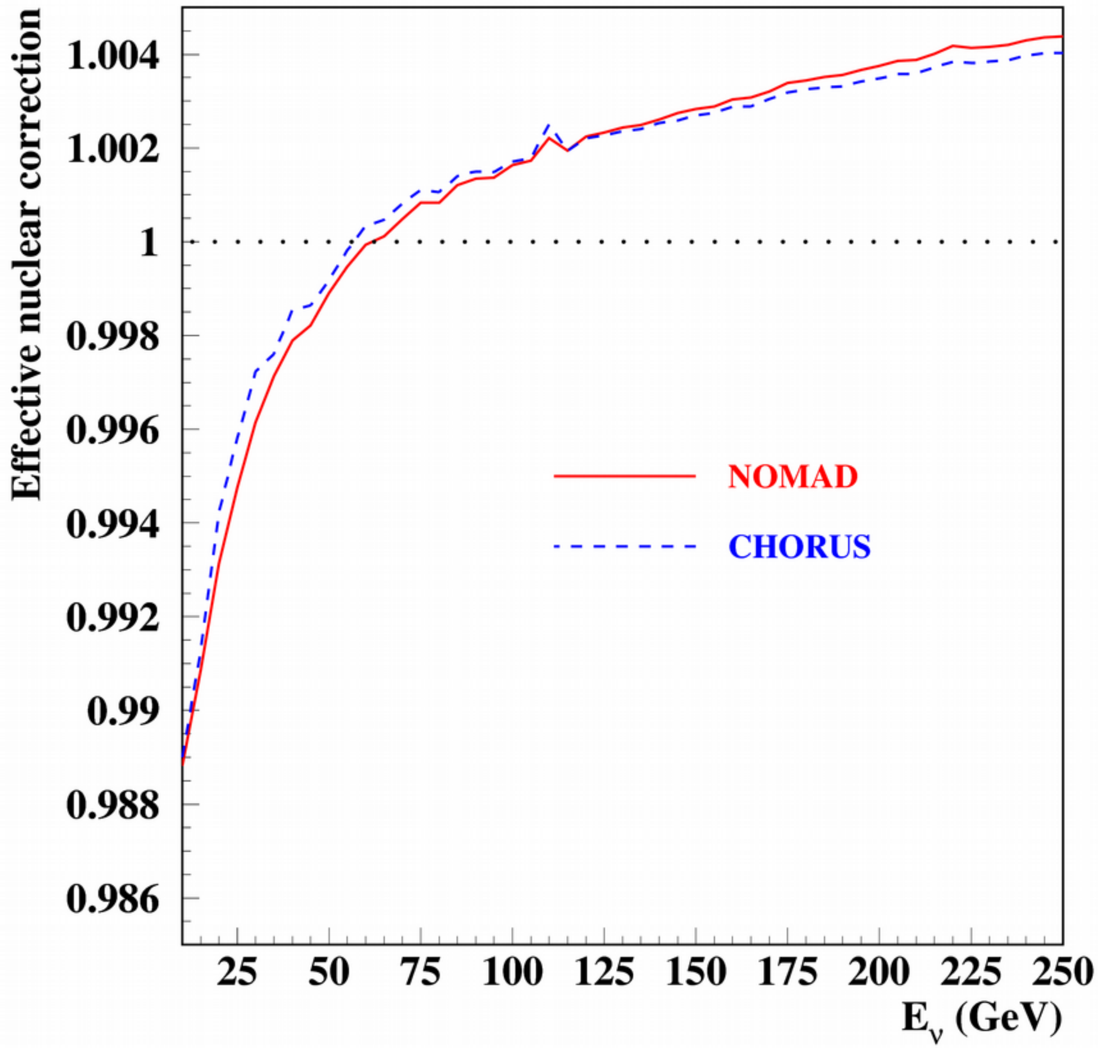
ATLAS arXiv:1612.03016



The epWZ16 strange-sea determined from analysis of the combined HERA-ATLAS data is enhanced as compared to other (earlier) determinations

ABM strange sea determination is in particular based on the dimuon neutrino-nucleon DIS production (NuTeV/CCFR and NOMAD) that gives a strange sea suppression ~0.5 at x~0.2

- *Disentangling d- and s- contribution?*
- *Impact of the nuclear corrections?*
- *…..?*



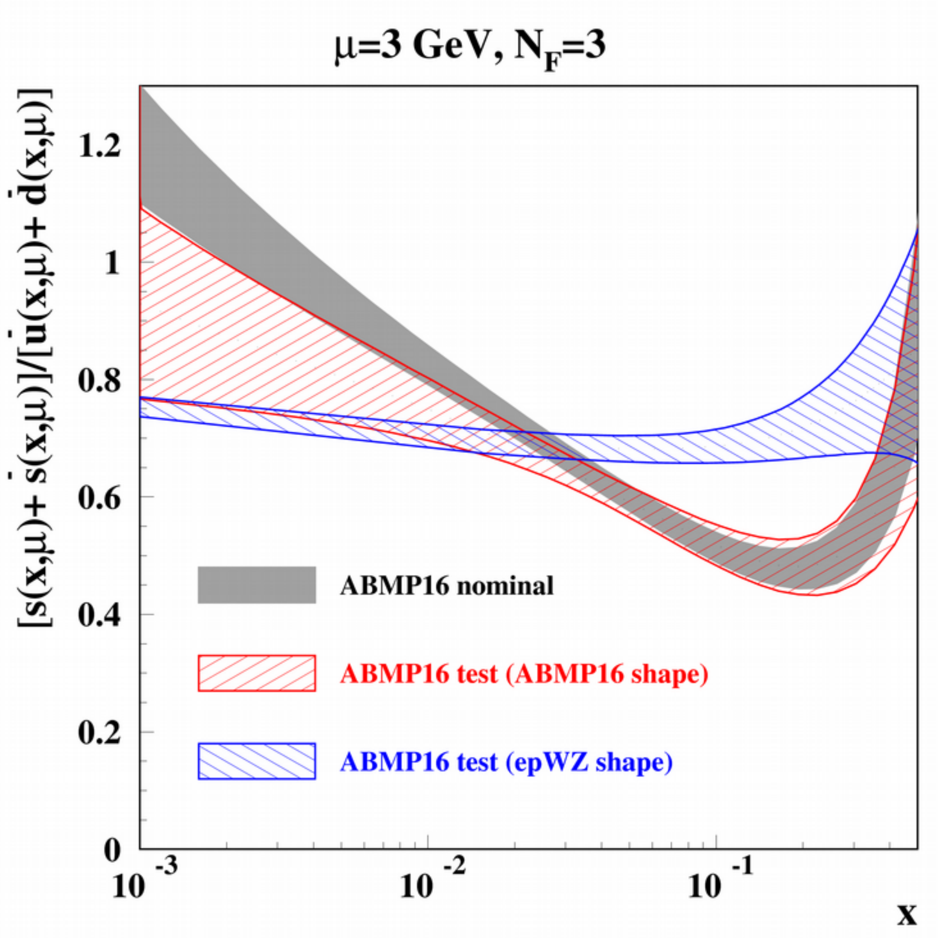
Nuclear effects greatly cancel in the 2μ/incl. CC ratio

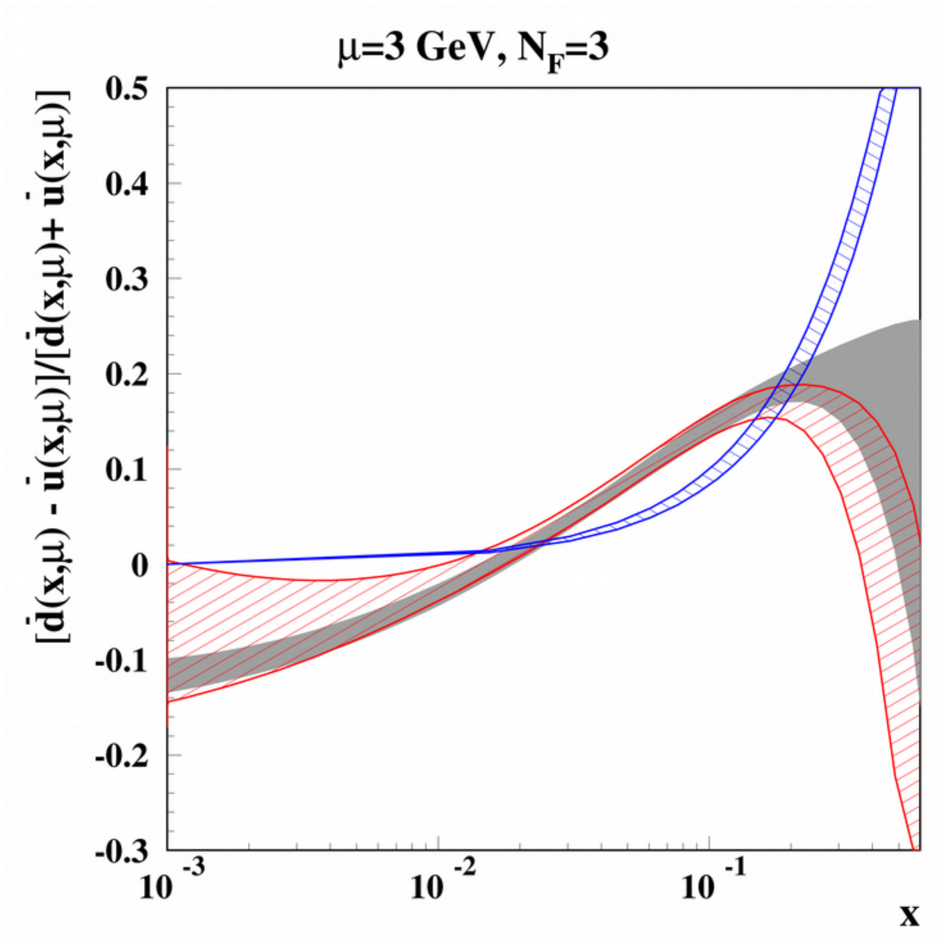
Details of the epWZ and ABMP16 fits

	epWZ16	ABMP16
Data	HERA, ATLAS W&Z	HERA, LHC and Tevatron W&Z, fixed-target DIS and charm production, fixed-target DY, ….
PDF shape	$xu_v(x,\mu_0^2) = A_{u_v} x^{B_{uv}} (1-x)^{C_{uv}} (1+E_{u_v} x^2)$, $xd_v(x,\mu_0^2) = A_{d_v} x^{B_{d_v}} (1-x)^{C_{d_v}}$, $x\bar{u}(x,\mu_0^2) = A_{\bar{u}} x^{B_{\bar{u}}} (1-x)^{C_{\bar{u}}}$, $x\bar{d}(x,\mu_0^2) = A_{\bar{d}} x^{B_{\bar{d}}} (1-x)^{C_{\bar{d}}}$, $xg(x,\mu_0^2) = A_g x^{B_g} (1-x)^{C_g} - A'_g x^{B'_g} (1-x)^{C'_g}$, $x\bar{s}(x,\mu_0^2) = A_{\bar{s}} x^{B_{\bar{s}}} (1-x)^{C_{\bar{s}}}$, 15 free parameters	$xq_v(x,\mu_0^2) = \frac{2\delta_{qu}+\delta_{qd}}{N_q^v} (1-x)^{b_{qv}} x^{a_{qv} P_{qv}(x)}$, $xq_s(x,\mu_0^2) = A_{qs} (1-x)^{b_{qs}} x^{a_{qs} P_{qs}(x)}$, $xg(x,\mu_0^2) = A_g (1-x)^{b_g} x^{a_g P_g(x)}$, $P_p(x) = (1+\gamma_{-1,p} \ln x)\left(1+\gamma_{1,p} x + \gamma_{2,p} x^2 + \gamma_{3,p} x^3\right)$, 25 free parameters

ABMP16 PDFs are selected more flexible in order to accommodate more data as compared to the EpWZ16 fit, which was evolved form the HERA data analysis

Test fit (the PDF shape comparison)



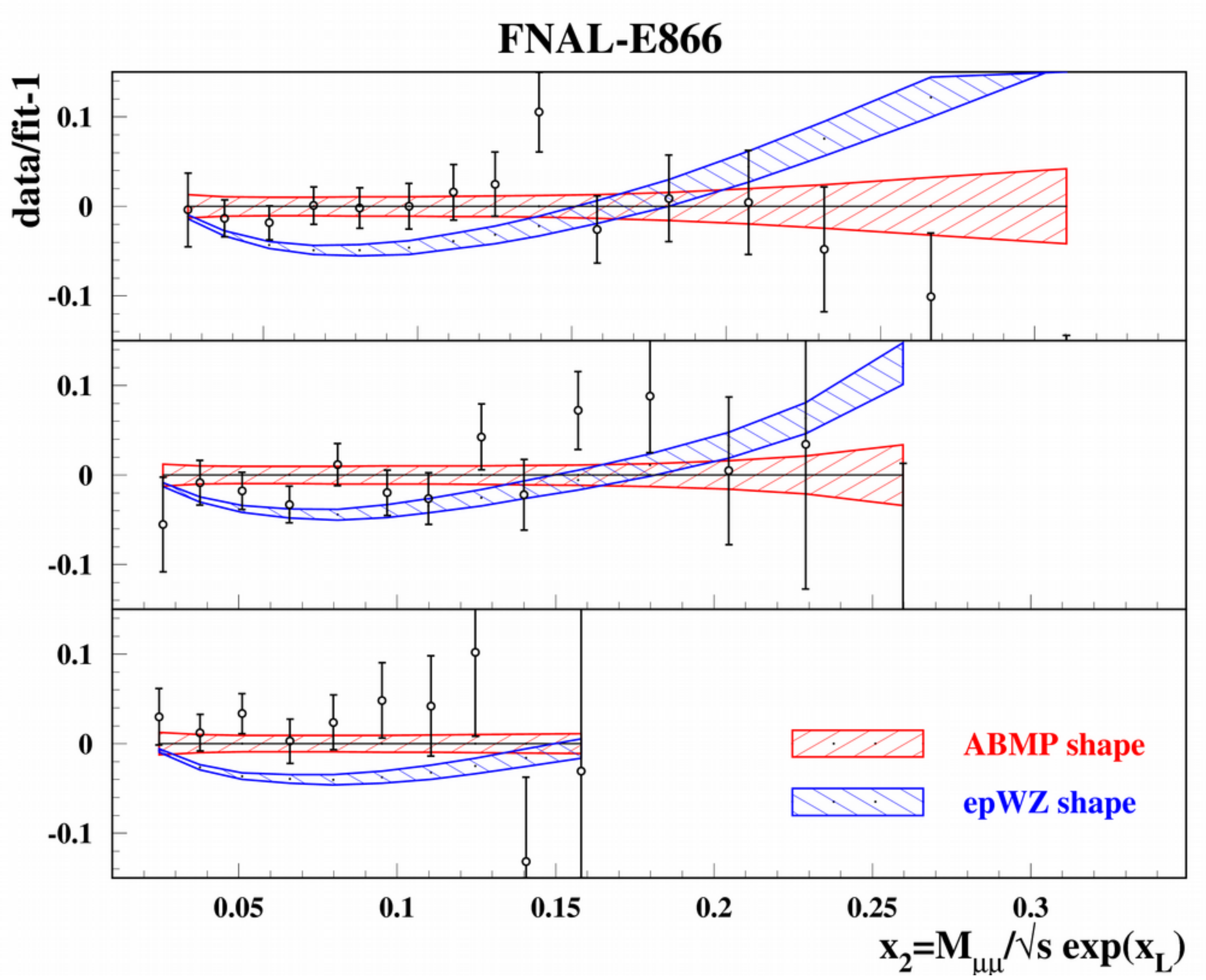


FRAMEWORK: collider data discarded and replaced by the deuteron ones
(fit is consistent with the nominal ABMP16 at x>0.01) **sa, Kulagin, Petti hep-ph/1704.00204**

The strange sea is enhanced for the epWZ shape despite the ATLAS data are not used. However, the dimuon data description is not deteriorated: χ^2=167 versus 161 for the ABMP shape ⇒ enhancement is achieved by the price of the d-quark sea suppression

sa, Blümlein, Caminada, Lipka, Lohwasser, Moch, Petti, Plačakytė PRD 91, 094002 (2015)

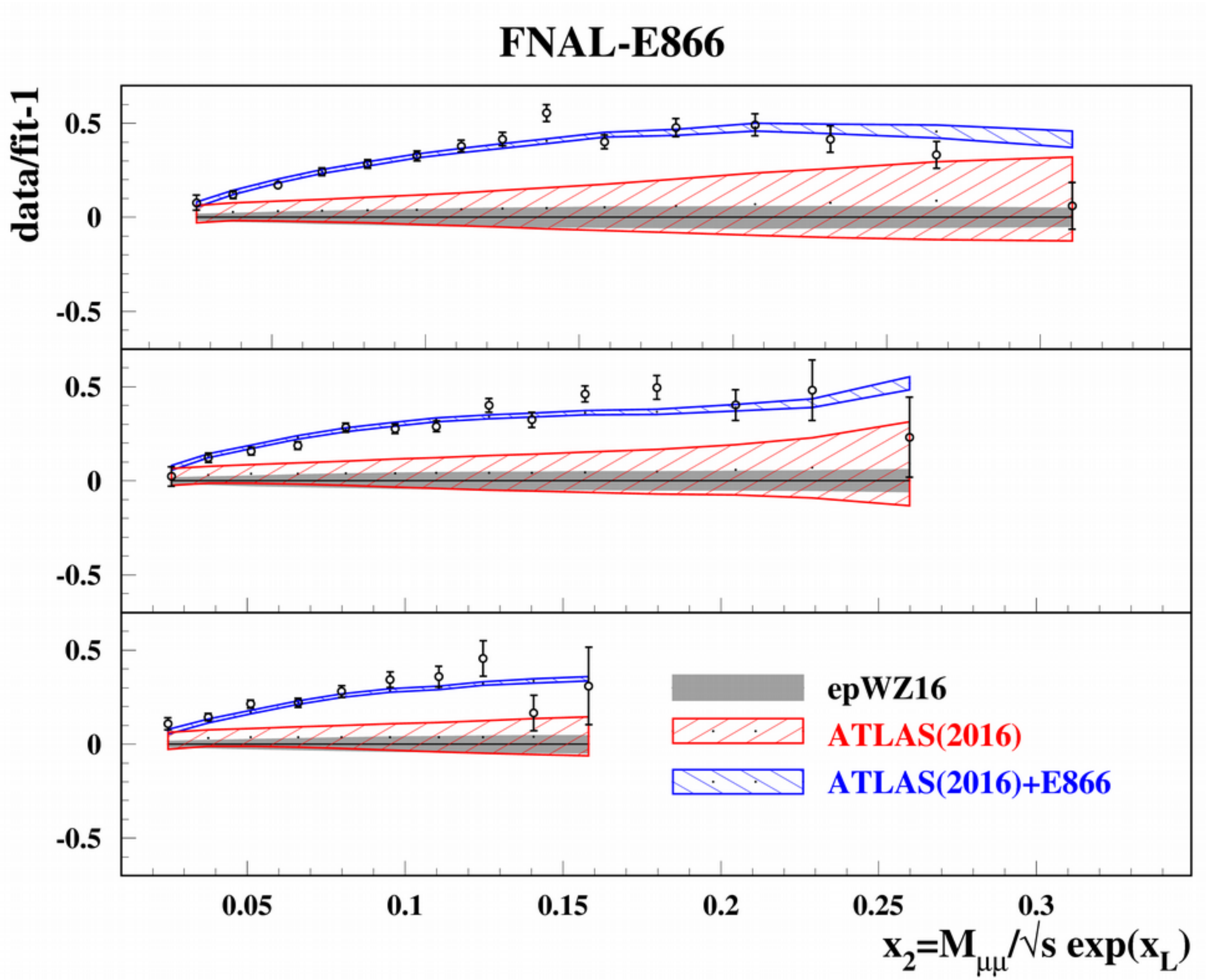
E866 data in the test fit



The E866 data on p/d DY cross sections are sensitive to the iso-spin sea asymmetry

The epWZ shape does not allow to accommodate E866 data: χ^2/NDP=96/39 versus 49/39 for the ABMP shape; the errors in epWZ predictions are suppressed at small x, evidently due to over-constrained PDF shape at small x

Consistency of ATLAS and E866 data



- The uncertainties in epWZ predictions are quite narrow and several σ off the E866 data ⇒ E866 cannot be accommodated into the fit

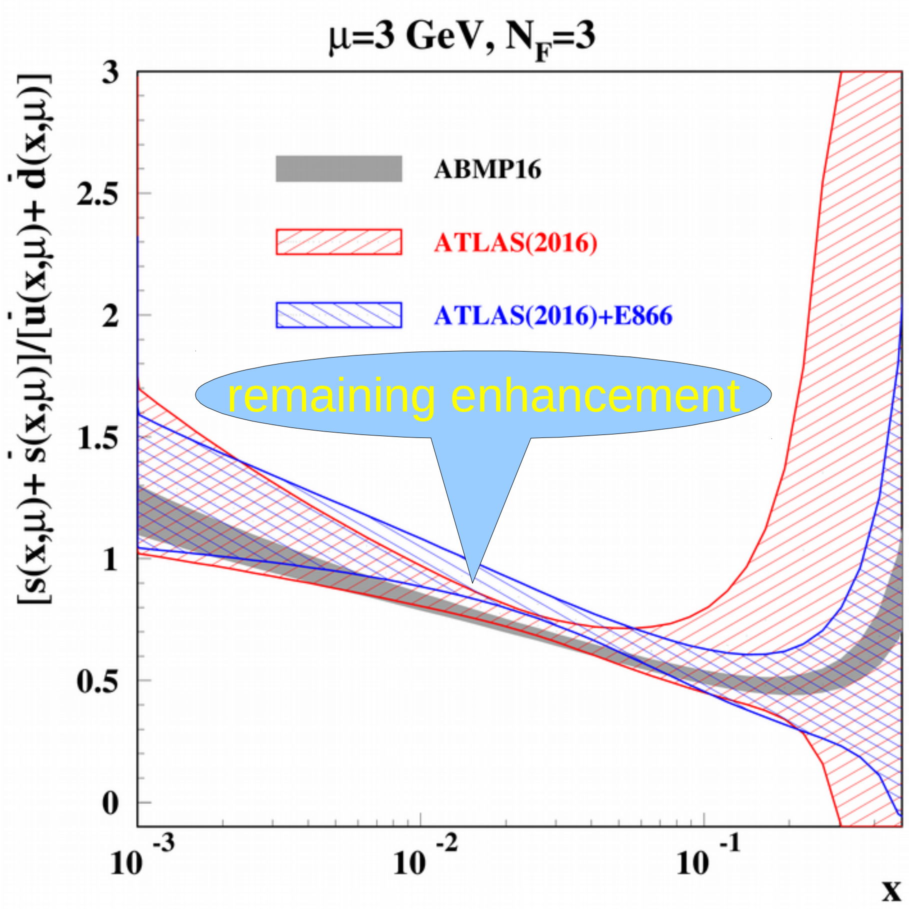
- The ABMP16 shape gives much wider error band ⇒ E866 data are well accommodated: χ^2/NDP=48/39 and 40/34 for the E866 and ATLAS, respectively

Impact of ATLAS data with flexible PDF shape

	$\kappa_s(\mu^2=20\ \mathrm{GeV}^2)$
HERA+ATLAS	0.81(18)
HERA+ATLAS+E866	0.72(8)
ABMP16(incl. NOMAD)	0.66(3)

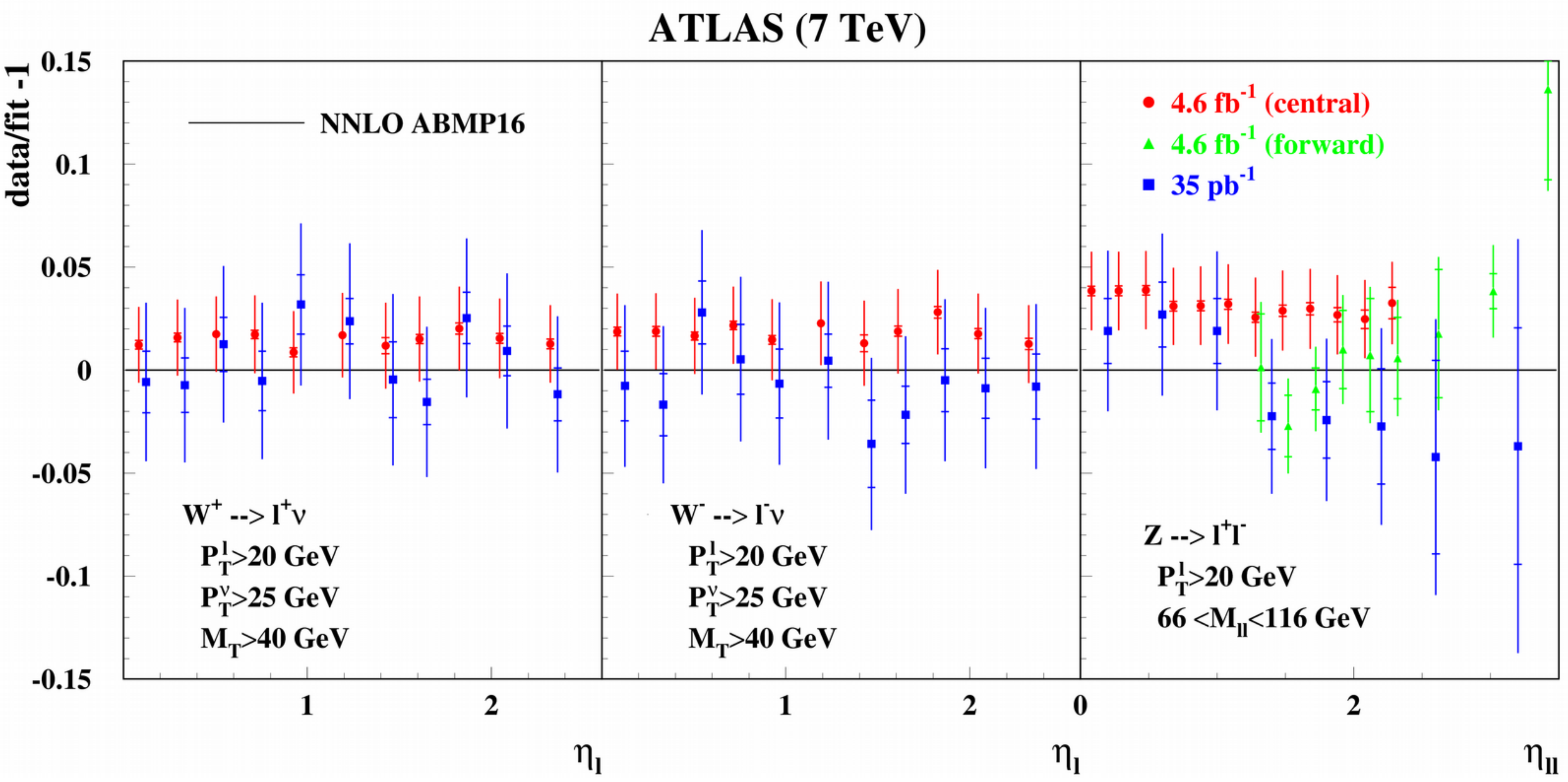
κ_s is integral strange sea suppression factor:

$$\kappa_s(\mu^2) = \frac{\int_0^1 x[s(x,\mu^2)+\bar{s}(x,\mu^2)]dx}{\int_0^1 x[\bar{u}(x,\mu^2)+\bar{d}(x,\mu^2)]dx},$$



- For the flexible PDF shape the strangeness is in a broad agreement with the one extracted from the dimuon data; small enhancement only is observed at x~0.01
- The E866 data are consistent with the ATLAS(2016) set: χ^2/NDP=48/39 and 40/34, respectively.

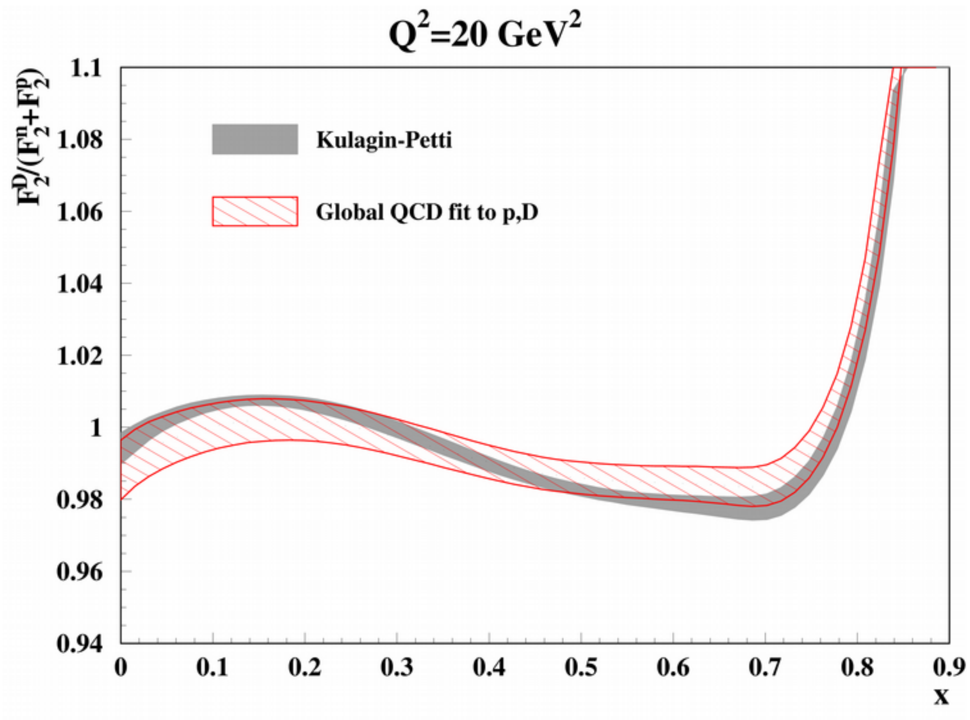
ATLAS data on the W&Z central production

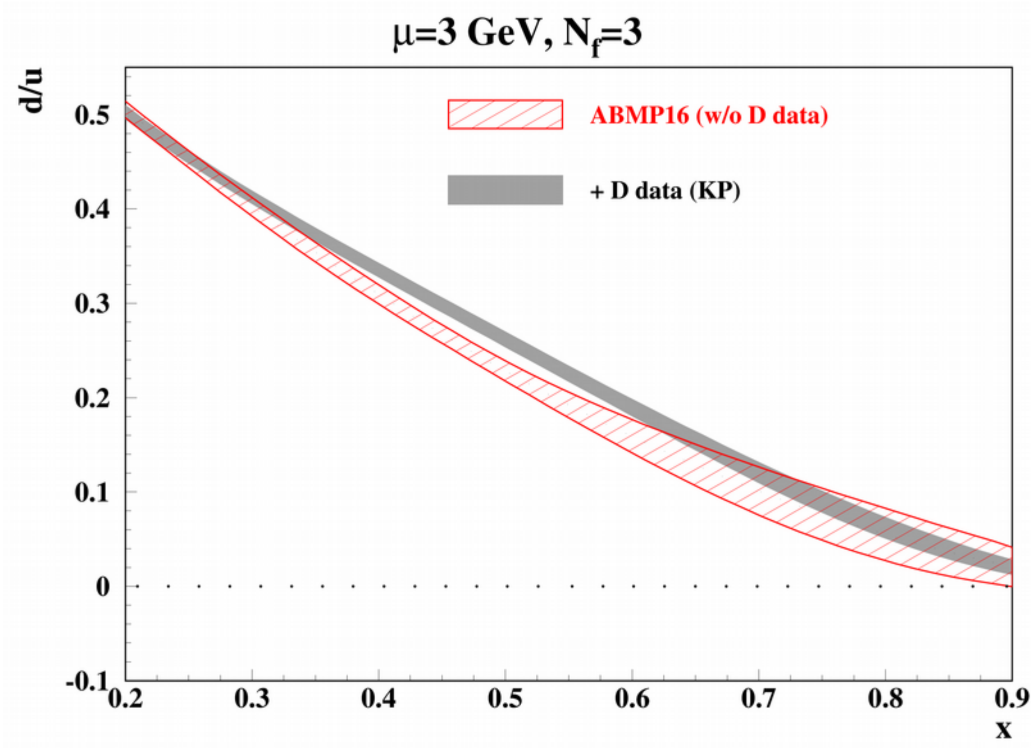


- The updated ATLAS data on $W^{\pm}$ production are in a good agreement with the earlier ATLAS sample; the data on Z production go higher, particularly at large rapidity ⇒ *impact on the strange sea at x~0.01*

- *Different trends for the central and forward Z-boson data*

Impact of fixed-target deuteron data





sa, Kulagin, Petti PRD 96, 054005 (2017)

Nuclear corrections extracted from the deuteron data are in good agreement with the results obtained from the heavy-target ones ⇒ universality of the off-shell function is justified ⇒ application to the nucleon-nucleon collisions

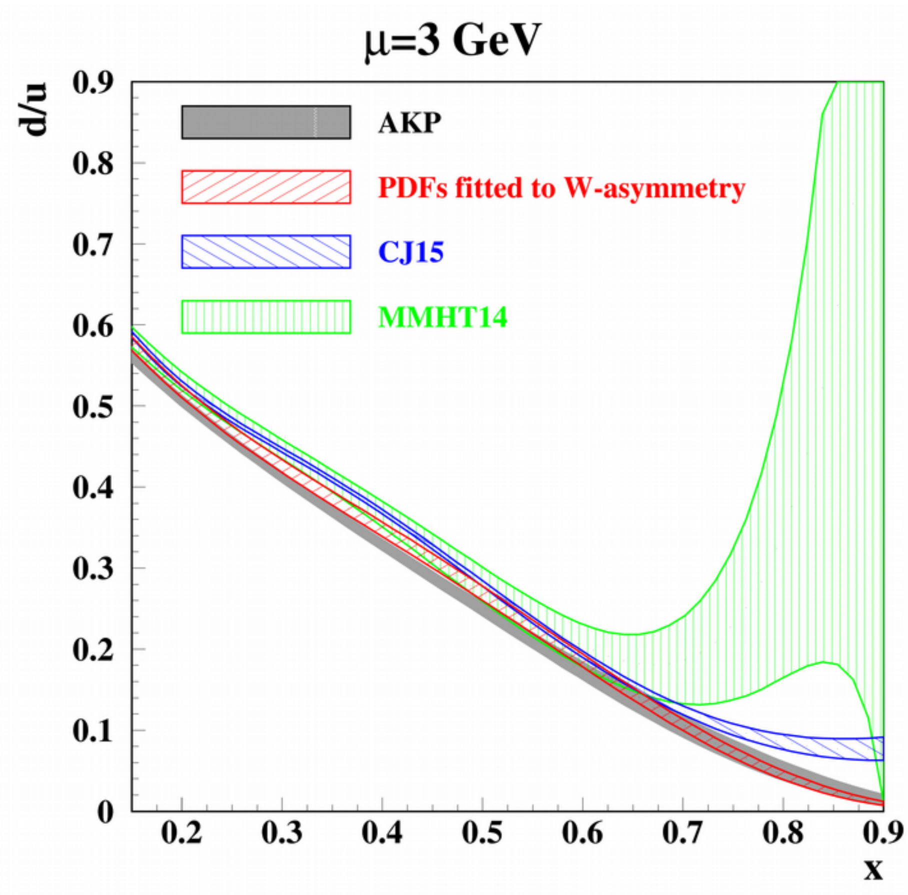
Kulagin, Petti NPA 765, 126 (2006)
Kulagin, Petti PRD 94, 113013 (2016)

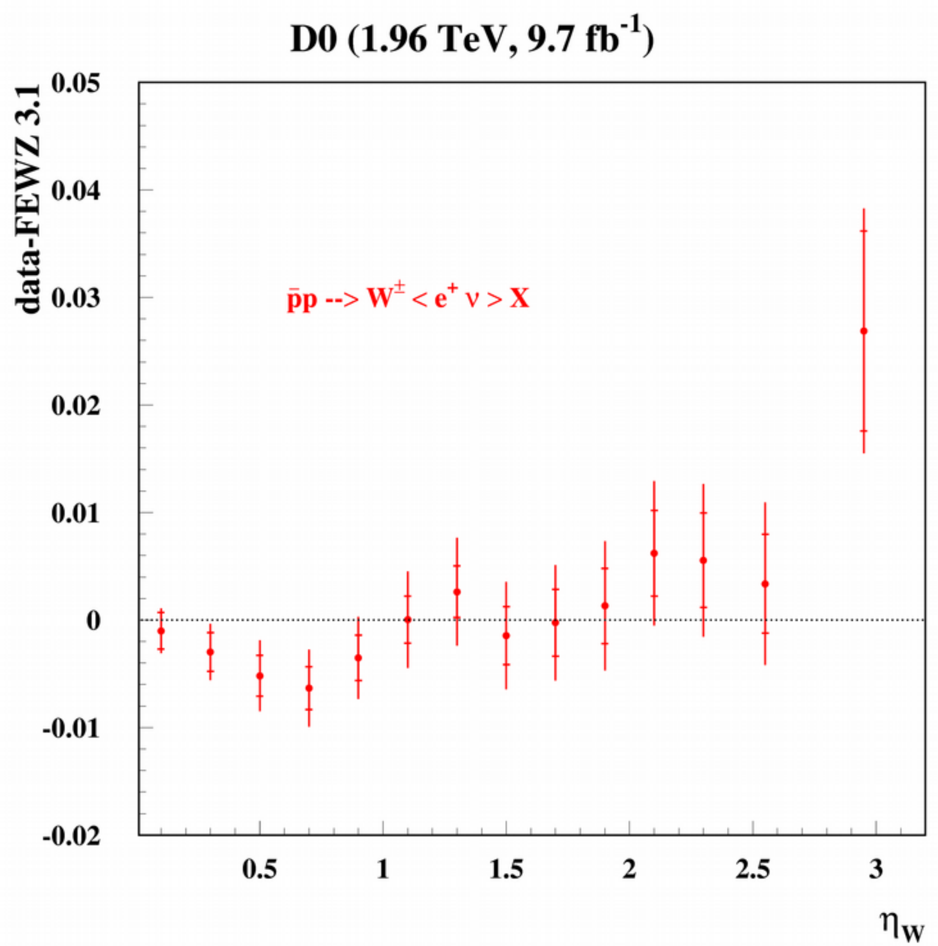
At large x the deuteron data further disentangle d- and u-distributions

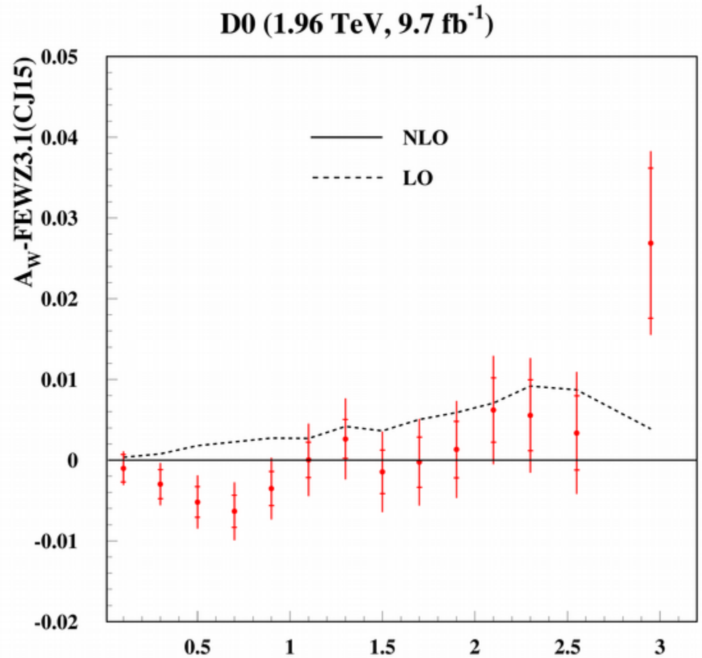
CJ15 results on the d/u ratio

Accardi, Brady, Melnitchouk, Owens, Sato PRD 93, 114017 (2016)

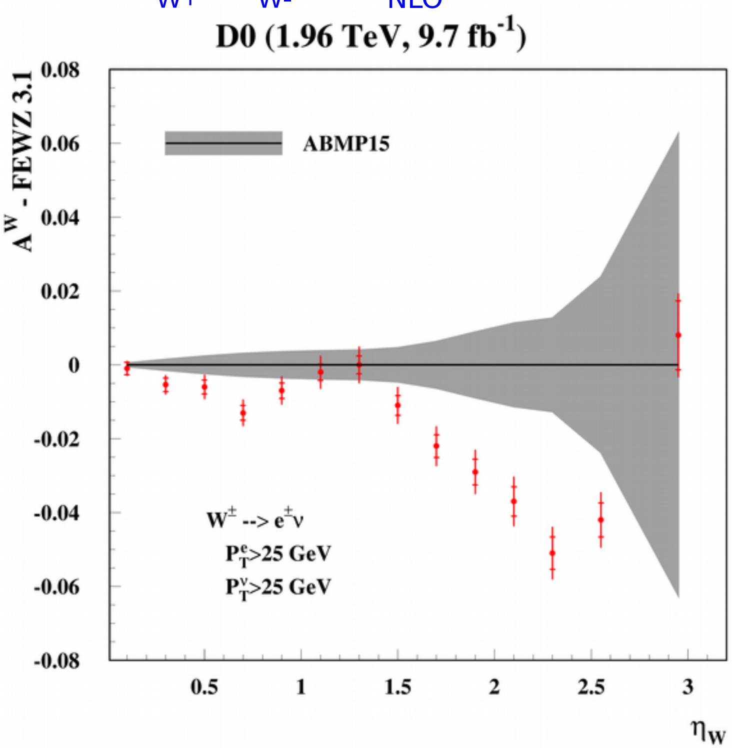
- NLO PDF fit including Tevatron data on W-asymmetry
- value of d/u~0.07 at large x is obtained using flexible PDF shape
- NLO FEWZ predictions with CJ15 PDFs miss data at large x ?



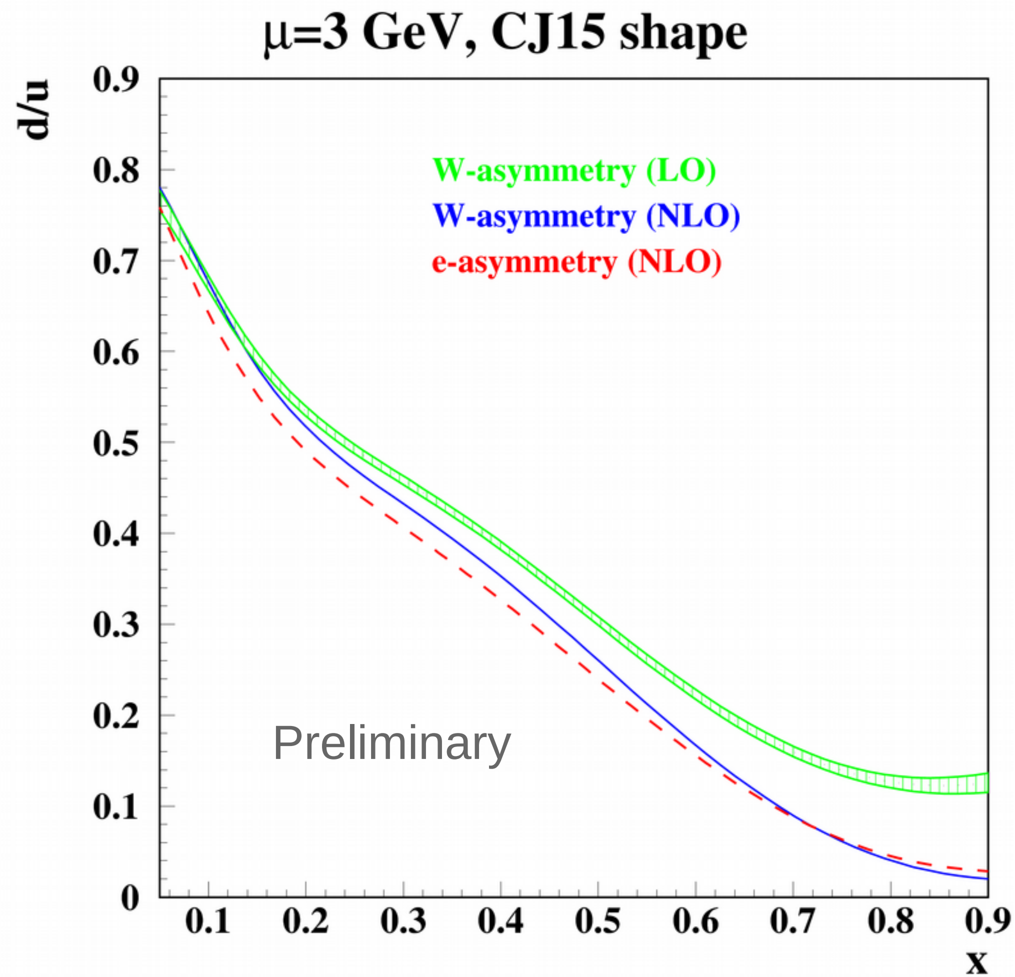




$\sigma_{W+} = \sigma_{W-} \Rightarrow K_{NLO} = 1$



W-asymmetry data go lower that predictions based on the e-asymmetry



- Account of the NNLO corrections moves d/u at large x down
- e-asymmetry data prefer lower d/u at x~0.3
- agreement with AKP results at large x; further comparison of deuteron correction in underway

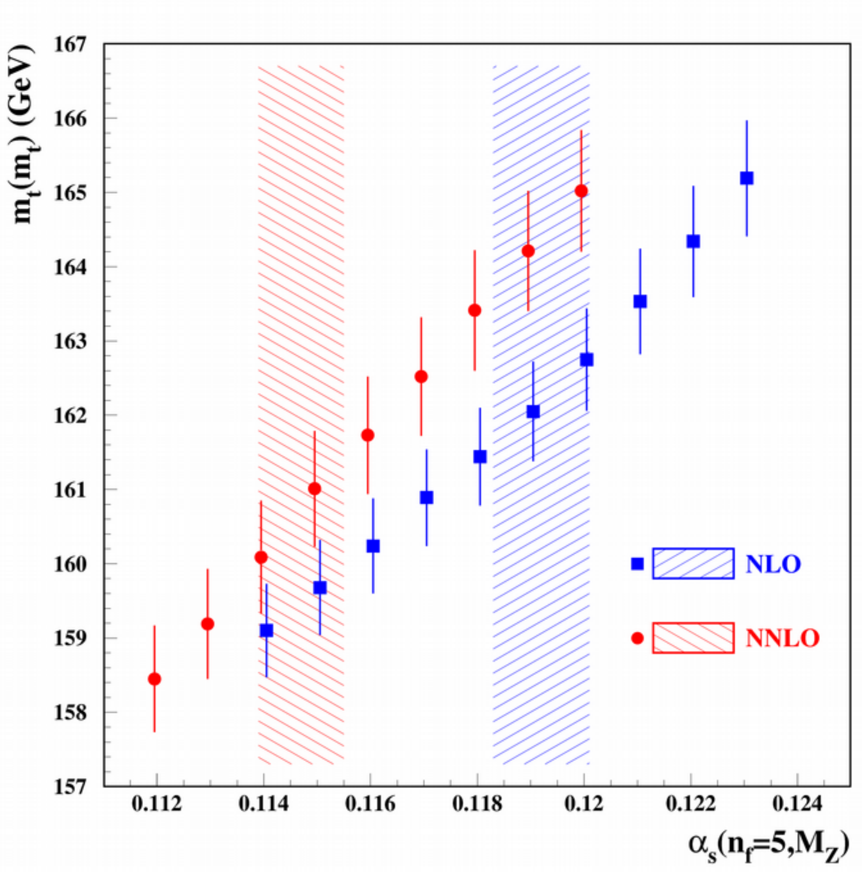
ABMP16 in NLO

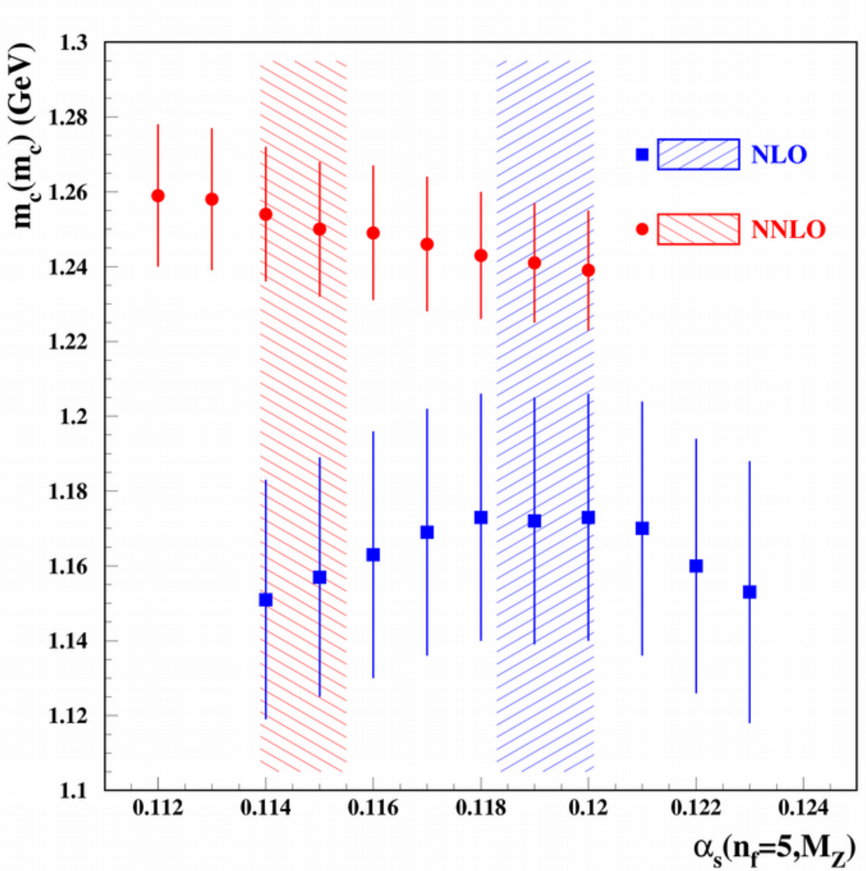
Experiment	Process	NDP	χ^2 NLO	χ^2 NNLO
DIS				
HERA I+II	$e^{\pm}p \to e^{\pm}X$ $e^{\pm}p \to \overset{(-)}{\nu}X$	1168	1528	1510
Fixed-target (BCDMS, NMC, SLAC)	$l^{\pm}p \to l^{\pm}X$	1008	1176	1145
DIS heavy-quark production				
HERA I+II	$e^{\pm}p \to e^{\pm}cX$	52	58	66 [a]
H1, ZEUS	$e^{\pm}p \to e^{\pm}bX$	29	21	21
Fixed-target (CCFR, CHORUS, NOMAD, NuTeV)	$\overset{(-)}{\nu}N \to \mu^{\pm}cX$	232	173	178
DY				
ATLAS, CMS, LHCb	$pp \to W^{\pm}X$ $pp \to ZX$	172	229	223
Fixed-target (FNAL-605, FNAL-866)	$pN \to \mu^{+}\mu^{-}X$	158	219	218
Top-quark production				
ATLAS, CMS	$pp \to tqX$	10	5.7	2.3
CDF&DØ	$\bar{p}p \to tbX$ $\bar{p}p \to tqX$	2	1.9	1.1
ATLAS, CMS	$pp \to t\bar{t}X$	23	14	13
CDF&DØ	$\bar{p}p \to t\bar{t}X$	1	1.4	0.2
Total		2855	3427	3378

[a] This value corrects a misprint in Table V of Ref. [4].

Slightly worse fit quality as compared to the NNLO

Masses and α_s





- Strong correlation between m_t and α_s
- Big difference in m_c between the orders (compensation of NNLO correction)

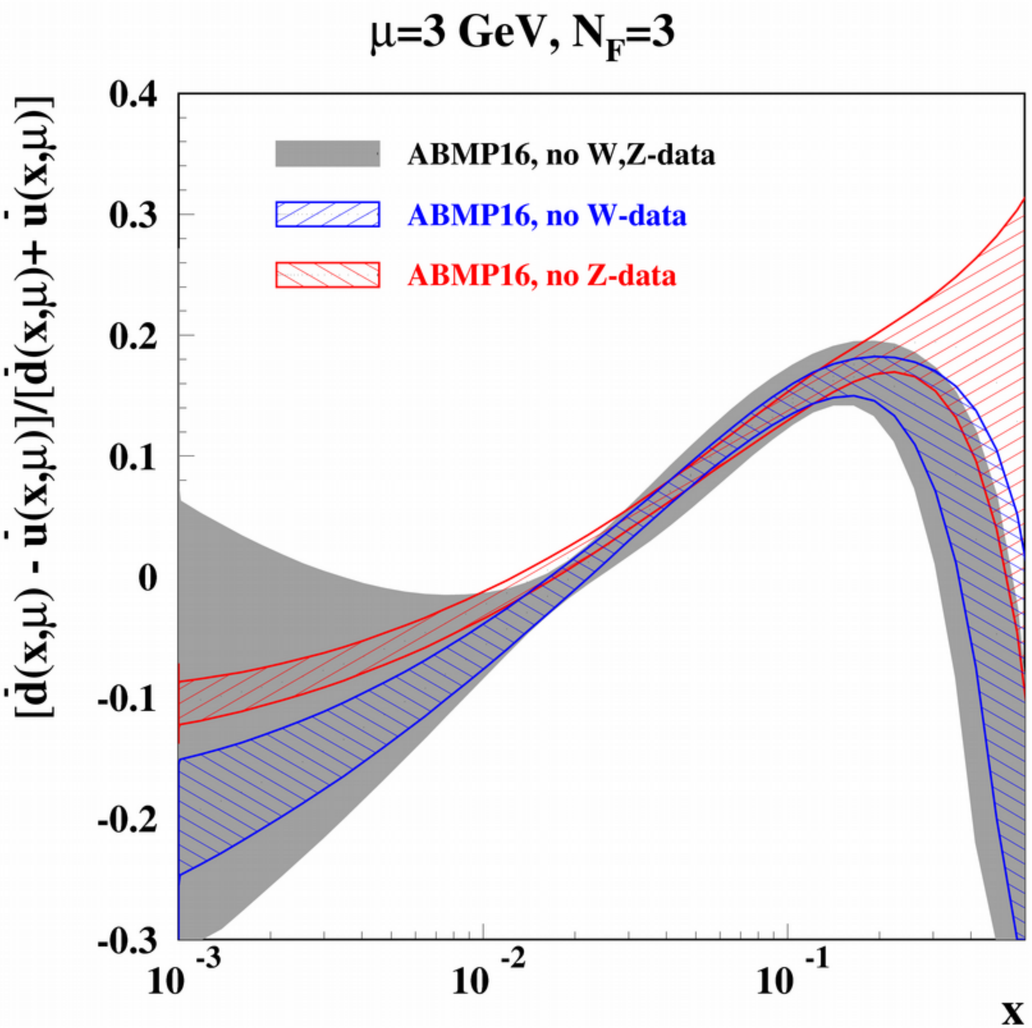
Consistent treatment of quark masses and α_s is needed

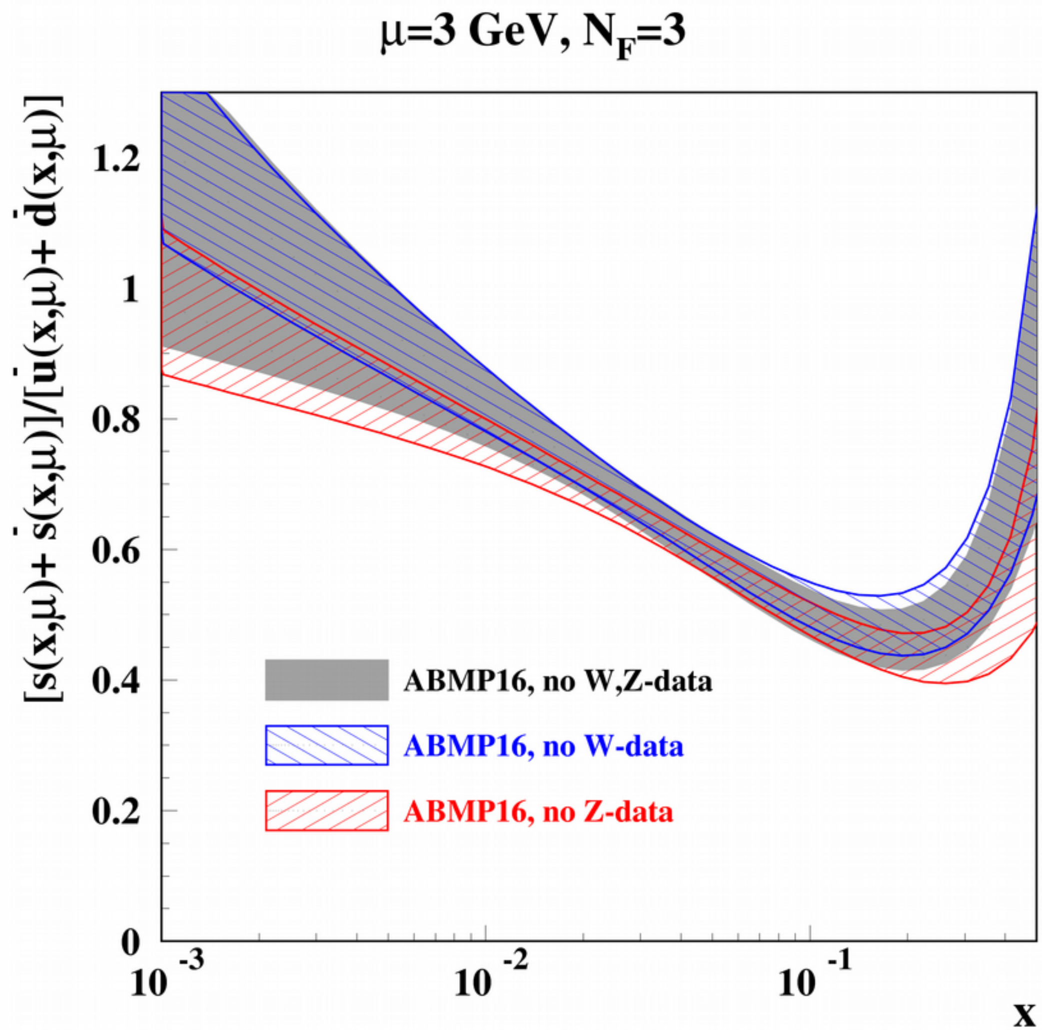
Summary

- Some features of the quark PDFs have been clarified:
  - The ATLAS analysis based on the combination of Drell-Yan and HERA DIS data demonstrates strange sea enhancement by the price of disagreement with the Fermilab fixed-target Drell-Yan data (E-866, E-906) and over-constrained PDF shape at small x.
  - Some strange-sea enhancement at x~0.01 still persist; further comparison with the refined CMS data is desirable
  - The large-x enhancement of d/u ratio observed in the NLO CJ15 analysis is sensitive to the NLO corrections on the W-asymmetry. In case of its consistent treatment the ratio goes much lower than the reported CJ15 result.
- NLO ABMP16 PDF are released, LHAPDF updated

EXTRAS

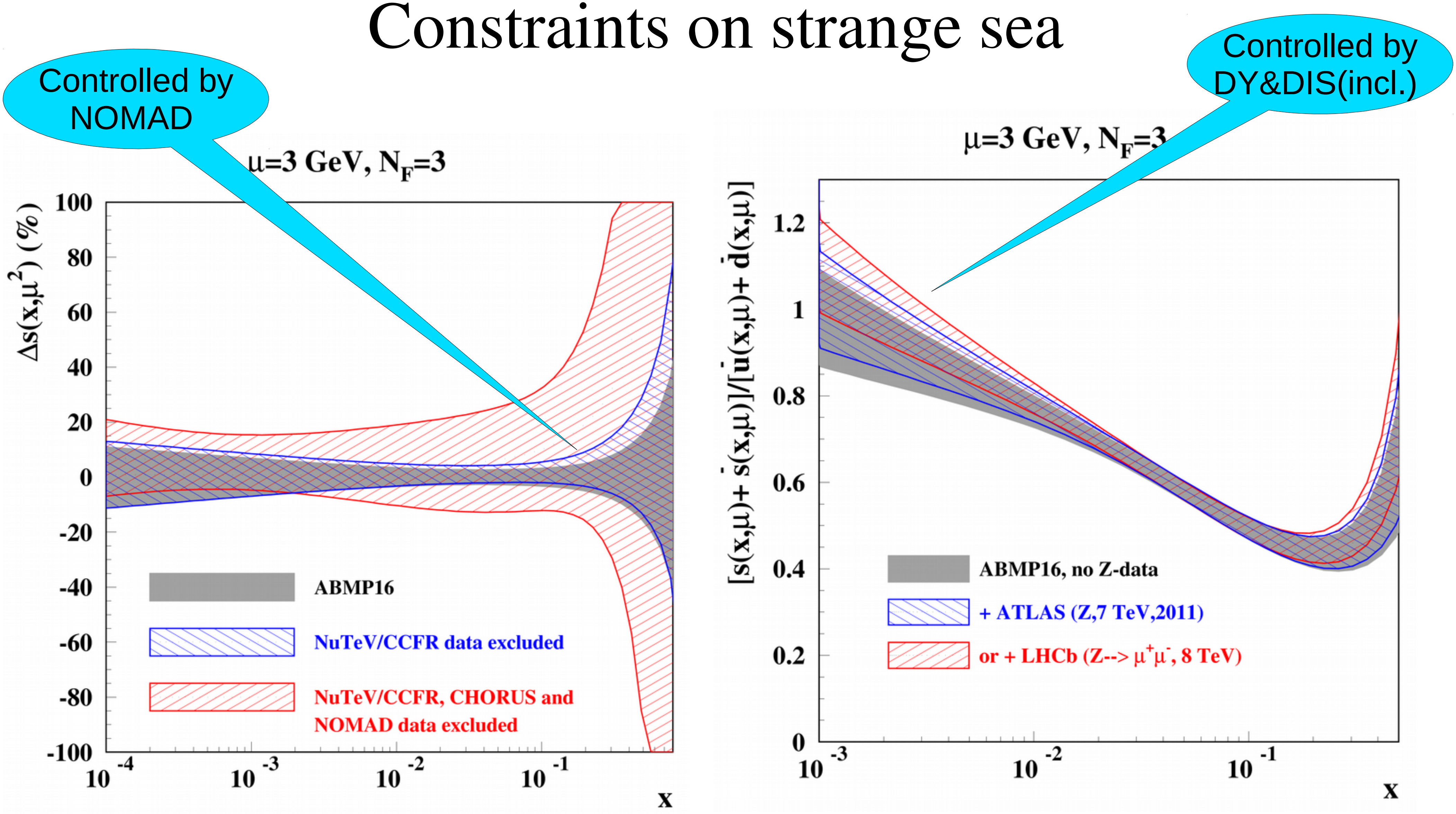
Impact of the W-, Z-data in ABMP16 fit





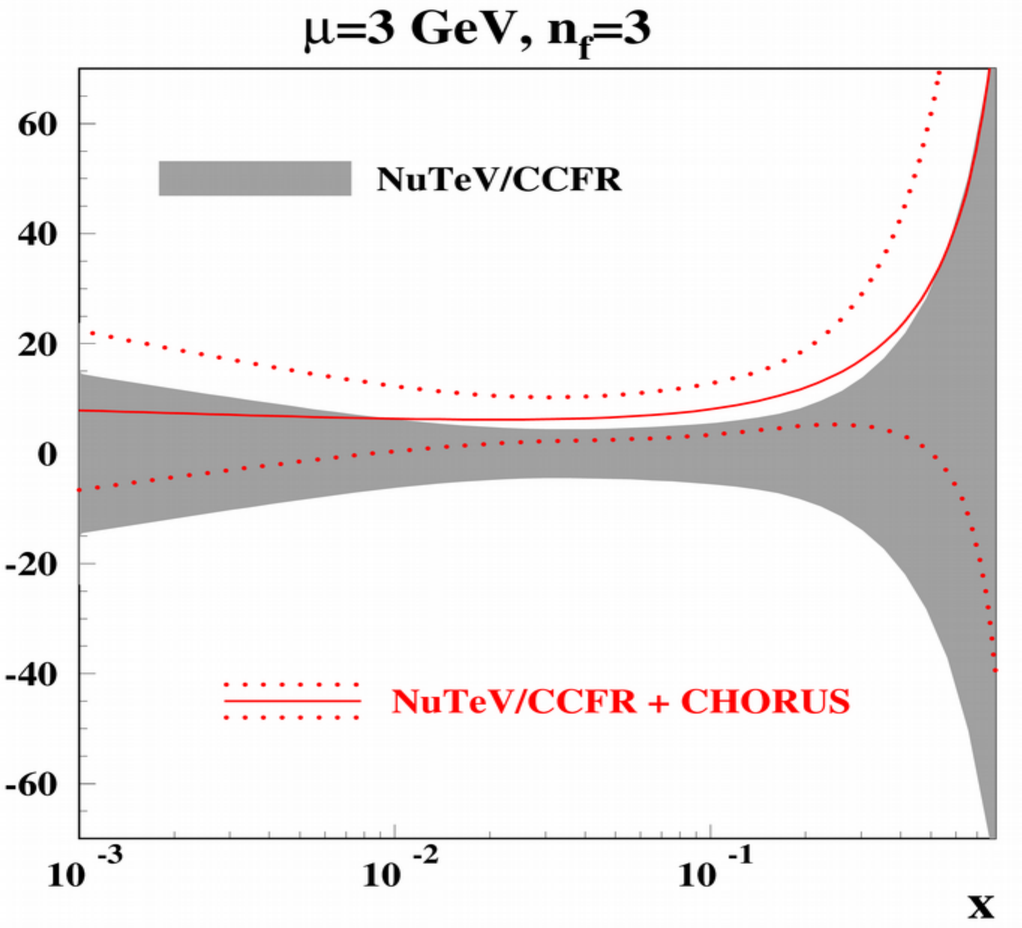
W-, Z-data really control quark disentangling at small x

Constraints on strange sea



- Uncertainty of ~5% is achieved at x around 0.1
- NuTeV/CCFR data play no essential role → impact of the nuclear corrections is greatly reduced (NOMAD and CHORUS give the ratio CC/incl.)

CHORUS charm data



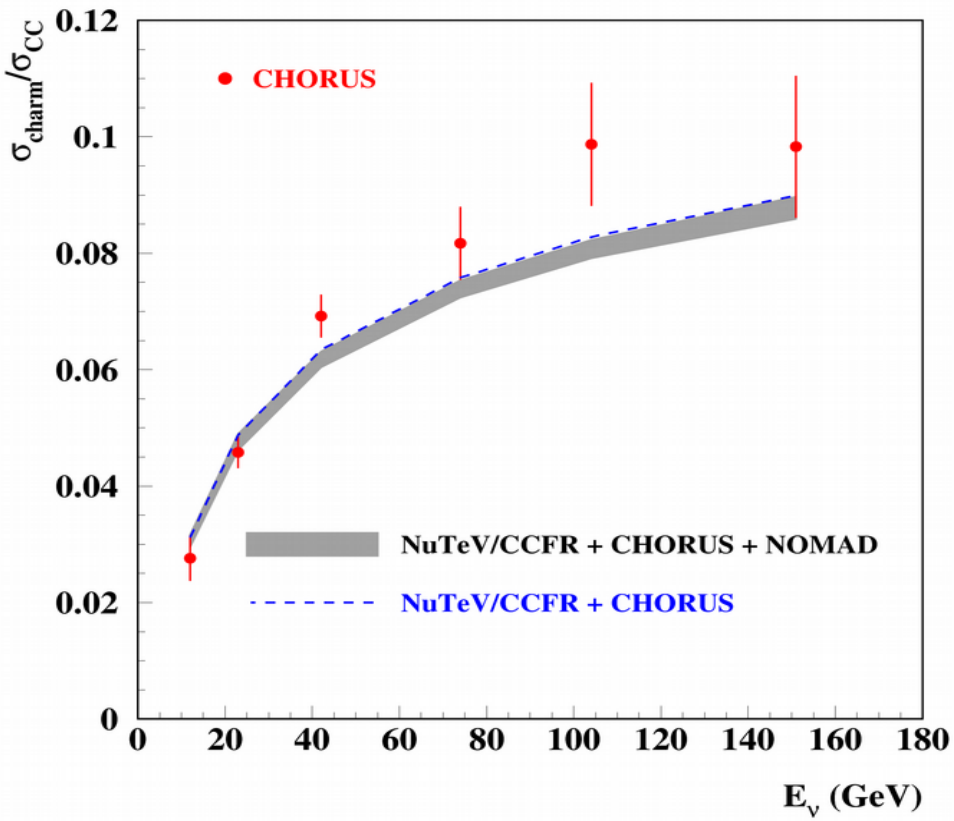
Emulsion data on charm/CC ratio with the charmed hadron vertex measured

CHORUS NJP 13, 093002 (2011)

– full phase space measurements

– no sensitivity to B_μ

– low statistics (2013 events)

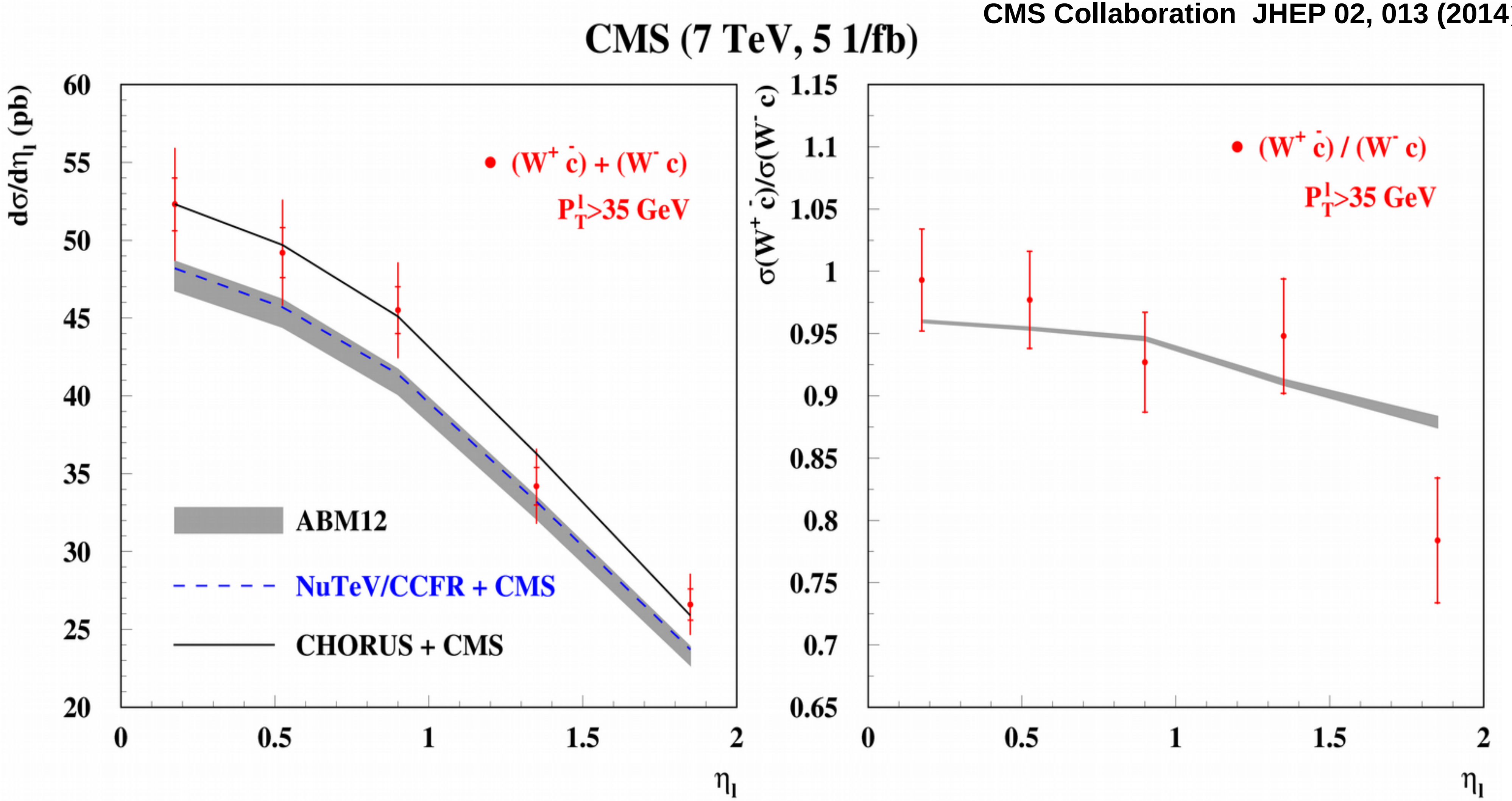


CHORUS data pull strangeness up, however the statistical significance of the effect is poor

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

CMS W+charm data

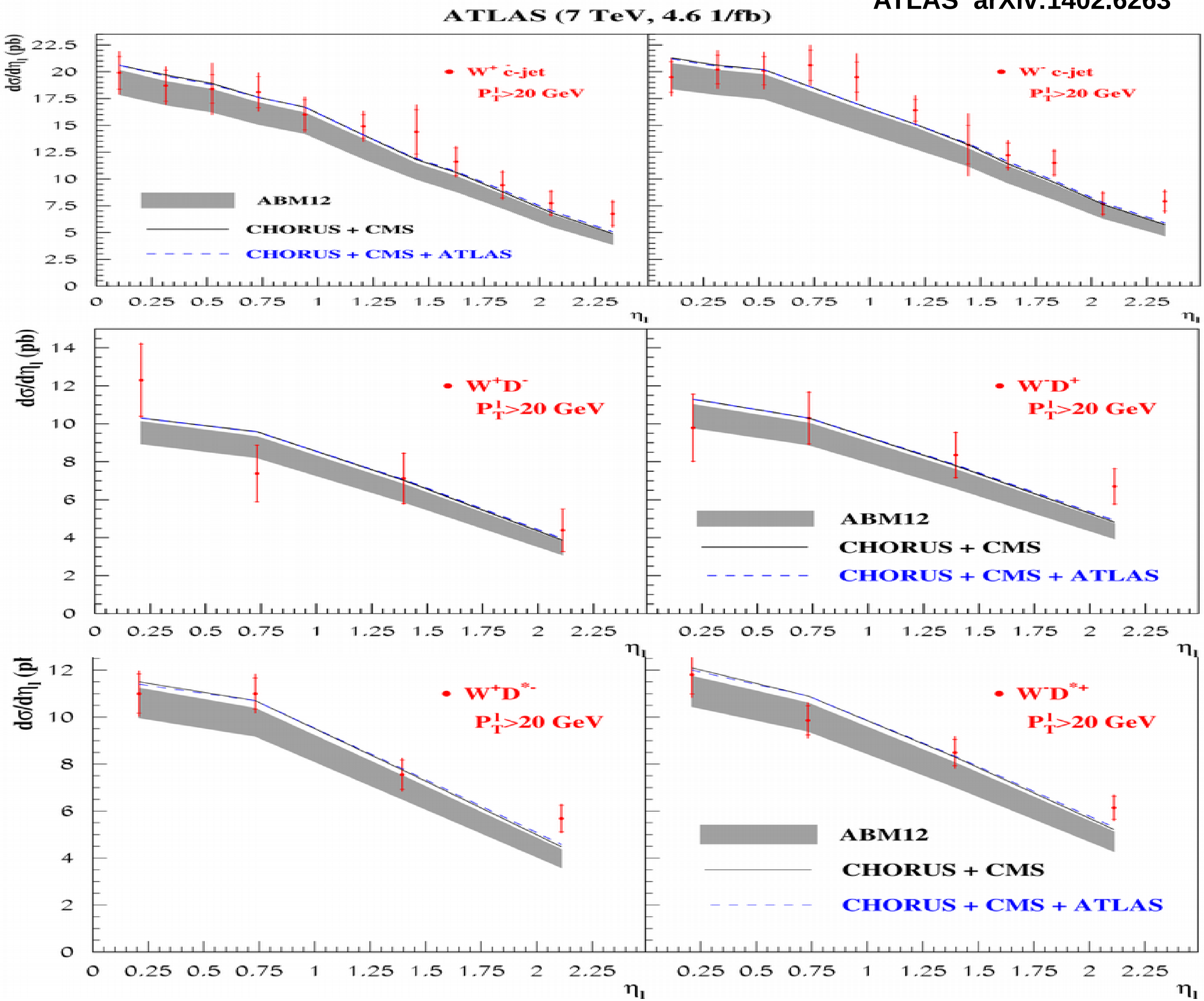
CMS Collaboration JHEP 02, 013 (2014)



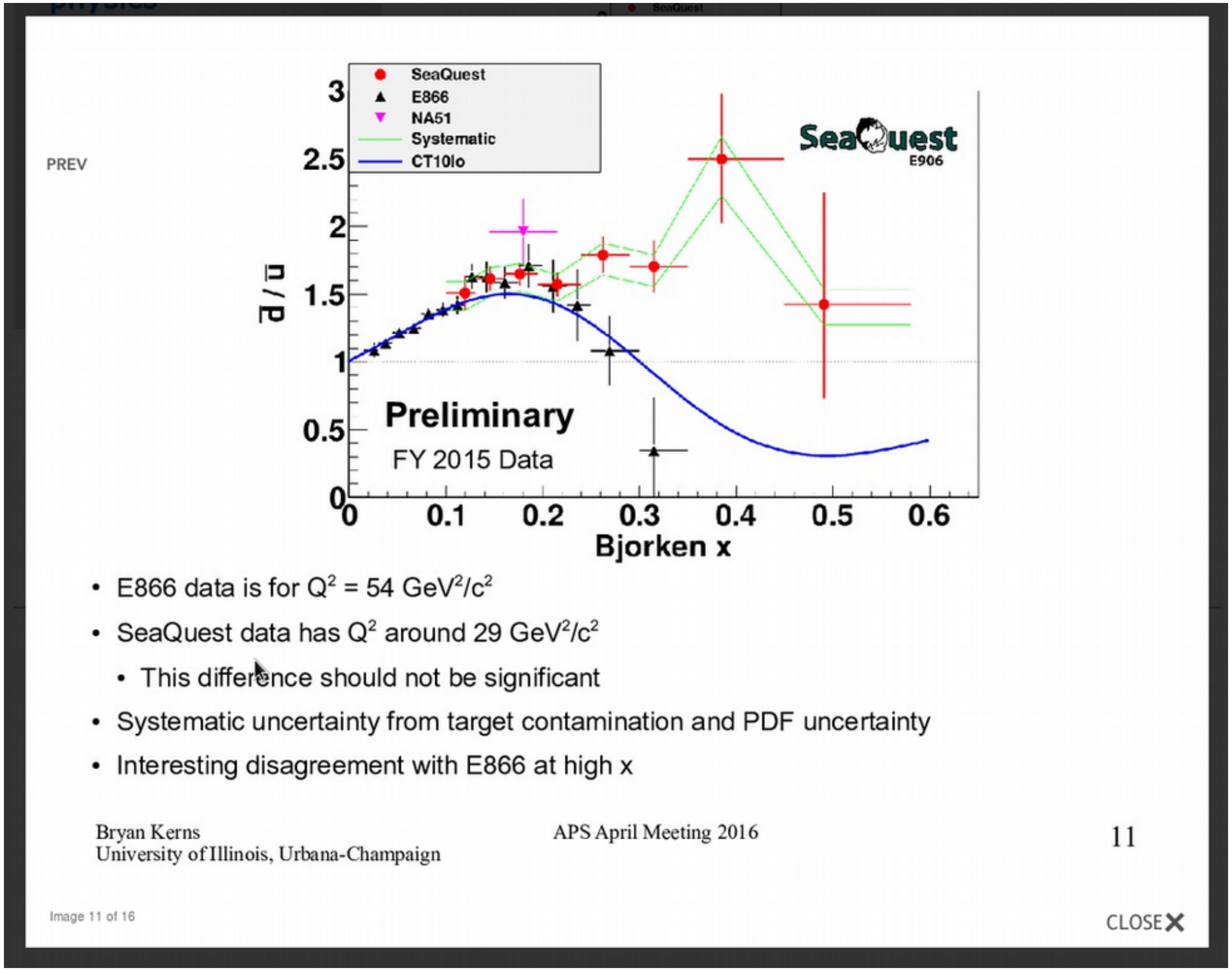
- CMS data go above the NuTeV/CCFR by 1σ; little impact on the strange sea
- The charge asymmetry is in a good agreement with the charge-symmetric strange sea
- Good agreement with the CHORUS data

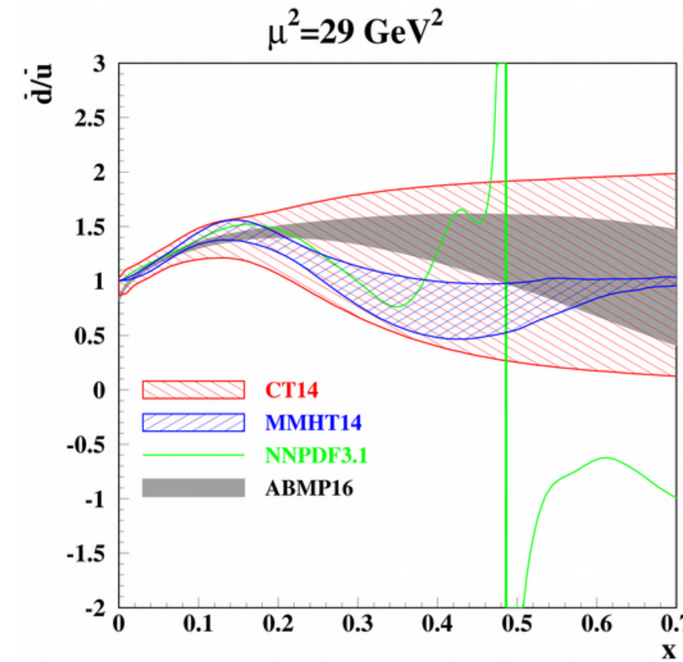
ATLAS W+charm data

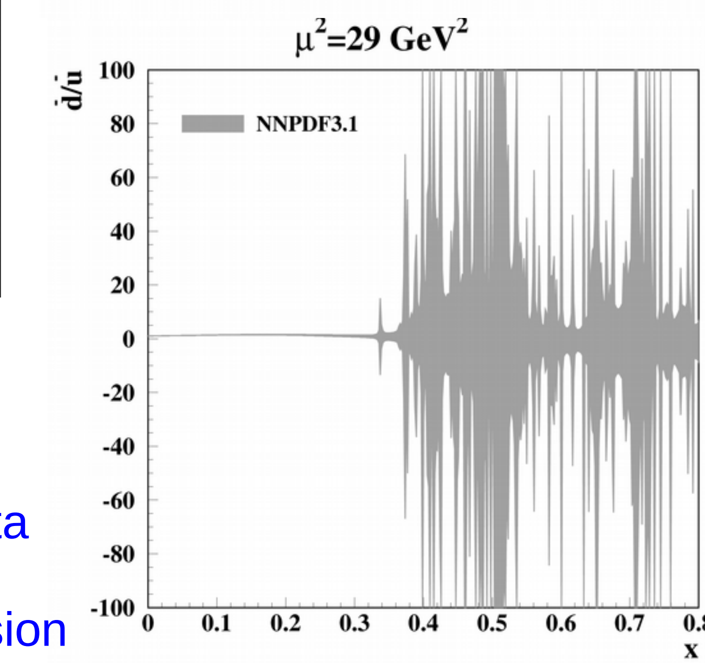
ATLAS arXiv:1402.6263



SeaQuest (FNAL-E906) prospects

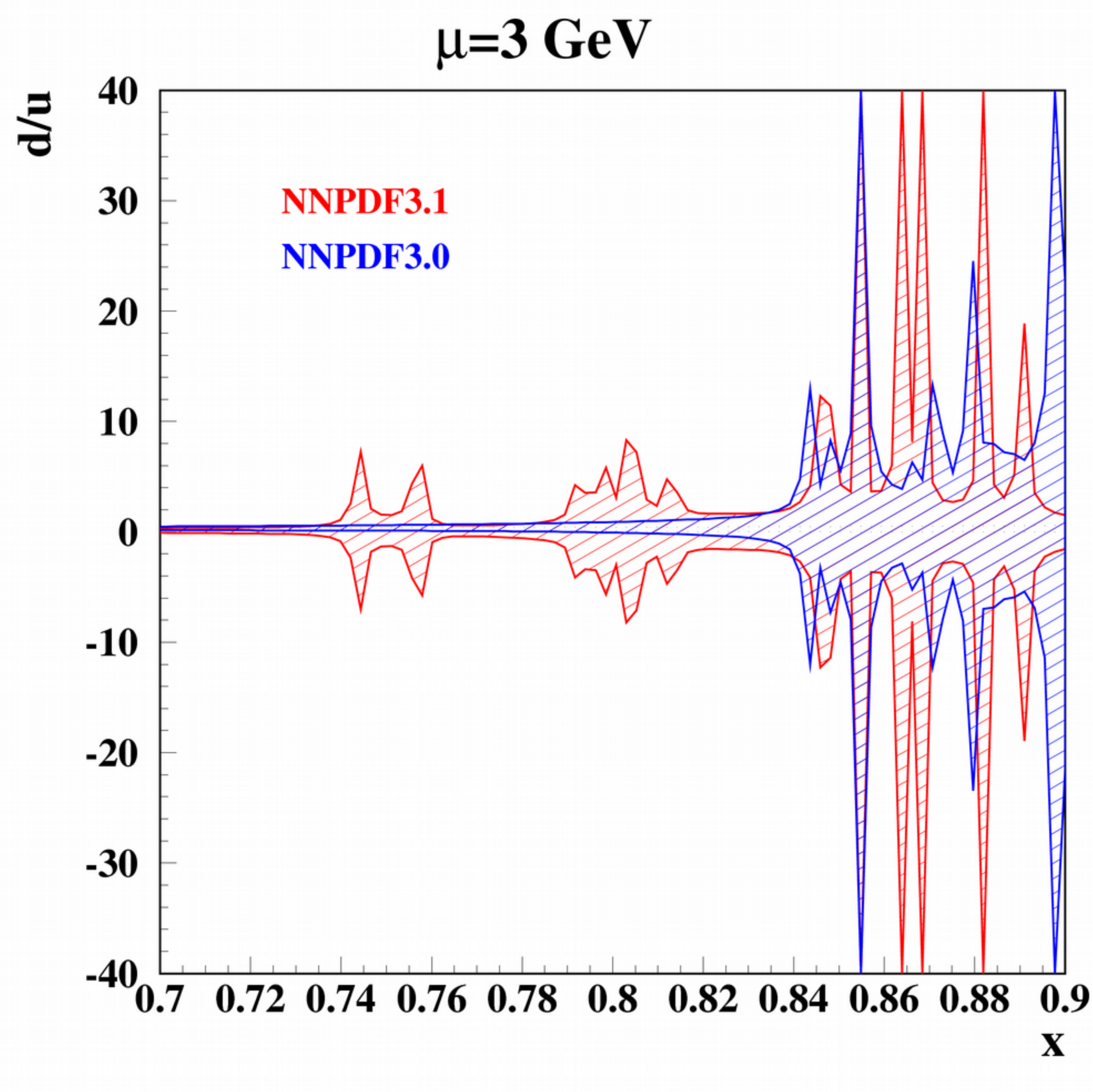






- E906 confirms the E866 results at x ~0.1 and continues the positive trend in the sea iso-spin asymmetry at bigger x
- The existing PDF sets can be consolidated with the E906 data
- HERMES/COMPASS data confirm the strangeness suppression

Borsa, Sassot, Stratmann hep-ph/1708.01630



μ=3 GeV
d/u
NNPDF3.1
NNPDF3.0
40
30
20
10
0
-10
-20
-30
-40
0.7
0.72
0.74
0.76
0.78
0.8
0.82
0.84
0.86
0.88
0.9
x

The ABMP16 fit ingredients

QCD:

- NNLO evolution
- NNLO massless DIS and DY coefficient functions
- NLO+ massive DIS coefficient functions (**FFN scheme**)
  - – NLO + NNLO(approx.) 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

DATA:

- DIS NC/CC inclusive (HERA I+II added)
- 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
- deuteron data are excluded

Power corrections:

- target mass effects
- dynamical twist-4 terms

sa, Blümlein, Moch, Plačakytė PRD 96, 014011 (2017)

…...

DY data selection in the ABMP16 fit

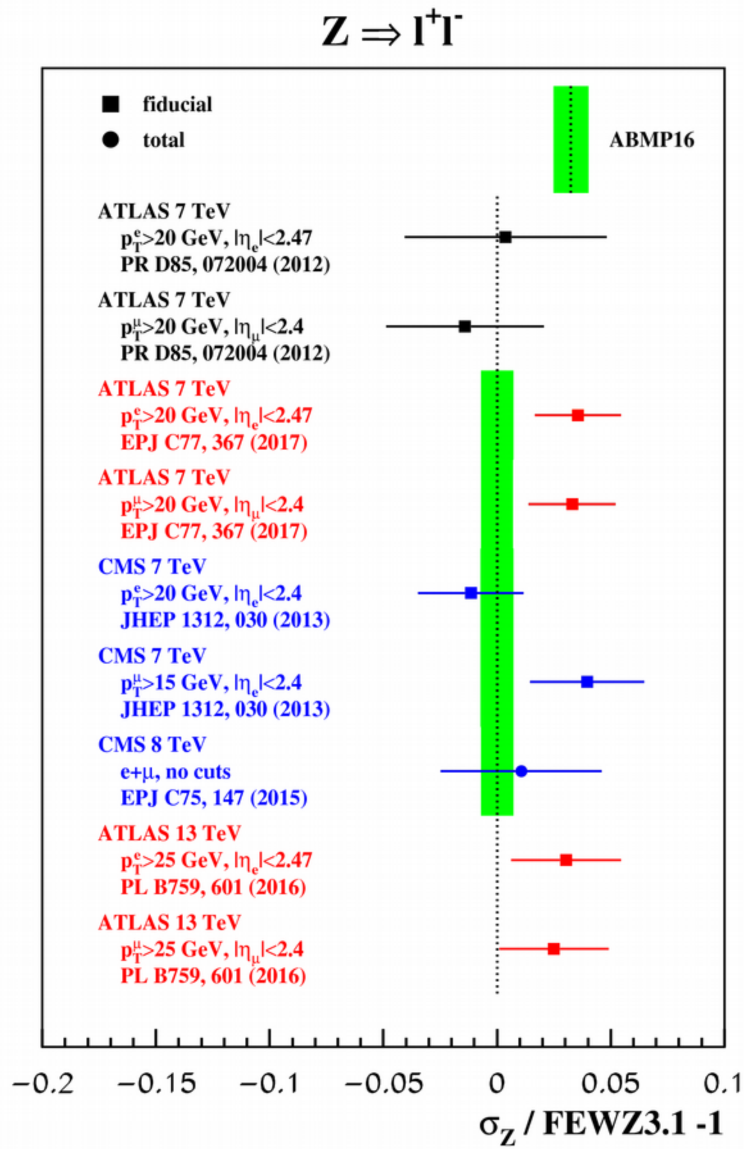
Experiment	ATLAS		CMS		DØ		LHCb		
$\sqrt{s}$ (TeV)	7	13	7	8	1.96		7	8	
Final states	$W^+ \to l^+\nu$ $W^- \to l^-\nu$ $Z \to l^+l^-$	$W^+ \to l^+\nu$ $W^- \to l^-\nu$ $Z \to l^+l^-$	$W^+ \to \mu^+\nu$ $W^- \to \mu^-\nu$ (asym)	$W^+ \to \mu^+\nu$ $W^- \to \mu^-\nu$	$W^+ \to \mu^+\nu$ $W^- \to \mu^-\nu$ (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
NDP	30	6	11	22	10	13	31(33) [a]	17	32(34)
ABMP16	31.0	9.2	22.4	16.5	17.6	19.0	45.1(54.4)	21.7	40.0(59.2)
CJ15	–	–	–	–	20	29	–	–	–
CT14	42	–	– [b]	–	–	34.7	–	–	–
HERAFitter	–	–	–	–	13	19	–	–	–
MMHT16	39 [c]	–	–	21	21 [c]	26	(43)	29	(59)
NNPDF3.1	29	–	19	–	16	35	(59)	19	(47)

[a] The values of NDP and χ^2 correspond to the unfiltered samples.
[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.
[c] The value obtained in MMHT14 fit.

sa, Blümlein, Moch, Plačakytė PRD 94, 114038 (2016)

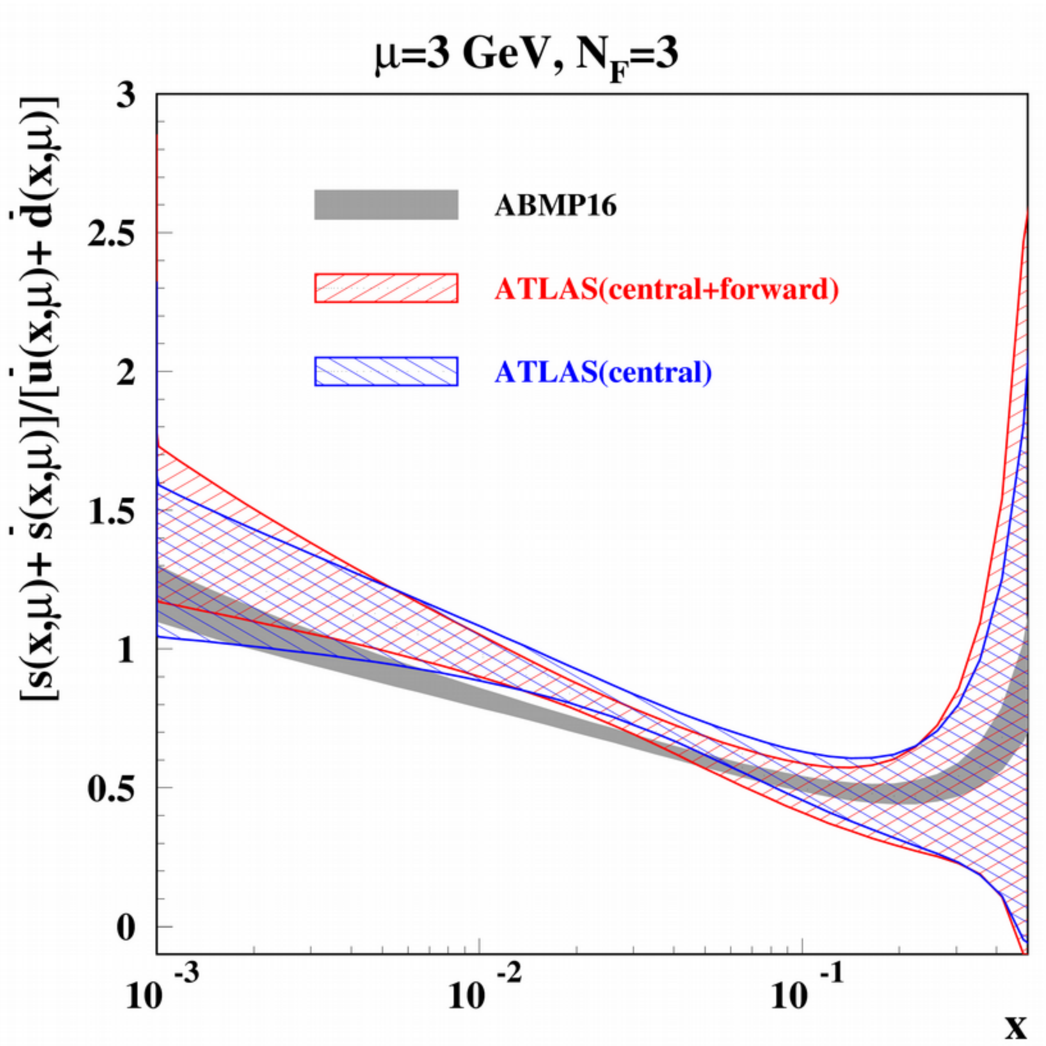
Many early low-statistical Tevatron and LHC data are not included into the fit

LHC data on central Z-boson production



The CMS data go somewhat lower than the ATLAS ones, however, significance of discrepancy is marginal and further clarification is necessary

recent CMS update at 8 TeV, 19.7 1/fb: hep-ex/1710.07955

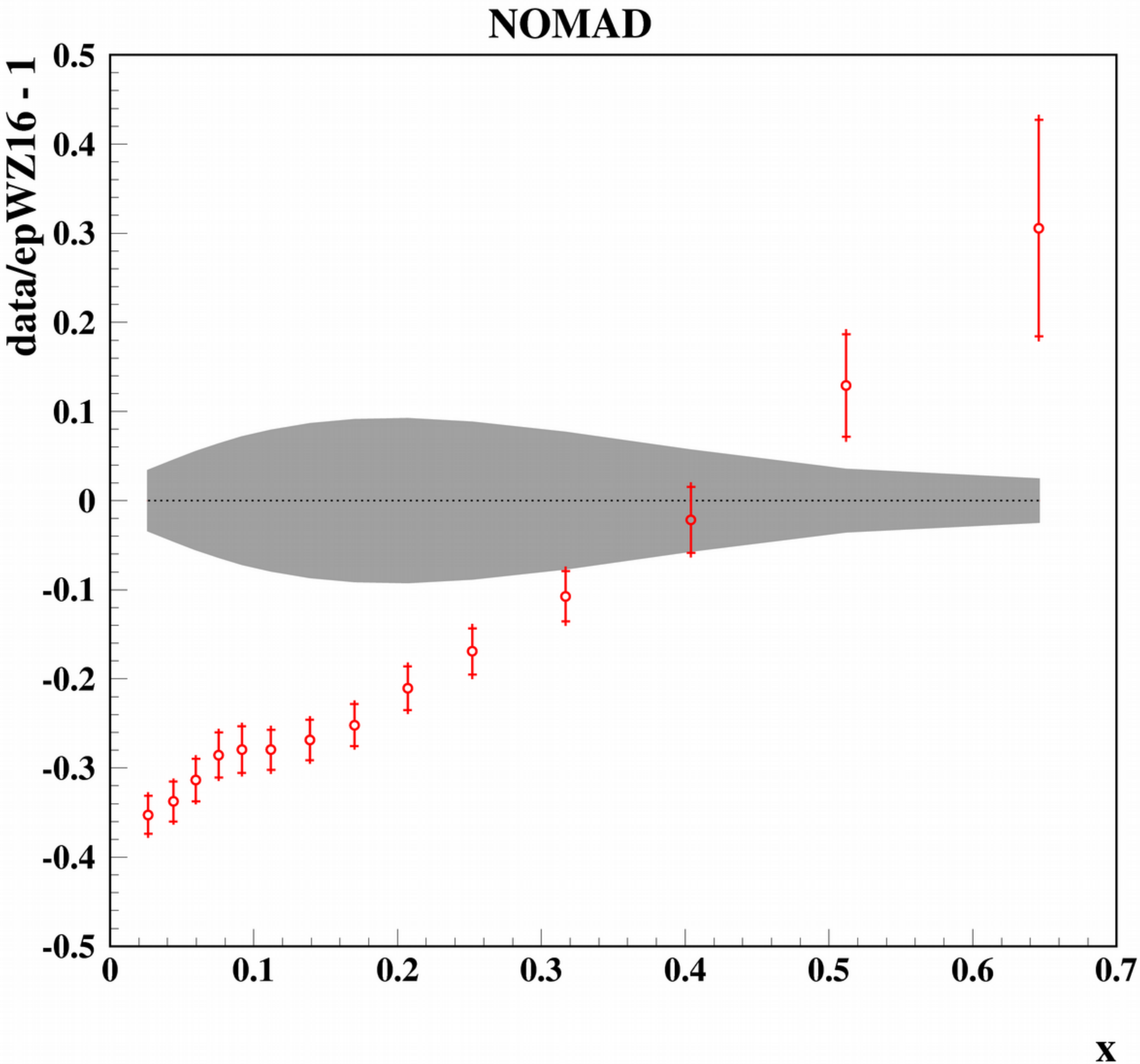


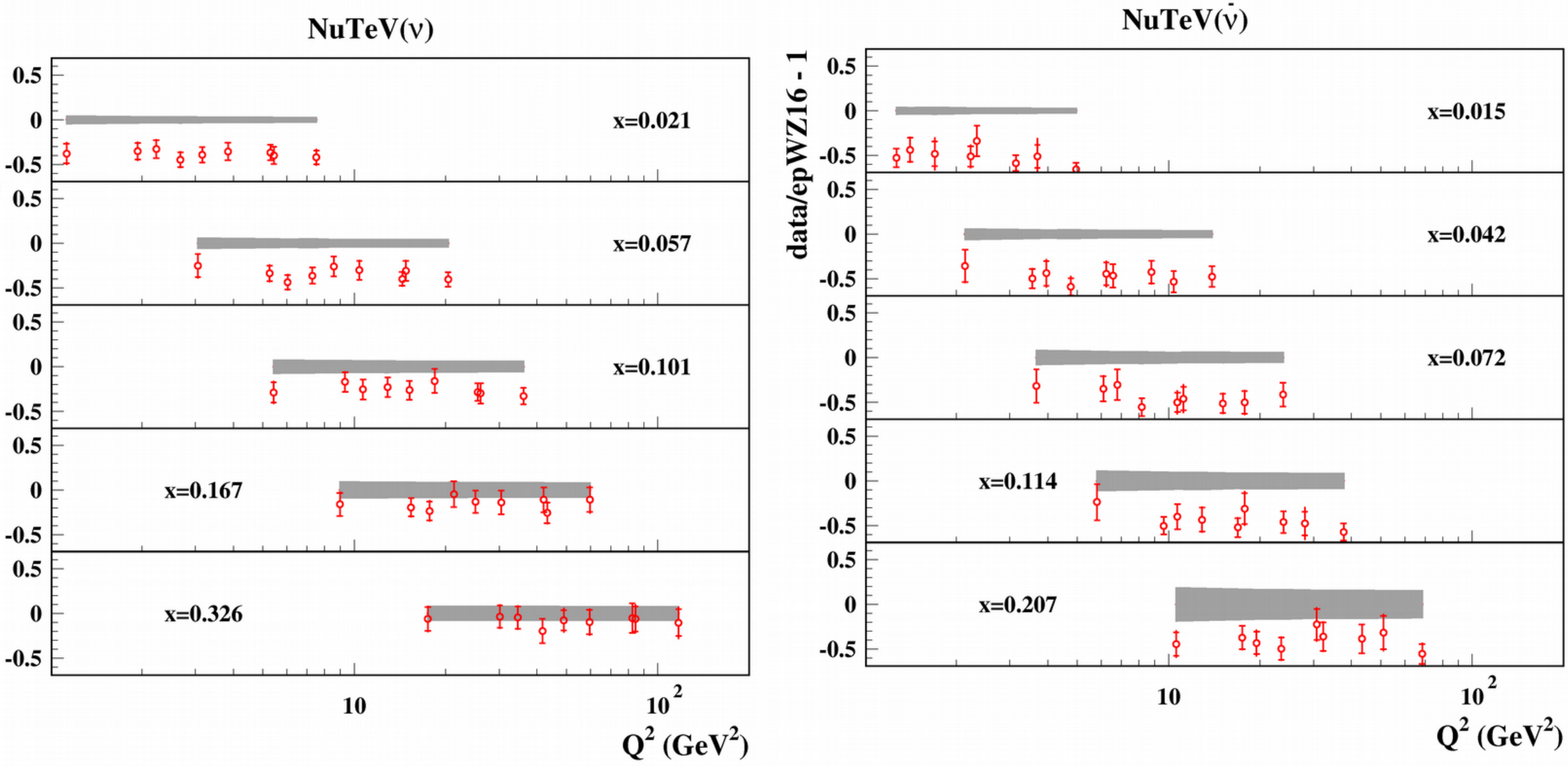
- Forward Z-boson data pull strangeness down
- Tension between central and forward Z-boson samples

	central	forward	central+ forward
X^2/NDP	40/34	36/31	76/43

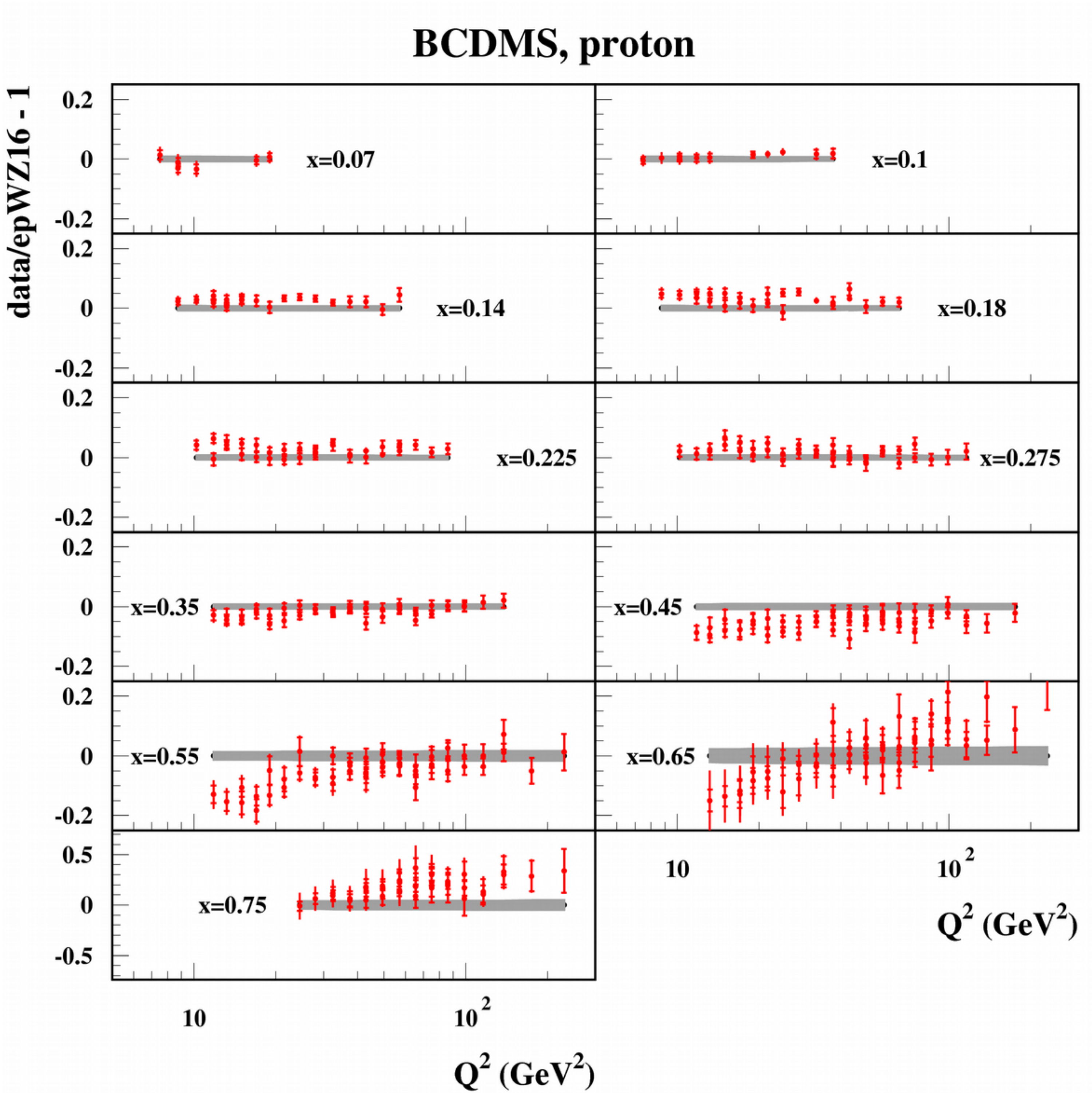
Data set	ATLAS-epWZ16 χ^2/n.d.f.
ATLAS $W^+ \to \ell^+\nu$	8.4 / 11
ATLAS $W^- \to \ell^-\bar{\nu}$	12.3 / 11
ATLAS $Z/\gamma^* \to \ell\ell$ ($m_{\ell\ell}$ = 46–66 GeV)	25.9 / 6
ATLAS $Z/\gamma^* \to \ell\ell$ ($m_{\ell\ell}$ = 66–116 GeV)	15.8 / 12
ATLAS forward $Z/\gamma^* \to \ell\ell$ ($m_{\ell\ell}$ = 66–116 GeV)	7.4 / 9
ATLAS $Z/\gamma^* \to \ell\ell$ ($m_{\ell\ell}$ = 116–150 GeV)	7.1 / 6
ATLAS forward $Z/\gamma^* \to \ell\ell$ ($m_{\ell\ell}$ = 116–150 GeV)	4.0 / 6
ATLAS Correlated + Log penalty	27.2
ATLAS Total	108 / 61

ATLAS arXiv:1612.03016

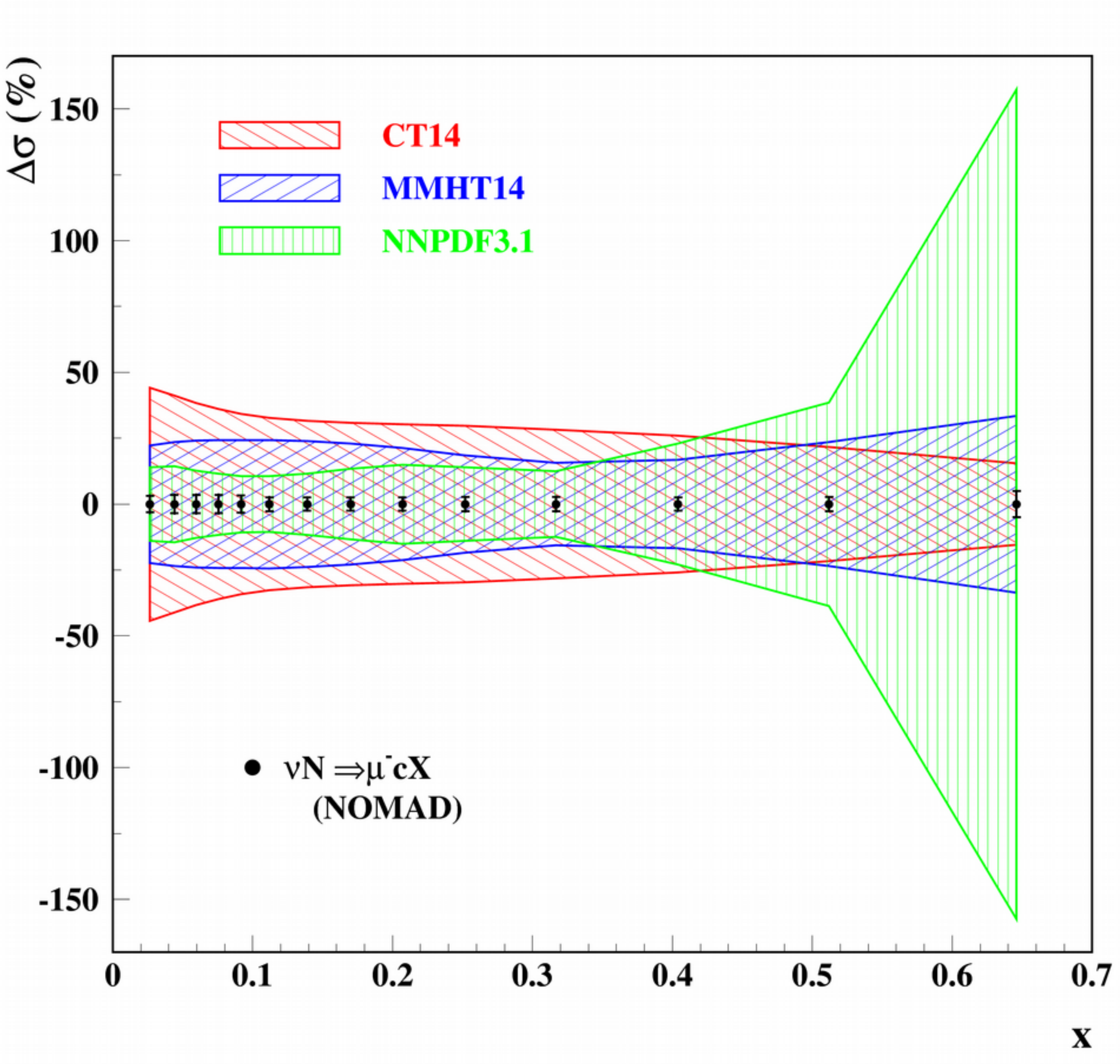

NOMAD
data/epWZ16 - 1
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
x



NuTeV(ν)
NuTeV($\bar{\nu}$)
data/epWZ16 - 1
x=0.021
x=0.057
x=0.101
x=0.167
x=0.326
x=0.015
x=0.042
x=0.072
x=0.114
x=0.207
0.5
0
-0.5
10
10 2
Q2 (GeV2)

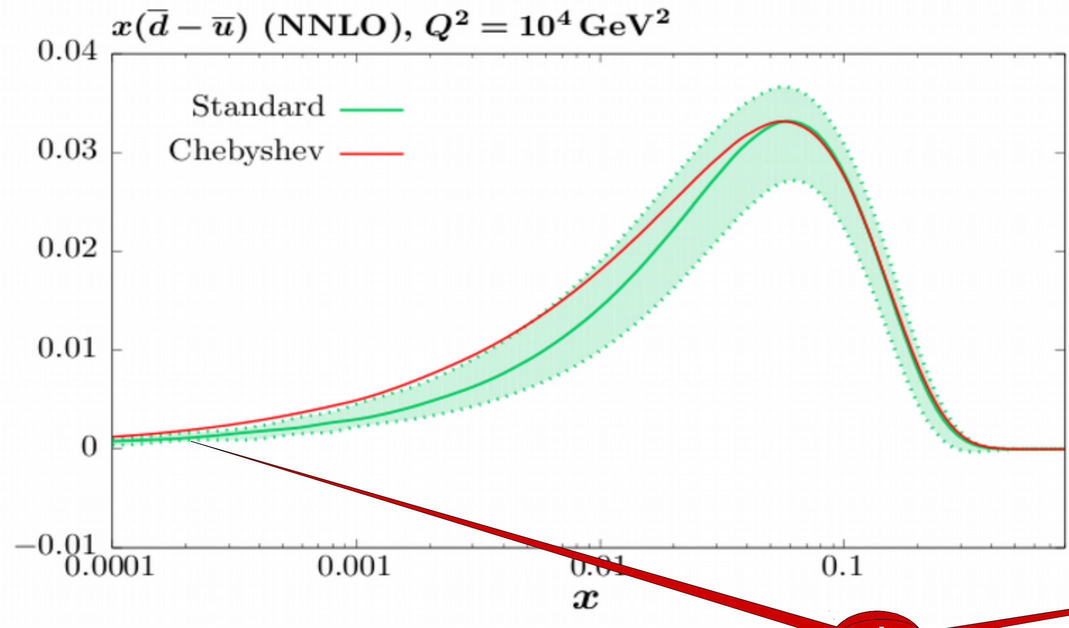

BCDMS, proton
data/epWZ16 - 1
x=0.07
x=0.1
x=0.14
x=0.18
x=0.225
x=0.275
x=0.35
x=0.45
x=0.55
x=0.65
x=0.75
0.2
0
-0.2
0.5
-0.5
10
10 2
Q2 (GeV2)

Impact of NOMAD data

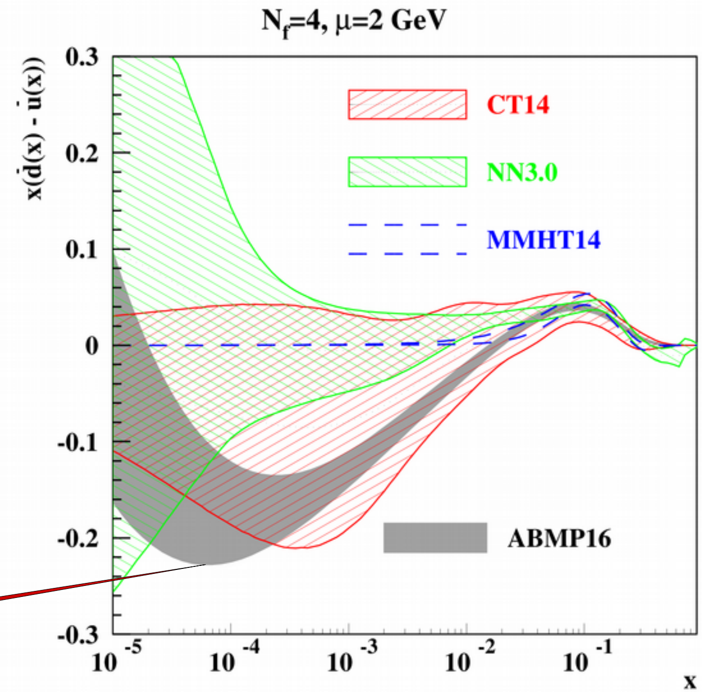


- Evident room for the PDF improvement by adding NOMAD data to various PDF fits
- Big spread in the predictions ⇒ PDF4LHC averaging provides inefficient estimate

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



Thorne, this conference



	no. points	NLO χ^2_{pred}	NLO χ^2_{new}	NNLO χ^2_{pred}	NNLO χ^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

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

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

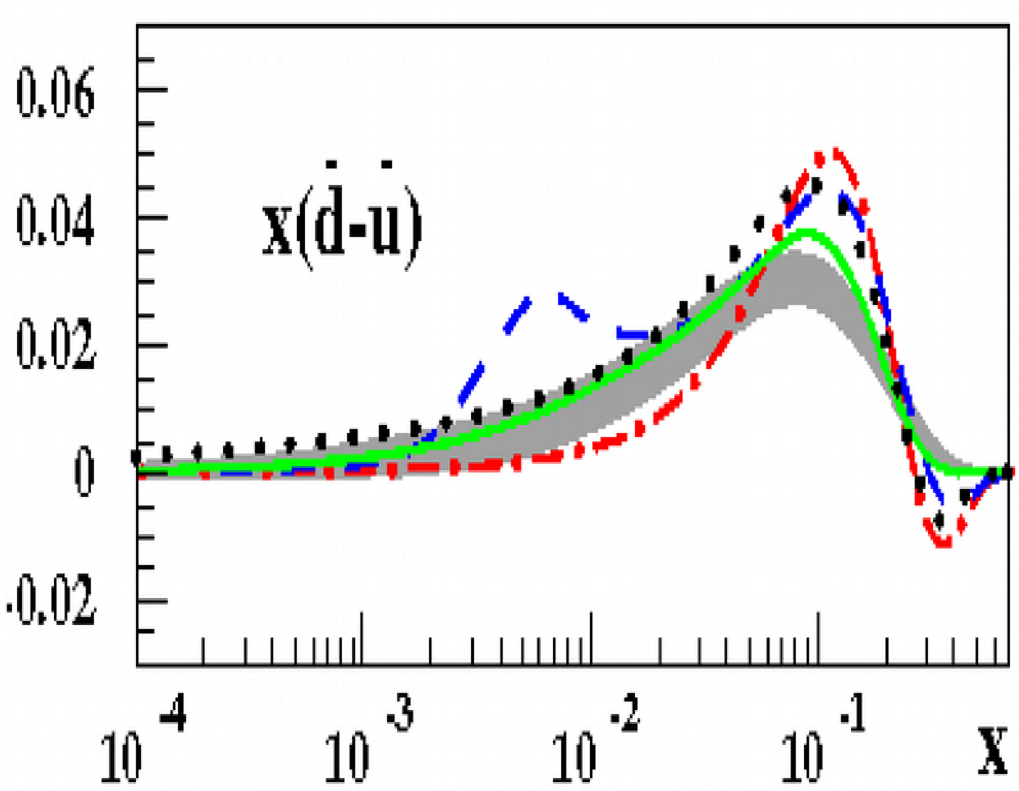
dbar≠ubar at small x
(the same applies for CT14)

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

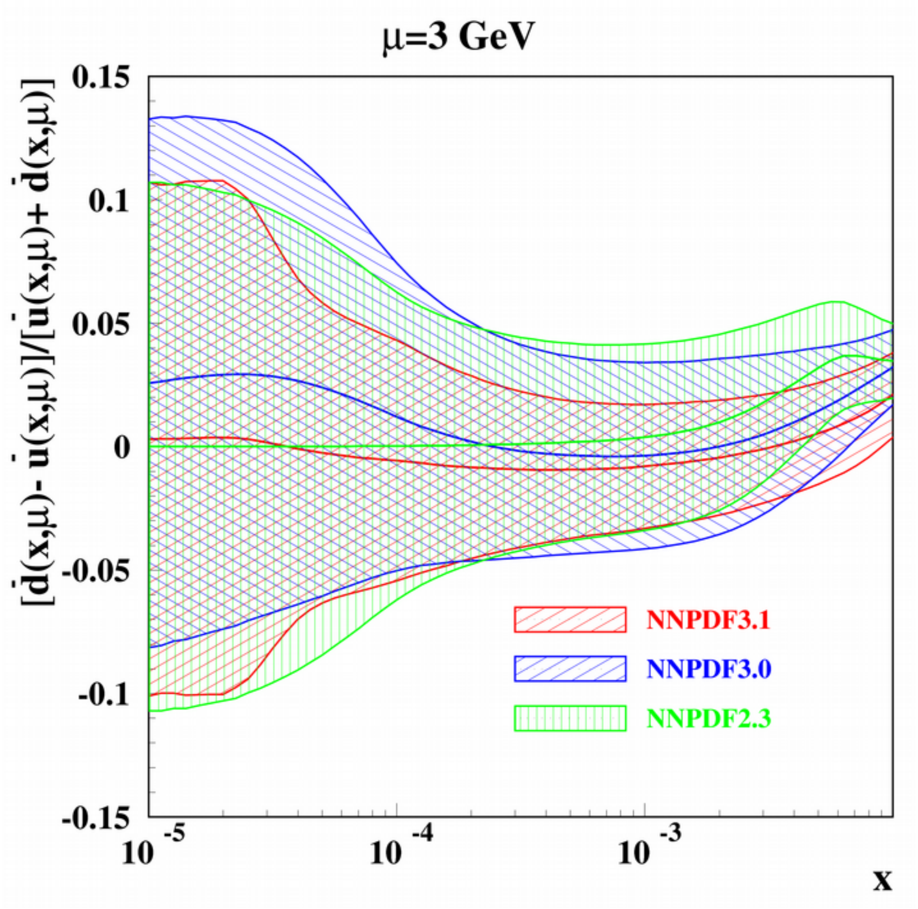
184/119 (MMHT16)

171/119 (ABMP16, no filtering), account of other DY data should increase the difference

Sea quark iso-spin asymmetry



ABM12 CT10 JR09 MSTW08 NNPDF2.3

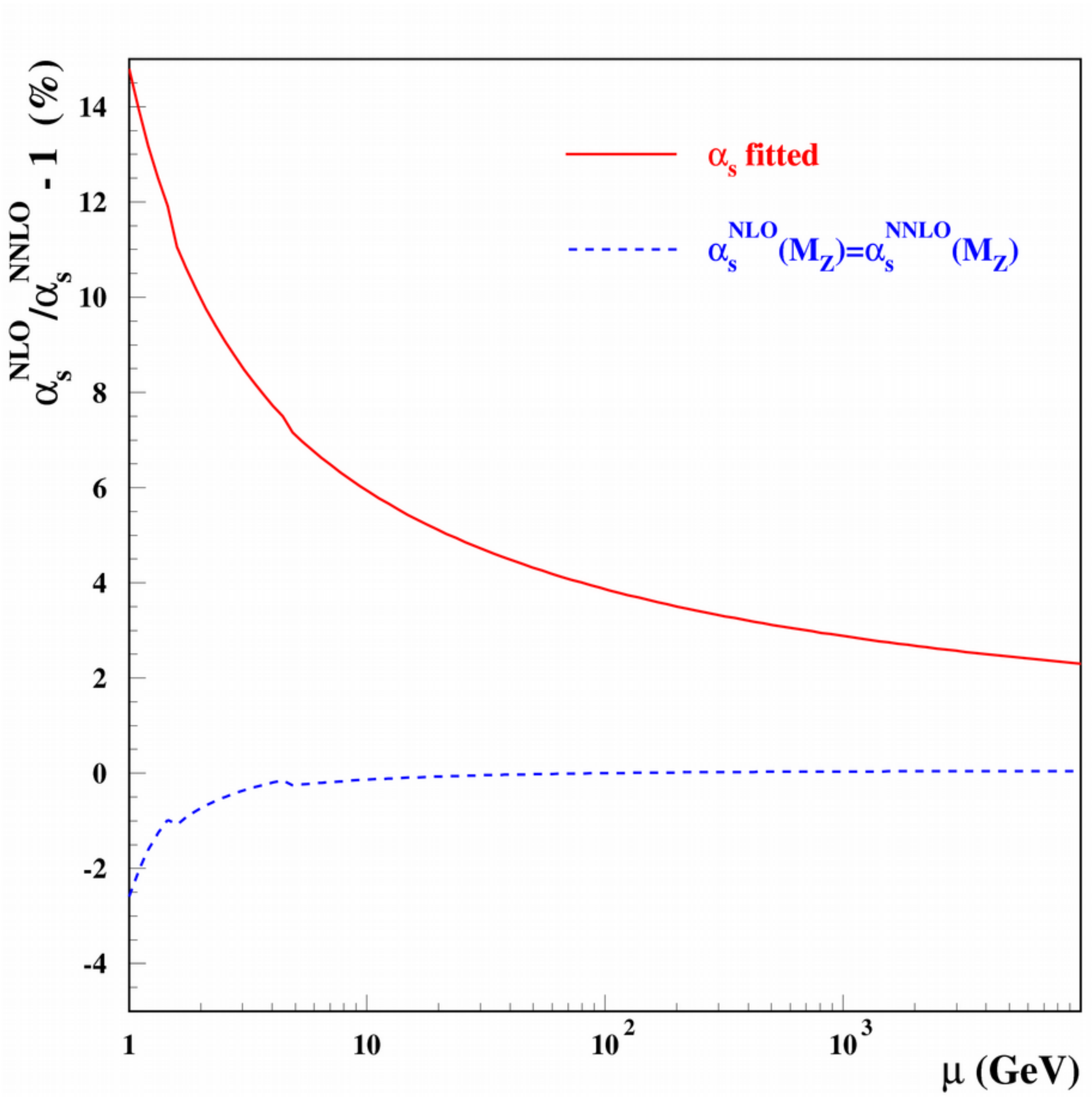


sa, Blümlein, Moch PRD 89, 054028 (2014)

- 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



$\alpha_s^{NLO}/\alpha_s^{NNLO}$ - 1 (%)
14
12
10
8
6
4
2
0
-2
-4
1
10
10^2
10^3
μ (GeV)
α_s fitted
$\alpha_s^{NLO}(M_Z)=\alpha_s^{NNLO}(M_Z)$