Strange and non-strange quark distributions

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Terascale alliance meeting, DESY, 28 Nov 2017

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

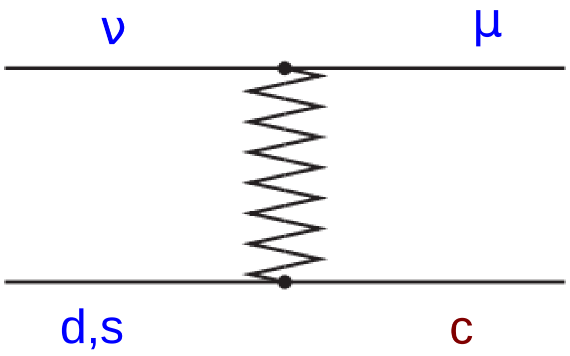
Power corrections:

- target mass effects
- dynamical twist-4 terms

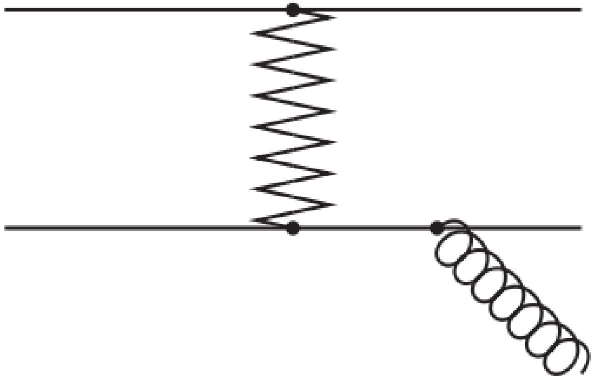
sa, Blümlein, Moch, Plačakytė PRD 96, 014011 (2017)
…...

Strange sea from the νN DIS

LO



NLO



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

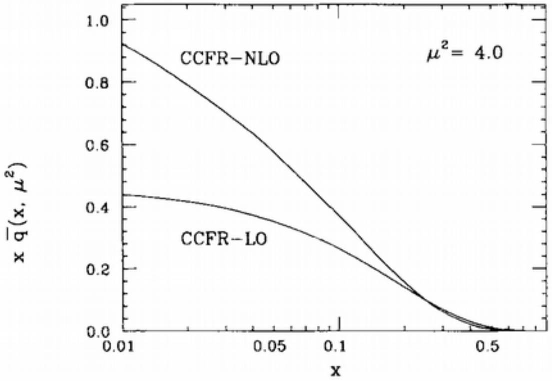


Fig. 3. The quark sea distribution $x\bar{q}(x, \mu^2 = 4.0\,\mathrm{GeV}^2/\mathrm{c}^2)$ determined at next-to-leading order and leading order

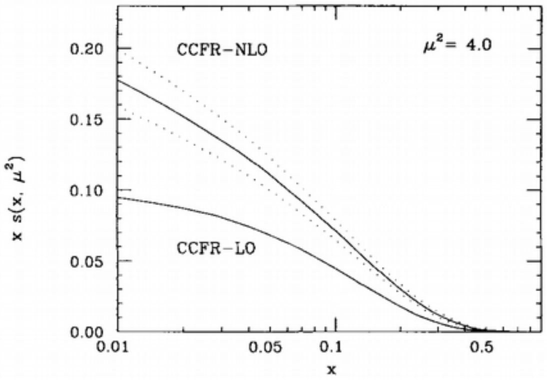
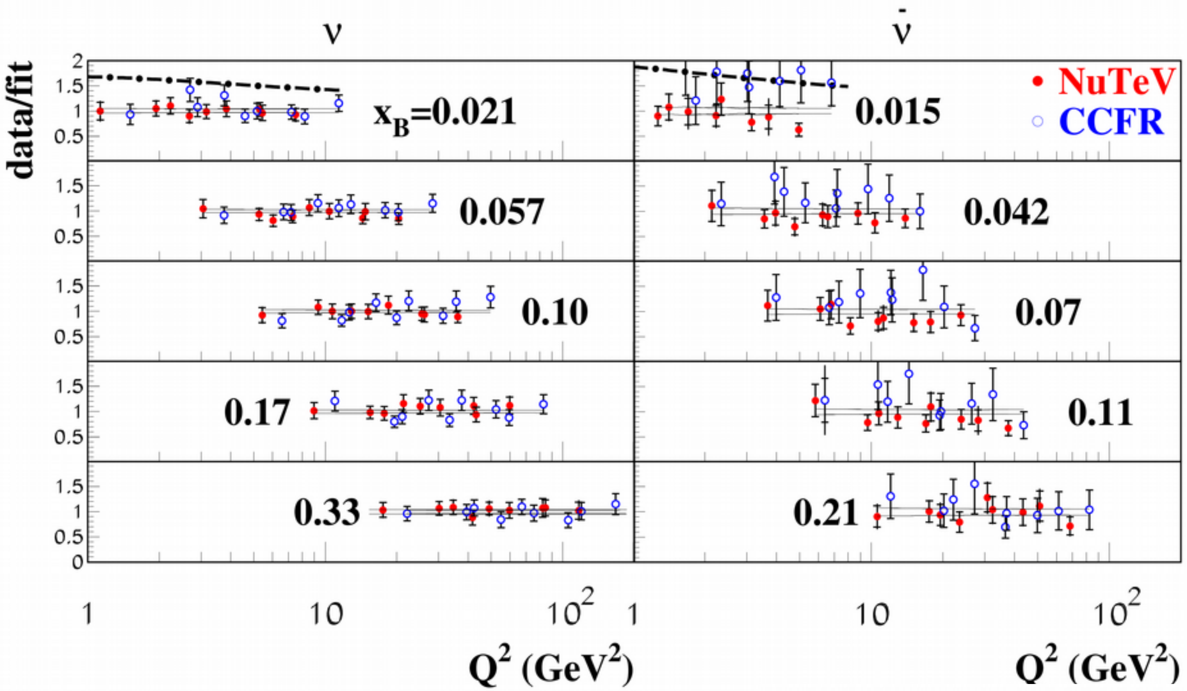


Fig. 4. The strange quark distribution $xs(x, \mu^2 = 4.0\,\mathrm{GeV}^2/\mathrm{c}^2)$ determined at next-to-leading order (described in section 4.1) and leading order. The band around the NLO curve indicates the $\pm 1\sigma$ uncertainty in the distribution

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

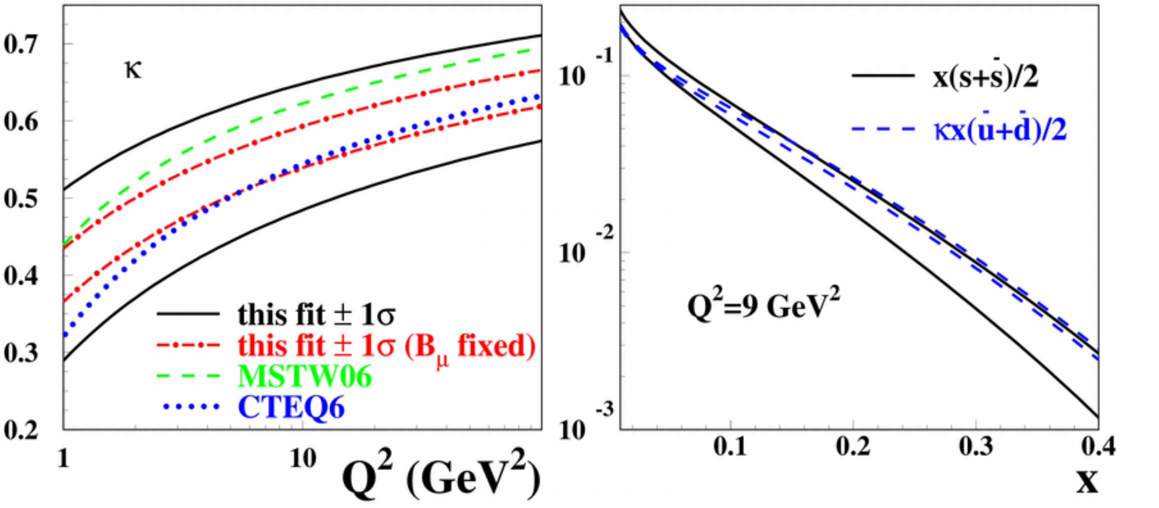


- CCFR and NuTeV are in a good agreement
- Charge asymmetry in the strange sea is consistent with 0 within uncertainties

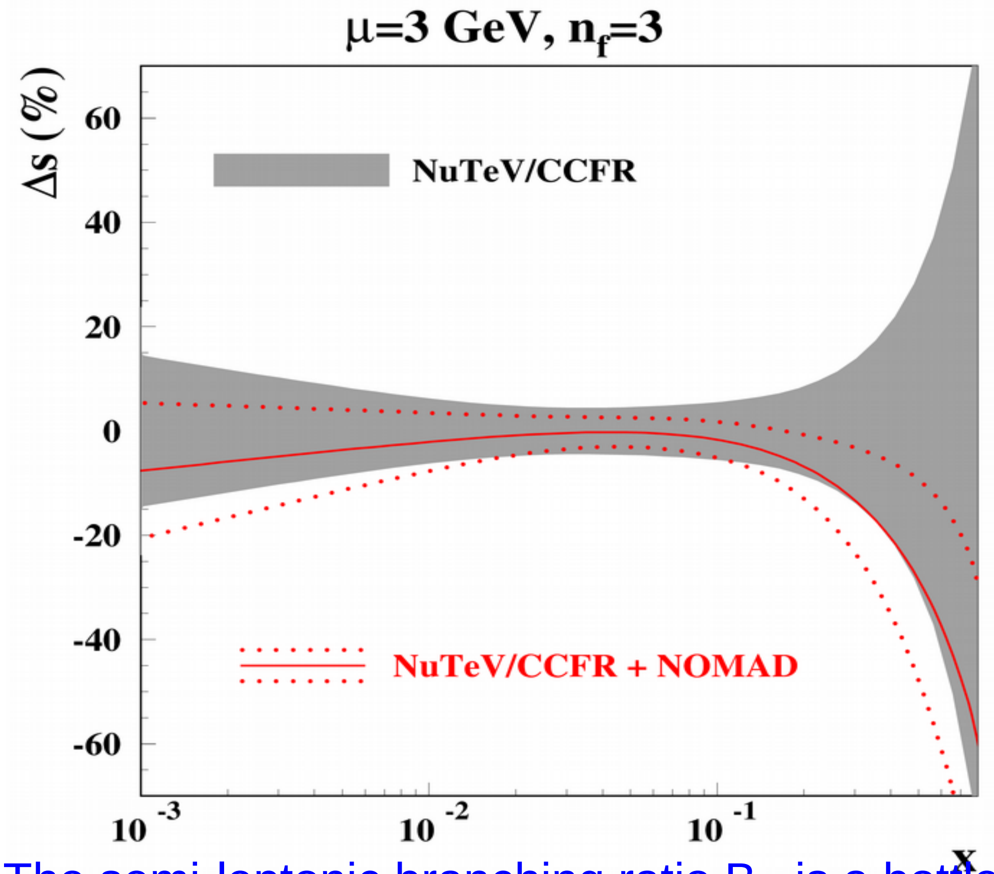
sa, Kulagin, Petti PLB 675, 433 (2009)

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

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



NOMAD charm data



NOMAD NPB 876, 339 (2013)

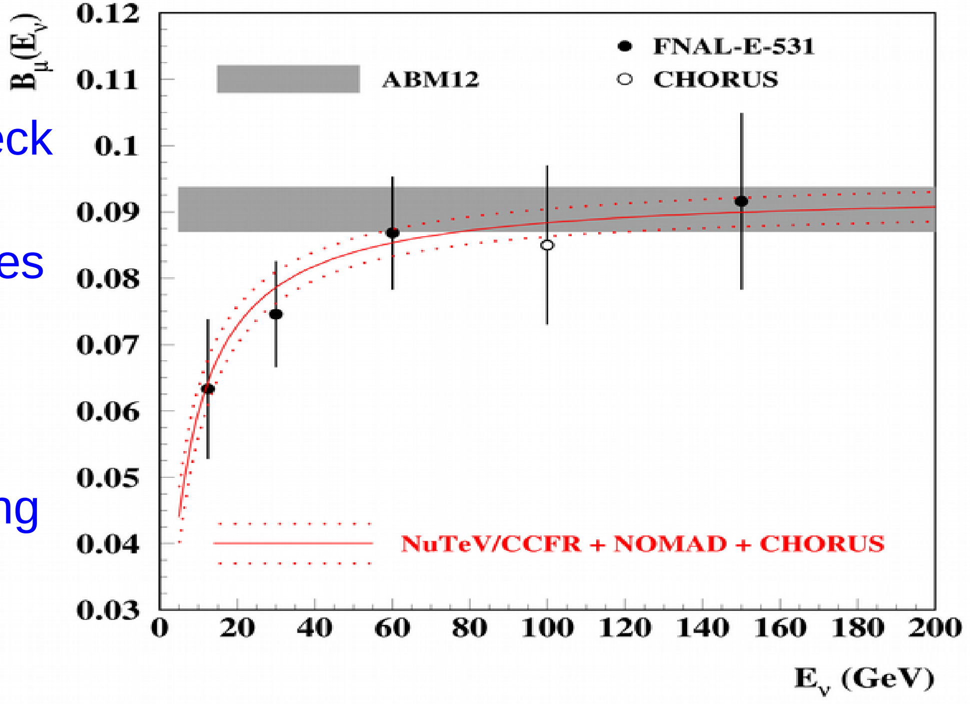
- The data on ratio 2μ/incl. CC ratio with the 2μ statistics of 15000 events (much bigger than in earlier CCFR and NuTeV samples).
- Systematics, nuclear corrections, etc. cancel in the ratio
- Pull down strange quarks at x>0.1 with a sizable uncertainty reduction

The semi-leptonic branching ratio B_μ is a bottleneck

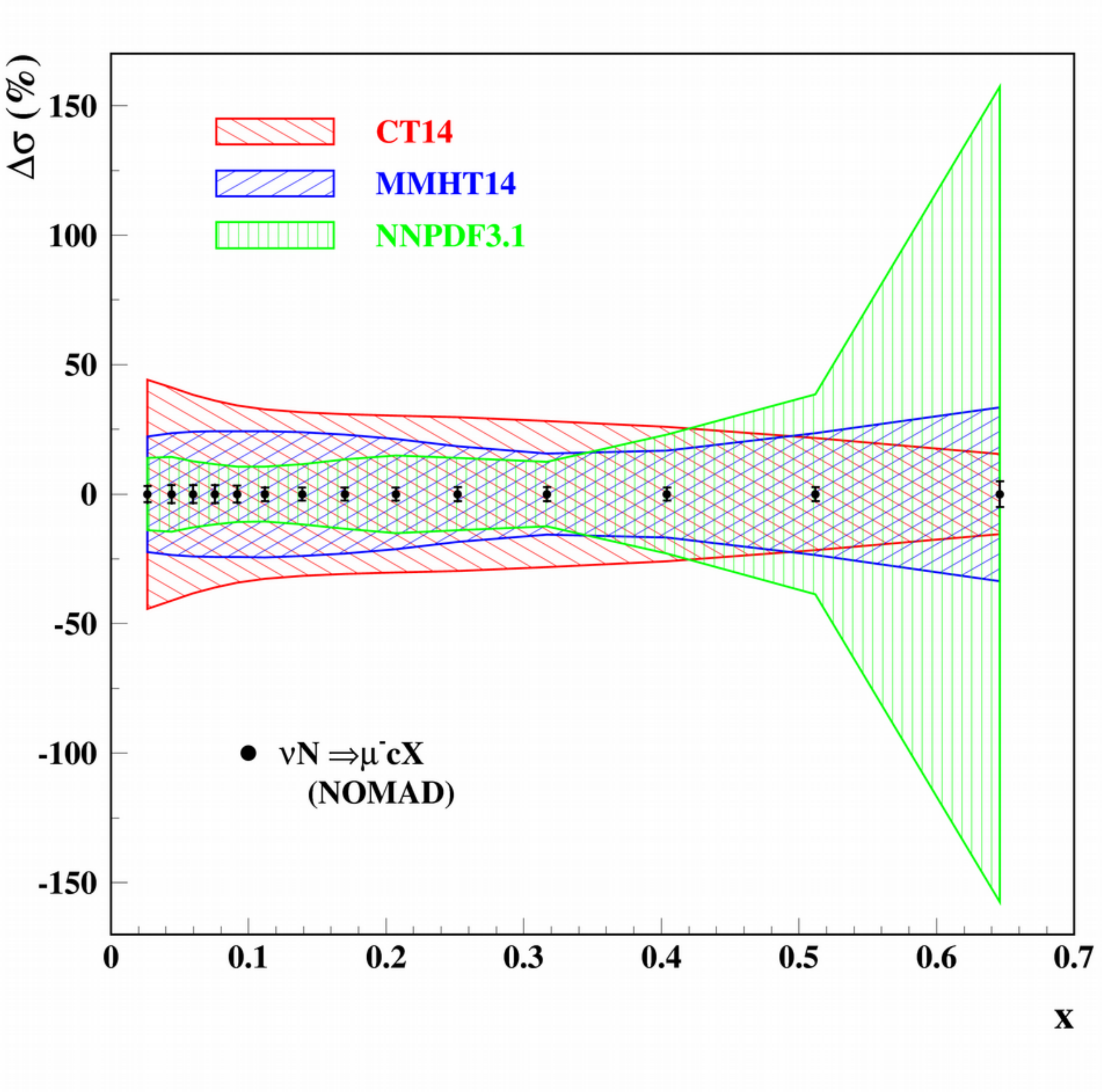
– weighted average of the charmed-hadron rates

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

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

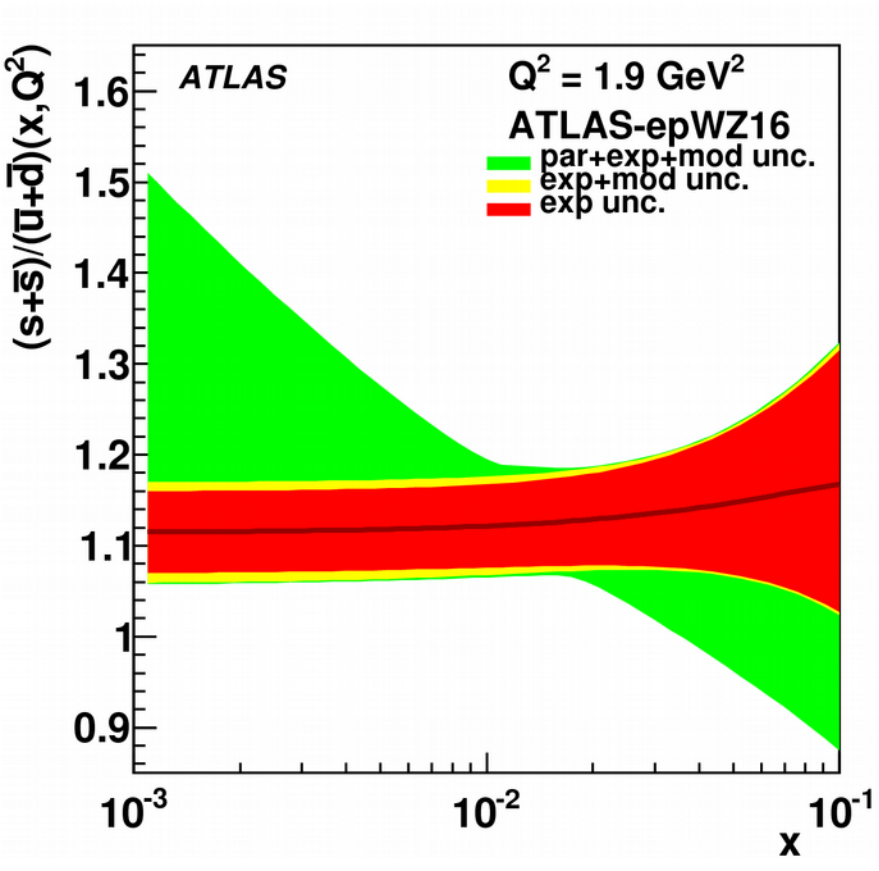


Impact of NOMAD data

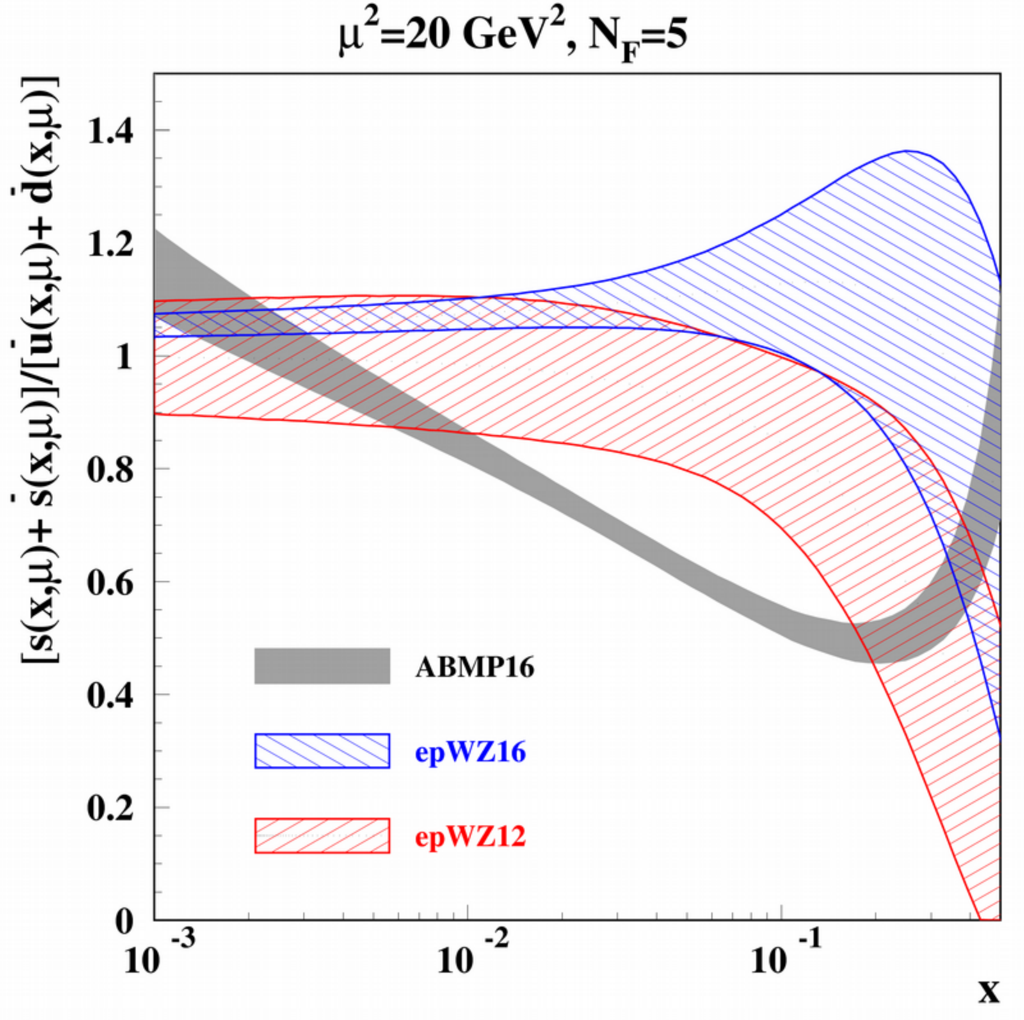


- Evident room for the PDF improvement by adding NOMAD data to various PDF fits
- Big spread in the predictions ⇒ PDF4LHC averaging provides inefficient estimate

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

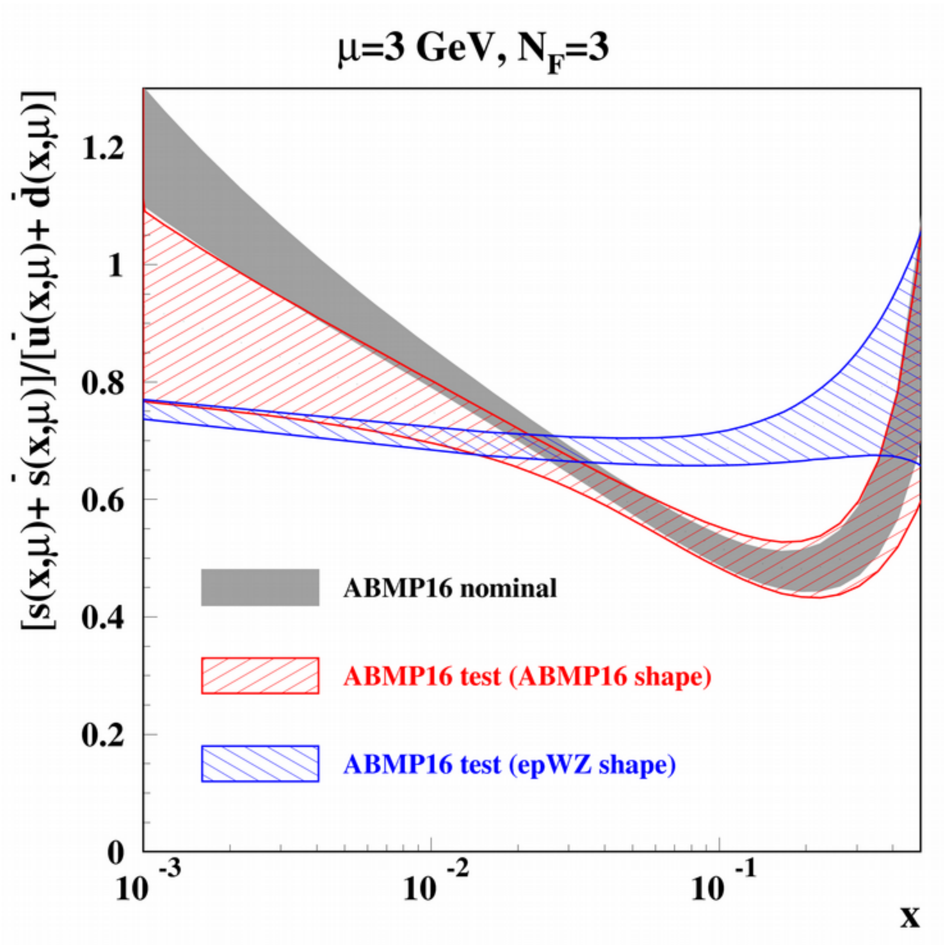
- *Disentangling d- and s- contribution?*
- *Impact of the nuclear corrections?*
- *…..?*

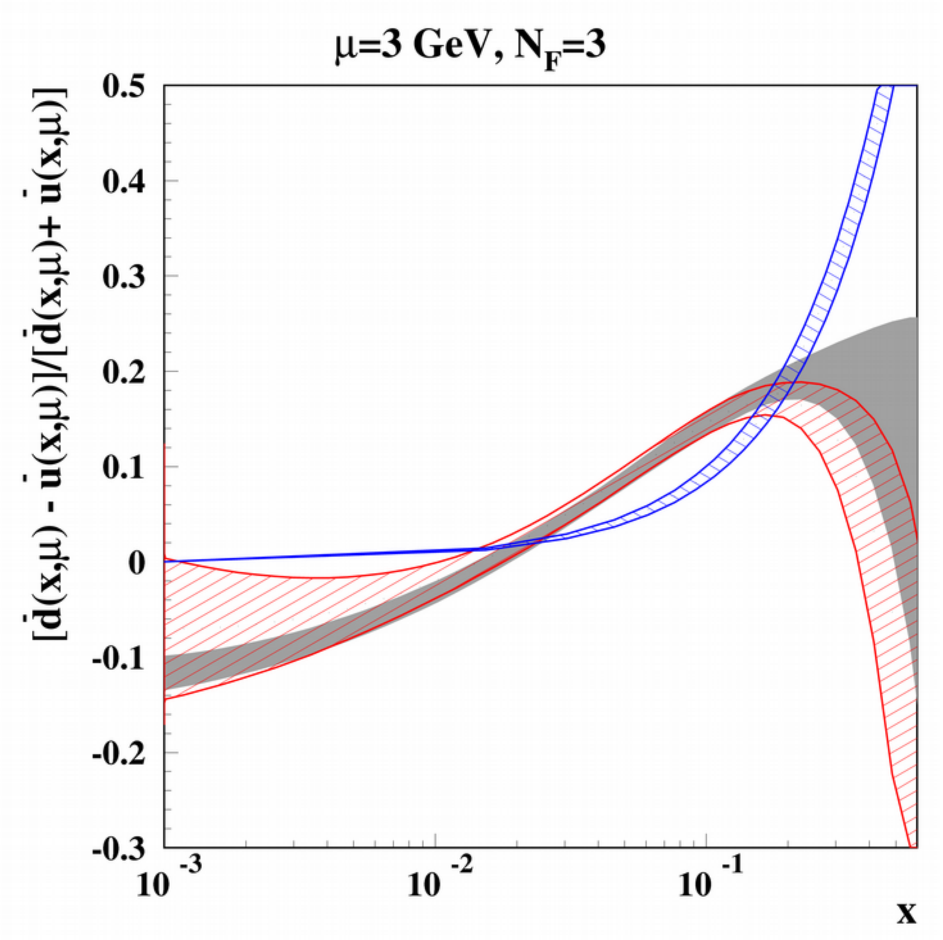
Details of the epWZ and ABMP16 fits

	epWZ16	ABMP16
Data	HERA, ATLAS W&Z	HERA, LHC and Tevatron W&Z, fixed-target DIS and charm production, fixed-target DY, ….
PDF shape	$xu_v(x,\mu_0^2) = A_{u_v} x^{B_{uv}} (1-x)^{C_{uv}} (1+E_{u_v} x^2)$, $xd_v(x,\mu_0^2) = A_{d_v} x^{B_{dv}} (1-x)^{C_{dv}}$, $x\bar{u}(x,\mu_0^2) = A_{\bar{u}} x^{B_{\bar{u}}} (1-x)^{C_{\bar{u}}}$, $x\bar{d}(x,\mu_0^2) = A_{\bar{d}} x^{B_{\bar{d}}} (1-x)^{C_{\bar{d}}}$, $xg(x,\mu_0^2) = A_g x^{B_g} (1-x)^{C_g} - A'_g x^{B'_g} (1-x)^{C'_g}$, $x\bar{s}(x,\mu_0^2) = A_{\bar{s}} x^{B_{\bar{s}}} (1-x)^{C_{\bar{s}}}$, 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)



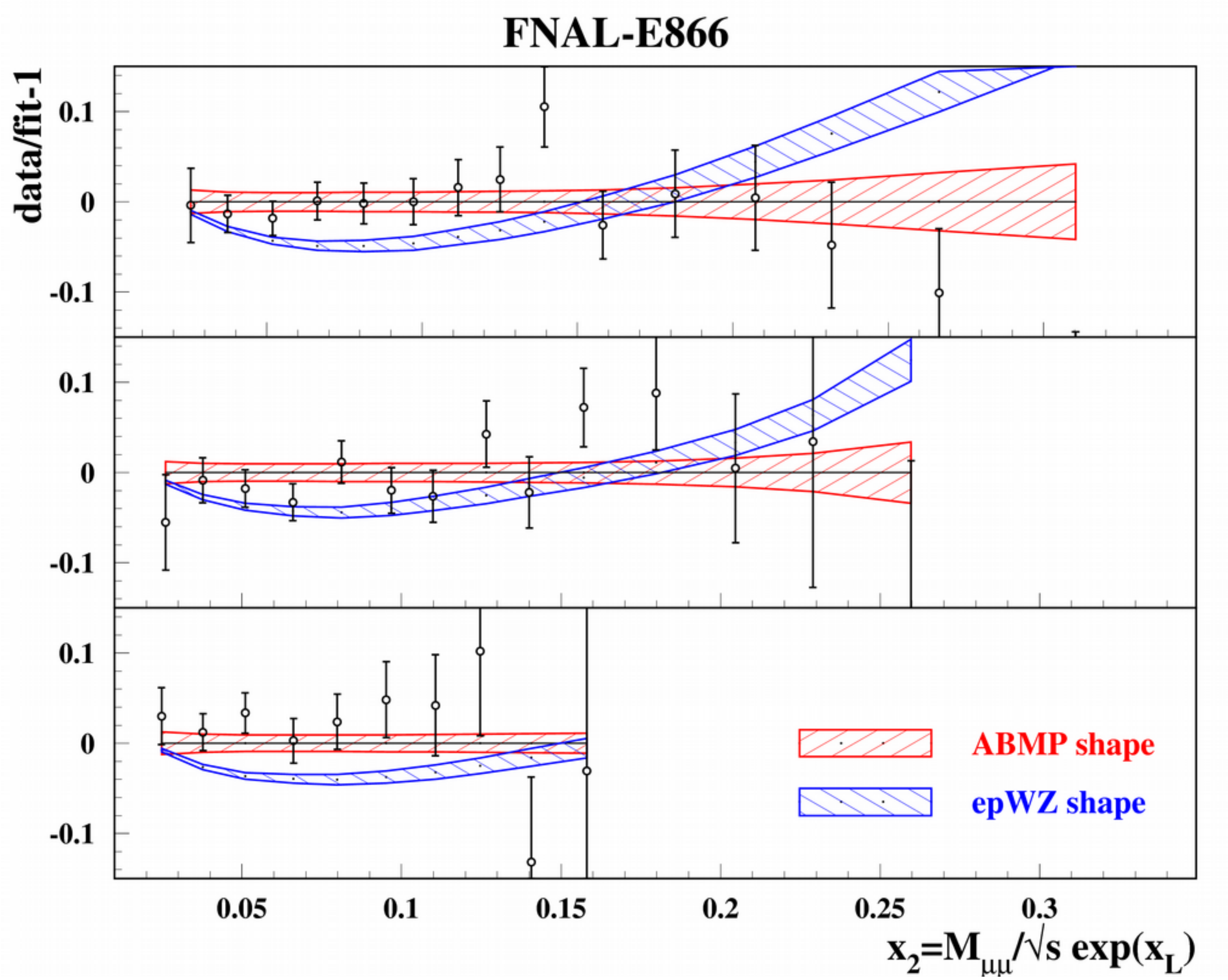


The data used in test fit: collider data discarded and replaced by the deuteron ones
(fit is consistent with the nominal ABMP16 at x>0.01) **sa, Kulagin, Petti hep-ph/1704.00204**

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)

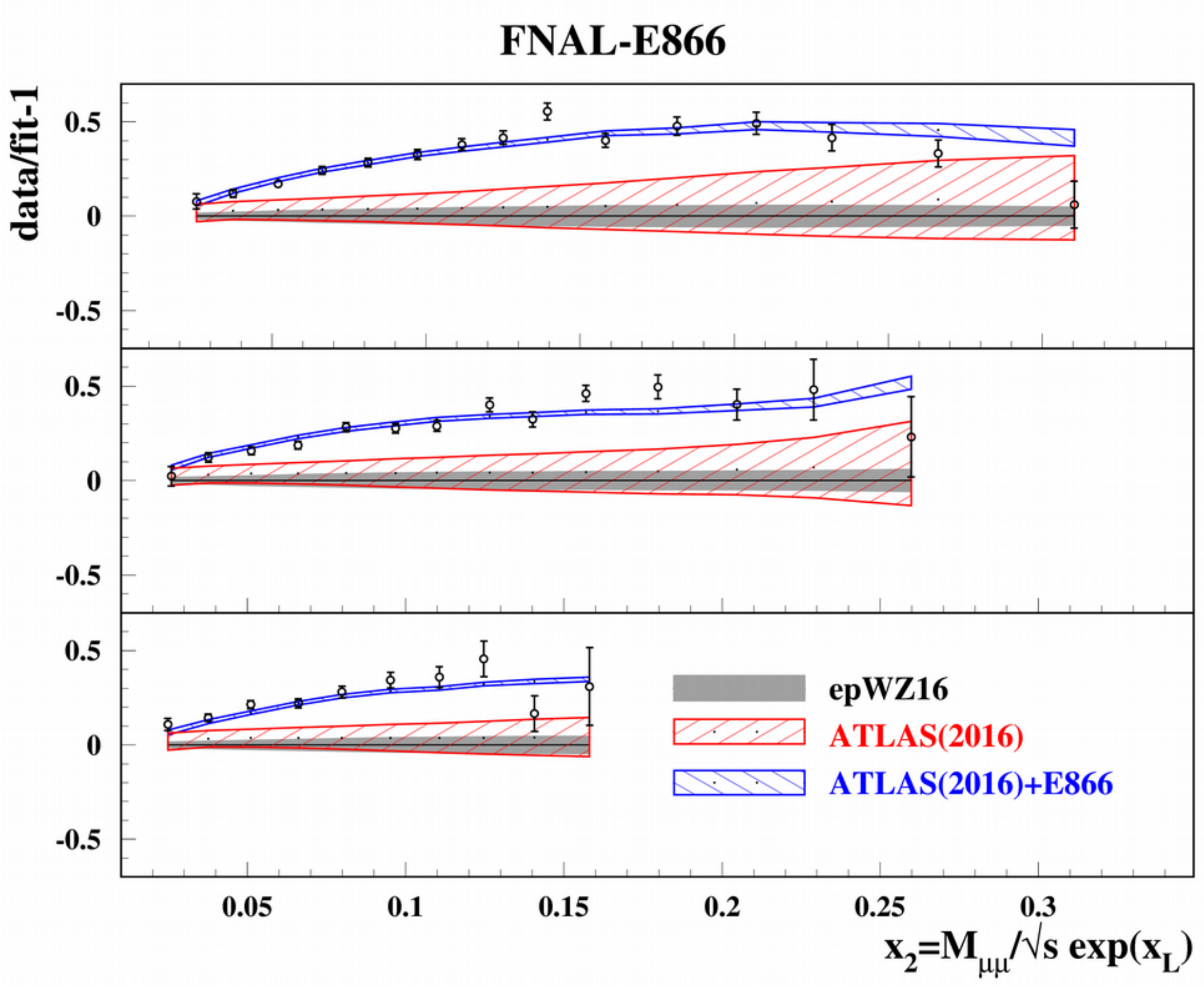
E866 data in the test fit



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

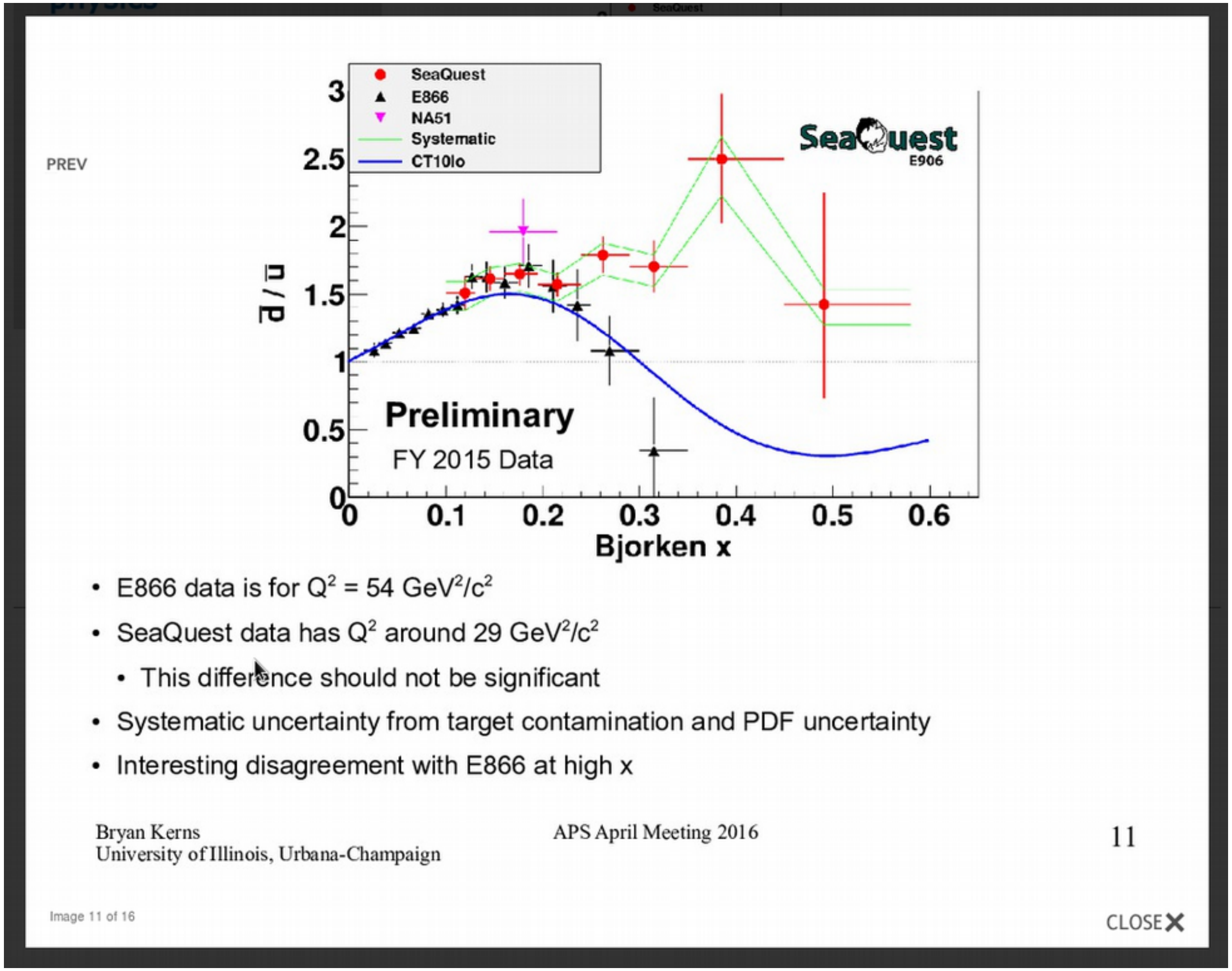


ATLAS, private communication

- 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

SeaQuest (FNAL-E906) prospects



- E866 data is for $Q^2 = 54$ GeV^2/c^2
- SeaQuest data has Q^2 around 29 GeV^2/c^2
  - This difference should not be significant
- Systematic uncertainty from target contamination and PDF uncertainty
- Interesting disagreement with E866 at high x

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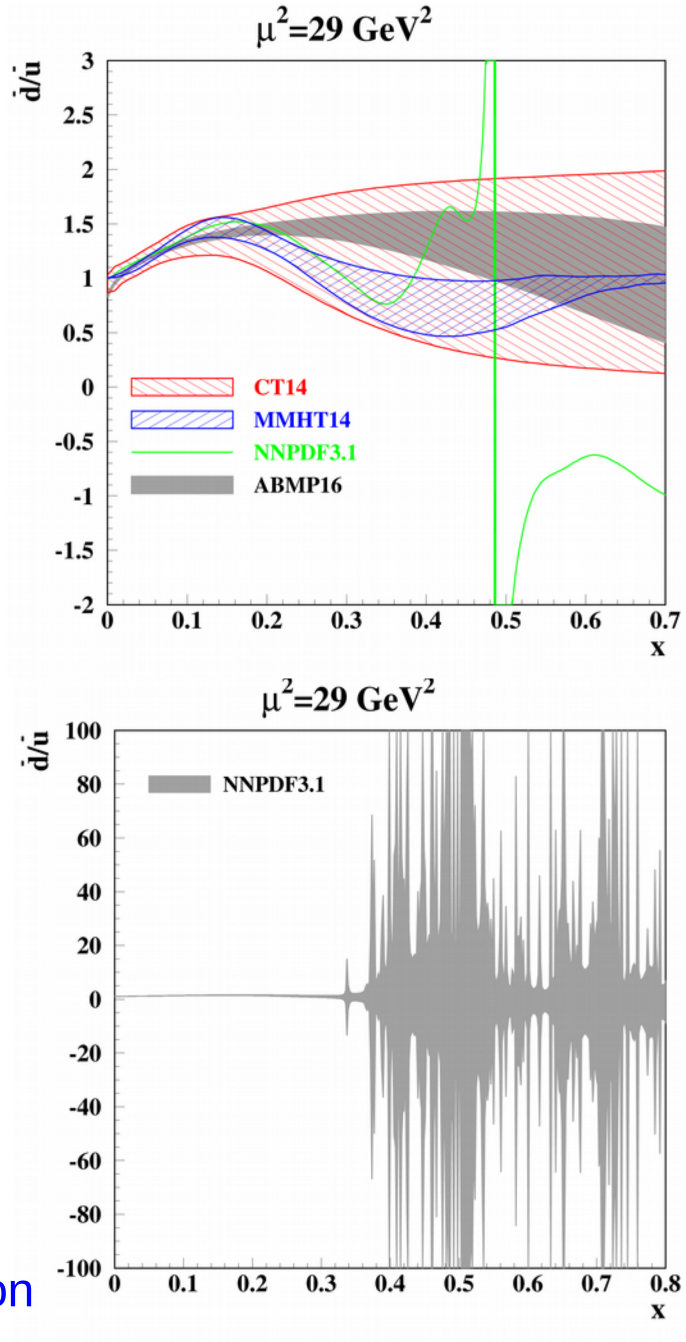
APS April Meeting 2016

11



- 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

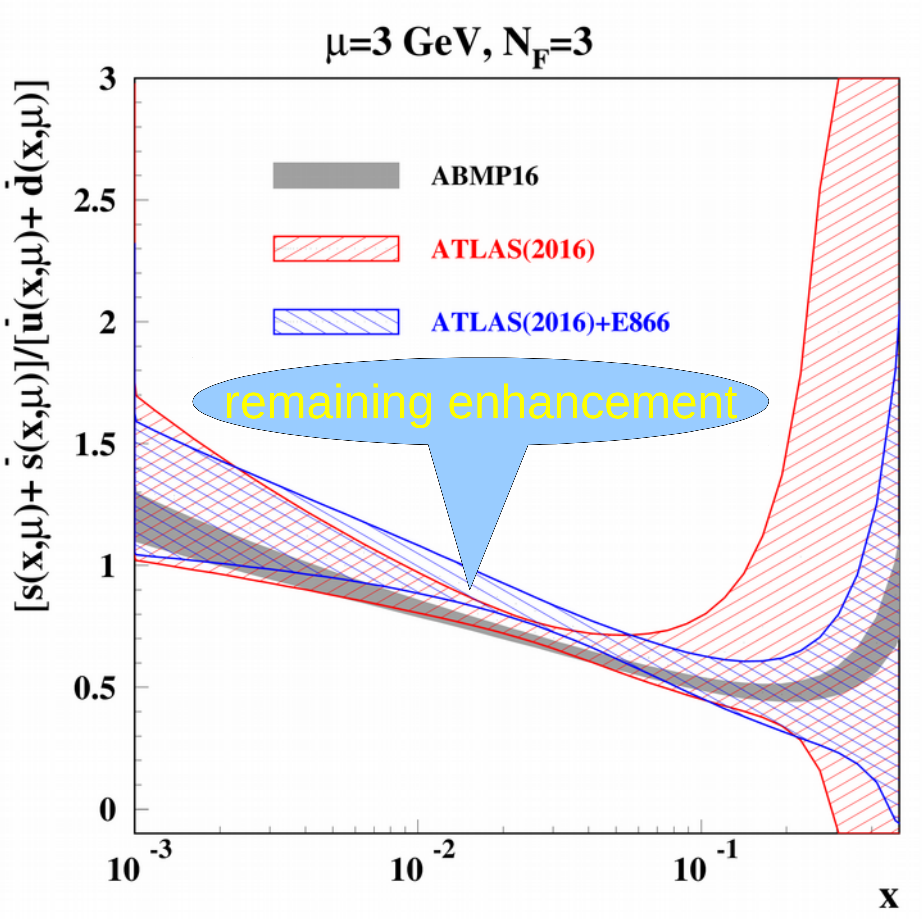
Borsa, Sassot, Stratmann hep-ph/1708.01630

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:

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

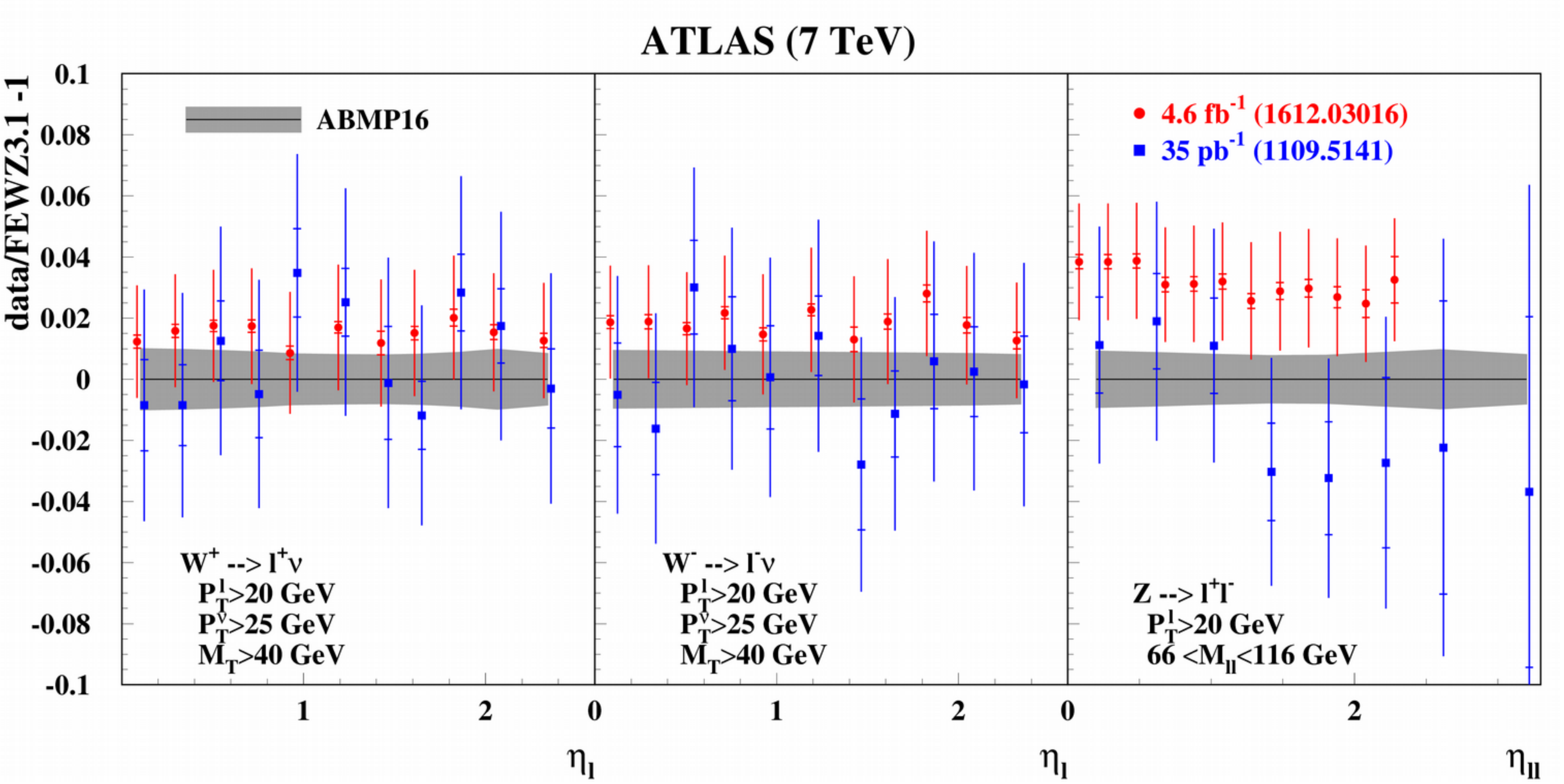


remaining enhancement

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

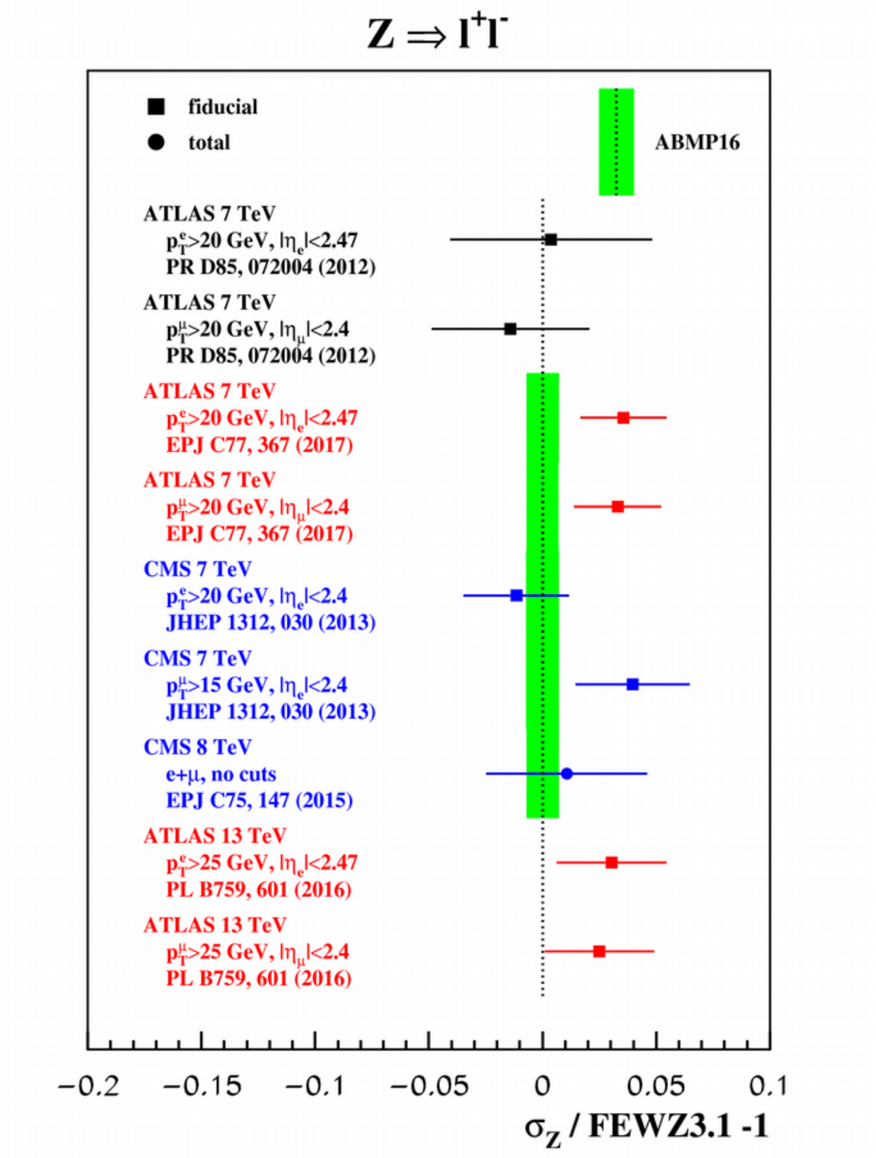
sa, Blümlein, Moch hep-ph/1708.01067

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*

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

Summary

- The strange sea suppression observed in the early νN DIS experiments is confirmed by recent precise measurements (NOMAD, CHORUS)

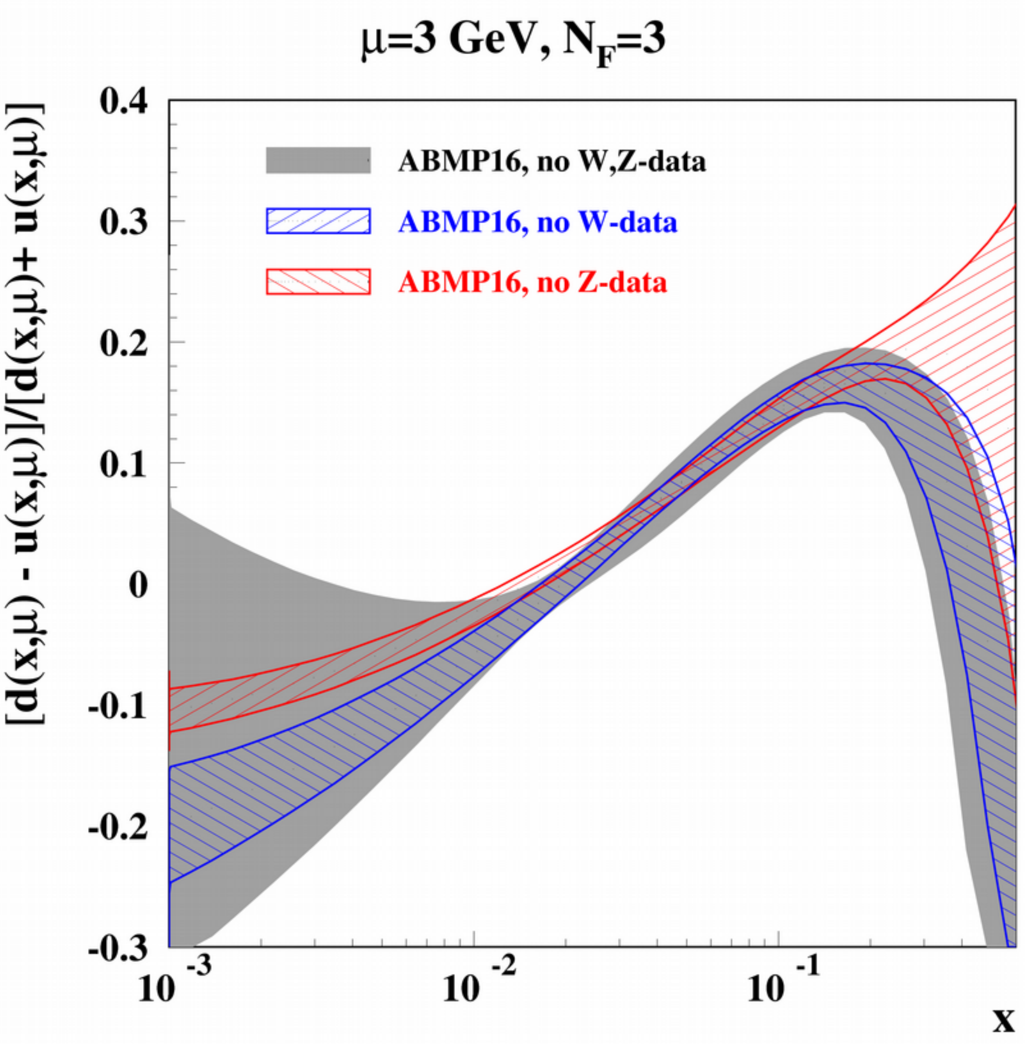
- These data sets can be accommodated into the global PDF fit with a consistent treatment of the fixed-target and collider Drell-Yan data

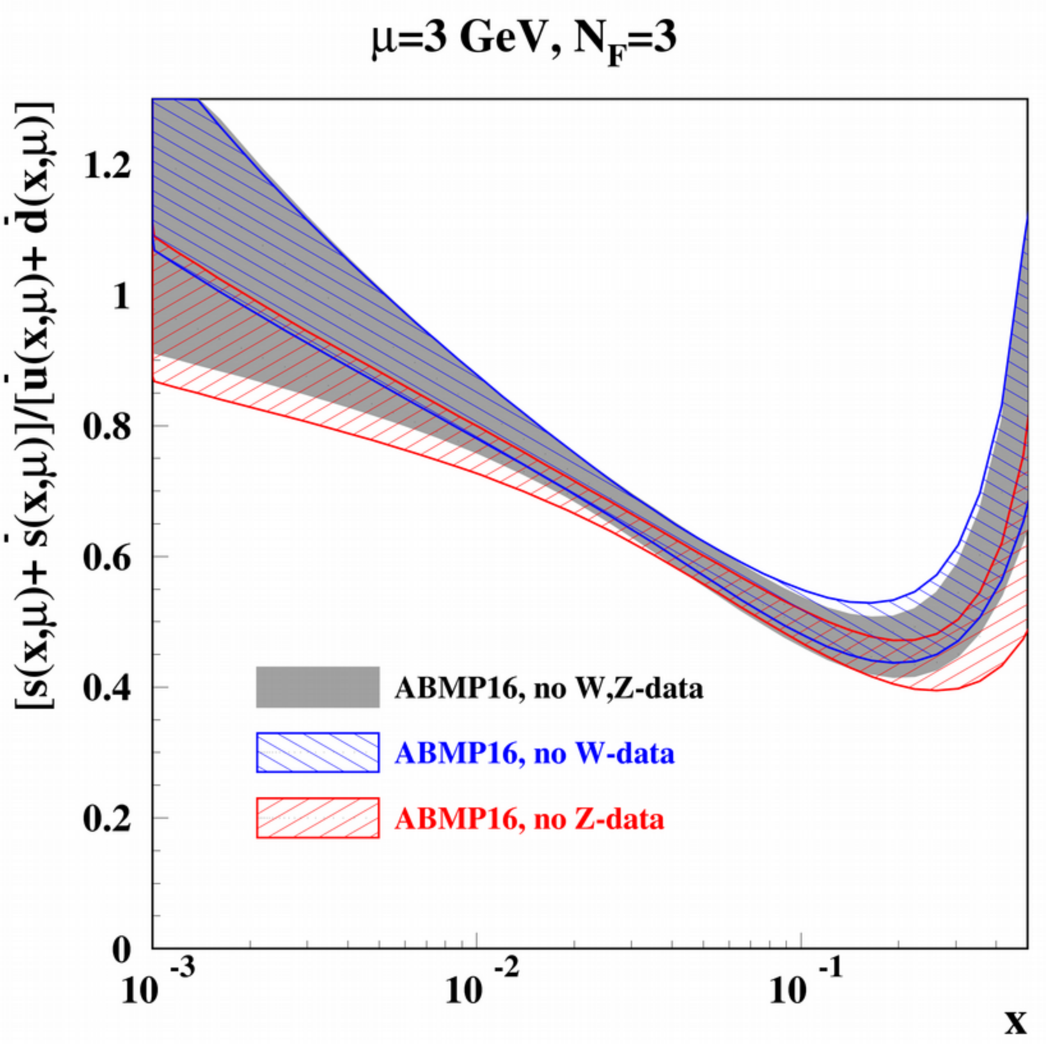
- The ATLAS analysis based on the combination of Drell-Yan and HERA DIS data demonstrates strange sea enhancement by the price of disagreement with the Fermilab fixed-target Drell-Yan data (E-866, E-906) and overconstrained PDF shape at small x

- A refined comparison with CMS measurements would be desirable in order to confirm small strange-sea enhancement at x~0.01 driven by the recent ATLAS Drell-Yan data

EXTRAS

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

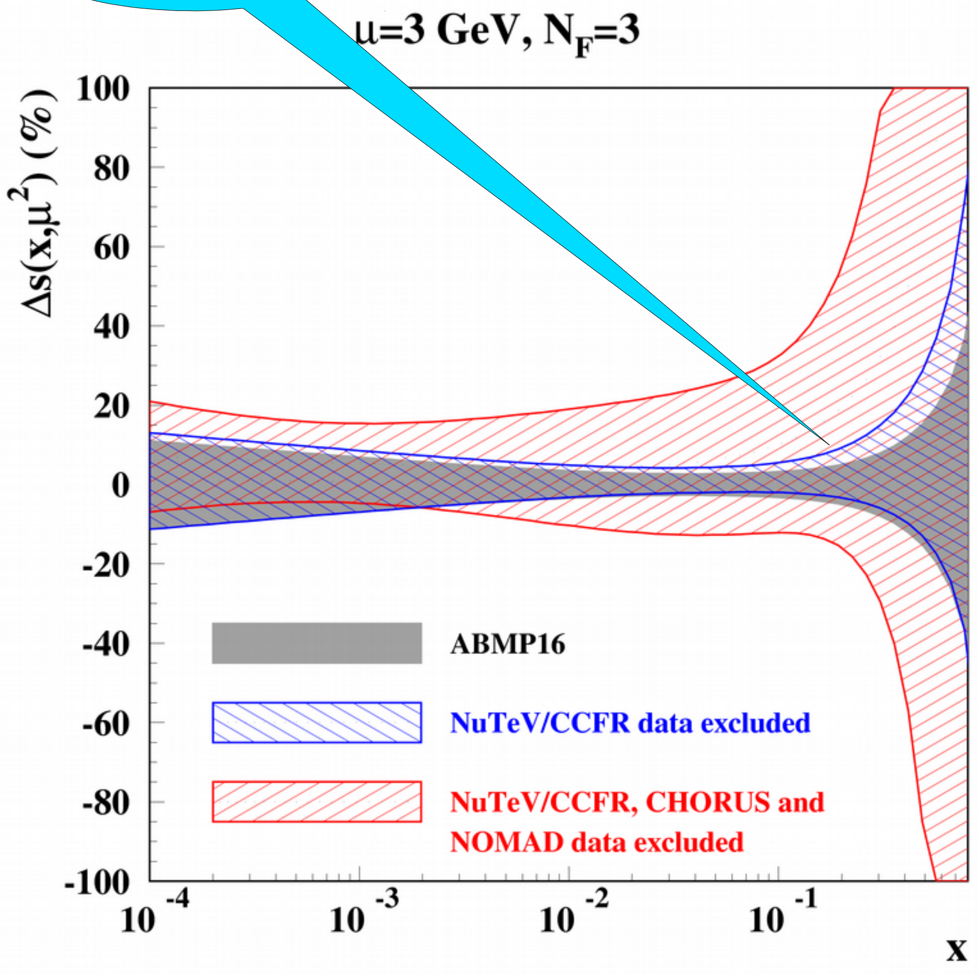




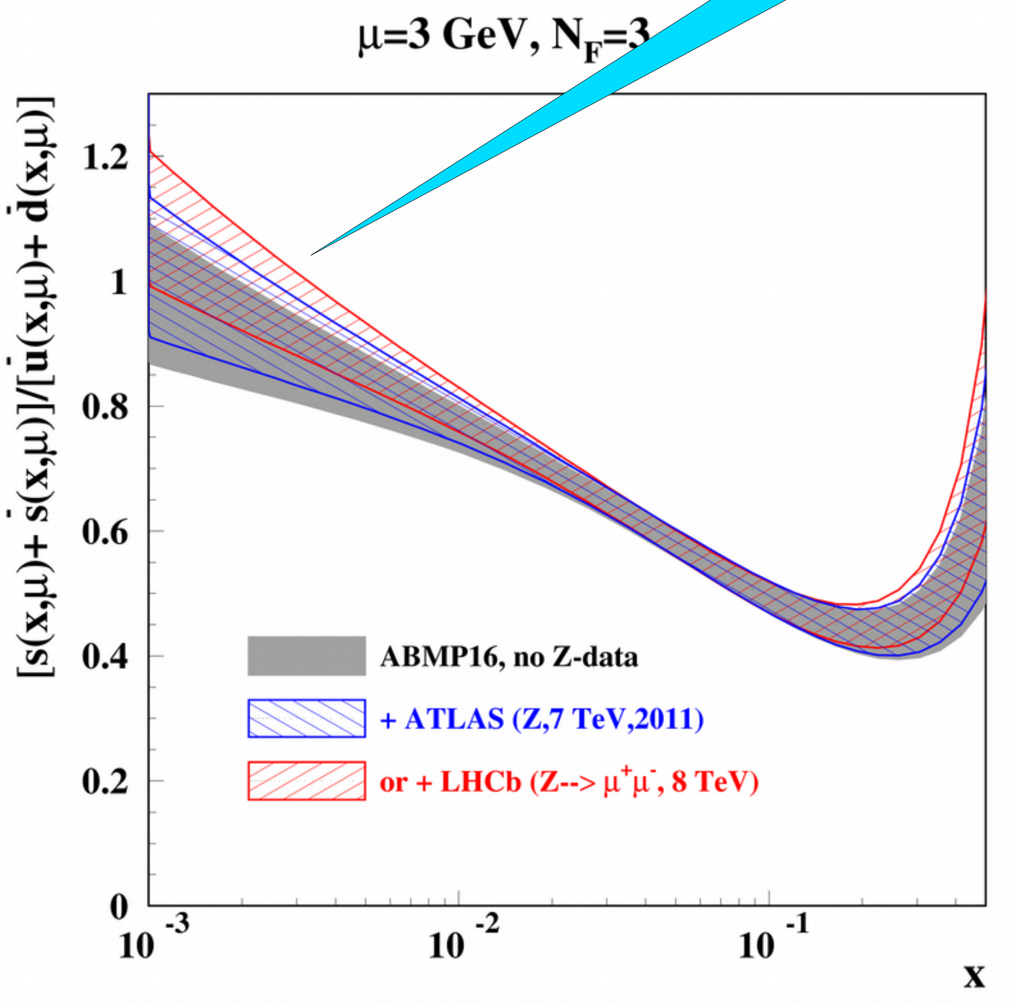
W-, Z-data really control quark disentangling at small x

Constraints on strange sea

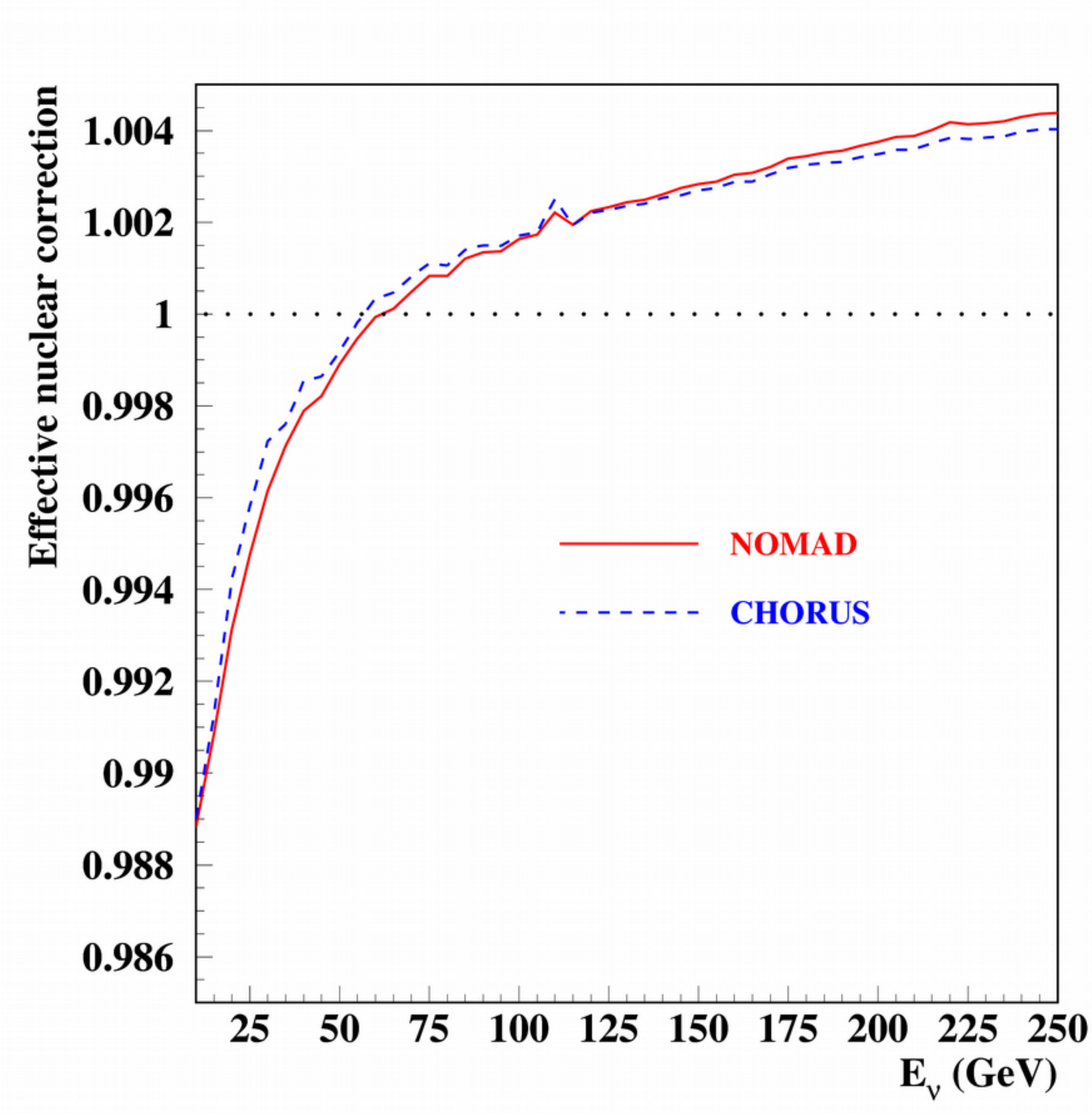
Controlled by NOMAD



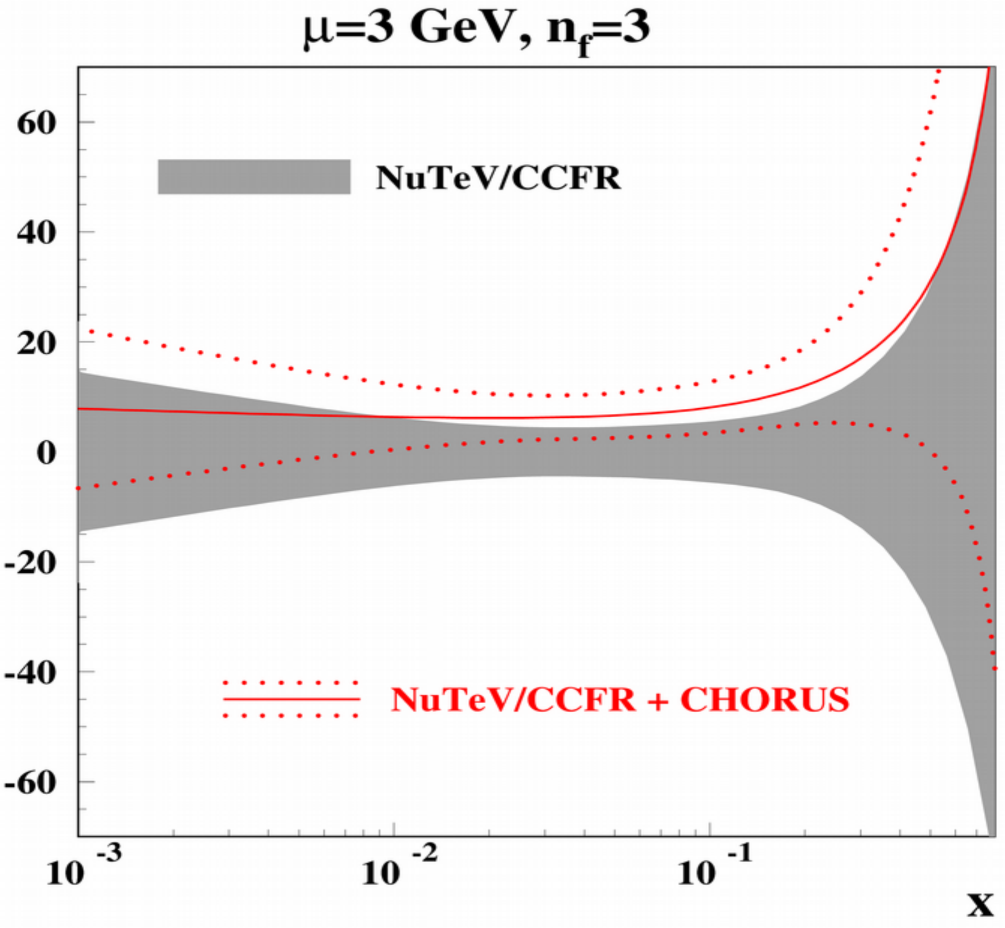
Controlled by DY&DIS(incl.)



- 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.)


Effective nuclear correction
1.004
1.002
1
0.998
0.996
0.994
0.992
0.99
0.988
0.986
25
50
75
100
125
150
175
200
225
250
E_ν (GeV)
NOMAD
CHORUS

CHORUS charm data



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

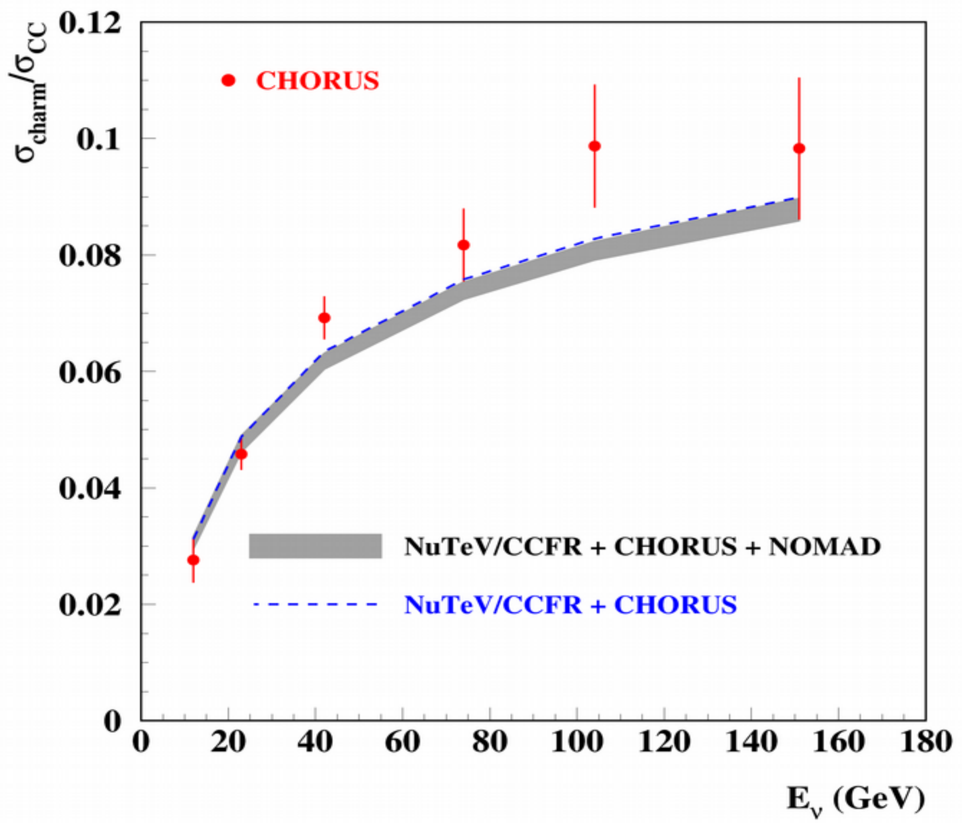
Emulsion data on charm/CC ratio with the charmed hadron vertex measured

CHORUS NJP 13, 093002 (2011)

– full phase space measurements

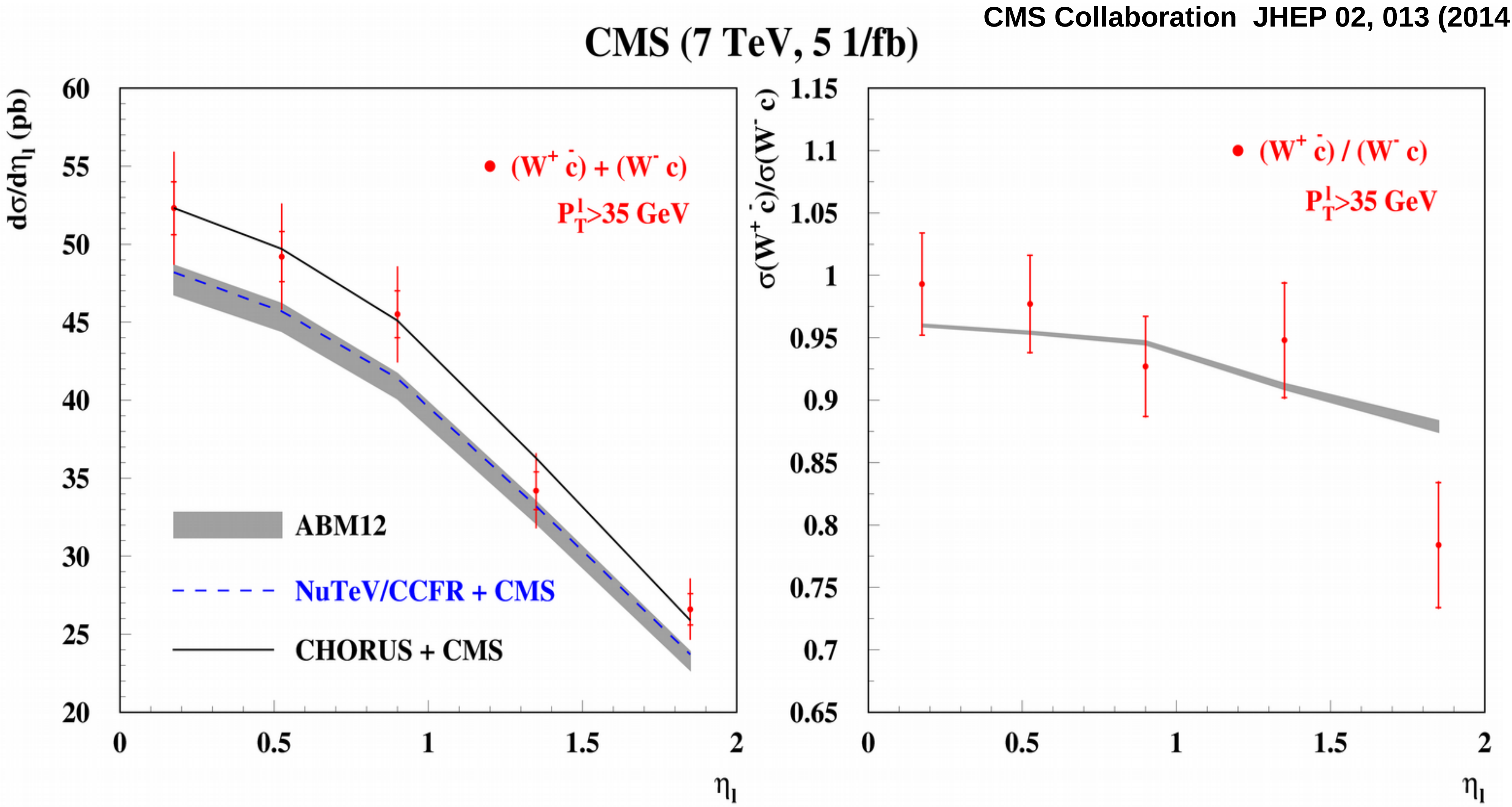
– no sensitivity to B_μ

– low statistics (2013 events)



CMS W+charm data

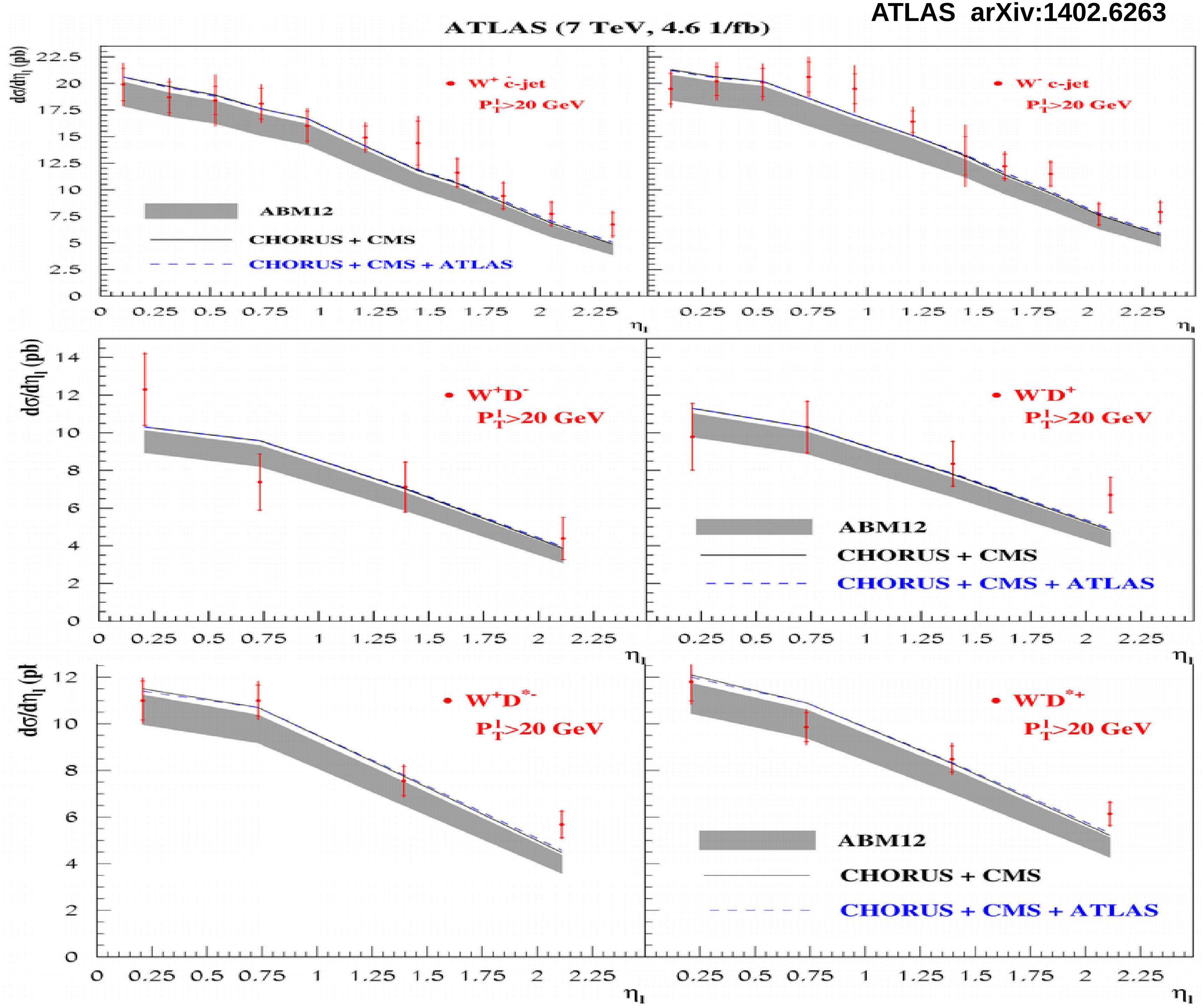
CMS Collaboration JHEP 02, 013 (2014)



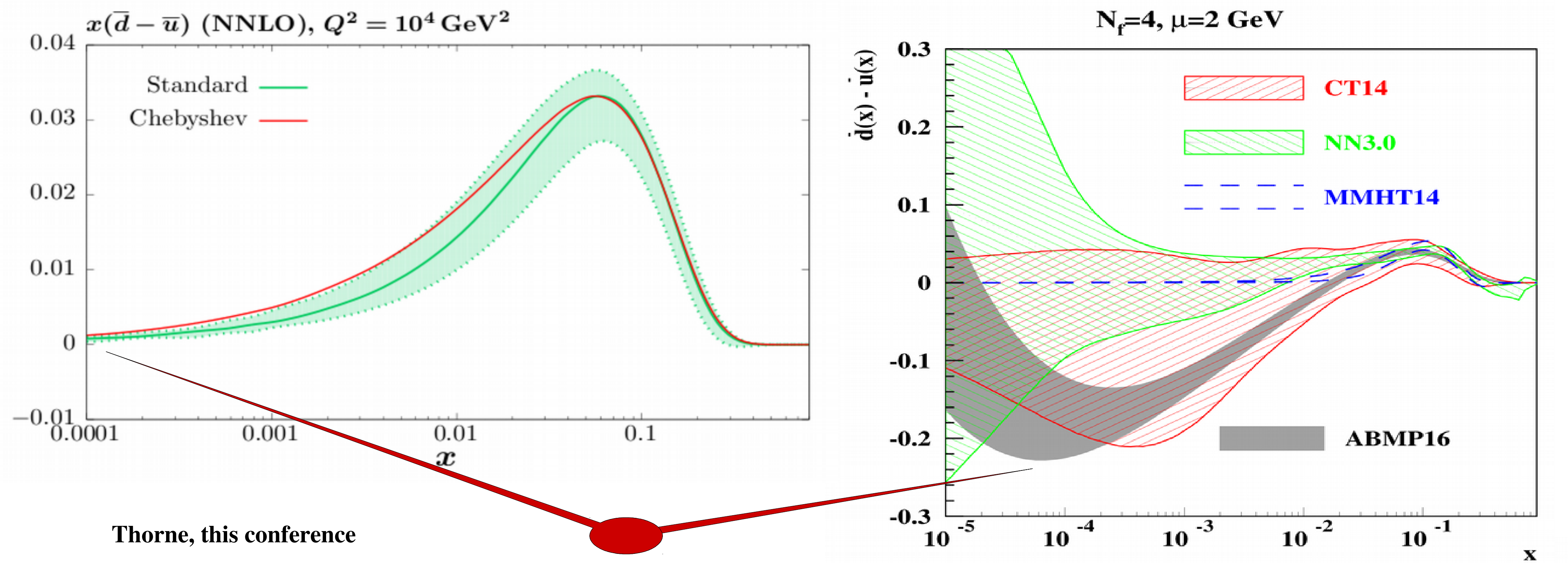
- CMS data go above the NuTeV/CCFR by 1σ; little impact on the strange sea
- The charge asymmetry is in a good agreement with the charge-symmetric strange sea
- Good agreement with the CHORUS data

ATLAS W+charm data

ATLAS arXiv:1402.6263



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



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

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

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

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 increases the difference