Disentangling quark PDFs with the collider and and fixed-target data in the ABM fit

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- Theory: NNLO CC at Q>> m_c
- Strange sea
  - – NOMAD and CHORUS fixed-target data
  - – CMS and ATLAS W+charm data
- Non-strange quarks
  - – CMS charged-lepton asymmetry
  - – D0 charged-lepton and W asymmetry

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

XXII-th international DIS workshop , Warsaw, 29 Apr 2014

The ABM fit ingredients

DATA:

- DIS NC inclusive
- DIS charm production
- DIS μμ CC production (NOMAD data)
- DIS charmed-hadron CC production (CHORUS data)
- fixed-target DY
- LHC DY distributions (CMS 4.7 1/fb)
- W+charm production (CMS and ATLAS data)

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 (DYNNLO 1.3 / FEWZ 3.1)
- NNLO inclusive ttbar production (pole / running mass)

Deuteron corrections in DIS:

- Fermi motion
- off-shell effects

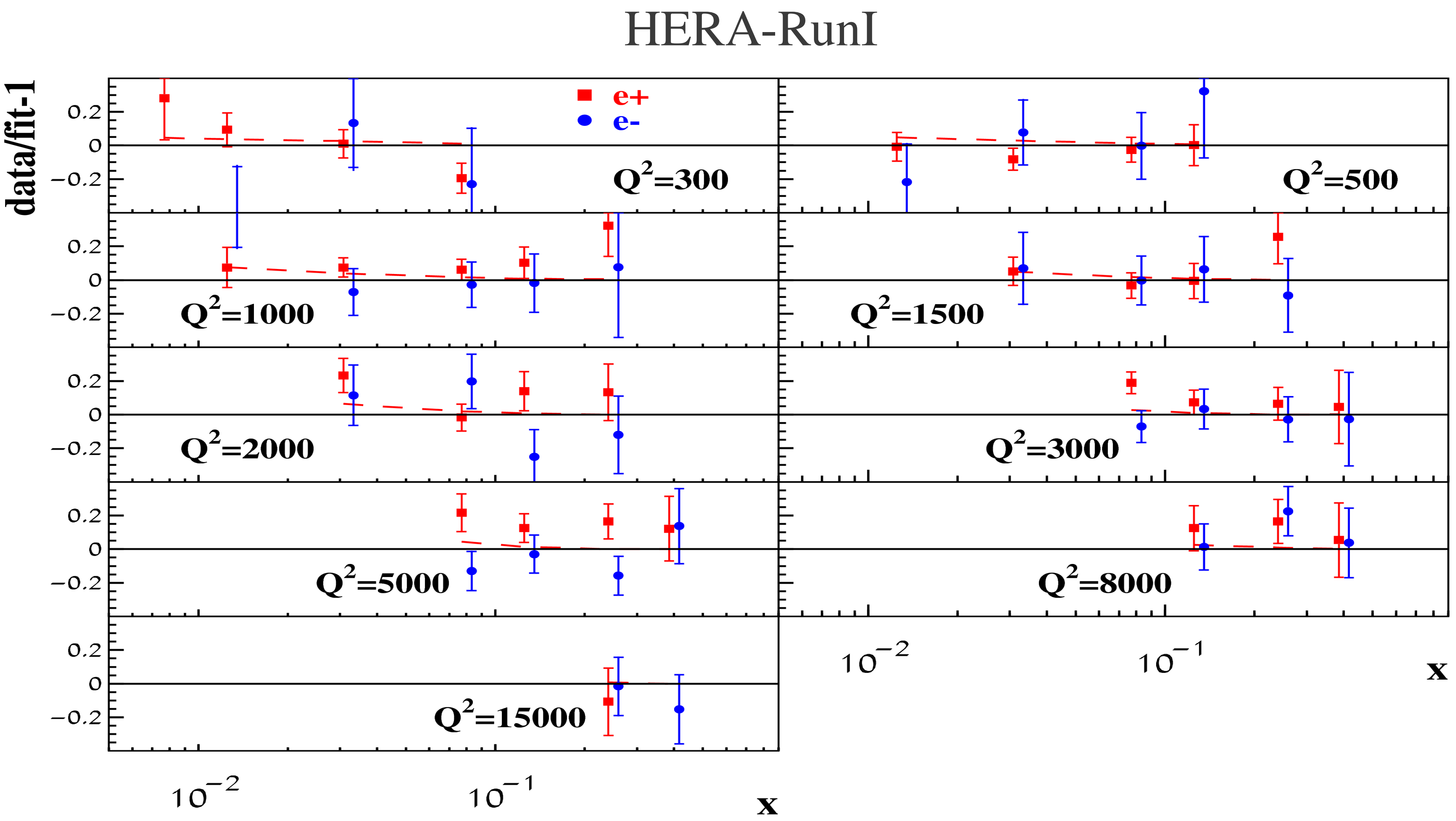
Power corrections in DIS:

- target mass effects
- dynamical twist-4 terms

The jet data are still not included: The NNLO corrections may be as big as 15-20%

Gehrmann-De Ridder, Gehrmann, Glover, Pires JHEP 1302, 026 (2013)

The NNLO CC corrections



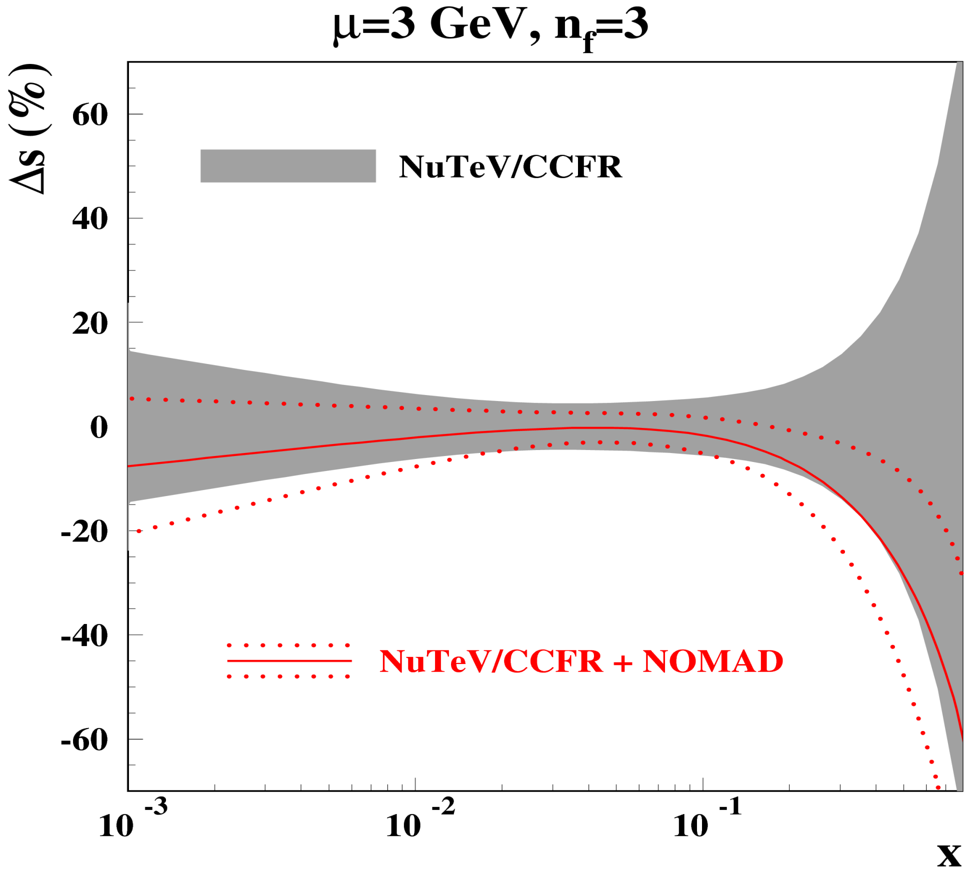
- Asymptotic NNLO CC corrections at Q>> m_c relevant for the HERA kinematics

Buza van Neerven, NPB 500, 301 (1997)
Blümlein, Hasselhuhn, Pfoh NPB881, 1 (2014)
Moch (2013) (unpublished)

- Effect is ~5% at small x

- ΔX^2 = -6/114 for the HERA RunI CC data; bigger impact for RunII expected

NOMAD charm data in the ABM fit



The data on ratio 2μ/incl. CC ratio with the 2μ statistics of 15000 events (much bigger than in earlier CCFR and NuTeV samples).

NOMAD NPB 876, 339 (2013)

Systematics, nuclear corrections, etc. cancel in the ratio

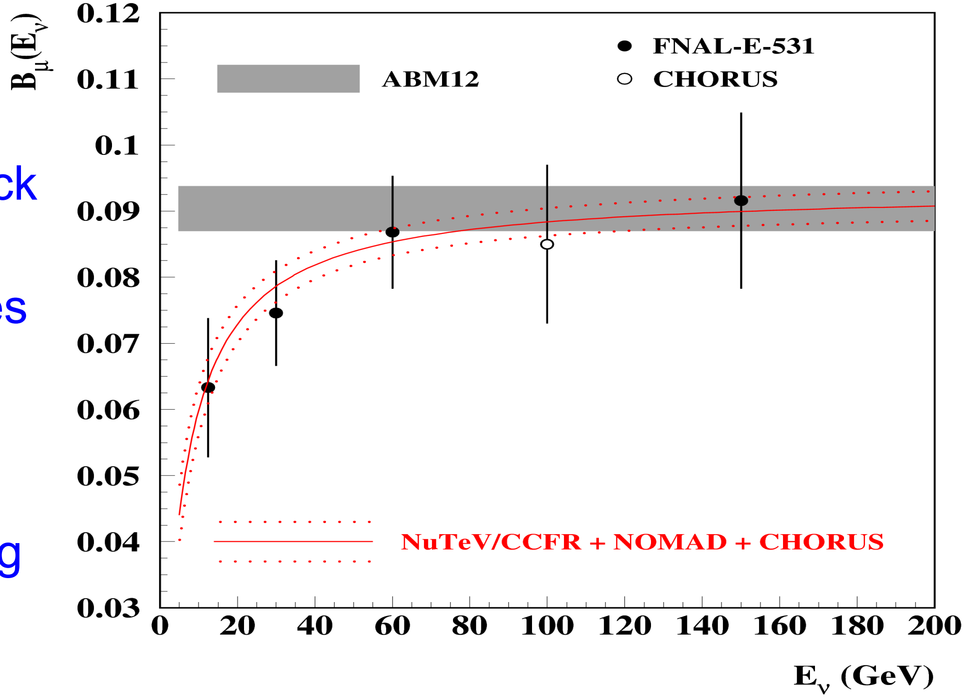
- pull down strange quarks at x>0.1 with a sizable uncertainty reduction
- $m_c(m_c)$=1.23±0.03(exp.) GeV is comparable to the ABM12 value

The semi-leptonic branching ratio B_μ is a bottleneck

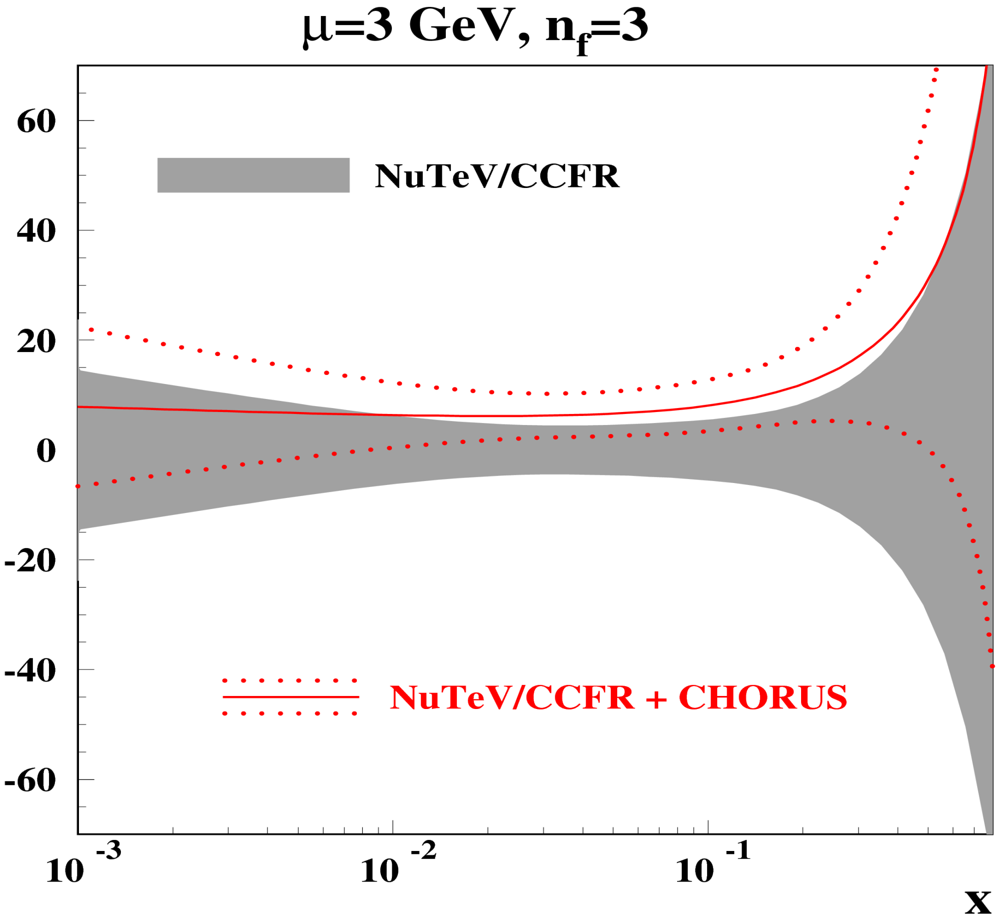
- weighted average of the charmed-hadron rates

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

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



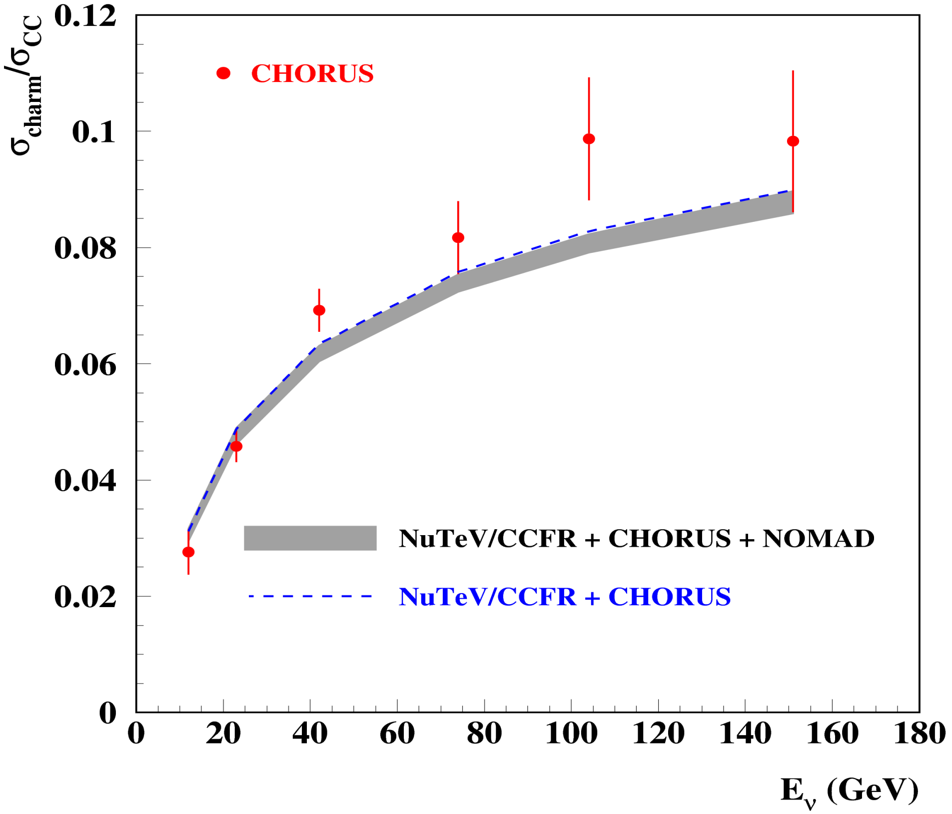
CHORUS charm data in the ABM fit



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

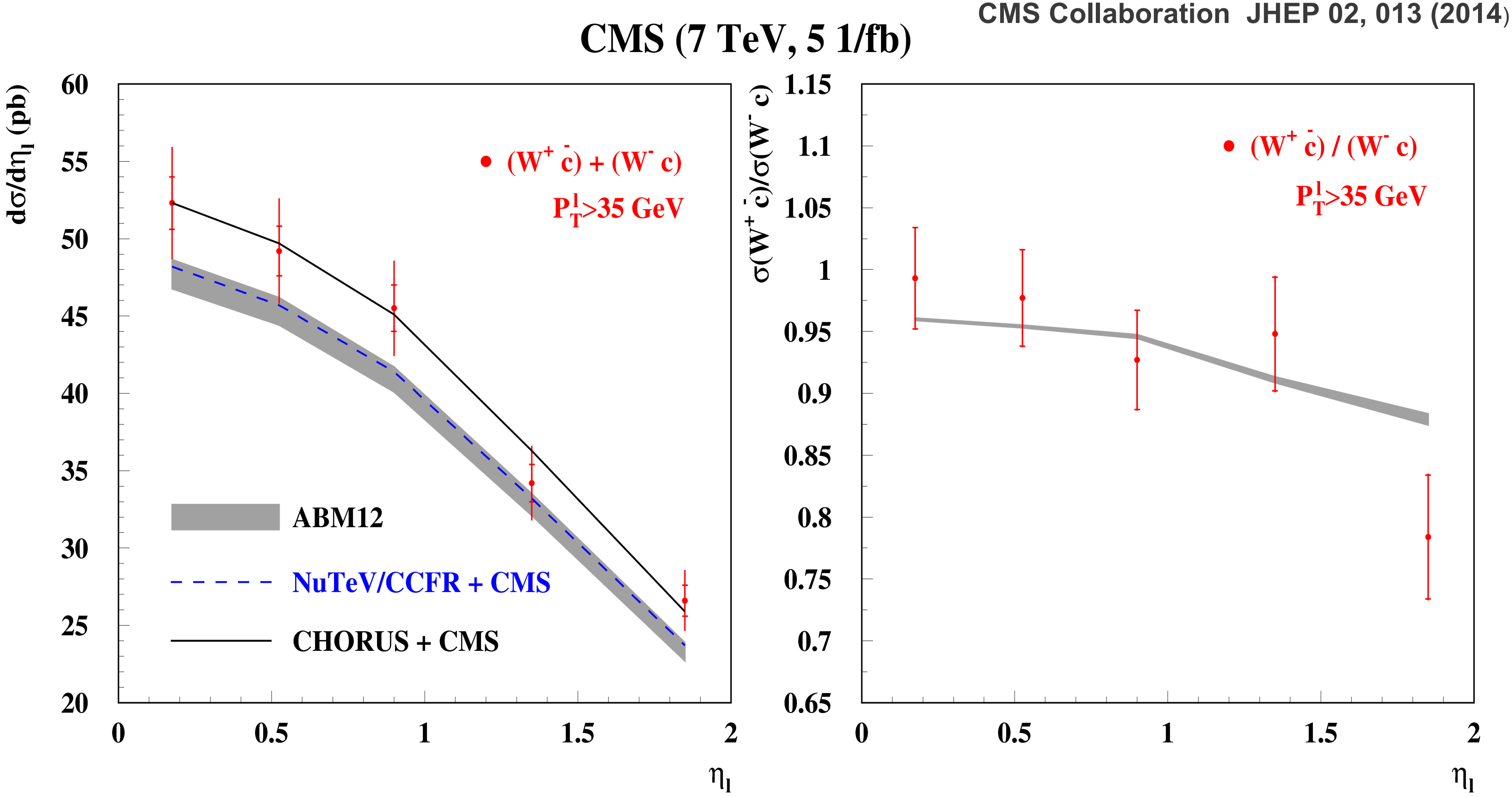
CHORUS NJP 13, 093002 (2011)

- 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

CMS W+charm data in the ABM fit

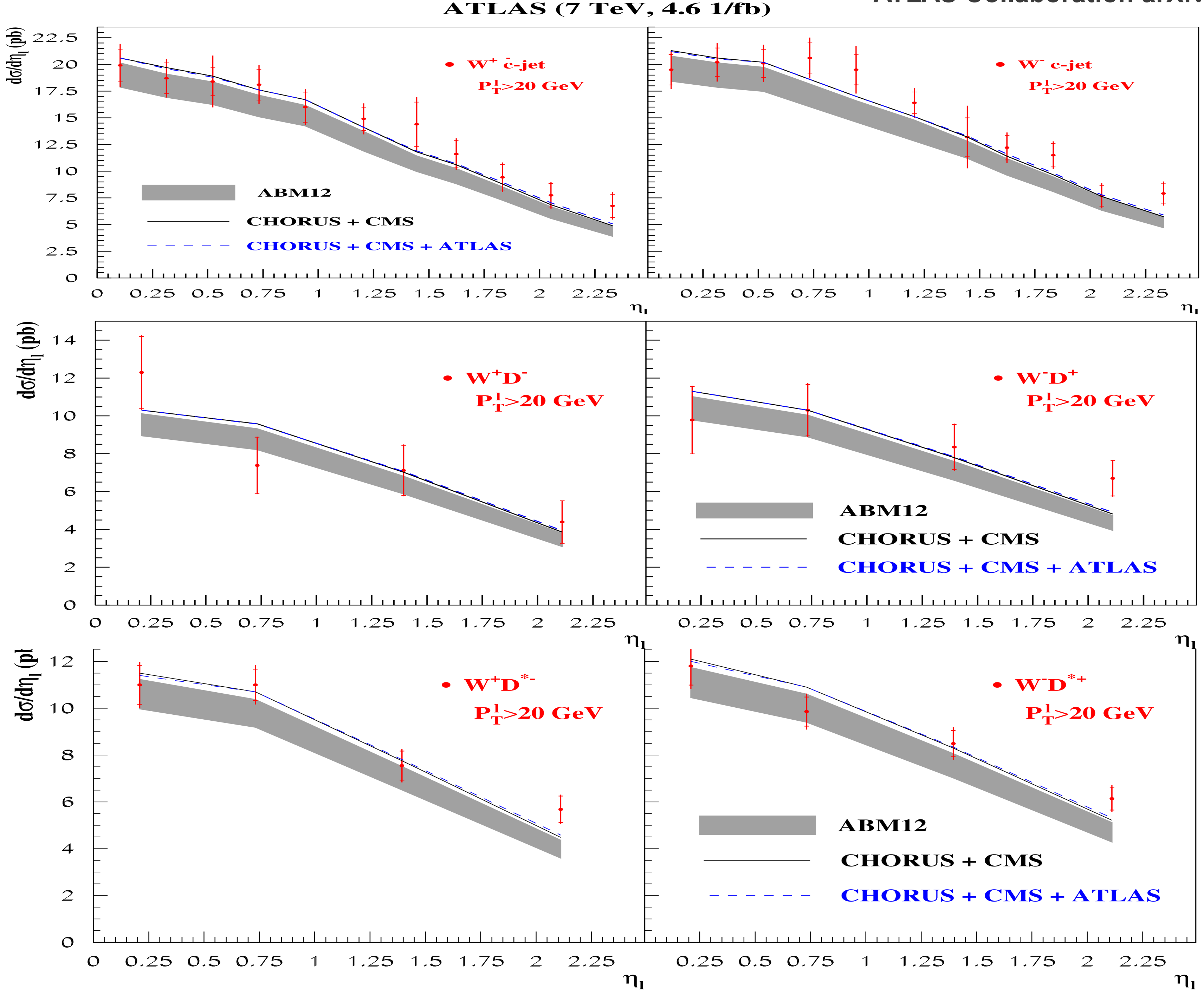


CMS Collaboration JHEP 02, 013 (2014)

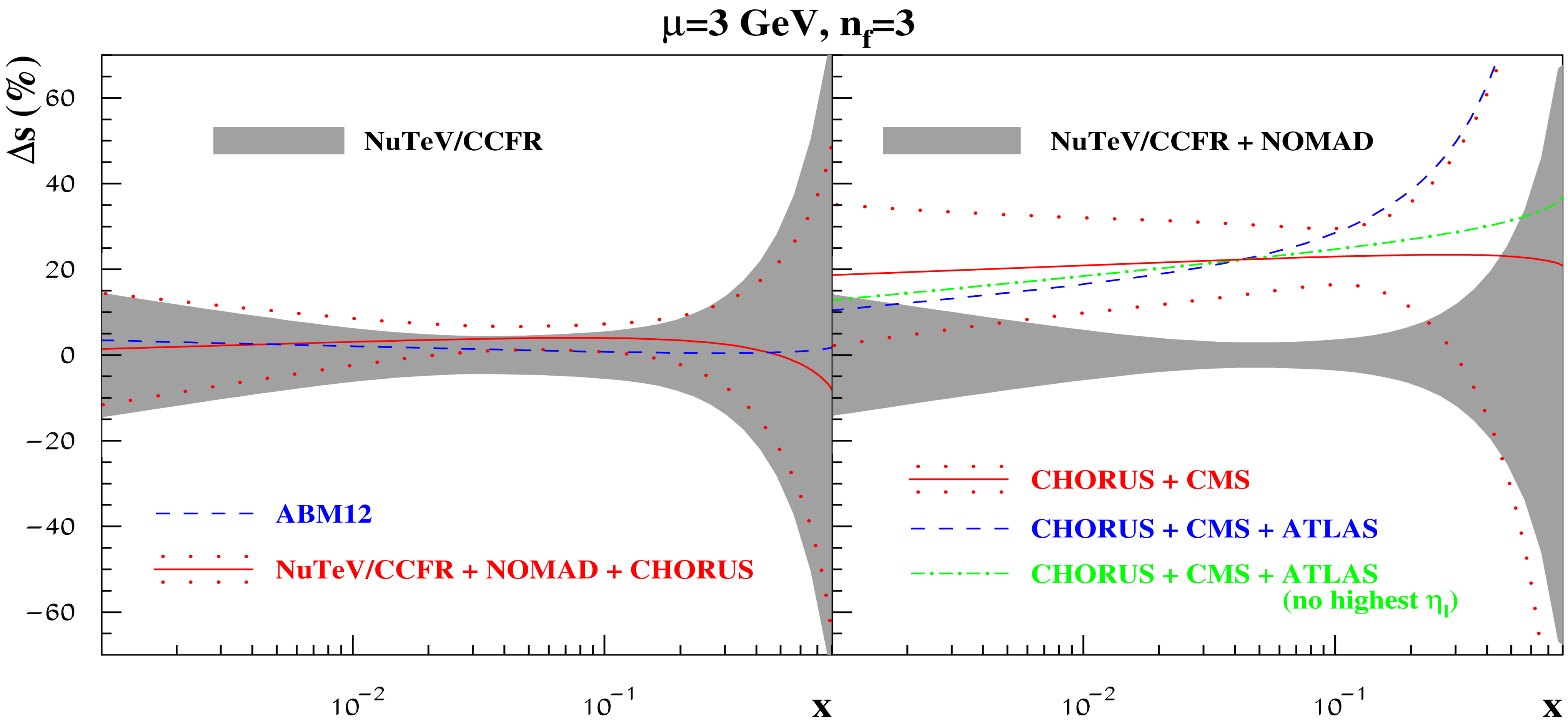
- CMS data go above the NuTeV/CCFR by 1σ; little impact on the strange sea
- The charge asymmetry is in a good agreement with the charge-symmetric strange sea
- Good agreement with the CHORUS data

ATLAS W+charm data in the ABM fit

ATLAS Collaboration arXiv:1402.6263

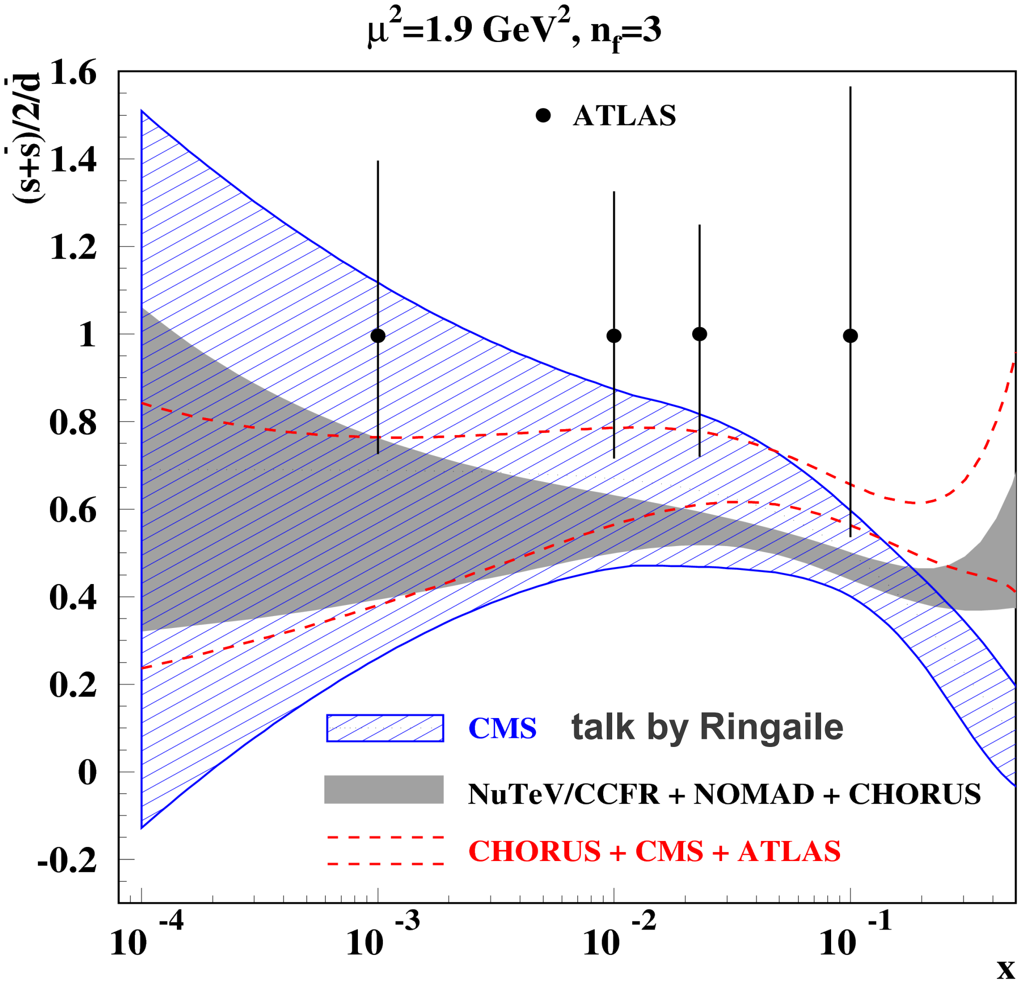


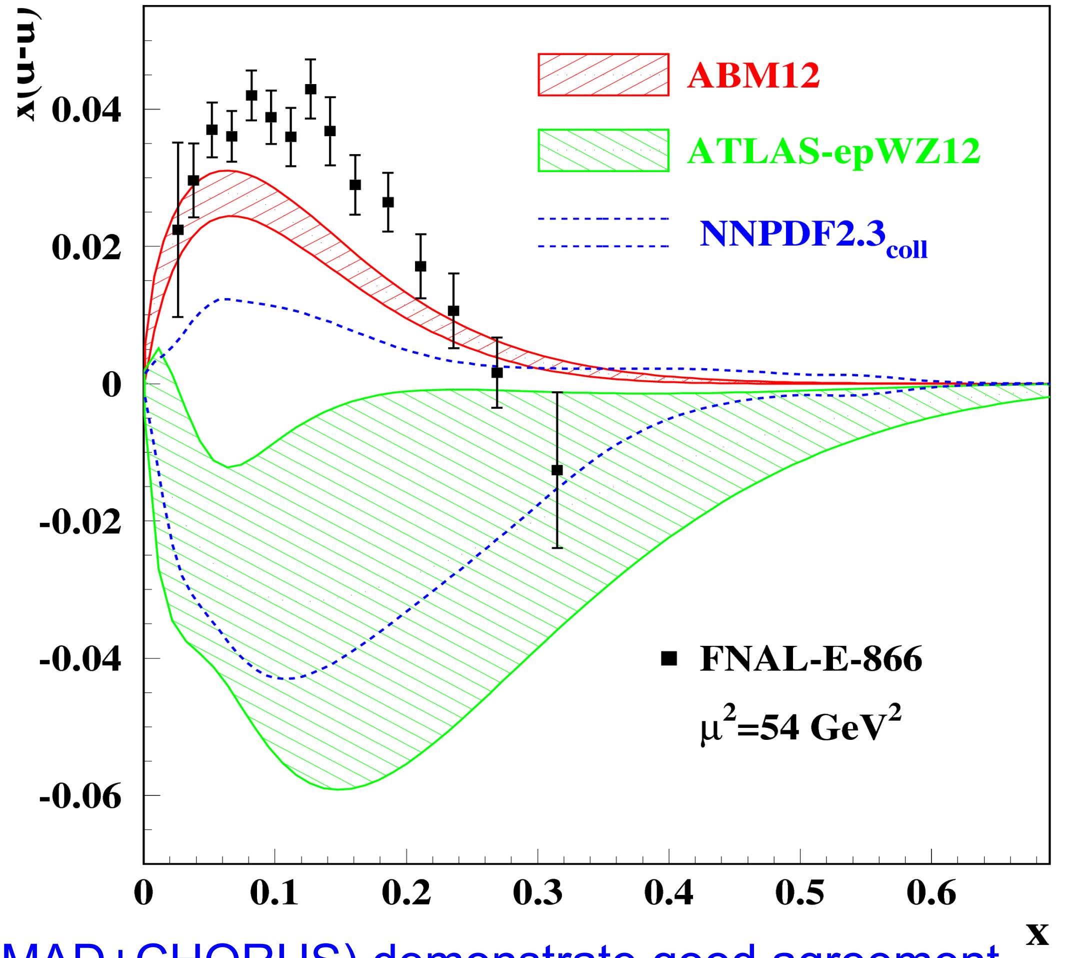
Strange sea preferred by different data combination



- NOMAD+CHORUS do not go far from NuTeV/CCFR; improved strangeness accuracy
- CHORUS+CMS+ATLAS differ from NuTeV/CCFR+NOMAD by 2-3σ at x~0.1
  (upper margin of the data tension)
- Largest-η ATLAS bin pulls strangeness up by 1σ – edge effect?

Comparison with earlier determinations





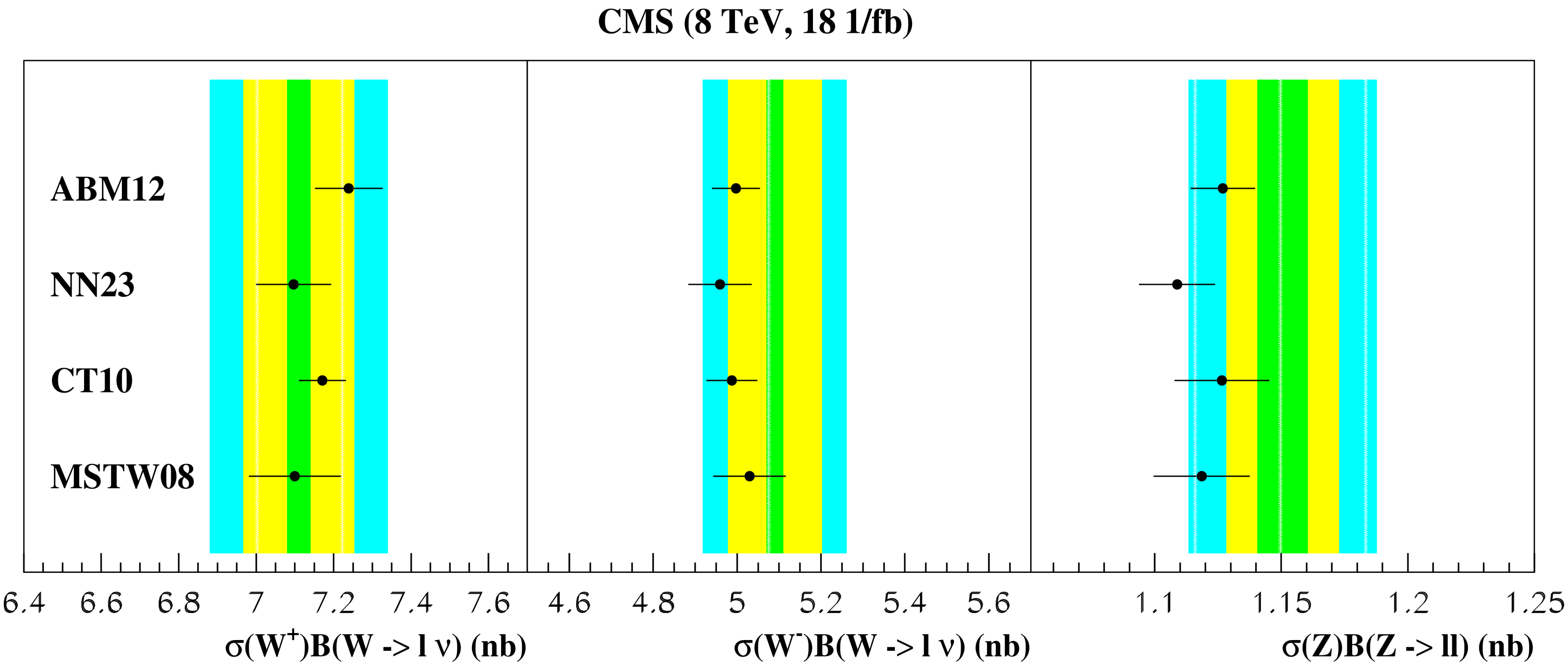
- Nominal ABM update (NuTeV/CCFR+NOMAD+CHORUS) demonstrate good agreement with the CMS results

- The ATLAS strange-sea in enhanced, however it is correlated with the d-quark sea suppression → disagreement with the FNAL-E-866 data

- Upper margin of the ABM analysis (CHORUS+CMS+ATLAS) is still lower than ATLAS

Integral rate of the W/Z production

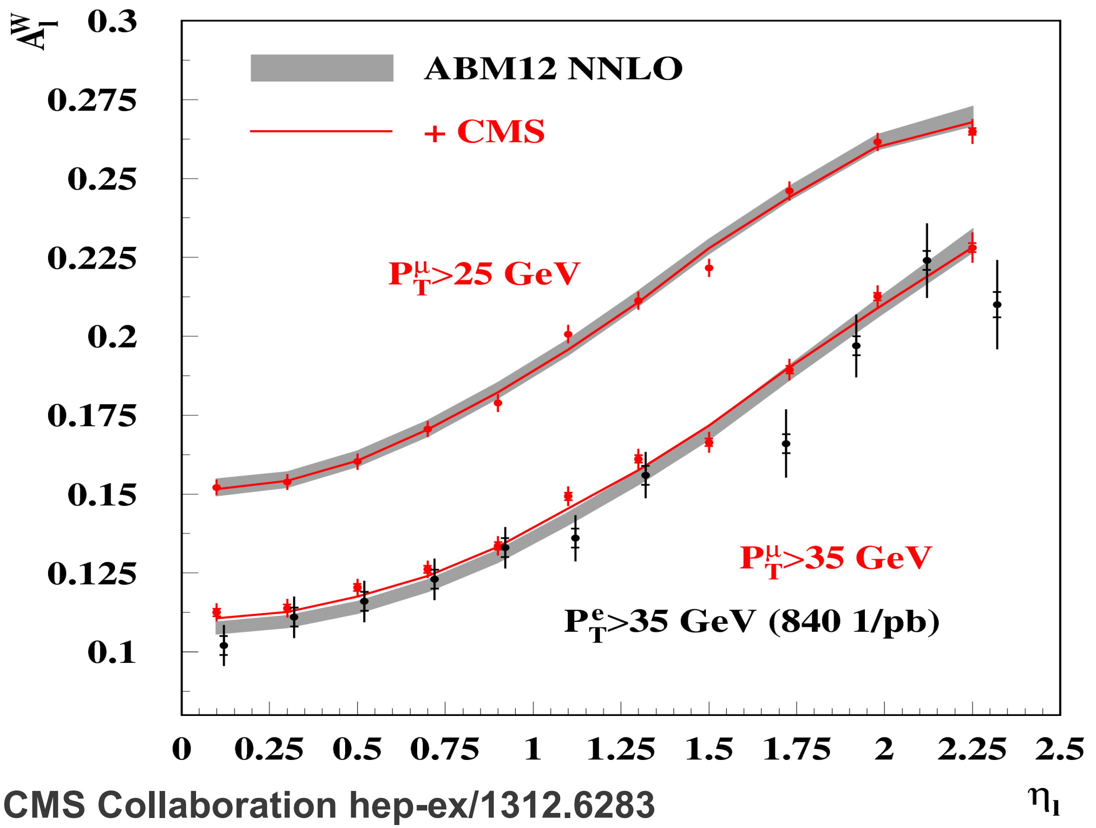
CMS Collaboration hep-ex/1402.2923



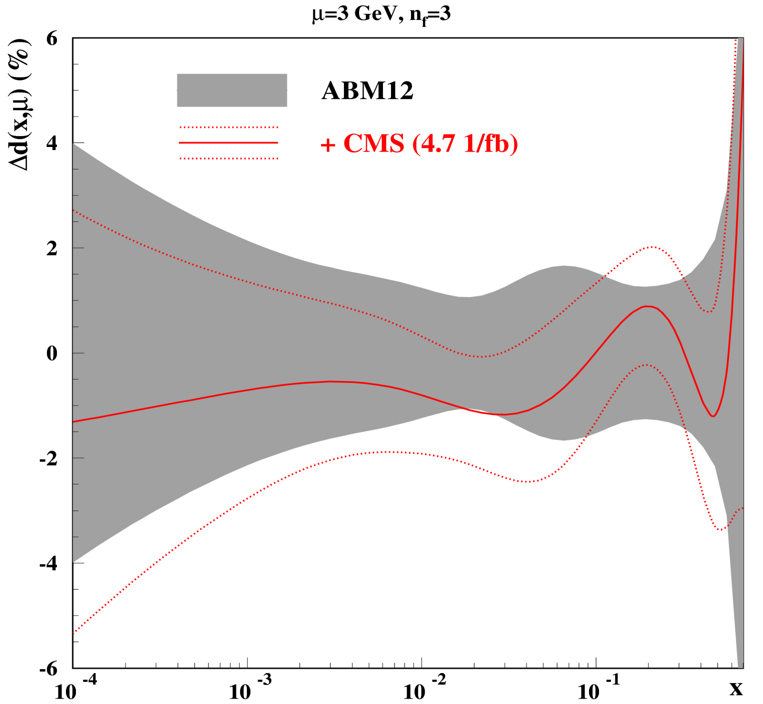
- Good overall agreement
- The errors in data are bigger than the errors in predictions
- Unmeasured phase space extrapolation?

Comparison with recent DY LHC data

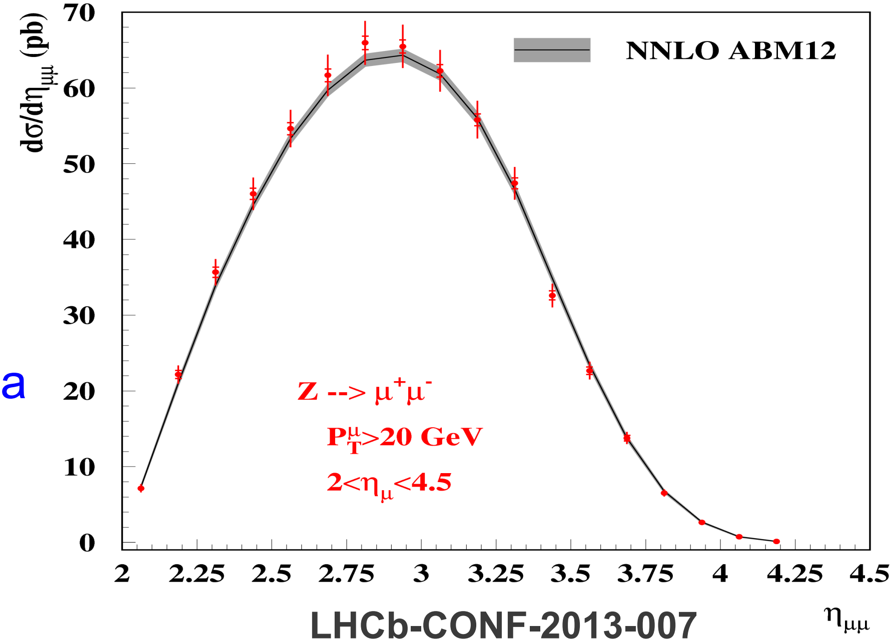
CMS (7 TeV, 4.7 1/fb)



CMS Collaboration hep-ex/1312.6283



LHCb (7 TeV, 1 1/fb)



LHCb-CONF-2013-007

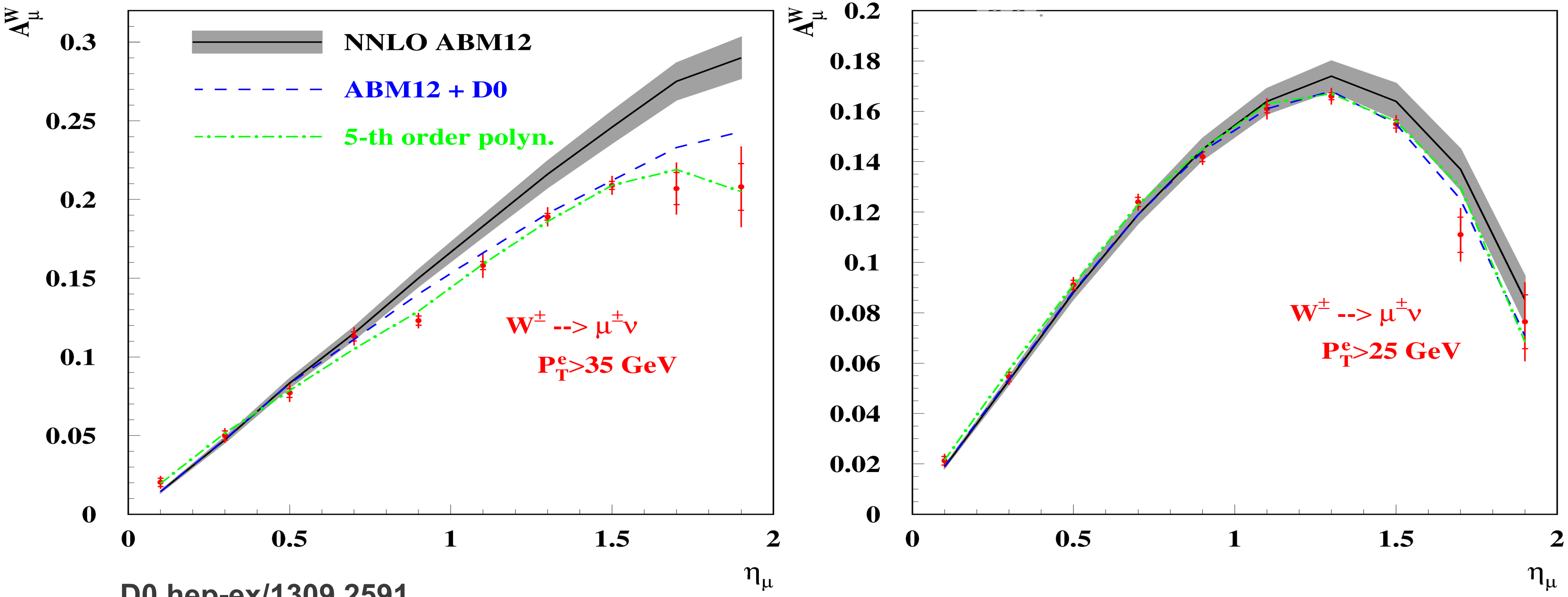
- Improved accuracy of predictions for the charged-lepton asymmetry (*7000h of DYNNLO to get a smooth curve*!)
  - – good agreement with the updated CMS data

P_T	>25 GeV	>35 GeV	
X^2	17	11	for NDP=11

  - – further improvement in d-u separation

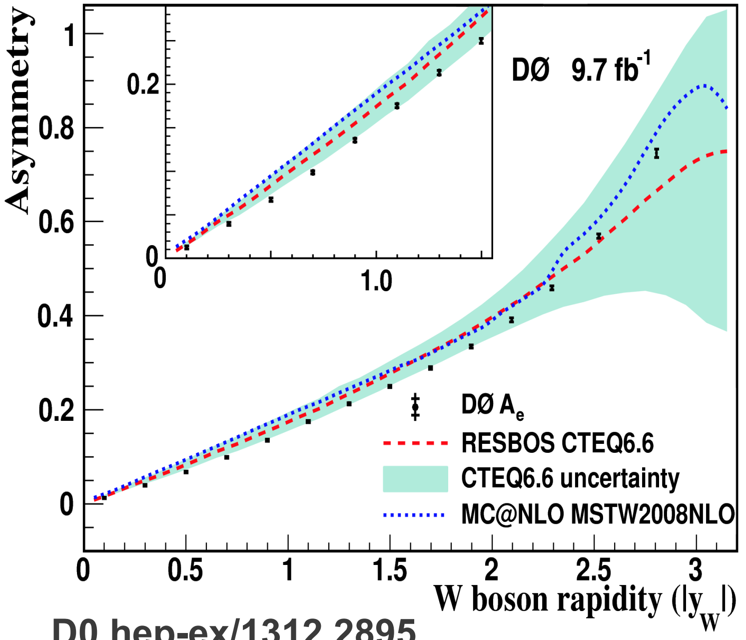
Comparison with recent DY Tevatron data

D0 (1.96 TeV, 7.3 1/fb)



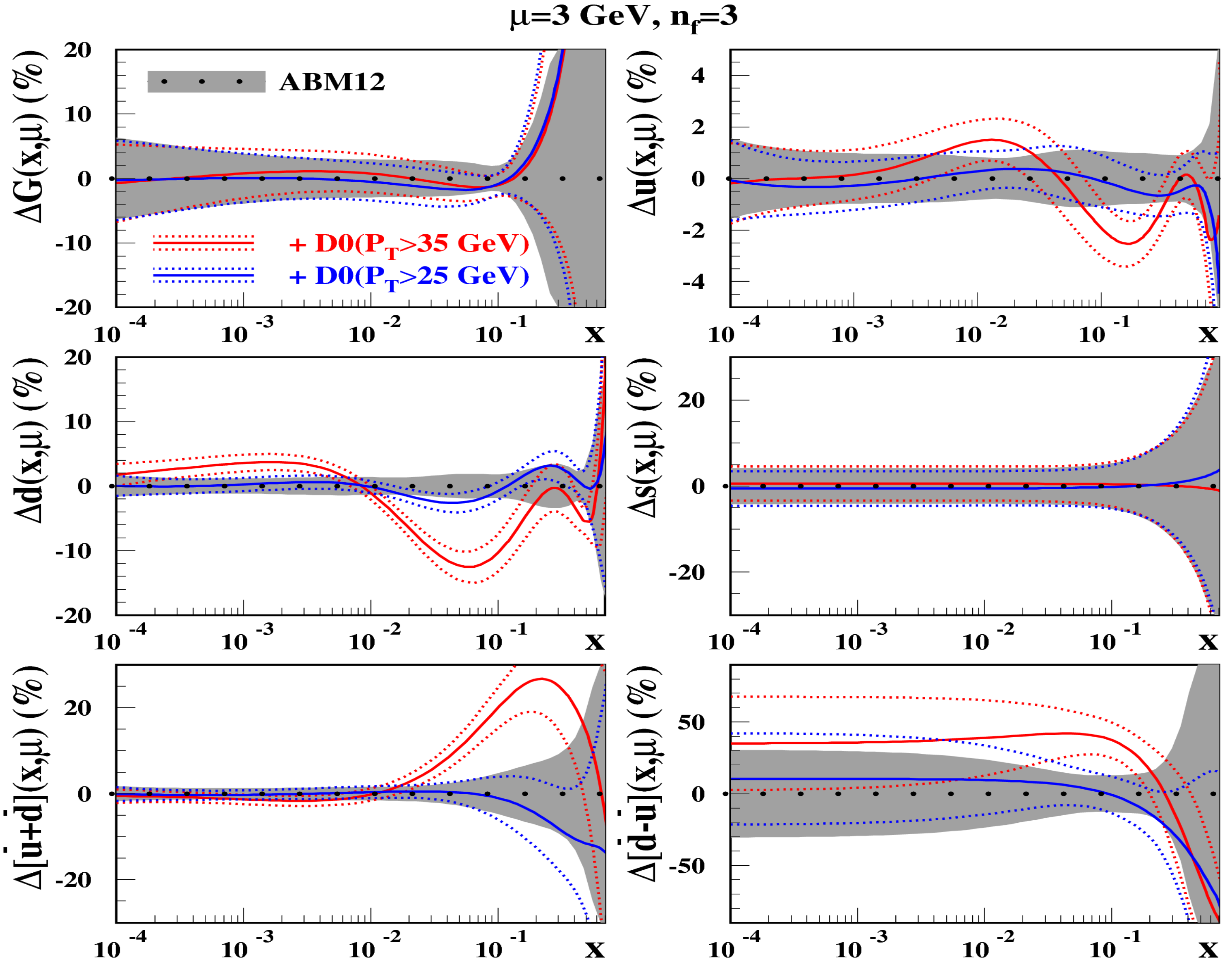
D0 hep-ex/1309.2591

- Poor agreement with the ABM12 predictions at P_T>35 GeV
- Poor description in the fit: χ^2=40/10 and 19/10 for P_T>35 and 25, respectively
- Polynomial fit gives χ^2=11/10, however displays a step structure at Y~1
- Smooth shape is observed in case of electron



D0 hep-ex/1312.2895

Impact of DY D0 data



Impact of the data on PDFs is quite sensitive to the the cut on P_T

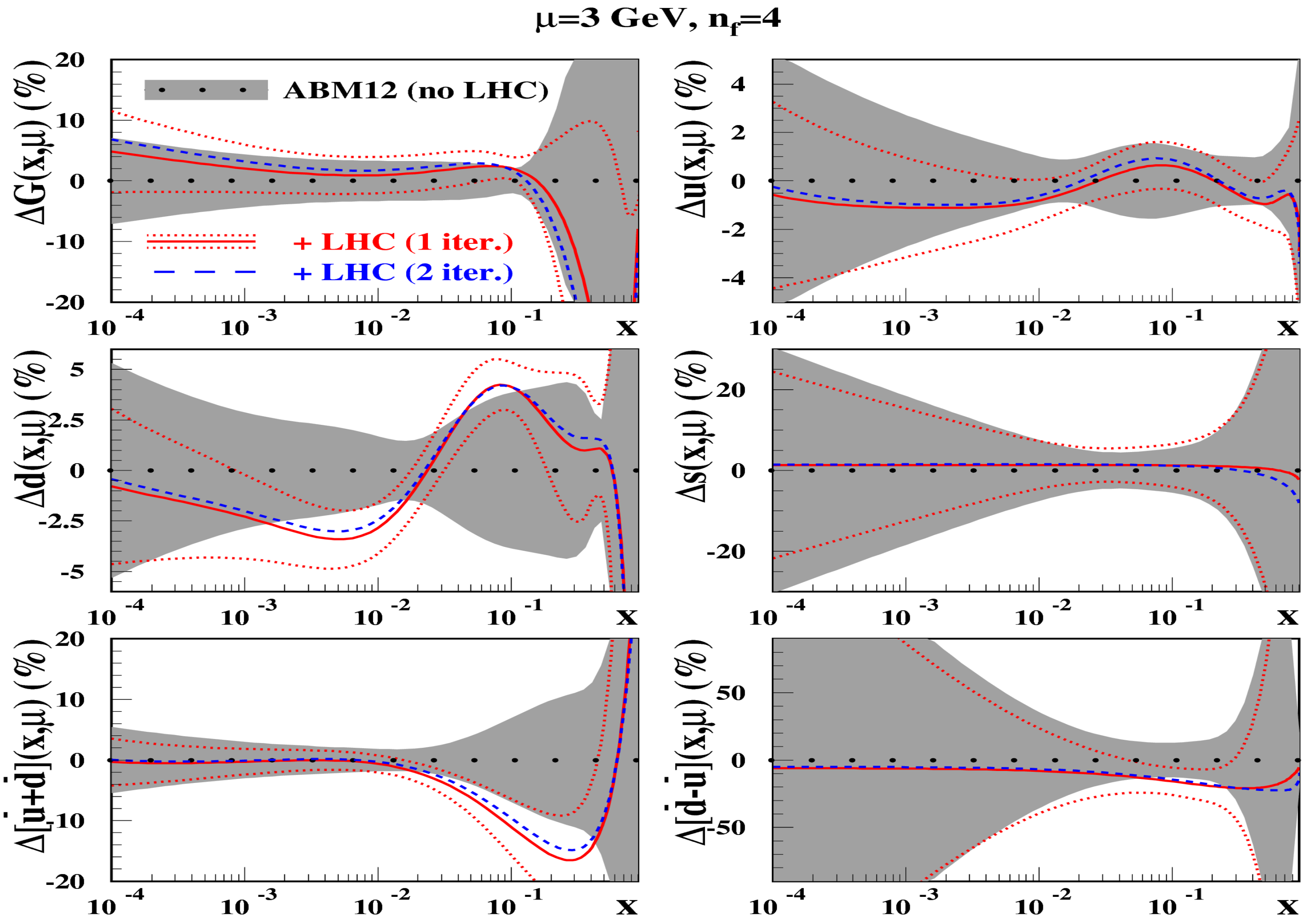
→ clarification is necessary

Summary

- Improved accuracy of strange sea using NOMAD and CHORUS data, factor of 2 at x~0.1
- Enhancement of ~20% due to CHORUS, CMS, and ATLAS data
  - statistical fluctuation?
  - impact of the NNLO corrections on W+charm production?
  - problems in B_μ or fragmentation model?
- The ATLAS and NNPDF2.3 strangeness determinations go above the ABM one due to suppression of the d-quark sea → separation of the quark species using only the collider data has strong limitation
- Good agreement with recent CMS data → further improvement in the d-u separation
- Poor agreement with the recent D0 data → clarification is necessary

Extras

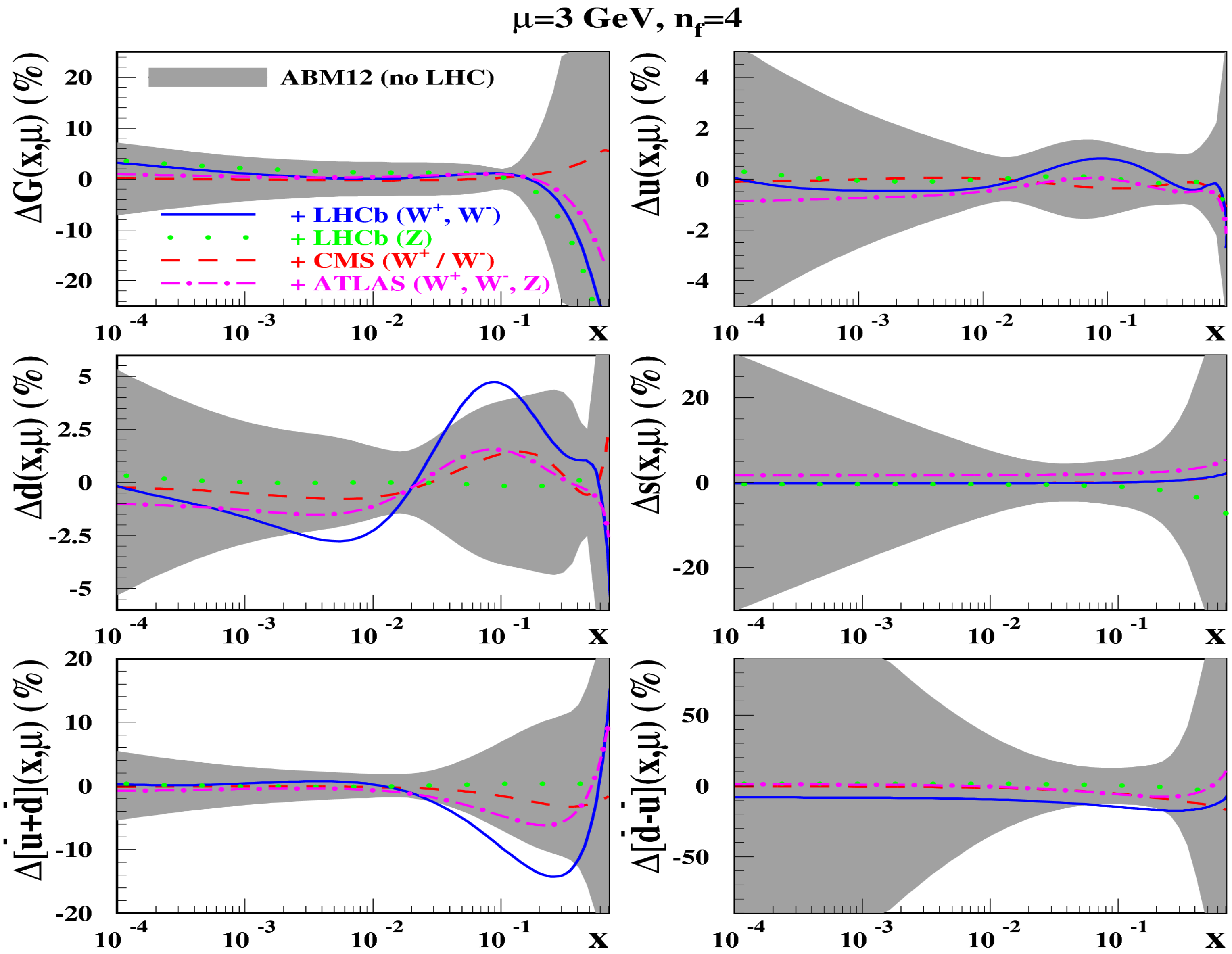
Impact of the LHC DY data on the PDFs



- d-quarks increase at x~0.1; *the errors get smaller*
- non-strange sea decrease at x~0.1
- strange sea stable → the enhancement observed by ATLAS is not reproduced

The algorithm used to include the LHC data is quite stable

Impact of the separate LHC data sets



The biggest effect come from the LHCb data, i.e. from the large rapidity region

NNLO DY corrections in the fit

The (N)NLO calculations are quite time-consuming → fast tools are employed (FASTNLO, Applegrid,.....)

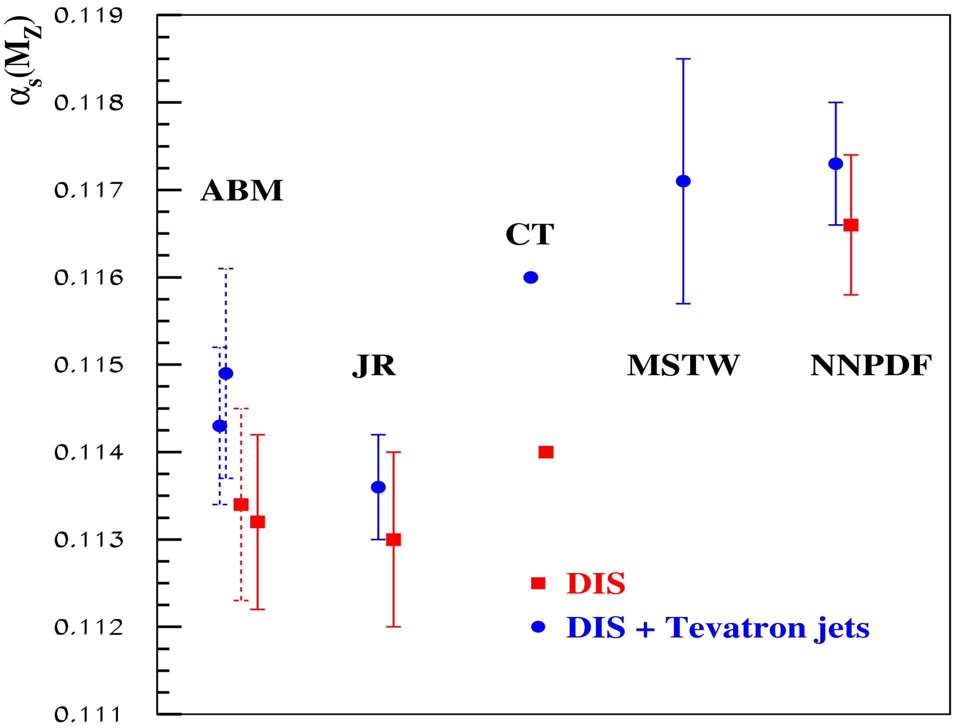
- the corrections for certain basis of PDFs are stored in the grid
- the fitted PDFs are expanded over the basis
- the NNLO c.s. in the PDF fit is calculated as a combination of expansion coefficients with the pre-prepared grids

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

Value of α_s in/from the PDF fits



- The Tevatron jet data push α_s up by ~0.001
- The MSTW and NNPDF values are bigger than the ABM one in particular due to impact of hight-twist terms and/or error correlations

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

- Recent CT 10 value is more close to ABM (no SLAC data used, stronger cut on Q^2, the error correlations are taken into account)

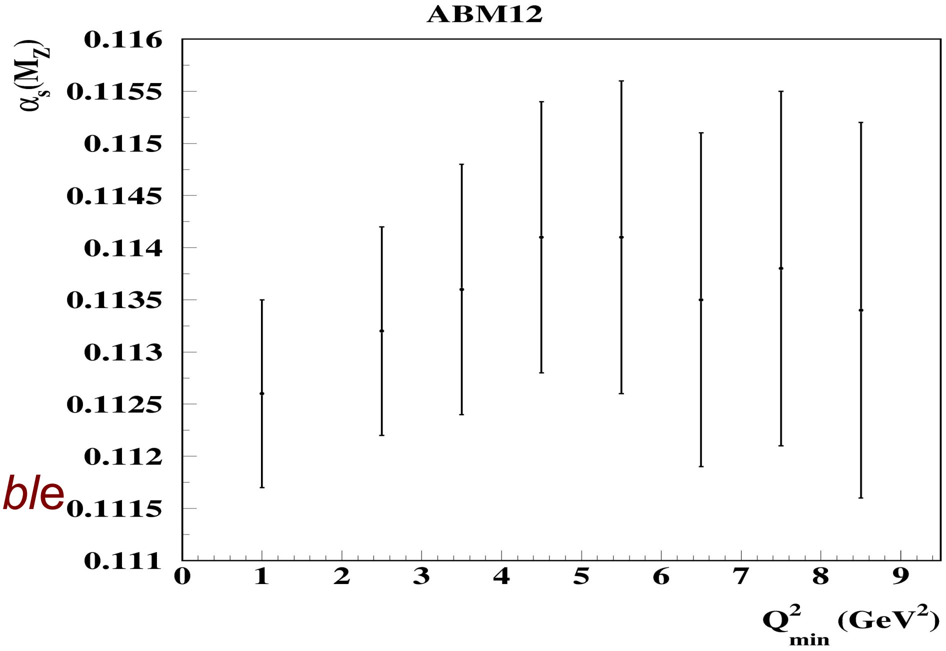
N.B. The MSTW update gives 0.1155 – 0.1171 depending on the jet data treatment

Thorne QCD@LHC2013

Consistent treatment of HT terms in the ABM fit:

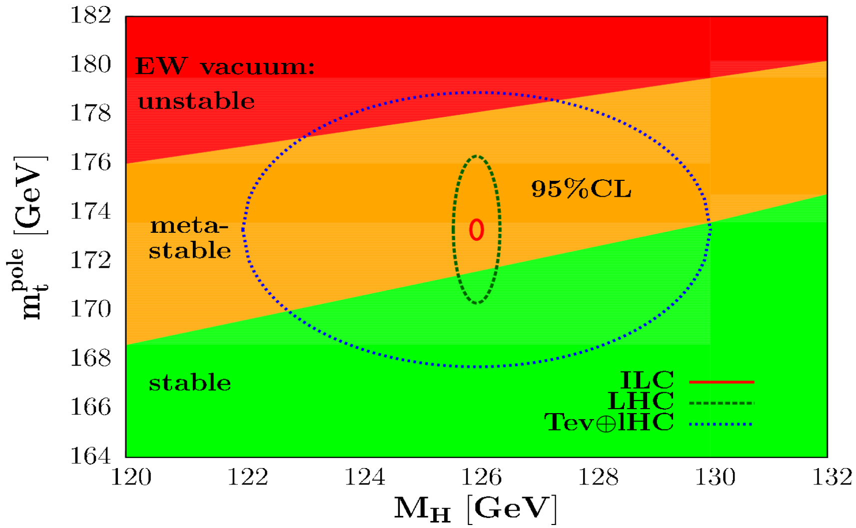
– no sensitivity to the low-Q cut

– $\alpha_s(M_z)$ = 0.1132(11) w/o SLAC and NMC data sensitive to the HT terms → *the cross-check with MSTW, CTEQ and NNPDF is highly desirable*



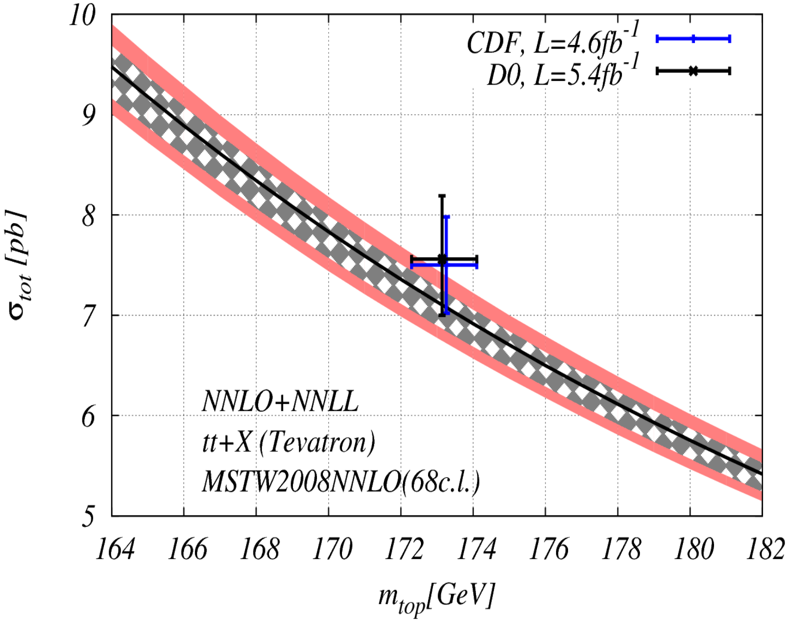
t-quark mass

- m_t(MC)=173.3±1 GeV (Tevatron/LHC)
- m_t(pole)≈ m_t(MC) - 1 GeV
- $m_t(m_t)$≈ m_t(pole) - 9 GeV



Vacuum stability condition requires m_t(pole)~171 GeV

sa, Djouadi, Moch PLB 716, 214 (2012)



Bärnreuther, Czakon, Mitov hep-ph/1204.5201

From the Tevatron c.s. m_t(pole)~171 GeV

CDF&D0	ABM11	JR09	MSTW08	NN21
$m_t^{\overline{MS}}(m_t)$	$162.0^{+2.3\,+0.7}_{-2.3\,-0.6}$	$163.5^{+2.2\,+0.6}_{-2.2\,-0.2}$	$163.2^{+2.2\,+0.7}_{-2.2\,-0.8}$	$164.4^{+2.2\,+0.8}_{-2.2\,-0.2}$
m_t^{pole}	$171.7^{+2.4\,+0.7}_{-2.4\,-0.6}$	$173.3^{+2.3\,+0.7}_{-2.3\,-0.2}$	$173.4^{+2.3\,+0.8}_{-2.3\,-0.8}$	$174.9^{+2.3\,+0.8}_{-2.3\,-0.3}$
(m_t^{pole})	$(169.9^{+2.4\,+1.2}_{-2.4\,-1.6})$	$(171.4^{+2.3\,+1.2}_{-2.3\,-1.1})$	$(171.3^{+2.3\,+1.4}_{-2.3\,-1.8})$	$(172.7^{+2.3\,+1.4}_{-2.3\,-1.2})$

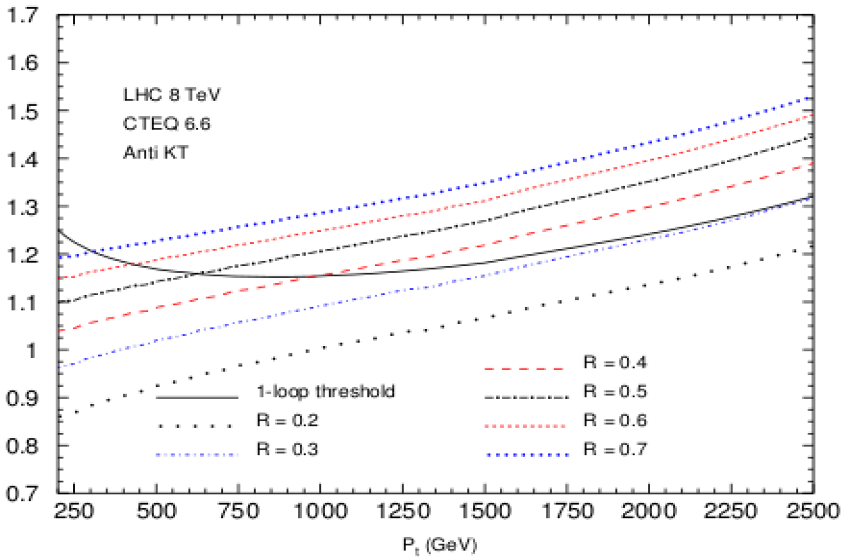
ATLAS&CMS	ABM11	JR09	MSTW08	NN21
$m_t^{\overline{MS}}(m_t)$	$159.0^{+2.1\,+0.7}_{-2.0\,-1.4}$	$165.3^{+2.3\,+0.6}_{-2.2\,-1.2}$	$166.0^{+2.3\,+0.7}_{-2.2\,-1.5}$	$166.7^{+2.3\,+0.8}_{-2.2\,-1.3}$
m_t^{pole}	$168.6^{+2.3\,+0.7}_{-2.2\,-1.5}$	$175.1^{+2.4\,+0.6}_{-2.3\,-1.3}$	$176.4^{+2.4\,+0.8}_{-2.3\,-1.6}$	$177.4^{+2.4\,+0.8}_{-2.3\,-1.4}$
(m_t^{pole})	$(166.1^{+2.2\,+1.7}_{-2.1\,-2.3})$	$(172.6^{+2.4\,+1.6}_{-2.3\,-2.1})$	$(173.5^{+2.4\,+1.8}_{-2.3\,-2.5})$	$(174.5^{+2.4\,+2.0}_{-2.3\,-2.3})$

Stronger correlation between m_t, PDFs and α_s at LHC

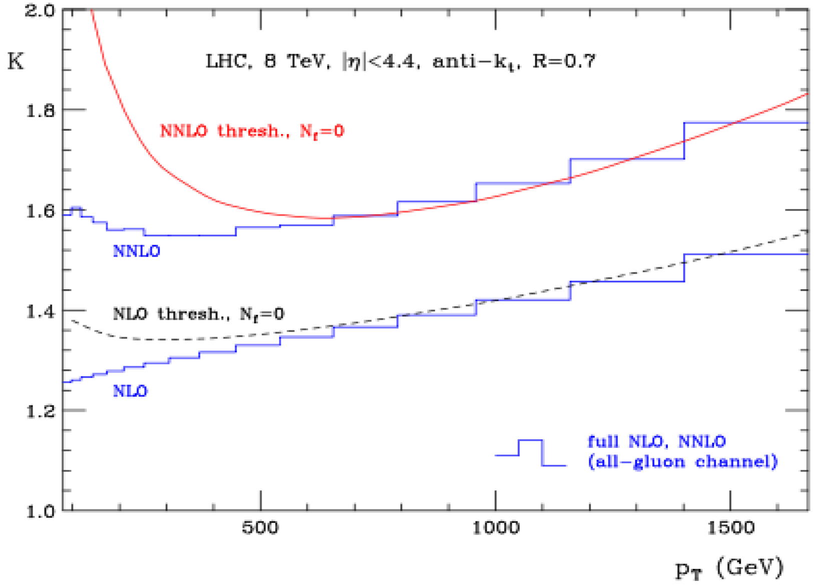
Status of QCD theory for jet cross sections

- One-jet inclusive jets hadro-production $P + P(\bar{P}) \rightarrow J(R) + X(s_4)$
  - NLO known since long
  - large threshold corrections of type $\alpha_s^l \, [\ln^{2l-1}(s_4/p_T^2)/s_4]_+$ from soft/collinear gluon radiation Kidonakis, Owens, hep-ph/0007268
  - $\ln R$ dependence on jet's cone size R in small cone approximation de Florian, Vogelsang, arXiv:0704.1677
- Threshold terms (Kidonakis, Owens '01) used as approximation to unknown NNLO corrections
  - applied in PDF analyses MSTW, arxiv:0901.0002
  - applied in experimantal analyses of jet data D0 Collaboration, arXiv:0911.2710, arXiv:1207.4957
- Check of validity of those approximations very important

Theoretical issues in the jet data analysis



- threshold logarithms alone (w/o $\ln R$) at 1-loop fail to describe exact results Kumar, Moch, arXiv:1309.5311



- cone size dependence $\ln R$ numerically important de Florian, Hinderer, Mukherjee, Ringer, Vogelsang, arXiv:1310.7192
- nice match with exact NNLO (purely gluonic) computation Currie, Gehrmann-De Ridder, Glover, Pires, arXiv:1310.3993

Revision of the NNLO PDF analyses based on jet data, particularly using the threshold resummation → impact on the PDF4LHC recommendation