Little is known about the strange sea

QCD analysis of the ATLAS and CMS W± and Z cross-section measurements and implications for the strange sea density

arXiv:1803.00968

CSKK: A. Cooper-Sarkar, K. Klimek

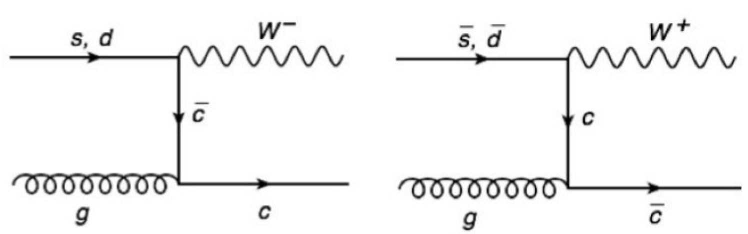
From my DIS14 talk ...

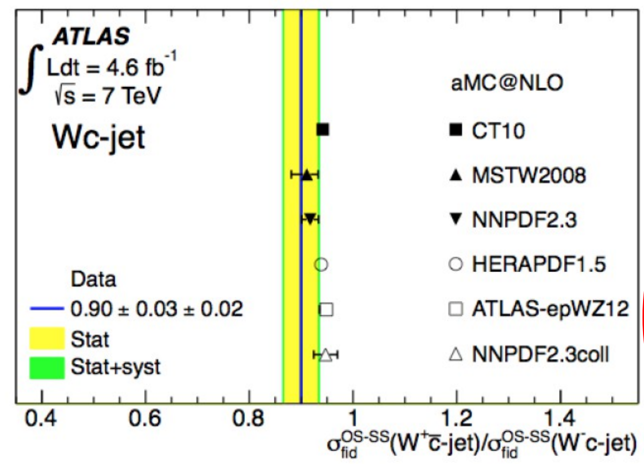
arXiv:1402.6263v1

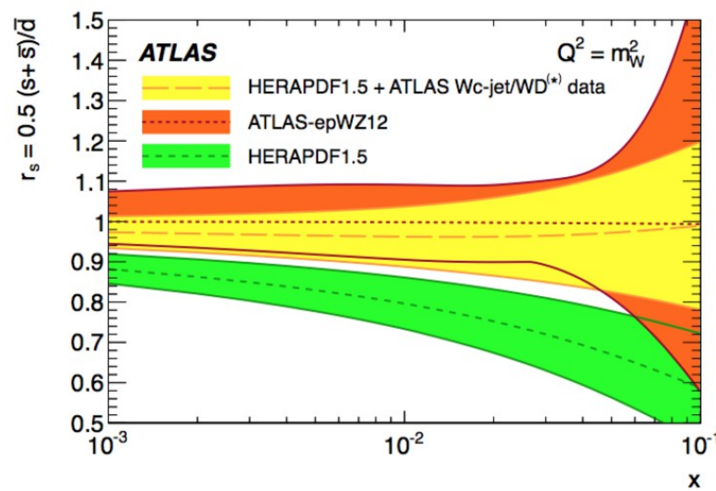
Prince Charming helps strangers

For details see G. Aad talk

- PDFs with different strange see assumptions
- Differential W and Z cross sections at LHC
  - constraints on strange sea at $Q^2 \sim M^2_{Z/W}$
  - ATLAS-epWZ12 PDF based on ATLAS W and Z cross-section + HERAI data
- W + charm measurements







SU(3)-symmetric light-quark sea hypothesis supported

$$r_s \equiv 0.5(s + \bar{s})/\bar{d} = 0.96 \,^{+0.16}_{-0.18}\,^{+0.21}_{-0.24}$$

K. Klimek, 28.04.14, Structure functions and parton densities

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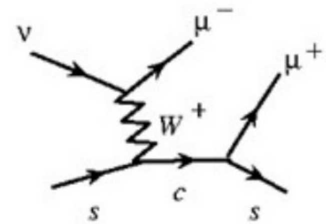
Motivation

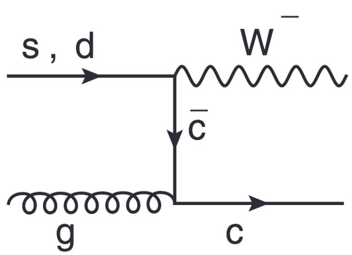
- PDFs fits x~0.01 mainlly constrained by HERA: light flavor quarks and antiquarks
- Flavor composition of total light sea not well determined by HERA data alone

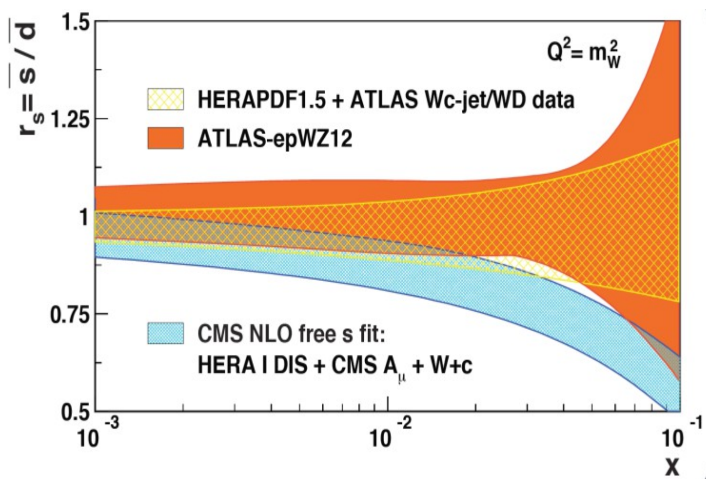
  → **<u>in particular little is known about strange sea</u>**
- This comes from di-muon production in neutrino induced deep inelastic scattering
  - sensitive to uncertainties from charm fragmentation and nuclear corrections
- Neutrino data suggest suppression of strange sea:

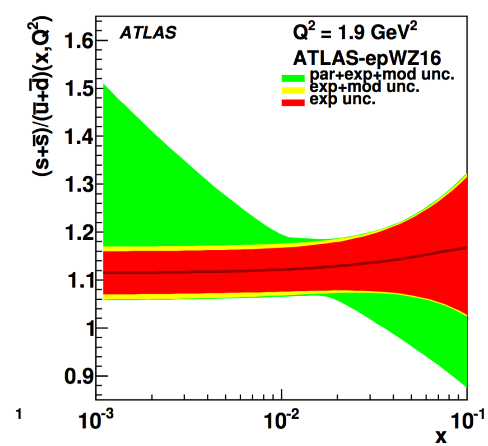
  sbar(x) = 0.5 dbar(x)



- At LHC W+c data give information on strangeness BUT involve assumptions on charm jet fragmentation and hadronisation
  - CMS W+charm analysis supports suppression
  - ATLAS W+charm analysis finds no suppression
  - New ATLAS inclusive W/Z production finds no suppression



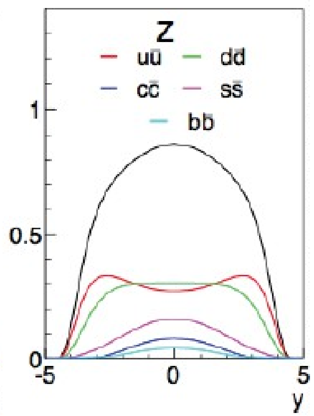




- Drell-Yan process and DIS are theoretically best understood processes

→ Interesting to investigate if this disagreement is present for the inclusive Drell Yan data of ATLAS and CMS

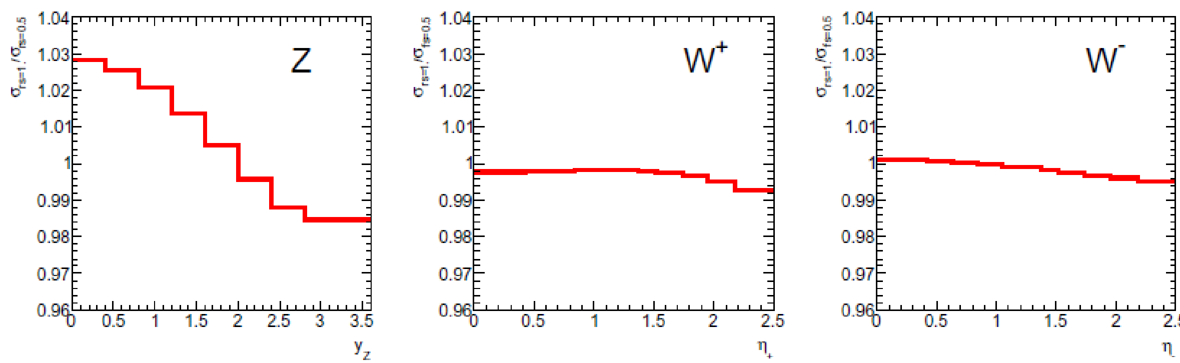
sbar(x) = 0.5 dbar(x) ⟶ sbar(x) = dbar(x)



small effect ~ 4%

→ can we see it?

→ yes we can!



Main fit – CSKK – includes inclusive DY production

- CMS Z @ 7 TeV CMS Collaboration, JHEP 12 (2013) 030, [arXiv:1310.7291].
- CMS W asymmetries @ 7 TeV
  CMS Collaboration, Phys. Rev. D 90 (2014) 032004, [arXiv:1312.6283].
- CMS W^{+-} cross sections @ 8 TeV
  CMS Collaboration, Eur. Phys. J. C 76 (2016) 469, [arXiv:1603.01803].
- ATLAS W and Z cross sections from one data sets – correlations
  ATLAS Collaboration, Eur. Phys. J. C 77 367 (2017), [arXiv:1612.03016]

→ for all Z data we use only Z-mass-peak measurements

→ off-peak Z data & CMS Z @ 8 TeV used as cross check

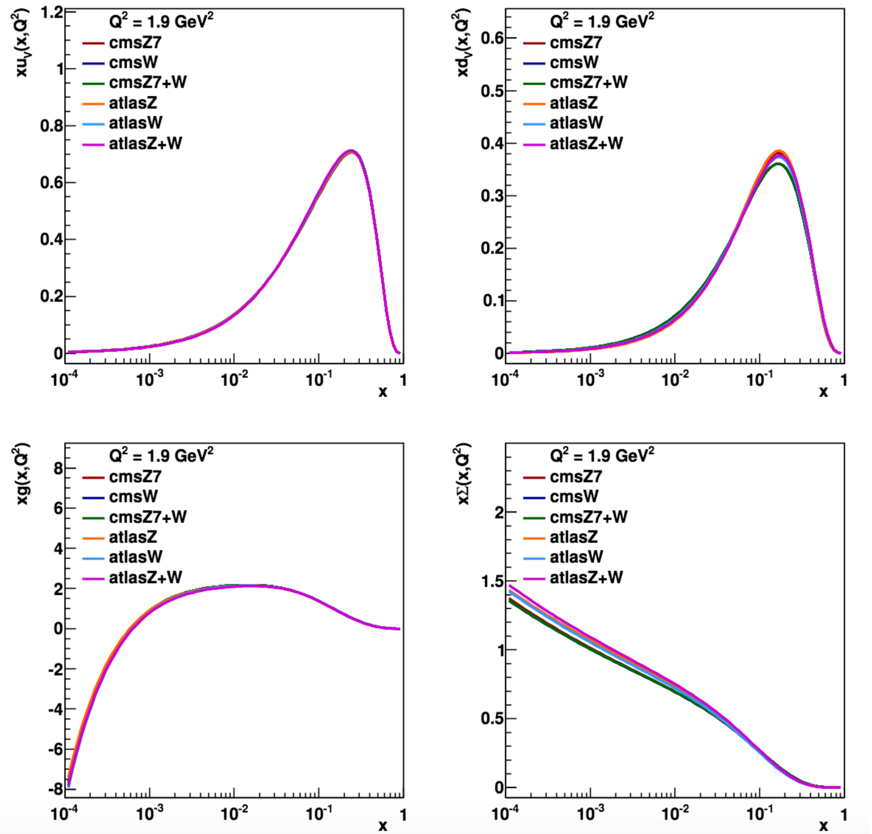
QCD analysis

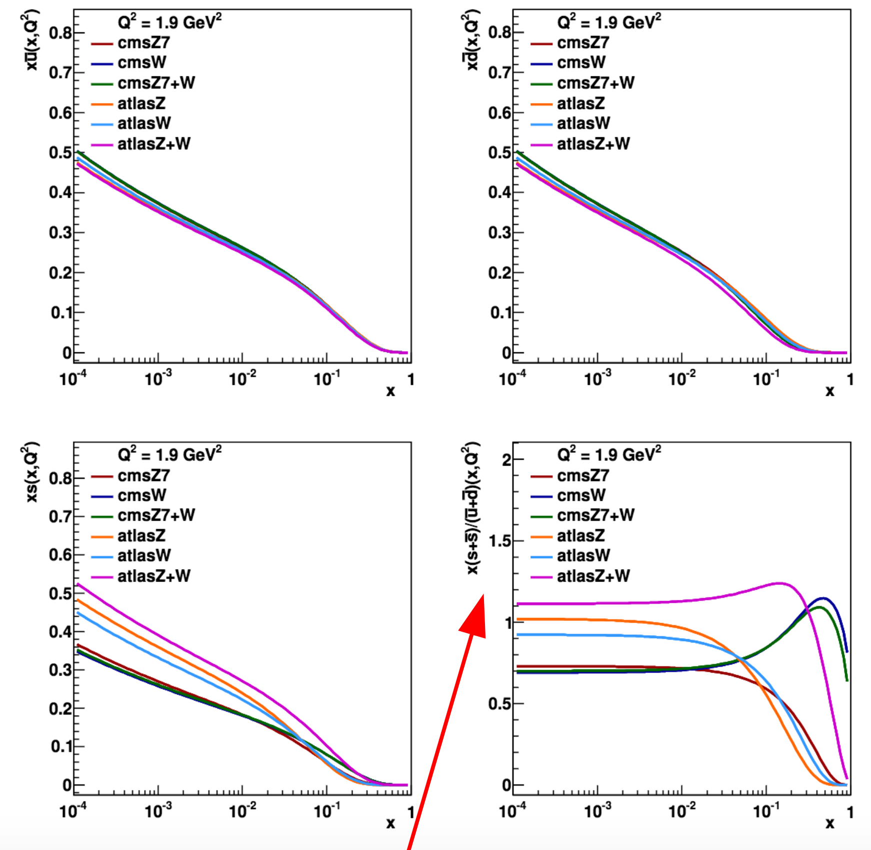
- QCD analysis at NNLO, following ATLAS paper, using xFitter + independent code
  - RTOPT, Q^2 of HERA data from 7.5 GeV^2
  - K-factors, APPLGRID predictions
- Parameterisation: 15 free parameters, 2 for strange sea
  - Chosen after parameterisation scan

$$
\begin{aligned}
xu_v(x) &= A_{u_v} x^{B_{u_v}} (1-x)^{C_{u_v}} (1 + E_{u_v} x^2)\,, \\
xd_v(x) &= A_{d_v} x^{B_{d_v}} (1-x)^{C_{d_v}}\,, \\
x\bar{u}(x) &= A_{\bar{u}} x^{B_{\bar{u}}} (1-x)^{C_{\bar{u}}}\,, \\
x\bar{d}(x) &= A_{\bar{d}} x^{B_{\bar{d}}} (1-x)^{C_{\bar{d}}}\,, \\
xg(x) &= A_g x^{B_g} (1-x)^{C_g} - A'_g x^{B'_g} (1-x)^{C'_g}\,, \\
x\bar{s}(x) &= A_{\bar{s}} x^{B_{\bar{s}}} (1-x)^{C_{\bar{s}}}\,,
\end{aligned}
\qquad (22)
$$

where $A_{\bar{u}} = A_{\bar{d}}$ and $B_{\bar{s}} = B_{\bar{d}} = B_{\bar{u}}$. Given the enhanced sensitivity to the strange-quark distribution through the ATLAS data, $A_{\bar{s}}$ and $C_{\bar{s}}$ appear as free parameters, assuming $s = \bar{s}$. The experimental data uncertainties are propagated to the extracted QCD fit parameters using the asymmetric Hessian method based on the iterative procedure of Ref. [128], which provides an estimate of the corresponding PDF uncertainties.

Fits to CMS & ATLAS data separately

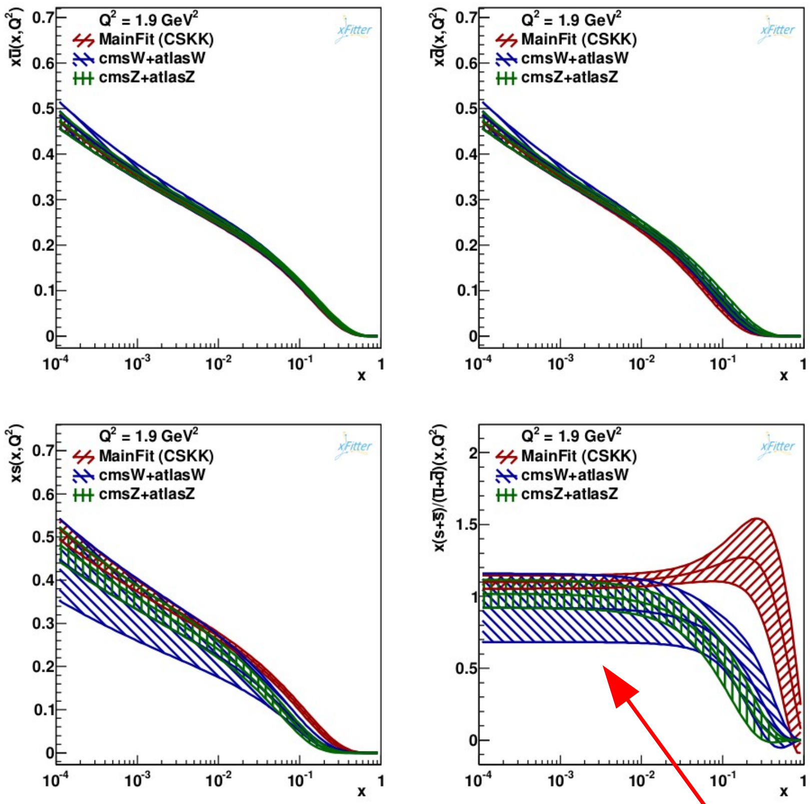




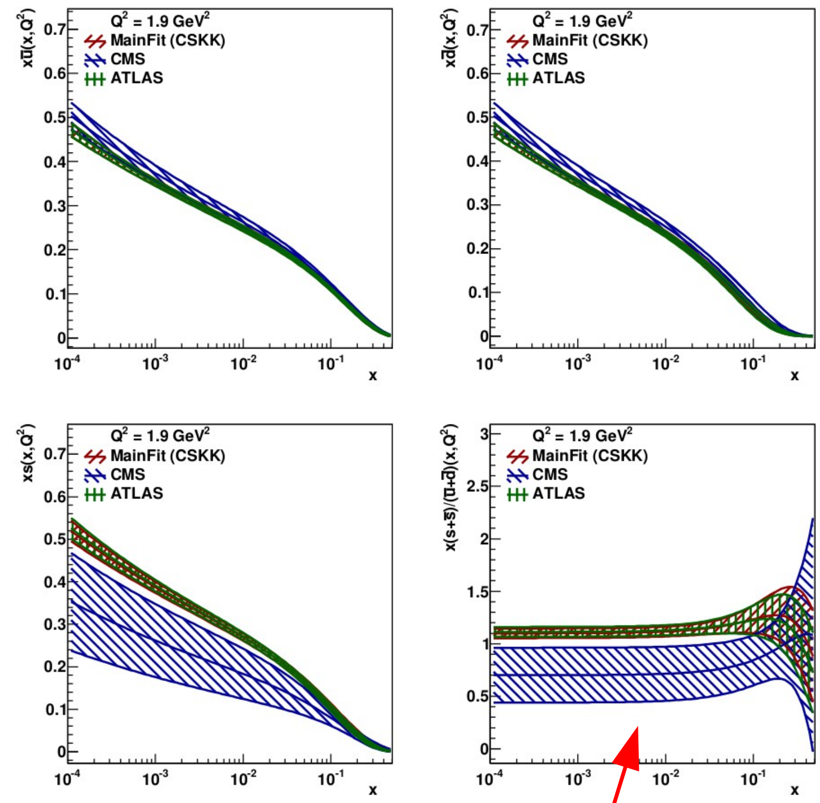
This ratio is unity if strange quarks are not suppressed in relation to light quarks and is ~ 0.5 for the conventional level of suppression.

- Valence, gluon and total sea similar
- Break-up of sea – sensitive to LHC data – different for CMS and ATLAS
- at small x neither data support conventional level of suppression
- For x > 0.1 parameterisation uncertainties usually large

W .vs. Z



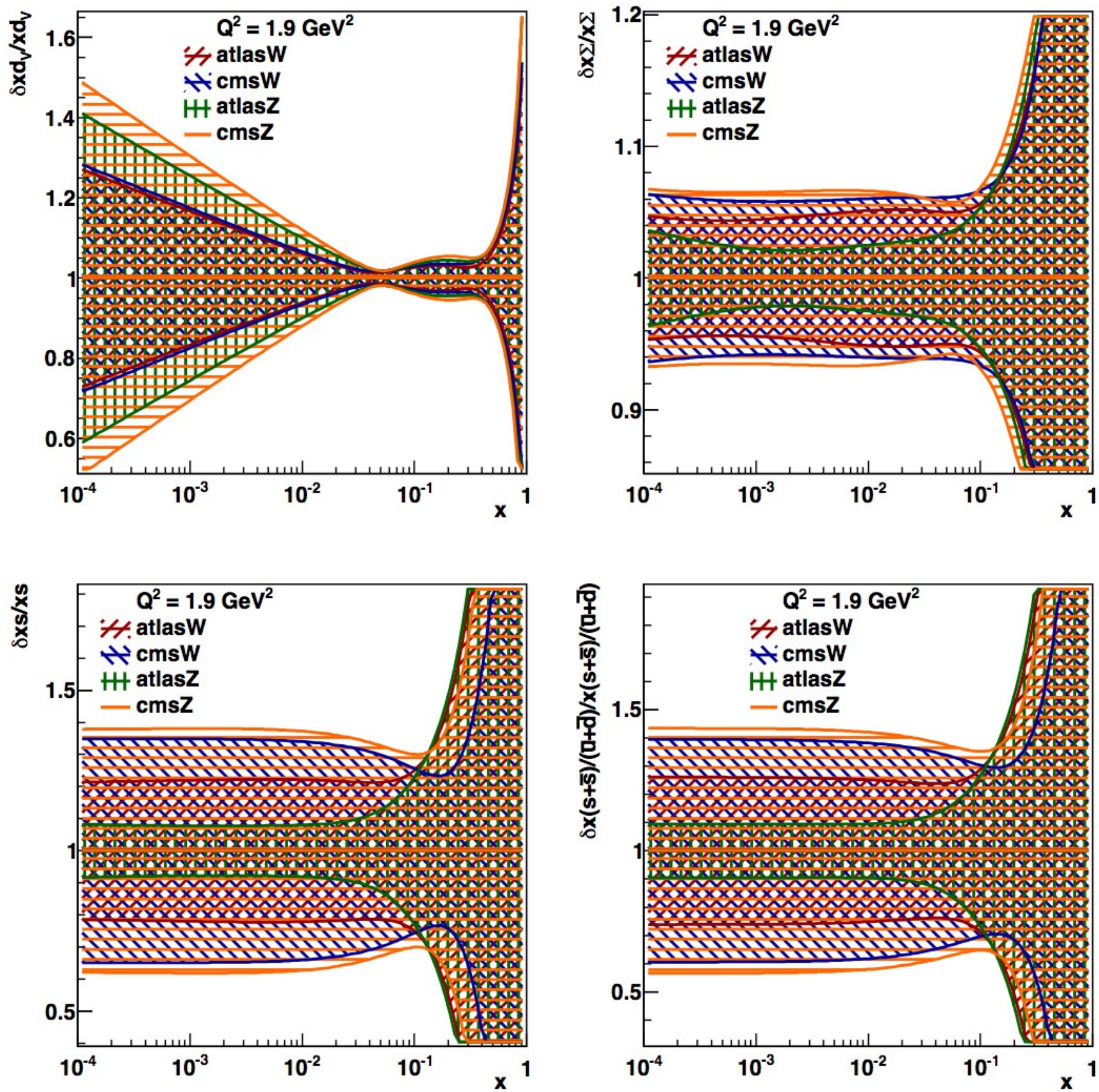
ATLAS .vs. CMS



- Experimental uncertainties
- Valence quarks, gluon and total sea similar
- Flavor break up of sea is similar at small x for W and Z data separately
  - Most information comes from Z data
  - For ATLAS correlations between Z and W important
- For x ~ 0.01 CMS ratio 1-2 sigma lower then ATLAS ratio
- However ALL configurations support unsuppressed strangeness > 0.5

Constraining power of various datasets

- Valence quarks best constrained by both CMS and ATLAS W data
- For total sea Σ ATLAS Z most constraining
  - followed by ATLAS W, CMS W and CMS Z
- Same ordering seen for ubar and dbar and is most pronounced for s and R_s



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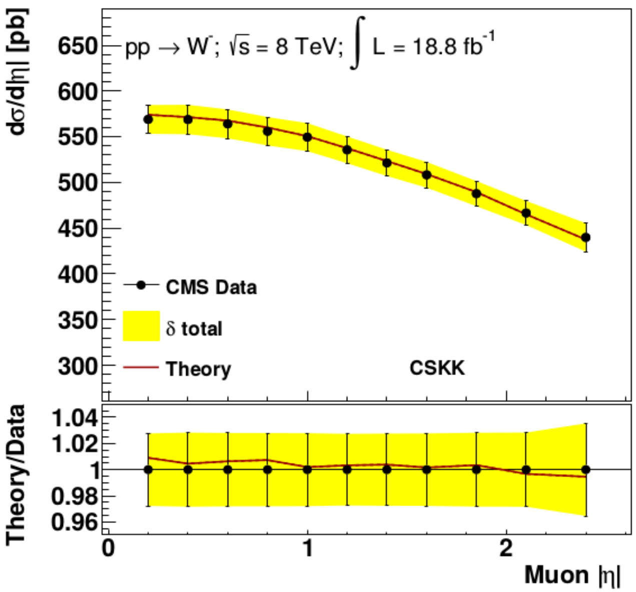
Fit quality

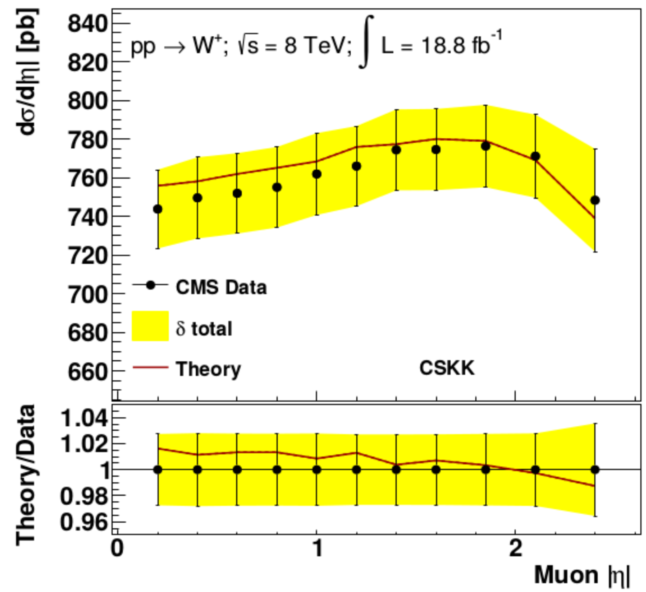
- Total and partial χ^2s for W/Z data samples good
- ATLAS + CMS with central Z fit → MainFit → CSKK
- clear that greater accuracy of ATLAS data dominates CSKK fit
  - combined fit has unsuppressed strangeness
  - CMS data are not in tension with this result → χ^2 for CMS data is still very good

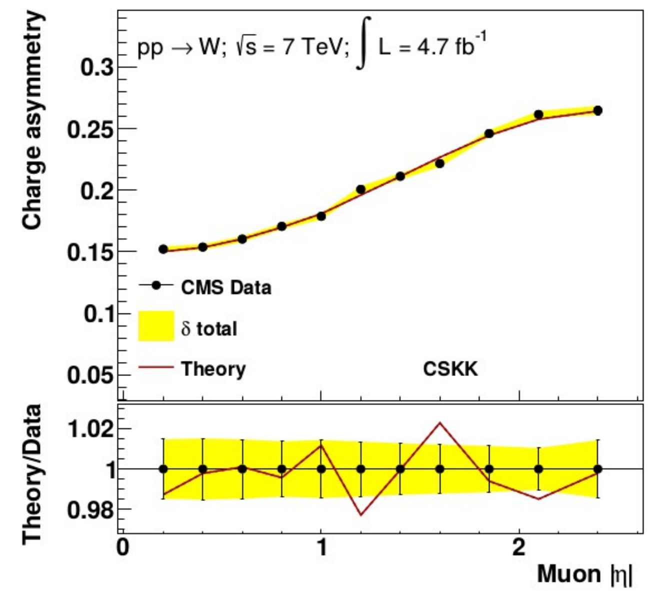
	ATLAS and CMS W	ATLAS and CMS Z	ATLAS and CMS W and Z, CSKK fit
Total χ^2/NDF	1265/1096 = 1.15	1244/1086 = 1.15	1308/1141 = 1.15
Data set, χ^2/NDP			
HERA	1159/1056	1157/1056	1163/1056
ATLAS W^+	12/11		13/11
ATLAS W^-	8/11		9/11
ATLAS central CC Z		14/12	16/12
ATLAS central CF Z		9/9	7/9
CMS 7 TeV central Z		12/24	12/24
CMS 7 TeV W-asym.	13/11		14/11
CMS 8 TeV W^+, W^-	6/22		5/22

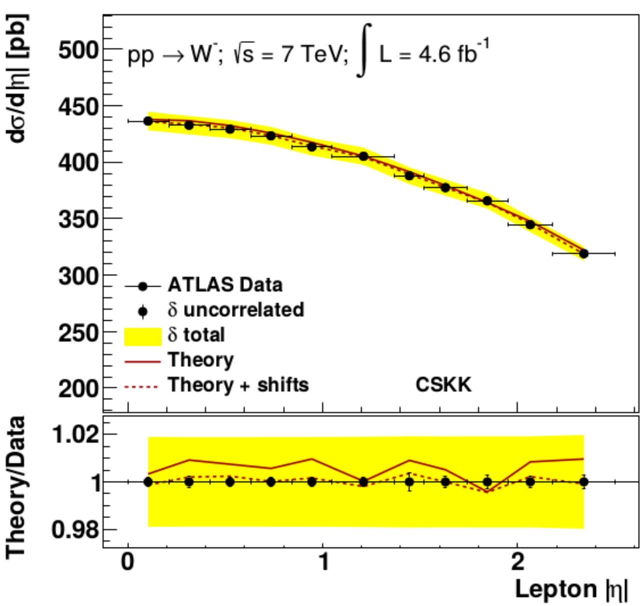
	CMS Z7	CMS W7,8	CMS Z7 + W7,8
Total χ^2/NDF	1218/1965	1225/1074	1236/1098
Data set, χ^2/NDP			
HERA	1156/1056	1157/1056	1157/1056
CMS 7 TeV central Z	11/24		11/24
CMS 7 TeV W-asymmetry		13/11	13/11
CMS 8 TeV W^+, W^-		4/22	4/22

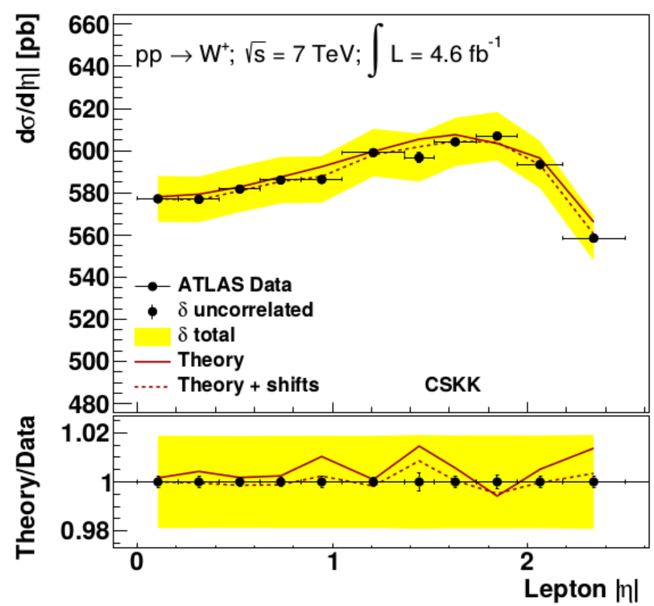
Data description: W



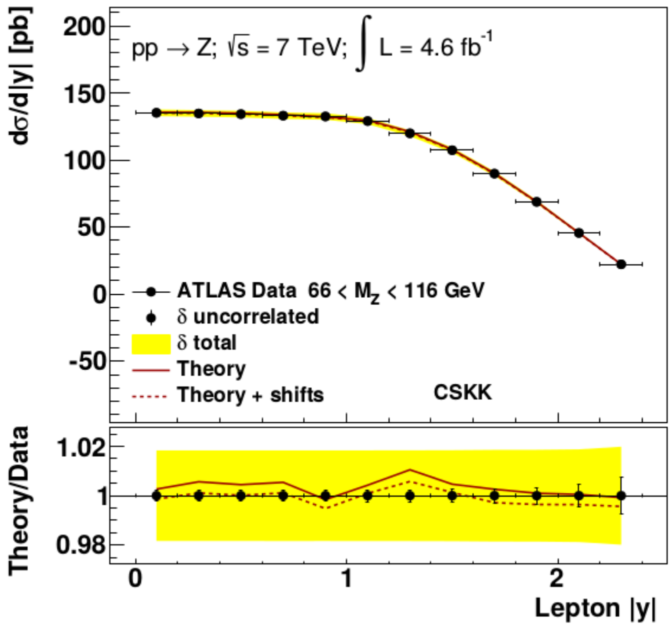


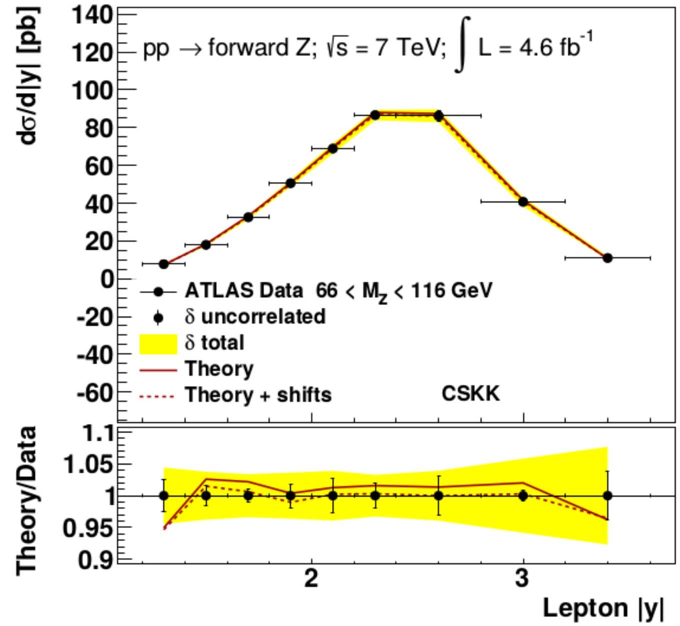


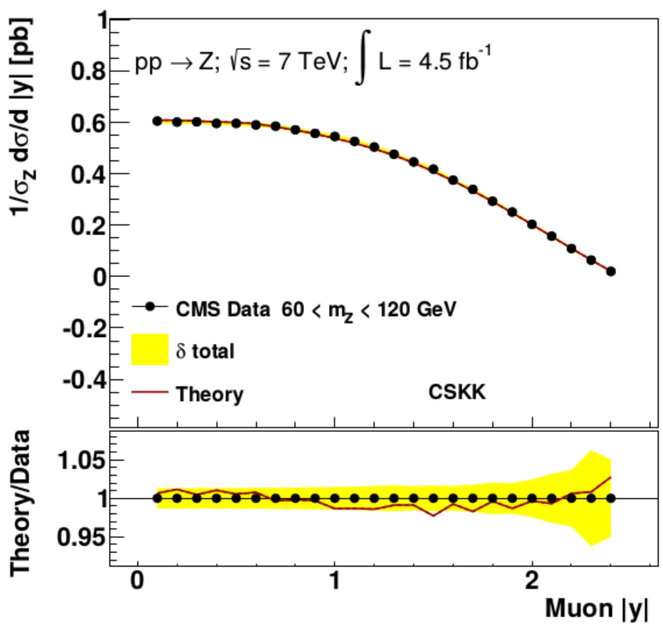




Data description: Z







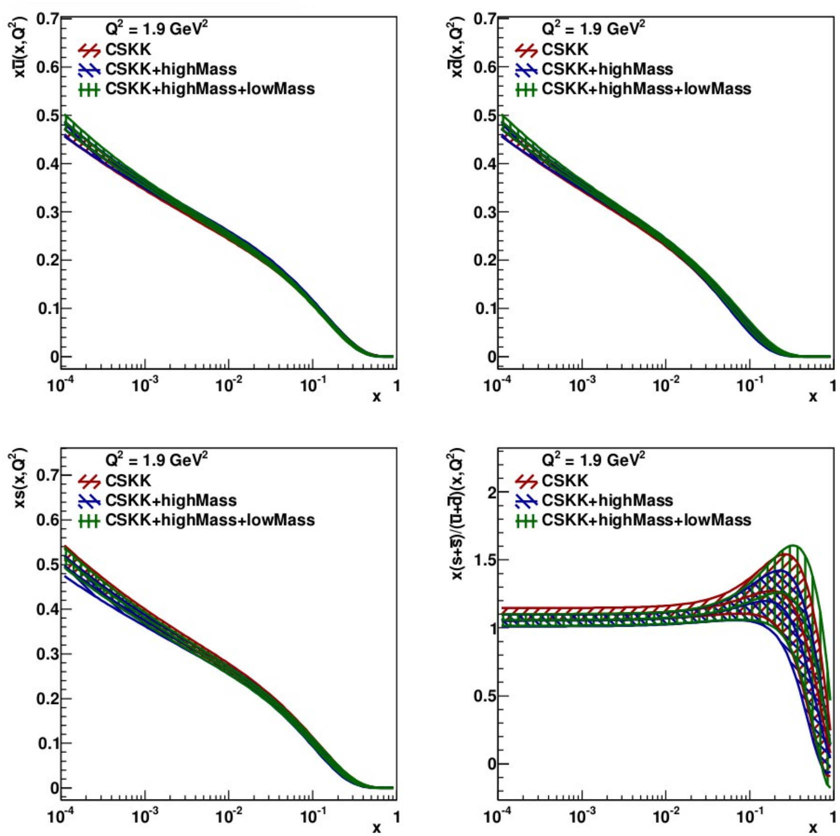
- Both CMS and ATLAS and W & Z data well described

Cross checks - adding more DY data

Adding off-peak Z 7 TeV data

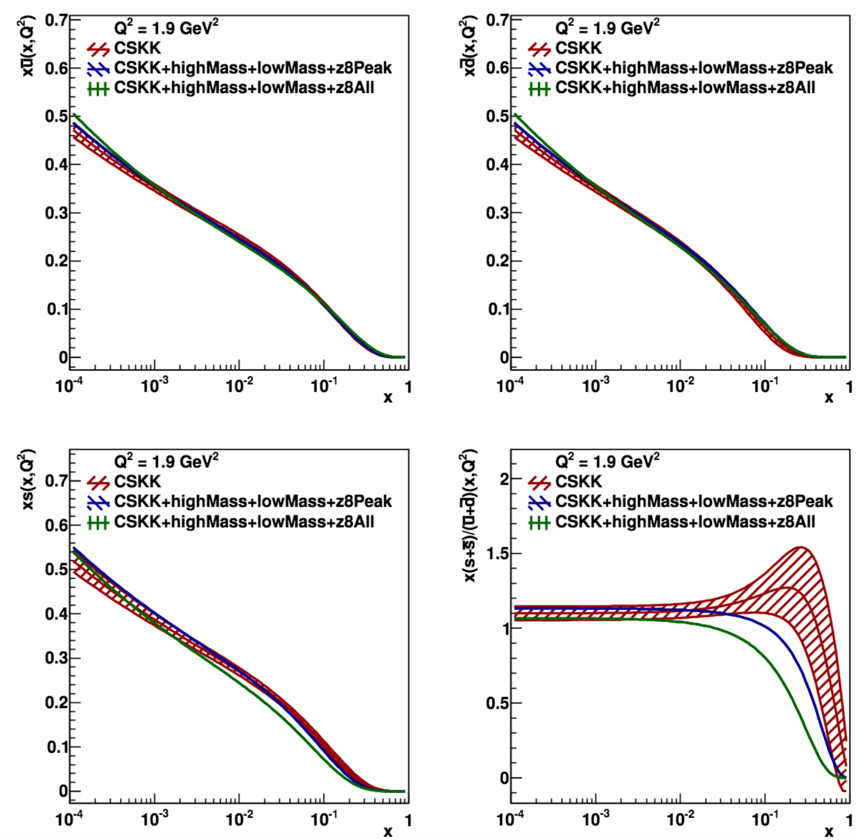
- results not changed substantially
- experimental uncertainties are also not much reduced

→ larger theoretical uncertainties, from electroweak effects and γ induced processes



→ Next CMS Z 8 TeV data added

- result not changed substantially
  - Strangeness consistent
- In fact CMS 8 TeV Z-peak data favor even larger strangeness than CSKK for small x



Model and α_s uncertainties

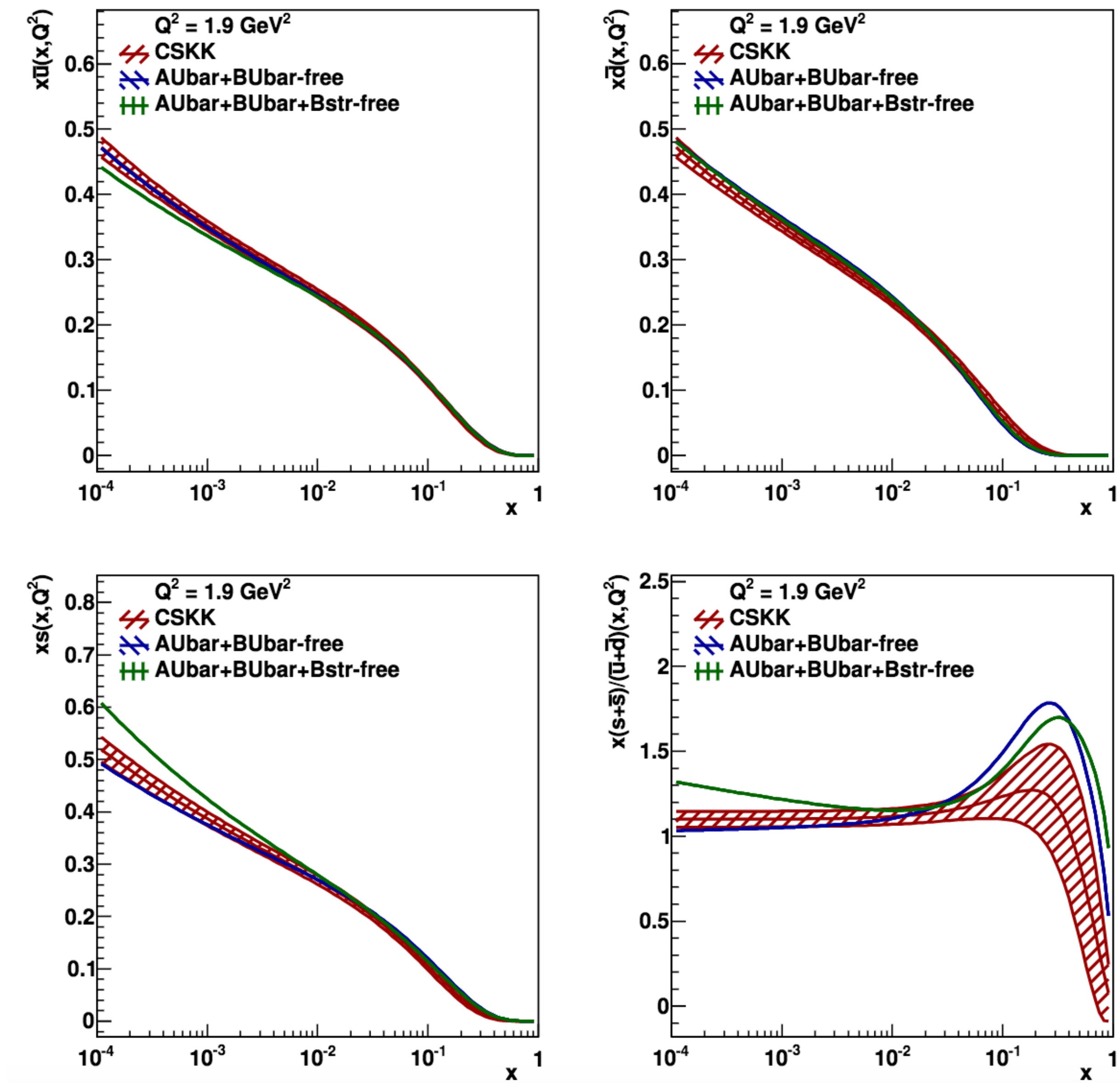
Variation	Total χ^2/NDF	$R_s = \frac{s+\bar{s}}{\bar{d}+\bar{u}}$ $x = 0.023$, $Q_0^2 = 1.9$ GeV^2	$R_s = \frac{s+\bar{s}}{\bar{d}+\bar{u}}$ $x = 0.013$, $Q_0^2 = 8317$ GeV^2
Nominal CSKK fit	1308 / 1141	1.14	1.05
Model variations			
$Q^2_{\rm min} = 5$ GeV^2	1375 / 1188	1.14	1.06
$Q^2_{\rm min} = 10$ GeV^2	1251 / 1101	1.14	1.05
$m_b = 4.25$ GeV	1307 / 1141	1.12	1.04
$m_b = 4.75$ GeV	1310 / 1141	1.16	1.06
$\mu^2_{f_0} = 1.6$ GeV^2 and $m_c = 1.37$ GeV	1312 / 1141	1.16	1.06
$\mu^2_{f_0} = 2.2$ GeV^2 and $m_c = 1.49$ GeV	1308 / 1141	1.12	1.05
$\alpha_s(M_Z)$ variations			
$\alpha_s(M_Z) = 0.116$	1308 / 1141	1.12	1.04
$\alpha_s(M_Z) = 0.117$	1308 / 1141	1.13	1.05
$\alpha_s(M_Z) = 0.119$	1309 / 1141	1.14	1.06
$\alpha_s(M_Z) = 0.120$	1310 / 1141	1.15	1.06

Parameterisation uncertainty

Variation	Total χ^2/NDF	$R_s = \frac{s+\bar{s}}{\bar{d}+\bar{u}}$ $x = 0.023$, $Q_0^2 = 1.9$ GeV^2	$x = 0.013$, $Q_0^2 = 8317$ GeV^2
Nominal CSKK fit	1308 / 1141	1.14	1.05
Parameterisation variations			
$B_{\bar{s}}$	1308 / 1140	1.12	1.05
D_{u_v}	1308 / 1140	1.13	1.05
D_{d_v}	1308 / 1140	1.14	1.05
D_g	1306 / 1140	1.15	1.06
$D_{\bar{u}}$	1305 / 1140	1.15	1.06
$D_{\bar{d}}$	1302 / 1140	1.09	1.04
E_{d_v}	1308 / 1140	1.14	1.05
$A_{\bar{u}}$ and $B_{\bar{u}}$ free	1306 / 1139	1.17	1.07
$A_{\bar{u}}$ and $B_{\bar{u}}$ and $B_{\bar{s}}$ free	1306 / 1138	1.17	1.07

Parameterisation study

- valence and gluon PDFs do not differ much
- low-x Dbar distribution consistent with Ubar for AUbar and BUbar free and for additional Bstr free
- strangeness ratio still consistent with unity for both

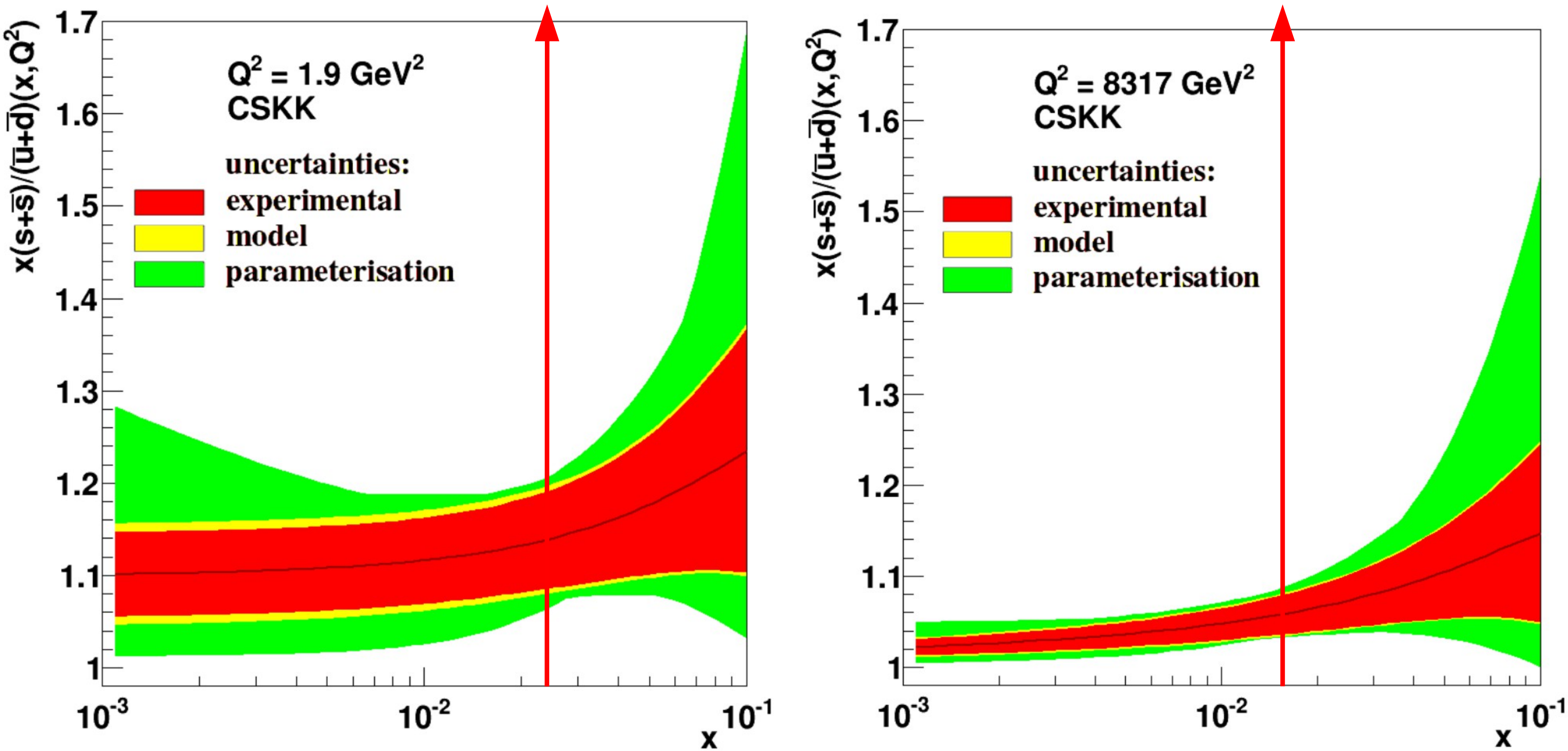


K. Kli

CSKK: ratio

$$R_s = 1.14 \pm 0.05 \text{ (experimental)}$$
$$\pm 0.03 \text{ (model)} {}^{+0.03}_{-0.05} \text{ (parameterisation)} {}^{+0.01}_{-0.02} (\alpha_s)$$

$$R_s = 1.05 \pm 0.02 \text{ (experimental)}$$
$${}^{+0.02}_{-0.01} \text{ (model)} {}^{+0.02}_{-0.01} \text{ (parameterisation)} \pm 0.01 (\alpha_s)$$



- Total uncertainty dominated by parameterisation uncertainty for most of x range
- R_s consistent with unity at low x

Additional parameterisation study

- For the CSKK fit, dbar-ubar at x~0.1 is negative, 2-3 sigma away from positive value suggested by E866 fixed-target Drell-Yan data
- Maybe if positive (dbar-ubar) imposed on the fit → strangeness decreases → larger dbar is correlated to smaller strangeness in the current parameterisation
  - However E866 observation made at x~0.1, whereas the LHC data have largest constraining power at x~0.01
- Cross-check made with a parameterisation which forces (dbar–ubar) to be in agreement with the E866 data
  - $R_s = 0.95 \pm 0.07$ (experimental) at $x = 0.023$ and $Q^2 = 1.9$ GeV^2
  - Still consistent with unity, however ~2 sigma lower than central result
- not included in parameterisation variations → not a good fit
  - X^2/NDF of this fit is 1363/1141 compared to 1308/1141 for CSKK

Summary

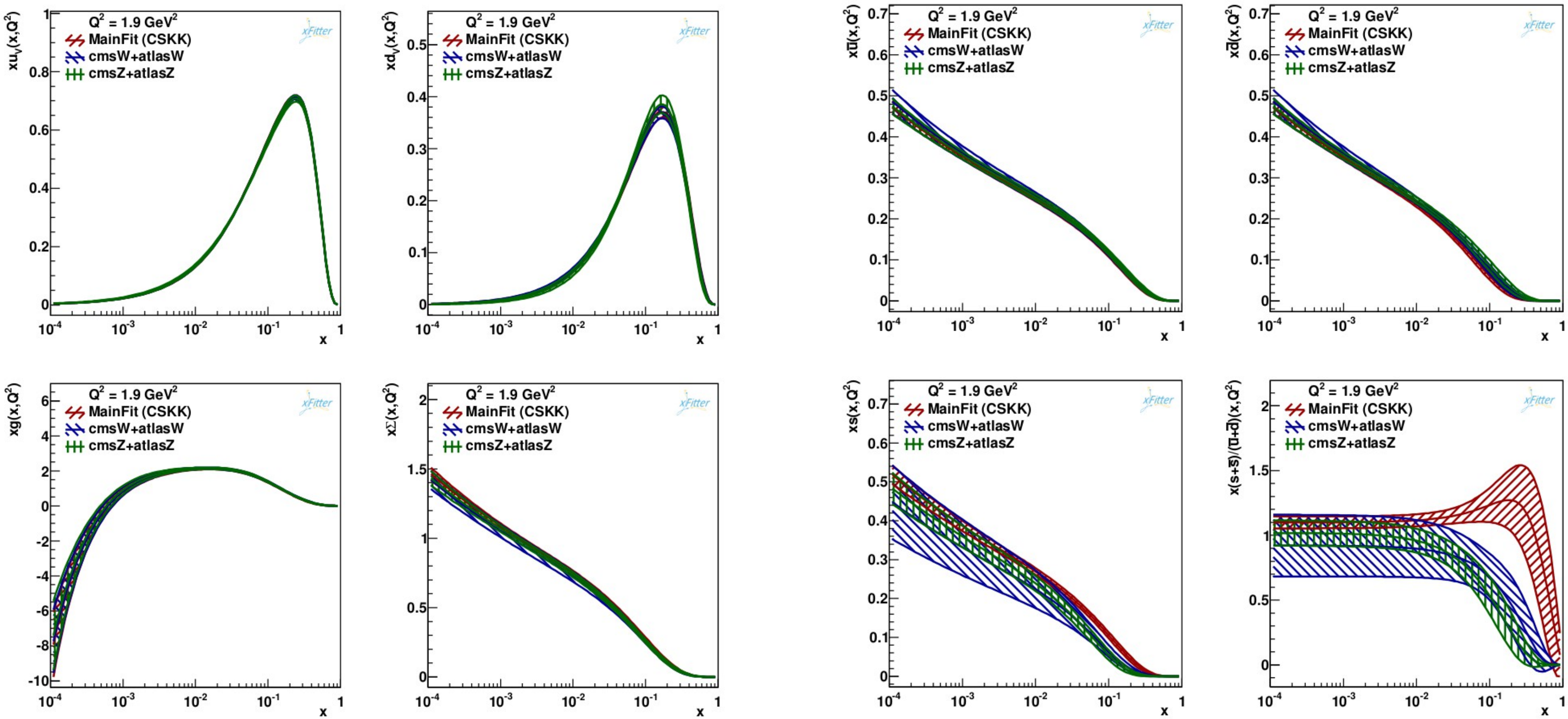
- We consider CSKK as our main fit
  - HERA inclusive data + W data + Z peak data
- Our main conclusion about data sets

→ There is no tension between the HERA data and the LHC data or between the LHC data sets

- We consider $R_s = \frac{s+\bar{s}}{\bar{d}+\bar{u}}$ distribution our main result
  - For comparison with ATLAS result we also calculate R_s at certain x and Q^2 values
  - Results with experimental, model and parameterisation uncertainties

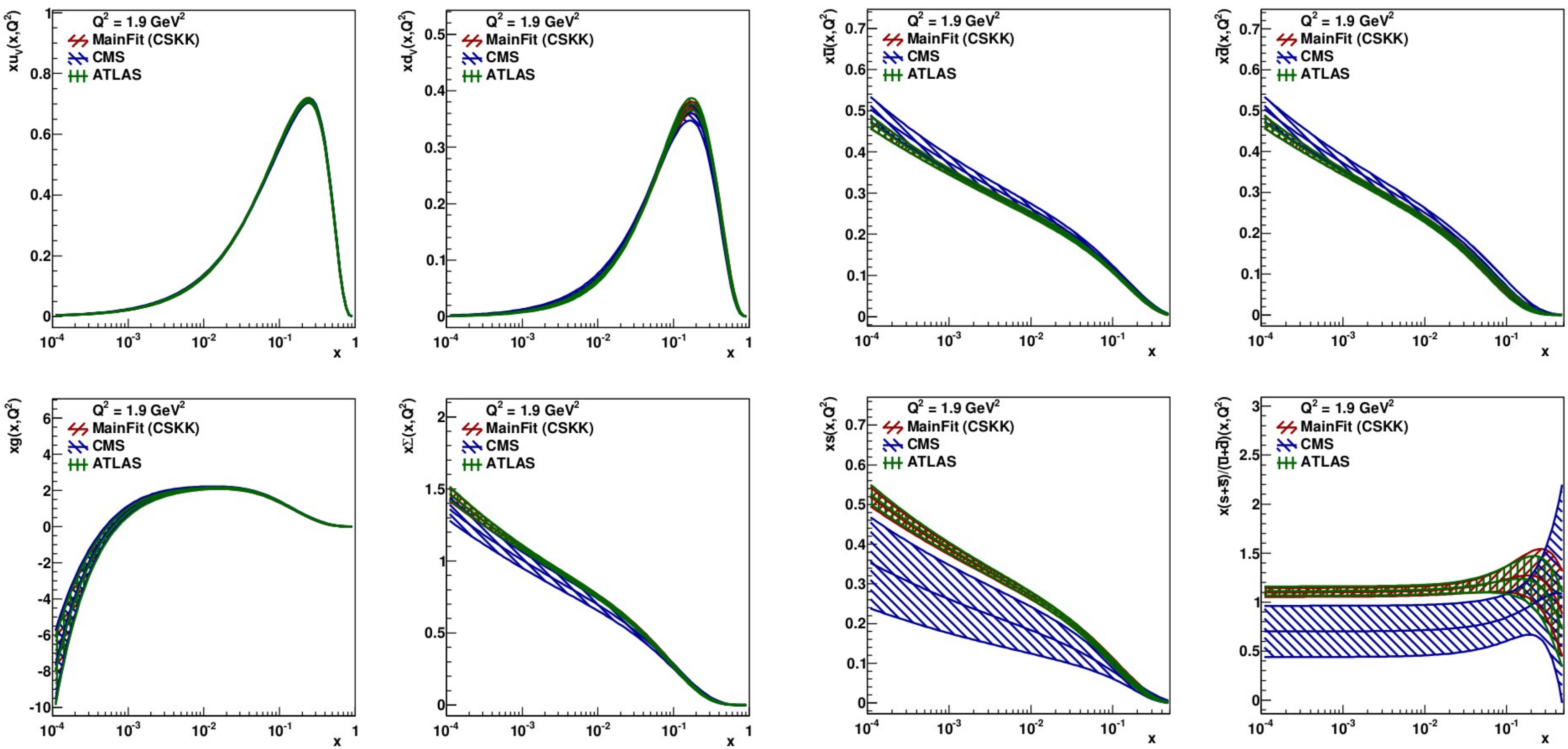
Buck-up slides

Fits to CMS & ATLAS data together



- Valence, gluon and total sea similar
- Flavor break up of sea is similar at small x for W and Z data separately
- Both data sets support unsuppressed strangeness
  - Most information comes from Z data
  - For ATLAS correlations between Z and W important
- For $x > 0.1$ parameterisation uncertainties become large

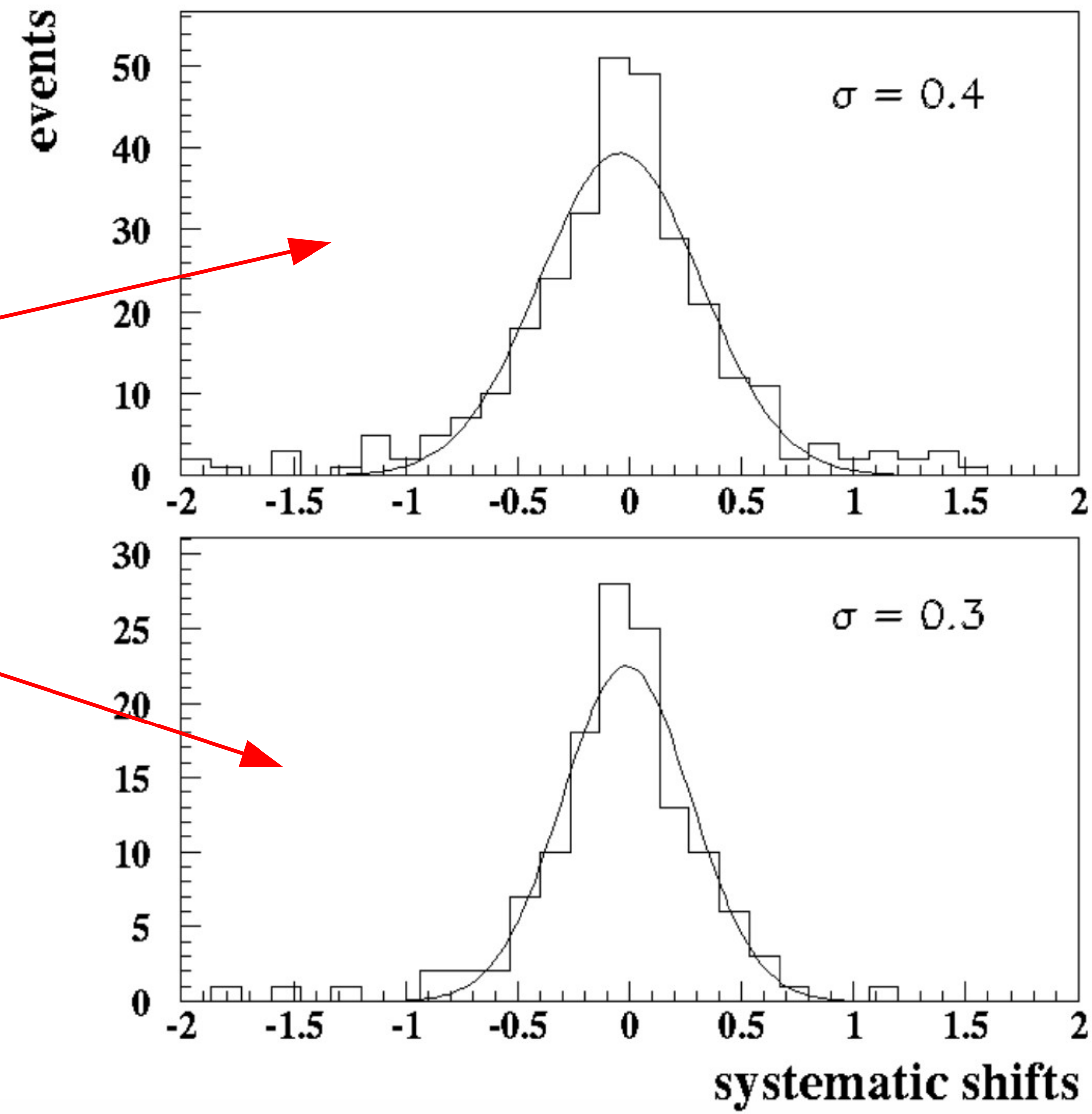
CMS vs ATLAS vs both



- Experimental uncertainties
- Valence, gluon and total sea are similar for PDFs from ATLAS and CMS data, small differences well within uncertainties
- Strange distributions differ
- For x ~ 0.01 CMS ratio 1-2 sigma lower then ATLAS ratio

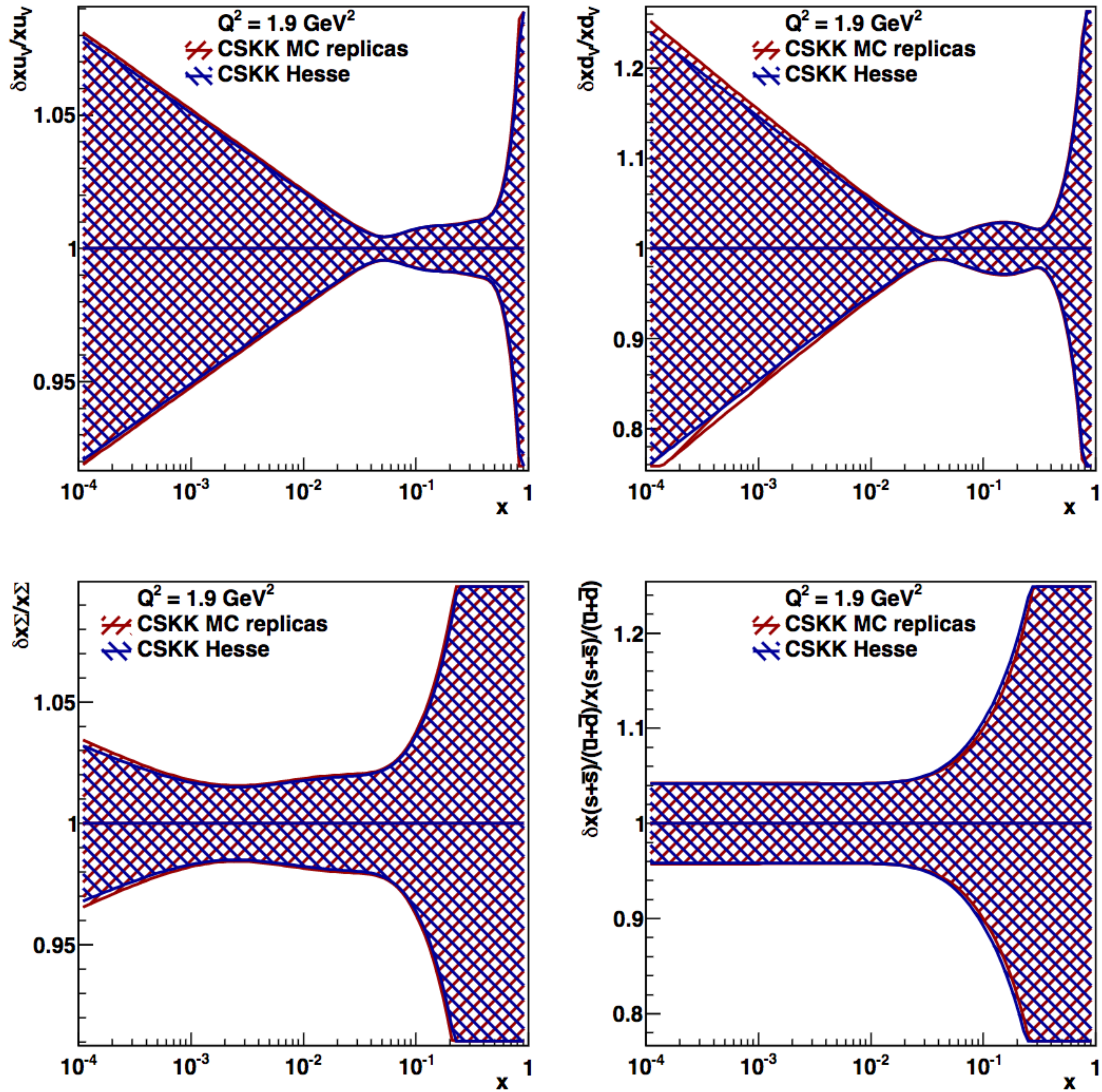
Fit quality – shifts of systematic uncertainties

- Shifts of correlated systematic uncertainties (treated as nuisanc parameters)
- HERA + ATLAS
- ATLAS only
- Looks OK



Hesse uncertainty .vs. MC replicas

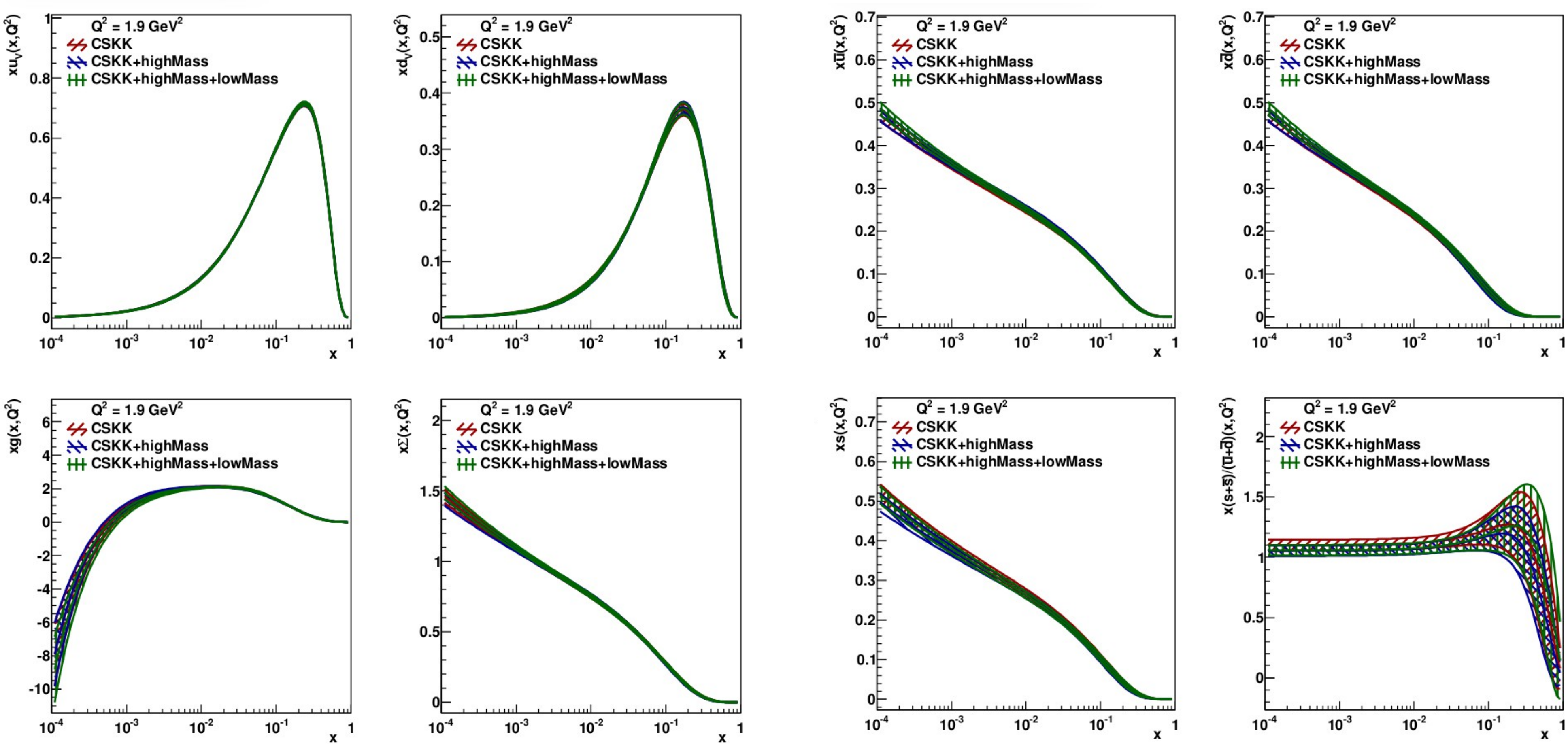
- Main method of experimental uncertainty estimation: Hesse
- Cross check done using MC replicas
- PDFs obtained with both methods agree well
- Uncertainties compatible



Adding Z off-peak data

- We added off-peak Z data → high mass first and then low mass
- results not changed substantially
- experimental uncertainties are also not much reduced

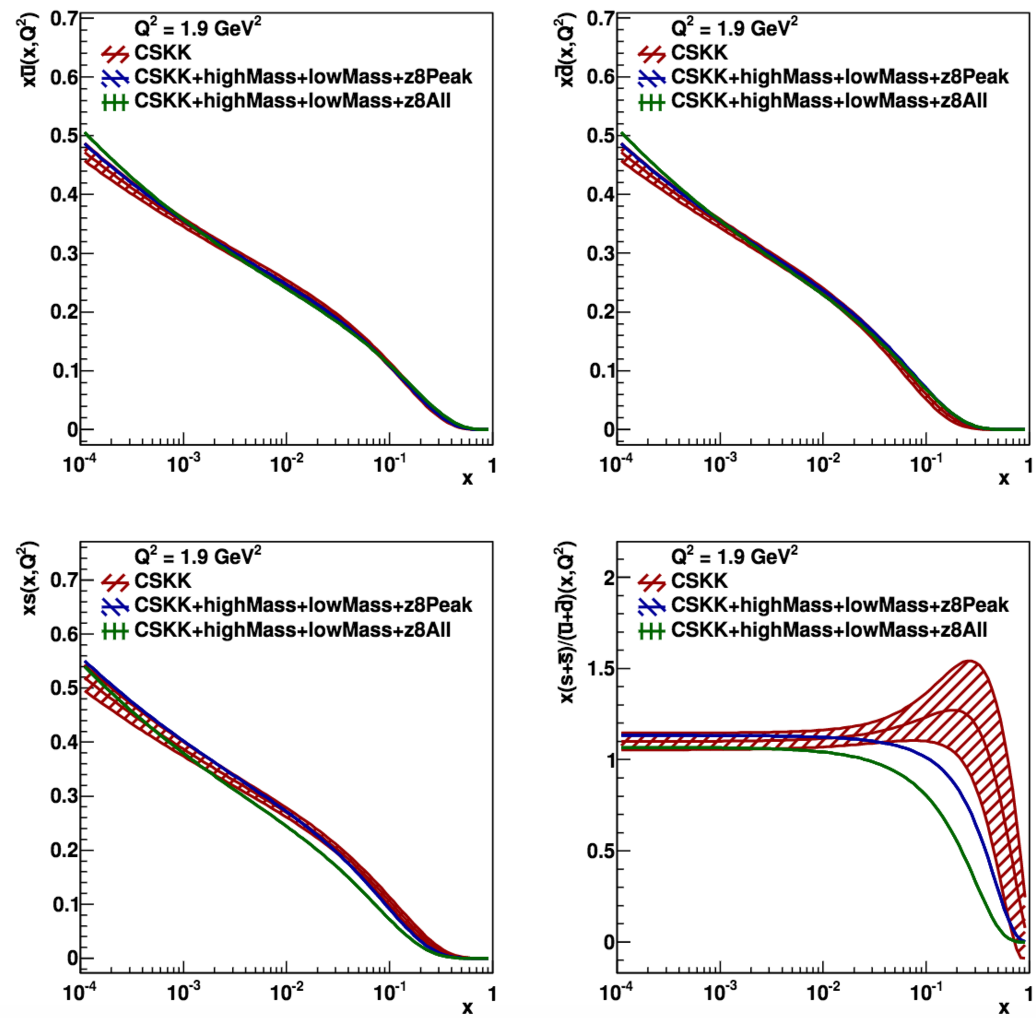
→ larger theoretical uncertainties, from electroweak effects and photon induced processes → MainFit CSKK contains peak data only



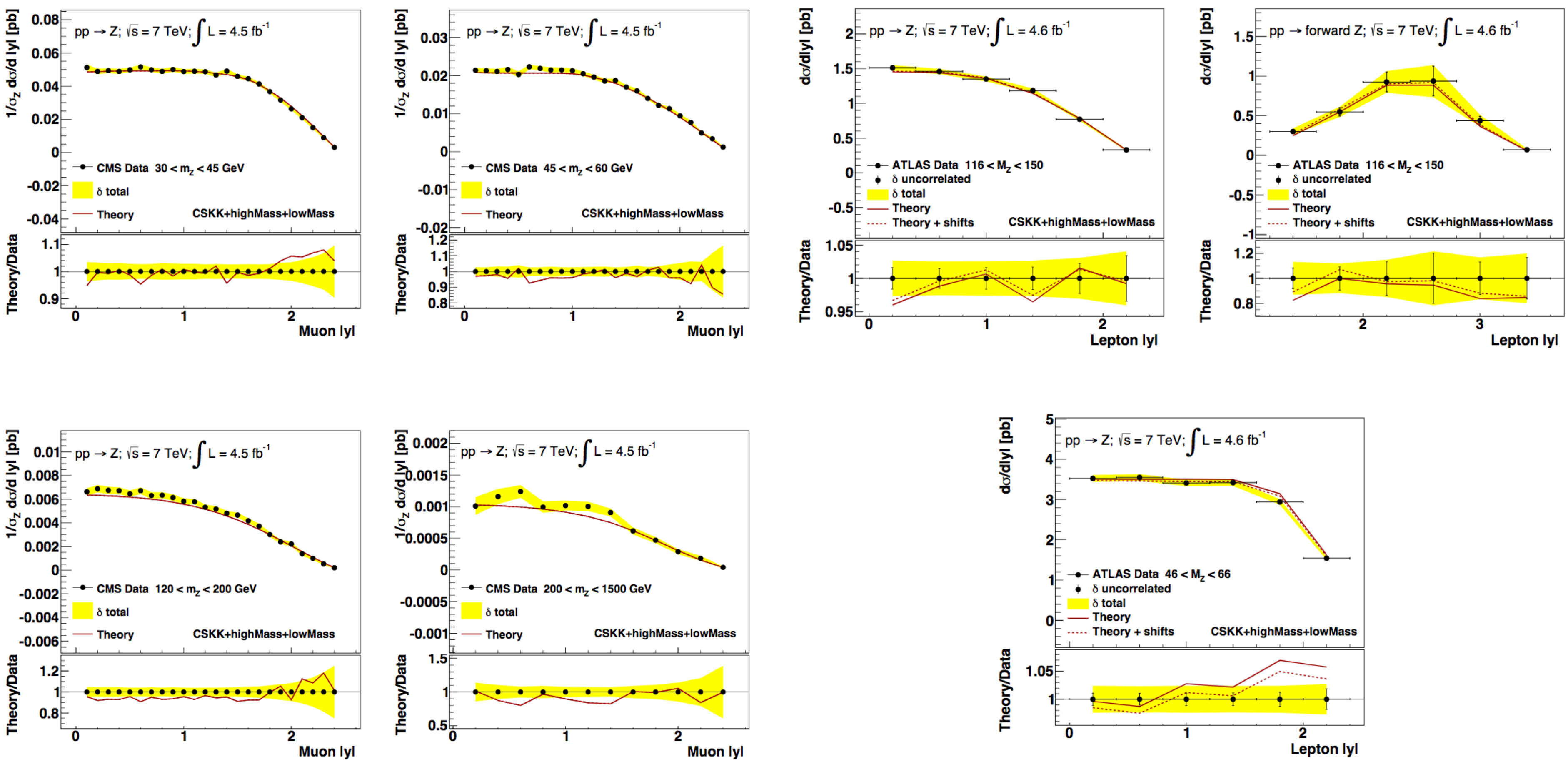
Adding CMS Z @ 8 TeV

K. Klimek

- CMS Z @ 8 TeV peak data + low/high mass added
- These data also do not change the result substantially
  - Valence, gluon, sea – very similar
  - Strangeness consistent
- In fact the CMS 8 TeV Z-peak data favor even larger strangeness than CSKK for small x



Adding Z off-peak data



- Not very good agreement for CMS off-peak data and ATLAS low-mass (seen in ATLAS analysis as well)
- There are larger theoretical uncertainties for off-peak mass regions coming from electroweak effects and photon induced processes
  → we use only peak data for nominal CSKK fit

CMS Z @ 8 TeV data

	ATLAS and CMS W and all Z bins		CMS W and
	Z at 7 TeV	Z at 7 and 8 TeV	all Z bins
Total χ^2/NDF	1481/1243 = 1.19	1814/1351 = 1.34	1596/1290 = 1.24
Data set, χ^2/NDP			
HERA	1163/1056	1178/1056	1186/1056
ATLAS W^+	13/11	12/11	
ATLAS W^-	9/11	15/11	
ATLAS central CC Z	15/12	26/12	
ATLAS central CF Z	7/9	8/9	
ATLAS CC Z, $116 < M_z < 150$ GeV	8/6	7/6	
ATLAS CF Z, $116 < M_z < 150$ GeV	4/6	4/6	
ATLAS CC Z, $46 < M_z < 66$ GeV	28/6	34/6	
CMS 7 TeV W-asym.	14/11	14/11	18/11
CMS 8 TeV W^+, W^-	5/22	7/22	5/22
CMS 7 TeV Z central	12/24	13/24	16/24
CMS 7 TeV Z, $120 < M_z < 200$ GeV	31/24	28/24	25/25
CMS 7 TeV Z, $200 < M_z < 1500$ GeV	20/12	19/12	17/12
CMS 7 TeV Z, $30 < M_z < 45$ GeV	35/24	35/24	36/24
CMS 7 TeV Z, $45 < M_z < 60$ GeV	22/24	20/24	20/24
CMS 8 TeV Z central		74/24	66/24
CMS 8 TeV Z, $120 < M_z < 200$ GeV		73/24	56/24
CMS 8 TeV Z, $200 < M_z < 1500$ GeV		14/12	12/12
CMS 8 TeV Z, $30 < M_z < 45$ GeV		38/24	37/24
CMS 8 TeV Z, $45 < M_z < 60$ GeV		29/24	20/24

- CMS Z @ 8 TeV are not well described
- Found by NNPDF too
- some tension with ATLAS central mass & rapidity Z appears
- not well fitted even when fitted together with just HERA and other CMS data

CSKK: ratio $R_s = \frac{s+\bar{s}}{\bar{d}+\bar{u}}$

- R_s at x = 0.023 and Q^2 = 1.9 GeV^2
  - Highest sensitivity at starting scale

$$R_s = 1.14 \pm 0.05\,(\text{experimental}) \pm 0.03\,(\text{model})\,^{+0.03}_{-0.05}\,(\text{parameterisation})\,^{+0.01}_{-0.02}\,(\alpha_\text{s})$$

- R_s at x = 0.013 and Q^2 = M_Z^2
  - Maximal sensitivity for LHC data

$$R_s = 1.05 \pm 0.02\,(\text{experimental})\,^{+0.02}_{-0.01}\,(\text{model})\,^{+0.02}_{-0.01}\,(\text{parameterisation}) \pm 0.01\,(\alpha_\text{s})$$

- Compared to ATLAS result at x = 0.023 and Q^2 = 1.9 GeV^2

$$R_s = \frac{s+\bar{s}}{\bar{u}+\bar{d}} = 1.13 \pm 0.05\,(\text{exp}) \pm 0.02\,(\text{mod})\,^{+0.01}_{-0.06}\,(\text{par})$$