Impact of ATLAS data on PDFs

A M Cooper-Sarkar

The ATLAS data on W^+,W^-, Z differential cross-sections from 36pb-1 of 2010 data (arXiv:1109.5141) have been shown to have more impact on the global PDFs as compared to the CMS and LHCb data from the same running period— e.g. see talk of M.Ubiali at DIS2012 + Thorne & Watt arXiv:1205.4024

The reason for the greater constraining power of the ATLAS data is the provision of correlated systematic uncertainties

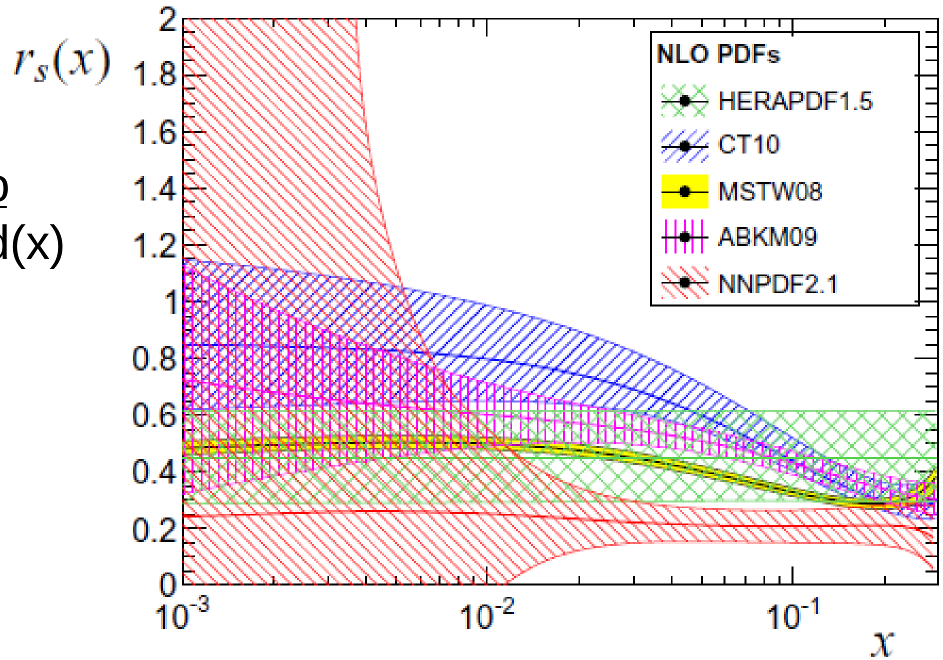
ATLAS 2010 jet data (arXiv:1112.6297) are also provided with correlated systematic uncertainties- as presented at PDF4LHC meeting Nov 28th 2011- experience with fitting these will be discussed at this meeting

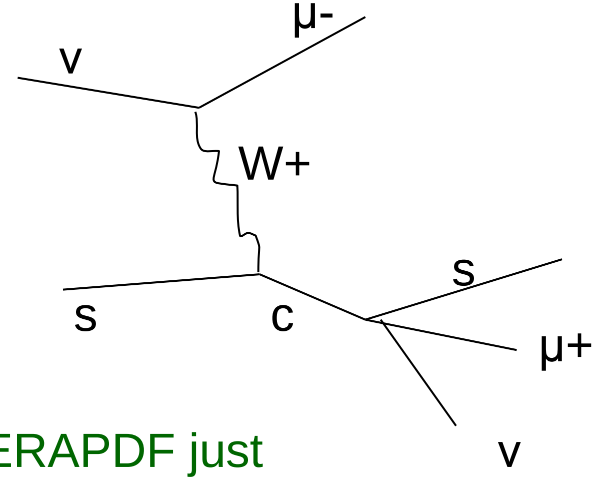
Many 2011 data sets with PDF impact are on the way…..

In this talk I will discuss constraints on the strangeness in the proton derived from the ATLAS W, Z data (arXiv:1203.4051 to be published in PRL)

What is the ratio of the strange parton distribution to the light quark PDFs?

Ratio
$x\bar{s}(x)/x\bar{d}(x)$





HERAPDF just assumed ~0.5 with a large error

We had a traditional view that $r_s(x)$ ~0.5. Why?

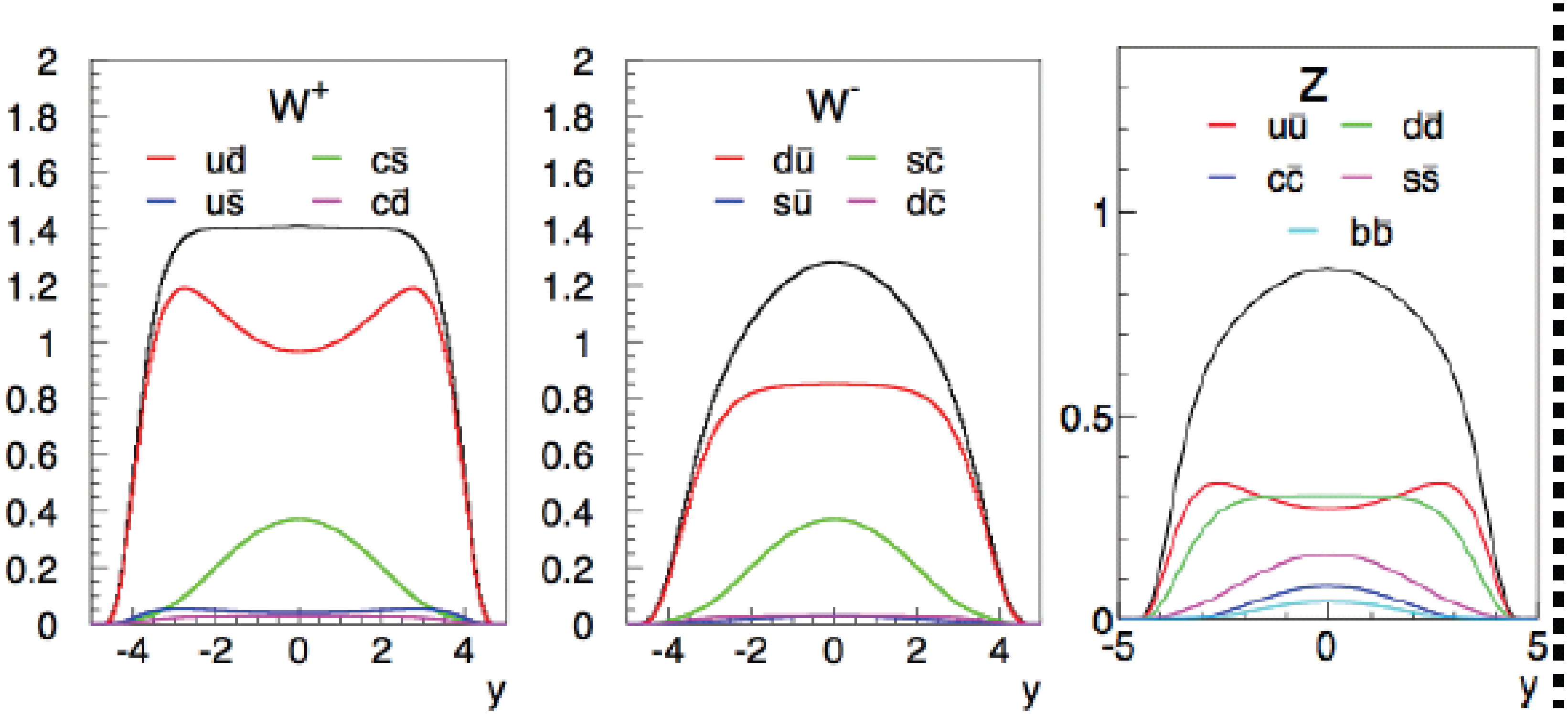
Because of neutrino opposite-sign dimuon data (NuTeV, CCFR)

This has been fed into fits CT10, NNPDF, MSTW, ABKM but look at the large discrepancies!

The NuTeV data provide information for x~0.1, but they needs nuclear target corrections, and understanding of the s →c threshold transition- note that charm treatment differs between the groups.

Even when there is agreement at x~0.1 there are discrepancies at lower x

Now ATLAS can give new information on this.

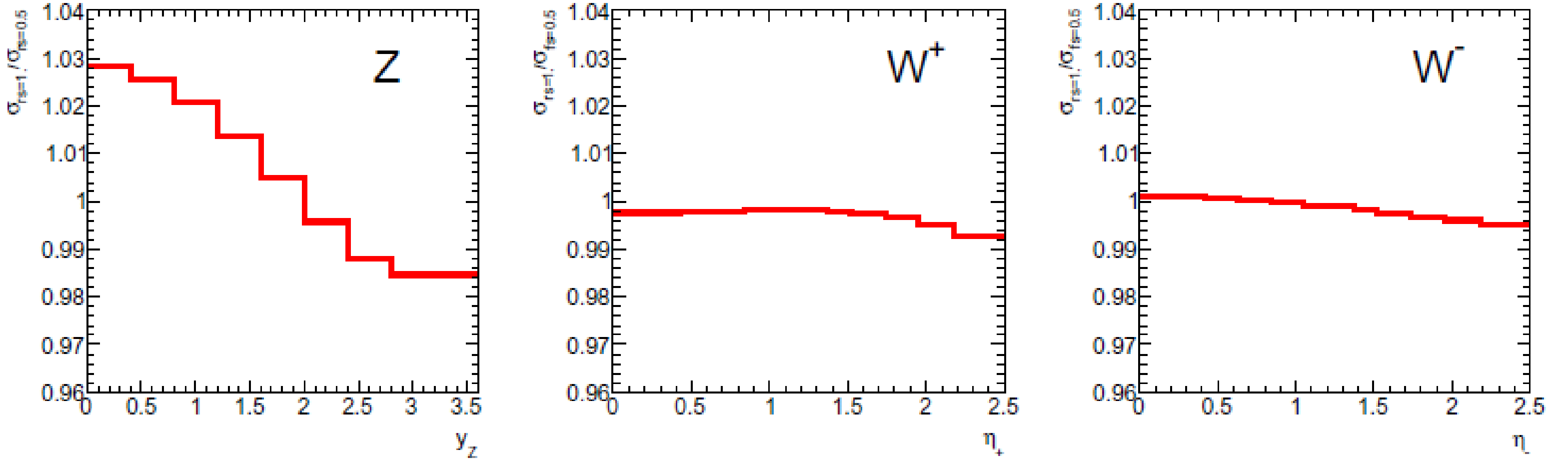


The strange PDF enters into the Z and W cross-sections differently from deep-inelastic structure functions. $F_2 \sim 4x\,[u(x) + c(x)] + x\,[d(x) + s(x)]$

The shape of the Z will be most affected by the amount of s+sbar

(these predictions were done for sbar = ½ dbar using HERAPDF)

For this analysis we will use s=sbar, all groups are agreed that s-sbar is very small



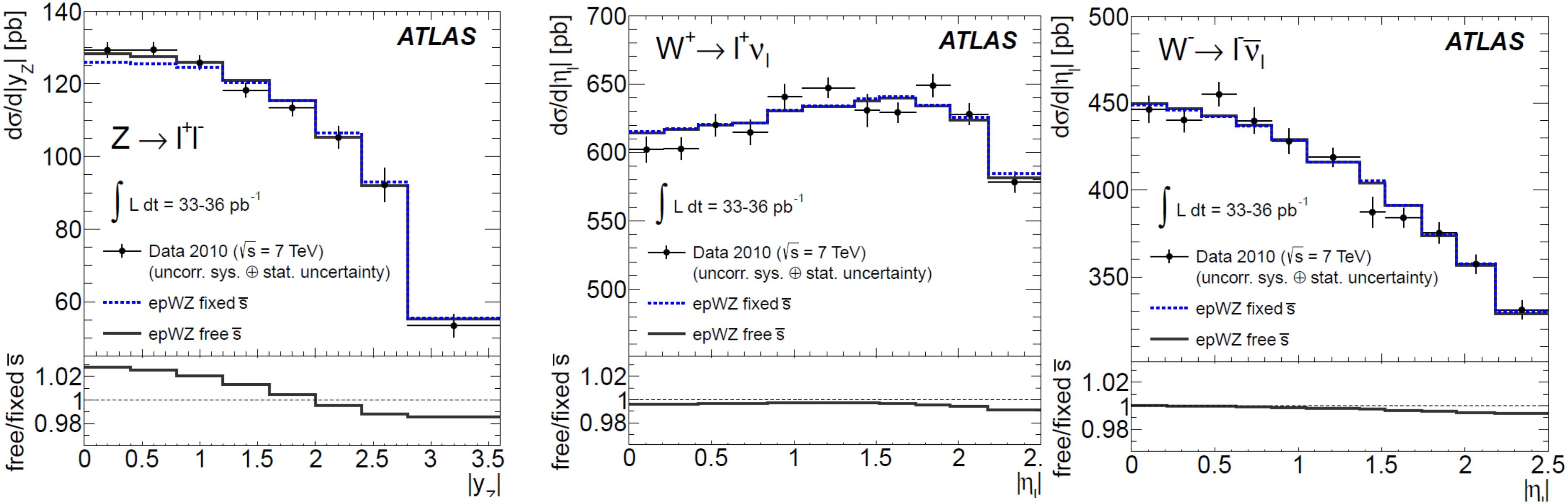
Here is the predicted ratio of Z and W cross-sections from HERAPDF for the assumptions r_s = dbar/sbar = 1.0 to r_s = 0.5

This is a small effect. Can we see it?

YES

We have not only the shape of the Z but also its absolute normalisation as tied to the W^+ and W^- cross-sections

AND we have the correlations between these three differential cross-sections.



Here are the measured differential cross sections of Z, W^+, W^- from ATLAS 2010 data

compared to PDF fits for which r_s = 0.5 and for which r_s was left free— and turned out to be ~1.0

We obtain

$r_s(x,Q^2) = 1.00 \pm 0.20_{(exp)} \pm 0.07_{(mod)} +0.10/-0.15_{(par)} +0.07/-0.06_{(\alpha s)} \pm 0.08_{(th)}$

$= 1.00 +0.25/-0.28$, for $x = 0.023$, $Q^2=1.9\,\mathrm{GeV}^2$

$r_s(x,Q^2) = 1.00 \pm 0.07_{(exp)} \pm 0.03_{(mod)} +0.04/-0.06_{(par)} \pm 0.03_{(\alpha s)} \pm 0.03_{(th)}$

$= 1.00 +0.09/-0.10$, for $x = 0.013 = M_Z/\sqrt{s}$, $Q^2=M_Z^2$

Now for a bit more explanation..

We input the ATLAS W,Z data to the HERAPDF framework using the HERAfitter

We use the published HERA-I deep-inelastic data as the back-bone of the PDF fits. NNLO QCD fits are made in the DGLAP formalism using QCDNUM

Parameterise PDFs using a standard form

$$xf(x) = Ax^B(1-x)^C(1+Dx+...)$$

where $D, E, ...$ are added only if they bring significant improvement in the fit ("parameterisation scan").

Parametrize the following PDFs at the starting scale Q^2_0

$$xg, xd_{val} = x(d-\bar{d}), xu_{val} = x(u-\bar{u}), x\bar{d}, x\bar{u}, x\bar{s}$$

Allow the gluon to have an extra negative term like MSTW

For strange sea, assume same B power as for d

$$x\bar{s} = xs = r_s A_{\bar{d}} x^{B_{\bar{d}}}(1-x)^{C_s}$$

This is fairly typical, e.g. MSTW,CTEQ do it this way

Heavy flavours xc, xb are predicted using VFNS, prescription of RT.

Perform fits

- **epWZ fixed sbar**: with 13 free PDF parameters: rs=0.5, Cs=Cdbar
- **epWZ free sbar**: with 15 free PDF parameters: rs, Cs free

Electroweak treatment

Electroweak parameters as specified in arXiv:1109.5141

To make NNLO predictions for the W,Z data we first make the NLO QCD predictions by using the Applgrid fast interface to MCFM to give exact predictions for every iteration of the PDF fit i.e. no k-factors at NLO

However the NNLO corrections are done with NNLO/NLO k-factors which must be iterated a posteriori. Note the NNLO PDF is used for both NLO and NNLO calculations.

We use FEWZ for the NNLO calculations and we cross-check with DYNNLO

Predictions differ by 0.2%, 0.5%, 1.0% for Z, W+, W- resp.

Missing pure electroweak corrections contribute at the per mille level

An uncertainty of 1% on the W/Z ratio covers this and gives the theoretical uncertainty on $r_s(x,Q^2)$

Fit results

The fit is made taking into account correlated systematic uncertainties on both the HERA data AND the ATLAS W,Z data.

There are 113 sources of correlated error for HERA-1 +0.5% normalisation

And 30 sources of correlated errors for ATLAS +3.4% normalisation.

These are accounted for using the usual Hessian method for PDF fitting such that the systematic shift parameters (nuisance parameters) are determined by the fit. These shifts are typically much smaller than one standard deviation.

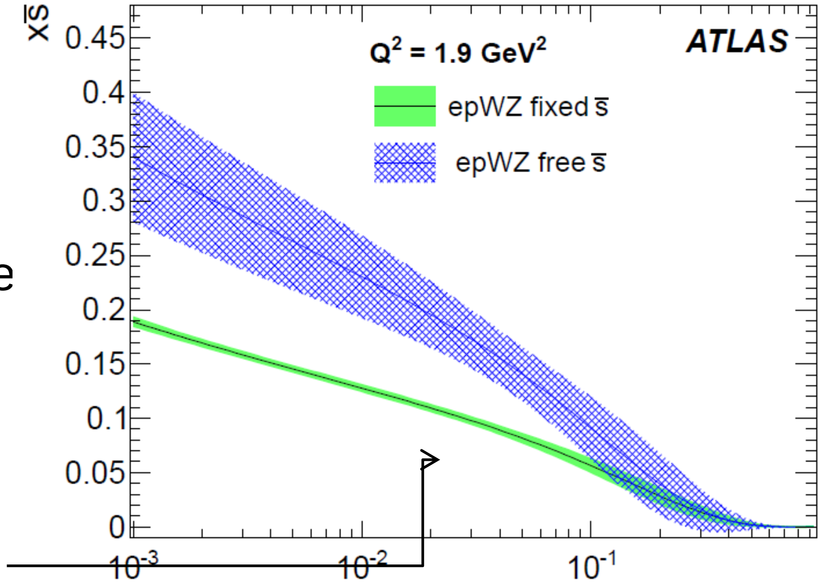
Fit with rs=0.5,Cs=Cdbar	Fit with rs, Cs free
epWZ fixed sbar	**epWZ free sbar**
χ2/ndf = 546.1/ 567	χ2/ndf = 538.4/ 565
ATLAS χ2/ndp = 44.5/ 30	ATLAS χ2/ndp = 33.9/ 30

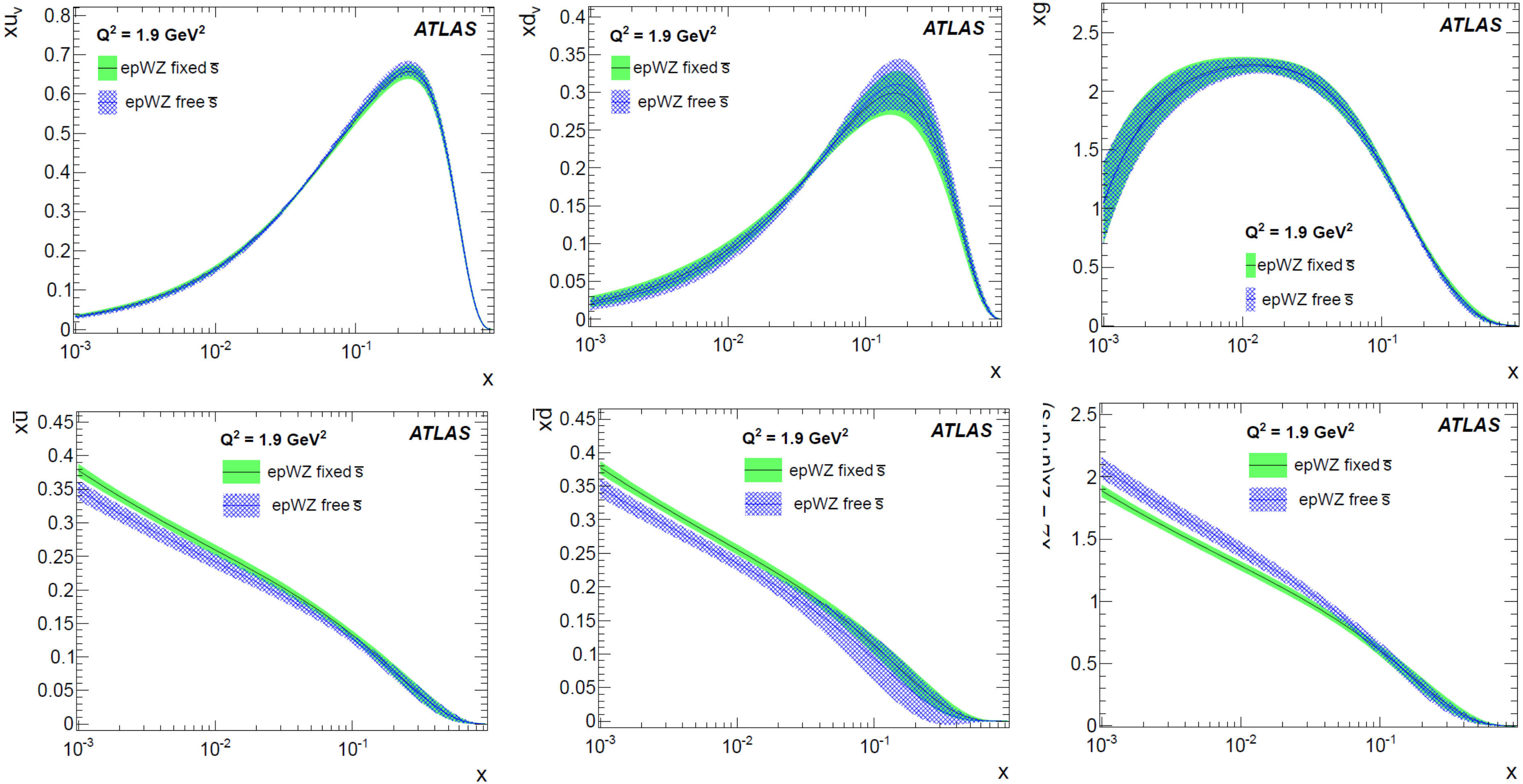
The fit with free strange gives the parameter r_s=1.00±0.20

$$x\bar{s} = xs = r_s A_{\bar{d}} x^{B_{\bar{d}}} (1-x)^{C_s}$$

The high-x powers of the $x\bar{s}(x)$ and $x\bar{d}(x)$ PDFs are similar but have large errors- hence strange can be suppressed at large x without having to be suppressed for all x.

The sensitivity of the ATLAS data is at x~0.023





The rest of the parton distributions are barely affected by this large difference in strange between the two fits:

1. The dbar and ubar are ~10% suppressed to compensate for the strange enhancement and
2. The Total Sea= 2*(ubar+dbar+sbar) is enhanced ~8%.

Vary the assumptions made in the fit

• Vary the masses of the charm and beauty quarks: m_c=1.4 is varied 1.25 to 1.55 GeV; m_b = 4.75 is varied 4.5 to 5.0 GeV

• Vary the minimum Q^2 of data entering the fit: Q^2_{min} =7.5 is varied 5.0 to 10.0 GeV^2

•Vary the starting scale for QCD evolution: Q^2_0 = 1.9 is varied to 1.5 GeV^2

These are the model uncertainties. The largest one is the charm mass (± 0.05) since this affects the amount of c+cbar, which also affects the Z and W distributions- just not as much as strange

Vary the form of the parametrisation by adding further parameters –e.g. the strange low-x power Bs— this means considering slightly different PDF shapes which have comparable $\chi2$

•Vary the value of $\alpha_S(M_Z)$ = 0.1176 from 0.114 to 0.121

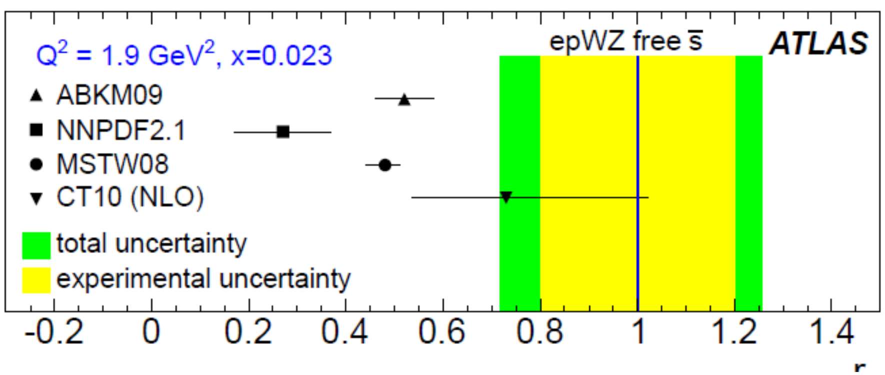
These compromise the extra uncertainties considered in addition to experimental uncertainties and the theory uncertainty (see page 7). Experimental uncertainties dominate.

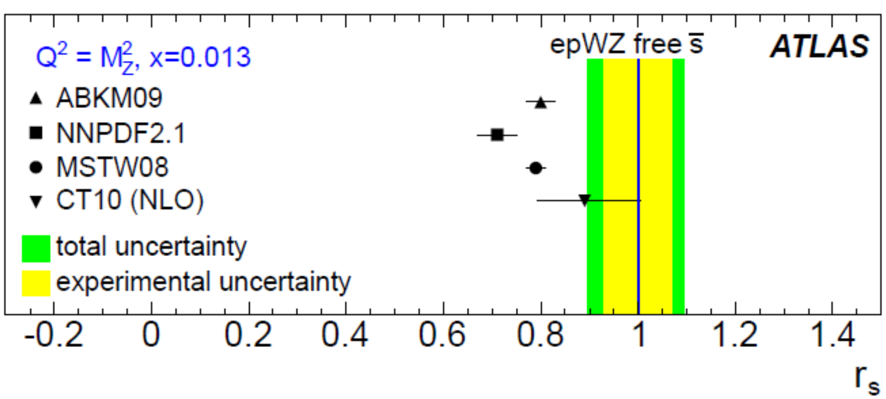
Note that if both r_s and Cs vary then the ratio sbar/dbar becomes a function of x, which is not equal to the PDF parameter r_s even at the starting scale for QCD evolution.

We quote our result as the ratio of $r_s(x,Q2)$ = sbar/dbar at specific x,Q^2 values where the ATLAS data have sensitivity

ATLAS data have sensitivity in the x range $10^{-3} < x < 10^{-1}$, $Q^2=M_Z^2$, We quote the ratio of sbar/dbar at the point of maximal sensitivity, $x=M_Z/\sqrt{s}$ (central rapidity)

QCD evolution makes this corresponds to $x \sim 0.023$ at the starting scale for evolution, $Q^2_0 = 1.9\ \mathrm{GeV}^2$, where our PDF parameters are set.





Note that if sbar < dbar at the starting scale then QCD evolution will cause it to increase since gluon → q-qbar splitting is flavour blind.
The uncertainties of all predictions decrease as Q^2 increases but the difference between the ATLAS result and previous predictions remains the same in terms of standard deviations.

Cross checks

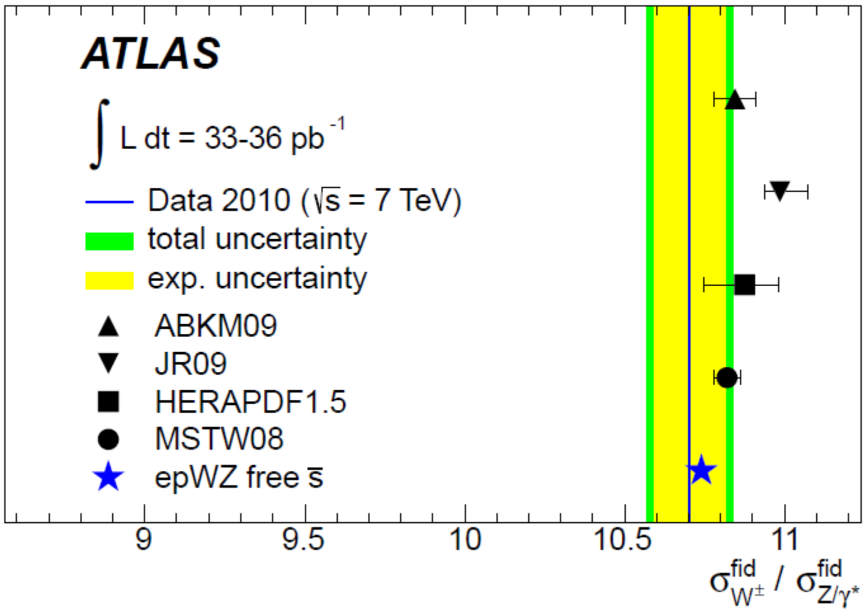
- Treating the correlated errors as uncorrelated gives $r_s(0.023,1.9) = 0.97 \pm 0.26$
- Fitting at NLO not NNLO gives $r_s(0.023,1.9) = 1.03 \pm 0.19$
- Changing the heavy quark treatment to ZMVFN(NLO) gives $r_s(0.023,1.9)=1.05 \pm 0.19$
- Allow dbar ≠ ubar at low-x gives $r_s(0.023,1.9)= 0.96 \pm 0.25$
- Allow s ≠ sbar gives sbar/s = 0.93±0.15 and sbar/dbar consistent with unity

These should be compared with our central result from the epWZ free sbar fit:
$r_s(0.023,1.9)= 1.00 \pm 0.20$

Tevatron data on W,Z can also have sensitivity to sbar/dbar
Fitting HERA-1 data and CDF W-asymmetry and Z rapidity gives
$r_s(0.081,1.9)= 0.66 \pm 0.29$
consistent with the present result- **particularly given the different x value-** but less accurate.
Fitting HERA, CDF and ATLAS data gives $r_s(0.023,1.9) = 0.95 \pm 0.17$

The ATLAS data are especially sensitive to sbar/dbar because the full differential cross-sections for W^+, W^- and Z data are available with correlations.

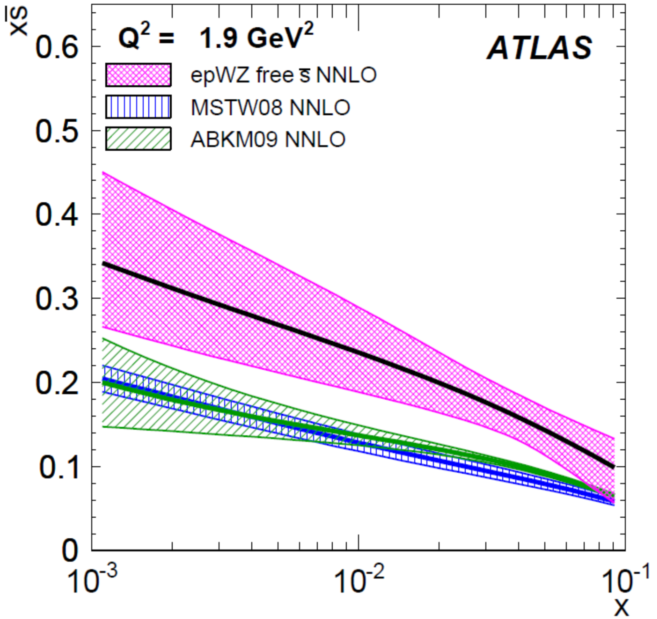
In particular the normalisation of the Z data is tied to that of the W data. The ratio of the W to Z cross-sections for the epWZ free sbar fit is 10.74 to be compared to 10.70± 0.15 for the data

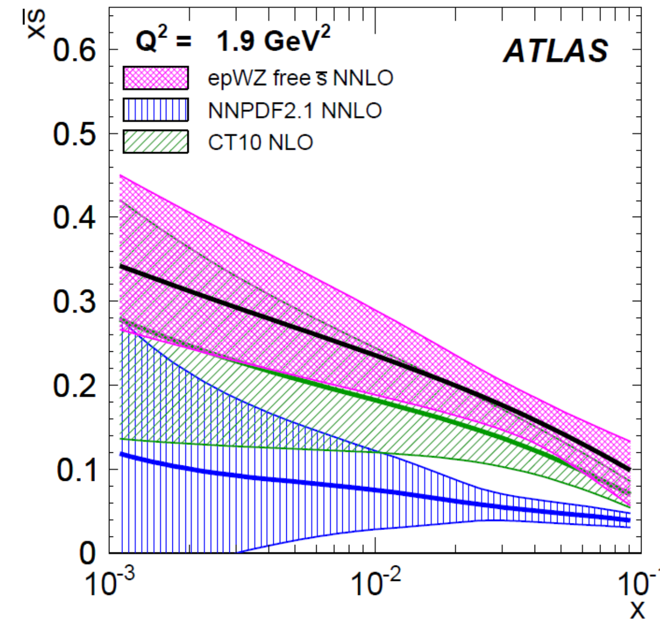


For example, if a fit is done to HERA data plus just the ATLAS Z data and W-asymmetry data, then it lacks this normalisation information and a less precise result is obtained for sbar/dbar

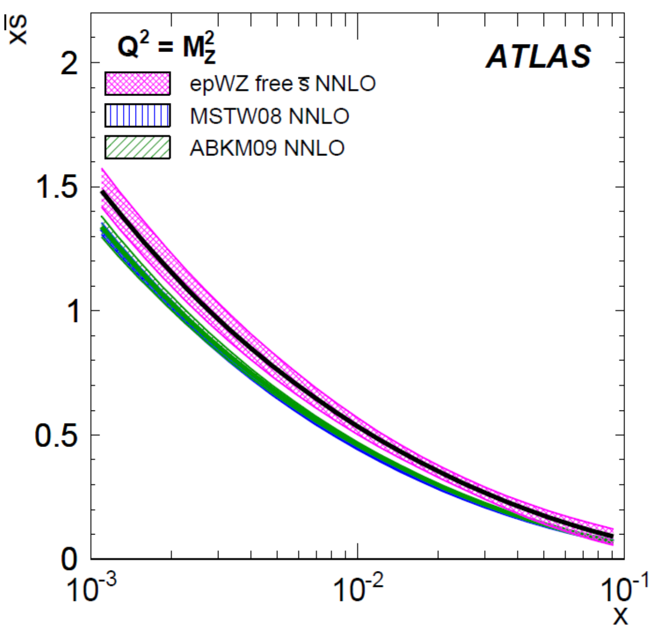
$r_s(0.023,1.9) = 0.92 \pm 0.31$

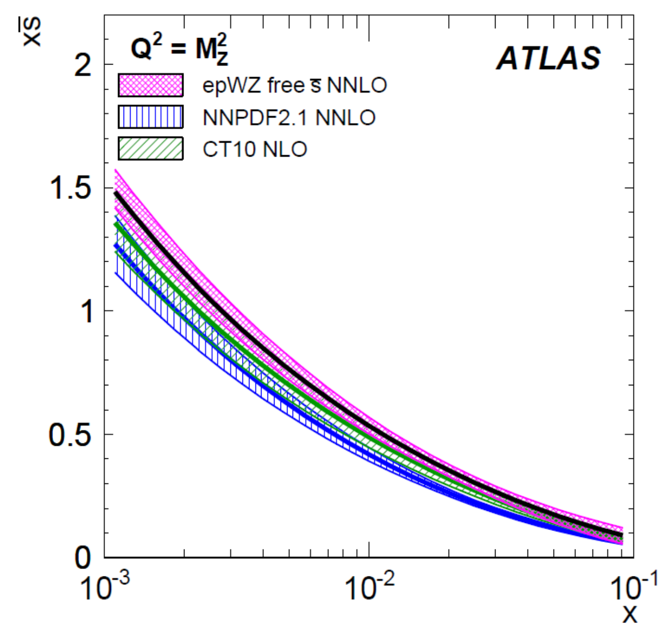
Strangeness compared to other PDFs



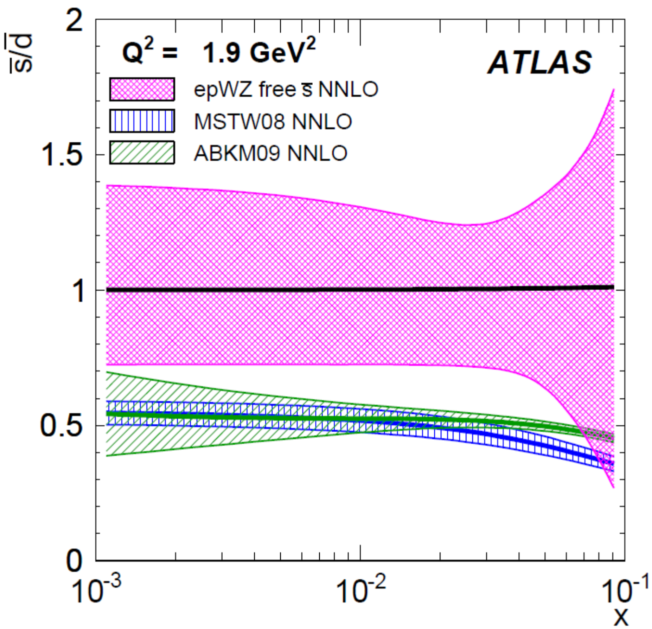


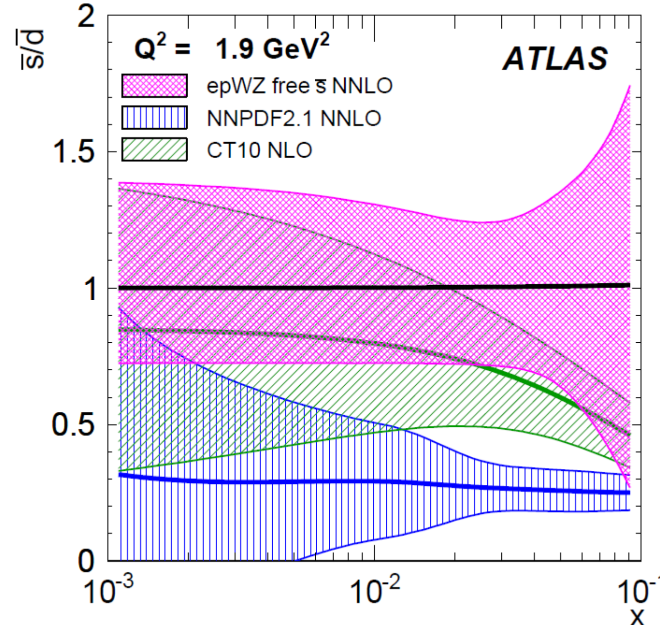
For the ATLAS fit the uncertainty bands include the model and parameterisation variations for other PDFs the 68%CL bands are used

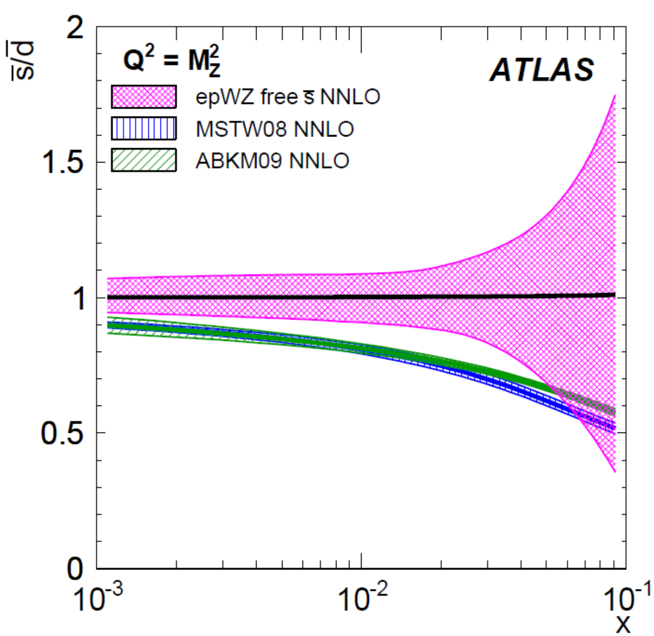


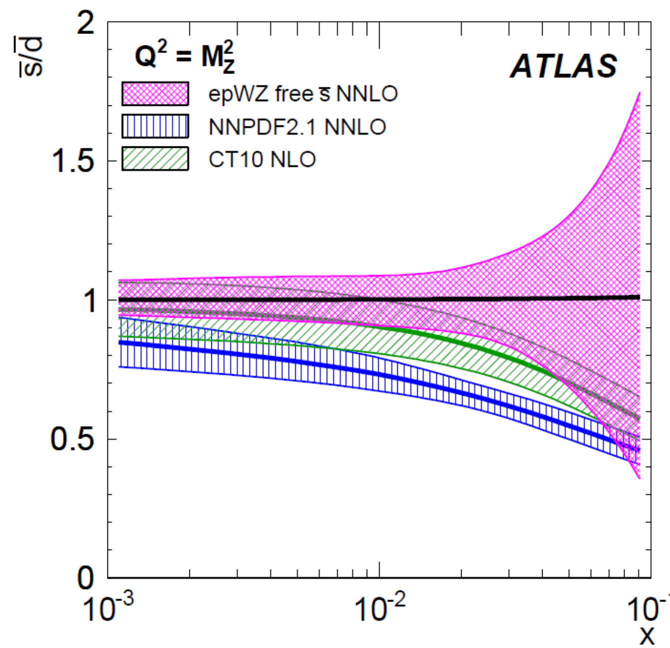


sbar/dbar compared to other PDFs









Conclusion

- ATLAS W+,W-, Z differential cross-sections from 2010 data give constraints on the strange quark content of the proton
- For x~0.01 the strange is not suppressed with respect to the light quarks.