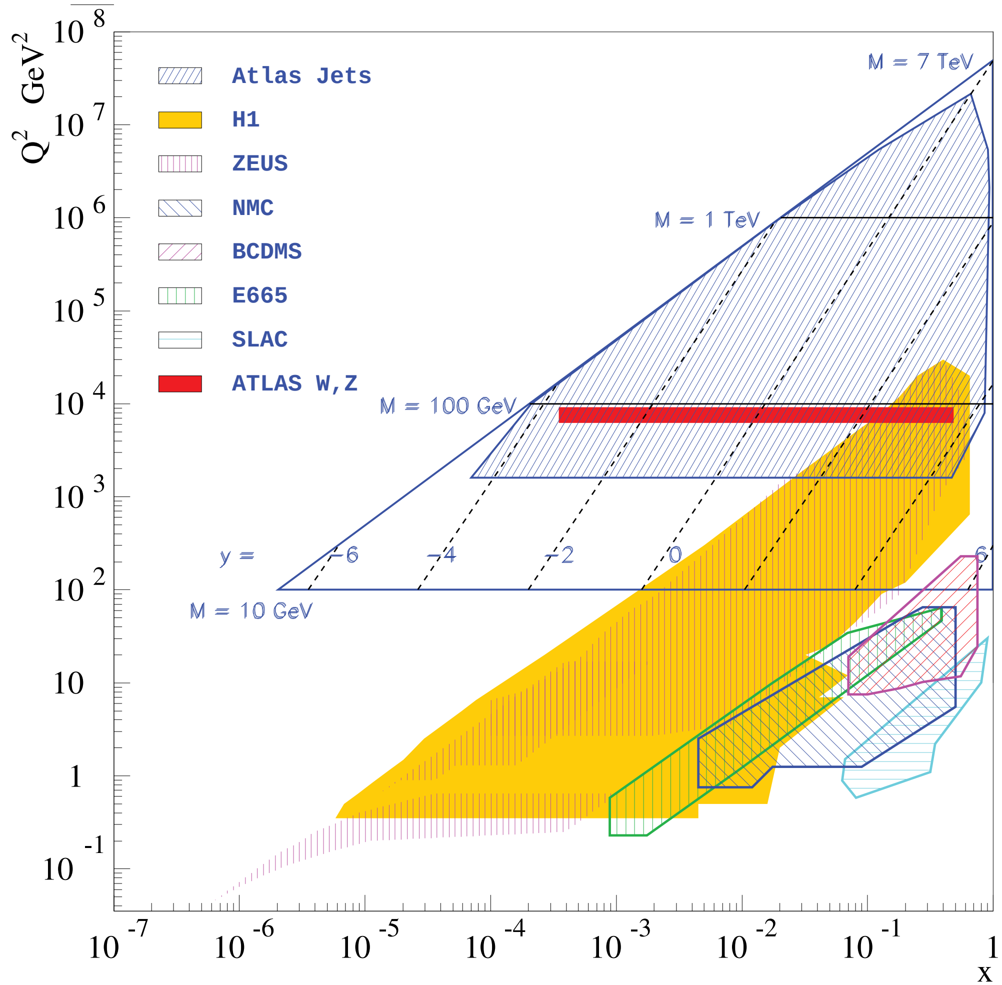
Status and challenges for PDF determinations

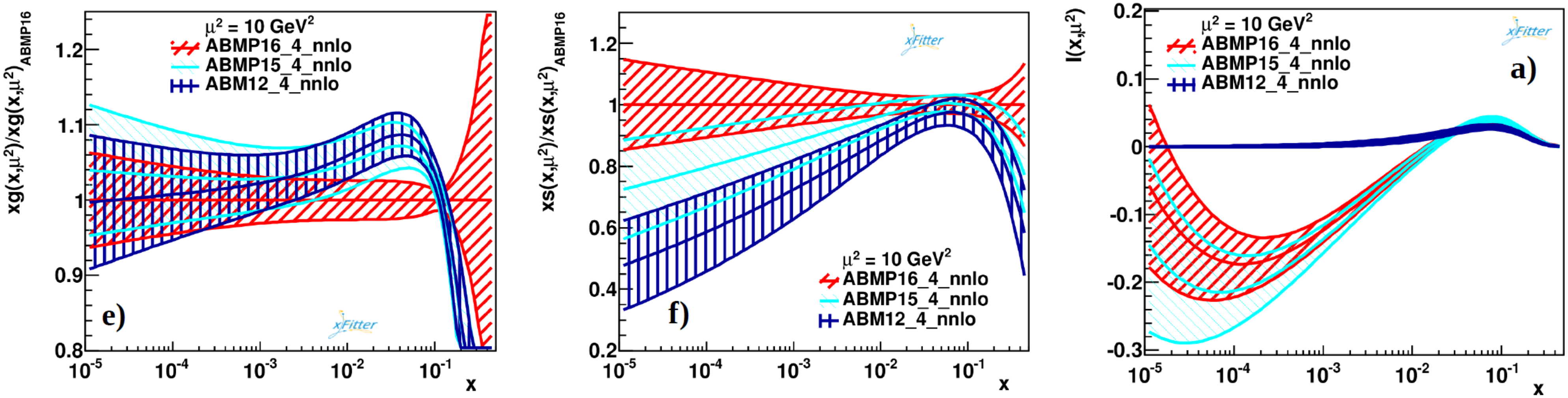
S. Glazov, EPS 7/07/2017

Cross sections at the LHC



The cross sections are given by a convolution of the parton densities and coefficient functions, $\sim x_1 f_1(x_1, \mu)\, x_2 f_2(x_2, \mu)\, \hat{\sigma}(x_1, x_2, \mu)$.
Leading order relation between rapidity y and x_1, x_2: $x_{1,2} = \frac{M_{\ell\ell}}{\sqrt{S}} e^{\pm y_{\ell\ell}}$.

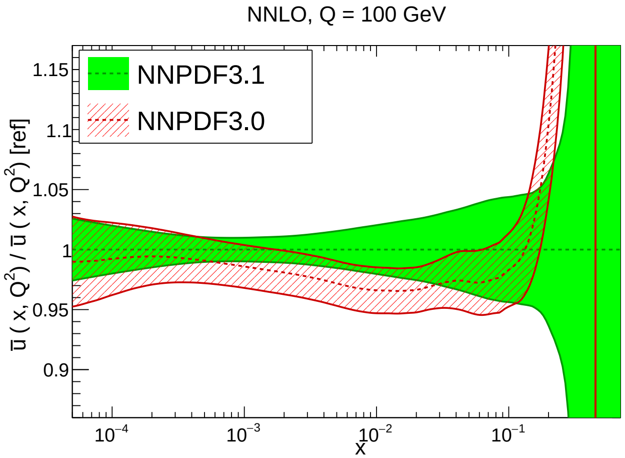
Highlights of the new ABMP2016 set

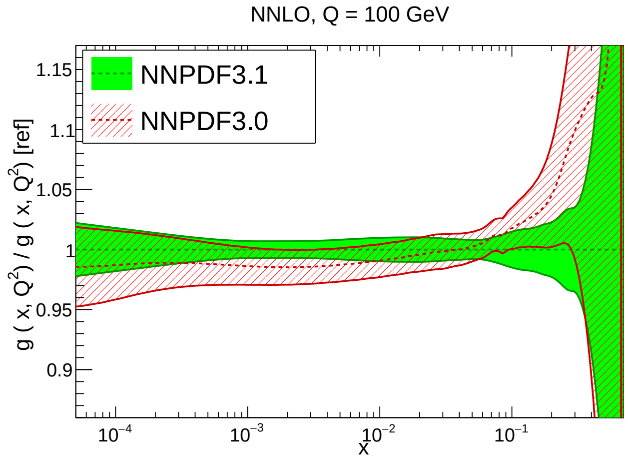


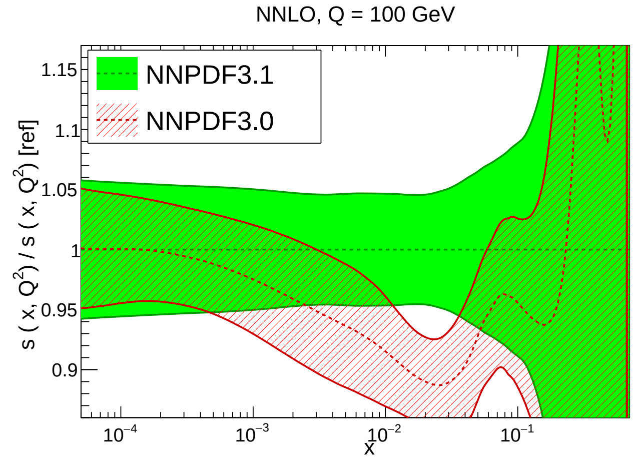
- Updates in input data: combined HERA data; new NOMAD and CHORUS for neutrino scattering DIS; DY sets from ATLAS, CMS, D0.
- Updated analysis of $\alpha_S = 0.1147 \pm 0.0008$.
- Harder gluon, increased strange-quark distribution at $x \sim 0.01$
- Relaxed assumption that $I = x\bar{d} - x\bar{u} \to 0$ for $x \to 0$

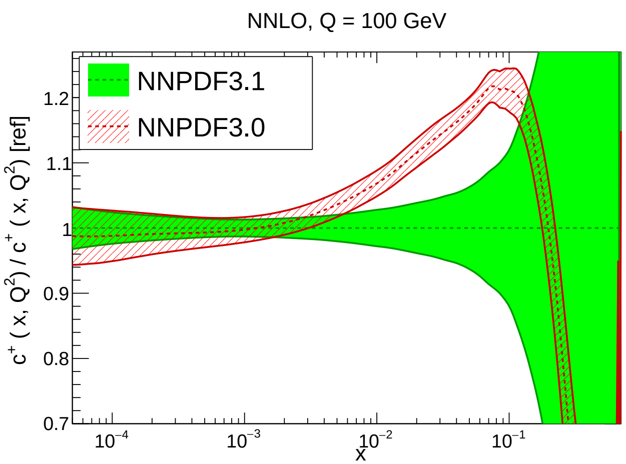
arXiv:1701.05838

Highlights of the new NNPDF3.1 set





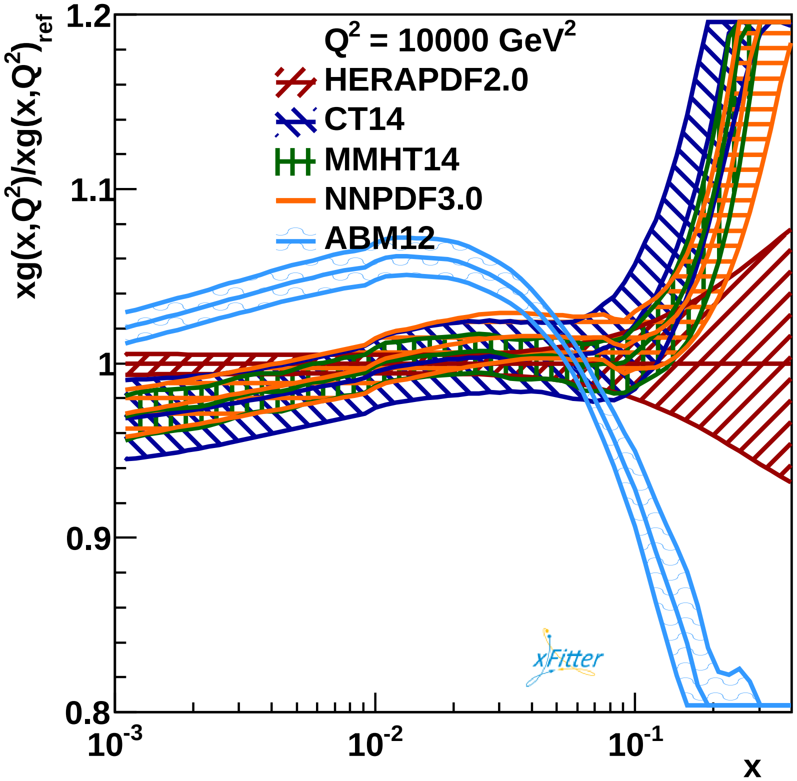




- Inclusion of HERA2.0 combined data: better description of DIS data, somewhat larger sea at low x.
- Inclusion of $t\bar{t}$, Z_{Q_T} data, theoretical uncertainty for the jet data: more accurate, softer gluon.
- Inclusion of ATLAS 2011 W, Z data: larger strange at low x
- Parameterised charm-quark distribution.

arXiv:1706.00428

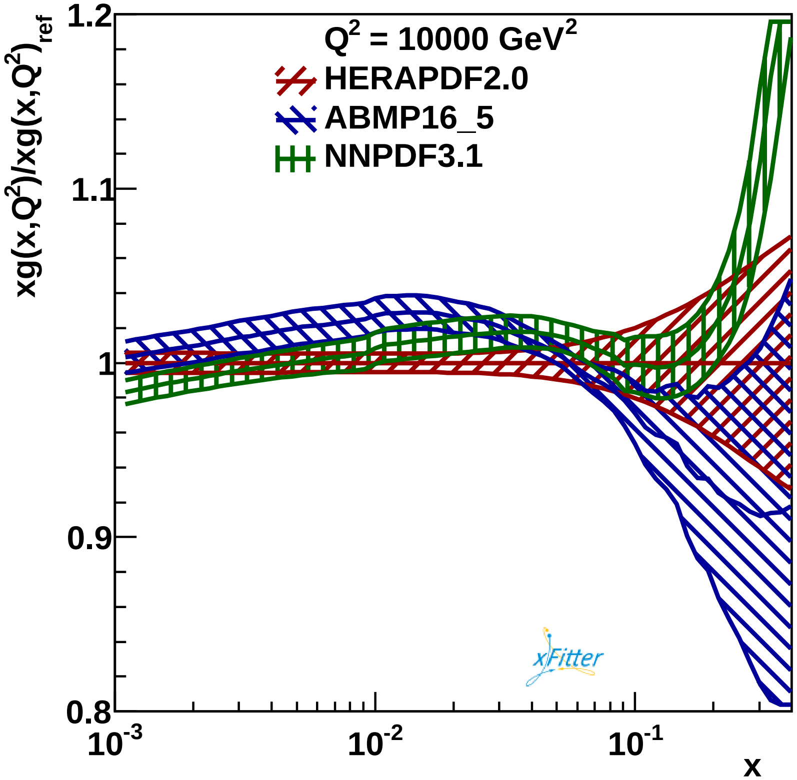
The gluon distribution from the 5 PDF sets



- Gluon at $x \sim 0.01$ important for Higgs production
- Gluon at $x > 0.3$ important for searches
- Gluon at $x \sim 0.1$ important for $t\bar{t}$ production.

- Good agreement of the three PDF4LHC sets (MMHT14, CT14 and NNPDF3.0)
- ABM12 set has different (low) α_S, differs the most.
- HERAPDF agrees with PDF4LHC for $0.01 < x < 0.1$, lower at high x and higher at low x.

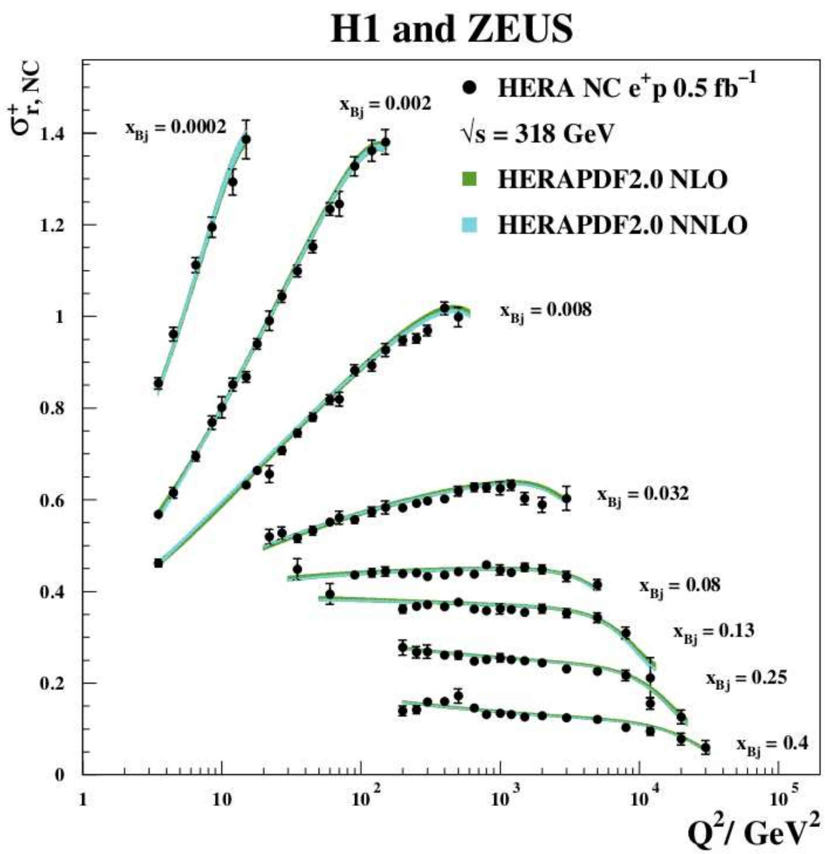
The gluon from ABMP16 and NNPDF3.1



- Gluon at $x \sim 0.01$ important for Higgs production
- Gluon at $x > 0.3$ important for searches
- Gluon at $x \sim 0.1$ important for $t\bar{t}$ production.

- ABMP16 with updated $\alpha_S = 0.1147$ is much closer to other sets, in broad agreement, taking uncertainties into account.
- NNPDF3.1 is closer to HERAPDF2.0 up to $x = 0.2$.

HERA data for the gluon distribution

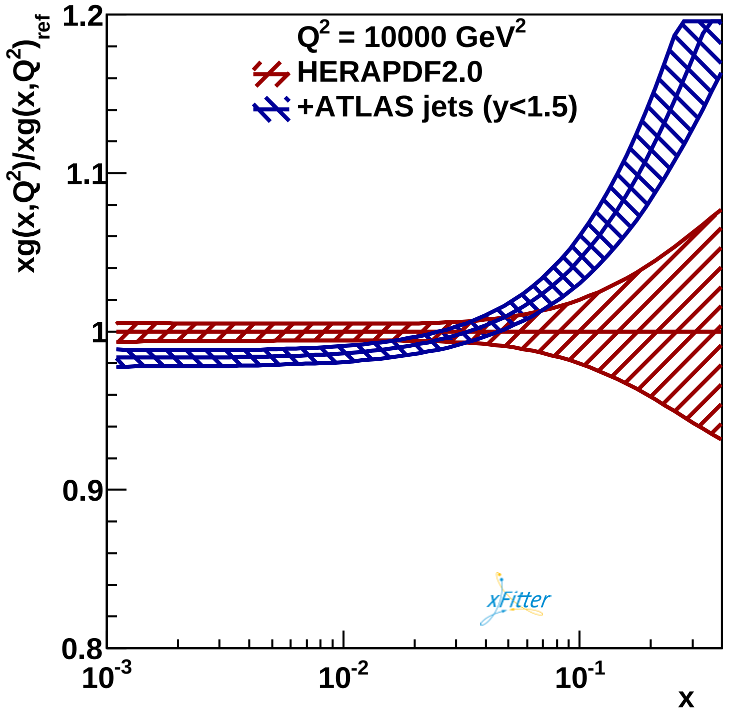


- Observable:
  $\sigma_r \approx F_2 - \frac{y^2}{1+(1-y)^2} F_L$
  where $0 < y \leq 1$ and
  $S\,xy = Q^2$.
- Constraints on $xg(x, Q^2)$ from scaling violation of the SF F_2:

$$\frac{dF_2}{d\log Q^2} \sim \alpha_S\, g$$

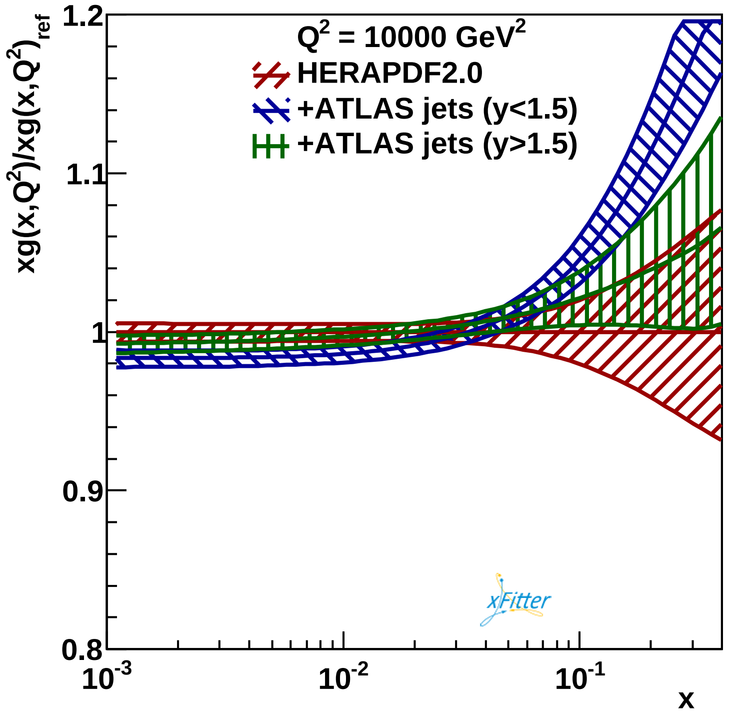
- The Q^2 dependence of F_2 is well constraint by the data, leading to experimentally precise determination
- Some tensions between data and theory with NLO (NNLO) fit $\chi^2/N_{\rm DF}$ = 1357/1131 (1363/1131). → N^{3}LO ?

Adding jet data ...



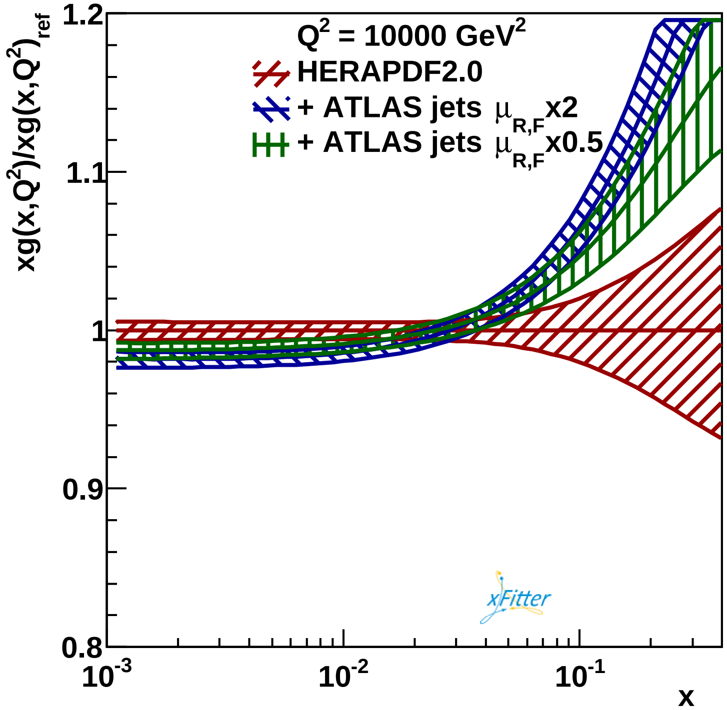
- Estimate impact data on the gluon distribution by employing PDF profiling of the HERAPDF2.0 set
- Use ATLAS jet $\sqrt{s} = 7$ TeV data ($R = 0.4$, JHEP02(2015)153)
- Predictions based on NLOJET++ plus NP and EWK corrections
- Use data for $y < 1.5$. Poor $\chi^2/N_{\mathrm{DF}} = 209/85$
- Strong pull towards PDF4LHC pdfs.

Adding jet data ...



- Estimate impact data on the gluon distribution by employing PDF profiling of the HERAPDF2.0 set
- Use ATLAS jet $\sqrt{s} = 7$ TeV data (JHEP02(2015)153)
- Predictions based on NLOJET++ plus NP and EWK corrections
- Use data for $y < 1.5$ ($1.5 < y < 3.0$). Poor $\chi^2/N_{\mathrm{DF}} = 209/85$ ($97/51$)
- Strong (moderate) pull towards PDF4LHC pdfs.

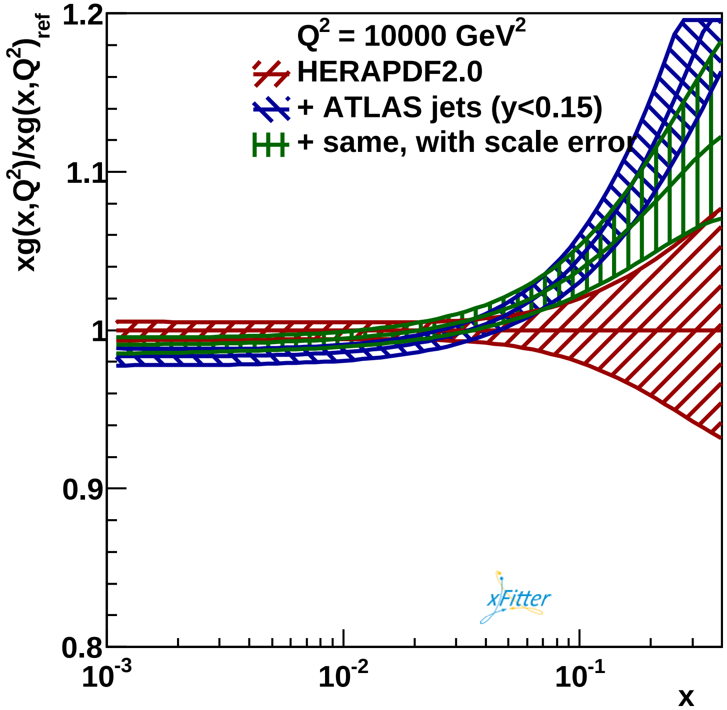
Effect of scale uncertainties on the jet data



- NLO predictions have substantial uncertainties, which can be estimated by varying μ_R and μ_F scale factors.
- Variation of $\mu_F = \mu_R = 0.5, 2$ vs default choice of inclusive p_T for the ATLAS data leads to substantial variation of the central value of the profiled gluon density.

→ PDFs with theoretical uncertainties.

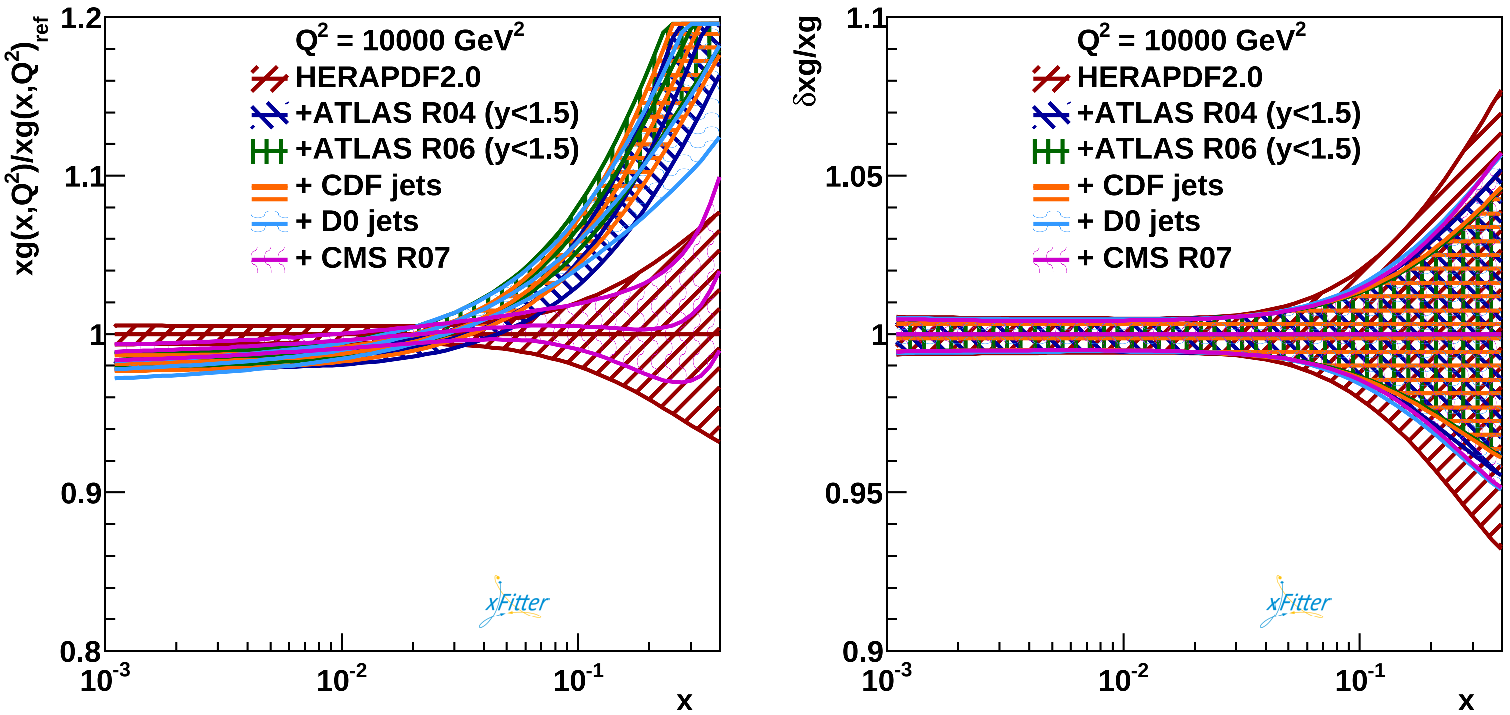
Effect of scale uncertainties on the jet data



- NLO predictions have substantial uncertainties, which can be estimated by varying μ_R and μ_F scale factors.
- Extra error due to variation of $\mu_F = \mu_R = 0.5, 2$ vs default choice of inclusive p_T for the ATLAS data leads to substantial change of the central value of the profiled gluon density.

→ PDFs with theoretical uncertainties, proper weights for data samples.

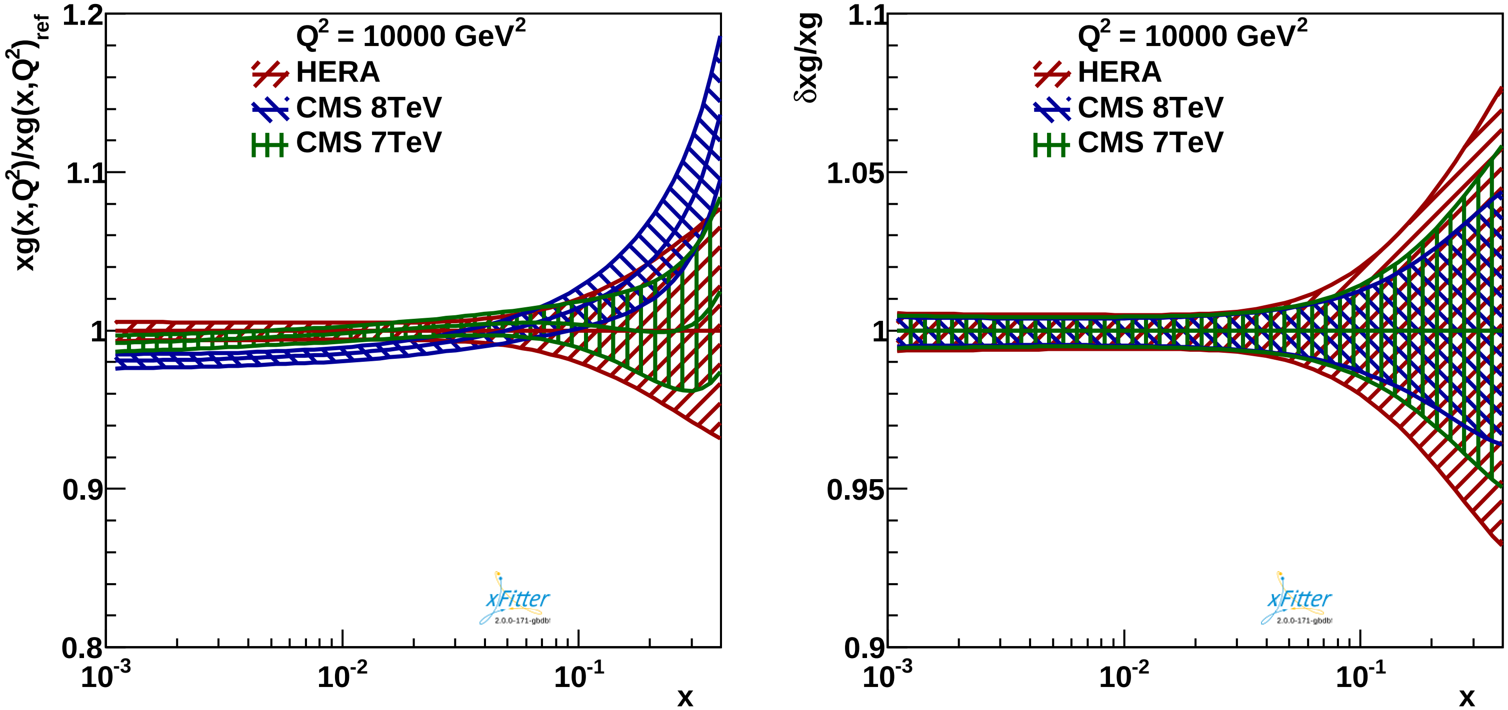
Other jet measurements



- Try different jet data: run-II DO PRL101:062001, CDF PRD78:052006, CMS at $\sqrt{s} = 7$ TeV ($R = 0.7$), Phys. Rev. D87 112002.
- All jet samples have comparable constraining power on gluon.
- D0,CDF and ATLAS $R = 0.4, 0.6$ jet measurements lead to harder gluon, CMS data do not change the shape significantly.

→ direct comparison of ATLAS and CMS data

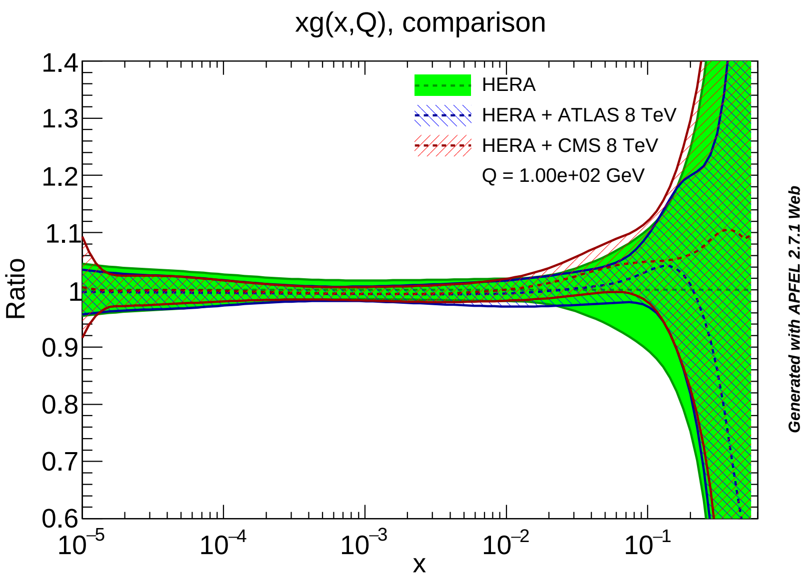
CMS jets at 7 and 8 TeV

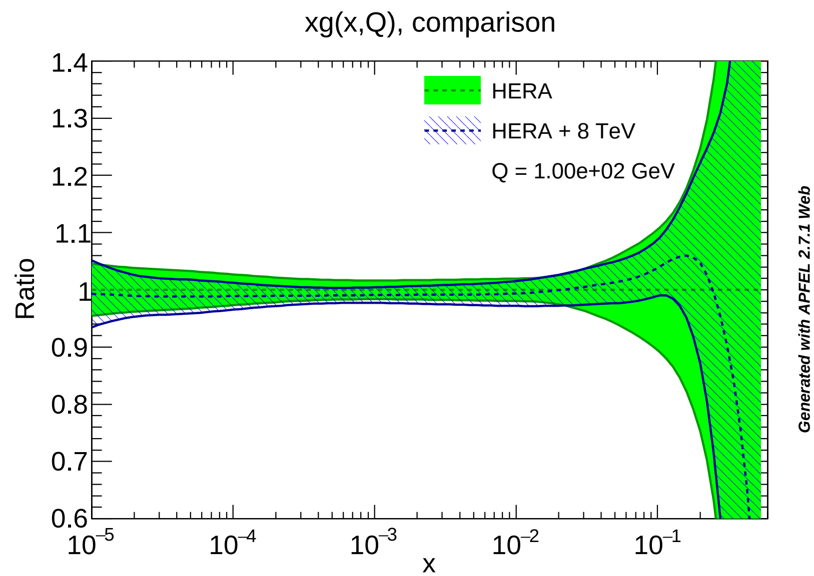


- New published CMS result at $\sqrt{s} = 8$ TeV arXiv:1609.05331.
- Improved constraining power vs $\sqrt{s} = 7$ TeV.
- Also consistent with HERAPDF2.0, but pulls gluon up, similar to other jet measurements.

$\rightarrow$ direct comparison of ATLAS and CMS data

Z_{p_T} data

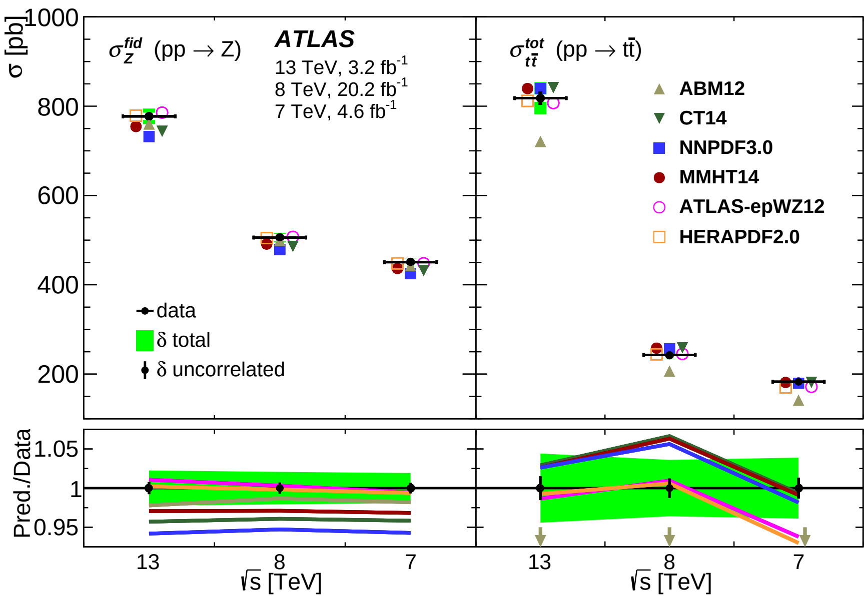


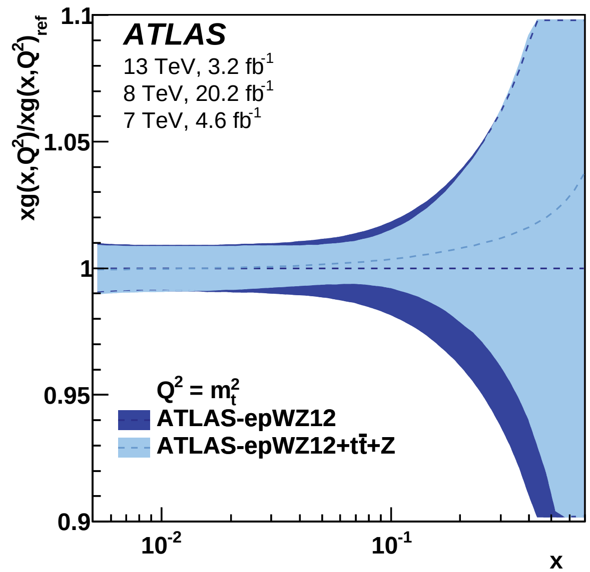


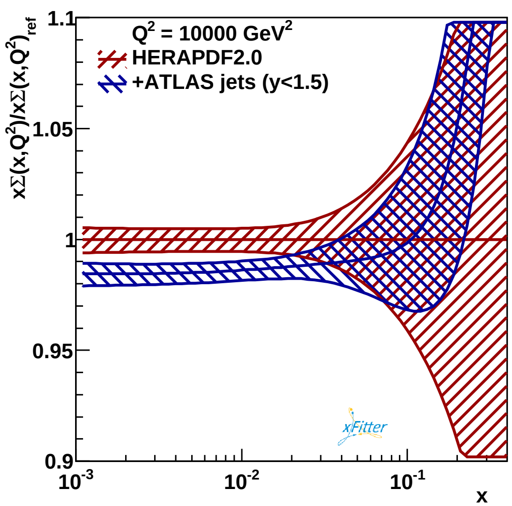
- Accurate measurements of the Z-boson transverse momentum are sensitive to Compton gq scattering, can be used to constrain gluon density.
- Recent NNLO calculations, PRL 118 (2017) 7 072002 → small theoretical uncertainties.
- Example analysis of arXiv:1705.00343 using NNPDF methodology.
- Consistent with HERA-only PDF fit.

→ fast NNLO grids

$t\bar{t}$ and Z production

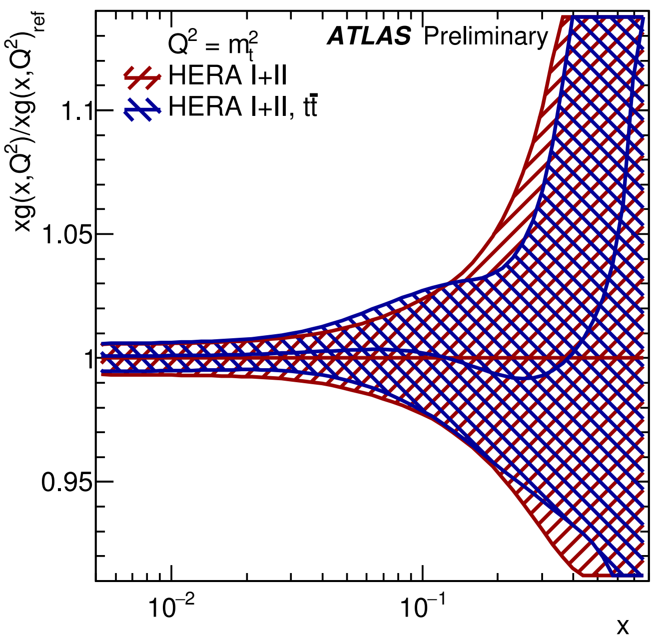


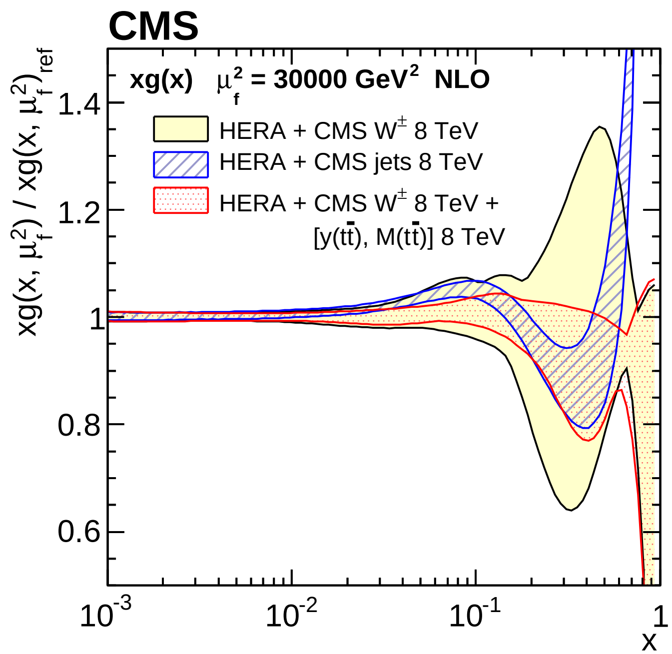




- Z production is mostly sensitive to $q\bar{q}$ while $t\bar{t}$ to gg.
- Compare recent ATLAS correlated σ_Z and $\sigma_{t\bar{t}}$ measurement with predictions at NNLO (+NNLL) using different PDF sets, profile ATLAS-epWZ set (arXiv:1612.03636).
- Best agreement with HERA-like sets for both σ_Z and $\sigma_{t\bar{t}}$. For PDF4LHC-sets, tension for σ_Z is due to anti-correlation of gluon g and light-quark sea $\Sigma = 2(\bar{u} + \bar{d} + \bar{s})$ distributions.

Differential $t\bar{t}$ measurements

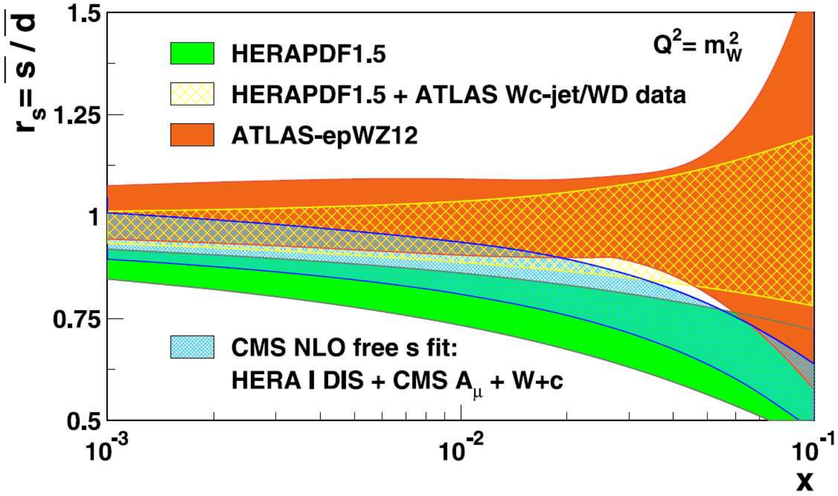




- CMS studies of HERA+different CMS sets reveals sensitivity to the gluon density of the jets and $t\bar{t}$ data. For $x \sim 0.1$, $\sqrt{s} = 8$ TeV jet data pulls gluon up, while differential $t\bar{t}$ data are fully consistent with HERA fit. arXiv:1703.01630,arXiv:1609.05331
- New ATLAS NLO analysis of differential leptonic distributions also finds gluon fully consistent with the HERA-only fit ATLAS-CONF-2017-044

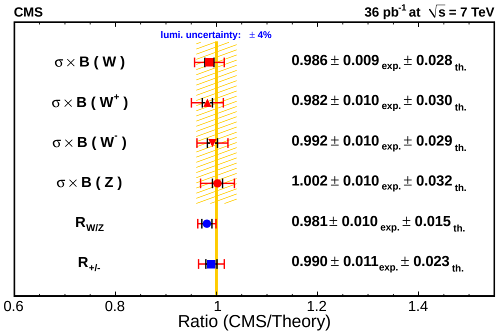
→ NNLO for differential $t\bar{t}$ cross sections with FS leptons.

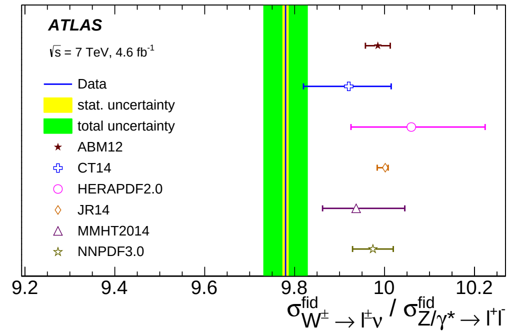
Strange-quark distribution

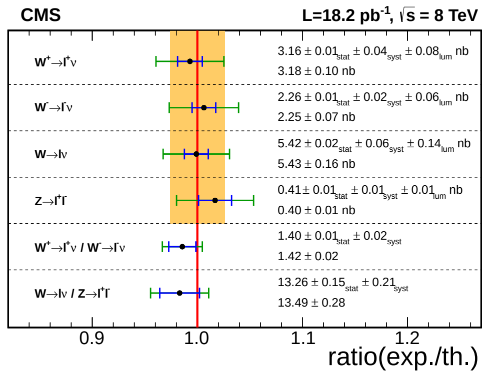


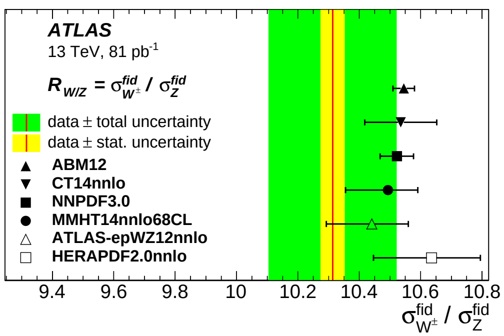
- Light-quark sea is likely to be symmetric for *u*- and *d*-quarks for small *x*. For the strange-quark distribution it might be different.
- Fixed-target neutrino data on $\nu_\mu s \to \mu^\pm c^\mp \to \mu^- \mu^x X$ scattering suggests suppression.
- LHC data are sensitive to the strange-quark distribution via:
  - *Z*-boson rapidity distribution (more central for $s\bar{s}$)
  - σ_W/σ_Z cross section ration (affects more *Z* vs *W*)
  - $gs \to W^\pm c^\mp \to \ell^\pm \nu c^\mp$ production of *W*-boson with tagged charm.

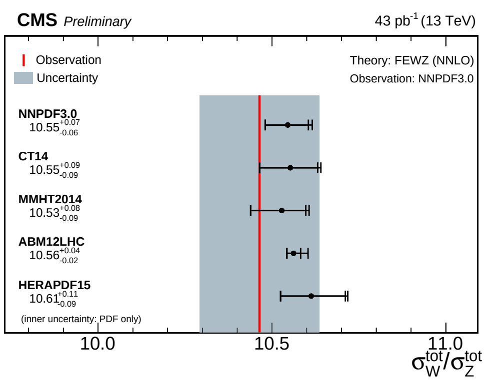
W/Z cross section ratios









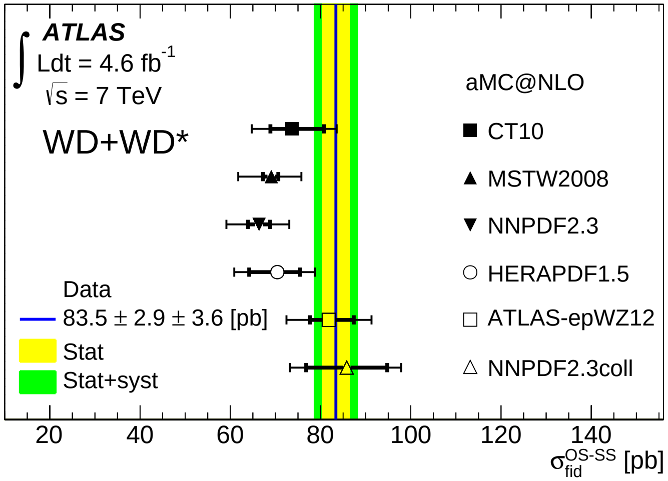


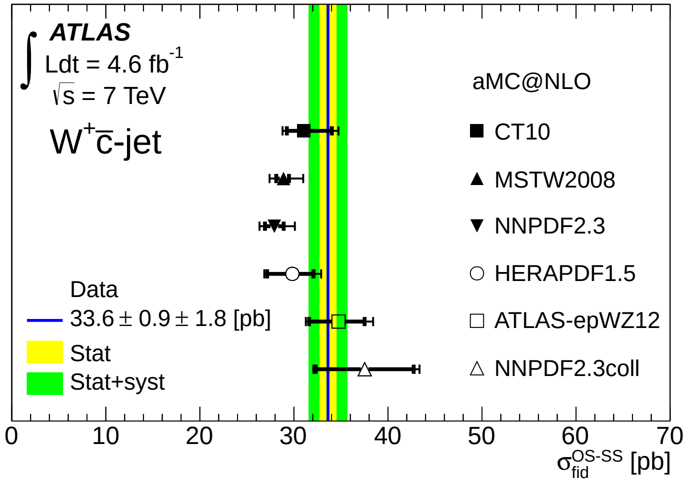
- All measured ratios σ_W/σ_Z tend to be below predictions for PDFs with suppressed strangeness.
- Best exp. accuracy is for fiducial cross sections, $\sqrt{s} = 7$ TeV ATLAS data in particular.
- Additional uncertainty for fiducial predictions: difference between FEWZ vs DYNNLO NNLO predictions for the ratio (at 0.5% level).

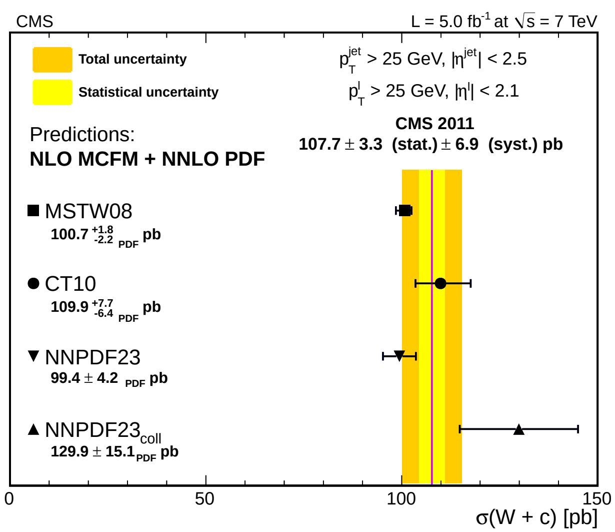
→ N3LO ?

CMS JHEP 10 (2011) 132, PRL 112 (2014) 191802, CMS-PAS-SMP-15-004, ATLAS PLB 759 (2016) 601, arXiv:1612.03016

Measurements of W+c from ATLAS and CMS



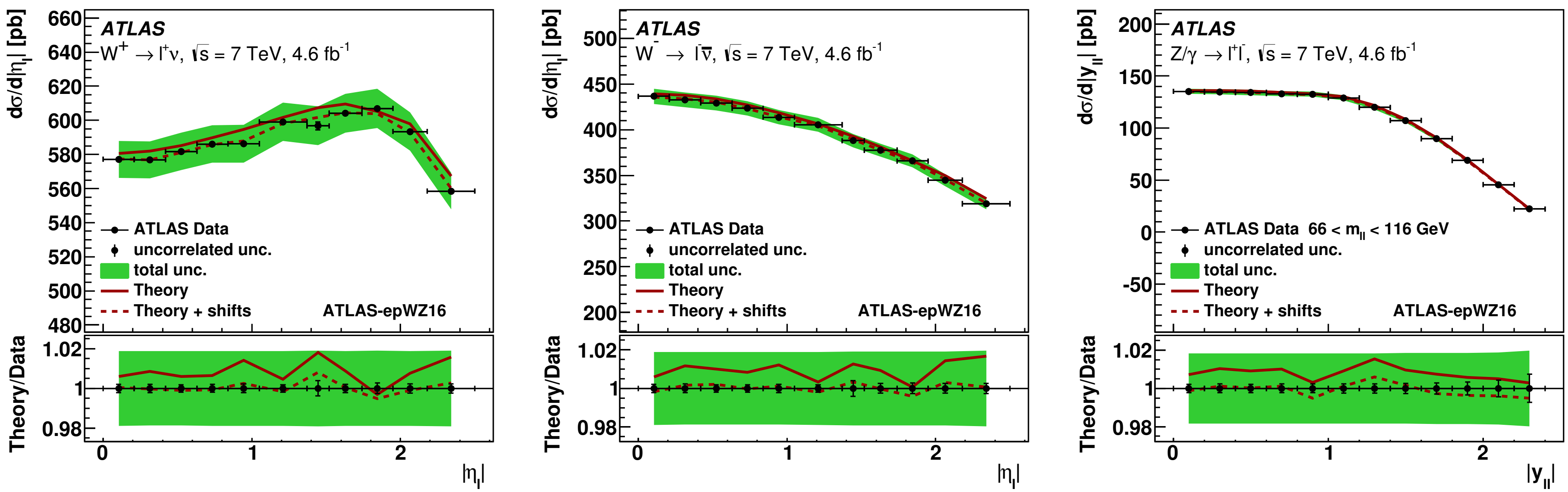




- Measurements of $\sigma(W^{\pm}c^{\mp}) - \sigma(W^{\pm}c^{\pm})$ from ATLAS and CMS (JHEP 02 (2014) 013, arXiv:1402.6263), using c-jets tagged by soft muons and $D^{(*)}$ mesons, to probe strange-sea PDF using $gs \to Wc$ process.
- Large NLO scale uncertainties. For $W + c$-jet ($p_T > 20$ GeV), can use NNLO for W+jet.

$\to$ NNLO for $W + D$

W and Z cross sections at $\sqrt{s} = 7$ TeV

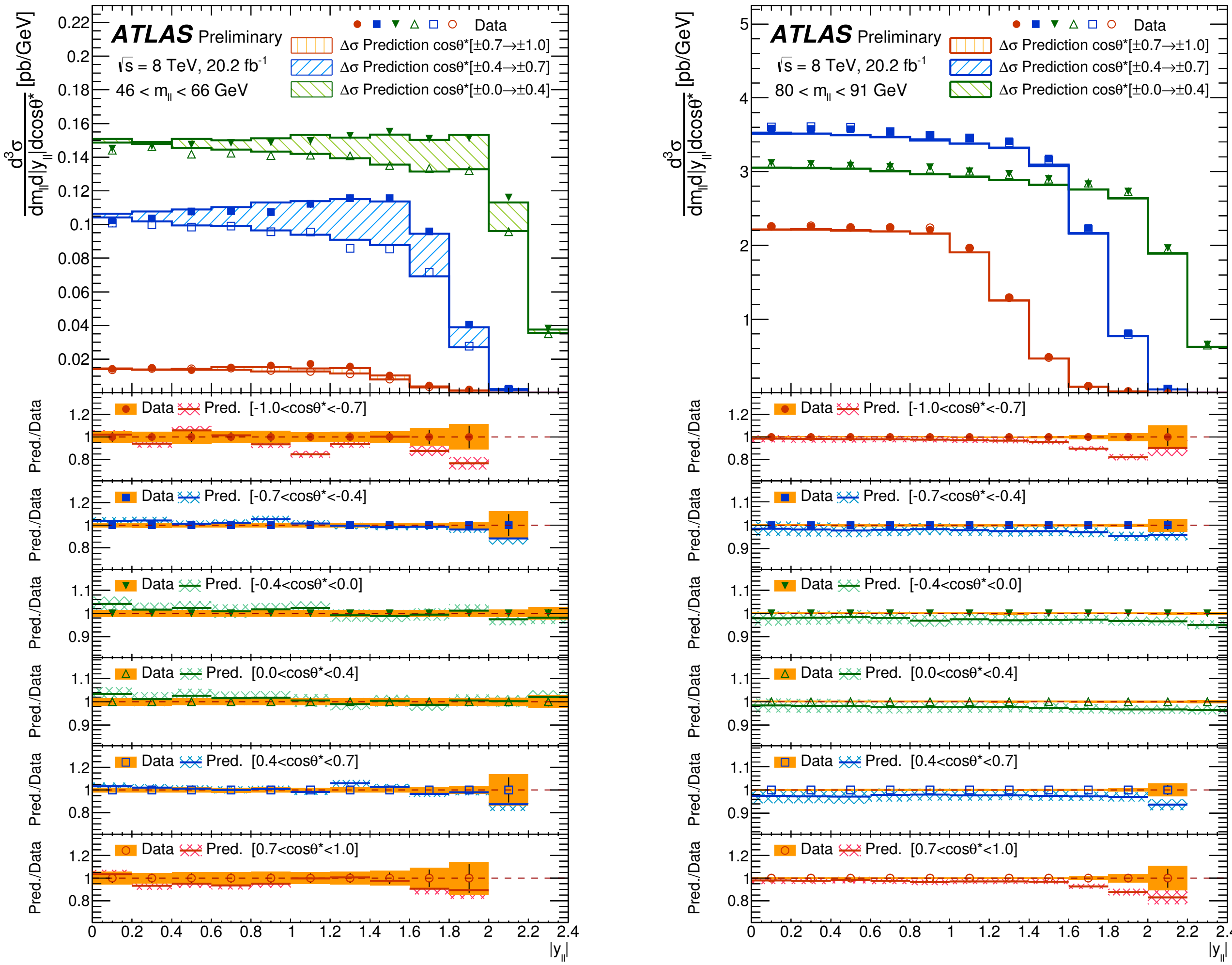


- ATLAS $W, Z/\gamma^*$ data together with the inclusive HERA-II data included in a QCD analysis at NNLO QCD + NLO EWK using xFitter program.

- Challenge for the theory to match the data accuracy, $\chi^2/\mathrm{N_{data}} = 108/61$ (ATLAS only) for the nominal scale settings $\mu_F = \mu_R = M_Z$, improving to $\chi^2/\mathrm{N_{data}} = 85/61$ for $\mu_F = \mu_R = 1/2M_Z$

$\rightarrow$ N^{3}LO ? NNLO+NNLL ?

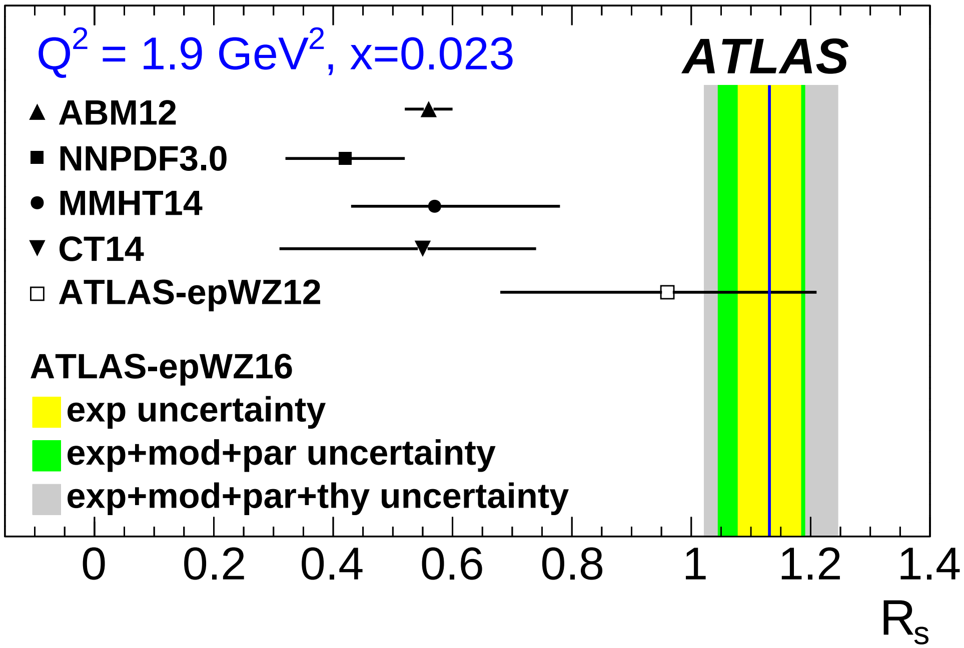
Triple differential $\frac{d^3\sigma_{\gamma,Z}}{d|y_{\ell\ell}|dm_{\ell\ell}d\cos\theta^*_{CS}}$ cross section.



- New ATLAS measurement of Z/γ^* fiducial ($p_T^\ell > 20$ GeV, $|\eta^\ell| < 2.4$) differential cross section using $\sqrt{s} = 8$ TeV data, triple differentially in $m_{\ell\ell}$, $y_{\ell\ell}$ and $\cos\theta^*_{CS}$.
- Large impact of fiducial cuts for large values of $\cos\theta^*$.

Data can be described by Powheg NLO+PS simulation,
→ NNLO+NNLL fits to Z data.

W and Z cross sections at $\sqrt{s} = 7$ TeV



- $R_s = \frac{s+\bar{s}}{\bar{u}+\bar{d}}$ determined from the QCD fit is consistent with unity with significantly reduced compared to previous ATLAS analysis experimental uncertainties.
- ABMP16 (3 flav): $R_s = 0.63 \pm 0.03$ (does NOT include ATLAS data). NNPDF3.1 (Hessian): 0.60 ± 0.13 (does include ATLAS data).

Summary

- Many new precision measurements, sensitive to PDFs.
- A number of new NNLO calculations, enabling usage of these data.
- Still need fast tools to perform NNLO fits directly, without using k-factors.
- A couple of new probes for the gluon density at high x may serve as alternative to the jet measurements, not always agree with them.
- Accuracy of the fiducial measurements for W, Z production reaches $< 0.5\%$, similar or less than NNLO uncertainties. Going beyond NNLO to NNLO+NNLL and ultimately to N^3LO could be required for these data.