use of x/HERAFitter within ATLAS

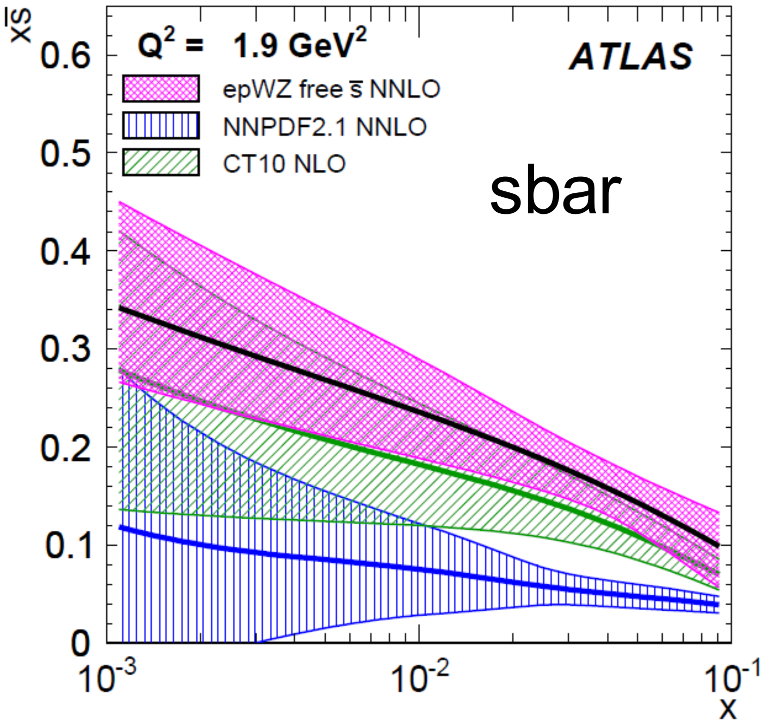
Amanda Cooper-Sarkar, Claire Gwenlan (Oxford)

1. strange – from W and Z 2010
2. ZAFB (forward-backward asymmetry)
3. W+charm
4. High Mass Drell Yan 7 TeV
5. Low Mass Drell Yan 7 TeV
6. 2.76/7 TeV jets
7. Direct photon (PUB note)
8. W mass uncertainties (PUB note)
9. Single top 7 TeV
10. ttbar differential cross sections

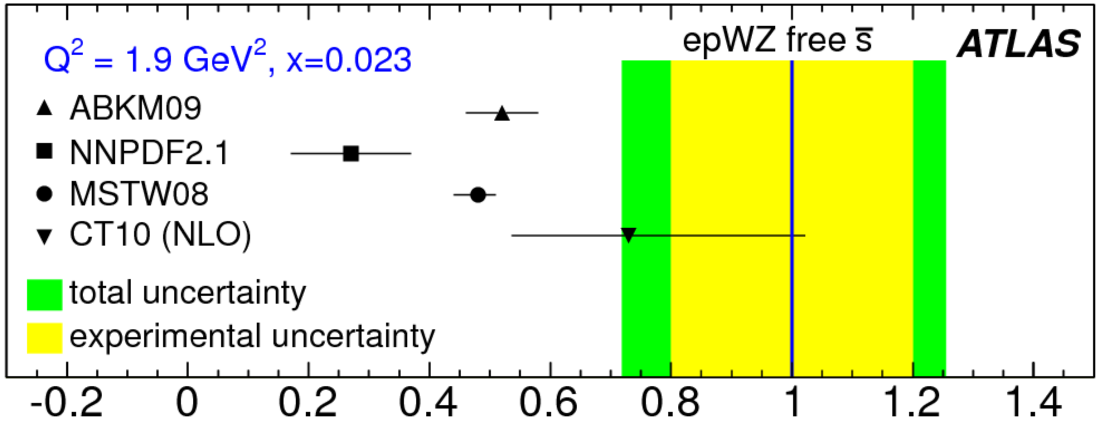
… as well as several other studies in progress/not yet public

1. **strange result** Phys Rev Lett 109 (2012) 012001

- **FULL HERAFitter PDF fit** of **ATLAS W+,W- and Z 2010 data** showed enhanced strangeness; comes from shape of the Z rapidity distribution, together with the normalisation provided by the W data



$r_s = 0.5(s+\bar{s})/\bar{d}$



$$r_s = 1.00 \pm 0.20\,\mathrm{exp} \pm 0.07\,\mathrm{mod}^{+0.10}_{-0.15}\,\mathrm{par}^{+0.06}_{-0.07}\,\alpha_S \pm 0.08\,\mathrm{th},$$

Also, one should not forget that the election and muon data were combined with **HERAaverager**

This study actually produced a whole PDF set not just a single number

Now called ATLAS-epWZ12 in LHAPDF as used in…

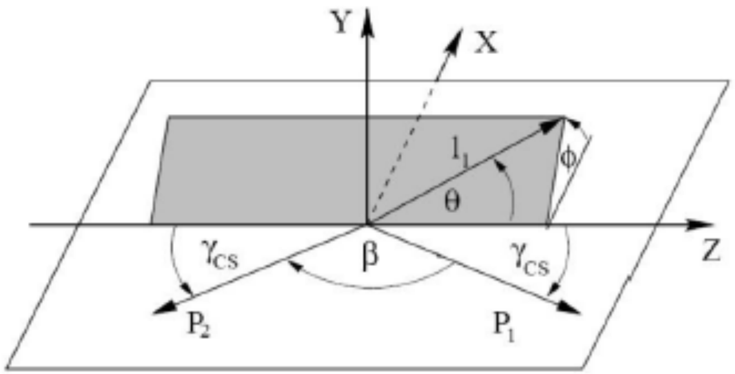
2. Z forward-backward asymmetry paper arXiv:1503. 03709 : measurement of $\sin^2\theta_W$

- depends on interplay of u and d-flavours, which MSTW2008 did not describe well in our kinematic region – so we decided to use a PDF closest to our own data
- a special LO version of the ATLAS-epWZ12 PDF was made for this paper, using **HERAFitter** (now also in LHAPDF)

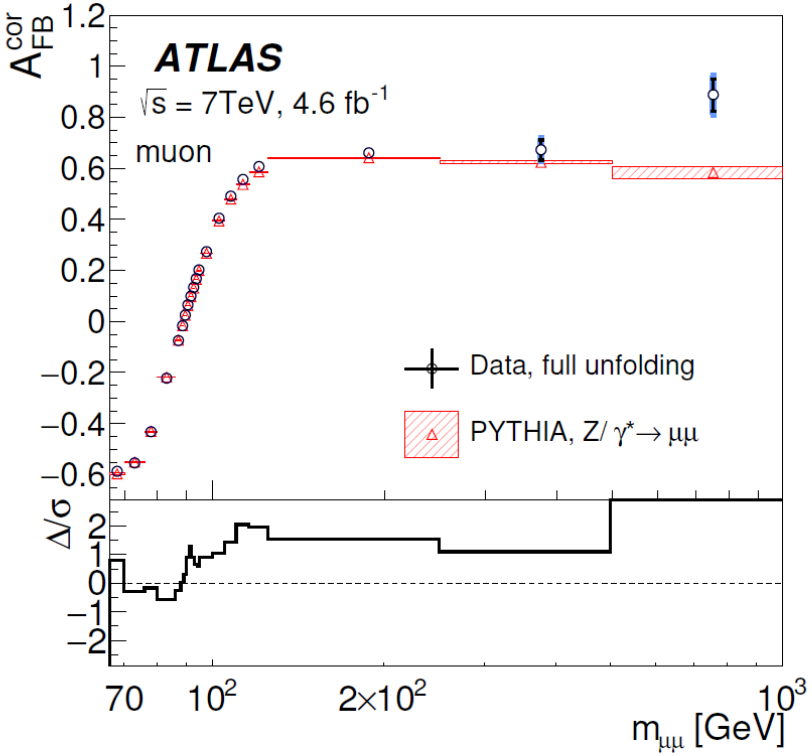
weak mixing angle θ_W can be extracted from the Z Forward-Backward asymmetry
(in the polar angle distribution of the leptons wrt the quark direction in the dilepton rest frame)

ZAFB – in the Collins-Soper frame

$$A_{FB} = (\sigma_F - \sigma_B) / (\sigma_F + \sigma_B)$$

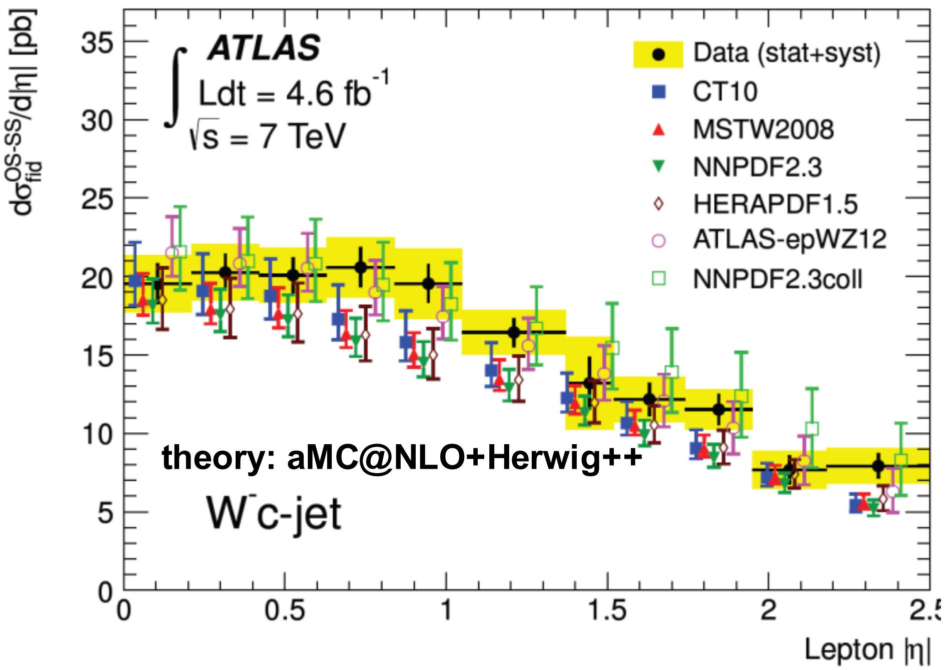


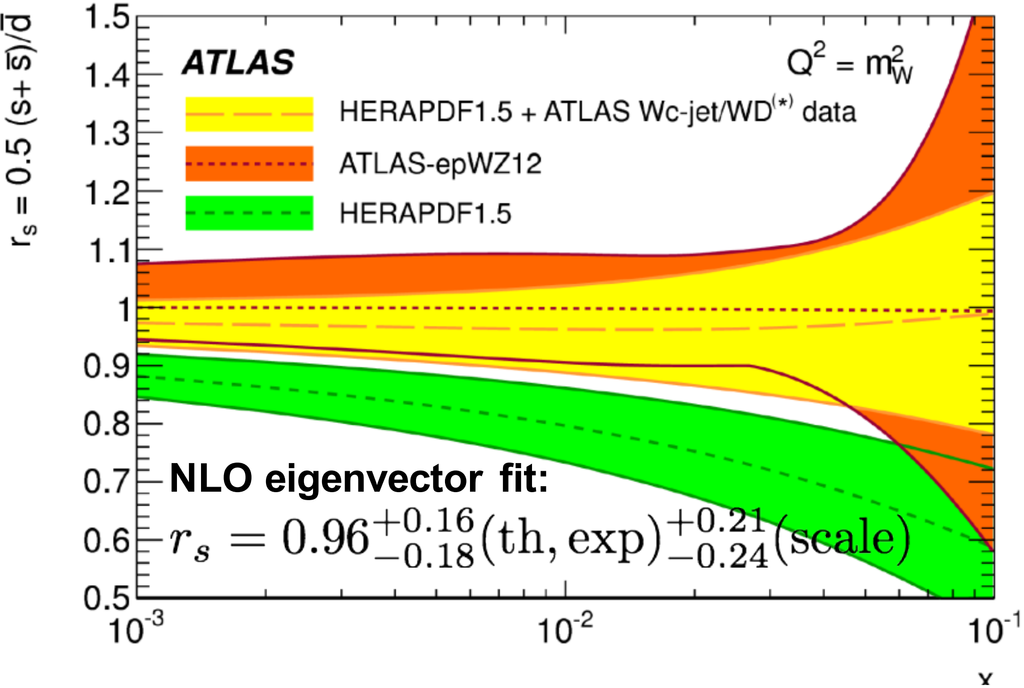
Colins-Soper frame: a particular dilepton rest frame; reduces uncertainties due to pt of incoming quarks



$$\sin^2\theta_{eff}^{\mathrm{lept}} = 0.2308 \pm 0.0005(\mathrm{stat.}) \pm 0.0006(\mathrm{syst.}) \pm 0.0009(\mathrm{PDF}) = 0.2308 \pm 0.0012(\mathrm{tot.}).$$

3. **ATLAS data on W+c** JHEP05(2014)068 favour the enhanced strangeness

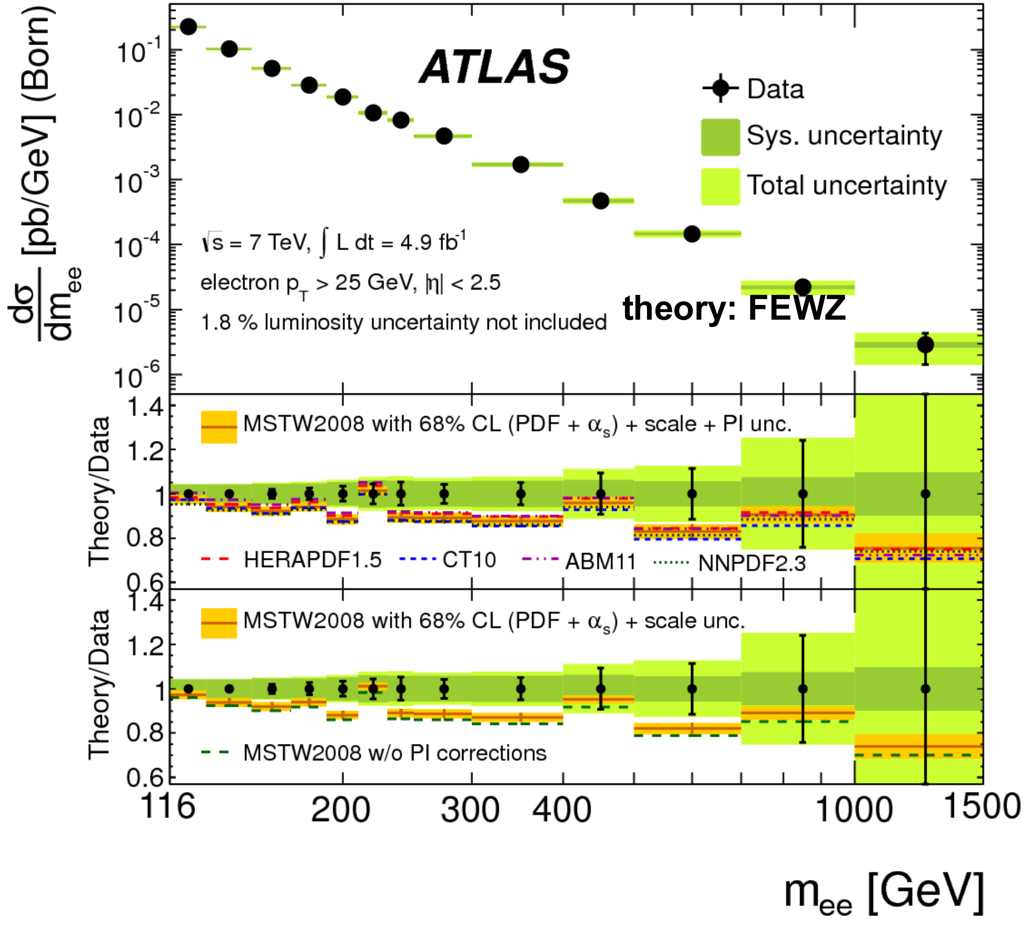




- paper uses **HERAaverager** to combine electron and muon channels for W+c-jet (W+c-jet and W+D(*) cross-sections)
- uses the ATLAS epWZ12 PDF fit (amongst others)
- uses the **quantitative tools of HERAFitter** to compare PDF predictions with data including theoretical uncertainties as well as data systematics (including asymmetric uncertainties)
- PDF uncertainty coming from the strangeness fraction in HERAPDF1.5 was then used to make an estimate of the strangeness fraction in the W+c data (example of **profiling**)

4. **High-Mass Drell-Yan** Phys Lett B725(2013)223

especially sensitive to poorly known antiquarks at high x



X2 takes into account PDF uncertainties:

$$\chi^2 = \sum_{k,i} w_k^i \frac{\left[\mu_k^i - m^i\left(1+\sum_j \gamma_{j,k}^i b_j + \sum_j (\gamma^{\rm theo})_{j,k}^i b_j^{\rm theo}\right)\right]^2}{(\delta_{{\rm sta},k}^i)^2 \Delta_i^k + (\delta_{{\rm unc},k}^i m^i)^2} + \sum_j b_j^2 + \sum_j (b_j^{\rm theo})^2,$$

where

$$\Delta_i^k = \mu_k^i m^i \left(1 - \sum_j \gamma_{j,k}^i b_j - \sum_j (\gamma^{\rm theo})_{j,k}^i b_j^{\rm theo}\right).$$

HERAFitter quantitiative tools were also used here

X2 for 13dp	NNLO PDF
13.9	MSTW2008
18.9	CT10
13.5	HERAPDF1.5
14.7	ABM11
14.8	NNPDF2.3

All PDFs give a good description

BUT **private HERAFitter PDF fitting** was also used and consideration of the fitted values for the nuisance parameters led us to question whether the background calculation was reliable

It was then that we realised that there was a need to consider the photon induced ('PI') part of the signal

5. Low-Mass Drell-Yan JHEP06(2014)112

- **HERAaverager** was used for the combination of electron and muon channels for the nominal range 26 – 66 GeV
- the **quantitative tools** were used for comparison on theory/data for FEWZ and POWHEG using MSTW2008 PDFs
- full **HERAFitter PDF fit** was made to both nominal and extended mass ranges

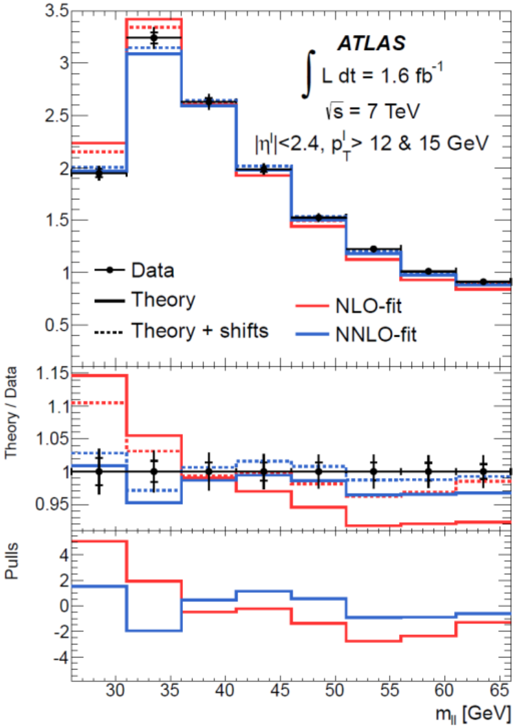
Prediction	χ^2 (8 points) Nominal	χ^2 (6 points) Extended
POWHEG NLO+LLPS	22.4 (19.8)	22.3 (18.6)
FEWZ NLO	48.7 (28.6)	139.7 (133.7)
FEWZ NNLO	13.9 (12.9)	7.1 (7.1)

*

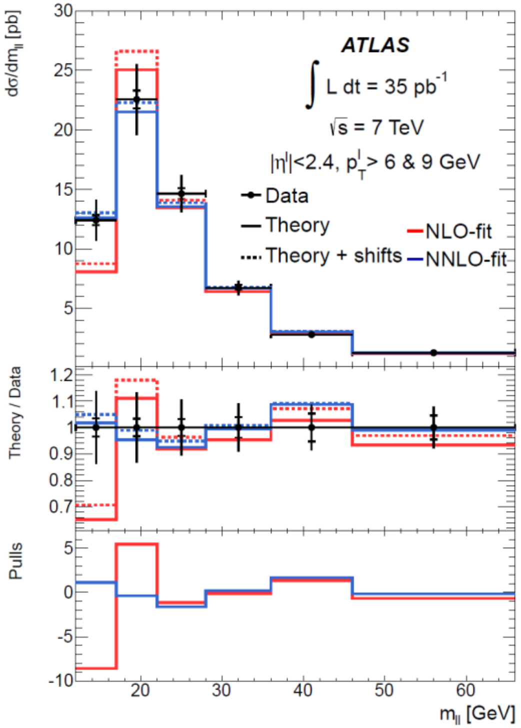
Full QCD fits including HERA and ATLAS LMDY:

Prediction	χ^2 (8 points) Nominal	χ^2 (6 points) Extended
NLO Fit	40.7	117.1
NNLO Fit	8.5	7.8

nominal mll: 26 – 66 GeV



extended mll: 12 – 66 GeV



Main point is that the NLO fits simply cannot handle the low-mass region

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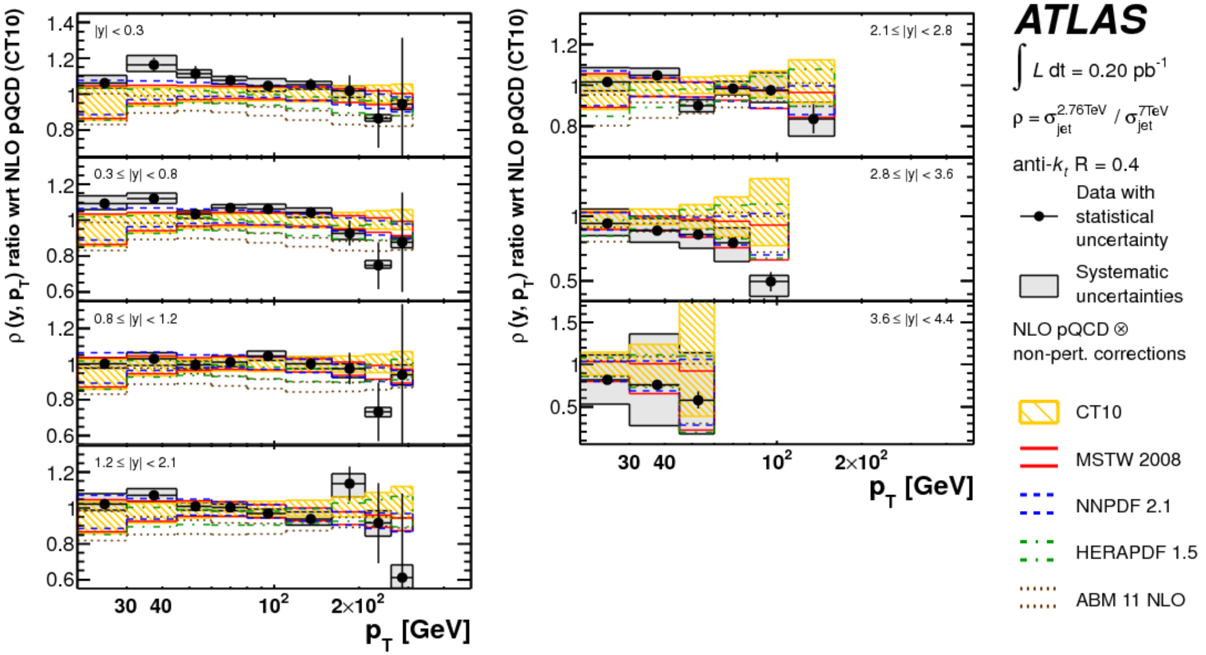
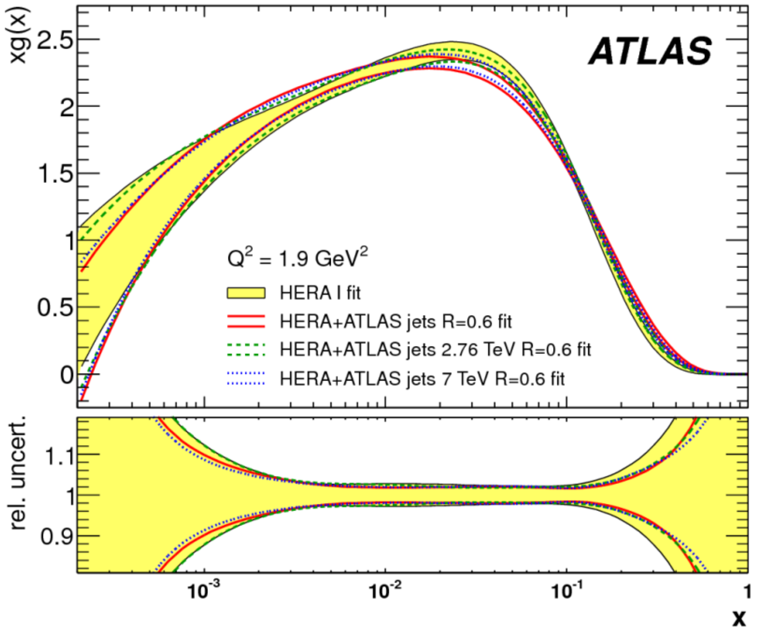
* numbers in brackets show X2 where PDFs and scale uncertainties on theoretical predictions taken into account

6. Ratios of the inclusive jet data at 2.76 and 7 TeV EPJC73(2013)2509

major experimental systematic - the Jet Energy Scale - largely cancels out in the ratio





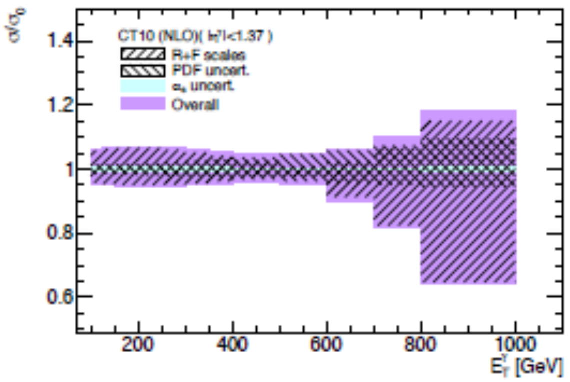
- the two different beam energies probe different x and Q^2 values for the same pt and y ranges so that the sensitivity to PDFs does not cancel in the ratio
- **full HERAFitter PDF fit was made**
- compare the gluon PDFs for a PDF fit using just HERA data and a fit using HERA+ ATLAS 2.76 and 7 TeV jet data.
  - **gluon becomes harder and the uncertainties on the gluon are reduced**
  - **corresponding PDF set is ATLAS-epJets13**

Of course we now have 7 TeV higher statistics inclusive, di-jet and tri-jet data PDF fits being done – NNLO jet calculations (forthcoming) could be important

7. **Prompt photon data** has been reintroduced as a possible input to determine the high-x gluon ATLAS-PHYS-PUB 2013-018

- **HERAFitter quantitative tools** used to compared with the data (arXIV:1311.1440), using a χ2 comparison which can account for PDF uncertainty as well as experimental uncertainties

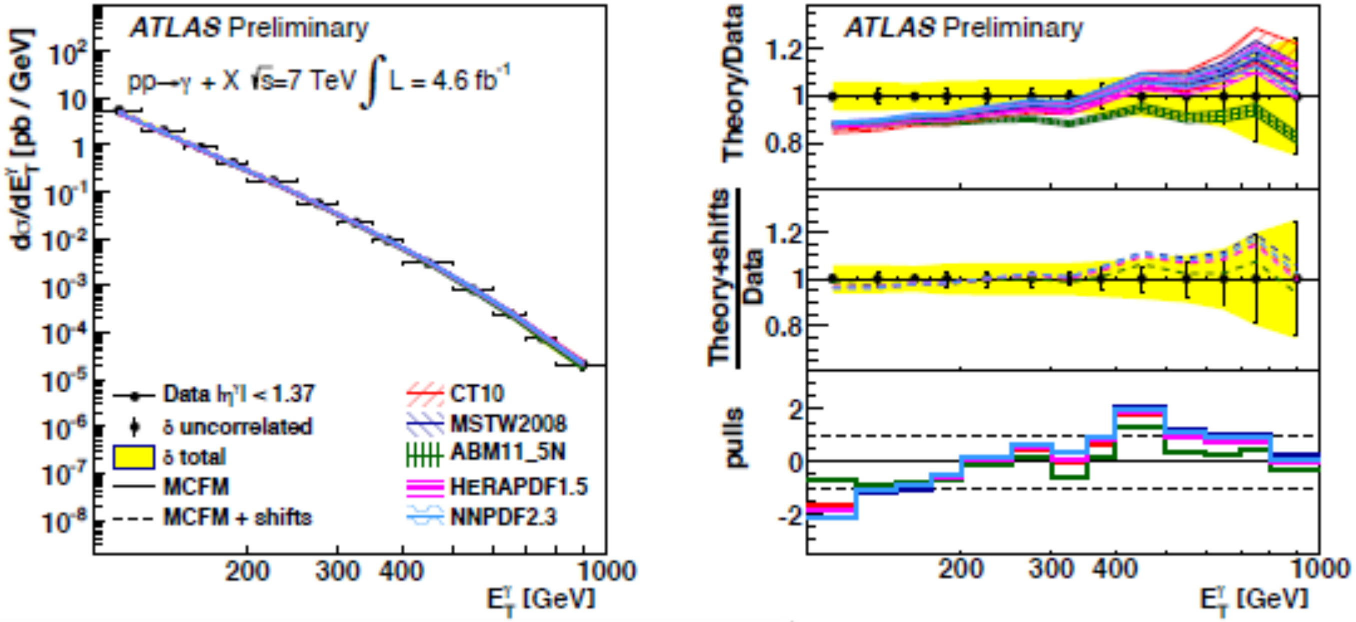
- scale uncertainty significant (2ET, ET/2) – may need NNLO for full exploitation

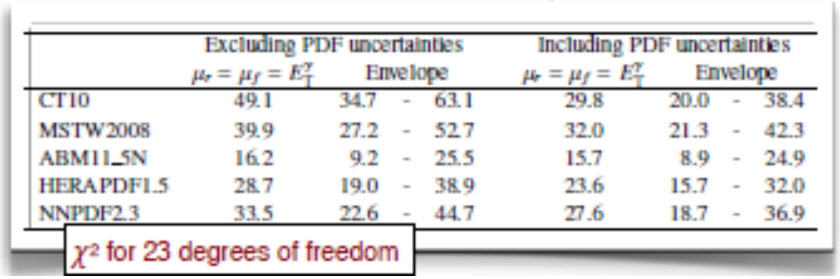


MCFM shown here →

JETPHOX? photon fragmentation to NLO, but no fast grid implementation yet (can use it for photon fragmentation k-factors)

Central photon production





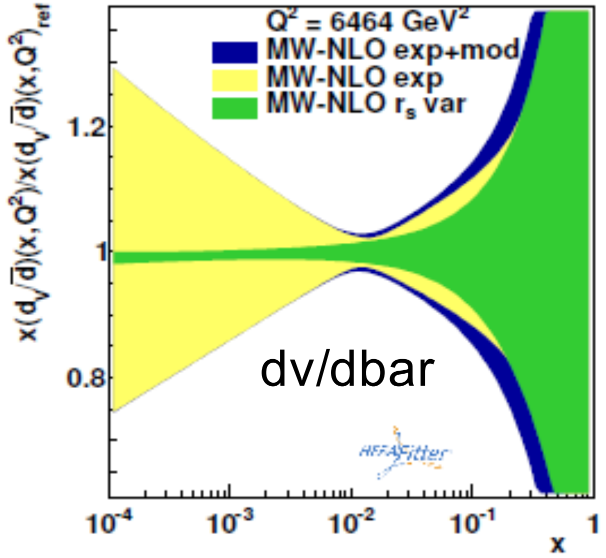
	Excluding PDF uncertainties		Including PDF uncertainties	
	$\mu_r = \mu_f = E_T^\gamma$	Envelope	$\mu_r = \mu_f = E_T^\gamma$	Envelope
CT10	49.1	34.7 - 63.1	29.8	20.0 - 38.4
MSTW2008	39.9	27.2 - 52.7	32.0	21.3 - 42.3
ABM11_5N	16.2	9.2 - 25.5	15.7	8.9 - 24.9
HERAPDF1.5	28.7	19.0 - 38.9	23.6	15.7 - 32.0
NNPDF2.3	33.5	22.6 - 44.7	27.6	18.7 - 36.9

χ^2 for 23 degrees of freedom

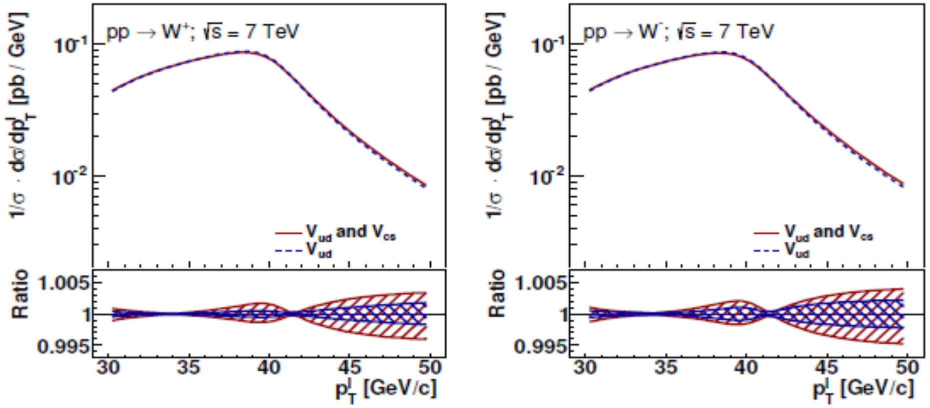
- Large variation of the predictions from MCFM with each PDF
  - Again, ABM11 softer at high E_T

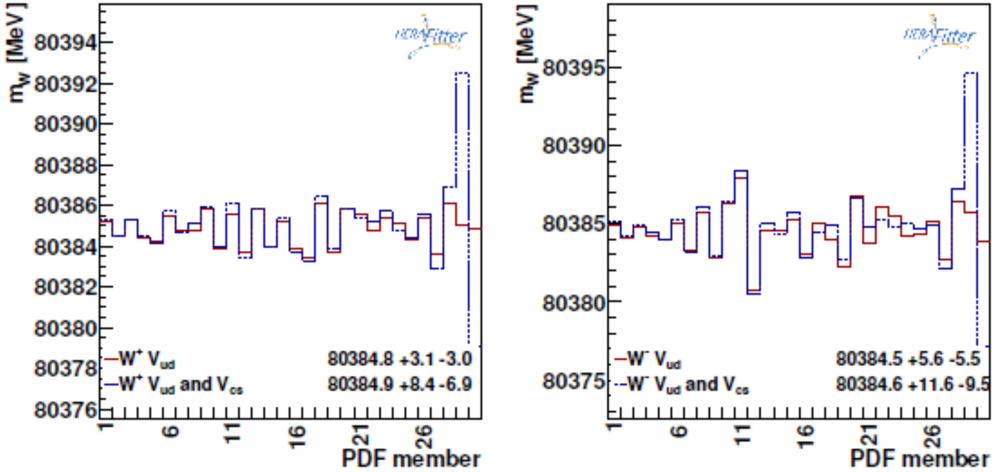
8. studies on theoretical uncertainties on W mass ATL-PHYS-PUB-2014-015

- W mass extraction using Pt-lepton spectrum from W+ and W- decay
- specialised PDFset (MW-NLO) was obtained using a **HERAFitter PDF fit** to HERA data; 13 free params, plus 4 model variations allowing varying of charm and strangeness fraction (up and down)



sources of PDF uncertainties were quantified





- large sensitivity PDFs from effect on average W polarisation, and impact on fraction of charm initiated processes – much of this comes from the uncertainty on the strangeness fraction

e.g. PDF uncertainties for Vud+Vcs setup (without spin correlations, to disentangle effects from polarisation) are ~10 MeV

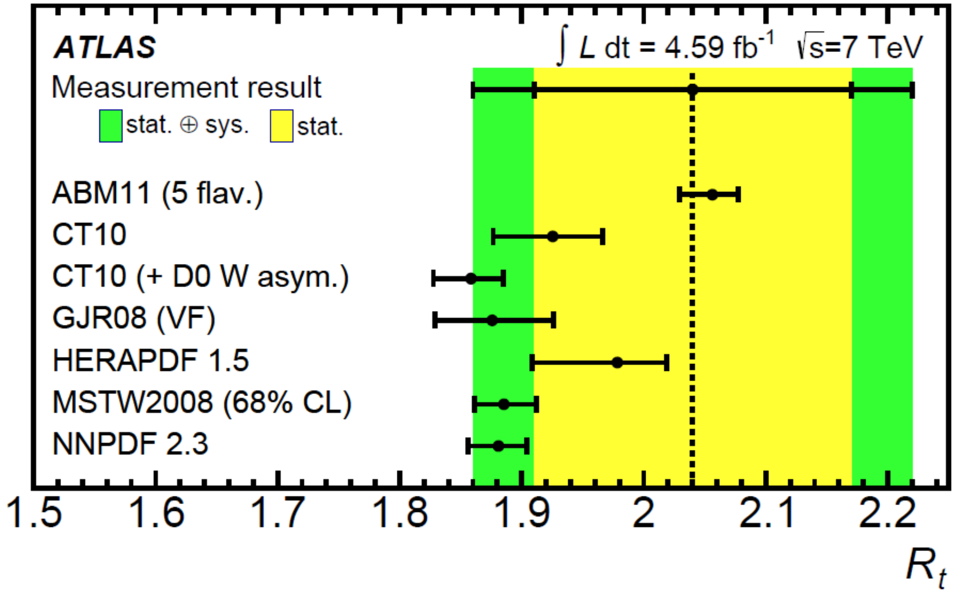
Prospects to improve!

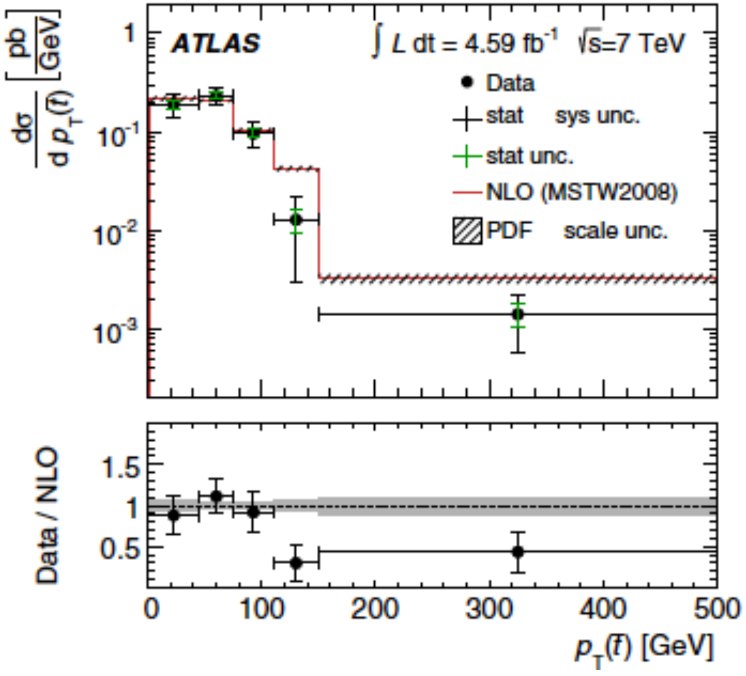
9. Single-top production

PRD90(2014)112006

top-quark and antitop-quark cross sections, and the ratio of top-quark/antitop-quark production (Rt)

HERAFitter tools were used for the χ2 comparison of the data to MSTW2008, including PDF uncertainties





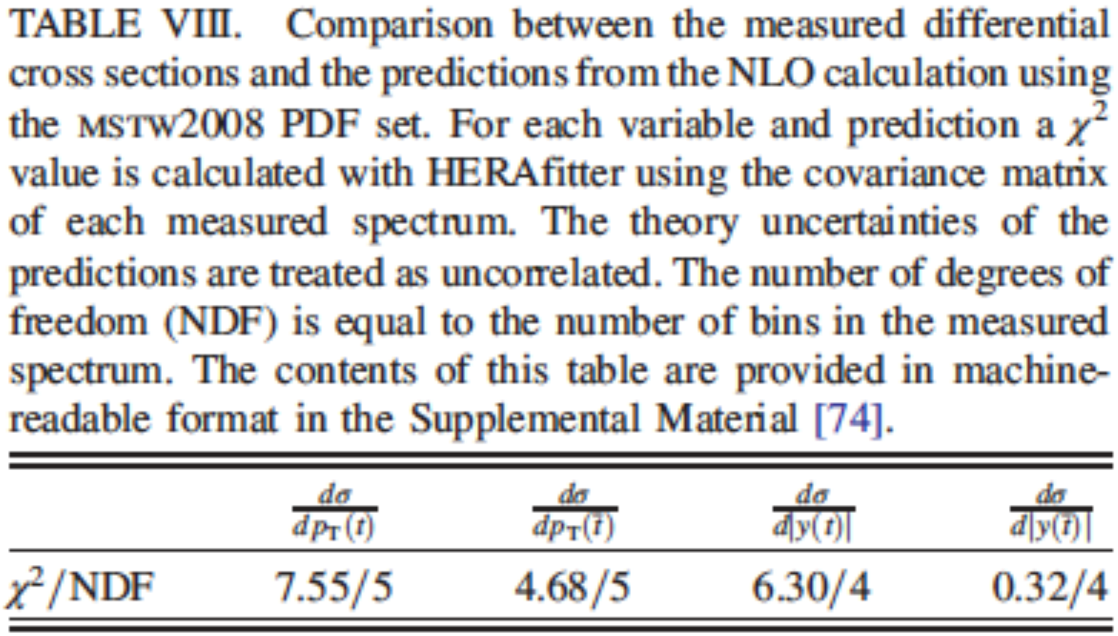


TABLE VIII. Comparison between the measured differential cross sections and the predictions from the NLO calculation using the MSTW2008 PDF set. For each variable and prediction a χ^2 value is calculated with HERAfitter using the covariance matrix of each measured spectrum. The theory uncertainties of the predictions are treated as uncorrelated. The number of degrees of freedom (NDF) is equal to the number of bins in the measured spectrum. The contents of this table are provided in machine-readable format in the Supplemental Material [74].

	$\frac{d\sigma}{dp_T(t)}$	$\frac{d\sigma}{dp_T(\bar{t})}$	$\frac{d\sigma}{d\lvert y(t)\rvert}$	$\frac{d\sigma}{d\lvert y(\bar{t})\rvert}$
χ^2/NDF	7.55/5	4.68/5	6.30/4	0.32/4

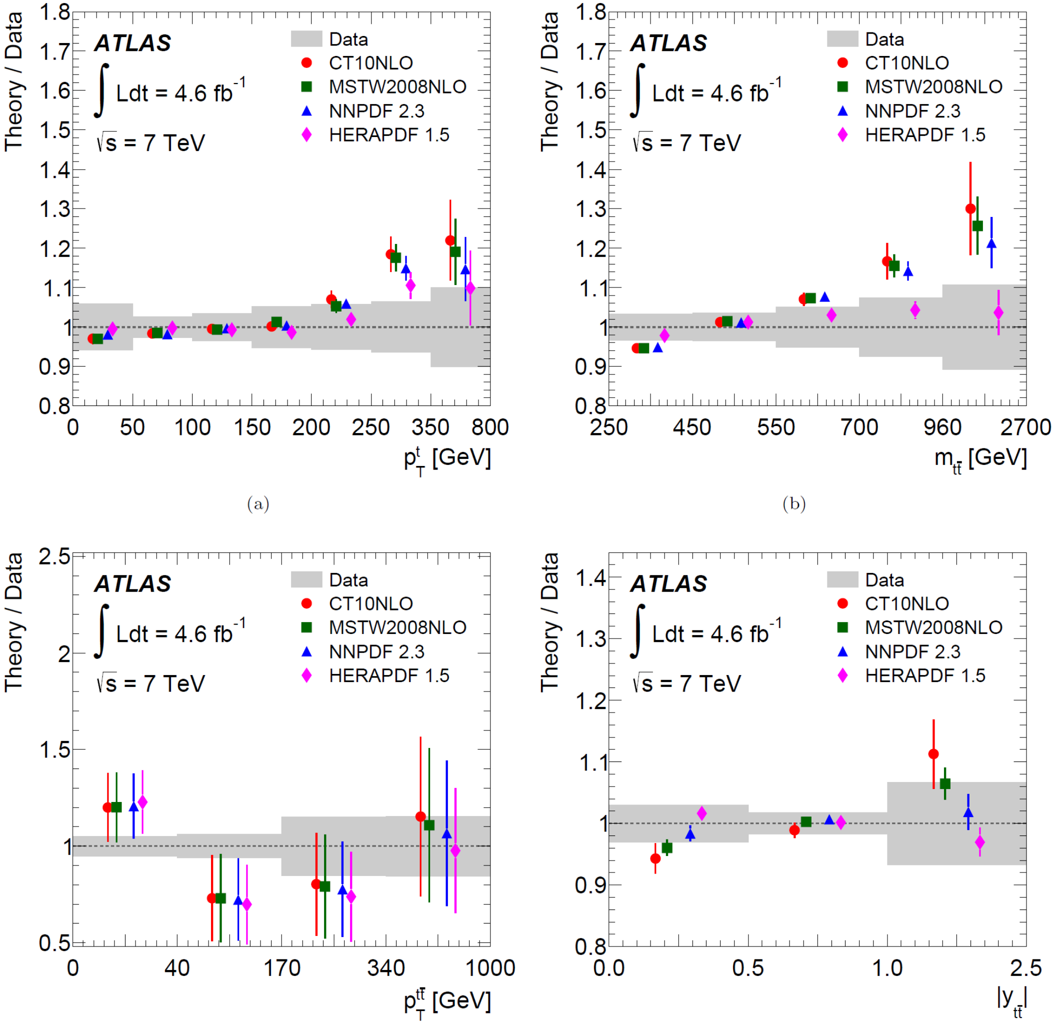
10. Top-antitop pair production 7 TeV

Phys Rev.D90(2014)072004

- Normalised ttbar differential distributions are compared to predictions using MCFM
- Clearly provide some PDF discrimination –but higher order QCD and EW corrections could be significant

NOTE: NLO QCD ttbar predictions, used with NLO PDFs

These nice comparisons do not actually use HERAFitter, BUT…



(a)

(b)

Variable	CT10		MSTW2008NLO		NNPDF 2.3		HERAPDF 1.5	
	χ^2/NDF	*p*-value	χ^2/NDF	*p*-value	χ^2/NDF	*p*-value	χ^2/NDF	*p*-value
p_T^t	9.5/6	0.15	9.8/6	0.14	8.2/6	0.22	5.5/6	0.49
$m_{t\bar{t}}$	5.5/4	0.24	6.0/4	0.20	5.2/4	0.27	0.63/4	0.96
$p_T^{t\bar{t}}$	14./3	0.00	13./3	0.01	12./3	0.01	9.1/3	0.03
$\lvert y_{t\bar{t}}\rvert$	3.7/2	0.16	4.0/2	0.13	1.3/2	0.52	0.44/2	0.80

8TeV also available arXiv:1511.04716

Since these data are public I think I can say that we HAVE made **HERAFitter PDF fits** using them

mass t-tbar, rapidity t-tbar and Pt-top, differential spectra with full statistical and systematic correlations have been fitted together

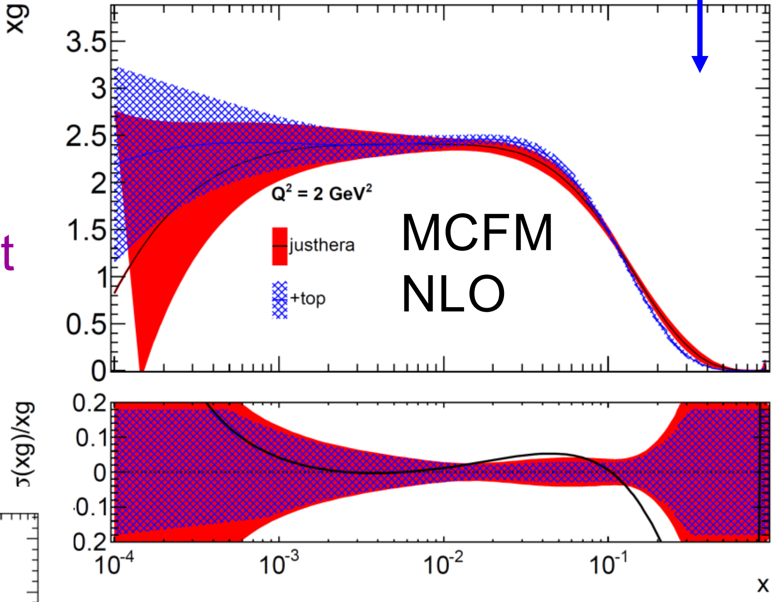
moderate impact BUT slightly softer high-x gluon **– some tension with jet data** – and modest decrease in absolute uncertainty

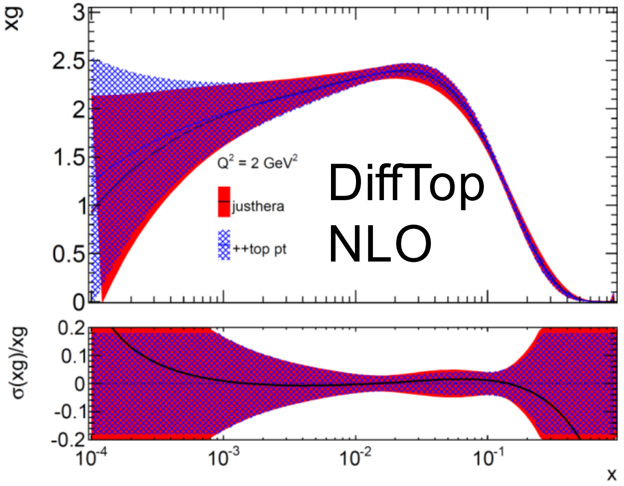
Need the NNLO calculations for both jets and top

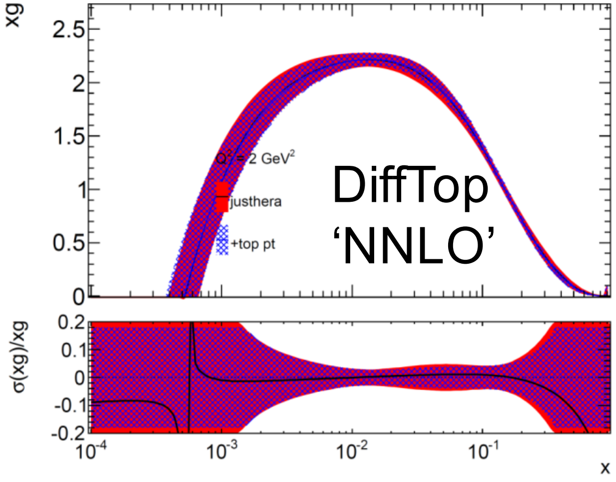
There is **DiffTop** (partial NNLO) but only for Pt-top(?)

DiffTop was tried both at NLO and NNLO

Main effect is that it gets the total cross-section right at NNLO. We always used to use normalised cross-sections at NLO to get around this – since the NLO cross-section was only ~140pb



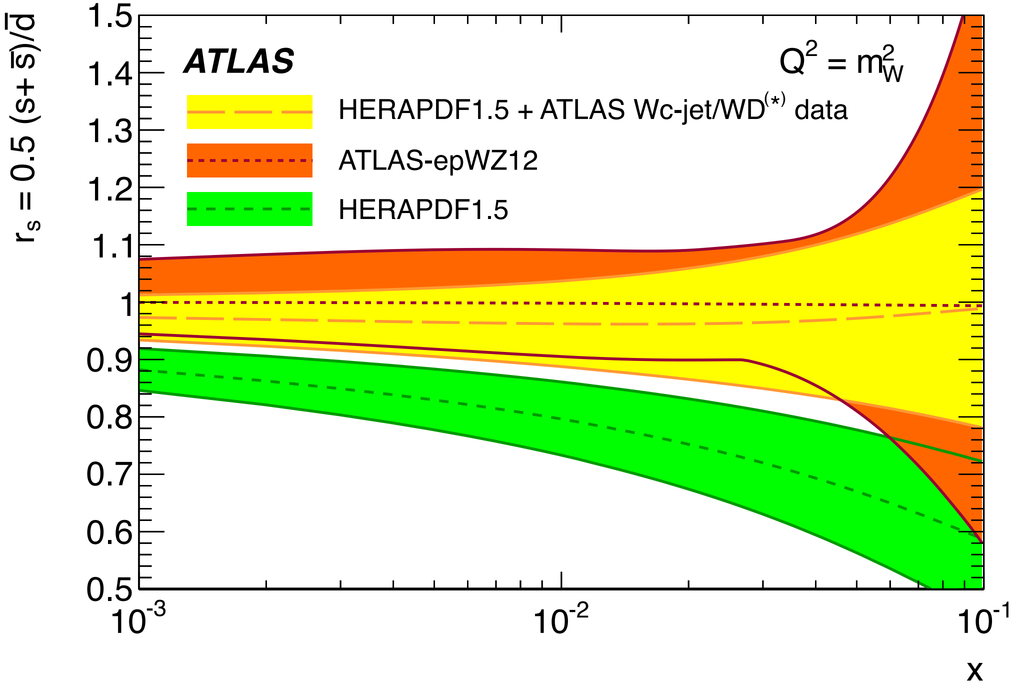




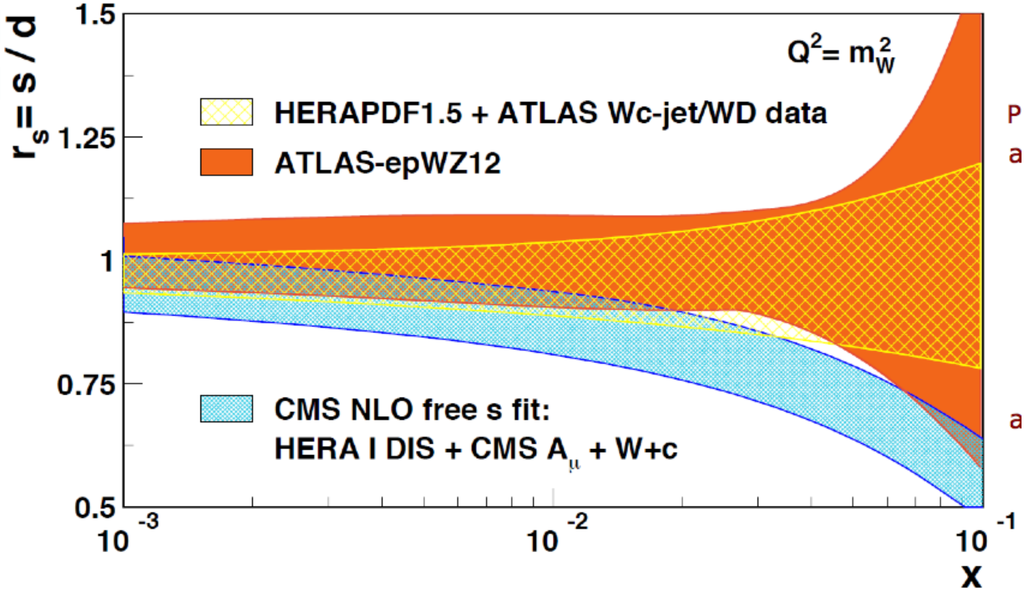
NNLO calculation does much better: ~177pb

Measured value:~173±10 pb

Full NNLO calculation also complete (Mitov et al), but not in publically useable form



ATLAS
$Q^2 = m_W^2$
HERAPDF1.5 + ATLAS Wc-jet/WD$^{(*)}$ data
ATLAS-epWZ12
HERAPDF1.5
$r_s = 0.5\,(s+\bar{s})/\bar{d}$
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
10^{-3}
10^{-2}
10^{-1}
x



$Q^2 = m_W^2$
HERAPDF1.5 + ATLAS Wc-jet/WD data
ATLAS-epWZ12
CMS NLO free s fit:
HERA I DIS + CMS A_μ + W+c
$r_s = \bar{s}/\bar{d}$
1.5
1.25
1
0.75
0.5
10^{-3}
10^{-2}
10^{-1}
x
P
a
a