Impact of ATLAS Data on Parton Density Functions

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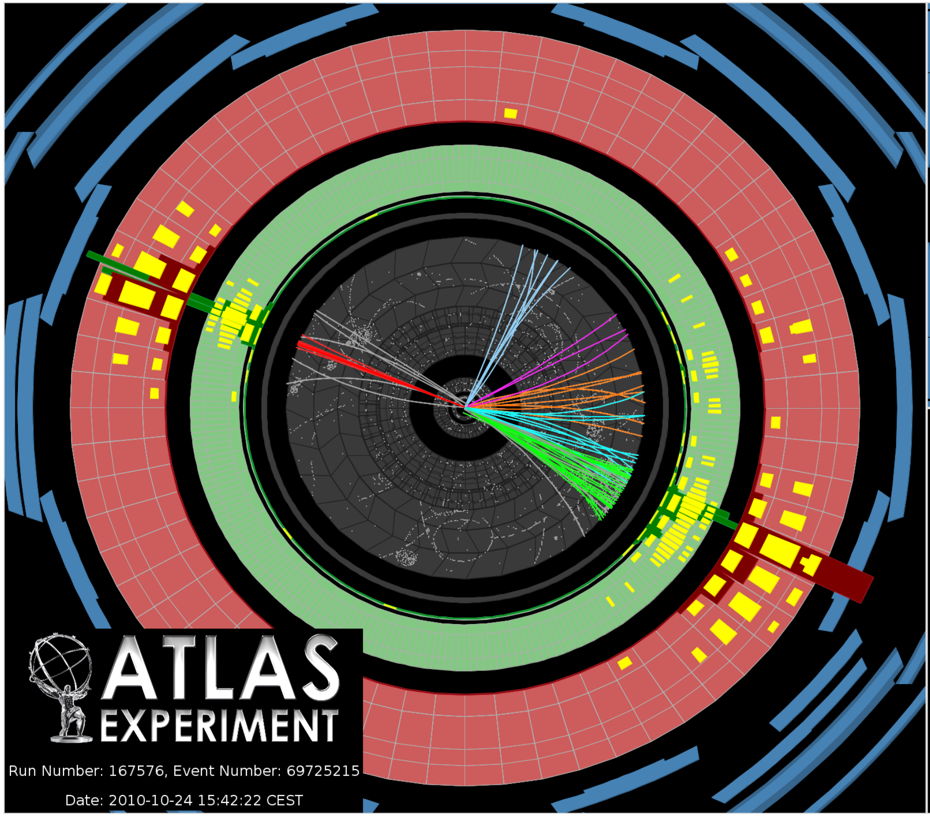
DIS '14, Warsaw
30 April 2014



- Electroweak gauge bosons

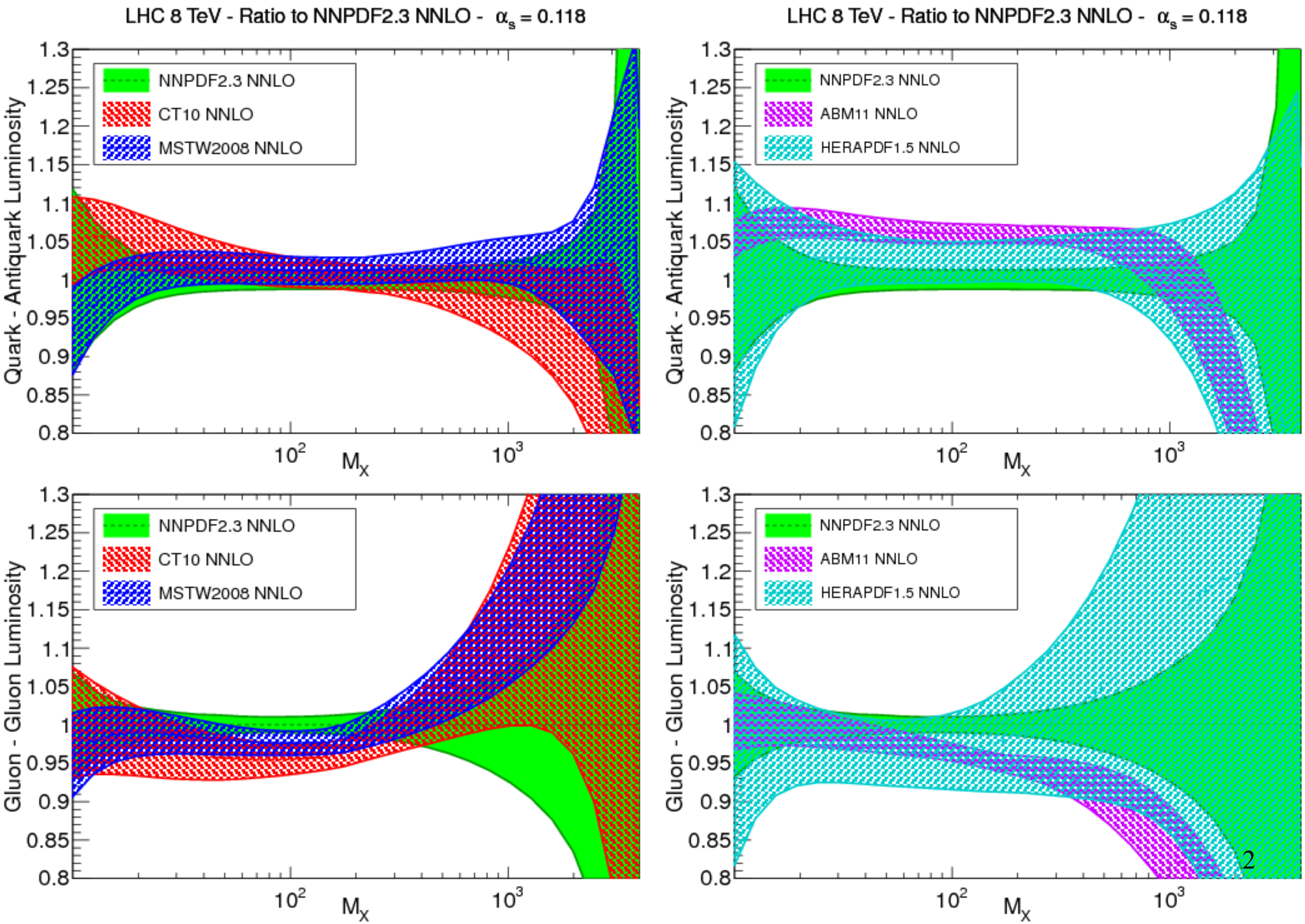
- High pT jet production

- Drell Yan
- Top Quarks
- Direct Photons

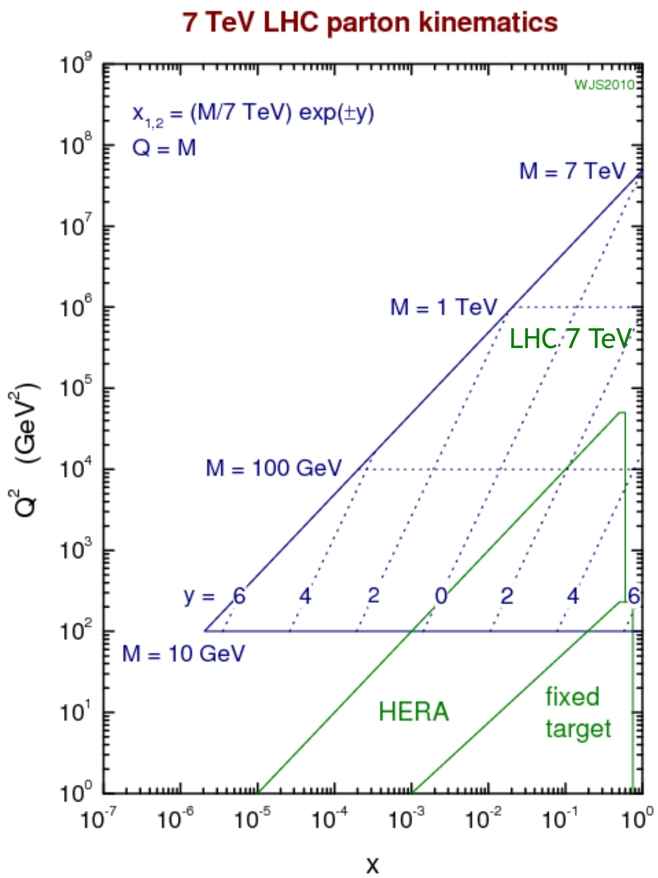
- Prospects

Current PDF Sets

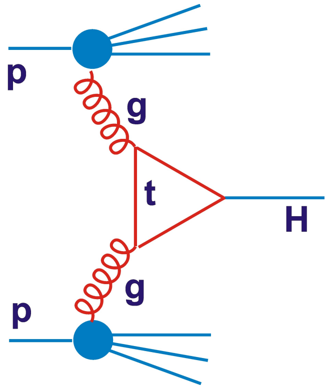
[R. Ball et al., JHEP 1304 (2013) 125]

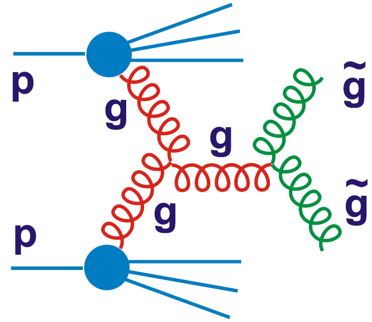


Potential Impact of LHC Data



- LHC search and Higgs programmes require a precise knowledge of PDFs.



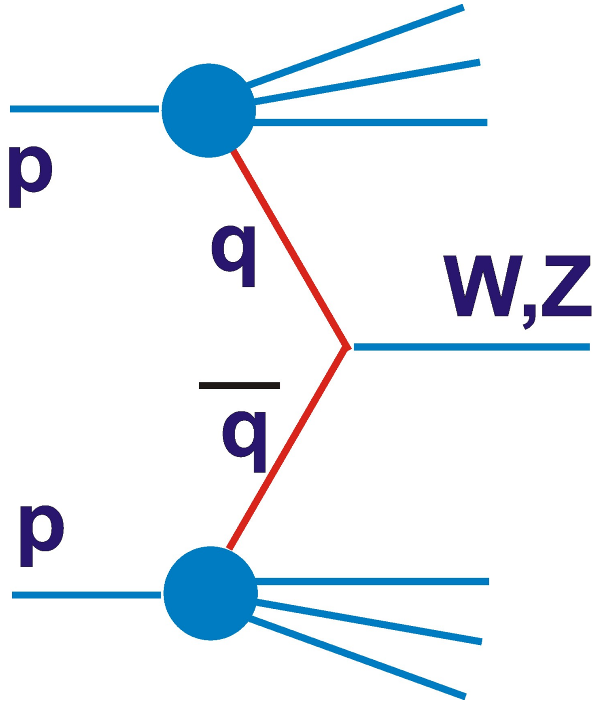


- LHC Standard Model processes can discriminate between PDF sets and add new constraints.

Theoretical Uncertainties:
- Hadronisation and Underlying Event
- Missing higher orders (QCD & EW)
- Large logs needing resummations

Experimental Issues:
- Systematics (energy scale …)
- Correlations between measurements

Electroweak Gauge Bosons



- Valence PDFs
- Sea
- Notably, strange sea

Rates high in LHC terms

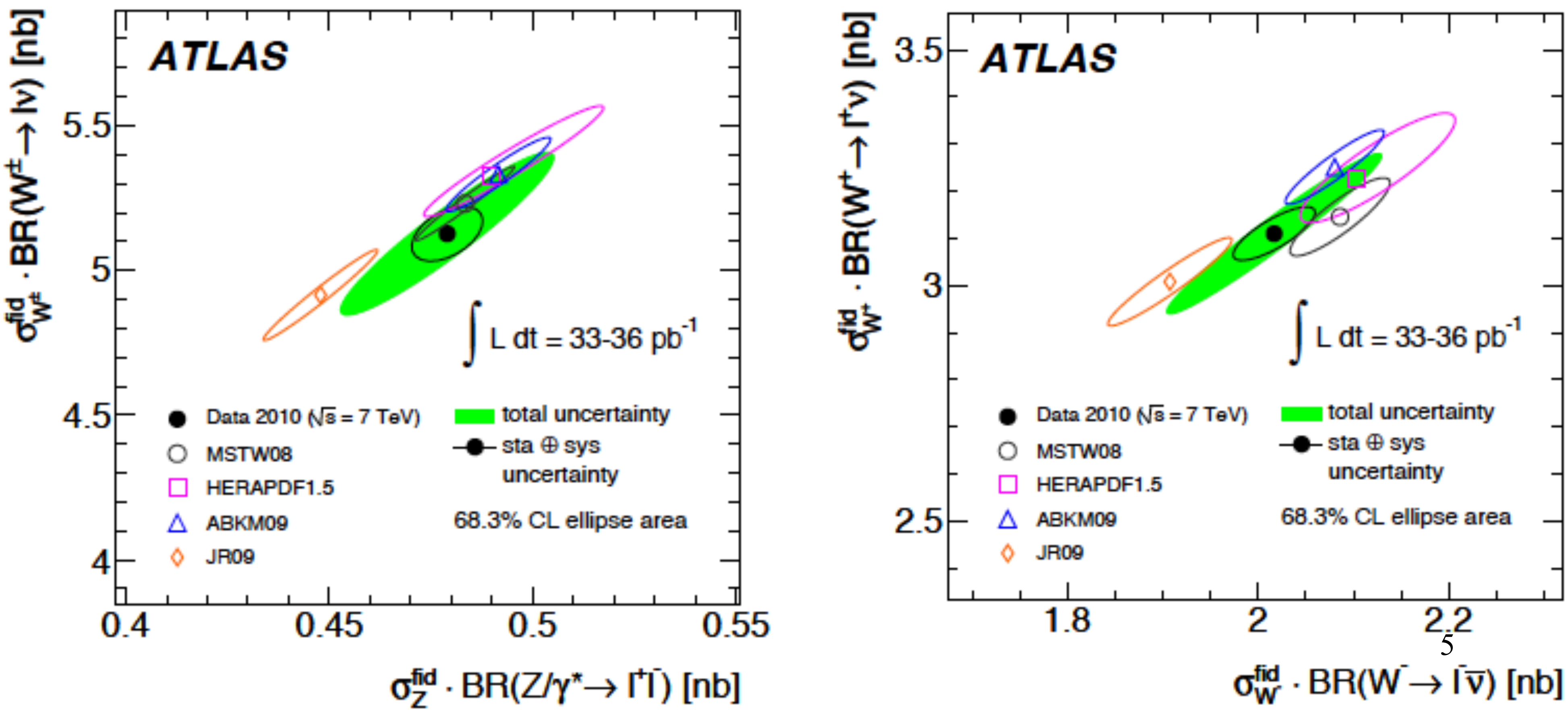
Known to NNLO (QCD)
and NLO (EW)

(See also talks by G Aad, H Martinez)

Inclusive Cross Sections

[Phys Rev D85 (2012) 072004]

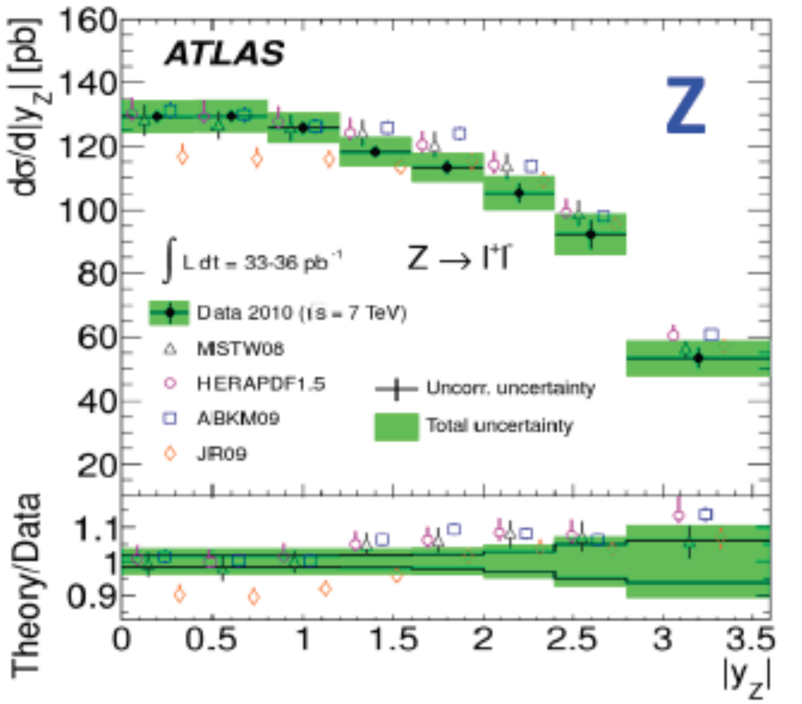
- Early data (e and μ combined) showed discriminatory power
- W / Z plane sensitive to sea flavour asymmetries
- W^+ / W^- plane sensitive to u / d, $u_v - d_v$
- All depend on couplings

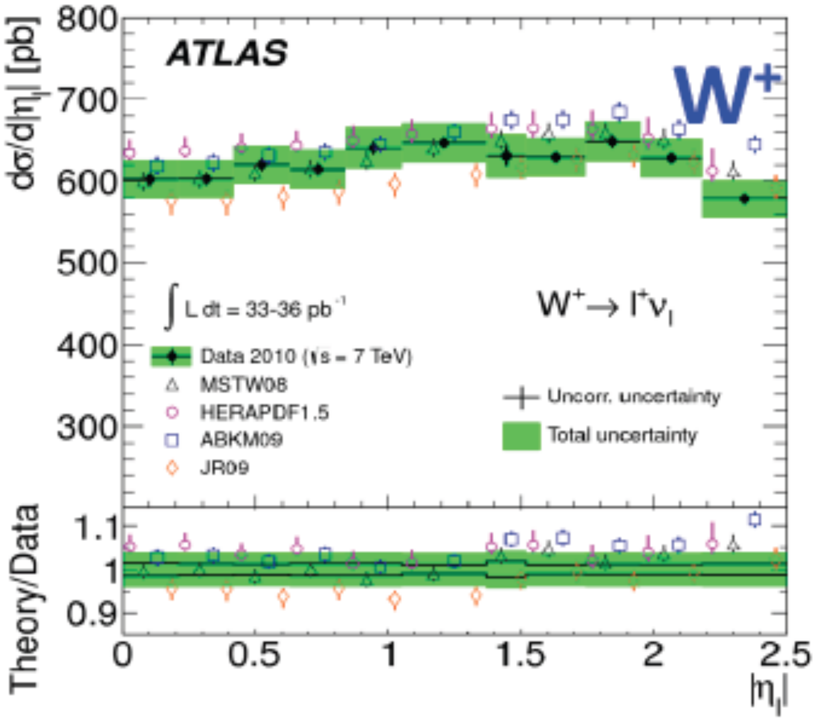


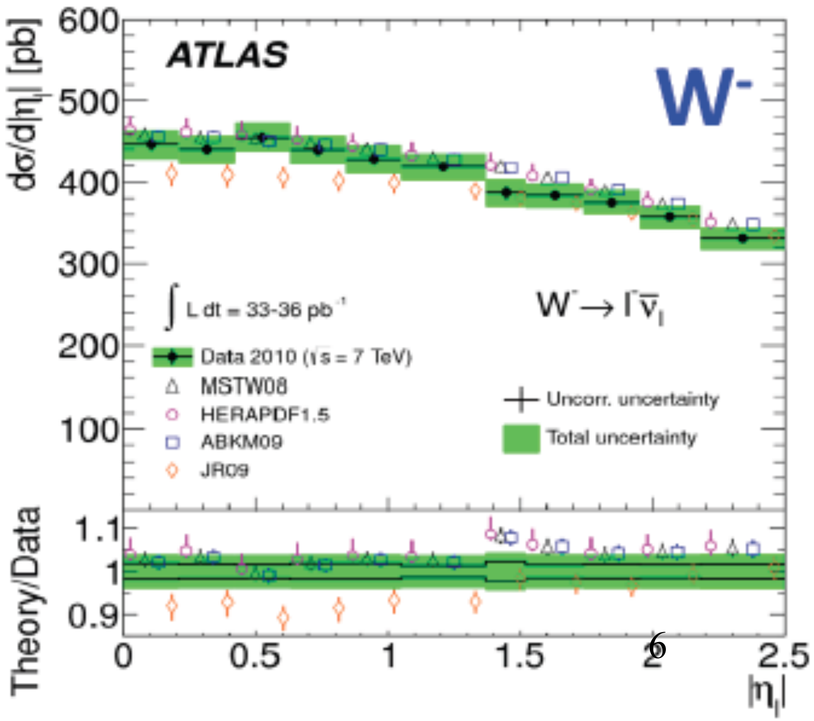
Differential Cross Sections

- Differential distributions give increased discriminatory power (e.g. JR09 and ABKM09 disfavoured)

- Shapes give added sensitivity to flavour decomposition …

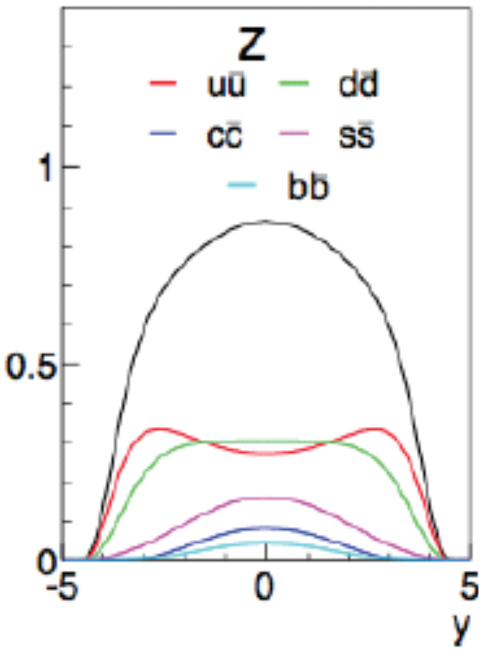






Strange Density

[PRL 109 (2012) 012001]

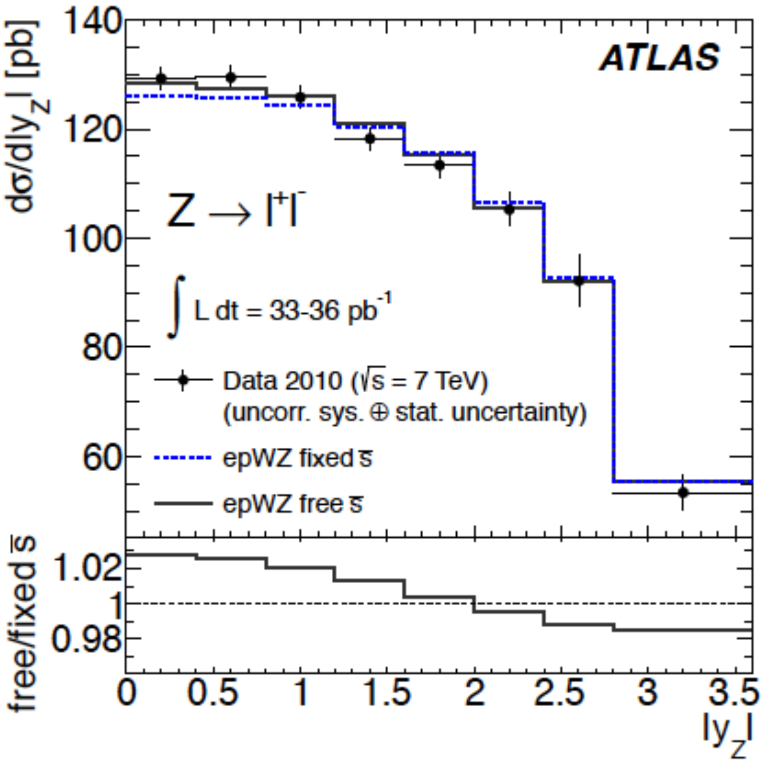


Z differential rapidity distribution
at central rapidity sensitive to s+sbar

→ Fit data for ratio r_s of s/d at x~0.01

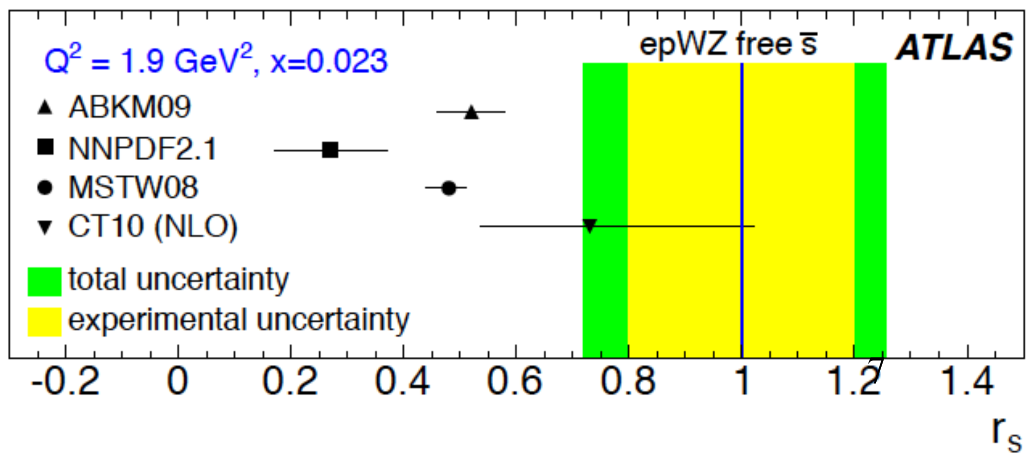
$$r_s = 1.00 \pm 0.20\,(\text{exp.}) \pm 0.07\,(\text{model})$$

$$^{+0.10}_{-0.15}\,(\text{param})\ ^{+0.06}_{-0.07}\,(\alpha_S)\ \pm 0.08\,(\text{theory})$$



→ ATLAS-epWZ12

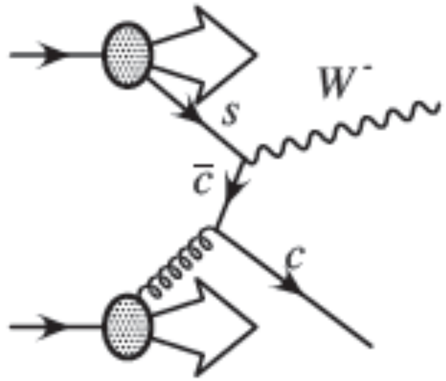
… significantly larger strange density than in most PDF sets.



Strange Density: More Directly

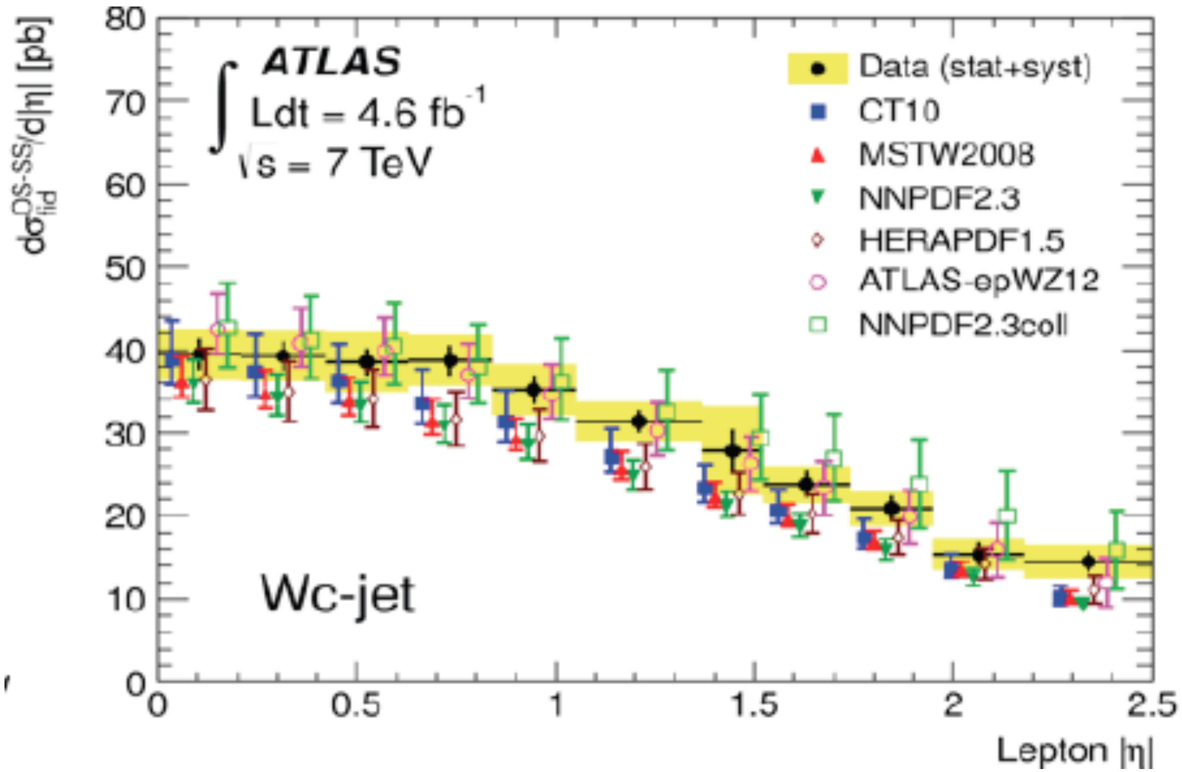
[arXiv:1402.6263]

Final states with W + charm are directly sensitive to the strange density.



Measurements using fully reconstructed D(*) or leptons associated with jets.

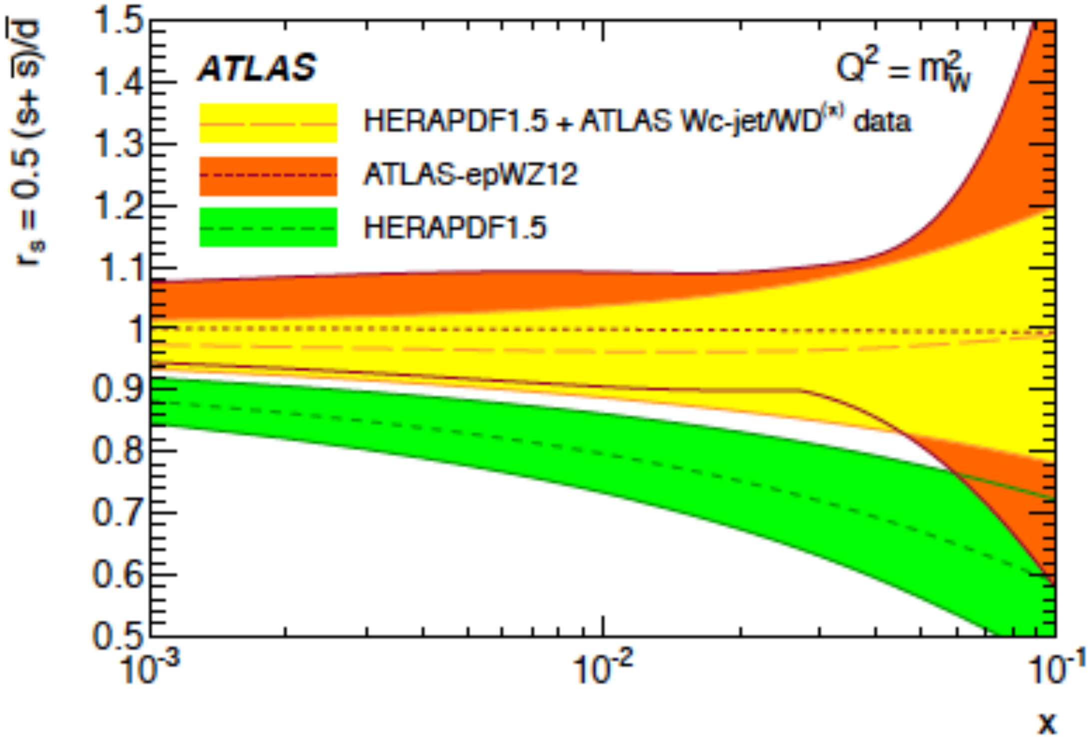
Cross section comparisons at NLO using aMC@NLO …



eg Semi-leptonic decays

Data prefer PDF sets with s/d ~ 1:
→ ATLAS-epWZ12
→ NNPDF2.3coll.

Strange Density: More Directly



Fit to W+c data derived from HERAPDF1.5, allowing both shape and normalisation of strange to vary independently of u, d

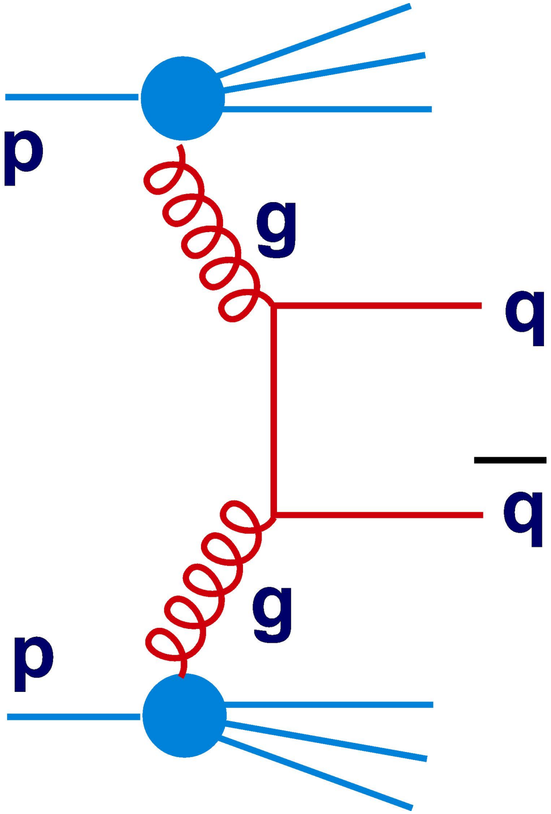
→ confirmation of low x flavour democracy

$$r_s = 0.96 \,^{+0.16}_{-0.18}\,(\text{Exp.} + \text{Thy.}) \,^{+0.21}_{-0.24}\,(\text{Scale})$$

Also, from W+ / W- comparison, s:sbar asymmetry small:

$$A_{s\bar{s}} = \frac{s - \bar{s}}{s} = 2 \pm 3\%$$ averaged over measured phase space

Jet Production



- Gluon density

Rates very high

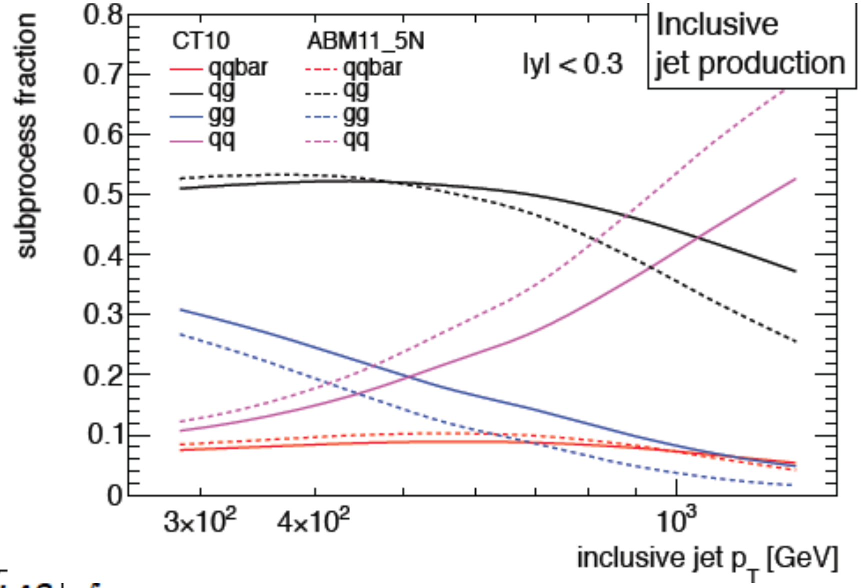
Limited experimentally by
Jet Energy Scale Uncertainty

Limited theoretically by not
yet available NNLO corrections

(See also talk by G Vardanyan)

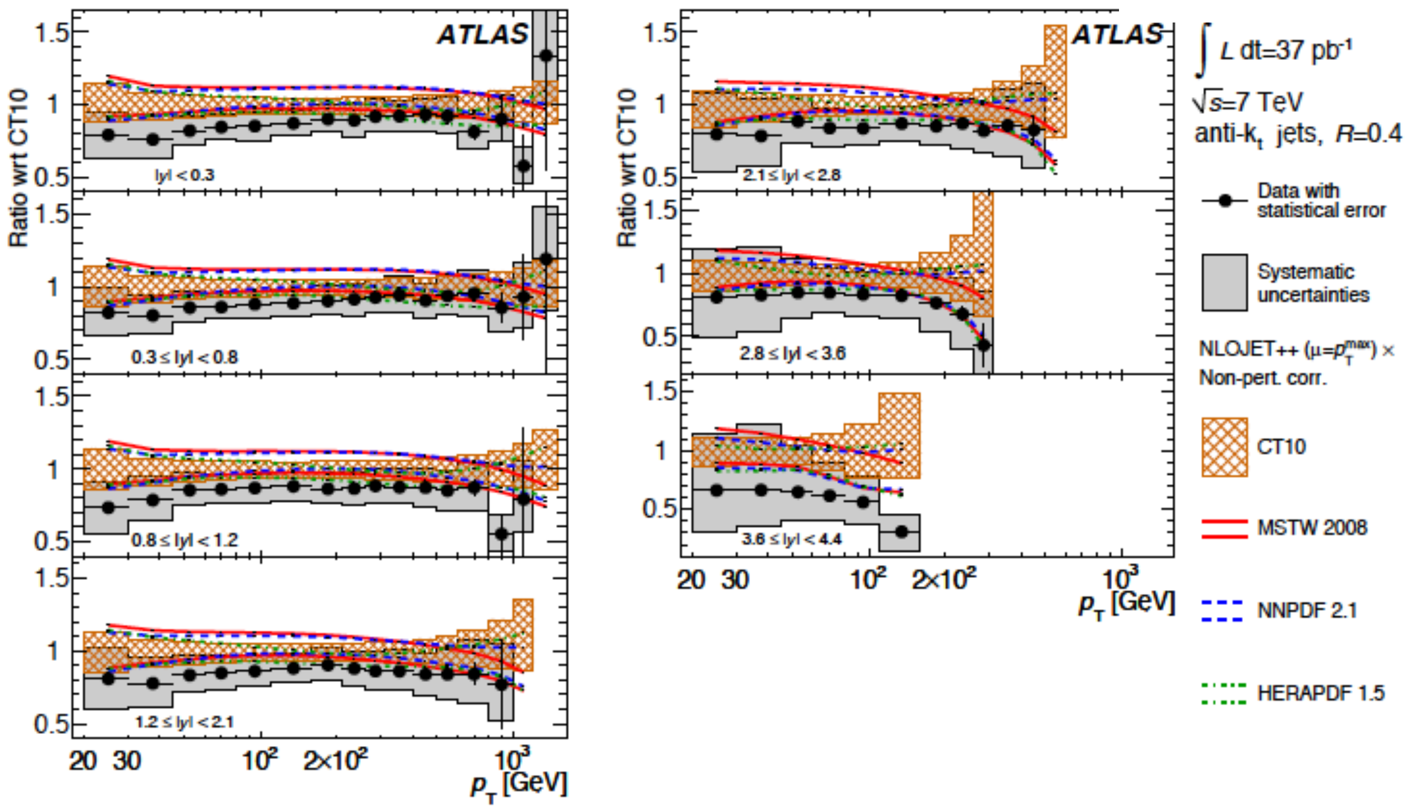
Inclusive Jets

[Phys Rev D86 (2012) 014022]



Inclusive jets with $p_t \rightarrow$ 2 TeV have sensitivity to gluon over wide x range (and also to quarks)

(2010 data, ~5% JES uncertainty)

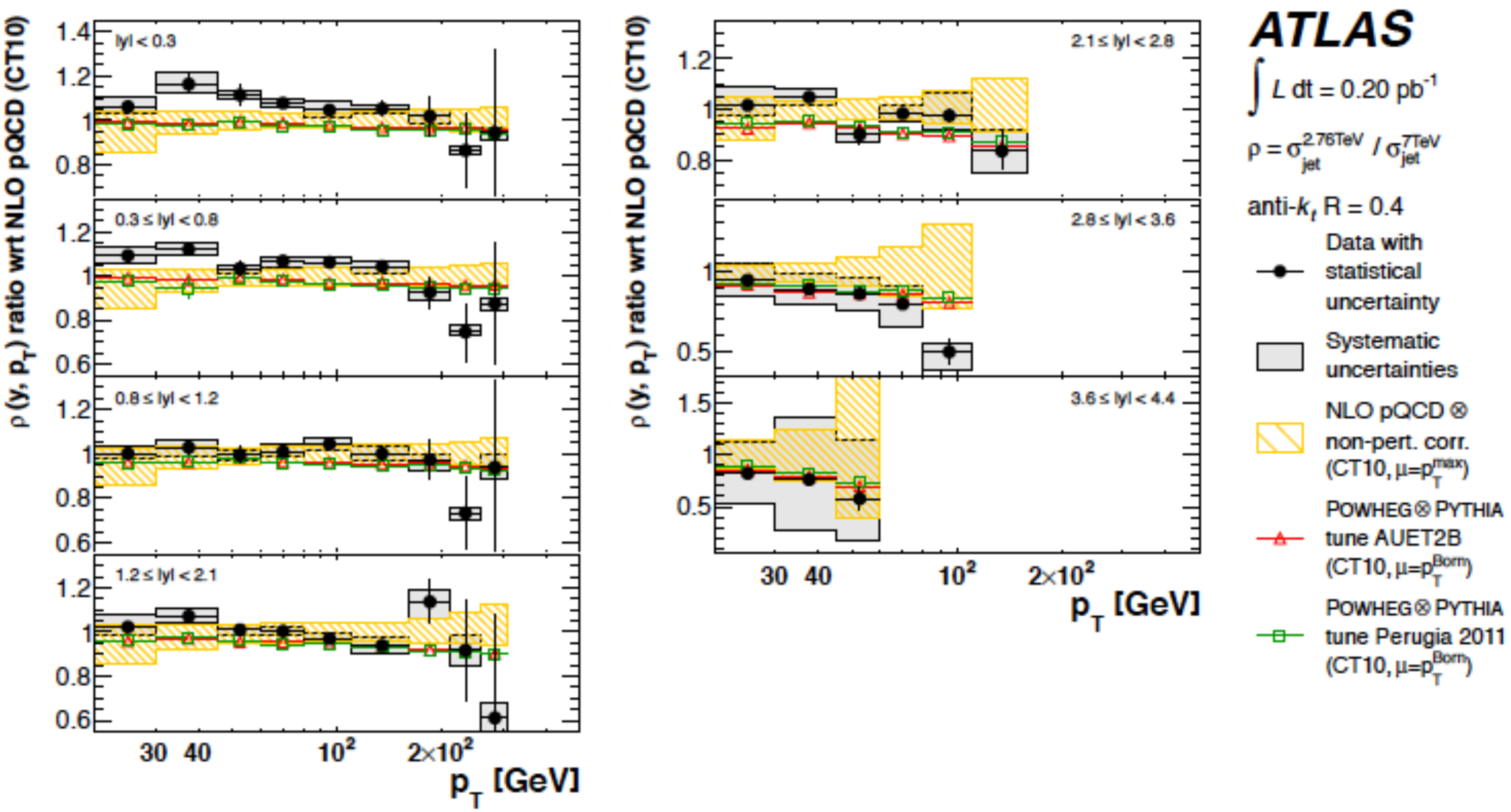


Already used in e.g. NNPDF2.3, but with limited impact

Beam Energy Ratios (√s = 2.76 / 7 TeV)

[EPJ C73 (2013) 2509]

Partial or complete cancellations of systematics improves precision of data and impacts correspondingly on PDFs

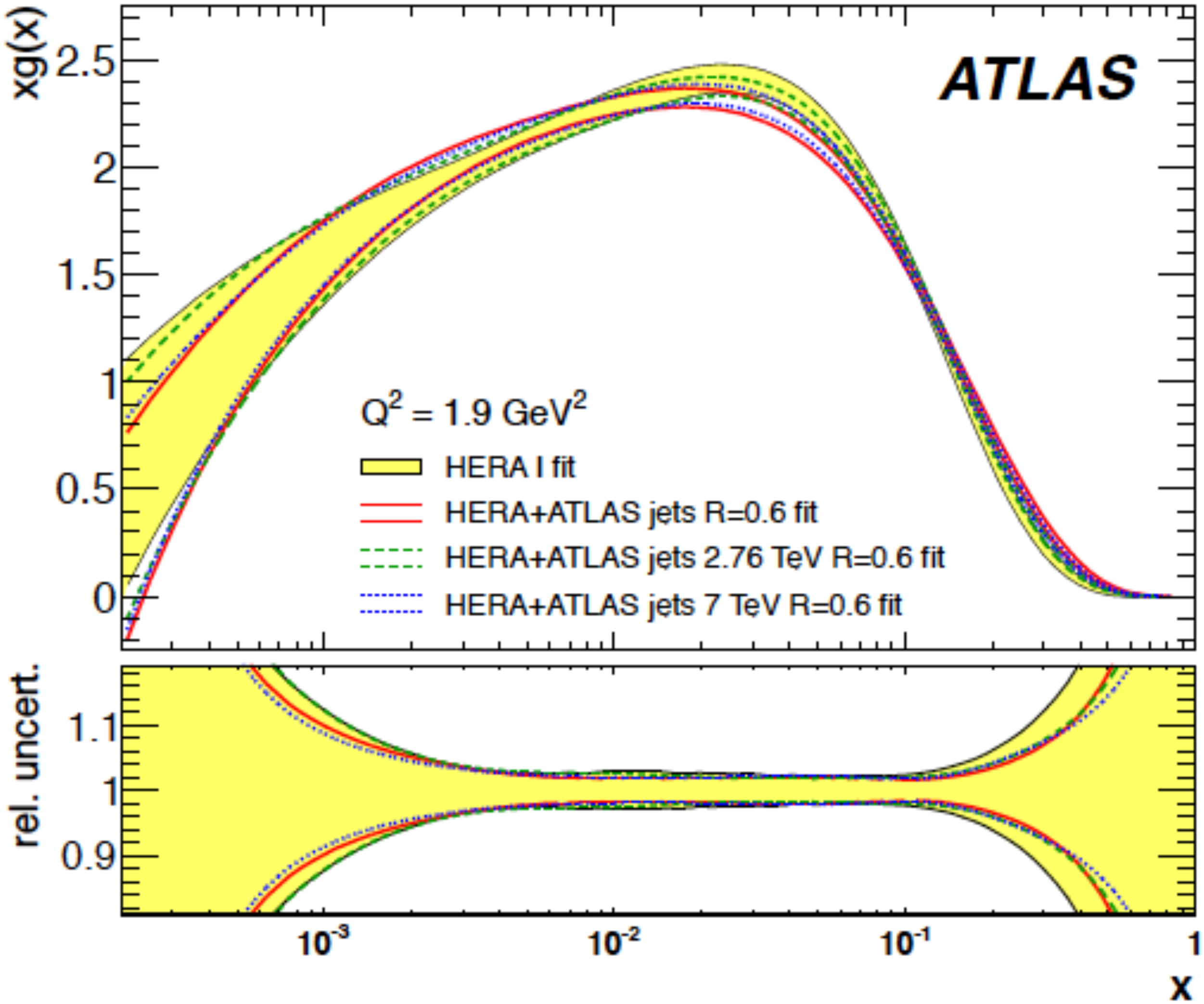


Double ratio (2.76 TeV / 7 TeV) (data / theory) constrained to better than 10% in best-measured region

Including Jet Data in PDF Fits

[EPJ C73 (2013) 2509]

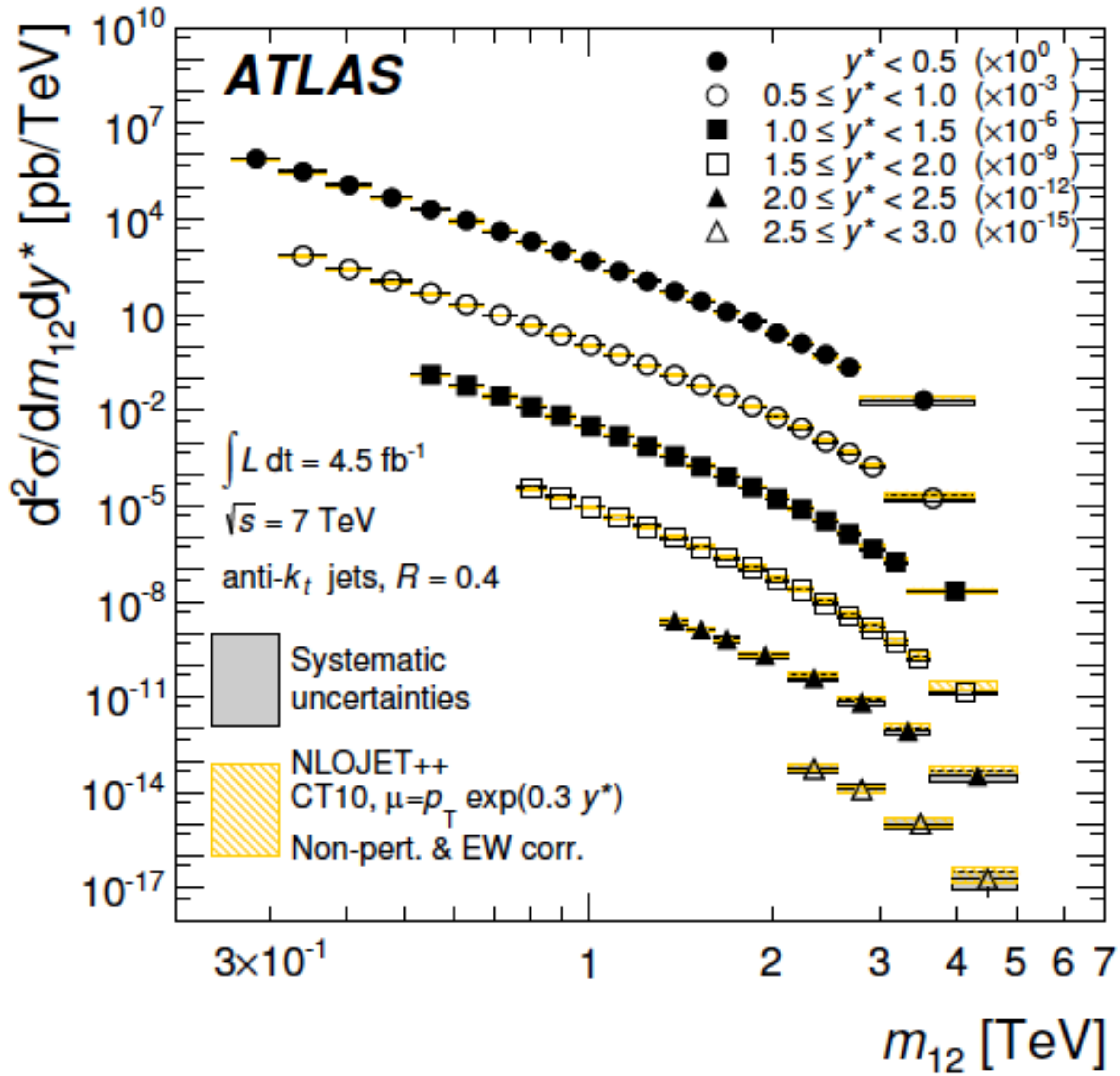
NLO fit in HERAFitter Framework, including 2.76 TeV and 7 TeV ATLAS jet data using APPLgrid



Influence of ATLAS jets relative to HERA-only is to make gluon slightly harder and to slightly reduce its uncertainty

New Dijet Data

[arXiv:1312.3524]

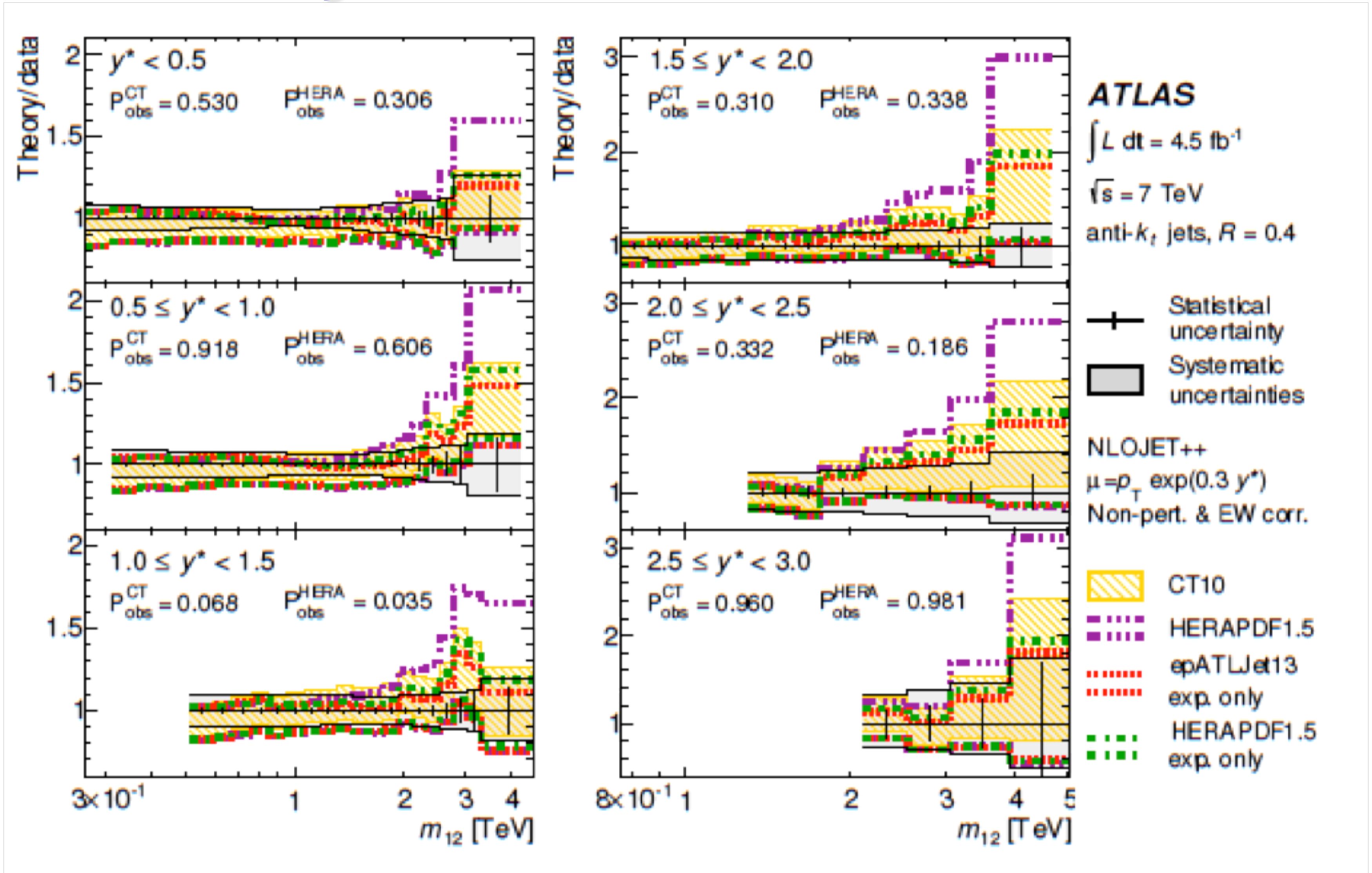


2011 data, JES uncertainty reduced to <~ 2%

QCD does impressive job of describing data extending to dijet invariant masses 5 TeV

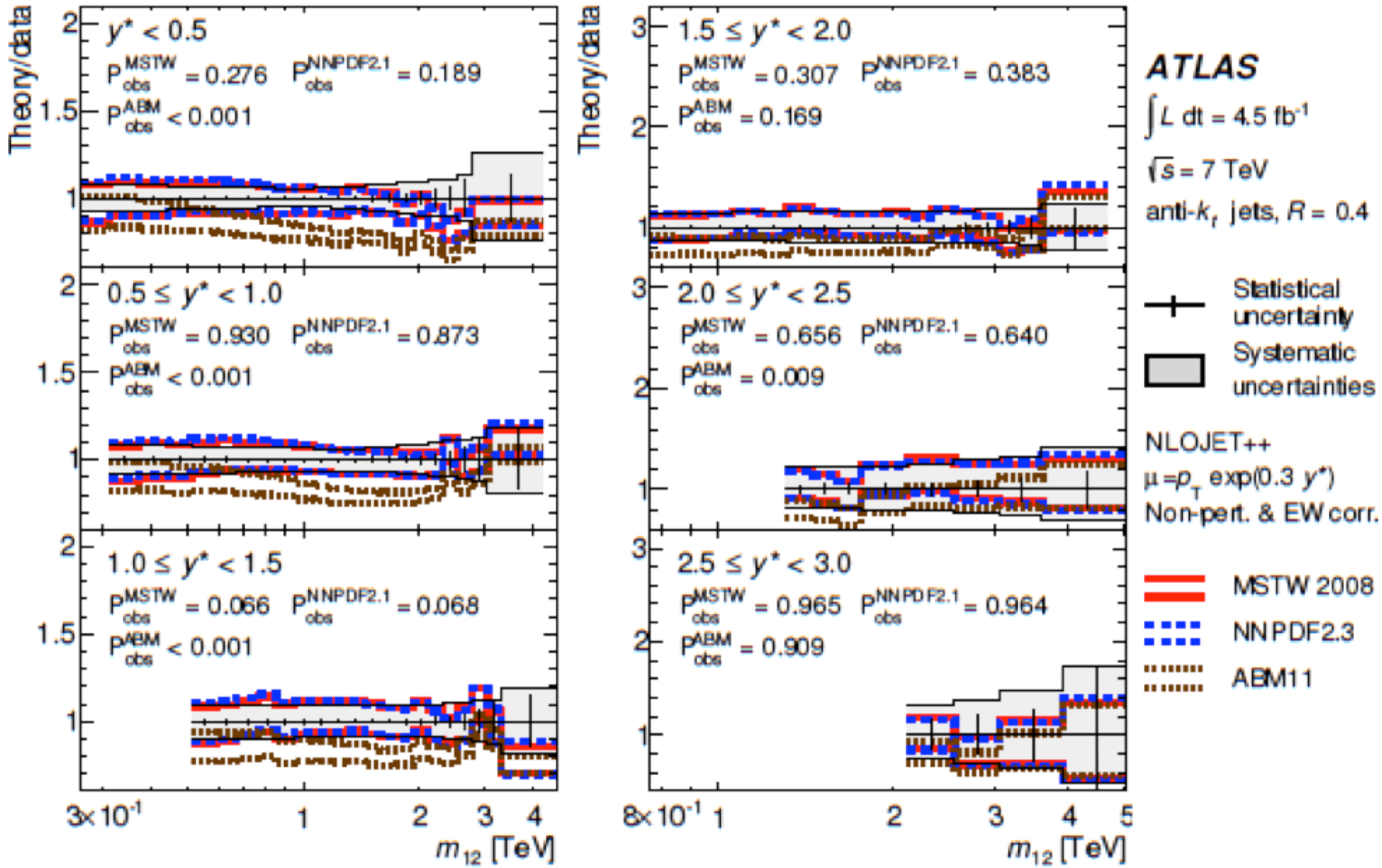
Comparisons with different PDF sets made via ratios …

Dijet Data versus PDFs



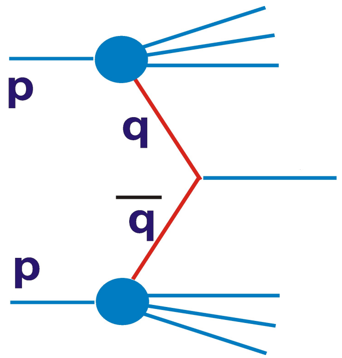
- CT10 agrees well with data
- HERAPDF1.5 OK except at largest masses (relatively soft gluon)

Dijet Data versus PDFs



- MSTW08 and NNPDF2.3 agree well with data
- ABM11 disfavoured

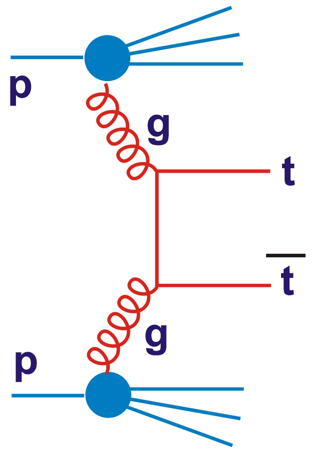
Other Promising Processes



<u>Drell-Yan away from Z pole</u>

- Sea Quarks at low and high x

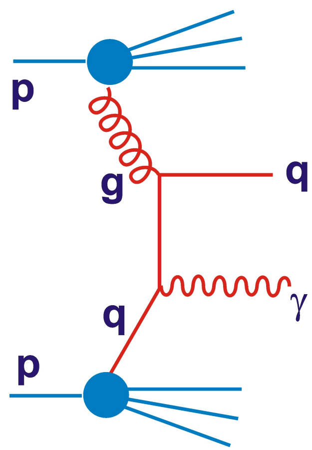
(see talk by E Yatsenko)



<u>Single Top Production and t-tbar</u>

- Gluon, u/d

(see talks by C Monini, P Skubic)

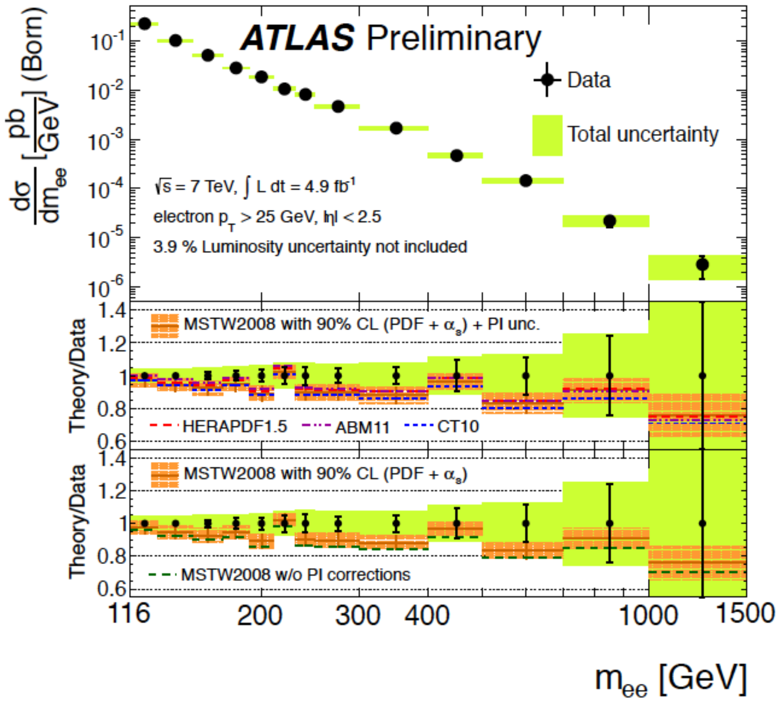


<u>Direct Photons</u>

-Gluon at high and low x

(see talk by J Cantero)

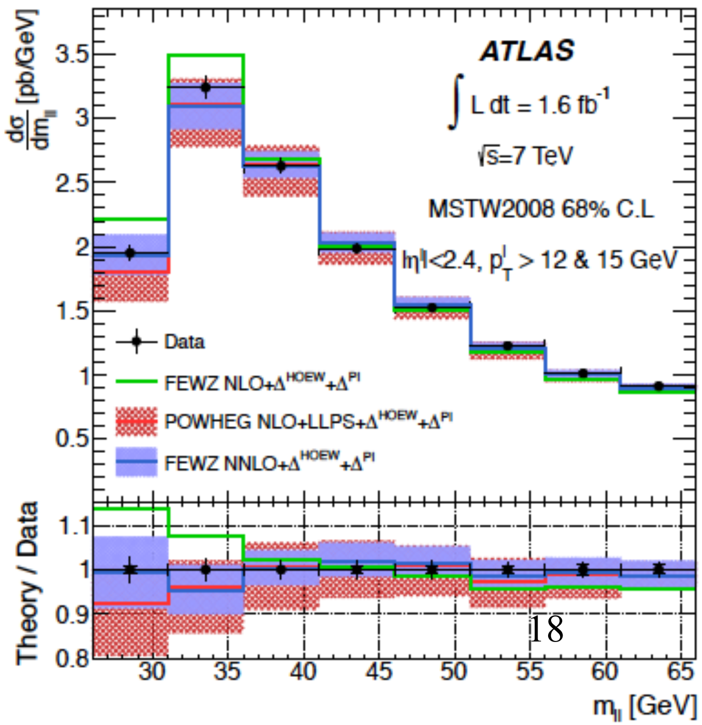
DY Beyond Z Pole [ATL-CONF-2012-159]



Potentially sensitive to large x sea etc

At current level of precision, no strong discrimination.

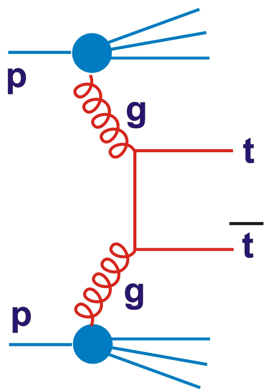
DY Below Z Pole [arXiv:1404.1212]



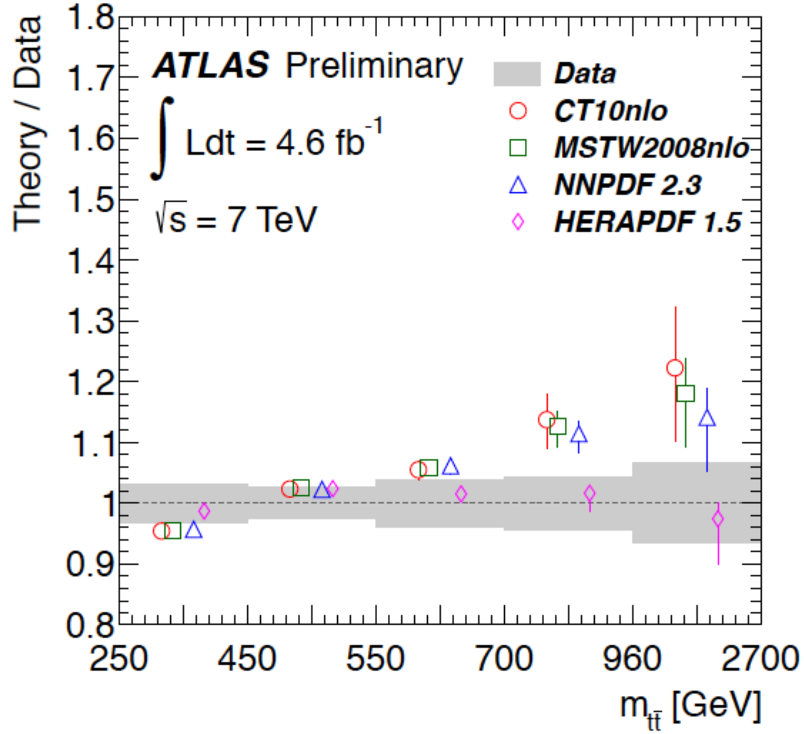
Most significant improvement in description from NLO → NNLO.

MSTW2008 OK.
Not yet used to distinguish between PDF sets or test DGLAP at low x

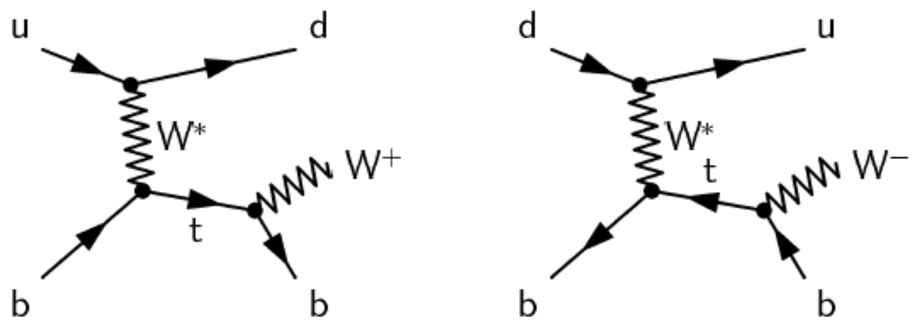
Top Pair Production [ATLAS-CONF-2012-134]

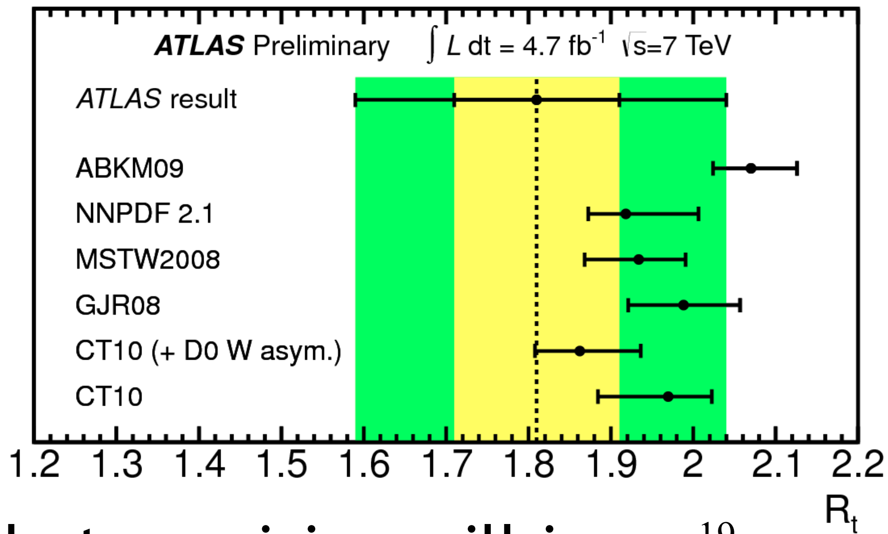


- Sensitive to high x gluon
- Some apparent sensitivity (HERAPDF favoured), but potentially large NNLO corrections and strong correlation with m_t and α_s



Single Top Production [ATLAS-CONF-2012-134]



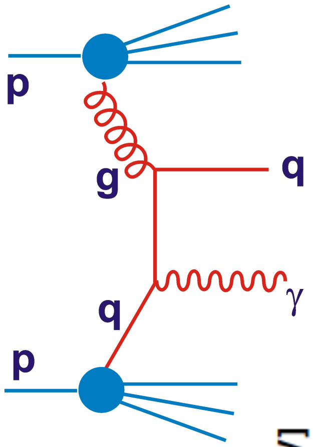


$R_t = \sigma(t) / \sigma(\text{tbar})$ sensitive to u/d

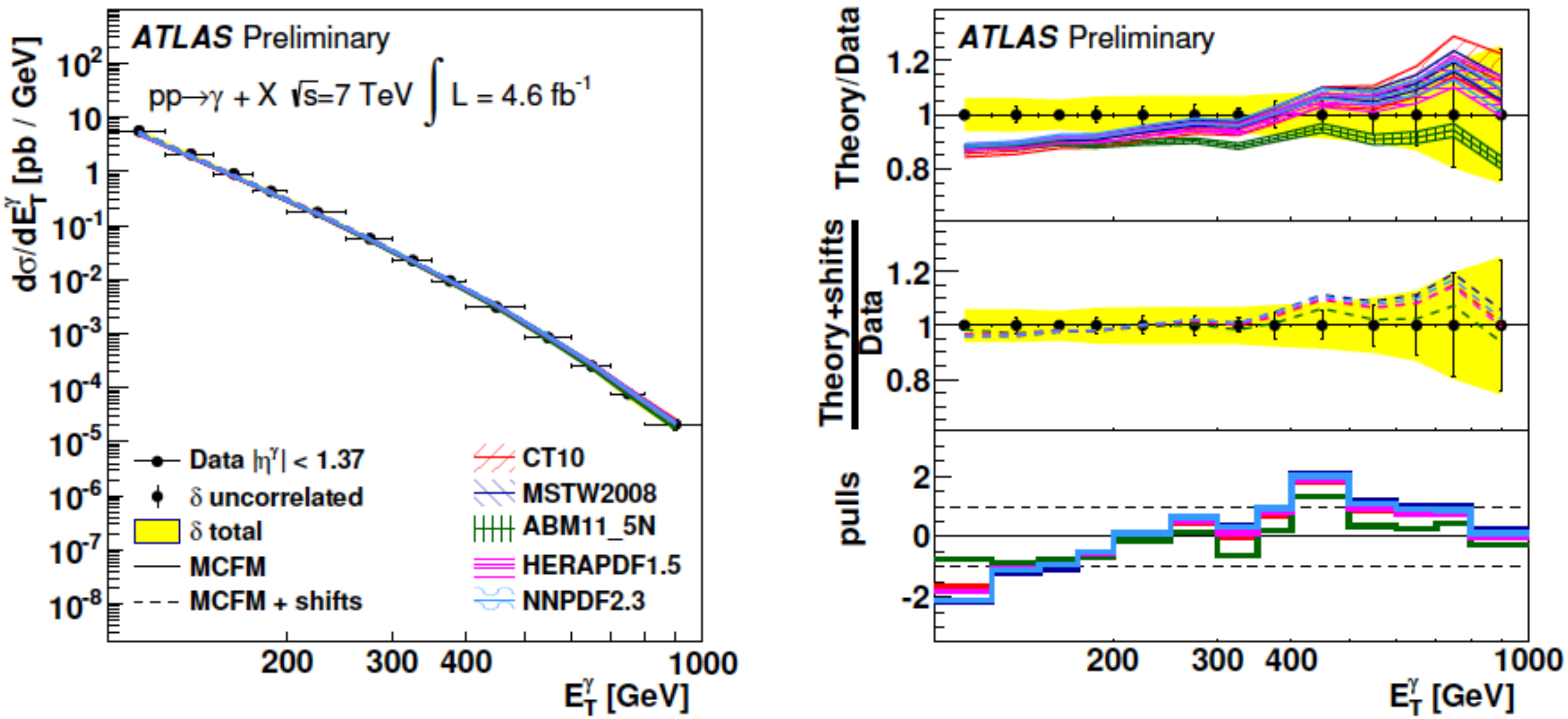
→ so far, compatible with all PDFs, but precision will improve …

Direct Photons

[ATL-PHYS-PUB-2013-018, Phys Rev D89 (2014) 052004]



Dominant diagram is ug → uγ (~60% of cross section)

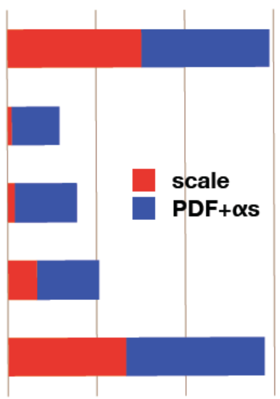


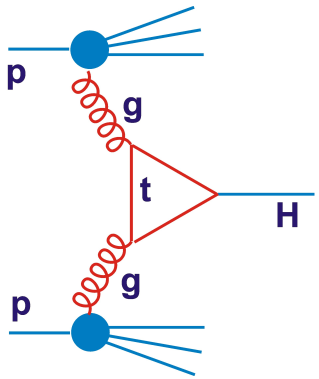
High sensitivity to large x gluon, but agreement with NLO (MCFM or Jetphox) questionable for all PDF sets and scale uncertainties large → Need NNLO to fully exploit data?

(Distant) Future: PDFs Limit LHC Physics?

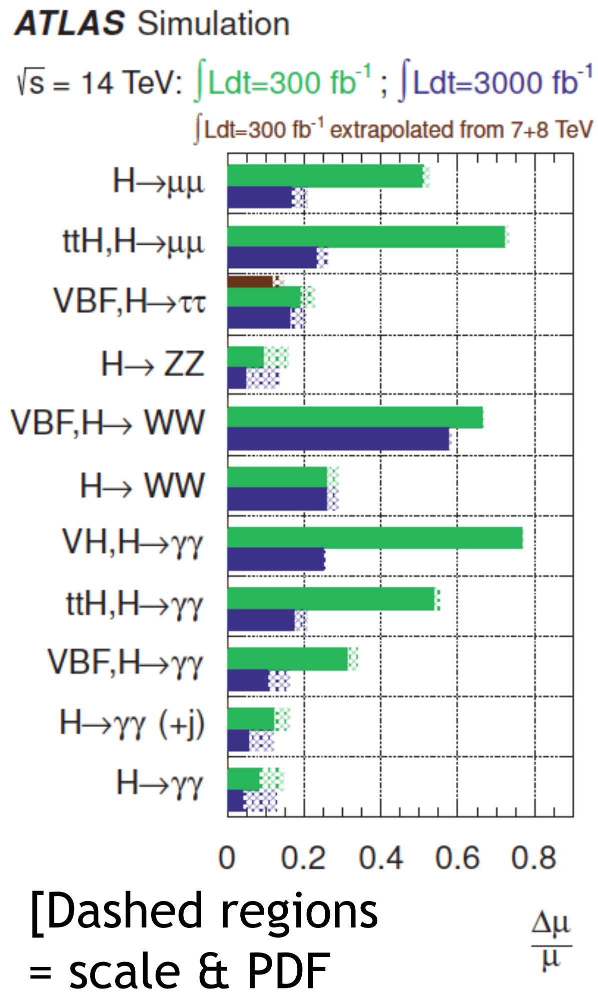
Theory Cross Section Uncertainties
(125 GeV Higgs J Campbell, ICHEP'12)

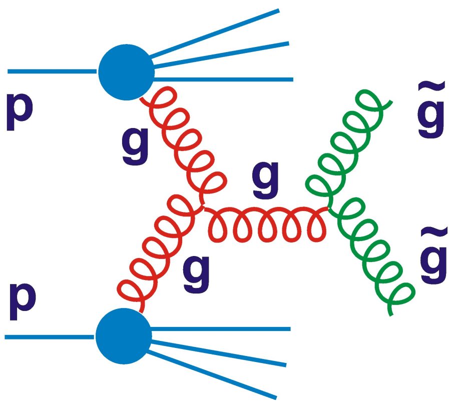
		σ (8 TeV)	uncertainty
NNLL QCD +NLO EW	gg→H	19.5 pb	14.7%
	VBF	1.56 pb	2.9%
NNLO QCD +NLO EW	WH	0.70 pb	3.9%
	ZH	0.39 pb	5.1%
NLO QCD	ttH	0.13 pb	14.4%

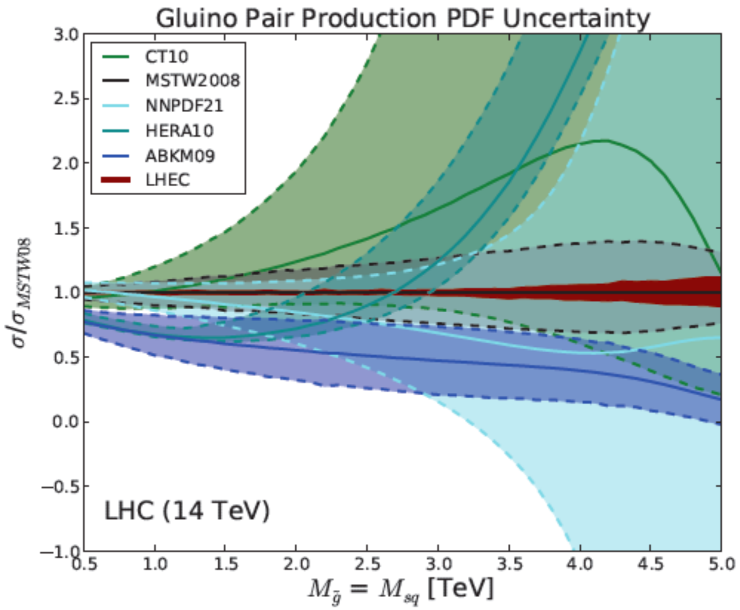




Projected Experimental Uncertainties

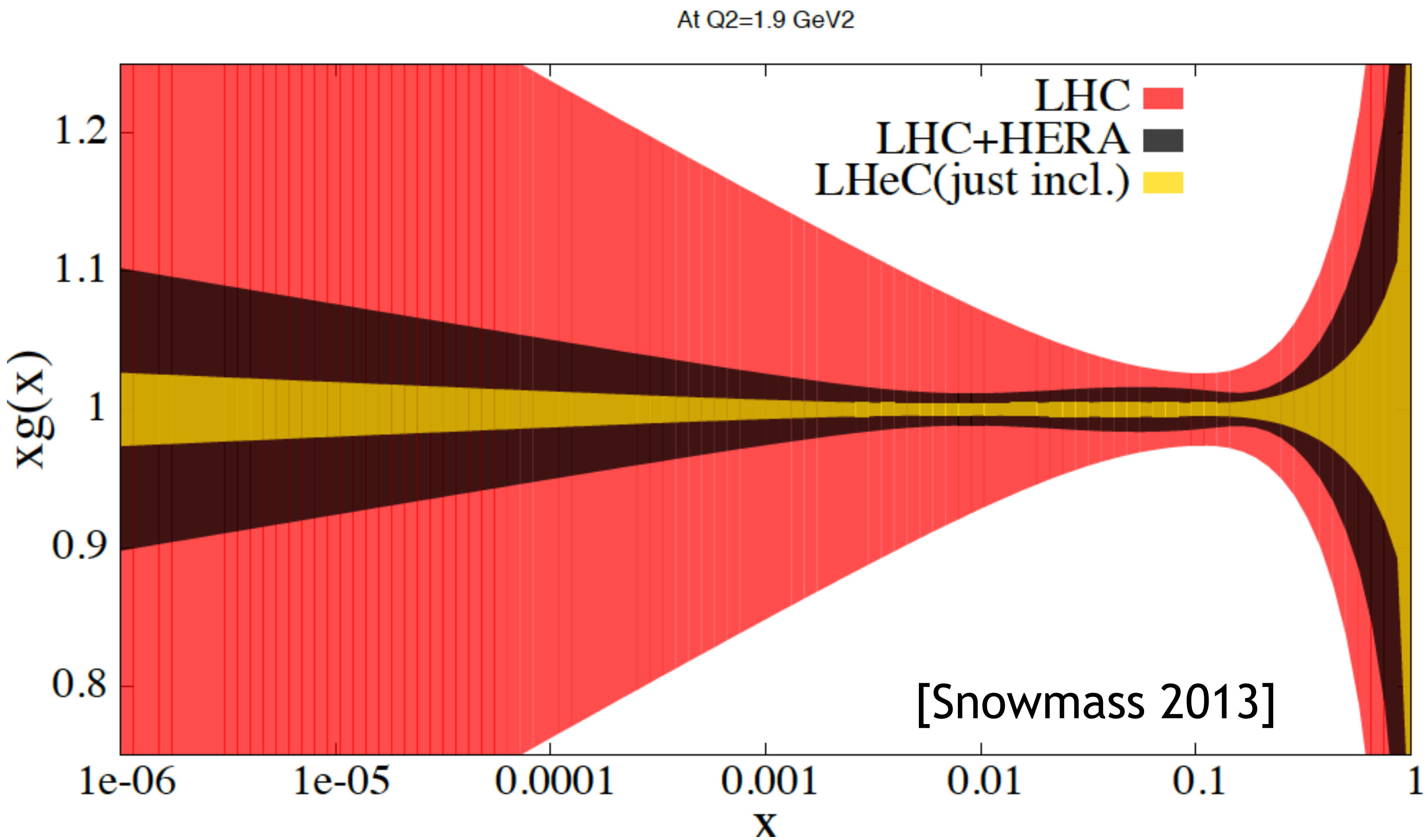






[Dashed regions = scale & PDF contributions

Where we are and Where we're Going



- LHC = current LHC W, Z and jet data
- Remarkable what can be achieved with LHC data alone
- Can we improve substantially? – Often already systs limited

Summary

- LHC data are improving PDF constraints
  - W and Z production
  - W + charm
  - Inclusive jets and Dijets
  - Drell Yan
  - Top Production
  - Direct Photons and photon + jet

    → Crucial to SM precision and BSM sensitivity

- Many areas which are not already systematics limited:
  - W, Z + c, b (intrincic charm, heavy flavour PDFs)
  - W, Z + jets, Z p_T distribution (gluon, u/d ...)
  - Ultra-peripheral charmonium (low x gluon)
  - Further progress with Drell Yan, direct photons, top ...

- Requires matching levels of theoretical progress (NNLO, MPI ...)

Back-ups

Parameterisation: Fits to HERA+ATLAS incl jets

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

- Additional constraints, A_g, A_{u_v}, A_{d_v} from sum rules, $B_{\bar{U}} = B_{\bar{D}}$ and $A_{\bar{U}} = A_{\bar{D}}(1-f_s)$ to ensure the same normalisation as $x \to 0$ and $C'_g = 25$
- For fits including jet data, the strange quark distribution is constrained to be proportional to the *d* type sea

$$xs = xf_sD$$

- This yields a 13 parameter fit, using a fixed strong coupling and a starting scale of $Q^2 = 1.9$ GeV^2

and ATLAS-epWZ12 (free strange) fit

as above but NNLO version

And for HERAPDF1.5 + ATLAS Wc

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

with free A and C parameters