ATLAS measurements sensitive to the Proton Structure

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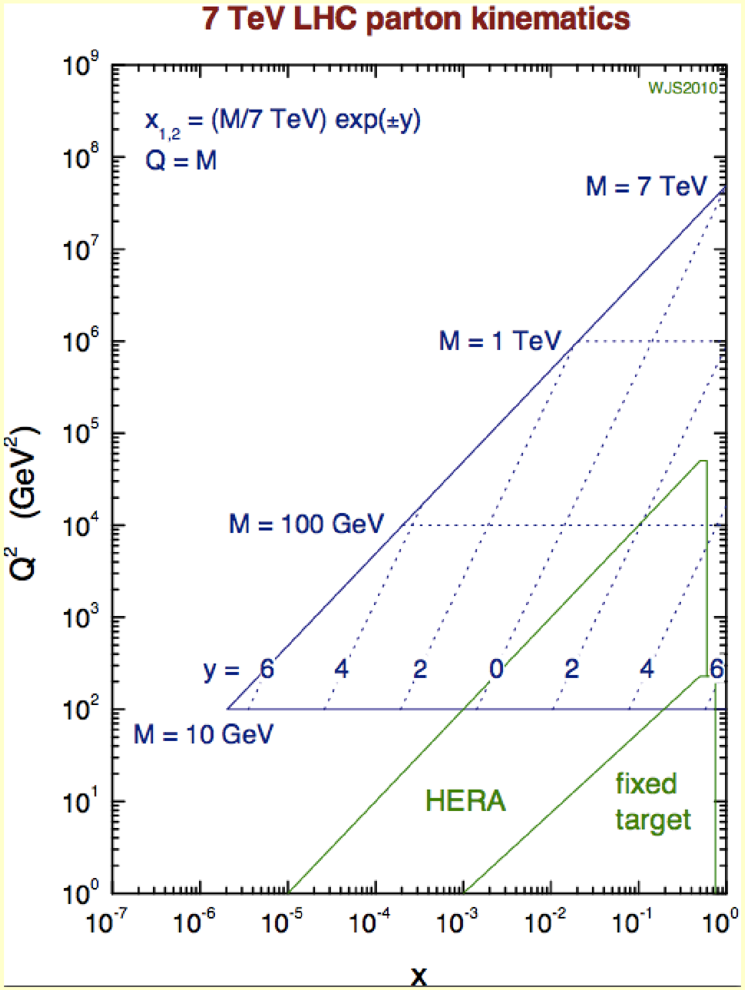
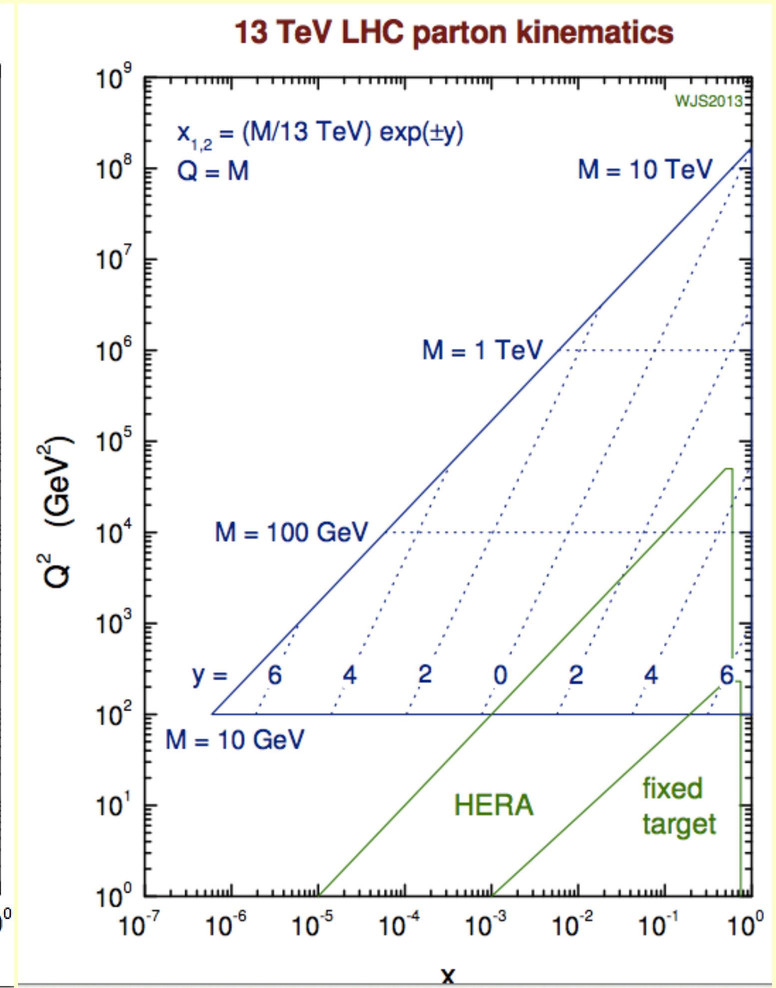
for the ATLAS Collaboration

ISMD-2015 **Wildbad Kreuth** October 2015

Why proton parton density functions (PDFs) are important.





James Stirling

They are universal and factorise.

Measured at some Q^2 value, extrapolated using DGLAP equations.

Need to be more fully determined at LHC energies.

Contribute to many measurements

- important theory uncertainty for Higgs production
- PDF uncertainties affect sensitivity in new particle production studies
- needed in most cross section determinations

ATLAS measurements sensitive to proton PDFs

Inclusive Jet, Di-Jet and Tri-jet production $\rightarrow$ gluon

Prompt photon $\rightarrow$ gluon

top pair $\rightarrow$ gluon

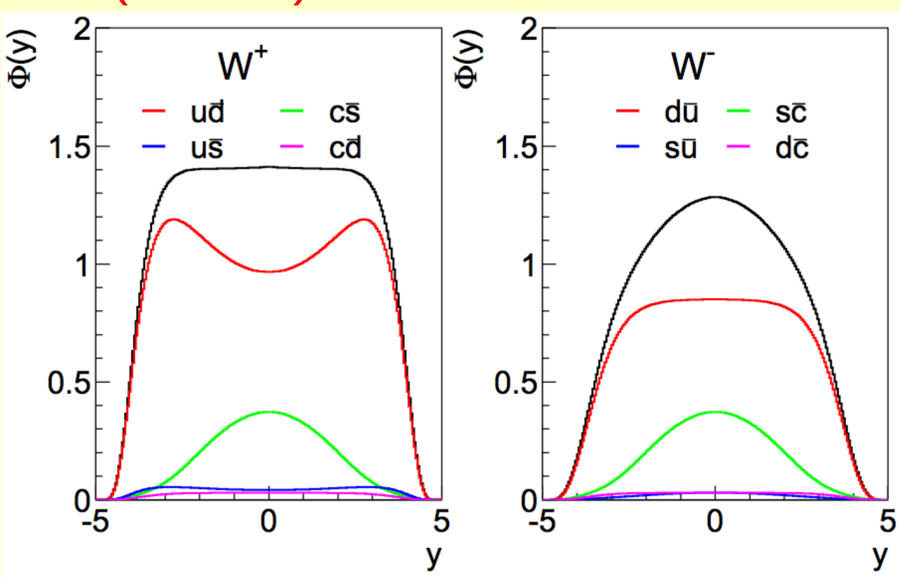
Drell-Yan $\rightarrow$ sea quarks

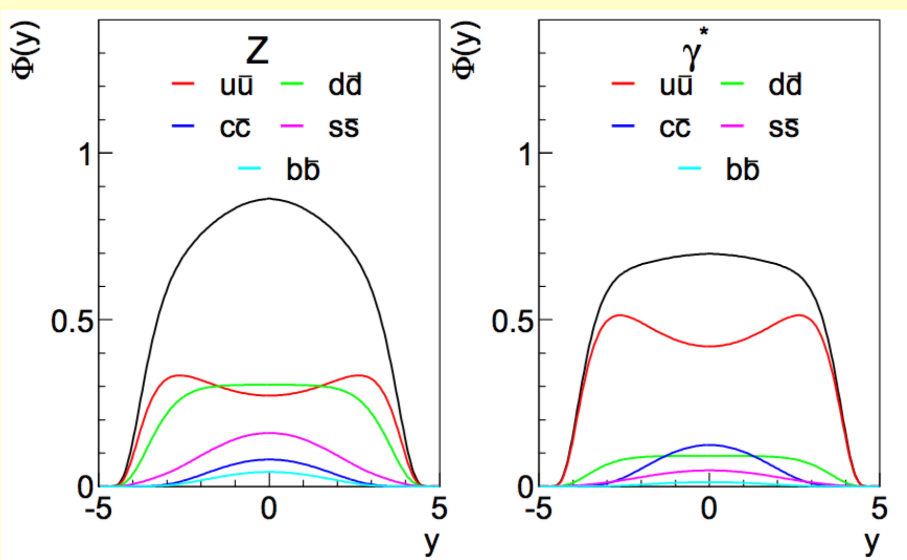
W, Z $\rightarrow$ strange, light sea

W + c $\rightarrow$ strange

W/Z ratios $\rightarrow$ u, d valence quarks

(13 TeV)





ATLAS

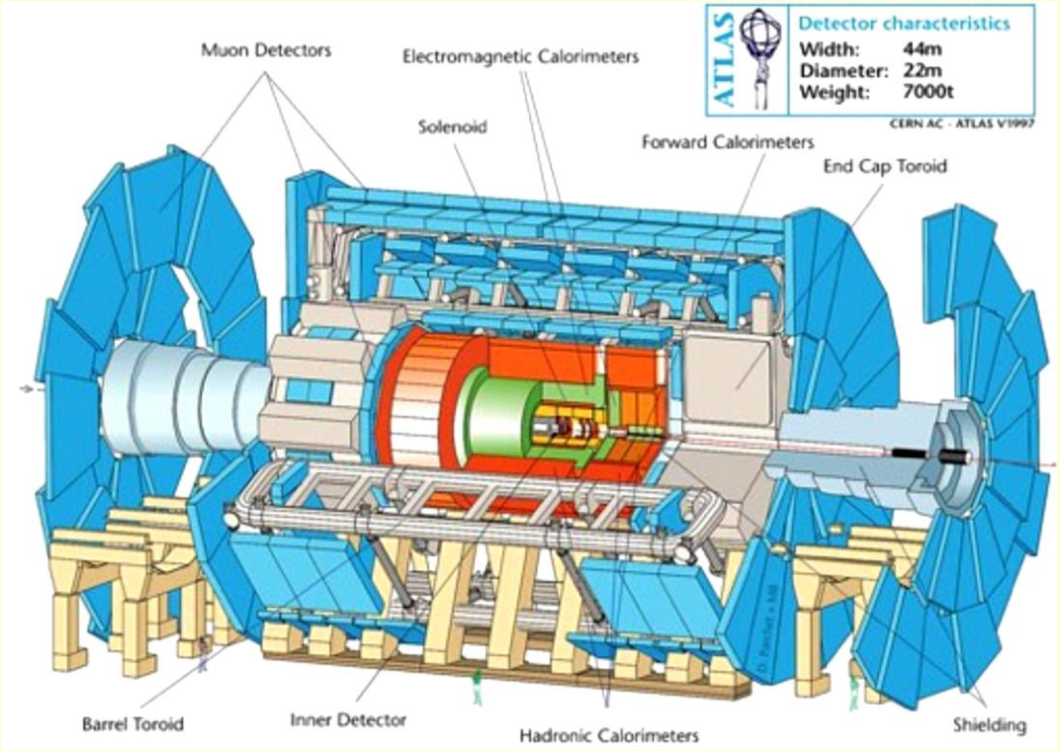
Magnetic field:
2 T solenoid + toroids

Tracker:
Si detectors, $\sigma/p_T = 5.10^{-4}\, p_T + 0.01$

e/m calorimeter:
Pb/liq. argon $\sigma/E = 0.1/E + 0.007$

Hadronic calorimeter:
Fe/scintillator $\sigma/E = 0.5/E + 0.03$

Muon detection system

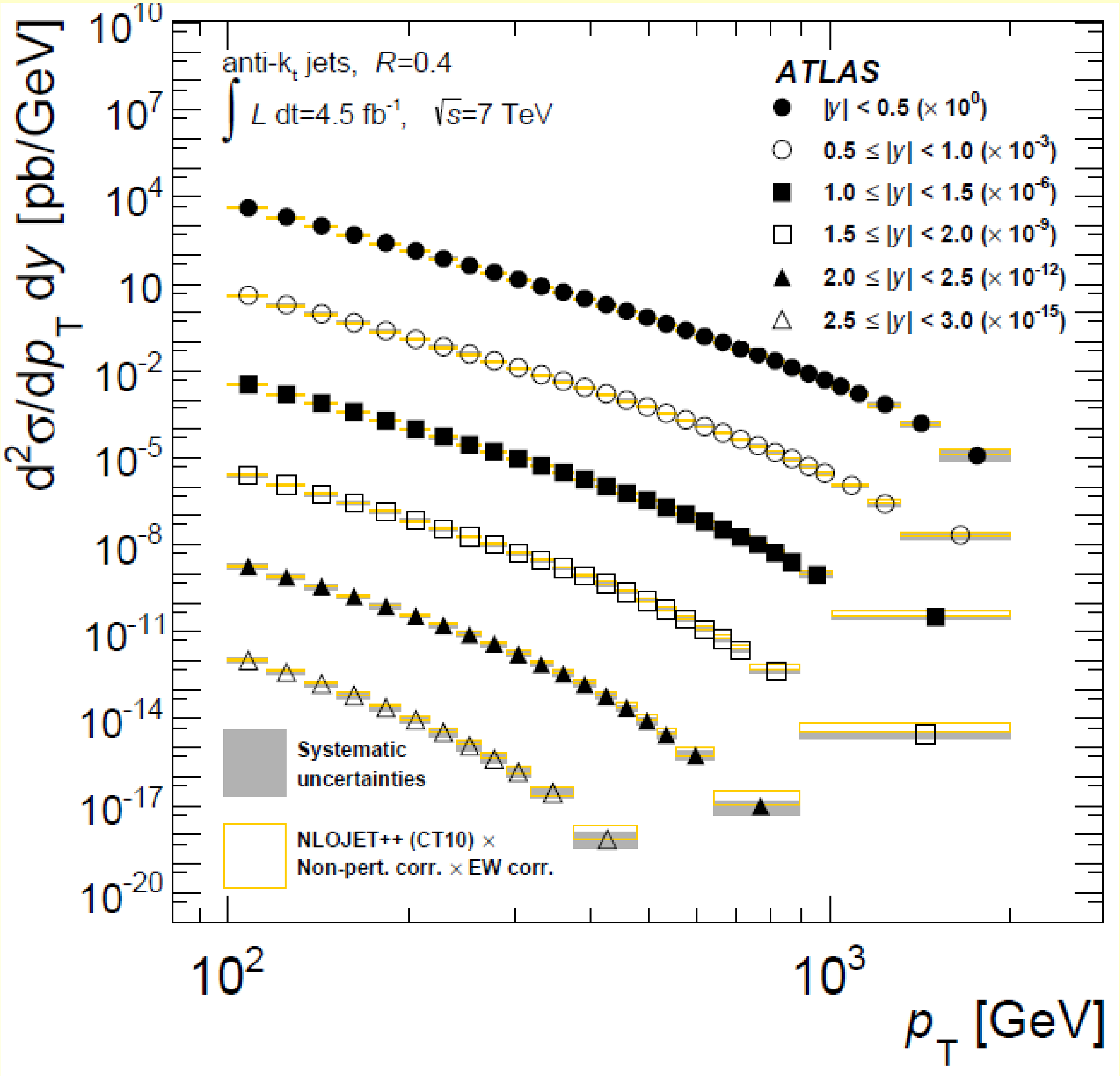


Jets at ATLAS are typically reconstructed with anti-k_T algorithm, R = 0.4 or 0.6

Jet energy scale uncertainty varies typically from ~1.8% at central rapidities to 4-5% in forward/rear directions

Non-perturbative (hadronisation) corrections are applied to parton-level theory calculations.

Jet measurements



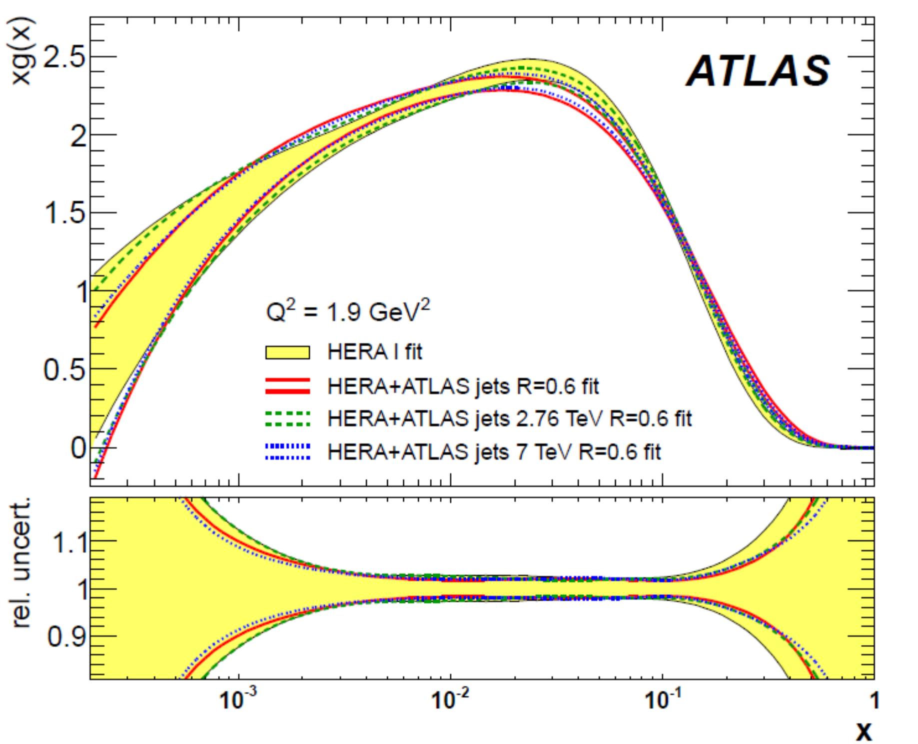
JHEP 02 (2015) 153

Inclusive jets at 7 TeV. Very good description by NLOJet++ and CT10 PDFset (QED corrections applied)

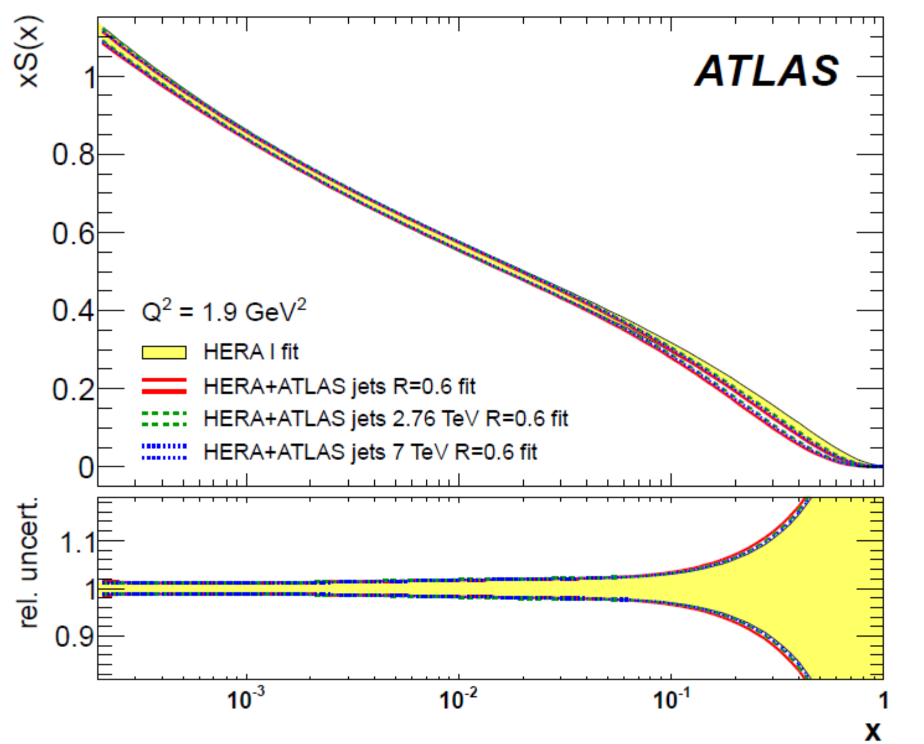
PDF fits:

Results from the earlier 2013 publication EPJ C 73 (2013) 2509

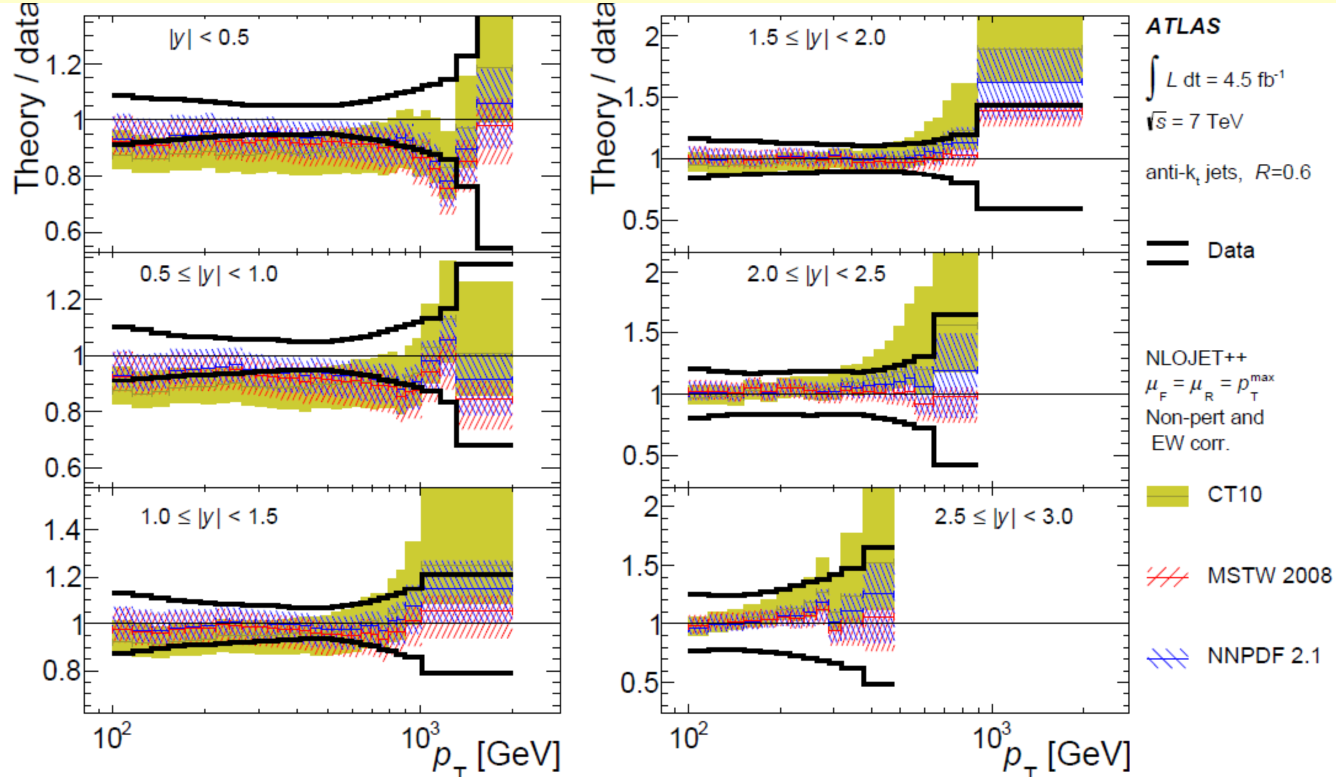
gluons

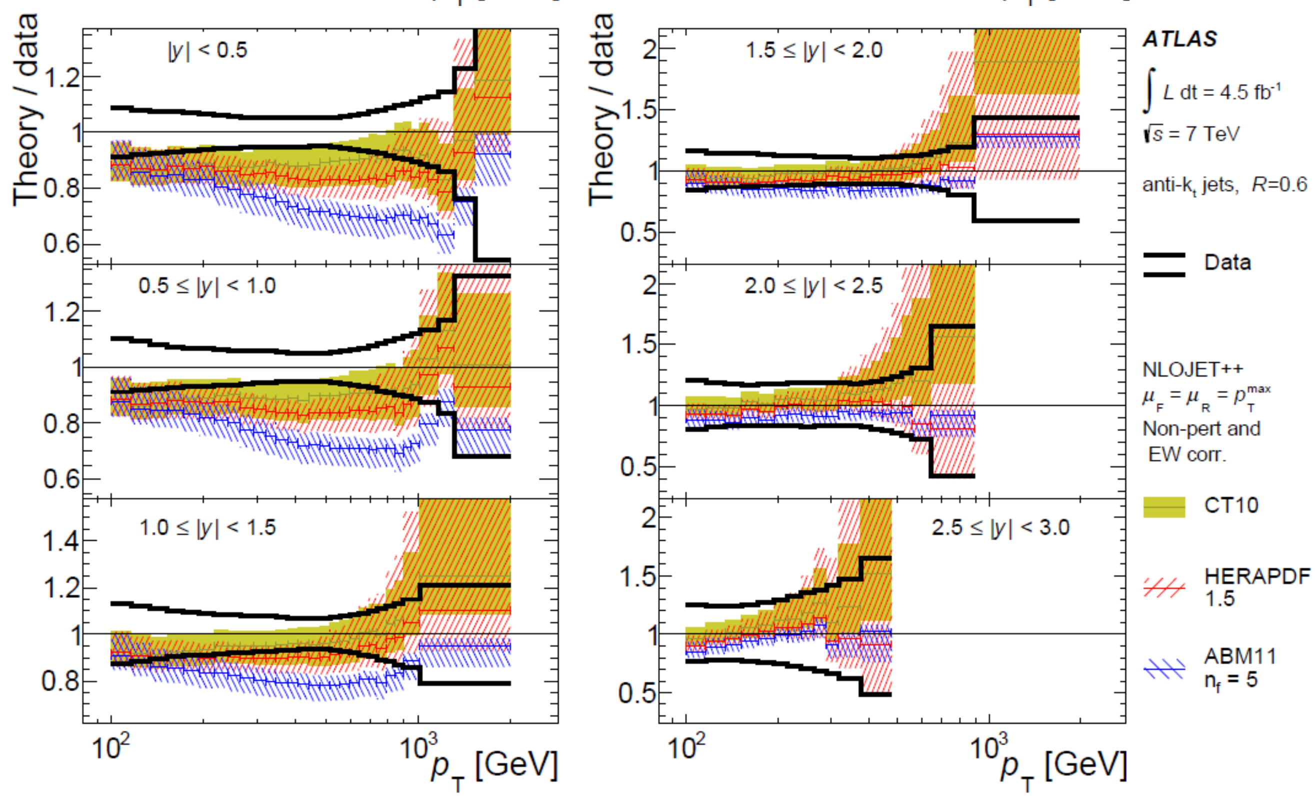


sea quarks



ATLAS jet measurements have scope for constraining gluon distributions and the sea quarks at high x. This analysis used the 2.76/7 TeV ratio to reduce systematics.





Inclusive jets at 7 TeV Comparison with different PDF sets:

CT10
MSTW 2008
NNPDF 2.1
HERAPDF 1.5
ABM11 (nf = 5)

Fit probabilities have been evaluated (see next page)

Jet energy scale is the dominant uncertainty.

y ranges	P_{obs}					
	NLO PDF set:	CT10	MSTW2008	NNPDF2.1	HERAPDF1.5	ABM11
$\lvert y \rvert < 0.5$		84%	61%	72%	56%	$< 0.1\%$
$0.5 \leq \lvert y \rvert < 1.0$		91%	93%	89%	49%	$< 0.1\%$
$1.0 \leq \lvert y \rvert < 1.5$		89%	88%	85%	93%	2.7%
$1.5 \leq \lvert y \rvert < 2.0$		93%	88%	91%	75%	55%
$2.0 \leq \lvert y \rvert < 2.5$		86%	82%	85%	26%	57%
$2.5 \leq \lvert y \rvert < 3.0$		95%	94%	97%	82%	85%

PDF fit probabilities in NLO framework.

CT10, MSTW2008, NNPDF2.1 are all good
HERAPDF1.5 satisfactory
ABM11 poor at low-medium |y|

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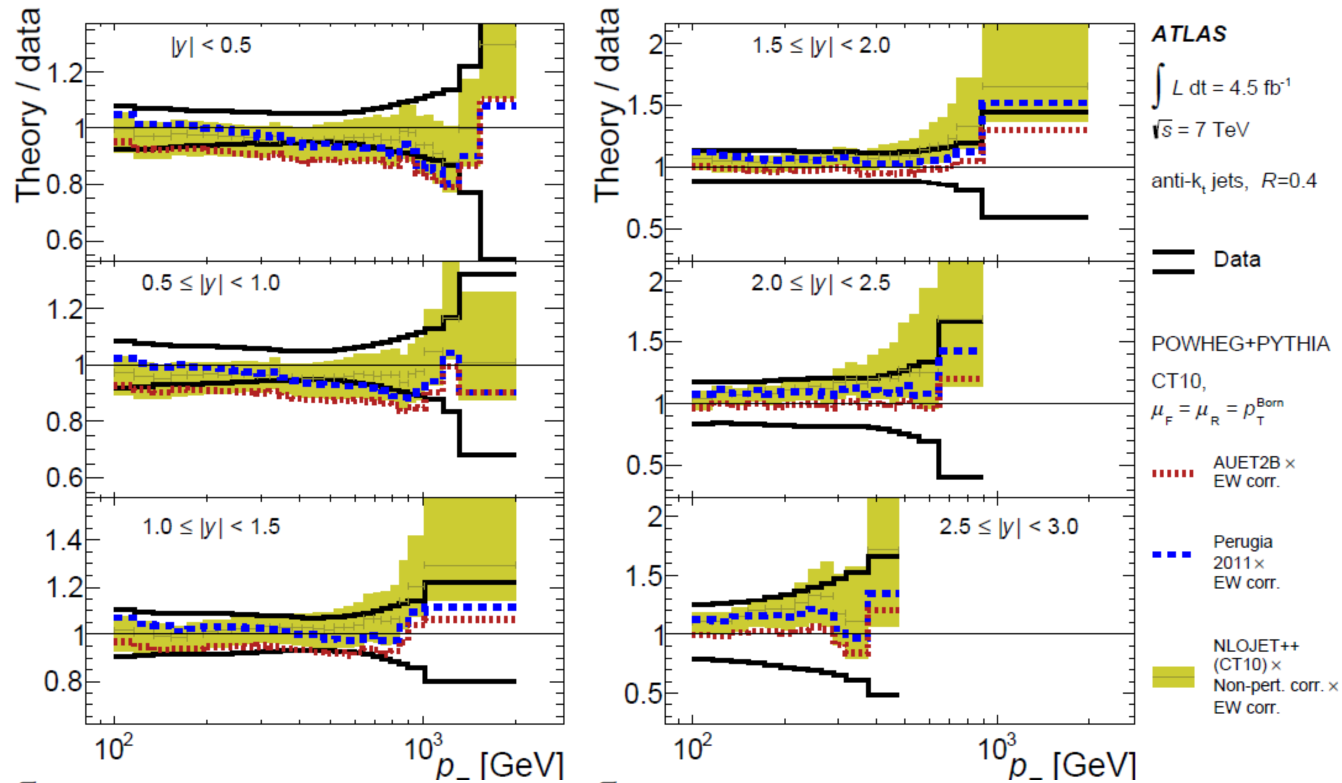
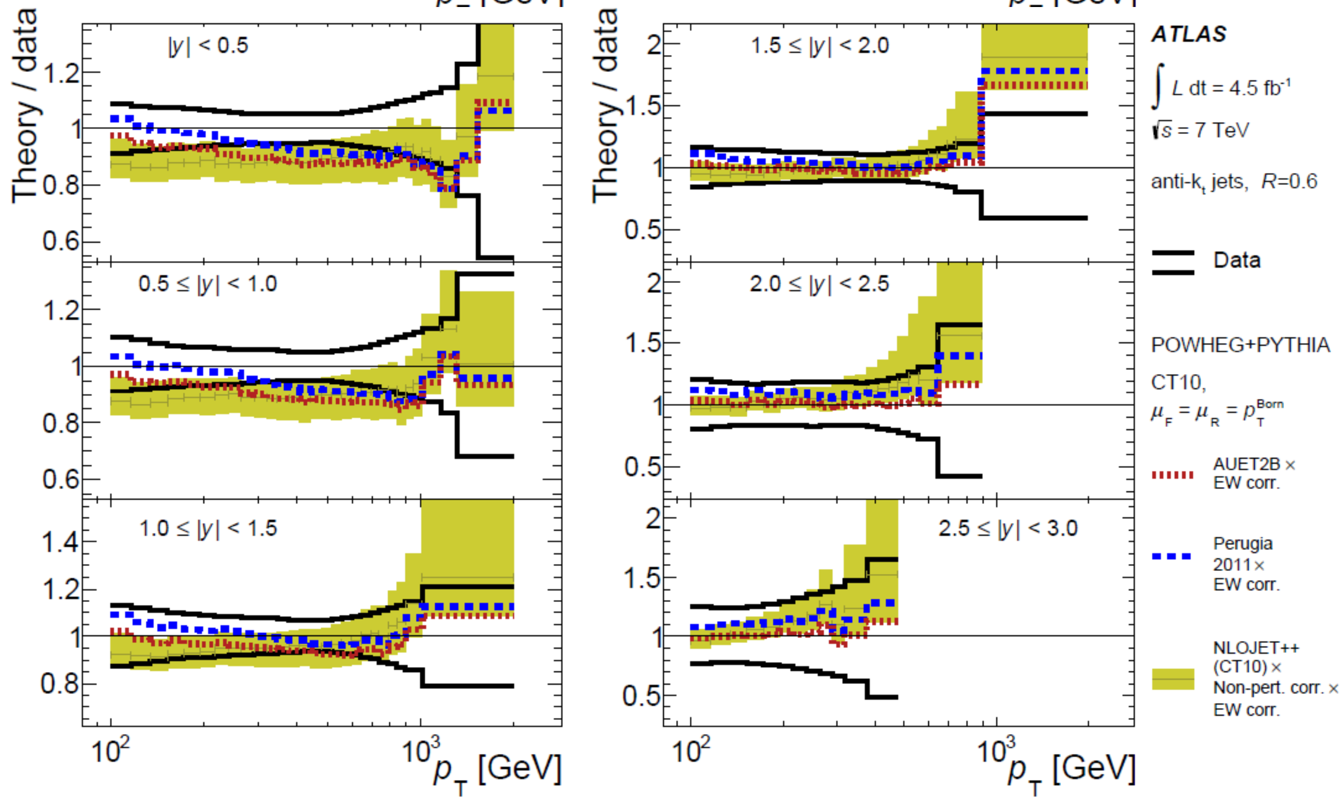




More variations
Tunes are another factor

POWHEG + CT10
+ Pythia tunes

AUET2B
Perugia 2011

NLOJet++ + CT10
is repeated.

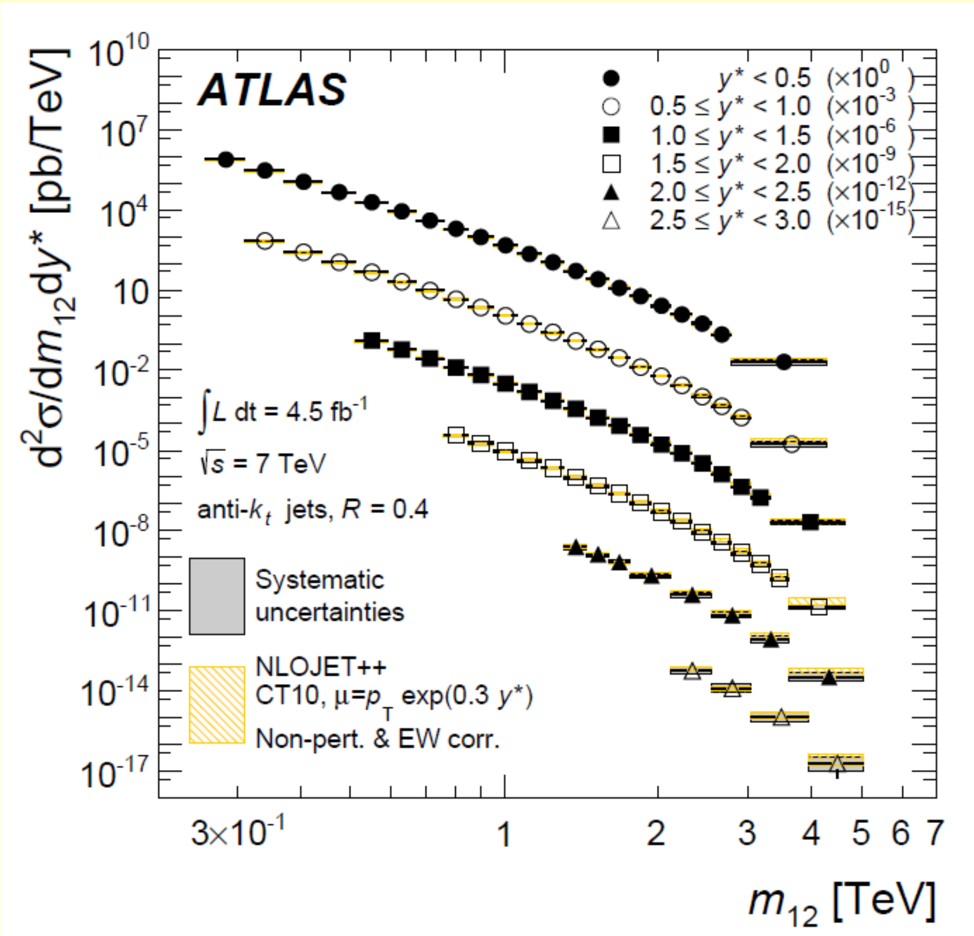
Effect of size of jet radius parameter

R = 0.4 (upper)
R = 0.6 (lower)

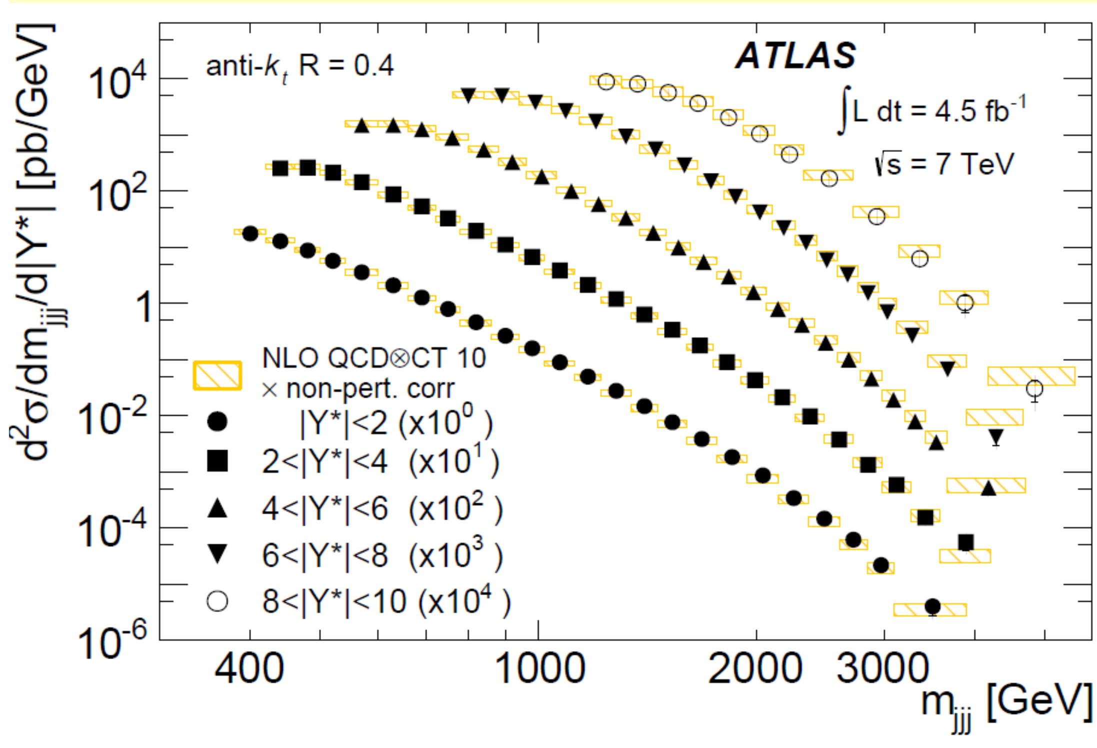
Both tunes OK
but better for R=0.4

Dijets and trijets

dijets JHEP05(2014)059



trijets EPJ C 75 (2015) 228



$y^* = |y1 - y2|/2$

p1, p2 > 100, 50 GeV

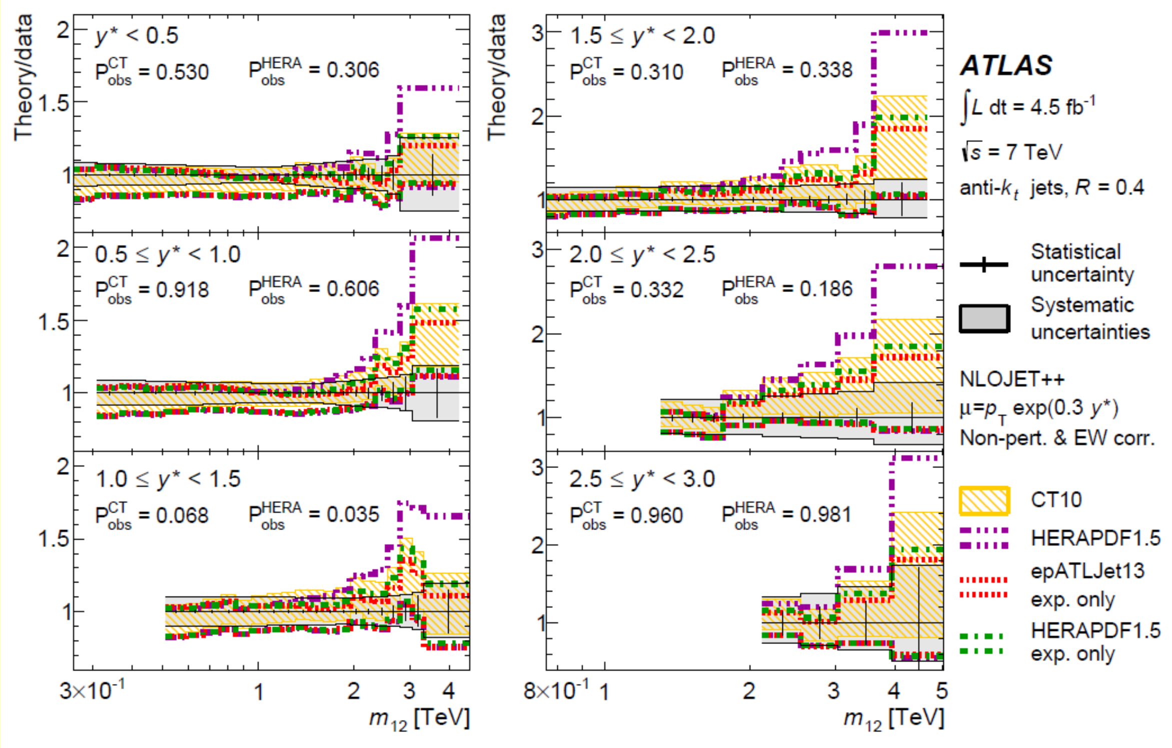
EW corrections applied. E.g.~12%

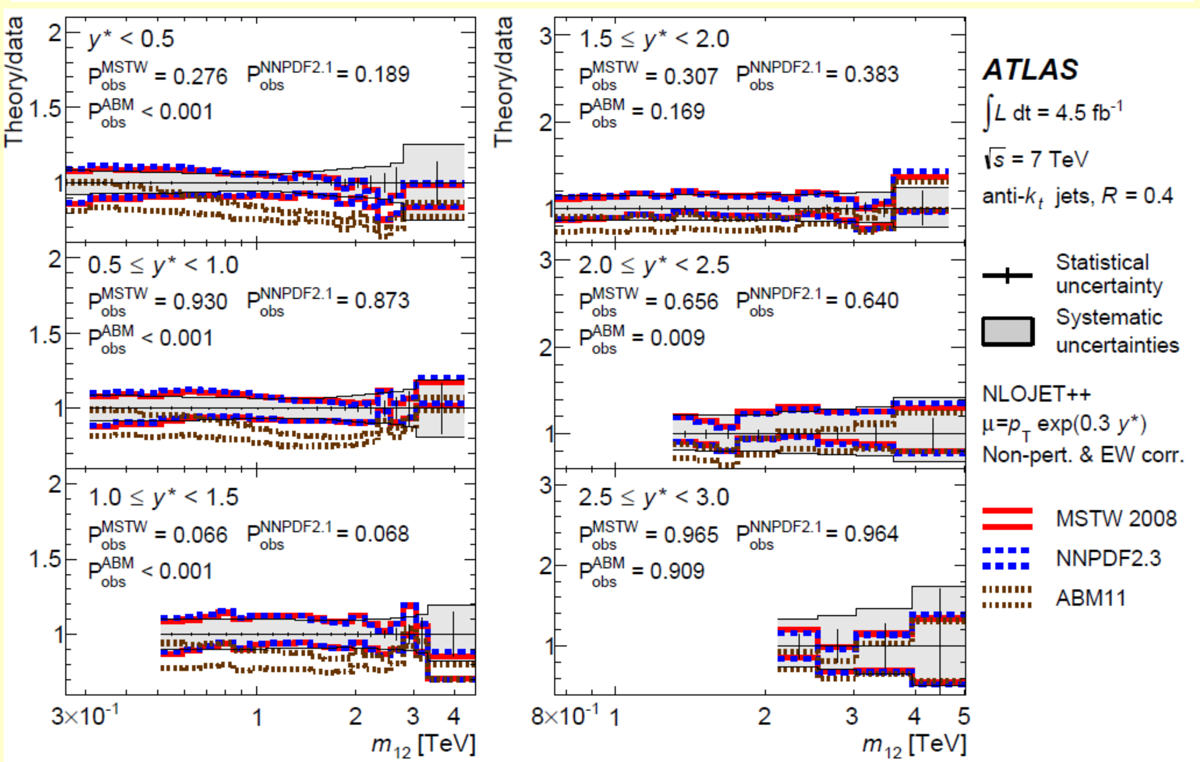
$Y^* = |y1 - y2| + |y2 - y3| + |y3 - y1|$

p1, p2, p3 > 150, 100. 50 GeV

no EW corrections available.

masses well described by NLOJET QCD + CT





Dijet distributions in detail

Comparisons with

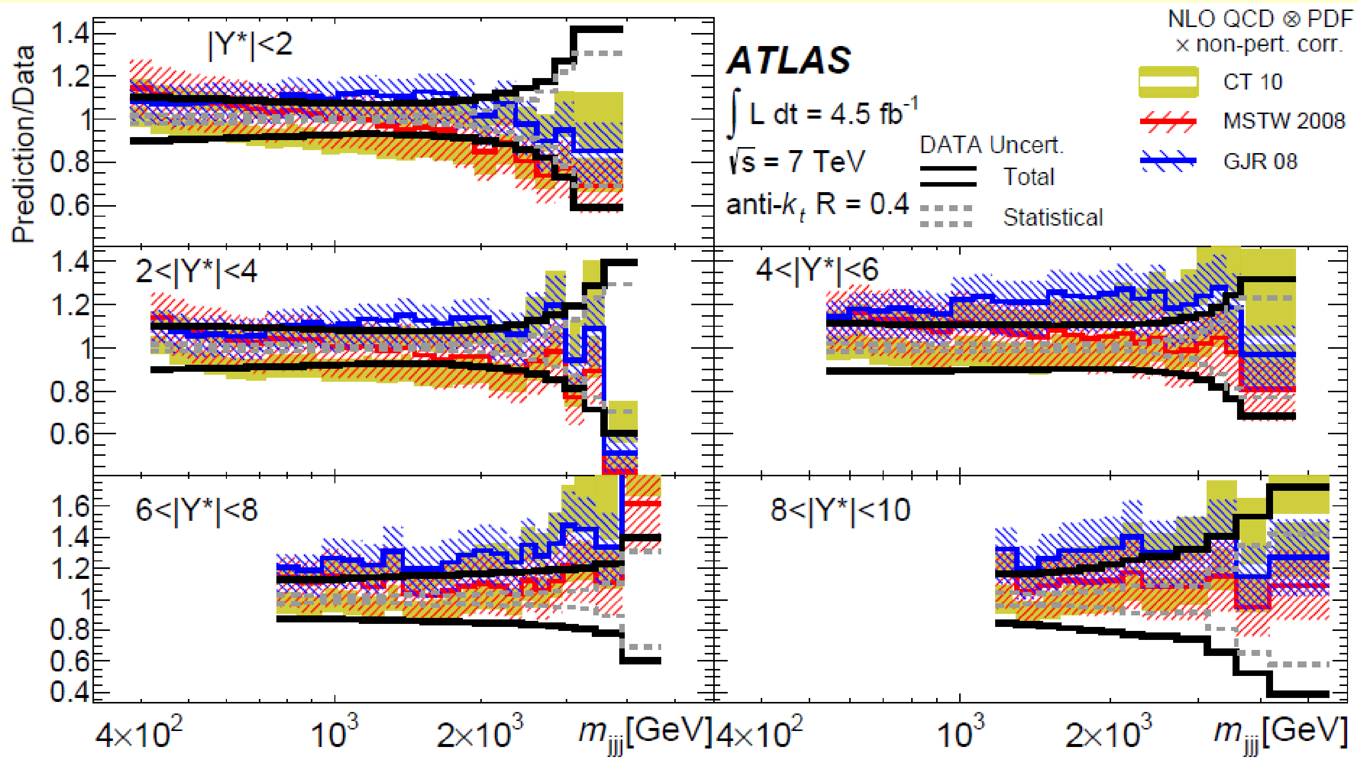
HERAPDF 1.5
(and exp errors only)
epATLjet 13
(dedicated
HERA+ATLAS fit, 2013)

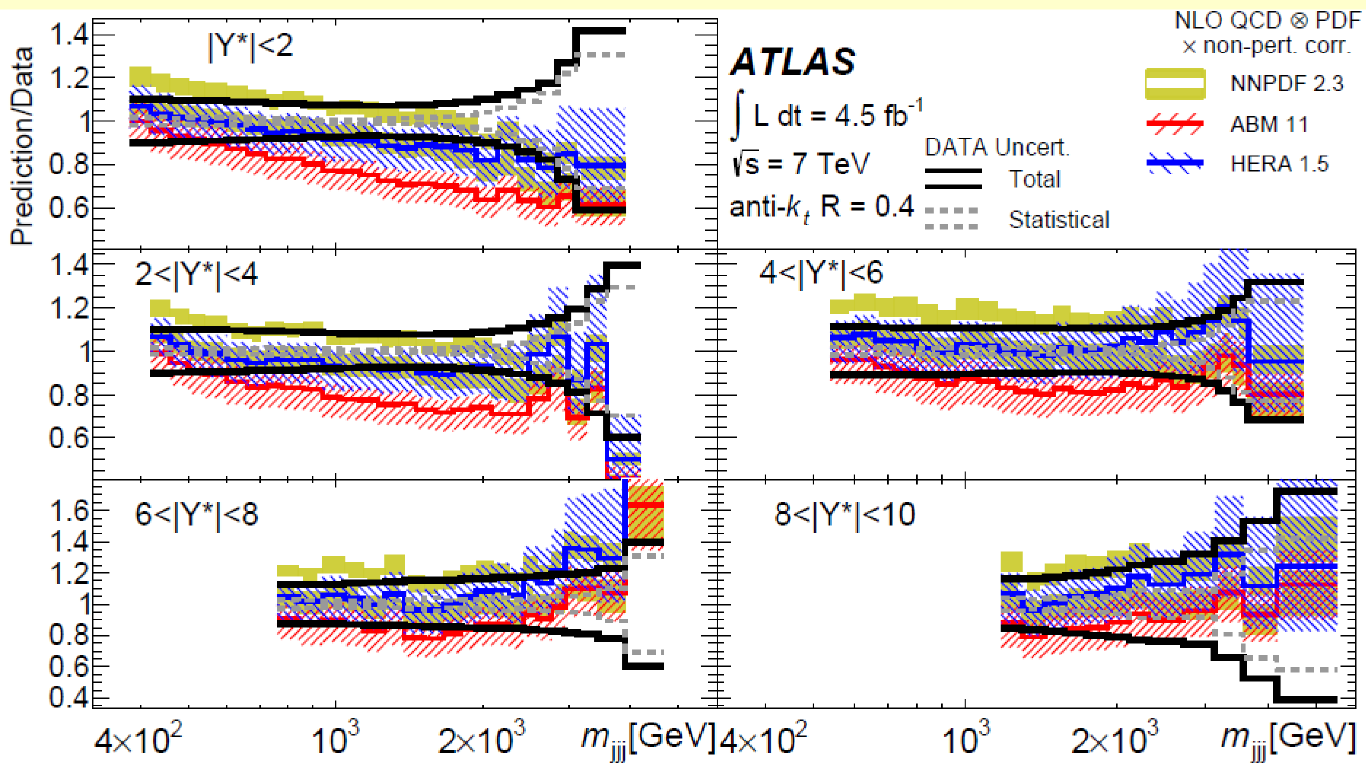
MSTW 2008
NNPDF2.3
ABM11

Of these, only ABM11
is unsatisfactory.

Similar results for R = 0.6

JHEP05(2014)059





Trijet distributions in detail

Comparisons with

CT 10
MSTW 2008
GJR 08

NNPDF2.3
ABM11
HERA 1.5

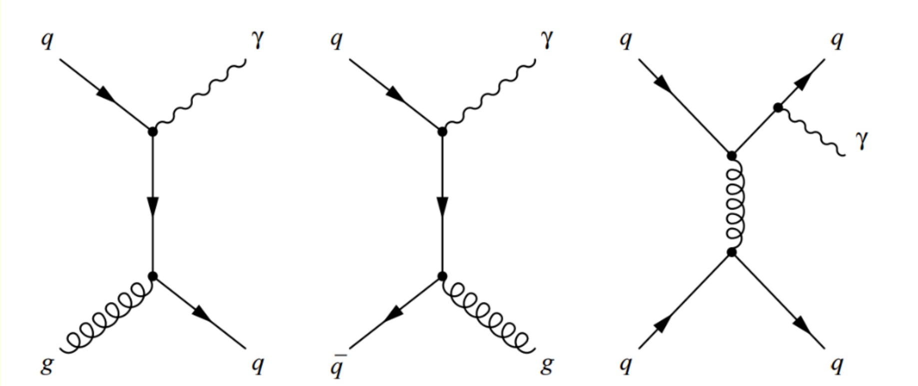
Of these, only ABM11 is unsatisfactory.

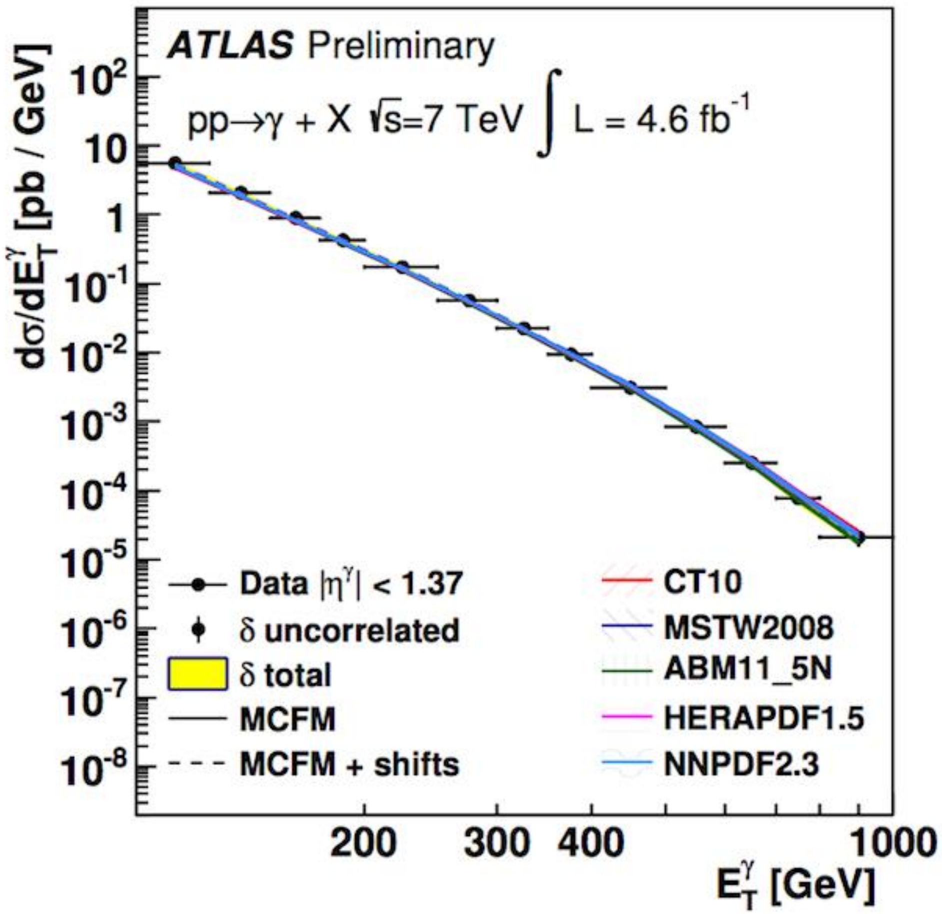
Similar results for R = 0.6

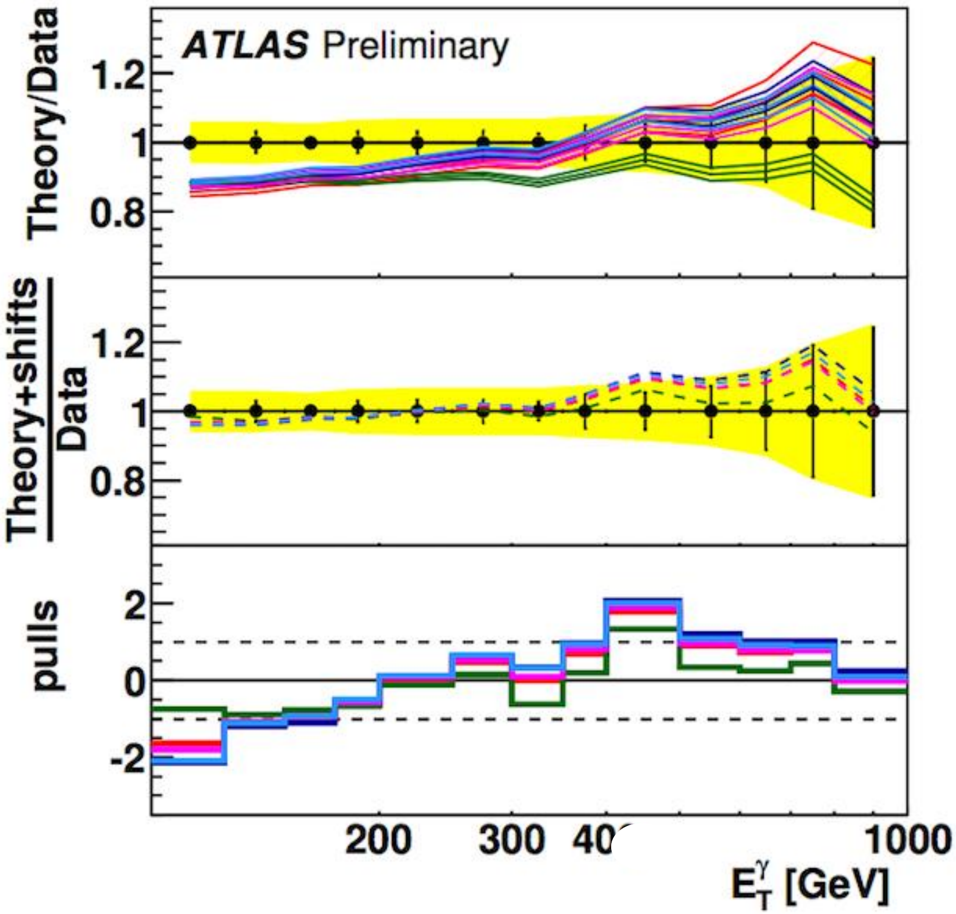
EPJ C 75 (2015) 228

Inclusive photon measurements

ATL-PHYS-PUB-2013-018

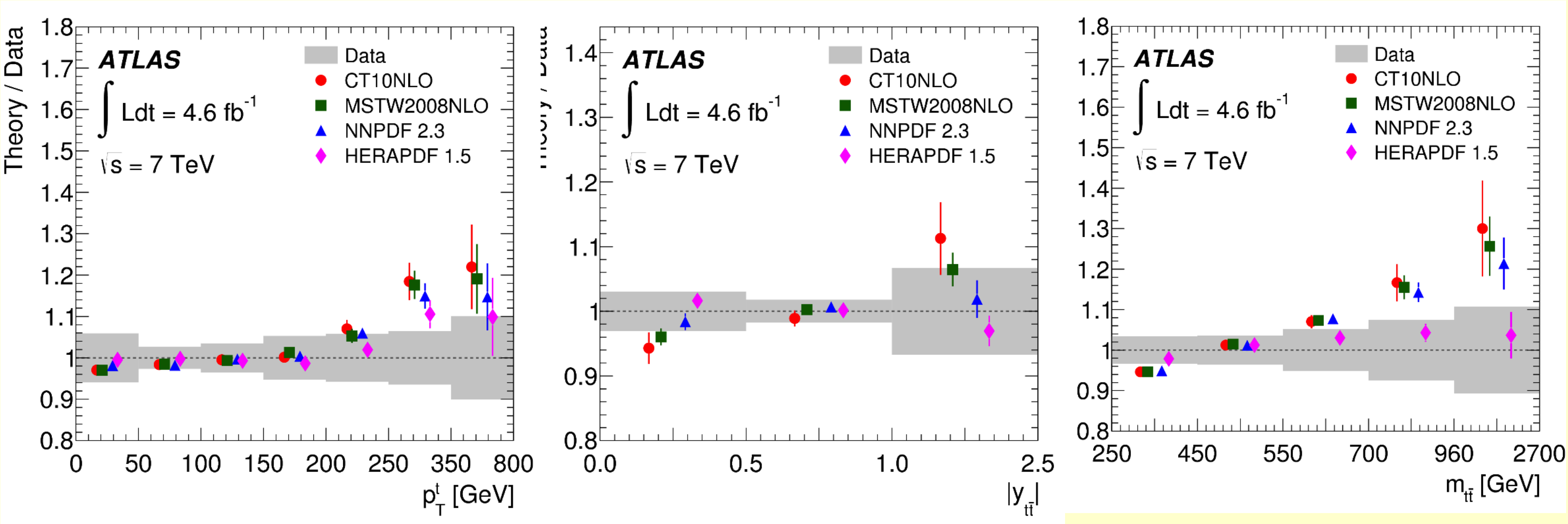






Sensitive to gluon and quark densities, MCFM model gives satisfactory results overall for all the PDFs. ABM is best. See talk by Claudia Glasman.

Top pair production (lepton + 4jets, b tag) Phys. Rev. D 90, 072004



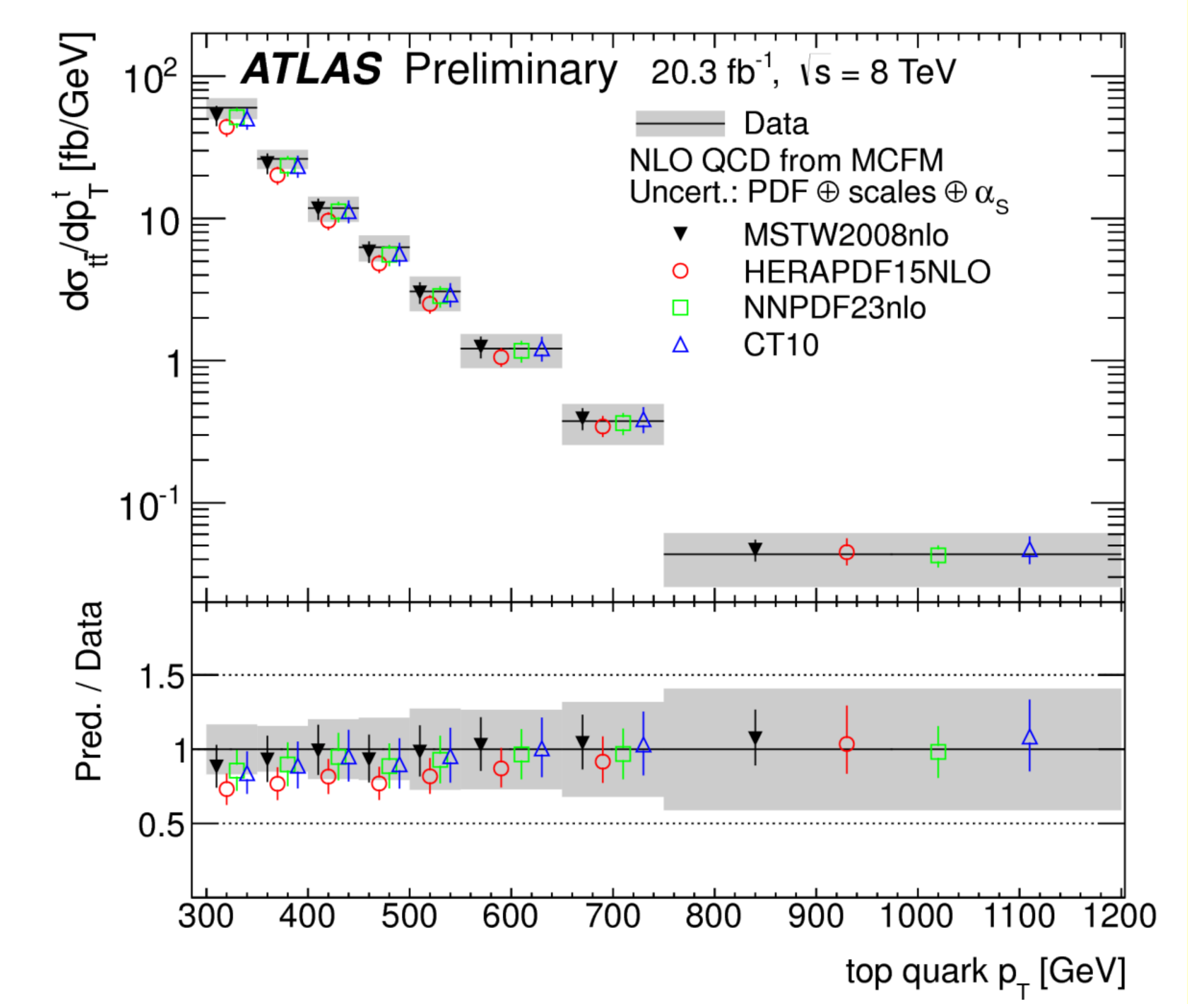
Normalised cross sections agree reasonably well with models based on ALPGEN, MC@NLO, POWHEG (all using HERWIG) and POWHEG+PYTHIA

Use NLO QCD theory to compare different PDFs
Overall the HERAPDF 1.5 PDF set is favoured.

Models tend to be higher than the data at high p_T^t e.g. > 250 GeV.

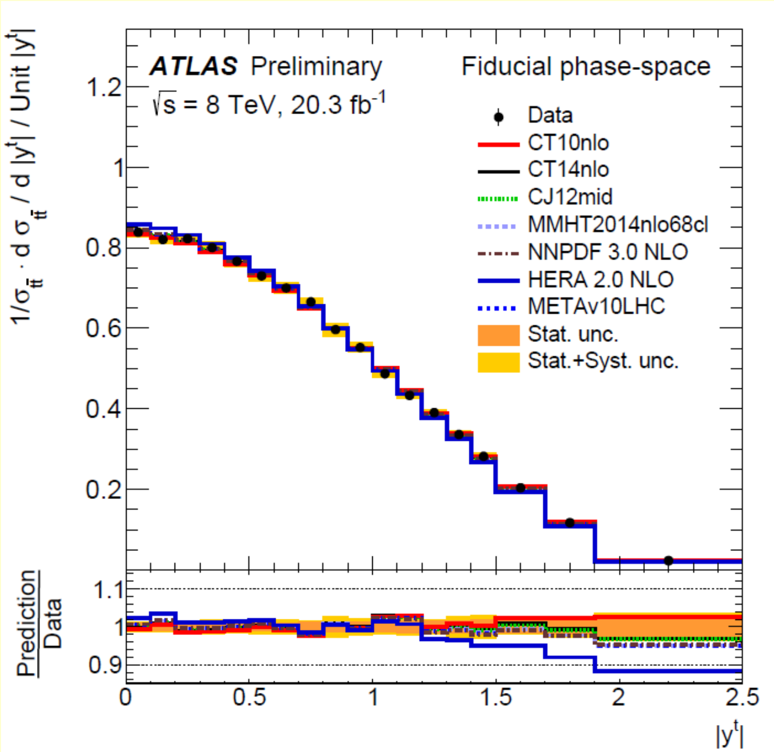
Further work needs to take into account EW corrections and NNLO effects.

Single highly boosted top production, 8 TeV

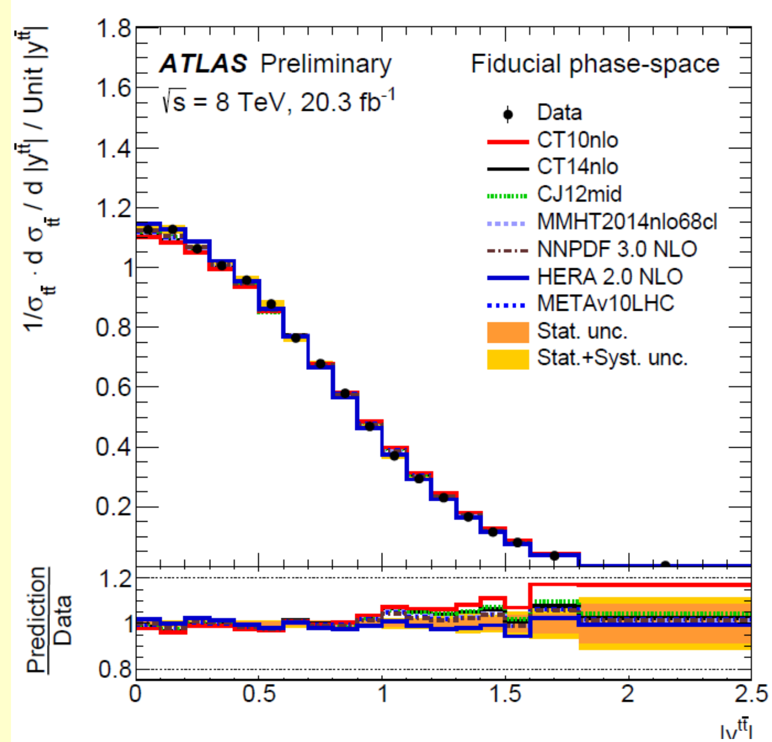


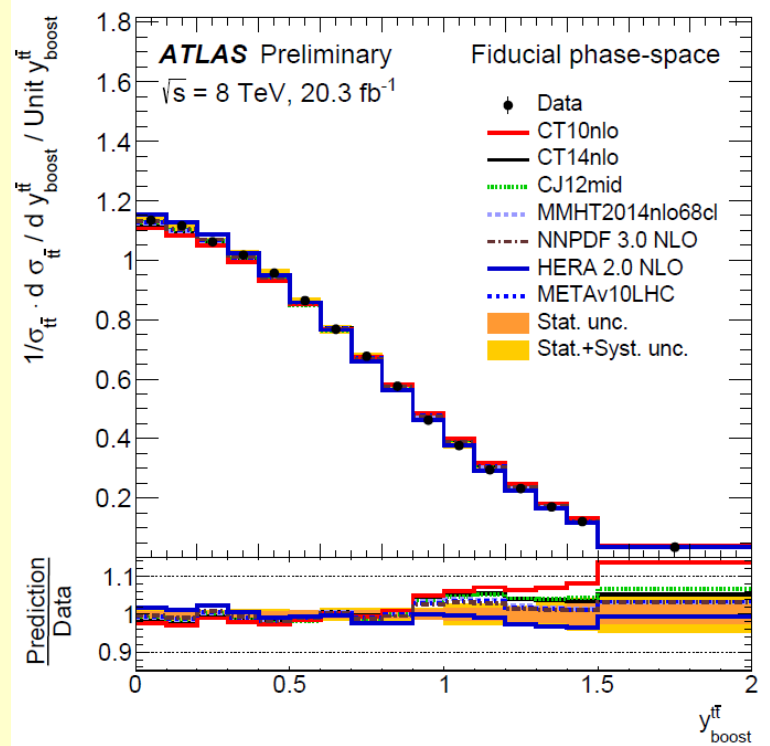
Top pairs sensitive to gluon PDFs, single top more sensitive to quarks.
Good description but little sensitivity at present.

top pair production (lepton + 4jets, b tag)
(preliminary, 8 GeV, ATLAS-TOPQ-2014-06)



(still NLO)





y of single t, t pair, tt boost
show some differing PDF sensitivities

CT variations (CT10 less good)
MMHT2014
NNPDF
HERA2.0 (less good)
METAv10LHC

Drell-Yan

Phys. Lett. B 725 (2013) 223
JHEP 06 (2014) 112

e^+e^- pairs were measured

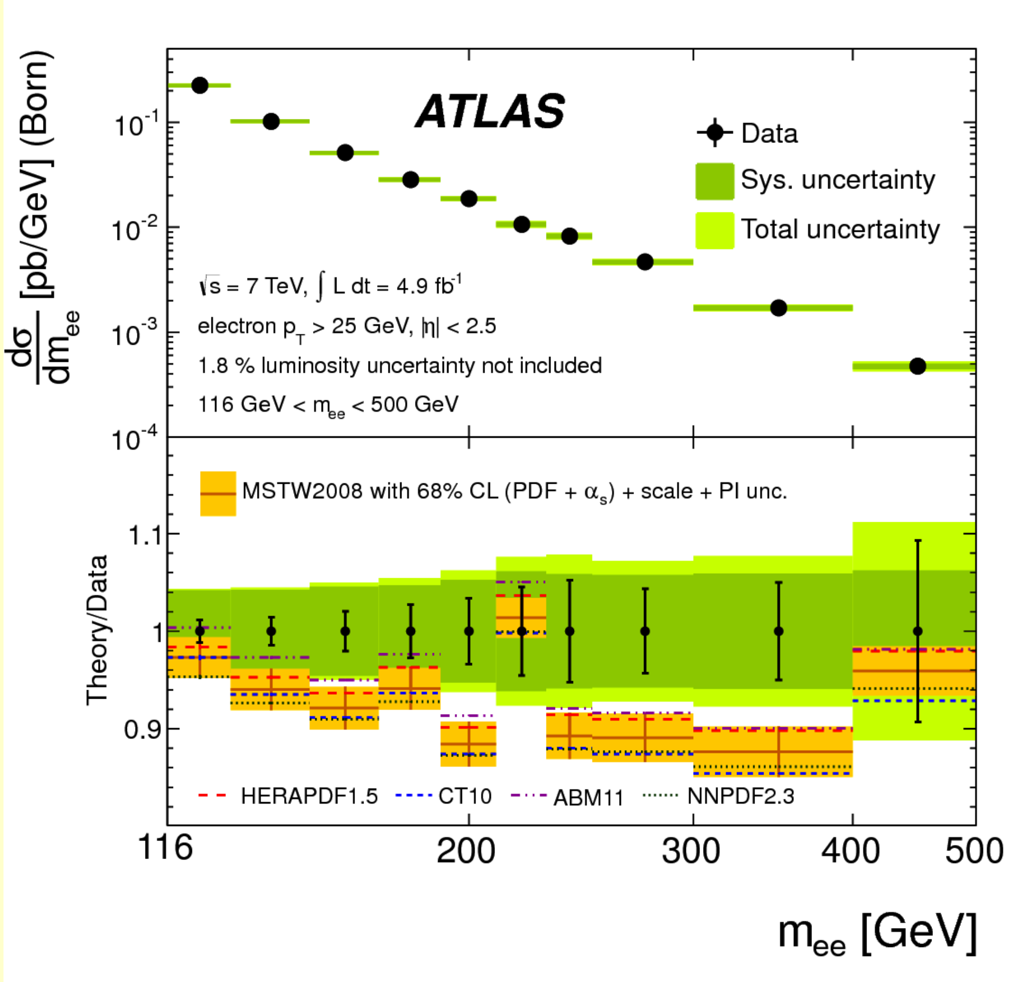
Low-mass region –
standard PDFs not compared.
Data agree with NNLO + PDF fit.
(NLO did not work)

High mass region:

HERAPDF 1.5
CT 10
AMB11
NNPDF2.3

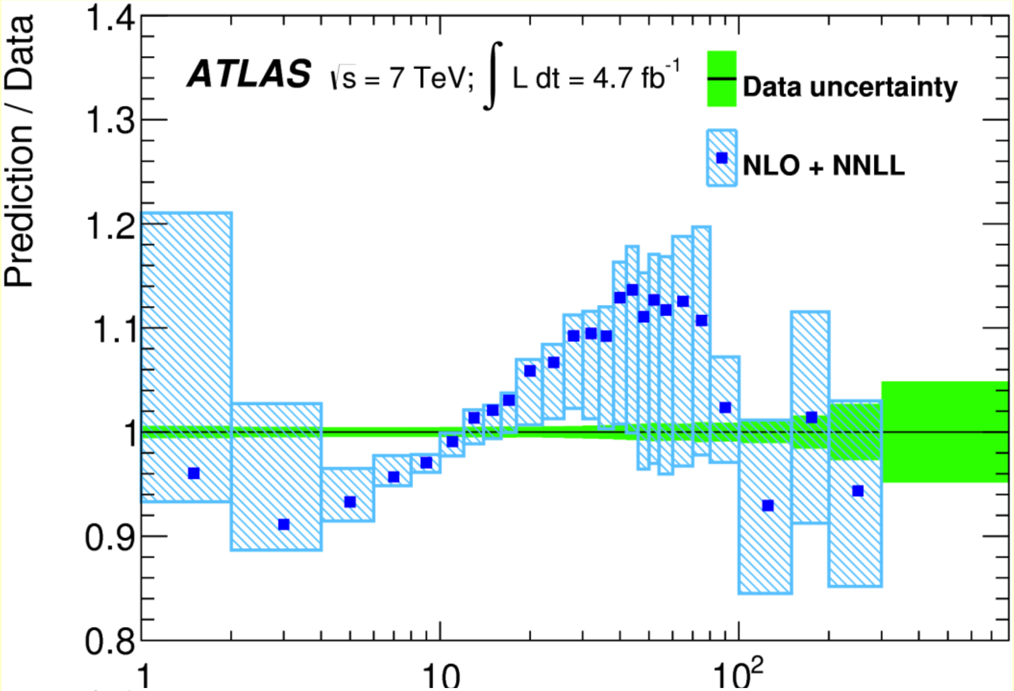
Photoproduction background must be subtracted.

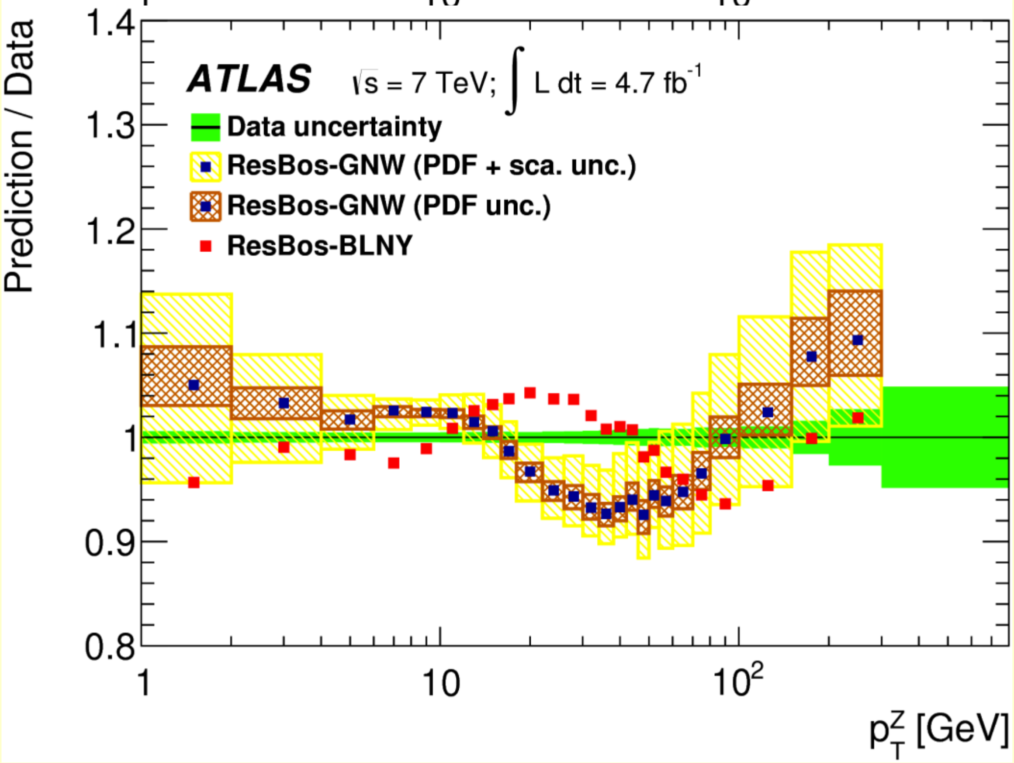
not much PDF sensitivity.
Large data uncertainties.
All the models fall below the data

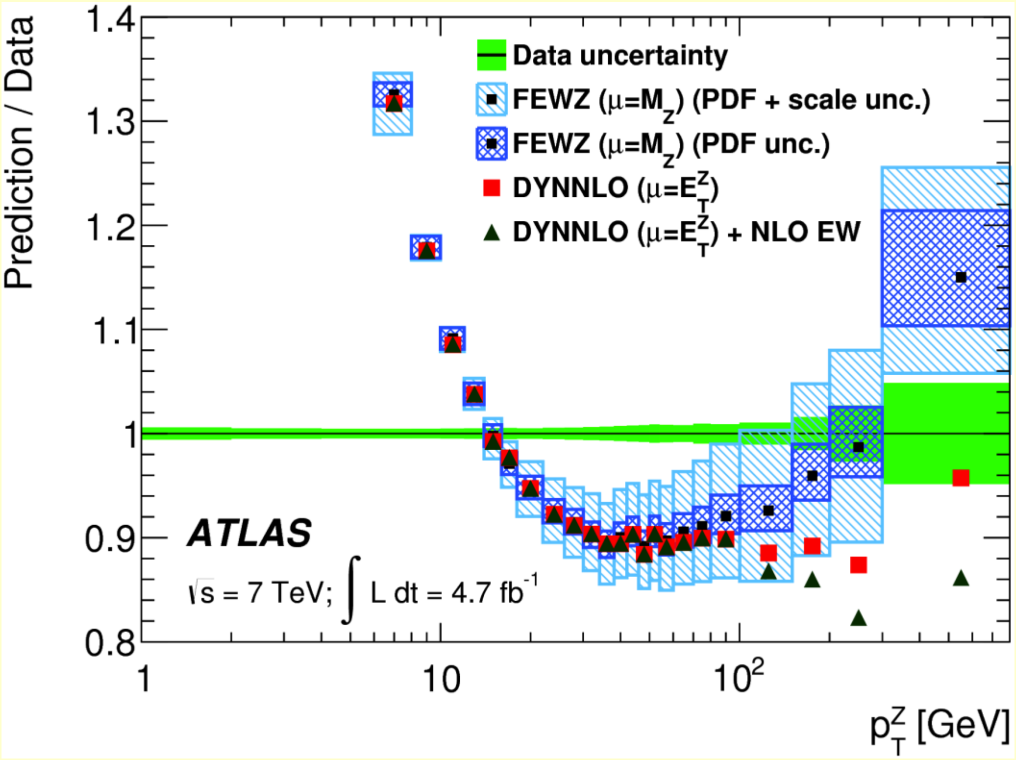


Further possibilities: Z production

JHEP09(2014)145





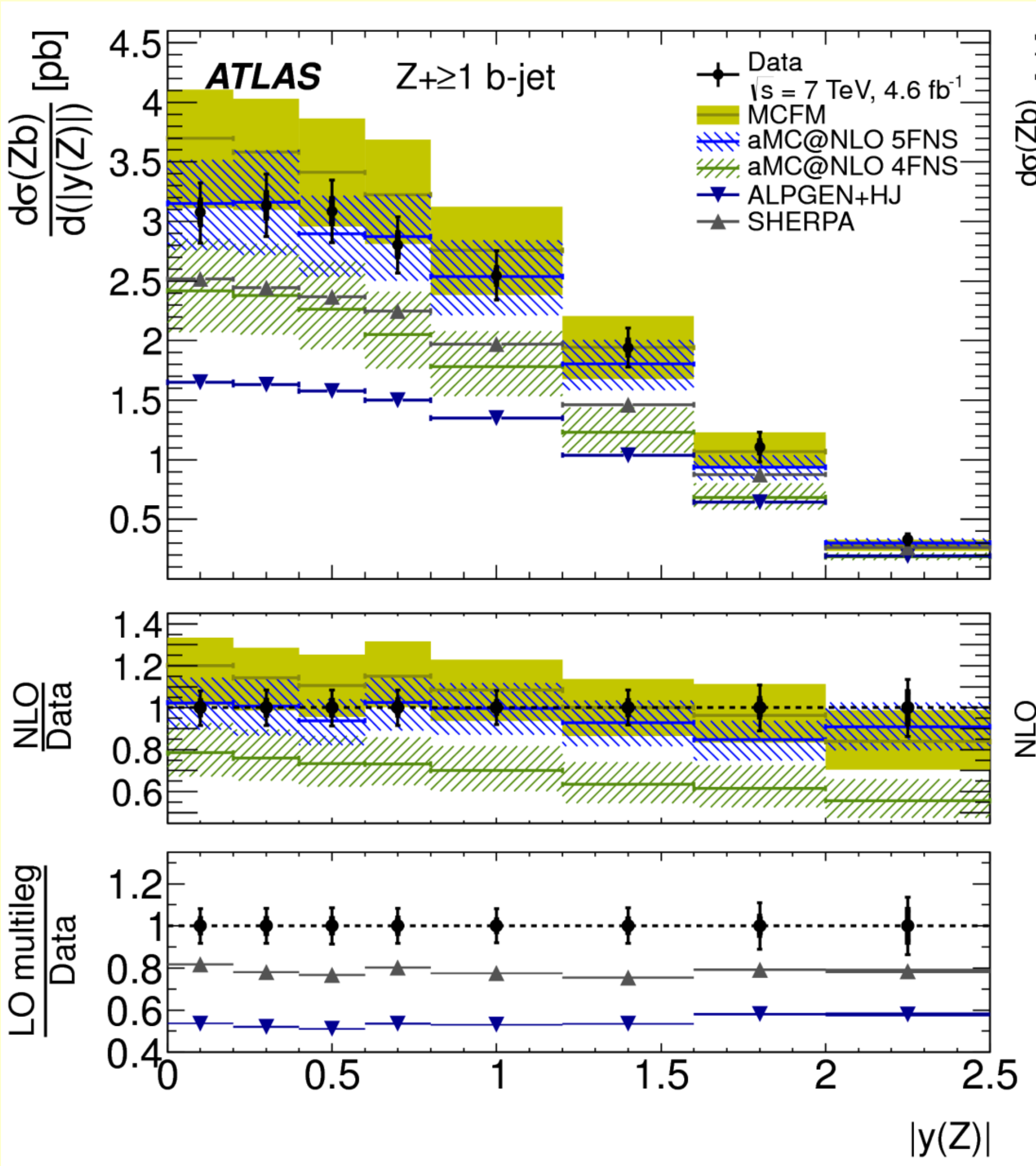


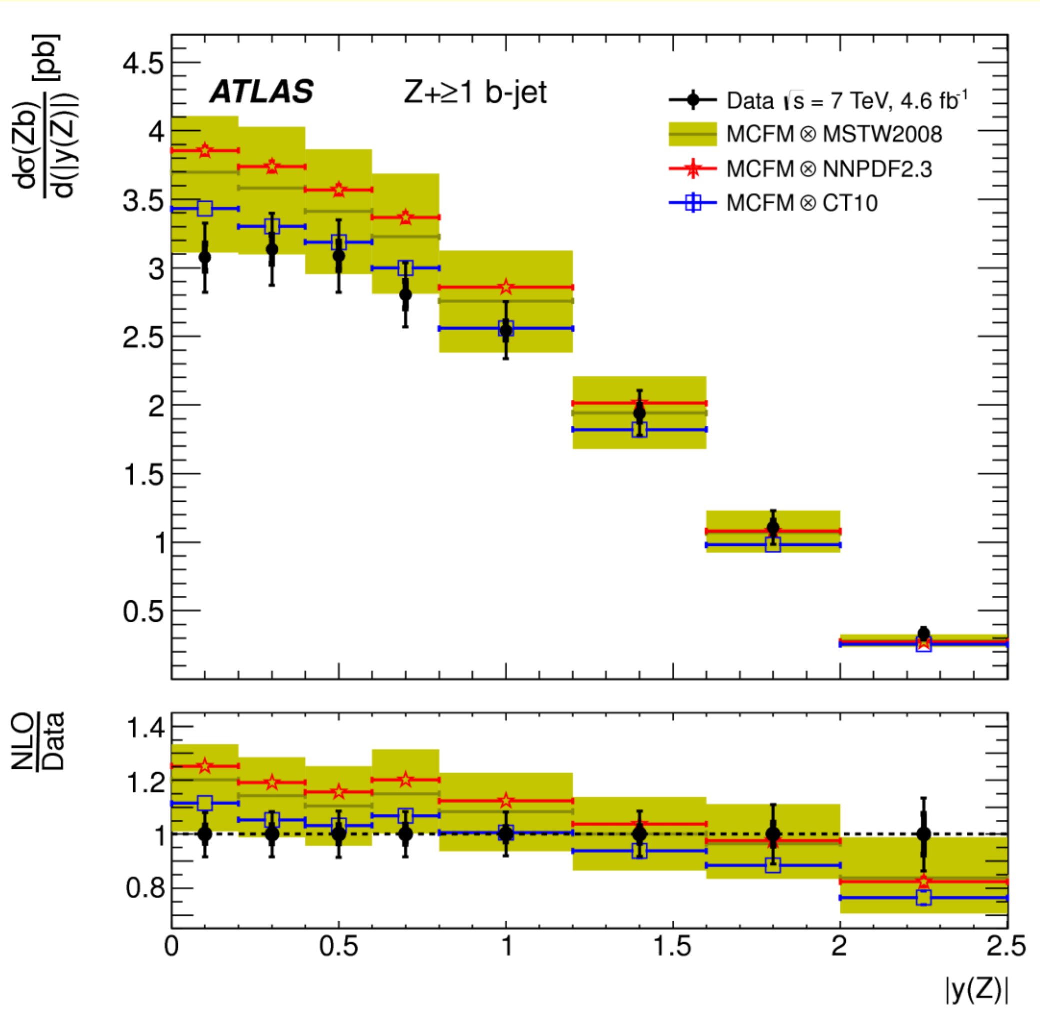
NLO+NNLL uses CTEQ6m PDFs

FEWZ, DYNNLO, ResBos use CT10

Modelling needs to be well understood.
Difficult to use this variable to constrain PDFs.

JHEP10(2014)141

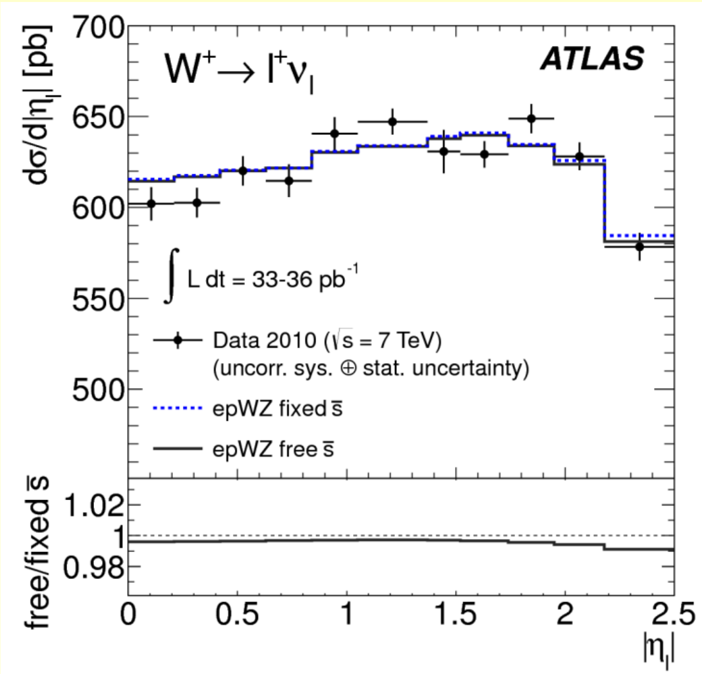


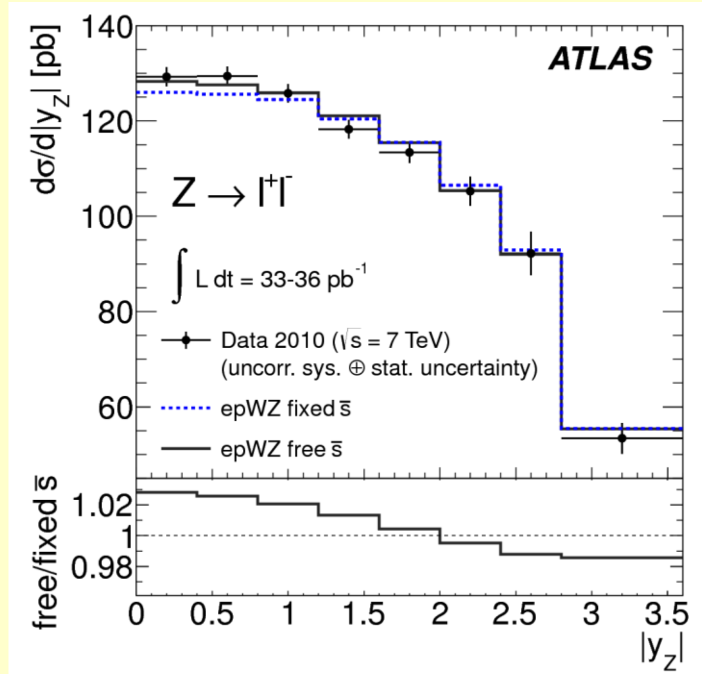


Scale errors dominate, and MCFM and aMC models work. Scope for improvement in PDF sensitivity.

W, Z to evaluate strange quark density in proton

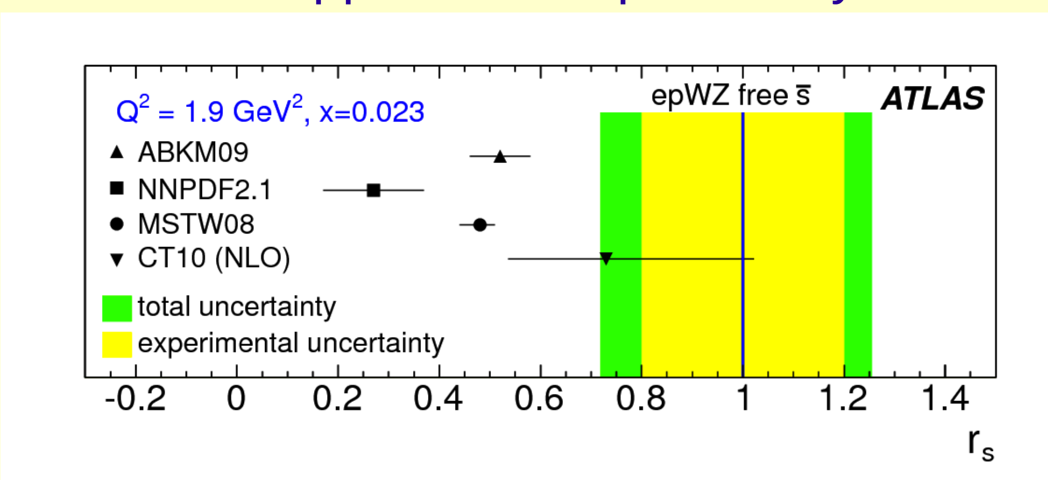
PRL109 (2012) 012001

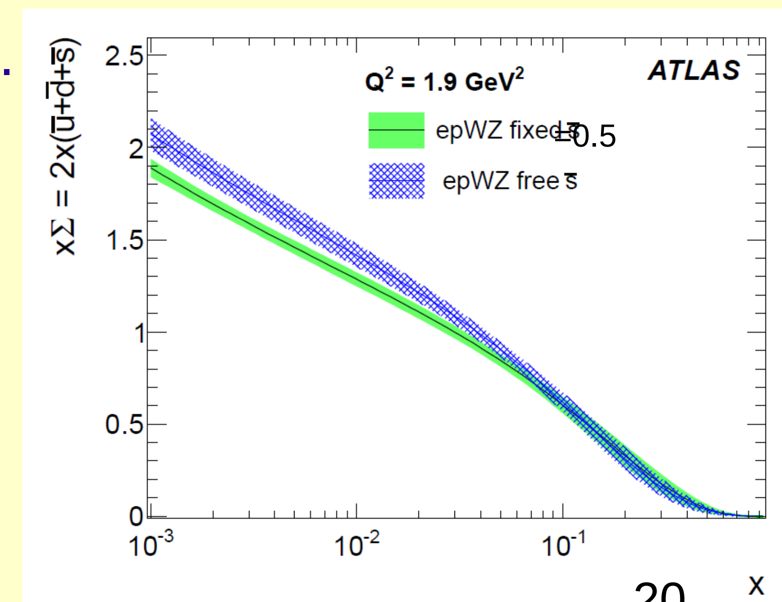




Do NNLO fit in combination with HERA data. (Inclusive ep scattering)

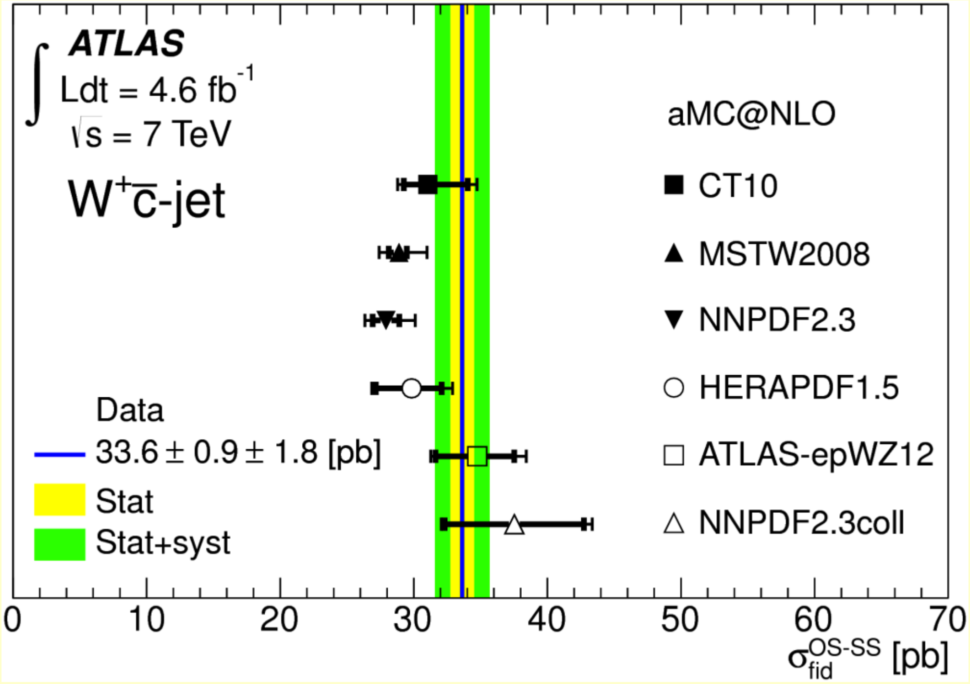
Extract $r_s = 0.5(s + s)/d$ Result affects other quarks. Is its value suppressed as previously assumed?

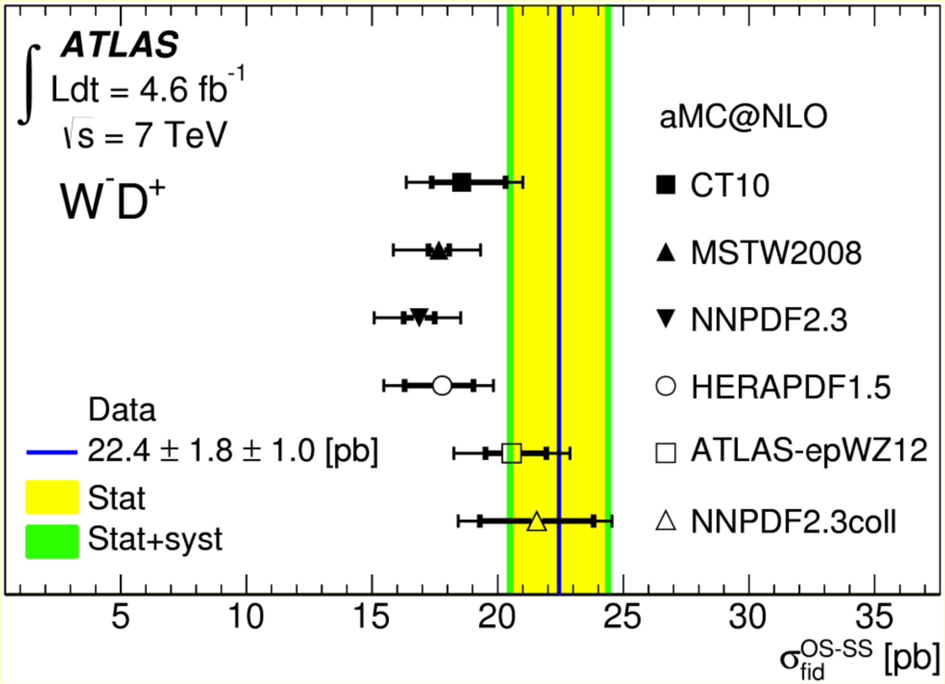




W + charm

JHEP05(2014)068

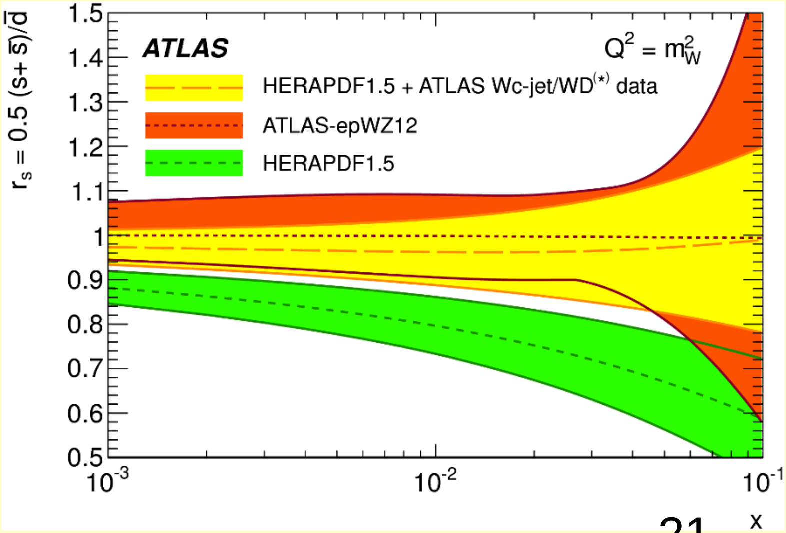




W + charm jet and WD cross sections best described by epWZ12 and NNPDF2 PDFs, which have unsuppressed c density.

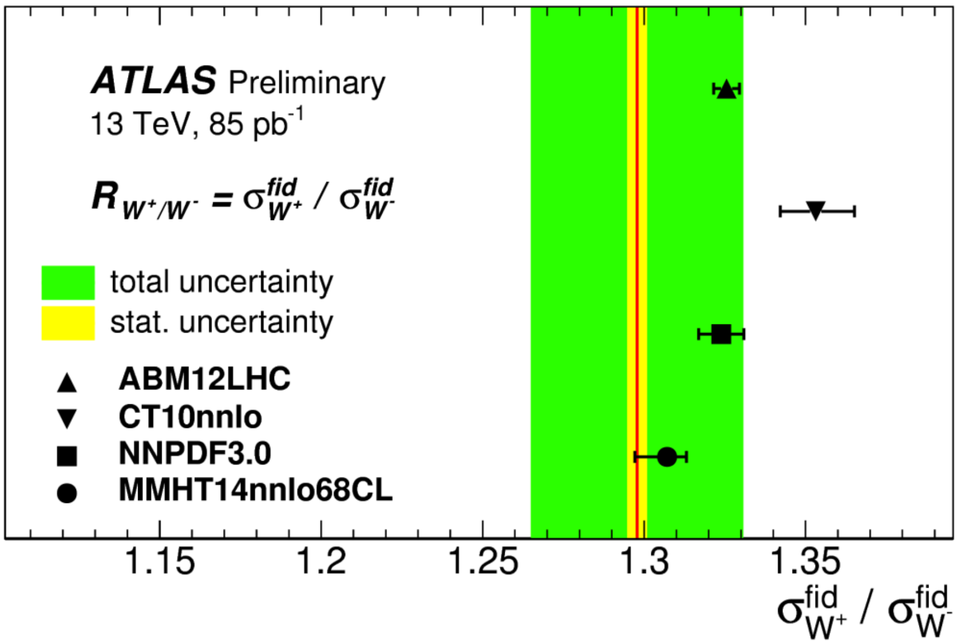
HERAFITTER allows r_s to be fitted and favours an unsuppressed value. Consistent with W, Z result.

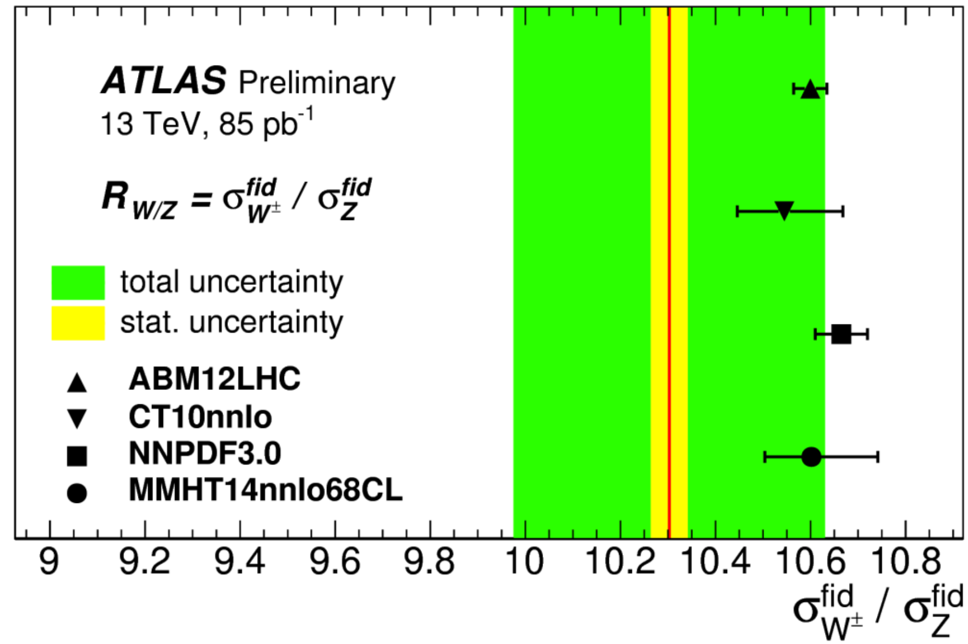
ATLAS is working on charm fragmentation functions to assist this PDF analysis!



W, Z and tt ratios

ATLAS-CONF-2015-039, 049, 033





13 TeV data!

$W \rightarrow \ell\nu$

$Z \rightarrow \ell\ell$ (e and μ)

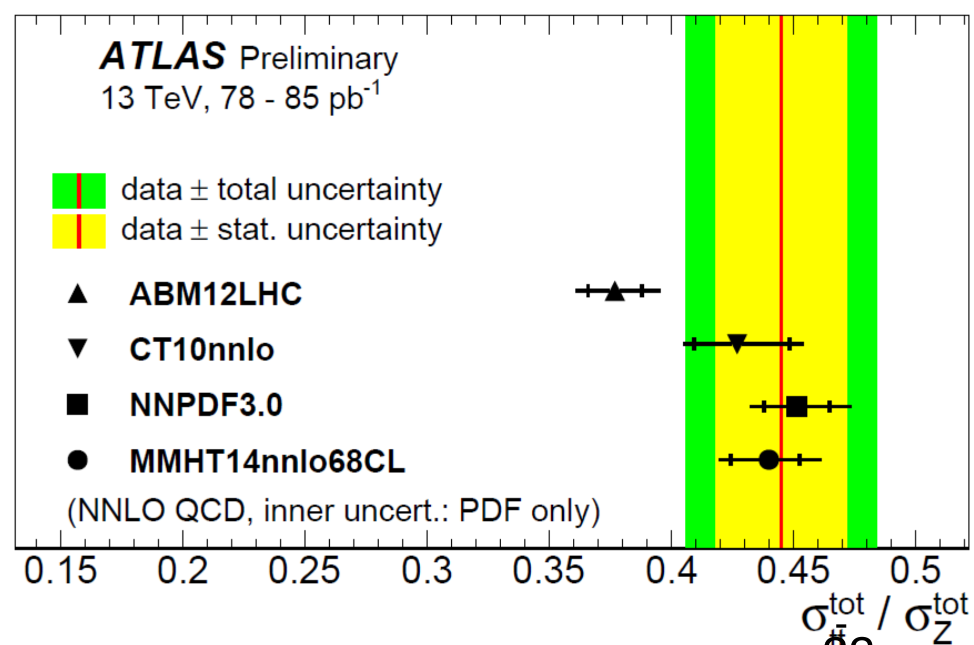
$tt \rightarrow e\mu$

EW corrections applied.

lepton $p_T > 25$ GeV

Total cross sections well modelled.

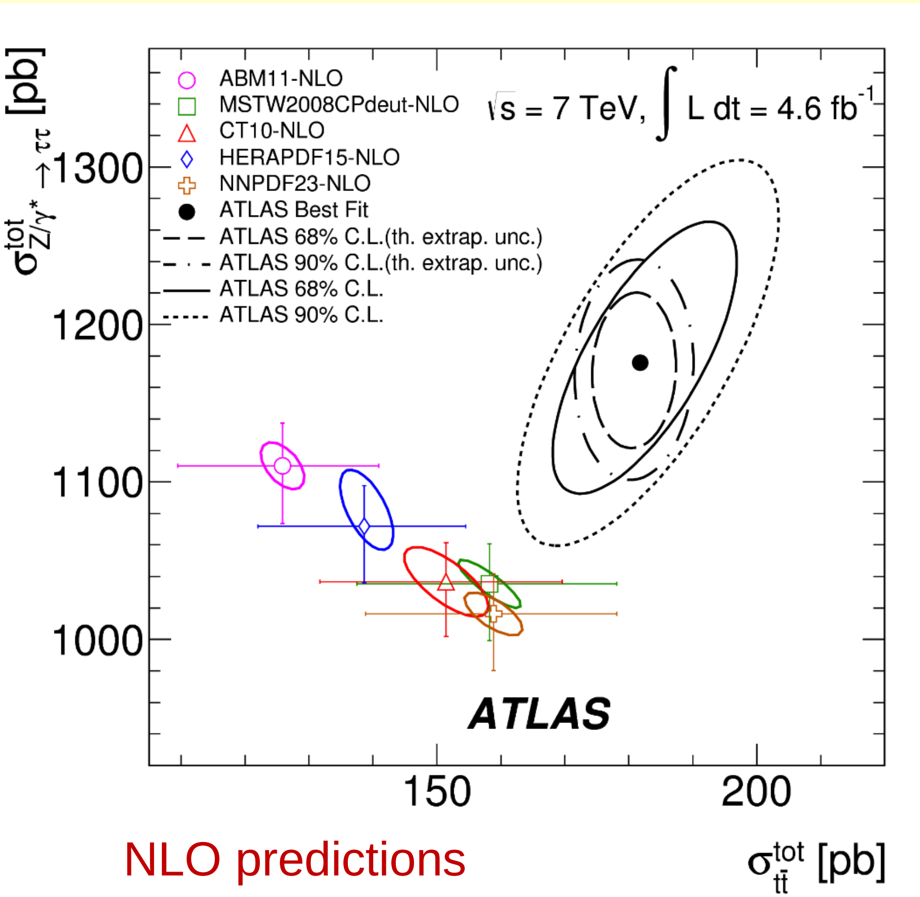
PDF sensitivities in W/Z and tt/Z



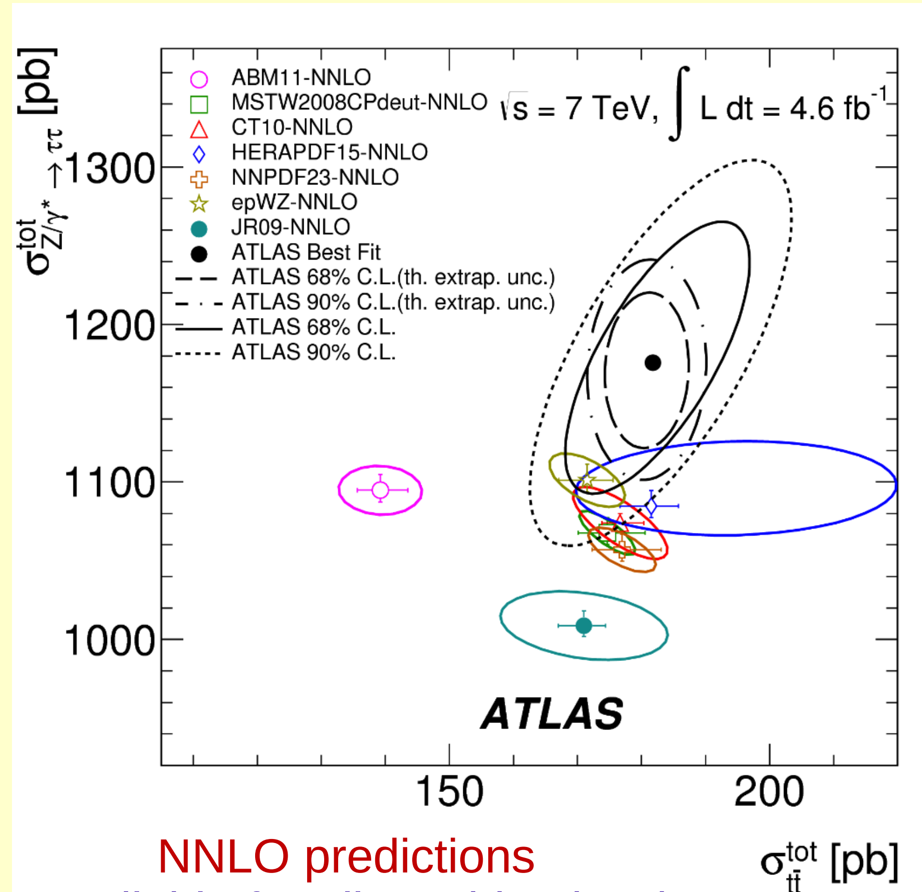
Simultaneous measurement of WW, Z and tt

PR D 91, 052005 (2015)

Z→ττ channel



NLO predictions



NNLO predictions
(not available for all combinations)

NNLO is much better. Other NLO combinations are similar to this one.

Scale uncertainty dominant on NLO, PDFs distinguishable with NNLO.

Most are consistent with data and each other, ABM11 and JR are poor.

Improvements for 13 TeV running:

- Insertible B Layer means better heavy quark measurements and better b-jet tagging
- Higher luminosity will be useful for some channels. (But there will be tougher running conditions to cope with.)
- Jet reconstruction expected to be improved with better techniques.
- Higher energy beams mean new perspectives on QCD processes. But some channels will have higher backgrounds (e.g. tt) and theoretical uncertainties.

SUMMARY

ATLAS have made a large number of measurements that are sensitive to proton PDFs. But in each case one must be confident in the basic theoretical description.

In many cases, there is good symbiosis with HERA measurements.

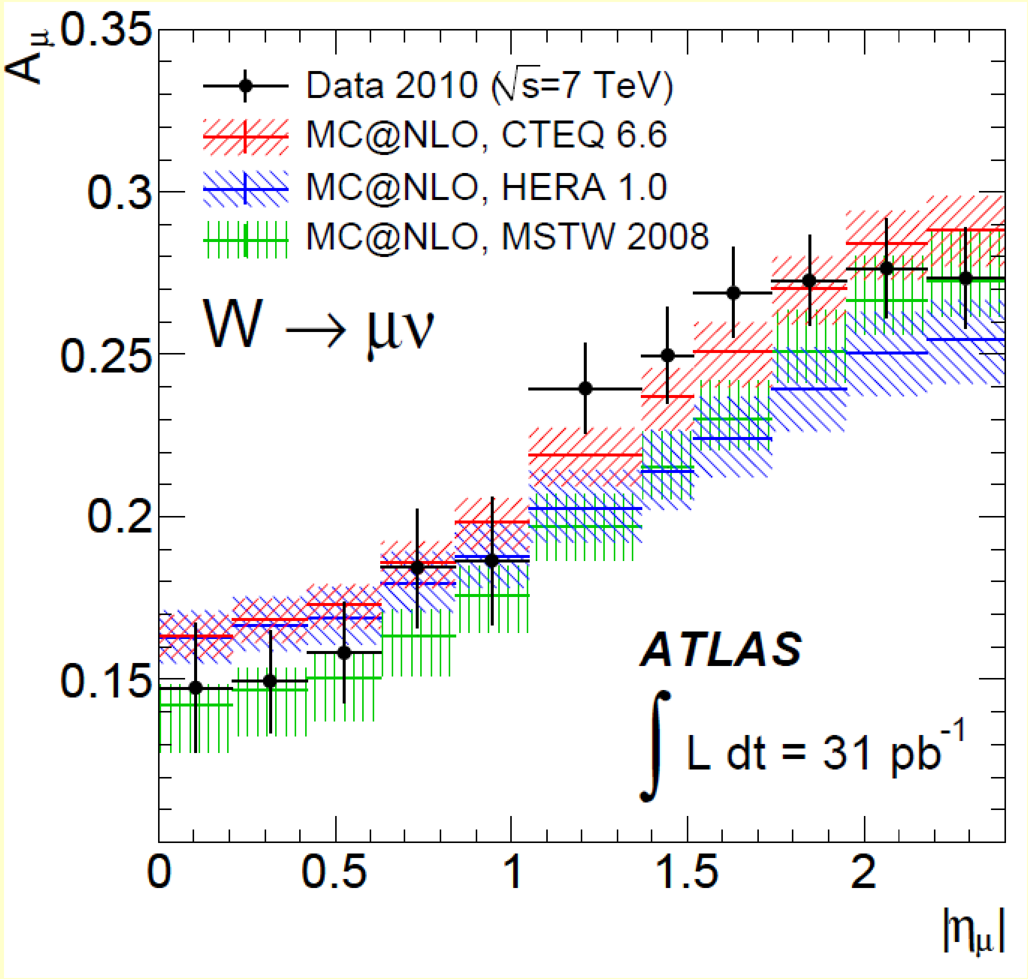
Theory errors and energy scale errors can be significant.

This progress will continue with the 13 TeV data and improved theoretical and experimental understandings. Also new kinematic reach is achieved.

Backups

W+/W- asymmetry

Phys.Lett. B701 (2011) 31



muon asymmetry.

A measurement that
is worth improving
if possible.

NNLO?

More topics

- The Z forward-backward asymmetry has potential sensitivity to PDFs, being looked at. Can use for better Weinberg angle measurement but only by improving PDF uncertainties by factor of 10.

- The extracted value for the W mass from the measured lepton specturm has sensitivity to PDFs, needs attention for getting the most precise values: