New ATLAS measurements to constrain the parton distributions in the proton

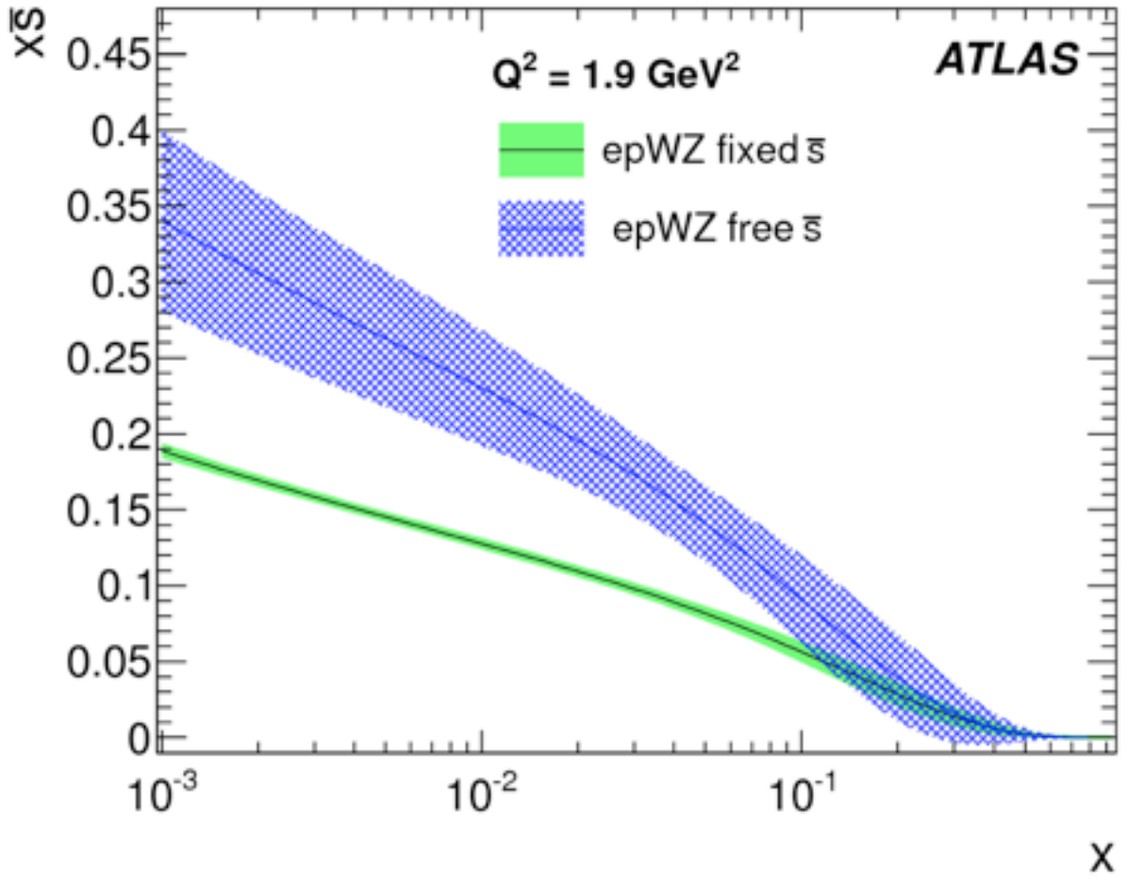
Mark Sutton,

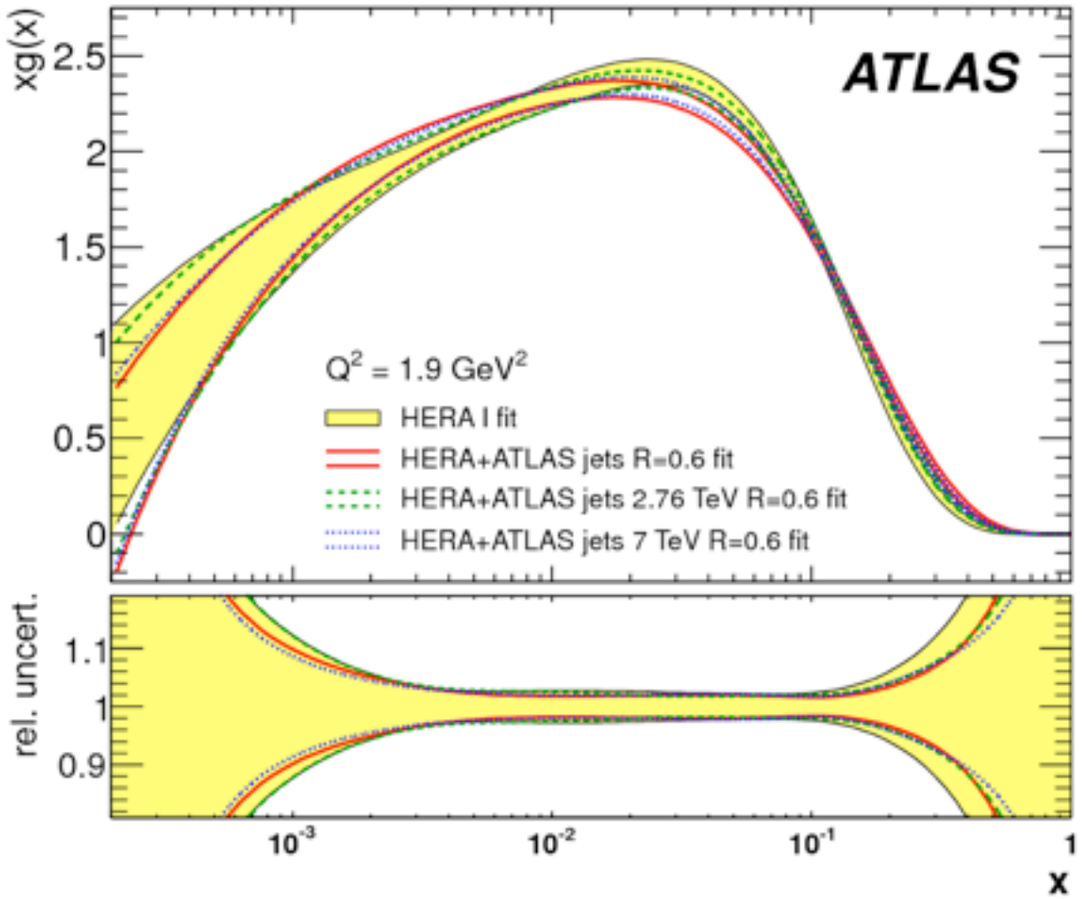
The University of Sussex

On behalf of the ATLAS Collaboration

Preface

- Previously, ATLAS has presented data, and fits, based on EW boson production, and jet data at 7 TeV and 2.76 TeV
  - $r_s = (s+s)/2d \sim 1.0$
  - Enhanced gluon contribution at high x
- ATLAS now has a significantly larger data sample allowing analyses with increased statistical precision, significantly at higher E_T
- Together with this, ATLAS has an increasingly large, and developing portfolio of precision measurements
  - Will discuss here only a subset of those which will be useful in a QCD fit
    - Dijet production
    - Inclusive prompt photon production
    - ttbar production
    - High mass Drell-Yan
    - Electroweak boson production with charm
- Developments with APPLgrid mean that all these processes can in principle be included simultaneously in a QCD fit



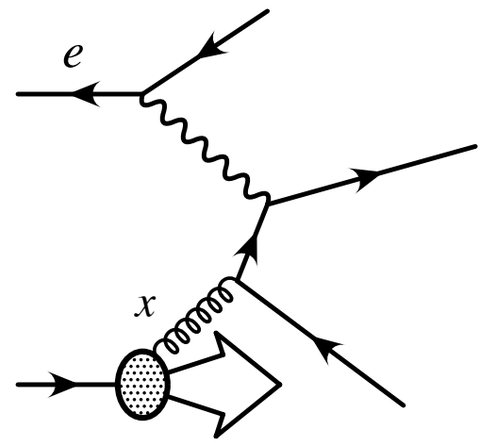


What are the contributions?

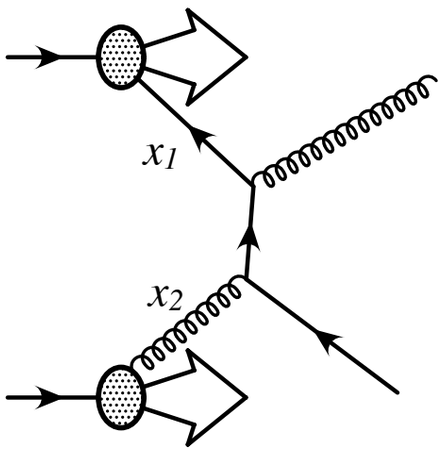
- Different final states provide information on different subprocesses
  - Published ATLAS fits currently, and will continue to include published HERA data
  - DIS, at Born level, scattering off of quarks, one momentum parton fraction *x*

$$d\sigma_{\rm DIS} \sim (1-(1-y_{\rm Bj})^2)F_2(x,Q^2) - y_{\rm Bj}^2 F_L(x,Q^2)$$

$$F_2 = x\sum_q e_q^2(q(x)+\bar{q}(x))$$



  - Sensitive to the gluon distribution only through $\mathcal{O}(\alpha_s)$ corrections

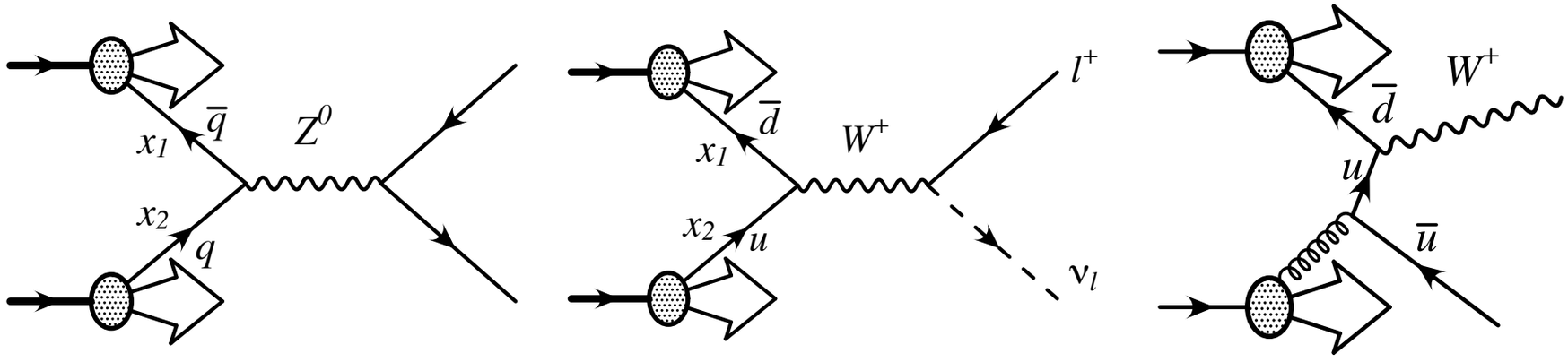


- For LHC collisions with two momentum fractions, x_1 and x_2

$$d\sigma = \sum_{i,j}\int dx_1 \int dx_2 \; f_i(x_1,\mu_F^2) f_j(x_2,\mu_F^2) \; \hat{\sigma}_{ij}(x_1,x_2,\mu_R^2)$$

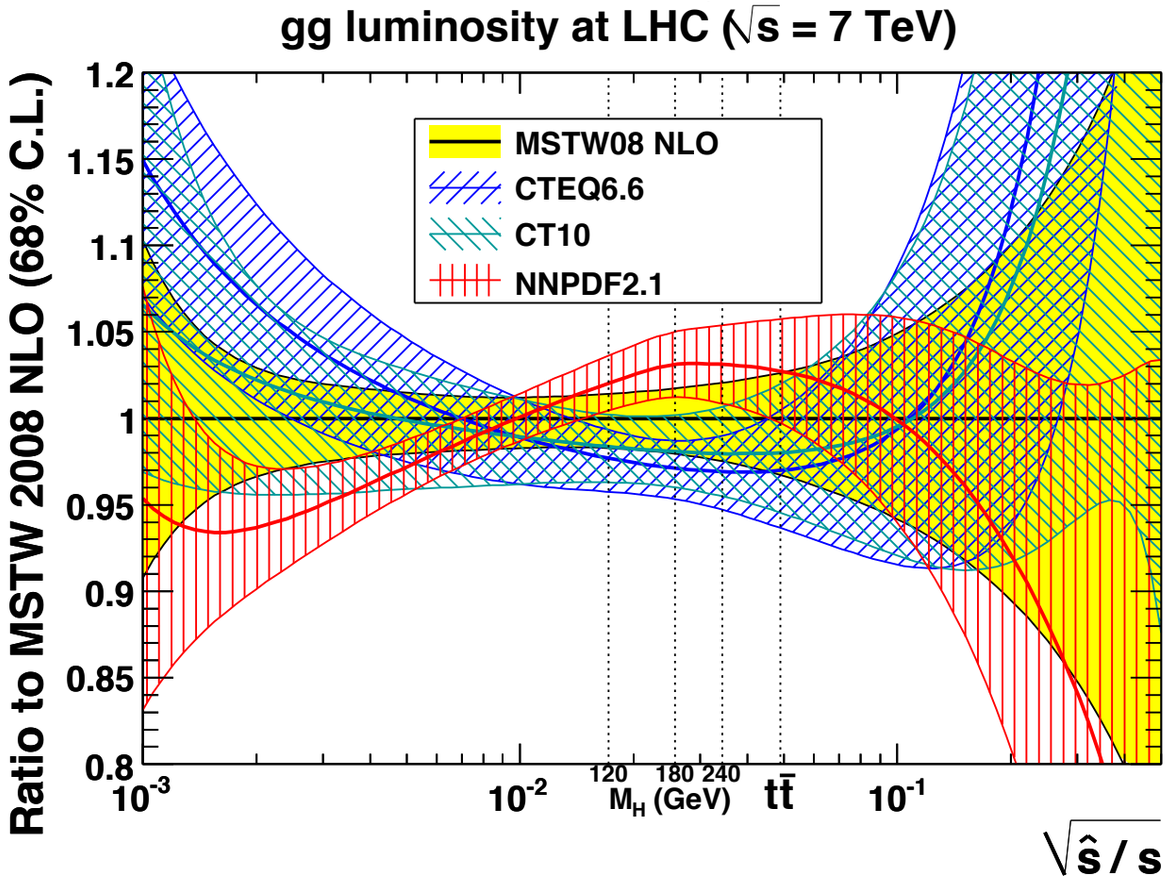
- Dijet production, ttbar, inclusive photon … all directly sensitive to the gluon distribution and the strong coupling - and the valence quarks at high E_T

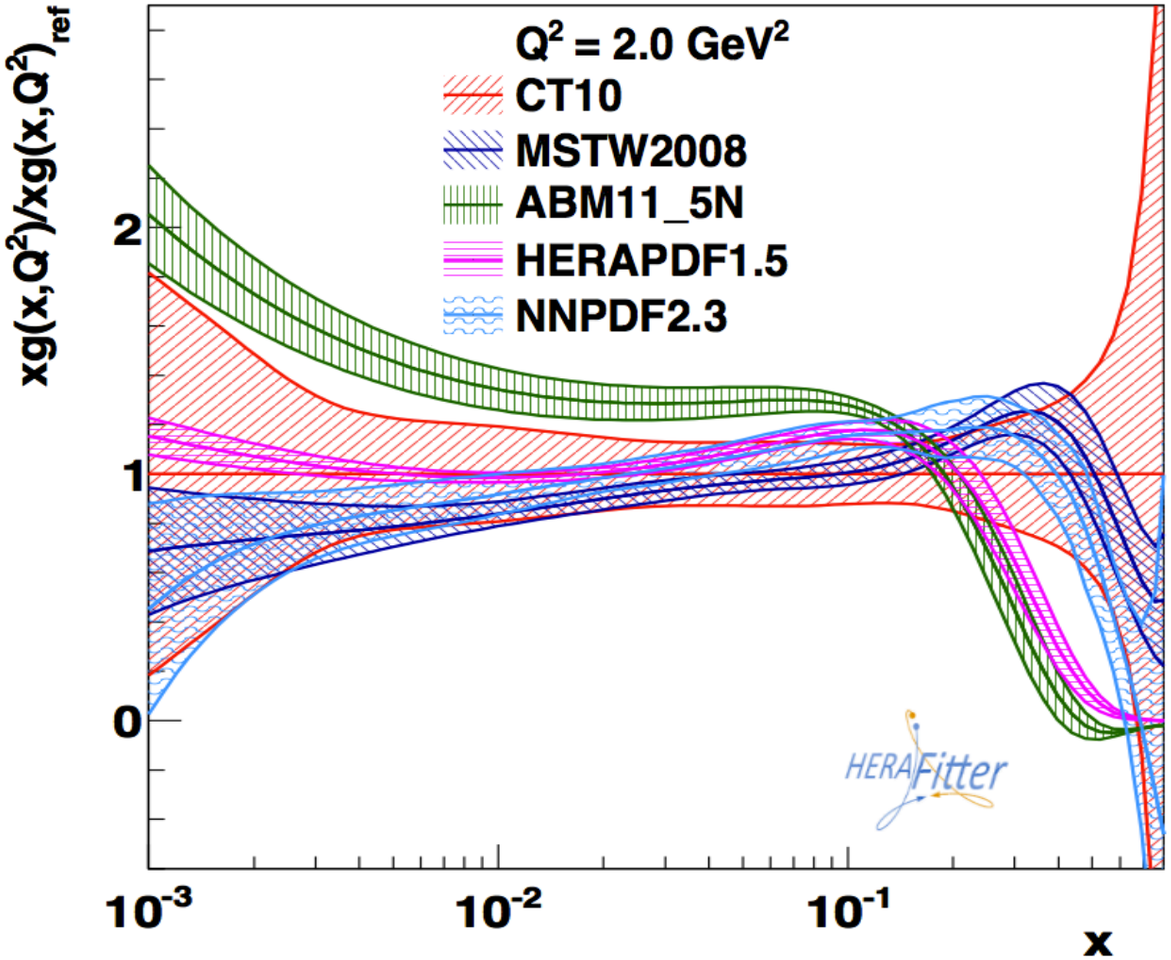
- Electroweak boson production sensitive to the valence and sea quarks
- EW bosons + jets also sensitive to the gluon



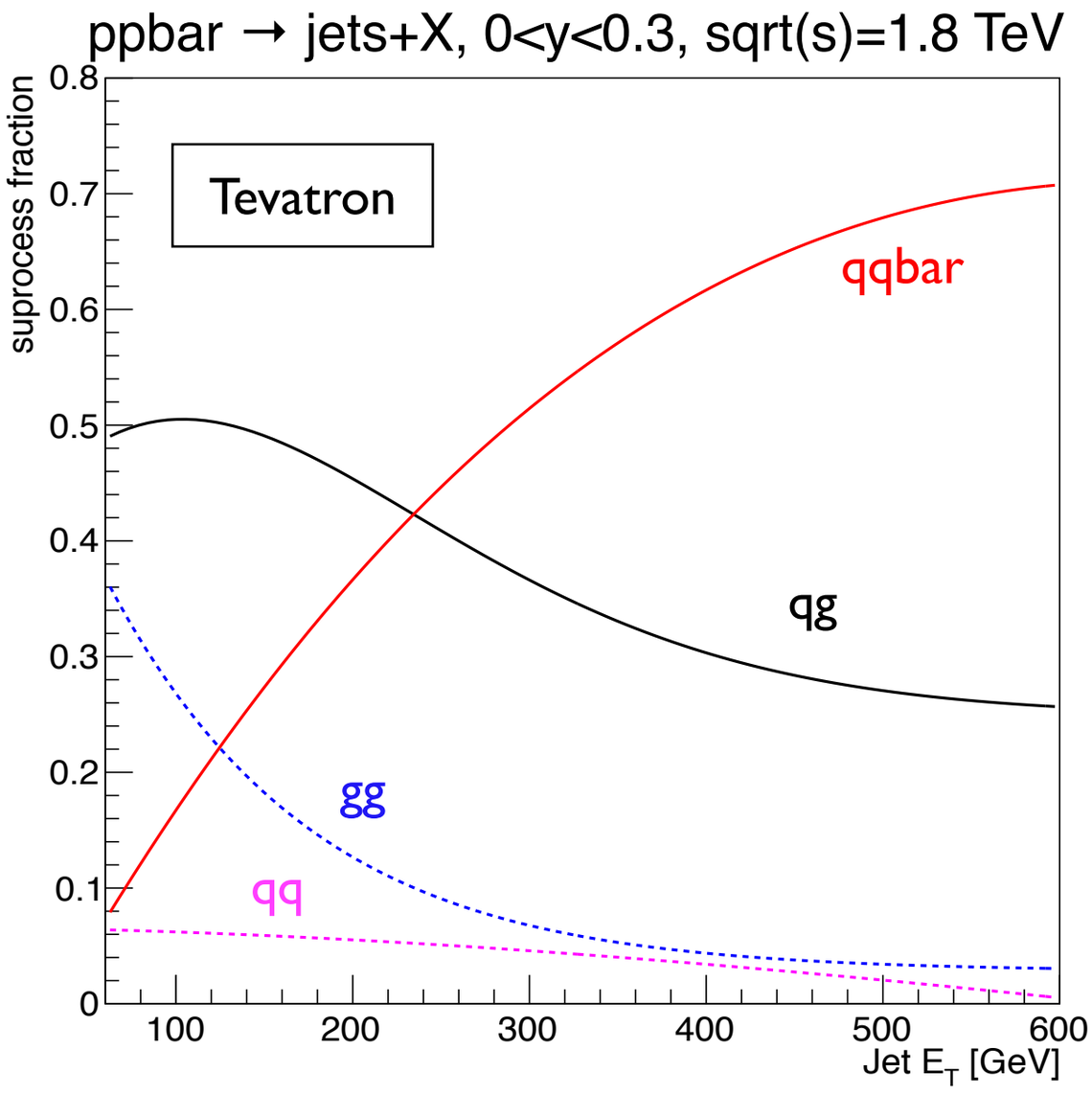
The gluon

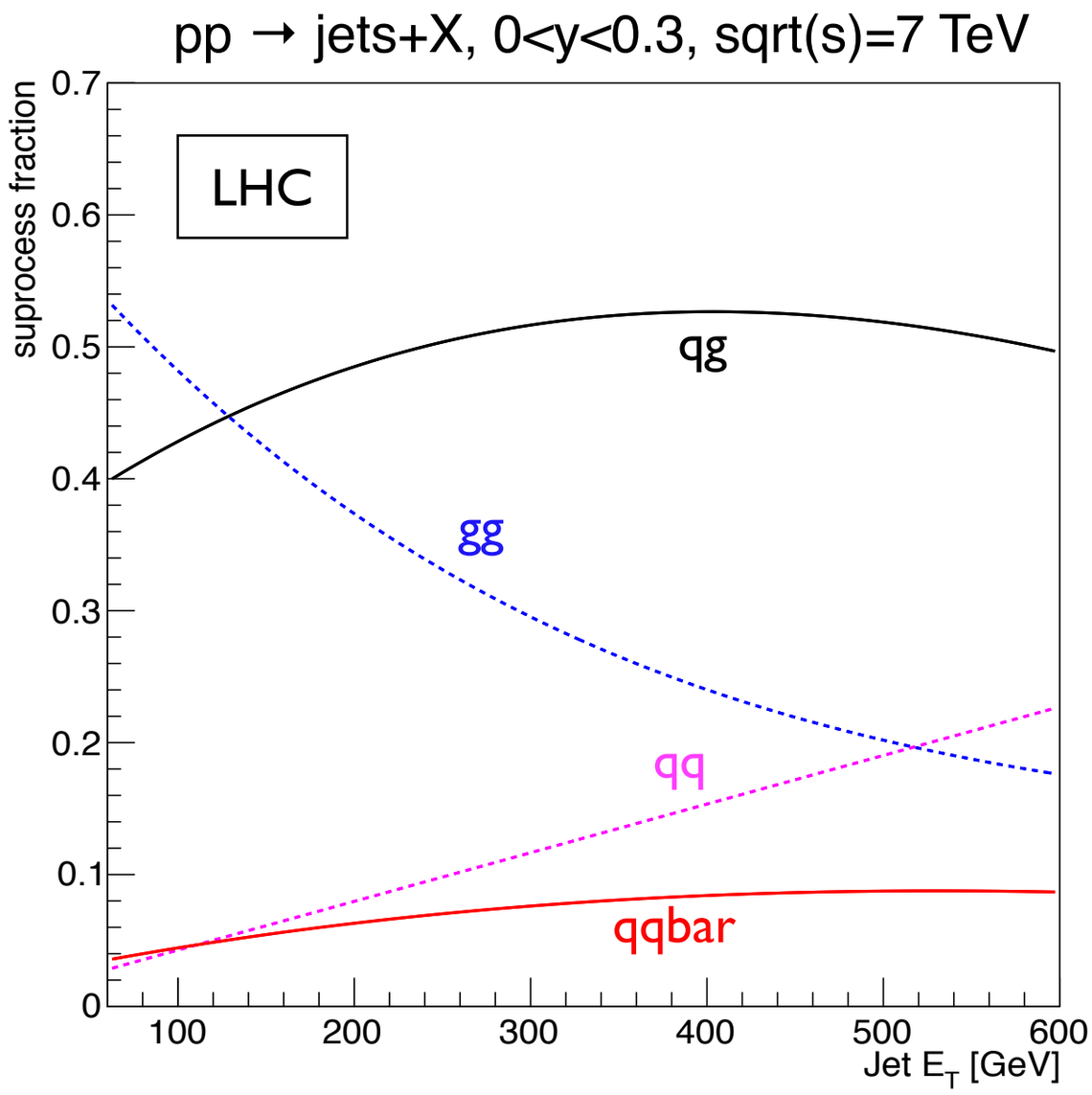
- PDF fits only constrained to data with lower momentum transfer than available at the LHC have large uncertainties for the LHC kinematic region
  - As large as ~ 5% for the gg→Higgs (and larger) for top production
  - Softer gluon distribution from ABM
  - HERPDF also slightly softer that CT10 (reference) at high x, but normalisation the same at lower x





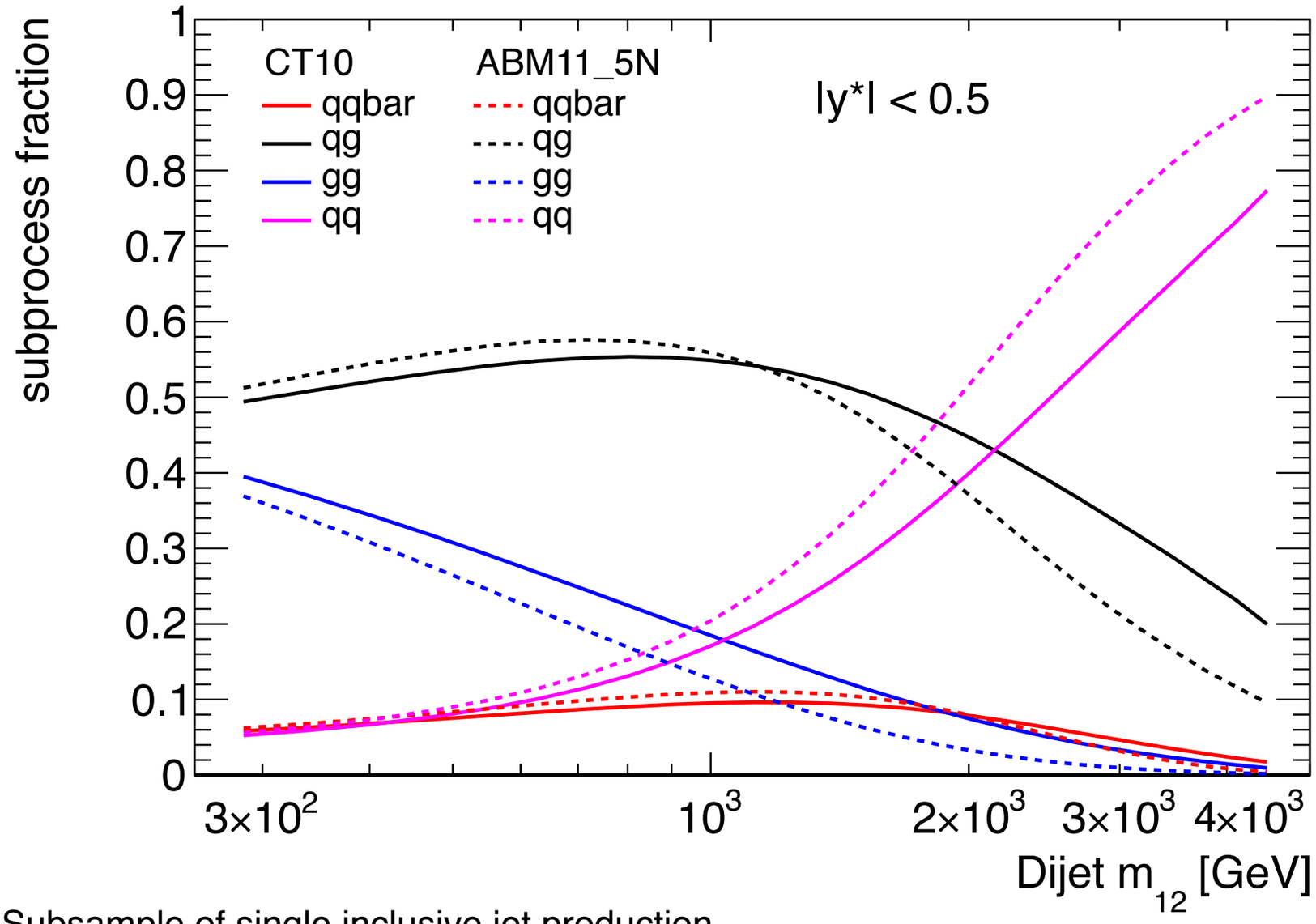
Incoming partons - inclusive jet production





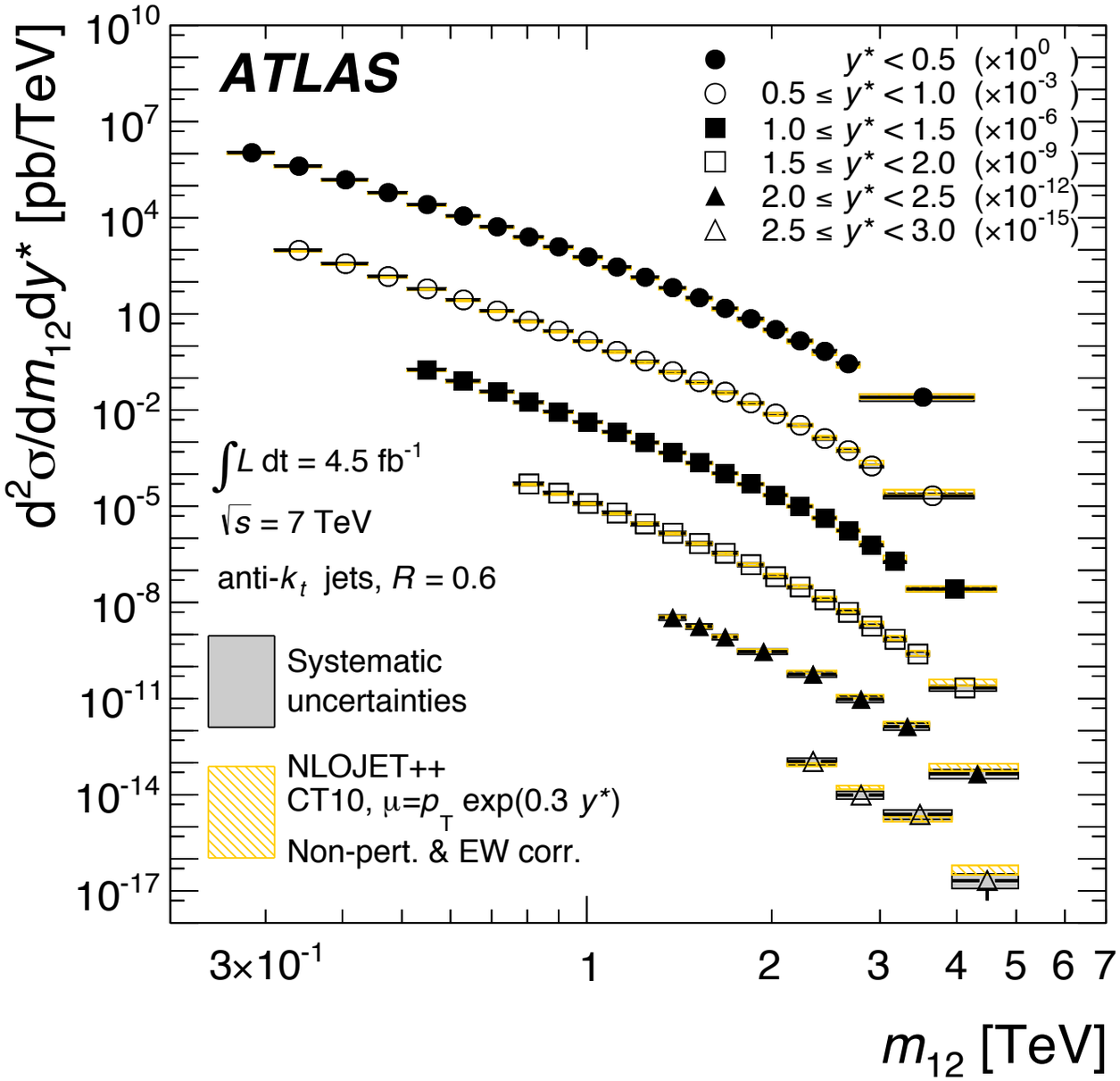
- High E_T jets (~ 500 GeV) at the Tevatron produced predominantly due to qq scattering.
- At the LHC, 500 GeV jets are produced from partons at much lower x
  - More significant contribution from the gluon
  - Larger phase space for initial state radiation.

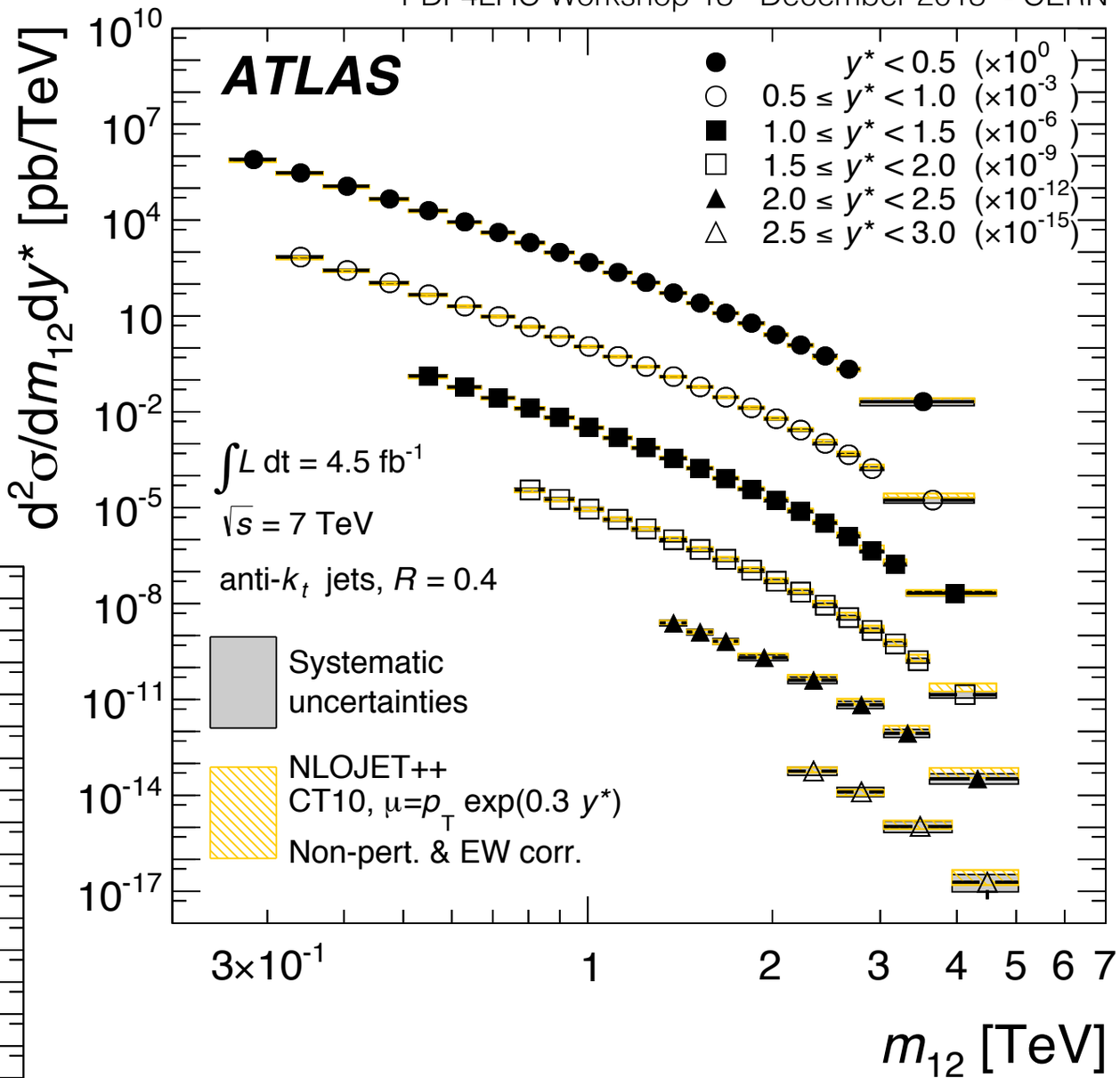
Dijet production



- Subsample of single inclusive jet production
- Subleading jet requirements may increases the renormalisation scale uncertainty,
- But have better control of hard process kinematics
- Still differences between PDF sets
  - Most notable at high masses and high ET where the data statistics are low and less constraining
- ABM typically has a softer gluon distribution

Dijet production from 2011data

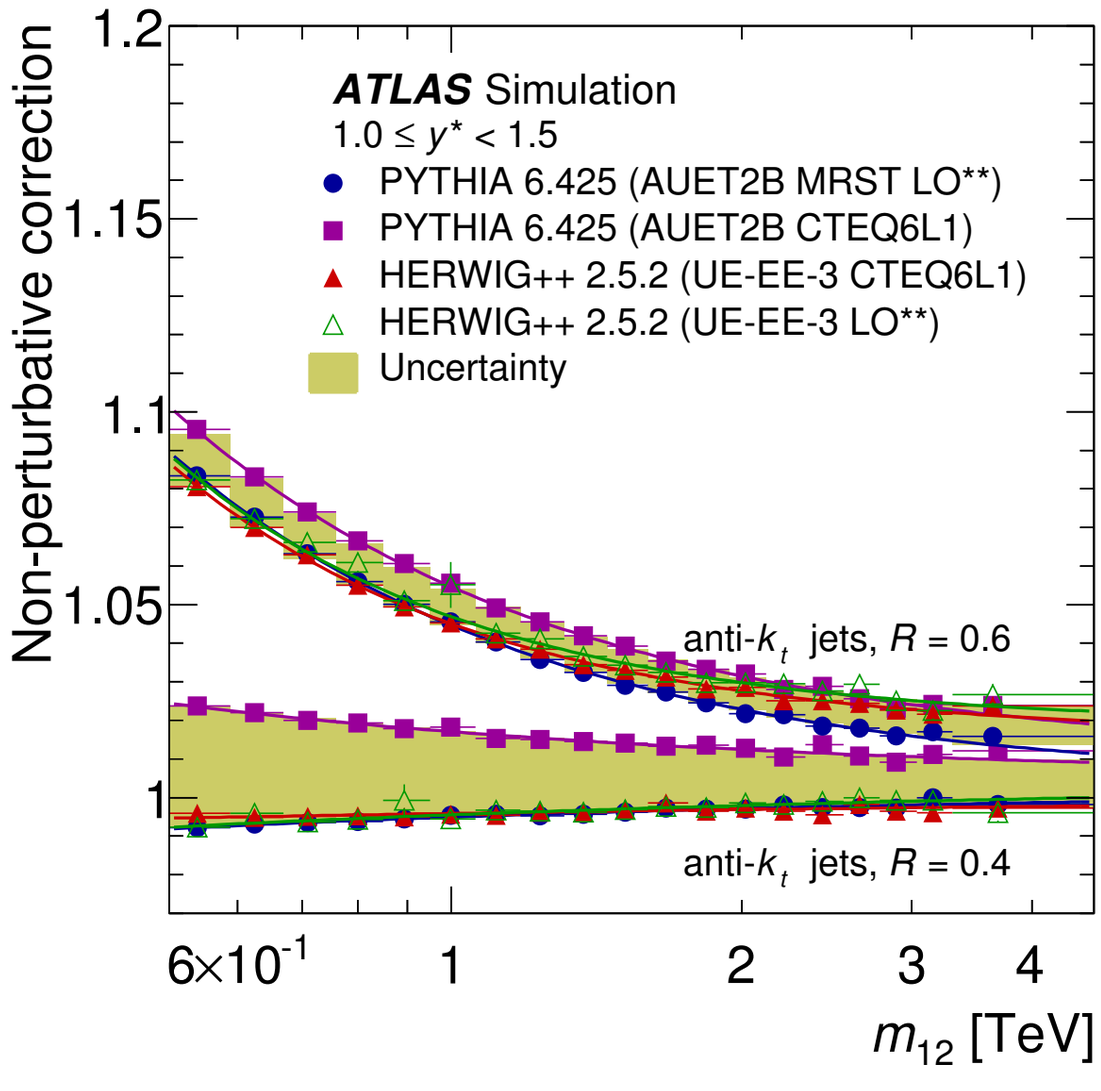


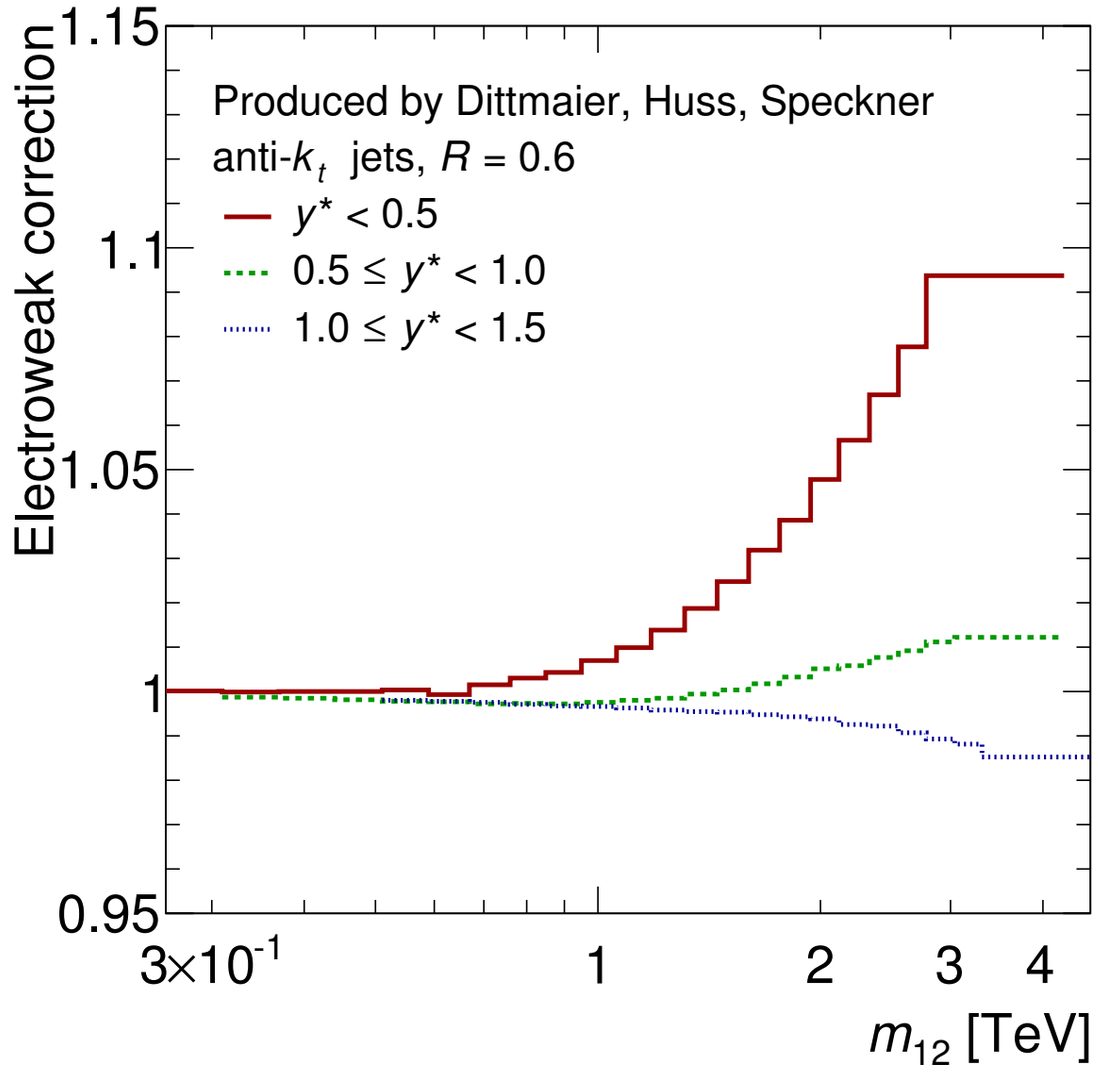


- **Submitted to JHEP: arXiv:1312.3524**

- Mass range from 300 GeV to ~5 TeV
- QCD does a reasonable job of describing the data over 8 orders of magnitude of the cross section

Nonperturbative and electroweak corrections





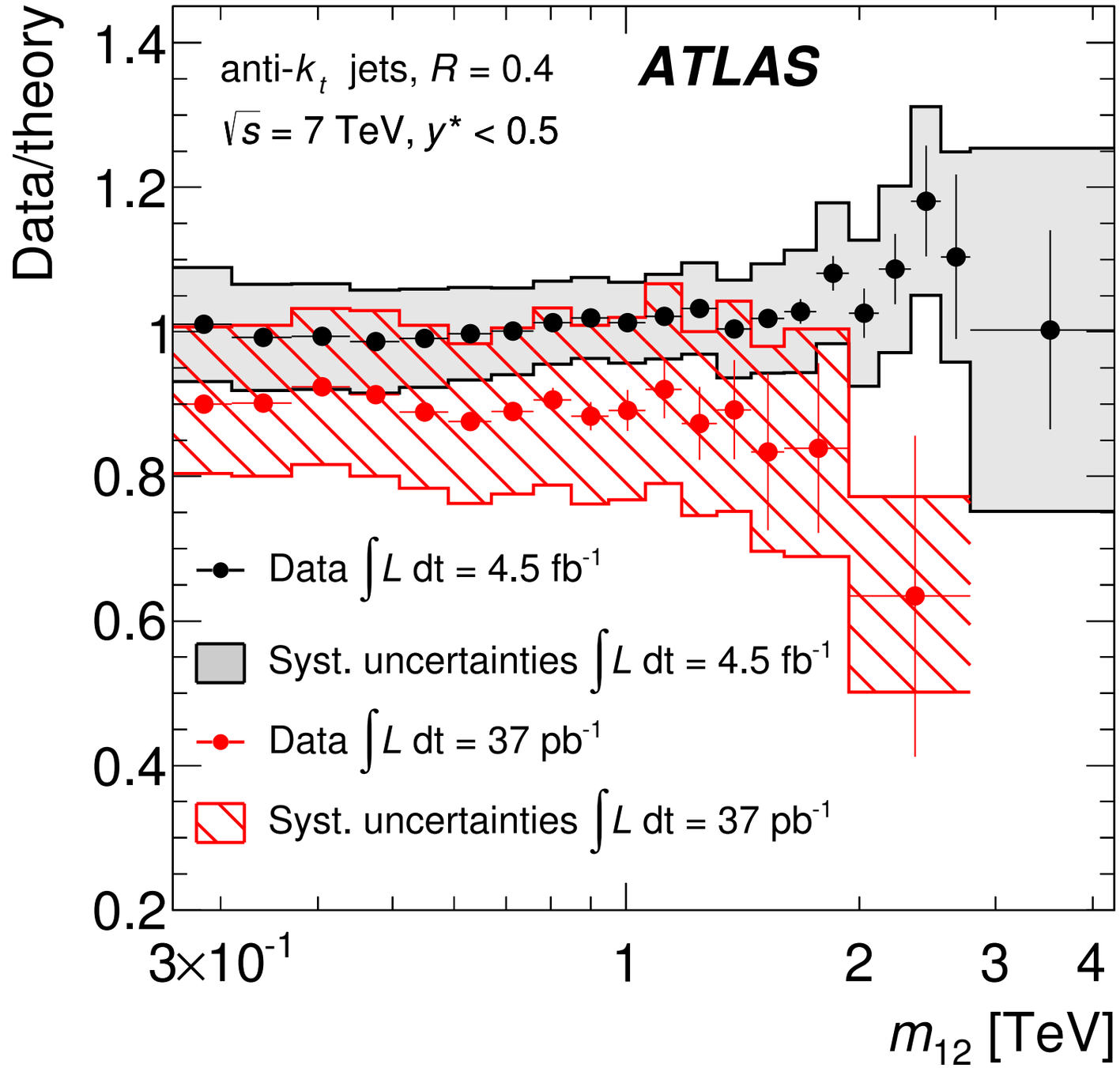
- Potentially large non-perturbative, (hadronisation and underlying event) corrections
  - Less significant for smaller jet radii

- Electroweak corrections as high as 10% for low rapidity high mass dijets pairs

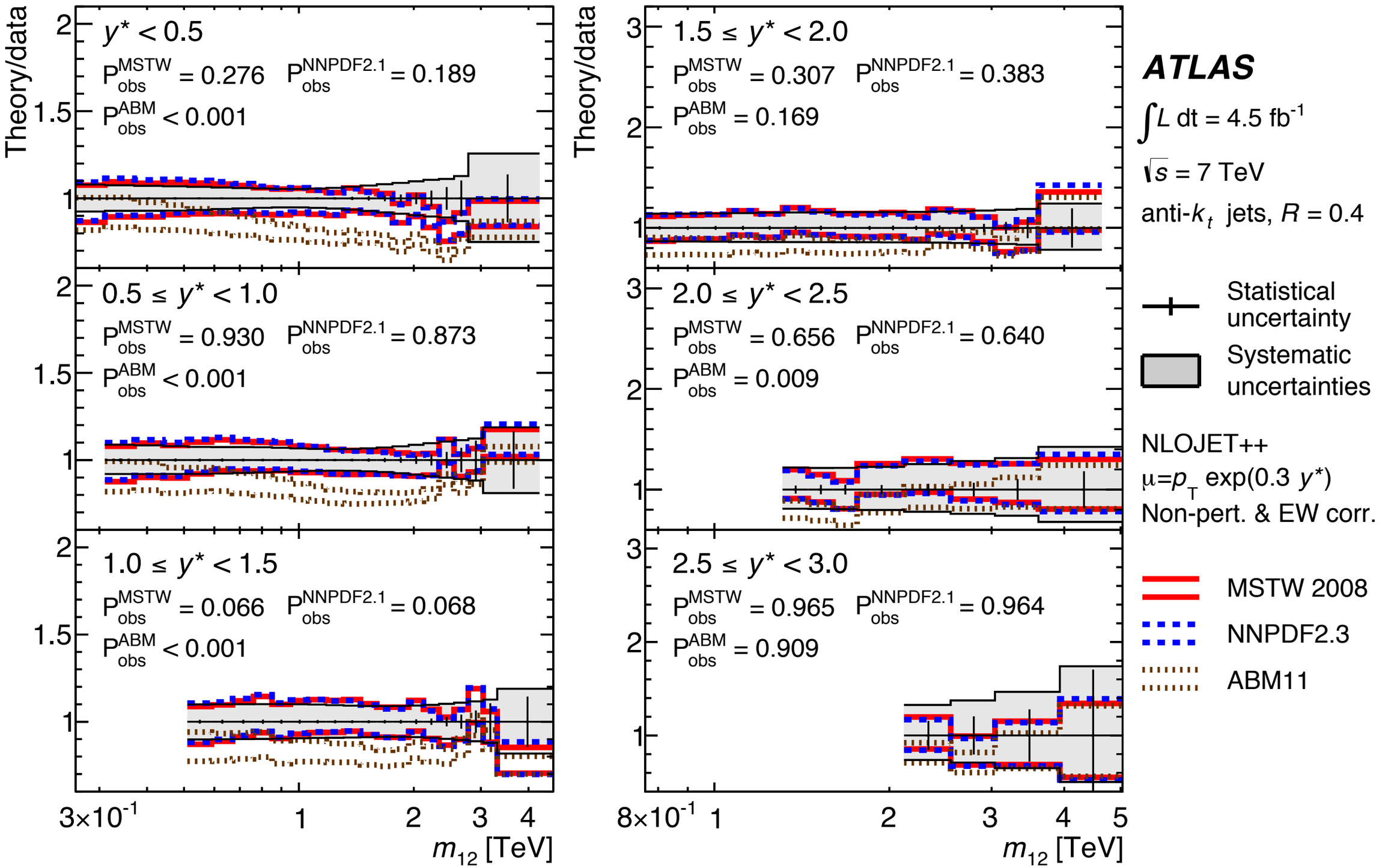
Comparison with 2010 data

- Significant improvement in both statistical and systematic uncertainty with respect to previous measurement
  - Nearly ~ 50 % reduction in systematic uncertainty at low and intermediate masses

- Kinematic range extended by ~ 1 TeV

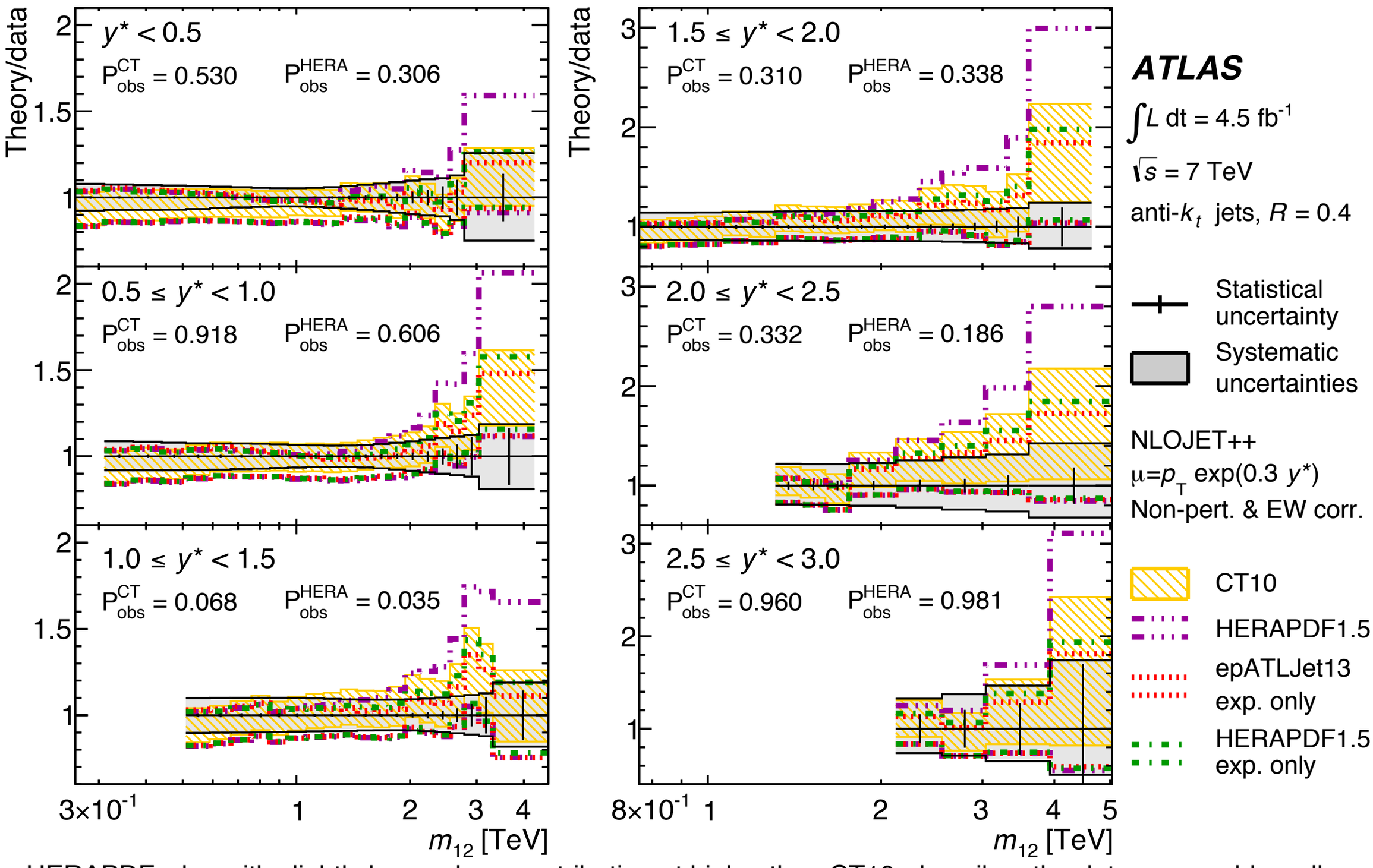


Dijet production from 2011 data



- Lower prediction from ABM, possibly due to the softer gluon

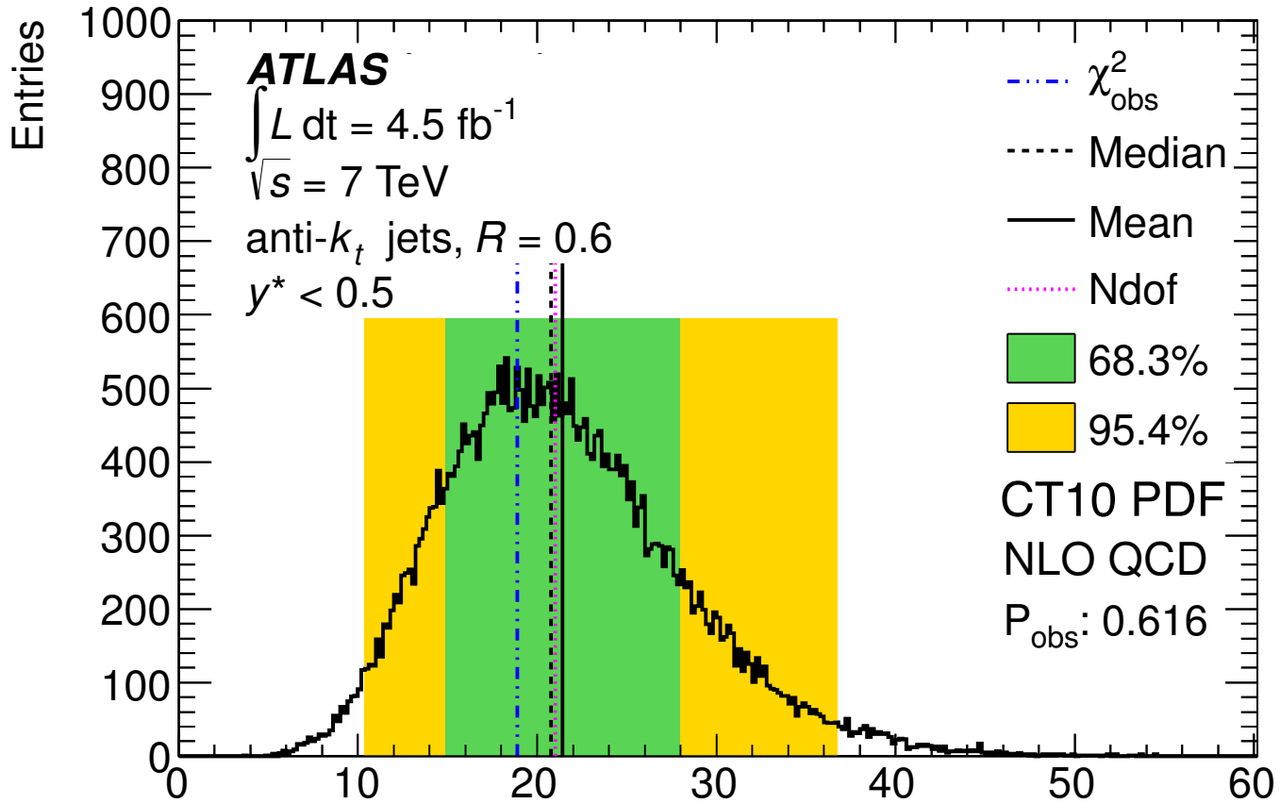
Dijet production from 2011 data



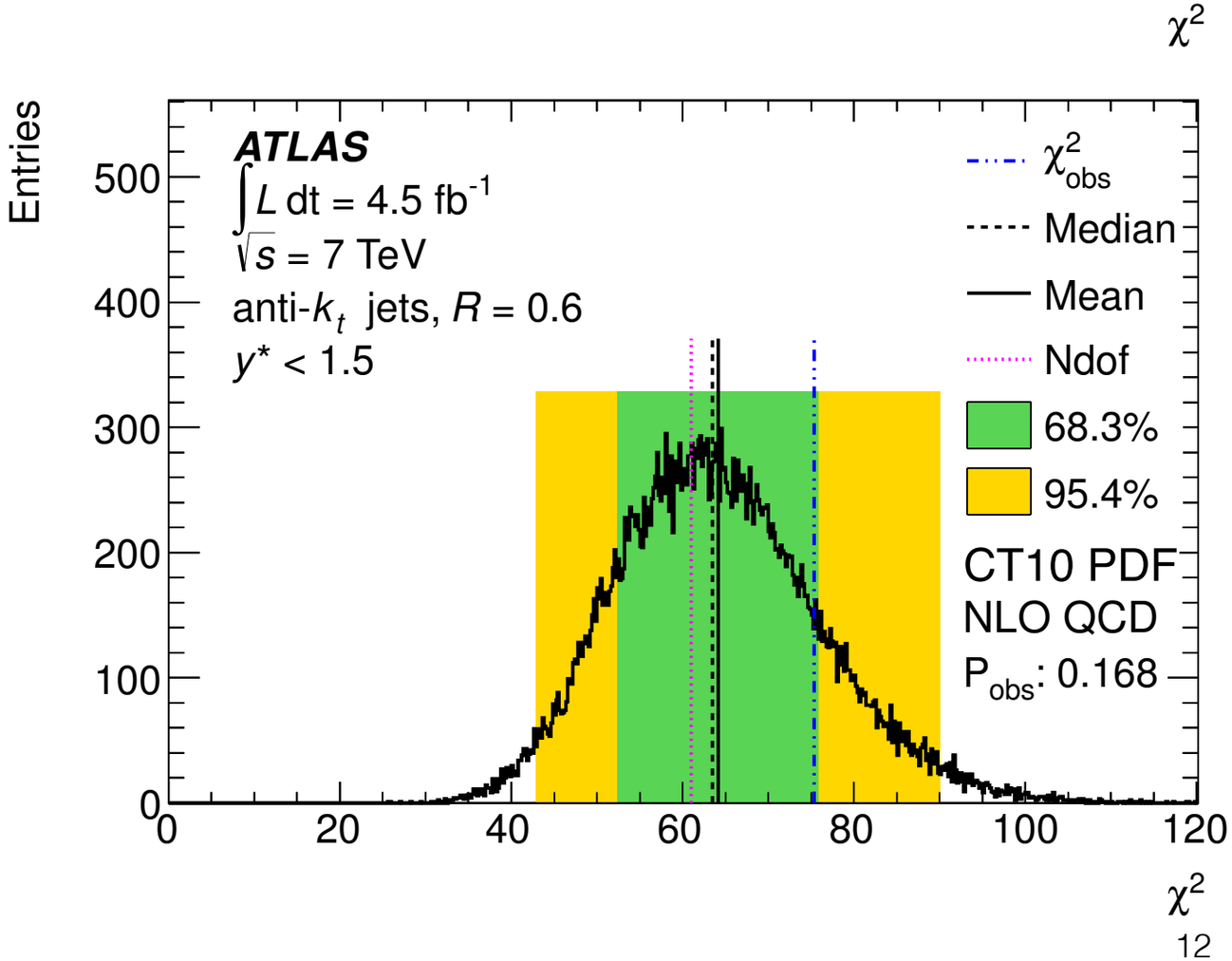
- HERAPDF, also with slightly lower gluon contribution at high x than CT10, describes the data reasonably well
- ATLAS jets fit, epATLJet13 has significantly smaller uncertainties at high masses

Quantitative analysis

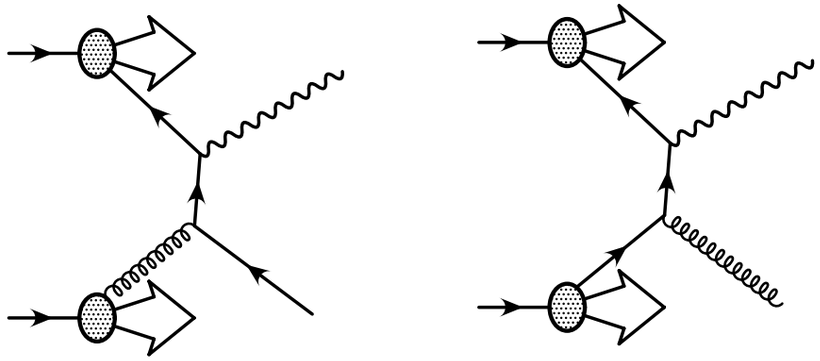
- Generate pseudo-experiments using different PDFs
  - Include PDF and other theory uncertainties in both generation and χ^2 definition
- Calculate the χ^2 for each replica, within the **Full** and **High** mass ranges
  - **High** defined as
    - $m_{12} > 1.31$ TeV $y^* < 0.5$
    - $m_{12} > 1.45$ TeV $0.5 < y^* < 1.0$
    - $m_{12} > 1.6$ TeV $1.0 < y^* < 1.5$



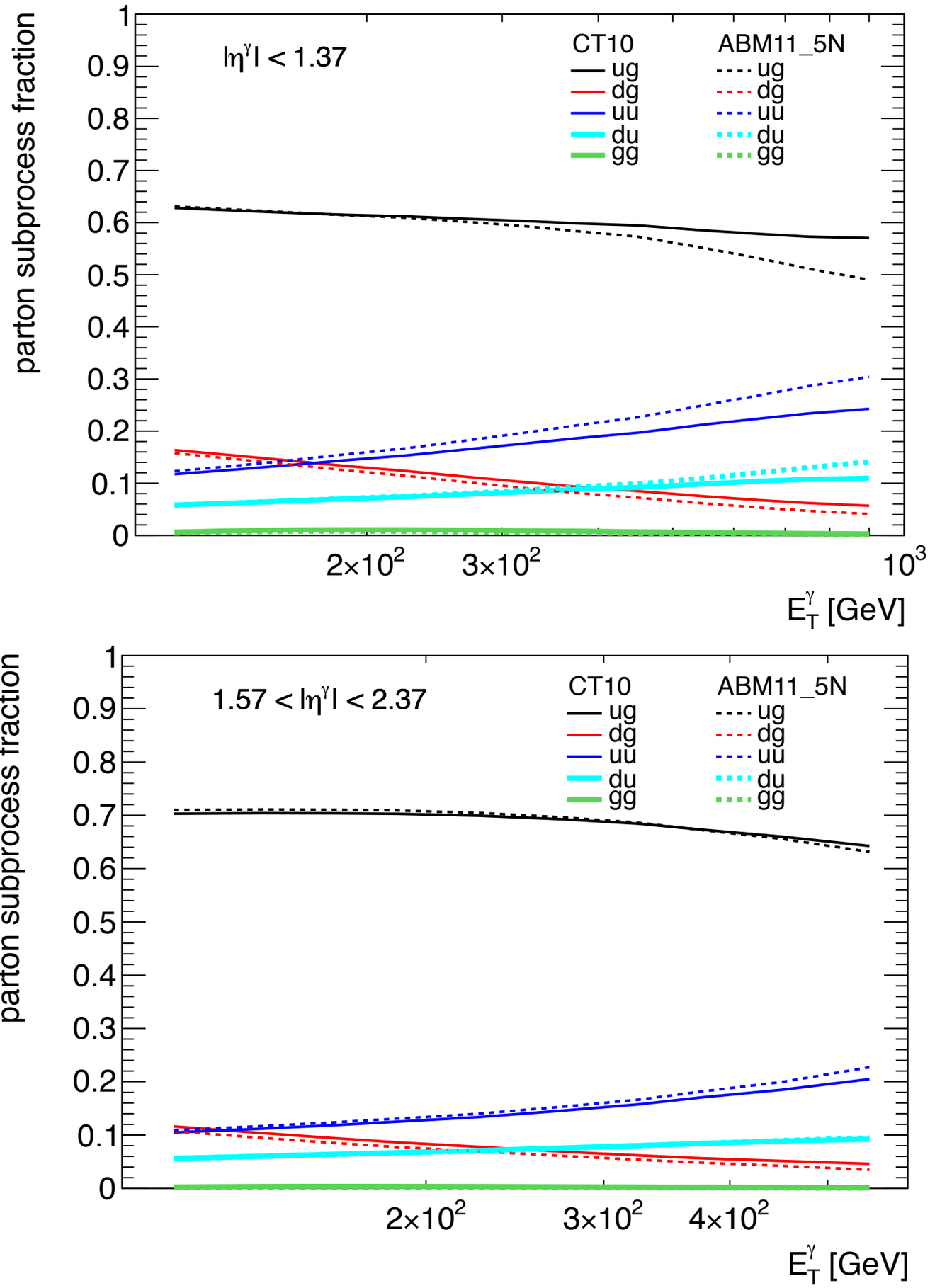
PDF set	y^* ranges	mass range (full/high)	P_{obs} $R=0.4$	P_{obs} $R=0.6$
CT10	$y^* < 0.5$	high	0.742	0.785
	$y^* < 1.5$	high	0.080	0.066
	$y^* < 1.5$	full	0.324	0.168
HERAPDF1.5	$y^* < 0.5$	high	0.688	0.504
	$y^* < 1.5$	high	0.025	0.007
	$y^* < 1.5$	full	0.137	0.025
MSTW 2008	$y^* < 0.5$	high	0.328	0.533
	$y^* < 1.5$	high	0.167	0.183
	$y^* < 1.5$	full	0.470	0.352
NNPDF2.1	$y^* < 0.5$	high	0.405	0.568
	$y^* < 1.5$	high	0.151	0.125
	$y^* < 1.5$	full	0.431	0.242
ABM11	$y^* < 0.5$	high	0.024	$< 10^{-3}$
	$y^* < 1.5$	high	$< 10^{-3}$	$< 10^{-3}$
	$y^* < 1.5$	full	$< 10^{-3}$	$< 10^{-3}$



Inclusive direct (prompt) photon production



- Prompt photon cross section sensitive to the gluon (and u quark) density at leading order
  - The ug contribution dominates due to the large u quark charge, +2/3
- Again, softer ABM gluon contribution - ug contribution small at high E_T
- Smaller differences for forward photons
- **Process implemented in APPLgrid using MCFM**

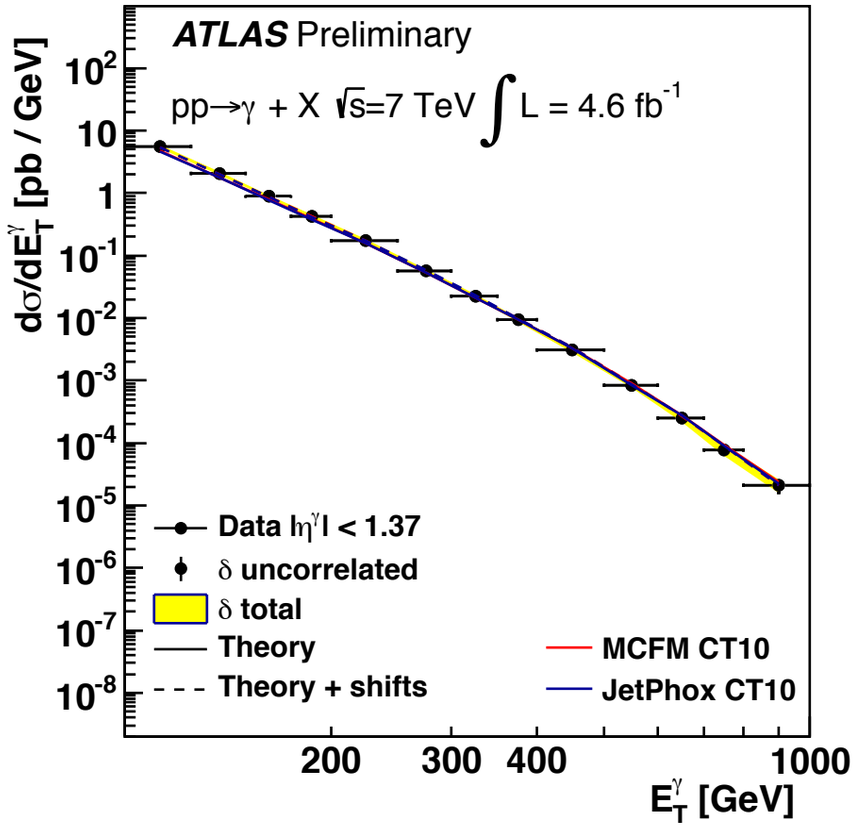


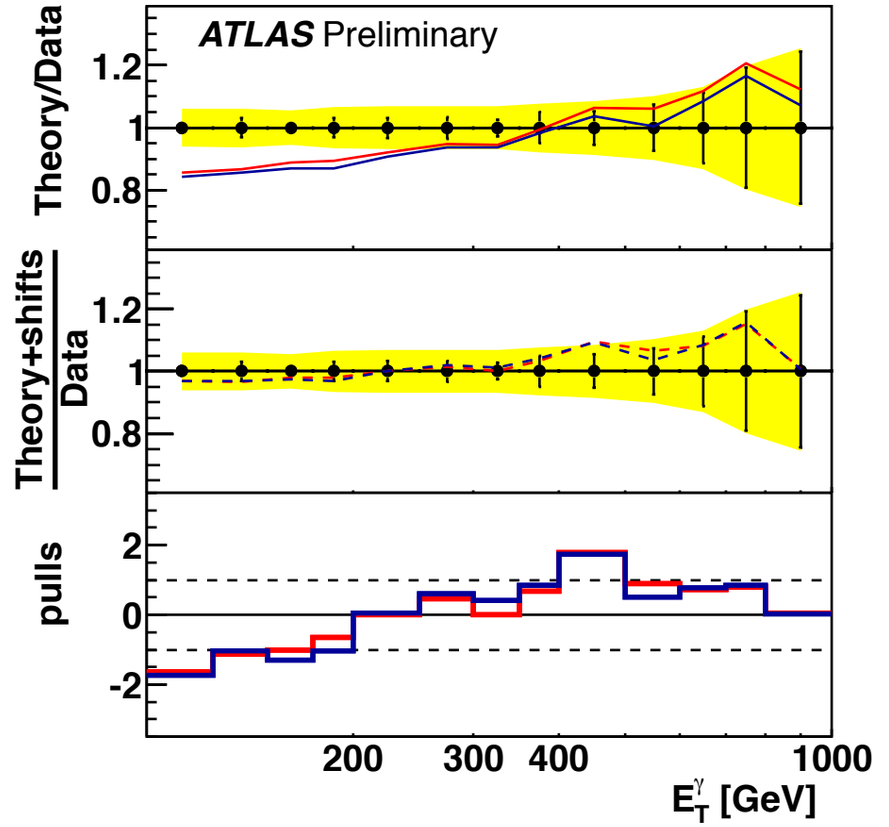
Direct photon production

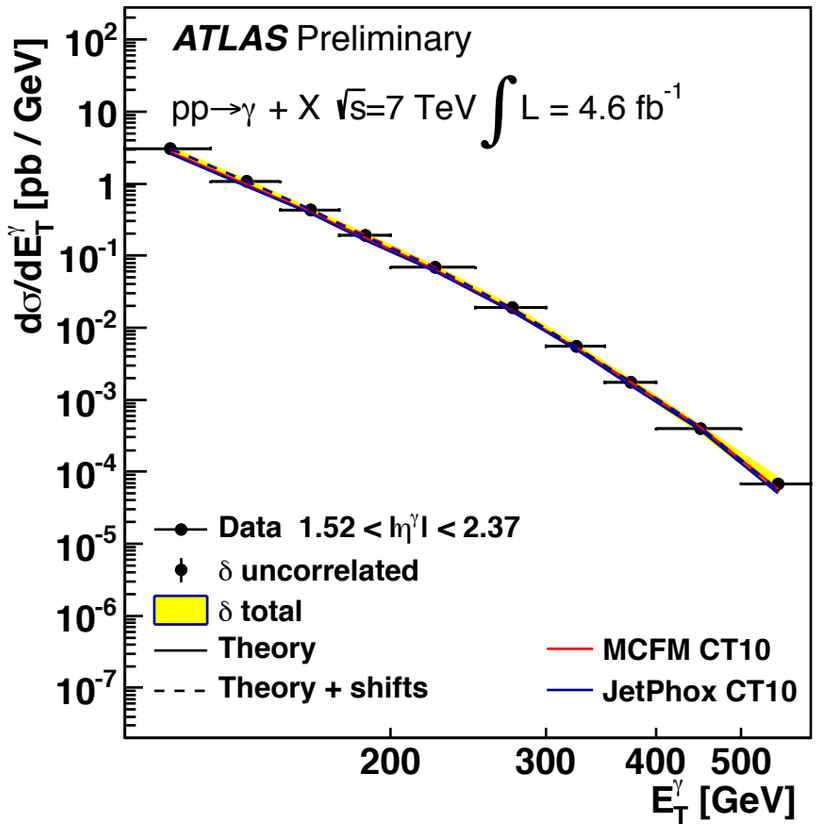
- **ATL-PHYS-PUB-2013-018**
- Data from **arXiv:1311.1440**

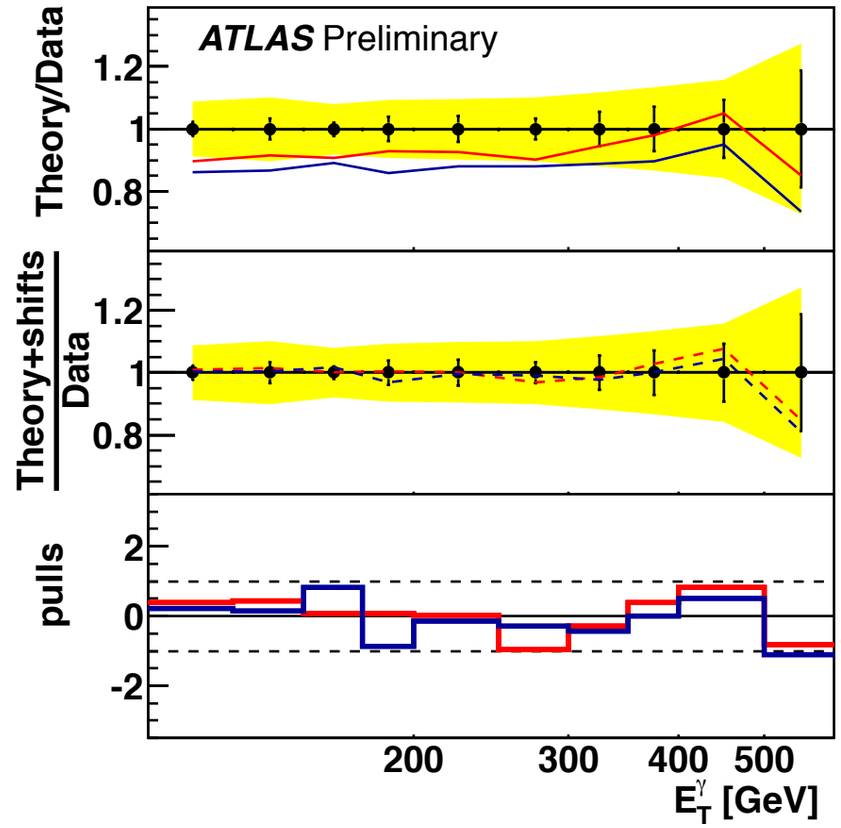
- Comparison of JetPhox and MCFM calculations with the data
  - NLO fragmentation calculated using JetPhox
  - Consistent shape between the calculations
- EW corrections not included

- Both calculations differ in shape with data for central photons
- Include effect of experimental systematic as nuisance parameter shifts

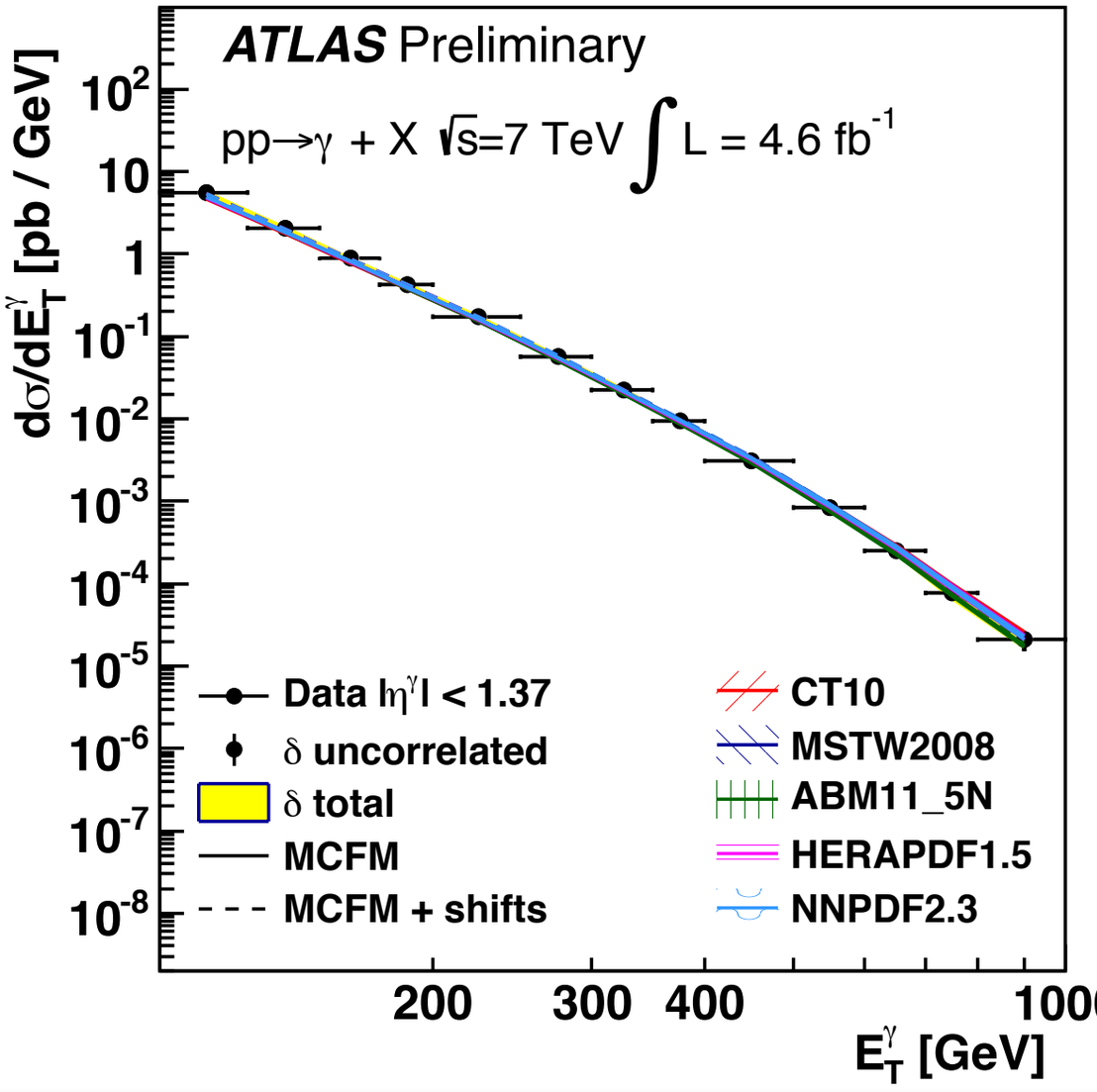


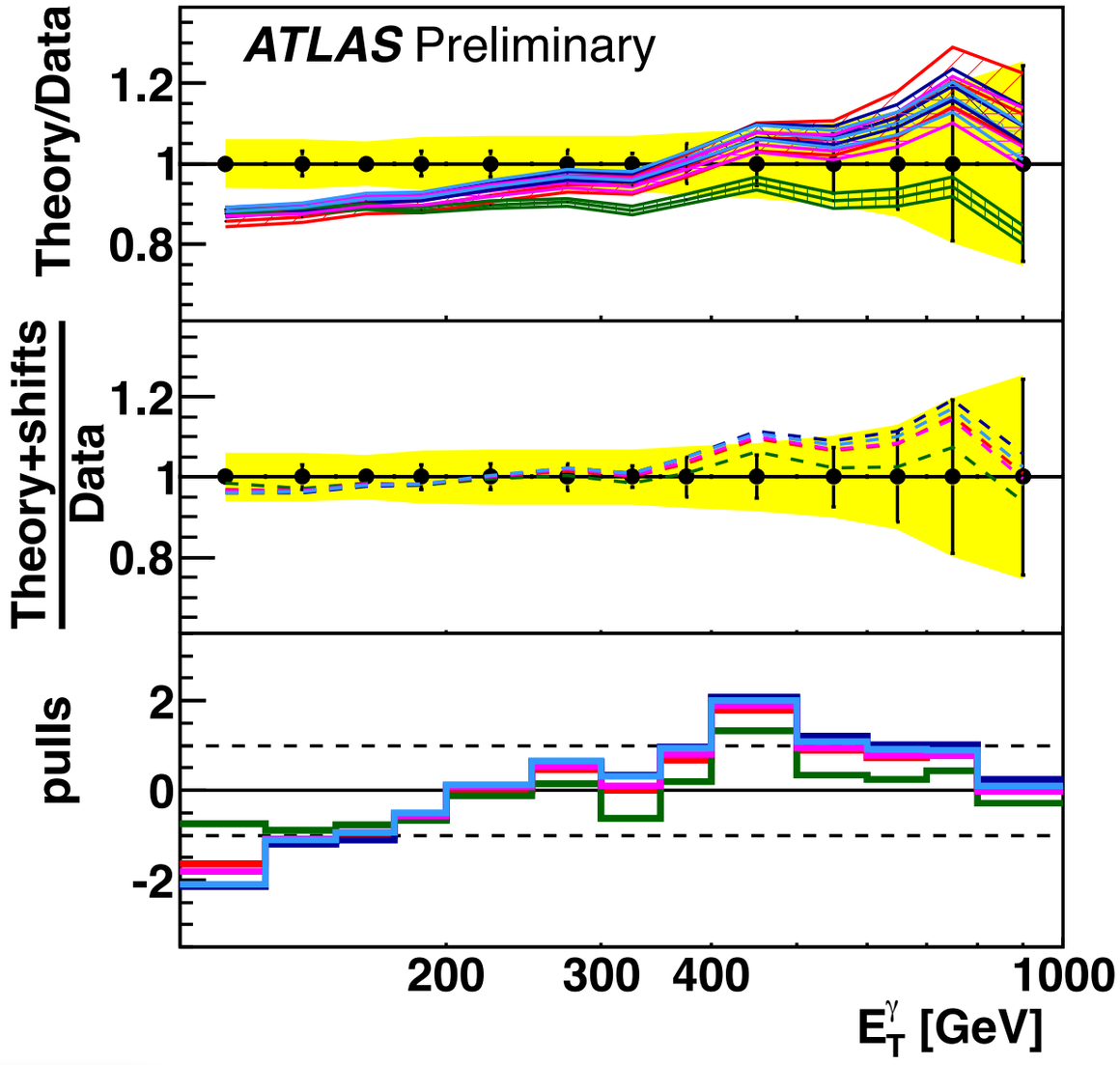






Central photon production



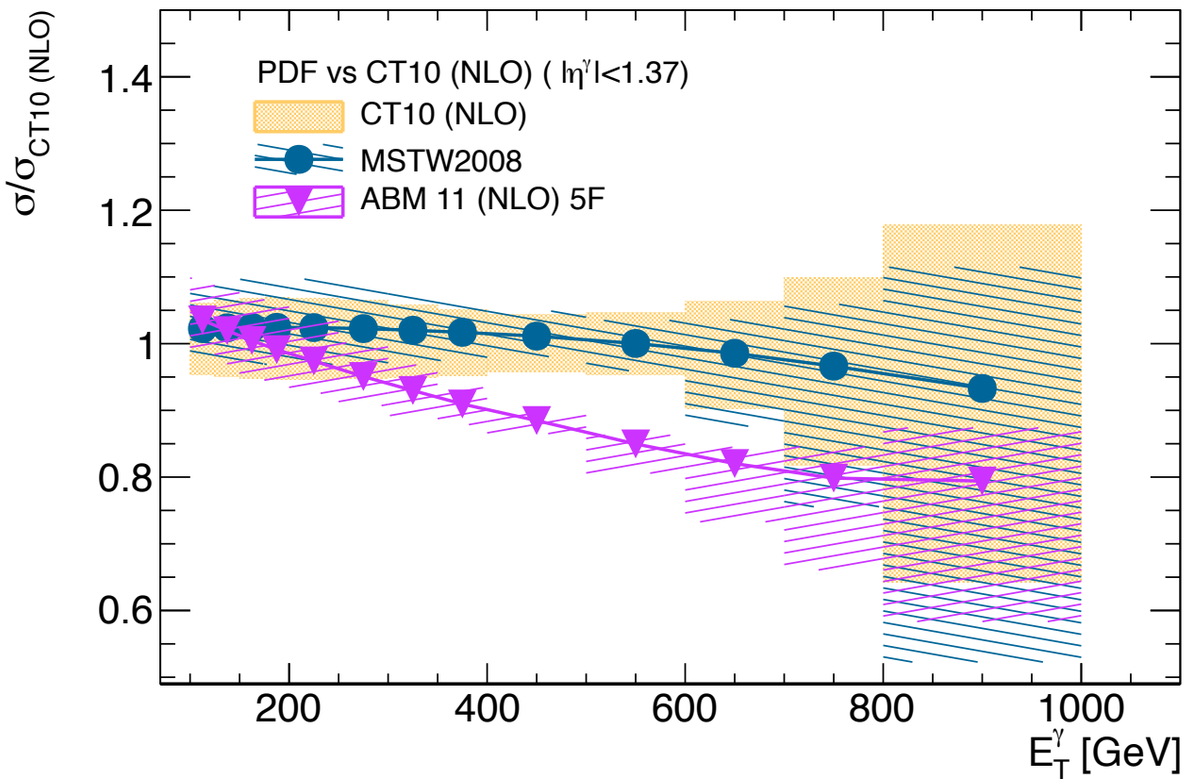


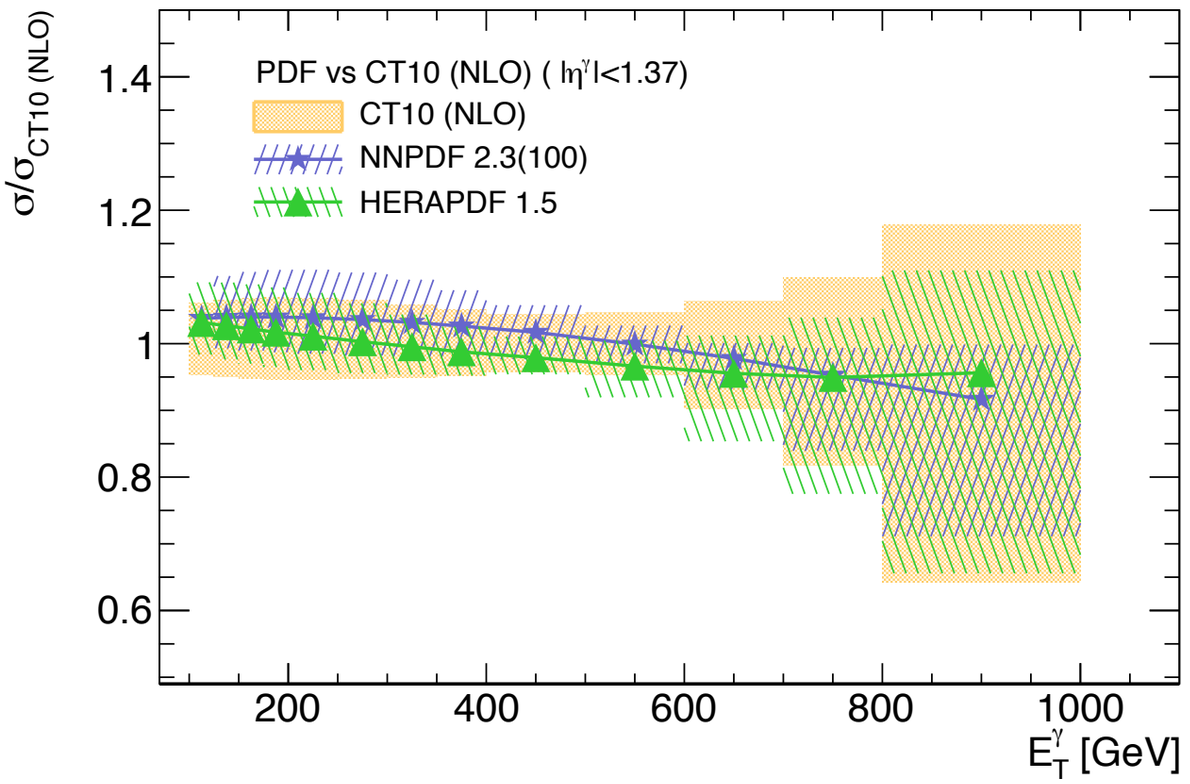
	Excluding PDF uncertainties			Including PDF uncertainties		
	$\mu_r = \mu_f = E_T^\gamma$	Envelope		$\mu_r = \mu_f = E_T^\gamma$	Envelope	
CT10	49.1	34.7	- 63.1	29.8	20.0	- 38.4
MSTW2008	39.9	27.2	- 52.7	32.0	21.3	- 42.3
ABM11_5N	16.2	9.2	- 25.5	15.7	8.9	- 24.9
HERAPDF1.5	28.7	19.0	- 38.9	23.6	15.7	-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

χ^2 for 23 degrees of freedom

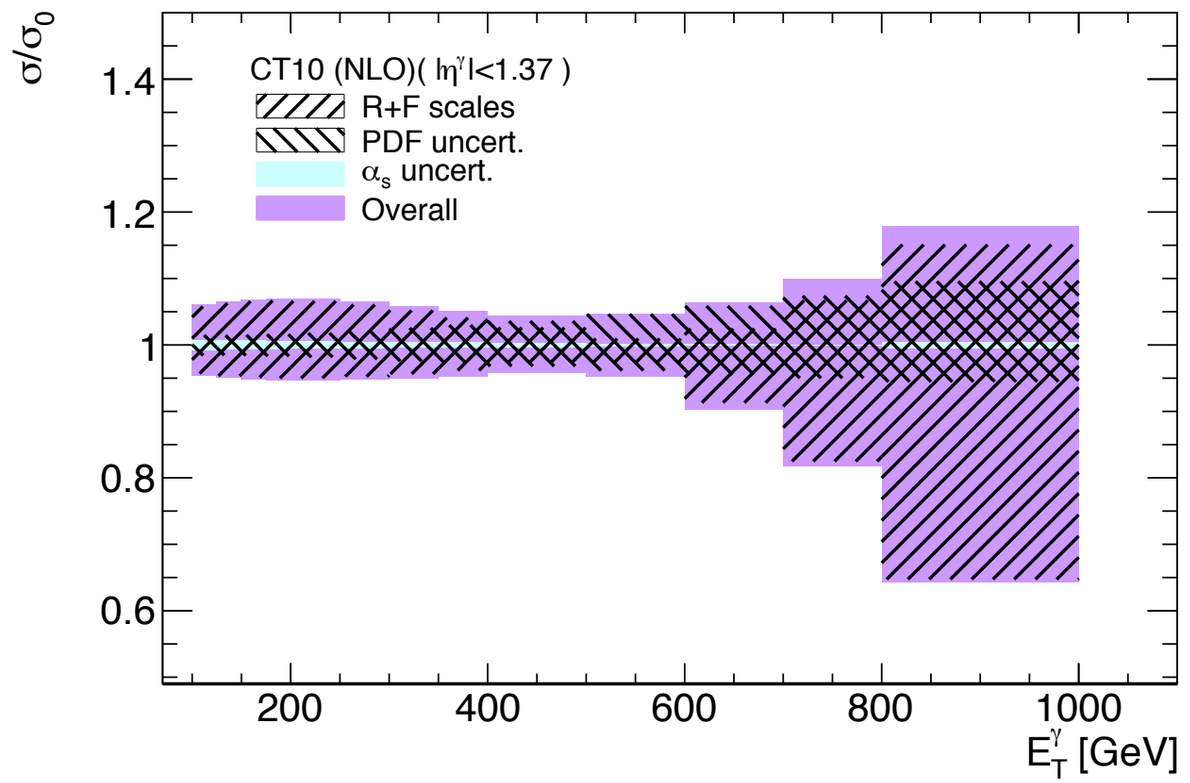
- Large variation of the predictions from MCFM with each PDF
  - Again, ABM11 softer at high E_T

Scale and PDF uncertainties



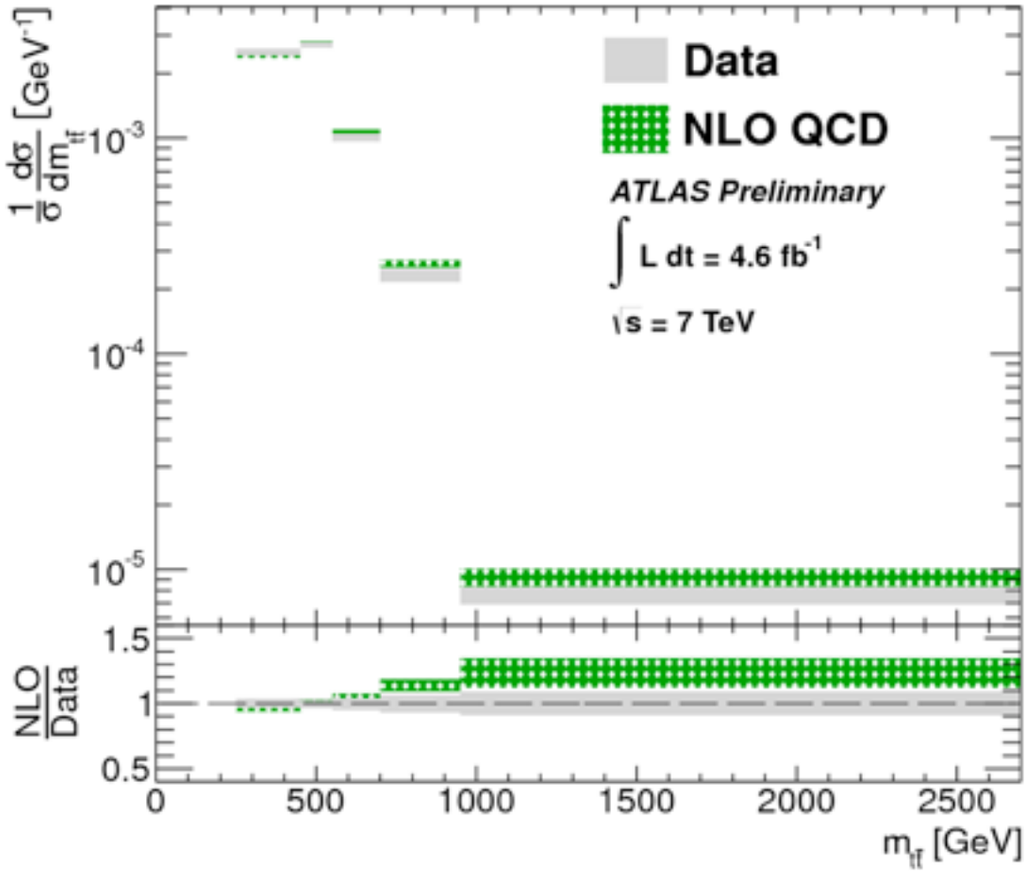


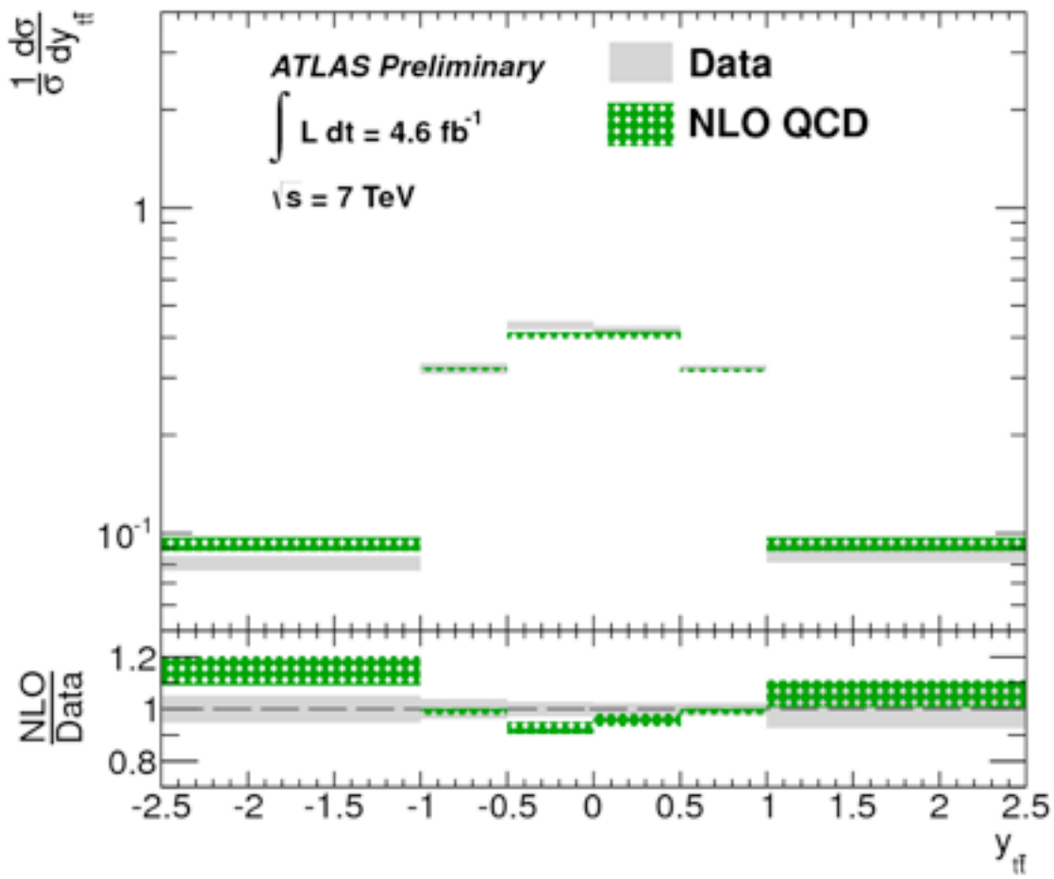
- Large scale uncertainties, comparable to individual PDF uncertainties
- Potentially large differences between PDFs, larger than quoted uncertainties on individual PDF sets for intermediate ET
  - Data should still have the potential to constrain the shape of the gluon distribution

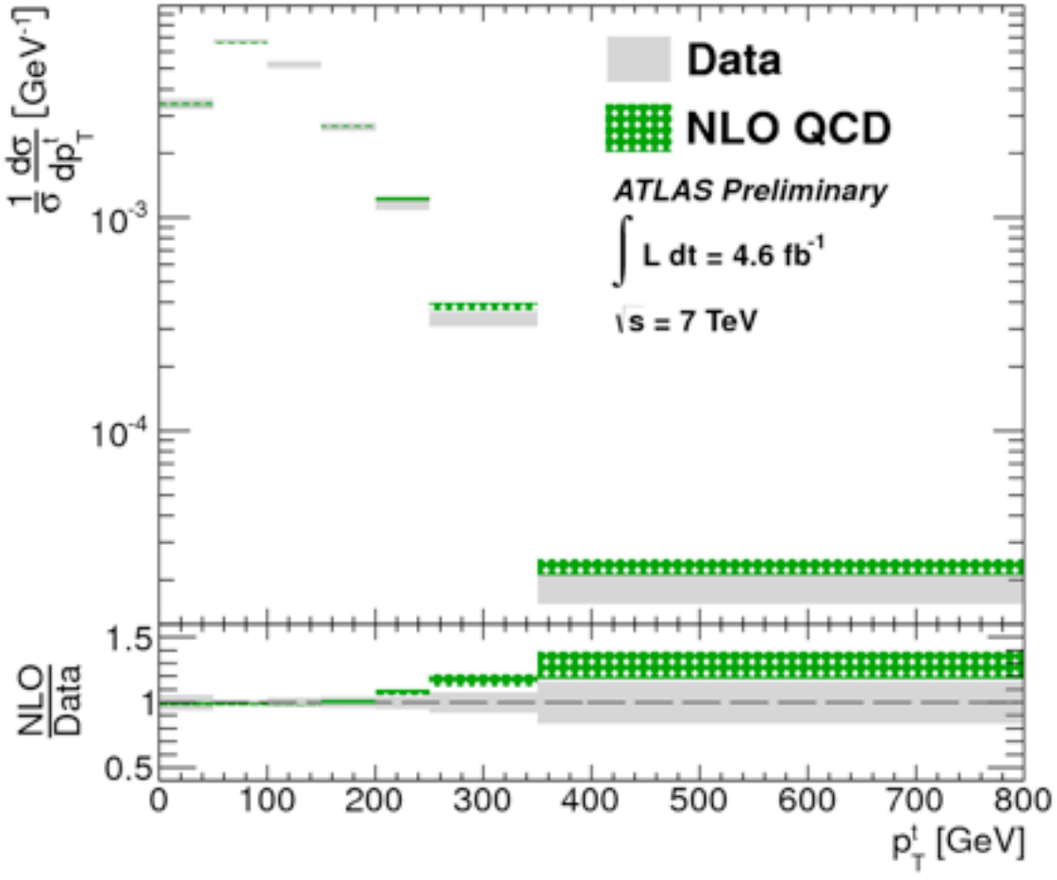


Top pair production

- **ATLAS-CONF-2013-099**
- Top pair production is sensitive to the gluon
- Data also available on p_T(ttbar pair) although calculation intrinsically at an extra order in α_S

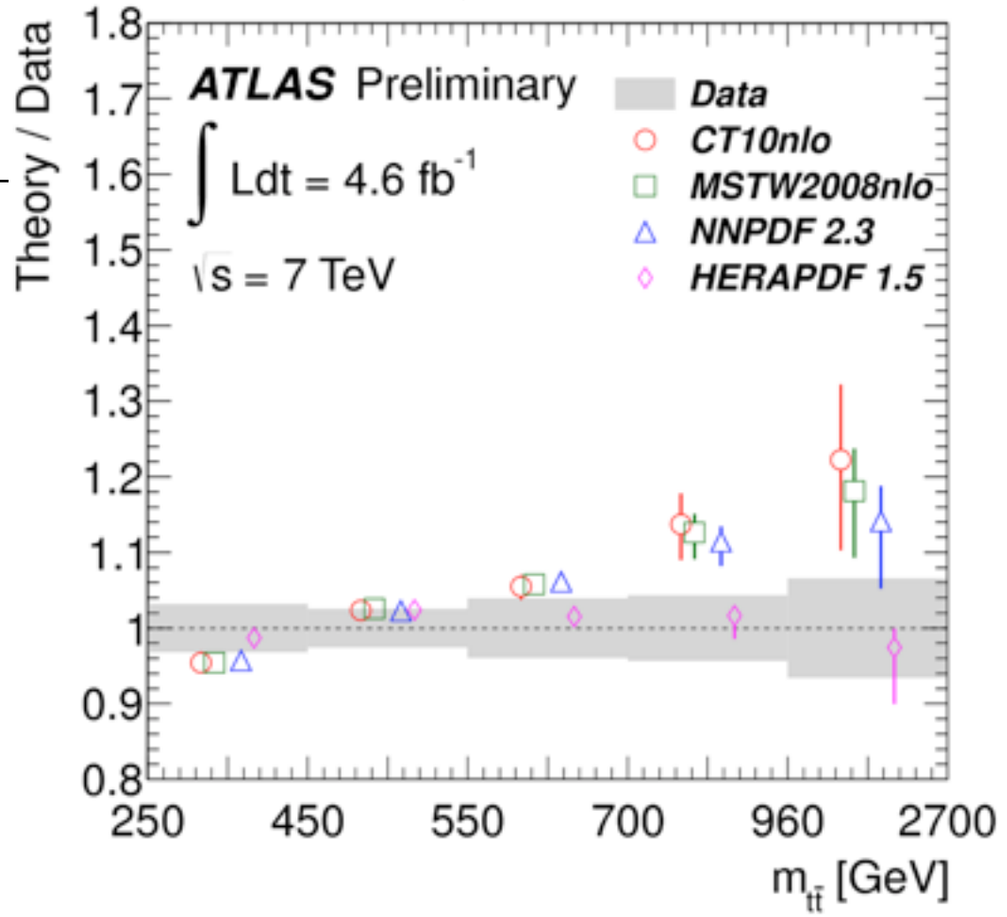


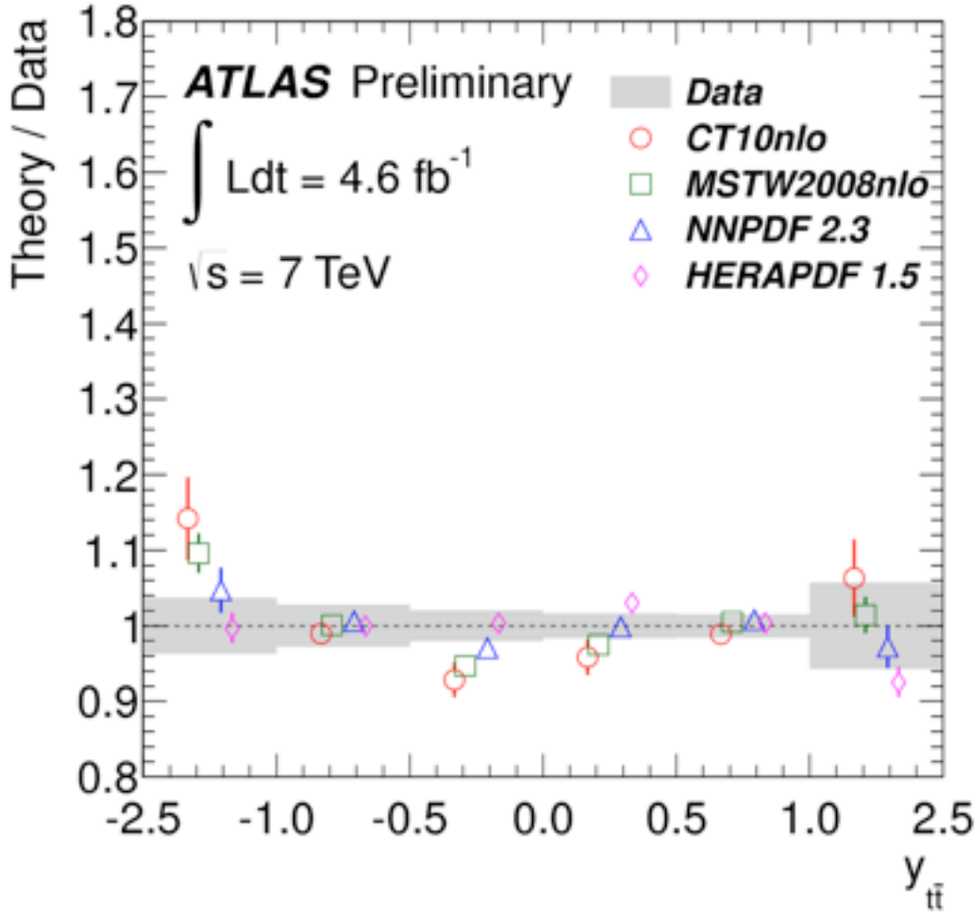


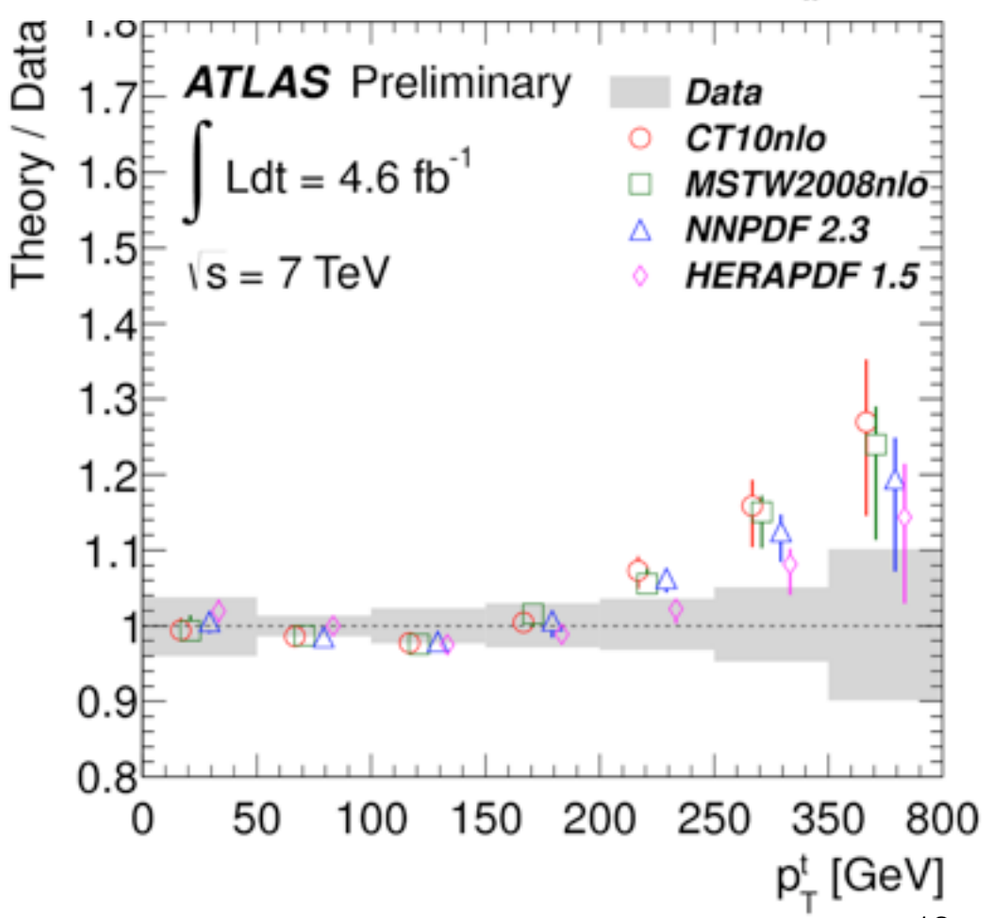


Top pair production

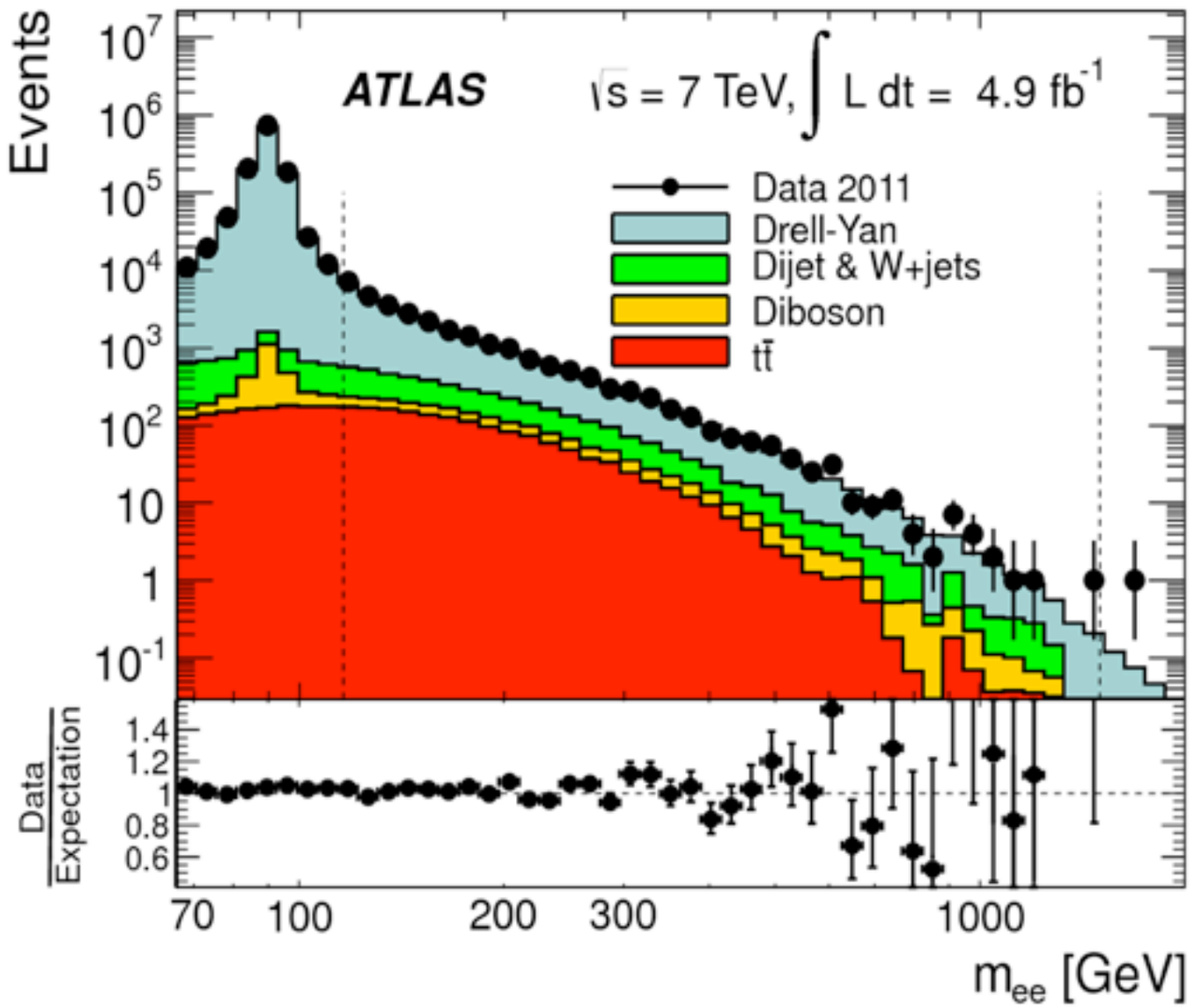
- Smaller gluon contribution at high x for the HERAPDF
- Overall better agreement with the data than the harder gluons from other fits which may include the Tevatron jet data
- Calculation in APPLgrid

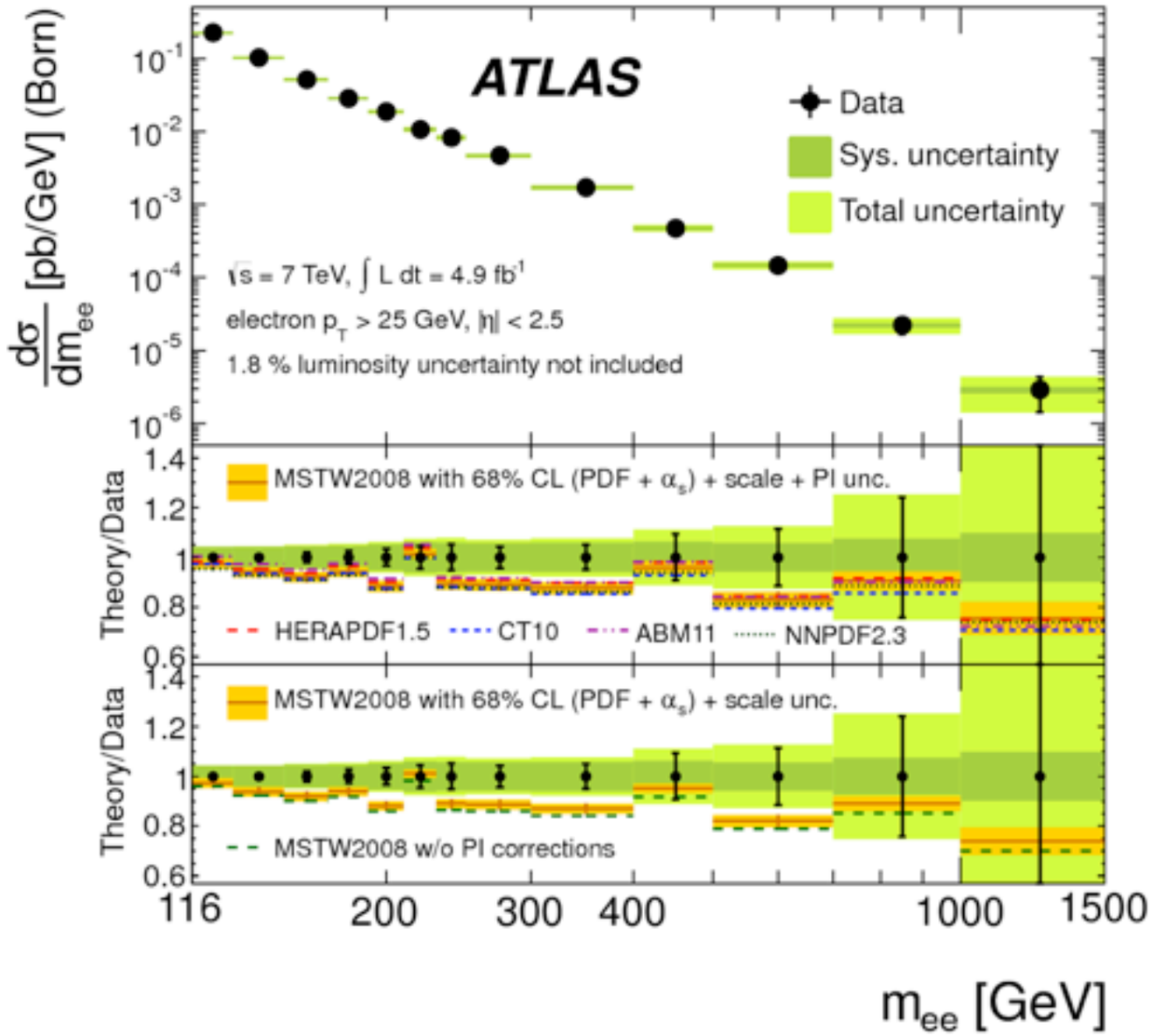






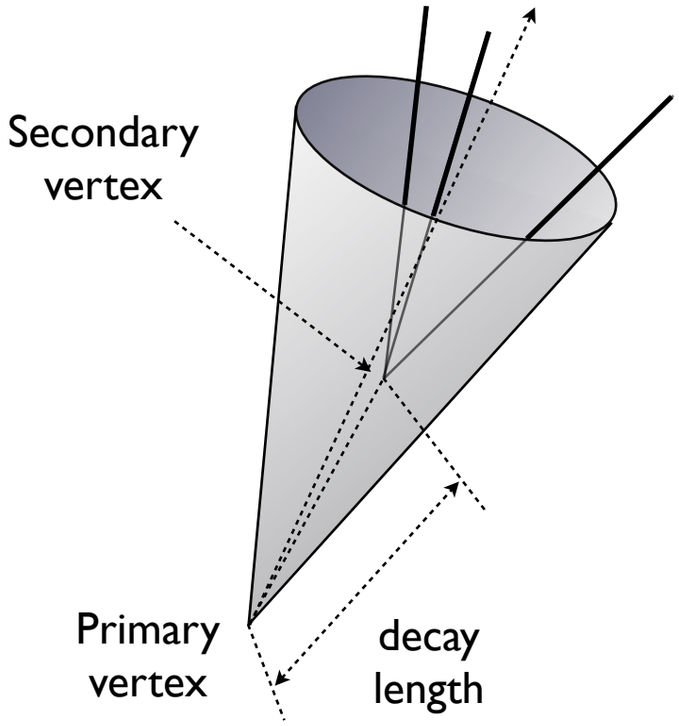
The high mass Drell-Yan cross section

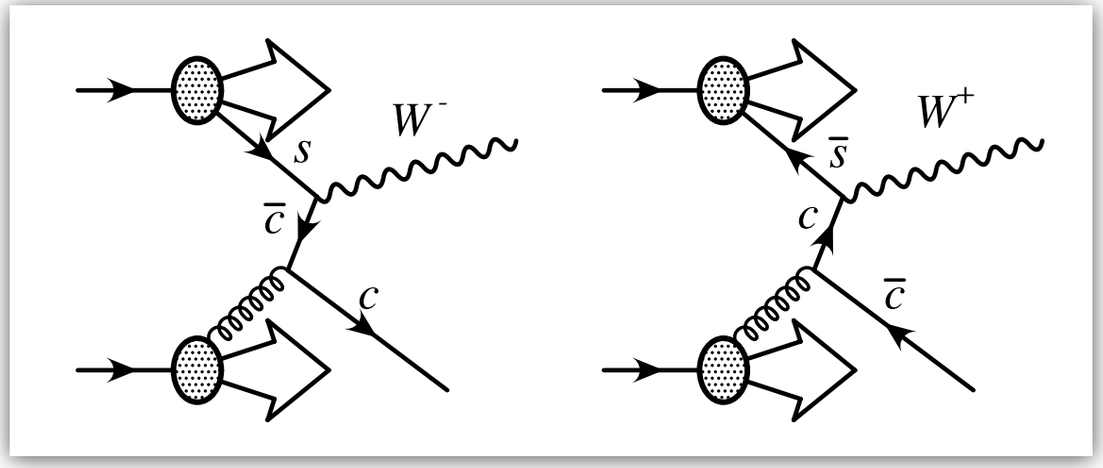




- **Phys. Lett. B 725 (2013) pp. 223-242**
- Complement the inclusive Z production cross section measurement
- Calculations from the different PDFs all lie below the data for $m_{ee} < 400$ GeV

W+charm production

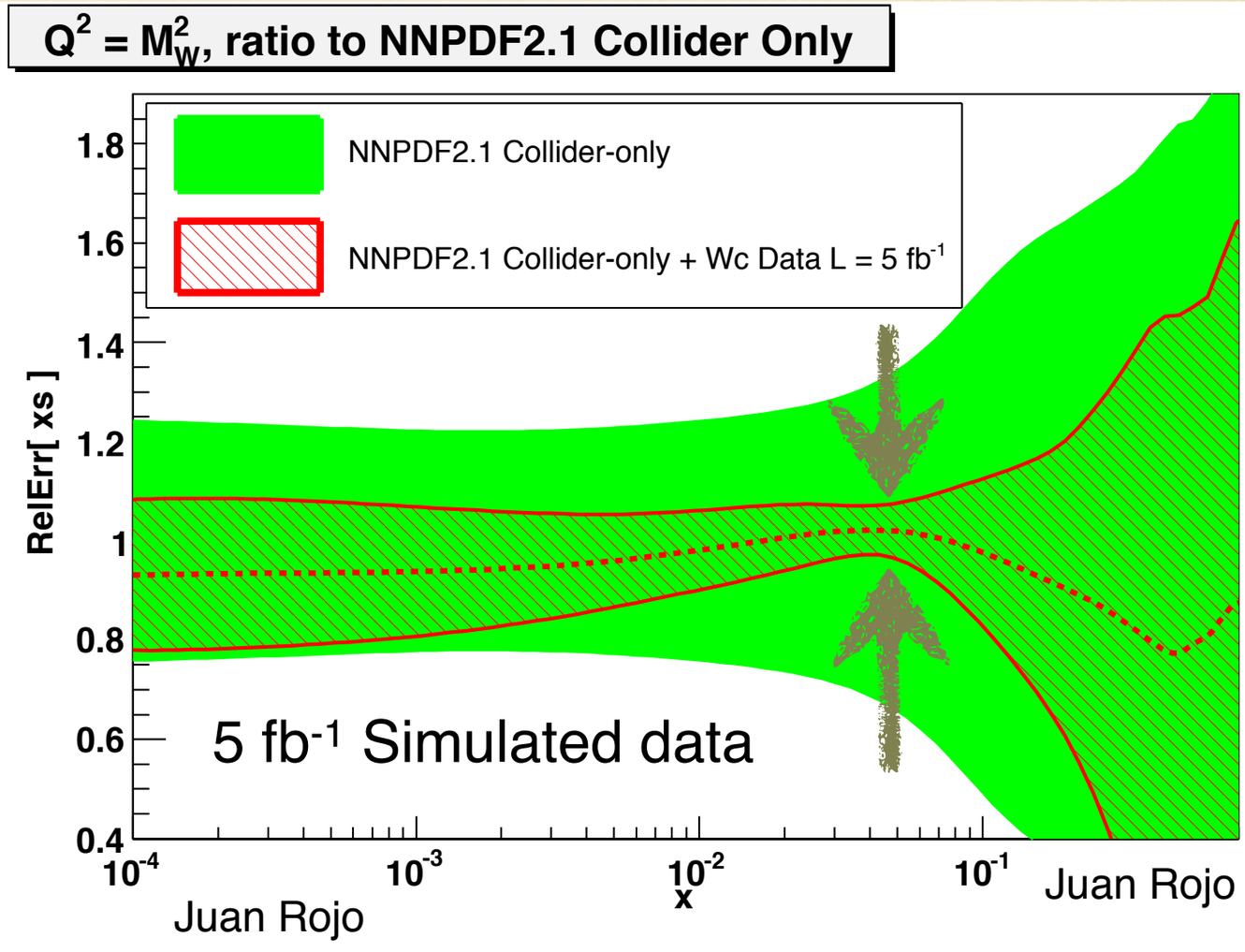




- **ATLAS-CONF-2013-045**
- Measure secondary vertices, use templates to extract relative contributions

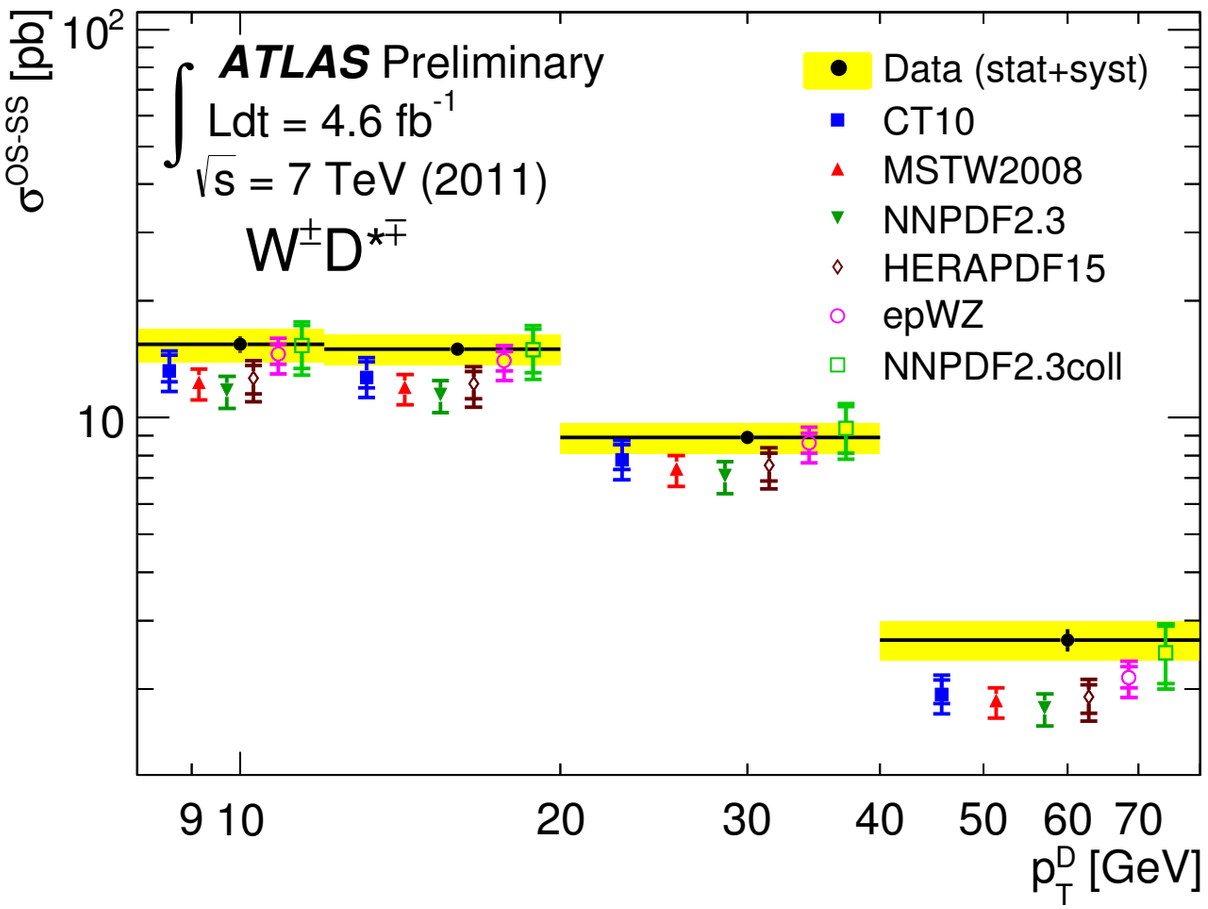
$$R_c^{\pm} = \frac{\sigma(W^+ + c)}{\sigma(W^- + c)}$$

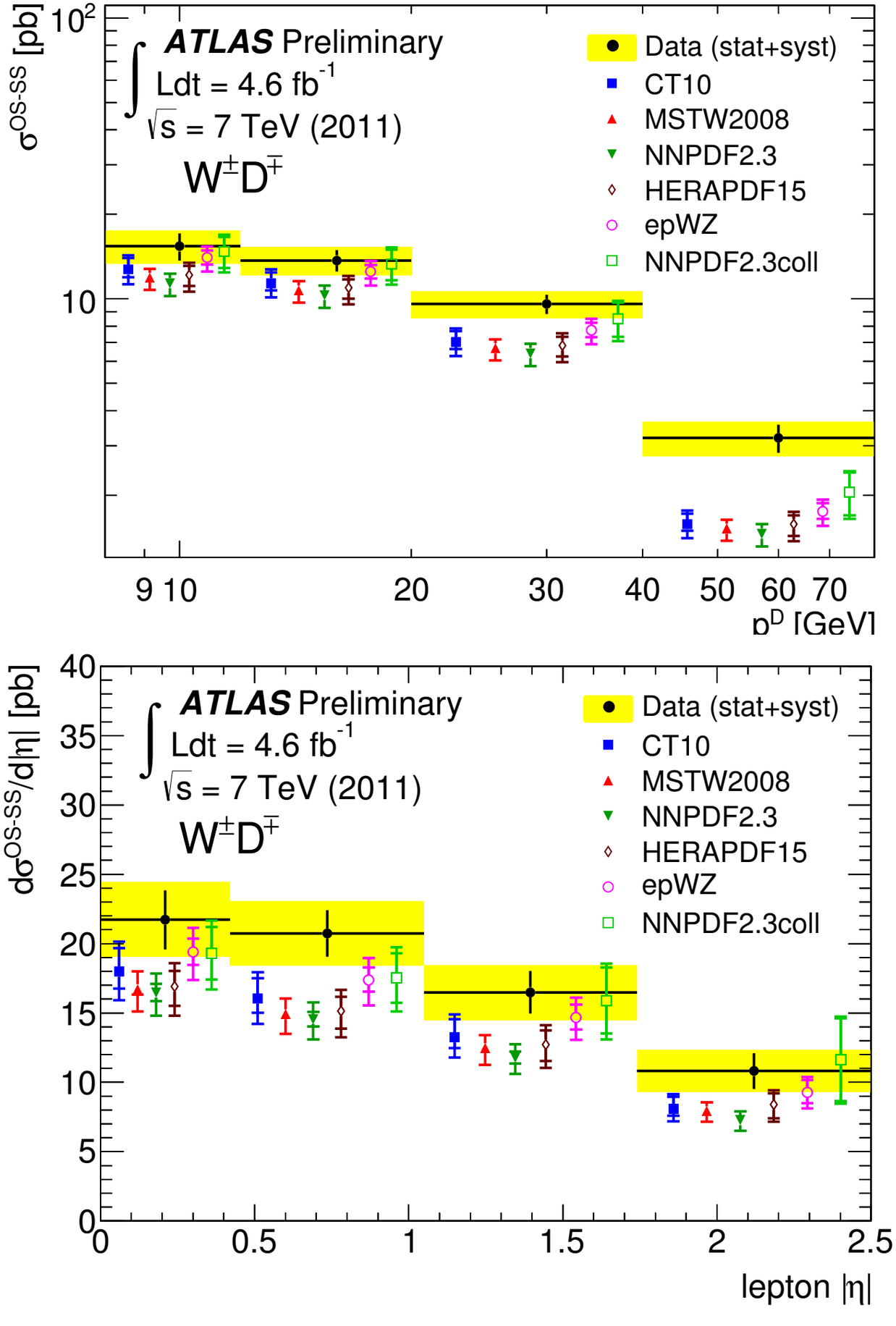
- Data directly sensitive to the strange quark distribution



W + D(*) meson production

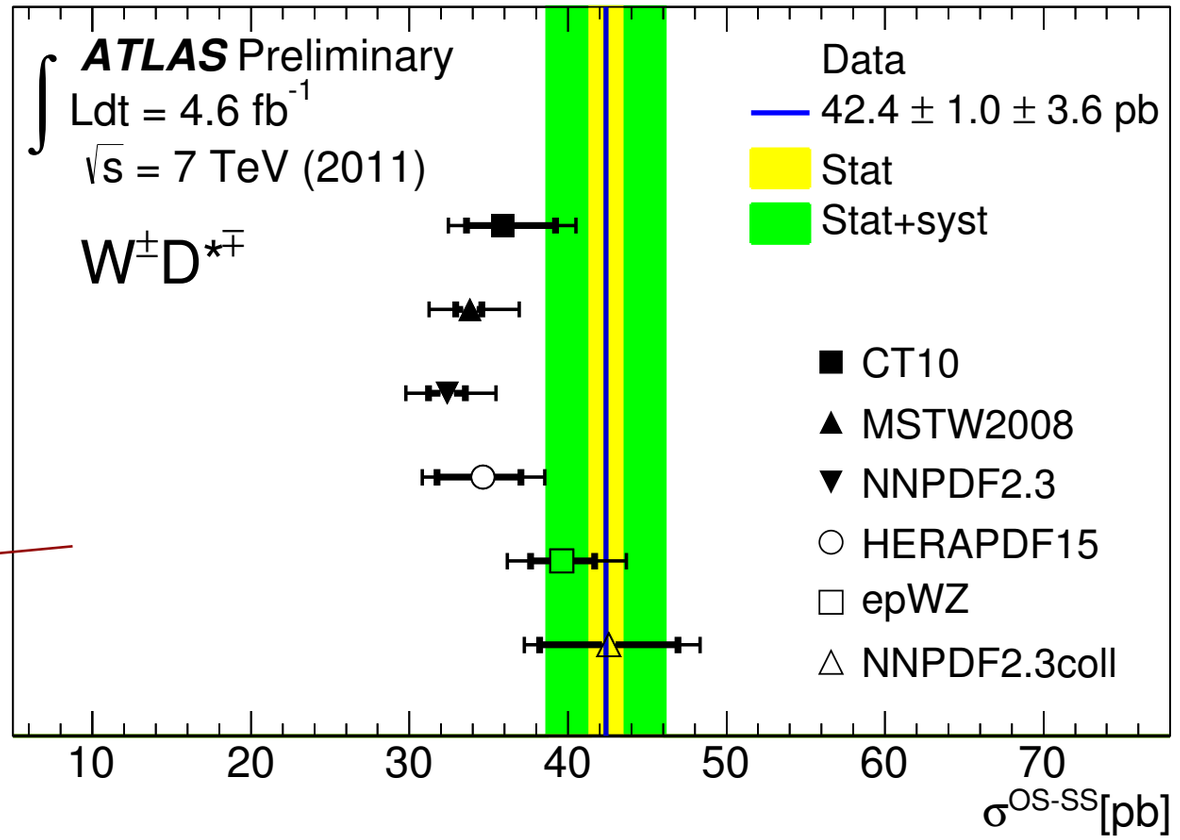
- Most PDFs fall below the data
- NNPDF 2.3 with collider data, and ATLAS-epWZ12 with an enhanced strange contribution more consistent with the data



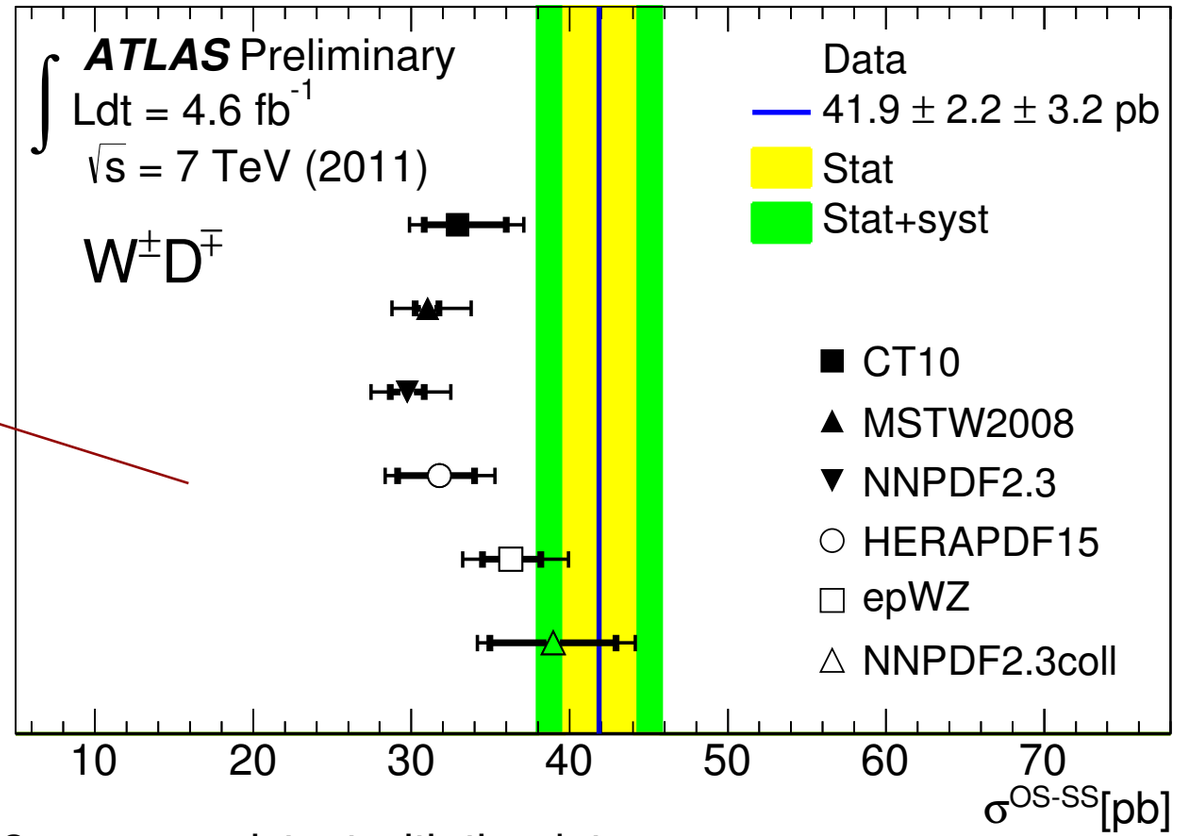


Cross section for W+ to W- + charm meson production

	$\sigma(W^+D^{*-})$ [pb]	$\sigma(W^-D^{*+})$ [pb]
Data	20.6 ± 0.7 (stat) ± 1.8 (syst)	21.4 ± 0.7 (stat) ± 1.8 (syst)
CT10	$17.3^{+1.7}_{-1.1}$	$18.6^{+1.7}_{-1.1}$
MSTW2008	$16.0^{+0.3}_{-0.5}$	$17.8^{+0.4}_{-0.4}$
NNPDF2.3	15.4 ± 0.6	17.0 ± 0.4
HERAPDF15	$16.7^{+1.2}_{-1.4}$	$18.0^{+1.2}_{-1.4}$
epWZ	$19.2^{+1.0}_{-1.0}$	$20.4^{+1.0}_{-1.0}$
NNPDF2.3coll	20.7 ± 2.2	21.9 ± 2.2

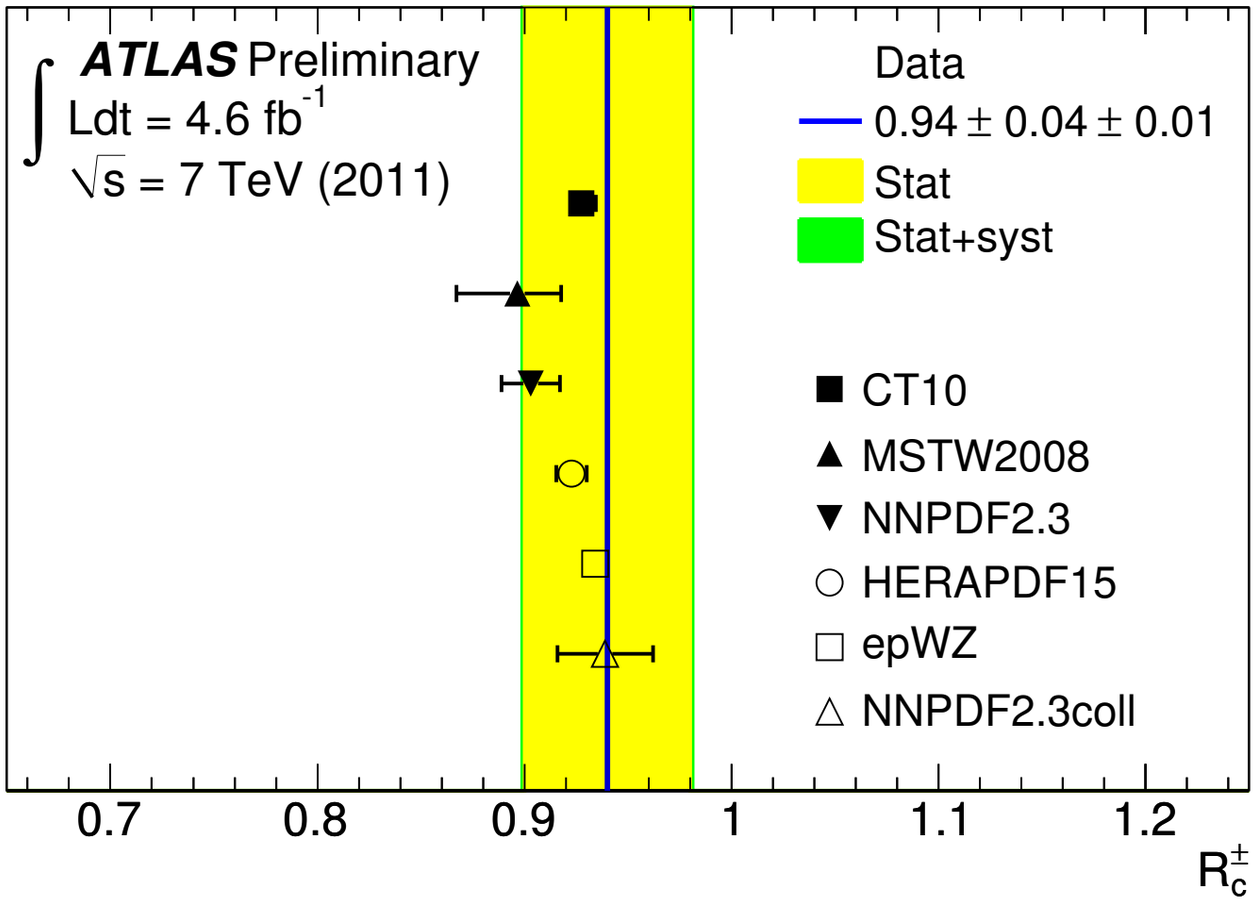


	$\sigma(W^+D^-)$ [pb]	$\sigma(W^-D^+)$ [pb]
Data	18.9 ± 1.7 (stat) ± 1.5 (syst)	23.0 ± 1.5 (stat) ± 1.8 (syst)
CT10	$15.8^{+1.5}_{-1.0}$	$17.1^{+1.5}_{-1.1}$
MSTW2008	$14.6^{+0.3}_{-0.4}$	$16.4^{+0.4}_{-0.4}$
NNPDF2.3	14.1 ± 0.5	15.7 ± 0.5
HERAPDF15	$15.2^{+1.1}_{-1.3}$	$16.6^{+1.1}_{-1.3}$
epWZ	$17.5^{+0.9}_{-0.9}$	$18.8^{+0.9}_{-0.9}$
NNPDF2.3coll	18.8 ± 2.0	20.1 ± 2.0



- Again, calculations using NNPDF2.3coll using ATLAS-epWZ12 more consistent with the data

Ratios of W^+ to W^- + charm meson production



	$\sigma(W^+D^-)/\sigma(W^-D^+)$	$\sigma(W^+D^{*-})/\sigma(W^-D^{*+})$
Data	0.82 ± 0.09 (stat) ± 0.01 (syst)	0.96 ± 0.04 (stat) ± 0.01 (syst)
CT10	$0.923^{+0.007}_{-0.005}$	$0.932^{+0.007}_{-0.005}$
MSTW2008	$0.893^{+0.021}_{-0.029}$	$0.900^{+0.021}_{-0.030}$
NNPDF2.3	0.899 ± 0.014	0.907 ± 0.014
HERAPDF15	$0.918^{+0.007}_{-0.007}$	$0.928^{+0.007}_{-0.008}$
epWZ	$0.935^{+0.006}_{-0.005}$	$0.939^{+0.006}_{-0.005}$
NNPDF2.3coll	0.930 ± 0.023	0.943 ± 0.023

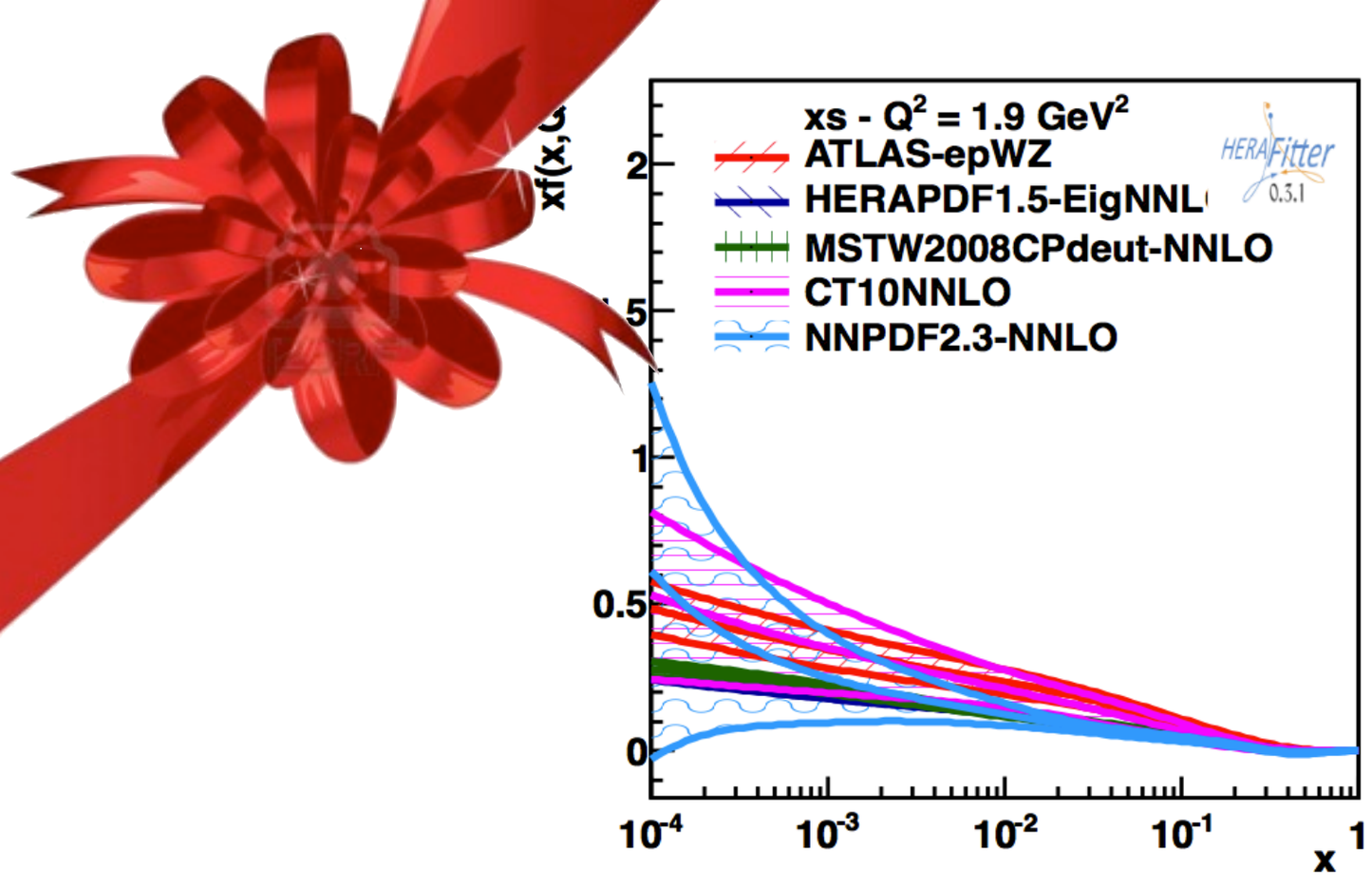
$$R_c^{\pm} \equiv \sigma(W^+D^{(*)-})/\sigma(W^-D^{(*)+})$$

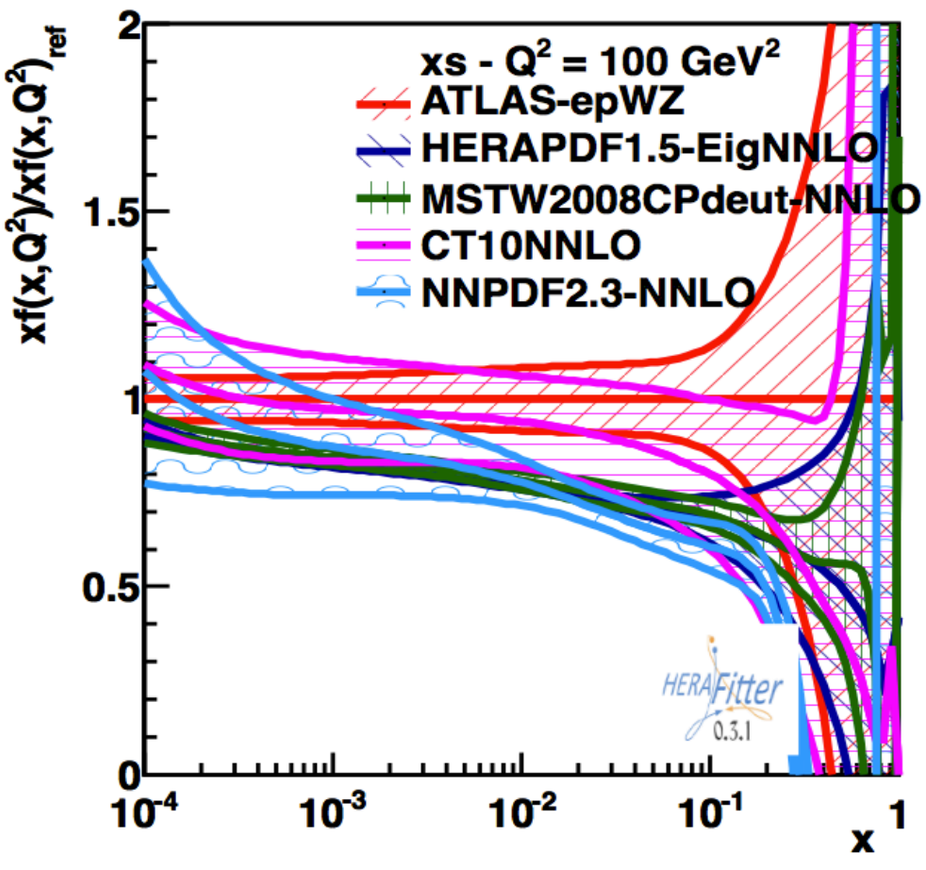
- All PDFs consistent with the ratios.

Summary

- ATLAS has a large, and growing portfolio of precision measurements available that all have the potential to help constrain the parton distributions in the proton
- Only a small selection has been discussed here
- Developments APPLgrid mean that it can be used for comparisons between measurements and theoretical predictions for an increasing list of available processes, inclusive single jet, **dijet**, trijet production, **Z** and **W** production, with, or without jets or **charm**, heavy quark and **ttbar** pair production, prompt **photons** ...

- It will be a very interesting time ahead ...





Epilogue: the ATLAS-epWZ12 fit

- The ATLAS epWZ with the enhanced strange contribution, **now available** from the LHAPDF PDF sets page
  - Eigen value set: ATLAS-epWZ12-EIG.LHgrid
  - Model variation set: ATLAS-epWZ12-VAR.LHgrid

- **So now everyone can perform their favourite calculations using the ATLAS fit !!!**