



# The photon PDF from high-mass Drell Yan data at the LHC

F. Giuli (on the behalf of the analysis team)

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# The photon PDF from high-mass Drell Yan data at the LHC

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*(Submitted on 30 Jan 2017)*

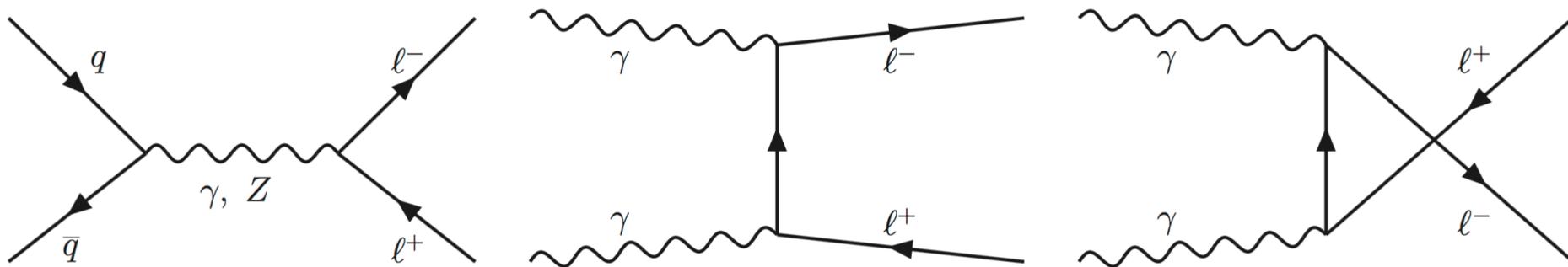
- Theory motivations
- ATLAS analysis at 8 TeV review
- Theory inputs
- Fit results
- Comparison of the fit with modern PDF sets
- Robustness and perturbative stability checks
- Concluding remarks

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**arXiv:1701.08553v1**  
(submitted to EPJC)

# Theoretical motivations

- Interpretation of the LHC data requires theoretical calculations that include not only QCD corrections, but also the EW effects for the TeV region.
- DY data at LHC can provide direct sensitivity to photon PDF: from  $q\bar{q}$   $s$ -channel scattering, from  $\gamma\gamma$   $t$ - and  $u$ - channels scattering mediated by a lepton



- An important ingredient of the EW corrections is the photon PDF of the proton:
  - Historically, the first set was MRST2004 QED: photon taken from a model and tested on direct photon production at HERA
  - NNPDF2.3 QED provided a first model independent determination from fits to DY LHC data
  - More photon PDFs followed: CT, NNPDF
  - A new approach from LUXqed: photon PDF calculated from inclusive lepton-proton DIS structure functions (% level precision); similarly HKR16

# Input dataset

JHEP 1608 (2016) 009

[arXiv:1606.01736](https://arxiv.org/abs/1606.01736)

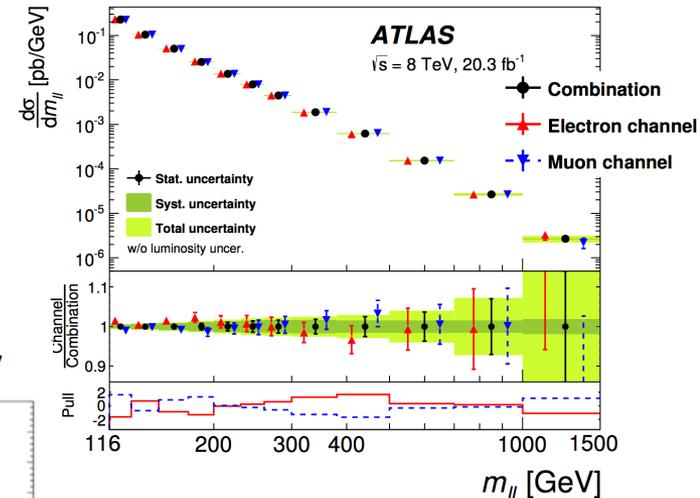
➤ ATLAS high mass Drell Yan at 8 TeV (published in June '16)

➤ 1D (dilepton mass distribution)

➤ 2D in mass and rapidity bins distribution

➤ 48 data points

➤ this is expected to provide most sensitivity to PDFs



➤ Quite precise data!  
(less of 5% unc. up to 700 GeV)

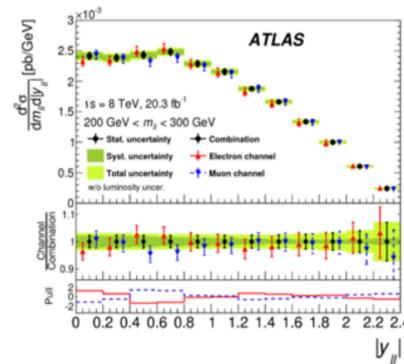
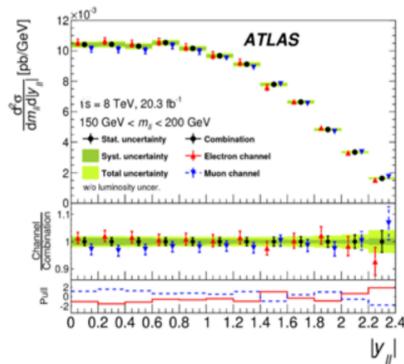
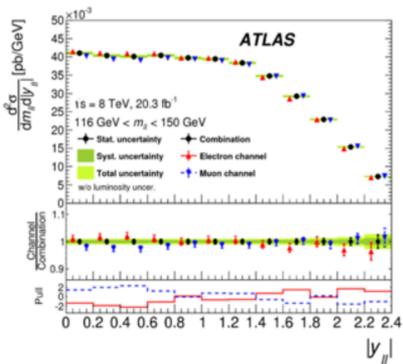
➤ Also 2D in mass and  $\Delta\eta$  bins distribution

➤ Inclusive HERA I+II used as the base (7 data sets) – for full PDF coverage

116 GeV < m < 150 GeV

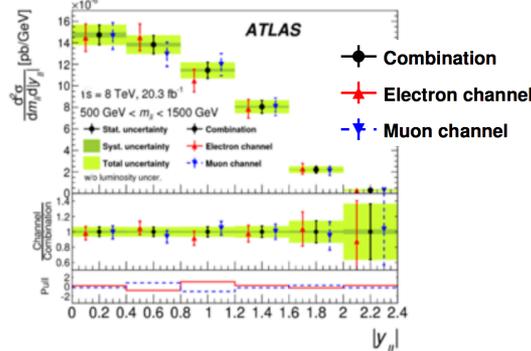
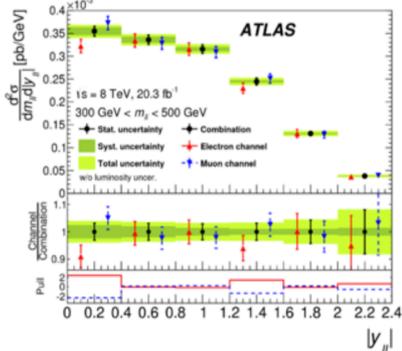
150 GeV < m < 200 GeV

200 GeV < m < 300 GeV



300 GeV < m < 500 GeV

500 GeV < m < 1500 GeV



$$\frac{d^2\sigma}{dm_{\ell\ell} d|y_{\ell\ell}|}$$

# Theory comparison

## ATLAS

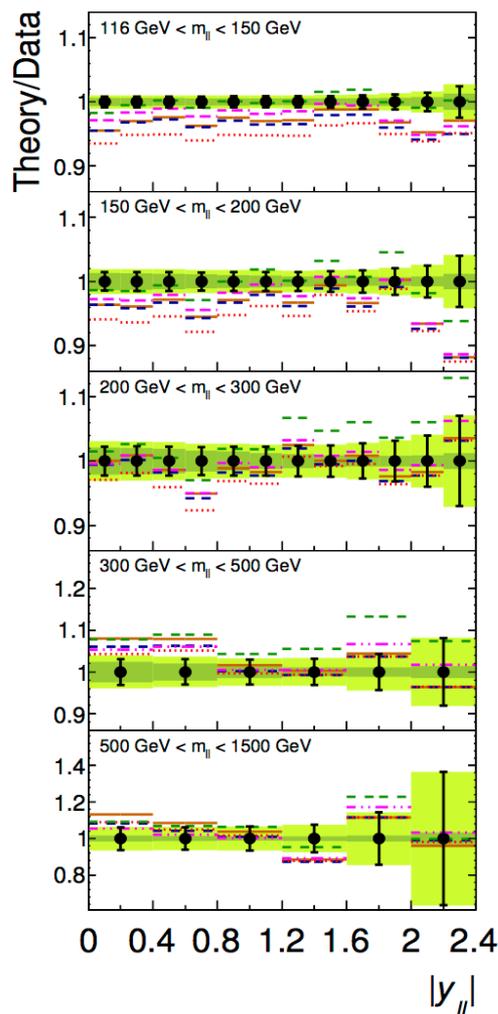
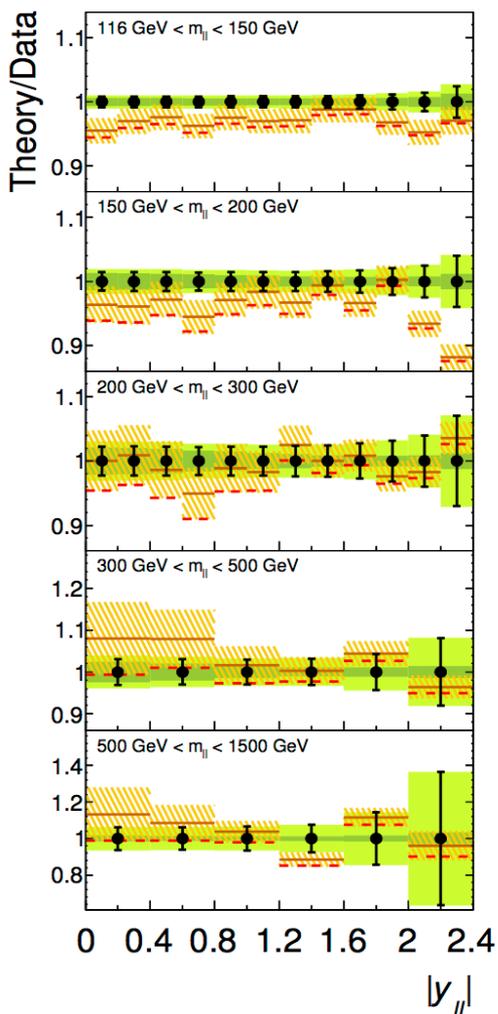
$\sqrt{s} = 8 \text{ TeV}, 20.3 \text{ fb}^{-1}$

MMHT2014 with 68% CL

(PDF +  $\alpha_s$ ) + scale + PI unc.

-- MMHT2014 w/o PI corrections

--- HERAPDF2.0    ● Data  
 --- CT14    ■ Sys. uncertainty  
 --- ABM12    ■ Total uncertainty  
 --- NNPDF3.0    w/o luminosity uncer.



$$\frac{d^2\sigma}{dm_{||}d|y_{||}|} \quad \text{data/theory ratio}$$

- Really precise data!
- Photon-induced (PI) contribution increases with  $m_{ll}$  and decreasing  $|y_{ll}|$
- PDF uncertainties calculated for each PDF scaled to 68% CL
- Compatibility of data to predictions with other PDFs test with  $\chi^2$  function

	$m_{\ell\ell}$	$ y_{\ell\ell} $	$ \Delta\eta_{\ell\ell} $
MMHT2014	18.2/12	59.3/48	62.8/47
CT14	16.0/12	51.0/48	61.3/47
NNPDF3.0	20.0/12	57.6/48	62.1/47
HERAPDF2.0	15.1/12	55.5/48	60.8/47
ABM12	14.1/12	57.9/48	53.5/47

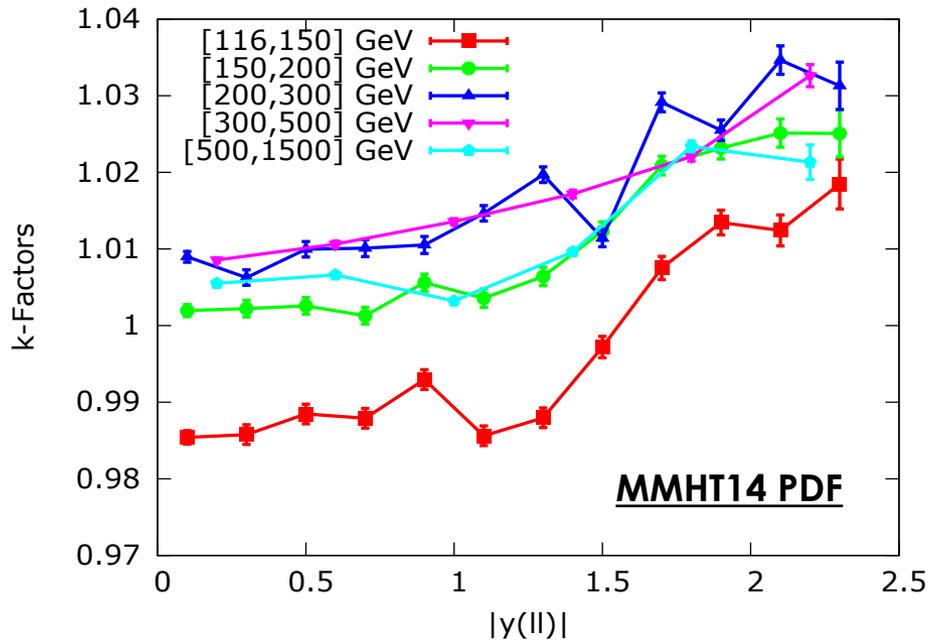
Data in good agreement with SM predictions

# Theory inputs

- **Fit Settings: xFitter 1.2.0**
- PDF evolution computed with APFEL program:
  - Accurate up to NNLO in QCD + NLO in QED
  - Includes relevant mixed QCD + QED correction
- HERA cross section: using FONLL-C HF scheme
- LHC hmDY cross sections calculated via Madgraph5\_aMC@NLO which includes PI diagrams
  - Interfaced to APPLgrid via aMCfast
  - Tailored version of APPLgrid used to account for photon contributions
- NNLO QCD + NLO QED predictions obtained using FEWZ3.1 (dynamical scales are used se to  $m_{ll}$ )

**NOVELTY!**

$$k_F(m_{ll}, |y_{ll}|) \equiv \frac{NNLO \text{ QCD} + NLO \text{ EW}}{NLO \text{ QCD} + LO \text{ EW}}$$



**Determined by the technique of saturation of the  $\chi^2$**

$$xu_v(x) = A_{u_v} x^{B_{u_v}} (1-x)^{C_{u_v}} (1 + E_{u_v} x^2),$$

$$xd_v(x) = A_{d_v} x^{B_{d_v}} (1-x)^{C_{d_v}},$$

$$x\bar{U}(x) = A_{\bar{U}} x^{B_{\bar{U}}} (1-x)^{C_{\bar{U}}},$$

$$x\bar{D}(x) = A_{\bar{D}} x^{B_{\bar{D}}} (1-x)^{C_{\bar{D}}},$$

$$xg(x) = A_g x^{B_g} (1-x)^{C_g} (1 + E_g x^2),$$

$$x\gamma(x) = A_\gamma x^{B_\gamma} (1-x)^{C_\gamma} (1 + D_\gamma x + E_\gamma x^2).$$

**PDF parameterisation**

(the number of parameters is increased one by one until the  $\chi^2$  does not improve further)

# Theory inputs

- **Fit Settings: xFitter 1.2.0**
- PDF evolution computed with APFEL program:
  - Accurate up to NNLO in QCD, NLO in QED
  - Includes relevant mixed QCD+QED correction
- HERA cross section: using FONLL-C HF scheme
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- NNLO QCD + NLO QED predictions obtained using FEWZ3.1 (dynamical scales are used se to  $m_{ll}$ )
- Chi2 definition: from H1 paper ([arXiv:1206.7007](https://arxiv.org/abs/1206.7007))
- $Q_0^2 = 7.5 \text{ GeV}^2$  (also  $Q^2$  cut on data)
- $r_s = \frac{s + \bar{s}}{2\bar{d}} = 1.0$  (ATLAS W,Z data)
- $M_c = 1.41 \text{ GeV}$
- $M_b = 4.5 \text{ GeV}$
- Experimental uncertainties: MC vs. Hessian

**NOVELTY!**

$$k_F(m_{ll}, |y_{ll}|) \equiv \frac{\text{NNLO QCD} + \text{NLO EW}}{\text{NLO QCD} + \text{LO EW}}$$

**Determined by the technique of saturation of the  $\chi^2$**

$$xu_v(x) = A_{u_v} x^{B_{u_v}} (1-x)^{C_{u_v}} (1 + E_{u_v} x^2),$$

$$xd_v(x) = A_{d_v} x^{B_{d_v}} (1-x)^{C_{d_v}},$$

$$x\bar{U}(x) = A_{\bar{U}} x^{B_{\bar{U}}} (1-x)^{C_{\bar{U}}},$$

$$x\bar{D}(x) = A_{\bar{D}} x^{B_{\bar{D}}} (1-x)^{C_{\bar{D}}},$$

$$xg(x) = A_g x^{B_g} (1-x)^{C_g} (1 + E_g x^2),$$

$$x\gamma(x) = A_\gamma x^{B_\gamma} (1-x)^{C_\gamma} (1 + D_\gamma x + E_\gamma x^2).$$

**PDF parameterisation**

$$\chi^2 = \sum_i \frac{[\mu_i - m_i (1 - \sum_j \gamma_j^i b_j)]^2}{\delta_{i,\text{unc}}^2 m_i^2 + \delta_{i,\text{stat}}^2 \mu_i m_i (1 - \sum_j \gamma_j^i b_j)} + \sum_j b_j^2 + \sum_i \ln \frac{\delta_{i,\text{unc}}^2 m_i^2 + \delta_{i,\text{stat}}^2 \mu_i m_i}{\delta_{i,\text{unc}}^2 \mu_i^2 + \delta_{i,\text{stat}}^2 \mu_i^2}$$

# Results

➤ **After minimisation** **1283.80** **1083** **1.185** ( $\chi^2$ / #degrees of freedom )

## HMDY 8 TeV

Dataset	1	8.96( -0.01)	12	HMDY rap 116-150
Dataset	2	15.36( +0.00)	12	HMDY rap 150 200
Dataset	3	13.81( -0.21)	12	HMDY rap 200 300
Dataset	4	4.82( +0.02)	6	HMDY rap 300 500
Dataset	5	3.96( +0.07)	6	HMDY rap 500 1500
Correlated Chi2	1.1654788144144461			
Log penalty Chi2	-0.11984831500646678			

$$\chi^2/\#\text{points} = 47.96/48$$

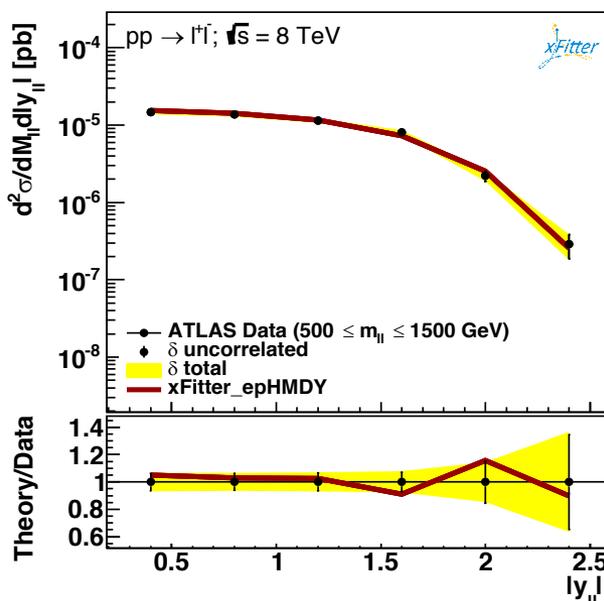
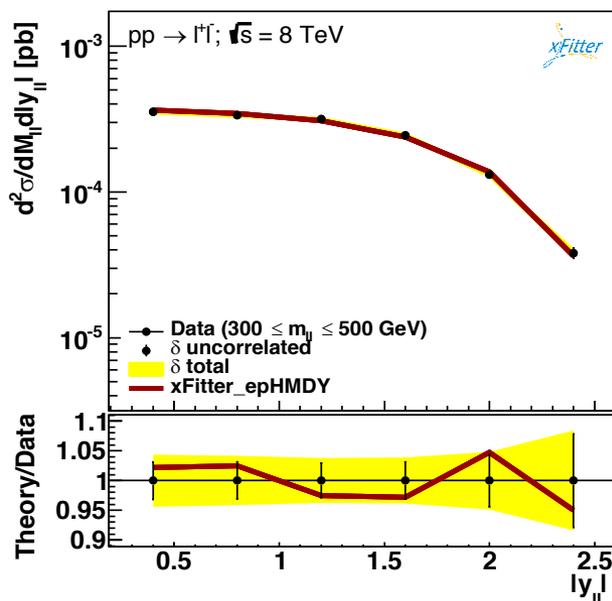
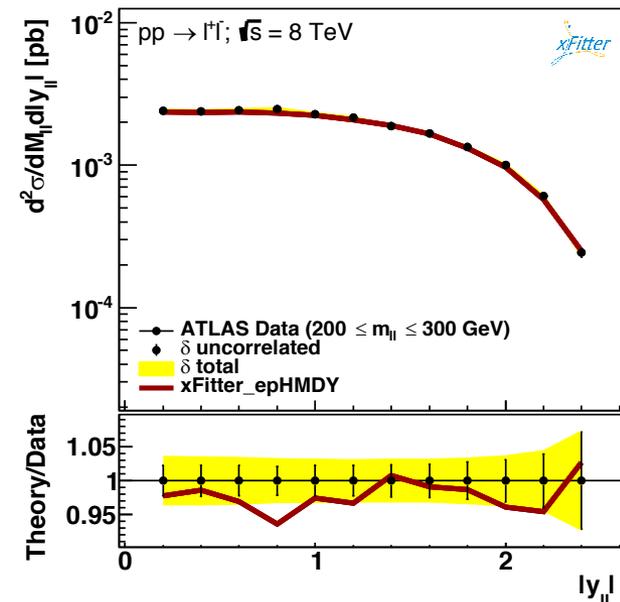
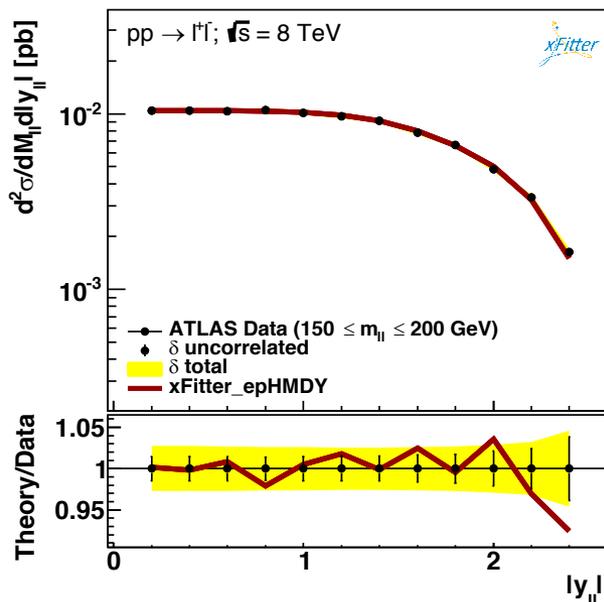
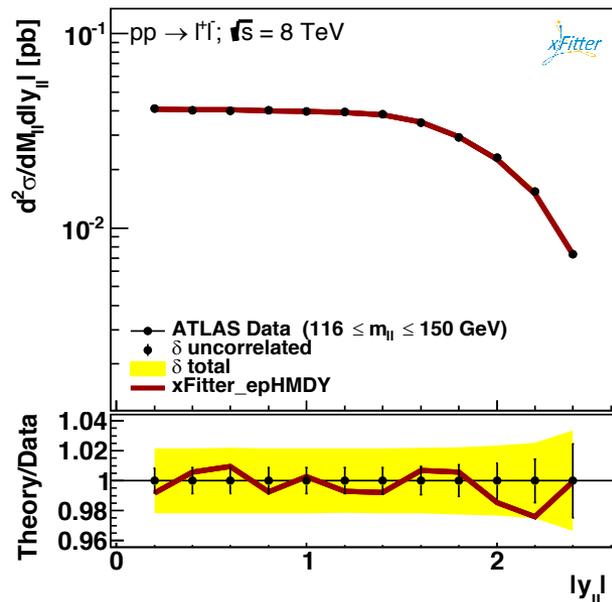
(data described well)

## HERA1+II

Dataset	1	218.79( -1.59)	159	HERA1+2 NCem
Dataset	2	383.22( +2.13)	332	HERA1+2 NCep 920
Dataset	3	60.49( -0.81)	63	HERA1+2 NCep 820
Dataset	4	197.41( +2.98)	234	HERA1+2 NCep 575
Dataset	5	207.41( -1.55)	187	HERA1+2 NCep 460
Dataset	6	54.61( -2.21)	42	HERA1+2 CCem
Dataset	7	48.52( +0.00)	39	HERA1+2 CCep
Correlated Chi2	66.4488724391			
Log penalty Chi2	-1.0519009775			

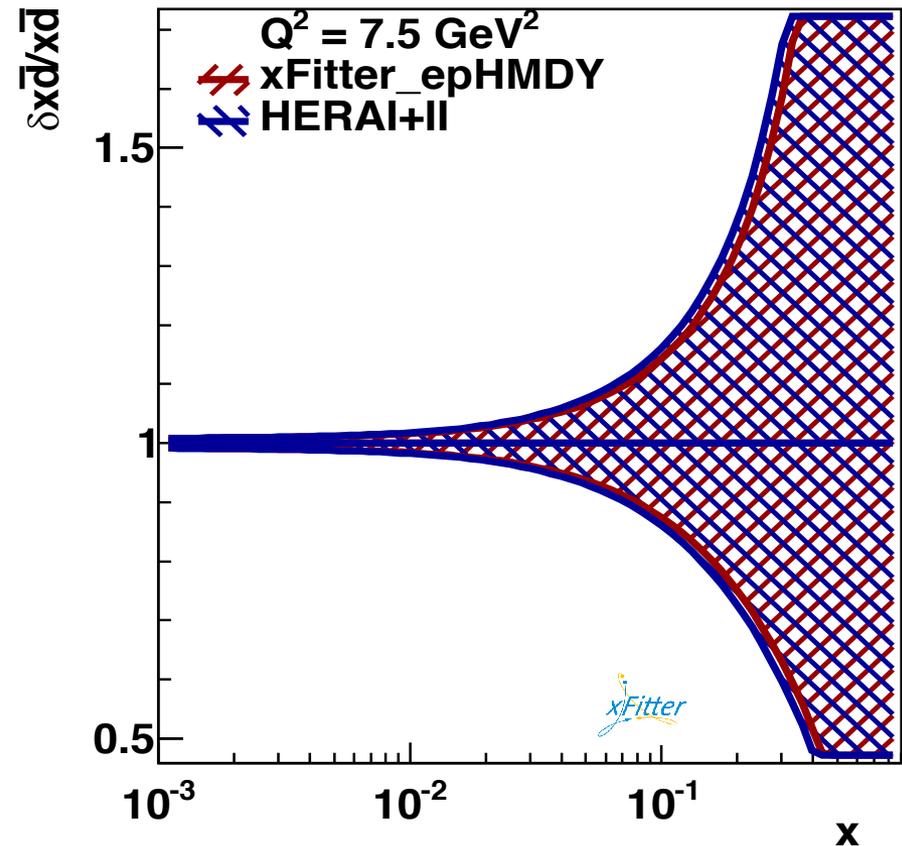
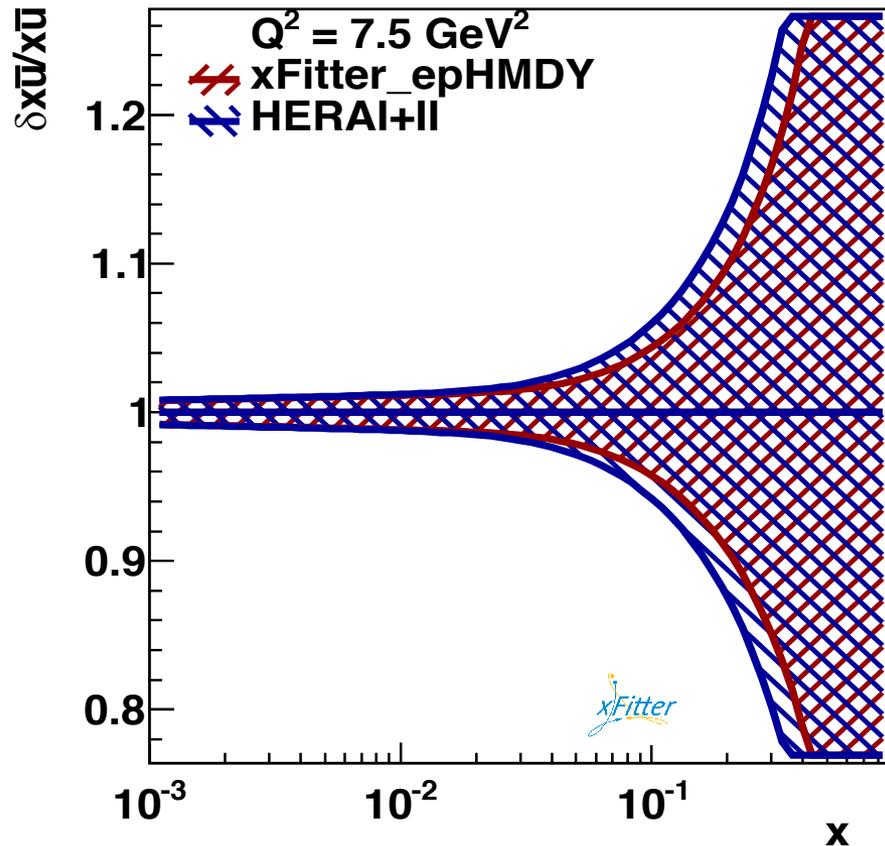
$$\chi^2 / \#\text{points} = 1235.85/1056$$

# Data Vs Theory

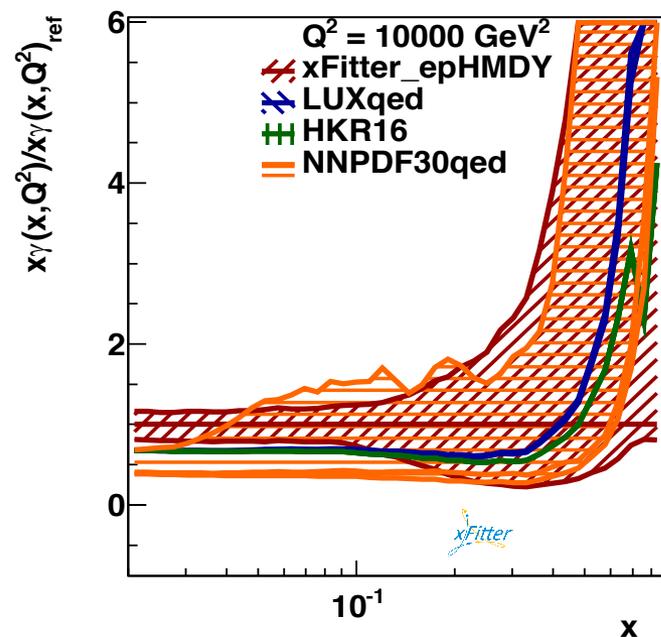
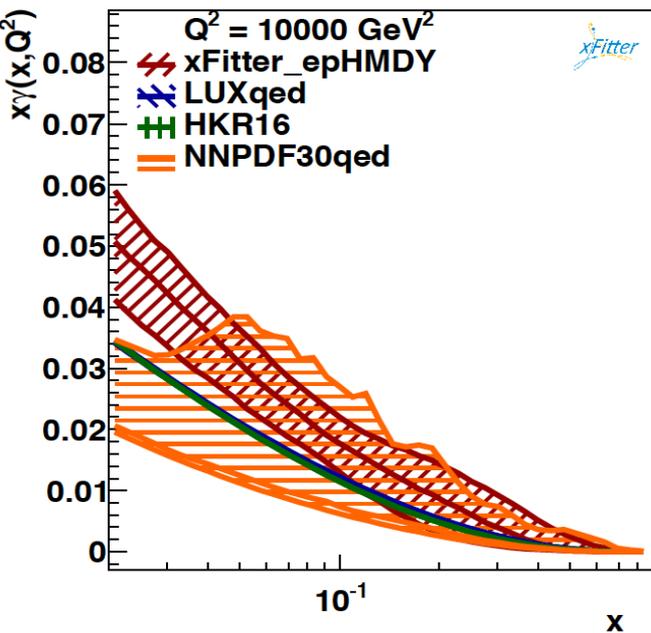


- Comparisons shown both in an absolute scale and as ratios to the central value of the experimental data
- Error bars on data correspond to statistical uncertainties
- Yellow bands indicate the size of the correlated systematic uncertainties
- **Good agreement between ATLAS data and NNLO theory predictions**

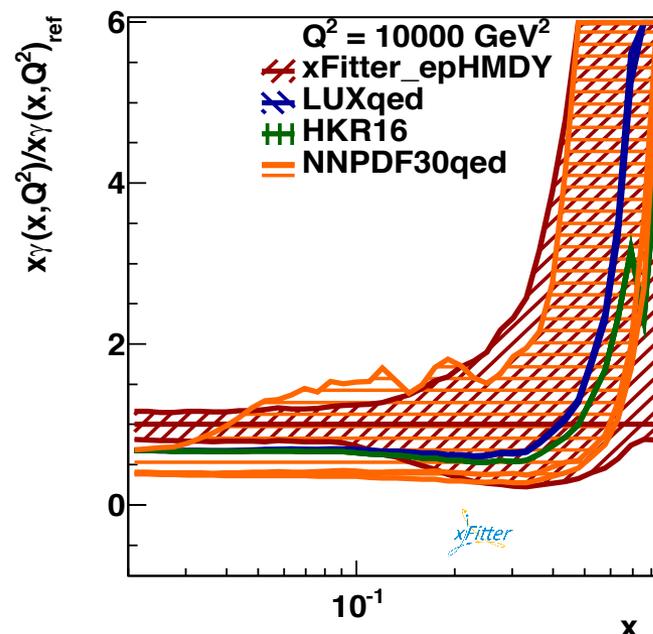
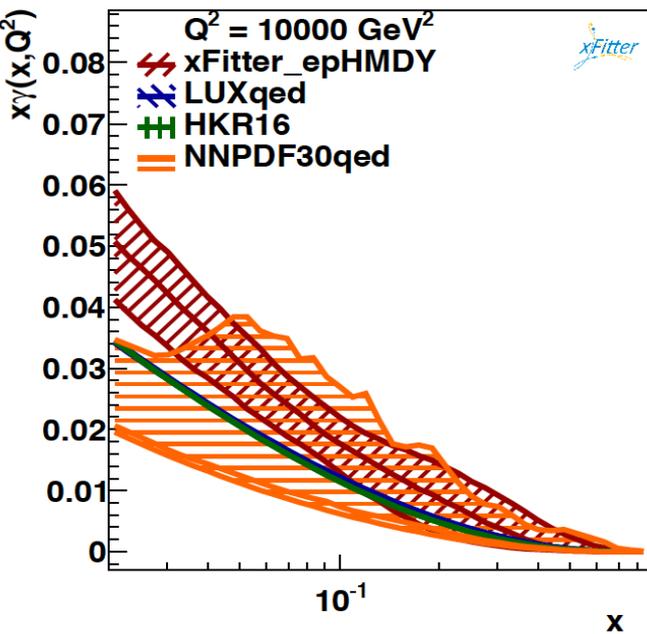
# Impact on the antiquark PDFs



The impact in the medium and large- $x$  antiquark distributions from the high mass DY data are rather moderate



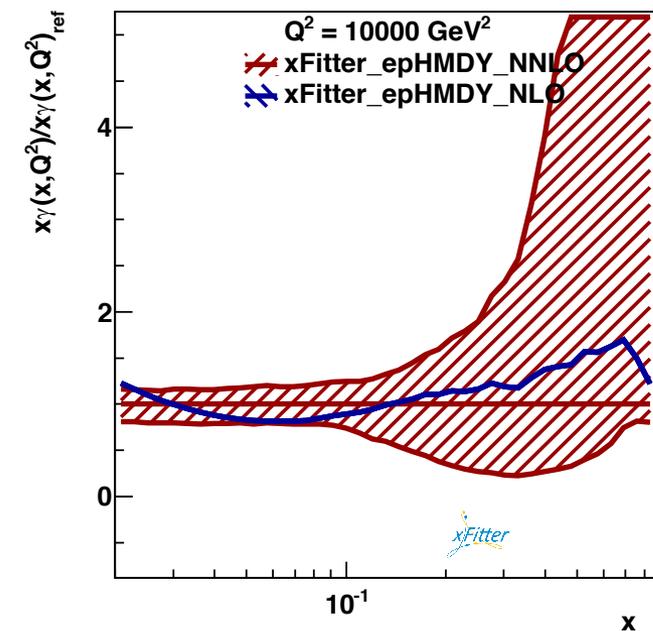
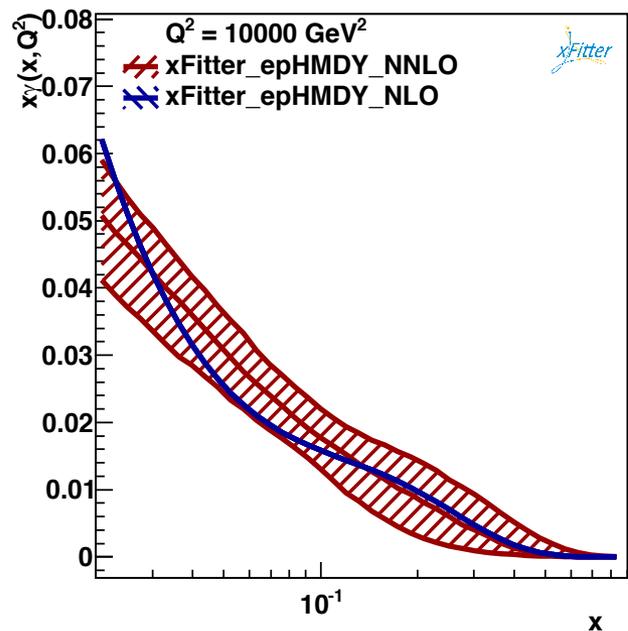
- $xy(x, Q^2)$  compared to LUXqed, HKR16 and NNPDF30qed
- Only experimental uncertainties at 68% confidence level (CL)
- $0.02 \leq x \leq 0.9$  (beyond that region very limited sensitivity)
- For  $x \geq 0.1$ , photon PDF determinations consistent; for smaller  $x$  values, in agreement at the  $2\sigma$  level
- For  $0.04 \leq x \leq 0.2$  smaller PDF uncertainties as compared to those from NNPDF30qed
- Uncertainties  $\sim 30\%$  for  $x \leq 0.1$
- Limited sensitivity of the ATLAS data to the photon PDF doesn't allow obtaining a determination of  $xy$  with uncertainties competitive with those of LUXqed and HKR16



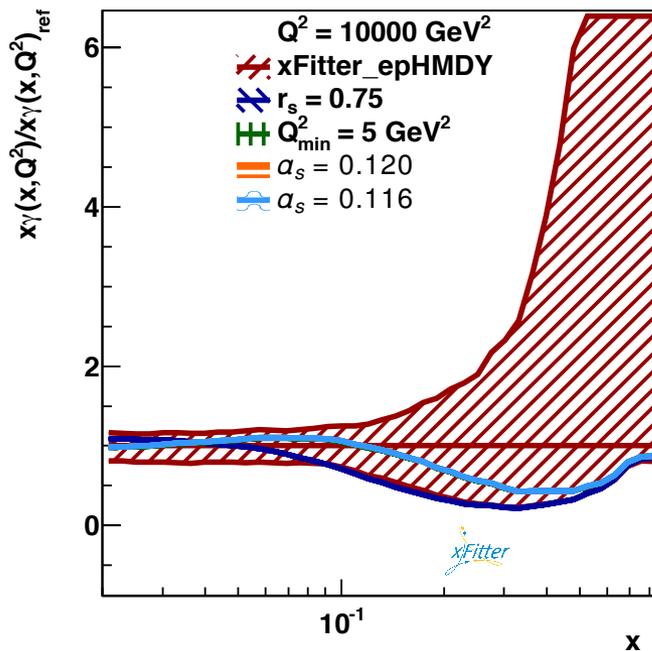
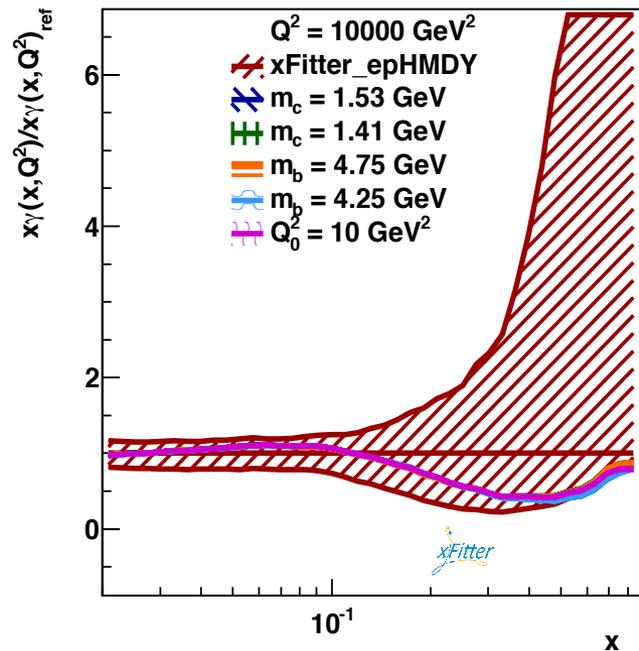
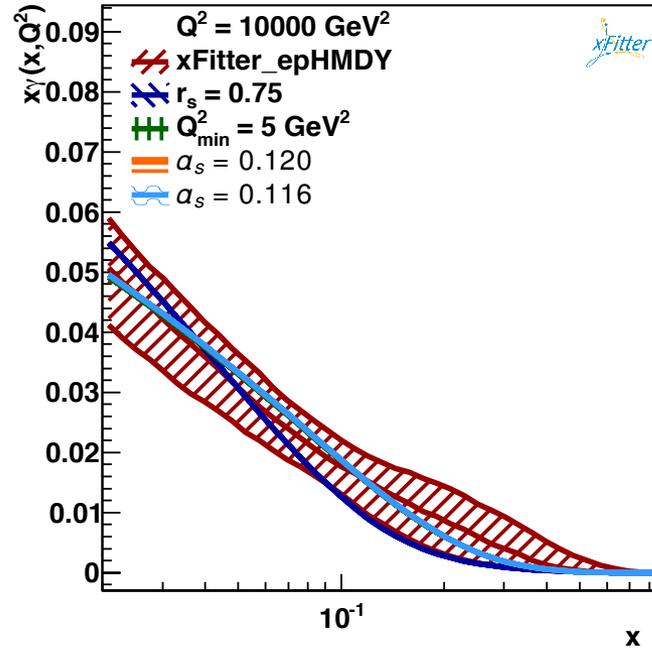
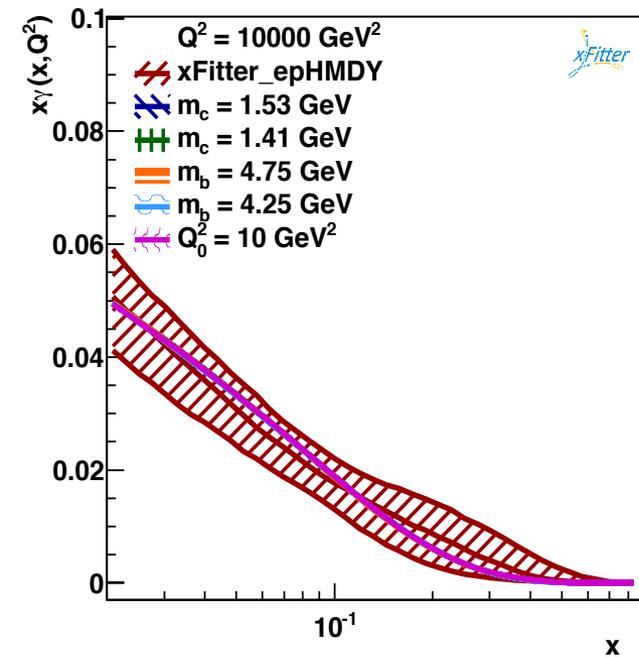
Comparison  
between **NLO** vs  
**NNLO** photon PDF



To quantify perturbative stability of photon PDF determination (QED part of the calculation identical in both cases)



The fit exhibits a reasonable perturbative stability, since the central value of the NLO fit is always contained in the  $1\sigma$  PDF uncertainty band (only exp. unc.)



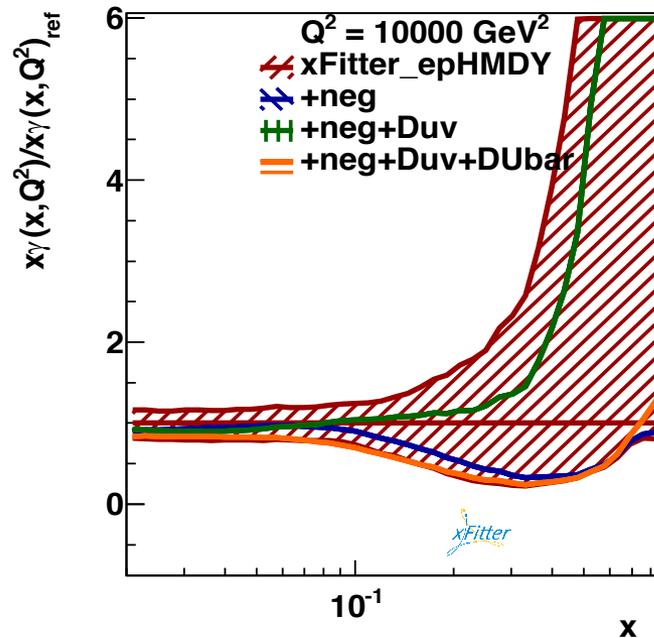
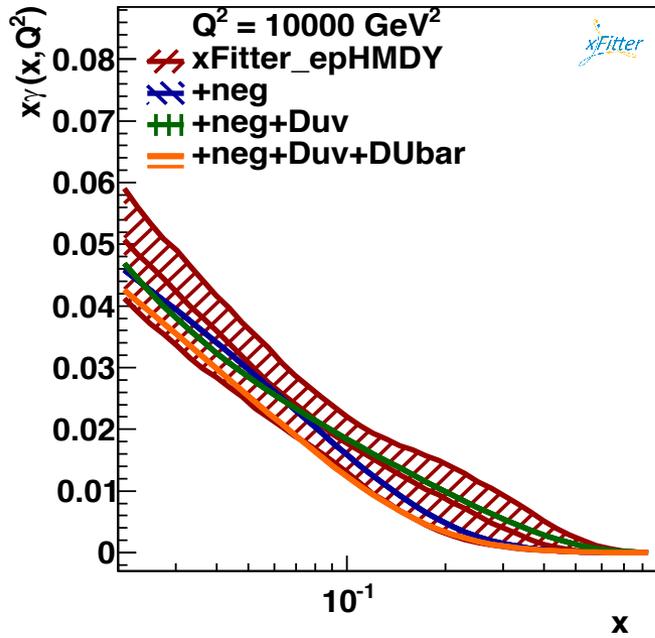
➤ Here, **NNLO Hessian** results for nine model variations:

- $a_s = 0.116$
- $a_s = 0.120$
- $r_s = 0.75$
- $Q^2$  cut =  $5 \text{ GeV}^2$
- $m_b$  down =  $4.25 \text{ GeV}$
- $m_b$  up =  $4.75 \text{ GeV}$
- $m_c$  down =  $1.41 \text{ GeV}$
- $m_c$  up =  $1.53 \text{ GeV}$
- $Q_0^2$  cut =  $10 \text{ GeV}^2$

➤ No changes in the  $\chi^2$

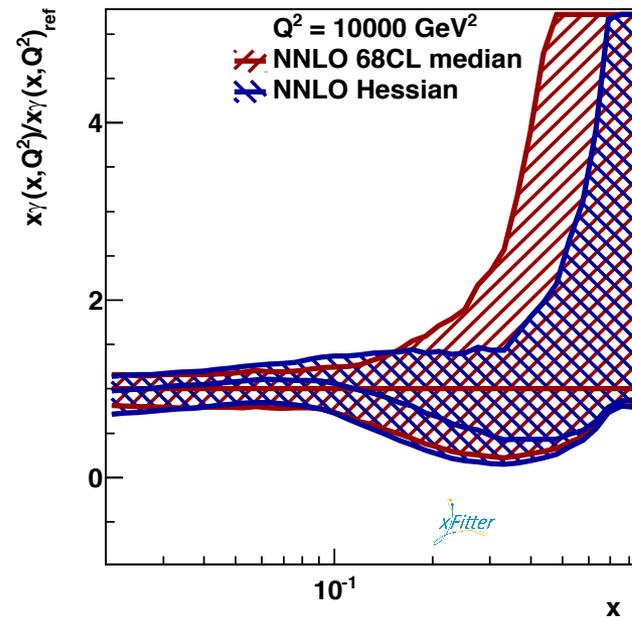
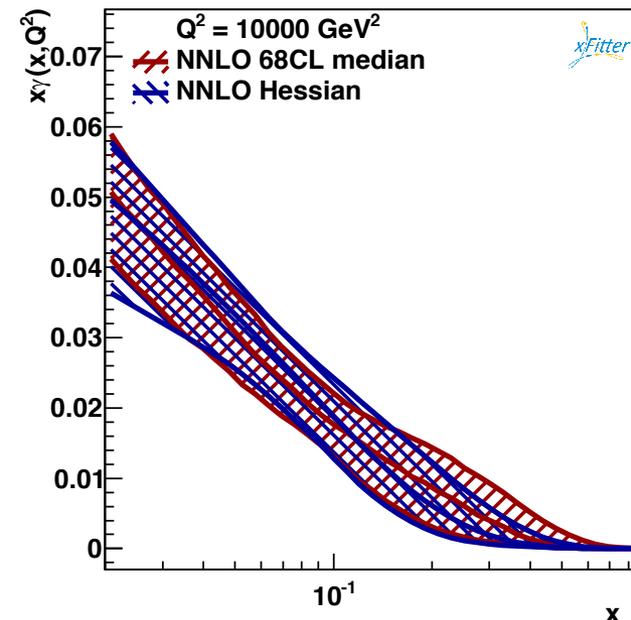
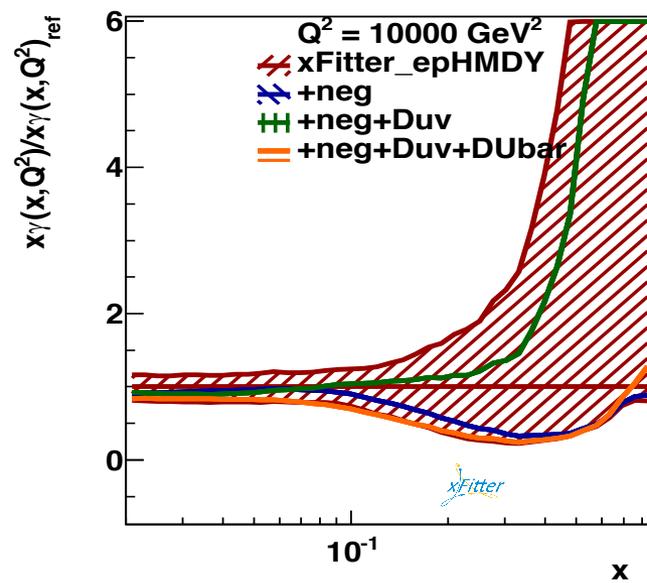
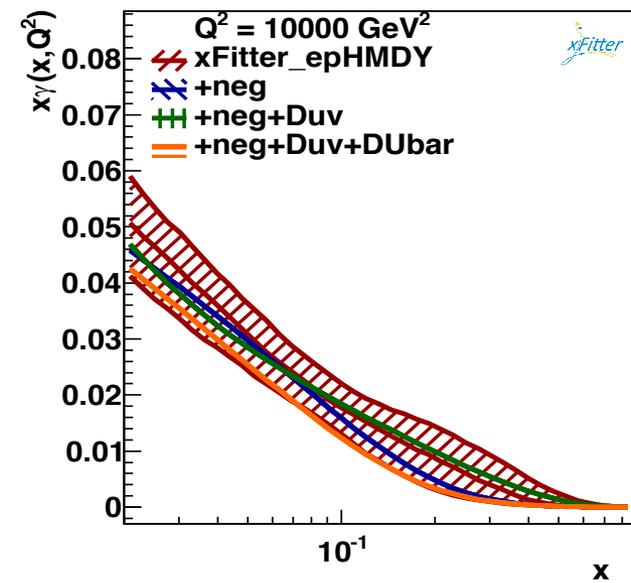
➤ All the central fit are inside the MC error bands (some of them overlap and they are not visible)

$$r_s = (s + \bar{s})/2\bar{d}$$



- Here, I'm showing the **NNLO Hessian results** for parameterisation variations:
  - +neg
  - +neg+Duv
  - +neg+Duv+DUbar
- All the central fit are inside the MC error bands

# Median $\pm$ 68% CL vs Hessian (asym)



- Bands = experimental uncertainties only
- Reasonable agreement between the two methods
- Central values with different fitting techniques similar to each other
- MC uncertainties larger than Hessian ones (especially for  $x \gtrsim 0.2$ , indicating deviations with respect to the Gaussian behaviour of the photon PDF)

# Summary

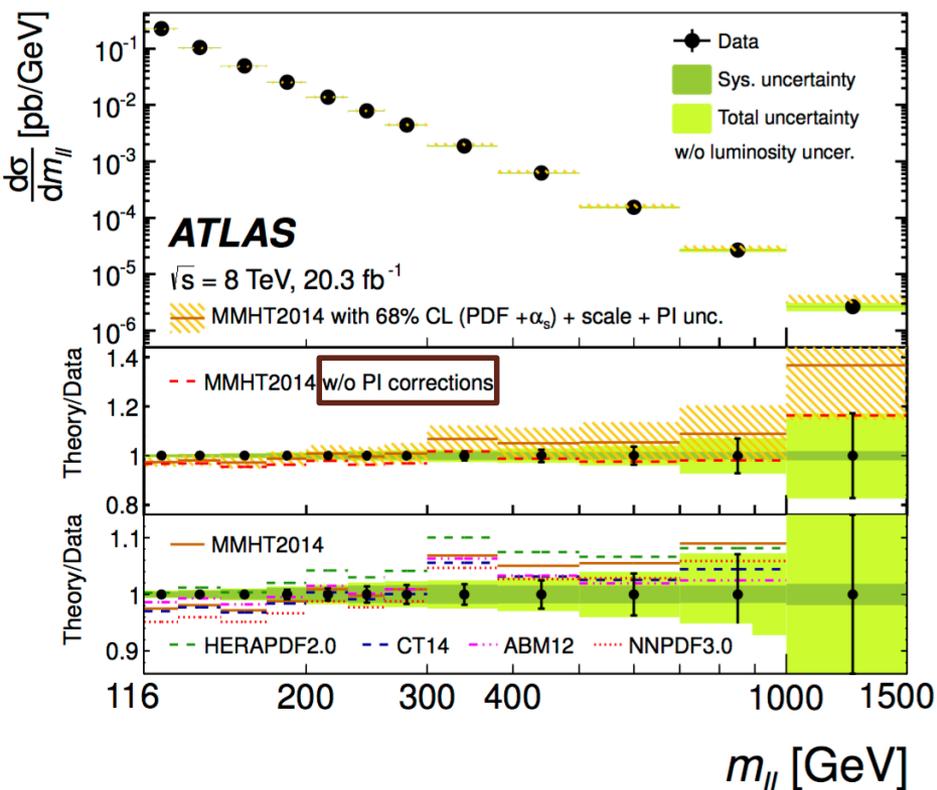
- New technical developments:
  - Full NLO QED corrections to the DGLAP evolution and DIS structure functions were implemented
  - Possibility to fit more than standard 12 PDFs
  - Extension of the APPLgrid to aMCfast for the presence of the photon-initiated channels
- Determination of  $x\gamma(x)$  with uncertainties at the 30% level for  $0.02 \leq x \leq 0.1$ , then they increase for higher values of  $x$
- Robustness of the fit and his perturbative stability shown
- Our results in agreement with LUXqed and HKR16 within uncertainties
- Direct determination of the photon PDF from hadron collider data is still far from being competitive with these calculations, based instead on precise measurements of the inclusive DIS structure functions of the proton
- This analysis provides further evidence that the information on the photon PDF provided by the most sensitive LHC data available so far is fully consistent with these two independent calculations
- Paper on the arXiv! [arXiv:1701.08553v1](https://arxiv.org/abs/1701.08553v1) (submitted to EPJC – in review)
- [Results of this study available in the LHAPDF6 format](#) (sent to Andy Buckley)

# ***Backup Slides***

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# Theory comparison

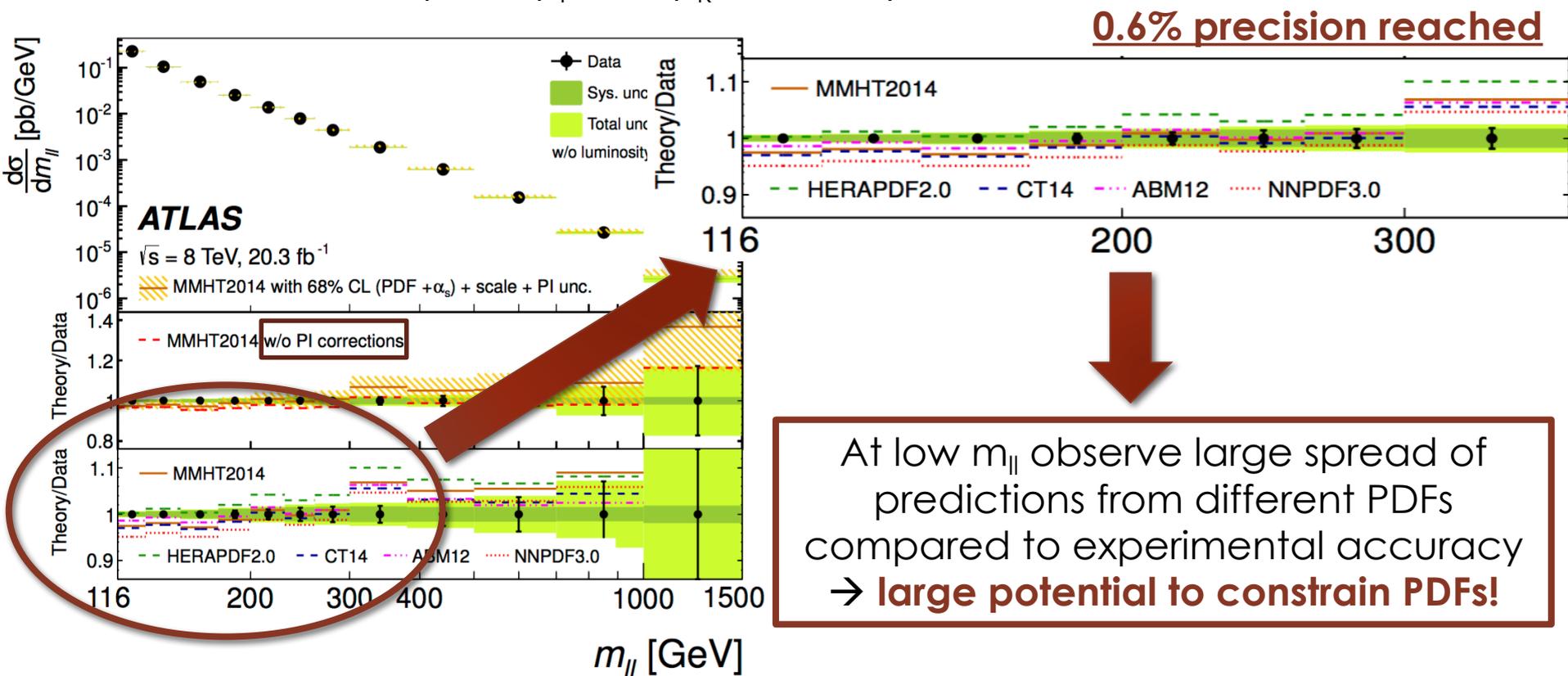
- The measured cross sections are compared to theoretical predictions using a selection of **recent PDF sets** (HERAPDF2.0, CT14, ABM12, NNPDF3.0)
- Theory = NNLO pQCD  $\otimes$  NLO EW + LO PI; pQCD uses MMHT14 NNLO PDF set
- LO PI uses NNPDF23qed for photon PDF  $\pm$  68% of replicas;  $\alpha_s = 0.118 \pm 0.001$
- Scale error: envelope of  $\mu_F$  and  $\mu_R$  varied by factors of 2



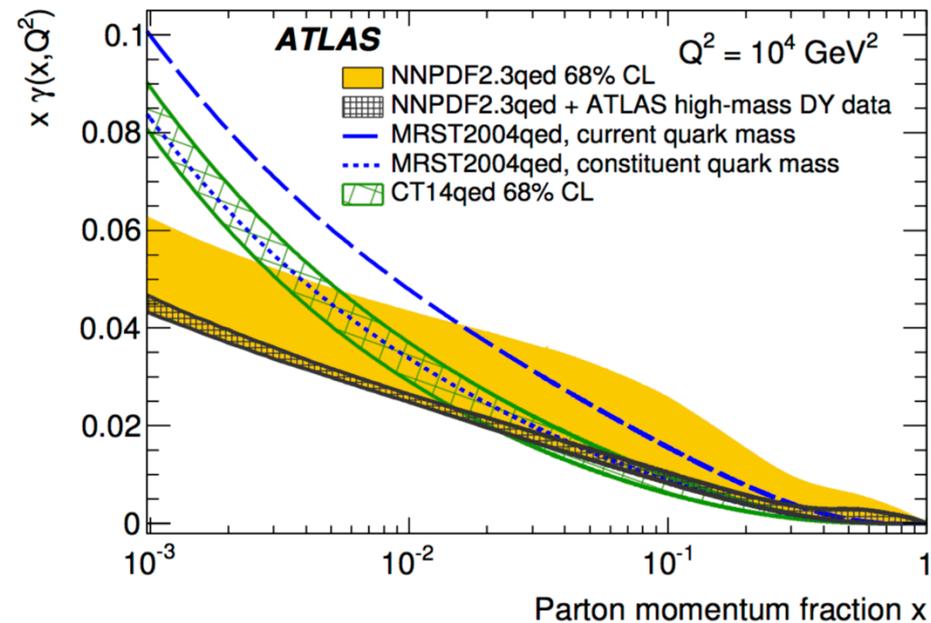
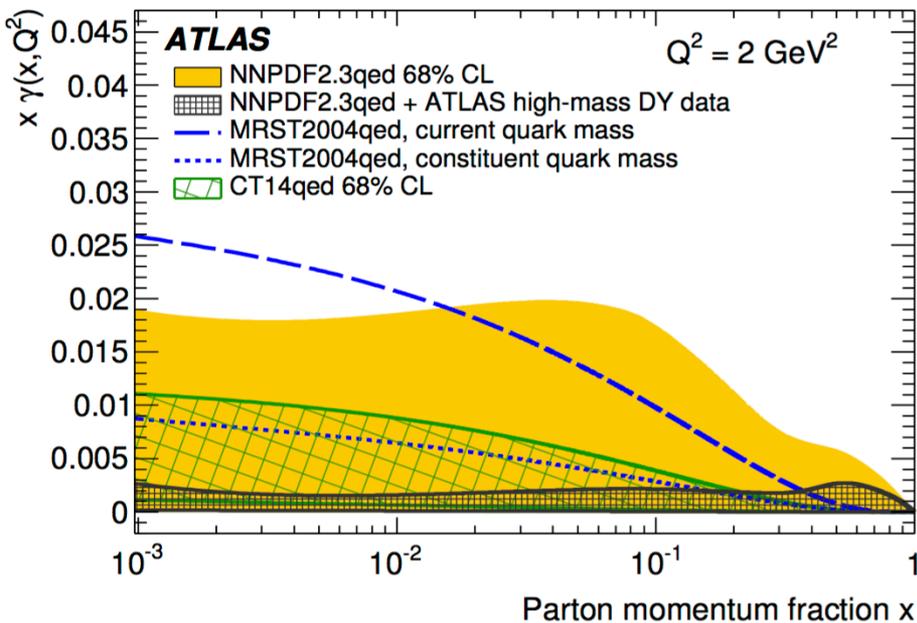
- Theory uncertainties are larger than data uncertainties  $\rightarrow$  **potential for PDF constraints**
- Theory generally in agreement with data
- Photon induced contribution reaches 15% at large  $m$
- Where PI contribution is large, theory uncertainty dominated by the PI piece
- Else PDF uncertainty dominates theory precision

# Theory comparison

- The measured cross sections are compared to theoretical predictions using a selection of **recent PDF sets** (HERAPDF2.0, CT14, ABM12, NNPDF30)
- Theory = NNLO pQCD  $\otimes$  NLO EW + LO PI; pQCD uses MMHT14 NNLO PDF set
- LO PI uses NNPDF23qed for photon PDF  $\pm 68\%$  of replicas;  $\alpha_s = 0.118 \pm 0.001$
- Scale error: envelope of  $\mu_F$  and  $\mu_R$  varied by factors of 2



# Photon PDF



- Assess impact of new data on photon PDF → use **Bayesian reweighting of NNPDF replicas**
- Each replica receives a weight according to  $\chi^2$  function (poorly fitting replicas receive a small weight; replicas fitting the data well receive a large weight)
- New PDF central value is estimated from mean of weighted replicas
- New PDF uncertainty determined from 68% CL
- **Original NNPDF uncertainty dramatically reduced in reweighting**

# APPLgrid settings

- The APPLgrids are produced using aMCfast (v01-03-00) and MG5\_aMC@NLO v2.4.3 – **one of the latest tag available**) technology and then transferred to xFitter for fitting
- Because photon PDF is a new addition to the lhapdf format type, a mapping of the indices is needed to assure that that the photon PDF contribution is actually accounted for:
  - use of the adjusted applgrid for photon PDF (thanks to V. Bertone / S. Carrazza)
  - use of the modern interface to LHAPDF (v6.1.6)
  - use of a dedicated branch of xFitter that is linked to the adjusted APPLgrid (PI\_apfel\_for\_lhaGridQED)
- Validation procedure then is performed using:
  - standalone reader of the APPLgrids (thanks to V. Bertone)
  - xfitter reader of the predictions

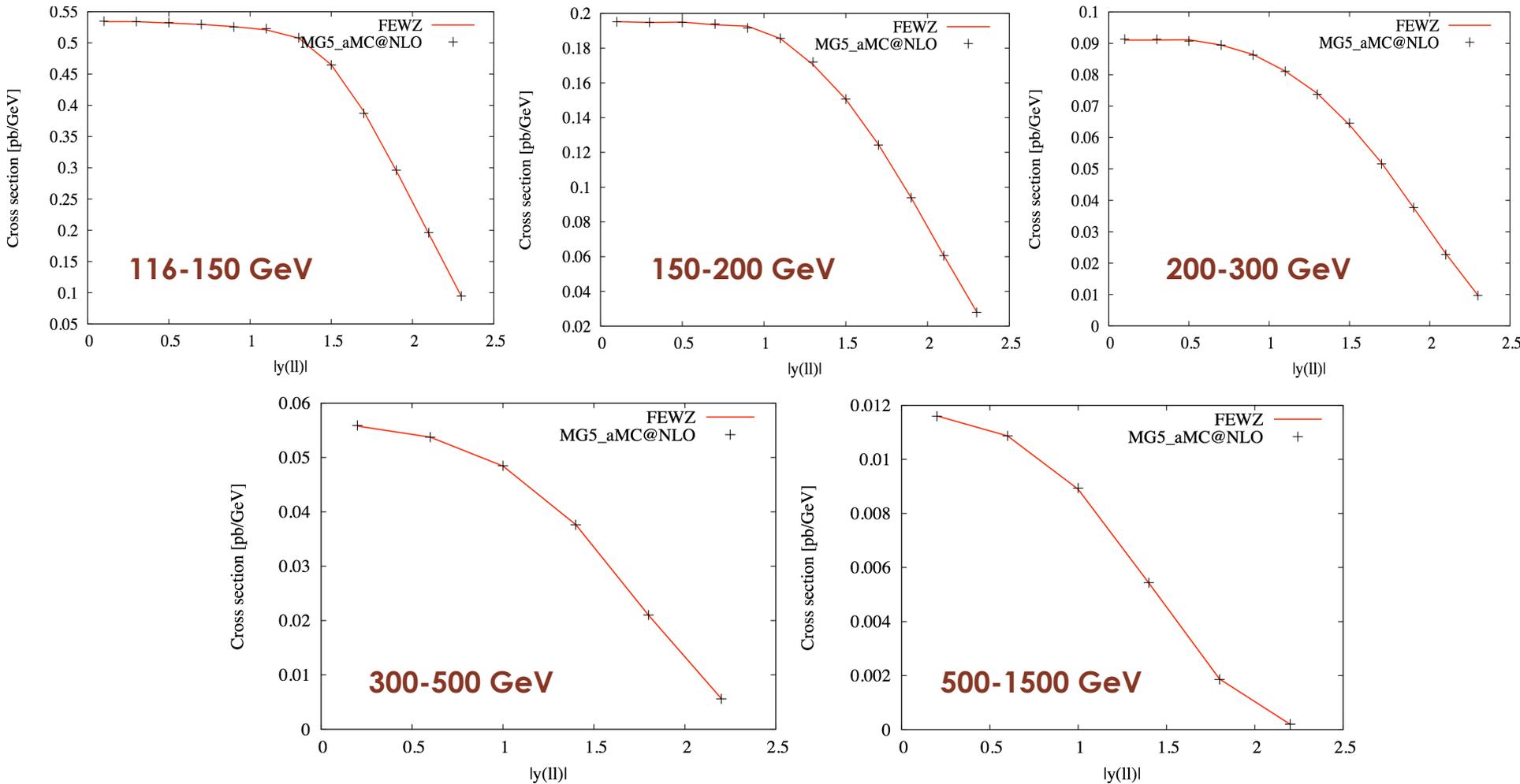
Following suggestion made by S. Glazov during one of the Internal xFitter meeting: increment the number of points in the grids and play a bit with  $Q^2_{\min}$  and  $Q^2_{\max}$  ... So I modified the following piece of code in my analysis:

```
*
*   Grid parameters
*
appl_Q2min  = (lower mass bin edge - 5 GeV)^2d0
appl_Q2max  = (higher mass bin edge + 5 GeV)^2d0
appl_xmin   = 1d-5
appl_xmax   = 1d0
appl_nQ2    = 10   (for QCD 1D distribution and for all LO PI = 70)
appl_Q2order = 3
appl_nx     = 30   (for QCD 1D distribution and for all LO PI = 50)
appl_xorder = 3
```

I'm also optimising the cut on  $m_{ll}$  at the generation level (lower mass bin edge - 5 GeV) and I'm using dynamical scales, set to the invariant mass of the lepton pair: in setscale.f

```
elseif(dynamical_scale_choice.eq.0) then
```

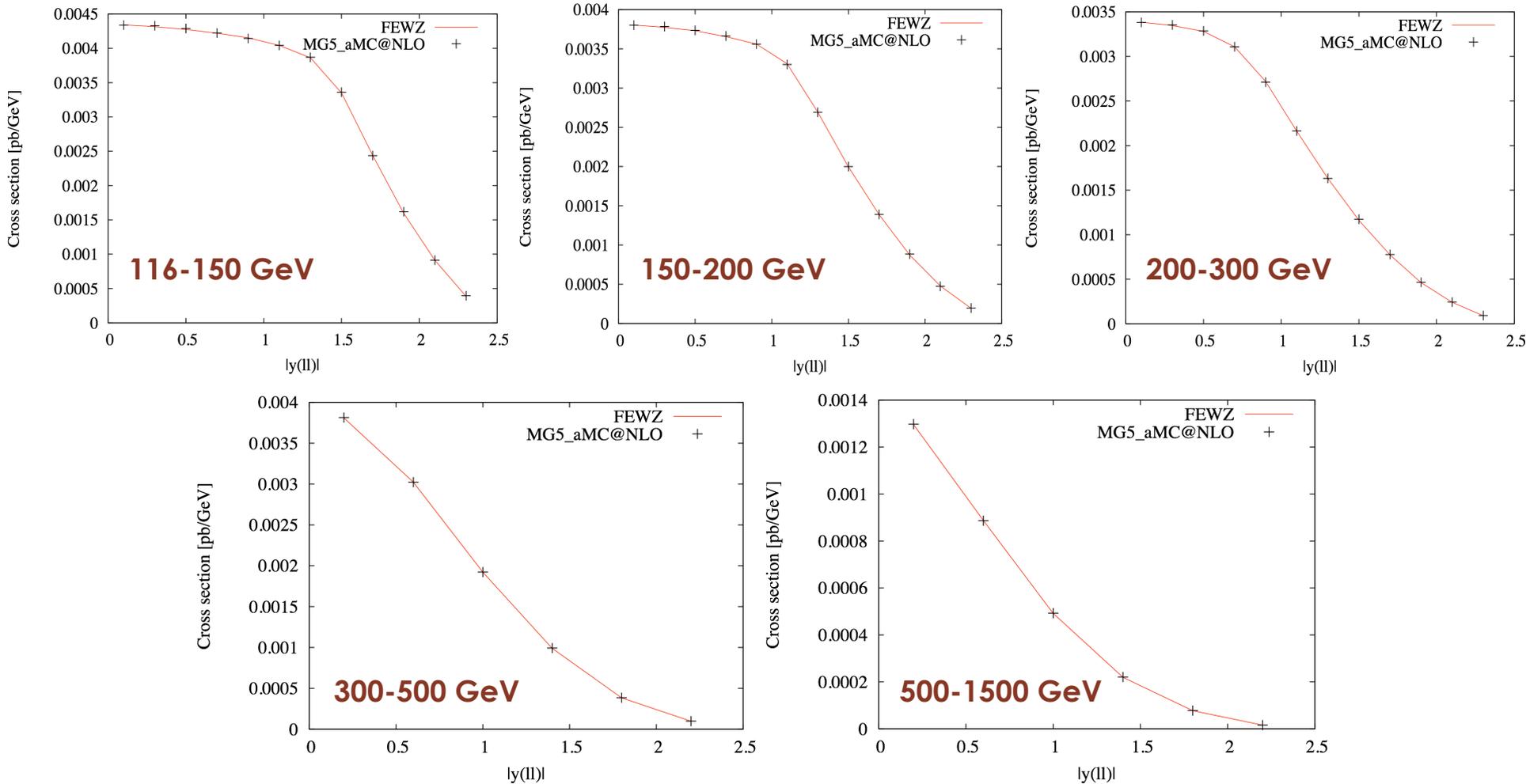
```
    temp_scale_id='Mll' ! use a meaningful
string
    tmp=dsqrt(2d0*dot(pp(0,3),pp(0,4)))
```



Here the NLO QCD predictions for MG5\_aMC@NLO 2.4.3 and FEWZ 3.1

Cross section as a function of  $|y_u|$  in five invariant mass bins

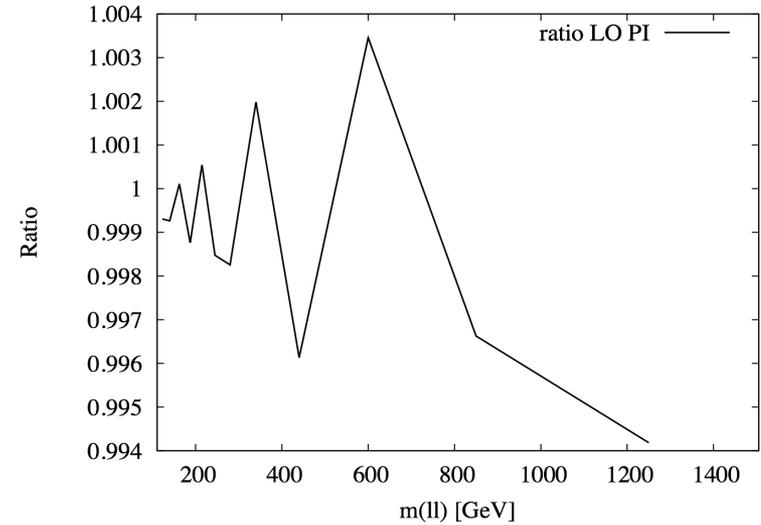
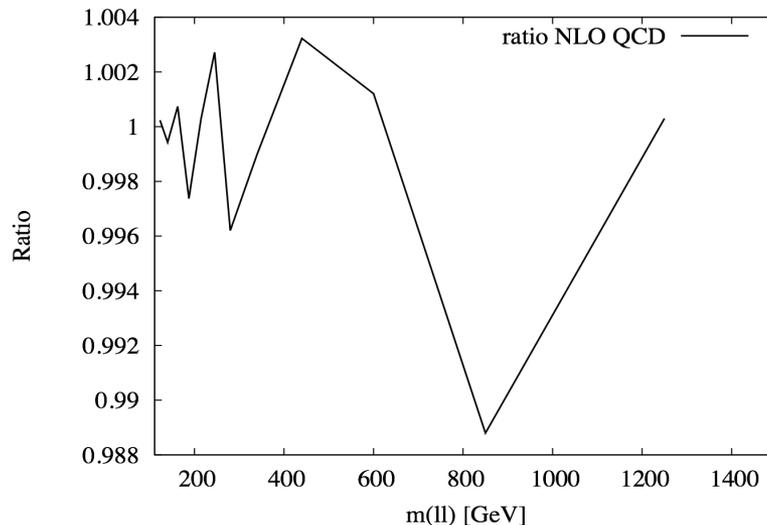
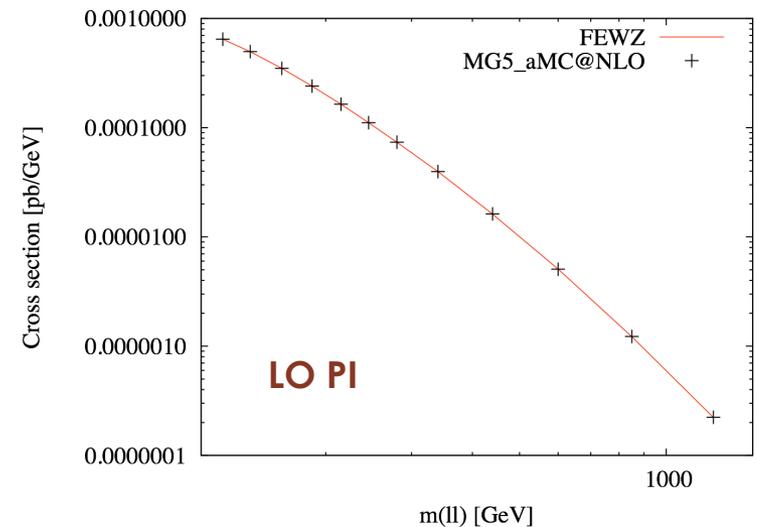
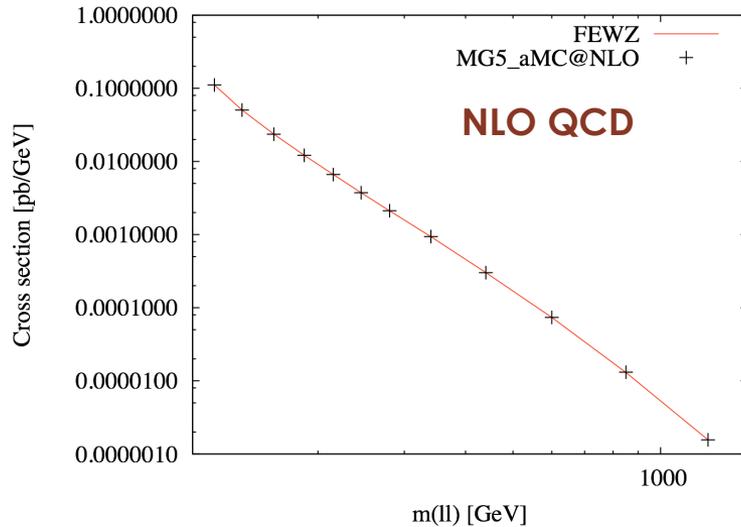
Difference between the two predictions at most 1%



Here the LO PI predictions for MG5\_aMC@NLO 2.4.3 and FEWZ 3.1

Cross section as a function of  $|y_u|$  in five invariant mass bins

Difference between the two predictions at most 1% as well



Here the predictions for MG5\_aMC@NLO 2.4.3 and FEWZ 3.1 regarding the 1D distribution  $d\sigma/(dM_{ll})$

Difference between the two predictions at most 1.5% for NLO QCD, around 4 per mille as regards LO PI

# LO PI contribution to total xsection

$m_{ll}$ [GeV]	$ y_{ll} $	QED/QCD
116 – 150	0.0 – 0.2	0.0252
116 – 150	0.2 – 0.4	0.0252
116 – 150	0.4 – 0.6	0.0250
116 – 150	0.6 – 0.8	0.0245
116 – 150	0.8 – 1.0	0.0241
116 – 150	1.0 – 1.2	0.0234
116 – 150	1.2 – 1.4	0.0227
116 – 150	1.4 – 1.6	0.0214
116 – 150	1.6 – 1.8	0.0184
116 – 150	1.8 – 2.0	0.0160
116 – 150	2.0 – 2.2	0.0138
116 – 150	2.2 – 2.4	0.0127
150 – 200	0.0 – 0.2	0.0524
150 – 200	0.2 – 0.4	0.0520
150 – 200	0.4 – 0.6	0.0507
150 – 200	0.6 – 0.8	0.0491
150 – 200	0.8 – 1.0	0.0473
150 – 200	1.0 – 1.2	0.0442
150 – 200	1.2 – 1.4	0.0380
150 – 200	1.4 – 1.6	0.0315
150 – 200	1.6 – 1.8	0.0263
150 – 200	1.8 – 2.0	0.0223
150 – 200	2.0 – 2.2	0.0188
150 – 200	2.2 – 2.4	0.0174

As expected:

- LO PI contribution increases when  $m_{ll}$  increases
- LO PI contribution decreases when  $|y_{ll}|$  increases
- LO PI contribution reached ~12% of the total  $\sigma$  in the last invariant mass bin
- LO PI contribution evaluated with our fit as PDF input; QCD part with MMHT14\_nnlo\_68cl
- Difference to prediction computed wrt. NNPDF30qed\_nnlo\_as\_0118\_qed ~3%

$m_{ll}$ [GeV]	$ y_{ll} $	QED/QCD
200 – 300	0.0 – 0.2	0.0837
200 – 300	0.2 – 0.4	0.0822
200 – 300	0.4 – 0.6	0.0793
200 – 300	0.6 – 0.8	0.0737
200 – 300	0.8 – 1.0	0.0643
200 – 300	1.0 – 1.2	0.0525
200 – 300	1.2 – 1.4	0.0421
200 – 300	1.4 – 1.6	0.0339
200 – 300	1.6 – 1.8	0.0279
200 – 300	1.8 – 2.0	0.0231
200 – 300	2.0 – 2.2	0.0202
200 – 300	2.2 – 2.4	0.0178
500 – 1500	0.0 – 0.4	0.1184
500 – 1500	0.4 – 0.8	0.0910
500 – 1500	0.8 – 1.2	0.0580
500 – 1500	1.2 – 1.6	0.0362
500 – 1500	1.6 – 2.0	0.0239
500 – 1500	2.0 – 2.4	0.0182
500 – 1500	0.0 – 0.4	0.1216
500 – 1500	0.4 – 0.8	0.0816
500 – 1500	0.8 – 1.2	0.0493
500 – 1500	1.2 – 1.6	0.0308
500 – 1500	1.6 – 2.0	0.0221
500 – 1500	2.0 – 2.4	0.0250

# Parameterisation variation

Starting point  $\rightarrow$  10p from HERA + Euv: **1340.22/1088** (1.230) -  $\chi^2$  / #degrees of freedom

	Dg	Eg	neg	Duv	Euv	Ddv	Edv	DUbar	EUbar	DDbar	EDbar	Dph	Eph
-	1311.27	1316.13	1312.98	1314.41	-	1309.50	1302.23	1313.55	1308.85	1313.82	1313.37	1285.24	X
+ Dph	1287.42	1289.77	1285.26	1287.24	-	1287.29	1287.33	1283.40	1280.64	1287.43	1285.53	-	1283.30
+ Eph	1283.30	1278.25	1274.66	1282.51	-	1280.41	1283.19	1277.93	1276.51	1283.32	1281.80	-	-
+ neg	1274.64	1274.39	-	1267.91	-	1274.49	1274.63	1272.20	1269.05	1274.42	1271.23	-	-
+ Duv	1267.92	1267.65	-	-	-	1267.79	1267.78	1253.34	1260.77	1267.89	1265.36	-	-
+ DUbar	1253.32	1253.10	-	-	-	1253.12	1253.23	-	1253.29	1253.30	1250.33	-	-
+EDbar	1250.32	1250.23	-	-	-	1249.81	1250.04	-	1250.28	1244.87	-	-	-

- Euv + Dph + Eph is our central fit (**NNLO**)
- We include the solutions +neg, +Duv, +DUbar (4<sup>th</sup>, 5<sup>th</sup> and 6<sup>th</sup> line) as parameterisation variation
- +DDbar solution didn't converge so we cannot take it into account
- Beyond +neg, Duv, DUbar no really significant decrease of the  $\chi^2$
- More checks on parameterisation scan in the following slide

# Extra checks on the parameterisation scan

- **NNLO fit with +Euv+Dph+Eph our baseline...** Are we sure that is the best solution?
- I performed a reversed parameterisation scan:
  - 16p:
 

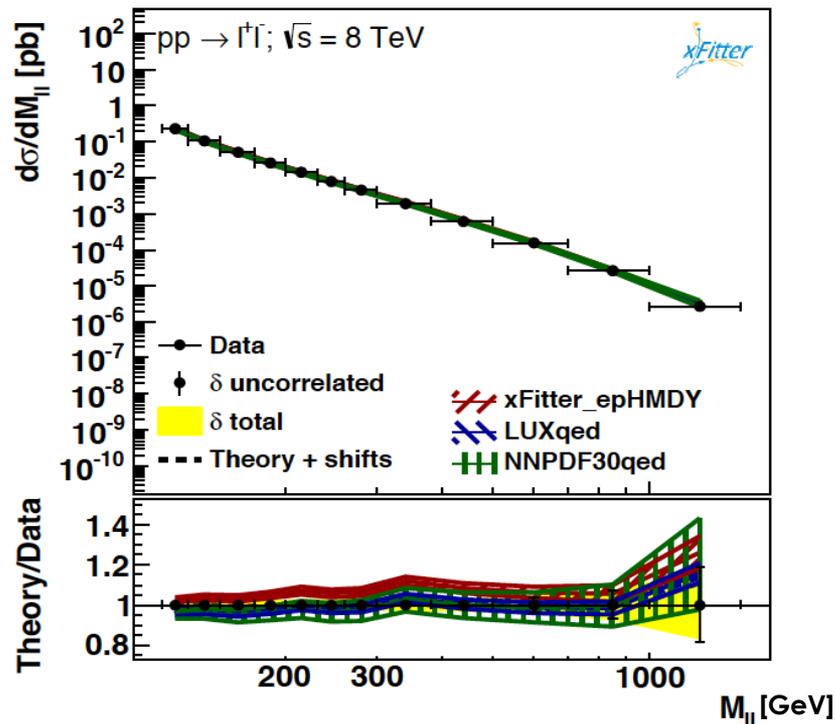
After minimisation	1283.80	1088	1.180
--------------------	---------	------	-------
  - 15p (no Eph):
 

After minimisation	1287.30	1089	1.182
--------------------	---------	------	-------
  - 15p (no Dph):
 

After minimisation	1286.58	1089	1.181
--------------------	---------	------	-------
  - 15p (no Euv):
 

After minimisation	1359.14	1089	1.25
--------------------	---------	------	------
- The impact of Dph, Eph on the chi2 is marginal but there's an improvement so it justifies our choice to have 13p+Euv+Dph+Eph as central fit

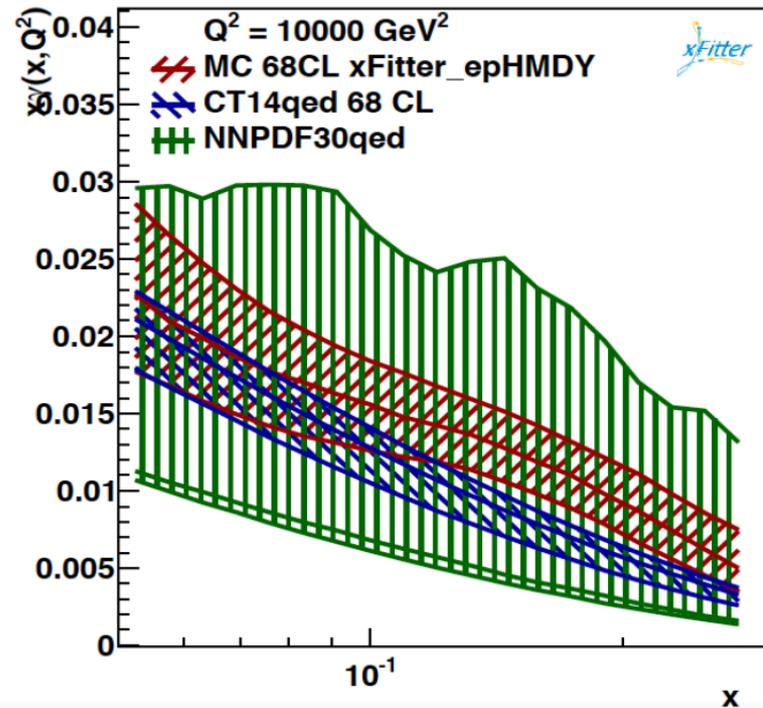
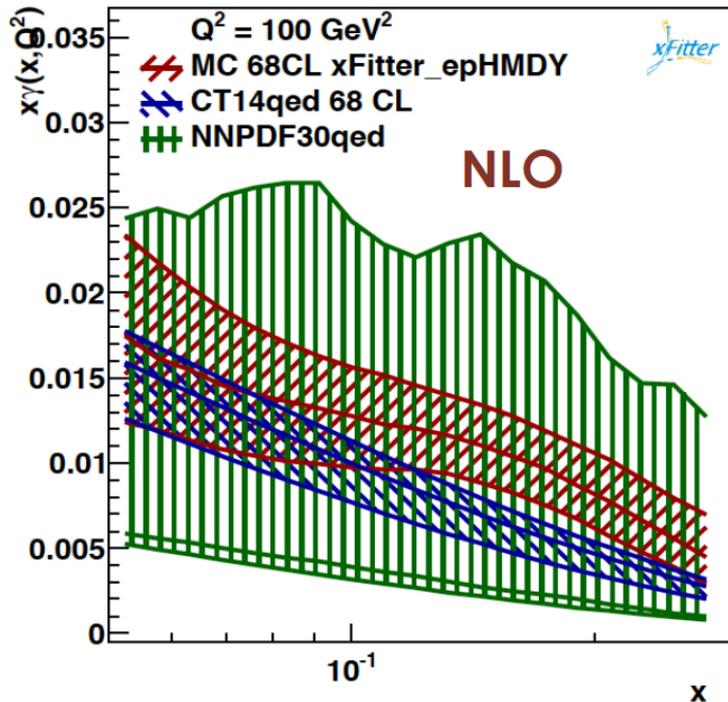
# Data Vs Theory (1D)



- Comparisons shown both in an absolute scale and as ratios to the central value of the experimental data
- Error bars on data correspond to statistical uncertainties
- Yellow bands indicate the size of the correlated systematic uncertainties
- **Good agreement between ATLAS data and NNLO theory predictions**
- Here, also comparison with two other NNLO PDF set: **LUXqed** and **NNPDF30qed**
- Compatible  $\chi^2$  between different predictions and all around 1 (pretty good data description)

Dataset	xFitter epHMDY	LUXqed	NNPDF30qed
HMDY Mass	11 / 12	12 / 12	12 / 12
Correlated $\chi^2$	5.8	4.5	5.3
Log penalty $\chi^2$	+0.30	+0.11	+0.04
Total $\chi^2$ / dof	17 / 12	17 / 12	17 / 12
$\chi^2$ p-value	0.15	0.16	0.15

# NLO fit results



- Drastically improvement in the errors size band compared to NNPDF30qed
- Agreement at  $1\sigma$  level with CT14qed prediction in the low- $x$  region
- In the medium-/high- $x$  region, agreement at  $1.5\sigma$  level