Drell-Yan cross-sections with fiducial cuts
-
Impact of linear power corrections and q_T-resummation in PDF determinations

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xFitter Workshop

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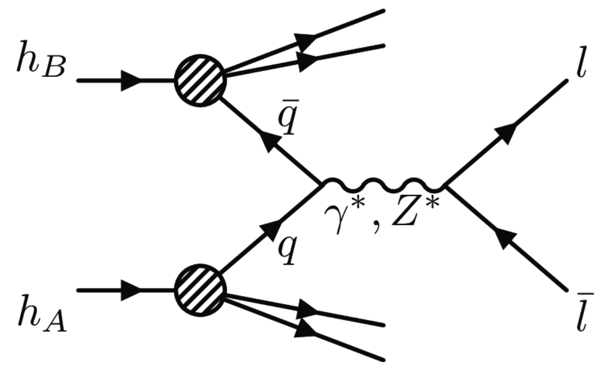
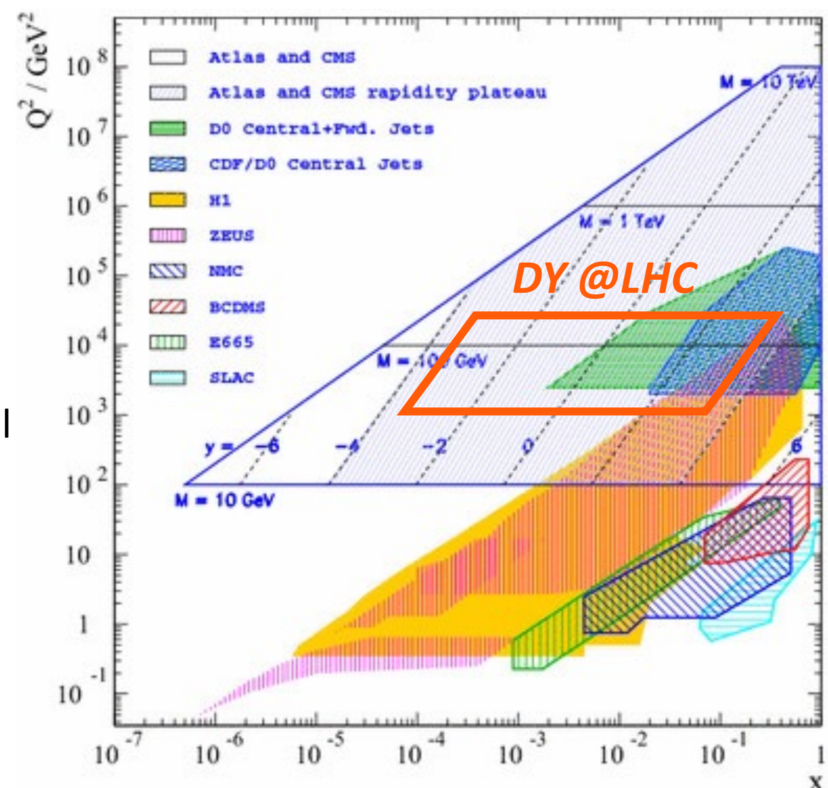
Drell-Yan process and PDF

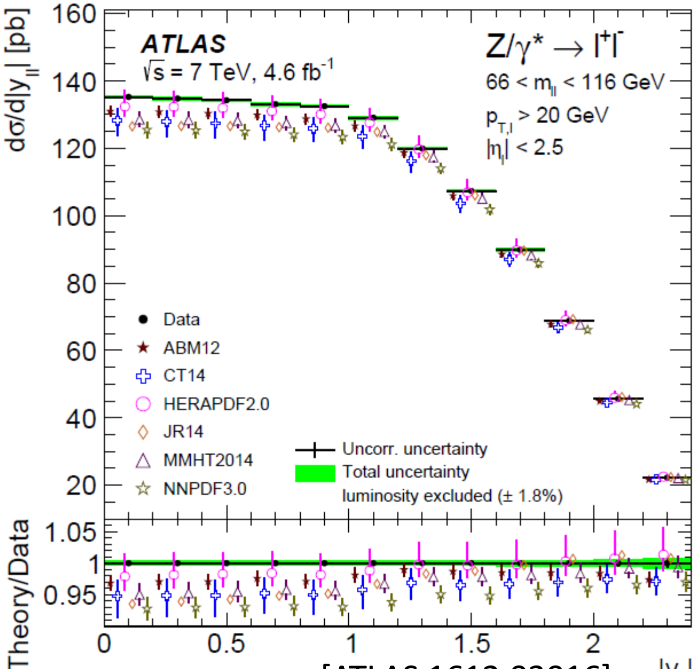


- Vector boson creation in hadron collisions
- Drell-Yan is the prime process for precision benchmark
- DY is predicted with high precision
  - NNLO fully differential result
  - N3LO [e.g. arXiv 2007.13313, arXiv 2107.09085, arXiv 2111.10379]
  - NLO EW
  - NNLO mixed QCDxEW
    - (E.g in arXiv:2106.11953, arXiv:2201.01754 arXiv:2203.11237)
- DY contribute to PDF knowledge
  - Accurate knowledge of PDF is fundamental part of LHC program
- Important for PDF evaluation
  - u- d- valence quark PDFs
  - $R_s = (s+\bar{s})/(\bar{u}+\bar{d})$



DY measurements at the LHC

- **High precision ATLAS 7TeV W/Z cross section**
  - Challenges the accuracy of theoretical predictions
  - Z peak accuracy at 0.5% (excluding luminosity uncert.)
  - high experimental precision requires equally high theory accuracy for inclusion in QCD fits
  - Difficult to describe in modern PDF fit



[ATLAS 1612.03016]

Ultimate goal – understand the effects of the mismatch:

- PDF fit at fixed order
- But PDF used in parton shower MC e.g. [arXiv:1406.7693]

Effort for ATLAS 7TeV started in [ATL-PHYS-PUB-2018-004]

ATLAS 7TeV W/Z measurement

- Fiducial volume for Z cross section

Central Channel

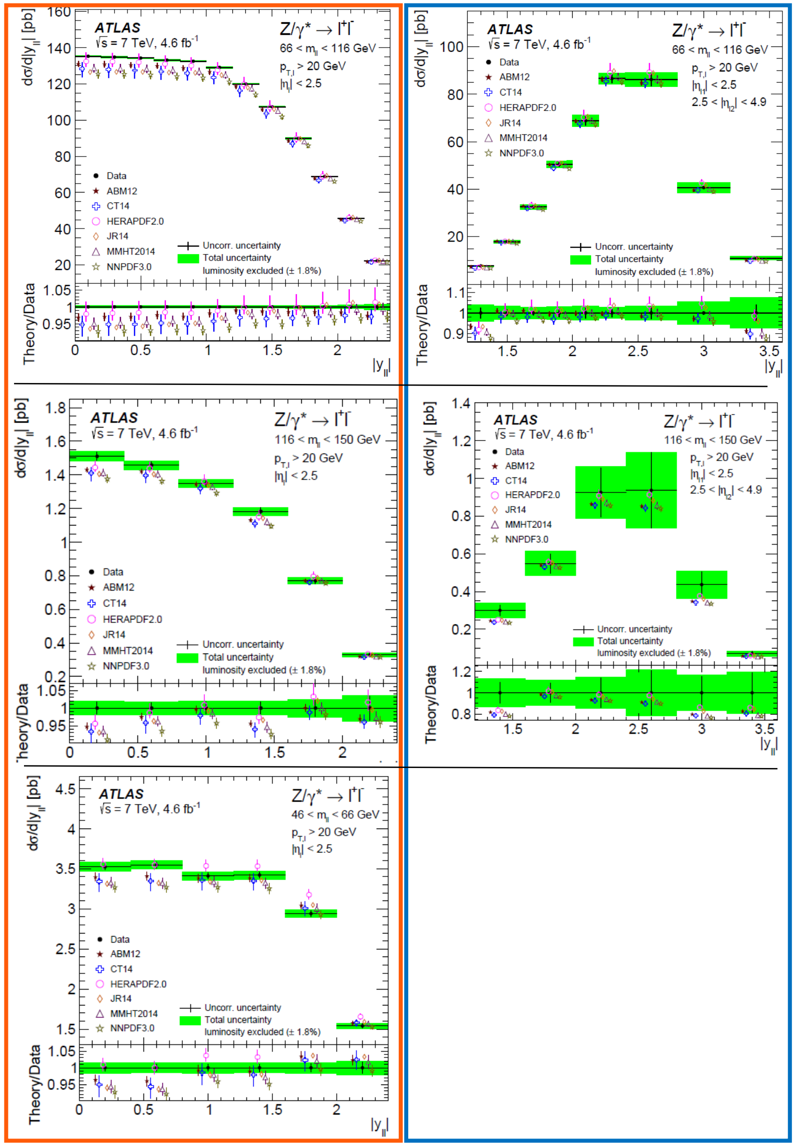
Forward Channel

High Mass

- Central Channel
  - $p_T^\ell > 20\text{GeV}$
  - $\eta < 2.5$

- Forward Channel
  - $p_T^\ell > 20\text{GeV}$
  - $|\eta^1| < 2.5, 2.5 < |\eta_2| < 4.9$

Z-Mass Peak



- **Symmetric p_T^ℓ cuts**

- $|y_{\ell\ell}|$ differential measurement in each mass bin
- Cross section extracted at Born level (prior final state QED radiation)

Low Mass

[ATLAS 1612.03016]

ATLAS 7TeV W/Z measurement

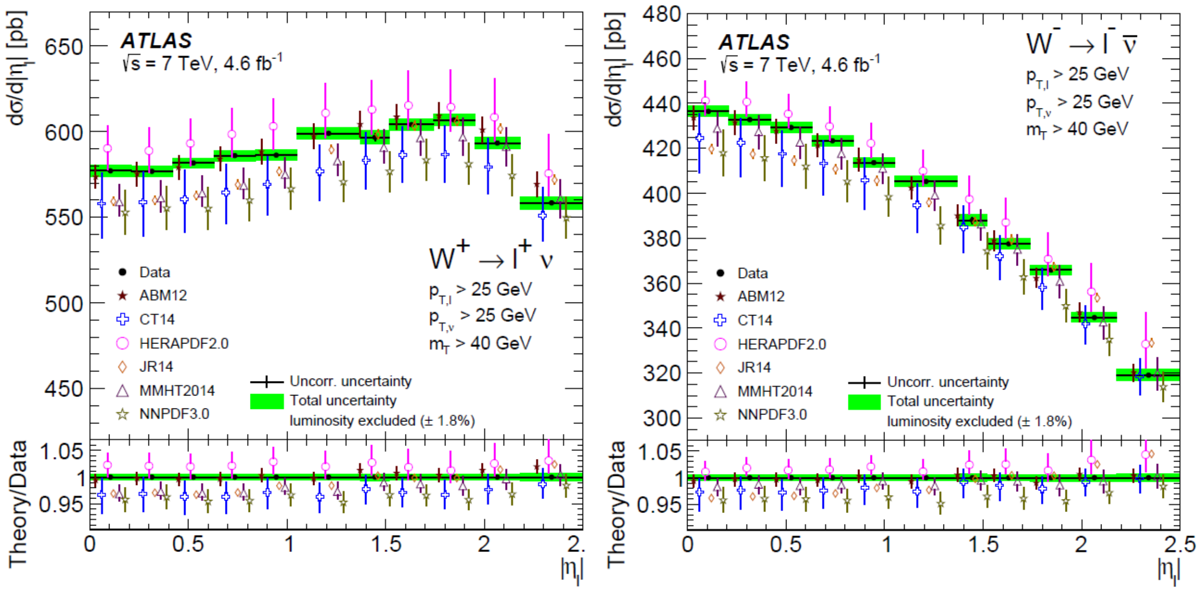
- Fiducial volume for $W^{+/-}$ cross section

- $p_{T,\ell} > 25\text{GeV}$
- $|\eta_\ell| < 2.5$
- $\boldsymbol{p_{T,\nu} > 25}$ **GeV**
- $m_T > 40$ GeV

- **Symmetric $\boldsymbol{p_T^\ell}$ cut**

- $|\eta_\ell|$ differential cross section
- Cross section extracted at Born level (prior final state QED radiation)

W^+ W^-



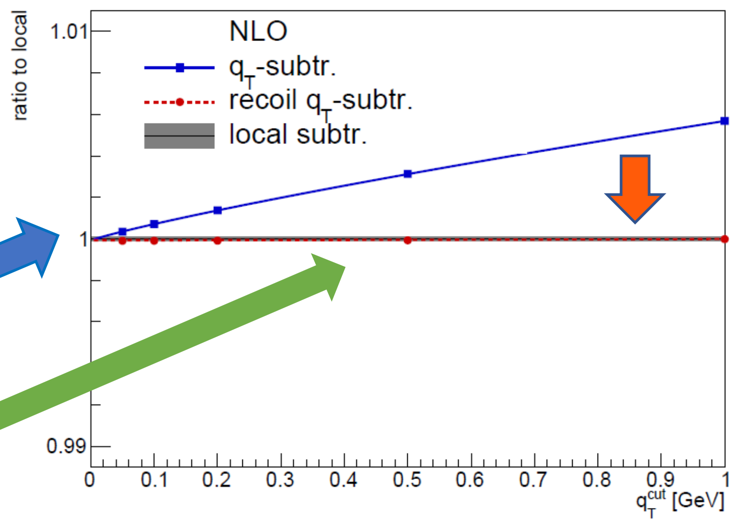
[ATLAS 1612.03016]

Drell-Yan at NNLO (QCD) - Fiducial Power Correction

NNLO (QCD) calculations (from different programs) differ at % level [arXiv 2104.02400]

➔ this spoils the nominal accuracy of the calculations

- The difference is shown to be connected to the **subtraction scheme…**
    - Local subtraction scheme
    - Non-local subtraction scheme (e.g. q_T -subtraction)
- …and due to the **symmetric lepton fiducial cuts** [arXiv:2006.11382]
    - These induce a **Linear q_T** dependence of the **acceptance**
    - $\mathbf{\Phi(q_T) - \Phi^{BORN} \sim q_T}$
    - ➔ **linear bias** in q_T sub. Scheme



Including boson q_T recoil prescription the nominal accuracy is recovered [arXiv:2102.08039]

- Recoil prescription from resummation results
- Implemented in codes SCETlib, MATRIX [arXiv2111.1366], DYTurbo [arXiv2111.14509]

Non-local/local sub. Scheme. q_T recoil allows us to recover $O(q_T^2)$ accuracy

Drell-Yan at NNLO (QCD) - q_T Resummation

Acceptance depend on small q_T values

➔ Enhanced q_T/Q *logarithms* affect the calculation regardless of the subtraction scheme used

- ***Need to resum fiducial power correction*** to obtain a meaningful prediction
  - We explore the differences in the predictions using $\mathrm{DYTurbo}$

Other approaches to the problem

- Asymmetric or Staggered cut [2106.08329] (avoid the linear power corrections)
- Defiducialization [2001.02933]

DYTurbo

- Fast Drell-Yan predictions with q_T subtraction [arXiv 1910.07049]
  - Improved reimplementation of DYNNLO + DYqT + DYRes
  - Fully differential up to N3LL' QCD [2103.0497]
  - **Implements q_T recoil prescription in Fixed order prediction**

We produce NNLO DY prediction with DYTurbo for the ATLAS measurement

Our setup:

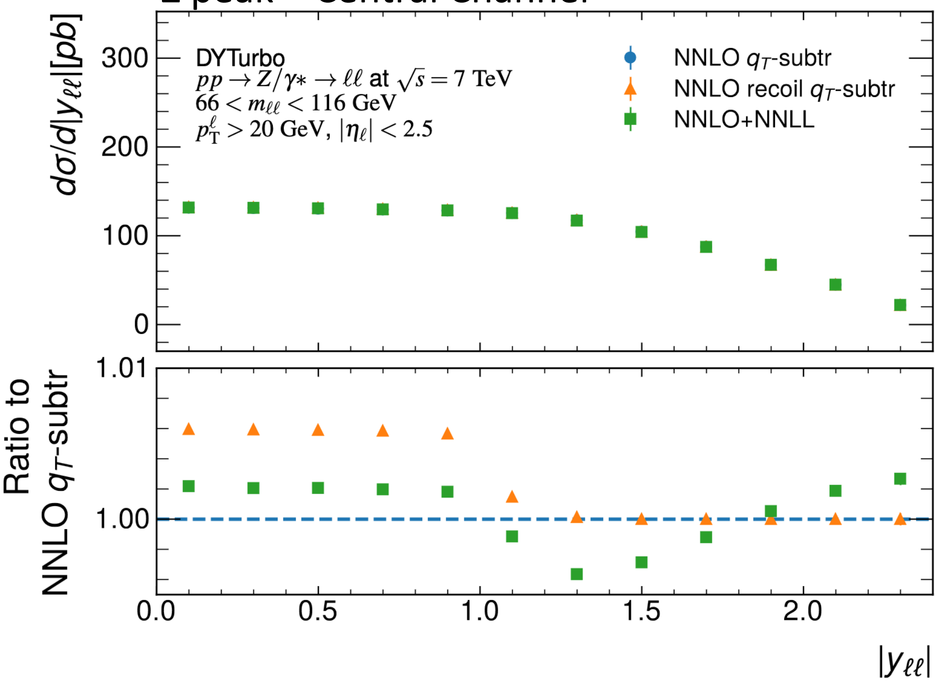
q_T subtr	
q_T^{cut}/Q	0.008
EW	
G_μ scheme	
m_W	80.385 GeV
m_Z	91.187 GeV
G_F	$1.167 \cdot 10^{-5}\ \mathrm{GeV}^{-2}$

QCD	
PDF set	NNPDF31nnlo
μ_R	$m_{\ell\ell}$
μ_F	$m_{\ell\ell}$

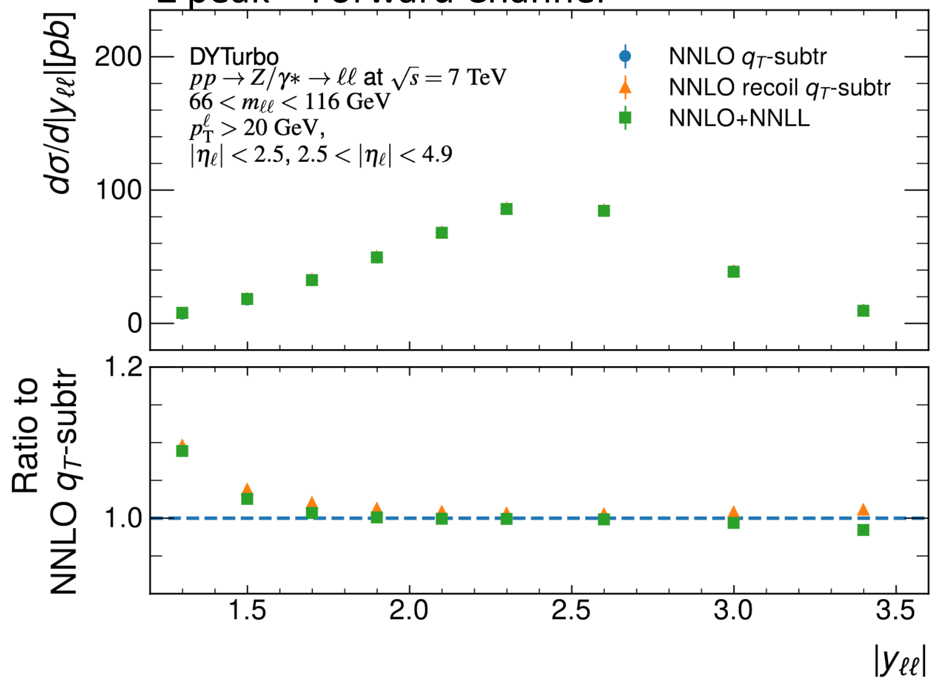
Resummation	
μ_{Res}	$m_{\ell\ell}$
Sudakov form factor	$\exp(-g_1 b^2), g_1 = 0.8$
Resummation damping	$\exp(-(k \cdot m_{\ell\ell} - q_T)^2/(\delta \cdot m_{\ell\ell})^2), k = 0.75, \delta = 0.5$

$NNLO$ QCD Predictions with DYTurbo

Z peak – Central Channel



Z peak – Forward Channel

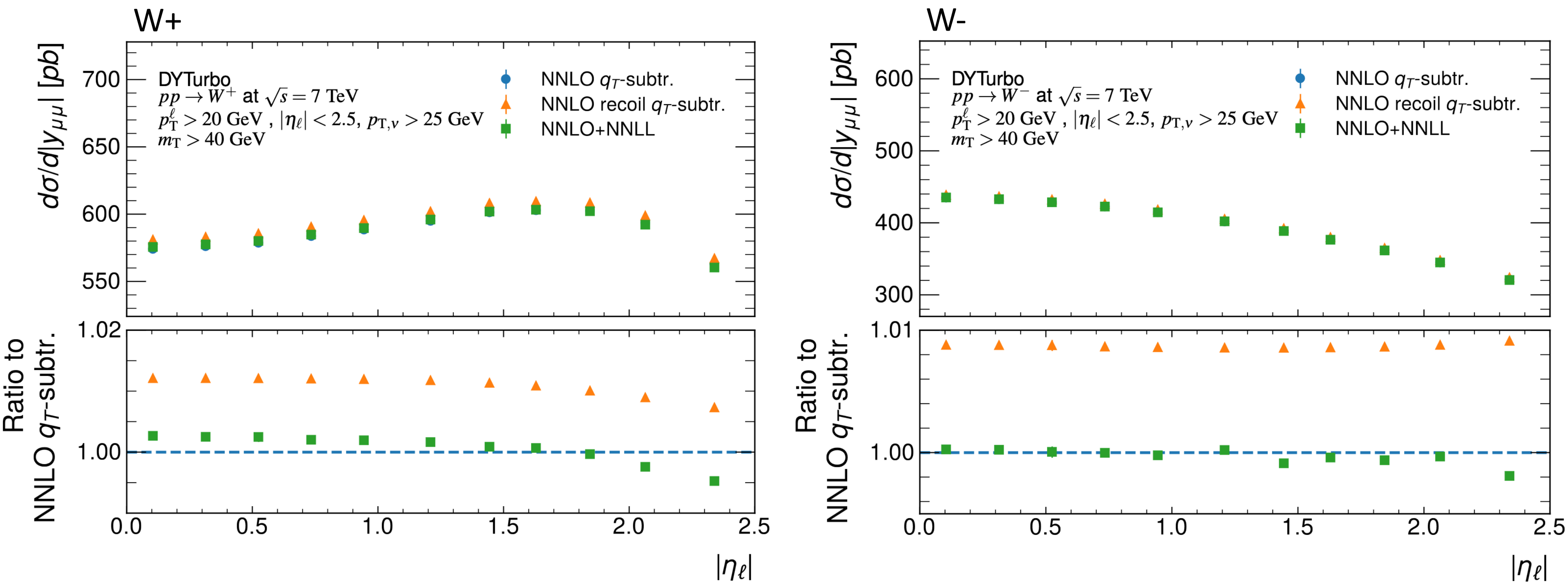


Prediction for Z **mass peak** (other bins in backup) cross section

- q_T subtraction result
- Include linear power corrections with q_T recoil
- Include q_T resummation

Negligible statistical uncertainty, $0.1 - 0.5$per mille

$NNLO$ QCD Predictions with DYTurbo



Prediction for $W^{+/-}$ cross section

- q_T subtraction result
- Include linear power corrections with q_T recoil
- Include q_T resummation

Negligible statistical uncertainty at $0.1 - 0.5$per mille

Comparison with data

Include NLO EW corrections from *ReneSANCe [*arXiv:2207.04332*]*

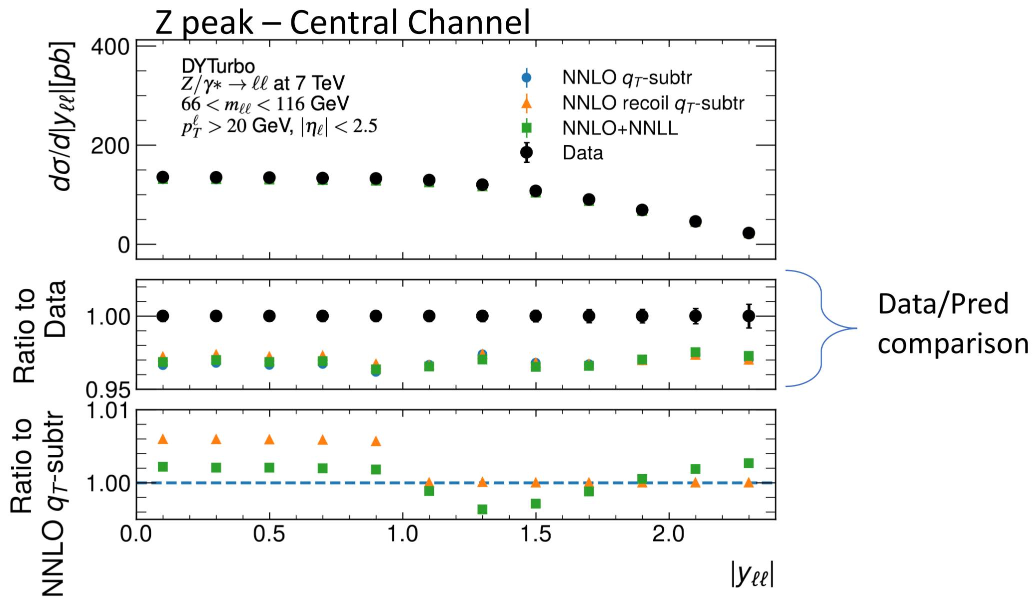
- Pure Weak
- Initial State QED Radiation
- Initial-Final QED Interference

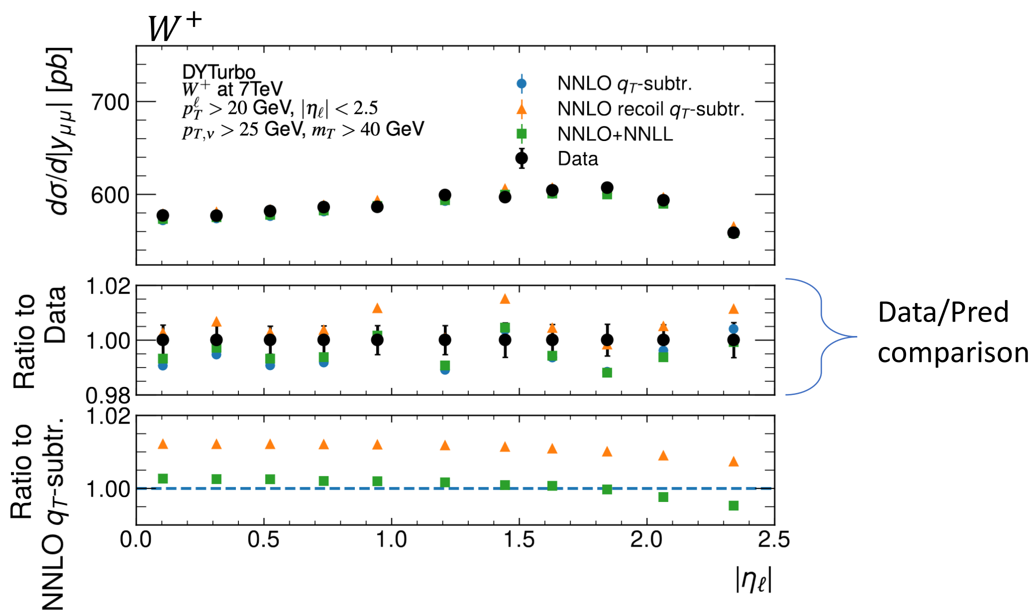
Use Kfactor applied multiplicatively

- $kF_{NLO(EW)} = \sigma^{LO(QCD)}_{NLO(EW)} / \sigma^{LO(QCD)}_{LO(EW)}$

EW correction important to describe the data

- We observe: $\Delta\chi^2_{NLO(EW)} \simeq 20$





Quantitative comparison with data

χ^2 data theory comparison

- Study performed with ***xFitter*** framework
- Include PDF uncertainties
- Theo. & exp. correlated uncertainty accounted with nuisance parameters $\boldsymbol{b^{th}}, \boldsymbol{b^{data}}$

$$\chi^2(\boldsymbol{b^{data}}, \boldsymbol{b^{th}}) = \sum_i \frac{\left[D_i - T_i\left(1 - \sum \gamma_{ij}^{th} b_j^{th} - \sum \gamma_{ij}^{data} b_j^{data}\right)\right]^2}{\Delta_i^2} \quad \text{Data set } \chi^2$$

$$+ \sum_j b_{j,\,data}^2 + \sum_k b_{k,th}^2 \quad \text{Correlated } \chi^2$$

We test different PDFs

- Theory points T_i obtained with PDF and NLO APPLgrid (generated with MCFM)
- NNLO QCD + NLO EW accuracy reached with *kFactors*
- NNLO QCD from DYTurbo

$$kF = \frac{\sigma_i^{NNLO(QCD)+NLO\ EW}}{\sigma_i^{NLO(QCD)}}$$

CT14nnlo 68%CL

Dataset	DYNNLO ATL. paper	DYTurbo q_T-subtr.
ATLAS W+ $\|\eta_\ell\|$	10 / 11	9.4 / 11
ATLAS W- $\|\eta_\ell\|$	9.0 / 11	8.2 / 11
ATLAS low mass Z $\|y_{\ell\ell}\|$	11 / 6	11 / 6
ATLAS peak CC Z $\|y_{\ell\ell}\|$	15 / 12	15 / 12
ATLAS peak CF Z $\|y_{\ell\ell}\|$	10 / 9	9.6 / 9
ATLAS high mass CC Z $\|y_{\ell\ell}\|$	6.3 / 6	6.0 / 6
ATLAS high mass CF Z $\|y_{\ell\ell}\|$	5.1 / 6	5.2 / 6
Correlated χ^2	39	39
Log penalty χ^2	-4.09	-4.33
Total χ^2 / dof	102 / 61	99 / 61
χ^2 p-value	0.00	0.00

Reproduce ATLAS paper results

Slightly better result → better stat of new predictions

Quantitative comparison with data

Use CT14 NNLO PDF rescaled at 68%CL

- Used in the ATLAS paper
- Does not include these data set

CT14nnlo 68%CL

Dataset	NNLO q_T-subtr.	NNLO recoil q_T-subtr.	NNLO+ NNLL
ATLAS W+ lepton rapidity	9.4 / 11	8.8 / 11	8.8 / 11
ATLAS W- lepton rapidity	8.2 / 11	8.7 / 11	8.2 / 11
ATLAS low mass Z rapidity	11 / 6 →	7.2 / 6 →	7.5 / 6
ATLAS peak CC Z rapidity	15 / 12 →	10 / 12 →	7.7 / 12
ATLAS peak CF Z rapidity	9.6 / 9	5.3 / 9	6.4 / 9
ATLAS high mass CC Z rapidity	6.0 / 6	6.5 / 6	5.8 / 6
ATLAS high mass CF Z rapidity	5.2 / 6	5.6 / 6	5.3 / 6
Correlated χ^2	39 →	40 →	32
Log penalty χ^2	-4.33	-3.39	-4.20
Total χ^2 / dof	99 / 61 →	88 / 61 →	77 / 61
χ^2 p-value	0.00	0.01	0.08

Improvement of single data set χ^2

Including resummation effects reduce the total $\Delta\chi^2$ of 10(20) points

Compare to other PDF sets

PDFs NOT include ATLAS 7TeV data sets

PDF set	Total χ^2 (ndf=61) NNLO q_T subtr.	NNLO recoil q_T-subtr	NNLO+NNLL
CT10nnlo68%CL	100	85	76
CT14nnlo68%CL	99	88	77
CT18NNLO68%CL	102	90	79
MMHT14nnlo68%CL	124	99	94
NNPDF30nnlo	139	133	111
ABMP16_5_NNLO	124	106	92
HERAII PDF	199	201	160

PDFs include ATLAS 7TeV data sets

PDF set	Total χ^2 (ndf=61) NNLO q_T subtr.	NNLO recoil q_T-subtr	NNLO+NNLL
CT18ANNLO68	96	84	74
MSHT20nnlo	111	87	79
NNPDF31	91	84	71
NNPDF40nnlo	89	83	69
MSHT20aN3LO	97	82	73

We always observe a reduction of the χ^2 when including q_T resummation ➔ $\Delta\chi^2 \sim 20(10)$

PDF profiling

Quantify the impact of new data in PDF determination

Use the shift b_{th} to update the PDF

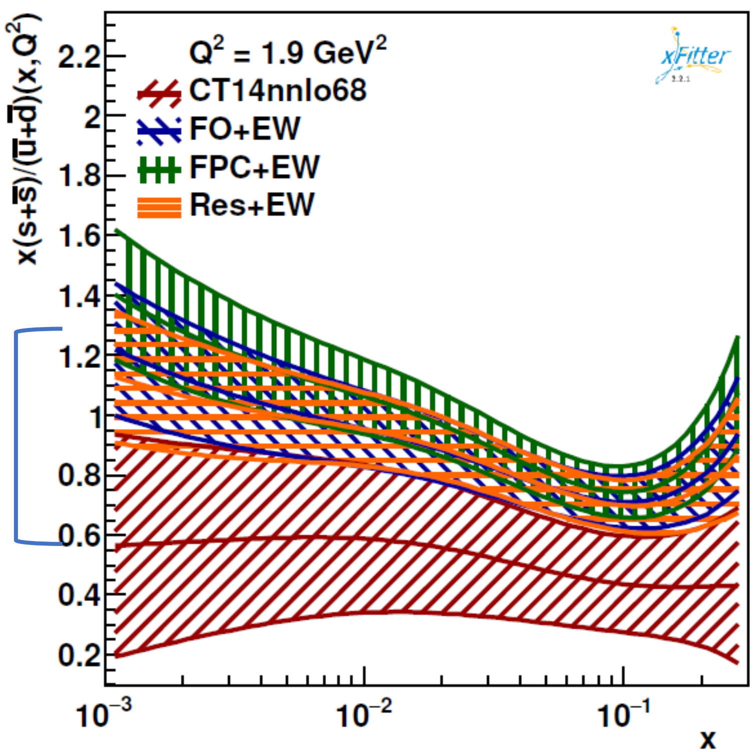
- Uncertainty reduction
- Shift of the central value

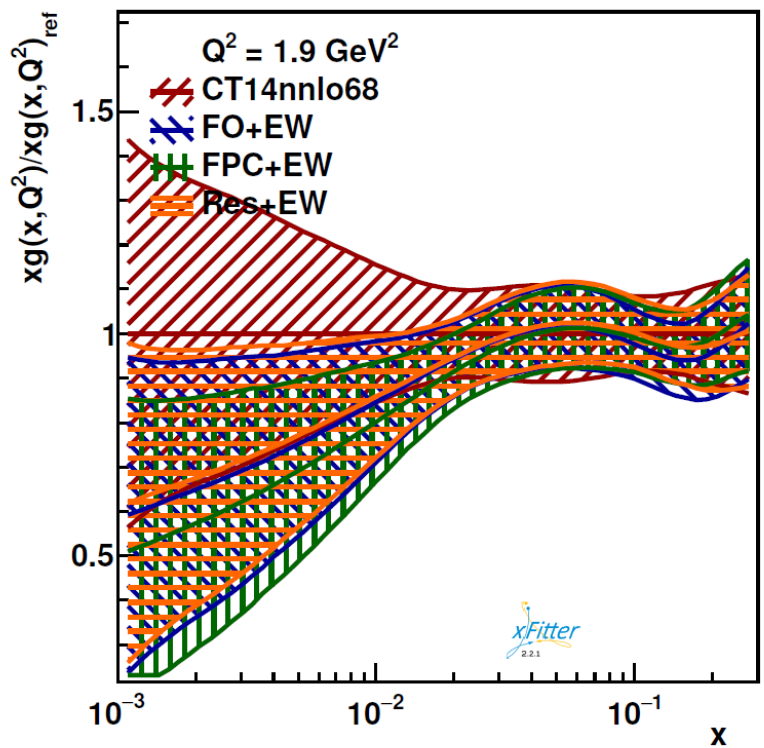
Profiled PDF

$$f'_0 = f_0 + \sum_k \beta_{k,\mathrm{th}}^{\min} \left(\frac{f_k^+ - f_k^-}{2} - \beta_{k,\mathrm{th}}^{\min} \frac{f_k^+ + f_k^- - 2f_0}{2} \right)$$

- ATLAS data give strong constrain on strange PDF
    - What changes with new predictions?

Impact of ATLAS data on strange PDF





PDF Fit

- Perform a fit with *xFitter*
  - HERA Data + ATLAS 7TeV DY Data
  - Use the different theories for DY data
- Same settings as $\mathrm{ATLASWZ16}$ PDF fit
  - $Q^2_{\mathrm{min}} > 10\ \mathrm{GeV}^2$
  - Fit parametrization:

$$
\begin{aligned}
xu_{\mathrm{v}}(x) &= A_{u_{\mathrm{v}}} x^{B_{u_{\mathrm{v}}}} (1-x)^{C_{u_{\mathrm{v}}}} (1 + E_{u_{\mathrm{v}}} x^2)\,, \\
xd_{\mathrm{v}}(x) &= A_{d_{\mathrm{v}}} x^{B_{d_{\mathrm{v}}}} (1-x)^{C_{d_{\mathrm{v}}}}\,, \\
x\bar{u}(x) &= A_{\bar{u}} x^{B_{\bar{u}}} (1-x)^{C_{\bar{u}}}\,, \\
x\bar{d}(x) &= A_{\bar{d}} x^{B_{\bar{d}}} (1-x)^{C_{\bar{d}}}\,, \\
xg(x) &= A_g x^{B_g} (1-x)^{C_g} - A'_g x^{B'_g} (1-x)^{C'_g}\,, \\
x\bar{s}(x) &= A_{\bar{s}} x^{B_{\bar{s}}} (1-x)^{C_{\bar{s}}}\,,
\end{aligned}
$$

PDF fit

χ^2 Fit Results

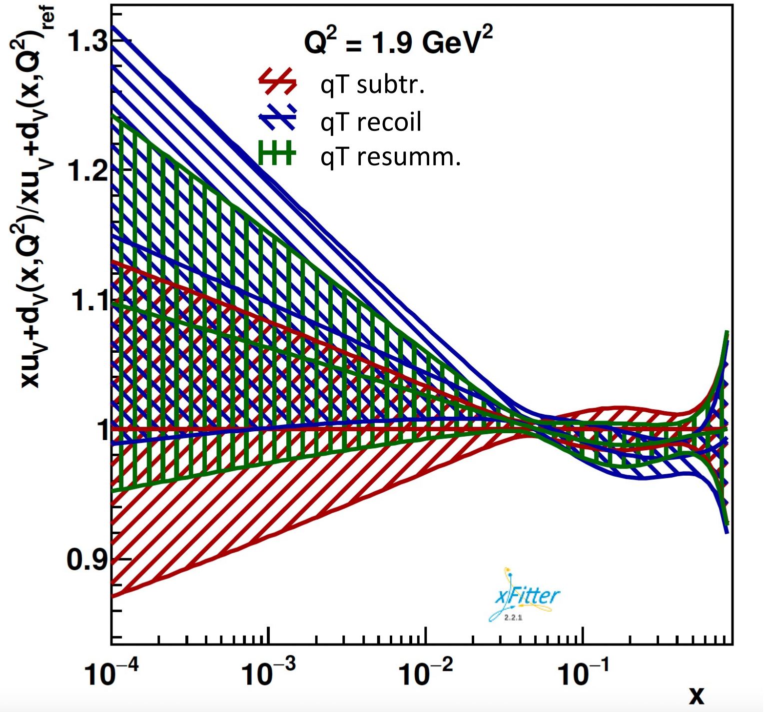
ATLAS DY data

Dataset	NNLO q_T-subtr.	NNLO recoil q_T-subtr.	NNLO+ NNLL
W^+ lepton rapidity	11/11	11/11	10/11
W^- lepton rapidity	7.3/11	7.3/11	7.1/11
Low mass, Z rapidity	28/6	17/6	16/6
Mass peak, central Z rapidity	14/12	8.1/12	6.4/12
Mass peak, forward Z rapidity	6.8/9	4.3/9	5.0/9
High mass, central Z rapidity	6.7/6	8.6/6	6.9/6
High mass, forward Z rapidity	4.1/6	4.6/6	4.3/6
HERA1+2 NCep 820	55/61	56/61	55/61
HERA1+2 NCep 460	194/177	195/177	195/177
HERA1+2 CCep	45/39	45/39	44/39
HERA1+2 NCem	223/159	224/159	223/159
HERA1+2 CCem	62/42	64/42	63/42
HERA1+2 NCep 575	187/221	188/221	188/221
HERA1+2 NCep 920	353/317	353/317	352/317
Correlated χ^2	76	79	71
Log penalty χ^2	-14.07	-17.65	-15.56
Total χ^2/dof	1258/1062	1249/1062	1232/1062
χ^2 p-value	0.00	0.00	0.00

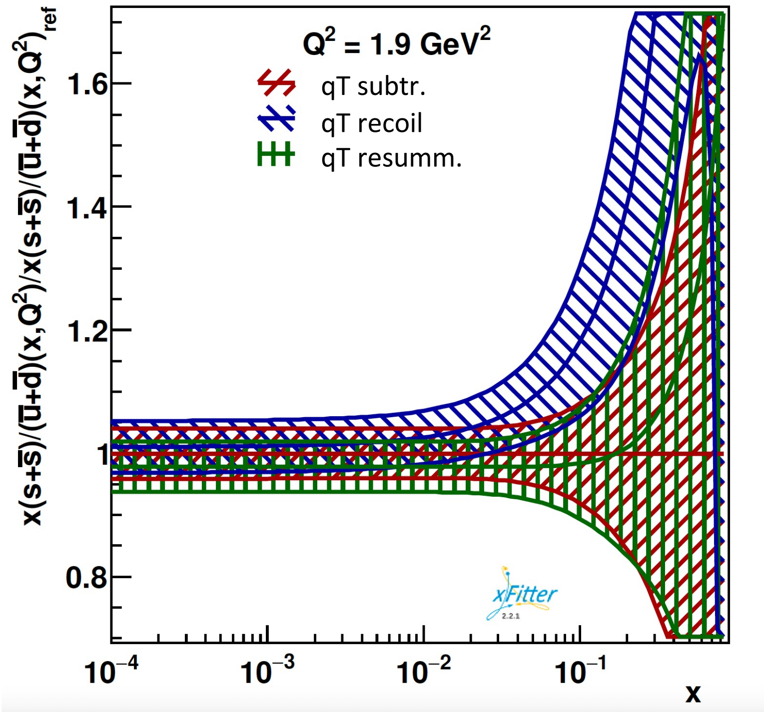
$\Delta\chi^2_{tot} \simeq 9$

$\Delta\chi^2_{tot} \simeq 26$

PDF Fit
Fit Results – PDF Ratio



Valence quark PDF



strange quark PDF

Conclusion and Outlook

- This work is now completed
  - Paper and *kFactor* will be out in ~ 1 month timescale

- We looked at the effects of linear power corrections and resummation in the ATLAS 7TeV data set
  - Resummation improves the data-MC agreement
  - Improvement in χ^2 with all the PDF sets
  - The impact of ATLAS data don't change much when using different theories

- It is interesting to check the effect of fiducial cuts in other measurement phase space, (LHCb)
- Perform a PDF fit to wide DY datasets with coherent theory predictions
  - NNLO + EW Corrections fit
  - NNLO+NNLL + EW Corrections fit

Thanks for the attention!

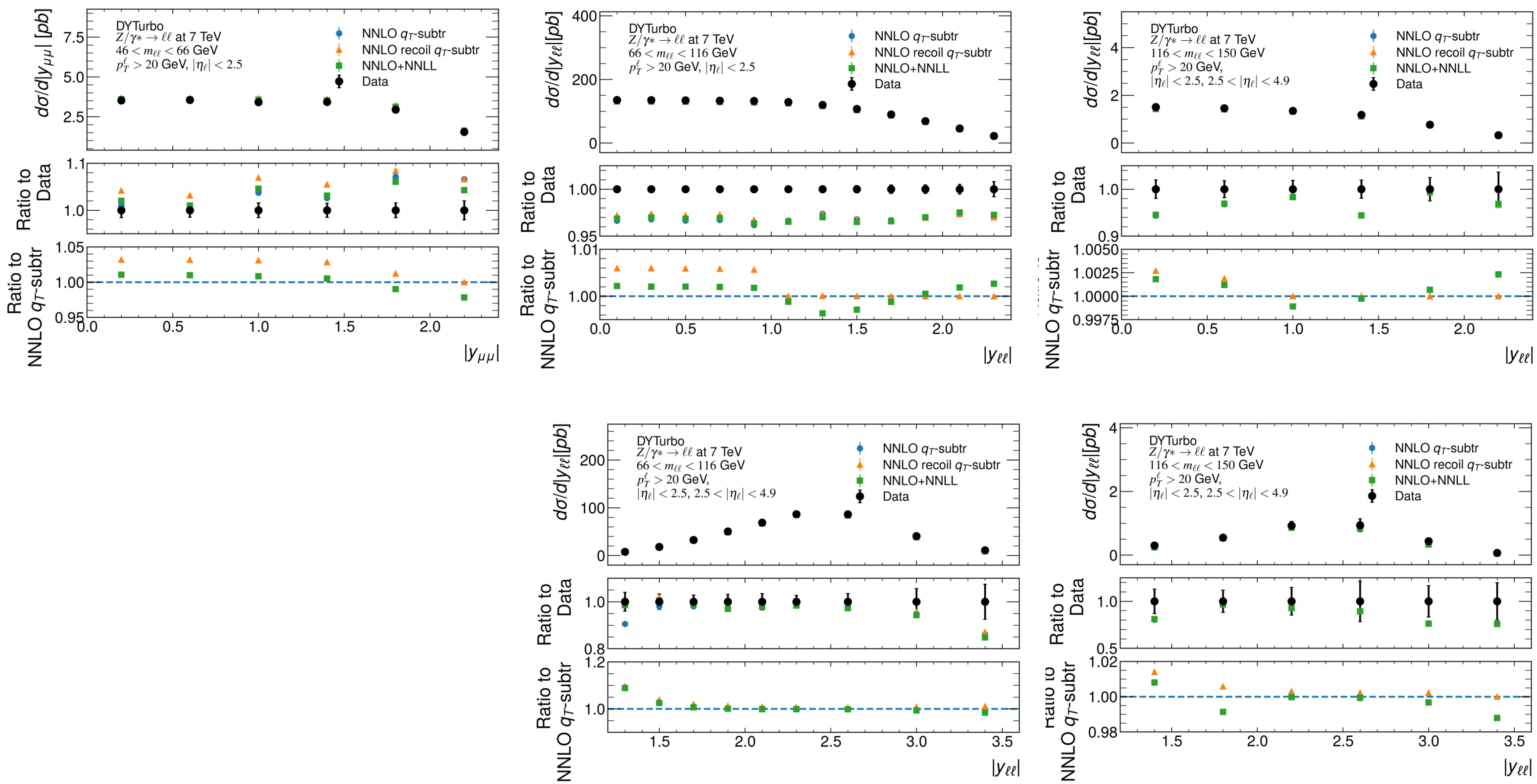
BACKUP

All Z cross sections

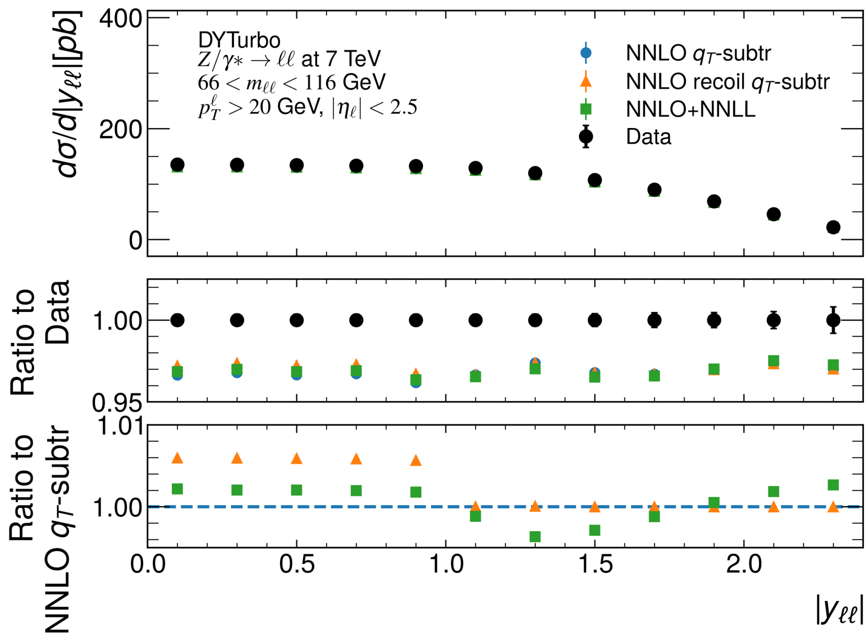
Low Mass | Z-Mass Peak | High Mass

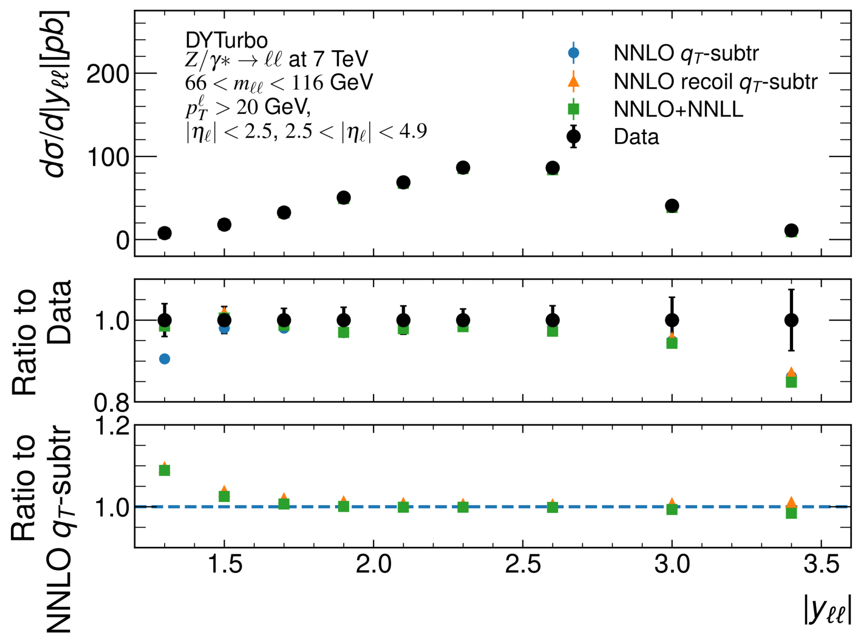
Central Channel

Forward Channel



Z peak


DYTurbo
$Z/\gamma* \rightarrow \ell\ell$ at 7 TeV
$66 < m_{\ell\ell} < 116$ GeV
$p_T^\ell > 20$ GeV, $|\eta_\ell| < 2.5$
NNLO q_T-subtr
NNLO recoil q_T-subtr
NNLO+NNLL
Data
$d\sigma/d|y_{\ell\ell}|[pb]$
Ratio to Data
Ratio to NNLO q_T-subtr
$|y_{\ell\ell}|$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$Z/\gamma* \rightarrow \ell\ell$ at 7 TeV
$66 < m_{\ell\ell} < 116$ GeV
$p_T^\ell > 20$ GeV,
$|\eta_\ell| < 2.5$, $2.5 < |\eta_\ell| < 4.9$
NNLO q_T-subtr
NNLO recoil q_T-subtr
NNLO+NNLL
Data
$d\sigma/d|y_{\ell\ell}|[pb]$
Ratio to Data
Ratio to NNLO q_T-subtr
$|y_{\ell\ell}|$