Ideas on possible Drell-Yan future measurements

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Main ideas

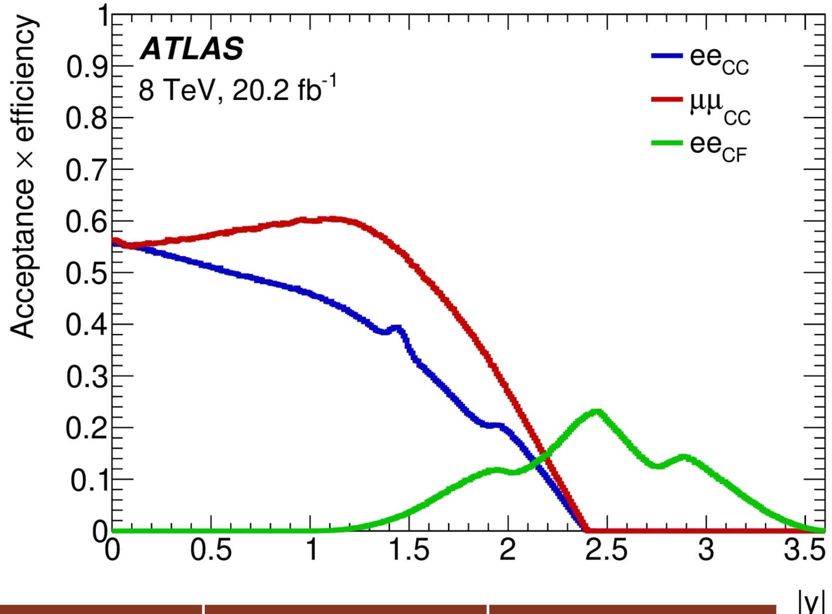
- Cross section measurement in full lepton phase space - EPJ C84 (2024) 315
- Low mass Drell-Yan – work in progress

Event selection

- 3 channels:
  - **ee$_{CC}$**: 2 electrons with p_T > 20 GeV, $|\eta|$ < 2.4
  - **$\mu\mu_{CC}$**: 2 muons with p_T > 20 GeV, $|\eta|$ < 2.4
  - **ee$_{CF}$**: central electron with p_T > 25 GeV, $|\eta|$ < 2.4, forward electron with p_T > 20 GeV, 2.5 < $|\eta|$ < 4.9

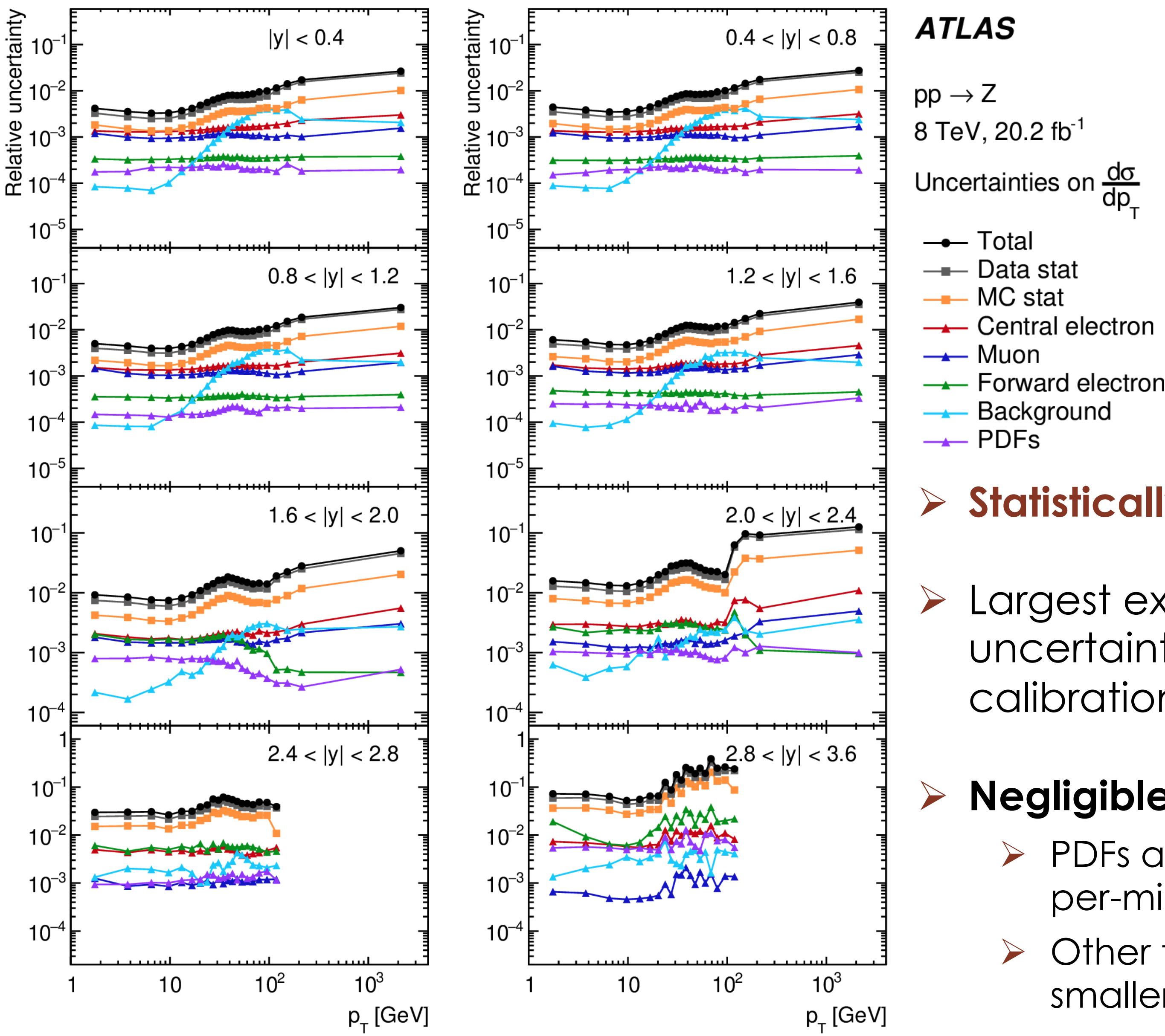
Channel	Events
ee$_{CC}$	6.2 M
$\mu\mu_{CC}$	7.8 M
ee$_{CF}$	1.3 M
Total	**15.3 M**

- $\sqrt{s}$ = 8 TeV, L = 20.2 fb^{-1}
- 80 < m$_{ll}$ < 100 GeV
- Double differential p_T, y cross section
  - 8 y bins over $|y|$ < 3.6
  - 23 p_T bins between 0.0 < p_T < 4000 GeV



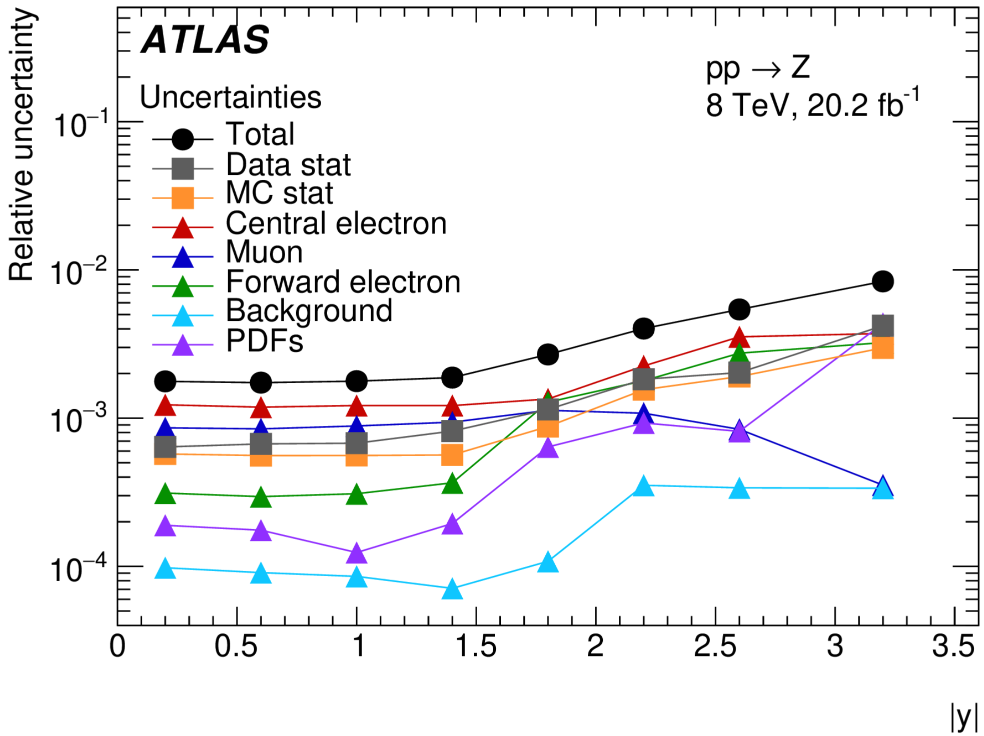
	UA1/UA2	LEP	Tevatron 1.96 TeV	LHC 8 TeV	LHC 13 TeV
Z → ll events	200	500 K	300 K	15 M	150 M

$d^2\sigma/dydp_T$ measurement uncertainties



- **Statistically dominated**
- Largest experimental systematic uncertainties from lepton calibration
- **Negligible theory uncertainties**
  - PDFs are at the level of 0.1-1 per-mille
  - Other theory uncertainties even smaller

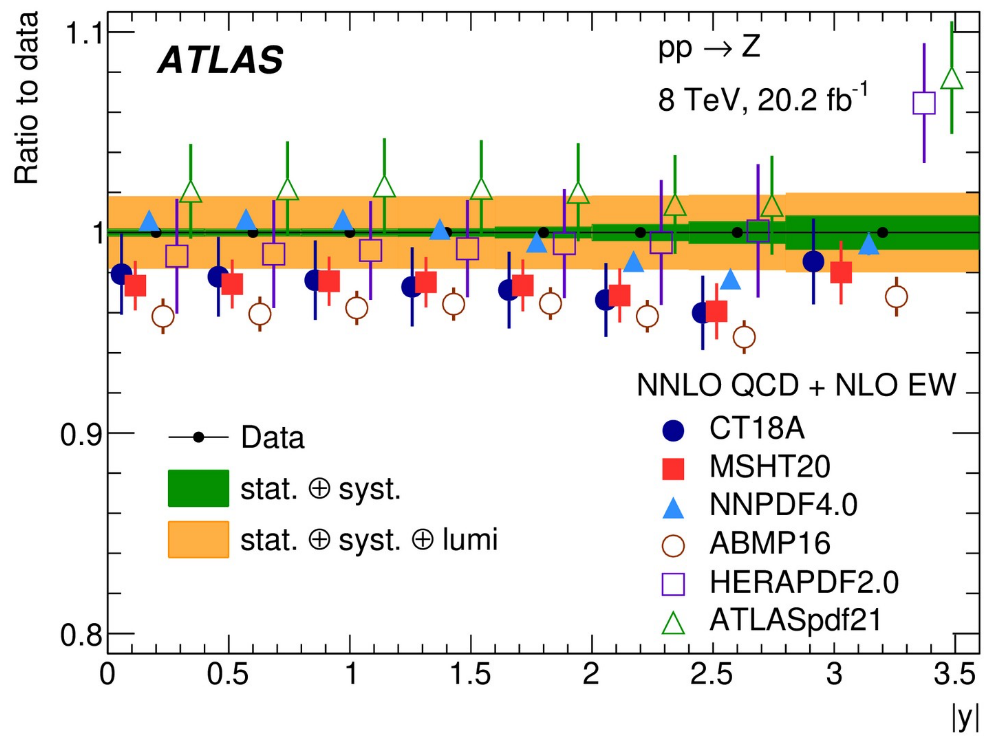
$d\sigma/dy$ measurement uncertainties



- Per-mille level precision in the central region
- **Sub-percent uncertainties up to |y| < 3.6** (x2 improvement in the forward region wrt previous measurement)
- Dominant uncertainties from lepton calibration
- **Small/negligible theory uncertainties (mostly PDFs)**

Full lepton phase-space rapidity

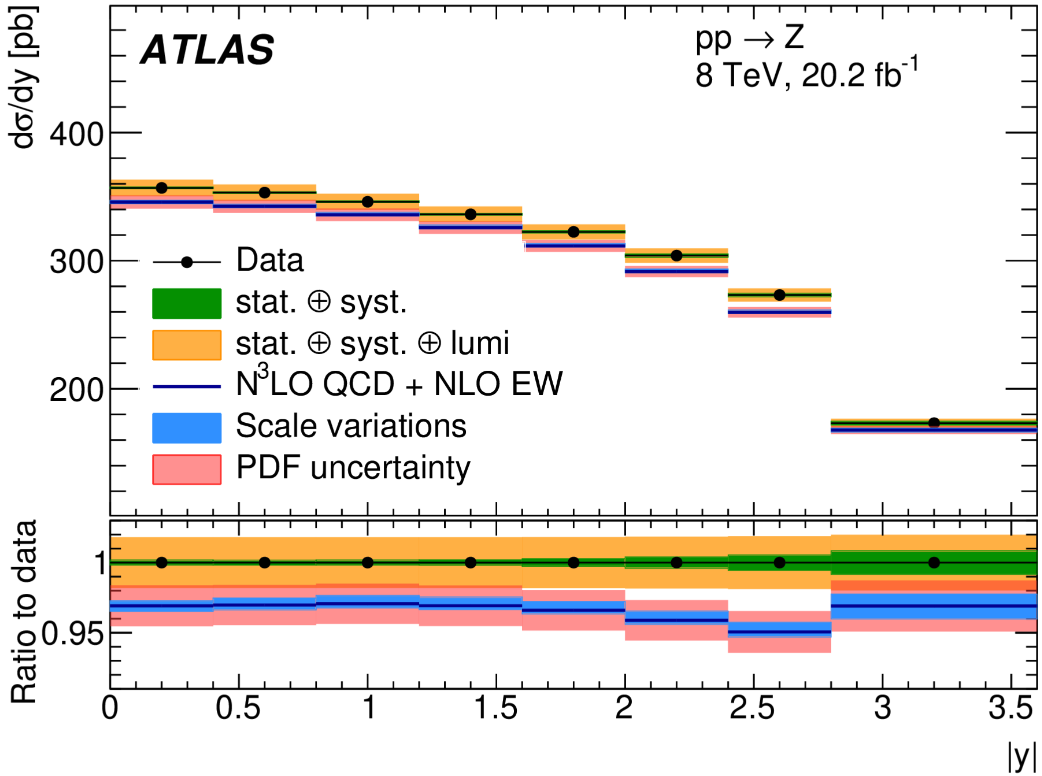
- Full-lepton phase space rapidity cross section enables precise and unambiguous PDF interpretation
- Measured cross sections agree with FO predictions within PDFs/luminosity uncertainty
- Measurement precision provides strong PDF sensitivity
- NLO EW corrections included in the comparison (-0.4%)



Data	σ_Z (pb) 1055 ± 19
MSHT20aN^{3}LO [60]	1023^{+6}_{-4} (scale) ± 15 (PDF)
CT18A [61]	1028 ± 19
MSHT20 [62]	1027 ± 13
NNPDF4.0 [63]	1054 ± 4
ABMP16 [64]	1014 ± 9
HERAPDF2.0 [65]	1058 ± 25
ATLASpdf21 [66]	1084 ± 25

PDF set	Total χ^2 / d.o.f.	χ^2 p-value	Pull on luminosity
MSHT20aN^{3}LO [60]	13/8	0.11	1.2 ± 0.6
CT18A [61]	12/8	0.17	0.9 ± 0.7
MSHT20 [62]	10/8	0.26	0.9 ± 0.6
NNPDF4.0 [63]	30/8	0.0002	0.0 ± 0.2
ABMP16 [64]	30/8	0.0002	1.8 ± 0.4
HERAPDF2.0 [65]	22/8	0.005	-1.3 ± 0.8
ATLASpdf21 [66]	20/8	0.01	-1.1 ± 0.8

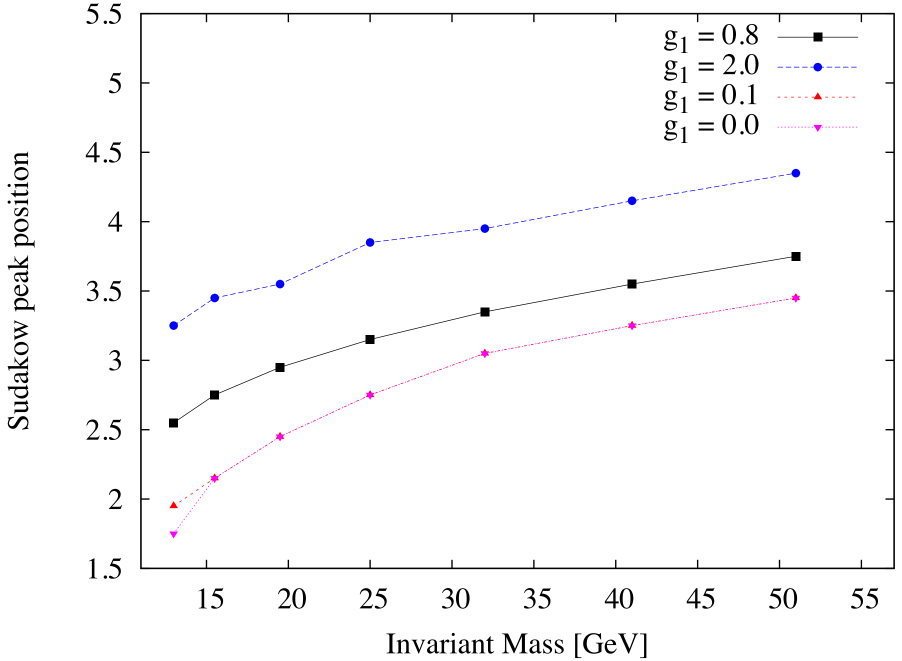
Full lepton phase-space rapidity

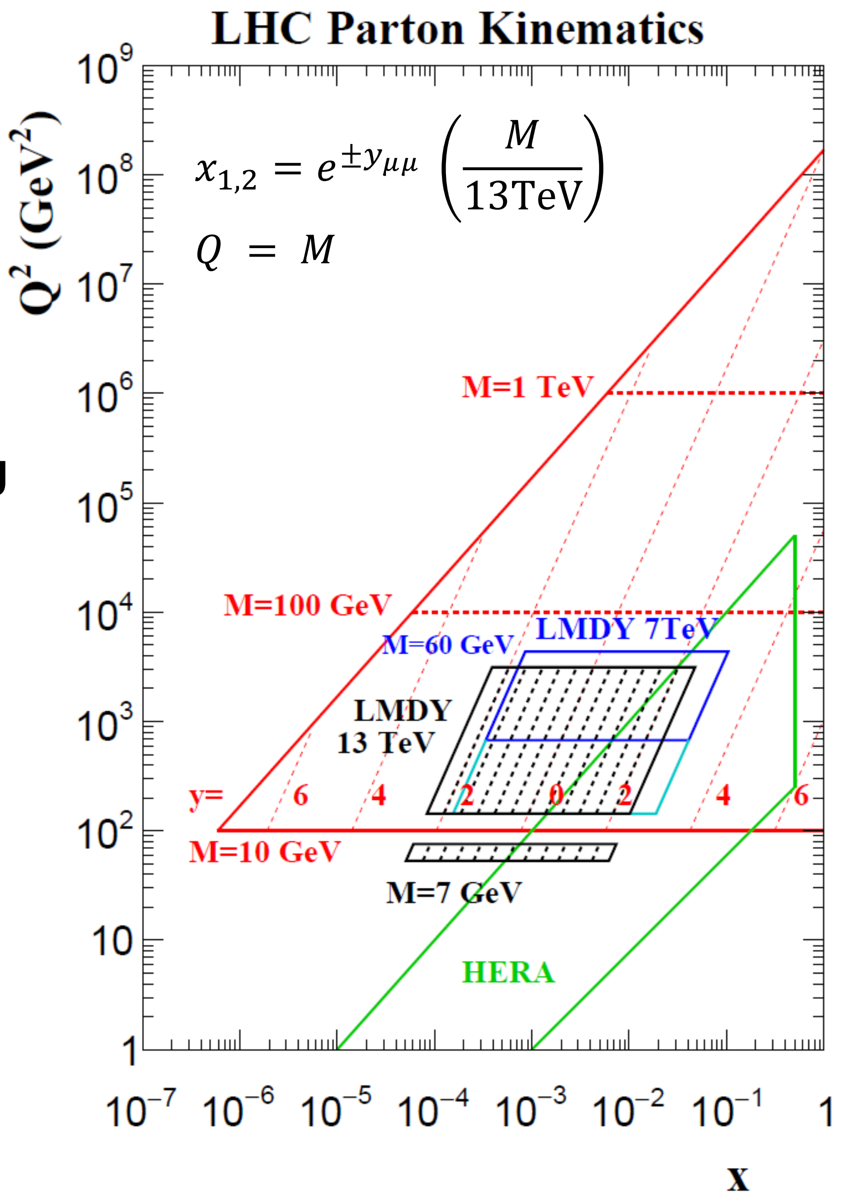


- First comparison to **N³LO QCD predictions**
- Enables precise and unambiguous PDF interpretation with QCD scale uncertainties now smaller than PDF ones
- Ideal measurement to be included in the <u>current and upcoming N³LO PDF fits</u>

Low mass DY - theoretical motivations

- Previous 7 TeV ATLAS lmDY measurement
- $d^2\sigma/dm_{\mu\mu}d|y_{\mu\mu}|$ and $d^2\sigma/dm_{\mu\mu}dp_{T,\mu\mu}$
- Advance our knowledge of the PDFs
- Sensitive to **small-x resummation** effects
- Constrain the **NP part** of the **Z p_T modelling** for future m_W determination





Low mass DY – major challenges

- Main challenges in this measurement:
  - QCD multijet background estimation
  - Isolation for low-p_T and low-mass muon
  - Trigger efficiencies

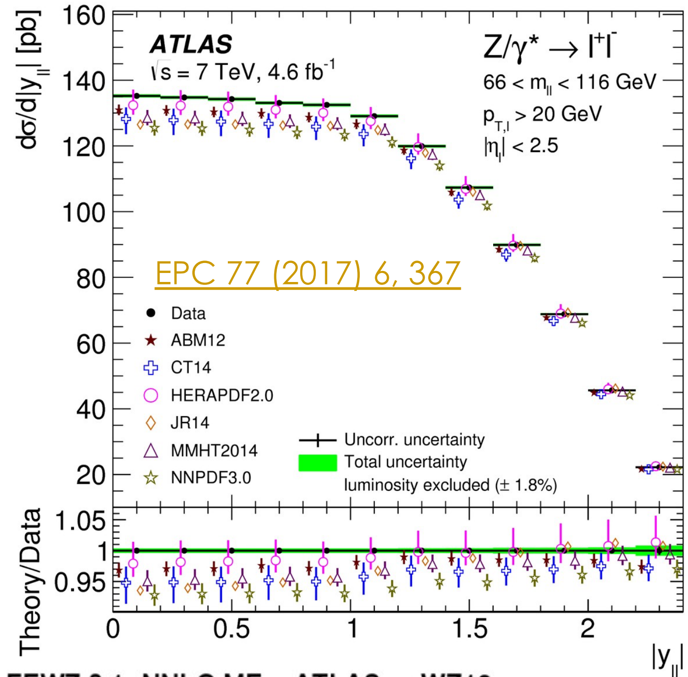
  Strongly reduced if low-μ runs

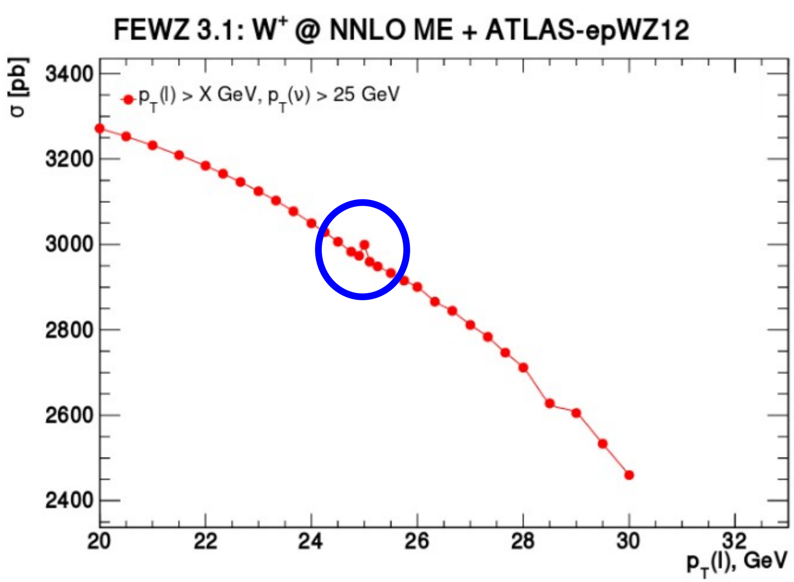
- Pinning down trigger efficiencies might be challenging
- Possible solution → lower L1 thresholds
- Fully open Barrel L1 eta trigger window in low pile-up runs
- Unfortunately missing the endcaps we can not go very low in x i.e. endcap thresholds are not efficient at low p_T
- Trigger-level analyses at HL-LHC?

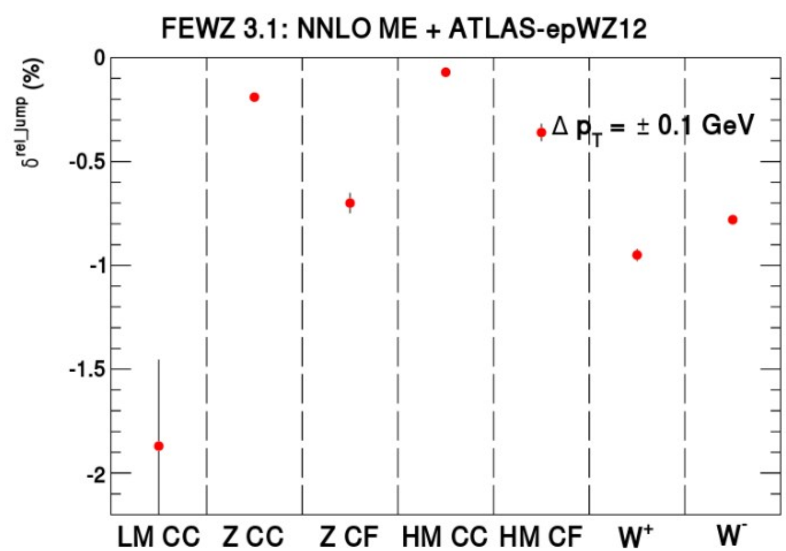
Backup Slides

Full lepton phase-space rapidity

- Interpretation of fiducial cross sections hampered by breakdown of fixed order (FO) perturbation theory
  - Fiducial cuts lead to unphysical FO predictions
  - When approaching the limit of $p_T^2 \to p_T^1$ FO becomes unreliable
  - The issue is more critical when p_T is closer to m_{ll} and at forward rapidities

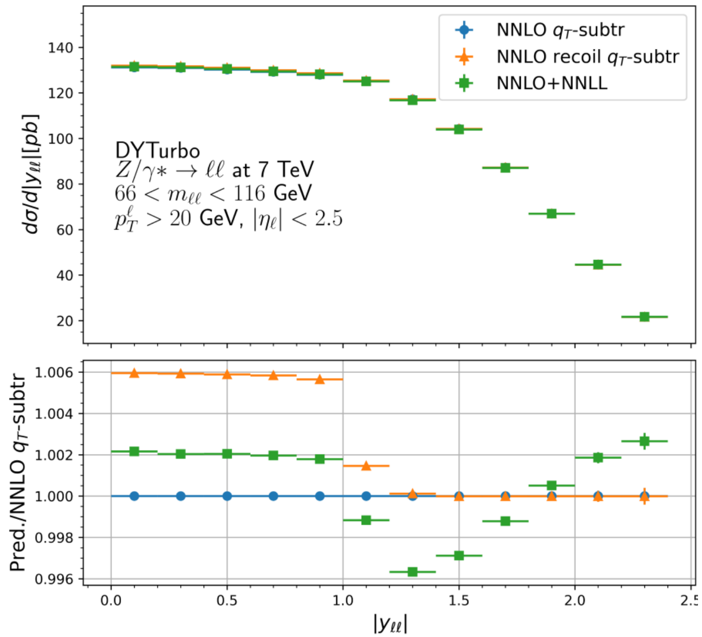






Full lepton phase-space rapidity

- Large attention to the problem, and several solutions proposed:
  - Local-subtraction scheme for FO predictions - 2104.02400
  - Change the definition of fiducial cuts - 2106.08329
  - Use A_i theory predictions to extrapolate measured cross sections - 2001.02933
  - Include resummation corrections into predictions - 2006.11382, 2209.13535



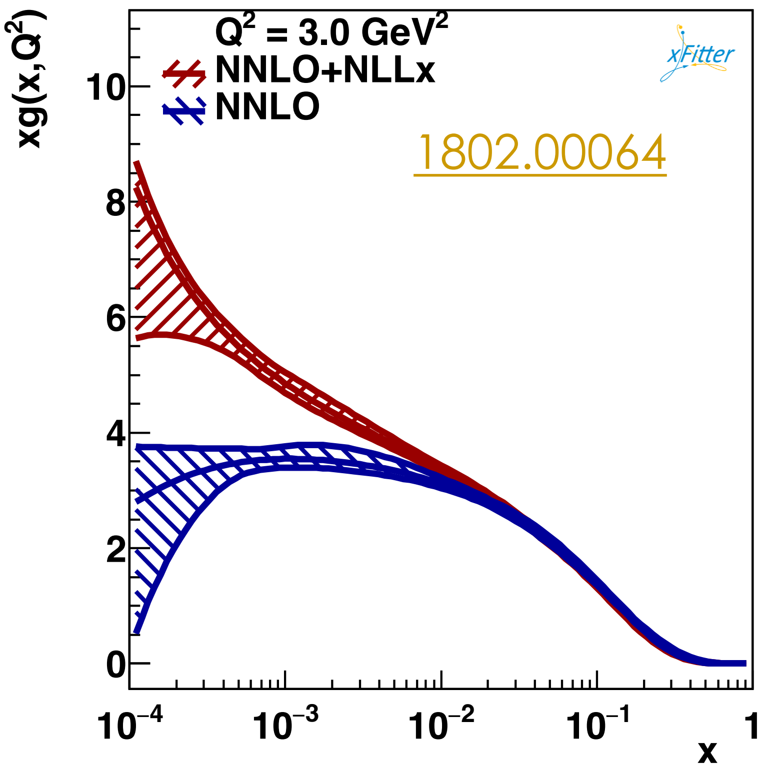
- **A_i – based elegant solution**:
  - Fiducial cuts removed by analytic integration of $(\cos\theta, \phi)$ in the full phase space of the decay leptons through the measured A_i coefficients
  - With only Run 1 8 TeV data, few per-mille total uncertainties for $d\sigma/dy$ and negligible theoretical uncertainties for all measurements

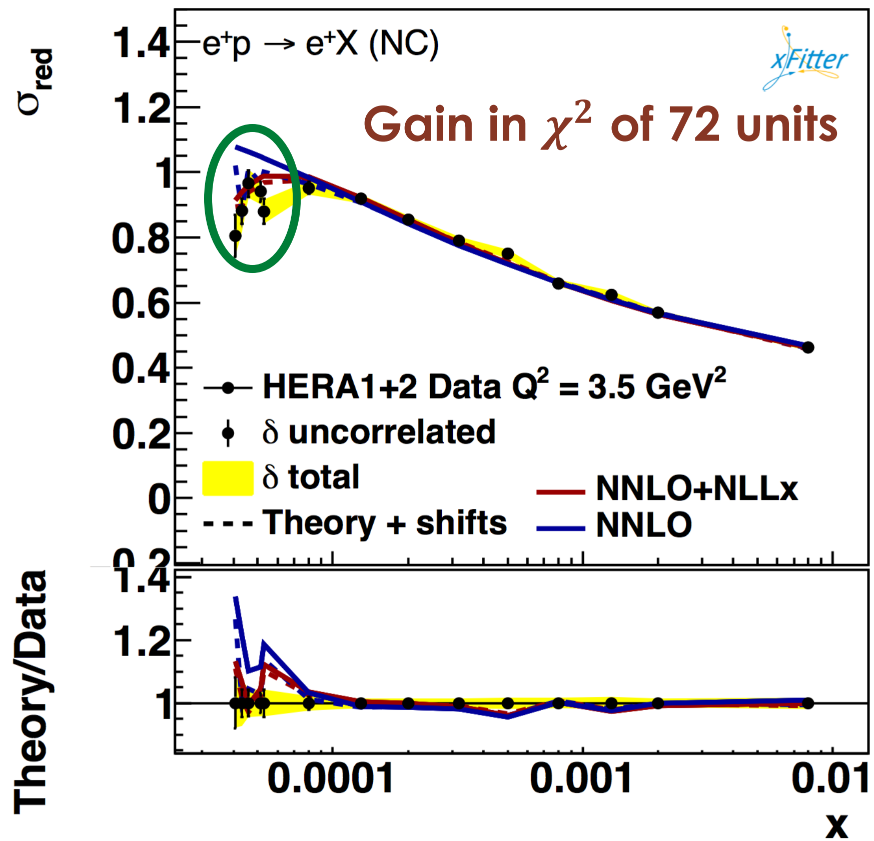
CT14nnlo 68%CL

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

Small-x resummation

- Resummation formalism based on **k_T-factorization** and **BFKL**
- Developed in the 90s-00s
- Recent developments: 1607.02153, 1708.07510
  - Resummation matched to NNLO, allowing NNLO+NLLx phenomenology
  - Public code: HELL





TMDs

- TMD factorisation applies for $q_T \ll Q$
- The region $q_T \simeq \Lambda_{QCD}$ is relevant for hadron structure, no matter how large Q
- As Q increases, the cross section drops and low q_T becomes hard to access