Low mu runs (ATLAS)

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LHC EW WG General Meeting

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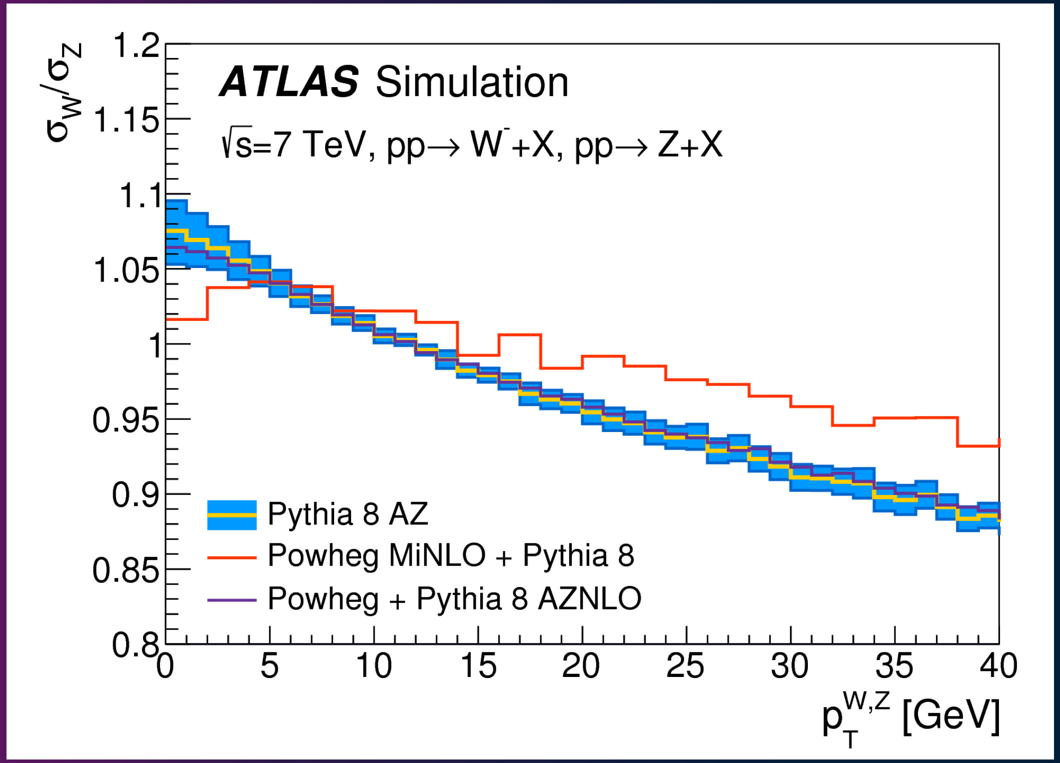
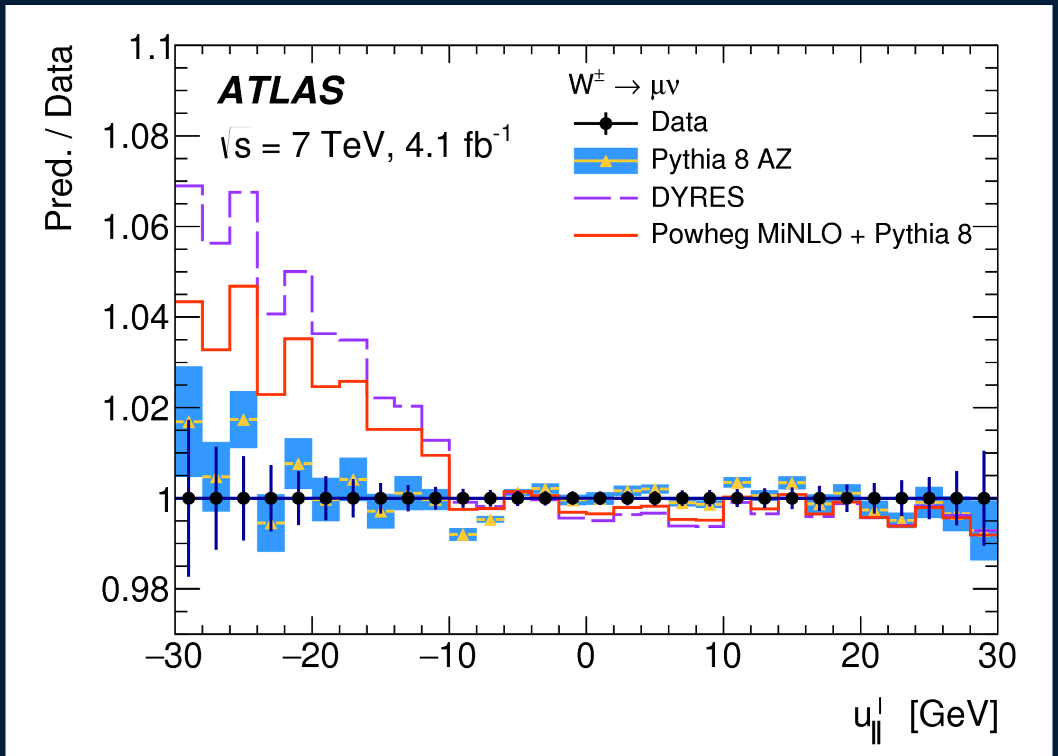
W p_T motivation : m_W

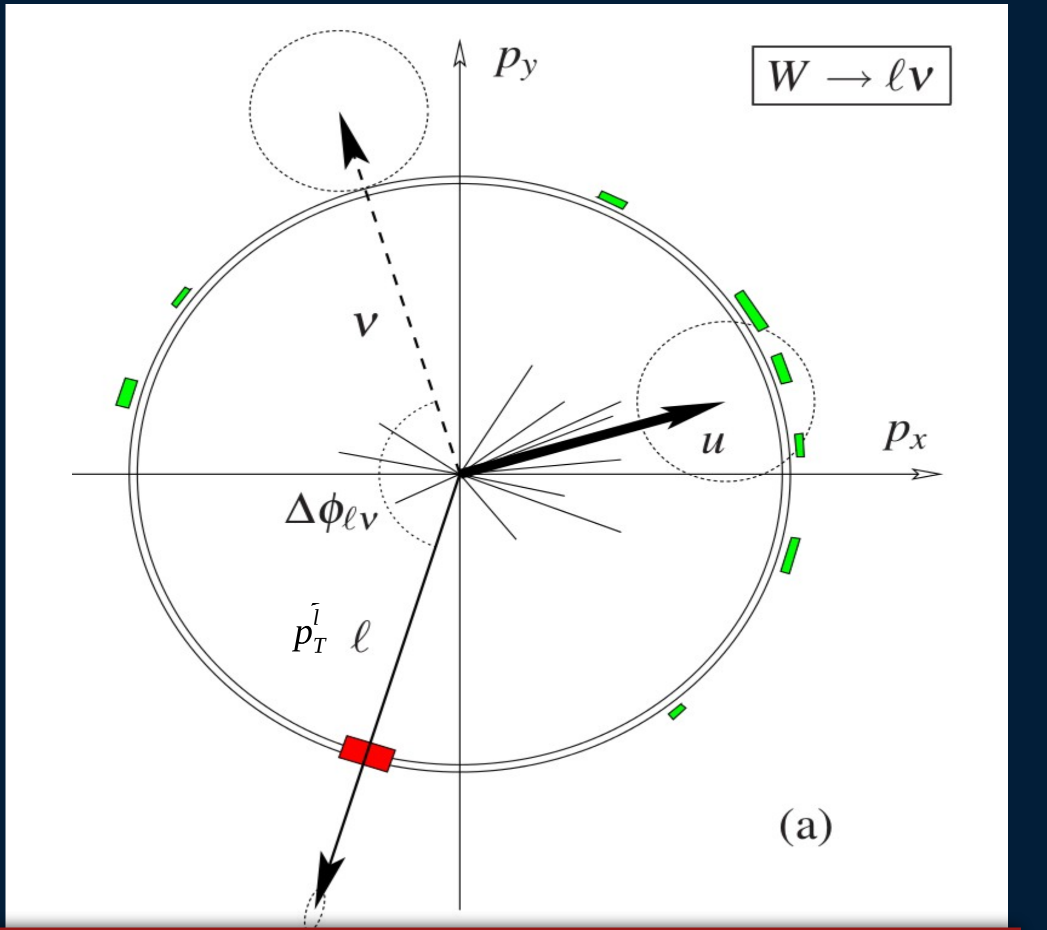




- Main motivation is to
  - Reduce the uncertainty from pTW in m_W measurements
  - Avoid relying on the pTZ measurement (needs assumptions on the extrapolation to W, pTW/pTZ predicted by theory)
    - 7 TeV m_W discarded some predictions based on u//_lepton
      - But not ideal to rely entirely on Z pT: need at least a direct cross-check: W pT in bins of ~5 GeV with ~1% uncertainty

Event topology, definitions of observables

- Detect single (inclusive) W boson decaying into a lepton and a neutrino
- The ATLAS detector measures :
  - The **lepton** charge and 4-vector (transverse momentum $\vec{p}_{T\ell}$)
  - The activity recoiling against the W **(hadronic recoil $\vec{u}_T$)**
    - measures additional jets from signal
    - Sensitive to additional interactions (pile-up) and underlying event
    - Enables to indirectly reconstruct the neutrino transverse momentum $\vec{p}_T^{miss} = -(\vec{u}_T + \vec{p}_{T\ell})$
    - Is the observable of which the distribution is unfolded to measure pTW

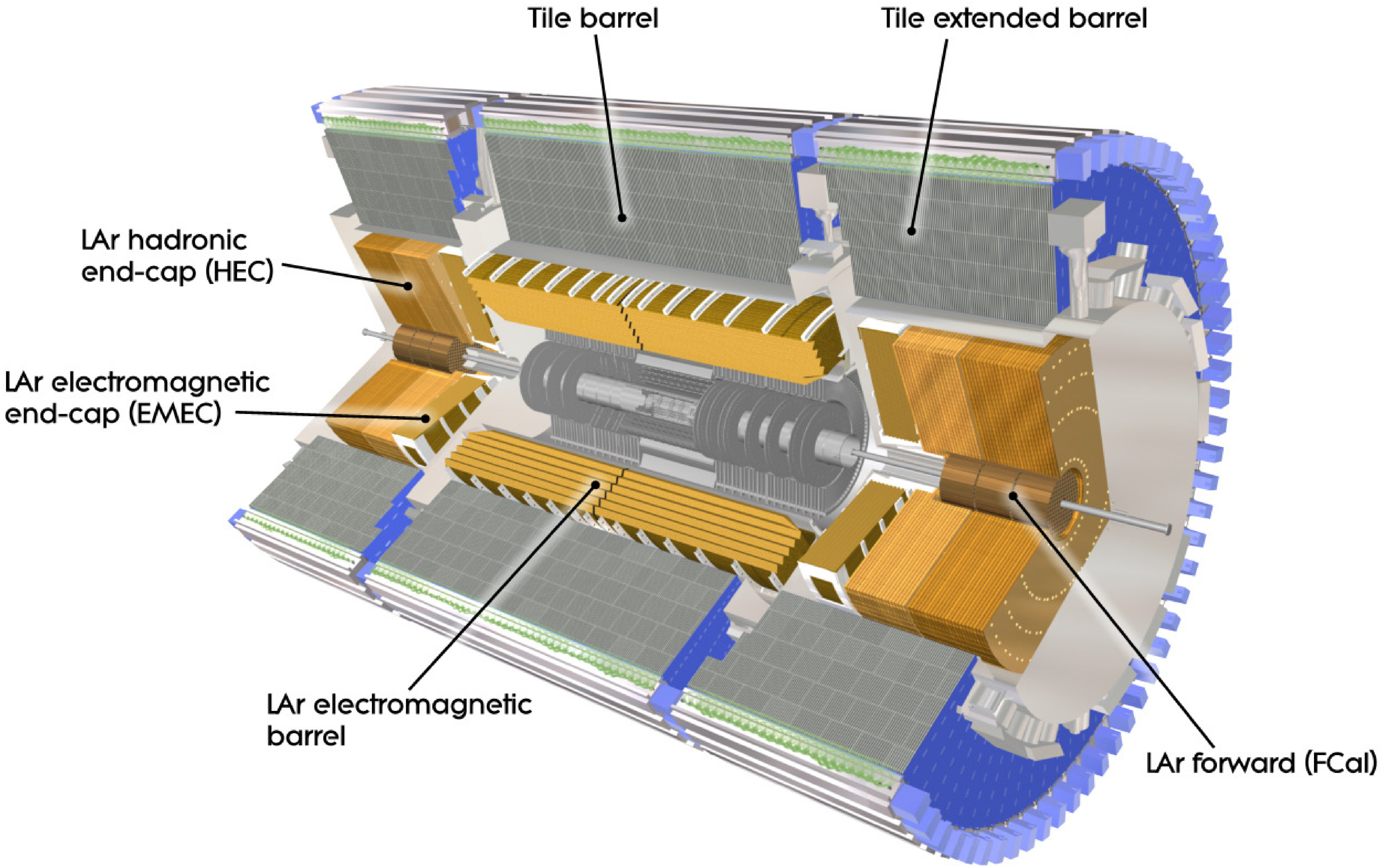


$\vec{u}_T$: vector sum of nPFOs and cPFOs excluding lepton deposits

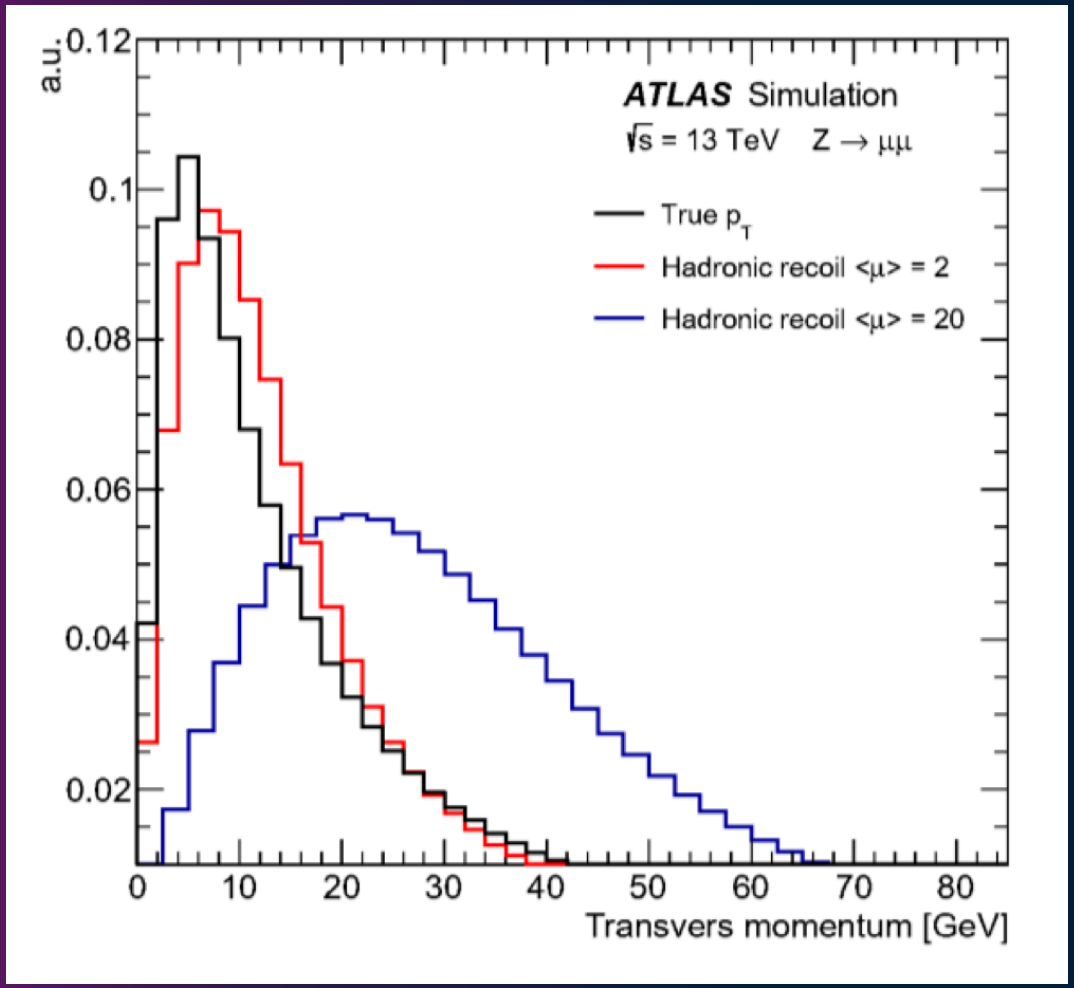
$m_T = \sqrt{[2\, p_{T\ell}\, p_T^{miss}\, (1-\cos\Delta\phi)]}$

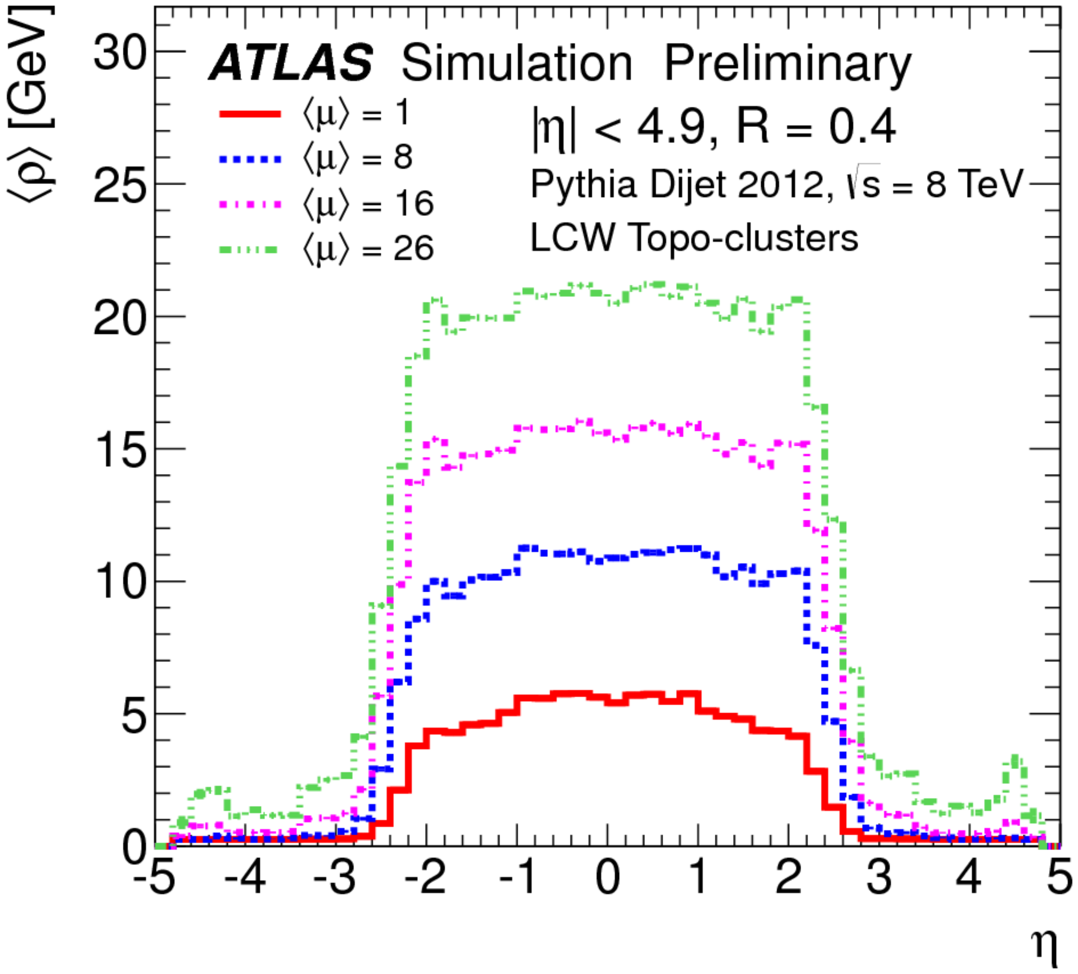
Impossible to fully reconstruct m_W because of the neutrino

Recoil resolution and the ATLAS calorimeter



Recoil resolution and the ATLAS calorimeter



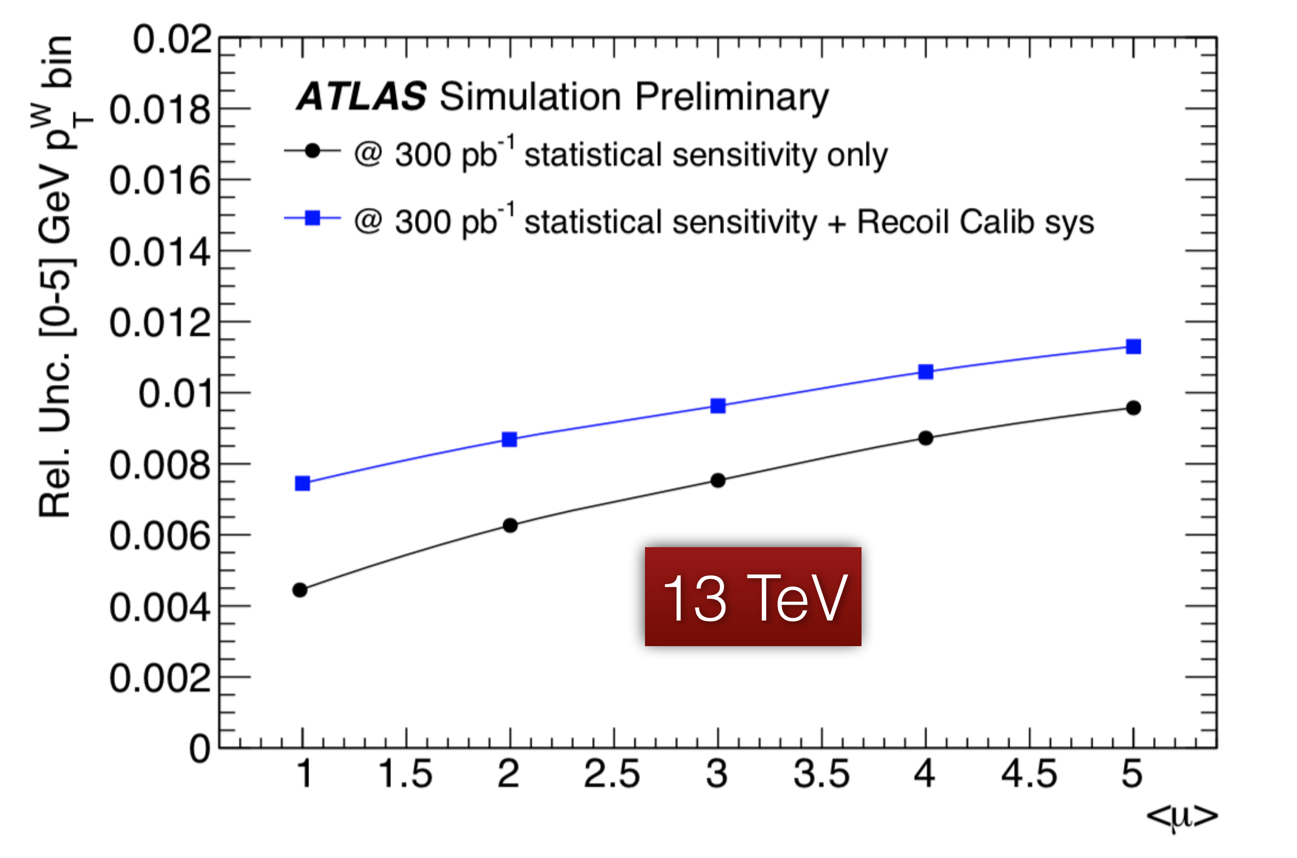


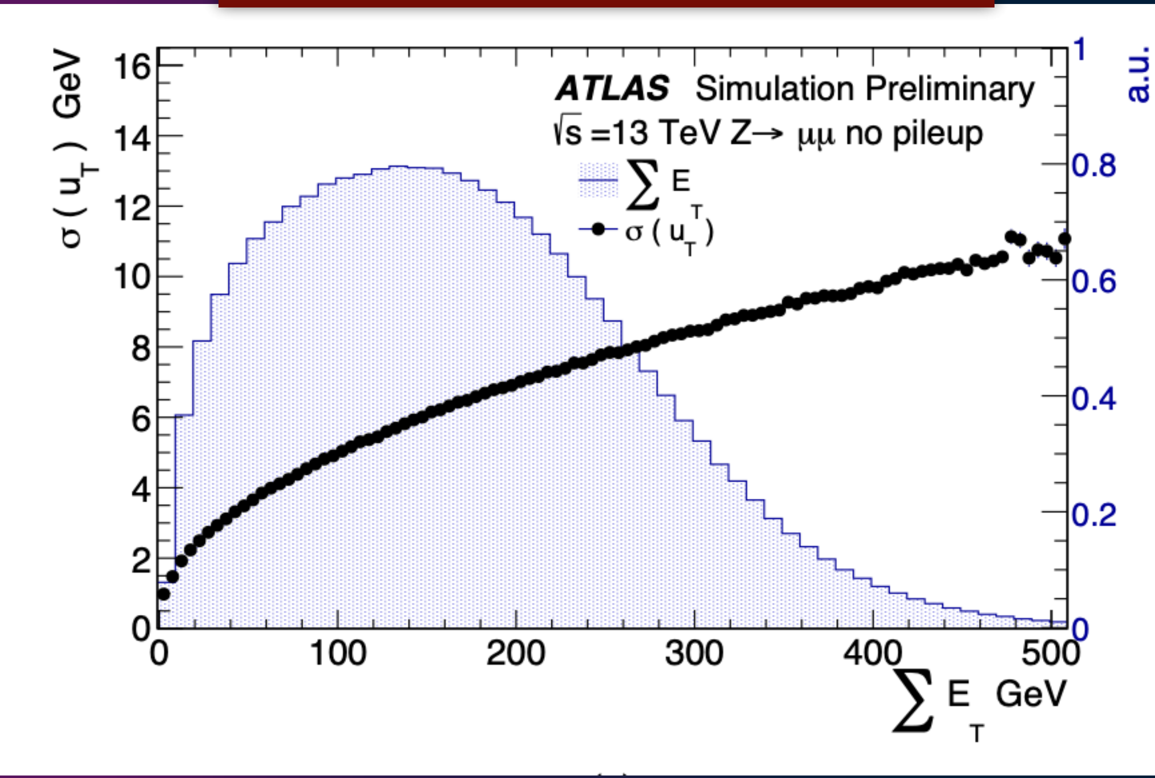
- Recoil resolution highly impacted by mu
- Median pT density (median of jets transverse momenta in the event)

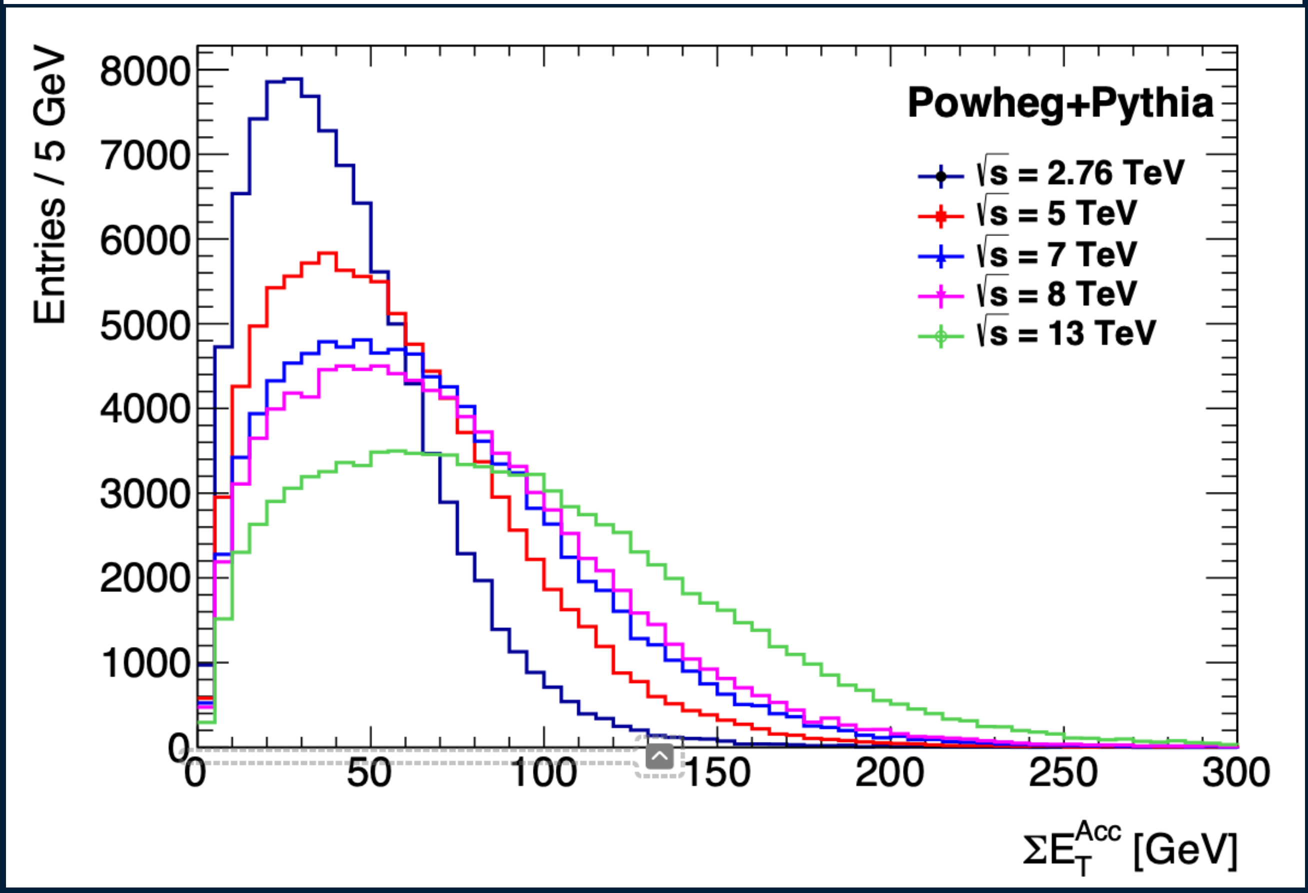
Recoil resolution and the ATLAS calorimeter

- Dependence of uncertainty (statistical + recoil calibration systematic) in first $p_T(W)$ bin (0-5 GeV) vs μ (pileup) for 300 pb^{-1} integrated luminosity
  - Goes >>1% for typical pileup values at LHC
- Dependence of ΣE_T as $(\sqrt{s})^{1/2}$

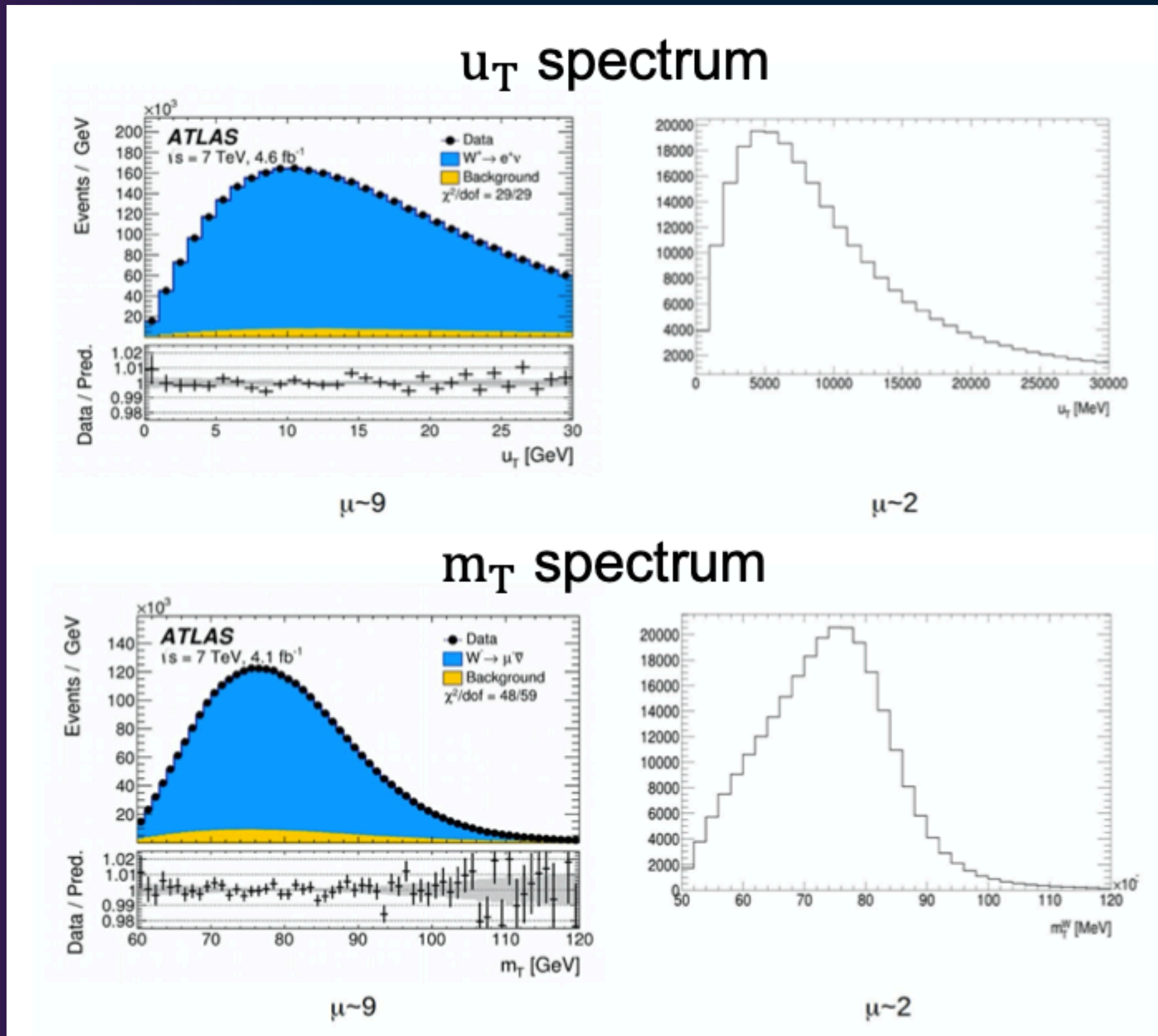
ATL-PHYS-PUB-2018-026/





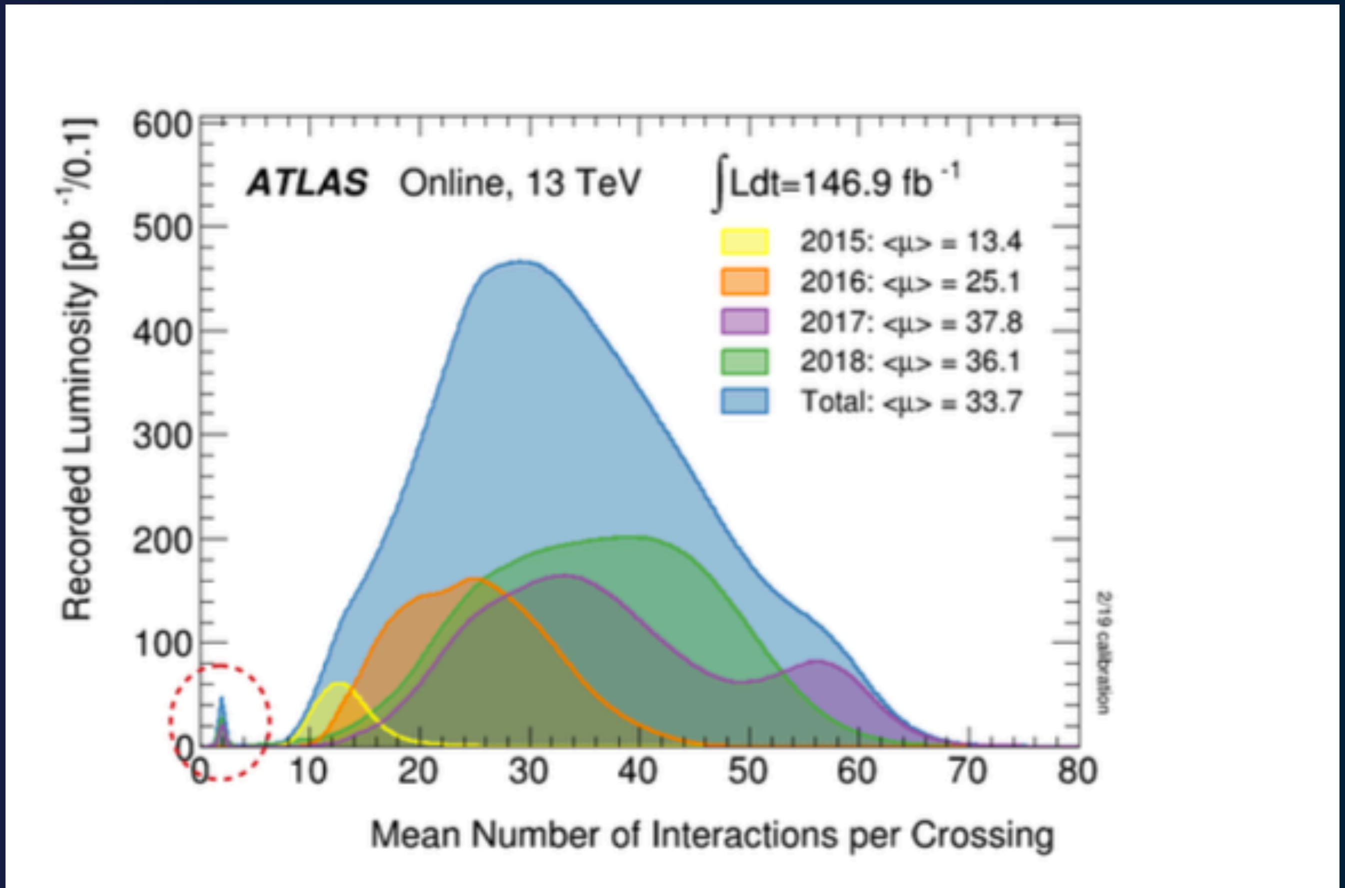


Recoil resolution and the ATLAS calorimeter



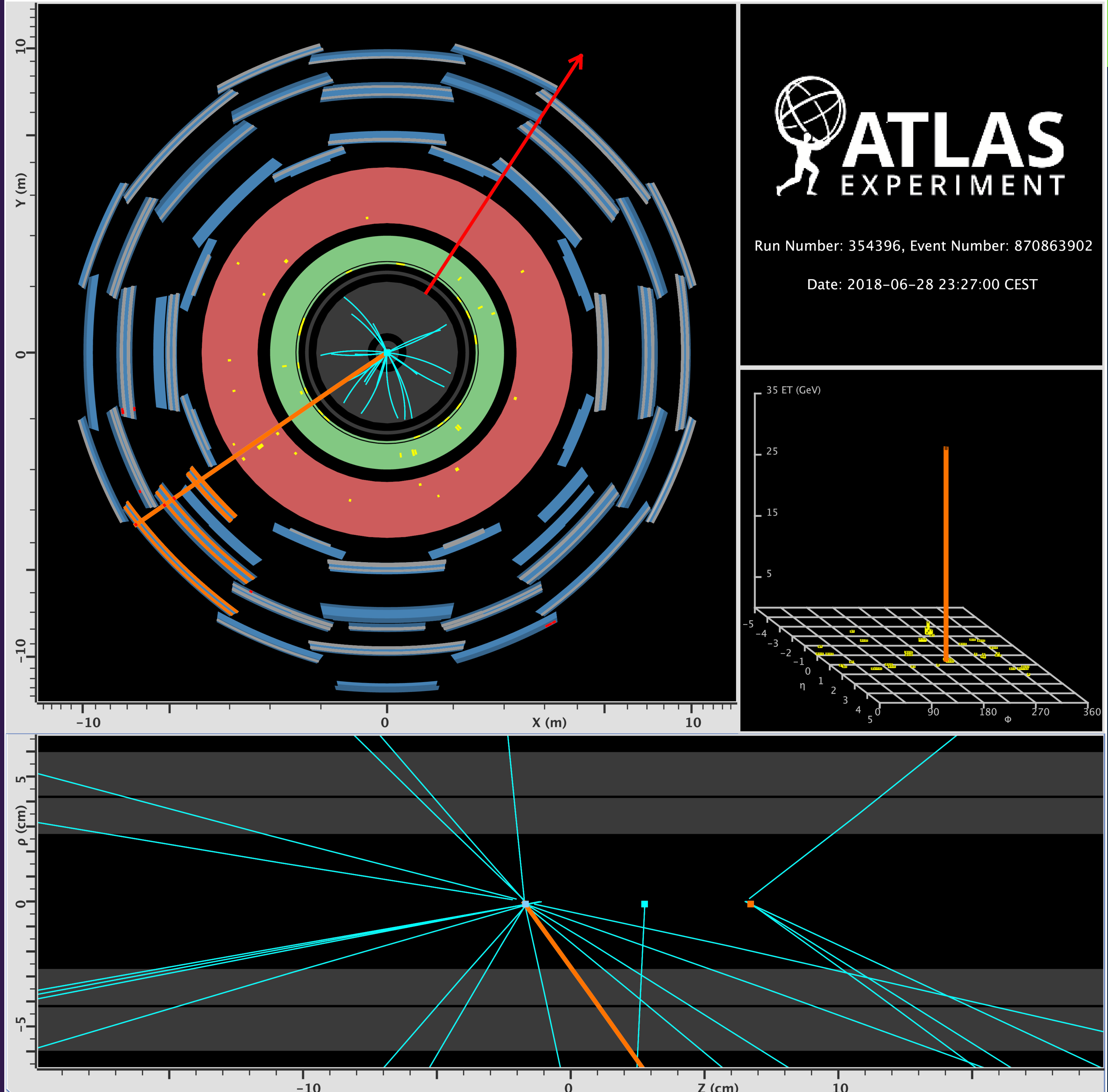
Datasets

arXiV:2404.06204



	2017, √s=5.02 TeV	2017+2018, √s=13 TeV
Luminosity (pb-1)	254.9 +- 2.6	338.1 +- 3.1
W+ events after selection	855k	2.27M
W- events after selection	538k	1.77M
Total W events after selection	1.39M	4.04M
Total Z events after selection	121k	379k

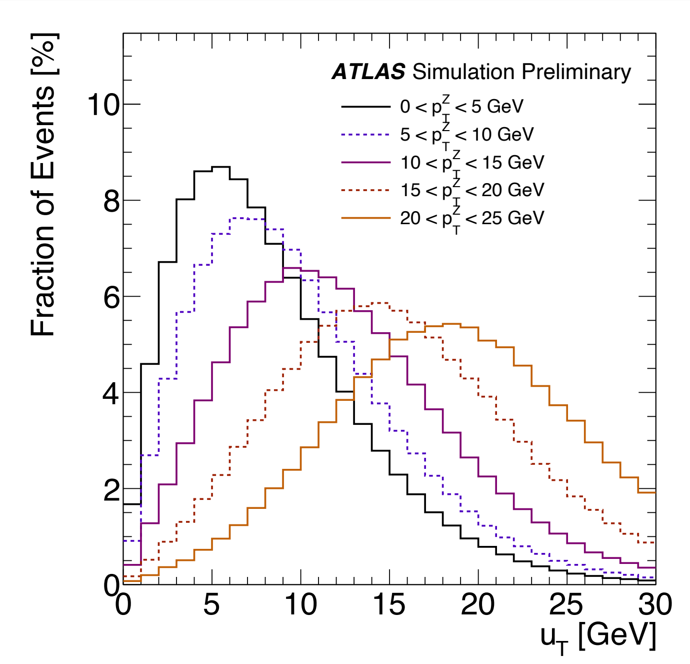
- Note the limited Z statistics, used for measuring $p_T(Z)$ but also for **calibration**

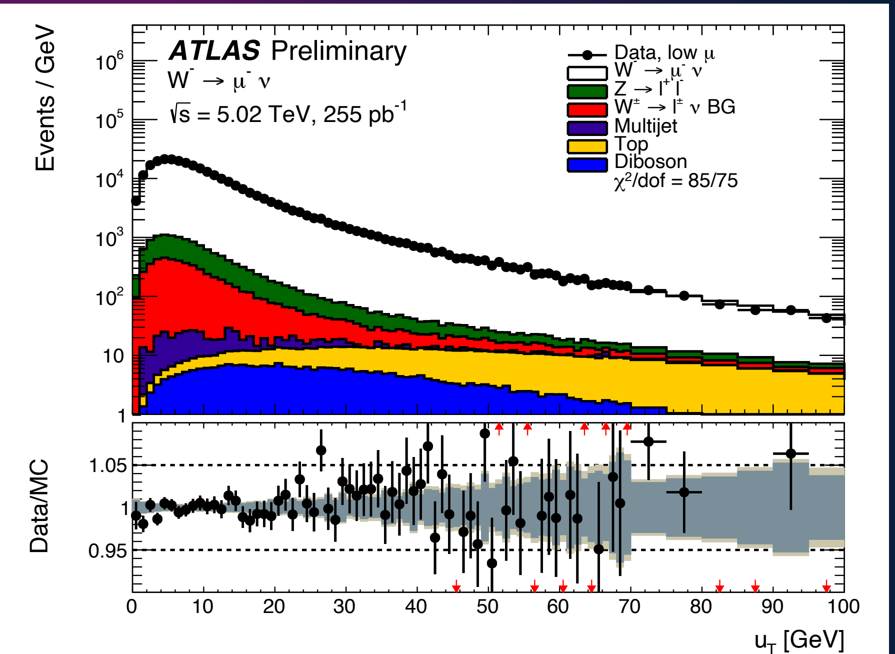

ATLAS
EXPERIMENT
Run Number: 354396, Event Number: 870863902
Date: 2018-06-28 23:27:00 CEST
Y (m)
X (m)
10
0
-10
35 ET (GeV)
25
15
5
η
Φ
0
90
180
270
360
ρ (cm)
Z (cm)

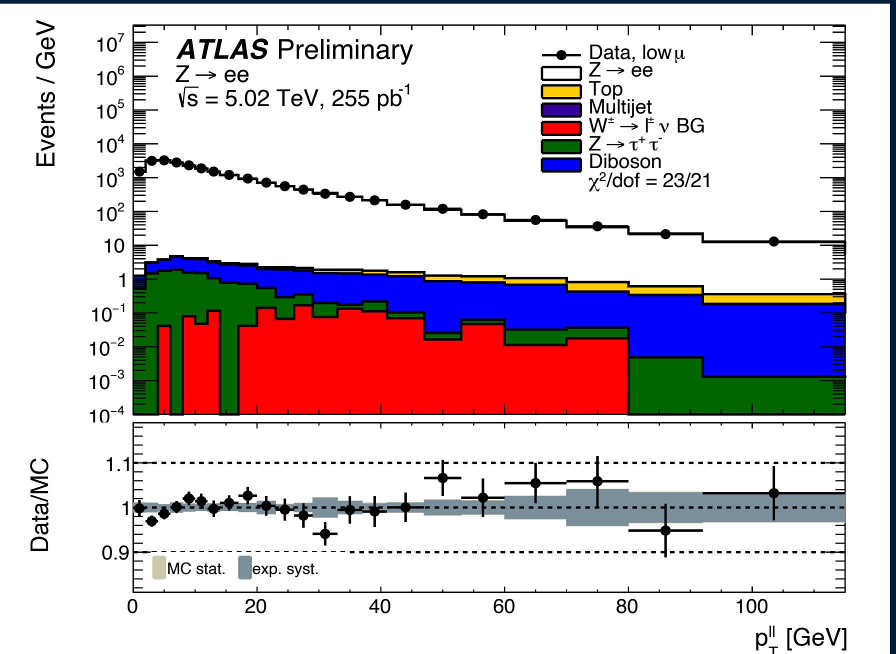
Analysis methodology

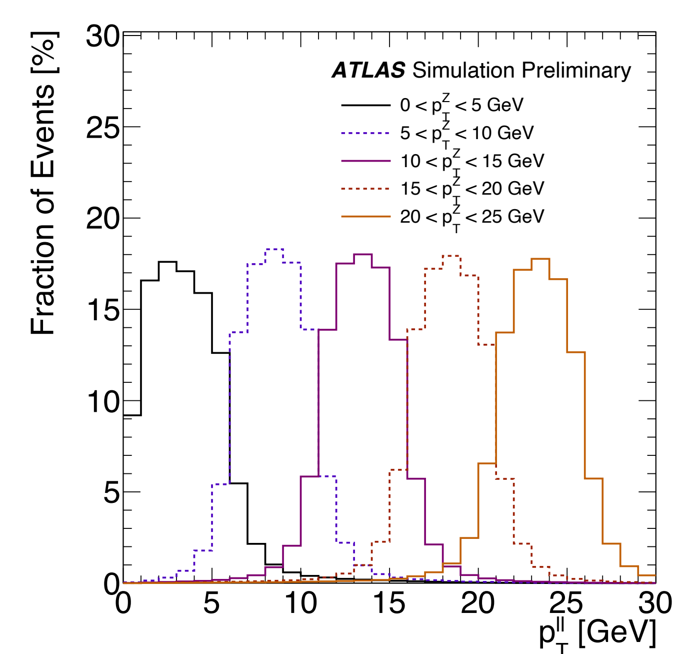
- Standard W and Z selections performed
- Multijet background estimated with data-driven ABCD method (improved and) similar as previous mW measurements
- Bayesian unfolding of u_T in the W and $p_T(\ell\ell)$ in the Z, separately in electron and muon channels
  - Binning and number of iterations optimised to minimise total uncertainty in the Sudakov region
    - 9 (25) iterations, 7 GeV bin width at low $p_T(W)$ for the W at 5.02 (13) TeV
    - 2 iterations, 2 GeV bin width at low $p_T(Z)$ for the Z
- electron and muon channels combined with BLUE, all giving good χ^2

Fiducial volume :
- lepton p_T > 25 GeV, lepton $|\eta|$ < 2.5
- W :
  - p_T^{ν} >25 GeV
  - m_T > 50 GeV
- Z : 66 < m_ll < 116 GeV

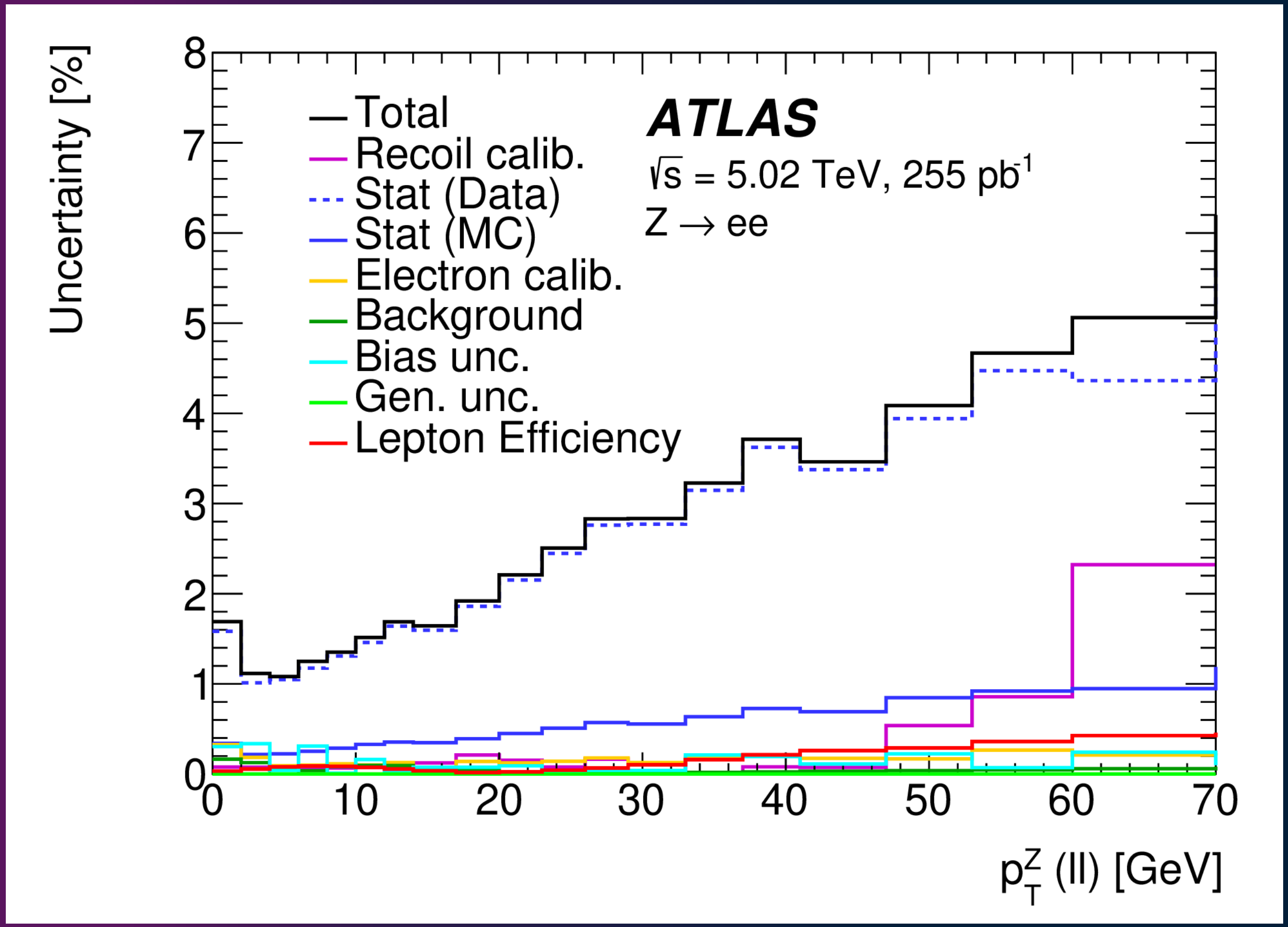


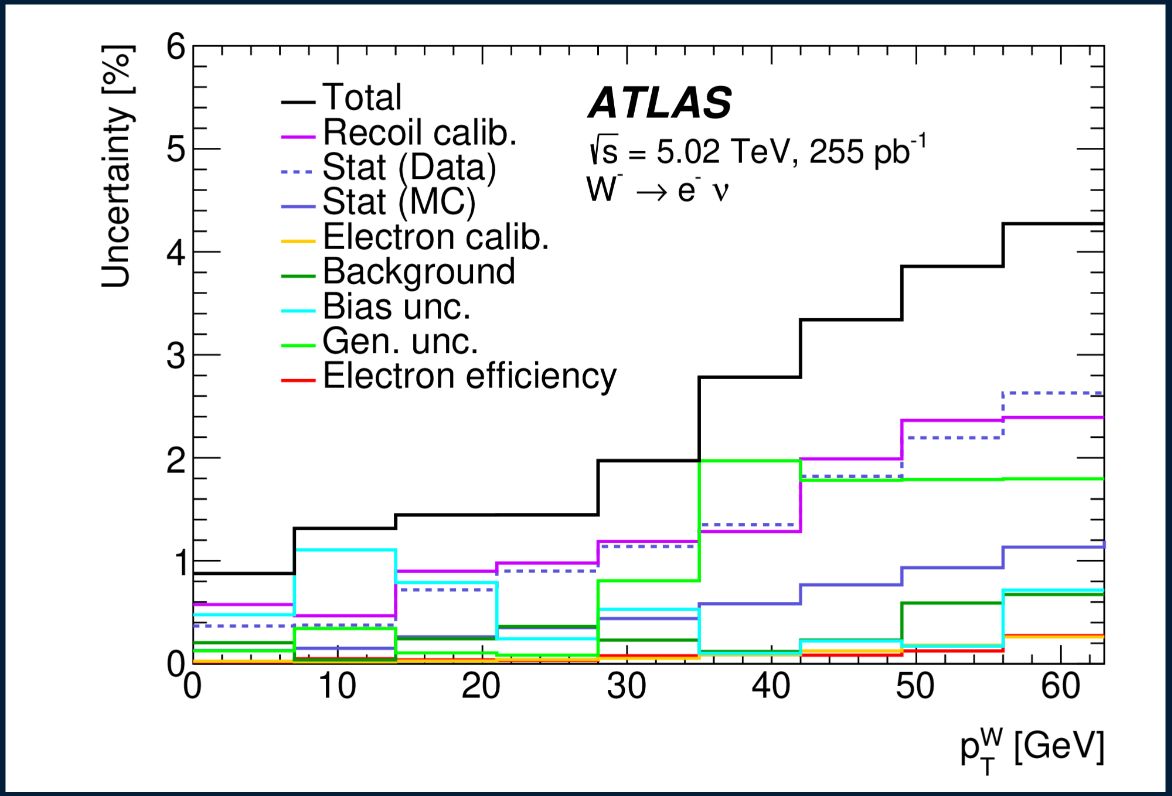


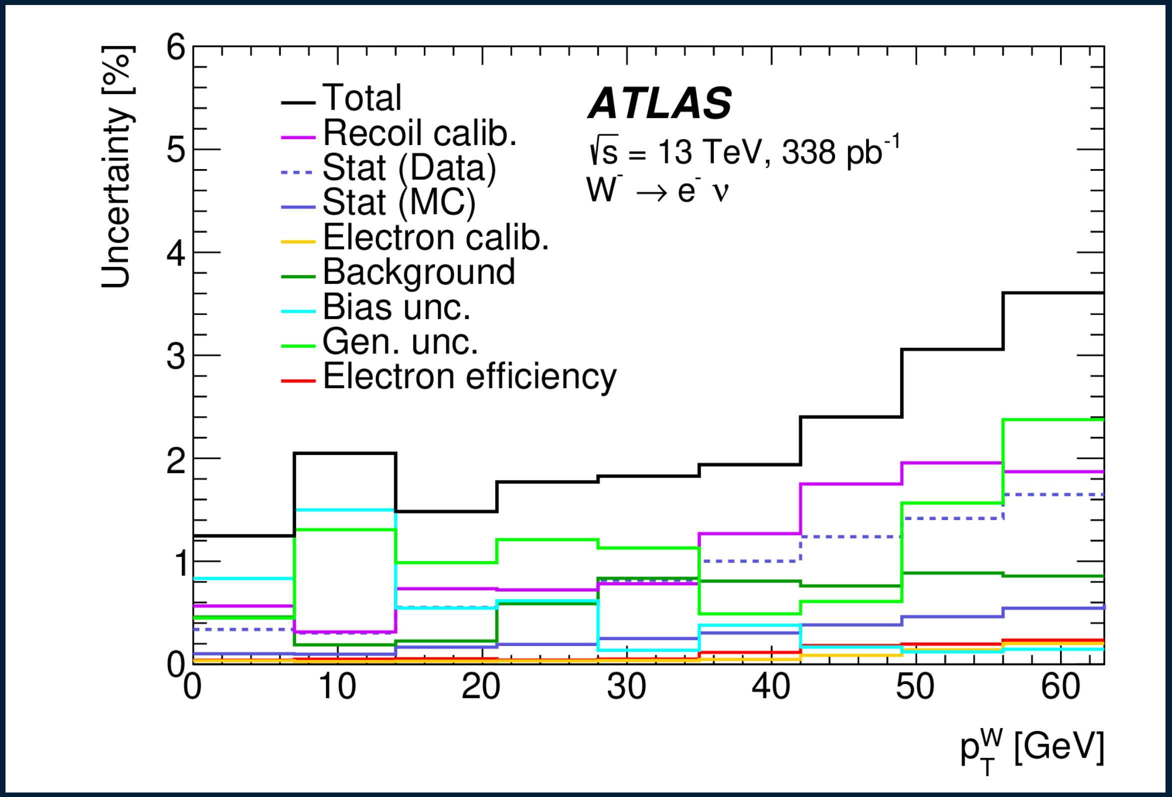




Results at unfolded level: uncertainties





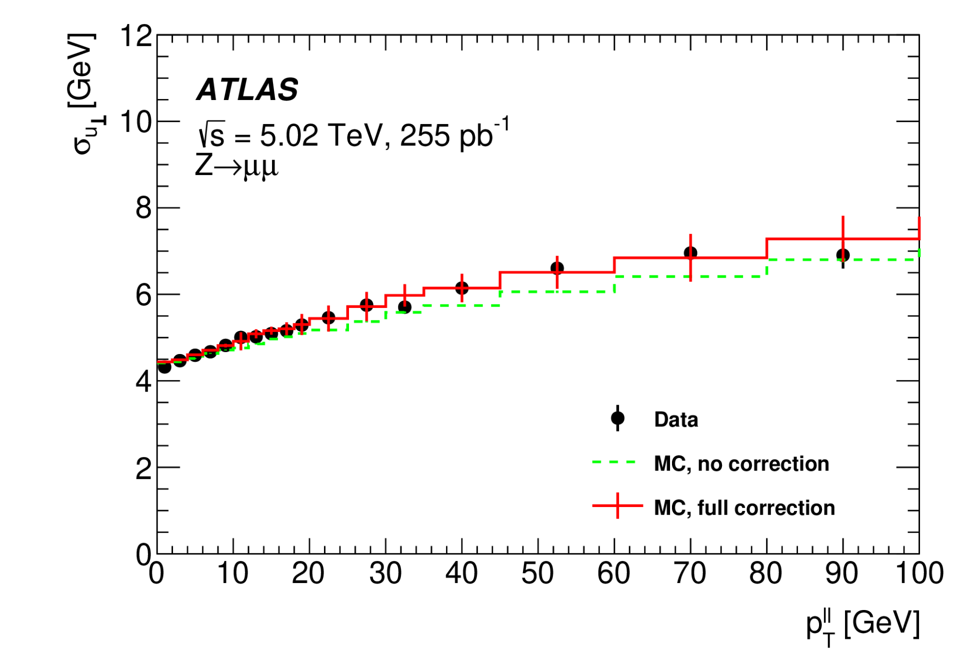


- Data statistics is clearly a limitation in the 5.02 TeV Z measurement
- Still large even in coarse bins for the W
  - Would like to reduce further the binning in future measurements

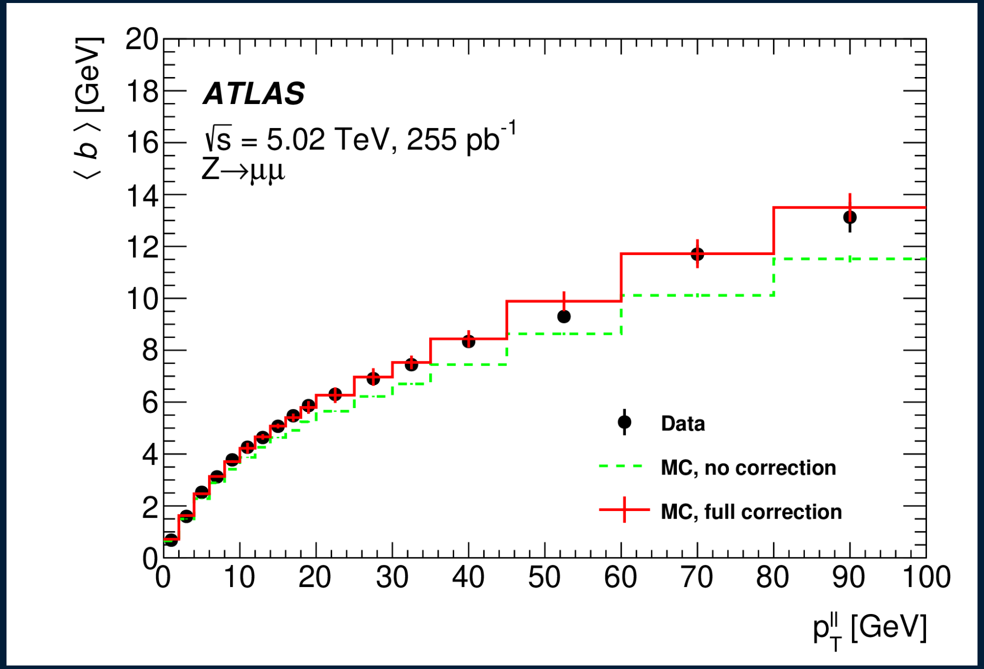
Recoil calibration: parenthesis

- Calibration of recoil *in-situ* using Z events
  - Modeling of underlying activity: $\Sigma E_T - u_T$
    - Reweight $\Sigma E_T - u_T$ in slices of $p_T(ll)$
    - Further correction in bins of calibrated u_T
  - Response and resolution corrections, azimuthal angle
    - Use projections of recoil onto Z axis (parallel and perpendicular) as a function of $p_T(ll)$ and $\Sigma E_T - u_T$
  - Multi-dimensional corrections, limited in statistics with a few 100k Z events !

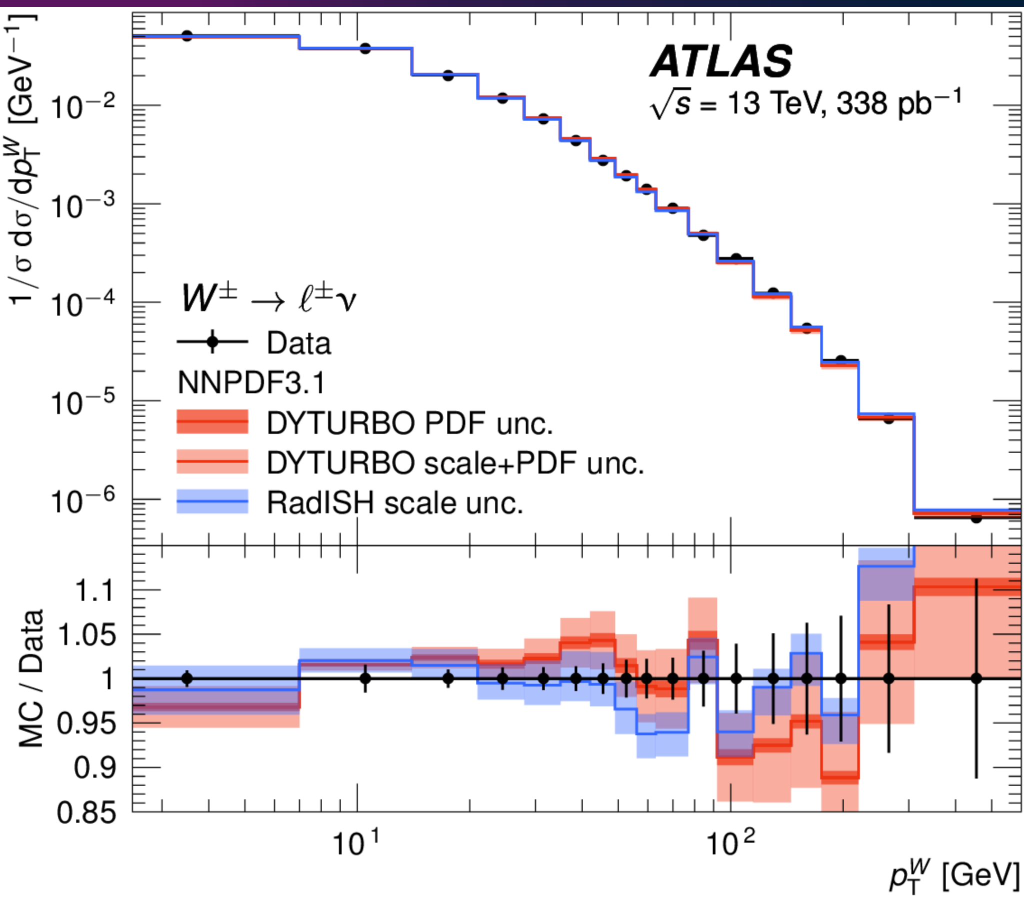
Resolution



Scale



Results : cross-sections and cross-section ratios



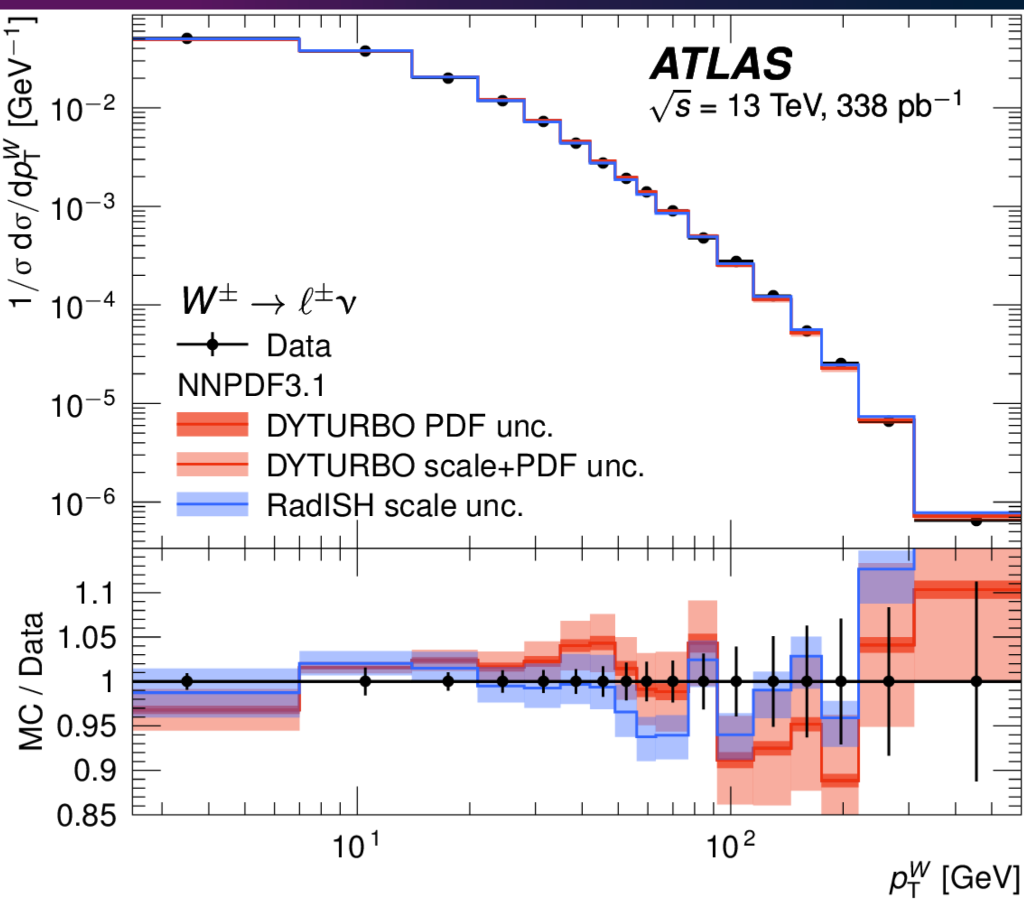
PDF set	$W^- \to \ell^- \nu$	$W^+ \to \ell^+ \nu$	$Z \to \ell\ell$
		$\sigma_{fid}(\sqrt{s} = 5.02$ TeV) [pb]	
Data	1384 ± 16	2228 ± 25	333.0 ± 4.1
CT18	1360 ± 10 (scale) $^{+30}_{-40}$ (PDF)	2200 ± 10 (scale) $^{+40}_{-70}$ (PDF)	320 ± 1 (scale) $^{+5}_{-9}$ (PDF)
MSHT20	1351 $^{+5}_{-6}$ (scale) $^{+22}_{-23}$ (PDF)	2180 ± 10 (scale) $^{+30}_{-40}$ (PDF)	324 ± 1 (scale) $^{+4}_{-5}$ (PDF)
NNPDF31	1381 ± 6 (scale) ± 16 (PDF)	2232 $^{+8}_{-9}$ (scale) ± 25 (PDF)	329 ± 1 (scale) ± 4 (PDF)
		$\sigma_{fid}(\sqrt{s} = 13$ TeV) [pb]	
Data	3486 ± 38	4571 ± 49	780.3 ± 10.4
CT18	3410 $^{+40}_{-20}$ (scale) $^{+60}_{-100}$ (PDF)	4460 $^{+40}_{-30}$ (scale) $^{+80}_{-130}$ (PDF)	748 $^{+5}_{-4}$ (scale) $^{+18}_{-25}$ (PDF)
MSHT20	3400 $^{+40}_{-20}$ (scale) $^{+40}_{-60}$ (PDF)	4460 $^{+40}_{-30}$ (scale) $^{+60}_{-70}$ (PDF)	763 $^{+6}_{-4}$ (scale) $^{+9}_{-12}$ (PDF)
NNPDF31	3450 $^{+40}_{-20}$ (scale) ± 30 (PDF)	4510 $^{+40}_{-30}$ (scale) ± 40 (PDF)	769 $^{+6}_{-4}$ (scale) ± 7 (PDF)

PDF set	$W^- \to \ell^- \nu$	$W^+ \to \ell^+ \nu$	$Z \to \ell\ell$
		$\sigma_{fid}(\sqrt{s} = 13$ TeV$)/\sigma_{fid}(\sqrt{s} = 5.02$ TeV)	
Data	2.516 ± 0.038	2.050 ± 0.030	2.344 ± 0.036
CT18	2.499 $^{+0.017}_{-0.005}$ (scale) $^{+0.043}_{-0.046}$ (PDF)	2.029 $^{+0.010}_{-0.007}$ (scale) $^{+0.029}_{-0.023}$ (PDF)	2.335 $^{+0.012}_{-0.009}$ (scale) $^{+0.049}_{-0.038}$ (PDF)
MSHT20	2.515 $^{+0.017}_{-0.005}$ (scale) $^{+0.018}_{-0.020}$ (PDF)	2.040 $^{+0.010}_{-0.007}$ (scale) $^{+0.014}_{-0.015}$ (PDF)	2.358 $^{+0.012}_{-0.009}$ (scale) $^{+0.018}_{-0.022}$ (PDF)
NNPDF31	2.500 $^{+0.017}_{-0.005}$ (scale) ± 0.031 (PDF)	2.022 $^{+0.010}_{-0.007}$ (scale) ± 0.029 (PDF)	2.335 $^{+0.012}_{-0.009}$ (scale) ± 0.026 (PDF)

https://arxiv.org/abs/2212.09379

- **Best precision on integrated fiducial cross-sections** for these processes, thanks to clean pileup conditions and **best luminosity determination (<1%)** achieved at LHC !
- Several centre of mass energies : may further help constrain parameters in parton shower tunes
- **Opens the window towards a low-pileup W mass measurement**, complementary to high-pileup existing one
  - more weight to transverse mass in these measurements

Results : cross-sections and cross-section ratios



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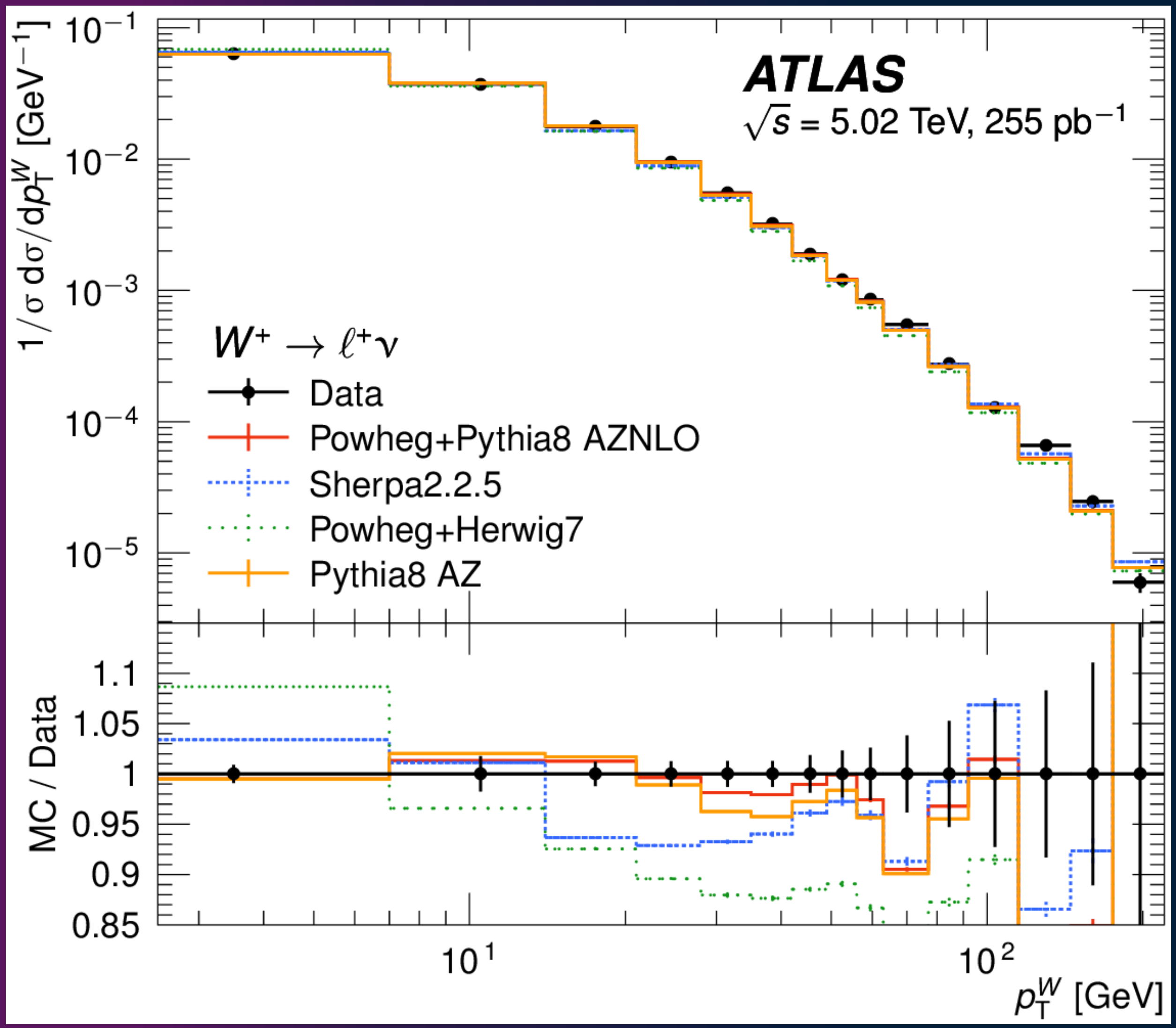
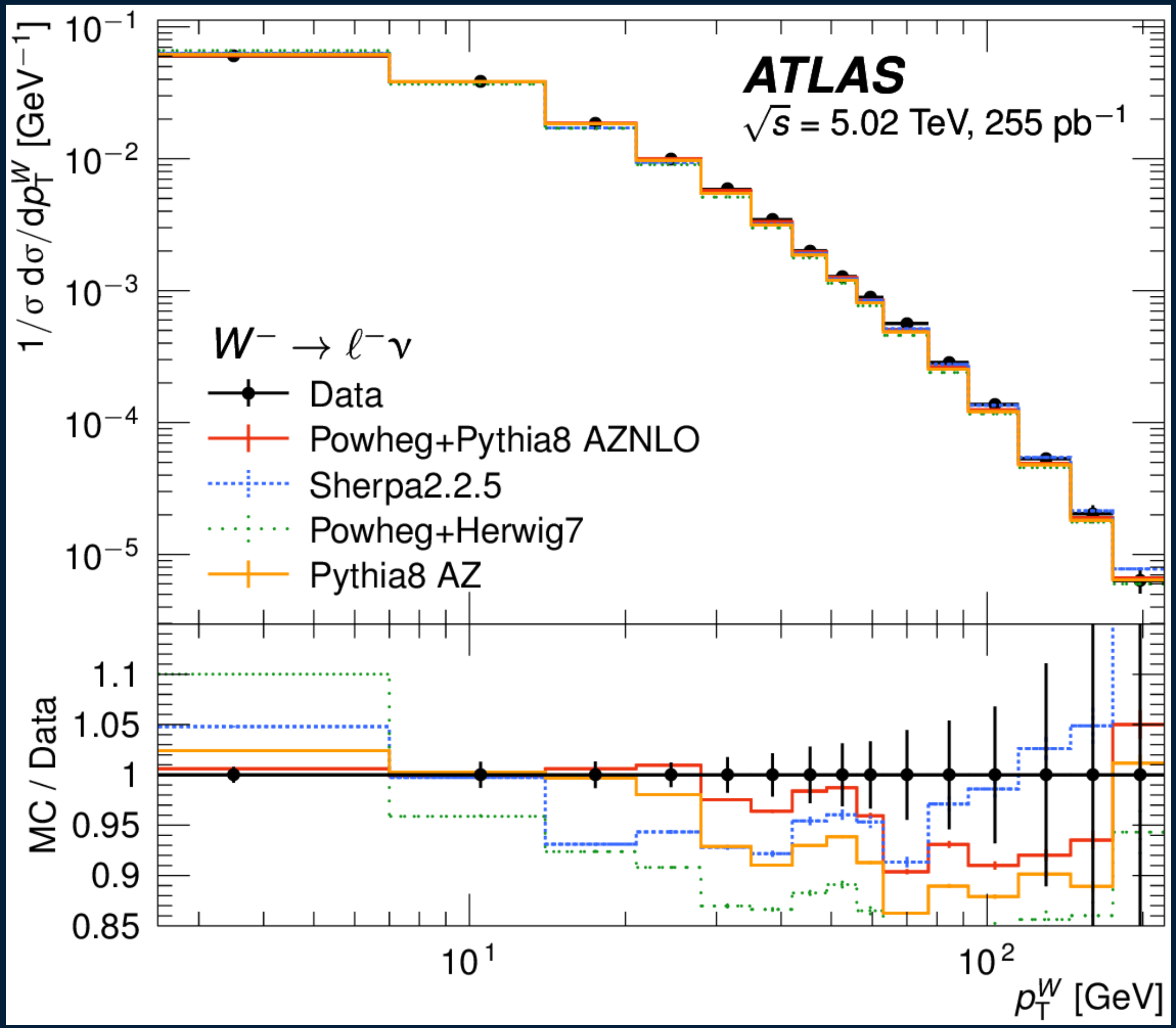
- **Best precision on integrated fiducial cross-sections** for these processes, thanks to clean pileup conditions and **best luminosity determination (<1%)** achieved at LHC !
- Several centre of mass energies : may further help constrain parameters in parton shower tunes
- **Opens the window towards a low-pileup W mass measurement**, complementary to high-pileup existing one
  - more weight to transverse mass in these measurements

Results at 5 TeV



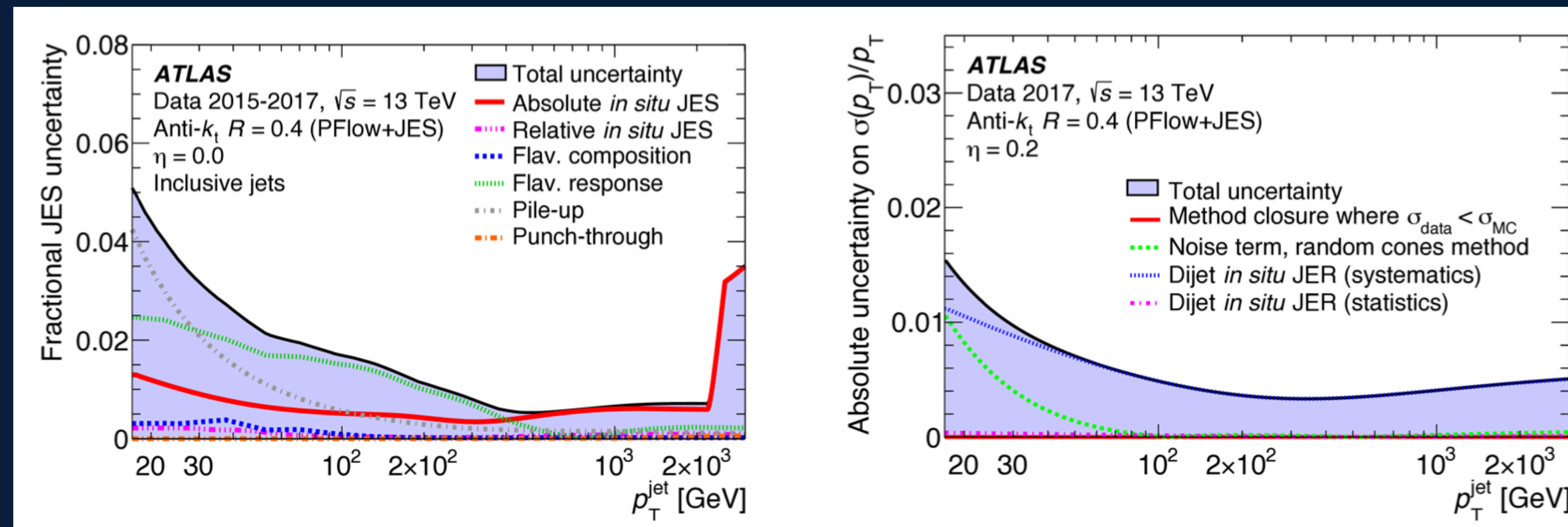


- Good description of W p_T from ATLAS tuned on 7 TeV Z data at low p_T
- Better performance of Sherpa 2.2.5 at high p_T

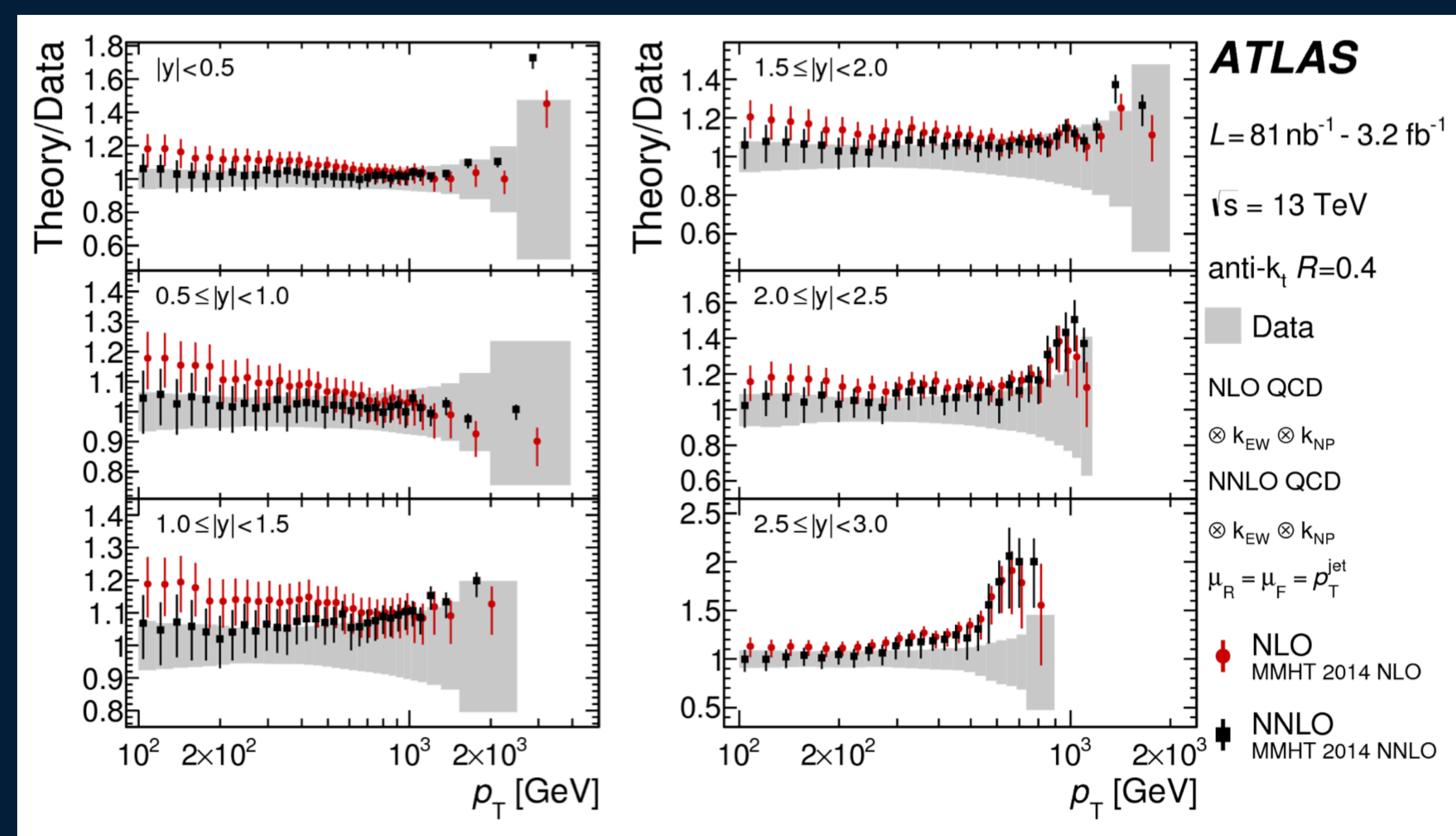
And now for something completely different

Jet physics

- Jet cross-sections have at low-pT the largest NNLO k-factors —> Strong test of pQCD!
    - Also, non-perturbative correction (hadronisation and underlying event) are quite large in this region, very interesting to probe!



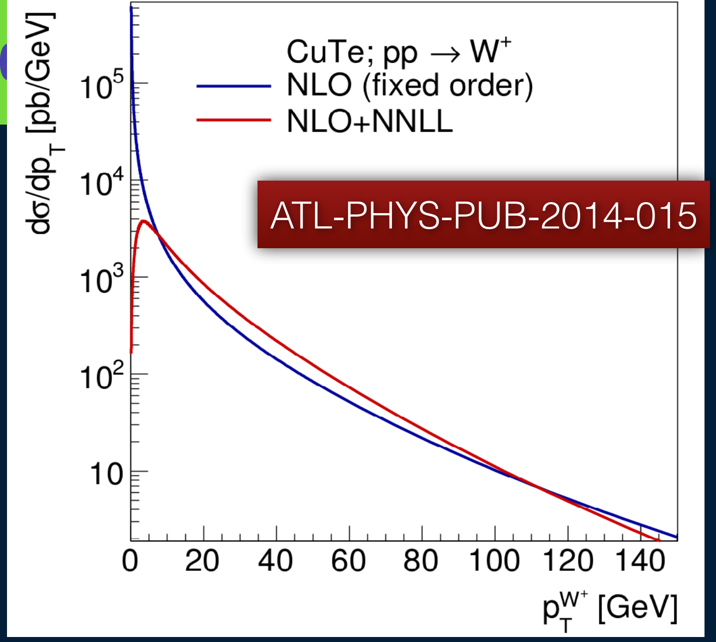
- Also possibility to extend measurements of the running of α_S to **lower scales (cross-section ratios)**
- Impact of pileup on jet uncertainties would be largely reduced with low-mu runs
    - At the moment, jet calibration for existing low mu is ongoing (useful for HI cross-calibration)
    - Very limited by statistics for forward jet calibration!



Outlooks

- $p_T(W)$ and $p_T(Z)$ measurements thanks to low-pileup data, **sensitivity to the Sudakov region** will bring improvements in future m_W measurements
  - 7 GeV bin width, in 8 channels, together with ratios, with uncertainty about 1.5-2% in the peak
  - Comes with **most precise integrated W/Z cross-sections**
  - Statistics is a dominant effect, in measurement and calibrations : **strong case for more low-pileup data taking at LHC**
    - **Estimated need : ~1fb-1 at mu~2**
- **Strong case for jet physics measurements using low mu data as well**
  - **More statistics can only help with calibrations (strong limitation at the moment in eta intercalibration)**

BACKUP



W p_T : let's diverge a little bit

- Pure fixed-order NNLO predictions : diverge when $p_T \rightarrow 0$ ($p_T << M$) due to the presence of soft and collinear emissions — spoiled by large logarithms of the type $\alpha_S^n \ln^m(M^2/p_T^2)$
- This can be resummed at all orders and gives

$$\frac{d\sigma}{d\tau dy dp_T^2} = \left(\frac{d\sigma}{d\tau dy}\right)_{Born} \frac{4\alpha_s}{3\pi} \frac{\ln s/p_T^2}{p_T^2} \exp\left(-\frac{2\alpha_s}{3\pi} \ln^2 s/p_T^2\right)$$

- Where the exponential is referred to as the 'Sudakov form factor'
- Approximation as this is assuming uncorrelated gluon emission (not even LL)
- Several resummation formalisms and calculations to resum the leading, next-to-leading and next-to-next-to leading logs
    - e.g., RESBOS, DYRES, Geneva, RADISH…
- Can also use parton showers (typically done in simulations) : Sherpa, Pythia, Herwig…

- high $p_T \sim M$: fixed-order V+1 jet (MC : fixed-order matrix elements) ; resummation does not work
    - $d\sigma/dp_T^2$ goes as $1/p_T^2$
- low $p_T << M$: fixed-order breaks down, resummation comes in (MC : Parton showers)
- Transition region : no fixed boundary
    - Resummation works but fixed-order gives sensible results as well
        - Best prediction from consistent combination of the two
        - MC : Matrix element + parton shower merging/matching