Measurements of transverse momentum of Z Boson with low pileup dataset

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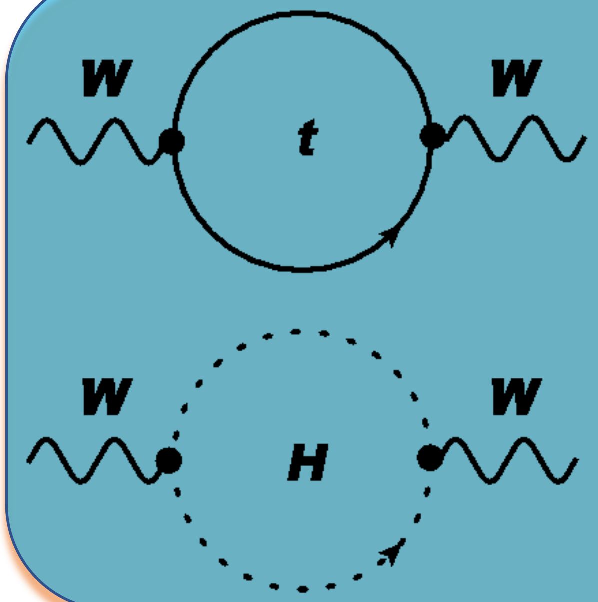
ATLAS
EXPERIMENT

Outline

- Motivation for p_T^Z measurement
- Low-pileup dataset
- Transverse momentum measurement strategy
- Uncertainty estimation
- Results
- Summary

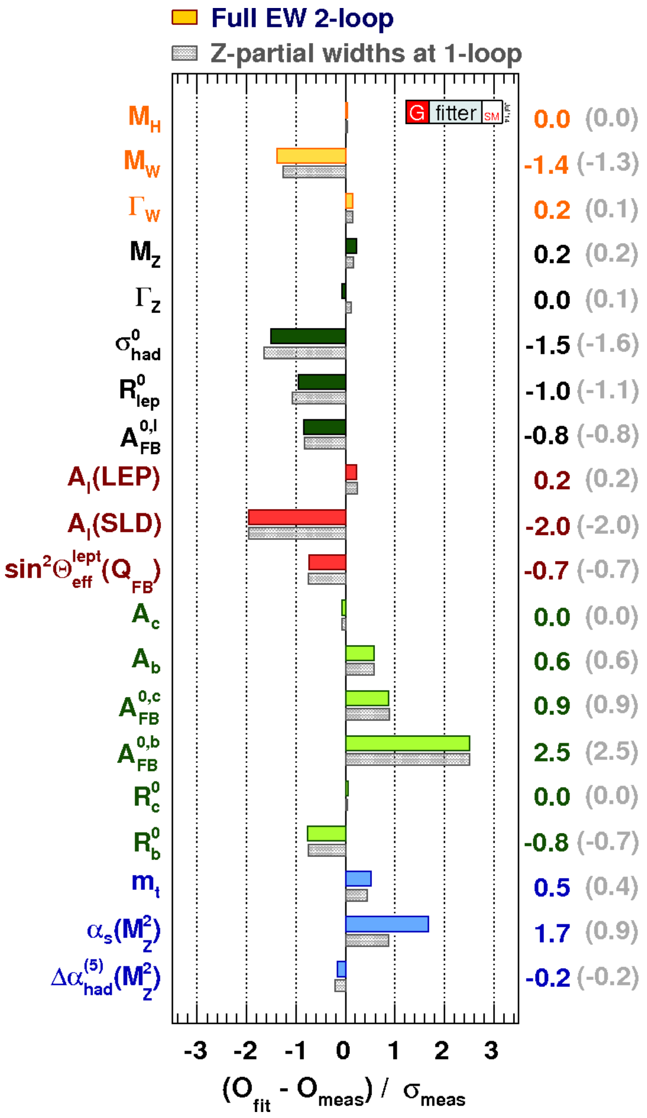
Importance of W mass measurement

Improving the precision of the m_W measurement is an important test of SM, and is sensitive to new physics.

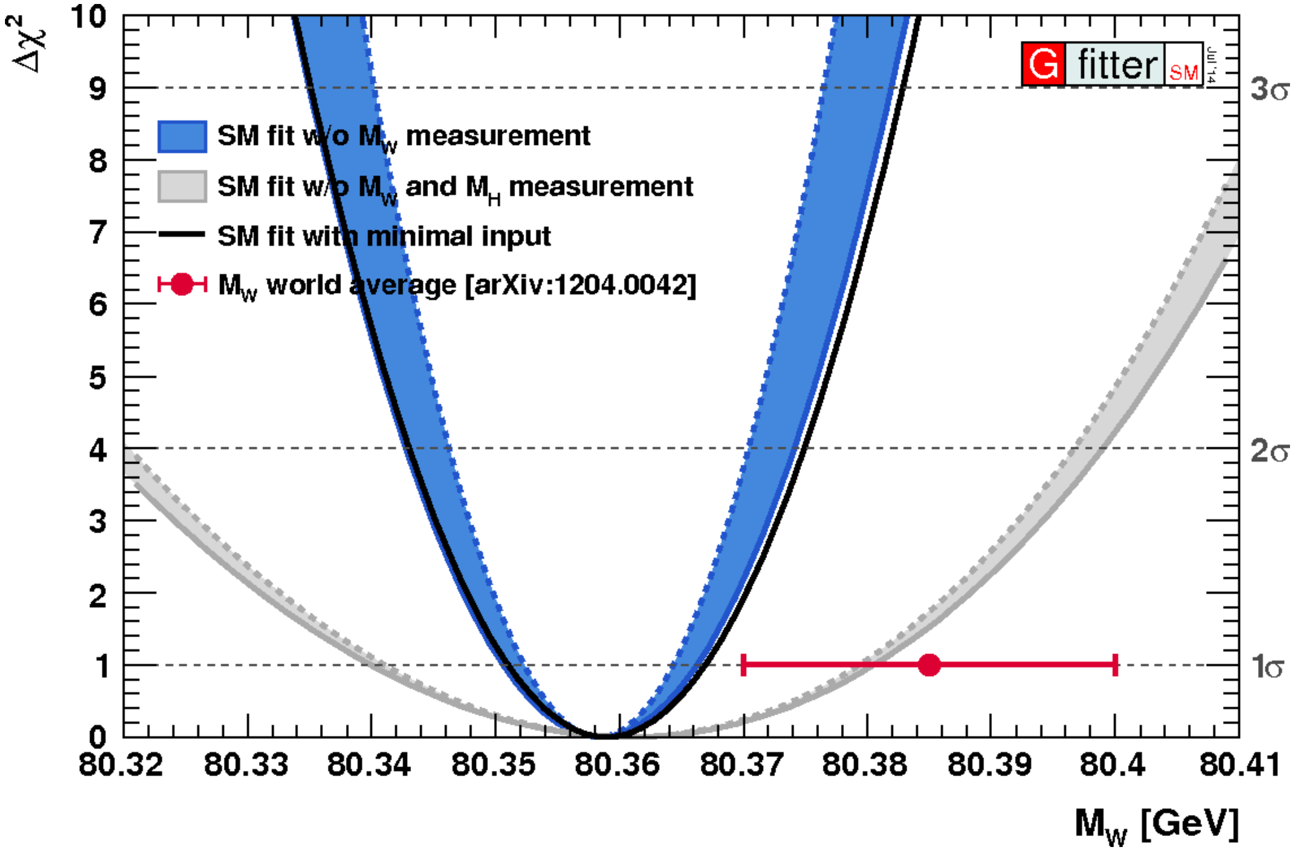


$$m_W^2\left(1-\frac{m_W^2}{m_Z^2}\right)=\frac{\pi\alpha}{\sqrt{2}G_\mu}(1+\Delta r),$$

Δr incorporates the effect of higher-order corrections. In the SM, Δr is particularly sensitive to the top-quark and Higgs-boson masses.



W mass precision measurement



m_W is one of the key parameter of the SM

$$\sin^2\theta_W = 1 - \left(\frac{M_W}{M_Z}\right)^2$$

m_W (EW fit) = 80.354 ± 0.007 GeV

PDG World Average:
$m_W =$
80379 ± 13 MeV

Tevatron: $m_W =$ 80387±16 MeV

ATLAS 7 TeV high μ run: $m_W = 80370 \pm 19$ MeV

Uncertainty of previous m_W measurement with ATLAS

W mass measurement with ATLAS at 7 TeV arXiv:1701.07240

Stat. Unc. (MeV)	Exp. Syst. Unc. (MeV)	Modelling Unc. (MeV)	Total Uncertainty (MeV)
6.8	10.6	***13.6***	18.5

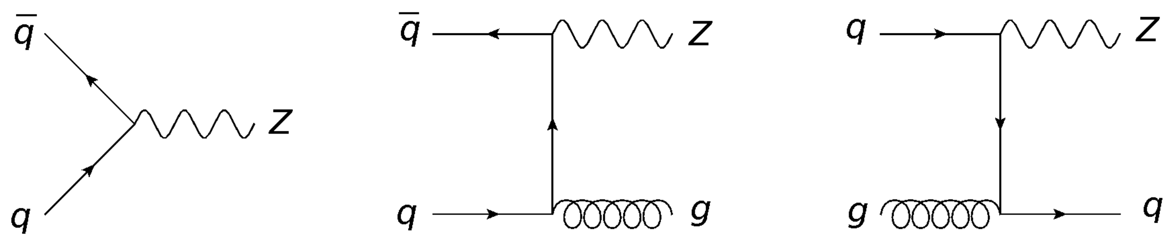
QCD Unc.	EW Unc.	PDF Unc.
8.3 MeV	5.5 MeV	9.2 MeV

m_W Unc. is dominated by QCD and PDF Unc.

QCD Unc. mainly comes from mismodelling of p_T^W < 30 GeV.

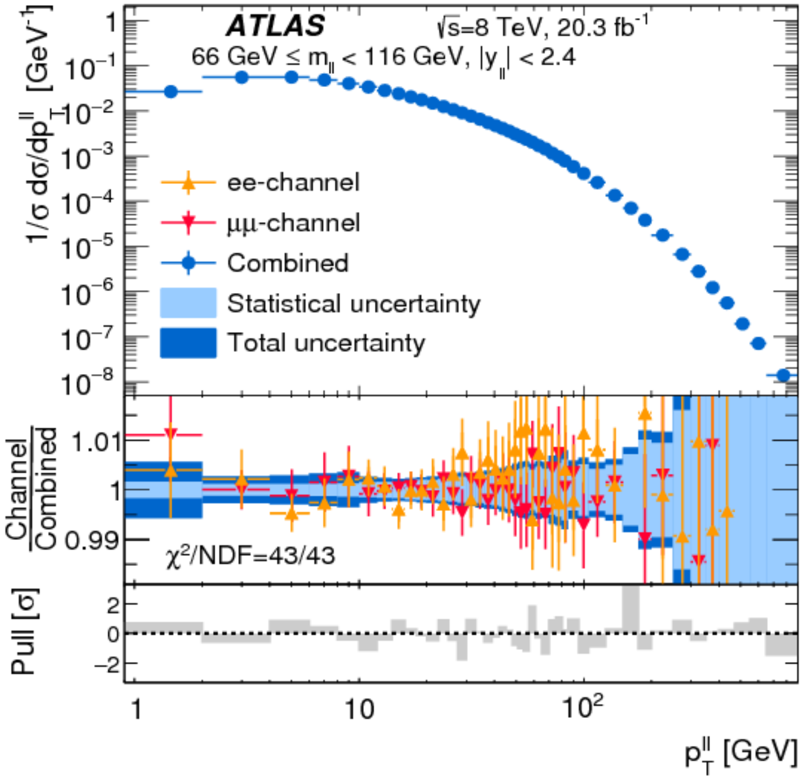
Motivation for p_T^Z measurement

Z boson is produced with non-zero p_T



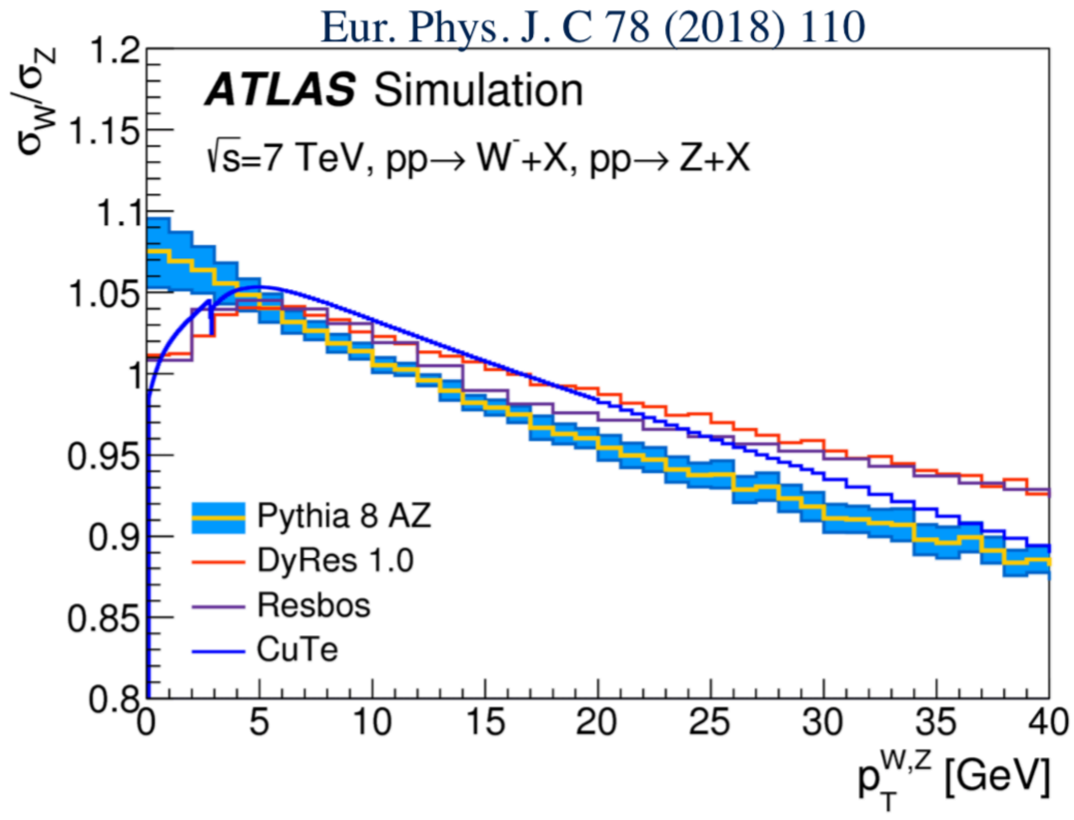
Precision p_T^Z measurement is an excellent probe of QCD, PDFs and Parton shower models.

arXiv:1512.02192

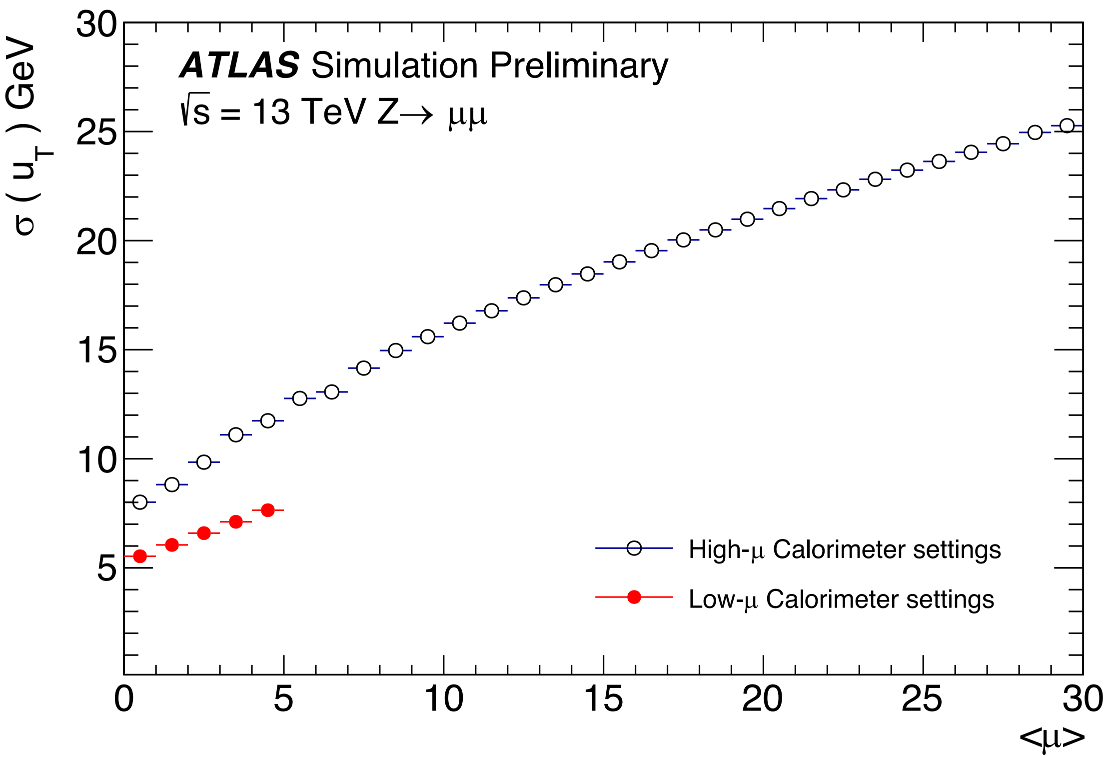


Low- μ dataset is fantastic opportunity to have first p_T^Z measurement at 5TeV with ATLAS!

W/Z p_T ratio modelling and measurement

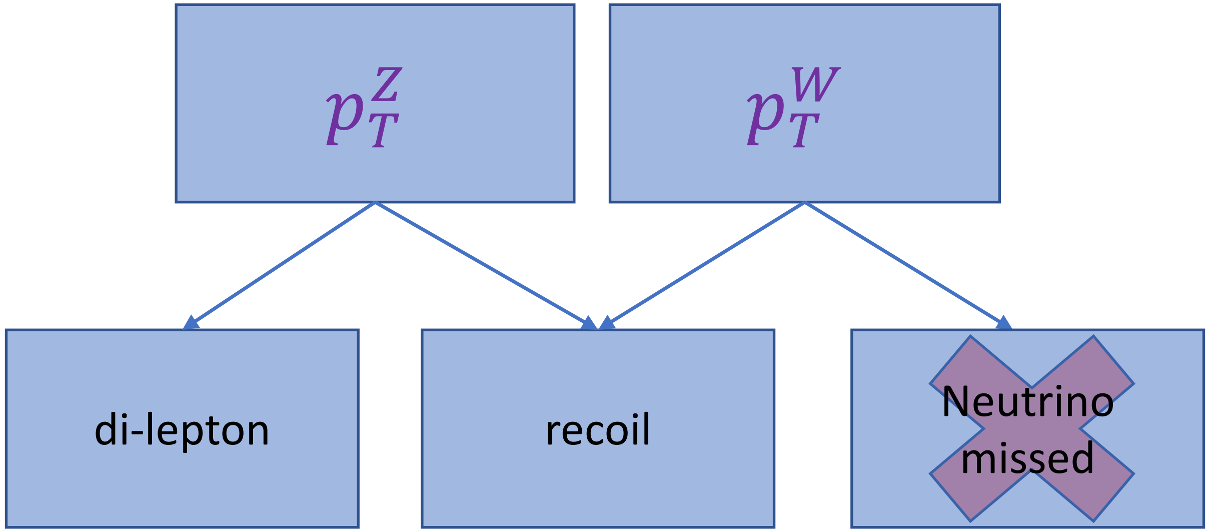


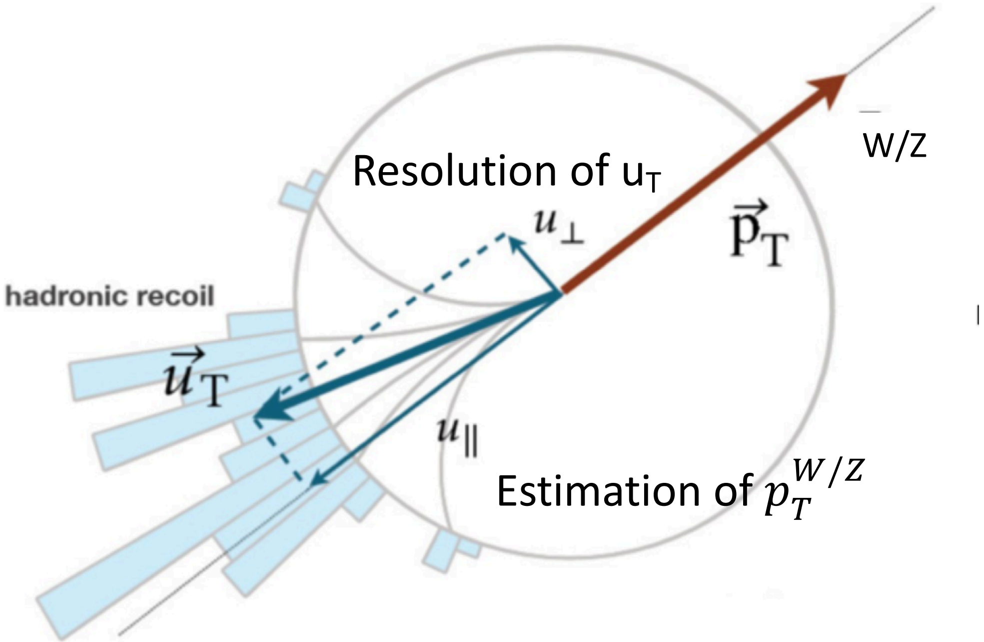
W/Z p_T measurements disagree with theoretic predictions



Pileup degrades measurement of the W/Z recoil.

The nice feature of p_T^Z measurement

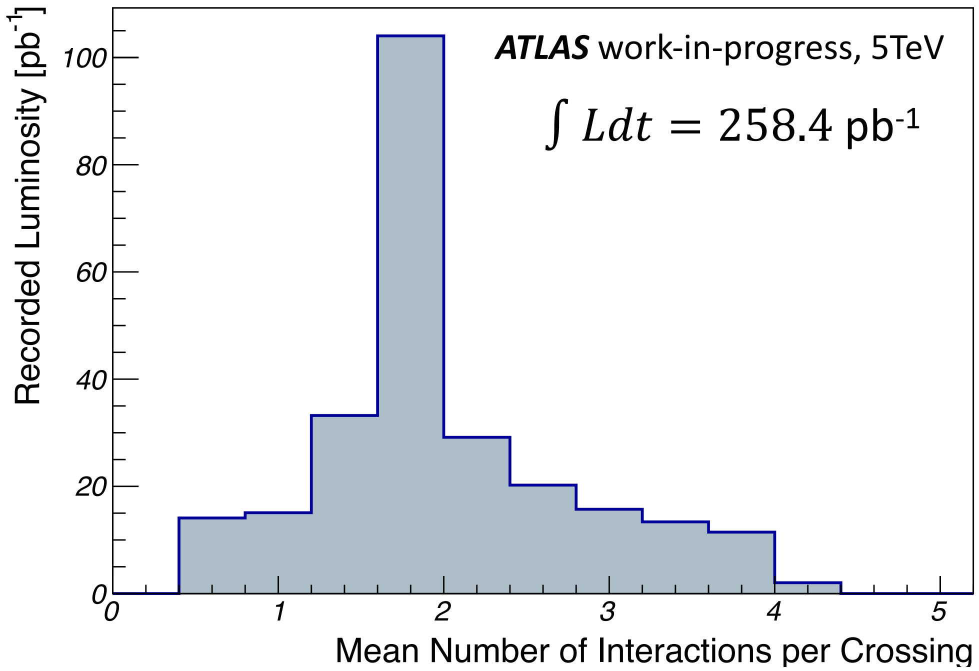


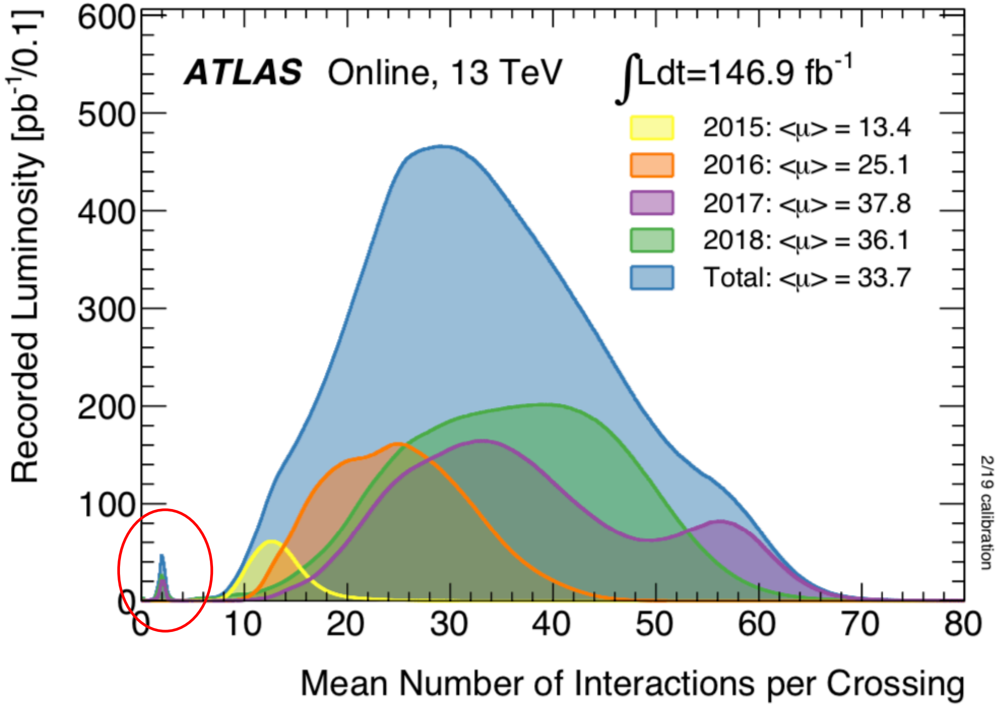


We measure p_T^Z using the lepton system and and validate had-recoil method for p_T^W measurement

Low pileup dataset

Pile-up: $<\mu>\sim 2$



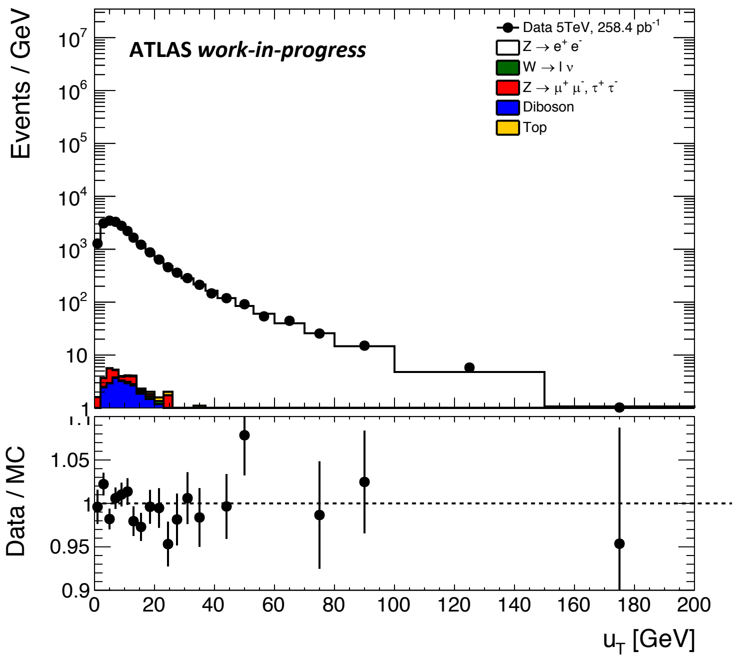


- **2017**:
  $\sqrt{s}$ = 5 TeV: 258.4 pb^{-1}

- **2017**:
  $\sqrt{s}$ = 13 TeV: 146.6 pb^{-1}
- **2018**:
  $\sqrt{s}$ = 13 TeV: 193.2 pb^{-1}

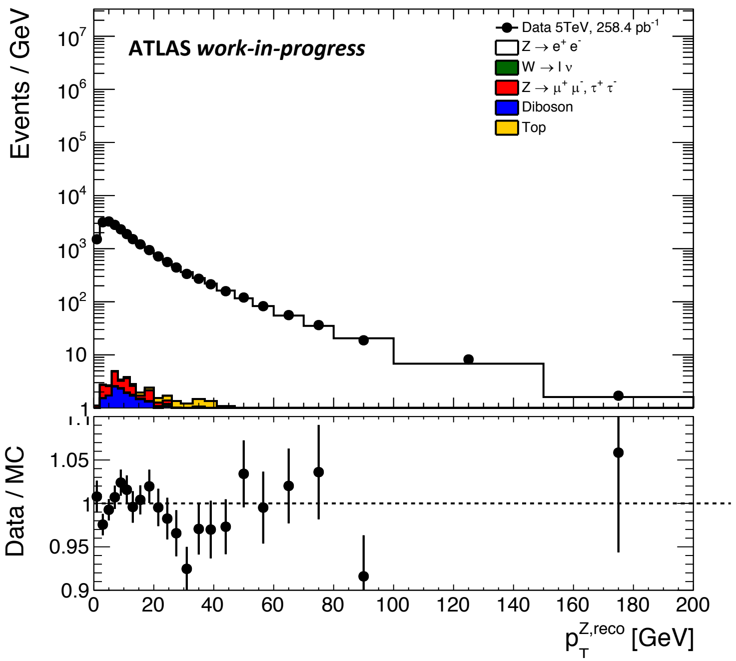
Data / MC compatibility

u_T



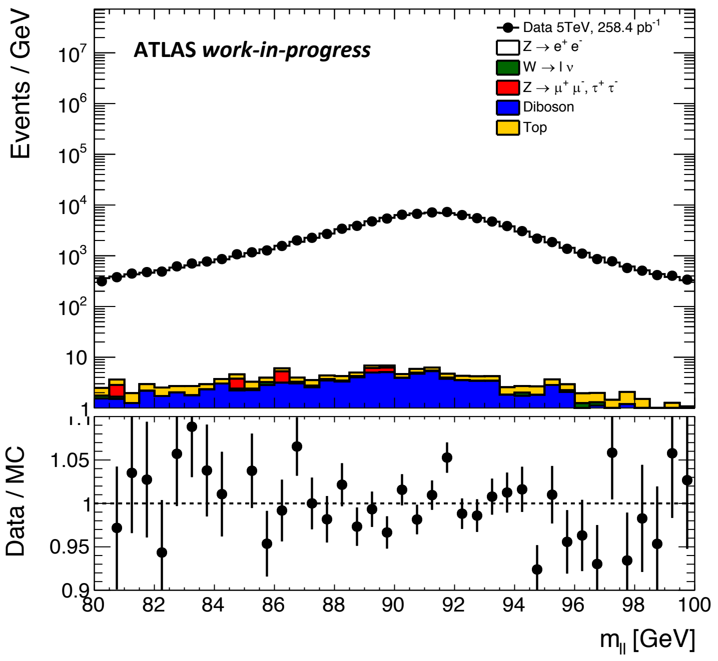
Estimation of $p_T^{W,Z}$ using recoil

p_T^Z



Measurement of p_T through di leptons only in Z

m_{ee}



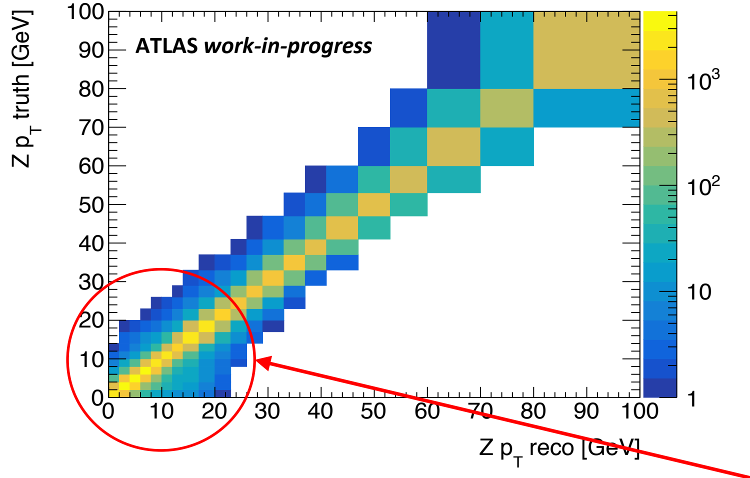
Invariant mass of Z boson

Selections and yield

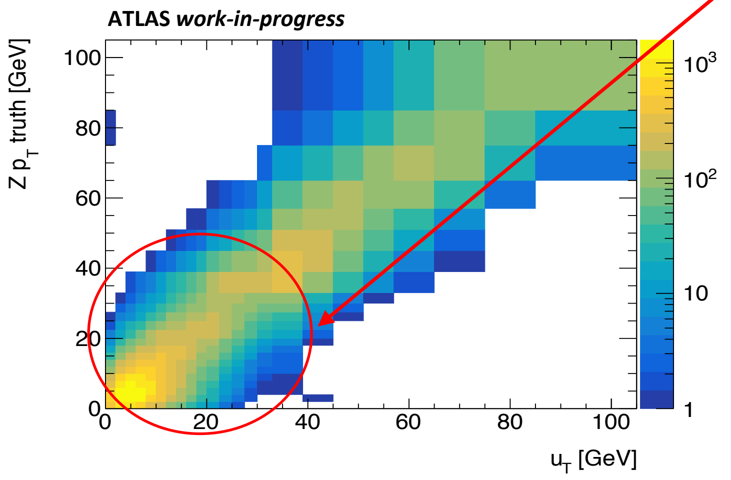
channel	$Z \to e^+e^-$	$Z \to \mu^+\mu^-$
Tracker acceptance	$\|\eta\| < 2.47$, excluding crack $1.37 < \|\eta\| < 1.52$	$\|\eta\| < 2.4$
Isolation	$\frac{p_T^{cone\ \Delta R=0.2}}{p_T^{e,\mu}} > 0.1$	
Phase space	$p_T^l > 25\ GeV$	
	$66\ GeV < m_{ll} < 116\ GeV$	
5 TeV yield	52 K	165 K
13 TeV yield	70 K	214 K

Bayesian unfolding strategy

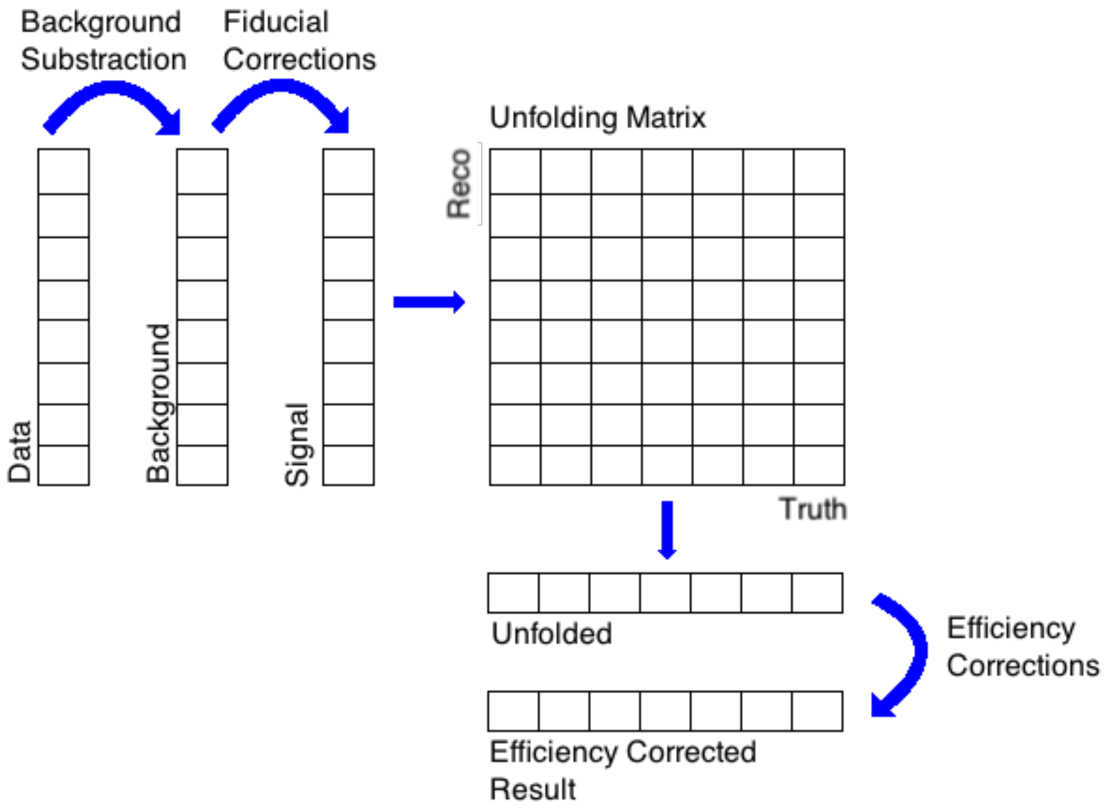
di-lepton



Hadronic recoil



Recoil resolution is much worse than di-lepton resolution.

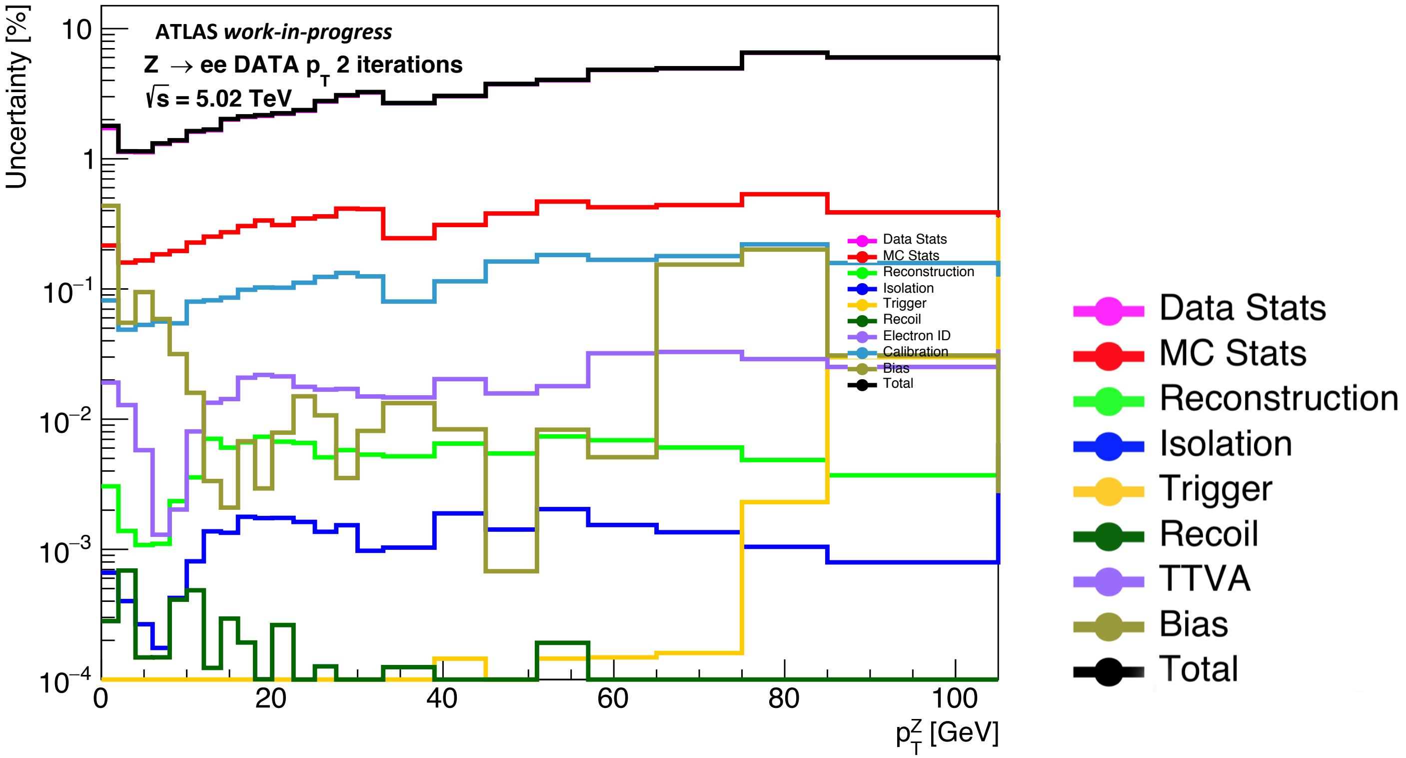


Unfolding procedure using Bayes' theorem

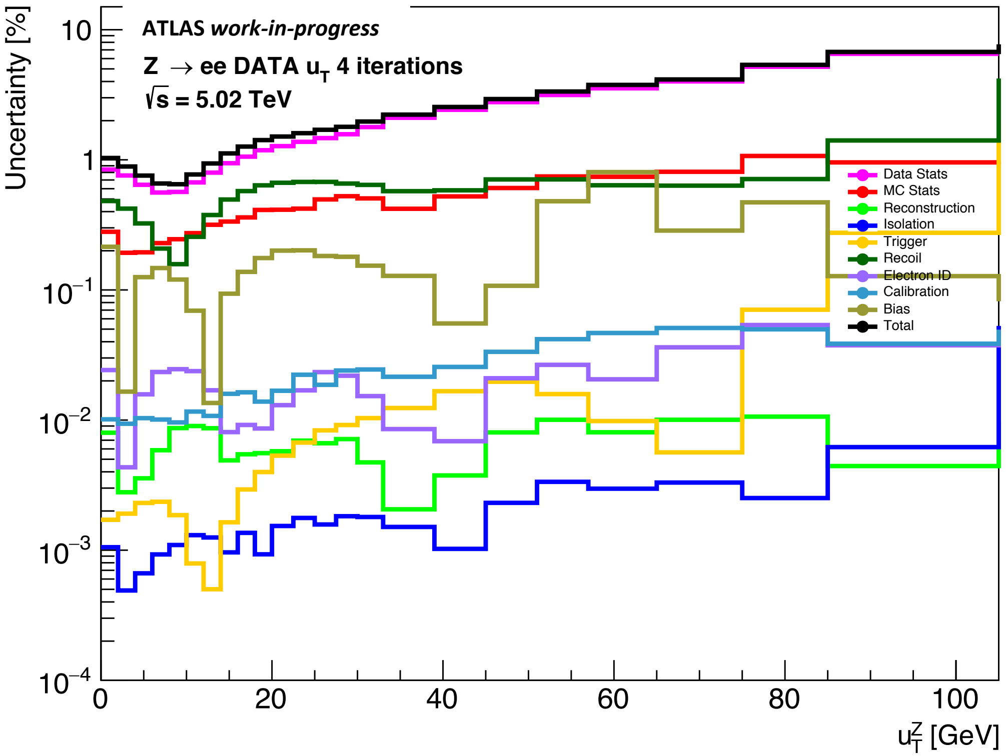
$$(P_{truth}|P_{reco}) = \frac{P(n_{reco}|n_{truth})P_{prior}(n_{truth})}{\Sigma_{n_{truth}} P(n_{reco}|n_{truth})P_{prior}(n_{truth})}$$

Uncertainty estimation

Di-lepton measurement



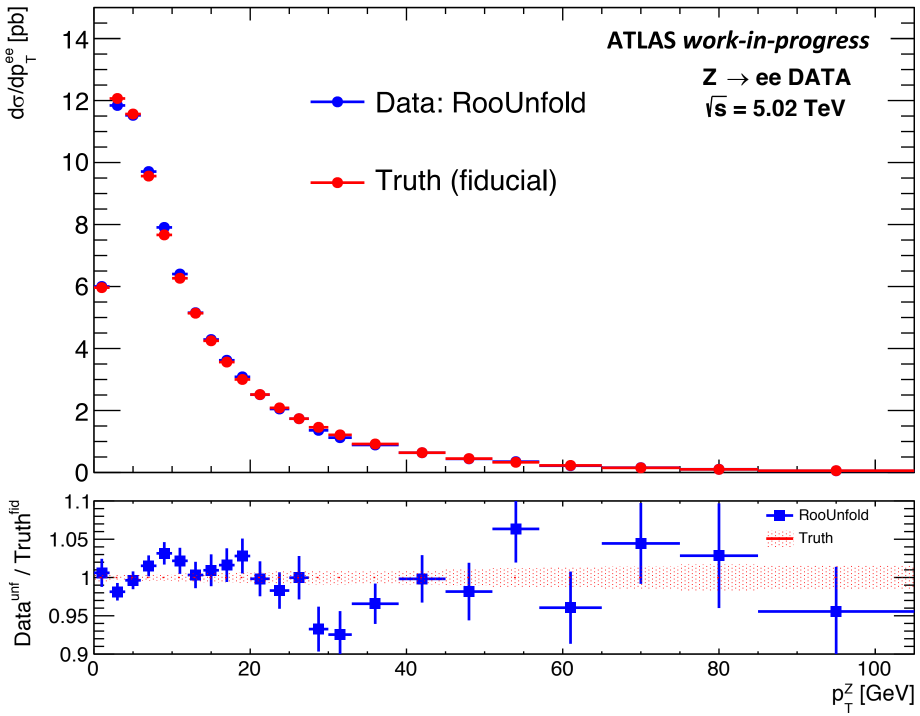
Had-recoil measurement



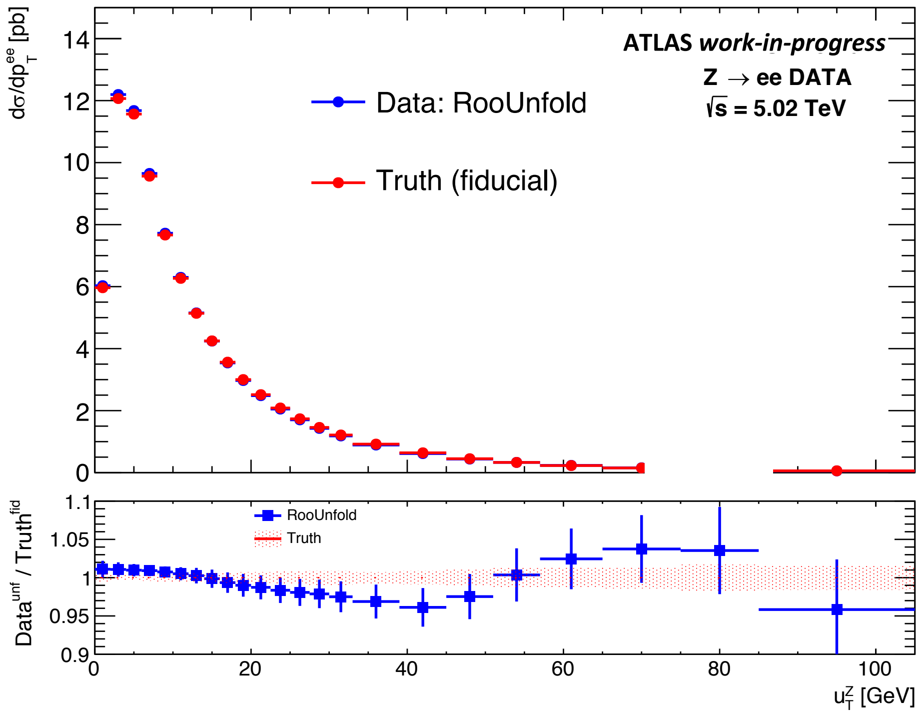
Due to cleanness in Z channel, statistic uncertainty dominates.

p_T^Z unfolding results

Di-lepton measurement

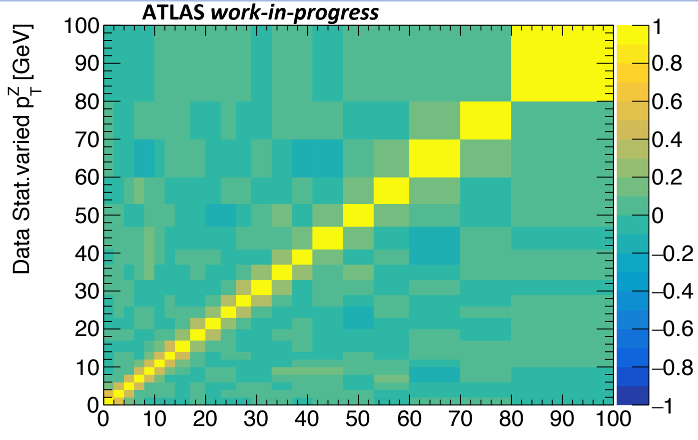


Had-recoil measurement

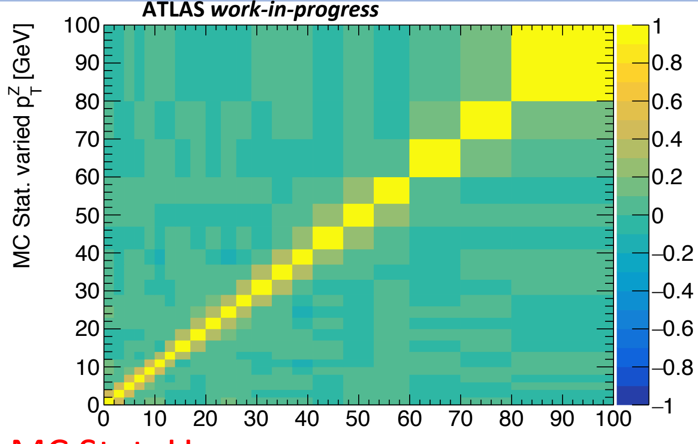


u_T is highly correlated bin by bin

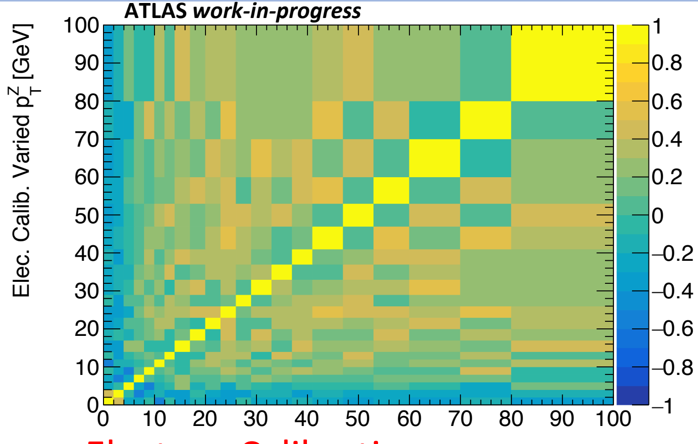
Correlations



Data Stat. Unc.



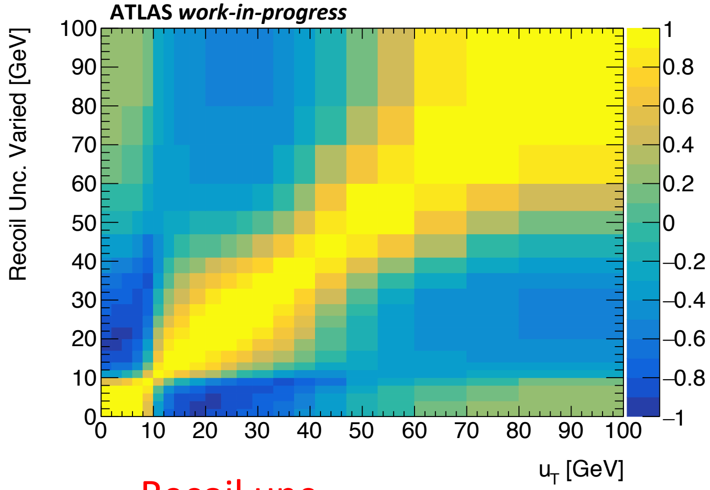
MC Stat. Unc.



Electron Calibration

p_T^{ll} is precisely measured and uncorrelated

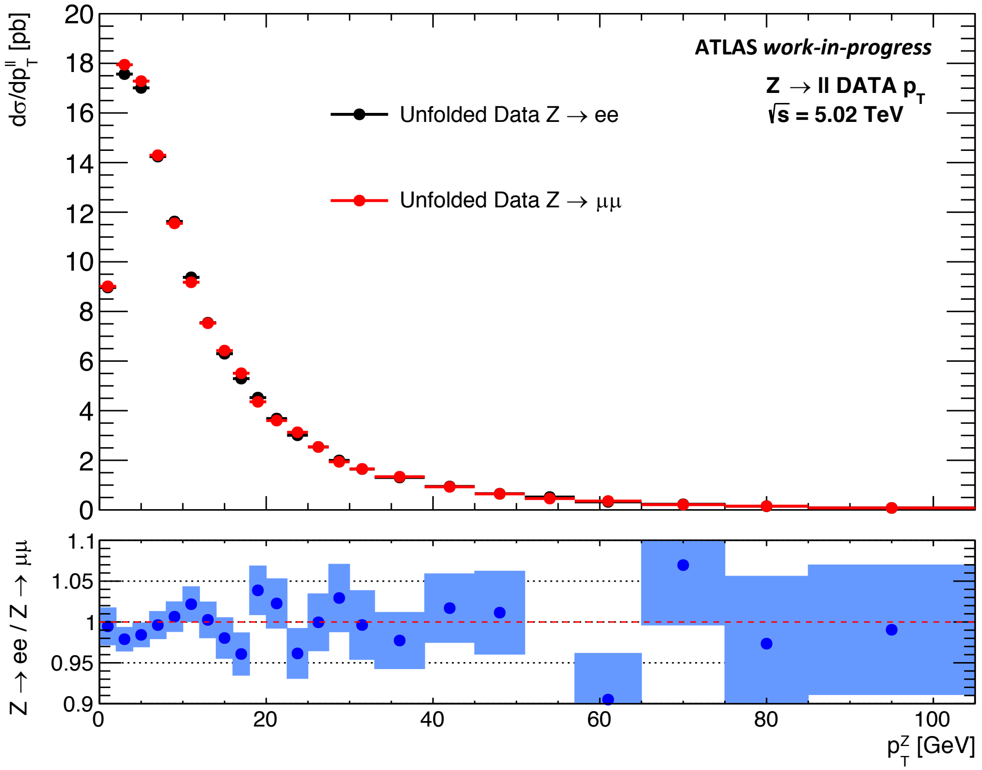
u_T is highly correlated bin by bin



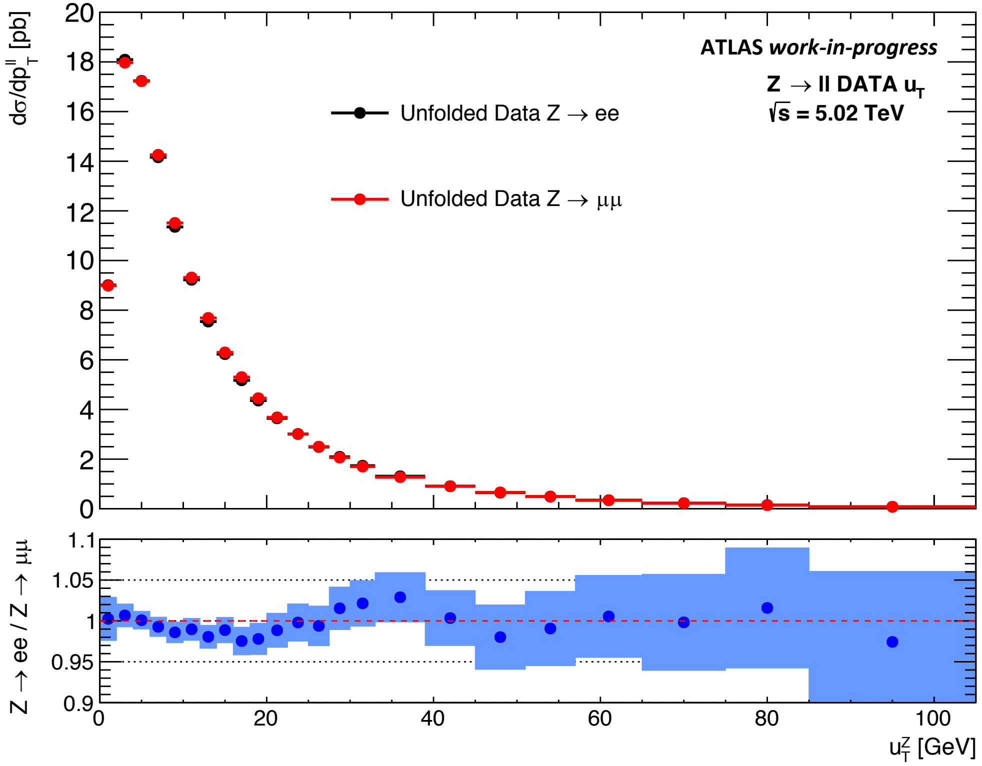
Recoil unc.

Compatibility between electron and muon channels

Di-lepton measurement



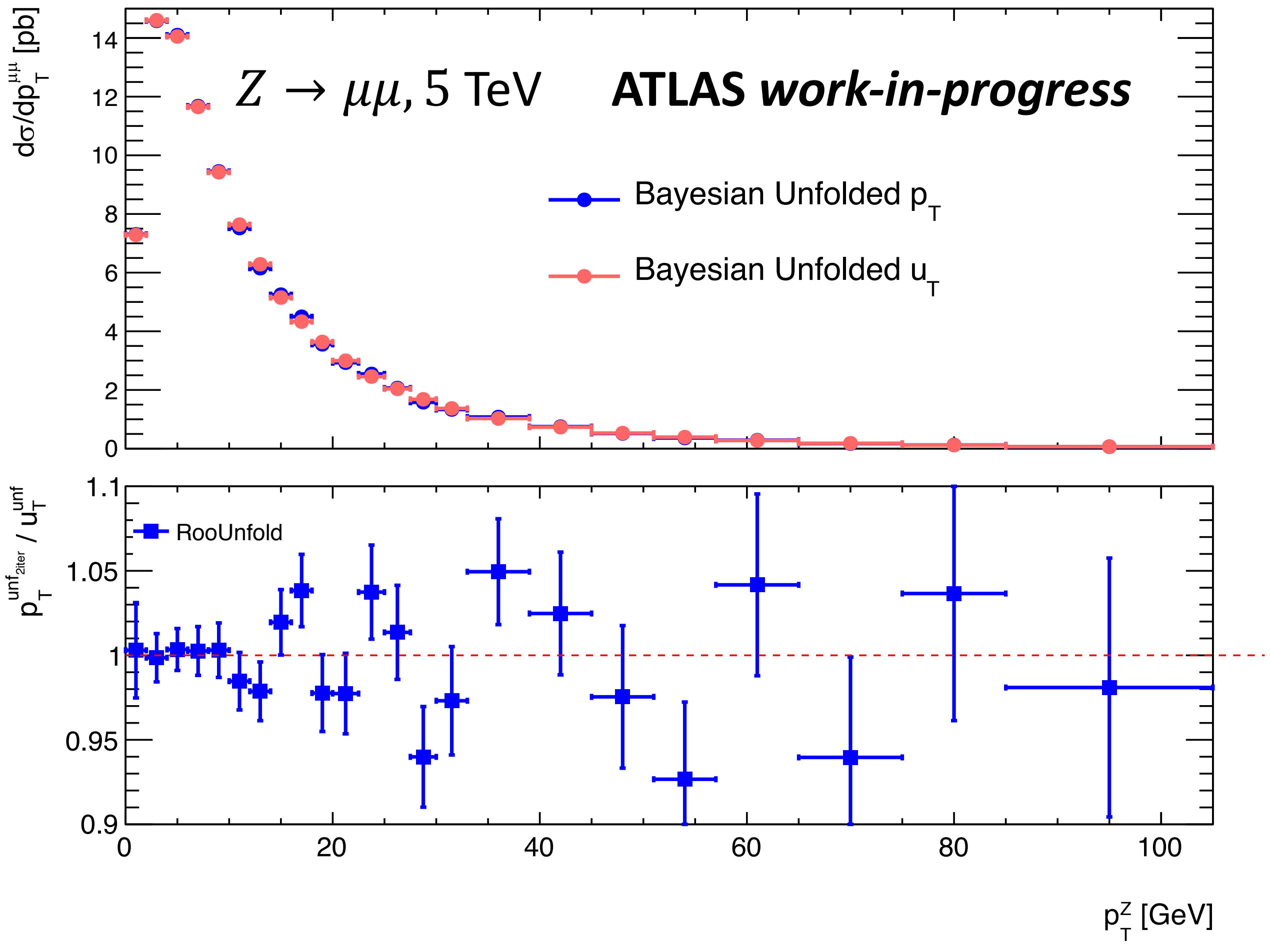
Had-recoil measurement



Good compatibility between $Z \rightarrow e^+e^-$ and $Z \rightarrow \mu^+\mu^-$ channels .

Compatibility between dilepton and u_T methods

Good compatibility between the di-lepton system and the had-recoil in p_T^Z measurement!



Good news for p_T^W measurement

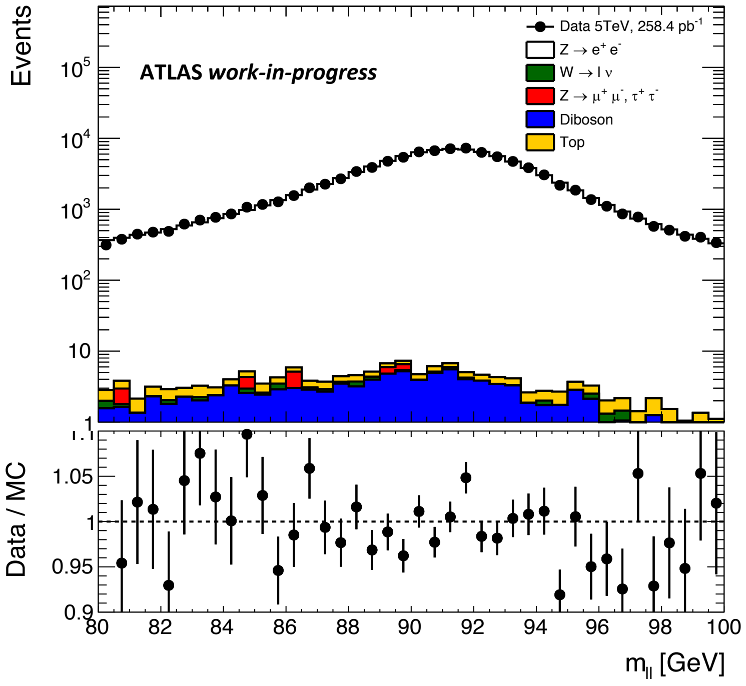
Summary

- Results of p_T^Z measurements using low-pileup dataset at 5TeV are present. This is crucial input for p_T^W / p_T^Z measurement, as well as for W mass measurement.
- The method using hadronic recoil to estimation p_T^Z is validation for p_T^W measurement.
- We plan to publish a p_T^W and p_T^Z paper for Moriond 2020.

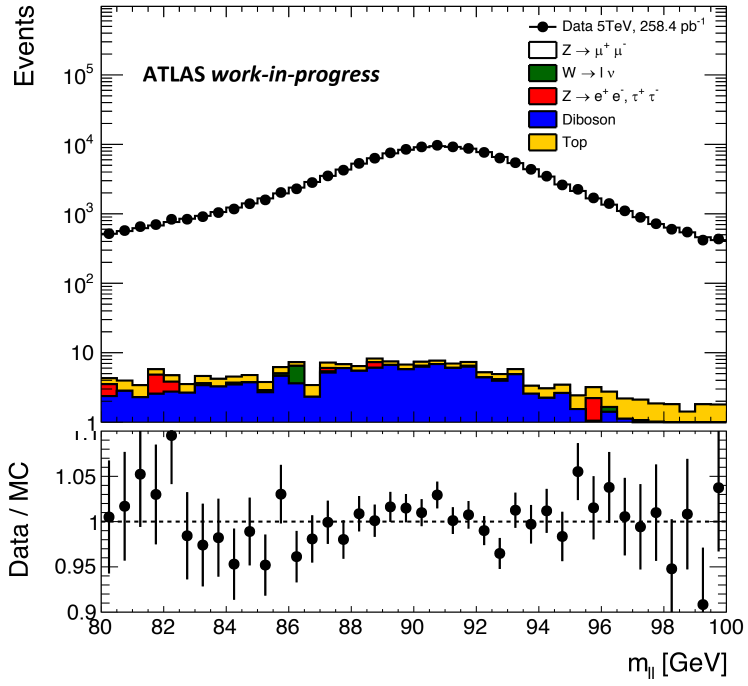
backup

Backgrounds estimation

5TeV $Z \to e^+e^-$



5TeV $Z \to \mu^+\mu^-$



	$Z \to ee$	VV->llll	top	$Z \to \tau\tau$	$W \to l\nu$
#events	51755	70	36	23	4
Frac. [%]	99.74%	0.13%	0.07%	0.04%	0.007%

	$Z \to \mu\mu$	VV->llll	top	$Z \to \tau\tau$	$W \to l\nu$
#events	51755	70	36	23	4
Frac. [%]	99.74%	0.13%	0.07%	0.04%	0.007%

Selections and yield

Electron ID:

- Trigger:HLT_e15_lhloose_nod0_L1EM12
- Medium electrons
- p_T^e> 25 GeV
- $|\Delta z0|$ < 0.5 and $|d0/\sigma|$< 5;
- $|\eta|$ < 2.47; $|\eta|$ ≤ 1.37 or $|\eta|$ ≥ 1.52
- ptvarcone20/ p_T^e < 0.1

Muon ID:

- trigger HLT_mu14
- p_T^μ>25 GeV
- |Δz0|<0.5 and|d0/σ|<3
- |η|<2.4
- ptvarcone20/ p_T^μ < 0.1

Z reconstruction selection

- 2 opposite sign electrons/muons
- 66 GeV < m_{ll}< 116 GeV

yield	5 TeV	13 TeV
$Z \to e^+e^-$	52 K	165 K
$Z \to \mu^+\mu^-$	70 K	214 K

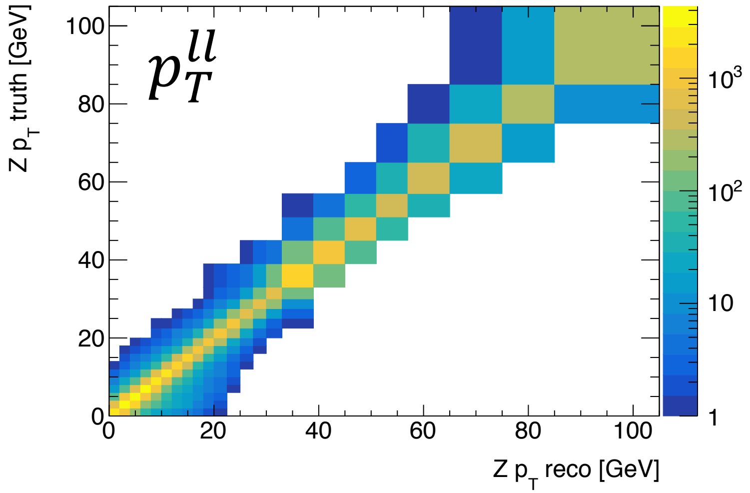
Overview of the lepton corrections

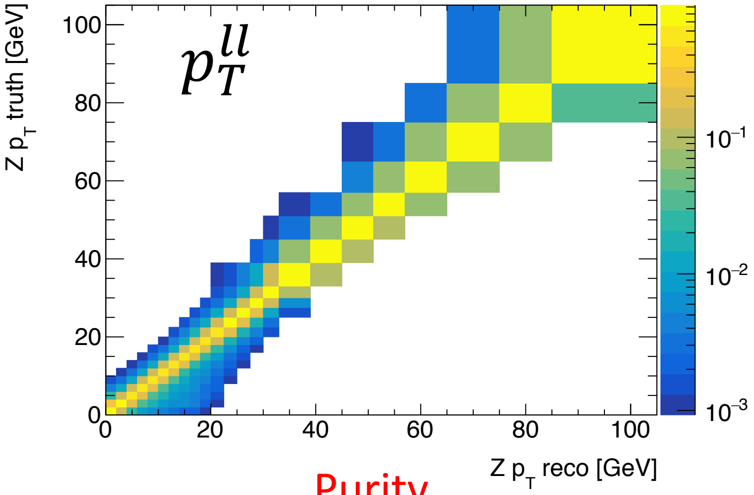
	derived in low-μ data	high-μ data extrapolated
electron calibration	separate for 5 and 13 TeV	
electron Reco SF		high-mu with extrapolation systematic
electron ID SF	separate for 5 and 13 TeV	
electron Iso SF	combining 5 and 13TeV SF	
electron Trigger SF	combining 5 and 13TeV SF	
Muon calibration		high-mu
Sagitta bias	custom, derived with low-μ 13TeV only	
Muon Reco SF		high-mu with extrapolation systematic
Muon TTVA	split into 5TeV and 13 TeV (2017+2018 combined)	
Muon Iso SF	split into 5TeV and 13 TeV (2017+2018 combined)	
Muon Trigger SF	split into 5TeV and 13 TeV (2017+2018 combined)	

details of the low-mu lepton correction in the first EB meeting

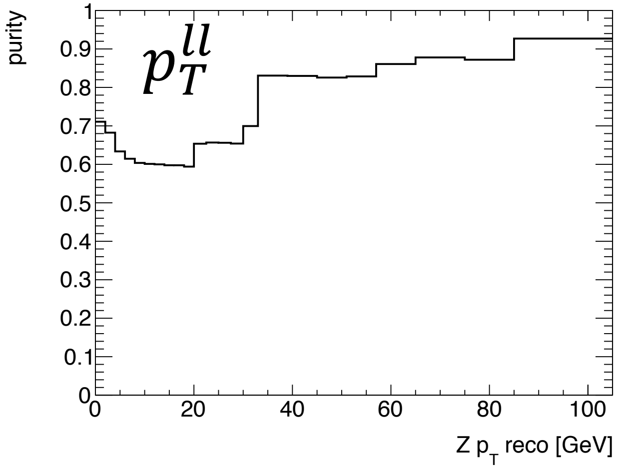
Migration and purity for 5 TeV $Z \rightarrow e^{+}e^{-}$

Less bin-to-bin migrations in di-lepton measurements.



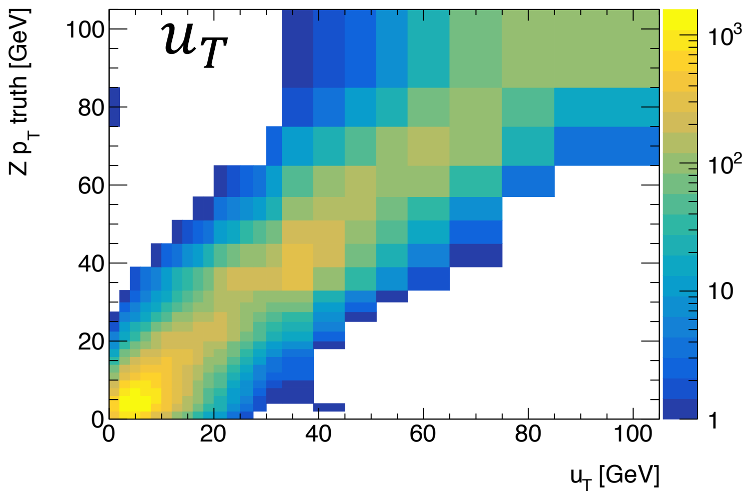


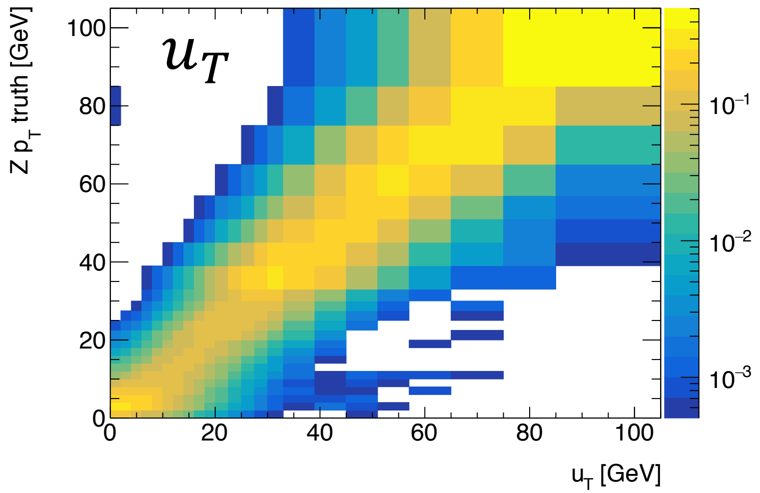
Purity

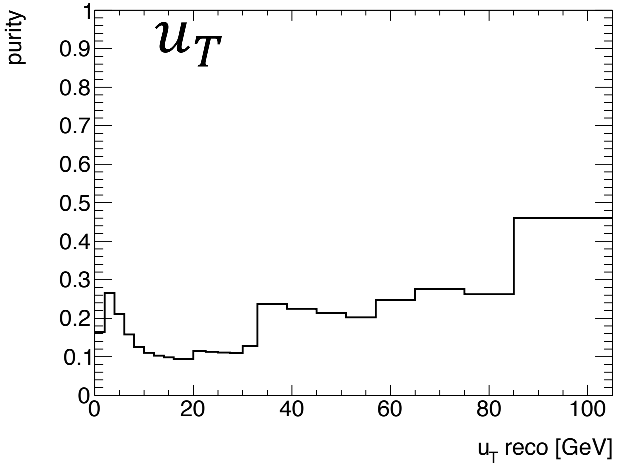


Purity

Migration matrix







Migration and purity for 5 TeV $Z \rightarrow \mu^+\mu^-$

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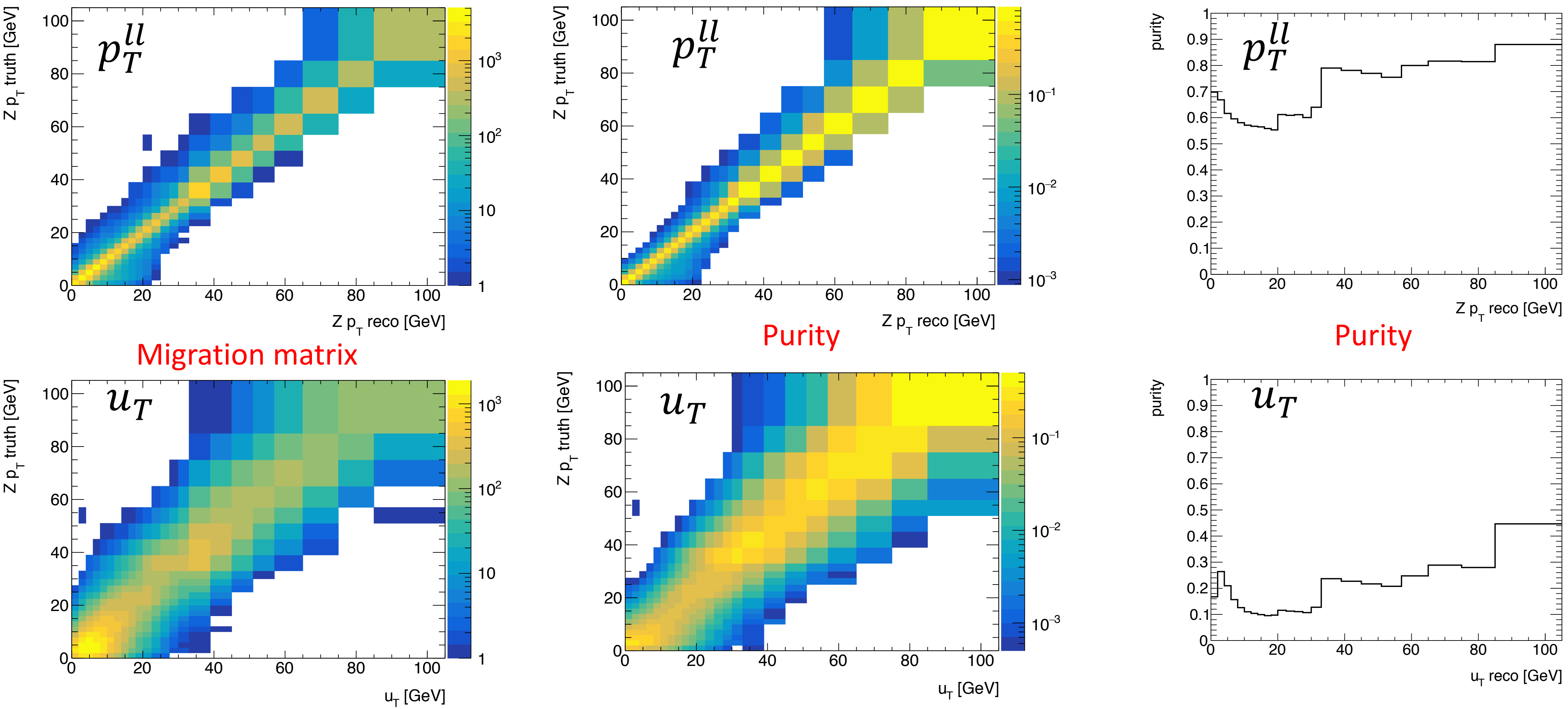
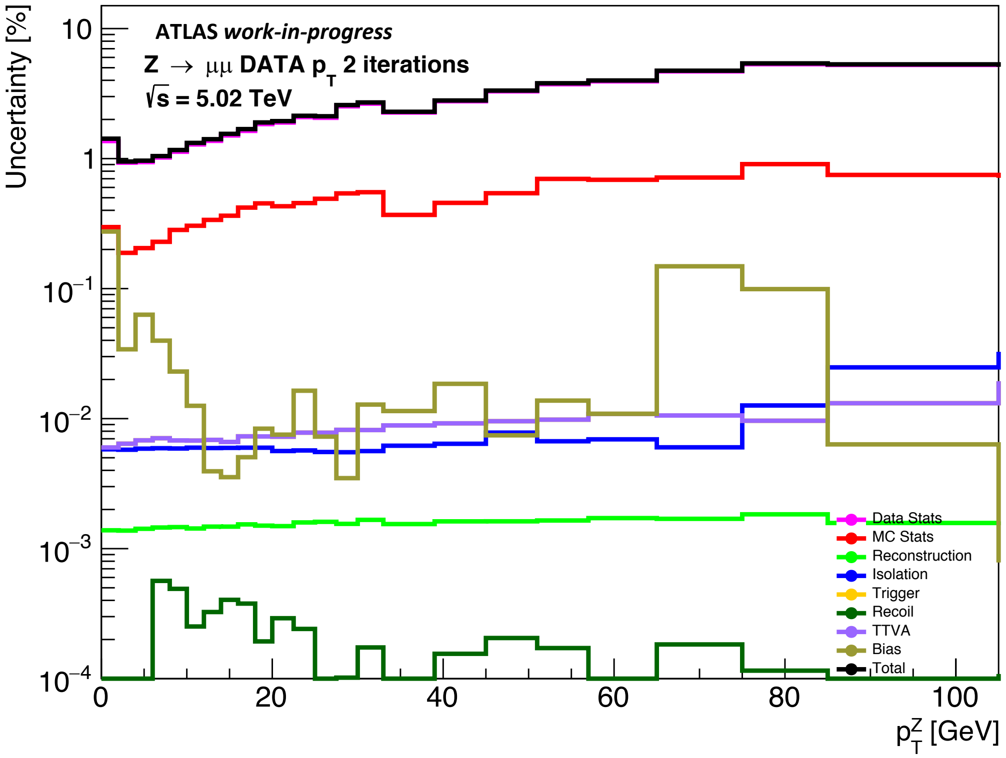
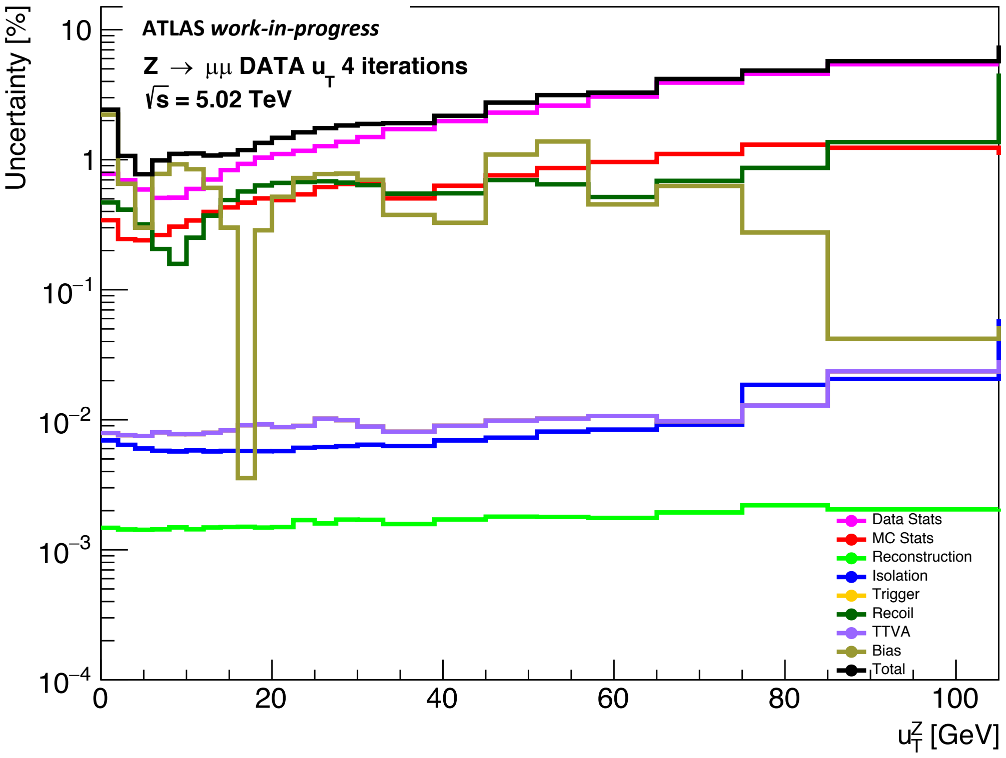


Uncertainty estimation for $Z \rightarrow \mu\mu$

Di-lepton measurement



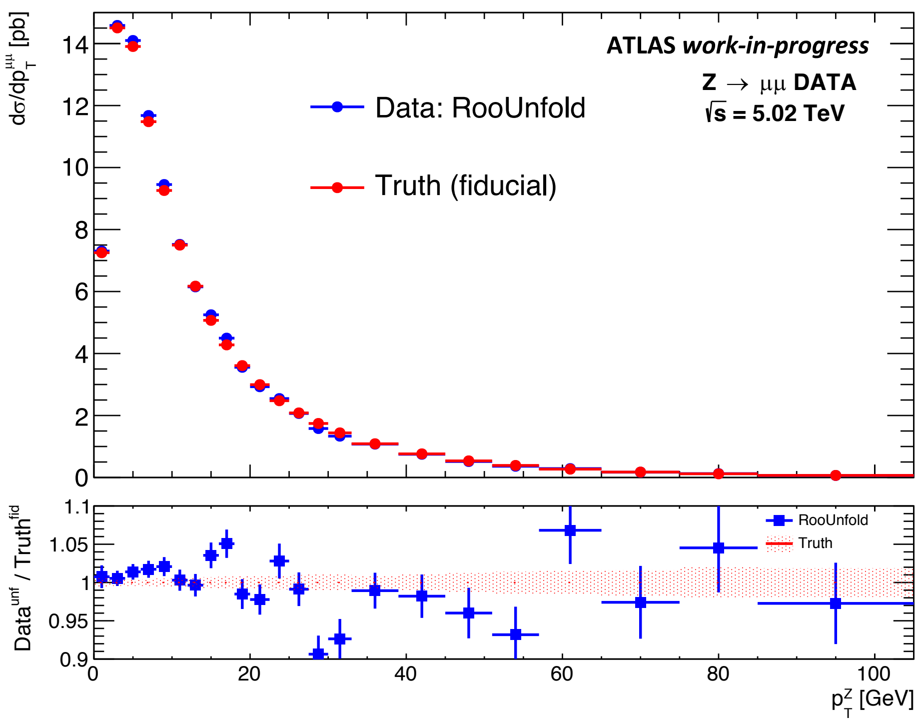
Had-recoil measurement



Due to cleanness in Z channel, the dominate uncertainty is statistic uncertainty.

p_T^Z unfolded results in $Z \to \mu\mu$ channel

Di-lepton measurement



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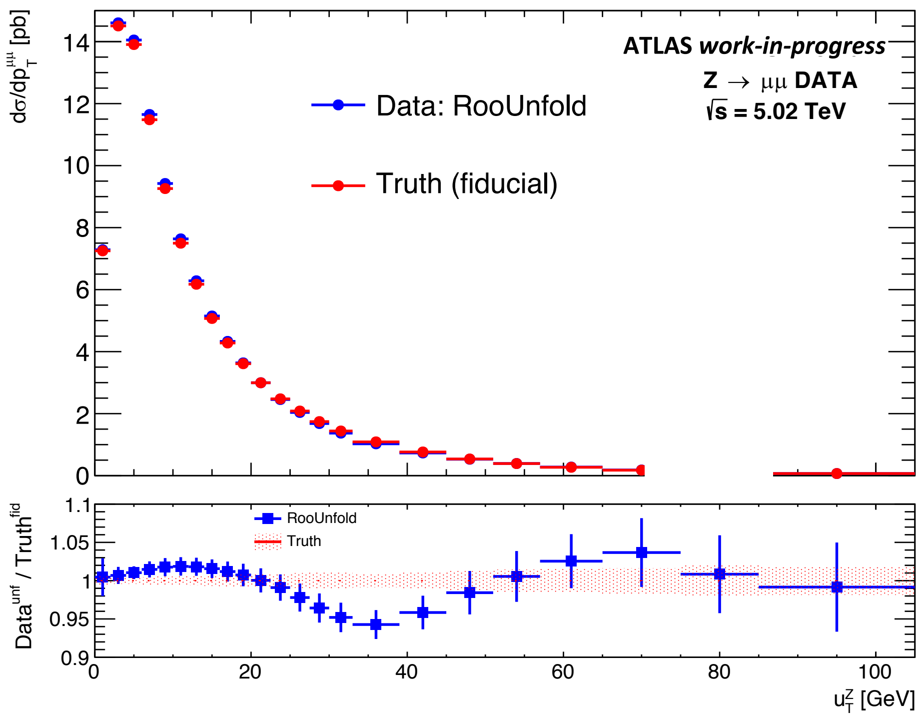
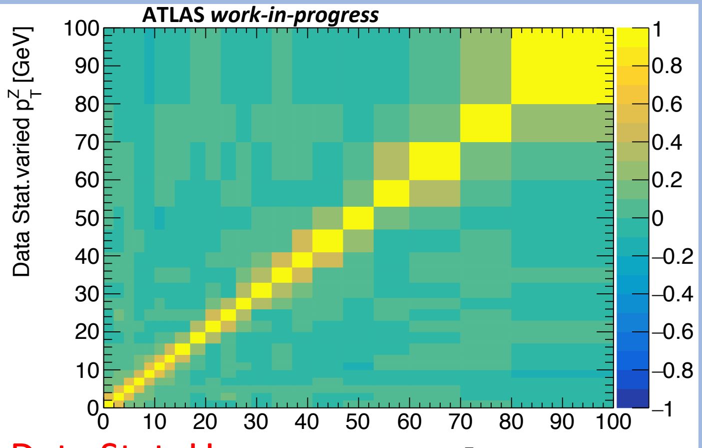
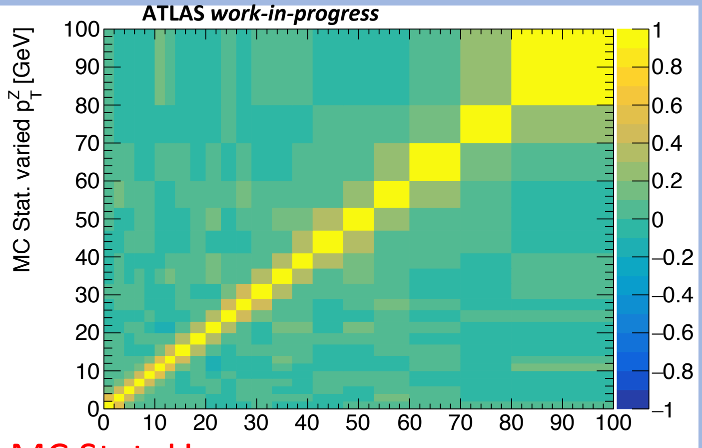


u_T is highly correlated bin by bin

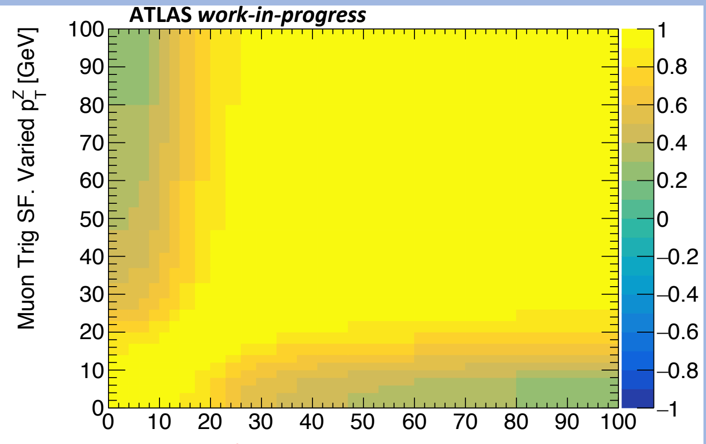
Correlations in $Z \rightarrow \mu\mu$ channel



Data Stat. Unc.



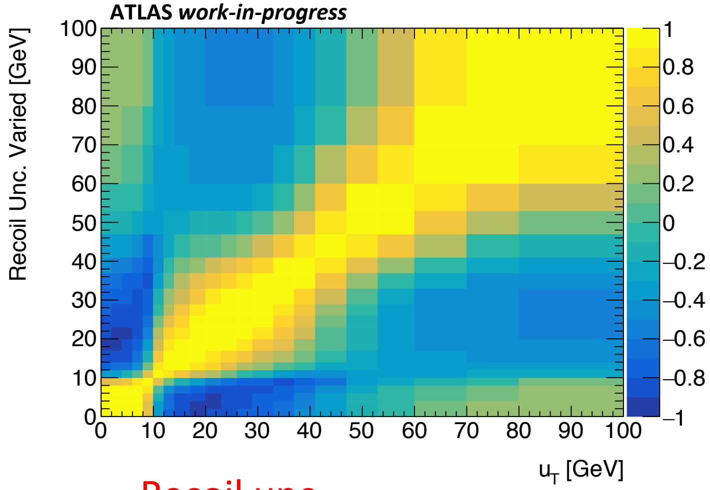
MC Stat. Unc.



Muon trigger SF Unc.

p_T^{ll} is totally uncorrelated

u_T is highly correlated bin by bin



Recoil unc.