Performance of the hadronic recoil in precision W boson measurements with low pileup dataset

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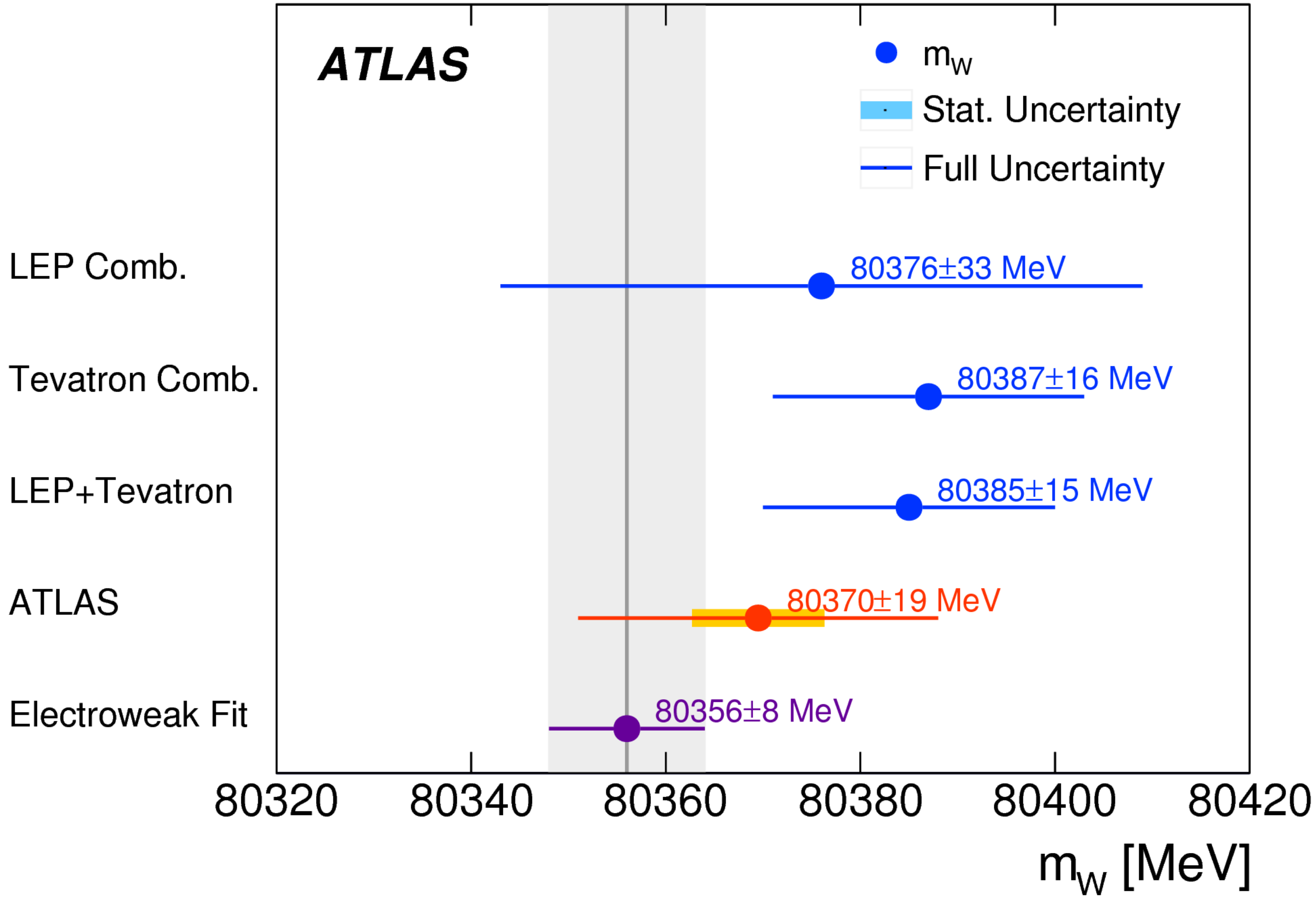
ATLAS EXPERIMENT

Outline

- Status and future of W Mass Measurements
- Introduction
- Dataset
- Hadronic recoil reconstruction
- Motivation for selections on particle flow object entering recoil
- Performance of recoil with different kinematic cuts
- Summary

Status and future of W boson mass measurements



ATLAS low pileup run:

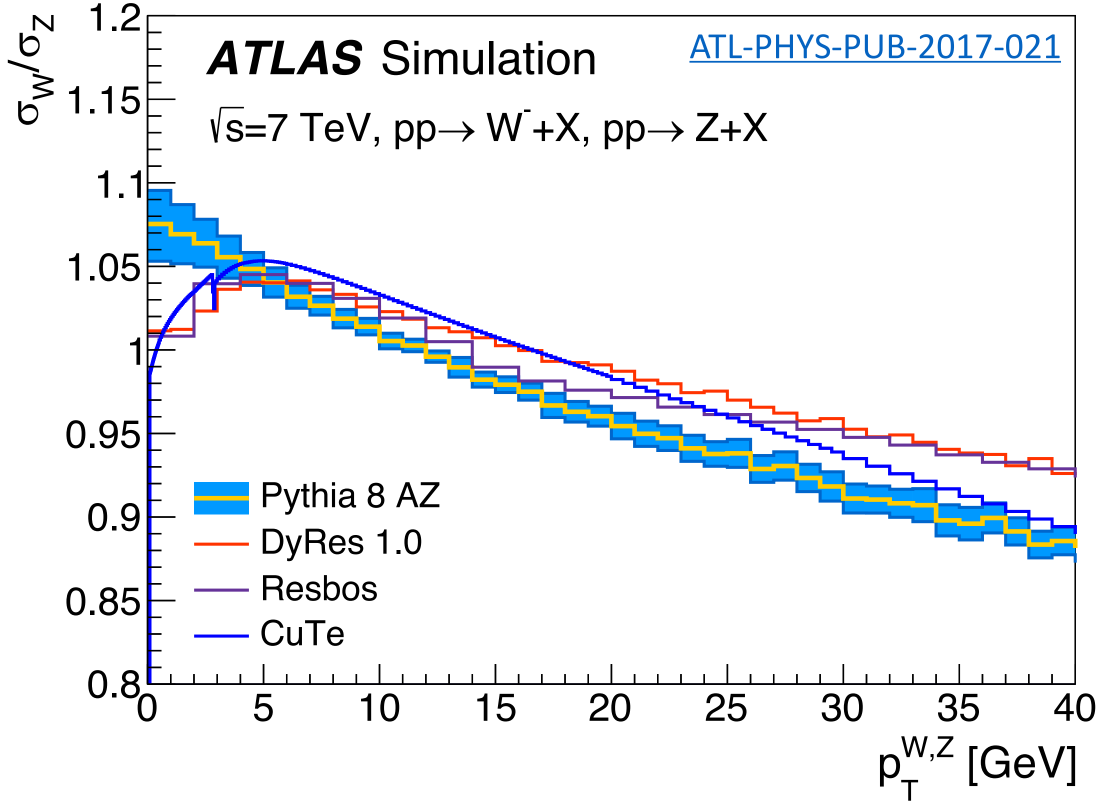
ΔM = 15~20 MeV

CEPC CDR arxiv:1811.10545

CEPC: ΔM = 1 ~ 3 MeV

Motivation for W boson transverse momenta measurement

W/Z p_T ratio was used to model p_T^W in W boson mass measurement

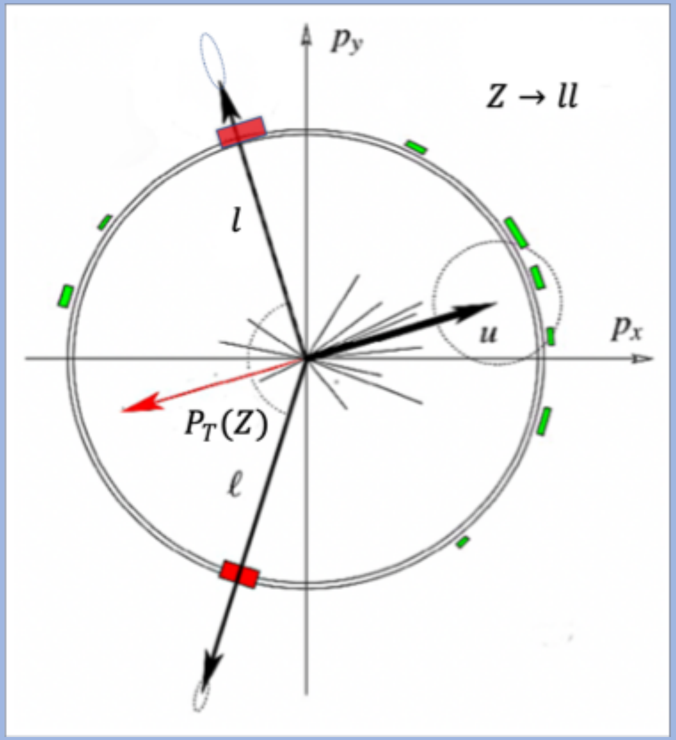


Precision measurements of p_T^W would be sensible to new physics!

W/Z p_T ratio is not well modelled at high order prediction.

Transverse momenta of W and Z boson

$\vec{p}_T^{\,Z}$ is directly reconstructed from two leptons.

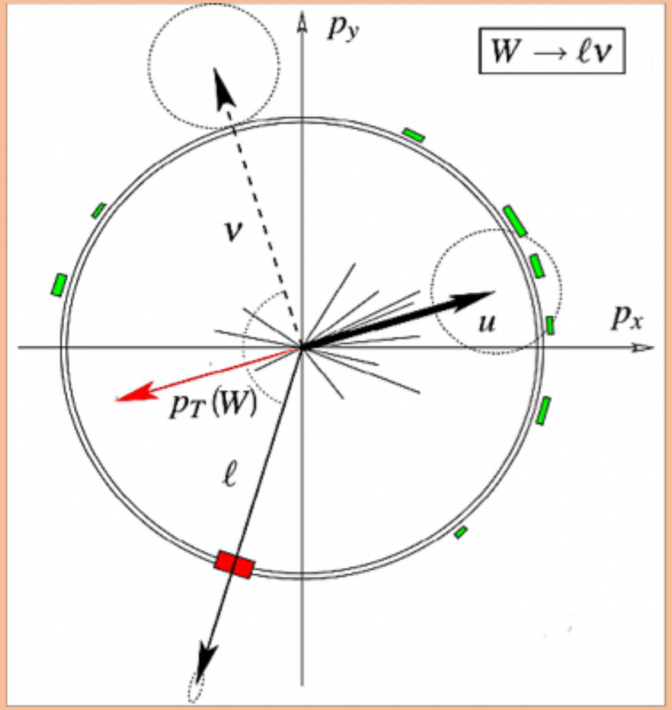


u_T is the sum of energy of the recoil in the transverse plane

$\vec{p}_T^{\,W}$ is estimated from $-\vec{u}_T$

$\vec{p}_T^{\,\nu} = -(\vec{p}_T^{\,l} + \vec{u}_T)$

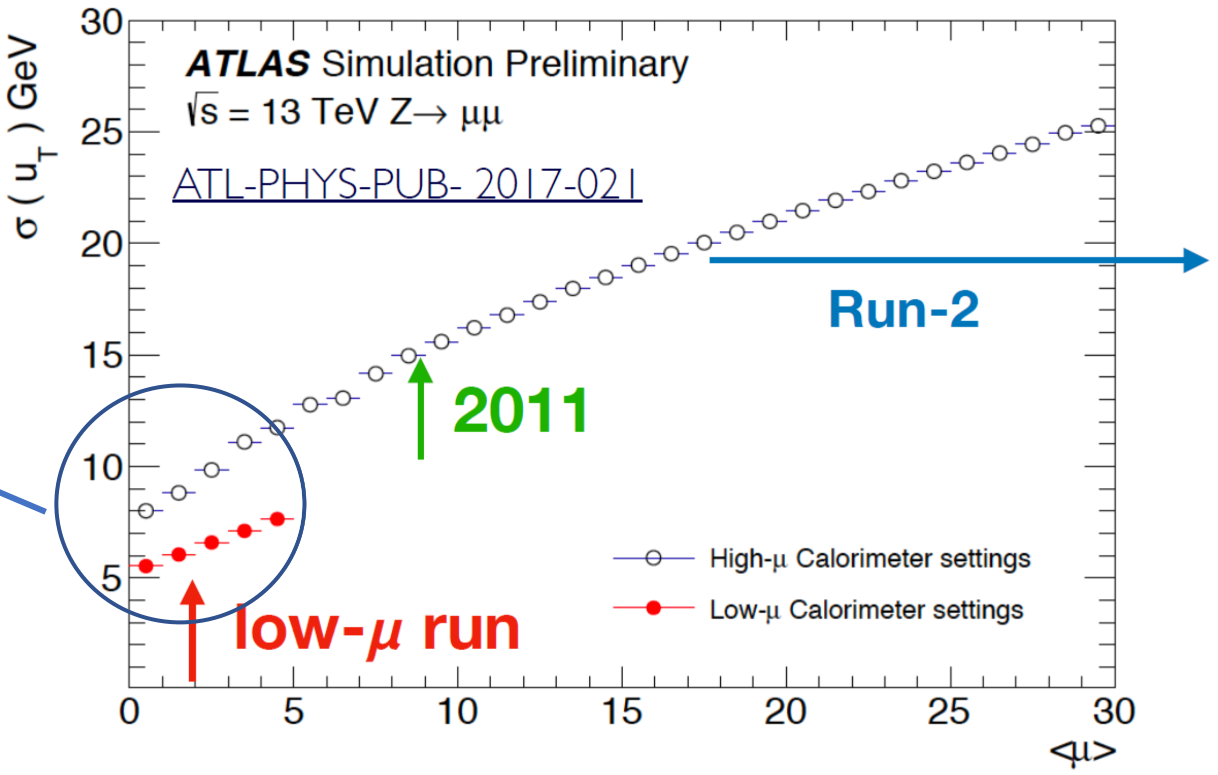
A good understanding of the $-\vec{u}_T$ is needed to reconstruct P_T^{ν} !



Pileup and precision measurement on W boson

A low pileup run is very important for W precision measurement.

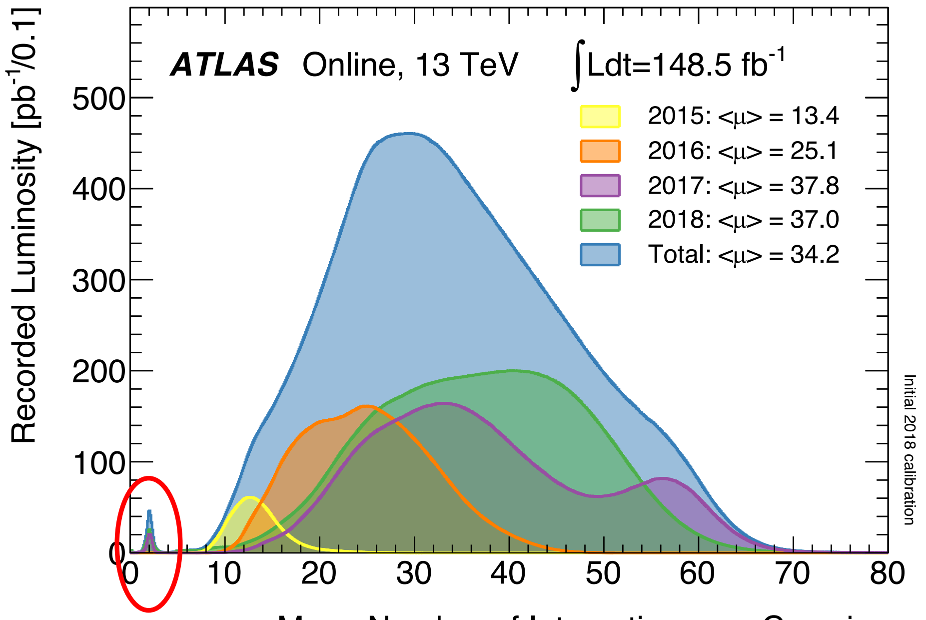
Low μ calorimeter settings improves hadronic recoil resolution ~1.5



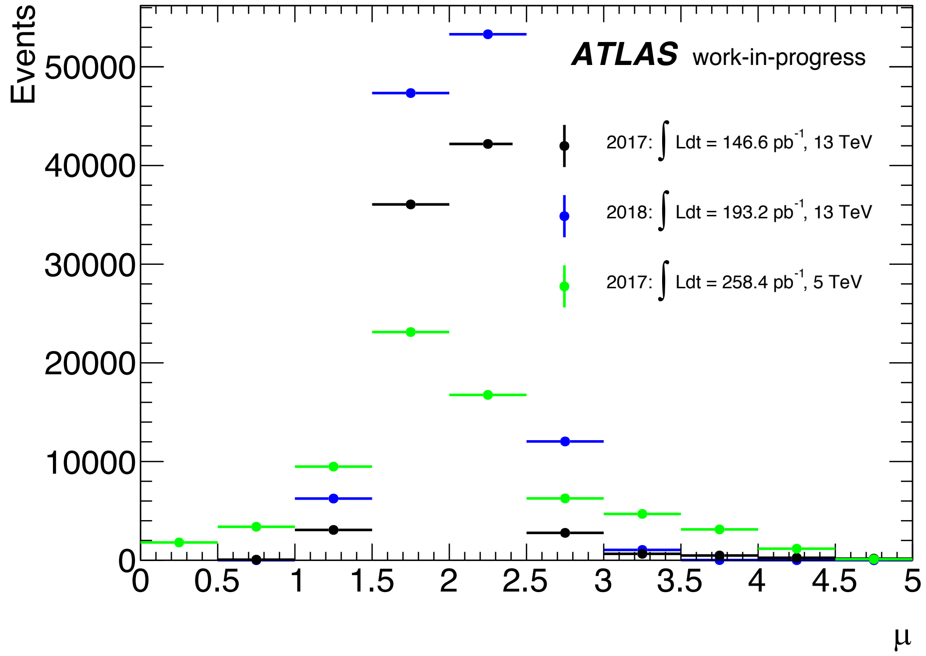
Pileup degrades the resolution of recoil measurement

Dataset

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/



2017 November



2018 July

2017 data was used for optimization

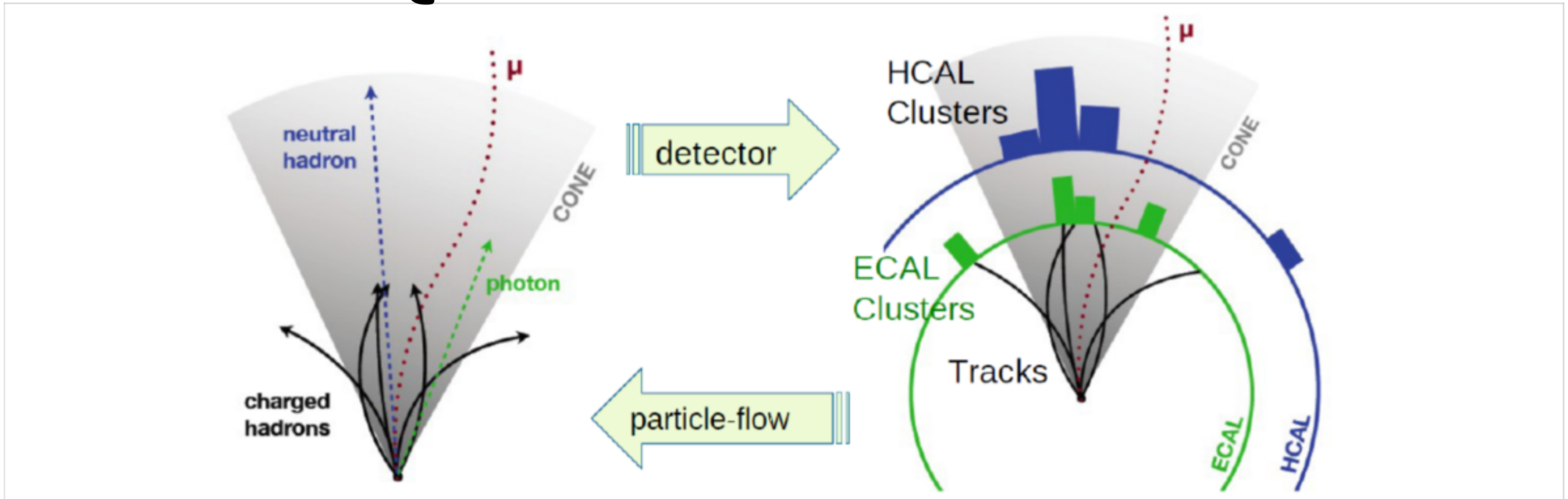
$258.4\ pb^{-1}$, 5 TeV
$146.6\ pb^{-1}$, 13 TeV

$193.2\ pb^{-1}$, 13 TeV

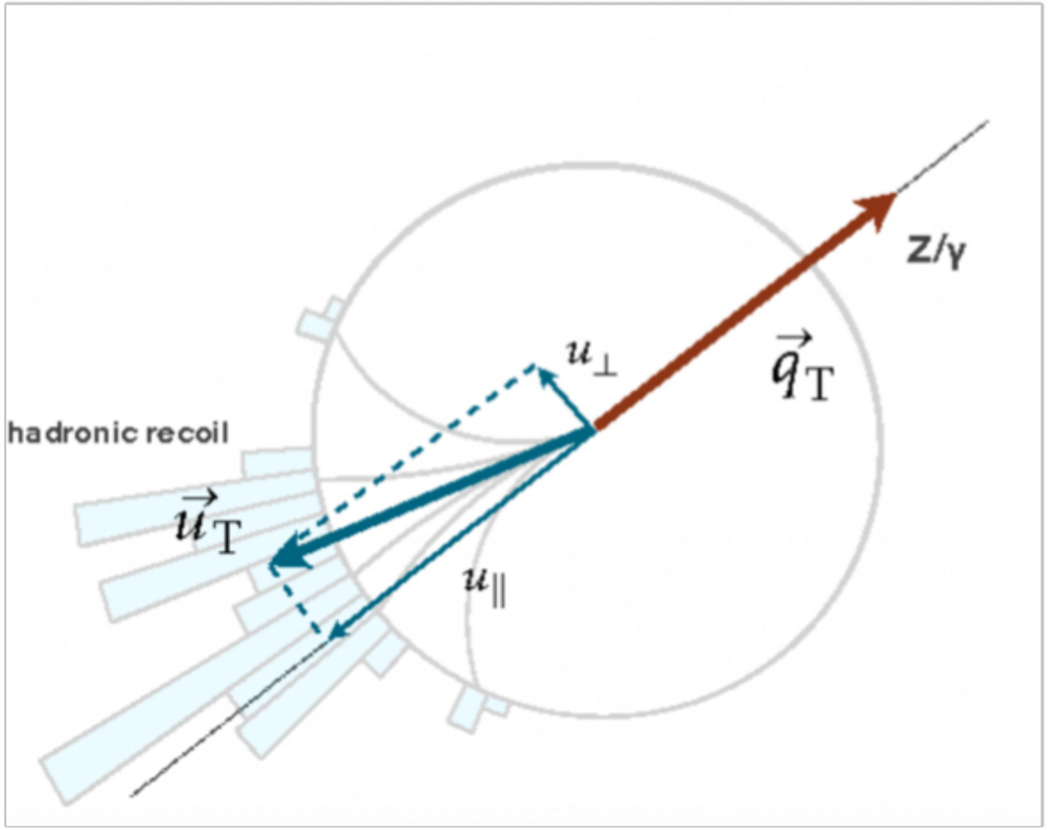
Hadronic recoil reconstruction

Hadronic recoil, $\vec{u}_T = \sum_i \vec{E}_{T,i}^{PFOs}$ is reconstructed using particle flow objects (PFOs)

PFO
- Charged: tracks associated to the primary vertex
- Neutral: clusters in electromagnetic calorimeter



Definition for $u_\perp$



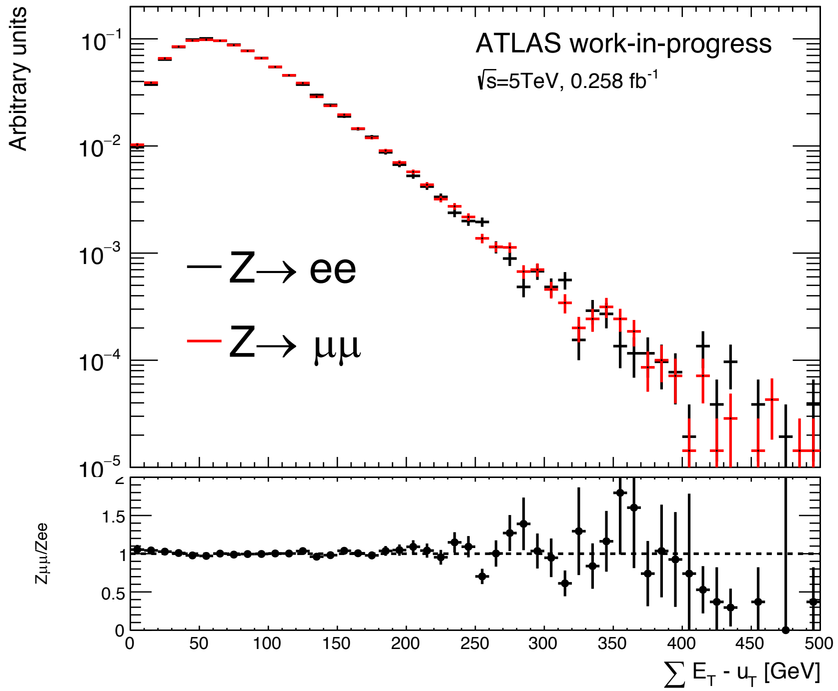
- $u_\perp$ is the projection of the recoil perpendicular to the direction of the Z boson.
- $u_\perp$ has an expected value of 0, as the recoil is by definition back-to-back with respect to the Z boson direction.
- The standard deviation of the $u_\perp$ distribution defines the resolution of the recoil.

Motivation for PFO selection optimization

- Increasing the p_T threshold would allow for better rejection of low p_T backgrounds, such as pileup or underlying event.
- The granularity of the calorimeter is coarser on the forward regions. Scanning on the $|\eta|$ acceptance may allow for better optimization.
- A scan is performed on the p_T and $|\eta|$ of the PFOs entering the recoil definition in order to achieve the best possible resolution.

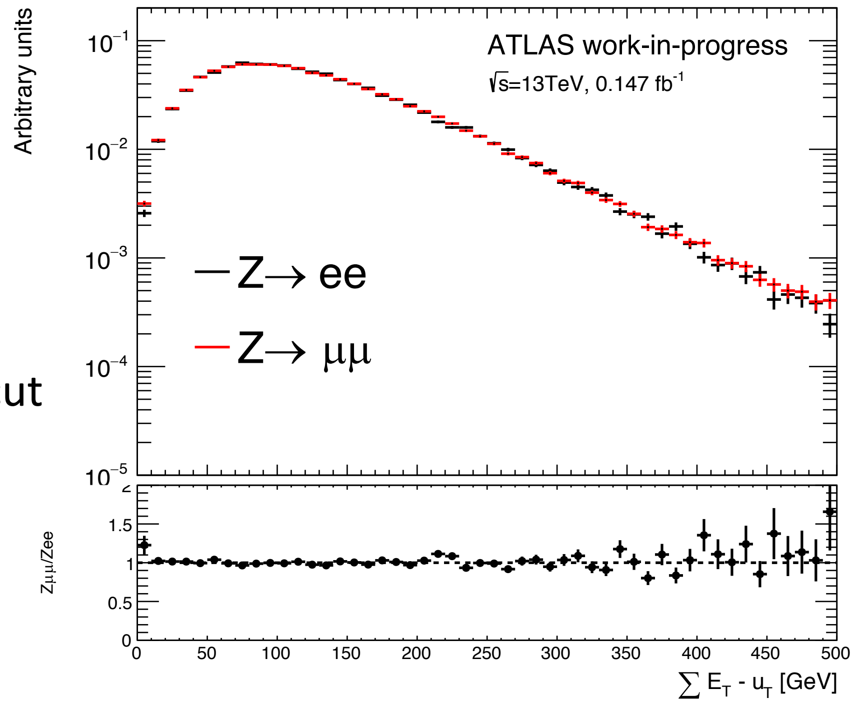
Comparison of $\sum E_T - u_T$

5 TeV



Full η, no p_T cut

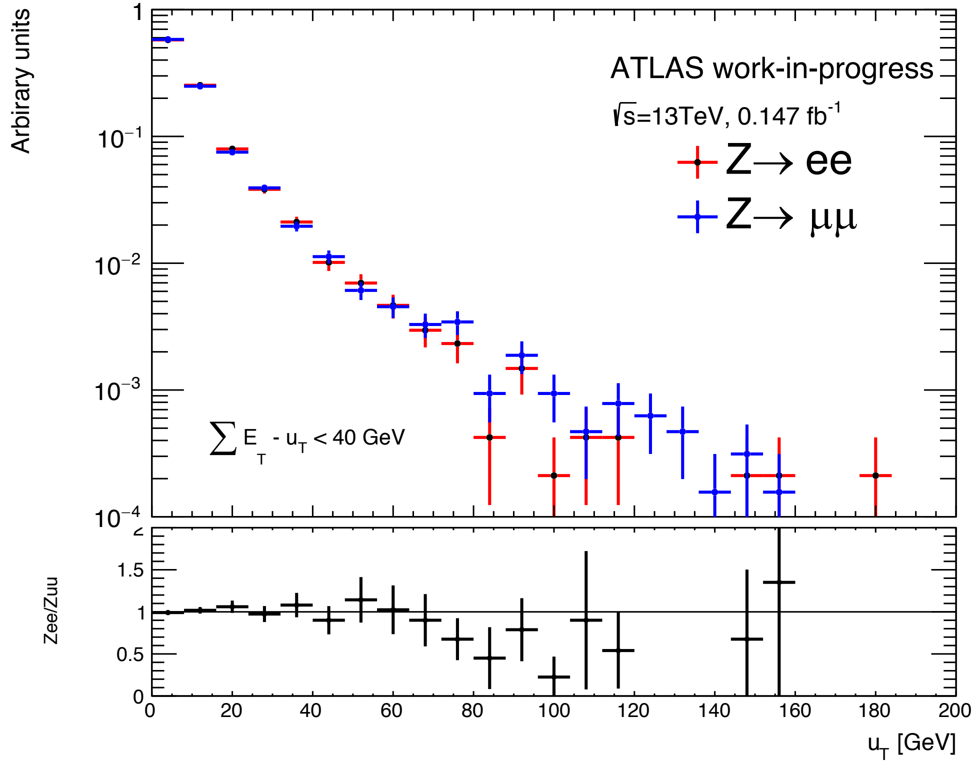
13 TeV



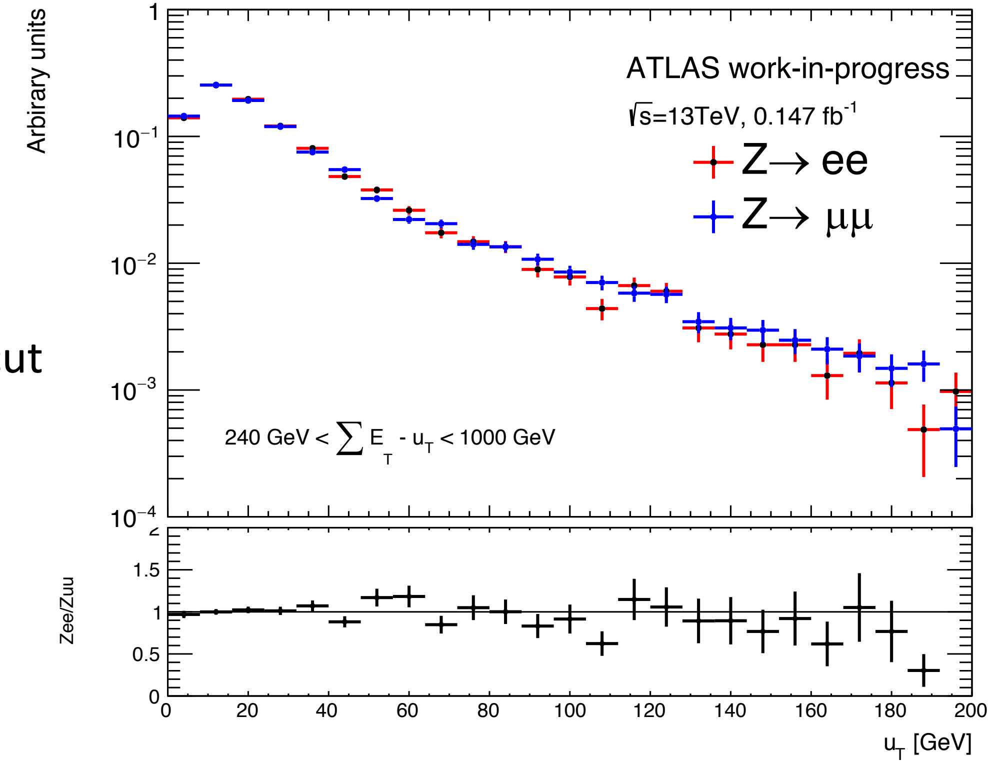
$\sum E_T - u_T$ ($\sum E_T$ sums up E_T of all PFOs except signal lepton), is sensitive to the activity of the underlying event, which degrades recoil resolution.

Comparisons of u_T

Low $\sum E_T - u_T$



High $\sum E_T - u_T$



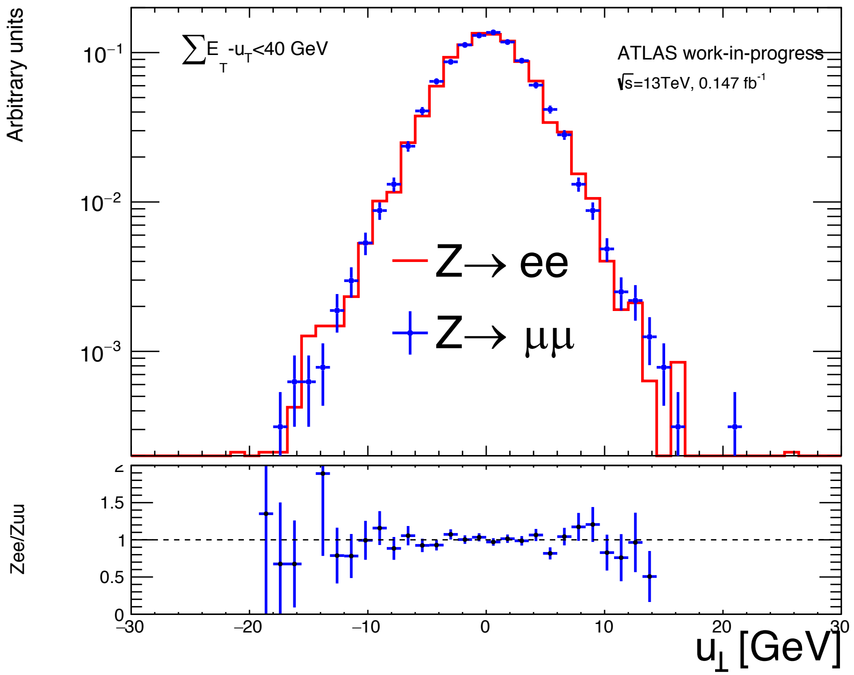
13 TeV

Full η, no p_T cut

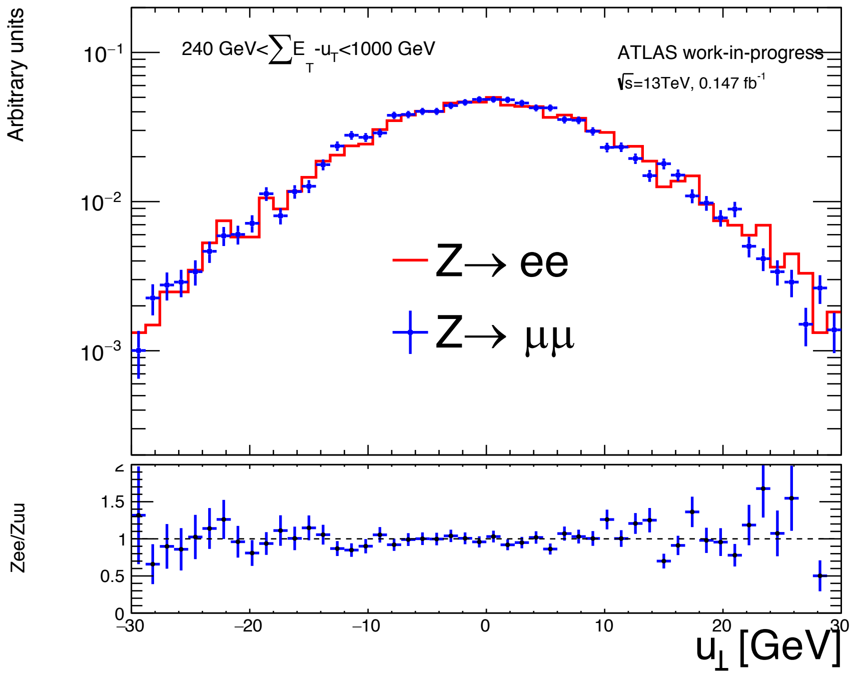
$Z \to ee$ and $Z \to \mu\mu$ are comparable in each $\sum E_T - u_T$ bins.

Comparisons of $u_{\perp}$

Low $\sum E_T - u_T$



High $\sum E_T - u_T$



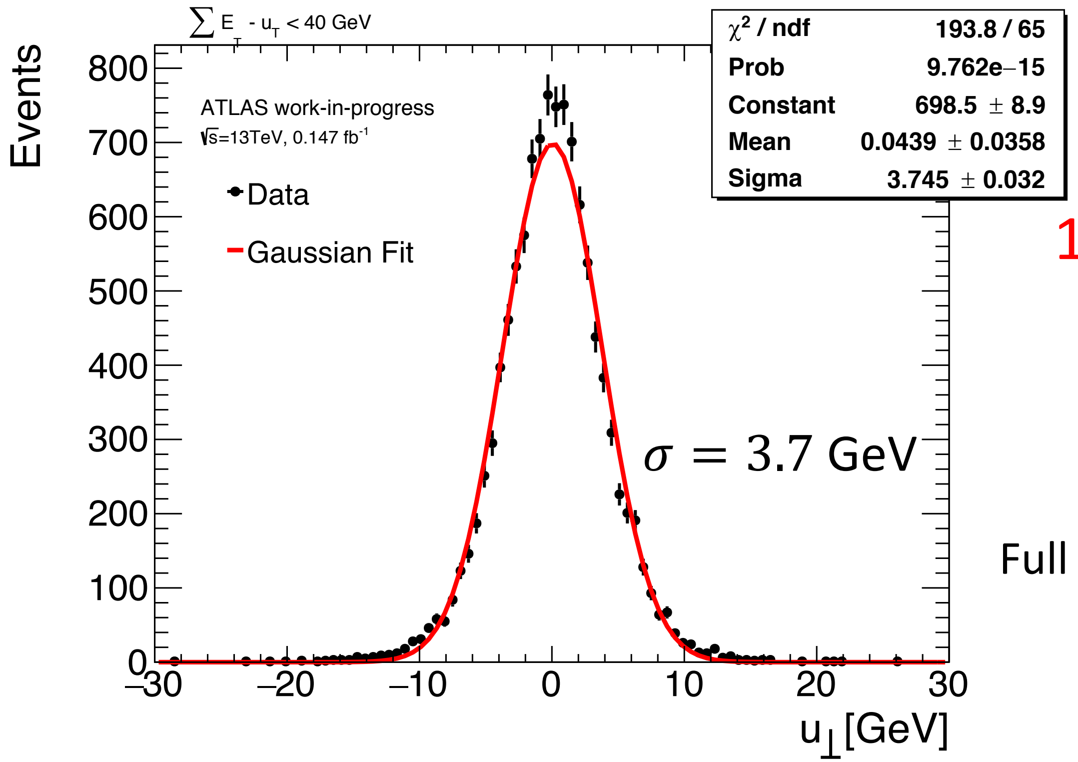
13 TeV

Full η, no p_T cut

Since $Z \rightarrow ee$ and $Z \rightarrow \mu\mu$ have the same u_T and $u_{\perp}$ distribution, we combined $Z \rightarrow ee$ and $Z \rightarrow \mu\mu$ channels in the following study.

Width of $u_\perp$ grows with $\sum E_T - u_T$

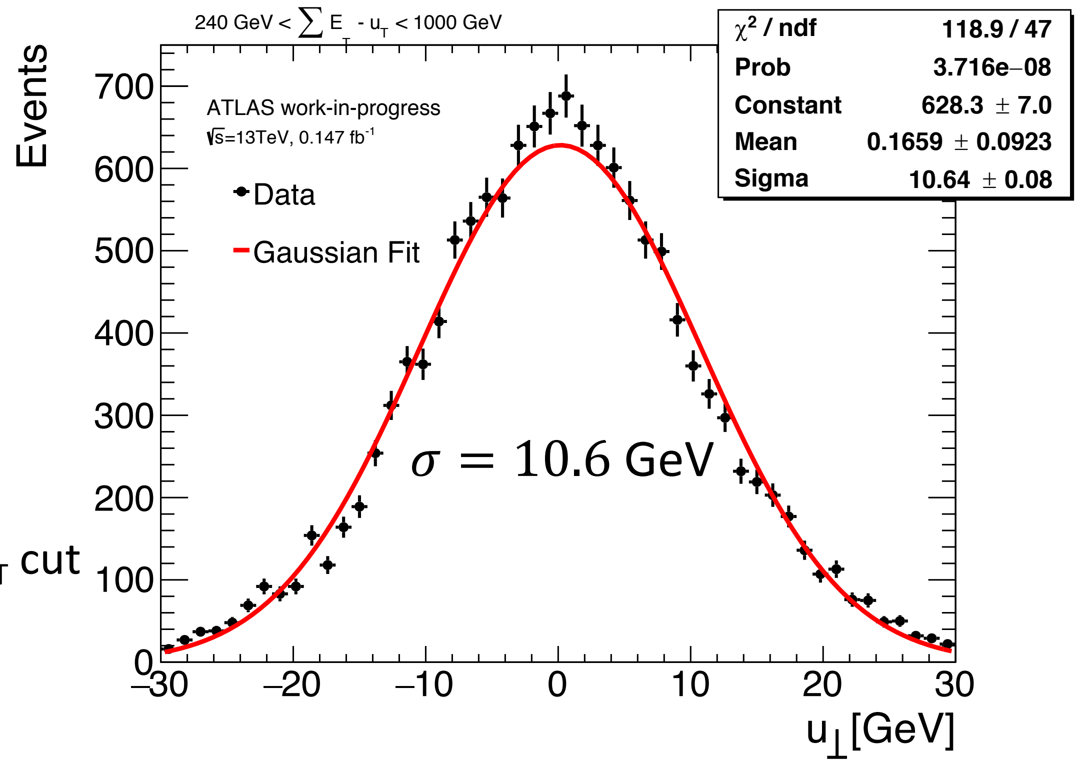
Low $\sum E_T - u_T$



13 TeV

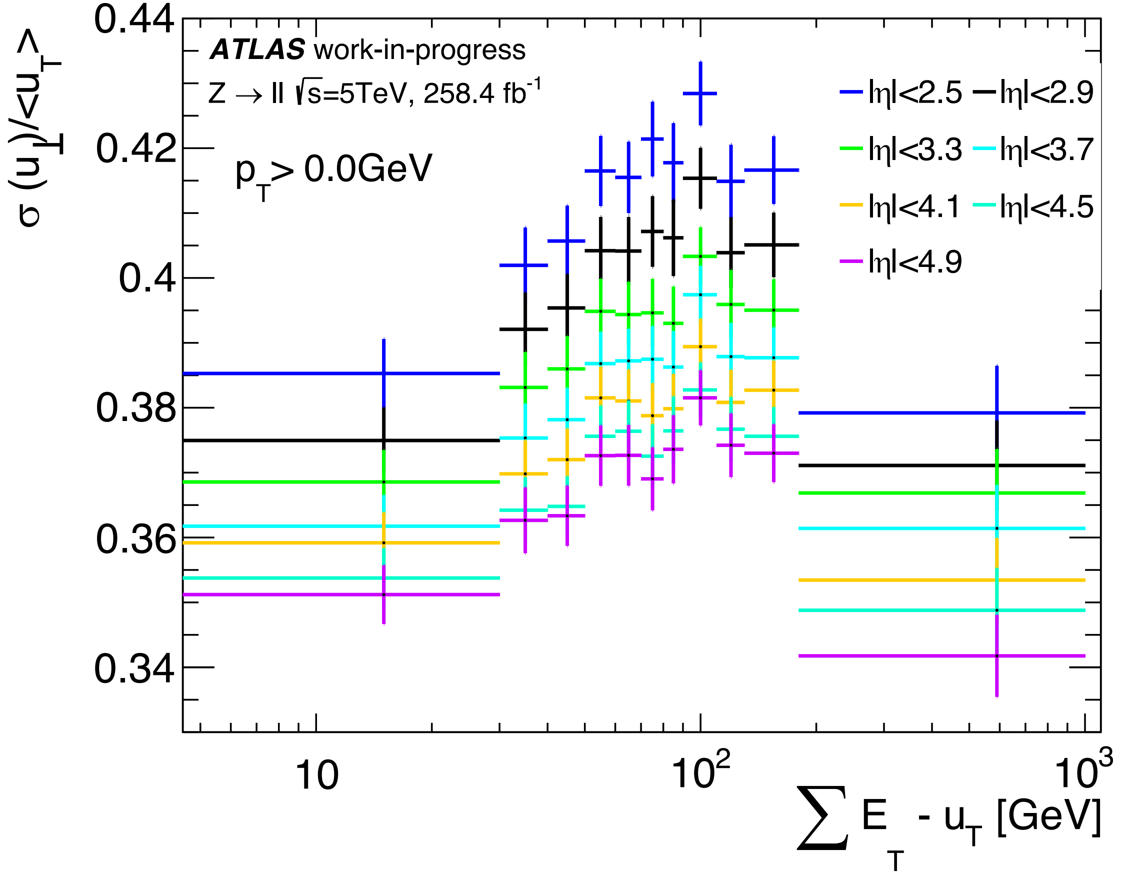
Full η, no p_T cut

High $\sum E_T - u_T$



The width of $u_\perp$ grows with $\sum E_T - u_T$. It is sensitive to the activity of the underlying event, which degrades recoil resolution.

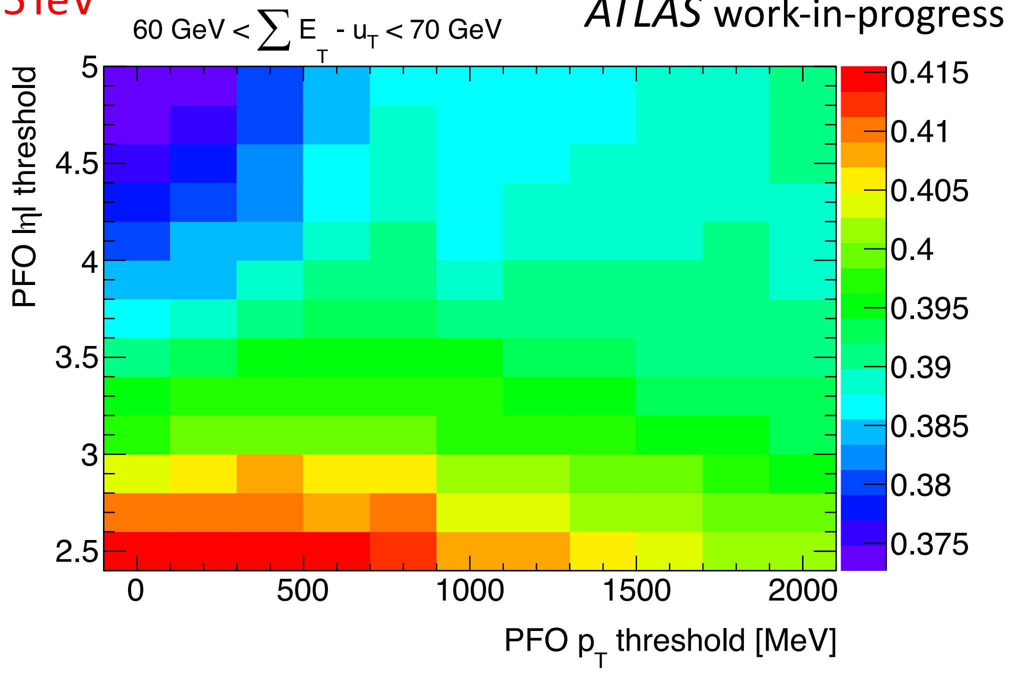
Resolutions with different η cuts on PFOs



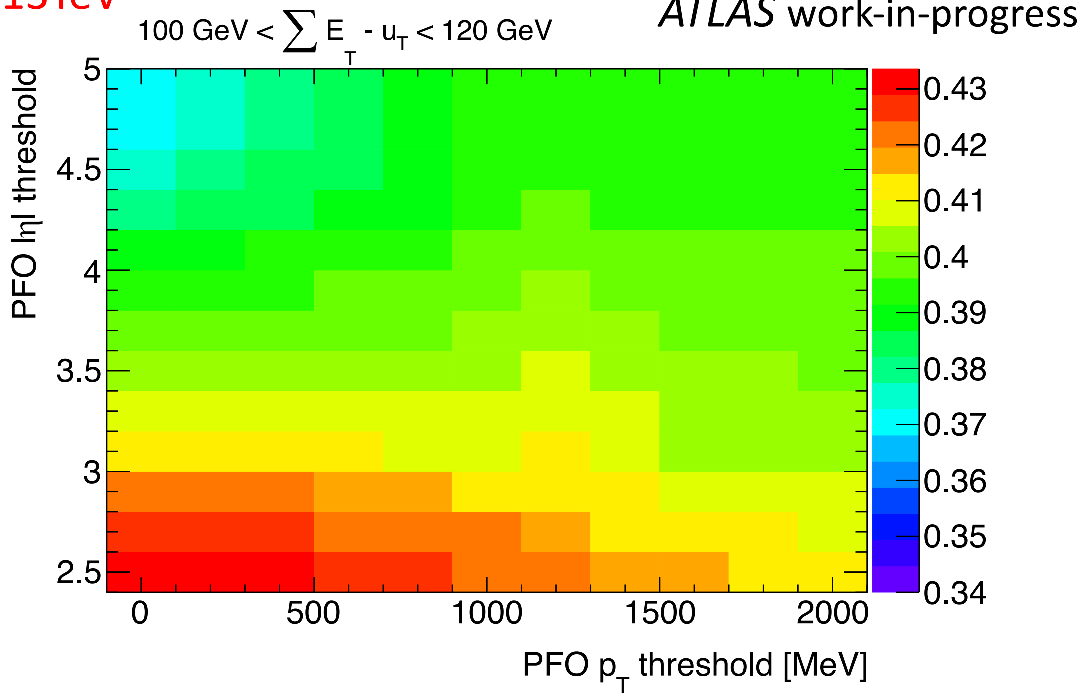
The best resolution is achieved with the full η region.

Recoil relative resolution: $\frac{\sigma(u_\perp)}{<u_T>}$

5TeV



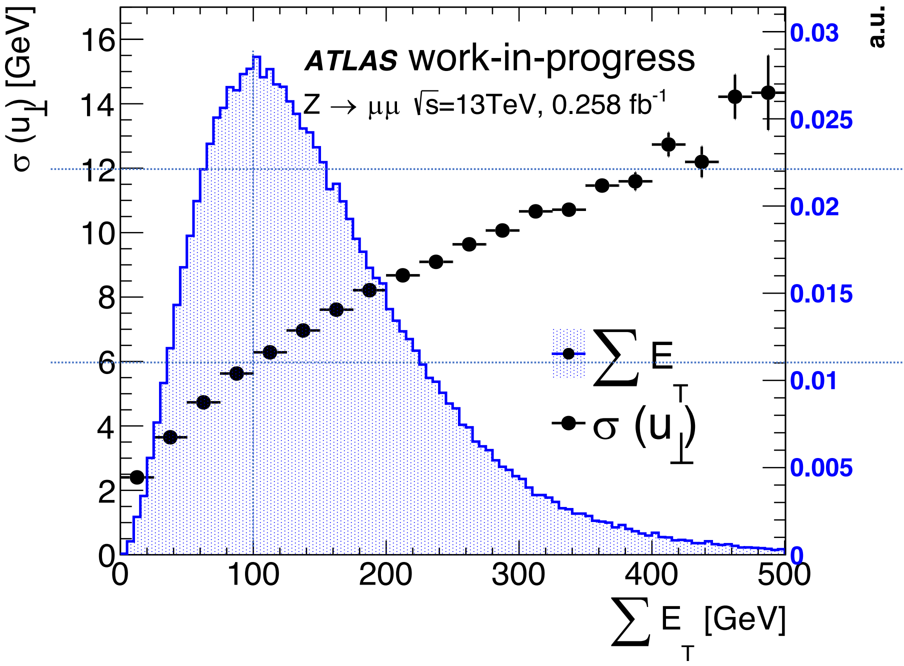
13TeV



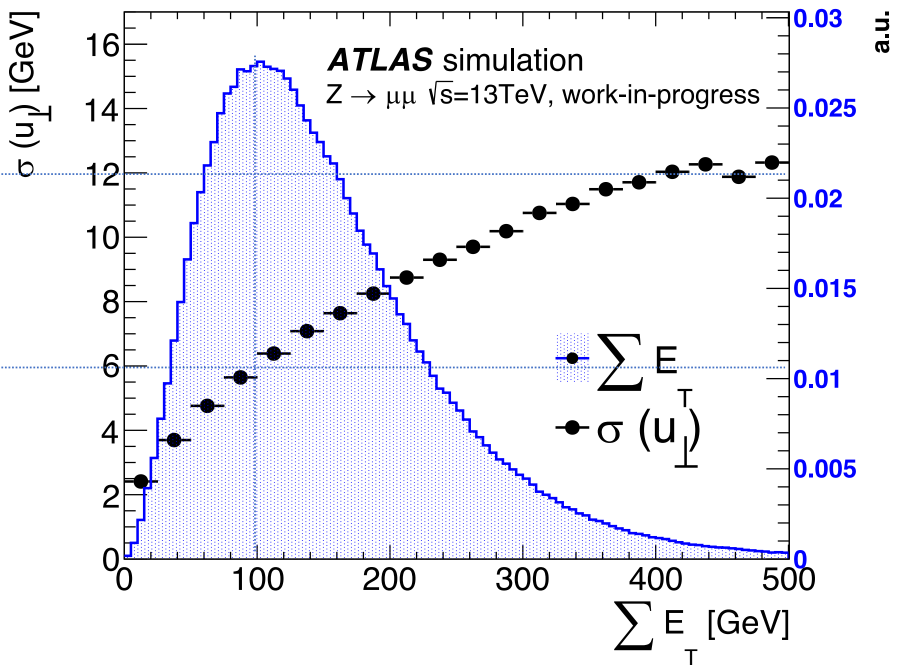
The best resolution of the hadronic recoil is achieved with p_T^{PFOs}> 0 GeV, and $|\eta^{PFOs}|$<4.9, which is the full phase space.

Data and simulation comparison of the recoil resolution

Recoil resolution with data



Resolution with Powheg+Pythia8

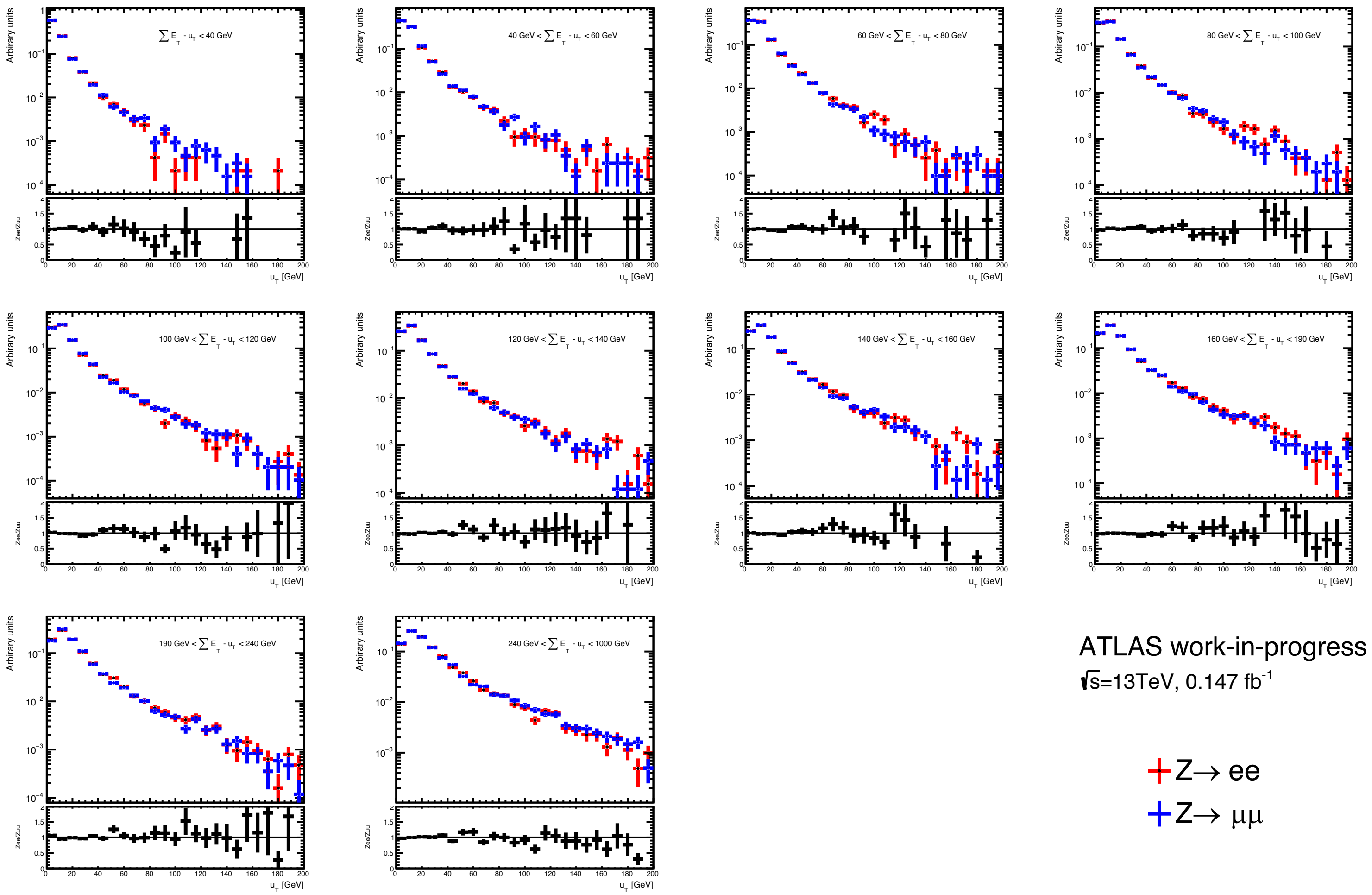


Recoil resolutions are the same between data and MC expectations

Summary

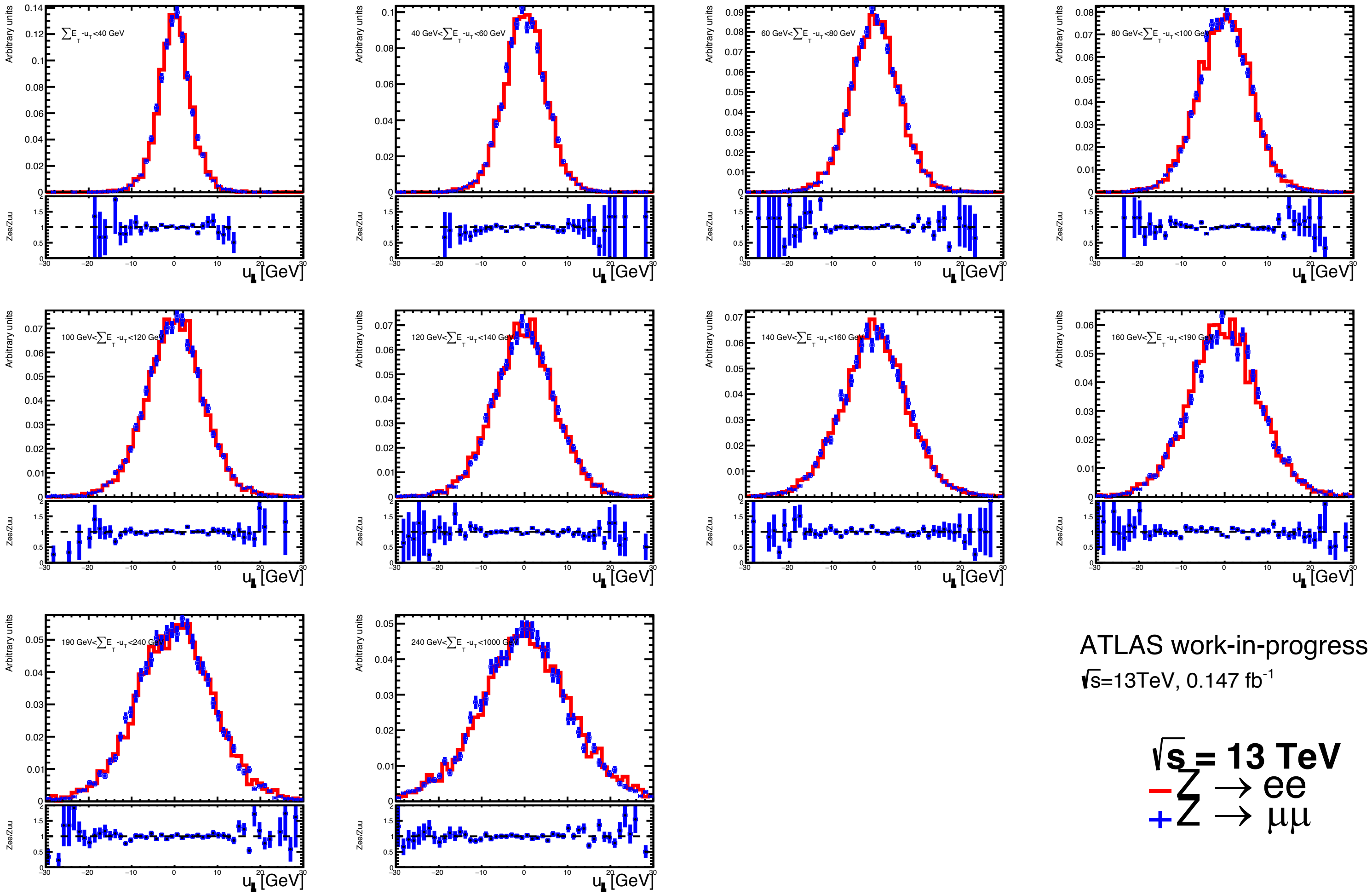
- A first study on the hadronic recoil resolution optimization with PFO algorithm with ATLAS is presented.
- The p_T and η thresholds on PFOs contained in hadronic recoil definition have been optimised within $p_{T,thres} \in [0, 2]$ GeV $\otimes$ $\eta_{thres} \in [2.5, 4.9]$. The best resolution of hadronic recoil is achieved with full phase space. ($p_{T,thres} = 0$ GeV , $\eta_{thres} = 4.9$).
- These results will be an important component in the next W boson transverse momenta and W boson mass measurements to be published.

Backup



ΣE_T - u_T < 40 GeV
40 GeV < ΣE_T - u_T < 60 GeV
60 GeV < ΣE_T - u_T < 80 GeV
80 GeV < ΣE_T - u_T < 100 GeV
100 GeV < ΣE_T - u_T < 120 GeV
120 GeV < ΣE_T - u_T < 140 GeV
140 GeV < ΣE_T - u_T < 160 GeV
160 GeV < ΣE_T - u_T < 190 GeV
190 GeV < ΣE_T - u_T < 240 GeV
240 GeV < ΣE_T - u_T < 1000 GeV
Arbitrary units
Zee/Zuu
u_T [GeV]
ATLAS work-in-progress
√s=13TeV, 0.147 fb^-1
Z→ ee
Z→ μμ

Backup

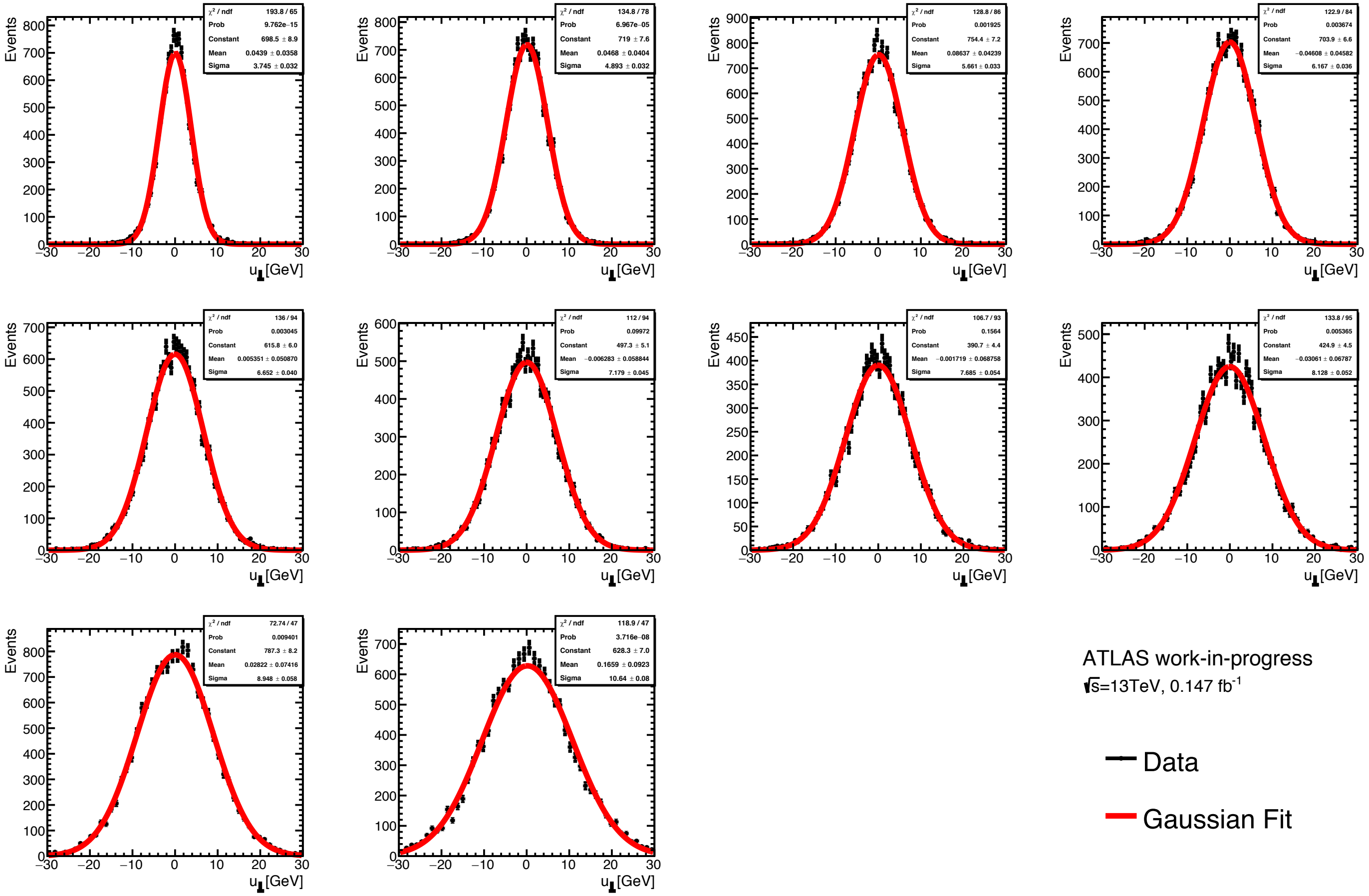

Arbitrary units
Zee/Zμμ
u∥ [GeV]
ATLAS work-in-progress
√s=13TeV, 0.147 fb⁻¹
√s = 13 TeV
Z → ee
Z → μμ

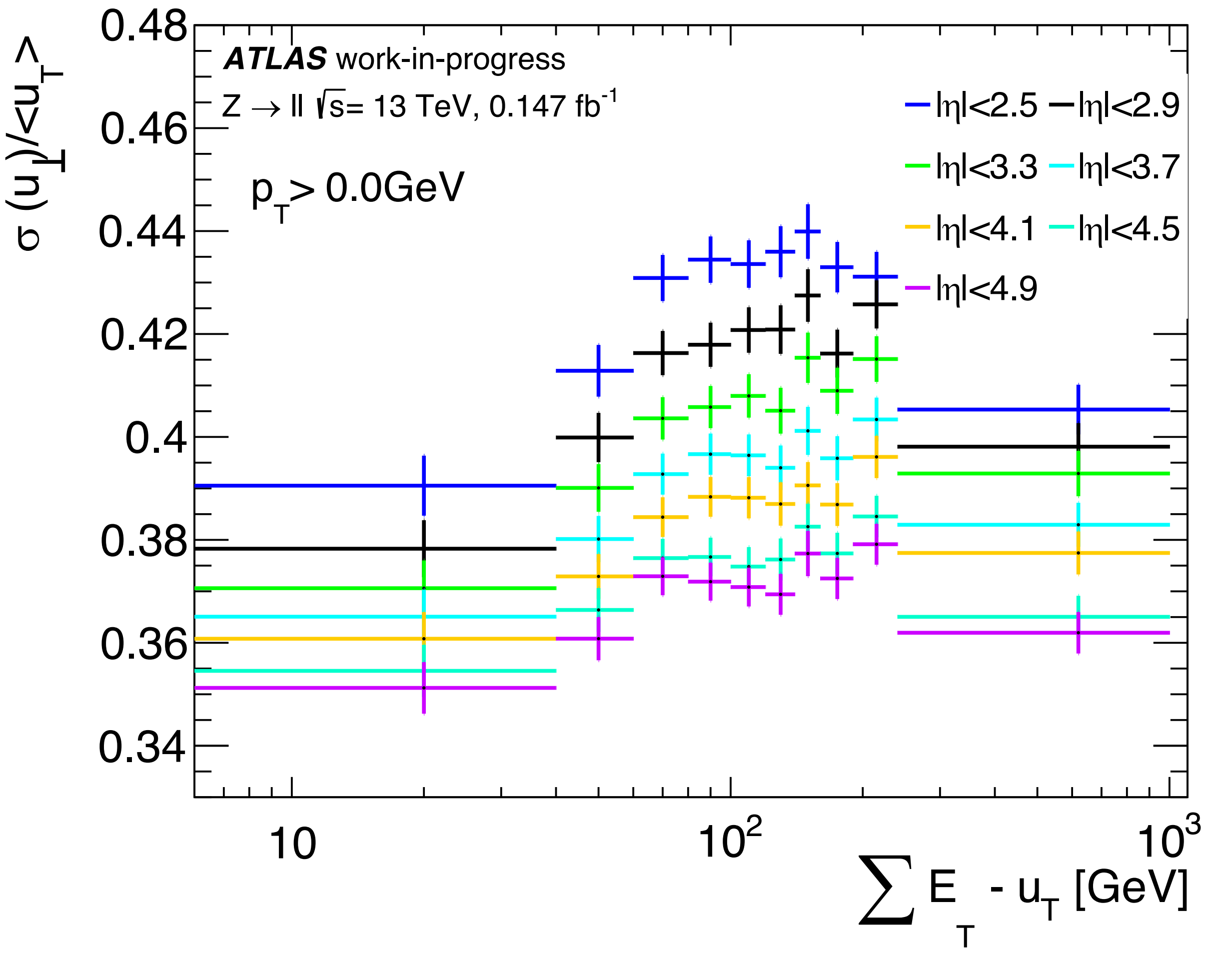
Backup: Absolute resolutions of $u_\perp$

Recoil resolution $\sqrt{s}$ = 5 TeV		
$\sum \bar{E}_T$ range	$\sigma_\perp(Z \to ee)$	$\sigma_\perp(Z \to \mu\mu)$
(0, 30) GeV	3.05 ± 0.04	3.08 ± 0.03
(30, 40) GeV	3.85 ± 0.05	3.86 ± 0.04
(40, 50) GeV	4.26 ± 0.05	4.29 ± 0.04
(50, 60) GeV	4.70 ± 0.05	4.71 ± 0.05
(60, 70) GeV	5.01 ± 0.06	4.93 ± 0.05
(70, 80) GeV	5.21 ± 0.06	5.23 ± 0.05
(80, 90) GeV	5.59 ± 0.07	5.53 ± 0.06
(90, 110) GeV	6.02 ± 0.06	5.96 ± 0.05
(110, 130) GeV	6.34 ± 0.08	6.51 ± 0.06
(130, 180) GeV	7.19 ± 0.08	7.09 ± 0.07
(180, 1000) GeV	8.45 ± 0.14	8.38 ± 0.13

Recoil resolution $\sqrt{s}$ = 13 TeV		
$\sum \bar{E}_T$ range	$\sigma_\perp(Z \to ee)$	$\sigma_\perp(Z \to \mu\mu)$
(0, 40) GeV	3.71 ± 0.05	3.75 ± 0.04
(40, 60) GeV	4.82 ± 0.05	4.92 ± 0.04
(60, 80) GeV	5.63 ± 0.05	5.62 ± 0.04
(80, 100) GeV	6.16 ± 0.05	6.13 ± 0.05
(100, 120) GeV	6.58 ± 0.06	6.65 ± 0.05
(120, 140) GeV	7.10 ± 0.07	7.18 ± 0.06
(140, 160) GeV	7.58 ± 0.08	7.68 ± 0.07
(160, 190) GeV	8.05 ± 0.08	8.14 ± 0.07
(190, 240) GeV	8.90 ± 0.09	8.75 ± 0.07
(240, 1000) GeV	10.7 ± 0.1	10.5 ± 0.1

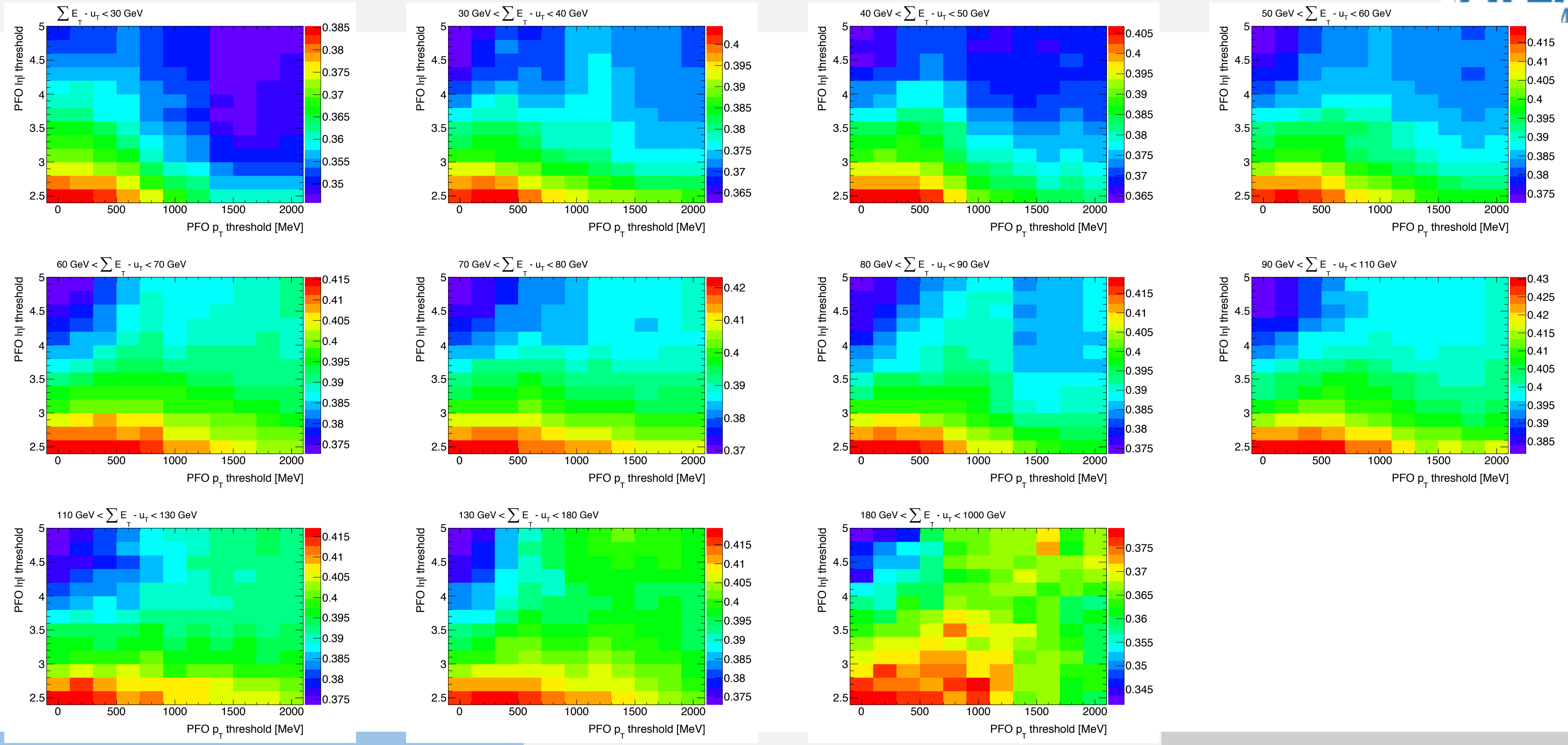
Backup


Events
u∥ [GeV]
ATLAS work-in-progress
√s=13TeV, 0.147 fb-1
Data
Gaussian Fit



ATLAS work-in-progress
Z → ll √s= 13 TeV, 0.147 fb-1
pT> 0.0GeV
|η|<2.5 |η|<2.9
|η|<3.3 |η|<3.7
|η|<4.1 |η|<4.5
|η|<4.9
σ (u⊥)/<uT>
∑ ET - uT [GeV]

Resolution maps with 5TeV data



Resolution maps with 13TeV data