Measurement of the *Z* boson transverse momentum spectrum on ATLAS in the dimuon channel

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DPF09: Electroweak I session

WSU, July 28, 2009

Outline

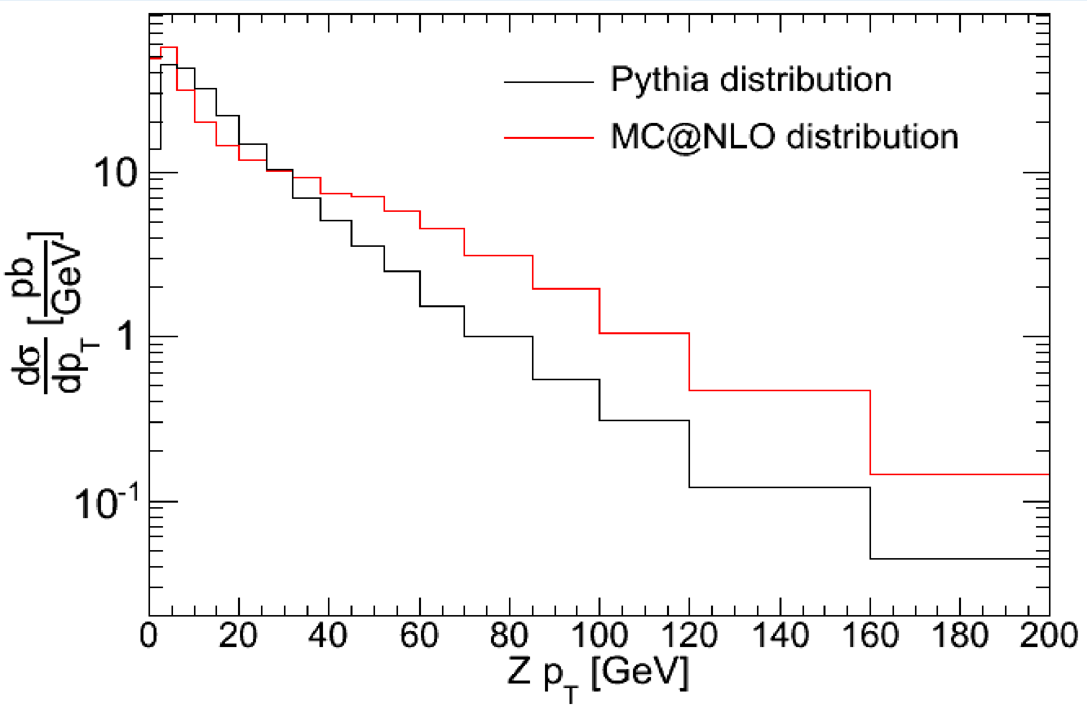
- Motivation for measuring the Z P_T spectrum
- Z boson selection criteria
- Backgrounds to $Z \rightarrow \mu\mu$ channel
  - isolation cuts
- Data-driven estimation of main backgrounds
- Z P_T distribution: raw and corrected
- Normalization: Z differential cross-section as a function of P_T
- Conclusion and outlook

Why measure the *Z* P_T spectrum?

1. Test of QCD predictions:

- Perturbative QCD corrections affect the *Z* P_T spectrum, in particular in the high-P_T region
- Non-perturbative corrections modify the low-P_T spectrum
- Electroweak and QCD corrections are being combined now, and new predictions are emerging

$\longrightarrow$ they can be tested by comparison with measured *Z* P_T spectrum



Z differential cross-section vs P_T from two different MC generators: Pythia, which uses leading-order matrix elements, and MC@NLO, which uses next-to-leading order matrix elements.

2. Discovery physics:

Exotic particles from various strongly couples scenarios are predicted to decay into high-P_T Z bosons

- right-handed heavy quarks
- gluinos and squarks
- technicolor condensates

$\rightarrow$ if any of these particles exist, their signature may be obvious in the Z P_T spectrum in the early data

3. Inferring properties of the $Z \rightarrow \nu\nu$ decay:

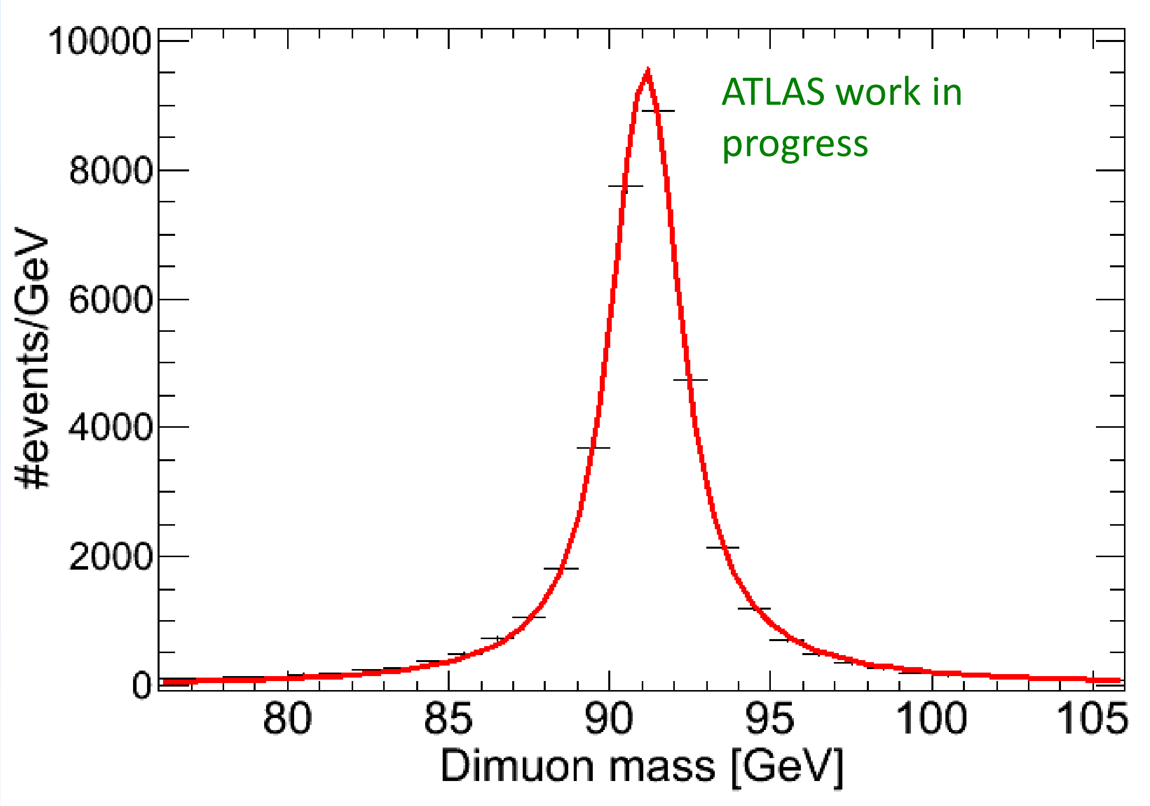
Invisible $Z \rightarrow \nu\nu$ decay is a background to many processes involving missing E_T

- e.g., a graviton escaping into a higher-dimensional bulk
- the $Z \rightarrow \mu\mu$ decay can be used to indirectly measure the rate and properties of the invisible mode

4. The total Z cross-section can be used as a luminosity monitor, but it requires a good understanding of the P_T spectrum

Our work

- We are developing an analysis to measure Z P_T spectrum in early data collected by ATLAS
- Analysis based on official datasets generated with Pythia at a center-of-mass energy of 10 TeV
  - PHOTOS used for final-state photon radiation
- Signal dataset corresponds to an integrated luminosity of 40 pb^{-1}



Dimuon invariant mass distribution at truth level in the Z peak region, with a Breit-Wigner fit.

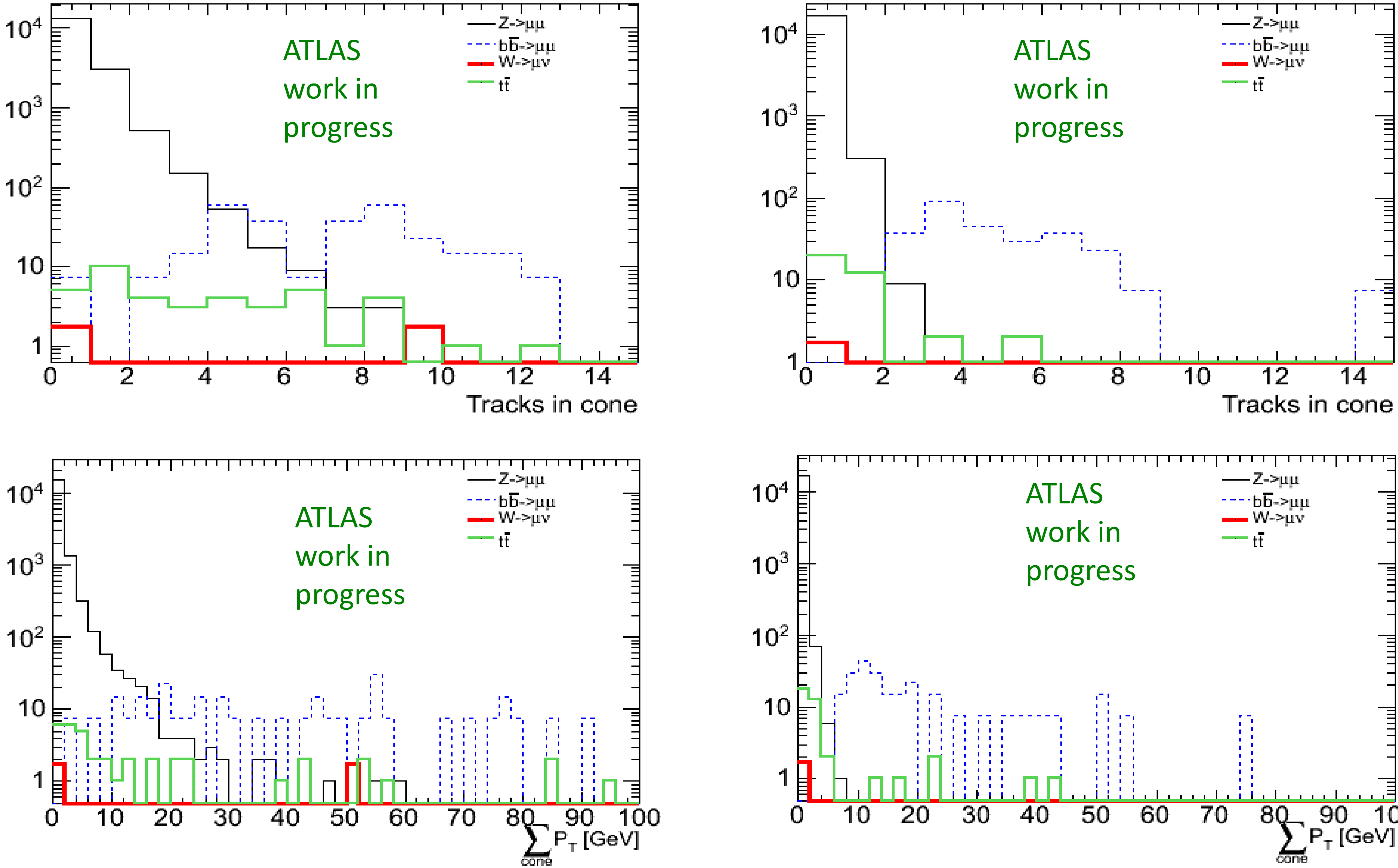
Z boson selection criteria

Selection criterion	Events passing cut (%)
20 GeV single muon trigger chain	69.7 ± 0.4
At least one μ^+ and one μ^- reconstructed	49.8 ± 0.3
$\lvert\eta\rvert < 2.5$ for both muons	47.1 ± 0.3
$P_T > 20$ GeV for both muons	41.6 ± 0.3
76 GeV $< M_{\mu\mu} <$ 106 GeV	38.5 ± 0.3

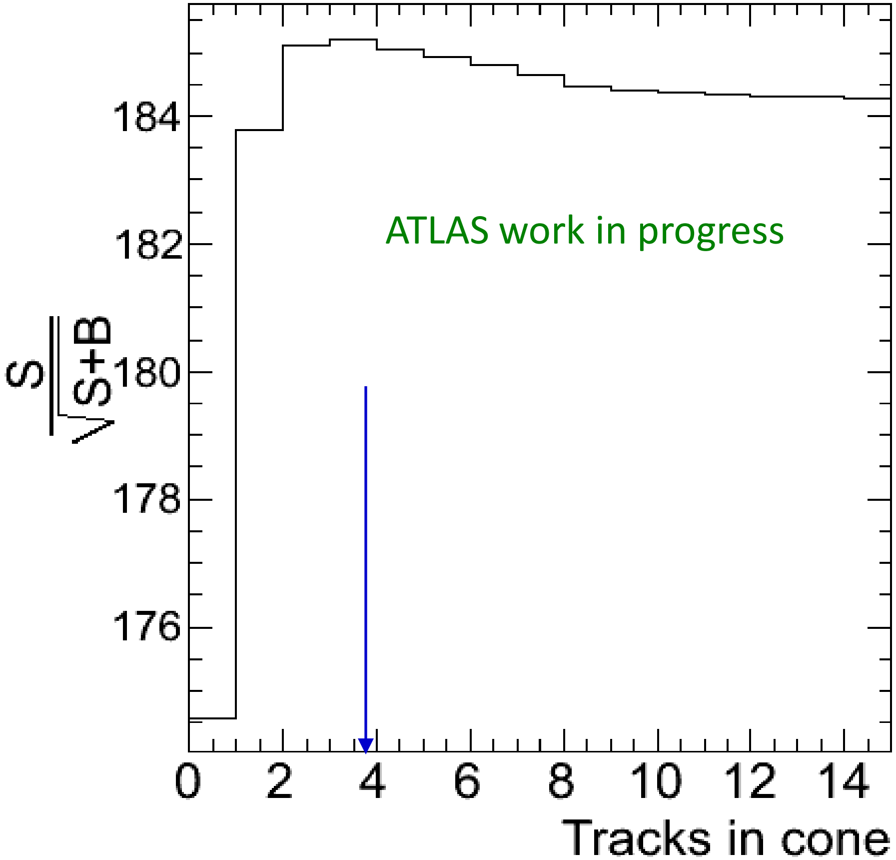
Errors reflect the finite statistics only

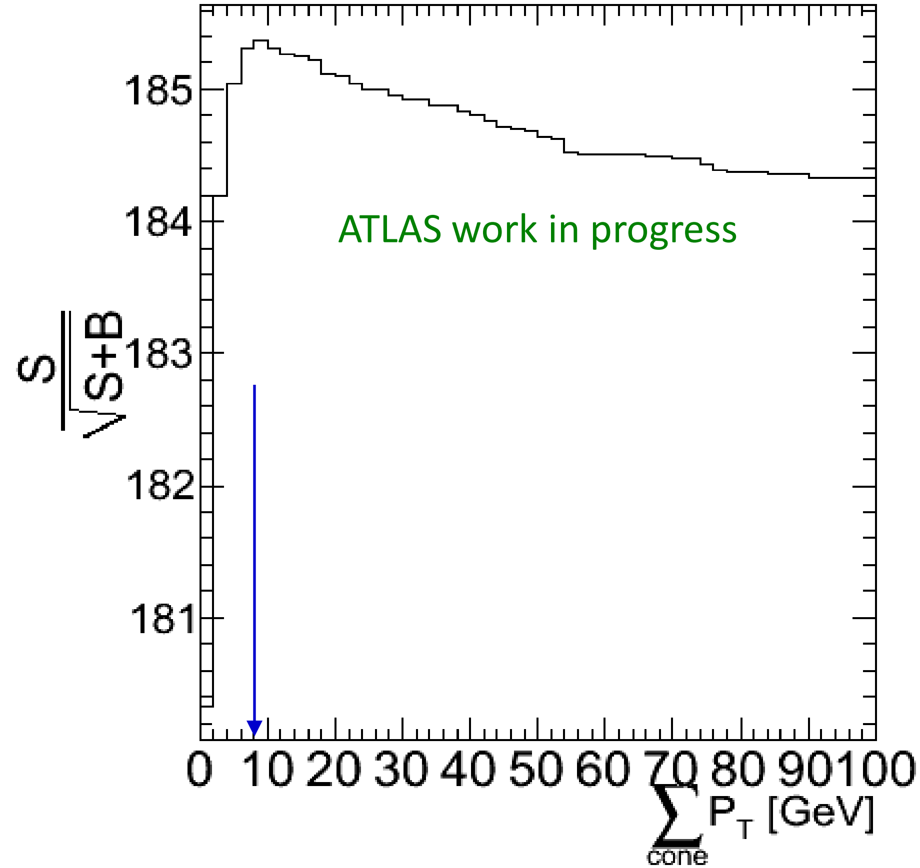
Backgrounds

- Physics backgrounds to signal channel are:
  - $W \to \mu\nu + \text{jet}$
  - $b\bar{b} \to \mu\mu + \text{X}$
  - $t\bar{t}$ dimuon decays
  - $Z \to \tau\tau \to \mu\nu_\mu\nu_\tau\ \mu\nu_\mu\nu_\tau$
  - *WW, ZZ, WZ*
- In this analysis, backgrounds are estimated from Monte Carlo
  - we are studying data-driven methods to estimate *W* and $b\bar{b}$ backgrounds
- To minimize backgrounds, we use two isolation criteria defined in a cone of $R = 0.4$ around muon track:
  - number of tracks in cone
  - ΣP_T of tracks in cone



#Tracks (*top*) and ΣP_T of tracks (*bottom*) in cone $R = 0.4$. Distributions for the muon with the larger value of the quantity is shown on the left, and those for the muon with the smaller value on the right.

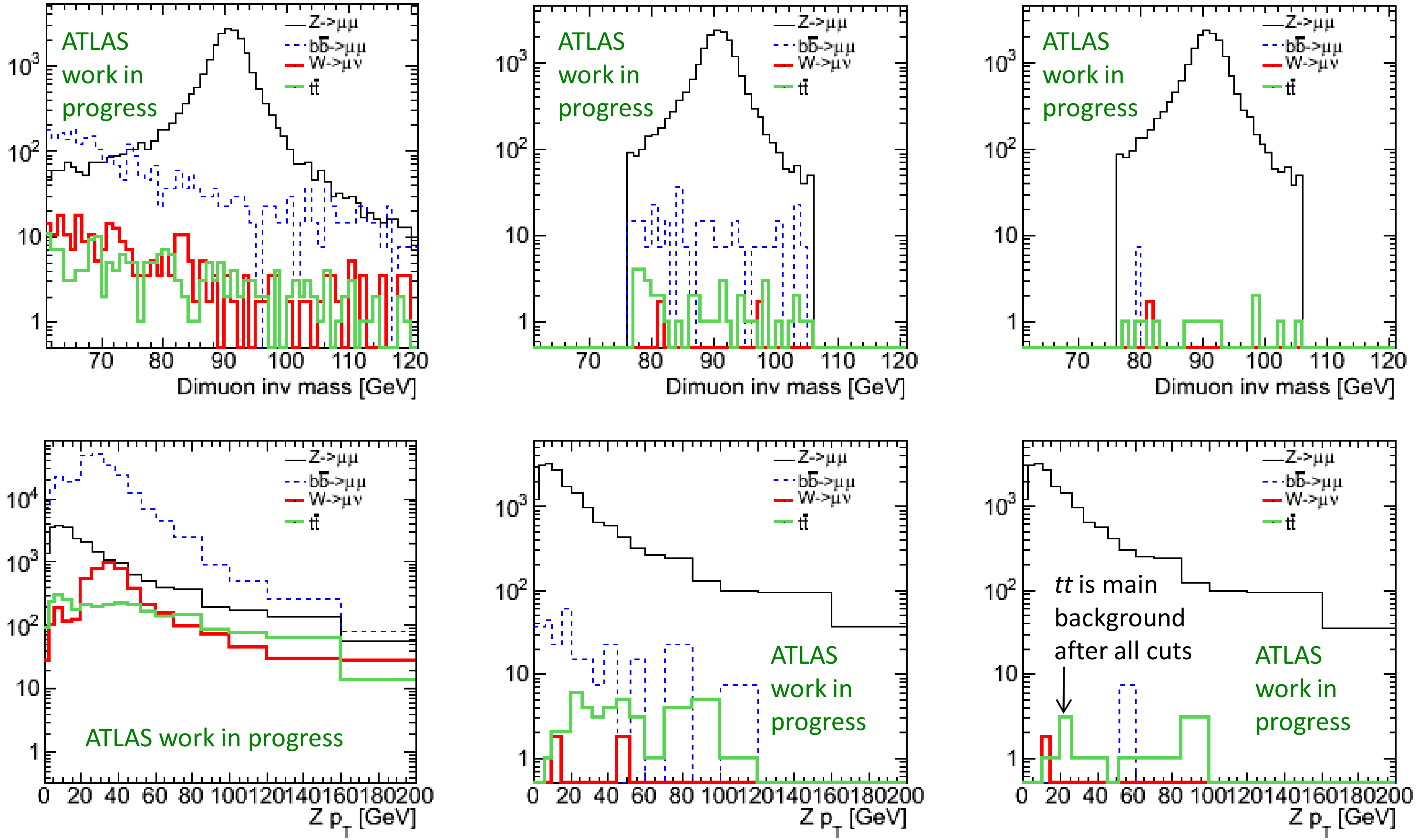




Optimization of the muon isolation cuts: *(left)* number of tracks in cone of size $R = 0.4$ around the muon track, and *(right)* ΣP_T of tracks in cone. Optimized values are:

Number of tracks < 4

ΣP_T of tracks < 8 GeV



Distribution of signal and background events in *Z* mass (*top*) and *Z* P_T (*bottom*) distributions. *Left:* before cuts, *middle:* after *Z* selection cuts, *right:* after isolation cuts.

Estimation of $W \rightarrow \mu\nu$ background in data

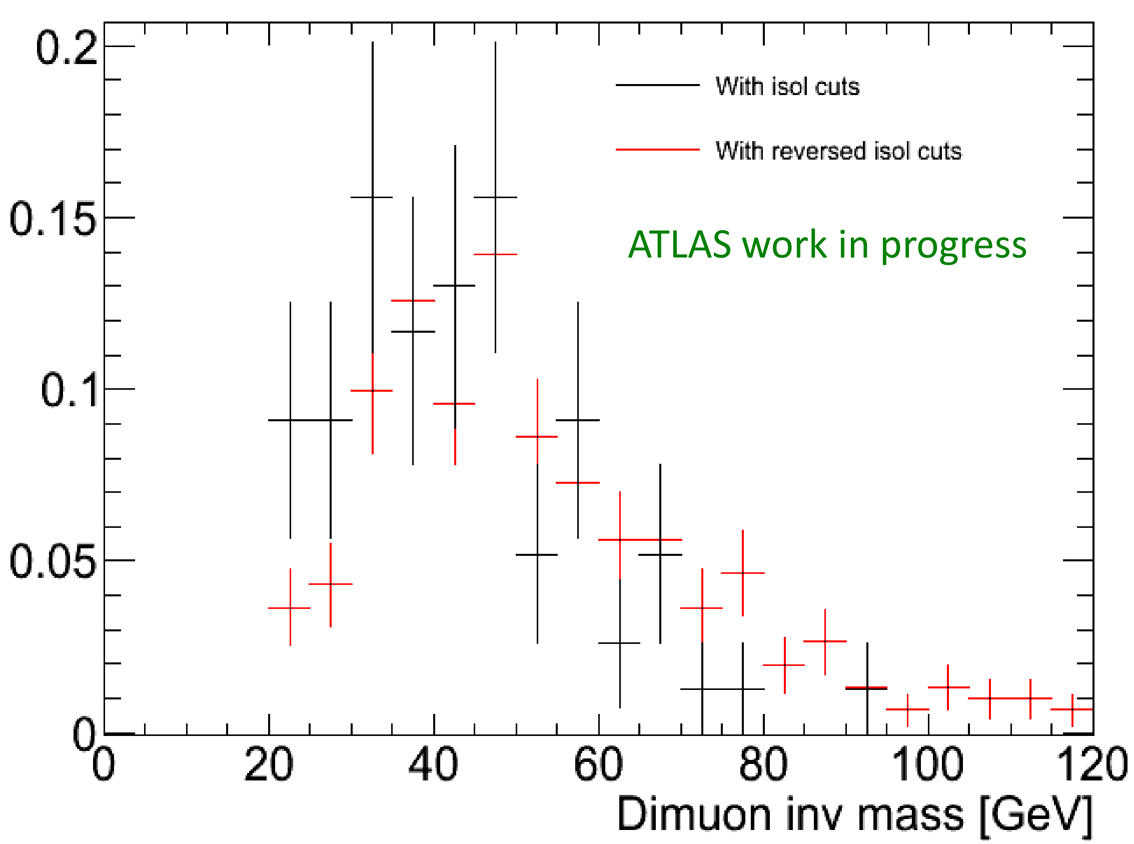
- W decay muon combines with a muon in a jet to fake Z signal
- Assumption: fraction of $Z \rightarrow \mu\mu$ events in which three muons pass kinematic and isolation cuts = fraction of $W \rightarrow \mu\nu$ events in which two muons pass same cuts
- In data, after applying Z selection and isolation cuts, count number of events in which three muons pass cuts
- Multiply by ratio $\sigma(W)/\sigma(Z)$ to estimate number of $W \rightarrow \mu\nu$ events
- In $Z \rightarrow \mu\mu$ sample, $0.029 \pm 0.008\%$ (13 events) have 3rd muon passing cuts
- In $W \rightarrow \mu\nu$ sample, $0.027 \pm 0.003\%$ events have a 2nd muon that pass cuts

$\longrightarrow$our assumption seems to be correct

Estimation of $b\bar{b}$ background in data

- Estimate $b\bar{b}$ background in data after isolation cuts using a sample of $b\bar{b}$ events with non-isolated muons

  - this method can work if, e.g., dimuon invariant mass distribution has similar shape for $b\bar{b}$ events with isolated and non-isolated muons



Dimuon invariant mass distribution in $b\bar{b}$ events with muon isolation cuts and with reversed isolation cuts, normalized to unit area. Within the limited statistics, the two distributions have similar shape.

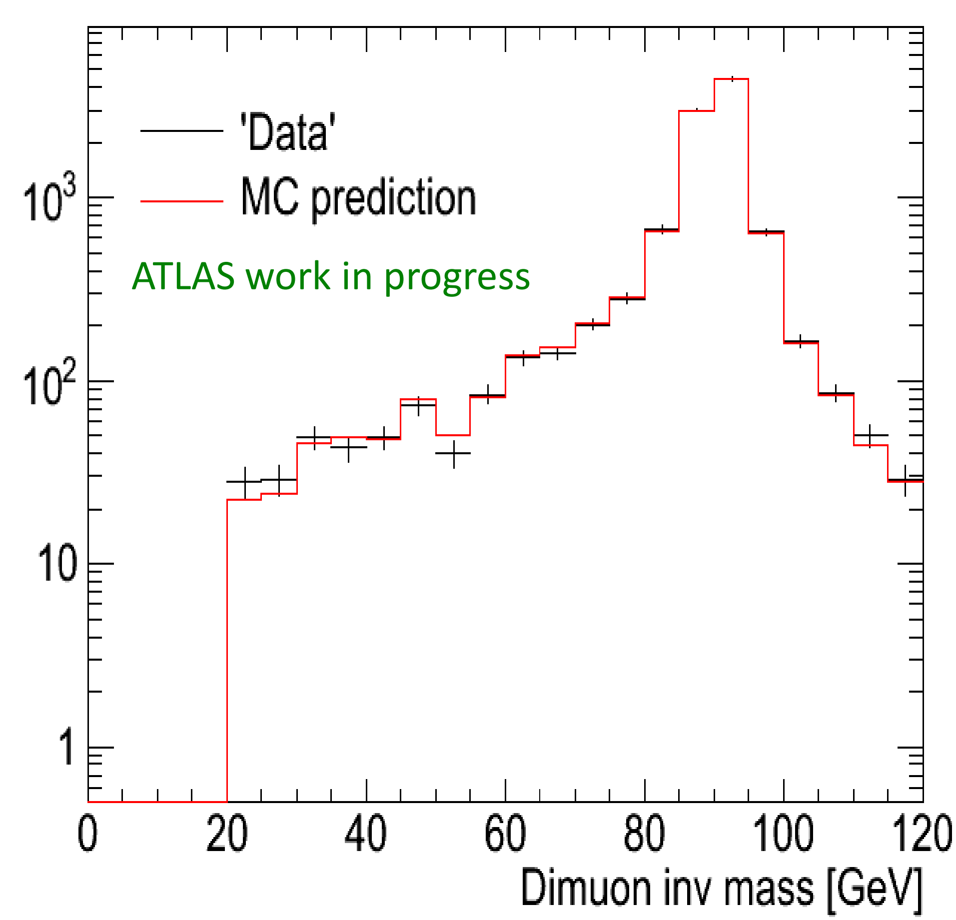
Template fit for $b\bar{b}$ background determination

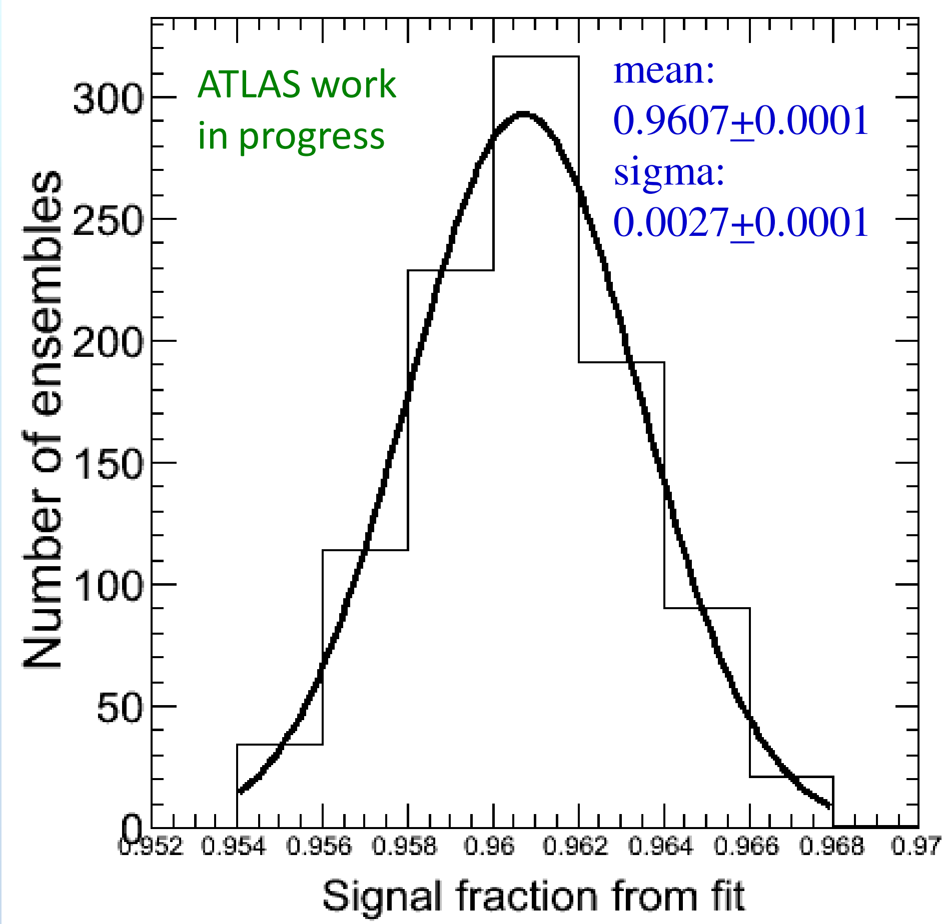
- Reverse isolation cuts on data sample

  → almost all events passing reversed cuts will be $b\bar{b}$ events with non-isolated muons
- This sample is used as a template for $b\bar{b}$ events with isolated muons
- Signal template is $Z \rightarrow \mu\mu$ events from Monte Carlo
- A template fit gives the fractions in which signal and $b\bar{b}$ templates must be combined to obtain the observed distribution
- Fit gives 96 ± 1% for signal fraction

  3.9 ± 0.4% for $b\bar{b}$ fraction
- Input was 97% signal events

  3.0% $b\bar{b}$ events





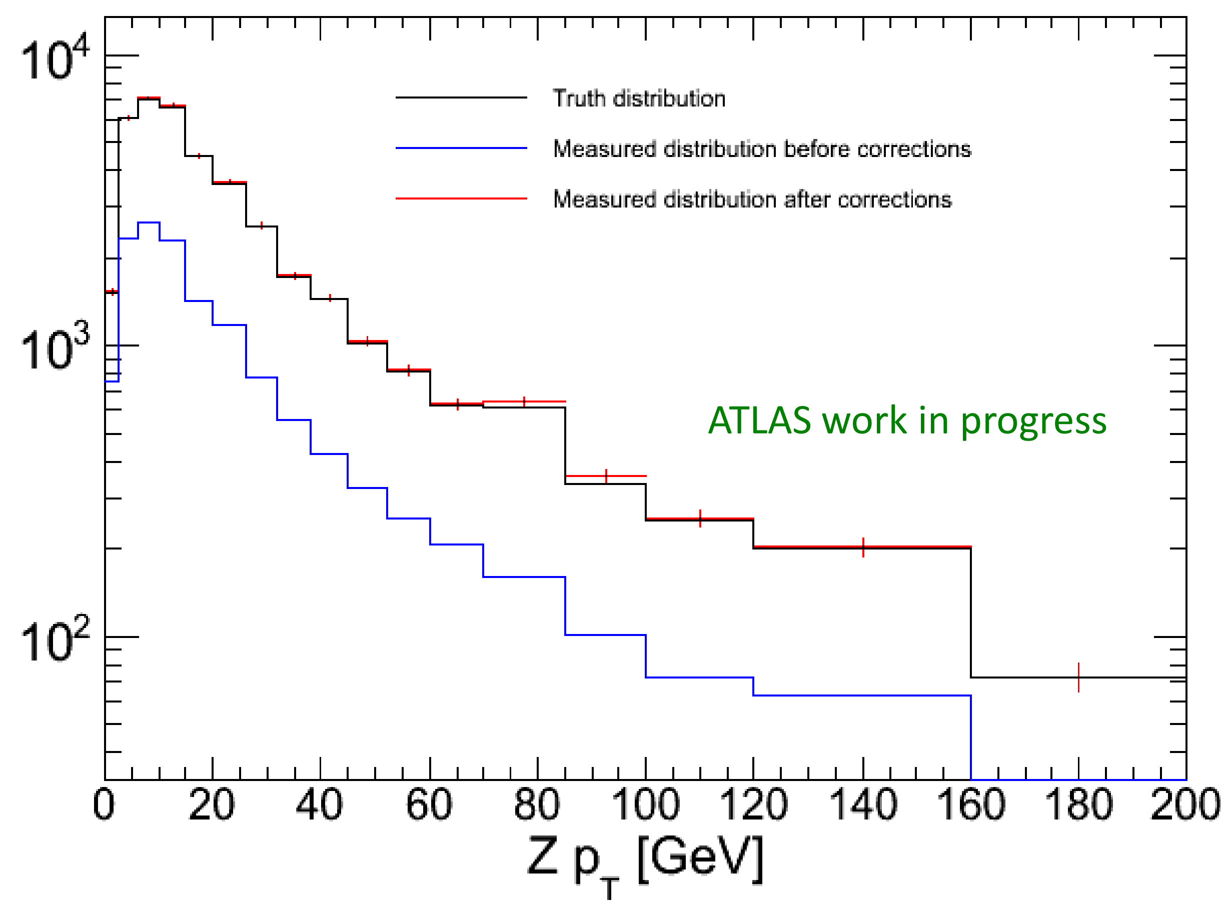
(*Left*) Dimuon invariant mass distribution from 'data' and from the template fit result. (*Right*) *Z* fractions from the template fit in 1000 pseudo-experiments, in which the content of each 'data' bin was varied using Poisson fluctuation. The Gaussian sigma is a measure of the resolution of the template fit.

Z P_T spectrum

- The raw P_T spectrum is corrected for:

  - reconstruction and trigger efficiencies
  - geometric and kinematic acceptance
  - resolution smearing

Correction factors obtained using truth information



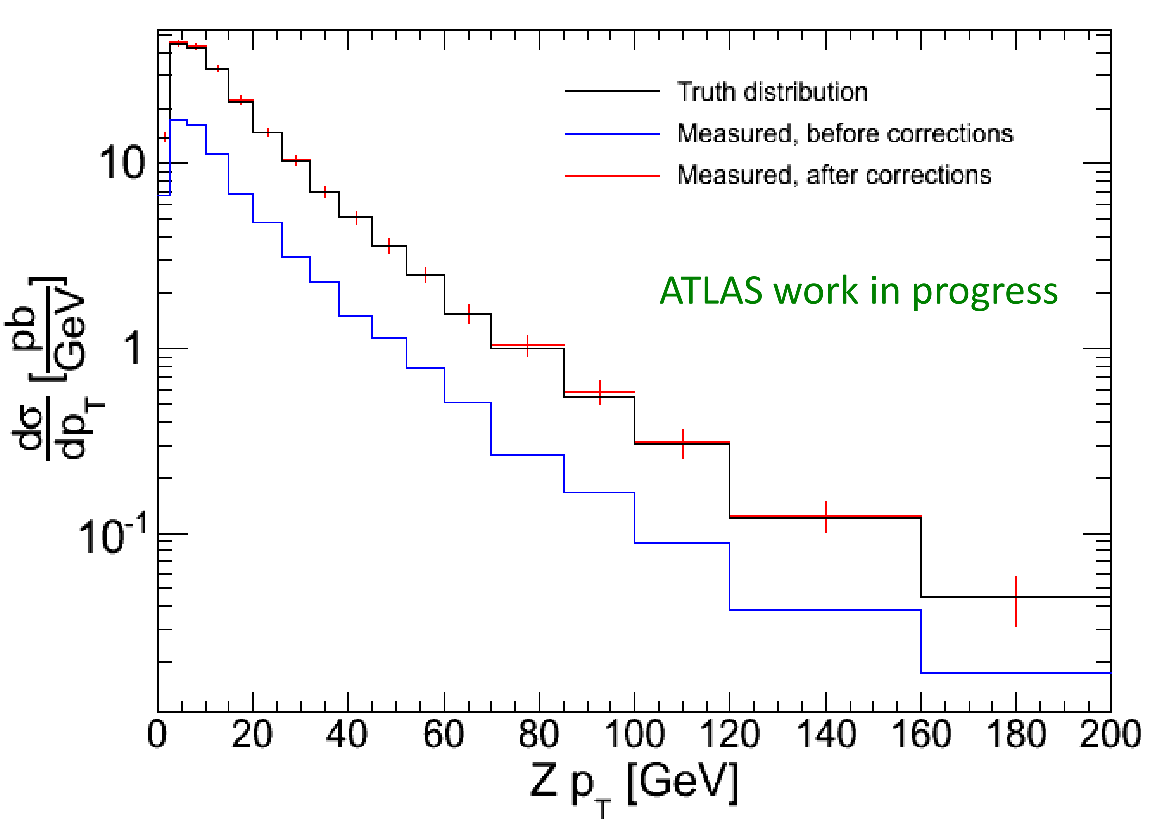
Z P_T distribution from Monte Carlo truth, measured (uncorrected) and corrected.

Plots correspond to 40 pb^{-1} of integrated luminosity. Errors are statistical.

Z differential cross-section vs P_T

$$\frac{d\sigma_i}{dP_T} = c_i \frac{s_i - b_i}{\Delta P_{T_i} L_{\text{int}} \varepsilon_i A_i}$$

s_i = signal events in i-th P_T bin
b_i = background events in i-th P_T bin
ΔP_{Ti} = width of i-th P_T bin
L_{int} = integrated luminosity
A_i = acceptance for i-th bin
ε_i = efficiency for i-th bin
c_i = smearing correction for i-th bin



Z differential cross-section vs P_T from Monte Carlo truth, measured (uncorrected) and corrected.

Plots correspond to 40 pb^{-1} of integrated luminosity. Errors are statistical.

Conclusion and outlook

- We are developing an analysis to measure the Z P_T spectrum from early data collected by the ATLAS detector
- We are studying ways to extract the major backgrounds with minimal dependence on Monte Carlo
- In the first LHC run, can expect ~10 pb^{-1} of collision data
- Instantaneous luminosity ~$10^{29\text{-}31}$ $cm^{-2}s^{-1}$

  - we do not expect large cavern background and event pileup

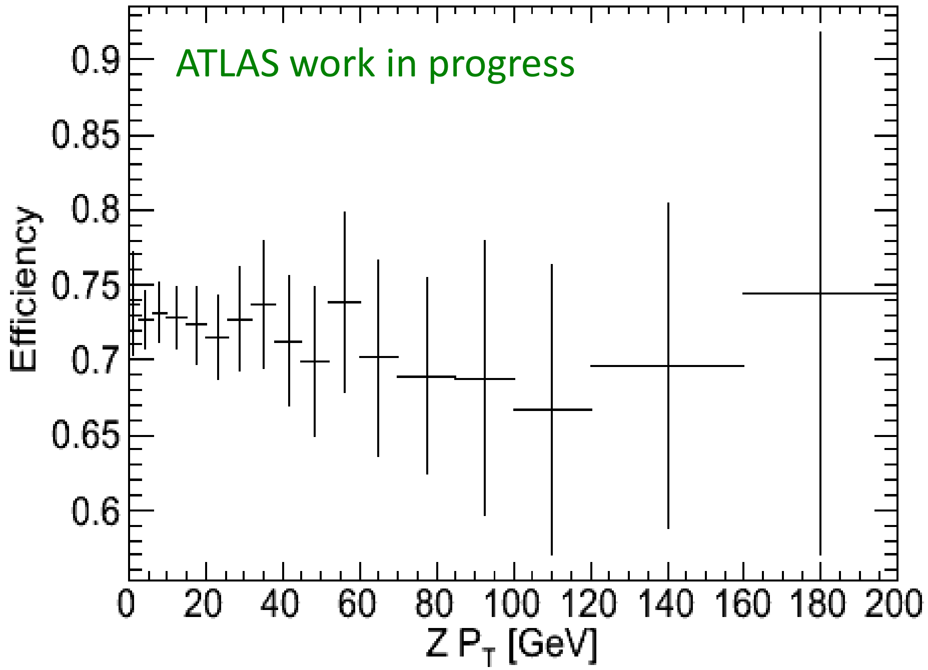
  $\longrightarrow$ relatively clean events
- A good understanding of the detector will be the major challenge for this analysis

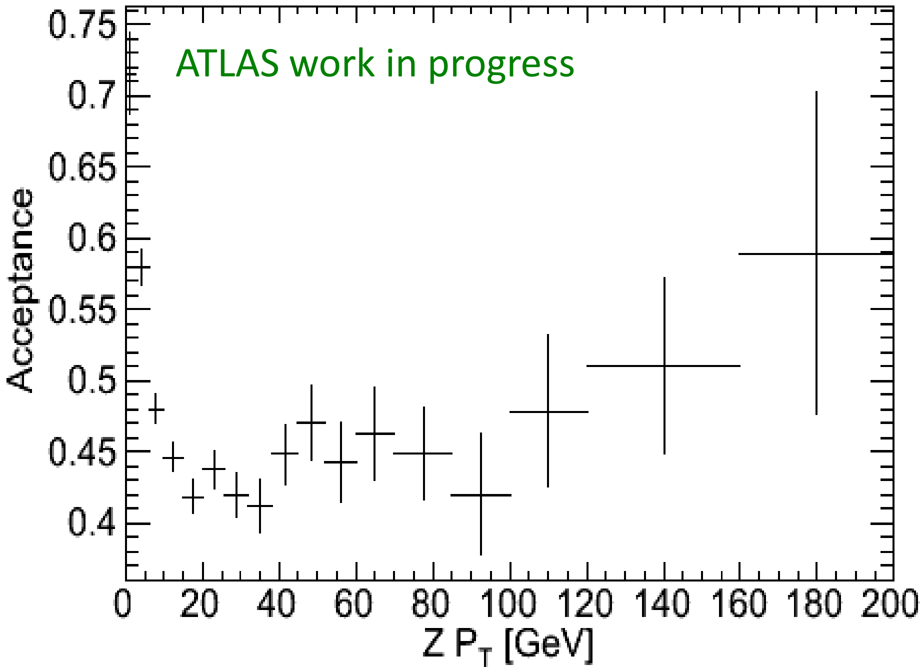
  - muon trigger acceptance and efficiency

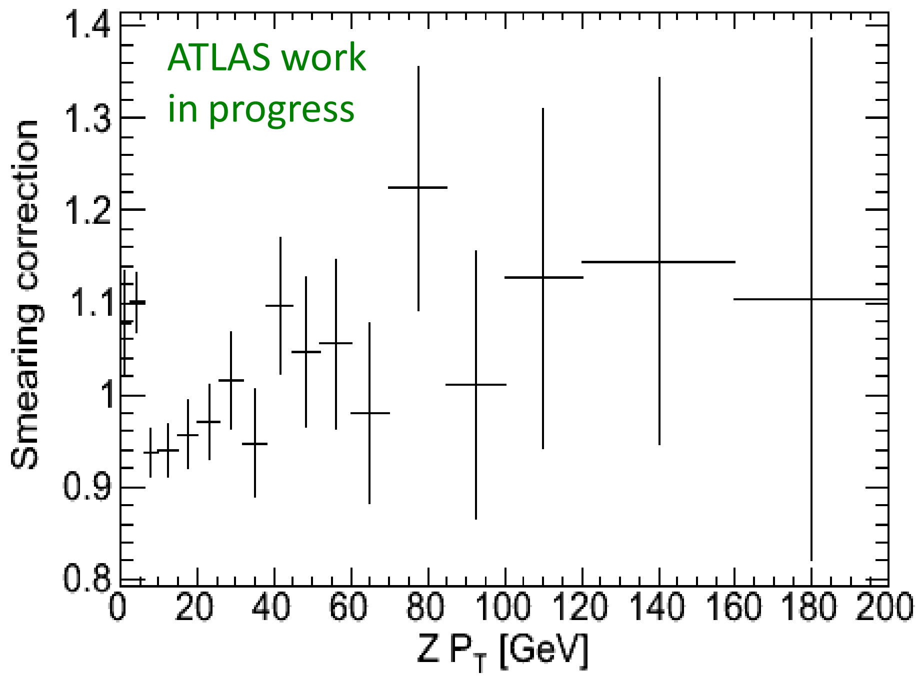
  - offline reconstruction efficiency

  - muon momentum scale and resolution

Extra slides





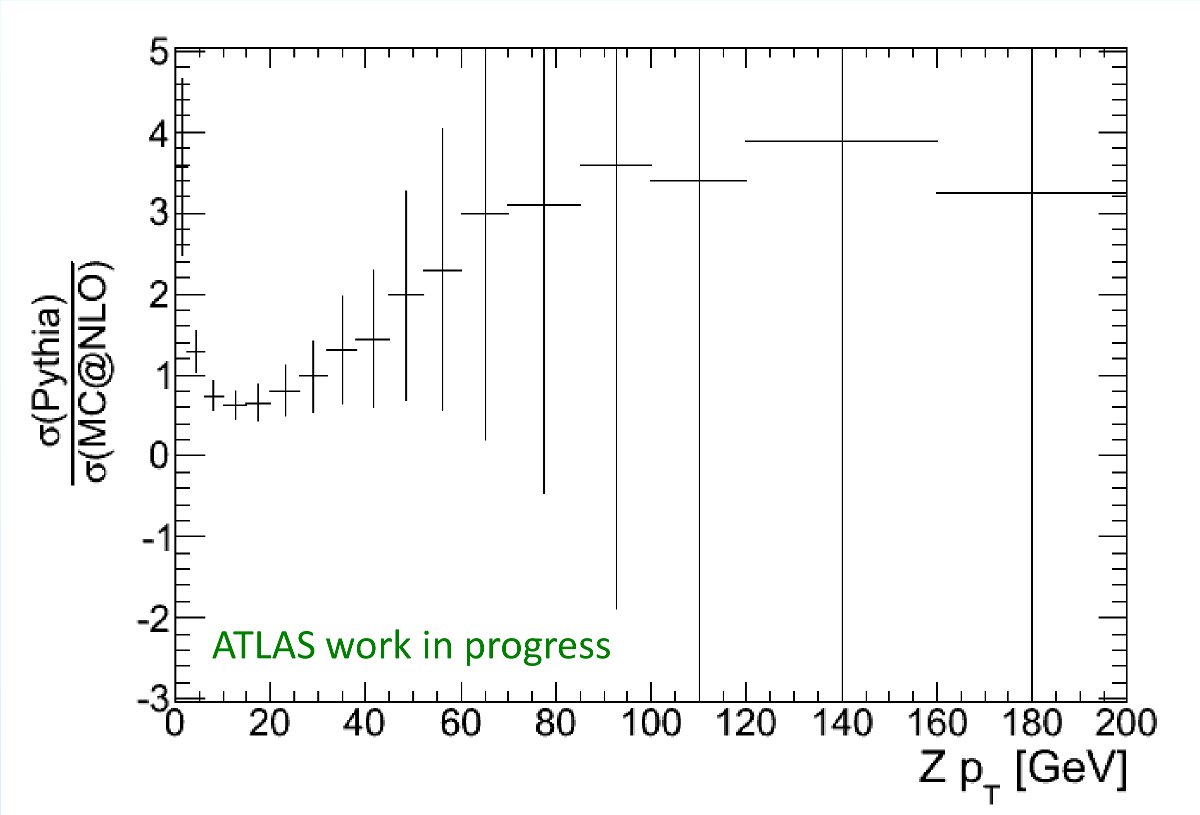


Correction factors as a function of *Z* P_T, extracted using truth information:

Top left: efficiency (reconstruction and trigger)

Top right: acceptance (geometric and kinematic)

Bottom left: correction for resolution smearing



Bin-by-bin ratio of $Z \rightarrow \mu\mu$ cross-section from Pythia to that from MC@NLO vs. Z P_T , at a center-of-mass energy of 10 TeV.