Muon Reconstruction Performance of the ATLAS Detector Using Run-3 pp collision data

Xingyu Wu* on behalf of the ATLAS Collaboration
*University of Science and Technology of China
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1. Abstract

Accurately measuring the muon performance of the ATLAS detector is essential for physics analyses involving muons. For LHC Run 3, the ATLAS Muon Spectrometer was significantly upgraded, most notably with the New Small Wheel project introducing new detectors. Evaluating these upgrades using Run 3 data is therefore crucial.

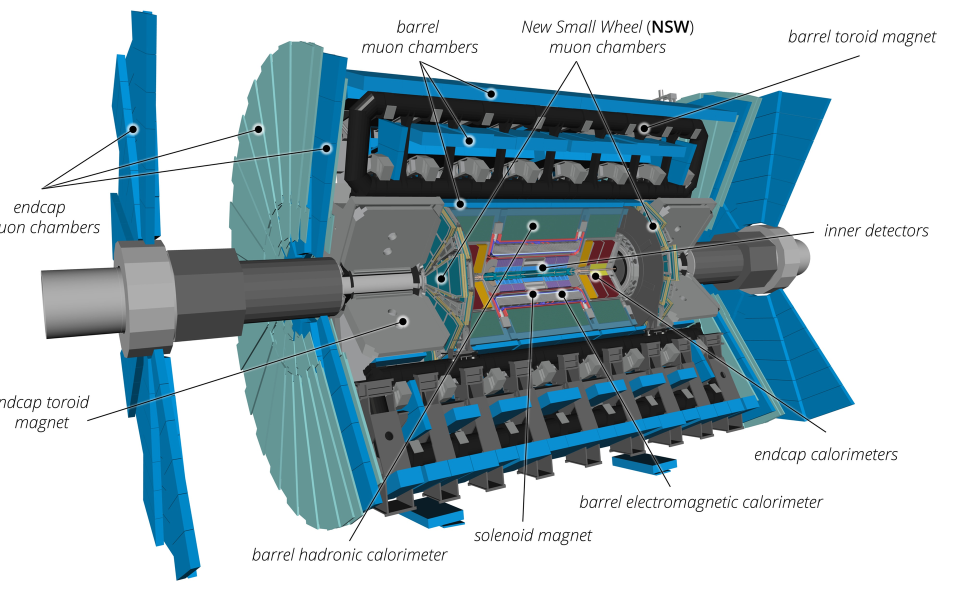

Figure 1: ATLAS detector

2. Run3 Inner Detector (ID) and Muon Spectrometer (MS)

- ID: Tracking detector up to $|\eta| < 2.5$ working in a 2 T solenoidal magnetic field.
- MS: Independent muon reconstruction in $|\eta| < 2.7$, working in a toroidal magnetic field.

3. Muon Identification and Isolation

- Identification: Several working points (WPs) are defined to suppress fake and non-prompt muons originating from light and heavy flavor decays.
  - Loose, Medium, Tight, High p_T and Low p_T.
- Isolation: Separate prompt muons from non-prompt backgrounds using track- and calo-based or particle flow information.
  - The Prompt Lepton Isolation Tagger (PLIT), a ML-based isolation algorithm utilizing a transformer neural network, outperforming traditional cut-based methods.

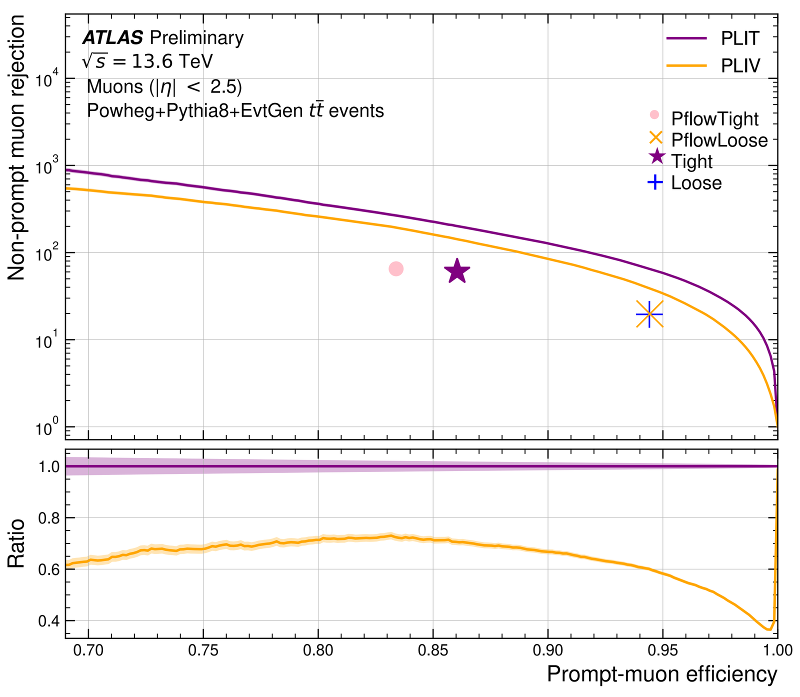

Figure2: The non-prompt lepton rejection factors as a function of prompt muon efficiency for PLIT and cut-based isolation WPs.

4. Muon Efficiency Measurement

Tag and Probe (T&P) method applied to Z and $J/\psi \to \mu\mu$ events.

- Tag: Pass Tight WP & trigger the online event selection.
- Probe: Pass a set of quality criteria (WP).
- Efficiency

$$\epsilon = \frac{N_{Probe}^{Pass\,WP}}{N_{Probe}^{All}}$$

- Scale Factor: Efficiency ratio to correct simulation.

$$SF = \frac{\epsilon^{Data}(WP)}{\epsilon^{MC}(WP)}$$

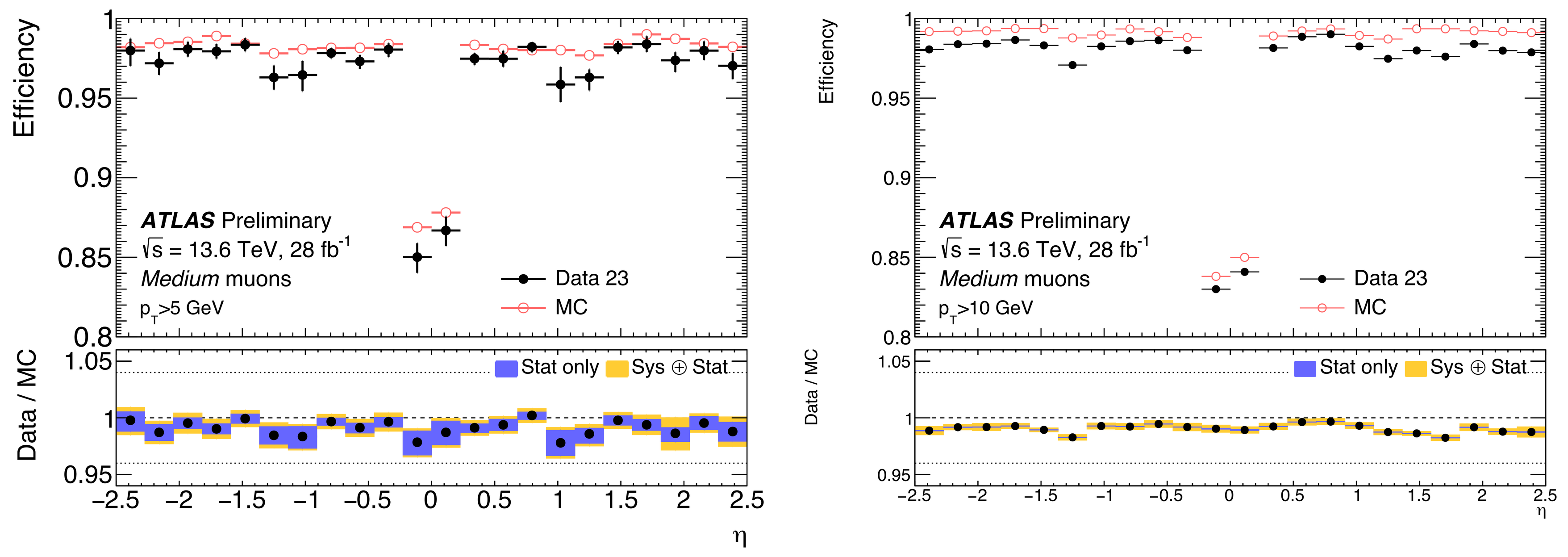

Figure3: Efficiency for reconstructing and identifying muons using the *Medium* ID WP, as a function of the muon pseudorapidity (η). The measurement is based on samples of $J/\psi \to \mu\mu$ (left) *and* $Z \to \mu\mu$ (right) candidate events from data collected in 2023.

5. Muon Momentum Calibration

- Charge-dependent bias corrections (on data).

$$m_{\mu\mu}^2 \sim \hat{m}_{\mu\mu}^2(1+\delta_s p_T^+)(1-\delta_s p_T^-) \quad \text{strength of the bias.}$$

  - Correct the bias from ID weak modes and MS alignment.
  - Minimize resolution between pos/neg charges.
- Scale and smearing corrections (on MC).

$$p_T^{Corrected} = \frac{p_T^{MC} + (s_0 + s_1 \cdot p_T^{MC})}{1 + (g_0 \cdot \frac{r_0}{p_T^{MC}} + g_1 \cdot r_1 + g_2 \cdot r_2 \cdot p_T^{MC})} \quad g = \mathcal{N}(0,1)$$

  - Correct the mismodelling in multiple scattering, energy loss, etc.
  - Use Z and J/ψ mass peaks to catch low-p_T and high-p_T features.

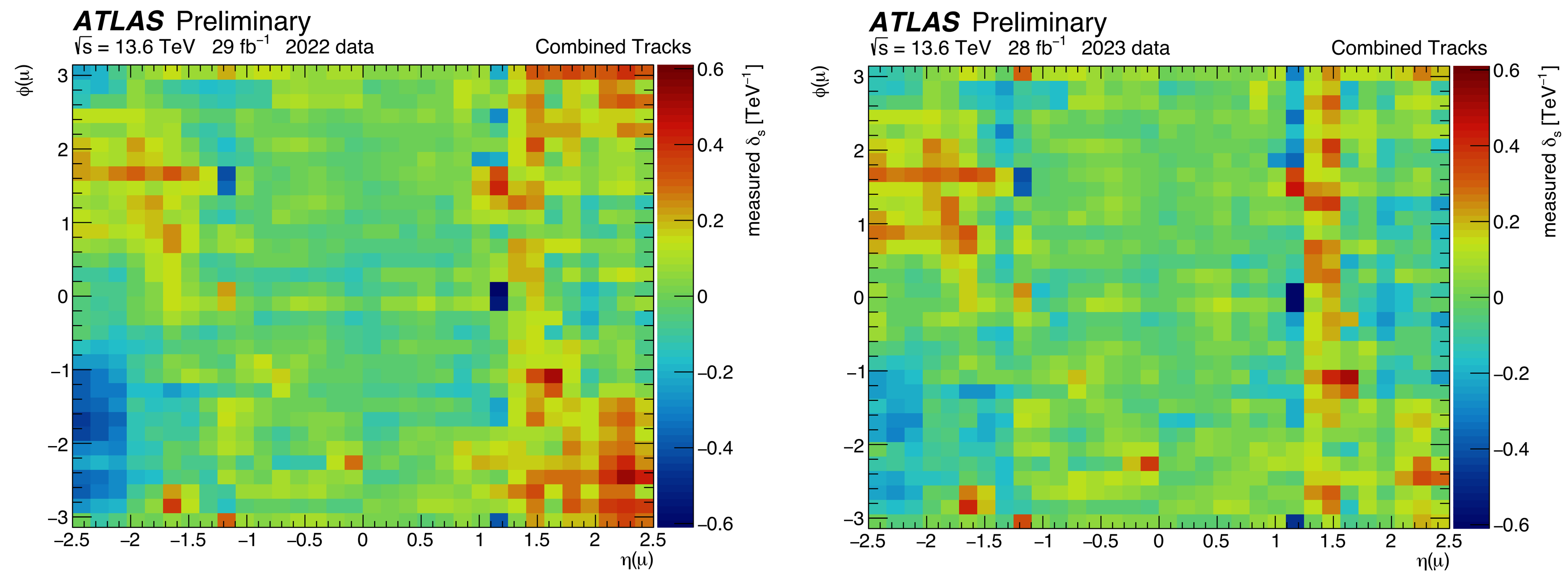

Figure 4: The measured δ_s from $Z \to \mu\mu$ events for the 2022 (left) and 2023 (right) data.

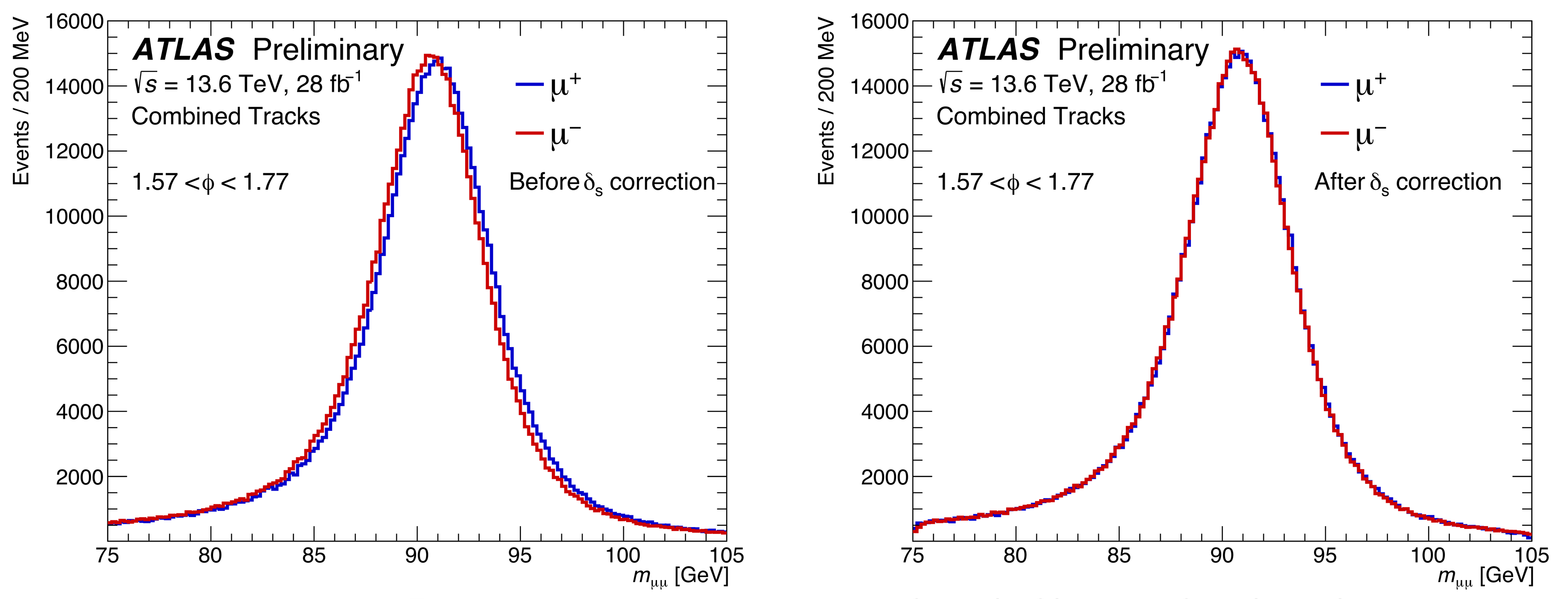

Figure5: $Z \to \mu\mu$ invariant mass, before (left) and after (right) applying the δ_s correction, 2023 CB tracks for example.

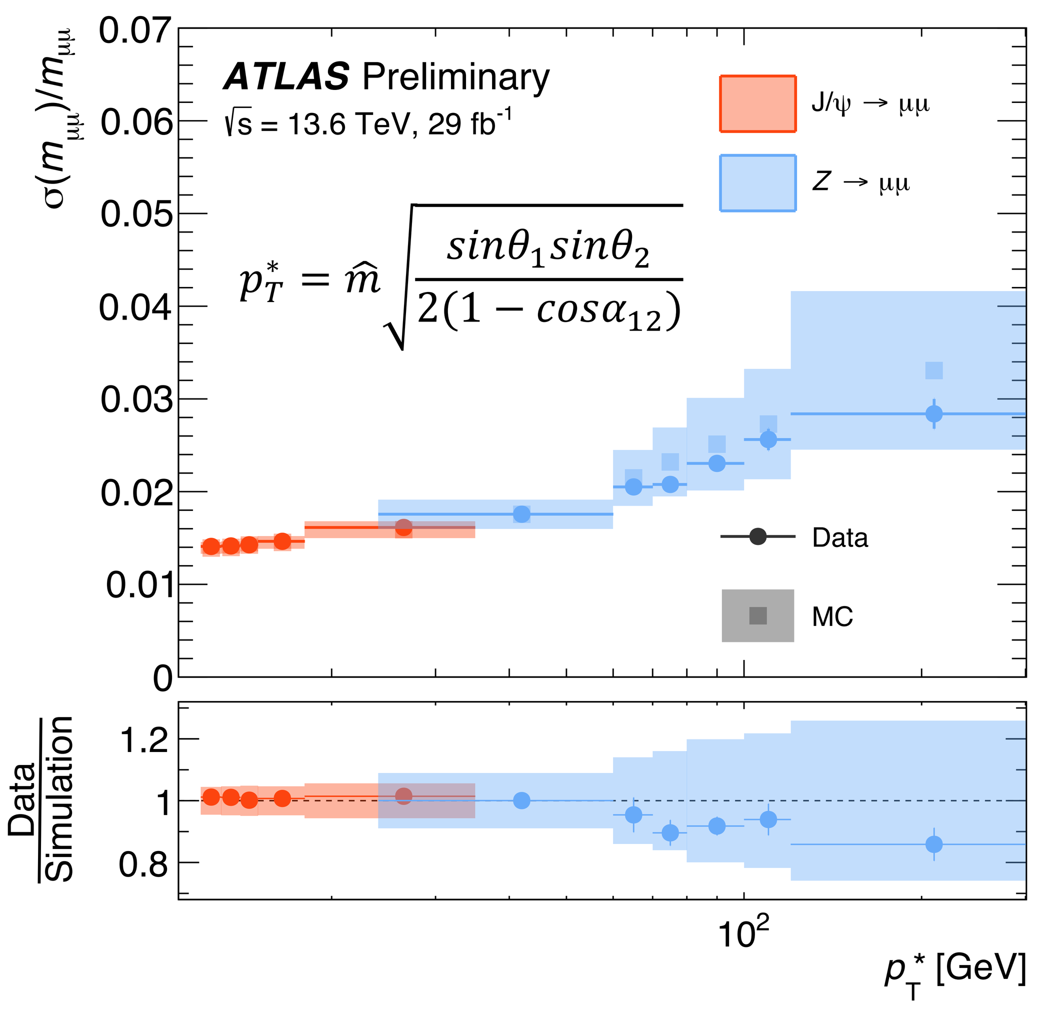

Figure7: Dimuon invariant mass resolution divided by the dimuon invariant mass for *Combined* muons. Mass resolution ~ 2%.

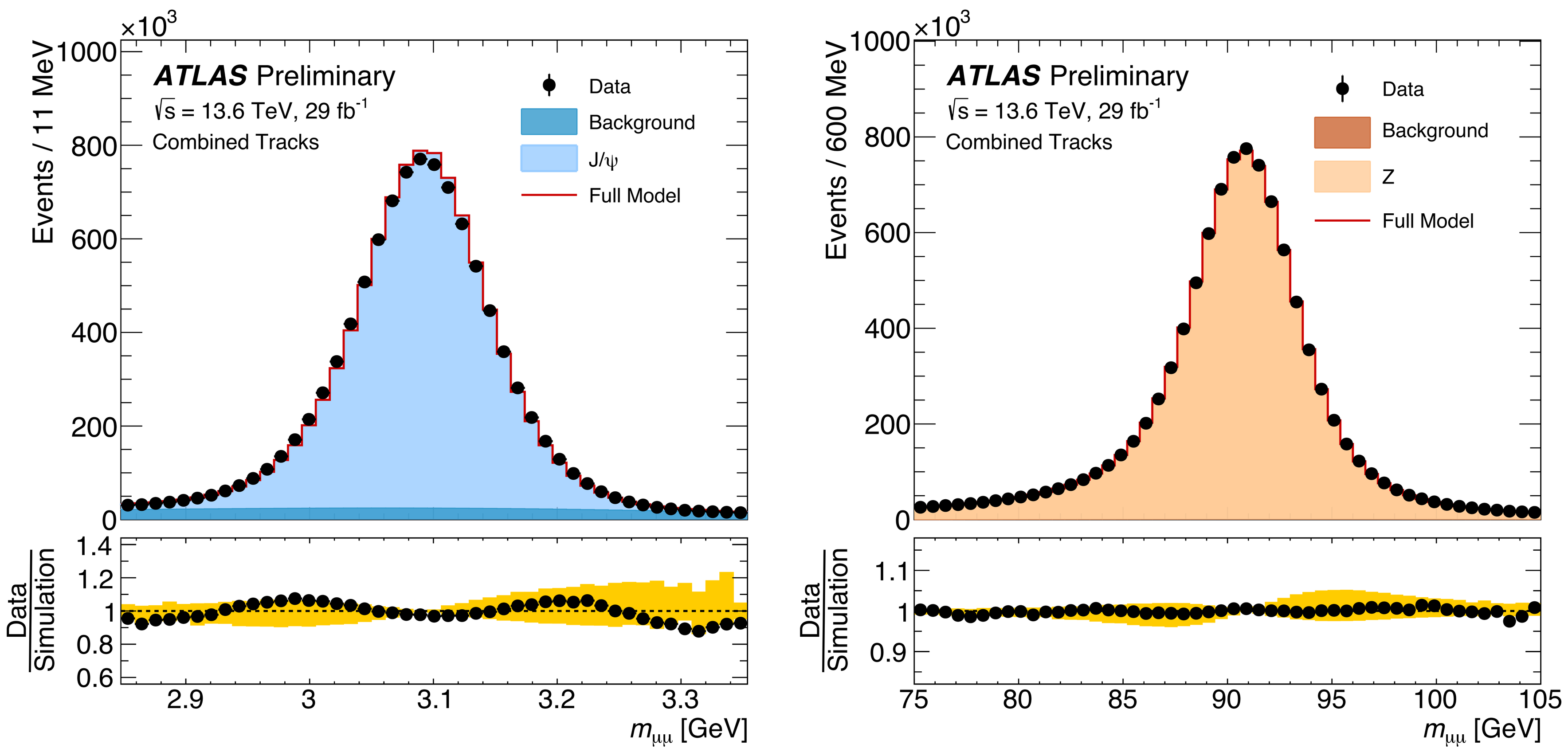

Figure6: Dimuon invariant mass distribution of $J/\psi \to \mu\mu$ (left) and $Z \to \mu\mu$ (right) candidate events reconstructed with *Combined* muons

6. Reference

- ATLAS Collaboration, Studies of the muon momentum calibration and performance of the ATLAS detector with pp collisions at TeV. Eur. Phys. J. C 83, 686 (2023).
- https://twiki.cern.ch/twiki/bin/view/AtlasPublic/MuonPerformancePublicPlots