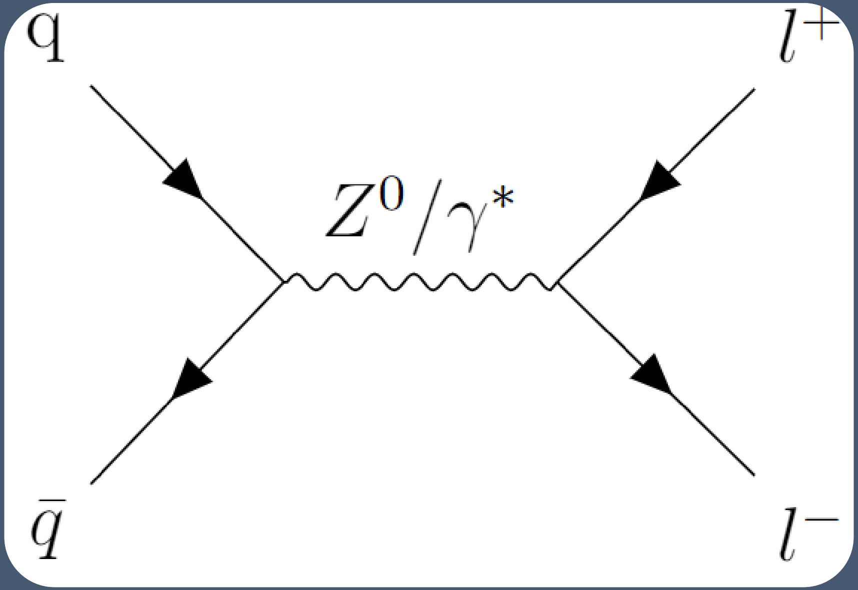

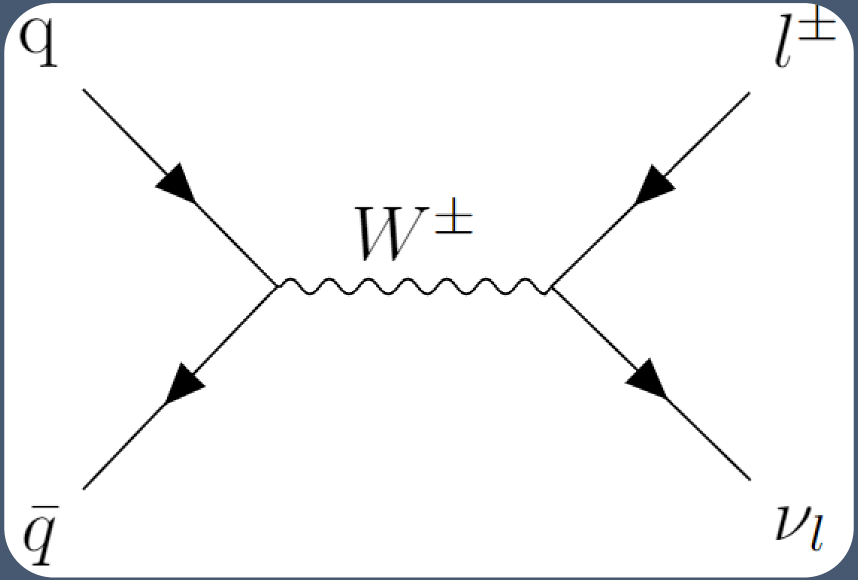

COUNTING OF Z BOSONS & ELECTRON ENERGY CALIBRATION FOR W MASS

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LIVERPOOL HEP MEETING

Z–Counting Overview

- Use the decays of Z bosons to electrons or muons to determine LHC proton-proton interaction rate (luminosity) (c.f. Run 2 ATLAS lumi paper [1])
- Independent confirmation of dominant time-dependence of systematic uncertainty of ATLAS preferred luminosity measurement – 0.8% (world record accuracy for pp collider)

$$\mathcal{L}_Z = \frac{N_Z}{\sigma_Z}$$

Monte Carlo correction factors and data-driven efficiencies are applied

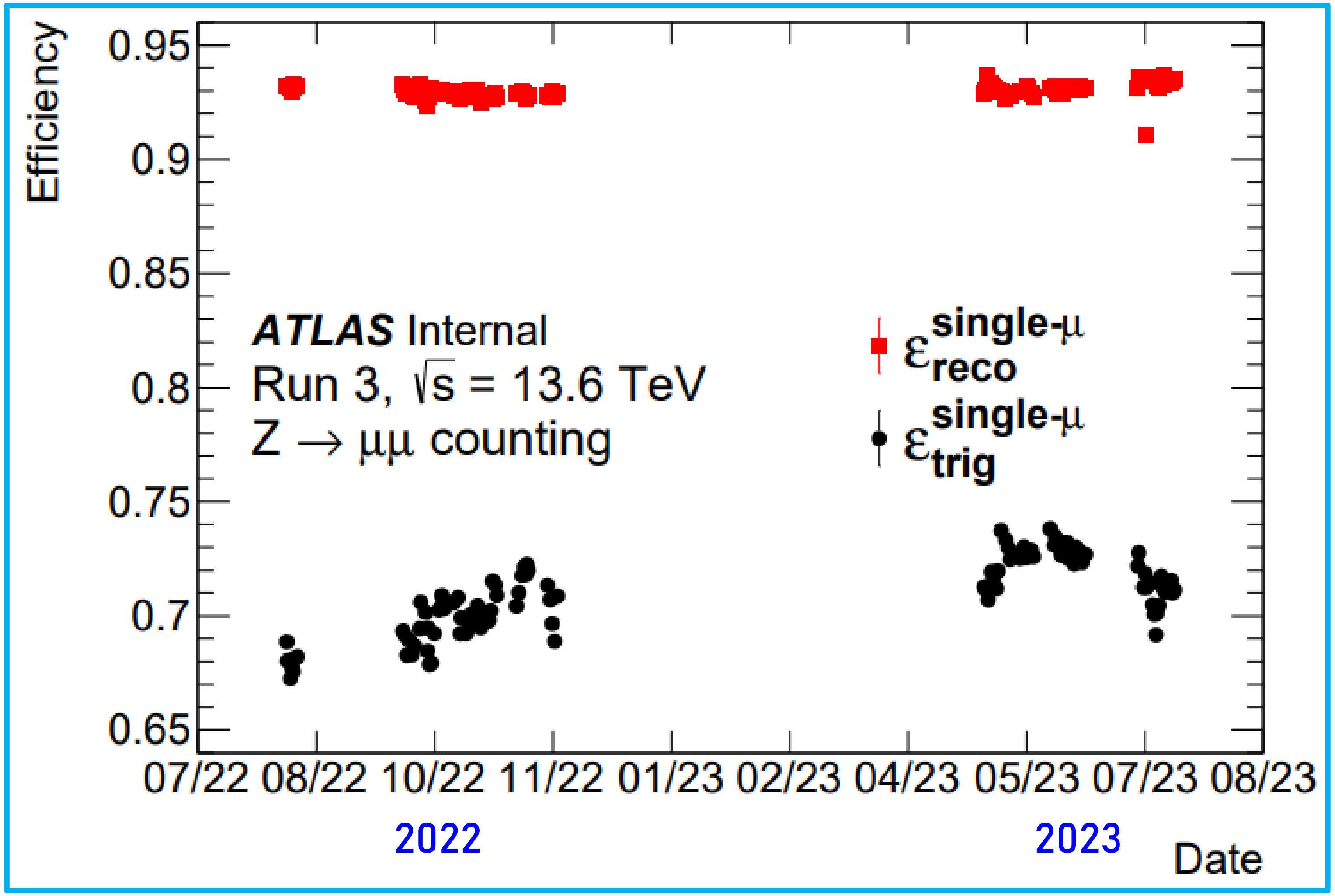
$$\mathcal{L}_Z(\Delta t) = \frac{N_{Z\to l^+l^-}(\Delta t) \times (1 - f_{bkg})}{F^{\mathrm{MC}}(\mu) \times A^{\mathrm{MC}} \times \epsilon^{T\&P}_{Z\to l^+l^-}(\Delta t) \times \sigma_{theory} \times \Delta t}$$

- Pileup-dependent Monte Carlo correction factors account for non-closure between data-driven reconstruction efficiency and the true ratio of reconstructed leptons to the true number of leptons given by Monte Carlo simulation
- Data-driven efficiency uses a combination of single-lepton reconstruction and trigger efficiencies to provide a full time and pileup-dependent, event-level efficiency

[1] Luminosity determination in pp collisions at √s = 13 TeV using the ATLAS detector at the LHC. Eur. Phys. J. C 83 (2023) 982

Z-Counting – Data-Driven Efficiency

$$\varepsilon^{T\&P}_{Z\to l^+l^-} = \left(1-(1-\varepsilon_{\mathrm{trig},\,1l})^2\right) \times (\varepsilon_{\mathrm{reco},\,1l})^2$$

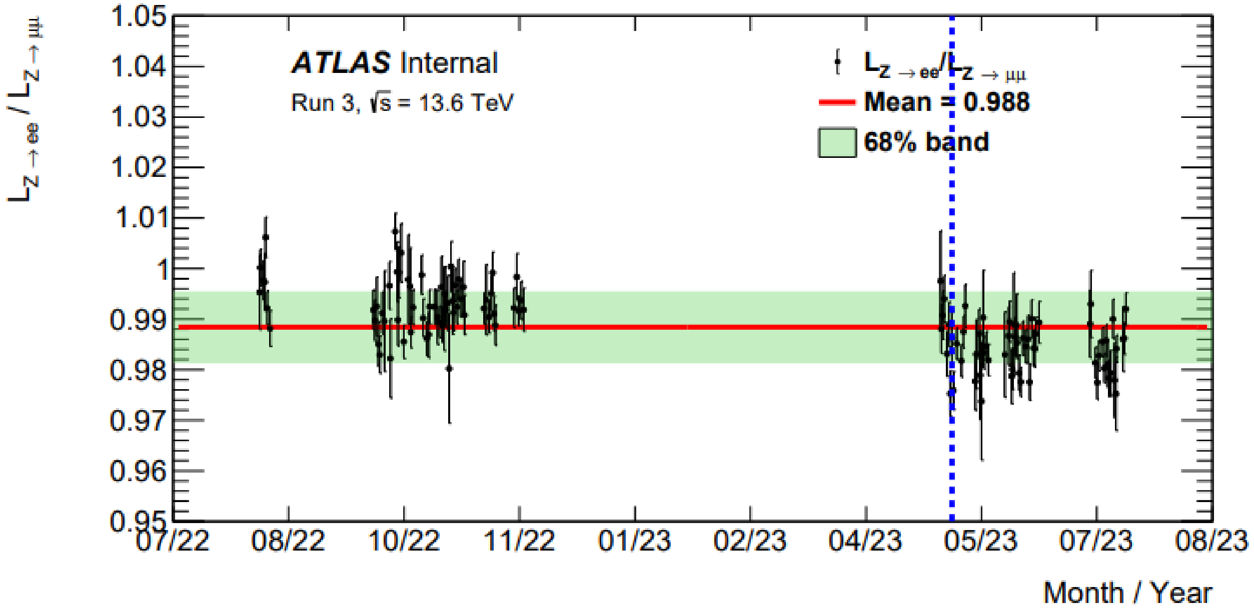


- Single-lepton reconstruction and trigger efficiencies are monitored on a short time basis (~ every 60s)
- Must be monitored in-situ due to small changes through time

Z-Counting – Luminosity Measurements

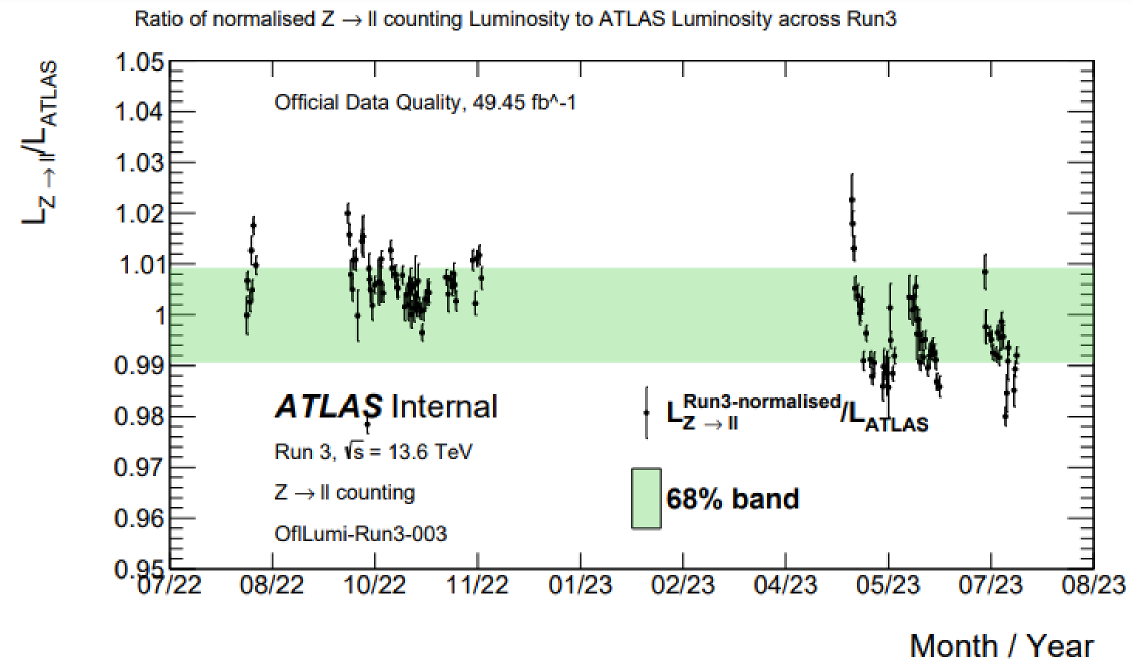
$\mathcal{L}_{e^+e^-}/\mathcal{L}_{\mu^+\mu^-}$ Ratio

- Provides a powerful cross-check for the individual methodologies of each channel (since efficiencies and acceptances are determined in different ways)



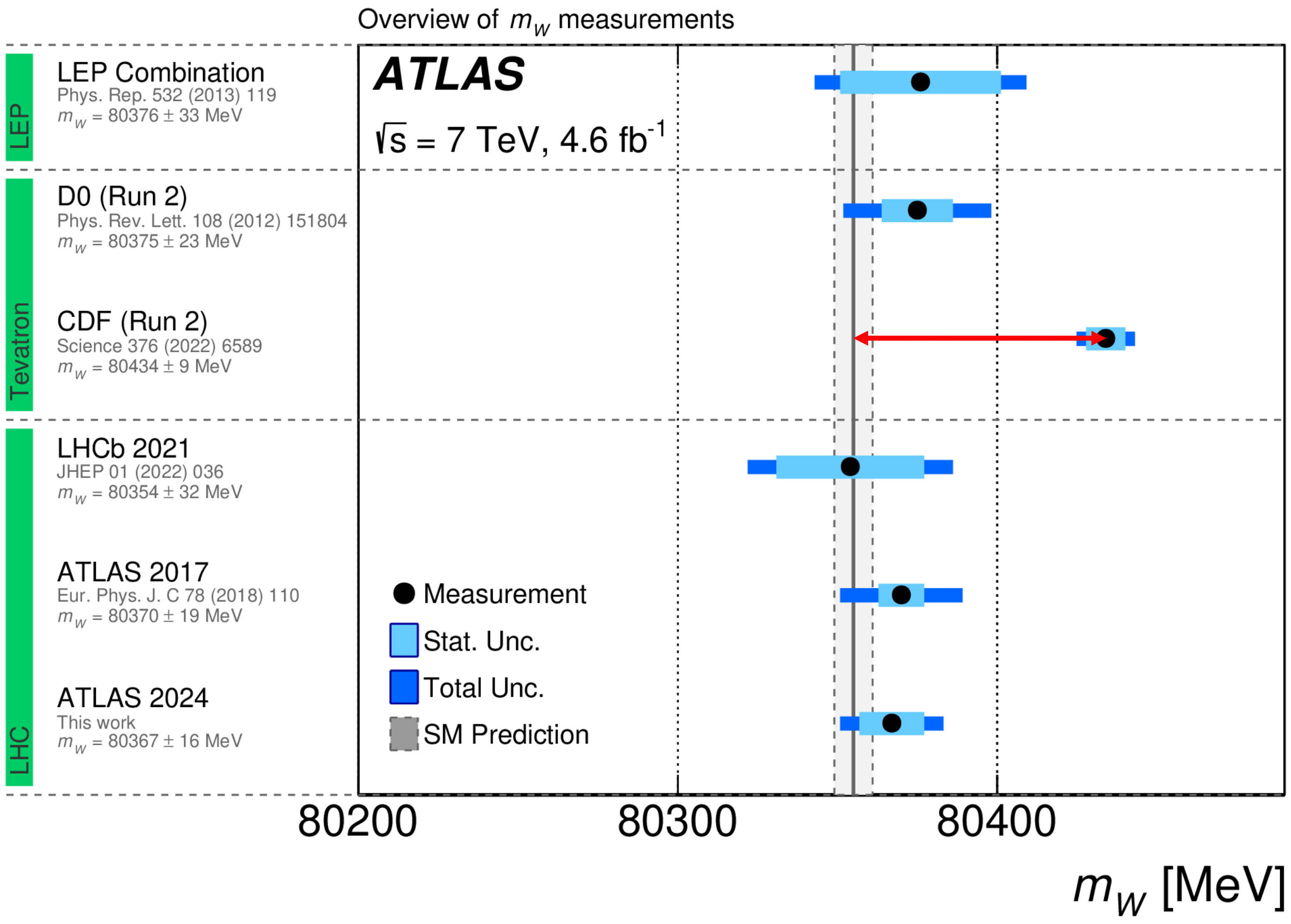
$\mathcal{L}_{l^+l^-}/\mathcal{L}_{ATLAS}$ Ratio

- Gives a direct comparison of Z-counting luminosity to ATLAS preferred luminosity



- $\mathcal{L}_{e^+e^-}/\mathcal{L}_{\mu^+\mu^-}$ ratio close to 1 – methodologies are under control at 1% level
- $\mathcal{L}_{l^+l^-}/\mathcal{L}_{ATLAS}$ ratio shows a spread of <1% across 2022/23 – comparable to Run 2 yearly calibration uncertainty

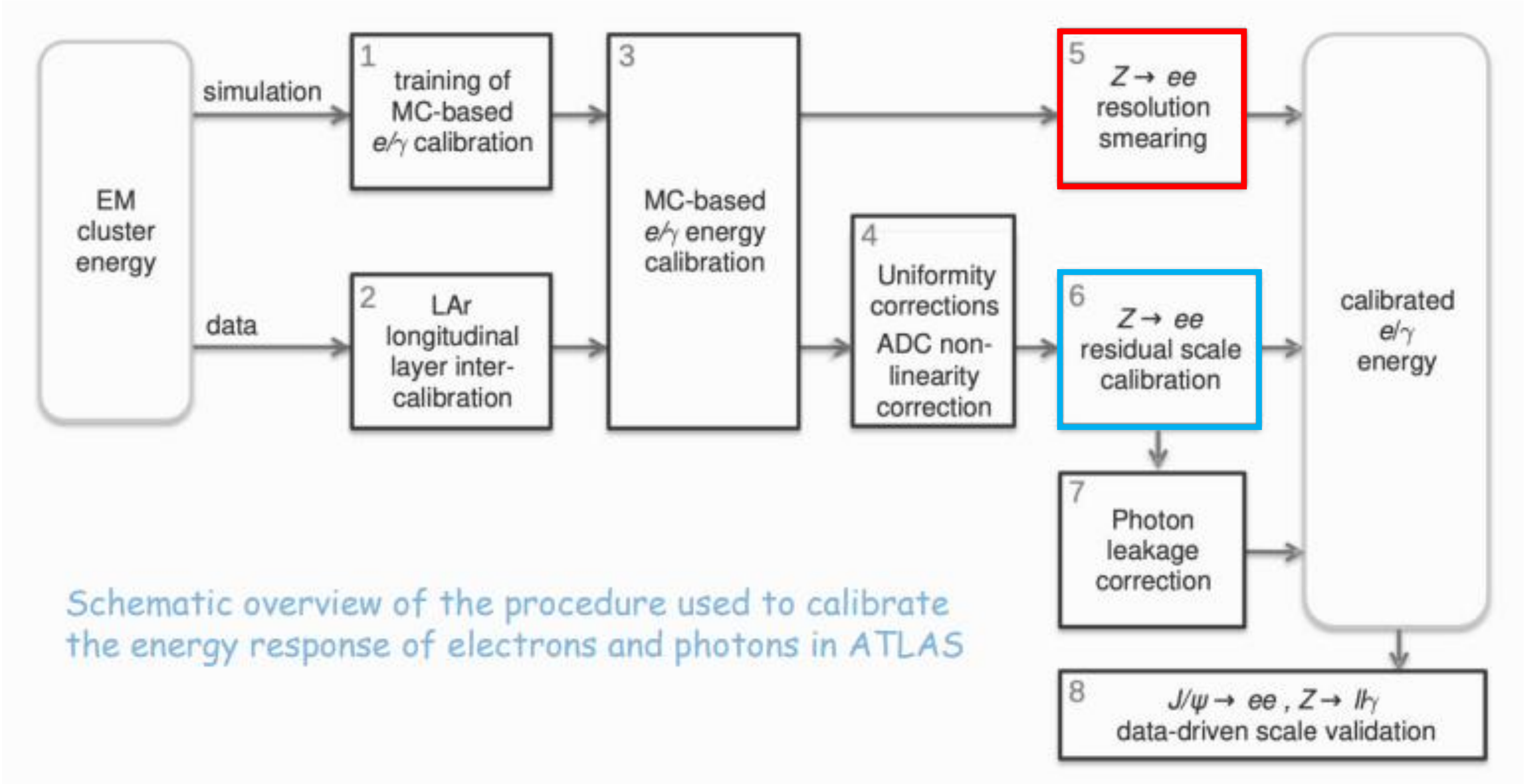
W Mass – Main Thesis Project



- My work so far: Electron energy calibration – precise m_W measurement requires calibration of EM calorimeter response

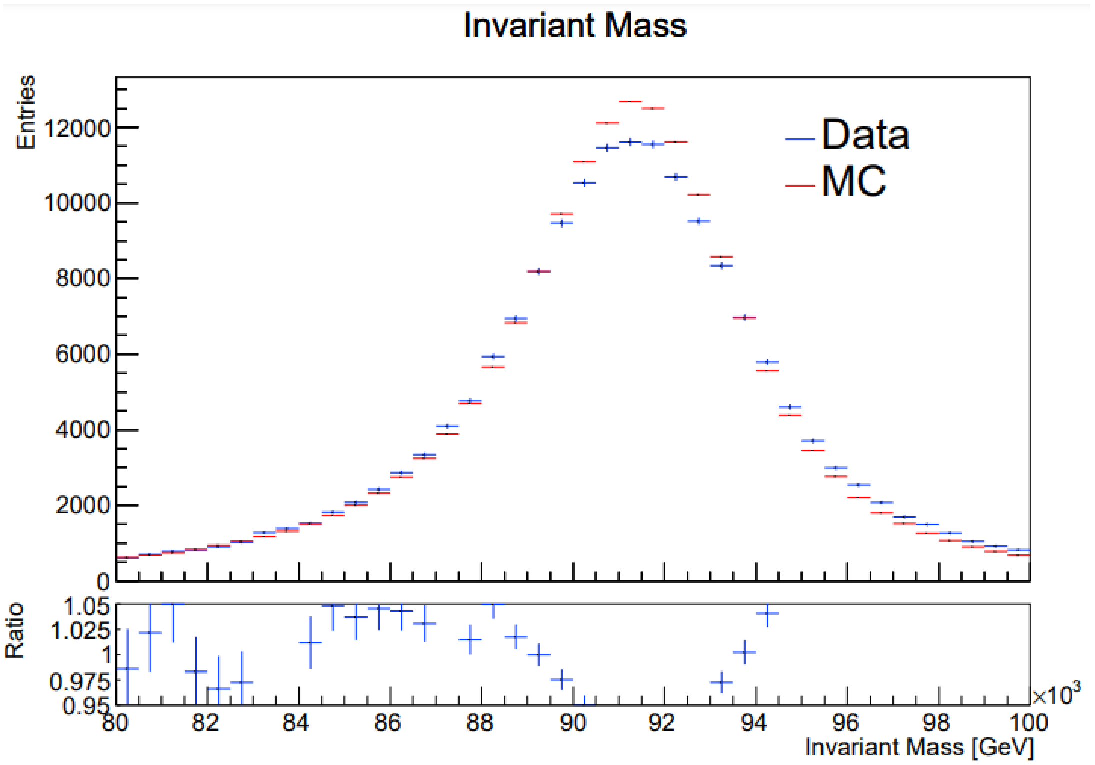
- Using special low-pileup ($\mu < 2$) runs from Run 2 at 5 and 13 TeV – aiming for similar ($\delta m_W \sim 15$ MeV) uncertainty

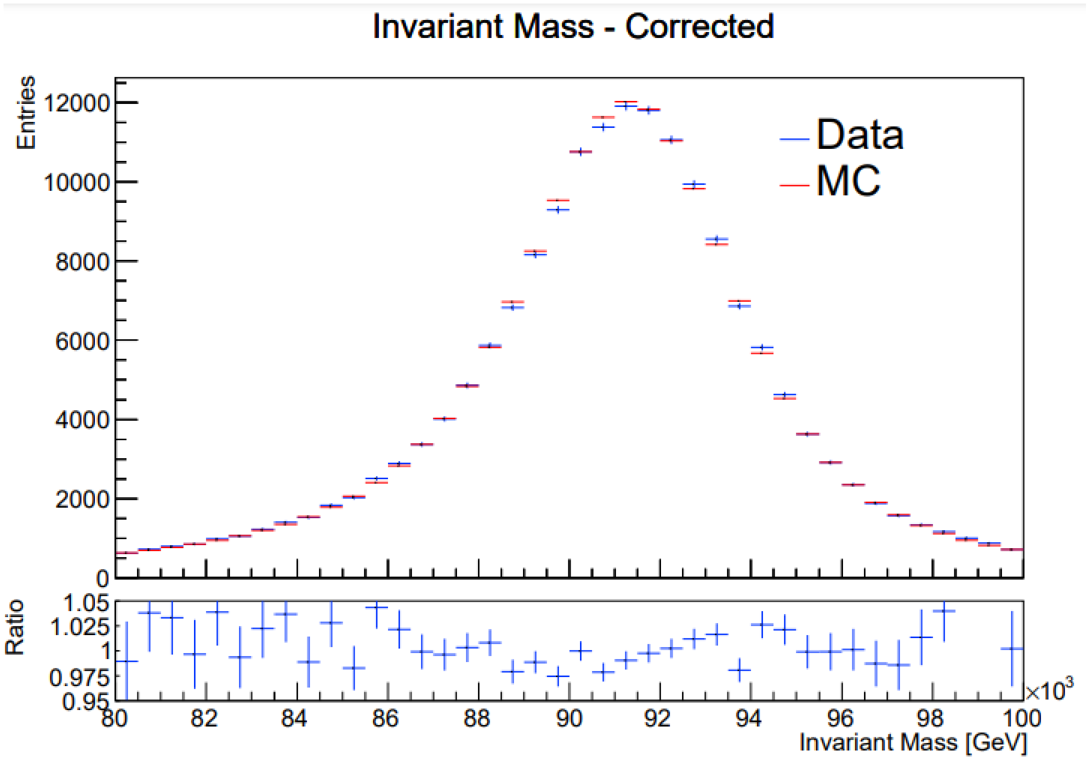
Electron Calibration



- Calibration is performed using low pileup Z mass resonance data at 5 and 13 TeV:
  - Gaussian Smearing, c (constant term): $$\left(\frac{\sigma(E)}{E}\right)^{data} = \left(\frac{\sigma(E)}{E}\right)^{MC} \oplus c(\eta^{calo})$$
  - Energy Shift, α (scale factor): $$E^{data} = E^{MC}\left(1 + \alpha(\eta^{calo})\right)$$

Electron Calibration





- Invariant mass distribution of Z $\rightarrow e^+e^-$ events before and after calibration
- Application of calibration coefficients brings data and MC lineshapes inline with each other
- Systematic uncertainties extracted from electron calibration results – consistent with total m_W target precision

Conclusion

Z–counting:

- Transferred methodology from Run 2 (13 TeV) to new ATLAS data at 13.6 TeV – full 2022 and 2023 datasets processed and analysed
- ATLAS author – continuing to work with luminosity team through 2024 data–taking

W Mass – Main thesis project:

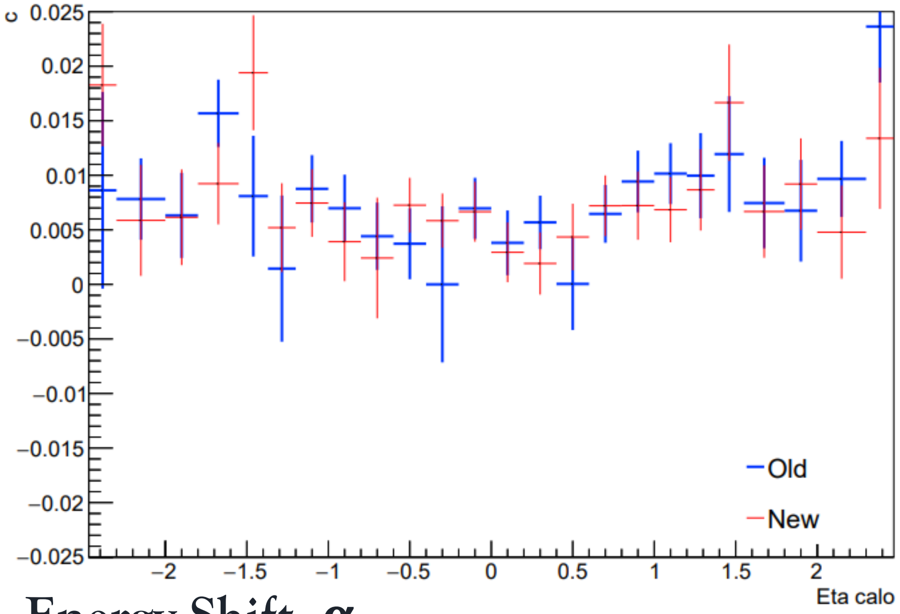
- Finished 1st W mass task: electron calibration for electromagnetic calorimeter response using low–mu dataset at 5 and 13 TeV – systematic uncertainties successfully extracted
- Further work will focus on reducing dominant systematic uncertainties resulting from W boson production modelling and knowledge of proton structure
- Currently working at DESY, Hamburg for 2 years

Backup – Why Z bosons?

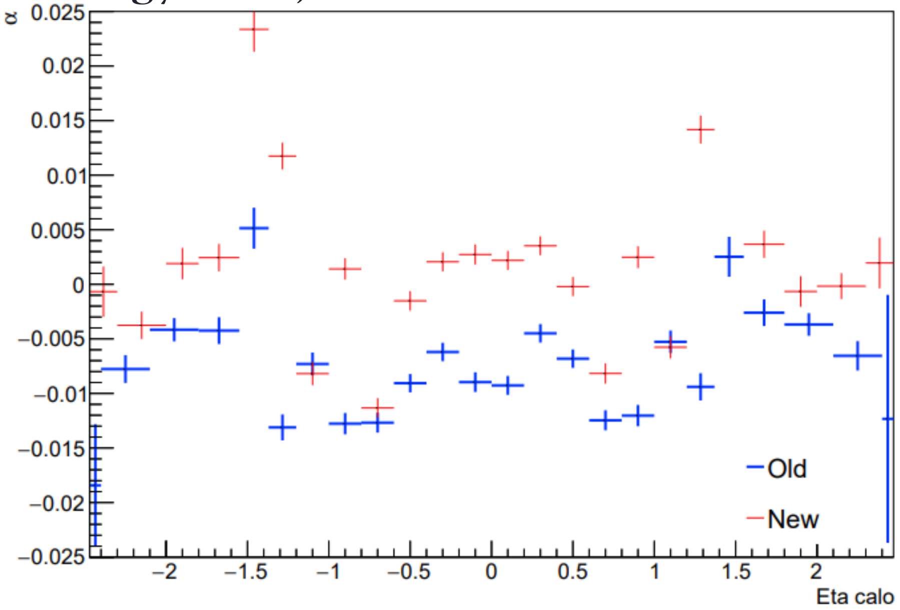
- Experimentally clean signature in electron and muon channels, even at high pileup (μ, number of simultaneous proton-proton interactions per bunch crossing)
- Good theoretical understanding of Z production and decay with production cross section known to high precision

Backup – Electron Energy Calibration Coefficients

Gaussian Smearing: c



Energy Shift, α



- Calibration results (α and c) as a function of psuedorapidity
- Global upward shift in α is expected due to new E1/E2 correction (same effect is seen at high mu)
- Both results compared to previous results using old model

Backup – Electron Energy Systematics