Precise Muon Momentum Measurement and Calibration Using the ATLAS Detector

Muons are identified by combining information from the Inner Detector (ID) and Muon Spectrometer (MS) detectors. About 96% of muons are reconstructed by fitting hits from ID and MS tracks.
In order to precisely measure the momentum of muons, two types of corrections are applied:
- Scale correction and smearing in simulation, based on template fitting on the invariant mass distribution of $\mu^-\mu^+$ pairs at the Z and J/ψ poles.
- Correction of local charge-dependent momentum scale biases in data, only corrects p_T^- vs p_T^+, leaving the di-muon scale invariant.

Inner Detector (ID) and Muon Spectrometer (MS)
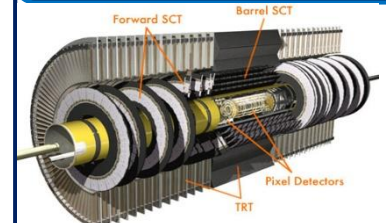
ID provides accurate measurements of the track parameters with acceptance of $|\eta|<2.5$ operating in a 2T solenoidal field.
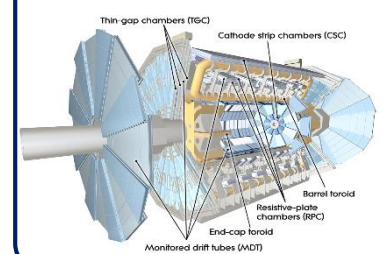
MS provides independent measurements of muon momentum with acceptance of $|\eta|<2.7$ using air core 0.6 T toroidal magnets

Scale Correction and Smearing

Δs_0:Energy loss in calorimeter and other materials, MS only

Δs_1:Magnetic field integral and radial distortions of the detector

$$p_T \to \frac{\Delta s_0 + (1 + \Delta s_1) \cdot p_T}{G(1, \sqrt{(\Delta r_0/p_T)^2 + \Delta r_1^2 + (\Delta r_2 \cdot p_T)^2})}$$

Δr_0:Energy loss fluctuations in the material, MS only

Δr_1:Multiple scattering, local radial distortions and local distortions of magnetic field

Δr_2:Intrinsic resolution and misalignments

Charge-dependent Corrections

Certain systematic misalignment modes can cause sagitta changes, for example, the curl and the twist changes, biasing the measured p_T of positive and negative muons in opposite directions. This effect is dominant in data of prompt reconstruction and that after inclusion of the effect in the alignment procedure the bias is greatly reduced. Sagitta biases cause a mass shift for charge asymmetric final states.

(a) curl   (b) twist

The sagitta bias correction is applied in data:

$$p_T \to \frac{\tilde{p}_T}{1 + q\tilde{p}_T \delta_s}$$
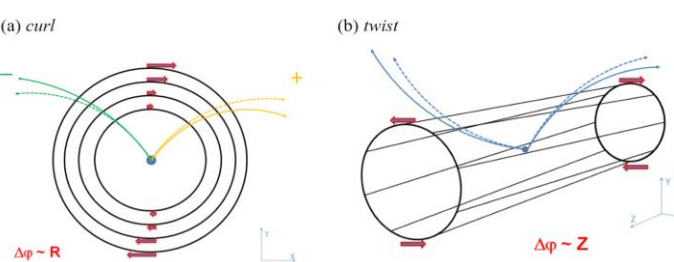
These misalignment modes leave the track chi-square unchanged.
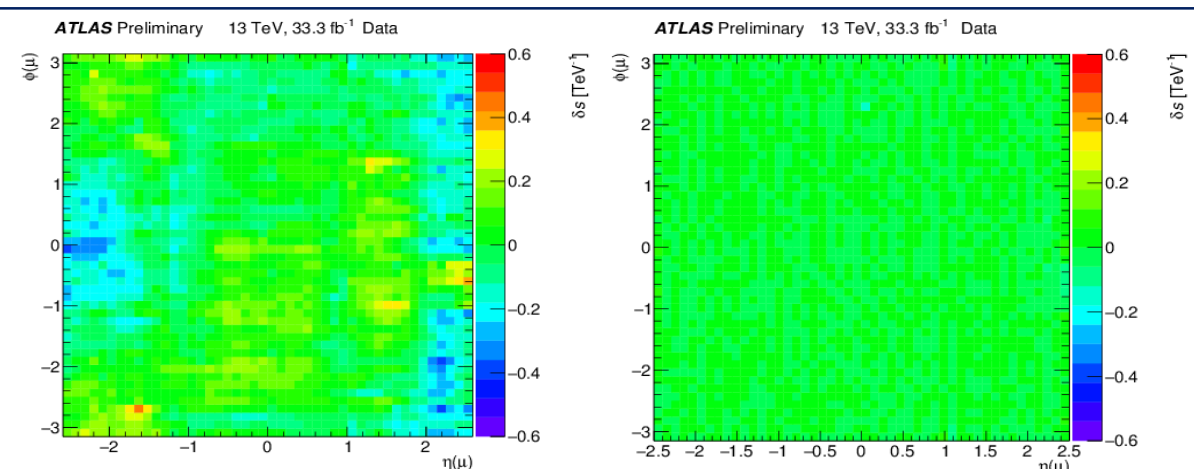
Local sagitta bias δs for combined muons as a function of η and φ evaluated from $Z \to \mu^-\mu^+$ decays with transverse momentum ranging from 5 GeV to 300 GeV from 2016 data, before (left) and after (right) sagitta bias correction. After the correction the residual bias is < 0.05 TeV⁻¹.
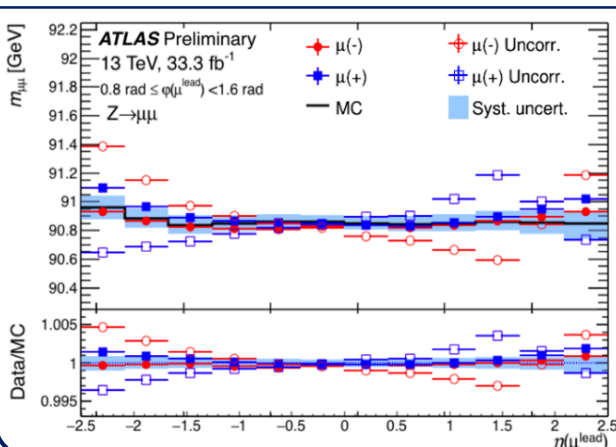

Invariant mass of $\mu^-\mu^+$ pairs as a function of η of leading μ^+ and μ^- in one phi region, before and after sagitta bias correction from 2016 data and simulation sample.

Scale and Resolution

The plots show the momentum scale and resolution of $\mu^-\mu^+$ pairs as functions of pseudo-rapidity of the leading muon obtained from reconstructed $Z \to \mu^-\mu^+$ candidates after all correction applied.
Systematic uncertainties (filled area), from energy loss modelling and imperfect modelling of second order effects in the momentum parametrization, are derived from ±1σ variations of the parameters used to derive the correction. The smallest uncertainty on scale is about 0.5‰ in central and up to 2 ‰ in forward region, on resolution is 5% in central and up to 20% in forward region.

Left two plots show the comparison of momentum scale and resolution between data and MC from 2016 33.3 fb⁻¹ full year data, and right two from 2017 15.4 fb⁻¹ data, after all corrections.
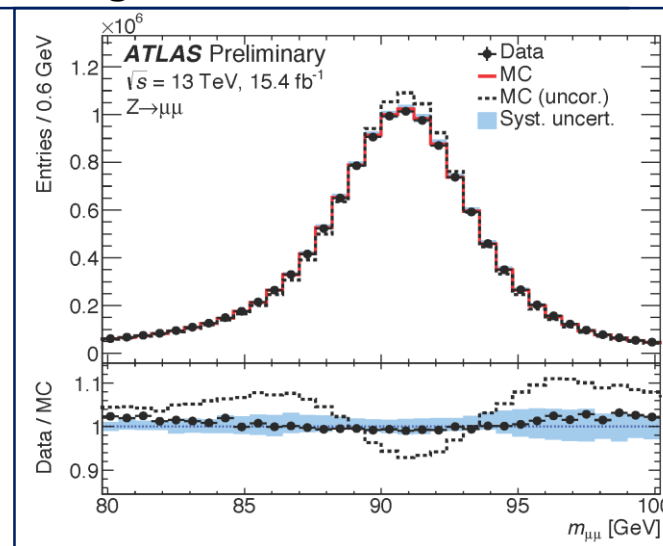
Invariant mass distribution of $\mu^-\mu^+$ pairs at the Z pole from 2017 data and simulation sample before and after correction.

Weitao Wang (University of Science and Technology of China) on behalf of the ATLAS Collaboration

ATLAS EXPERIMENT