Muon Momentum Scale and Resoulution Calibration for CMS

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The precise calibration of the muon transverse momentum (p_{T}) is a key requirement for physics analyses at the CMS experiment. The measurement of p_{T} relies on the curvature of charged-particle tracks in the magnetic field, and is therefore sensitive to residual tracker misalignments, local variations of the magnetic field map, and simulation imperfections. These effects introduce systematic distortions that manifest as **momentum scale biases** and **resolution mismodelling**, both of which must be corrected to achieve reliable comparisons between data and simulation.

For the **scale calibration**, two parameters are defined in bins of azimuthal angle ϕ and pseudorapidity η: a multiplicative factor $\kappa(\phi, \eta)$, which accounts for magnetic field mismodelling, and an additive parameter $\lambda(\phi, \eta)$, which corrects for detector misalignments:

$$\left(\frac{1}{p_{\mathrm{T}}}\right)_{\mathrm{corr}} = \frac{\kappa}{p_{\mathrm{T}}} + Q \cdot \lambda. \tag{1}$$

Their initial values are obtained from curvature distributions ($1/p_{\mathrm{T}}$) of reconstructed muons and are iteratively tuned by aligning the invariant mass peaks of $Z \to \mu\mu$ and $J/\psi \to \mu\mu$ resonances with those at generator level. This procedure ensures consistent peak positions across data and simulation.

The **resolution calibration** is derived by studying the ratio $p_{\mathrm{T}}^{\mathrm{RECO}}/p_{\mathrm{T}}^{\mathrm{GEN}}$ in simulation, extracting a parametrization of detector resolution effects. Residual differences between data and simulation are corrected by applying an additional smearing factor, optimized with the dimuon invariant mass spectrum. In total, eight parameters govern the resolution correction, ensuring that reconstructed distributions reproduce the detector performance observed in data.

The effectiveness of this approach is directly visible in the dimuon invariant mass spectra: before calibration, significant shifts and broadenings of the Z and J/ψ peaks are observed, while after applying the scale and resolution corrections, data and simulation exhibit excellent agreement (see Figures 1–1).

The calibration procedure has been implemented in the **Muon ScaReKIT**, a transparent and efficient toolkit maintained within CMS. Its application for Run 3 data substantially reduces systematic uncertainties and ensures robust modelling of muon momentum scale and resolution across the detector acceptance.

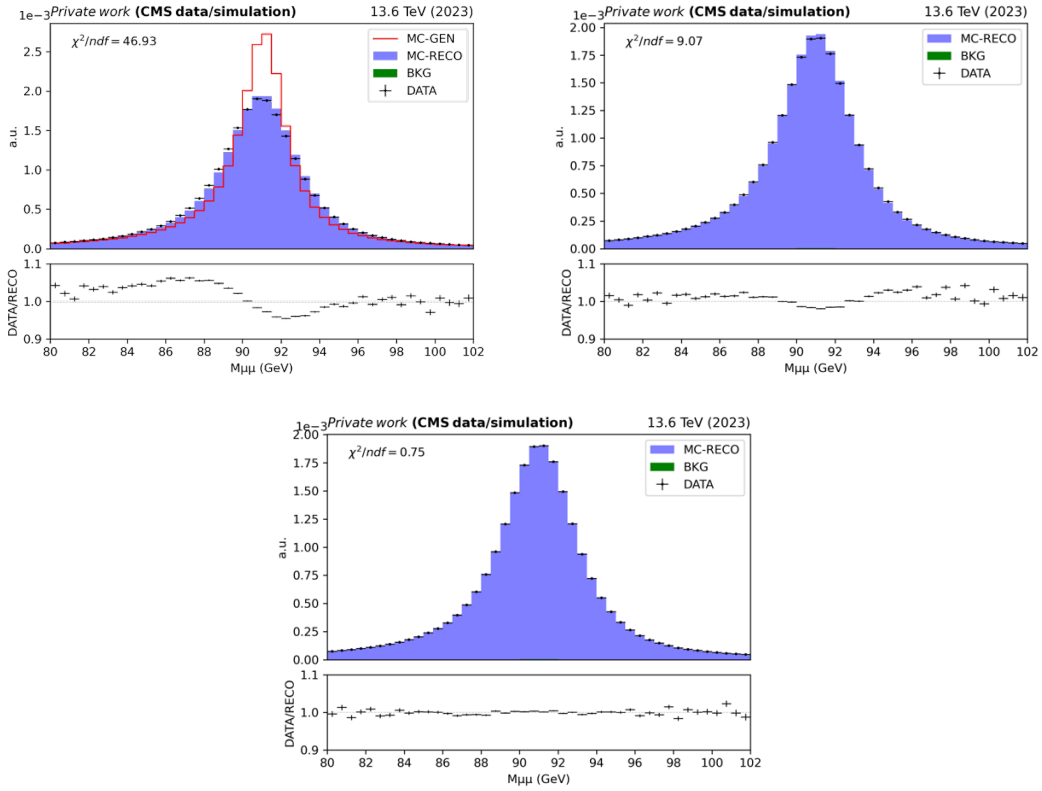

Abbildung 1: Dimuon invariant mass spectra before calibration (top left), after scale calibration (top right), and after scale+resolution calibration (bottom).