Charge-dependent curvature bias corrections using a pseudomass method

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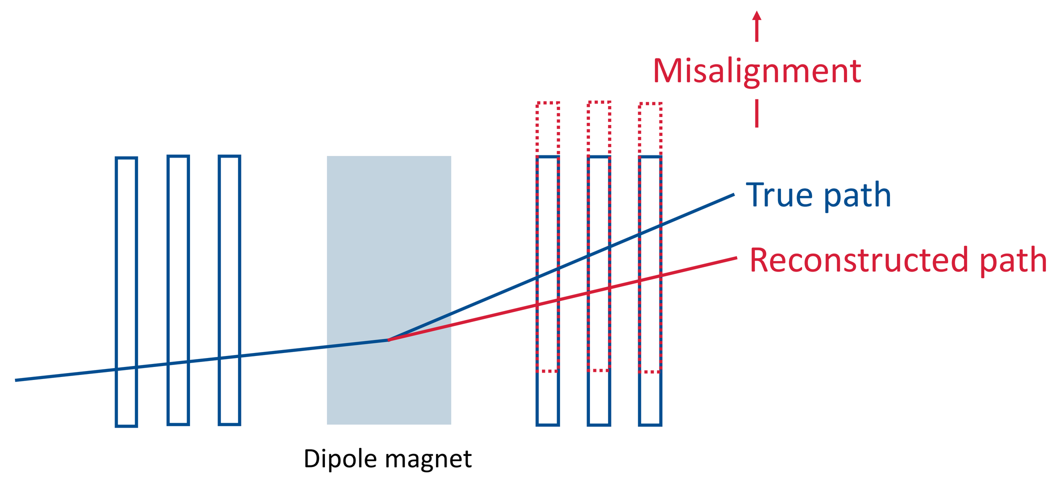
The LHCb detector's unique forward coverage allows it to provide measurements of electroweak (EW) physics in a complementary region of phase space to other LHC experiments. However, high precision EW measurements are extremely sensitive to detector misalignment effects, such as the one shown in the sketch. For example, a 5 µm translational misalignment can lead to a 50 MeV bias in the measurement of m_W. Therefore, a method of correcting for such biases is required – the **pseudomass ($M^{\pm}$) method**.



The pseudomass method

- Detector misalignments can cause a charge-dependent curvature bias:

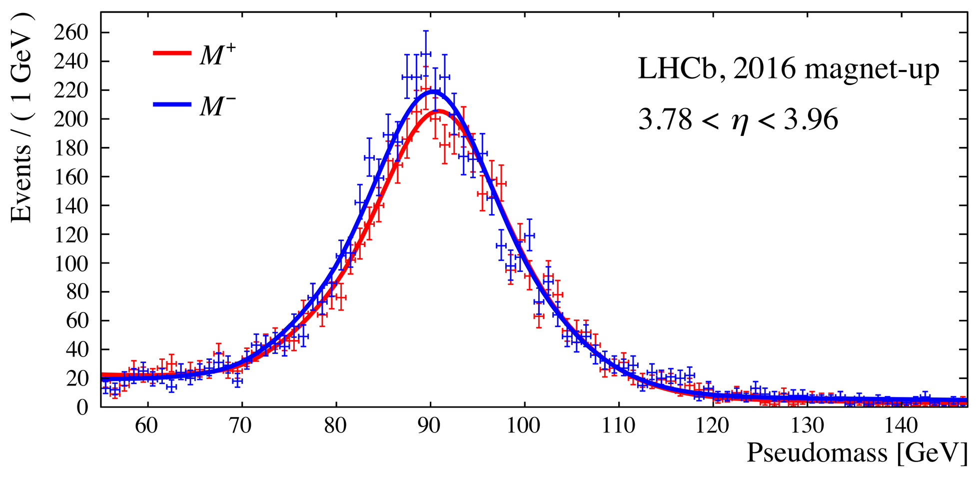
$$\frac{q}{p} \rightarrow \frac{q}{p'} = \frac{q}{p} + \delta$$

- We can correct for these curvature biases using the **pseudomass method**
- Z bosons tend to be produced with low transverse momentum (p_T), and so for $Z \rightarrow \mu^+\mu^-$ decays, conservation of momentum implies $p_T^+ \approx p_T^-$
- Allows us to derive an approximation for the dimuon invariant mass ($m_{\mu\mu}$) which uses the **momentum of one μ** and only the **direction of the other**:

$$M^{\pm} \equiv \sqrt{\frac{p_T^{\pm}}{p_T^{\mp}}}\, m_{\mu\mu} = \sqrt{2p^+p^- \frac{p_T^{\pm}}{p_T^{\mp}}(1-\cos\theta)} = \sqrt{2p^{\pm}p_T^{\pm}\frac{p^{\mp}}{p_T^{\mp}}(1-\cos\theta)}$$

- δ is proportional to the asymmetry in the peak position of the M^+ and M^- distributions:

$$\delta = -\frac{A}{2}\left(\left\langle\frac{1}{p^+}\right\rangle + \left\langle\frac{1}{p^-}\right\rangle\right)$$



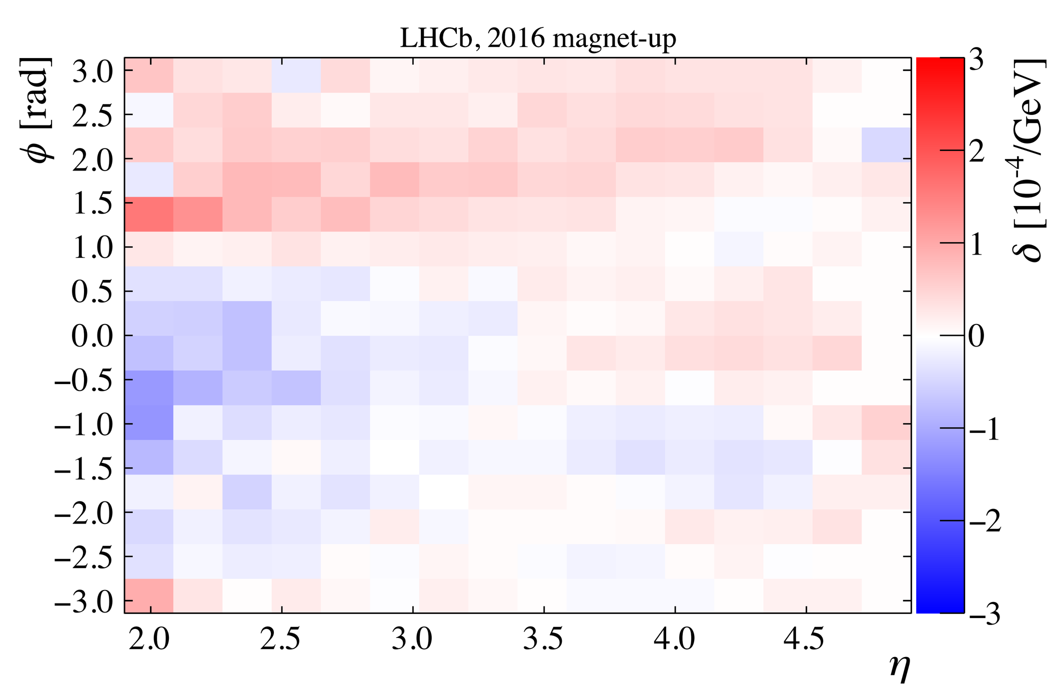
- This allows δ to be mapped across the detector and the measured momenta can then be corrected to remove the misalignment effects

Determining the curvature biases

- The approximation $p_T^+ \approx p_T^-$ is not perfect, resulting in small biases in the peak positions of M^+ and M^-
- MC corresponds to **"perfect" detector alignment** ⇒ δ_{MC} contains information about this physics bias
- To avoid including this physics bias in δ, it is calculated as

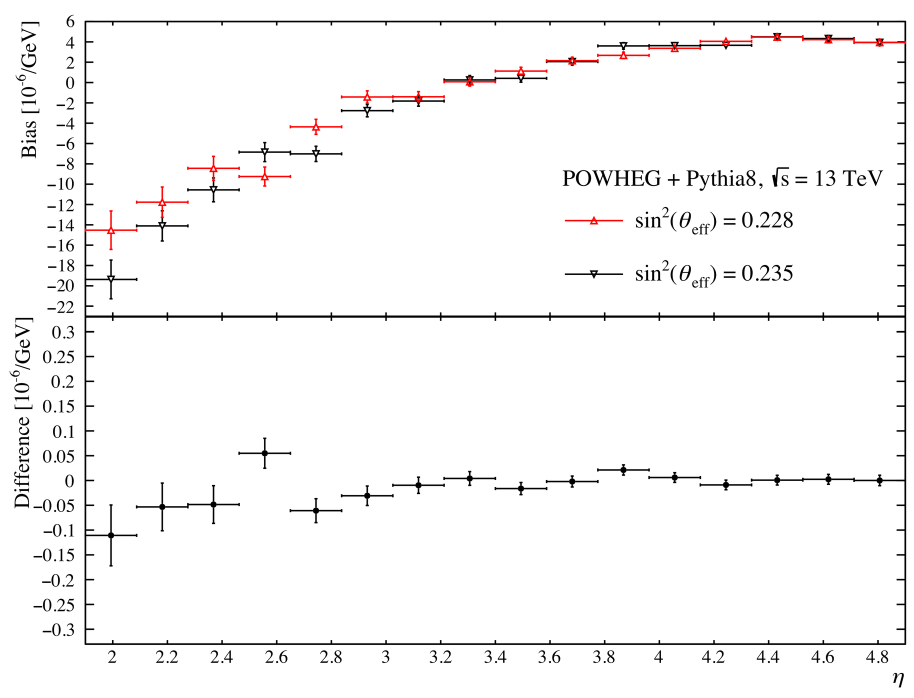
$$\delta = \delta_{\text{data}} - \delta_{\text{MC}}$$

- δ_{MC} are 1 – 2 orders of magnitude smaller than δ_{data} ⇒ the **effect of the physics bias is much smaller than the curvature biases** that we are correcting for
- Curvature biases determined separately for each **magnet polarity** and **data-taking period**, in bins of **pseudorapidity** and **azimuthal angle**



Biases from fundamental physics

- Different p_T of the positive and negative muons from a $Z \rightarrow \mu^+\mu^-$ decay mediated by the weak mixing angle (θ_W)
- Interested in measuring θ_W ⇒ corrections **shouldn't** depend on its modelling
- Verified using generator level simulation produced using $\sin^2\theta_W = 0.228$ and 0.235. These variations are ~ 40 times larger than the uncertainty of the world average value

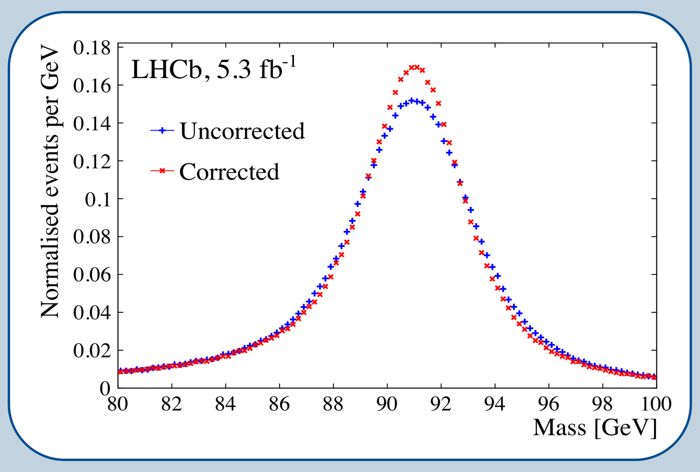


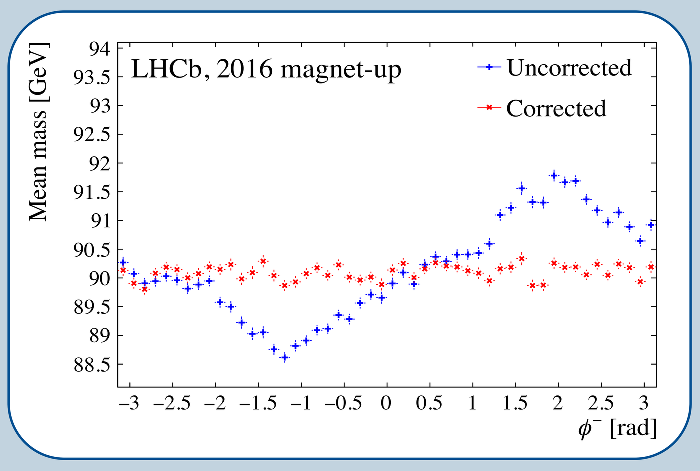
- Biases are much smaller than the corrections applied to data
- Varying $\sin^2\theta_W$ leads to consistent sets of biases

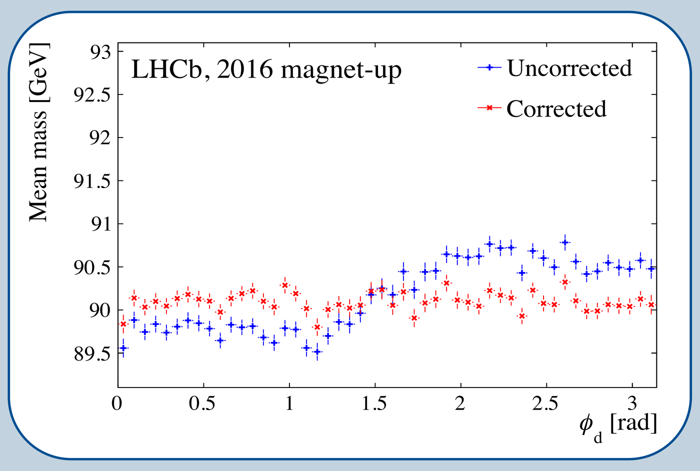
⇒ **Physics modelling has negligible impact** on the implementation of the pseudomass method

Impact of corrections

$Z \rightarrow \mu^+\mu^-$

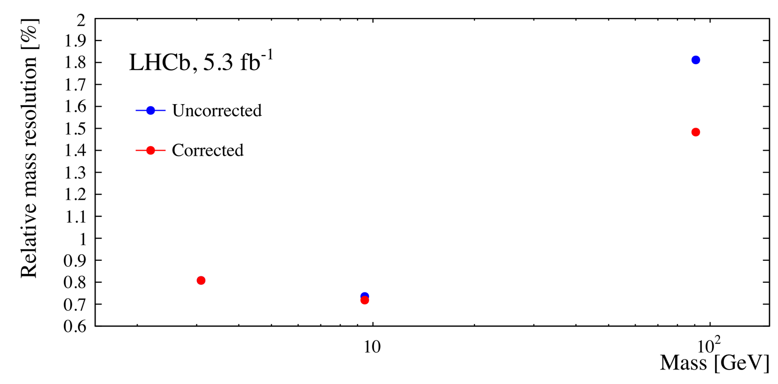






$\phi_d = \cos^{-1}\left(\frac{\vec{D}\cdot\vec{B}}{|\vec{D}|}\right)$, where $\vec{D} = \vec{p}_+ \times \vec{p}_-$ and $\vec{B}$ is the magnetic field

- Relative mass resolution of the J/ψ, $\Upsilon(1S)$ and Z mass peaks with and without the pseudomass method applied:



- **$O(20\%)$ improvement** in the resolution of the width of the Z mass peak
- Reduced impact for lower momentum muons
- Detector misalignments lead to **non-physical trends** in the mean $m_{\mu\mu}$ as a function of angular variables → such trends are **removed by the pseudomass method**

References

[1] W. Barter, M. Pili, and M. Vesterinen, *A simple method to determine charge-dependent curvature biases in track reconstruction in hadron collider experiments*, Eur. Phys. J. **C81** (2021) 251, arXiv: 2101.05675 [hep-ex].
[2] LHCb collaboration, *Charge-dependent curvature bias corrections using the pseudomass method*, submitted to JINST, arXiv: 2311.04670 [hep-ex]