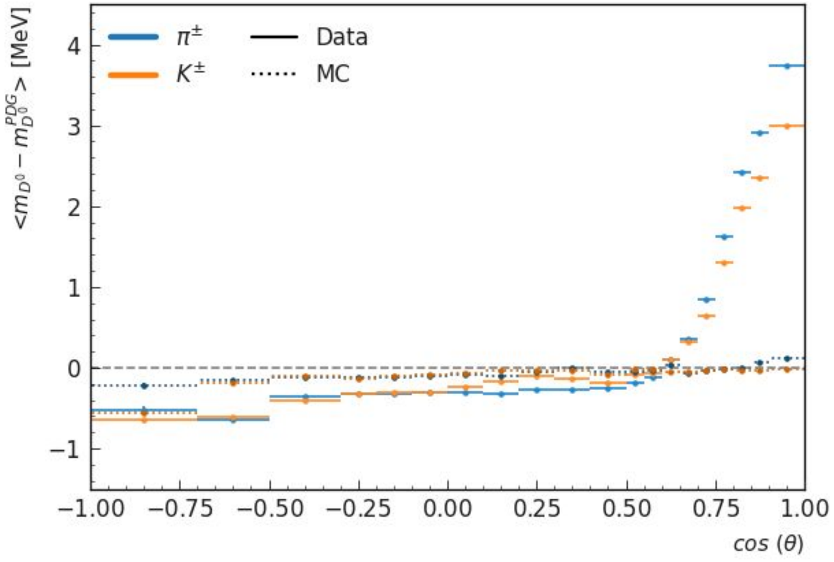
Track momentum scale and energy bias corrections

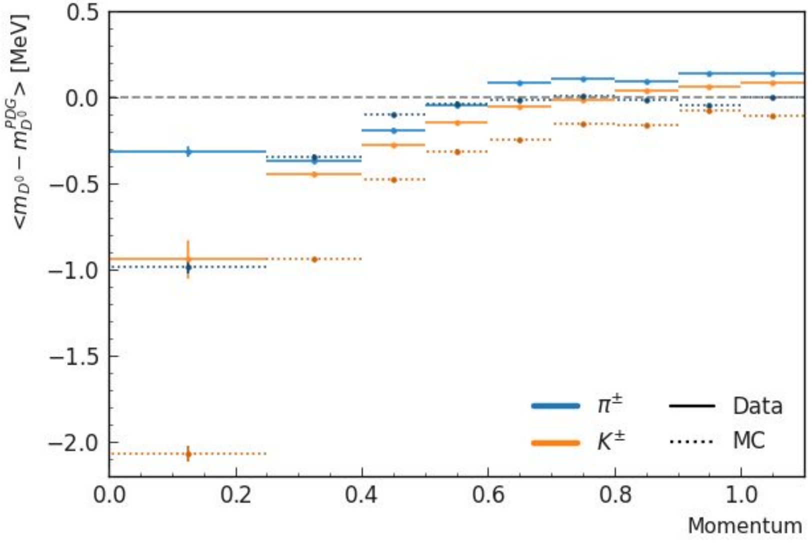
Run 1 Data & MC

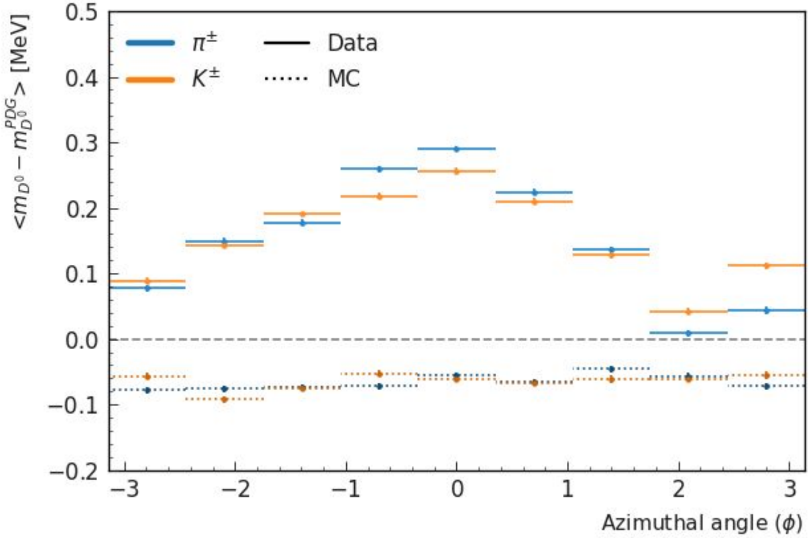
Raimundo Hoppe, Armine Rostomyan & Daniel Pitzl
Hamburg, 01.10.2024

Summary of the problem

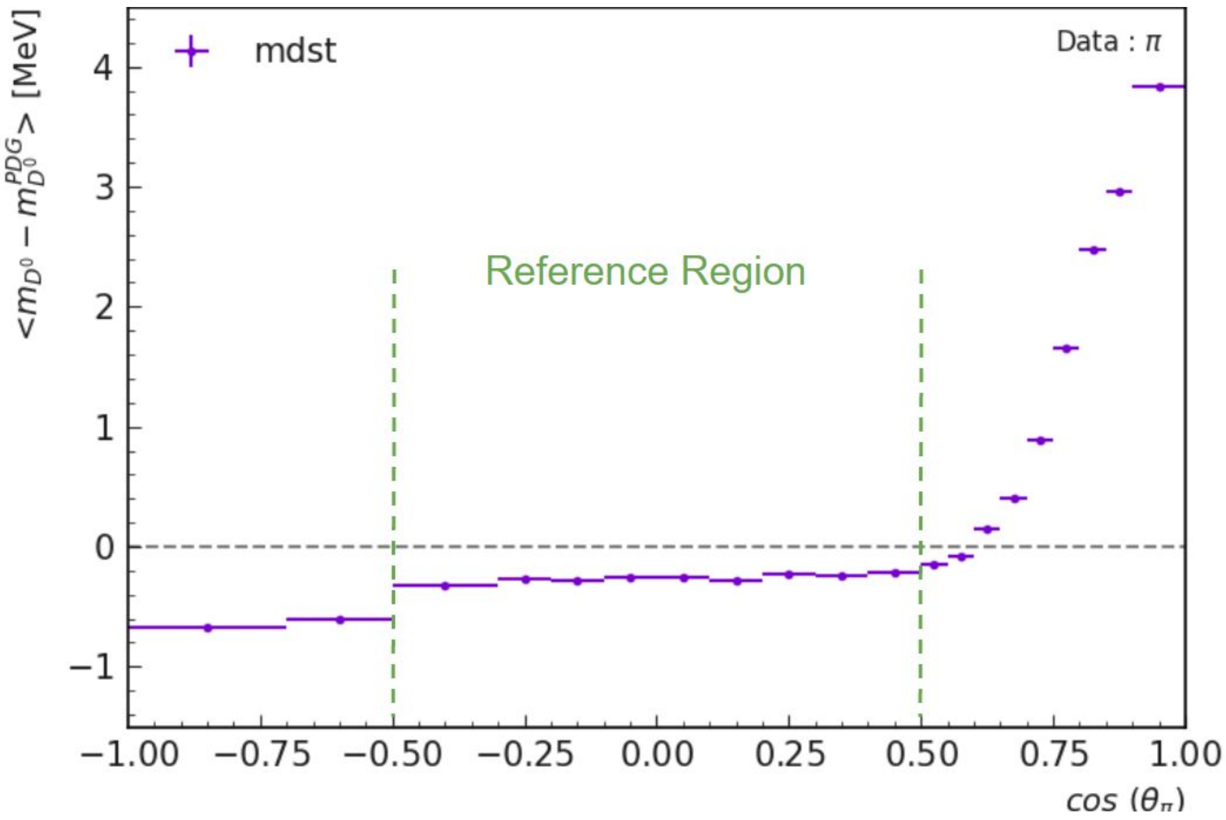
- A disparity between the reconstructed mass of particles and the PDG nominal values was found.
  - Polar angle (θ) ➡ Attributed to a misestimation of the detector magnetic field
    Corrected
    - Sample dependent (MC / Data)
  - Momentum ➡ Attributed to an insufficient energy loss correction due to detector material
    Corrected
    - Sample and Particle type dependent
  - Azimuthal angle (φ) ➡ Reason still unknown
    Not Corrected
    - Sample, Charge and decay topology dependent

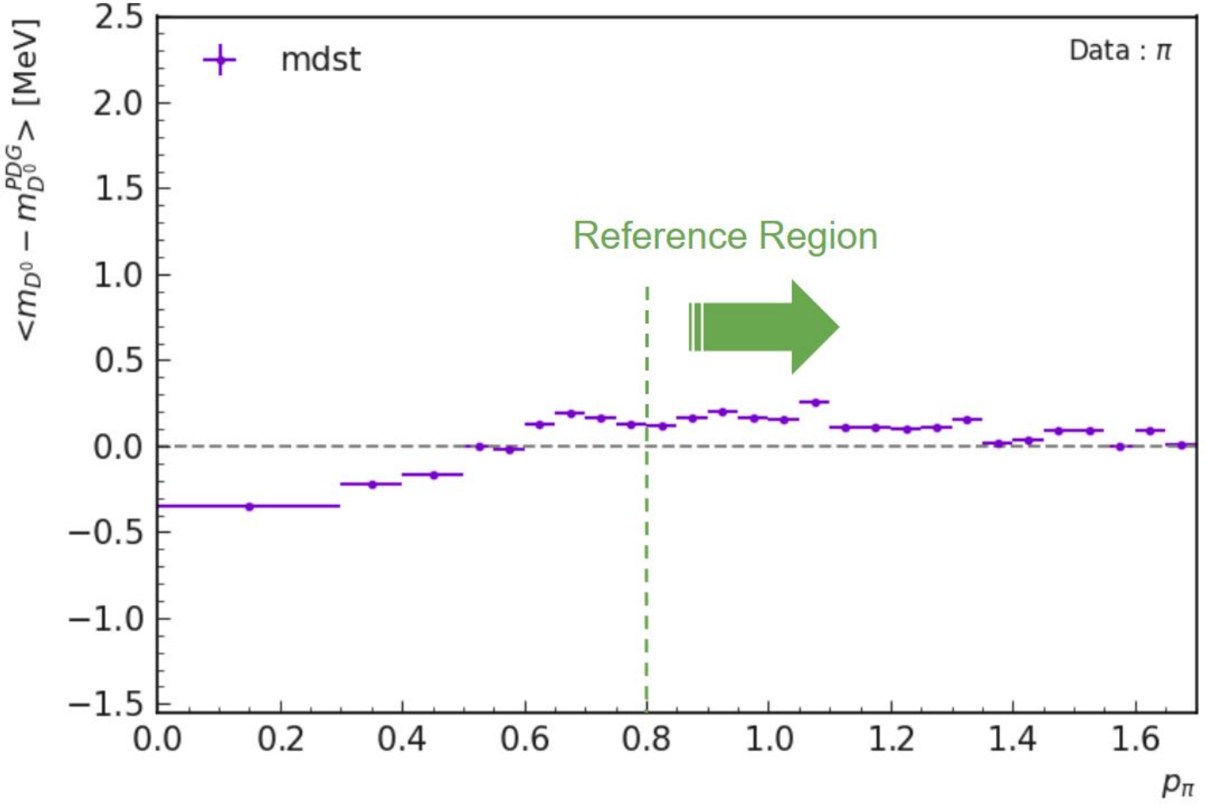






Reference Region





- We define a reference region, where the data shows the smallest deviation and the MC doesn't show any shift

  `-0.5 < cos(θ) < 0.5    &    p > 0.8 GeV`

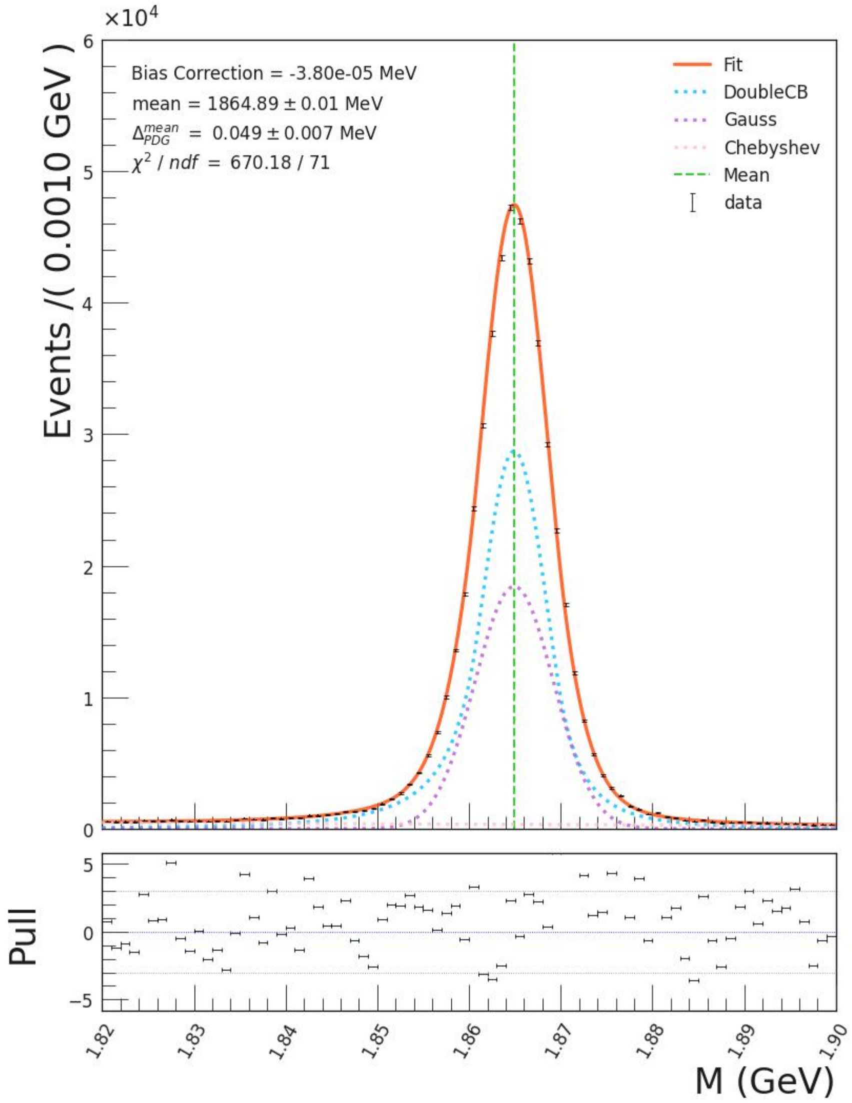
- When estimating the corrections for one particle, the other one is required to be within this reference region

PDF Choice

- Many functions were tested to find the one with the best fit
- The criteria for this selection included the minimization of both, the fit reduced χ^2 (at high and low statistics regimes) and the mass peak bias

  ➡Were the peak bias is taken as the deviation of the measured peak on MC within the reference region
- Each model includes a chebyshev polynomial to account for the nearly flat background

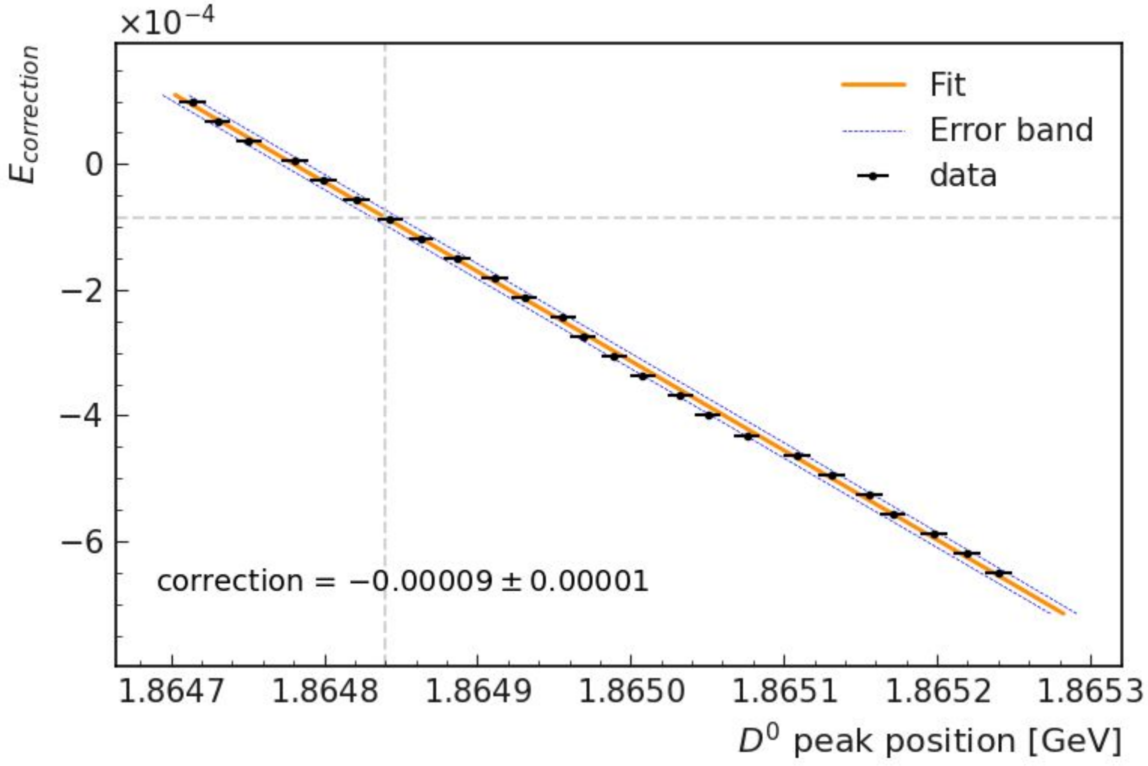
Models	Bias (Δ_{PDG} in Ref. region) [MeV]	reduced χ^2 Reference region	reduced χ^2 Data Bin example (low statistics)
Bifurcated Gaussian	0.022	24.9	5.75
skewed TStudent + Gaussian	−0.269	4.07	4.60
Crystal Ball + Gaussian	0.004	3.36	5.71
Double Crystal Ball + Gaussian	0.038	1.22	5.49



Estimating the Corrections

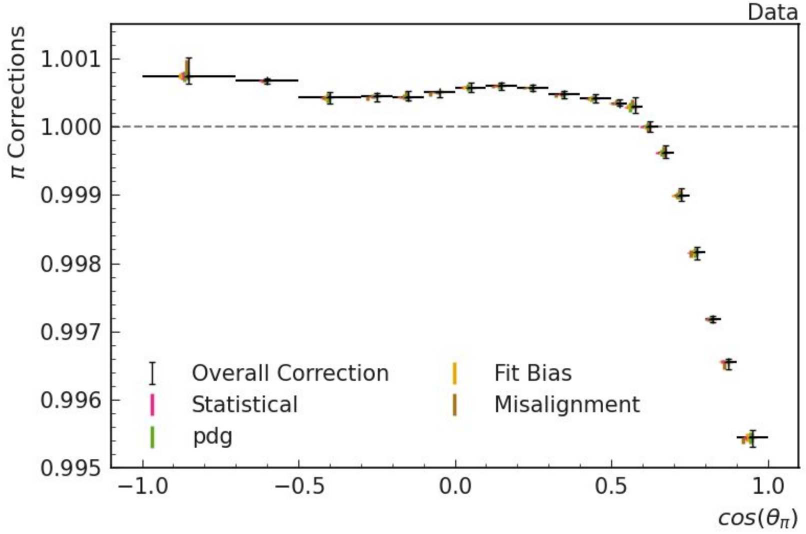
- Correction payloads were developed for the cos(θ) and momentum dependent shifts.
- The corrections for both were estimated in the same manner using $D^0 \rightarrow K^{\pm}\pi^{\mp}$ events.
- Correction estimation:
  1. The data is separated into bins [cos(θ) or p].
  2. A list of ‘N’ guess corrections is generated around the “identity correction”.
  3. In each bin the data is replicated ‘N’ times and each guess correction is applied to one of this copies.
  4. The mass peak position resulting from the fit in each replica is plotted against the guess correction that was used (scan plot on the right).
  5. A 1D polynomial is fitted to the resulting scan plot to extract the correction value corresponding to the PDG D^0 mass for each bin.
- Due to their nature, the corrections are performed differently:

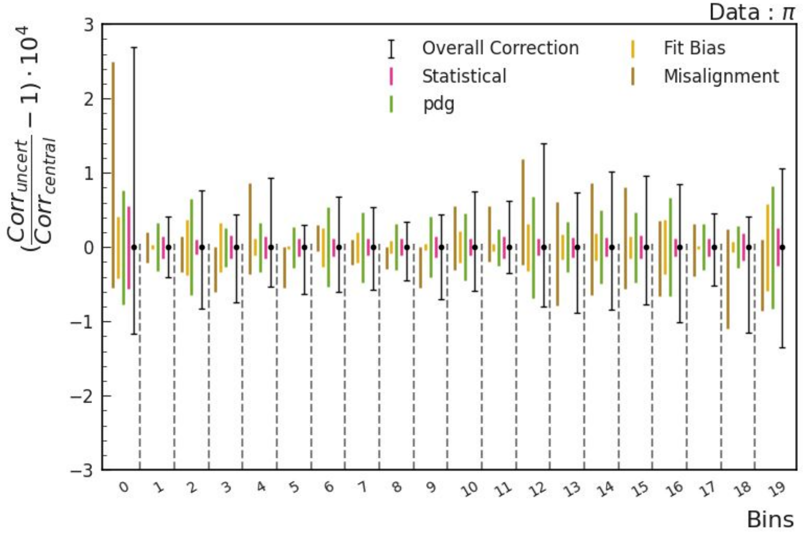
The cos(θ) corrections:	Energy Loss correction:
$P_{new} = P_{old} \cdot corr$	$E_{new} = E_{old} + corr$



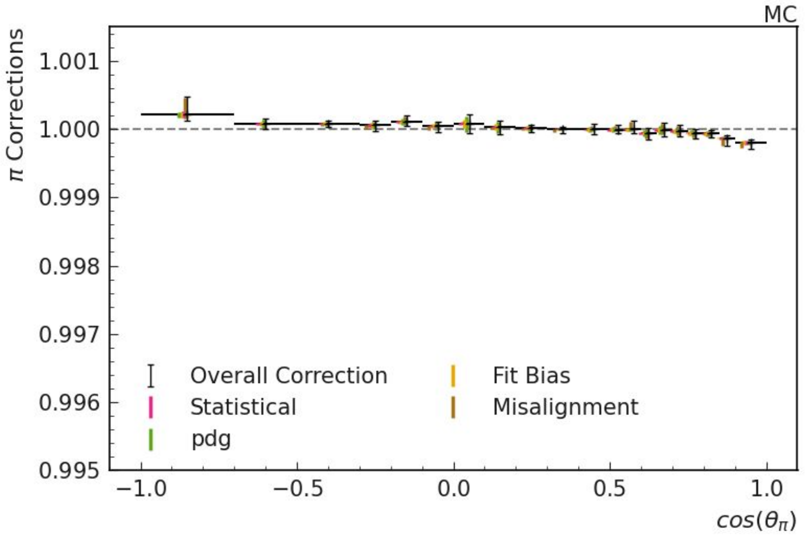
Resulting Cos(θ) Corrections

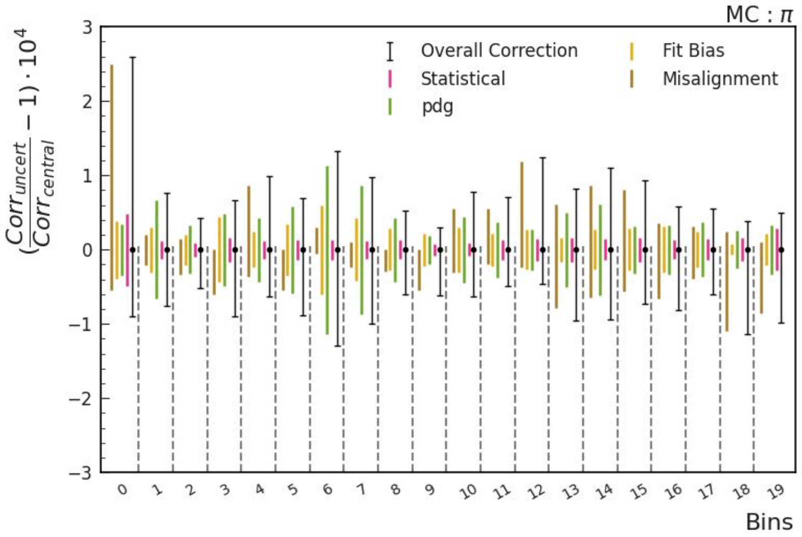
Data





MC



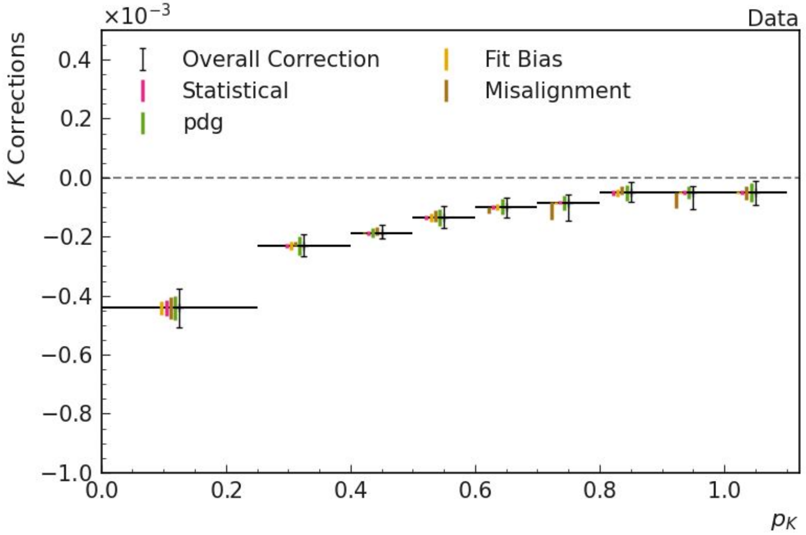


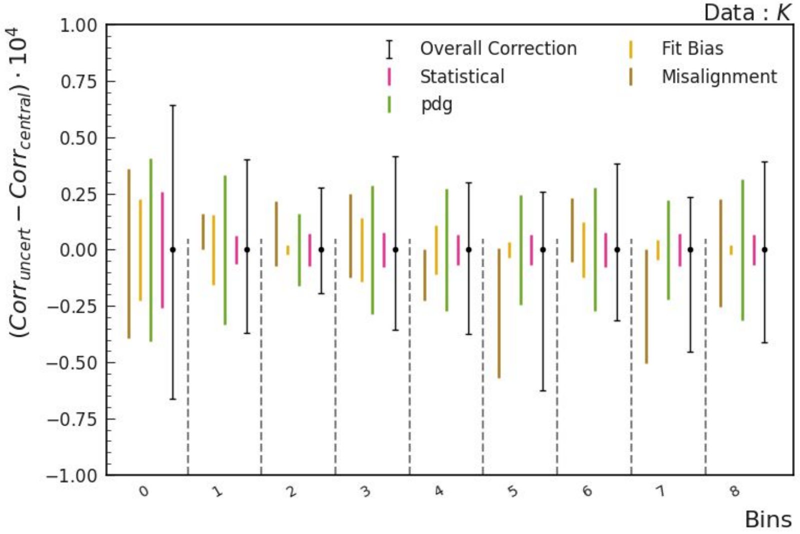
- The uncertainty of Cos(θ) corrections are at the per mil level, with them being constrained by the D^0 Mass uncertainty

Resulting Energy Loss Corrections

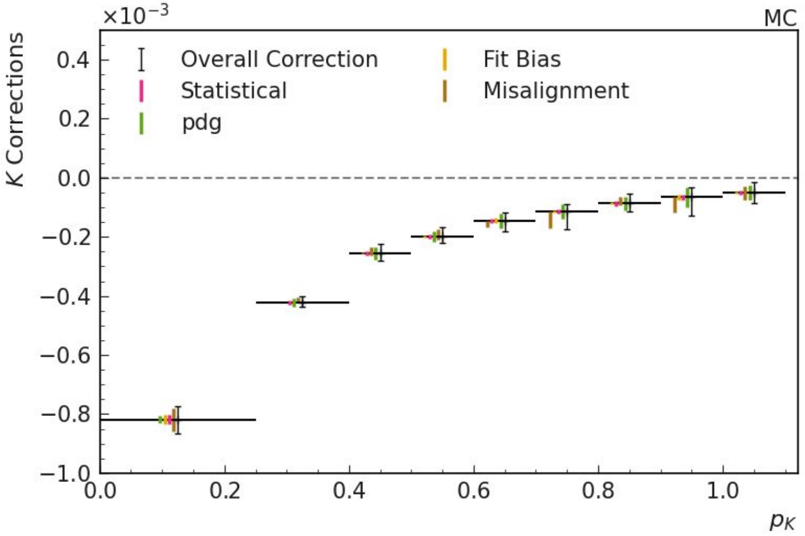
(Showing only Kaon corrections)

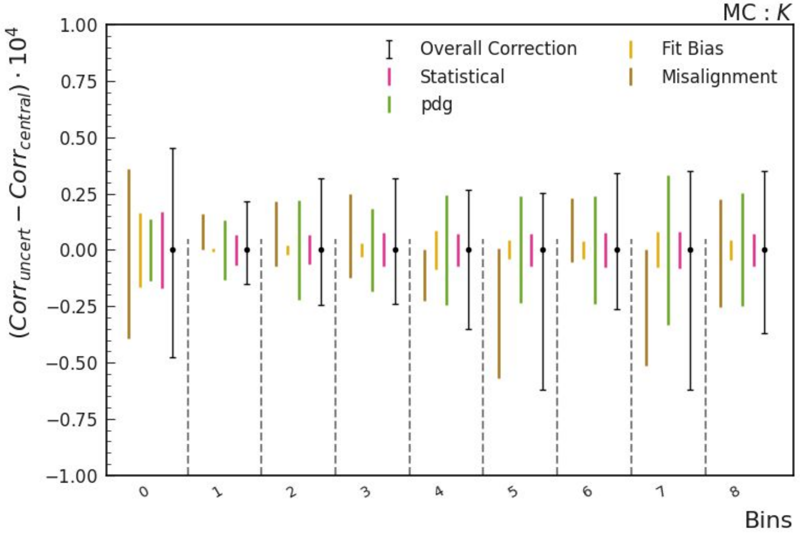
Data





MC





- The uncertainty of Cos(θ) corrections are at the percent level, with them being constrained by the D^0 Mass uncertainty

Final Result

(Showing only Kaon corrections)

- To Facilitate comparison between many decays, we implement a new observable:

$$Q = M_{rec} - \sum M_{daughters}$$

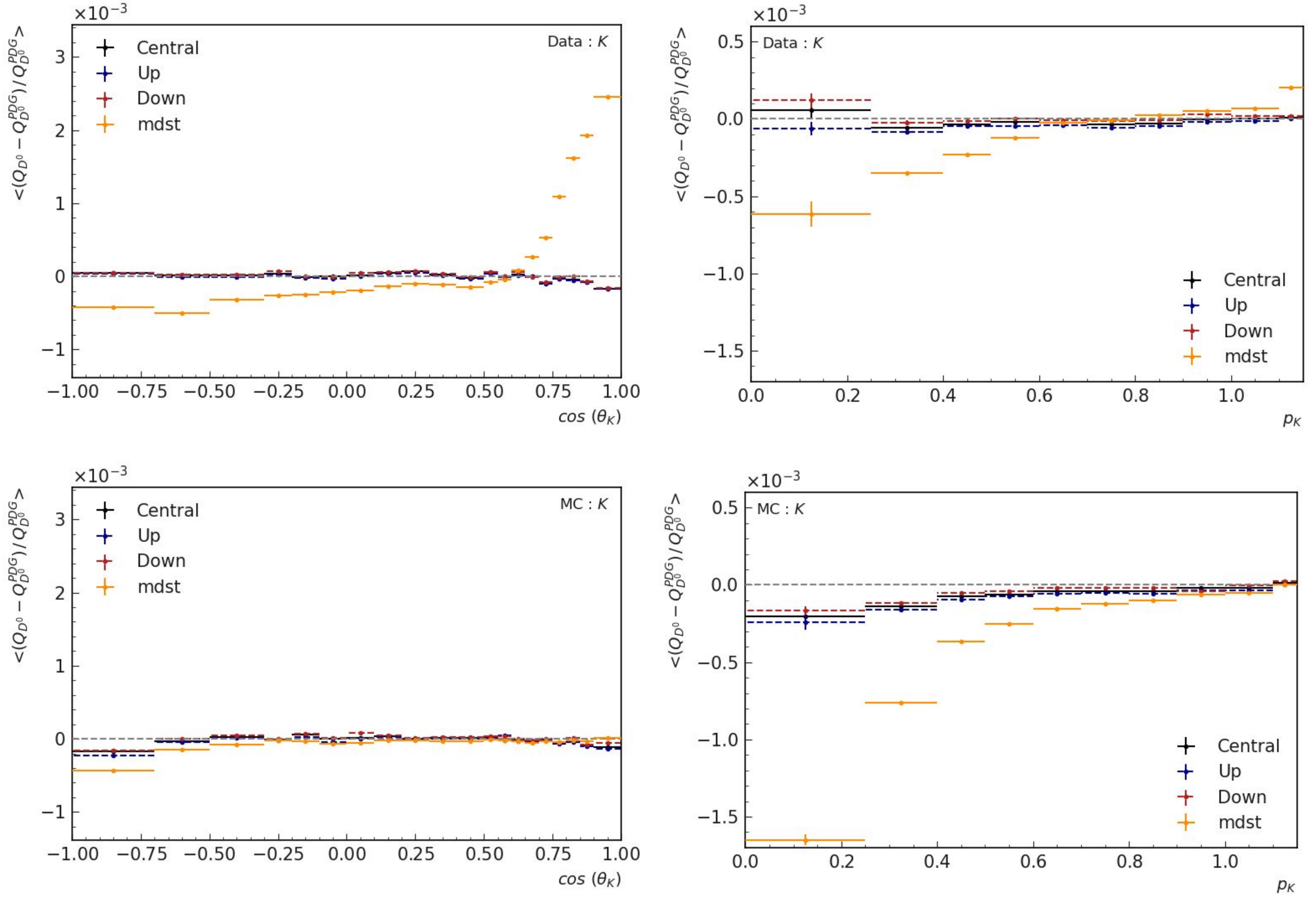
- We apply the corrections to the initial sample alongside the total up and down uncertainties in each bin. An improvement can be seen across the board

- At low momentum the kaons are undercorrected in MC

Cos(θ) Momentum

Data

MC



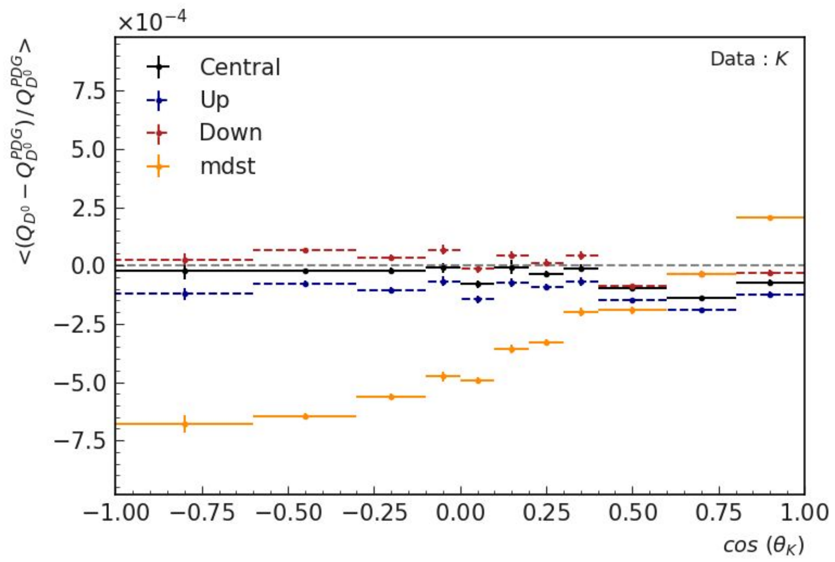
Cross Checks: D0→K3π

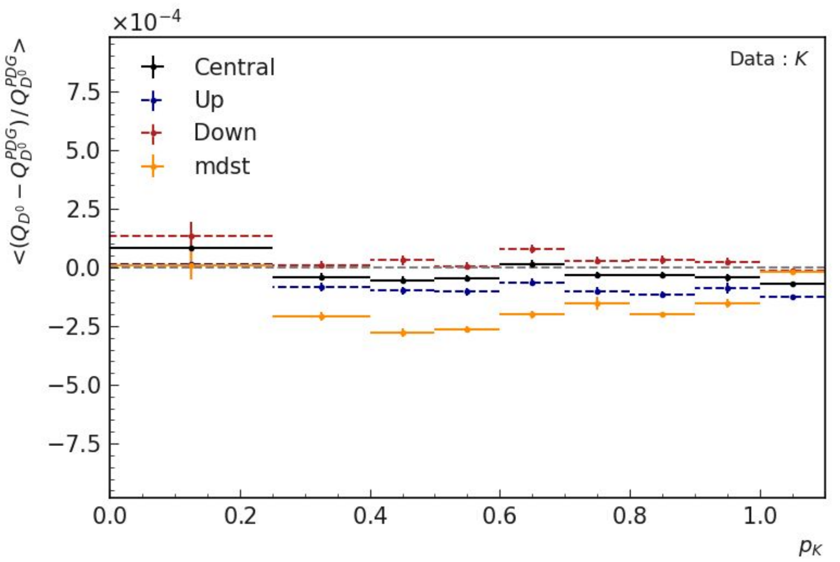
- We conclude by cross checking the corrections in the K3π sample
- An improvement can be seen with no significant deviation after applying both corrections
- The remaining pions follow a similar shape

Cos(θ)

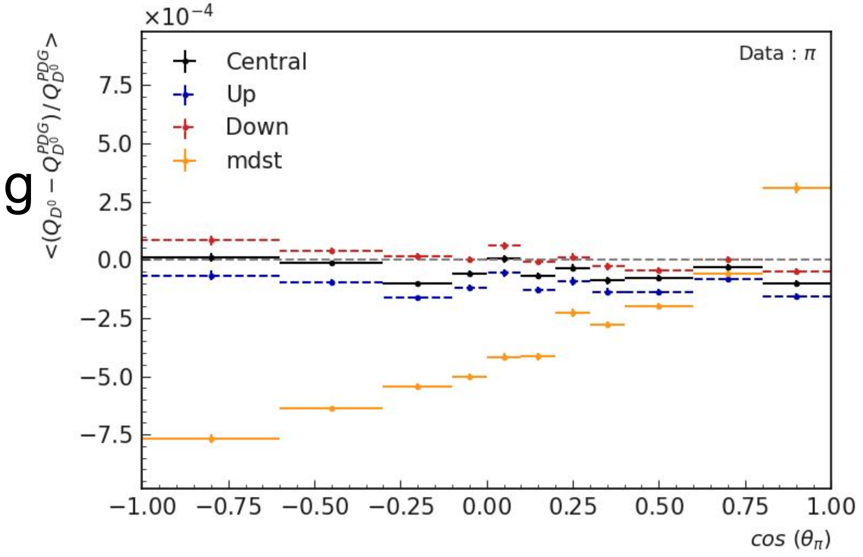
Momentum

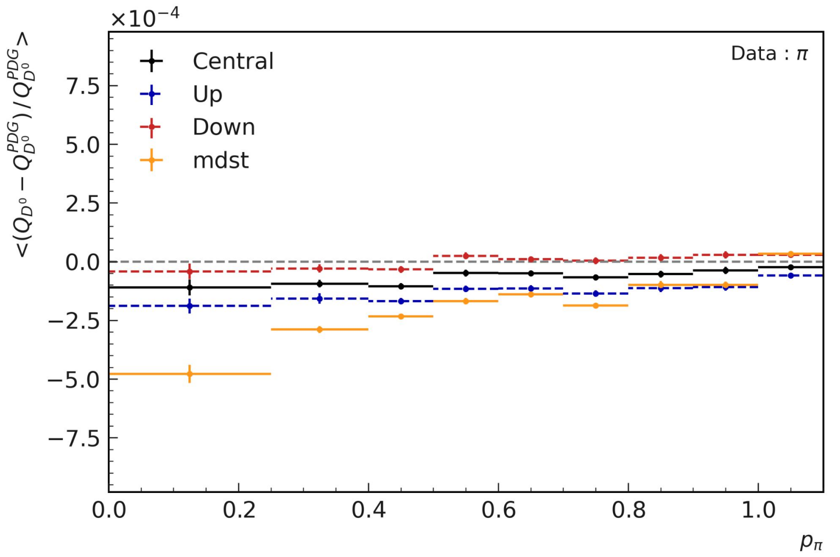
Kaons





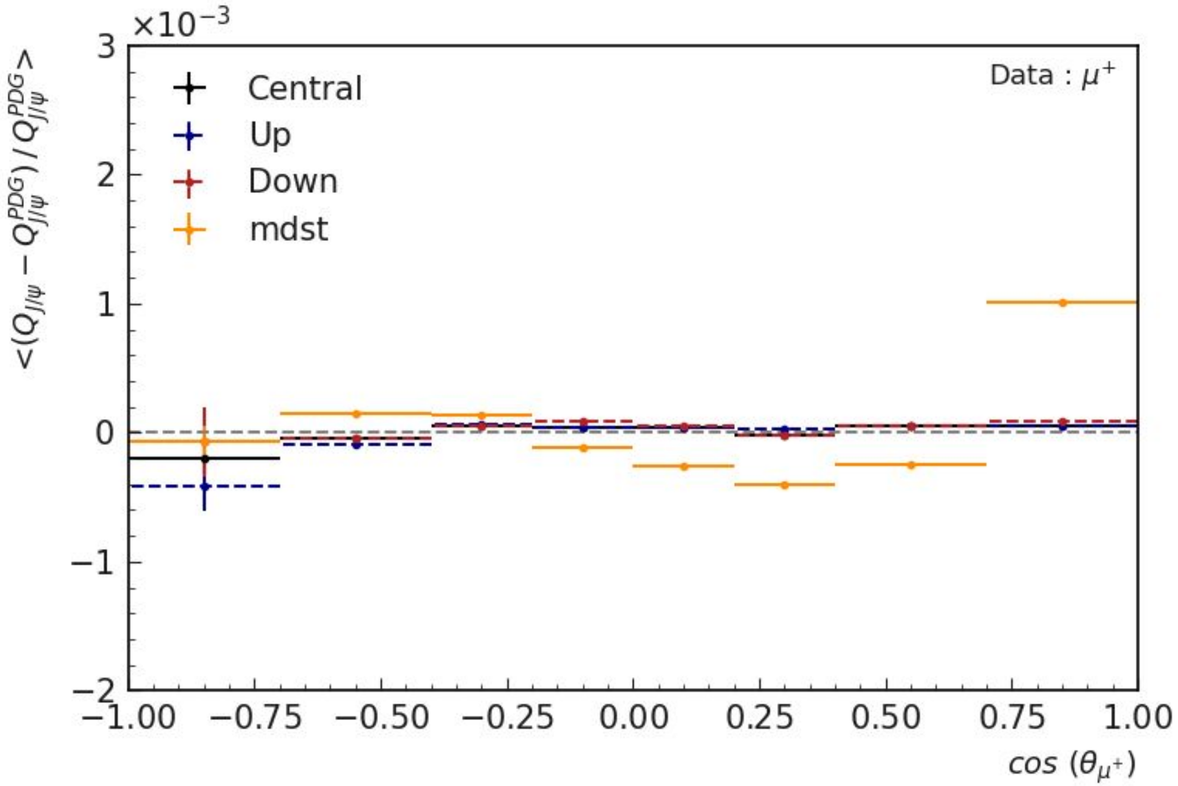
Leading Pion



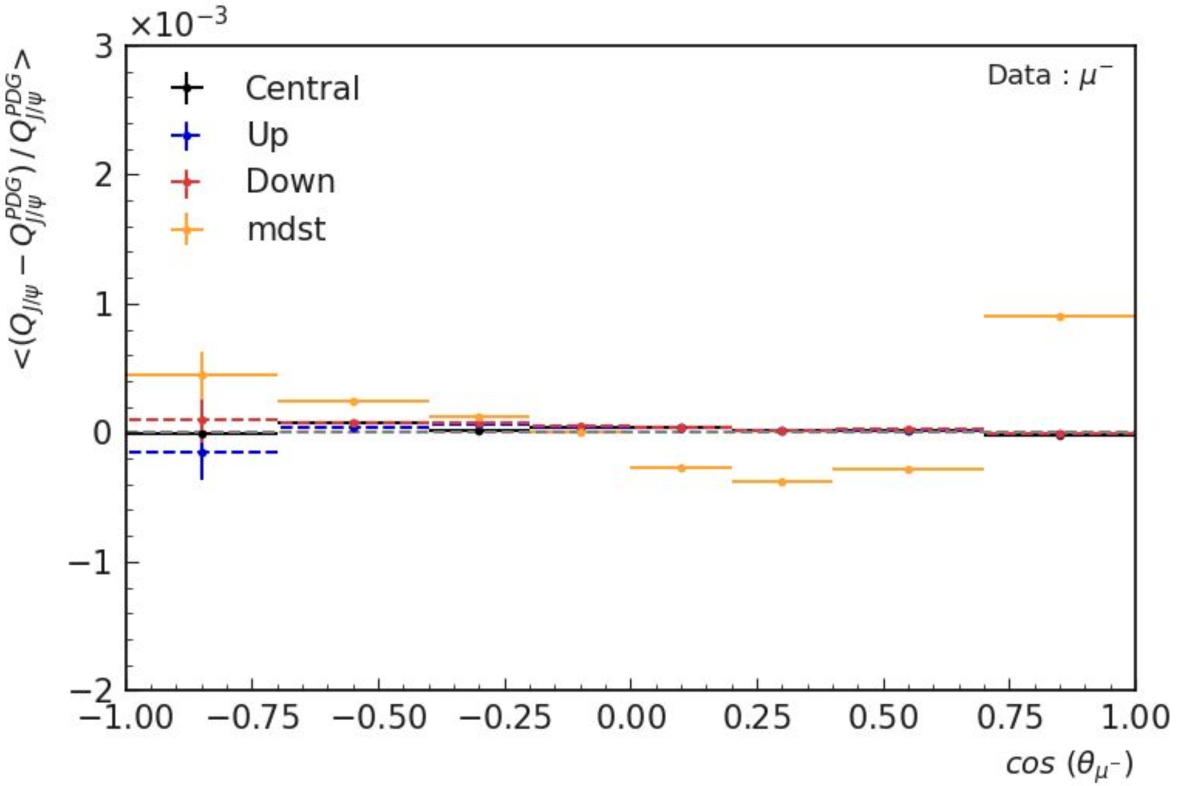


Cross Checks: J/ψ

μ+



μ-



- A subsequent cross check in the $J/\psi \rightarrow \mu^{\pm}\mu^{\mp}$ decay shows an improvement and no significant deviation
- Due to the J/ψ decay topology, the energy loss correction cannot be checked (correction is needed for particles with $p<1.1$ GeV)

How To access these Corrections right now

- The correction payloads are available in the conditions DB.
- They are expected to be applied **together**.
- The necessary tools to apply the corrections are in basf2 since version light-2311-nebelung
- A total of 4 payloads are going to be available
  - cos(θ) dependent corrections:
    - Data: “tracking_MomentumScaling_Data”
    - MC: “tracking_MomentumScaling_MC”
  - Momentum dependent corrections:
    - Data: “tracking_EnergyLoss_Data”
    - MC: “tracking_EnergyLoss_MC”
- Analyzers must applying according to their needs

We plan to change this “soon”
See next Slide

```
## To use the corrections before the note gets through review process
available_gt = set(["PUBLISHED","RUNNING", "TESTING", "VALIDATED", "OPEN"])
b2.conditions.expert_settings(usable_globaltag_states = available_gt)
b2.conditions.expert_settings(connection_timeout=300, stalled_timeout=300)
# --------
## Choose the GT, payload, particle lists and SF name
gt_name = "tracking_MomentumScaleEnergyLoss_Run1_v1"
payload_name_cosTheta = "tracking_MomentumScaling"
payload_name_Eloss = "tracking_EnergyLoss"
sf_name = "central"
particle_lists = ["pi+:all"] #choose your lists

if data_type == "Data":
    payloadName_cosTheta+="_Data"
    payloadName_Eloss +="_Data"
else:
    payloadName_cosTheta+="_MC"
    payloadName_Eloss +="_MC"

## scale track momenta according to SFs given in the payload
b2.conditions.prepend_globaltag(gt_name)
ma.scaleTrackMomenta(particle_lists, payloadName=payload_name_cosTheta,
    scalingFactorName=sf_name, path=my_path)
ma.correctTrackEnergy(particle_lists, payloadName=payload_name_Eloss,
    correctionName=sf_name, path=my_path)
```

Choose between Data or MC payloads

How To access these Corrections soon

- The basf2 module is going to apply the MC or Data payload based on the flag: "*Environment::Instance().isMC()*"
- Implementation just needs to be merged to main basf2 branch
- A total of 2 payloads are going to be available to analyzers
  - cos(θ) dependent corrections:
    - "tracking_MomentumScaling"
  - Momentum dependent corrections:
    - "tracking_EnergyLoss"

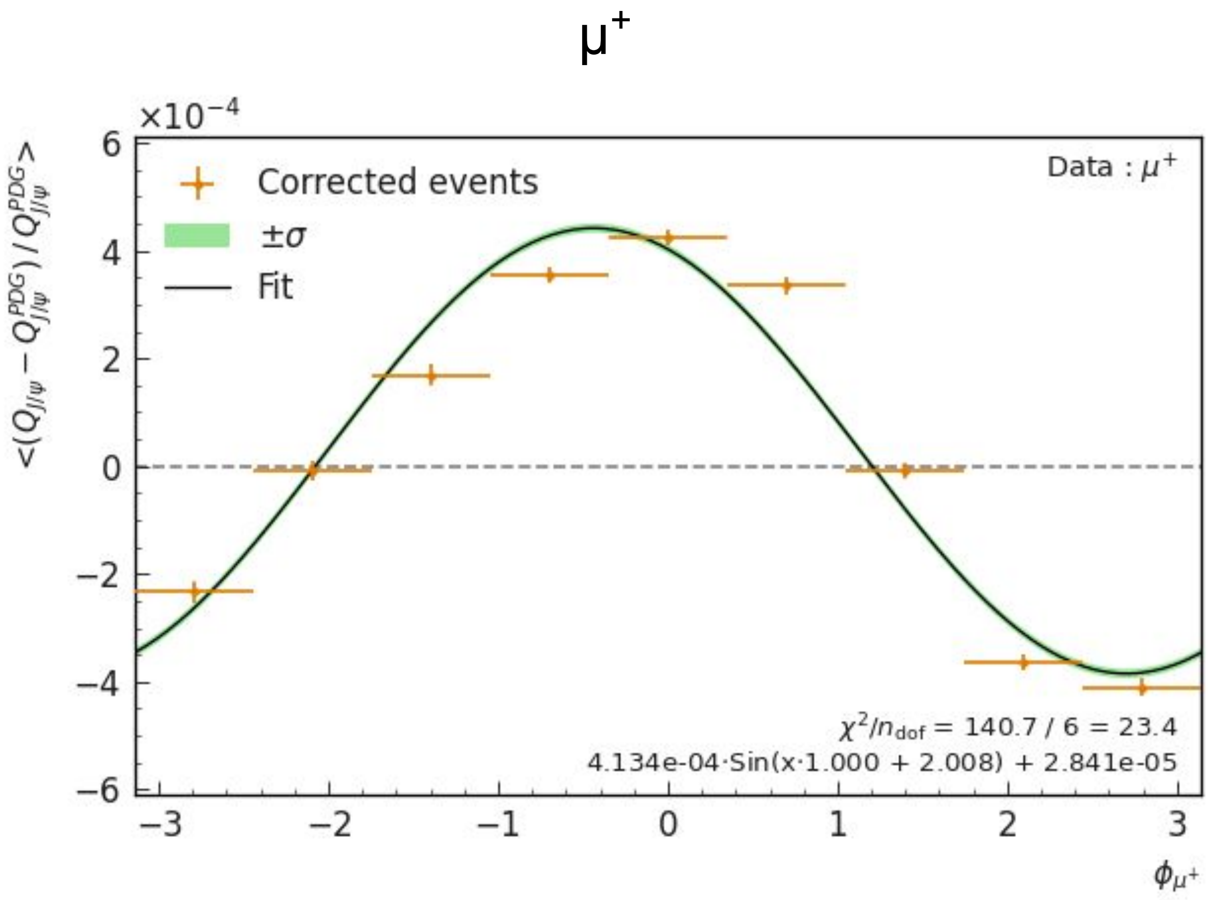
Available SF keys:

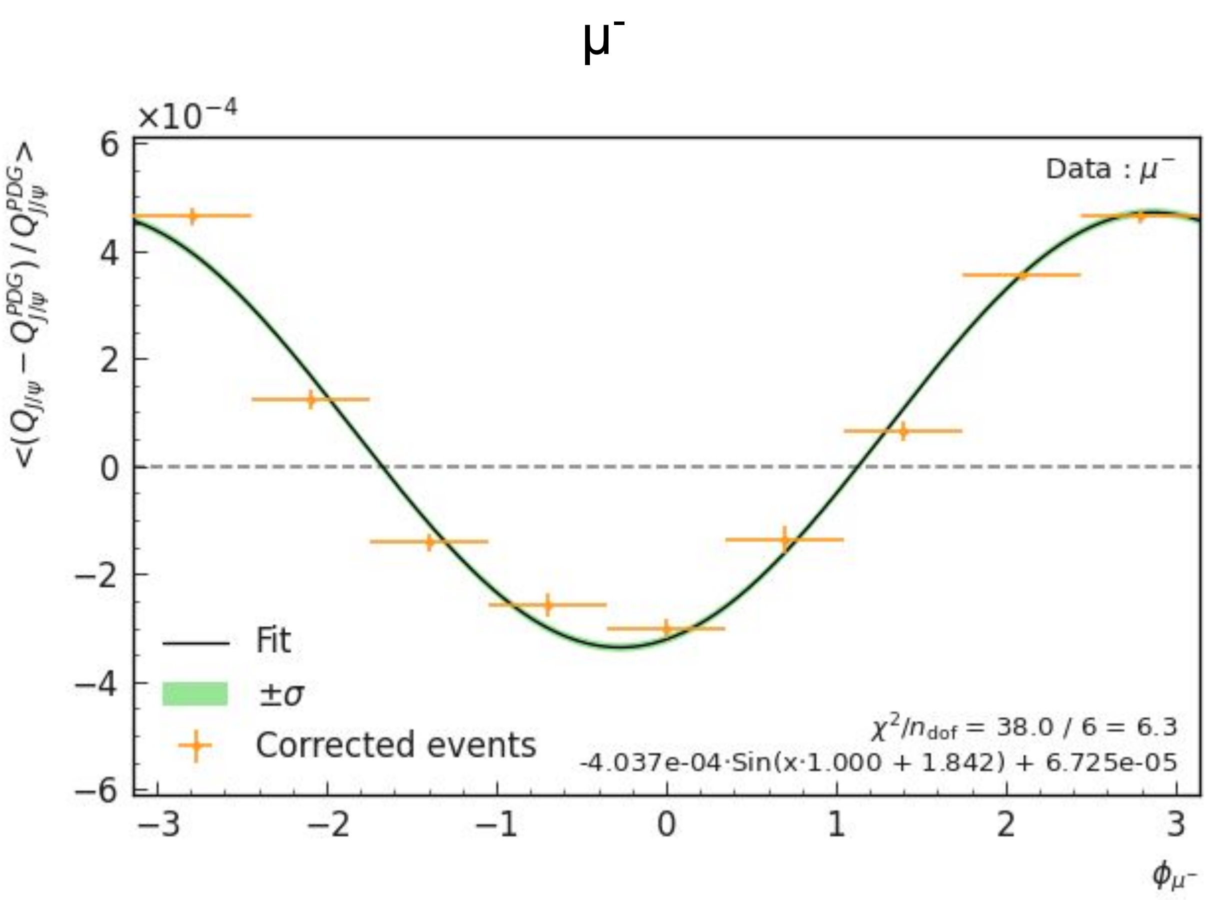
```
sf_keys = ["central",
          "misalignment_down", "misalignment_up",
          "bias_corr_down", "bias_corr_up",
          "pdg_down", "pdg_up",
          "stat_down", "stat_up",
          "total_down", "total_up"]
```

```
## Choose the GT, payload, particle lists and SF name
gt_name = "tracking_MomentumScaleEnergyLoss_Run1_v1"
payload_name_cosTheta = "tracking_MomentumScaling"
payload_name_Eloss = "tracking_EnergyLoss"
sf_name = "central"
particle_lists = ["pi+:all"] #choose your lists
```

```
## scale track momenta according to SFs given in the payload
b2.conditions.prepend_globaltag(gt_name)
ma.scaleTrackMomenta(particle_lists, payloadName=payload_name_cosTheta,
    scalingFactorName=sf_name, path=my_path)
ma.correctTrackEnergy(particle_lists, payloadName=payload_name_Eloss,
    correctionName=sf_name, path=my_path)
```

Discovery of Azimuthal angle dependent shifts in J/ψ events

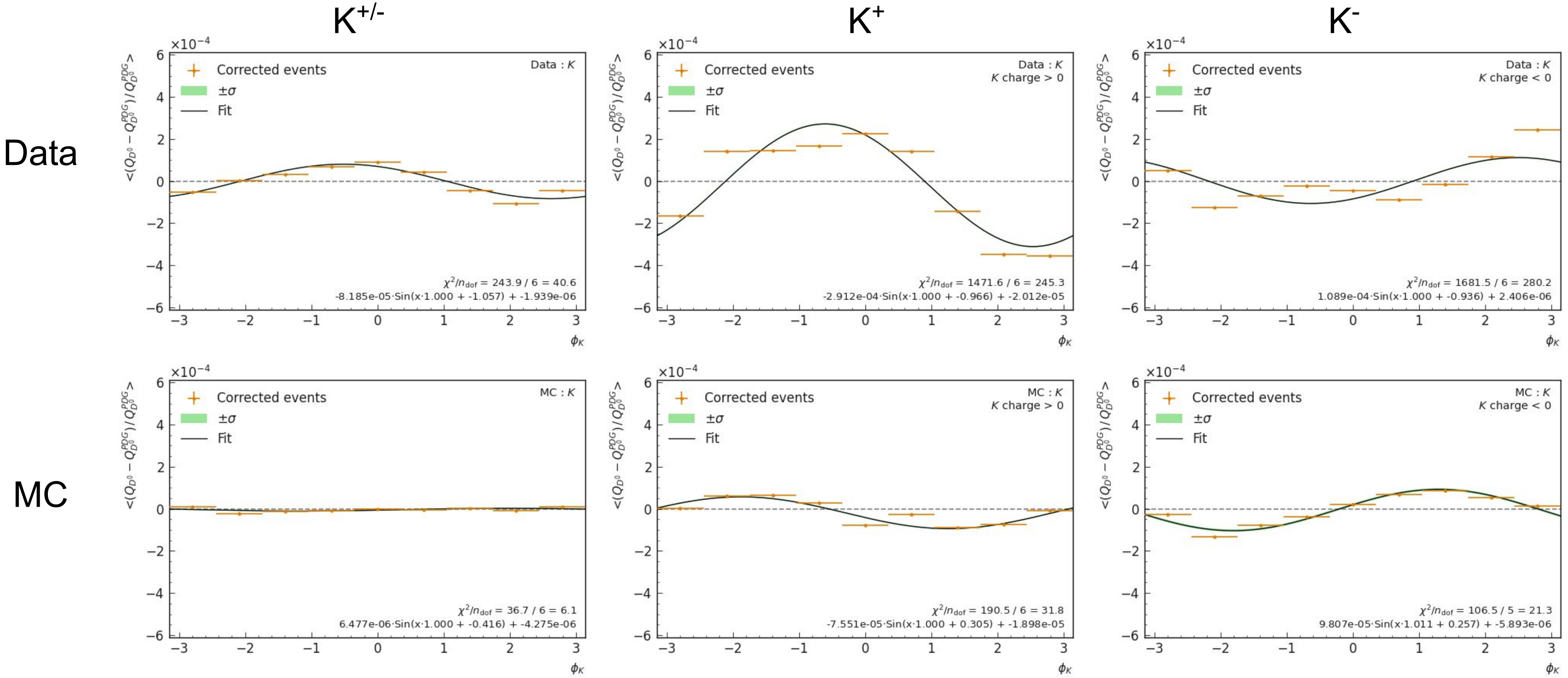




- Significant φ modulation in terms of precision and relevance in J/ψ sample, up to a 1.5 MeV shift
- An Empirical sine model is used to fit the data
- Parameters are amplitude and phase for negative and positive tracks

φ dependent shifts in $D^0 \to K\pi$

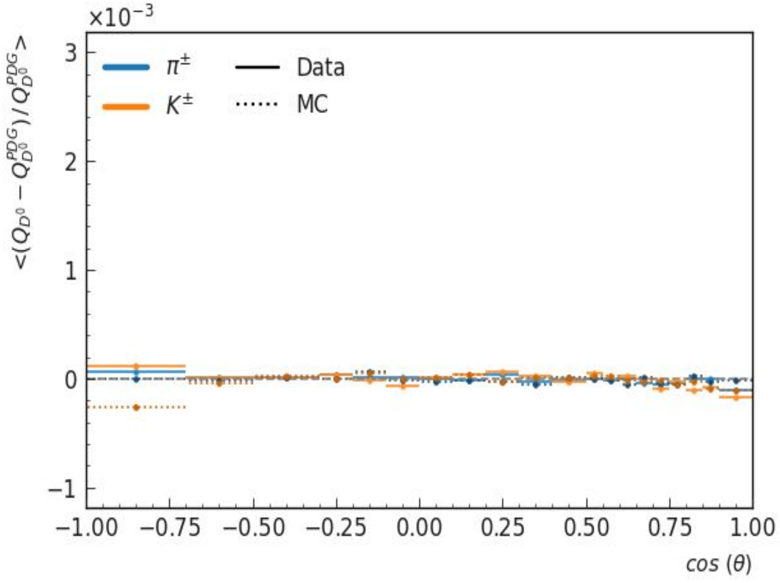
(Showing only Kaon corrections)

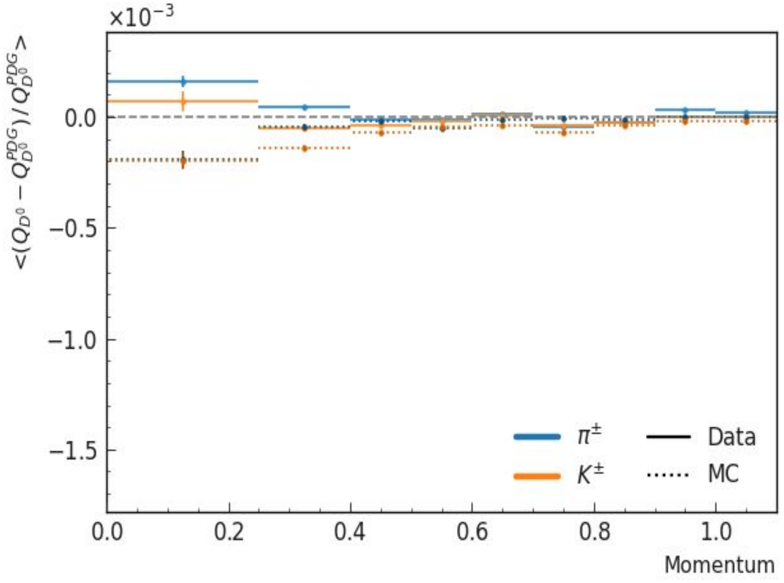


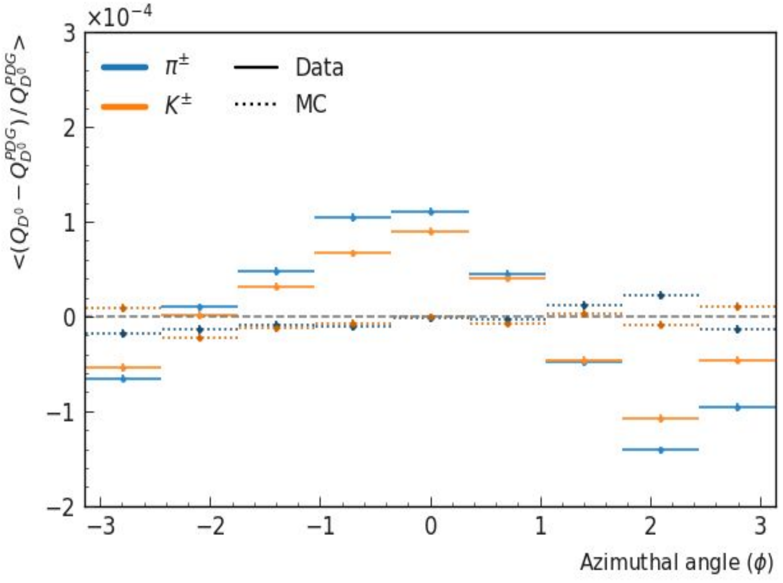
- Sine wave is less prominent in $D^0 \to k\pi$ data events compared to $J/\psi \to \mu\mu$ events ➡ decay topology dependent
- Empirical sine model breaks for $D^0 \to k\pi$ events

Summary

- Correction Payloads are available. Currently waiting for approval on the Note.
- Some small mass peak shifts still remain in low momentum MC events.
- Azimuthal angle shifts are still present and their cause is unknown.
- The corrections have been validated for Release 8 using chunk 1. No problems were found (Slide on backup)







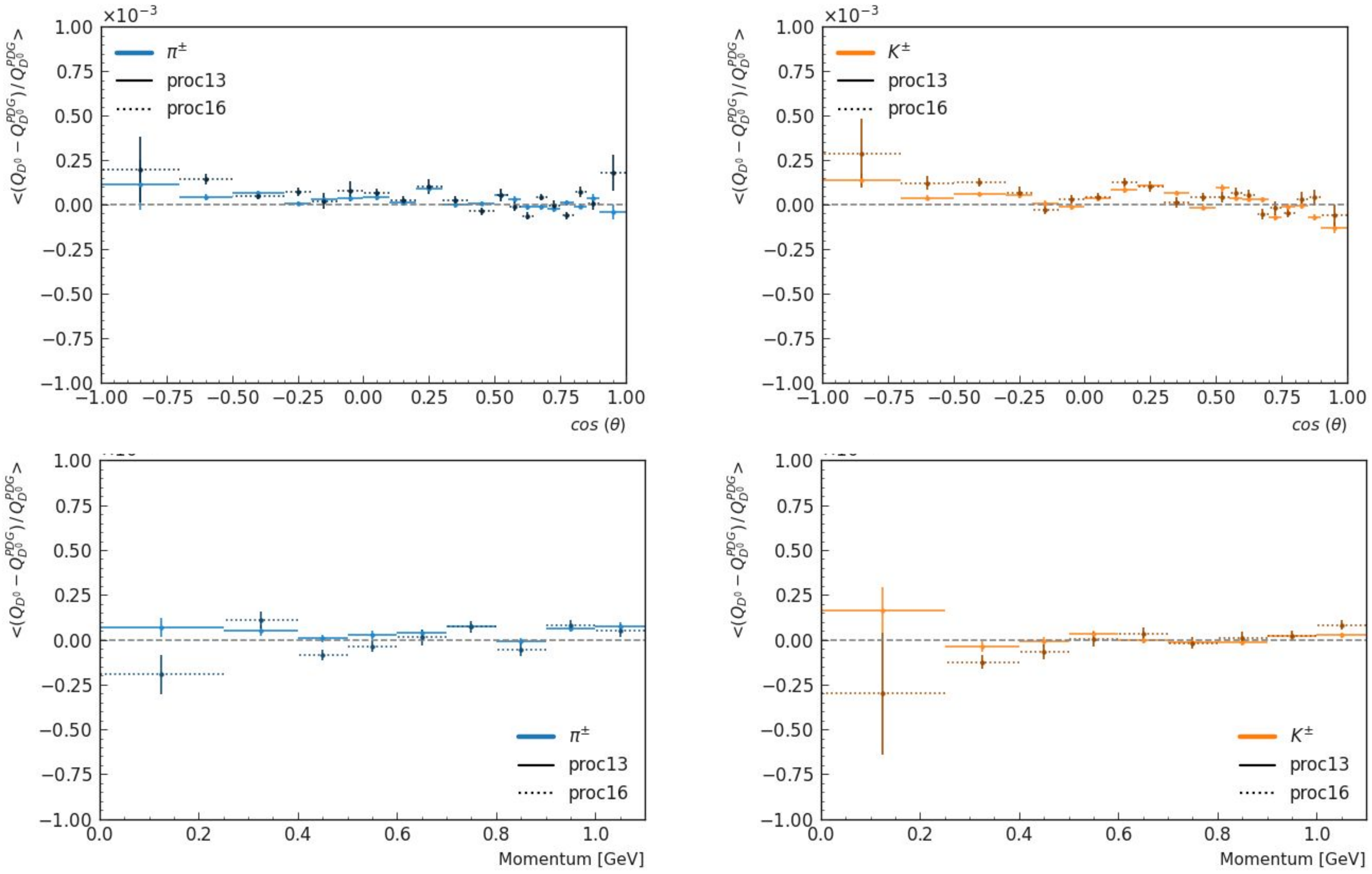
Backup

Release 8 Validation

K±
π±

Cos(θ)

Momentum

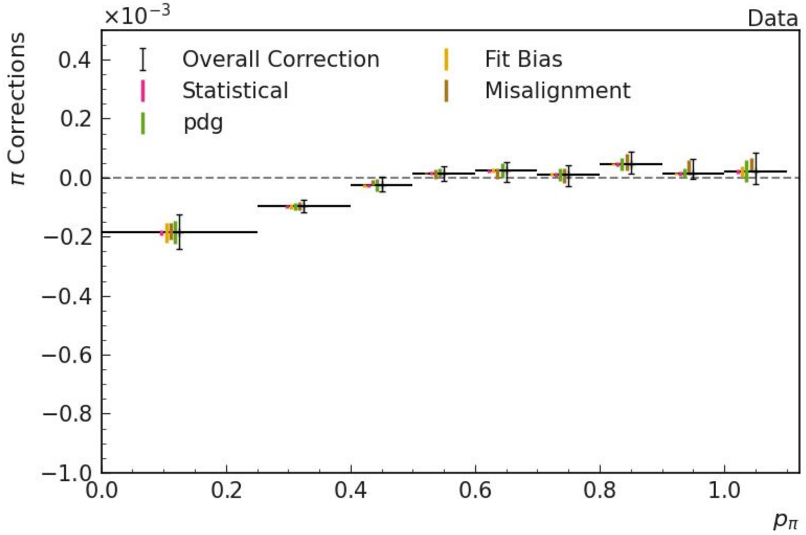


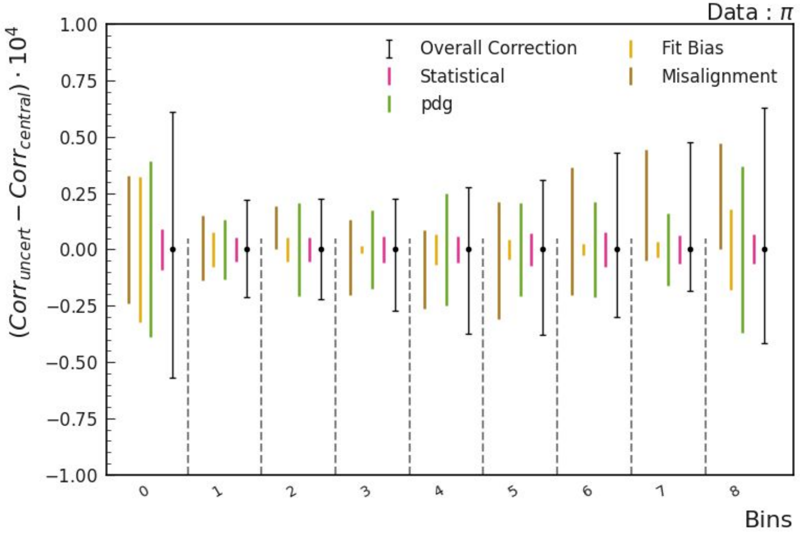
- After applying the both corrections on the first chunk of Release 8, we see no significant mass peak shifts. with the variations falling within the corrections systematic uncertainty

Resulting Energy Loss Corrections

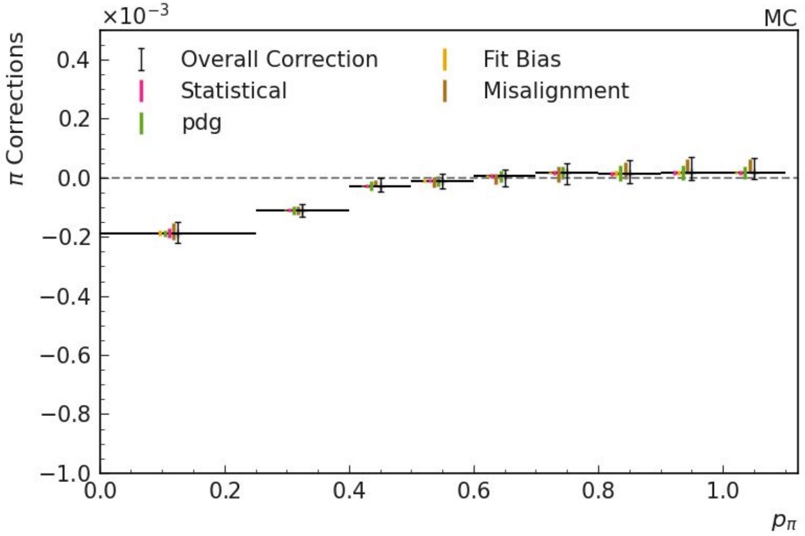
(Showing only Pion corrections)

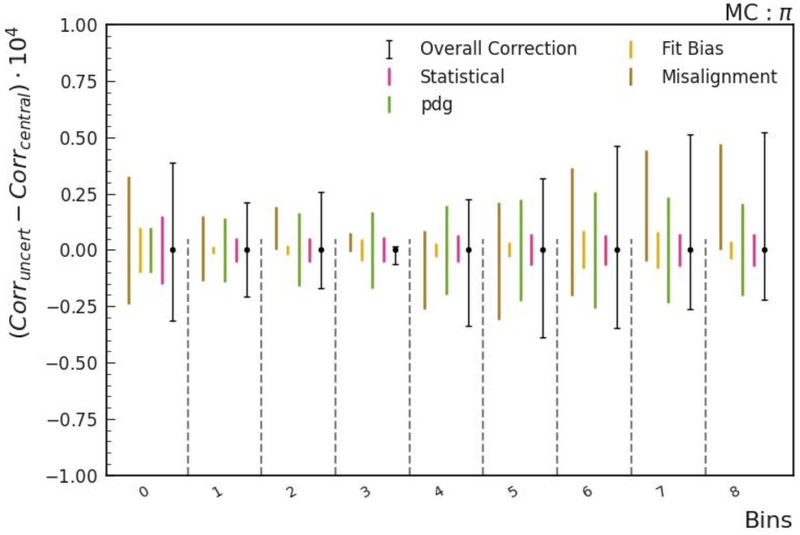
Data





MC





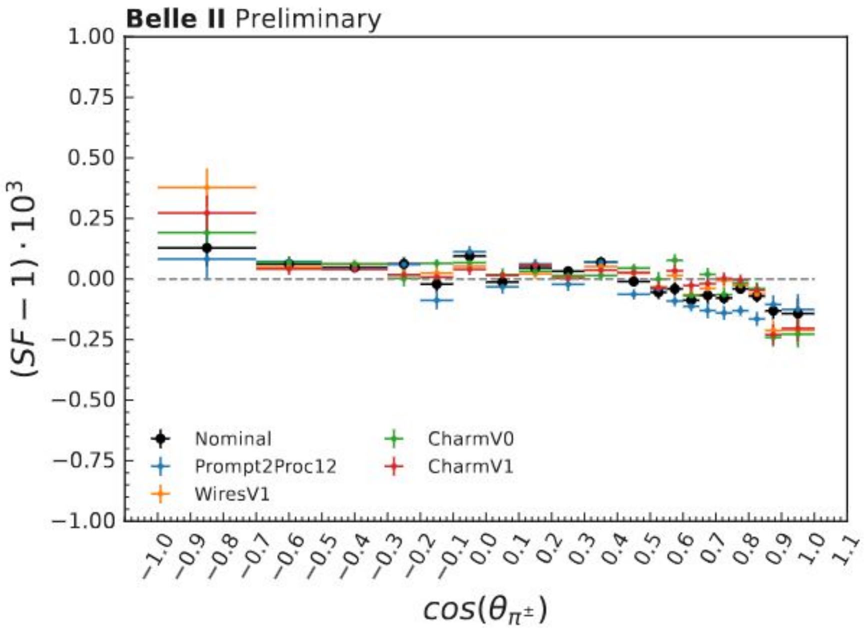
- The uncertainty of Cos(θ) corrections are at the percent level, with them being constrained by the D^0 Mass uncertainty

Misalignment

- The misalignment uncertainty is obtained by estimating the corrections in 4 different MC misalignment scenarios and taking the maximum difference between the obtained corrections.

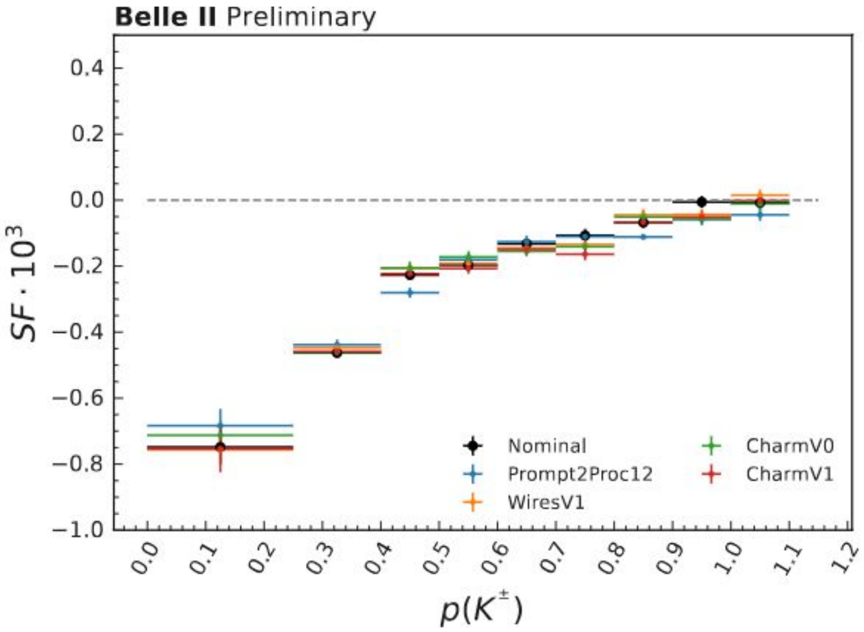
- 10M events where produced for each misalignment scenario:
  - Prompt2Proc12
  - WiresV1
  - CharmV0
  - CharmV1

Cos(θ) corrections

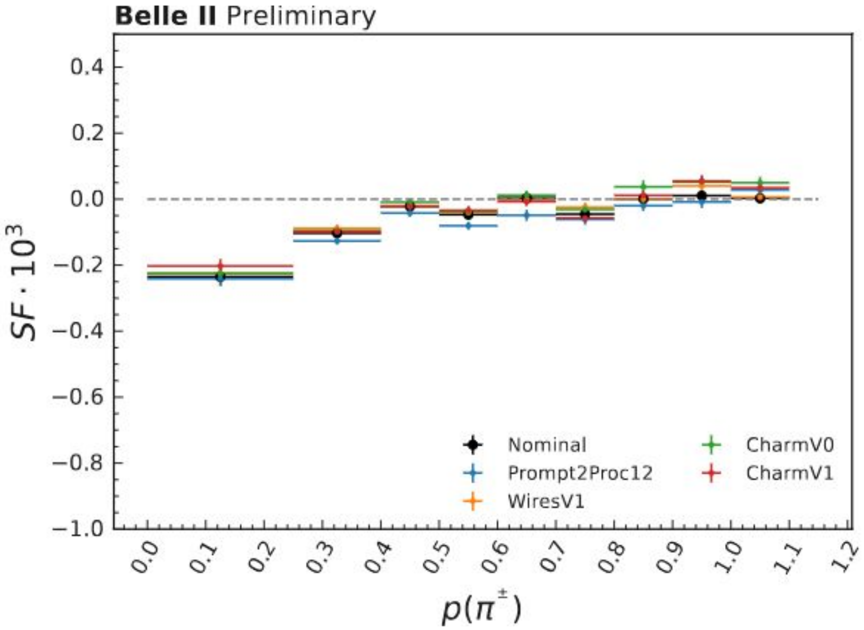


Momentum Corrections

$K^\pm$ →



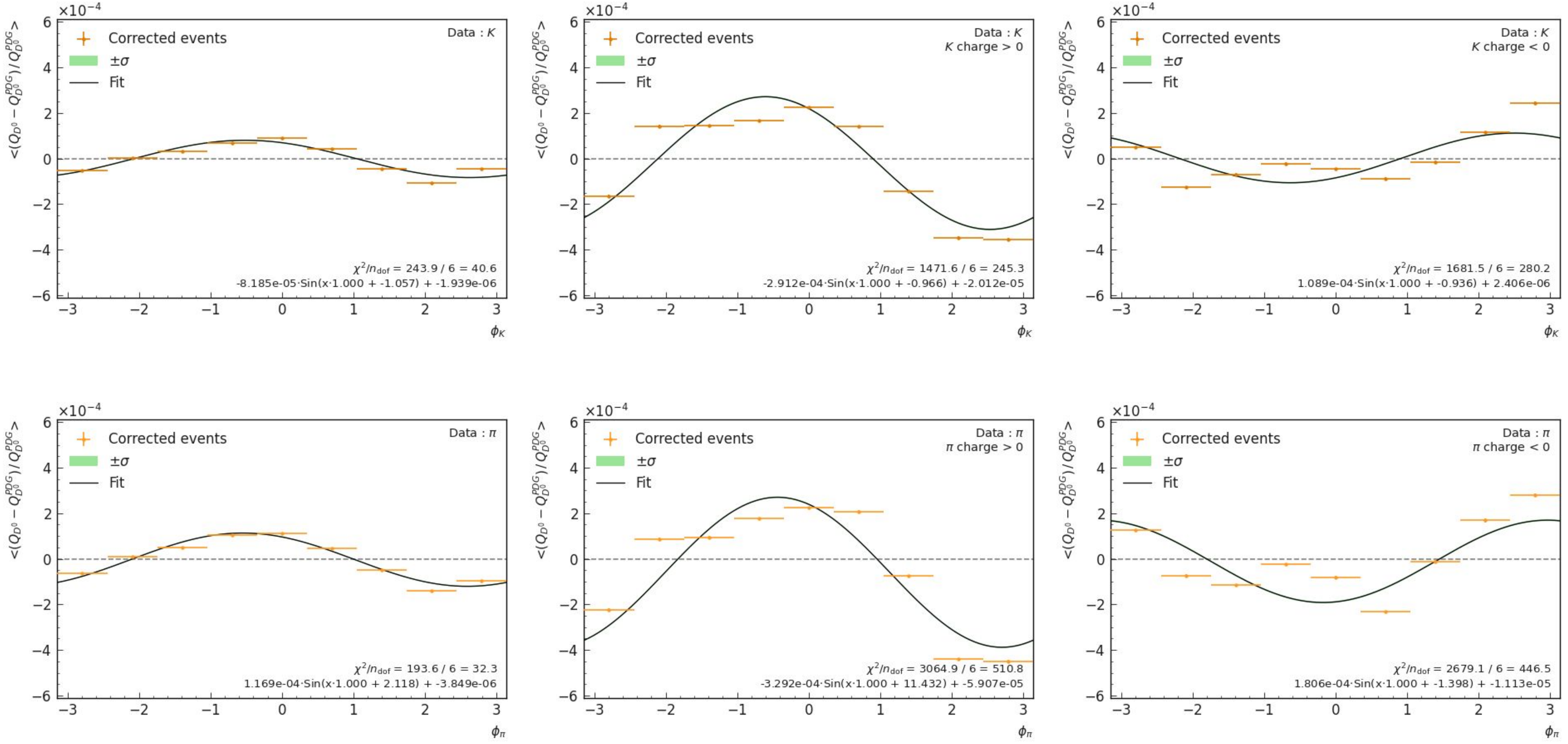
$\pi^\pm$ →



φ dependent shifts in $D^0 \to K\pi$ (Data)

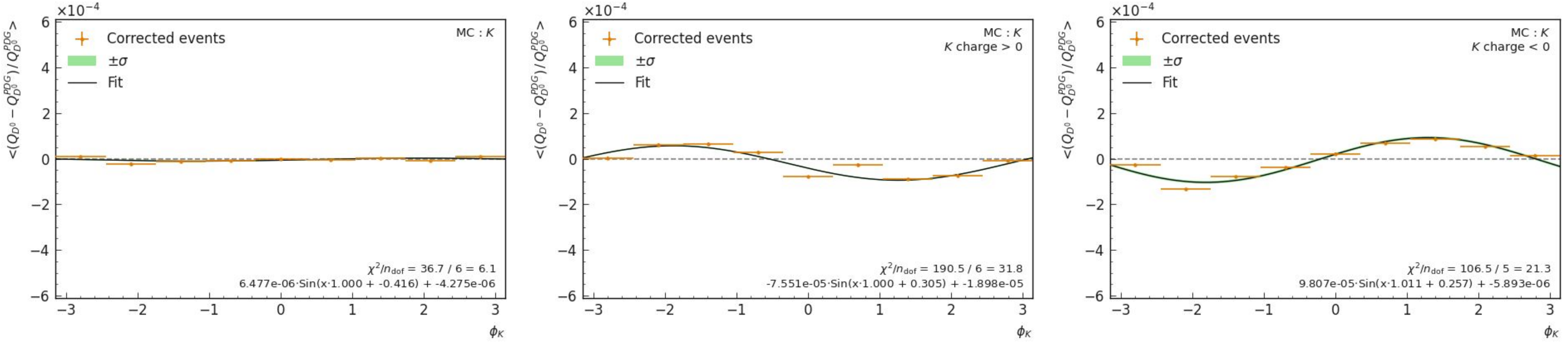
Kaons

Pions

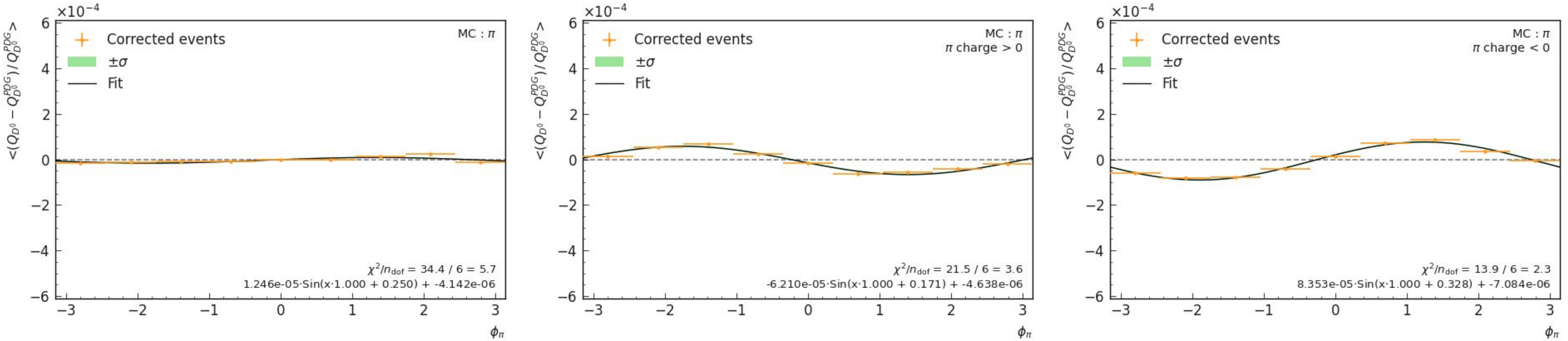


φ dependent shifts in $D^0 \to K\pi$ (MC)

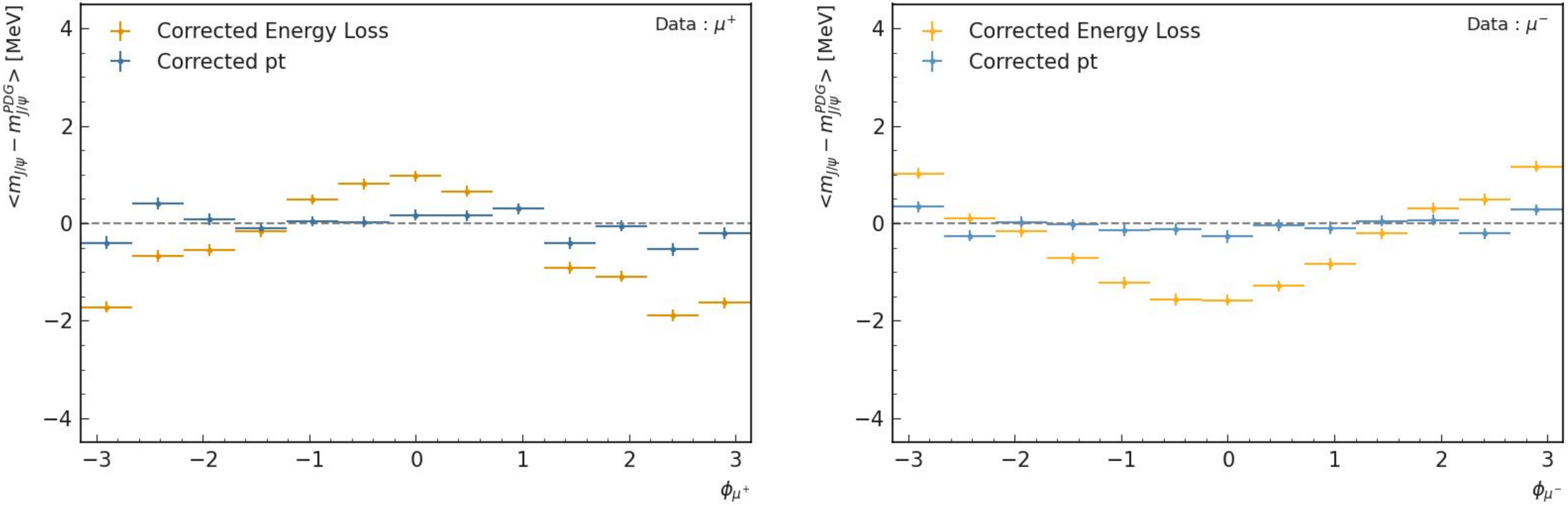
Kaons



Pions



First Approach to address φ dependent shifts



- Scaling the transverse momentum by a factor $P_T^{new} = P_T^{old} \cdot$ (1- [Fitted Sine wave]) corrects for the observed shift
- Solving the problem like this would necessitate correction payloads dependent on the sample, charge and decay topology
- This solution would be unreasonable and would avoid the root of the problem, which is still unknown