New Tracker Alignment Prompt Calibration Loop

CMS week

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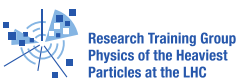
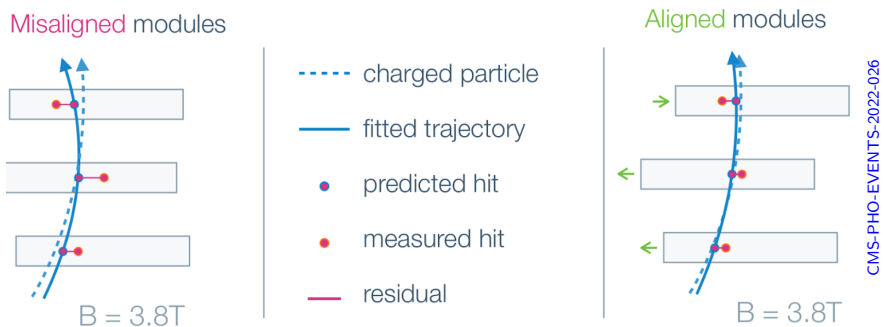


Track-based Alignment

- Determine **orientation, position and surface deformation** of CMS tracker sensors
- **Goal:** Alignment precision σ_{align} of same scale as hit resolution $\sim \mathcal{O}(10\,\mu\text{m})$
- After mechanical alignment: $\sigma_{\text{align}} \sim \mathcal{O}(100\,\mu\text{m})$

$\Rightarrow$ With track-based alignment $\sigma_{\text{align}} \sim \mathcal{O}(10\,\mu\text{m})$

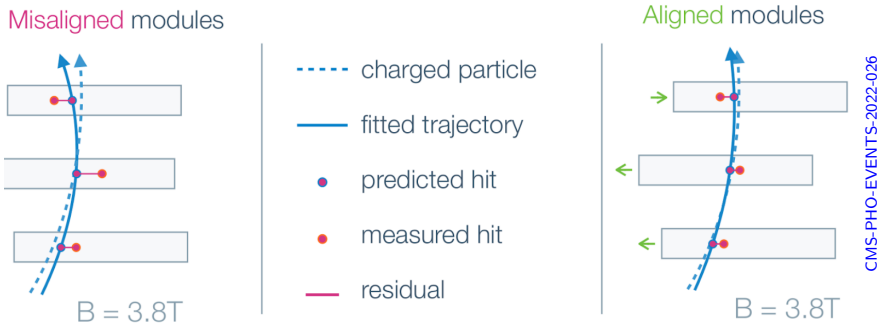


Track-based Alignment

$$\chi^2(\boldsymbol{p},\boldsymbol{q}) = \sum_{j}^{\text{tracks}} \sum_{i}^{\text{hits}} \left(\frac{m_{ij} - f_{ij}(\boldsymbol{p},\boldsymbol{q_j})}{\sigma_{ij}} \right)^2$$

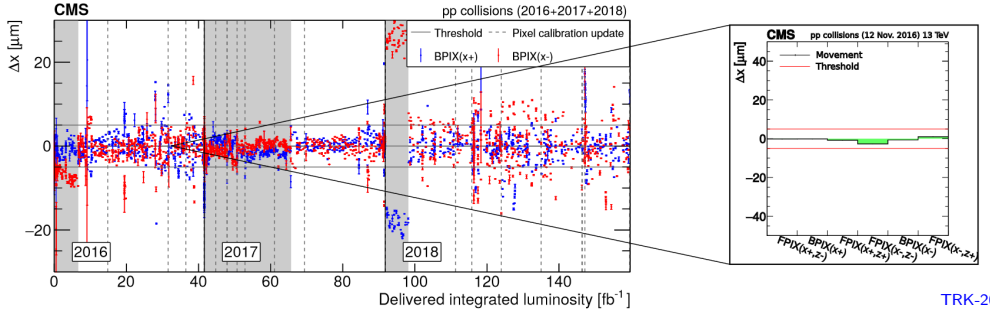
$m_{ij},\ f_{ij}$: measured and predicted hit position

$\boldsymbol{p},\ \boldsymbol{q}$: alignment and track parameters



Run 2: Low Granularity PCL alignment

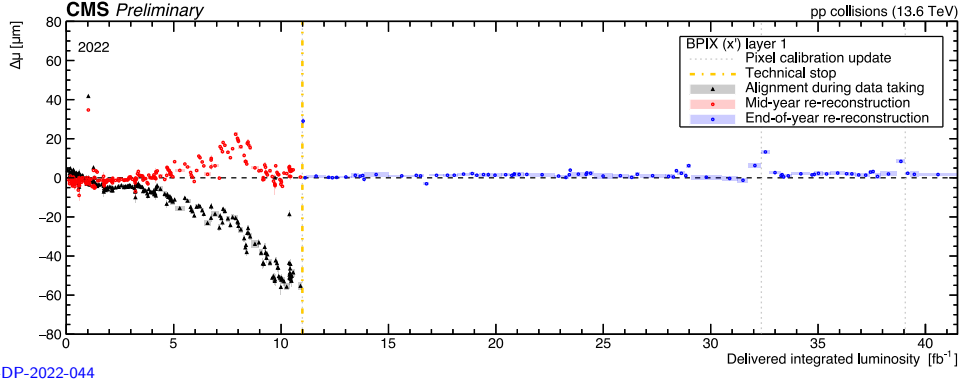
- Alignment of **large structures** (HLS) of the pixel detector ($\Rightarrow$ LG)
  - 2 BPIX barrels, 4 FPIX half-cylinders, 6 dof per structure $\rightarrow 6 \times 6 = 36$ parameters
- MillePede 2 algorithm runs in the Prompt Calibration Loop (PCL) at Tier-0
- Uses *express* MinBias data
- Alignment **automatically updated**, if movements within set requirements
- Due to LG cannot account for some effect, e.g. radiation damage



TRK-20-001

Run 3: High Granularity PCL alignment

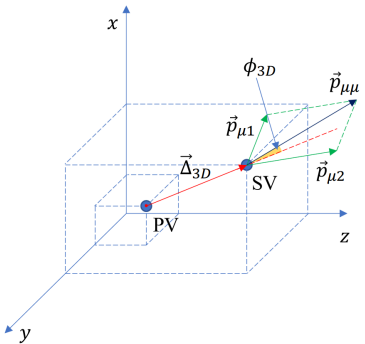
- Change from HLS-based to **ladder/panel-based** alignment
  - $\Rightarrow$ Increase number of parameters from 36 to ~ 5000
- Improved performance wrt LG PCL alignment
- But: More parameters $\Rightarrow$ Cannot be fully constrained by MinBias data set

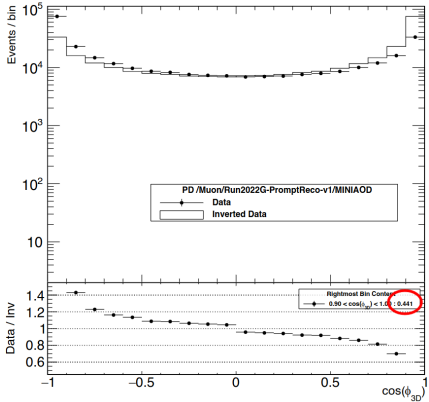


CMS-DP-2022-044

High Granularity PCL Bias: $\cos\phi_{3D}$

- $\cos\phi_{3D}$: Cosine of angle between direction of the **SV wrt PV** and the direction of the **di-leptons system**
  - $\Rightarrow$ Expected to be symmetrical for DY
- Used in analyses with dimuon SV to reduce combinatorial background





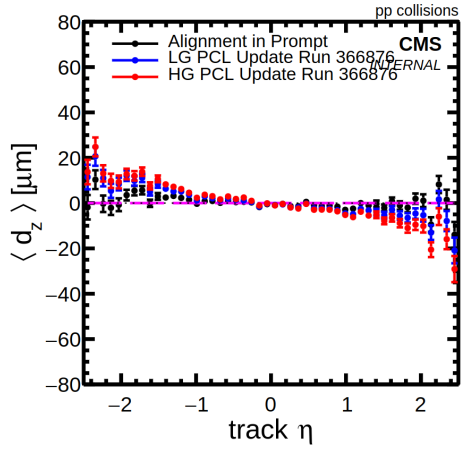
- Last bin asym. (run 2): $< 10\%$
- Last bin asym. (run 3): $\sim$ 20-50%
  - $\Rightarrow$ Increased through HG PCL

Details see Attilio Santocchia's talk here

High Granularity PCL Bias: d_z vs η

PV validation

- PV reconstruction driven by pixel detector
- Validation: Redetermine PV without track of interest
- $\boldsymbol{d_z}$: Longitudinal distance between track and redetermined PV
- Expect distribution of mean d_z vs track η to be flat



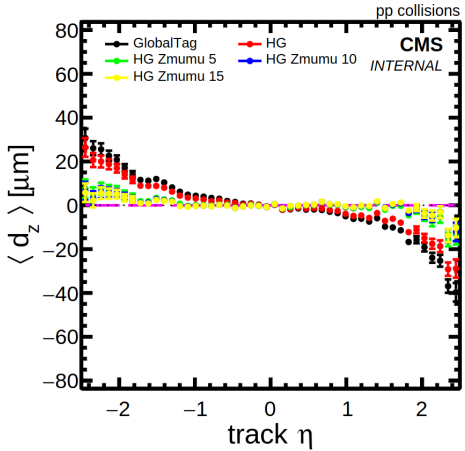
$\Rightarrow$ Introduction of bias, probably correlated with $\cos\phi_{\text{3D}}$ bias

$\Rightarrow$ Try to reduce bias by inclusion of Z $\rightarrow \mu\mu$ data

Inclusion of Z $\rightarrow \mu\mu$: d_z vs η

Validation Strategy

- Run Pseudo-PCL alignment on run that shows prominent d_z vs η bias in prompt reco, using
  1. Only MinBias data (standard)
  2. MinBias and Z $\rightarrow \mu\mu$ data
- But: $\sim$ 20 times more MinBias than Z $\rightarrow \mu\mu$ tracks
  - $\Rightarrow$ Introduce weighting factor of Z $\rightarrow \mu\mu$ tracks in alignment procedure
  - $\Rightarrow$ Test weights of 5, 10, 15



Details see here

$\Rightarrow$ Significant bias reduction by including strongly weighted Z $\rightarrow \mu\mu$ tracks

Inclusion of $Z \to \mu\mu$: $\cos\phi_{3D}$

Validation Strategy

- Run Pseudo-PCL alignment on run that shows prominent d_z vs η bias in prompt reco, using
  1. Only MinBias data (standard)
  2. MinBias and $Z \to \mu\mu$ data
- But: $\sim$ 20 times more MinBias than $Z \to \mu\mu$ tracks
  - $\Rightarrow$ Introduce weighting factor of $Z \to \mu\mu$ tracks in alignment procedure
  - $\Rightarrow$ Test weights of 5, 10, 15

$\cos\phi_{3D}$ results

- Recalculate last bin asymmetry using alignments derived with different $Z \to \mu\mu$ weights

$Z \to \mu\mu$ weight	Last bin asymm.
0 (HG PCL)	$41\% \pm 3\%$
5	$11\% \pm 2\%$
10	$8\% \pm 2\%$
15	$6\% \pm 2\%$

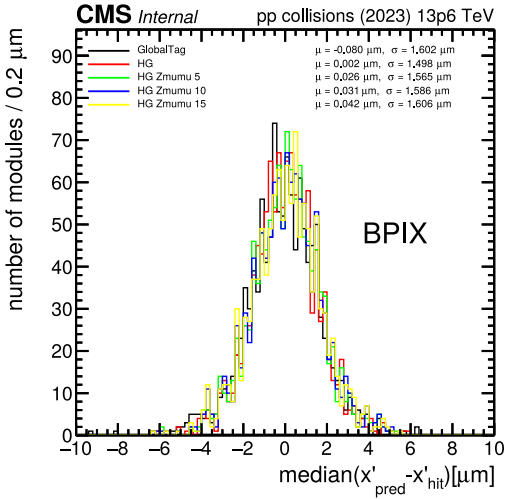
Details see here

$\Rightarrow$ Significant bias reduction by including strongly weighted $Z \to \mu\mu$ tracks

DMR validation: BPIX

DMR validation

- Refit track without hit of interest
- Measure distance between **measured hit** and **prediction by the fit** wrt local module coordinates (denoted x' etc.)
- Calculate the median of these "residuals" for each module

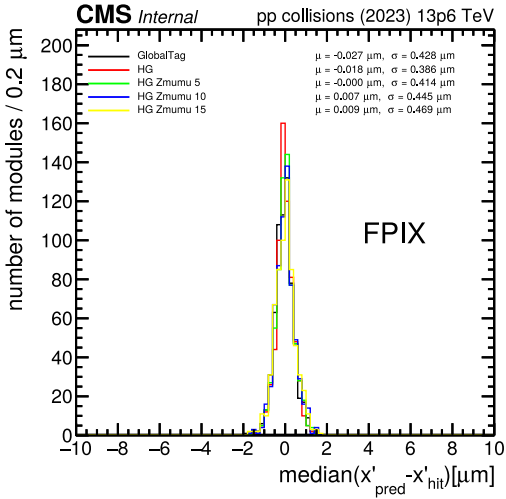


⇒ No significant loss in alignment performance

DMR validation: FPIX

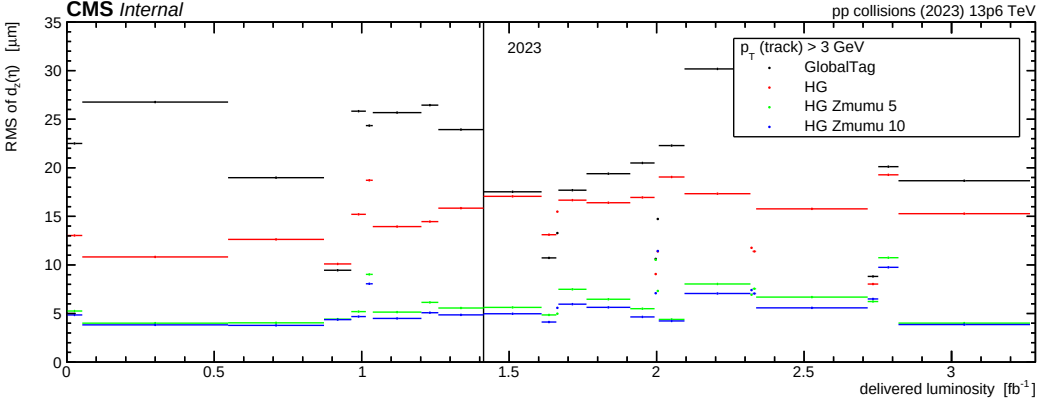
DMR validation

- Refit track without hit of interest
- Measure distance between **measured hit** and **prediction by the fit** wrt local module coordinates (denoted x' etc.)
- Calculate the median of these "residuals" for each module



⇒ No significant loss in alignment performance

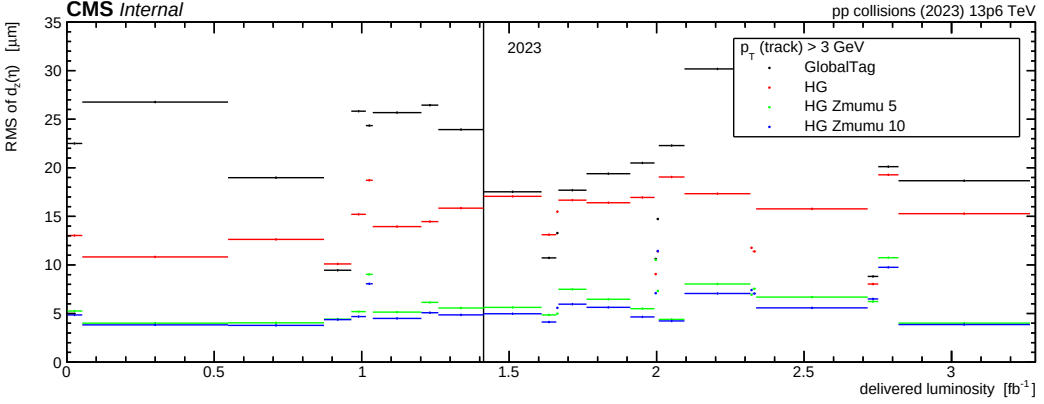
Long-term studies



Details see here

- Simulate iterative alignment updates, using previous alignment as input
- 2023Cv4 data, run 367881 to 368423
- Iterative propagation might lead to larger deviations between different PCL options

Long-term studies



Details see here

- Large d_z vs η asymmetry $\Rightarrow$ large RMS of $d_z(\eta)$

$\Rightarrow$ Bias reduction over whole lumi range through introduction of Z $\rightarrow \mu\mu$ tracks

- Checked DMR vs lumi as well, no significant differences

Outlook and Summary

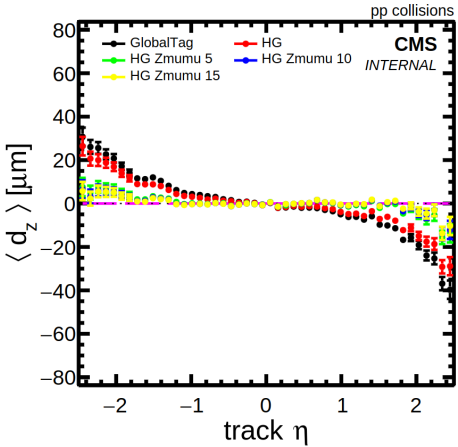
Summary

- HG PCL performs well but leads to bias in specific variables
- Inclusion of Z $\rightarrow \mu\mu$ tracks in alignment procedure leads to
  - Reduced bias in $d_z(\eta)$ and $\cos\phi_{3D}$
  - No significant change in DMR

$\Rightarrow$ Reduced need for re-reconstruction passes during Run 3

- Studies done using *prompt* data, while PCL runs on *express*
  - Smaller fraction of Z $\rightarrow \mu\mu$ tracks expected in *express*

  $\Rightarrow$ Use larger weight of 10

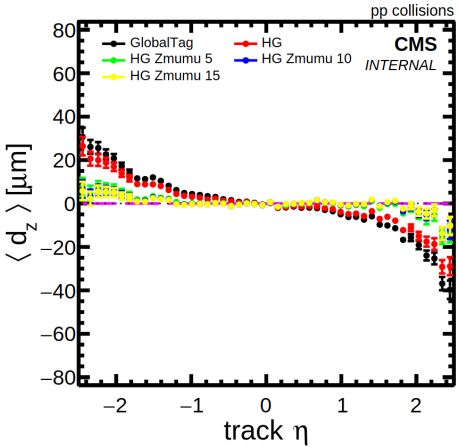


Outlook and Summary

Operational Plan

- PR with PCL update included recently merged into CMSSW_14_0_X
- Planning to test it on the tier-0 replay
  - Starting within next few days
- If validation successful, create new tag such that 3 workflows are in place::
  1. LG PCL alignment (MinBias only)
  2. HG PCL alignment (MinBias only)
  3. HG PCL alignment (MinBias + $Z \to \mu\mu$)
- Plan to use 2. in production tag during 900 GeV after first offline update with 3. in dummy tag.

  $\to$ If trend plots look ok, plan to deploy 3. for collisions at 13.6 TeV

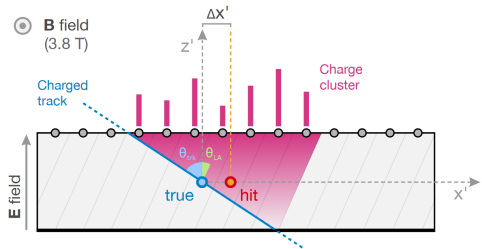


Backup

Lorentz drift

- Accumulated radiation affects Lorentz drift in tracker modules
  - → Biases local hit reconstruction
  - → New pixel calibration every $\sim 10\,\mathrm{fb}^{-1}$
- Opposite effect on modules with inward and outward pointing E field in BPIX

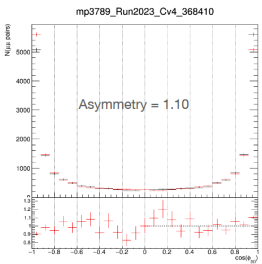
⇒ High granularity alignment (HG) can correct these radiation effects



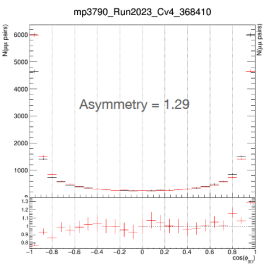
- Distribution of median residuals for inward/outward pointing modules

⇒ Difference between both means ($\Delta\mu$) can quantify radiation effects

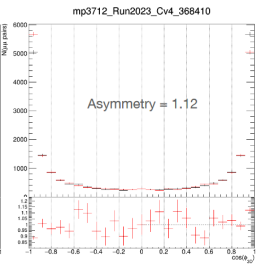
Inclusion of other Dimuon Resoncances



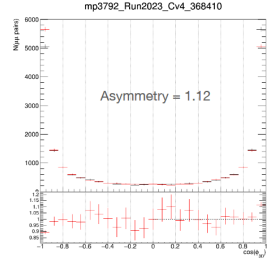
- mp3789
  - all dimuon resonances, no min-bias



- mp3790
  - min-bias and JPsi



- mp3712
  - min-bias and Z(μμ) [w=10]



- mp3792
  - min-bias, JPsi and Z(μμ)[w=10]

- Tracks from JPsi are not so effective as the ones from Z, despite larger stat.
- Adding JPsi tracks in addition to Z (and min-bias) to the alignment does not seem to contribute to reduce the bias further -just judging from this one validation.

Taken from this talk

Long-term studies: $\Delta\mu$ BPIX

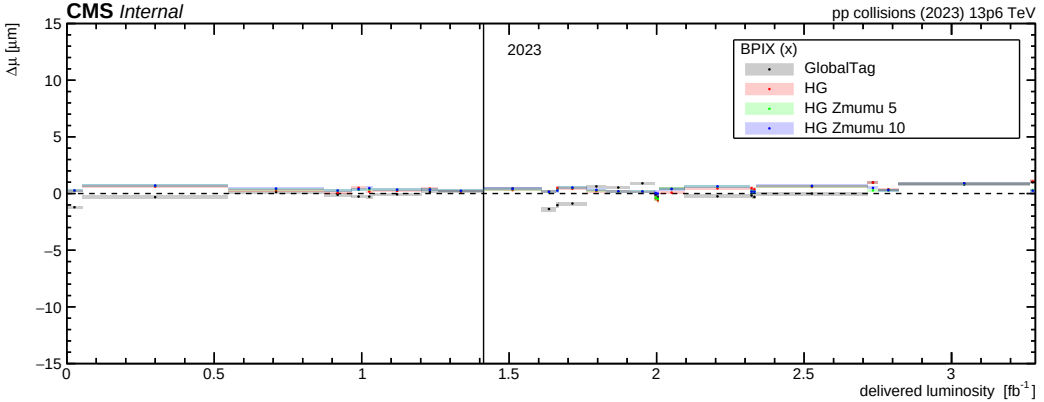


Figure: $\Delta\mu$ parameter in BPIX as function of luminosity

Long-term studies: $\Delta\mu$ FPIX

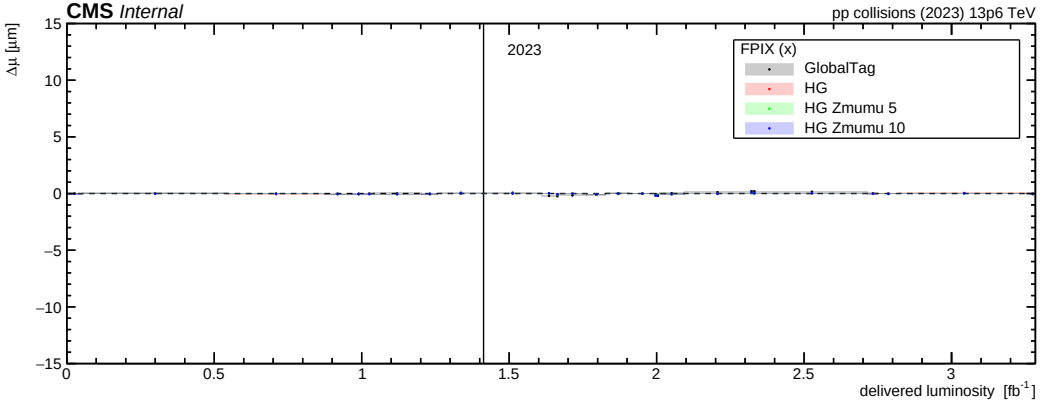


Figure: $\Delta\mu$ parameter in FPIX as function of luminosity