PERFORMANCE AND TRACK-BASED ALIGNMENT OF THE UPGRADED CMS PIXEL DETECTOR

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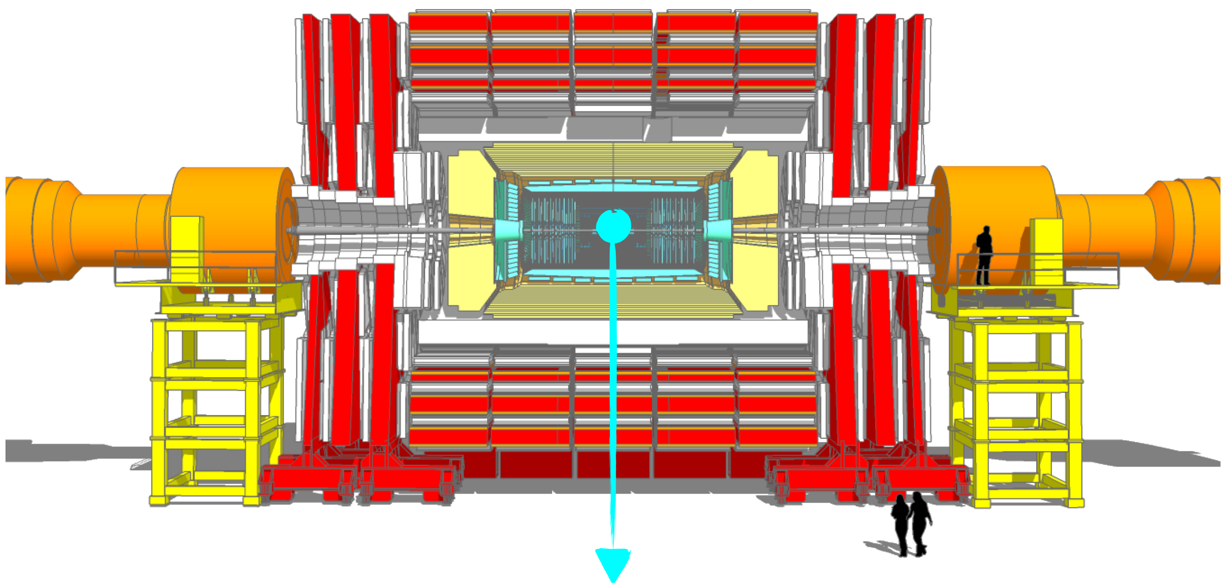
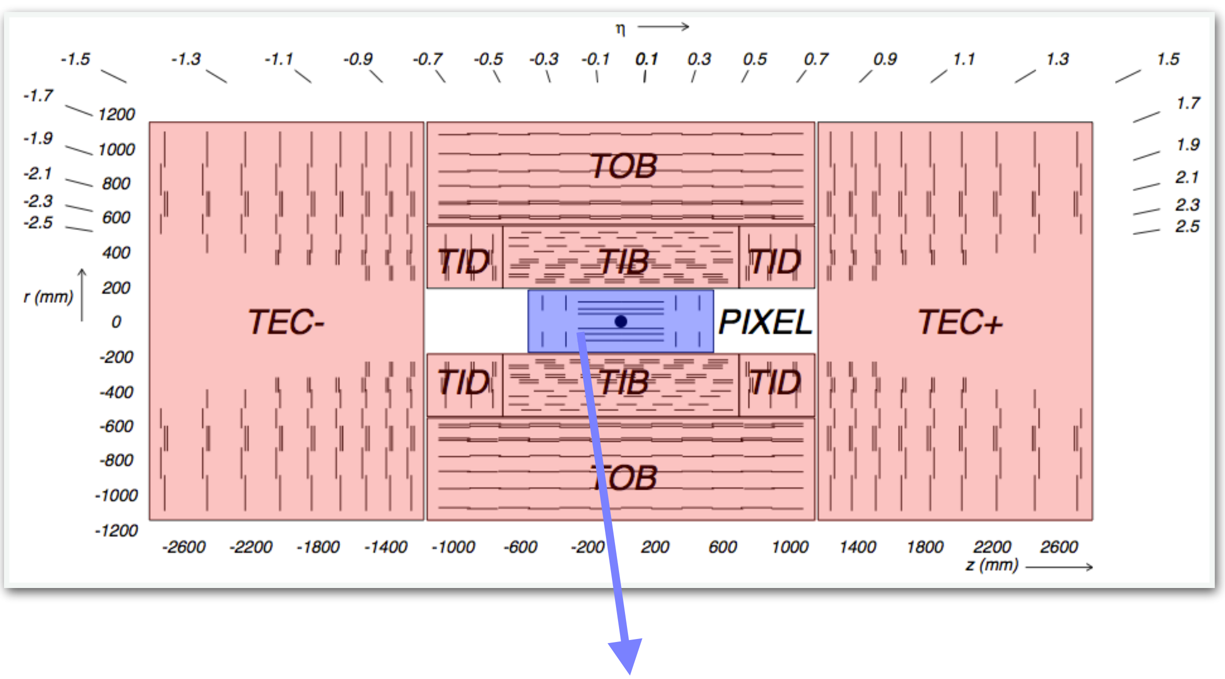
on behalf of the CMS Collaboration

EPS Conference on High Energy Physics - Venice, 5-12 July 2017

THE CMS TRACKER



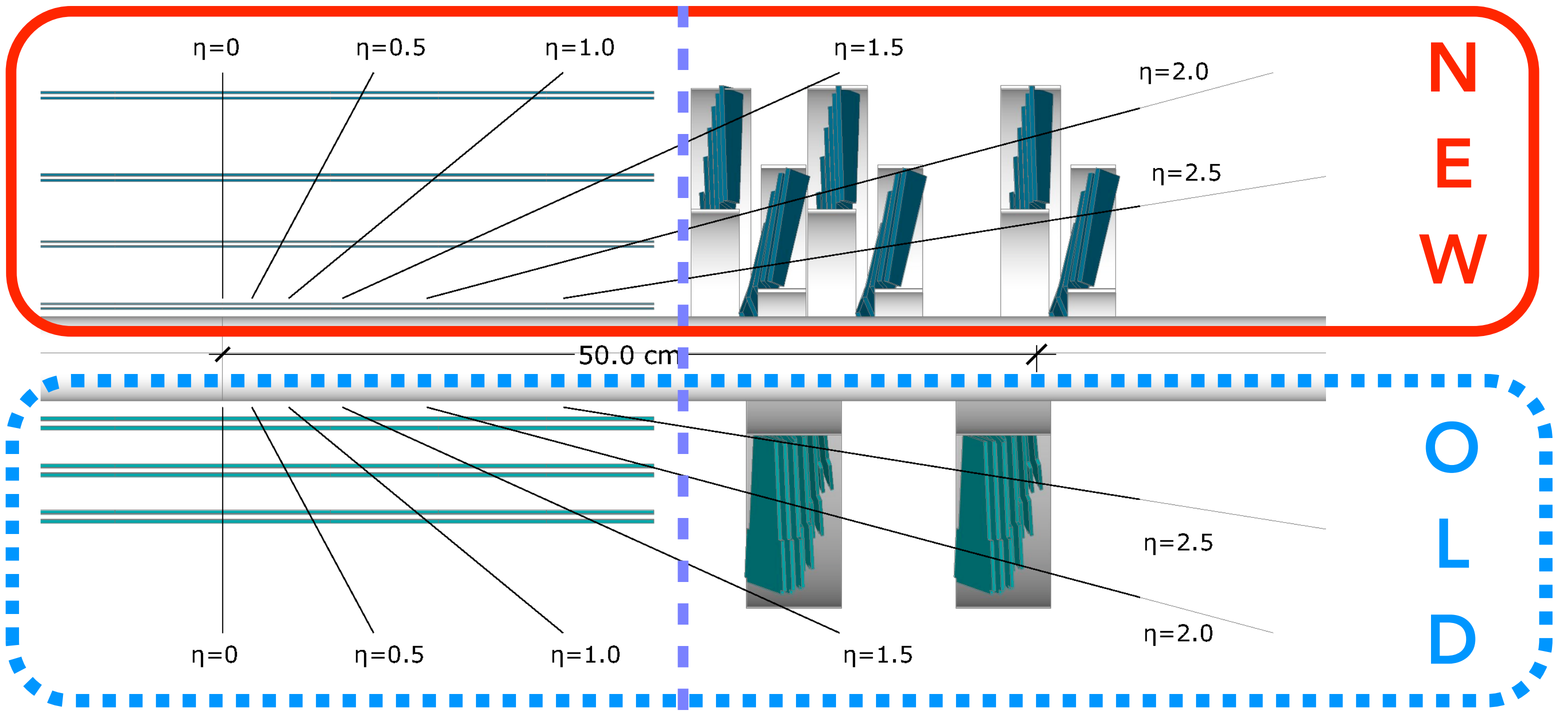


pixel layout before upgrade

- Innermost part of the CMS detector
- Composed by silicon modules
  - Pixel
  - Strip
- Modules arranged in
  - Cylindrical layers in the central region “barrel”
  - Disks in the forward regions “endcaps”
- The *Pixel* detector has been replaced and upgraded

THE UPGRADED PIXEL DETECTOR

Pixel Barrel (BPix) | Pixel Forward (FPix)



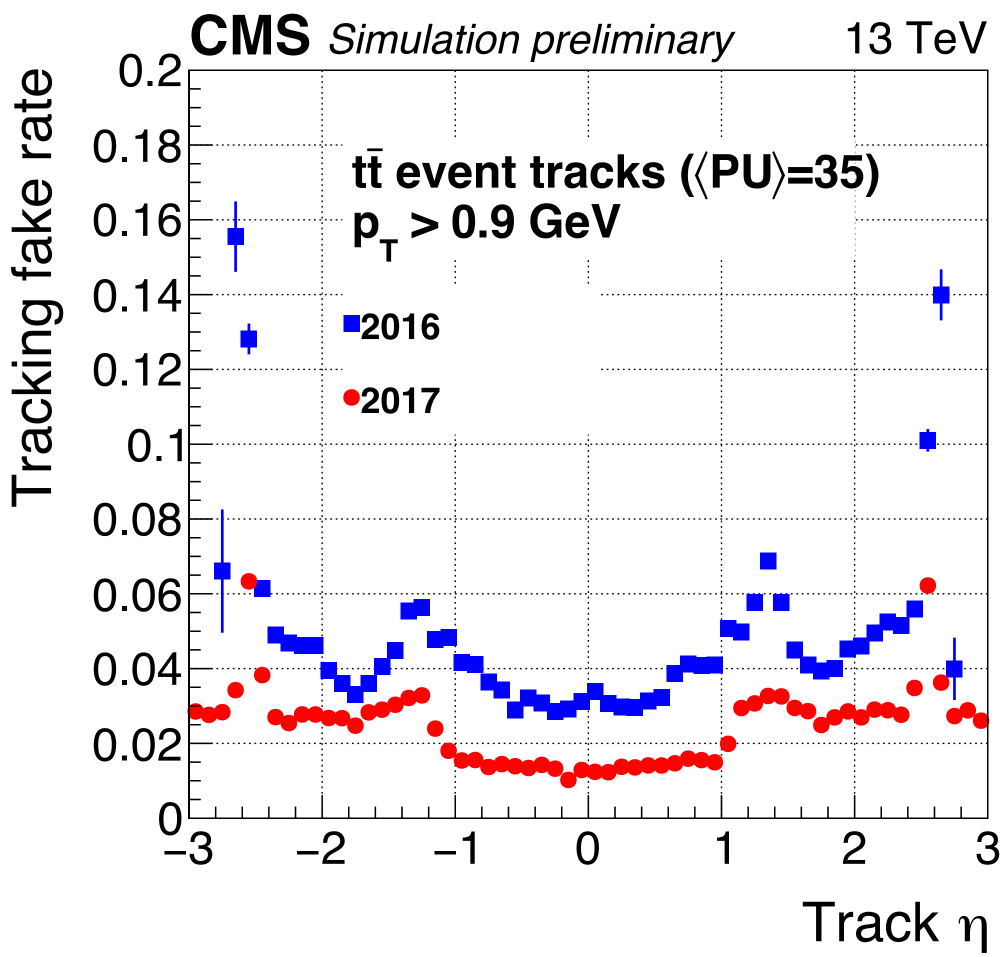
More in the previous talk by R. Bartek on construction and commissioning of the new pixel

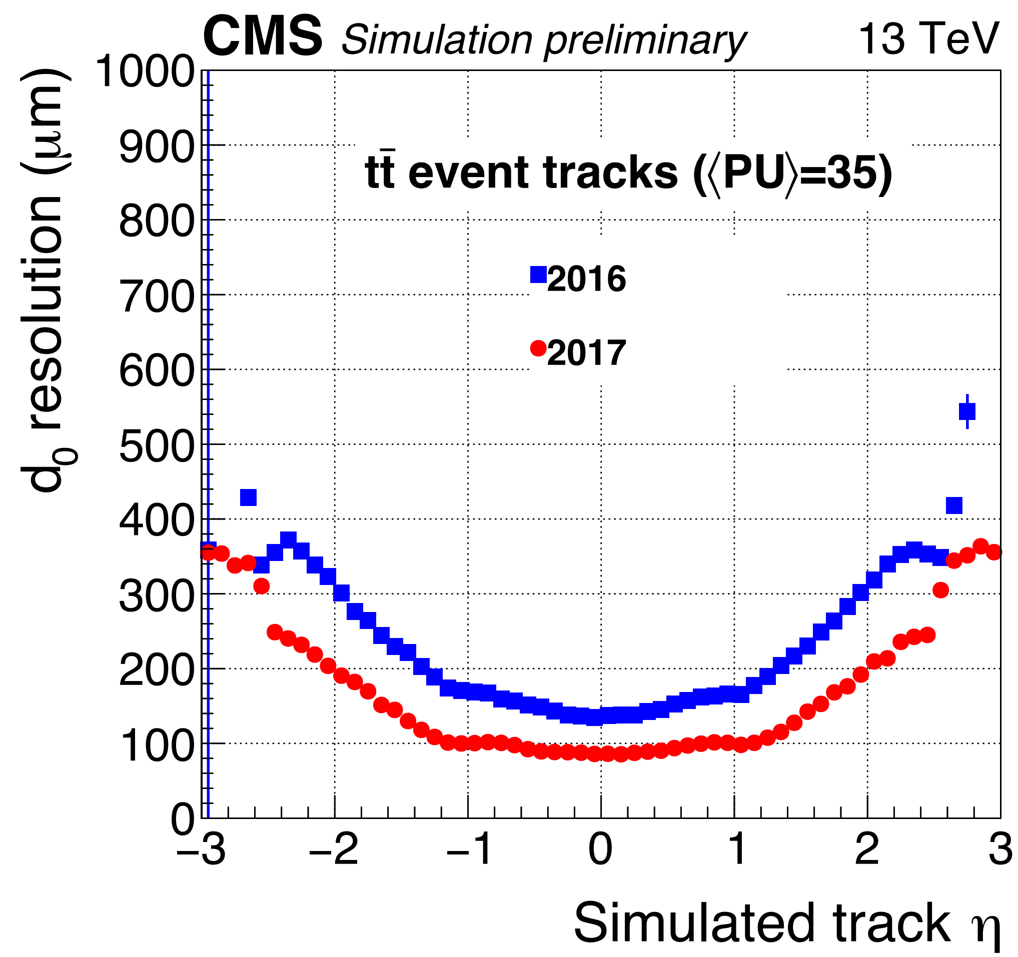
- One more barrel layer, one more forward disk
- Innermost barrel layer closer to the interaction point
- Improved readout electronics
- Lower material budget (CO_2 cooling)

} Better tracking also at high instantaneous luminosities

EXPECTED TRACKING PERFORMANCE

New (2017) vs. old (2016) tracker, from simulation



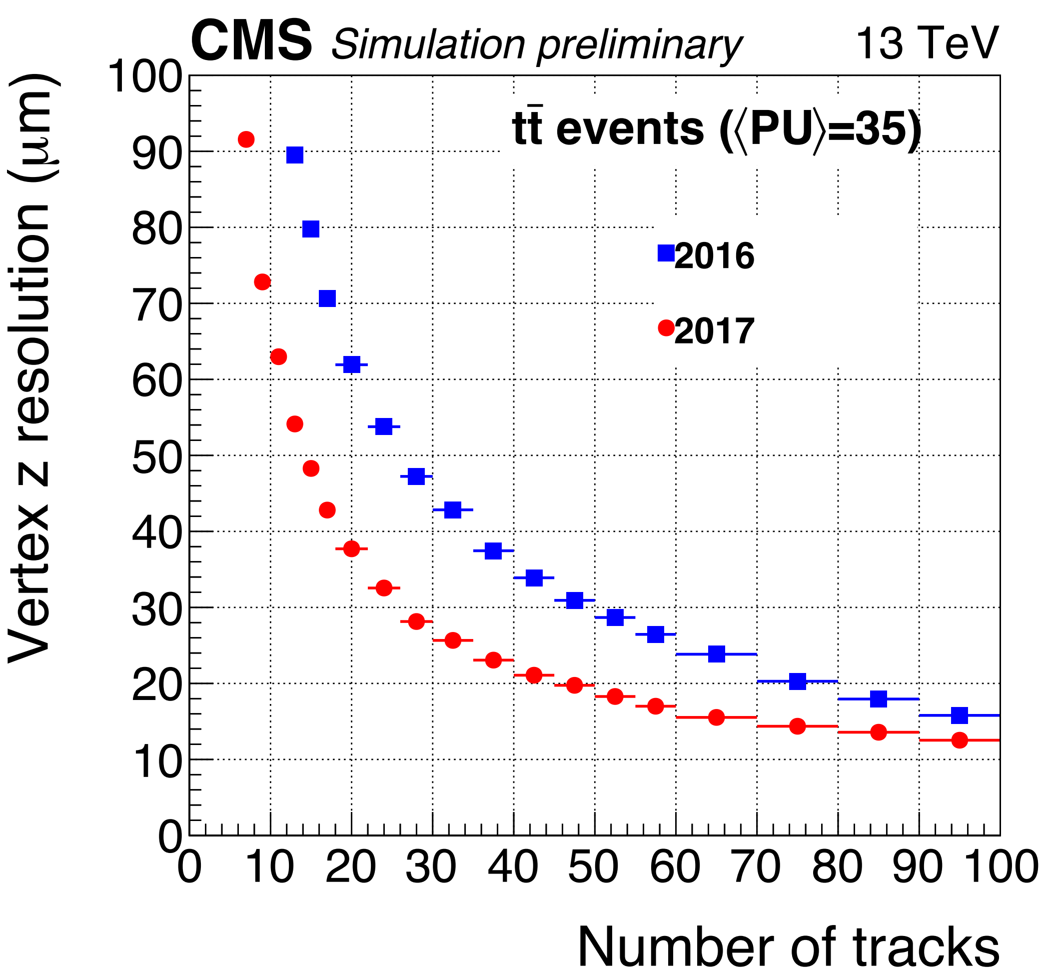


- Fake rate reduced by a factor ~3, and higher track efficiency
- Better track impact parameter resolution by ~ 30%

EXPECTED VERTEX AND B-TAG PERFORMANCE

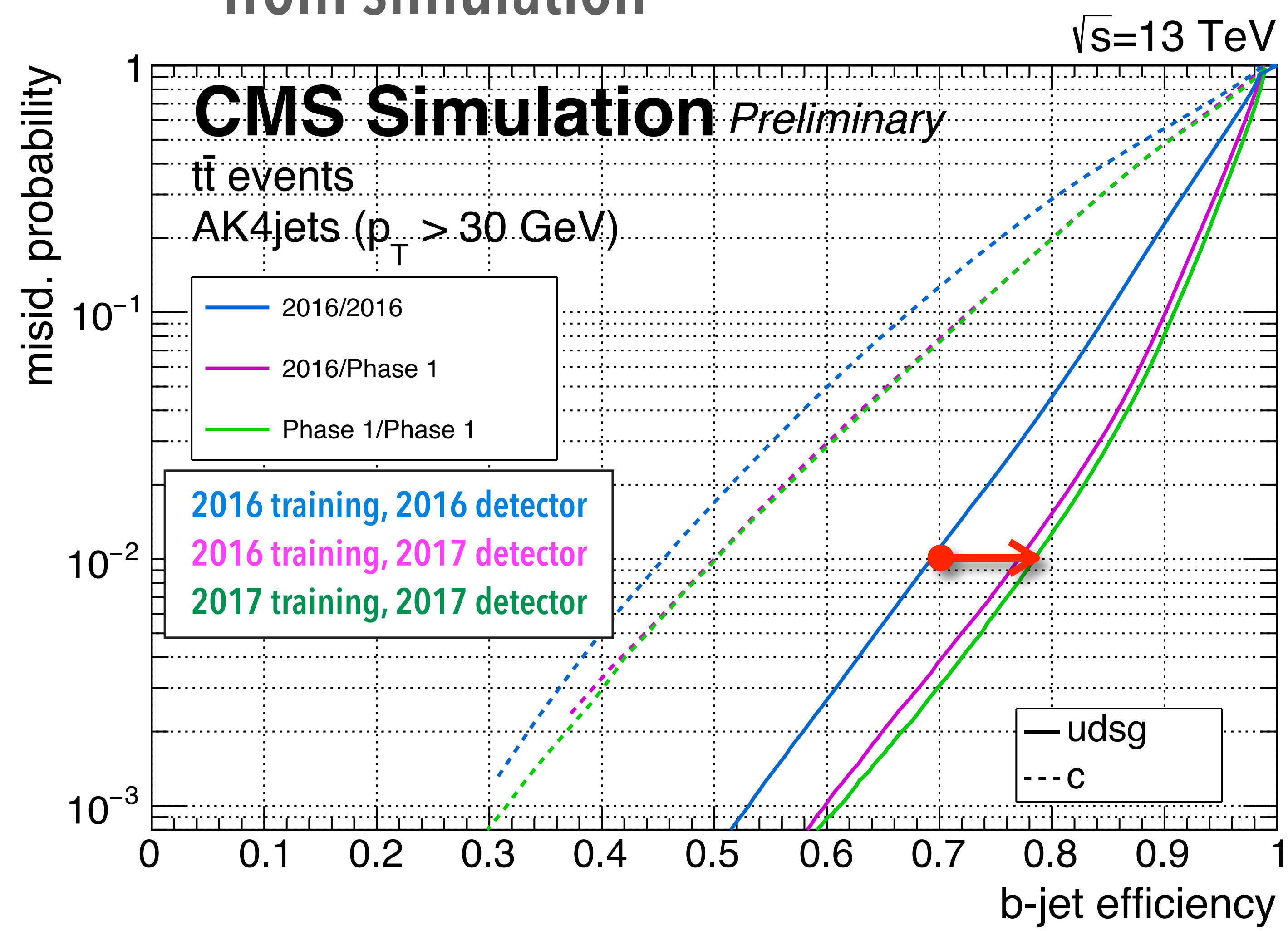
New (2017) vs. old (2016)

from simulation



New (Phase1) vs. old (2016)

from simulation



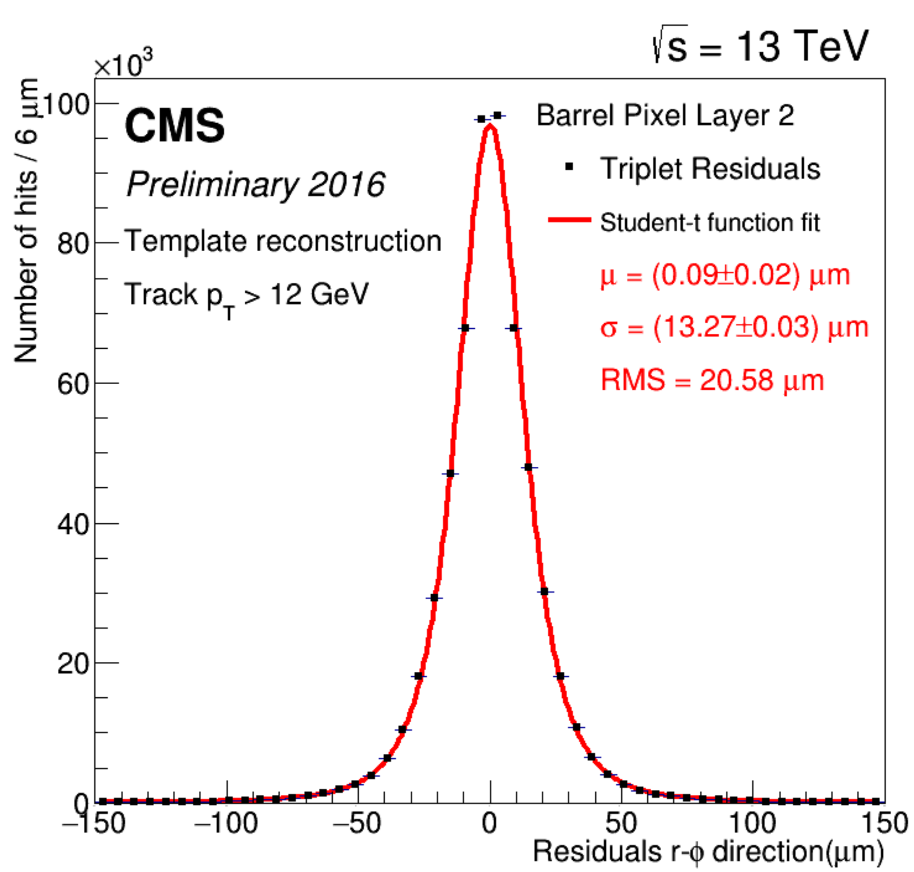
- Better identification of b-jets, +10% efficiency at the same fake rate.

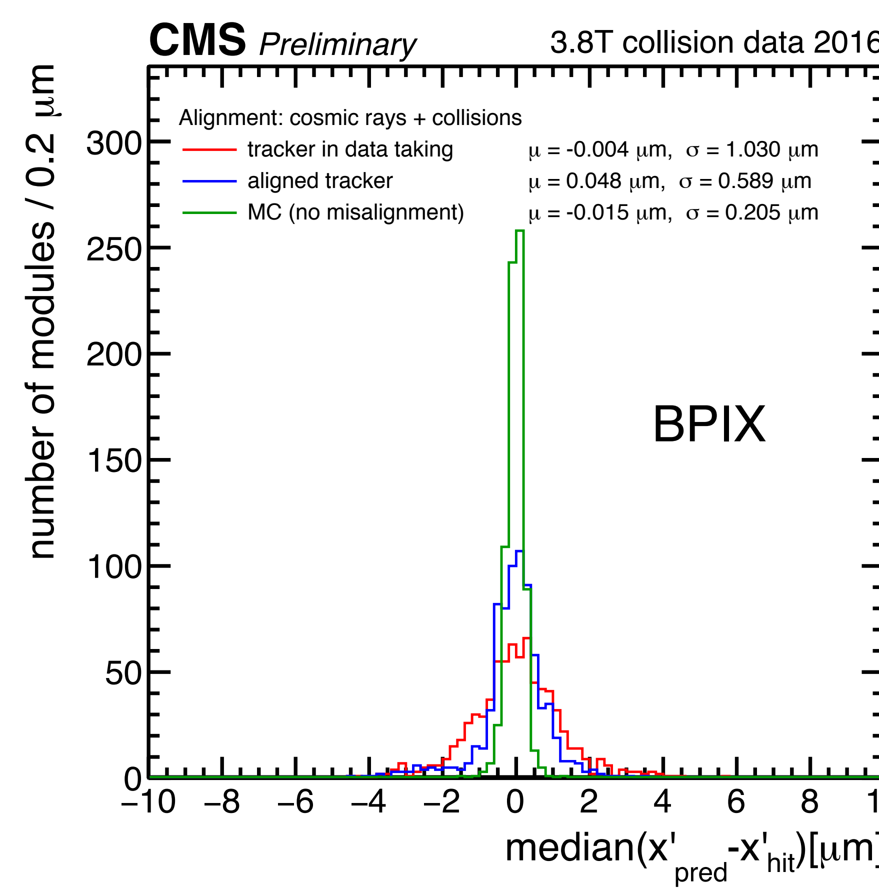
REACHING THE EXPECTED PERFORMANCE

The expected design performance can be achieved only with excellent hardware and calibration

- Position resolution $\sigma_{pos} = \sigma_{hit} \oplus \sigma_{align}$. For pixel hits
  - σ_{hit} : intrinsic hit resolution, O(10 μm)
  - σ_{align} : uncertainty on the modules positions, O(1 μm)

2016

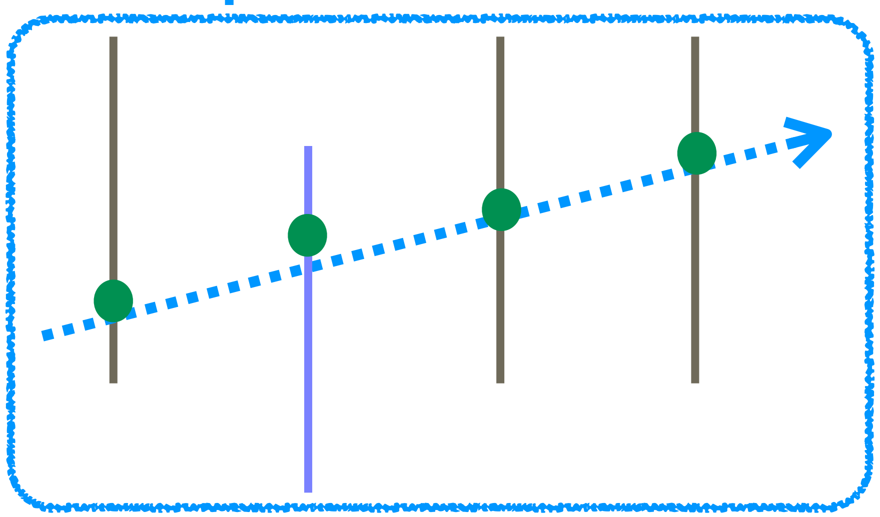




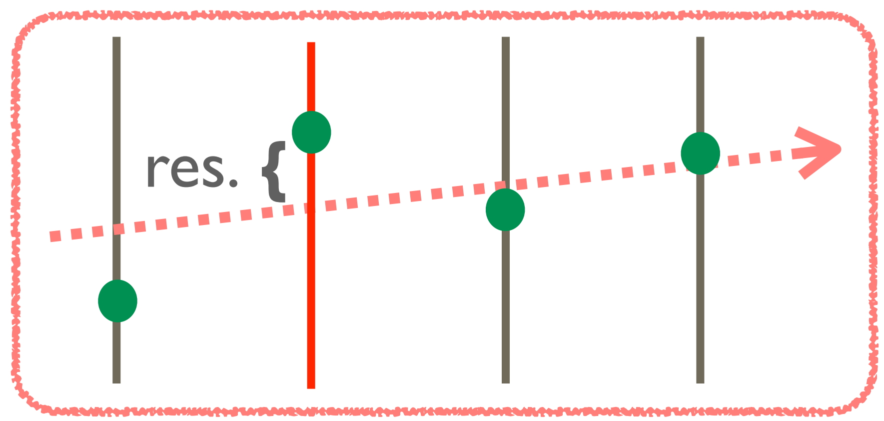
TRACK-BASED ALIGNMENT

- Tracks are reconstructed fitting a set of hits on the tracker modules.
- Assuming wrong modules positions leads to bias in the reconstructed track: real ≠ fitted

real positions, real track



wrong positions, fitted track



- Wrong positions leads to large residuals
- Track-hit residuals are an measure of misalignment

- Measure the real modules positions, with a large set of tracks that correlate the alignment parameters, minimising track-hit residuals:

measured fitted alignment param.

$$\chi^2(\mathbf{p},\mathbf{q}) = \sum_j^{\text{tracks}} \sum_i^{\text{hits}} \left(\frac{m_{ij} - f_{ij}(\mathbf{p},\mathbf{q}_j)}{\sigma_{ij}}\right)^2$$

track par.

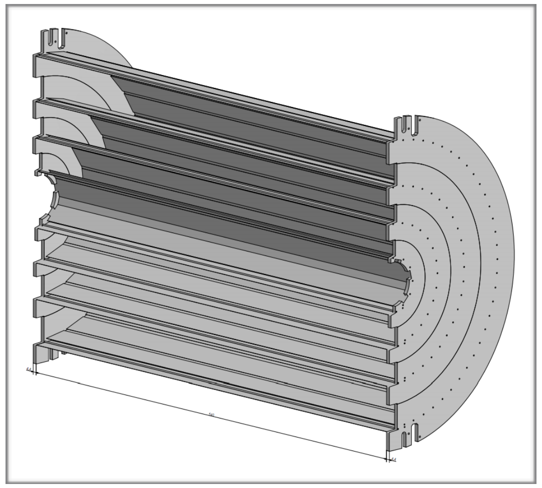
Can achieve a precision $\lesssim$ O(10 μm) with large statistics and several track topologies

PIXEL ALIGNMENT WITH COSMIC RAYS

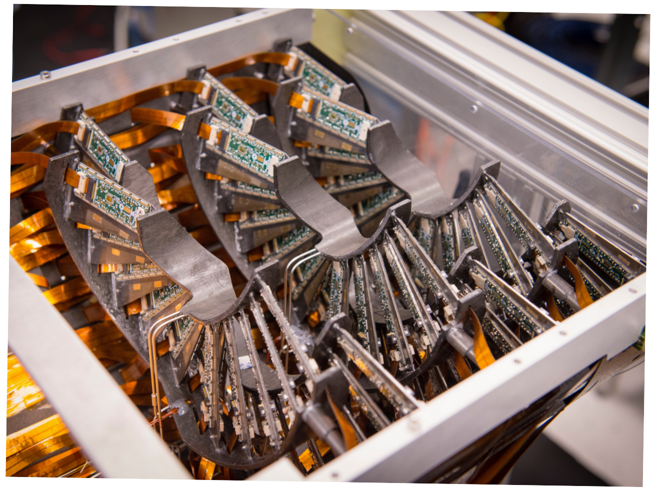
- Potentially large initial misalignment of the new pixel
  - Several alignments performed, with increasing granularity

1. alignment of forward and barrel pixel *high-level structures*
2. alignment of the whole pixel at module level

half-shell of the barrel pixel



half-cylinder of the forward pixel



- Cosmic ray data taking (before pp collisions)

CMS Magnet off (0T)

1. alignment of forward pixel
2. alignment of barrel pixel
3. alignment at module-level

CMS Magnet on (3.8T)

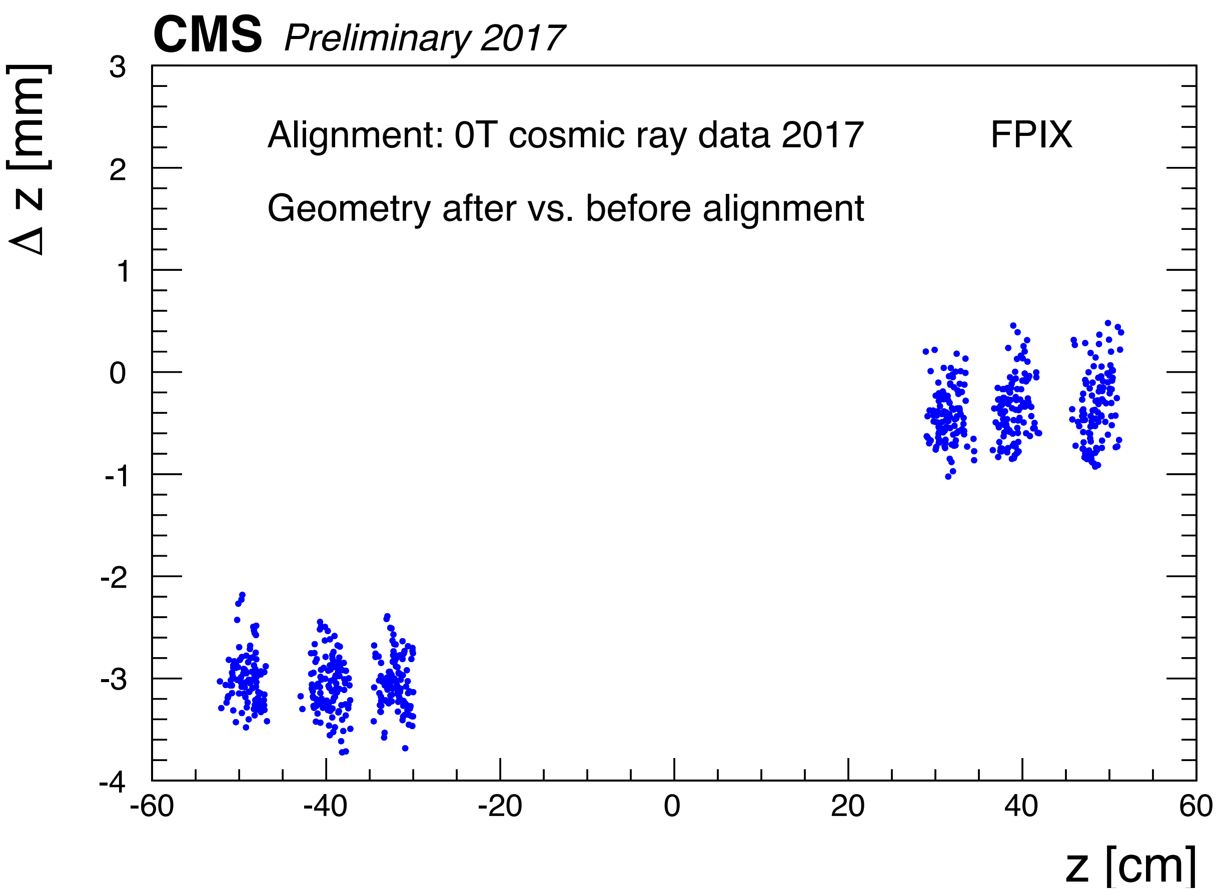
4. update of high-level structures alignment

(no module level due to stat.)

end of cosmic ray data taking, start of p-p run

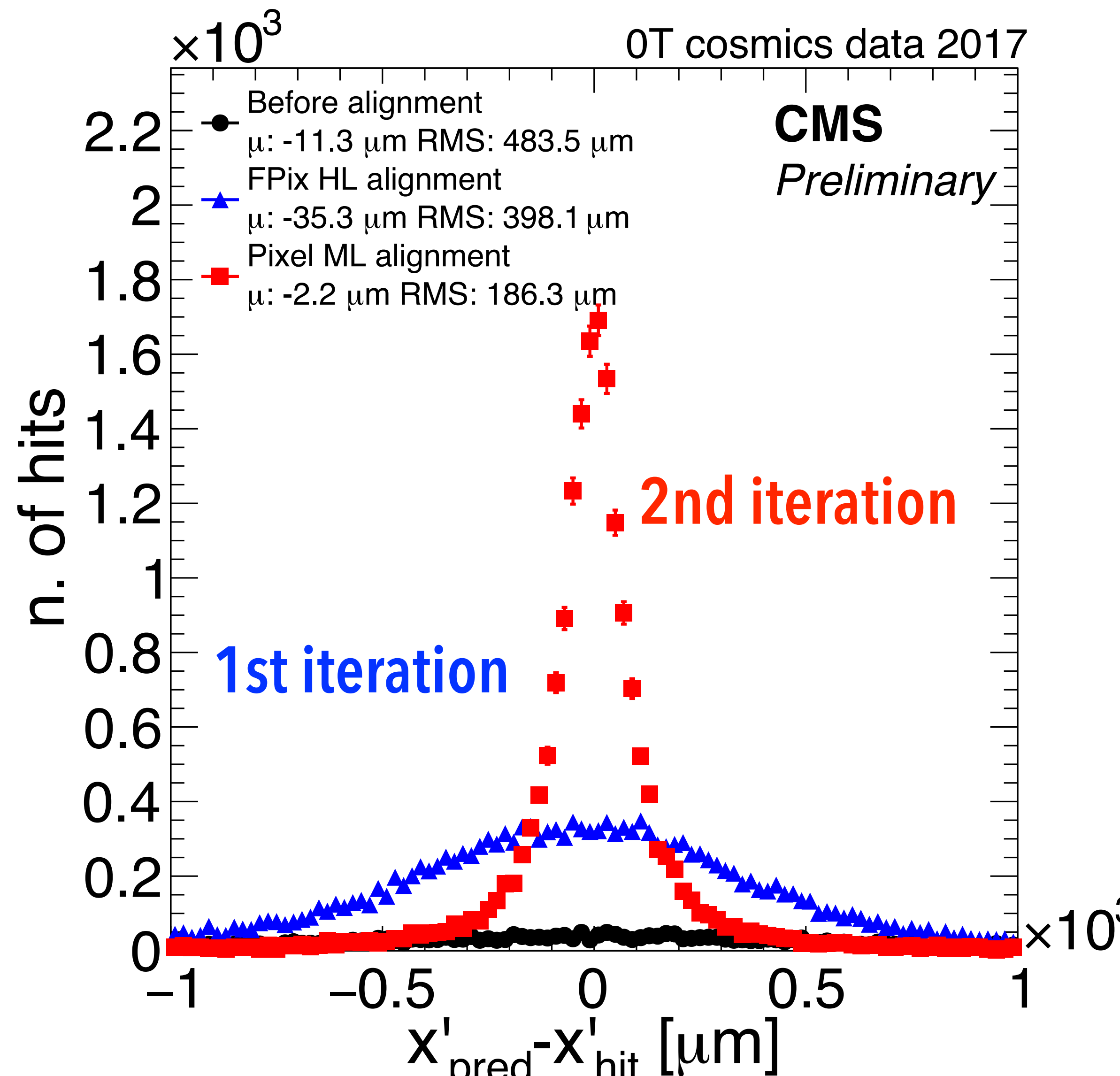
RESULTS ON 0T COSMIC RAY DATA - FPIX

The largest (and first) position correction was a 3 mm shift of the FPIX z-minus endcap



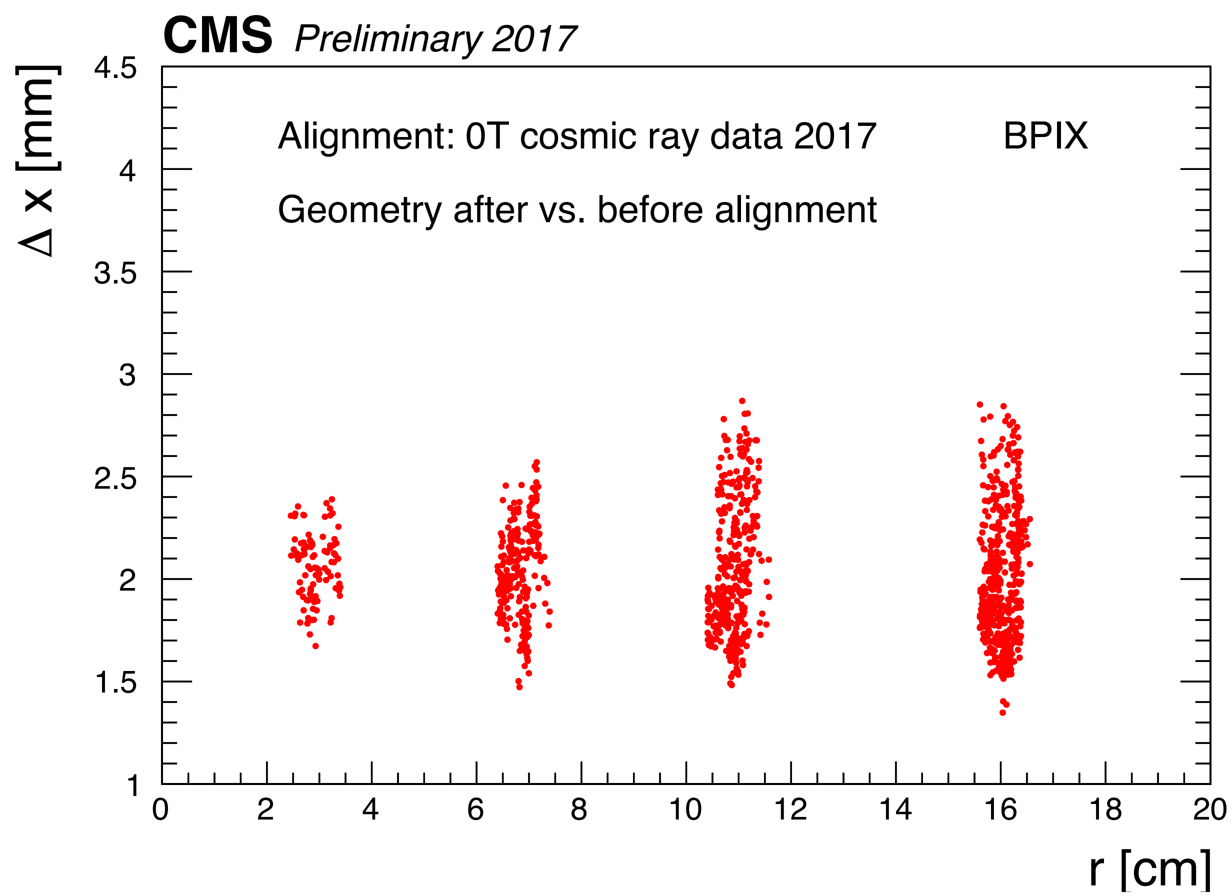
- Unbiased track-hit residuals, the hit under consideration is not used in the track fit
- Reduced bias (syst. effects) and width (local precision) after each alignment iteration.

Residuals in forward pixel, x′ direction

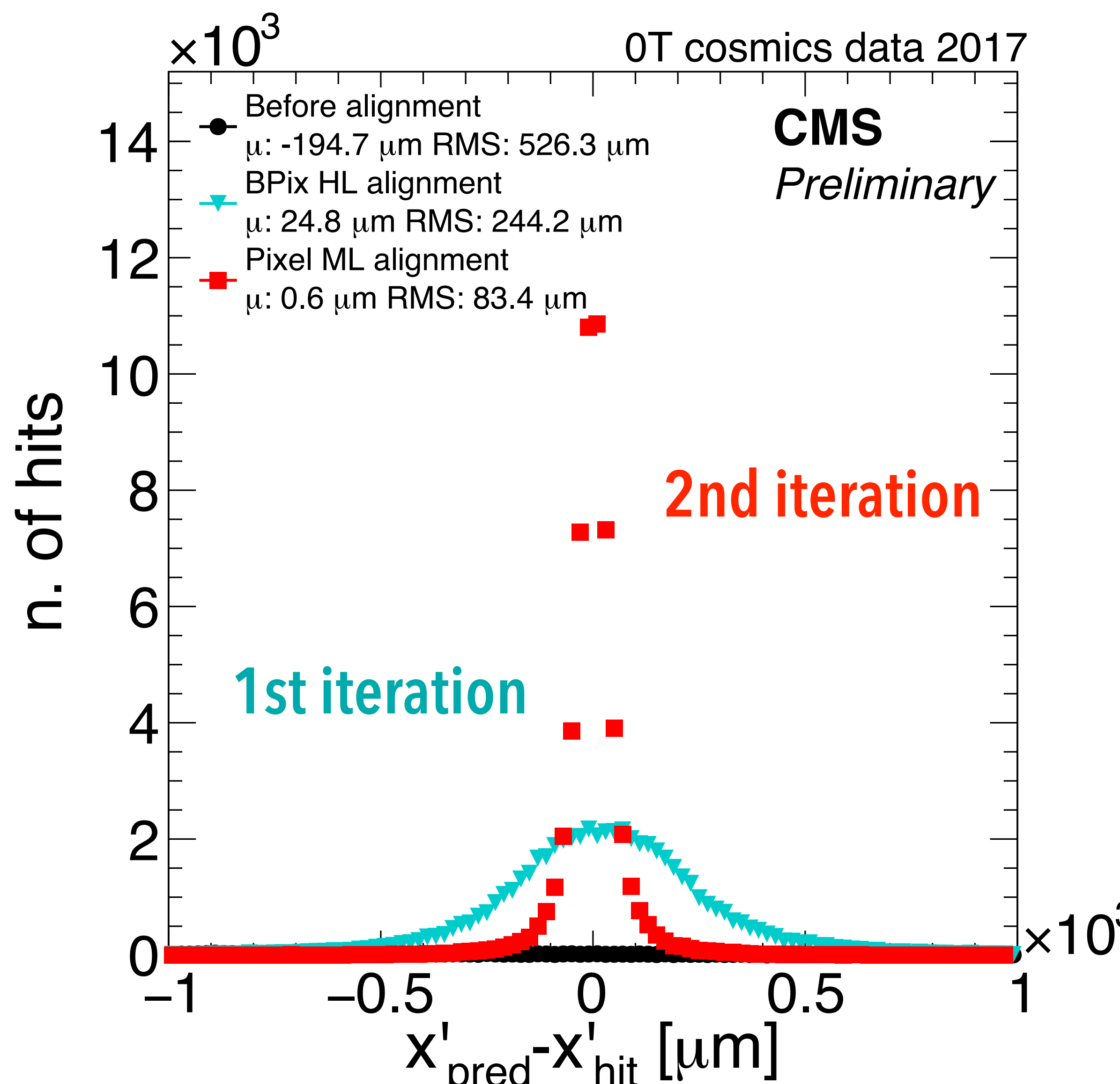


RESULTS ON 0T COSMIC RAY DATA - BPIX

For the barrel pixel, the largest position correction was a 2 mm horizontal shift along x



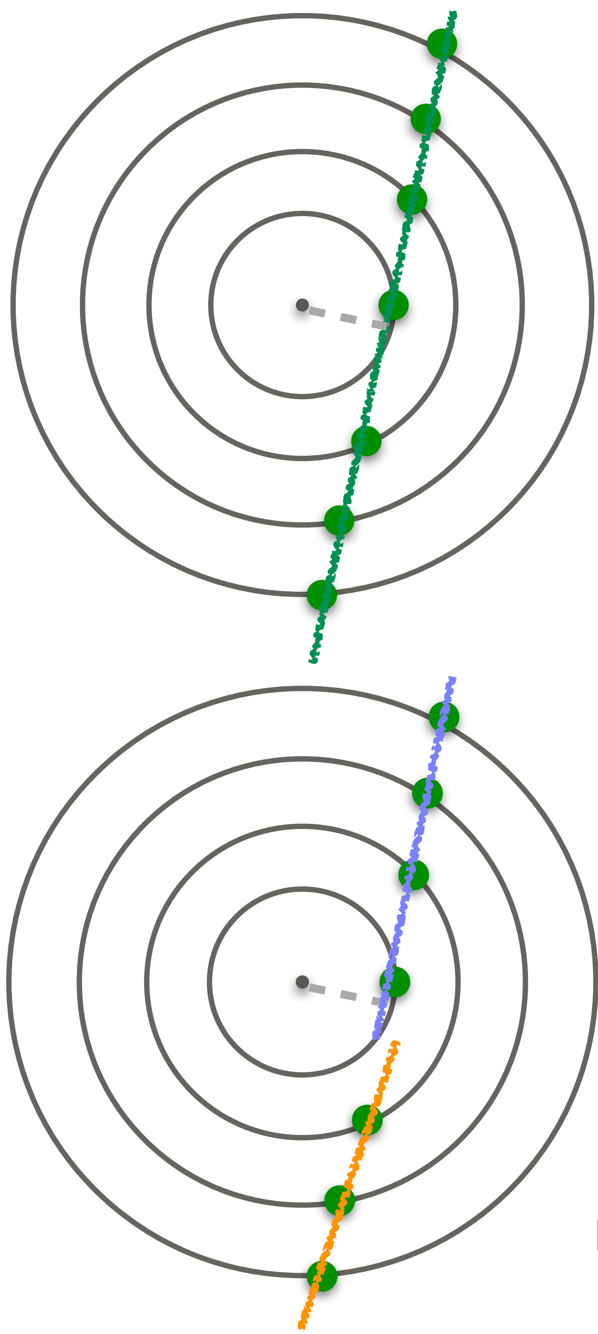
Residuals in barrel pixel, x′ direction

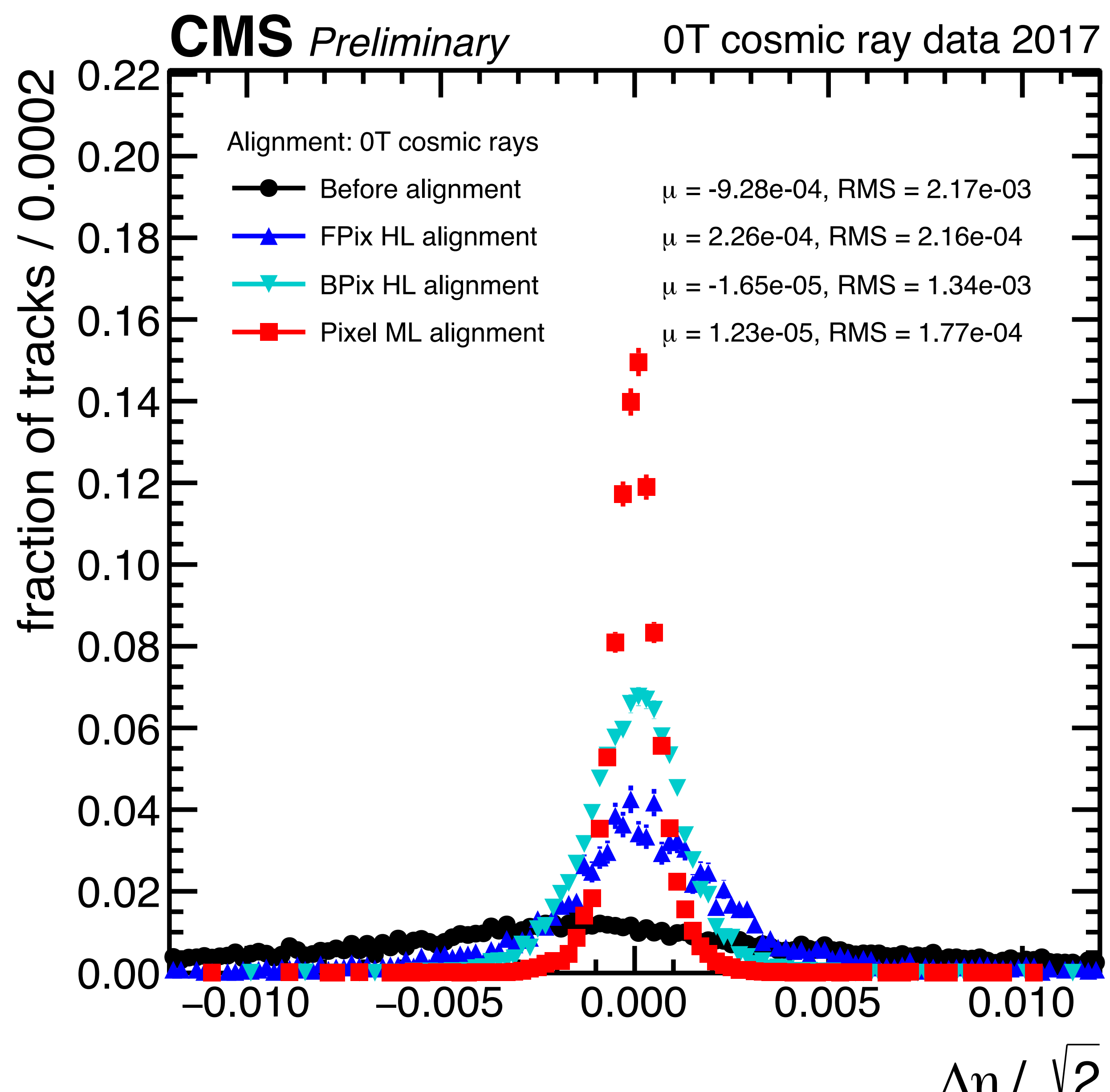


- Unbiased track-hit residuals, the hit under consideration is not used in the track fit
- Reduced bias (syst. effects) and width (local precision) after each alignment iteration.

TRACK SPLIT VALIDATION - 0T COSMIC RAY DATA

- Cosmic ray tracks are split in two halves, look at differences in their track parameters



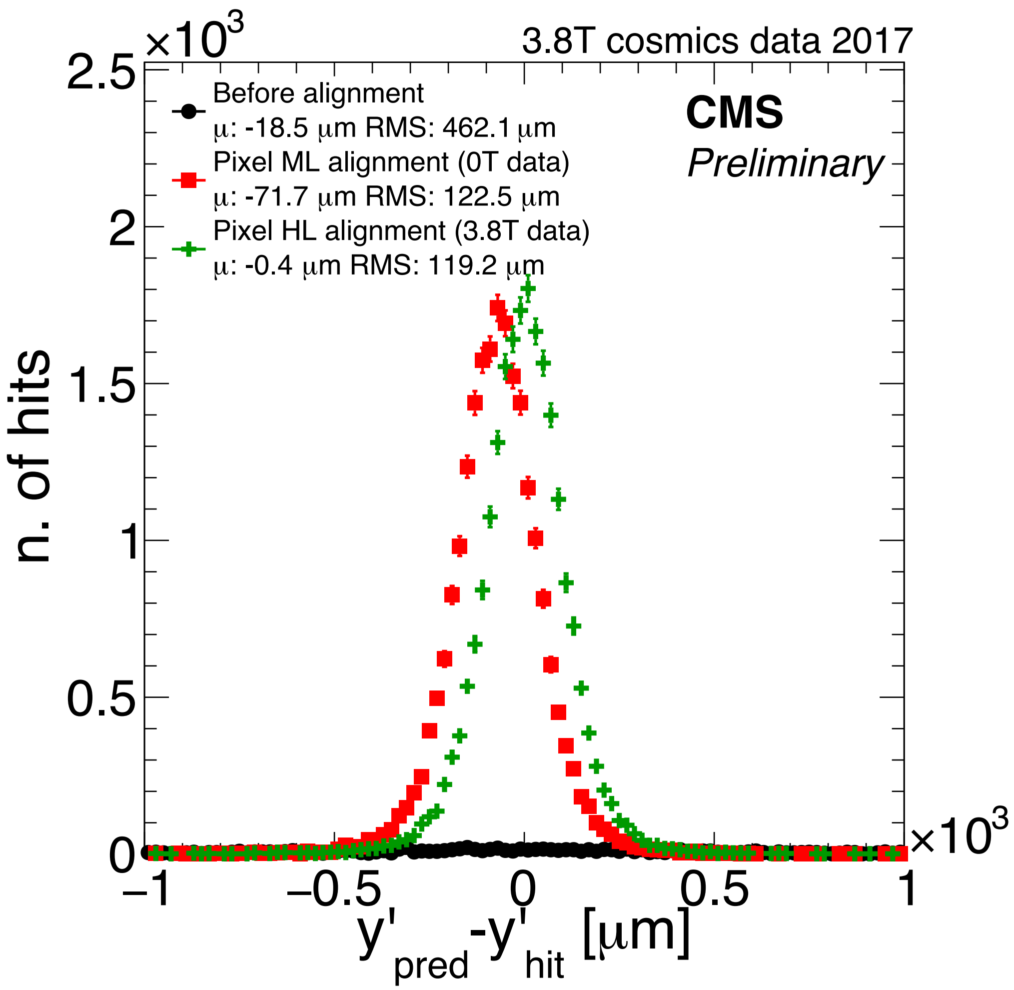


- After each alignment iteration, reduced bias (syst. effects) and width (local precision)

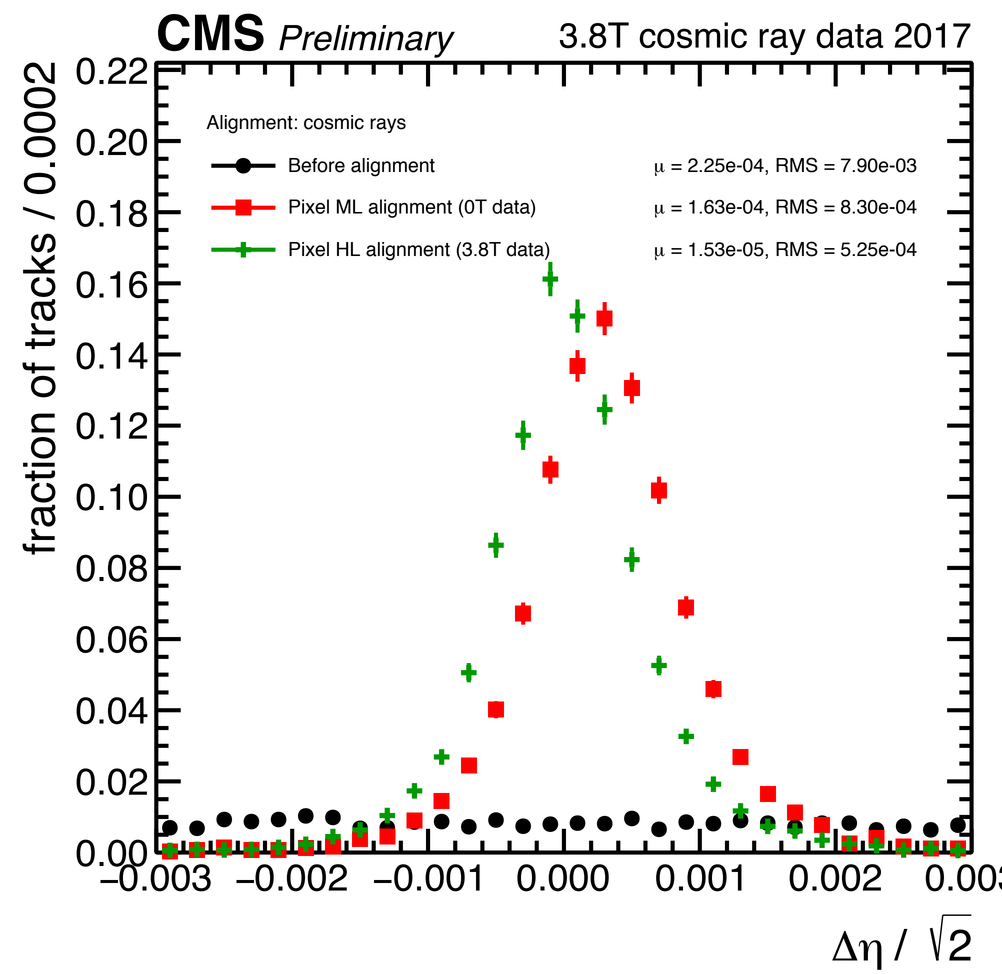
RESULTS ON 3.8T COSMIC RAY DATA

- Magnetic field change induces movements in the detector, need to update the alignment (at high-level due to limited stat.)

Track-hit residuals in barrel pixel, z direction



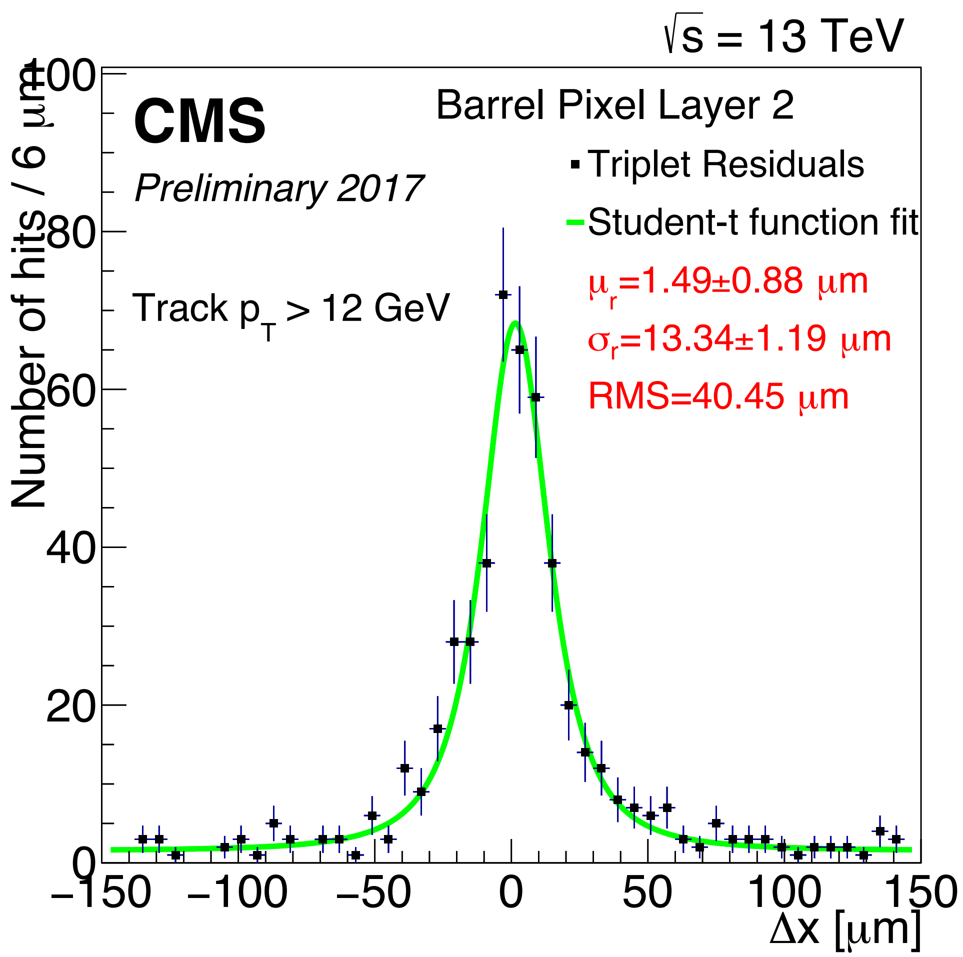
Track split, $\Delta\eta$ of the two track halves

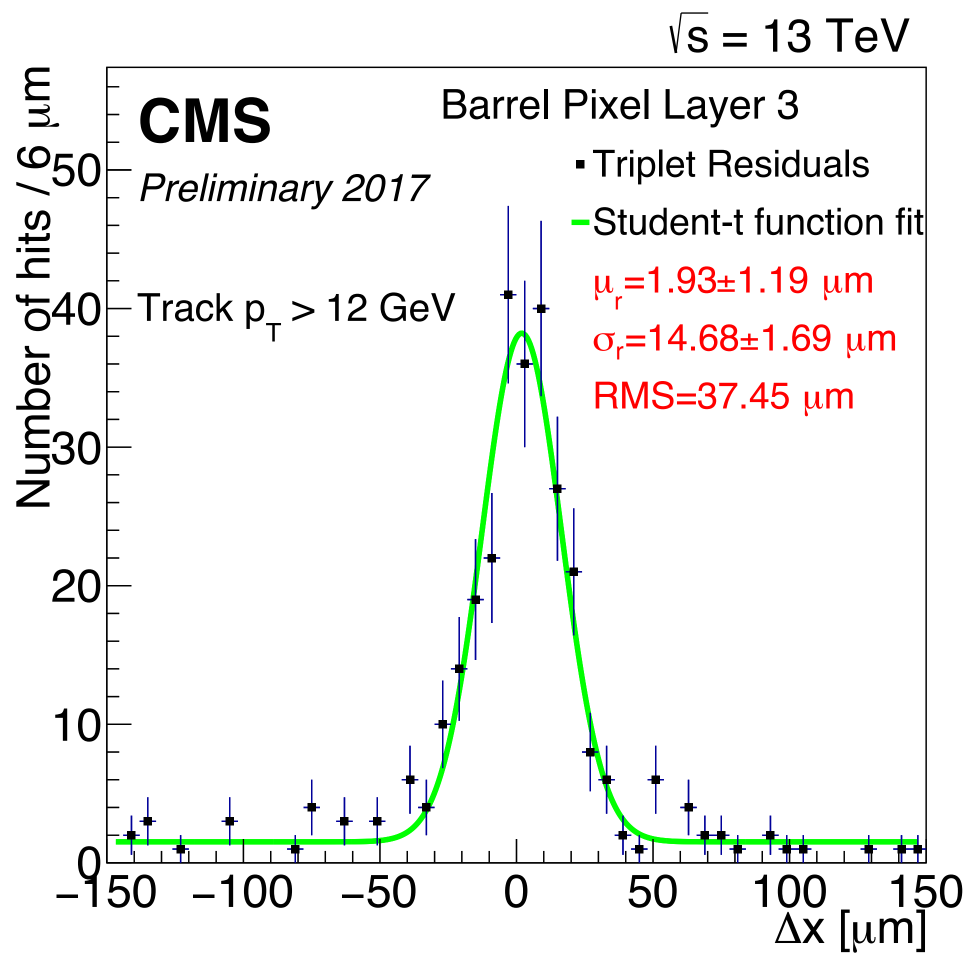


Successfully measured the pixel modules position after installation, good starting point for the collision run.

PIXEL HIT RESOLUTION - BPIX LAYERS 2-3

- Tracks with hits in layers 1,2,3 (2,3,4) refitted excluding layer-2(3)hit.
- Fit to distribution of hit residuals between hit position and interpolated track





- Layer 2 and 3 resolutions are compatible with each other
- Layer 2 resolution compatible with the one for the old detector

SUMMARY

- Shown expected improvements in tracking, vertexing and b-tagging thanks to the new CMS pixel detector
- Presented results of the first track-based alignment of the new pixel detector
  - performed with cosmic-ray data prior to LHC proton-proton run
  - successfully measured the pixel position after installation
  - very good starting point for the pp data taking
- Presented first performance results of the new pixel detector
  - first hit resolution measurements in line with expectations

THANK YOU FOR YOUR ATTENTION!

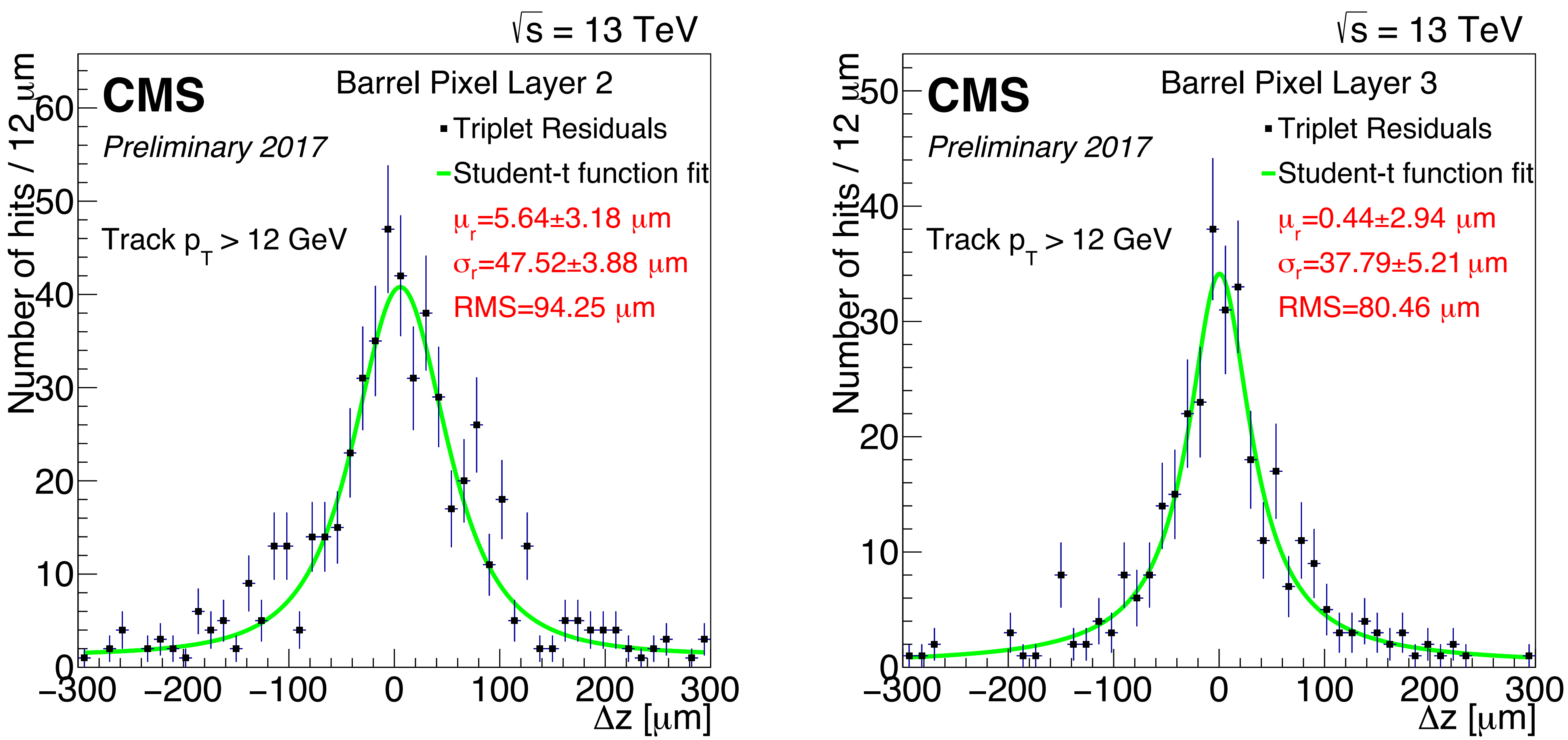
REFERENCES

1. CMS Collaboration, CMS Technical Design Report for the Pixel Detector Upgrade (2012) CERN-LHCC-2012-016
2. CMS Collaboration "Alignment of the CMS tracker with LHC and cosmic ray data" 2014 JINST 9 P06009 doi:10.1088/1748-0221/9/06/P06009
3. CMS Collaboration "Alignment of the CMS silicon tracker during commissioning with cosmic rays" 2010 JINST 5 T03009 doi: 10.1088/1748-0221/5/03/T03009

BACKUP - ADDITIONAL MATERIAL

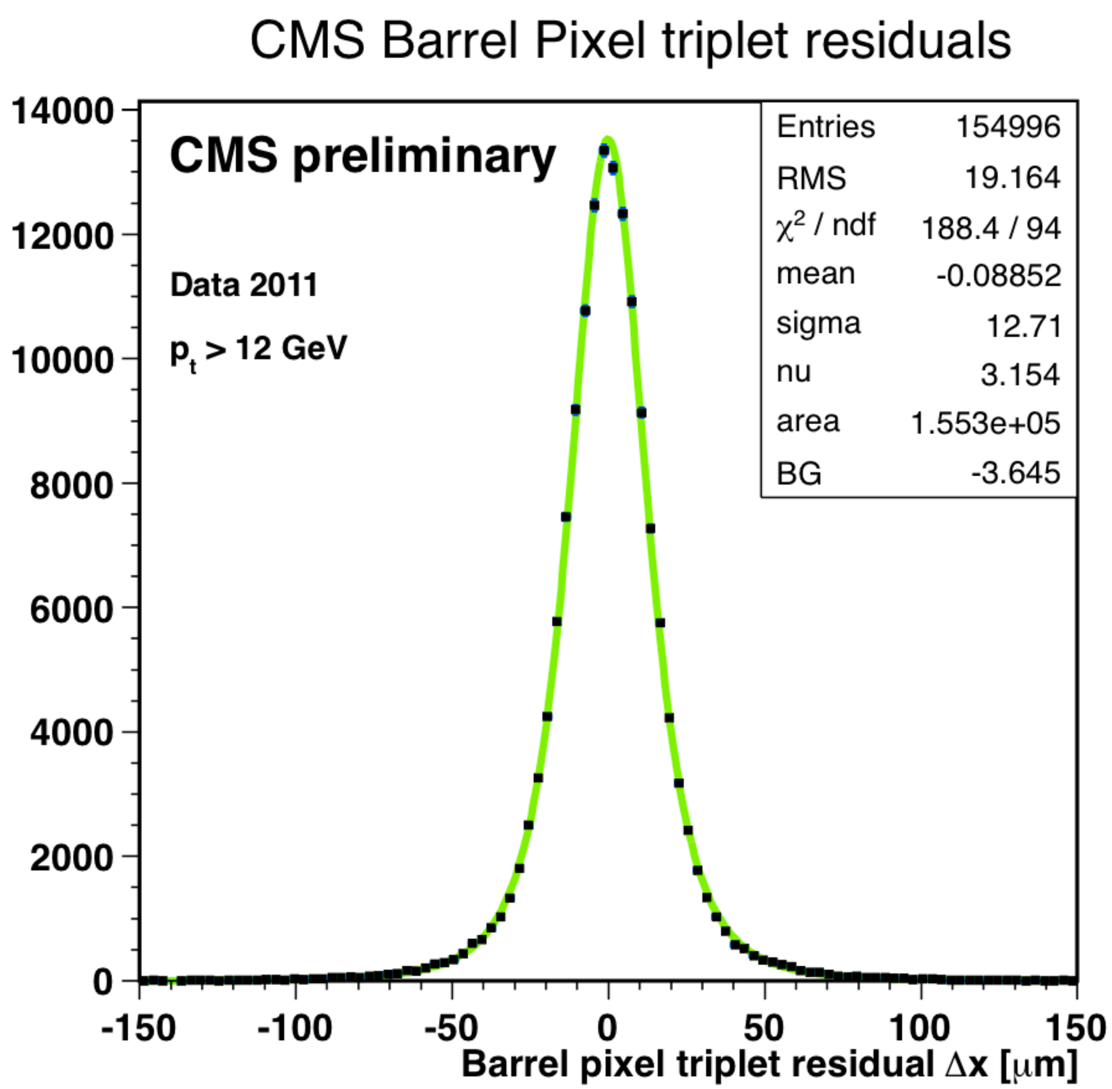
PIXEL HIT Z-RESOLUTION - BPIX LAYER 2-3

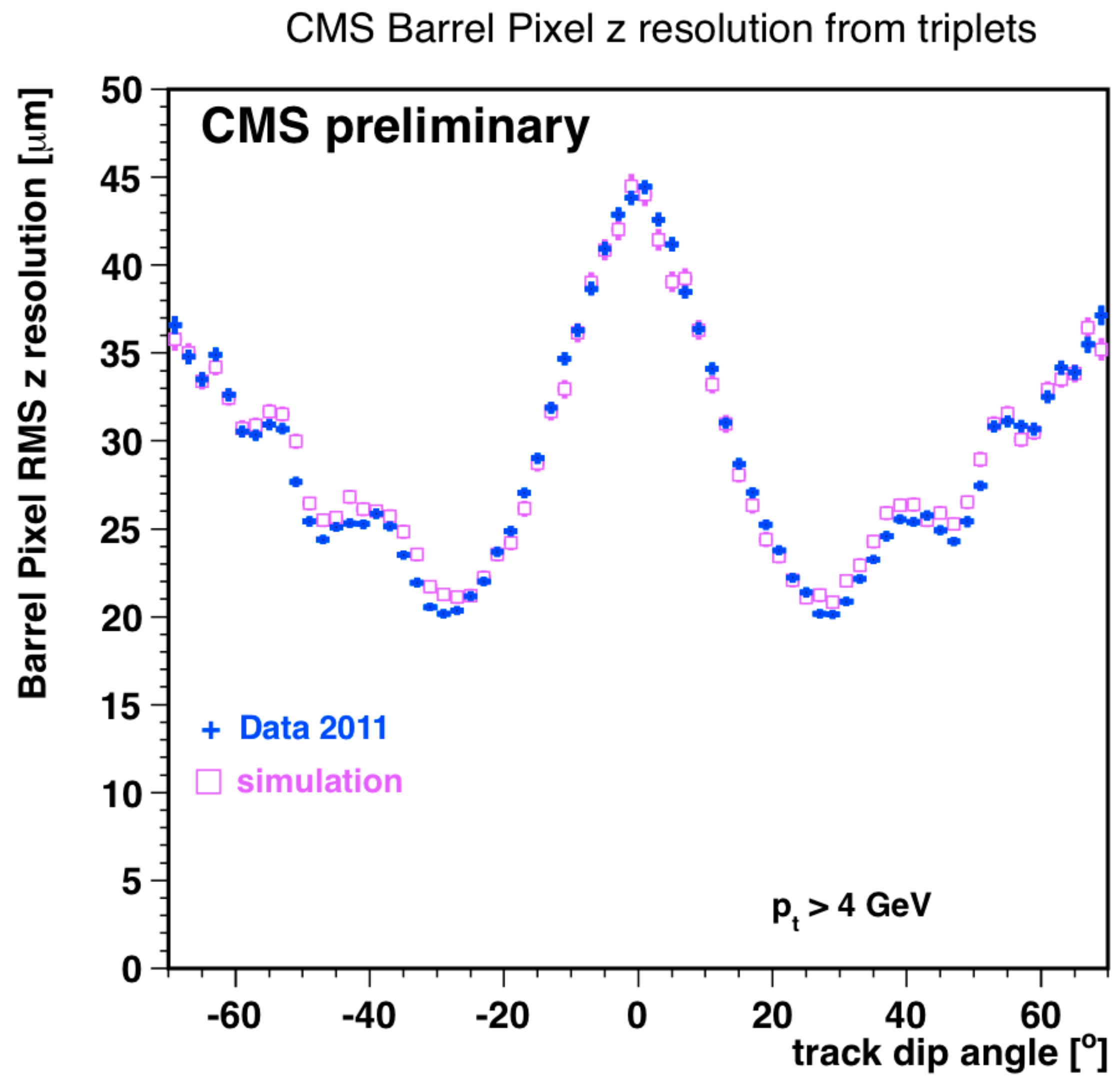
- Tracks with hits in layers 1,2,3 (2,3,4) refitted excluding layer-2 (3) hit.
- Fit to distribution of hit residuals between hit position and interpolated track



- Resolution in z-direction known to have dependence on the track angle

PIXEL HIT RESOLUTION IN 2010





TRACK SPLIT VALIDATION - 0T COSMIC RAY DATA

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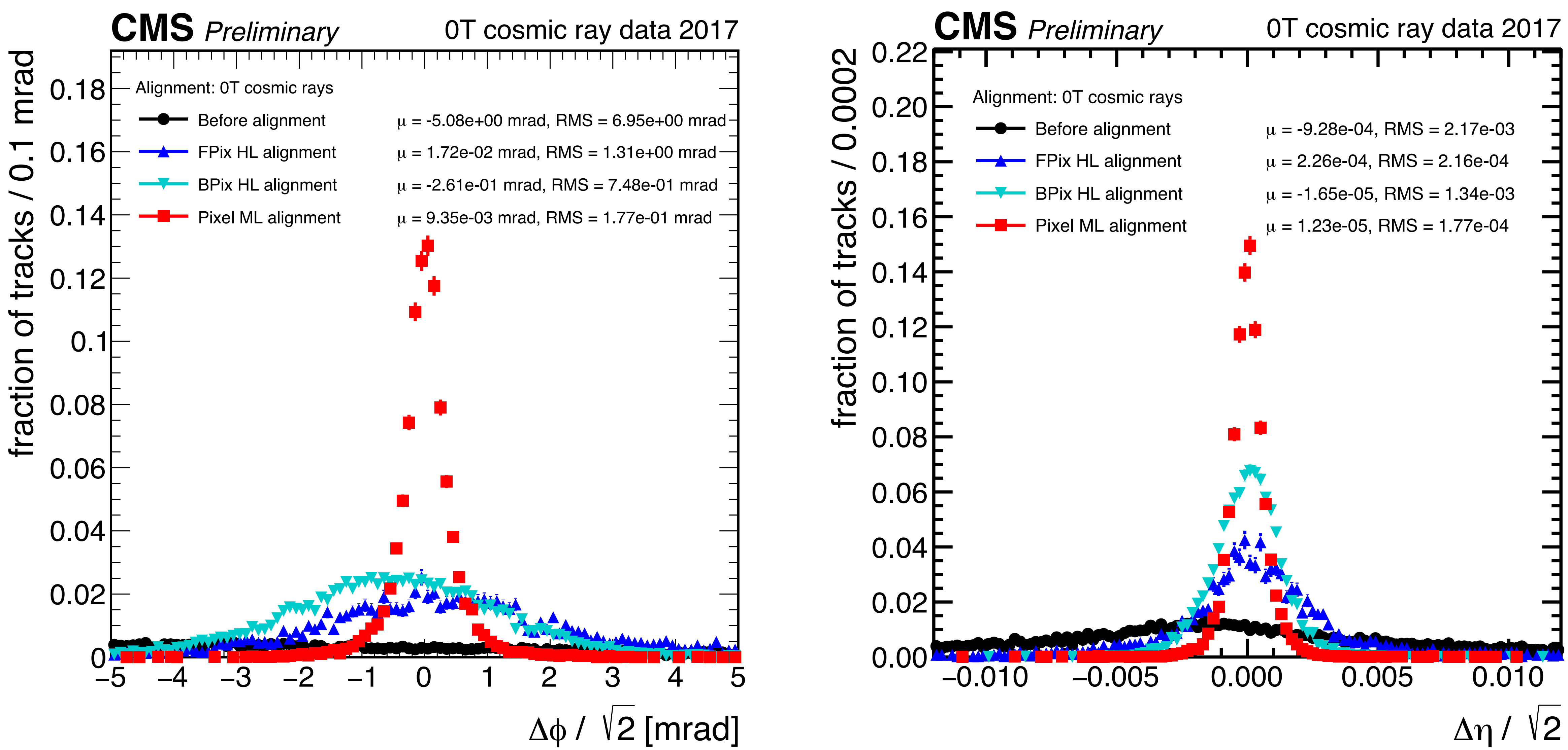
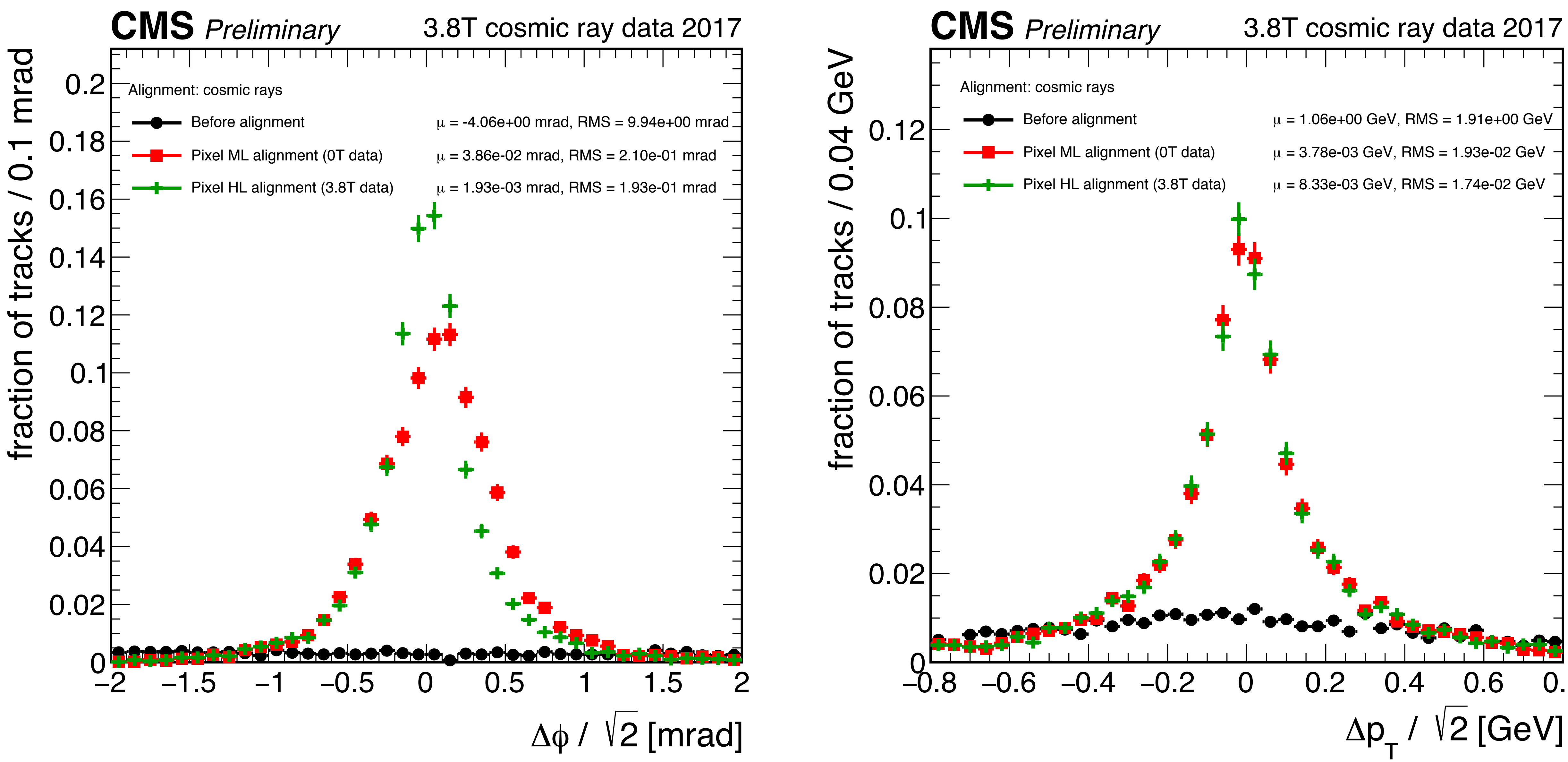


- After each alignment iteration, reduced bias (syst. effects) and width (local precision)

TRACK SPLIT VALIDATION - 3.8T COSMIC RAY DATA

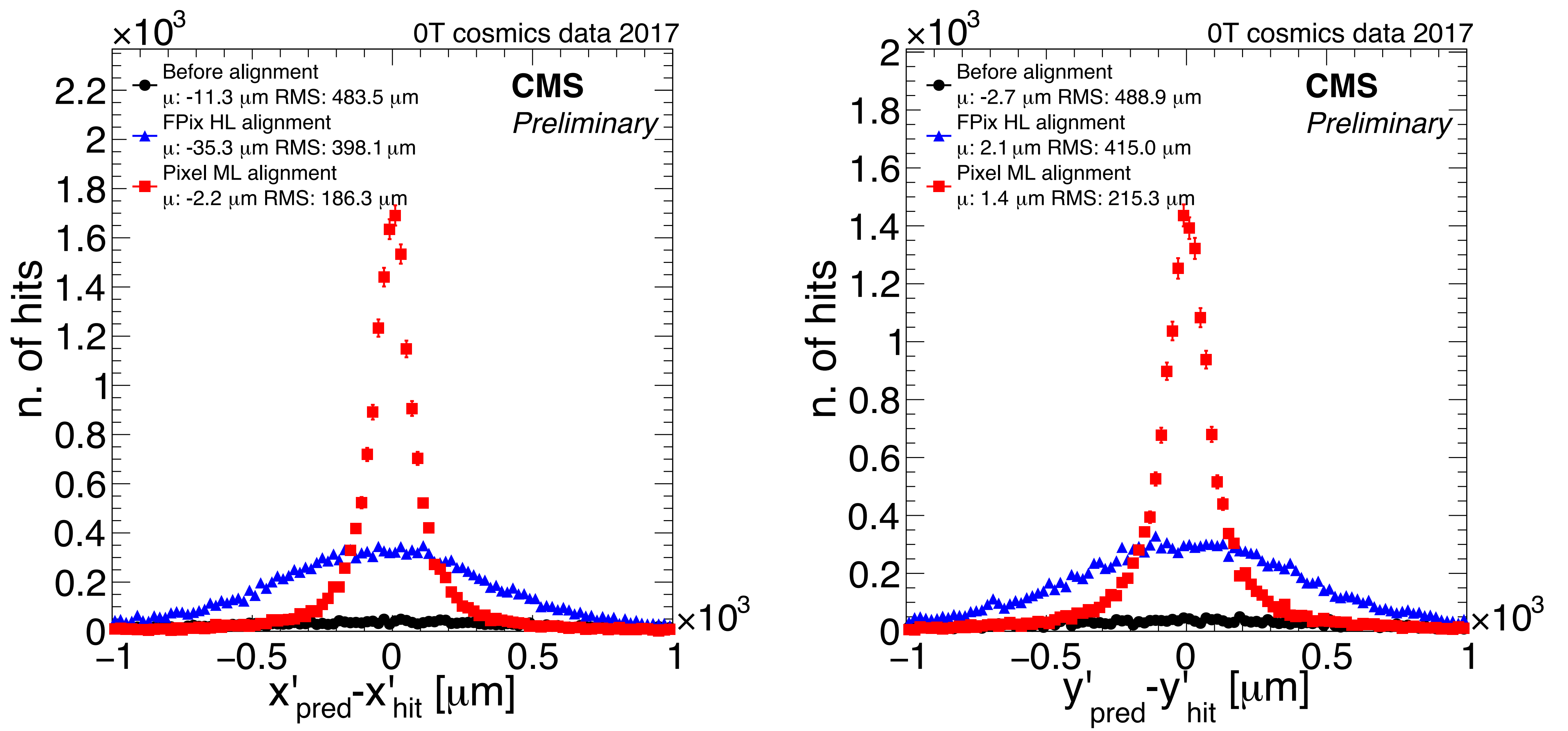
- Cosmic ray tracks are split in two halves, look at differences in their track parameters



- After each alignment iteration, reduced bias (syst. effects) and width (local precision)

RESULTS ON 0T COSMIC RAY DATA - FPIX RESIDUALS

- Unbiased track-hit residuals (the hit under consideration is not used in the track fit)
- After each alignment iteration, reduced bias and width



RESULTS ON 0T COSMIC RAY DATA - BPIX RESIDUALS

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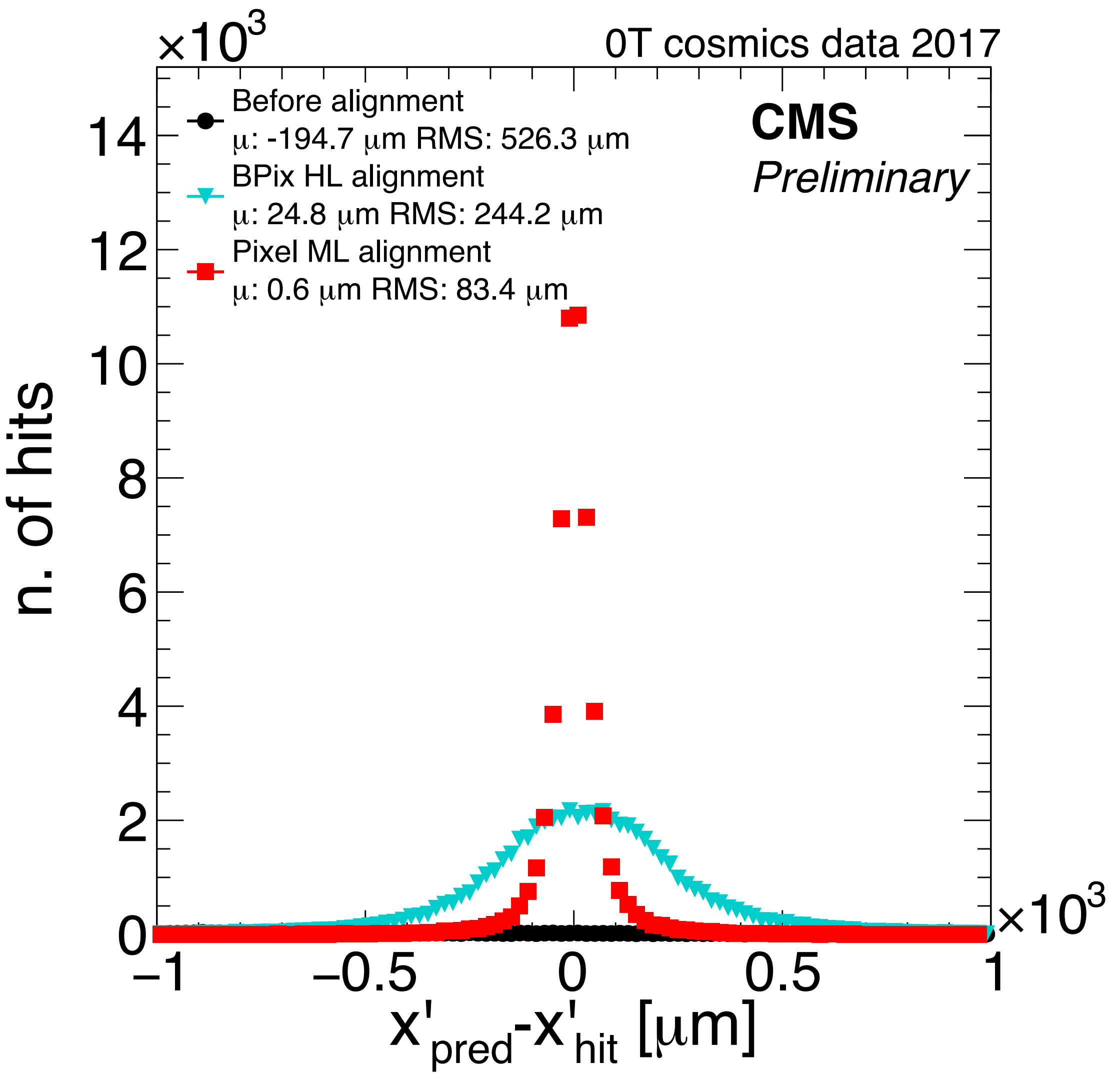

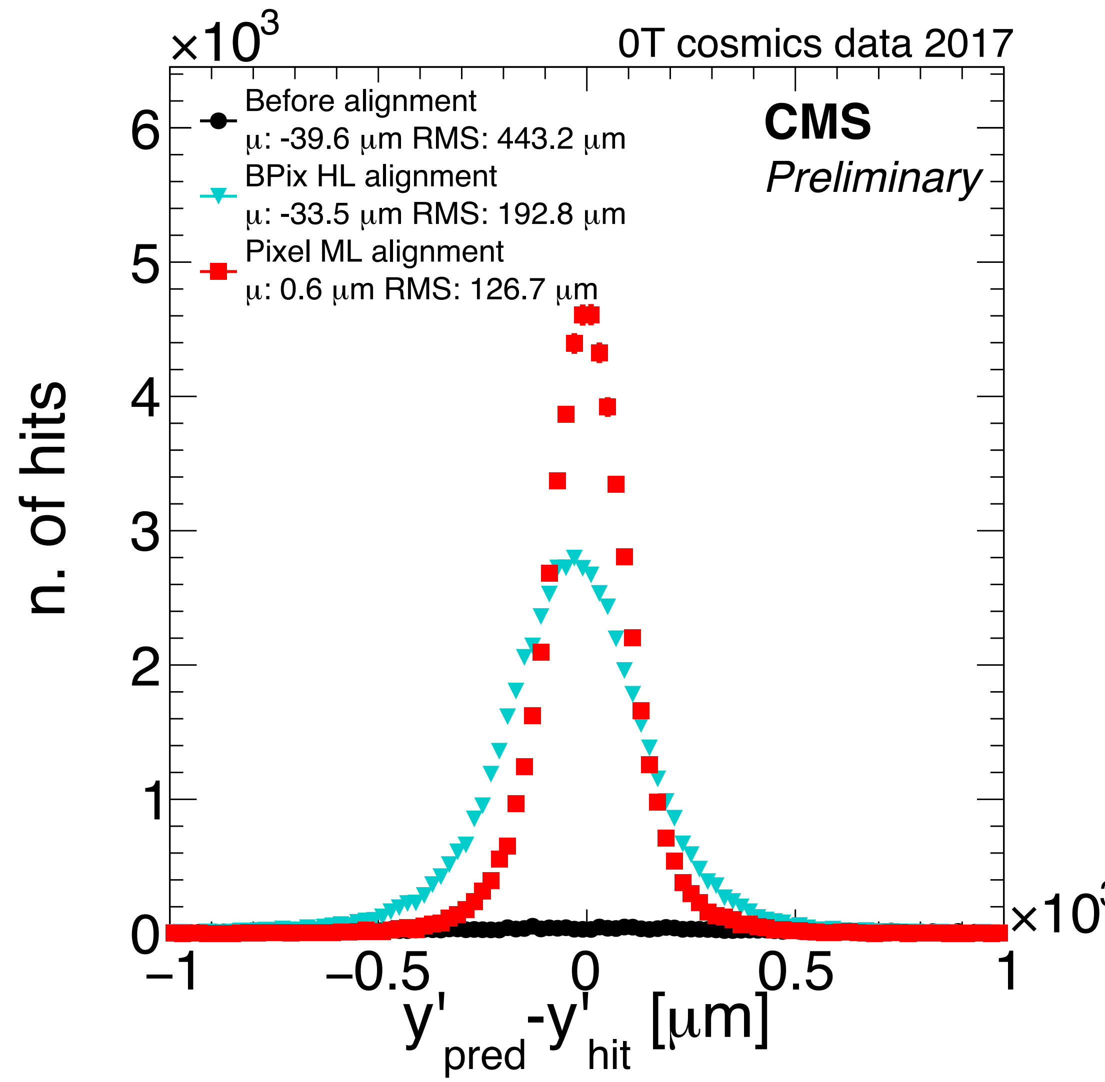

RESULTS ON 3.8T COSMIC RAY DATA - BPIX RESIDUALS

- Unbiased track-hit residuals, the hit under consideration is not used in the track fit
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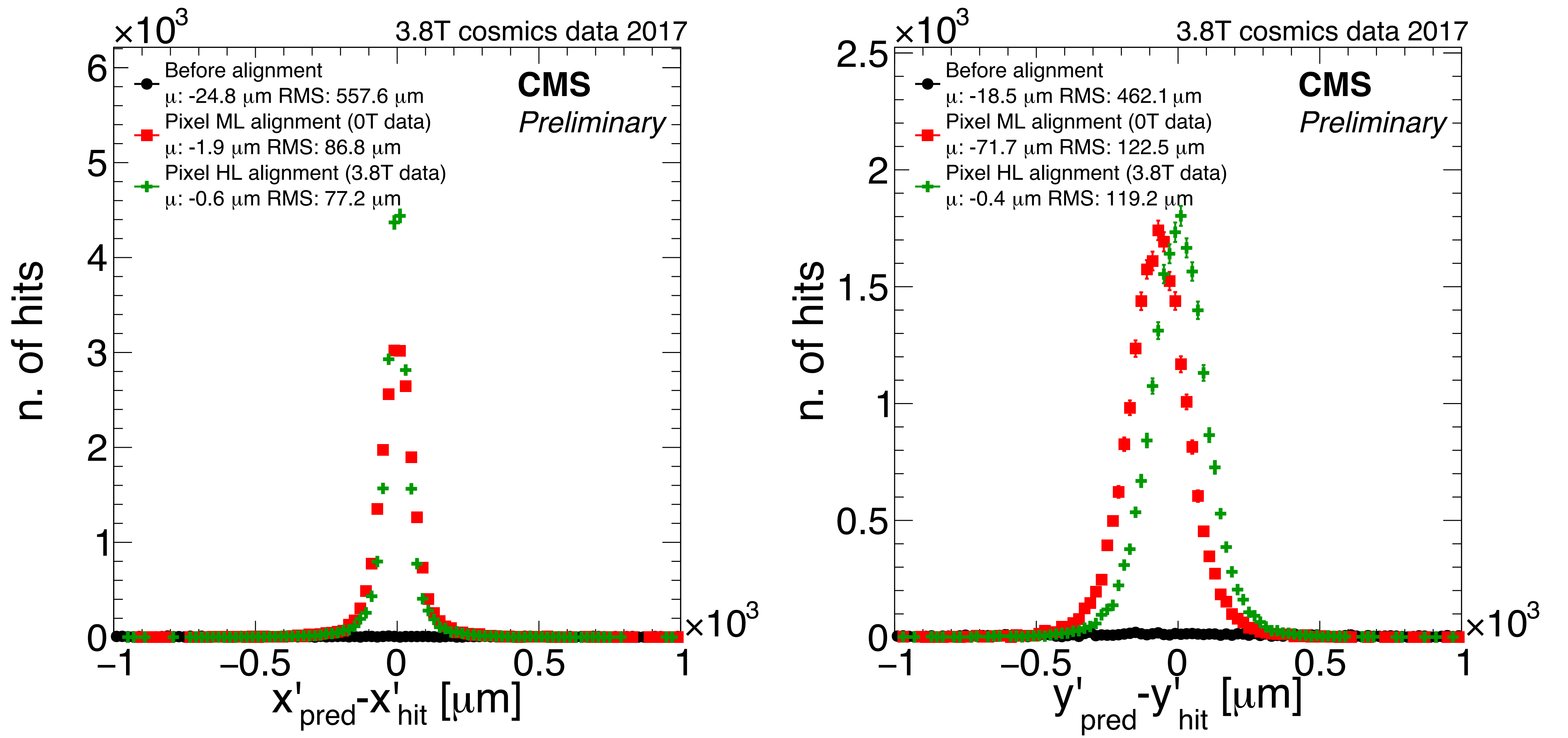

RESULTS ON 3.8T COSMIC RAY DATA - FPIX RESIDUALS

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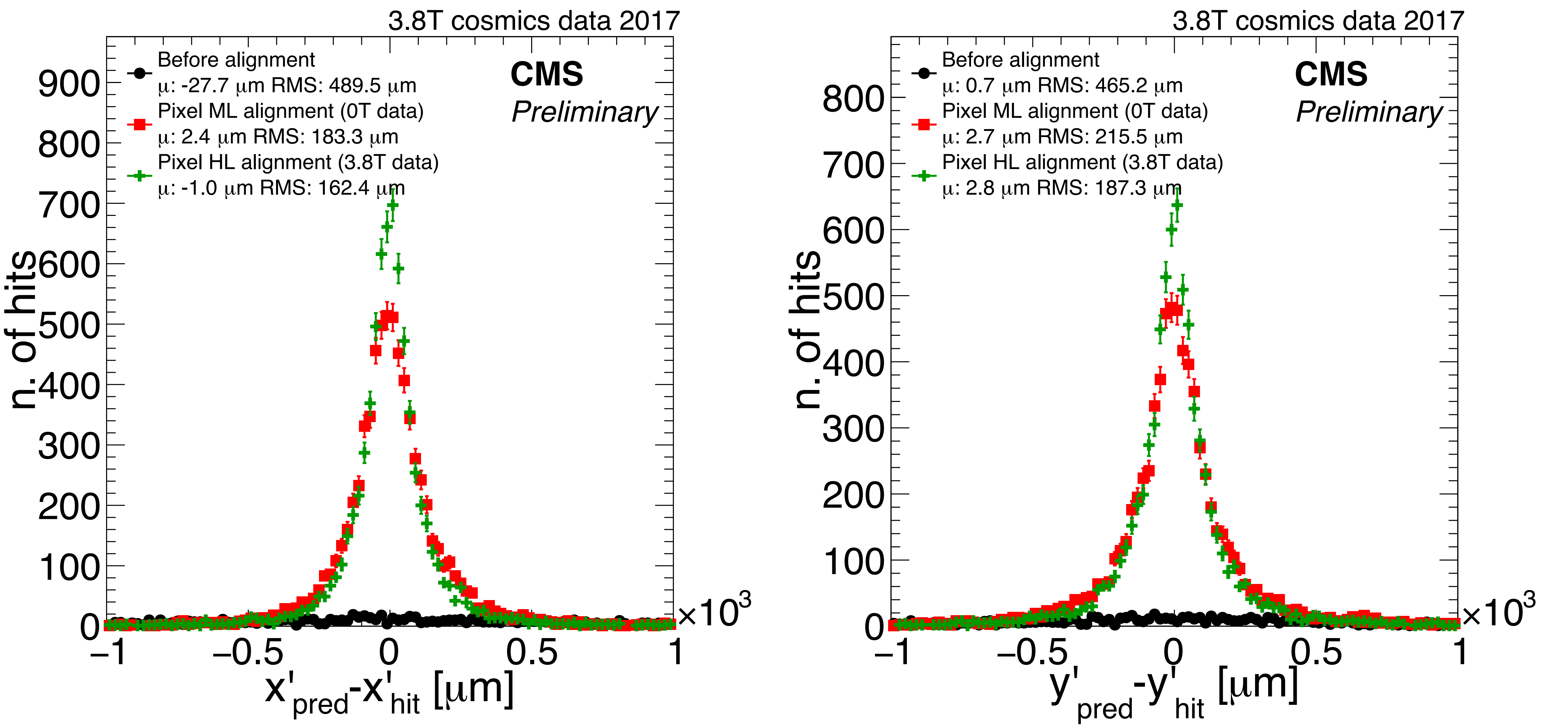
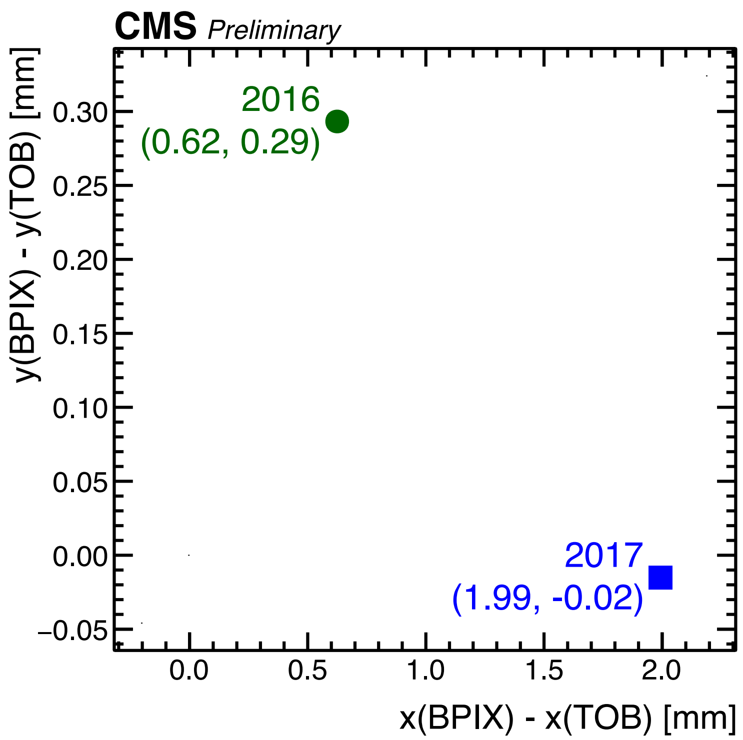
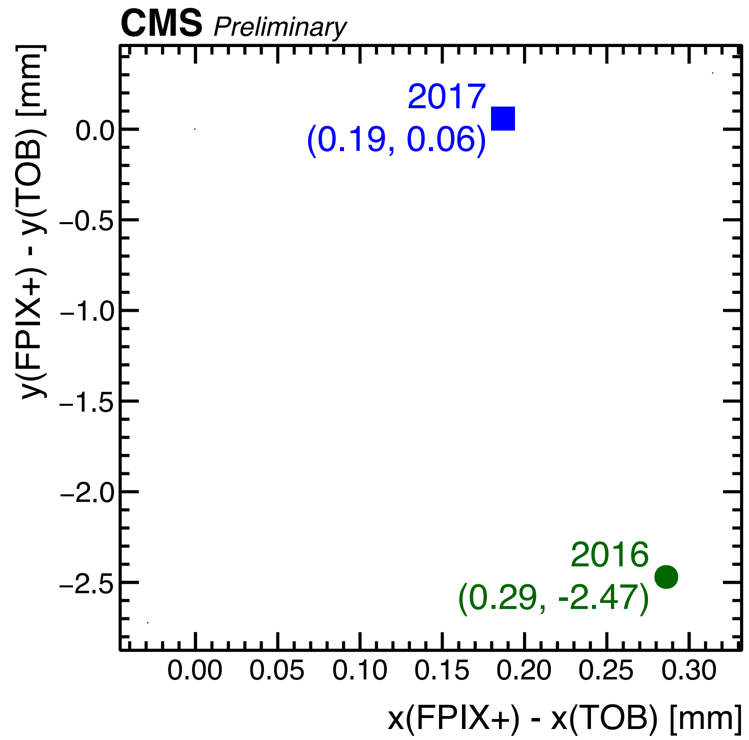
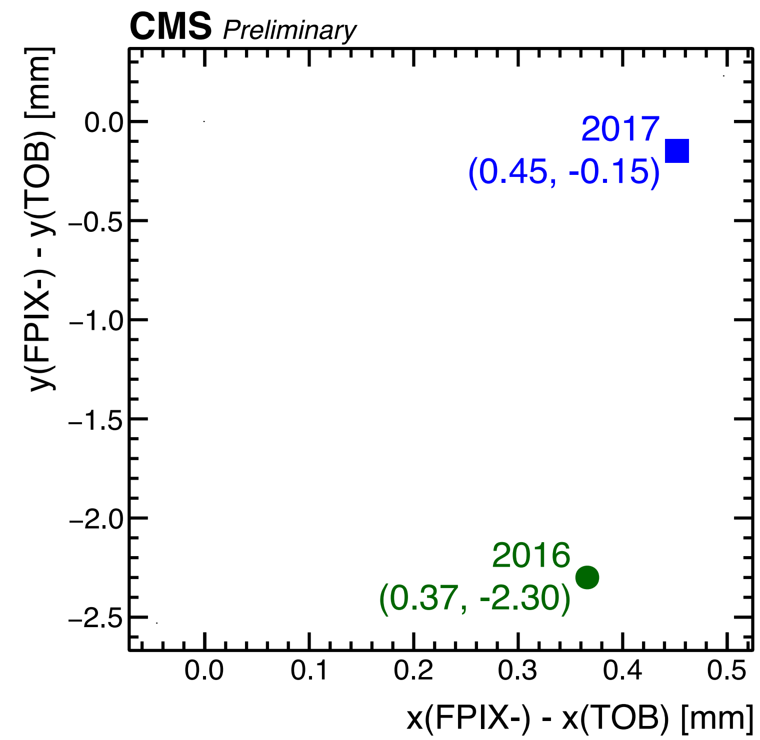


PIXEL BARYCENTRE POSITIONS

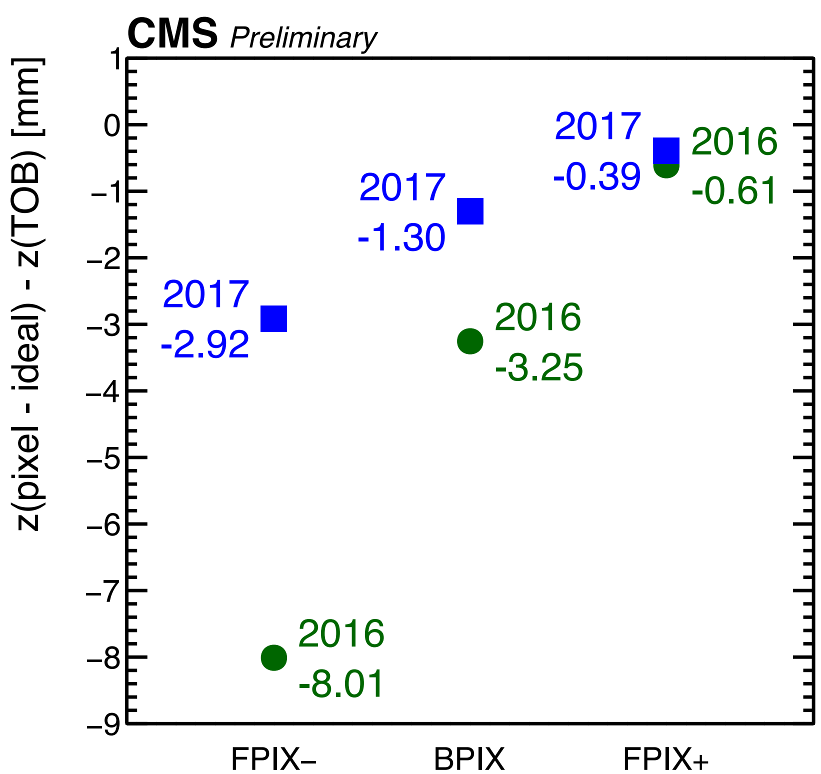
x-y





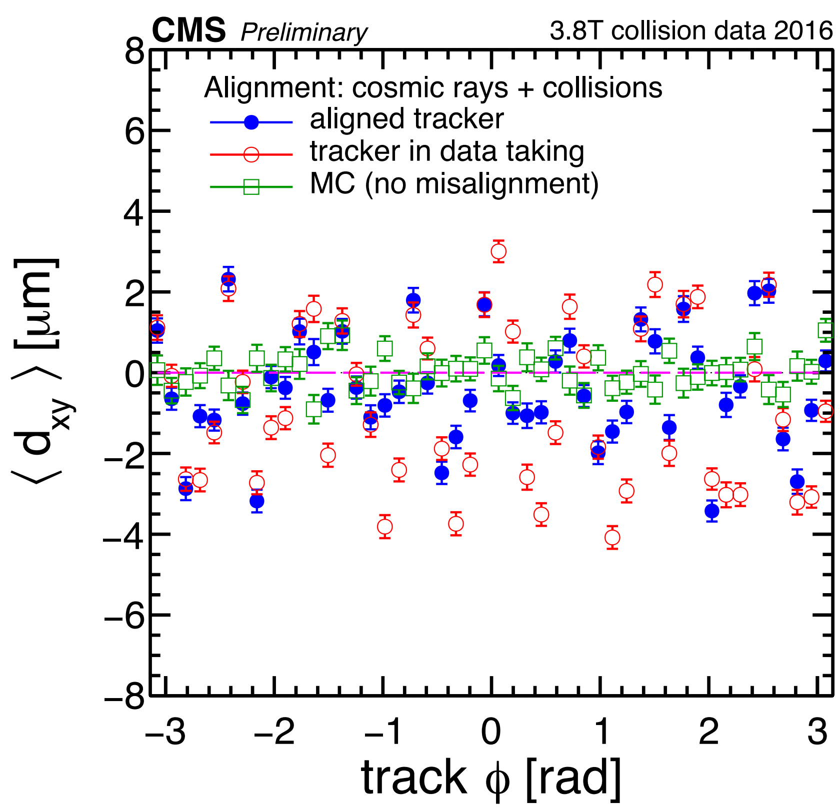


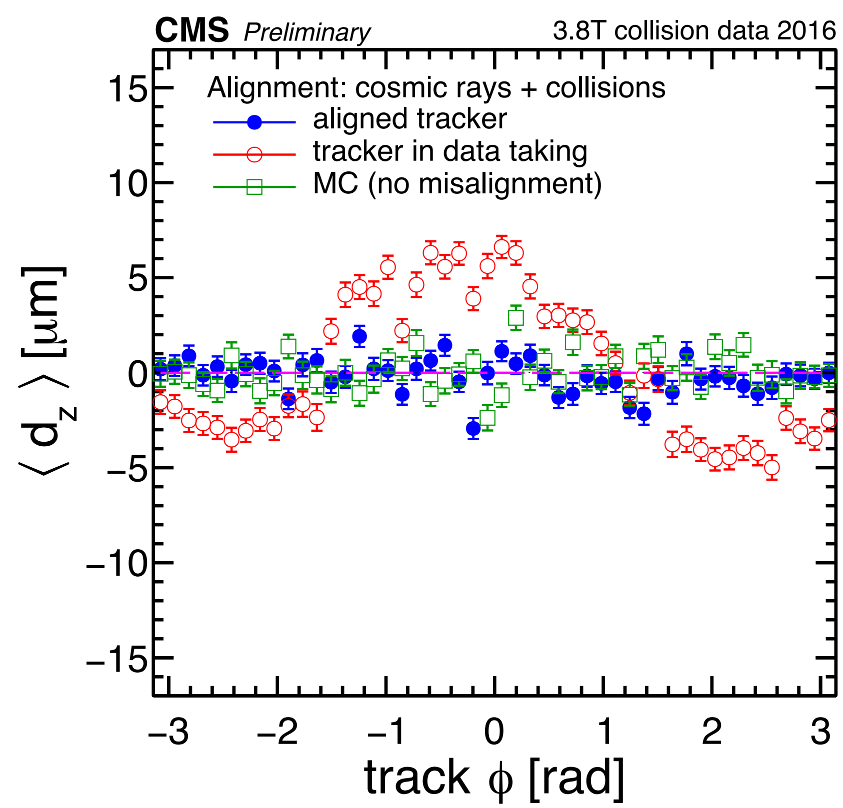
z



- Positions of the pixel detector centres with respect to the tracker outer barrel.
- For the new pixel tracker, the measure is obtained from the alignment derived using 3.8T cosmic-ray data collected in 2017.

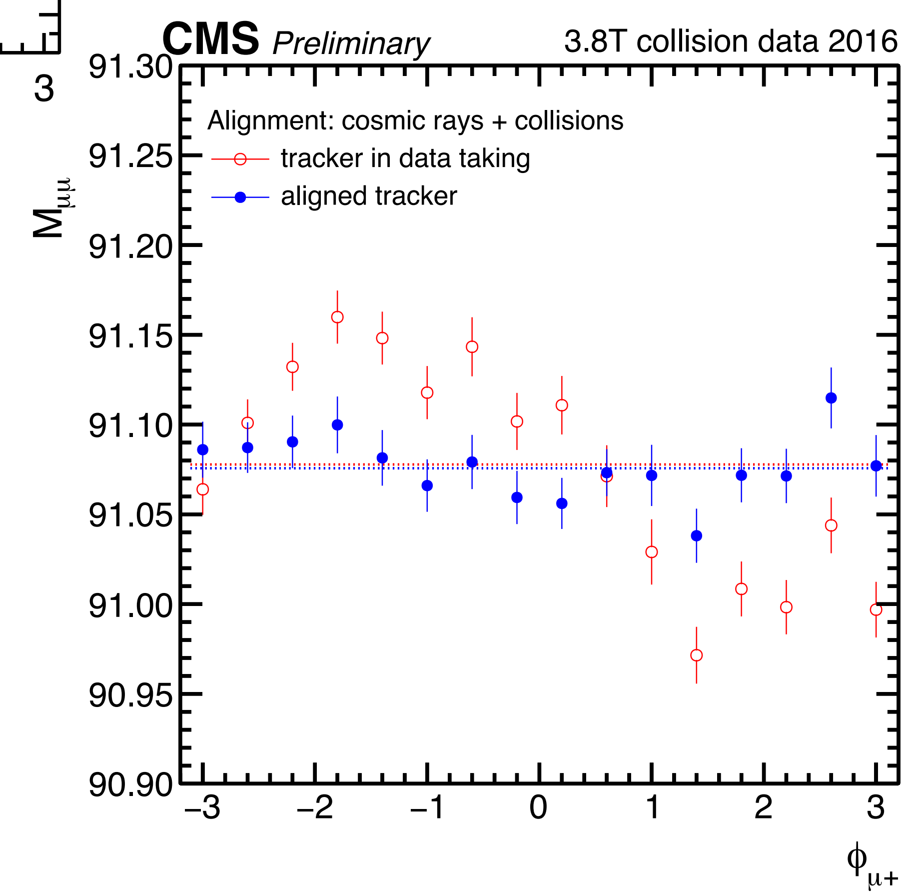
2016 ALIGNMENT PERFORMANCE





- Unbiased track-vertex residuals

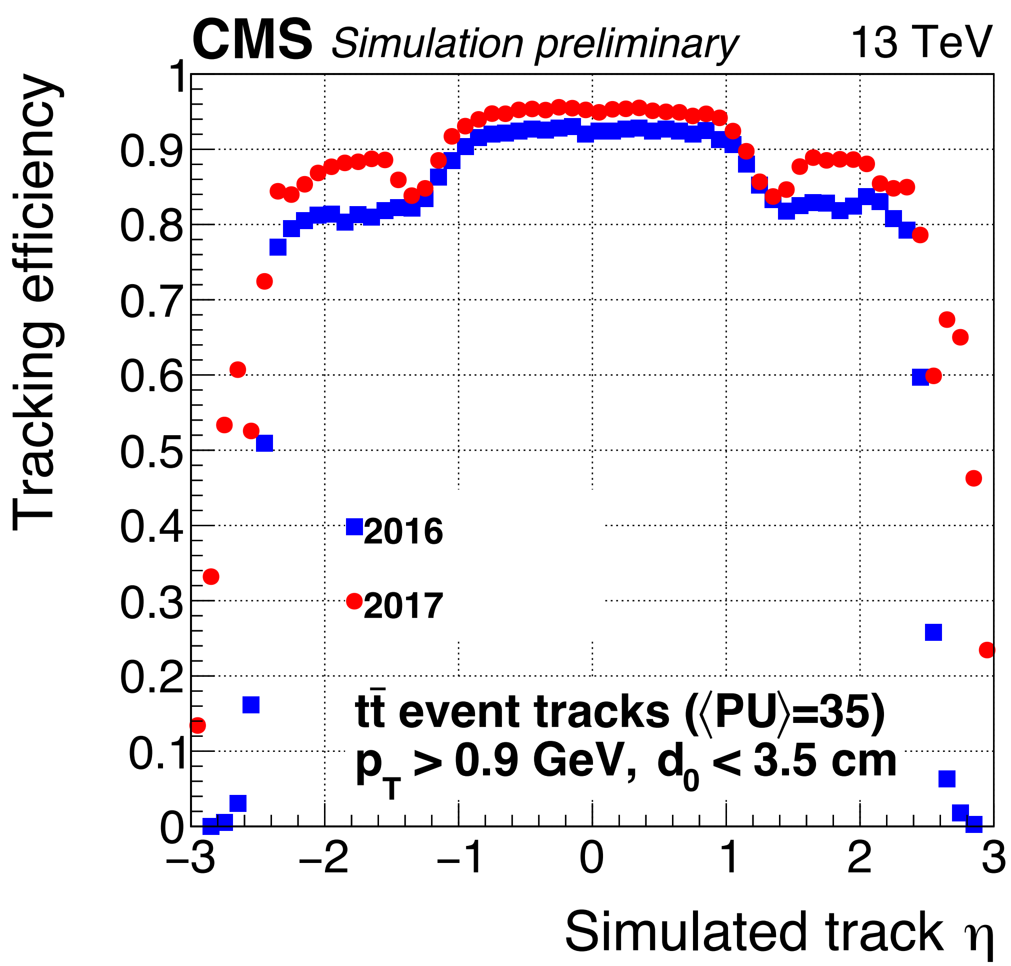
- Z mass from di-muon events



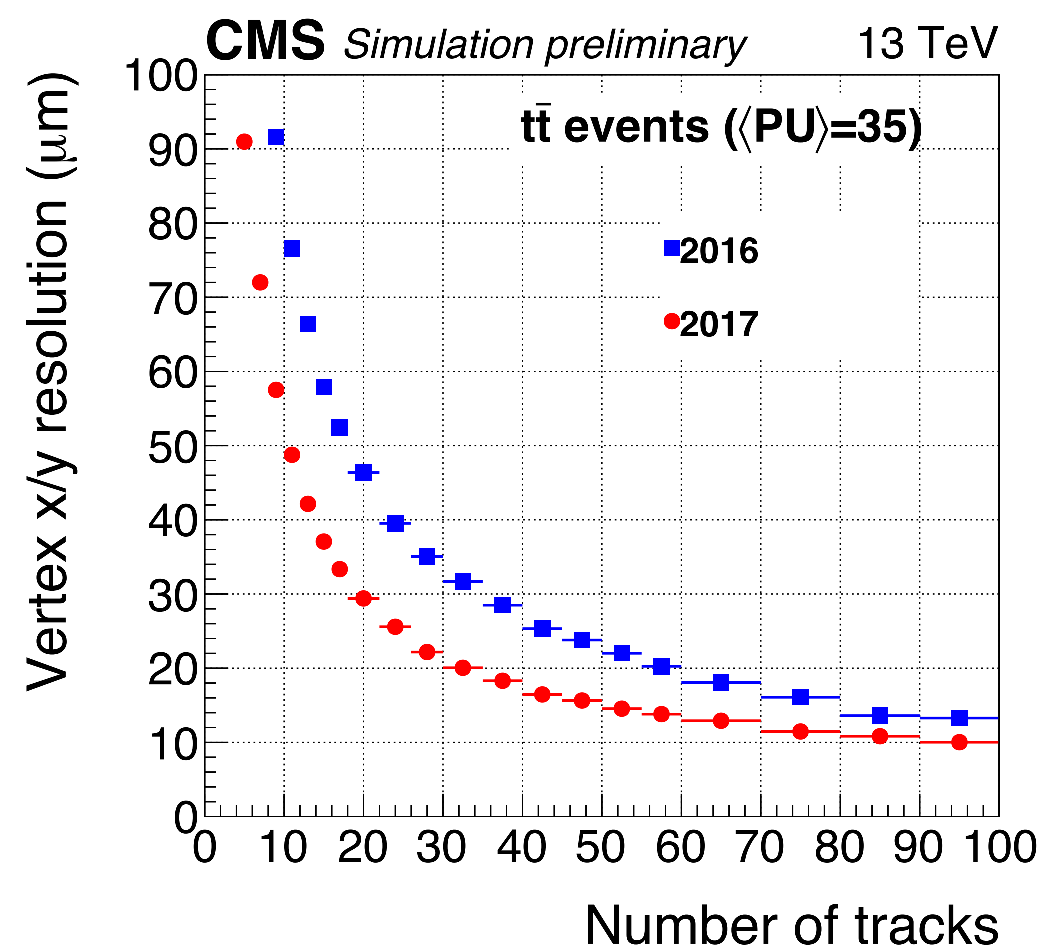
EXPECTED TRACKING PERFORMANCE

New (2017) vs. old (2016) tracker, from simulation

- Higher track efficiency



- Better vertex resolution (xy plane)



TRACKING - PILE UP DEPENDENCE

New (2017) vs. old (2016) tracker, from simulation