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

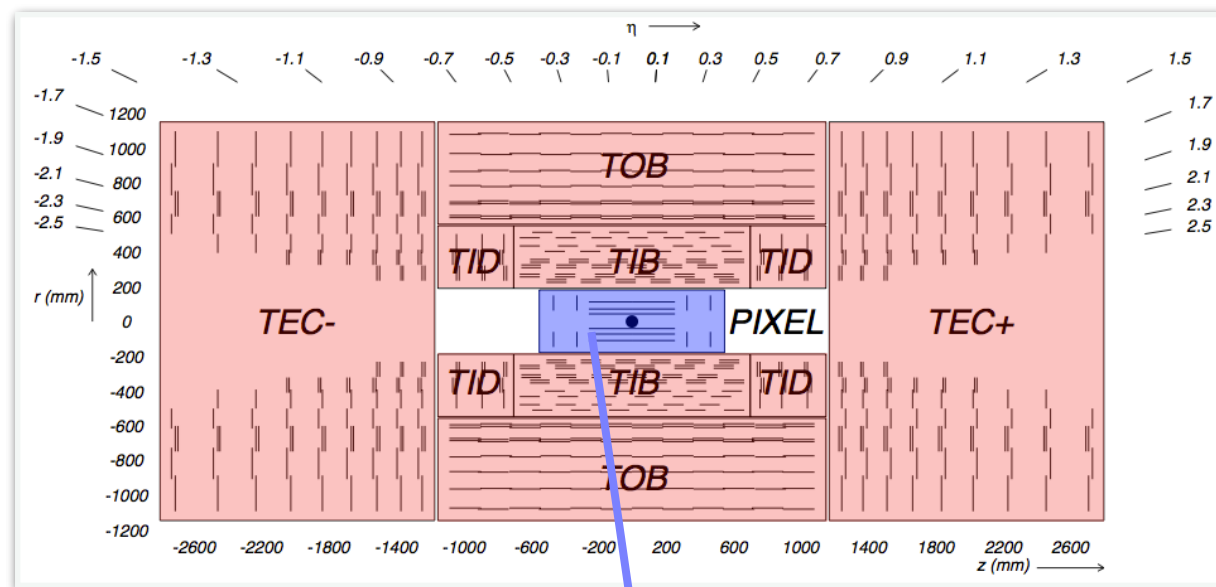
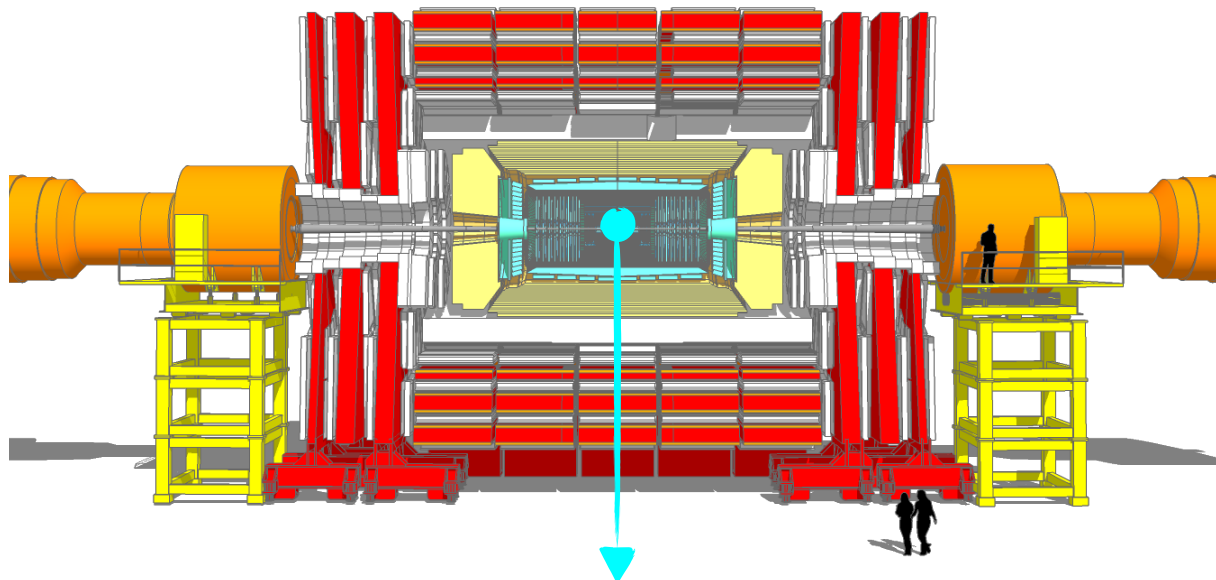


Valeria Botta (DESY)
on behalf of the CMS Collaboration



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

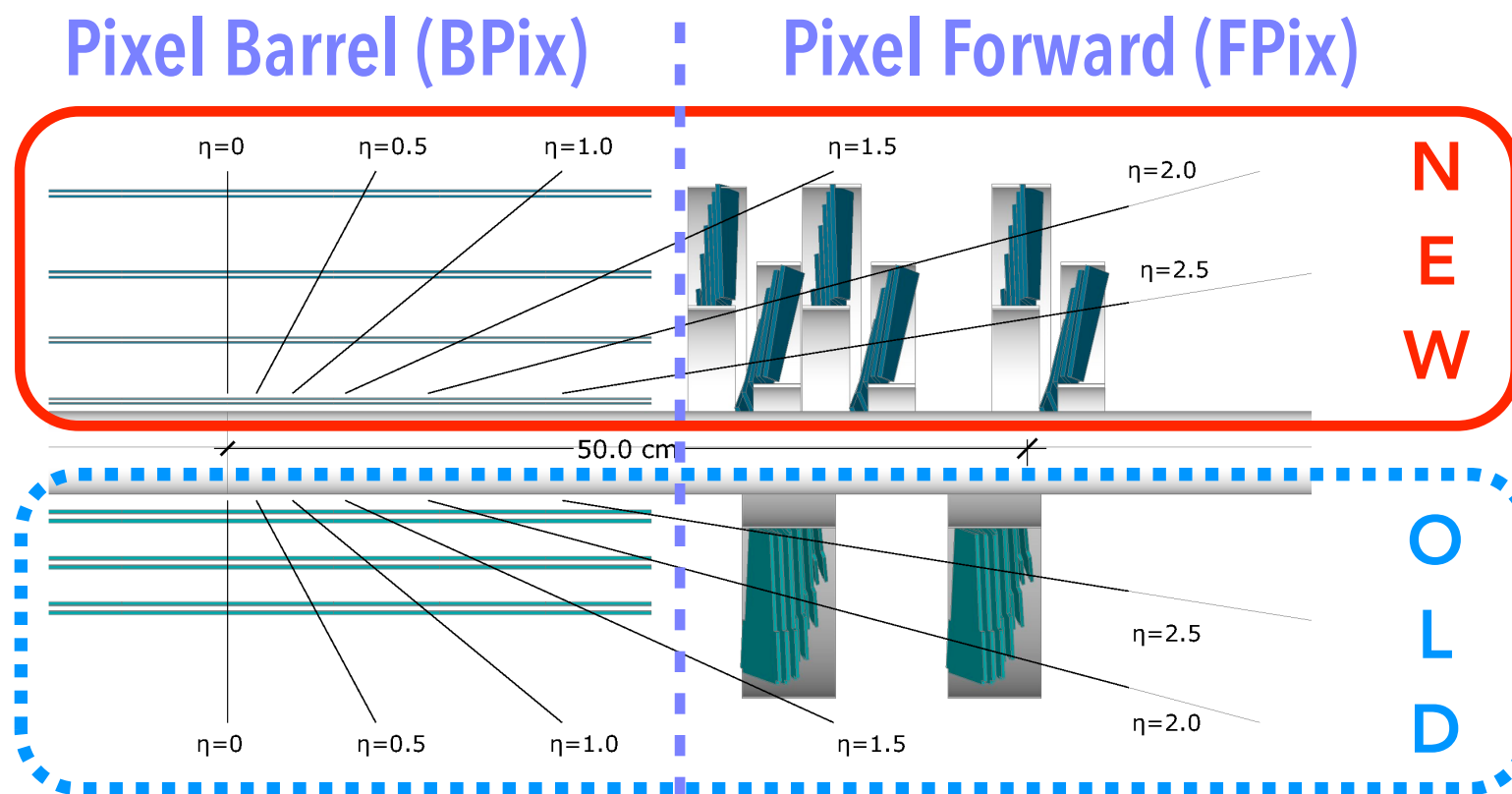
THE CMS TRACKER



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



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

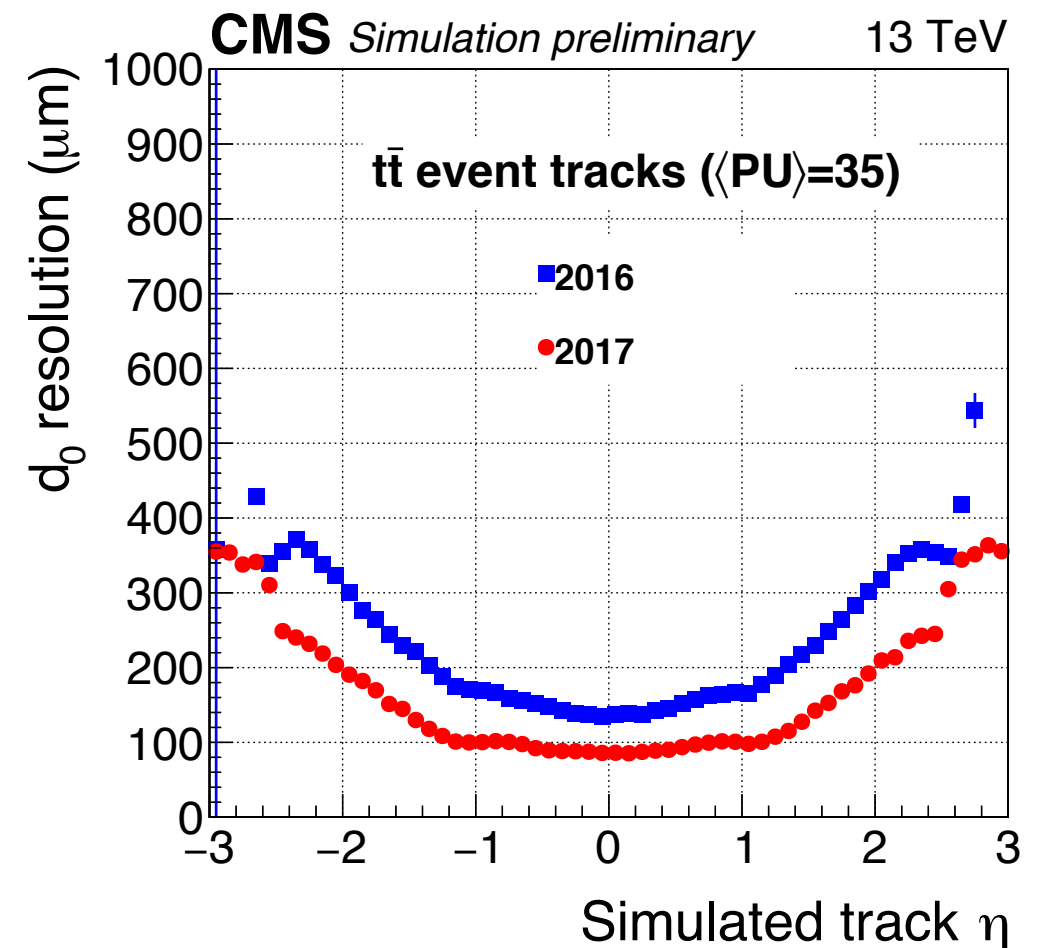
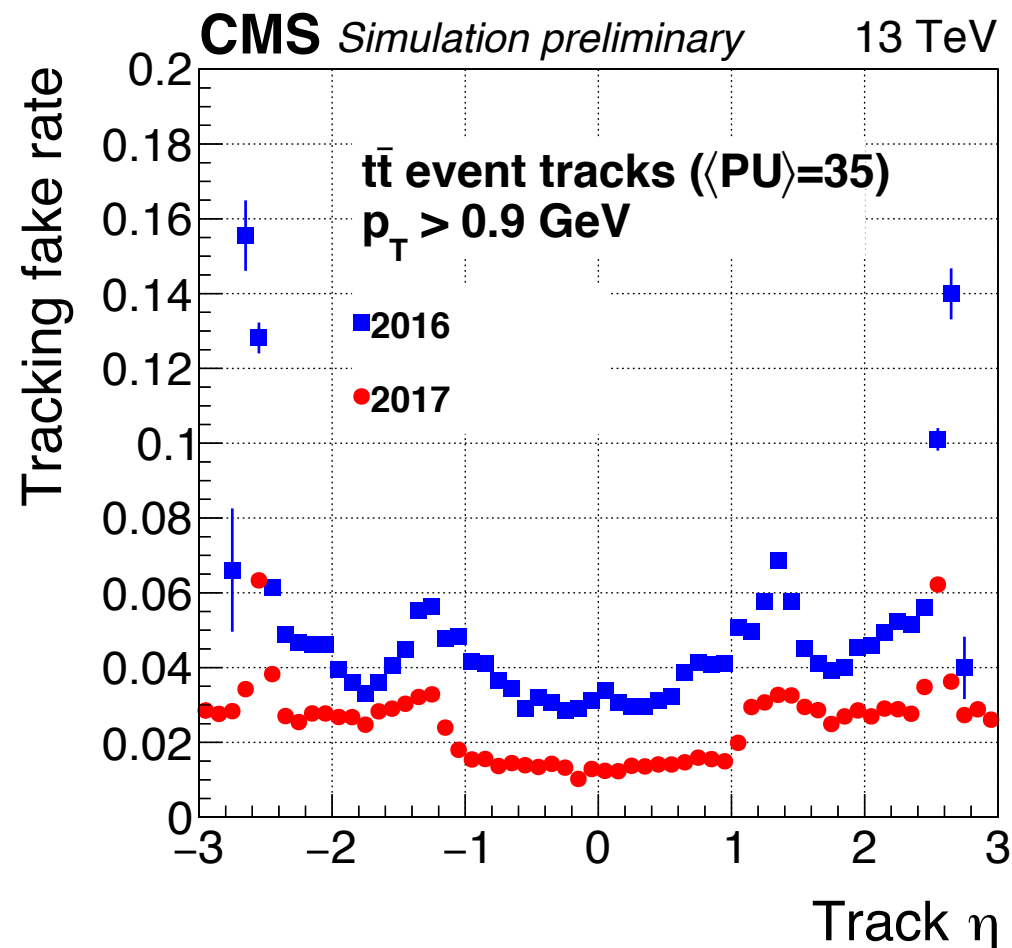
- One more barrel layer, one more forward disk
- Innermost barrel layer closer to the interaction point
- Improved readout electronics
- Lower material budget (CO₂ cooling)

Better tracking
also at high
instantaneous
luminosities

EXPECTED TRACKING PERFORMANCE



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



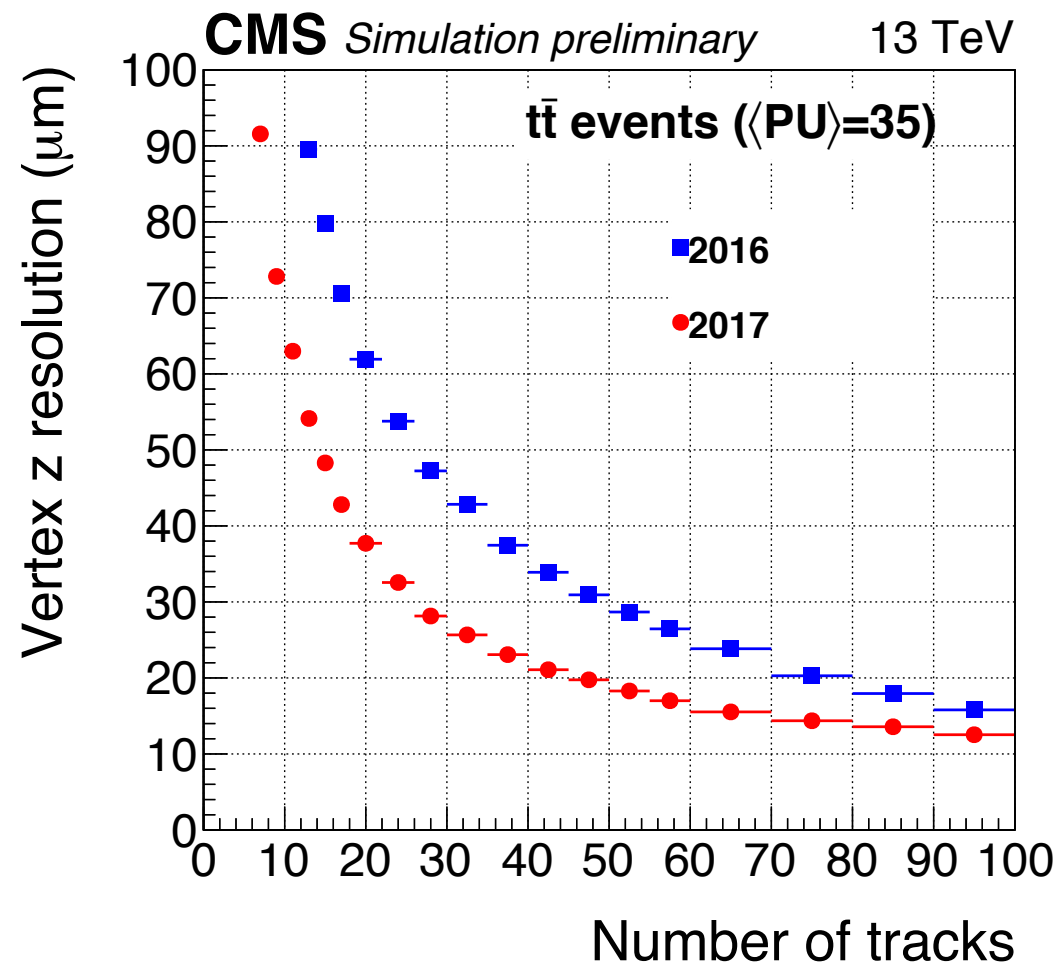
- Fake rate reduced by a factor ~ 3 , and higher track efficiency

- Better track impact parameter resolution by $\sim 30\%$

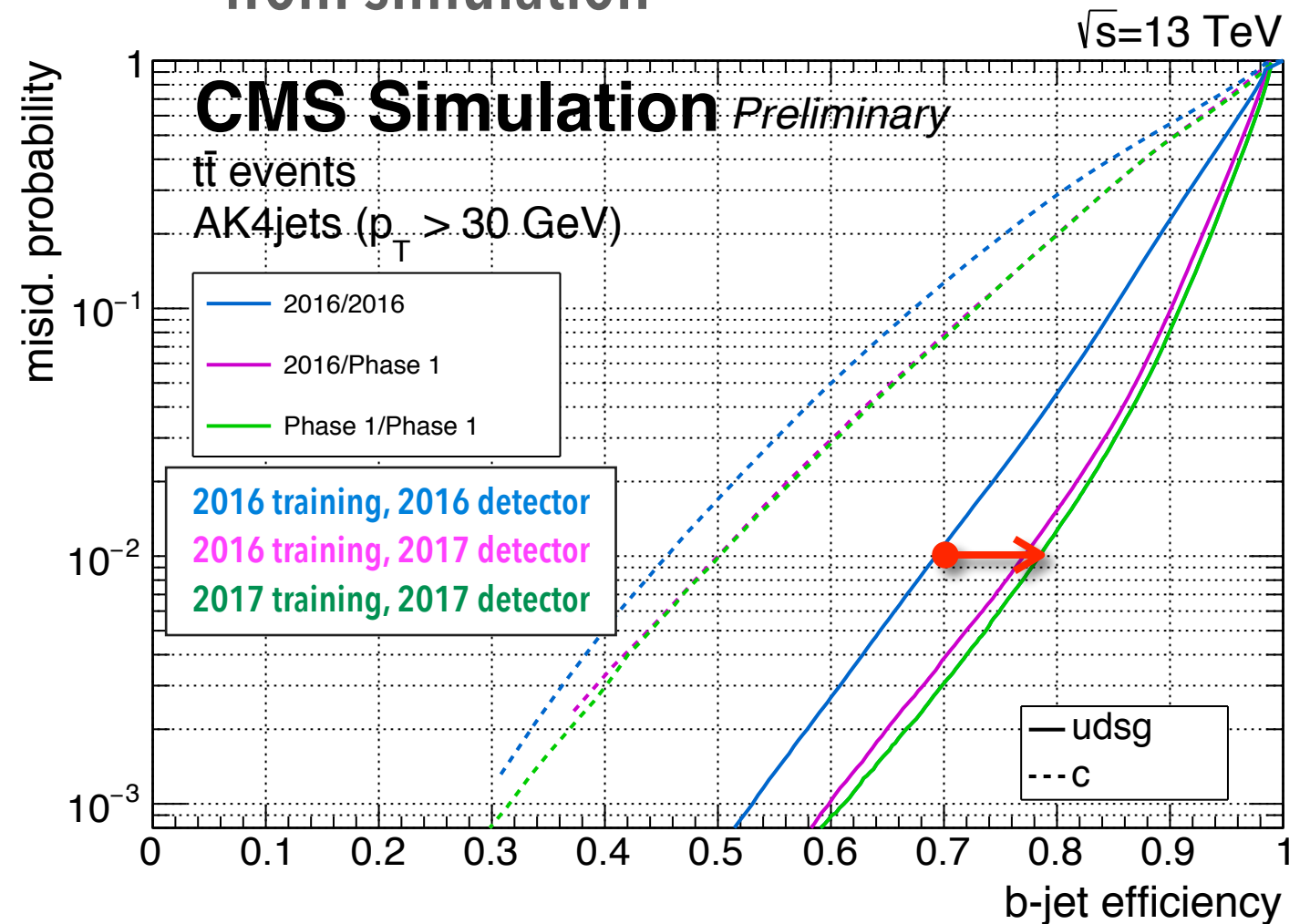
EXPECTED VERTEX AND B-TAG PERFORMANCE



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



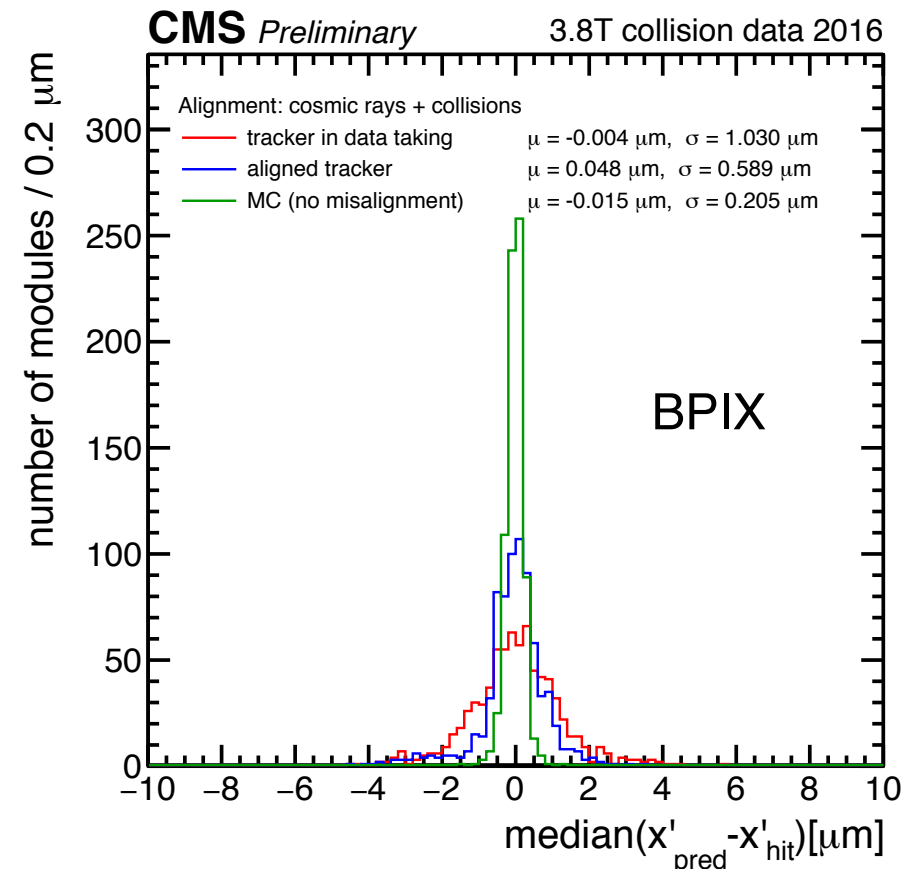
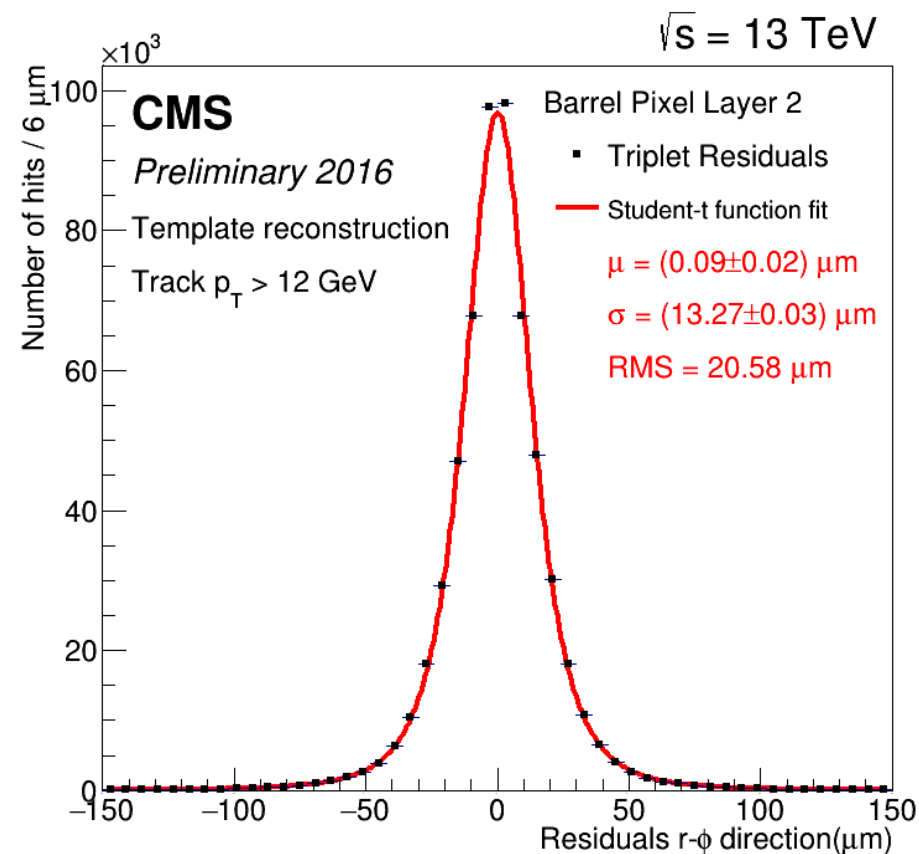
The expected design performance can be achieved only with excellent hardware and calibration

■ Position resolution $\sigma_{\text{pos}} = \sigma_{\text{hit}} \oplus \sigma_{\text{align}}$. For pixel hits

■ σ_{hit} : intrinsic hit resolution,
 $0(10 \mu\text{m})$

■ σ_{align} : uncertainty on the
modules positions, $0(1 \mu\text{m})$

2016

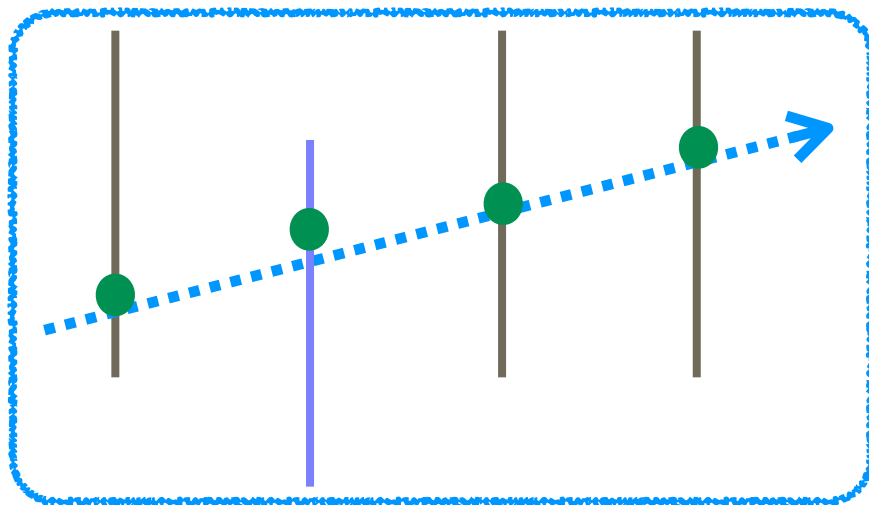


TRACK-BASED ALIGNMENT

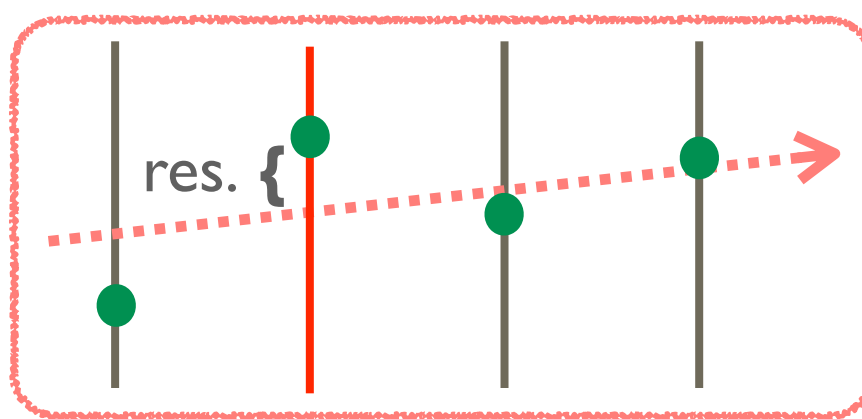


- Tracks are reconstructed fitting a set of hits on the tracker modules.
- Assuming wrong modules positions leads to bias in the reconstructed track: **real** $\neq$ **fitted**

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:

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

track par.

Can achieve a precision $\approx 0(10 \mu\text{m})$ with large statistics and several track topologies

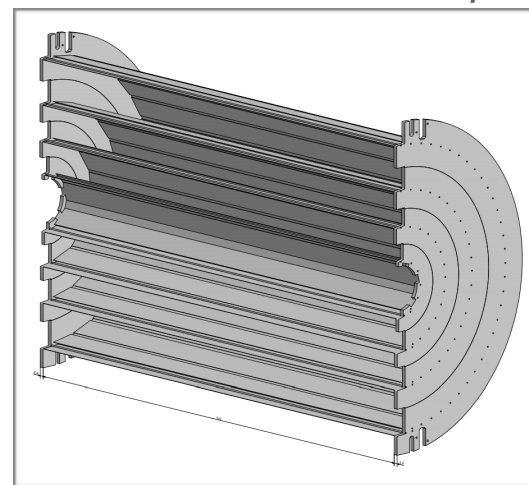
PIXEL ALIGNMENT WITH COSMIC RAYS



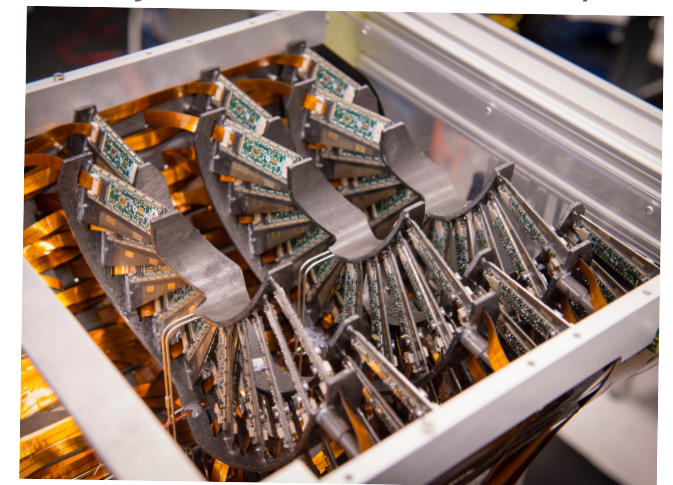
- Potentially large initial misalignment of the new pixel
 - Several alignments performed, with increasing granularity

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)

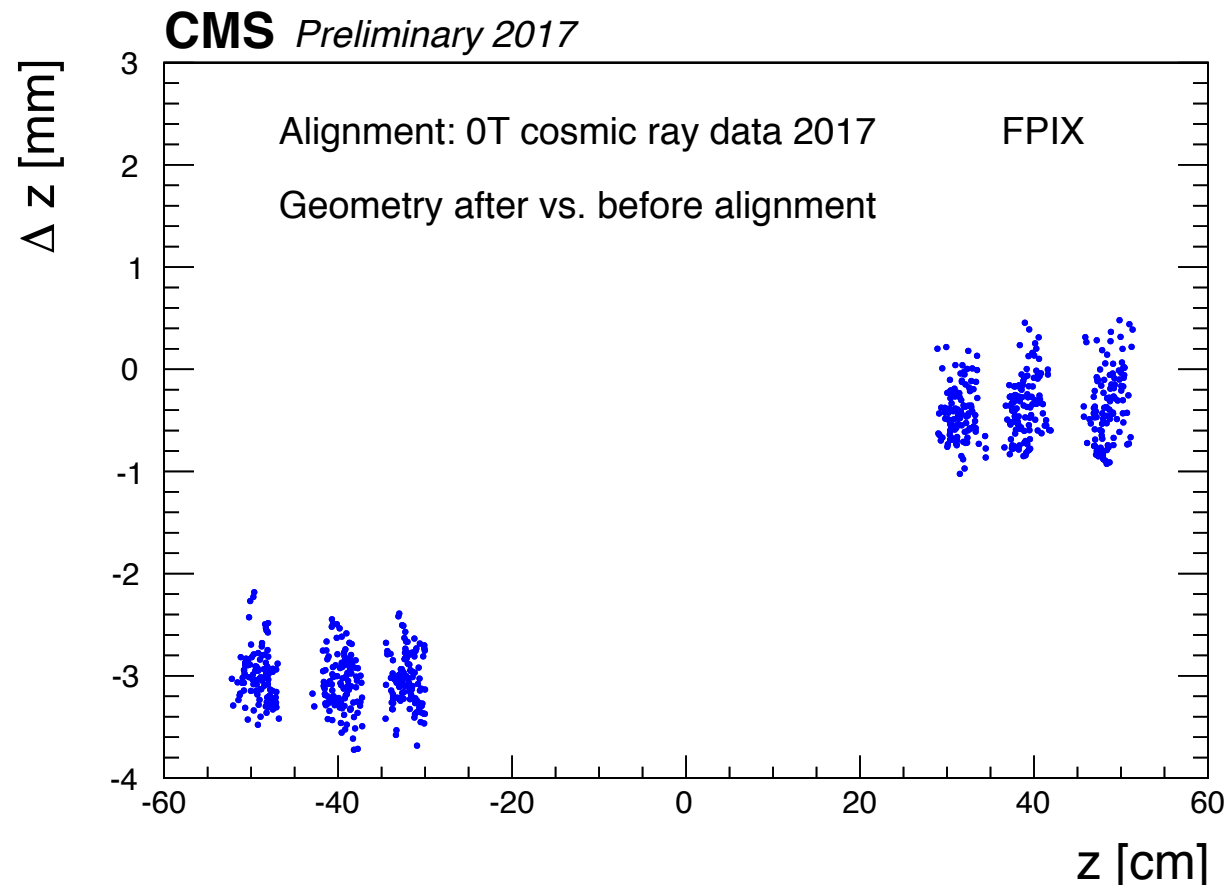
4. update of high-level structures alignment
(no module level due to stat.)

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

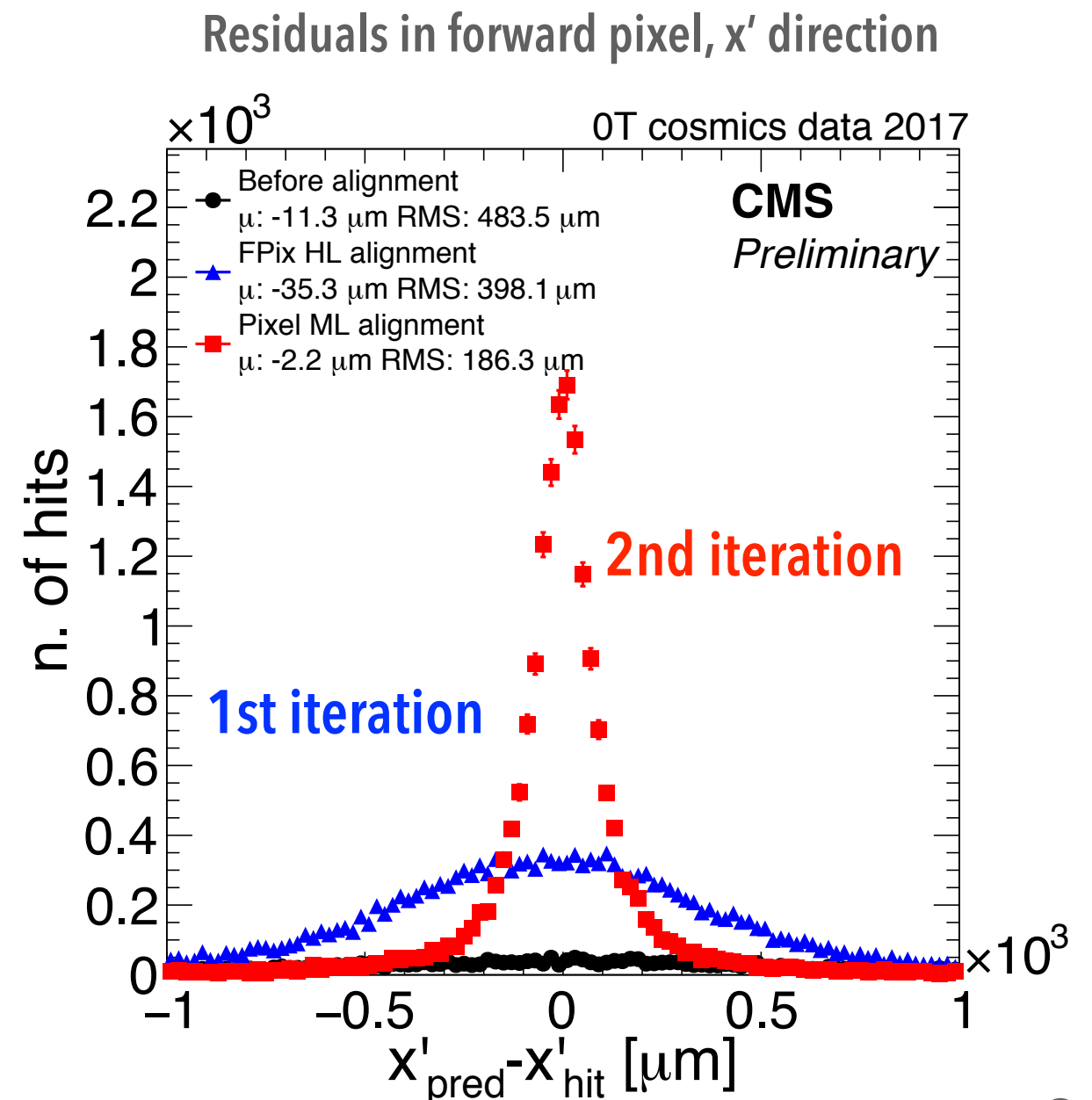
RESULTS ON OT COSMIC RAY DATA - FPIX



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



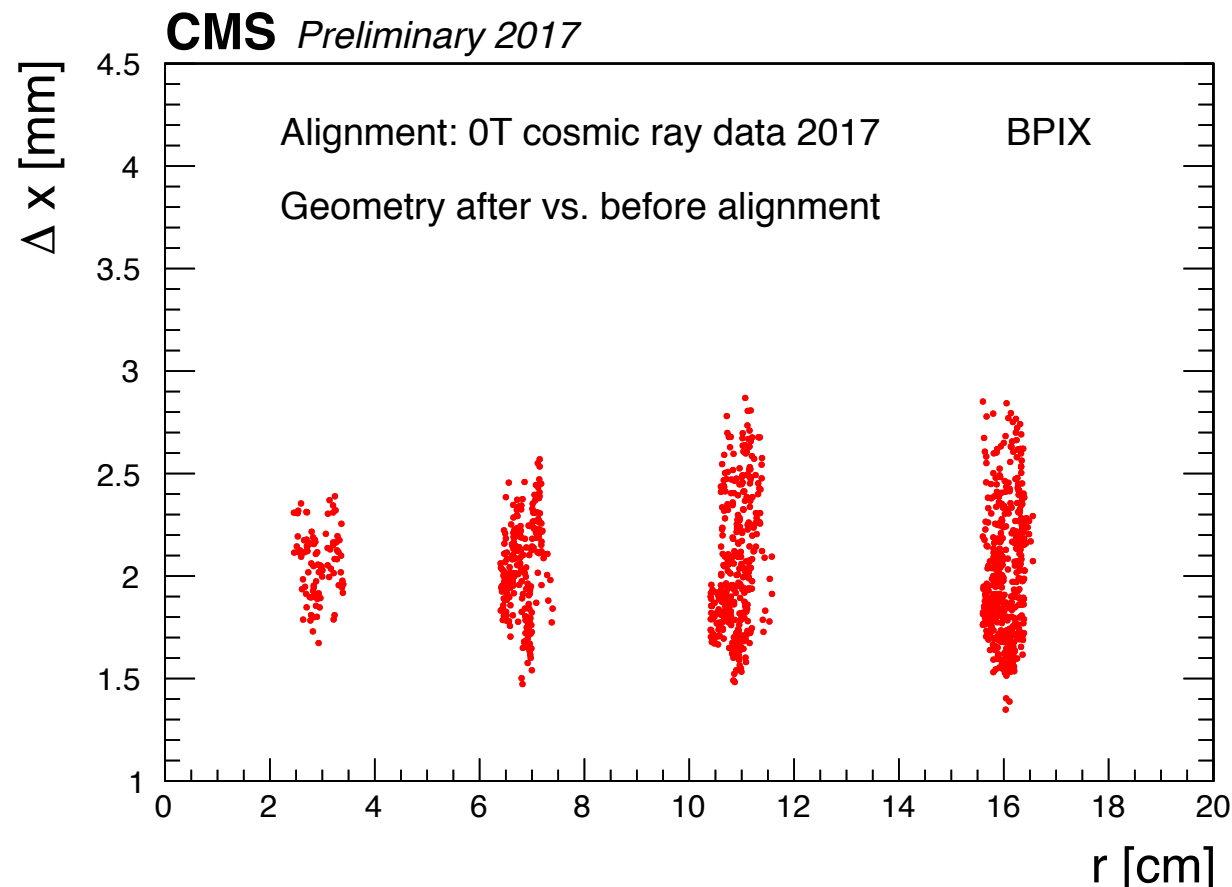
- Unbiased track-hit residuals, the hit under consideration is not used in the track fit
- Reduced **bias (syst. effects)** and **width (local precision)** after each alignment iteration.



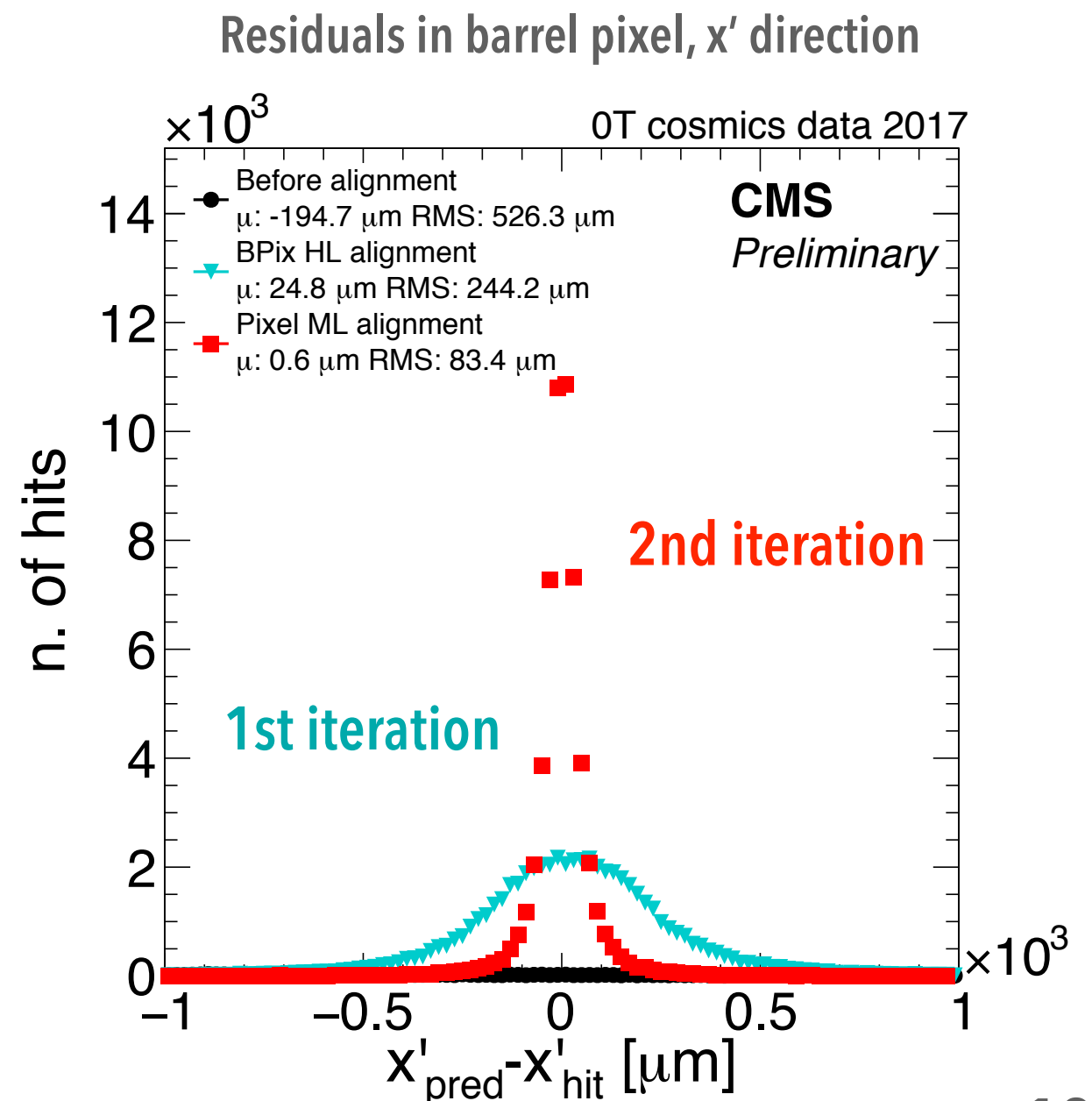
RESULTS ON OT COSMIC RAY DATA - BPIX



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



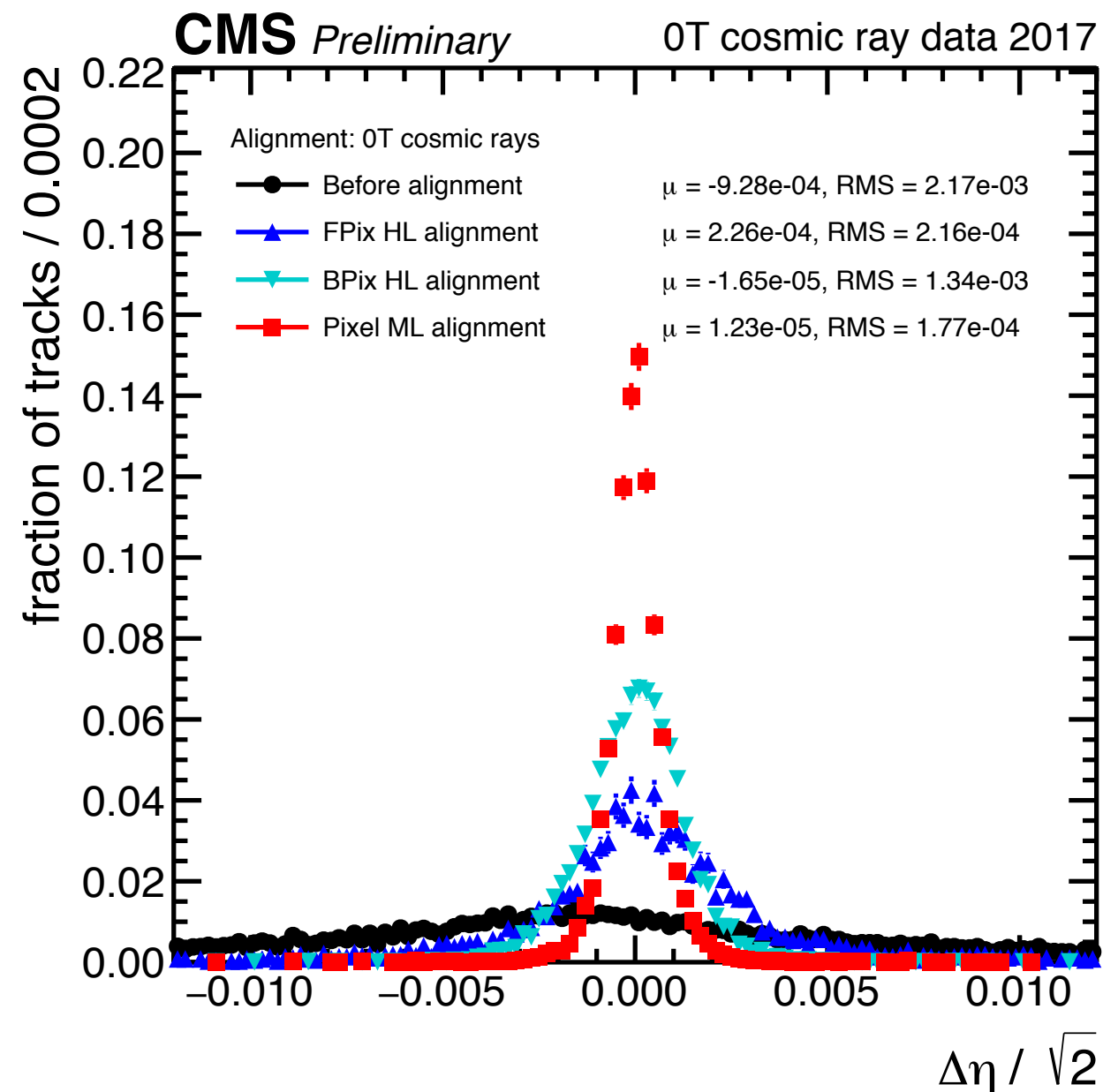
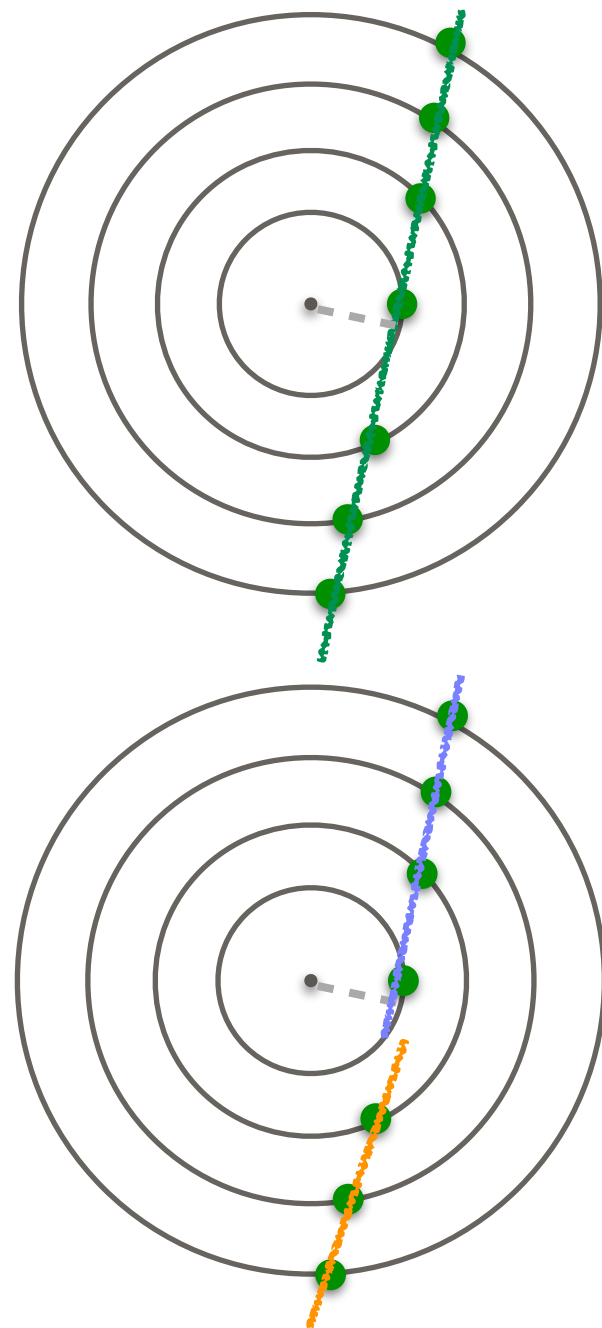
- Unbiased track-hit residuals, the hit under consideration is not used in the track fit
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TRACK SPLIT VALIDATION - 0T COSMIC RAY DATA



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



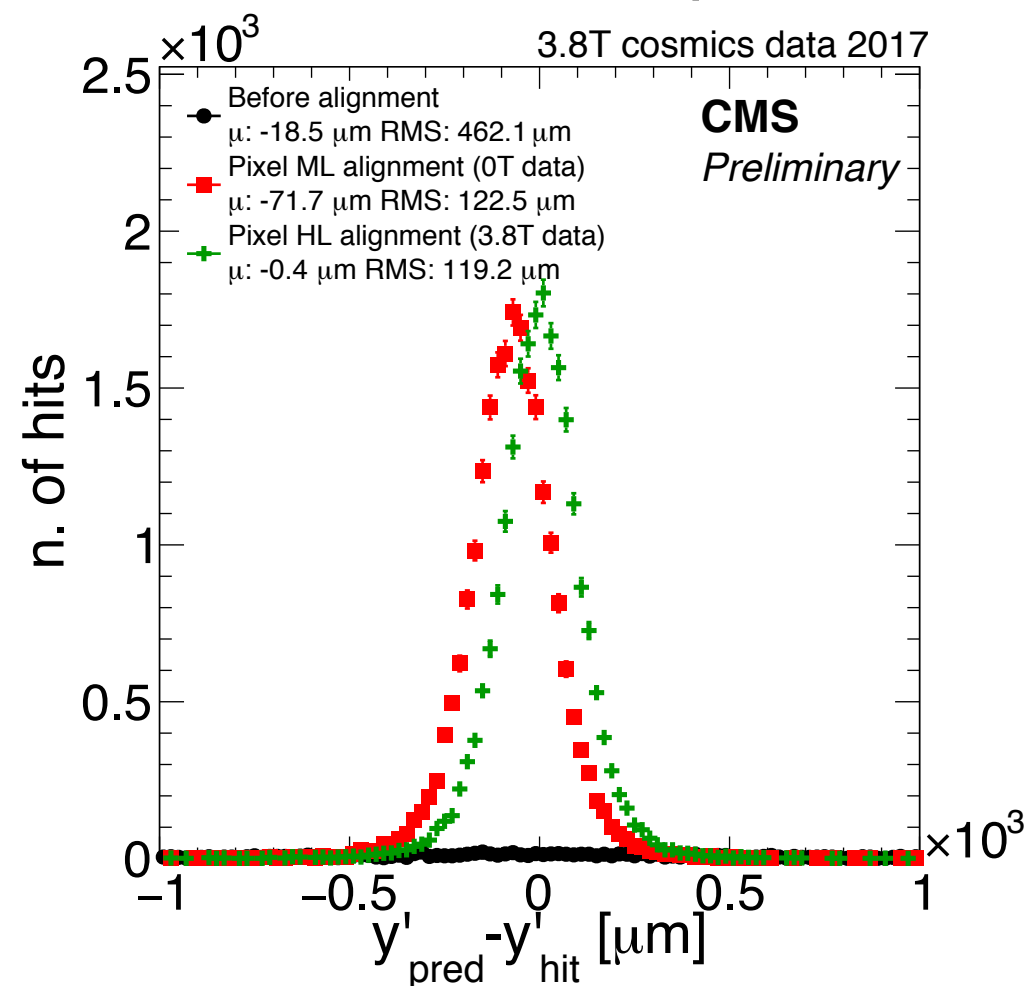
- After each alignment iteration, reduced **bias (syst. effects)** and **width (local precision)**

RESULTS ON 3.8T COSMIC RAY DATA

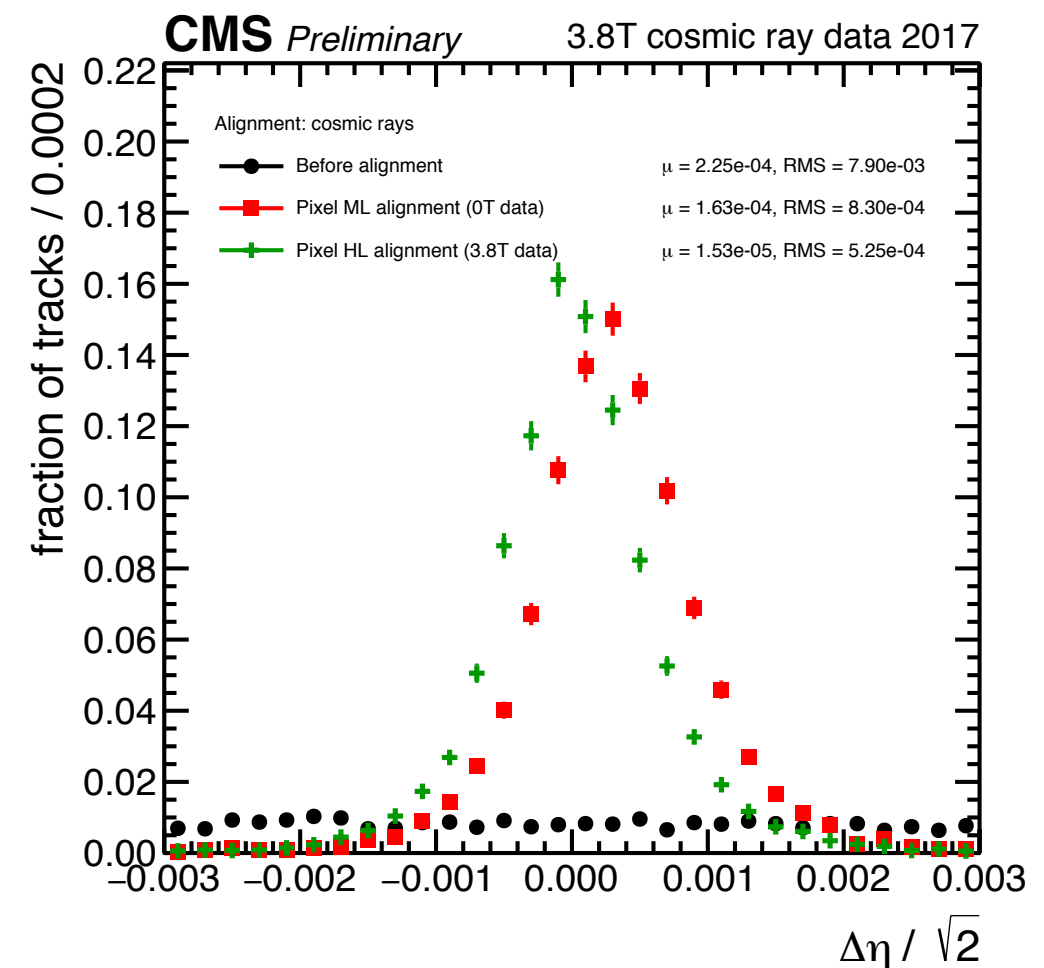


- Magnetic field change induces movements in the detector, need to update the alignment (at high-level due to limited stat.)

Track-hit residuals in barrel pixel, z direction



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

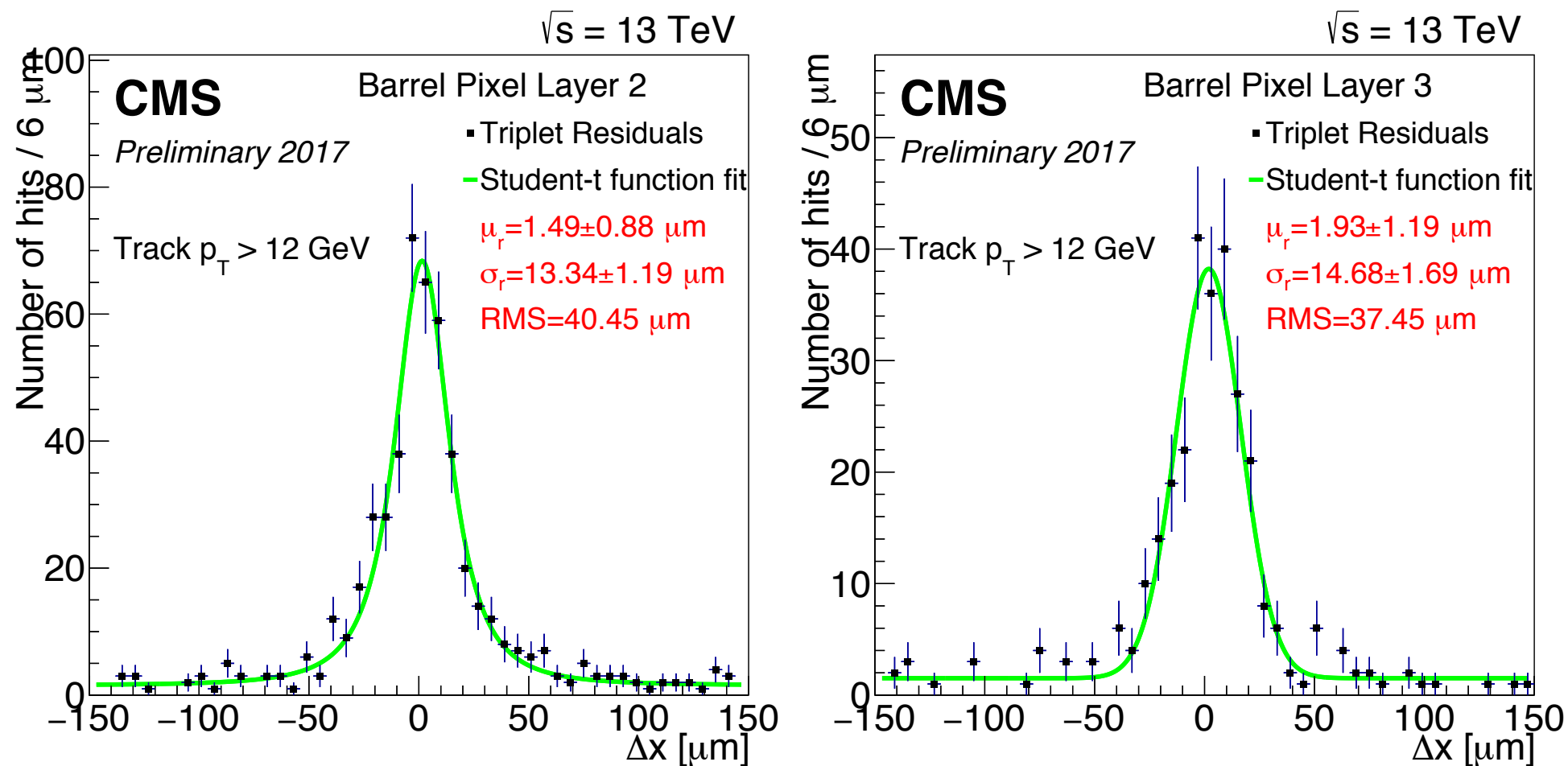


Successfully measured the pixel modules position after installation,
good starting point for the collision run.

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



- 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!



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

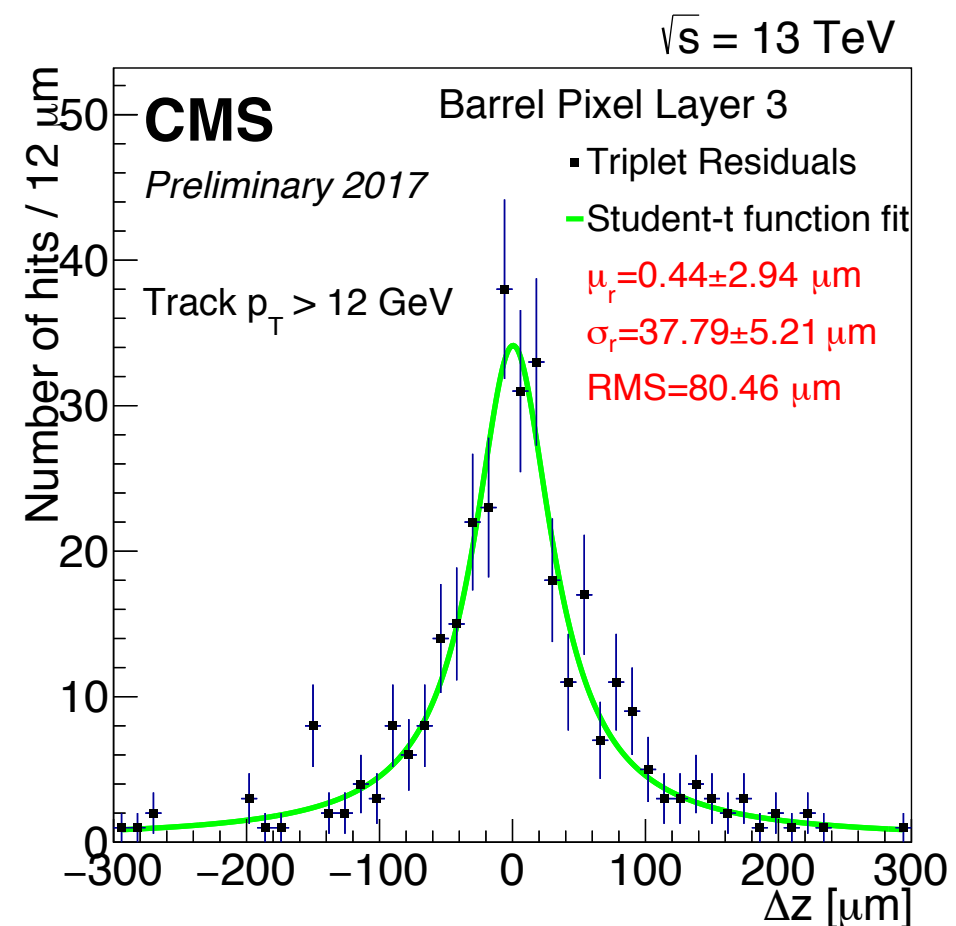
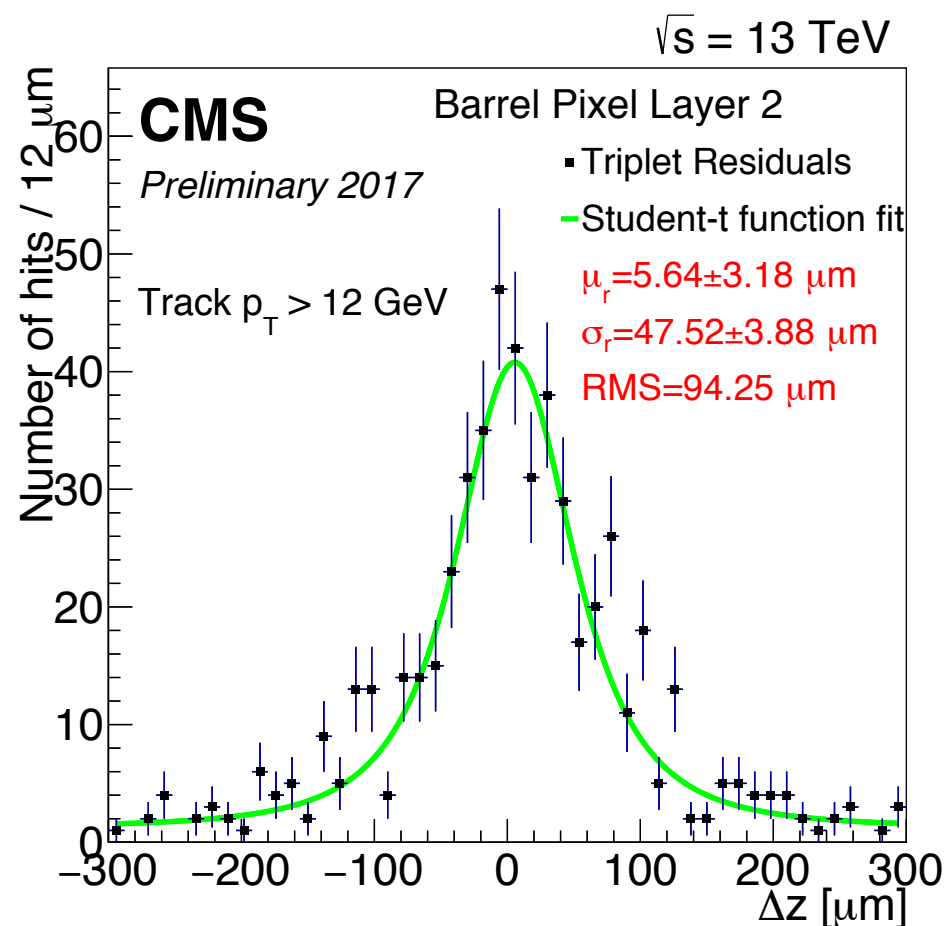
BACKUP - ADDITIONAL MATERIAL



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

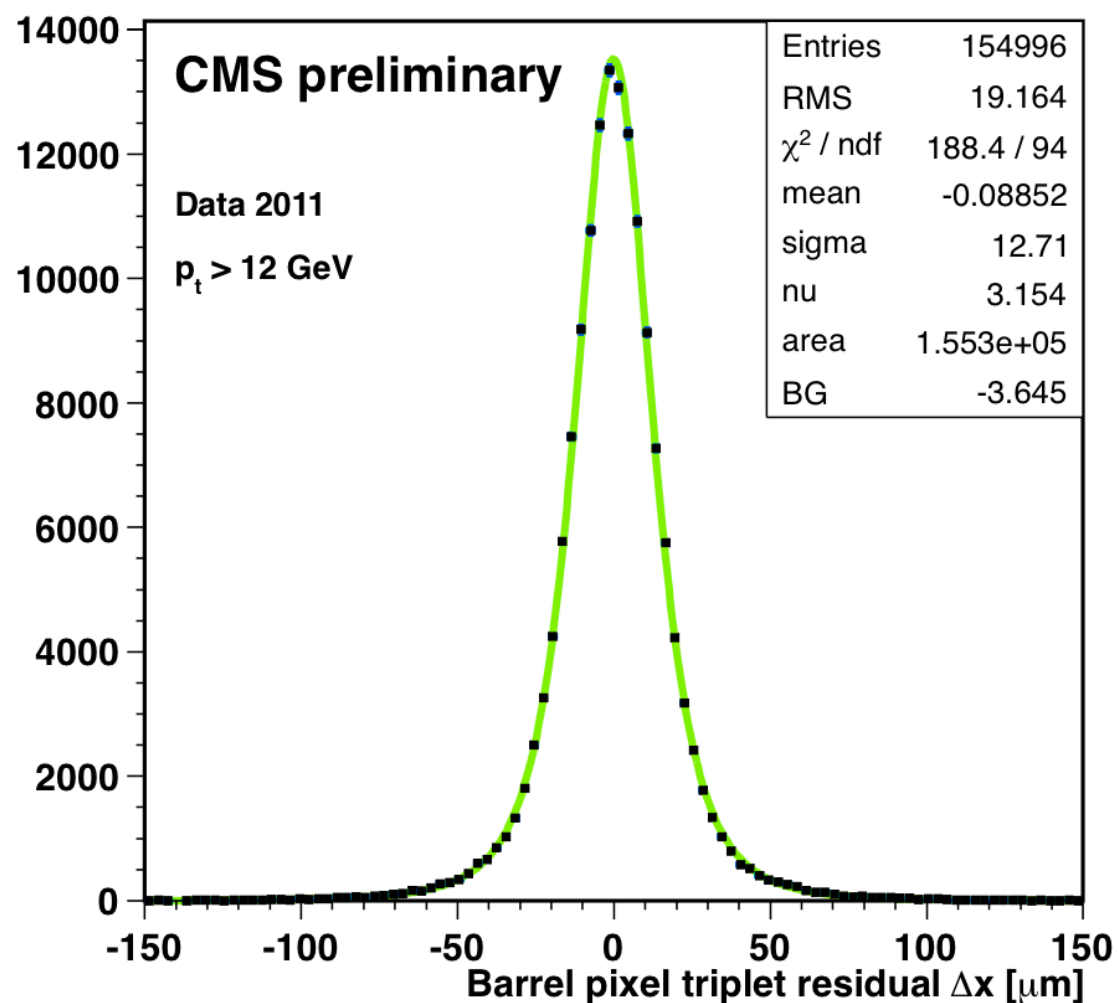


- Resolution in z-direction known to have dependence on the track angle

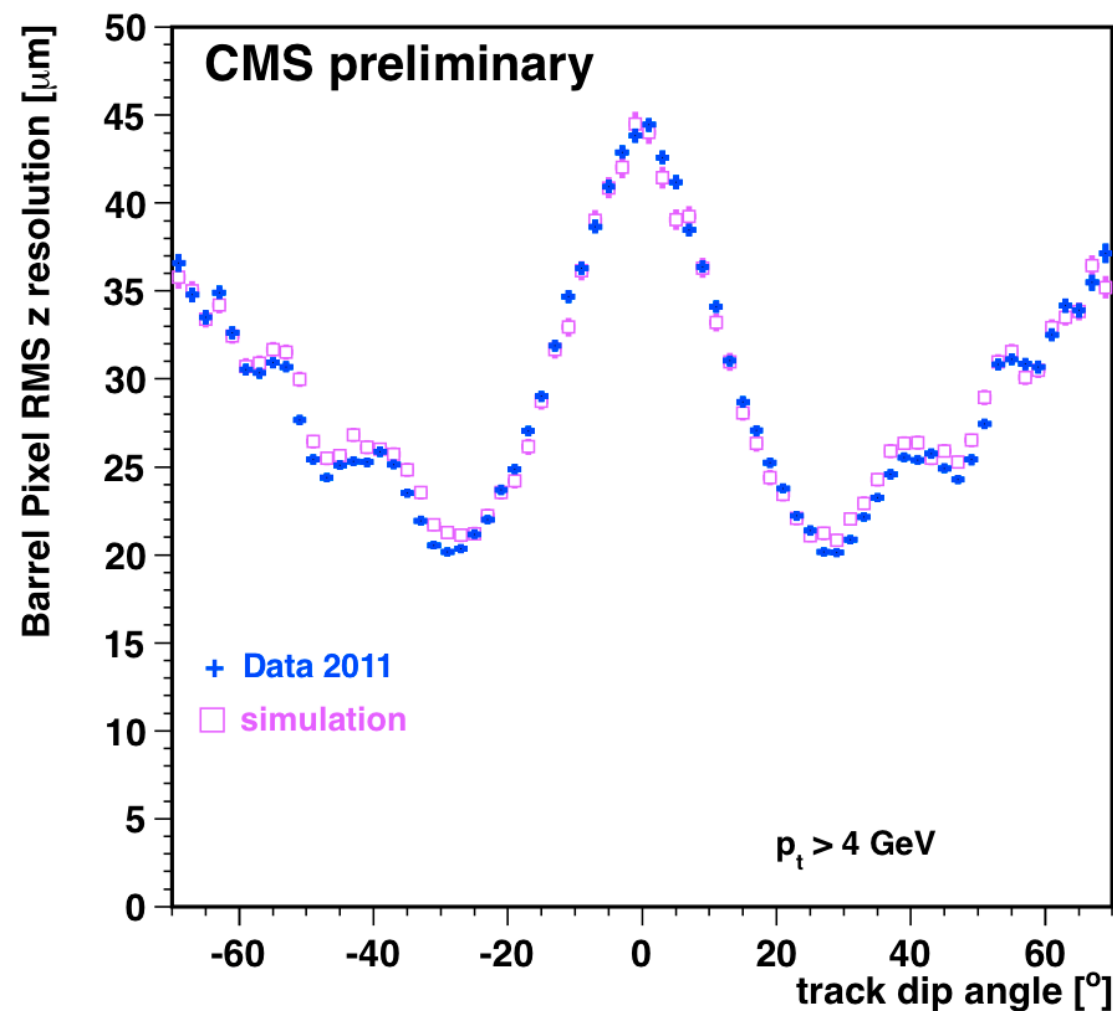
PIXEL HIT RESOLUTION IN 2010



CMS Barrel Pixel triplet residuals



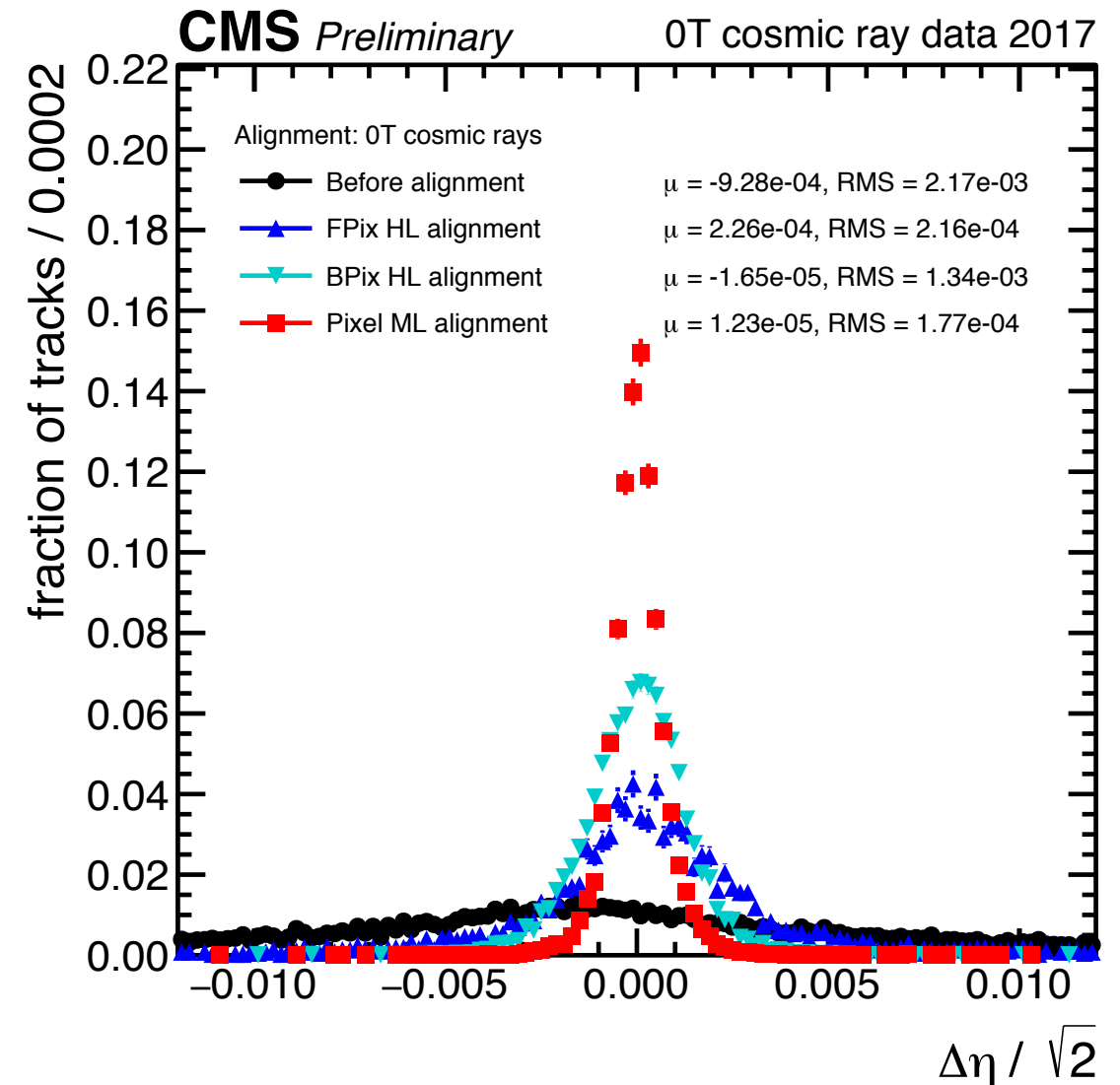
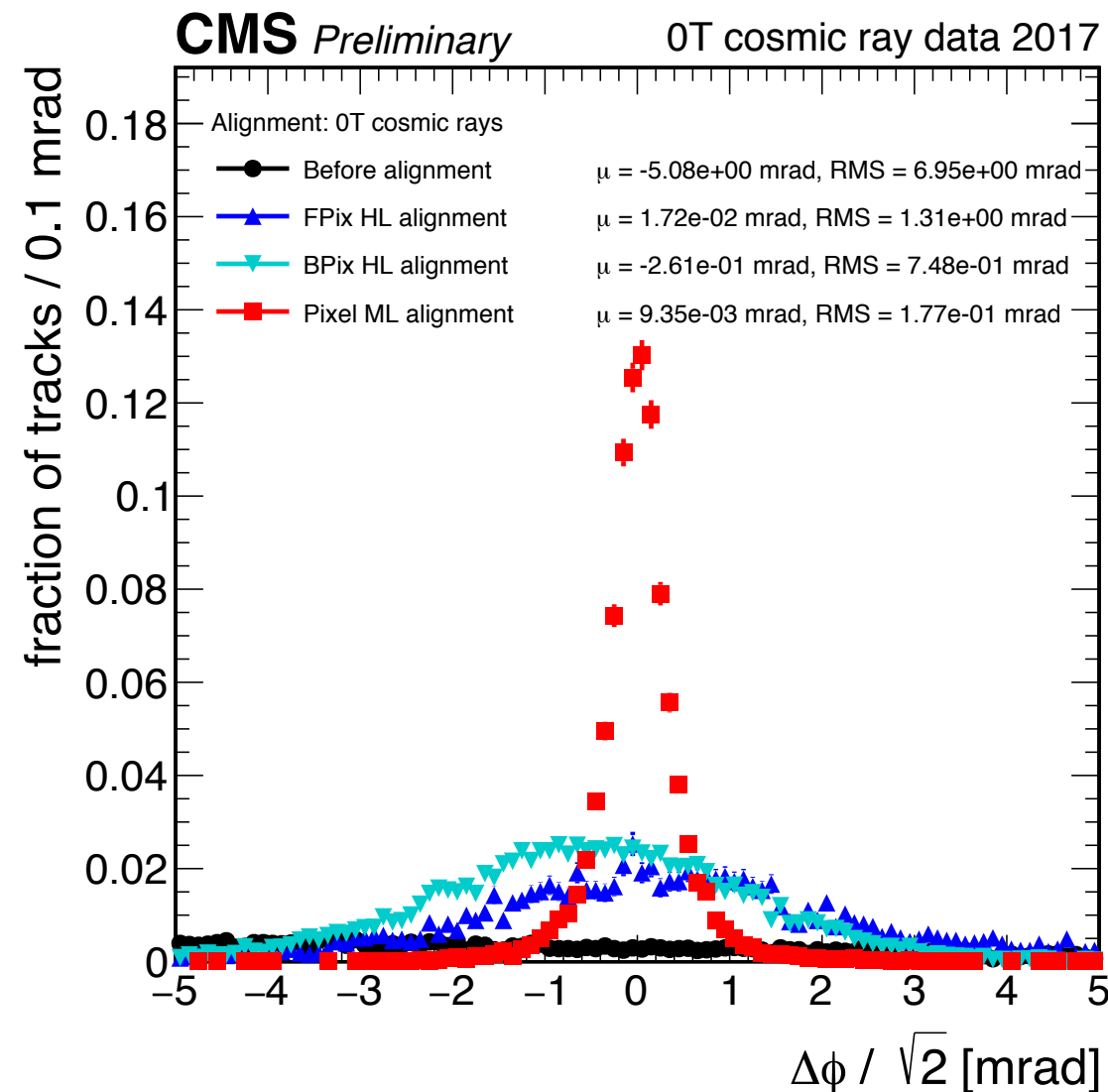
CMS Barrel Pixel z resolution from triplets



TRACK SPLIT VALIDATION - OT COSMIC RAY DATA



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

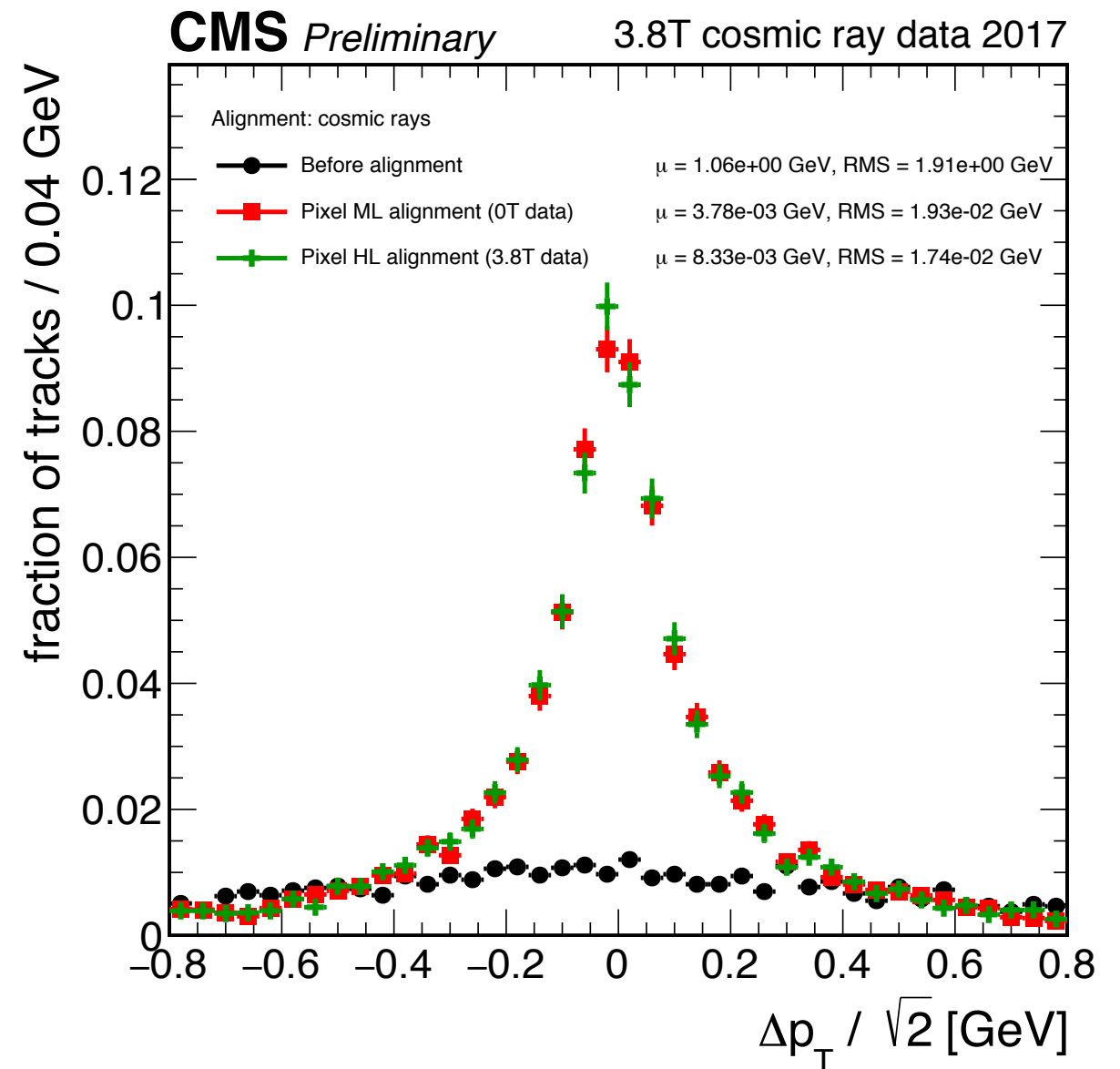
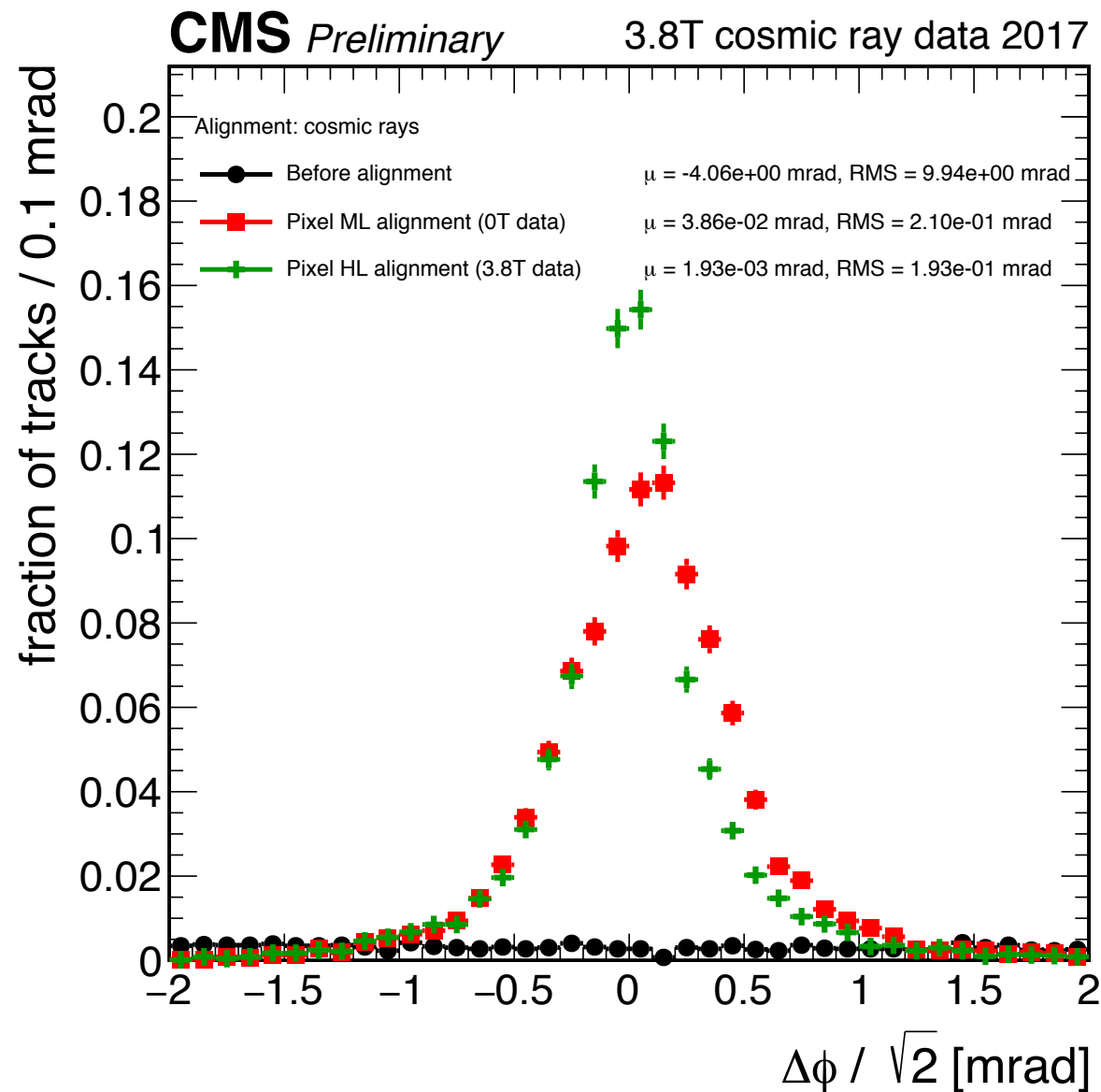


- After each alignment iteration, reduced **bias (syst. effects)** and **width (local precision)**

TRACK SPLIT VALIDATION - 3.8T COSMIC RAY DATA



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

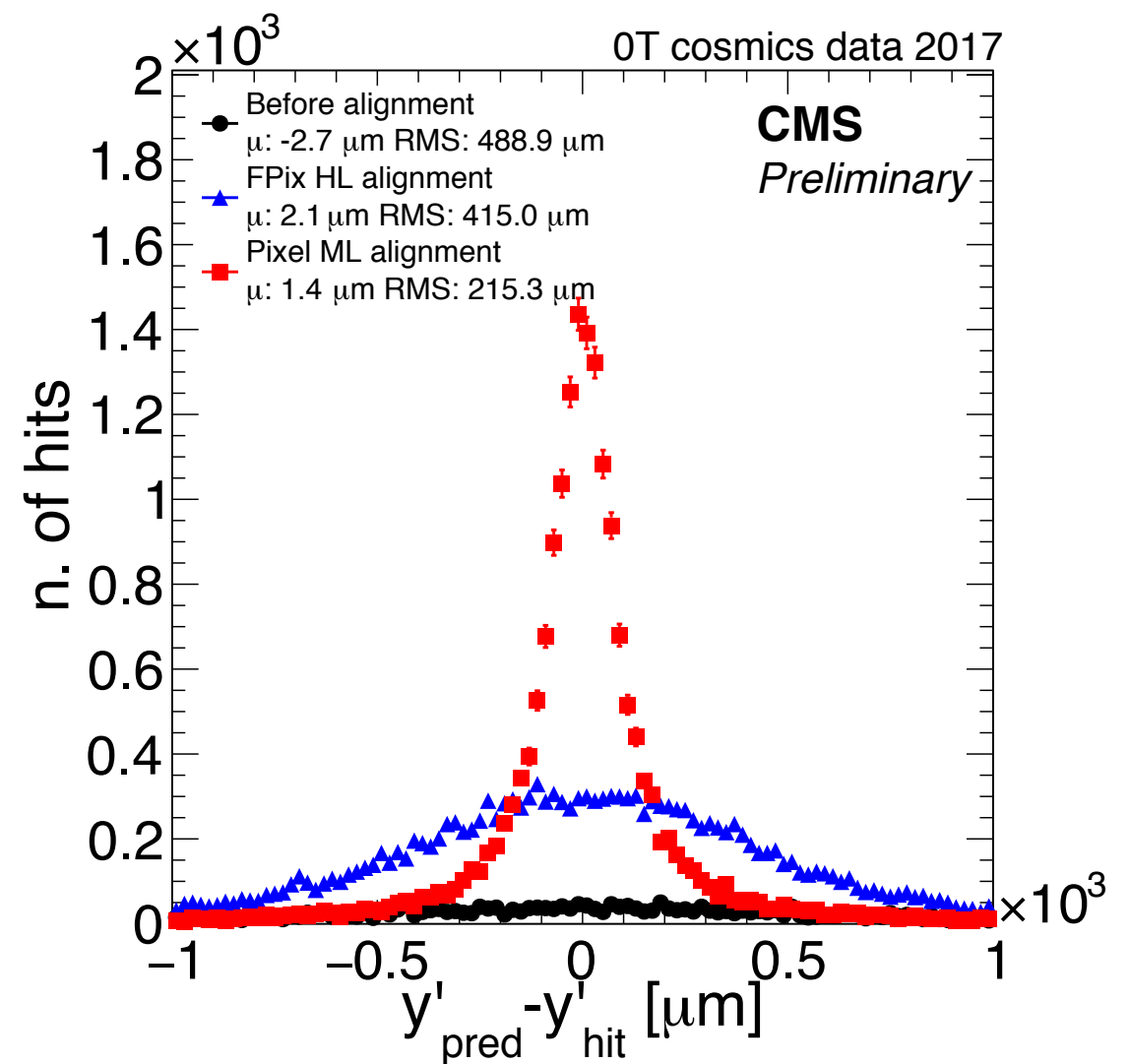
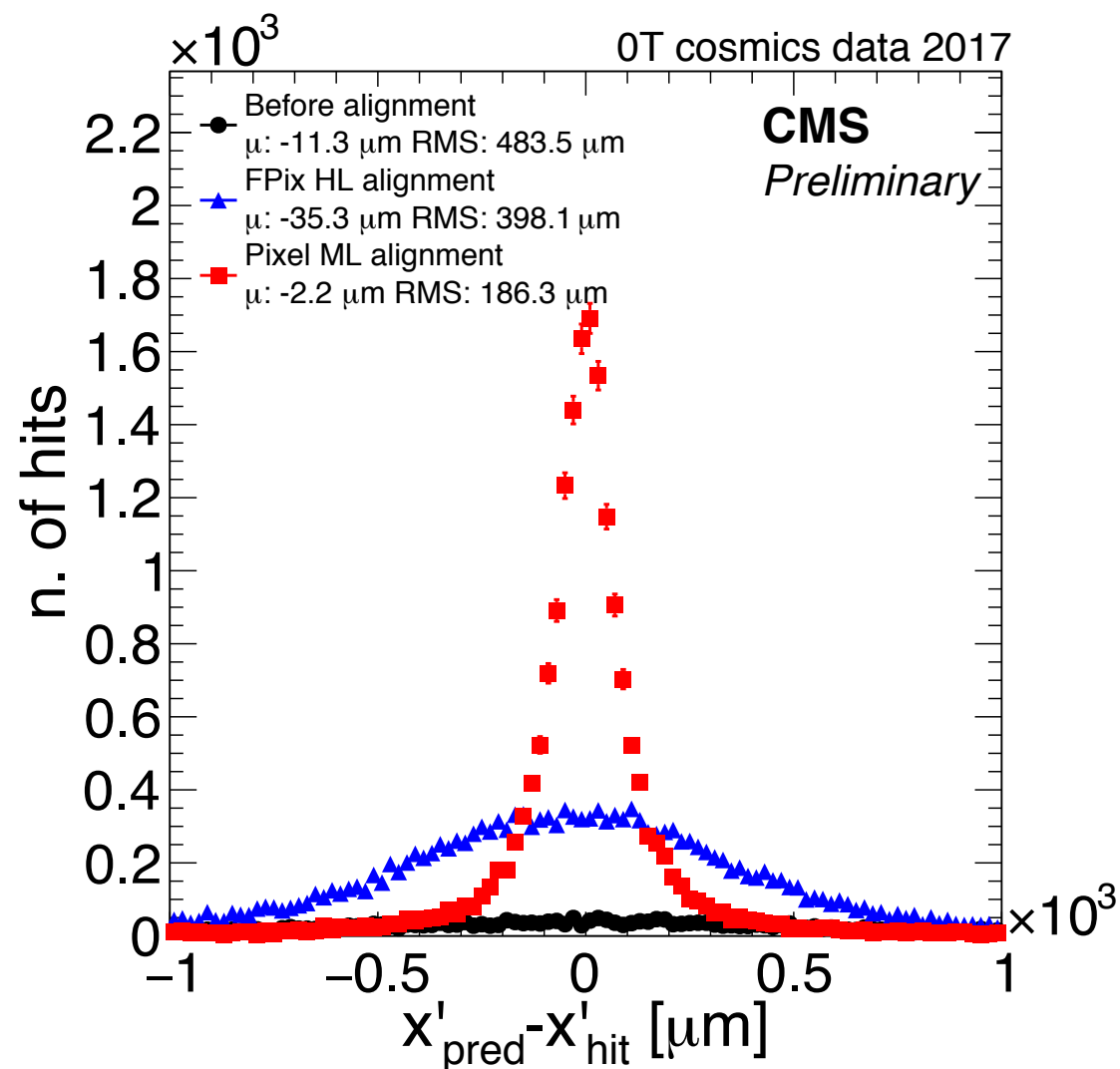


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RESULTS ON OT COSMIC RAY DATA - FPIX RESIDUALS



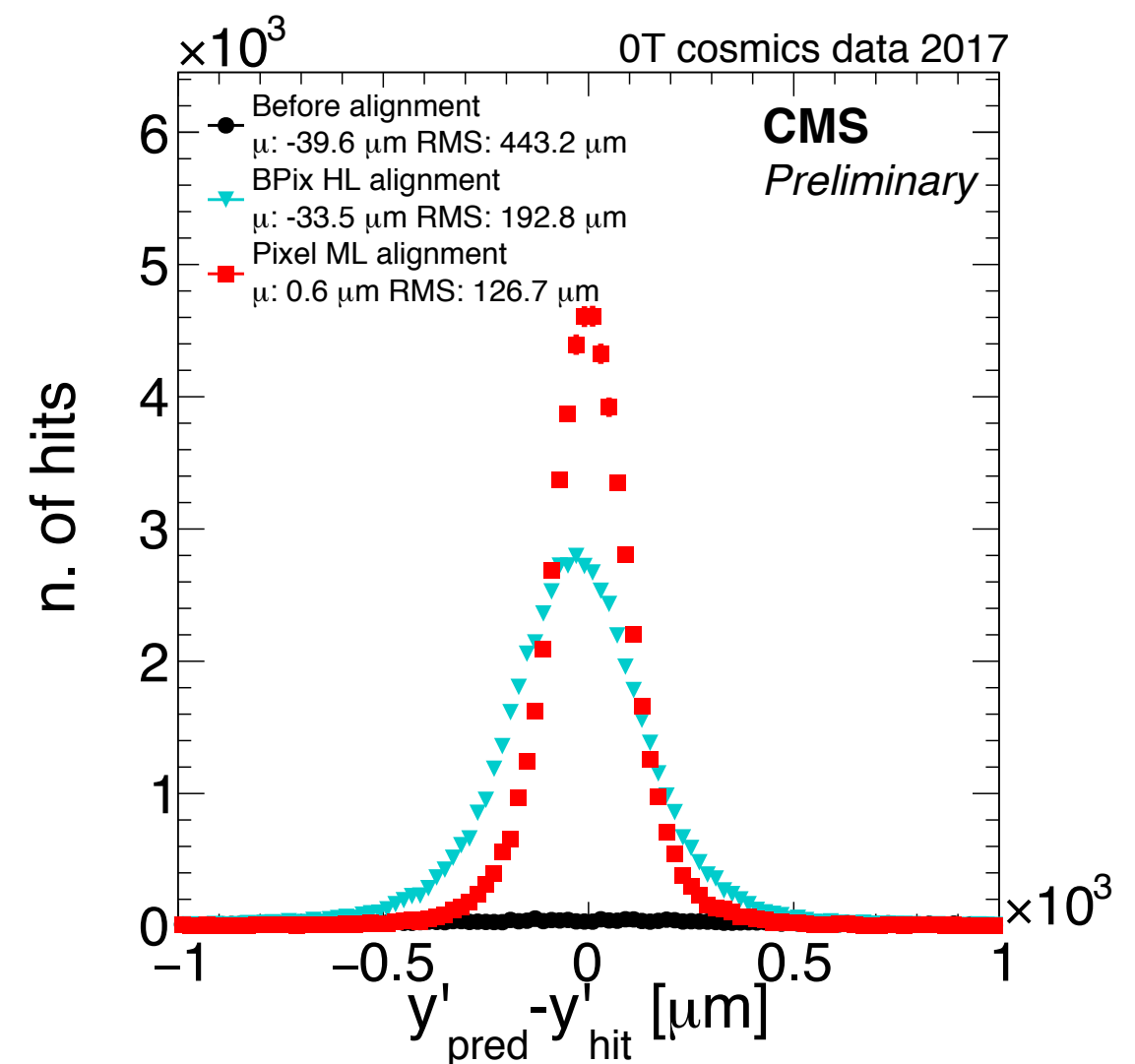
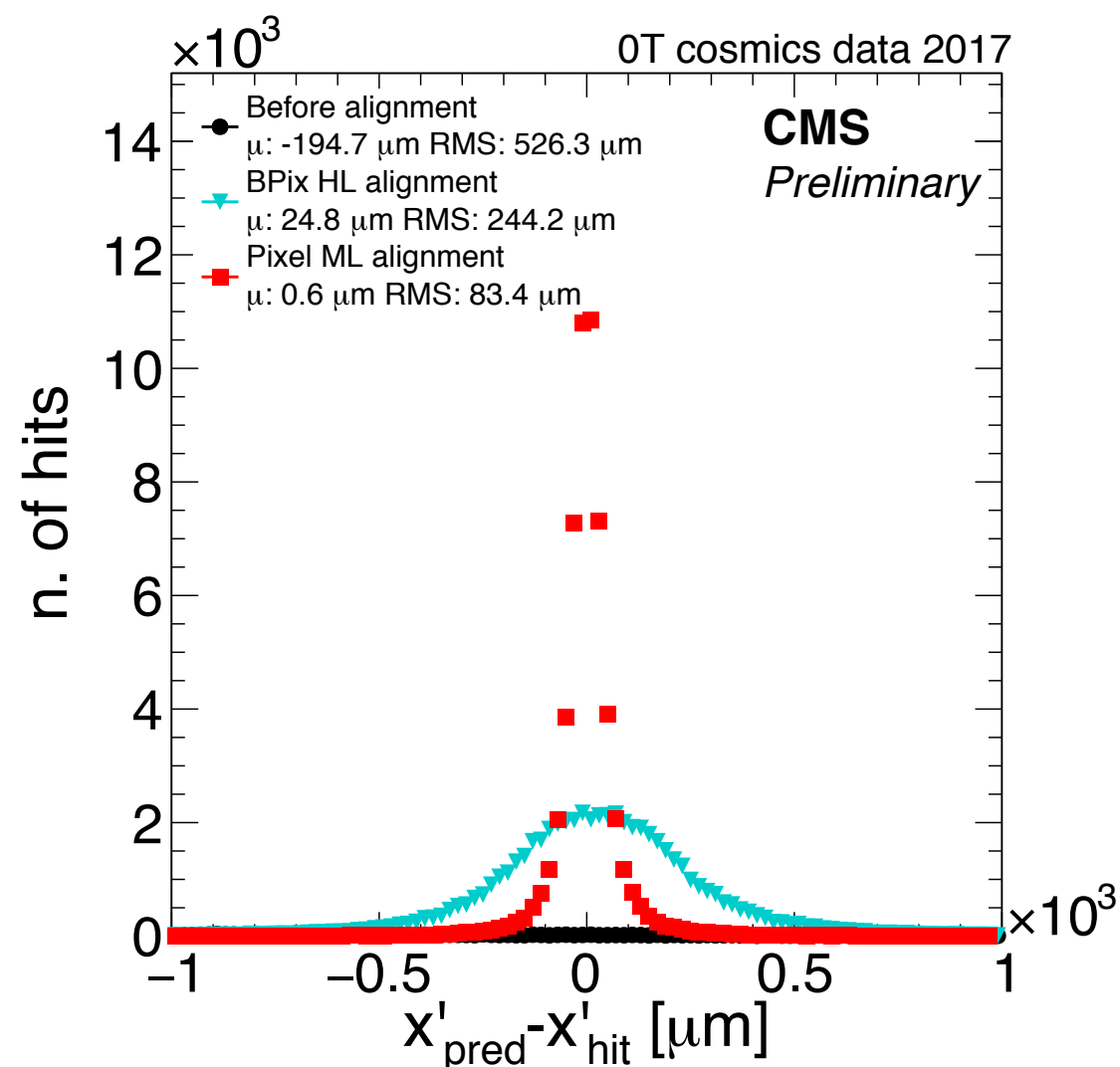
- Unbiased track-hit residuals (the hit under consideration is not used in the track fit)
- After each alignment iteration, reduced bias and width



RESULTS ON OT COSMIC RAY DATA - BPIX RESIDUALS



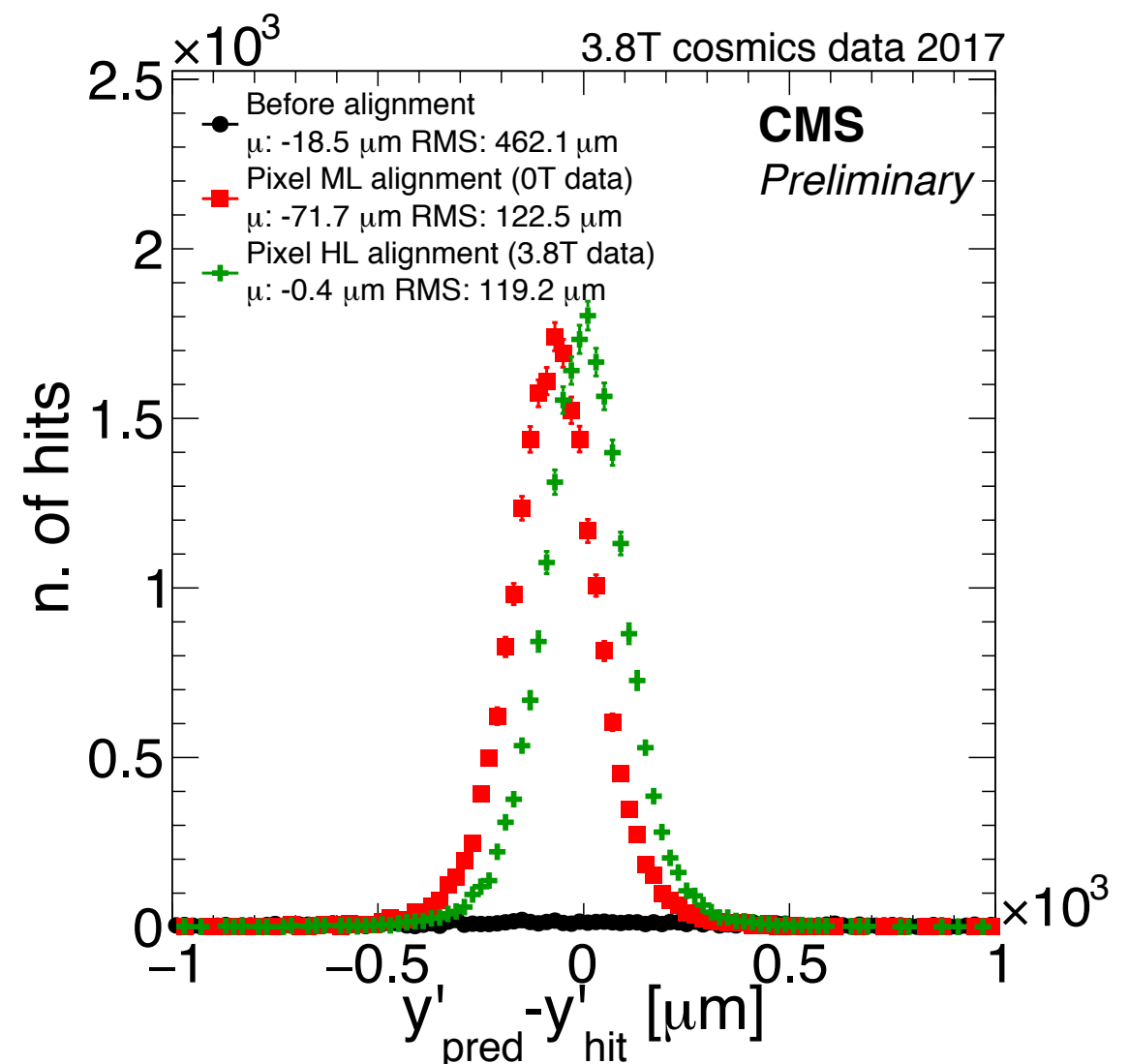
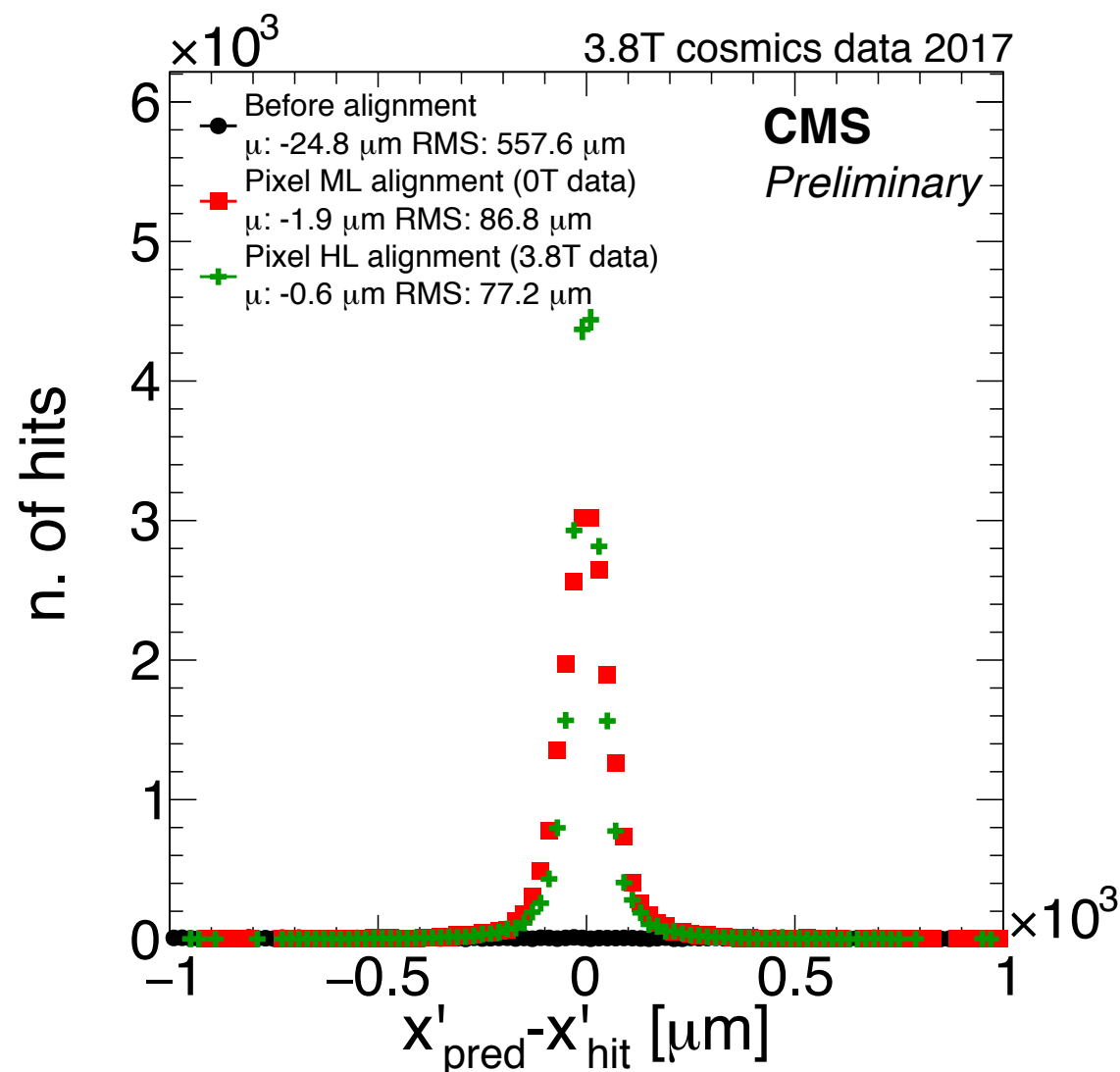
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RESULTS ON 3.8T COSMIC RAY DATA - BPIX RESIDUALS



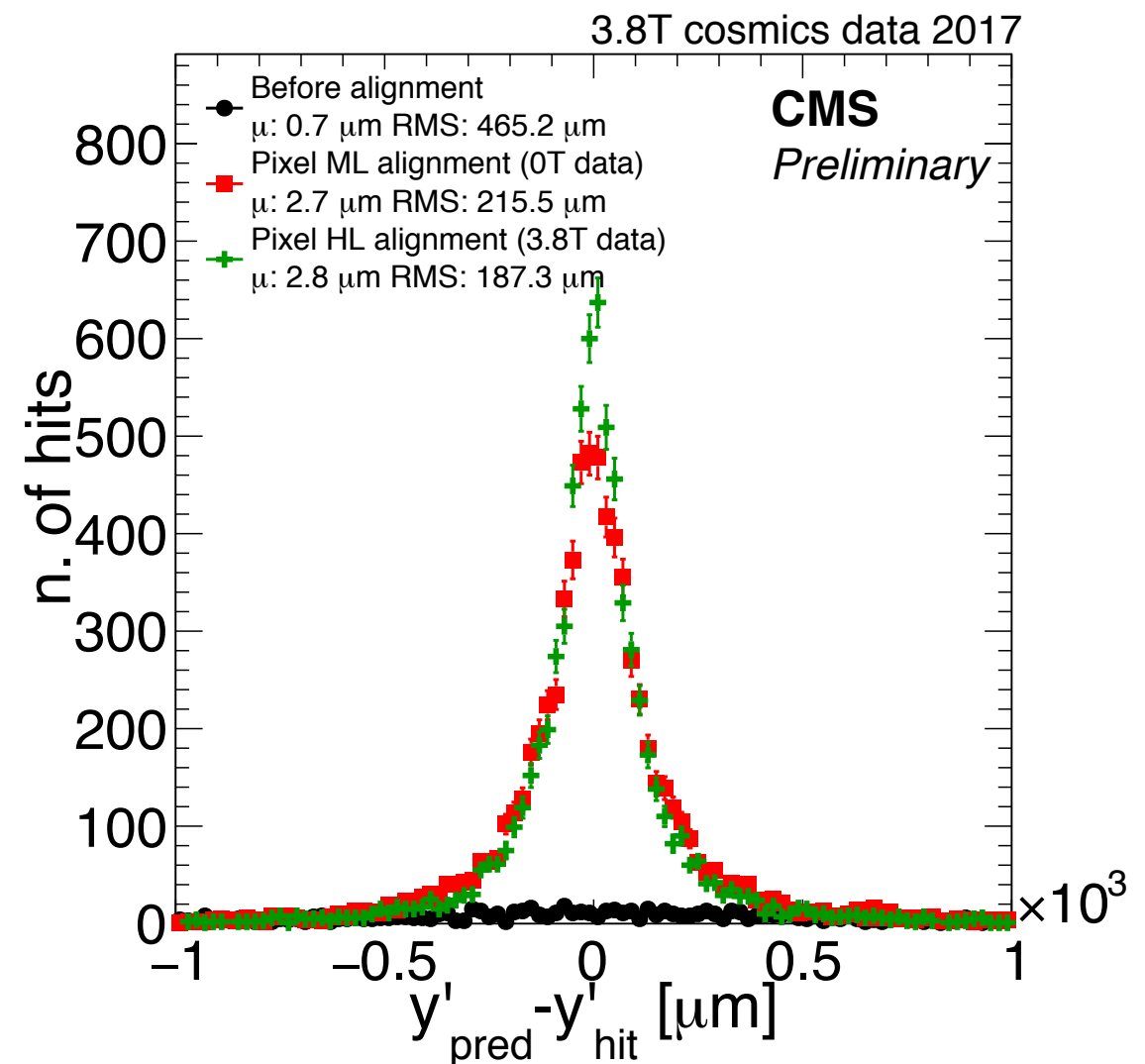
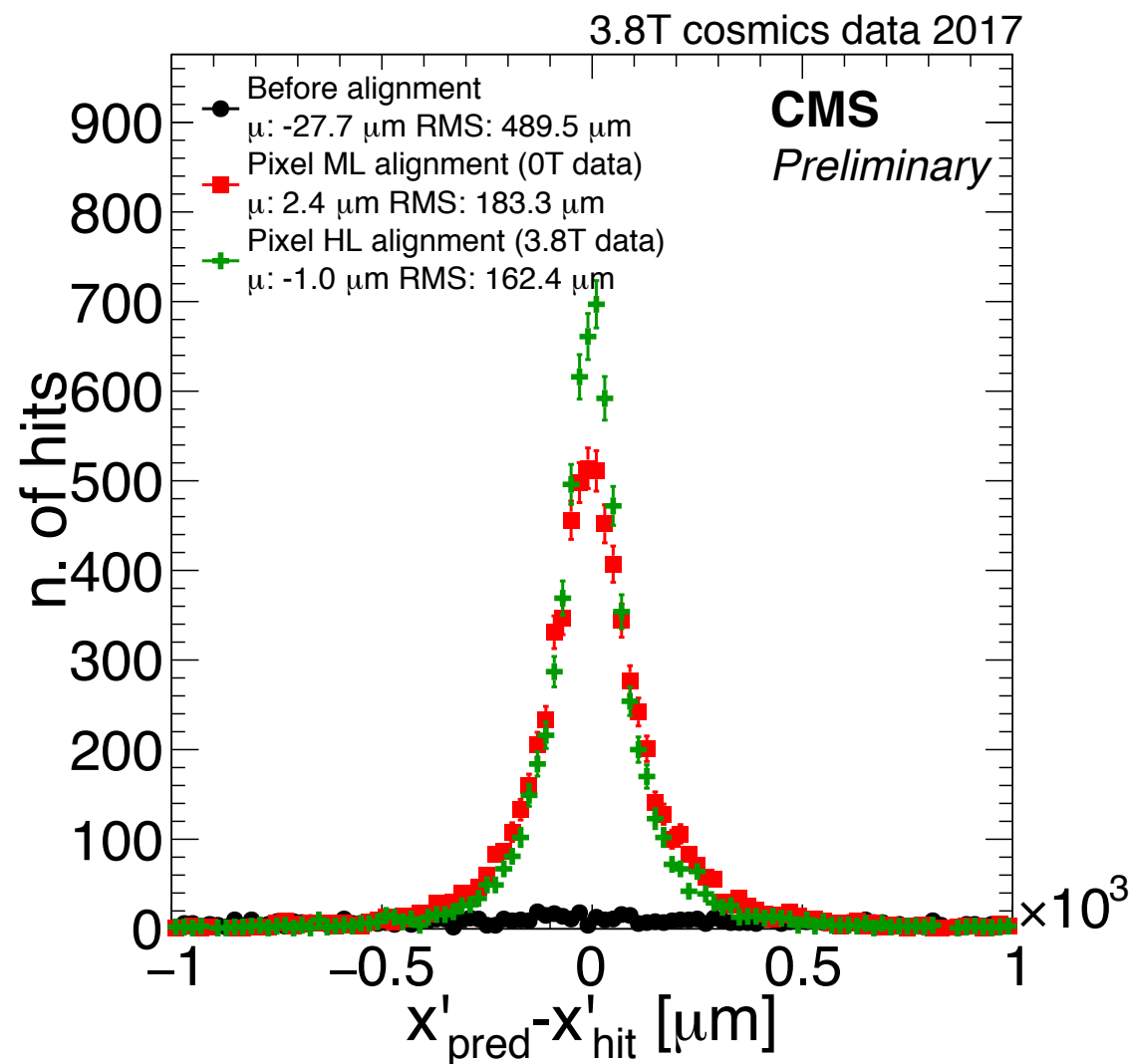
- Unbiased track-hit residuals, the hit under consideration is not used in the track fit
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RESULTS ON 3.8T COSMIC RAY DATA - FPIX RESIDUALS



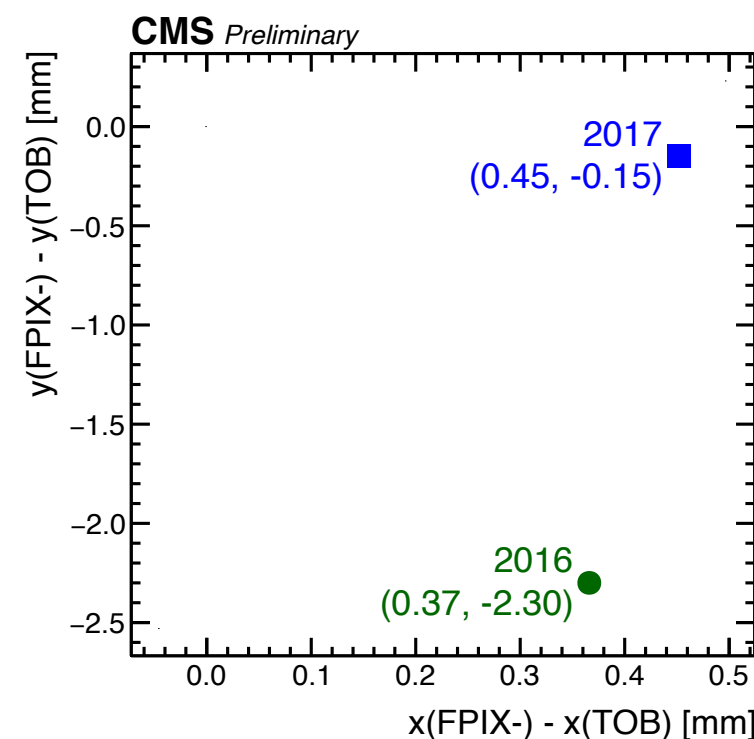
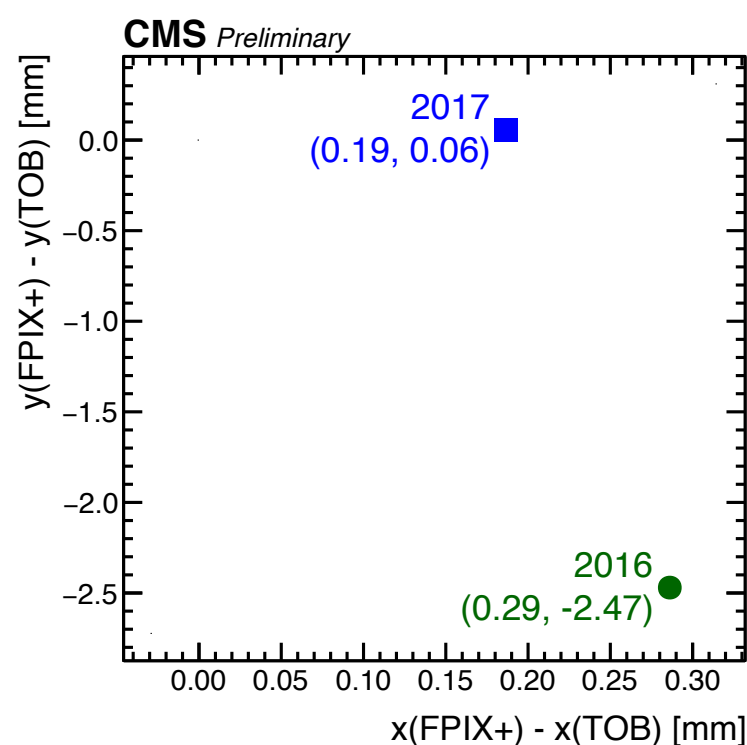
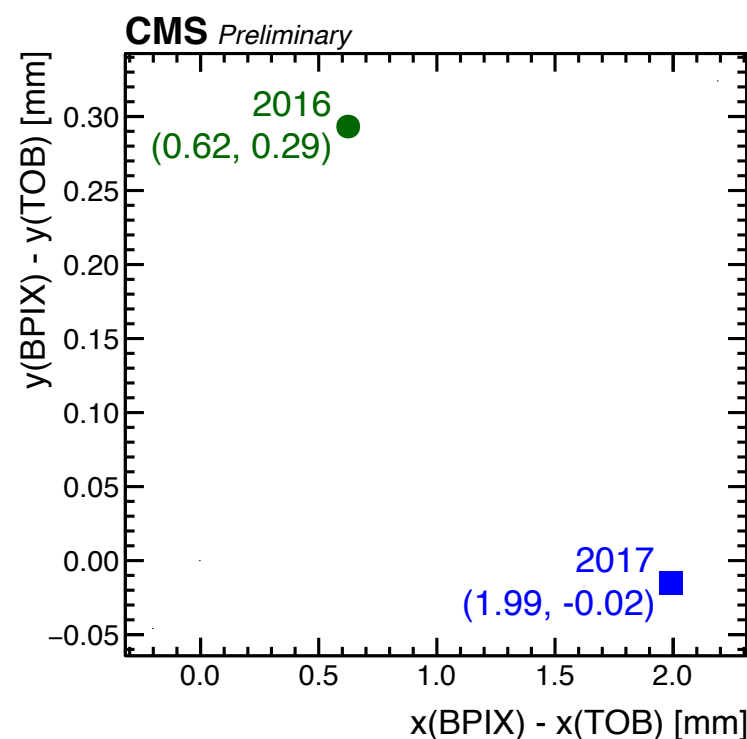
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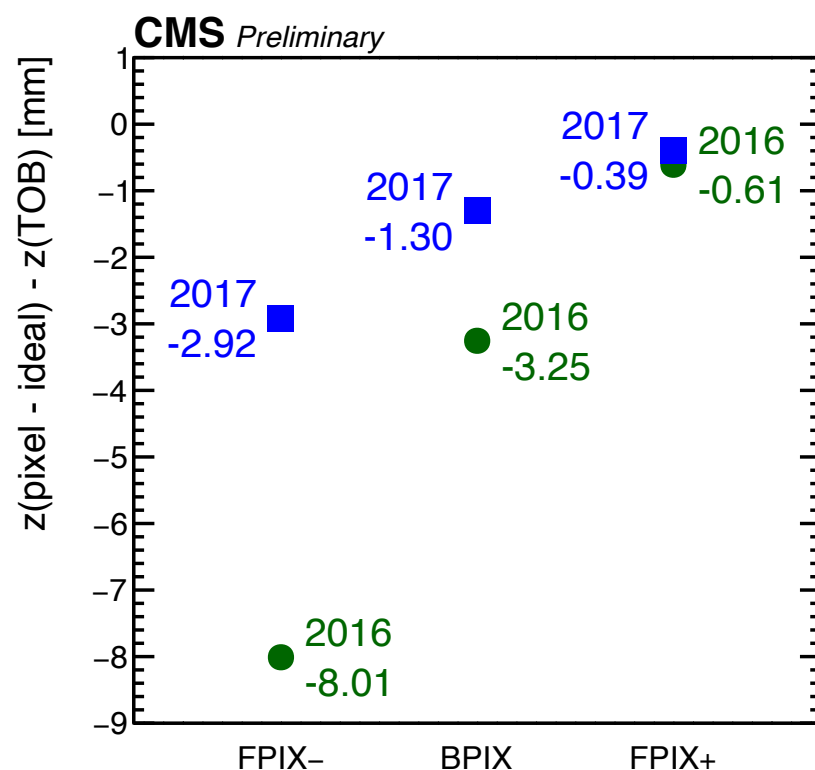
PIXEL BARYCENTRE POSITIONS



x-y

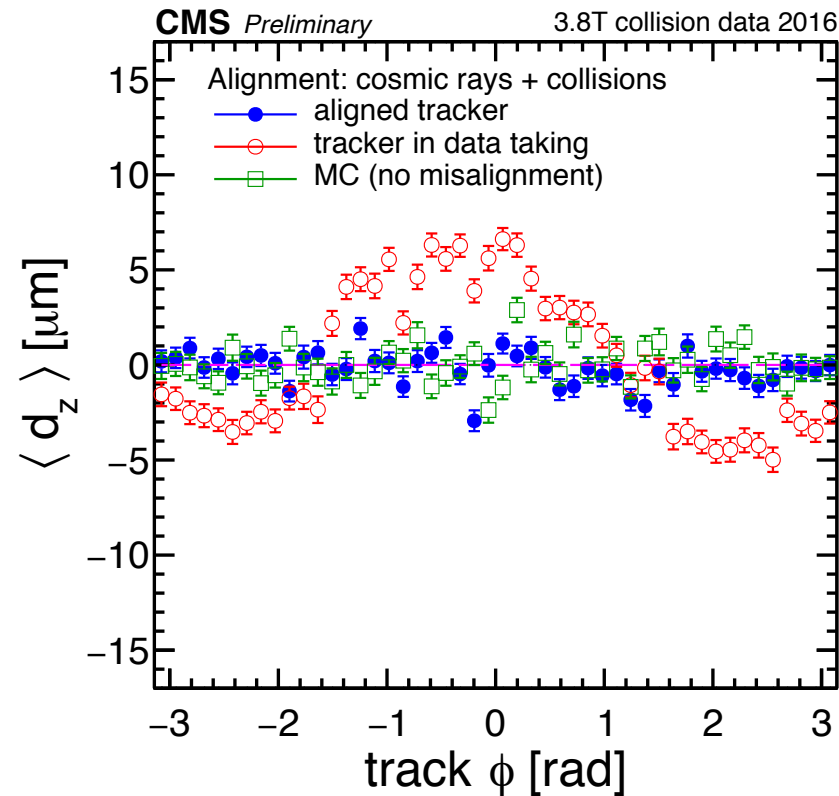
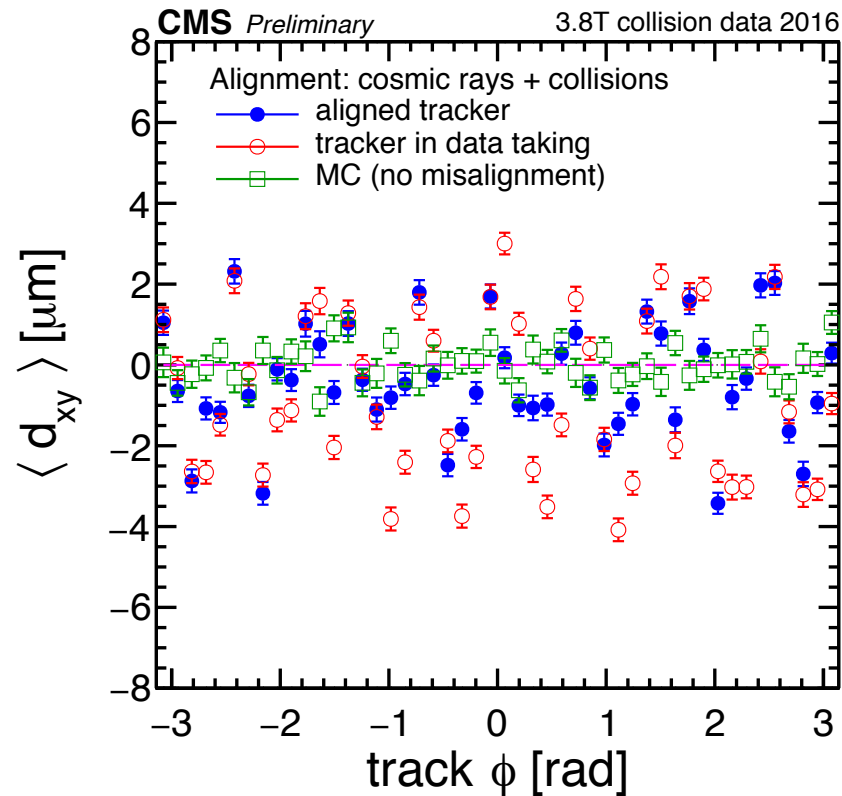


z



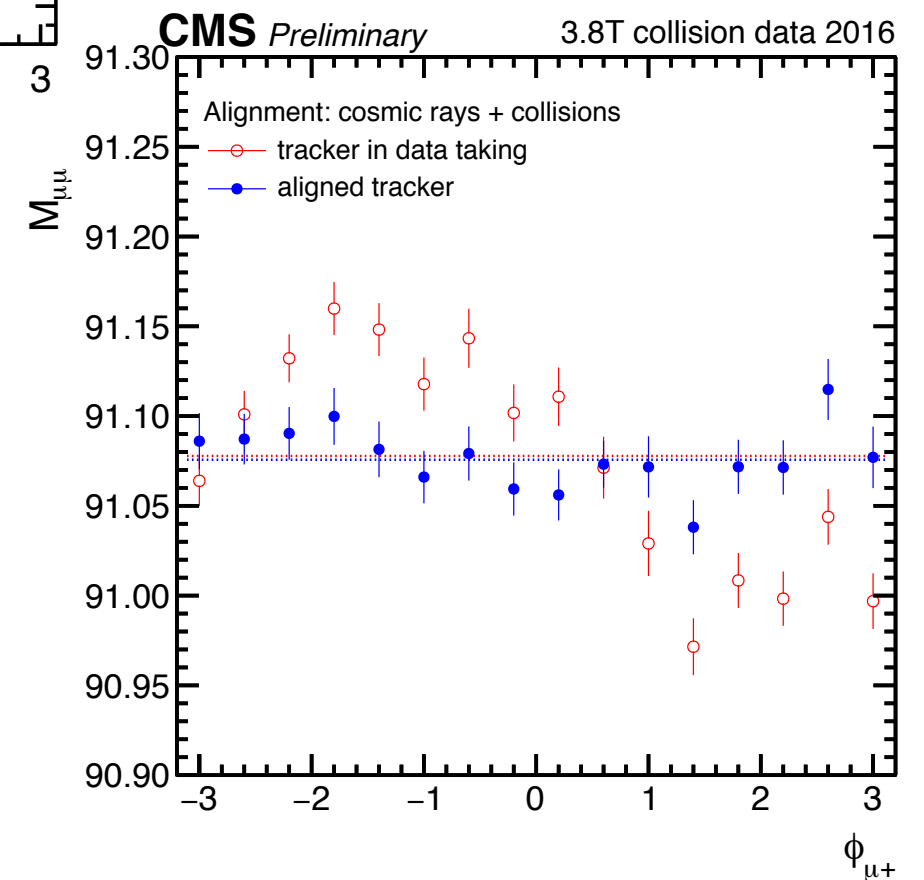
- Positions of the pixel detector centres with respect to the tracker outer barrel.
- For the new pixel tracker, the measure is obtained from the alignment derived using 3.8T cosmic-ray data collected in 2017.

2016 ALIGNMENT PERFORMANCE



■ Unbiased track-vertex residuals

■ Z mass from di-muon events

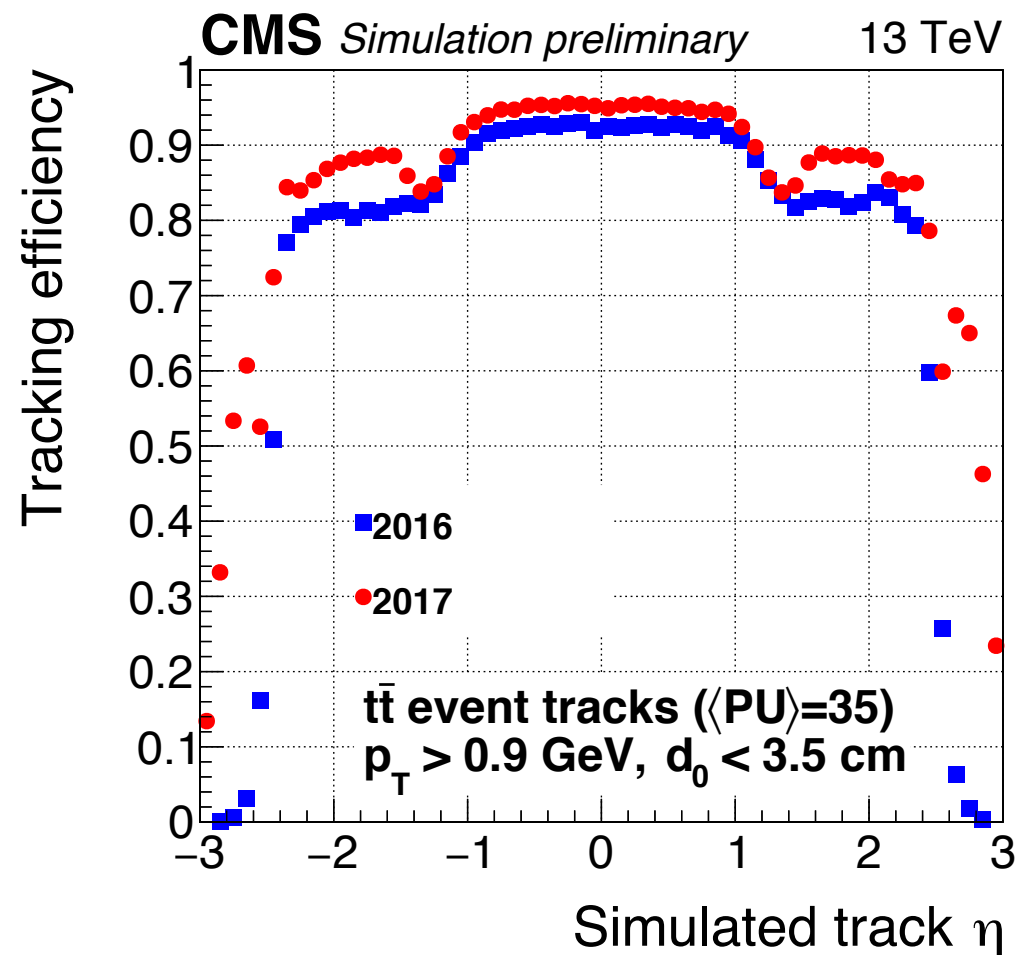


EXPECTED TRACKING PERFORMANCE

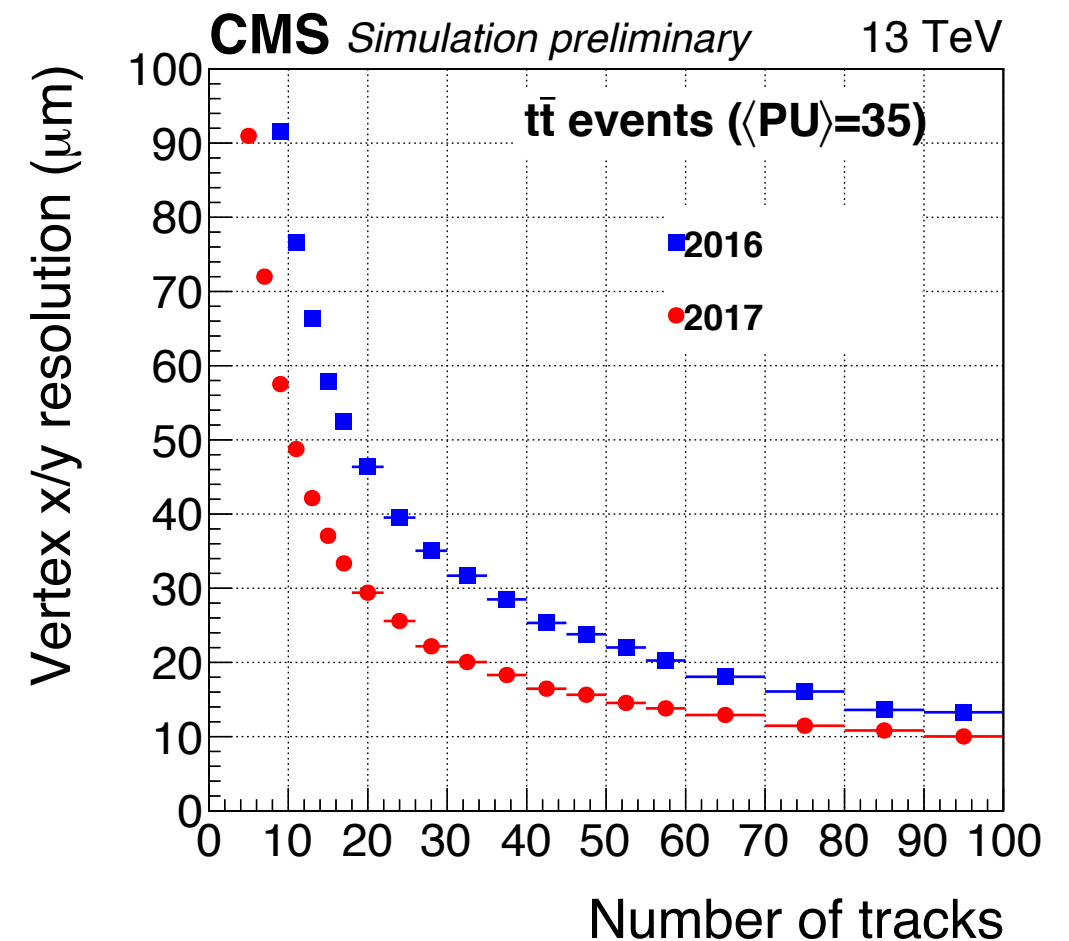


New (2017) vs. old (2016) tracker, from simulation

■ Higher track efficiency



■ Better vertex resolution (xy plane)



TRACKING - PILE UP DEPENDENCE



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

