CMS Silicon Tracker Alignment: First Run II Results

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on behalf of the CMS collaboration

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Ann Arbor, MI

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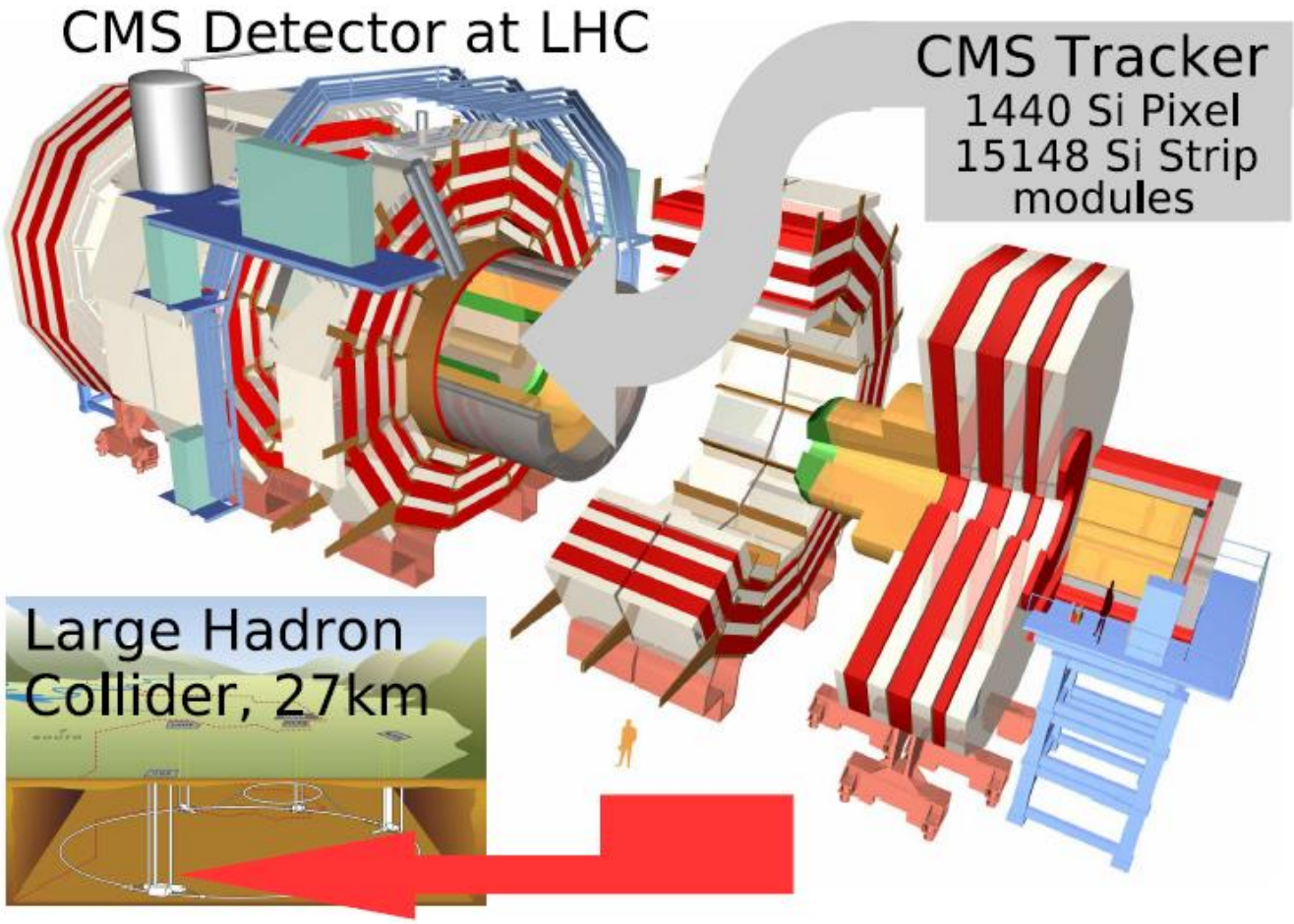
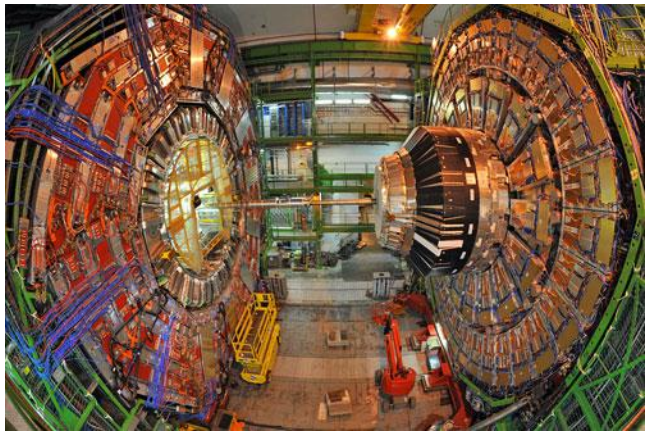
The CMS tracker



Purpose

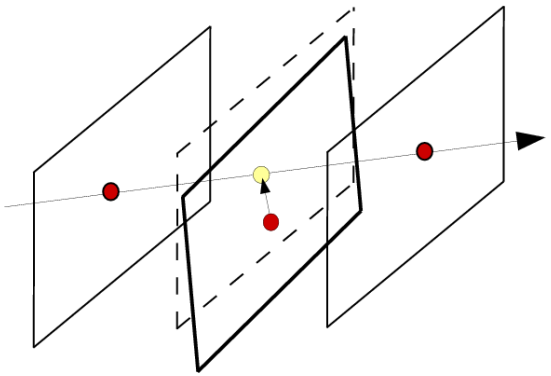
- For optimal performance, positions of sensors need to be known better than intrinsic resolution ($\sim 10\ \mu\mathrm{m}$)
- Since the end of Run I:
  - Barrel pixel repair
  - Many modules replaced
  - CMS opened and entire pixel detector removed



- B field changes ⇒ modules shift
- Other effects (some unpredictable) can also cause movements

Alignment procedure

- Minimize residuals:



$$\chi^2(\vec{p}_{\text{modules}}, \vec{q}_{\text{tracks}}) = \sum_{i=1}^{N_{\text{residuals}}} \vec{r}_i^{\,T} \boldsymbol{V}_i^{-1} \vec{r}_i$$

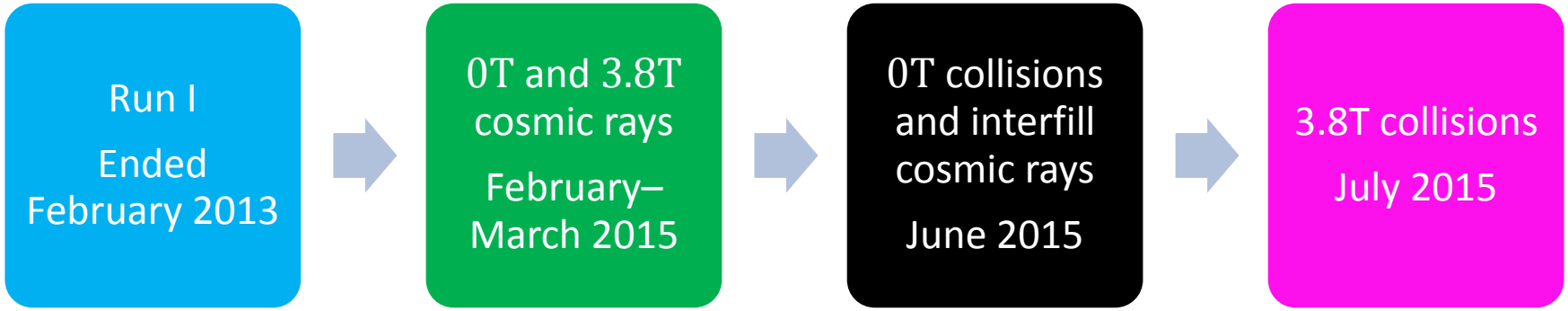
Local approach (Hit and Impact Point; HIP)

- Run in iterations
- Fit the tracks using the results of the previous iteration
- Use the tracks to fit the module positions

Global approach (Millepede II)

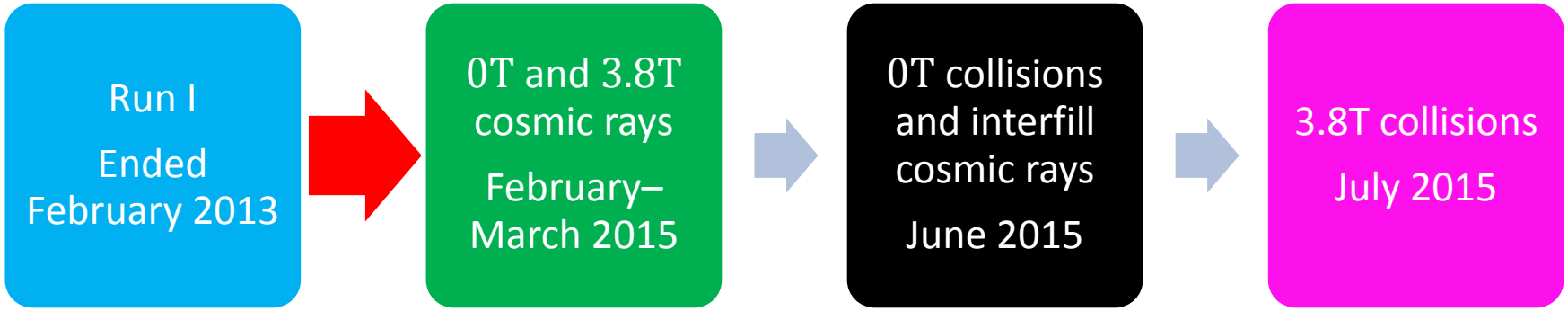
- Fit all track and module parameters simultaneously
- Invert $\sim 10^6 \times 10^6$ matrix

Timeline



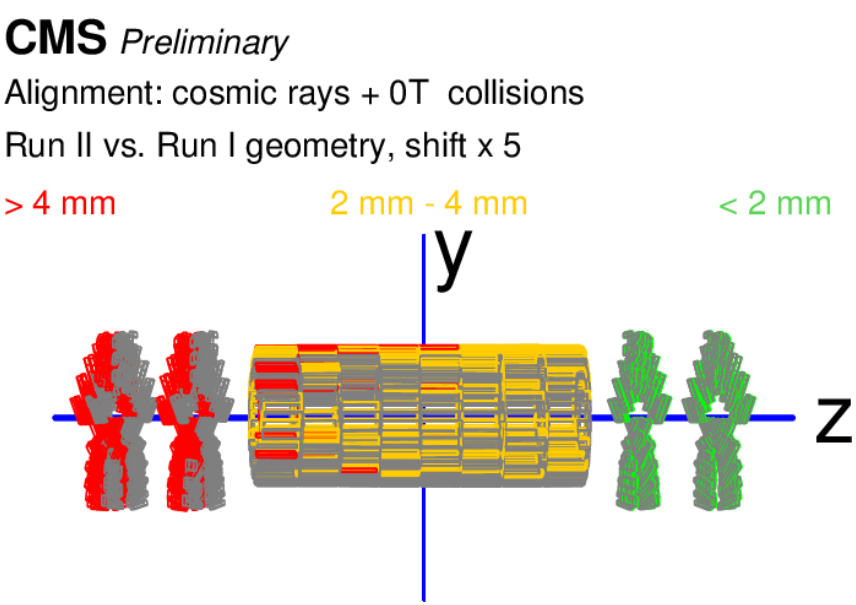
- Several distinct data-taking periods so far in 2015
- Due to changes in the magnetic field, each has a unique detector geometry

Timeline



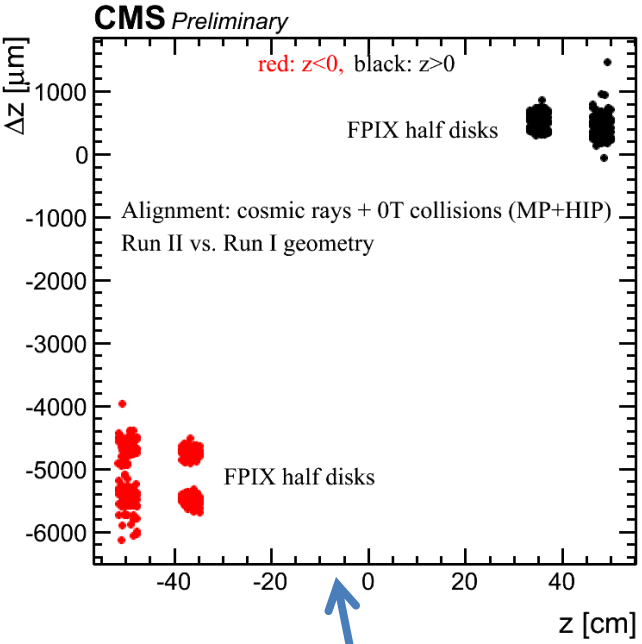
- The largest movements took place during the shutdown between Run I and Run II
- Aligned with cosmic rays
- Recovered performance before the start of collisions

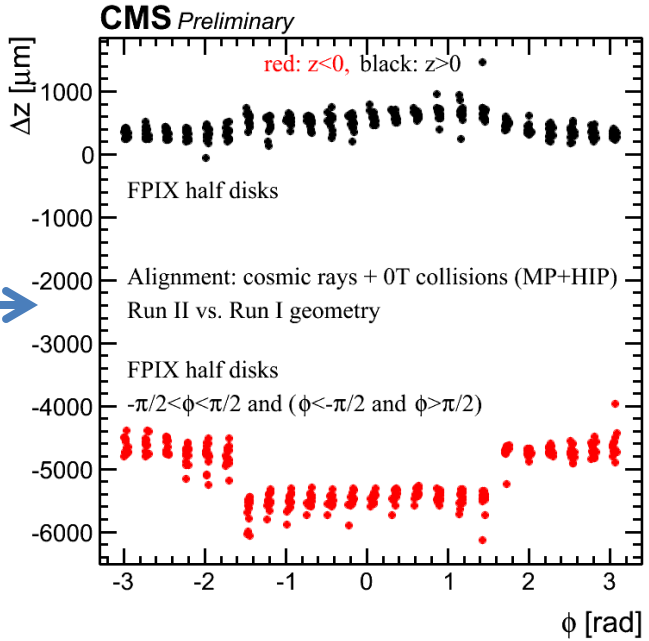
Pixel movements since Run I: overview

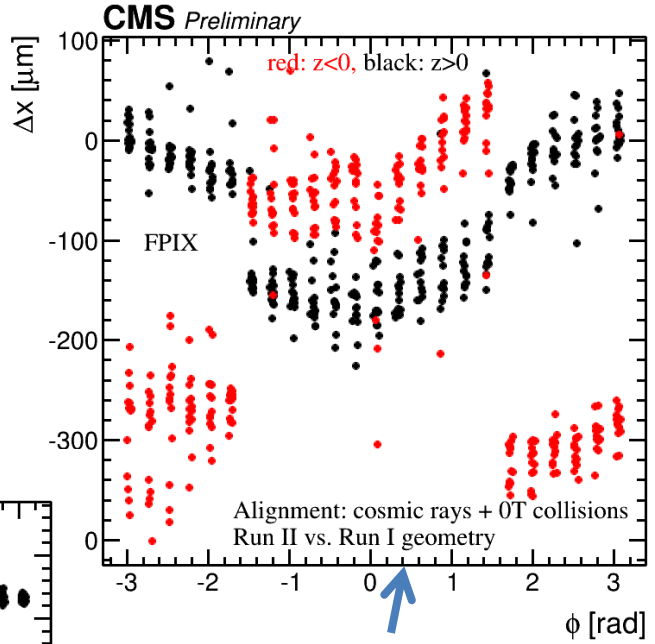


- Module position shift between Run I and Run II, multiplied by 5 for visualization
- Found and corrected:
  - FPIX($z-$) shifted by about 5 mm away from the barrel
  - BPIX moved to recenter it
  - Repair in the $+x$ half barrel (into the picture in side view, to the left in cross sections) ; some modules in this half barrel are red
  - Tilt of the $+x$ half barrel

Pixel movements since Run I: FPIX





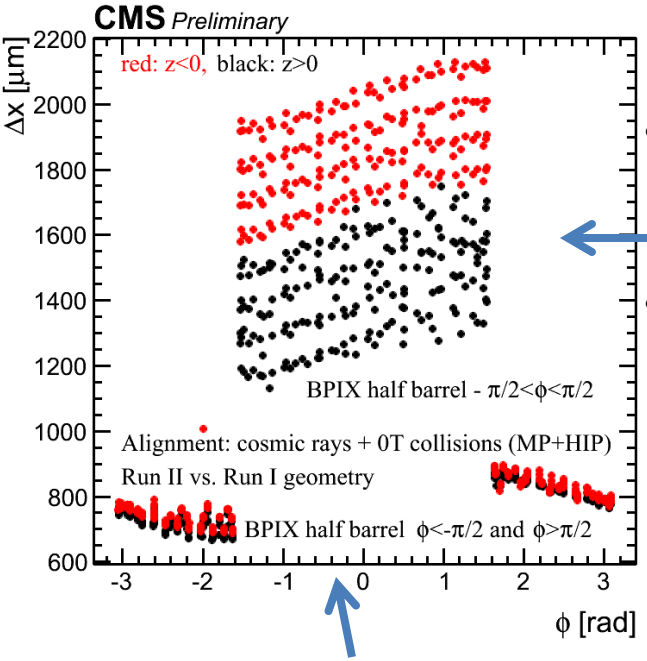


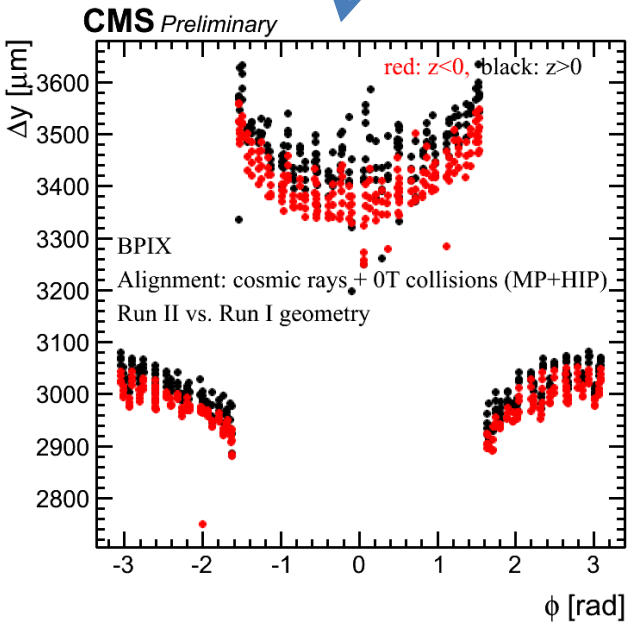
- FPIX($-z$) movements in more detail.
- $-x$ half disks moved by 4.5 mm
- $+x$ half disks moved by 5.5 mm

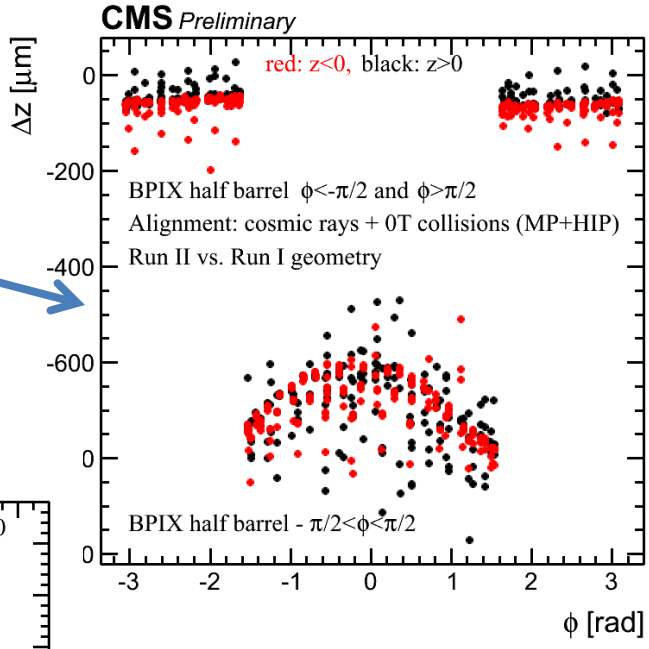
- FPIX half disks also moved relative to each other in the x direction
- Largest movement:
  - $-x, -z$ disks
  - 300 μm

Pixel movements since Run I: BPIX

- Movements in x, y, and z directions of the pixel half barrels
- $+x$ half barrel was repaired and many modules were replaced
- Barrel was also recentered around the beampipe

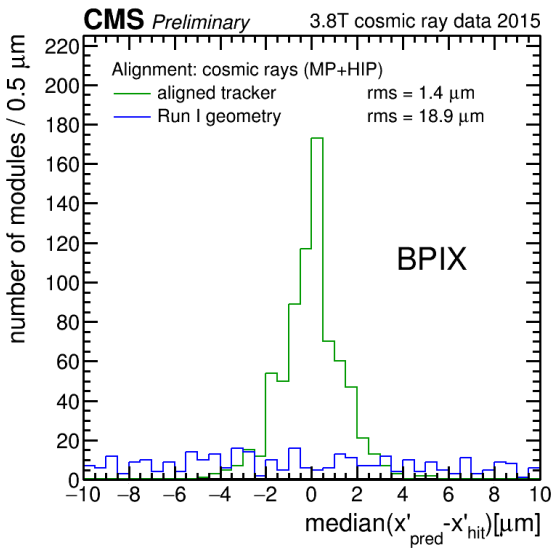




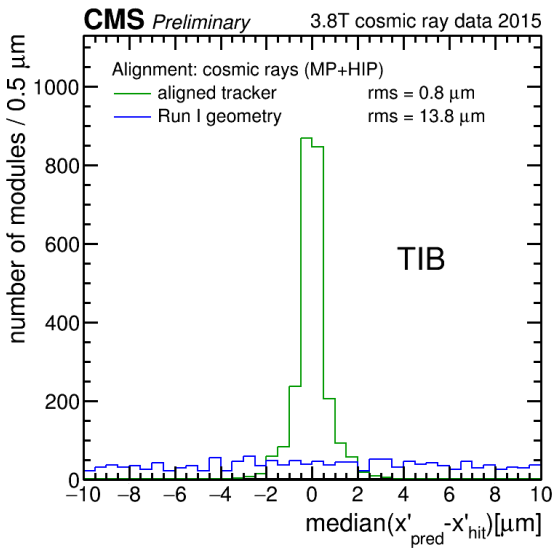


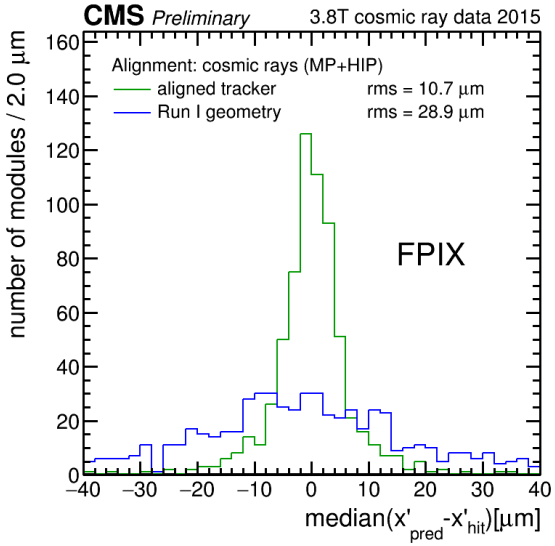
- Spread of 1 mm in $+x$ half barrel modules
- Tilt in the z–x plane

Distributions of median residuals: first Run II data and alignment

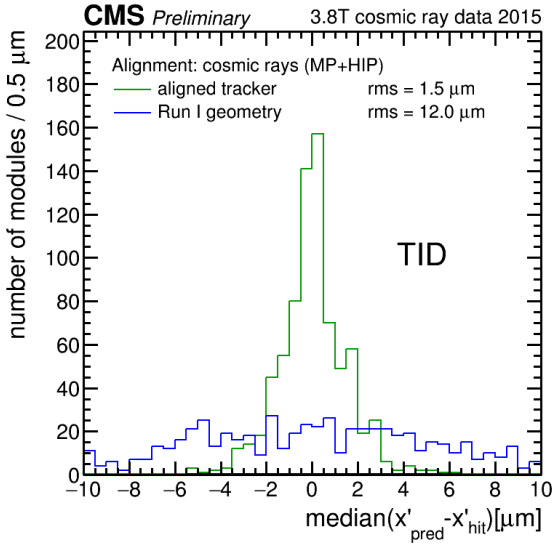


- Distributions of medians of unbiased track-hit residuals (DMRs)
- Width of DMR contains contributions both from statistical precision and from local tracker precision
- Deviations from zero indicate possible biases

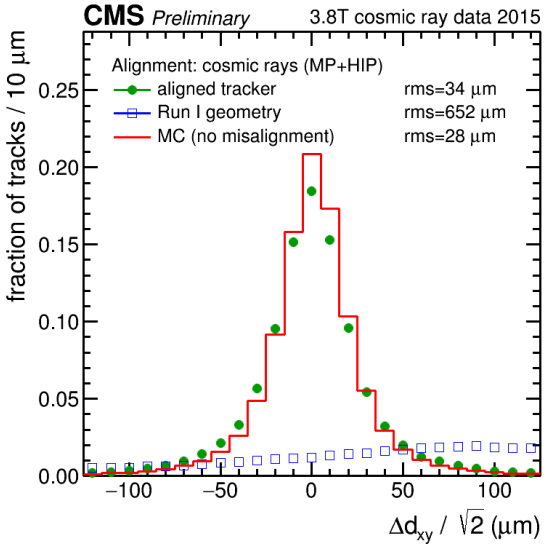




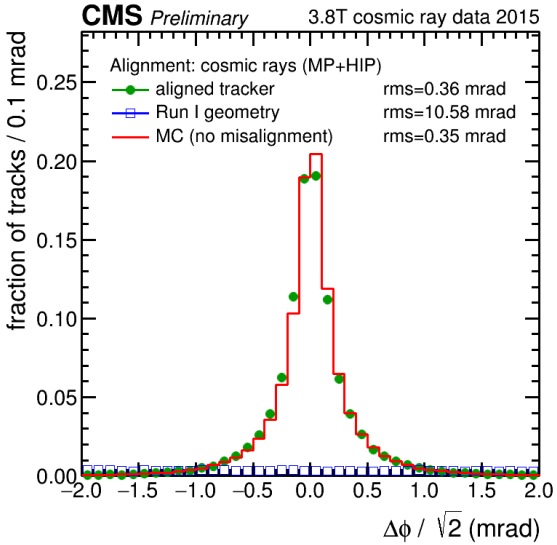
- Residual Calculation:
  - Track is re-fit with alignment under consideration
  - Hit prediction from track without hit in question
  - Per module: median of distribution of unbiased hit residuals

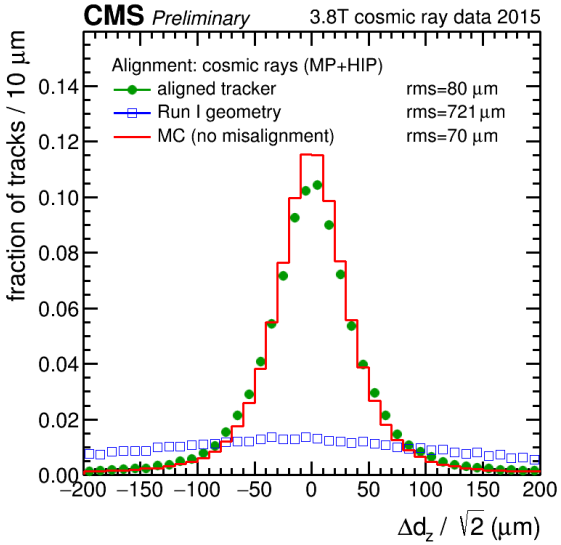


Cosmic track splitting: first Run II data and alignment

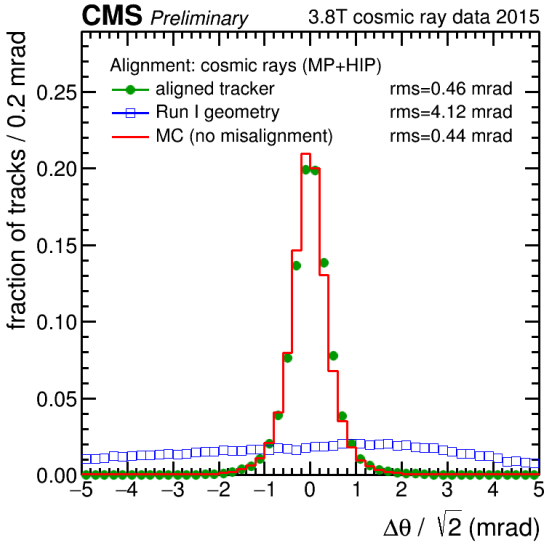


- Split cosmic ray track in half at its closest point to the origin
- Study the difference between the two halves in various track parameters
- Width is a measure of track resolution
- Deviations from zero indicate possible biases

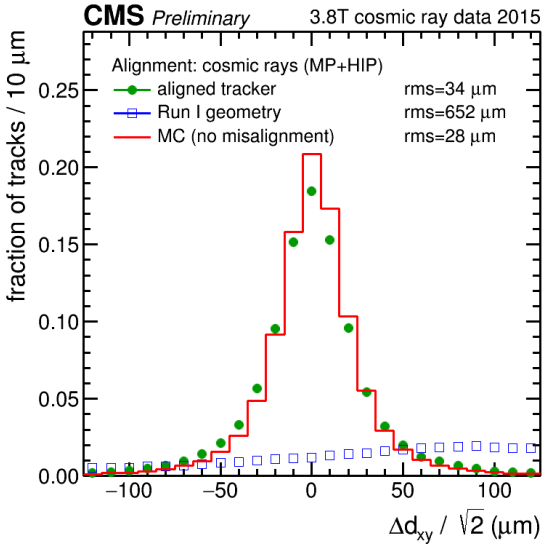


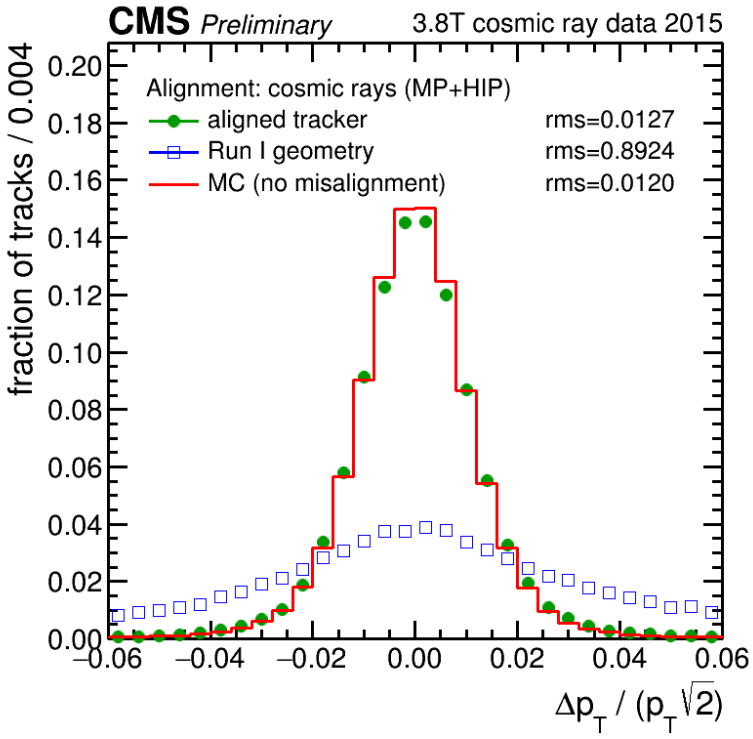


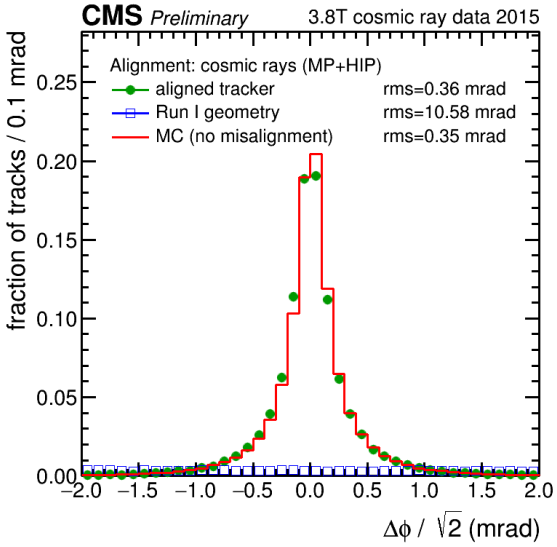
- After alignment, all distributions are close to ideal Monte Carlo
- Spatial resolution: $\sim\mathbf{30}\ \boldsymbol{\mu\mathrm{m}}$ in the xy directions, $\sim\mathbf{80}\ \boldsymbol{\mu\mathrm{m}}$ in z
- Angular resolution: $\sim\mathbf{0.02}°$ in ϕ, $\sim\mathbf{0.03}°$ in θ

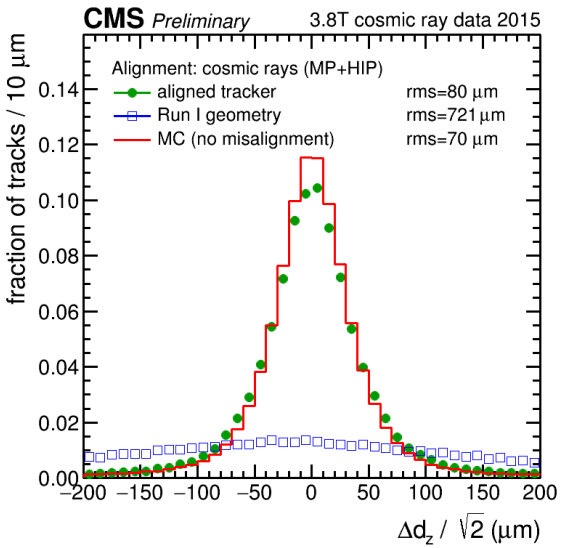


Cosmic track splitting: first Run II data and alignment

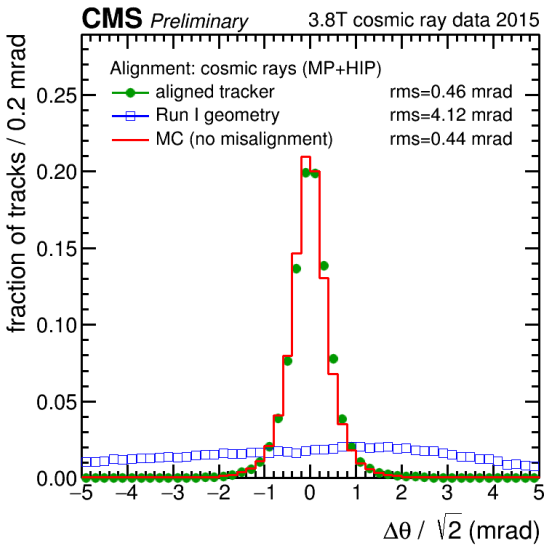




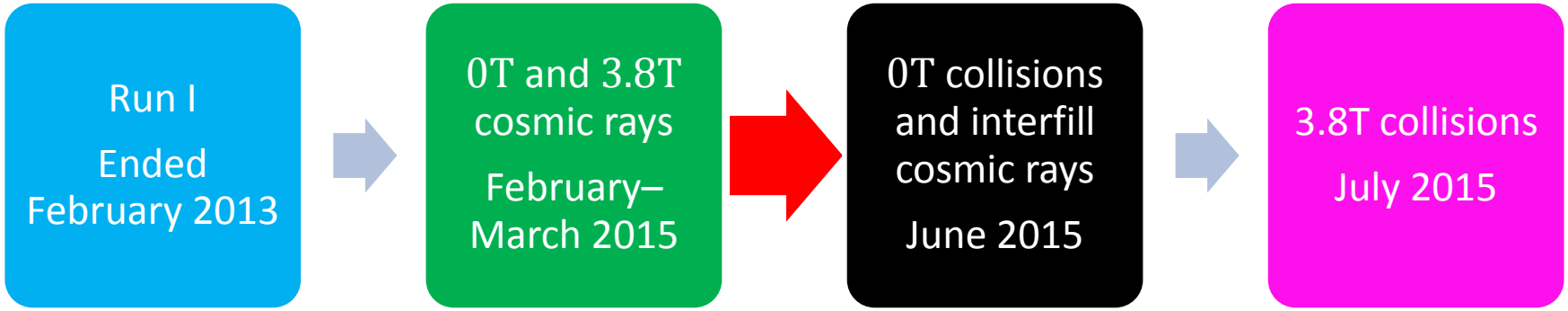




- Momentum resolution: $\sim\mathbf{1}\%$
- Spatial resolution: $\sim\mathbf{30}\ \boldsymbol{\mu}\mathbf{m}$ in the xy directions, $\sim\mathbf{80}\ \boldsymbol{\mu}\mathbf{m}$ in z
- Angular resolution: $\sim\mathbf{0.02}°$ in ϕ, $\sim\mathbf{0.03}°$ in θ

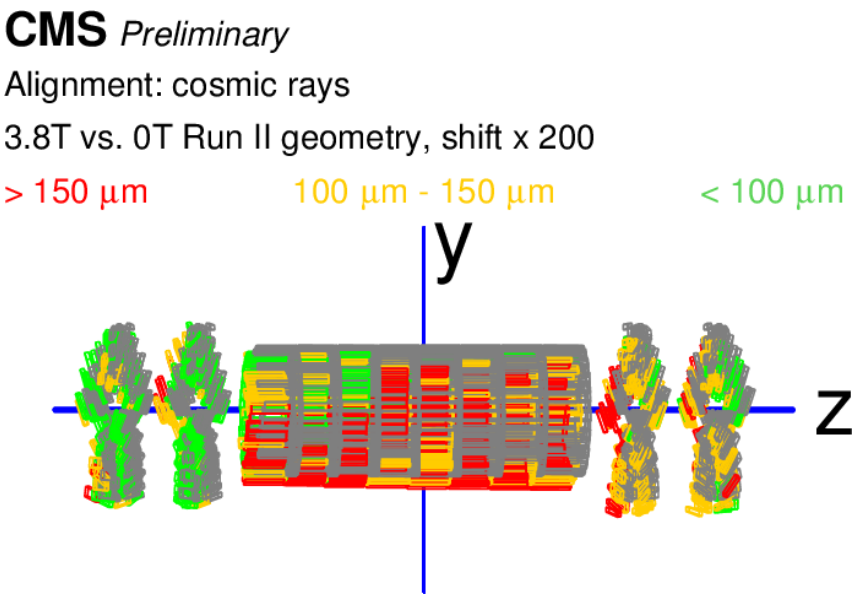


Timeline



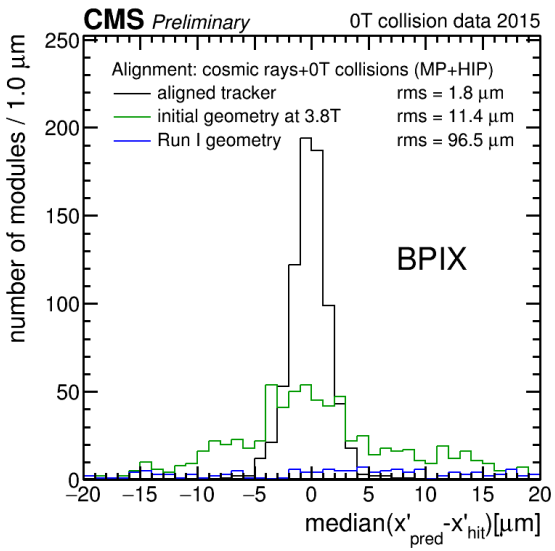
- Turning off the magnetic field caused the tracker to shift again
- Magnitude of the movements is $\sim 100\ \mu\mathrm{m}$
  - compare to shifts of a few mm during the shutdown
- Pixels are aligned at module level, strips at high level

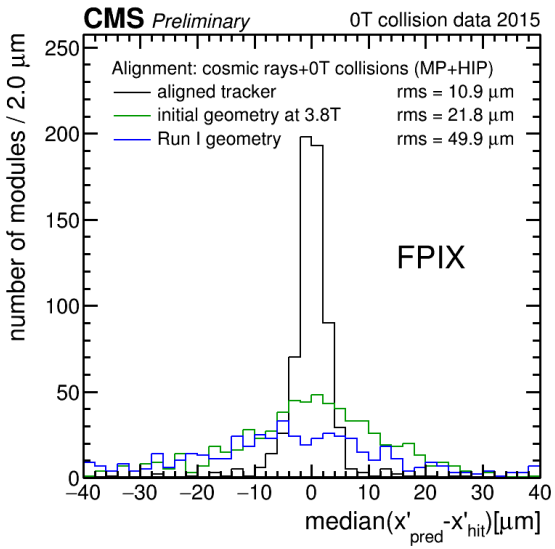
Effect of magnetic field



- Module position shift between 0T and 3.8T geometries, multiplied by 200 for visualization
- Largest movements are of order 100 μm, mostly found in the barrel
- Similar effects during each magnetic field change, but the process is not reversible

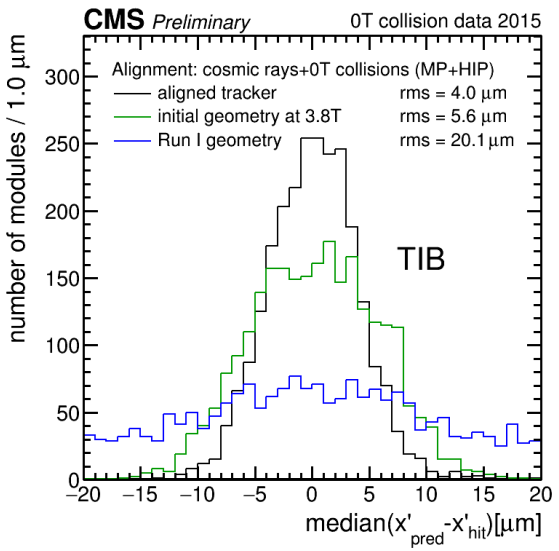
Distributions of median residuals: 0T collisions

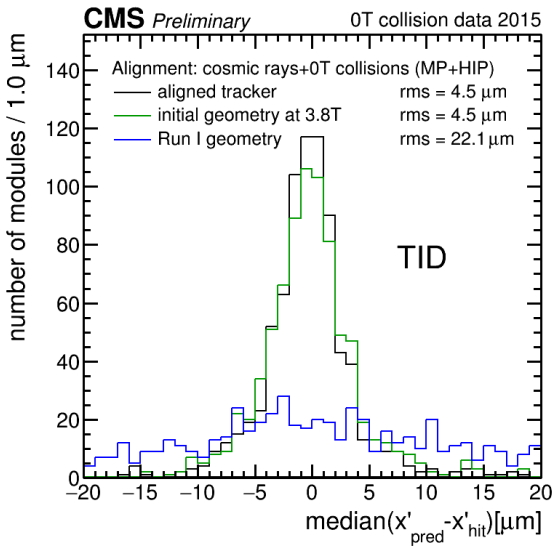




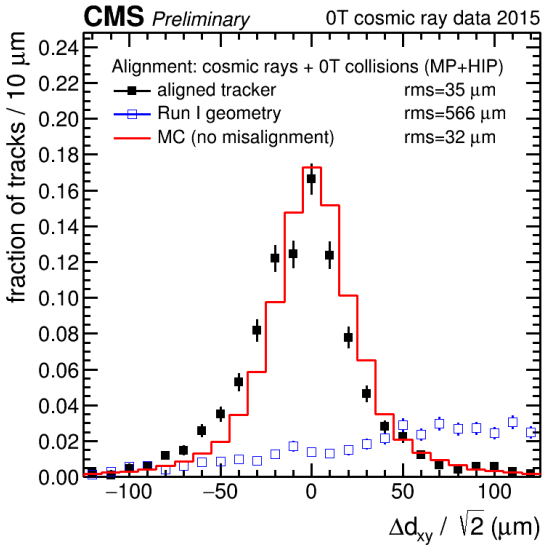
- Distributions of medians of unbiased track-hit residuals (DMRs)
- Width of DMR contains contributions both from statistical precision and from local tracker precision
- Deviations from zero indicate possible biases
- (see slide 10 for more details)

- The magnetic field change affects the pixels much more than the strips

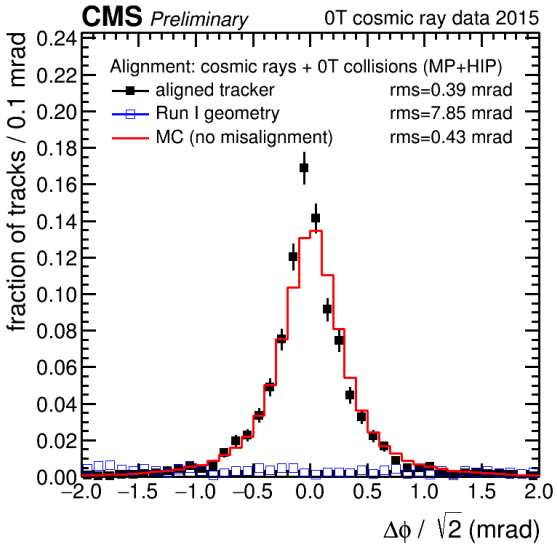


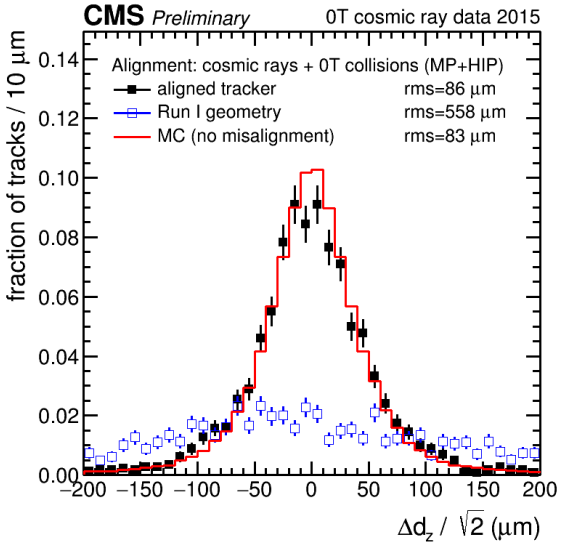


Cosmic track splitting: 0T interfill cosmic rays

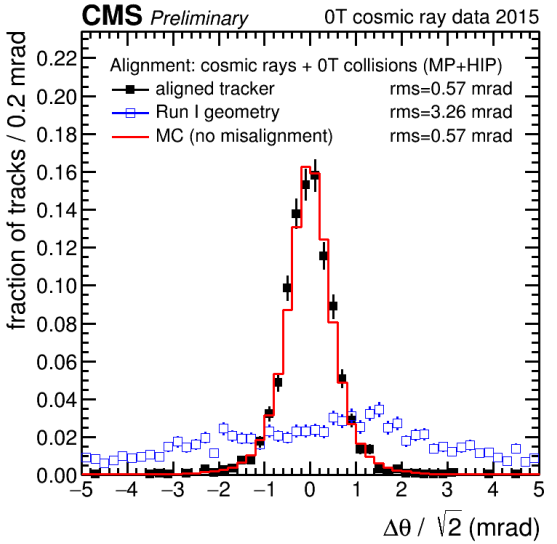


- Split cosmic ray track in half at its closest point to the origin.
- Study the difference between the two halves in various track parameters.
- Width is a measure of track resolution.
- Deviations from zero indicate possible biases

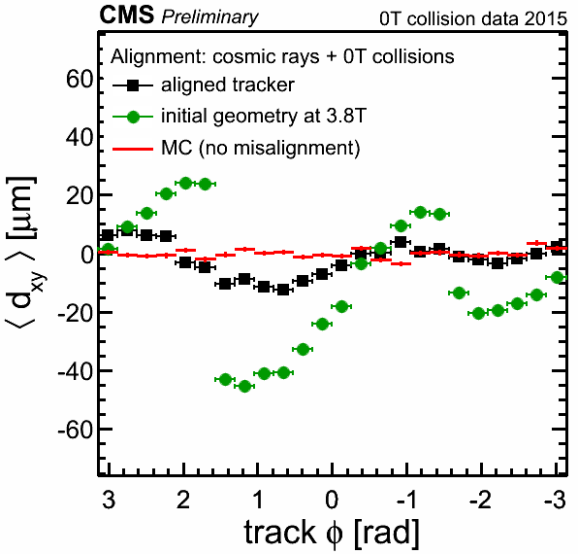


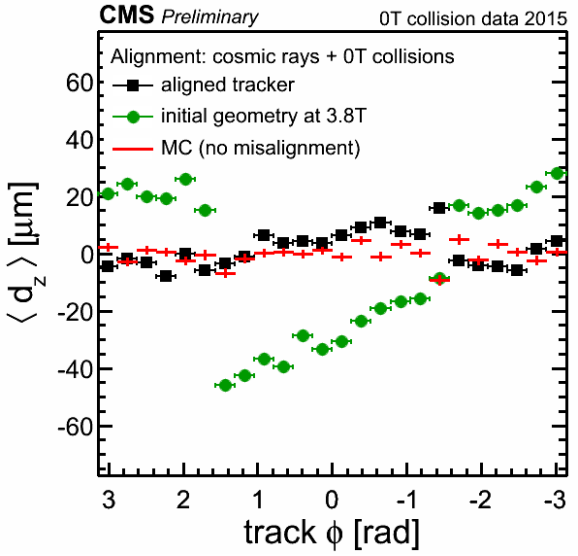


- Again, all distributions are close to those of the ideal Monte Carlo



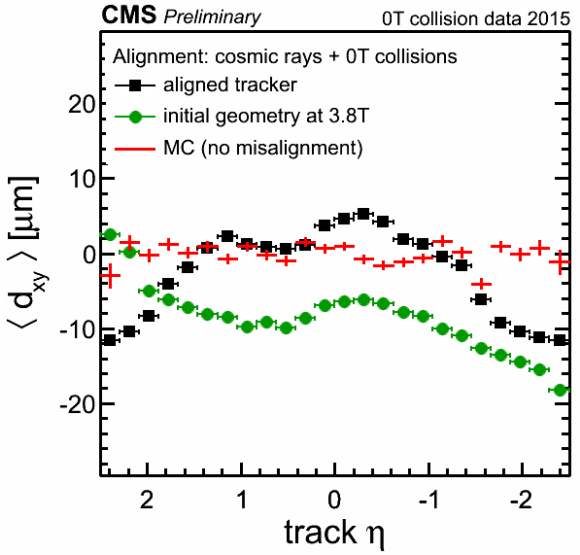
Primary Vertex: 0T collisions

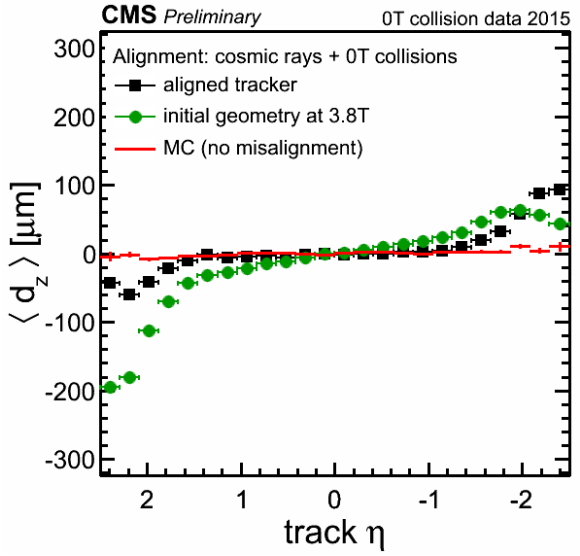




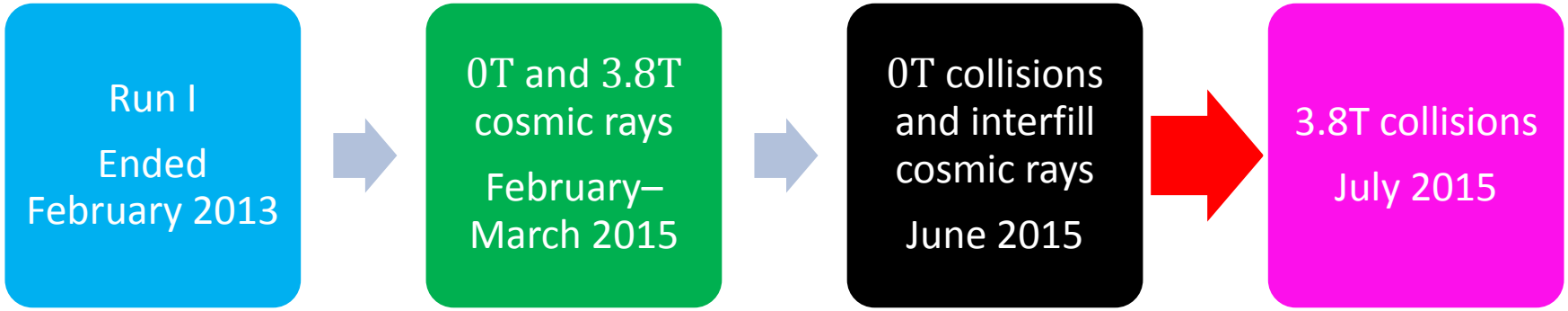
- One “probe” track per event.
- Calculate the vertex position excluding the probe track.
- Study the distance between the vertex and the probe
- Particularly sensitive to pixel-detector movements
- Direct relation to physics performance

- Performance is close to optimal except at large η
  - Need more 3.8T collisions to achieve better alignment of the high η region of the tracker



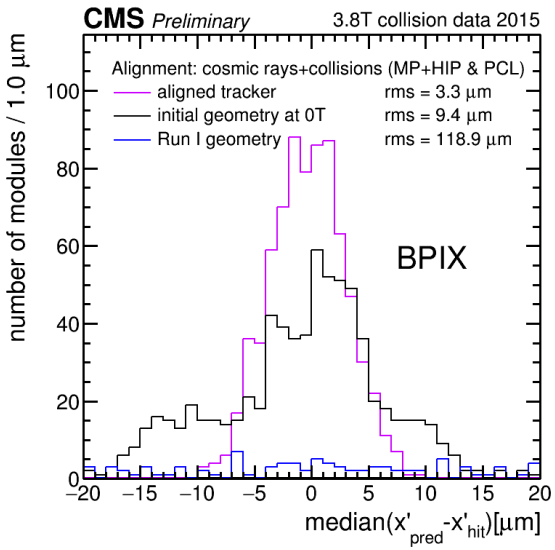


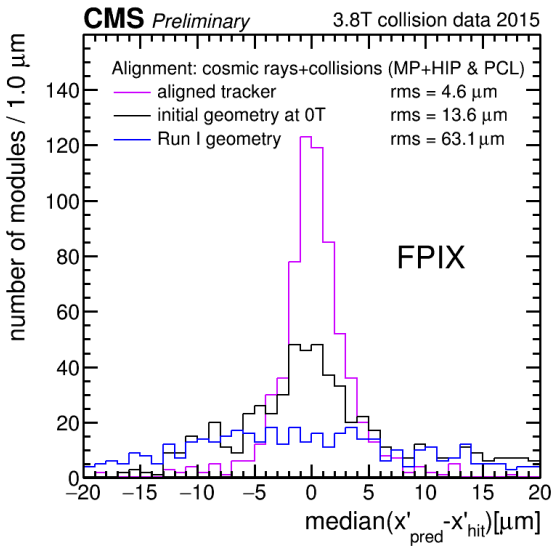
Timeline



- Magnetic field was turned back on for the first 3.8T collisions of Run II
- Alignment of the pixel structures
  - 6 total, with 6 D.O.F. each
  - automatic process: Prompt Calibration Loop (PCL)
  - Alignment done as data are collected and processed.
  - New alignments are provided in ~hours
  - This corrects the largest effects
  - Full alignment is then performed on a scale of days or weeks.

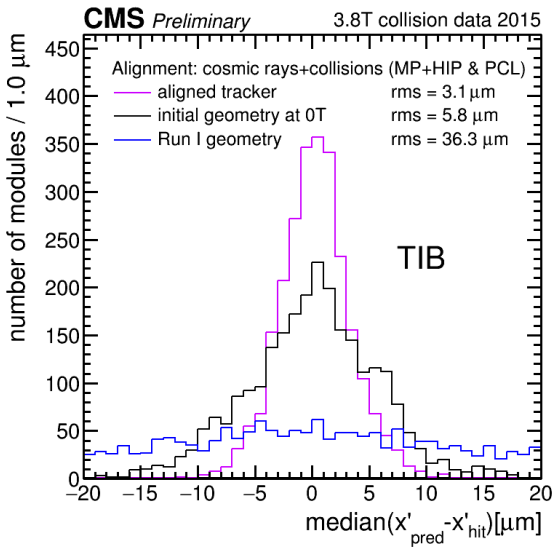
Distributions of median residuals: 3.8T collisions

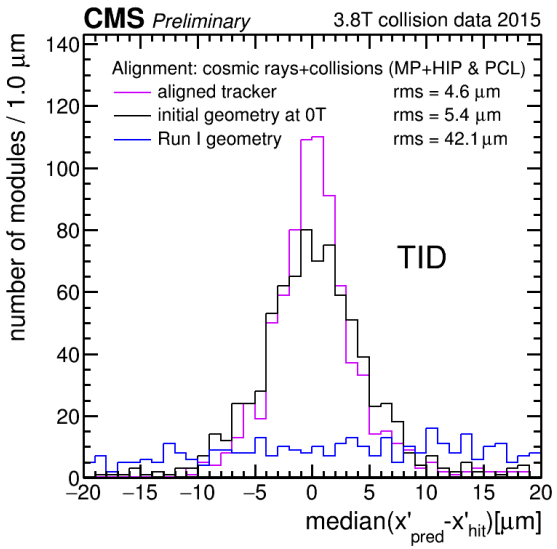




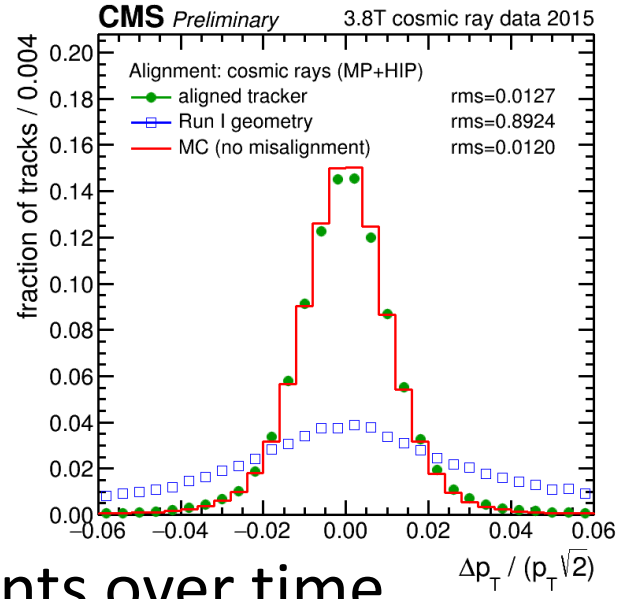
- Distributions of medians of unbiased track-hit residuals (DMRs)
- Width of DMR contains contributions both from statistical precision and from local tracker precision
- Deviations from zero indicate possible biases
- (see slide 10 for more details)

- Notice that even though the strip detectors are not aligned, the performance there still improves
- The improvement in the pixels results in a more accurate track, with effects felt even in the strips





Summary



- 16588 modules in the CMS tracker
- Need precision of $< 10\ \mu m$
- Recovered the changes since Run I
- Continually correcting for movements over time
- Design performance for most observables
- Complementary statistical methods—best combination of global & local
- Automatic alignment of the most important degrees of freedom, providing quick results during data collection

Run I
Ended February 2013

0T and 3.8T cosmic rays
February–March 2015

0T collisions and interfill cosmic rays
June 2015

3.8T collisions
July 2015

More physics results
2015 and on