Alignment of the CMS muon system with beam halo and cosmic tracks

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on behalf of the CMS Collaboration

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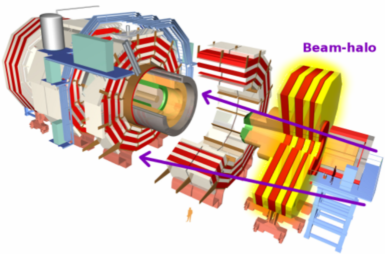
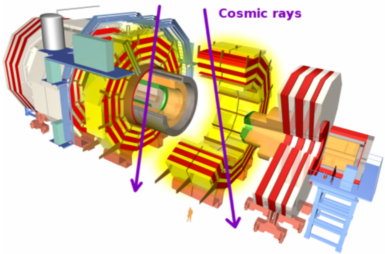
Outline

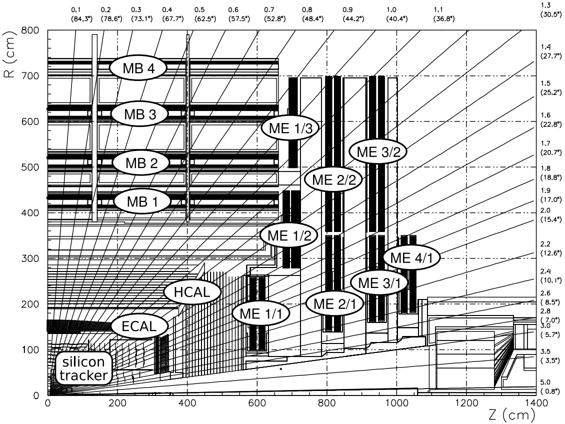
- Quick overview of the CMS muon system
- Alignment of endcap chambers with LHC beam-halo tracks
- Alignment of barrel chambers with cosmic rays





CMS muon system

- Tracking in modular chambers: 6 to 12 layers each
- Global track formed from chambers' segments and the silicon tracker

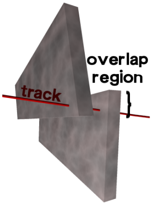


- Barrel (drift tube) chambers grouped into 4 radial stations, 5 longitudinal wheels
- Endcap (cathode strip) chambers grouped into 8 rings per endcap

- This talk will be about aligning the individual chambers
- Target for alignment is scale of $r\phi$ hit resolutions: $\mathcal{O}(100\text{–}300~\mu\text{m})$

Beam-halo alignment method

- Endcap muon chambers were designed with a small overlap region for alignment
- Tracks passing through overlap region connect chambers without any intervening scattering material or long-distance propagation
- High-precision relative alignment of chamber pairs



- Propagate pair corrections around each ring with a simultaneous solution of 18 (36) chambers $\times$ 3 parameters (1 translation, 2 angles)

pair-wise residuals

alignment corrections

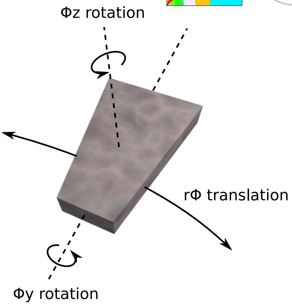
$$\chi^2 = (\alpha_{12} - A_1 + A_2)^2 + (\alpha_{23} - A_2 + A_3)^2 + \ldots$$

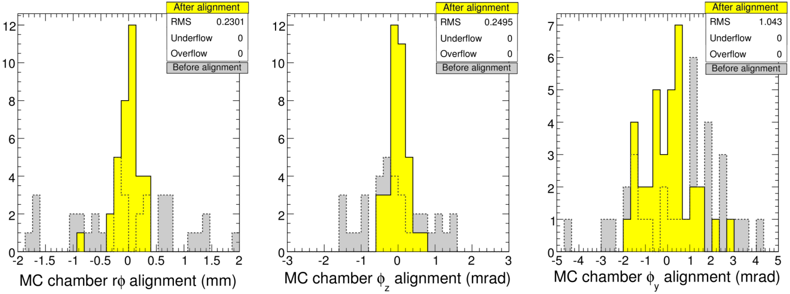
$$\frac{1}{2}\frac{\partial \chi^2}{\partial A_2} = (\alpha_{12} - A_1 + A_2) - (\alpha_{23} - A_2 + A_3) = 0$$

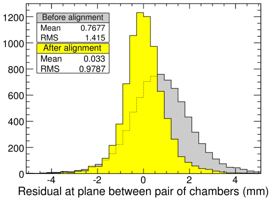
- Followed by rigid-body alignment of internally-aligned ring with global tracks, to connect ring's coordinate system to silicon tracker

Test of method in Monte Carlo

- Procedure applied to Monte Carlo sample with statistics comparable to 2008 LHC single-beam run
- Plot aligned minus true value for each of the 3 parameters for each chamber (histogram entry)
  - this is the accuracy predicted by MC



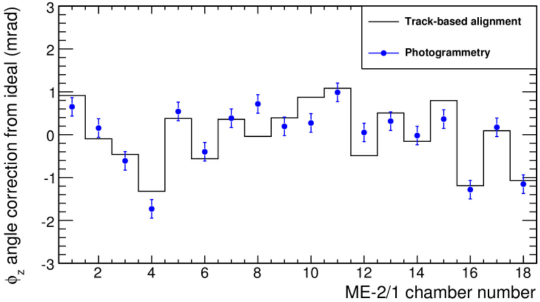




- Procedure applied to September 2008 LHC beam-halo dataset
- ME−2/1 and ME−3/1 only (highest statistics from beam-2)
- Narrows and centers residuals distribution (left)

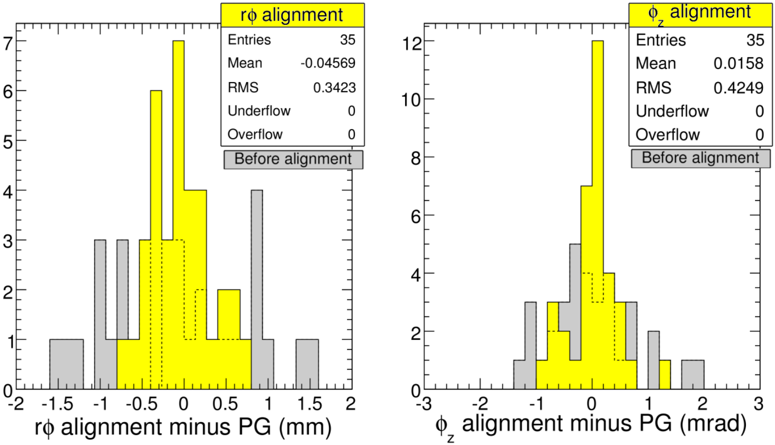
- Verified by independent photogrammetry: alignment from a literal photograph of the detector

- Both saw corrections relative to the design description, with high correlation

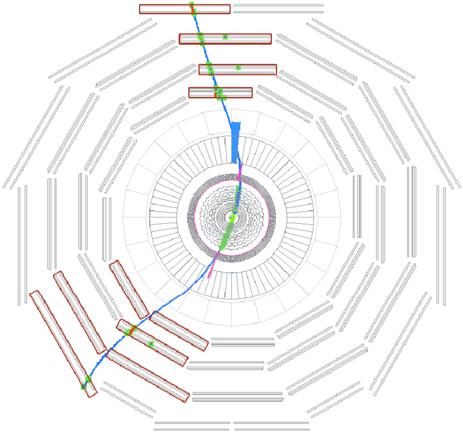


2008 LHC beam-halo data

- Chamber-by-chamber comparisons with photogrammetry:
  - agreement with 270 μm position and 0.35 mrad angular accuracy
  - close to the 166 μm intrinsic hit uncertainty (for these chambers)
  - 33,000 events from a 9-minute long run (3/4 of 2008 beam data)



Global muon alignment



Method

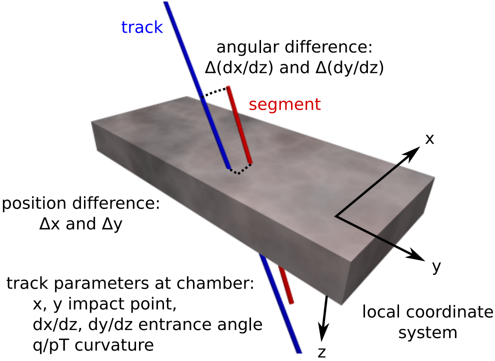
- Select tracks that pass through muon chambers and tracker
- Fit track using tracker information only
- Align chamber to optimize residuals

Rationale

- Obtain consistent, CMS-wide coordinate system in one step

- Can be applied to all chambers using collisions muons and most barrel chambers when using cosmic rays (central wheels -1, 0, $+1$, all sectors except the horizontal ones: 1 and 7)

Chamber residuals



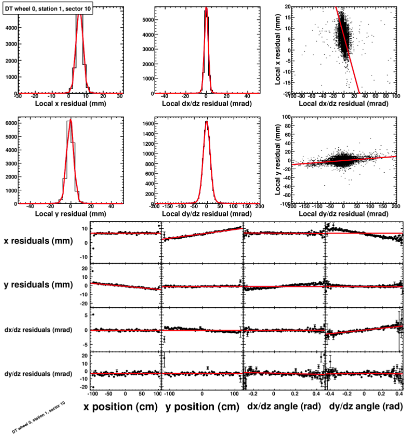
- Chamber measures 2-D position and direction: 4-component residuals
- Access to 6 rigid-body alignment parameters (3 translation, 3 rotation) through a 6×4 derivatives matrix

Alignment fit

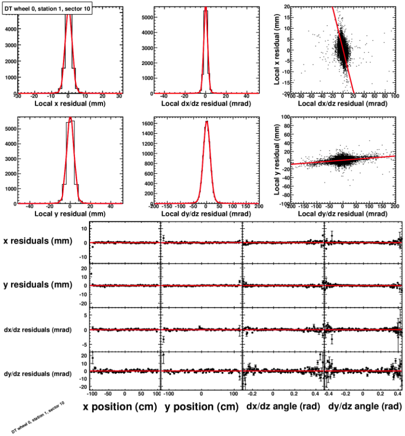
- Single fit function for each chamber, including all geometric and propagation effects
- Project 8-dimensional, 16-parameter fit onto all coordinates for validation

Sample fit results: MC

Before alignment



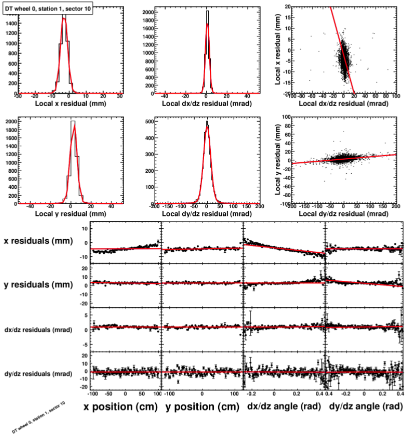
After alignment



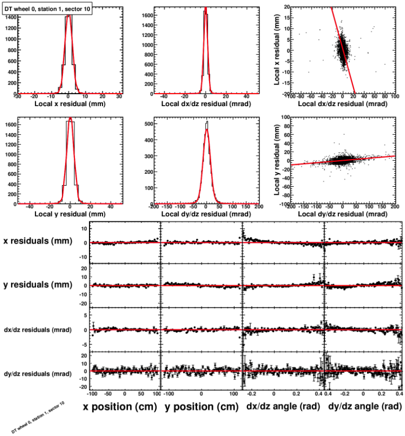
- Projection of fits (all parameters = 0 other than the one shown) overlaid on *simulated* data (profile plots)
- All of the above is for one chamber; the rest are similar

Sample fit results: data

Before alignment



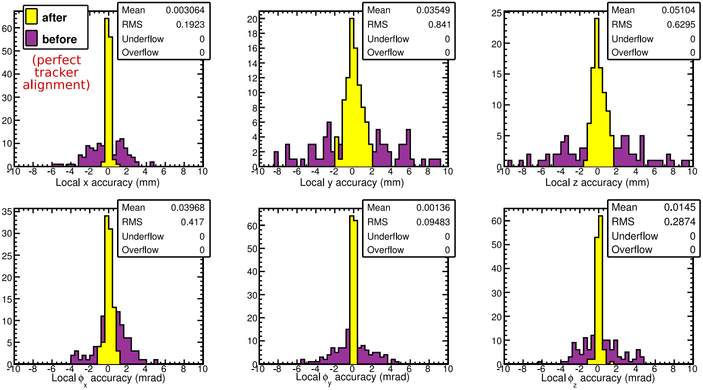
After alignment



- Projection of fits (all parameters = 0 other than the one shown) overlaid on *real* data (profile plots)
- This is the same chamber in real data

MC cosmic ray results

- Plot aligned minus true value of each of the 6 parameters for each chamber (histogram entry)
  - predicted resolution for local x (global $r\phi$) is 200 μm
  - systematics dominated
- MC tracker geometry is ideal: this demonstrates the reach of the muon alignment method, given a well-aligned tracker

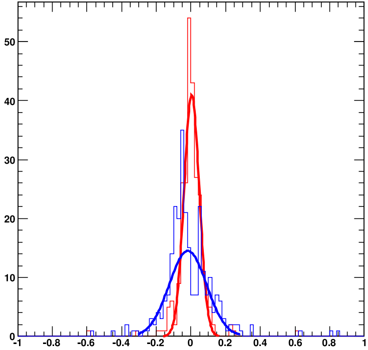


Data-driven p_T resolution

- Split $p_T \gtrsim 200$ GeV cosmic rays into upper and lower halves, refit each half independently and compare the results
- Two track-fits for each cosmic ray: any mismatch is instrumental

Before muon alignment

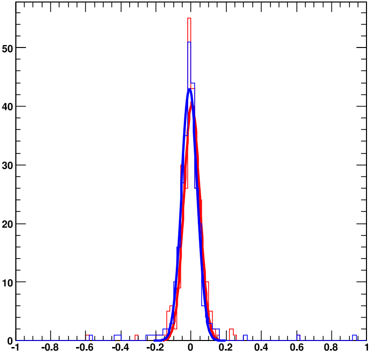
	mean	sigma
Tracker-only:	0.0040	0.044
With first muon station:	−0.0180	0.108



$$\frac{(1/p_T)_{\text{upper}} - (1/p_T)_{\text{lower}}}{\sqrt{2}\,(1/p_T)_{\text{lower}}}$$

After muon alignment

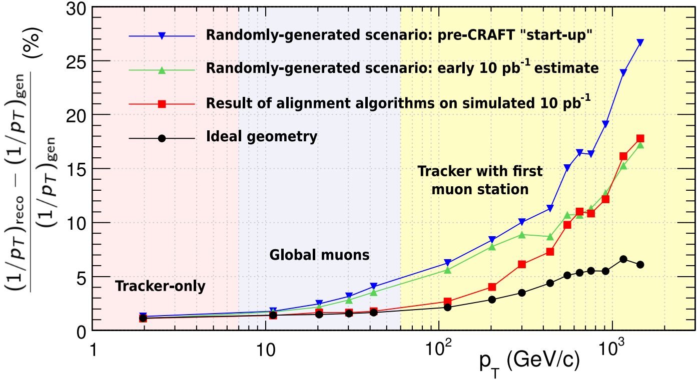
	mean	sigma
Tracker-only:	0.0042	0.045
With first muon station:	−0.0097	0.045



$$\frac{(1/p_T)_{\text{upper}} - (1/p_T)_{\text{lower}}}{\sqrt{2}\,(1/p_T)_{\text{lower}}}$$

- MC resolution vs. p_T with different alignment scenarios
- Track reconstruction method optimized by p_T

  (at high p_T, use only first muon station to avoid hit confusion from muon showering)



- Alignment algorithms yield much better results than early estimates
- Cosmic ray splitting at $p_T \sim 200$ GeV is 4.5% in real data (prev page)

Conclusions

- Though track-based alignment methods are designed for collisions data, they can be applied to available beam-halo and cosmic rays
- Observed data resembles Monte Carlo
- Monte Carlo studies predict high accuracy
- Results in data are cross-checked by independent methods (photogrammetry, cosmic ray splitting) and demonstrate significant improvement