Alignment Progress, Startup Alignment, and Comparison with Optical Alignment

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Alignment needs

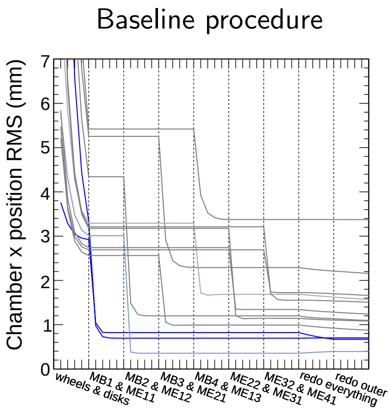
- for analysis:
  - Procedure for aligning with large datasets (10/100 pb^{-1})
  - All the necessary software tools
  - Full systematics studies
- for commissioning:
  - Procedure that uses minimal collisions data
  - Tests with real data
  - Procedures for integration with optical alignment
- for validation:
  - Monitoring plots
  - Comparison with optical alignment

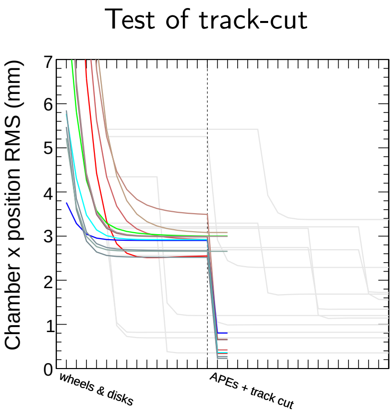
Long-term alignment procedure

- Baseline procedure is stable and has been for some time
  - Based on the HIP algorithm
  - Aligns one station at a time (from the inside out)
- Hierarchial structure of the code matches system design
  - Fast alignment of large structures ($\sim$1000 muons)
  - Built-in support for constraints from prior knowledge, photogrammetry, optical system
  - Possible to combine measurements from different sources
- Optimization of parameters is in progress for faster convergence and better accuracy
  - Track-fitting parameters (APEs) tuned for each station
  - Intelligent track selection to supress strongly scattering tracks
  - Optimized track-fitting to better use structure of the detector and material distribution (pending tests)

$100\ \mathrm{pb}^{-1}$ simulation results

Illustration of improvements ("intelligent track selection")





Each line is a station's resolution as a function of iteration

Improved alignment reaches 300 μm for inner stations (which drive momentum resolution)

Commissioning & early alignment become primary focus (and subject for this talk)

- Can't accurately align all chambers with limited statistics
- But can quickly align large structures if internal alignment is known from other sources
- Track-based candidates:
  - beam-halo perfect for endcap
  - cosmics for barrel
- Optical very useful for cross-checks and filling in gaps
  - e.g. z alignment, to which beam-halo is insensitive

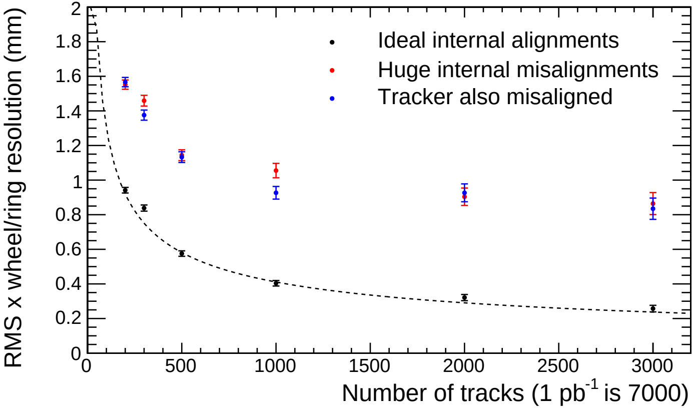
Outline

1. Procedures for endcap alignment without any (many) collisions
2. How to test these procedures with cosmic rays
3. Procedures and tools for comparison and integration with optical alignment
4. Status of software tools

Motivation...

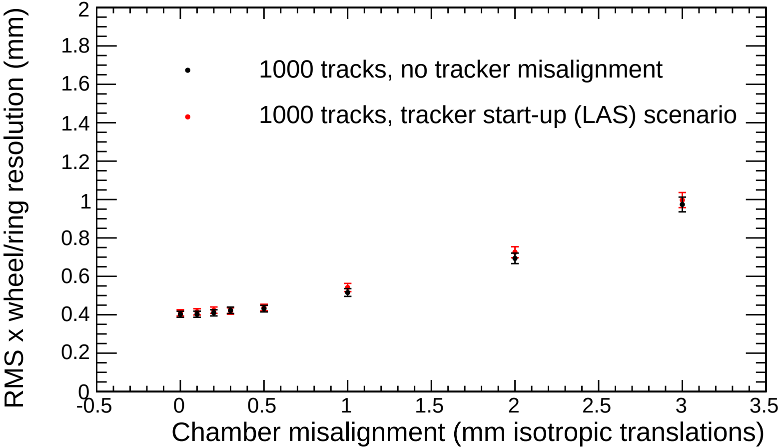
Momentum resolution depends on absolute alignments, which are a combination of

$$\sigma_{\text{absolute}} = \sqrt{\sigma_{\text{relative chambers}}{}^2 + \sigma_{\text{ring}}{}^2}$$



With well-aligned chambers in a ring, we can very quickly establish full absolute alignment

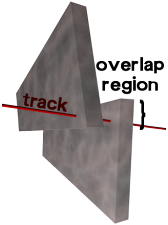
Wheel/ring simulation results



- With ∼1 mm chamber misalignments, x-y 0.6 mm, z 3 mm, ϕ_z 0.1 mrad
- Tracker misalignment is negligible for such large solid angles

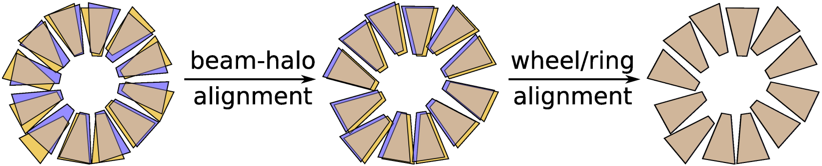
No collisions alignment

- Beam-halo through overlap regions (no ME1/3)
- Minimal track propagation, measure x, y, ϕ_y, ϕ_z
- Beam-halo rate hard to predict
- With sufficient rate, good for layer alignment
- Chambers are aligned relative to one another within each ring



Few-collisions alignment

- Align rings relative to tracker with 1000 GlobalMuons
- Compliments beam-halo for a complete alignment



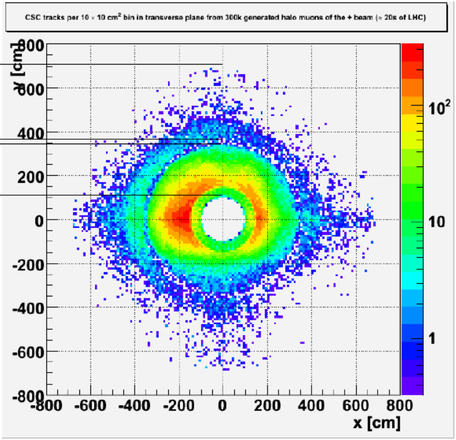
Beam-halo: Károly Banicz

- 6600 tracks/sec $\times$ 0.02 in overlap = 130 Hz $\stackrel{\times}{\div}$100
- 2 hours $\times$ 130 Hz = 1 million muons $\rightarrow$ 100's of μm resolution (if we're off by $\times$100, 2 hours $\rightarrow$ 8 days...)
- Steeply falling function of energy and radius (better for ring 1)

outer ring

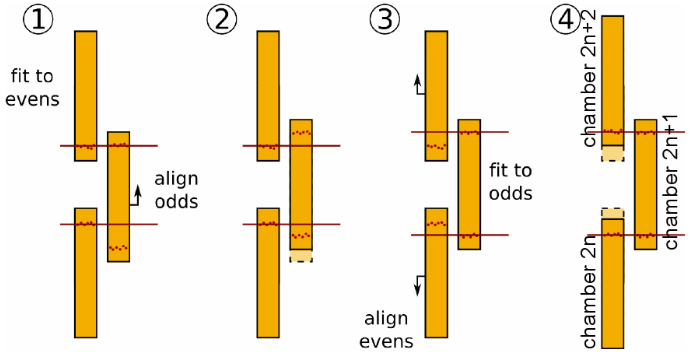
inner ring

133k tracks reconstructed in the endcap muon chambers



Beam-halo procedure

- Uses the same framework, reconfigured for local alignments
- Tightly refit tracks to even-numbered chambers in a station, loosely fit to odd-numbered to get local extrapolation from even to odd
- Alternate and repeat



- Repeat process with layers when enough tracks are available

Early alignment timescales

- Beam-halo
  - Beginning with single-beam in June
  - Rate estimates are high but uncertain: naïve worst case ~8 days
  - Continue to collect beam-halo during normal data-taking

- Start-up wheel/ring
  - Beginning with first collisions in July(?)
  - $\leq$ 4 days

"First month" integrated luminosity ramp-up

Bunches	Luminosity (cm^{-2}/s)	Time for 1000 muons (W, Z)
1 × 1	10^{27}	~~4.1 years~~
43 × 43	3.8×10^{29}	4.0 days
43 × 43	1.7×10^{30}	21 hours
43 × 43	6.1×10^{30}	5.9 hours
156 × 156	1.1×10^{31}	3.3 hours
156 × 156	5.6×10^{31}	39 minutes
156 × 156	1.1×10^{32}	20 minutes

Beam-halo procedure

- Run beam-halo procedure on horizontal MTCC cosmic rays

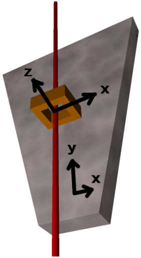
GlobalMuon procedures (wheel/ring and chamber-level)

- April CRAFT cosmic ray run includes full tracker
- Select near-IP muons: $\sim$1 million through barrel wheel 0
  $\sim$10,000 in ME1/3 (which has no overlap hits for beam-halo)

Need beam-halo, cosmic ray MC, MTCC reprocessed in 2_0_0,
HLT paths and AlCa streams for real beam-halo and cosmic rays

Optical comparisons: 0 pb^{-1}

- Beam-halo and SLM lines both measure x
- SLM lines can also measure z
- Caveats
  - Beam-halo and optical must both work in the same ring coordinates
  - Track-based measures strips and wires, optical measures the box: must know layer positions relative to alignment pins



Suggested procedure:

1. Measure SLM lines underground at 4T, full COCOA fit
2. Propagate to averaged layer position through layer measurements
3. Constrain track-based ring positions to be the same as COCOA
4. Align chambers within rings with beam-halo, compare x
5. If it agrees, apply z measurement to ring (z, ϕ_x, and ϕ_y)

Optical measurements: 1000 muons

- Transfer lines, Z sensors measure outer ring in 6 d.o.f.
- So does GlobalMuon alignment
- GlobalMuon alignment puts rings into tracker coordinates
- Tests full link system down to tracker in 6 d.o.f.

Relevant measurements for comparison

- MTCC SLM measurements for beam-halo MTCC test $\surd$
- Barrel measurements during CRAFT GlobalMuon test in April
- SLM measurements during beam-halo data-taking in June
- Transfer line, Z sensor, link system measurements during start-up collisions in July
- Integration of layer positions with SLM measurements
- Output in CSCSurveyRcd format (to apply ring constraints)

Software status

- Parallelized 10/100 pb^{-1} procedure $\surd$
- Added CSCRing as an alignable structure $\surd$
- DB $\leftrightarrow$ human-editable files and plots (monitoring) $\frac{1}{2}$ done
- Tool for setting arbitary patterns of hit weights (APEs) $\surd$
- Improved track cut and alternate refitter for upcoming tests $\surd$
- Mechanism for setting global coordinate system $\surd$
- HLT paths and AlCa streams for beam-halo, cosmics
- Beam-halo and cosmic MC production cfg

Procedure status

- 10/100 pb^{-1} GlobalMuons: baseline working, can be optimized further, studied in more detail
- Cosmic ray version of high-lumi GlobalMuons: need MC
- Beam-halo: procedure designed, needs to be implemented
- 1000 muon ring alignment: easy adaptation of GlobalMuon

Conclusions

- Several different projects in parallel
  - Big alignments: relevant for physics reach
  - Little alignments: initial geometry without many collisions
  - Comparisons with optical: for commissioning, validation, dependence on time
- All alignments tested in cosmic rays before any LHC beam (even single-beam)
- Special alignment datasets need to be collected: Making sure the data paths exist
- Making sure all the software is written and submitted on time

0 pb^{-1} beam-halo plus optical

	x	y	z	ϕ_x	ϕ_y	ϕ_z
C	700 μm	2 mm	3 mm	3 mrad	0.8 mrad	0.65 mrad
R	200 μm	200 μm	230 μm	0.08 mrad	0.08 mrad	0.03 mrad

1 pb^{-1} beam-halo plus GlobalMuon ring

	x	y	z	ϕ_x	ϕ_y	ϕ_z
C	700 μm	2 mm	3 mm	3 mrad	0.8 mrad	0.65 mrad
R	600 μm	600 μm	3 mm	1 mrad	1 mrad	0.1 mrad

10 and 100 pb^{-1} track-based (without improvements)

	x	y	z	ϕ_x	ϕ_y	ϕ_z
C	700 μm	2 mm	3 mm	3 mrad	0.8 mrad	0.65 mrad

Alignment record types

CSCAlignmentRcd	CSCSurveyRcd	OpticalAlignments
x, y, z	x, y, z	x, y, z
ϕ_x, ϕ_y, ϕ_z (non-standard Z-Y-X Euler angles)	α, β, γ (standard Z-X-Z Euler angles)	three angles
one entry for each chamber and each layer	one entry for each endcap, disk, ring, chamber, and layer	one entry per. . . ?
3×3 covariance matrix for positions	6×6 covariance matrix for positions and angles	diagonal error matrix for positions and angles
		additional information about optical system