Alignment Status and Commissioning Plans

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Alignment Needs

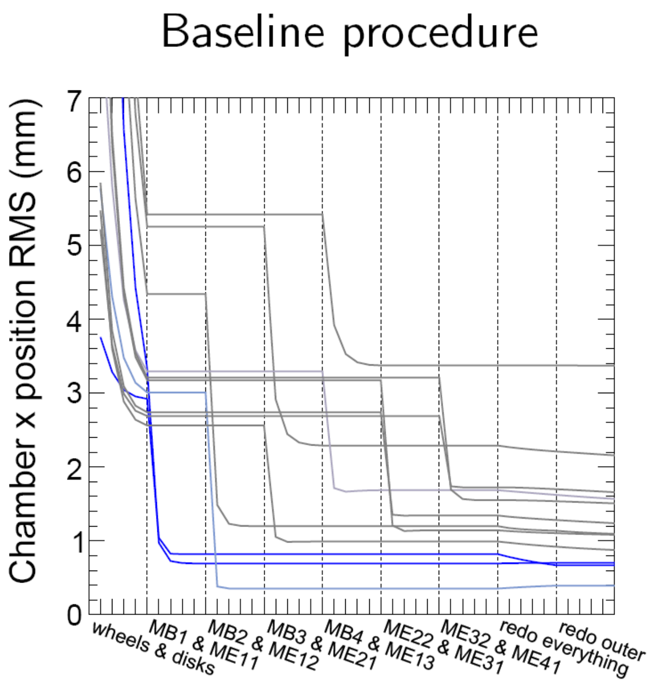
- Physics analysis alignment (10/100 pb^{-1}) :
  - Full procedure using large datasets
  - Necessary software tools
  - Full systematics studies
- Validation:
  - Tests with real data to validate the procedure early
    - Cosmics, beam halo
  - Comparisons with other alignment information
    - Photogrammetry, optical, and hardware alignment
- Commissioning(0-10 pb^{-1}):
  - Procedure that uses minimal collisions data
    - Quick alignment of larger structures
    - Cosmics and beam halo for internal alignment measurements
    - Integration of other sources of alignment information (PG, HW)

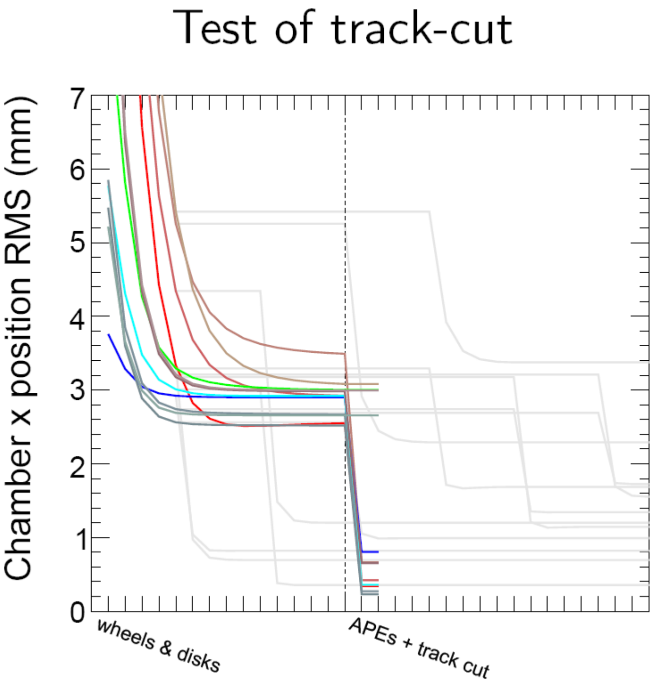
Baseline Procedure

- Baseline procedure for physics quality datasets has been stable for some time
  - Based on the HIP algorithm
  - I Aligns one station at a time (from the inside out)
- Hierarchical code structure matches system design
  - Fast alignment of large structures (~1000 muons)
  - Built-in support for constraints from prior knowledge
    - Photogrammetry, optical system
  - Capable of combining 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)

Improvements to Baseline Procedure

- Illustration of improvements:
  - "Intelligent track selection" (MC, 100 pb^{-1})





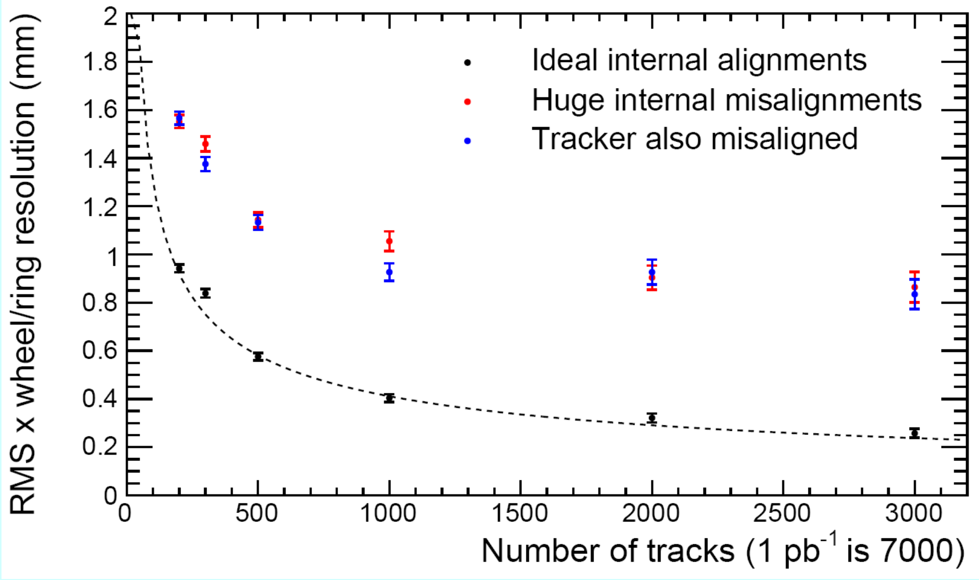
- Each line is a station's resolution as a function of iteration
  - Improved alignment reaches 300 μm for inner stations (which drive momentum resolution)

Considerations for Early Commissioning

- 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 or collision tracks passing through overlap regions - EMU
  - Cosmics for barrel
- Non-track based:
  - Hardware alignment and photogrammetry very useful for cross-checks and filling in gaps
    - E.g. CSC z alignment, to which beam-halo is insensitive
      - Although less important for momentum resolution in collision data

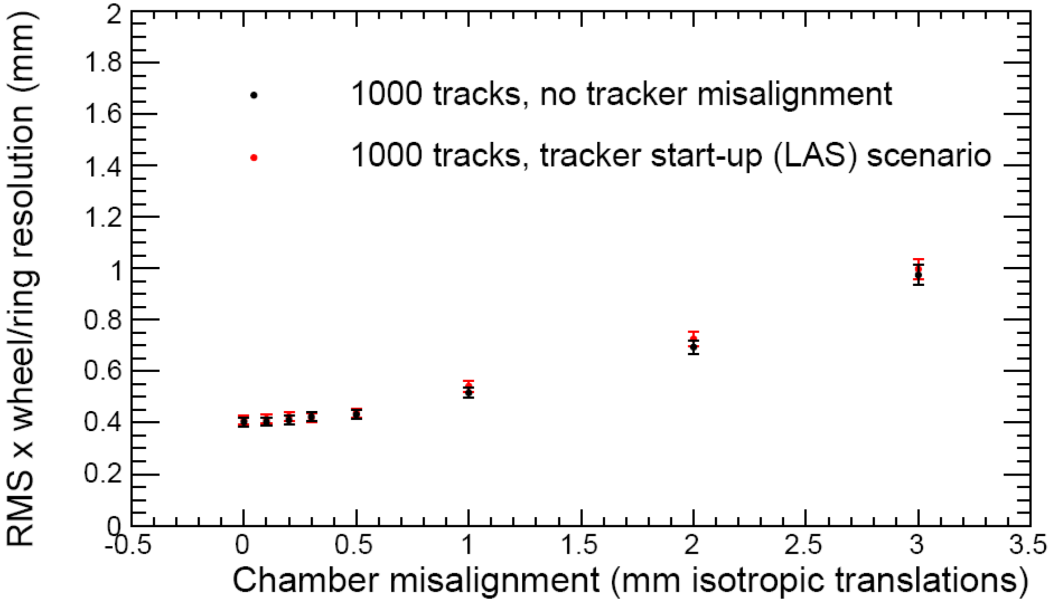
Momentum resolution depends on absolute alignments, which are a combination of

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



Large Structure Alignment

- Alignment of large structures weakly depends on internal misalignments:



- For ~1 mm chamber misalignments:
  - $RMS_{x,y}$~0.6 mm, RMS_{z}~3 mm, $RMS_{\phi-z}$~ 0.1 mrad
- Tracker misalignment is negligible for such large solid angles

Commissioning Plan

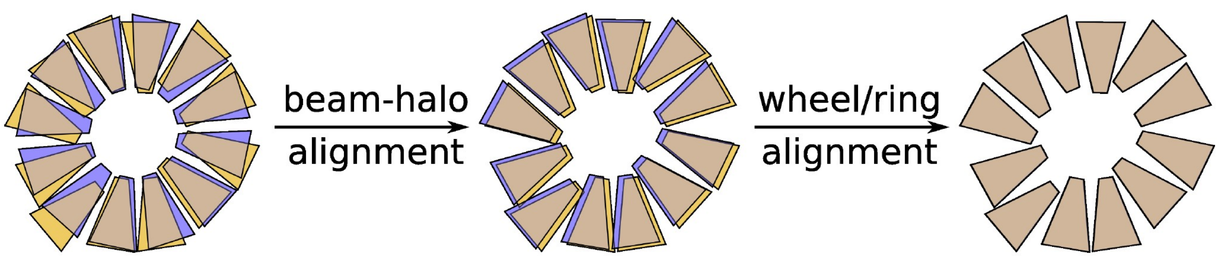
- CRAFT Tracker to Chamber Alignment (May):
    - Near-IP Muons: ~1M in Barrel 0, ~10k in ME1/3
  - Validation of the baseline procedure
    - Sanity checks: residuals for tracker muons
  - Comparisons with PG and HW alignment (ME1/3 & barrel)
    - Exercise use of HW and PG as constraints
- Beam halo internal ring alignment (June):
  - Re-configured baseline procedure
  - Similarly, cosmics could be used for Barrel
- Collisions (July?):
  - Ring alignment using internal alignment results
    - Similarly, we will align wheels if internal alignment available
  - Overlap tracks to cross-check internal alignment
  - Comparisons with PG and HW alignment
  - Use of PG and HW as constraints in baseline procedure

Next few slides provide details of the implementation

Internal Alignment with Beam Halo

- 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

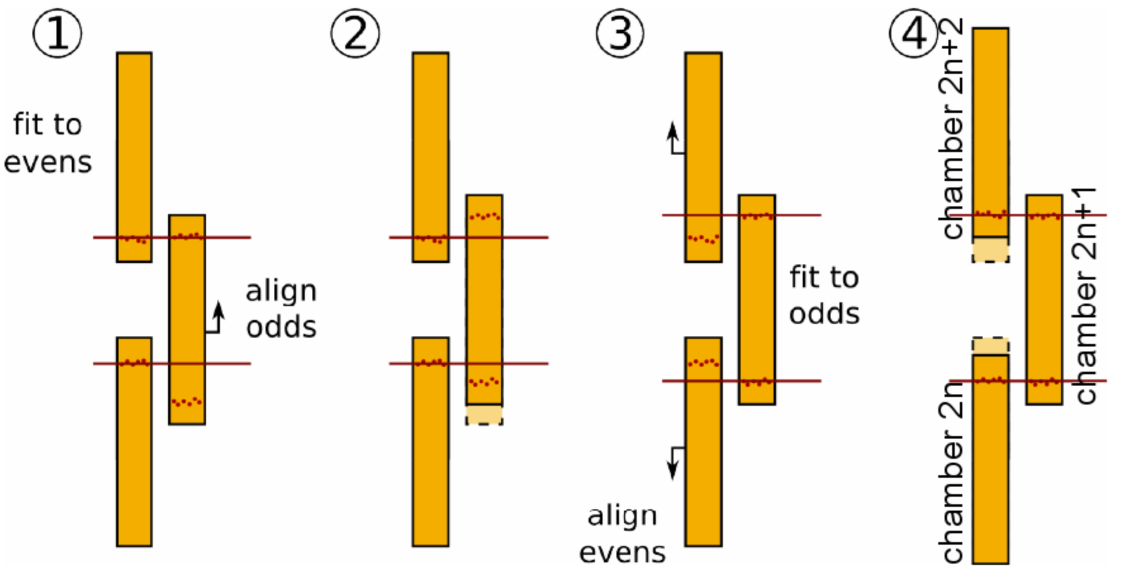
- Few-collisions alignment
  - Align rings relative to tracker with ~1000 GlobalMuons
  - Complements beam-halo for a complete alignment



Chambers misaligned within ring, ring position unknown | *Chambers aligned within ring, ring position unknown* | *Chambers aligned within ring, ring position known*

Internal Alignment with Beam Halo

- CSC chambers in the same ring overlap
  - Easy to align w.r.t. each other using tracks passing through overlap regions
- Algorithm:
  - Tightly refit tracks to even-numbered chambers
  - Loosely fit to odd-numbered to get local extrapolation from even to odd
  - Alternate and repeat, iterate
- Will be done in the same framework
  - Re-configured for local alignments



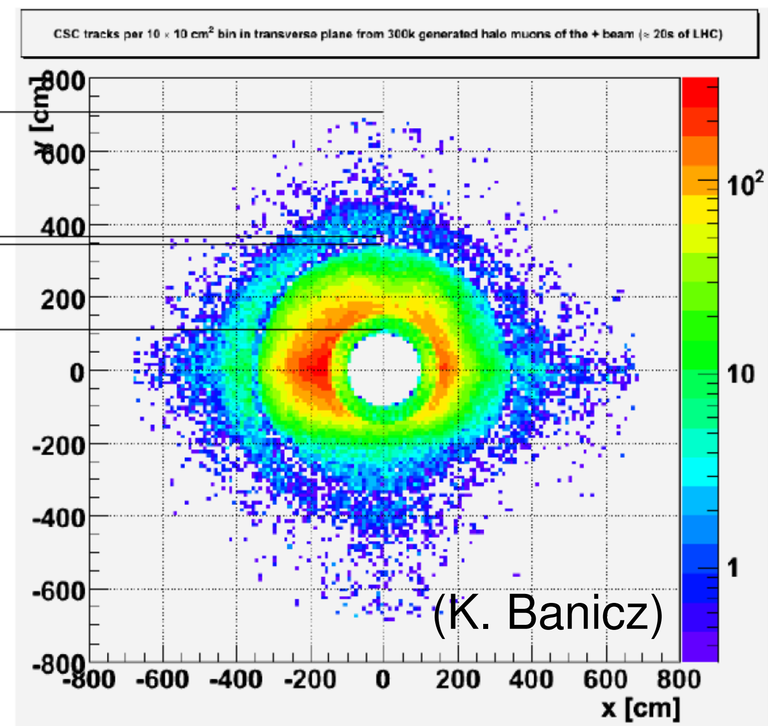
Beam Halo Rate

- Beam halo rate is 6600 tracks/sec (known up to a factor of 100)
- Rate of overlap tracks 6600 × 0.02 = 130 Hz
  - 2 hours to collect 1
    - Means 100's of µm resolution
    - 8 days if we're off by ×100
  - Steeply falling function of energy and radius (better for internal rings)
  - Trigger proposed, HLT path is being defined now

outer ring

inner ring

133k tracks reconstructed in the endcap muon chambers



Alignment Framework Status

- Recent progress
  - Parallelized 10/100 pb–1 procedure
  - Added CSCRing as an alignable structure
  - Tool for setting arbitrary patterns of hit weights (APEs)
  - Improved track cut and alternate refitter for upcoming tests
  - Mechanism for setting global coordinate system
  - HLT paths and AlCa streams for beam-halo, cosmics
  - Beam-halo and cosmic MC production cfg
  - DB interface with human-editable files and monitoring plots – ½ done
- 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, being implemented
  - 1000 muon ring alignment: easy adaptation of GlobalMuon

Datasets and Procedures

AlCa Streams	L1	HLT	AlCa Cuts	Procedure
"All Muons"	Single-muon	(Non-iso OR iso)	10 GeV	Baseline tracker-to-chamber (absolute chamber positions); Structure Alignment; Layer alignment procedure
Muons in CSC overlap	Single-muon	(Non-iso OR iso) AND overlap	5 GeV in CSC and overlap on track	Even-odd procedure (relative chamber alignment within ring)
All Beam-halo	Beam-halo	(Non-iso OR iso)	5 GeV in CSC	Layer alignment procedure
Beam-halo in CSC overlaps	Beam-halo	(Non-iso OR iso) AND overlap	5 GeV in CSC and overlap on track	Even-odd procedure (relative chamber alignment within ring)
Dedicated Cosmics	RBC	(Non-iso OR iso)	?	Internal barrel alignment?

- Single Muon trigger will be evolving with time
- All Muons stream will be selecting all of these:
  - Cosmic rays during CRAFT
  - Very loose muons (single LCT) during commissioning
  - Good muons in long term
- Overlap muon samples will have to be split by station
- AlCa cuts will start loose and will evolve with time
  - Additional selections for now will be applied downstream

Pre-Requisites for PG and HW Comparisons

- Results of HW and PG have to be in the standard form to be able to do comparisons
- Specific requirements:
  - Format of measurements (HW **and** PG):
    - Layer positions corrected for shifts (Oleg's calculations)
    - Chamber positions must be defined as average position of layers (accounted for shifts)
    - CSCAlignmentRcd, DTAlignmentRcd delivered to Conditions DB
- We propose to make comparisons of alignment measurements during these periods:
  - CRAFT, Beam halo data taking, Collisions
  - Results of HW alignment measurements have to be uploaded to Conditions DB to make comparisons

Possible Comparisons with HW and PG

- **CRAFT Period** Comparisons with HW:
  - A direct comparison of chamber positions in global coordinates, as reported by HW alignment and track-based system using *DB Comparison tool*
  - Effectively a test of the HW alignment in the barrel from chambers to tracker through the Link System
  - Pre-requisite: HW alignment results have to be propagated down to layer positions
    - Actually, that's what AlignmentRcd holds
- PG measurements:
  - Some sort of fitting will be needed: fit the two geometries for compatibility up to a rotation and translation
    - Accounts for PG (0,0,0) not being on tracker (0,0,0)

Possible Comparisons with HW and PG

- **Beam Halo Period:**
- Verification of relative chamber positions on each CSC ring
  - Beam-halo measures x and y positions
  - HW measures x (and z) with SLM lines
  - Will use the same fit method to check compatibility of x-measurements
- Comparison with PG:
  - Fit to check compatibility of x- and y-measurements of chamber positions on the ring

Possible Comparisons with HW and PG

- **Collisions Data (**first ~1000 muons**):**
- Comparison with HW alignment:
  - Assuming completed inner alignment measured with beam halo, we have full alignment (down to chambers), so does HW
  - A direct comparison of chamber positions (defined as average layer positions) with the *DB Comparison tool*
- Comparison with PG:

Suggested alignment scenarios

- Chamber/Ring/Disk (C/R/D)

0 pb–1 beam-halo plus HW measurements

	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
D	200 µm	200 µm	3 mm	1 mrad	1 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

Conclusions

- Muon track based alignment system is functional:
  - Flexible to allow relative (local on structures) and global (w.r.t. tracker) alignment due to hierarchical structure reflecting design of the muon system
  - Ability to incorporate external alignment information in a consistent fashion as constraints or initial alignment
  - When recent improvements included, expected to reach design accuracy with 100 pb^{-1}, further optimization ongoing
- Updated alignment scenarios are conservative
  - Do not include recent improvements
- Presented commissioning plan makes best use of information as it becomes available

Startup Luminosities

Startup Luminosities

Each step lasts ~ 1 week

Bunches	β^*	I_b	Luminosity	Pileup	Time for 1000 muons
1 x 1	18	10^{10}	10^{27}	Low	4.1 years
43 x 43	18	3×10^{10}	3.8×10^{29}	0.05	4.0 days
43 x 43	4	3×10^{10}	1.7×10^{30}	0.21	21 hours
43 x 43	2	4×10^{10}	6.1×10^{30}	0.76	5.9 hours
156 x 156	4	4×10^{10}	1.1×10^{31}	0.38	3.3 hours
156 x 156	4	9×10^{10}	5.6×10^{31}	1.9	39 minutes
156 x 156	2	9×10^{10}	1.1×10^{32}	3.9	20 minutes