Status of Beam-Halo Alignment

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In a nutshell

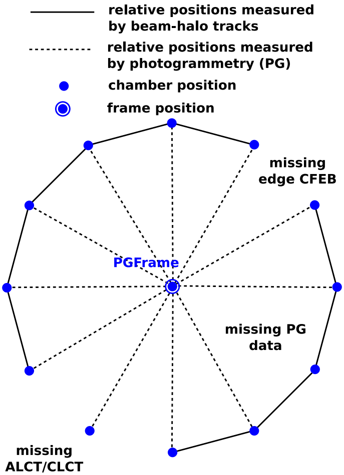
- Beam-halo + "other constraints" technically works (needed to fill the gaps in beam-halo data)
- Beam-halo (2010) and PG (2007) agree in $r\phi$ at the level of 0.6 mm (RMS), which is the same level of agreement that Oleg found between hardware (2010) and PG
- Ring radii required for beam-halo closure and radius predicted by Oleg disagree by at most 1.75 mm
  - not in all rings, only ME$x/2$
  - ring radius has a negligible impact on reconstruction
  - but closure is a prerequisite for $r\phi$ alignment
- Documentation is about $\frac{1}{4}$ done

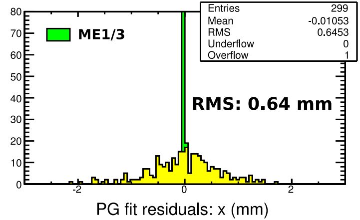
- One-dimensional alignment parameters ($r\phi$ or ϕ_z) are variables that we want to solve for A_i
- Agreement of beam-halo segments in neighboring segments are measurements of alignment differences between neighboring chambers: $m_{i,i+1} = A_i - A_{i+1}$
- Other constraints, such as photogrammetry, relate pairs m_{ij} where j usually corresponds to an external coordinate frame (A_j is allowed to float)
- General objective function: $\chi^2 = \sum_i \sum_j q_{ij} \frac{(m_{ij} - A_i + A_j)^2}{{\sigma_{ij}}^2} + \text{L.M.}$

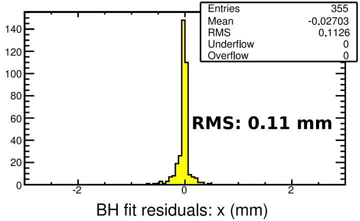
  is minimized when m_{ij} are as close as possible to $A_i - A_j$.
  - $q_{ij} = 0$ if measurement i-j does not exist, $q_{ij} = 1$ if it does
  - σ_{ij} is the uncertainty in measurement m_{ij}
  - L.M. is a Lagrange Multiplier (required to set a coordinate system)
  - $\frac{\partial \chi^2}{\partial A_i} = 0$ has an exact solution for all i by a matrix inversion
- Do the above for $r\phi$, then for ϕ_z, then $r\phi$ again...

Beam-halo/PG agreement

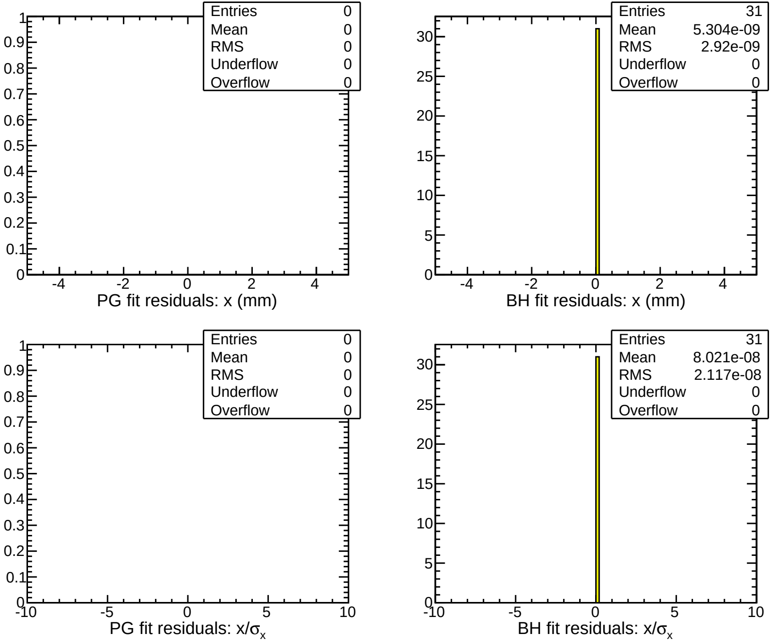
- "Fit residual" $= (m_{ij} - A_i + A_j$ where A_i, A_j are the alignment solution
- Beam-halo σ_{ij} are smaller so fit prefers beam-halo, but PG constraints are not strongly violated



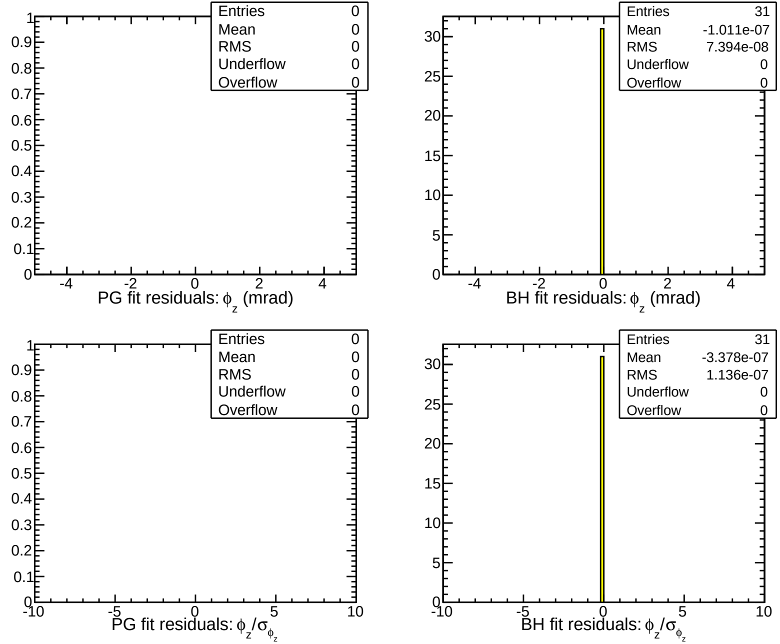




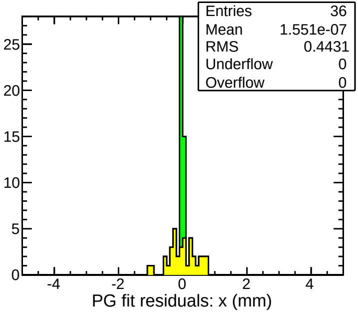
All results: ME$-1/1$ $r\phi$

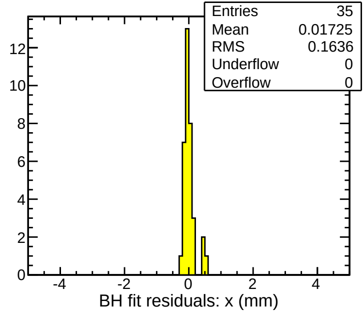


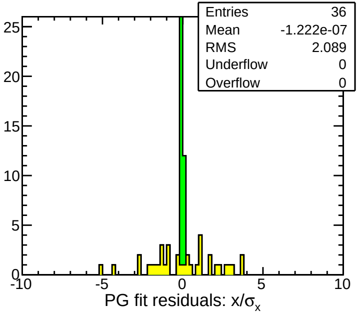
All results: ME$-1/1$ ϕ_z

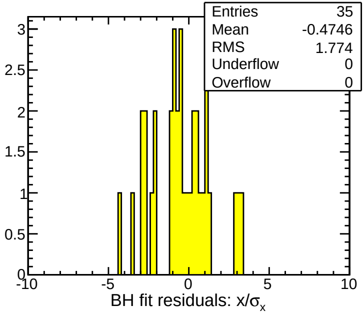


All results: YE-1 $r\phi$

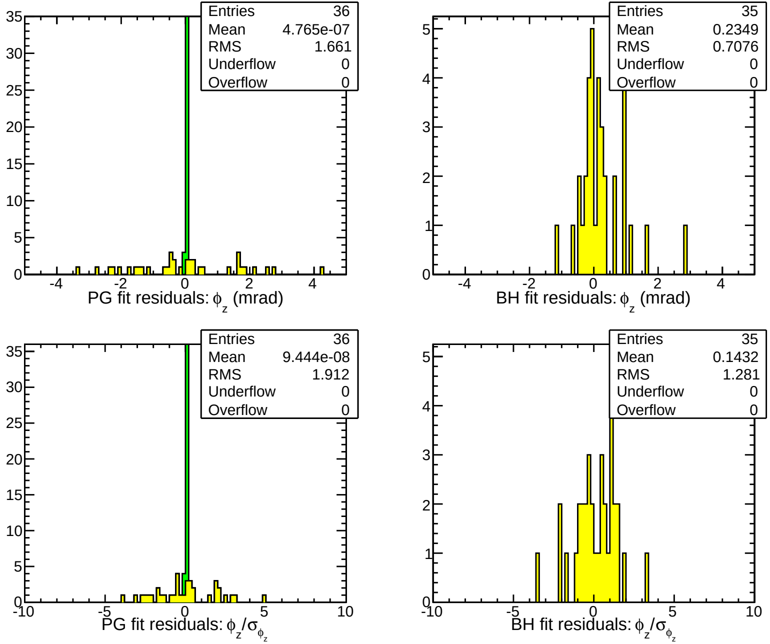




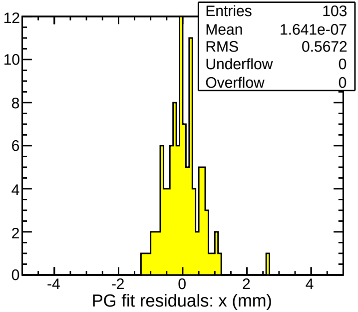


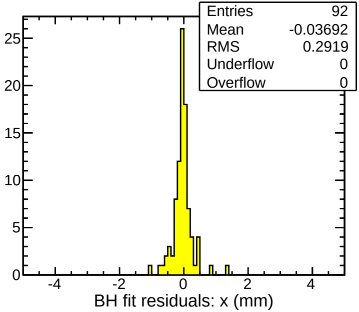


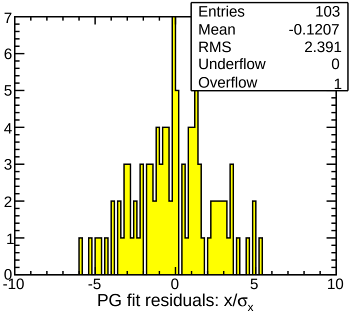
All results: YE-1 ϕ_z

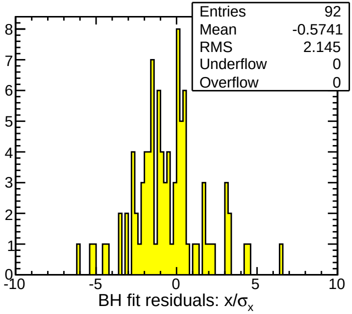


All results: YE−2 $r\phi$

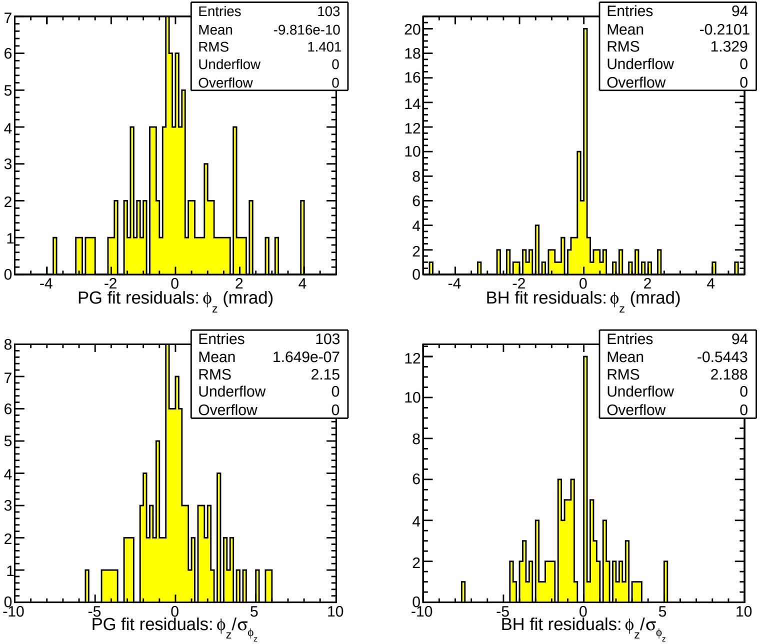




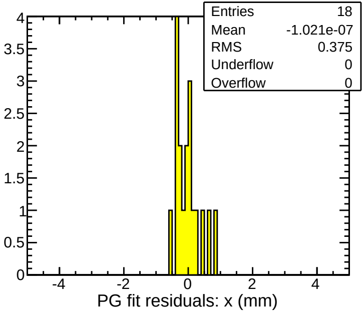


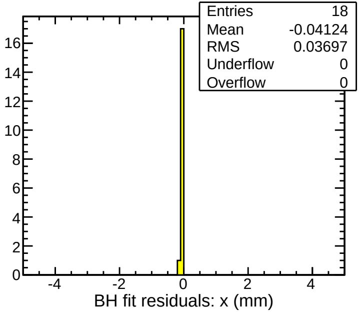


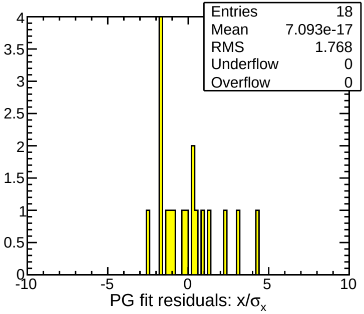
All results: YE−2 ϕ_z

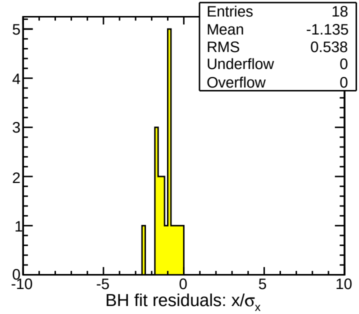


All results: ME−4/1 $r\phi$

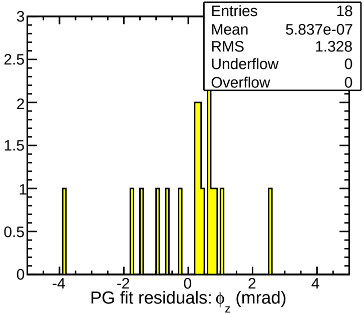


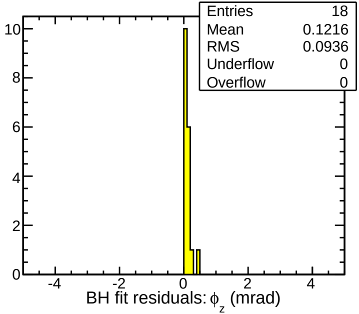


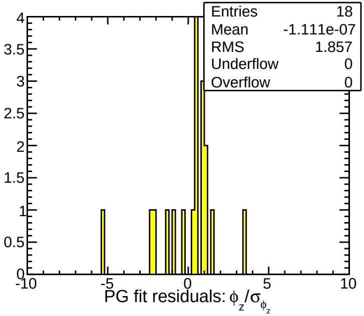


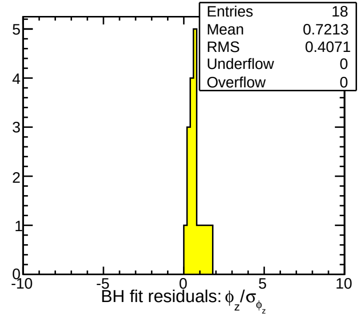


All results: ME$-4/1$ ϕ_z

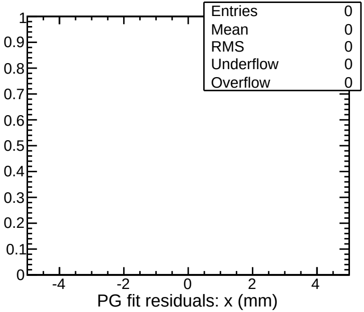


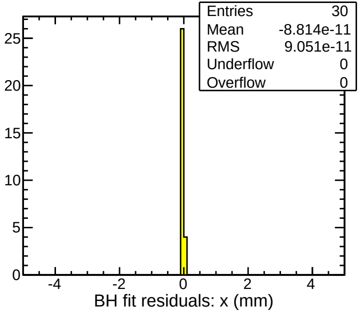


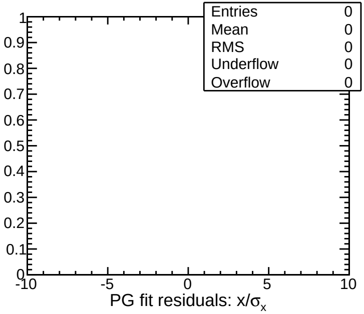


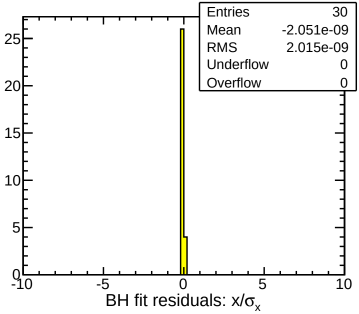


All results: ME+1/1 $r\phi$

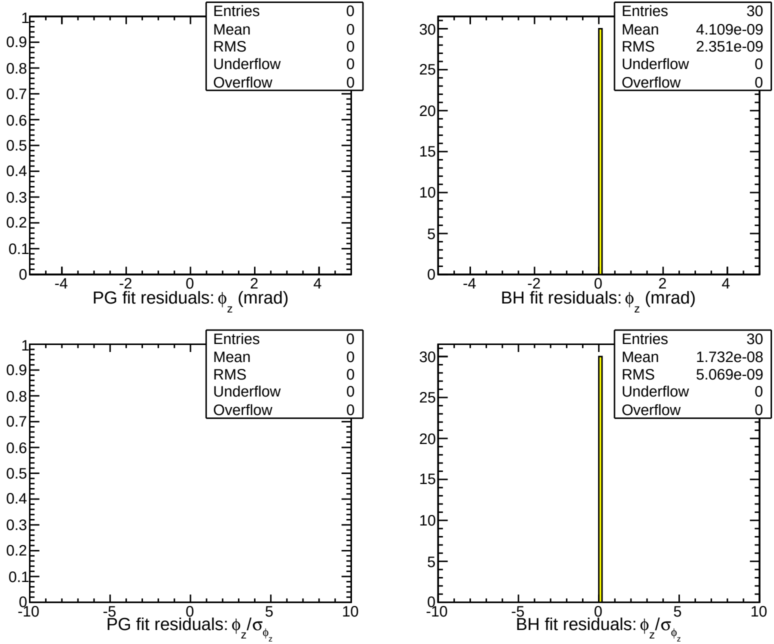




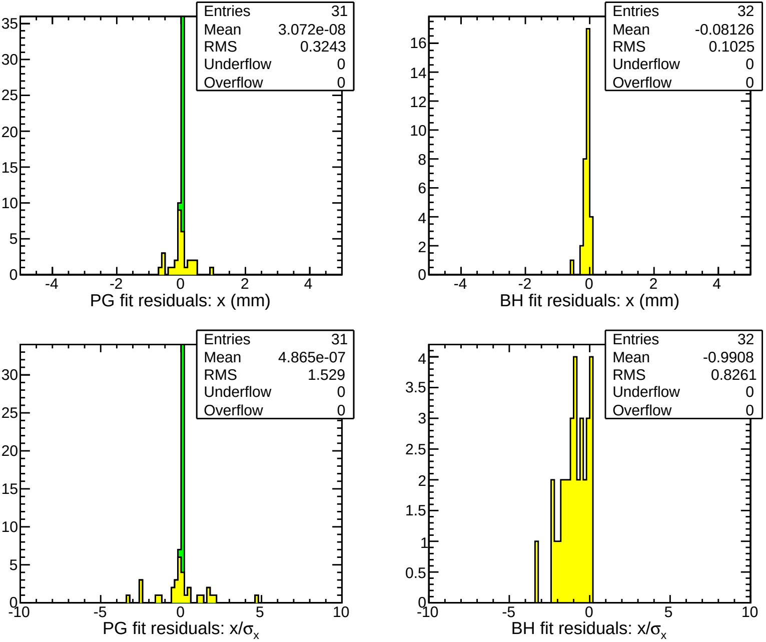




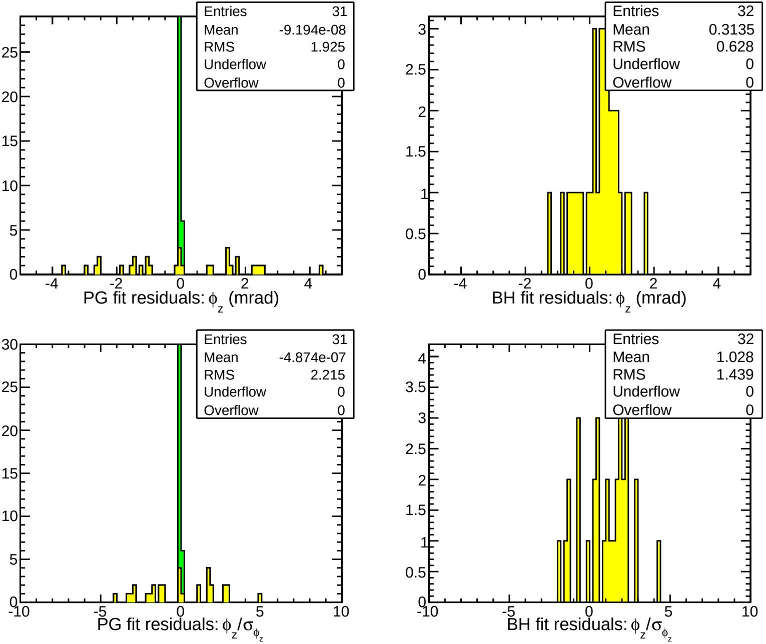
All results: ME+1/1 ϕ_z



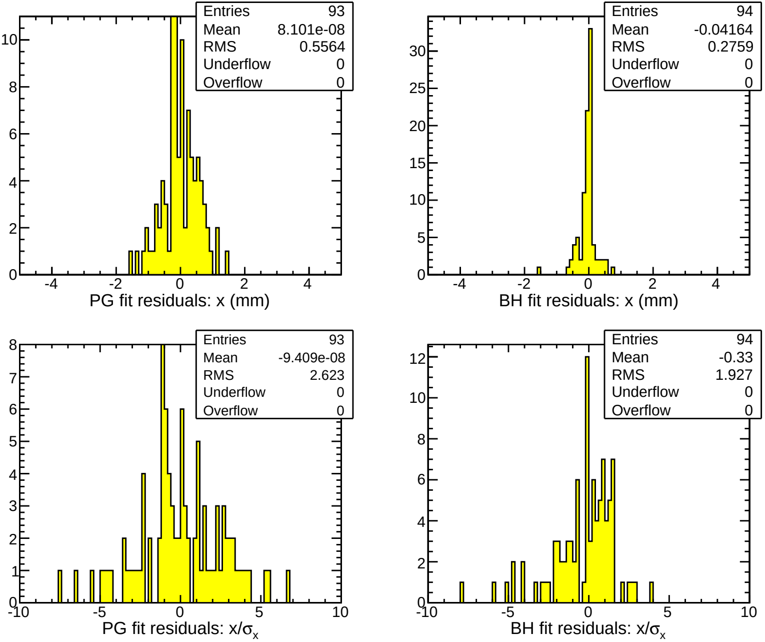
All results: YE+1 $r\phi$



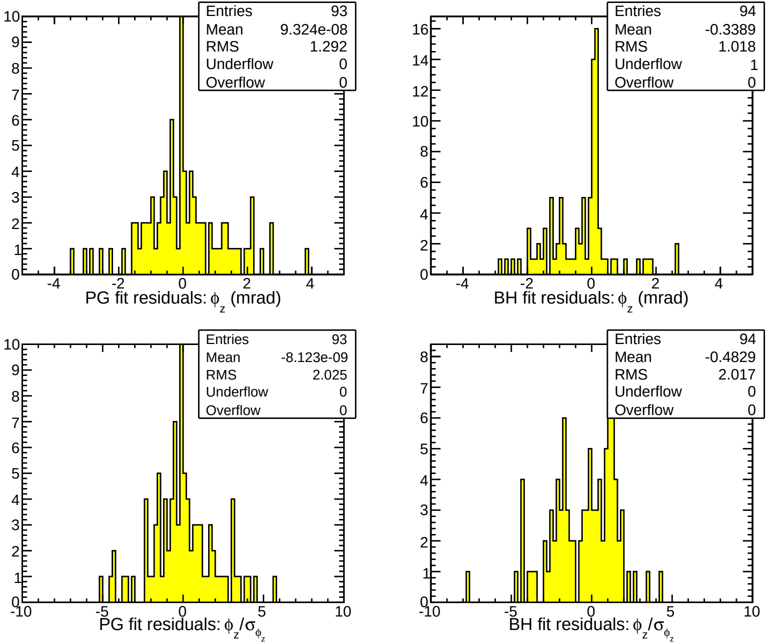
All results: YE+1 ϕ_z



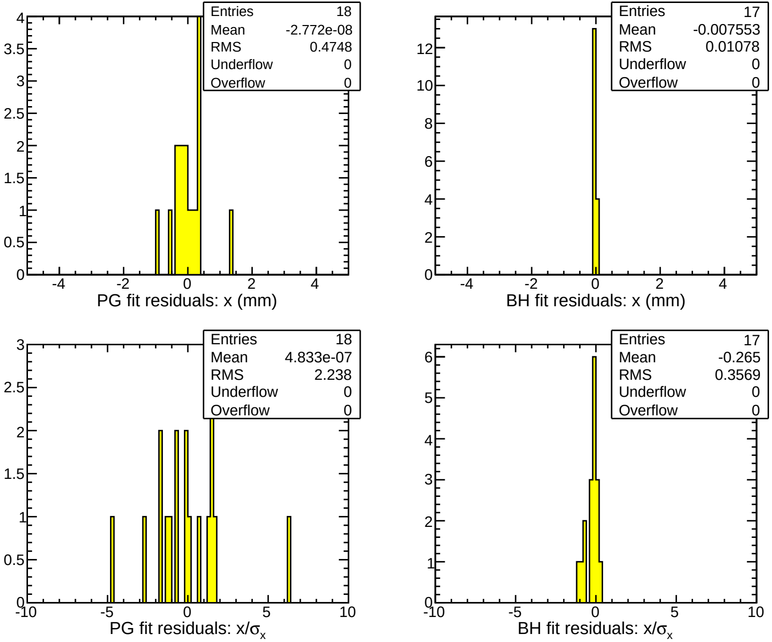
All results: YE+2 $r\phi$



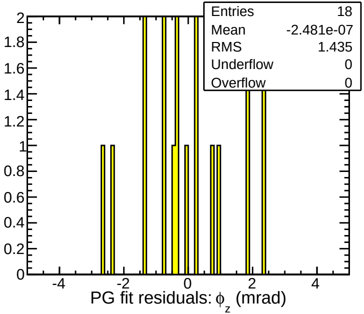
All results: YE+2 ϕ_z

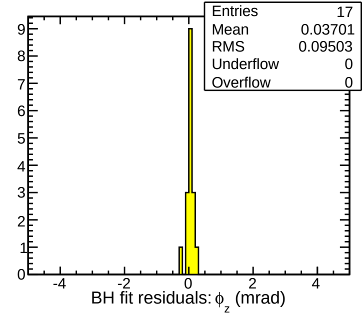


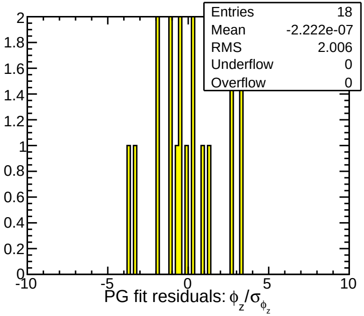
All results: ME+4/1 $r\phi$

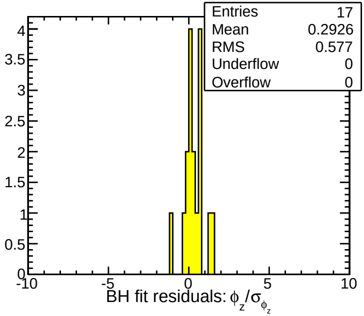


All results: ME+4/1 ϕ_z

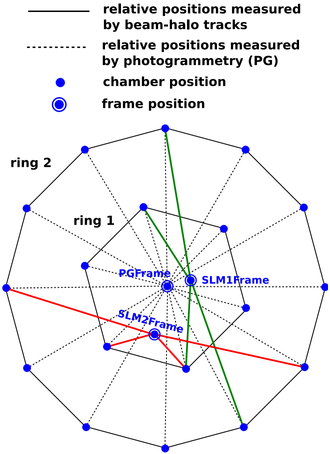








- PG is consistent only at the level of 2σ (0.6 mm $= 2 \times 0.3$ mm)
- We may be seeing a drift from 2007 to 2010, or with magnetic field
- We can request a new PG with the next long shutdown, but we should also be able to use $r\phi$ and ϕ_z constraints from SLM lines
- The fact that SLM lines only cover $\frac{1}{6}$ of chambers is okay because we only need it to fill the gaps in beam-halo data (as long as gaps in SLM and beam-halo data don't line up!)
- Any topology and any constraint can be applied at the configuration file level. We'd have to convert the SLM constraints into a special text file format (not hard)

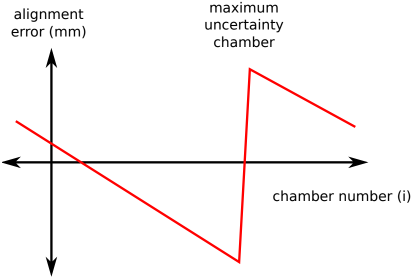


- Why it's needed: the value of $\sum_i m_{i,i+1}$ is unaffected by alignment, so if $\sum_i m_{i,i+1} \neq 0$, the pull is uniformly distributed around the ring:

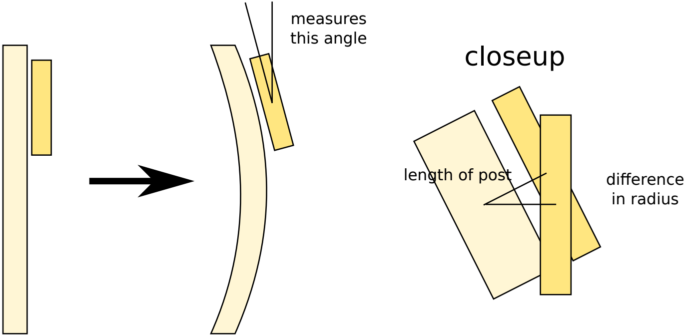
$$\text{pull}_{ij} = \frac{(m_{ij} - A_i + A_j)^2}{{\sigma_{ij}}^2}$$

- Uncertainties σ_{ij} vary by at least factors of 2, so in practice this means that only a few chambers absorb nearly all $\sum_i m_{i,i+1}$.

A small error in radius $\Delta R = \dfrac{1}{2\pi} \displaystyle\sum_i m_{i,i+1}$, so $\Delta R \sim 1$ mm can mean introducing a $\mathcal{O}(6\text{ mm})$ error in the alignment, usually distributed like this:



- We can try to get the ring radius correction from sources outside of beam-halo alignment:
  1. Oleg measures bending of disks in magnetic field (from SLMs)
  2. Oleg gives me the lengths of posts (even and odd-numbered chambers)
  3. I put these angles and the implied ring-radius correction into the geometry
  4. I calculate $\sum_i m_{i,i+1}$ from the data using the new geometry
  5. I make an additional correction so that $\sum_i m_{i,i+1} \to 0$



Ring radius correction

Values of that "additional correction" (step 5)

Ring	additional (mm)	Ring	additional (mm)
ME+1/2	+0.60	ME−1/2	+0.11
ME+2/1	+0.37	ME−2/1	+0.04
ME+2/2	−1.75	ME−2/2	−0.79
ME+3/1	+0.33	ME−3/1	−0.11
ME+3/2	−1.52	ME−3/2	−1.56
ME+4/1	−0.53	ME−4/1	−0.55

Documentation

- Gradually being filled in:

  http://hepr8.physics.tamu.edu/pivarski/talks/alignment_tutorial/alignment_tutorial.pdf

- Beam-halo alignment touches on all aspects of alignment in a pedagogical way (each of the issues can be treated individually, not all at once)
- So I'm writing this as a general alignment tutorial, but starting with the aspects which are particular to beam-halo alignment
- Intended audience: *any* new graduate student— I'm trying to encapsulate my expertise in this document
- Includes working toy MC examples that I used to build my own intuition (quick little scripts)

Documentation

- Chapter 1: Introduction (done)
- Chapter 2: Propagating Alignment Measurements (almost done)

  Combining alignment measurements into a consistent system: motivating examples, solution space is not R^N, logic and formalism of simultaneous fitting with "constraint diagrams", Hessian, and working toy example scripts. Overconstrained systems and closure tests. Error analysis: decomposition of statistical errors into weak and strong modes, characterization of the undetermined and weakest modes, systematic errors in measurements.
- Chapter 3: Measuring Detector Positions with Tracks

  Alignment measurements from tracks: 6-DOF rigid body parameter space, track residuals space including the 4 relevant track parameters, and the differential map (2dresid, 3doflargestruct, 6dof, 5dof, 6dofrphi) between them (linearization and iteration), significance of the chamber origin, simple studies using elements of the map, example from CRUZET alignment, toy example in pyROOT (linear fit to plot and transformed residuals), full track-parameter/alignment-parameter correlations and their solutions: large-scale iteration and Millepede, Reference-Target factorization of the problem.
- Chapter 4: Realistic Tracking and Diagnostics of Track-Bias

  Systematic errors in realistic tracking: magnetic field errors, material budget errors, and the q/pT, q/pz plots, Rutherford and multiple scattering, argument for fitting to the peak, rather than mean (CRUZET example), extension of the objective function and non-linear minimization (PyMinuit example), cross-checks of redundant constraints in the differential map, diagnosing track biases: discontinuities at chamber boundaries (map plots), differences of residuals on the same track (segment-difference plots), and scaling of phi, theta, and curvature bias scaling with pathlength.
- Chapter 5: CSCOverlapsAlignmentAlgorithm: a Complete Alignment Package

  Technical details of the software package; layout of classes, built-in diagnostics, etc.
- Chapter 6: Concluding Remarks