Beam-halo Alignment with Constants

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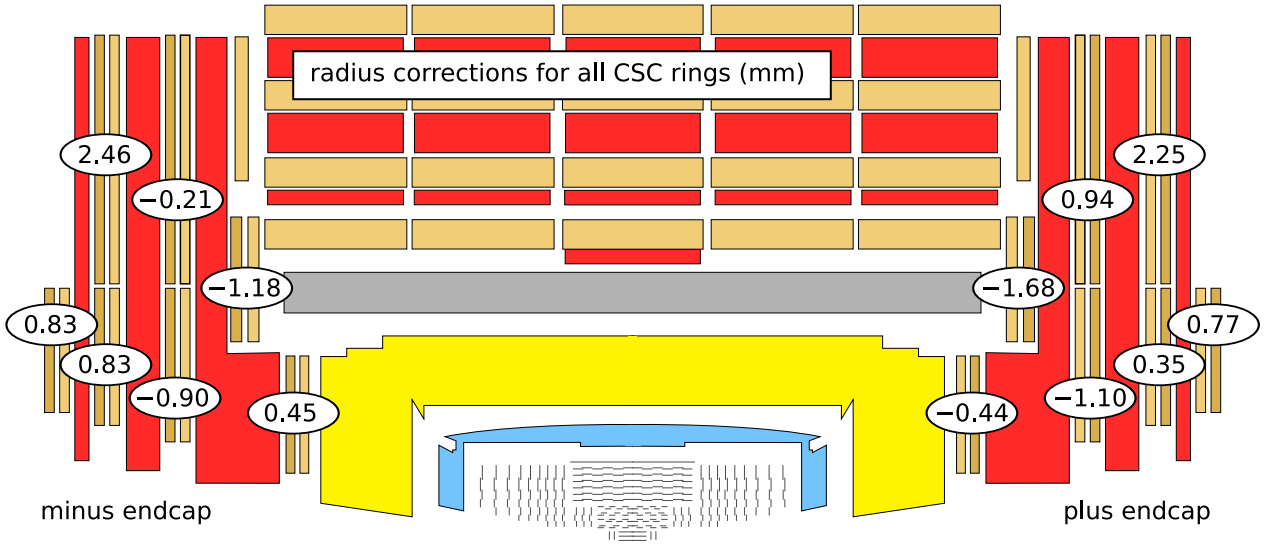
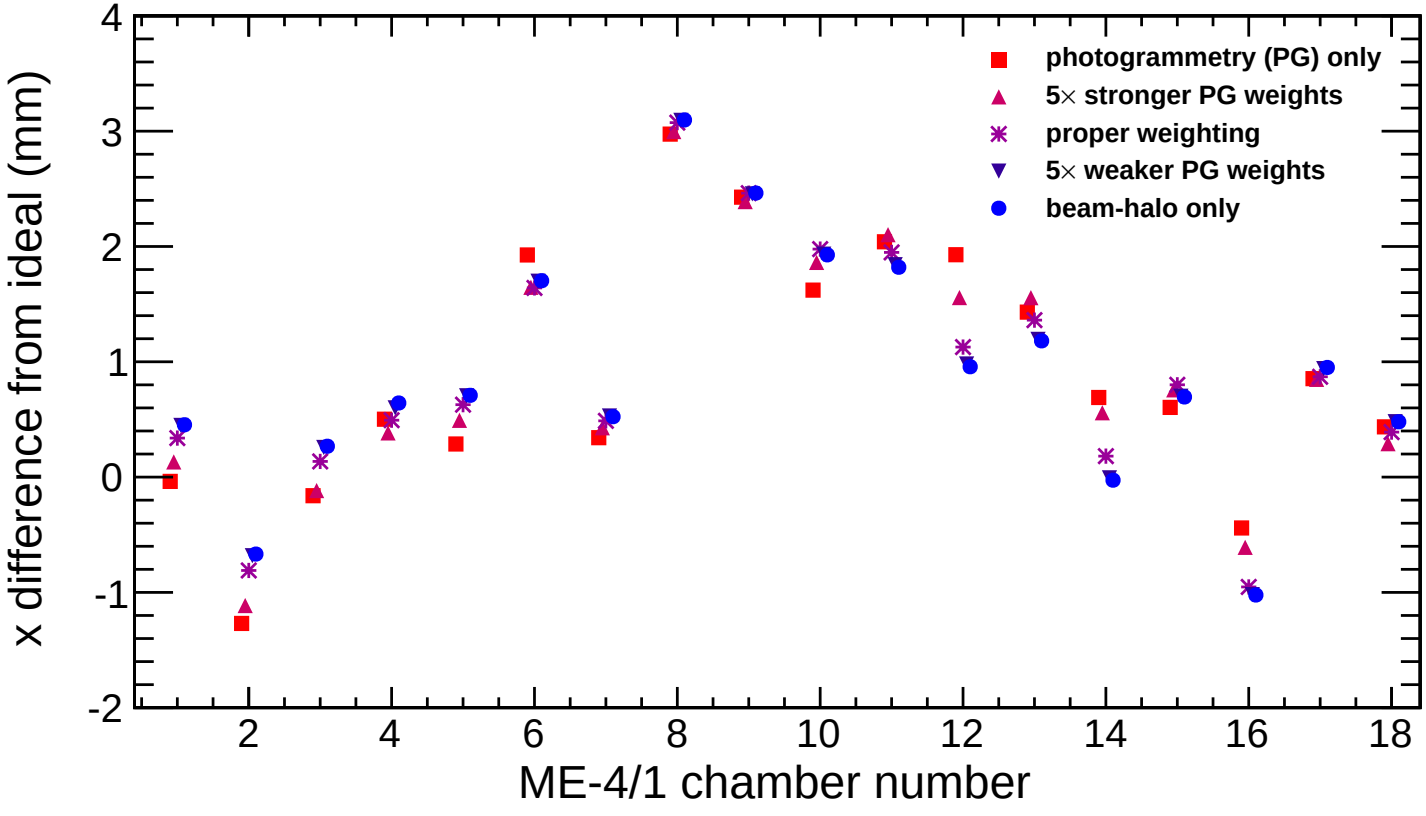
Ring-radius corrections

- Last week, I showed that ring-radius corrections estimated from disk-bending improve track-based closure by a factor of 2
- If we assume that the remaining non-closure is due to wrong ring-radii, we can apply it as a track-based correction
  - strong assumption that the internal CSC geometry is correct
  - closure was zero in 2008 $\vec{B} = 0$ data
- Size of these corrections (after all others have been applied) have an interesting pattern:



New constants (*nearly* final)

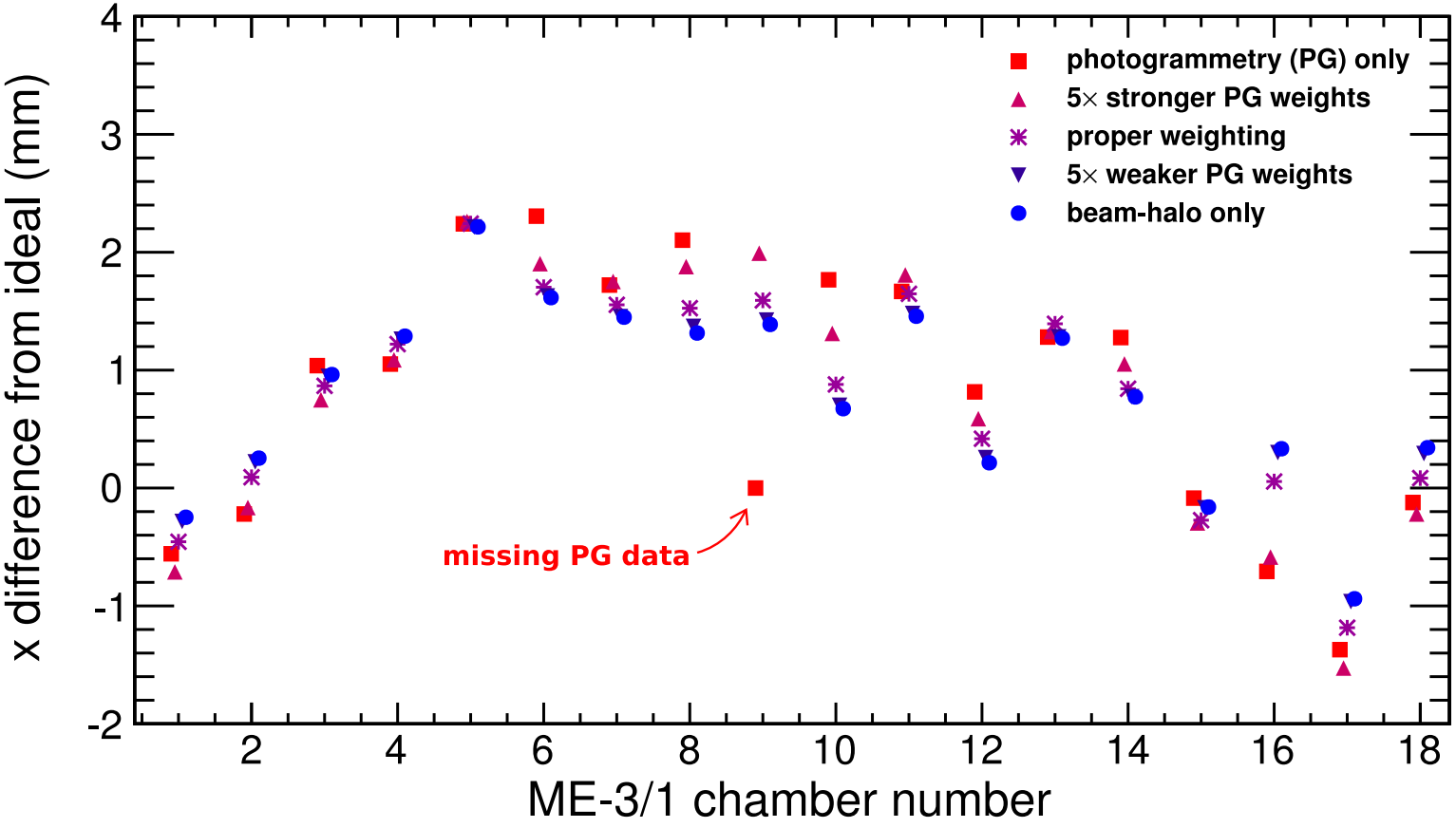
- Assuming the new ring-radii is a prerequisite for $r\phi$ alignment
- New constants, assuming the new ring-radii



- Pure PG is not very far from pure beam-halo, but now we can align them in a combined fit (demonstrated by varying weights)

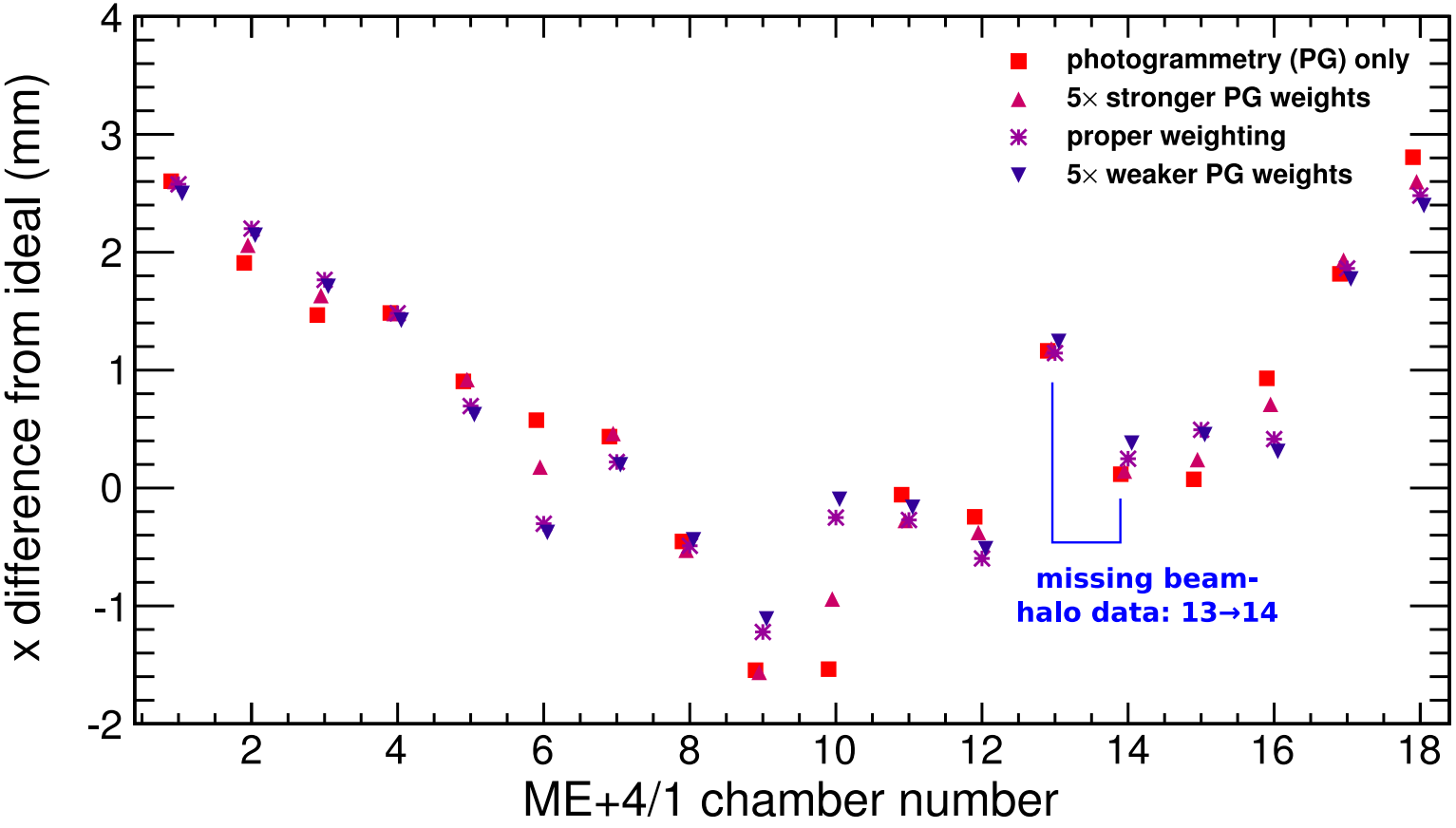
New constants (*nearly* final)

- Another example: this ring has incomplete PG
- Pure PG has no information about this chamber (set to ideal), but even strongly-weighted PG yields a reasonable value for the missing chamber because it is "filled in" by beam-halo data



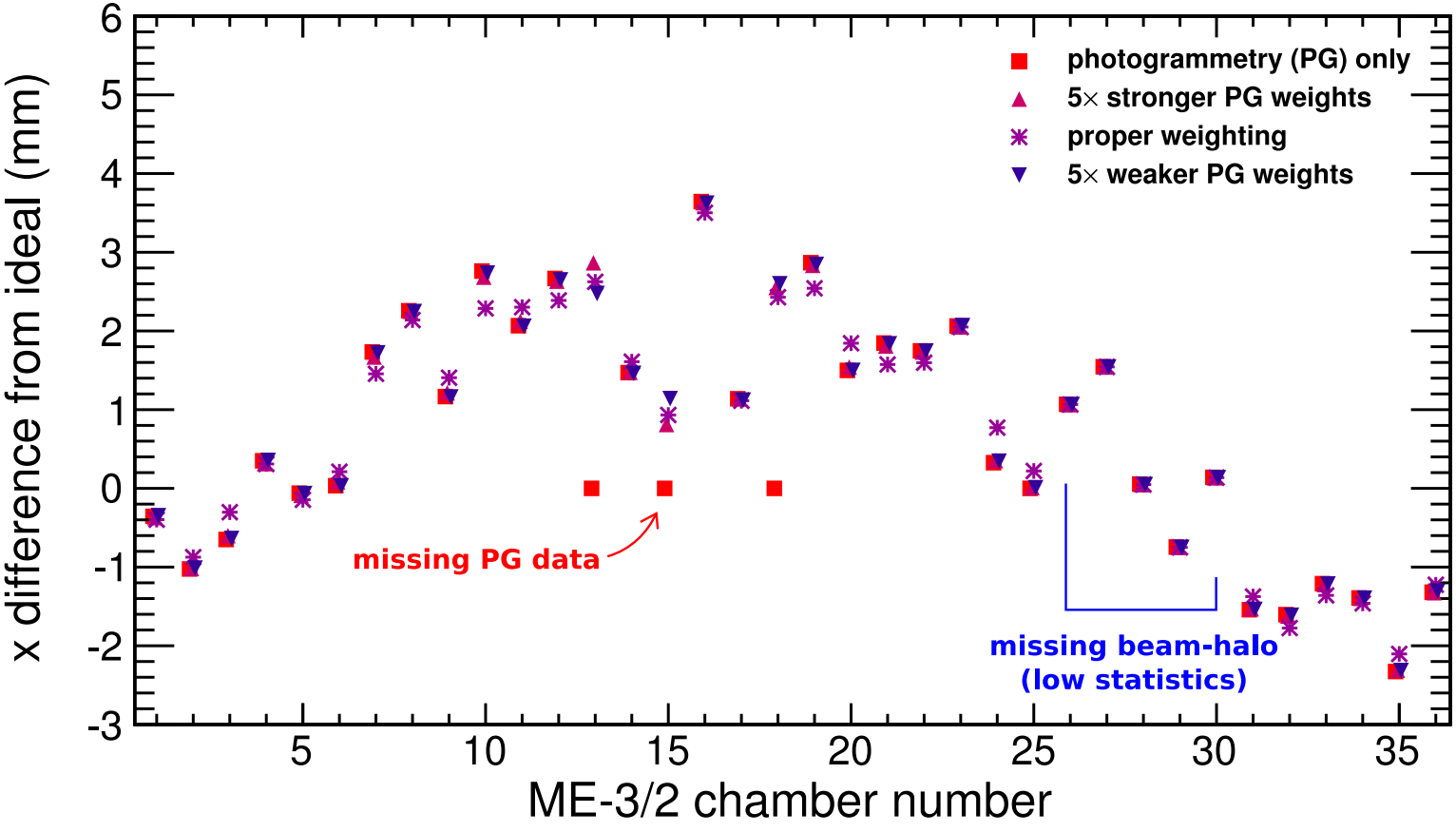
New constants (*nearly* final)

- This ring has incomplete beam-halo; system of equations cannot be solved without external information
- Even weakly-weighted PG yields a reasonable value for the missing overlap



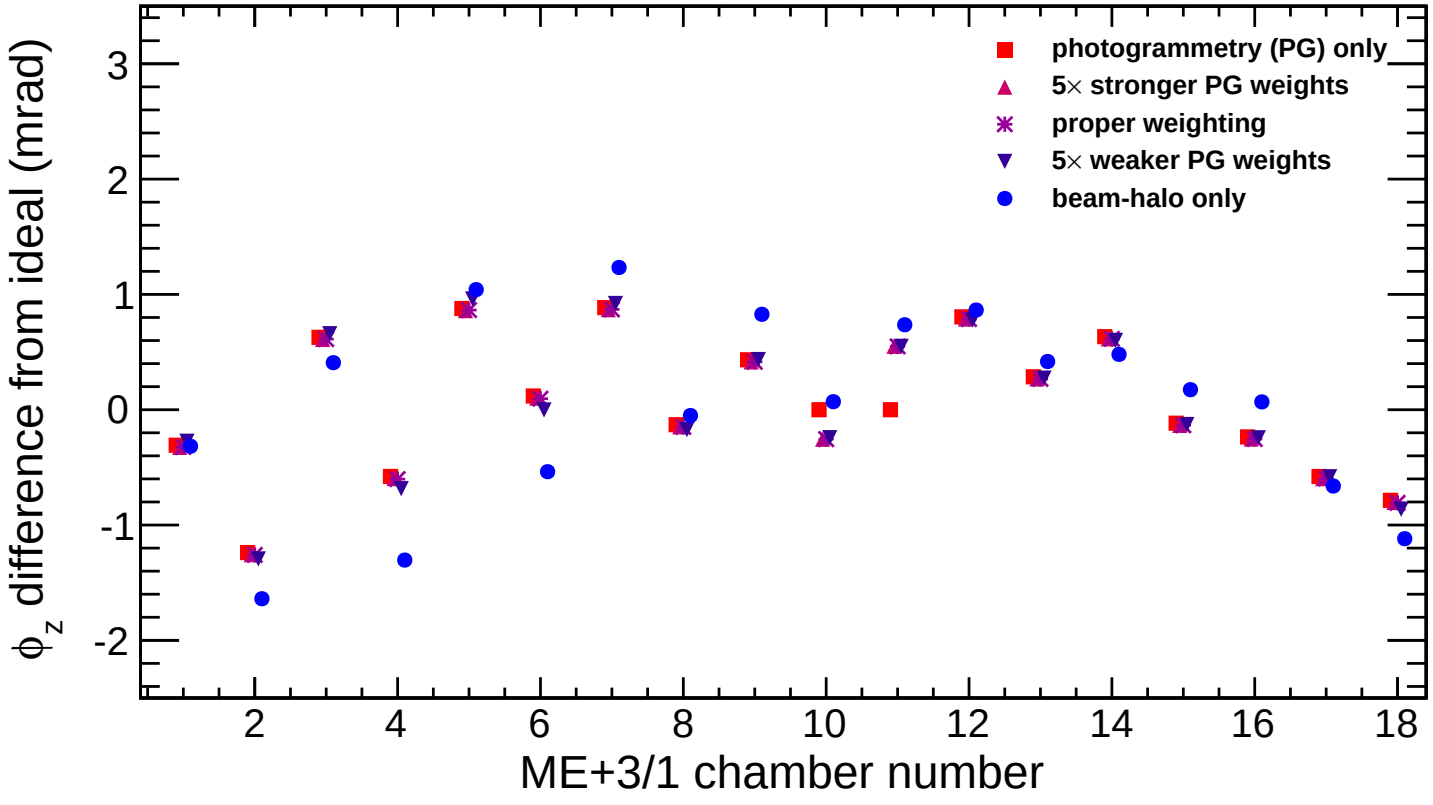
New constants (*nearly* final)

- An outer ring (low beam-halo statistics) with several missing chambers in a row: the relative positions of these are entirely determined by PG



New constants (*nearly* final)

- Also works for ϕ_z rotation angle



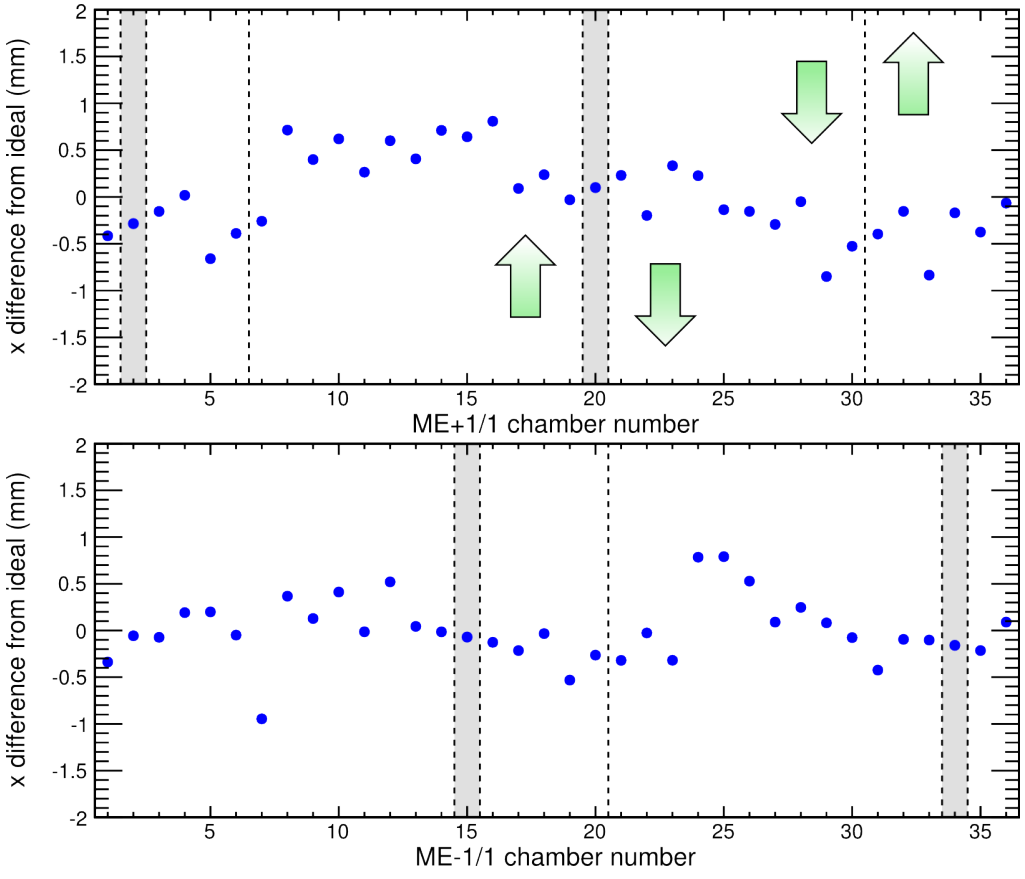
- Two alignment parameters, $r\phi$ and ϕ_z, in addition to ring radii
  - third possible parameter, ϕ_y, is imprecise when measured with beam-halo (ideal geometry is more accurate, so leave as ideal)

New constants (*nearly* final)

- ME1/1 is a special case: PG constraints are not compatible with beam-halo data, so they could not be combined

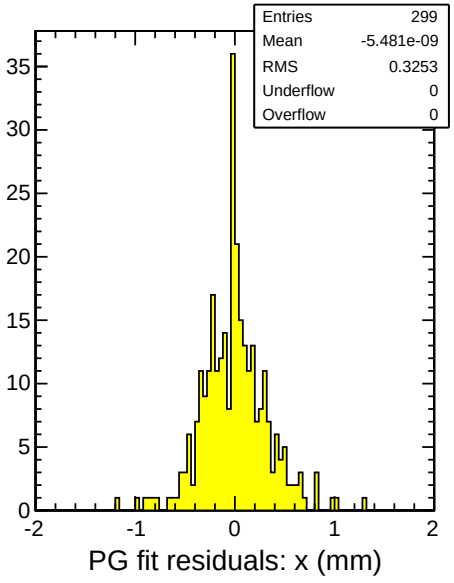
  `https://hypernews.cern.ch/HyperNews/CMS/get/muon-alignment/512.html?inline=-1`

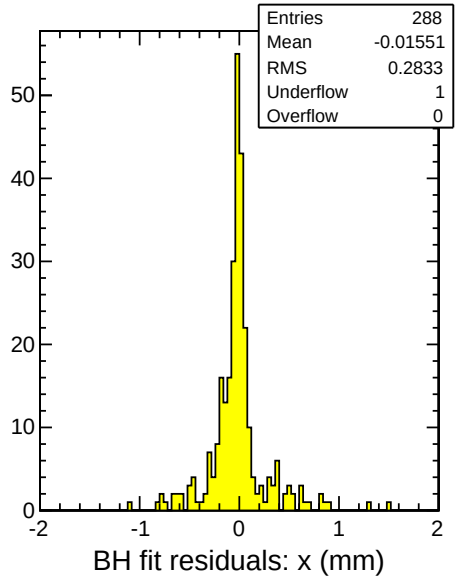
- Alignment graph is not fully connected, not a complete solution

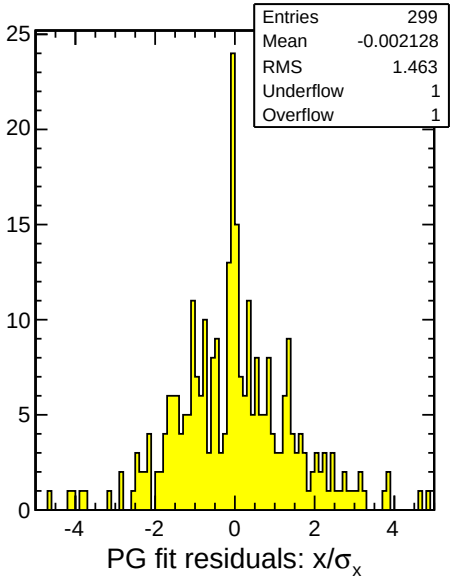


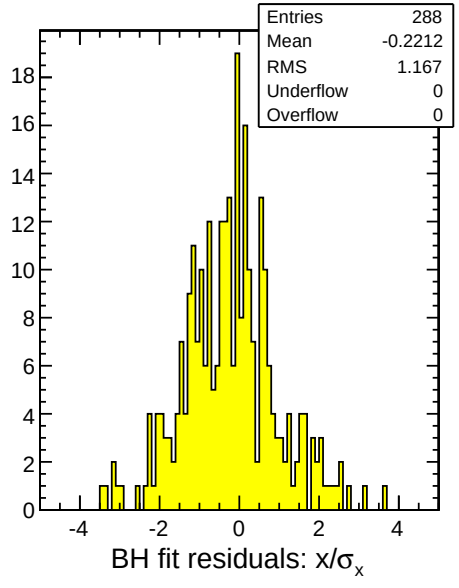
- Dashed lines indicate missing connections
- We can align the disconnected sections, but these sections will later need to be positioned relative to the tracker using globalMuons
- Interestingly, ME1/1 geometry is nearly ideal (more so than other rings)

Compatibility of PG and BH



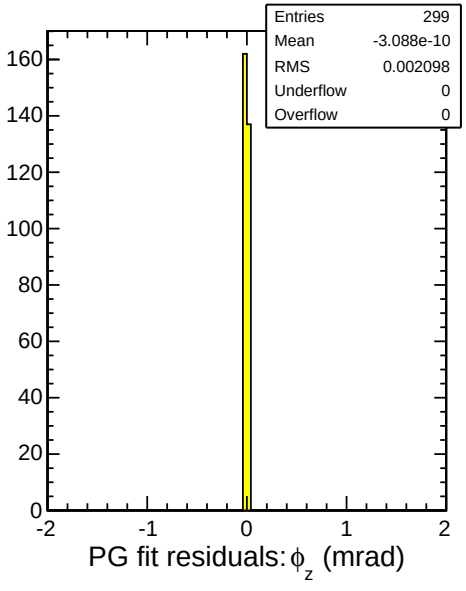


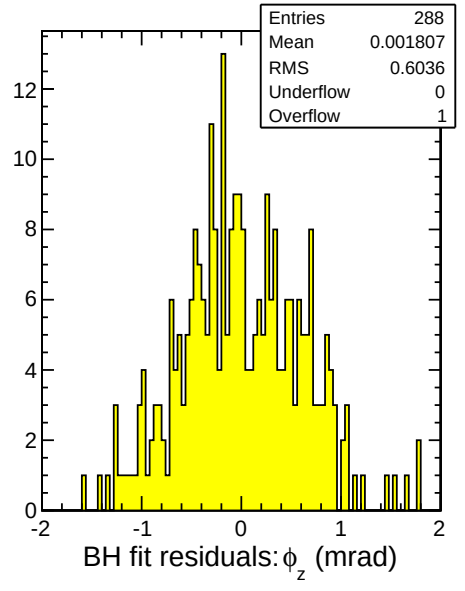


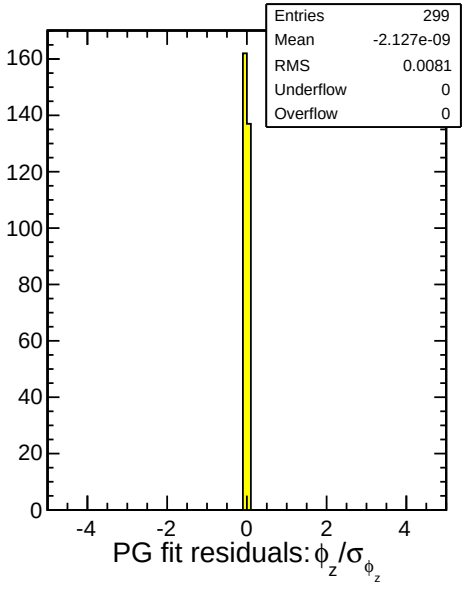


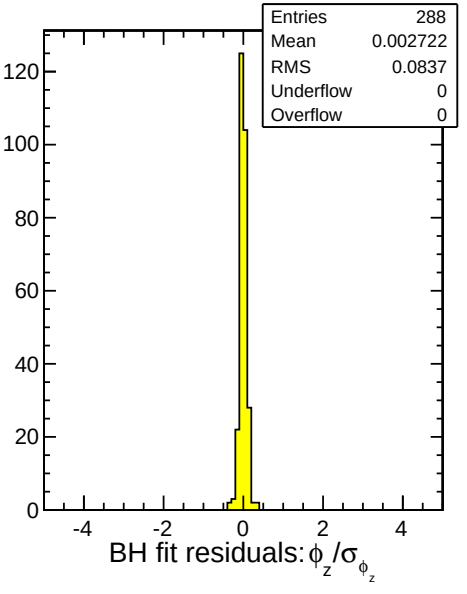
- Plot PG and beam-halo residuals with respect to the combined alignment solution
- Each are compatible with the solution at the level of 0.3 mm
- Level of statistical compatibility: $x/\sigma_x \sim 1.4$

Compatibility of PG and BH





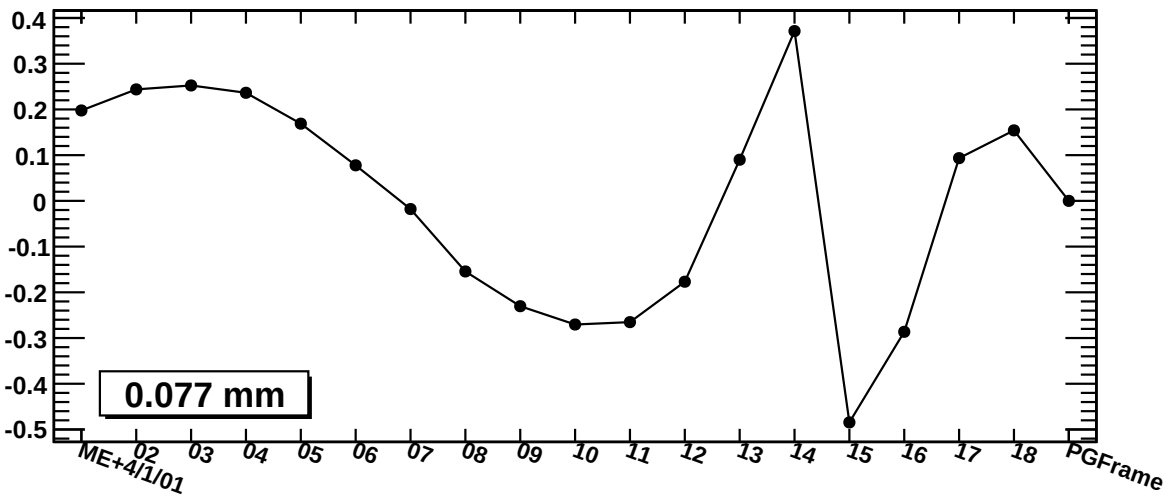




- Same for ϕ_z angles
- Beam-halo ϕ_z uncertainties are overestimated, and the fit takes the PG values
- Beam-halo ϕ_z agree with this on the level of 0.6 mrad; this is just a matter of weighting them properly
- I've found the problem and am working on a solution...

Error analysis ($r\phi$)

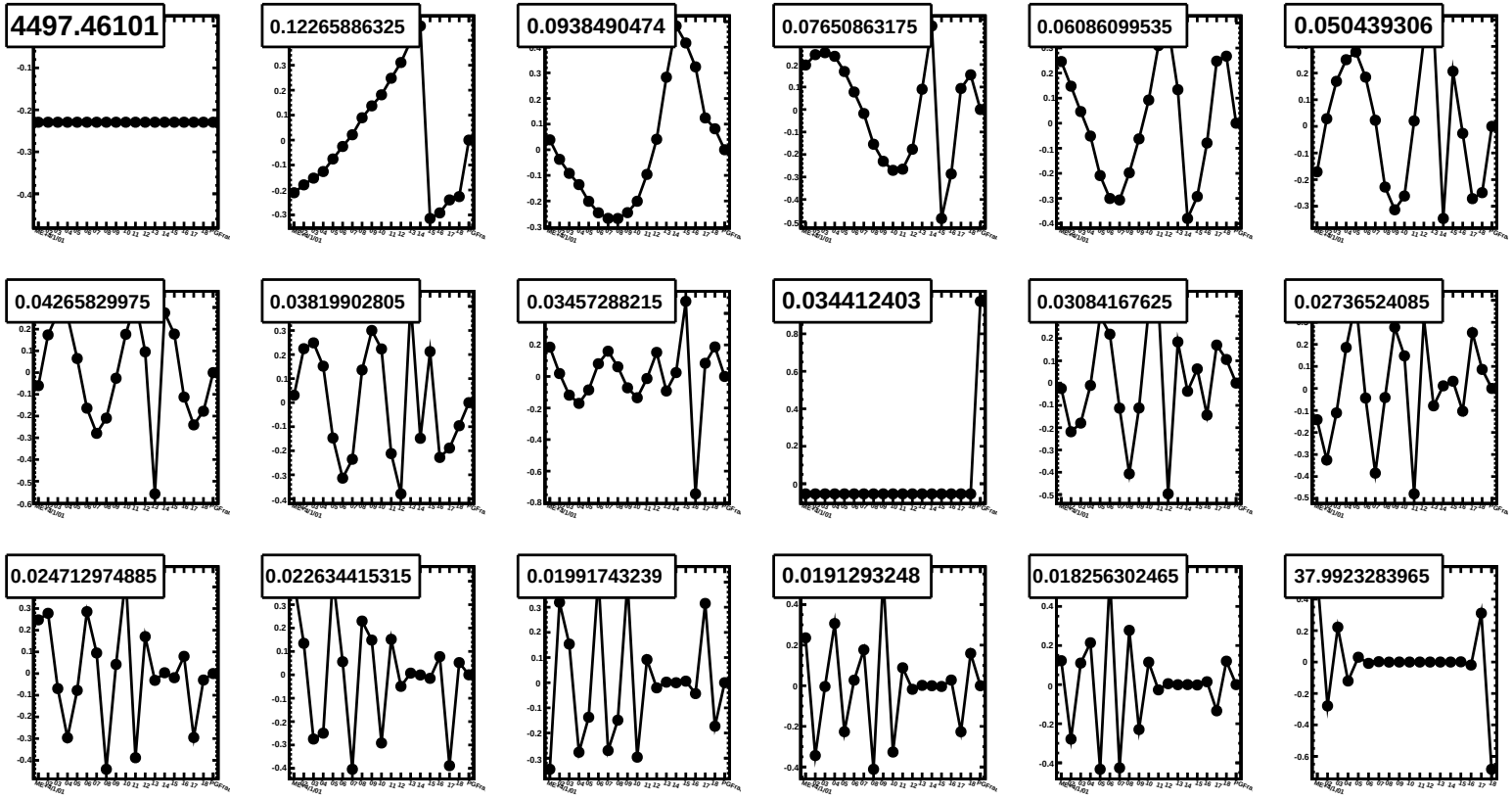
- What is the uncertainty in chamber positions?
  - a complicated question because chamber uncertainties are highly correlated by the system of equations
- However, the system can be decomposed into statistically independent modes, each of which is a linear combination of chamber positions, a normalized direction in $N_{\text{alignables}}$-dimensional space with an associated uncertainty. Example mode:



- The modes with largest uncertainty are called *weak modes* and are generally smoother than the strong modes

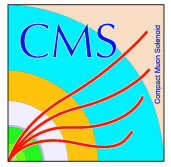
Error analysis ($r\phi$)

- All modes in ME+4/1 (uncertainties in mm)



- First mode is the undetermined rigid-body position of the whole ring, controlled with a Lagrange multiplier (proportional to an arbitrary constant, set to a large number)
- Complete set: `https://hypernews.cern.ch/HyperNews/CMS/get/muon-alignment/513.html`

Error analysis

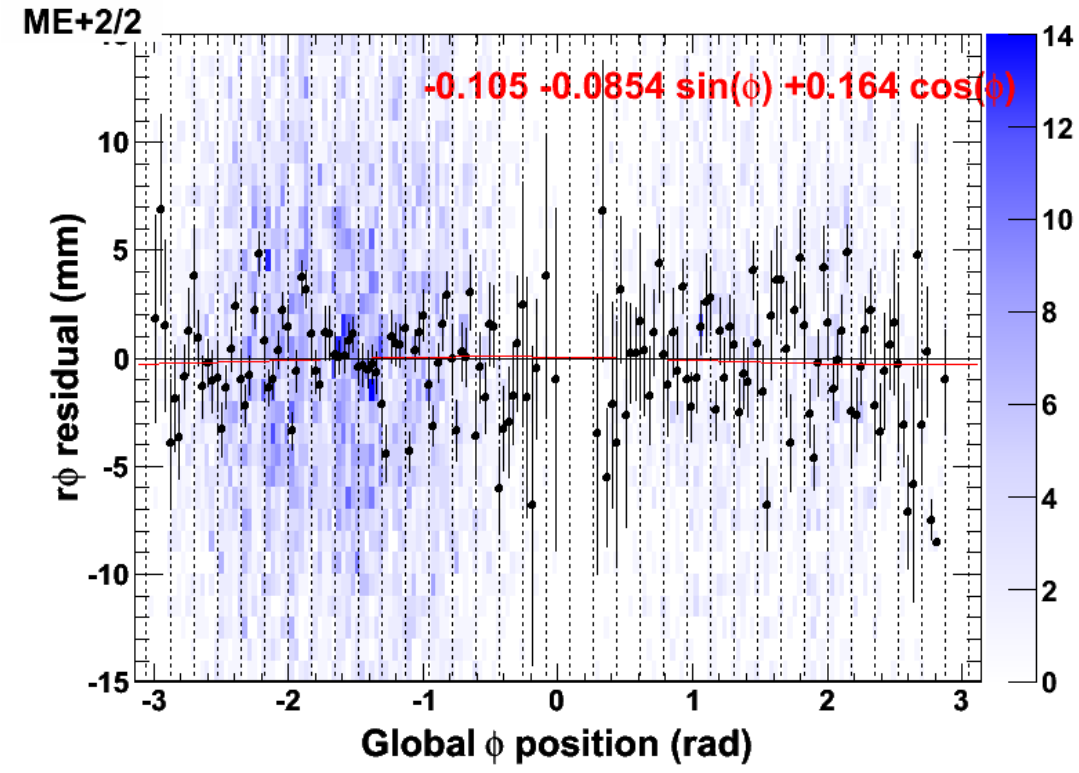


- Statistical uncertainties are in the range of a few hundred microns

ring	largest mode (mm)	sum in quadrature of all (mm)
ME+1/1	0.29	0.54
ME+1/2	0.20	0.60
ME+2/1	0.14	0.23
ME+2/2	0.26	0.76
ME+3/1	0.11	0.19
ME+3/2	0.24	0.70
ME+4/1	0.12	0.21
ME−1/1	0.47	0.79
ME−1/2	0.15	0.51
ME−2/1	0.13	0.21
ME−2/2	0.15	0.69
ME−3/1	0.09	0.18
ME−3/2	0.19	0.67
ME−4/1	0.10	0.18

Ring alignment with 2010 data

- Now performed in an automated way (new script by Vadim)
- Preliminary plot: seems to be working

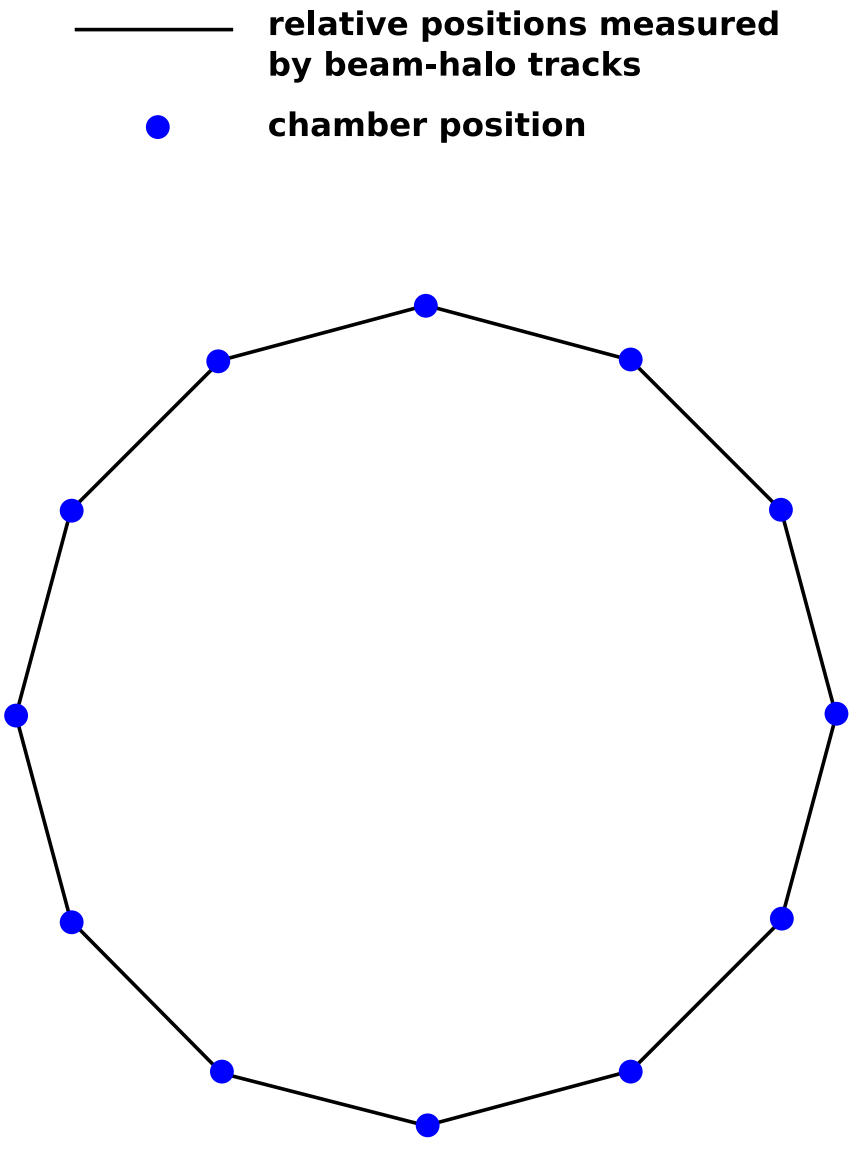


- Lower efficiency on the top of CMS ($\phi > 0$) than bottom: more like CRAFT-08 than CRAFT-09
- Low statistics is an issue for some rings (especially MEx/1)

Conclusions

- For now, using track closure as a measurement of ring-radii
  - assumes CSC widths are well known, and we have $\vec{B} = 0$ data validating that
- Produced a complete set of CSC beam-halo constants, regardless of completeness of rings
  - ME1/1: without PG constraints— missing data lead to piecewise lack-of-constraint
  - all others except ME1/3: aligned *with* PG constraints— formed a mutually consistent solution
  - ME1/3: no overlaps— only PG
- Final constants for next Monday or earlier
- Final sign-off next Wednesday

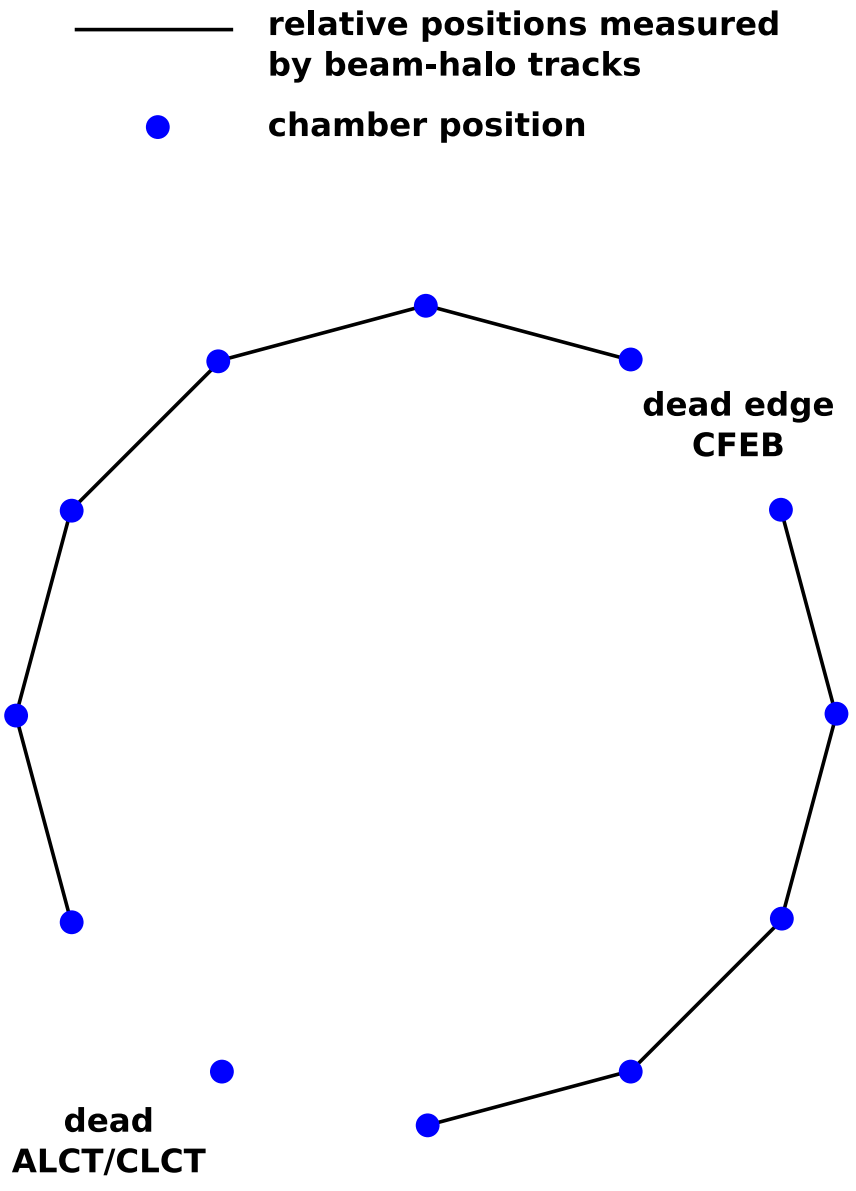
Mathematical framework



- Residuals relate chambers i and $i+1$: for N chambers, that's N equations
- Rotation angle of whole ring cannot be determined, so really only $N-1$ independent equations
- Last constraint is closure:

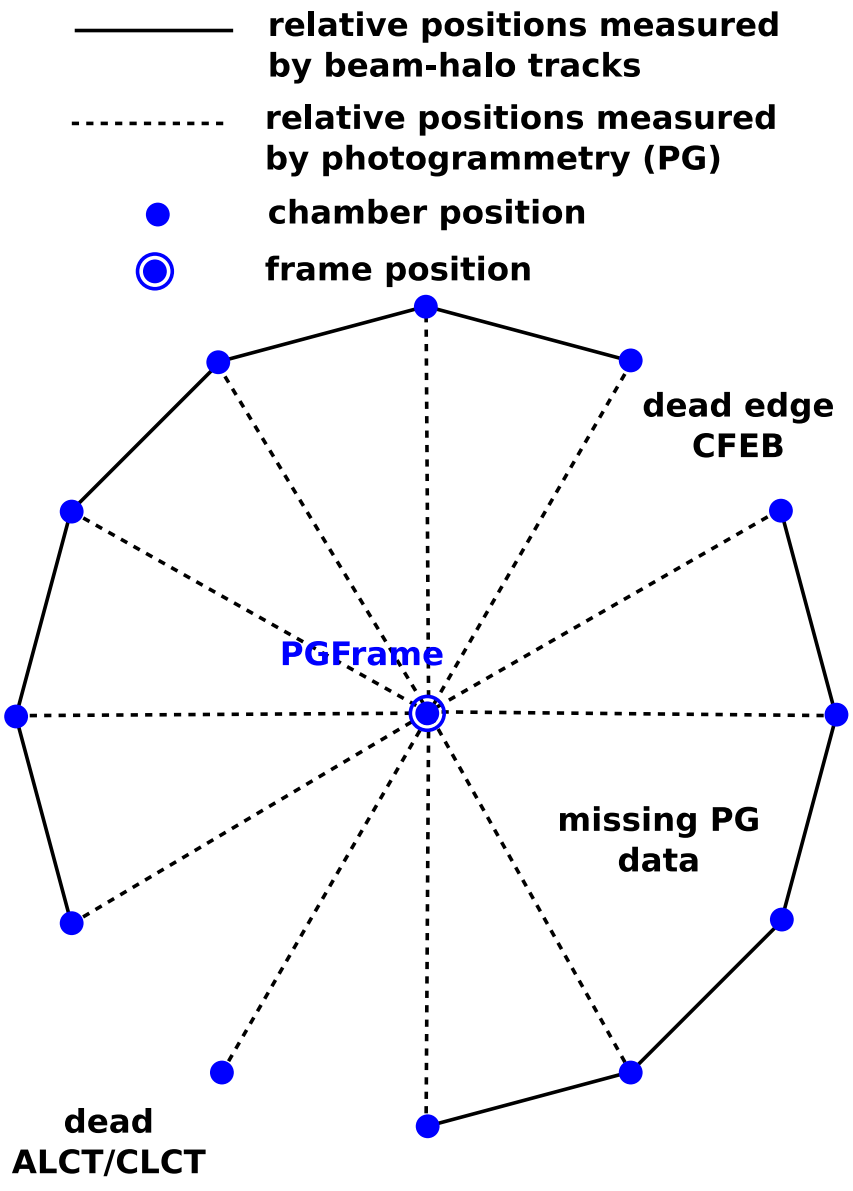
$$\frac{1}{N}\sum_{i}^{N} r_i \text{ should be zero}$$

Mathematical framework



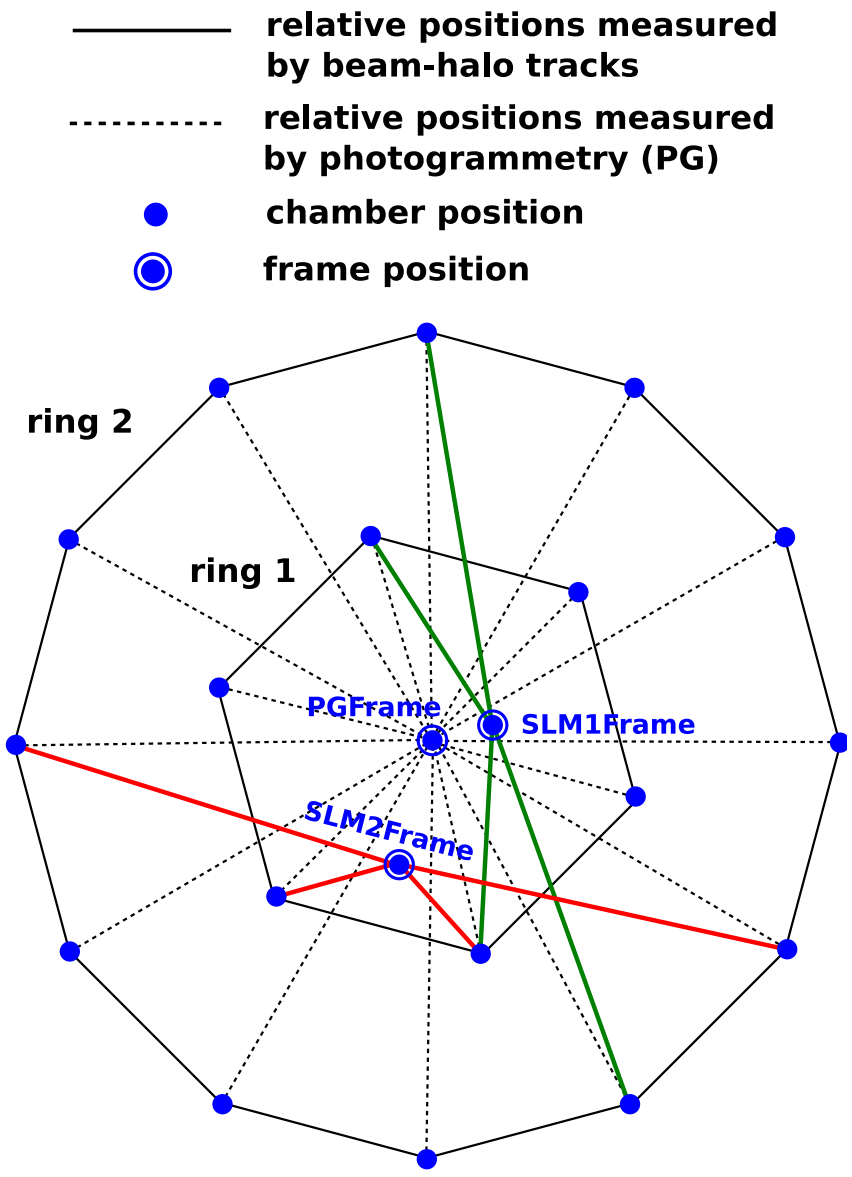
- If one constraint is missing, we could fill in the information by *assuming* closure
- Problem: closure became non-zero when the field was turned on (will revisit later in this talk)
- Another problem: many rings had more than one missing constraint— system is underdetermined
- However, in complete rings we find that photogrammetry (PG) is still accurate: can use PG as a new constraint

Mathematical framework



- New framework to combine beam-halo and PG on an equal footing:
  - generalize equations to relate any i and j
  - PG measurements relate each chamber i with an external frame, a new chamber-like object
- Even with gaps in beam-halo and PG, the system is always constrained or overconstrained (graph is fully connected)

Mathematical framework



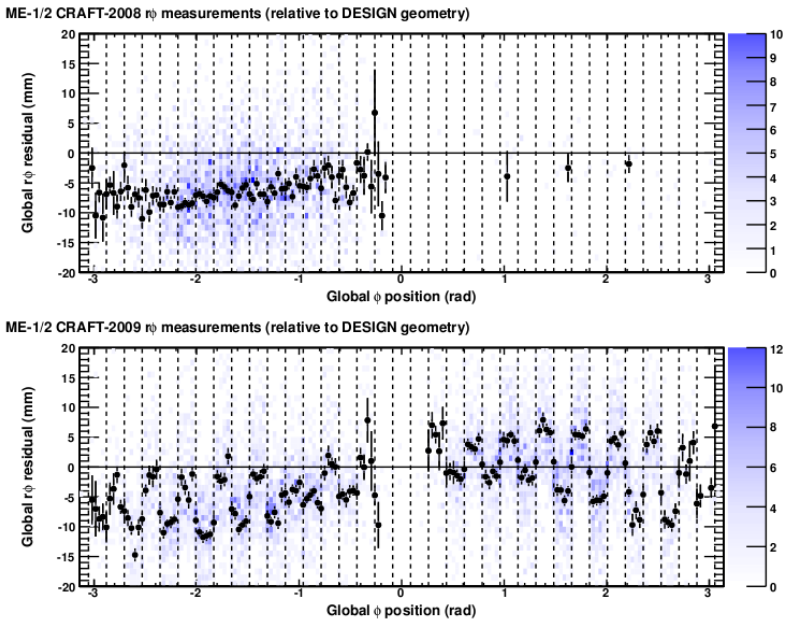
- New framework to combine beam-halo and PG on an equal footing:
  - generalize equations to relate any i and j
  - PG measurements relate each chamber i with an external frame, a new chamber-like object
- Even with gaps in beam-halo and PG, the system is always constrained or overconstrained (graph is fully connected)
- Potential extension (not in this talk): SLMs also relate groups of chambers to frames; I made new software flexible enough to possibly include it

Ring alignment with 2010 data

- We once had issues with low-momentum cosmics: do we still?
- This is all preliminary— literally a first look

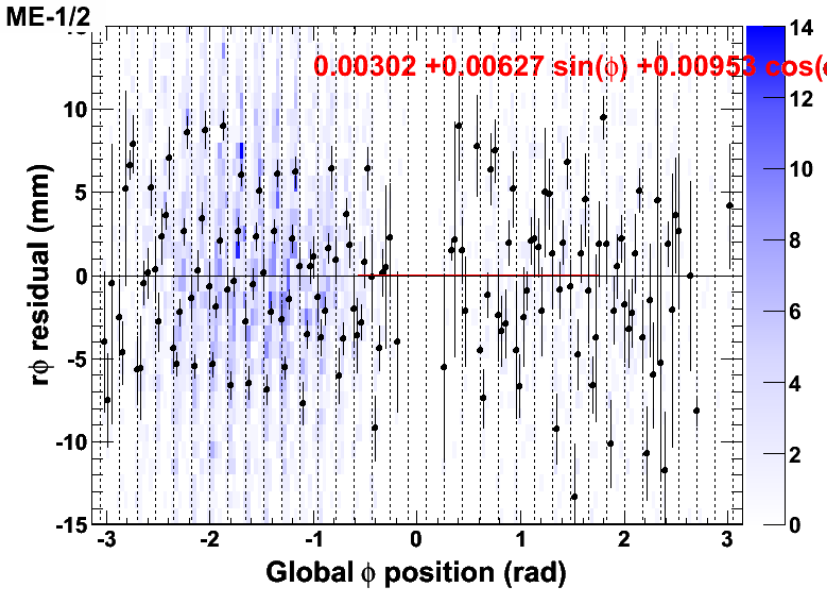
CRAFT-09 and -10

($p_T > 40$ GeV, relative to ideal)



2010 cosmic rays

($20 < p_T < 100$ GeV, relative to -09)



- The even-vs-odd alternation (which was never understood) is gone
- It has been replaced by a residual-vs-ϕ slope in each chamber
  - this effect is also seen in the barrel ("sawtooth effect")