CSC Beam-Halo Alignment

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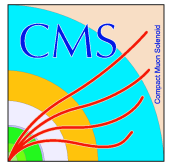
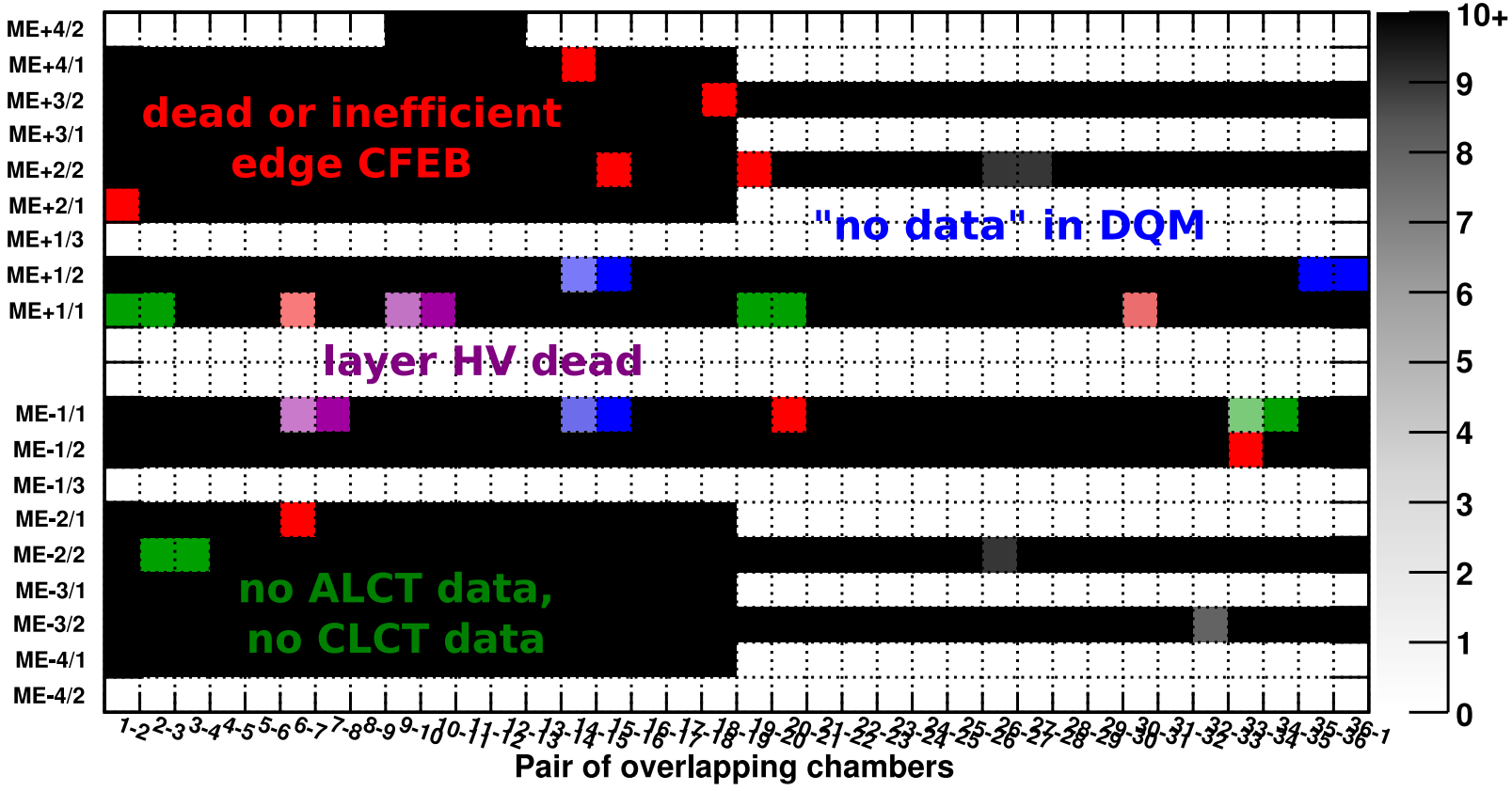
Outline



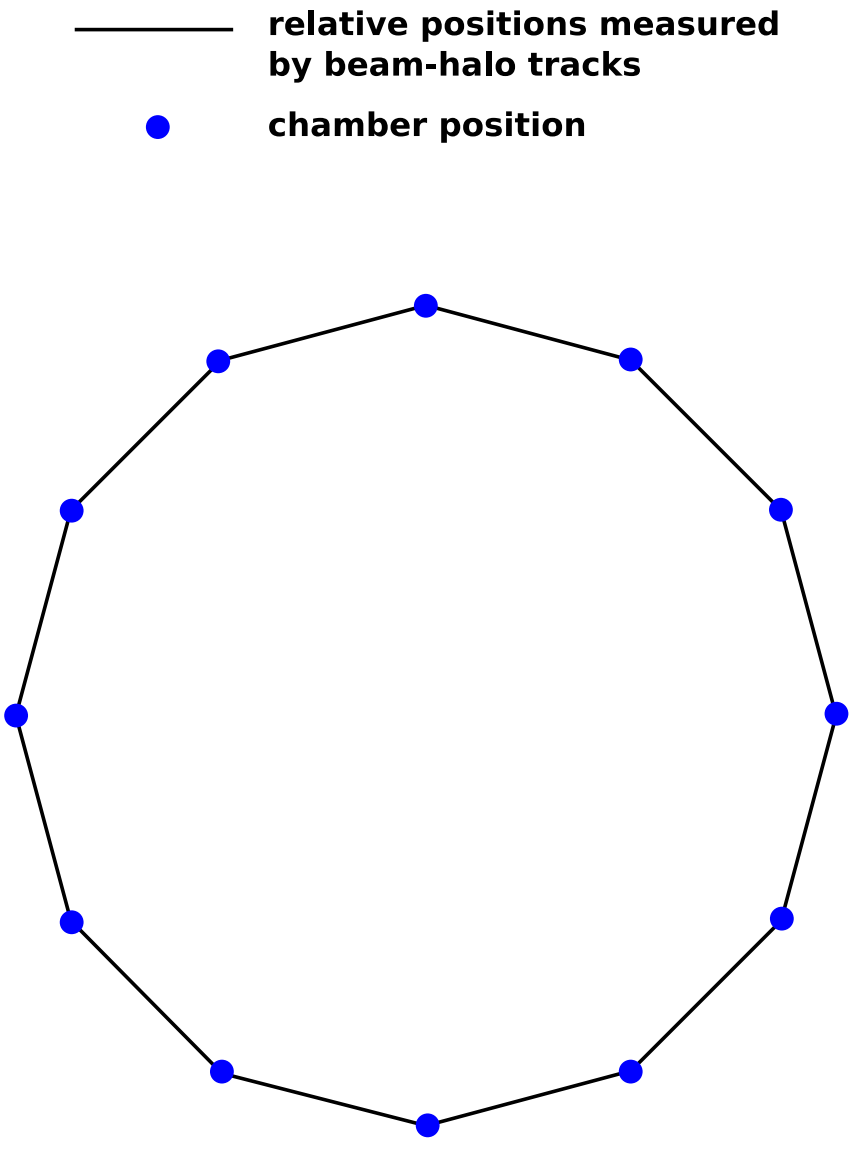
- Method to align all rings, not just complete ones
- Ring-radius corrections
- New constants
- Error analysis

Reminder



- We can't rely on reading out data from all CSC edges
- Old procedure relied on complete rings for a full set of equations
- That left only 4 alignable rings— not acceptable

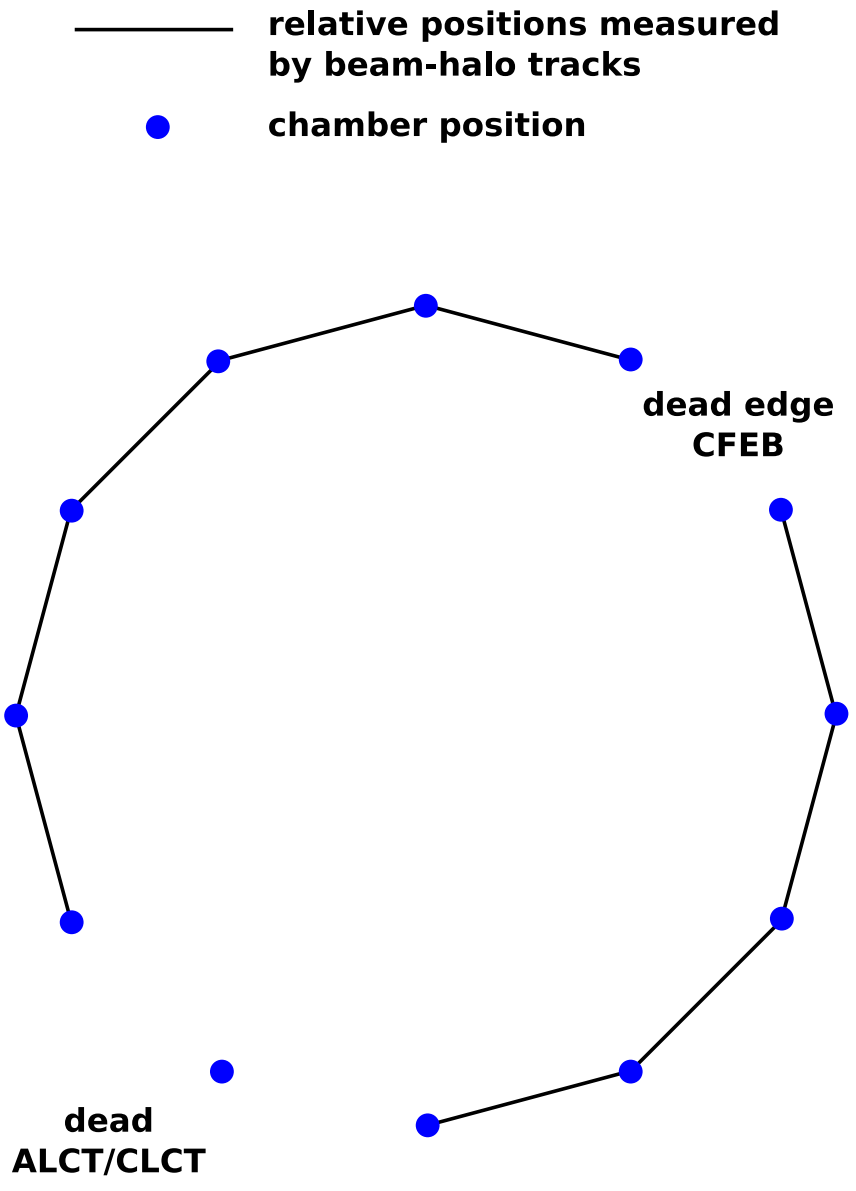
Mathematical framework



- 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:

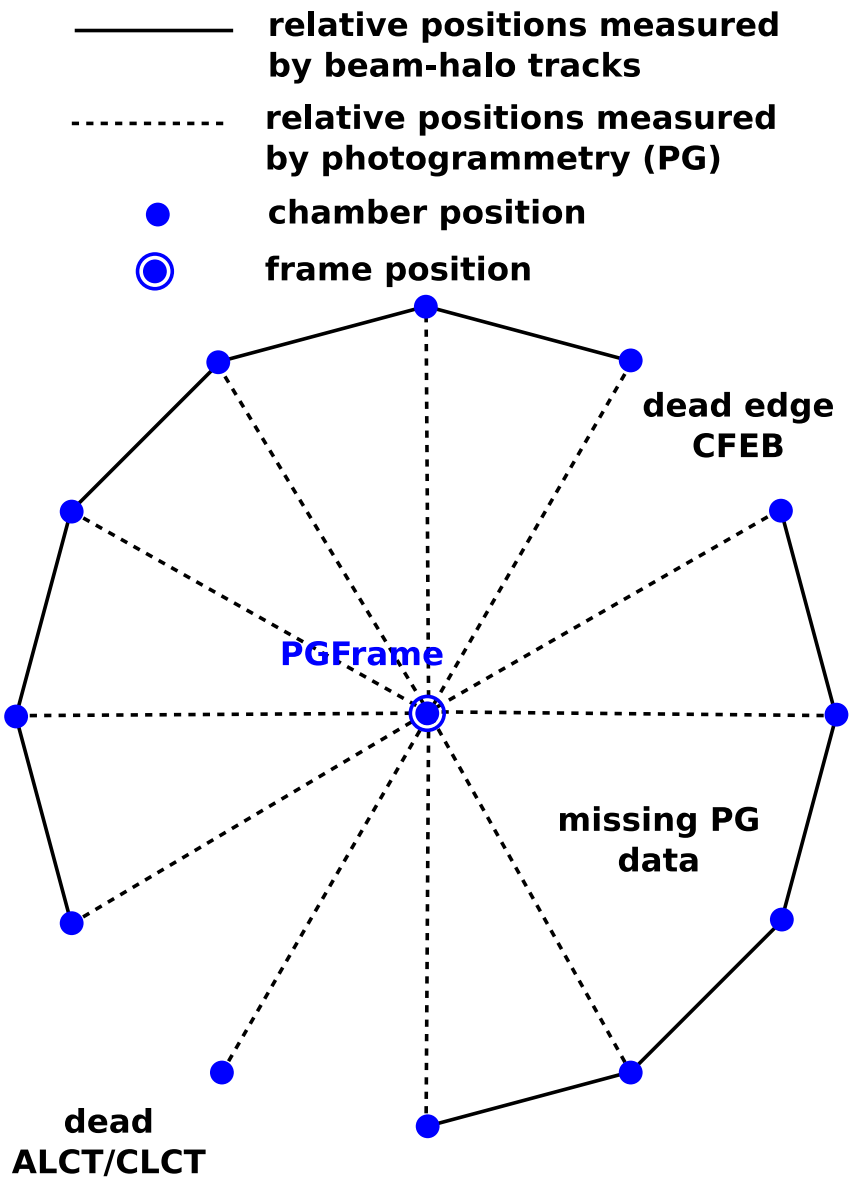
$$\frac{1}{N}\sum_{i}^{N} r_i \text{ should be zero}$$

Mathematical framework



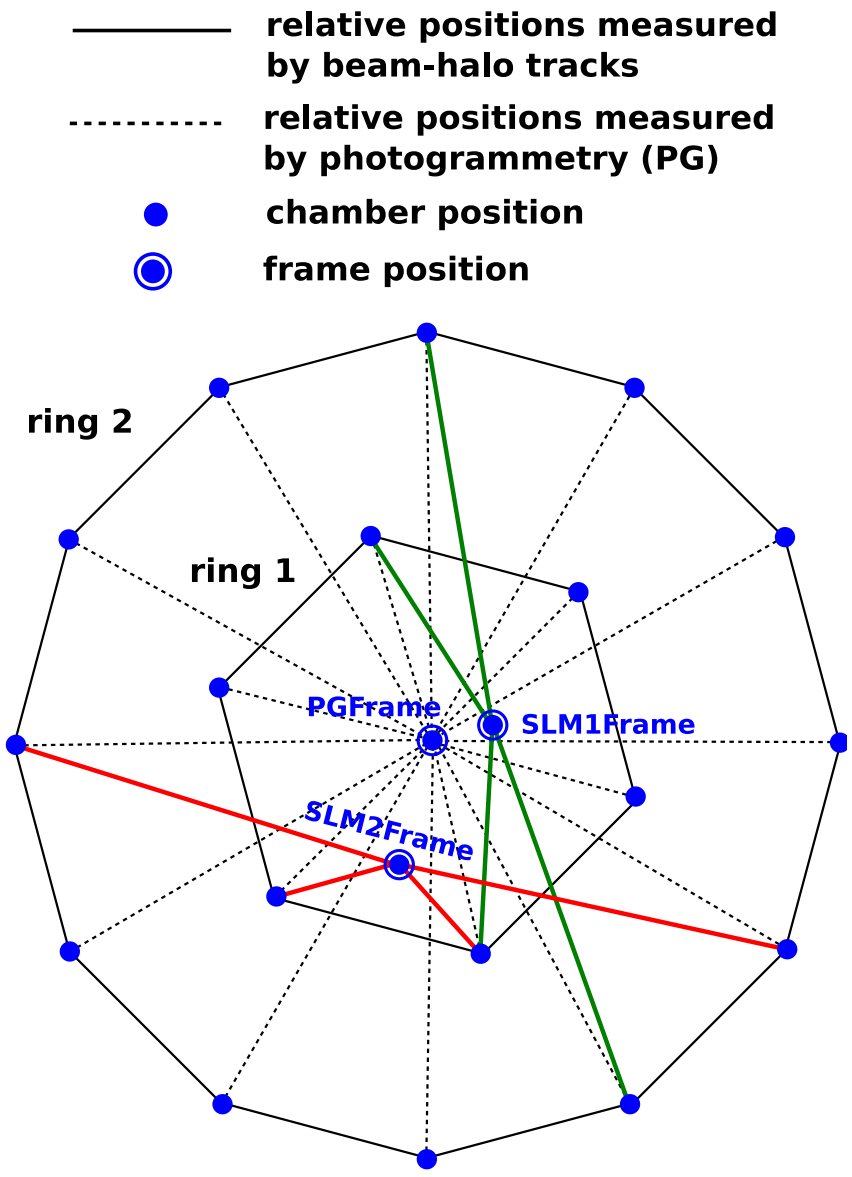
- If one constraint is missing, we could fill in the information by *assuming* closure
- Problem: closure became non-zero when the field was turned on (will revisit later in this talk)
- Another problem: many rings had more than one missing constraint— system is underdetermined
- However, in complete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

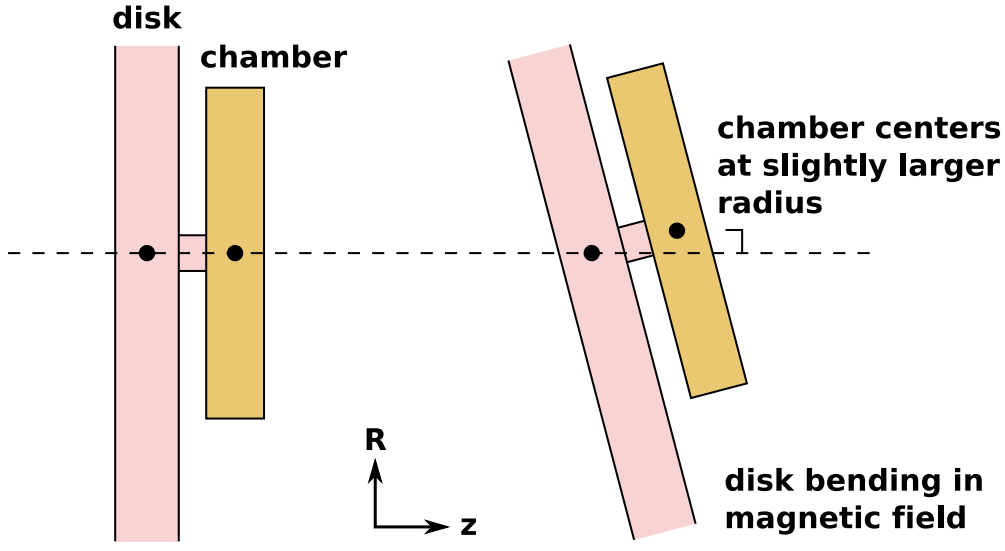
Mathematical framework



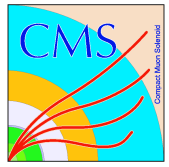
- New framework to combine beam-halo and PG on an equal footing:
  - generalize equations to relate any i and j
  - PG measurements relate each chamber i with an external frame, a new chamber-like object
- Even with gaps in beam-halo and PG, the system is always constrained or overconstrained (graph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

Radius corrections

- Closure constraint in 2008 $\vec{B} = 0$ data uncovered detector width issue
- Shape of individual chambers has not changed (in reality and software)
- New data with full $\vec{B}$ has non-zero closure, independent of momentum
- Non-zero closure is equivalent to either incorrect detector widths *or* incorrect ring radius
- Disk bending *does* change ring radius, since chamber centers are displaced in z from the disk: rotation is around a point outside the chamber



Radius corrections



- Oleg did a back-of-the-envelope calculation and predicted that including this effect would account for half of the observed discrepancy
- Putting these numbers into the full reconstruction (accounting for the fact that even- and odd-numbered chambers have different length posts) yields Oleg's prediction

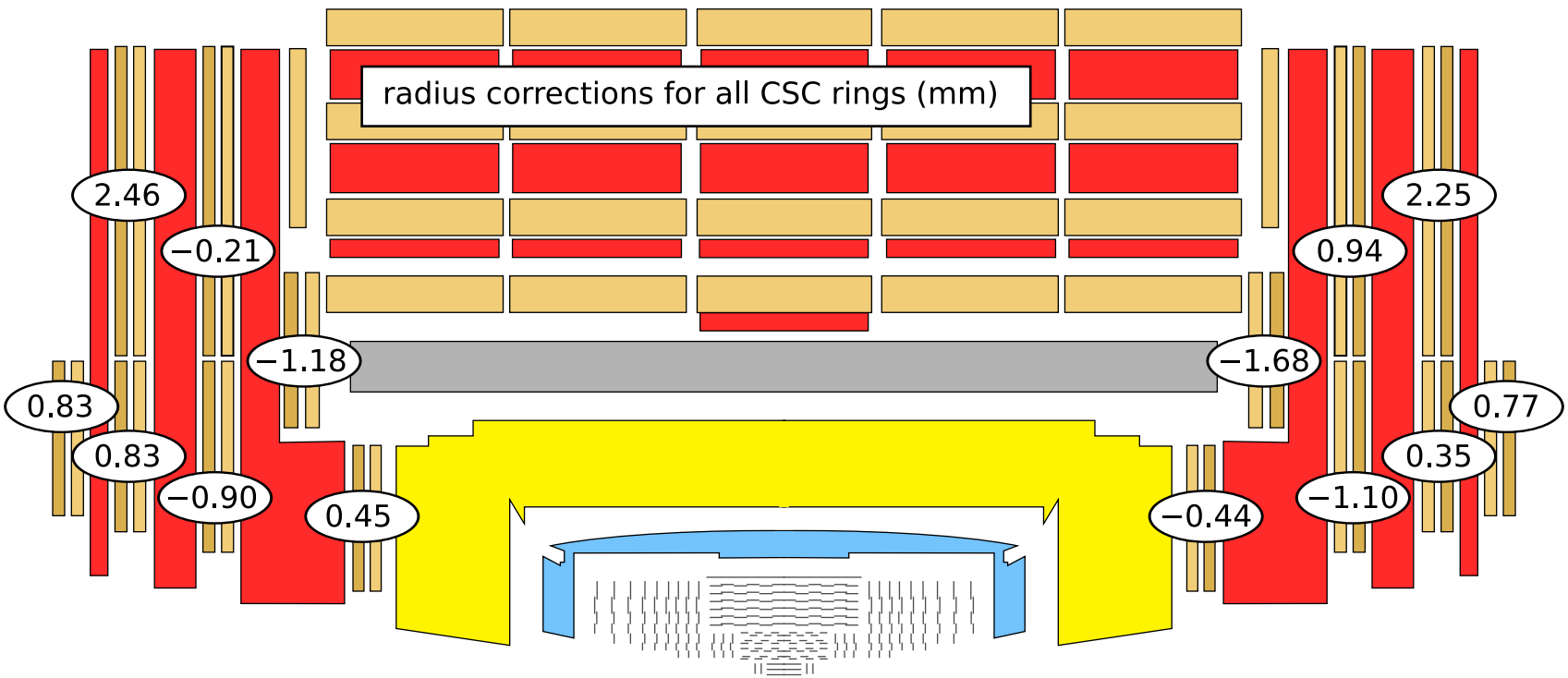
	2008 (no $\vec{B}$)	2010 (full $\vec{B}$)	corrected 2010
ME+3/1		+298 mm	$+100 \pm 9$ μm
ME−2/1	-40 ± 23 μm		
ME−3/1	-20 ± 28 μm	+486 mm	$+278 \pm 9$ μm
ME−3/2		+572 mm	$+446 \pm 27$ μm
ME−4/1		+440 mm	$+267 \pm 10$ μm

Radius corrections

- We can calculate approximate closure of incomplete rings by averaging the residuals we do see:

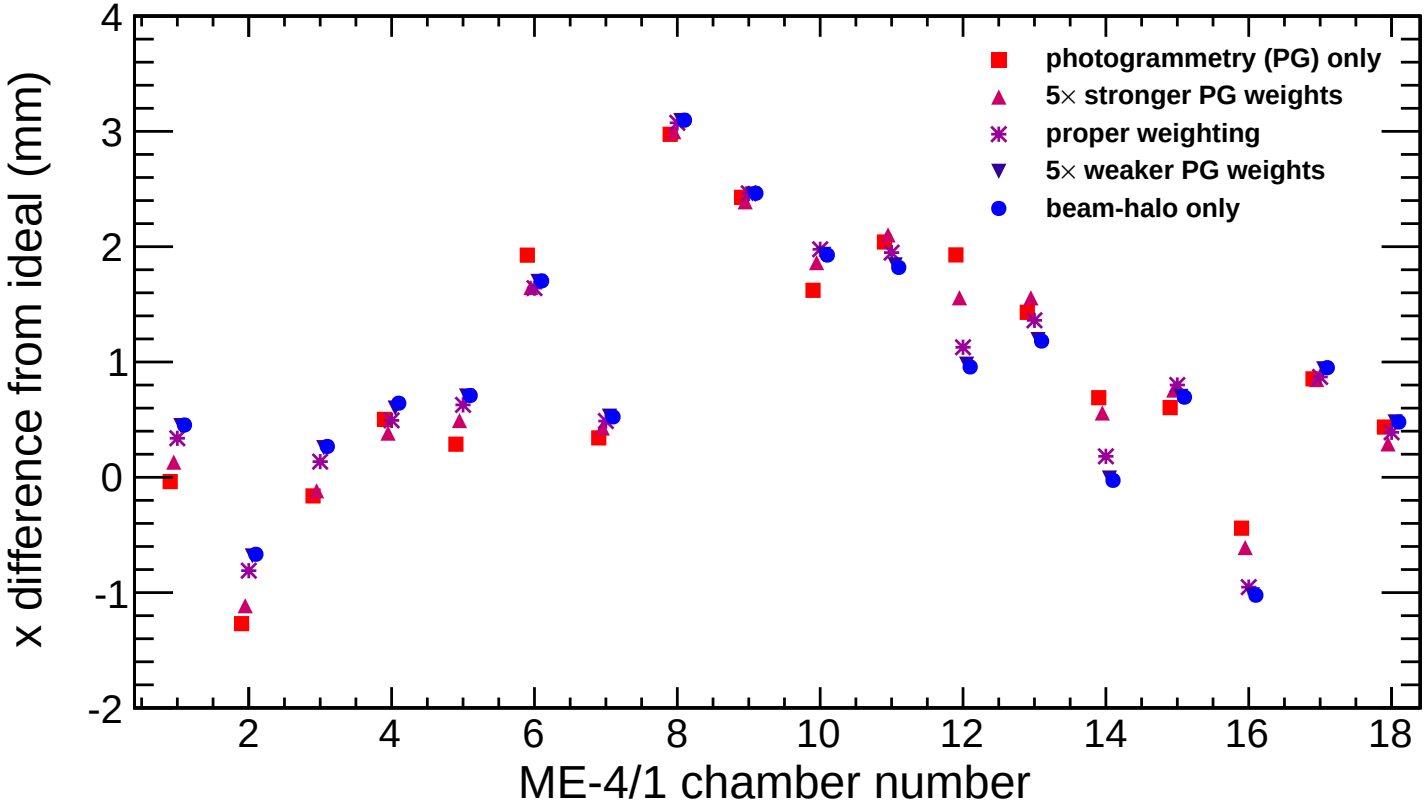
$$c = \frac{1}{N_{\text{visible}}} \sum_{i}^{N_{\text{visible}}} r_i \approx \frac{1}{N} \sum_{i}^{N} r_i \qquad \Delta\text{radius} = \frac{c \times N}{2\pi}$$

- Pattern has a compelling symmetry/antisymmetry: strongly suggests a real effect (for which we don't have a complete model)



New constants

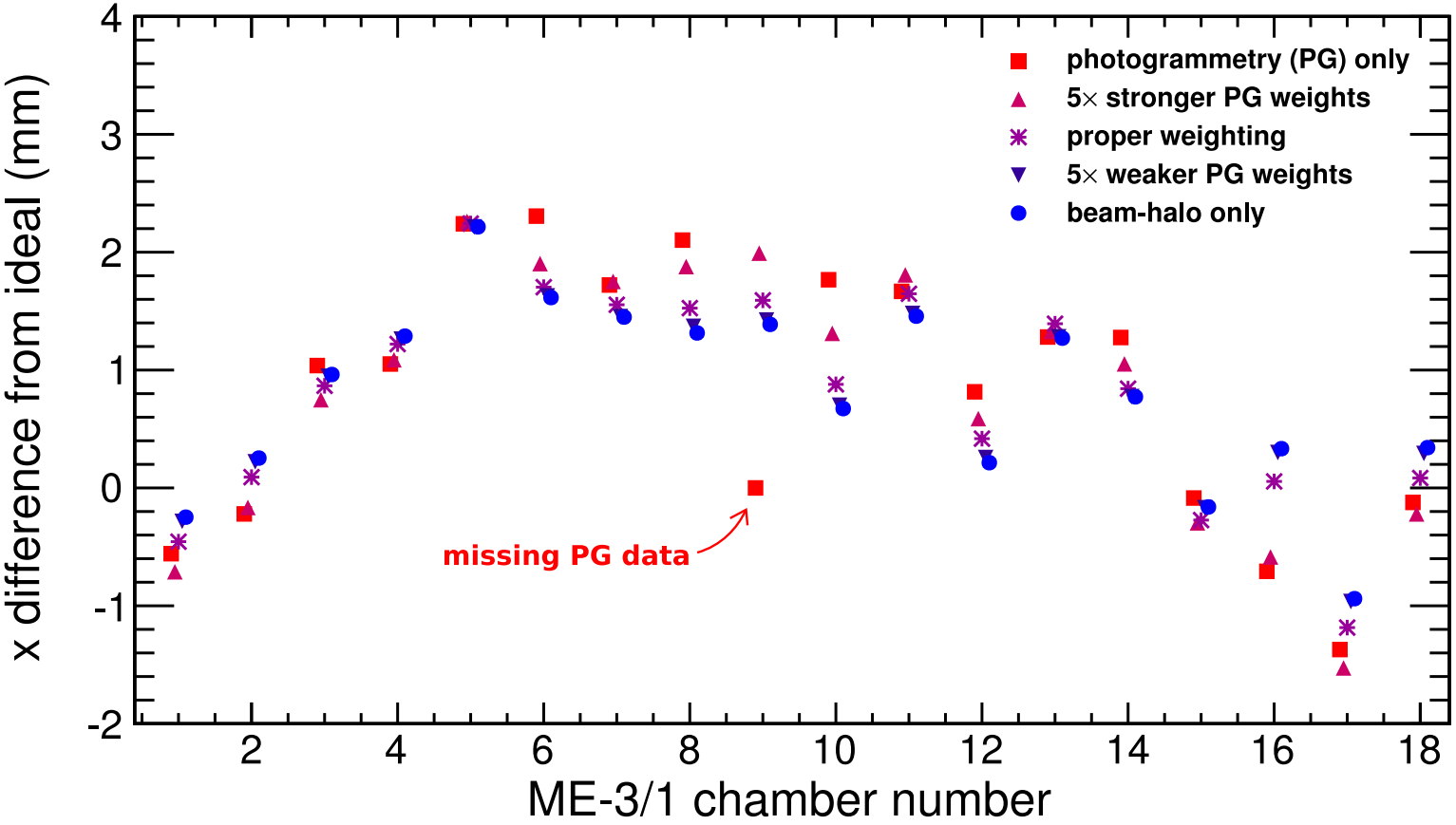
- If we apply the observed closures as *measurements* of ring radii, we can move on to align $r\phi$ and ϕ_z of all CSCs (except ME1/3)
- Let's look at some of the $r\phi$ alignment results, given the new radii



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

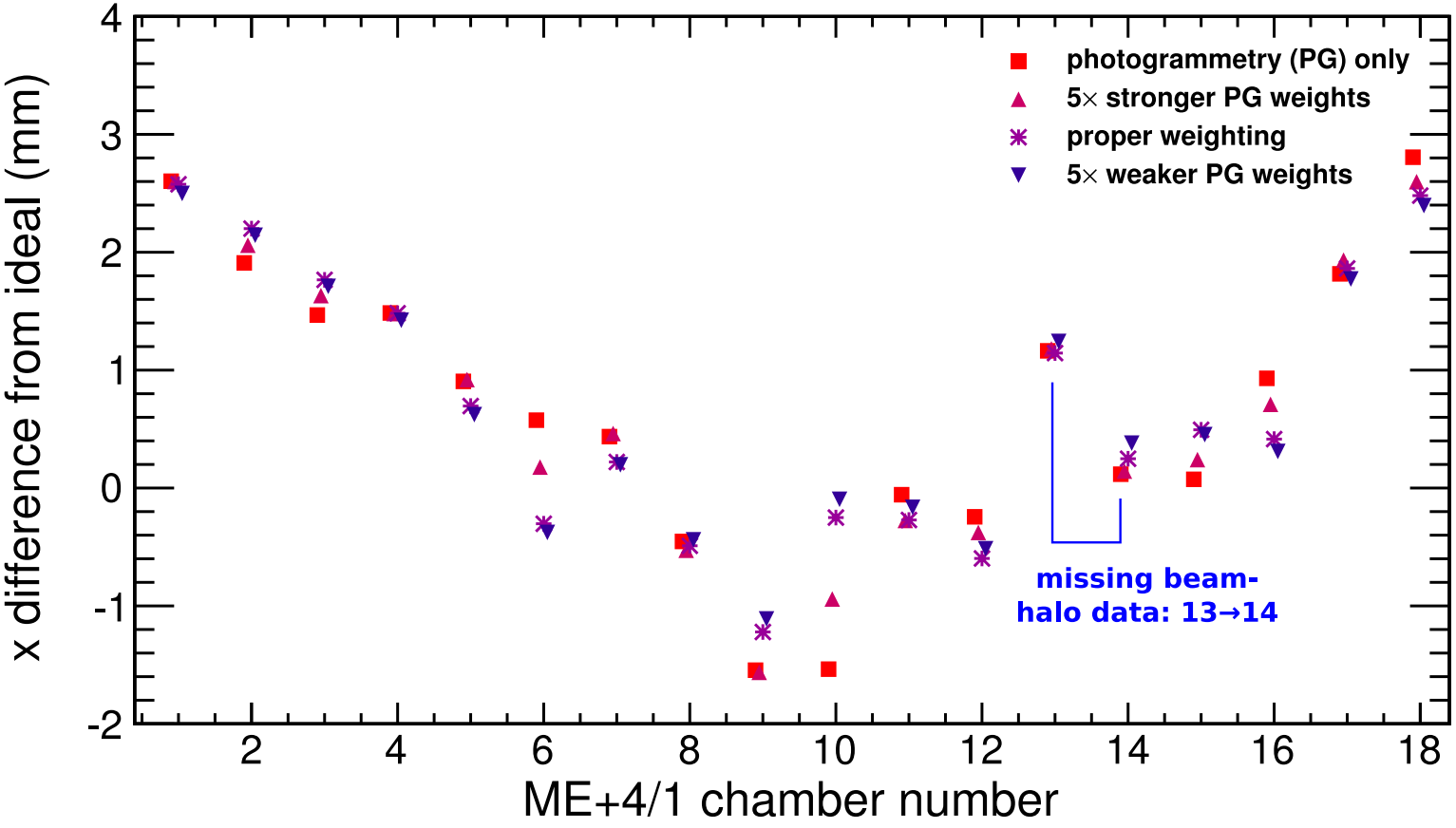
New constants

- 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



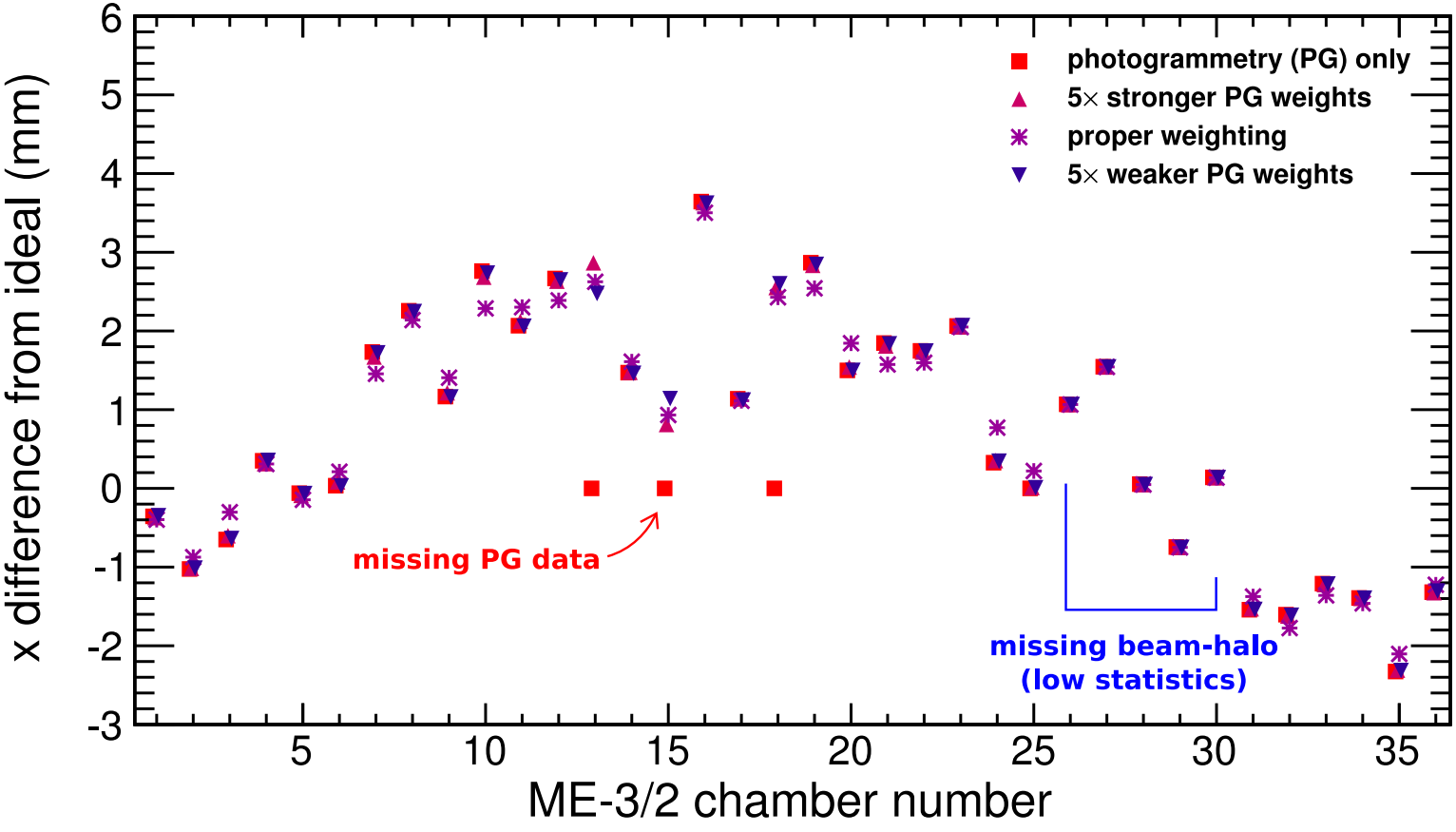
New constants

- 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



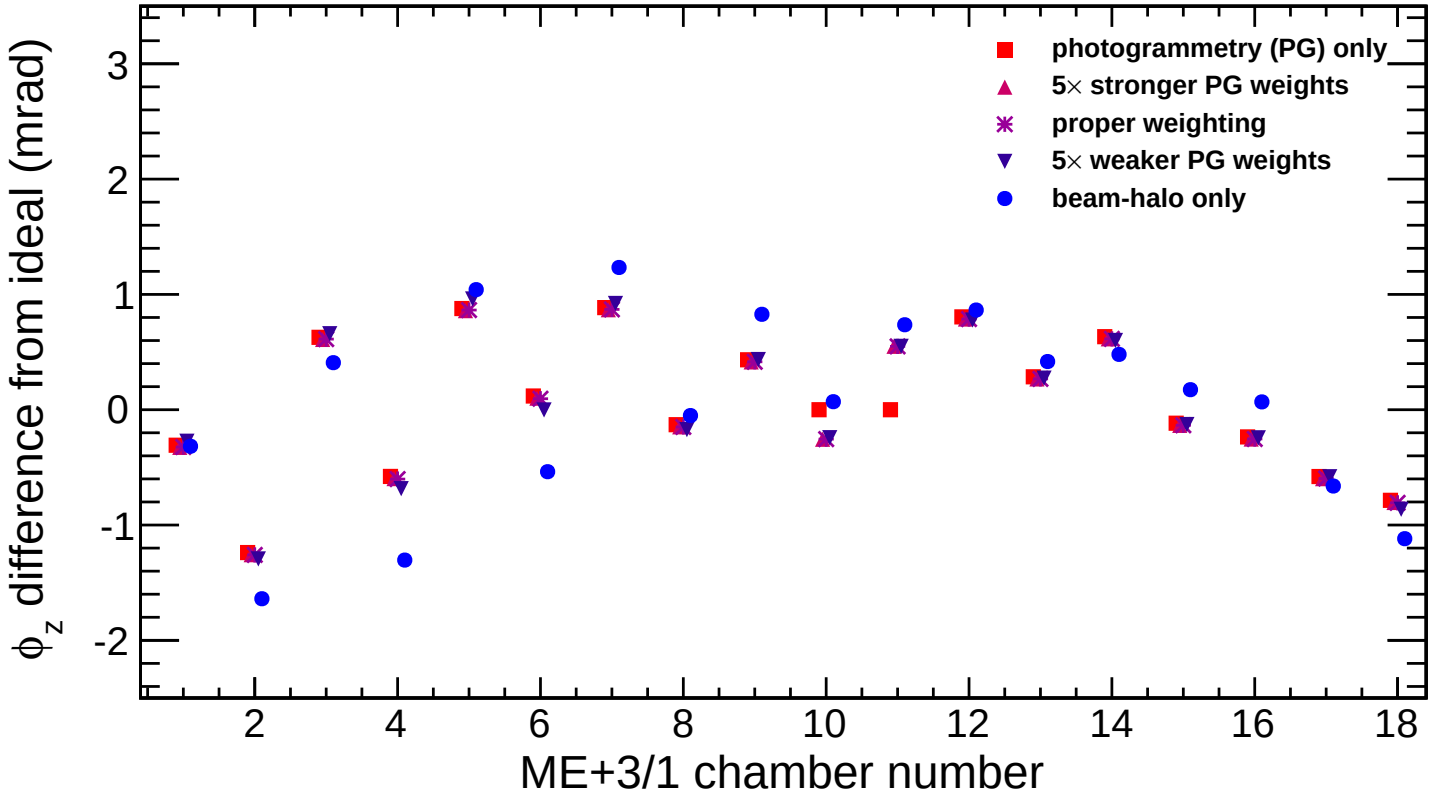
New constants

- 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

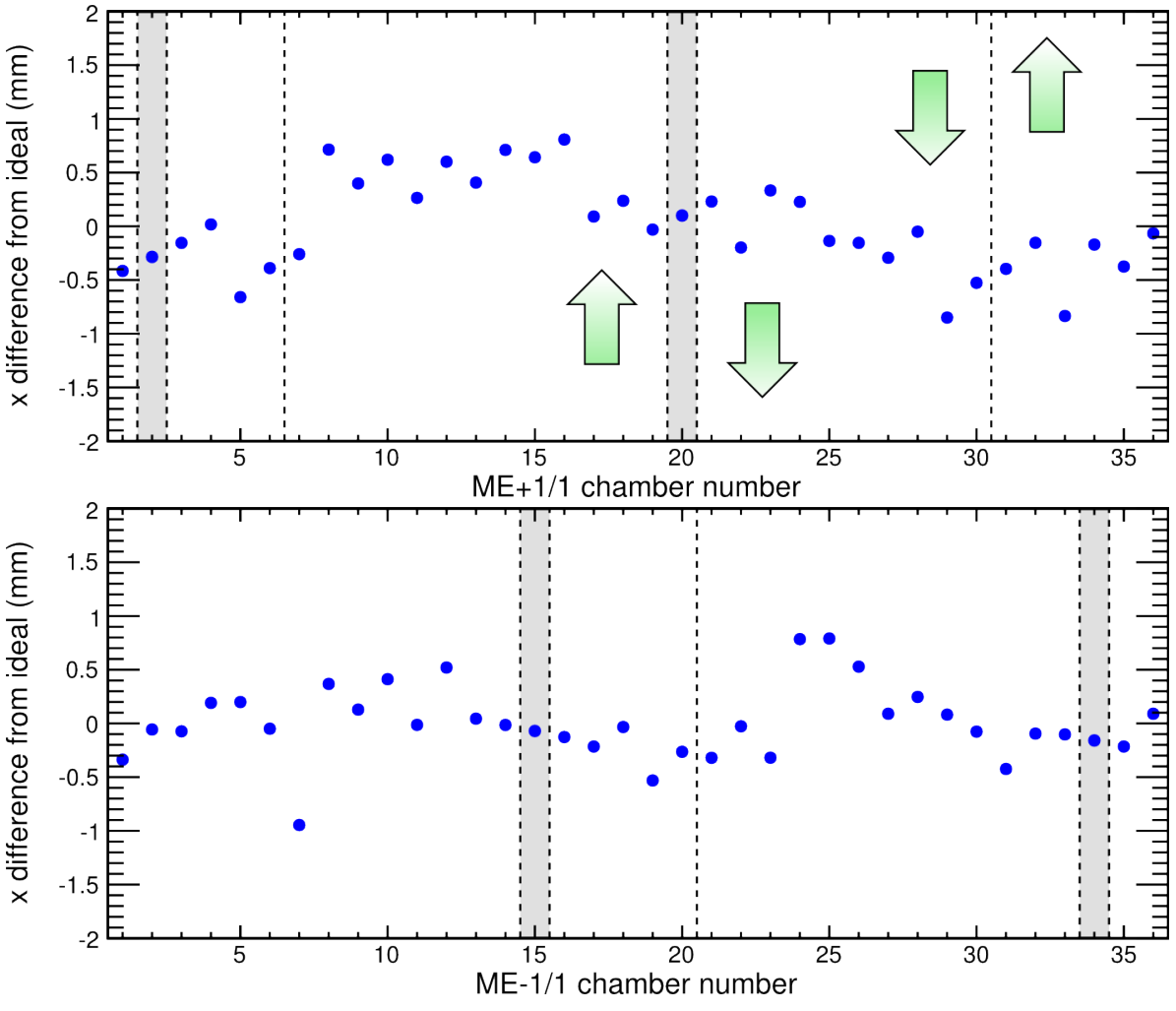
- Also works for ϕ_z rotation angle



- 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)

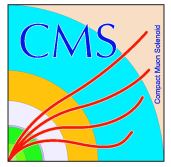
New constants

- ME1/1 is a special case: no PG constraints available, and some chambers are missing (alignment graph is not fully connected)



- 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
- ME1/1 geometry is very nearly ideal

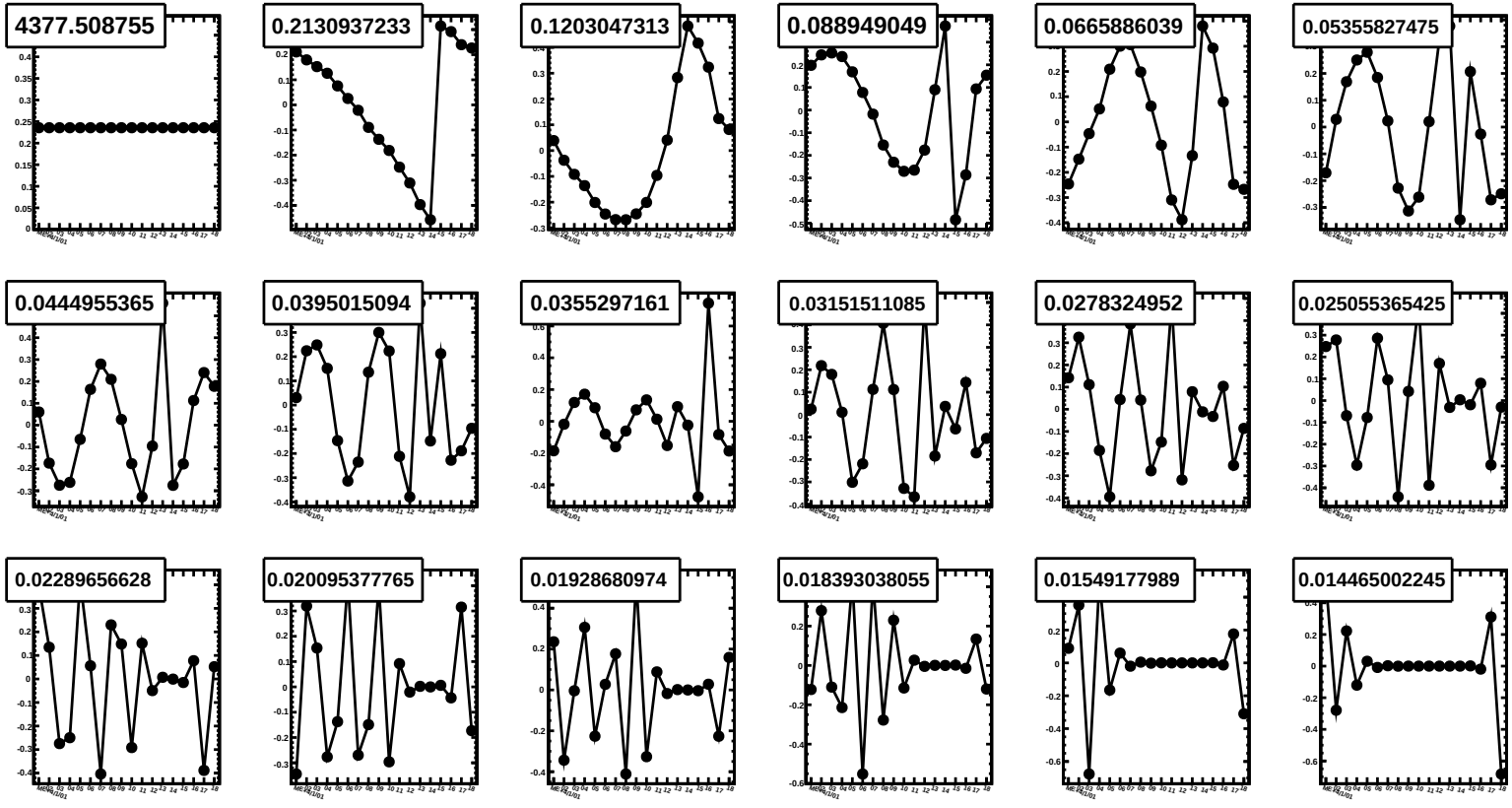
Error analysis



- What is the uncertainty in chamber positions?
- . . . a complicated question because chamber uncertainties are highly correlated by the system of equations
- However, the equations can be represented as a matrix, and that matrix can be diagonalized to identify a basis of linearly-independent combinations of alignment parameters
- These are "modes": modes with small uncertainties are strong modes, modes with large uncertanties are *weak modes*
- There are as many modes as there are chambers in the alignment

Error analysis

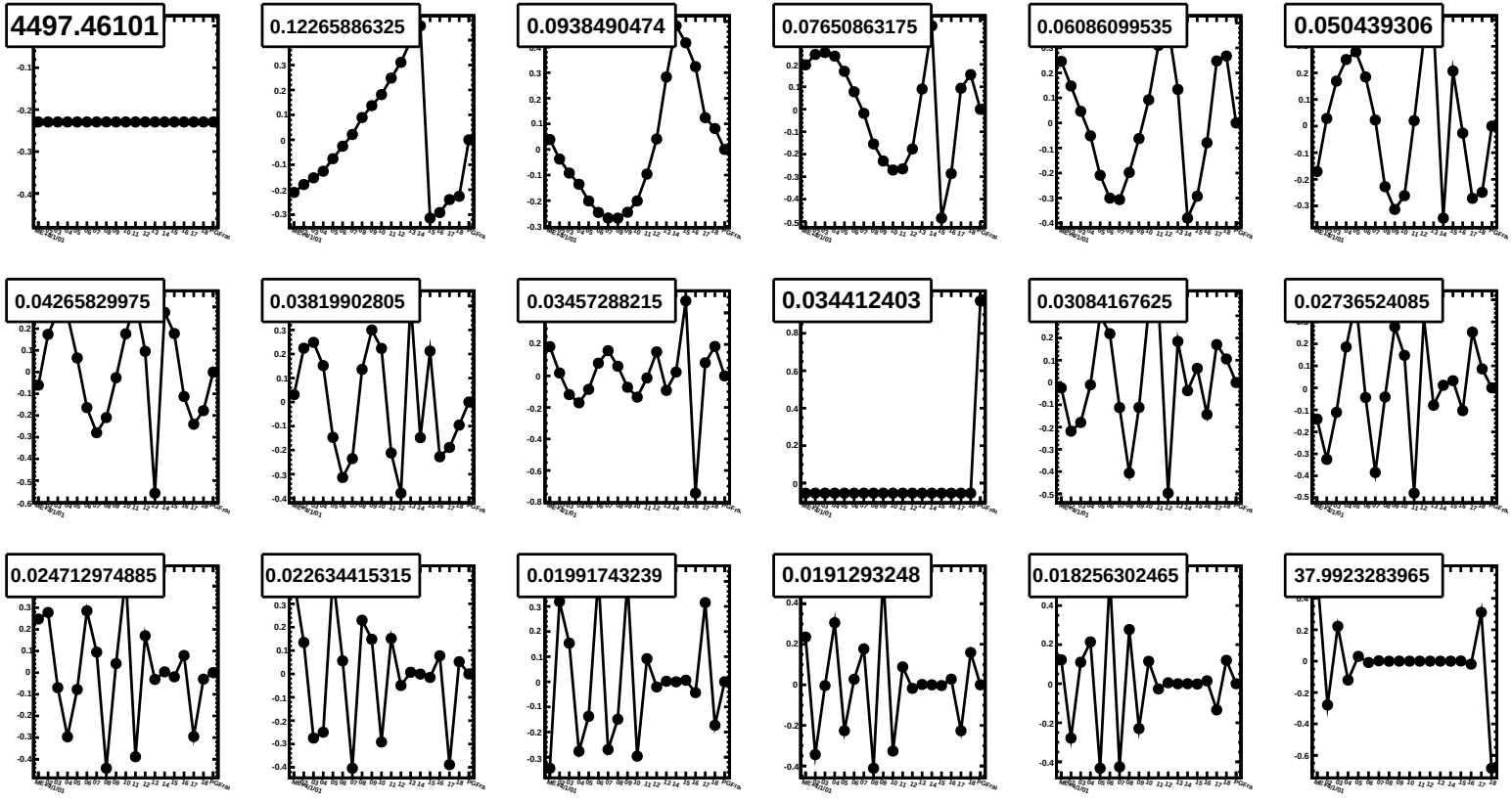
- Uncertainty in each mode (mm) for ME+4/1 with a plot of the mode as normalized eigenfunction versus chamber number



- First mode is uncertainty in the position of the whole ring, proportional to an arbitrary constant λ (set to a large number)
- Whole ring position (relative to tracker) requires external globalMuons

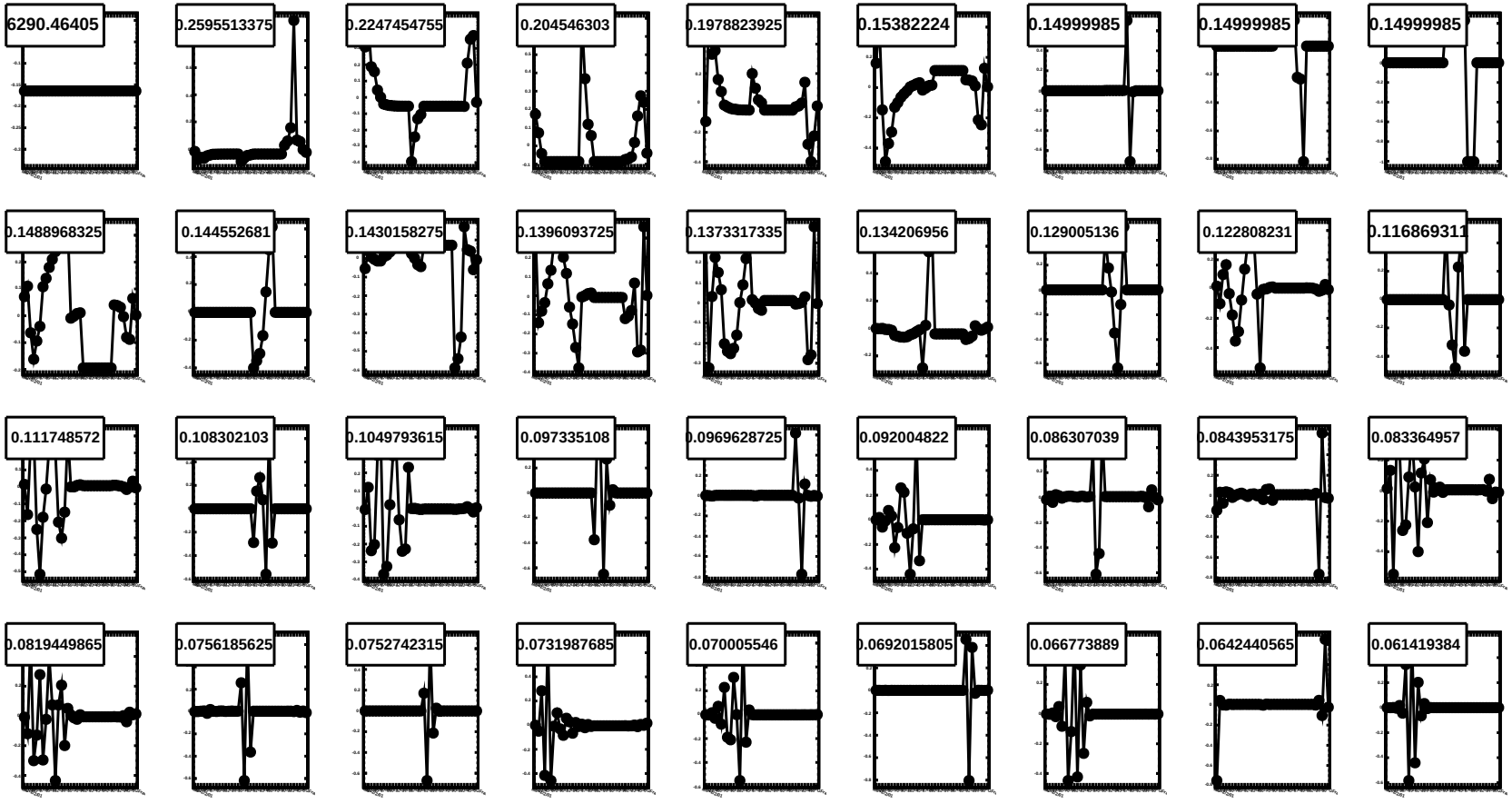
Error analysis

- Uncertainty in each mode (mm) for ME+4/1, this time wtih PG constraint: "PGFrame" is last point, right edge of plot window



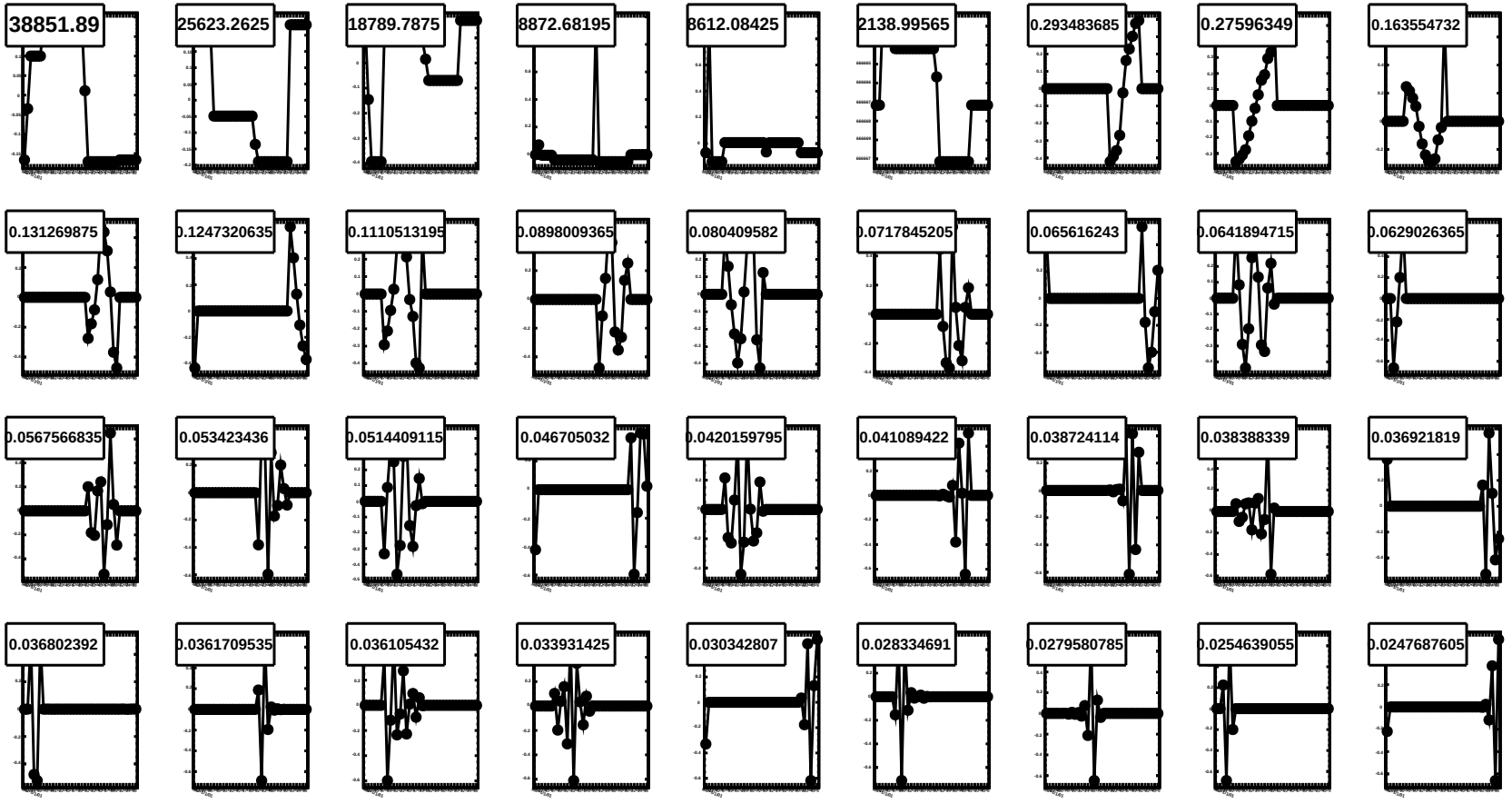
Error analysis

- A bigger example: ME+2/2
- The largest meaningful uncertainty is 0.26 mm



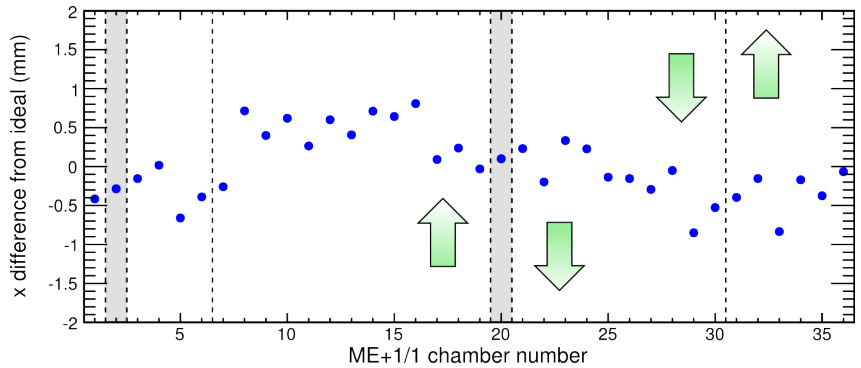
Error analysis

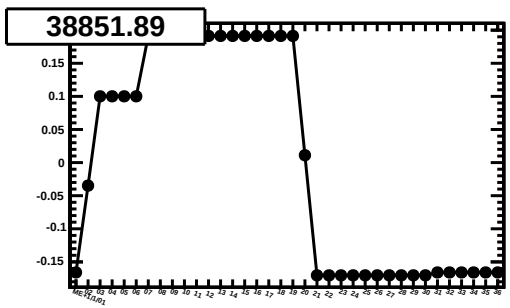
- The special case: ME+1/1
- The first 6 modes are proportional to λ, indicating separate sections

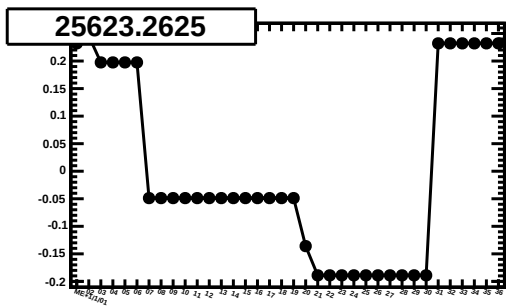


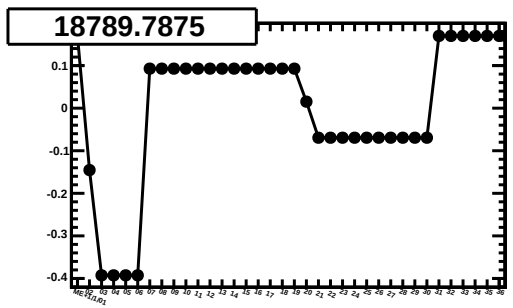
Error analysis

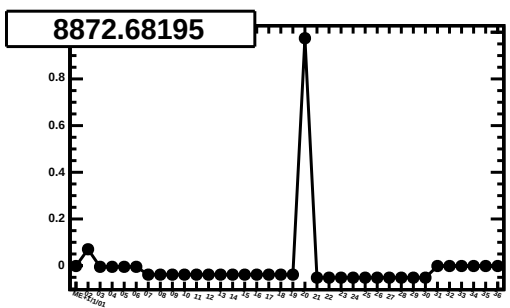
- Remember that ME1/1 has break-points with missing data (no PG and missing chambers for beam-halo)
- These modes describe arbitrary positions of each of the sections relative to the others: just a reminder that we'll need to align the sections as rigid bodies later

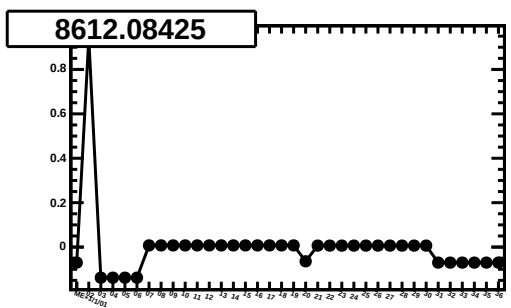


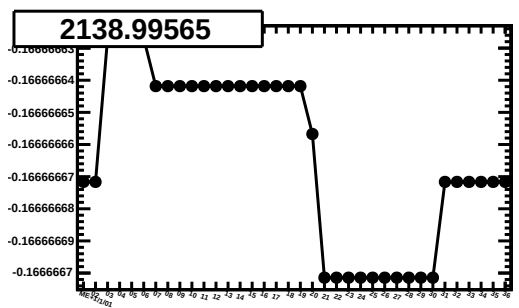




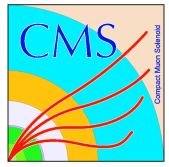








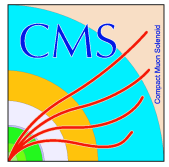
Error analysis



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

ring	largest mode (mm)	sum in quadrature (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

Conclusions



- Missing chambers forced a re-formulation of beam-halo alignment
- Complete rings reveal that PG is still valid; use PG as a constraint
- Need to interpret non-zero closure as radial corrections, but they form a suggestive pattern in the two endcaps
- Beam-halo + PG combination has the right limits as weight of PG constraint is varied
- Statistical uncertainty in the result can be calculated by decomposing into modes (a few hundred microns)
- ME1/1 ring is incomplete, only aligned in sections
- Whole rings (and ME1/1 sections) will need to be aligned relative to the tracker with globalMuons; work on this using CRAFT-10 cosmics is underway, following same procedure as CRAFT-09