Evaluation and Optimization of Orbit Correction System Configuration of 12 GeV CEBAF

Preliminary Results on Steering Configuration Analysis for 12 GeV Arc 8

This is a subset of results obtained by applying an analytical probability-based program to the evaluation and (eventual) optimization of the orbit correction configuration in the 12 GeV Arc 8 design.

Without considerable elaboration it may be hard to convey the precise message contained in the following graphs. I expect this to happen in the form of discussion instead of pages of texts. But it may help to provide some background and a rudimentary description here so these graphs make some minimal amount of sense.

All thoughts, conscious or not, going into orbit correction system designs take into account only linear processes[1]. Thus it is conceivable that its final performance can be characterized entirely in probabilistic language describing events at a certain extent of the standard deviation, by way of robust linear calculations only. The advantage of this approach is that, due to its analytical nature, it reliably and immediately explores the entire parameter space by definition, which can be very taxing if done by simulation. For example, in a system with 1000 sources of errors, which is typical, the parameter space volume to explore is the 1000-th power of some scale factor, roughly speaking[2]. This can imply tremendous demand on computing power and human interpretation. Without going to such extent in simulation, on the other hand, one cannot be sure the worst case scenario has been identified. The analytical method on the other hand is guaranteed to find the worst case at a given multiple of the standard deviation, and thus to unequivocally bless or reject the system based on well-defined numerical criteria, in negligible computation time, provided one can establish robust linear methods to handle the 1000 dimensional matrices. The last criterion is proven quite within reach by the package developed for this purpose. The analytical method has the additional advantages of providing insights into structural defects of the system, affording a logical scheme in which to compare scenarios[3], and identifying directions for improvements, not readily visible from a simulation approach. The graphs in the following pages, based on the most up-to-date Arc 8 optics and steering configuration[4], and the same error distribution as used in DIMAD simulations[5], all came out of this linear probability-based analysis[6,7].

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[1] This is excluding exotic cases in some special systems that do not concern the dominant majority of machines.
[2] Some combinatorial volume-normalizing factors may be present too, granted.
[3] For example, with simulation, extra care must be given to explain away a seemingly fatal outcome based on its possibility of accidentally lying on a, say, 7σ envelope.
[4] Based on most recent Benesch revision to make S/R consistent with 6 GeV.
[5] With a few differences. For example injection errors are used here but not in DIMAD.
[6] The outcome of this analysis package has been verified to agree with high statistics simulation in other cases.
[7] If you are interested in more detail:

- For details and full scope of the methodology see LHC Report 470
- Some condensed versions in talk slides:

The following numbers further illustrate the efficiency of the analytical method. Suppose in a particular case the 4σ extent (99.5% probability) of the underlying post-correction orbit distribution at point A is 1 mm, how many simulation runs will it take to get one instance where this orbit is 1 mm or larger? The table below gives the answer for several cases of the 4σ extents in mm, or different widths of the distribution. The center column merely indicates how many σ's the 1 mm mark corresponds to.

4-sigma extent covering 99% of events (mm)	1 mm extent in units of sigma	No. of runs needed to get one event above 1 mm
0.859567	4.65351	1000
1.00762	3.96975	200
1.09806	3.64277	100
1.21582	3.28995	50
1.30337	3.06897	33
1.3772	2.90444	25
1.4431	2.77181	20

Thus at 4σ extent slightly below 1 mm, one may need to make up to 1000 simulation runs to see the orbit exceed 1 mm, not to mention there is no immediate indication of where this event sits in the 1000-dimensional distribution when it does happen. Even at 4σ extent of 1.1 mm one still needs to run about 100 cases to explore this region of the parameter space. In contrast a comprehensive and coherent representation of the same results, and much more, at every point of the beam line takes only a few minutes via the analytical method.

This document uses the combined 8th Spreader-Arc-Recombiner as example. The same analysis and necessary optimization will be performed on the remainder of the 12 GeV design as more sub-sections are finalized. The result of the latter will be updated in a complementary document.

- CASA Seminar
- ABS Workshop Presentation

- Extensions applied to other systems that may be applicable in future 12 GeV analysis:
  - Extension to 4D Steering
  - Extension to Multiple Lines, which may be relevant to evaluating multi-pass linac steering.

Error distributions, all assumed Gaussian, used in the current analysis[8] are shown in the table below. Some other parameters invoked in the calculation are also included.

Error Type	Used in X	Used in Y	σ	Comment
Injection Position (mm)	√	√	0.25	Not used in DIMAD
Injection Angle (mrad)	√	√	0.025	Not used in DIMAD
Horz. Dipole Field (%)	√		0.02	
Vert. Dipole Field (%)		√	0.02	
Horz. Dipole Roll (mrad)		√	0.267	Not used in DIMAD
Vert. Dipole Roll (mrad)	√		0.267	Not used in DIMAD
Horz. Quad Offset (mm)	√		0.2	
Vert. Quad Offset (mm)		√	0.2	
Horz. Kick from Special Elem. (μrad)	√		5.0	None identified yet
Vert. Kick from Special Elem. (μrad)		√	5.0	None identified yet
Horz. BPM Offset (mm)	√		0.2	
Vert. BPM Offset (mm)		√	0.2	
Horz. BPM Resolution (mm)	√		0.1	Not Used
Vert. BPM Resolution (mm)		√	0.1	Not Used
Horz. Corrector Error (mrad)	√		0.1	Not Used
Vert. Corrector Error (mrad)		√	0.1	Not Used
Parameter Type				
Horz. Corrector Range[9] (mrad)	√		0.360	
Vert. Corrector Range (mrad)		√	0.360	
End Angle Monitor	√	√		

It is worth noting that all calculations in this note are done at the 3σ boundary, as opposed to the 2σ & 6σ options allowed in DIMAD. Since everything is linear, it is straightforward to scale the results to desired multiple of σ. Below is a look-up table for probability content vs. σ.

Sigma	Fraction
1	0.5205
2	0.842701
3	0.966105
4	0.995322
5	0.999593
6	0.999978

[8] Mostly provided by Y. Roblin & Y. Zhang. Additional parameters picked from typical values.
[9] Corrector ranges will be changed according to corrector type and beam momentum.

A. Maximal Underlying Orbit after Correction at 3σ Probability Contour – at All Elements

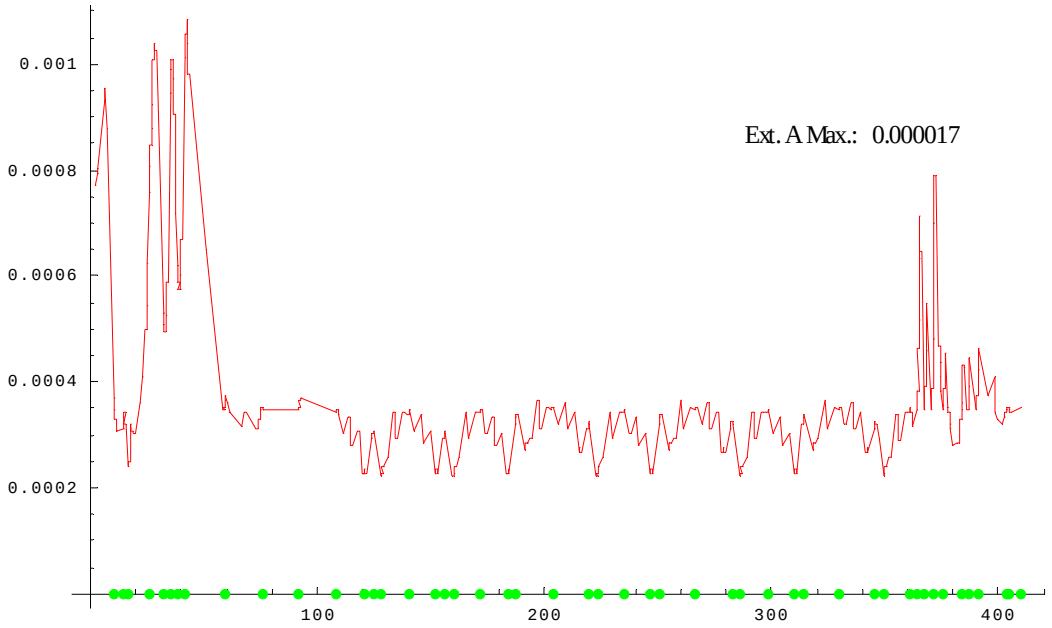
The top graph on the next page shows, at every element of the line, the 3σ extent of the real underlying orbit (as opposed to that apparent on the BPMs) in meters after an SVD-based orbit correction in the X plane, taking into account all error sources (including BPM offsets) on an equal probabilistic footing.

- To anchor orbit at the end, virtual BPM's and beam "angle" monitors playing the role of monitors beyond the line (i.e., South Linac) are included in the analysis.
- The 3σ extent of the real exit angle after correction, an important measure of performance, is also shown printed in the graph to be 17 μrad.
- The first few leading "offenders", or locations with the largest 3σ residual orbits, are further studied in the following graphs. These graphs show the orbit pattern corresponding to each offender, and the composition of errors (lying on the 3σ boundary, of course), as well as corrector strengths, responsible for this pattern. Note that injection errors are also printed. Explanation of all components in the plot will be held off for now.
- Since the process is linear, interpolation/extrapolation is straightforward. For example, if the 3σ (96.6% probability) extent of the real underlying orbit at a point is 3 mm, then its 2σ (84.3% probability) extent of the real underlying orbit at that point is 2 mm, assuming everything is Gaussian, of course.
- The X-plane analysis is followed by that for Y-plane. It should be noted that, besides the periodic peaks in the Arc proper, one of the leading offenders (the 9-th leading) is caused by the inability to handle injection errors coming into the Spreader[10].

[10] Inclusion of dipole or dipole strings for steering can be done under the current scheme of analysis, but has not been done yet.

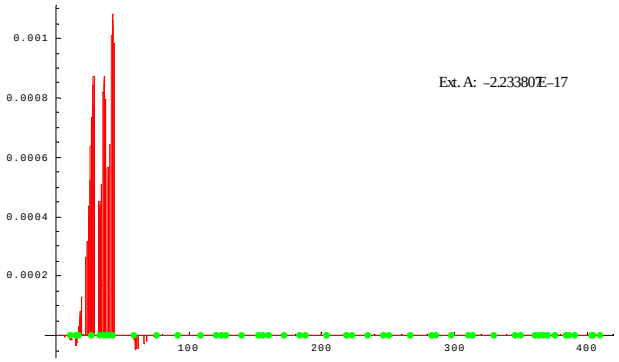
3σ Extent of the Real Underlying Orbit after Orbit Correction in X

Arc8_elem0.errh_BALL_CALL_MO_testX
Maximum underlying corrected orbit at all-elem.

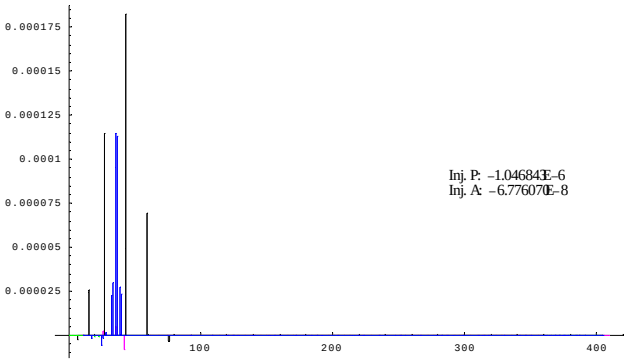


Offending Orbit & Error Composition No. 1

Arc8_elem0.errh_BALL_CALL_MO_testX
Leading underlying corrected orbit at
MQA8S10

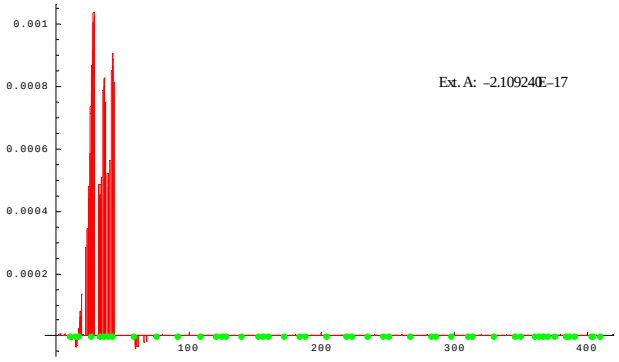


Arc8_elem0.errh_BALL_CALL_MO_testX
Leading error & monitor offset corresp. to Max. per-axis uncorrectable orbit at
MQA8S10

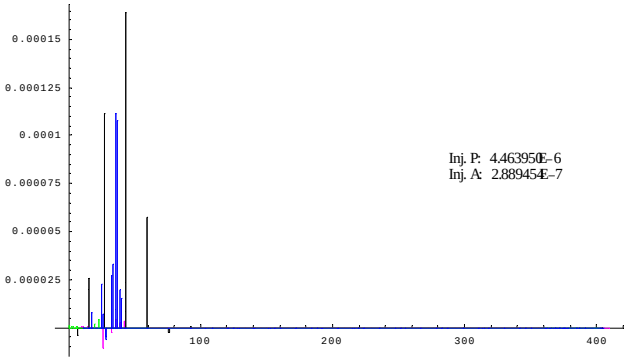


Offending Orbit & Error Composition No. 4

Arc8_elem0.errh_BALL_CALL_MO_testX
Leading underlying corrected orbit at
MQA8S06

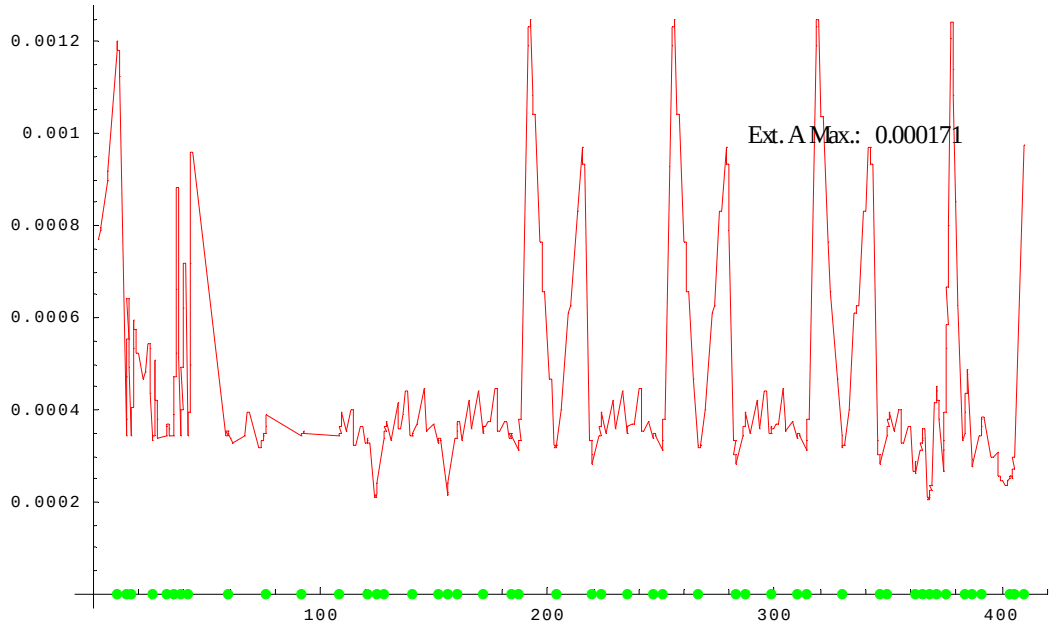


Arc8_elem0.errh_BALL_CALL_MO_testX
Leading error & monitor offset corresp. to Max. per-axis uncorrectable orbit at
MQA8S06



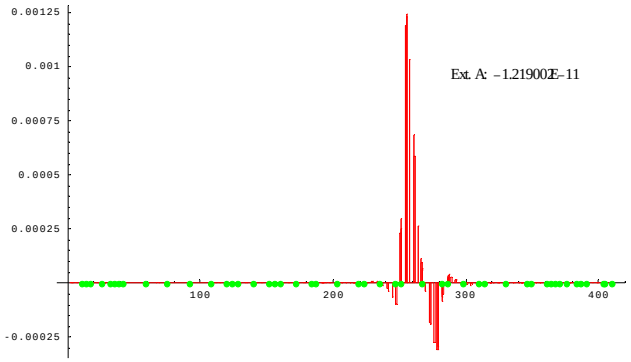
3σ Extent of the Real Underlying Orbit after Orbit Correction in Y

Arc8_elem0.errv_BALL_CALL_MO_testY
Maximum underlying corrected orbit at all-elem.

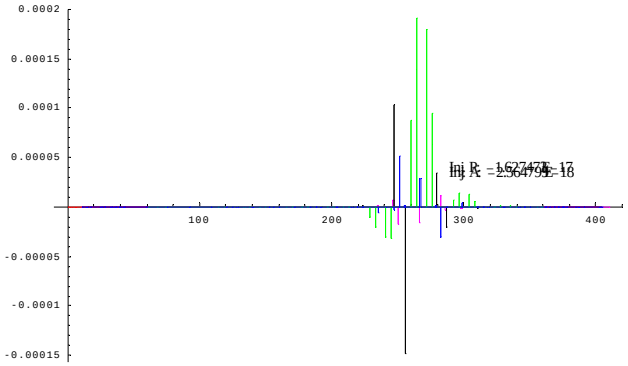


Offending & Error Composition Orbit No. 1

Arc8_elem0.errv_BALL_CALL_MO_testY
Leading underlying corrected orbit at
D133

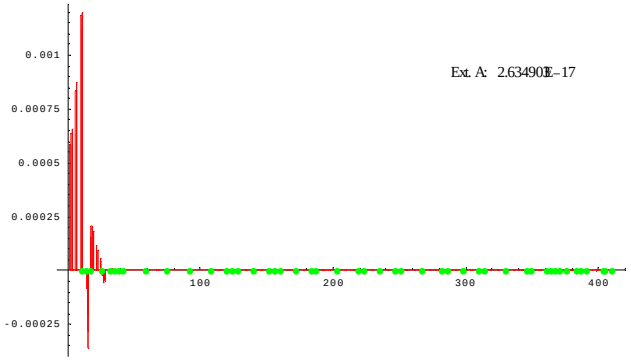


Arc8_elem0.errv_BALL_CALL_MO_testY
Leading error & monitor offset corresp. to Max. per-axis uncorrectable orbit at
D133

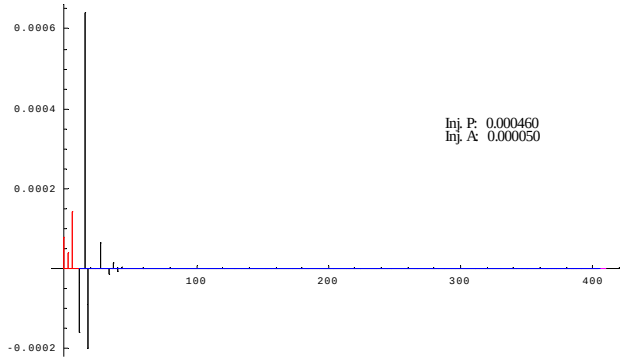


Offending & Error Composition Orbit No. 9

Arc8_elem0.errv_BALL_CALL_MO_testY
Leading underlying corrected orbit at
D5



Arc8_elem0.errv_BALL_CALL_MO_testY
Leading error & monitor offset corresp. to Max. per-axis uncorrectable orbit at
D5

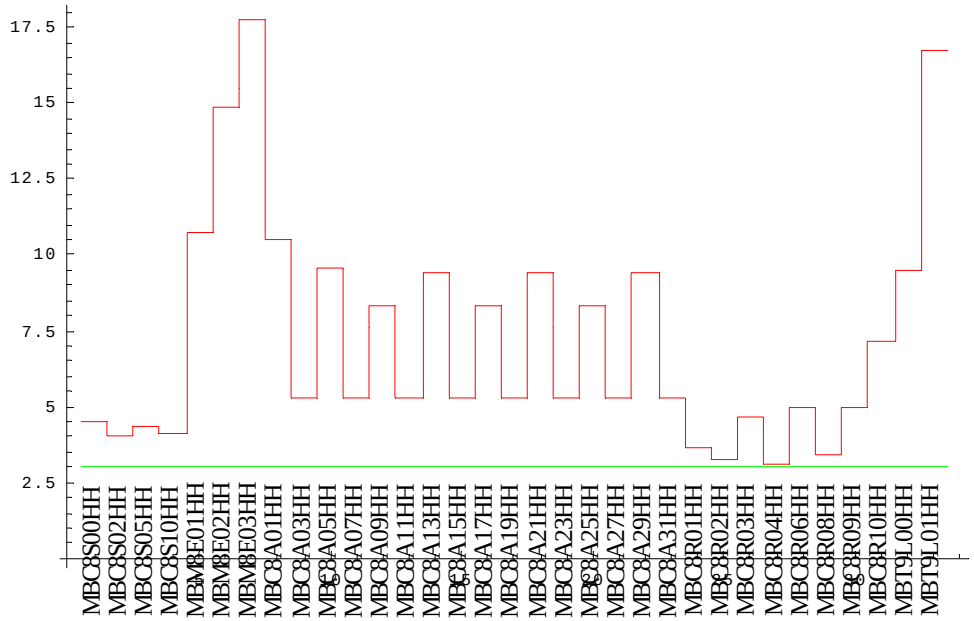


B. Corrector Range in Units of Correctable Error σ

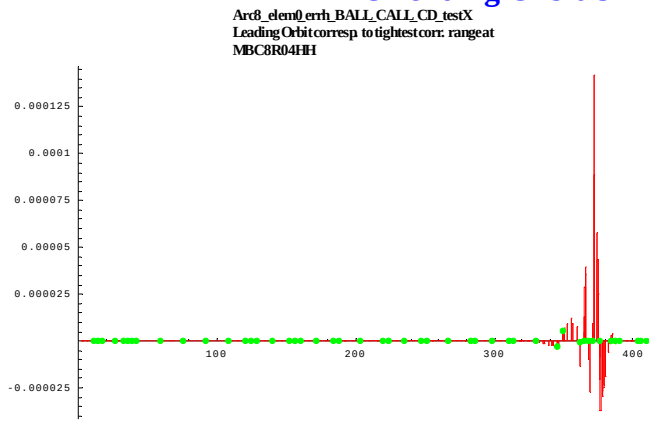
The top graph on the next page shows the maximal amount of error, in units of σ that each corrector can handle before reaching the design limit. Viewed from a different angle, as one expands the envelope in the error distribution space, the extent of the envelope in terms of σ translates into progressively larger worst-case strength for each corrector (e.g., via an SVD based correction scheme). The envelope σ, at which point the worst-case strength coincides with the design range of the corrector in question, is what's plotted here. The green line in each graph corresponds to the 3σ level. Thus correctors with range falling below the green line will not be able to handle all 3σ errors.

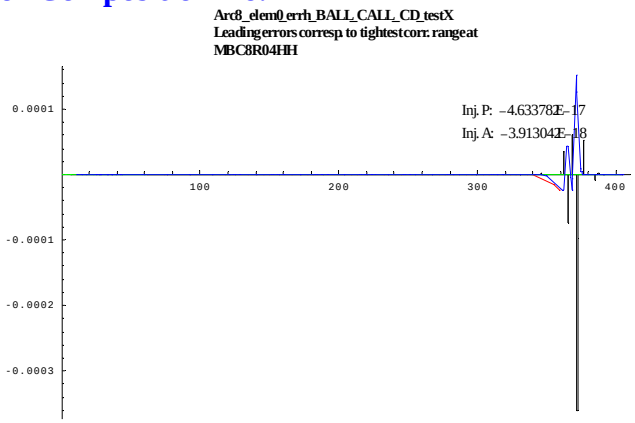
- The first few leading "offenders", or correctors least capable of correction within design range, are further studied in the following graphs. These graphs show the orbit pattern corresponding to each offending case, and the composition of errors, as well as corrector strengths, responsible for this pattern. Injection errors are also printed. Explanation of all components in the plot will be held off for now.
- Consistent with the previous analysis on residual orbits, the Y results here indicates that a 3σ event dominated by injection error into the Spreader may cause the leading corrector max-out in this line.
- The injection error dominated 3σ events in X are borderline cases, again in agreement with the previous analysis. All these imply that, short of horizontal dipoles in the Spreader, injection errors in X need be controlled to a very tight level in order to meet either the residual orbit or the corrector limit criterion.

Range of Correctors in Multiples of σ of Error Distribution That Can be Corrected in X

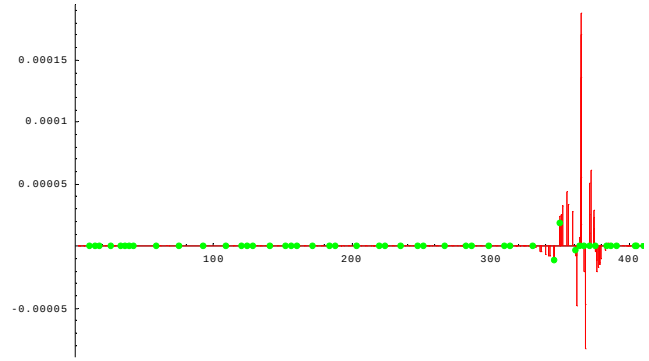


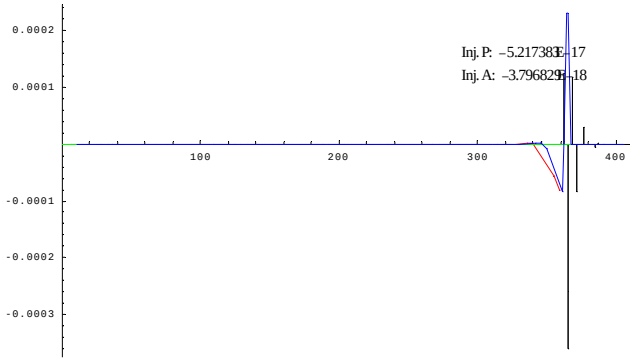
Offending Orbit & Error Composition No. 1



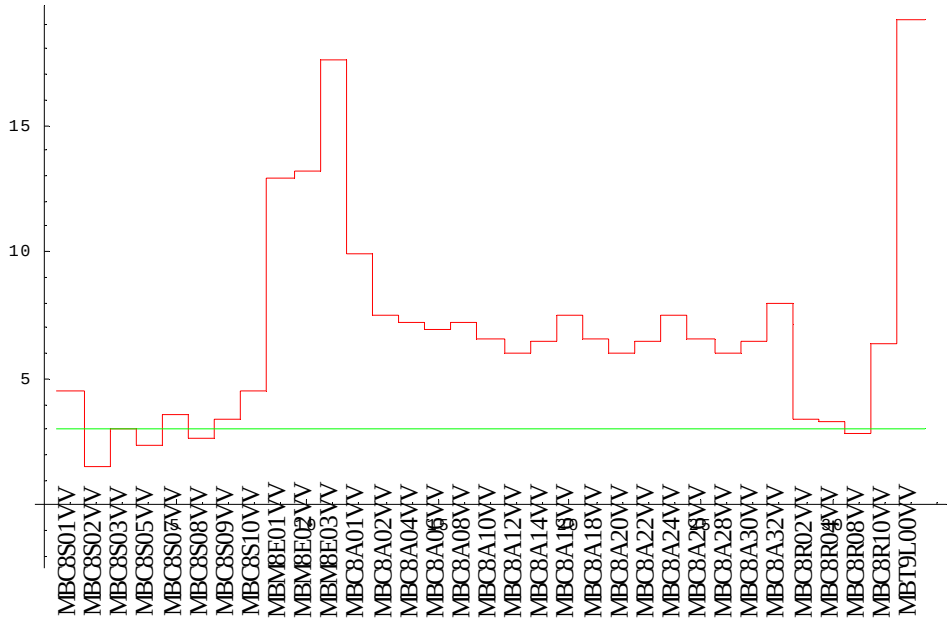


Offending Orbit & Error Composition No. 2

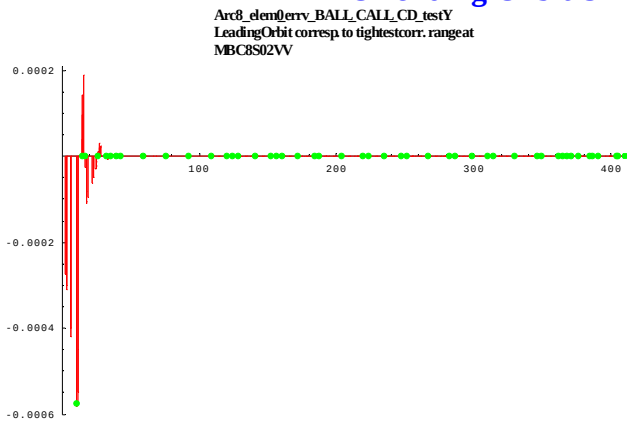


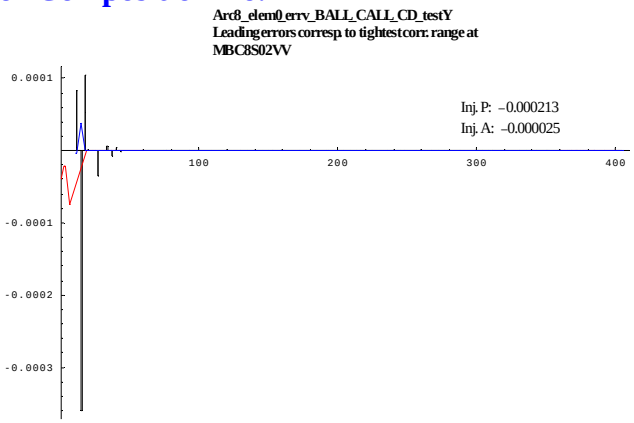


Range of Correctors in Multiples of σ of Error Distribution That Can be Corrected in Y

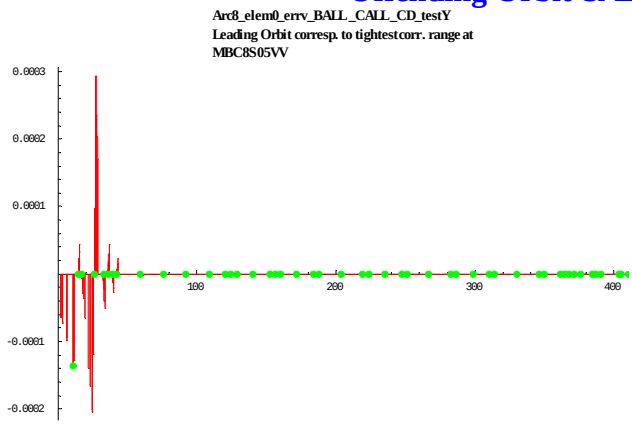


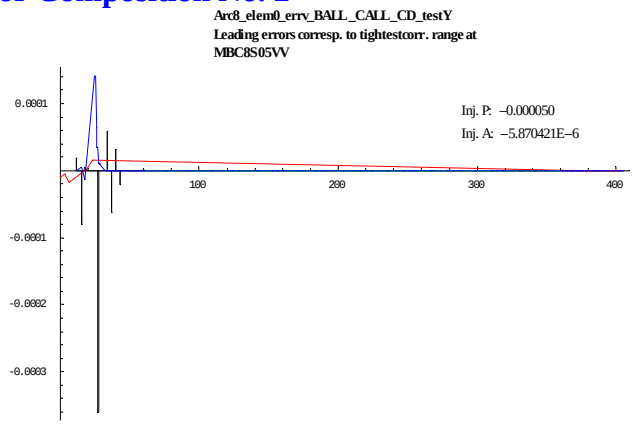
Offending Orbit & Error Composition No. 1





Offending Orbit & Error Composition No. 2





C. More Performance Measures

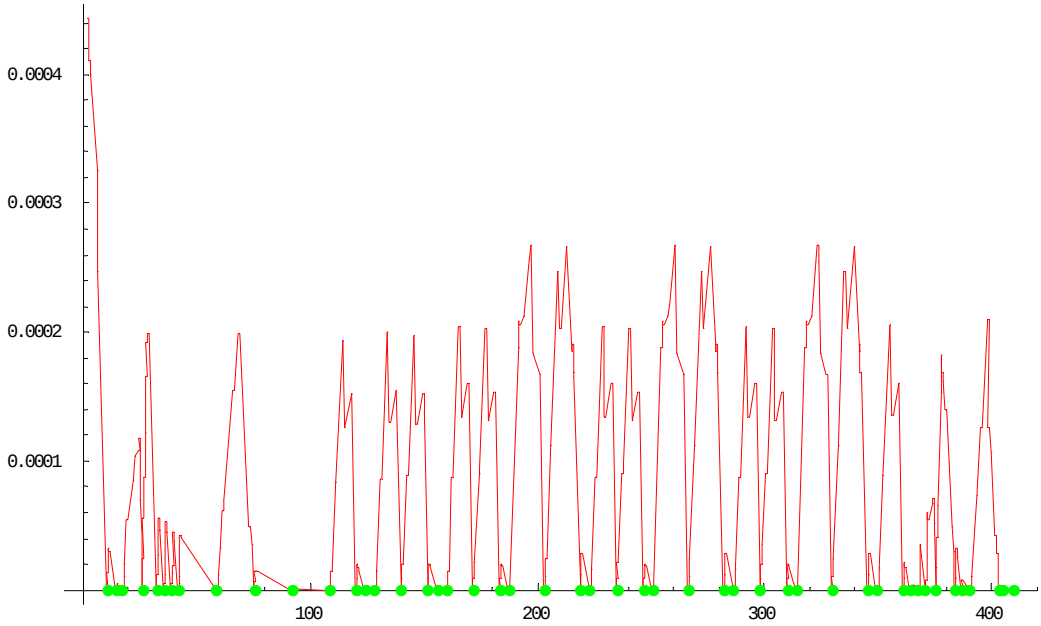
The following pages contain a few more measures of the performance of the steering configuration. Without going into too much detail, these are:

- The worst case 3σ event-induced orbit at all elements when all BPM's read 0, namely, when an apparent perfect orbit is registered. This is a measure of the fundamental observability of the system involving only monitors.
- Another measure of observability, showing the 3σ extent of underlying orbit at all elements when the apparent orbit RMS is equal to that of the BPM offset. These plots share some characteristics with the underlying corrected orbits above, as they represent closely related concepts.
- Corrector range similar to the previous graphs, but assuming unlimited monitoring power, namely the ability to monitor orbit at every element. This is one measure of the fundamental correctability of the system involving only correctors. Also the representation is different from the previous one, in that here the green line represents the corrector limit (at 360 μrad), while the bar heights indicate strengths needed to correct 3σ errors at each corrector.
- Maximal fundamental uncorrectable orbit at every BPM due to 3σ event-induced errors. This is another measure of the fundamental correctability of the system involving both monitors and correctors.
- Another important performance measure is the singularity of the response matrices. It is more involved and will be skipped for the time being.
- There are also well-defined processes to improve on the steering configuration guided by the above criteria. Since it is analytical in nature, the process is deterministic and does not require massive simulation to search for/verify improvement at every stage. This has not been carried out at this point.

3σ Error Projection onto the Null Space of the Response Matrix in X

Arc8_elem0_errh_BALL_CALL_MD_testX

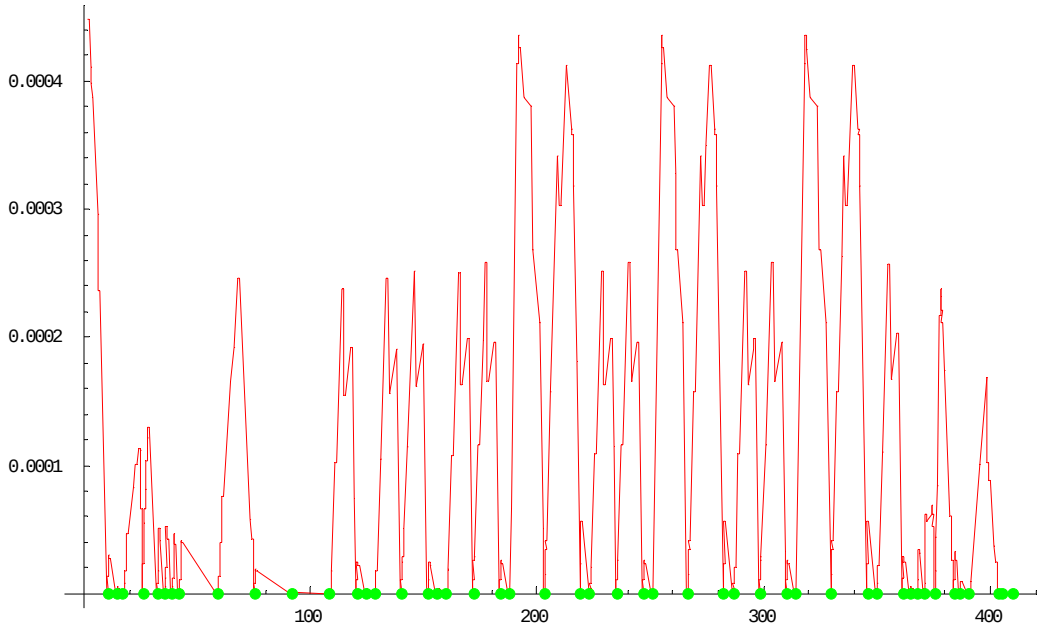
Max. per−axis error null proj.



3σ Error Projection onto the Null Space of the Response Matrix in Y

Arc8_elem0_errv_BALL_CALL_MD_testY

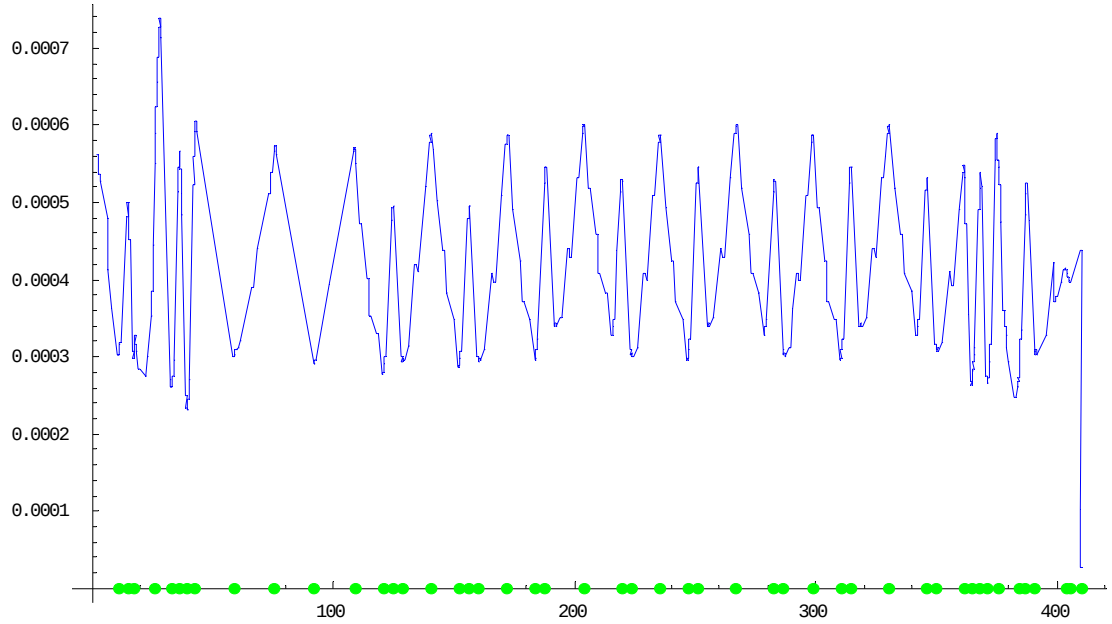
Max. per−axis error null proj.



3σ Extent of Underlying Orbit When Apparent Orbit RMS Equals BPM Offset in X

Arc8_elem0_errh_BALL_CALL_MD_testX

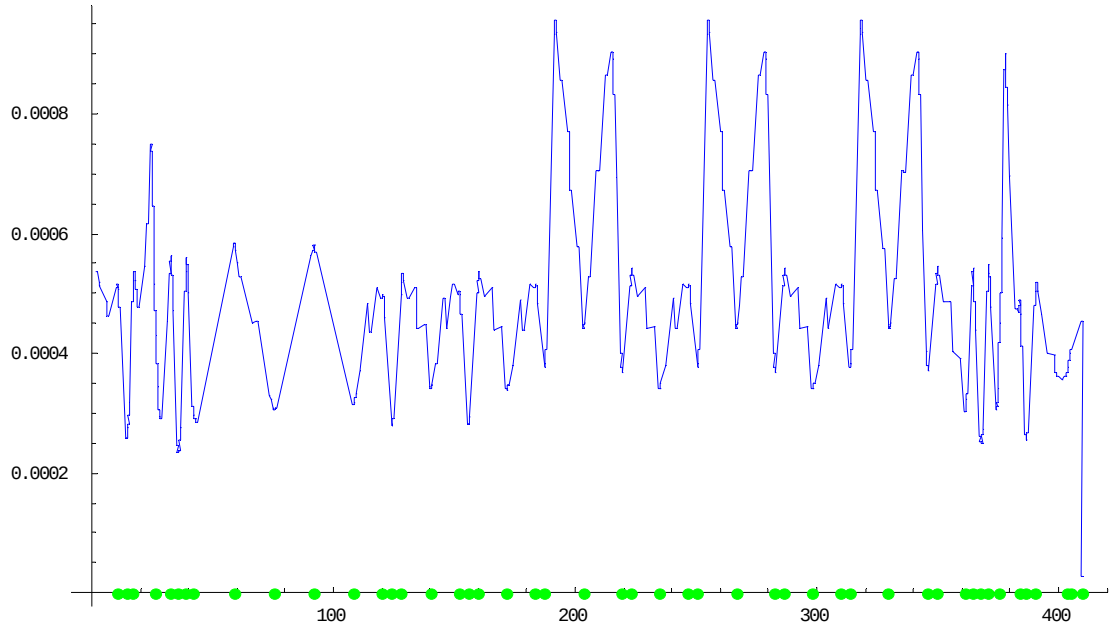
Max. per−axis orbit with combined error−monitor probability



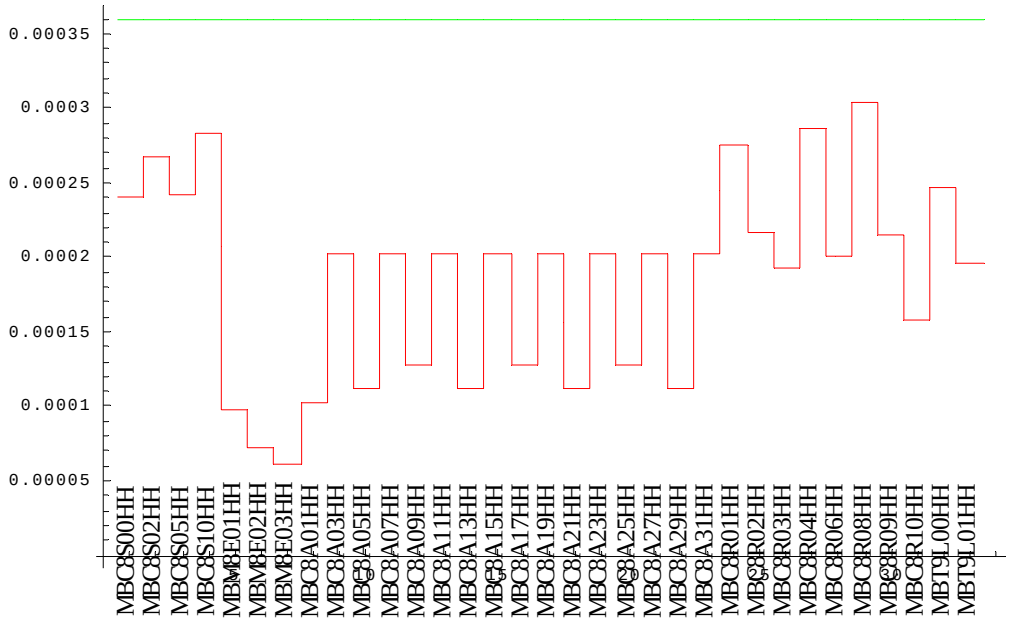
3σ Extent of Underlying Orbit When Apparent Orbit RMS Equals BPM Offset in Y

Arc8_elem0_errv_BALL_CALL_MD_testY

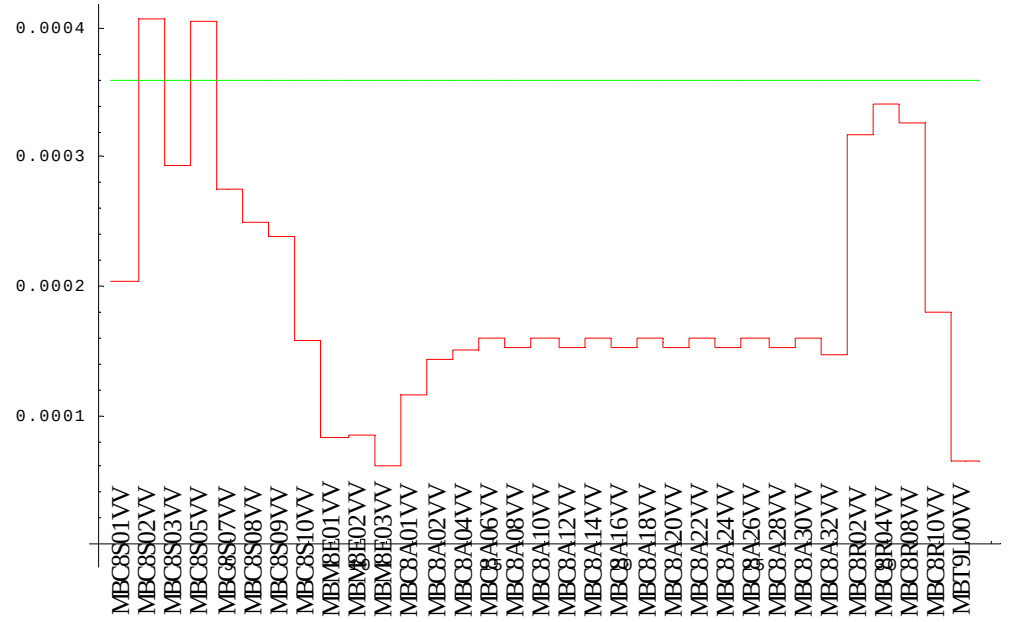
Max. per−axis orbit with combined error−monitor probability



Corrector Strengths Needed for 3σ Error with Unlimited Monitoring Power in X



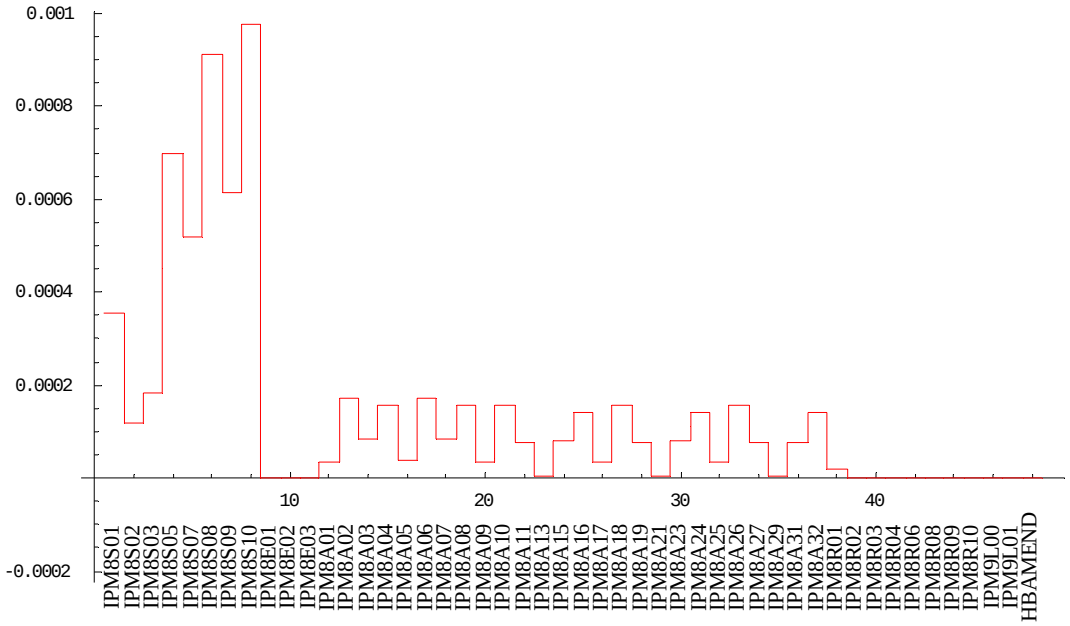
Corrector Strengths Needed for 3σ Error with Unlimited Monitoring Power in Y



Fundamental Uncorrectable Orbit at all BPMs due to 3σ Error in X

Arc8_elem0_errh_BALL_CALL_CD_testX

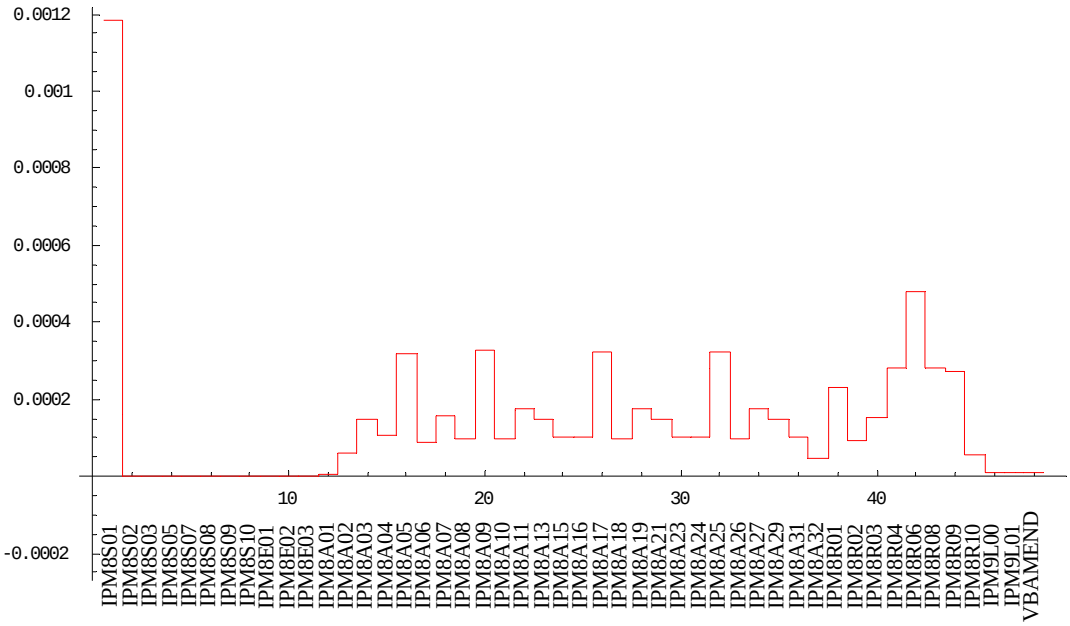
Max. per–BPM uncorrectable orbit proj.



Fundamental Uncorrectable Orbit at all BPMs due to 3σ Error in Y

Arc8_elem0_errv_BALL_CALL_CD_testY

Max. per–BPM uncorrectable orbit proj.



First Cut at Optimizing Orbit Correction Configuration of 12 GeV Design

This is a how this effort may pay off. Looking at the above example, and more complete results shown in the Appendix, One can't fail to notice the pronounced periodic peaks in the Y underlying orbit after correction, a 3-period pattern common to all Arcs. This is corroborated by the simulation results shown by Arne. It is a trait not only of 12 GeV, but also of 6 GeV.

Some inspection of the analytical results, which I will not elaborate, suggested the following moves of BPM's (Arc 8 as an example)[11]:

IPM8A11 → IPM8A12
IPM8A15 → IPM8A14
IPM8A19 → IPM8A20
IPM8A23 → IPM8A22
IPM8A27 → IPM8A28
IPM8A31 → IPM8A30

The effect of these moves is quite significant in the Arc. The following pages[12] show that they have a slight negative impact on the X-plane performance, but all Y peaks in the Arc are gone. Even the Y corrector ranges improved, albeit not appreciably.

It is clear that if enough effort is put into this, we can reach a level of orbit correction performance much better than the baseline, very likely without adding many components (if not deleting them). The program has provision for testing finer adjustments than moving BPM's from one girder to another. It is quite possible that we have not found the best trade-off between X & Y yet.

Also note that the first period of each Arc is more heavily instrumented than the following three, making the orbit behavior good in both planes. Here we try to reach a good balance between X & Y without adding BPM's. If cost is not a concern, all 3 periods can be outfitted like the first and both X & Y behaviors would be as good as the first.

In the new scheme shown I also removed two vertical correctors, MBC8S02V and MBC8S08V, based on singularity indications alone. They don't impact on the Y-peaks in the Arc, other than slightly improving the corrector range in the Spreader. This is an example of how less can do more.

Two questions come to mind:

- If we make these moves in every Arc, how would the tracking result change?

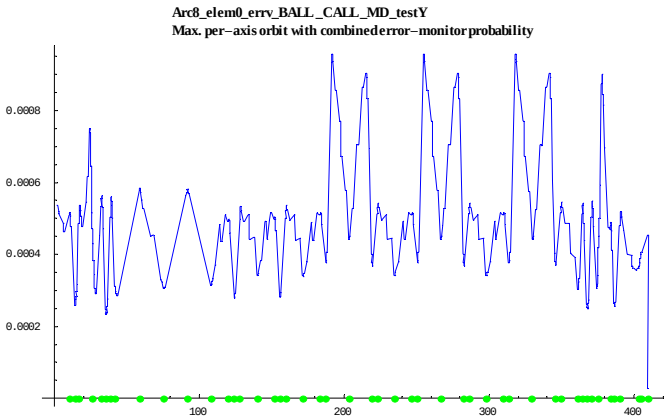
[11] The original scheme apparently resorted to a rough eyeballing of the beta functions, but such scheme breaks down in cases where competing factors (for example amplitude and phase) interact so subtly that one quickly loses track of what's going on. Only the response matrices can provide unambiguous answers in such cases, of which the one shown here is a good example.

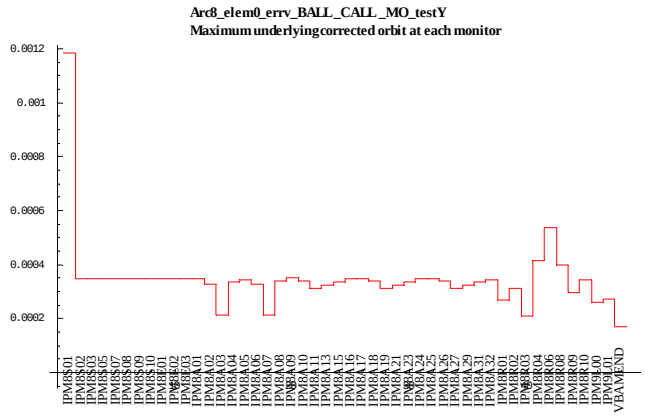
[12] In each page the top graph shows the original scheme, and the bottom one shows the new scheme.

Cancellation of higher order magnet field errors depends on completion of the 4-period integral phase advance by the beam sampling the "same" field error in each period, if I understand things correctly. The instrumentation of the Arc is such that the orbit most likely will sample at large amplitude only 3 out of the 4 periods[13], and thus does not close the cycle. By making all 4 periods more similar, will emittance growth due to field nonlinearity improve? At least it is easy to check.

- Is this something worth attention for 6 GeV?

The problem is really about blind spots, which exist in all the Arcs as currently configured. The plot in the left below is the "observability" graph explained in the other document. It basically shows that in Arc 8, as in all other Arcs, we have this 3-fold pattern of blind spots, matching those seen in the post-correction orbit plots. The plot on the right shows 3σ post-correction orbits at all BPM's as currently configured. It looks perfect in the Arc. The devil is of course between the BPM's.

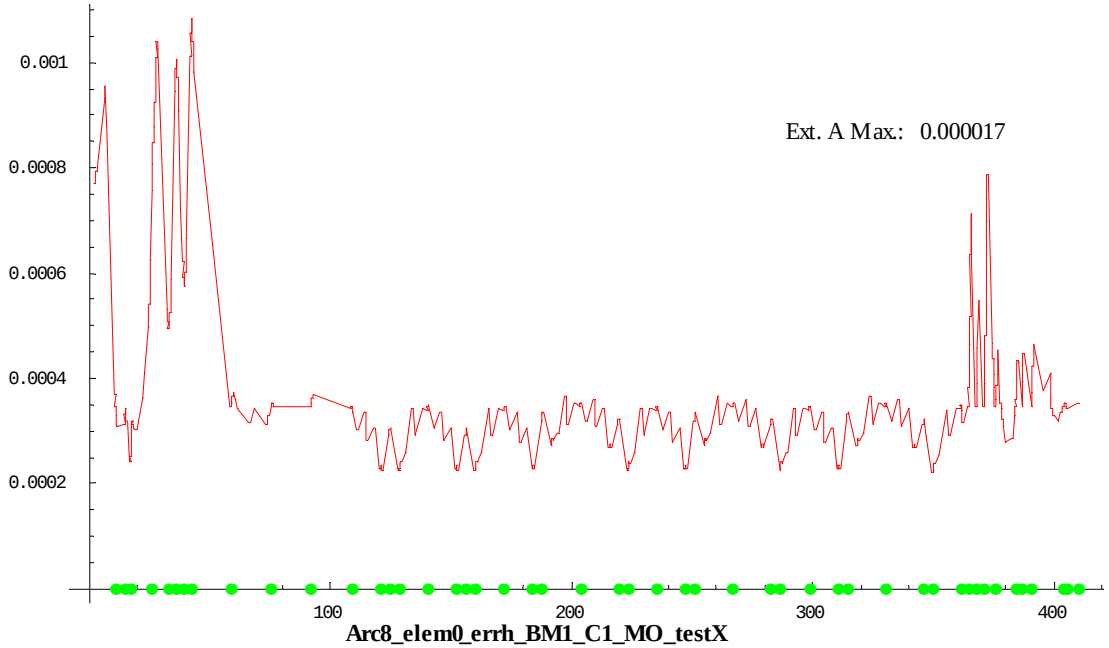




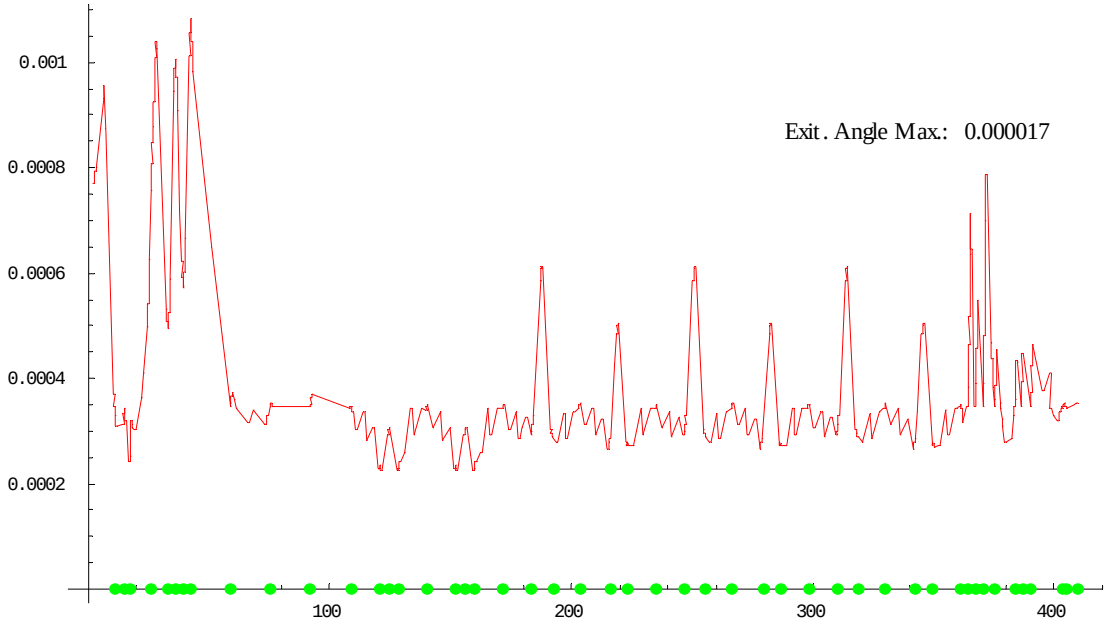
[13] This statement is not quite rigorous, but only has a qualitative justification. I'm not sure it's not total nonsense upon closer scrutiny.

X Plane

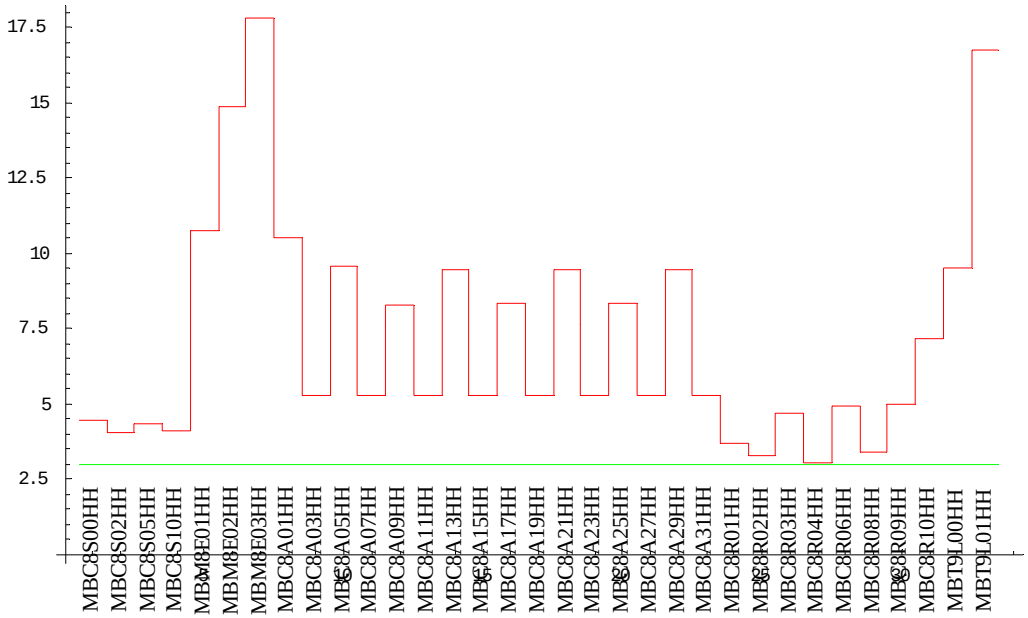
Arc8_elem0_errh_BALL_CALL_MO_testX
Maximum underlying corrected orbit at all−elem



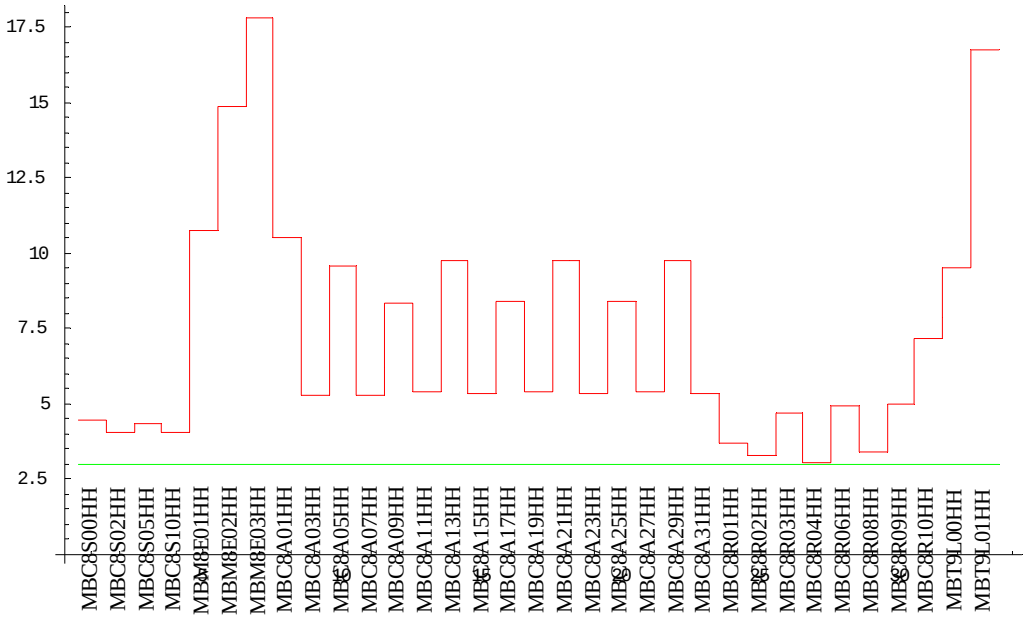
Arc8_elem0_errh_BM1_C1_MO_testX
Maximum underlying corrected orbit at all−elem



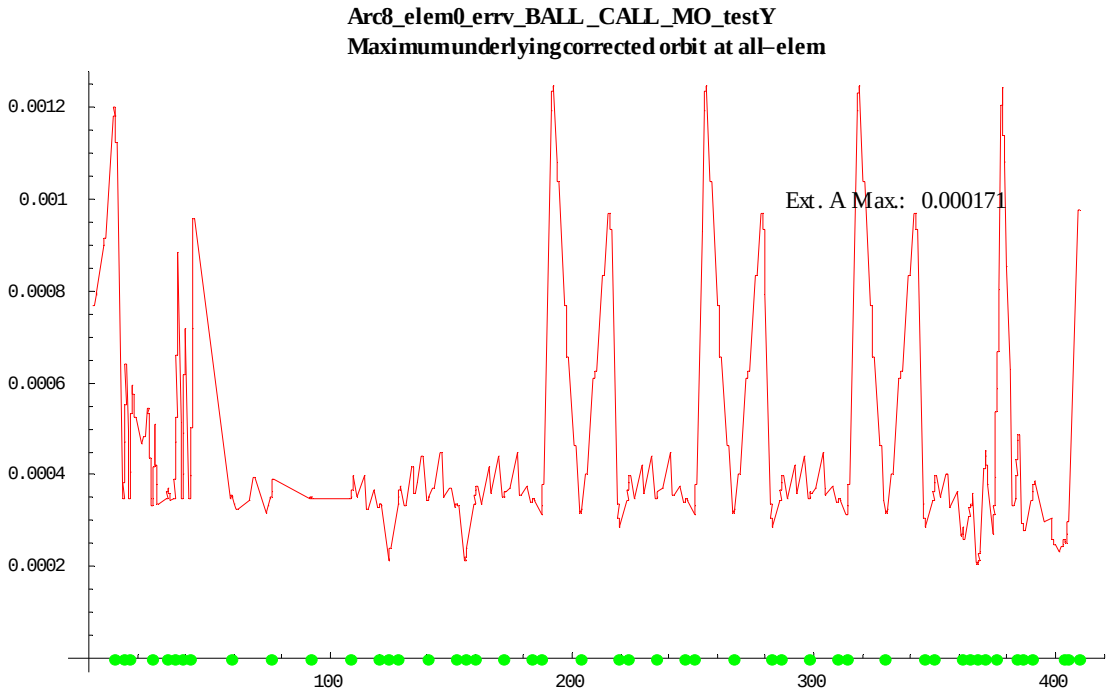
Arc8_elem0_errh_BALL_CALL_CD_testX
Corrector range in units of projected sigma

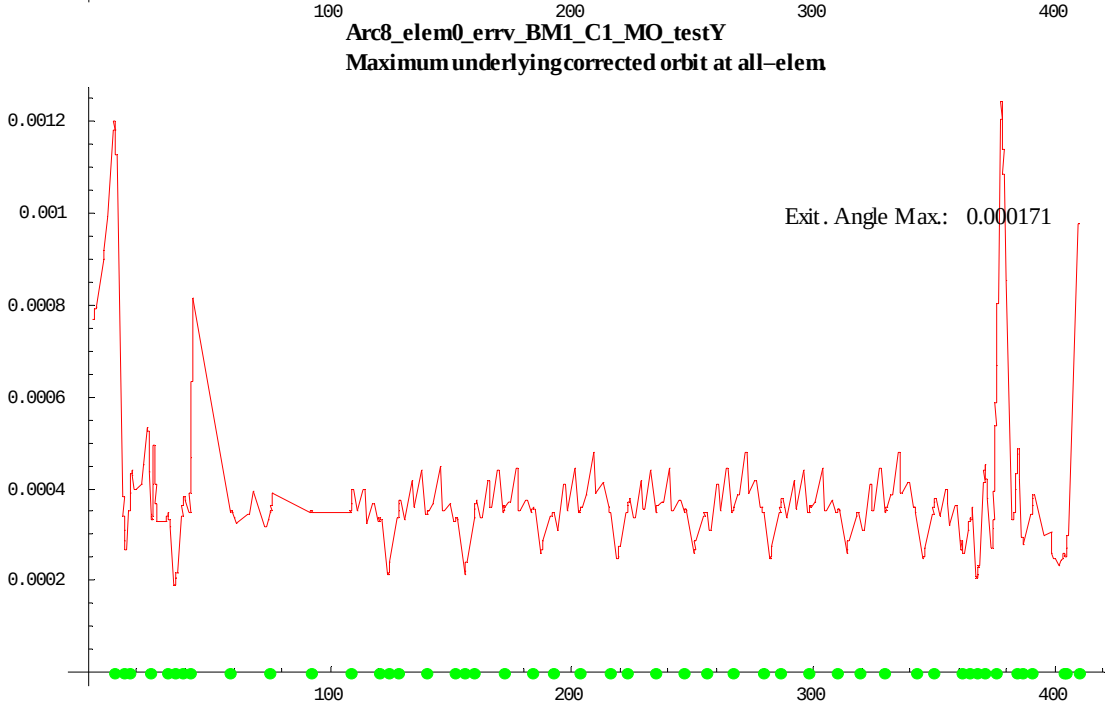


Arc8_elem0_errh_BM1_C1_CD_testX
Corrector range in units of projected sigma (clipped at 25.)

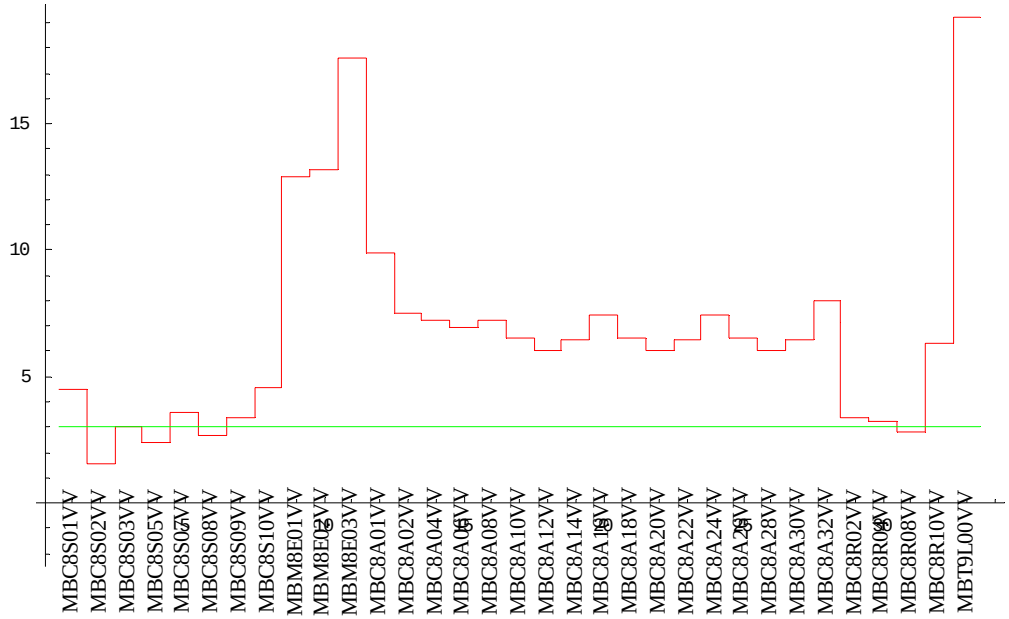


Y Plane

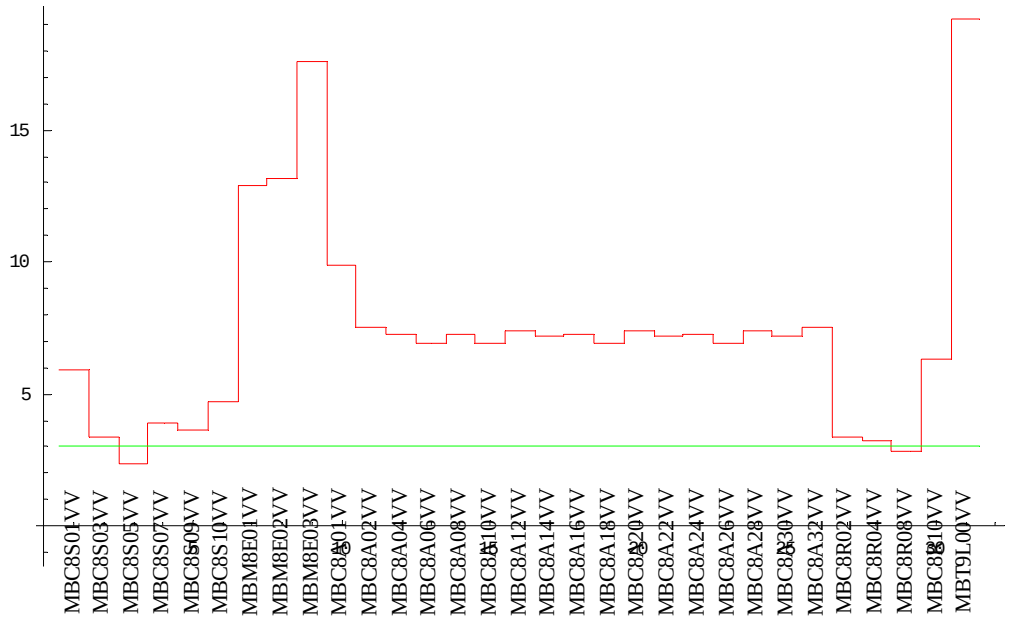

Arc8_elem0_errv_BALL_CALL_MO_testY
Maximum underlying corrected orbit at all–elem
0.0012
0.001
0.0008
0.0006
0.0004
0.0002
Ext. A Max: 0.000171
100
200
300
400


Arc8_elem0_errv_BM1_C1_MO_testY
Maximum underlying corrected orbit at all–elem
0.0012
0.001
0.0008
0.0006
0.0004
0.0002
Exit. Angle Max: 0.000171
100
200
300
400

Arc8_elem0_errv_BALL_CALL_CD_testY
Corrector range in units of projected sigma



Arc8_elem0_errv_BM1_C1_CD_testY
Corrector range in units of projected sigma (clipped at 25.)



Appendix. Complete 12 GeV Steering Configuration Analysis (Arcs 1 to 10)

This is a summary of the orbit correction configuration analysis for all Arcs[14] (including Spreaders & Recombiners) in the 12 GeV design. Explanation of rationale, methodology and detail of each plot are all given in the companion document for Arc 8. Only numerical results and discussion of exceptions will be given here.

For examples of how optimization can be effected through configuration improvements, see optimization example for Arc 8.

Special Case of Arc 2

In the case of Arc 2, contrary to most other arcs directly modeled on existing 6 GeV configurations, an anomaly in the steering configuration is apparent in both planes. The 3σ extent of the underlying post-correction orbit and the corrector range in units of σ both show grossly deficient performance in both planes, as shown in the following 4 plots. The cause is immediately clear if one looks at the output of the program where corrector configuration singularity is evaluated:

X-plane:

```
Sing. Val: 2.82653×10^11 Corrector Index: 5 Degenerate Corrs.: 4   6
Sing. Val:  1080.16  Corrector Index:  7  Degenerate Corrs.:  8   6
Sing. Val:  1005.91  Corrector Index:  3  Degenerate Corrs.:  2   4
```

Y-plane:

```
Sing. Val: 1.33321×10^11 Corrector Index: 5 Degenerate Corrs.: 4   6
Sing. Val:  970.535  Corrector Index:  2  Degenerate Corrs.:  3   4
Sing. Val:  903.334  Corrector Index:  8  Degenerate Corrs.:  7   9
```

The first line in each plane points to an unacceptable degree of degeneracy, as indicated by the singular values, as well as the offending corrector[15,16]. Successive lines show new singular values of the system as the next offending correctors are removed iteratively. By only removing the most offending corrector in each plane we can already arrive at a reasonably behaved system as shown by the much more manageable singular values. These are displayed in the following plots, with similar performance as Arcs 4-8 largely restored.

Arc 2 shares the same weakness in terms of steering performance as the other arcs in the limited ability to handle injection errors, especially in X. Arc 2 appears to be also more

[14] Not complete yet.
[15] The index 5 in both planes correspond to the correctors MBT2S06H & MBT2S06V. The corrector MBT2S06H actually does not seem to be a Channel Access resolvable symbol.
[16] The physical cause of this singularity is the lack of a BPM between the 2T05 & 2T06 correctors, exacerbated by interplay of betatron phases.

susceptible to errors in controlling exit orbit in X, unlike the higher arcs. The reason and possible remedy is under investigation.

Special Case of Arc 7

Analysis of corrector pattern in Arc 7 revealed singularity due to excess correctors in the vertical, as indicated by the singular values.

Y-plane:

```
Sing. Val:  5366.67  Corrector Index:  31  Degenerate Corrs.:  32    33
Sing. Val:  3493.81  Corrector Index:  2  Degenerate Corrs.:  1     3
```

It is straightforward to remove these excessive correctors indicated above. The performance criteria before & after this removal are included under displays for Arc 7 below.

Special Case of Arc 10

Minor details in Arc 10 layout are still in flux. Taking the backbone geometry and optics one can apply the analysis to get some initial idea. The corrector set in this preliminary design appears to be a slight overkill in the vertical, as indicated by the singular values.

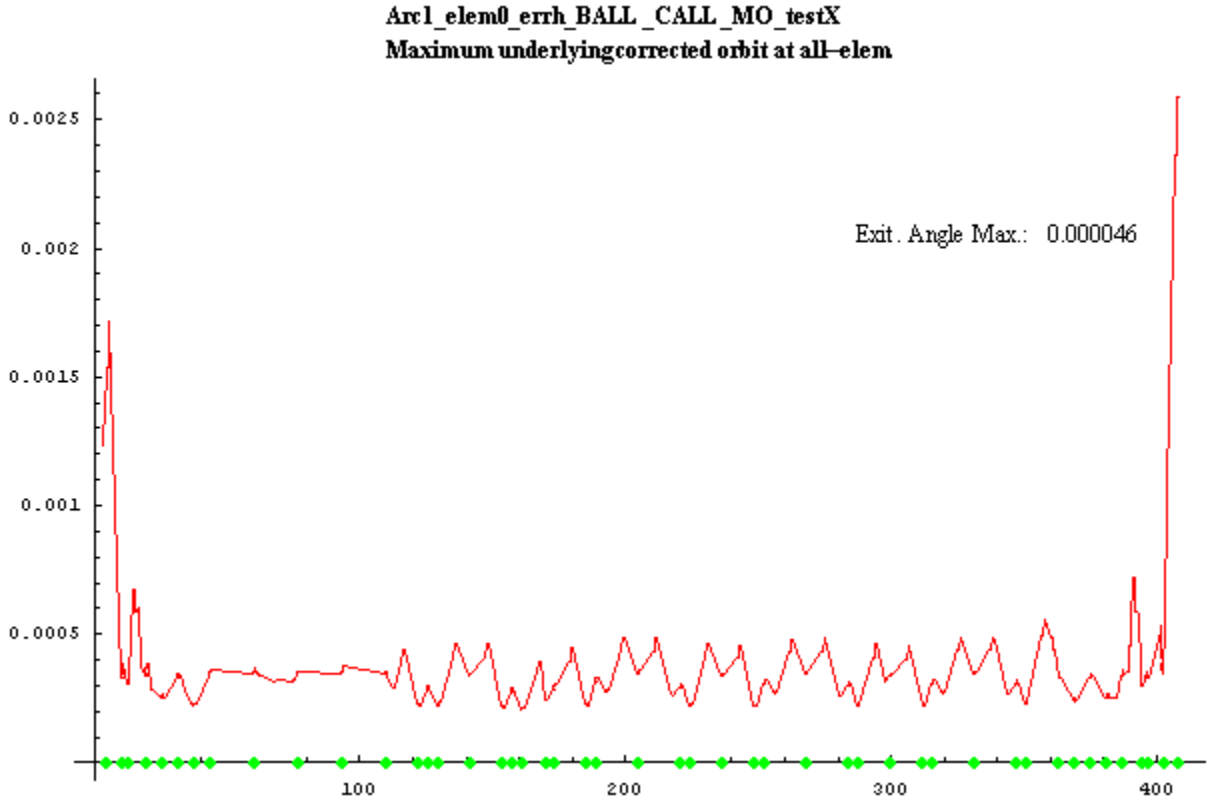
Y-plane:

```
Sing. Val:  96252.2  Corrector Index:  32  Degenerate Corrs.:  31    33
Sing. Val:  4660.72  Corrector Index:  4  Degenerate Corrs.:  5     3
```

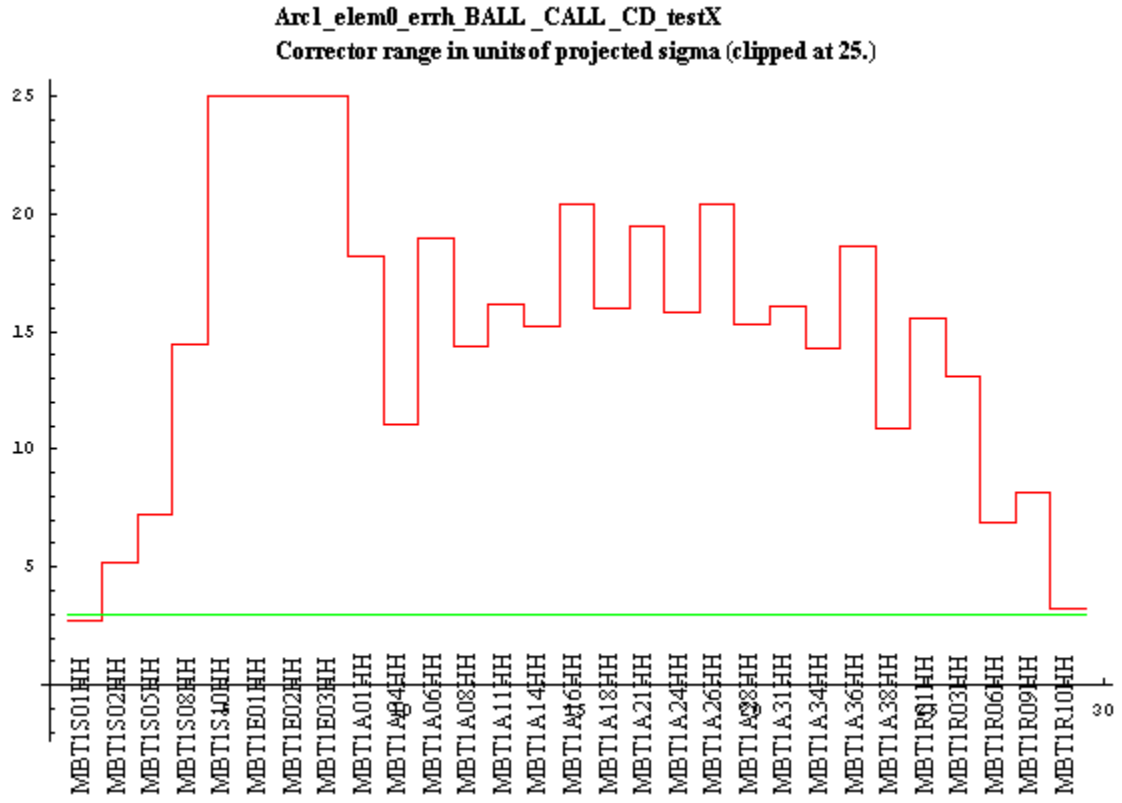
It is straightforward to remove these excessive correctors indicated above. The performance criteria before & after this removal are included under displays for Arc 10 below.

ARC 1

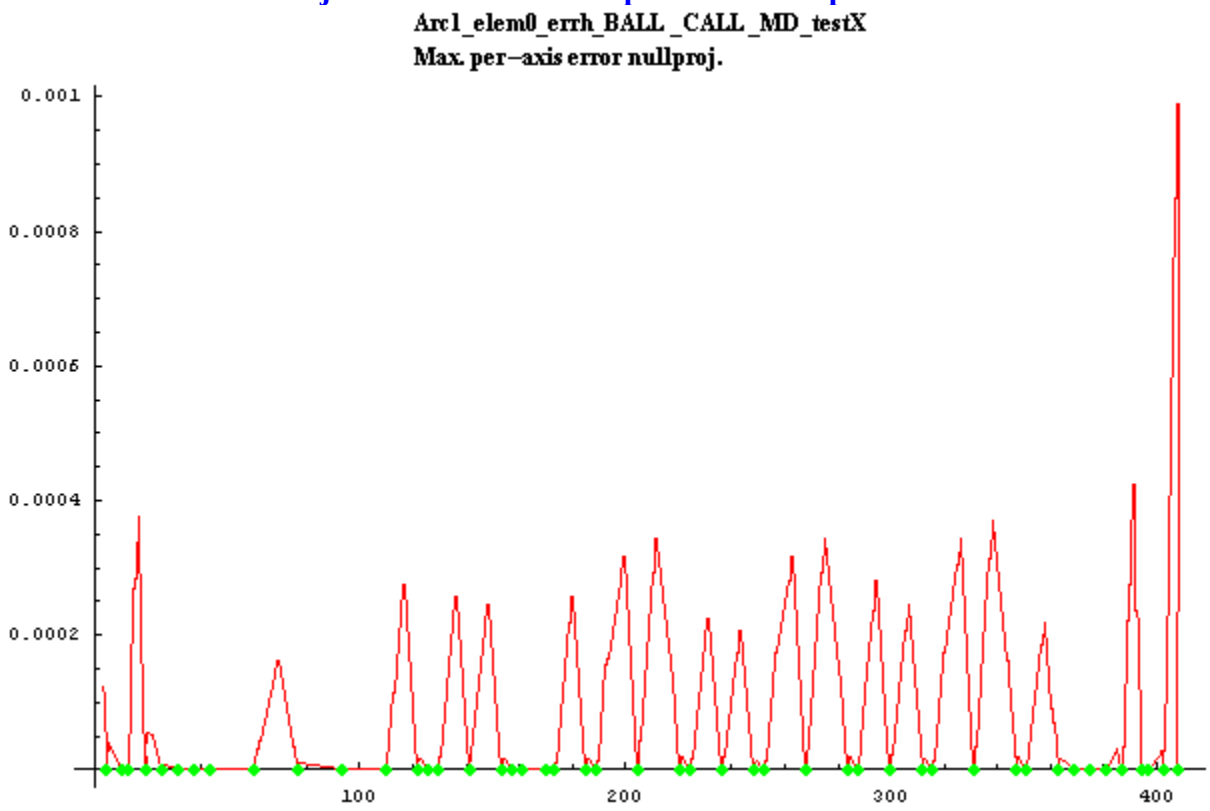
3σ Extent of the Real Underlying Orbit after Orbit Correction in X



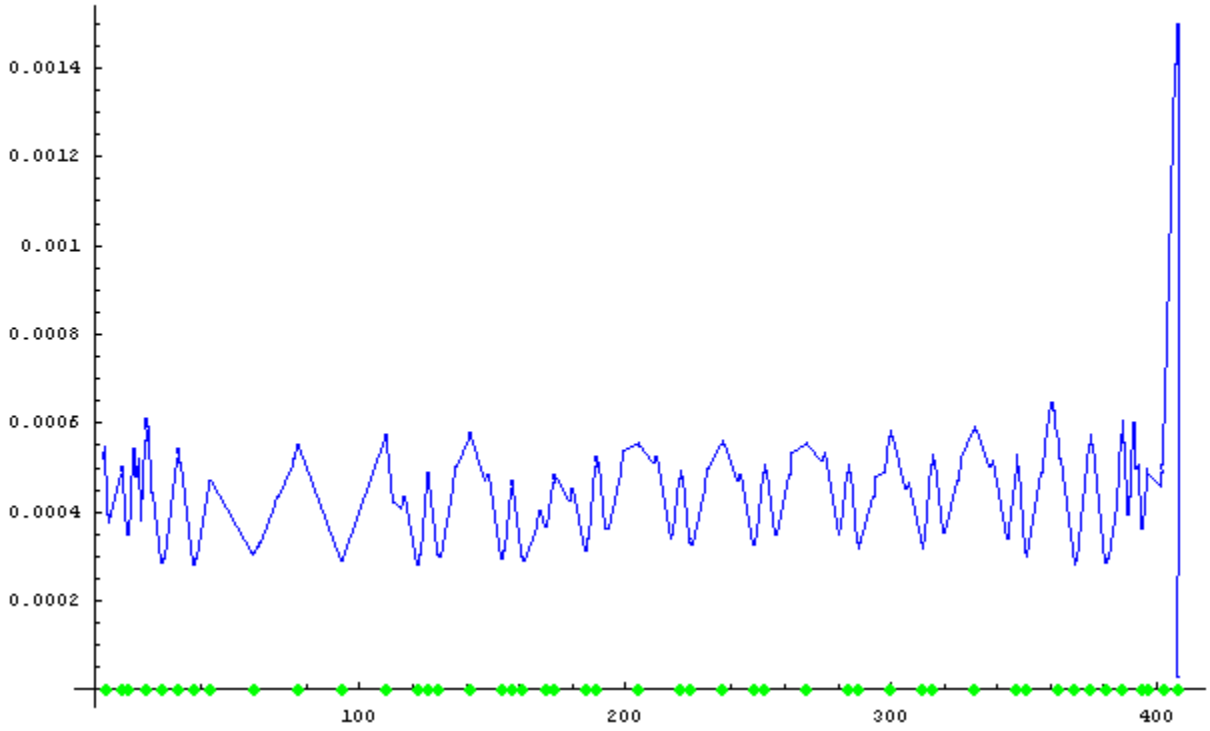
Range of Correctors in Multiples of σ of Error Distribution That Can be Corrected in X



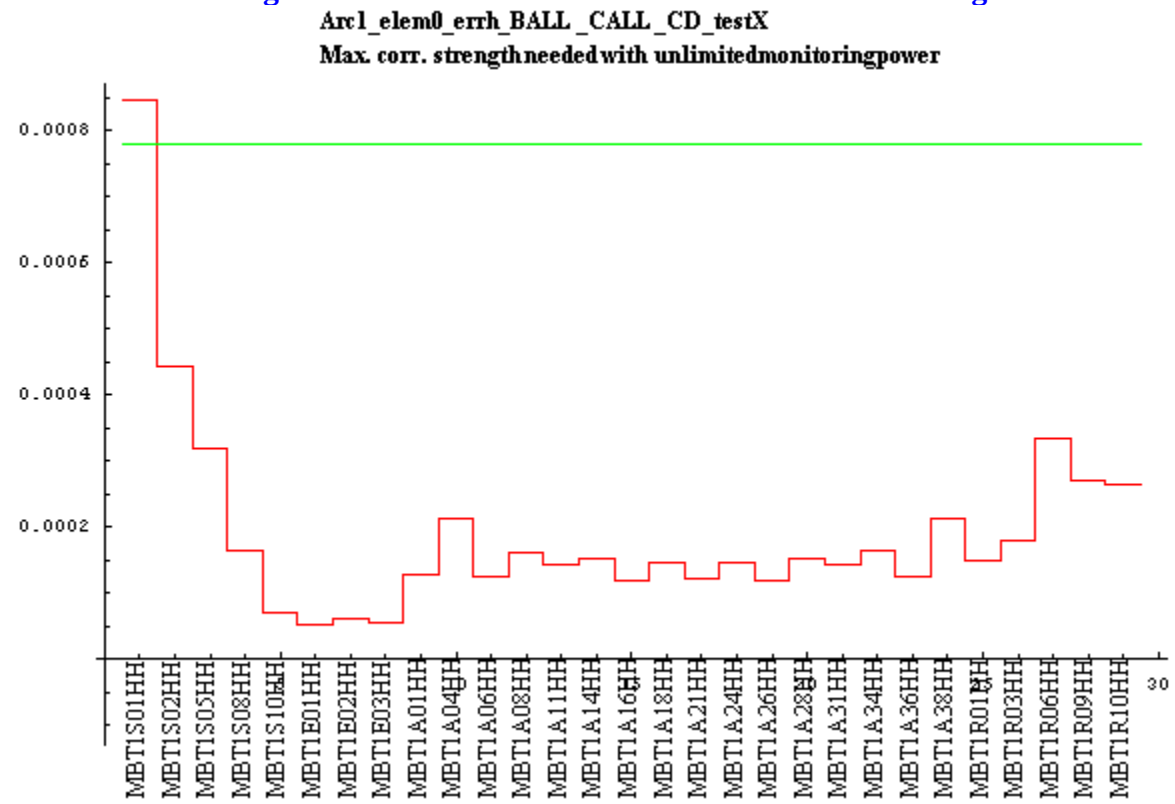
3σ Error Projection onto the Null Space of the Response Matrix in X



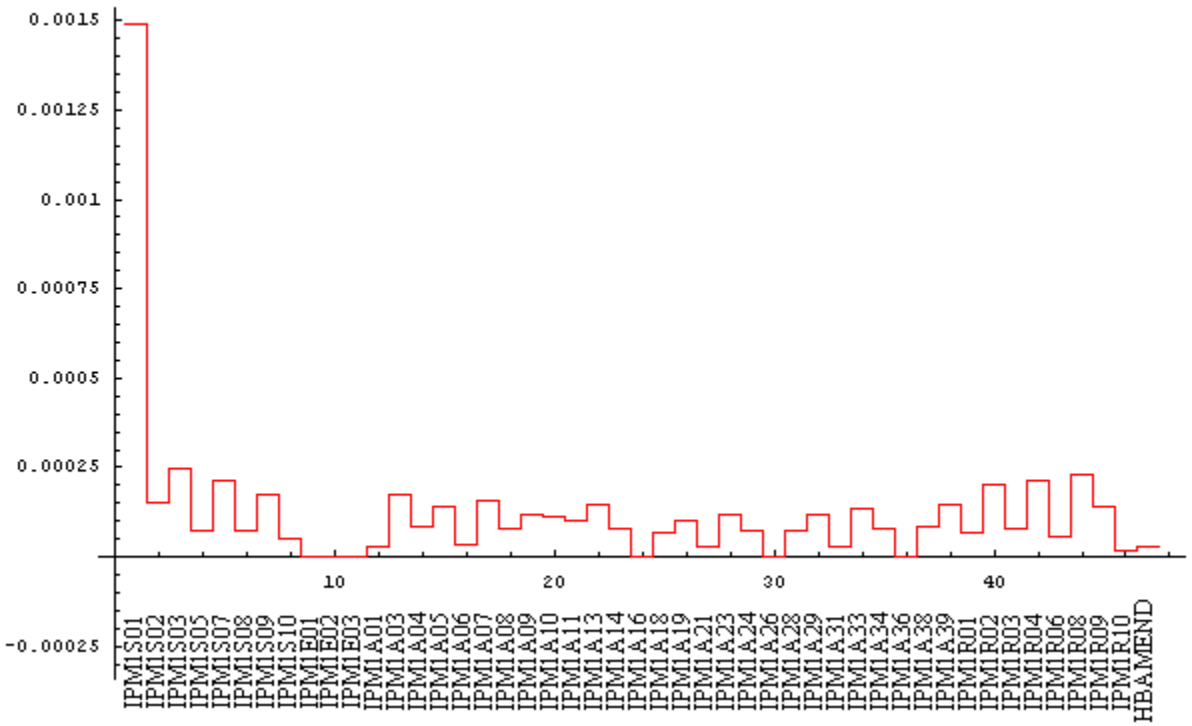
3σ Extent of Underlying Orbit When Apparent Orbit RMS Equals BPM Offset in X



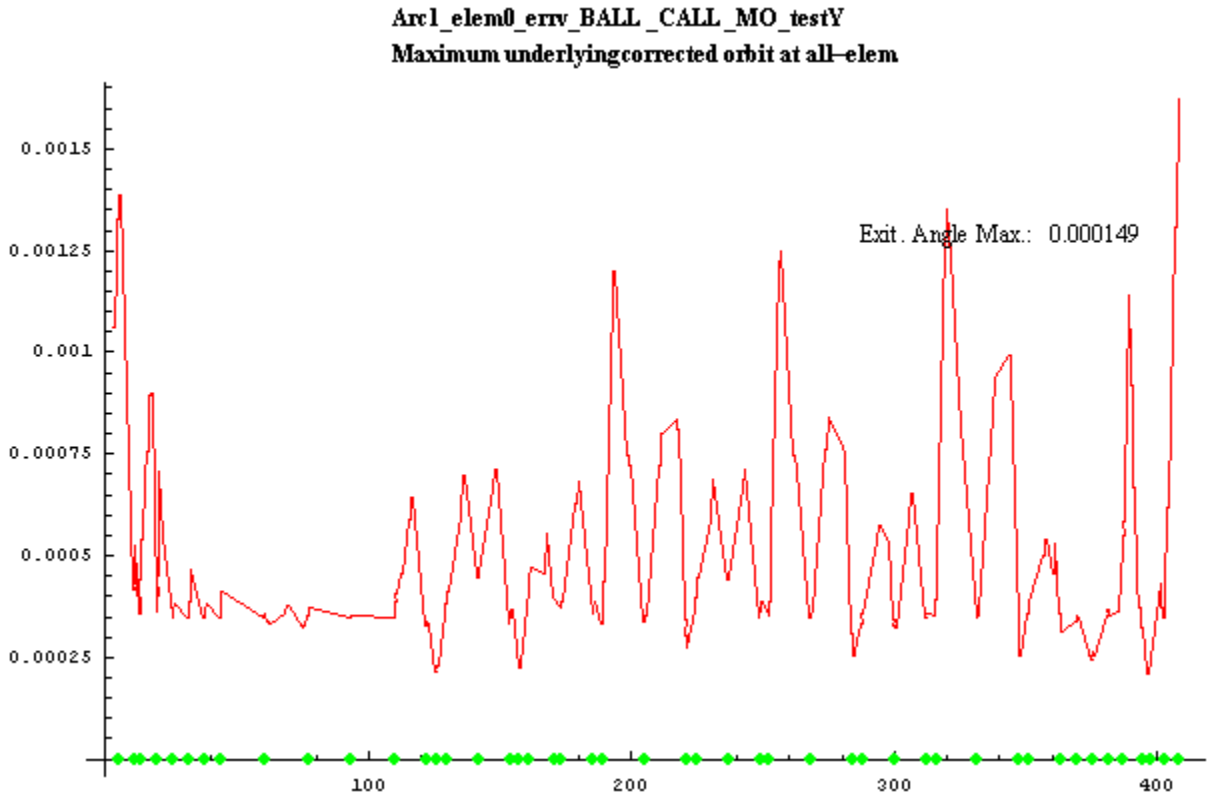
Corrector Strengths Needed for 3σ Error with Unlimited Monitoring Power in X



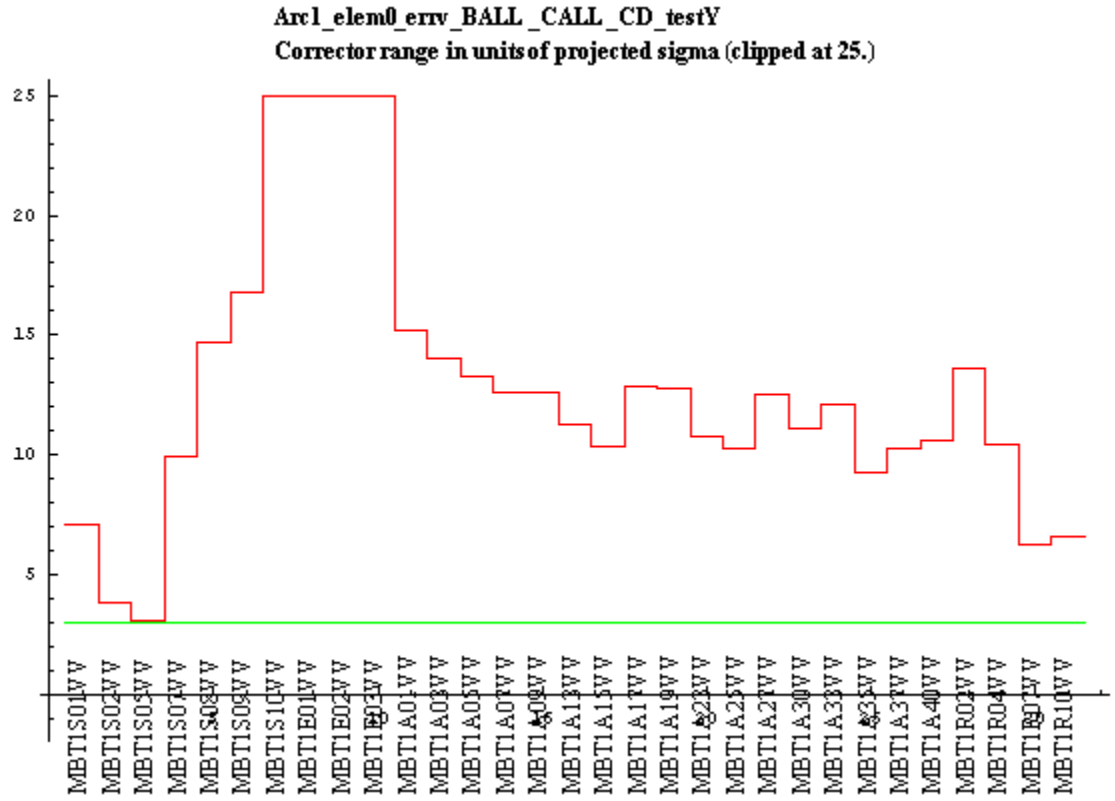
Fundamental Uncorrectable Orbit at all BPMs due to 3σ Error in X



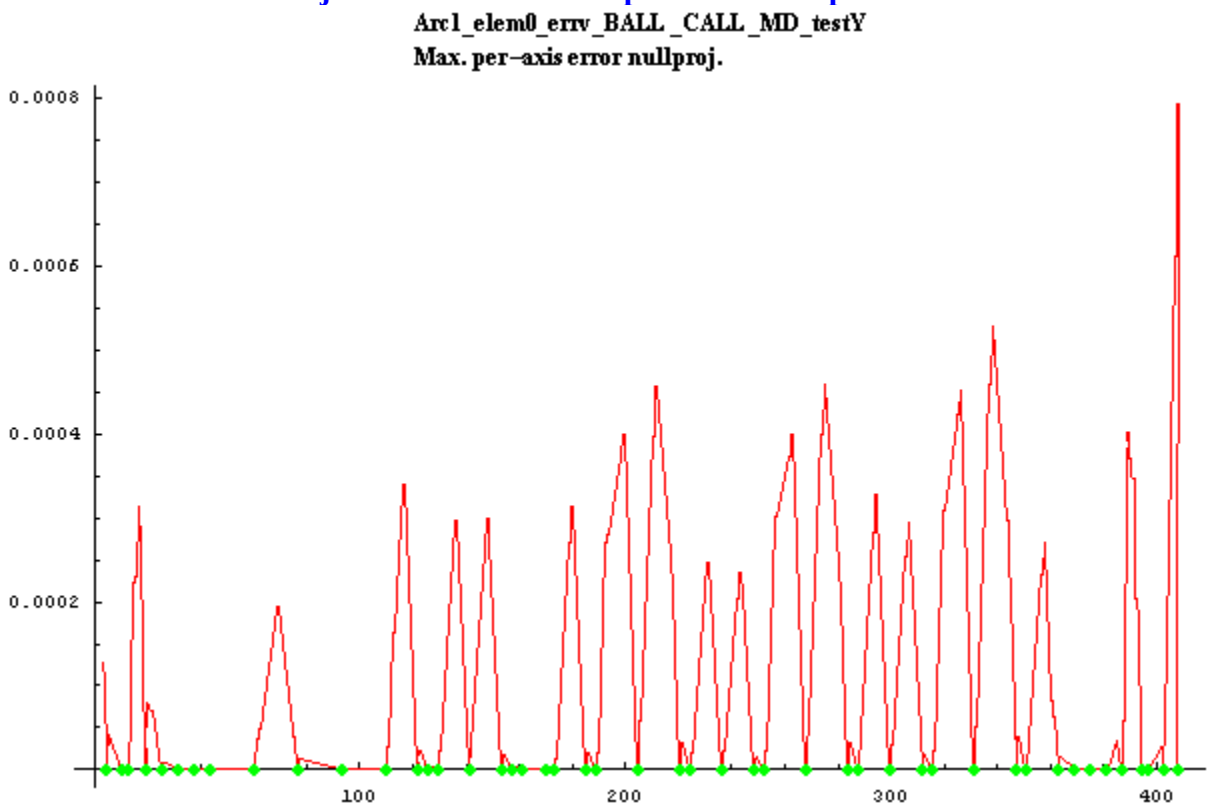
3σ Extent of the Real Underlying Orbit after Orbit Correction in Y



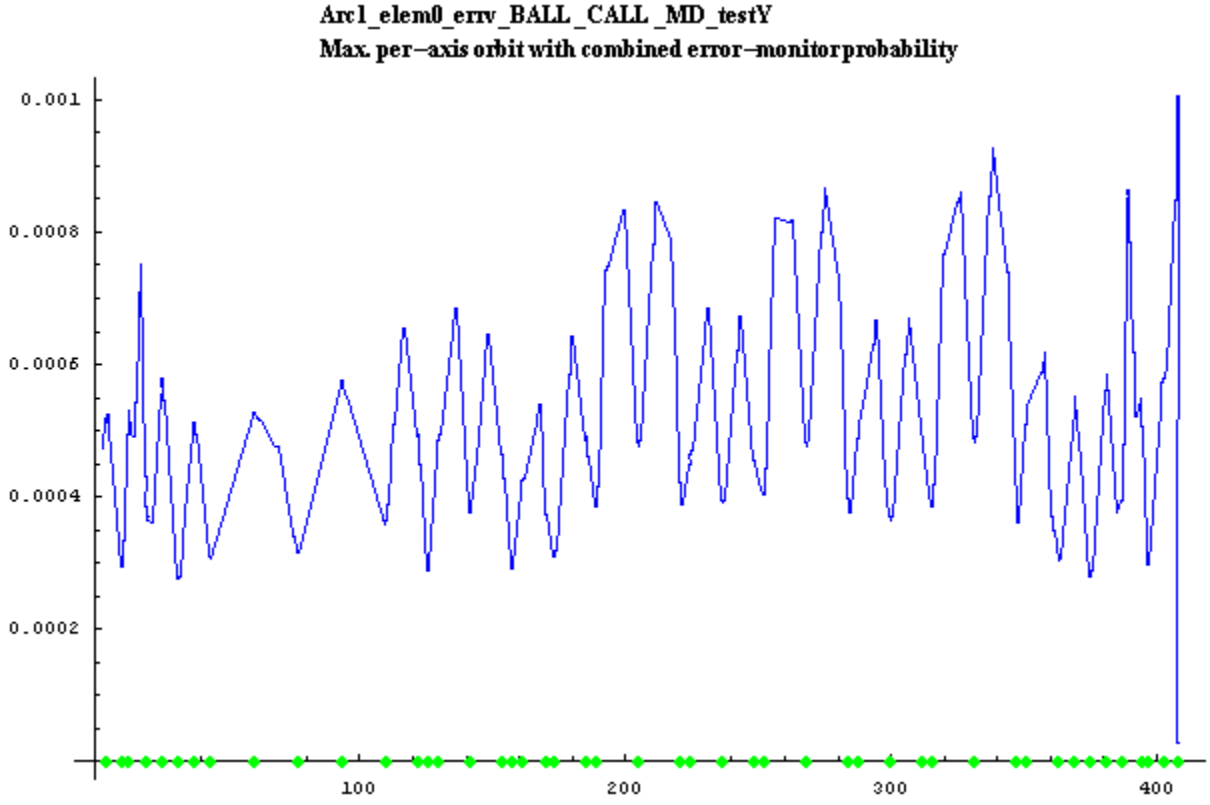
Range of Correctors in Multiples of σ of Error Distribution That Can be Corrected in Y



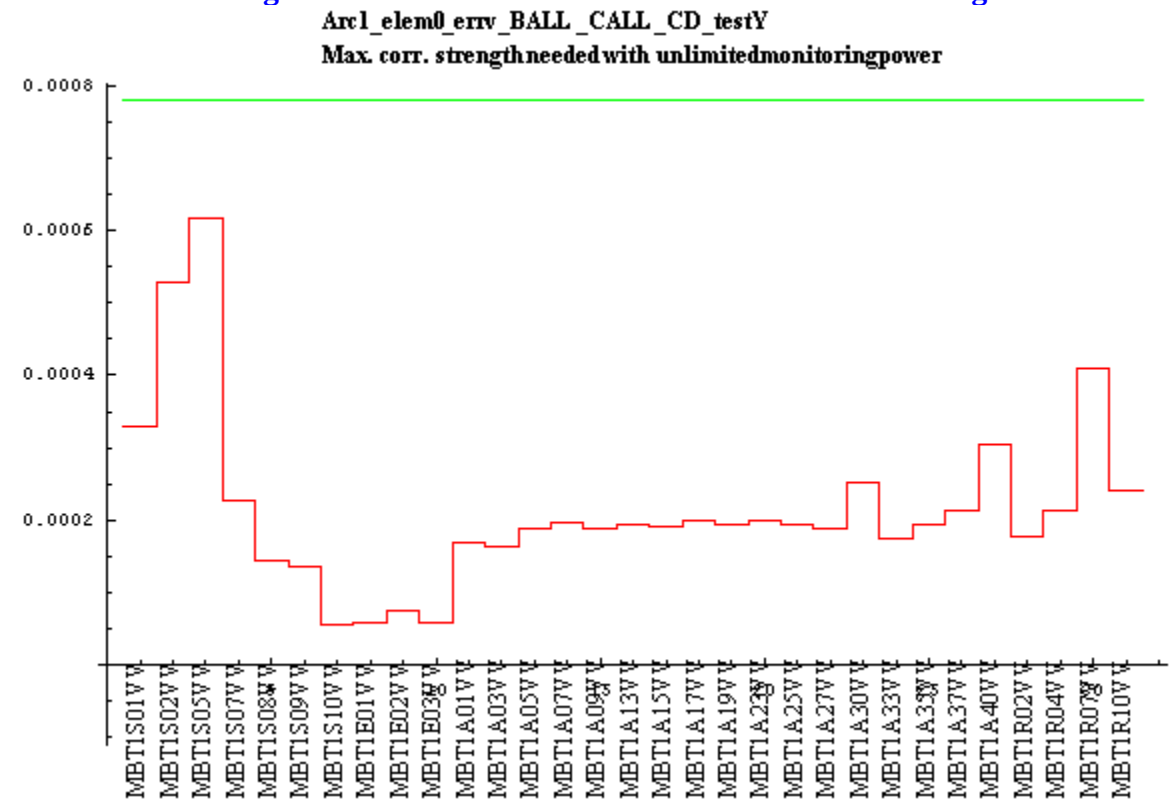
3σ Error Projection onto the Null Space of the Response Matrix in Y



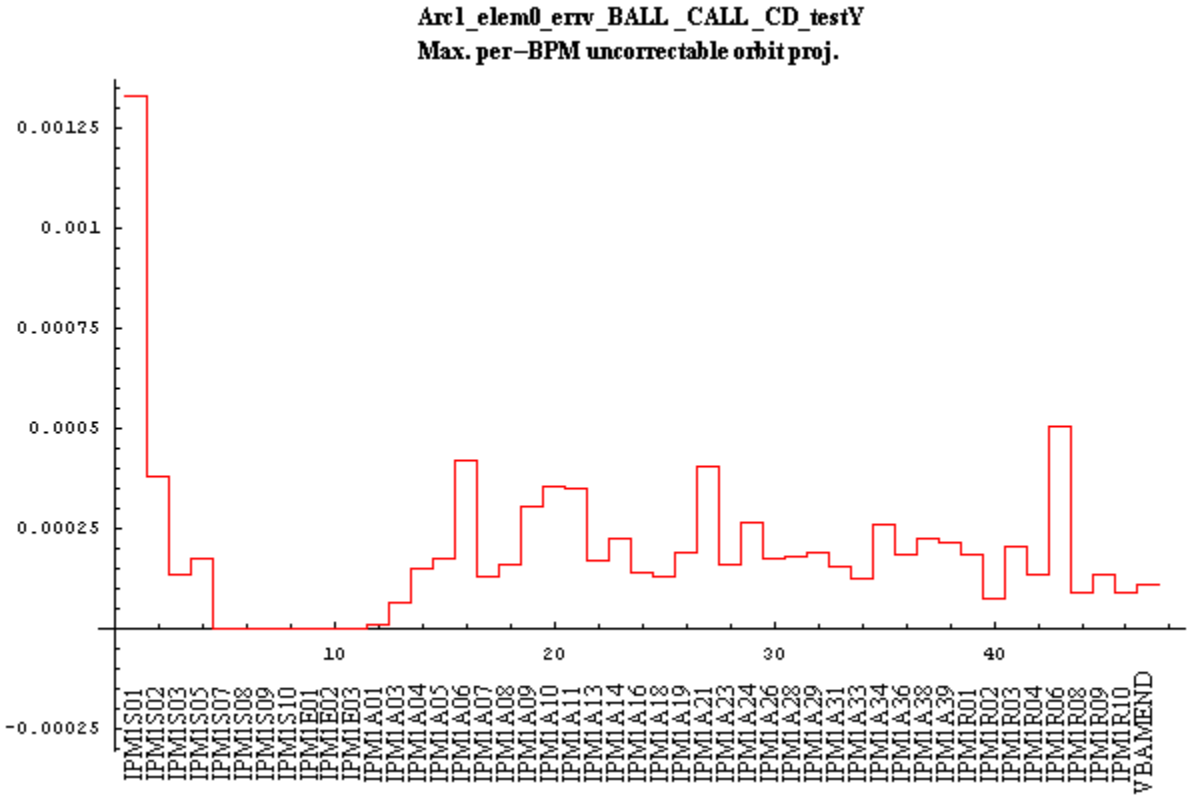
3σ Extent of Underlying Orbit When Apparent Orbit RMS Equals BPM Offset in Y



Corrector Strengths Needed for 3σ Error with Unlimited Monitoring Power in Y

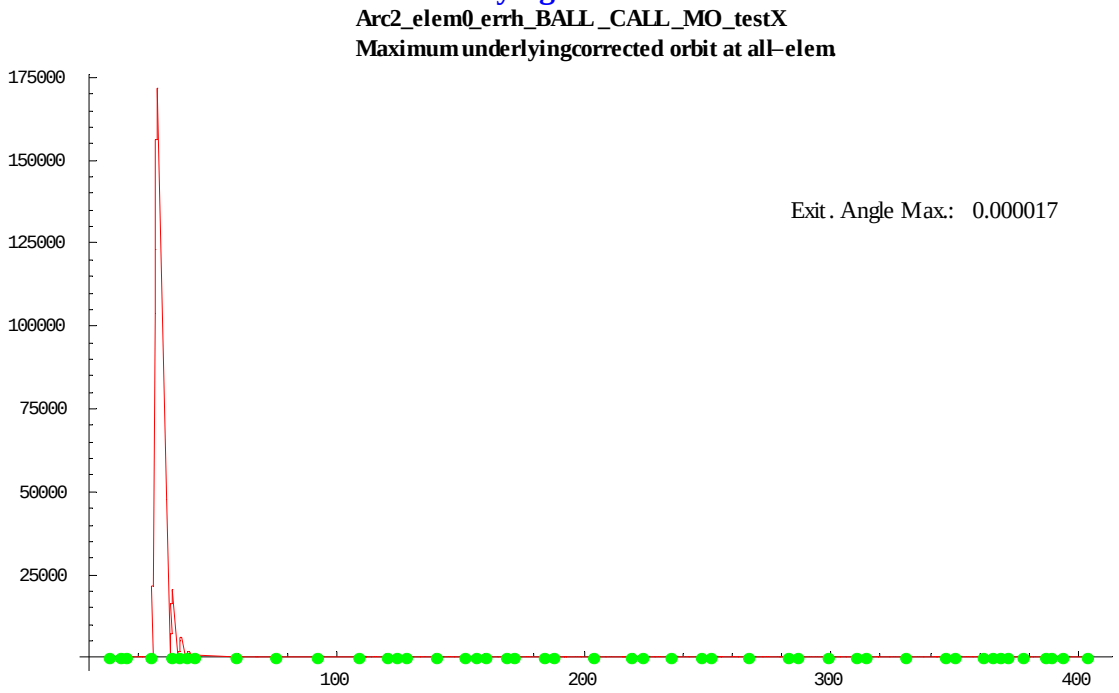


Fundamental Uncorrectable Orbit at all BPMs due to 3σ Error in Y

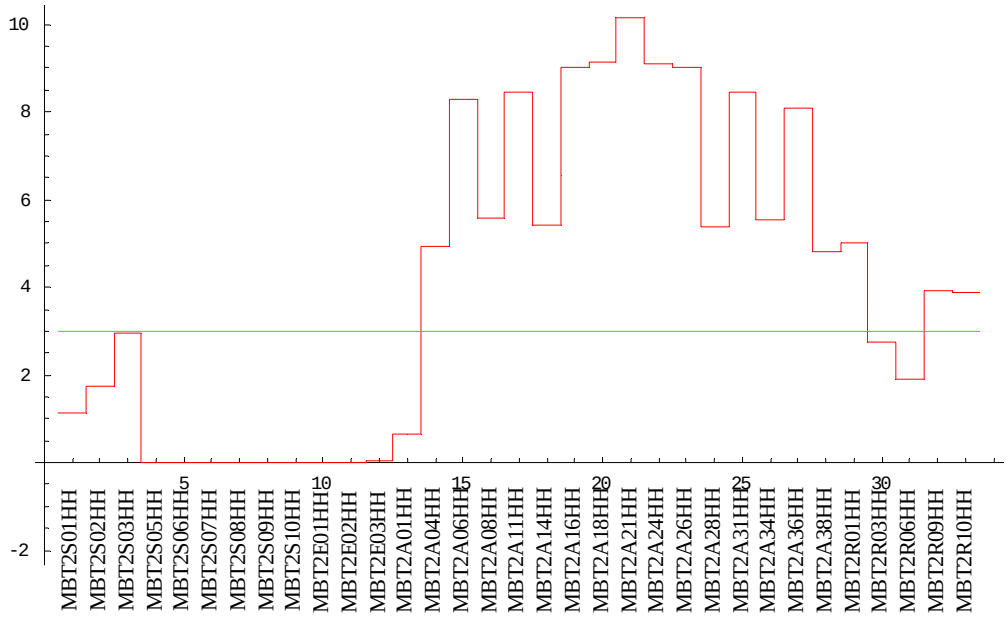


ARC 2 (Before Removing Singular Correctors in X & Y)

3σ Extent of the Real Underlying Orbit after Orbit Correction in X



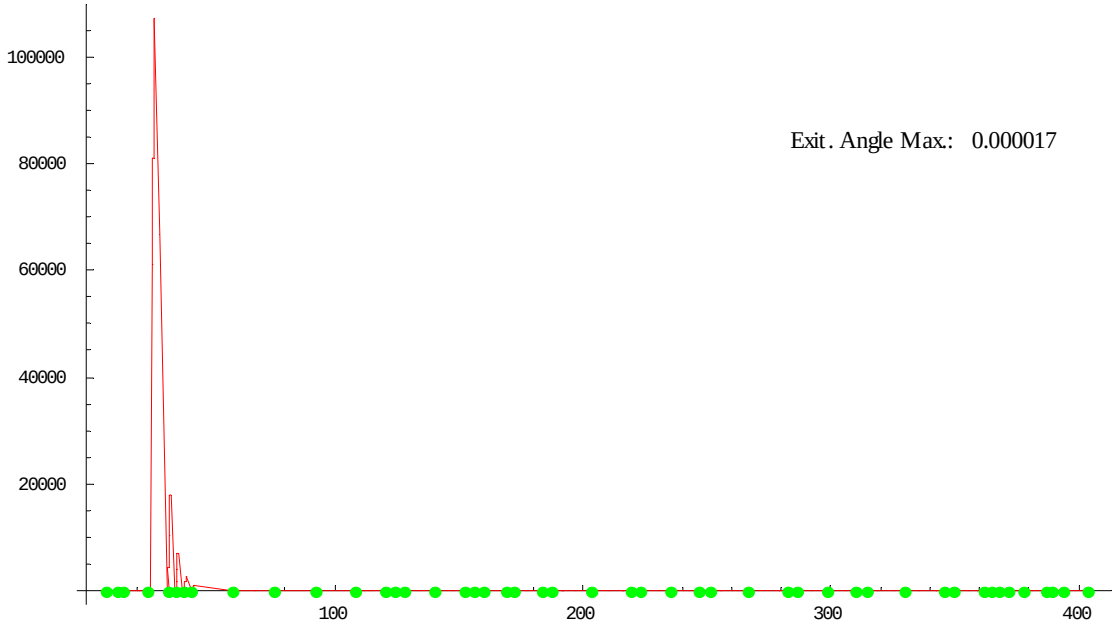
Range of Correctors in Multiples of σ of Error Distribution That Can be Corrected in X



3σ Extent of the Real Underlying Orbit after Orbit Correction in Y

Arc2_elem0_errv_BALL_CALL_MO_testY

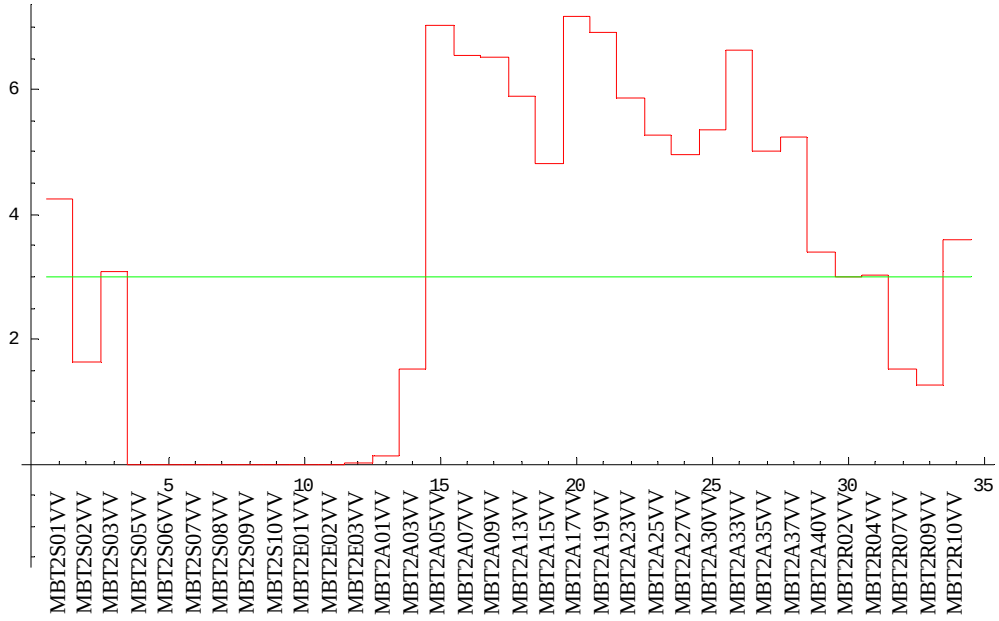
Maximum underlying corrected orbit at all–elem



Range of Correctors in Multiples of σ of Error Distribution That Can be Corrected in Y

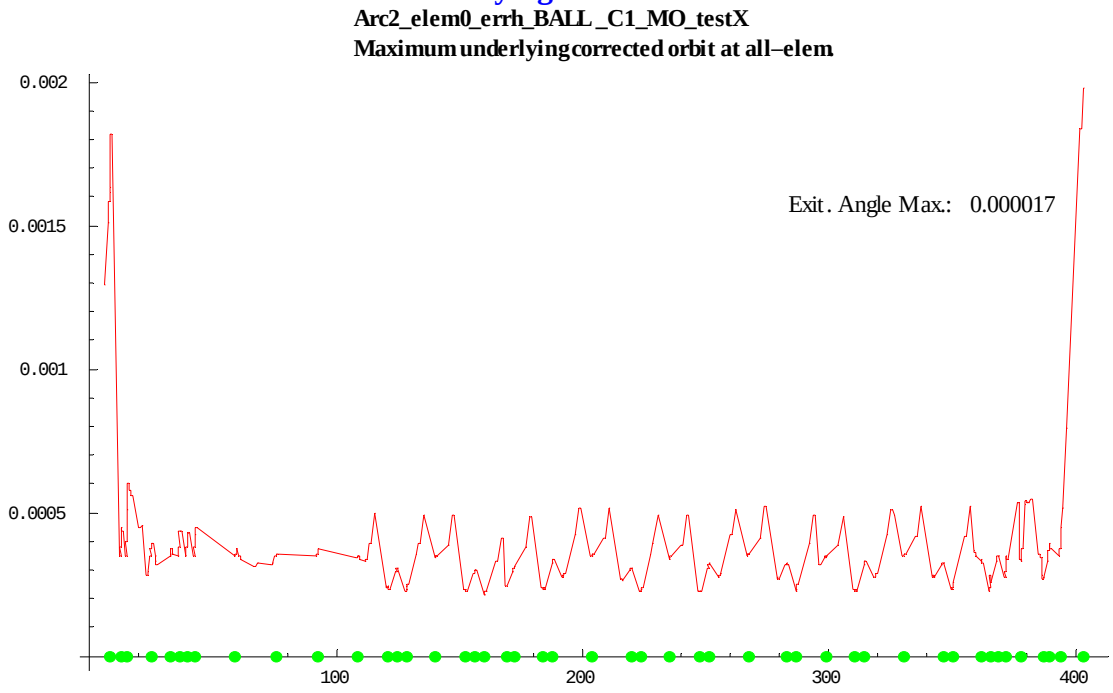
Arc2_elem0_errv_BALL_CALL_CD_testY

Corrector range in units of projected sigma (clipped at 25.)

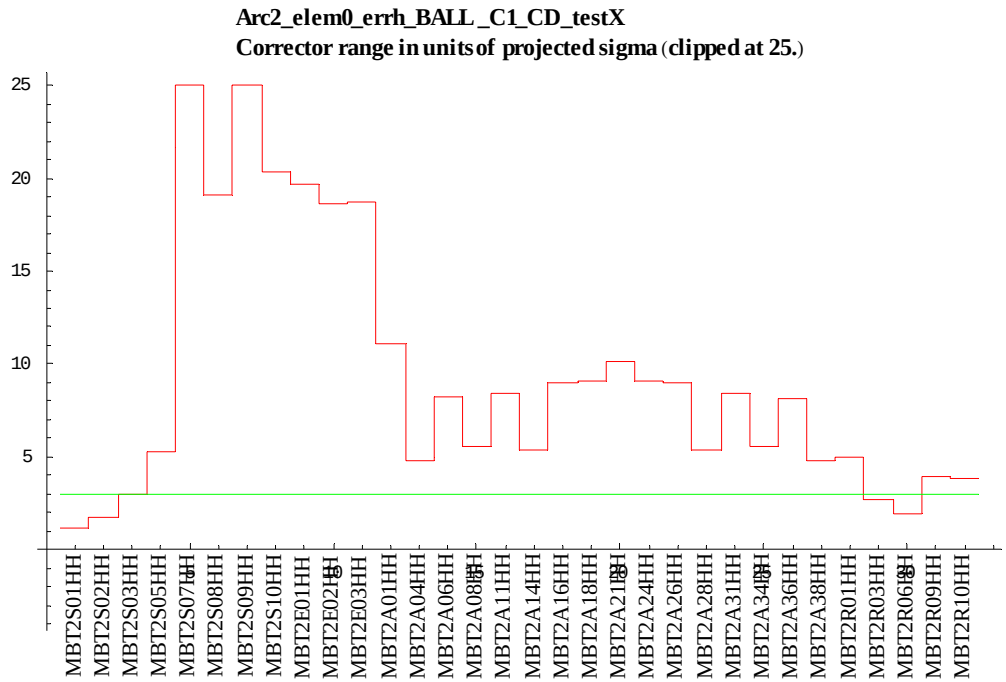


ARC 2 (After Removing Singular Correctors in X & Y)

3σ Extent of the Real Underlying Orbit after Orbit Correction in X

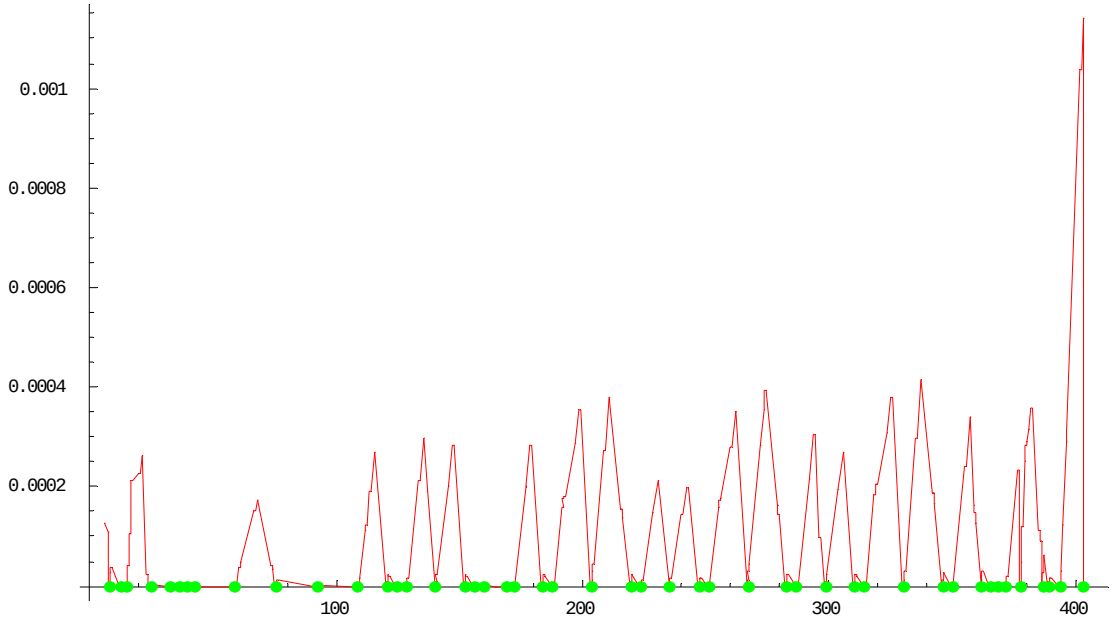


Range of Correctors in Multiples of σ of Error Distribution That Can be Corrected in X



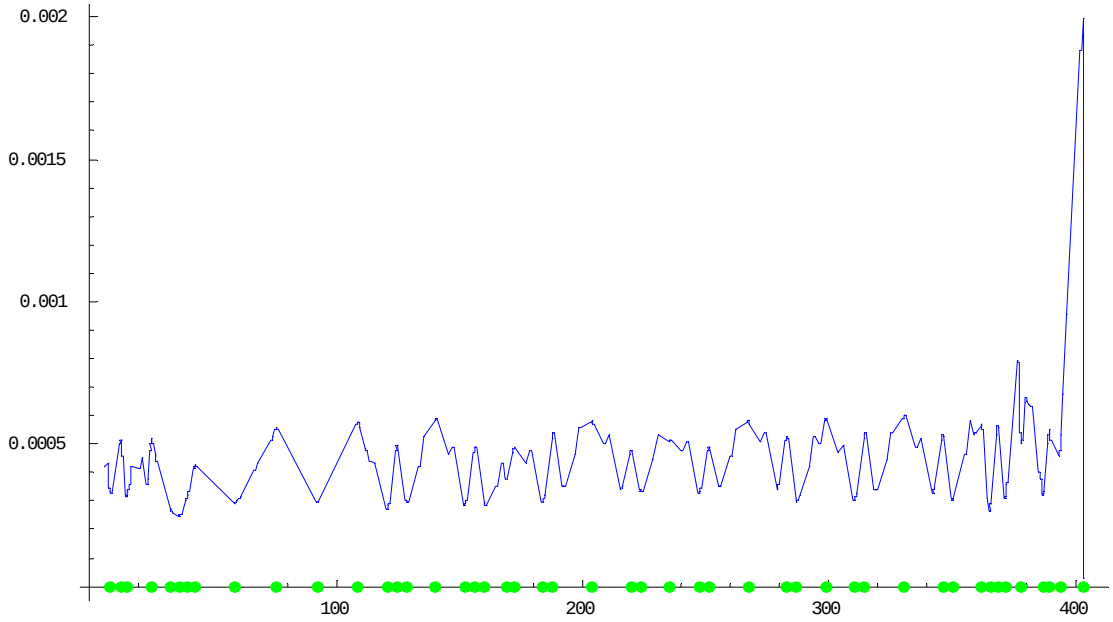
3σ Error Projection onto the Null Space of the Response Matrix in X

Arc2_elem0_errh_BALL_C1_MD_testX
Max. per−axis error null proj.



3σ Extent of Underlying Orbit When Apparent Orbit RMS Equals BPM Offset in X

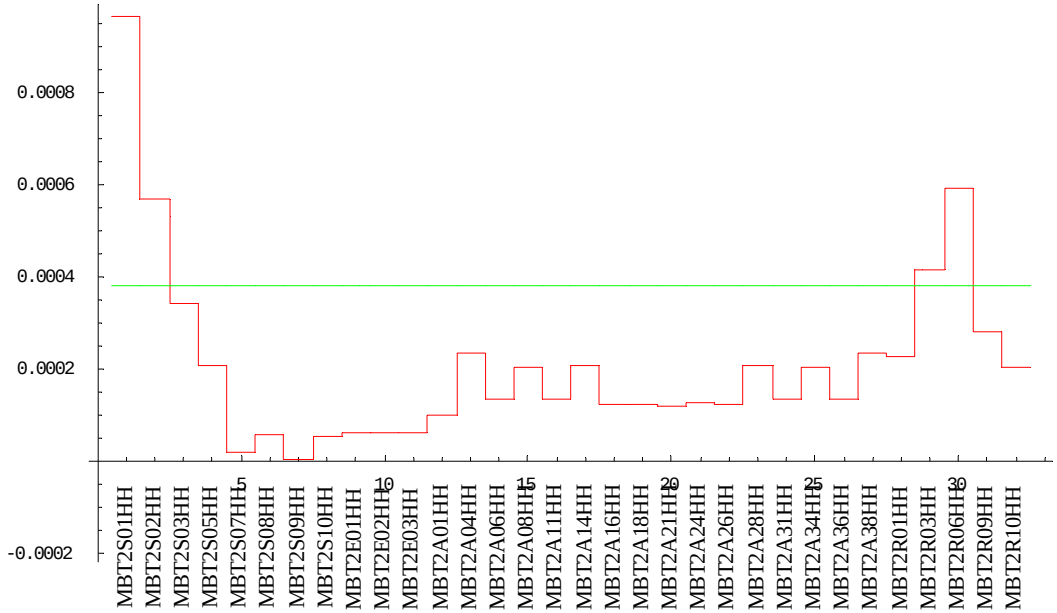
Arc2_elem0_errh_BALL_C1_MD_testX
Max. per−axis orbit with combined error−monitor probability



Corrector Strengths Needed for 3σ Error with Unlimited Monitoring Power in X

Arc2_elem0_errh_BALL_C1_CD_testX

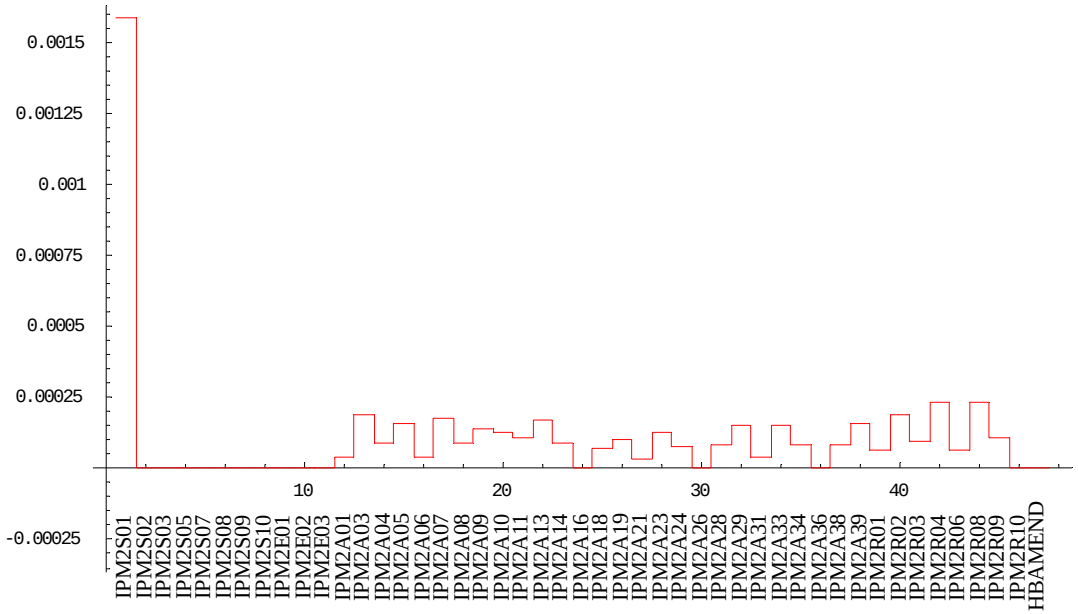
Max. corr. strength needed with unlimited monitoring power



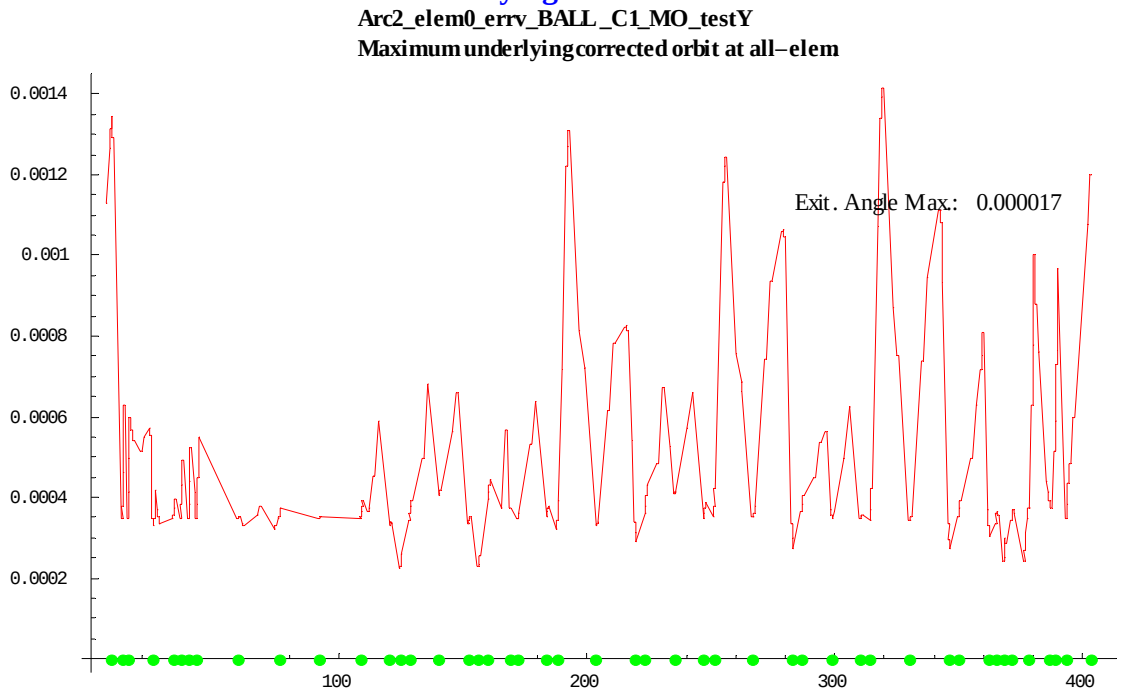
Fundamental Uncorrectable Orbit at all BPMs due to 3σ Error in X

Arc2_elem0_errh_BALL_C1_CD_testX

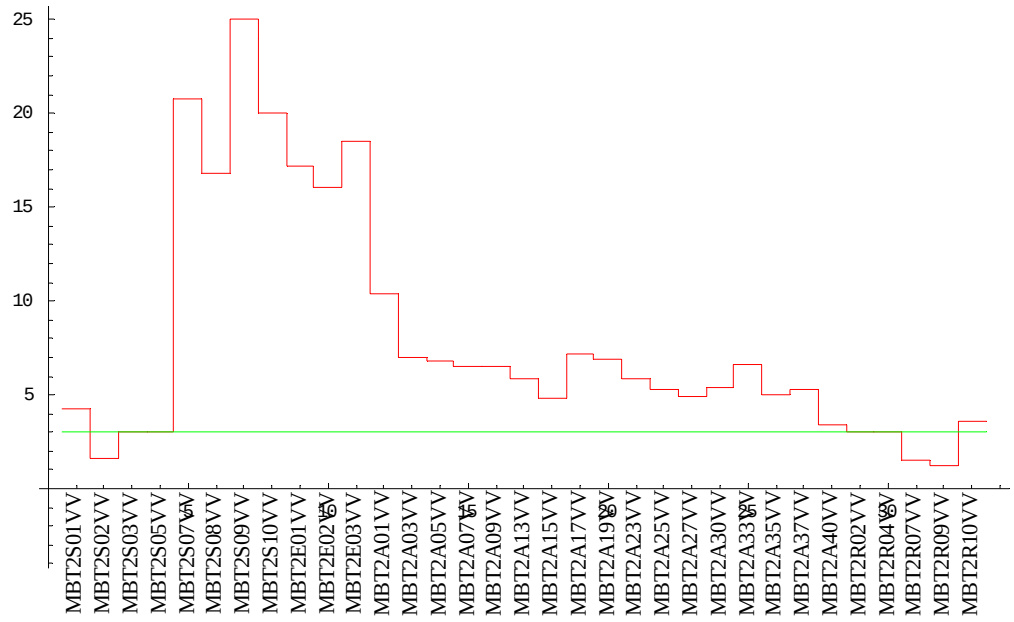
Max. per−BPM uncorrectable orbit proj.



3σ Extent of the Real Underlying Orbit after Orbit Correction in Y



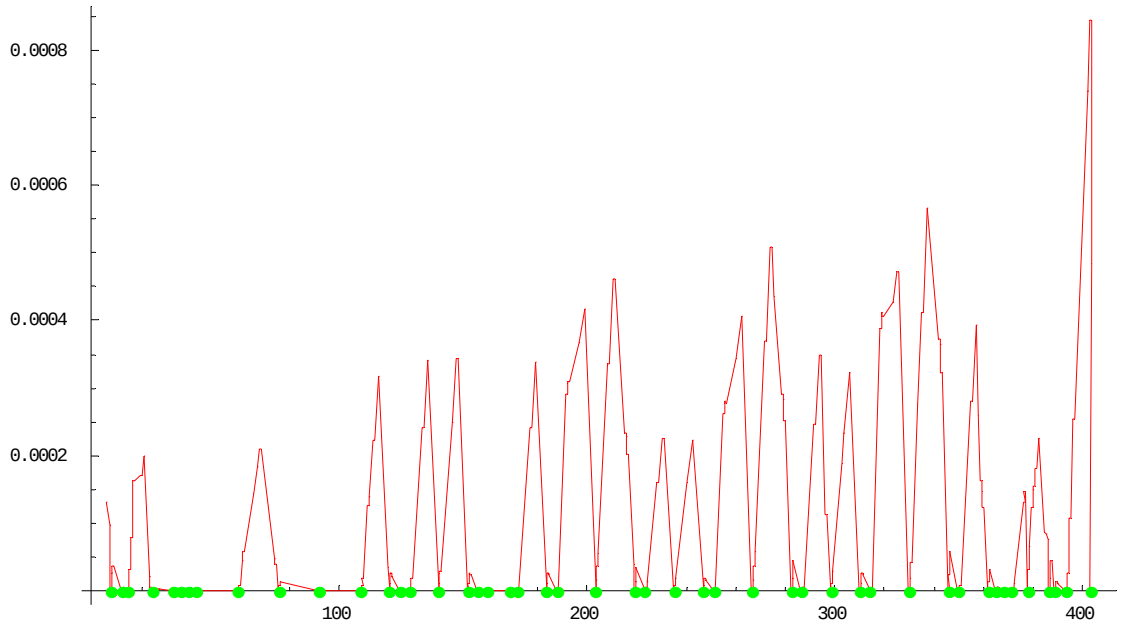
Range of Correctors in Multiples of σ of Error Distribution That Can be Corrected in Y



3σ Error Projection onto the Null Space of the Response Matrix in Y

Arc2_elem0_errv_BALL_C1_MD_testY

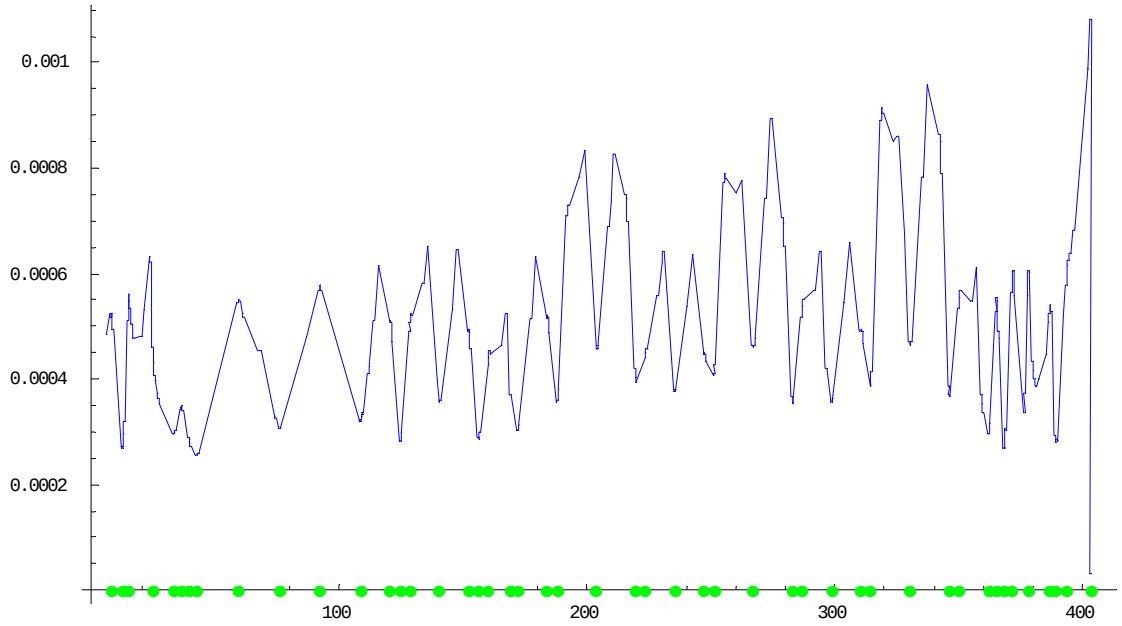
Max. per−axis error null proj.



3σ Extent of Underlying Orbit When Apparent Orbit RMS Equals BPM Offset in Y

Arc2_elem0_errv_BALL_C1_MD_testY

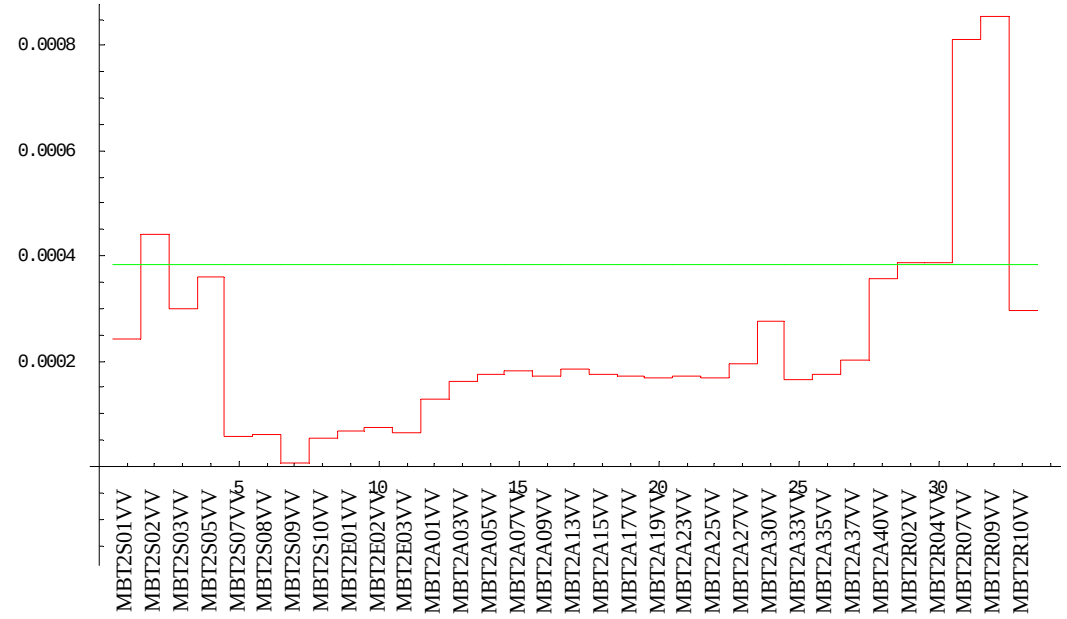
Max. per−axis orbit with combined error−monitor probability



Corrector Strengths Needed for 3σ Error with Unlimited Monitoring Power in Y

Arc2_elem0_errv_BALL_C1_CD_testY

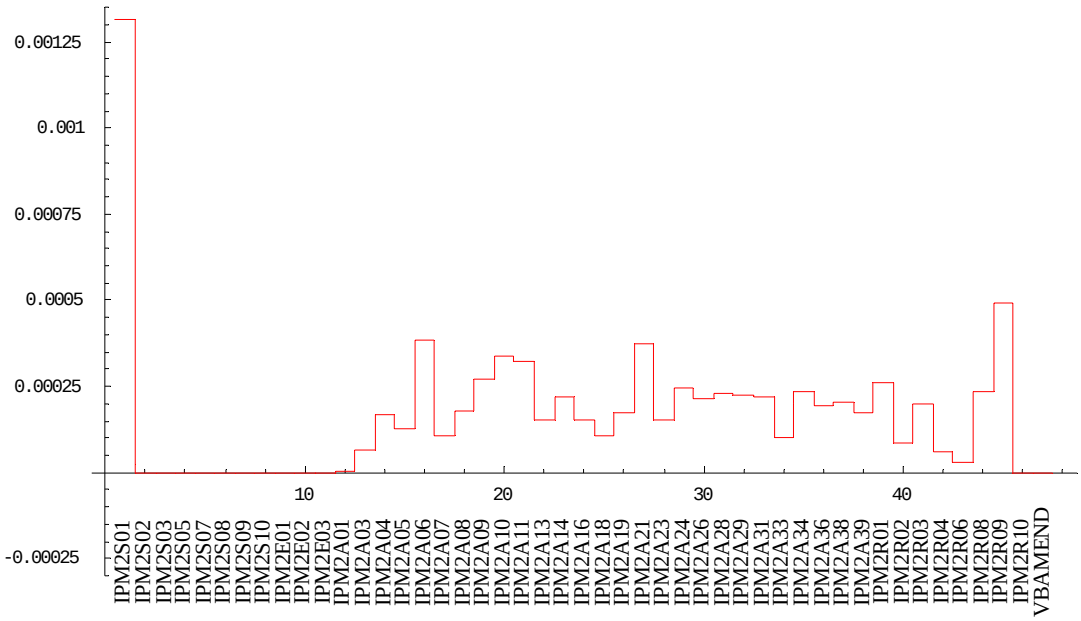
Max. corr. strength needed with unlimited monitoring power



Fundamental Uncorrectable Orbit at all BPMs due to 3σ Error in Y

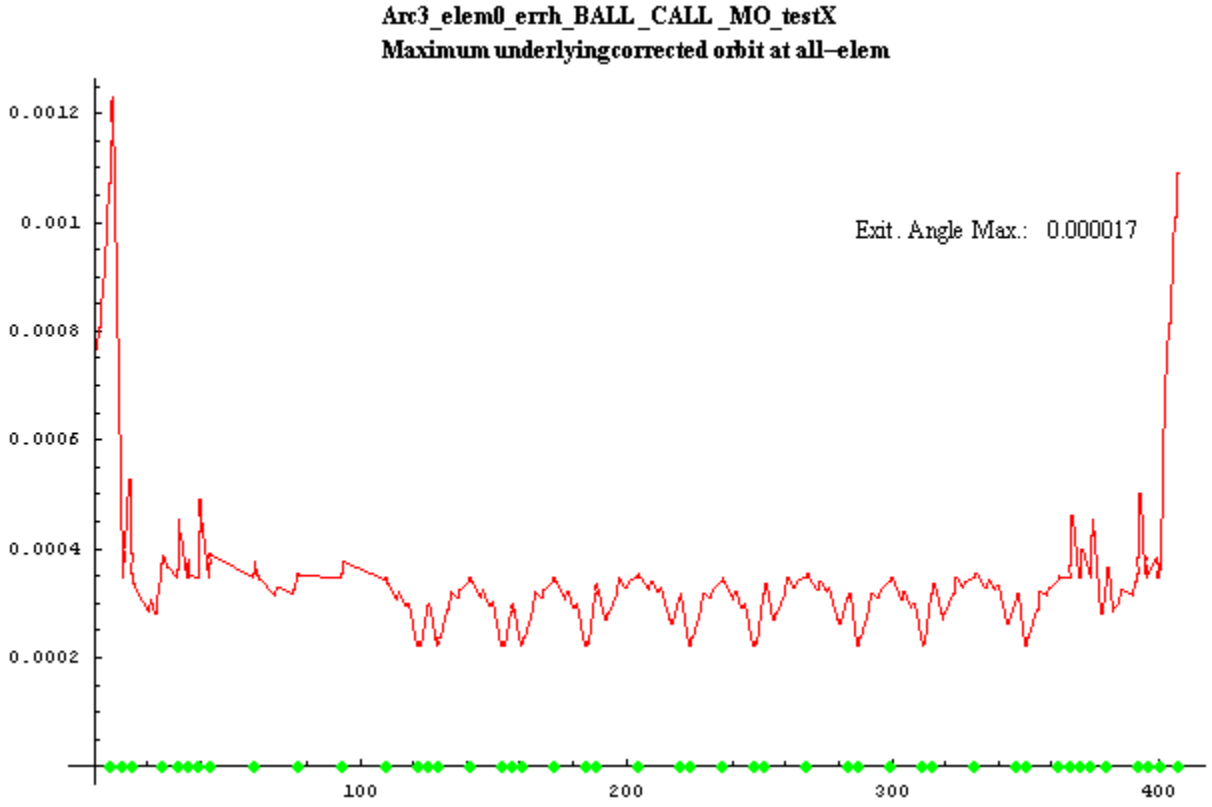
Arc2_elem0_errv_BALL_C1_CD_testY

Max. per–BPM uncorrectable orbit proj.

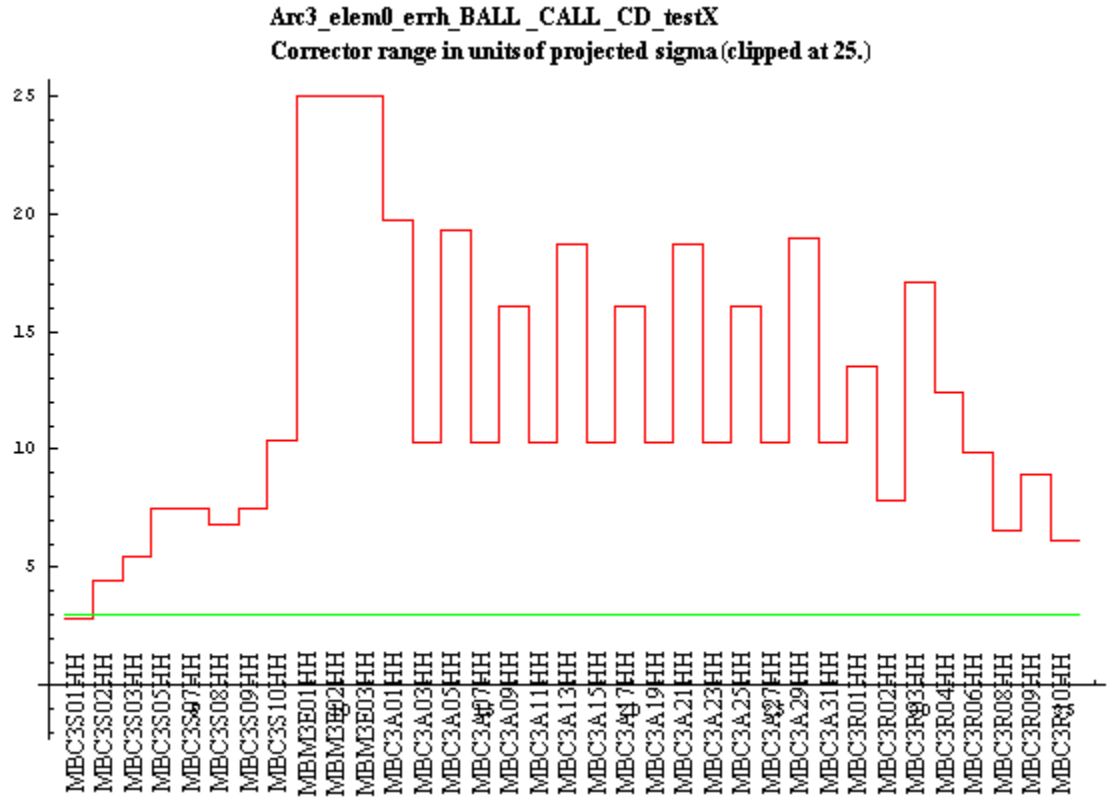


ARC 3

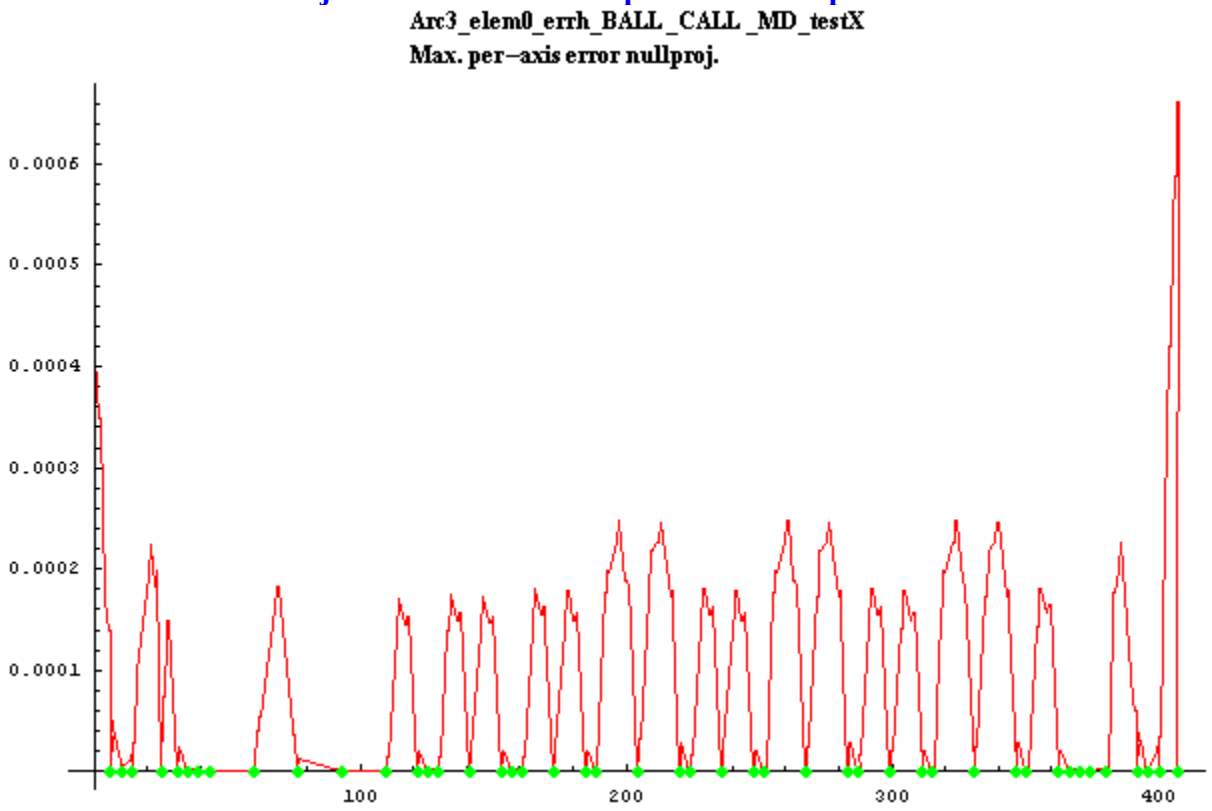
3σ Extent of the Real Underlying Orbit after Orbit Correction in X



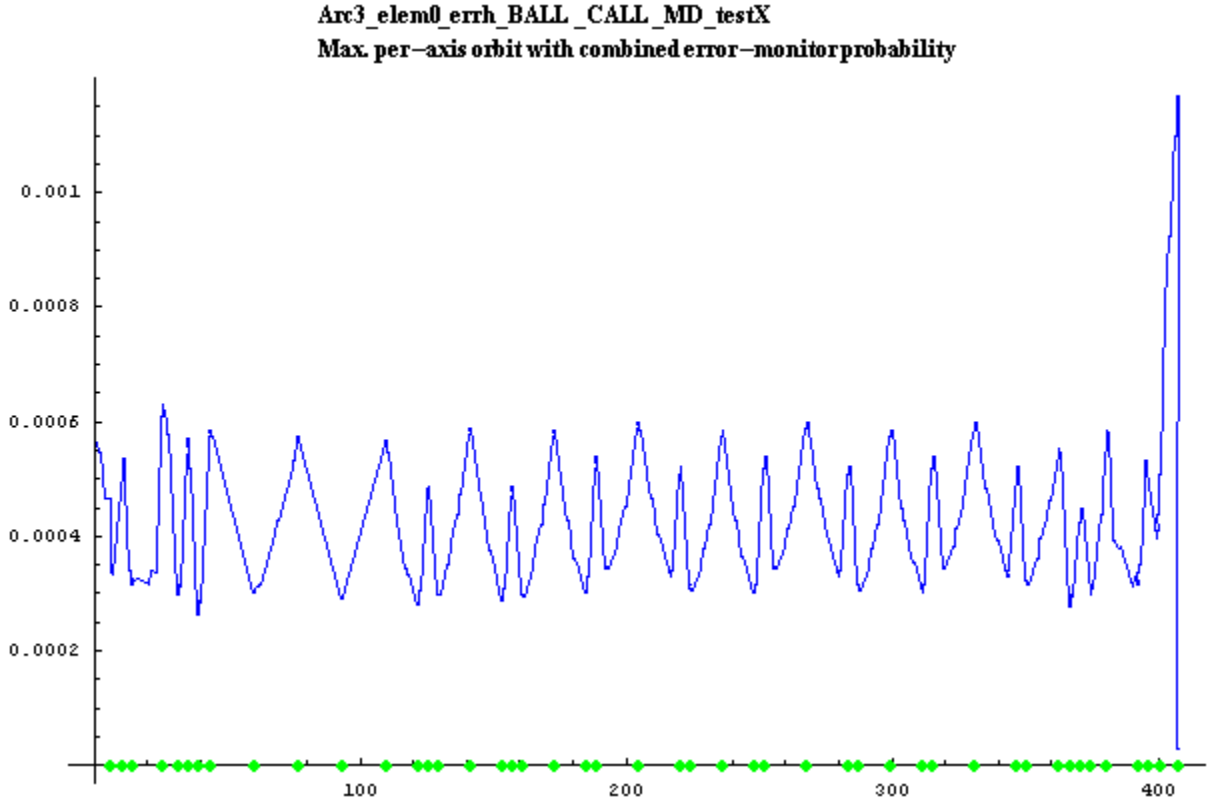
Range of Correctors in Multiples of σ of Error Distribution That Can be Corrected in X



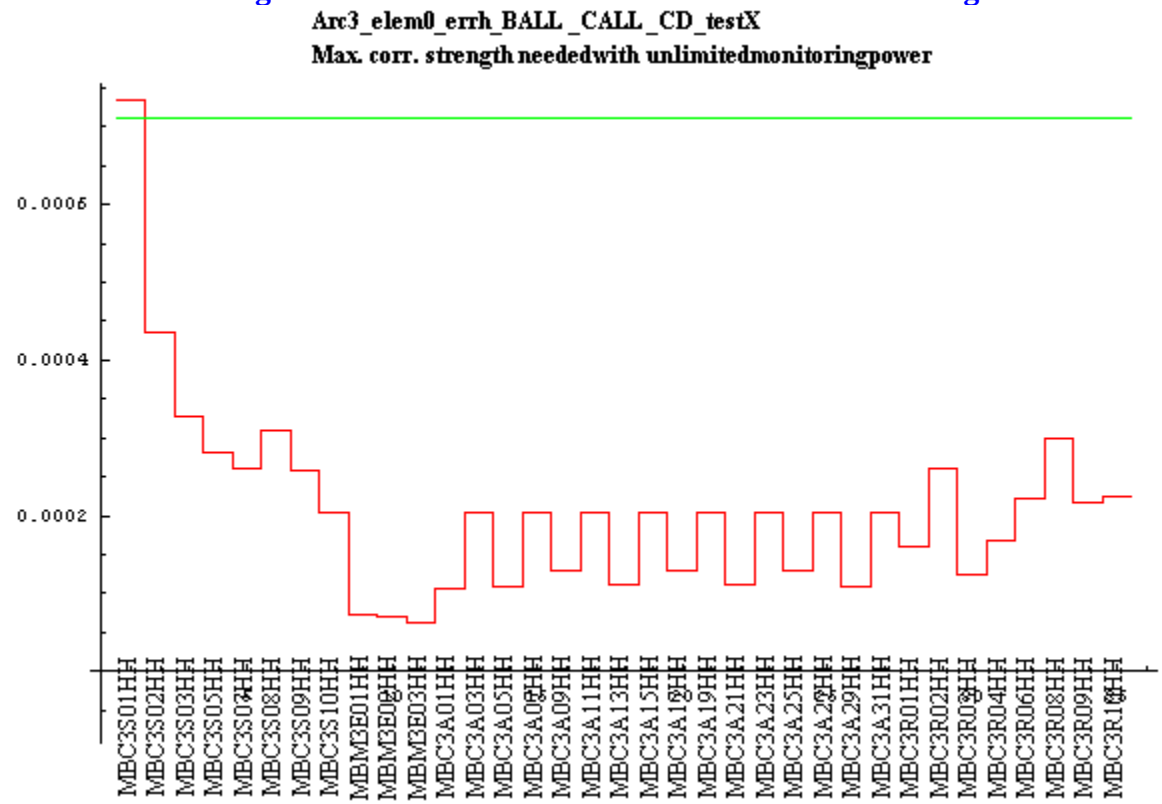
3σ Error Projection onto the Null Space of the Response Matrix in X



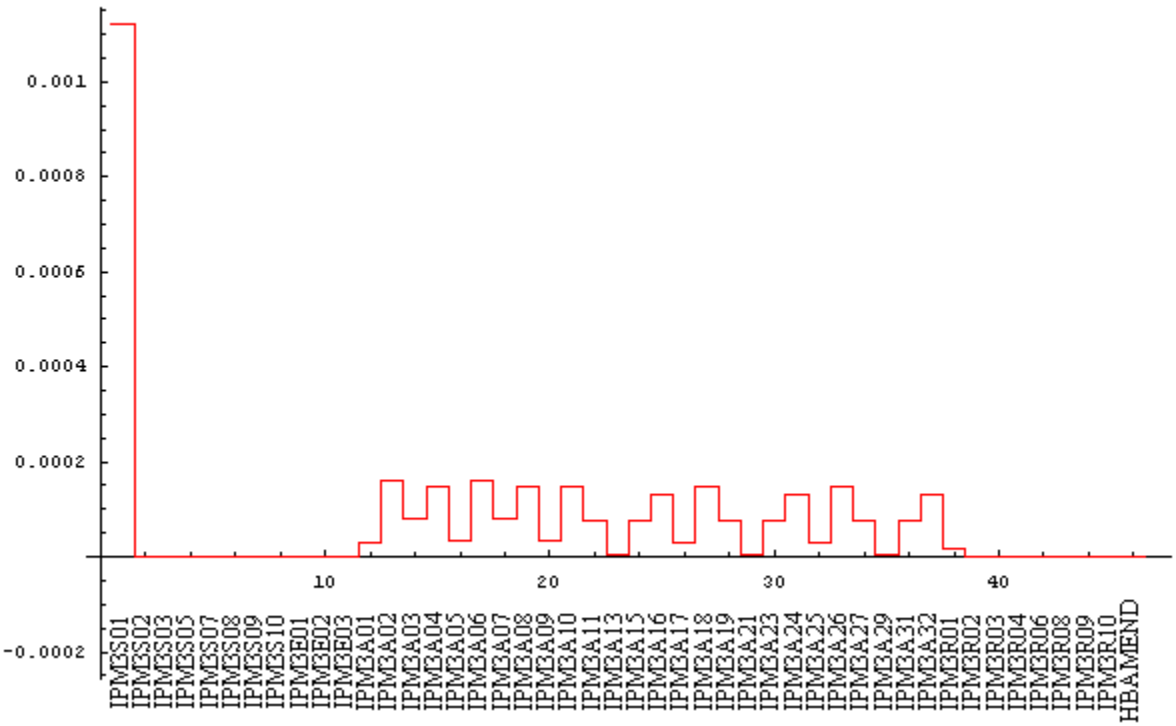
3σ Extent of Underlying Orbit When Apparent Orbit RMS Equals BPM Offset in X



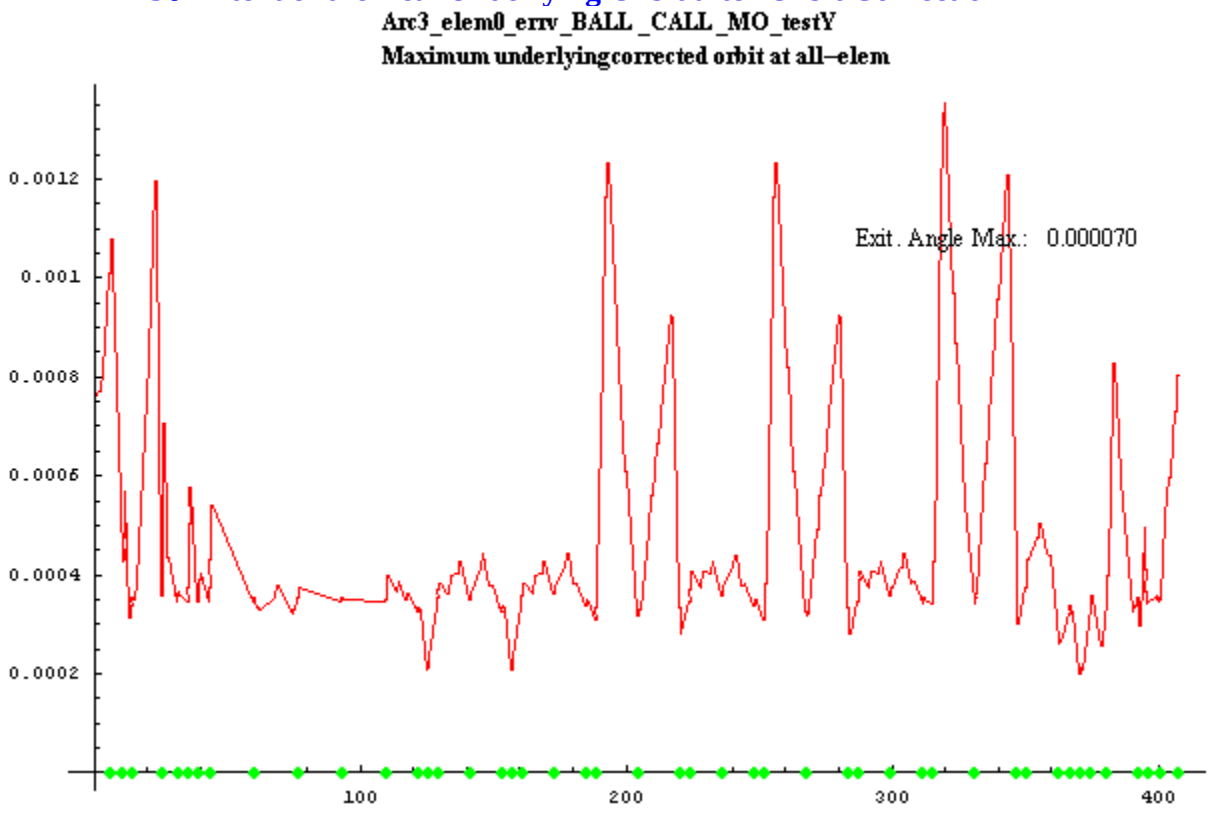
Corrector Strengths Needed for 3σ Error with Unlimited Monitoring Power in X



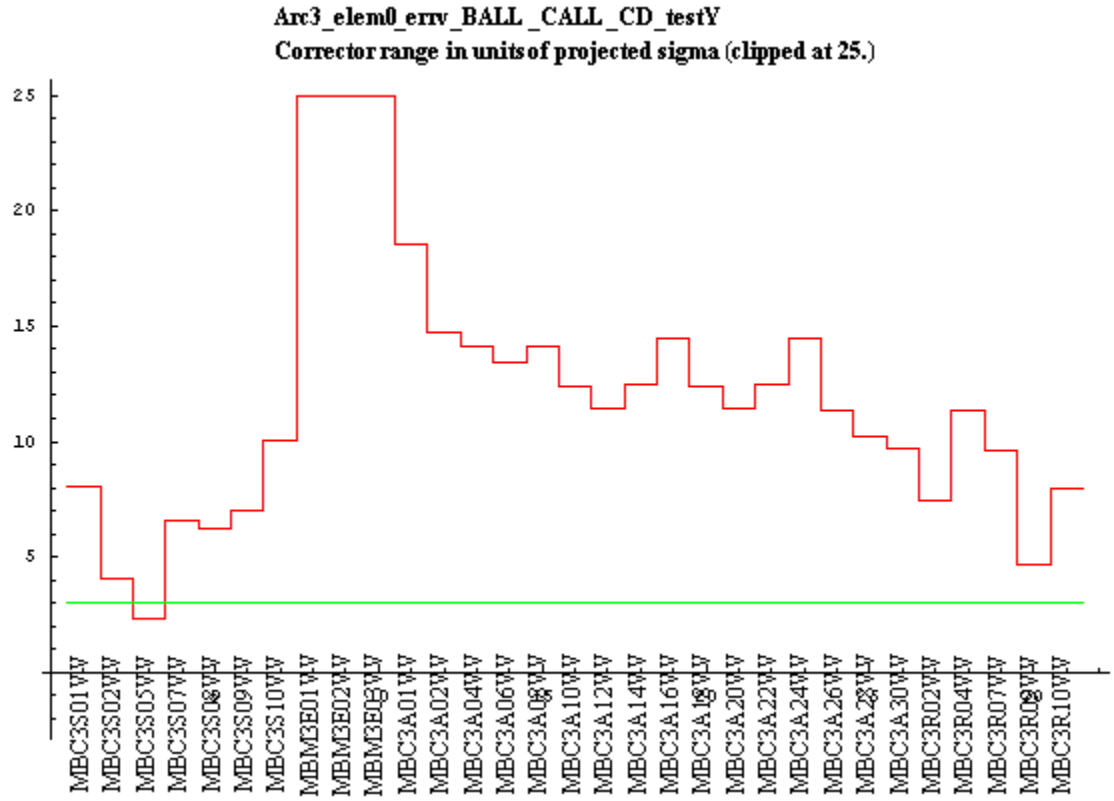
Fundamental Uncorrectable Orbit at all BPMs due to 3σ Error in X



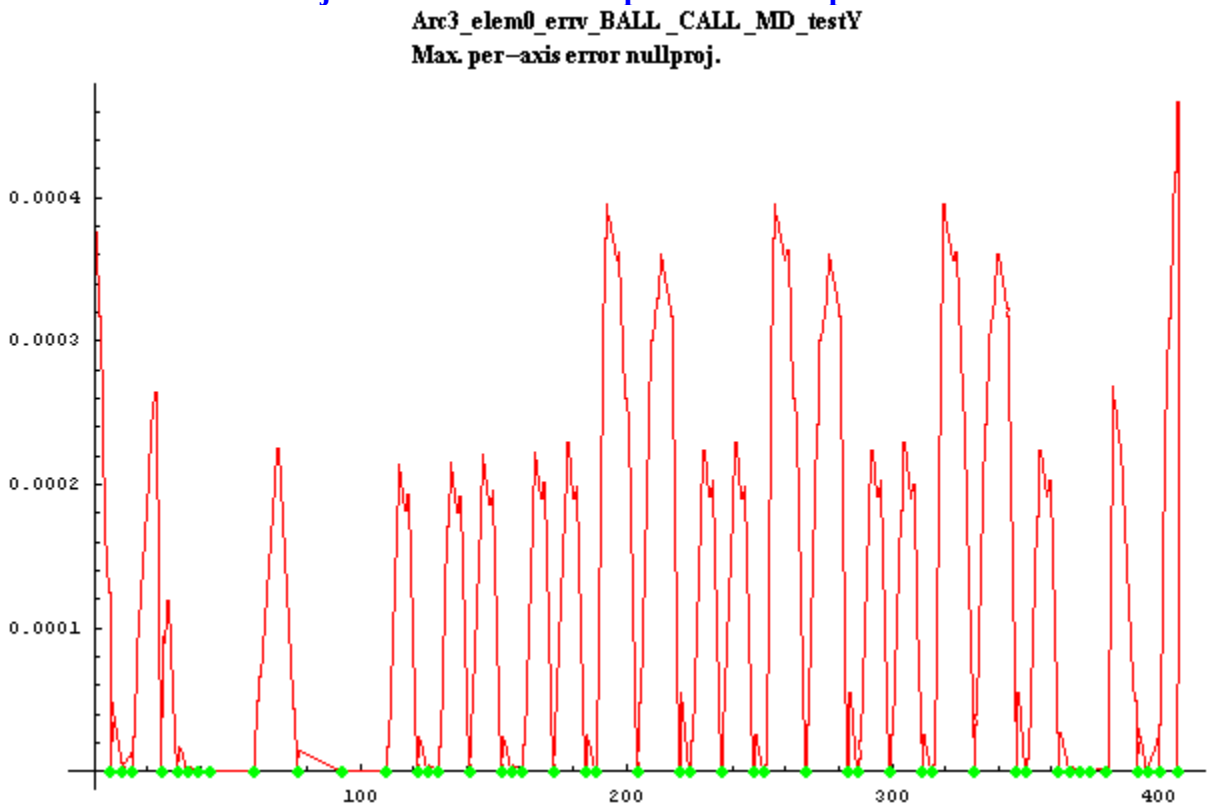
3σ Extent of the Real Underlying Orbit after Orbit Correction in Y



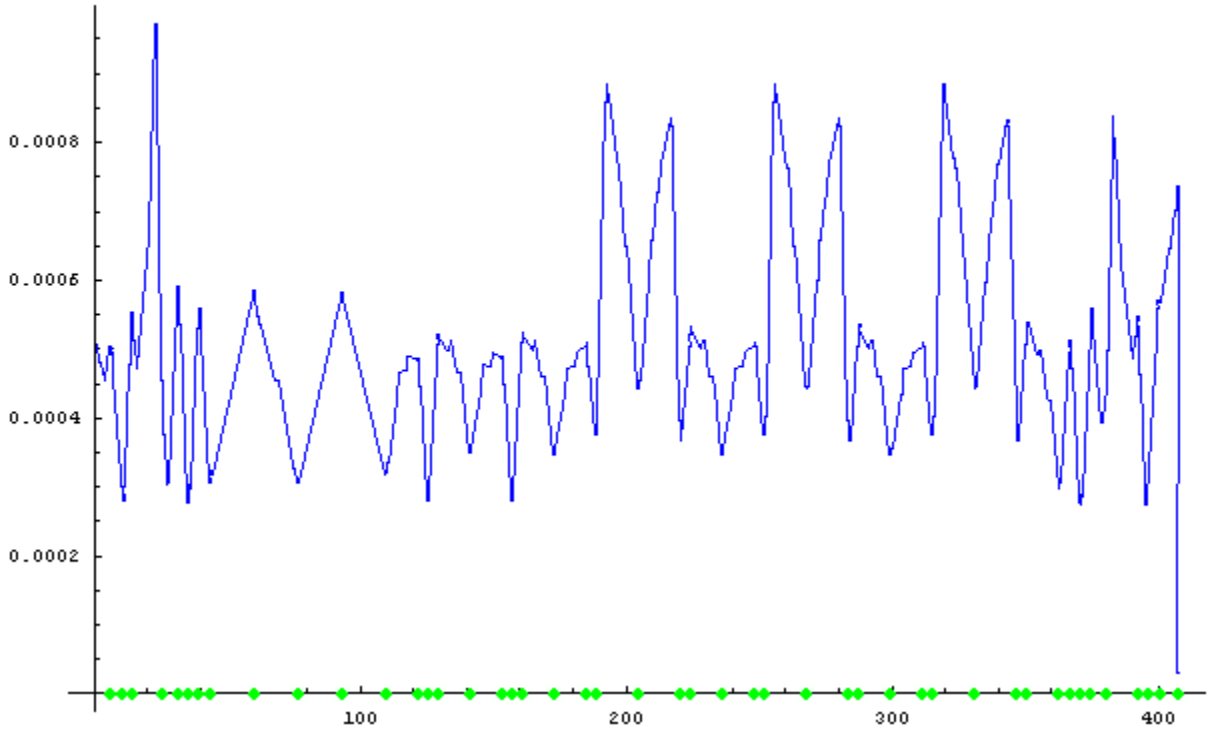
Range of Correctors in Multiples of σ of Error Distribution That Can be Corrected in Y



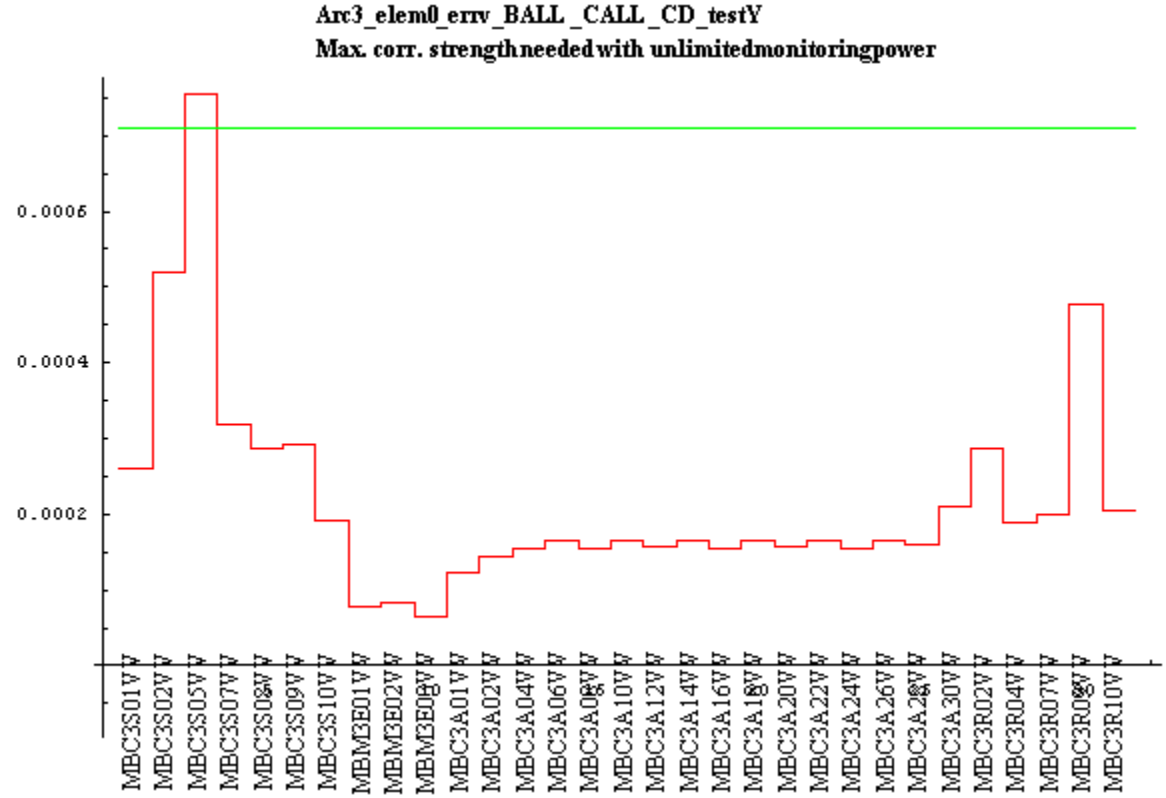
3σ Error Projection onto the Null Space of the Response Matrix in Y



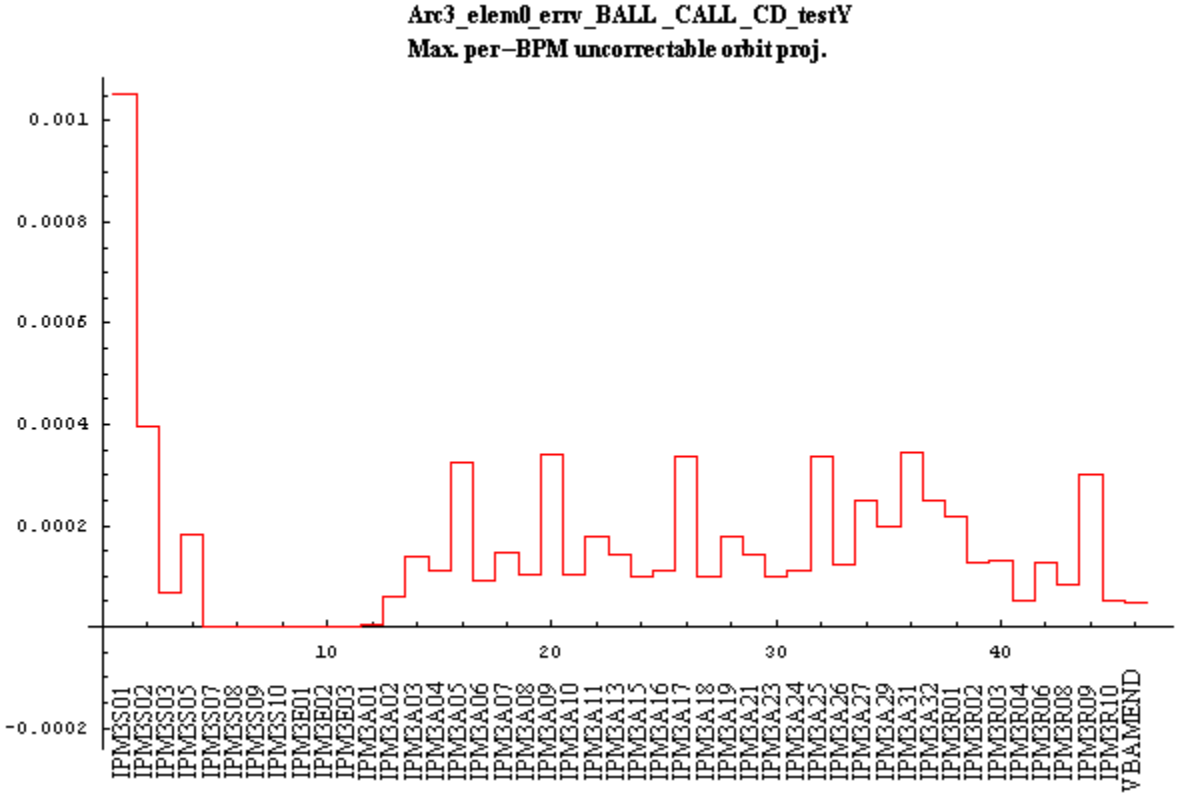
3σ Extent of Underlying Orbit When Apparent Orbit RMS Equals BPM Offset in Y



Corrector Strengths Needed for 3σ Error with Unlimited Monitoring Power in Y

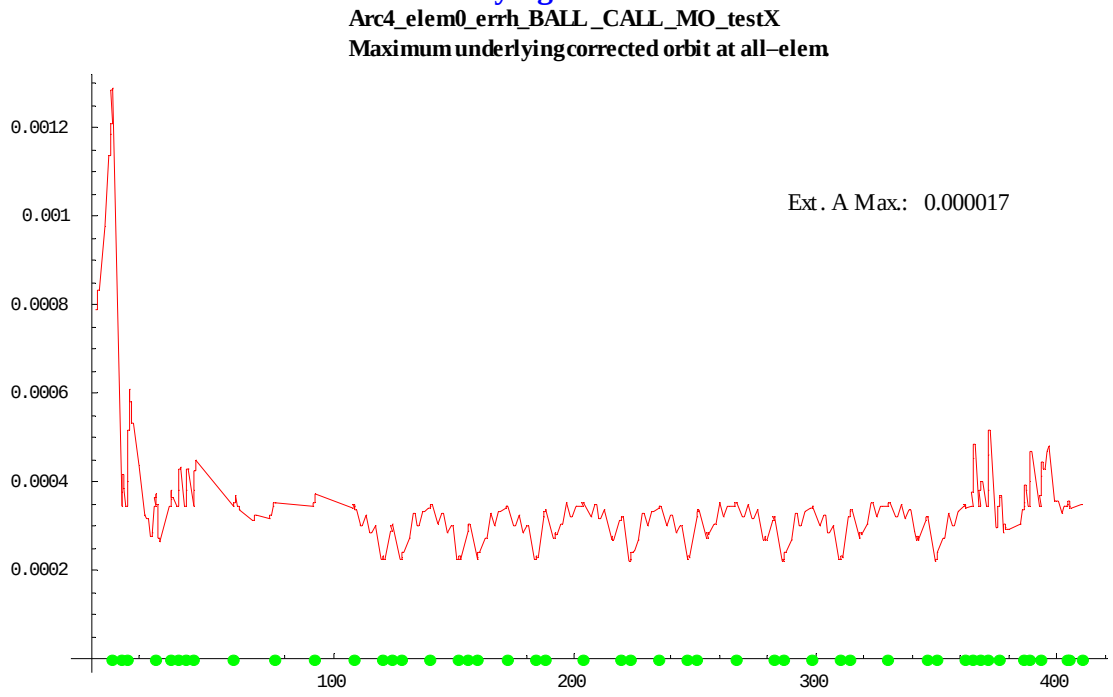


Fundamental Uncorrectable Orbit at all BPMs due to 3σ Error in Y

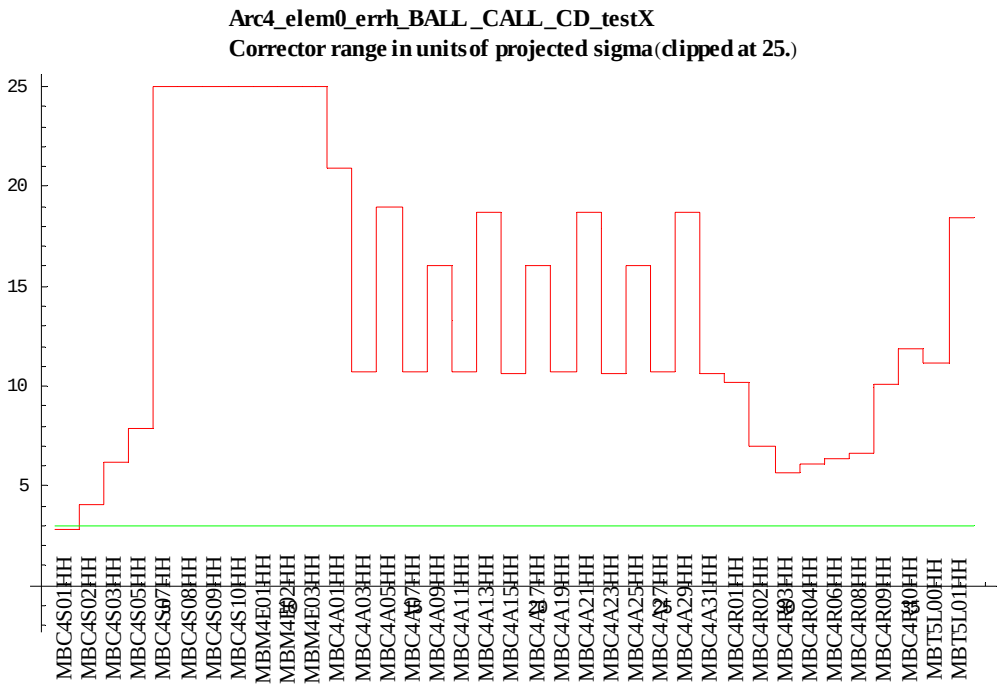


ARC 4

3σ Extent of the Real Underlying Orbit after Orbit Correction in X



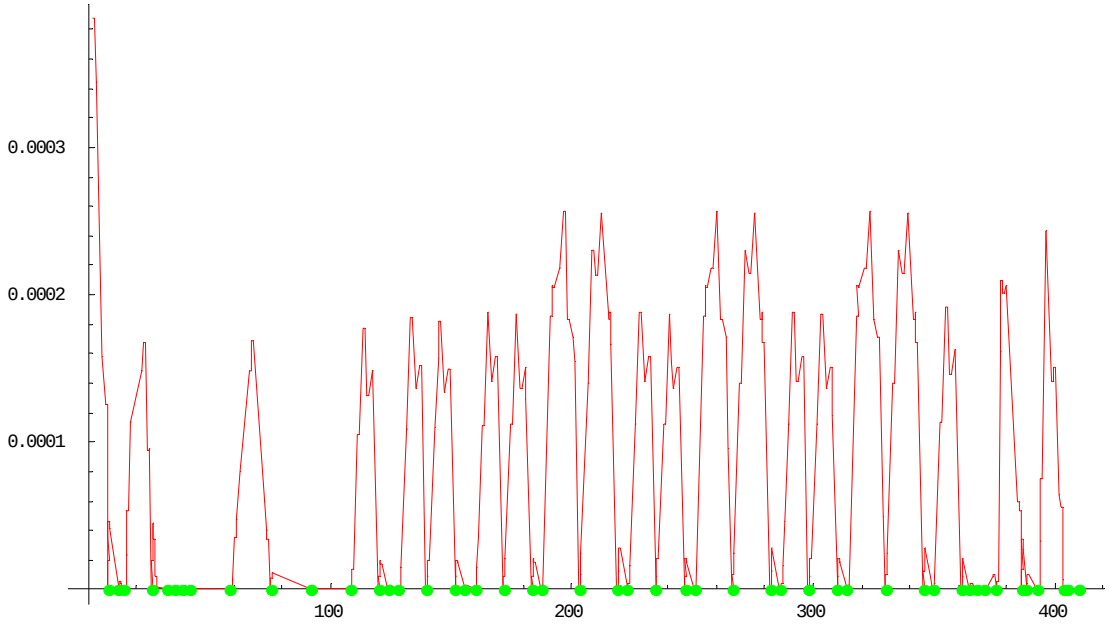
Range of Correctors in Multiples of σ of Error Distribution That Can be Corrected in X



3σ Error Projection onto the Null Space of the Response Matrix in X

Arc4_elem0_errh_BALL_CALL_MD_testX

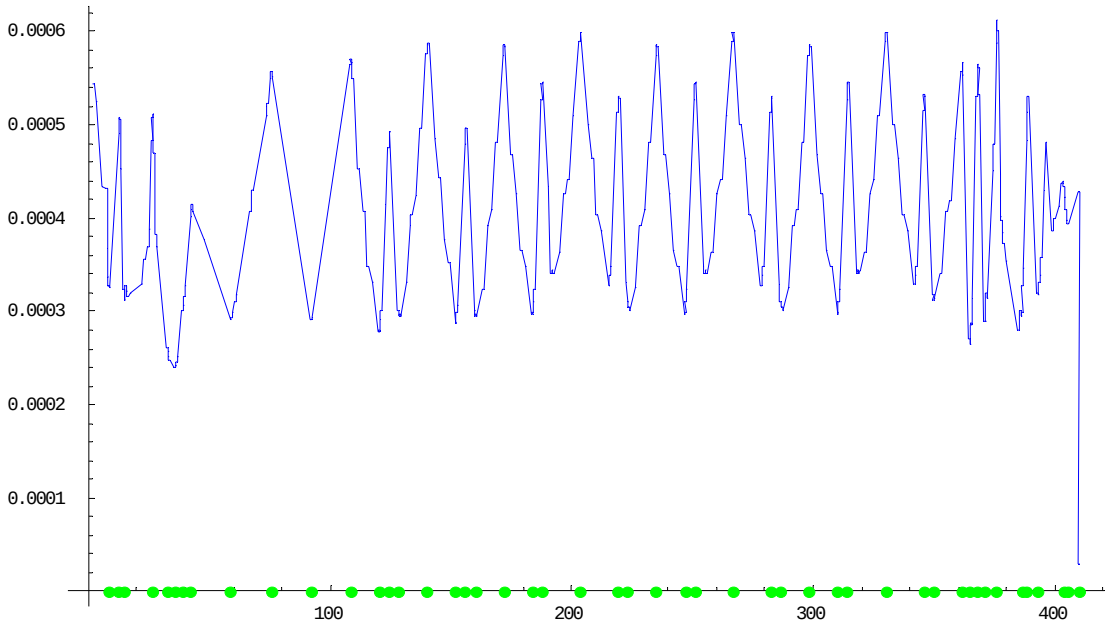
Max. per−axis error null proj.



3σ Extent of Underlying Orbit When Apparent Orbit RMS Equals BPM Offset in X

Arc4_elem0_errh_BALL_CALL_MD_testX

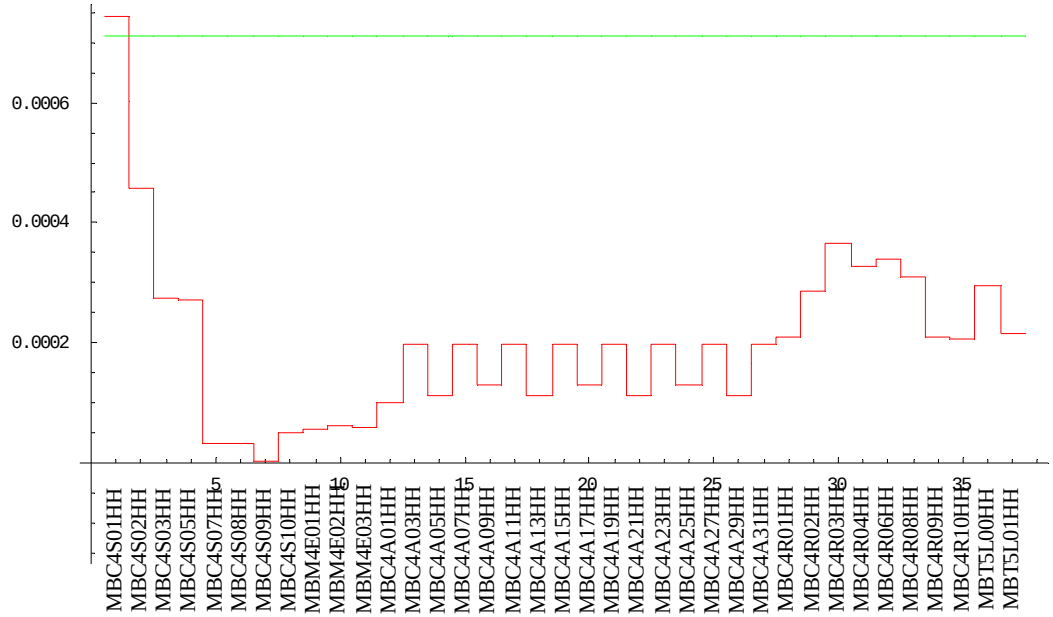
Max. per−axis orbit with combined error−monitor probability



Corrector Strengths Needed for 3σ Error with Unlimited Monitoring Power in X

Arc4_elem0_errh_BALL_CALL_CD_testX

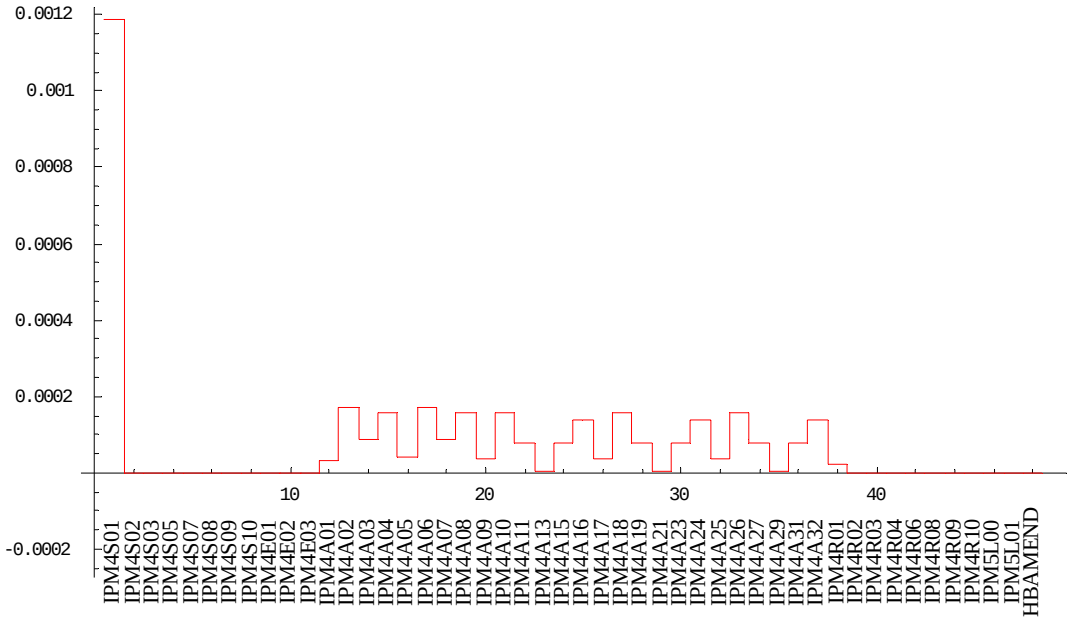
Max. corr. strength needed with unlimited monitoring power



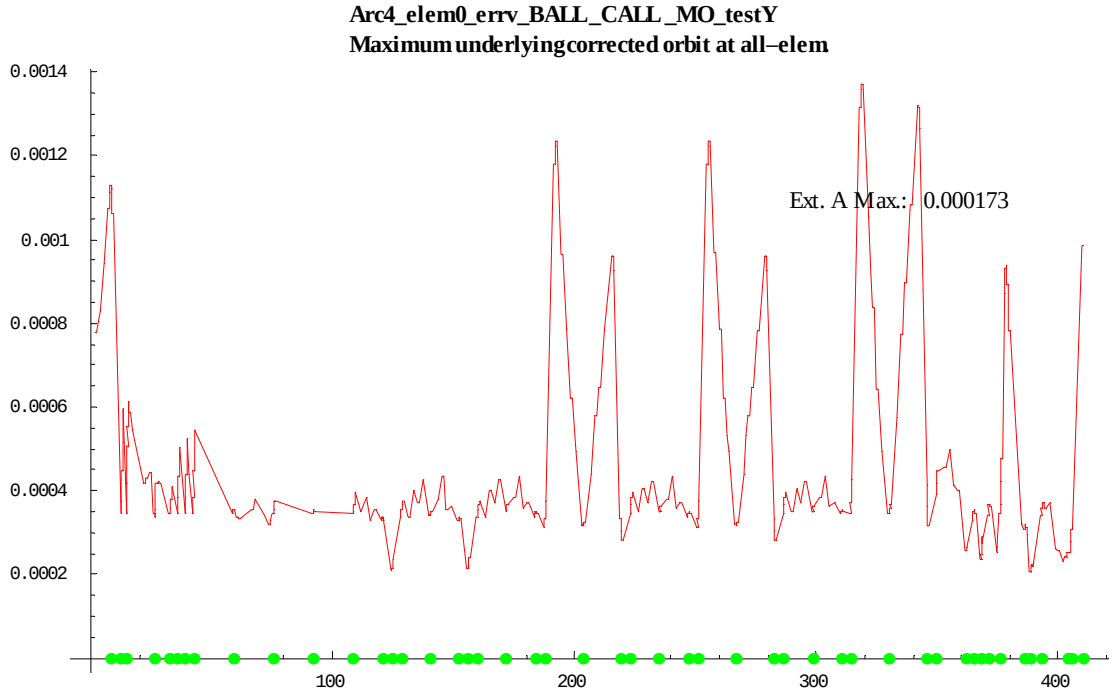
Fundamental Uncorrectable Orbit at all BPMs due to 3σ Error in X

Arc4_elem0_errh_BALL_CALL_CD_testX

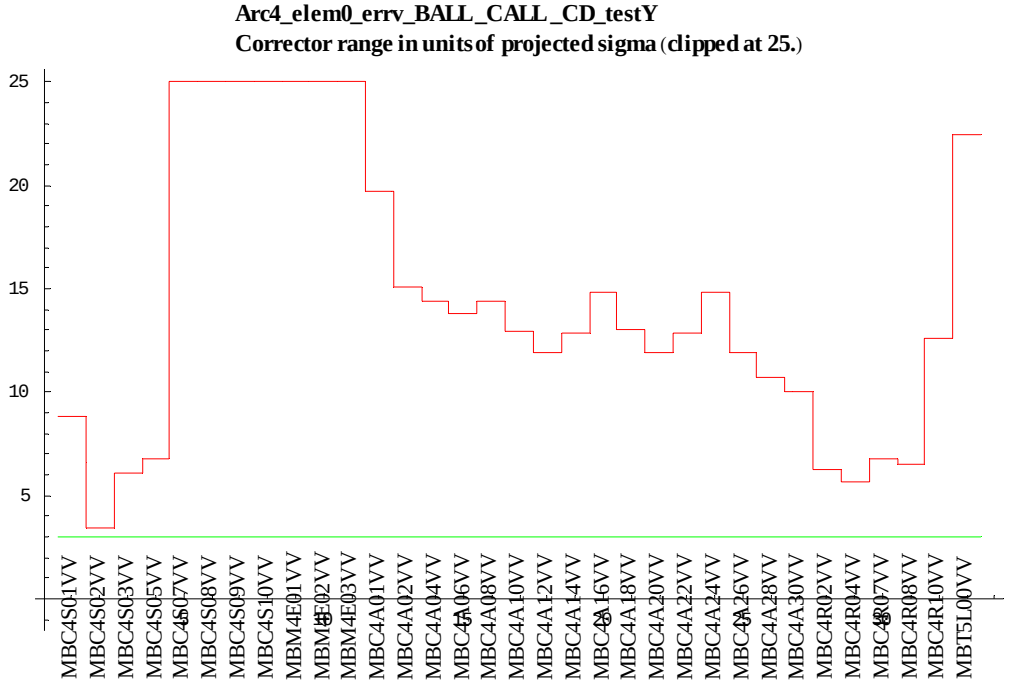
Max. per−BPM uncorrectable orbit proj.



3σ Extent of the Real Underlying Orbit after Orbit Correction in Y



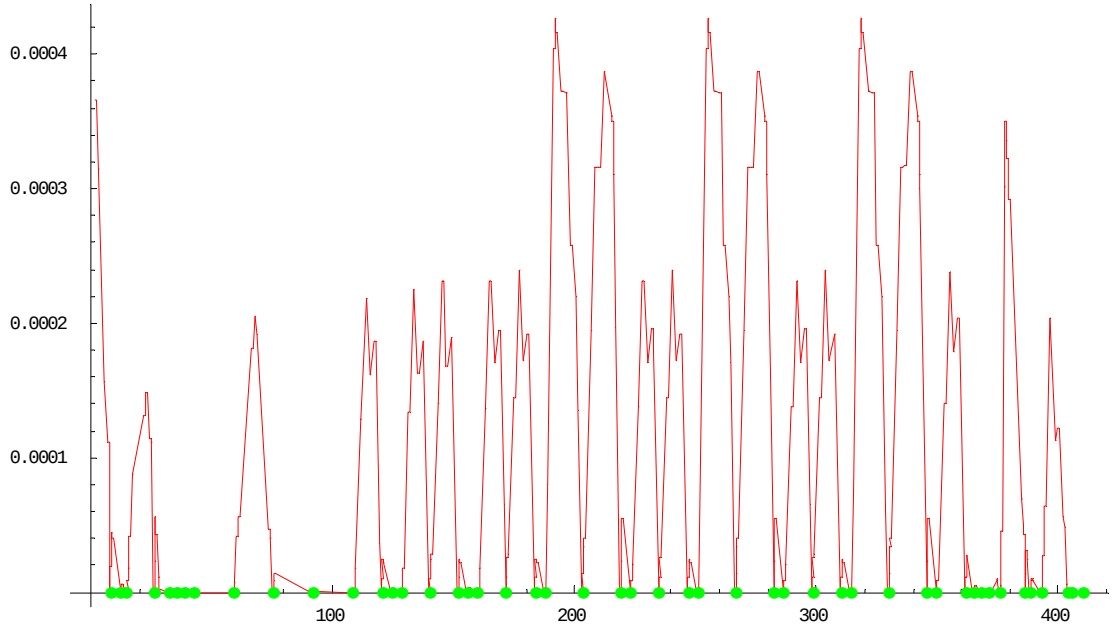
Range of Correctors in Multiples of σ of Error Distribution That Can be Corrected in Y



3σ Error Projection onto the Null Space of the Response Matrix in Y

Arc4_elem0_errv_BALL_CALL_MD_testY

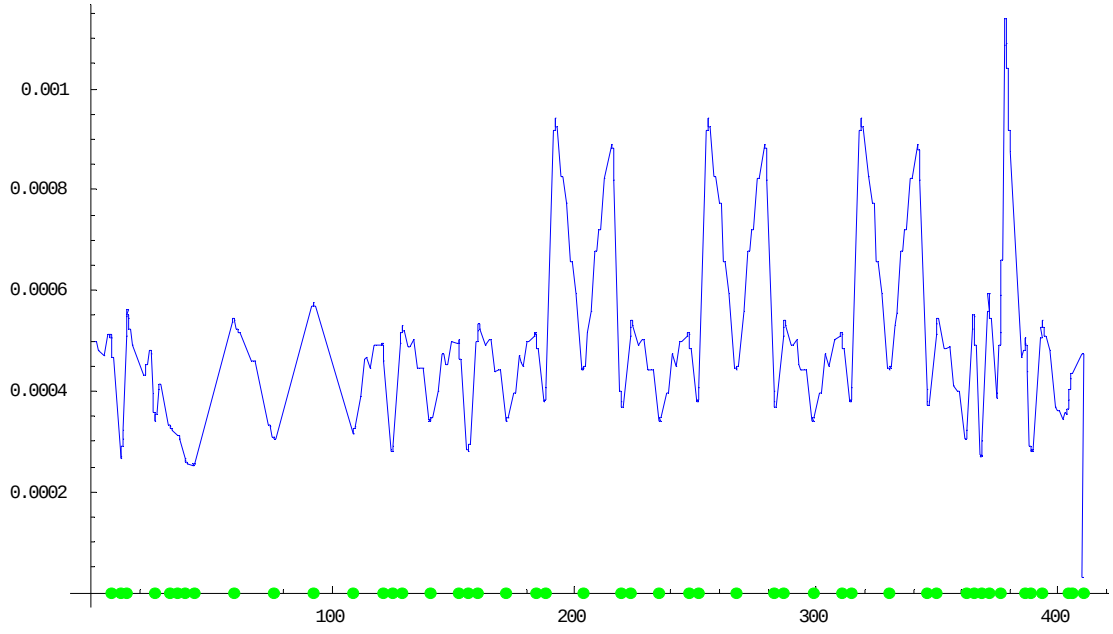
Max. per−axis error null proj.



3σ Extent of Underlying Orbit When Apparent Orbit RMS Equals BPM Offset in Y

Arc4_elem0_errv_BALL_CALL_MD_testY

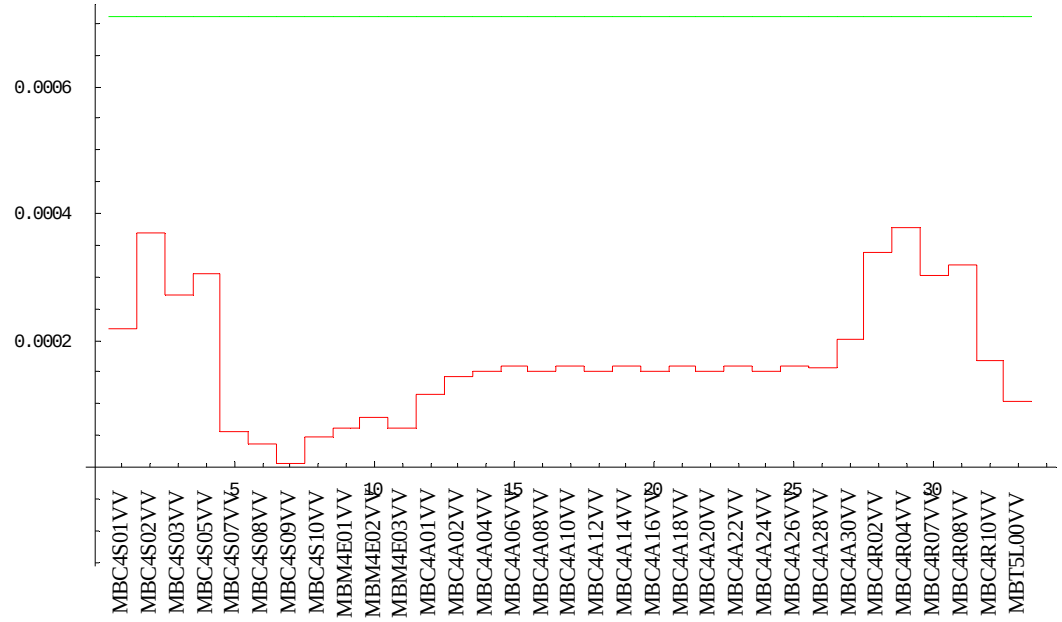
Max. per−axis orbit with combined error−monitor probability



Corrector Strengths Needed for 3σ Error with Unlimited Monitoring Power in Y

Arc4_elem0_errv_BALL_CALL_CD_testY

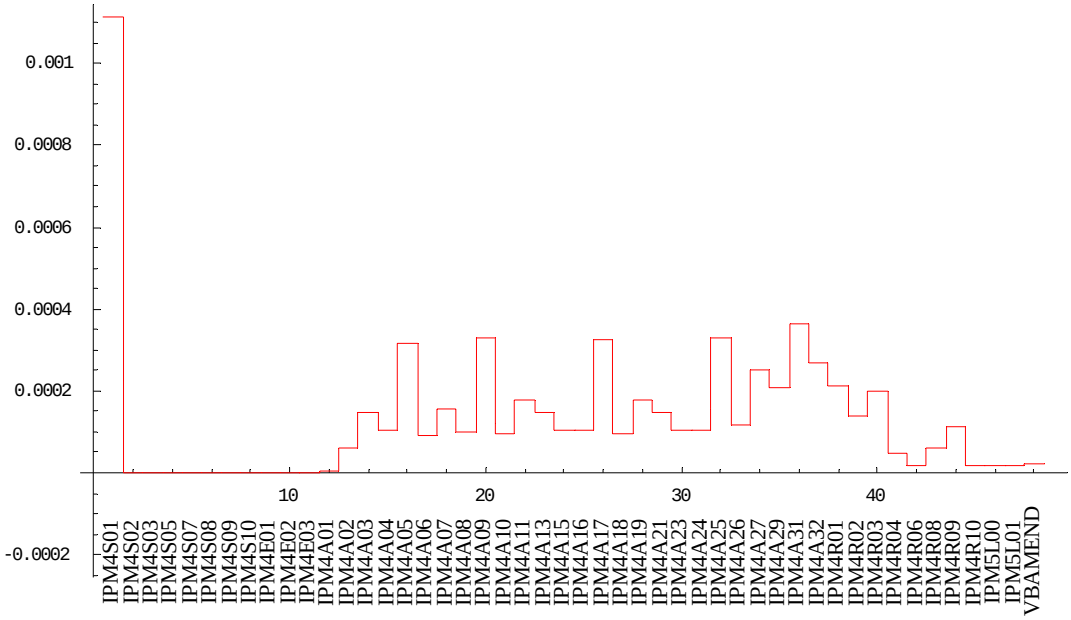
Max. corr. strength needed with unlimited monitoring power



Fundamental Uncorrectable Orbit at all BPMs due to 3σ Error in Y

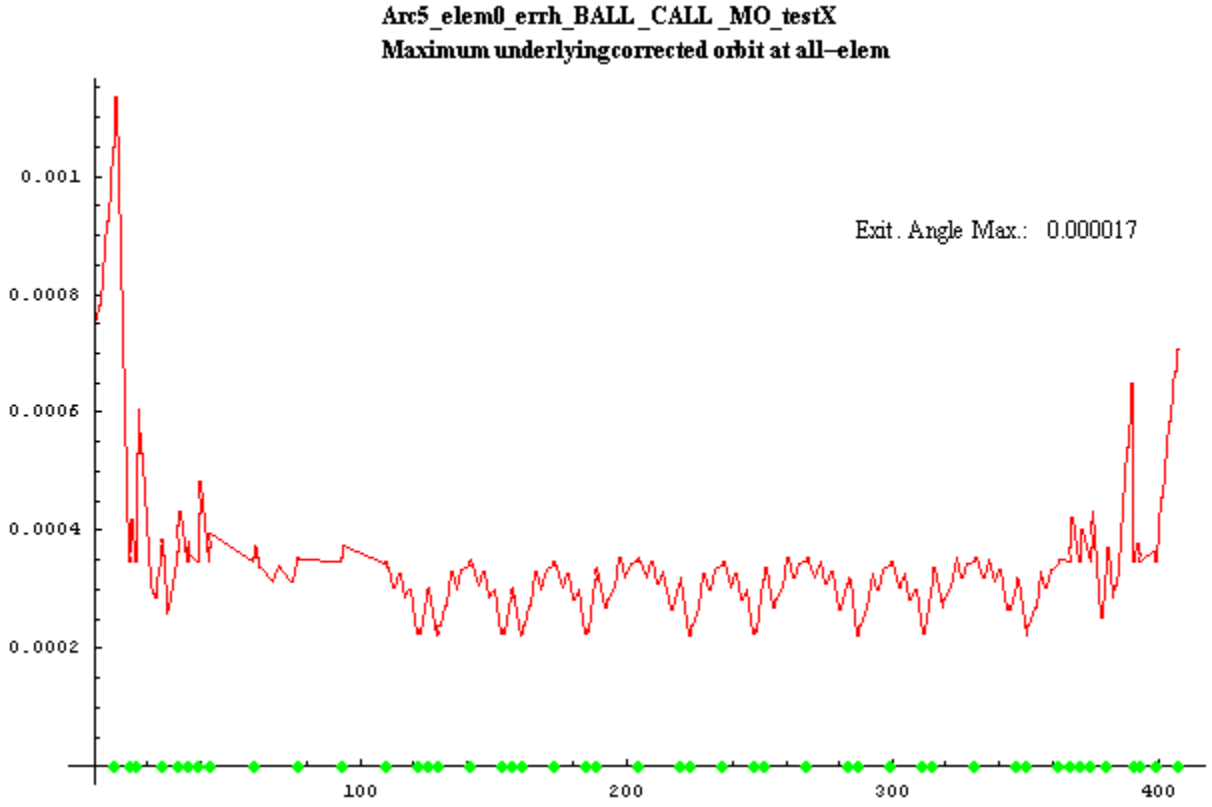
Arc4_elem0_errv_BALL_CALL_CD_testY

Max. per–BPM uncorrectable orbit proj.

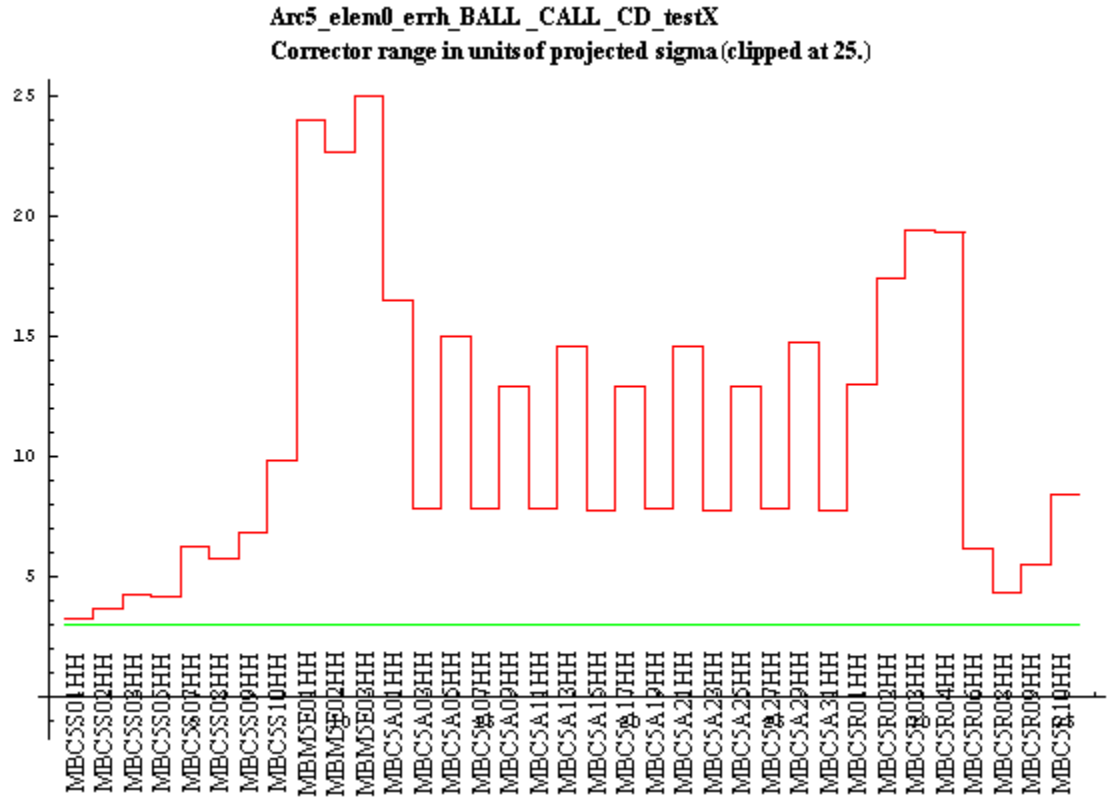


ARC 5

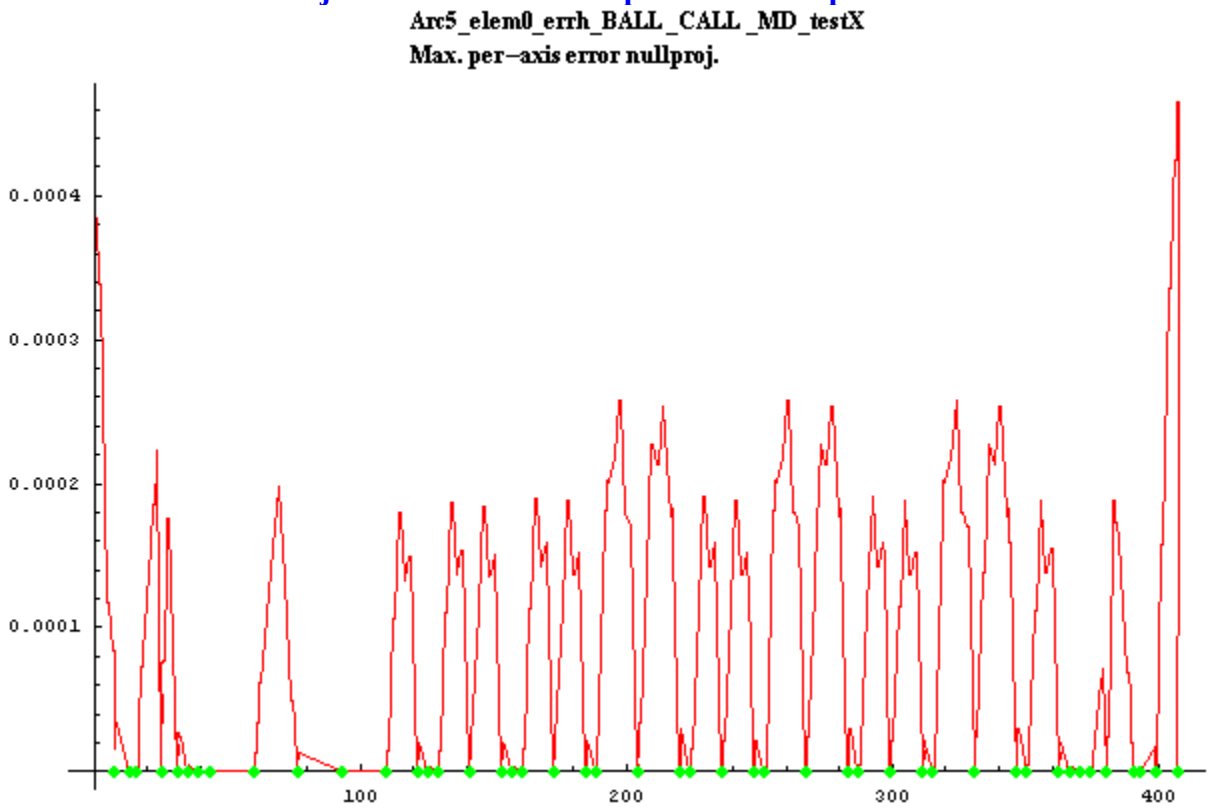
3σ Extent of the Real Underlying Orbit after Orbit Correction in X



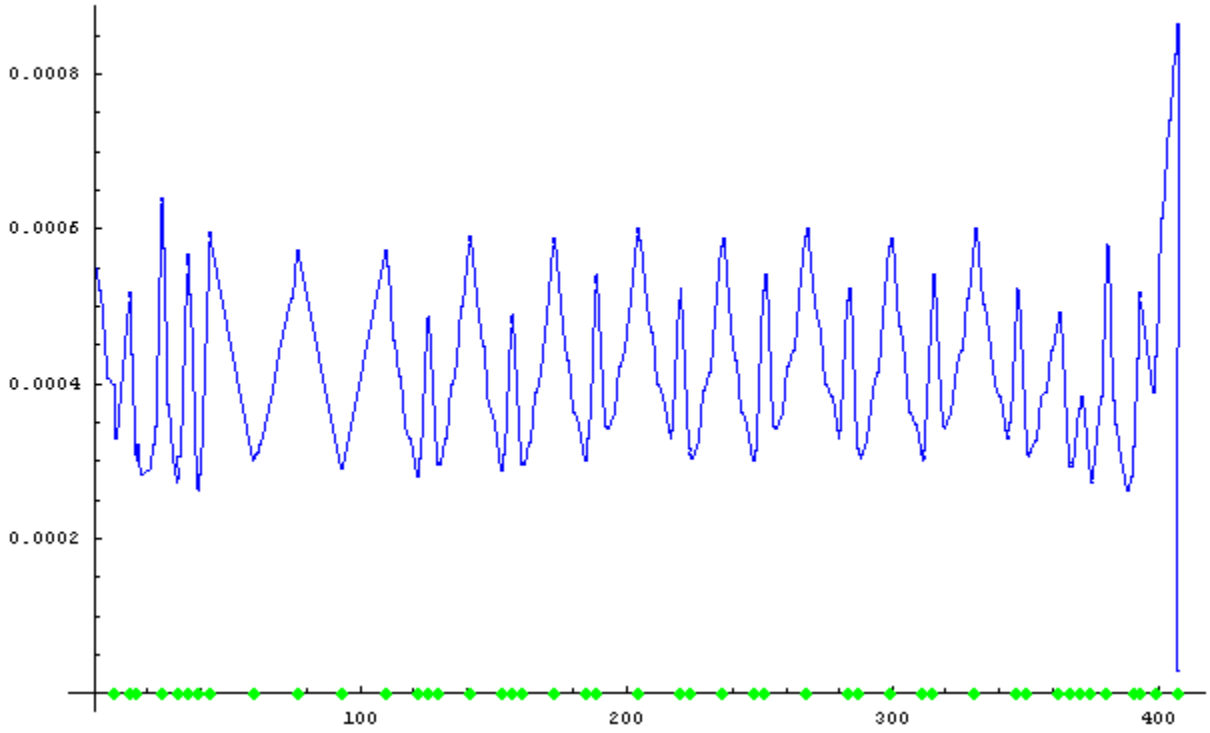
Range of Correctors in Multiples of σ of Error Distribution That Can be Corrected in X



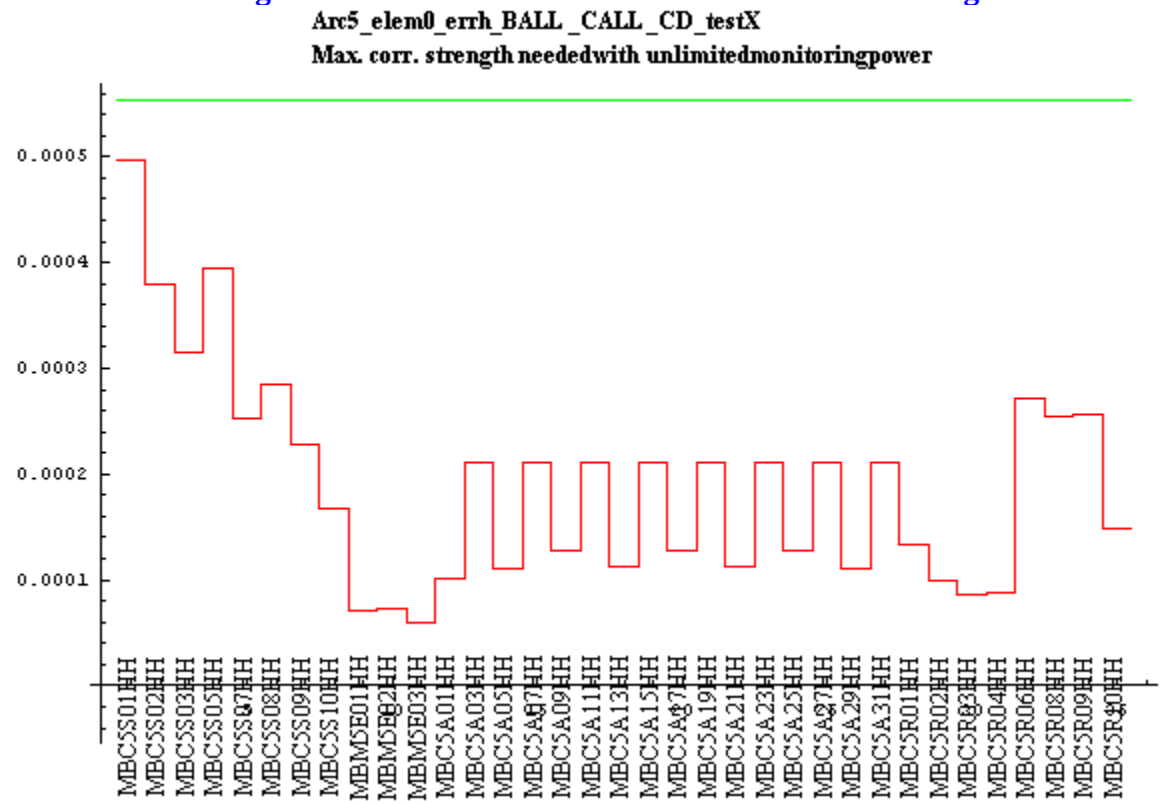
3σ Error Projection onto the Null Space of the Response Matrix in X



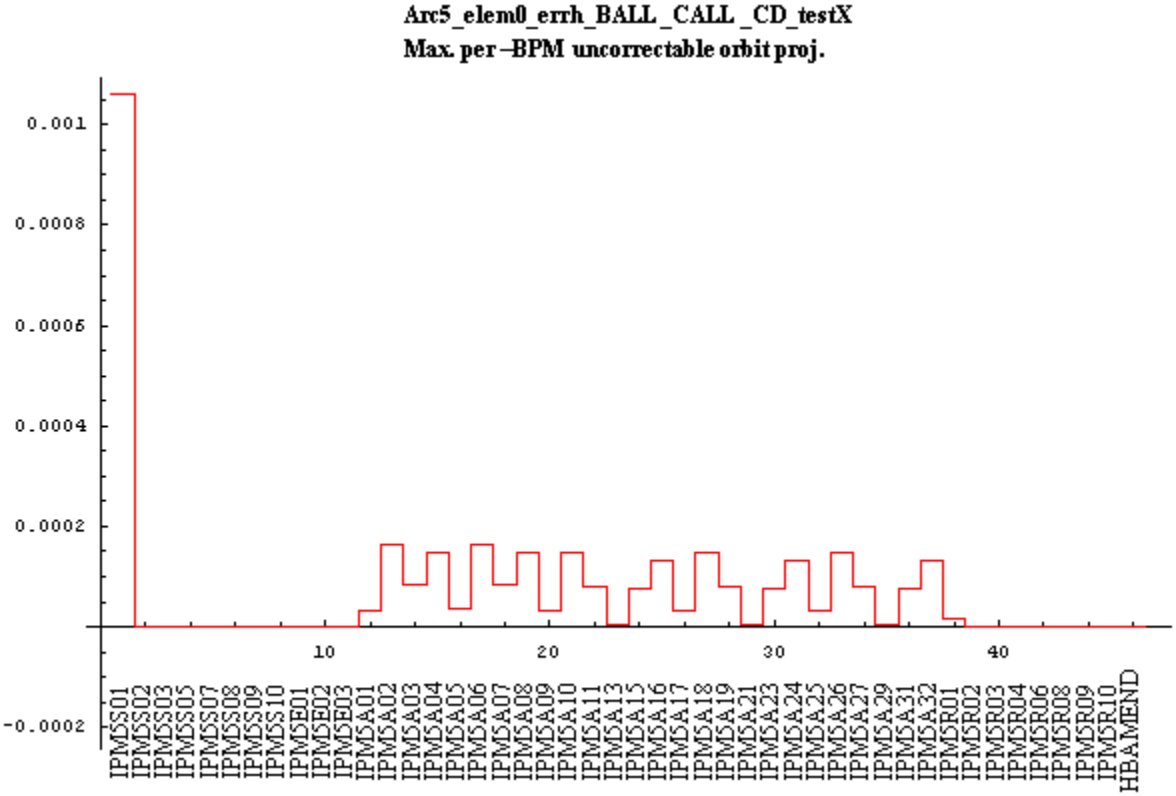
3σ Extent of Underlying Orbit When Apparent Orbit RMS Equals BPM Offset in X



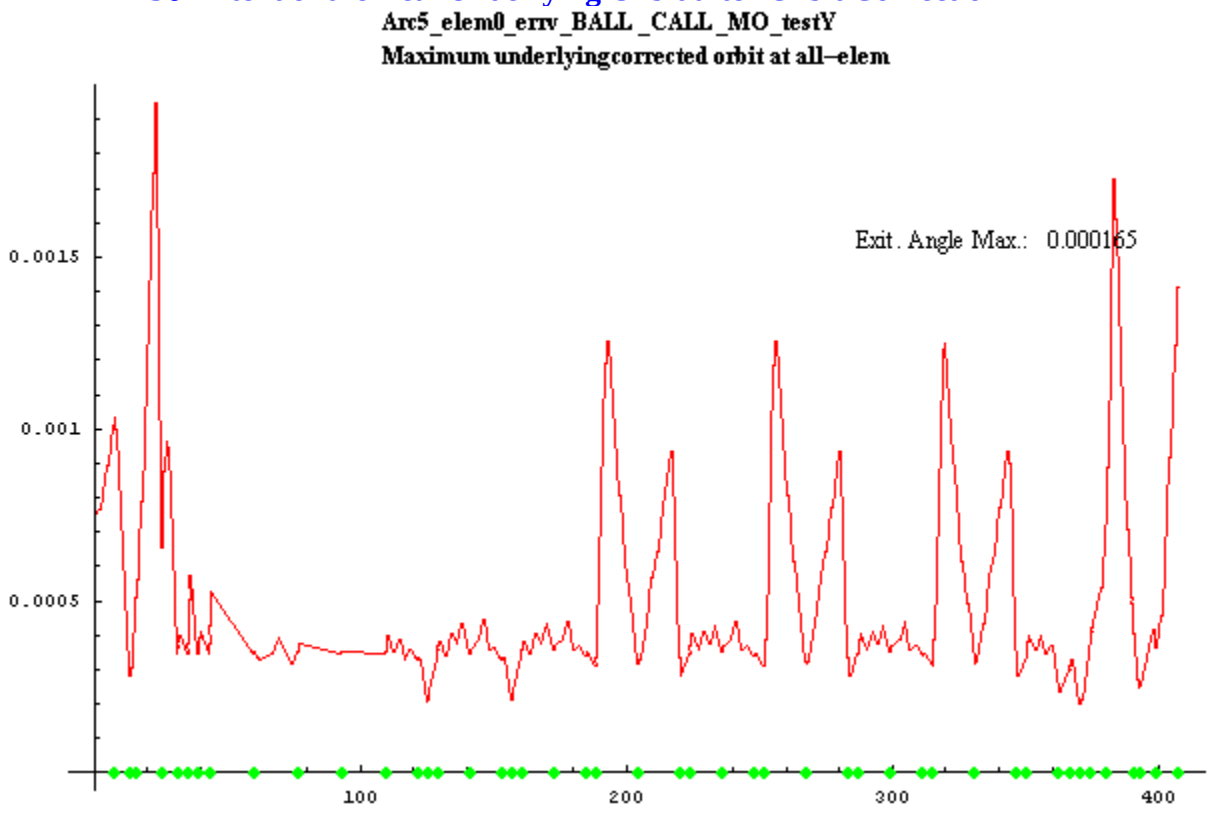
Corrector Strengths Needed for 3σ Error with Unlimited Monitoring Power in X



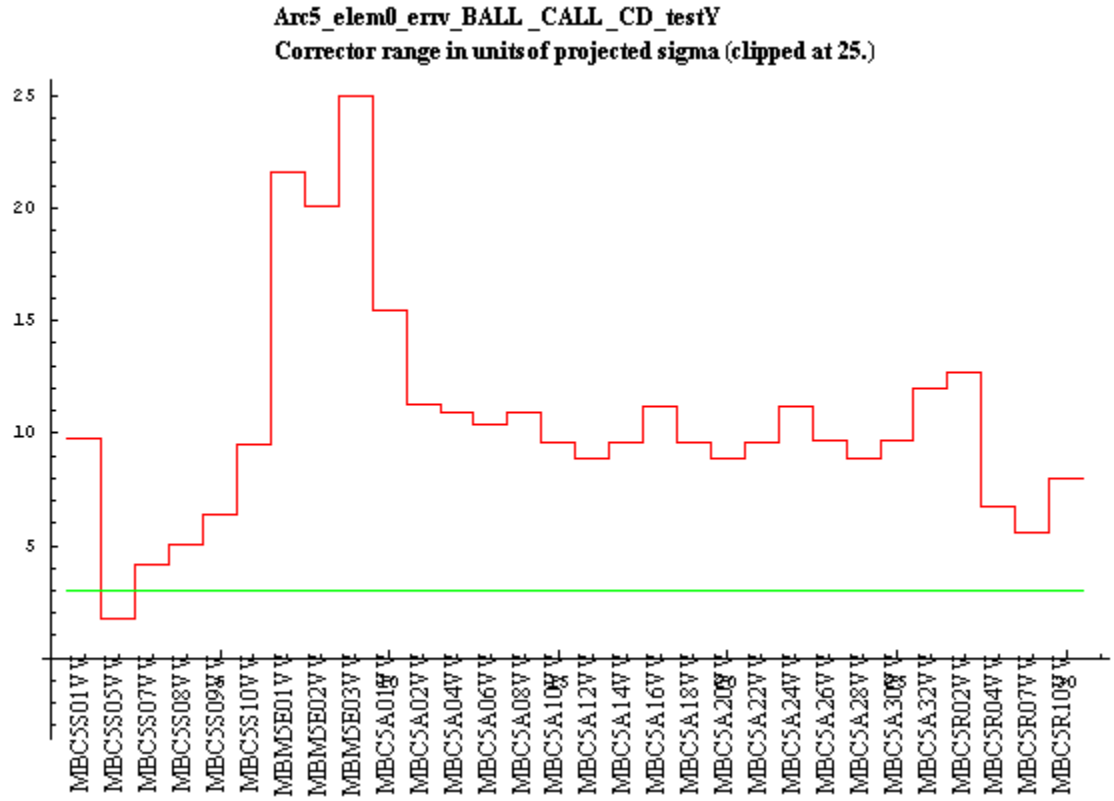
Fundamental Uncorrectable Orbit at all BPMs due to 3σ Error in X



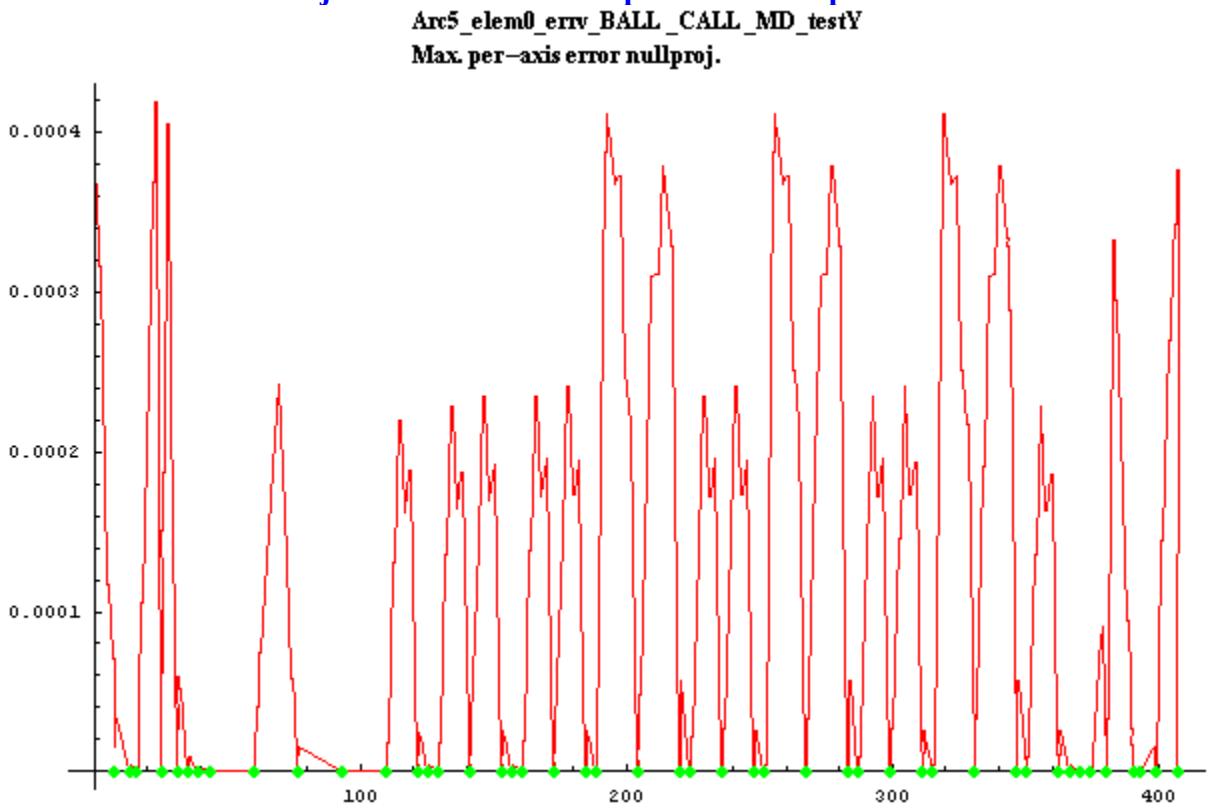
3σ Extent of the Real Underlying Orbit after Orbit Correction in Y



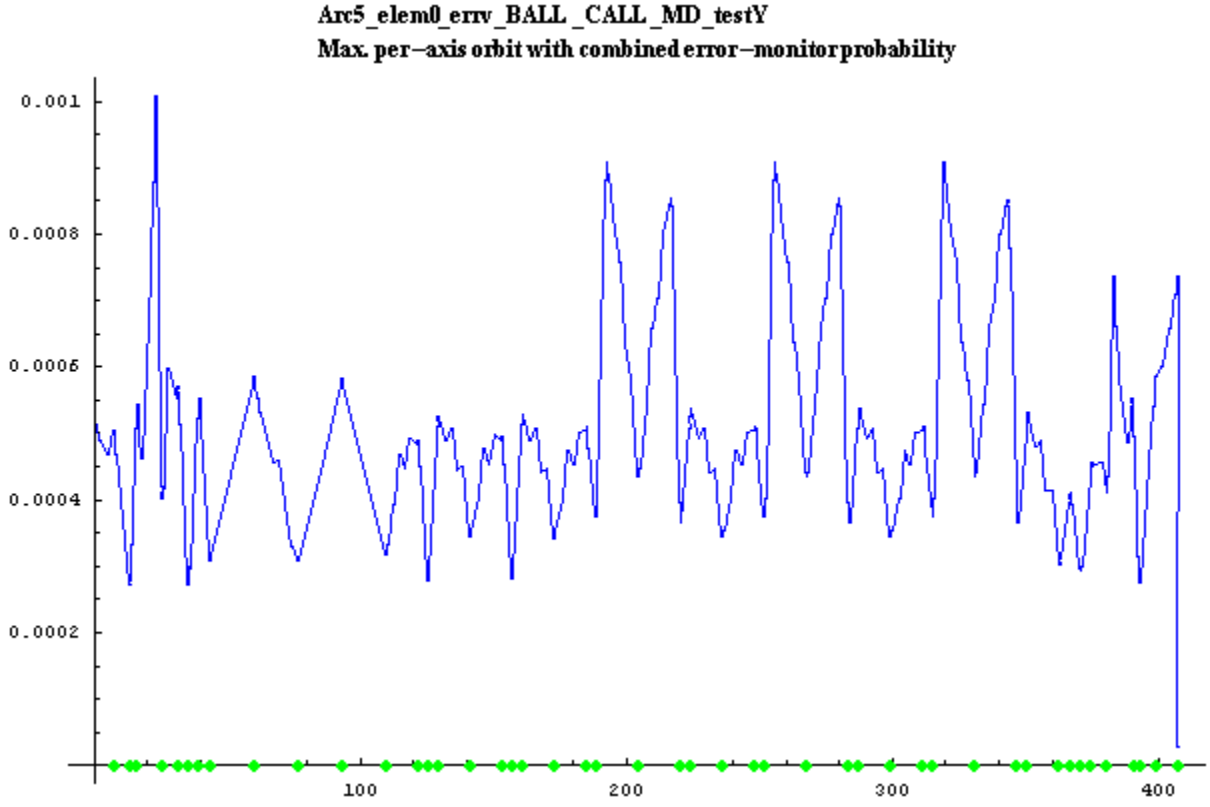
Range of Correctors in Multiples of σ of Error Distribution That Can be Corrected in Y



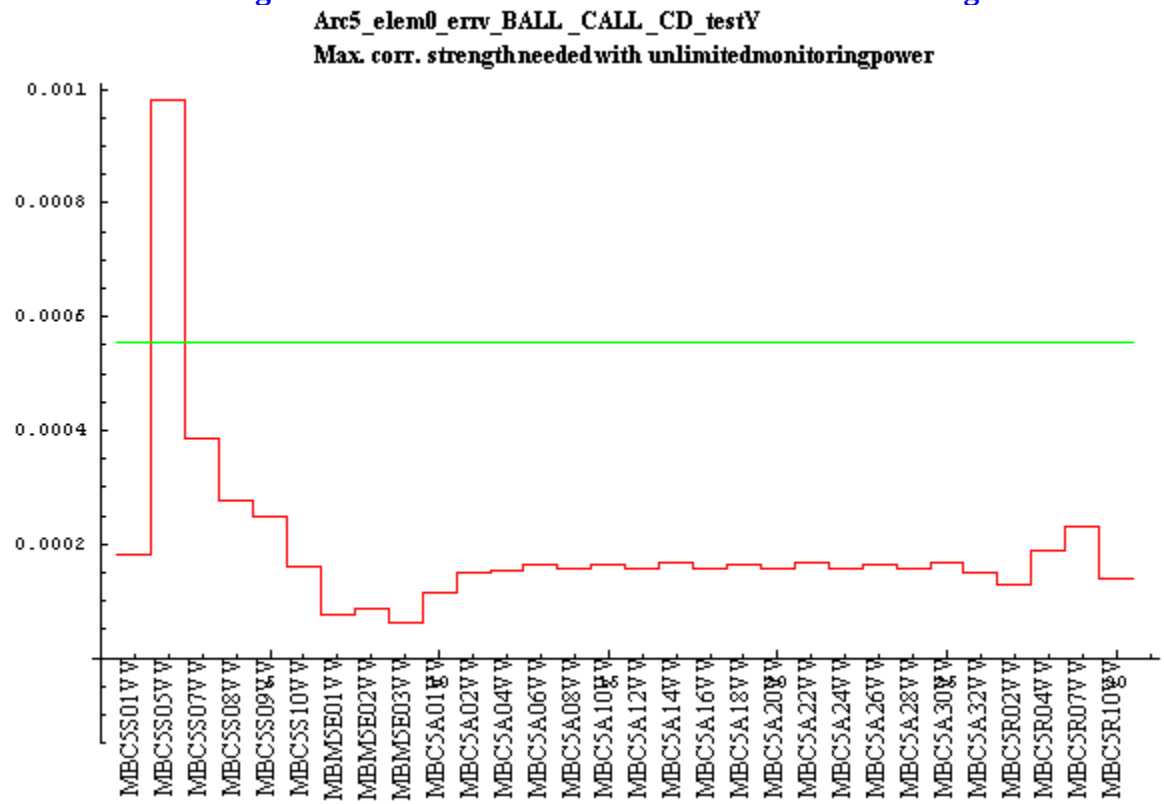
3σ Error Projection onto the Null Space of the Response Matrix in Y



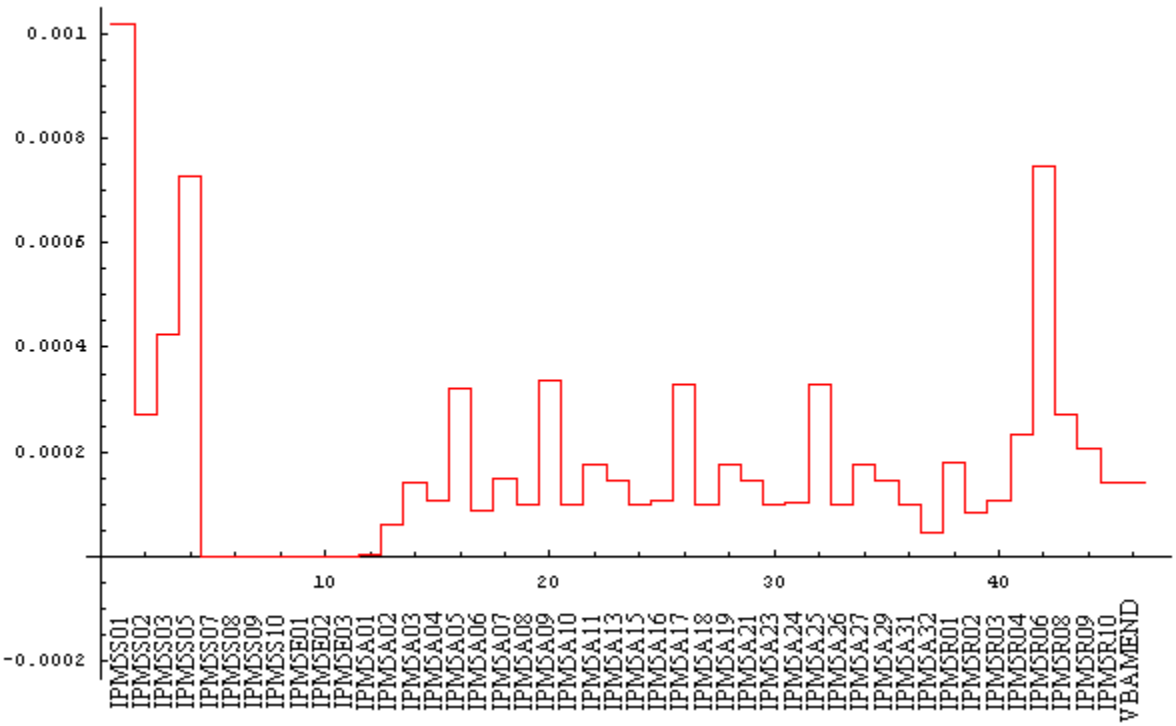
3σ Extent of Underlying Orbit When Apparent Orbit RMS Equals BPM Offset in Y



Corrector Strengths Needed for 3σ Error with Unlimited Monitoring Power in Y



Fundamental Uncorrectable Orbit at all BPMs due to 3σ Error in Y

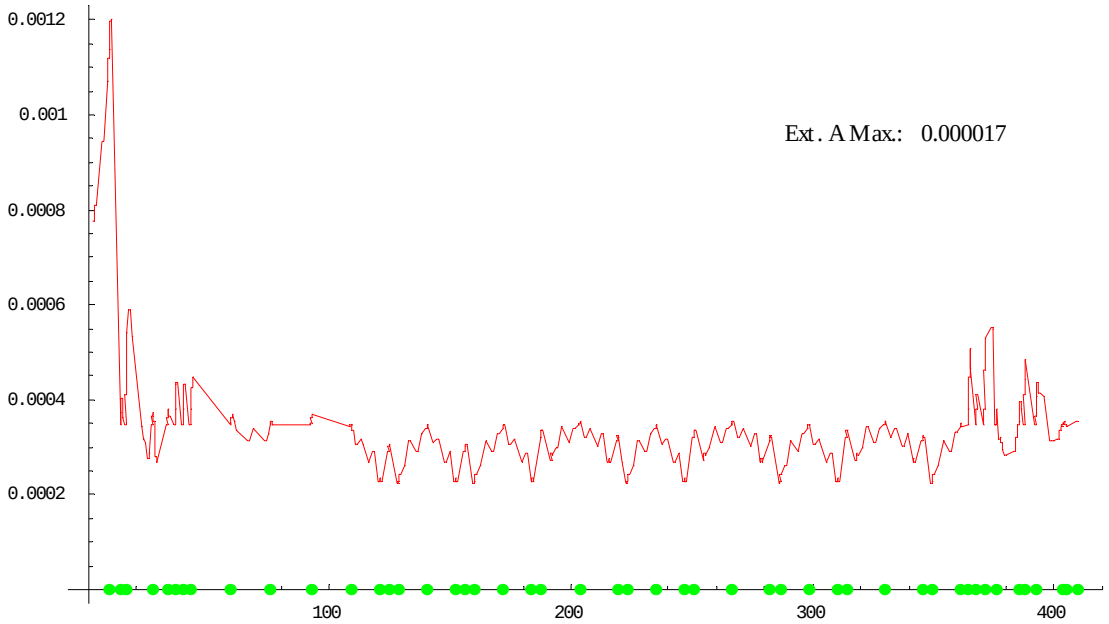


ARC 6

3σ Extent of the Real Underlying Orbit after Orbit Correction in X

Arc6_elem0_errh_BALL_CALL_MO_testX

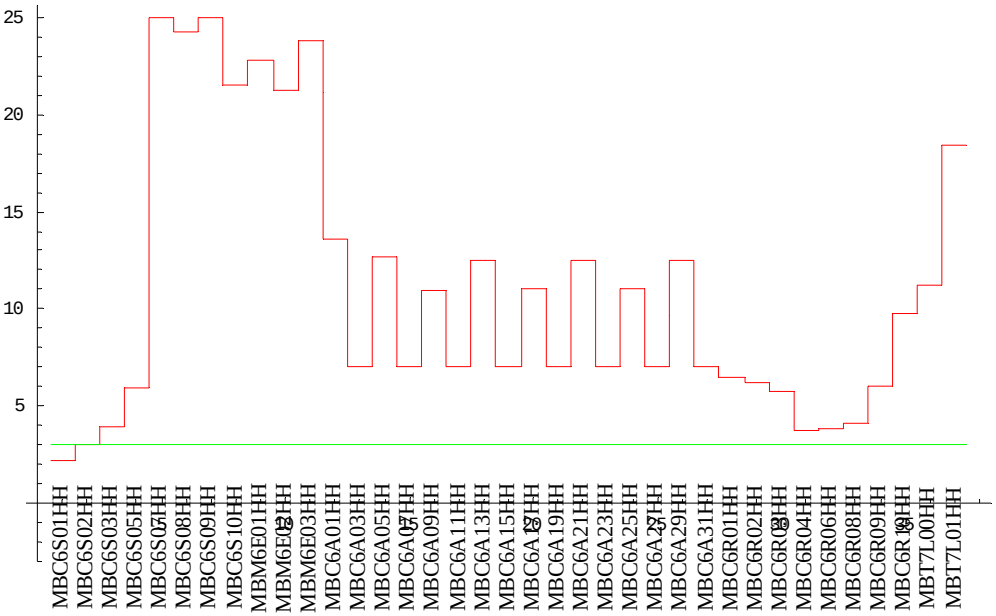
Maximum underlying corrected orbit at all–elem



Range of Correctors in Multiples of σ of Error Distribution That Can be Corrected in X

Arc6_elem0_errh_BALL_CALL_CD_testX

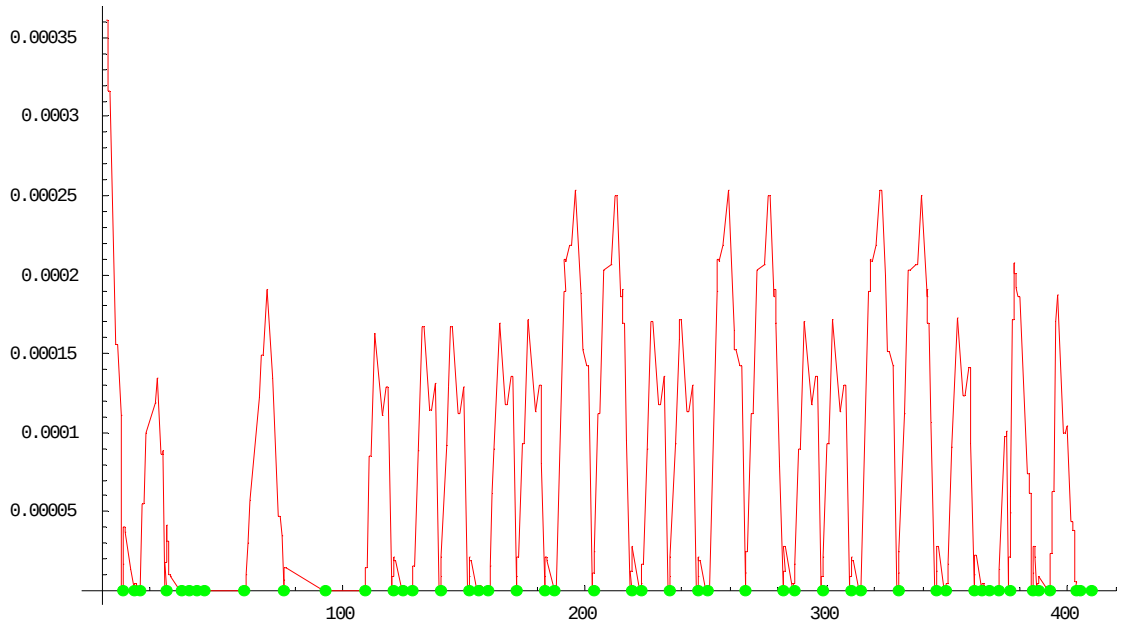
Corrector range in units of projected sigma (clipped at 25.)



3σ Error Projection onto the Null Space of the Response Matrix in X

Arc6_elem0_errh_BALL_CALL_MD_testX

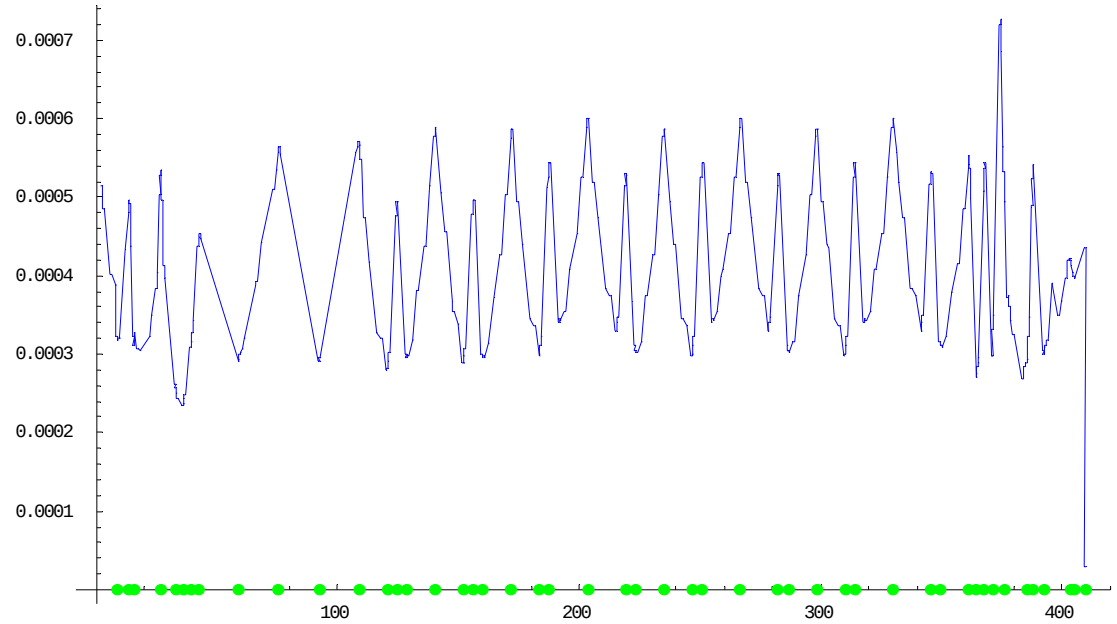
Max. per−axis error null proj.



3σ Extent of Underlying Orbit When Apparent Orbit RMS Equals BPM Offset in X

Arc6_elem0_errh_BALL_CALL_MD_testX

Max. per−axis orbit with combined error−monitor probability



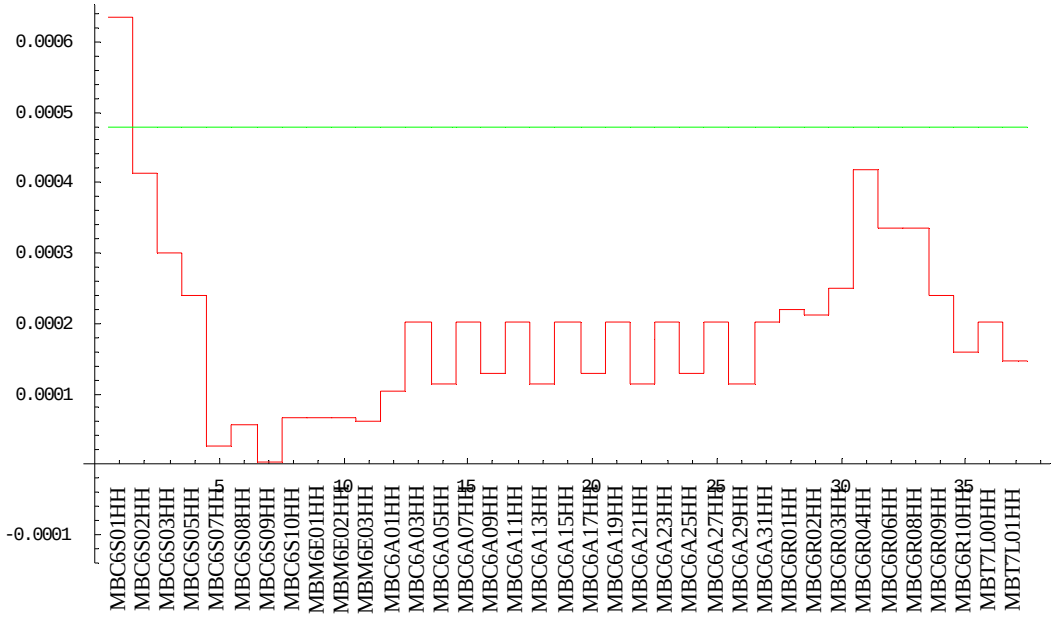
File used:

Arc6_elem0_errh_BALL_CALL_CD_testX

Corrector Strengths Needed for 3σ Error with Unlimited Monitoring Power in X

Arc6_elem0_errh_BALL_CALL_CD_testX

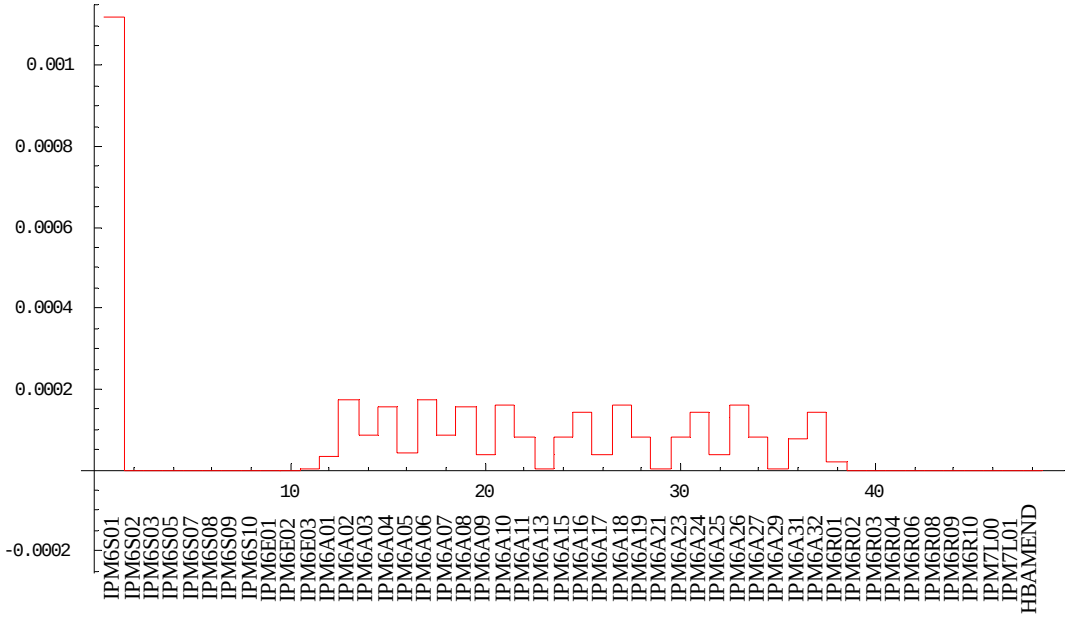
Max. corr. strength needed with unlimited monitoring power



Fundamental Uncorrectable Orbit at all BPMs due to 3σ Error in X

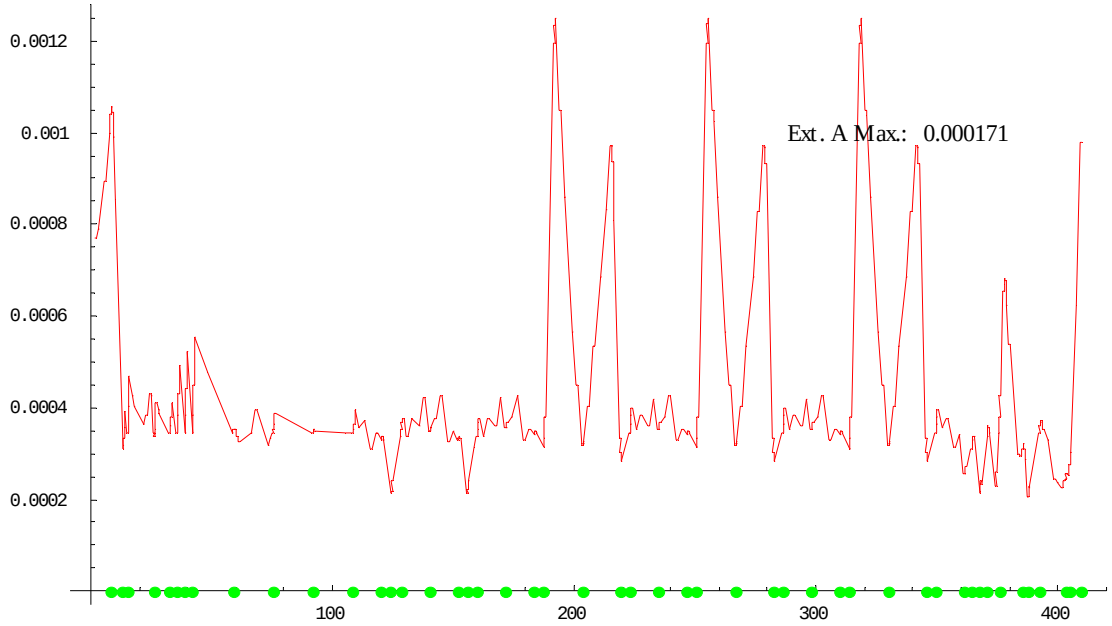
Arc6_elem0_errh_BALL_CALL_CD_testX

Max. per–BPM uncorrectable orbit proj.



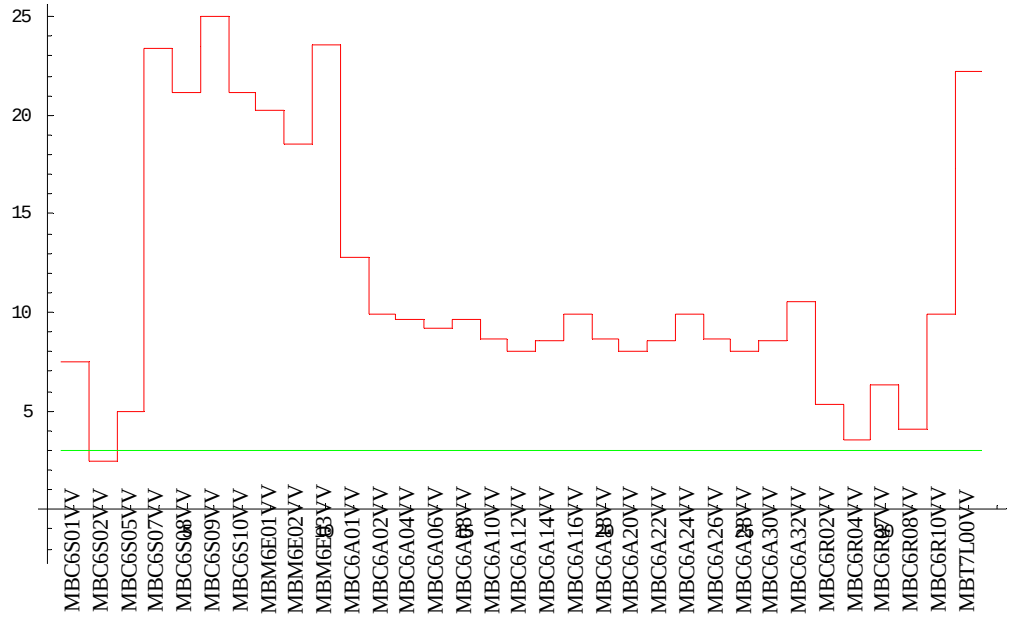
3σ Extent of the Real Underlying Orbit after Orbit Correction in Y

Arc6_elem0_errv_BALL_CALL_MO_testY
Maximum underlying corrected orbit at all–elem



Range of Correctors in Multiples of σ of Error Distribution That Can be Corrected in Y

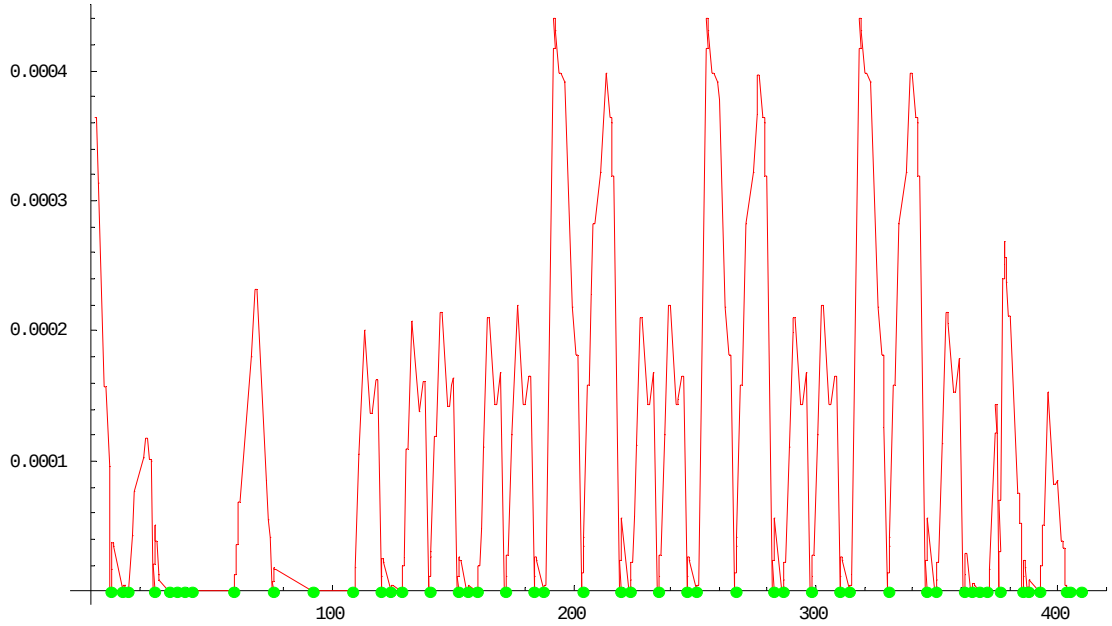
Arc6_elem0_errv_BALL_CALL_CD_testY
Corrector range in units of projected sigma (clipped at 25.)



3σ Error Projection onto the Null Space of the Response Matrix in Y

Arc6_elem0_errv_BALL_CALL_MD_testY

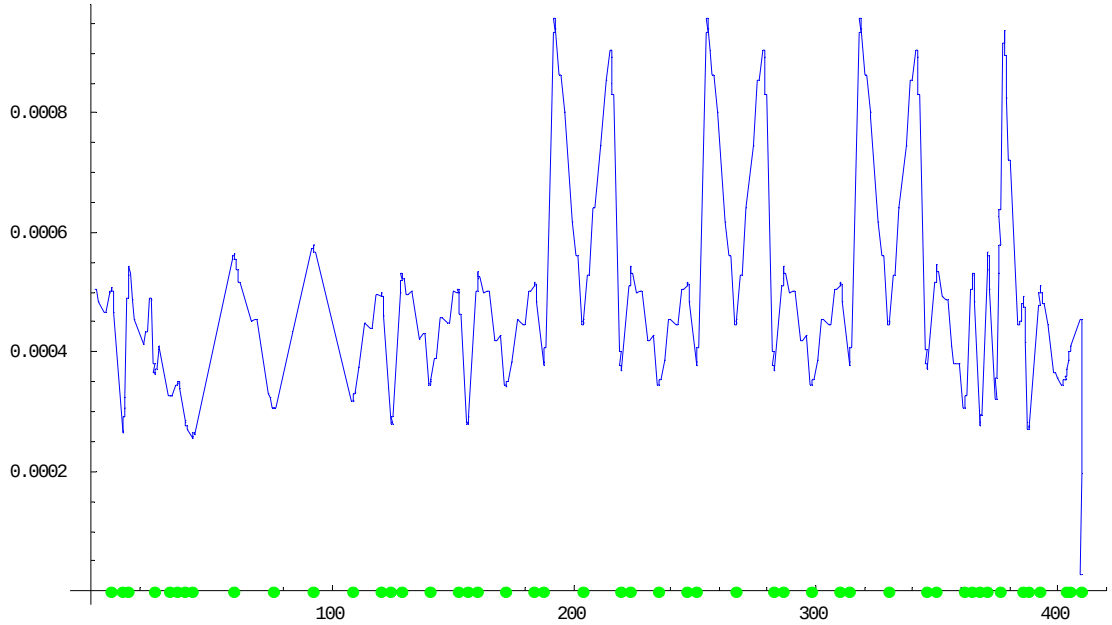
Max. per−axis error null proj.



3σ Extent of Underlying Orbit When Apparent Orbit RMS Equals BPM Offset in Y

Arc6_elem0_errv_BALL_CALL_MD_testY

Max. per−axis orbit with combined error−monitor probability



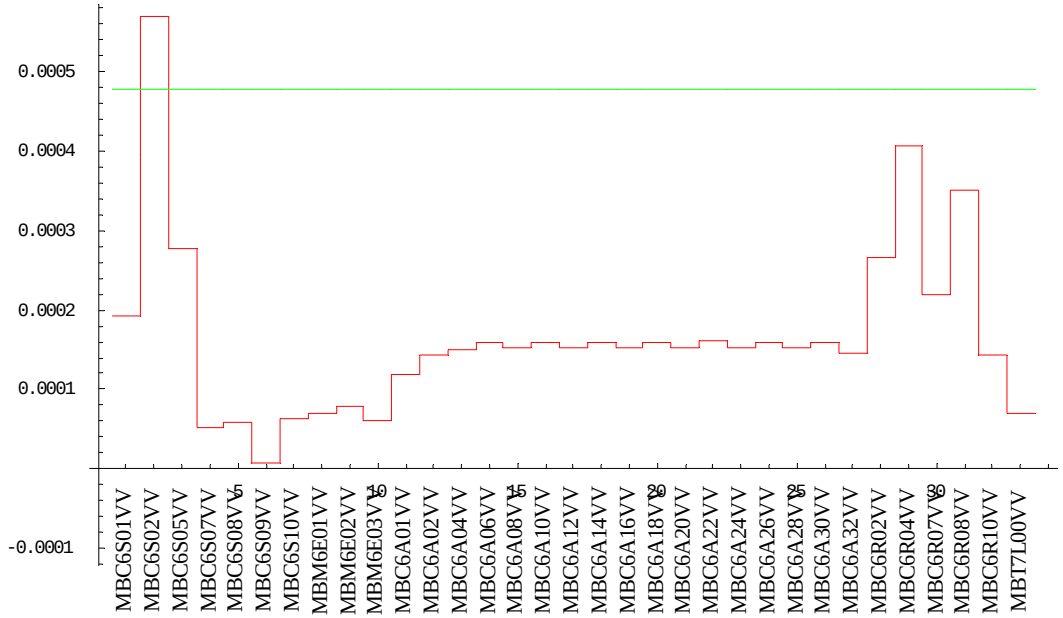
File used:

Arc6_elem0_errv_BALL_CALL_CD_testY

Corrector Strengths Needed for 3σ Error with Unlimited Monitoring Power in Y

Arc6_elem0_errv_BALL_CALL_CD_testY

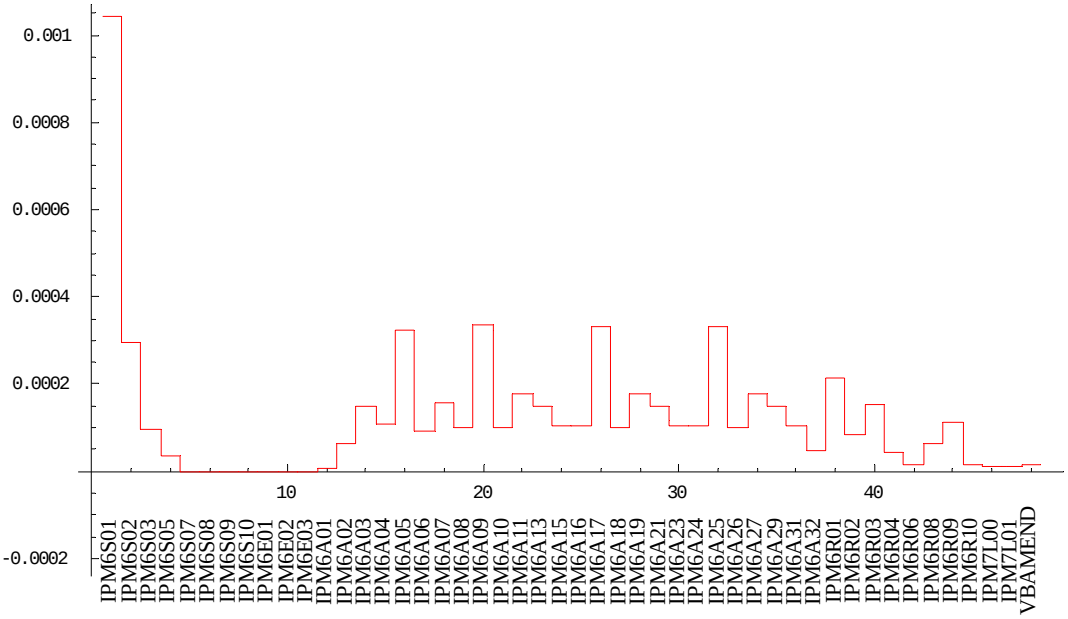
Max. corr. strength needed with unlimited monitoring power



Fundamental Uncorrectable Orbit at all BPMs due to 3σ Error in Y

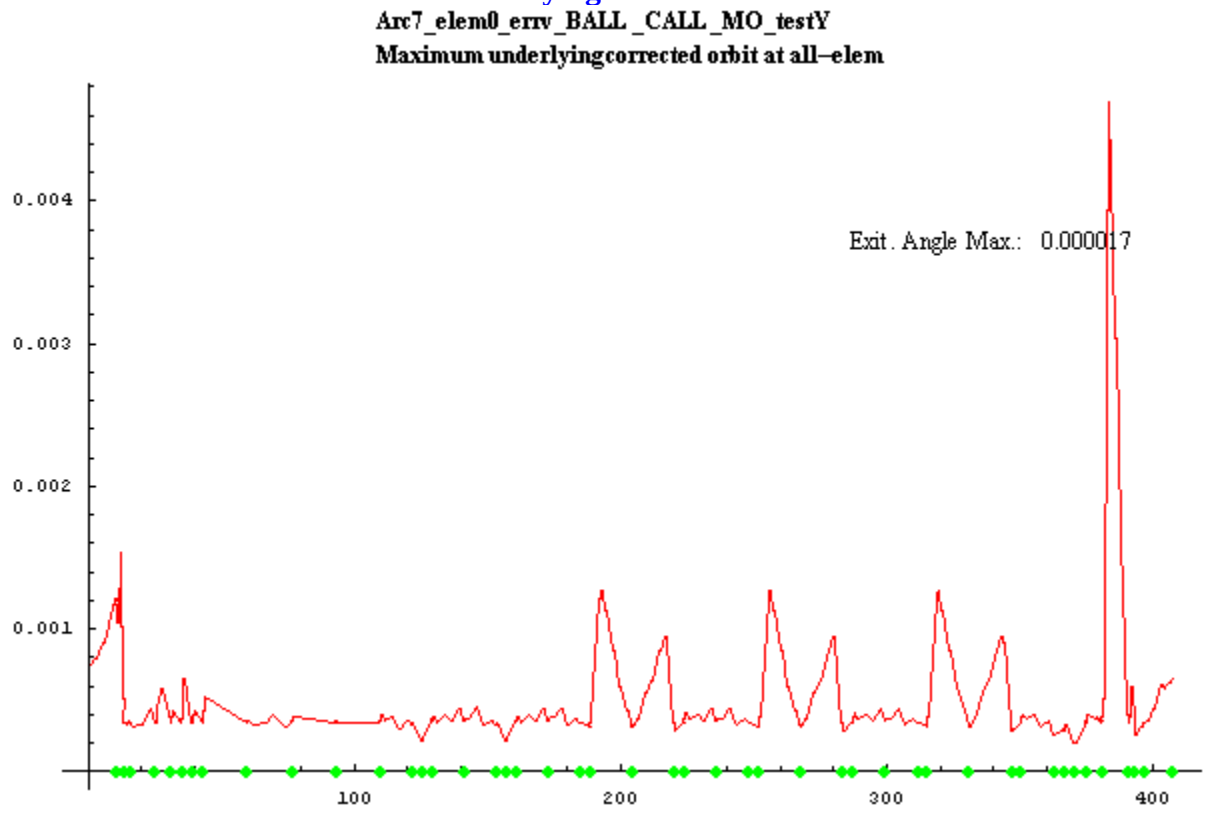
Arc6_elem0_errv_BALL_CALL_CD_testY

Max. per−BPM uncorrectable orbit proj.

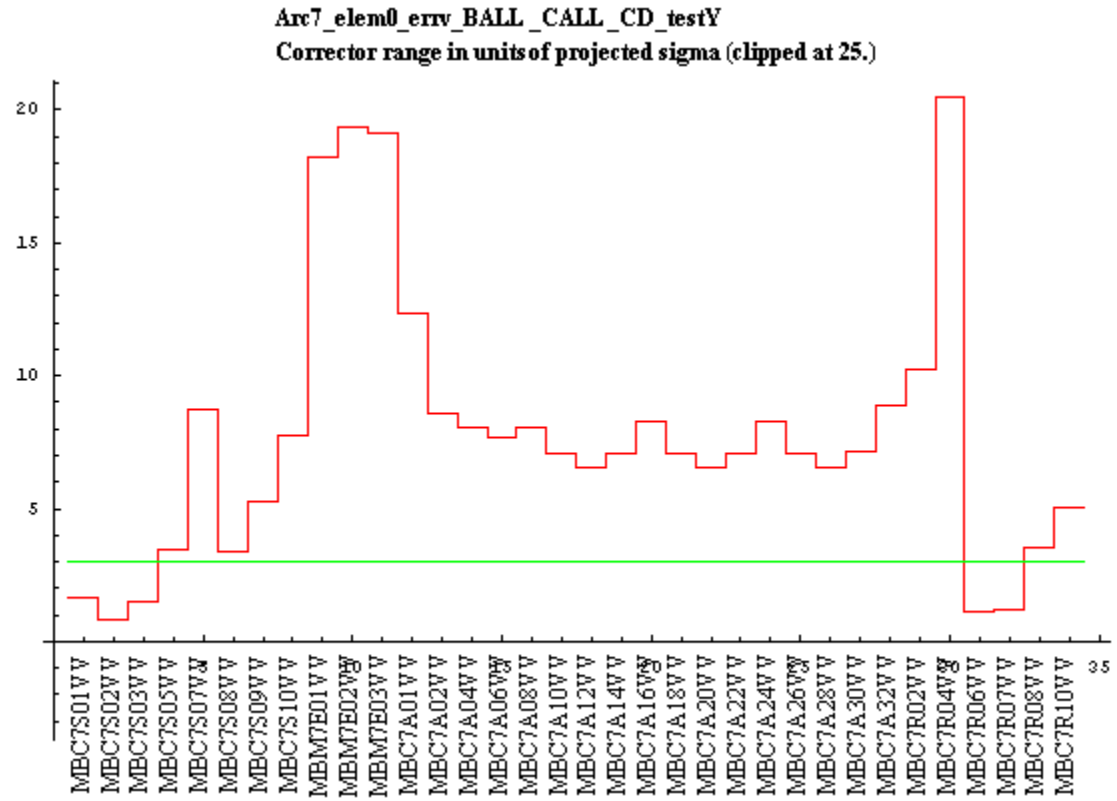


ARC 7 (Before Removing Singular Correctors in Y)

3σ Extent of the Real Underlying Orbit after Orbit Correction in Y

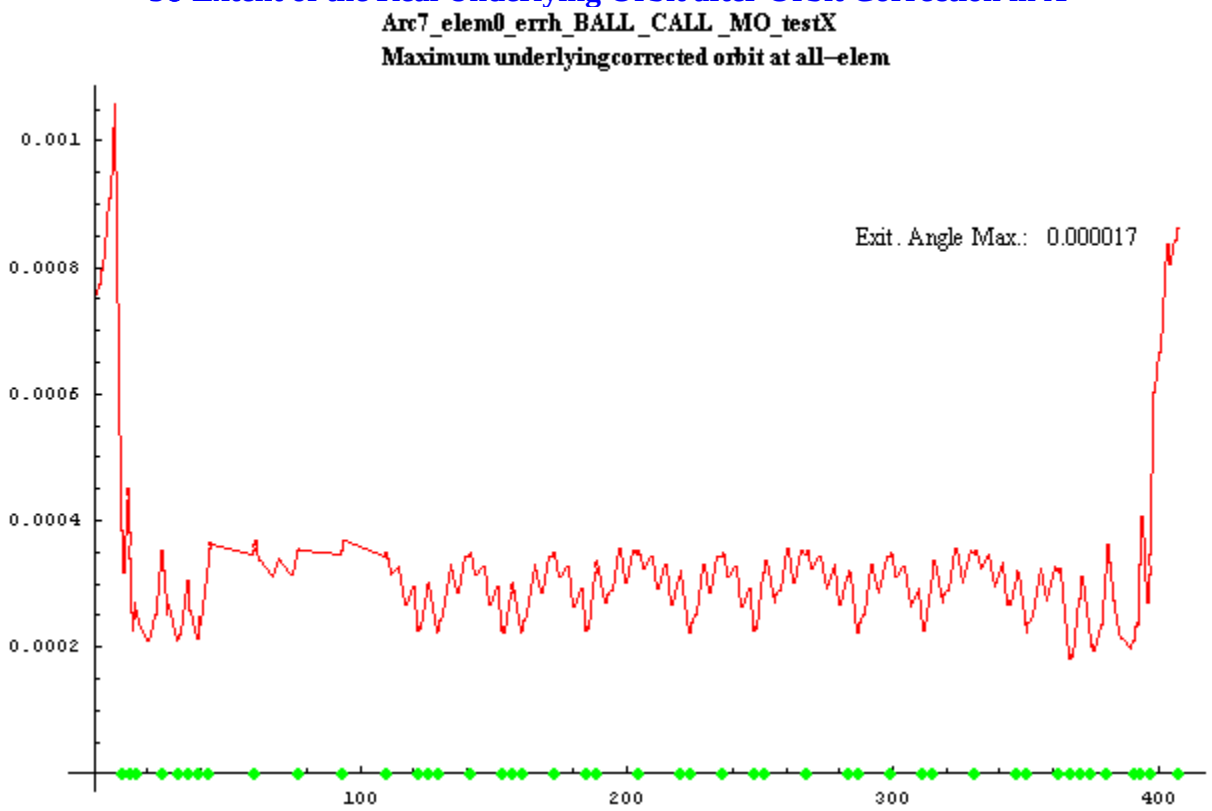


Range of Correctors in Multiples of σ of Error Distribution That Can be Corrected in Y

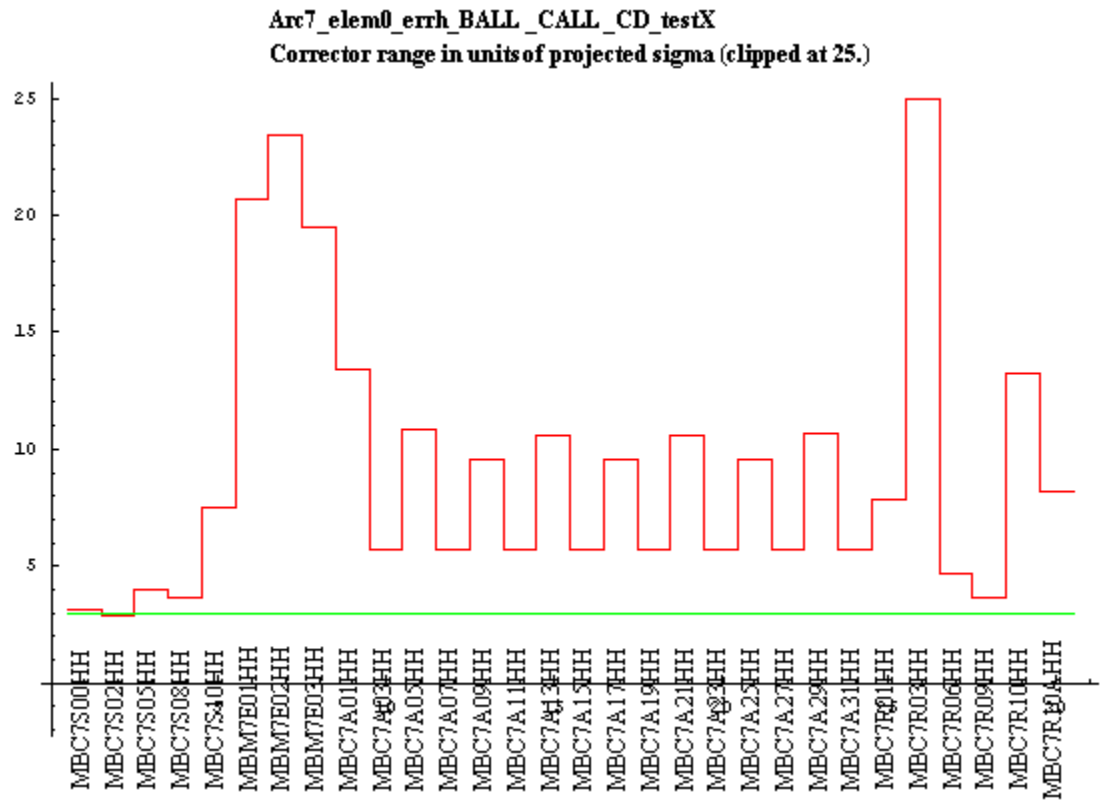


ARC 7 (After Removing Singular Correctors in Y)

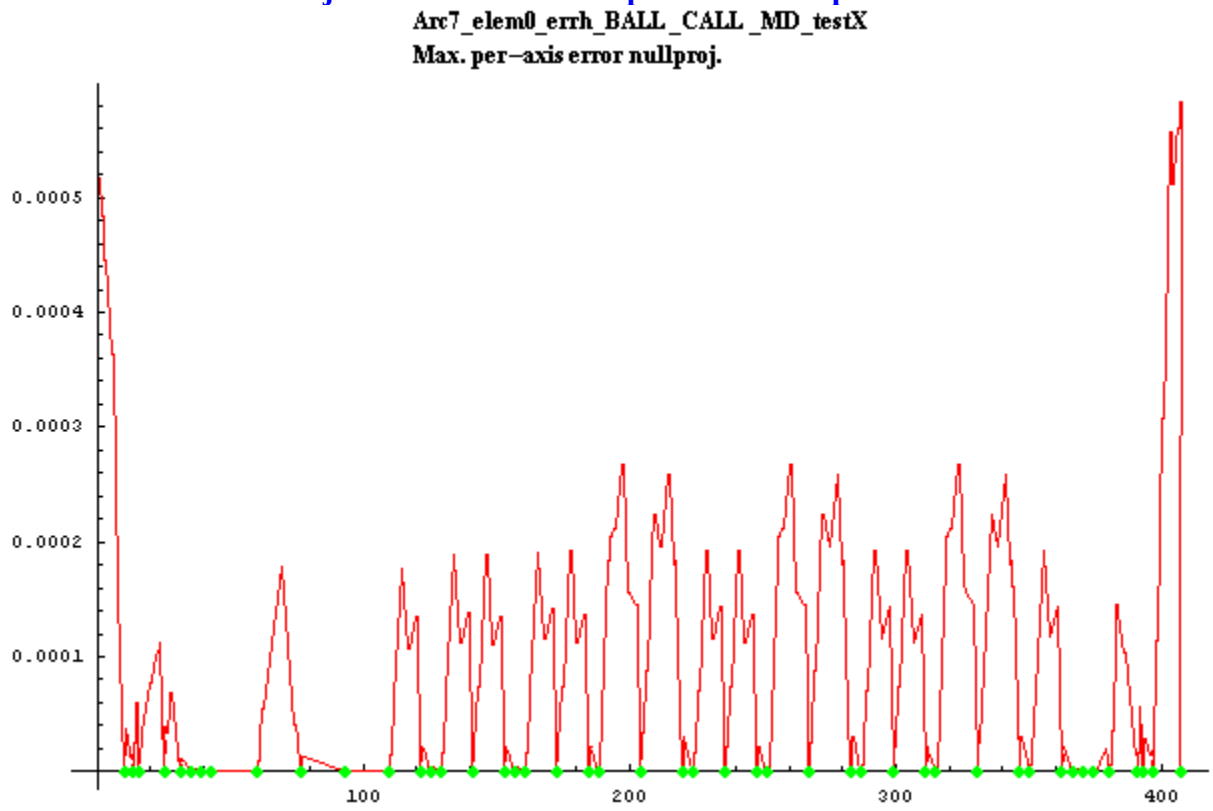
3σ Extent of the Real Underlying Orbit after Orbit Correction in X



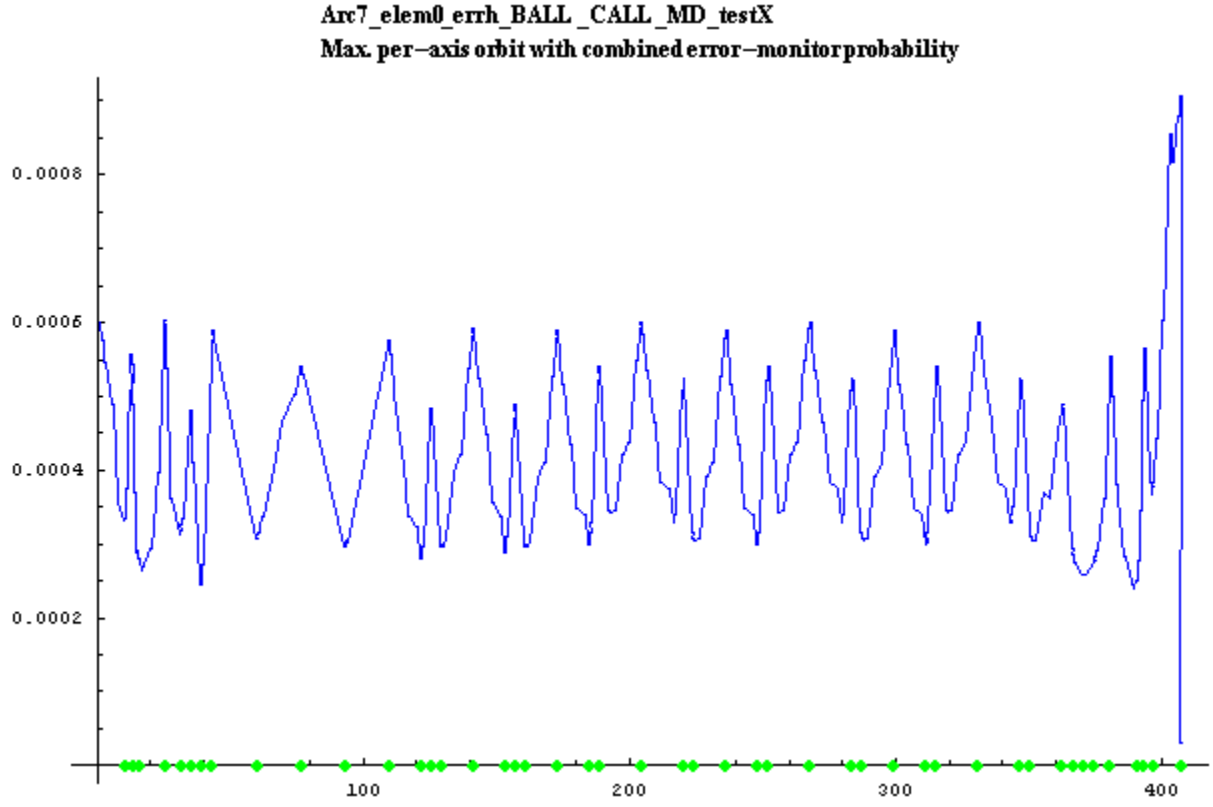
Range of Correctors in Multiples of σ of Error Distribution That Can be Corrected in X



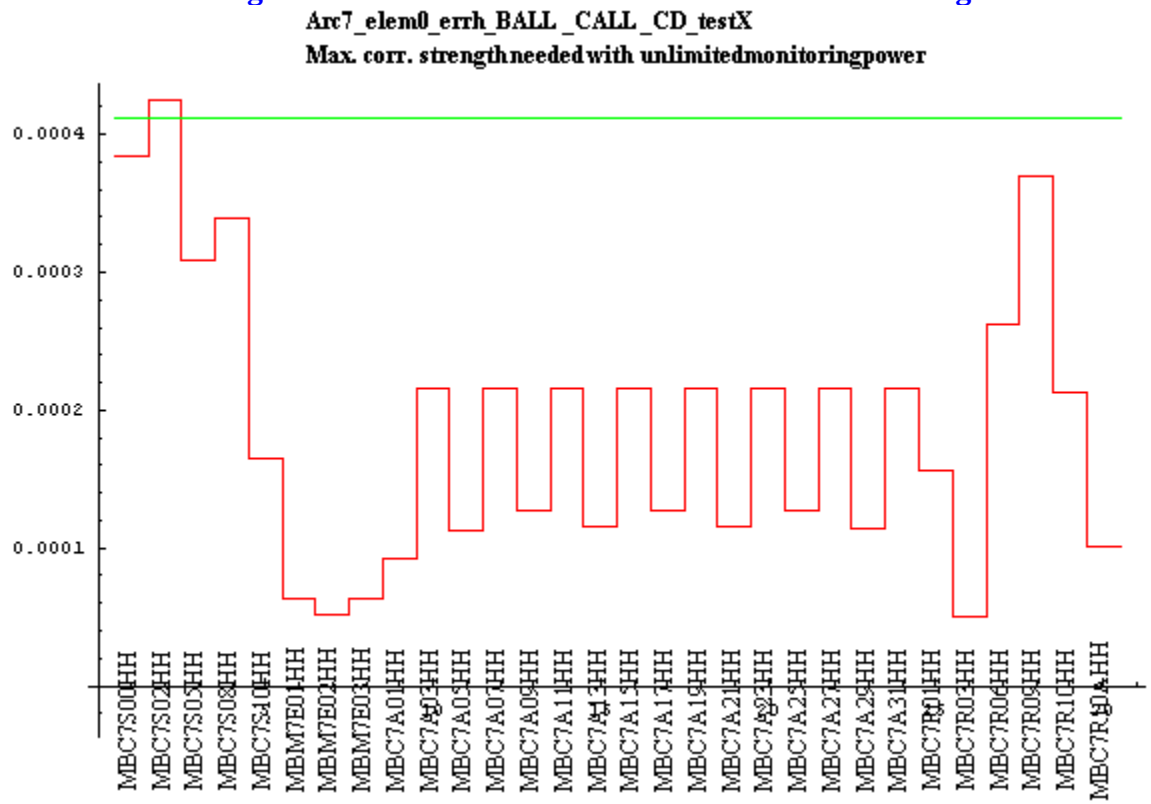
3σ Error Projection onto the Null Space of the Response Matrix in X



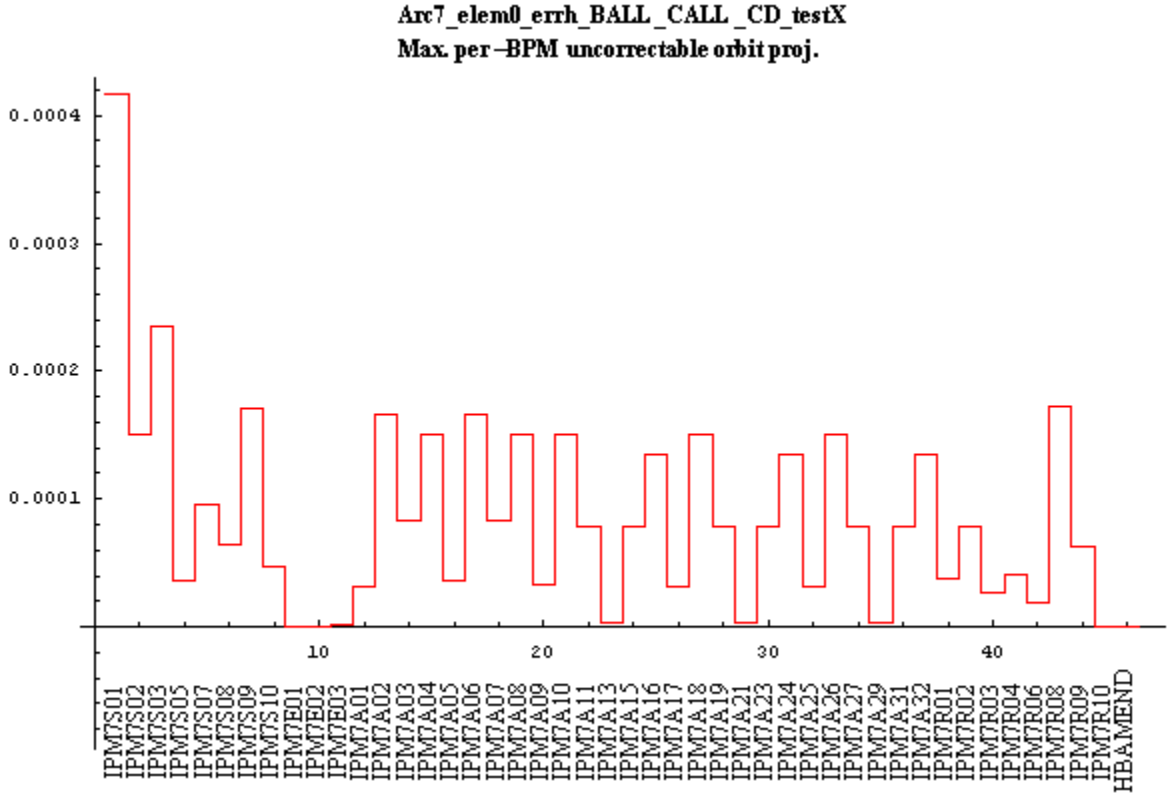
3σ Extent of Underlying Orbit When Apparent Orbit RMS Equals BPM Offset in X



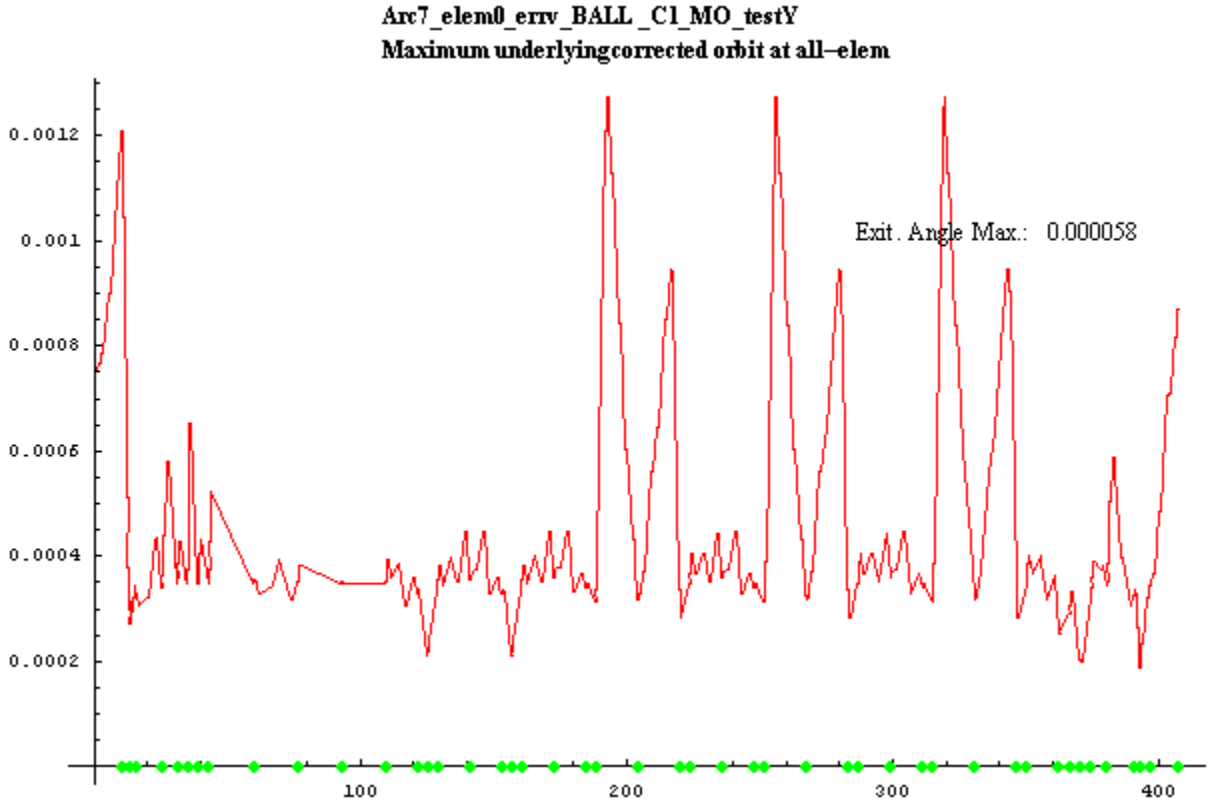
Corrector Strengths Needed for 3σ Error with Unlimited Monitoring Power in X



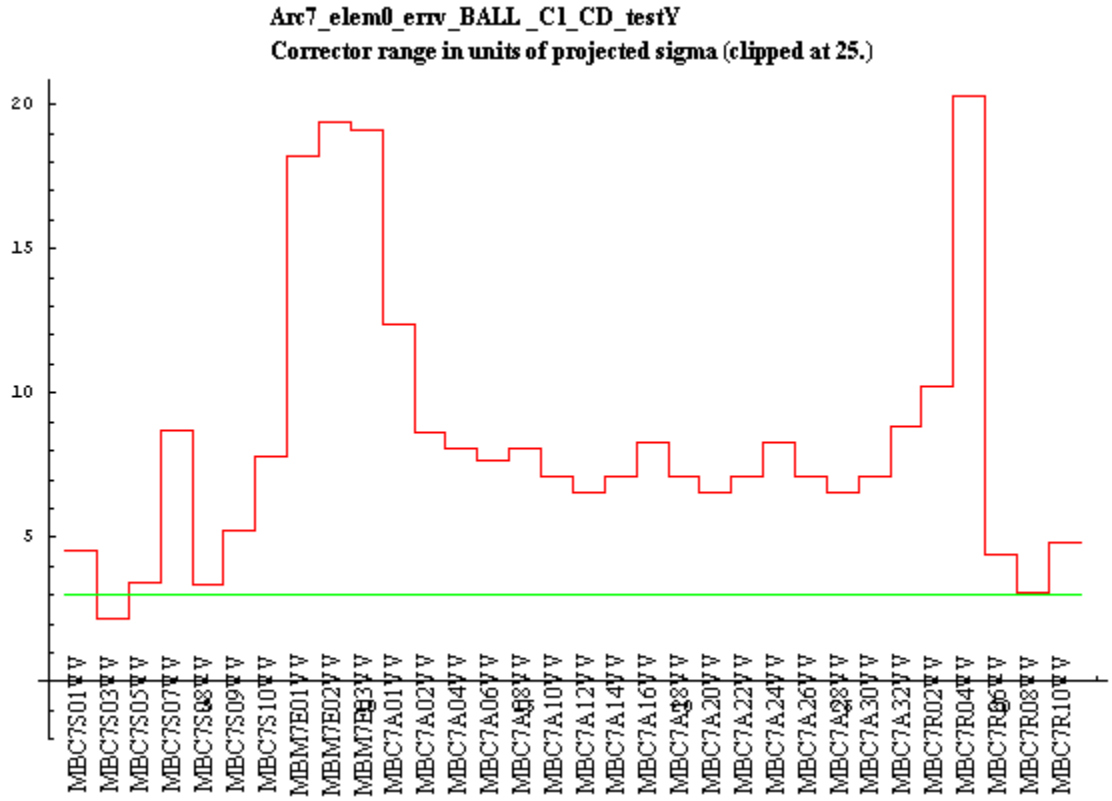
Fundamental Uncorrectable Orbit at all BPMs due to 3σ Error in X



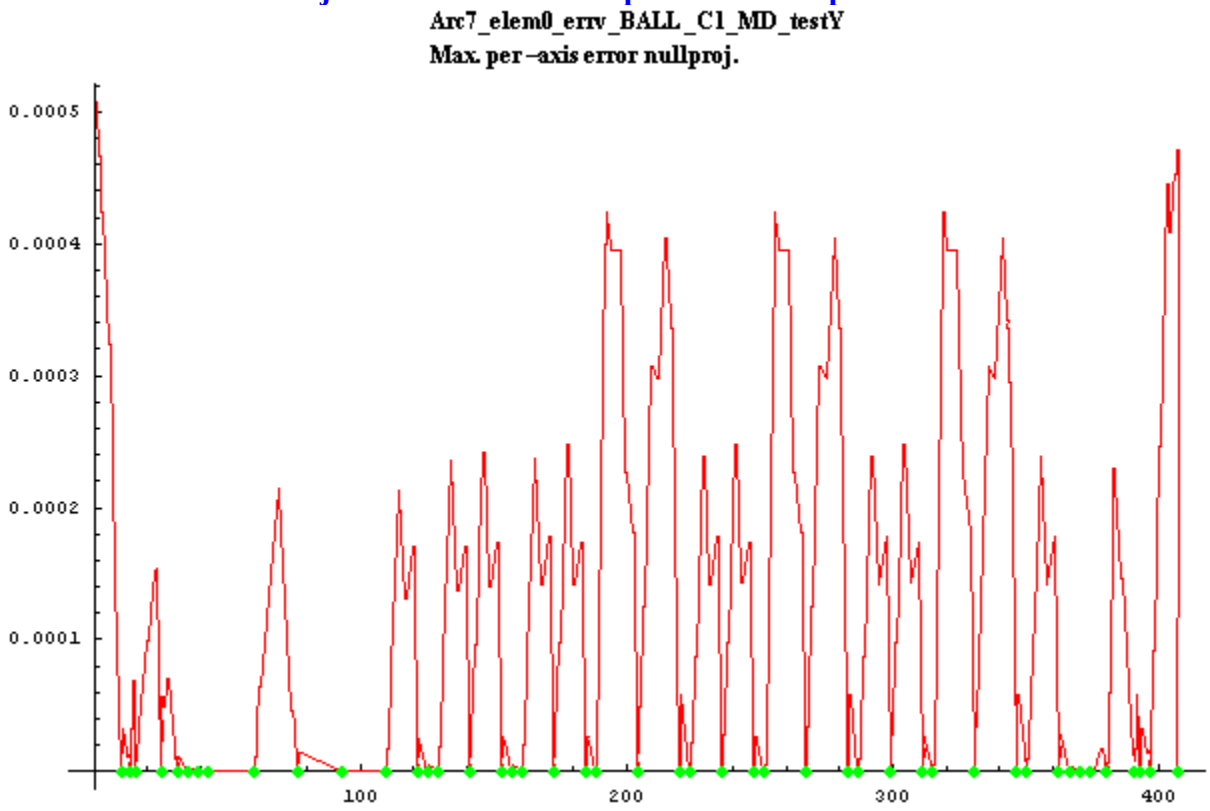
3σ Extent of the Real Underlying Orbit after Orbit Correction in Y



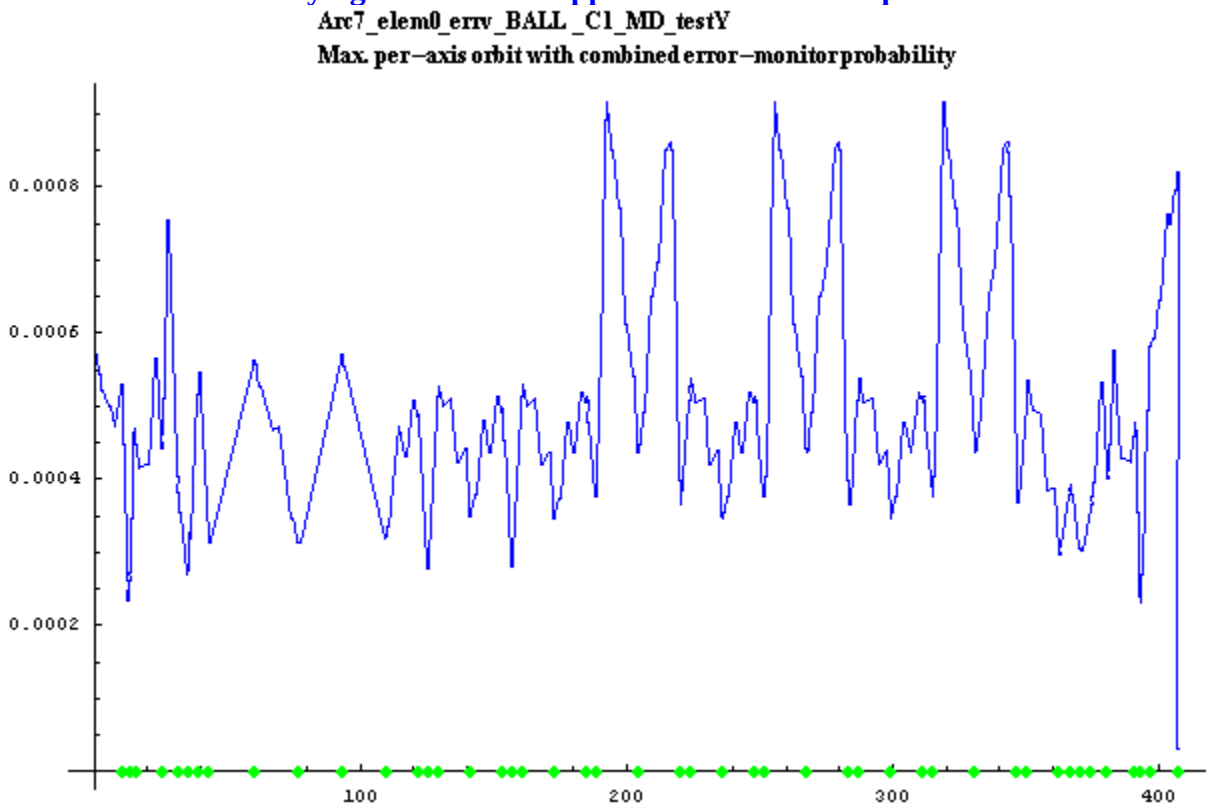
Range of Correctors in Multiples of σ of Error Distribution That Can be Corrected in Y



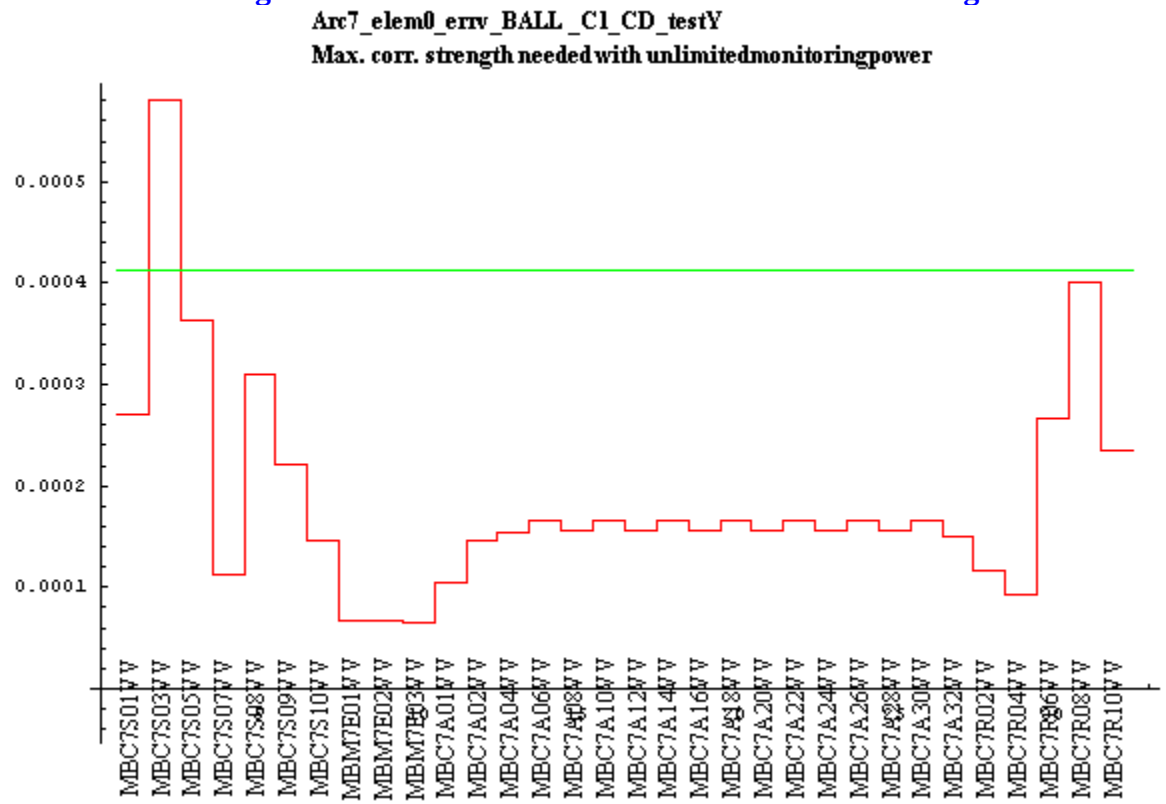
3σ Error Projection onto the Null Space of the Response Matrix in Y



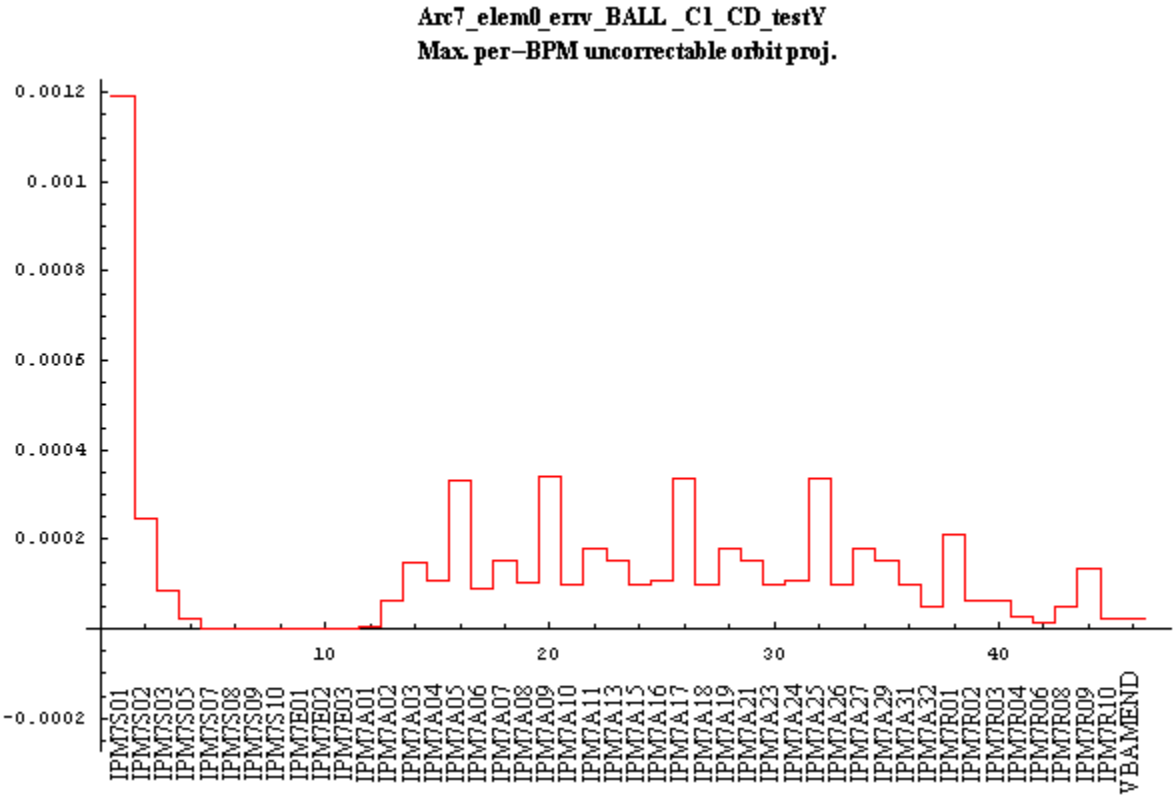
3σ Extent of Underlying Orbit When Apparent Orbit RMS Equals BPM Offset in Y



Corrector Strengths Needed for 3σ Error with Unlimited Monitoring Power in Y



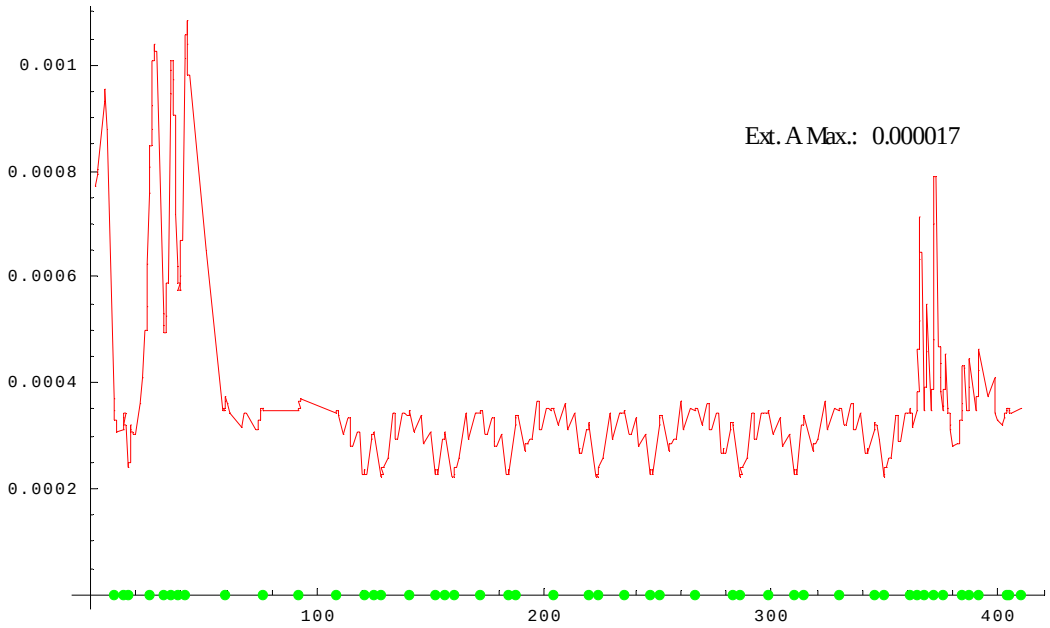
Fundamental Uncorrectable Orbit at all BPMs due to 3σ Error in Y



ARC 8

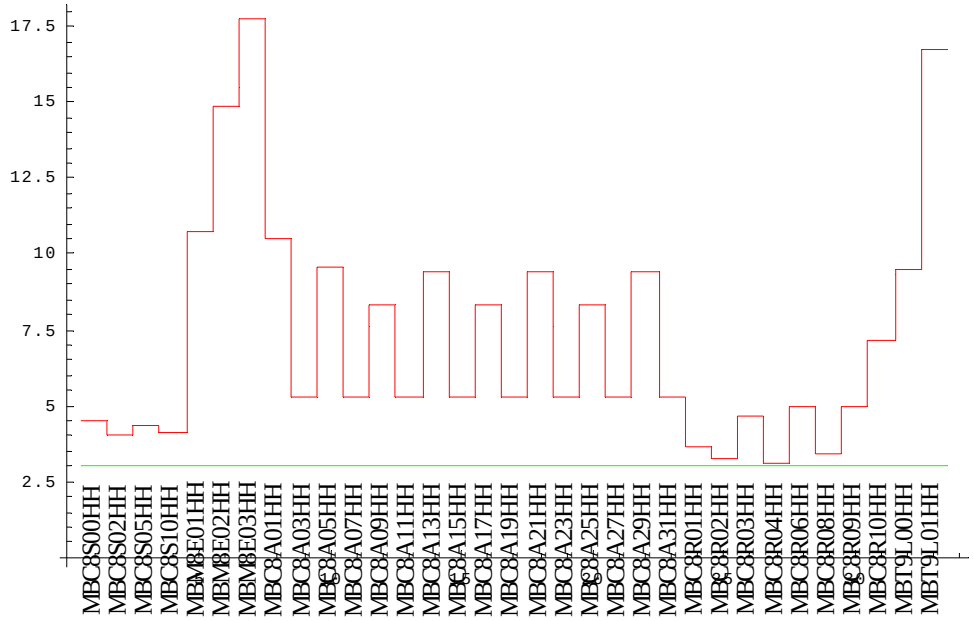
3σ Extent of the Real Underlying Orbit after Orbit Correction in X

Arc8_elem0errh_BALL_CALL_MO_testX
Maximum underlying corrected orbit at all-elem



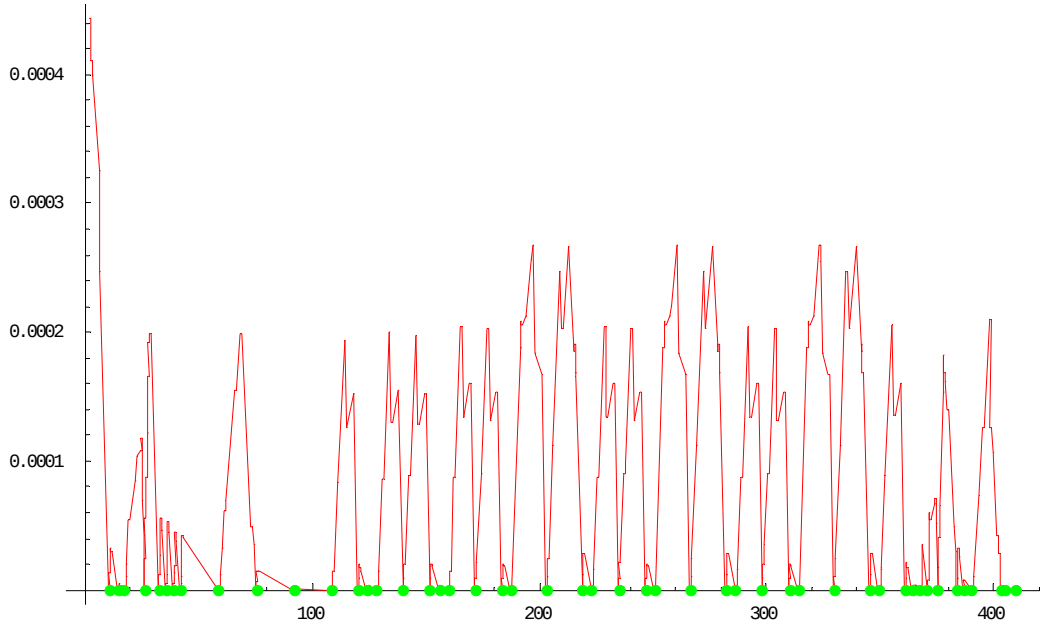
Range of Correctors in Multiples of σ of Error Distribution That Can be Corrected in X

Arc8_elem0errh_BALL_CALL_CD_testX
Corrector range in units of projected sigma



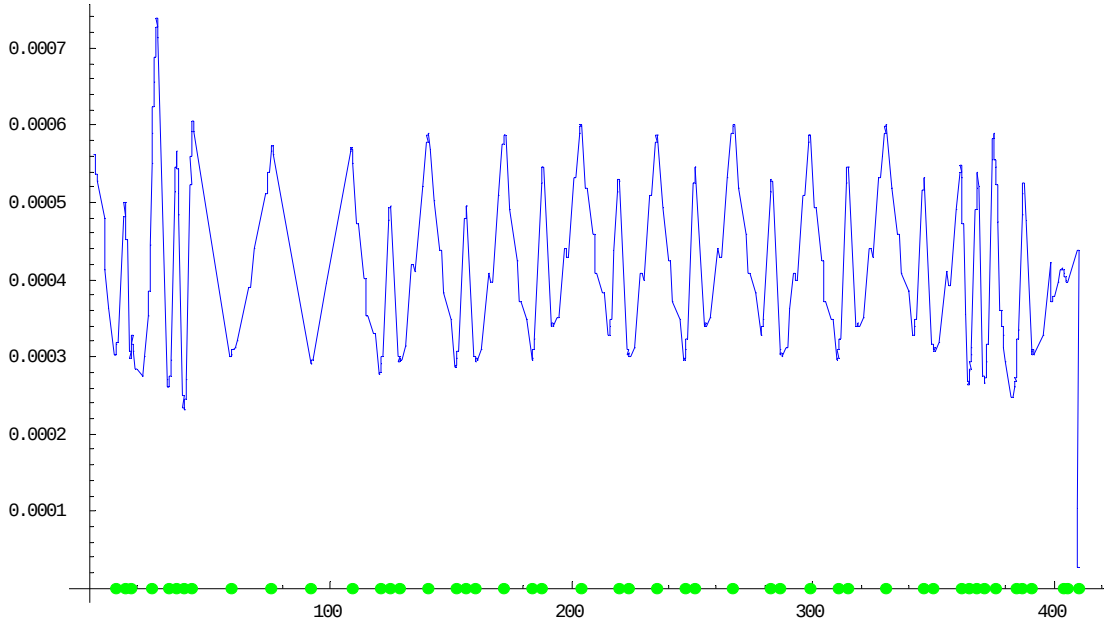
3σ Error Projection onto the Null Space of the Response Matrix in X

Arc8_elem0_errh_BALL_CALL_MD_testX
Max. per−axis error null proj.



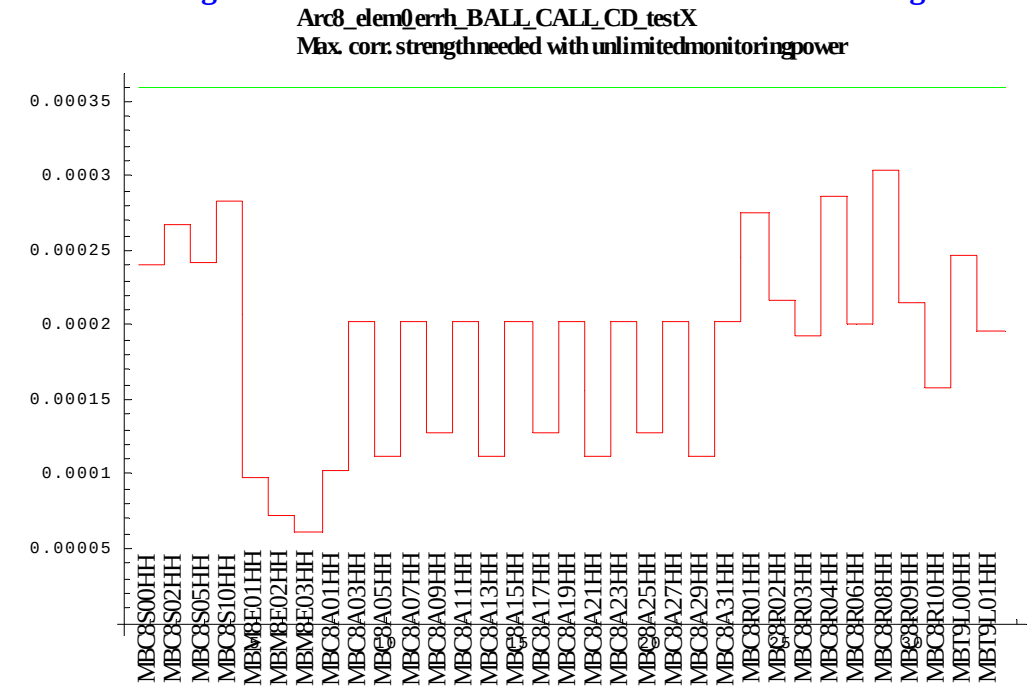
3σ Extent of Underlying Orbit When Apparent Orbit RMS Equals BPM Offset in X

Arc8_elem0_errh_BALL_CALL_MD_testX
Max. per−axis orbit with combined error−monitor probability

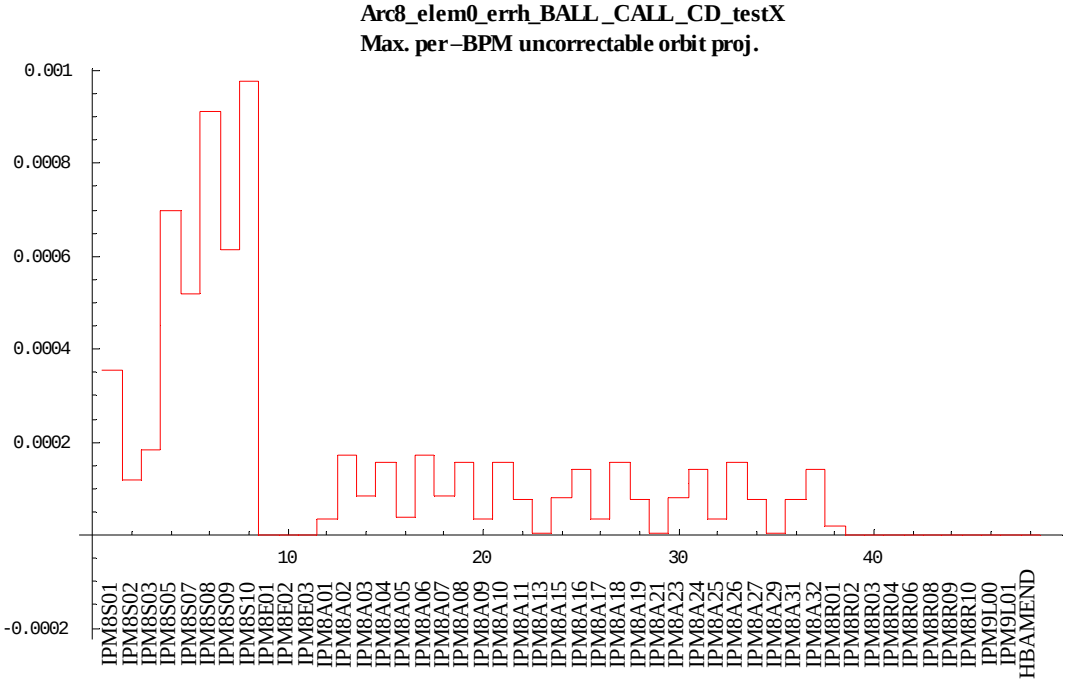


File used:
Arc6_elem0_errh_BALL_CALL_CD_testX

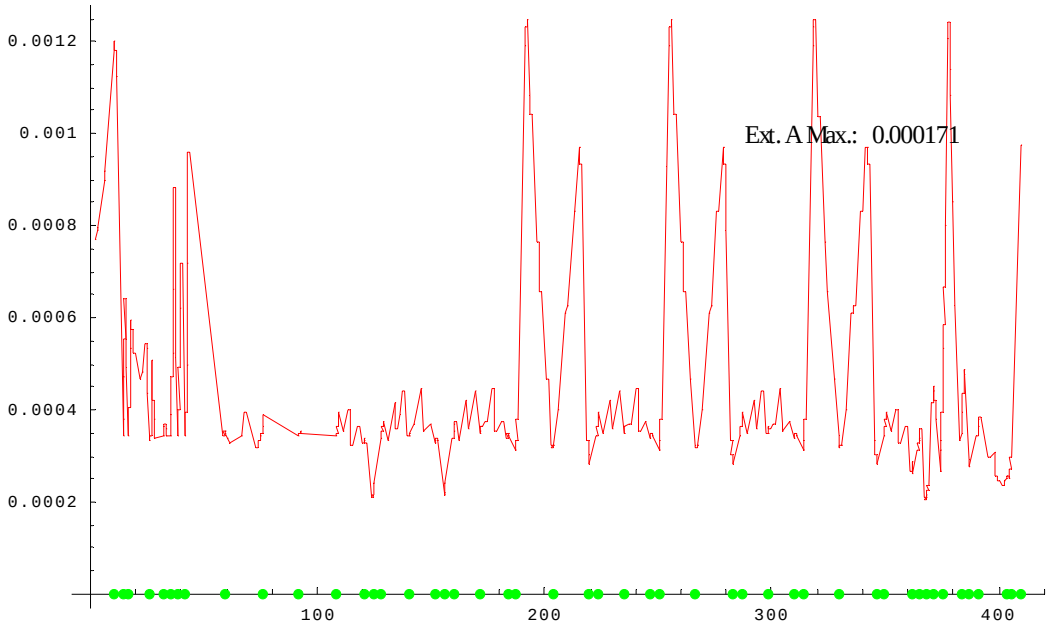
Corrector Strengths Needed for 3σ Error with Unlimited Monitoring Power in X



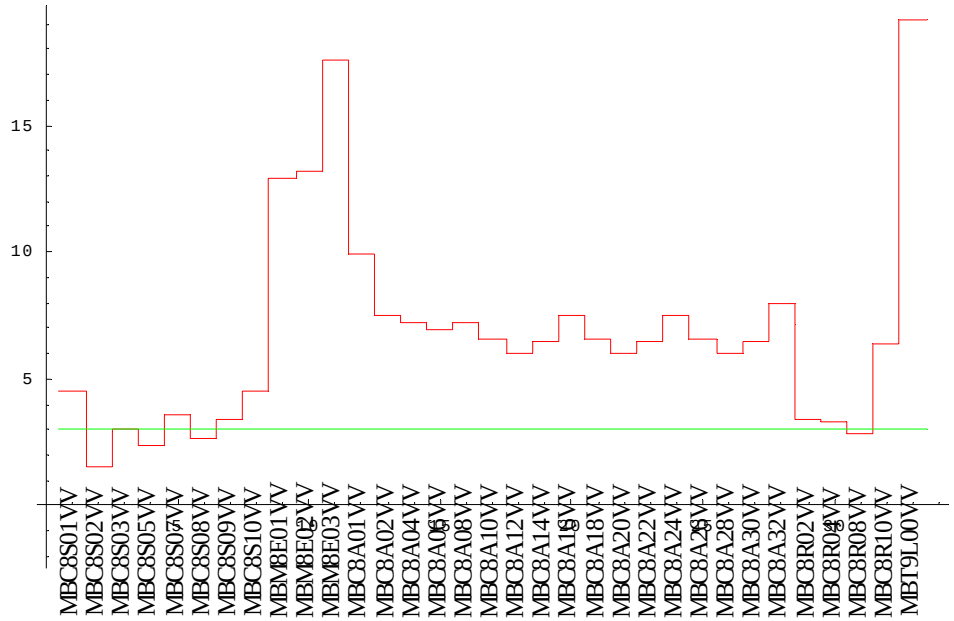
Fundamental Uncorrectable Orbit at all BPMs due to 3σ Error in X



3σ Extent of the Real Underlying Orbit after Orbit Correction in Y



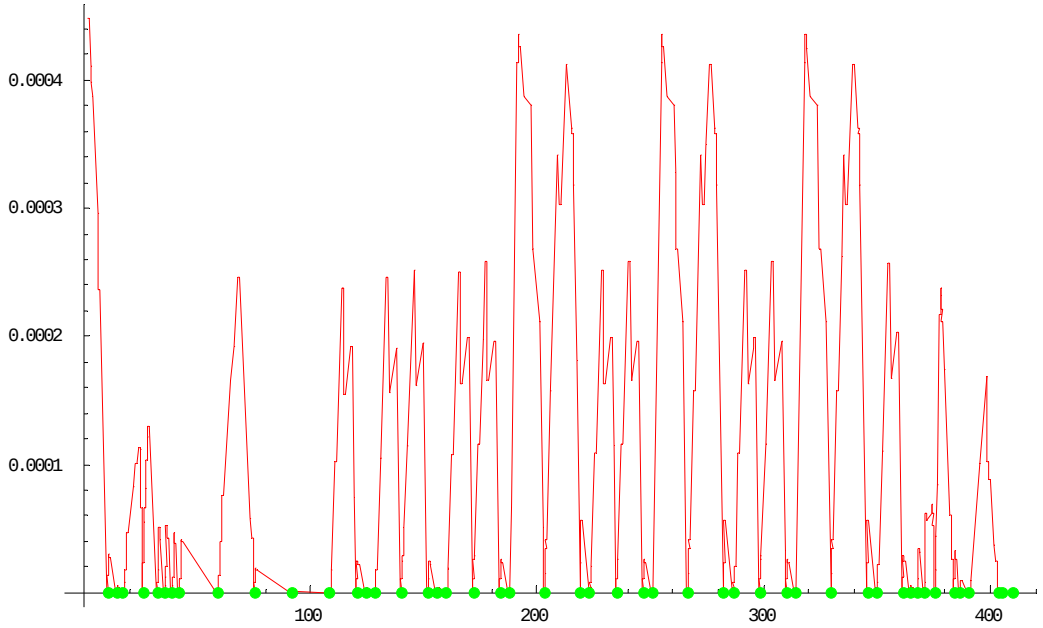
Range of Correctors in Multiples of σ of Error Distribution That Can be Corrected in Y



3σ Error Projection onto the Null Space of the Response Matrix in Y

Arc8_elem0_errv_BALL_CALL_MD_testY

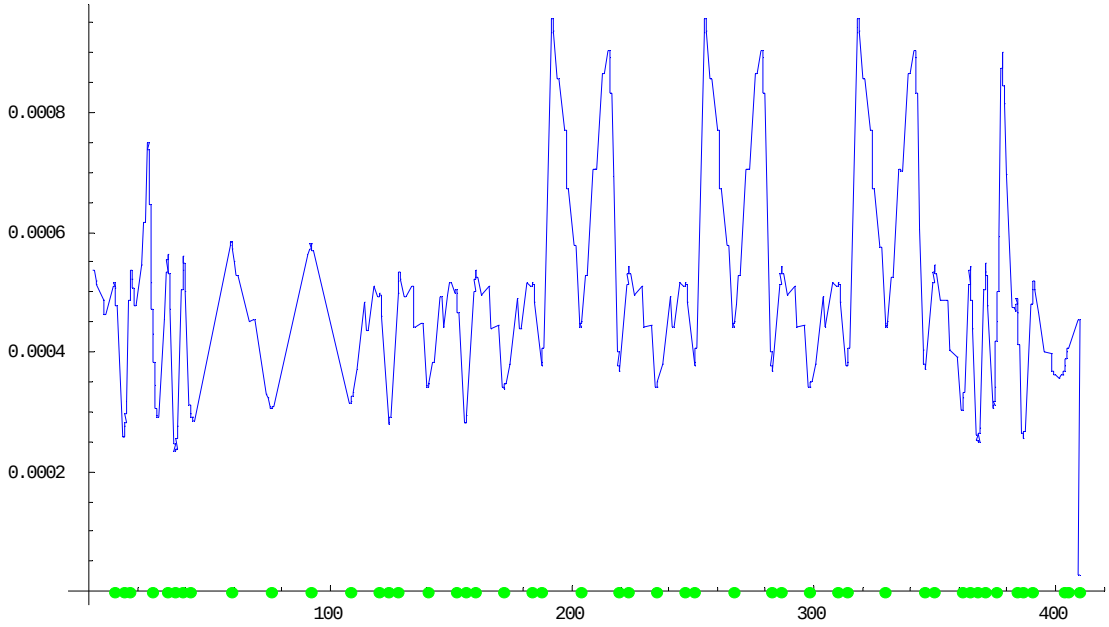
Max. per−axis error null proj.



3σ Extent of Underlying Orbit When Apparent Orbit RMS Equals BPM Offset in Y

Arc8_elem0_errv_BALL_CALL_MD_testY

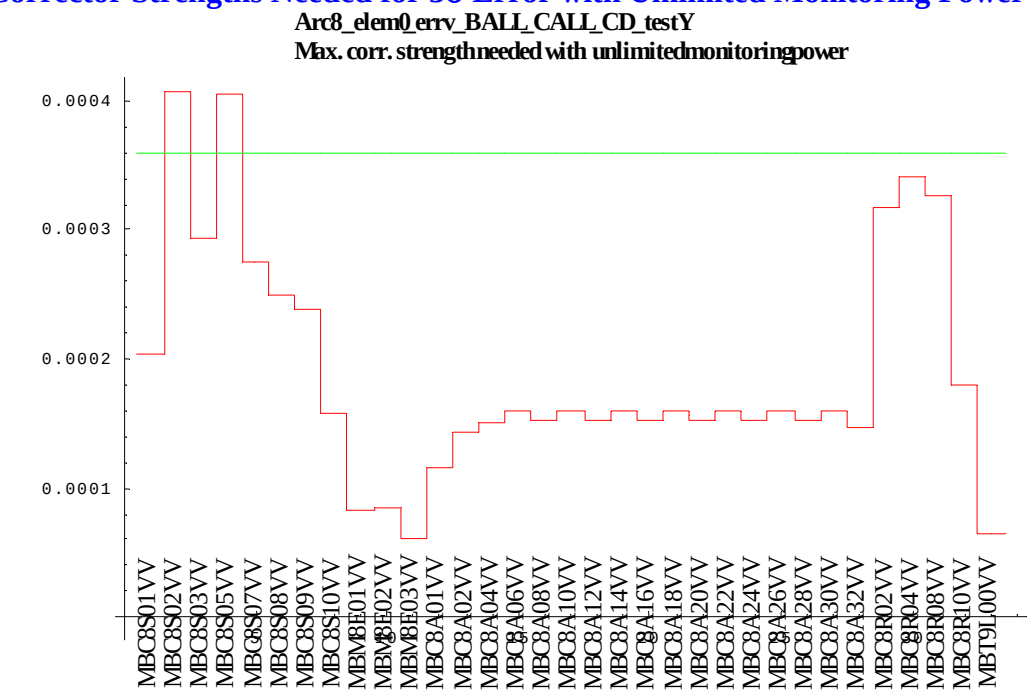
Max. per−axis orbit with combined error−monitor probability



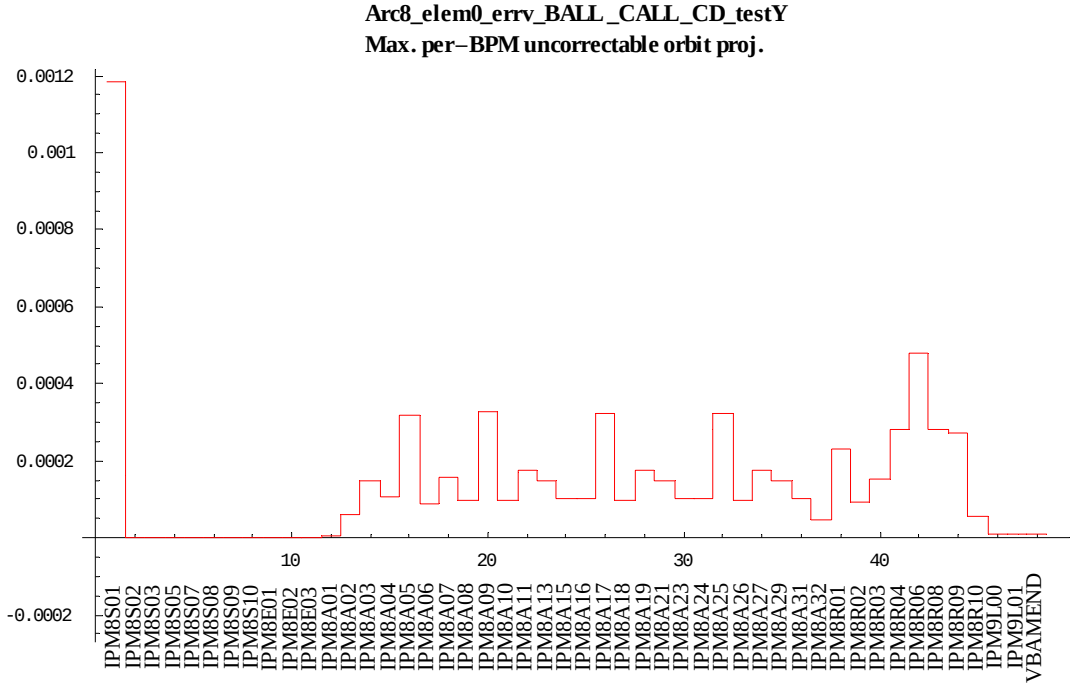
File used:

Arc6_elem0_errv_BALL_CALL_CD_testY

Corrector Strengths Needed for 3σ Error with Unlimited Monitoring Power in Y

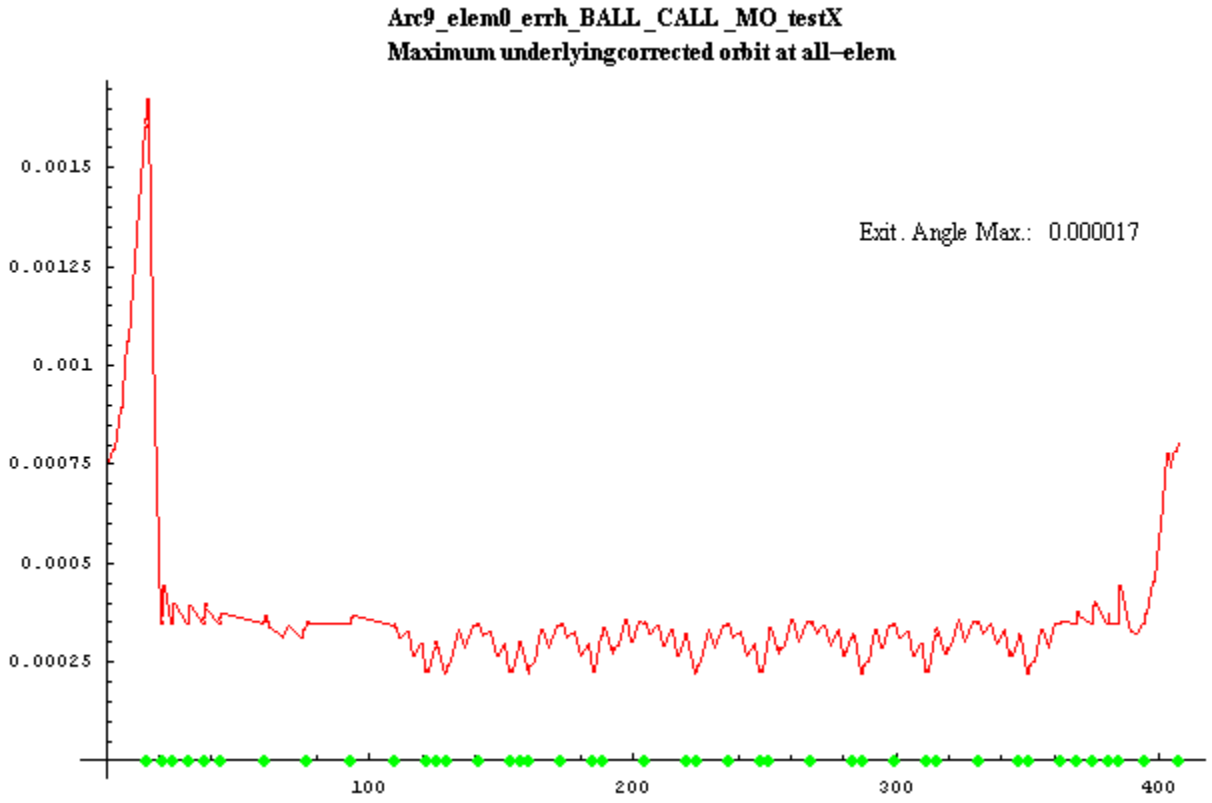


Fundamental Uncorrectable Orbit at all BPMs due to 3σ Error in Y

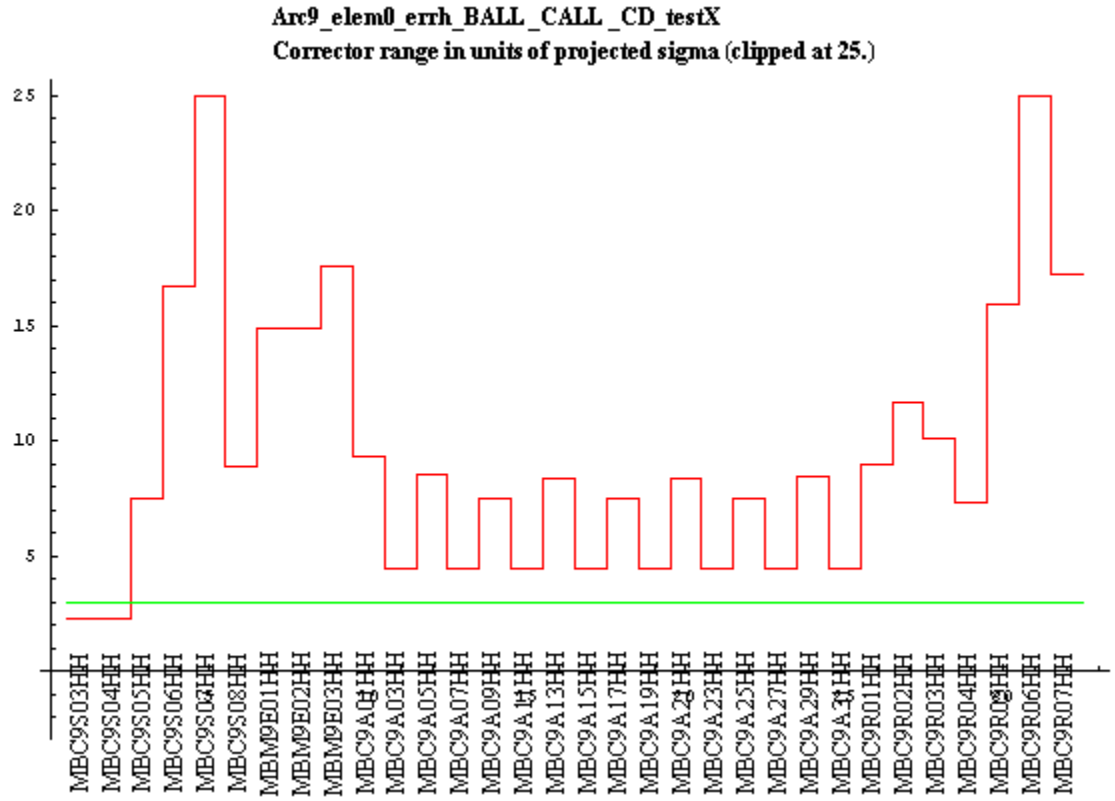


ARC 9

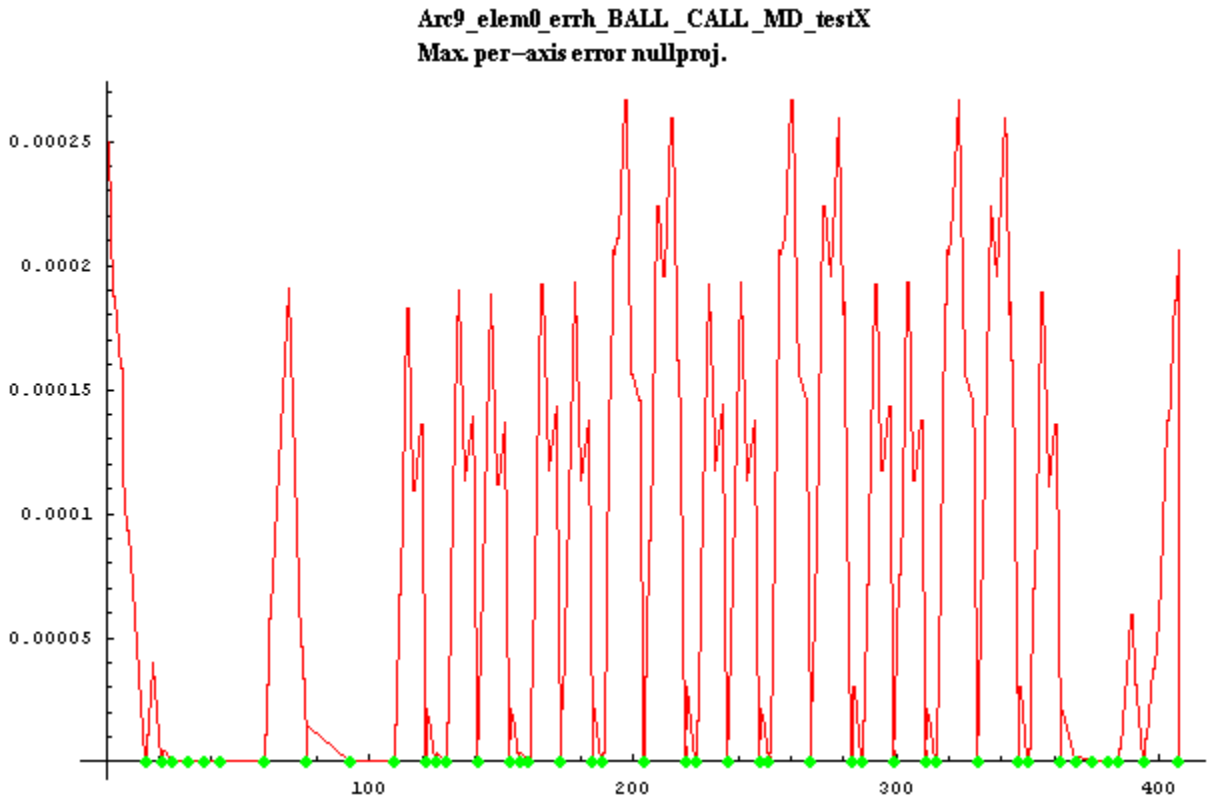
3σ Extent of the Real Underlying Orbit after Orbit Correction in X



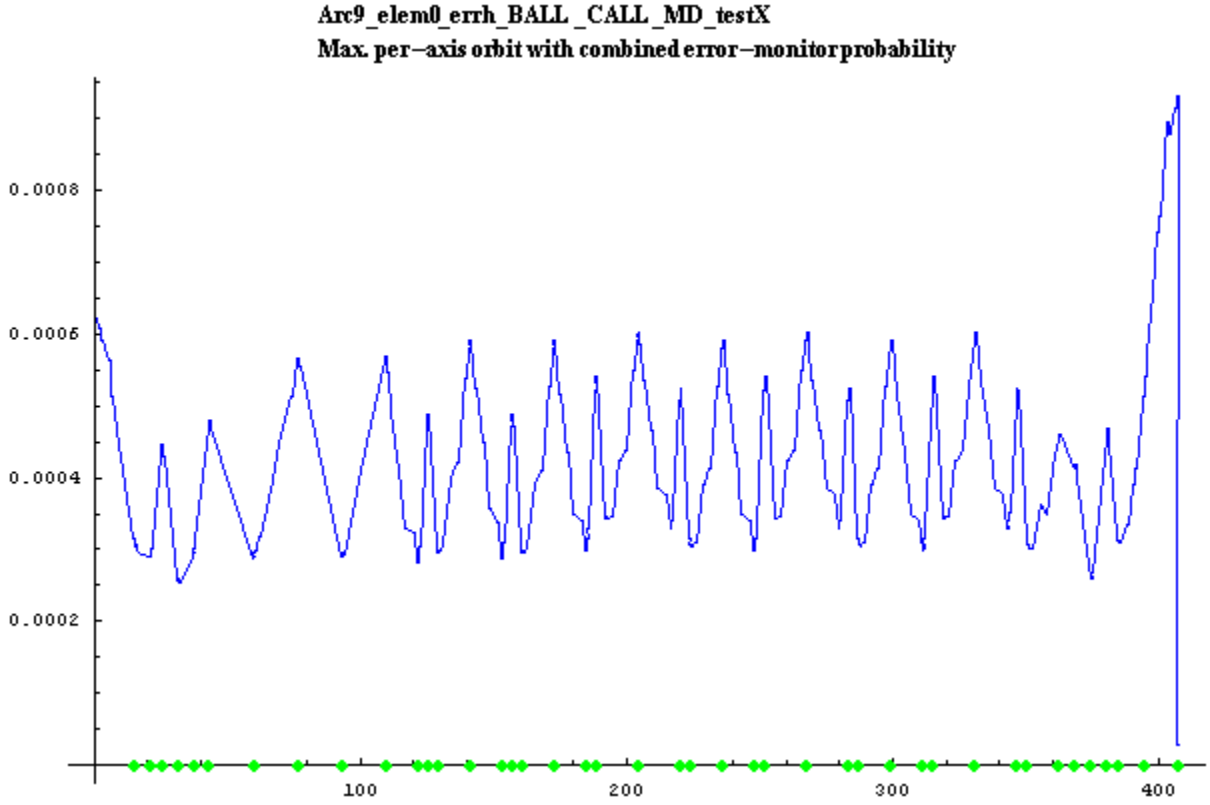
Range of Correctors in Multiples of σ of Error Distribution That Can be Corrected in X



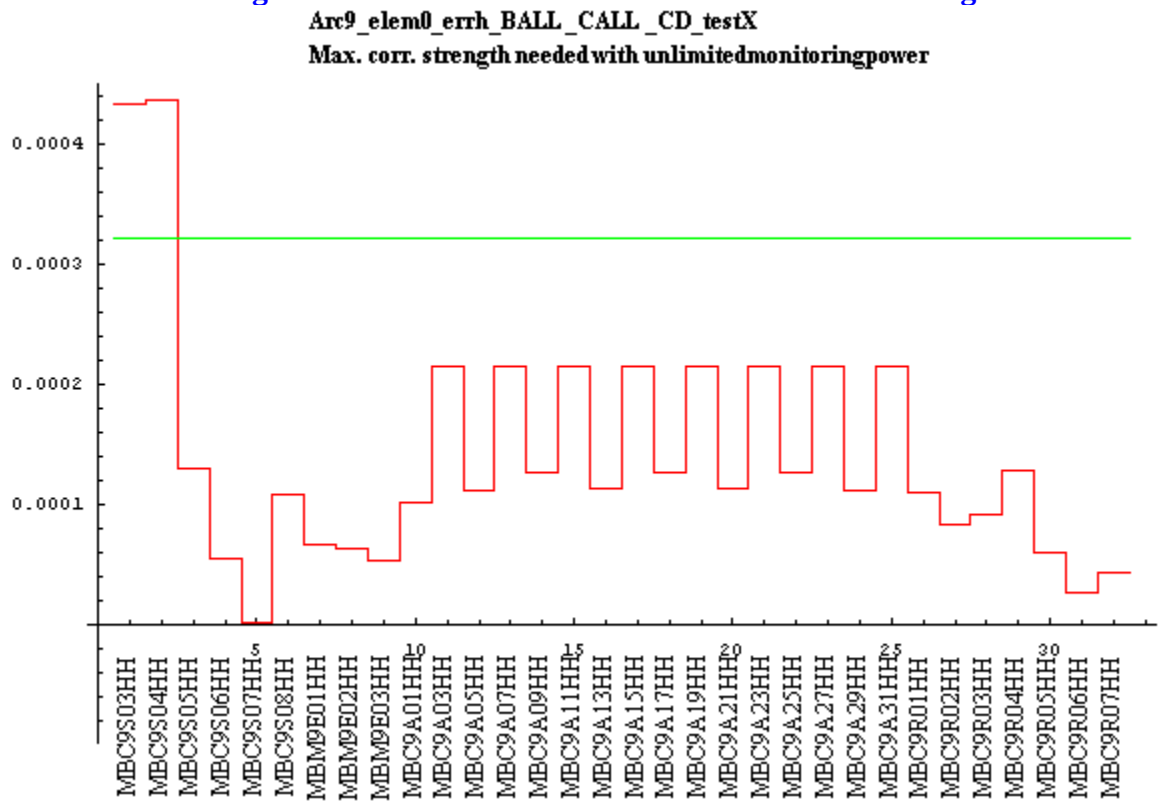
3σ Error Projection onto the Null Space of the Response Matrix in X



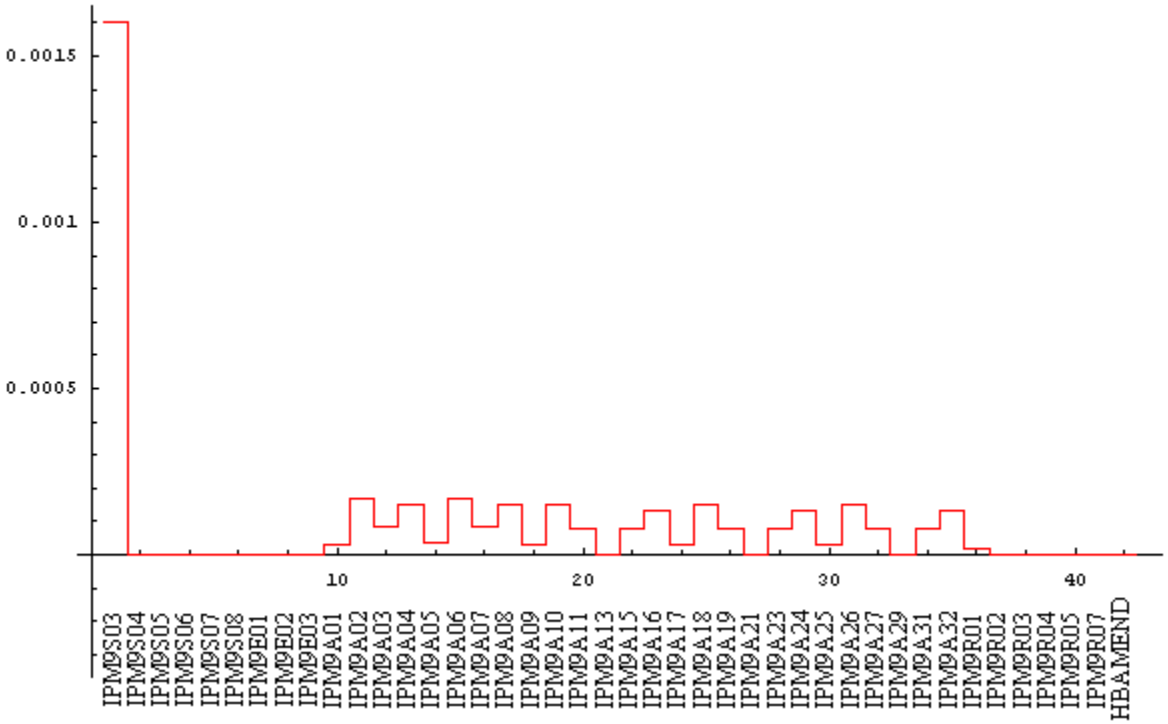
3σ Extent of Underlying Orbit When Apparent Orbit RMS Equals BPM Offset in X



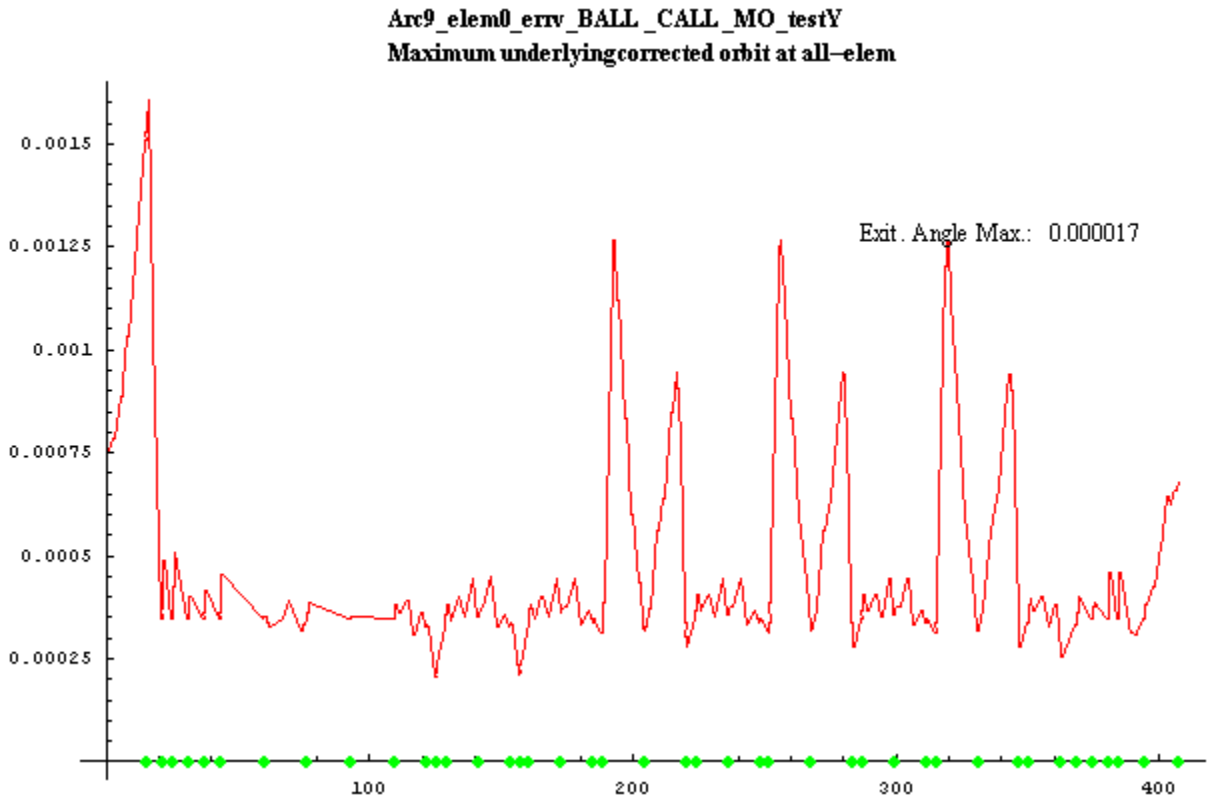
Corrector Strengths Needed for 3σ Error with Unlimited Monitoring Power in X



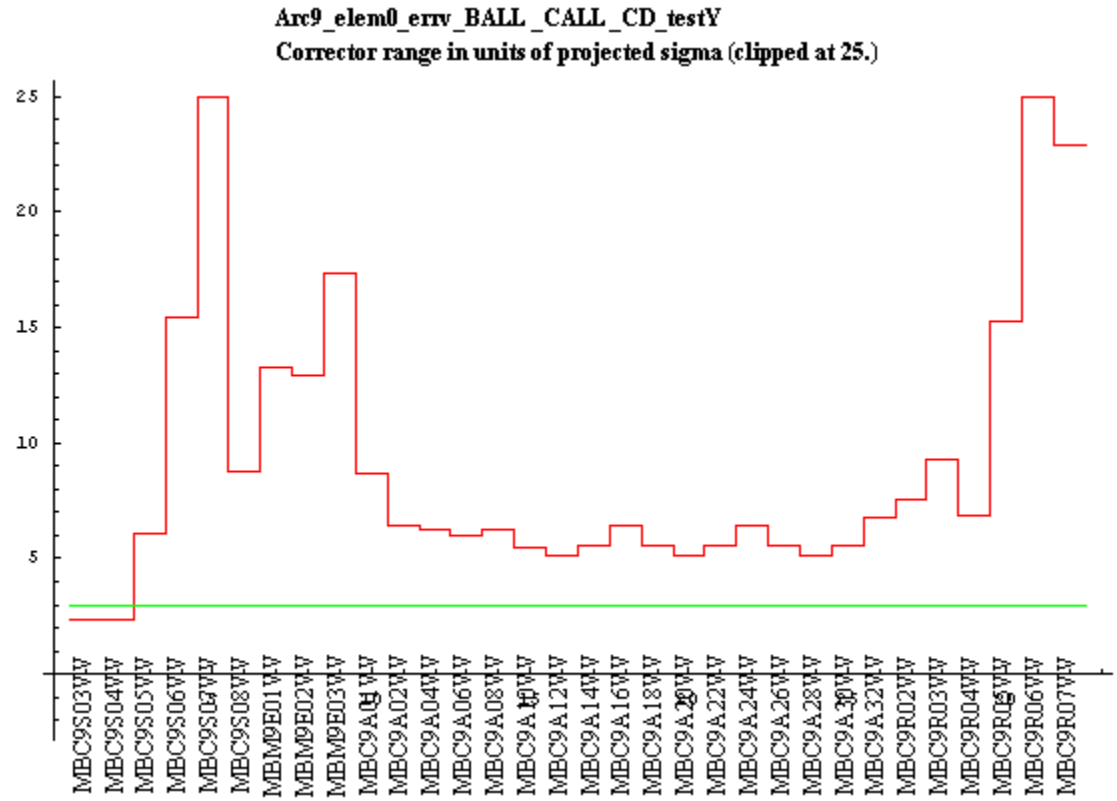
Fundamental Uncorrectable Orbit at all BPMs due to 3σ Error in X



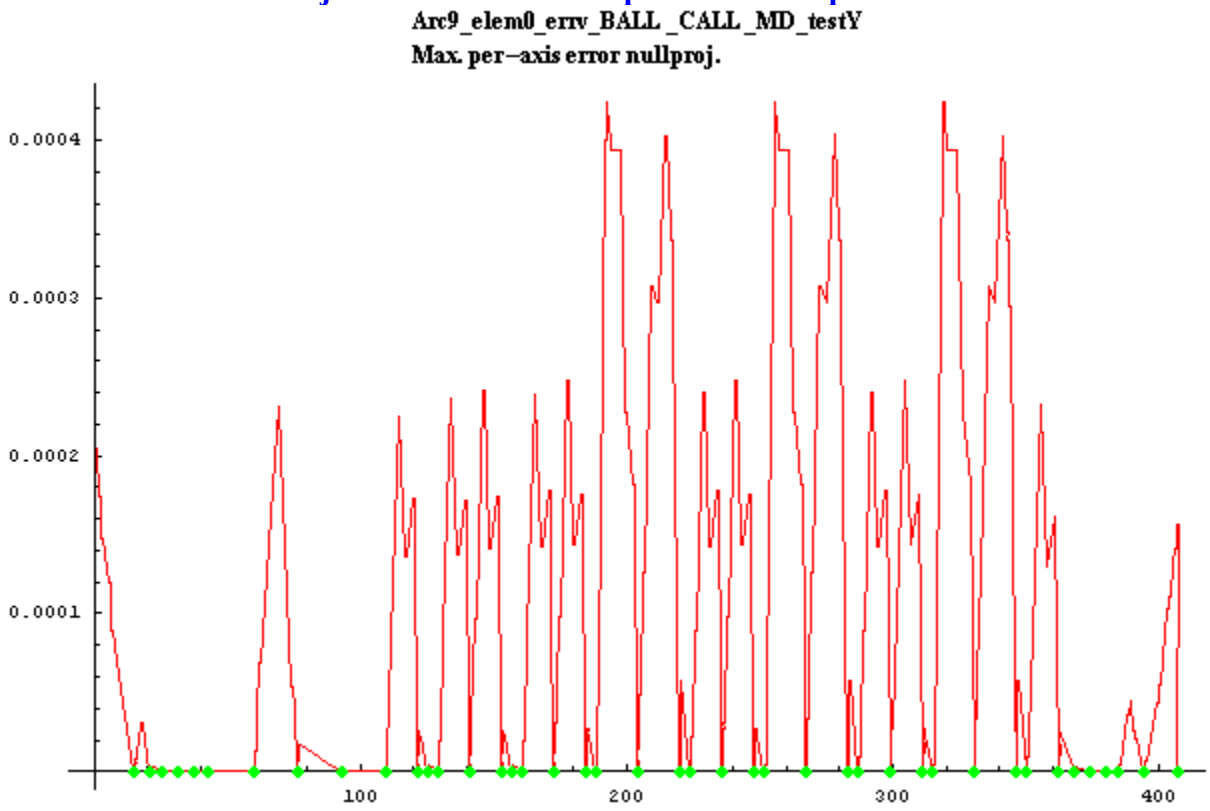
3σ Extent of the Real Underlying Orbit after Orbit Correction in Y



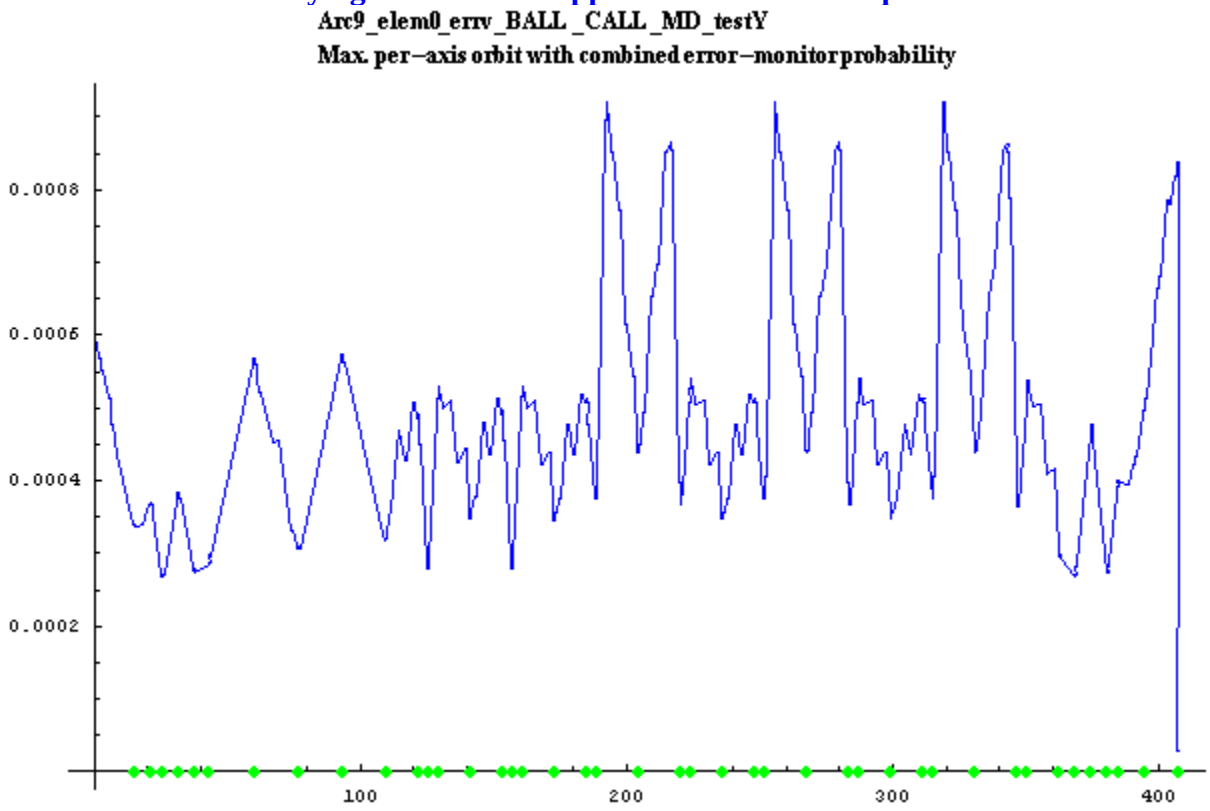
Range of Correctors in Multiples of σ of Error Distribution That Can be Corrected in Y



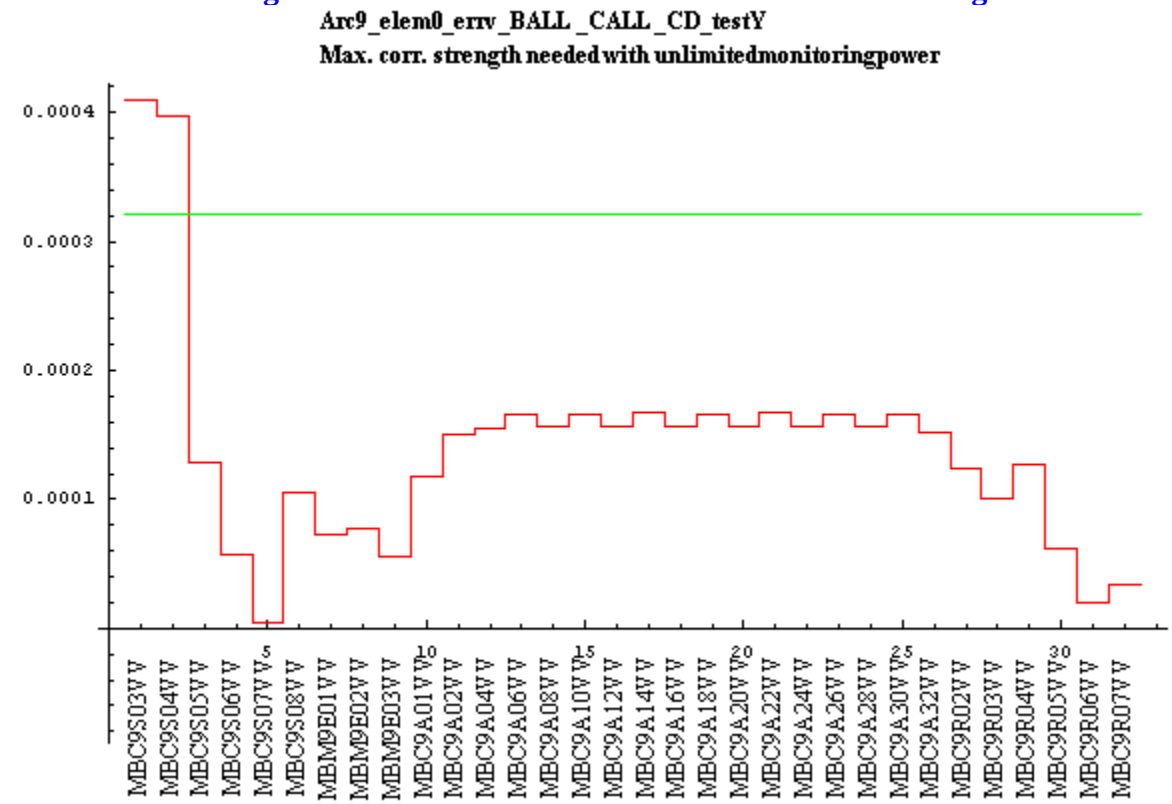
3σ Error Projection onto the Null Space of the Response Matrix in Y



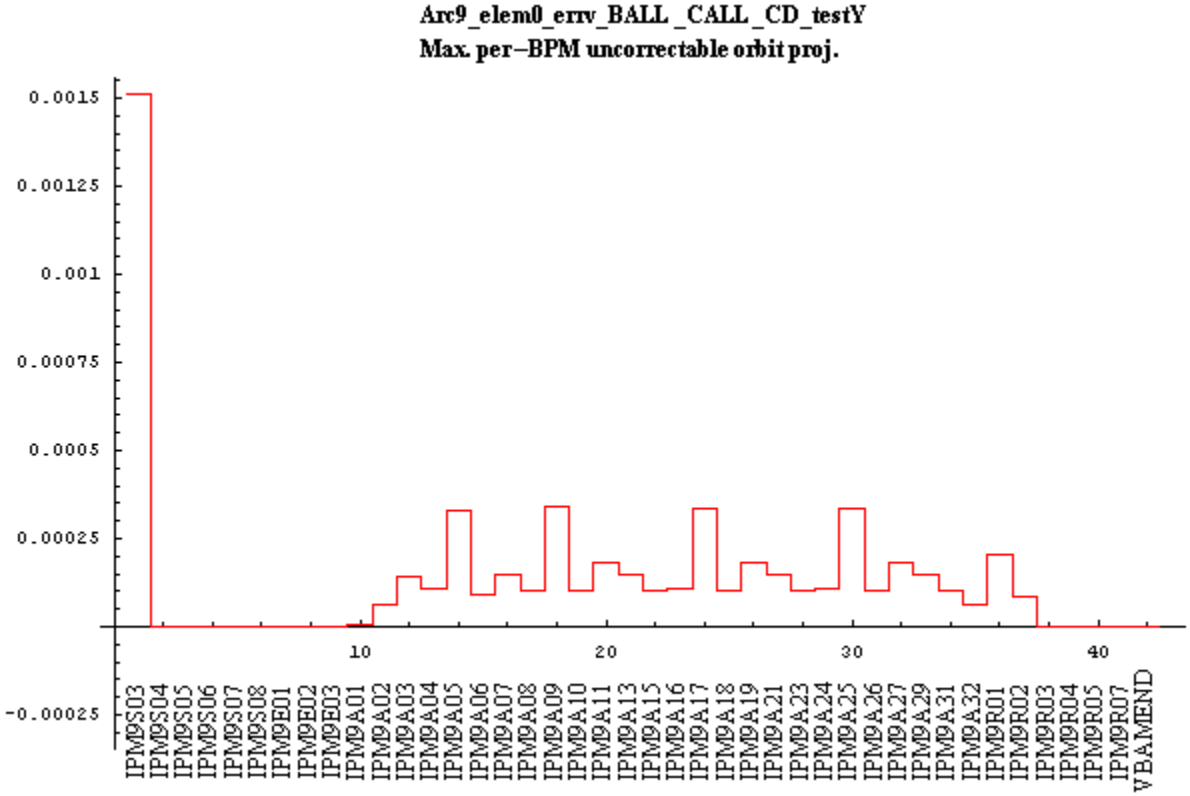
3σ Extent of Underlying Orbit When Apparent Orbit RMS Equals BPM Offset in Y



Corrector Strengths Needed for 3σ Error with Unlimited Monitoring Power in Y



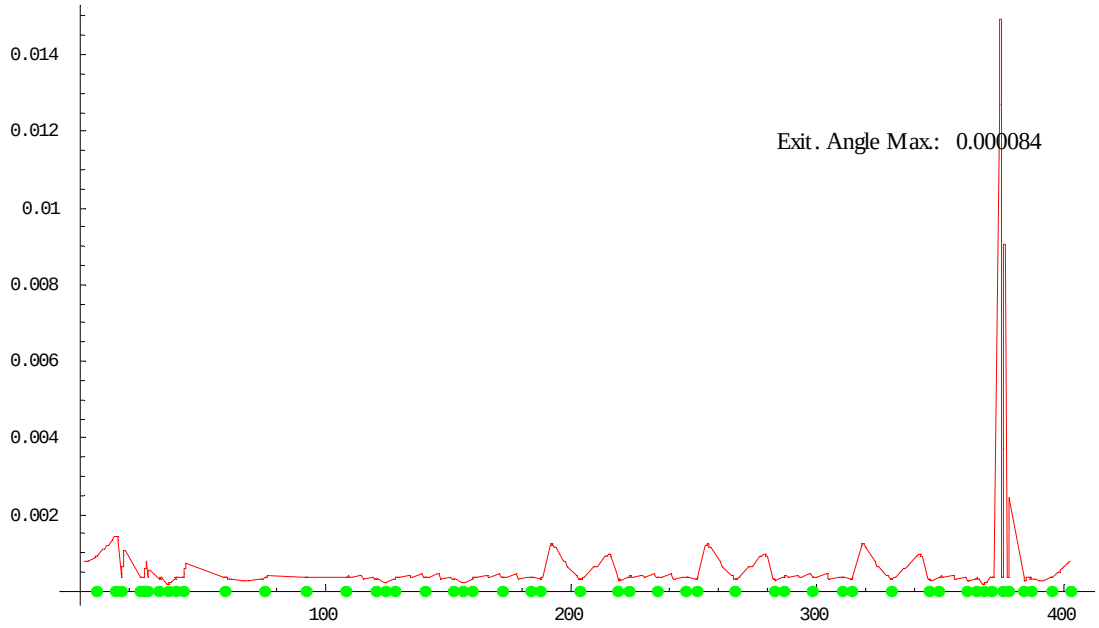
Fundamental Uncorrectable Orbit at all BPMs due to 3σ Error in Y



ARC 10 (Before Removing Singular Correctors in Y)

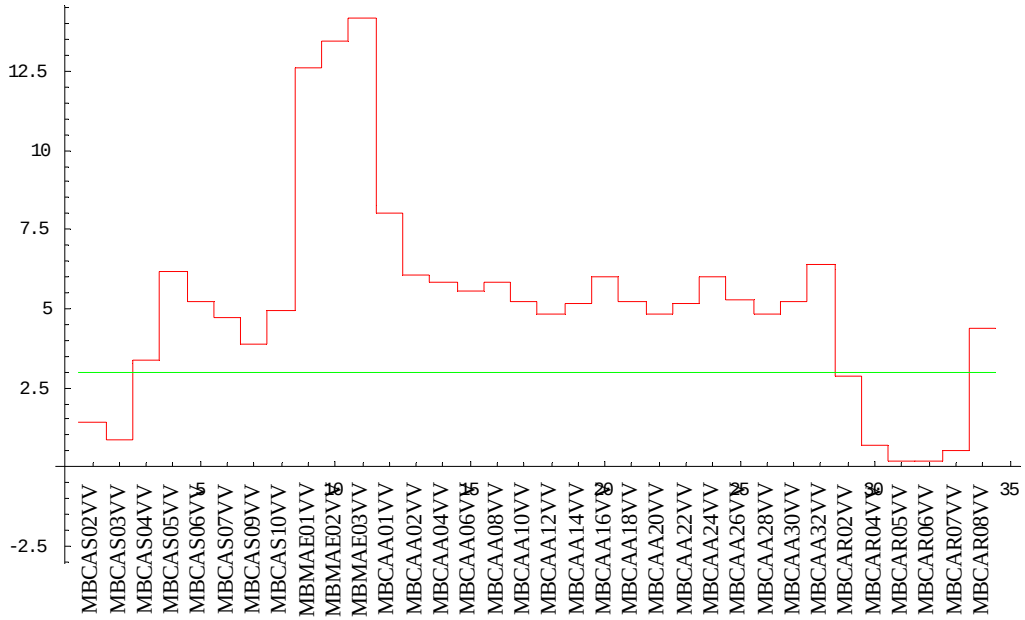
3σ Extent of the Real Underlying Orbit after Orbit Correction in Y

ArcA_elem0_errv_BALL_CALL_MO_testY
Maximum underlying corrected orbit at all–elem



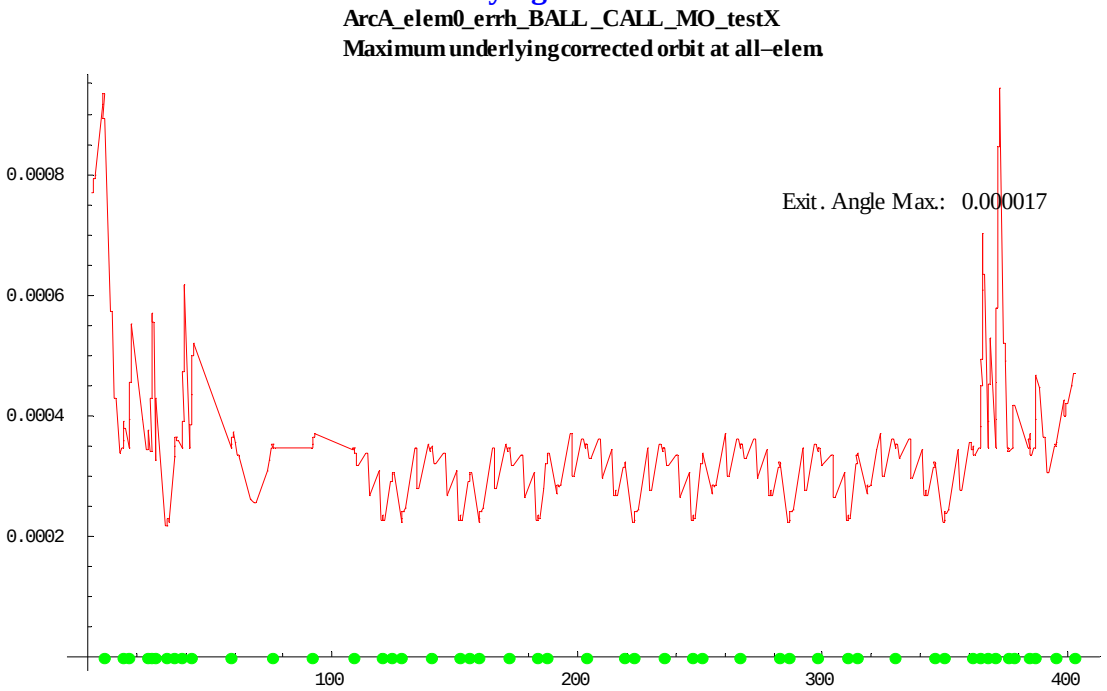
Range of Correctors in Multiples of σ of Error Distribution That Can be Corrected in Y

ArcA_elem0_errv_BALL_CALL_CD_testY
Corrector range in units of projected sigma (clipped at 25.)

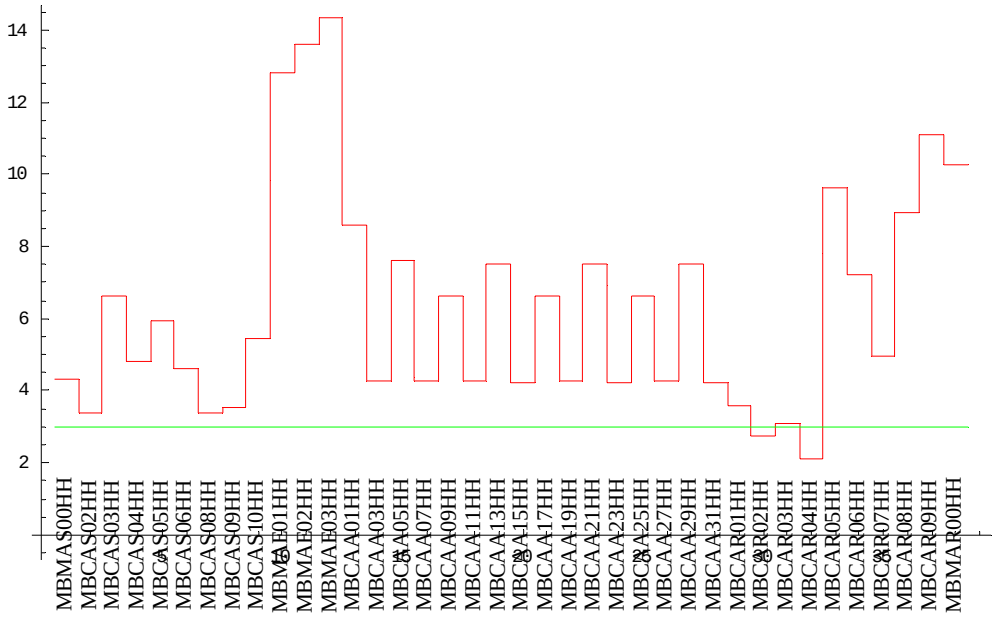


ARC 10 (After Removing Singular Correctors in Y)

3σ Extent of the Real Underlying Orbit after Orbit Correction in X

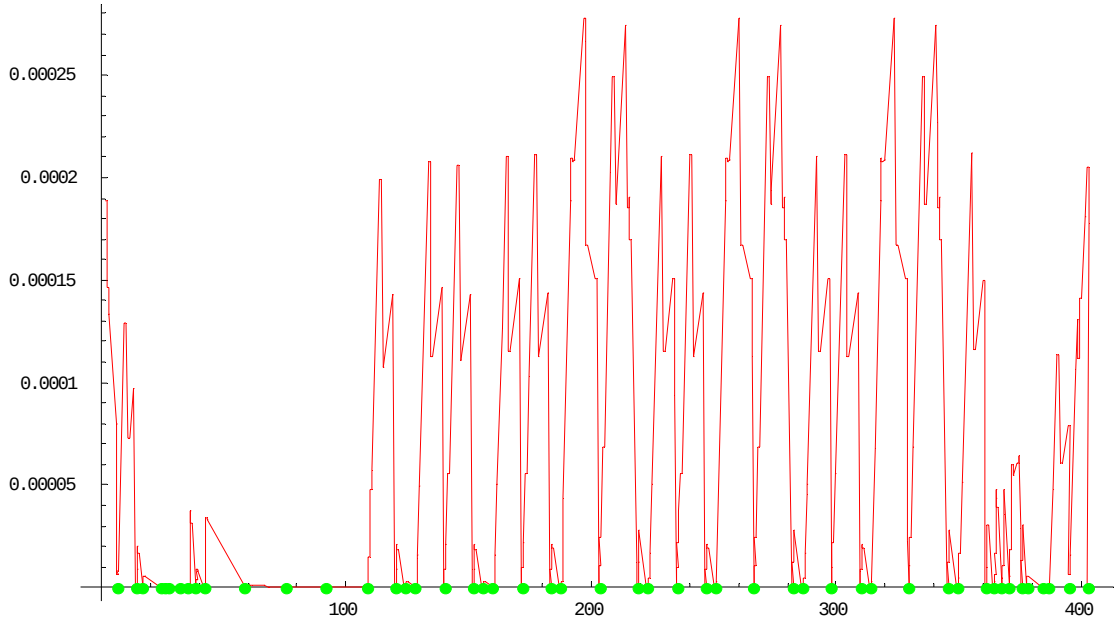


Range of Correctors in Multiples of σ of Error Distribution That Can be Corrected in X



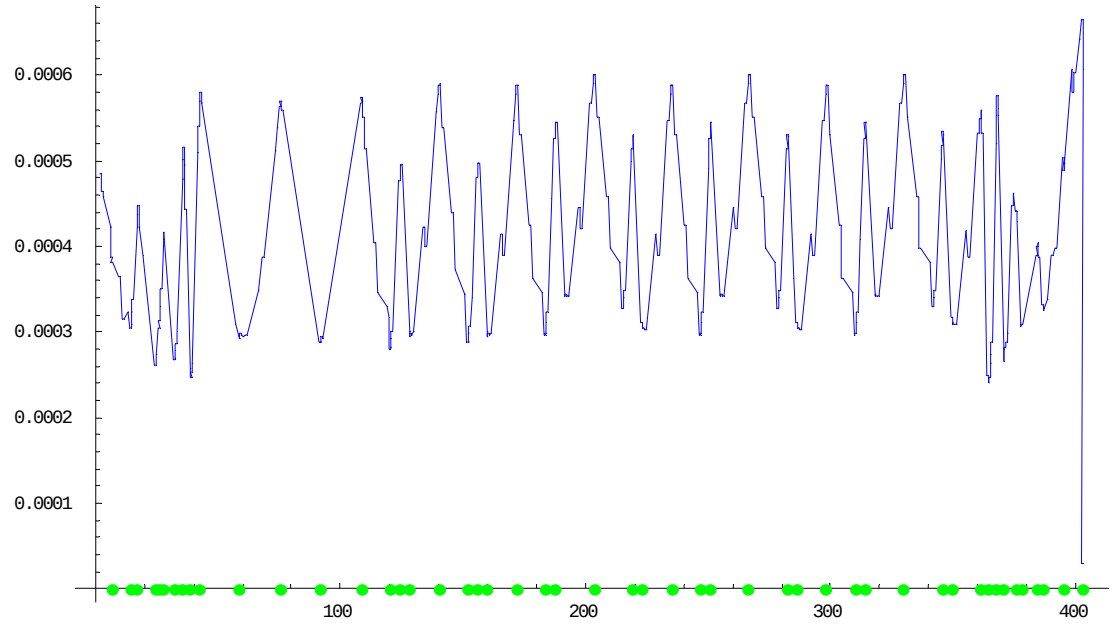
3σ Error Projection onto the Null Space of the Response Matrix in X

ArcA_elem0_errh_BALL_CALL_MD_testX
Max. per−axis error null proj.



3σ Extent of Underlying Orbit When Apparent Orbit RMS Equals BPM Offset in X

ArcA_elem0_errh_BALL_CALL_MD_testX
Max. per−axis orbit with combined error−monitor probability

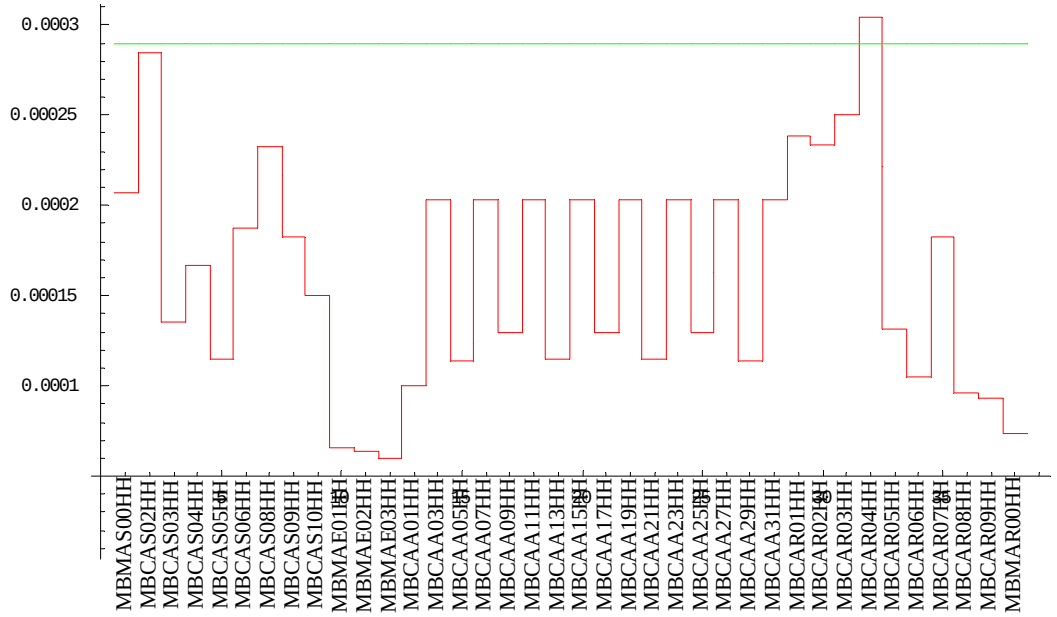


File used:
Arc6_elem0_errh_BALL_CALL_CD_testX

Corrector Strengths Needed for 3σ Error with Unlimited Monitoring Power in X

ArcA_elem0_errh_BALL_CALL_CD_testX

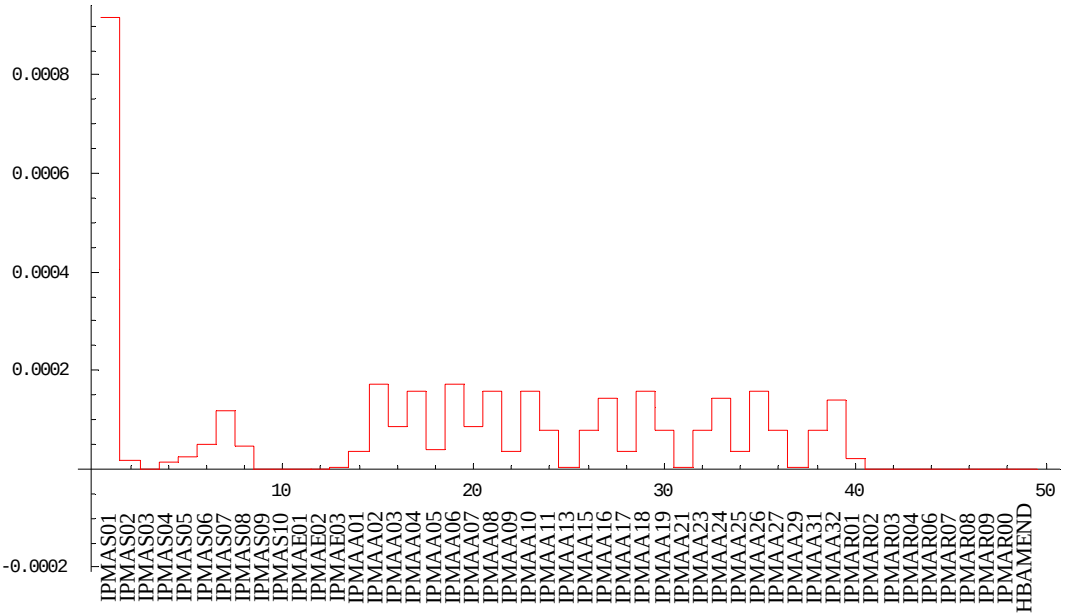
Max. corr. strength needed with unlimited monitoring power



Fundamental Uncorrectable Orbit at all BPMs due to 3σ Error in X

ArcA_elem0_errh_BALL_CALL_CD_testX

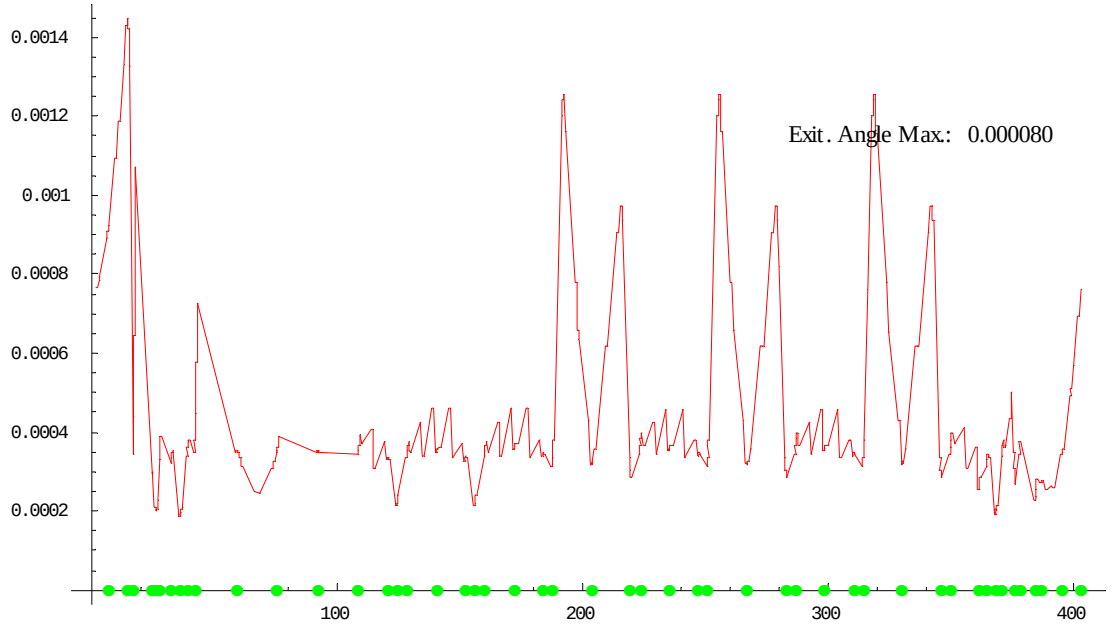
Max. per−BPM uncorrectable orbit proj.



3σ Extent of the Real Underlying Orbit after Orbit Correction in Y

ArcA_elem0_errv_BALL_C1_MO_testY

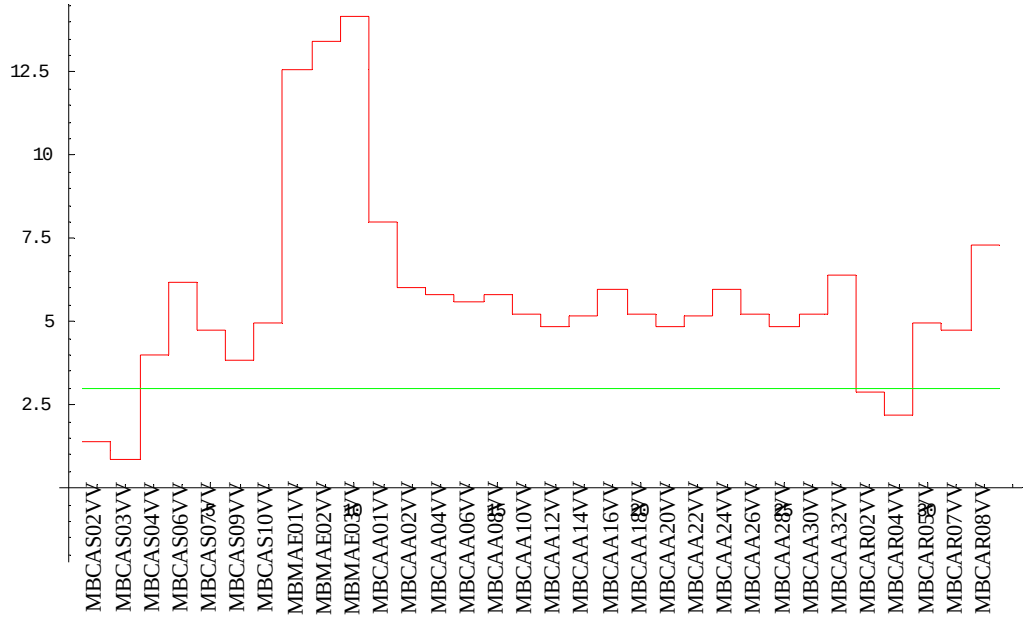
Maximum underlying corrected orbit at all–elem



Range of Correctors in Multiples of σ of Error Distribution That Can be Corrected in Y

ArcA_elem0_errv_BALL_C1_CD_testY

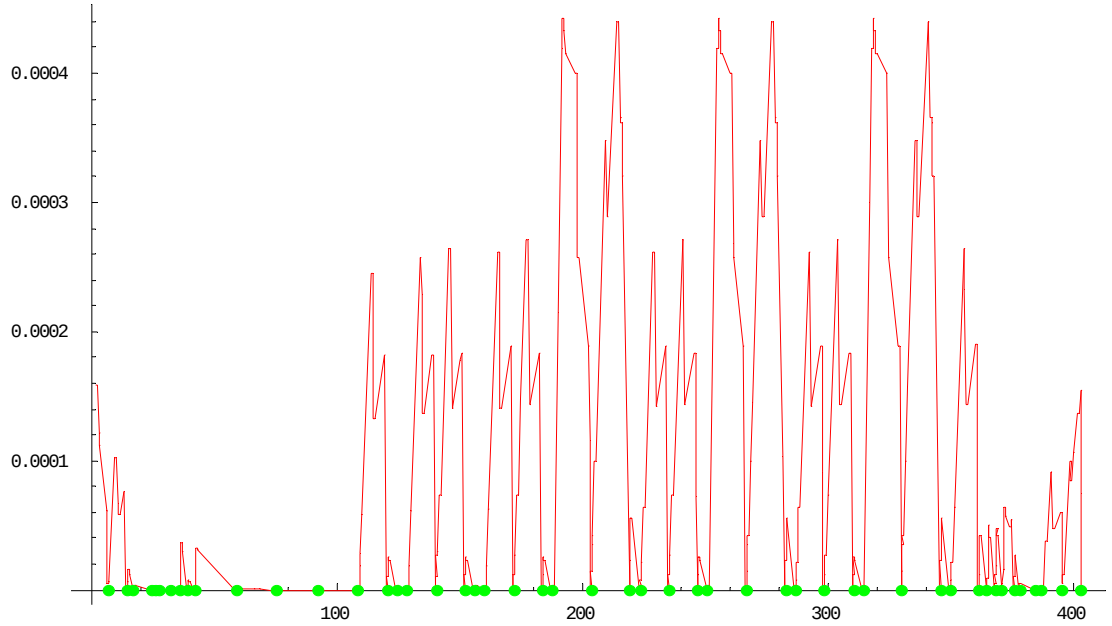
Corrector range in units of projected sigma (clipped at 25.)



3σ Error Projection onto the Null Space of the Response Matrix in Y

ArcA_elem0_errv_BALL _C1_MD_testY

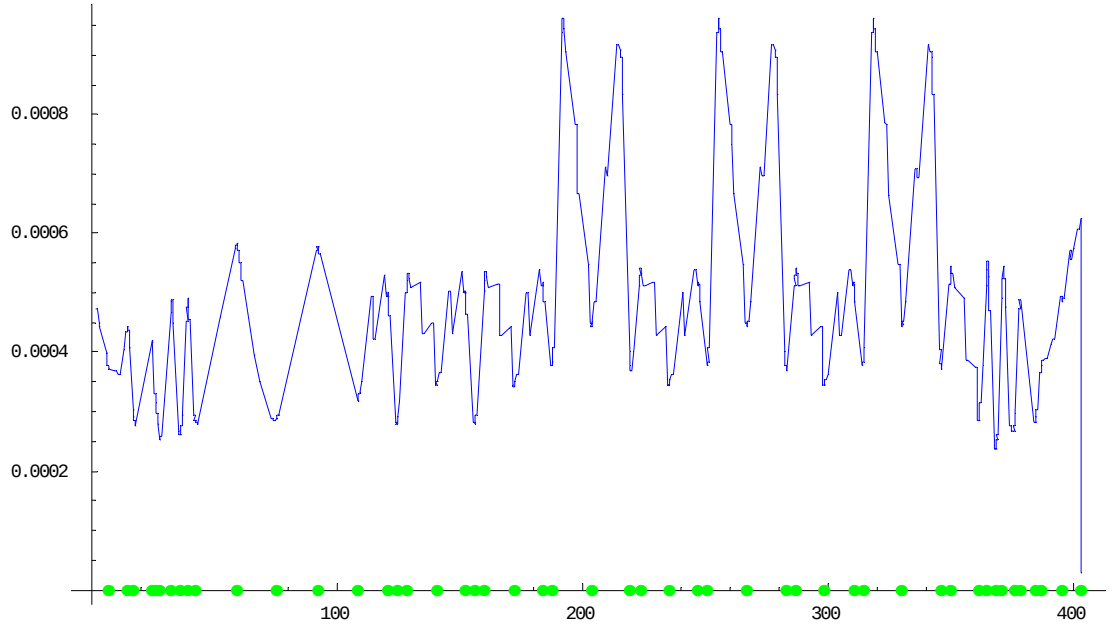
Max. per−axis error null proj.



3σ Extent of Underlying Orbit When Apparent Orbit RMS Equals BPM Offset in Y

ArcA_elem0_errv_BALL_C1_MD_testY

Max. per−axis orbit with combined error−monitor probability



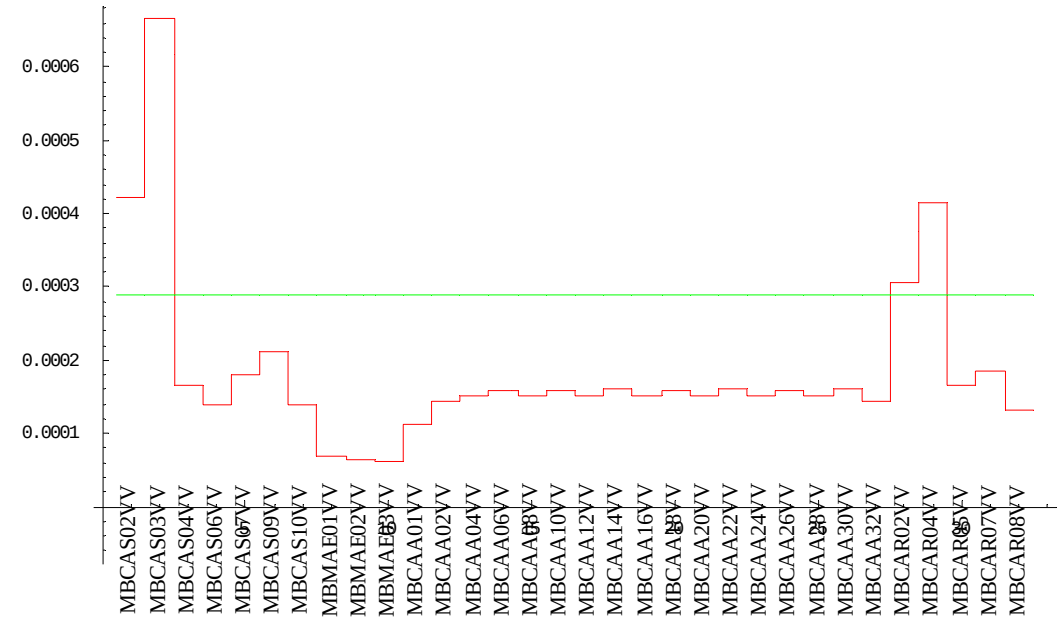
File used:

Arc6_elem0_errv_BALL_CALL_CD_testY

Corrector Strengths Needed for 3σ Error with Unlimited Monitoring Power in Y

ArcA_elem0_errv_BALL_C1_CD_testY

Max. corr. strength needed with unlimited monitoring power



Fundamental Uncorrectable Orbit at all BPMs due to 3σ Error in Y

ArcA_elem0_errv_BALL_C1_CD_testY

Max. per−BPM uncorrectable orbit proj.