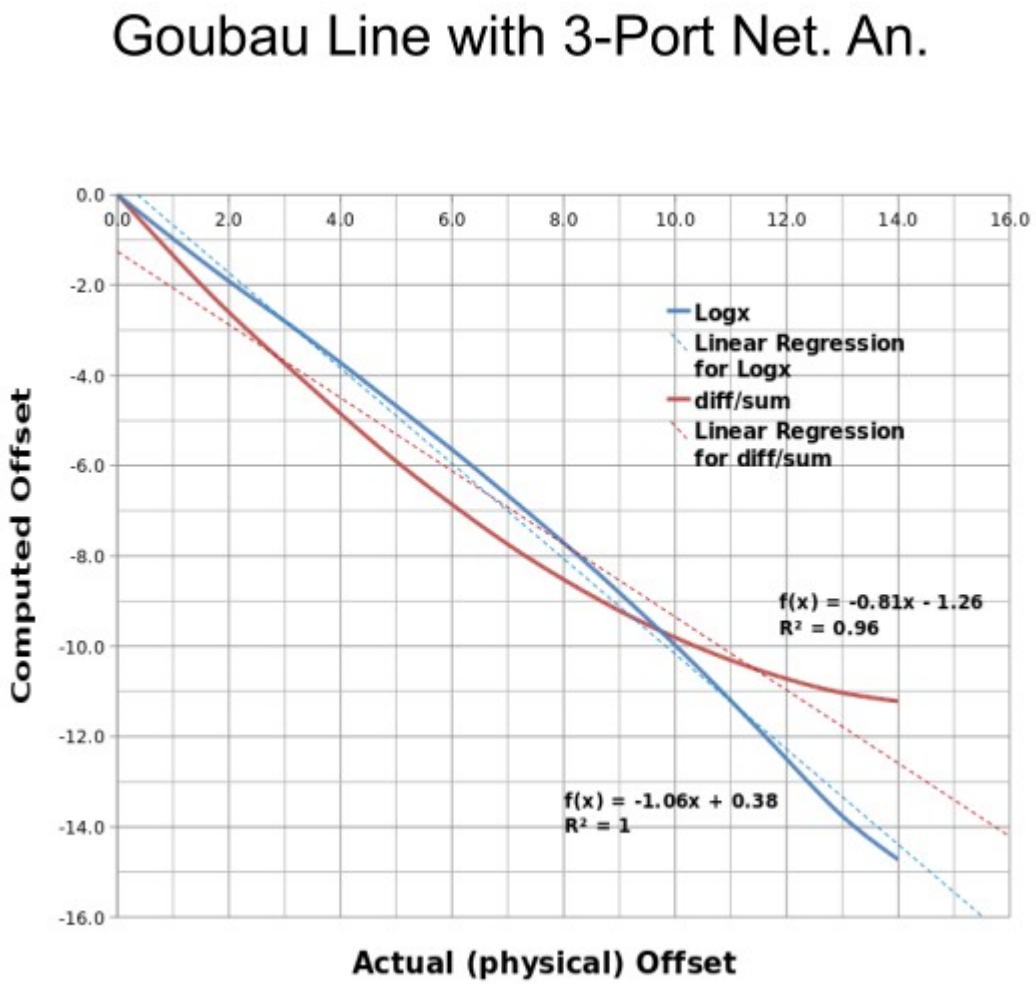
BPM accuracy

Jay Benesch

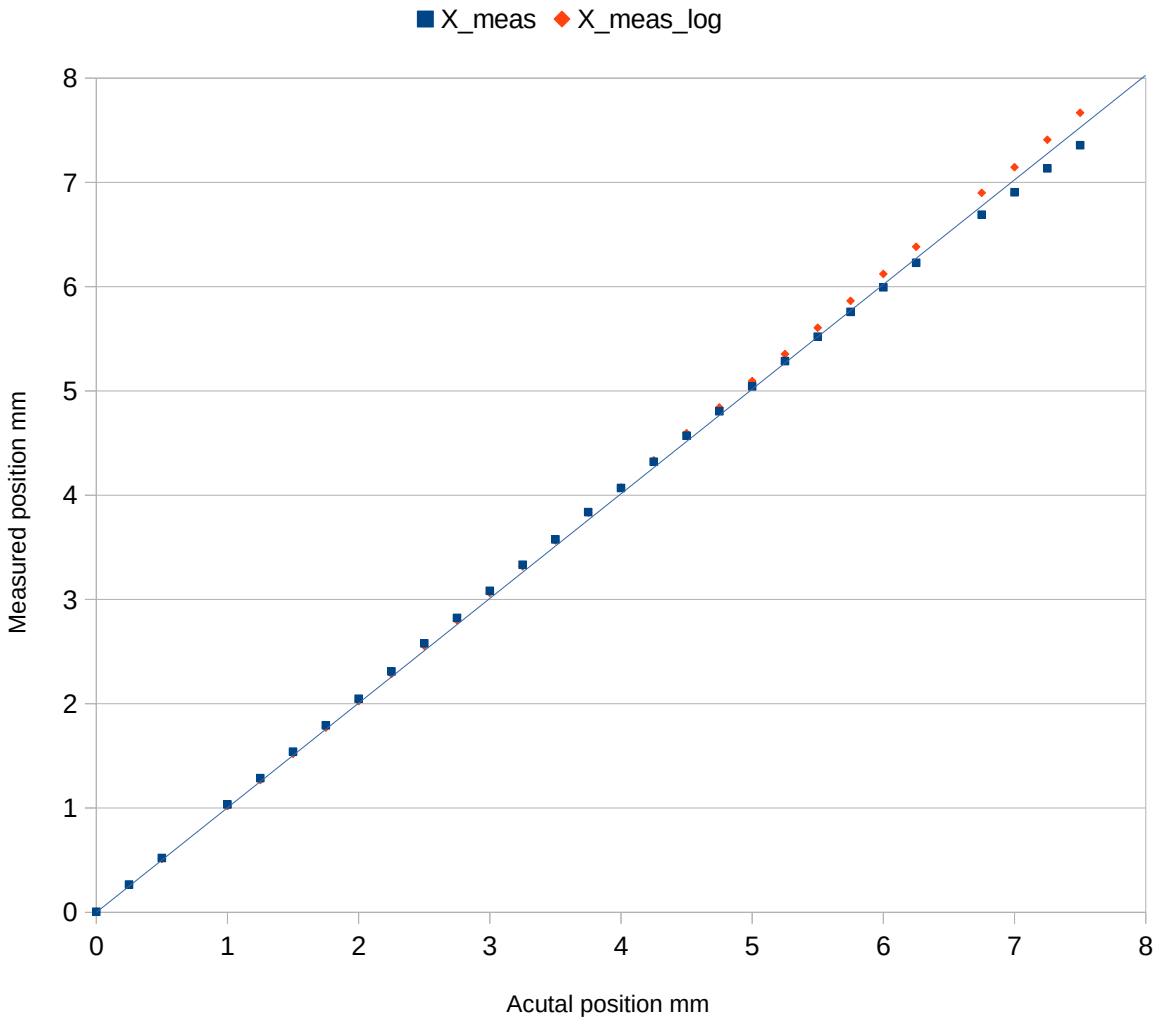
3 October 2024

Why I asked for John Musson's talk



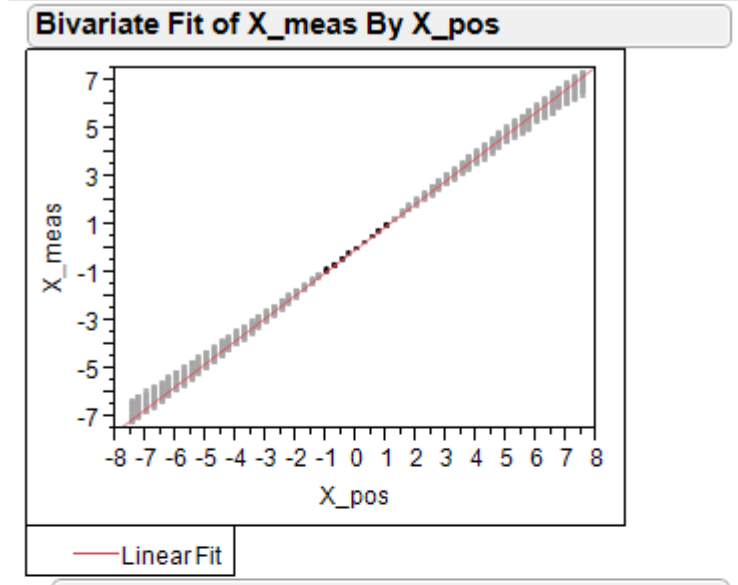
This plot shows the diff/sum algorithm is far less accurate than the logX algorithm. 7 mm computed vs 6 mm actual, for instance. 2012 data, perhaps clamped at (0,0) and (10,10)

More recent data, plotted by me



Diagonal applied by hand. Residuals = measured-actual, are small.
Most plots that follow are of residuals. X_meas = diff/sum algorithm

Full span of X data

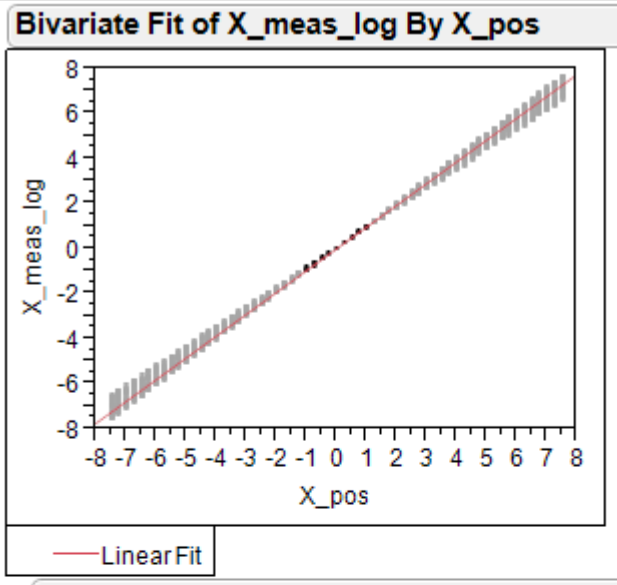


Linear Fit

X_meas = 0.0172474 + 0.9514854*X_pos

Summary of Fit

RSquare	0.997983
RSquare Adj	0.997982
Root Mean Square Error	0.188356
Mean of Response	0.017247
Observations (or Sum Wgts)	3721



Linear Fit

X_meas_log = 0.0181101 + 0.9672984*X_pos

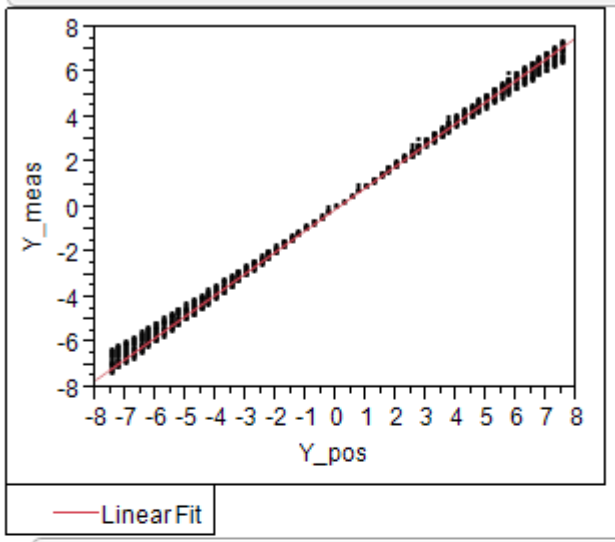
Summary of Fit

RSquare	0.997921
RSquare Adj	0.99792
Root Mean Square Error	0.19439
Mean of Response	0.01811
Observations (or Sum Wgts)	3721

For all Y in [-7.5, 7.5] mm

Full span of Y data

Bivariate Fit of Y_meas By Y_pos



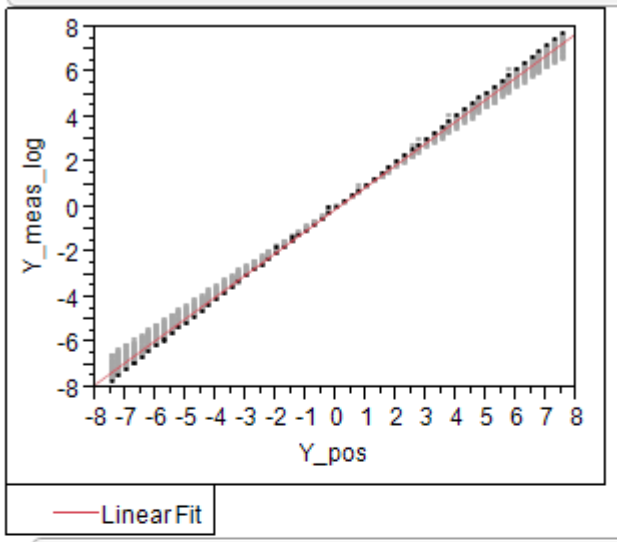
Linear Fit

Y_meas = -0.00765 + 0.9513095*Y_pos

Summary of Fit

RSquare	0.997938
RSquare Adj	0.997937
Root Mean Square Error	0.190387
Mean of Response	-0.00912
Observations (or Sum Wgts)	3721

Bivariate Fit of Y_meas_log By Y_pos



Linear Fit

Y_meas_log = -0.008137 + 0.9736574*Y_pos

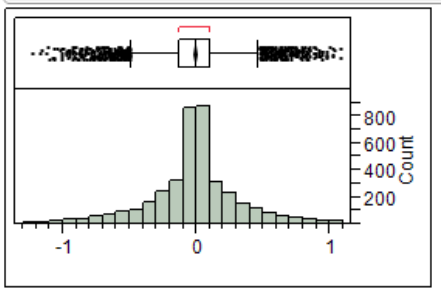
Summary of Fit

RSquare	0.997845
RSquare Adj	0.997844
Root Mean Square Error	0.199219
Mean of Response	-0.00964
Observations (or Sum Wgts)	3721

For all X in [-7.5, 7.5] mm

Residuals with encoder wire positions

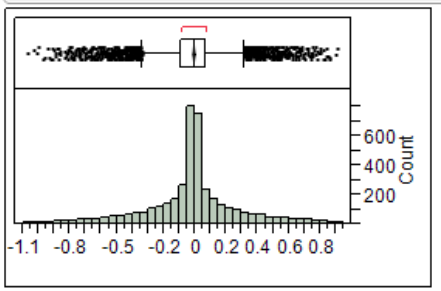
X_resid



Quantiles		
100.0%	maximum	1.082
99.5%		0.92
97.5%		0.67475
90.0%		0.347
75.0%	quartile	0.108
50.0%	median	-0.003
25.0%	quartile	-0.1325
10.0%		-0.3868
2.5%		-0.735
0.5%		-0.9874
0.0%	minimum	-1.231

Moments	
Mean	-0.011651
Std Dev	0.3087173
Std Err Mean	0.0050609
Upper 95% Mean	-0.001729
Lower 95% Mean	-0.021574
N	3721

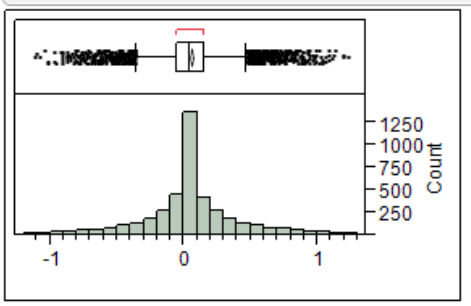
X_resid_log



Quantiles		
100.0%	maximum	0.907
99.5%		0.77873
97.5%		0.58095
90.0%		0.29
75.0%	quartile	0.072
50.0%	median	-0.003
25.0%	quartile	-0.092
10.0%		-0.3288
2.5%		-0.6379
0.5%		-0.8666
0.0%	minimum	-1.073

Moments	
Mean	-0.012294
Std Dev	0.2607493

Y_resid

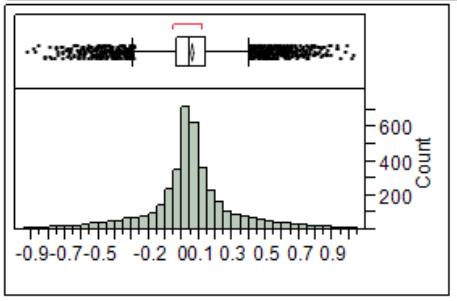


Quantiles		
100.0%	maximum	1.227
99.5%		0.99858
97.5%		0.75175
90.0%		0.4098
75.0%	quartile	0.158
50.0%	median	0.047
25.0%	quartile	-0.049
10.0%		-0.2898
2.5%		-0.625
0.5%		-0.8758
0.0%	minimum	-1.115

Moments	
Mean	0.05371
Std Dev	0.2971901
Std Err Mean	0.004872
Upper 95% Mean	0.063262
Lower 95% Mean	0.044158
N	3721

Full [-7.5,7.5] mm span,
both planes.

Y_resid_log

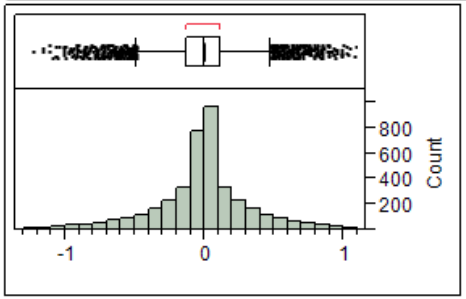


Quantiles		
100.0%	maximum	1.025
99.5%		0.83678
97.5%		0.62995
90.0%		0.334
75.0%	quartile	0.141
50.0%	median	0.049
25.0%	quartile	-0.033
10.0%		-0.203
2.5%		-0.492
0.5%		-0.7186
0.0%	minimum	-0.929

Moments	
Mean	0.0562239
Std Dev	0.2389693
Std Err Mean	0.0039175
Upper 95% Mean	0.0639046
Lower 95% Mean	0.0485431
N	3721

Residuals with John's adjusted zero

X_resid



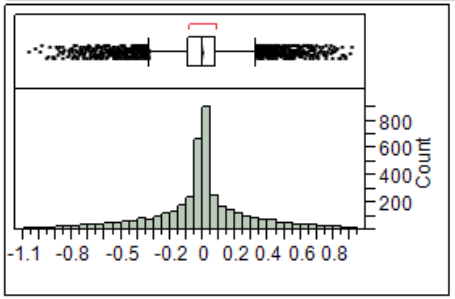
Quantiles

100.0%	maximum	1.088
99.5%		0.926
97.5%		0.68075
90.0%		0.353
75.0%	quartile	0.114
50.0%	median	0.003
25.0%	quartile	-0.1265
10.0%		-0.3808
2.5%		-0.729
0.5%		-0.9814
0.0%	minimum	-1.225

Moments

Mean	-0.005651
Std Dev	0.3087173
Std Err Mean	0.0050609
Upper 95% Mean	0.004271
Lower 95% Mean	-0.015574
N	3721

X_resid_log



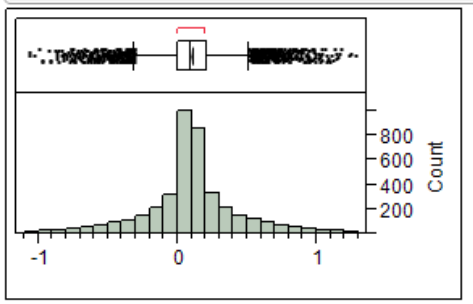
Quantiles

100.0%	maximum	0.913
99.5%		0.78473
97.5%		0.58695
90.0%		0.296
75.0%	quartile	0.078
50.0%	median	0.003
25.0%	quartile	-0.086
10.0%		-0.3228
2.5%		-0.6319
0.5%		-0.8606
0.0%	minimum	-1.067

Moments

Mean	-0.006294
Std Dev	0.2607493

Y_resid



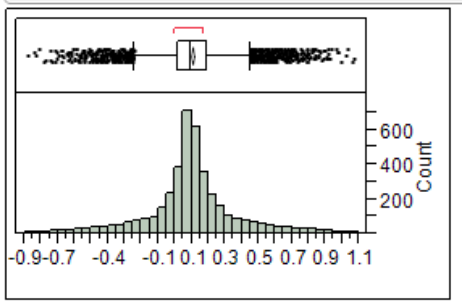
Quantiles

100.0%	maximum	1.275
99.5%		1.04658
97.5%		0.79975
90.0%		0.4578
75.0%	quartile	0.206
50.0%	median	0.095
25.0%	quartile	-0.001
10.0%		-0.2418
2.5%		-0.577
0.5%		-0.8278
0.0%	minimum	-1.067

Moments

Mean	0.10171
Std Dev	0.2971901
Std Err Mean	0.004872
Upper 95% Mean	0.111262
Lower 95% Mean	0.092158
N	3721

Y_resid_log



Quantiles

100.0%	maximum	1.073
99.5%		0.88478
97.5%		0.67795
90.0%		0.382
75.0%	quartile	0.189
50.0%	median	0.097
25.0%	quartile	0.015
10.0%		-0.155
2.5%		-0.444
0.5%		-0.6706
0.0%	minimum	-0.881

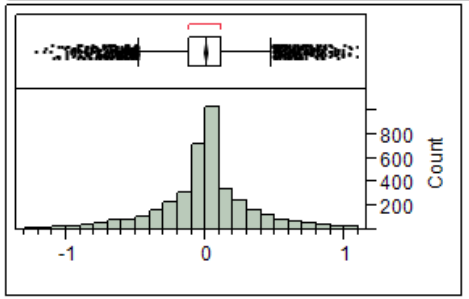
Moments

Mean	0.1042239
Std Dev	0.2389693
Std Err Mean	0.0039175
Upper 95% Mean	0.1119046
Lower 95% Mean	0.0965431
N	3721

Full [-7.5,7.5] mm span, both planes.

Residuals with zero adjusted to zero their means

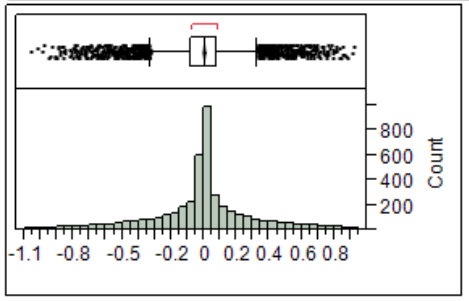
X_resid



Quantiles		
100.0%	maximum	1.093
99.5%		0.931
97.5%		0.68575
90.0%		0.358
75.0%	quartile	0.119
50.0%	median	0.008
25.0%	quartile	-0.1215
10.0%		-0.3758
2.5%		-0.724
0.5%		-0.9764
0.0%	minimum	-1.22

Moments	
Mean	-0.000651
Std Dev	0.3087173
Std Err Mean	0.0050609
Upper 95% Mean	0.009271
Lower 95% Mean	-0.010574
N	3721

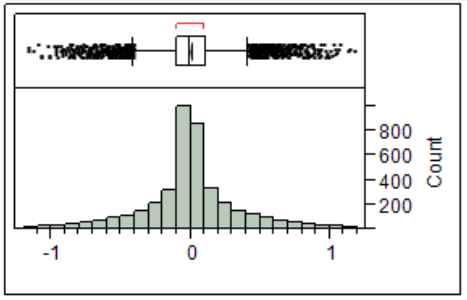
X_resid_log



Quantiles		
100.0%	maximum	0.918
99.5%		0.78973
97.5%		0.59195
90.0%		0.301
75.0%	quartile	0.083
50.0%	median	0.008
25.0%	quartile	-0.081
10.0%		-0.3178
2.5%		-0.6269
0.5%		-0.8556
0.0%	minimum	-1.062

Moments	
Mean	-0.001294
Std Dev	0.2607493

Y_resid

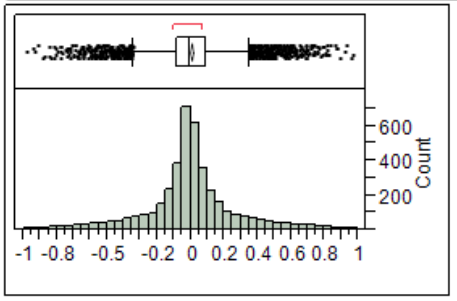


Quantiles		
100.0%	maximum	1.175
99.5%		0.94658
97.5%		0.69975
90.0%		0.3578
75.0%	quartile	0.106
50.0%	median	-0.005
25.0%	quartile	-0.101
10.0%		-0.3418
2.5%		-0.677
0.5%		-0.9278
0.0%	minimum	-1.167

Moments	
Mean	0.00171
Std Dev	0.2971901
Std Err Mean	0.004872
Upper 95% Mean	0.011262
Lower 95% Mean	-0.007842
N	3721

Full [-7.5,7.5] mm span, both planes.

Y_resid_log

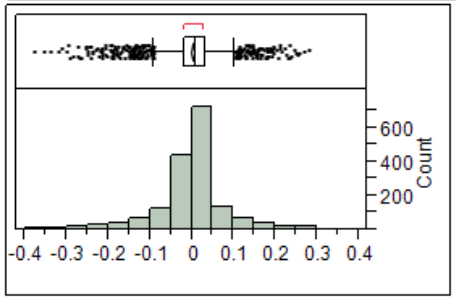


Quantiles		
100.0%	maximum	0.973
99.5%		0.78478
97.5%		0.57795
90.0%		0.282
75.0%	quartile	0.089
50.0%	median	-0.003
25.0%	quartile	-0.085
10.0%		-0.255
2.5%		-0.544
0.5%		-0.7706
0.0%	minimum	-0.981

Moments	
Mean	0.0042239
Std Dev	0.2389693
Std Err Mean	0.0039175
Upper 95% Mean	0.0119046
Lower 95% Mean	-0.003457
N	3721

Residuals [-5,5] span adjusted near-zero mean

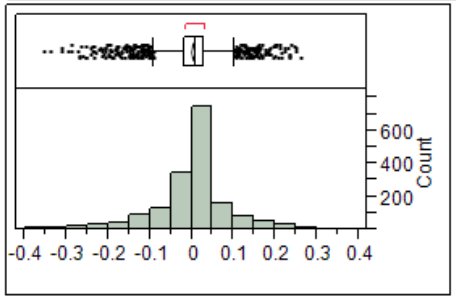
X_resid



Quantiles		
100.0%	maximum	0.281
99.5%		0.23698
97.5%		0.16497
90.0%		0.0759
75.0%	quartile	0.031
50.0%	median	0.008
25.0%	quartile	-0.017
10.0%		-0.0829
2.5%		-0.192
0.5%		-0.291
0.0%	minimum	-0.378

Moments	
Mean	0.0022887
Std Dev	0.075312
Std Err Mean	0.0018828
Upper 95% Mean	0.0059818
Lower 95% Mean	-0.001404
N	1600

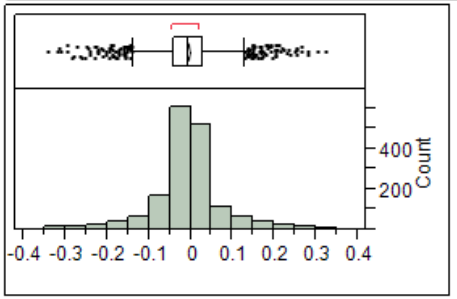
X_resid_log



Quantiles		
100.0%	maximum	0.261
99.5%		0.23298
97.5%		0.16497
90.0%		0.086
75.0%	quartile	0.03
50.0%	median	0.009
25.0%	quartile	-0.018
10.0%		-0.088
2.5%		-0.196
0.5%		-0.273
0.0%	minimum	-0.352

Moments	
Mean	0.0032238
Std Dev	0.0770462

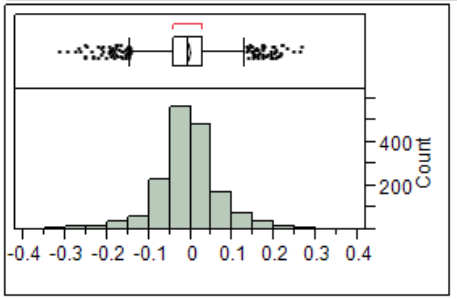
Y_resid



Quantiles		
100.0%	maximum	0.321
99.5%		0.253
97.5%		0.1769
90.0%		0.075
75.0%	quartile	0.028
50.0%	median	-0.007
25.0%	quartile	-0.039
10.0%		-0.075
2.5%		-0.18
0.5%		-0.2819
0.0%	minimum	-0.343

Moments	
Mean	-0.004304
Std Dev	0.0752493
Std Err Mean	0.0018812
Upper 95% Mean	-0.000614
Lower 95% Mean	-0.007994
N	1600

Y_resid_log

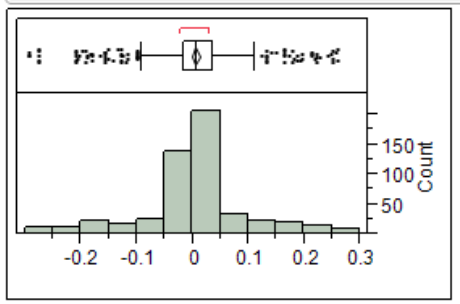


Quantiles		
100.0%	maximum	0.263
99.5%		0.21399
97.5%		0.15397
90.0%		0.073
75.0%	quartile	0.029
50.0%	median	-0.007
25.0%	quartile	-0.04
10.0%		-0.0789
2.5%		-0.164
0.5%		-0.252
0.0%	minimum	-0.314

Moments	
Mean	-0.005452
Std Dev	0.0700914
Std Err Mean	0.0017523
Upper 95% Mean	-0.002015
Lower 95% Mean	-0.008889
N	1600

X residuals with Y=[-1,1] mm

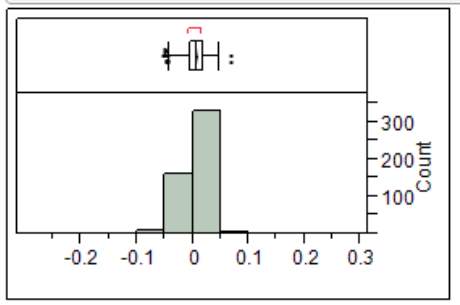
X_resid



Quantiles		
100.0%	maximum	0.259
99.5%		0.25811
97.5%		0.22155
90.0%		0.104
75.0%	quartile	0.037
50.0%	median	0.007
25.0%	quartile	-0.017
10.0%		-0.1
2.5%		-0.21
0.5%		-0.295
0.0%	minimum	-0.295

Moments	
Mean	0.005748
Std Dev	0.0895685
Std Err Mean	0.0040546
Upper 95% Mean	0.0137146
Lower 95% Mean	-0.002219
N	488

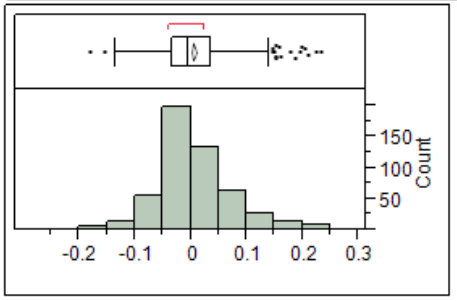
X_resid_log



Quantiles		
100.0%	maximum	0.069
99.5%		0.05966
97.5%		0.043
90.0%		0.03
75.0%	quartile	0.019
50.0%	median	0.007
25.0%	quartile	-0.005
10.0%		-0.028
2.5%		-0.041
0.5%		-0.051
0.0%	minimum	-0.053

Moments	
Mean	0.0052295
Std Dev	0.0212106

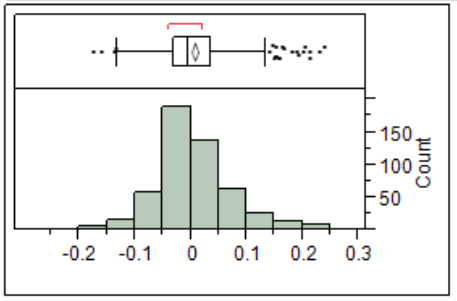
Y_resid



Quantiles		
100.0%	maximum	0.232
99.5%		0.21777
97.5%		0.152
90.0%		0.0881
75.0%	quartile	0.037
50.0%	median	-0.0055
25.0%	quartile	-0.0348
10.0%		-0.054
2.5%		-0.1016
0.5%		-0.1462
0.0%	minimum	-0.18

Moments	
Mean	0.0056701
Std Dev	0.0616051
Std Err Mean	0.0027887
Upper 95% Mean	0.0111495
Lower 95% Mean	0.0001907
N	488

Y_resid_log



Quantiles		
100.0%	maximum	0.238
99.5%		0.22288
97.5%		0.15855
90.0%		0.09
75.0%	quartile	0.03675
50.0%	median	-0.004
25.0%	quartile	-0.031
10.0%		-0.0562
2.5%		-0.1058
0.5%		-0.1518
0.0%	minimum	-0.175

Moments	
Mean	0.0062152
Std Dev	0.0627166
Std Err Mean	0.002839
Upper 95% Mean	0.0117935
Lower 95% Mean	0.0006369
N	488

Full [-7.5,7.5] mm span in X plane.
Residuals are subset of those adjusted to have near-zero mean.

Conclusions

- John's presentation spoke to resolution as a function of beam current and showed that 100 μm resolution is obtained around 100 nA beam current within [-5,5] mm span in both planes.
- The G-line data shown here demonstrates that either algorithm provides 100 μm accuracy at only ~80% of points within that span for M15 can.
- John will scan a M20 can, used at extraction, at my request. It will be interesting to compare those results with the previous figure.