Unified Spatial Metrology Network

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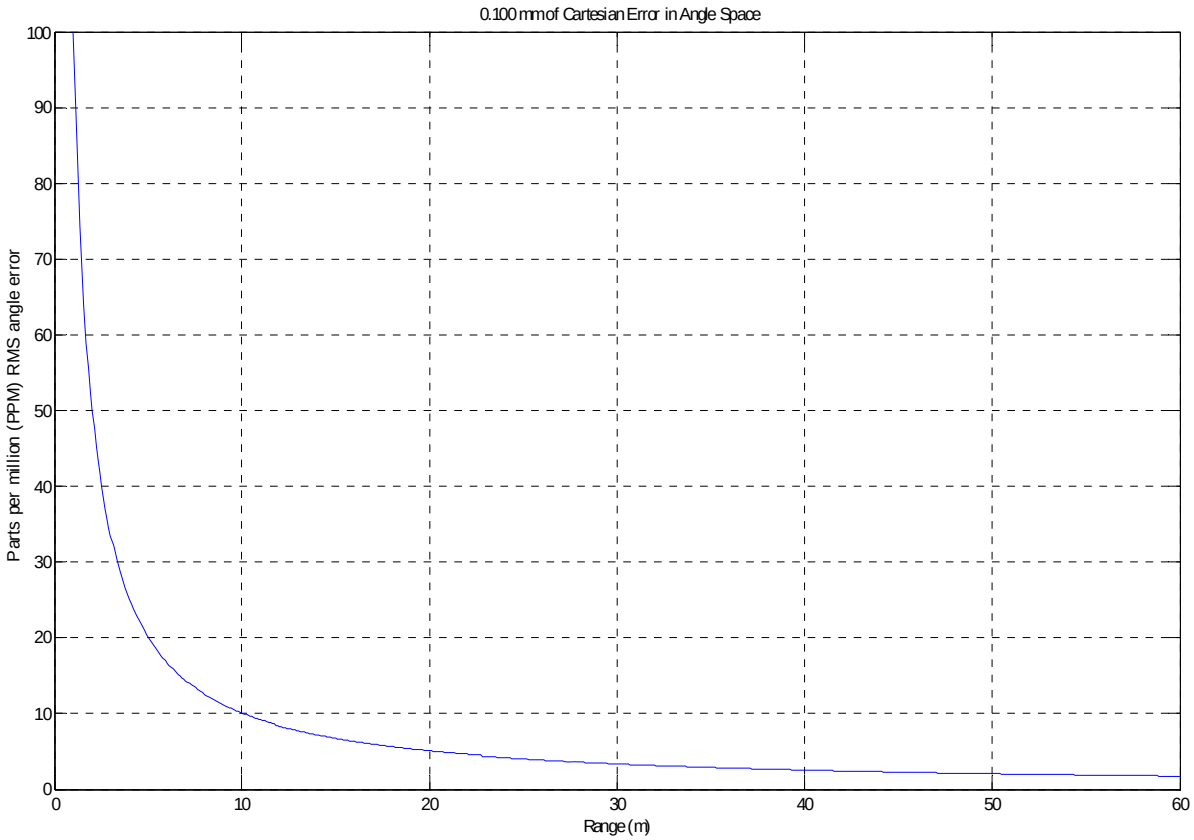
Unified Spatial Metrology Network (Developed by New River Kinematics)

- Spherical Coordinate Uncertainty
- Best Fit in Cartesian vs. Spherical Space Simulation
- USMN Goals
- SA Best Fit vs. USMN Simulation & Results
- USMN Network Measurement Uncertainty
- Checking Instrument Operation
- USMN Considerations

Cartesian uncertainty in Spherical/Polar coordinates

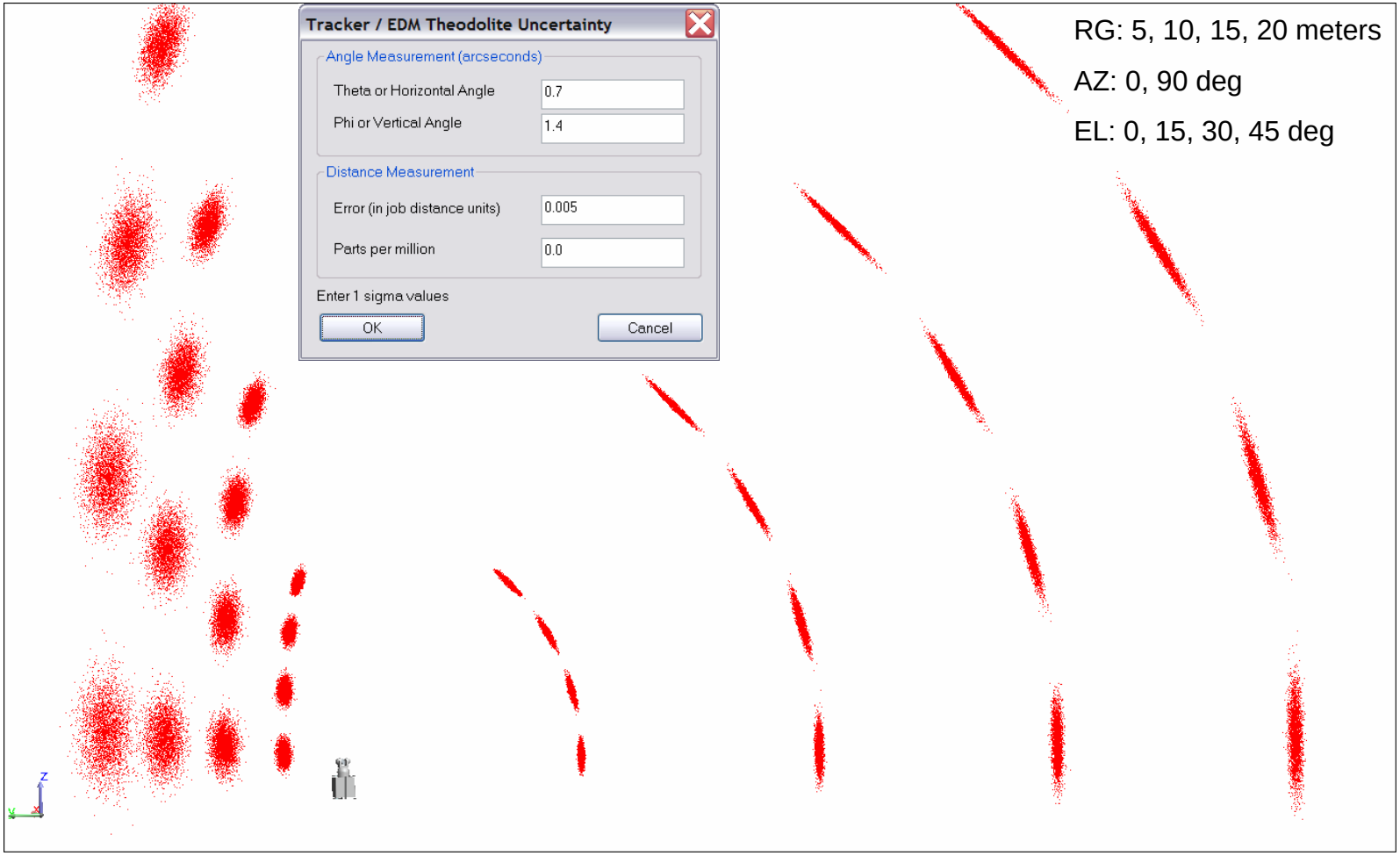
Question: What is the “goodness” of an instruments angle encoder that has 0.100 mm of RMS of residual error to 20 repeated measurements?

Answer: It depends on the range of the instrument to the measurand.



1 PPM = 1 μRad = 0.21 arc-sec = 0.057 mdeg

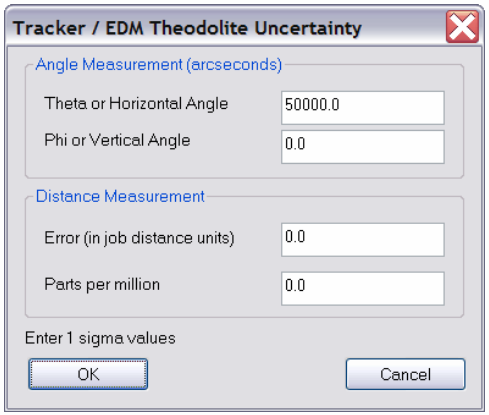
Spherical Coordinate Uncertainty



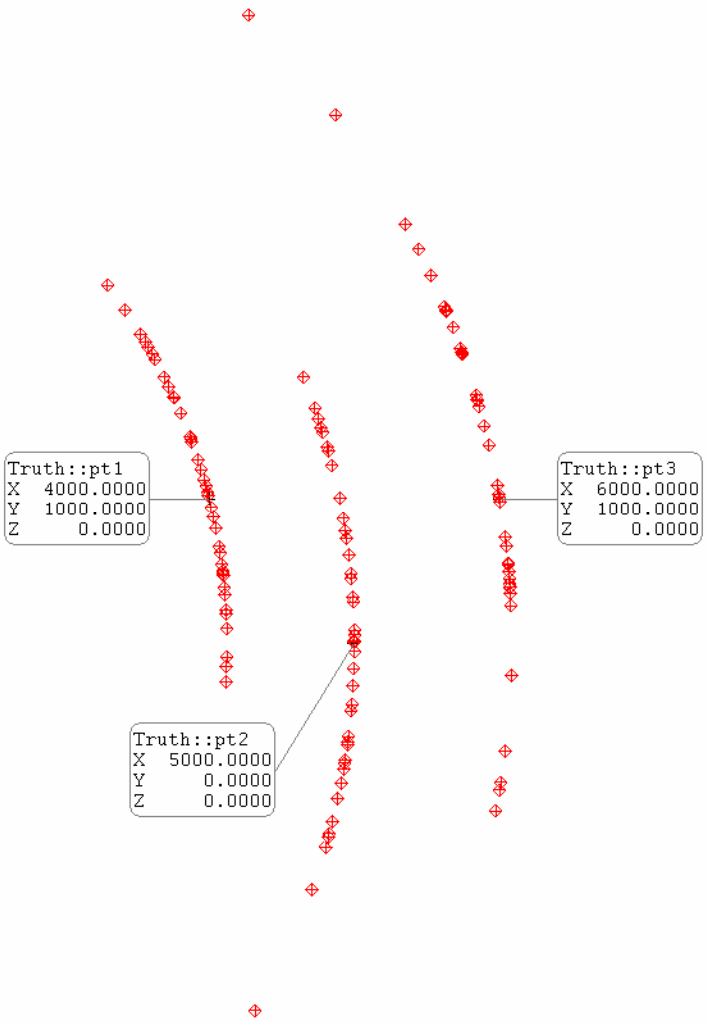
Constant spherical uncertainty ***is not constant*** in Cartesian space.
The uncertainty point cloud size & orientation changes in Cartesian space

Simulated Spherical Measurements

40 Simulated measurements for each of three ‘Truth’ points



Instrument: X:0, Y:0, Z:0



Cartesian & Spherical Best Fit Functions

For the 40 simulated measurements (for each of the three ‘Truth’ points)

- Cartesian Best Fit

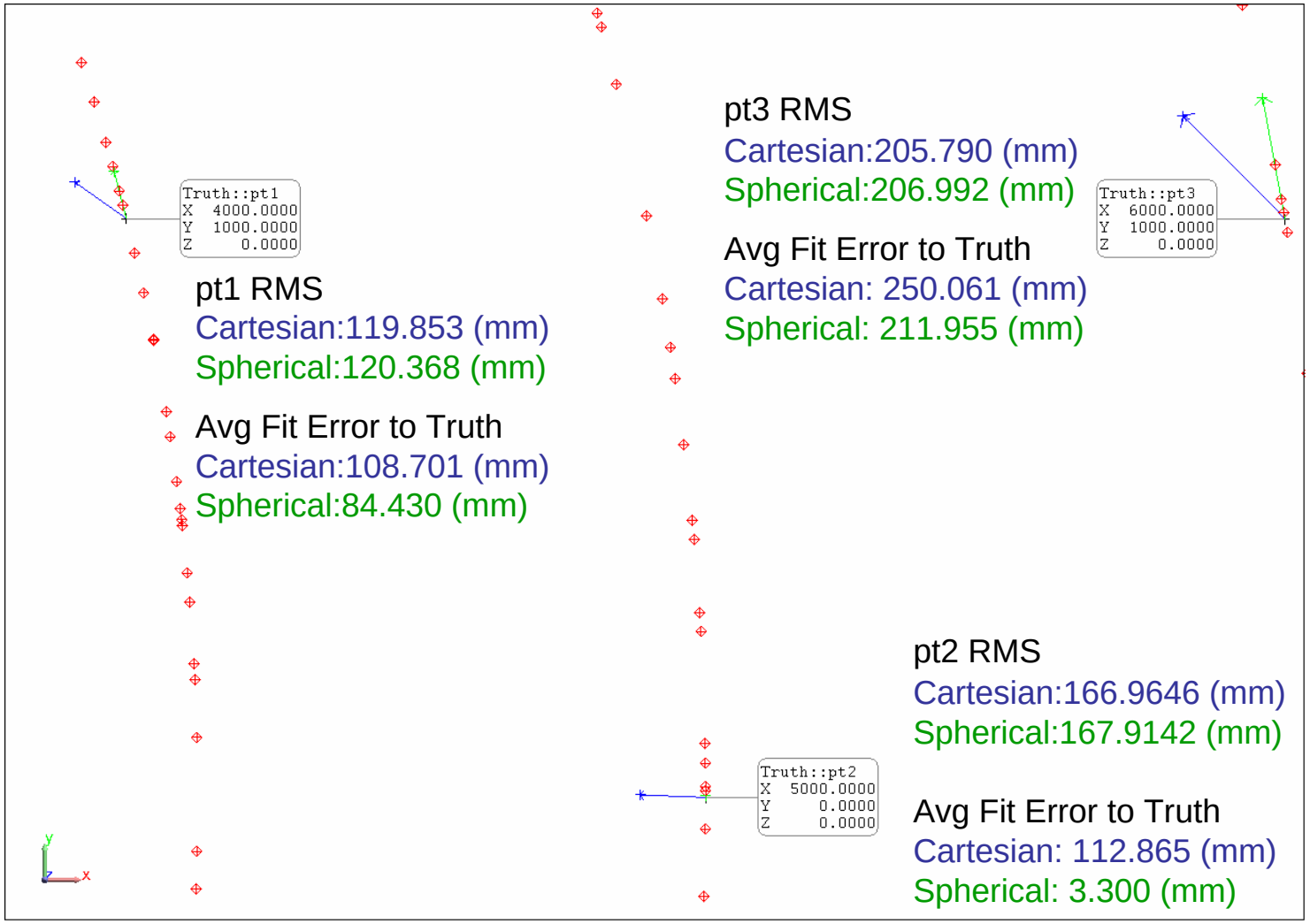
  XAvgC = mean(X(i)), YAvgC = mean(Y(i)), ZAvgC = mean(Z(i))

- Spherical Best Fit

  RgAvg = mean(Rg(i)), AzAvg = mean(Az(i)), ElAvg = mean(El(i))

  [XAvgS, YAvgS, ZAvgS] = Sph2CartCLR(RgAvg, AzAvg, ElAvg)

Cartesian vs. Spherical Best Fit Results



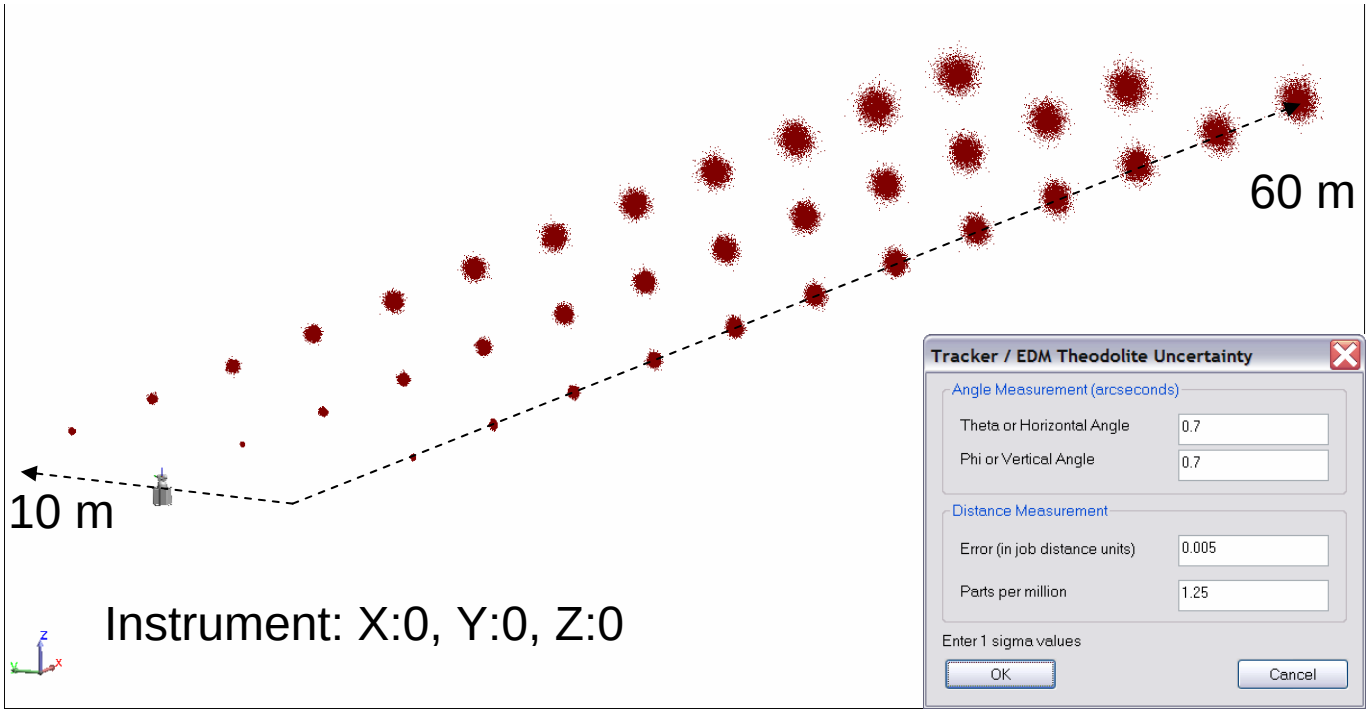
USMN Goals

To provide the best estimate of measured points in the global reference frame by employing *weighted* Least Squares solutions of all measurements *in each instruments own reference frame*

To provide a more accurate estimate of each measurements uncertainty based on the tie-in network topology
(can be completed before the job begins)

To provide an analysis of the working instruments total uncertainty in the working environment (during the job or for determining calibration)

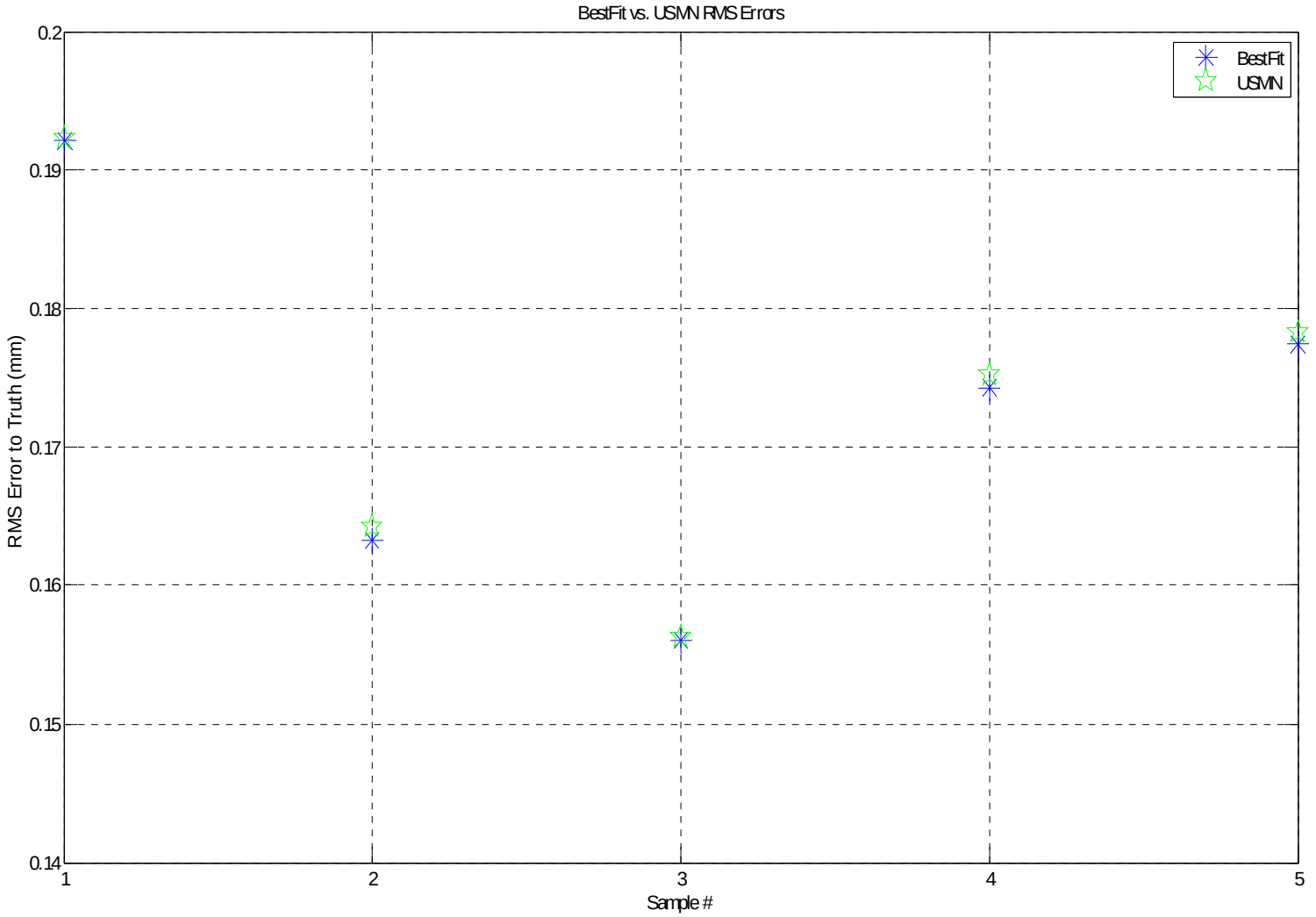
USMN vs. Best Fit Simulation



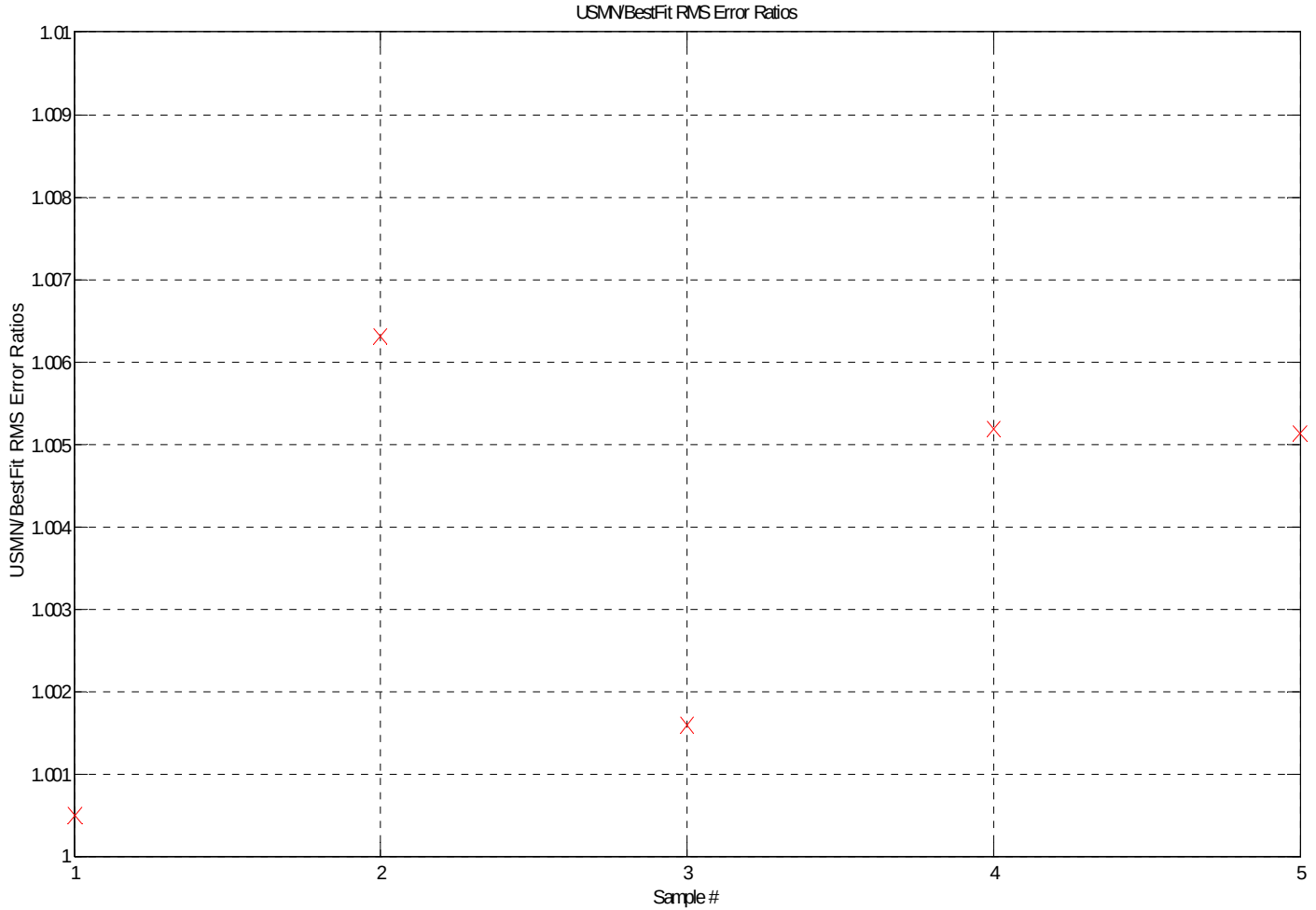
Simulate five separate measurement sets (with simulated errors) at 36 truth points spaced from five to sixty meters in range & ten meters wide.

Use Spatial Analyzer's Best-Fit & USMN to locate the instrument to the 'true' points and see how much error is introduced at the instruments location (translation & orientation) for each of the five measurement sets.

RMS Errors from True Points to Measurements after SA BestFit & USMN

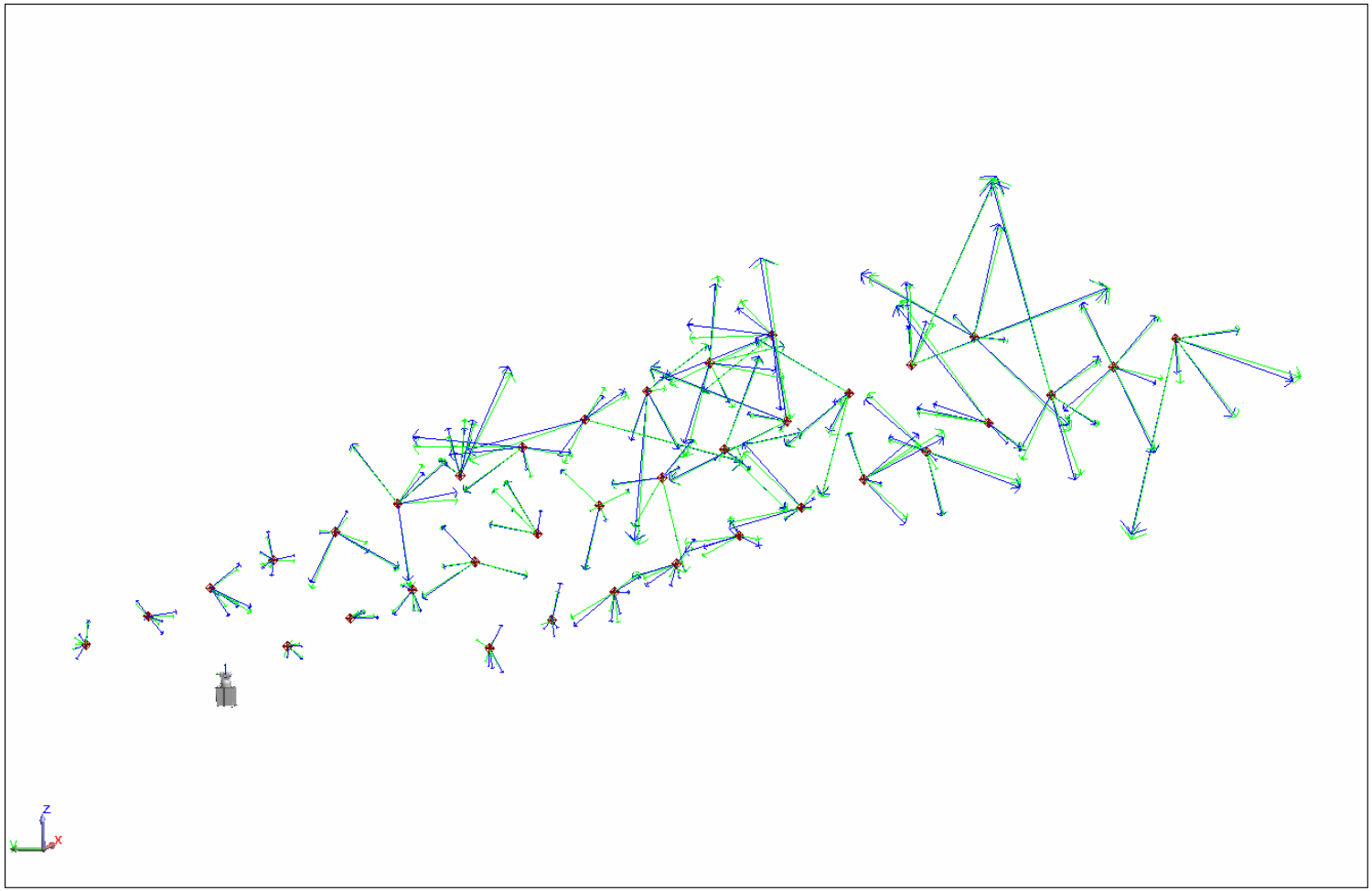


USMN/BestFit RMS Error Ratios

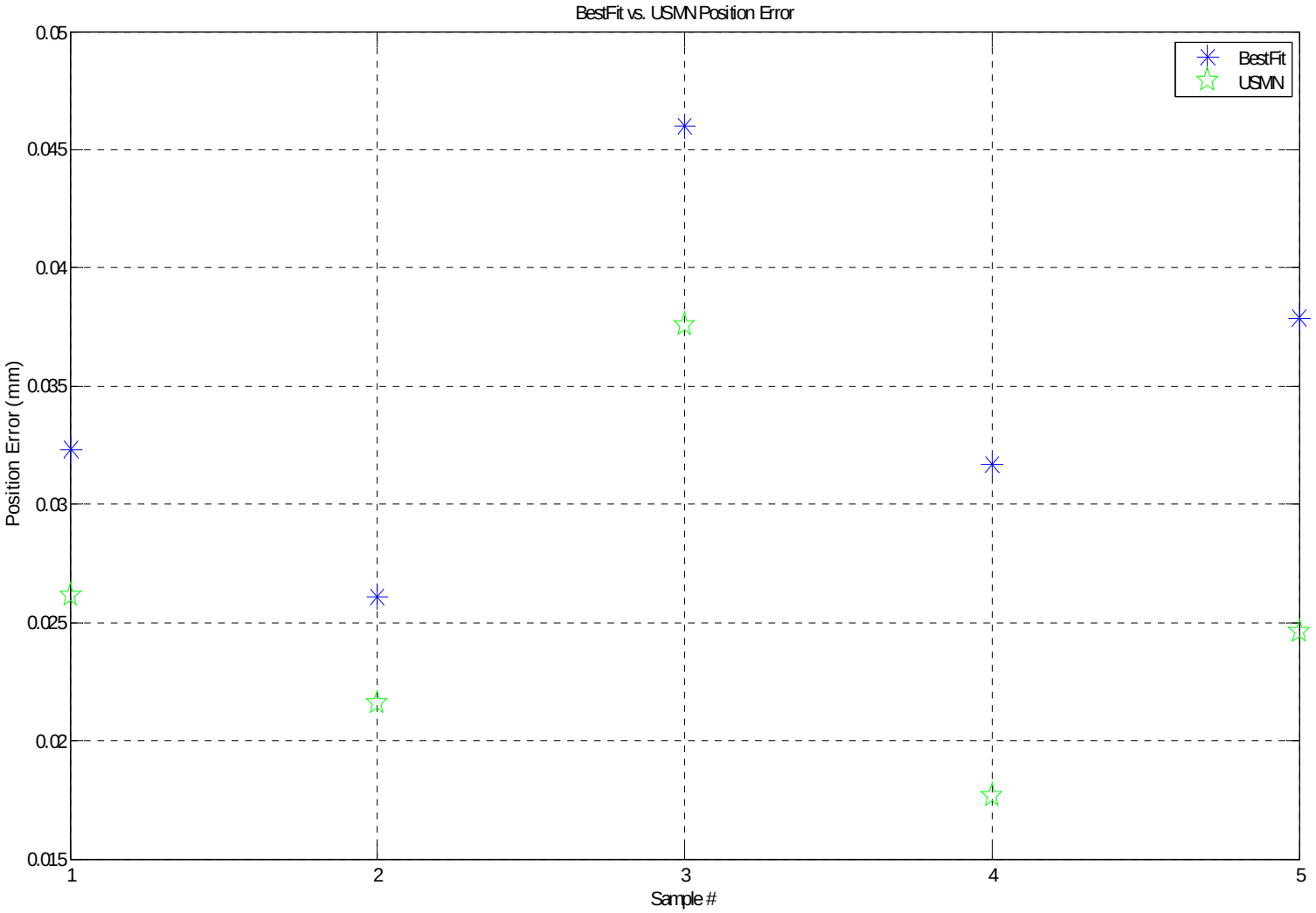


The USMN RMS error is ~0.04% Larger than the Best Fit RMS Error

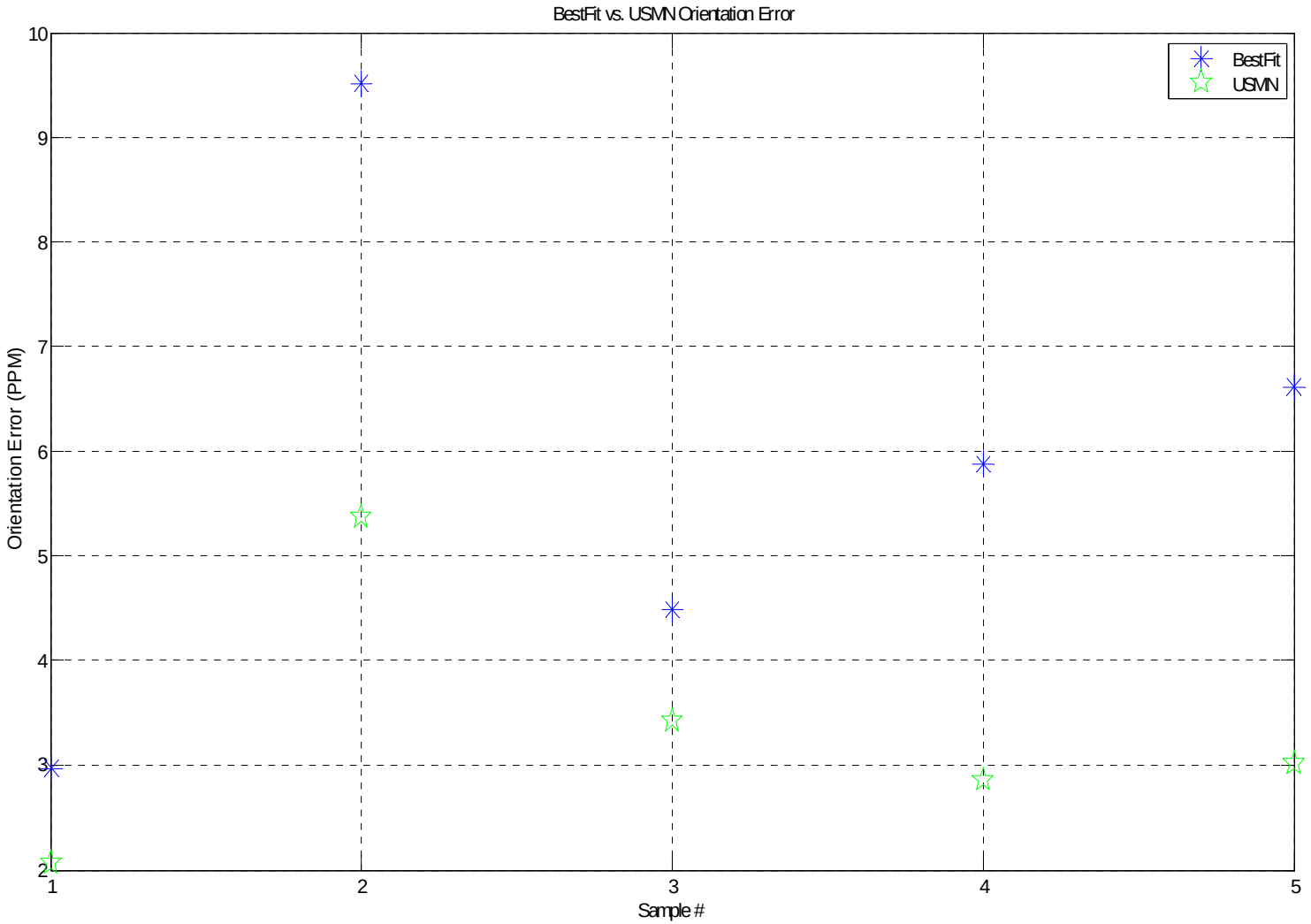
Vector Errors from True Points to Measurements after SA BestFit & USMN



Instrument Position Error

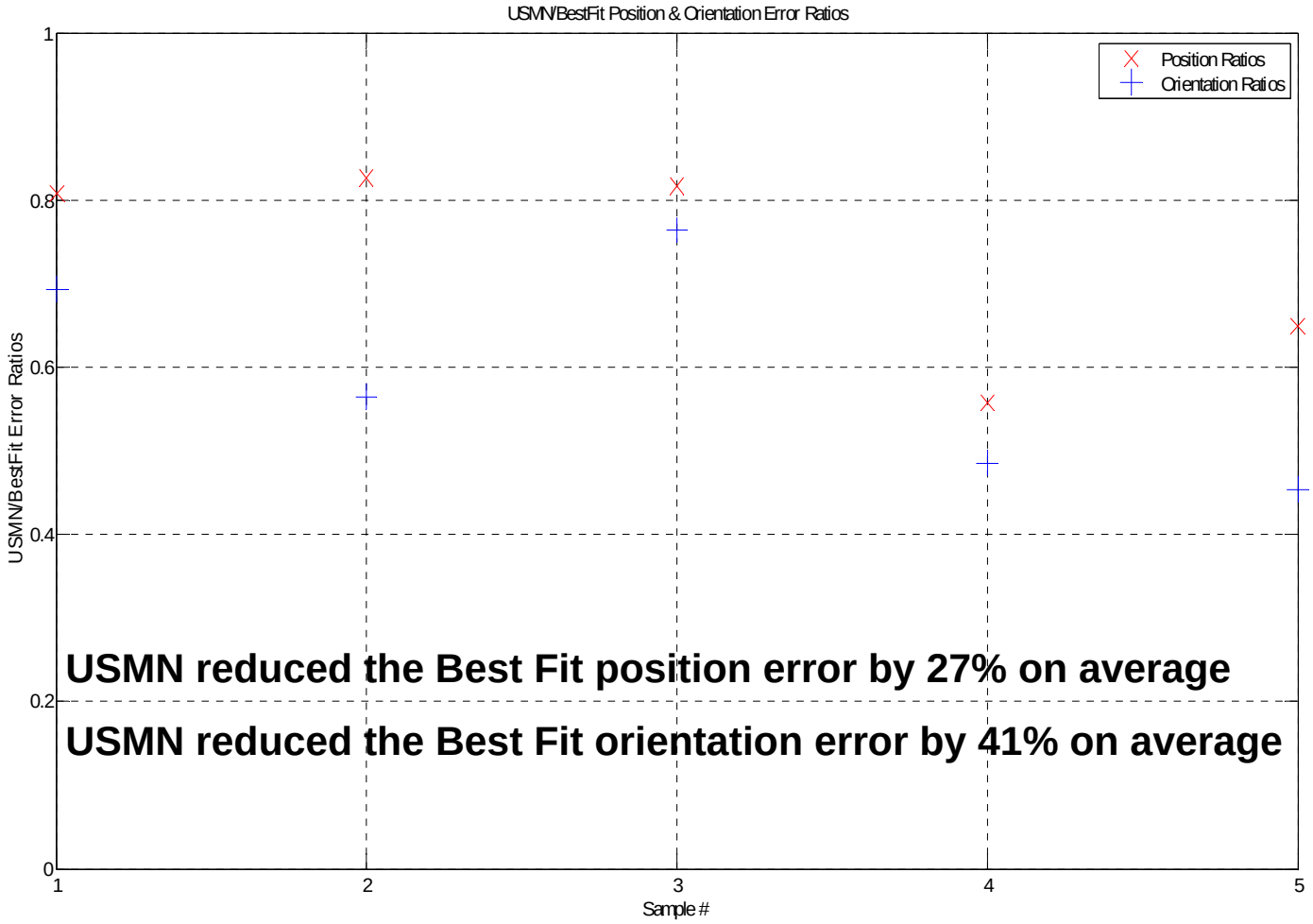


Instrument Orientation Error

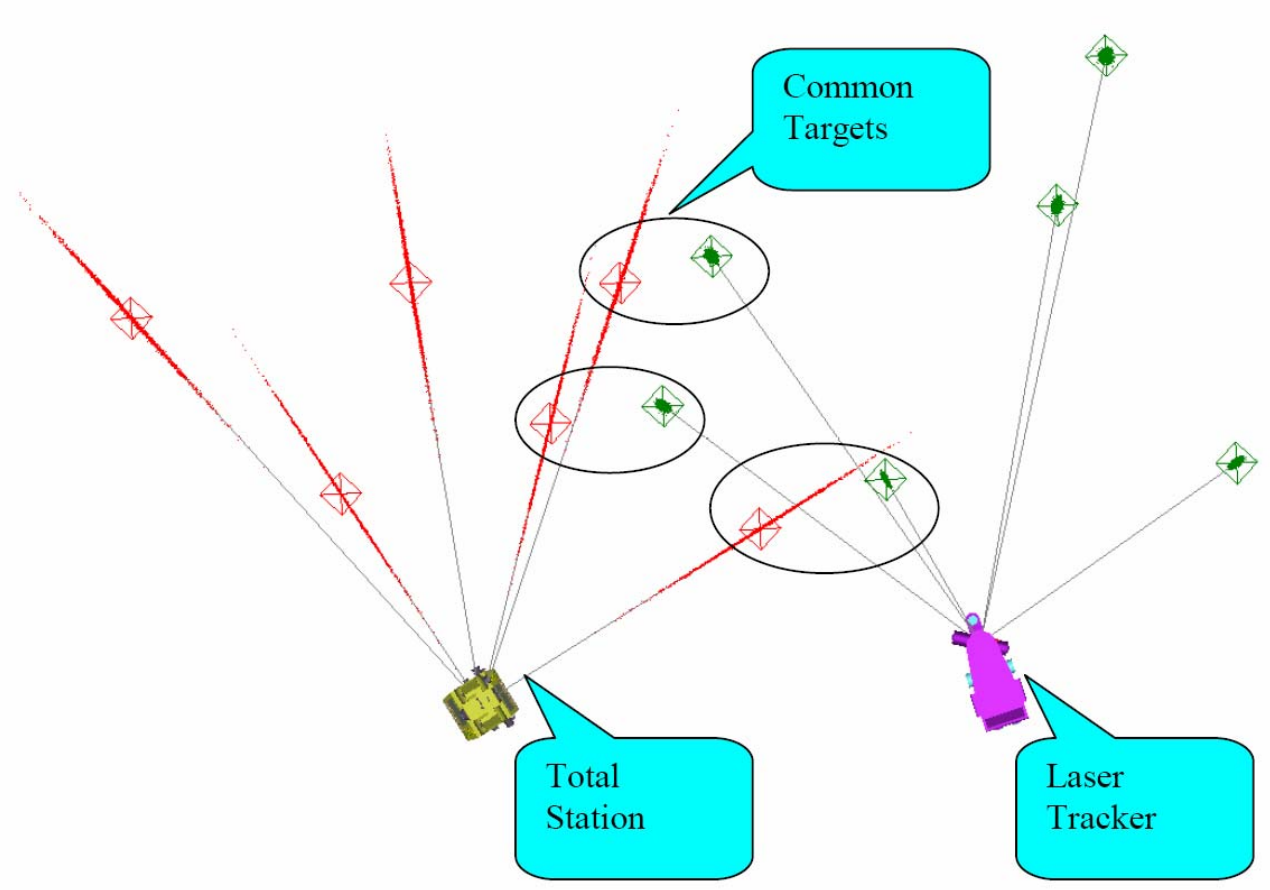


1 PPM = 1 µRad = 0.21 arc-sec = 0.057 mdeg

Instrument USMN/BestFit Position & Orientation Error Ratios

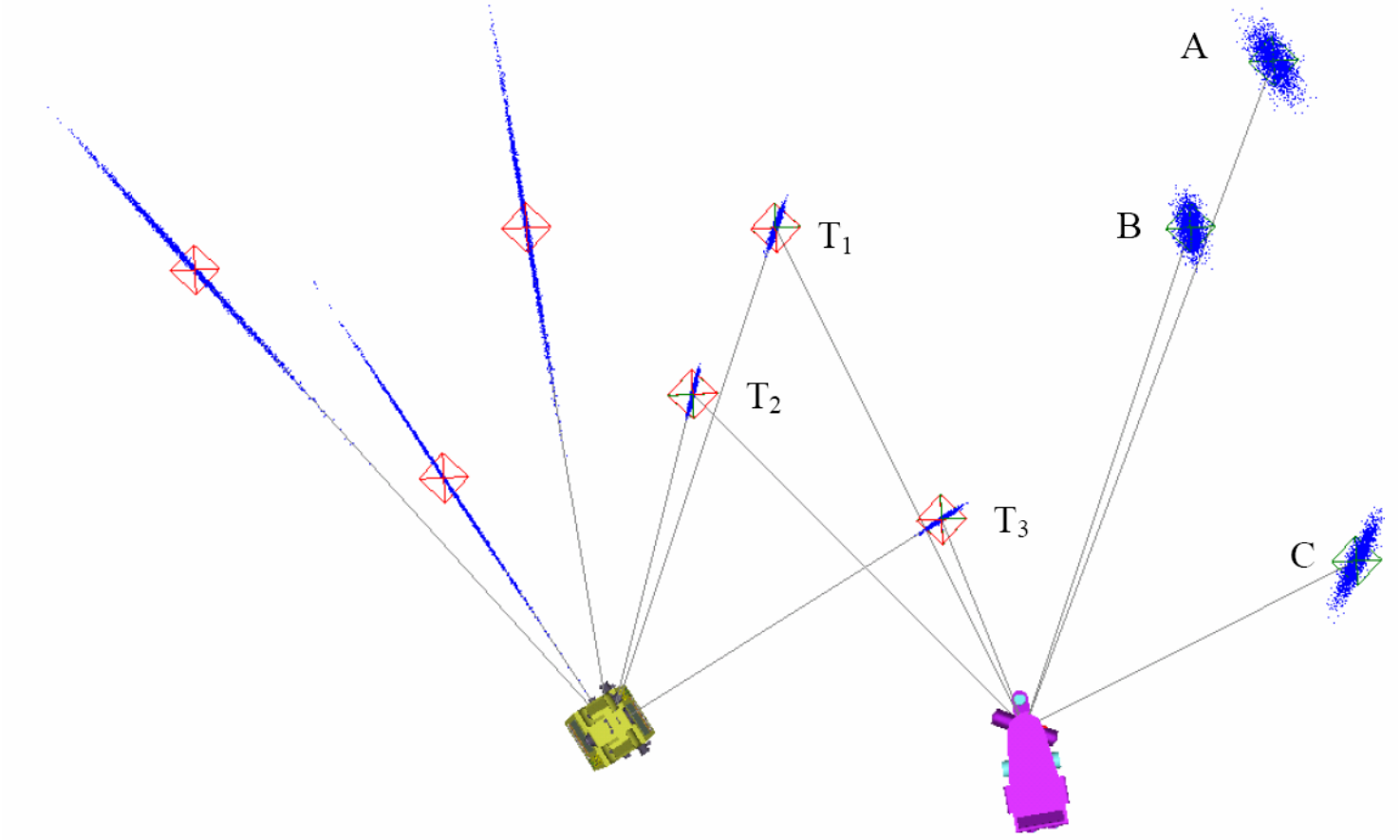


Uncertainty Clouds Before Tie-In



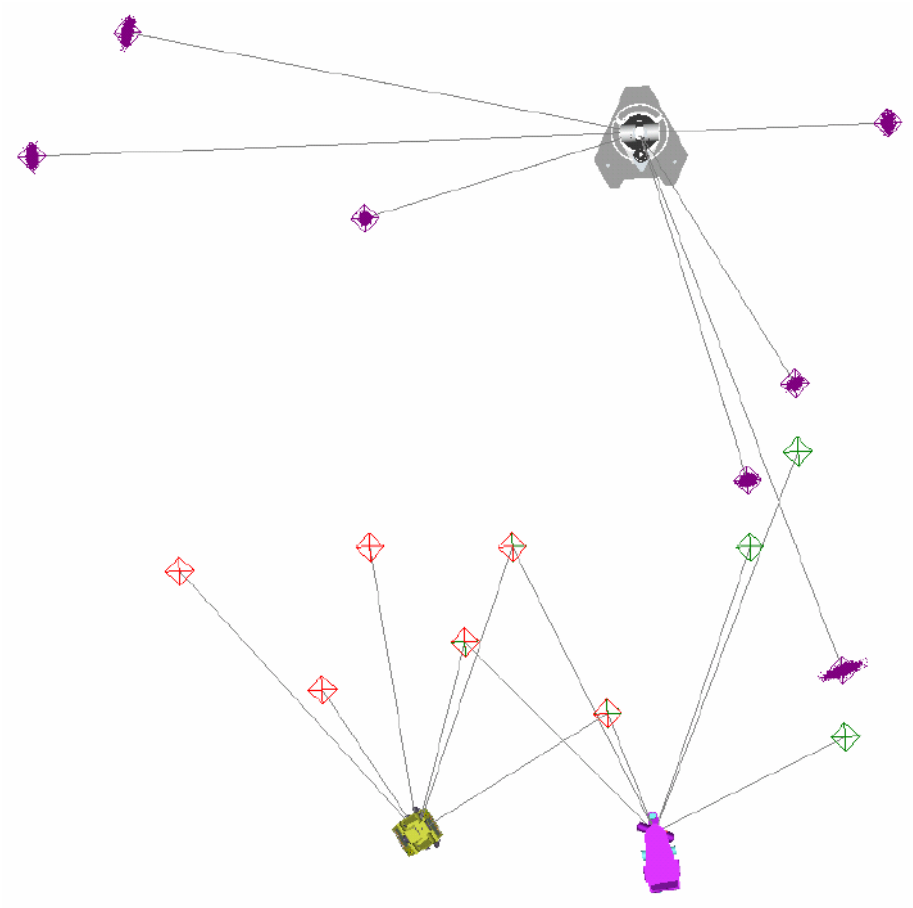
"SA USMN Manual.pdf": p101

Uncertainty Clouds after Tie-In



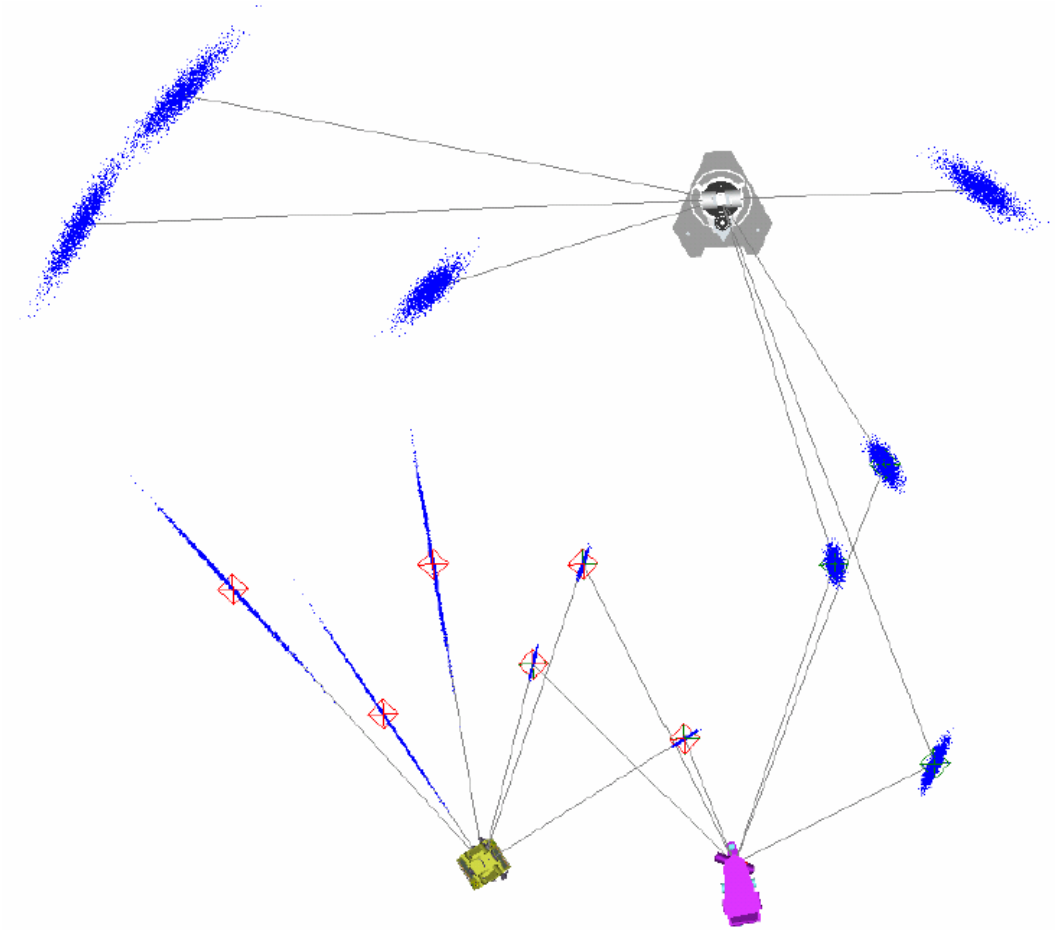
"SA USMN Manual.pdf": p103

New Instrument for Network Tie-In



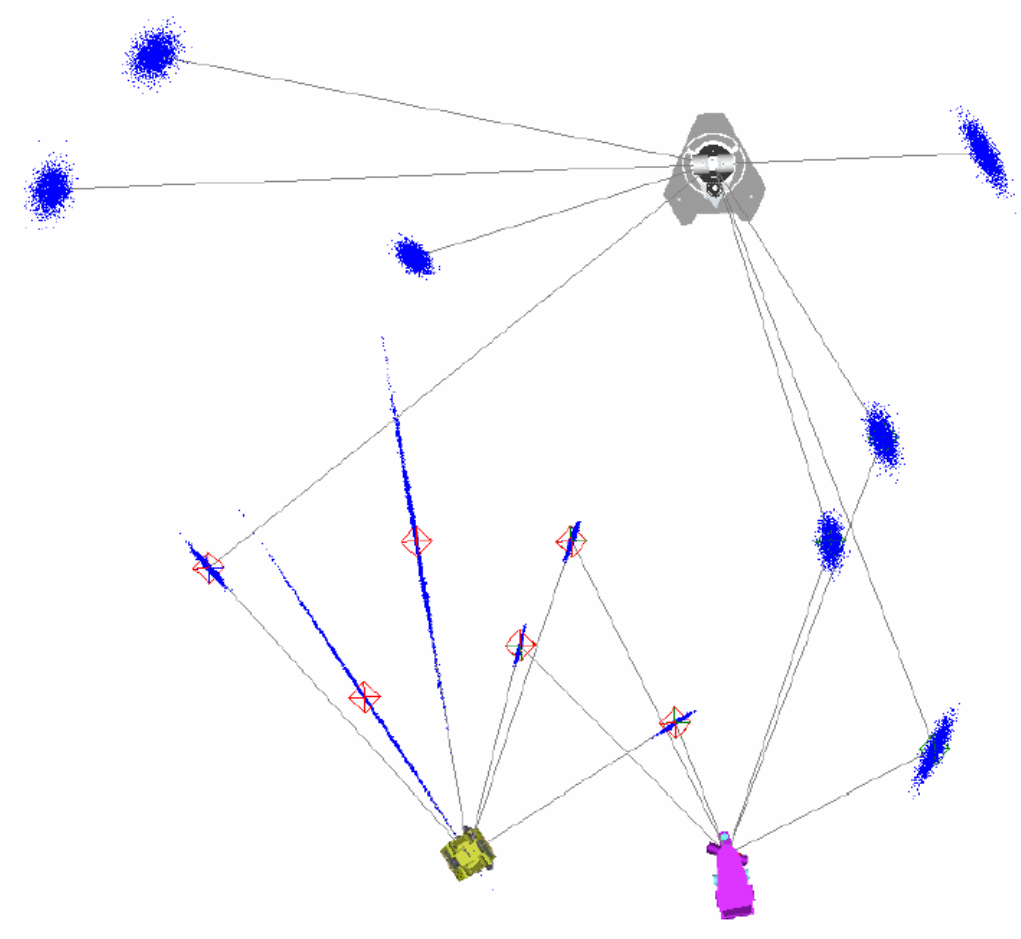
"SA USMN Manual.pdf": p105

New Uncertainty Clouds after New Instrument Tie-In



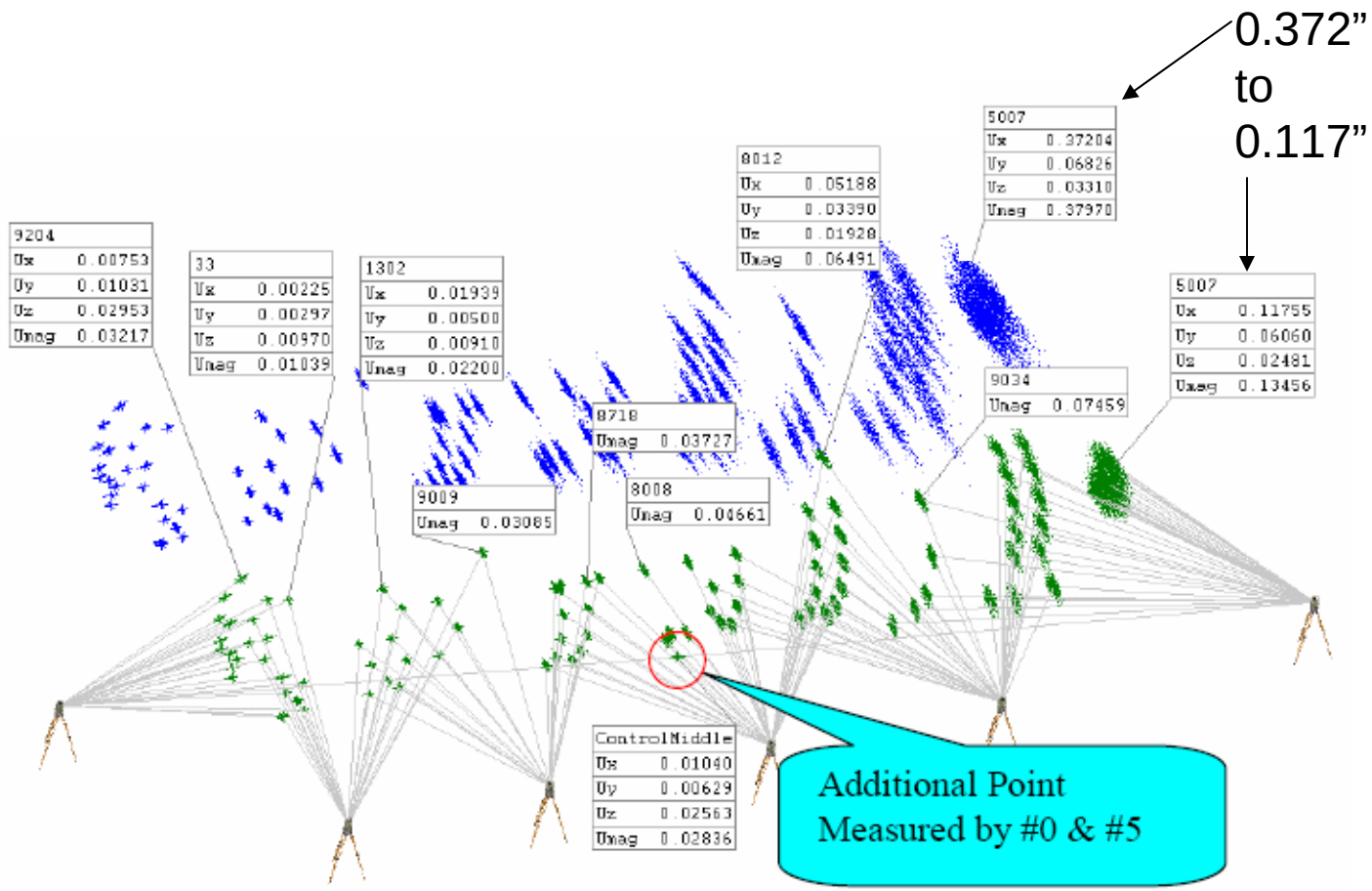
"SA USMN Manual.pdf": p106

New Instrument Tie-In back to Ground Greatly Reduces Network Uncertainty



"SA USMN Manual.pdf": p107

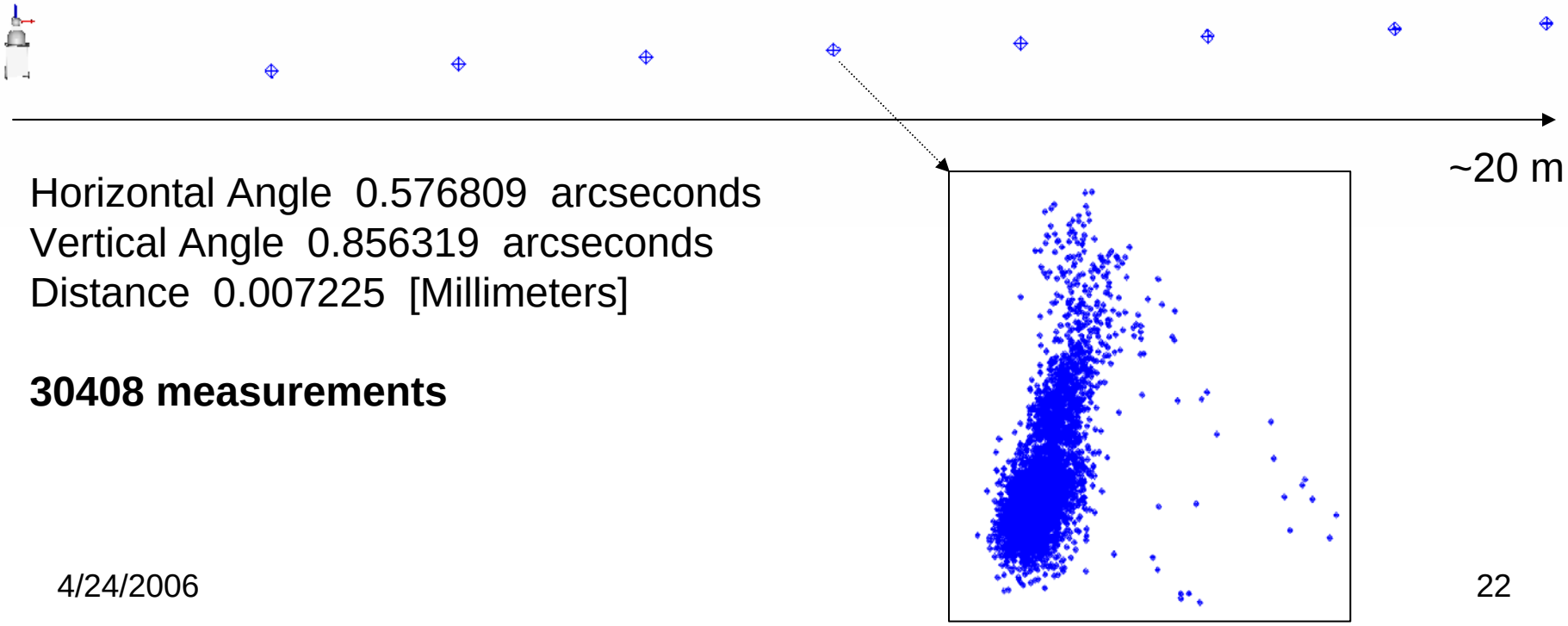
Steam Turbine Tie-in With Additional Grounding Point



“SA USMN Manual.pdf”: p171

Using USMN to Detect Motion on Repeatability Measurements

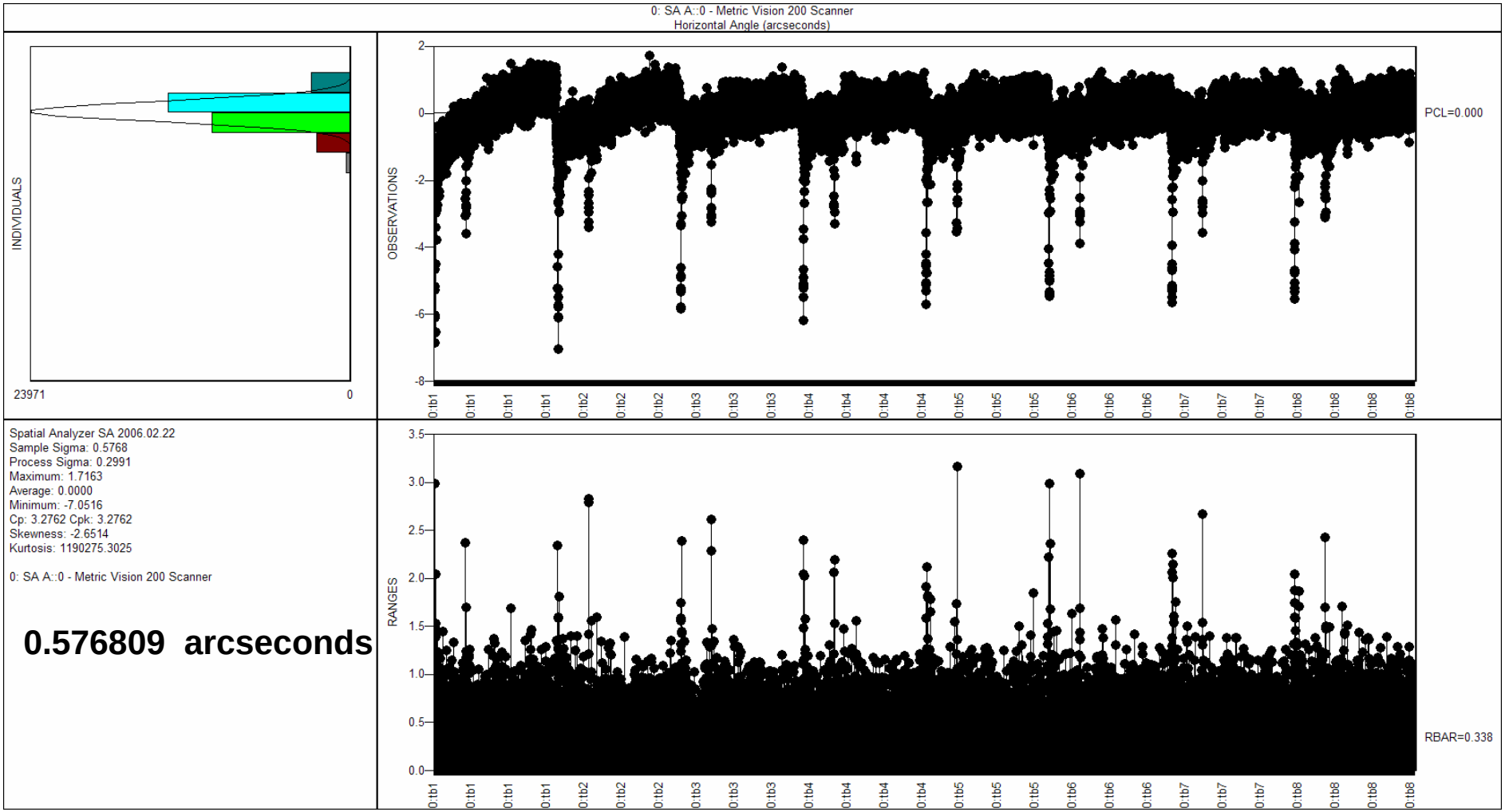
66 hours (2 ¾ days) data collection time on eight tooling balls



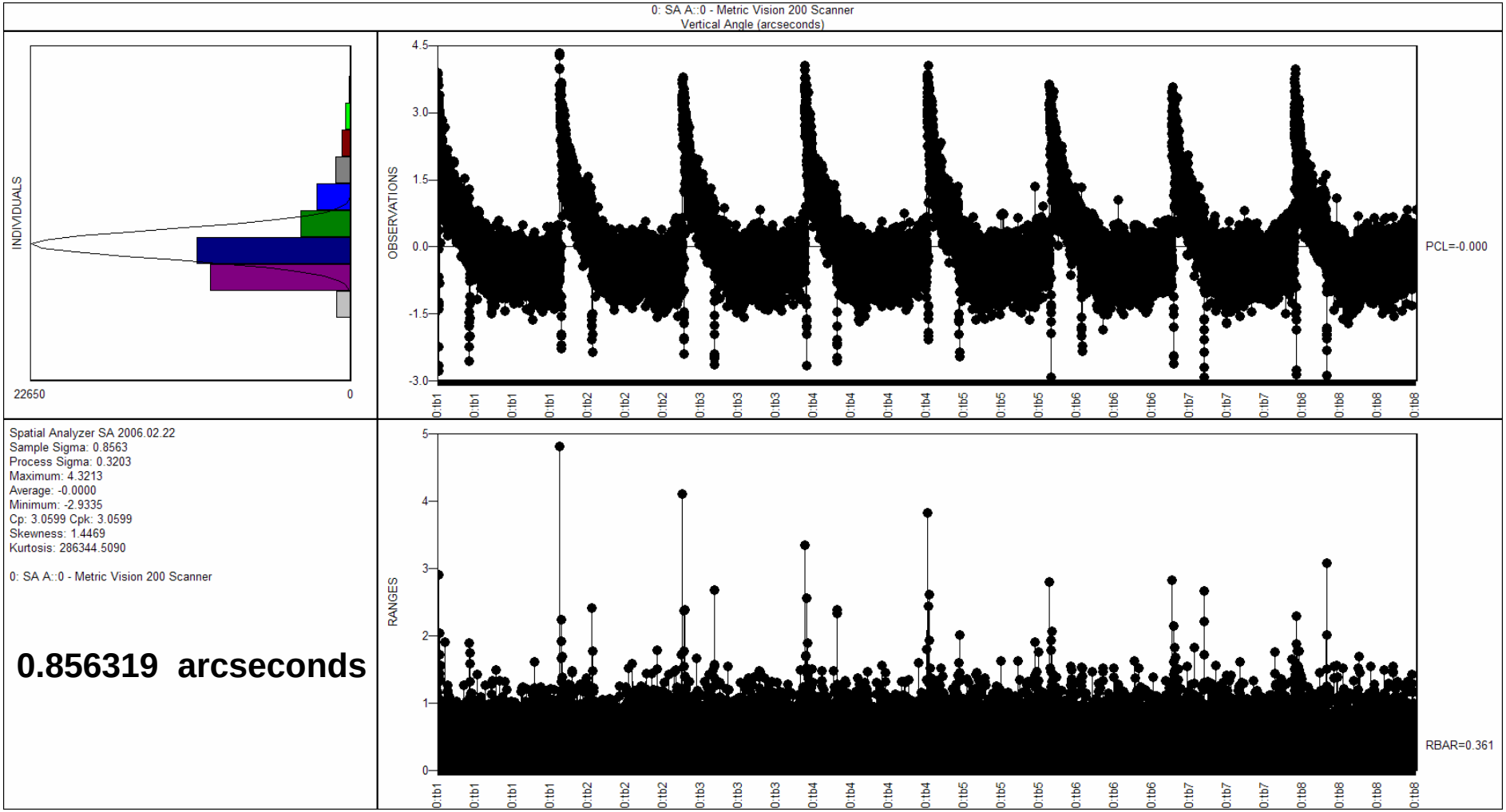
Horizontal Angle 0.576809 arcseconds
Vertical Angle 0.856319 arcseconds
Distance 0.007225 [Millimeters]

30408 measurements

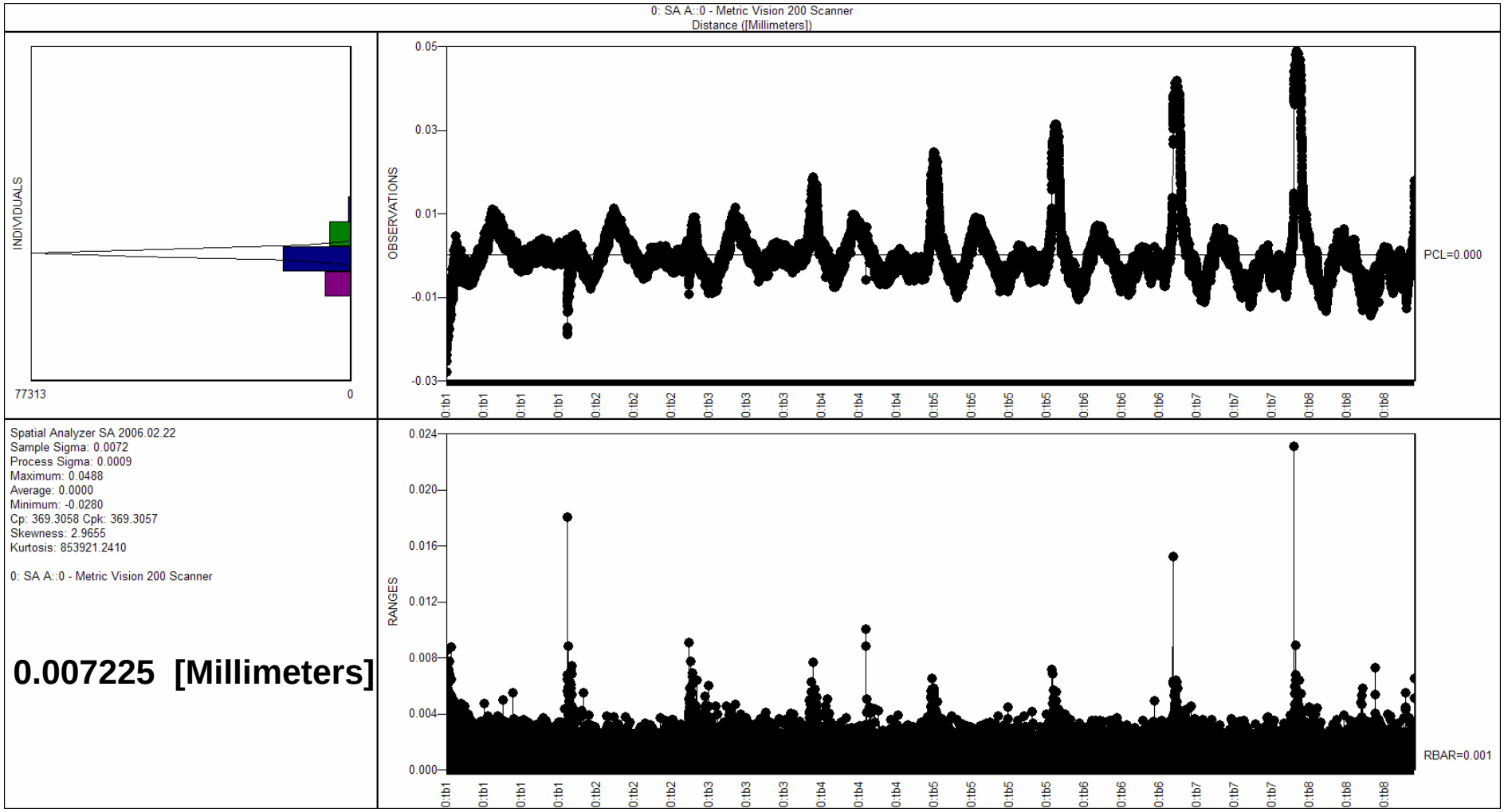
66 Hour Azimuth Repeatability



66 Hour Elevation Repeatability

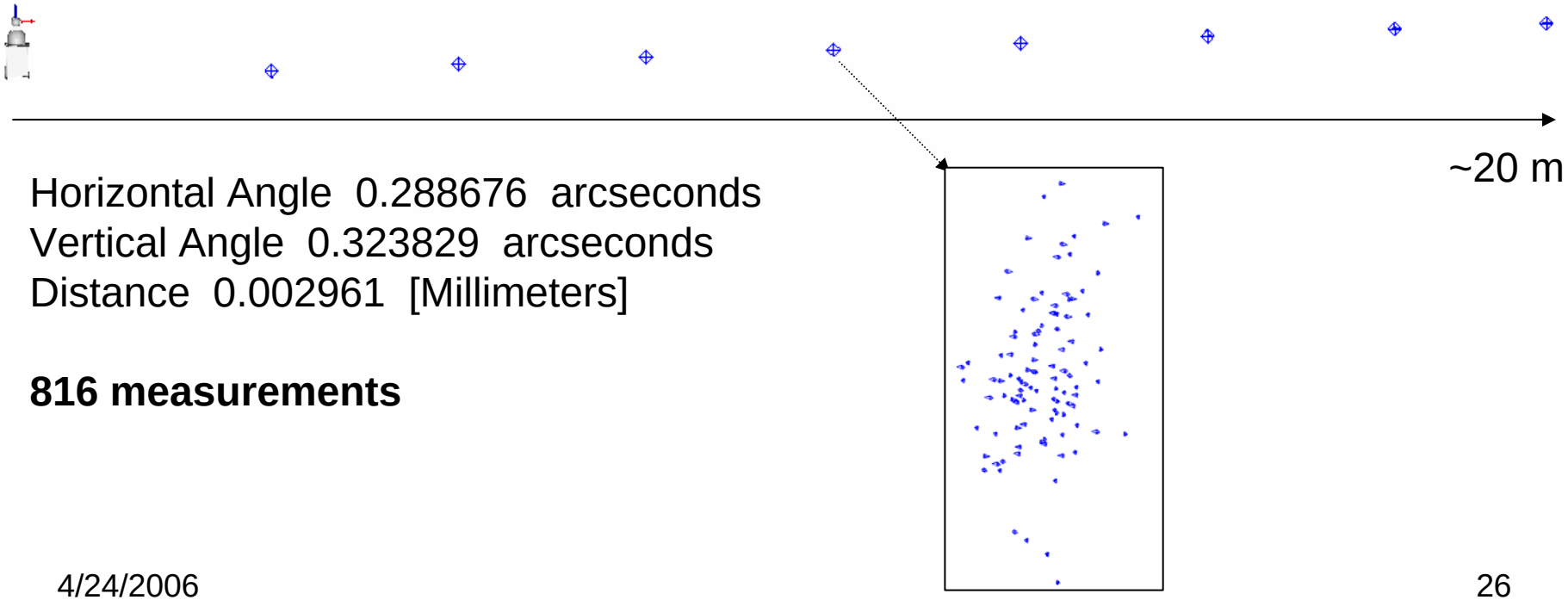


66 Hour Range Repeatability



Using USMN to Detect Motion on Repeatability Measurements

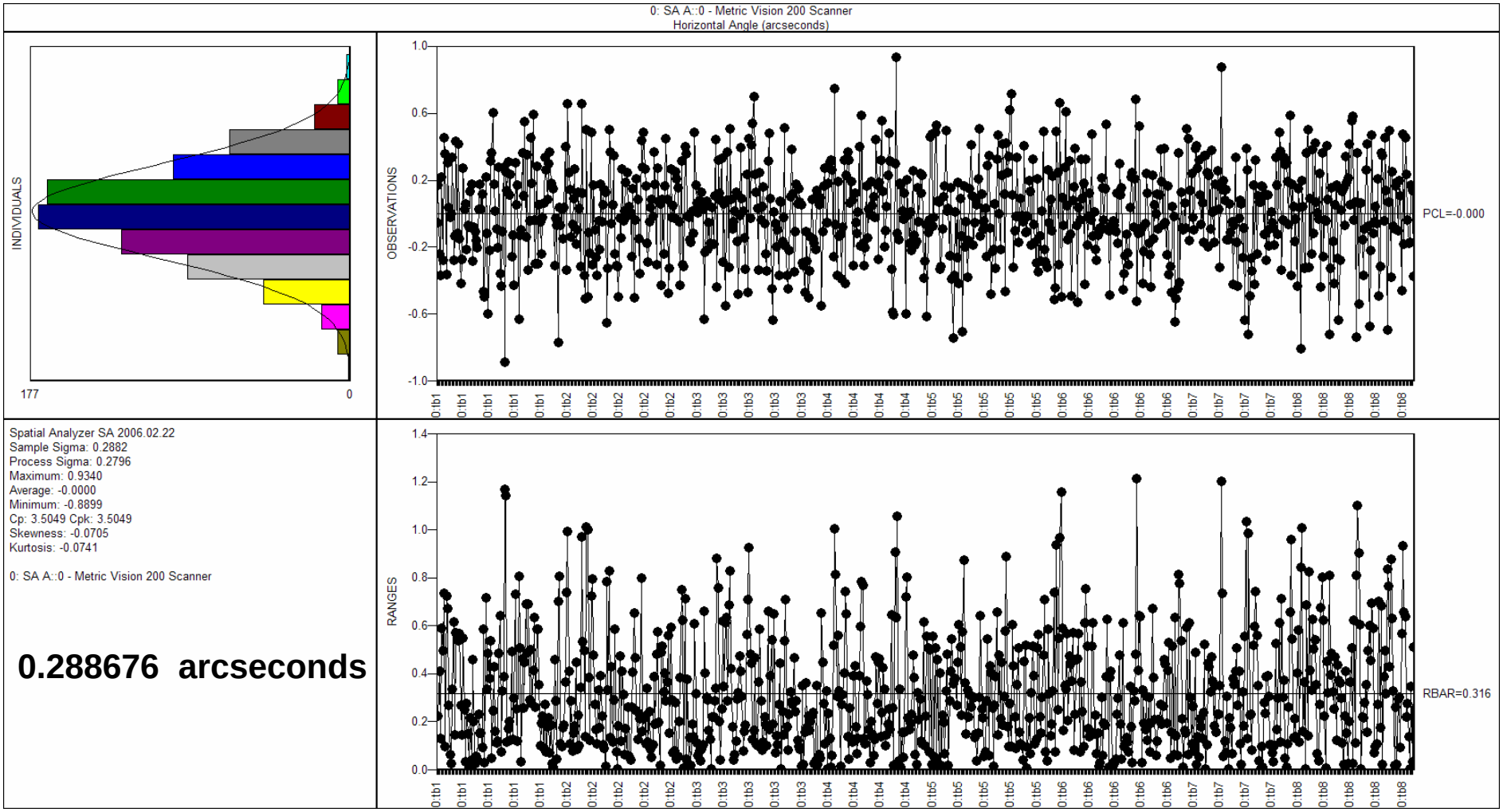
Final 100 minutes data collection time on eight tooling balls



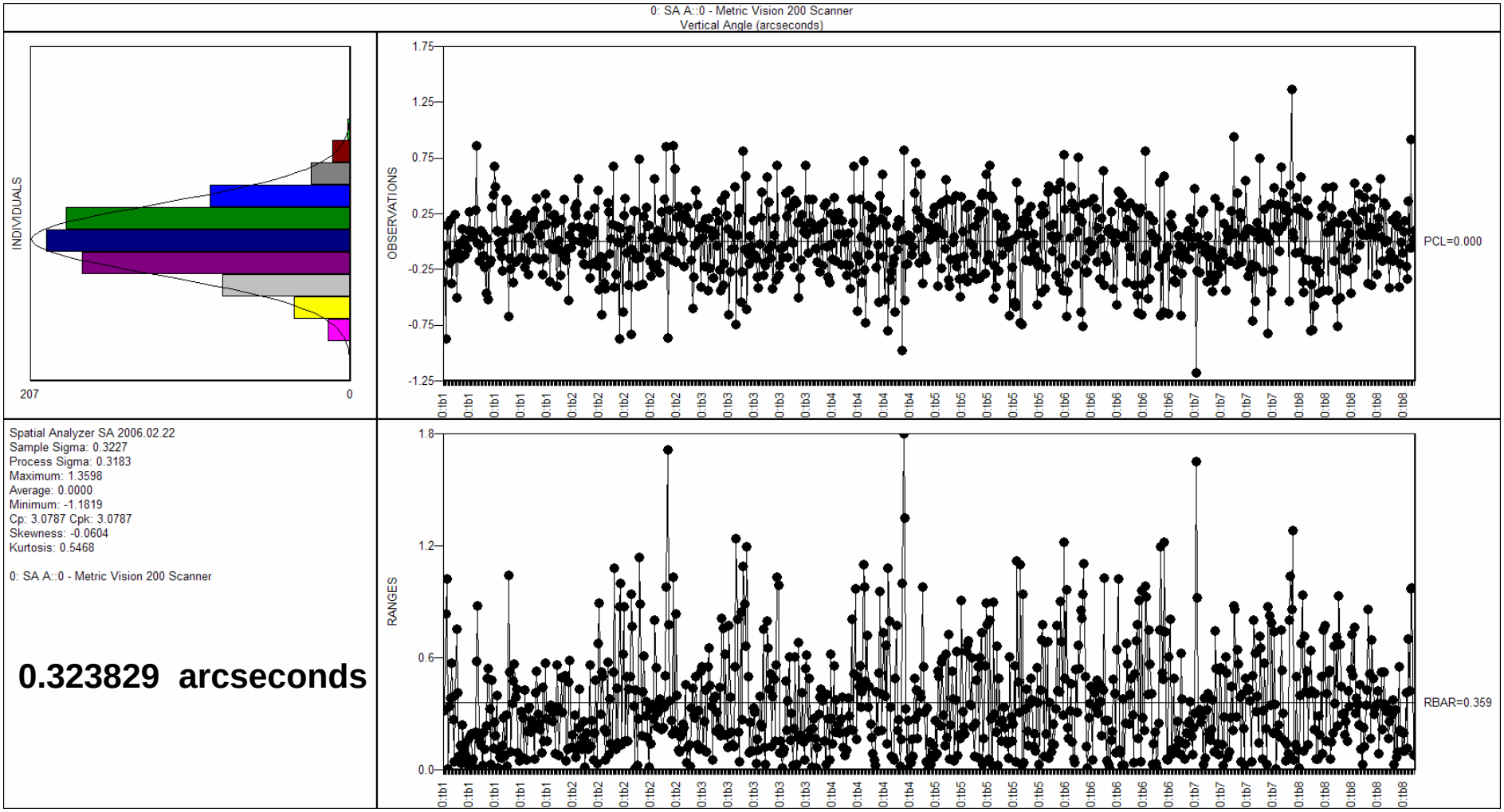
Horizontal Angle 0.288676 arcseconds
Vertical Angle 0.323829 arcseconds
Distance 0.002961 [Millimeters]

816 measurements

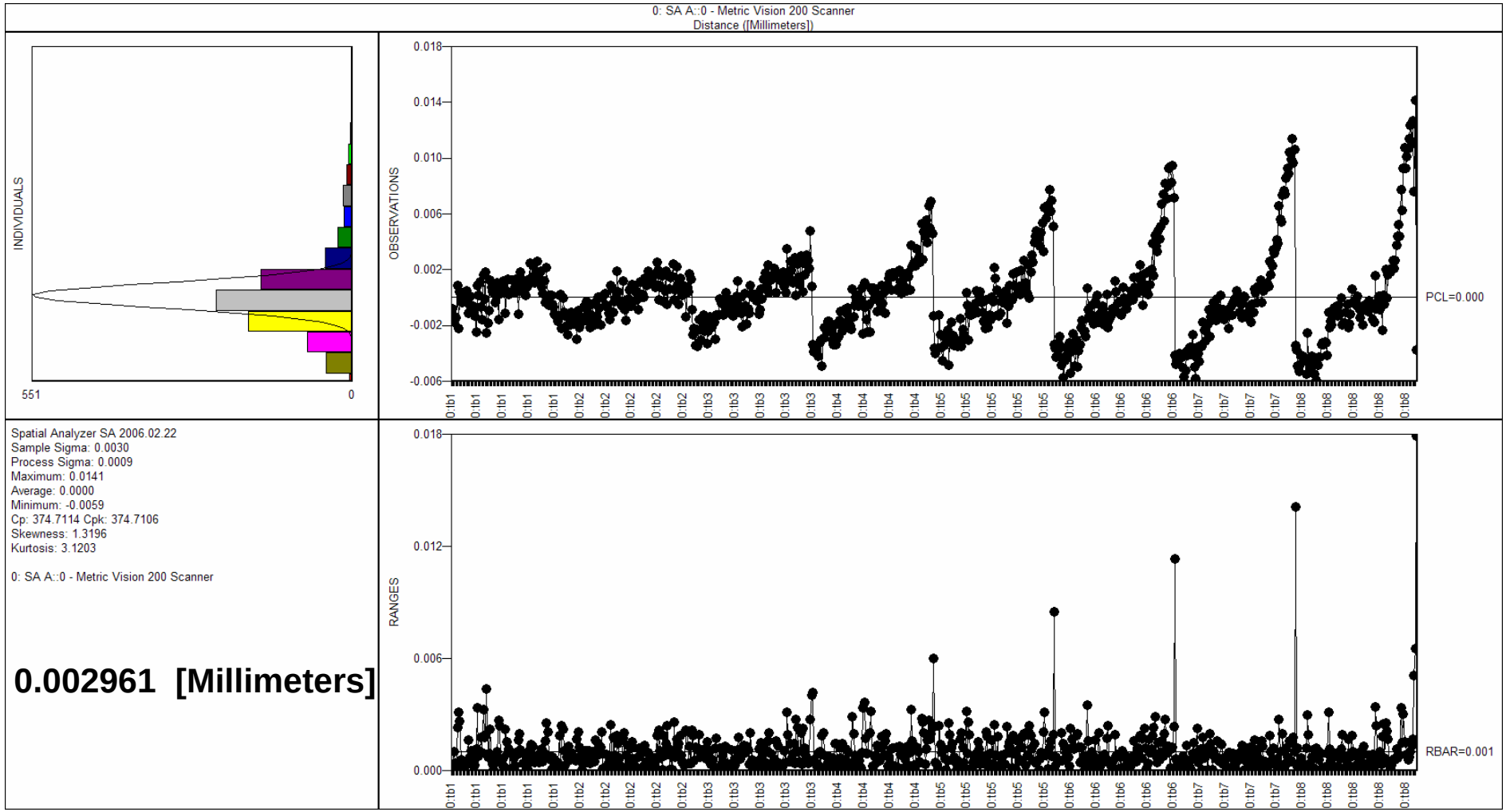
100 Minute Azimuth Repeatability



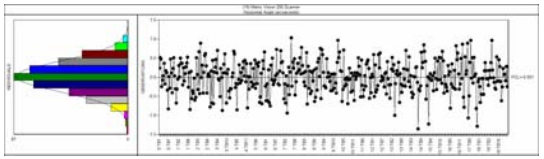
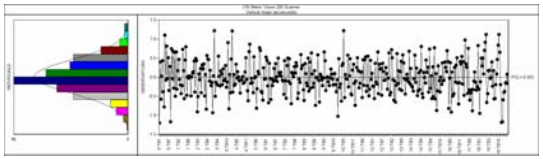
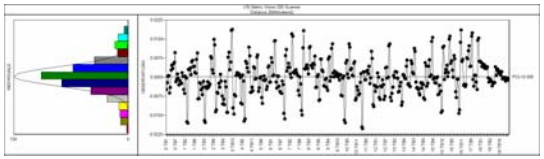
100 Minute Elevation Repeatability

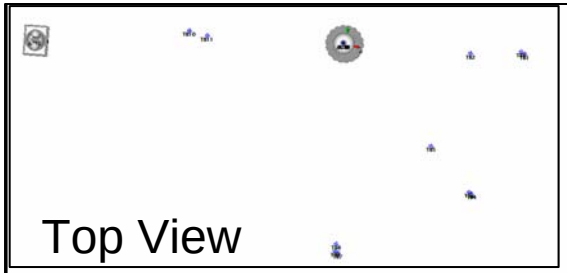


100 Minute Range Repeatability



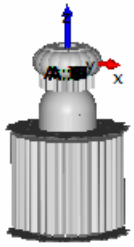
USMN Global Instrument Uncertainty



Horizontal Angle 0.407644 arcseconds
Vertical Angle 0.431126 arcseconds
Distance 0.006983 [Millimeters]
432 measurements

1 Outside Orientation
10 Front Site TB Measurements



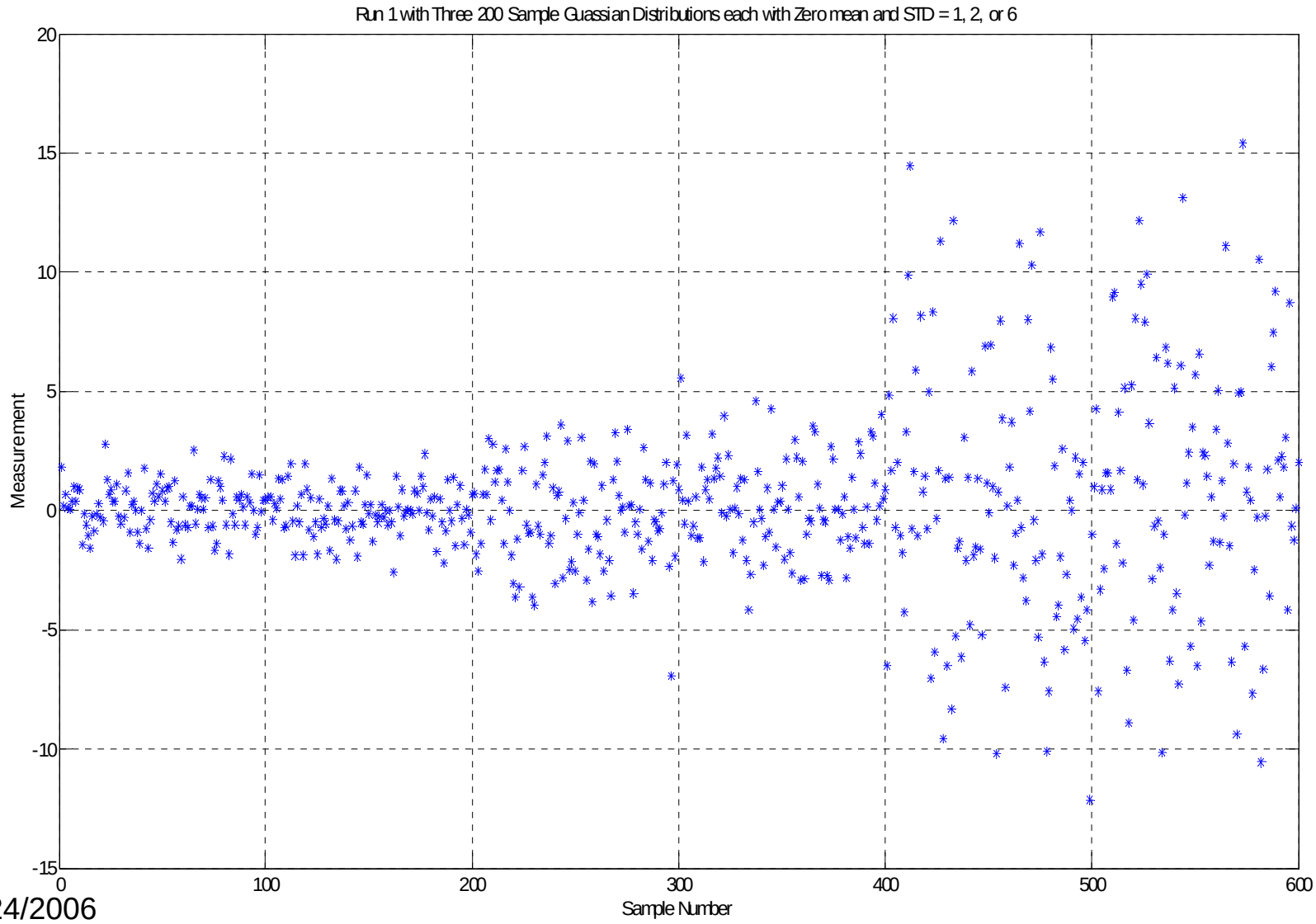
18 Different Inside Orientations
Front & Back Site *Separate* TB Measurements

USMN Considerations

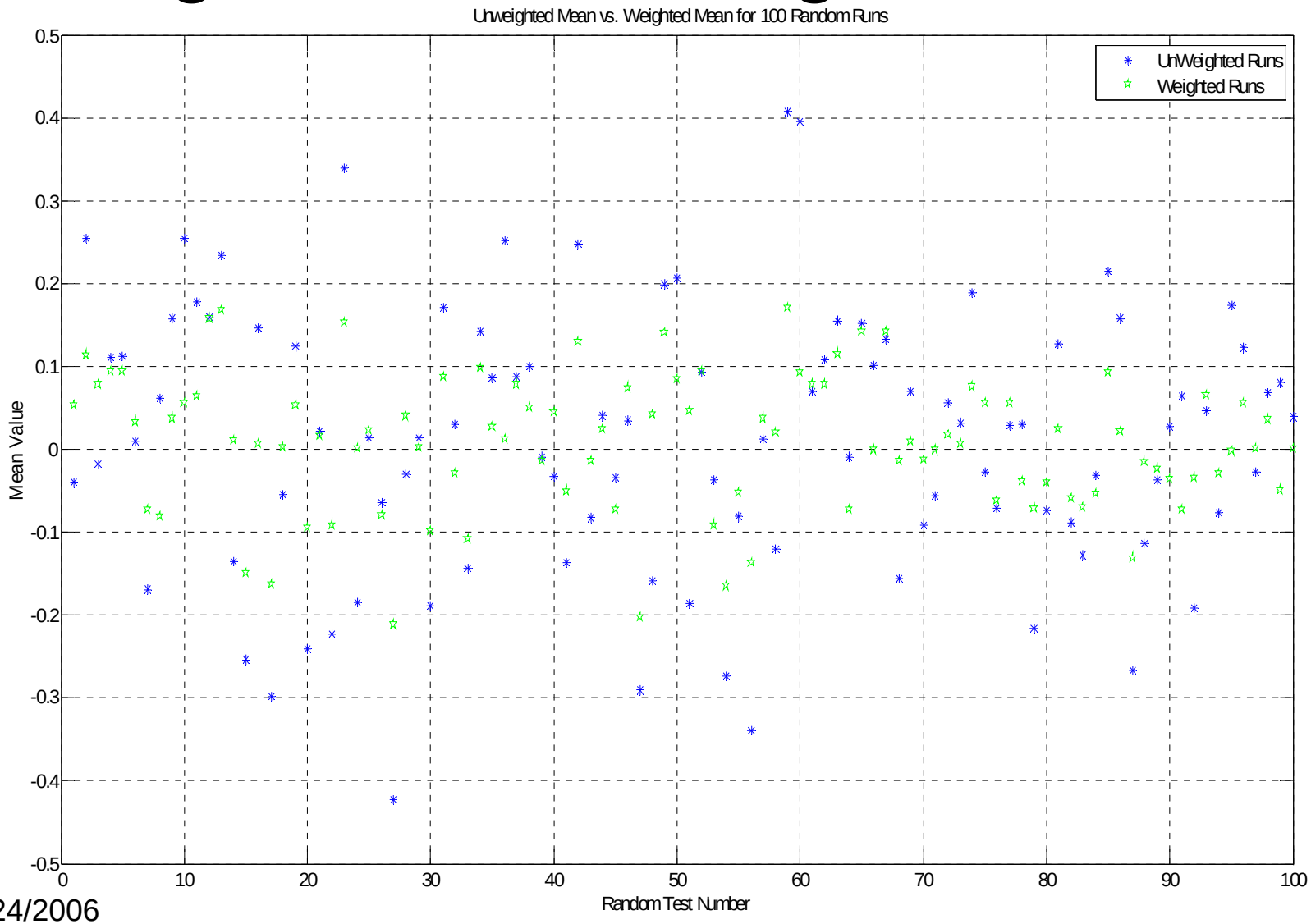
- The *local* error distribution is assumed to be Gaussian ***noise*** when it is typically a combination of bias & noise
- The Least Squares uncertainty weightings are based on the user/manufacturer inputs and not based on the reality of the uncertainty of the instrument (or environment) at a specific point in time
- USMN can not separate instrument uncertainty from the uncertainty induced by the environment (temperature changes, vibrations, drift, etc.)
- SA Spherical/Polar angle uncertainty formulations do not allow for uncertainty variation with range
- The uncertainty clouds are centered about the measurements when the measurement may in reality be on the tail distribution

Questions?

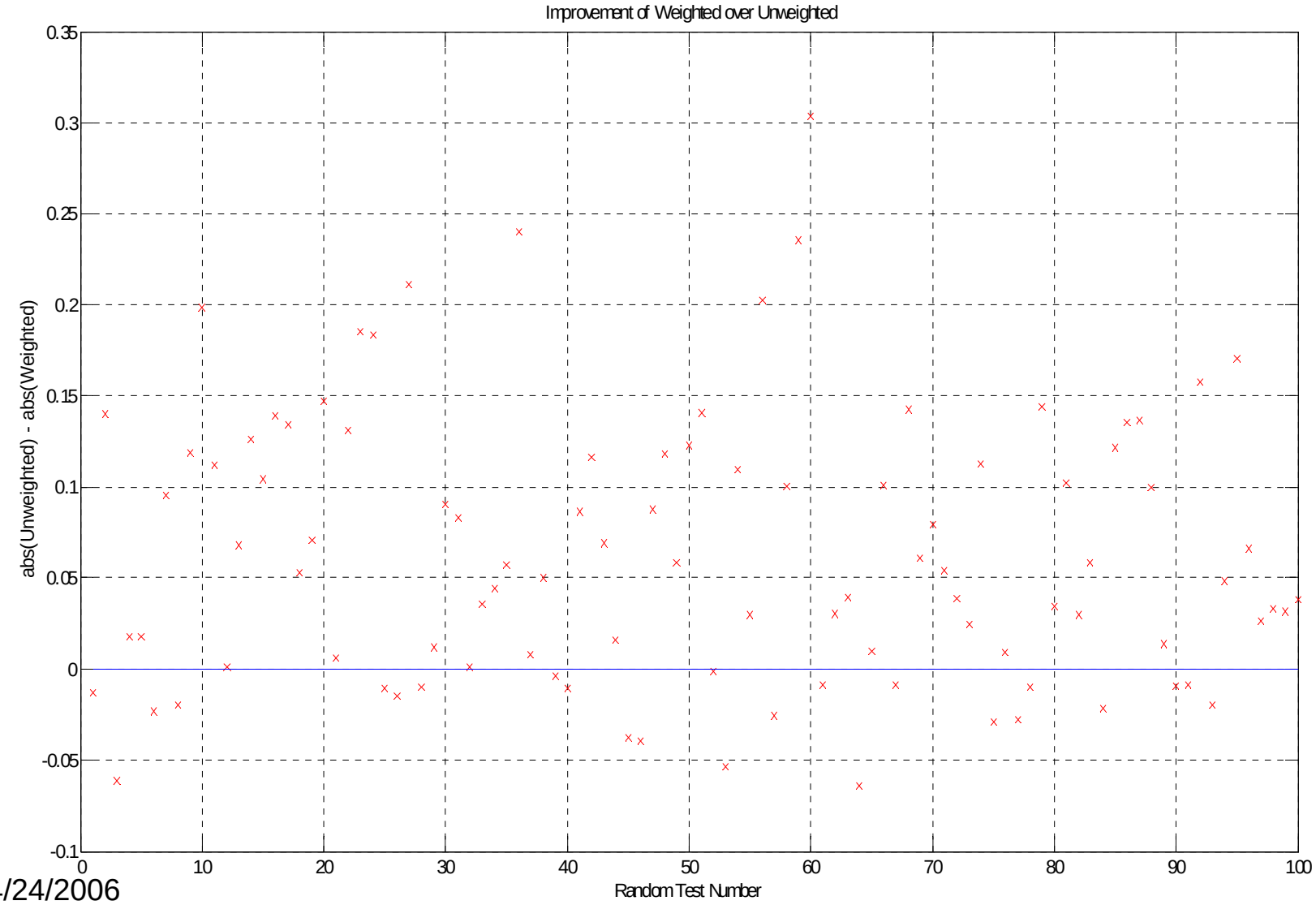
Run1 (out of 100) Data Set



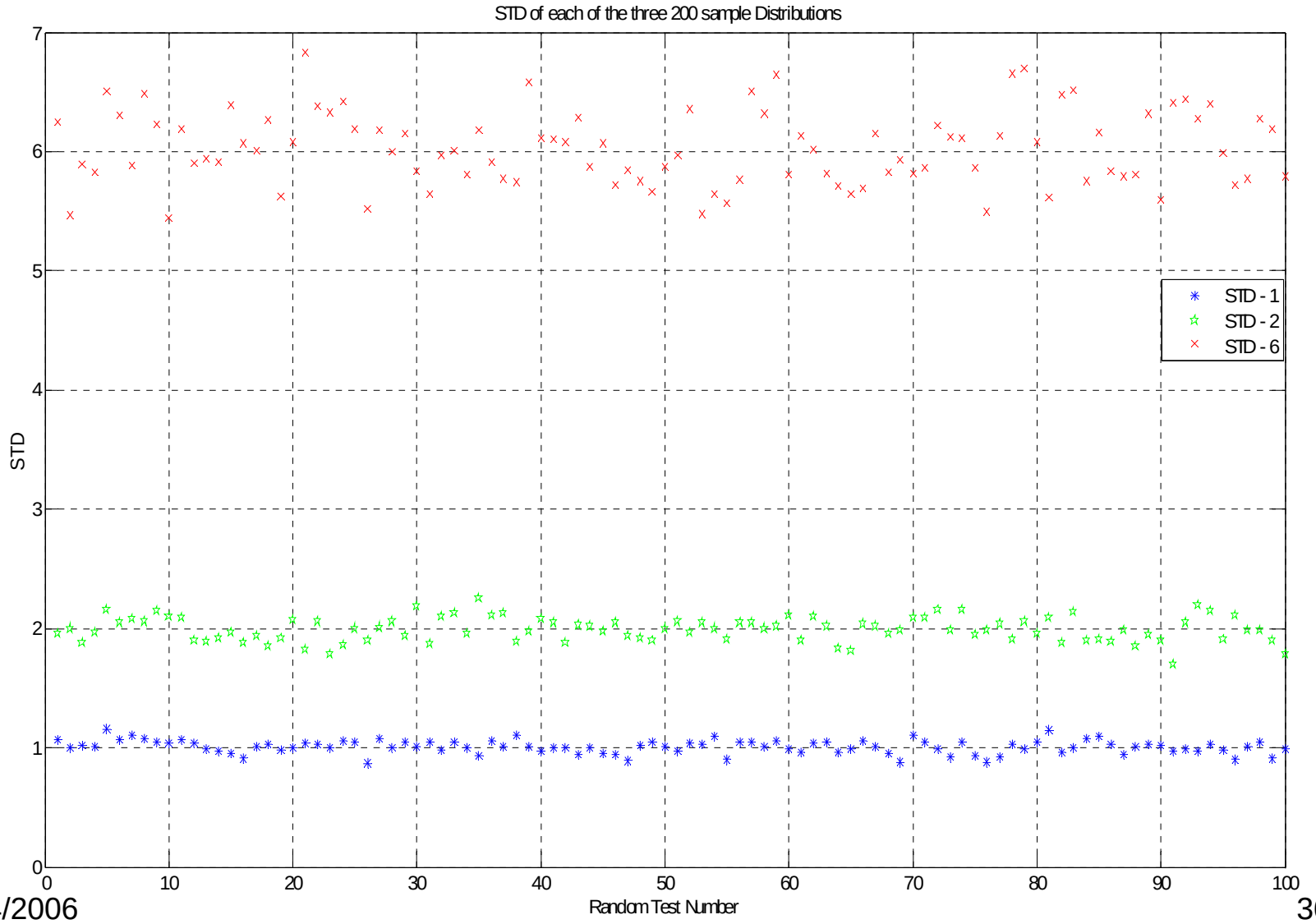
Weighted vs. Unweighted Means



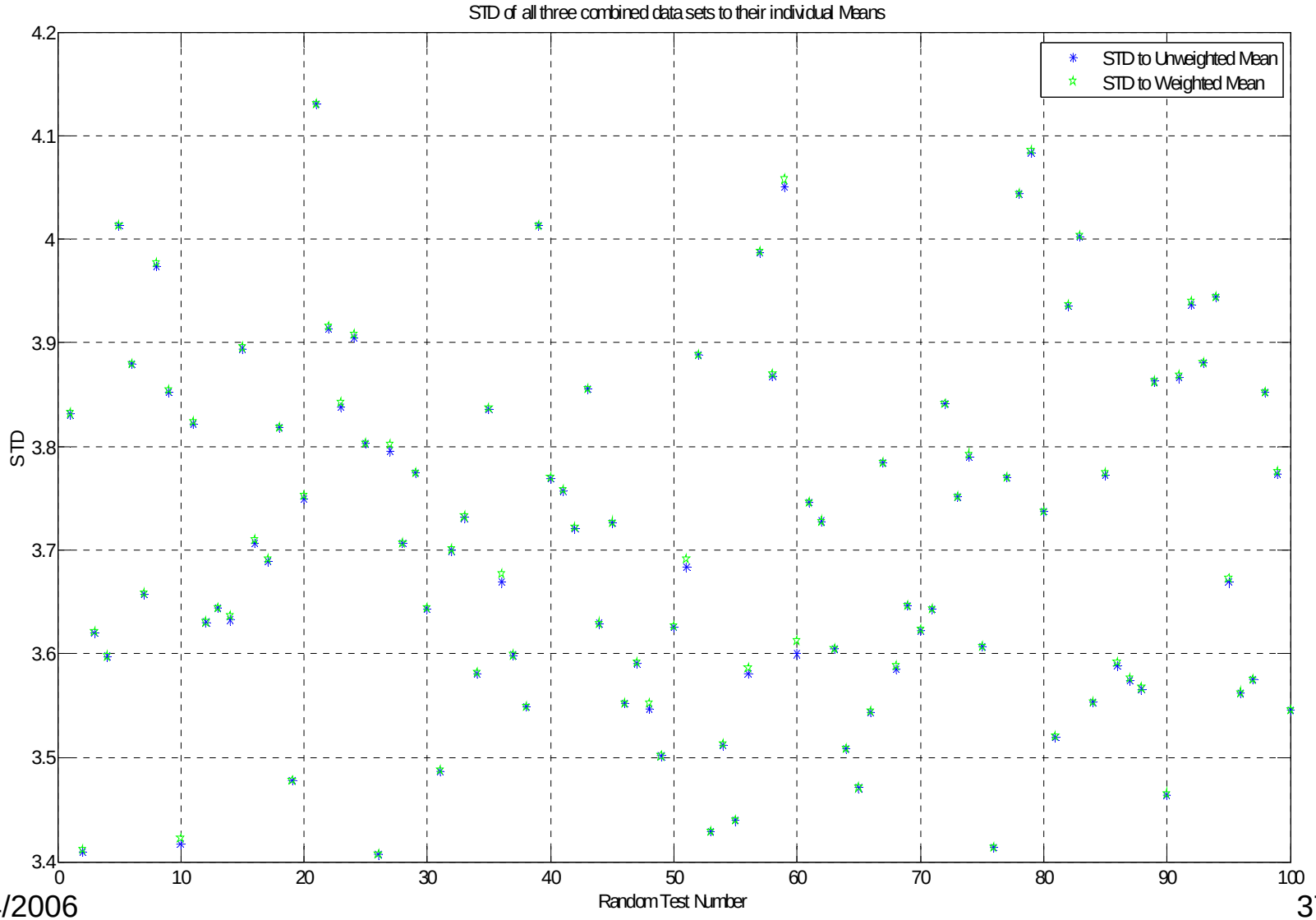
Improvement of Weighted over Unweighted Mean (to true zero)



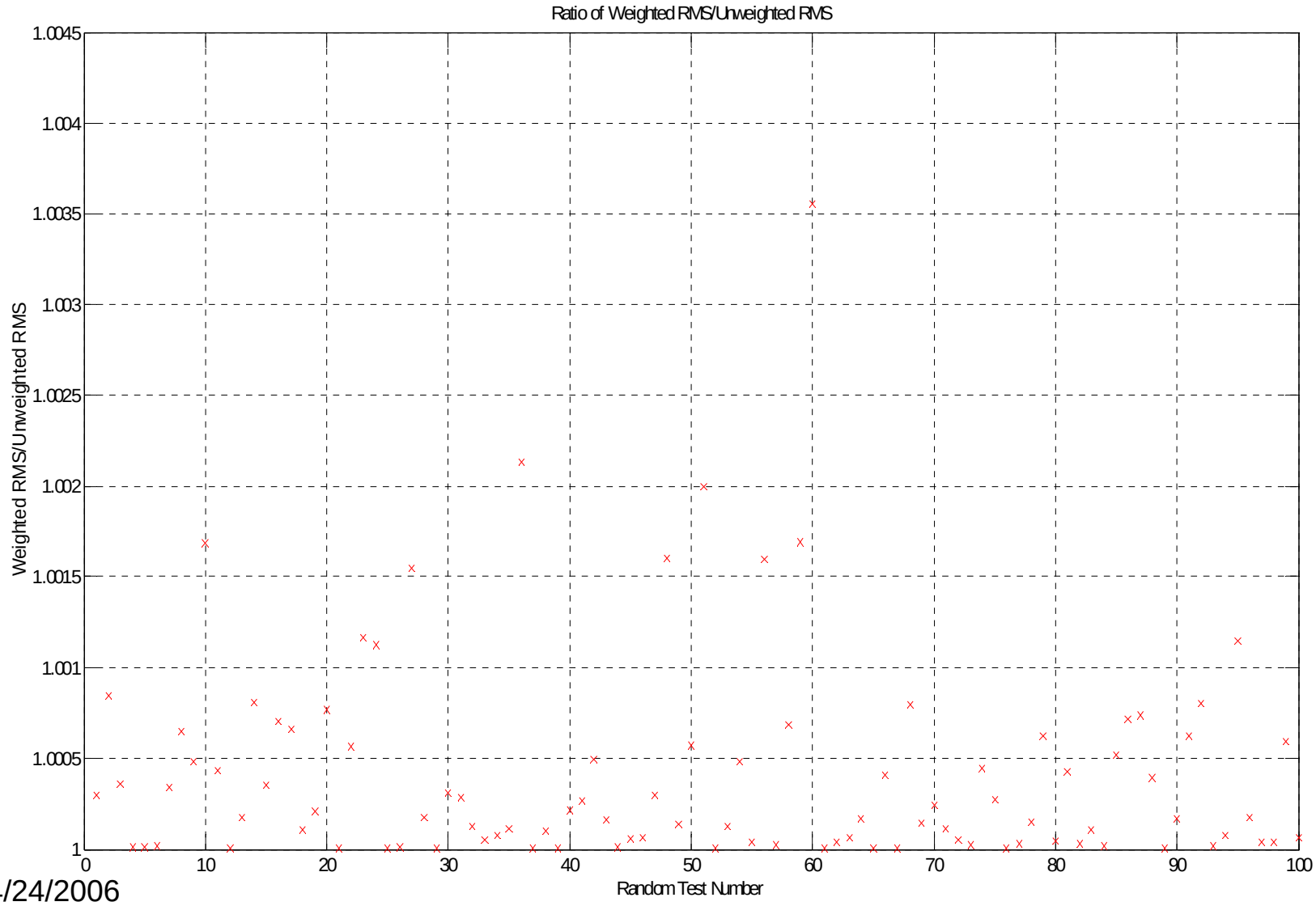
RMS to Calculated Mean



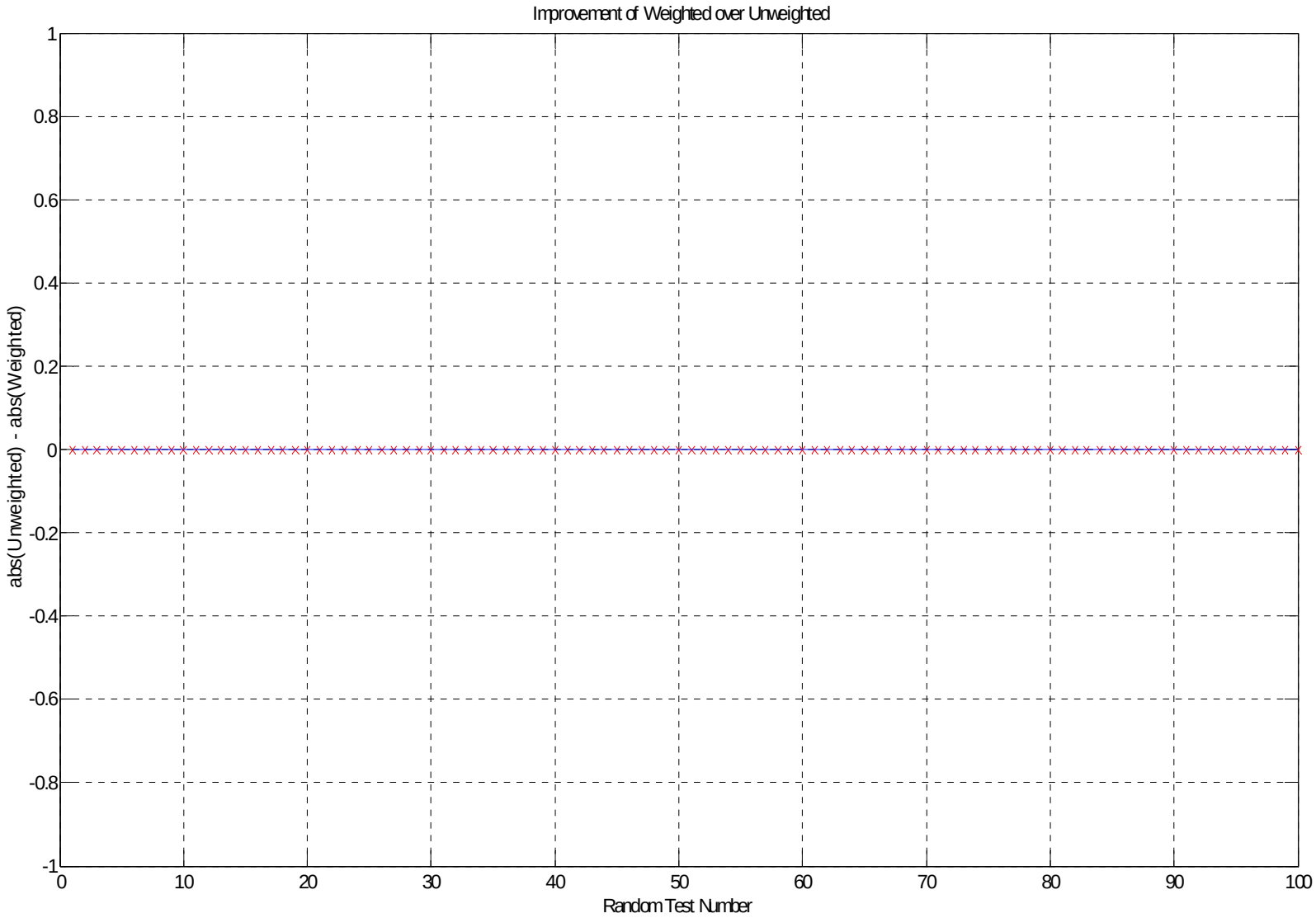
STD of data to Calculated Mean Values



Weighted RMS/Unweighted RMS



Even Weighting Applied



Even Weighting Applied