Effects of Applying Distance Constraints within Measurement Networks

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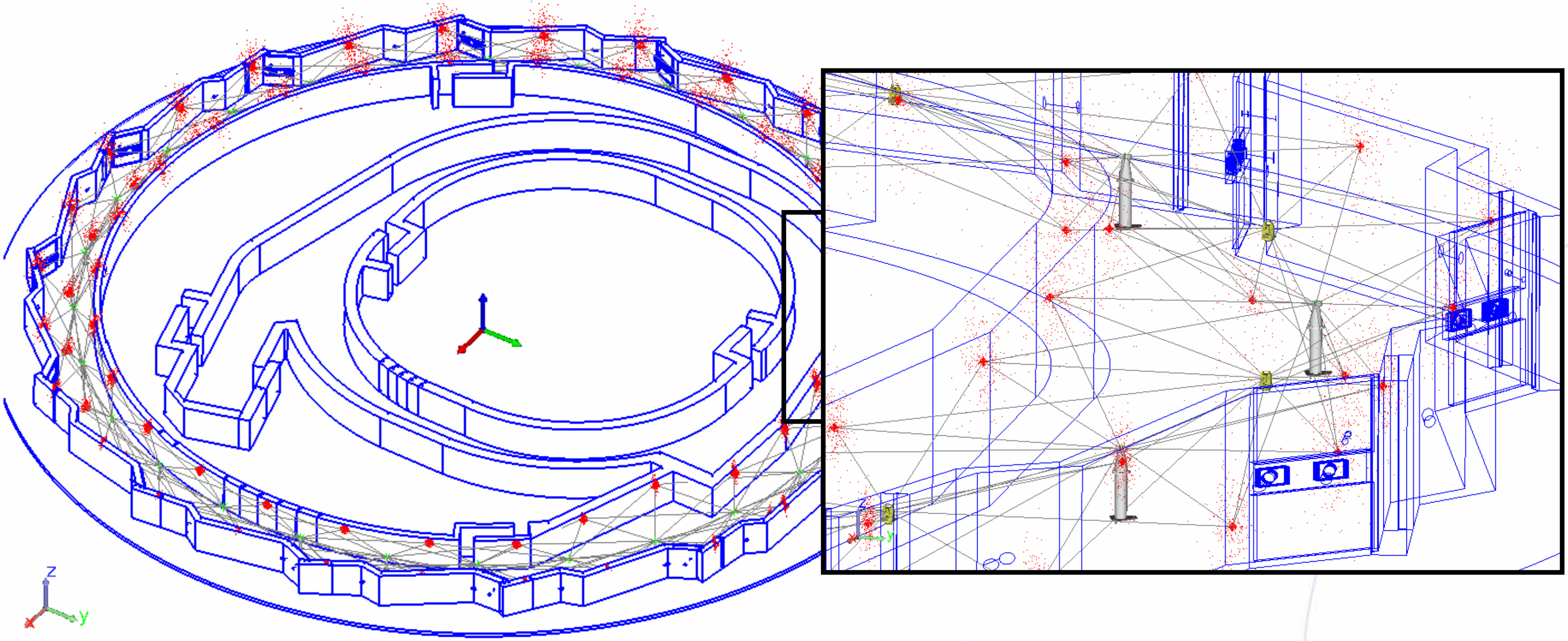
Engineered for Extreme Measures.

International Workshop on Accelerator Alignment
KEK, Tsukuba, Japan

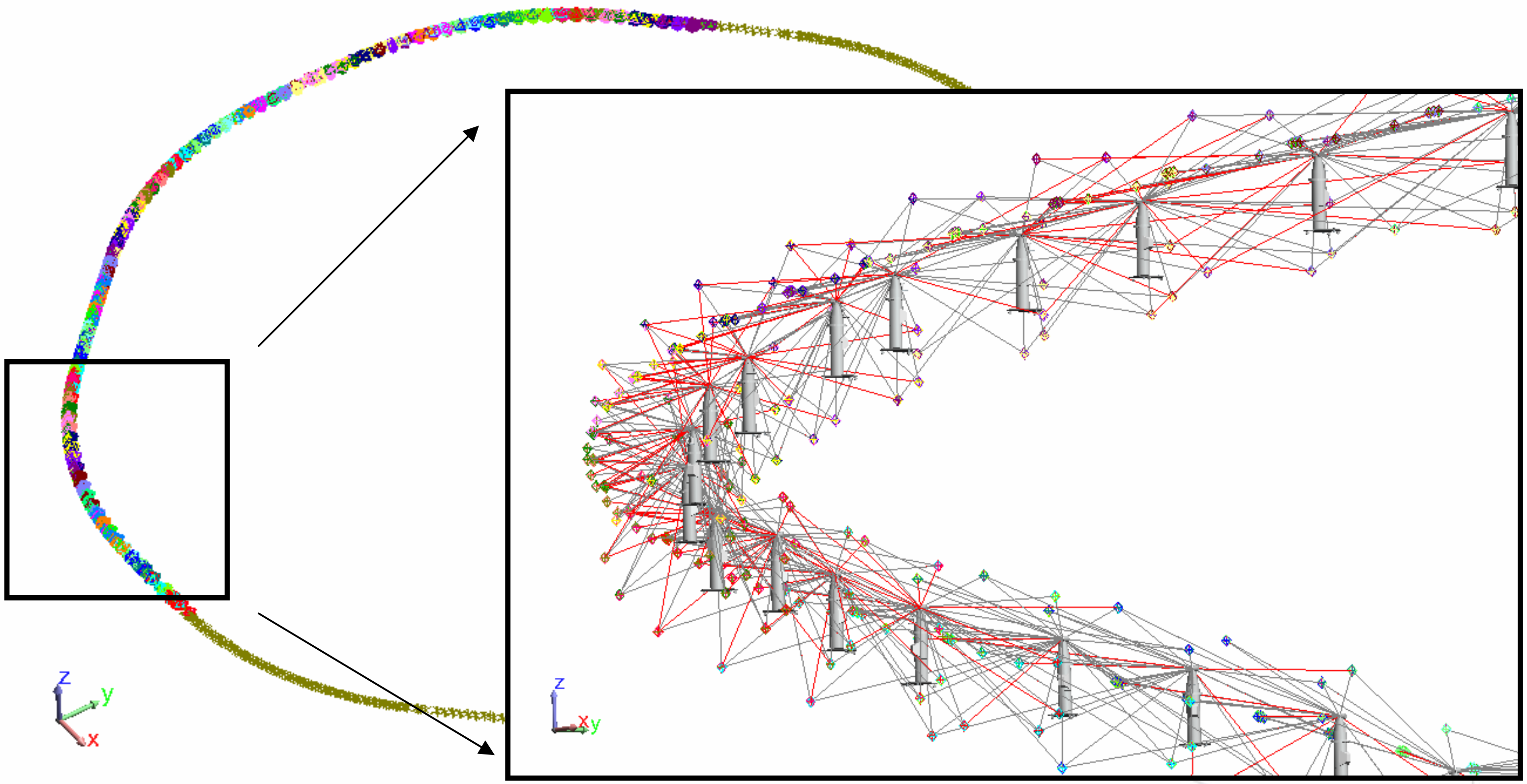
Introduction

- Accelerator Ring Alignment Surveys
  - Instruments (Types and Stations)
  - Point/Observation Network
  - Network Adjustment
  - Control/Constraints (Instrument Performance, Environment)
  - Uncertainty Analysis – Study – Confidence
- Scale Constraints
  - Point to Point distance constraints (type & traceability)
  - Inner Ring and Outer Ring constraints
- Automating Accelerator Alignment Surveys
  - Custom Interface via Excel/ODBC Automation
- Conclusions

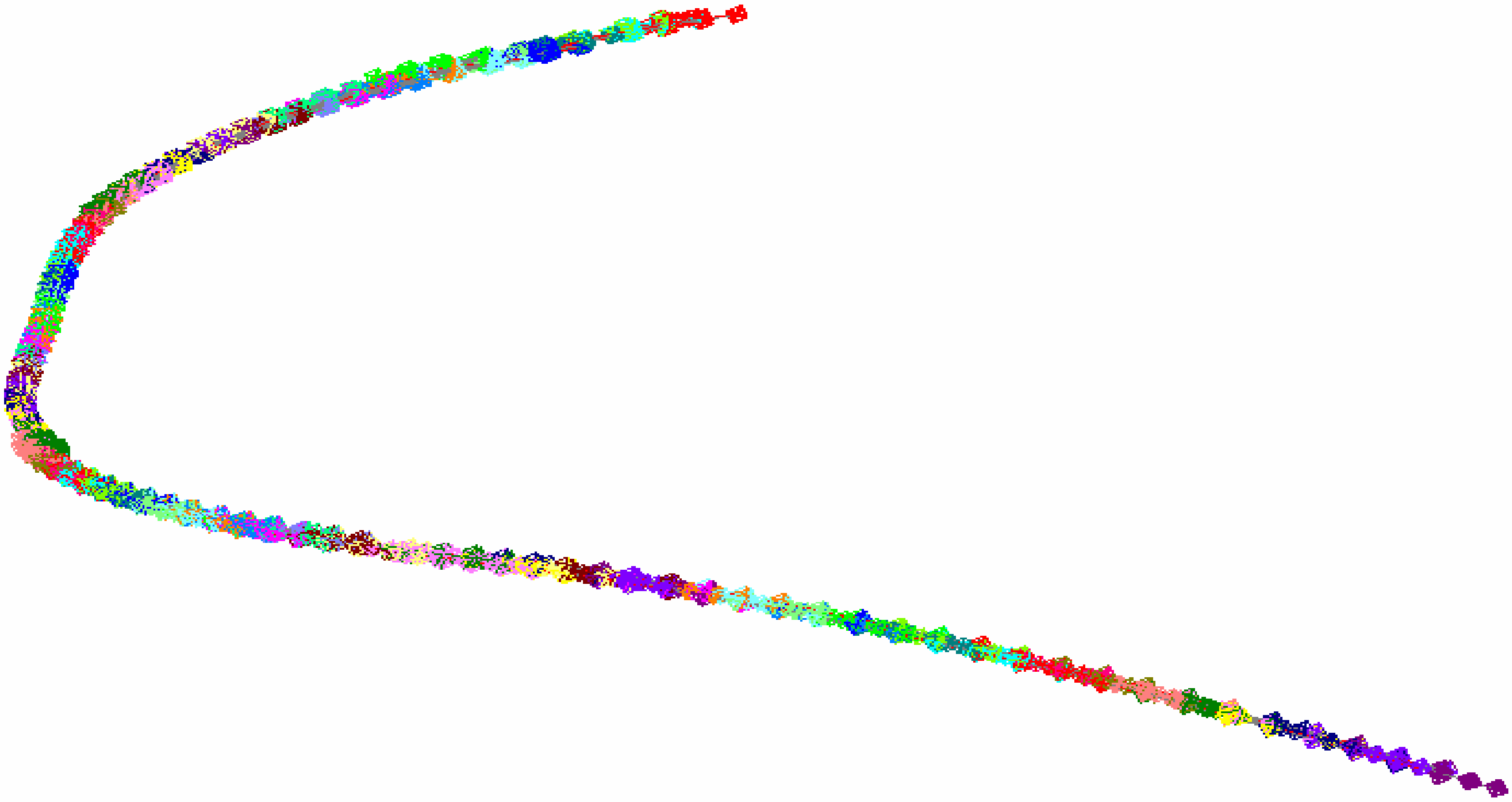
Accelerator Ring Alignment Surveys



Accelerator Ring Alignment Surveys

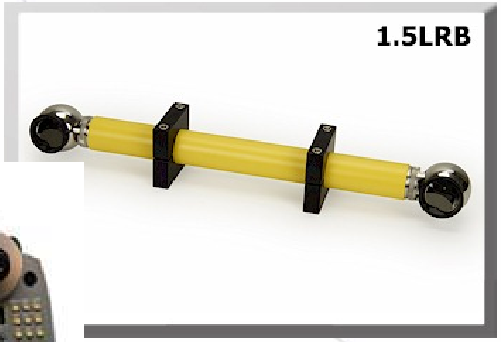


Network Constraints…



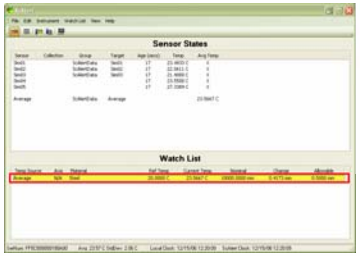
Instruments (Types and Stations)

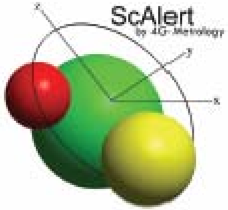
- Types:
  - 3D → Laser Trackers, Total Stations
  - 1D → Scale Bars, Laser Rail, Digital Levels, Mekometer

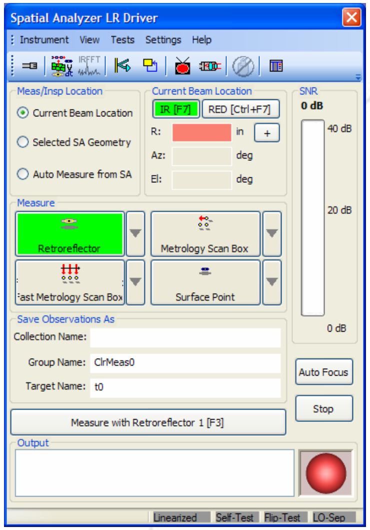


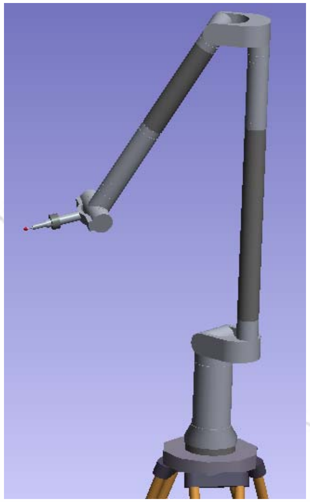
Instrument Interfaces …

- New Instrument Interfaces
  - ScAlert
  - MV-200 Scanner Interface
  - Romer Sigma Arms & Arm Scanner
  - API Laser Rail
  - Sokkia Net1 Total Station
  - Faro Arm Scanner
  - T Scan Interface









Scaling 3D Metrology to Ref Temperature

- Why Scale 3D Measurements?
  - Object dimension is dependent on temperature
  - Reference Temperature is 20° C (68° F)
  - Nominals are given at reference temperature
  - Objects are measured at temperatures other than at reference
- Scale object measurements from actual to reference temperature
  - Scale is dependent on:
    - Material Properties (CTE)
    - Temperature difference from reference
    - Object constraints

Thermal Length Compensation

Must scale measurements to reference temperature for comparison against nominals or between surveys

$$L_i = L_0(1 - \alpha\Delta T)$$

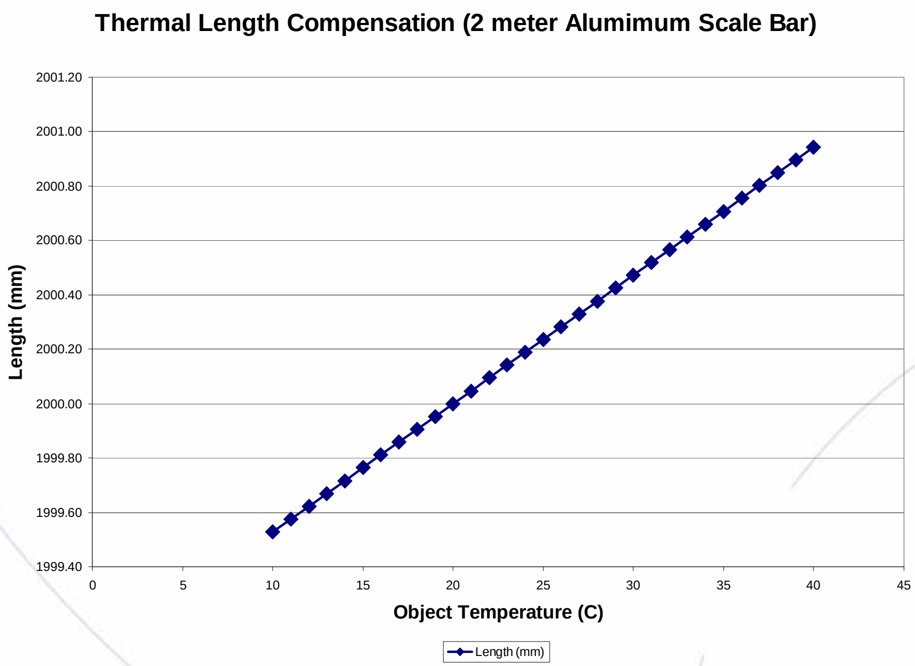
where:

L_i = actual length at temperature

L_0 = calibrated length at reference temperature

α = CTE for scale bar material (ppm/^oC)

ΔT = temperature delta between actual and reference temperature (^oC)



Objects change length as temperatures changes

Process: 3D Measurement Traceability

- Survey scale is set with calibrated Temperature and CTE
  - Thermocouples to measure object temperature … e.g., ± 0.5° C (k = 2)
  - Published Material Type CTE e.g., ± 3-5% (k = 2)
- Survey scale is checked (confirmed) against traceable lengths (NIST, PTB, NPL)
  - Bars calibrated with interferometer at reference temperature
  - Fixed Targets on Bars
  - Bar Material = Object Material
  - Length uncertainty set by lab

Input Component Uncertainties…

- Measurement uncertainty is higher
  - CTE uncertainty characterization is significant (> 5% of CTE)
  - Material temperature measurement uncertainty
  - Object temperature measurements one or a few observations
- Survey scale is set with uncertain temperature and CTE
- Process time is lost
  - Get measurements of scale bars to check to tight tolerances … re-measure bars n times → find right temperature
- Setting scale with less precise process then having to check with higher precision

CTE Thermal Length Uncertainty

$$L_i = L_0(1 - \alpha \Delta T)$$

$$f(L_0, \alpha, \Delta T) = L_i$$

Uncertainty of L_i is a function of $L_0, \sigma_L, \alpha, \sigma_\alpha, \Delta T, \sigma_T$

Example: 2 meter Alum Scale Bar from 10^o to $40^o C$

$L_0 = 2000$ mm $\sigma_L = 0.02$ mm

$\Delta T = -10 \ldots 20\ ^oC$ $\sigma_T = 0.5^oC$

$\alpha_{alum} = 23.8\ ppm/^oC$ $\sigma_\alpha = 5\% \alpha$

Propagation of Uncertainty

$$\text{Model}: L_i = L_0(1-\alpha\Delta T) = f(L_i)$$

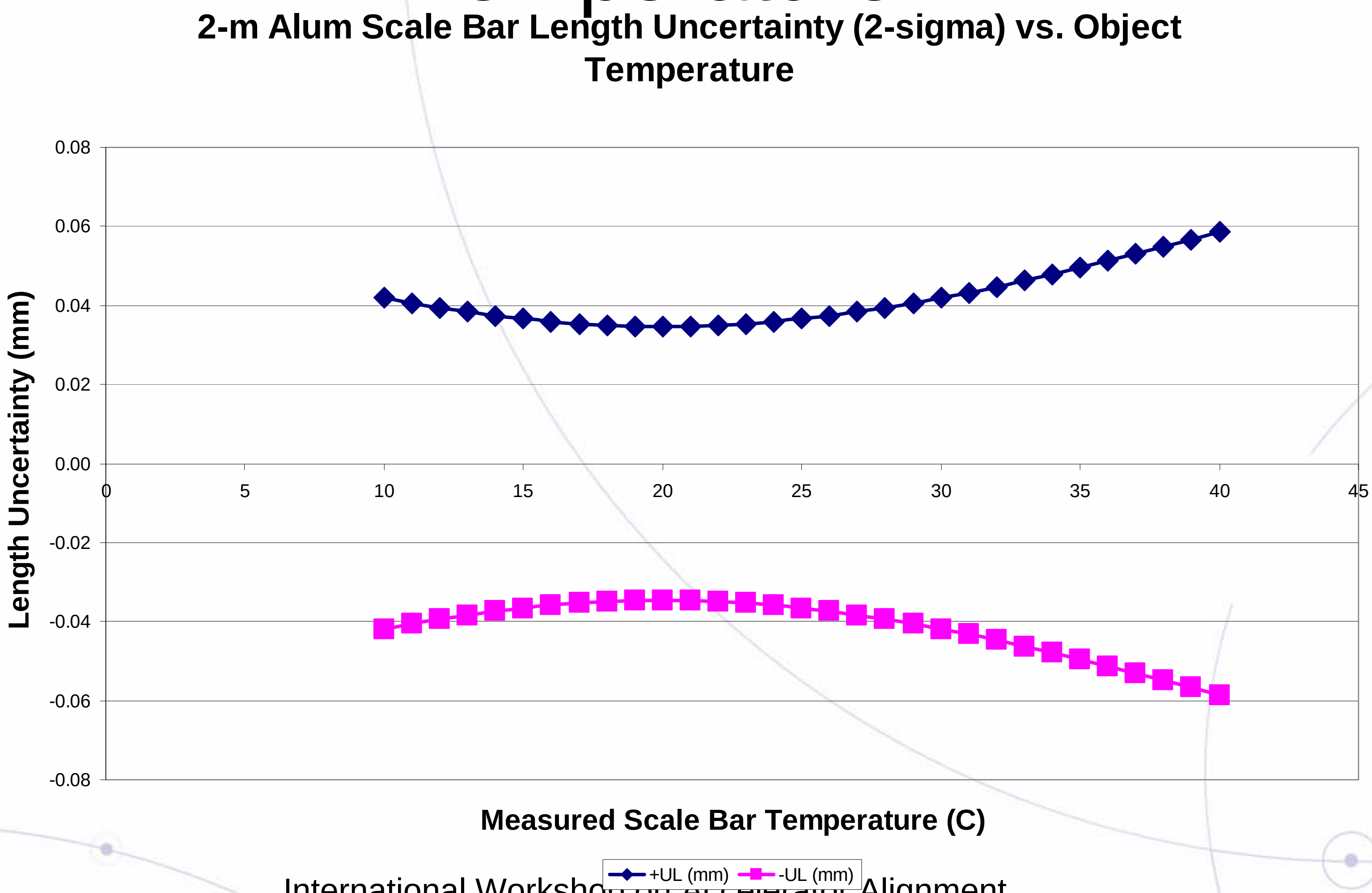
$$U[f] = s_f = \sqrt{\left(\frac{\delta f}{\delta L_0}\right)^2 \sigma_L^2 + \left(\frac{\delta f}{\delta \alpha}\right)^2 \sigma_\alpha^2 + \left(\frac{\delta f}{\delta \Delta T}\right)^2 \sigma_T^2}$$

$$U[L_i] = s_L = \sqrt{(1-\alpha\Delta T)^2 \sigma_L^2 + (L_0\Delta T)^2 \sigma_\alpha^2 + (L_0\alpha)^2 \sigma_T^2}$$

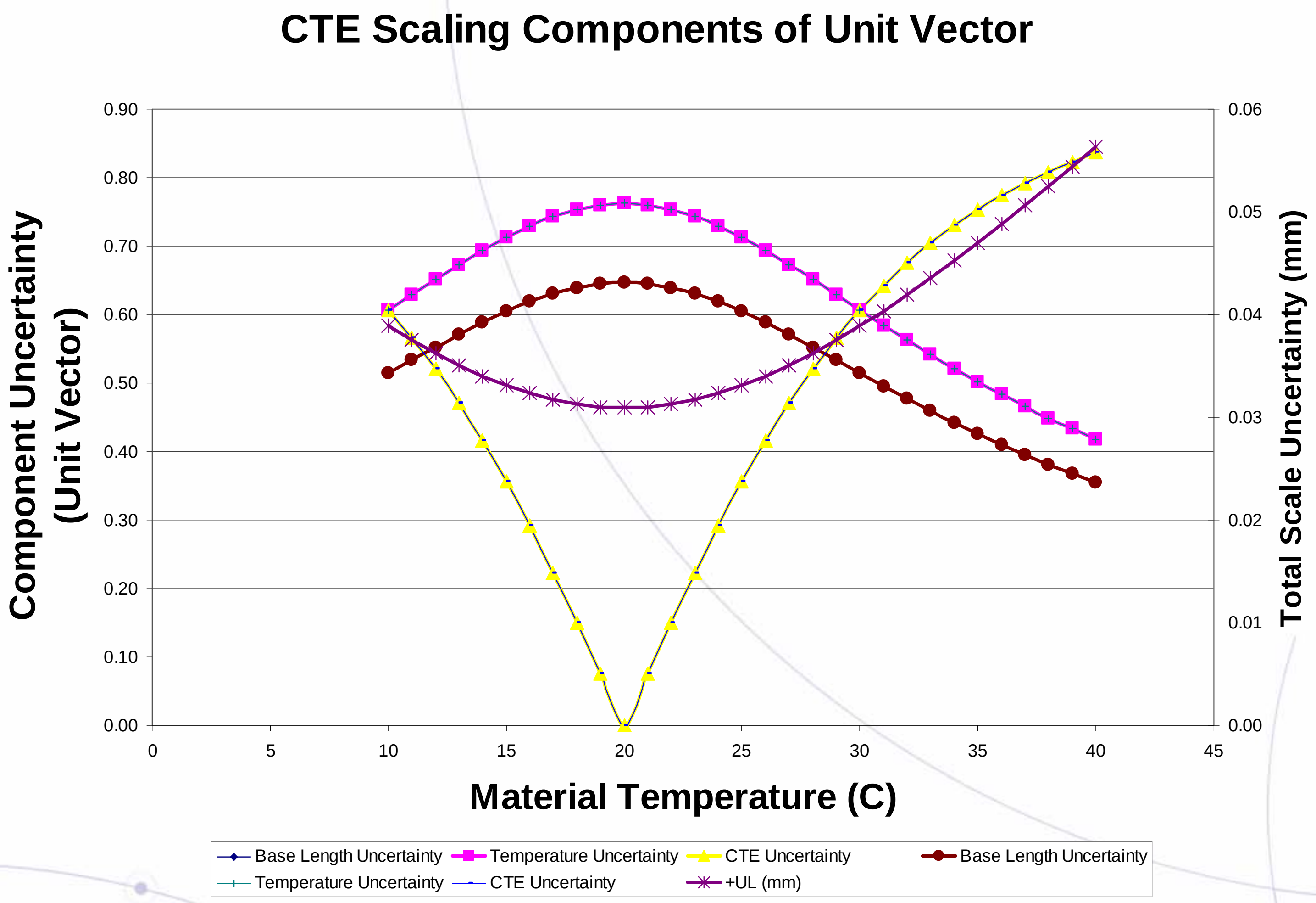
- Formula for the variance between products
- Propagation of error approach combines estimates from individual auxiliary measurements`

Leo Goodman (1960). ***"On the Exact Variance of Products"*** in *Journal of the American Statistical Association*, December, 1960, pp. 708-713.

Scale Bar Length Uncertainty vs. Temperature



Scale Length Uncertainty Components



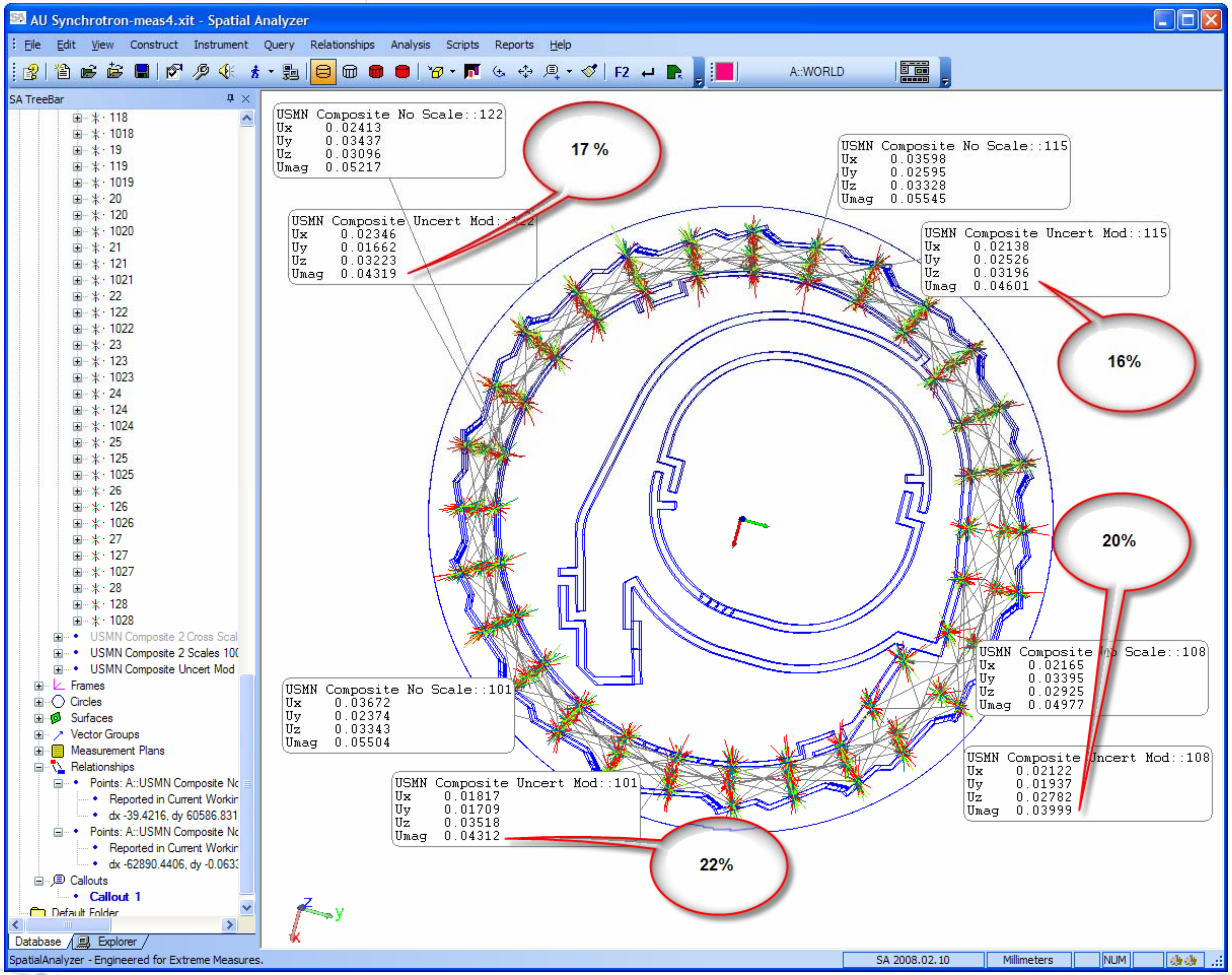
Scale Length in USMN

- Integrate scale length into Uncertainty Field Analysis
  - Scale length uncertainty from traceable certification
  - Multiple bar positions and orientations
  - Multiple stations
  - Local scale deformations due to environmental temperature gradient

Monte-Carlo Uncertainty Analysis

- Uncertainty Field Analysis includes scale bar constraints
  - Report Only
  - As Constraints
    - Weighted based on length and published uncertainty from lab
- Monte-Carlo Uncertainty Analysis and Validation for network with modeled scale bar constraints…
  - Confirm an instruments or stations performance within a network against certified length
  - Network Target field uncertainty analysis with graphical and component output
- Automated outlier characterization (Ranking %) and possible elimination
- Shop floor users to consistently and effectively use this advanced optimization technique

Target Uncertainty Analysis w/ Length Constaints



Automation Mechanisms

- Measurement Plan support for Laser Rail
- Digital Level Integration
- Custom interfaces
  - ODBC → Put/Get
  - Interactive Excel exchange (Variables)
- Open Instrument Interface
- Parallel Processing
  - Automatically use Multiple Processors when available

Conclusions … Summary

- Scaling with certified lengths reduces measurement uncertainty
  - Reduced Uncertainty
  - Enhance Traceable Reporting
- Certified Length Standard are weighted in network optimization
- Instruments Uncertainty Analysis and Reports are against traceable length standards
- Target Uncertainty Field Analysis includes traceable length standards

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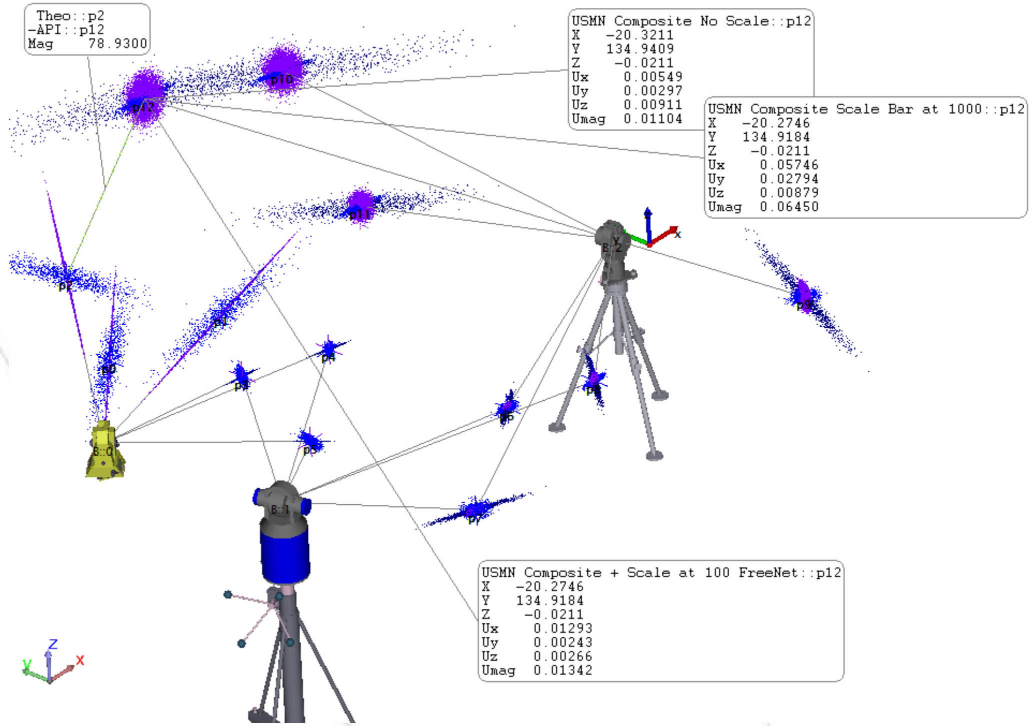
- Questions



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