SAND2010-5165P

Meter-Scale Coordinate Measuring Machine Interlaboratory Comparison

Hy D. Tran
Primary Physical Standards
Sandia National Laboratories

and the Dimensional Metrology Committee (148) & colleagues

NCSLI Workshop & Symposium
Providence, RI
July 26, 2010

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Sandia National Laboratories

Outline

- Motivation & history
- Organization of the ILC
- Measurement Instructions
- Preliminary Results
- Determination of the Reference Values
- Comparison Results
- Conclusions

Sandia National Laboratories

Why a CMM ILC?

"Laboratories measuring the same material or standard should obtain the same result to within the experimental uncertainty."

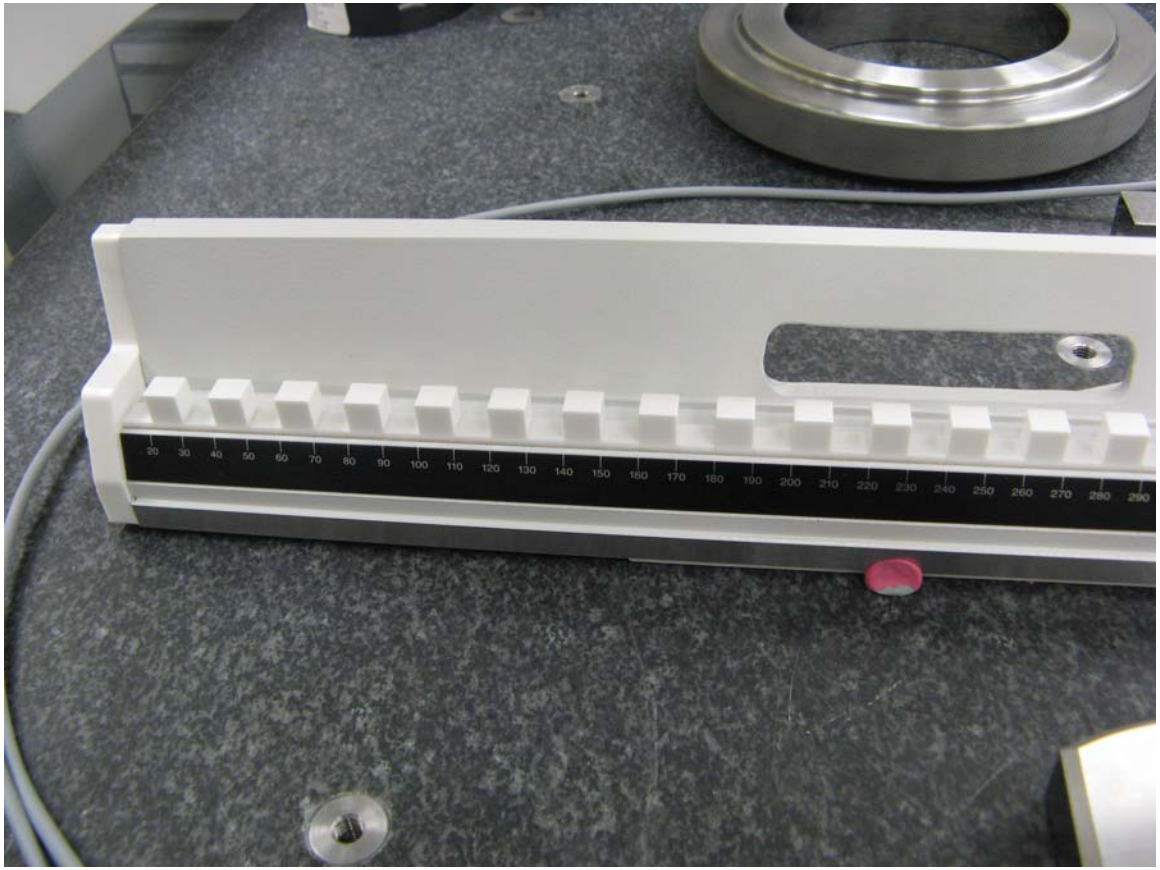
- **CMM's are complicated measurement systems**
- **Commercial CMM's now available with submicrometer specifications**
- **Use CMM's as inspection tools? Use CMM's as gage calibration tools?**

Sandia National Laboratories

ILC Organization

- Informal discussion among members of Committee 148
- Jim Salsbury volunteers a 1 meter step gage
- Hy Tran volunteers as ILC coordinator
- Each participant responsible for shipping costs & own labor costs; no charge for participation
- Circular pattern, per NCSLI RP-15

Artifact to be Measured



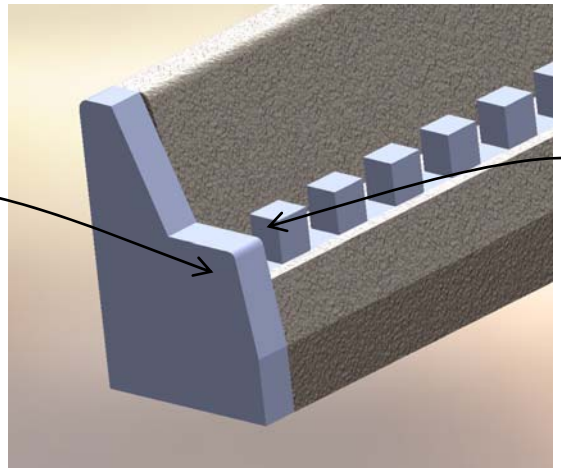
Sandia National Laboratories

Measurand

- **Distance from step(n) to index**
  - **Length measurement (meter)**
  - **Distance between two points?**

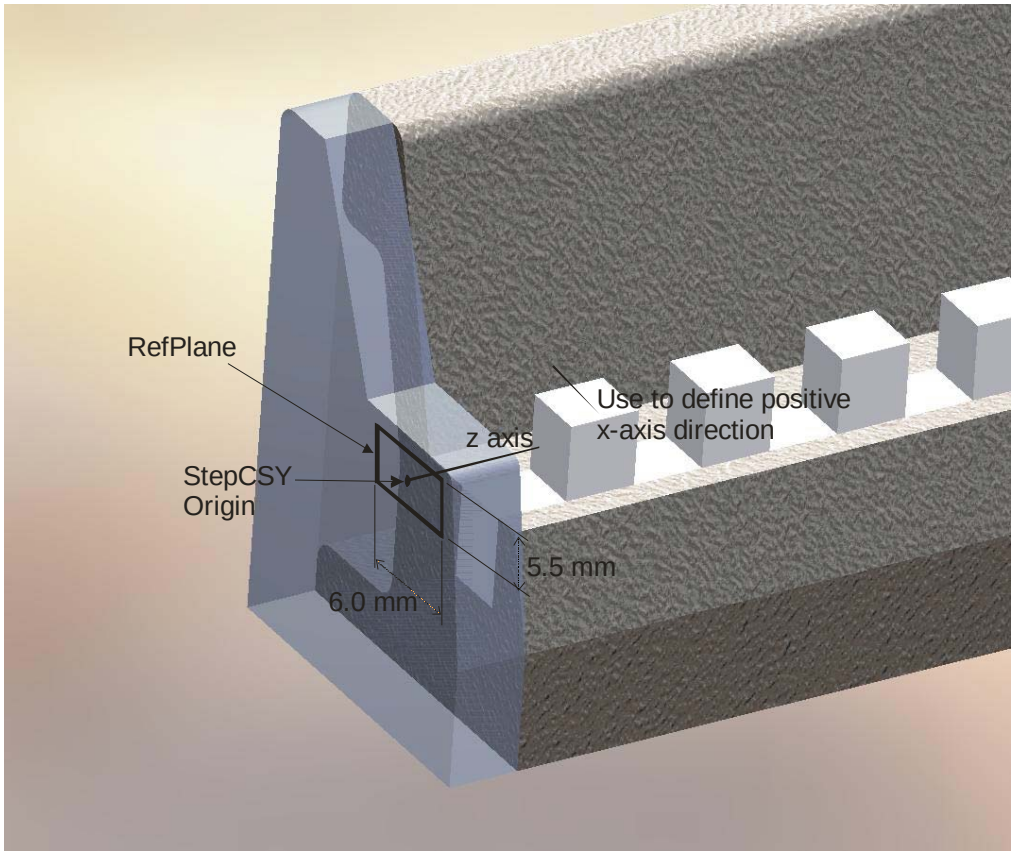
$$d = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2}$$

- **Where are the points?**
  - **Which point on a plane?**



Measurement Instructions

- **Need to define points to be measured unambiguously for all participants**
- **Use point definition described by Mitutoyo US**
- **CMM's are programmed:**
  - **Index plane sets the coordinate system (alignment)**
  - **Index plane defined by the projection of the gage blocks on the bar**



Sandia National Laboratories

Management

- Step bar provided by Mitutoyo, ID MM031
- Each step nominally 10 mm
- Not everyone is capable of measuring 1010 mm
- Each lab uses their own procedures, writes their own test program, and evaluates their own measurement uncertainties
- Data is sent to the ILC coordinator (Hy Tran). Data is kept anonymous.

Reported data

- Each participant reports distances from the index step, and U (k=2), in mm
- Coordinator assigns an anonymous code name for public reporting
- Coordinator recalculates data, as “deviation from nominal in micrometers”:
  - Step #1 has nominal=10 mm. If evaluated data shows 9.999 502 mm, show -0.498 μm
- This allows showing data on same scale for all participants
- Data will be shown in alphabetical order (by code)

Participants

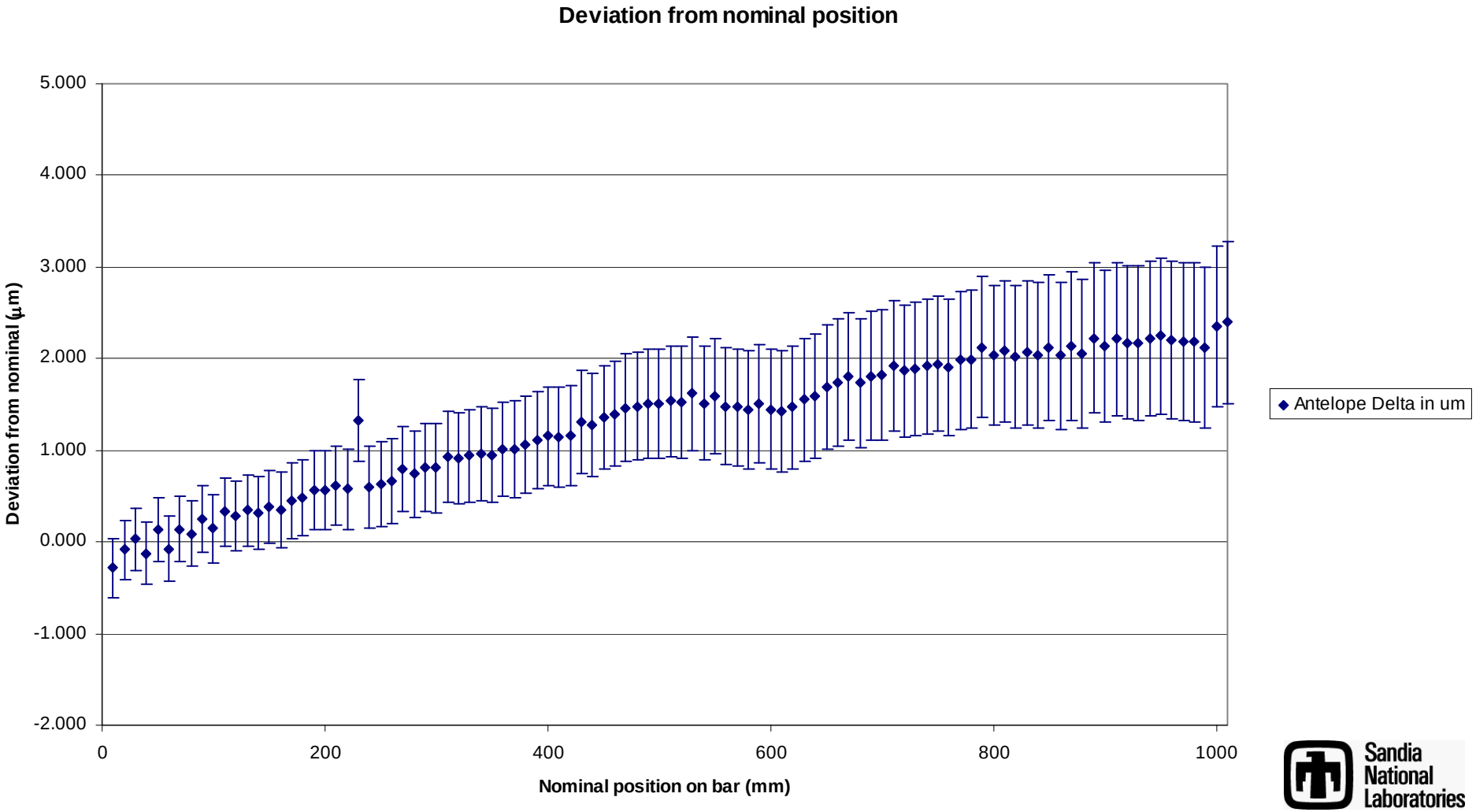
Data has been reported

- Antelopes
- Bats
- Bears
- Beavers
- Buffalos
- Cobras
- Eagles
- Frogs
- Mooses (Meese?)
- Owls

Still waiting for data

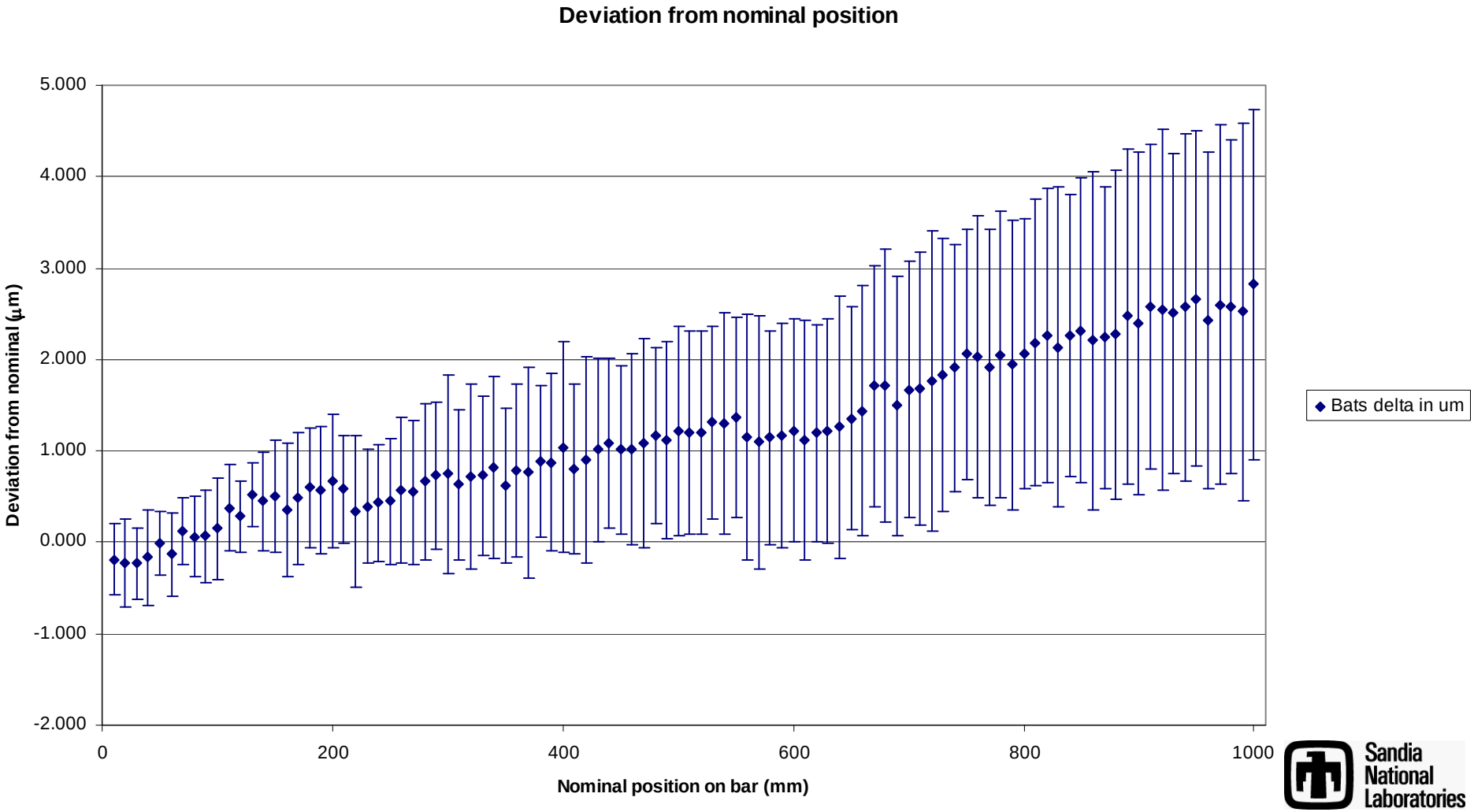
- Alligators
- Badgers
- Dragons
- Etc.

Antelopes



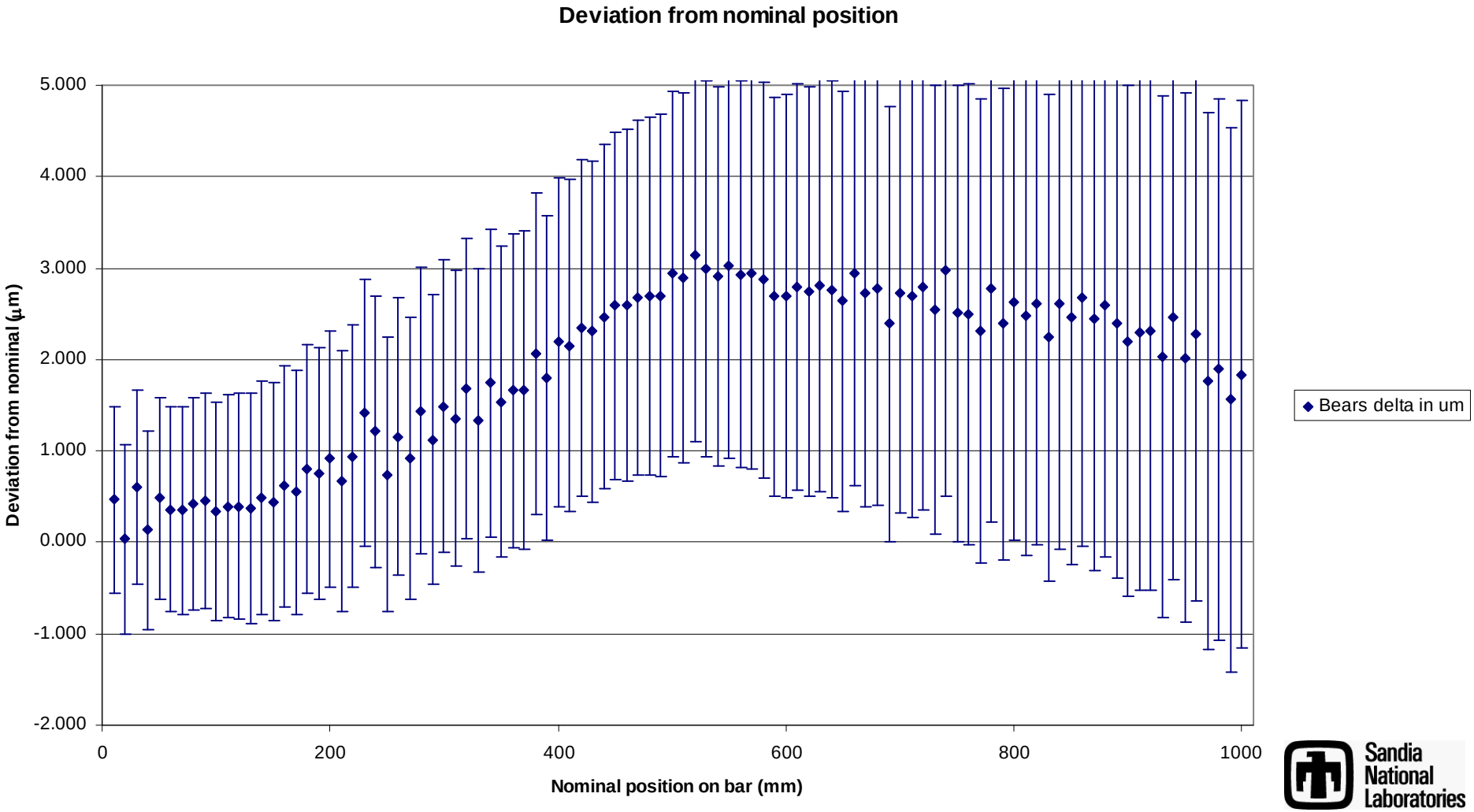
Sandia National Laboratories

Bats



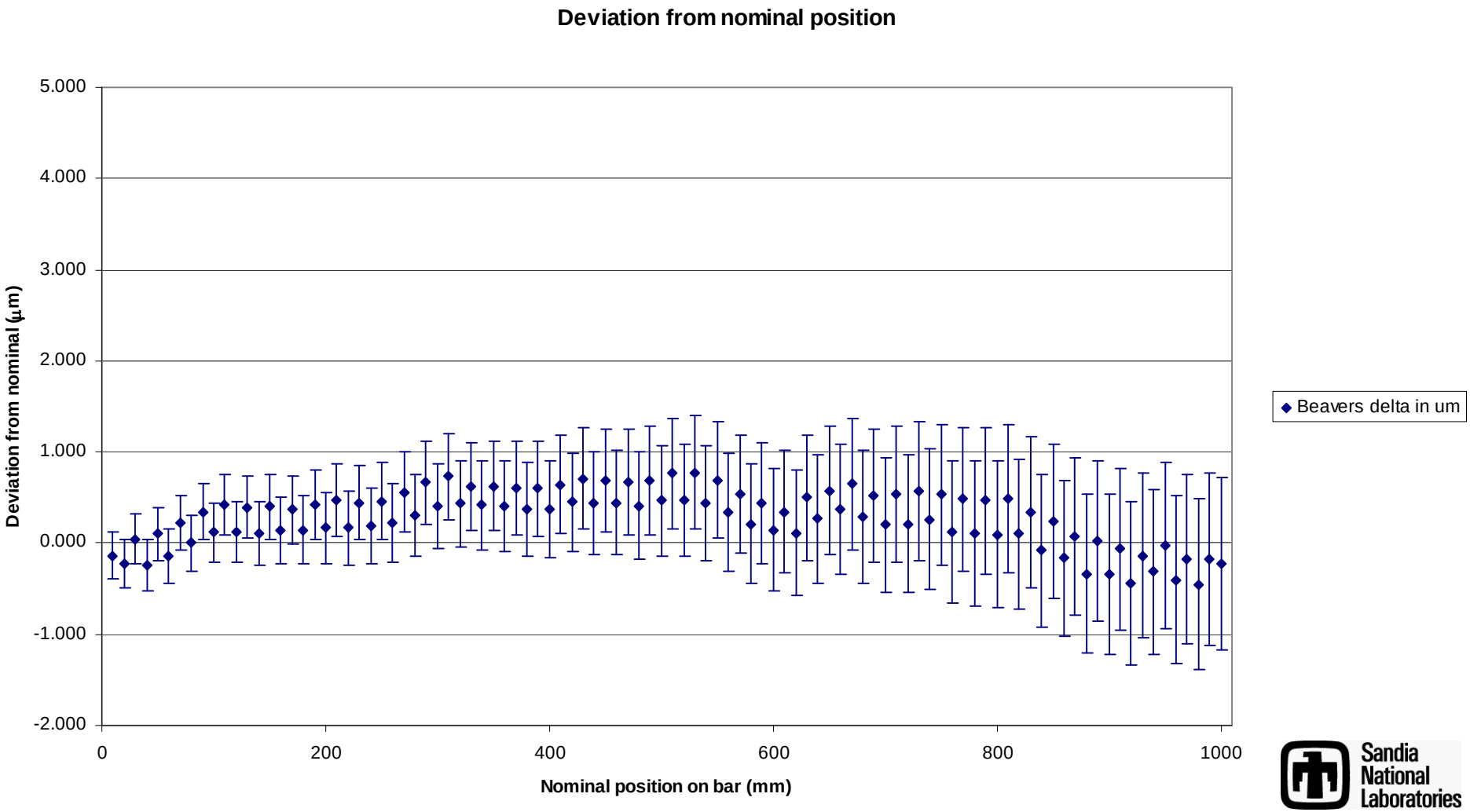
Sandia National Laboratories

Bears



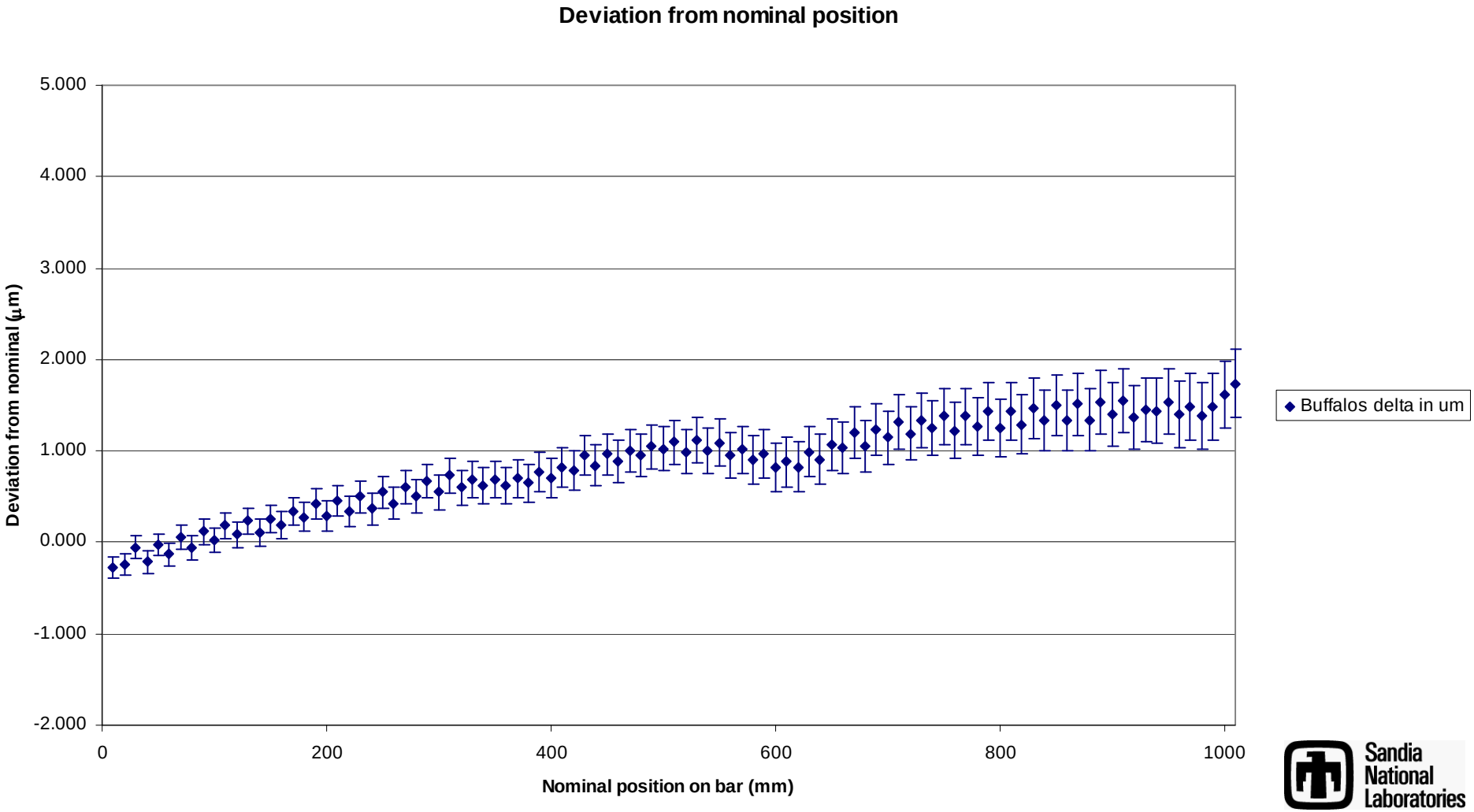
Sandia National Laboratories

Beavers



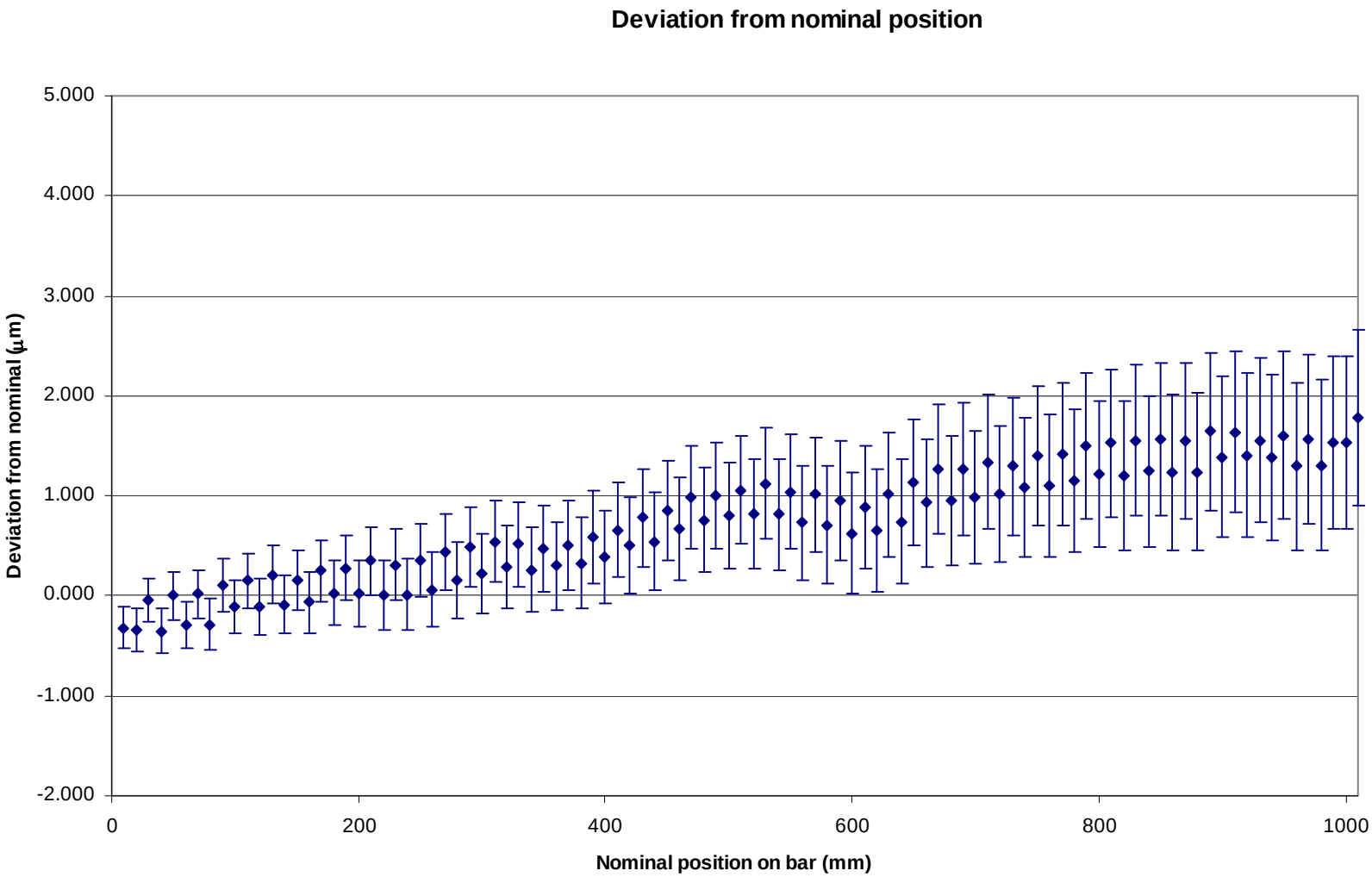
Sandia National Laboratories

Buffalos



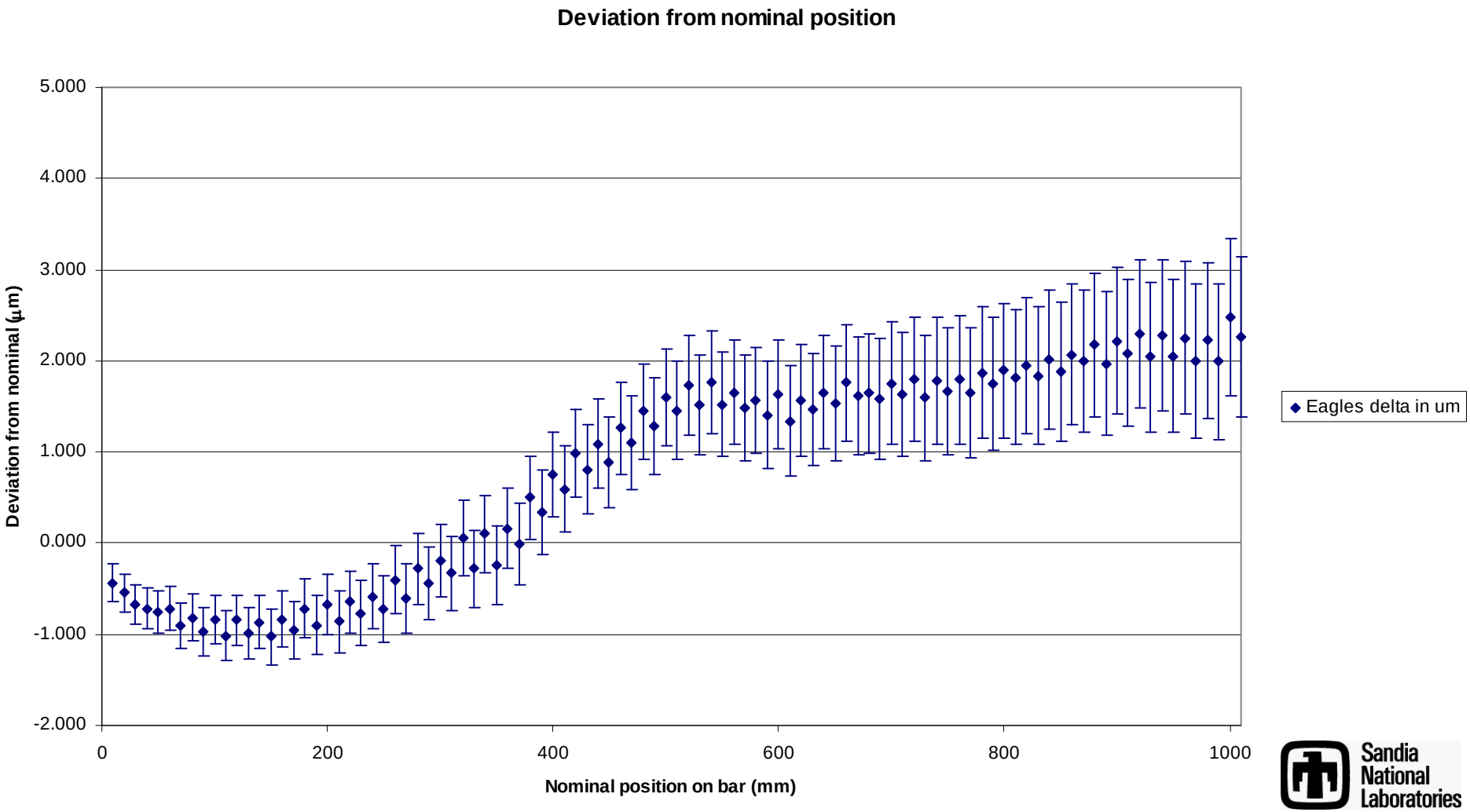
Sandia National Laboratories

Cobras



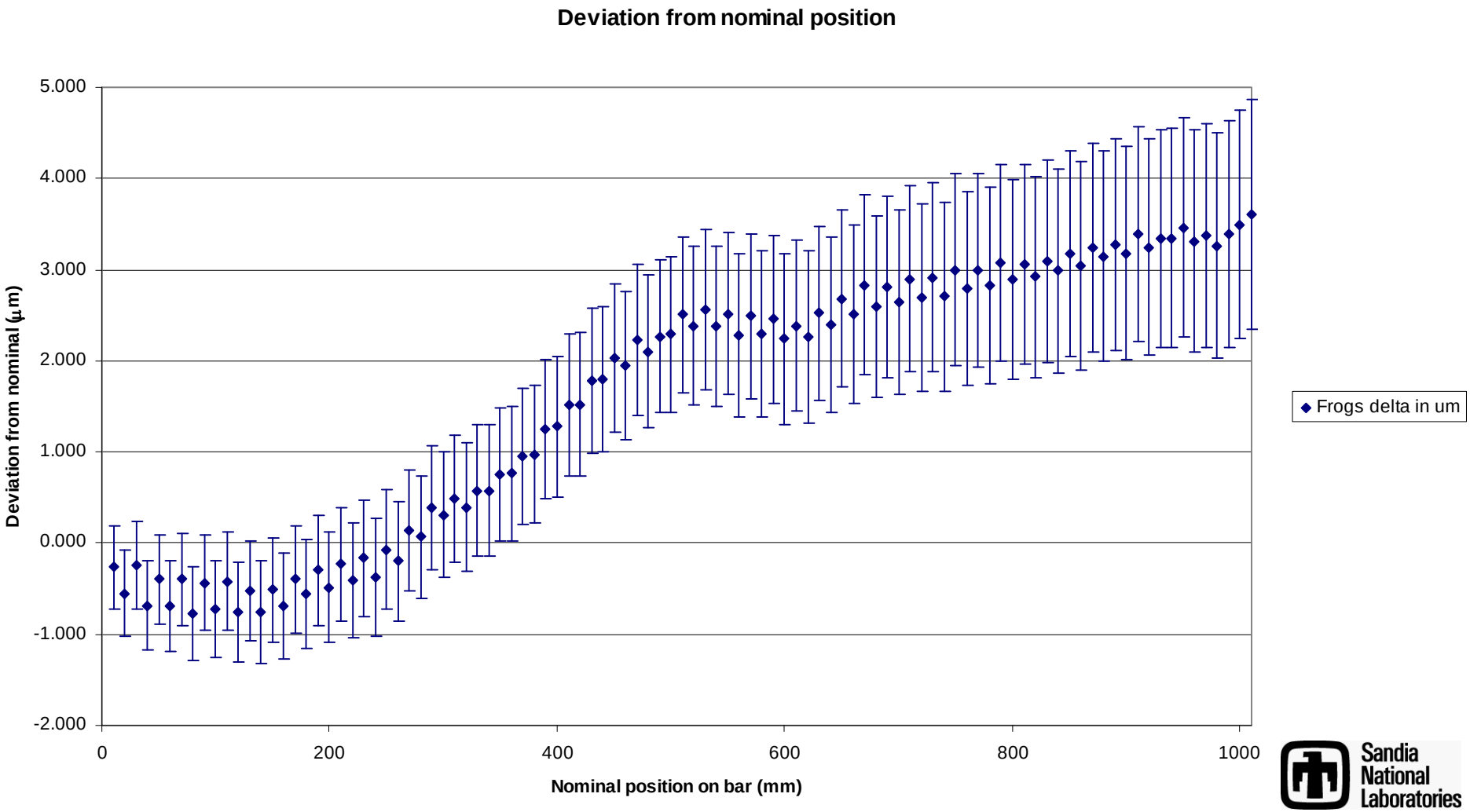
Sandia National Laboratories

Eagles



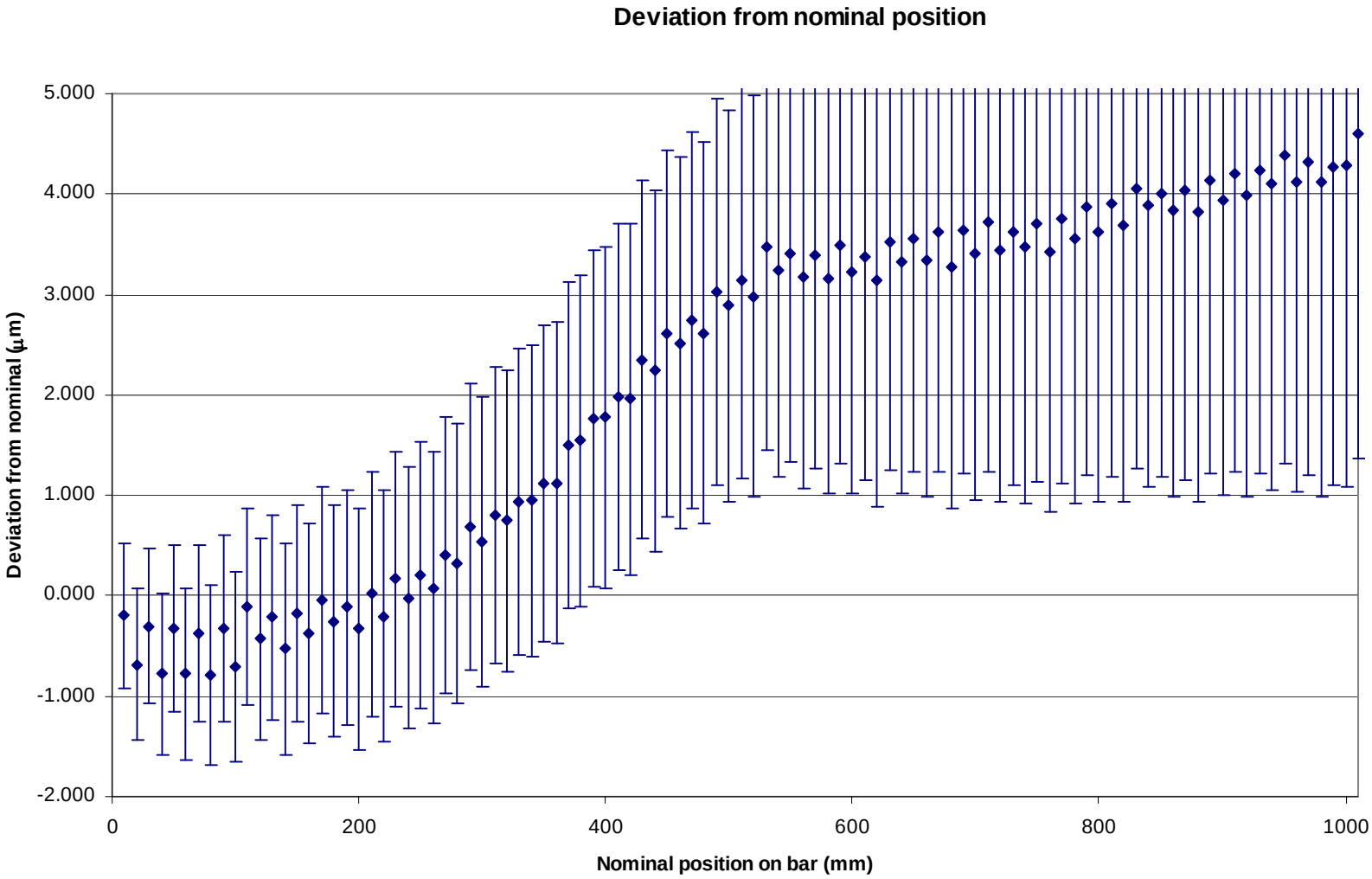
Sandia National Laboratories

Frogs



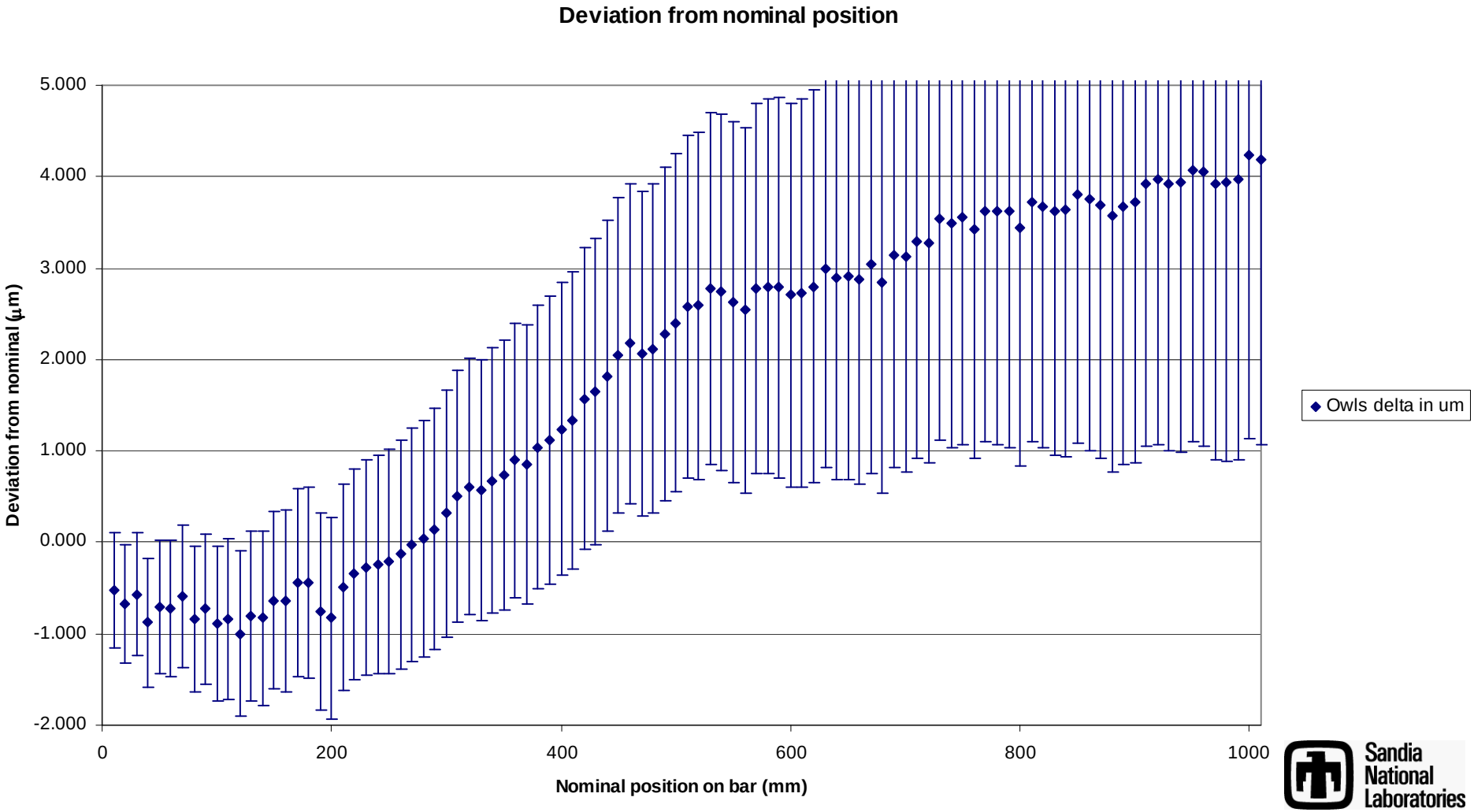
Sandia National Laboratories

Mooses



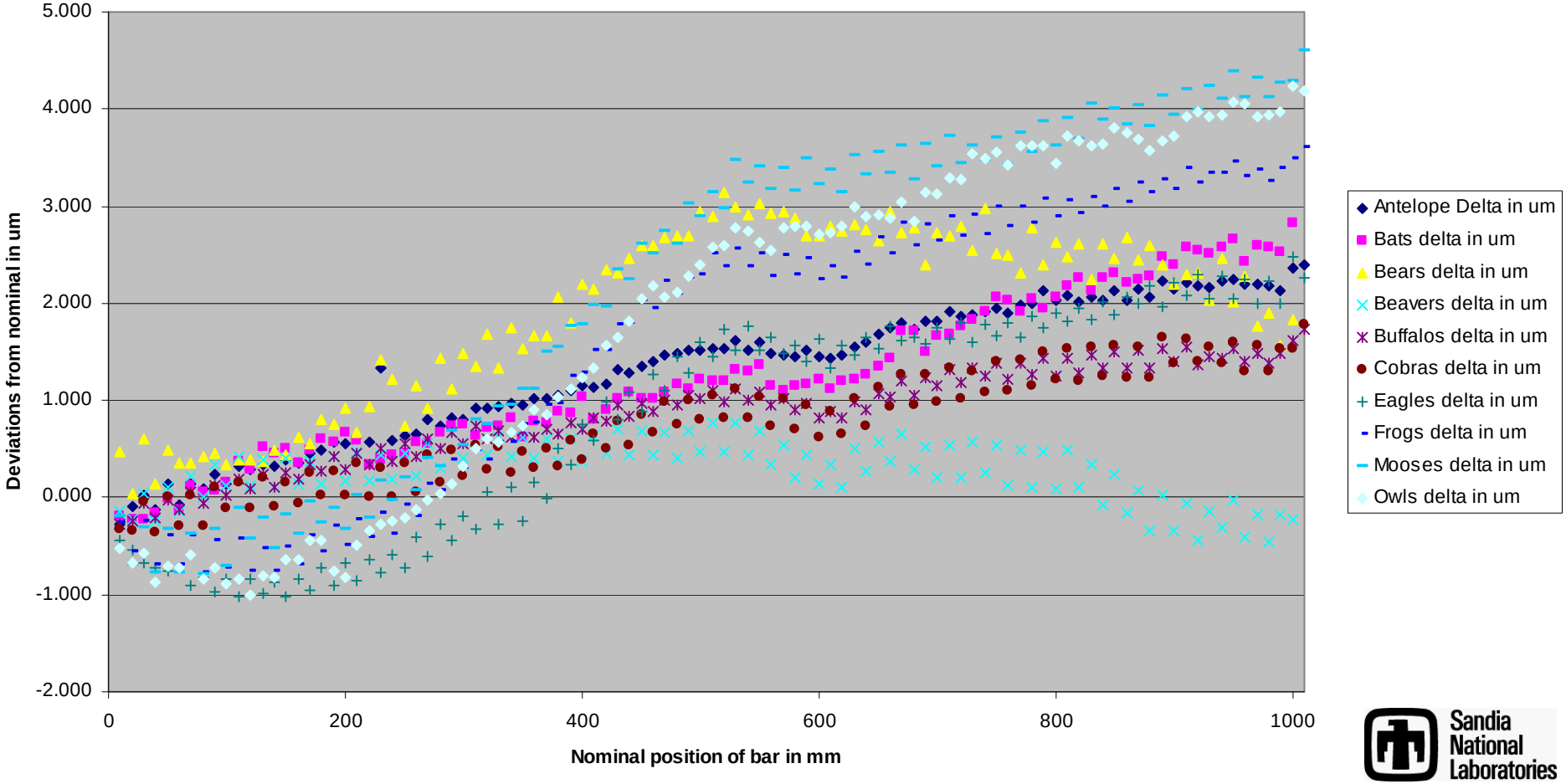
Sandia National Laboratories

Owls



Sandia National Laboratories

Everyone



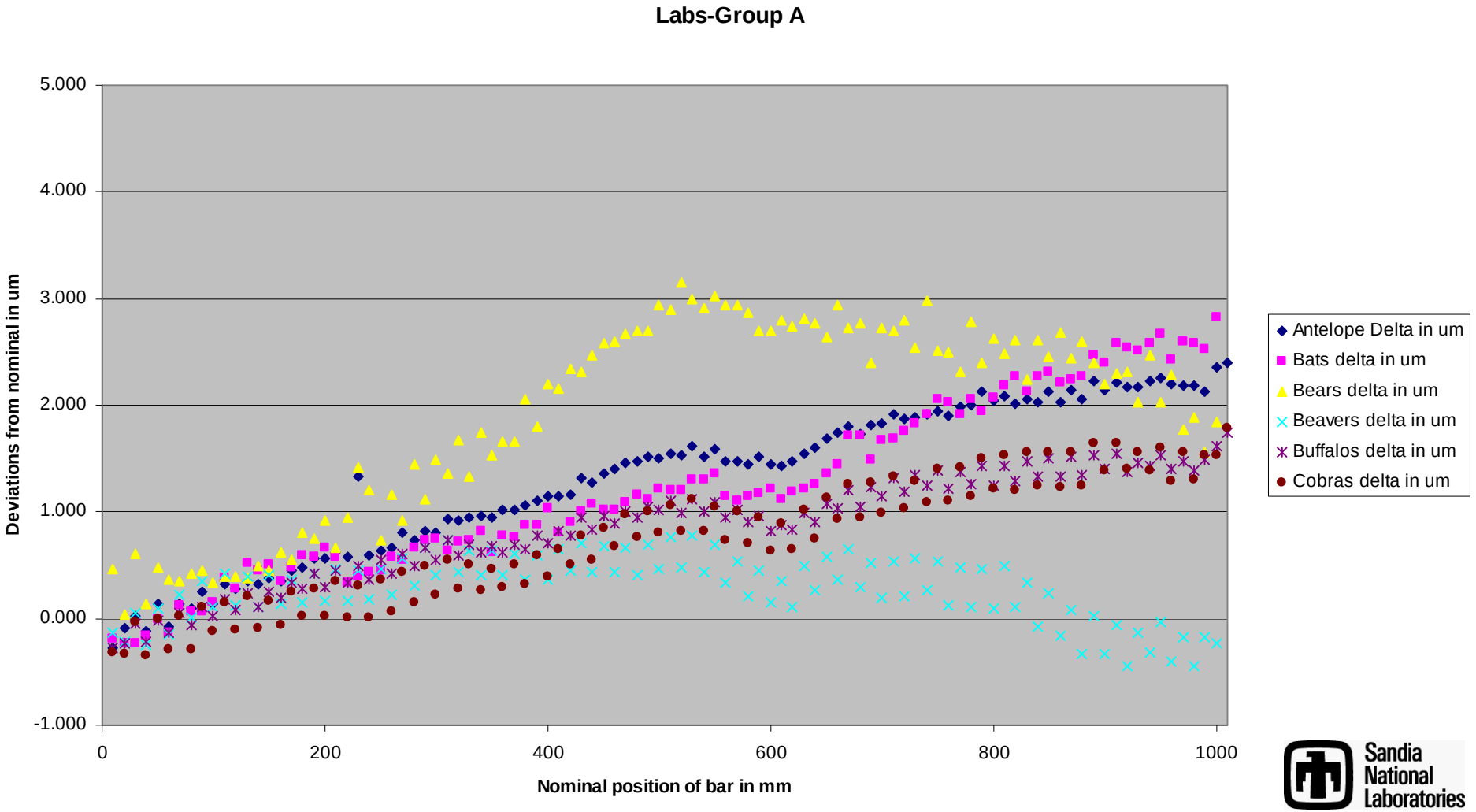
Sandia National Laboratories

What does it mean?

- **Temporal grouping:**
  - **A: Antelopes, Bats, Bears, Beavers, Buffalos, Cobras**
  - **B: Bears, Eagles, Frogs, Mooses, Owls, Beavers-2, Cobras-2**

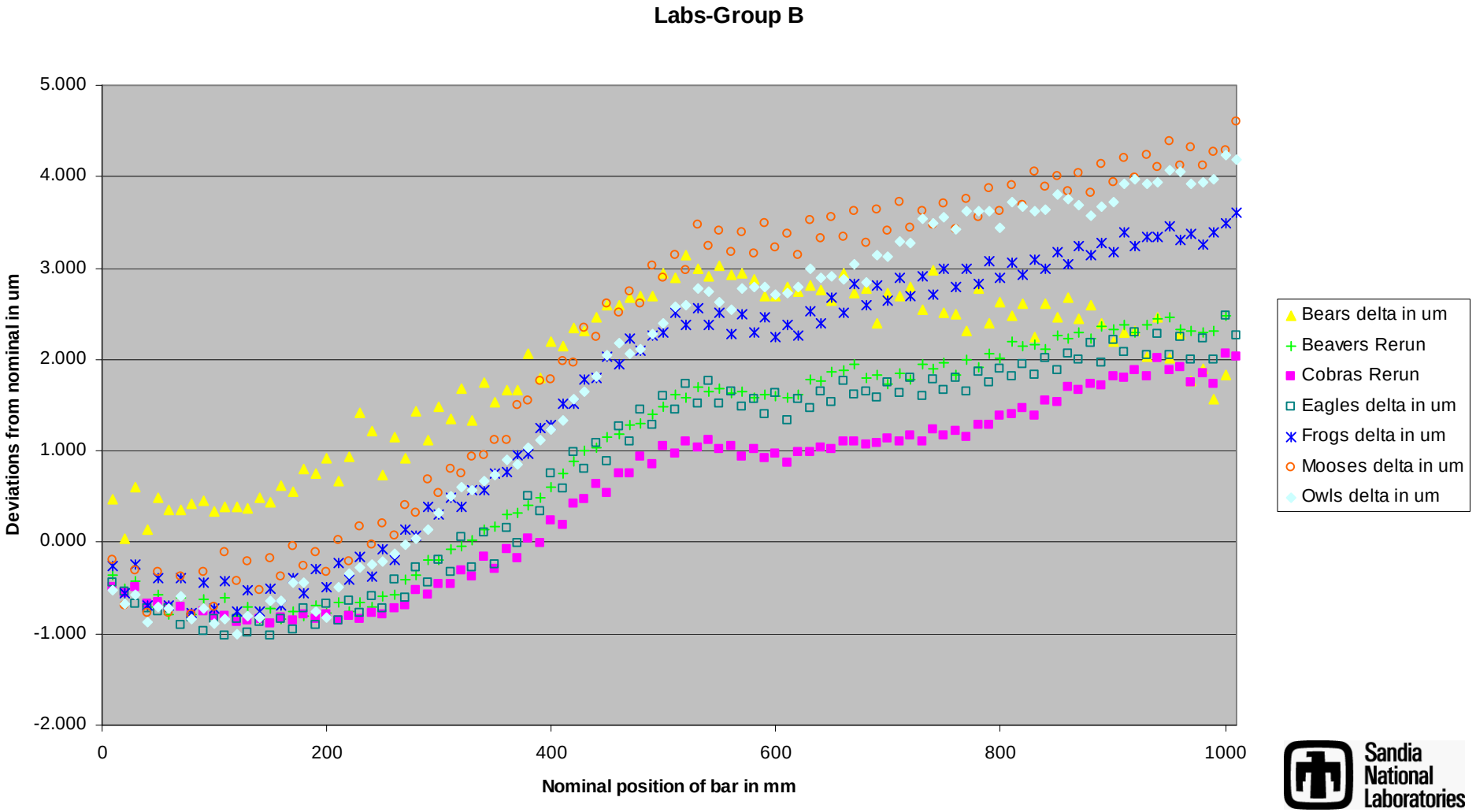
- **Bears did not run twice, but Beavers & Cobras did a second run. Bears are at the midpoint in the temporal grouping, so we plot twice**

Comparison for first measurement group



Sandia National Laboratories

Comparison of second temporal group



Sandia National Laboratories

Shift in bar

- Data indicates that step bar has physically changed.
- One lab reported damage in shipping, but this was in the middle of first time group, and 3 consecutive labs (including the lab reporting damage, middle lab) show similar data
- Inner box damage is not correlated with data shift

What's the reference value?

- **101 reference values (10mm, 20mm, …1010mm)**
- **Some labs get better results than other labs**
- **Use a maximum likelihood type algorithm to select labs for calculating reference values**
- **H Nielsen, "value voted most likely" algorithm**

- **"Visual" pick of "most likely" values**
- **Use a weighted average based on the selected labs & their reported measurement uncertainties**

$$\overline{x} = \sum_i w_i x_i$$

$$w_i = c \frac{1}{\sigma_i^2}$$

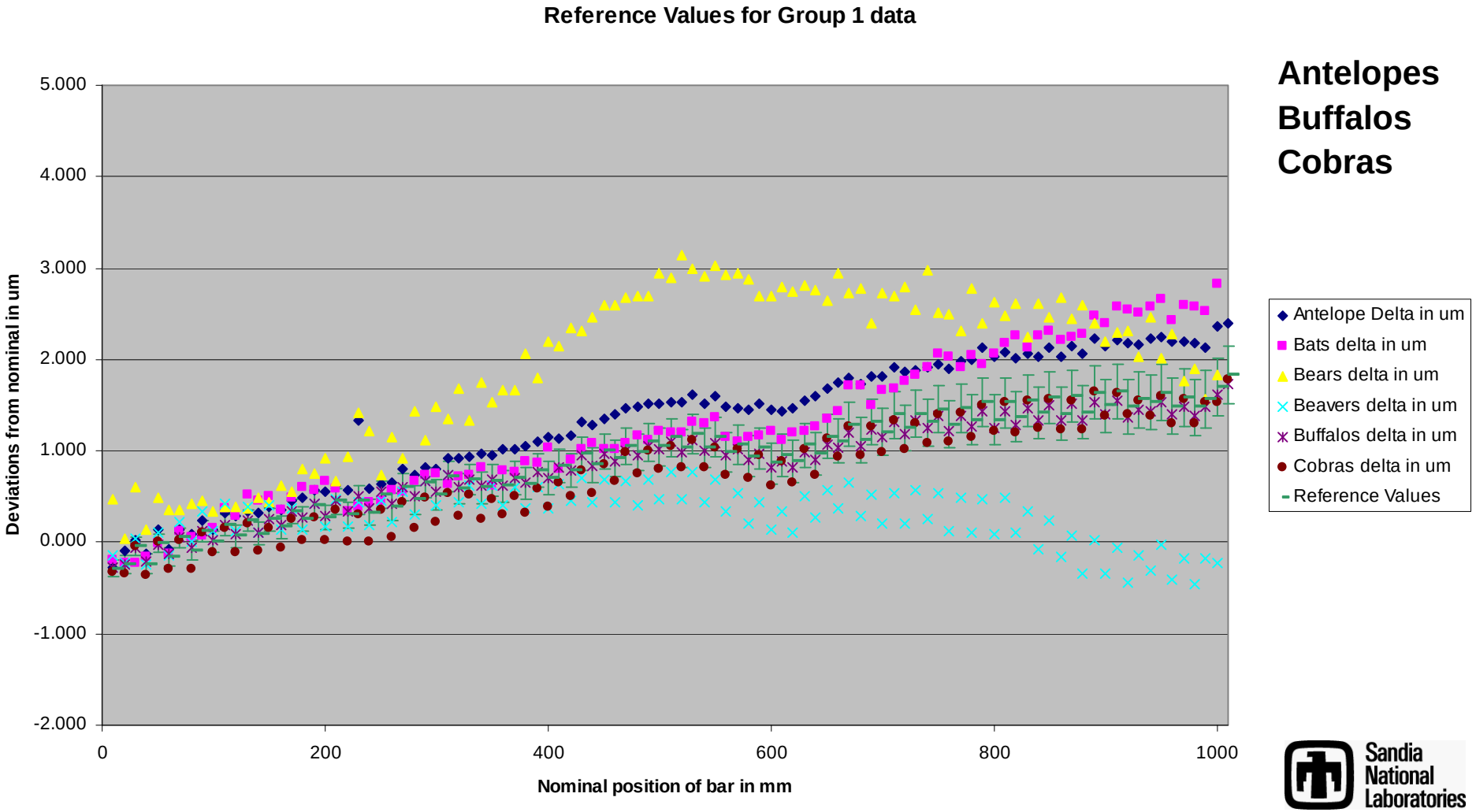
$$c = \left(\sum_i \frac{1}{\sigma_i^2} \right)^{-1}$$

$$U_{step} = k \cdot \sqrt{\left(\sum_i \frac{1}{\sigma_i^2} \right)^{-1}}$$

Note that there is a typographical error in proceedings for equation of U_{step}

Sandia National Laboratories

Value Voted Most Likely: Group 1

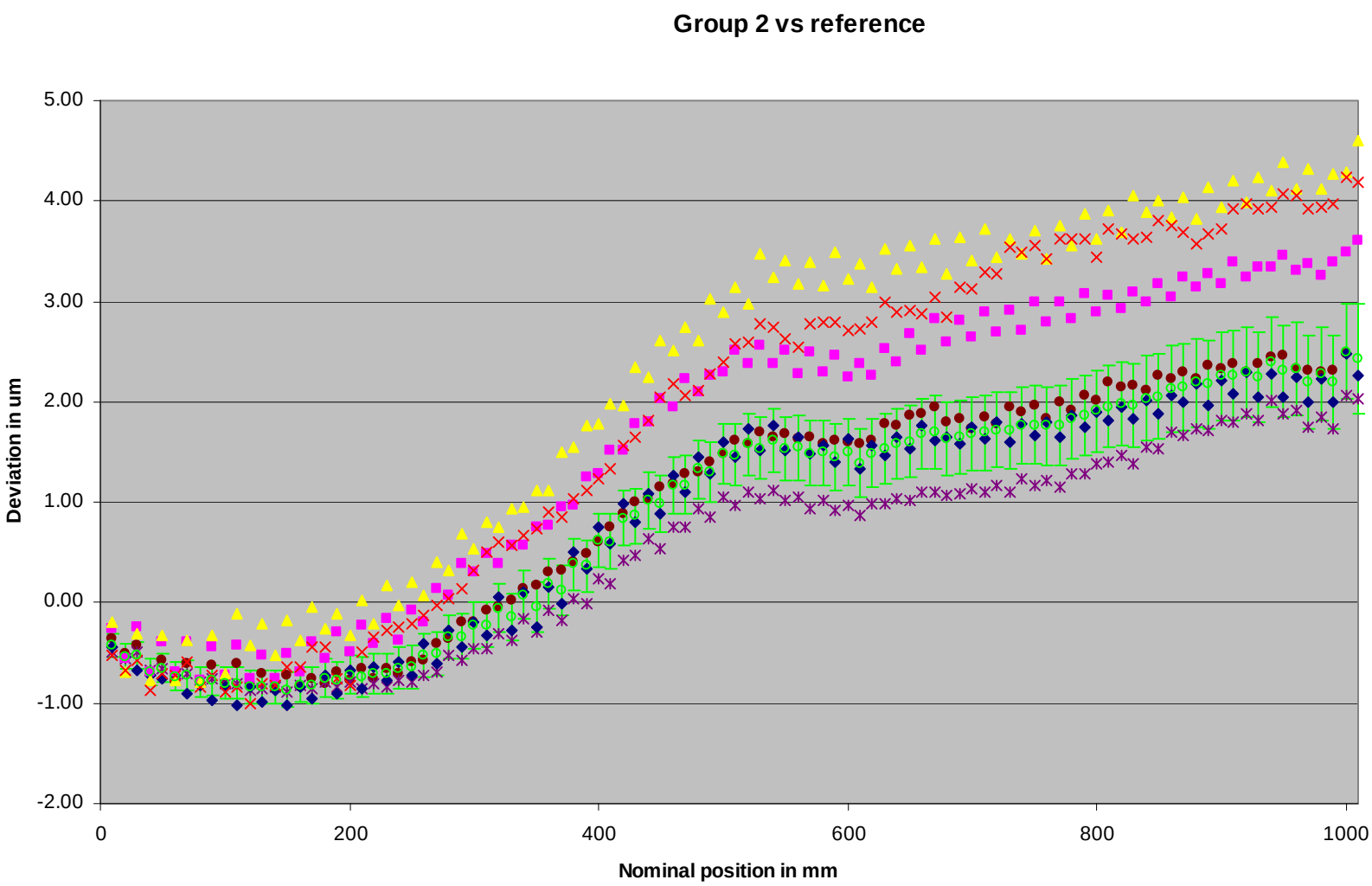


Antelopes
Buffalos
Cobras

Sandia National Laboratories

Weighted Average, Group 2

Beavers(2)
Cobras(2)
Eagles
Frogs



Sandia National Laboratories

Discussion

- **Owner of step bar has reported stable long term history for this bar**
- **Owner of step bar has reported stable long term dimensions thru shipping for this class of bars**

"Laboratories measuring the same material or standard should obtain the same result to within the experimental uncertainty."

- **Data indicates two distinct measurement groupings, which are separated in time**
- **Treat as two separate ILCs?**

Sandia National Laboratories

Results by Temporal Group: Group 1

- Temporal group 1:
  - Antelopes, Bats, Bears, Beavers, Buffalos, Cobras
  - Antelopes, Buffalos, Cobras used to determine reference value
- Antelopes, Buffalos, Cobras all report relatively small uncertainties
- Antelopes, Bats, Bears, Buffalos, Cobras, when considering U, all within weighted average for reference value
- Beavers probably had a method/setup issue

Results by Temporal Group: Group 2

- Beavers (rerun), Cobras (rerun), Eagles, Frogs, Mooses, Owls
- Mooses/Owls have significantly higher U compared to rest of group, so we don't figure into the weighted average
- Data appear to correlate well for all participants when factoring participant U

Work in progress

- Analysis still ongoing
- Additional participants & re-measurements for those labs requesting a ‘remeasure’

- Thanks to Ed Pritchard for pushing the ILC idea; Jim Salsbury for providing the artifact, & John Stoup, Mike Wheeler, Paul Vanatta, Mike Cadenhead, John Horwell, Sam Ramsdale & personnel for volunteering (or being volunteered!)

End of presentation

- **Extra slides below**

Sandia National Laboratories

Various Step Gage Calibration Methods

July 26, 2010

Hy D. Tran
Primary Physical Standards
Length/Mass/Force Metrology
Sandia National Laboratories

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Step Gage measurement at Sandia

- Method/setup
  - Check standards
  - Environment
- Calibration of CMM & traceability
- Estimate of U

Sandia National Laboratories

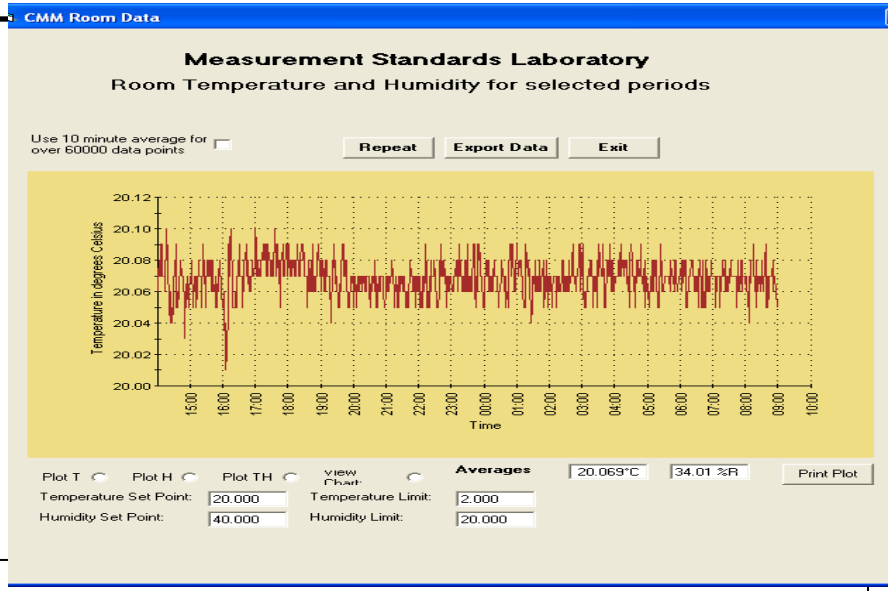
Equipment & setup

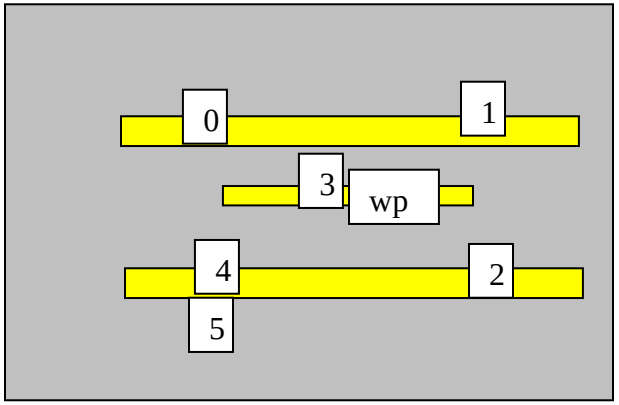
- **Leitz PMM-C-Infinity 12.10.6 (fixed bridge, moving table; XFYZ), installed 6/2008**
- **MPE_e=(0.3+L/1000)μm**
- **80mm long × 5mm stylus**
- **Probing force set to 0.05 N**
- **Point probing chosen**
- **Programmed in Quindos v7**
- **Temperature compensation performed offline**

Brands listed for identification purpose only

Sandia National Laboratories

Measurement environment





0.05°C temperature difference across 6 thermistors in workspace

Sandia National Laboratories

Measurement program

- Workpiece fixed with modeling clay on table
- Stylus qualified, then, checked on 500 mm gage block
- Manual alignment, then, automatic alignment
- Each face measured as a plane (0 face is large plane; each other face is small)
- Step bar is cleaned if plane has bad form
- 5-7 measurements are run overnight with no operator in room
- Temperature correction manually offline
- Average of measurements used

Calibration, traceability, & uncertainty

- **Machine is calibrated by Leitz/Hexagon field service**
  - **Initial calibration using HP/Agilent 5528 laser interferometer system for scales**
  - **Mapping of axis error motions using interferometer, levels, straightedge, & offset probes on step bar**
  - **Verification to ISO 10360 against step bar (traceable to NPL) and gage blocks (traceable to PTB)**
  - **Temperature by thermistors calibrated to SPRT to fixed point cells**
- **Uncertainty-the lazy method:**
  - **MPE_e is k=3, so $U=(2/3)\times MPE_e$**
  - **MPE_e is rectangular, so $U=2\times 0.577\times MPE_e$**

Sandia National Laboratories