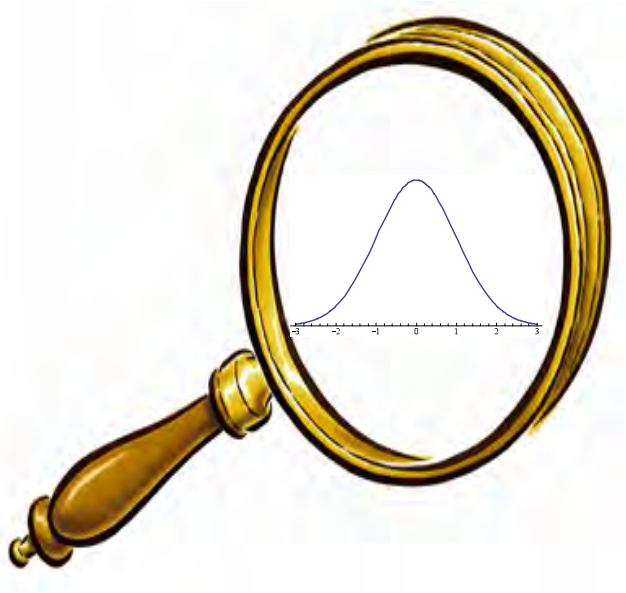
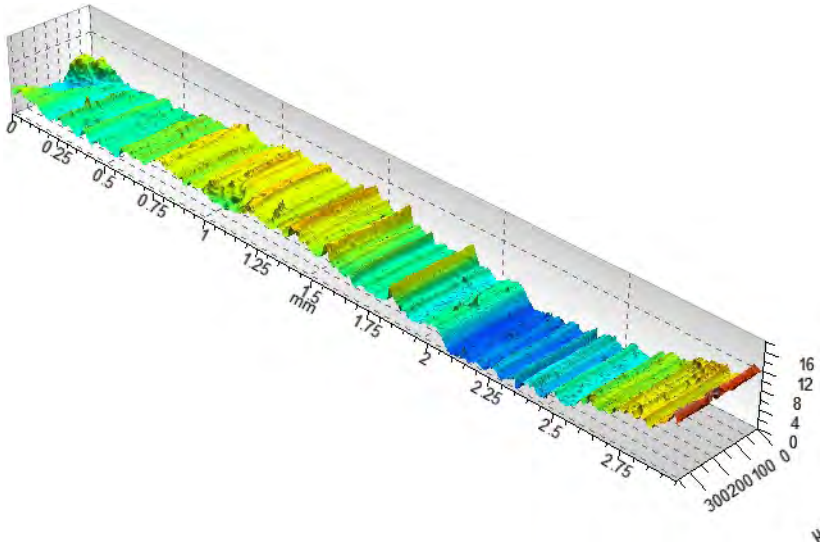
Addressing the National Academy of Sciences' Challenge:





Methods for Statistical Pattern Comparison of Striated Tool Marks

Outline

- Introduction and the Daubert Standard
- Previous Statistical Studies on Striated Tool Marks
- Details of Our Approaches
  - Results of “Low Cost” method
  - Preliminary Results with Confocal Microscopy

Introduction

- DNA profiling the most successful application of statistics in forensic science.
  - Responsible for current interest in “raising standards” of other branches in forensics…??
- No protocols for the application of statistics to comparison of tool marks.
  - Our goal: **application of objective, numerical computational pattern comparison to tool marks**

Caution: Statistics is not a panacea!!!!

The Daubert Standard

- Daubert (1993)- Judges are the "**gatekeepers**" of scientific evidence.
- Must determine if the science is reliable
  - Has **empirical testing** been done?
    - **Falsifiability**
  - Has the science been subject to **peer review**?
  - Are there known **error rates**?
  - Is there **general acceptance**?
- Federal Government and 26(-ish) States are "Daubert States"

Previous Statistical Studies On Striated Tool marks

- Basiotti 1959, **Consecutive Matching Striations**
- Geradts 1994, **TRAX** database
- Neel and Wells 2007, **CMS testing**, 4000 striated tool mark comparisons.
  - "There is a statistically significant difference between the CMS runs observed in the best KNM and the most conservative KM."
- Bajic, Morris, Chumbley, Craft *et al*. (2007, 2010)
  - Database of striated tool mark profiles and corresponding software for identifications

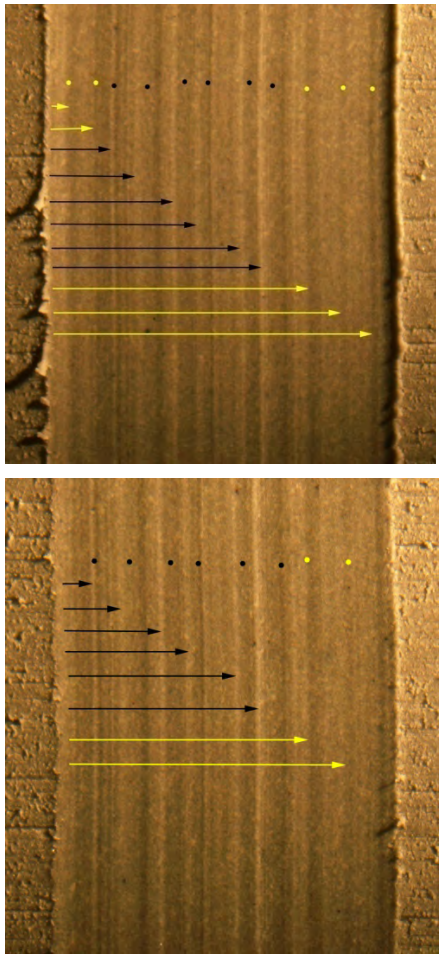
Previous Statistical Studies On Striated Tool marks

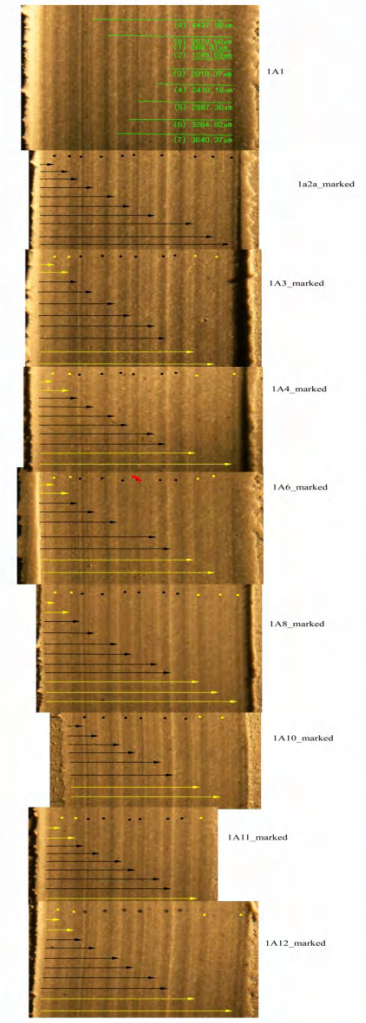
- Howitt, Tulleners et al. (2008)
  - A theory for striation patterns
- Bachrach, Koons et al. (2010),
  - Screwdrivers and Pliers
  - ID software for use with confocal microscopy
- Wei, Vorburger, Ballou, et al. (2010)
  - L.E.A.s on bullets
  - Also ID software for use with confocal microscopy

“Low cost” Approach For Striated Tool Marks

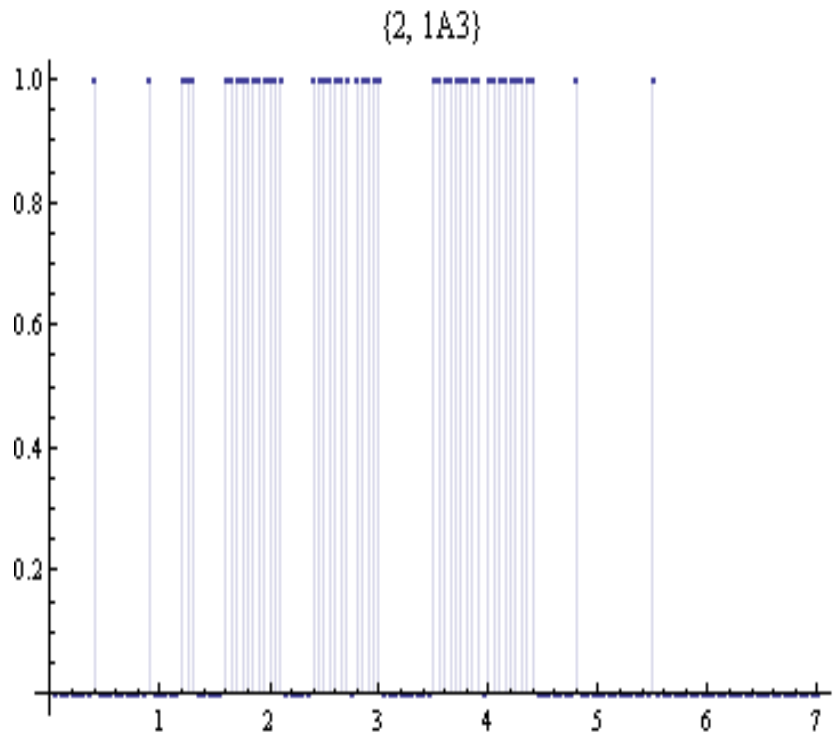
- Collect several high quality 0.25’’ slotted screwdrivers
  - All screwdrivers purchased in packages of three

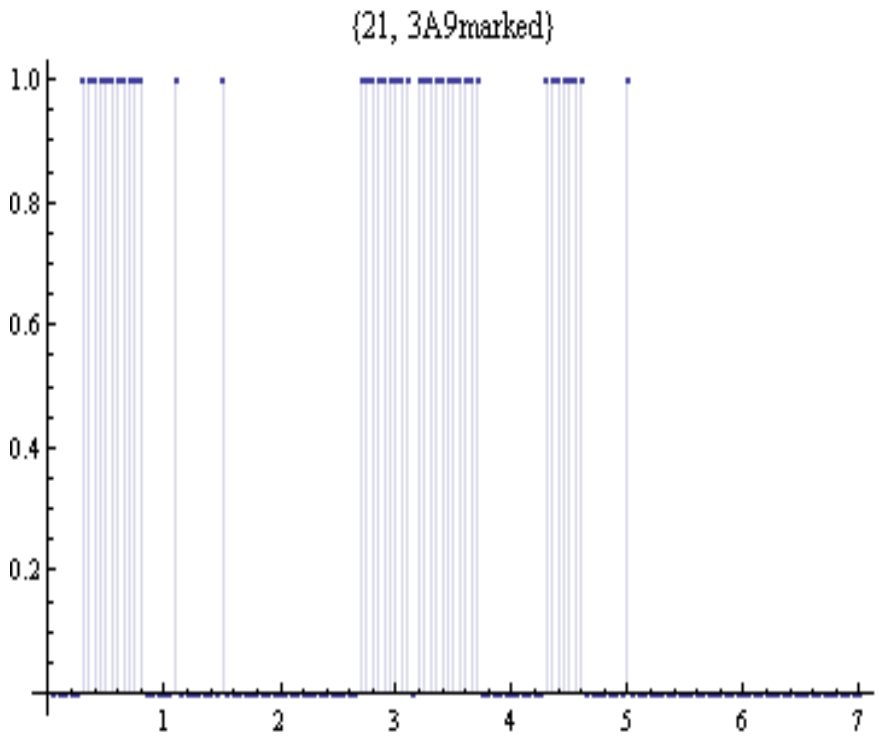
- Generate many standard reproducible striation patterns for each screwdriver.
  - Modeling clay used as impression medium





- Measure line/grove positions from edges of patterns
- Descritize width of pattern into 0.05 mm increments
  - In list 140 increments long (7 mm) record 1 if line/grove in a box, 0 otherwise
    - Gives 140-dimentional **feature vectors** for each pattern

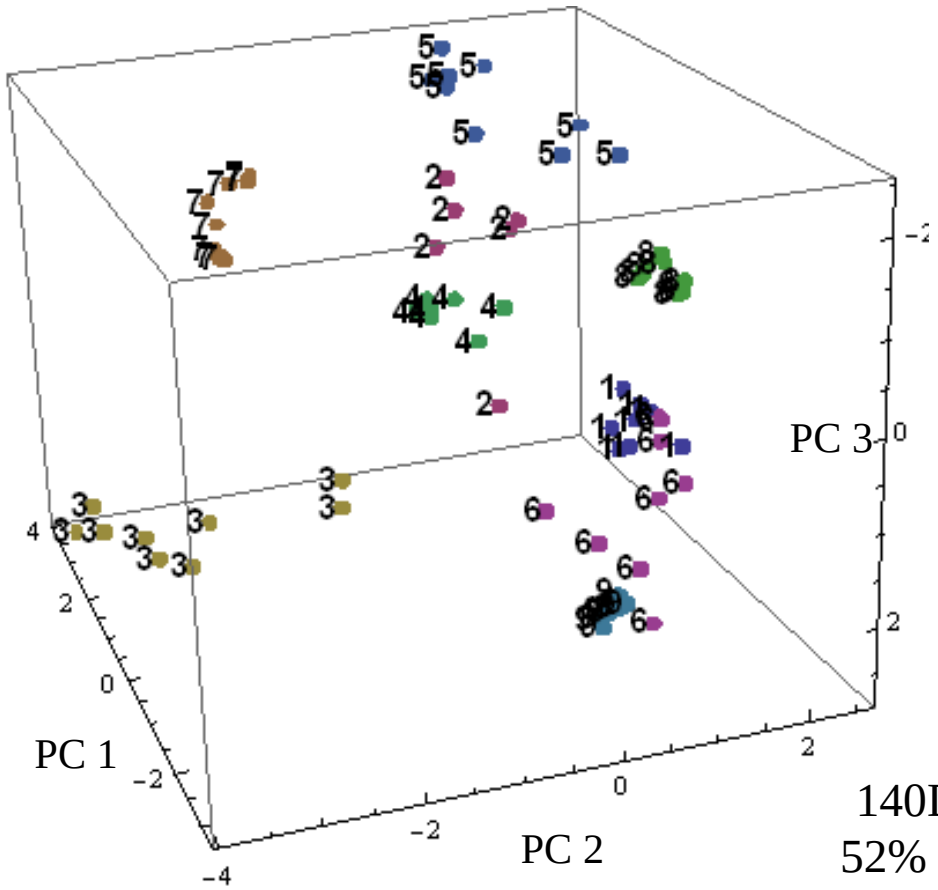


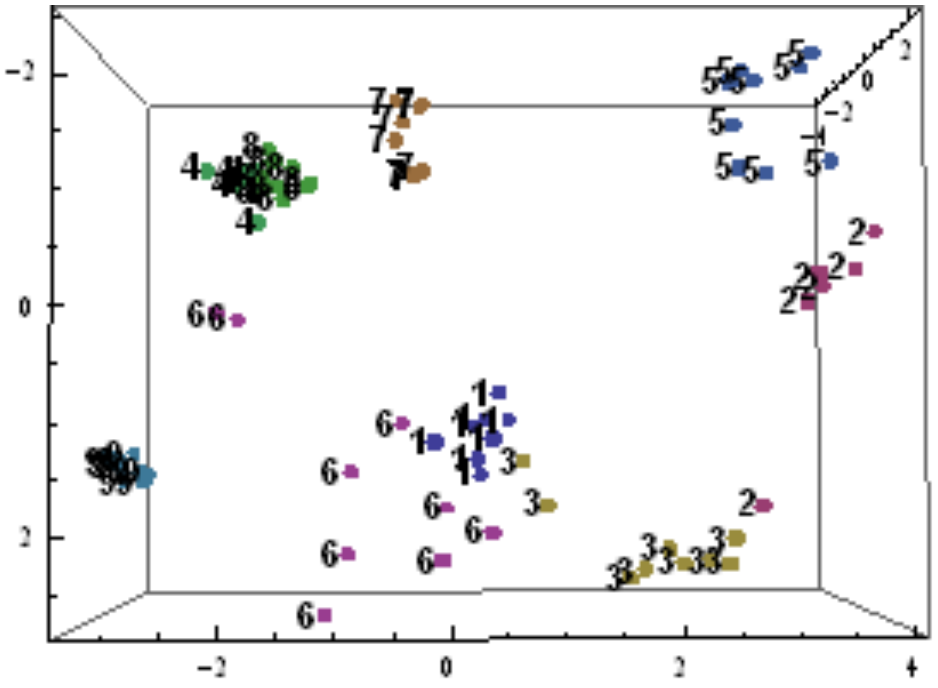


- Slightly shift intra-screwdriver patterns if necessary (**registration**)
- For this study:
  - Nine screwdrivers so far
  - Data recorded for side A of screwdrivers
    - Screwdriver 1, 8 striation patterns
    - Screwdriver 2, 6 striation patterns
    - Screwdriver 3, 9 striation patterns
    - Screwdriver 4, 8 striation patterns
    - Screwdriver 5, 9 striation patterns
    - Screwdriver 6, 9 striation patterns
    - Screwdriver 7, 8 striation patterns
    - Screwdriver 8, 9 striation patterns
    - Screwdriver 9, 9 striation patterns
  - Total 75 striation patterns so far

Statistics

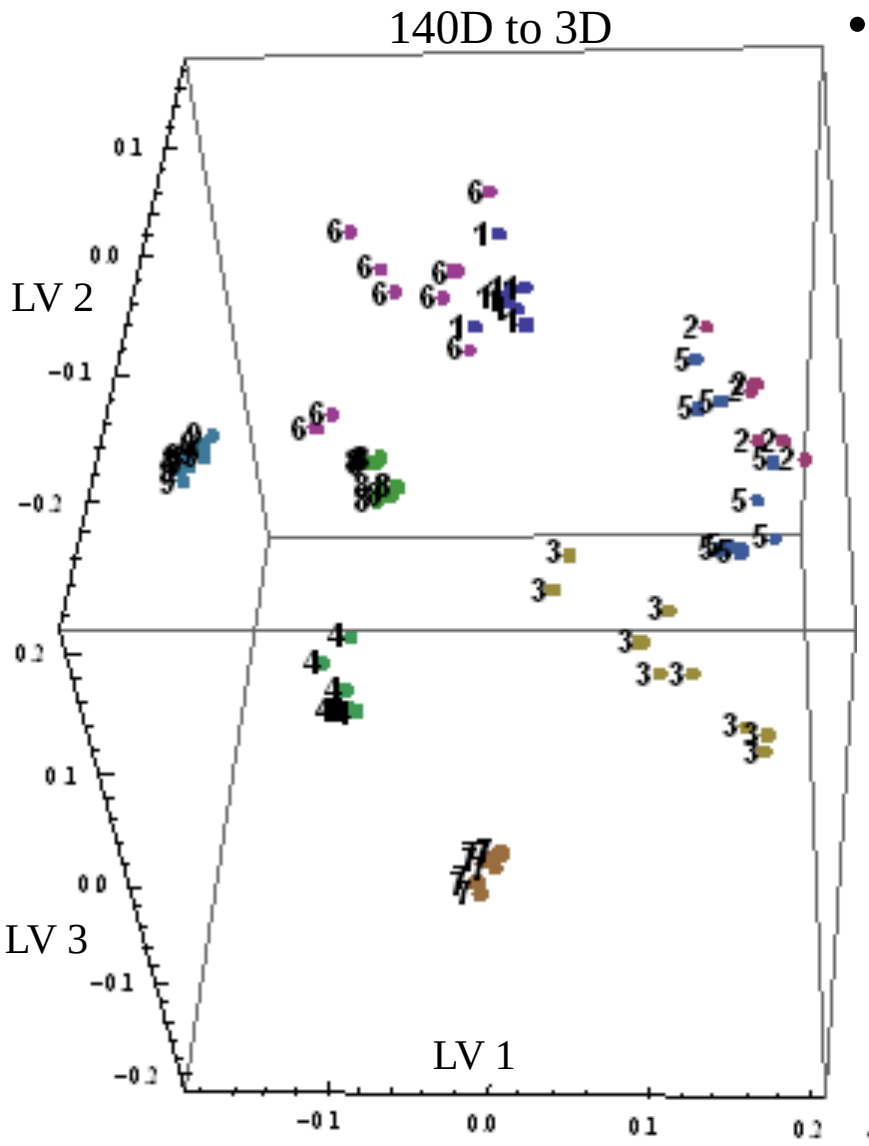
- Principal Component Analysis
  - Why?
    - Judges and Juries Like Pictures!!





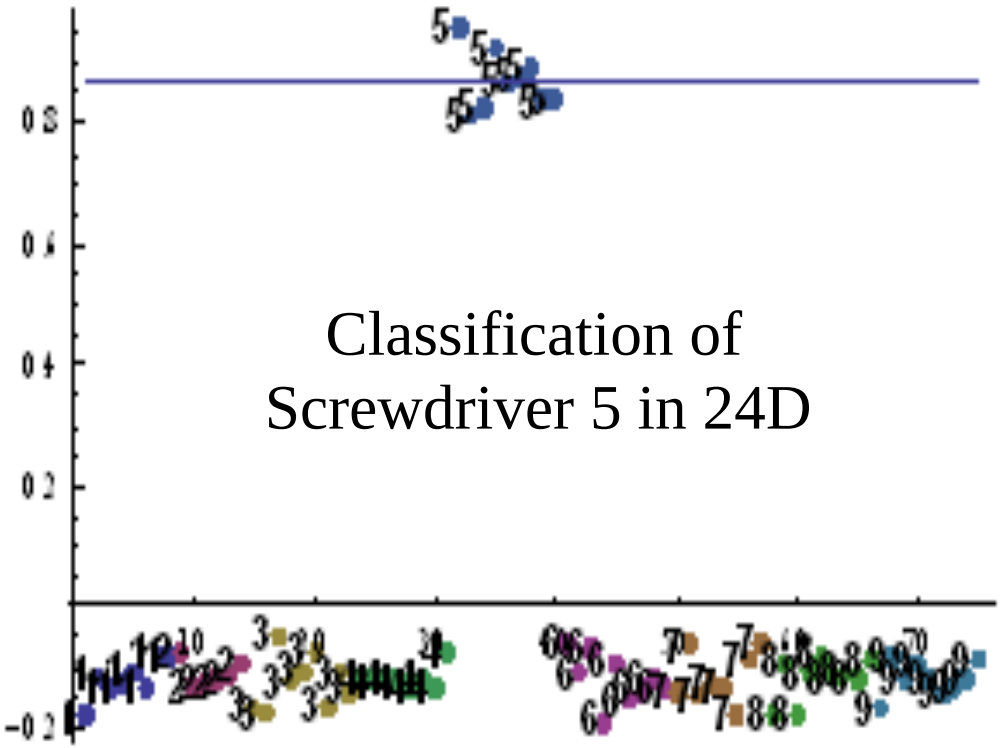
140D to 3D
52% variance

- Kernel Partial Least Squares



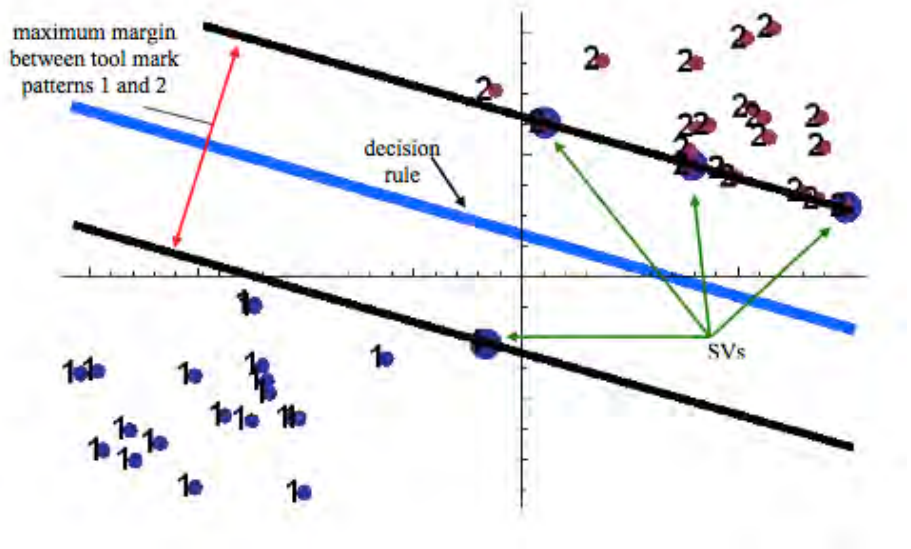
- Find lowest dimensional "summary" of striation pattern that is still able to predict screwdriver identity.

$$\hat{\mathbf{Y}} = \hat{\mathbf{X}}\mathbf{Q}^{T} + \mathbf{Err}$$



Pattern Identification and Error Rates

- Determine efficient decision rules in the absence of any knowledge of probability densities for the data
  - Maximum margins of separation, **SVM**:



- 4D PCA-SVM
  - Range of estimated error rates: 0%-2%
- 8D PLS-DA
  - Range of estimated error rates: 0%-3%

- Conformal Prediction Theory
  - New, but has roots in 1960's with *Kolmogorov's* ideas on *randomness* and *algorithmic complexity*.
  - Can be *used with any* statistical pattern classification *algorithm*.
  - *Independent of* data's underlying *probability distribution*.
    - This is a very important property for forensic tool mark analysis!!
  - For identification of patterns, method produces:
    - Level of **confidence**, 1-ε
      - Measure of how likely identification is to be correct
    - Level of **credibility**
      - Indicative of quality of data set
  - Results are *valid*: $P(\text{error}) \leq \varepsilon$

- Conformal Prediction Theory
  - 95% CPT on **3-nearest neighbour** classification rules :

	Data Dimension		
On-Line Mode	4D	121D	121D-SIM
% Error	0%	6%	4%
% Unique and Correct I.D. Produced	100%	94%	96%
% Efficiency	100%	100%	100%
% Empty Intervals	0%	6%	4%
Off-Line Mode			
% Error	0%	6%	6%
% Unique and Correct I.D. Produced	100%	94%	94%
% Efficiency	100%	100%	100%
% Empty Intervals	0%	6%	6%

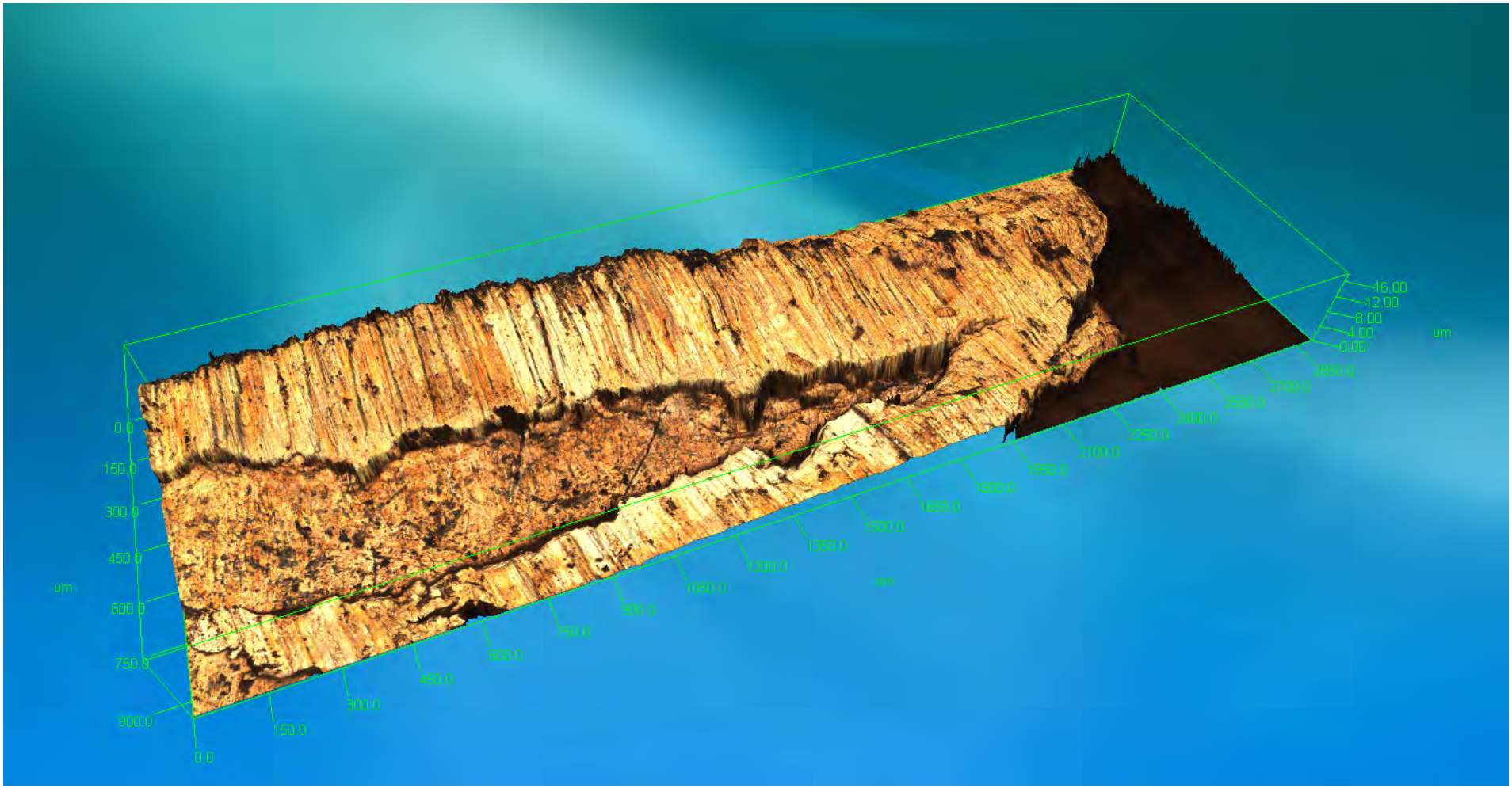
  - 95% CPT on **PCA-SVM** classification rules :

	Data Dimension		
On-Line Mode	4D	121D	121D-SIM
% Error	6%	6%	4%
% Unique and Correct I.D. Produced	94%	94%	96%
% Efficiency	100%	100%	100%
% Empty Intervals	6%	6%	4%
Off-Line Mode			
% Error	0%	6%	3%
% Unique and Correct I.D. Produced	100%	88%	97%
% Efficiency	100%	94%	100%
% Empty Intervals	0%	6%	3%

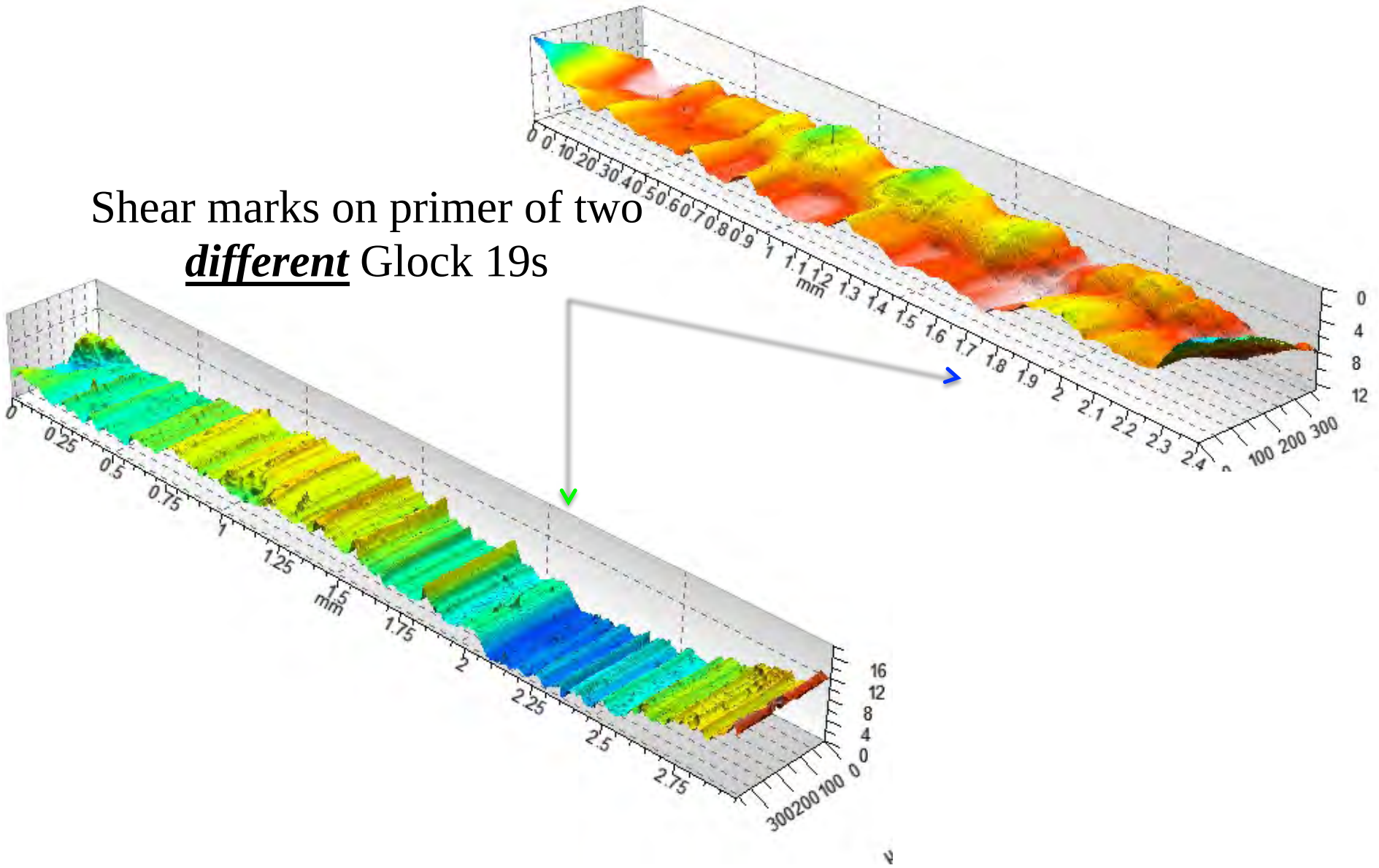
Current Approach For Striated Tool Marks

- Obtain striation pattern profiles form 3D confocal microscopy

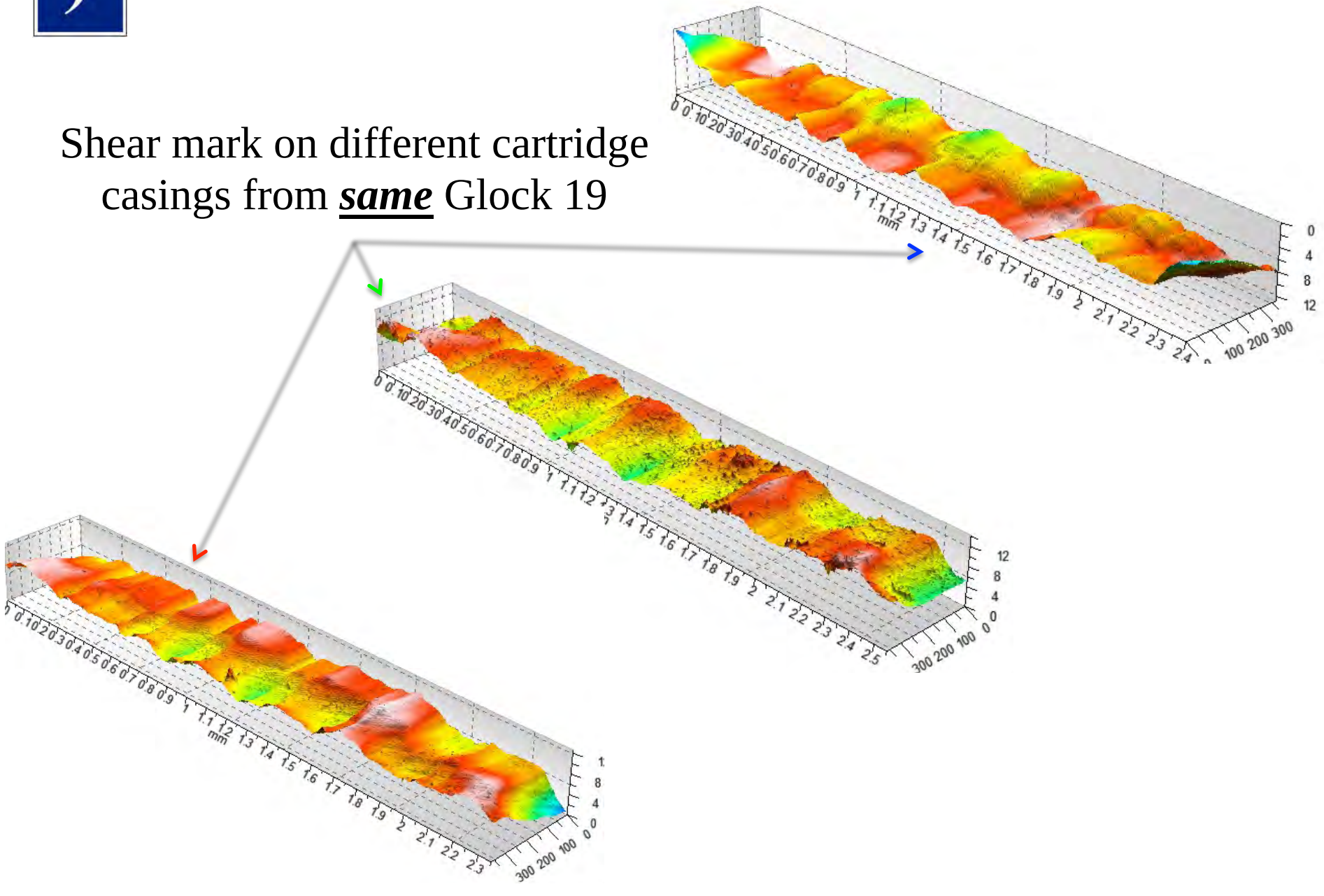
- 3D confocal image of entire shear pattern



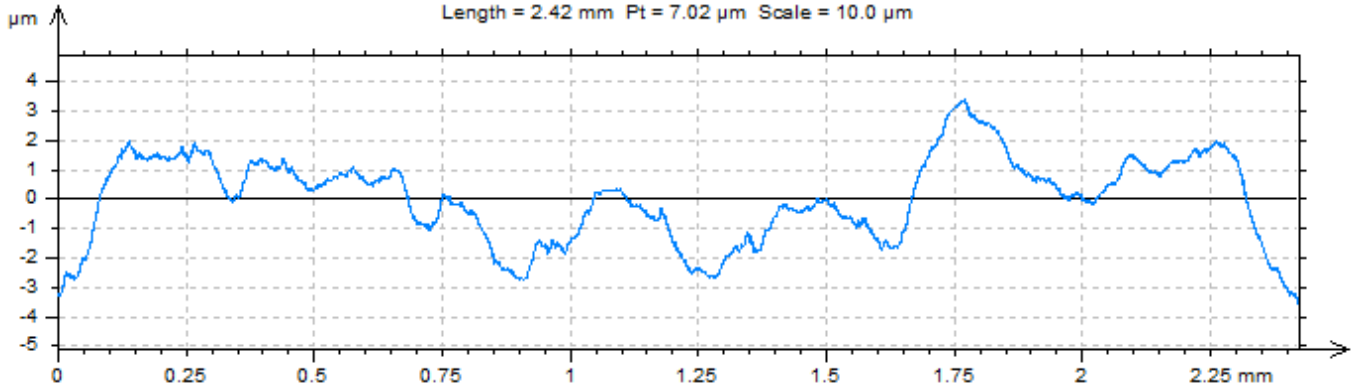
Shear marks on primer of two ***different*** Glock 19s



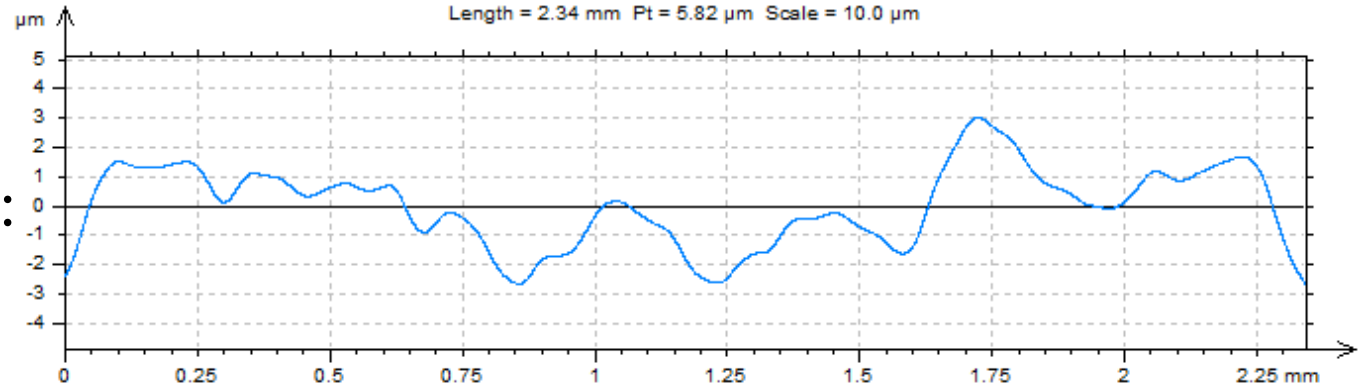
Shear mark on different cartridge casings from ***same*** Glock 19



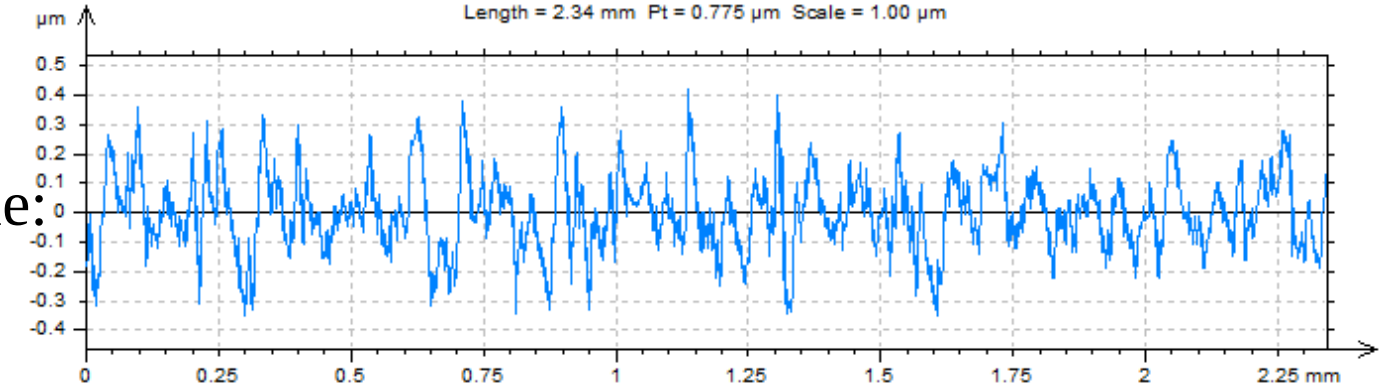
Mean profile:



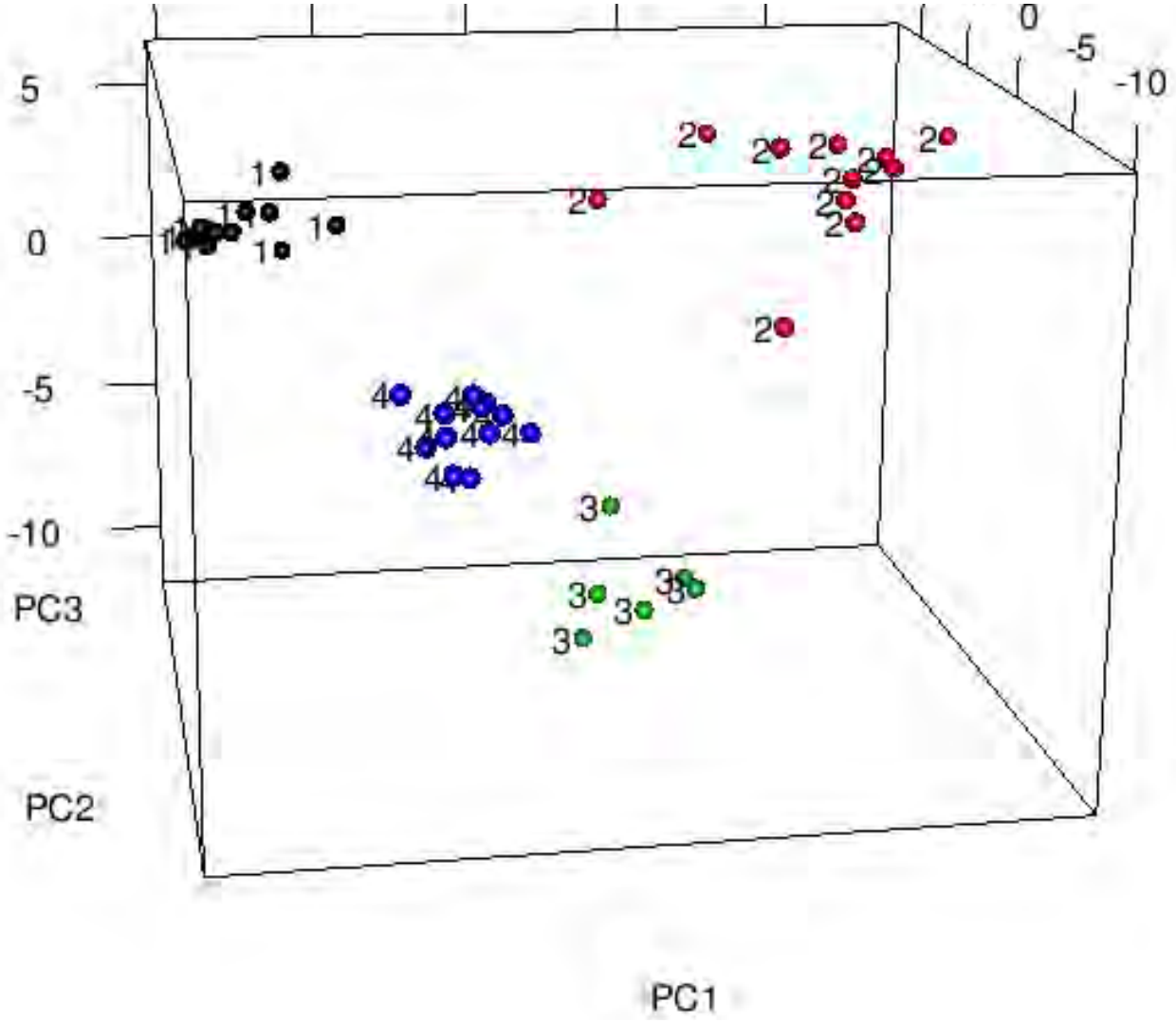
"Waviness" profile:



"Roughness" profile:



- 3D PCA-SVM Bootstrap error rate ~1%:



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