Population Statistics for Firearm Toolmark Analysis

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Disclaimer

Certain commercial equipment, instruments, or materials are identified in this presentation to specify the experimental procedure adequately. Such identification is not intended to imply recommendation or endorsement by the National Institute of Standards and Technology (NIST), nor is it intended to imply that the materials or equipment identified are necessarily the best available for the purpose.

Funding for this project was provided by the National Institute of Justice (NIJ) under IAA: 1608-683-68

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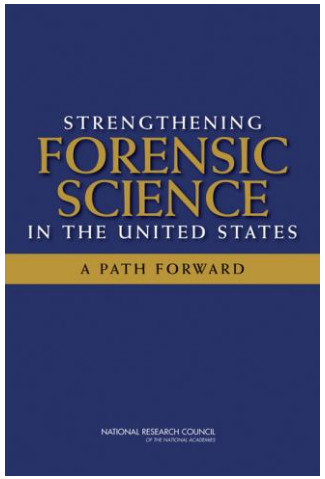
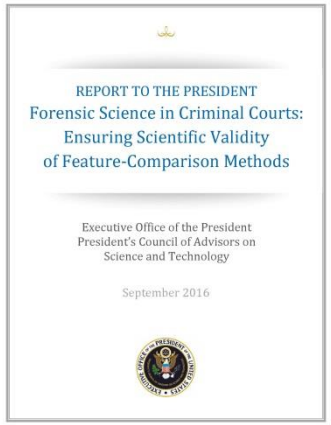
Motivation



- NAS 2009 "..the decision of the toolmark examiner remains a **subjective decision** based on unarticulated standards and no statistical foundation for **estimation of error rates**."

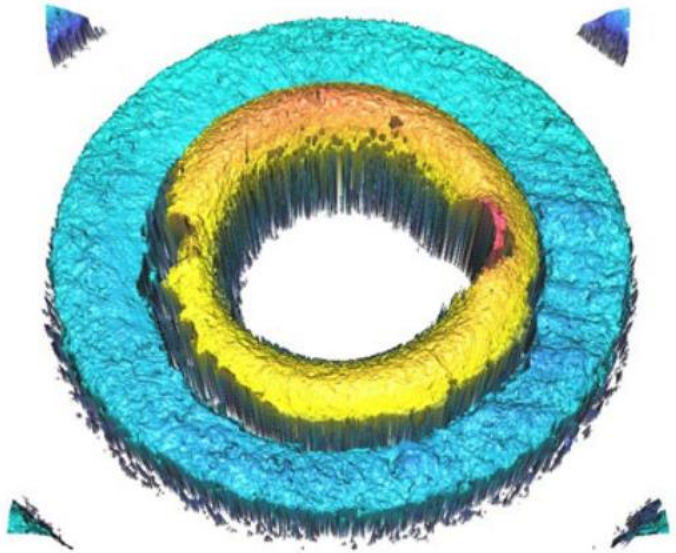


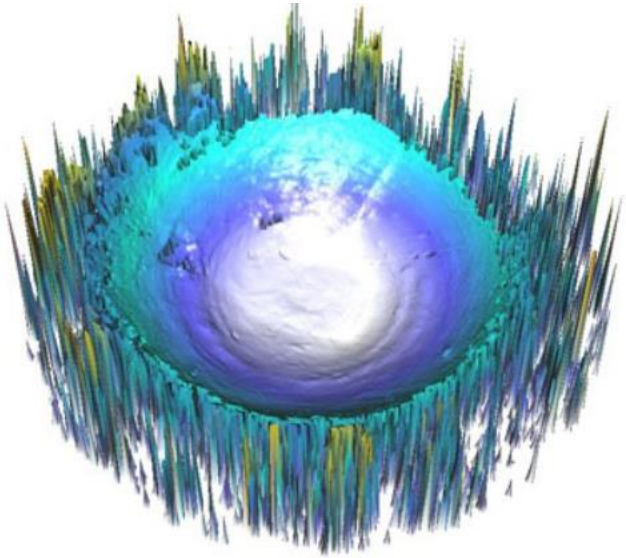
- PCAST 2016: "PCAST finds that firearms analysis currently falls short of the criteria for foundational validity, because there is only a single appropriately designed study to **measure validity and estimate reliability**."

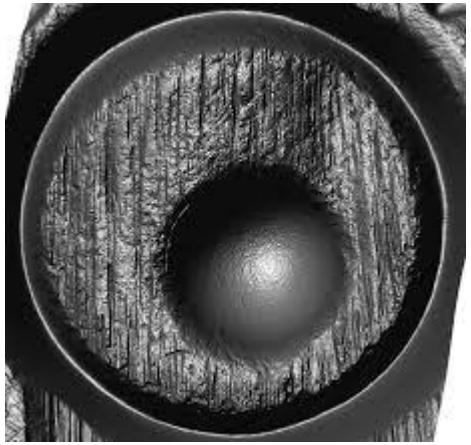
  "If firearms analysis is allowed in court, the scientific criteria for validity as applied should be understood to require **clearly reporting the error rates seen in appropriately designed black-box studies.**"

  "A second – and more important – direction is … to convert firearms analysis **from a subjective method to an objective method**…"

3D Measurements







Bullet Land Engraved Area

Documentary Standards

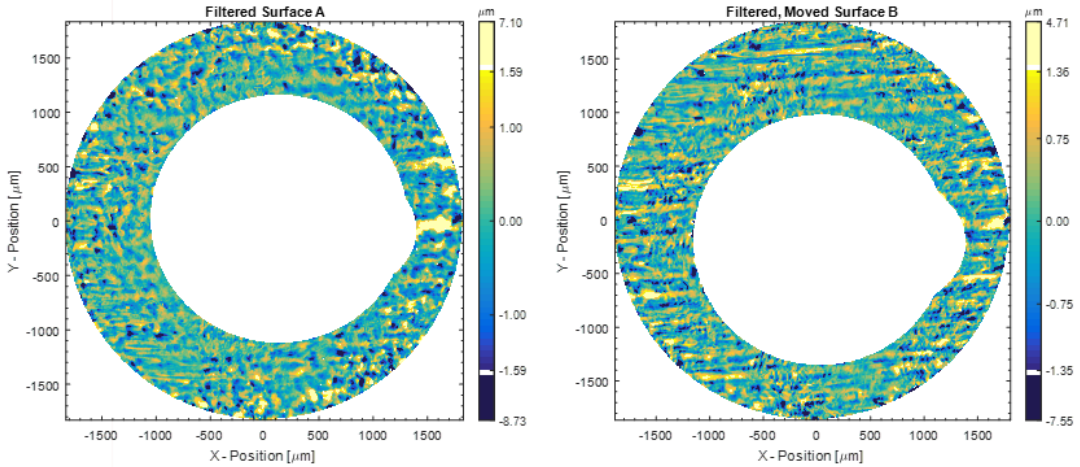
- Standard for Toolmark Topography Comparison Software
- Standard for Implementation of 3D Technologies in Forensic Laboratories
- Standard for 3D Measurement Systems and Measurement Quality Control

- Best Practice guides for Quality Assurance of 3D instruments that are used for VCM.
- Procedure for Conducting a Virtual Comparison Microscopy (VCM) Deployment Validation for Firearms and Toolmarks

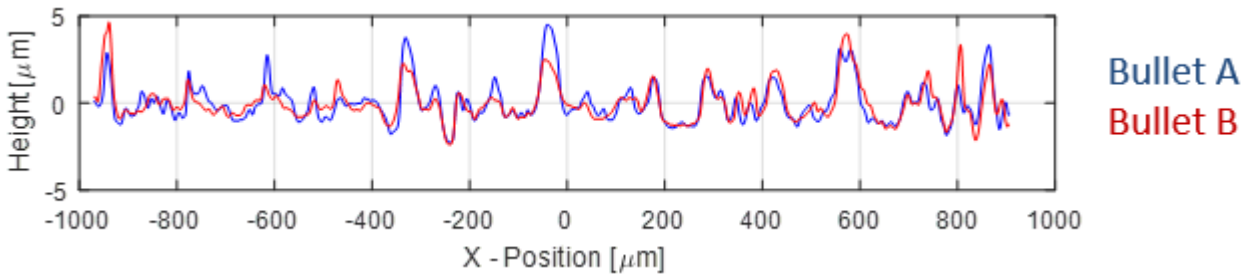
- Unambiguous file exchange standard
- Open-FMC.org
- ISO25178-72 XML 3D Profile

Algorithms

Area Based Correlation

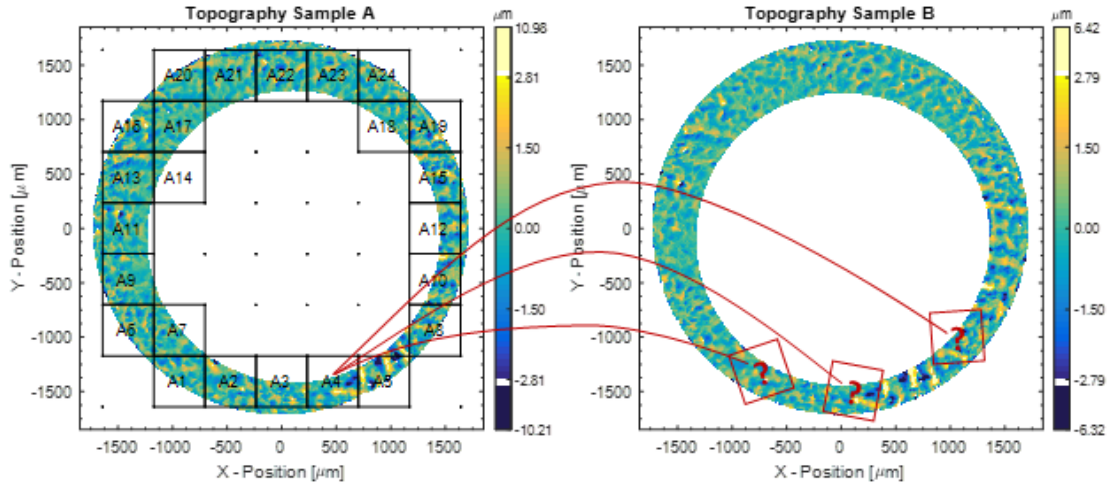


Areal Cross Correlation Function ($ACCF_{MAX}$)

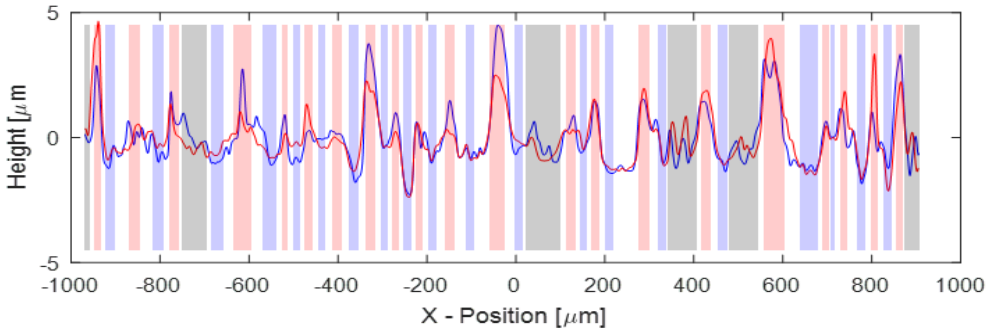


Cross Correlation Function (CCF_{MAX})

Feature Based Correlation

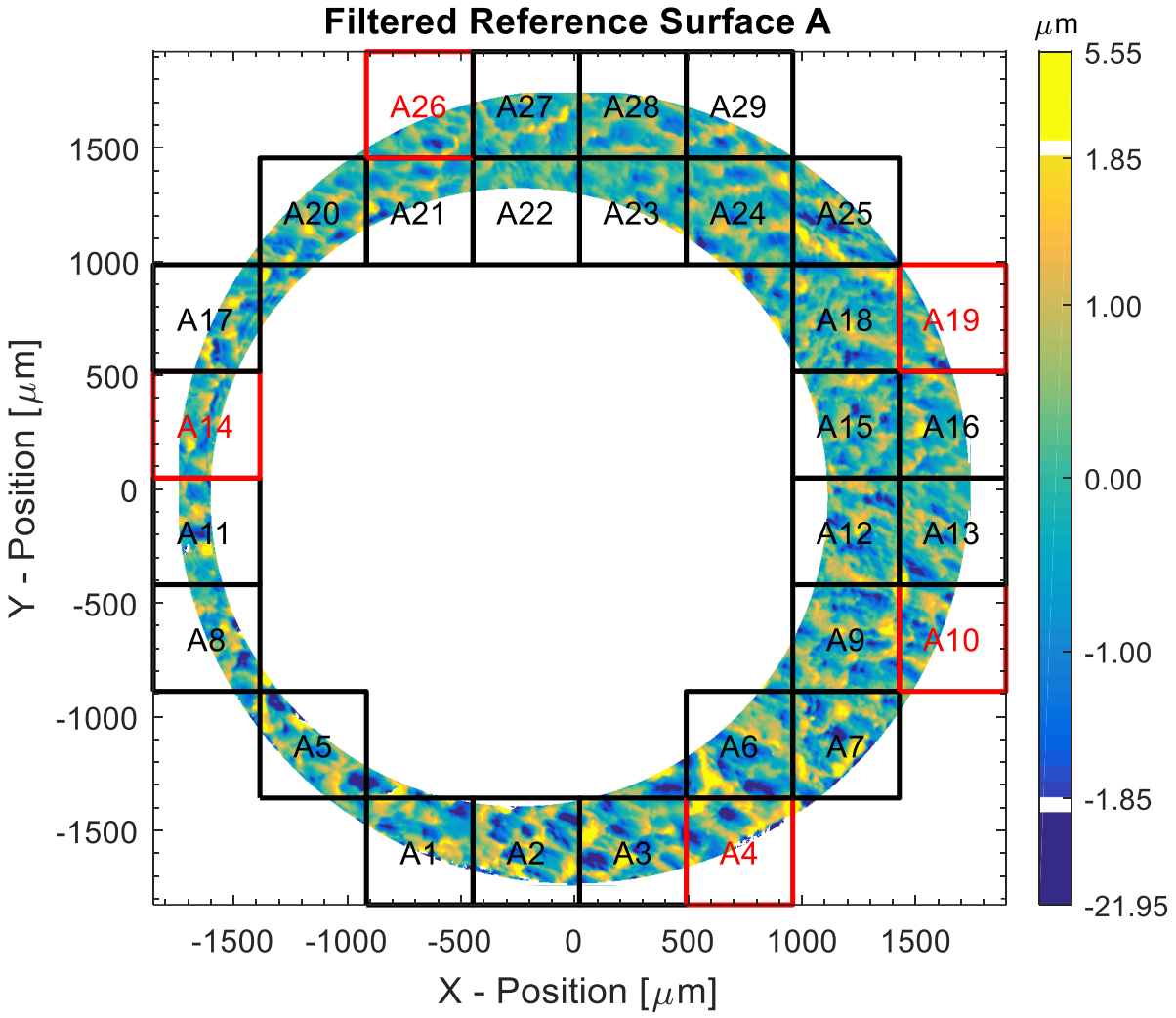


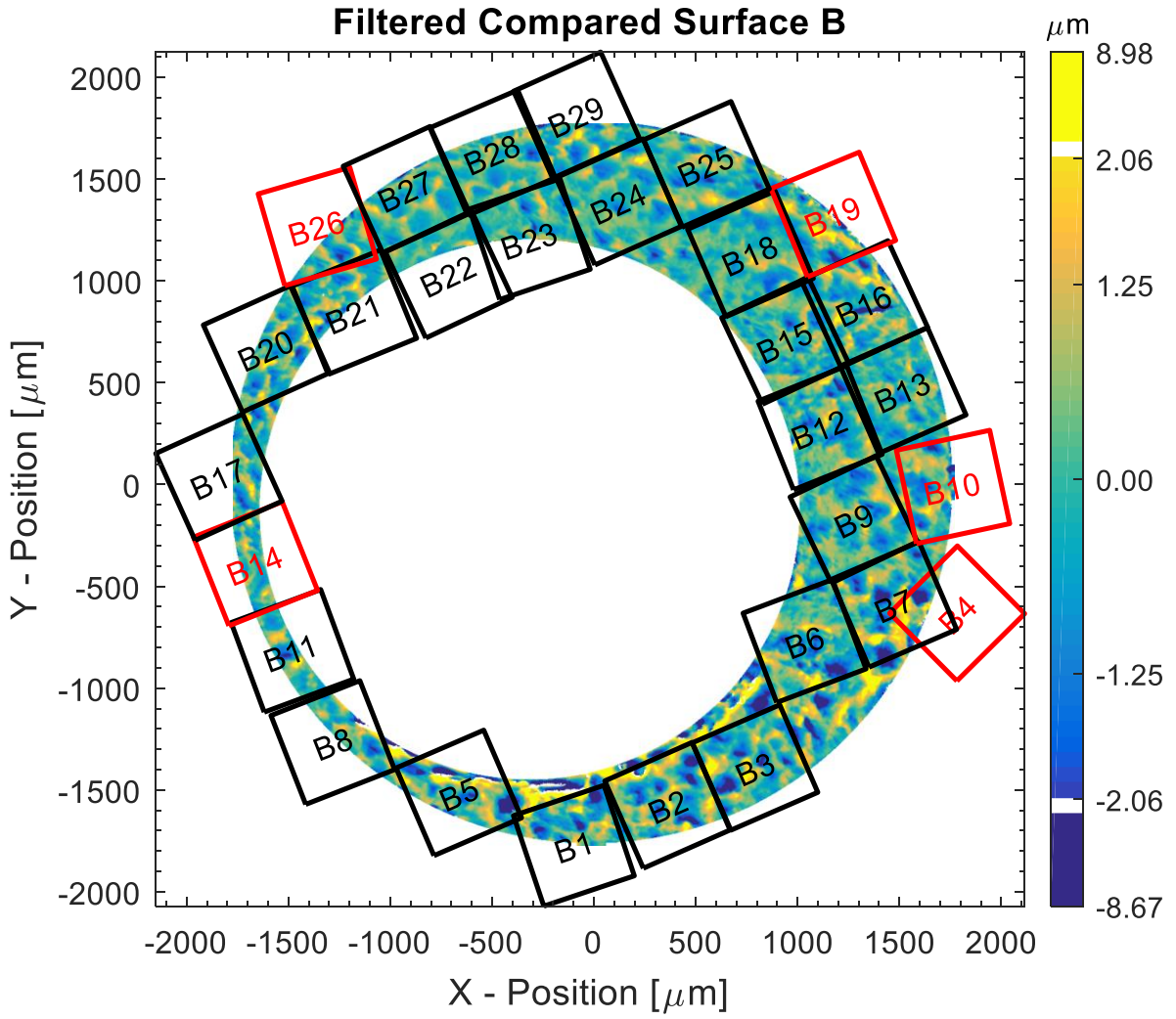
Congruent Matching Cells (*CMC*)



Consecutive Matching Striae (*CMS*)

CMC Algorithm – KM





24 CMCs

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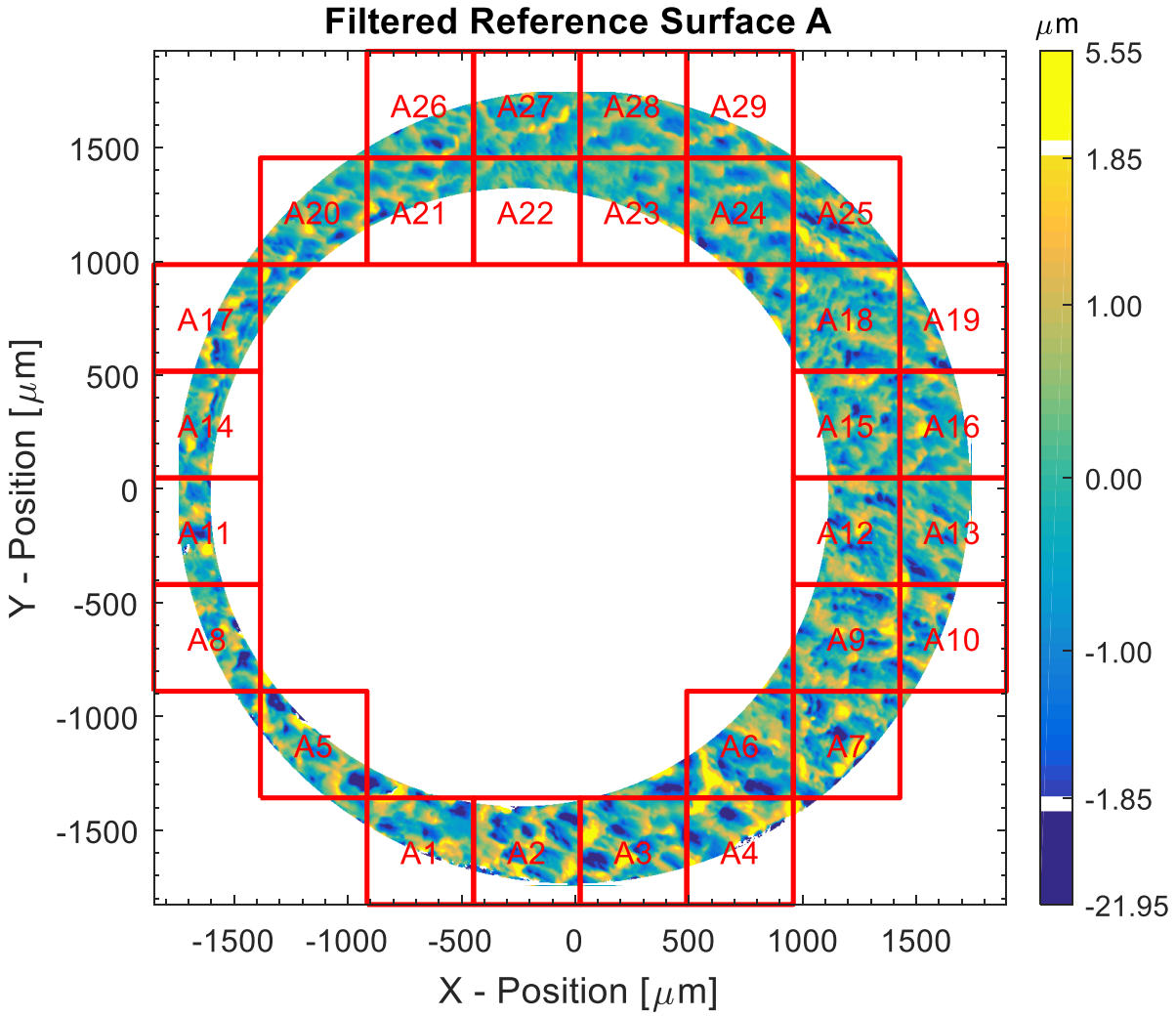
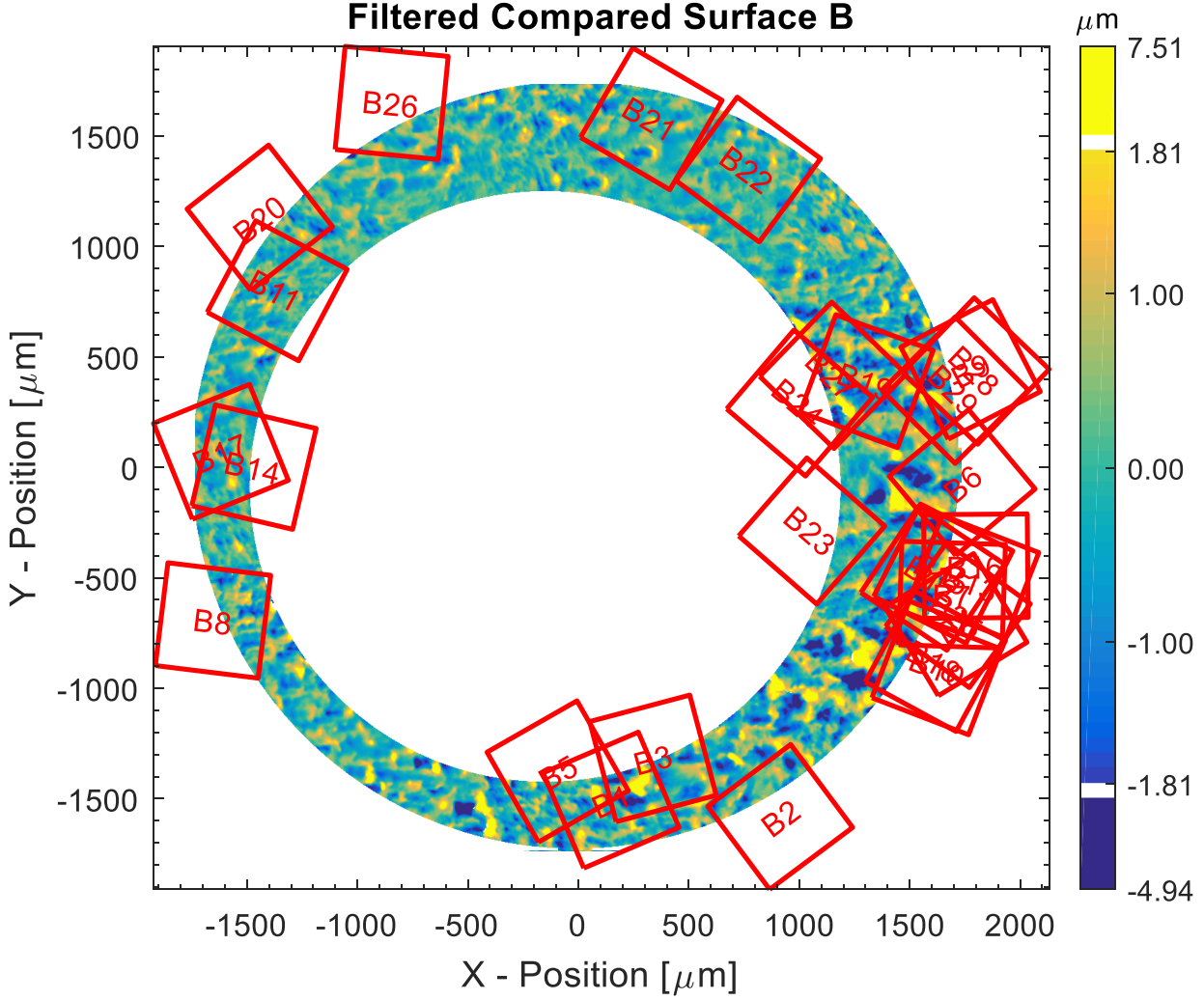
CMC Algorithm - KNM





0 CMCs

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Firearm Brand and Ammo

104 Firearms

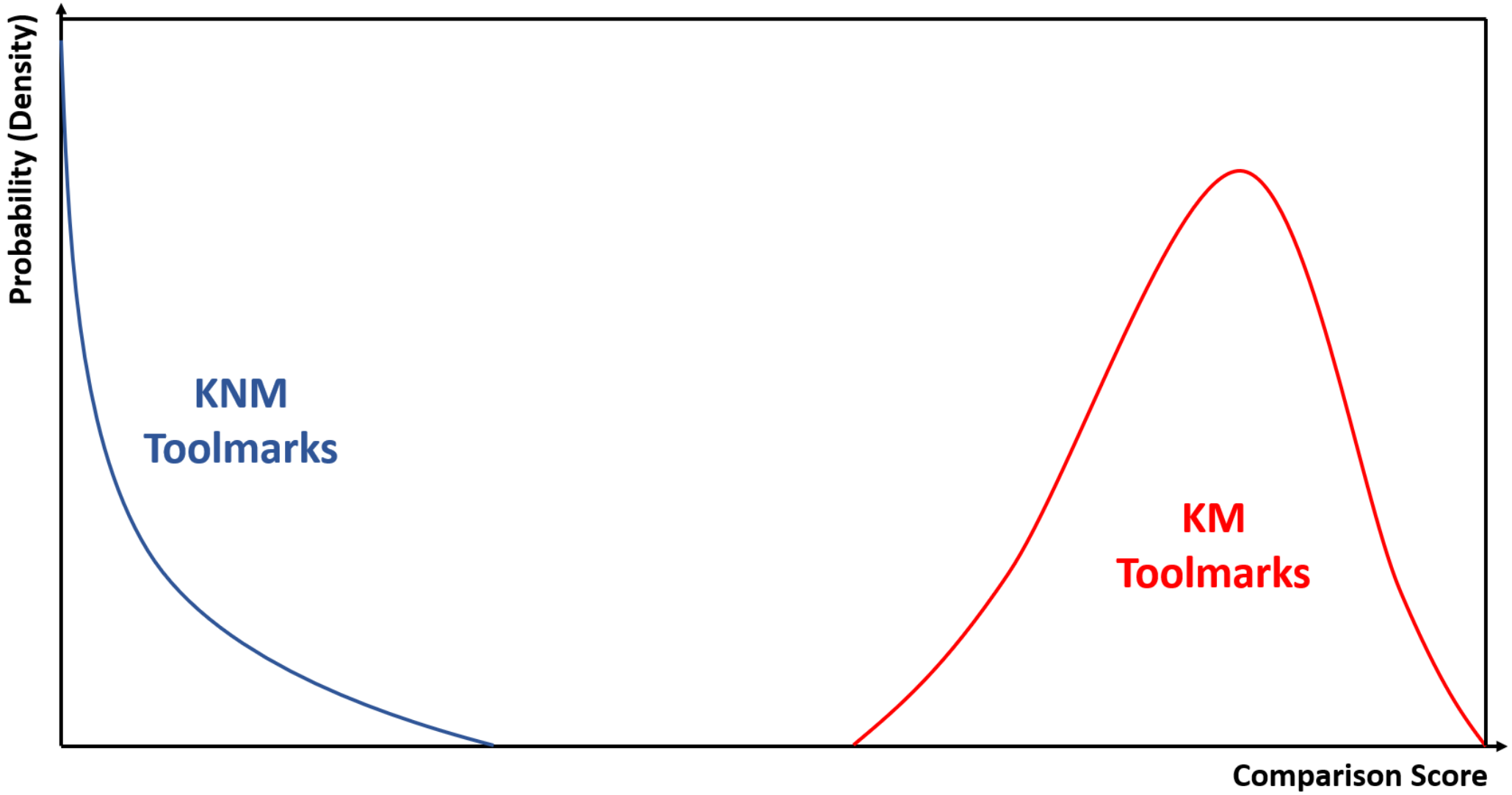
100 Firearms

115 Gr FMJ

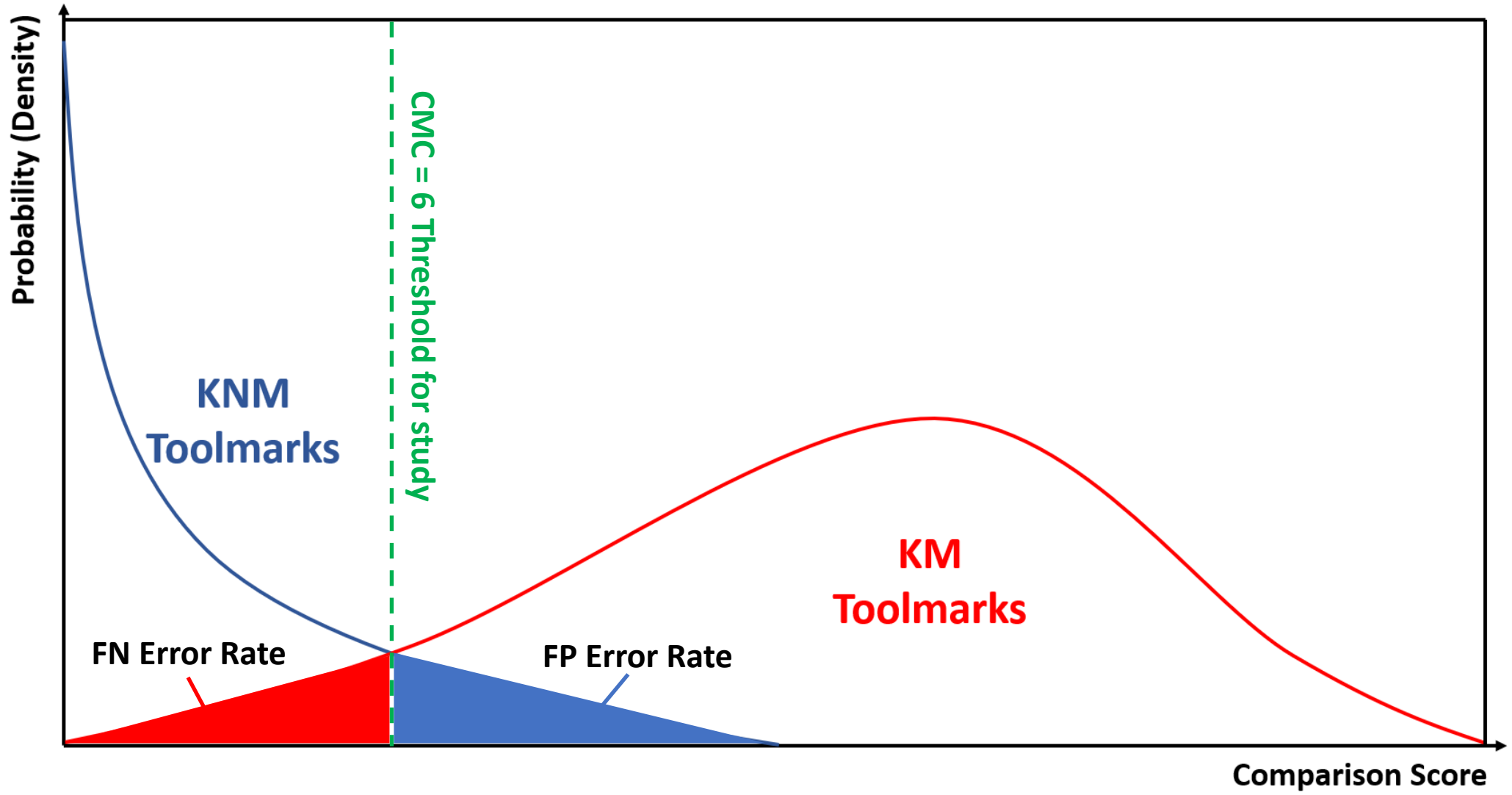
115 Firearms

91 Firearms

Perfect World

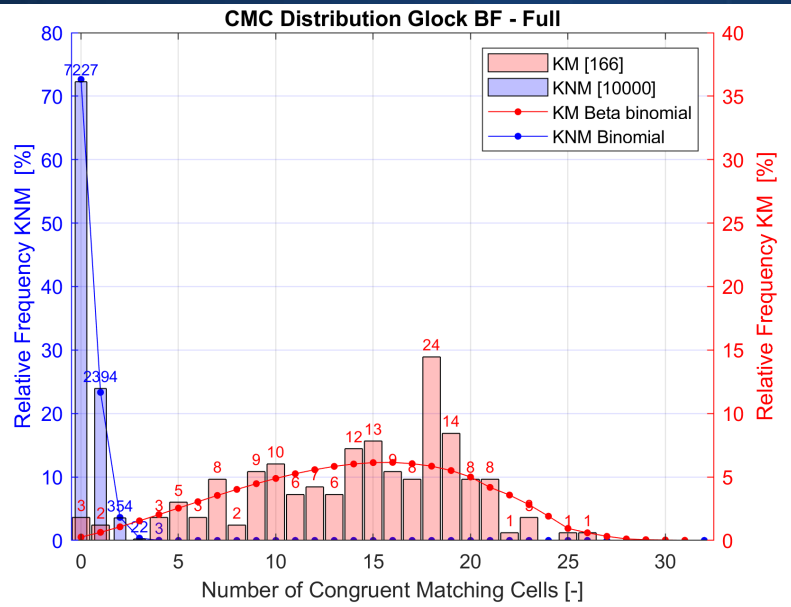


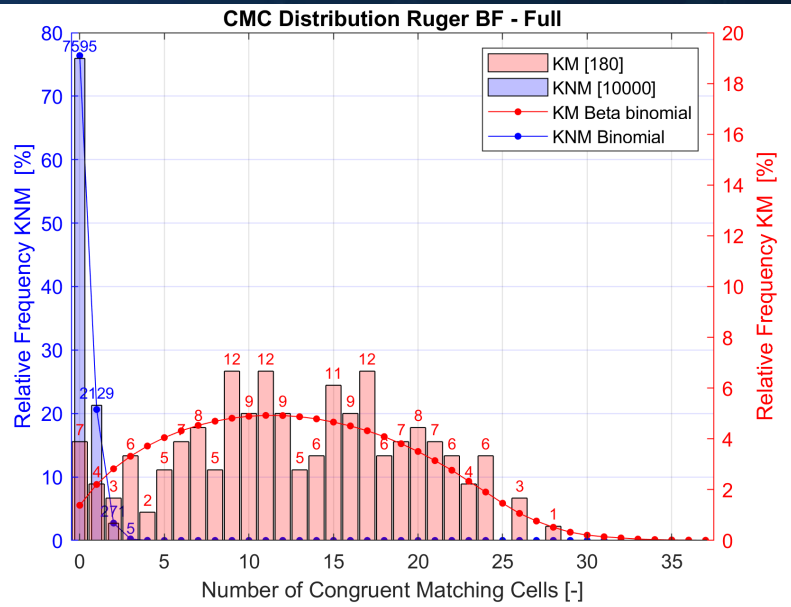
System Error Rates

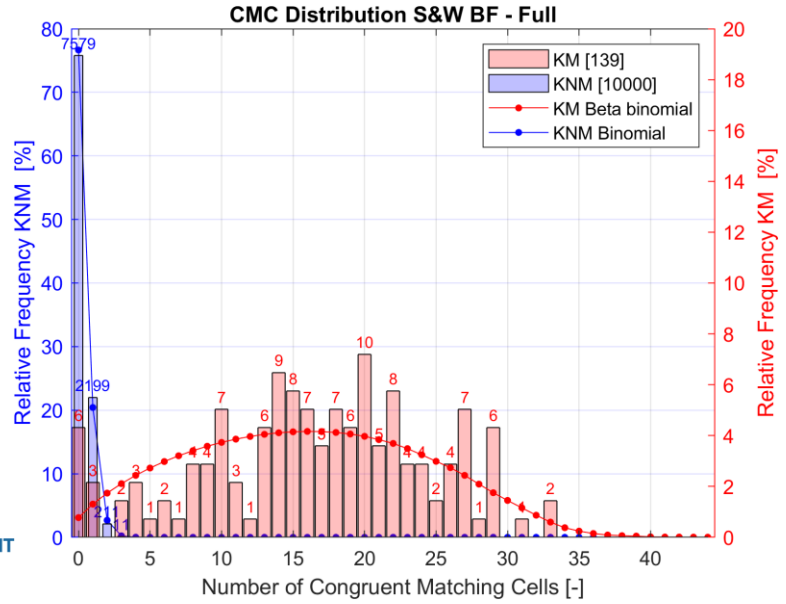


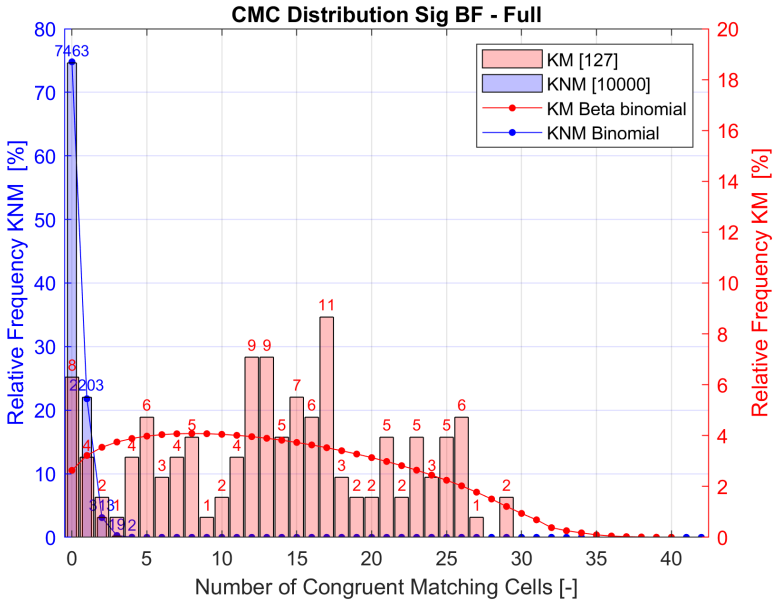
Song J, et.al., "Estimating error rates for firearm evidence identifications in forensic science," Forensic Sci. Int. 2018 Mar; 284: 15-32

Full BF Populations

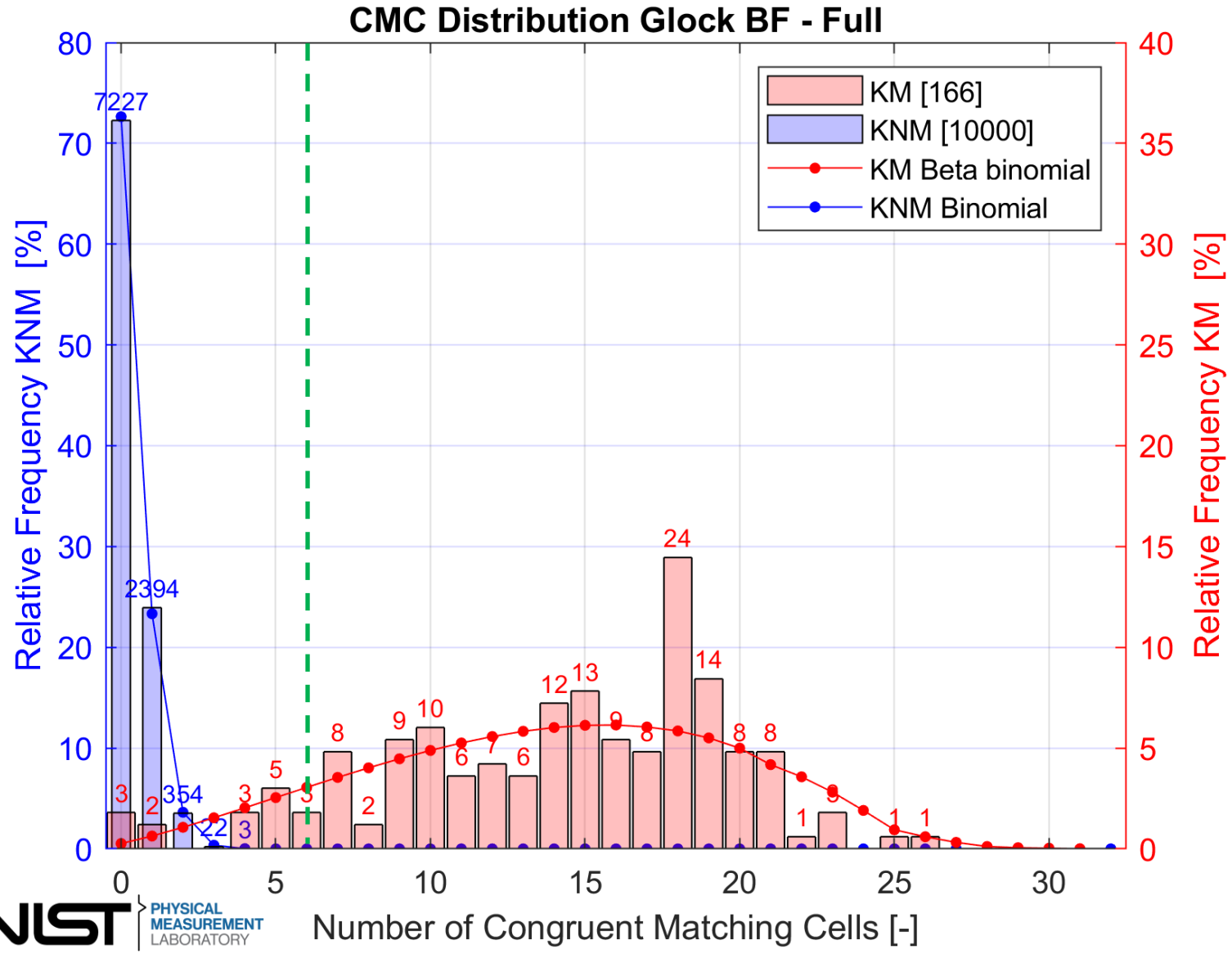








Glock – Full Population



Cumulative False Positive Probability:

0.000071 %

Cumulative False Negative Probability:

8.10 %

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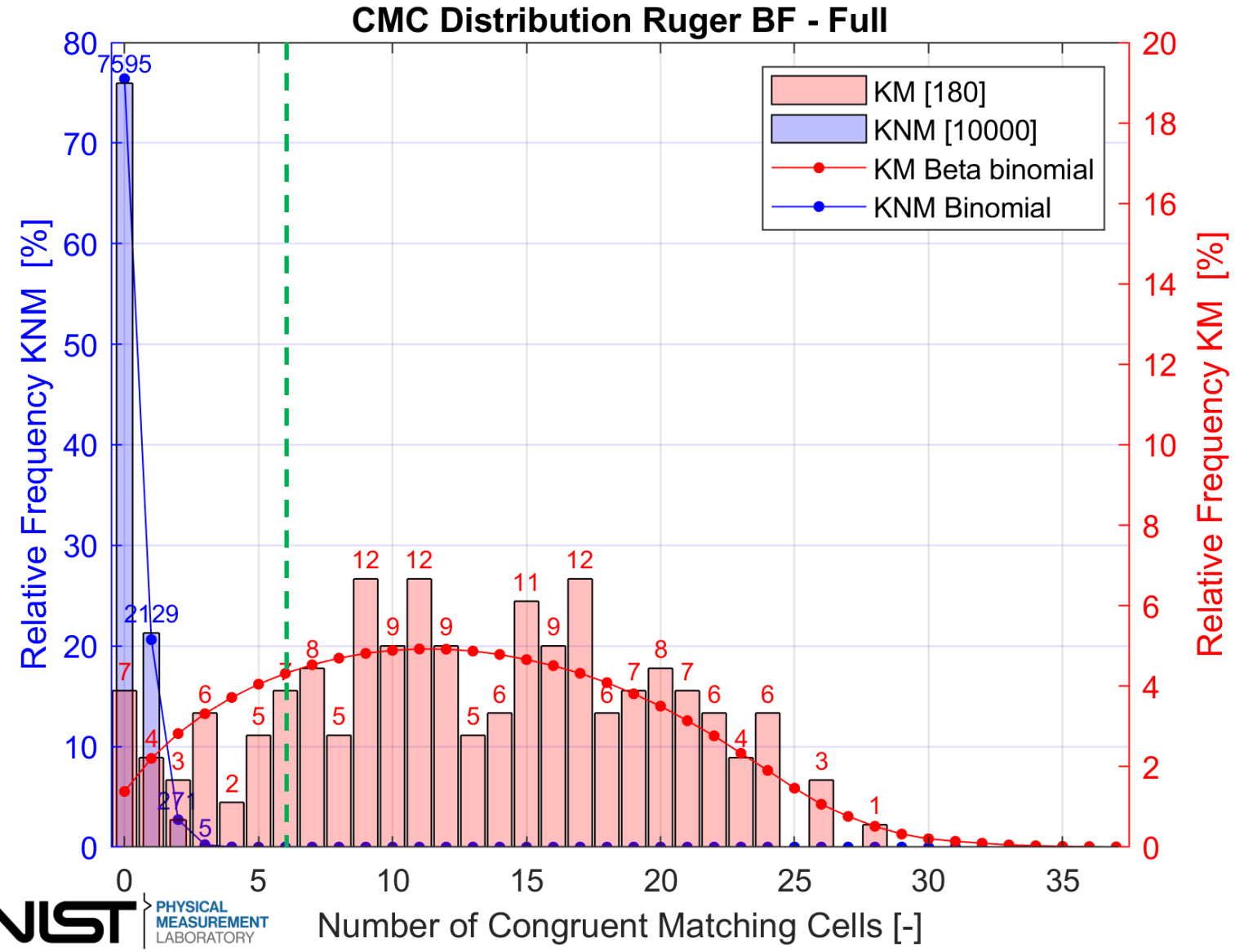
Ruger – Full Population



Cumulative False Positive Probability:

0.000031 %

Cumulative False Negative Probability:

17.49 %

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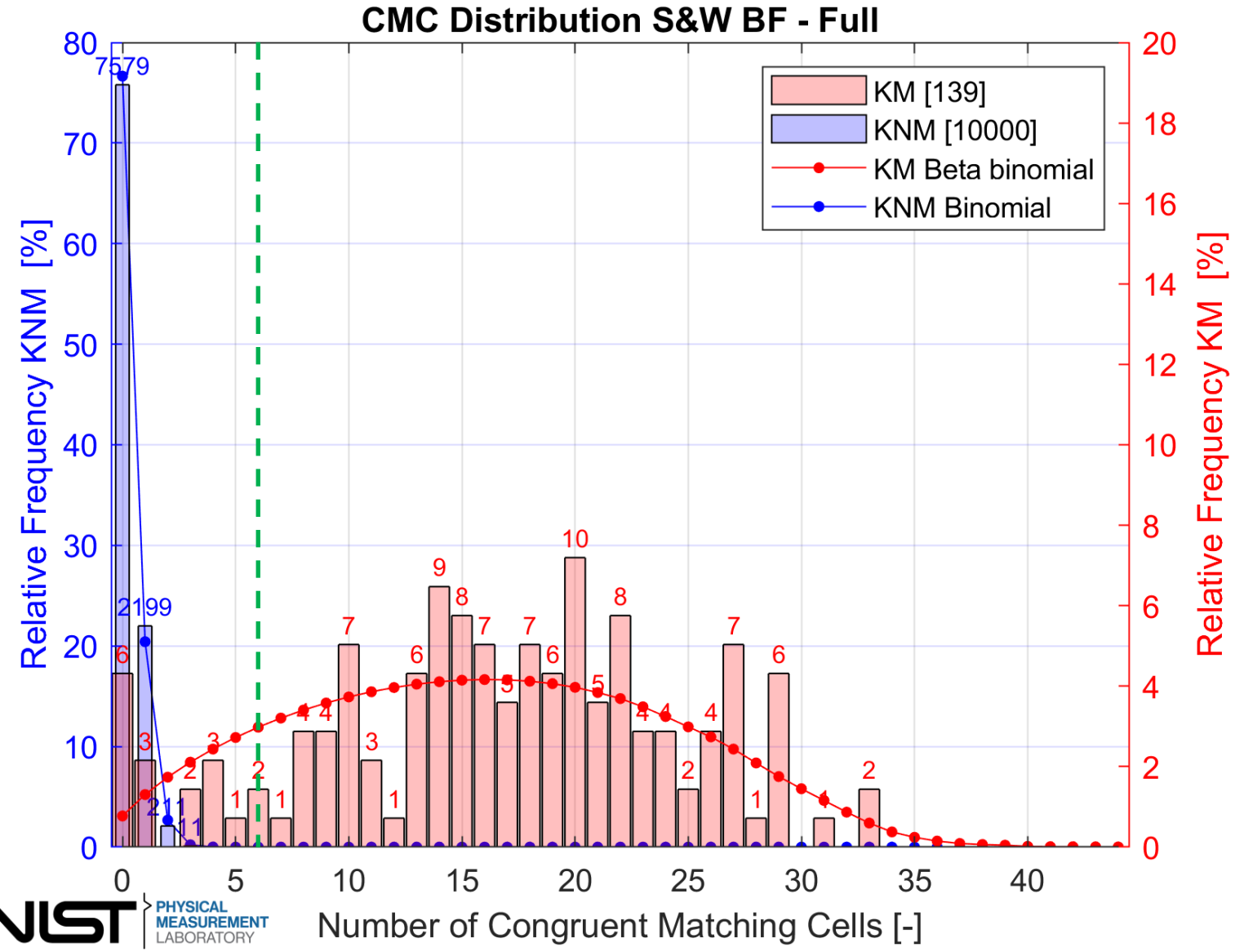
S&W – Full Population



Cumulative False Positive Probability:

0.000031 %

Cumulative False Negative Probability:

11.09 %

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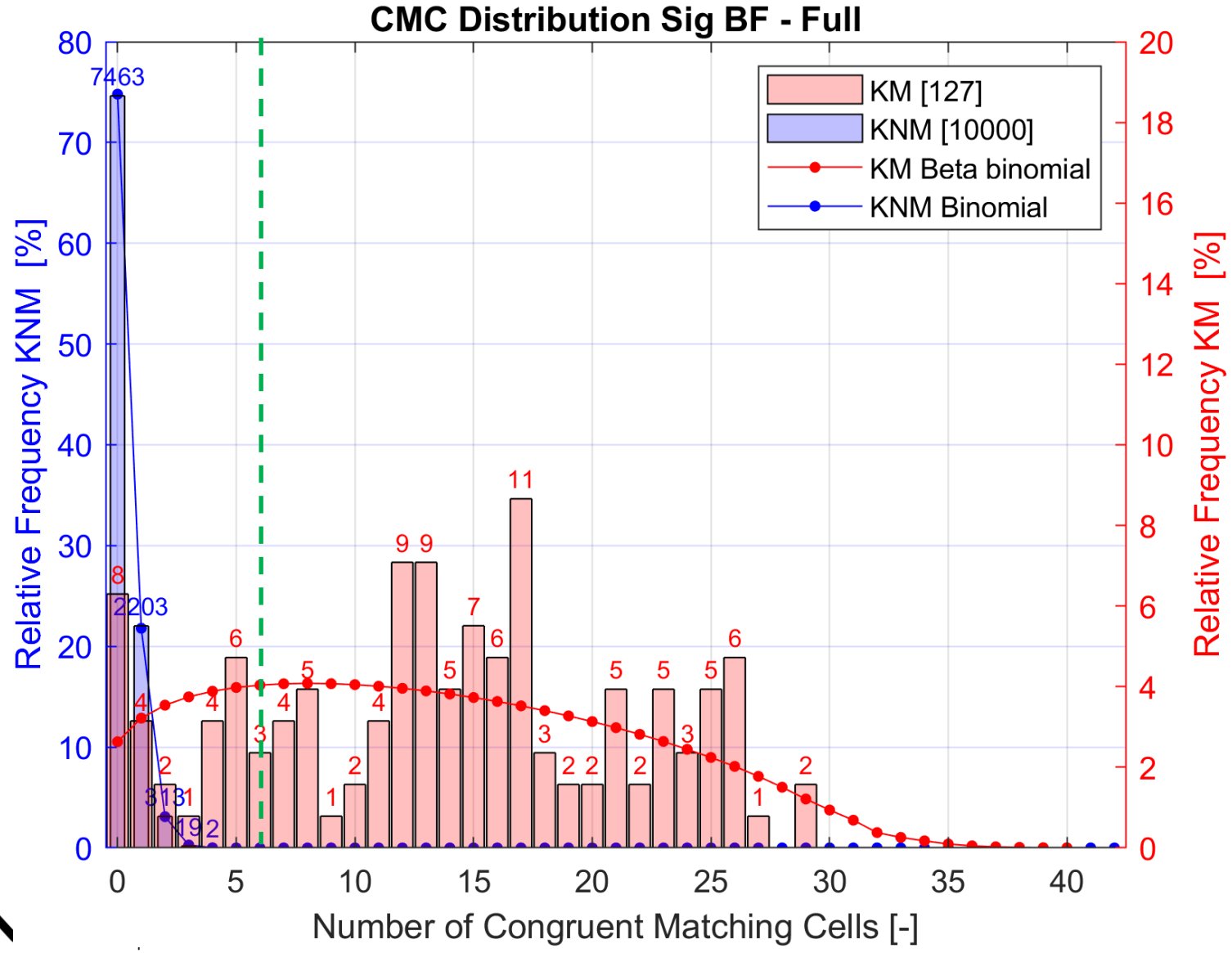
Sig – Full Population



Cumulative False Positive Probability:

0.000046 %

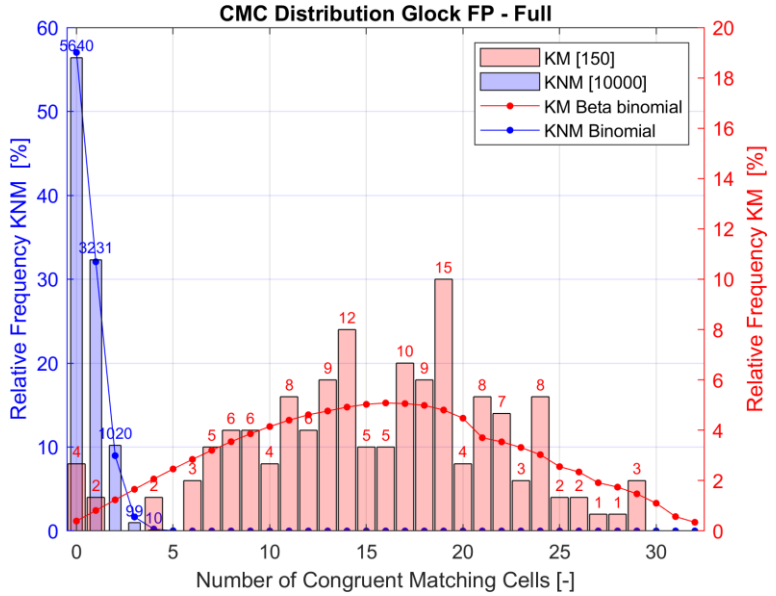
Cumulative False Negative Probability:

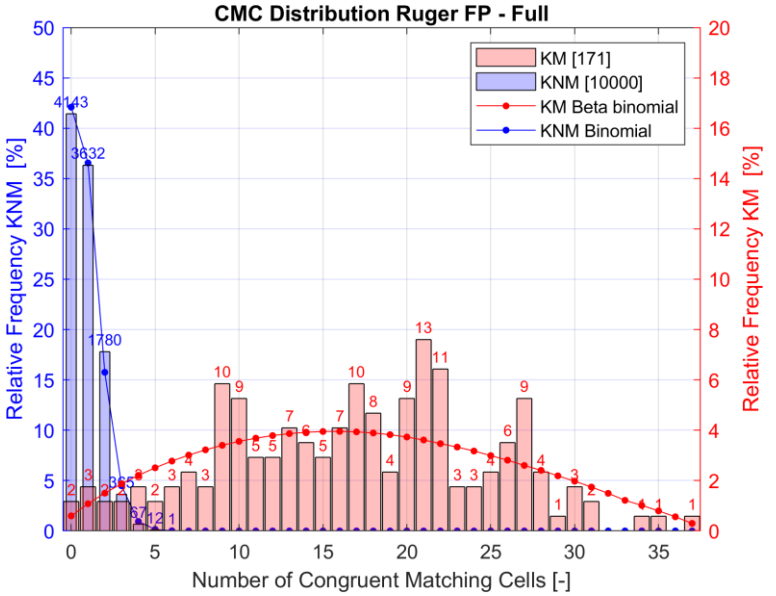
21.01 %

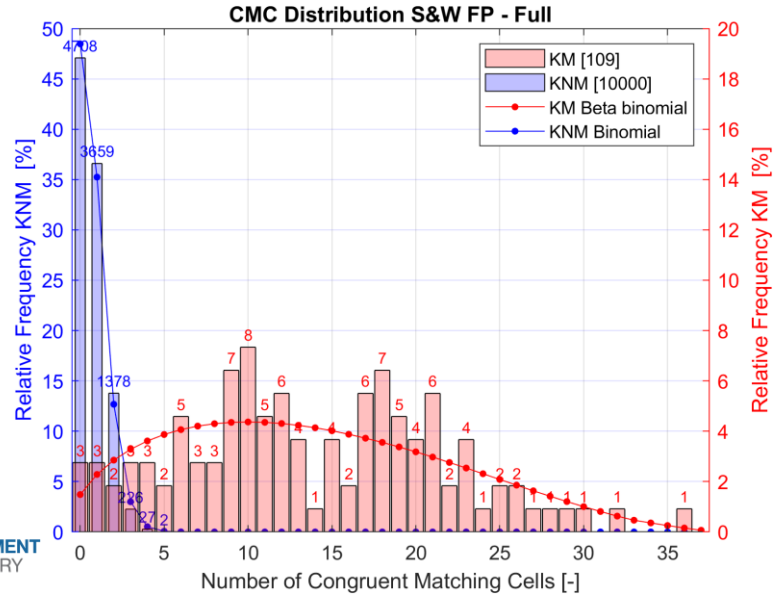
BF Data Summary

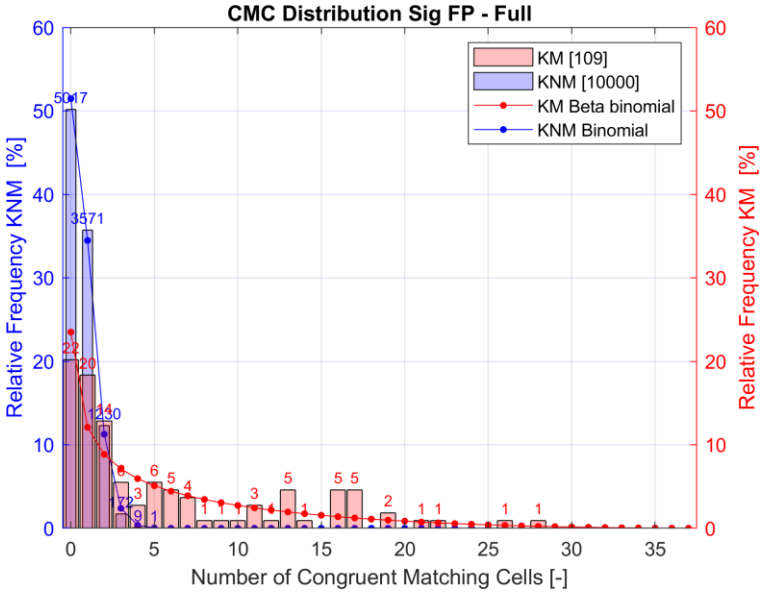
Population	Cumulative False Positive Error Rate	Cumulative False Negative Error Rate
Glock Full	0.000071 %	8.10 %
Glock Granular	0.000049%	8.68 %
Glock Parallel	0.00021 %	6.39 %
Ruger Full	0.000031 %	17.49 %
Ruger Granular	0.000023 %	18.17 %
Ruger Parallel	0.000055 %	16.77 %
S&W Full	0.000031 %	11.09 %
S&W Granular	0.000019 %	18.86 %
S&W Parallel	0.000075 %	1.62 %
Sig Full	0.000046 %	21.01 %
Sig Granular	0.000014 %	26.50 %
Sig Parallel	0.00027 %	15.24 %

Full FP Populations





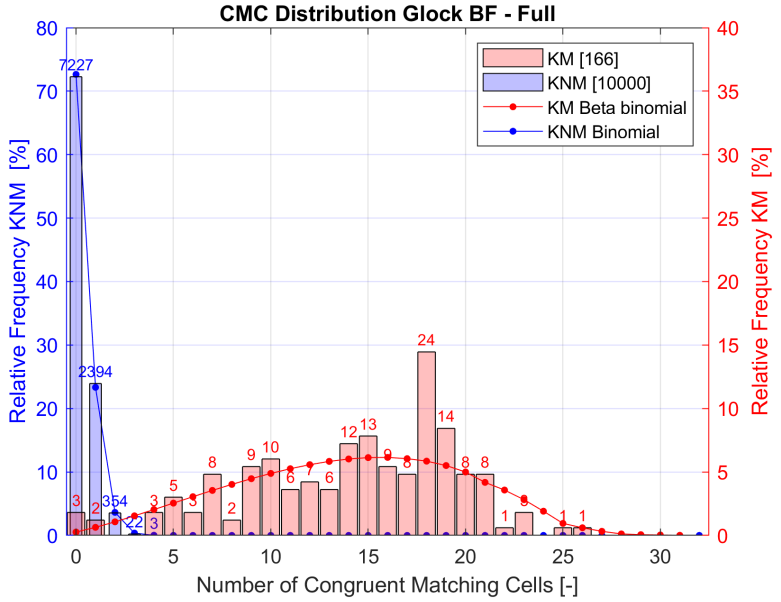




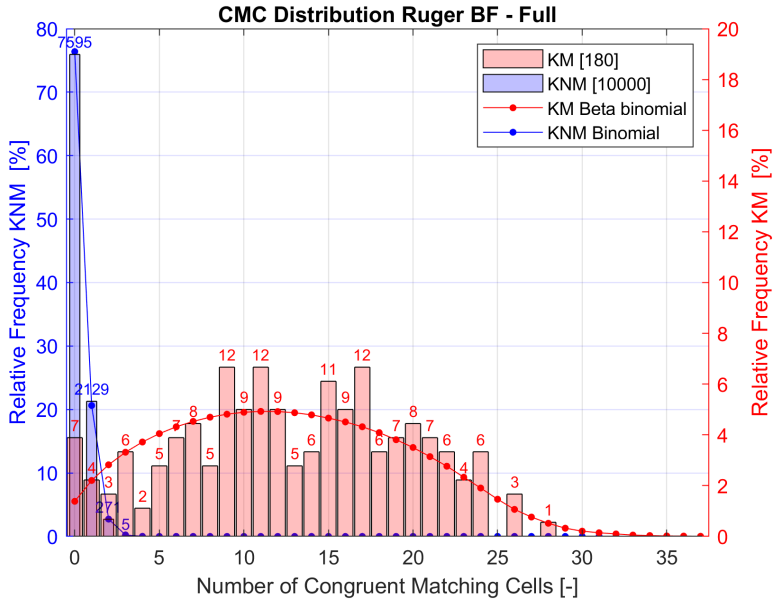
FP Data Summary

Population	Cumulative False Positive Error Rate	Cumulative False Negative Error Rate
Glock Full	0.0025 %	8.62 %
Ruger Full	0.024 %	9.78 %
S&W Full	0.0088 %	17.39 %
Sig Full	0.0047 %	62.59 %

1 in 10 Million

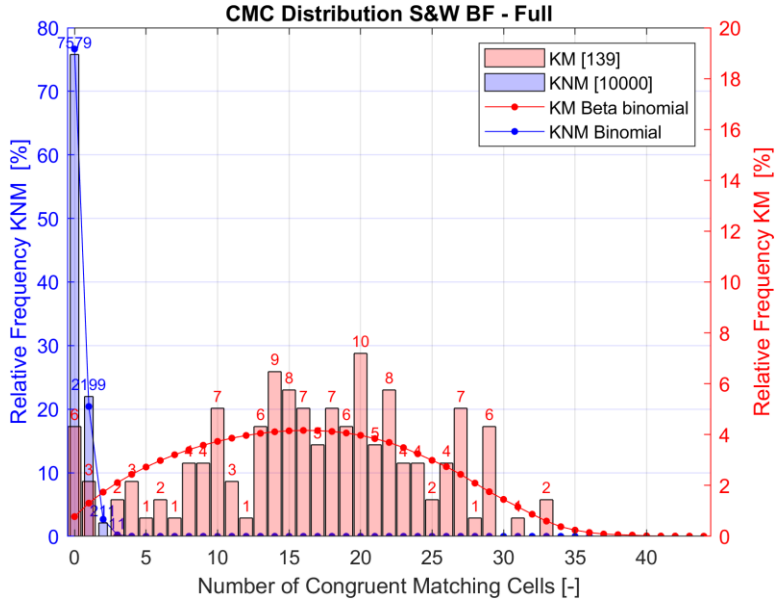


Probability of CMC = 6
given KNM
6.81E-07

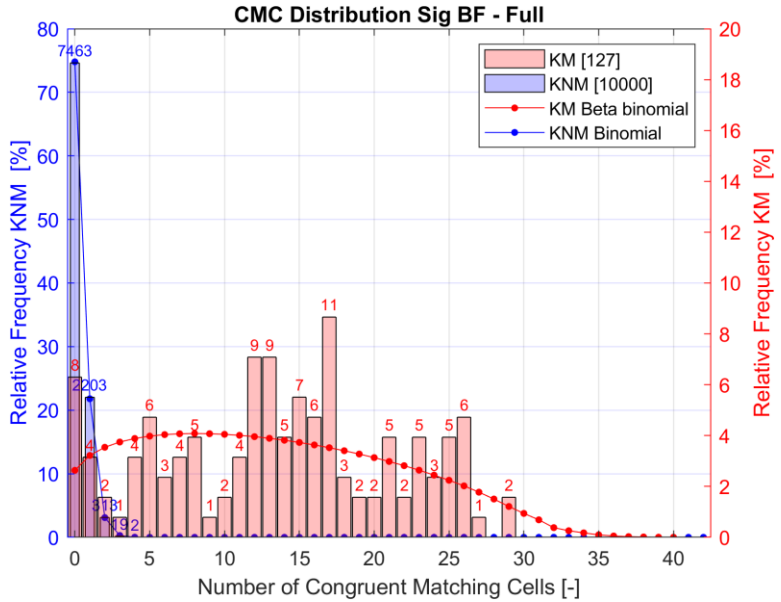


Probability of CMC = 6
given KNM
3.03E-07

1 in 10 Million



Probability of CMC = 6
given <u>KNM</u>
3.03E-07



Probability of CMC = 6
given <u>KNM</u>
4.44E-07

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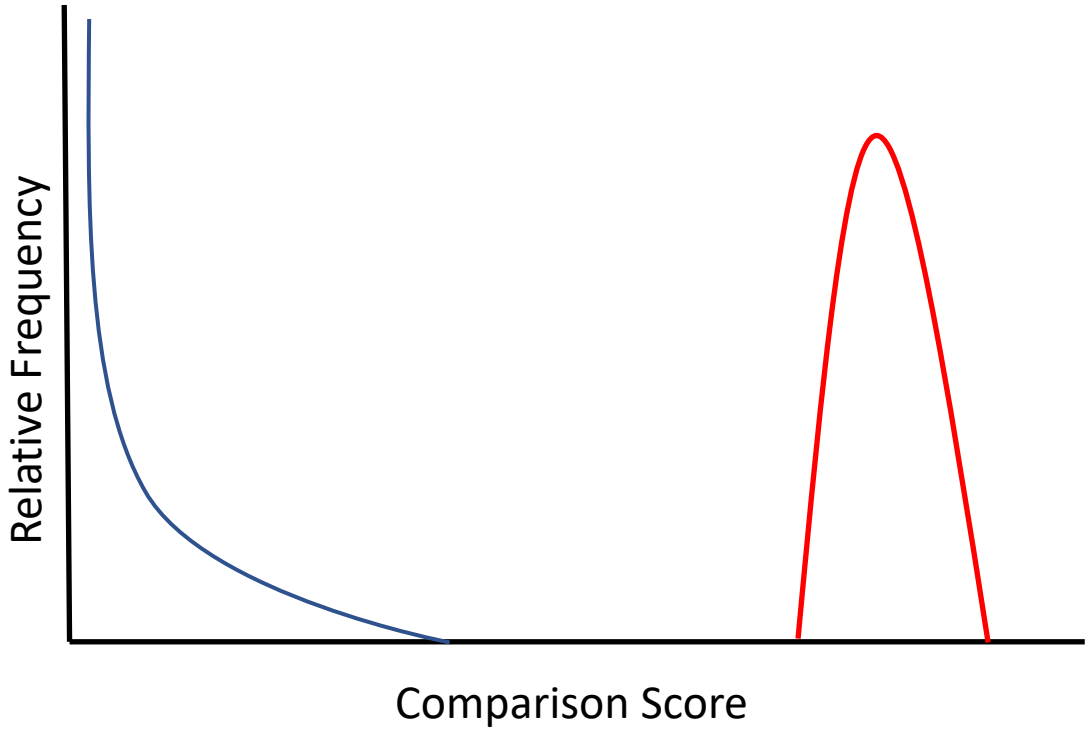
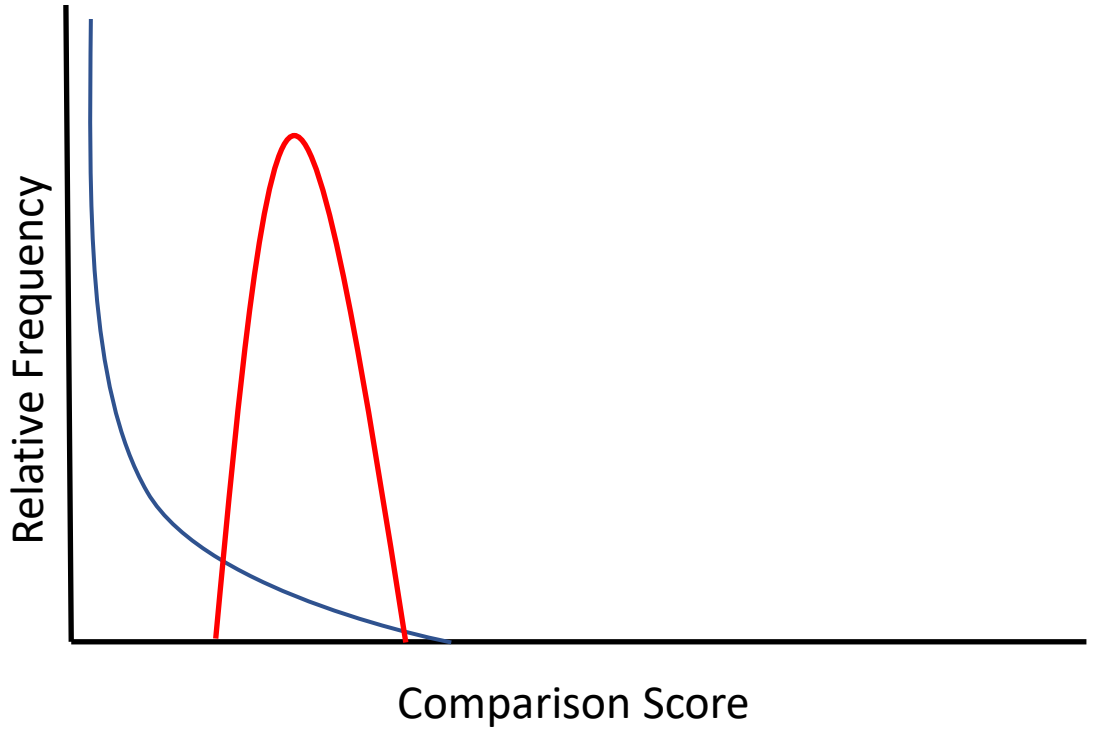
Weigh Both Propositions





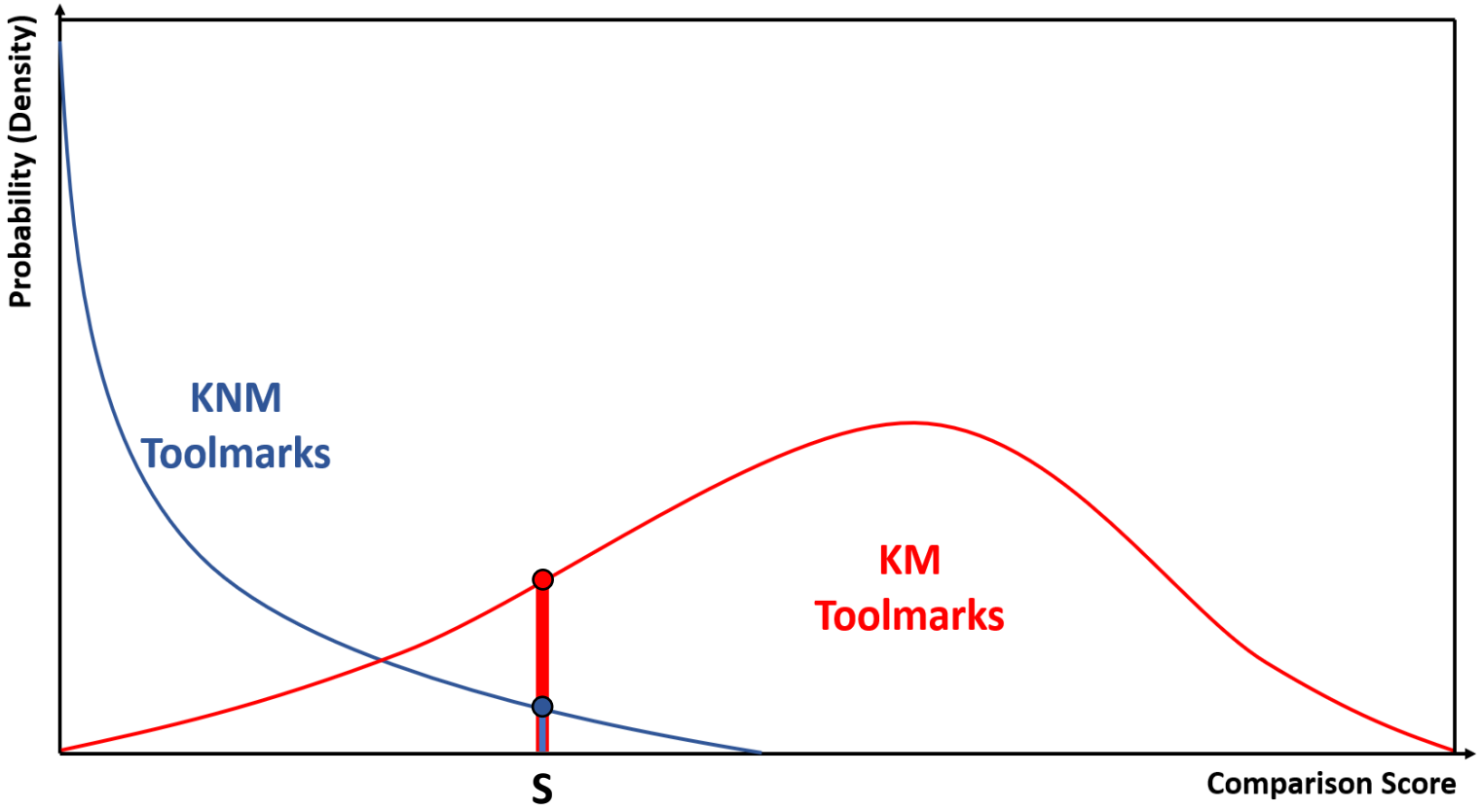
Very different weight of evidence in these two scenarios

Score-based Likelihood Ratios

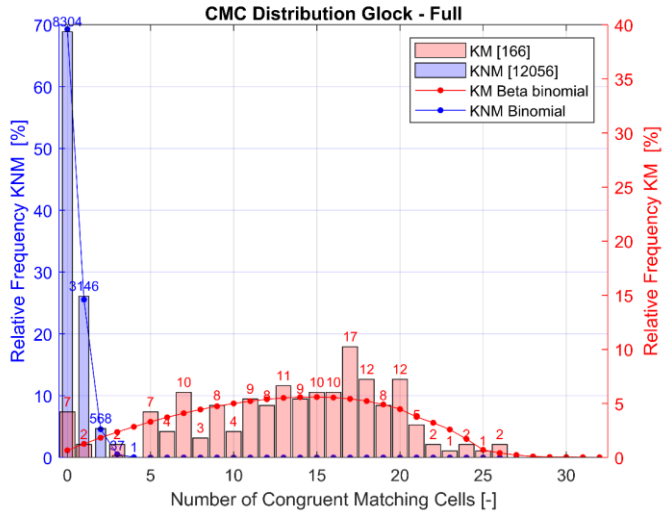
Score-based Likelihood Ratio

$$\mathbf{SLR} = \frac{P(S|\boldsymbol{KM})}{P(S|\boldsymbol{KNM})}$$

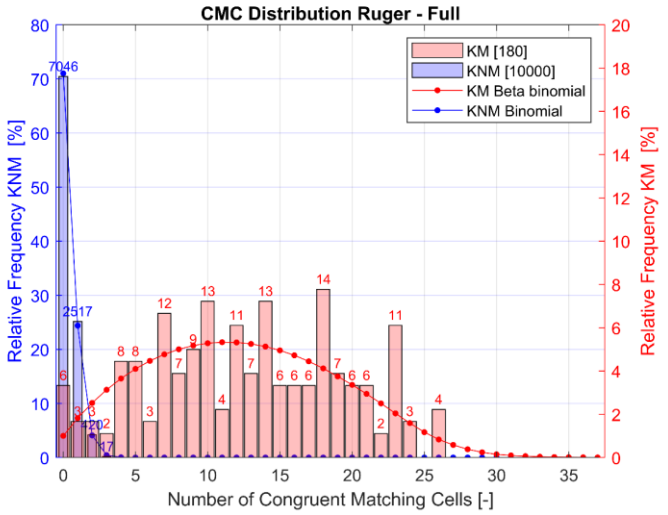
- SLR < 1: Support that this cartridge case did not originate from the suspected firearm
- SLR = 1: Equally likely to observe a score "S" from either the KM and KNM population.
- SLR > 1: Support that this cartridge case originate from the suspected firearm



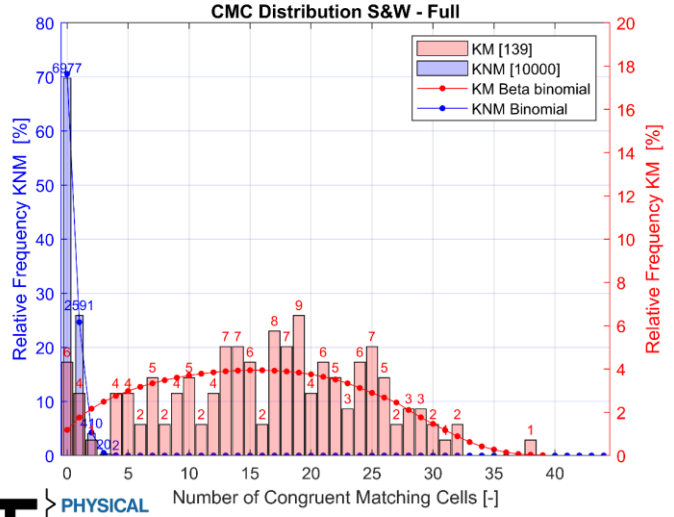
SLRs are not Fixed



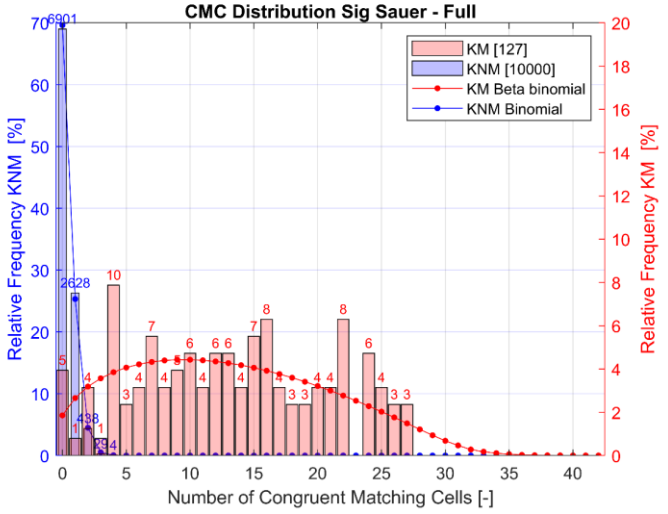
CMC = 6
SLR = 24986



CMC = 6
SLR = 21687

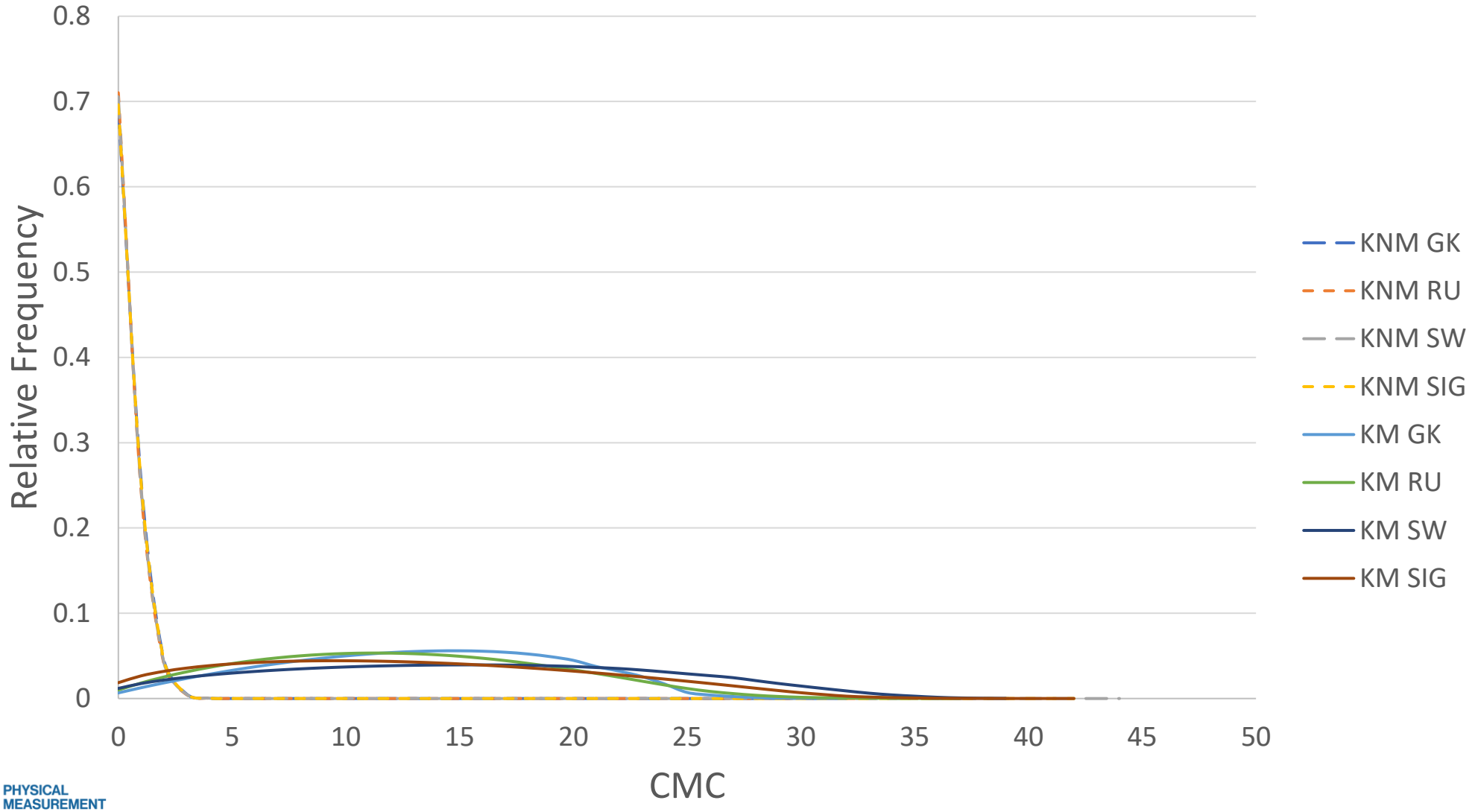


CMC = 6
SLR = 38477

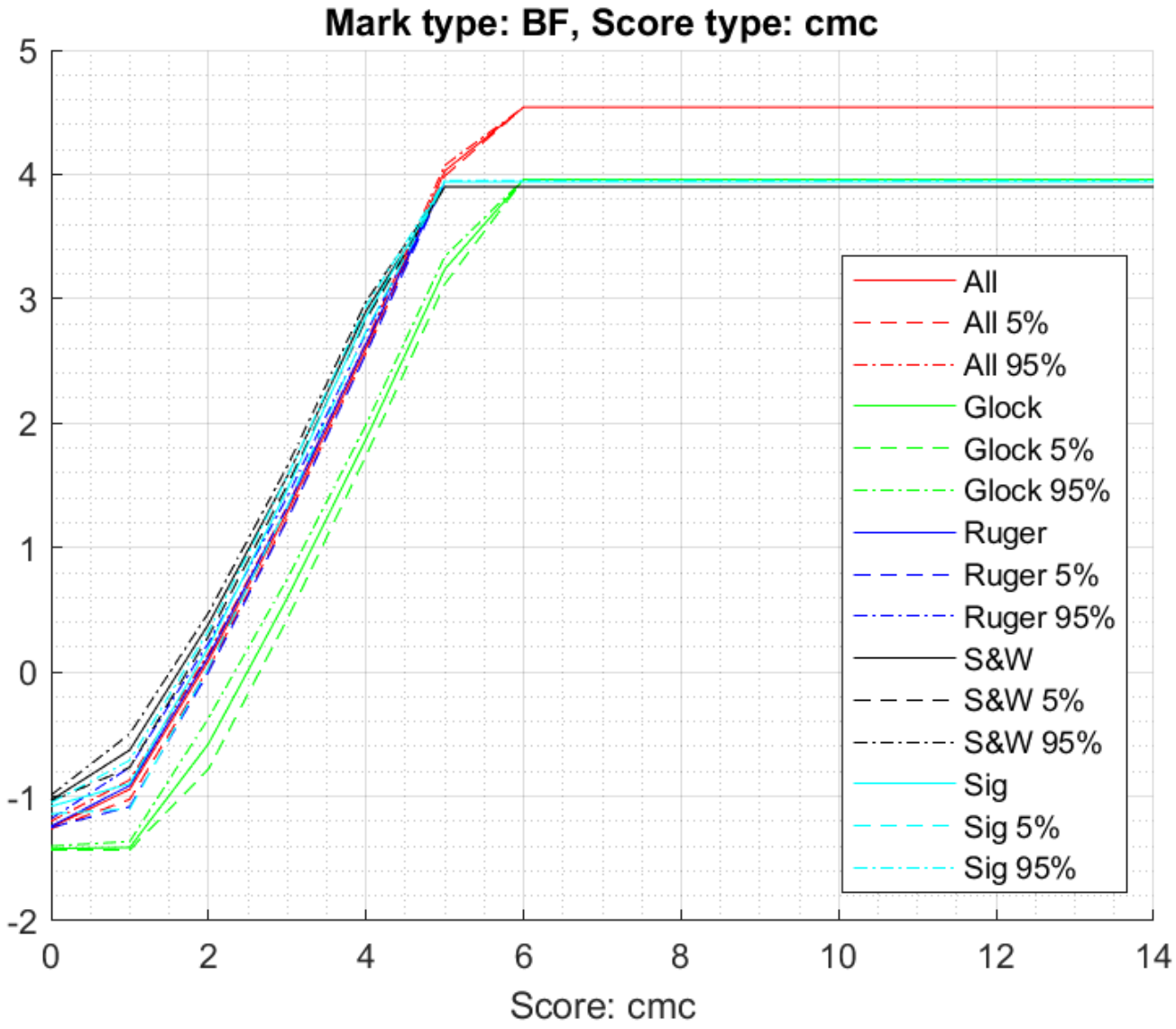


CMC = 6
SLR = 26509

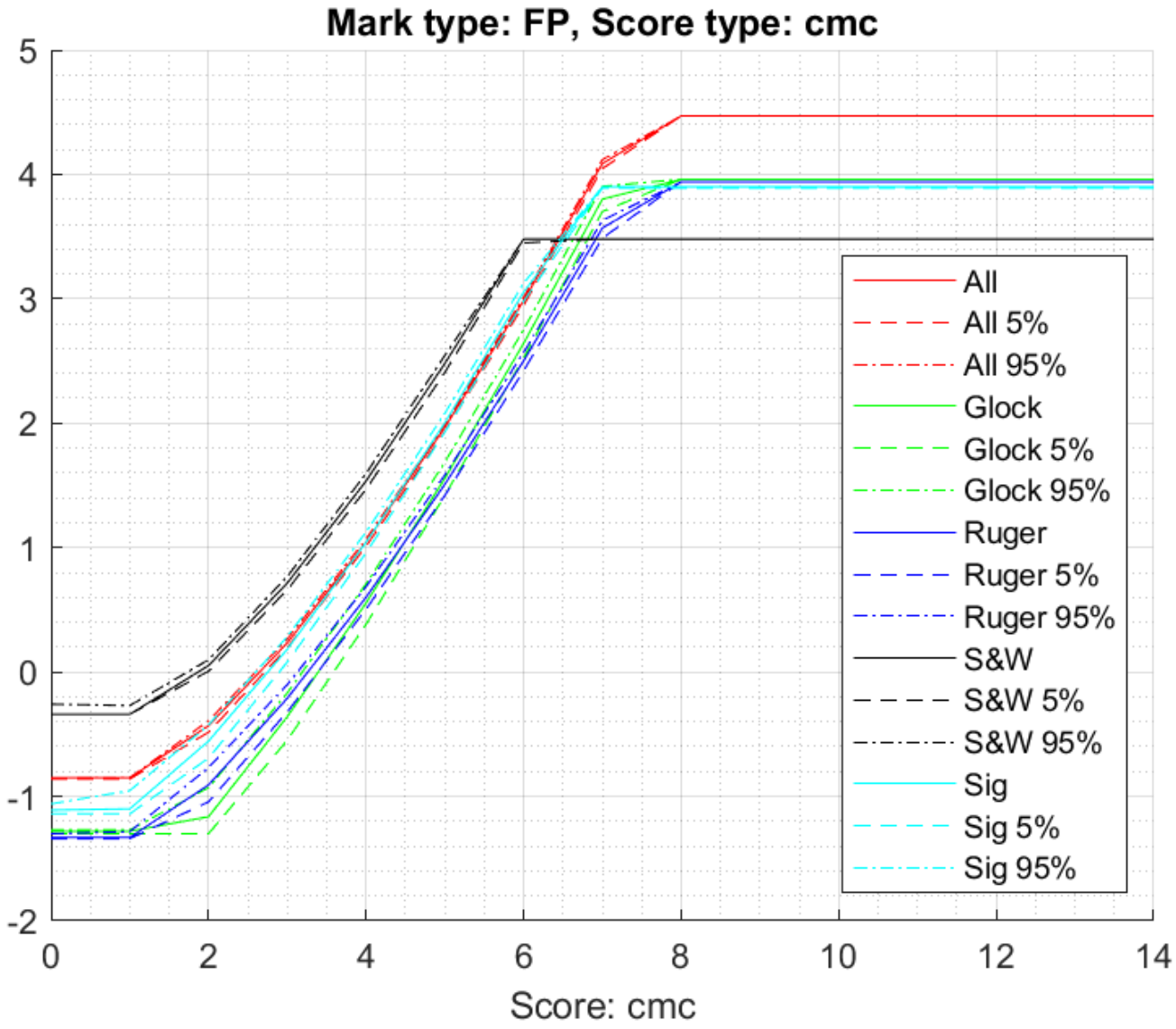
Combine All Four Mfg.



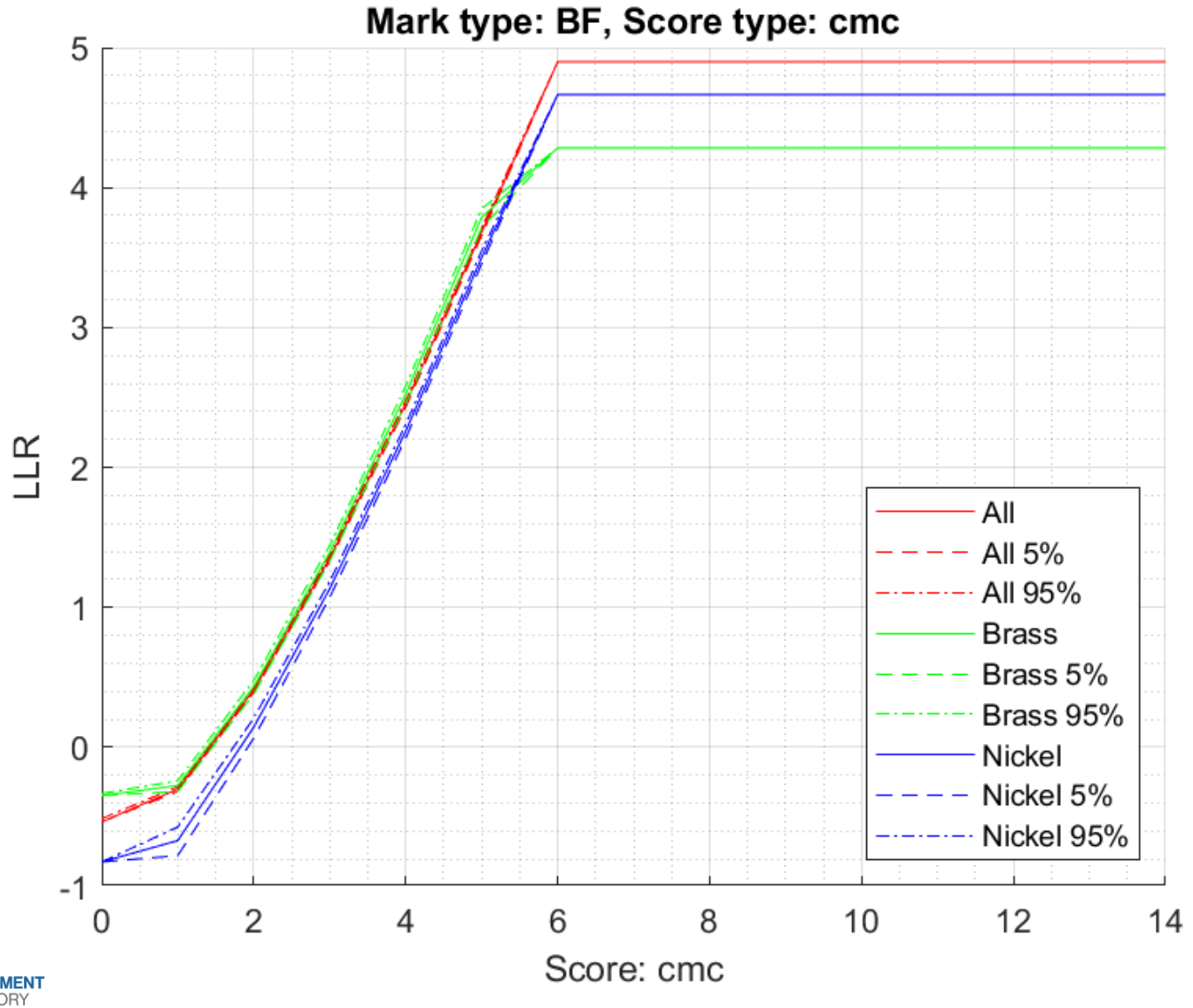
LR with Different Mfg. Distributions



LR with Different Mfg. Distributions



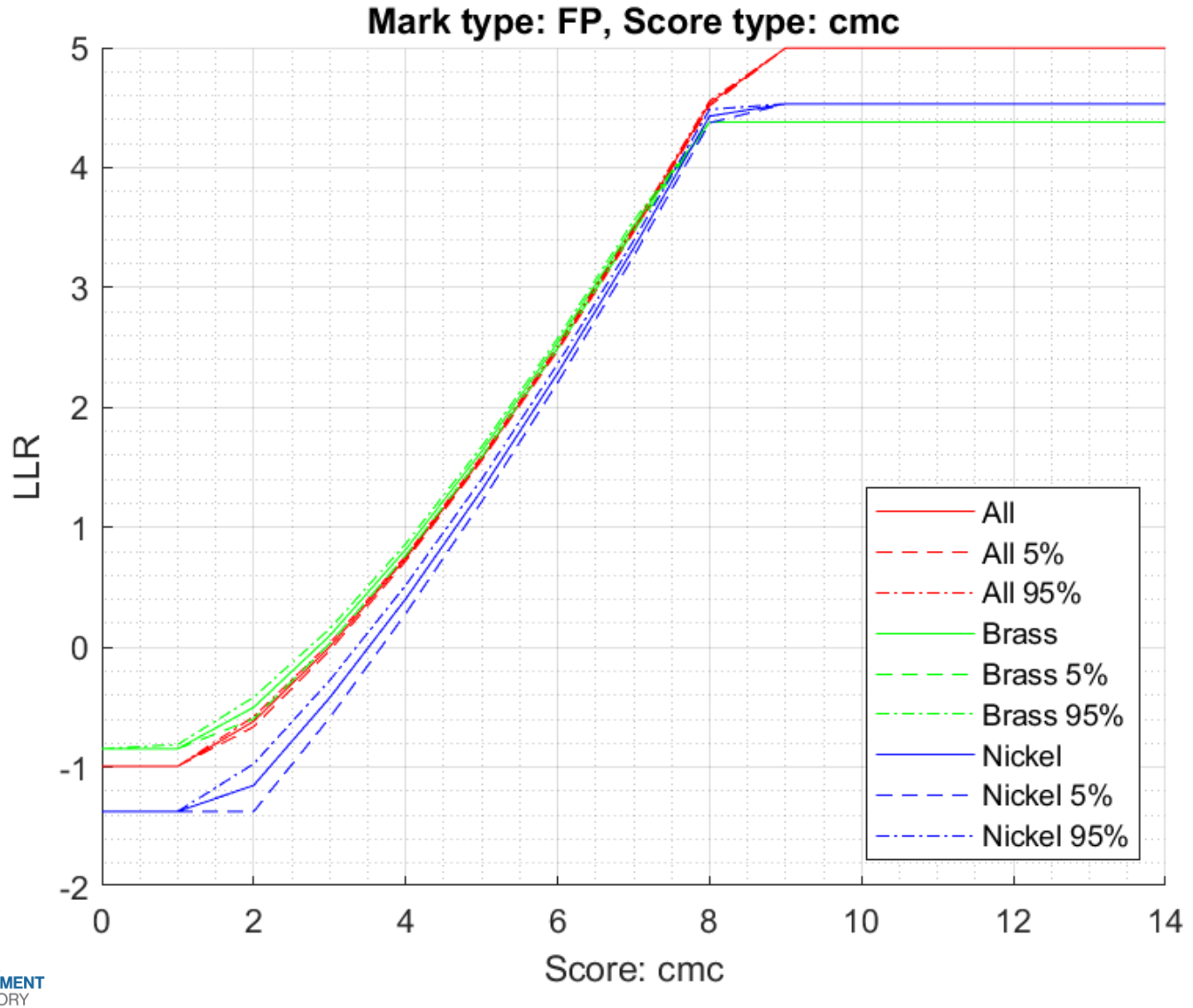
LR with Different Material Types - BF



NFI Glock Database

Analysis conducted by Dr. Martin Baiker at the Netherlands Forensics Institute

LR with Different Material Types - FP



NFI Glock Database

Analysis conducted by Dr. Martin Baiker at the Netherlands Forensics Institute

Discussion

- The CMC algorithm yields repeatably low false positive rates across all populations. This leads to low variability in LRs across different populations.
- Large reference populations with varying firearm and ammunition class characteristics are required to build the appropriate relevant populations.
- Additional research is required to determine which parameter heavily influence the SLR value.