# Ongoing MINEX Report Card

## Matcher F

NIST

**National Institute of
Standards and Technology**

U.S. Department of Commerce

Last Updated: October 9, 2015

## Participant Details

**Company:** Innovatrics
**Date Submitted:** 2/1/2005
**Date Validated:** 3/15/2005
**Date Completed:** 3/21/2006

| Library | Size (bytes) | MD5 Checksum |
|---|---|---|
| minexDLL.dll | 335872 | `86a332f8069bb3acde1c5688ba7a16c2` |

*NOTE: NIST plans to decertify Windows-based libraries in MINEX III.*

## Compliance Test Results

The following presents **PIV compliance** results per the criteria detailed in NIST Special Publication 800-76-2: Biometric Specifications for Personal Identity Verification.

**PIV Level One: PASS**
- Must match templates from all certified template generators with an $\text{FNMR}_{\text{FMR}}(0.01) \leq 0.01$ using two fingers (4.5.2.1-4). ✓

**PIV Level Two: FAIL**
- Must pass PIV level one compliance. ✓
- Native template generator must pass level one compliance. ✗
- Must match templates from native template generator with an $\text{FNMR}_{\text{FMR}}(0.0001) \leq 0.02$ using one finger (4.5.3-2) ✗

## Notes

- This report will be updated as new matching algorithms and template generators pass the compliance test. These updates will not change the PASS/FAIL decision above.

- NIST reserves the right to decertify a matcher if it later discovers the matcher violates PIV specifications in some previously undetected way.

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# 1 Introduction

This report card presents measurements of performance and interoperability for a single fingerprint matching algorithm submitted to NIST as part of the ongoing MINEX Evaluation. It reports whether the matcher passes the technical requirements for PIV-compliance described in the NIST Special Publication 800-76-2: Biometric Specifications for Personal Identity Verification.

# 2 Methodology

Testing is performed at a NIST facility. Each participant's submission is validated by NIST (http://www.nist.gov/itl/iad/ig/ominex.cfm) before undergoing full testing to ensure it operates correctly. If the matcher passes the validation procedure, it is then used to compare standard fingerprint templates. Performance is assessed against templates created by a template generation algorithm submitted by the participant as well as templates created by other compliant template generators.

## 2.1 Dataset

Testing is performed over a single dataset of sequestered fingerprint images. The images were collected by U.S. Visit at ports of entry into the United States. They consist of Live-scan plain impressions of left and right index fingers. WSQ [1] compression was applied to all images at a ratio of 15:1. The most recent capture of each subject was treated as the authentication sample, and the next most recent as the enrolled sample.

The dataset was divided into $123\,962$ mated and $124\,994$ non-mated subject pairings. Since both left and right index fingerprints are available for each subject, this provides $247\,924$ mated and $249\,988$ nonmated single-finger comparisons (after database consolidation). This also means that when left and right index fingers are fused at the score level [2, 6], the sets condense to $123\,962$ mated and $124\,994$ nonmated comparison scores.

## 2.2 Accuracy Metrics

Core matching accuracy is presented in the form of Detection Error Tradeoff (DET) plots [5], which show the trade-off between the False Match Rate (FMR) and the False Non-Match Rate (FNMR) as a decision threshold is adjusted. Formally, let $m_i$ ($i = 1 \ldots M$) be the $i$th mated comparison score, and $n_j$ ($j = 1 \ldots N$) the $j$th non-mated comparison score. Then the statistics are

$$\text{FNMR}(\tau) = \frac{1}{M} \sum_{i=1}^{M} \mathbb{1}\{m_i < \tau\}, \tag{1}$$

$$\text{FMR}(\tau) = \frac{1}{N} \sum_{j=1}^{N} \mathbb{1}\{n_j \geq \tau\}. \tag{2}$$

where $\mathbb{1}\{A\}$ is the indicator [3] of event $A$. Equations 1 and 2 define the curve parametrically with the decision threshold, $\tau$, as the free parameter. In some figures and tables, FNMR is presented as a function of FMR. This relationship is determined by

$$\text{FNMR}_{\text{FMR}}(\alpha) = \min_{\tau} \{ \text{FNMR}(\tau) \mid \text{FMR}(\tau) \leq \alpha \}, \tag{3}$$

which reads as the smallest FNMR that can be achieved while maintaining an FMR less than or equal to $\alpha$, the targeted FMR. This method of relating the two error statistics ensures FNMR is well-defined for all $0 \leq \alpha \leq 1$. When the matching algorithm produces only a few unique comparison scores, the maximum threshold, $\tau_0$, that elicits an $\text{FMR}(\tau_0) \leq \alpha$ may, in fact, be quite a bit lower than $\alpha$. Thus, Equation 3 imposes a natural penalty on matching algorithms that produce overly discretized scores.

Some figures show *pooled* DET accuracy, which is a measure of the accuracy of the matcher against all compliant template generators. Accuracy is measured by concatenating all comparison scores involving the matcher together and computing FMR and FNMR using Equations 2 and 1. This roughly simulates performance for a biometric system that employs one matcher and templates created by several template generators.

Figure 1: MINEX Interoperability Test Setup

## 2.3   Interoperability

Interoperability is tested in a manner similar to *Scenario 1* from the MINEX Evaluation Report [4] (see Figure 1). An enrolment template is prepared using submission X. Submission Y is used to prepare the authentication template and perform the match. The authentication template is always prepared by the same submission used to compare the templates. However, enrolment templates need not originate from the same submission. When they do, we refer to it as "native" mode.

# 3 Results

This section details the performance of matcher F when it compares verification templates created by its own template generator to enrolment templates created by all MINEX compliant template generators. Sections 3.1 and 3.2 present accuracy results for single finger and two finger matching respectively. Sections 3.3 and 3.4 present potentially useful statistics not directly related to the performance of the matcher.

## 3.1 Single Finger

Singe finger comparison results show the combined results for left and right index comparisons. For reference, *NIST Special Publication 800-76-2* requires that the matcher and template generator achieve a native accuracy of $\text{FNMR}_{\text{FMR}}(0.0001) \leq 0.02$.



Figure 2: *Single finger DET statistics for matcher F. Each box shows the distribution of FNMRs at a fixed FMR across all MINEX compliant template generators. The ends of the whiskers show the minimum and maximum FNMRs. The orange DET curve shows pooled performance against all template generators.*
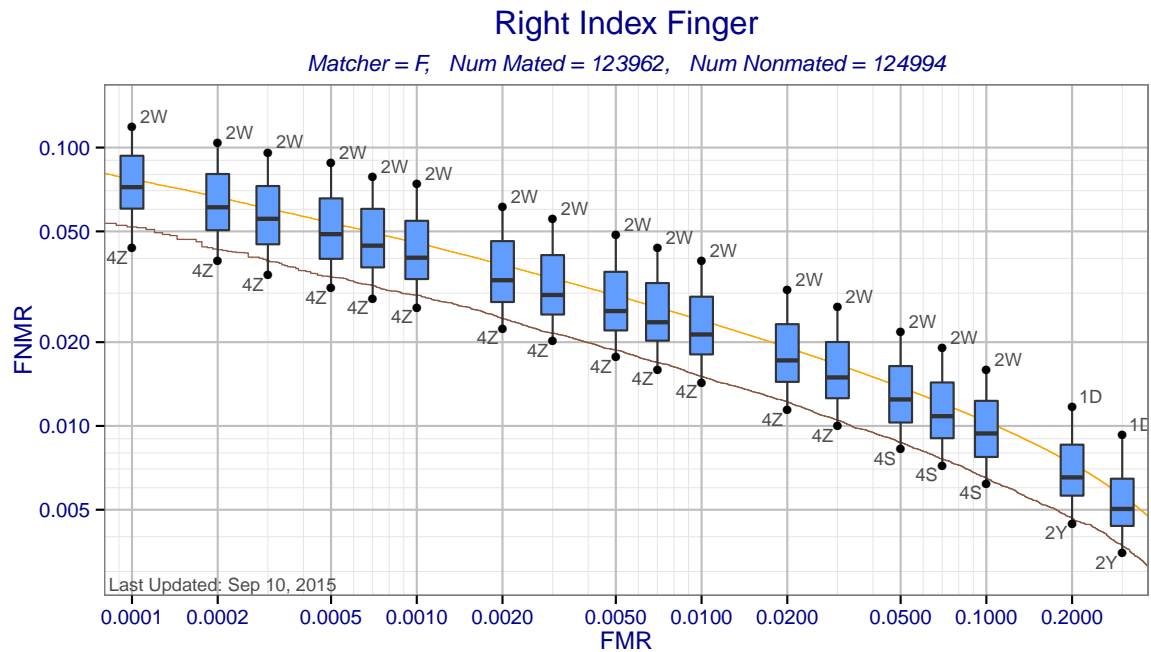
Figure 3: *Right index finger DET statistics for matcher F. Each box shows the distribution of FNMR at a fixed FMR across all MINEX compliant template generators. The ends of the whiskers show the minimum and maximum FNMRs. The orange DET curve shows pooled performance against all template generators.*
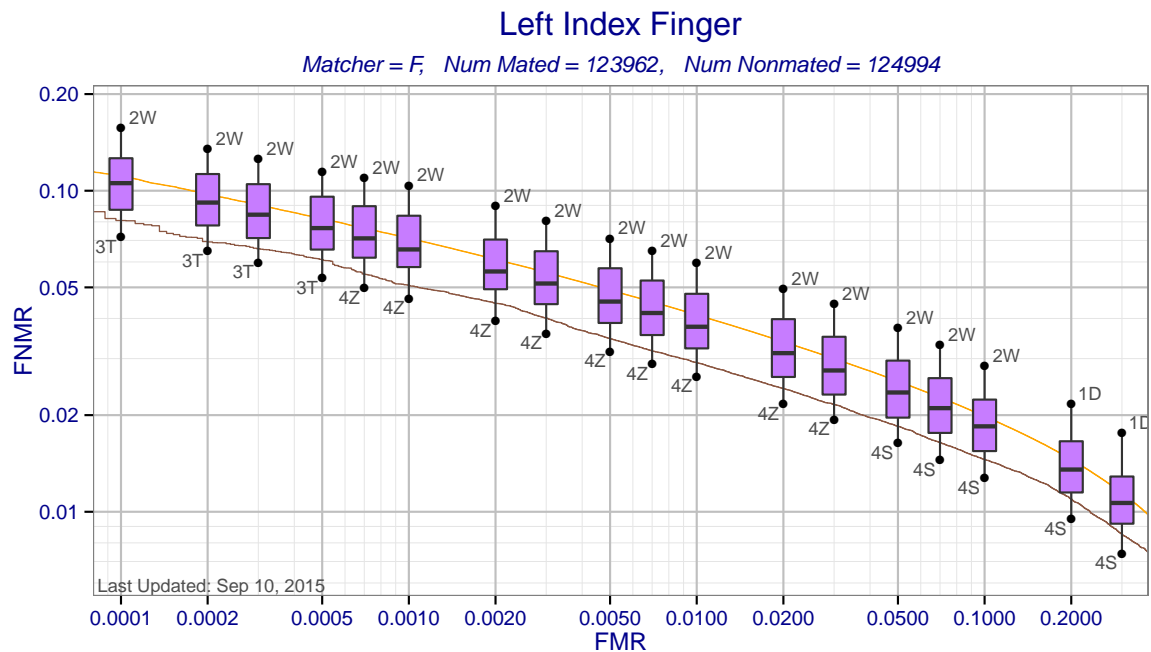


Figure 4: *Left index finger DET statistics for matcher F. Each box shows the distribution of FNMRs at a fixed FMR across all MINEX compliant template generators. The ends of whiskers show the minimum and maximum FNMRs. The orange DET curve shows pooled performance against all template generators.*
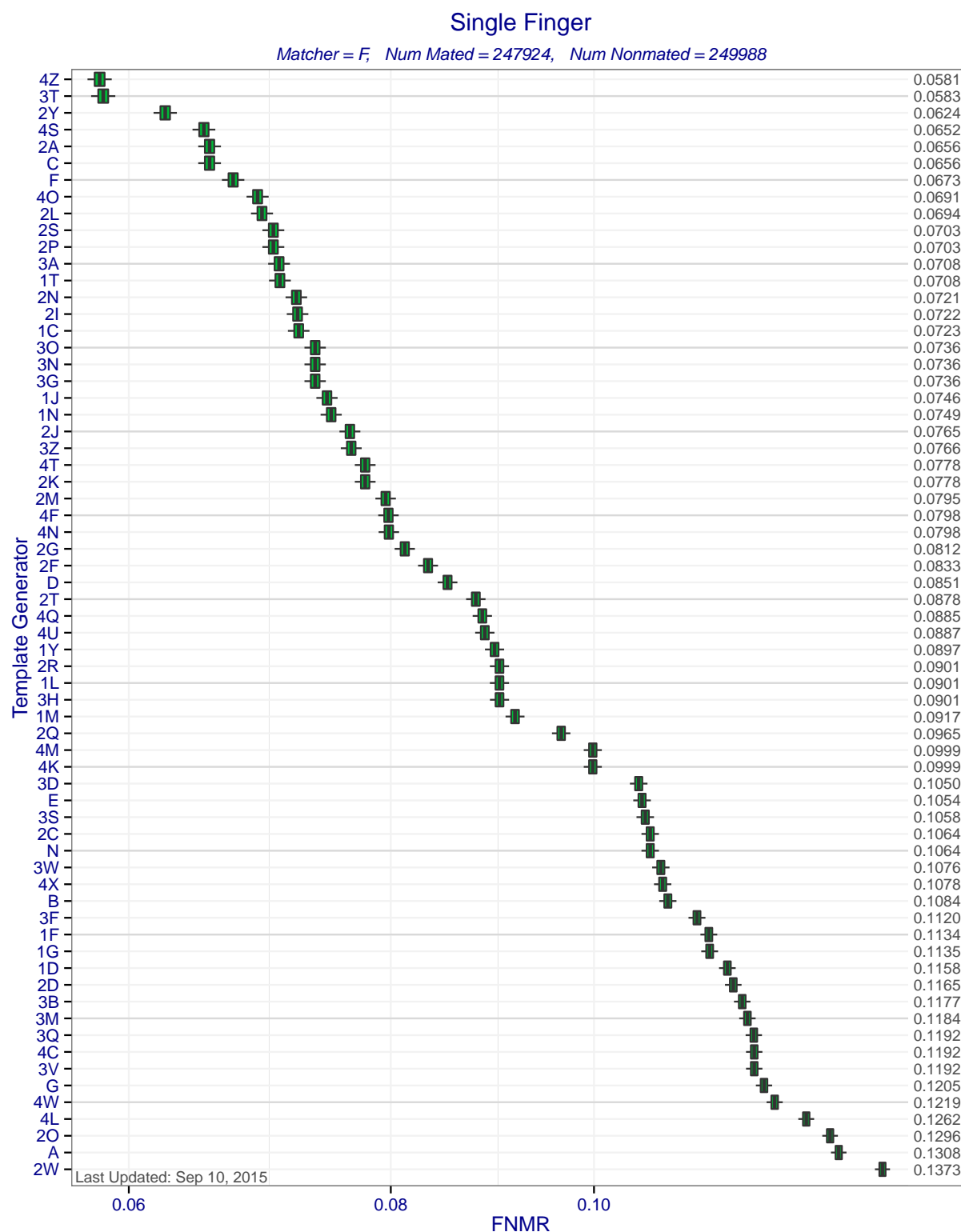
Figure 5: *Single finger FNMRs at FMR = 0.0001 when matcher F compares templates created by different template generators. The ends of the whiskers show the minimum and maximum FNMRs. Each box represents uncertainty about the true FNMR. The box edges mark the 50% confidence intervals while the whiskers mark the 90% confidence intervals. The numbers on the right show the actual computed FNMRs.*
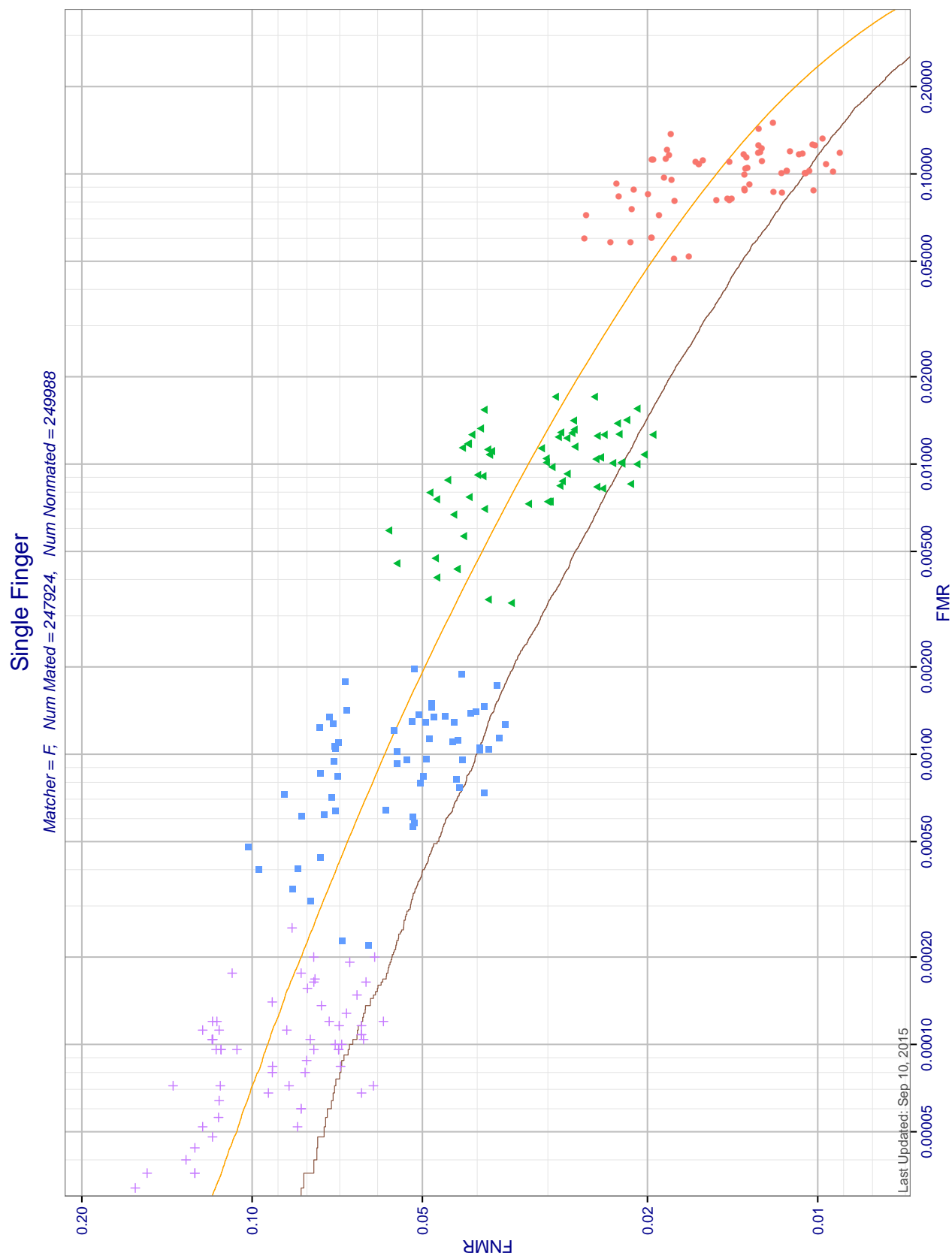
Figure 6: *Single finger DET accuracy for matcher F. Each cluster of points represents the variation in FMR and FNMR across MINEX compliant template generators at a fixed decision threshold. Each point corresponds to an (FMR, FNMR) pair for a specific template generator at a particular decision threshold. Four clusters are produced corresponding to four decision thresholds which produce pooled FMRs of $10^{-1}$, $10^{-2}$, $10^{-3}$, and $10^{-4}$. The orange DET curve shows pooled performance against all template generators.*

## 3.2   Two Finger

This section presents accuracy when matcher F compares templates created by all MINEX compliant template generators. Two-finger fusion is achieved by averaging the scores for left and right index fingers for each person. *NIST Special Publication 800-76-2* requires the matcher to achieve an accuracy of $\text{FNMR}_{\text{FMR}}(0.01) \leq 0.01$ for all MINEX compliant template generators.
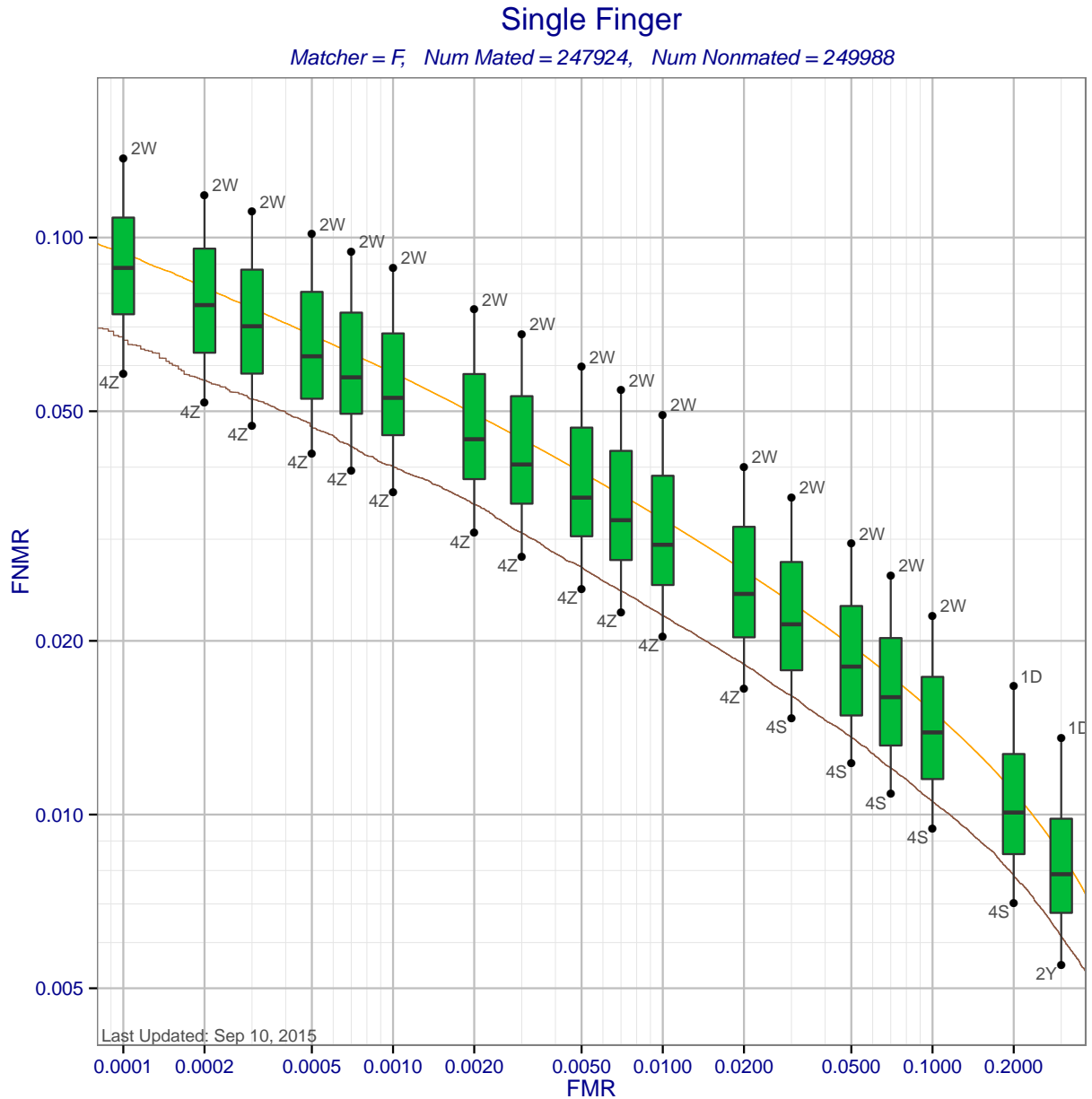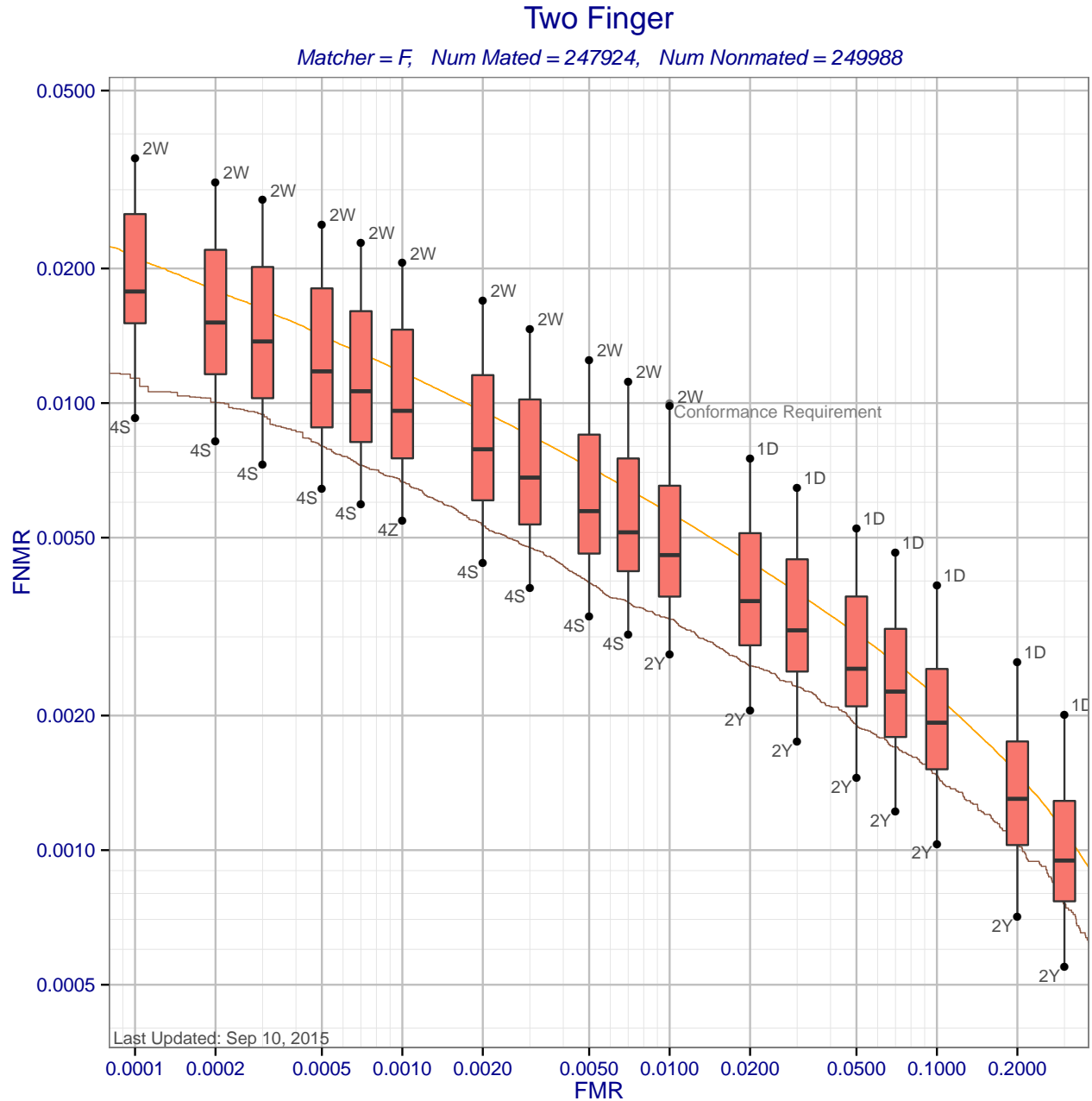


**Figure 7:** *Two finger DET statistics for matcher F. Each box shows the distribution of FNMRs at a fixed FMR across all MINEX compliant template generators. The whisker ends show the minimum and maximum FNMRs. The orange DET curve shows pooled performance against all template generators. Score-level fusion is achieved by averaging the scores for left and right index fingers.*
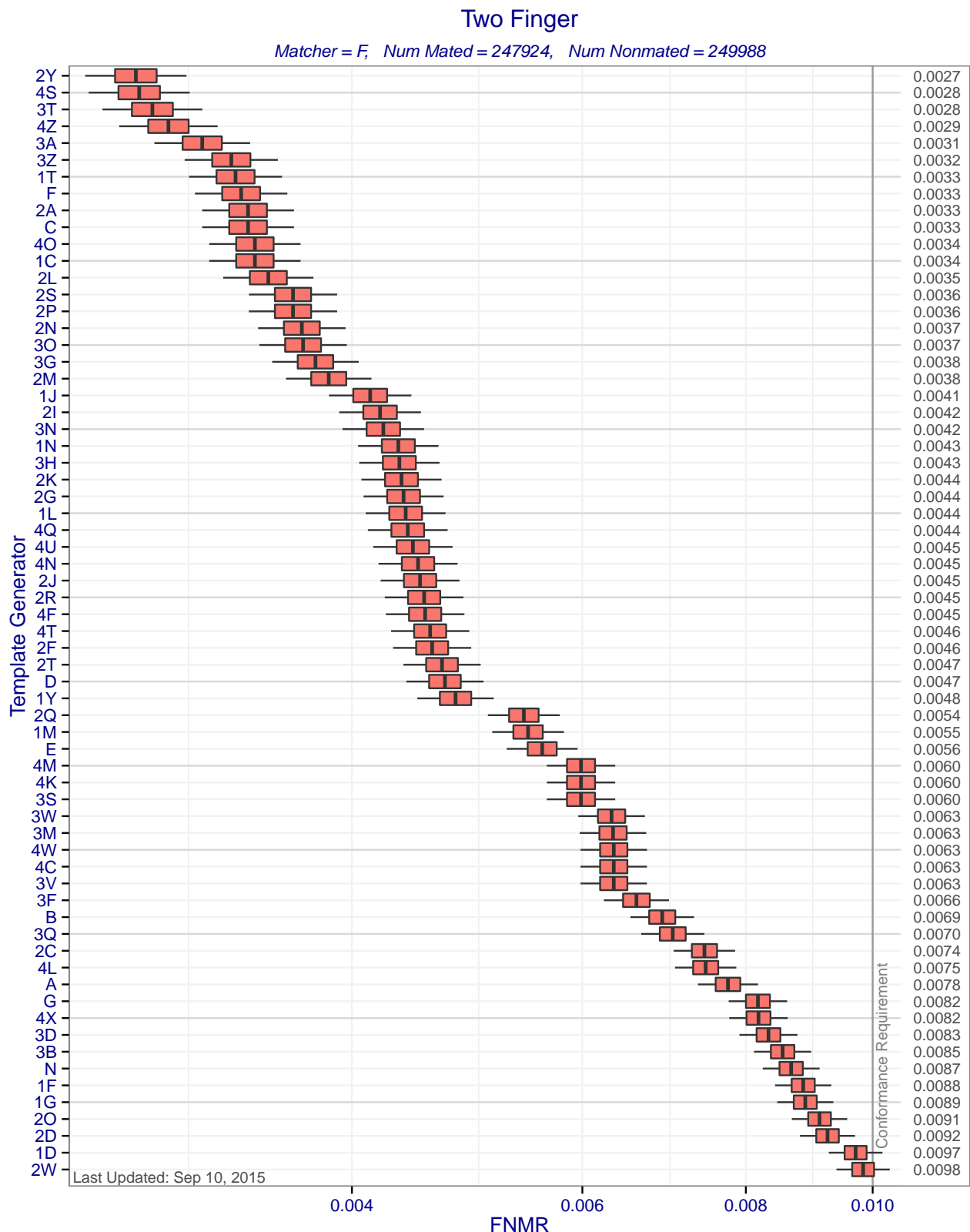
Figure 8: *Two finger FNMR at FMR=0.01 when matcher F compares templates created by different template generators. Each box represents uncertainty about the true FNMR. The box edges mark the 50% confidence intervals while the whiskers mark the 90% confindence intervals. The numbers on the right show the actual computed FNMRs. Score-level fusion is achieved by averaging the scores for left and right index fingers.*
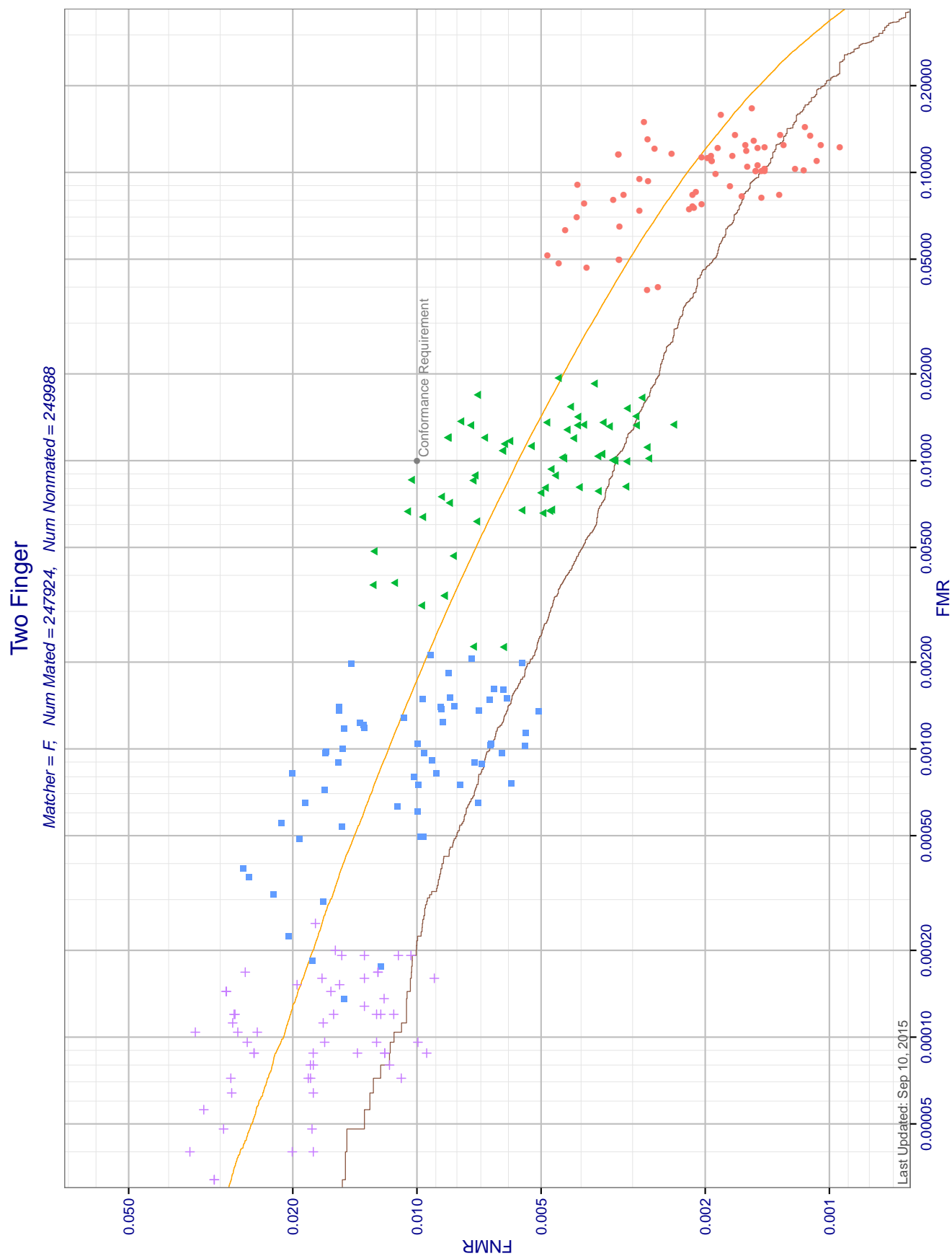
Figure 9: *Two finger DET accuracy for matcher F. Each cluster of points represents the variation in FMR and FNMR across MINEX compliant template generators at a fixed decision threshold. Each point corresponds to an (FMR, FNMR) pair for a specific template generator at a particular decision threshold. Four clusters are produced corresponding to four decision thresholds which produce pooled FMRs of $10^{-1}$, $10^{-2}$, $10^{-3}$, and $10^{-4}$. The orange DET curve shows pooled performance against all template generators. Score-level fusion is achieved by averaging the scores for left and right index fingers.*

## 3.3    Threshold Statistics

Results in this section are computed by concatenating comparison scores for matcher F across all MINEX compliant template generators.
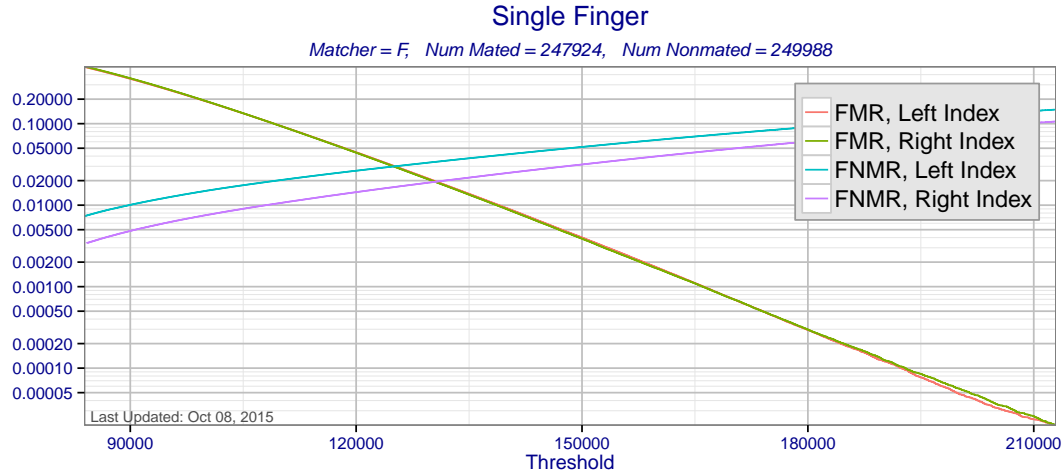


Figure 10: *Single finger FMR and FNMR as a function of score threshold for matcher F using templates created by all MINEX compliant template generators. Separate curves are presented for left and right index fingers.*
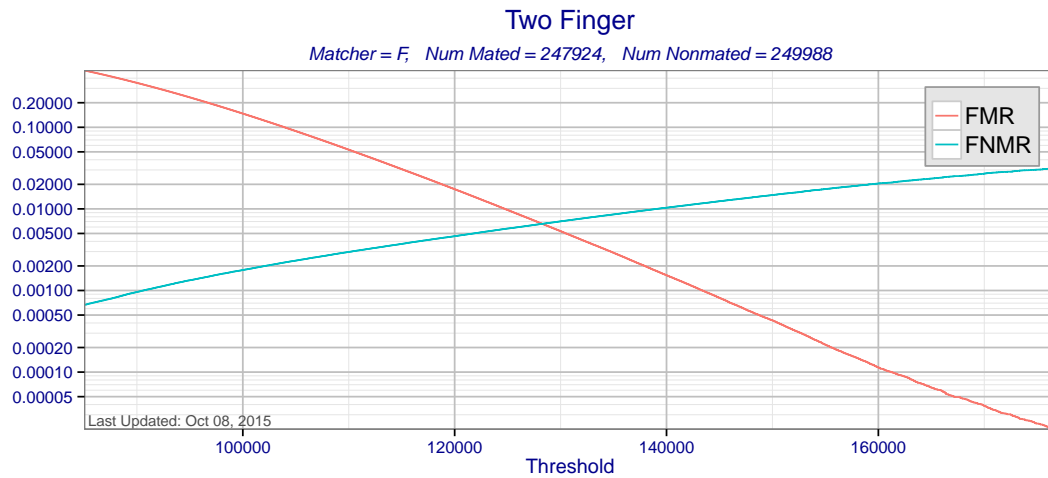


Figure 11: *Two finger FMR and FNMR as a function of score threshold for matcher F using templates created by all MINEX compliant template generators. Score-level fusion is achieved by averaging scores for the left and right index fingers.*

|                      | FMR=0.1 | FMR=0.01 | FMR=0.001 | FMR=0.0001 |
|----------------------|---------|----------|-----------|------------|
| Right index finger   | 109200  | 138750   | 166090    | 192980     |
| Left index finger    | 109230  | 139060   | 166240    | 192450     |
| Single finger        | 109210  | 138900   | 166120    | 192430     |
| Two finger           | 104030  | 124810   | 143440    | 161290     |

Table 1: *Threshold calibration table. The cells show the thresholds corresponding to the FMR indicated by the column header.*

## 3.4   Q-Q Plot

The Q-Q plot compares two probability distributions. It plots the quantile of one distribution as a function of the other. If the curve follows the $y = x$ line, then the distributions are identical. If the FMR curve is above the $y = x$ line, then the left index finger tends to produce lower non-mated scores than the left index finger. If the FNMR curve is above the $y = x$ line, then the left index finger tends to produce lower mated scores than the left index finger. A jagged and/or truncated cur ve is indicative of discretized scores.
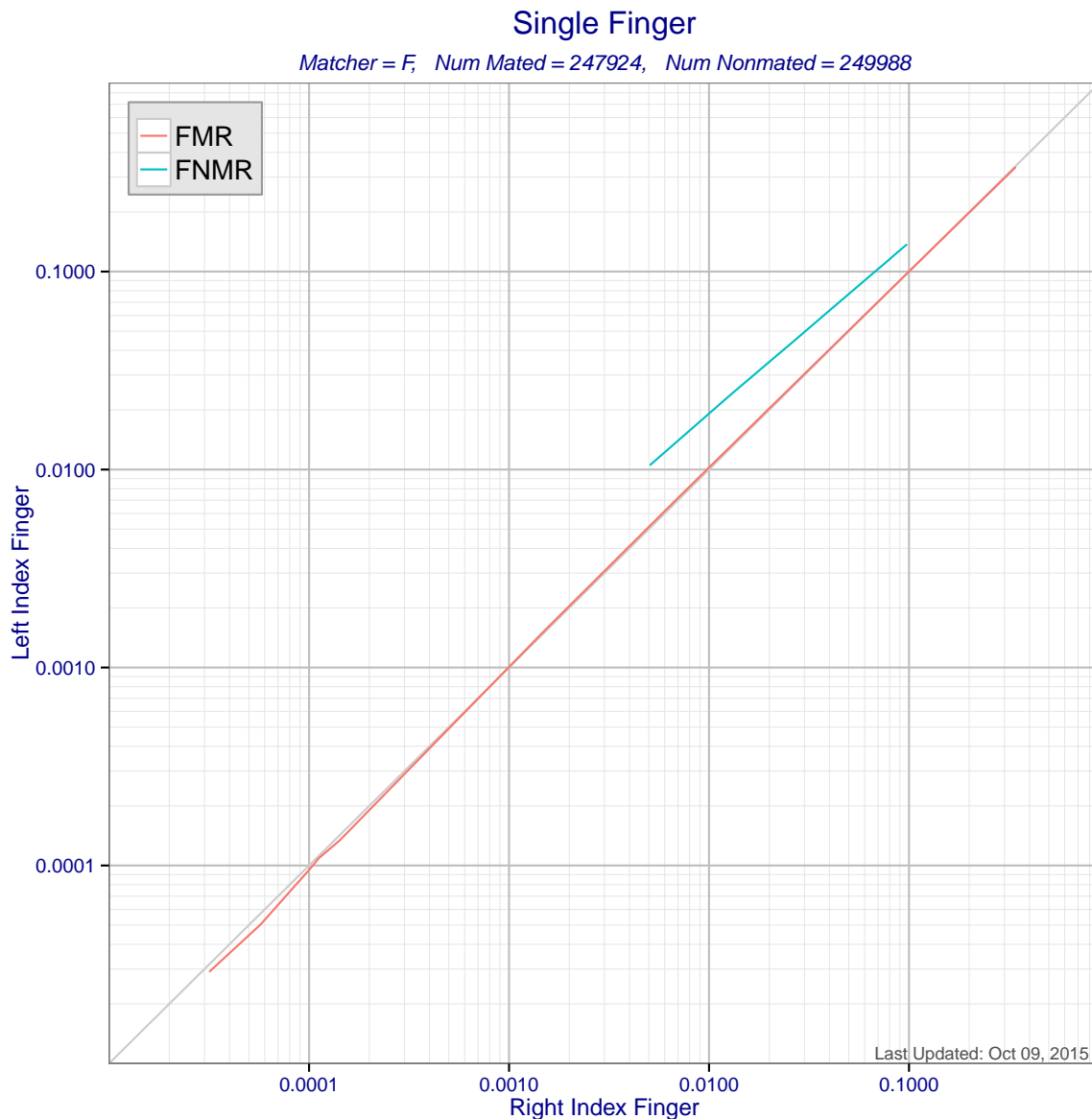


Figure 12: *Q-Q plot comparing score distributions for left and right index fingers.*

## 3.5   Minutiae Count Statistics

This section shows how the number of minutia found in the samples affects recognition accuracy. To be robust to spoofing and other active attacks, the algorithm should not allow FMR to rise sharply as the number of available minutia decreases. Nor should it allow FMR to rise sharply as the number of detected minutia increases.
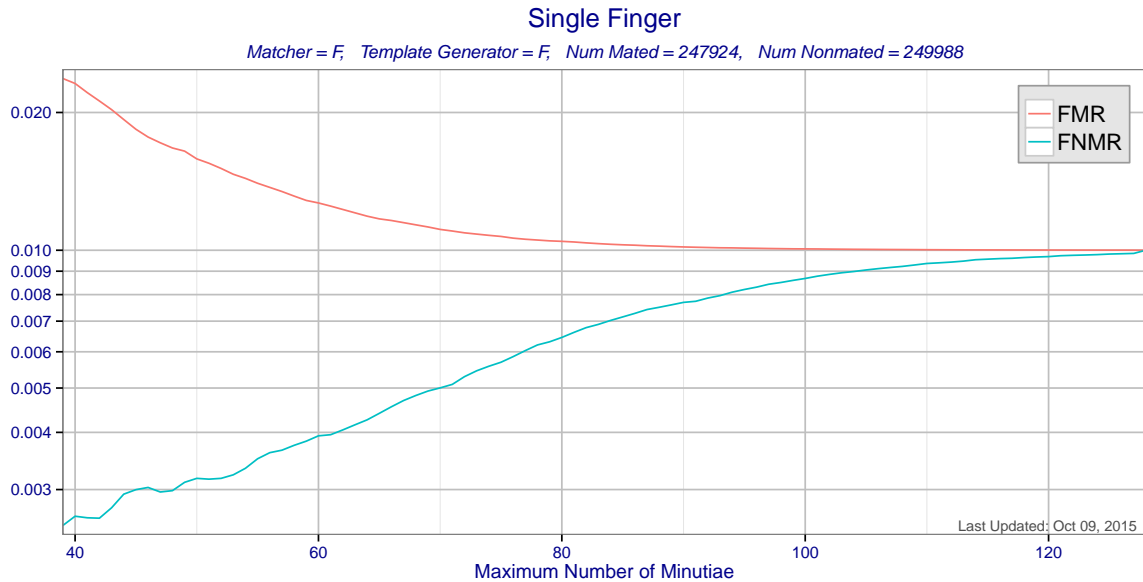


Figure 13: *FNMR and FMR as a function of the number of minutia found by the template generator. The vertical axis defines a filter criterion such that FNMR and FMR are computed over only those comparisons where at least one of the compared templates has* no more *than the specified number of minutia. The threshold is fixed separately for FNMR and FMR to elicit an error rate of approximately 0.01 over unfiltered comparisons.*
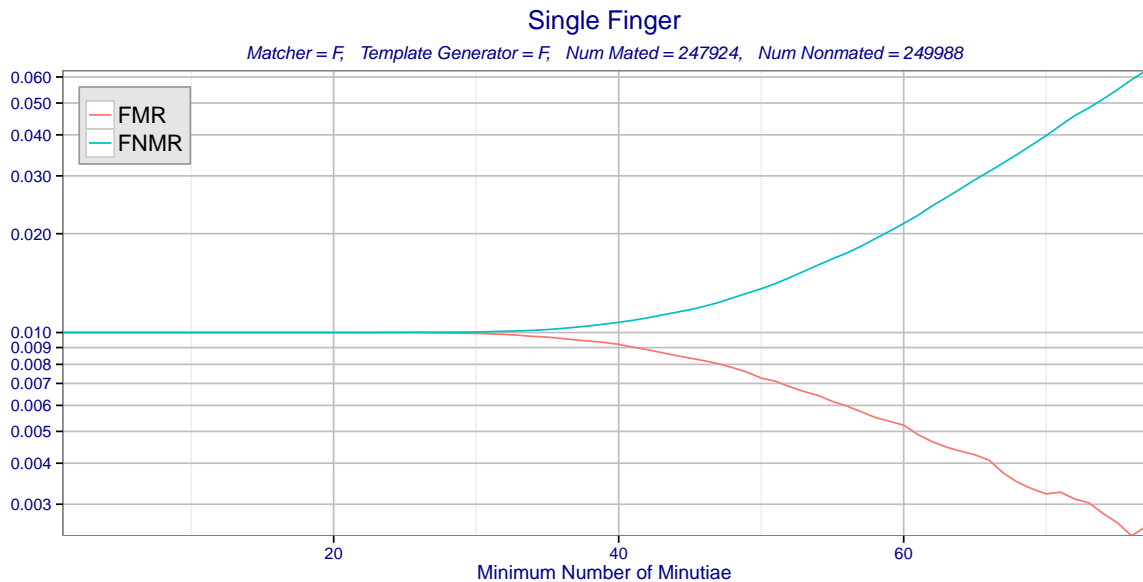


Figure 14: *FNMR and FMR as a function of the number of minutia found by the template generator. The vertical axis defines a filter criterion such that FNMR and FMR are computed over only those comparisons where at least one of the compared templates has* at least *the indicated number of minutia. The threshold is fixed separately for FNMR and FMR to elicit an error rate of approximately 0.01 over unfiltered comparisons.*

# 4 Performance Tables

The following tables present accuracy number, including estimates of uncertainty in the form of 90% confidence bounds. These tables are provided because most of the figures in the main body of this report do not present numerical results.

Table 2: *Single finger FNMRs at various FMRs when matcher F compares templates created by its template generator and PIV-compliant template generators.*

| Enroller | FNMR @ FMR=0.01 | FNMR @ FMR=0.001 | FNMR @ FMR=0.0001 |
|----------|-----------------|------------------|-------------------|
| A | $0.0453 \pm 0.0007$ | $0.0826 \pm 0.0009$ | $0.131 \pm 0.001$ |
| B | $0.0380 \pm 0.0006$ | $0.0683 \pm 0.0008$ | $0.108 \pm 0.001$ |
| C | $0.0222 \pm 0.0005$ | $0.0398 \pm 0.0006$ | $0.0656 \pm 0.0008$ |
| D | $0.0297 \pm 0.0006$ | $0.0528 \pm 0.0007$ | $0.0851 \pm 0.0009$ |
| E | $0.0337 \pm 0.0006$ | $0.0601 \pm 0.0008$ | $0.105 \pm 0.001$ |
| F | $0.0221 \pm 0.0005$ | $0.0401 \pm 0.0006$ | $0.0673 \pm 0.0008$ |
| G | $0.0435 \pm 0.0007$ | $0.0768 \pm 0.0009$ | $0.121 \pm 0.001$ |
| N | $0.0425 \pm 0.0007$ | $0.0731 \pm 0.0009$ | $0.106 \pm 0.001$ |
| 1C | $0.0247 \pm 0.0005$ | $0.0443 \pm 0.0007$ | $0.0723 \pm 0.0009$ |
| 1D | $0.0434 \pm 0.0007$ | $0.0738 \pm 0.0009$ | $0.116 \pm 0.001$ |
| 1F | $0.0434 \pm 0.0007$ | $0.0769 \pm 0.0009$ | $0.113 \pm 0.001$ |
| 1G | $0.0435 \pm 0.0007$ | $0.0770 \pm 0.0009$ | $0.114 \pm 0.001$ |
| 1J | $0.0266 \pm 0.0005$ | $0.0459 \pm 0.0007$ | $0.0746 \pm 0.0009$ |
| 1L | $0.0304 \pm 0.0006$ | $0.0555 \pm 0.0008$ | $0.0901 \pm 0.0009$ |
| 1M | $0.0304 \pm 0.0006$ | $0.0544 \pm 0.0007$ | $0.0917 \pm 0.0010$ |
| 1N | $0.0273 \pm 0.0005$ | $0.0473 \pm 0.0007$ | $0.0749 \pm 0.0009$ |
| 1T | $0.0234 \pm 0.0005$ | $0.0422 \pm 0.0007$ | $0.0708 \pm 0.0008$ |
| 1Y | $0.0295 \pm 0.0006$ | $0.0527 \pm 0.0007$ | $0.0897 \pm 0.0009$ |
| 2A | $0.0222 \pm 0.0005$ | $0.0398 \pm 0.0006$ | $0.0656 \pm 0.0008$ |
| 2C | $0.0385 \pm 0.0006$ | $0.0677 \pm 0.0008$ | $0.106 \pm 0.001$ |
| 2D | $0.0437 \pm 0.0007$ | $0.0746 \pm 0.0009$ | $0.117 \pm 0.001$ |
| 2F | $0.0292 \pm 0.0006$ | $0.0529 \pm 0.0007$ | $0.0833 \pm 0.0009$ |
| 2G | $0.0278 \pm 0.0005$ | $0.0501 \pm 0.0007$ | $0.0812 \pm 0.0009$ |
| 2I | $0.0272 \pm 0.0005$ | $0.0470 \pm 0.0007$ | $0.0722 \pm 0.0009$ |
| 2J | $0.0284 \pm 0.0005$ | $0.0491 \pm 0.0007$ | $0.0765 \pm 0.0009$ |
| 2K | $0.0271 \pm 0.0005$ | $0.0488 \pm 0.0007$ | $0.0778 \pm 0.0009$ |
| 2L | $0.0240 \pm 0.0005$ | $0.0426 \pm 0.0007$ | $0.0694 \pm 0.0008$ |
| 2M | $0.0261 \pm 0.0005$ | $0.0496 \pm 0.0007$ | $0.0795 \pm 0.0009$ |
| 2N | $0.0248 \pm 0.0005$ | $0.0453 \pm 0.0007$ | $0.0721 \pm 0.0009$ |
| 2O | $0.0445 \pm 0.0007$ | $0.0801 \pm 0.0009$ | $0.130 \pm 0.001$ |
| 2P | $0.0245 \pm 0.0005$ | $0.0446 \pm 0.0007$ | $0.0703 \pm 0.0008$ |
| 2Q | $0.0317 \pm 0.0006$ | $0.0588 \pm 0.0008$ | $0.0965 \pm 0.0010$ |
| 2R | $0.0289 \pm 0.0006$ | $0.0521 \pm 0.0007$ | $0.0901 \pm 0.0009$ |
| 2S | $0.0245 \pm 0.0005$ | $0.0446 \pm 0.0007$ | $0.0703 \pm 0.0008$ |
| 2T | $0.0292 \pm 0.0006$ | $0.0524 \pm 0.0007$ | $0.0878 \pm 0.0009$ |
| 2W | $0.0493 \pm 0.0007$ | $0.0886 \pm 0.0009$ | $0.137 \pm 0.001$ |
| 2Y | $0.0209 \pm 0.0005$ | $0.0381 \pm 0.0006$ | $0.0624 \pm 0.0008$ |
| 3A | $0.0230 \pm 0.0005$ | $0.0420 \pm 0.0007$ | $0.0708 \pm 0.0008$ |
| 3B | $0.0437 \pm 0.0007$ | $0.0777 \pm 0.0009$ | $0.118 \pm 0.001$ |
| 3D | $0.0394 \pm 0.0006$ | $0.0673 \pm 0.0008$ | $0.105 \pm 0.001$ |

Table 2: *(continued)*

| Enroller | FNMR @ FMR=0.01 | FNMR @ FMR=0.001 | FNMR @ FMR=0.0001 |
|---|---|---|---|
| 3F | $0.0371 \pm 0.0006$ | $0.0660 \pm 0.0008$ | $0.112 \pm 0.001$ |
| 3G | $0.0234 \pm 0.0005$ | $0.0413 \pm 0.0007$ | $0.0736 \pm 0.0009$ |
| 3H | $0.0291 \pm 0.0006$ | $0.0508 \pm 0.0007$ | $0.0901 \pm 0.0009$ |
| 3M | $0.0394 \pm 0.0006$ | $0.0728 \pm 0.0009$ | $0.118 \pm 0.001$ |
| 3N | $0.0273 \pm 0.0005$ | $0.0472 \pm 0.0007$ | $0.0736 \pm 0.0009$ |
| 3O | $0.0241 \pm 0.0005$ | $0.0430 \pm 0.0007$ | $0.0736 \pm 0.0009$ |
| 3Q | $0.0387 \pm 0.0006$ | $0.0706 \pm 0.0008$ | $0.119 \pm 0.001$ |
| 3S | $0.0349 \pm 0.0006$ | $0.0625 \pm 0.0008$ | $0.106 \pm 0.001$ |
| 3T | $0.0207 \pm 0.0005$ | $0.0378 \pm 0.0006$ | $0.0583 \pm 0.0008$ |
| 3V | $0.0387 \pm 0.0006$ | $0.0720 \pm 0.0009$ | $0.119 \pm 0.001$ |
| 3W | $0.0365 \pm 0.0006$ | $0.0636 \pm 0.0008$ | $0.108 \pm 0.001$ |
| 3Z | $0.0255 \pm 0.0005$ | $0.0470 \pm 0.0007$ | $0.0766 \pm 0.0009$ |
| 4C | $0.0387 \pm 0.0006$ | $0.0720 \pm 0.0009$ | $0.119 \pm 0.001$ |
| 4F | $0.0291 \pm 0.0006$ | $0.0510 \pm 0.0007$ | $0.0798 \pm 0.0009$ |
| 4K | $0.0346 \pm 0.0006$ | $0.0622 \pm 0.0008$ | $0.0999 \pm 0.0010$ |
| 4L | $0.0440 \pm 0.0007$ | $0.0805 \pm 0.0009$ | $0.126 \pm 0.001$ |
| 4M | $0.0346 \pm 0.0006$ | $0.0622 \pm 0.0008$ | $0.0999 \pm 0.0010$ |
| 4N | $0.0270 \pm 0.0005$ | $0.0483 \pm 0.0007$ | $0.0798 \pm 0.0009$ |
| 4O | $0.0226 \pm 0.0005$ | $0.0409 \pm 0.0007$ | $0.0691 \pm 0.0008$ |
| 4Q | $0.0302 \pm 0.0006$ | $0.0547 \pm 0.0008$ | $0.0885 \pm 0.0009$ |
| 4S | $0.0208 \pm 0.0005$ | $0.0389 \pm 0.0006$ | $0.0652 \pm 0.0008$ |
| 4T | $0.0270 \pm 0.0005$ | $0.0481 \pm 0.0007$ | $0.0778 \pm 0.0009$ |
| 4U | $0.0305 \pm 0.0006$ | $0.0559 \pm 0.0008$ | $0.0887 \pm 0.0009$ |
| 4W | $0.0386 \pm 0.0006$ | $0.0716 \pm 0.0009$ | $0.122 \pm 0.001$ |
| 4X | $0.0389 \pm 0.0006$ | $0.0680 \pm 0.0008$ | $0.108 \pm 0.001$ |
| 4Z | $0.0204 \pm 0.0005$ | $0.0362 \pm 0.0006$ | $0.0581 \pm 0.0008$ |

Table 3: *Right index finger FNMRs at various FMRs when matcher F compares templates created by its template generator and PIV-compliant template generators.*

| Enroller | FNMR @ FMR=0.01 | FNMR @ FMR=0.001 | FNMR @ FMR=0.0001 |
|---|---|---|---|
| A | $0.0346 \pm 0.0009$ | $0.068 \pm 0.001$ | $0.110 \pm 0.001$ |
| B | $0.0282 \pm 0.0008$ | $0.053 \pm 0.001$ | $0.088 \pm 0.001$ |
| C | $0.0154 \pm 0.0006$ | $0.0291 \pm 0.0008$ | $0.049 \pm 0.001$ |
| D | $0.0214 \pm 0.0007$ | $0.0399 \pm 0.0009$ | $0.063 \pm 0.001$ |
| E | $0.0259 \pm 0.0007$ | $0.0477 \pm 0.0010$ | $0.086 \pm 0.001$ |
| F | $0.0151 \pm 0.0006$ | $0.0295 \pm 0.0008$ | $0.052 \pm 0.001$ |
| G | $0.0320 \pm 0.0008$ | $0.059 \pm 0.001$ | $0.099 \pm 0.001$ |
| N | $0.0321 \pm 0.0008$ | $0.058 \pm 0.001$ | $0.094 \pm 0.001$ |
| 1C | $0.0184 \pm 0.0006$ | $0.0341 \pm 0.0008$ | $0.059 \pm 0.001$ |
| 1D | $0.0328 \pm 0.0008$ | $0.058 \pm 0.001$ | $0.094 \pm 0.001$ |
| 1F | $0.0326 \pm 0.0008$ | $0.061 \pm 0.001$ | $0.097 \pm 0.001$ |
| 1G | $0.0327 \pm 0.0008$ | $0.061 \pm 0.001$ | $0.097 \pm 0.001$ |
| 1J | $0.0184 \pm 0.0006$ | $0.0331 \pm 0.0008$ | $0.061 \pm 0.001$ |
| 1L | $0.0214 \pm 0.0007$ | $0.0417 \pm 0.0009$ | $0.078 \pm 0.001$ |
| 1M | $0.0220 \pm 0.0007$ | $0.0429 \pm 0.0009$ | $0.073 \pm 0.001$ |
| 1N | $0.0195 \pm 0.0006$ | $0.0354 \pm 0.0009$ | $0.065 \pm 0.001$ |
| 1T | $0.0170 \pm 0.0006$ | $0.0319 \pm 0.0008$ | $0.057 \pm 0.001$ |
| 1Y | $0.0215 \pm 0.0007$ | $0.0409 \pm 0.0009$ | $0.072 \pm 0.001$ |
| 2A | $0.0154 \pm 0.0006$ | $0.0291 \pm 0.0008$ | $0.049 \pm 0.001$ |
| 2C | $0.0277 \pm 0.0008$ | $0.053 \pm 0.001$ | $0.086 \pm 0.001$ |
| 2D | $0.0326 \pm 0.0008$ | $0.061 \pm 0.001$ | $0.101 \pm 0.001$ |
| 2F | $0.0206 \pm 0.0007$ | $0.0397 \pm 0.0009$ | $0.065 \pm 0.001$ |
| 2G | $0.0194 \pm 0.0006$ | $0.0389 \pm 0.0009$ | $0.065 \pm 0.001$ |
| 2I | $0.0191 \pm 0.0006$ | $0.0350 \pm 0.0009$ | $0.061 \pm 0.001$ |
| 2J | $0.0211 \pm 0.0007$ | $0.0384 \pm 0.0009$ | $0.067 \pm 0.001$ |
| 2K | $0.0192 \pm 0.0006$ | $0.0366 \pm 0.0009$ | $0.065 \pm 0.001$ |
| 2L | $0.0172 \pm 0.0006$ | $0.0322 \pm 0.0008$ | $0.054 \pm 0.001$ |
| 2M | $0.0195 \pm 0.0006$ | $0.0389 \pm 0.0009$ | $0.074 \pm 0.001$ |
| 2N | $0.0176 \pm 0.0006$ | $0.0336 \pm 0.0008$ | $0.056 \pm 0.001$ |
| 2O | $0.0333 \pm 0.0008$ | $0.064 \pm 0.001$ | $0.109 \pm 0.001$ |
| 2P | $0.0173 \pm 0.0006$ | $0.0328 \pm 0.0008$ | $0.056 \pm 0.001$ |
| 2Q | $0.0233 \pm 0.0007$ | $0.0462 \pm 0.0010$ | $0.081 \pm 0.001$ |
| 2R | $0.0208 \pm 0.0007$ | $0.0389 \pm 0.0009$ | $0.072 \pm 0.001$ |
| 2S | $0.0173 \pm 0.0006$ | $0.0328 \pm 0.0008$ | $0.056 \pm 0.001$ |
| 2T | $0.0203 \pm 0.0007$ | $0.0405 \pm 0.0009$ | $0.069 \pm 0.001$ |
| 2W | $0.0391 \pm 0.0009$ | $0.074 \pm 0.001$ | $0.118 \pm 0.002$ |
| 2Y | $0.0146 \pm 0.0006$ | $0.0286 \pm 0.0008$ | $0.052 \pm 0.001$ |
| 3A | $0.0165 \pm 0.0006$ | $0.0325 \pm 0.0008$ | $0.058 \pm 0.001$ |
| 3B | $0.0328 \pm 0.0008$ | $0.061 \pm 0.001$ | $0.096 \pm 0.001$ |
| 3D | $0.0295 \pm 0.0008$ | $0.055 \pm 0.001$ | $0.086 \pm 0.001$ |

Table 3: *(continued)*

| Enroller | FNMR @ FMR=0.01 | FNMR @ FMR=0.001 | FNMR @ FMR=0.0001 |
|---|---|---|---|
| 3F | $0.0282 \pm 0.0008$ | $0.053 \pm 0.001$ | $0.097 \pm 0.001$ |
| 3G | $0.0166 \pm 0.0006$ | $0.0312 \pm 0.0008$ | $0.061 \pm 0.001$ |
| 3H | $0.0212 \pm 0.0007$ | $0.0390 \pm 0.0009$ | $0.078 \pm 0.001$ |
| 3M | $0.0309 \pm 0.0008$ | $0.060 \pm 0.001$ | $0.094 \pm 0.001$ |
| 3N | $0.0192 \pm 0.0006$ | $0.0353 \pm 0.0009$ | $0.061 \pm 0.001$ |
| 3O | $0.0174 \pm 0.0006$ | $0.0325 \pm 0.0008$ | $0.063 \pm 0.001$ |
| 3Q | $0.0283 \pm 0.0008$ | $0.056 \pm 0.001$ | $0.102 \pm 0.001$ |
| 3S | $0.0260 \pm 0.0007$ | $0.050 \pm 0.001$ | $0.091 \pm 0.001$ |
| 3T | $0.0144 \pm 0.0006$ | $0.0287 \pm 0.0008$ | $0.0456 \pm 0.0010$ |
| 3V | $0.0299 \pm 0.0008$ | $0.060 \pm 0.001$ | $0.098 \pm 0.001$ |
| 3W | $0.0272 \pm 0.0008$ | $0.050 \pm 0.001$ | $0.087 \pm 0.001$ |
| 3Z | $0.0180 \pm 0.0006$ | $0.0349 \pm 0.0009$ | $0.059 \pm 0.001$ |
| 4C | $0.0299 \pm 0.0008$ | $0.060 \pm 0.001$ | $0.098 \pm 0.001$ |
| 4F | $0.0212 \pm 0.0007$ | $0.0380 \pm 0.0009$ | $0.065 \pm 0.001$ |
| 4K | $0.0259 \pm 0.0007$ | $0.050 \pm 0.001$ | $0.082 \pm 0.001$ |
| 4L | $0.0323 \pm 0.0008$ | $0.064 \pm 0.001$ | $0.105 \pm 0.001$ |
| 4M | $0.0259 \pm 0.0007$ | $0.050 \pm 0.001$ | $0.082 \pm 0.001$ |
| 4N | $0.0195 \pm 0.0006$ | $0.0370 \pm 0.0009$ | $0.060 \pm 0.001$ |
| 4O | $0.0163 \pm 0.0006$ | $0.0304 \pm 0.0008$ | $0.057 \pm 0.001$ |
| 4Q | $0.0227 \pm 0.0007$ | $0.0434 \pm 0.0010$ | $0.071 \pm 0.001$ |
| 4S | $0.0147 \pm 0.0006$ | $0.0285 \pm 0.0008$ | $0.050 \pm 0.001$ |
| 4T | $0.0196 \pm 0.0006$ | $0.0366 \pm 0.0009$ | $0.061 \pm 0.001$ |
| 4U | $0.0232 \pm 0.0007$ | $0.0451 \pm 0.0010$ | $0.073 \pm 0.001$ |
| 4W | $0.0297 \pm 0.0008$ | $0.059 \pm 0.001$ | $0.105 \pm 0.001$ |
| 4X | $0.0294 \pm 0.0008$ | $0.054 \pm 0.001$ | $0.090 \pm 0.001$ |
| 4Z | $0.0143 \pm 0.0006$ | $0.0266 \pm 0.0008$ | $0.0436 \pm 0.0010$ |

Table 4: *Left index finger FNMRs at various FMRs when matcher F compares templates created by its template generator and PIV-compliant template generators.*

| Enroller | FNMR @ FMR=0.01 | FNMR @ FMR=0.001 | FNMR @ FMR=0.0001 |
|----------|-----------------|------------------|-------------------|
| A | $0.056 \pm 0.001$ | $0.098 \pm 0.001$ | $0.153 \pm 0.002$ |
| B | $0.0478 \pm 0.0010$ | $0.084 \pm 0.001$ | $0.130 \pm 0.002$ |
| C | $0.0290 \pm 0.0008$ | $0.051 \pm 0.001$ | $0.082 \pm 0.001$ |
| D | $0.0381 \pm 0.0009$ | $0.066 \pm 0.001$ | $0.106 \pm 0.001$ |
| E | $0.0417 \pm 0.0009$ | $0.072 \pm 0.001$ | $0.122 \pm 0.002$ |
| F | $0.0292 \pm 0.0008$ | $0.051 \pm 0.001$ | $0.081 \pm 0.001$ |
| G | $0.055 \pm 0.001$ | $0.095 \pm 0.001$ | $0.142 \pm 0.002$ |
| N | $0.053 \pm 0.001$ | $0.089 \pm 0.001$ | $0.125 \pm 0.002$ |
| 1C | $0.0312 \pm 0.0008$ | $0.055 \pm 0.001$ | $0.088 \pm 0.001$ |
| 1D | $0.054 \pm 0.001$ | $0.090 \pm 0.001$ | $0.130 \pm 0.002$ |
| 1F | $0.054 \pm 0.001$ | $0.093 \pm 0.001$ | $0.126 \pm 0.002$ |
| 1G | $0.055 \pm 0.001$ | $0.093 \pm 0.001$ | $0.126 \pm 0.002$ |
| 1J | $0.0349 \pm 0.0009$ | $0.059 \pm 0.001$ | $0.086 \pm 0.001$ |
| 1L | $0.0394 \pm 0.0009$ | $0.070 \pm 0.001$ | $0.104 \pm 0.001$ |
| 1M | $0.0390 \pm 0.0009$ | $0.066 \pm 0.001$ | $0.106 \pm 0.001$ |
| 1N | $0.0351 \pm 0.0009$ | $0.060 \pm 0.001$ | $0.087 \pm 0.001$ |
| 1T | $0.0300 \pm 0.0008$ | $0.052 \pm 0.001$ | $0.086 \pm 0.001$ |
| 1Y | $0.0374 \pm 0.0009$ | $0.065 \pm 0.001$ | $0.110 \pm 0.001$ |
| 2A | $0.0290 \pm 0.0008$ | $0.051 \pm 0.001$ | $0.082 \pm 0.001$ |
| 2C | $0.049 \pm 0.001$ | $0.083 \pm 0.001$ | $0.128 \pm 0.002$ |
| 2D | $0.055 \pm 0.001$ | $0.089 \pm 0.001$ | $0.134 \pm 0.002$ |
| 2F | $0.0378 \pm 0.0009$ | $0.066 \pm 0.001$ | $0.099 \pm 0.001$ |
| 2G | $0.0361 \pm 0.0009$ | $0.061 \pm 0.001$ | $0.094 \pm 0.001$ |
| 2I | $0.0353 \pm 0.0009$ | $0.059 \pm 0.001$ | $0.086 \pm 0.001$ |
| 2J | $0.0358 \pm 0.0009$ | $0.060 \pm 0.001$ | $0.091 \pm 0.001$ |
| 2K | $0.0352 \pm 0.0009$ | $0.061 \pm 0.001$ | $0.092 \pm 0.001$ |
| 2L | $0.0307 \pm 0.0008$ | $0.053 \pm 0.001$ | $0.090 \pm 0.001$ |
| 2M | $0.0328 \pm 0.0008$ | $0.060 \pm 0.001$ | $0.092 \pm 0.001$ |
| 2N | $0.0321 \pm 0.0008$ | $0.058 \pm 0.001$ | $0.088 \pm 0.001$ |
| 2O | $0.056 \pm 0.001$ | $0.095 \pm 0.001$ | $0.148 \pm 0.002$ |
| 2P | $0.0318 \pm 0.0008$ | $0.057 \pm 0.001$ | $0.085 \pm 0.001$ |
| 2Q | $0.0403 \pm 0.0009$ | $0.072 \pm 0.001$ | $0.113 \pm 0.001$ |
| 2R | $0.0371 \pm 0.0009$ | $0.065 \pm 0.001$ | $0.110 \pm 0.001$ |
| 2S | $0.0318 \pm 0.0008$ | $0.057 \pm 0.001$ | $0.085 \pm 0.001$ |
| 2T | $0.0382 \pm 0.0009$ | $0.064 \pm 0.001$ | $0.106 \pm 0.001$ |
| 2W | $0.059 \pm 0.001$ | $0.104 \pm 0.001$ | $0.157 \pm 0.002$ |
| 2Y | $0.0272 \pm 0.0008$ | $0.0479 \pm 0.0010$ | $0.075 \pm 0.001$ |
| 3A | $0.0295 \pm 0.0008$ | $0.052 \pm 0.001$ | $0.082 \pm 0.001$ |
| 3B | $0.055 \pm 0.001$ | $0.094 \pm 0.001$ | $0.140 \pm 0.002$ |
| 3D | $0.049 \pm 0.001$ | $0.080 \pm 0.001$ | $0.125 \pm 0.002$ |

Table 4: *(continued)*

| Enroller | FNMR @ FMR=0.01 | FNMR @ FMR=0.001 | FNMR @ FMR=0.0001 |
|---|---|---|---|
| 3F | $0.0459 \pm 0.0010$ | $0.079 \pm 0.001$ | $0.126 \pm 0.002$ |
| 3G | $0.0301 \pm 0.0008$ | $0.051 \pm 0.001$ | $0.088 \pm 0.001$ |
| 3H | $0.0370 \pm 0.0009$ | $0.063 \pm 0.001$ | $0.101 \pm 0.001$ |
| 3M | $0.0480 \pm 0.0010$ | $0.087 \pm 0.001$ | $0.137 \pm 0.002$ |
| 3N | $0.0353 \pm 0.0009$ | $0.059 \pm 0.001$ | $0.086 \pm 0.001$ |
| 3O | $0.0307 \pm 0.0008$ | $0.053 \pm 0.001$ | $0.084 \pm 0.001$ |
| 3Q | $0.049 \pm 0.001$ | $0.085 \pm 0.001$ | $0.134 \pm 0.002$ |
| 3S | $0.0432 \pm 0.0009$ | $0.075 \pm 0.001$ | $0.125 \pm 0.002$ |
| 3T | $0.0270 \pm 0.0008$ | $0.0469 \pm 0.0010$ | $0.072 \pm 0.001$ |
| 3V | $0.0474 \pm 0.0010$ | $0.084 \pm 0.001$ | $0.140 \pm 0.002$ |
| 3W | $0.0456 \pm 0.0010$ | $0.077 \pm 0.001$ | $0.129 \pm 0.002$ |
| 3Z | $0.0331 \pm 0.0008$ | $0.059 \pm 0.001$ | $0.097 \pm 0.001$ |
| 4C | $0.0474 \pm 0.0010$ | $0.084 \pm 0.001$ | $0.140 \pm 0.002$ |
| 4F | $0.0371 \pm 0.0009$ | $0.064 \pm 0.001$ | $0.094 \pm 0.001$ |
| 4K | $0.0431 \pm 0.0009$ | $0.074 \pm 0.001$ | $0.118 \pm 0.002$ |
| 4L | $0.056 \pm 0.001$ | $0.097 \pm 0.001$ | $0.142 \pm 0.002$ |
| 4M | $0.0431 \pm 0.0009$ | $0.074 \pm 0.001$ | $0.118 \pm 0.002$ |
| 4N | $0.0346 \pm 0.0009$ | $0.060 \pm 0.001$ | $0.098 \pm 0.001$ |
| 4O | $0.0289 \pm 0.0008$ | $0.051 \pm 0.001$ | $0.081 \pm 0.001$ |
| 4Q | $0.0377 \pm 0.0009$ | $0.066 \pm 0.001$ | $0.109 \pm 0.001$ |
| 4S | $0.0269 \pm 0.0008$ | $0.049 \pm 0.001$ | $0.080 \pm 0.001$ |
| 4T | $0.0345 \pm 0.0009$ | $0.060 \pm 0.001$ | $0.098 \pm 0.001$ |
| 4U | $0.0377 \pm 0.0009$ | $0.067 \pm 0.001$ | $0.105 \pm 0.001$ |
| 4W | $0.0477 \pm 0.0010$ | $0.085 \pm 0.001$ | $0.138 \pm 0.002$ |
| 4X | $0.048 \pm 0.001$ | $0.081 \pm 0.001$ | $0.126 \pm 0.002$ |
| 4Z | $0.0263 \pm 0.0007$ | $0.0461 \pm 0.0010$ | $0.072 \pm 0.001$ |

Table 5: *Two finger FNMRs at various FMRs when matcher F compares templates created by its template generator and PIV-compliant template generators.*

| Enroller | FNMR @ FMR=0.01 | FNMR @ FMR=0.001 | FNMR @ FMR=0.0001 |
|---|---|---|---|
| A | $0.0078 \pm 0.0003$ | $0.0166 \pm 0.0004$ | $0.0292 \pm 0.0006$ |
| B | $0.0069 \pm 0.0003$ | $0.0151 \pm 0.0004$ | $0.0291 \pm 0.0006$ |
| C | $0.0033 \pm 0.0002$ | $0.0068 \pm 0.0003$ | $0.0118 \pm 0.0004$ |
| D | $0.0047 \pm 0.0002$ | $0.0096 \pm 0.0003$ | $0.0170 \pm 0.0004$ |
| E | $0.0056 \pm 0.0002$ | $0.0117 \pm 0.0004$ | $0.0232 \pm 0.0005$ |
| F | $0.0033 \pm 0.0002$ | $0.0067 \pm 0.0003$ | $0.0114 \pm 0.0003$ |
| G | $0.0082 \pm 0.0003$ | $0.0169 \pm 0.0004$ | $0.0304 \pm 0.0006$ |
| N | $0.0087 \pm 0.0003$ | $0.0168 \pm 0.0004$ | $0.0287 \pm 0.0006$ |
| 1C | $0.0034 \pm 0.0002$ | $0.0069 \pm 0.0003$ | $0.0128 \pm 0.0004$ |
| 1D | $0.0097 \pm 0.0003$ | $0.0191 \pm 0.0005$ | $0.0348 \pm 0.0006$ |
| 1F | $0.0088 \pm 0.0003$ | $0.0166 \pm 0.0004$ | $0.0325 \pm 0.0006$ |
| 1G | $0.0089 \pm 0.0003$ | $0.0166 \pm 0.0004$ | $0.0325 \pm 0.0006$ |
| 1J | $0.0041 \pm 0.0002$ | $0.0077 \pm 0.0003$ | $0.0145 \pm 0.0004$ |
| 1L | $0.0044 \pm 0.0002$ | $0.0095 \pm 0.0003$ | $0.0167 \pm 0.0004$ |
| 1M | $0.0055 \pm 0.0002$ | $0.0107 \pm 0.0003$ | $0.0203 \pm 0.0005$ |
| 1N | $0.0043 \pm 0.0002$ | $0.0083 \pm 0.0003$ | $0.0167 \pm 0.0004$ |
| 1T | $0.0033 \pm 0.0002$ | $0.0067 \pm 0.0003$ | $0.0122 \pm 0.0004$ |
| 1Y | $0.0048 \pm 0.0002$ | $0.0102 \pm 0.0003$ | $0.0184 \pm 0.0004$ |
| 2A | $0.0033 \pm 0.0002$ | $0.0068 \pm 0.0003$ | $0.0118 \pm 0.0004$ |
| 2C | $0.0074 \pm 0.0003$ | $0.0153 \pm 0.0004$ | $0.0266 \pm 0.0005$ |
| 2D | $0.0092 \pm 0.0003$ | $0.0189 \pm 0.0004$ | $0.0310 \pm 0.0006$ |
| 2F | $0.0046 \pm 0.0002$ | $0.0101 \pm 0.0003$ | $0.0177 \pm 0.0004$ |
| 2G | $0.0044 \pm 0.0002$ | $0.0091 \pm 0.0003$ | $0.0164 \pm 0.0004$ |
| 2I | $0.0042 \pm 0.0002$ | $0.0082 \pm 0.0003$ | $0.0150 \pm 0.0004$ |
| 2J | $0.0045 \pm 0.0002$ | $0.0091 \pm 0.0003$ | $0.0178 \pm 0.0004$ |
| 2K | $0.0044 \pm 0.0002$ | $0.0084 \pm 0.0003$ | $0.0177 \pm 0.0004$ |
| 2L | $0.0035 \pm 0.0002$ | $0.0071 \pm 0.0003$ | $0.0133 \pm 0.0004$ |
| 2M | $0.0038 \pm 0.0002$ | $0.0076 \pm 0.0003$ | $0.0154 \pm 0.0004$ |
| 2N | $0.0037 \pm 0.0002$ | $0.0071 \pm 0.0003$ | $0.0157 \pm 0.0004$ |
| 2O | $0.0091 \pm 0.0003$ | $0.0193 \pm 0.0005$ | $0.0338 \pm 0.0006$ |
| 2P | $0.0036 \pm 0.0002$ | $0.0068 \pm 0.0003$ | $0.0152 \pm 0.0004$ |
| 2Q | $0.0054 \pm 0.0002$ | $0.0117 \pm 0.0004$ | $0.0217 \pm 0.0005$ |
| 2R | $0.0045 \pm 0.0002$ | $0.0096 \pm 0.0003$ | $0.0167 \pm 0.0004$ |
| 2S | $0.0036 \pm 0.0002$ | $0.0068 \pm 0.0003$ | $0.0152 \pm 0.0004$ |
| 2T | $0.0047 \pm 0.0002$ | $0.0098 \pm 0.0003$ | $0.0175 \pm 0.0004$ |
| 2W | $0.0098 \pm 0.0003$ | $0.0206 \pm 0.0005$ | $0.0353 \pm 0.0006$ |
| 2Y | $0.0027 \pm 0.0002$ | $0.0057 \pm 0.0002$ | $0.0115 \pm 0.0004$ |
| 3A | $0.0031 \pm 0.0002$ | $0.0062 \pm 0.0003$ | $0.0125 \pm 0.0004$ |
| 3B | $0.0085 \pm 0.0003$ | $0.0176 \pm 0.0004$ | $0.0304 \pm 0.0006$ |
| 3D | $0.0083 \pm 0.0003$ | $0.0163 \pm 0.0004$ | $0.0299 \pm 0.0006$ |

Table 5: *(continued)*

| Enroller | FNMR @ FMR=0.01 | FNMR @ FMR=0.001 | FNMR @ FMR=0.0001 |
|----------|-----------------|-------------------|--------------------|
| 3F | $0.0066 \pm 0.0003$ | $0.0140 \pm 0.0004$ | $0.0263 \pm 0.0005$ |
| 3G | $0.0038 \pm 0.0002$ | $0.0073 \pm 0.0003$ | $0.0137 \pm 0.0004$ |
| 3H | $0.0043 \pm 0.0002$ | $0.0091 \pm 0.0003$ | $0.0180 \pm 0.0004$ |
| 3M | $0.0063 \pm 0.0003$ | $0.0147 \pm 0.0004$ | $0.0266 \pm 0.0005$ |
| 3N | $0.0042 \pm 0.0002$ | $0.0086 \pm 0.0003$ | $0.0153 \pm 0.0004$ |
| 3O | $0.0037 \pm 0.0002$ | $0.0075 \pm 0.0003$ | $0.0134 \pm 0.0004$ |
| 3Q | $0.0070 \pm 0.0003$ | $0.0150 \pm 0.0004$ | $0.0265 \pm 0.0005$ |
| 3S | $0.0060 \pm 0.0003$ | $0.0126 \pm 0.0004$ | $0.0253 \pm 0.0005$ |
| 3T | $0.0028 \pm 0.0002$ | $0.0057 \pm 0.0002$ | $0.0099 \pm 0.0003$ |
| 3V | $0.0063 \pm 0.0003$ | $0.0143 \pm 0.0004$ | $0.0248 \pm 0.0005$ |
| 3W | $0.0063 \pm 0.0003$ | $0.0129 \pm 0.0004$ | $0.0227 \pm 0.0005$ |
| 3Z | $0.0032 \pm 0.0002$ | $0.0076 \pm 0.0003$ | $0.0134 \pm 0.0004$ |
| 4C | $0.0063 \pm 0.0003$ | $0.0143 \pm 0.0004$ | $0.0248 \pm 0.0005$ |
| 4F | $0.0045 \pm 0.0002$ | $0.0092 \pm 0.0003$ | $0.0187 \pm 0.0004$ |
| 4K | $0.0060 \pm 0.0003$ | $0.0121 \pm 0.0004$ | $0.0222 \pm 0.0005$ |
| 4L | $0.0075 \pm 0.0003$ | $0.0155 \pm 0.0004$ | $0.0307 \pm 0.0006$ |
| 4M | $0.0060 \pm 0.0003$ | $0.0121 \pm 0.0004$ | $0.0222 \pm 0.0005$ |
| 4N | $0.0045 \pm 0.0002$ | $0.0093 \pm 0.0003$ | $0.0174 \pm 0.0004$ |
| 4O | $0.0034 \pm 0.0002$ | $0.0065 \pm 0.0003$ | $0.0125 \pm 0.0004$ |
| 4Q | $0.0044 \pm 0.0002$ | $0.0095 \pm 0.0003$ | $0.0178 \pm 0.0004$ |
| 4S | $0.0028 \pm 0.0002$ | $0.0055 \pm 0.0002$ | $0.0093 \pm 0.0003$ |
| 4T | $0.0046 \pm 0.0002$ | $0.0096 \pm 0.0003$ | $0.0178 \pm 0.0004$ |
| 4U | $0.0045 \pm 0.0002$ | $0.0091 \pm 0.0003$ | $0.0175 \pm 0.0004$ |
| 4W | $0.0063 \pm 0.0003$ | $0.0142 \pm 0.0004$ | $0.0258 \pm 0.0005$ |
| 4X | $0.0082 \pm 0.0003$ | $0.0172 \pm 0.0004$ | $0.0308 \pm 0.0006$ |
| 4Z | $0.0029 \pm 0.0002$ | $0.0055 \pm 0.0002$ | $0.0098 \pm 0.0003$ |

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