Deriving a new NRR from ANSI S12.6B method, inter-laboratory reproducibility of data, precision of the data

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HELP

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WORKPLACE SAFETY AND HEALTH

When Have Enough Subjects Been Tested?

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Where We're Going . . .

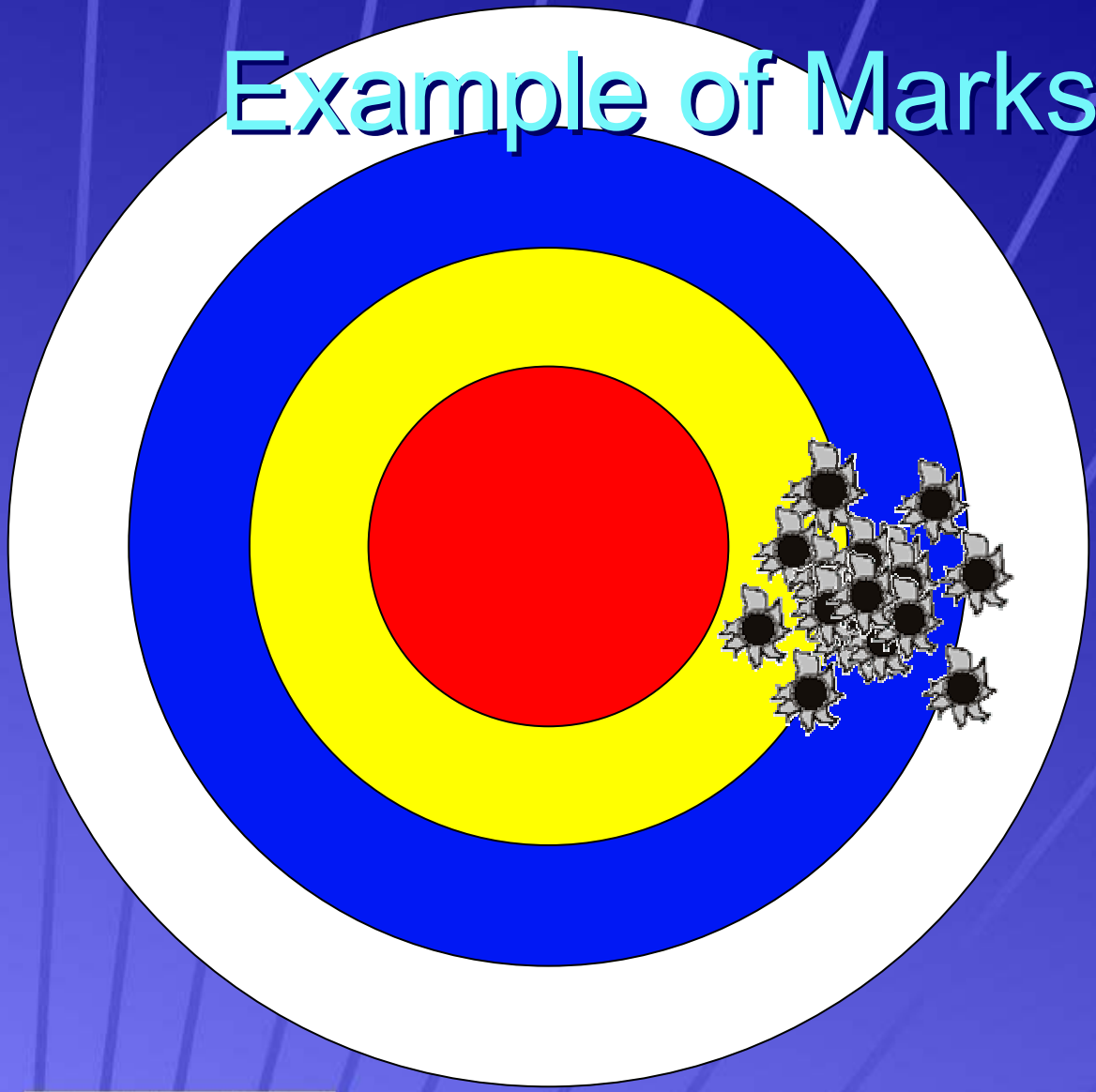
- What are Precision and Accuracy?
- What is the Noise Reduction Rating?
- How were the sample sizes determined?
- Where is the Error in the NRR?
- 3 Ways to Estimate NRR Error.
- How to use the NRR Error?
- Classification of Protectors by Precision

Precision & Accuracy

- Precision is the error in the estimation of a rating *relying solely upon the data* from the tested sample population

- Accuracy is the error when the rating estimate is *applied different noise spectrum*.

Example of Marksmanship



You can be very Precise...

…and still be inaccurate!

Selected Rating Methods

- NRRSF Rating (NHCA Task Force, 1994)
  - Naïve Subj. Fit, 20 Subjects, 2 REAT trials
- SNR Rating (ISO 4869-2, 1992)
  - Subj. Fit, 16 subjects, 1 REAT trial
- HML Rating (ISO 4869-2, 1992)
  - Subj. Fit, 16 subjects, 1 REAT trial
- NRR Rating (40 CFR 211, U.S. EPA)
  - Exp. Fit, 10 subjects, 3 REAT trials

Noise Reduction Rating for Subject-Fit Data

- Measure REAT: 10 or 20 subjects, 2 Trials, 7 Frequencies
- Determine Mean, $\bar{\mu}$, and Std. Dev, σ
- Calculate A-weighted Protected Exposure Level for Pink Noise:

$$L_{Af} - (\bar{\mu}_f - \sigma_f)$$

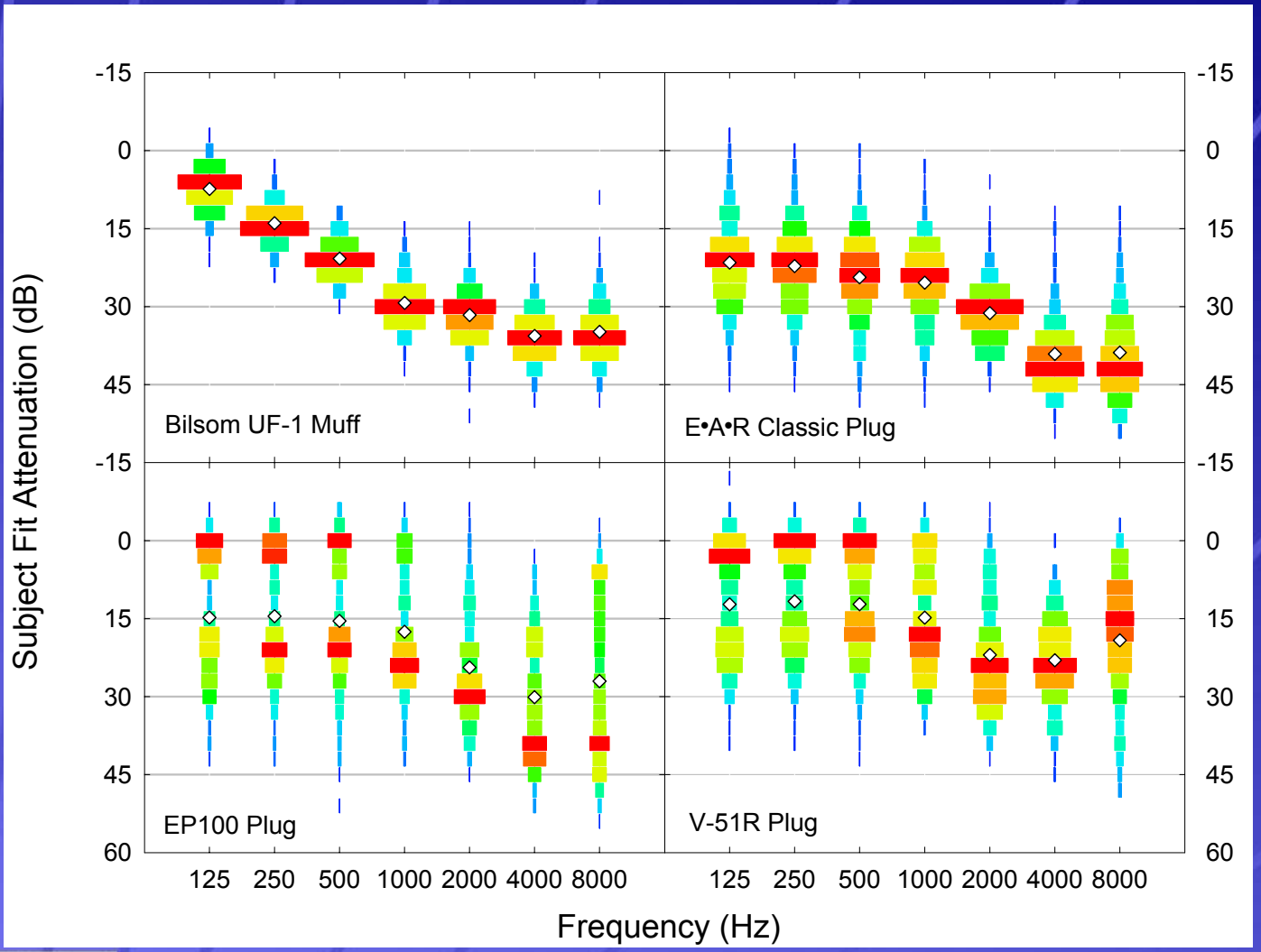
- Subtract from C-weighted Pink Noise
- Subtract 5 dB for C-A correction factor

$$NRR(sf) = 108.5dBC - 10\log \sum_{f=63}^{8000} 10^{0.1(L_{Af} - APV_{f84})} - 5dB$$

Why 10 and 20 subjects?

- Four-lab interlaboratory study
  - Informed User Fit versus Subject-Fit
  - Analyzed the variability of the REAT data
- Subject-Fit data were less variable across laboratories
- Earplugs more variable than Earmuffs

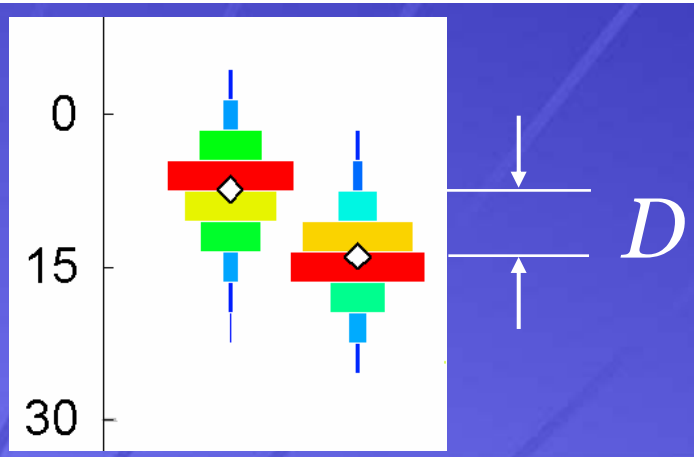
Distributions of REAT Data



Minimum Detectable Difference

- The standard error, σ, can be used to estimate, D, the minimum detectable difference between REAT measurements

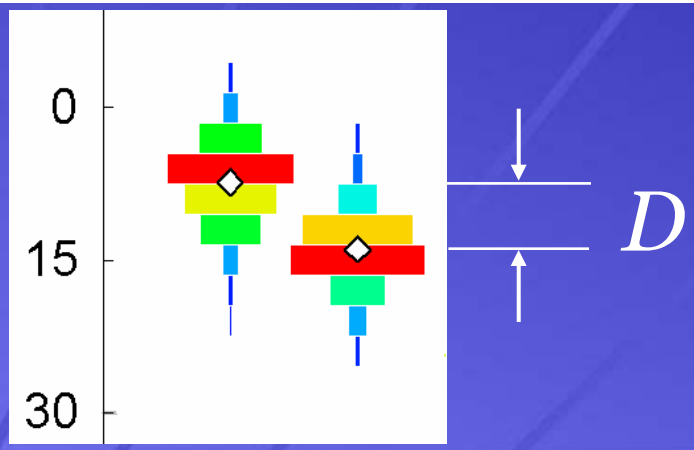
$$D = (\text{Probit}(1-\alpha) + \text{Probit}(1-\beta))\sqrt{2}\sigma$$



Minimum Detectable Difference

- The standard error, σ, can be used to estimate, D, the minimum detectable difference between REAT measurements

$$D = 2.5966\sigma$$

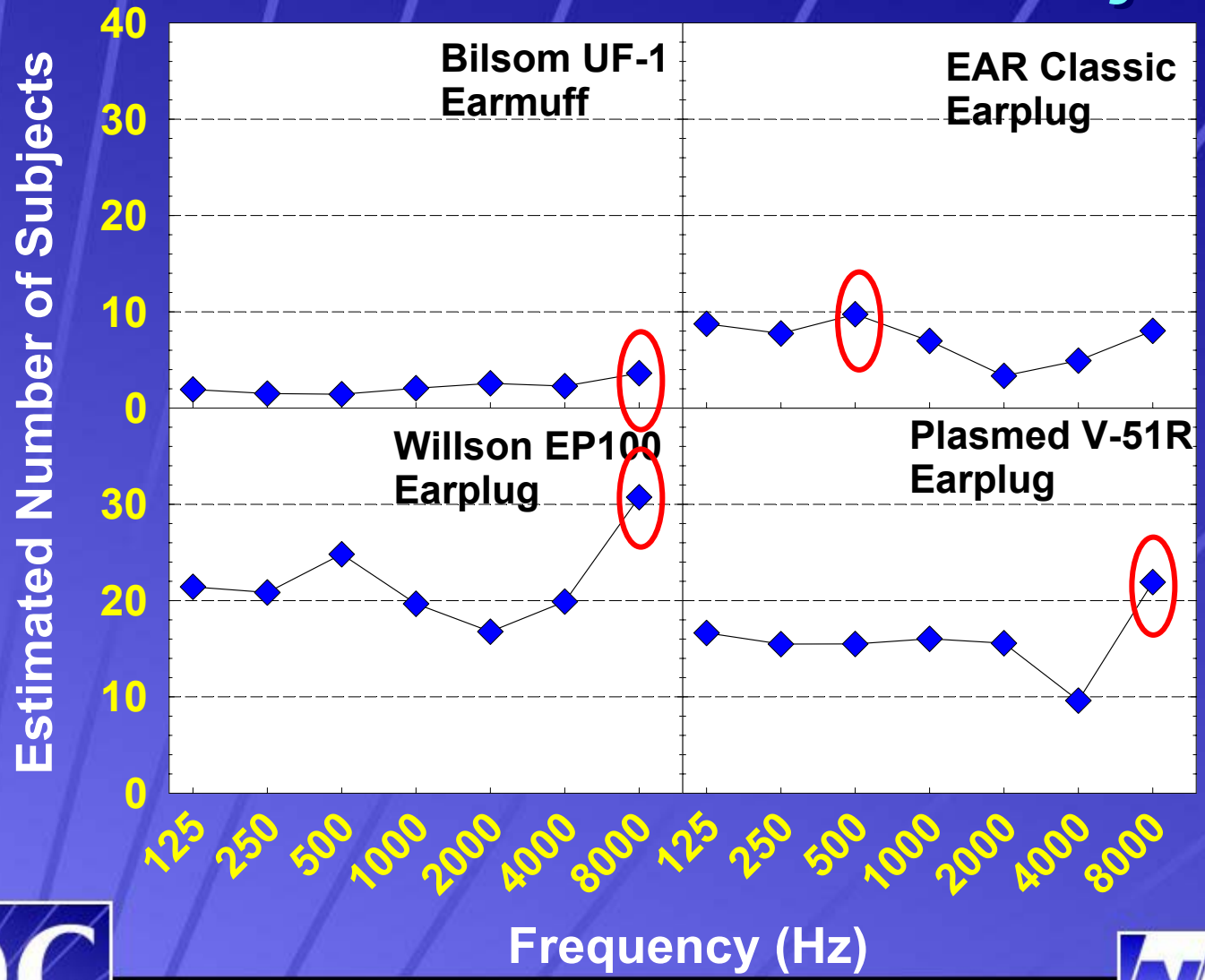


Estimating Minimum Number of Subjects for a Desired Resolution

- Choose a desired resolution, R, and the number of subjects tested while determining the minimum detectable difference, D.

$$N_{\text{subjects}} = n_s \left(\frac{2.5966\sigma}{R} \right)^2$$

Estimated Number of Subjects



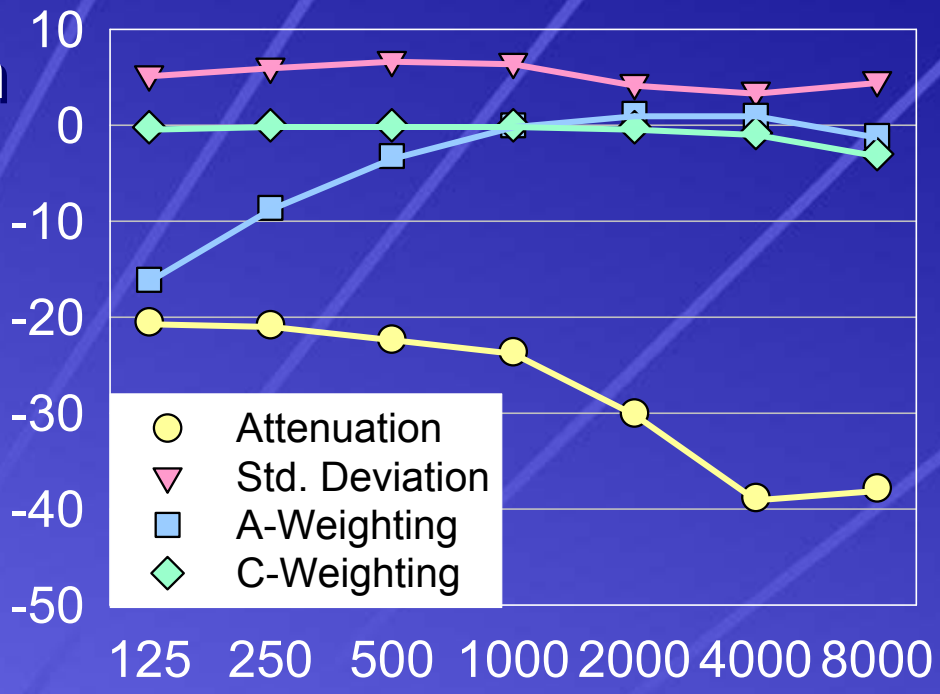
Problems with Reproducibility

- Subject estimates are different across frequencies
- Highest estimate is conservative
- Can we do better?

Consider the Error in the NRR

Elements of Error in the NRR

- Frequency Dependence in the NRR
  - Attenuation
  - Standard Deviation
  - A weighting
  - C-weighting



Why should I care about Error?

- Estimate Number of Subjects

$$N_{\text{subjects}} = n_s \left(\frac{2.5966\sigma}{R} \right)^2$$

- Determining Meaningful differences between protector tests
  - Quality Control
  - Retests and Audits
  - Comparison between competing products

How to estimate NRR Error

- Direct computation
  - Means and Covariance
- Monte Carlo Simulation
  - Probabilistic Subject Simulation

- Bootstrap Simulation
  - Resample REAT Data

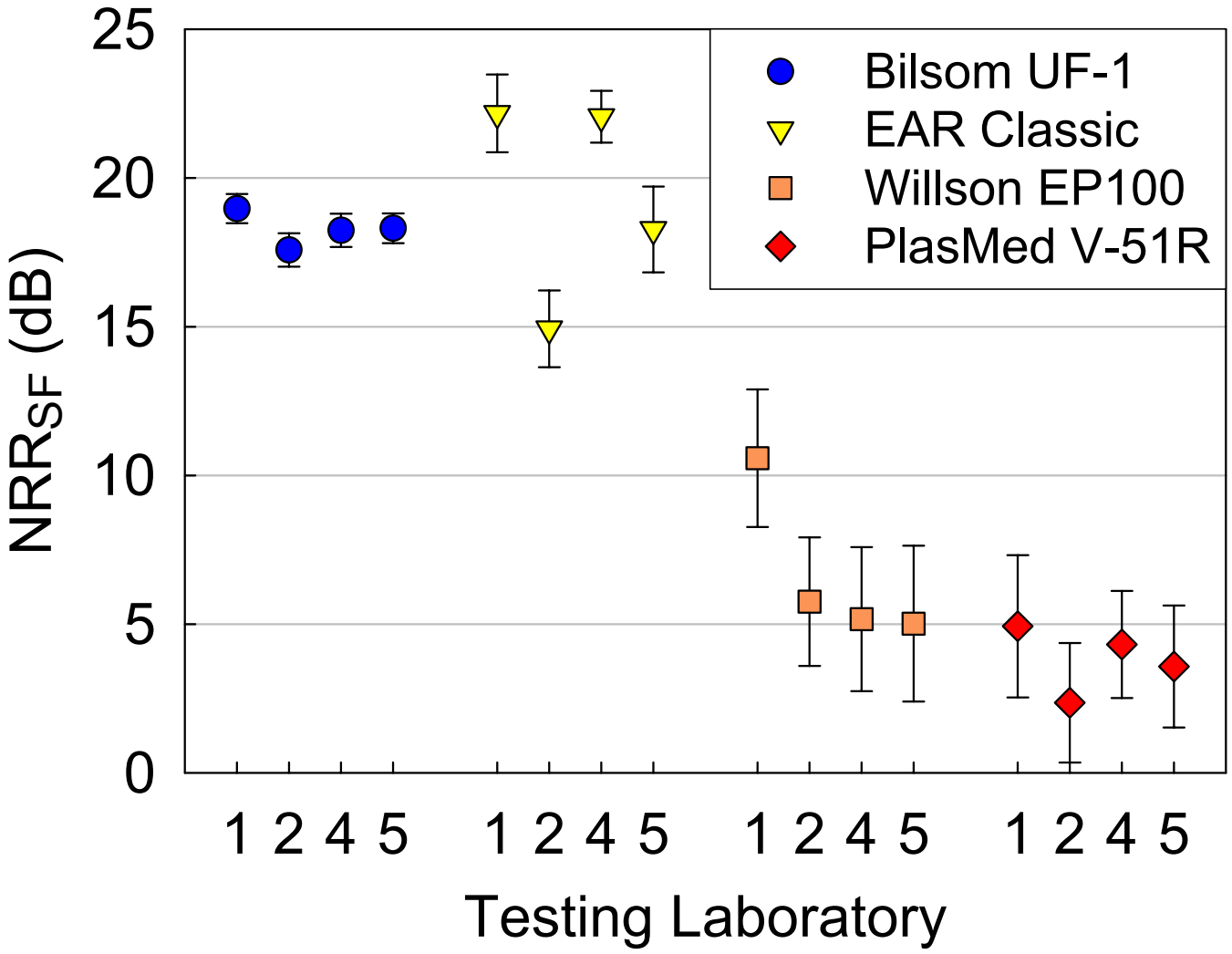
Direct Computation

- REAT Means and Standard Deviations
- Covariance from the original data
  - Weighted for each band
  - Depends upon α, σ, $\bar{\mu}$ and N.

$$\sigma^2_{\mathrm{NRR_{SF}}} = \sum_{i=125}^{8000}\sum_{j=125}^{8000} \sigma_i \sigma_j w_i w_j + \sum_{i=125}^{8000}\sum_{j=125}^{8000} \sigma_{\sigma_i} \sigma_{\sigma_j} w_i w_j$$

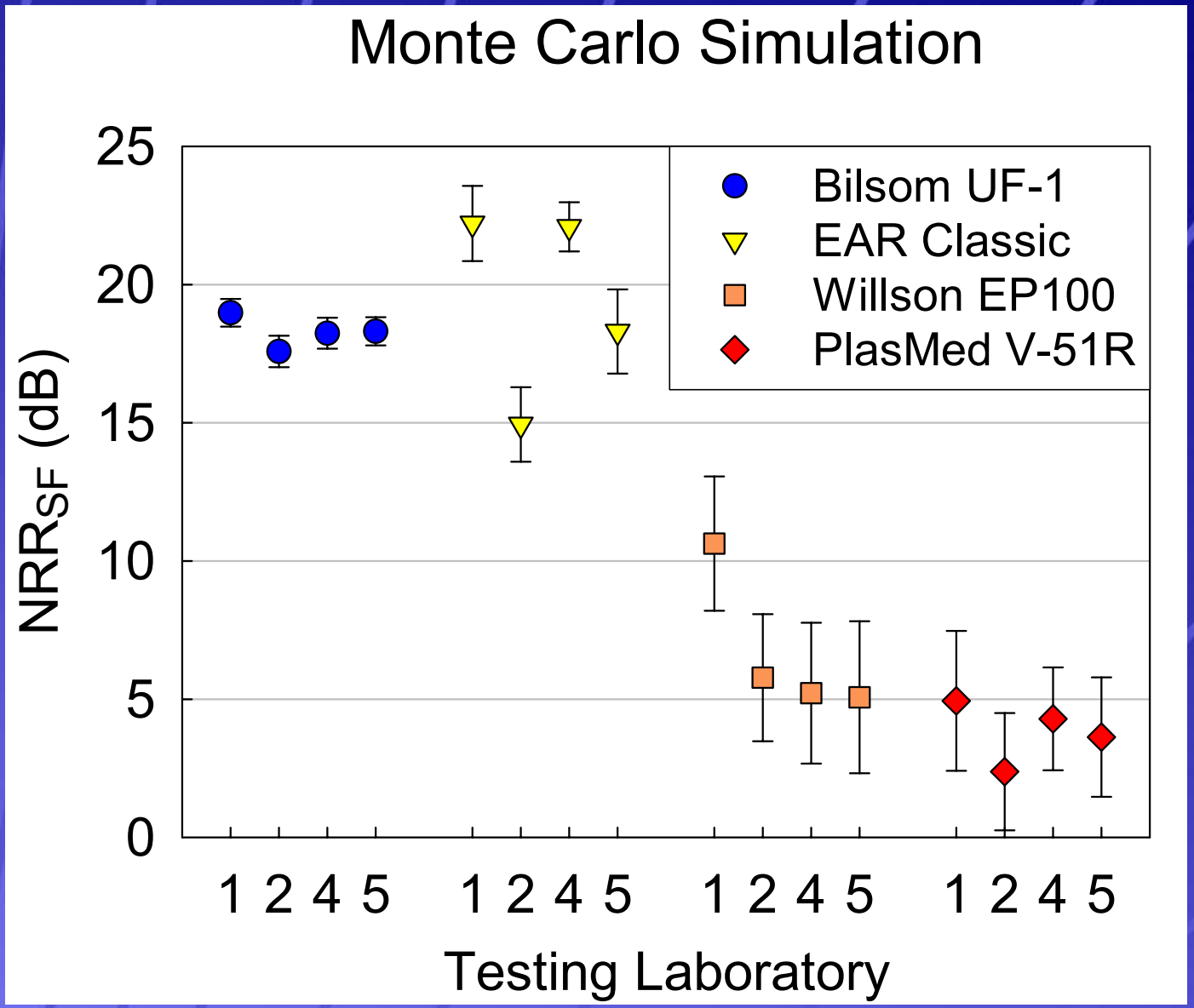
- Data may not be normally distributed.

Direct Computation



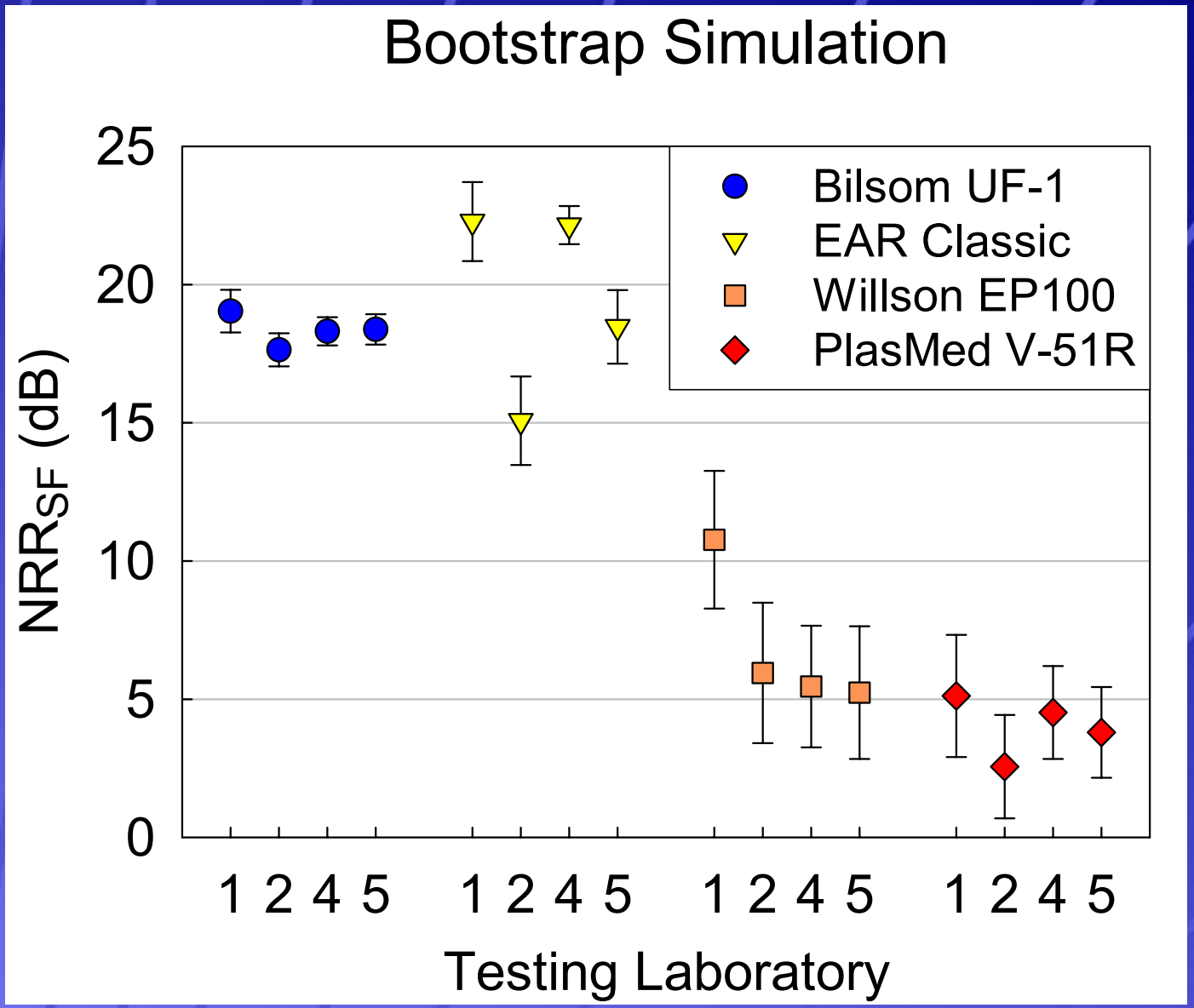
Monte Carlo Simulation

- Use original REAT data covariance.
- Generate sets of random numbers
  - Maintain $\bar{\mu}$, σ and σ_{xy}
- Calculate NRR_{SF} for each set.
- Repeat many times
- Estimate NRR_{SF} and, σ_{NRRSF}
- Data may not be normally distributed.


Monte Carlo Simulation
25
20
15
10
5
0
NRRSF (dB)
Bilsom UF-1
EAR Classic
Willson EP100
PlasMed V-51R
1 2 4 5 1 2 4 5 1 2 4 5 1 2 4 5
Testing Laboratory

Bootstrap Simulation

- Repeatedly resample the REAT data
- Estimate NRR_{SF} and, σ_{NRRSF}
- Reproduces non-normal data
- Directly estimates the standard error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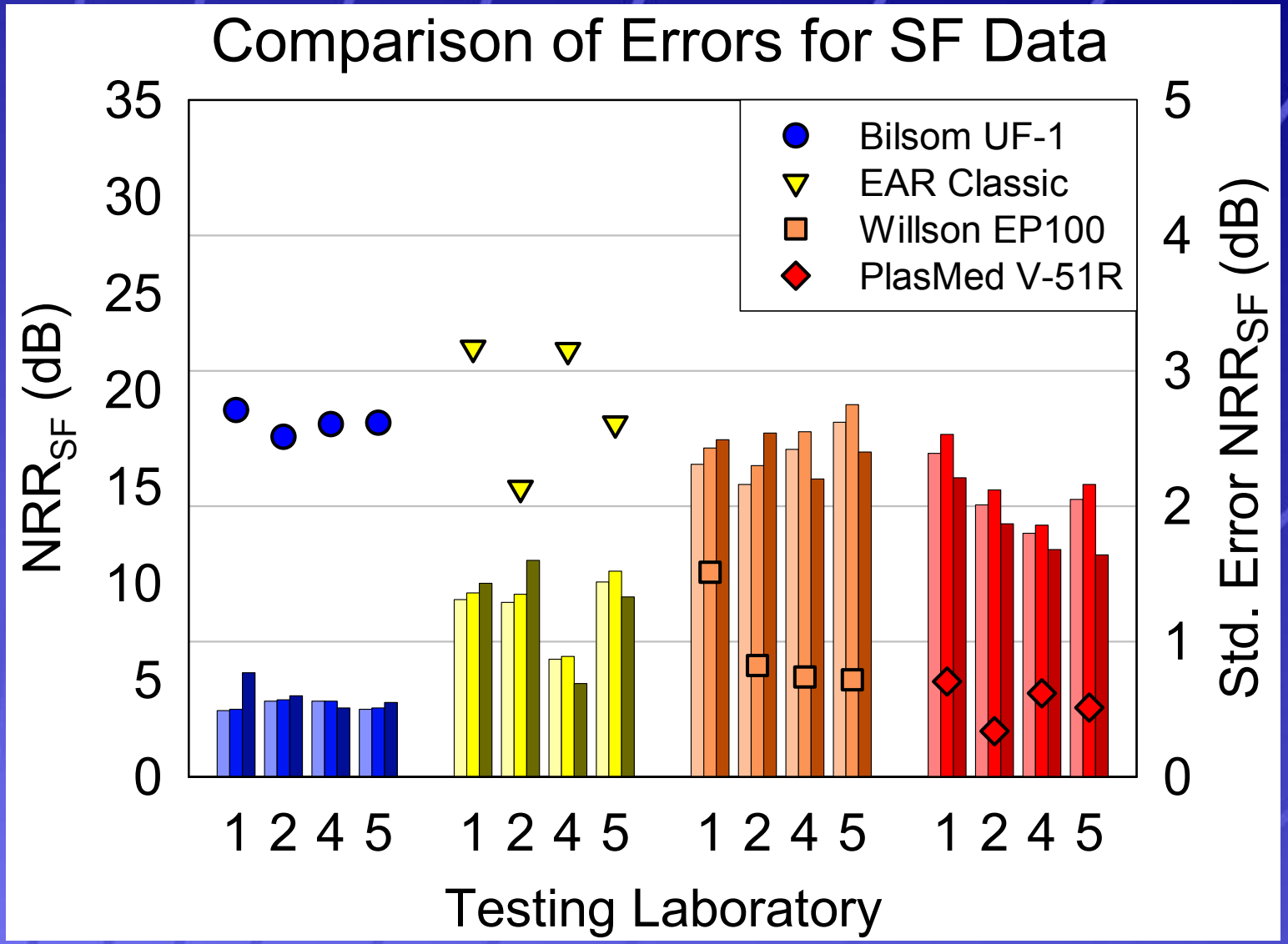
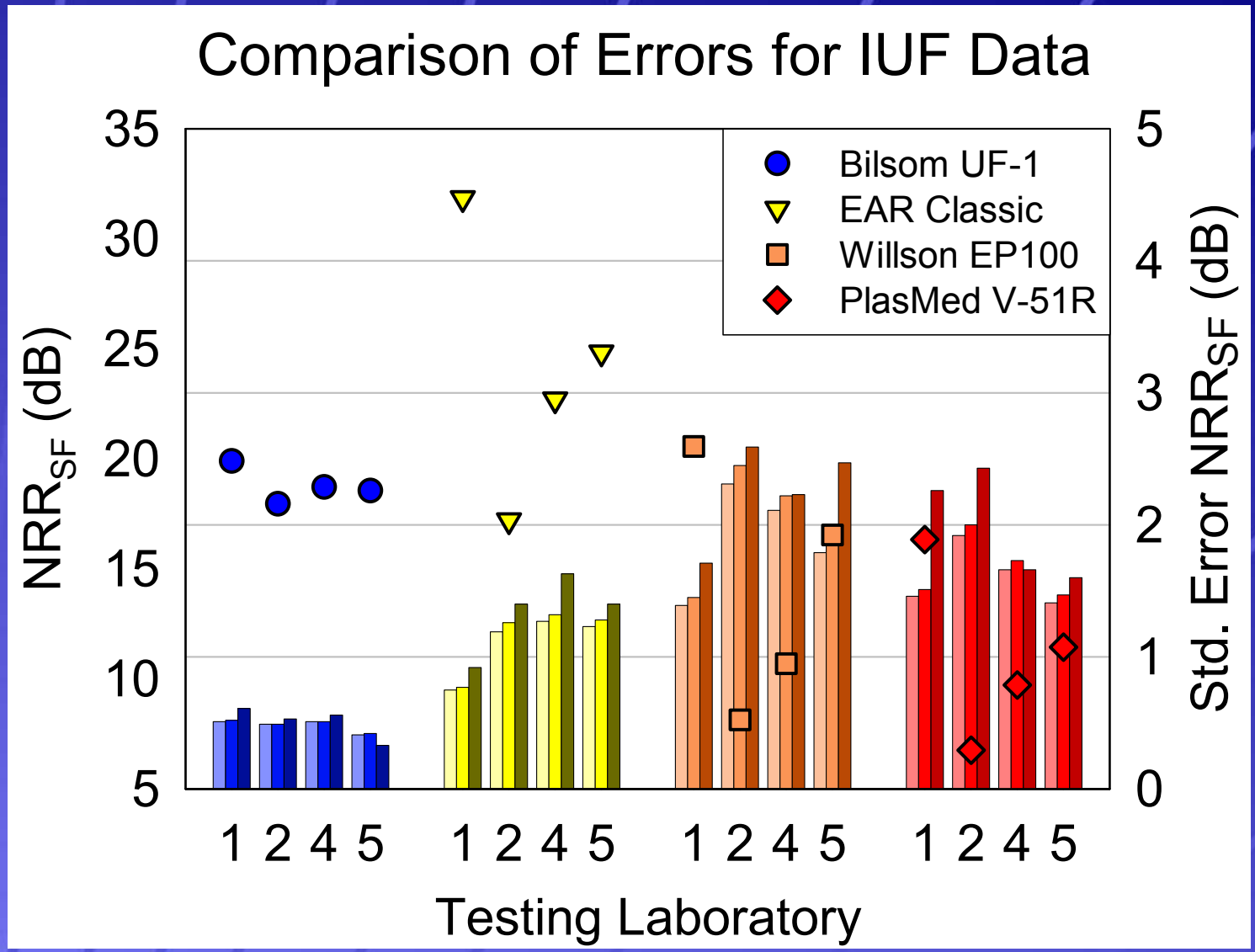
Testing Laboratory


Comparison of Errors for SF Data
Bilsom UF-1
EAR Classic
Willson EP100
PlasMed V-51R
NRRSF (dB)
Std. Error NRRSF (dB)
35
30
25
20
15
10
5
0
5
4
3
2
1
0
1 2 4 5 1 2 4 5 1 2 4 5 1 2 4 5
Testing Laboratory


Comparison of Errors for IUF Data
35
30
25
20
15
10
5
NRR$_{SF}$ (dB)
5
4
3
2
1
0
Std. Error NRR$_{SF}$ (dB)
Bilsom UF-1
EAR Classic
Willson EP100
PlasMed V-51R
1 2 4 5 1 2 4 5 1 2 4 5 1 2 4 5
Testing Laboratory

Which Error?

- Direct Computation
  - Assumes normality
  - Easily computed
- Monte Carlo Simulation
  - Assumes normality (can be modified)
  - Requires computer simulation
- Bootstrap Simulation
  - Requires computer simulation
  - Does not assume normality

Which Error?

- Bootstrap Simulation
  - –Requires computer simulation
  - –Does not assume normality

NRR_{SF} Error, What Next?

- Estimate minimum detectable difference using the NRR_{SF} error.
- Classify Precision based upon

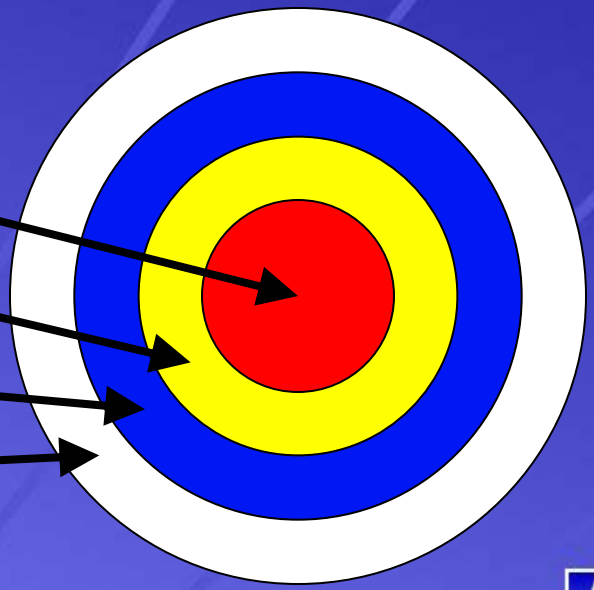
  NRR_{SF} Error

  < 1.0 dB Red

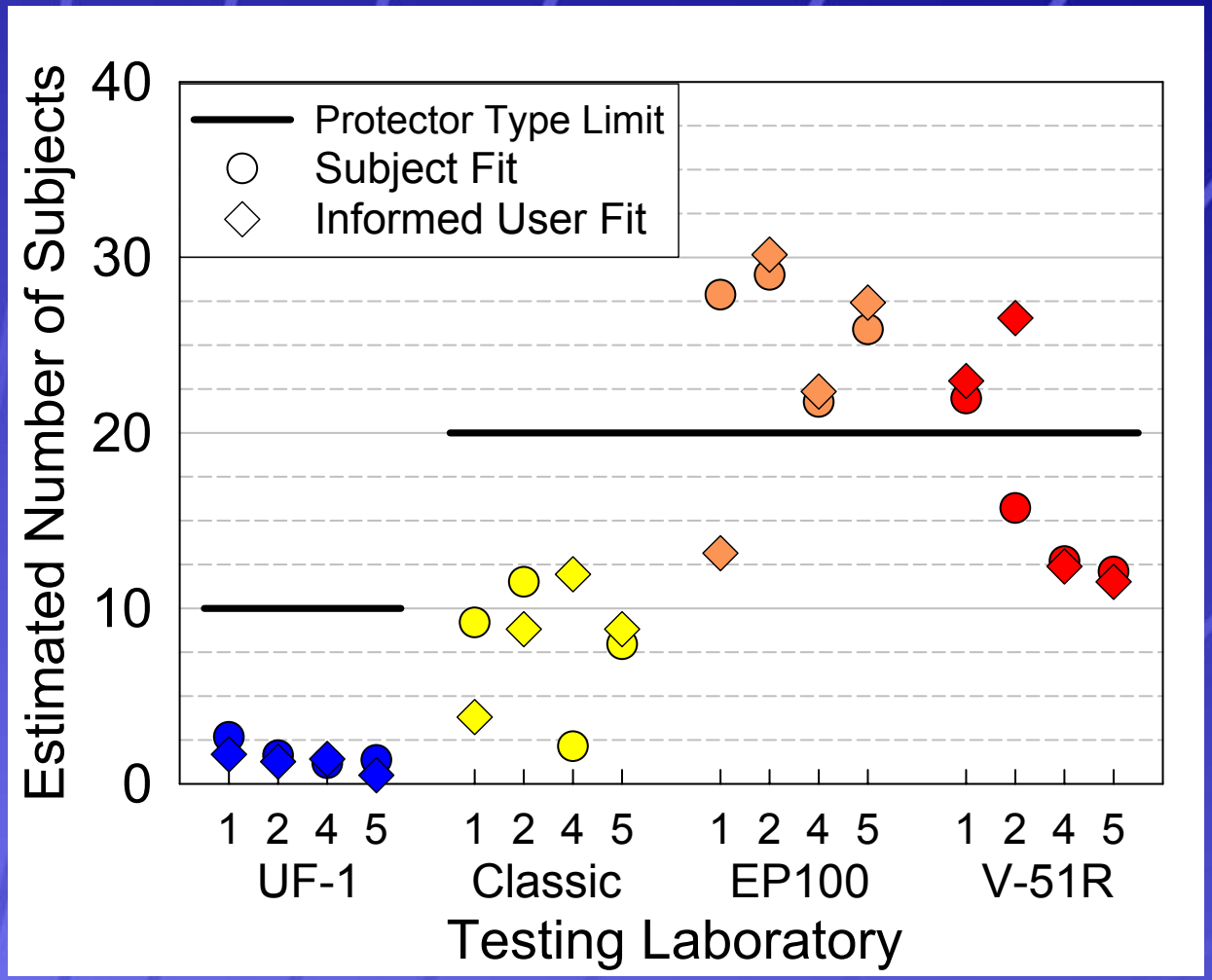
  < 2.0 dB Yellow

  < 3.0 dB Blue

  > 3.0 dB White



Estimate of Sample Size



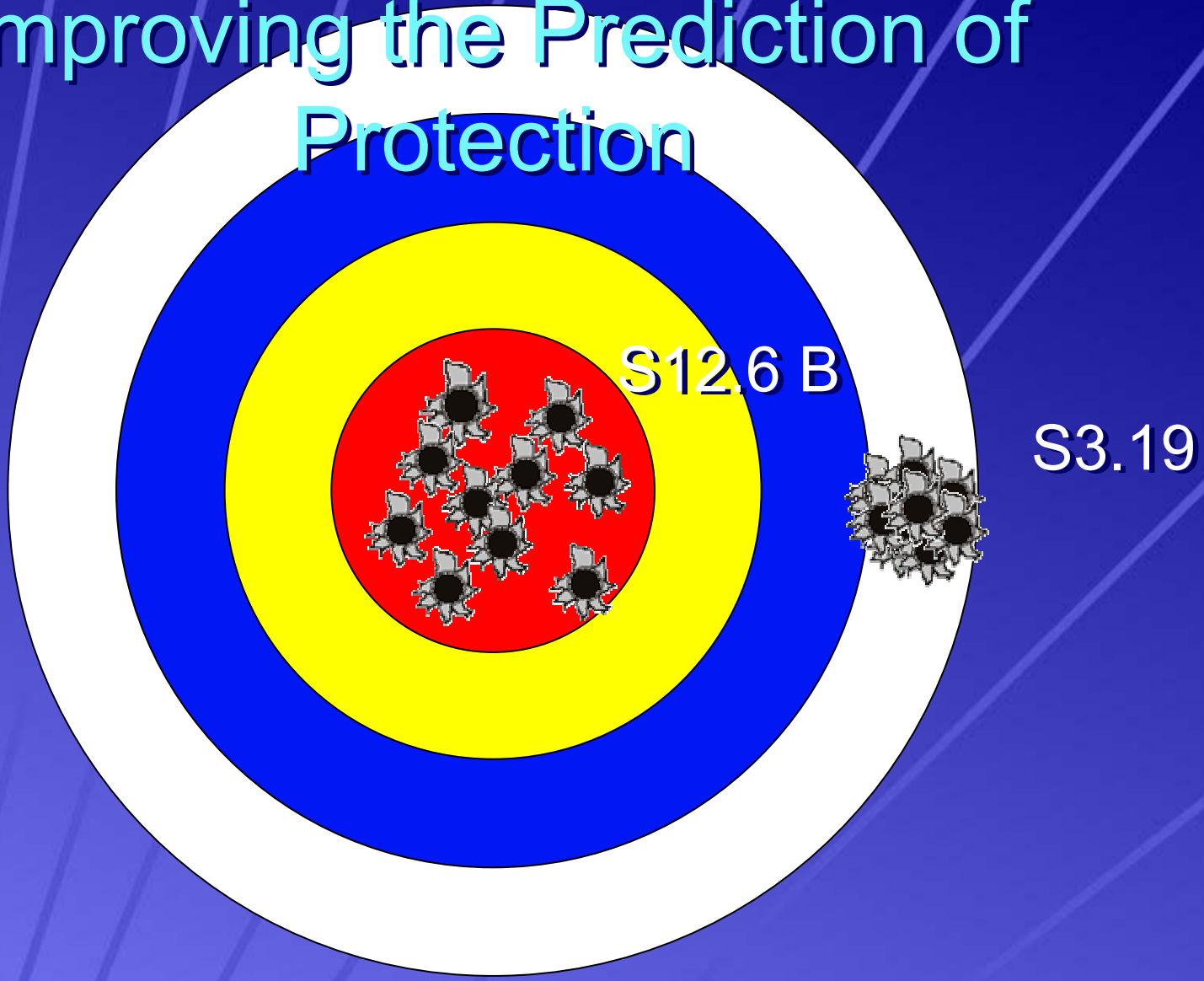
When does Precision Matter?

- High Noise Environment
- Overprotection of Workers' Hearing
  - Speech Communication
  - Audibility of Warning Sounds
- Reduced Hearing Loss

Precision in the Real World

- Subject-fit data better predict real-world outcome.
- The utility of the rating is driven by predictive ability.
- The trustworthiness of the rating is driven by the precision

Improving the Prediction of Protection



Summary

- Precision is a function of the test data
  - Can be determined for any rating method
- 3 methods to estimate NRR error
  - Comparable results from each method
  - Useful in power calculations
  - Useful in comparisons
- Protector precision should be classified
  - Will facilitate correct selection of protection