Communicating Measurement Results in the Courtroom:

A Matter of Error, Uncertainty and Inference

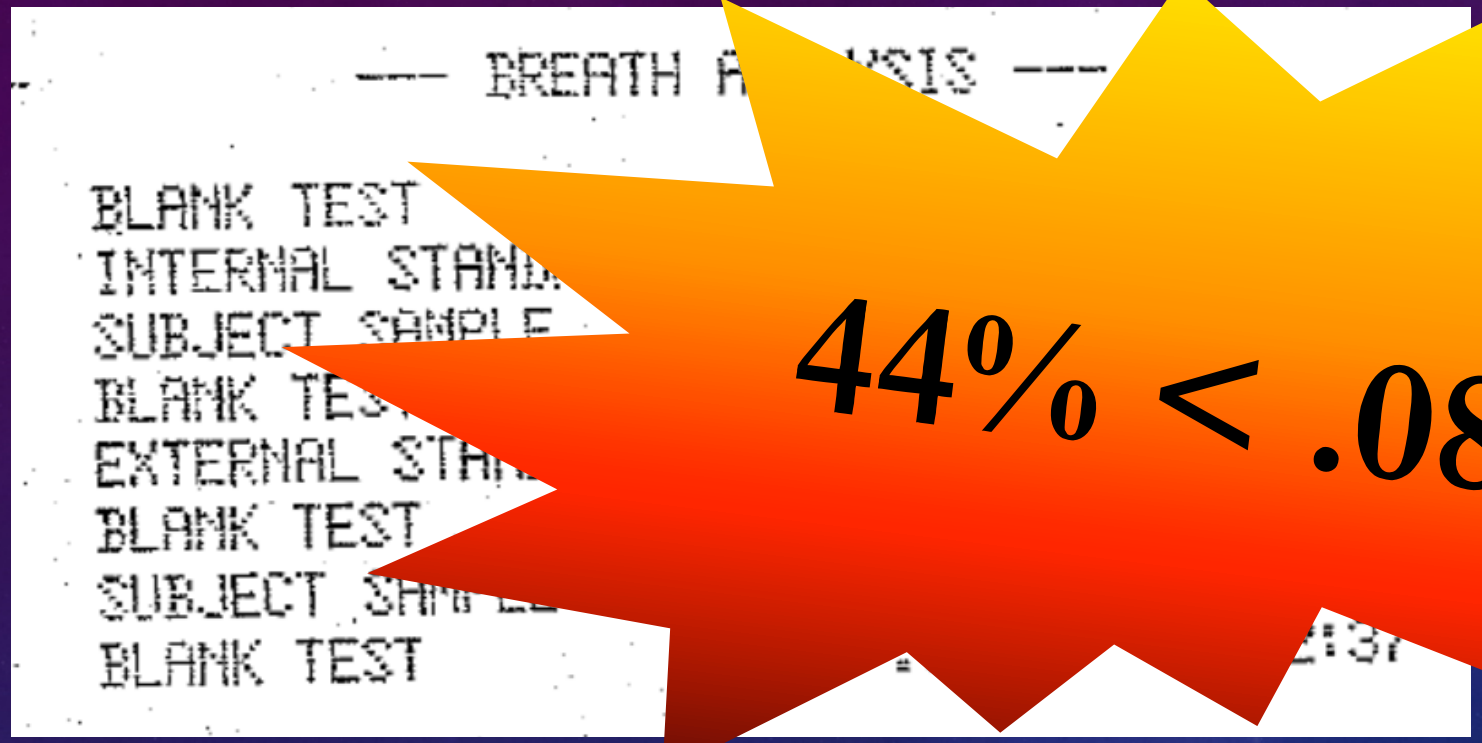
What does a measured result tell us?

--- BREATH ANALYSIS ---

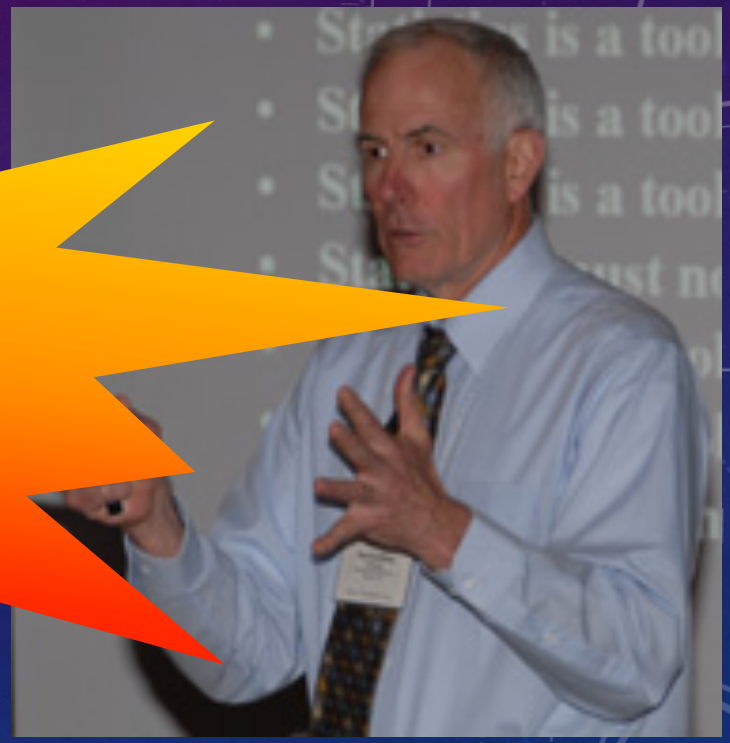
BLANK TEST	.000	02:32
INTERNAL STANDARD	VERIFIED	02:32
SUBJECT SAMPLE	.080	02:33
BLANK TEST	.000	02:34
EXTERNAL STANDARD	.082	02:34
BLANK TEST	.000	02:35
SUBJECT SAMPLE	.081	02:37
BLANK TEST	.000	02:37

"That is an ACCURATE AND RELIABLE test result…"

What does a measured result tell us?



44% < .08



"…I can say that this individual's BrAC exceeds a 0.08 BEYOND A REASONABLE DOUBT."

Epistemology

The Question of How Do We Know What We Know?

Study of knowledge and justified belief

- What is knowledge?
- How is it created?
- What are its limitations?

Creation of Scientific Knowledge

Information + Inference → Knowledge

Information	Inference	Knowledge
Empirical	Transformation Rules	Info-Infer Network
Input/output	Scientific Laws	Conclusions
Prior Knowledge	Heuristics	Beliefs

Nature of Scientific Statements

Citizen has a BrAC in excess of 0.08 g/210L

Intended Subject	Actual Subject
Result Reflection of Reality	Result Conveys Information
Physical State	Inference
Actual BrAC	Believed BrAC

Can NOT KNOW actual BrAC

Can only BELIEVE based on information & inference

Nature of Scientific Knowledge

Information + Inference → Knowledge

Empirical	Transformation Rules	Info-Infer Network
Input/output	Scientific Laws	Conclusions
Prior Knowledge	Heuristics	Beliefs

Manner in which information is generated

+

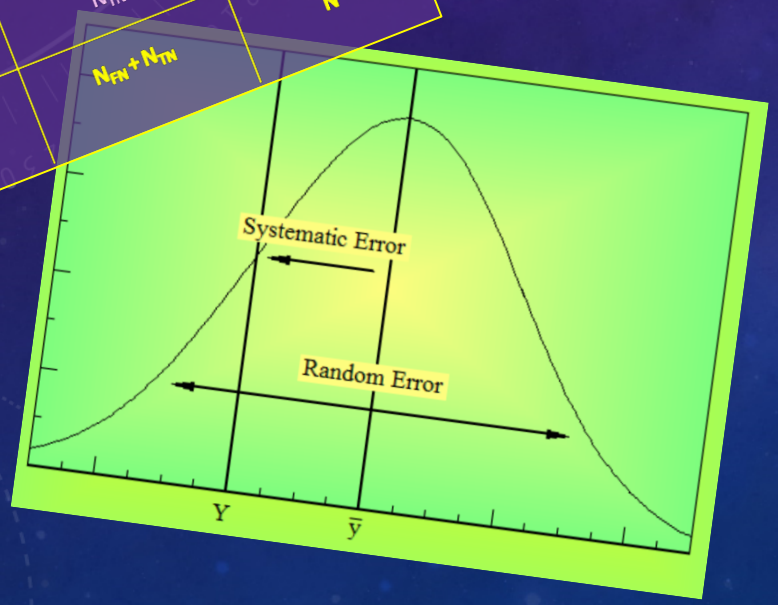
Rules of inference employed

Metric of robustness of beliefs/conclusions

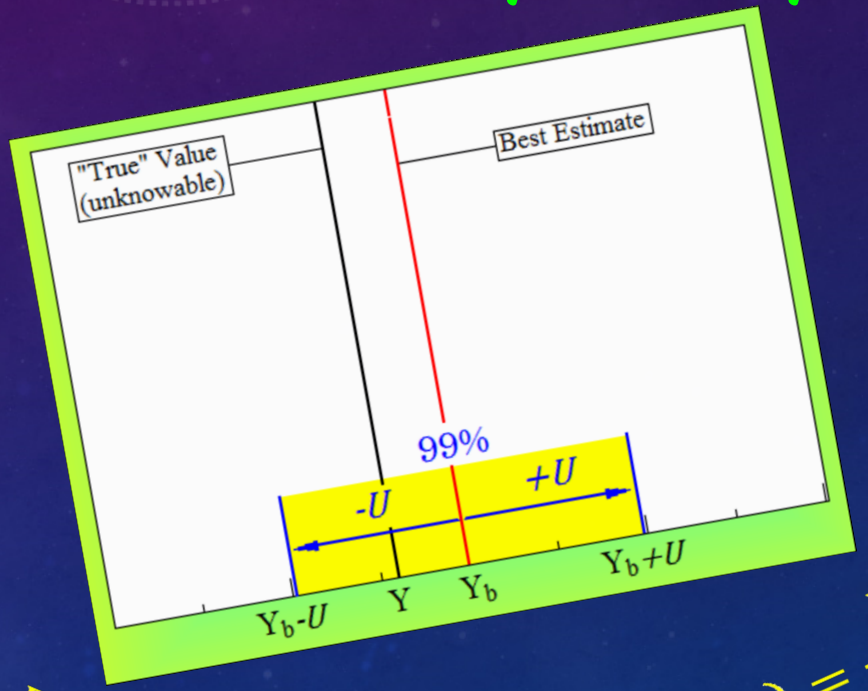
Epistemological Metrics of Robustness

Error Analysis

	Test Result A	Test Result ¬A	
A	True Positive N_{TP}	False Negative N_{FN}	$N_{TP}+N_{FN}$
¬A	False Positive N_{FP}	True Negative N_{TN}	$N_{FP}+N_{TN}$
	$N_{TP}+N_{FP}$	$N_{FN}+N_{TN}$	N



Uncertainty Analysis



$$P(A|B) = \frac{P(A)P(B|A)}{P(B)}$$

$$L(B|A) = \frac{P(B|A)}{P(B|\neg A)}$$

Meaning of Probability

10 White marbles & 10 Blue marbles

Frequentist

Relative Frequency

$P(b)_{is}$ = 0% - 100%

$P(b)_{sel}$ = 50%

Probability refers to process, frequency of selection during repeated sampling, not unique or determined event.

Meaning of Probability

10 White marbles & 10 Blue marbles

Bayesian

Relative Degree of Belief

$P(b)_{is} = 50\%$

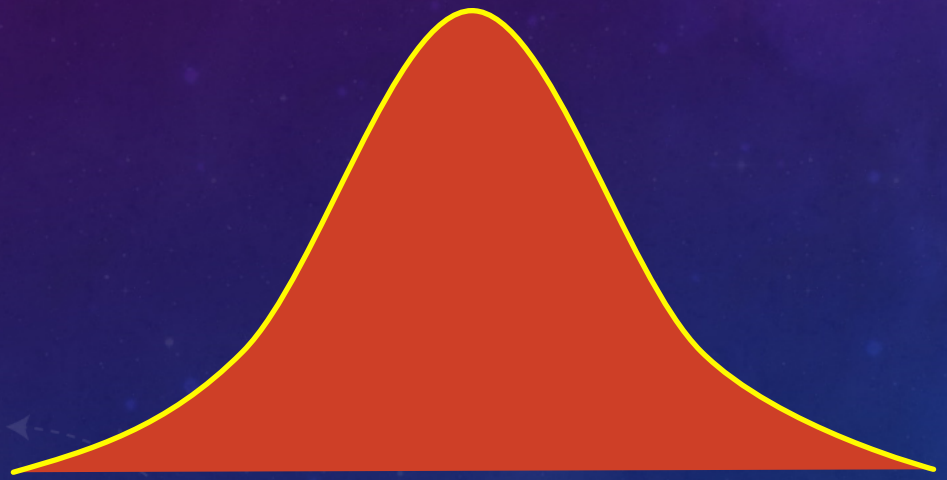
$P(b)_{sel} = 50\%$

Probability refers to state of knowledge, relative strength of belief, includes unique or determined event.

Meaning of Probability

Frequentist

Relative Frequency



Bayesian

Relative Degree of Belief

Science is Applied Epistemology

Information

Empirical

Input/output

Prior Knowledge

Inference

Transformation Rules

Scientific Laws

Heuristics

Knowledge

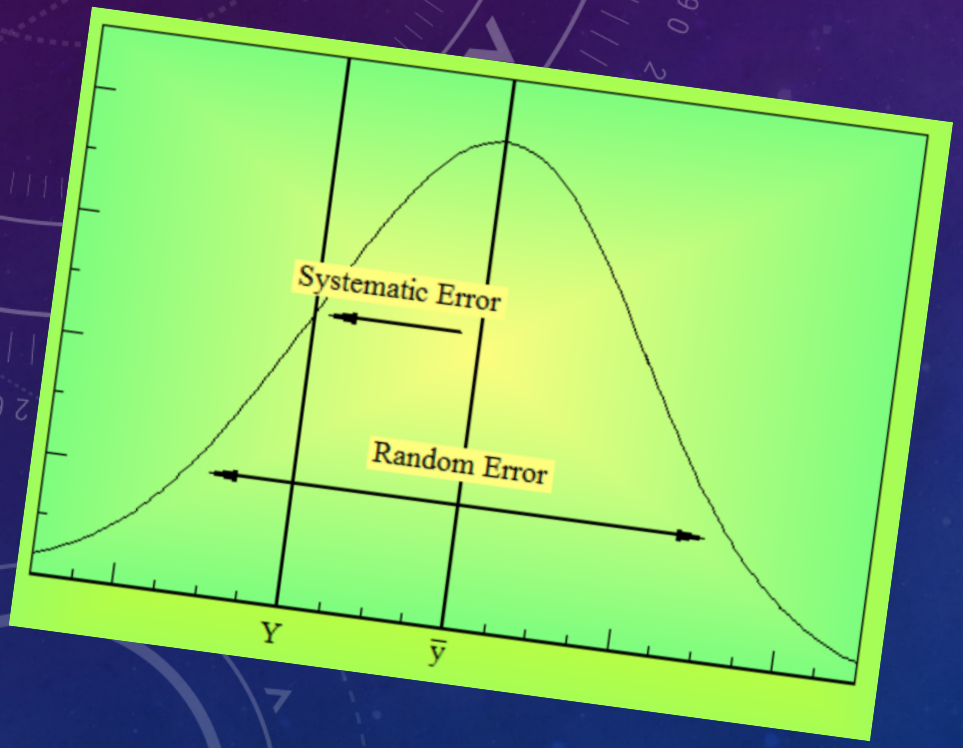
Info-Infer Network

Conclusions

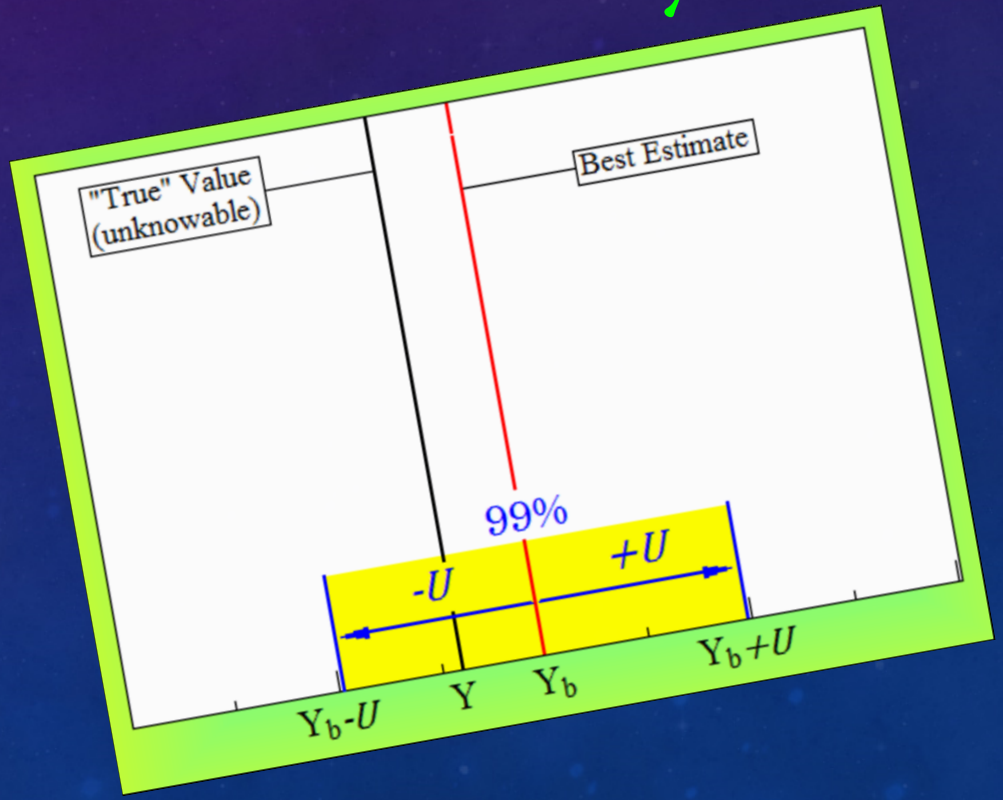
Justified Belief

Epistemological Metrics in Measurement

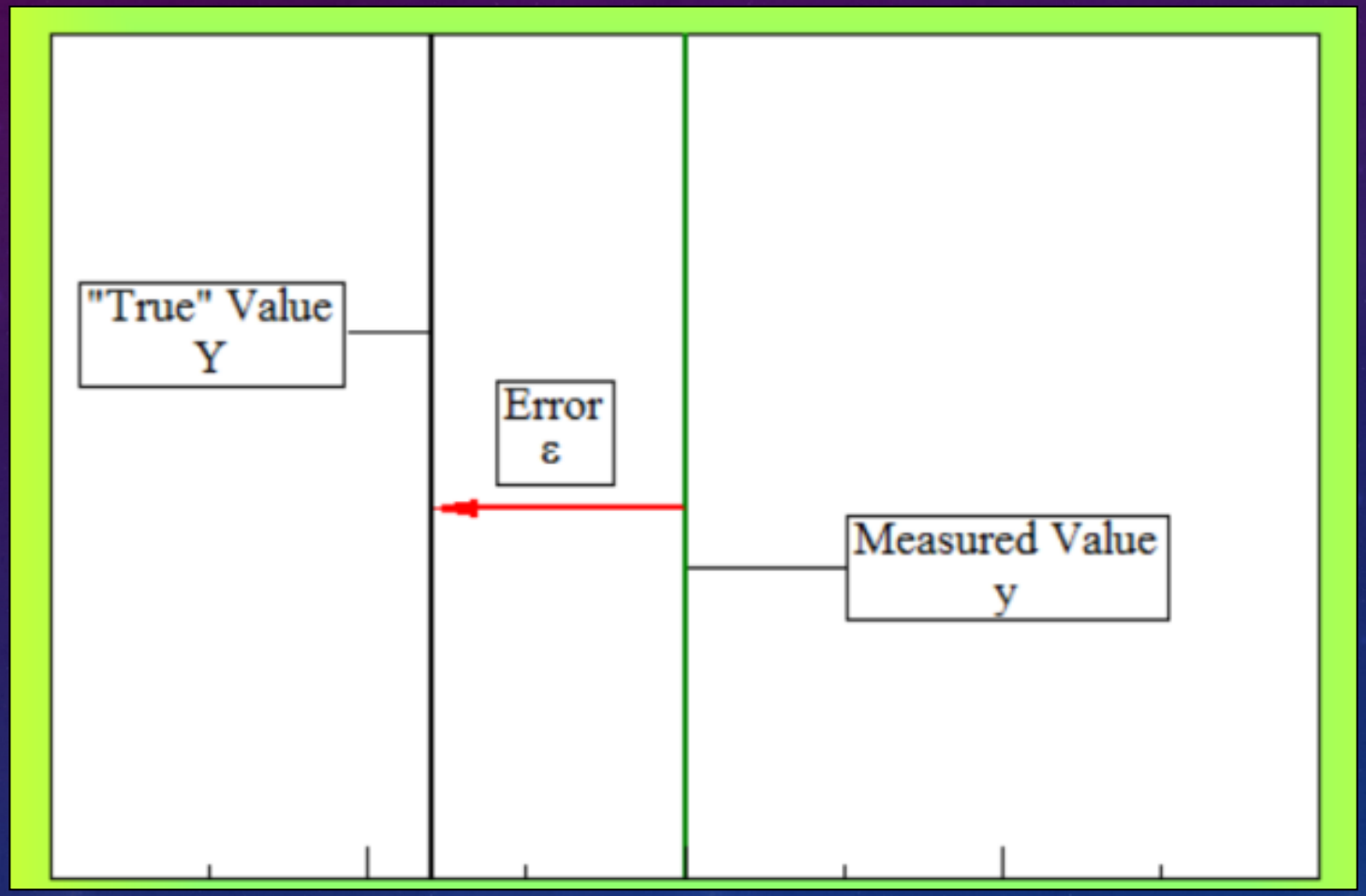
Measurement Error



Measurement Uncertainty



Measurement Error

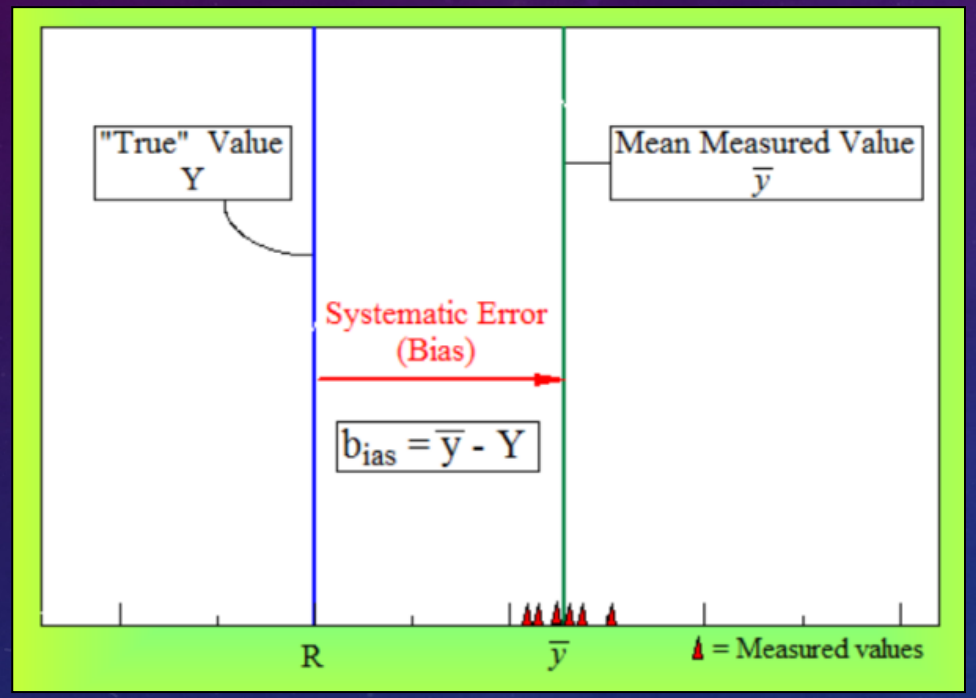


$$\varepsilon_{meas} = Y_{true} - y_{meas}$$

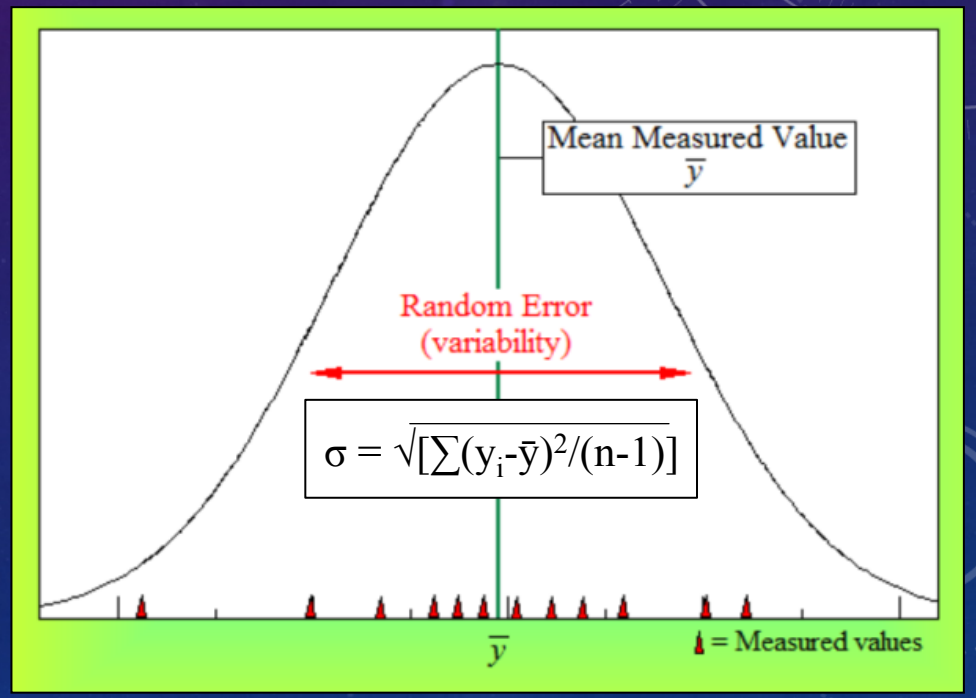
Measurement Error

$$\varepsilon_{meas} = \varepsilon_{sys} + \varepsilon_{ran}$$

ε_{sys}



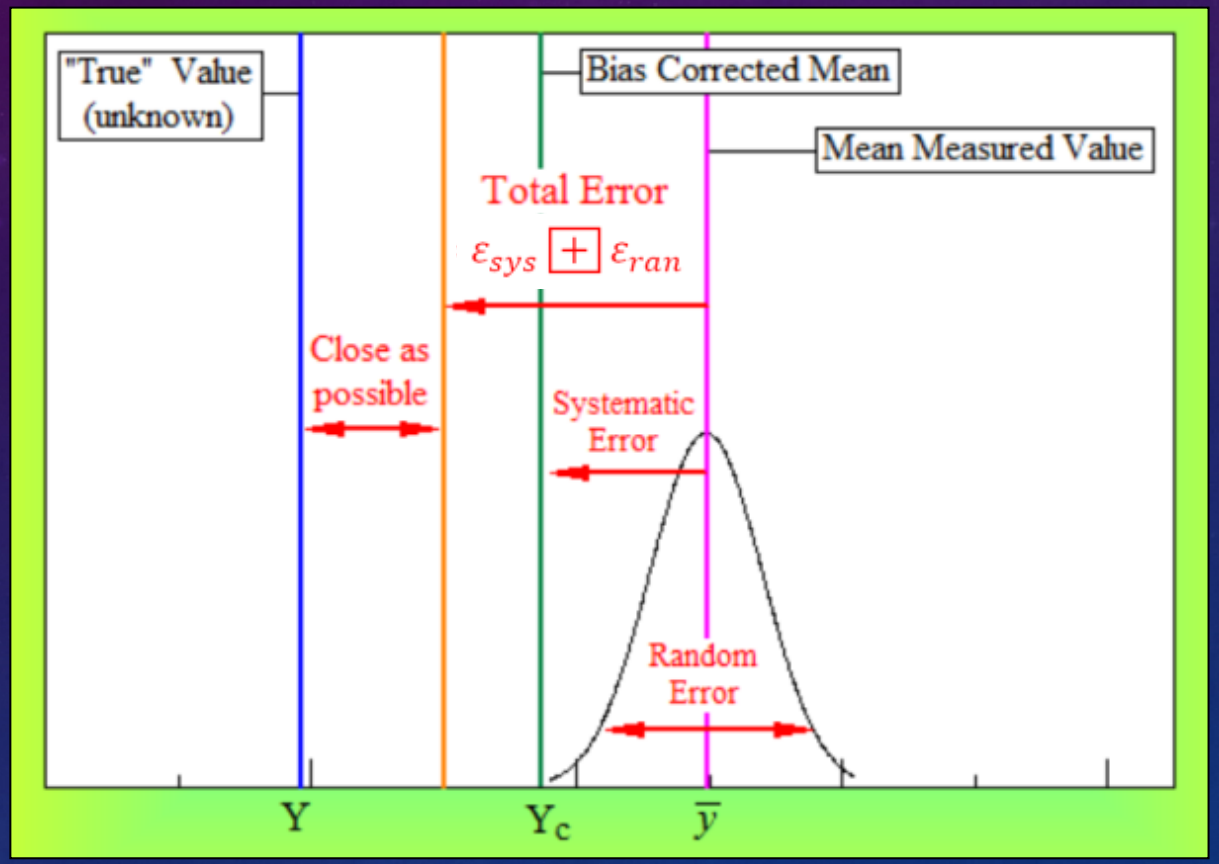
ε_{ran}



Focus is measurand: physical reality

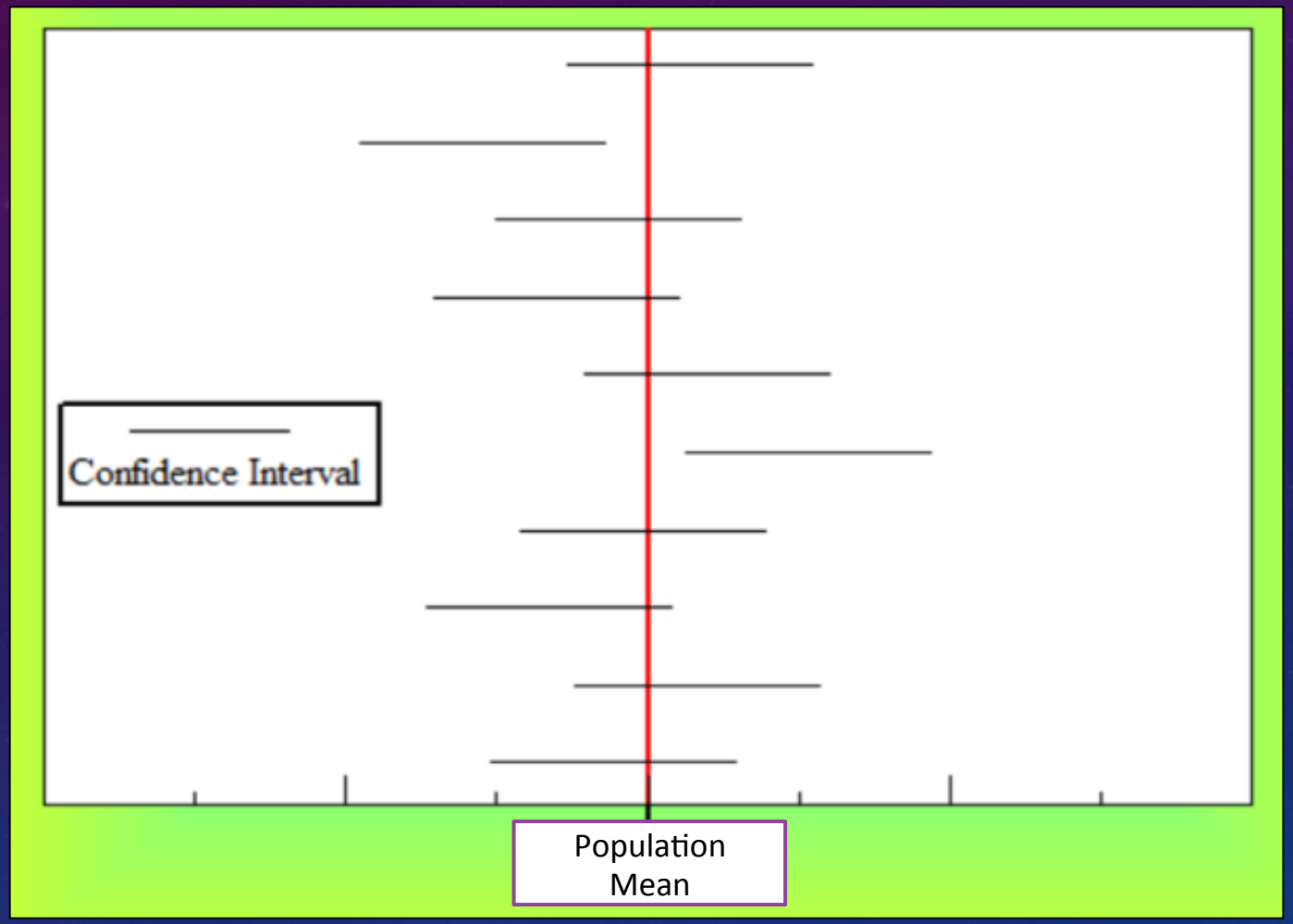
Measurement Error

Estimate as close as possible to *the* true value.



$$Y_{true} \approx y_{meas} - \varepsilon_{meas}$$

Confidence Interval



$$C.I. = \overline{y}_{meas} \pm 3\Delta$$

Measurement Error & Analysis

$$\varepsilon_{meas} \measuredangle \varepsilon_{sys} \boxed{+} \varepsilon_{ran}$$

Total Analytical Error

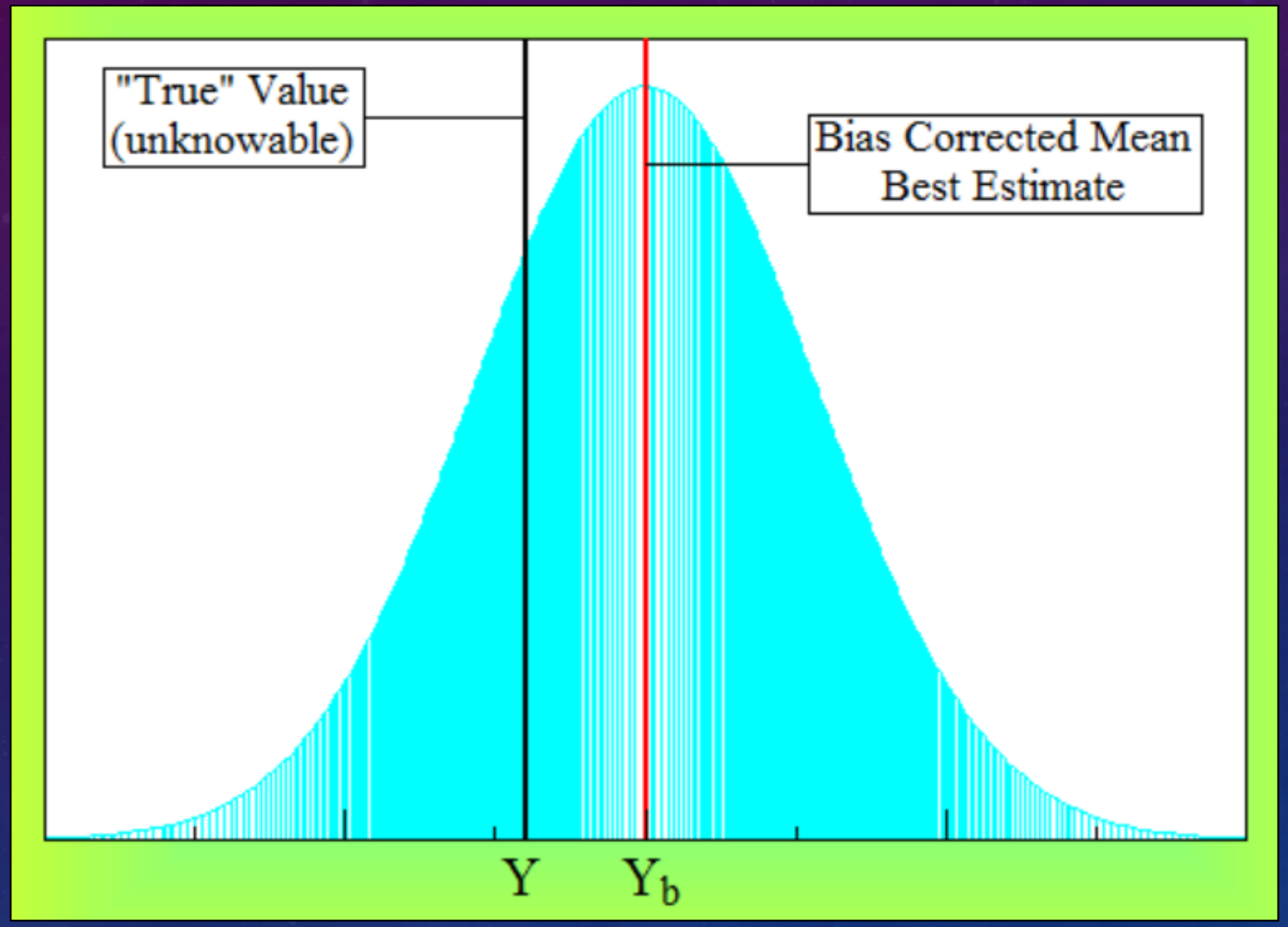
$$\varepsilon_{max} \sim b_{ias} + 3\sigma$$

Confidence Interval

$$C.I. = \overline{y}_{meas} \pm 3\sigma$$

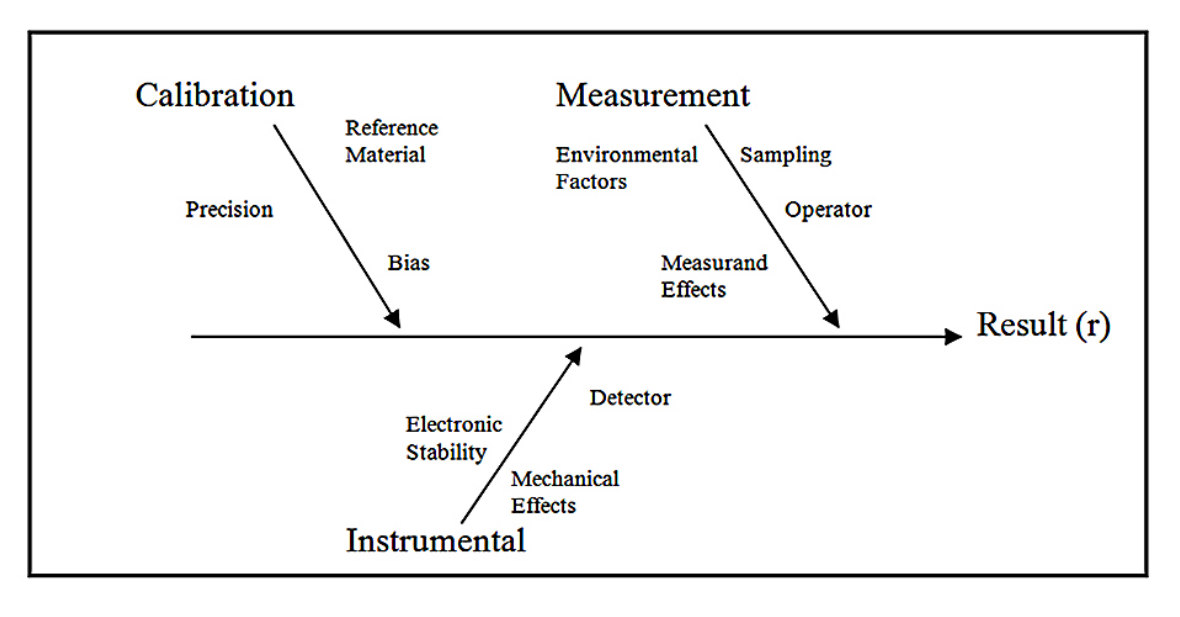
Measurement Uncertainty

Measurement Uncertainty



y_{meas} = Prob. Dist.

Determining Uncertainty

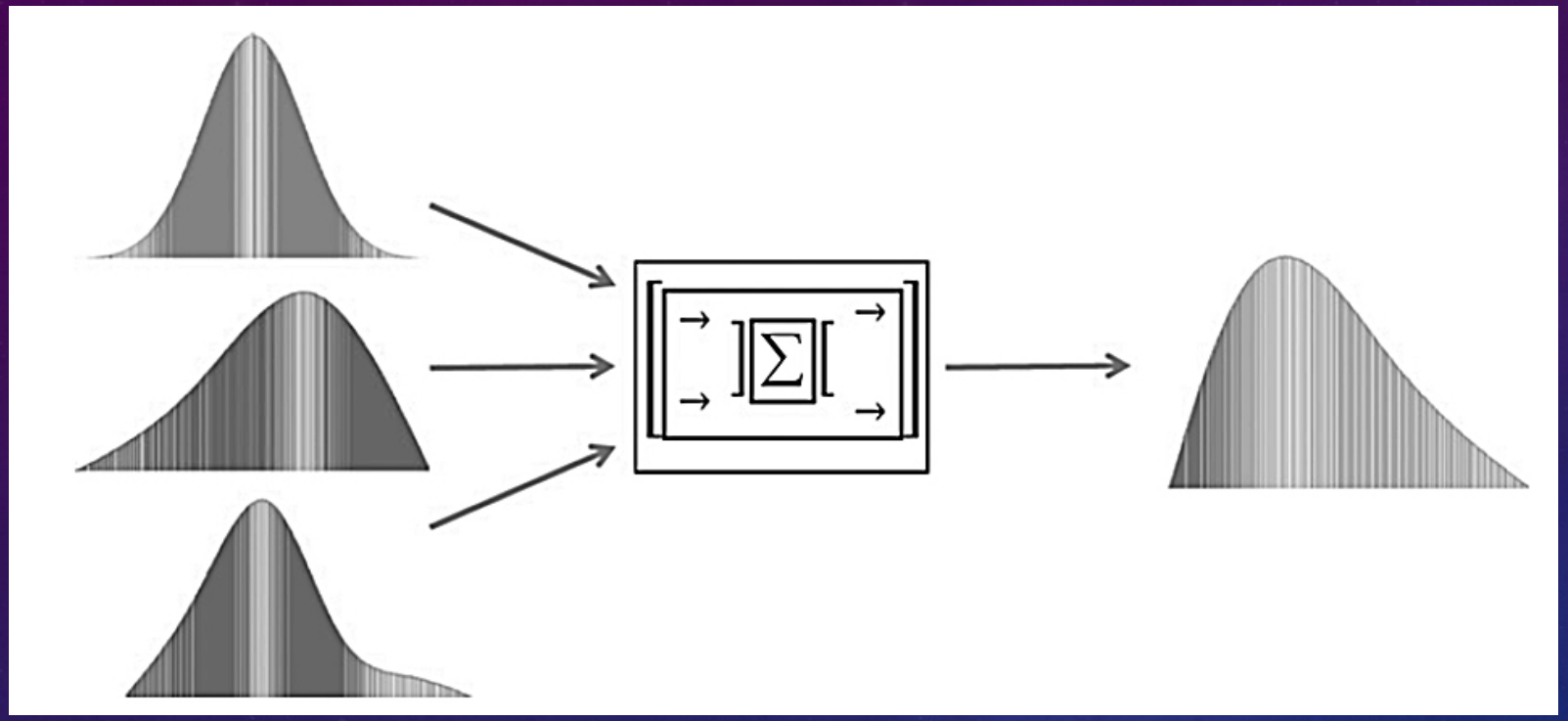


Uncertainty Source	Type A	Type B	
Calibration			
Ref. Mat.		.052	
Precision	. 080		
Bias	.068		
Combined Uncertainty by Type	.105	.052	
Combined Uncertainty Calibration			.117
Instrumental			
Mechanical Effects	.064		
Electronic Stability	.055		
Detector		.041	
Combined Uncertainty by Type	.084	.041	
Combined Uncertainty Instrumental			.093
Measurement			
Environmental Factors	.101		
Sampling	.112		
Operator	.064		
Measurand Effects		.055	
Combined Uncertainty by Type	.164	.055	
Combined Uncertainty Measurement			.173
Total Uncertainty			
Combined Uncertainty			.229
Expanded Uncertainty (k=2)			± .458

Propagation of Uncertainty:

$$\mu_y = \sqrt{\sum_{i=1}^{N}\left(\frac{\partial f}{\partial x_i}\cdot \mu_{x_i}\right)^2 + 2\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\frac{\partial f}{\partial x_i}\cdot\frac{\partial f}{\partial x_j}\cdot \mu_{x_i x_j}}$$

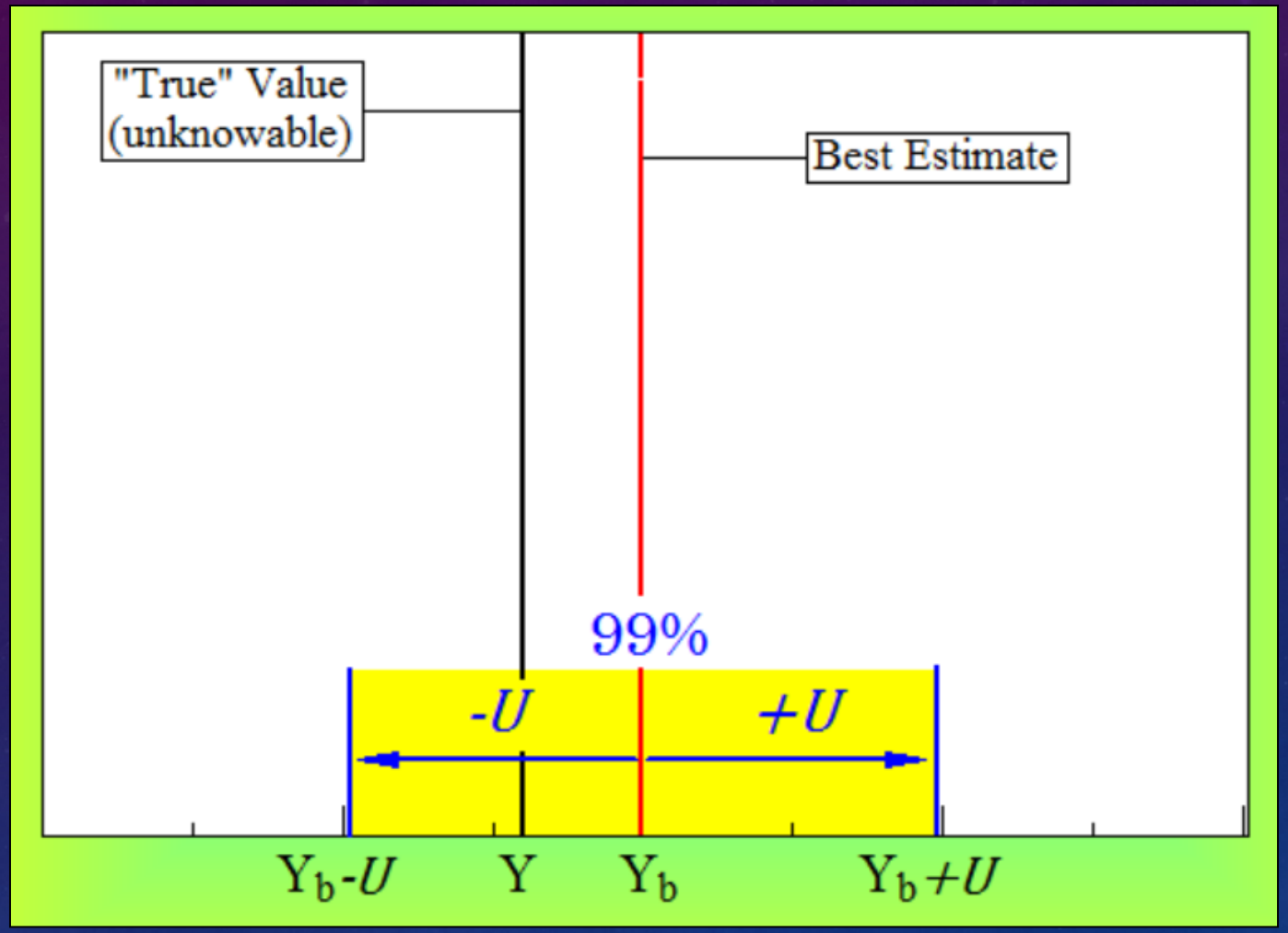
Determining Uncertainty



Monte Carlo :

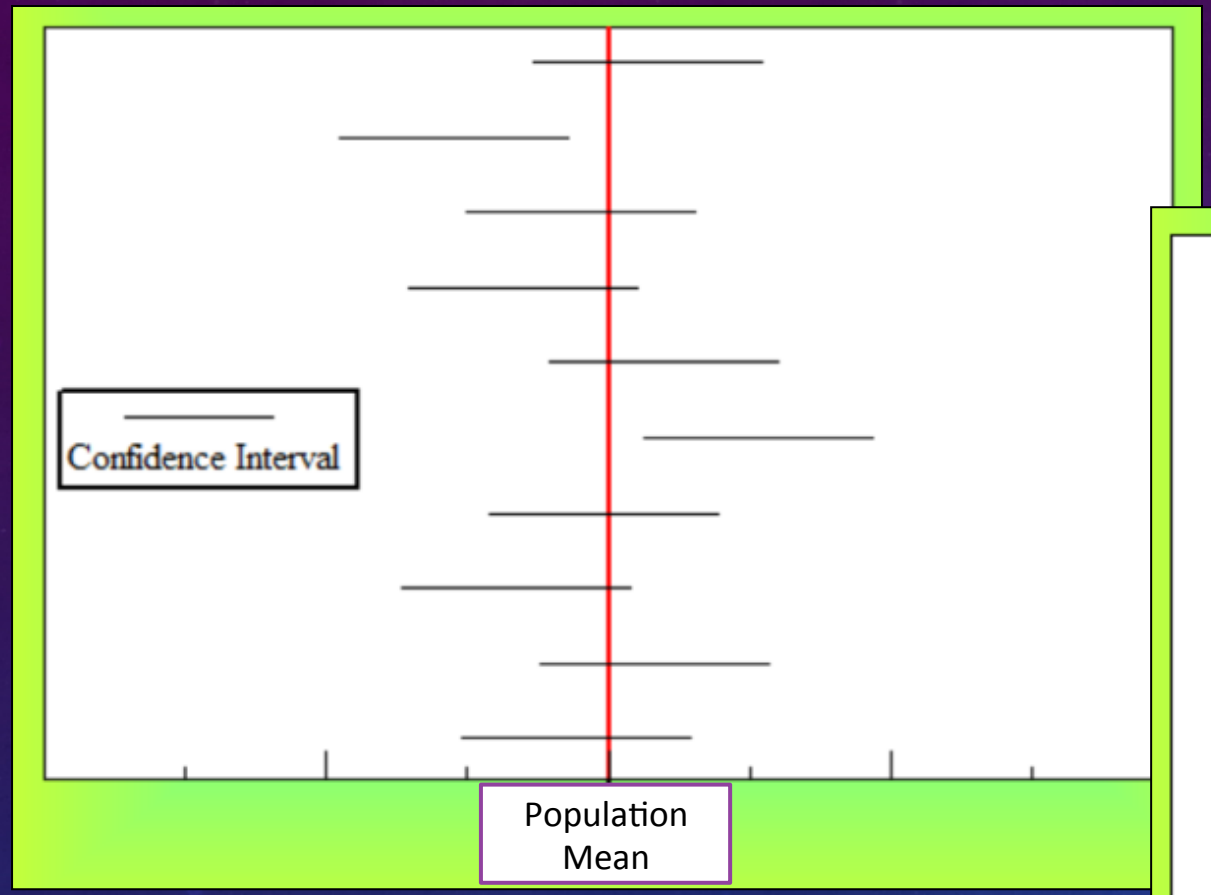
Model based iterative simulation process.

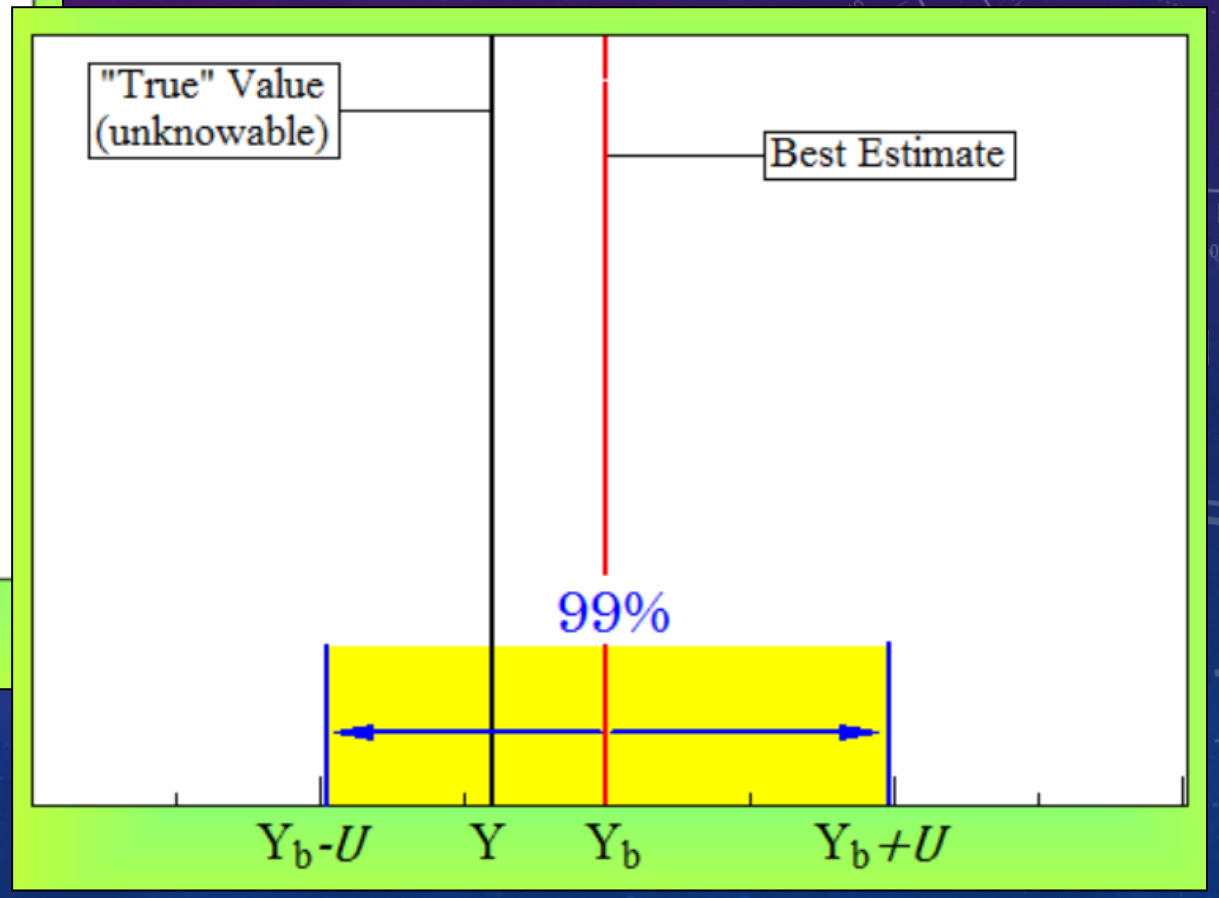
Expressing Uncertainty



$$Y_{true} = Y_b \pm U\ (99\%)$$

Confidence Interval ≠ Coverage Interval





Measurement Uncertainty

Measurement ≡ Information Based Inference

Mapping Measurement to State of Knowledge

Coverage interval

$$Y_{true} = Y_b \pm U\ (99\%)$$

Error v. Uncertainty

Measurement error is an *unknowable* quantity in the realm of the *state of nature*.

Measurement uncertainty is a *quantifiable* parameter in the realm of the *state of knowledge about nature*.

Forensic uncertainty

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BLANK TEST	.000	02:32
INTERNAL STANDARD	VERIFIED	02:32
SUBJECT SAMPLE	.080	02:33
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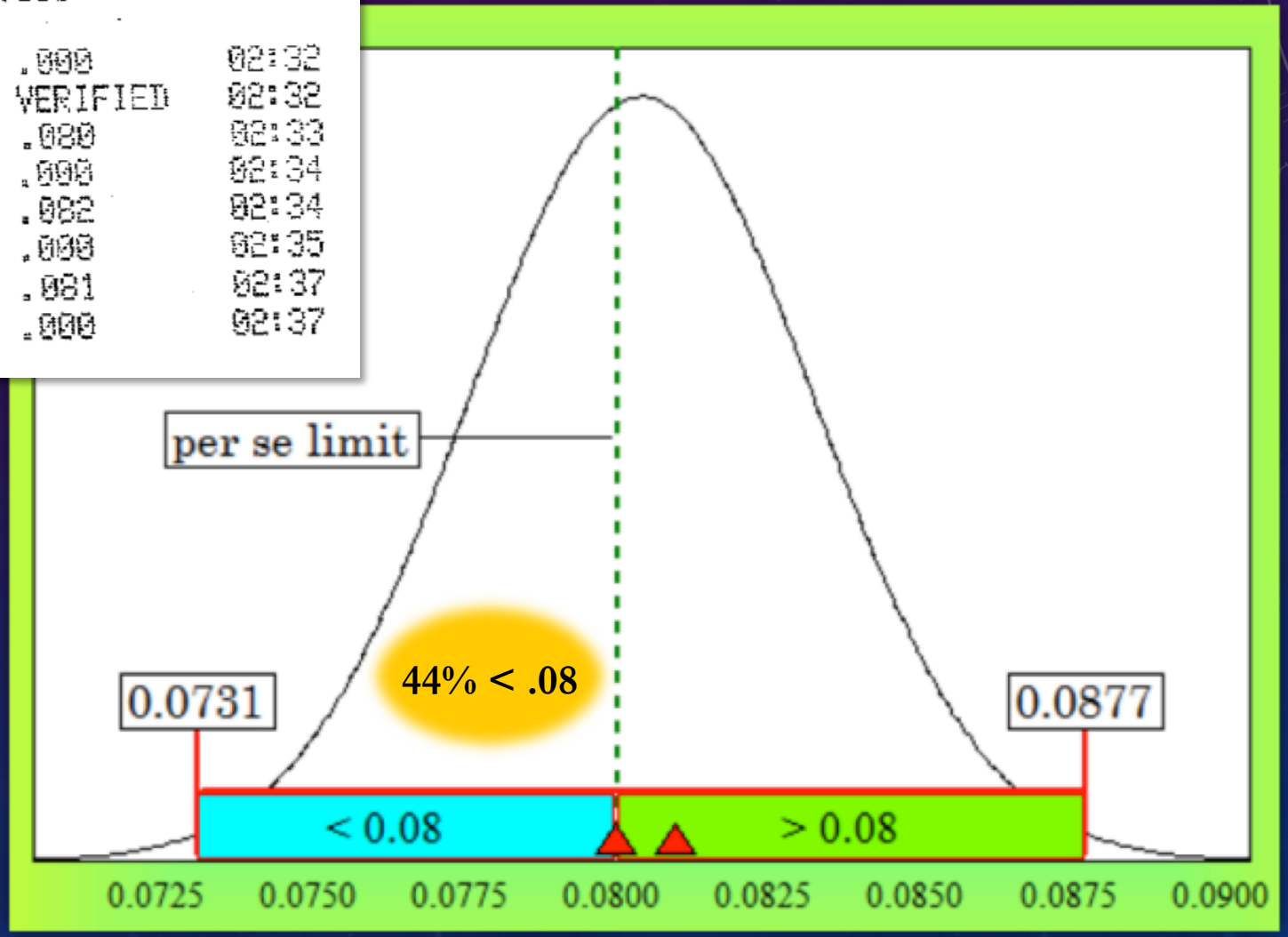


Identical Results

--- BREATH ANALYSIS ---

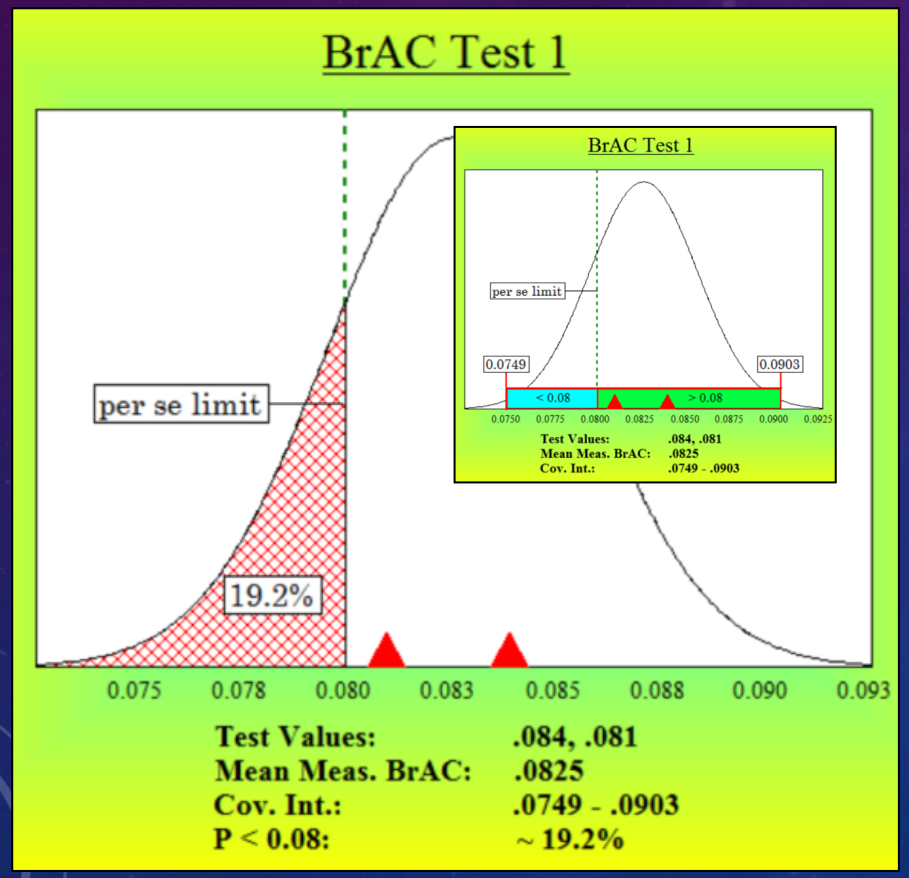
BLANK TEST	.000
INTERNAL STANDARD	VERIFIED
SUBJECT SAMPLE	.084
BLANK TEST	.000
EXTERNAL STANDARD	.082
BLANK TEST	.000
SUBJECT SAMPLE	.081
BLANK TEST	.000

--- BREATH ANALYSIS ---

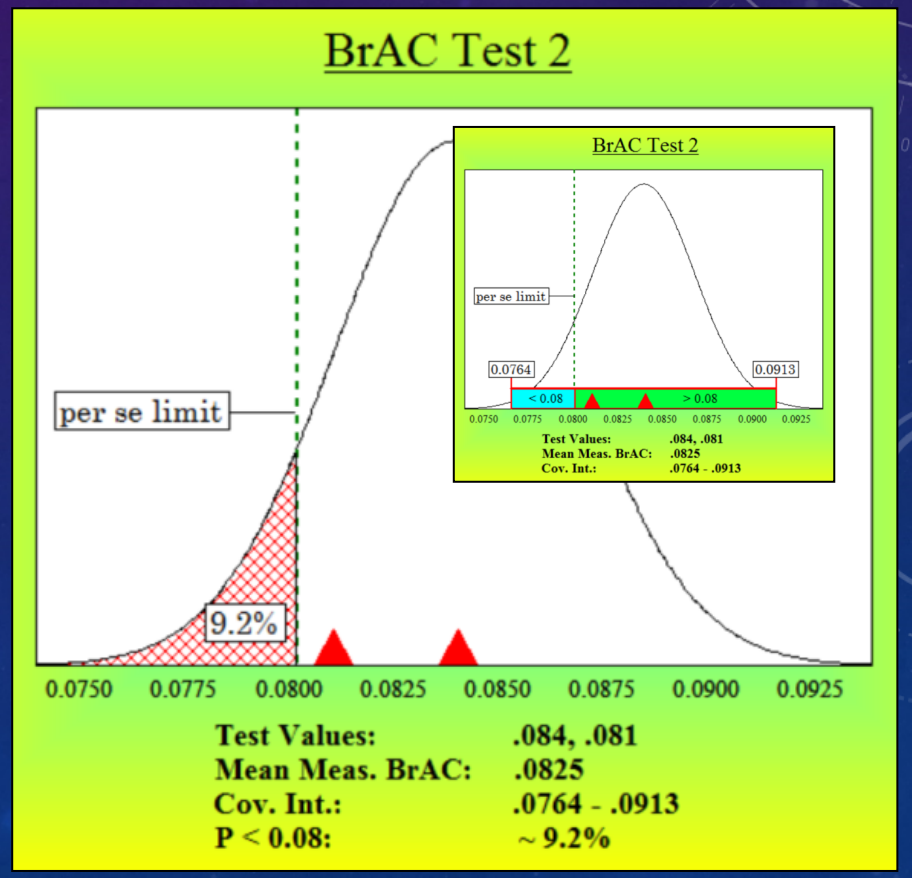
BLANK TEST	.000
INTERNAL STANDARD	VERIFIED
SUBJECT SAMPLE	.084
BLANK TEST	.000
EXTERNAL STANDARD	.079
BLANK TEST	.000
SUBJECT SAMPLE	.081
BLANK TEST	.000

Identical Results, Different Meanings

--- BREATH ANALYSIS ---	
BLANK TEST	.000
INTERNAL STANDARD	VERIFIED
SUBJECT SAMPLE	.084
BLANK TEST	.000
EXTERNAL STANDARD	.082
BLANK TEST	.000
SUBJECT SAMPLE	.081
BLANK TEST	.000

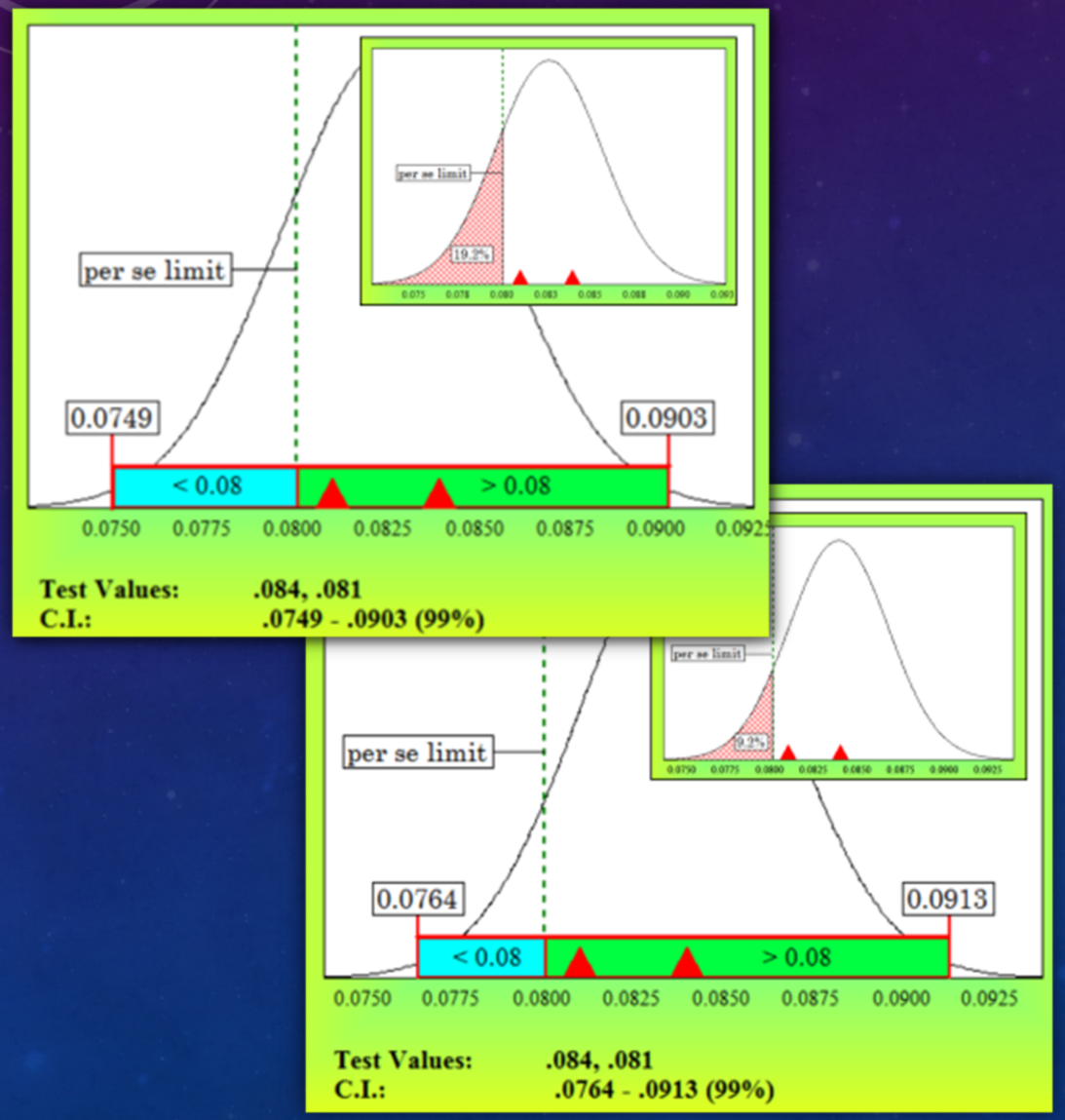


--- BREATH ANALYSIS ---	
BLANK TEST	.000
INTERNAL STANDARD	VERIFIED
SUBJECT SAMPLE	.084
BLANK TEST	.000
EXTERNAL STANDARD	.079
BLANK TEST	.000
SUBJECT SAMPLE	.081
BLANK TEST	.000



Importance of Uncertainty

"Absent the reporting of uncertainty, there is a substantial possibility that even an expert would not make a meaningful analysis of a particular breath reading." *State v. Fausto*, No. C076949 (King Co. Dist. Ct. WA – 09/20/2010).



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International Symposium on Forensic Science Error Management – Detection, Measurement and Mitigation.

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